1. BlackGEM (Blagorodnova).
   Wide field and shallow optical synoptic surveyor.
2. Dark Energy Camera surveys (Dawson).
   A 5-sq degree imager on a 4-m telescope. Available now for all sorts of astrophysical projects.
3. DESI (Nugent).
   Massively multiplexed (5000 channels) optical spectrograph with 8 sq degrees.
4. Gattini IR (De).
   Wide field and shallow NIR synoptic surveyer.
5. KMT Network (Sang-Chul KIM)
   A trio of 1.6-m telescopes (Chile, Australia, South Africa) equipped with moderate field (2 sq degree) fine optical imagers and optimized for 24-hour coverage of the Southern Sky (particularly the Bulge).
6. KPED (Kitt Peak Electron Multiplying CCD Demonstrator) (Coughlin & Kulkarni)).
   A dedicated optical imager suitable for fast framing (electron multiplying CCD) on the robotic Kitt Peak 84-inch telescope.
7. The Kyoto 3.8-m Telescope (Maeda).
   A spanking new, moderate size (3.8-m) fast slewing large telescope right here in Japan.
8. LAMOST (Mao).
   Large field of view (5 sq deg), massively multipliexed (4000 channels) optical spectropgrah behind 4-m Schimidt type telescope.
9. MAXI (Kawai).
   Wide field and shallow X-ray synoptic surveyor.
10. MOA (Sumi).
    A 1.8-m telescope equipped 2.2 sq degree fine optical imager, located in New Zealand, and dedicated for micro-lensing studies.
11. PFS (Yasuda).
    Moderate field (1.3 sq deg), massively multiplexed (2394) and high sensitivity 0.38-1.26 micron spectrograph on 8-m telescope.
12. PRIME (Sumi).
    A 1.8-m telescope equipped with the widest field NIR imager (1.5 sq deg) and also a spectrograph, located in South Africa.
13. SDSS Phase V (Konidaris & Kollmeier).
    The next phase of SDSS aimed at "dynamic highly multiplexed stellar and interstellar" spectroscopy.
14. SEDM (Spectral Energy Distribution Machine) (Konidaris).
    An IFU spectrograph optimised for transient classification and high operational efficiency. Presentation by the PI of SEDM.
15. SEDM: Performance & DRP (Neill).
    The current performance and data reduction pipeline (DRP) of the SEDM (after upgrade and fixes). Presentation by the Project Scientist.
16. Supernova Surveys from China (Wang).
    A variety of SN searches from China.
17. Subaru Transient Surveys (Tominaga).
    Deep (25 mag or better) nightly (including intra-night) surveys for shock breakout and super-luminous supernovae.
18. Spektr Roengten Gamma (Rau).
    Synoptic X-ray survey of the sky. Rosat on steroids. Imminent launch.
19. TESS (provided by Blagorodnova).
    Wide field and high precision survey of the bright (I<14 mag) sky. Aimed at extra-solar planes. Unique. Already working.
20. Tomo-e Gozen (provided by Tanaka).
    Wide field but second timescale survey of the optical sky. Unique. Working already.
21. Zwicky Transient Facility: Coaddition Facility (Goldstein).
    Coadding allows a good match between ZTF & DESI and perhaps even ZTF & PFS.
22. Zwicky Transient Facility: Science (Yan).
    Science from ZTF.

```
# For Unix aficionados:
# Problem: how to automatically "build a book" from a website?
# (you can have any ordering by using sort but here it is by alpha)

# change directory to Files4Facilities/

$ wkhtmltopdf ../IndexedFacilities.html AAATable.pdf
$ pdfunite $(ls -1 *.pdf | xargs) ../AllFacilities.pdf
```

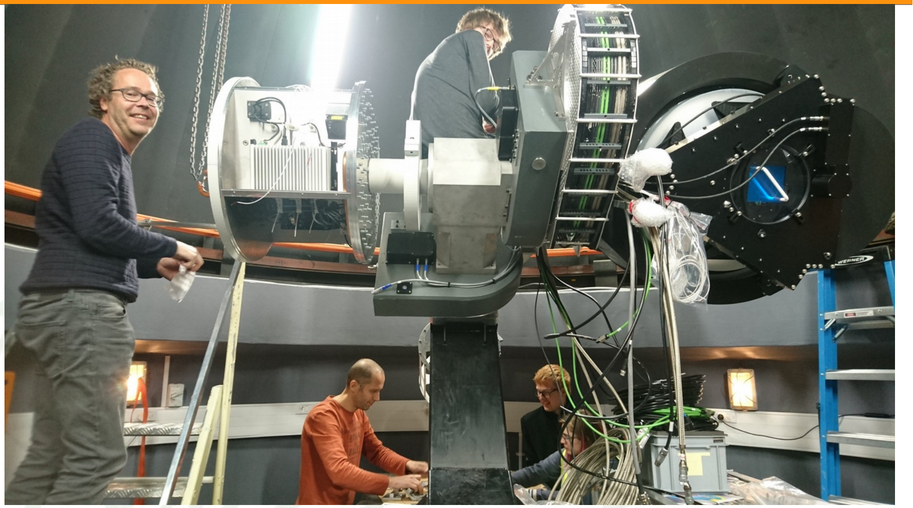
BlackGEM

Nadia Blagorodnova

of behalf of the BlackGEM team:

PI: Paul Groot
Project Manager: Steven Bloemen
Project Scientist: PeterJonker
Operations Manager: Paul Vreeswijk

BlackGEM

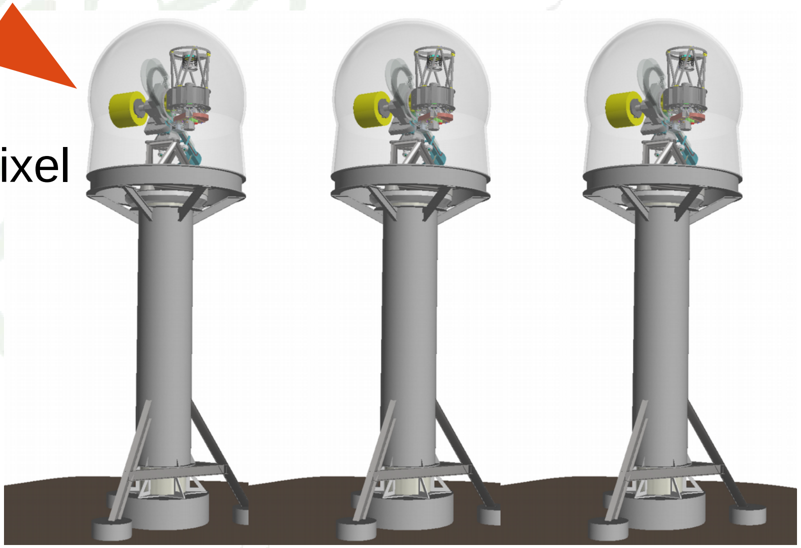


<u>Science:</u>

- ***Gravitational wave counterparts***
- Southern All Sky Survey
- Fast Transients & Variables
- Nearby Universe Survey

<u>Phase 1:</u>

- 3 wide field telescopes (8.1 square degr. total)
- Primary mirror: 65cm diameter
- Sensitivity: *g=23 in 5 minutes*
- Location: ESO La Silla
- Optical quality: seeing limited, 0.9” median
- Camera: 1 CCD/telescope, 10k x 10k, 0.56”/pixel
- Filters: *u,g,q,r,i,z* filter set, change in 3s



<u>Phase 2:</u>

- Expansion to 15 telescopes
- 40 square degrees total field of view (@ 0.56”/pix)
- Location: ESO La Silla; or combi ESO, NZ and SA

Radboud University

BlackGEM Surveys

BlackGEM Southern Sky Survey: ***'Southern Sloan'***

→ 30 000 sqd down to 22nd mag in *u,g,q,r,i,z* at 1” median seeing

→ By itself a fantastic resource for all kinds of science:

(galactic streams/structure, dwarf galaxies, stellar populations, 'gems', quasars, weak lensing, high-z galaxies, etc.)

→ ***Includes a 1-minute integration q-band scan of available Southern Sky (10000 sqd) every two weeks, down to q~21.5***

- **BlackGEM Fast Synoptic Survey**: ***'Kepler on steroids'***

→ High cadence (1 min), multi-colour (simultaneous), wide-field

→ Kepler Short Cadence-type sampling on millions of objects

→ Deep drilling fields: thousands of exposures over weeks time-scale

→ Flexibility for experiments: continuous read-out, six filters, etc.

(fast transients, asteroids, KBOs, early SN, interacting binaries, eclipses etc.)

- **BlackGEM Twilight Program**

→ Every twilight (30 minutes) Local Universe galaxies in 3 bands *(u,q,z*) for new transients (incl. SMC/LMC, Fornax Cluster, Cen A/M83 group, etc.). Fifteen fields (120sqd) per twilight.

- **BlackGEM Trigger Mode**: ***' Transients Galore'***

→ GW error box coverage in multiple colours

→ 100s of sqd in multiple times over ~week time scale down to *g*=23

(TDEs, SN of all types, Dwarf Novae, SN .Ia, SN Iax, etc.)

BlackGEM Team & Consortium

Principal Investigator: Paul Groot (Radboud University)
Project Scientist: Peter Jonker (SRON/Radboud University
Project Manager: Steven Bloemen (Radboud University)

Consortium Institute Partners in Phase 1:

NOVA

Radboud Universiteit

KU Leuven

NOVA = Amsterdam, Leiden, Groningen, Radboud

Manchester U., Tel Aviv U., U Canterbury, UC Davis, Weizmann, Hebrew U, Northwestern committed at PI-level

Possibility for new partners (for 5 year operation):

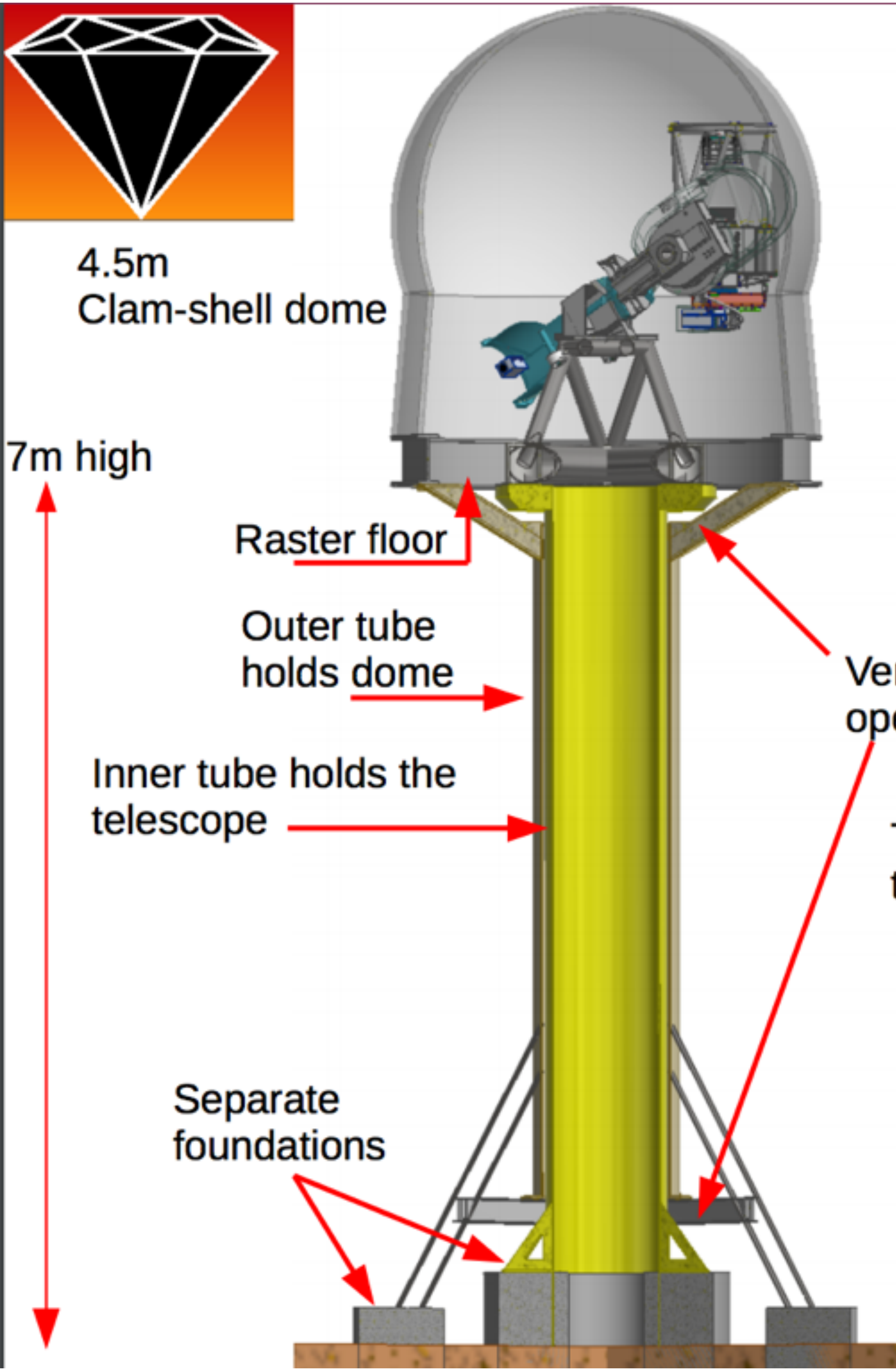
- 150 kEuro to join at PI-level (one faculty member + PDRAs/PhDs)
  (all data, science team, lead science case)
- 1 MEuro to join at Institute level (full institute)
  (all data, science team, lead science case, consortium board)

→ Combinations with in-kind contributions (e.g. follow-up telescope time) possible

www.blackgem.org ; **@BlackGEM_Array**

Location

Dome & Tower

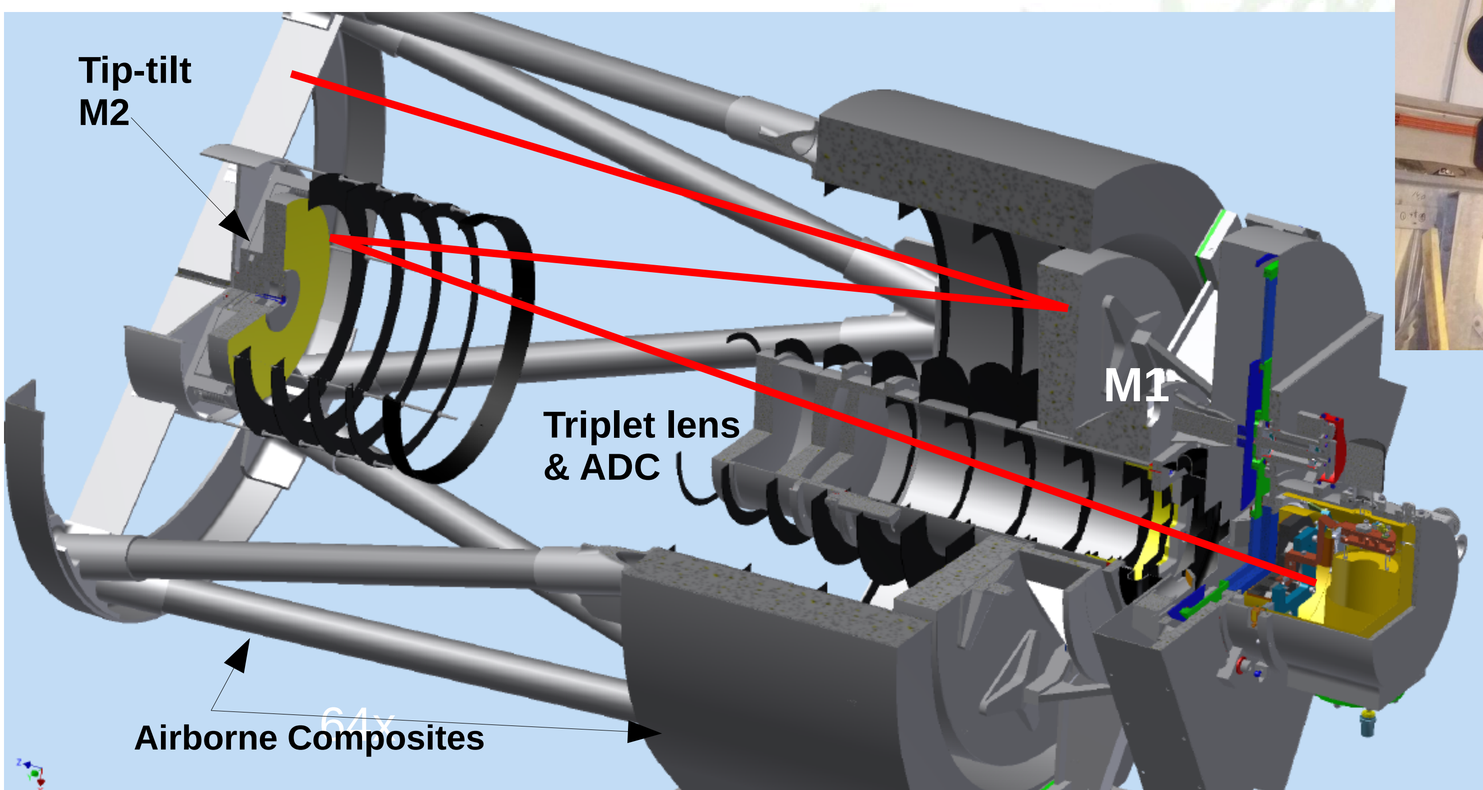

4.5m
Clam-shell dome
7m high
Raster floor
Outer tube
holds dome
Inner tube holds the
telescope
Ventilation
openings
TiO coating on outside
to prevent daytime heating
Separate
foundations


Will replace GPO
Building @ESO La Silla

BlackGEM Unit telescope

- Wynn-Harmer design incl. M2 on tip-tilt piezo stage
- 110 Mpix camera (1 STA 1600 chip)
- 2.7 square degree field-of-view
- 10 second readout + filter change + repointing
- Carbon-fibre structure
- Atmospheric Dispersion Corrector in triplet lens barrel
- Fornax 200 mount
- Fully robotic
- Cooled electronics, in counterweight

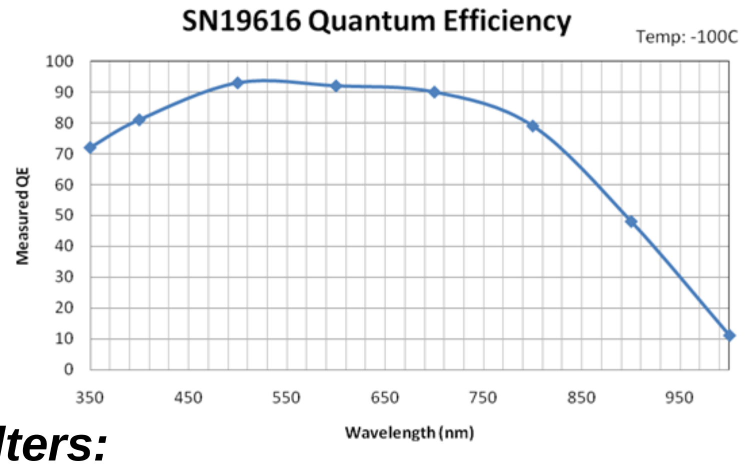
Finished Prototype

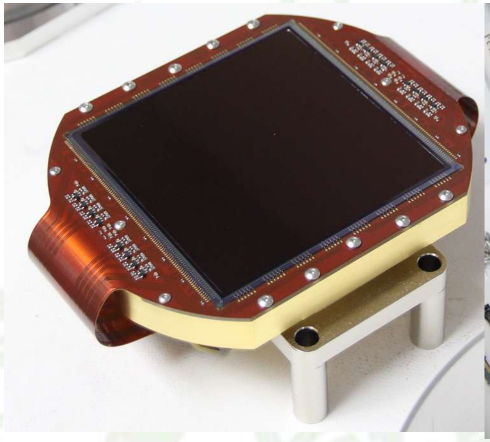


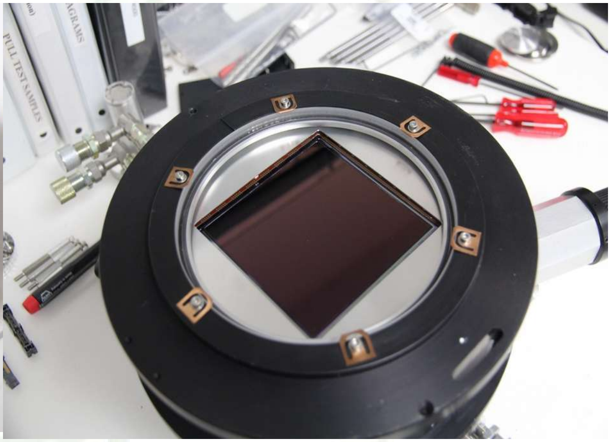
Design

CCD & Filters

- STA1600, 10.5k x 10.5k CCD, 9 µ pixel : 110 Mpixel chip
- Scale on sky: 0.562”/pix, total field of view: 2.7 sqd/telescope
- Readout time: 7 seconds (at 1 MHz on 16 ports), RON: 5.5 e-

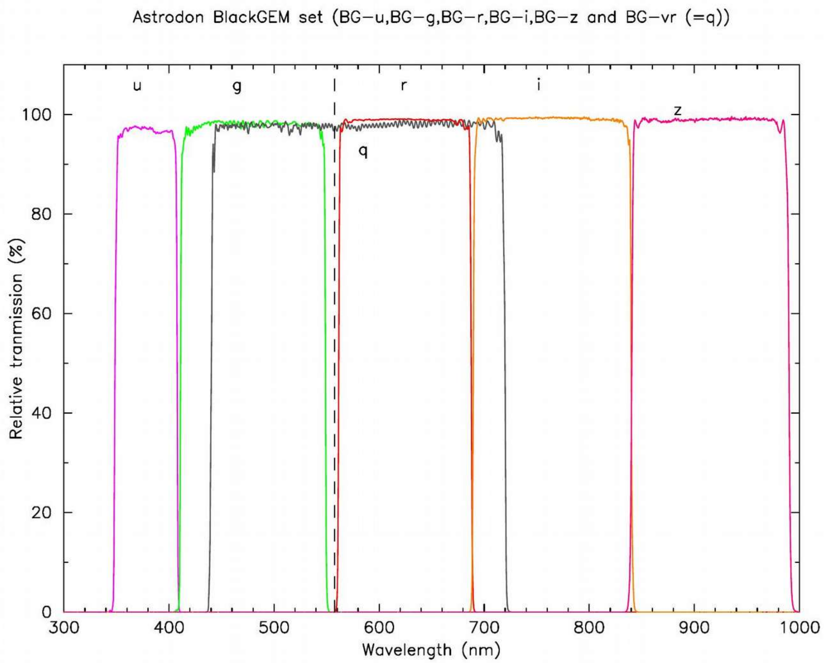


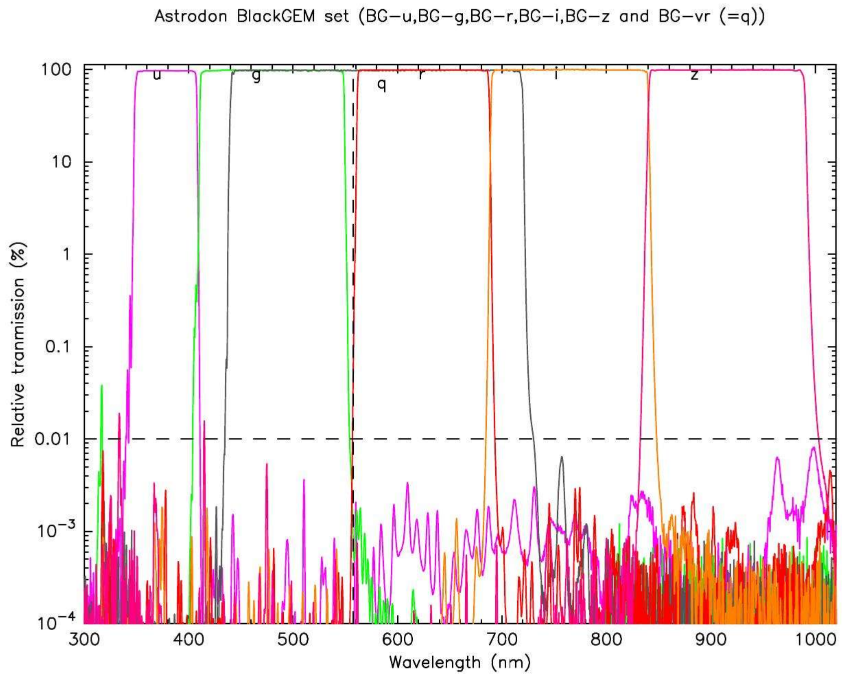




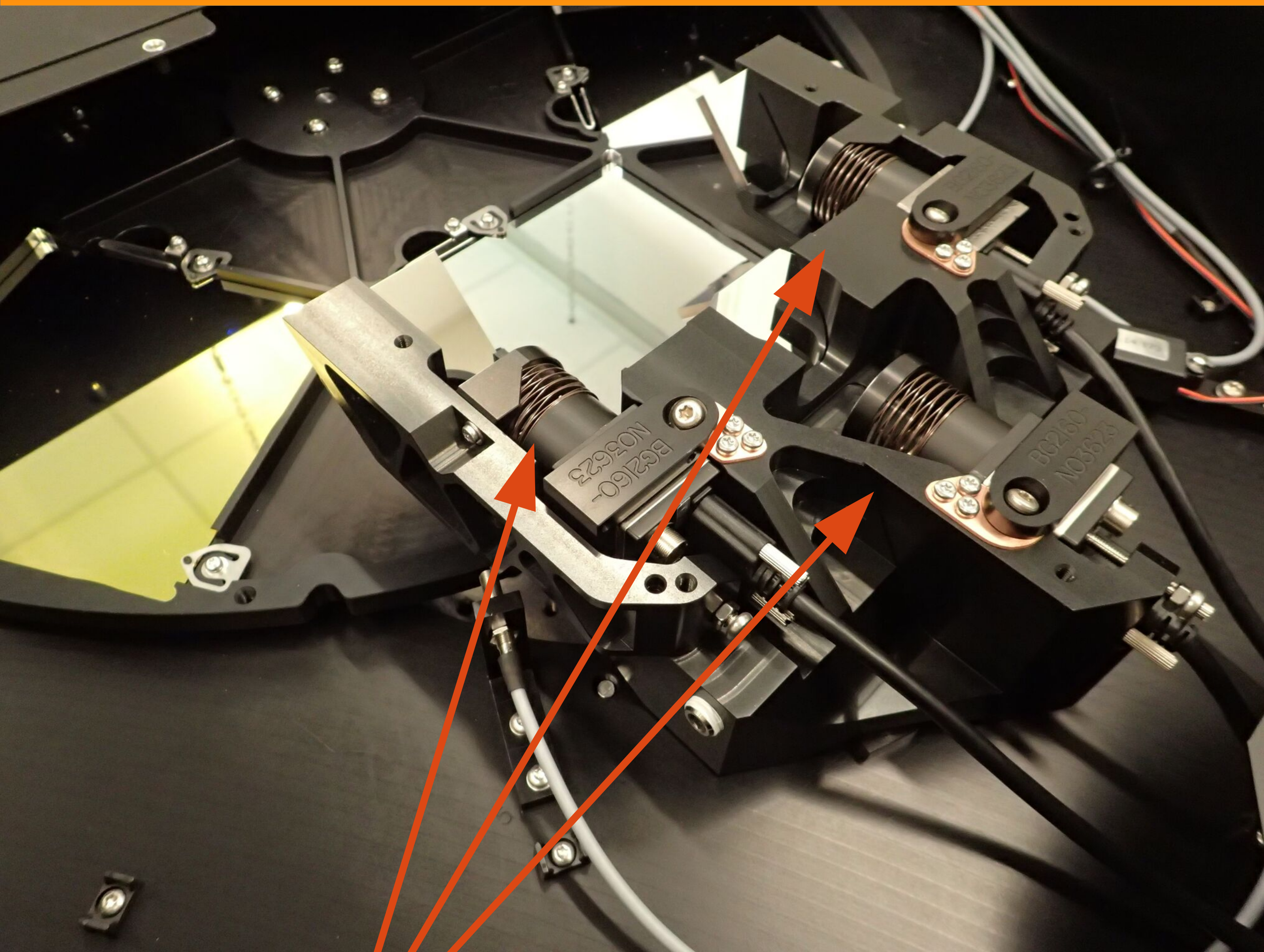
Filters:

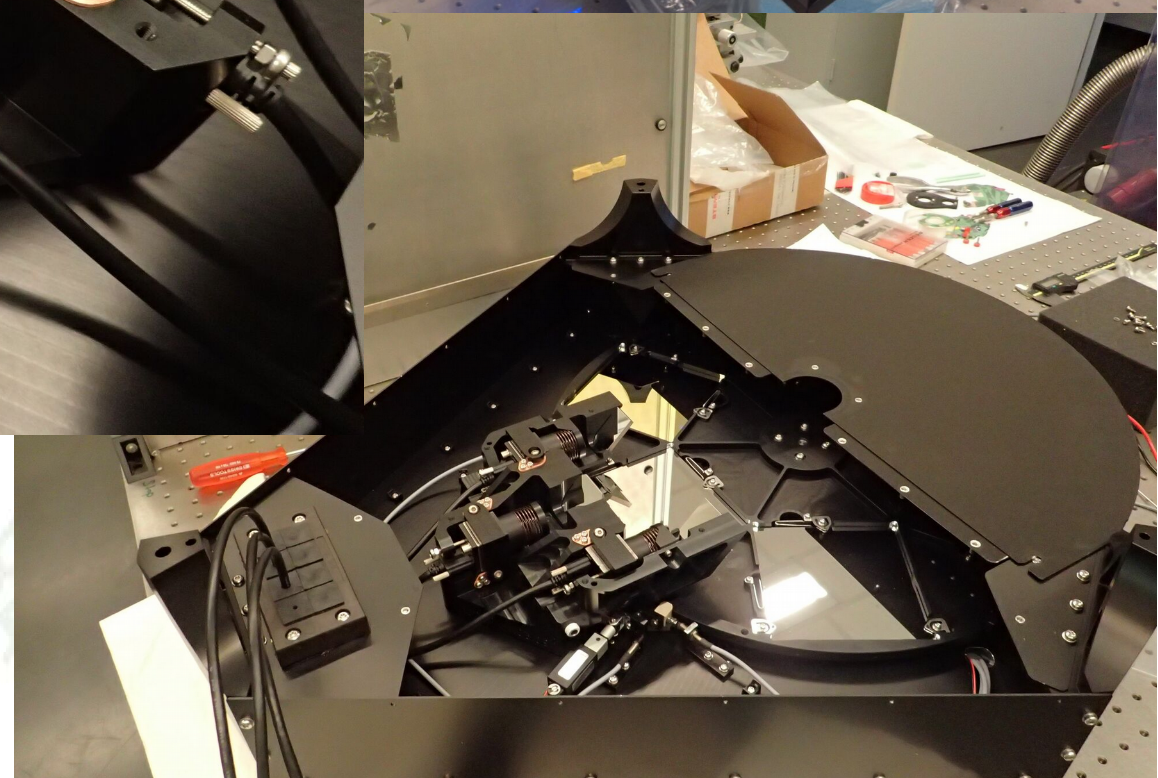
Sloan u,g,r,i,z filters plus broad-band q (440-720nm)



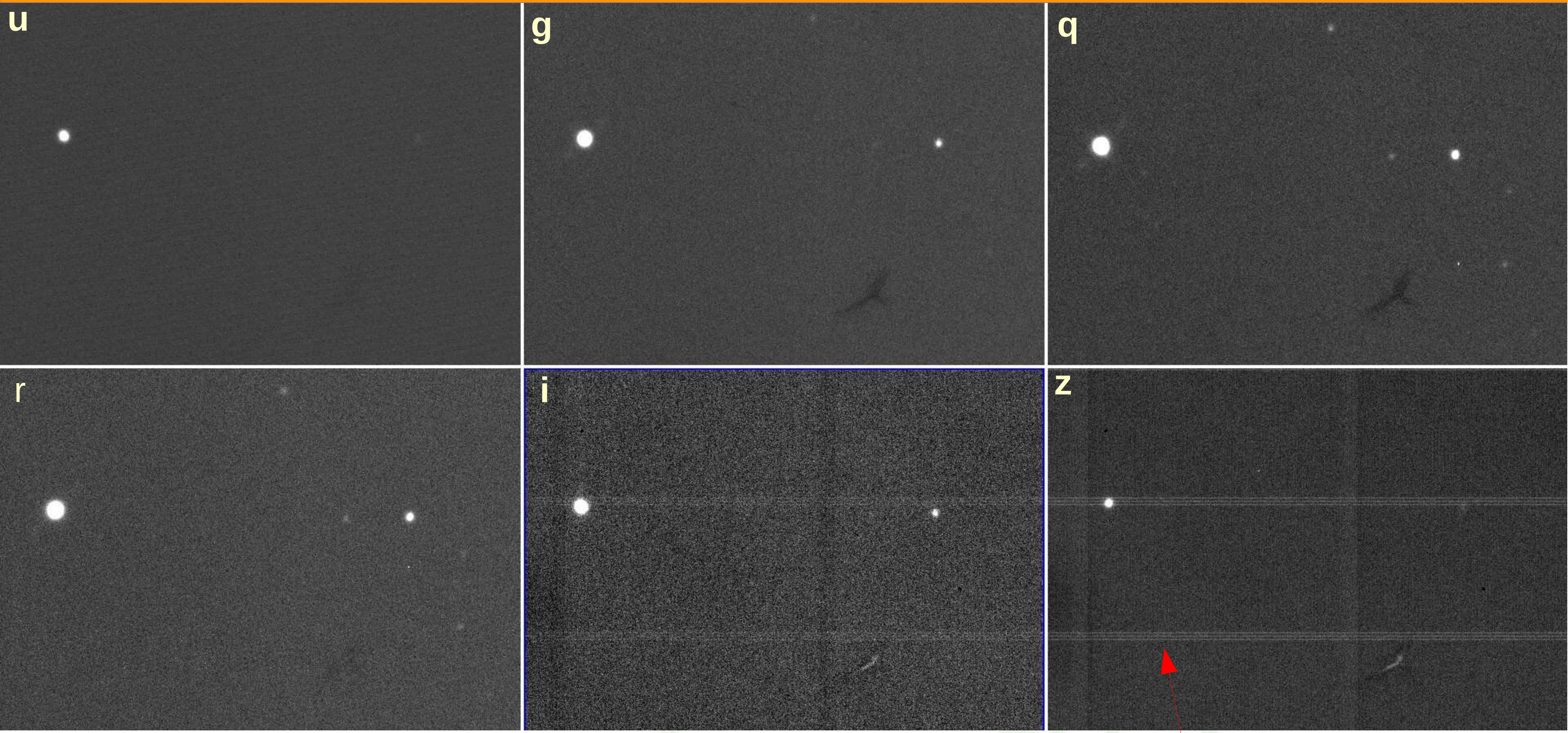


Guide cameras & Filters





Filter performance

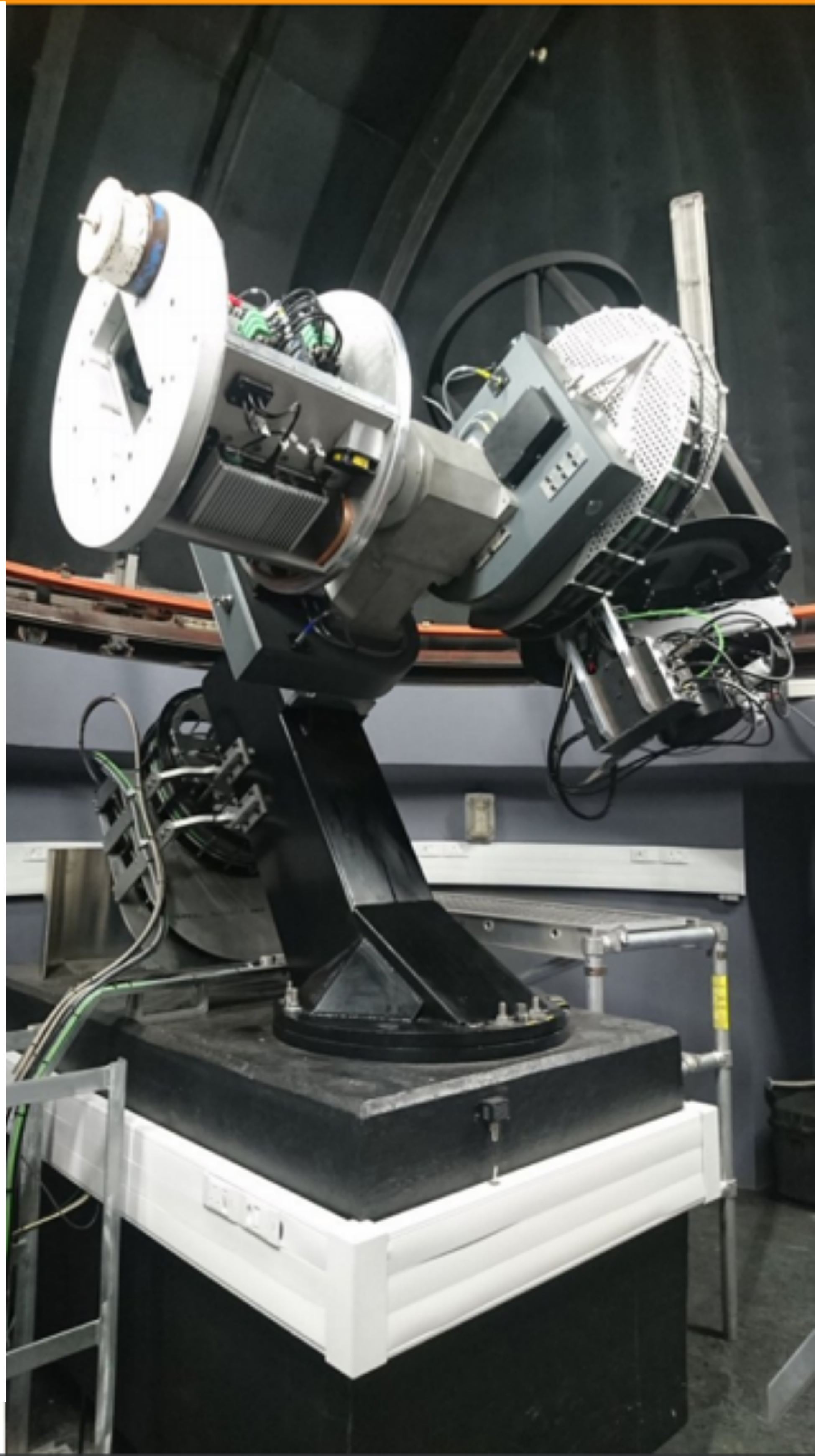


All exposures 5 seconds, unguided, on Pole

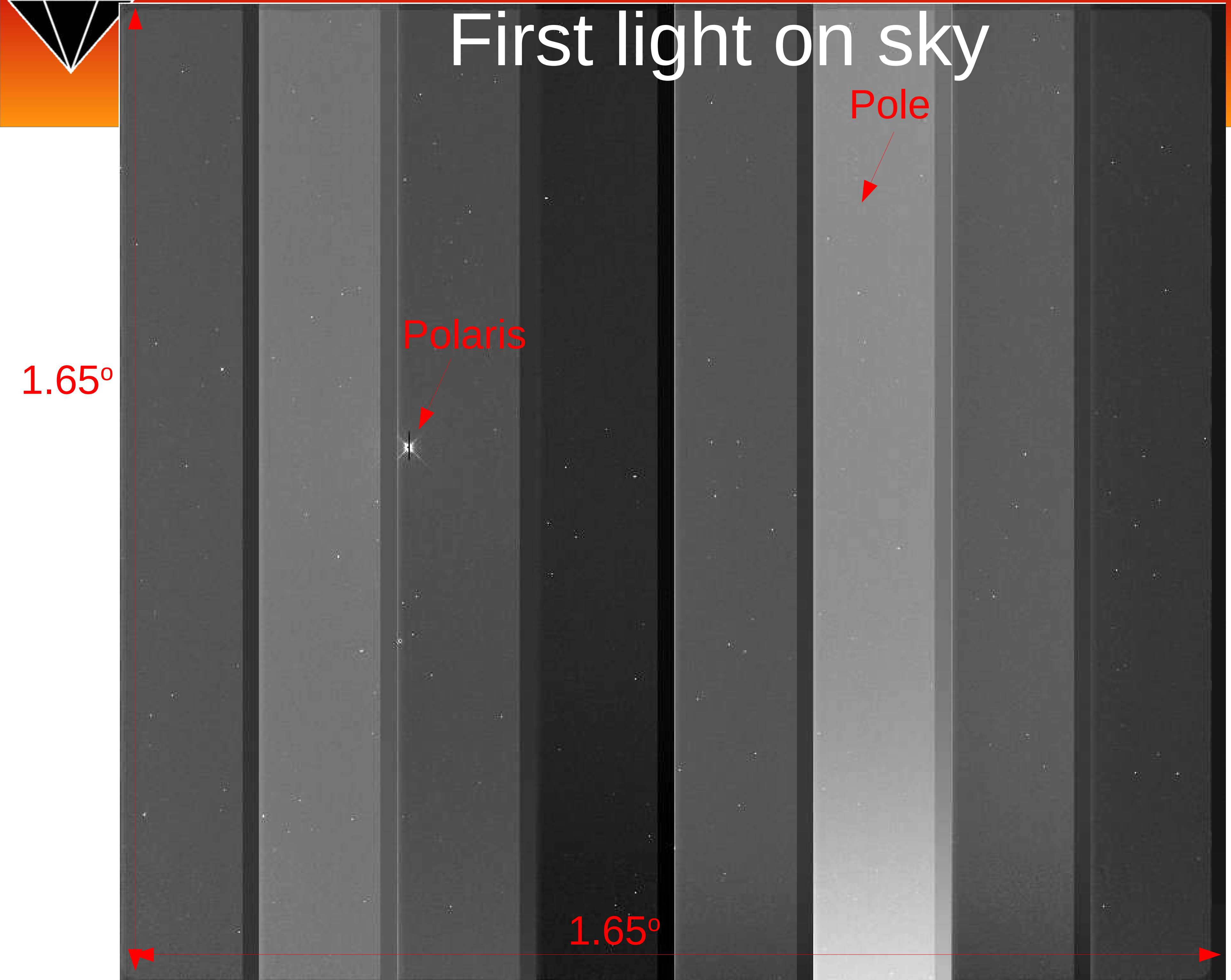
Reflection on backing structure CCD

MeerLICHT Prototype

- **Inaugurated on 25 May 2018** in South African Astronomical Observatory (SAAO).
- Strongly linked to the ThunderKAT and TRAPUM MeerKAT (inaugurated on 18 July 2018) Large Survey Projects.
- **Simultaneous radio and optical** multi-band observations
- Short time-scale **radio-optical correlations** in astrophysical transients: dwarf novae, novae, X-ray binaries, pulsars, fast radio bursts, supernovae, gamma-ray bursts, AGN, gravitational wave events and sources yet unknown.
- MeerLICHT hardware and software is used as a prototype for BlackGEM.



First light on sky



MeerLICHT image of LMC

BlackCloud: A cloud solution

- Aim is to make all BlackGEM data instantly accessible:
  → A live database of any transient is maintained 'on the fly',
  live processing of 'previous' image during the night, instant alerts (T+5min)
  → All images kept on (spinning) disk for re-reductions and target photometry
  at any time
  → A live database of all sources, including variability.

- Complete set-up ideal for ***cloud solution*** on compute, database, storage BlackGEM data: the ***BlackCloud***.

- 1.8 Pb of data storage, 150 Tbyte of live database
  (3 telescopes)

Pipelines and calibration

- Data reduction software: **BlackBOX**: optimal image subtraction (Zackay, Ofek & Gal-Yam 2016) for the detection of transients
- **Photometric calibration** based on **stellar template fitting** of a combination of Gaia DR2/SDSS/PS1/SkyMapper/GALEX NUV and 2MASS J-band photometry
- Catalog with tens of millions of sources
    - 100 - 1000 stars per field in the BlackGEM photometric system
    - Ready to calibrate any image

Schedule BlackGEM

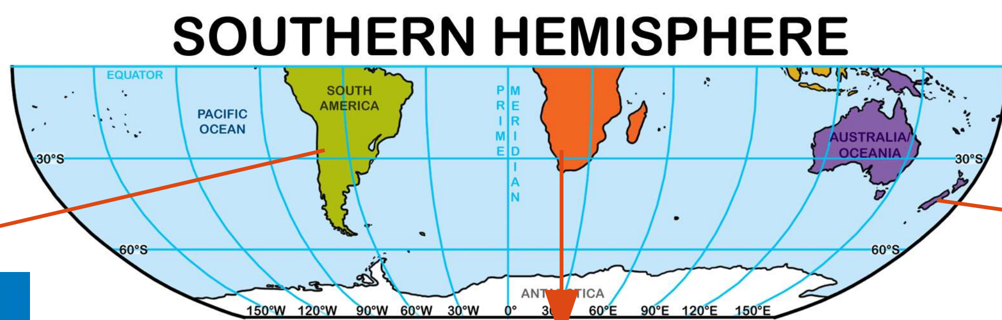
- Prototype testing @Radboud — February 2017
- Shipment MeerLICHT prototype → ZA — June 2017
- Commissioning MeerLICHT @SAAO — August-December 2017
- **Inauguration MeerLICHT — May 2018**
- Final Design Review BlackGEM — March, 2017
- Manufacturing BlackGEM-Phase1 2017 – 2018
- Testing BlackGEM telescopes in Groningen — 2018

now

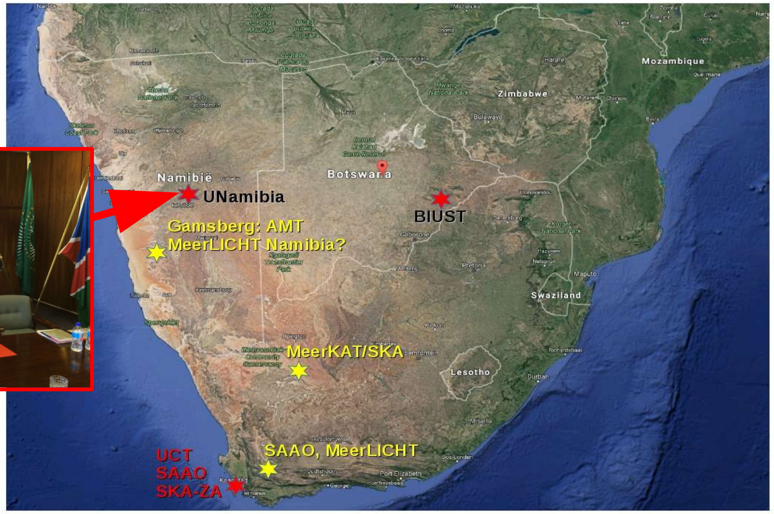
- Shipment BlackGEM → Chile — Early 2019
- **Commissioning BlackGEM-Phase1 — March 2019**
- Start operations Phase1 — April 2019

Future plans

- Expansion of BlackGEM to 15 telescopes (requires additional 15 MEuro)
- Chile, or NZ and/or Southern Africa
- Development/addition of low-cost spectroscopic telescopes



South Africa or Namibia



Mt. John
U. of Canterbury
Christchurch

CTIO Dark Energy Camera Capabilities & Surveys Summary

Time Domain Astronomy in the Era of Massively Multiplexed Spectroscopy

Will Dawson & Nathan Golovich
Lawrence Livermore National Laboratory

February 8-10, 2019

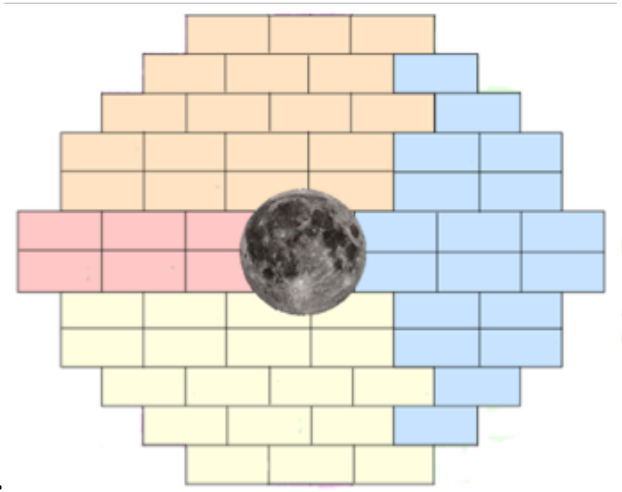
LLNL-PRES-766214
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

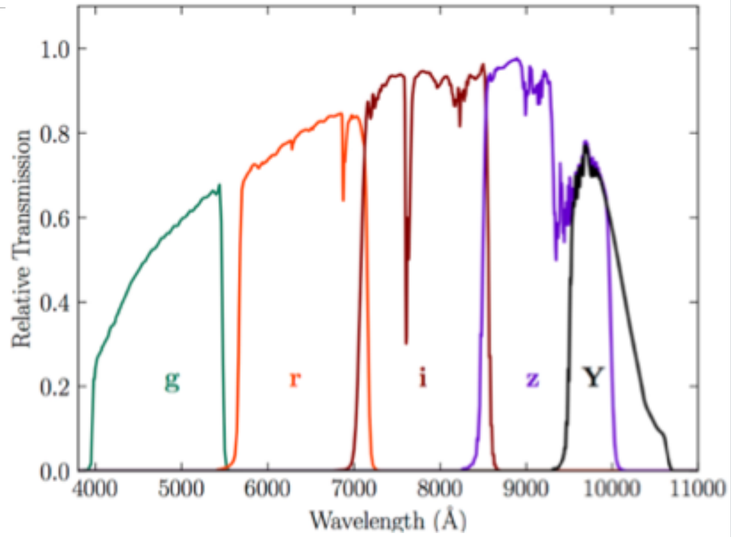
Lawrence Livermore National Laboratory

The CTIO Blanco 4-meter Telescope & The Dark Energy Camera

CTIO Blanco 4-meter and the Dark Energy Camera (DECam, which was built for the Dark Energy Survey)

- Located in Chile
- Blanco 4 m telescope
- Field of View: 2.2 deg; 3 deg^2
- Typical seeing ~1”
- 62 CCDs; 570 Mpix; 0.632” pixels
- Readout time: 20s
- **It is a community telescope**
  - **You can do short high-cadence surveys**
  - **You can do long sparse-cadence surveys**
  - **It is hard to do long high-cadence surveys (e.g. KMTNet, MOA, ZTF, OGLE, etc.)**

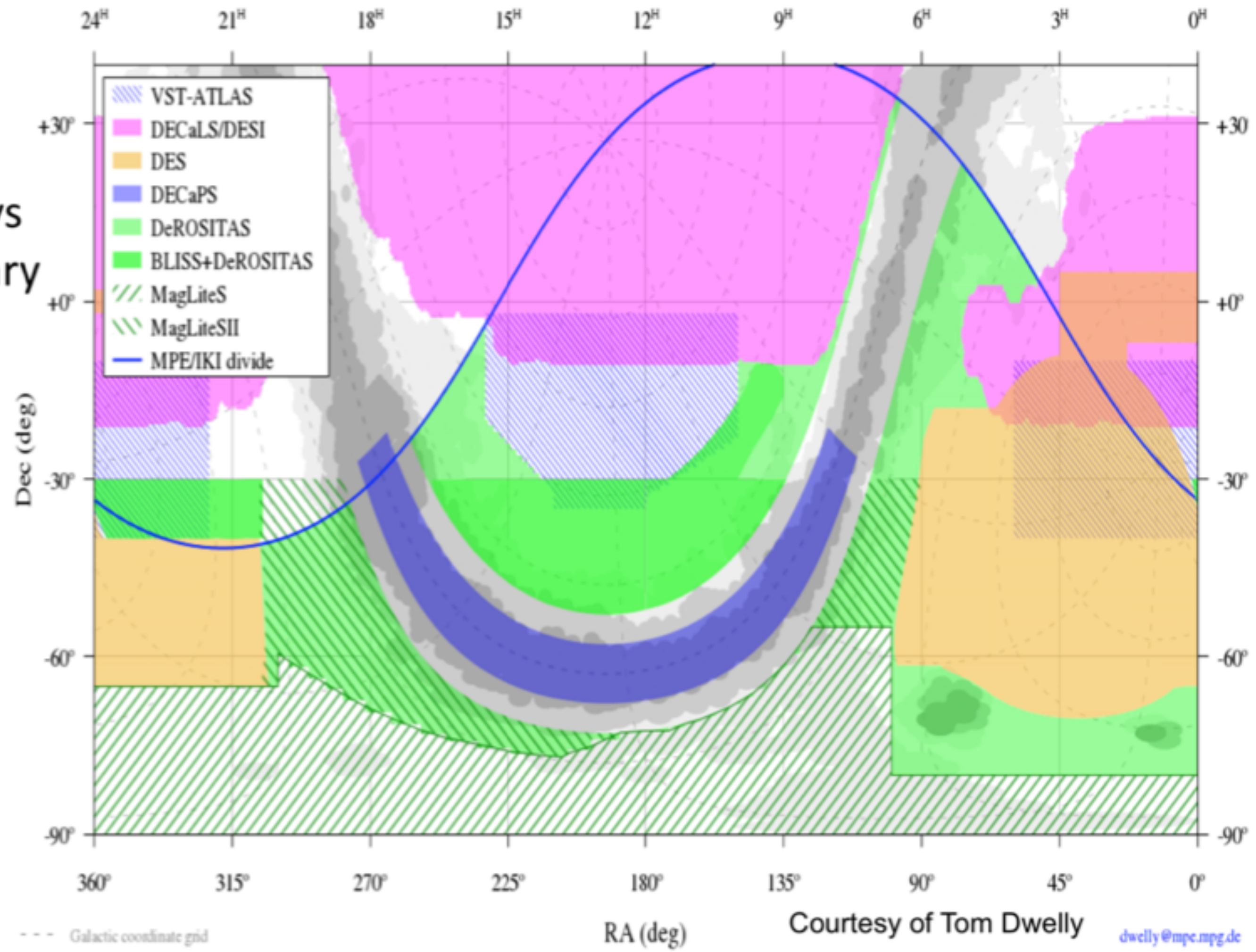




Existing and Planned Surveys

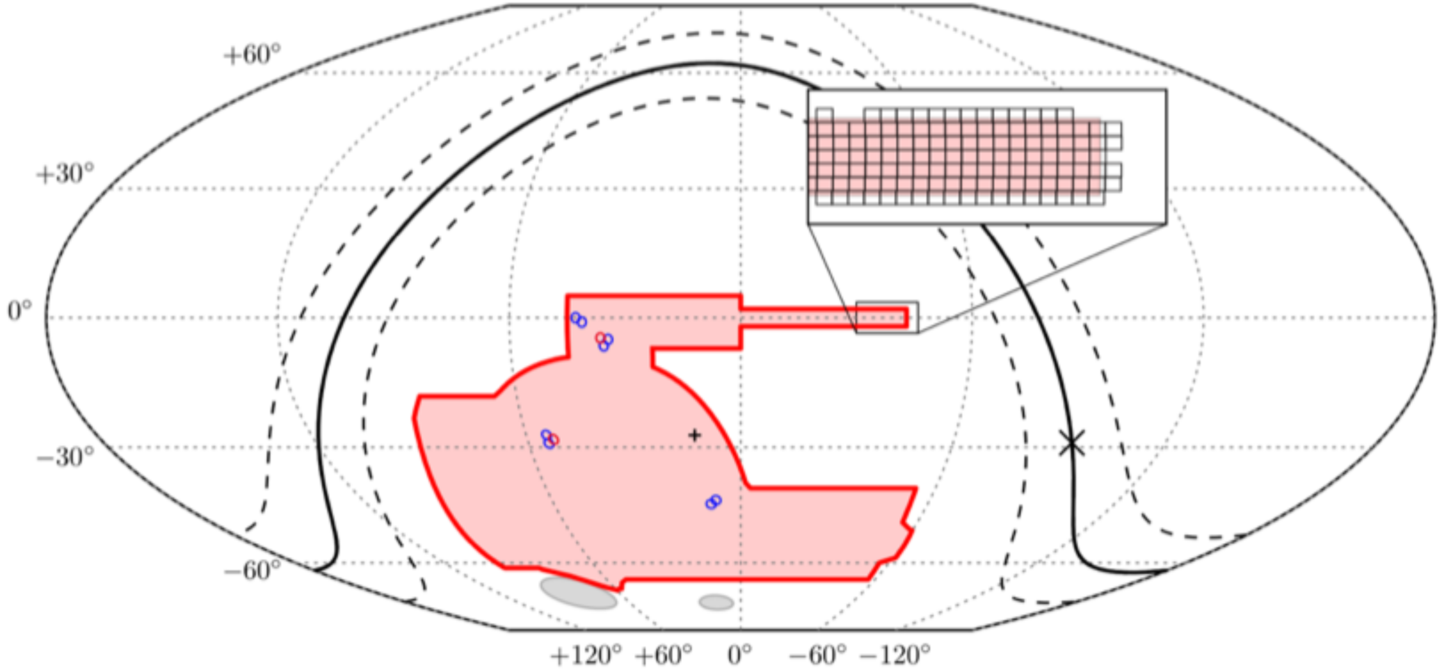
The vast majority of DECam time has been devoted to "non-time-domain" imaging surveys

Big Surveys Summary



Courtesy of Tom Dwelly

The Dark Energy Survey did include a time-domain survey component: The DES Supernova Survey



Blue circles: Shallow Fields
Red circles: Deep Fields

- 5-month-long seasons
- *griz* filters
- ~1 per week in all bands
- 8 shallow fields
  - ~23.5 mag per epoch
- 2 deep fields
  - ~24.5 mag per epoch

2019A Approved "Survey" Programs

Programs: 160
Nights: 673.84

Approved NOAO Survey Programs

PI / *Proposal Title*	Institution	Prop. ID	Site	Tel.	Nts.
Drlica-Wagner, Alex *DECam Dwarf Galaxy Survey*	Fermi National Accelerator Laboratory	2019A-0305	CTIO	4m	22
Hardegree-Ullman, Kevin *Atmospheric Survey of Giant Exoplanets Discovered by TESS*	California Institute of Technology--IPAC	2019A-0364	CTIO	SOAR	5
Hartigan, Patrick *The Carina Time-Series Deep Field*	Rice University	2019A-0101	CTIO	4m	21
Hartigan, Patrick *The Carina Time-Series Deep Field*	Rice University	2019A-0101	CTIO	SOAR	3
Penny, Matthew *Multi-band Imaging Survey for High-Alpha PlanetS (MISHAPS): Surveying the demographics of transiting hot Jupiters in the alpha-rich Galactic bulge*	Ohio State University	2019A-0315	CTIO	4m	3
Schlegel, David *The DECam Legacy Survey of the SDSS Equatorial Sky*	Lawrence Berkeley National Laboratory	2014B-0404	CTIO	4m	7
Trilling, David *The Deep DECam Outer Solar System Survey (DDOSSS)*	Northern Arizona University	2019A-0337	CTIO	4m	8.5
Zenteno, Alfredo *The DECam eROSITA Survey (DeROSITAS)*	Cerro Tololo Inter-American Observatory	2019A-0272	CTIO	4m	12
					81.5

DECam Time Domain Surveys

https://www.noao.edu/gateway/proplist/props19a/

2019A Approved "Long Term" Programs

Approved Long Term Programs

PI / *Proposal Title*	Institution	Prop. ID	Site	Tel.	Nts.
Bechtol, Keith *Magellanic Satellites Survey: The Search for Hierarchical Structures within the Local Group (Phase 2)*	Large Synoptic Survey Telescope	2018A-0242	CTIO	4m	6
Burgasser, Adam *Mass Measurements Across the Hydrogen Burning Limit: Astrometric Orbits for Spectral Binaries (Northern Sample)*	University of California, San Diego	2017A-0141	GEM-N	GEM-NQ	1.154
Dawson, William *PALS: Paralensing Survey of Intermediate Mass Black Holes*	Lawrence Livermore National Laboratory	2018A-0273	CTIO	4m	6
Gallenne, Alexandre *Multiplicity of Galactic Cepheids from long-baseline interferometry*	European Southern Observatory	2019A-0071	MtWilson	CHARA	4
Macri, Lucas *Cosmography of the innermost Zone of Avoidance with the 2MASS Redshift Survey*	Texas A & M University	2019A-0247	CTIO	SOAR	5
Malhotra, Sangeeta *Lyman Alpha Galaxies in the Epoch of Reionization*	NASA Goddard Space Flight Center	2018B-0327	CTIO	4m	5
Moskovitz, Nicholas *The Mission Accessible Near-Earth Object Survey (MANOS)*	Lowell Observatory	2017B-0111	CTIO	SOAR	6
Rest, Armin *Light Echoes of the Crab Supernova (SN 1054)*	Space Telescope Science Institute	2018A-0369	CTIO	4m	1.5
Rest, Armin *Photometric Time Series of Carinae's Great Eruption*	Space Telescope Science Institute	2018B-0122	CTIO	4m	4.5

DECam Time Domain Surveys

https://www.noao.edu/gateway/proplist/props19a/

Some examples of time domain surveys with DECam

Black hole dark matter microlensing searches should be carried out by DOE

One of five highlighted projects

recommend by US Cosmic Visions Report Complementarity Working Group

US Cosmic Visions: New Ideas in Dark Matter 2017 : Community Report

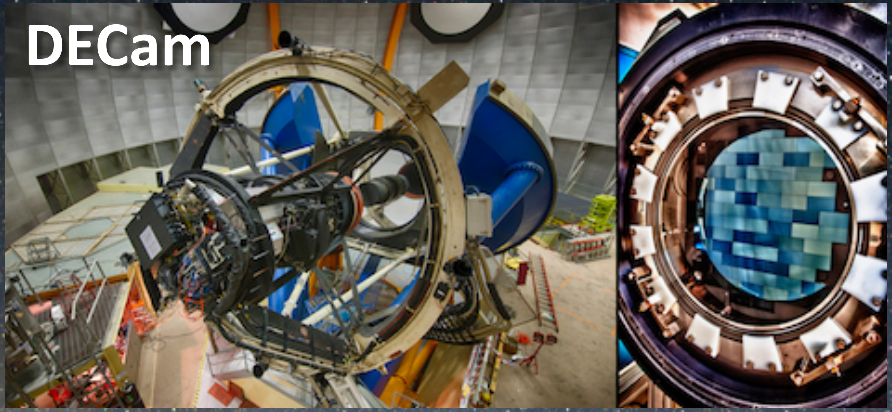
Marco Battaglieri (SAC co-chair),[1] Alberto Belloni (Coordinator),[2] Aaron Chou (WG2 Convener),[3] Priscilla Cushman (Coordinator),[4] Bertrand Echenard (WG3 Convener),[5]

- *Microlensing Searches for Solar Mass Black Hole Dark Matter.* The LIGO observation of colliding $\sim 30 M_{\odot}$ mass black holes has renewed interest in the possibility that such black holes make up some or all of the dark matter. **The LIGO discovery of gravitational waves from colliding black holes strongly motivate a proposed microlensing search that can confirm or exclude the possibility of intermediate mass black hole dark matter using existing facilities with minimal funding.**

NOAO – Carrying out pilot 32 night / 2 year survey for primordial black holes; **highest rated proposal** in 2017. Invited to DECam Science Workshop 2018. **Recommended future survey** (NOAO, May 2018).

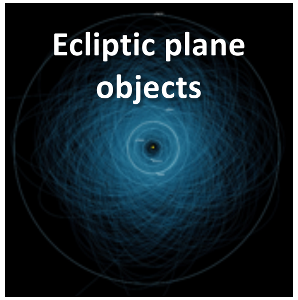
The ongoing PALS: DOE DECam Microlensing Survey could deliver constraints within the year

- 3 fields: Bulge, LMC, SMC
- 32 nights over 2-years
- First light February 2018
- Could place the <u>tightest and most direct constraints</u> on primordial black hole dark matter
- Can directly measure mass and location of individual black holes
  - — Particle phase-space that can only be measured astrophysically



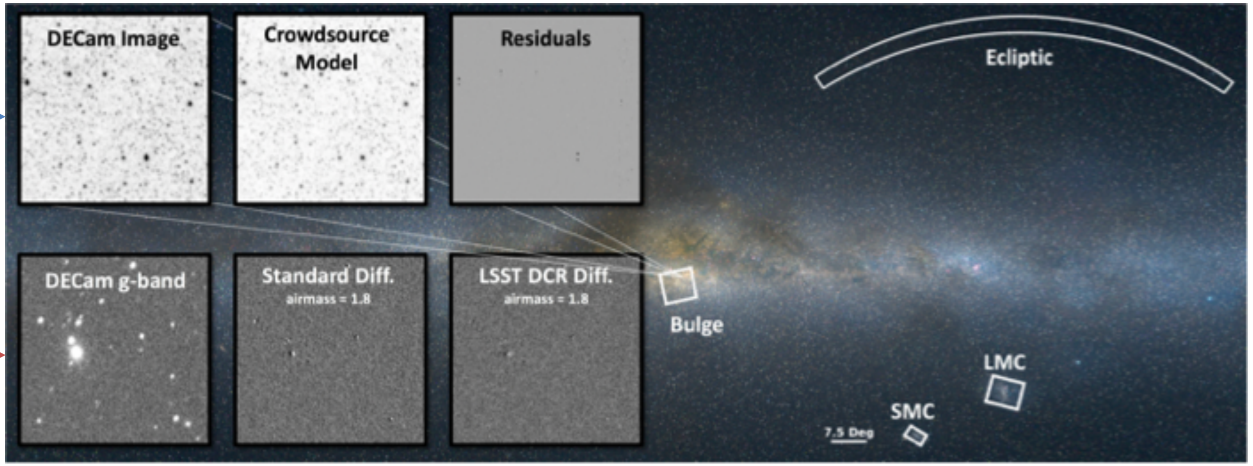
LLNL has an LDRD funded and NOAO awarded DECam black hole microlensing pilot survey

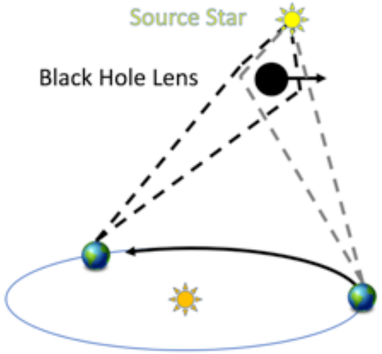
- Ongoing 32 night – two year DECam survey as LSST precursor
- Proposal submitted to extend current DECam black hole dark matter survey
  - *Grow survey 98 nights per year for the next three years; LSST precursor*
  - Add shorter time cadence aspect which will:
    - Detect free floating black holes and neutron stars
    - Detect exo-planets via planetary microlensing
    - Characterize variable stars in the Milky Way
    - Discover NEOs and PHAs and other ecliptic plane objects

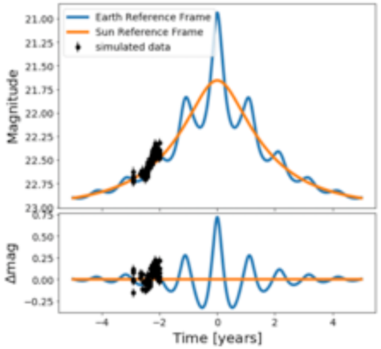


Crowdsource dense field photometry

LSST DM Stack Difference Imaging







The DECam NEO Survey of Near Earth Asteroids

NEO Survey Observations

- DECam Survey: 30 nights over 3 semesters
- Cover >340 sq. deg. in ~600 exposures per full night
- 40 sec. exposures in VR filter ($5\sigma = 23.5$ mag)
- 5 exposures per field with 5 minute cadence = 1 "quad"
- repeat fields on 2nd and 3rd (and 4th…) night

https://www.noao.edu/meetings/decam2018/presentations/Allen-Lori.pdf

The DECam NEO Survey of leveraged the large etendue to characterize NEOs from 1000 m – 10 m in a 30 night survey

THE ASTRONOMICAL JOURNAL, 154:170 (10pp), 2017 October https://doi.org/10.3847/1538-3881/aa8036

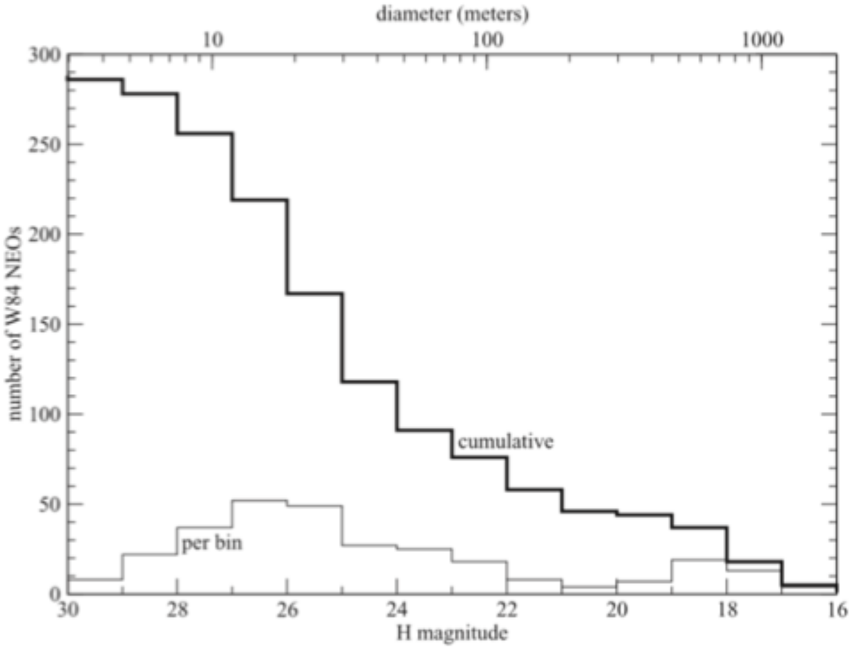
CrossMark

The Size Distribution of Near-Earth Objects Larger Than 10 m

D. E. Trilling[1,2,3,8], F. Valdes[4], L. Allen[4,8], D. James[5,8], C. Fuentes[6,8], D. Herrera[4,8], T. Axelrod[7,8], and J. Rajagopal[4,8]
[1] Department of Physics and Astronomy P.O. Box 6010 Northern Arizona University Flagstaff, AZ 86011, USA; david.trilling@nau.edu
[2] South African Astronomical Observatory P.O. Box 9 7935 Observatory, South Africa
[3] University of the Western Cape Bellville Cape Town 7535, South Africa
[4] National Optical Astronomy Observatory 950 N. Cherry Avenue Tucson, AZ 85719, USA
[5] Cerro Tololo Inter-American Observatory National Optical Astronomy Observatory Casilla 603 La Serena, Chile
[6] Departamento de Astronomia Universidad de Chile Camino El Observatorio #1515 Casilla 36-D Las Condes Santiago, Chile
[7] University of Arizona Steward Observatory 933 N. Cherry Avenue Tucson, AZ 85721, USA
Received 2016 April 21; revised 2017 July 4; accepted 2017 July 7; published 2017 September 29

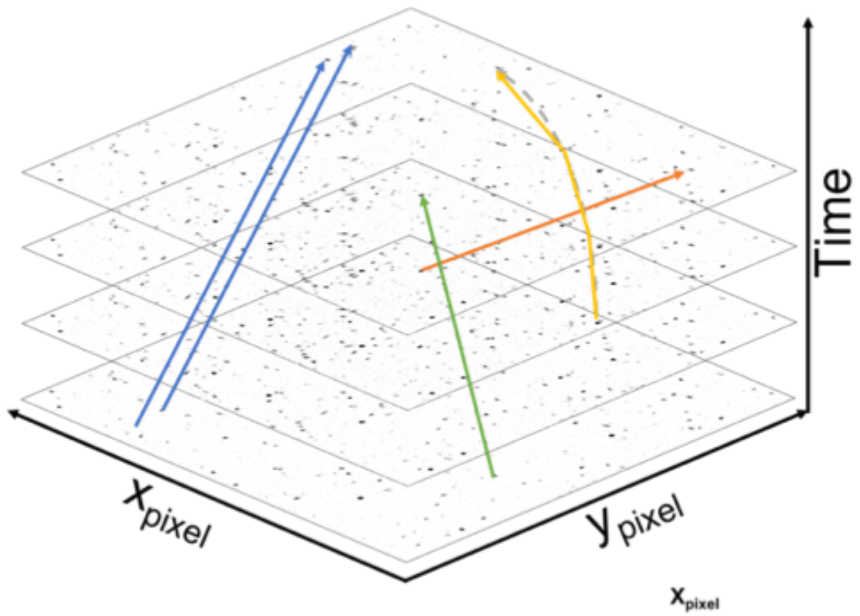
Abstract

We analyzed data from the first year of a survey for Near-Earth Objects (NEOs) that we are carrying out with the Dark Energy Camera (DECam) on the 4 m Blanco telescope at the Cerro Tololo Inter-American Observatory. We implanted synthetic NEOs into the data stream to derive our nightly detection efficiency as a function of magnitude and rate of motion. Using these measured efficiencies and the solar system absolute magnitudes derived by the Minor Planet Center for the 1377 measurements of 235 unique NEOs detected, we directly derive, for the first time from a single observational data set, the NEO size distribution from 1 km down to 10 m. We find that there are $10^{6.6}$ NEOs larger than 10 m. This result implies a factor of 10 fewer small NEOs than some previous results, though our derived size distribution is in good agreement with several other estimates.

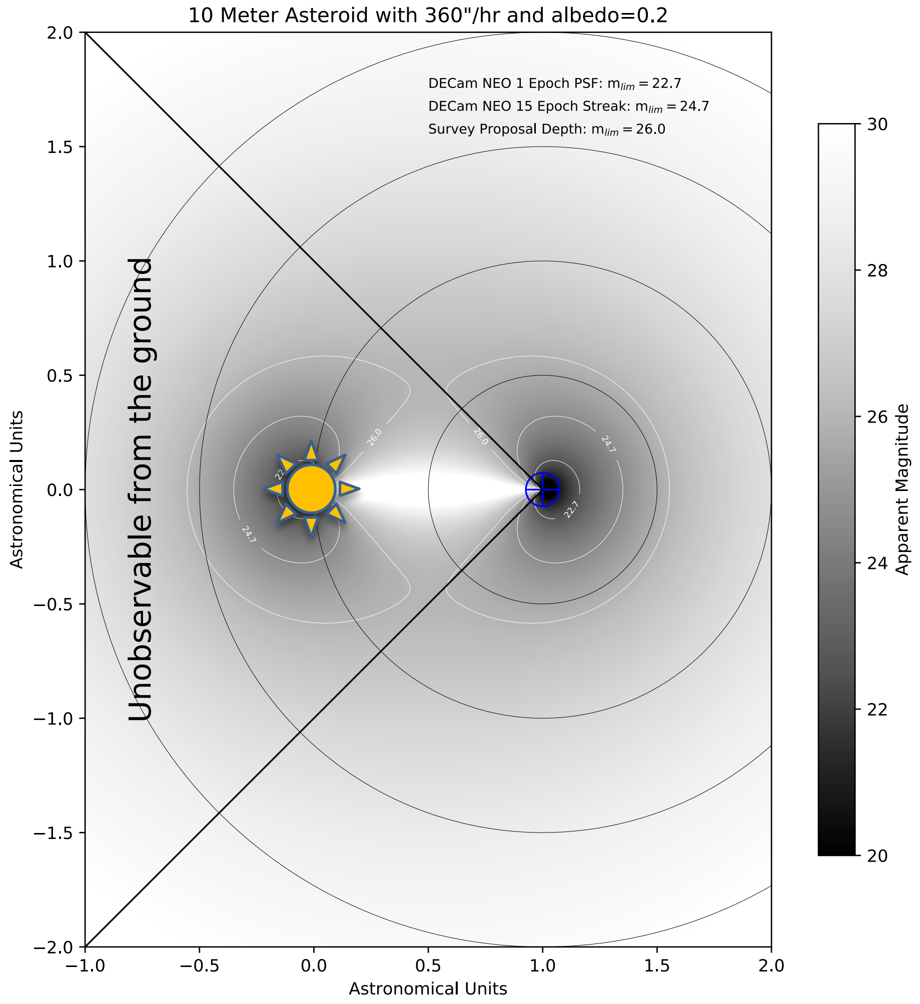


There is room for NEO survey improvement through algorithms and atypical survey strategy

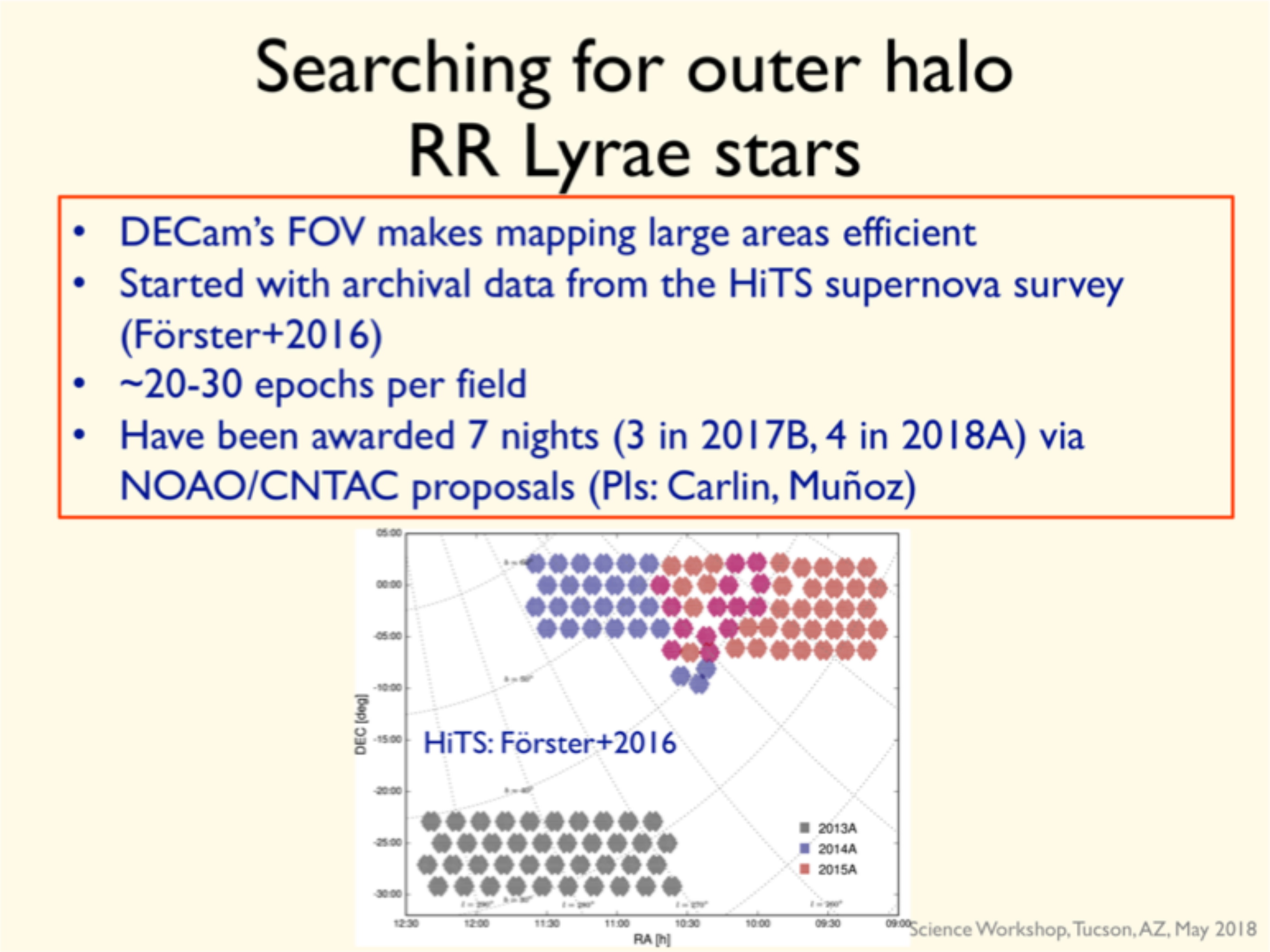
Shift and stack algorithms can enable > order of magnitude improvement in faint asteroid identification/characterization.

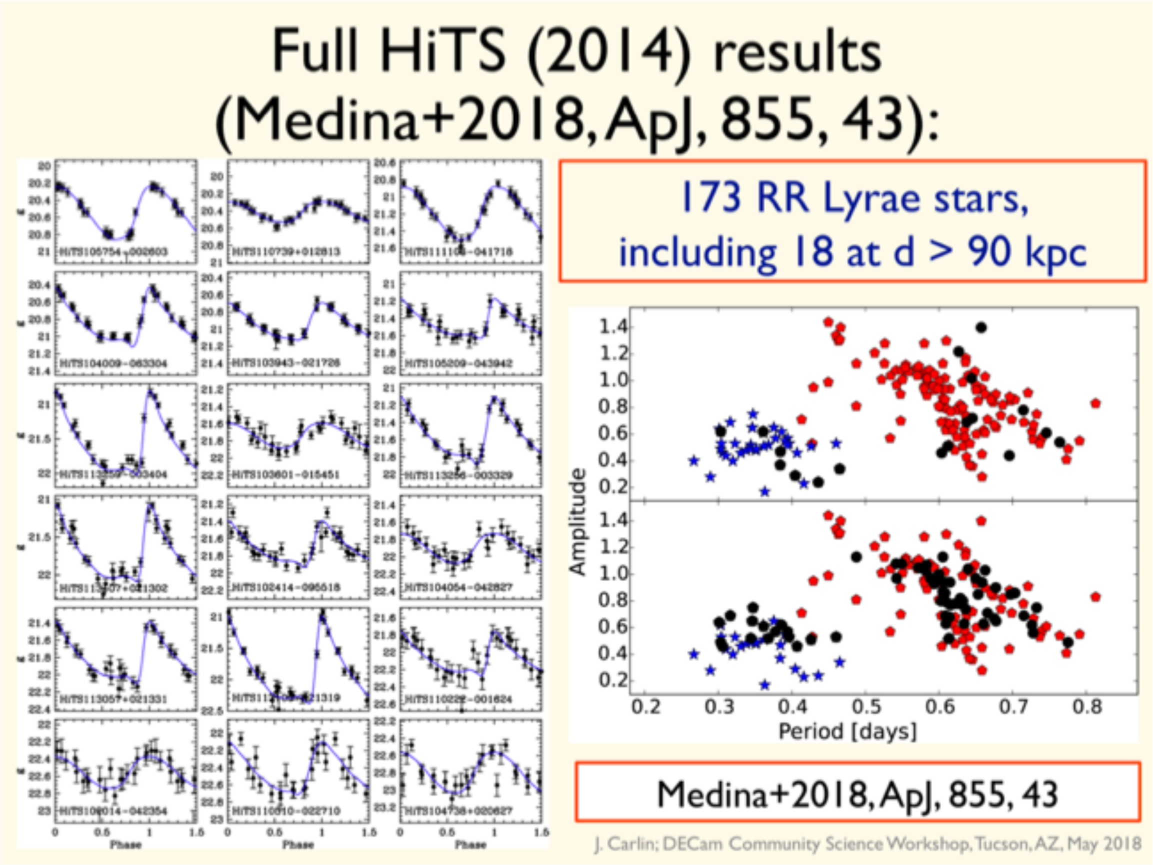


Observing strategy changes can make NEO Trojans and other potentially hazardous asteroids more observable from ground-based telescopes.



DECam searches for RR Lyrae stars





https://www.noao.edu/meetings/decam2018/presentations/Carlin-Jeff.pdf

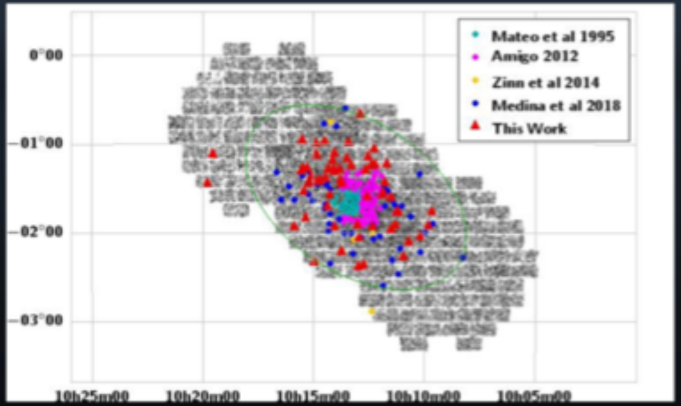
DECam searches for dwarf Cepheid stars

The challenge of observing dwarf cepheid stars

- Faint (2-3 mags below HB)
- Periods are short (1-2 hours) → exposure times cannot be long
- Some galaxies are quite extended

DECam Community Science Workshop 2018 10

Observations



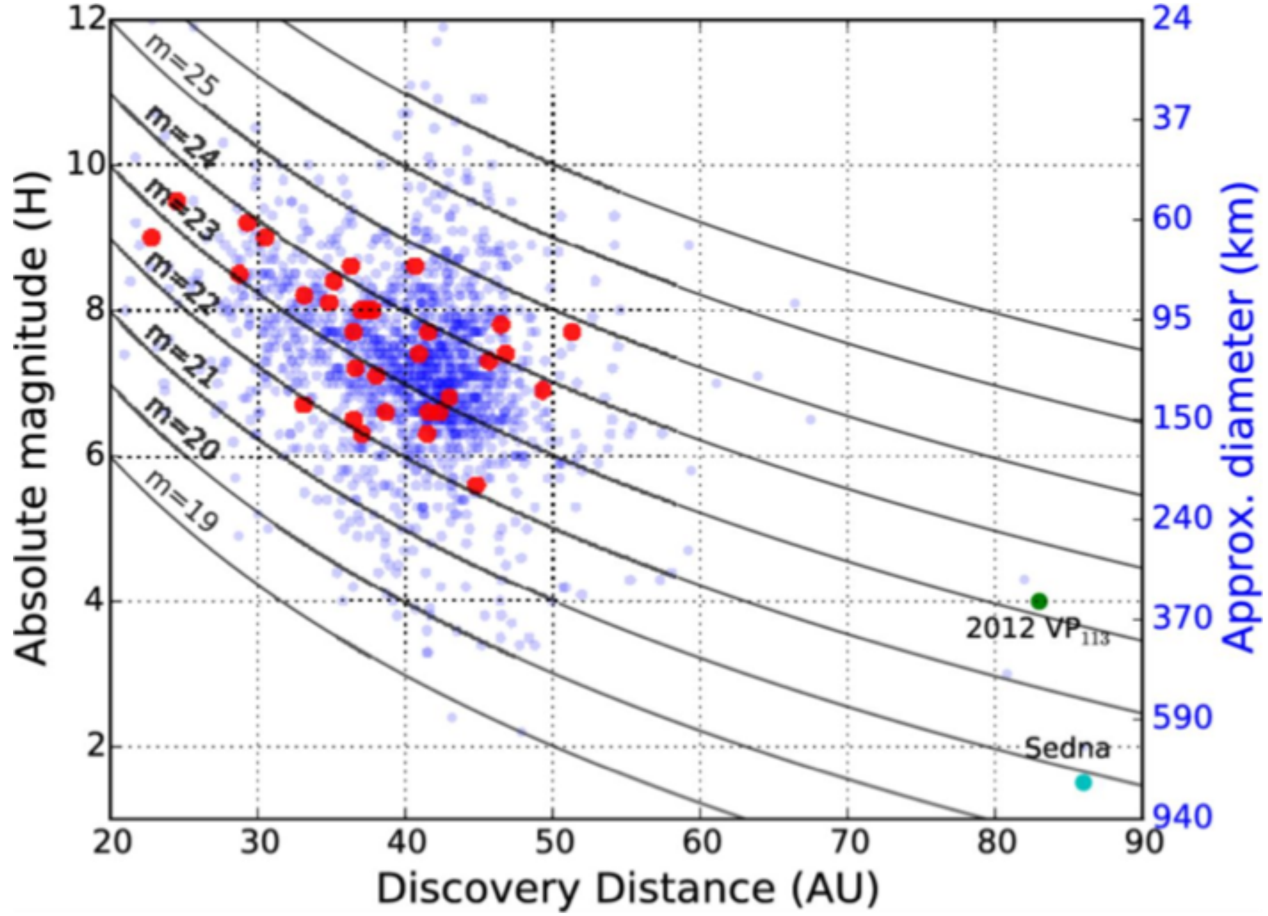
Tidal radius = 83.2 arcmin (Roderick et al 2017)

Time series in g and r (~30 epochs/band, with a cadence of ~10 minutes). Central field has multi-epoch data only in g

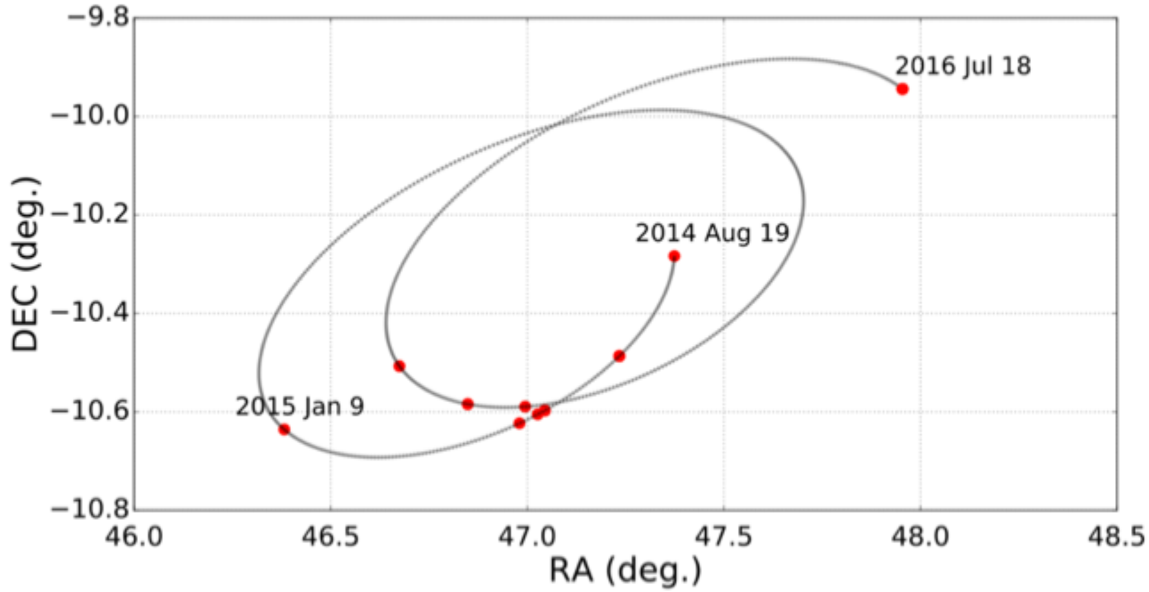
DECam Community Science Workshop 2018 18

https://www.noao.edu/meetings/decam2018/presentations/Vivas-Kathy.pdf

Trans-Neptunian Objects, Keiper Belt Objects, & Planet 9 Survey enabled by large etendue



DES Collaboration 2016



Gerdes et al. 2017

Some examples of time domain surveys with DECam

Note that a 2016 study did not state multi-object-spectroscopy as an important complement to transient science (What will we find?)

Maximizing Science in the Era of LSST: A Community-Based Study of Needed US OIR Capabilities

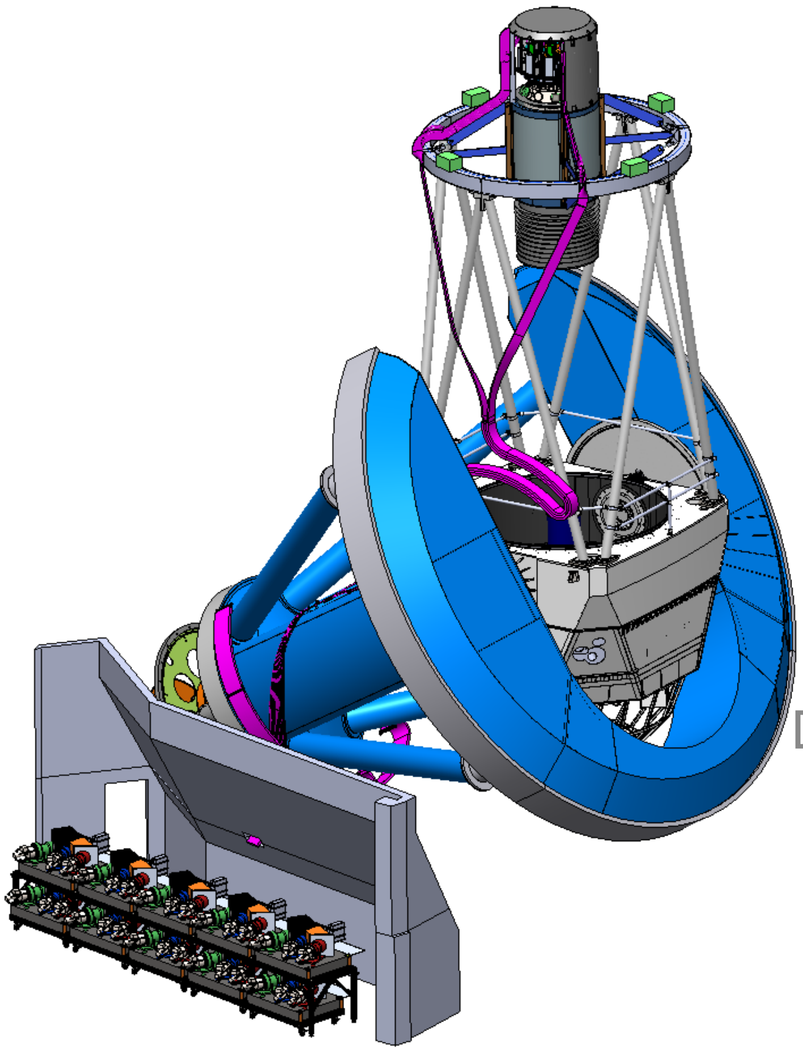
A report on the Kavli Futures Symposium organized by NOAO and LSST

Joan Najita (NOAO) and Beth Willman (LSST)
Douglas P. Finkbeiner (Harvard University)
Ryan J. Foley (University of California, Santa Cruz)
Suzanne Hawley (University of Washington)
Jeffrey Newman (University of Pittsburgh)
Gregory Rudnick (University of Kansas)
Joshua D. Simon (Carnegie Observatories)
David Trilling (Northern Arizona University)
Rachel Street (Las Cumbres Observatory Global Telescope Network)
Adam Bolton (NOAO)
Ruth Angus (University of Oxford)
Eric F. Bell (University of Michigan)
Derek Buzasi (Florida Gulf Coast University)
David Ciardi (IPAC, Caltech)
James R. A. Davenport (Western Washington University)
Will Dawson ((Lawrence Livermore National Laboratory)

Table 11.1. Instrumentation Capabilities Needed to Maximize LSST Science

Capability	Telescope Aperture			
	< 3m	3–5m	8–10m	≳ 25m
Optical Imager (Wide-field)	Solar System **Stars** Transients *Dark Energy*	**Solar System** **Stars** Milky Way Transients *Dark Energy*	**Solar System** **Stars** Transients Galaxy Evolution	Transients *Solar System*
NIR Imager		Transients	Transients *Milky Way*	Transients
AO IFU R ~ 5000			**Galaxy Evolution** Dark Energy	**Galaxy Evolution** Dark Energy
OIR MOS R = 5000 0.35–1.3 micron		**Stars** **Galaxy Evolution** **Dark Energy**	**Stars** **Milky Way** **Galaxy Evolution** **Dark Energy**	**Galaxy Evolution** Dark Energy *Milky Way*
Optical SOS R = 1k–5k 0.35–2.5 micron	Stars	**Solar System** Stars Transients	**Solar System** **Transients** **Galaxy Evolution** Stars *Milky Way* *Dark Energy*	**Transients** Solar System
Optical SOS R > 20,000			Stars *Transients* *Galaxy Evolution*	Stars *Transients* *Galaxy Evolution*
OIR MOS R > 20,000			**Milky Way** **Stars**	**Stars** *Milky Way*

Entries in boldface type indicate that the capability is **Priority 1 (critical)** for that science topic.
Roman type indicates Priority 2 (very important).
Italic type indicates *Priority 3 (important).*



DESI Project Overview

Peter Nugent(LBNL)
Department Head for Computational Science
Lawrence Berkeley National Laboratory

DESI Scientific Experiment Goals

Using the DESI Instrument fabricated by the project…

- We will observe 14,000 deg^2 of the night sky
- Will study the distribution of ~ 35M distant galaxies (correlations between them)
- The DESI Science Goals echo the CD-0 and P5 recommendations: precision measurement of dark energy, while making important contributions to the physics of inflation and neutrinos
- The Science Requirements Document (SRD) flows these science goals to the instrument requirements
- We use a rigorous Systems Engineering approach to tie the science to the requirements for the experiment

CD-0 Mission Need Statement defines the DESI science goals

- Mission Need Statement:
  - *1. Determine as well as possible whether the accelerating expansion is consistent with a cosmological constant.*
  - *2. Measure as well as possible any time evolution of the dark energy.*
  - *3. Search for a possible failure of general relativity through comparison of the effect of dark energy on cosmic expansion with the effect of dark energy on the growth of cosmological structures like galaxies or galaxy clusters.*

- Will use Baryon Acoustic Oscillation (BAO) & Redshift Space Distortion (RSD) techniques
- BAO gives us a ruler in the sky and enables us to measure the expansion of the Universe
- RSD allows us to measure the pull of gravity and check General Relativity

DESI will be the largest spectroscopic survey for dark energy. Each spectrum measures a galaxy redshift.

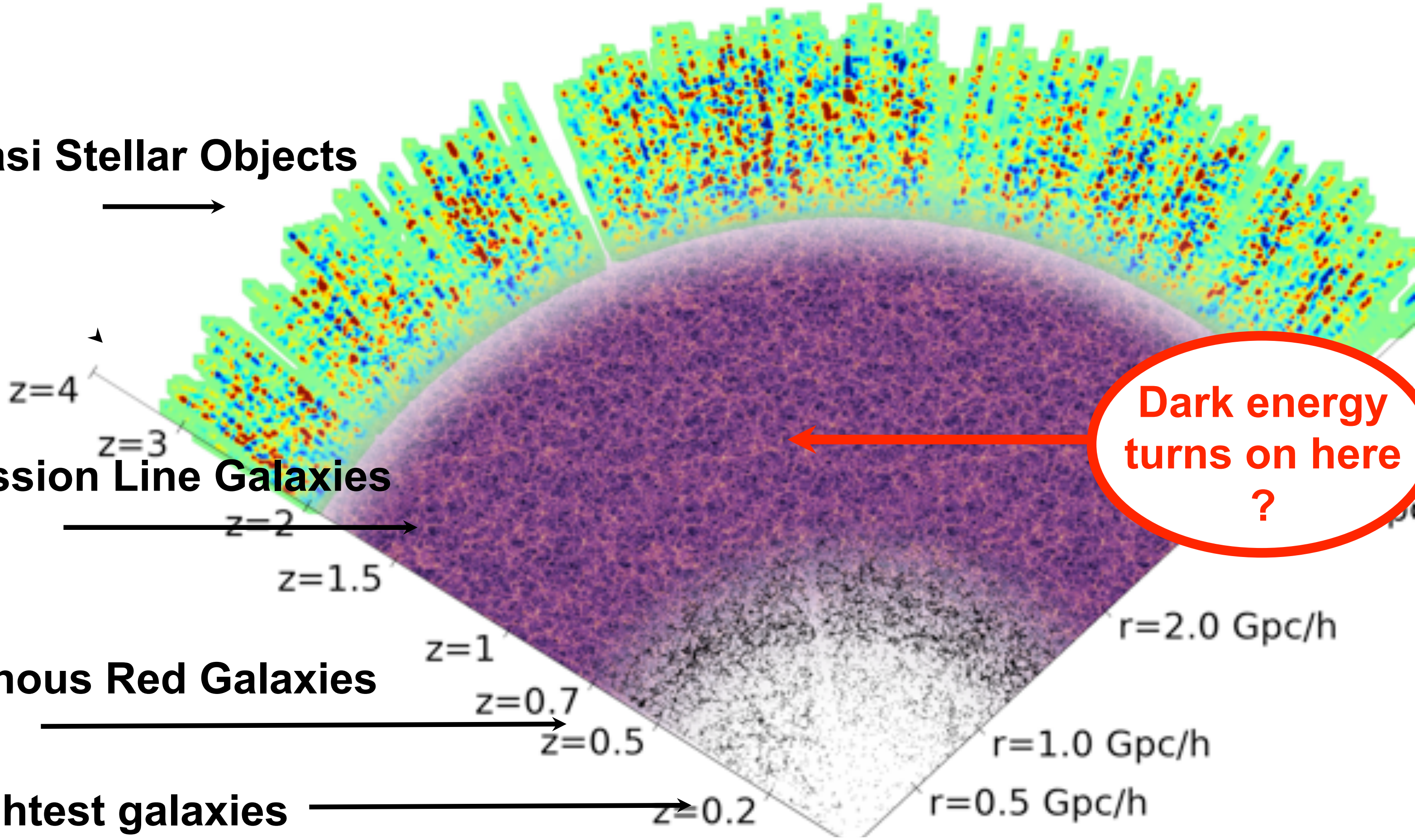
DESI will explore a x30 larger map over a x10 larger volume than SDSS

2.4 million Quasi Stellar Objects (QSO)

17 million Emission Line Galaxies (ELG)

4 million Luminous Red Galaxies (LRG)

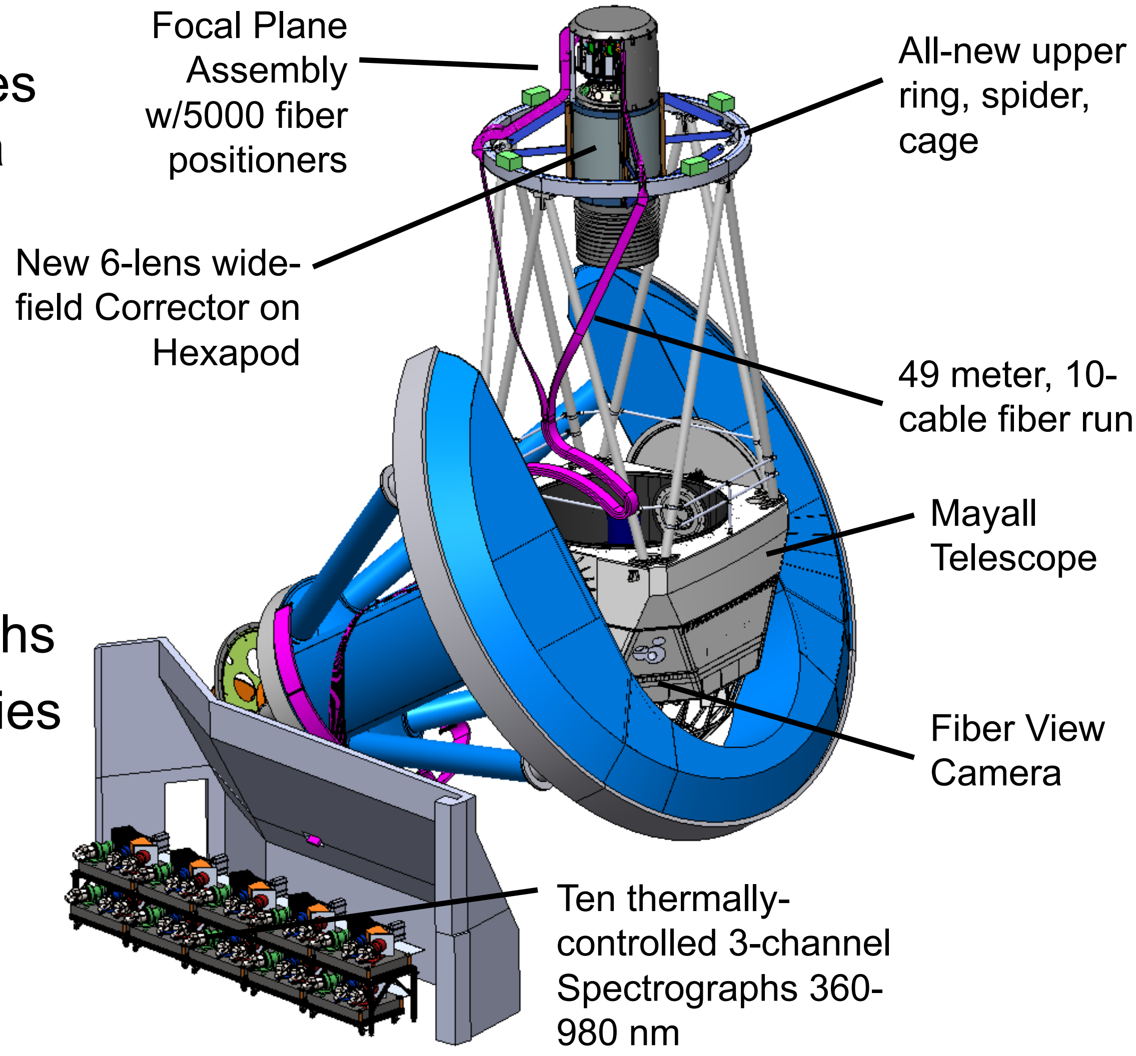
10 million brightest galaxies



DESI is being installed at the Mayall 4-m Telescope at Kitt Peak, Arizona

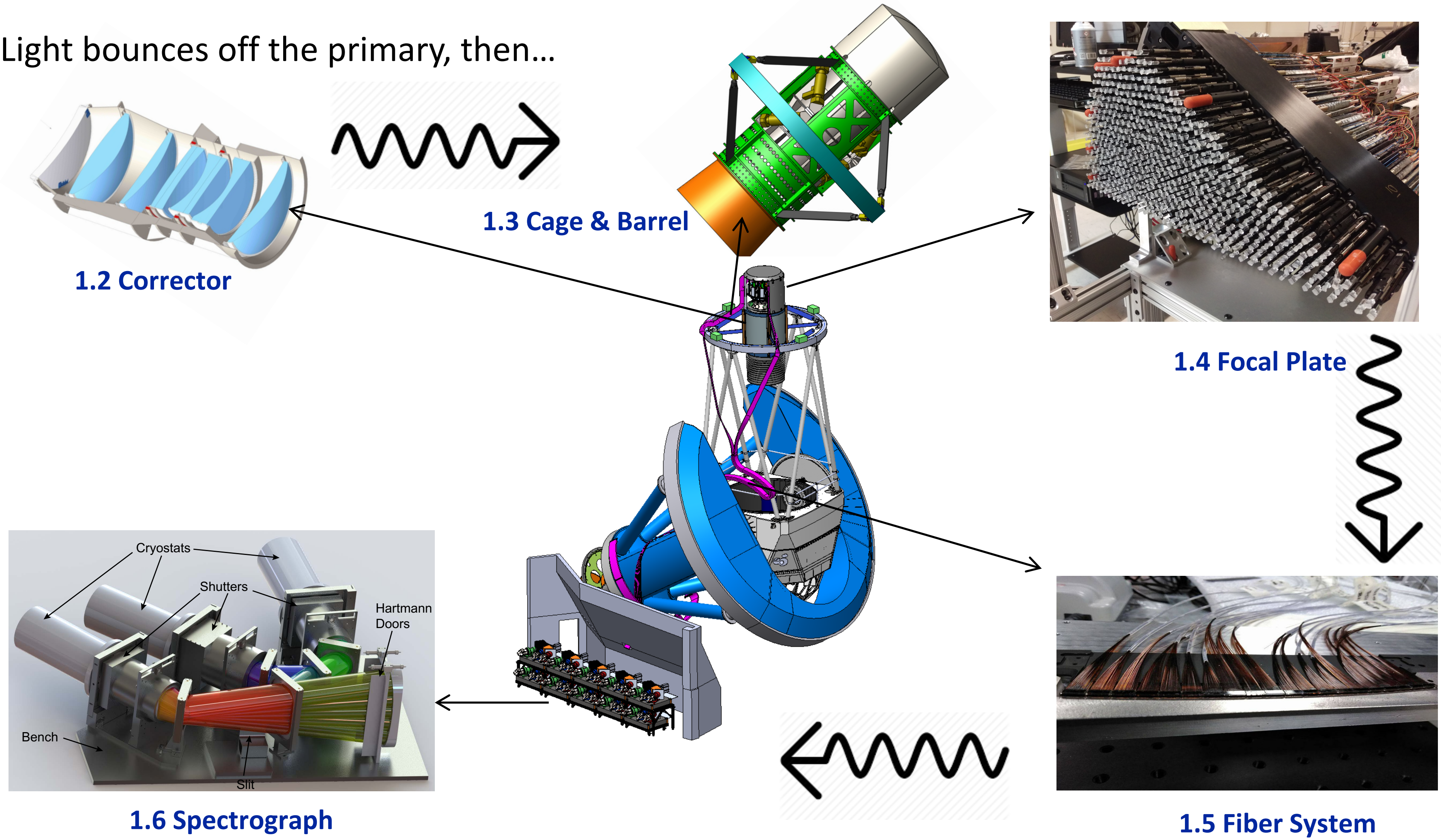
DESI Overview

- DESI is a Fiber-fed multi-object spectrograph. It uses robotic control to position a fiber optic strand onto the location of a known galaxy
- 5000 robotically positioned optical fibers on the focal plane
- New 8 sq.deg. FOV
- Ten 3-channel spectrographs
- Spectra of 35 million galaxies and quasars over 14,000 deg^2 in five years



Hardware Elements: following the path of a photon

Light bounces off the primary, then…



Top-end removal

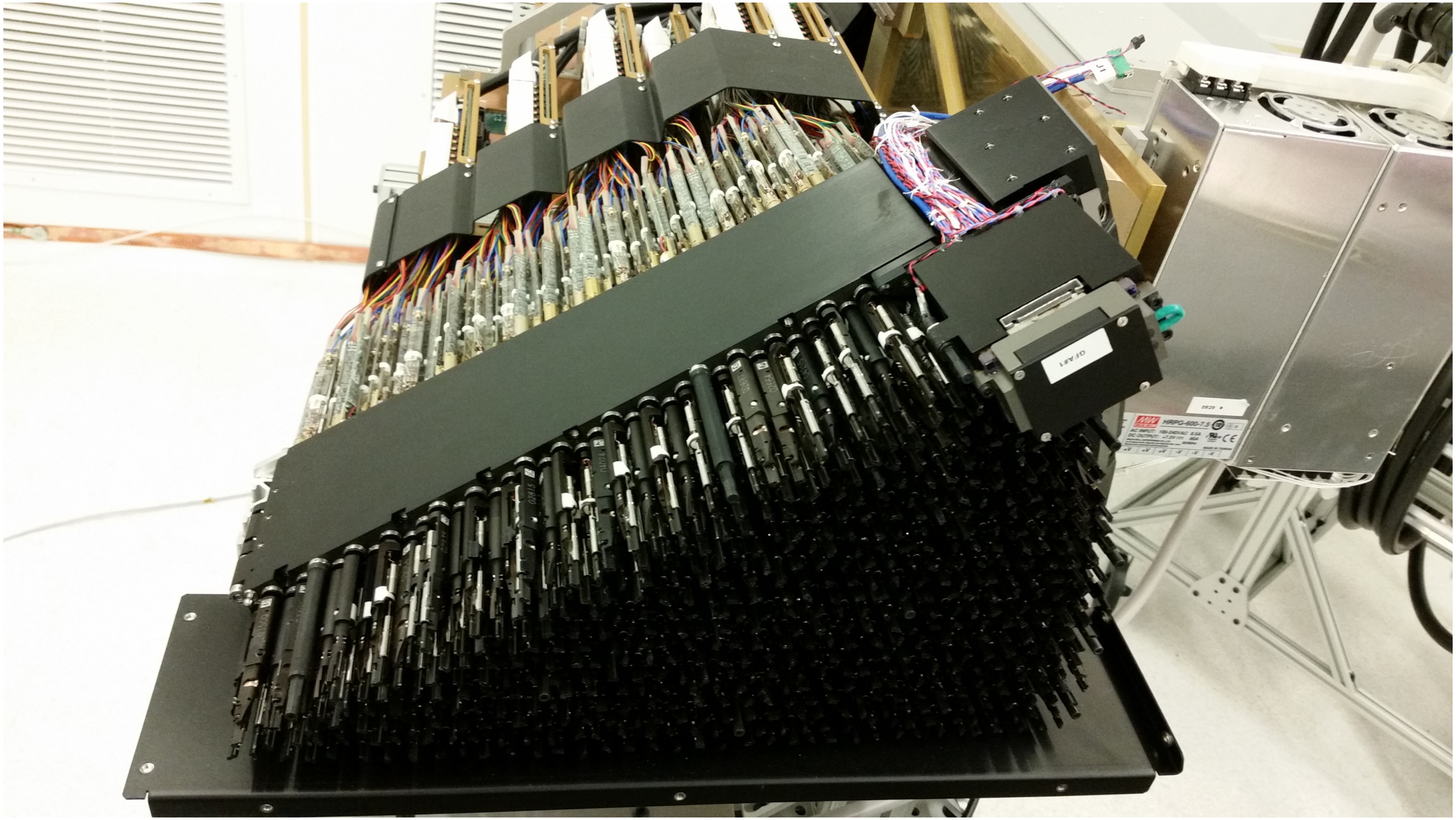
With help of a very large crane….

WBS 1.3 Corrector Mechanical Support System is complete (FNAL deliverable)

Cage and Ring being delivered to the Mayall telescope building

Assembled to go on the top-end of the telescope

WBS 1.4 Completed Production Petal with Guider, eight of ten are finished

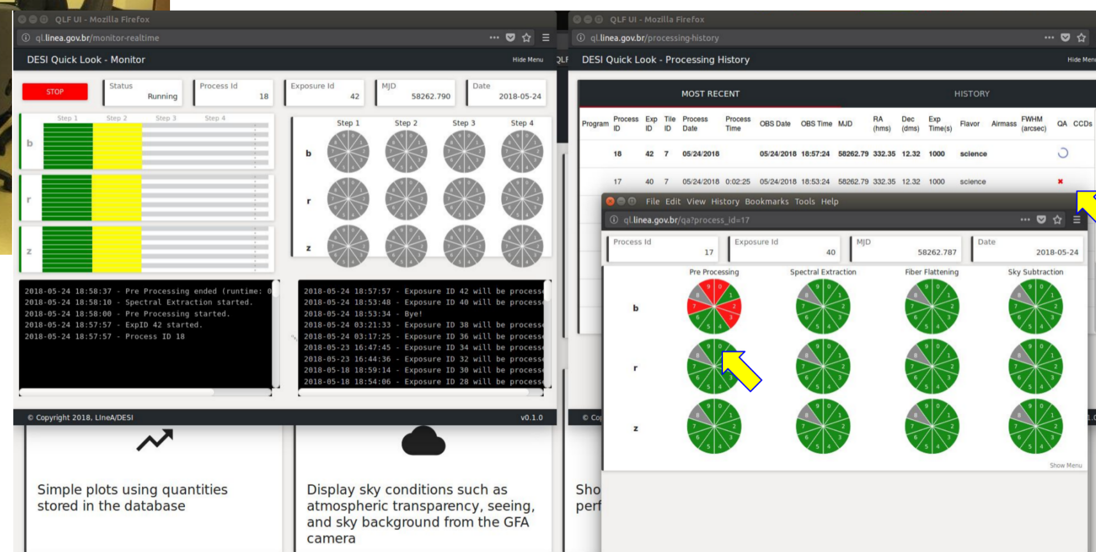


WBS 1.6 Spectrograph System

First of ten spectrographs delivered to Kitt Peak

WBS 1.7 Instrument Control System is completed

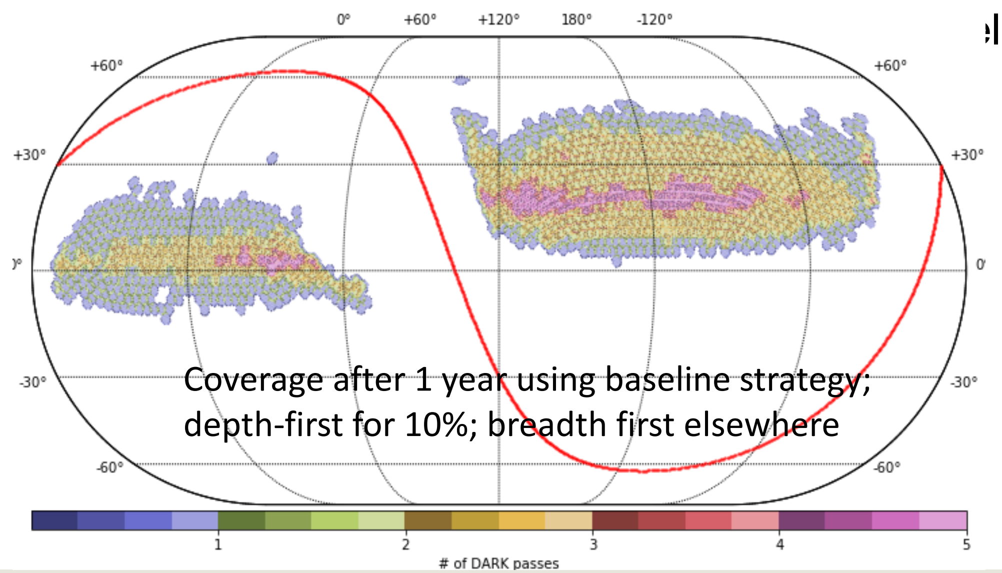
- New control room constructed
- Mock Observing Run at Kitt Peak
- All deliverables received and accepted

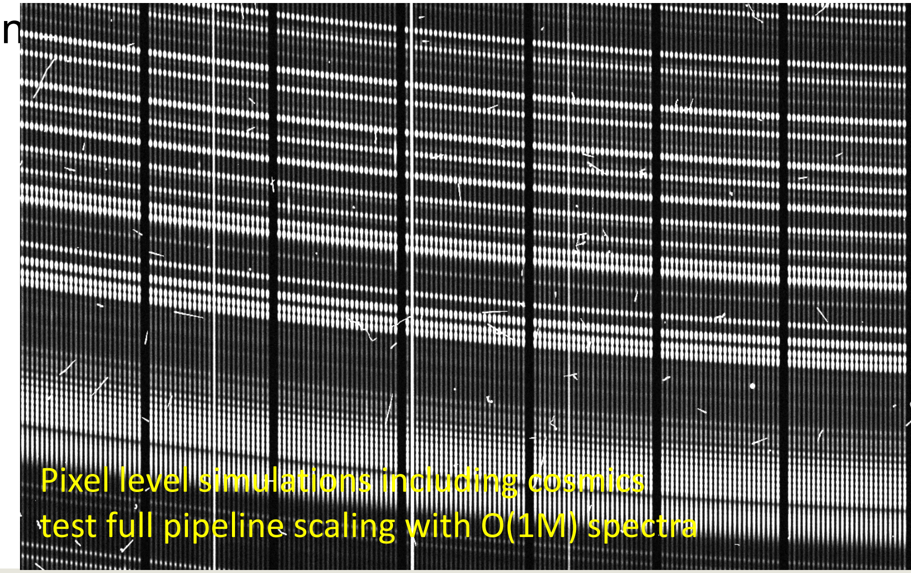


WBS 1.8 Data Systems is completed

WBS 1.8 Data Systems

- All deliverables received and accepted
- Spectroscopic data reduction pipeline
  - Refined algorithms using EM spectrograph data, e/BOSS data, pixel-level sims
  - Testing performance and scaling at NERSC, routinely processing ~1M spectra
- Data challenges at multiple levels of fidelity / completeness
  - Full 5 year survey operations simulations
  - Spectra simulations + calibrations + redshifts for ~5M spectra

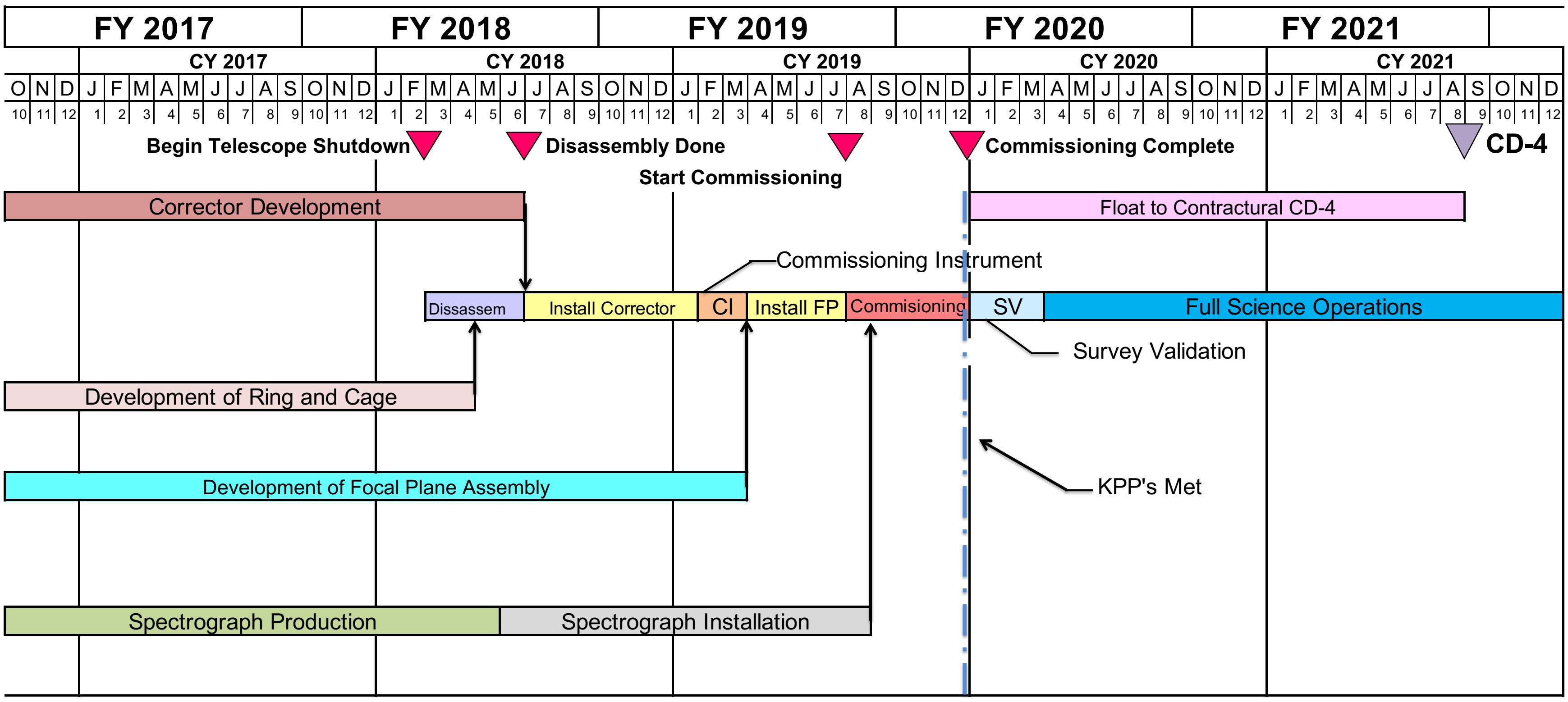




Transition to Operations Schedule

Activities for transitioning from design and fabrication of the instrument to reaching full science operations at the Mayall telescope

Schedule of Activities for Transition to Operations **2019-09-30**



Status on imaging

Pre-imaging over 14,000 sq. deg required for target selection

Three optical surveys

- **North** **BASS** gr **95% completed**
  (*5k deg^2*) **MzLS** z **100% completed**
- **South** **DECaLS** grz **97% completed**
  (*9k deg^2*)

One infrared survey

- **All Sky WISE**
  (NASA satellite)
  W_1 W_2 **125% completed**

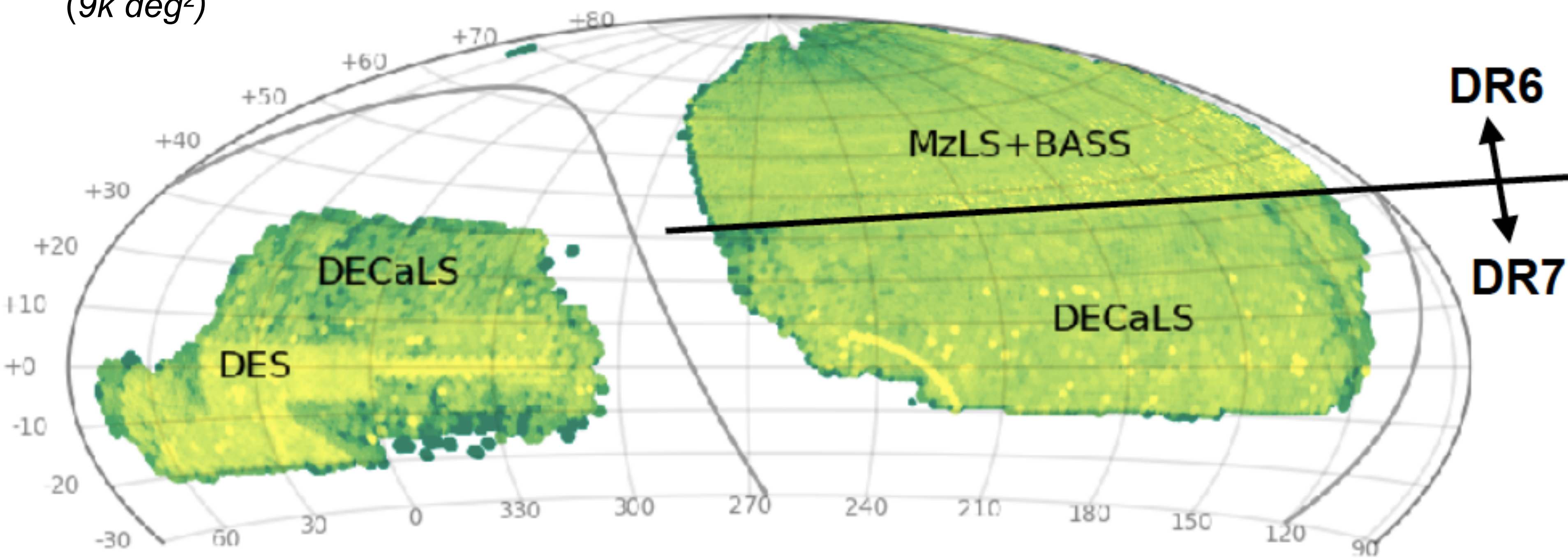
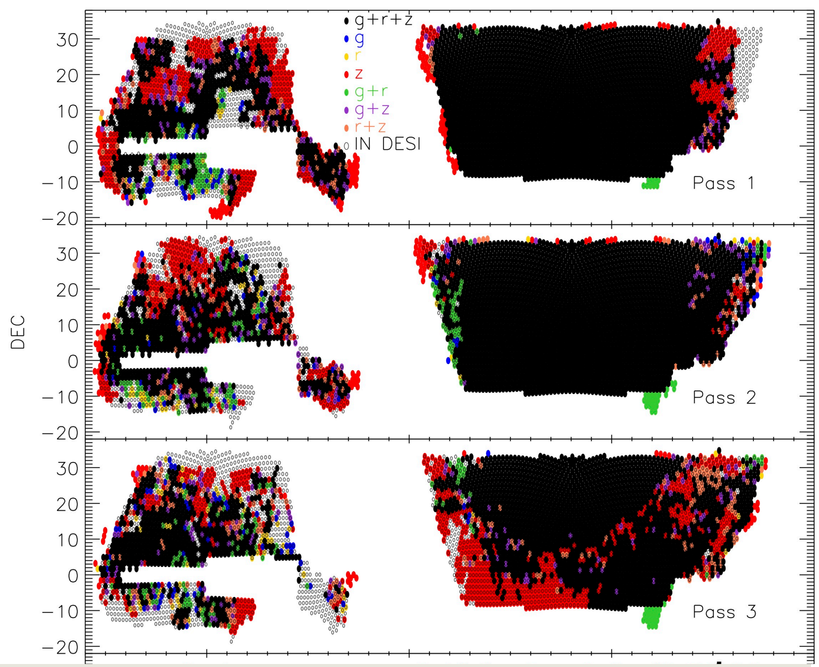


Image validation WG chair: E. Gaztanaga

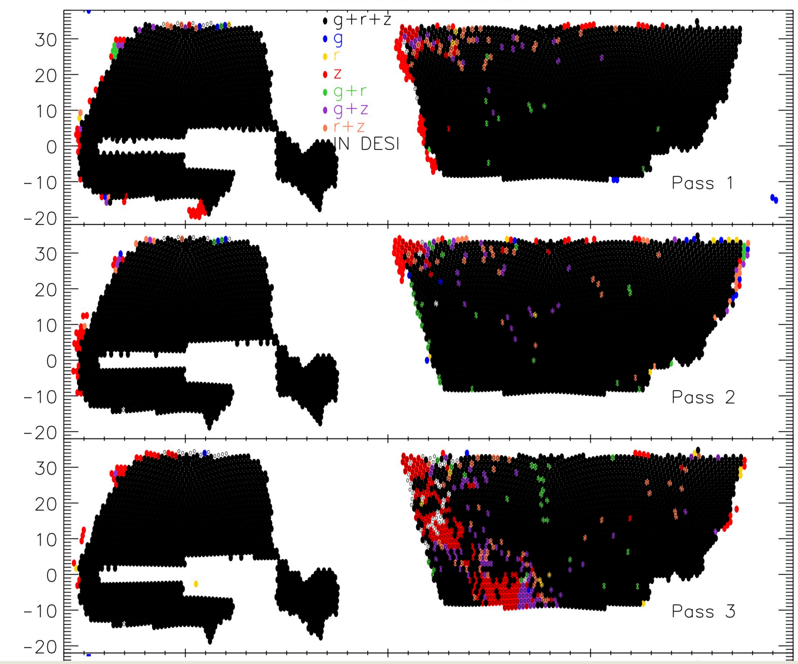
Imaging Survey Progress

- DECam imaging in the SGC has largely been completed in 2018B.
  - Thanks to major support from NOAO!
- This retires a substantial survey risk, i.e., what to observe in the fall.
- There is time remaining until Feb 2019 to finish DECaLS and BASS, but we are well above the threshold of a viable survey.

March 18, 2018



November 11, 2018



Status on imaging

- Robust data reduction through custom software *Tractor*
- All data made public via releases every six months
  - DR1 May 2015 DECaLS through DeC 2014 + WISE 1yr
  - …
  - DR6 Feb 2018 BASS+MzLS through Jul 2017 + WISE 4yrs
  - DR7 Jul 2018 DECaLS through Mar 2018 + WISE 5yrs (final)
  - **DR8** Jan 2019 DECaLS through Jun 2018 + BASS final + MzLS final

    → **Imaging for Survey Validation**
  - **DR9** Jun 2019 DECaLS final, BASS, MzL

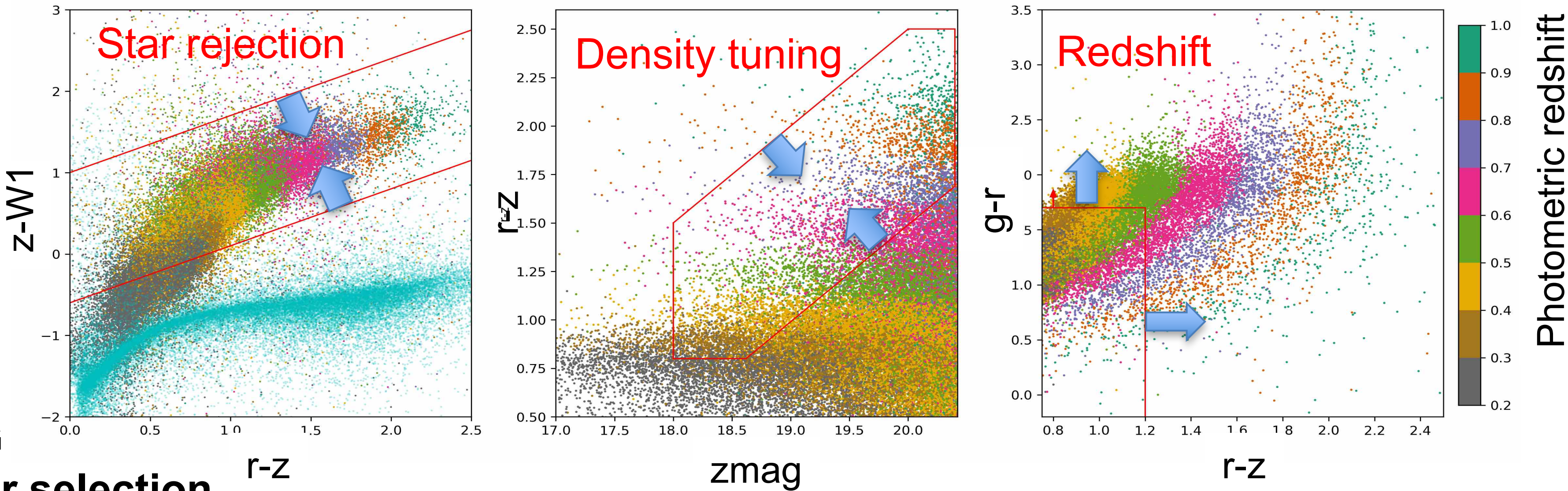
    → **Final imaging data release for DESI TS**
- Superb public image viewer to inspect the data and link to catalogs
  - http://www.legacysurvey.org/viewer
- Overview paper of imaging surveys submitted to ApJ
  (*Dey et al., arXiv:1804.08657, 153 authors*)

Target selection

Galaxy type	Redshift range	Bands used	Targets per deg^2	Exposures per deg^2	Good z's per deg^2	Baseline sample
LRG	0.4–1.0	g,r,z,$W1$	480	610	430	6.0 M
ELG	0.6–1.6	g,r,z	2400	1870	1220	17.1 M
QSO (tracers)	< 2.1	g,r,z,$W1$,$W2$	170	170	120	1.7 M
QSO (Ly-α)	> 2.1	g,r,z,$W1$,$W2$	90	240	50	0.7 M
Total in dark time			**3140**	**2890**	**1820**	**25.5 M**
BGS	0.05–0.4	r	800+	740	710	9.9 M
MWS	0.0	g,r (Gaia μ)	800+	720	720	10.1 M
Total in bright time			**1600+**	**1460**	**1430**	**20.0 M**

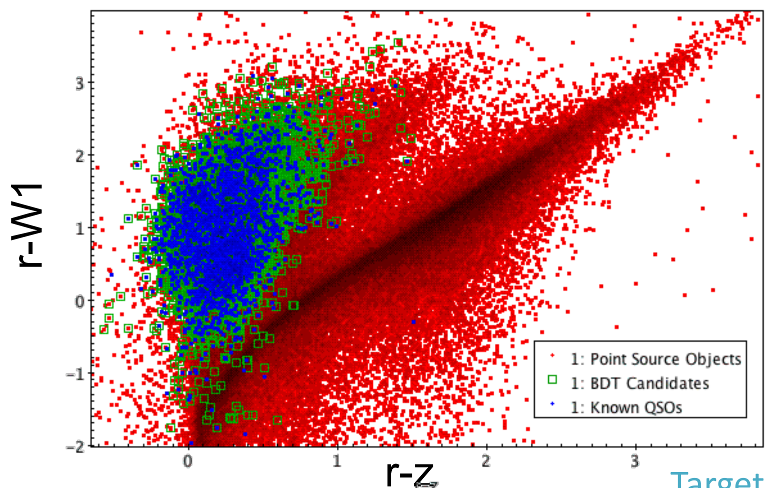
- Design & evaluation of algorithms by target selection working group
- Implementation on imaging data on project (*desitarget* package)
- Status:
  - Algorithms are converging, LRG, QSO tracers & BGS reaching FDR goals
  - Currently on 2nd generation algorithms (machine-learning methods) for QSO Lyα (working) and ELGs (being optimized & tested via pilot surveys)
- The BGS is currently proposed to consist of a bright high priority sample to an r-band magnitude limit r ~ 19.5, with a fainter low priority sample to r ~ 20.

Target selection



LRG
color selection

QSO
random forest
selection



Point sources
Known QSOs
Random Forest selection

Target selection WG chairs: Ch. Yèche & A. Raichoor

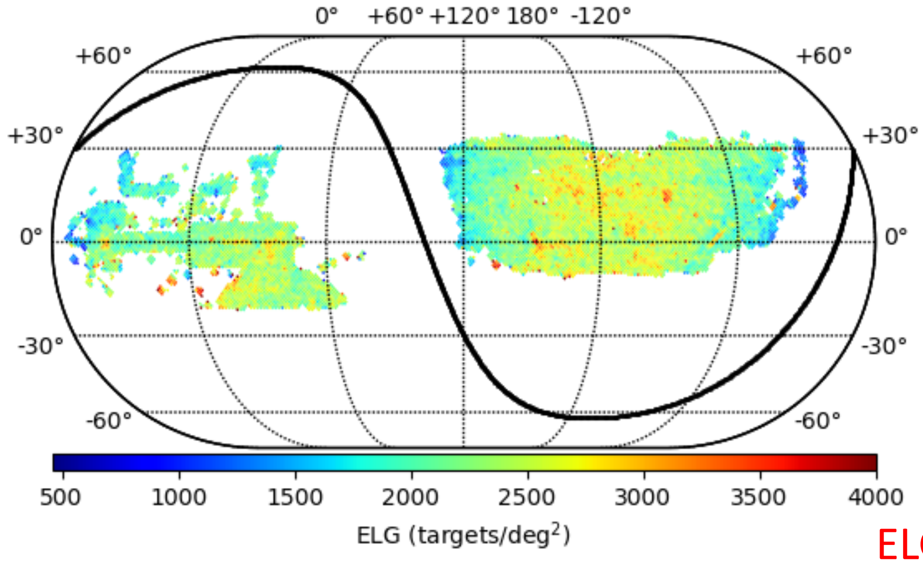
Target selection

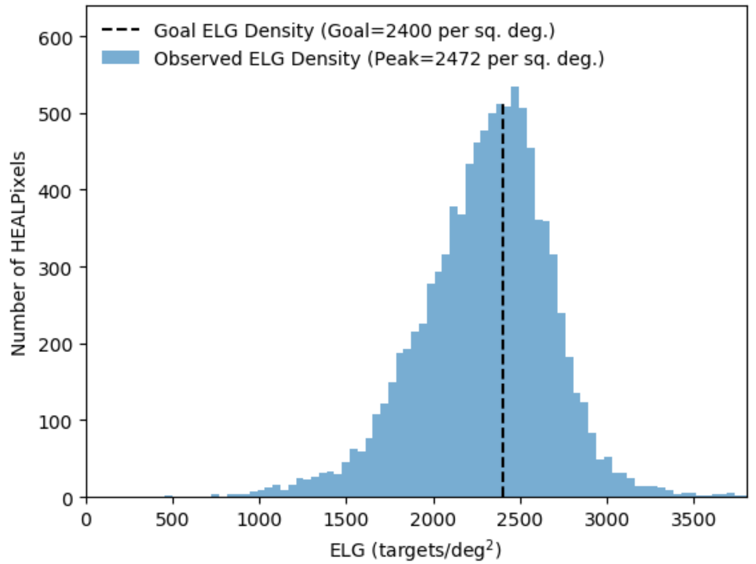
DESI-3349

AlsoBO3.3 Bailey/Guy

- Separate optimization for North and South
  to best accommodate different depth & bands of photometric surveys
- Optimization retuned with each imaging data release

- Target selection code ~1 hr for all 35 M targets on NERSC
- Automatic QA plots





ELG DR5

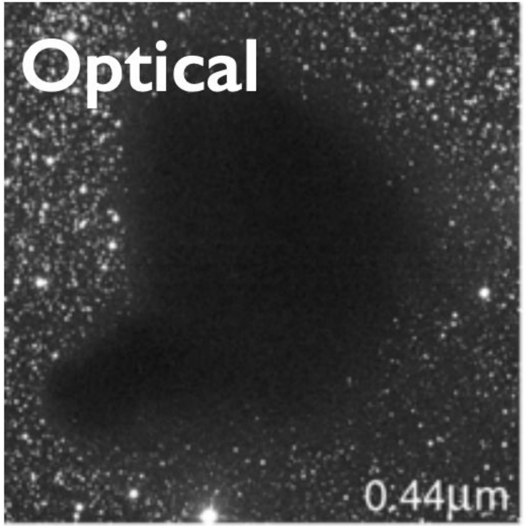
Target selection project lead: Adam Myers

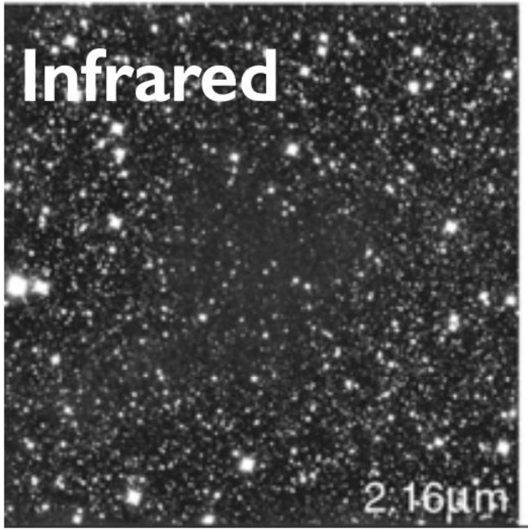
Systematic exploration of the dynamic infrared sky with Palomar Gattini-IR

Kishalay De
Caltech
On behalf of the Palomar Gattini-IR team

Why search for transients in infrared?

- Explore phase space of transients invisible to optical transient surveys due to dust obscuration
  - Dusty classical novae in the galaxy
  - Obscured supernovae in nearby galaxies



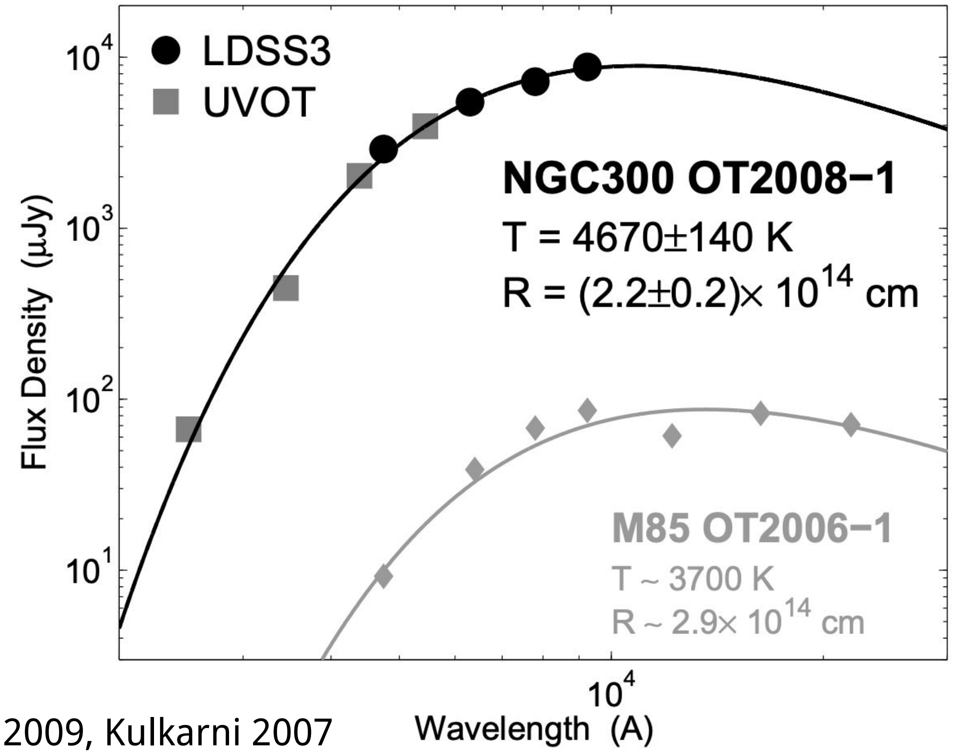


Credit: ESO

Why search for transients in infrared?

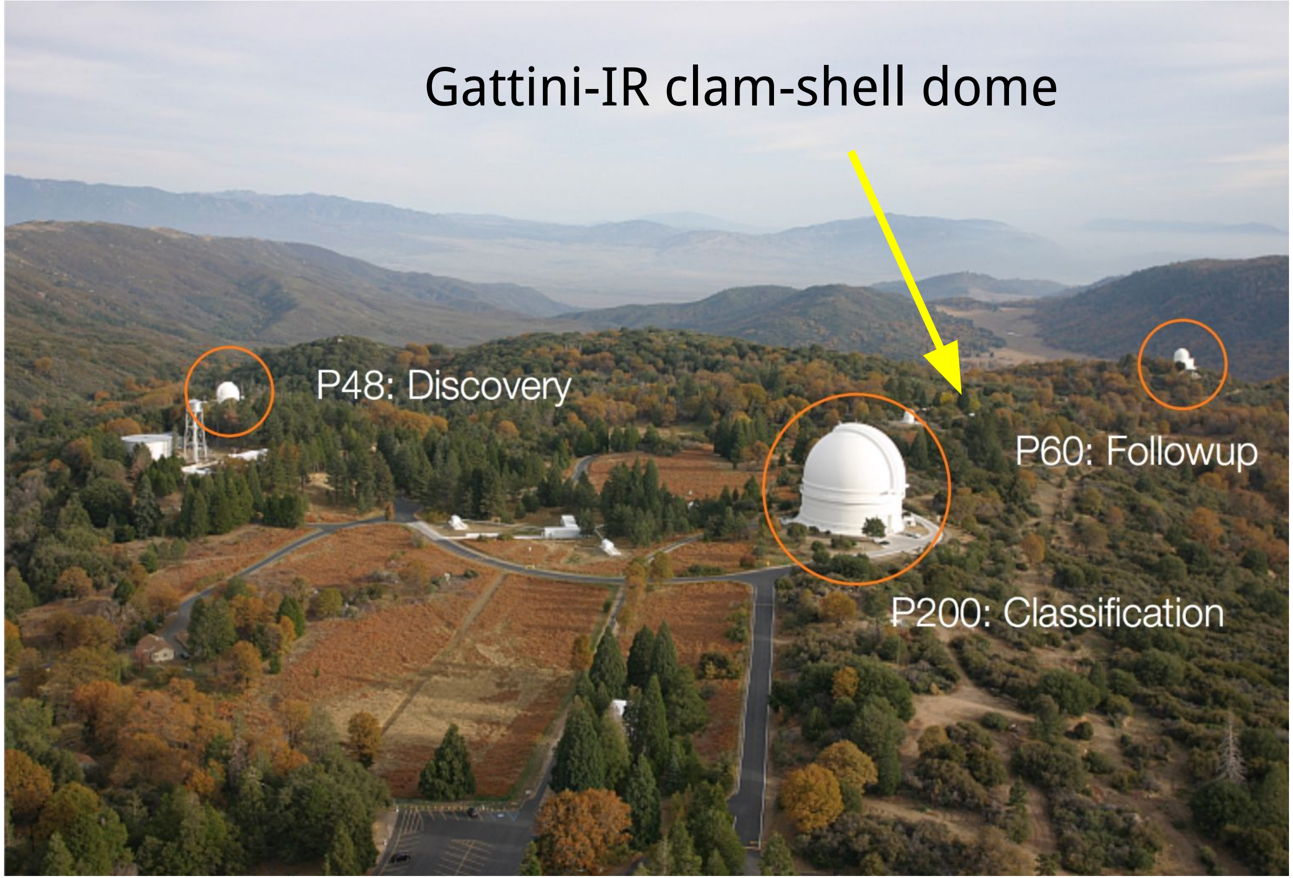
- Intrinsically red transients
  - Luminous red novae (stellar mergers)
  - Intermediate luminosity red transients
  - Kilonova counterparts of GW events

Emission peaks in the infrared

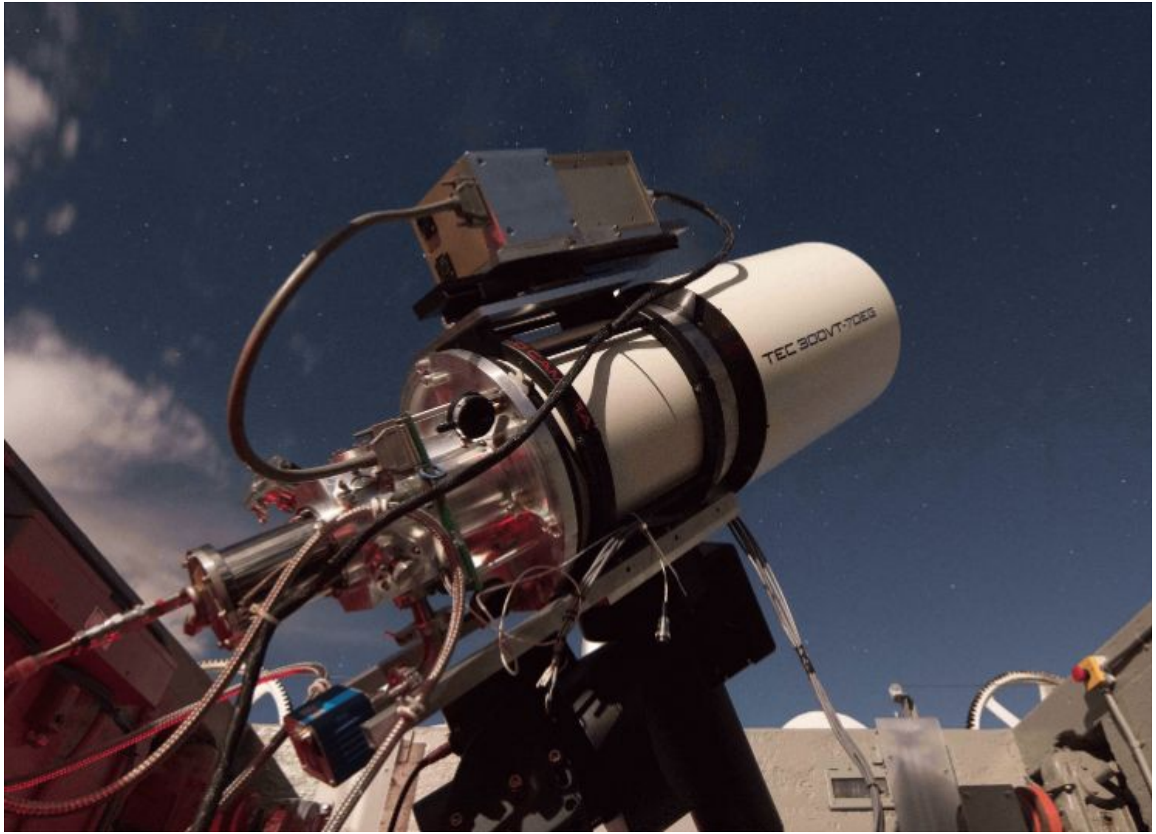


Berger+ 2009, Kulkarni 2007

Gattini-IR at Palomar observatory



Telescope and Detector



- 30 cm aperture
- f/1.4 optics
- 2K x 2K H2RG detector, cooled to 80 K
- 18 μm pixels
- 8.7 arcsec/pixel
- 25 sq. deg. FOV
- J-band filter

Field of View: Comparison (in cyan)

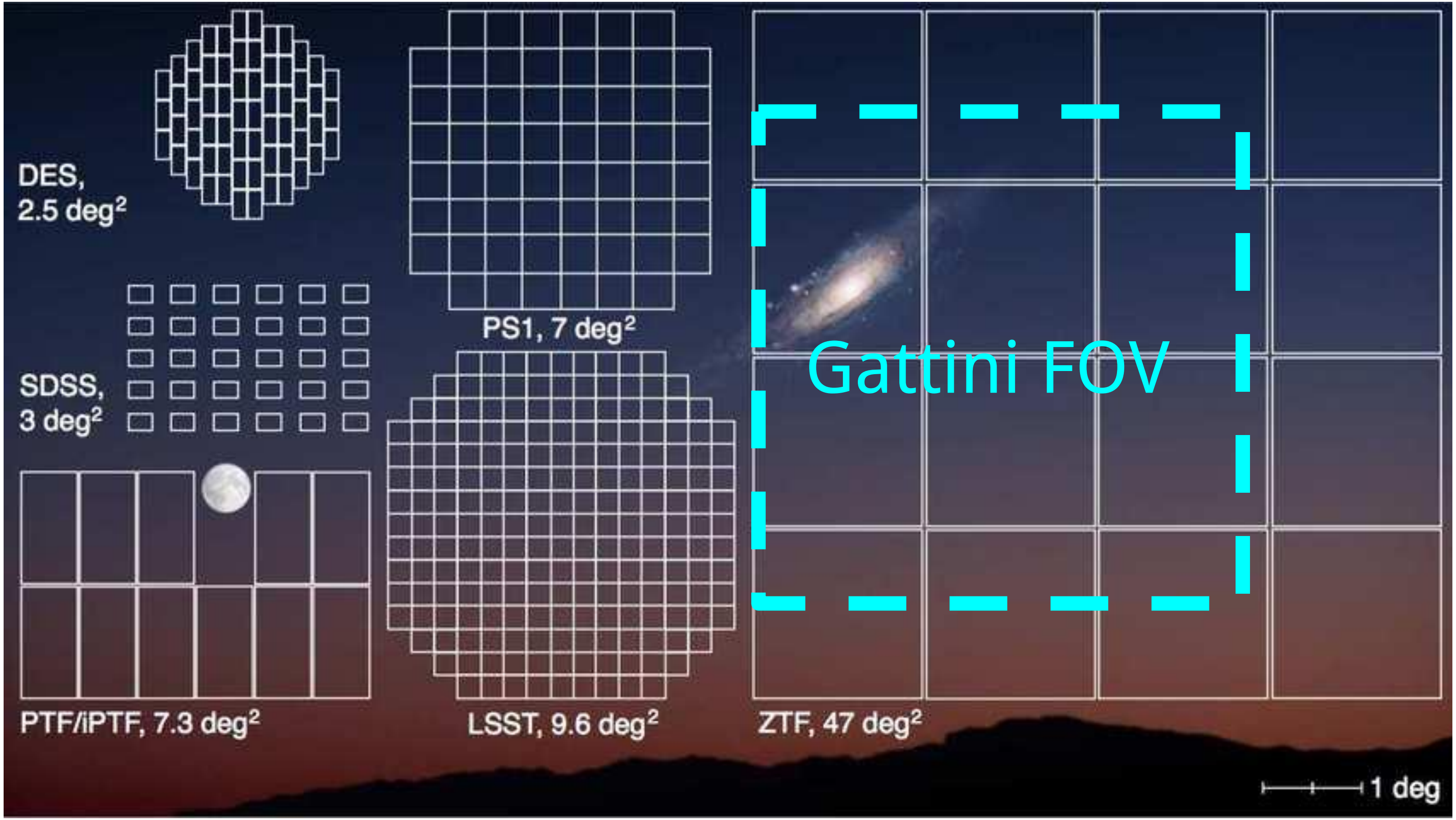
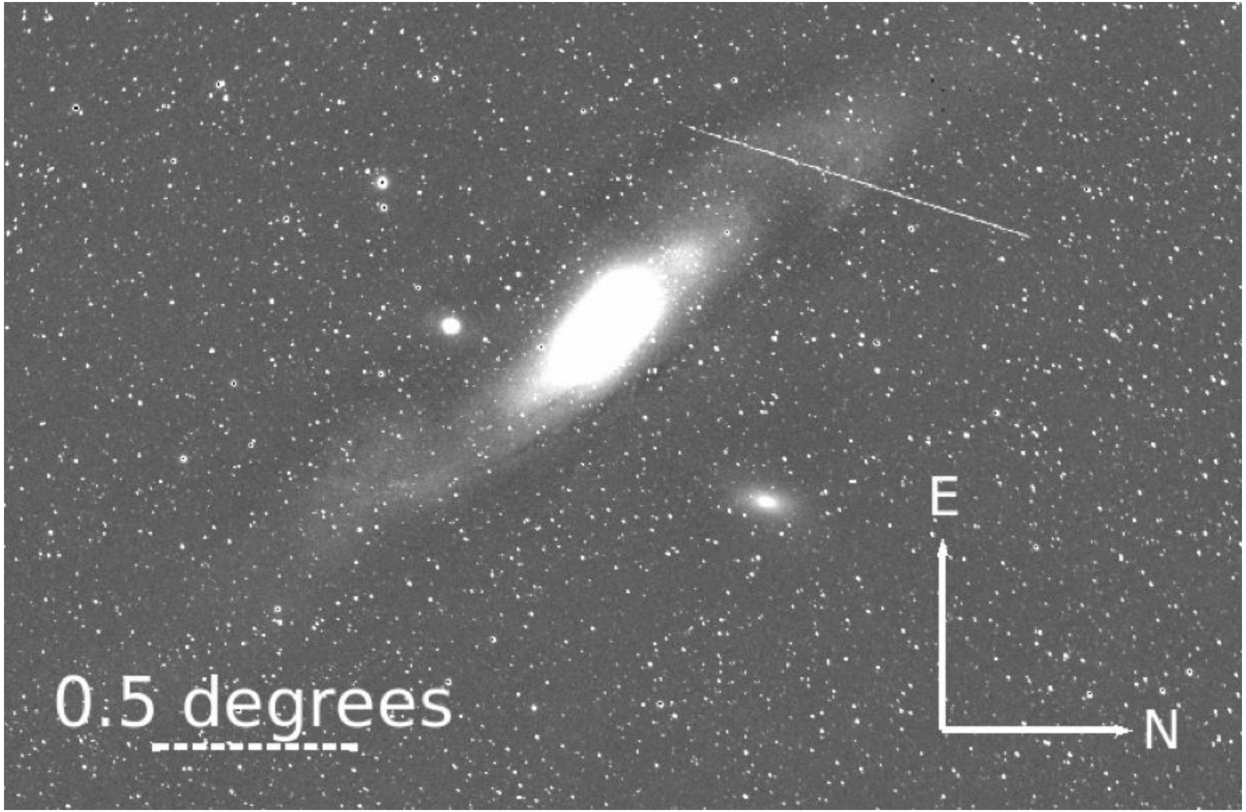


Figure adapted from Laher 2017

First light



First light image of M31 from September 2018 (total exposure time of 36 s)

Nominal survey design

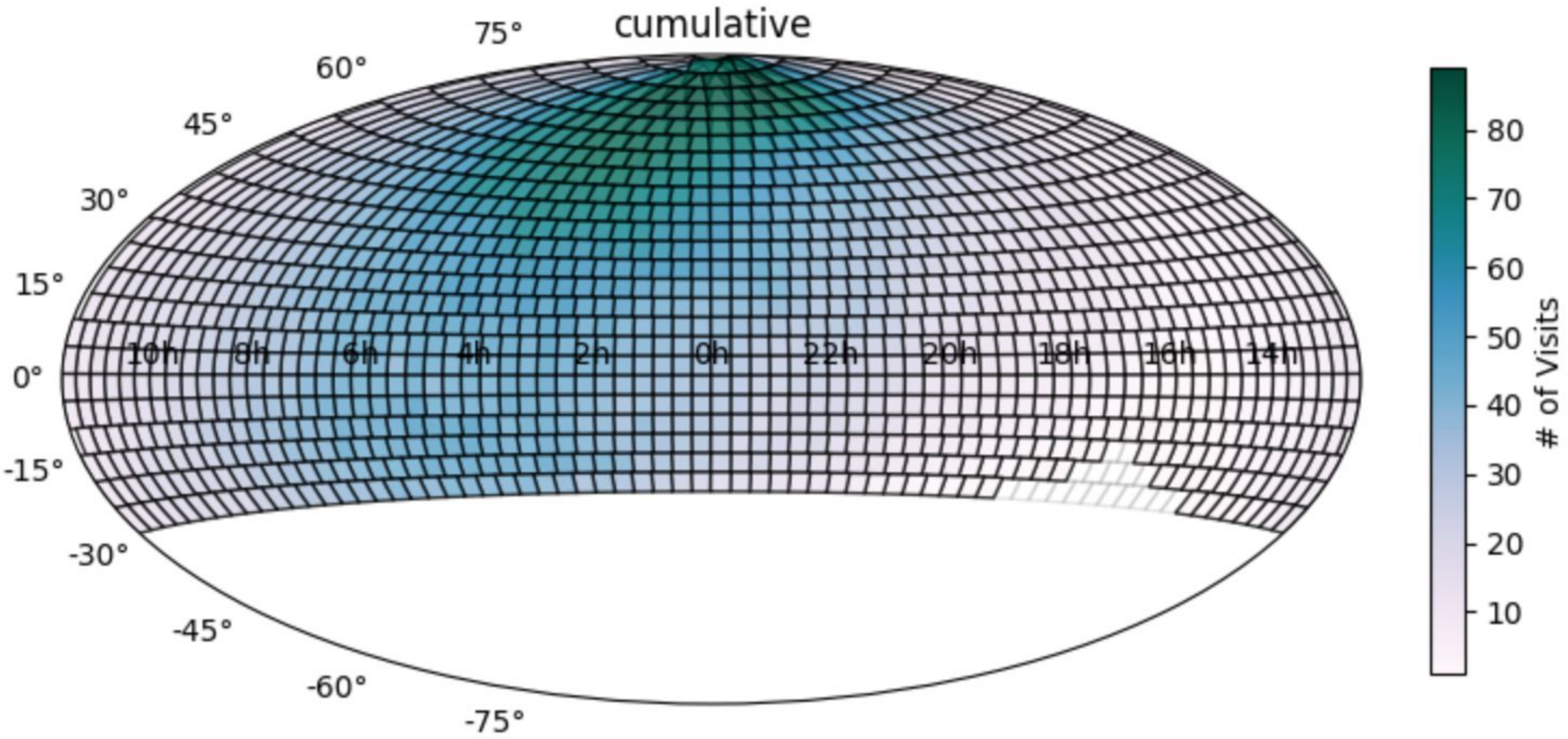
- Entire Palomar sky divided into fixed grid of ~ 1330 fields

- Each field visit = 8 dithered exposures with a total exposure time of 65 s. Dither amplitude ~ 3 arcmin.
- Aimed sensitivity of 16.4 AB (15.5 Vega) mag every night.

- Sky coverage ~ 20,000 sq. deg. every night. Typical cadence ~ 1 - 2 days over entire sky.

- ToO interrupts for deeper coverage of exceptional events (GW triggers, neutrinos, etc.)

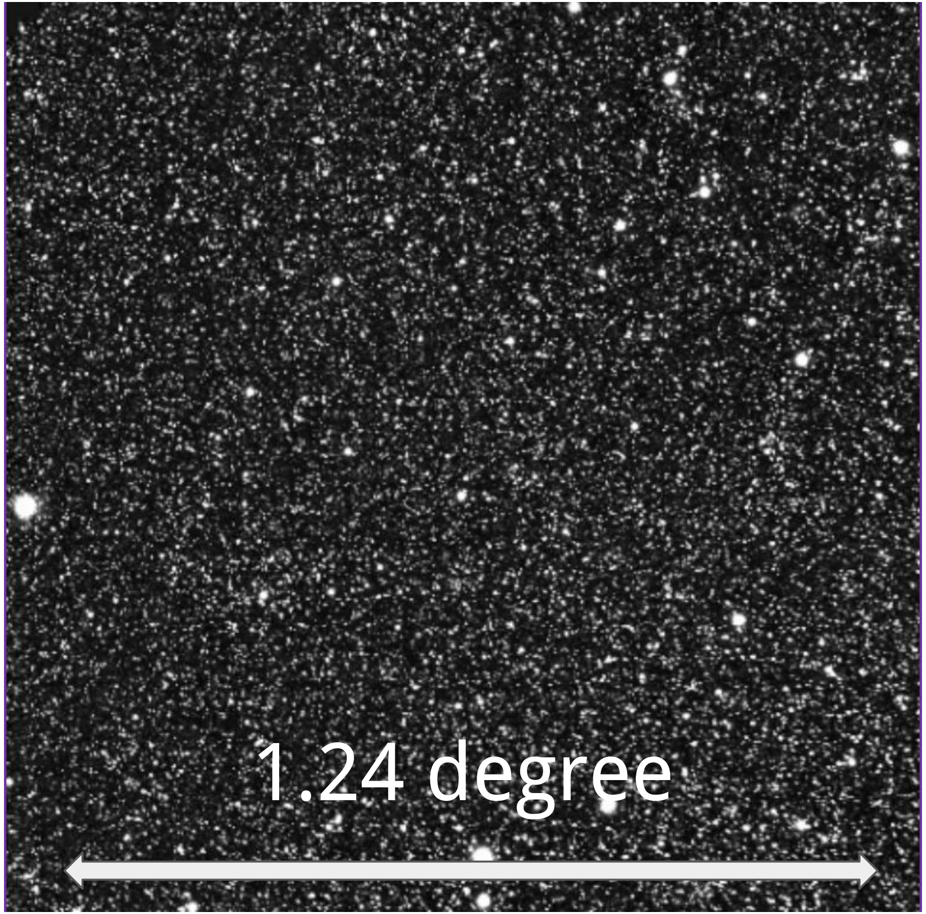
Sky coverage so far

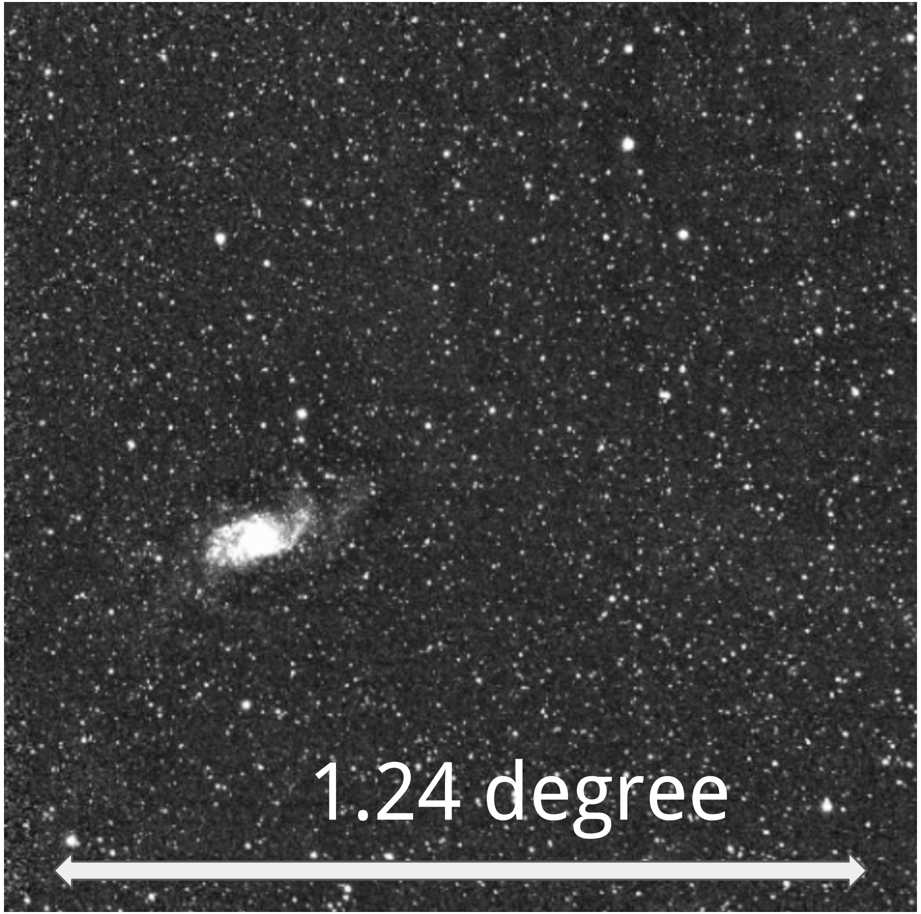


Data reduction pipeline

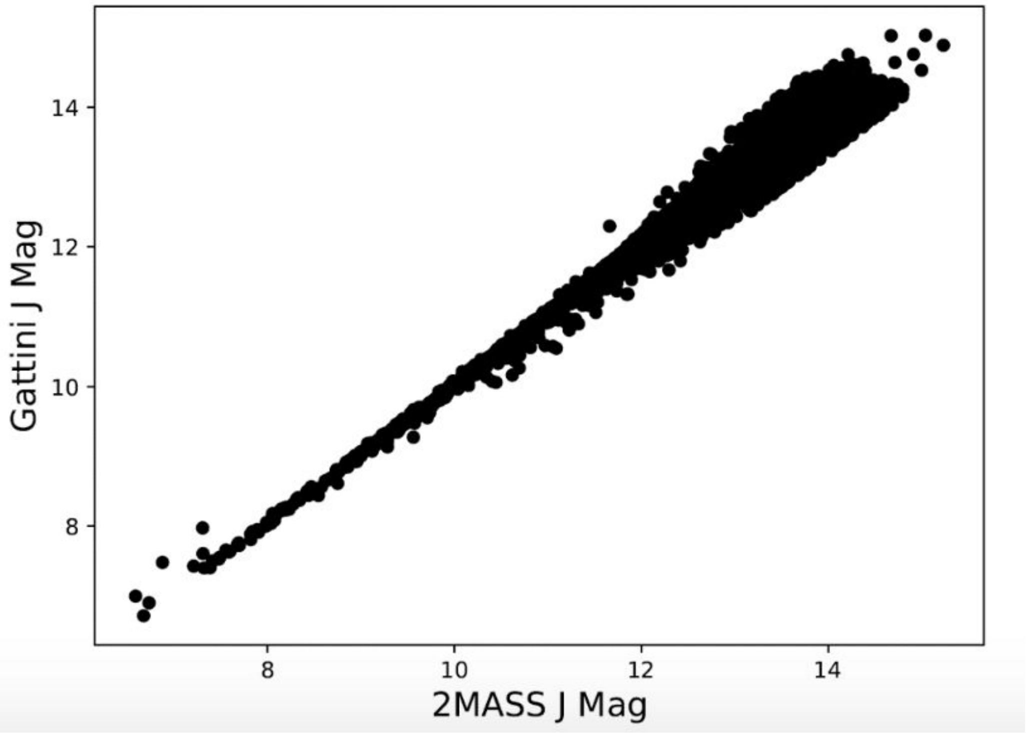
- Raw images divided into four quadrants (1K x 1K).
- Followed by flat-fielding and Gaia-based astrometric solutions for each image. Dithered frames are stacked by `drizzling’ on to a 2x finer pixel grid (4.3 arcsec / pixel).
- Photometric solutions by cross-match to 2MASS stars.
- Image subtraction for transient discovery based on ZOGY algorithm (Zackay+ 2016).

Examples: Drizzled nightly products





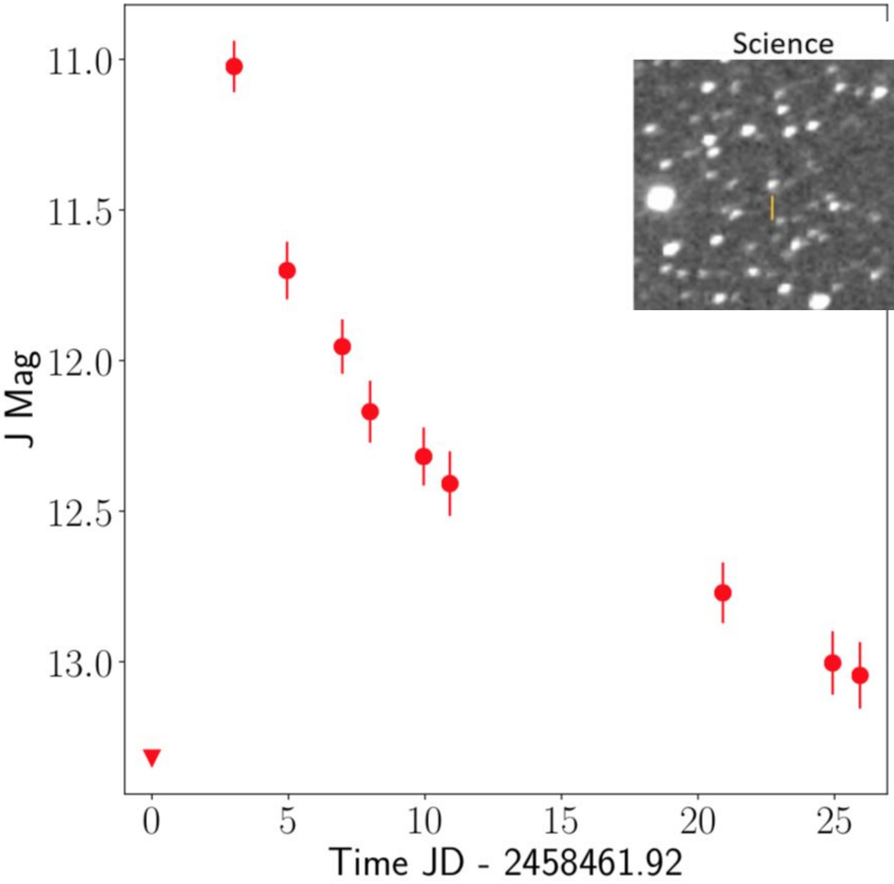
Gattini photometry against 2MASS

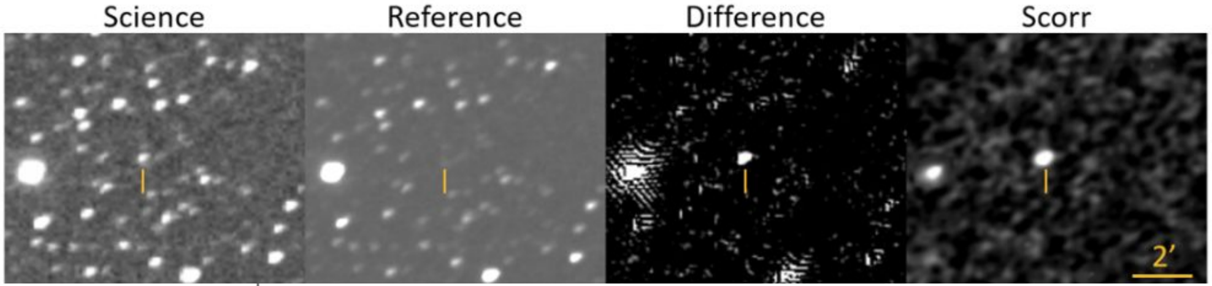


- Currently achieving median depth of ~ 15 Vega mag (15.9 AB).
- Sensitivity limited by variations in optical focus quality.
- **Tools available to get J-band light curves of any detected object**

Early science from commissioning data

Light curve of dwarf nova AT 2018jro





Palomar Gattini-IR J band detections of AT 2018jro

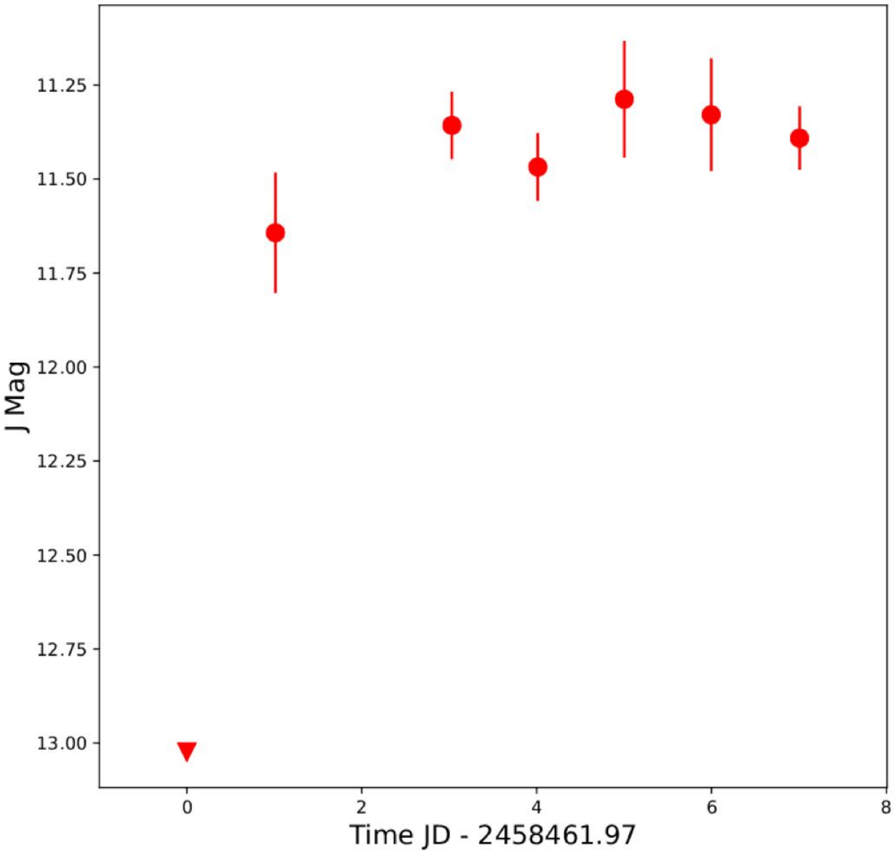
ATel #12305; *K. De (Caltech), M. Hankins (Caltech), M. M. Kasliwal (Caltech), A. Moore (ANU), S. M. Adams (Caltech), M. Ashley (UNSW), J. Burnham (SRL/Caltech), A. Delacroix (COO/Caltech), T. Greffe (COO/Caltech), D. Hale (COO/Caltech), R. Lau (JAXA), D. McKenna (COO/Caltech), E. O. Ofek (Weizmann), R. Smith (COO/Caltech), J. Sokoloski (Columbia), J. Soon (ANU), T. Travouillon (ANU)*

*on **18 Dec 2018; 03:33 UT***

Credential Certification: Kishalay De (kde@astro.caltech.edu)

Subjects: Infra-Red, Optical, Nova

NIR brightening of blazars



- J band light curve of blazar S50716+714
- R band brightening reported in Atel #12298
- Coincident J band brightening of ~ 1.5 mags recovered in Gattini data

Timeline

- Telescope commissioned at Palomar in September 2018.
- Robotic telescope operations began in October 2018.
- Real-time data reduction pipeline running since November 2018 (De et al. in prep).

- Real-time image subtraction pipeline implemented in January 2019. Effort going into automating search for `real’ transients from subtractions.

- **Gattini-IR serves as a test-bed for future IR transient surveys (WINTER at Palomar, DREAMS in Australia).**

Korea Microlensing Telescope Network (KMTNet) : Wide-field Photometric System

Sang Chul KIM[1], Chung-Uk Lee[1], Seung-Lee Kim[1], Dae-Sik Moon[2]

TDA-MMS 2019

2019 Feb 9-10, Nikko, Japan

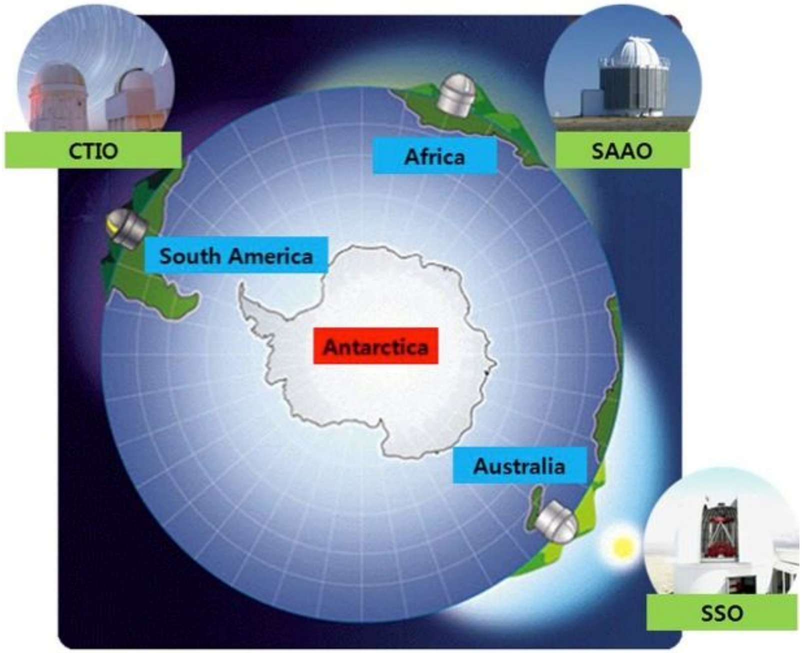
1 Korea Astronomy and Space Science Institute (KASI), Korea

2 University of Toronto, Canada

Project Overview

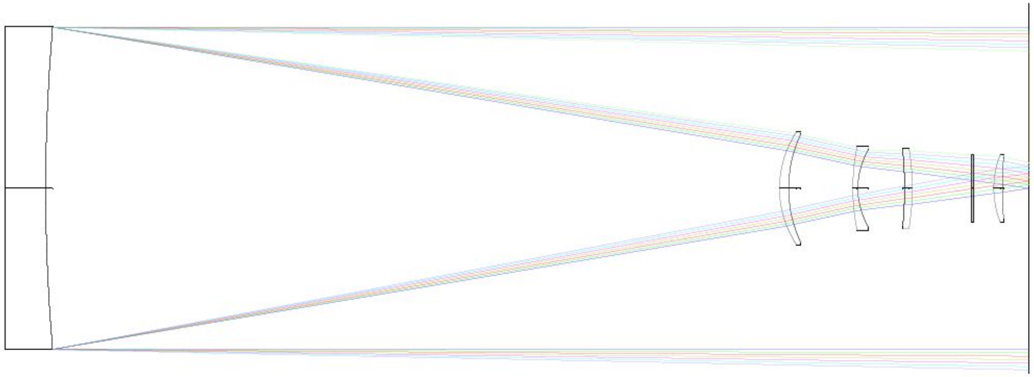
- Development of the **KMTNet** System
  - **K**orea **M**icrolensing **T**elescope **Net**work
  - Three Identical Observing Systems
  - 24-hours uninterrupted Monitoring of night sky at Southern Hemisphere
  - It has been installed at CTIO in Chile, SAAO in South Africa, SSO in Australia

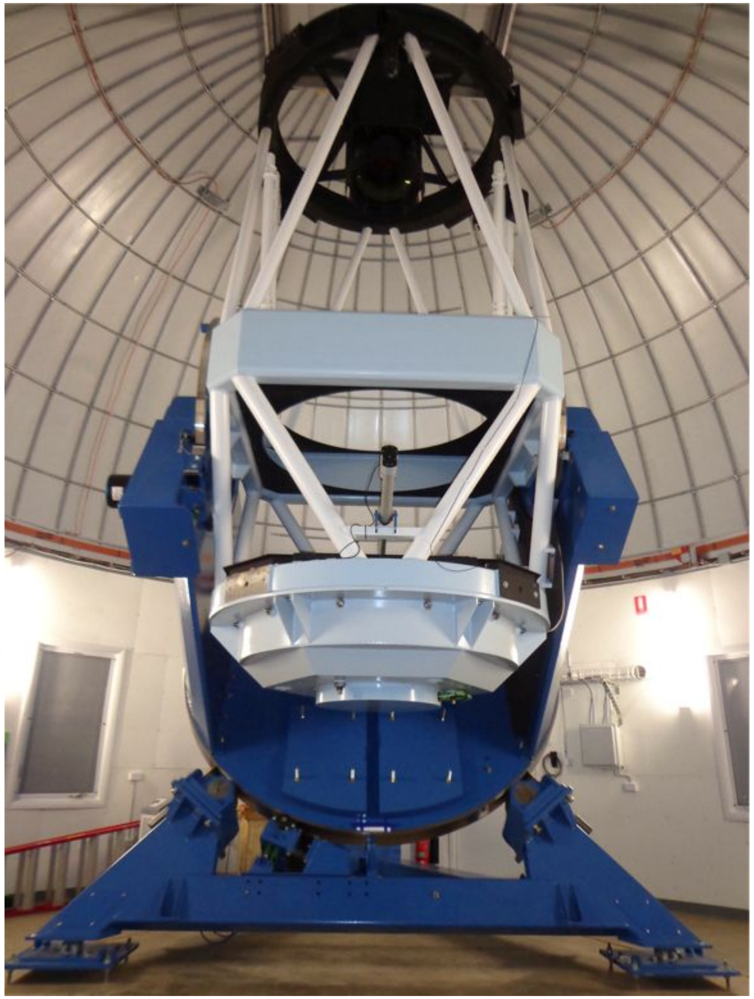
- Budget
  - Development : ~20M$ for 6 years from 2009 to 2014
  - Operation : ~2M$ per year from 2015



Telescope

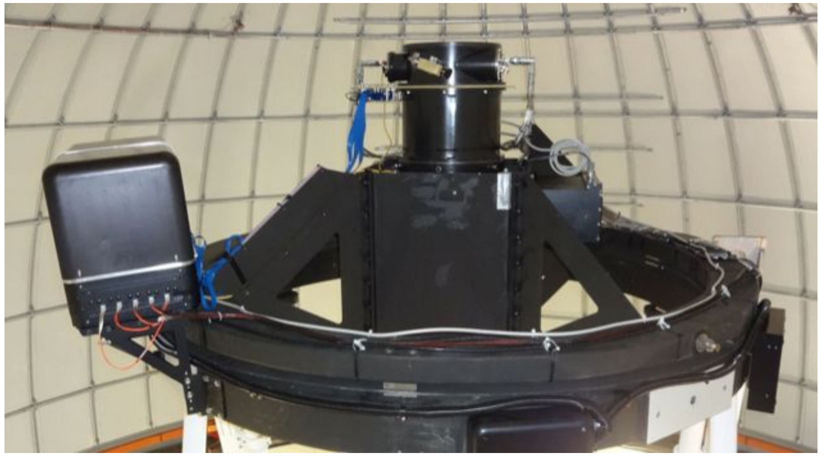
- Wide Field Optical Telescope
  - Primary Mirror with 1.6m Diameter
  - Prime Focus type Reflector
  - Equatorial Mount
  - Effective Focal Length of 5160mm
  - Four Field Corrector Lenses
  - Delivered Image Quality of 1.0 arcsec FWHM under 0.75 arcsec seeing

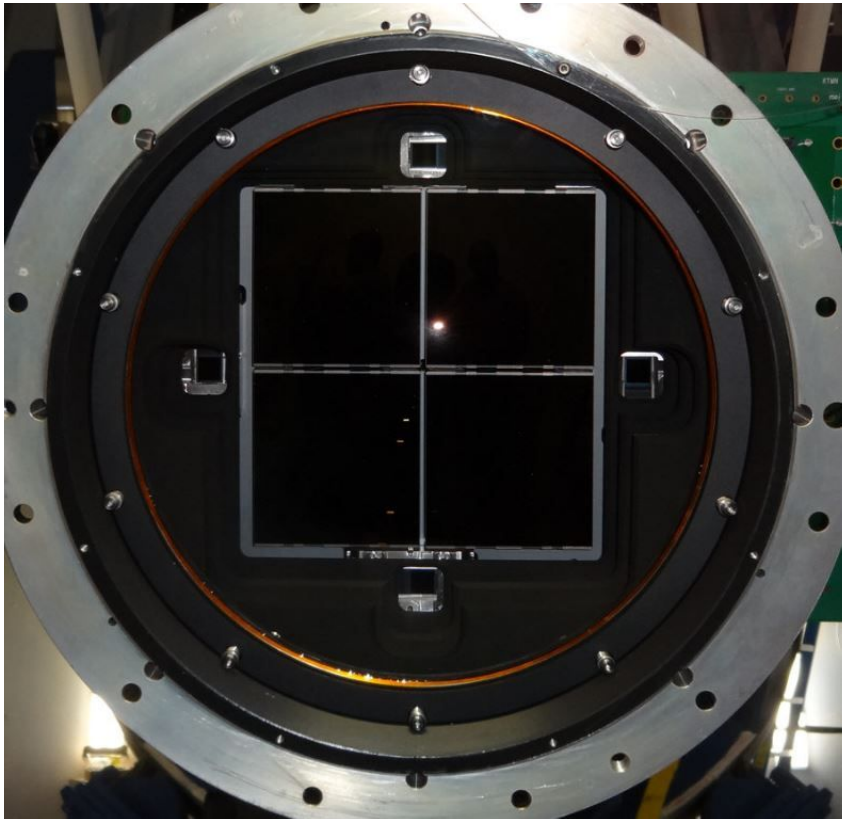




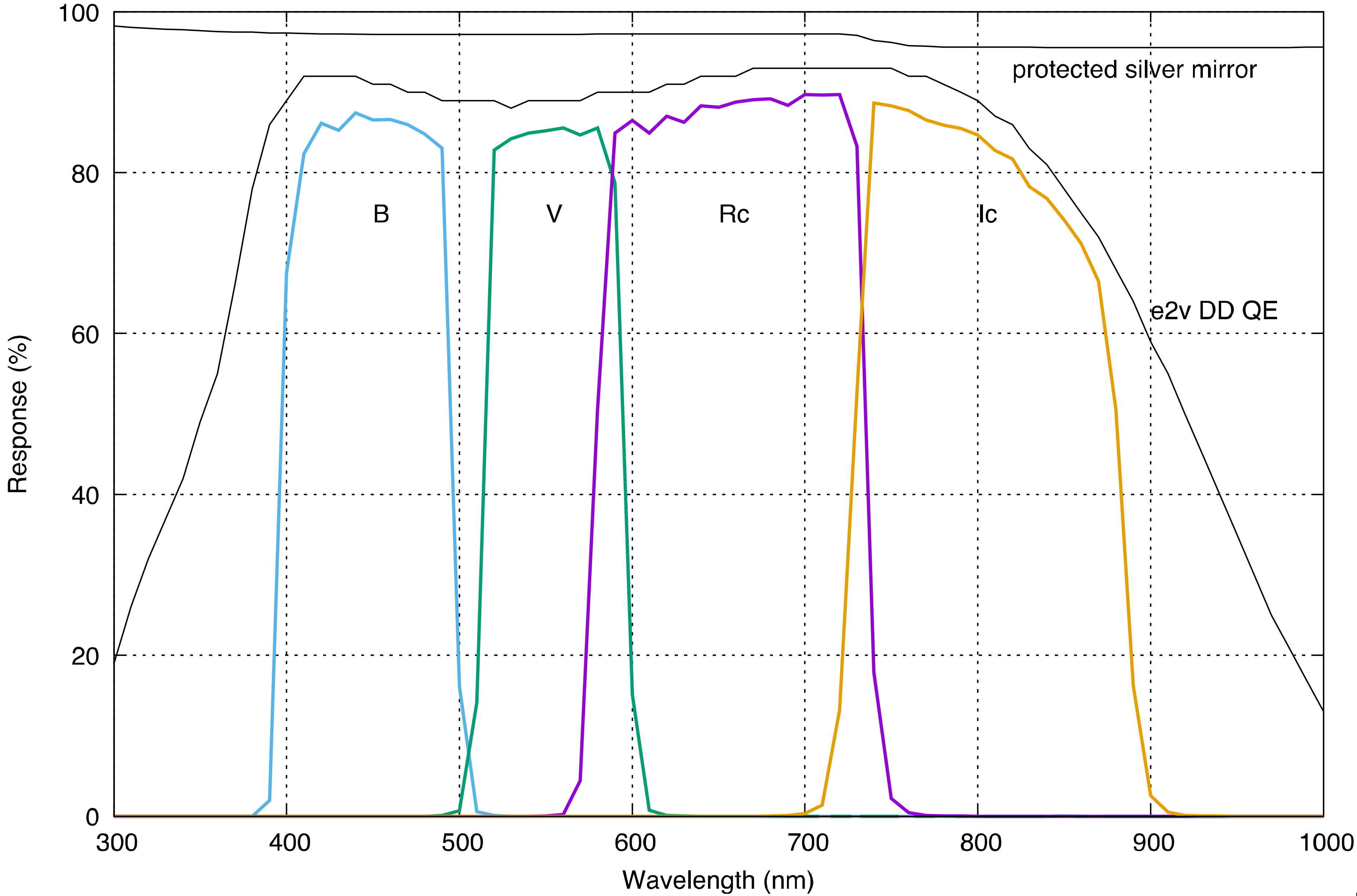
Camera

- Large-Format Mosaic CCD camera
  - Four e2v Chips with 9k × 9k pixels
  - 10 μm × 10 μm pixel
  - 0.4 arcsec/pixel, 2°×2° Field Of View (FOV)
  - High Quantum Efficiency of ~90%
  - Cryogenic Cooling System

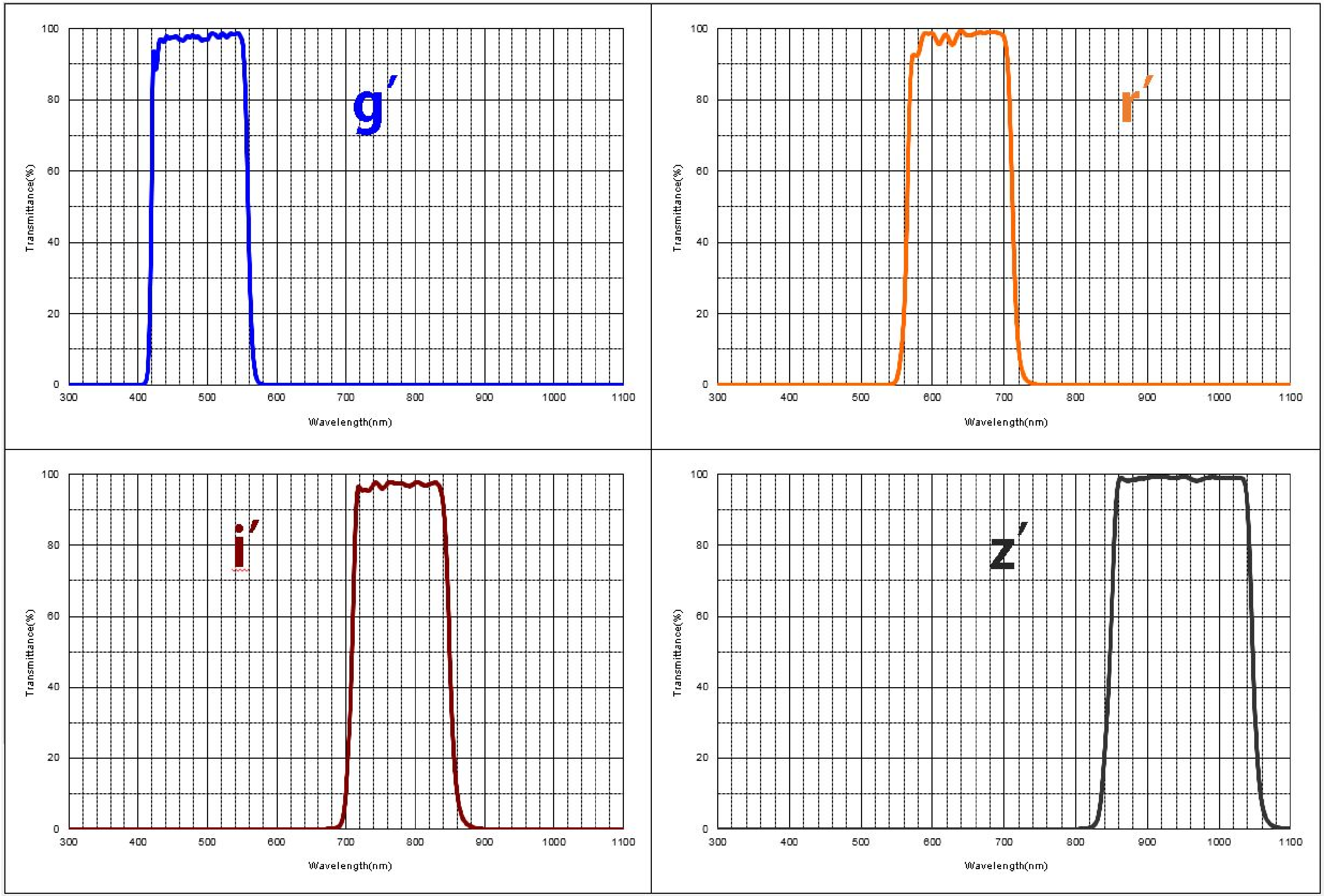




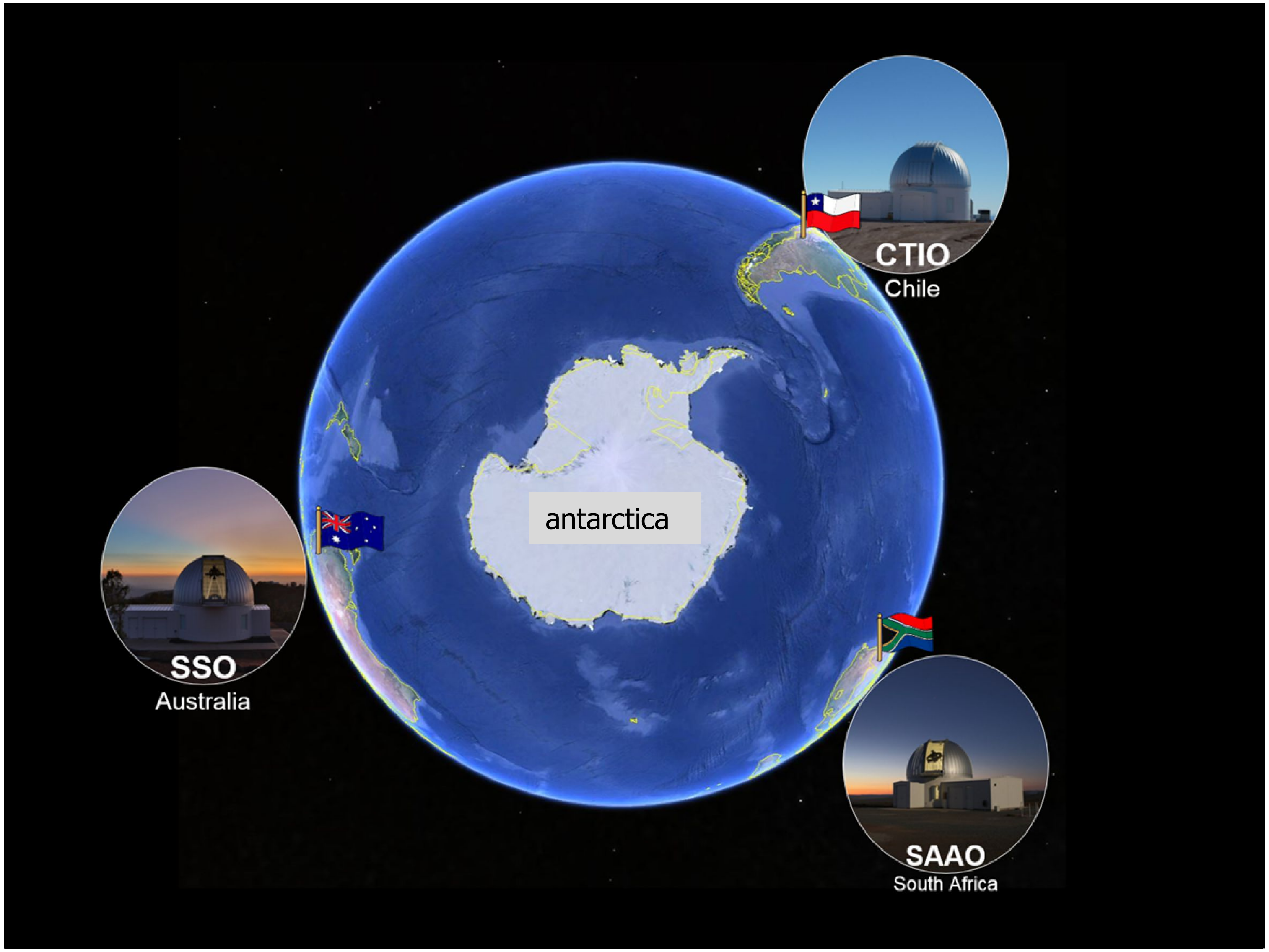
BVRI Filters (3 sites) : Grade 1, Deep depletion, Astro multi-2



SDSS band pass filters at CTIO



Observation Sites



Installation

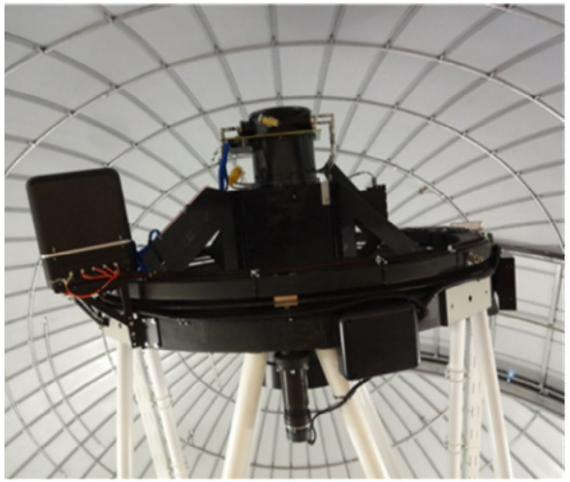
- Installation of the Three Telescopes in 2014 and Test Observation with a 4K CCD Camera

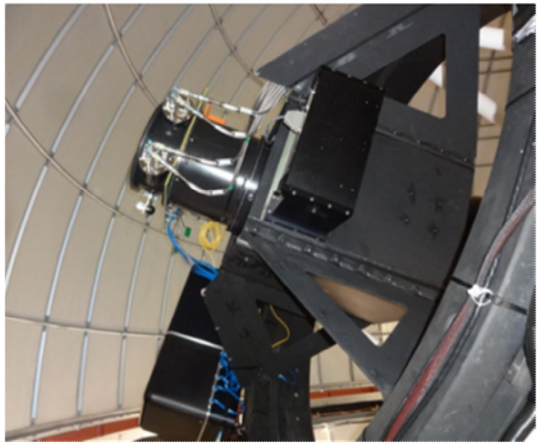
Upper) From left to right, CTIO in Chile on March 2014, SAAO in South Africa on July 2014, and SSO in Australia on November 2014

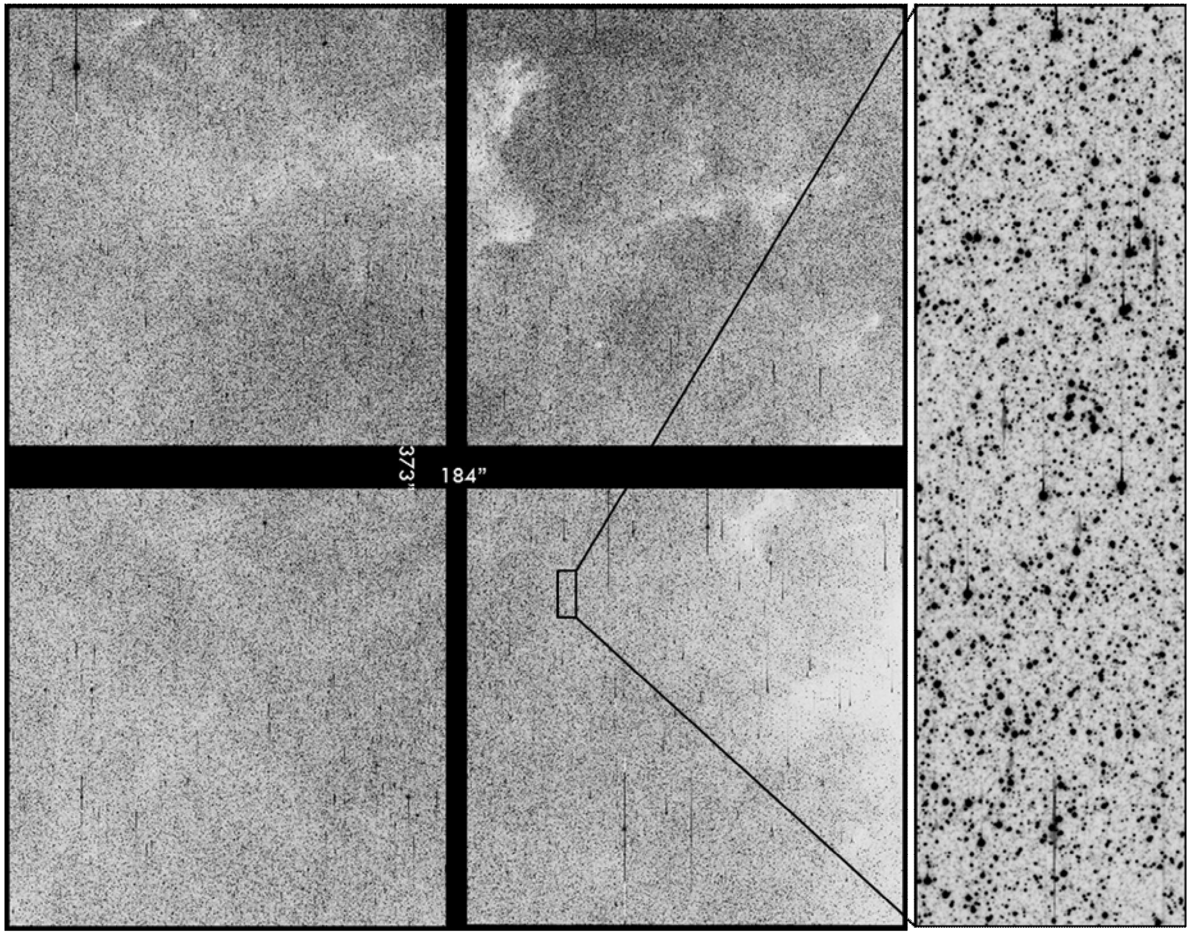
Lower) From left to right, Trifid nebula taken at CTIO, Eagle nebula at SAAO, and Tarantula nebula at SSO. 900sec in B, 600sec in V, and 300sec in I-band

Installation

- Installation of the Three Cameras by the end of June 2015







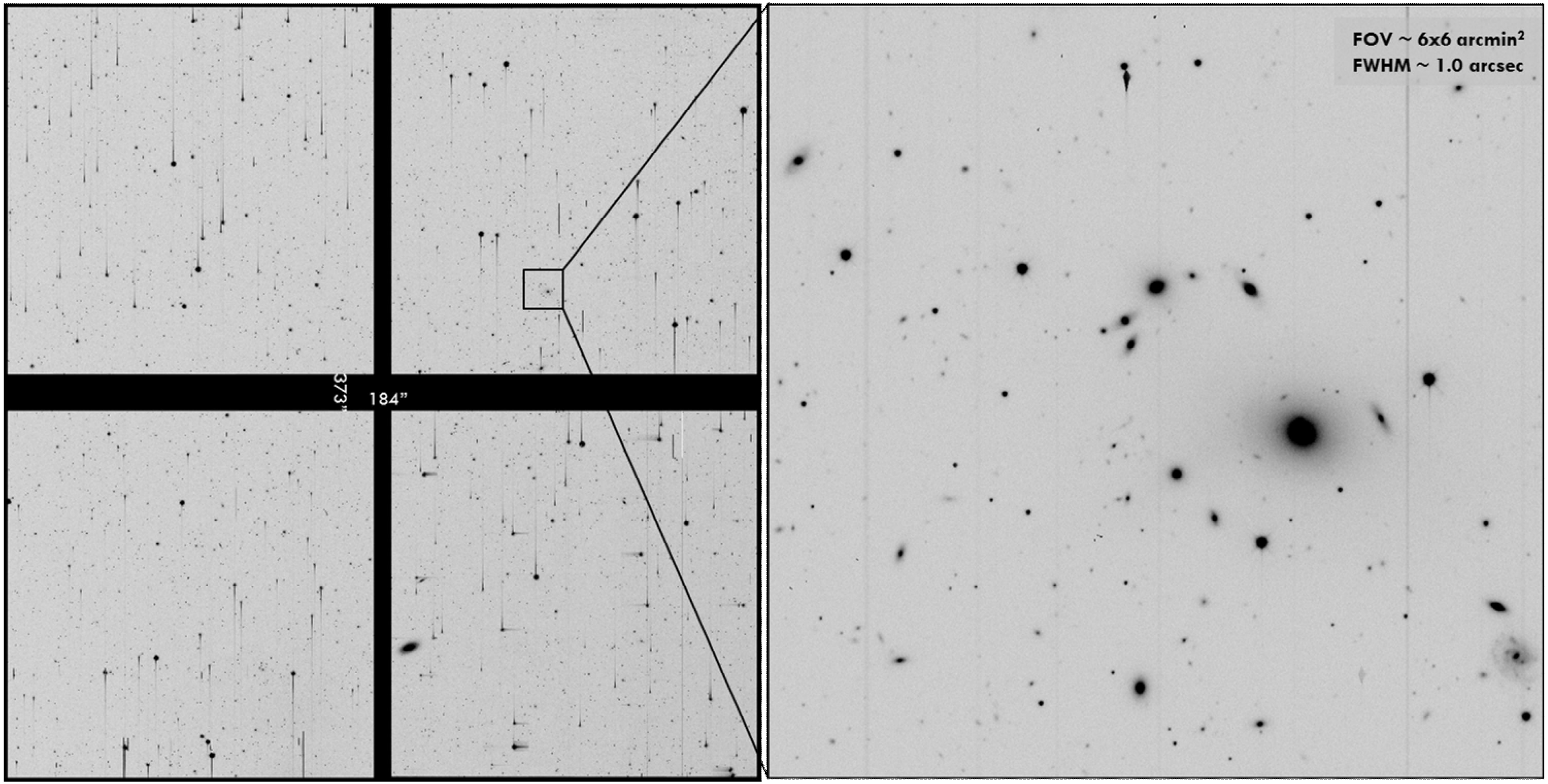
Left) Mosaic 18k CCD camera attached to the 1.6m telescope at CTIO in Chile

Center) Mosaic CCD image sample of the Galactic Bulge taken at SAAO on March 2015

Right) A zoomed image to show a dense stellar field of the Galactic Bulge

Sample of Test Images

- Test run of an external galaxy on February, 2015 at CTIO. 120 sec exposure with R filter

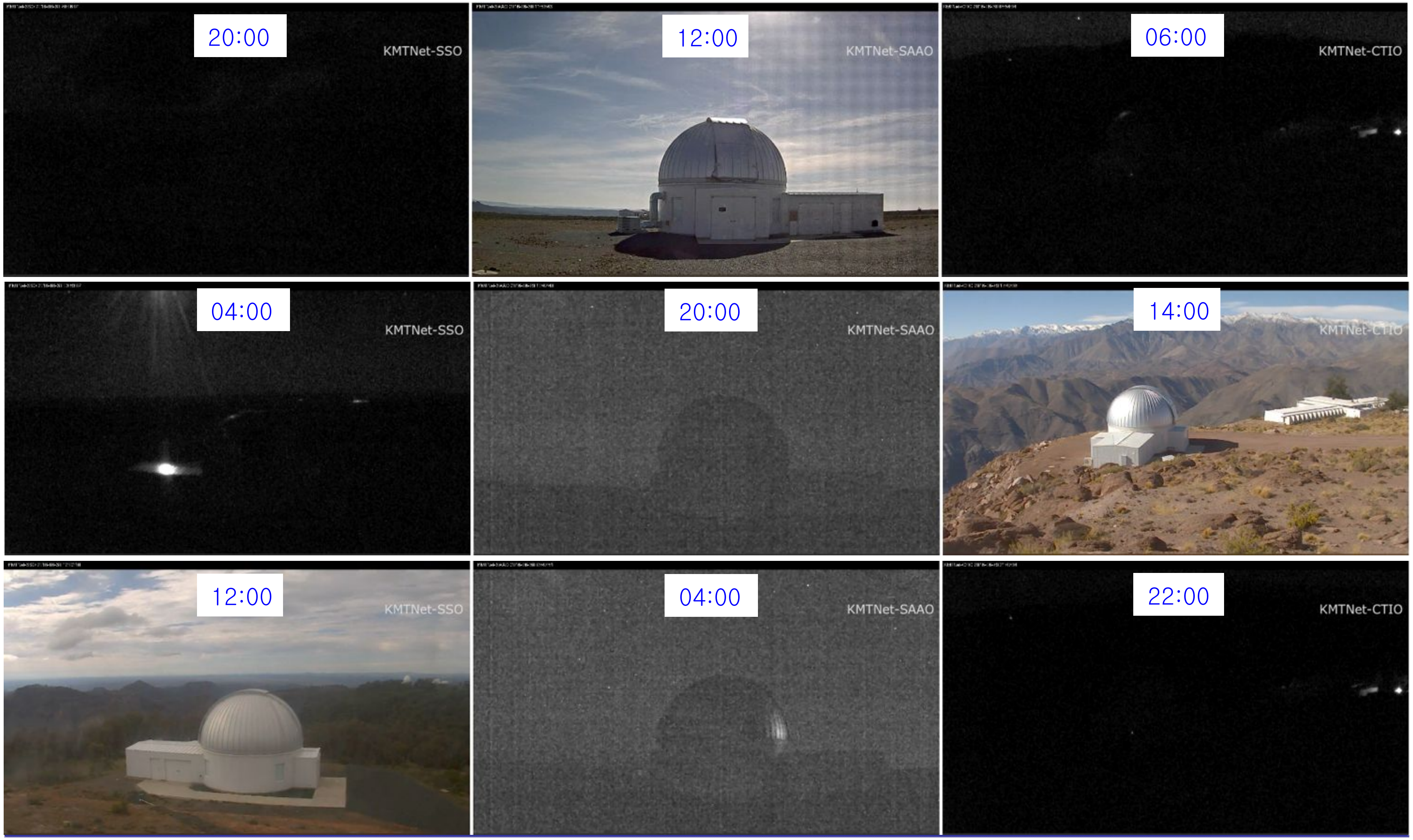


Left) Mosaic CCD image sample

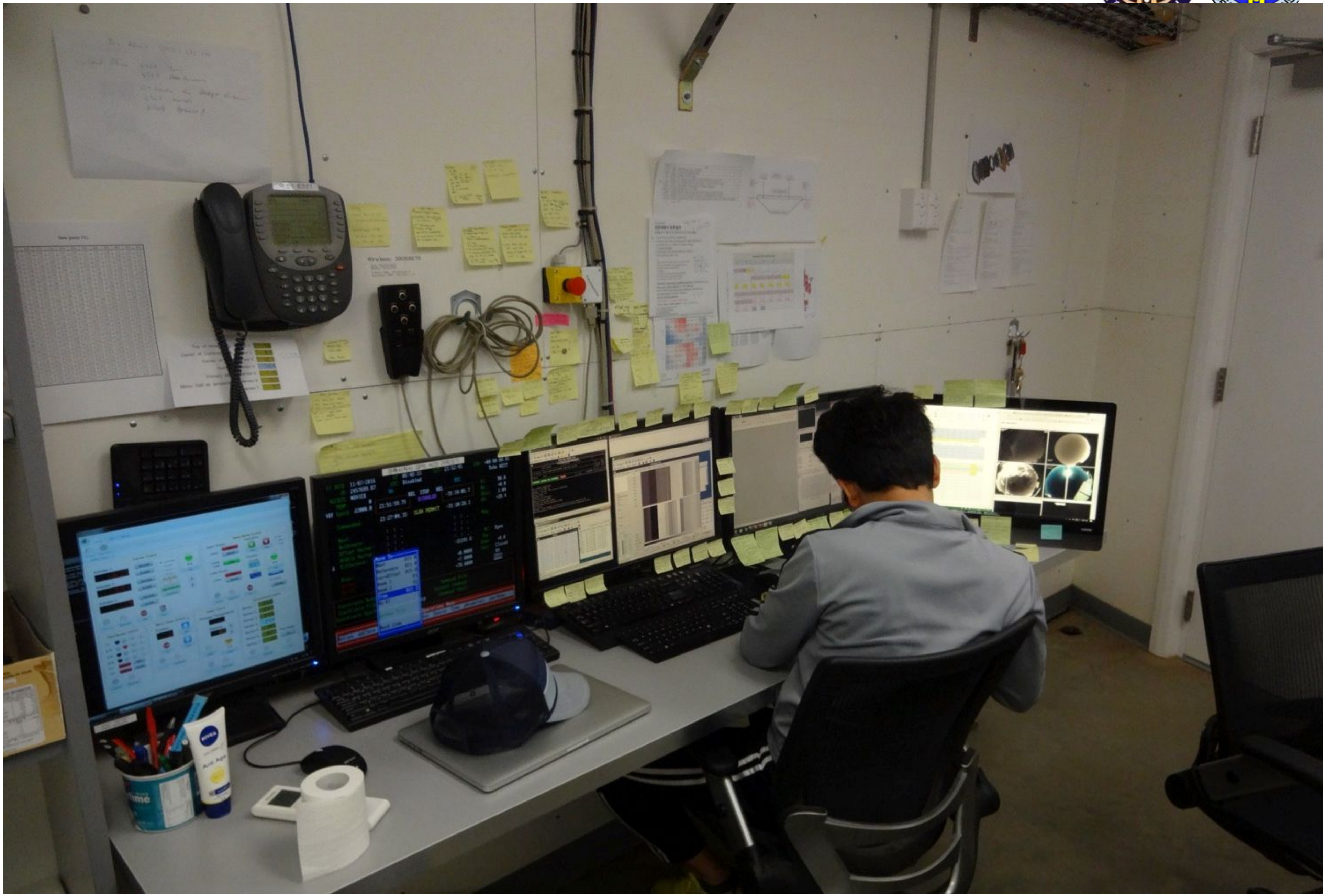
Right) A zoomed image to represent a cluster of galaxies

KMTNet – 24-hour continuous observation

UTC+10 — 8H — UTC+2 — 6H — UTC-4

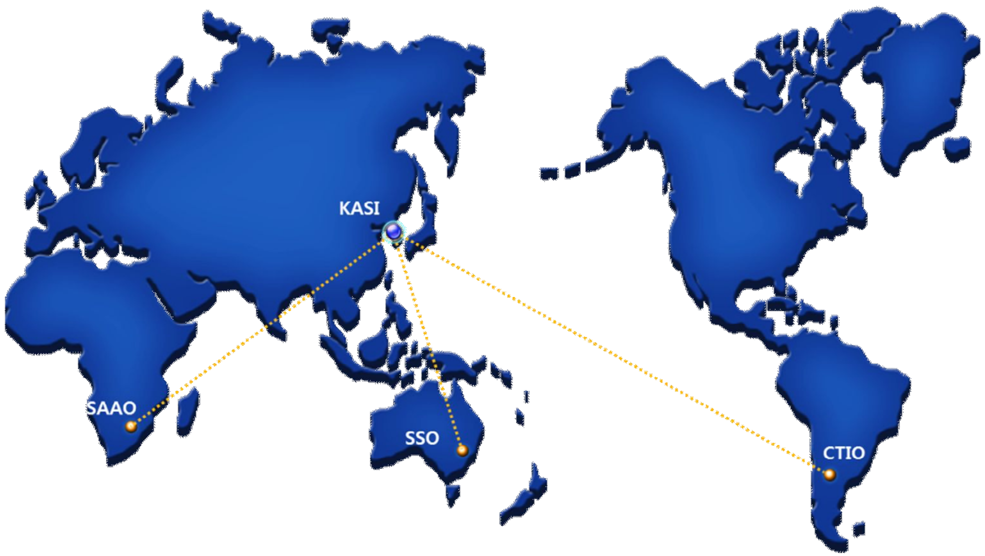


Observing Room

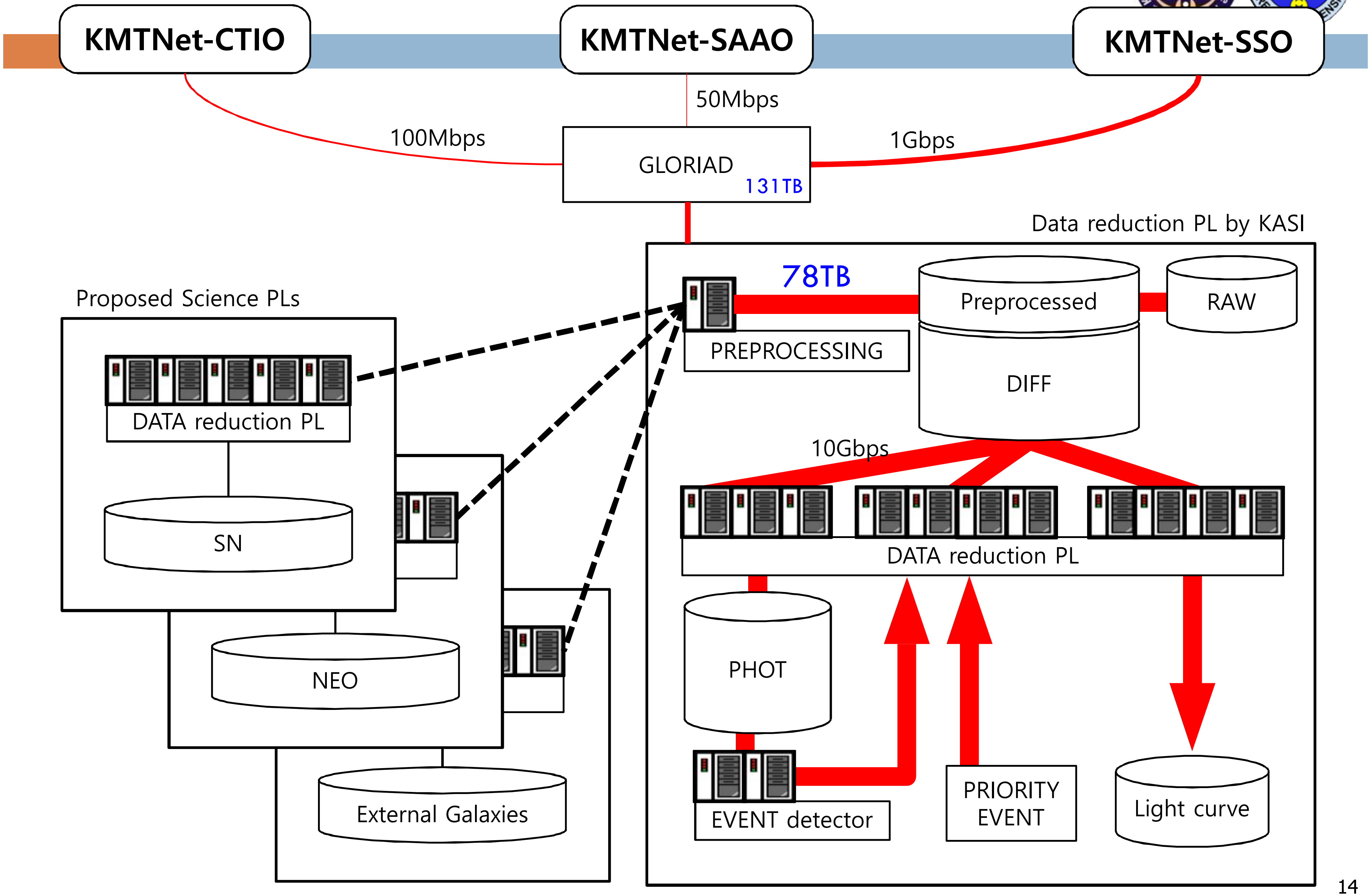


Data Handling

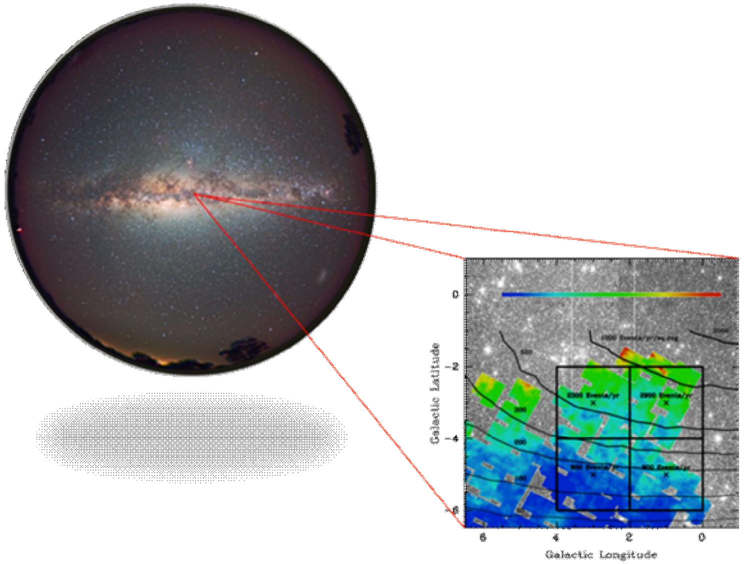
- Data Acquisition
  - Two residence observers (+ visiting observers) perform the observation at each site.
- Data transfer
  - A mosaic 18k × 18k CCD image with 680 MByte can be transferred from CTIO, SAAO, and SSO to KASI in 2 minutes after the observation with a rate of higher than 45 Mbps.
- Image Processing
  - All the CCD images are pre-processed with the pipeline which was developed at KASI.
  - Project P.I.(s) can download the pre-processed images within 1~2 days after the observation.
  - Difference Image Analysis (DIA) is applied to the Bulge data to search for variable objects.

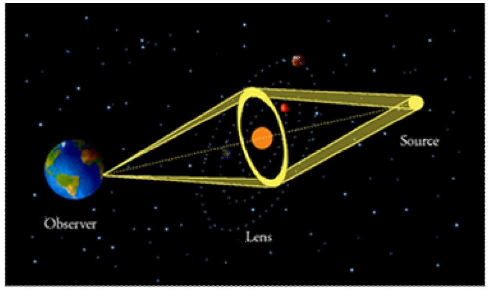


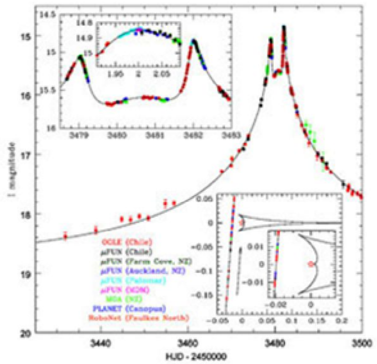
Data reduction pipeline



Main Science







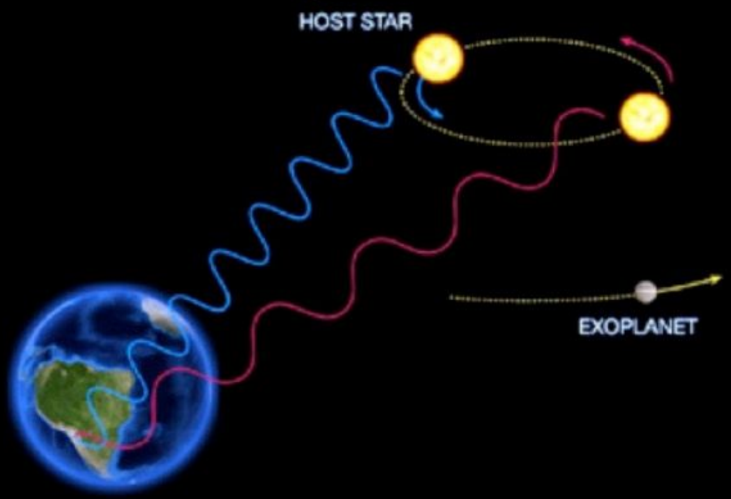
Monitoring the Galactic Bulge

Detection of micro-
Gravitational Lensing events

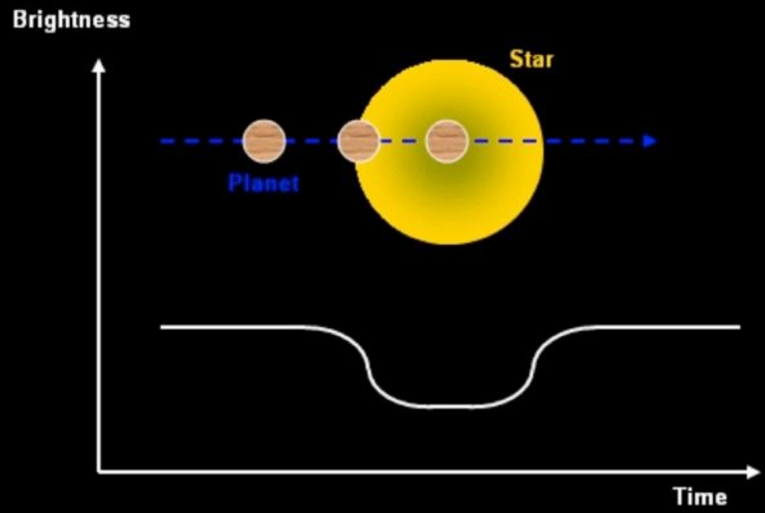
Discovery of
extra-solar planets

Big four

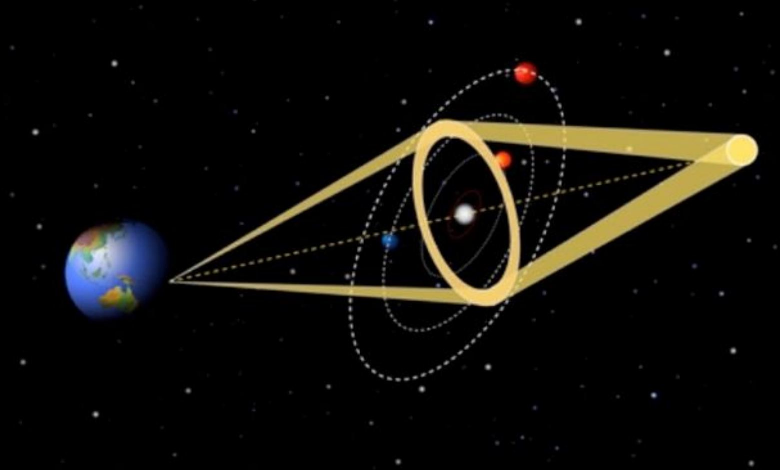
Radial Velocity



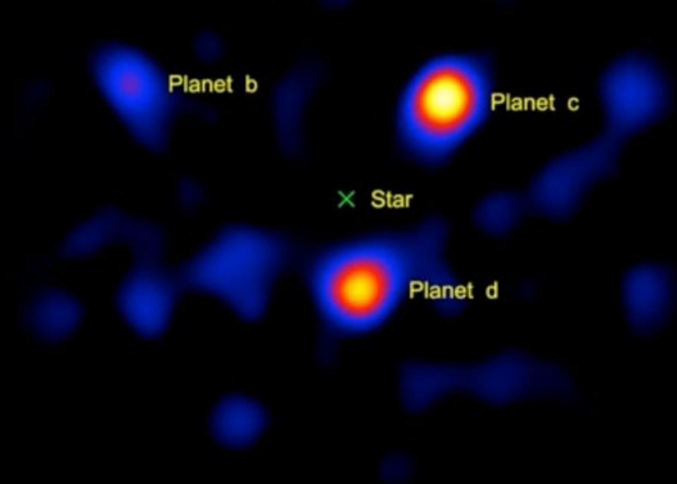
Transit Photometry



Microlensing

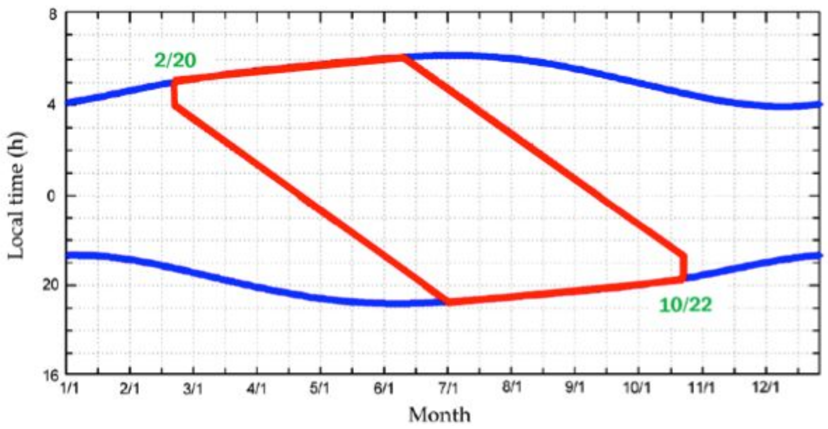


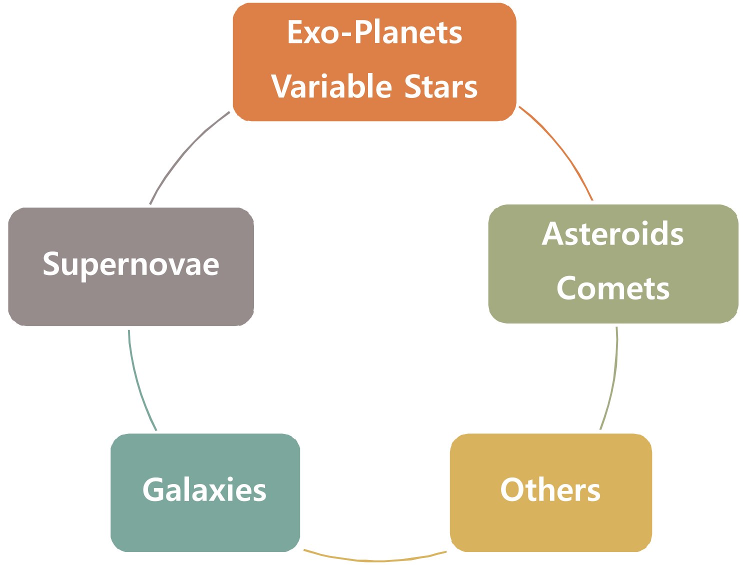
Direct Imaging



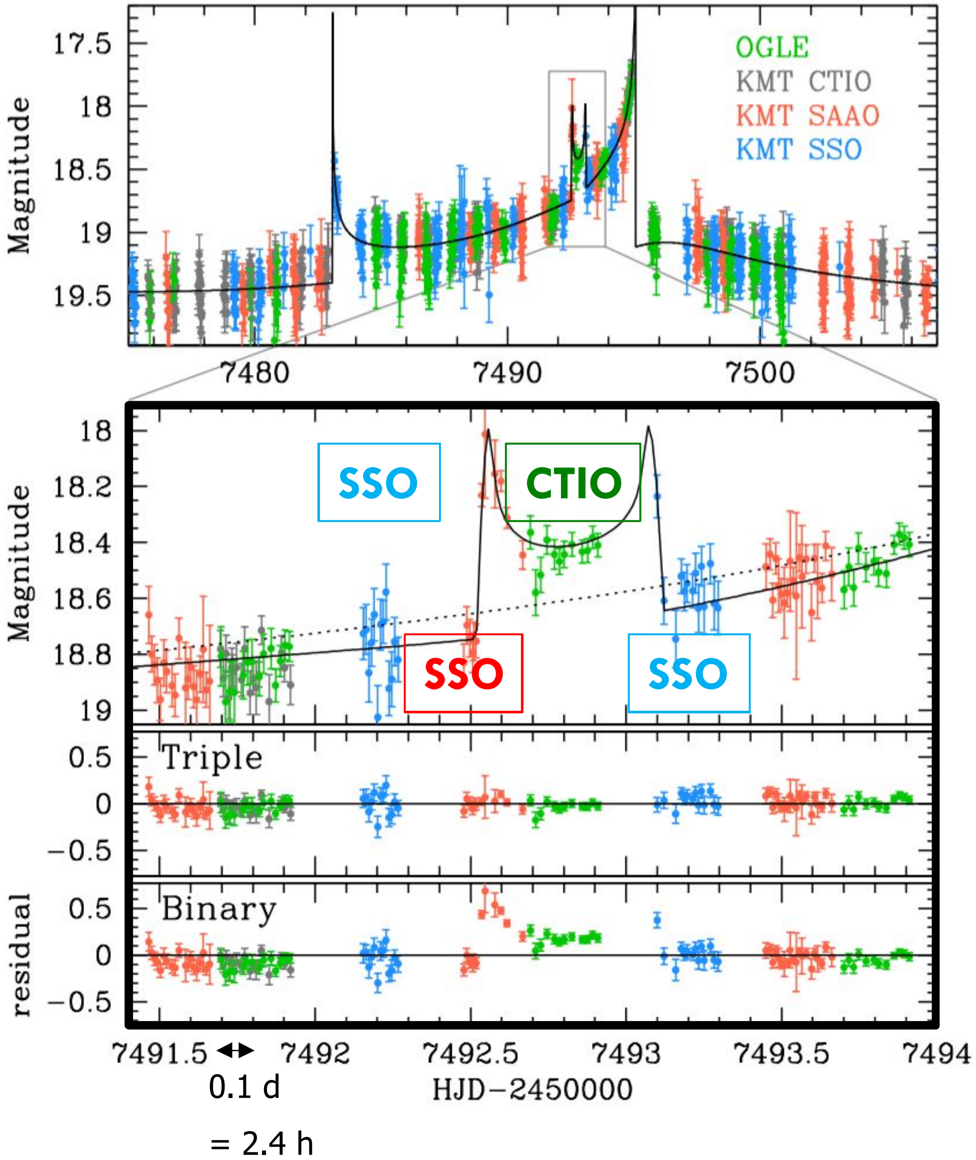
Sciences

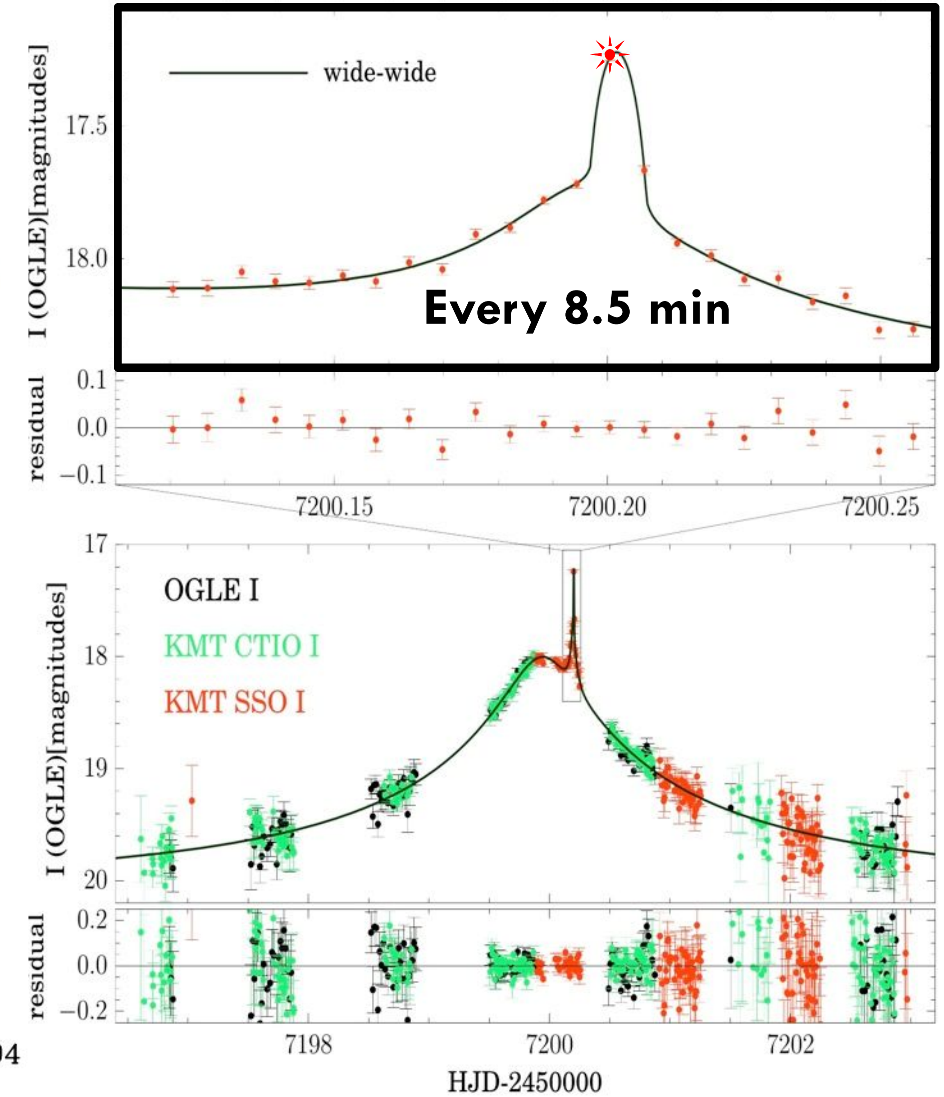
- Galactic Bulge Season (Red)
  - Search for Extra-solar Planets with the micro-gravitational lensing technique, especially, Earth-mass Planets in the Habitable Zones
  - Search for Variable Objects (e.g. eclipsing binaries, pulsating stars, planetary transits, stellar flares, novae, other transient events)
- Non-Bulge Season (Blue)
  - Seven observation programs selected on 2012 will be performed for 5 years from 2015
  - Survey of Supernovae
  - Survey of Asteroids and Comets, especially, Near-Earth Objects
  - Multiband Photometry of External Galaxies
  - Others (e.g. Collaboration with the Host Countries, Director/Maintenance Time)





KMTNet – high cadence of 8.5 min





KMTNet (Unique) Advantages

► (Highly) Competitive Etendue ($A \times \Omega$)

KMTNet: $1.6^2 \times 2^2 \approx 10.2$ (m^2 sqd)

► Excellent Pixel Sampling & Filter Sets

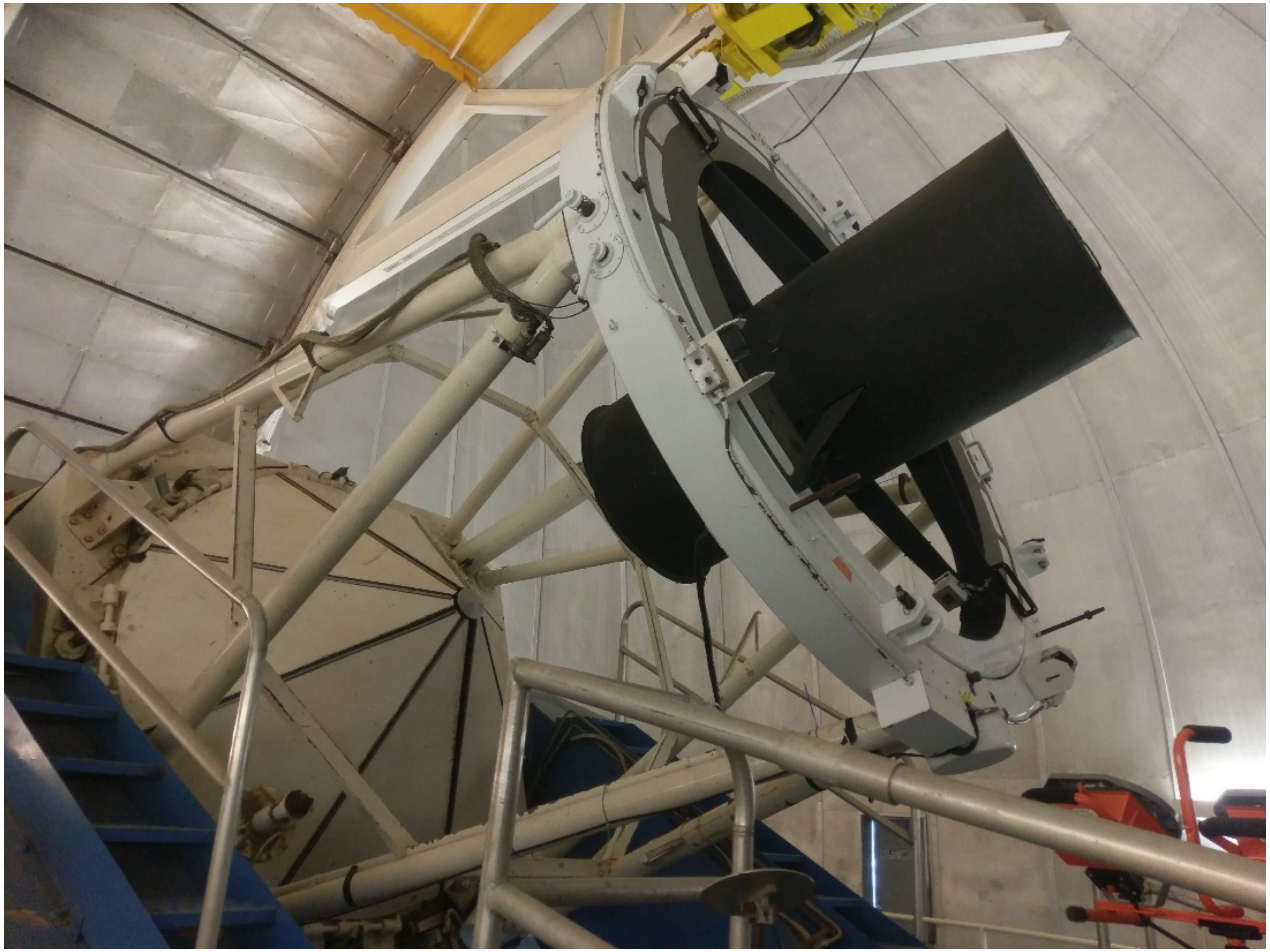
KMTNet: 0.4″/pixel, BVRI (*g′r′i′z′*) Hα

► (Unique) 24-hr Continuous Sky Coverage

(Supernovae: Early, rare, and high-cadence monitoring)

The Kitt Peak EMCCD Demonstrator (KPED)

The Kitt Peak 84 inch



Principal Investigator: S. R. Kulkarni
Project Scientist: M. W. Coughlin

The Kitt Peak EMCCD Demonstrator (KPED)

A sensitive, flexible, multi-spectral optical imaging capability for high-cadence follow-up of the transient universe.

Instrument	Science
Hardware 1. EMCCD – Andor iXon 888 2. Filter Wheel – Finger Lakes (10 slot) 3. Filters – Johnson UBVRI, Sloan g and r 4. Corrector Lens 5. Mounting plates 6. Computer *Feeney/Riddle/Dekany/ Coughlin*	ZTF transient follow-up (GWs, SGRBs, TNOs) *Ahumada/Coughlin/Dekany/Kulkarni* WD Binaries – PTF and ZTF *Burdge/Coughlin/Prince/van Roestel*
Software 1. EMCCD – Andor SDK + Python wrapper 2. Filter Wheel – FLI SDK + Python wrapper 3. Telescope Control – Robo-AO 4. Reductions – Robo-AO + Chimera *Riddle/Duev/Coughlin*	Gravitational Lens Time Delays *Coughlin* Astroseismology *Fuller*
Telescope/Camera 1. F/# = 4.864 2. FOV = 4.4 x 4.4 arcmin 3. 2.1 meter primary *Feeney/Riddle/Dekany/ Coughlin*	Calibration/Technical *Coughlin*

Instrument: Coughlin, Dekany, Feeney, Kulkarni, Riddle
Science: Ahumada, Burdge, Coughlin, Dekany, Fuller, Kulkarni, Prince, Riddle

Example Science Cases

Science

WD Binaries - PTF, ZTF and ATLAS

- Monitoring of the WD binary systems identified in the original PTF data.
- Follow-up of potential ZTF WD binary systems
- Follow-up of potential ATLAS WD binary systems

ZTF transient follow-up (GWs, SGRBs)

- Monitoring of the ZTF transients identified in the SGRB follow-up work.
- ZTF transients, especially those identified as fast fading, in preparation for SGRB and GW follow-up, is important.

Asteroseismology

- Low-mass pulsating white dwarfs

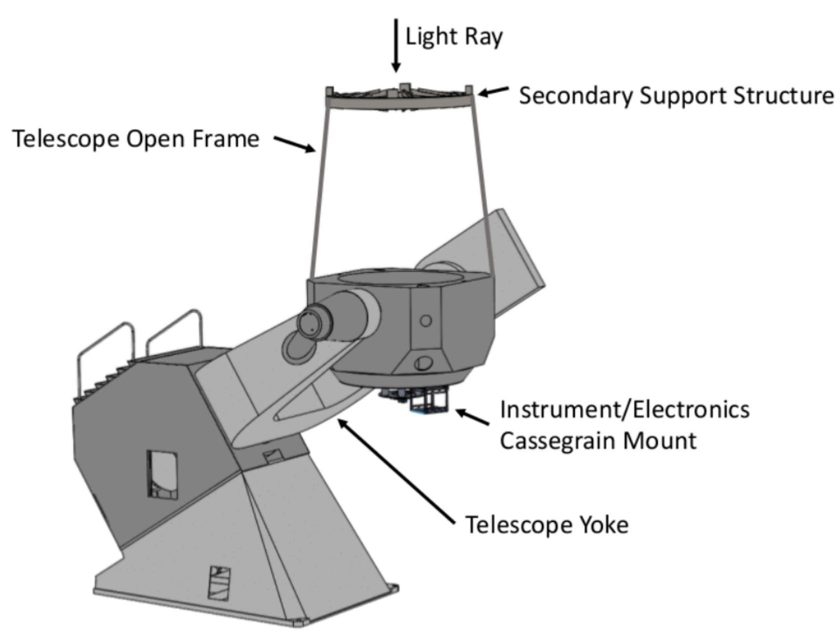
Gravitational Lens Time Delays

- Time delay measurement for GAIA + PS1 lens systems
- https://arxiv.org/abs/1803.07601

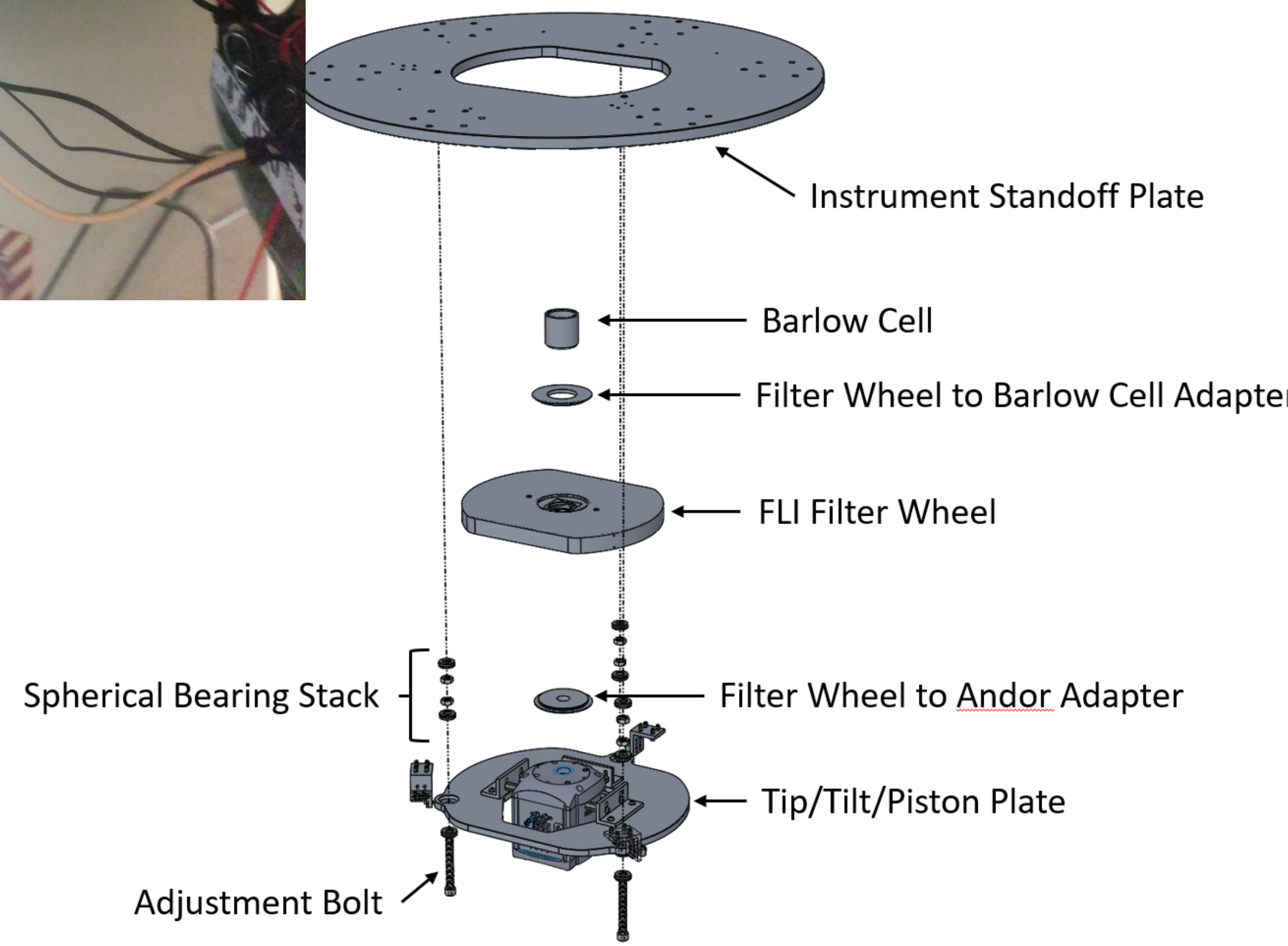
Calibration/Technical

- Photometric stability and performance of EMCCDs as a function of EM gain.
- Multiband colors in UBVRI of hot DA white dwarf stars from Gaia.

Instrument Breakdown



Instrument breakdown exploded view

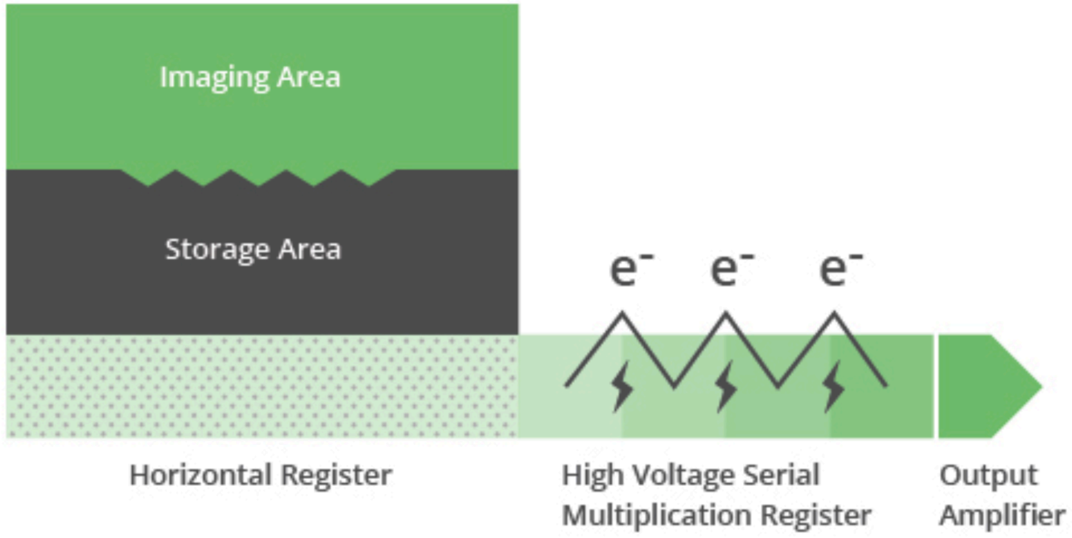


Electron Multiplying CCD (EMCCD)

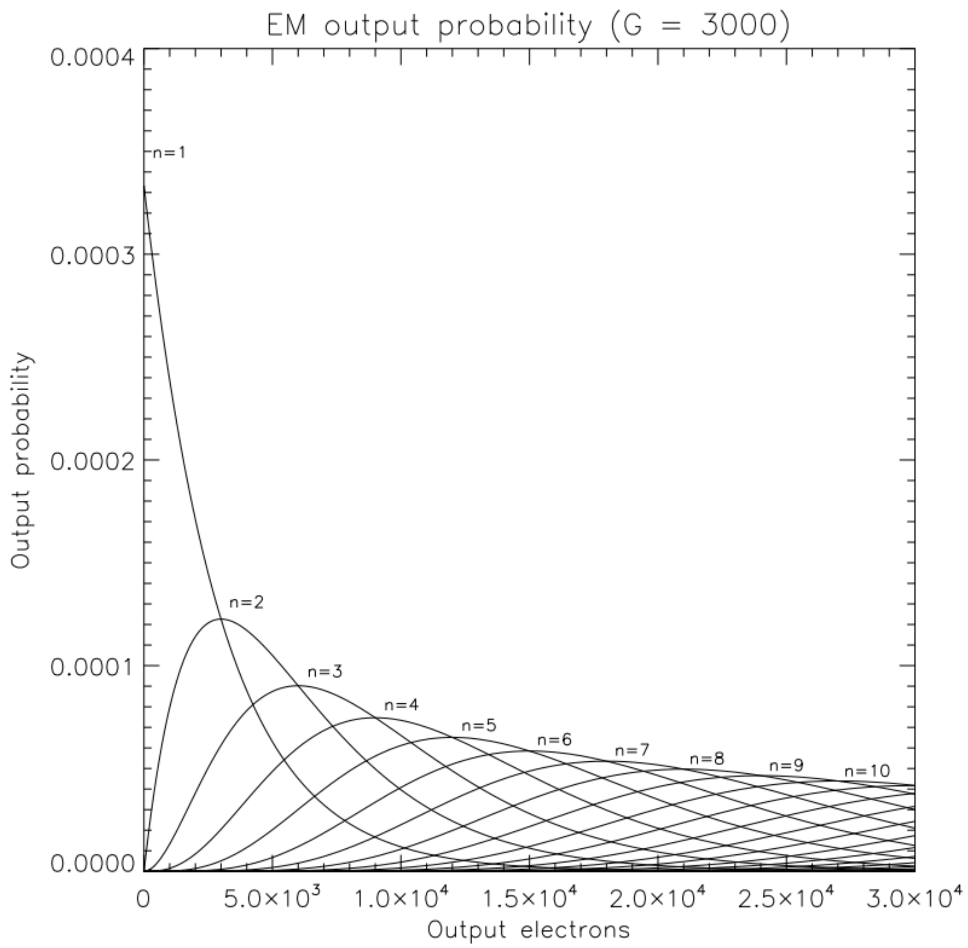
Enable sub-electron read-out noise!

but…

- Thermal noise: Cooling to -80 degrees Celsius
- EM Gain / Excess Noise Factor: The multiplication process involved is stochastic (square root 2 penalty, equivalent to half the quantum efficiency)
- Clock Induced Charges (CIC): Dominant over dark noise at high frame rate (at least an order of magnitude higher than the dark noise at 1 Hz).
- Charge Transfer Efficiency: Photoelectrons left behind during the charge transfer process, especially at high readout speeds



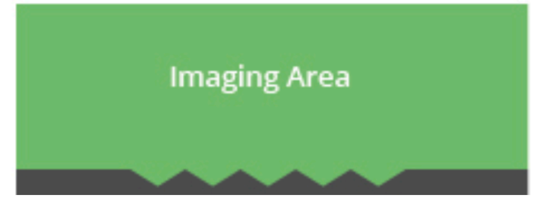
www.nuvucameras.com



Diagle et al. 2008 (0908.0528)

Electron Multiplying CCD (EMCCD)

Enable sub-electron read-out noise!



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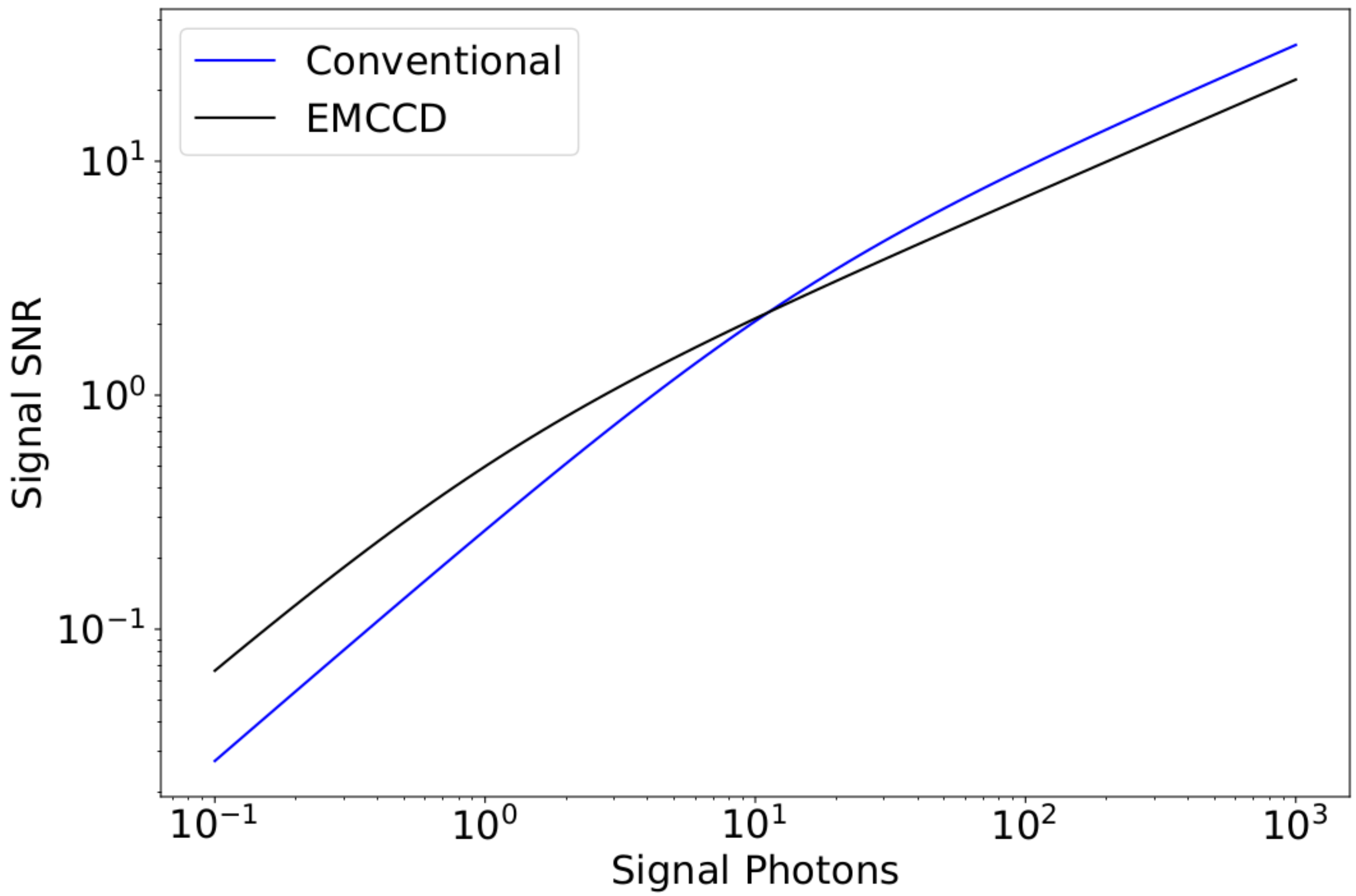
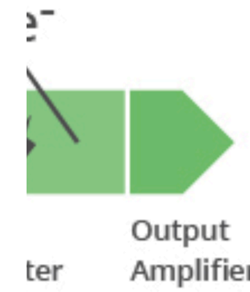
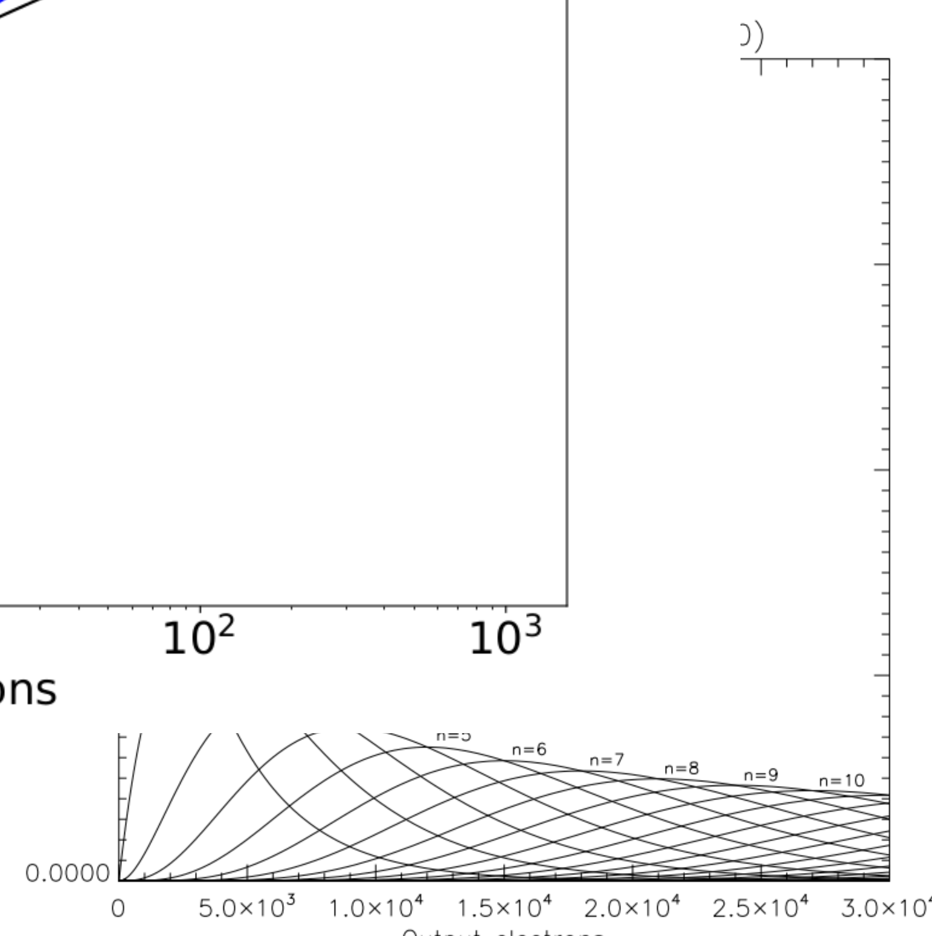






Diagle et al. 2008 (0908.0528)

Software

Telescope and Camera Control

- Based on Robo-AO and ZTF control system
- Simple, terminal based observation system
- Observation guide is documented here:

https://docs.google.com/document/d/14qMSYqB5meju1MuetaBHBBxcGyQp5c6Y1_-ECV-EBHU/edit#

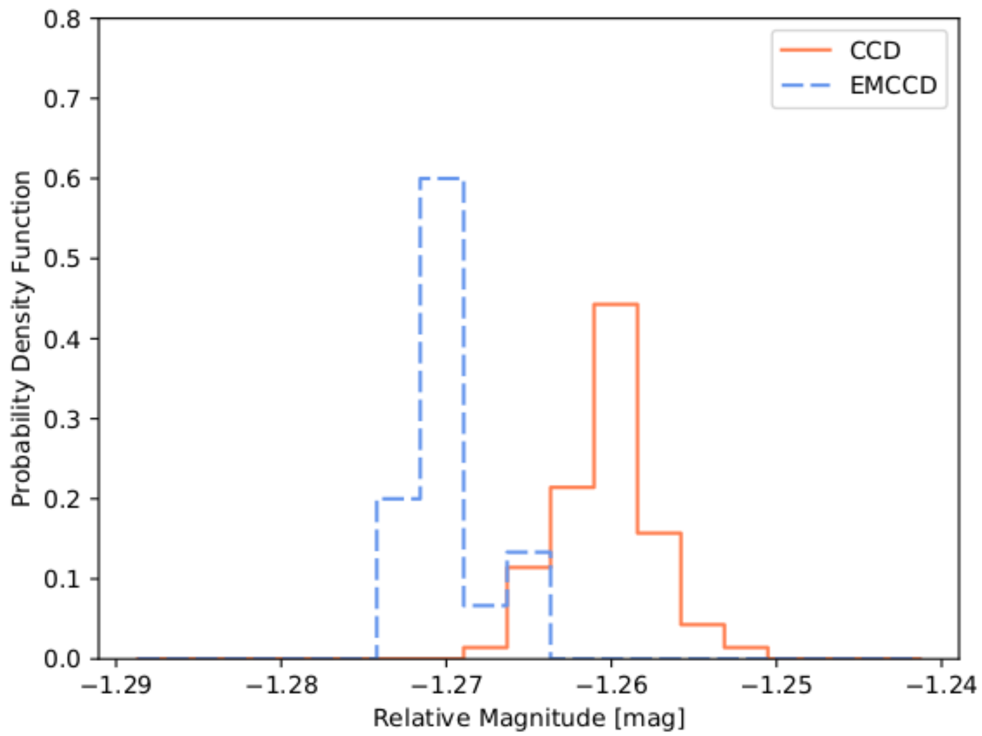
Photometric Reductions

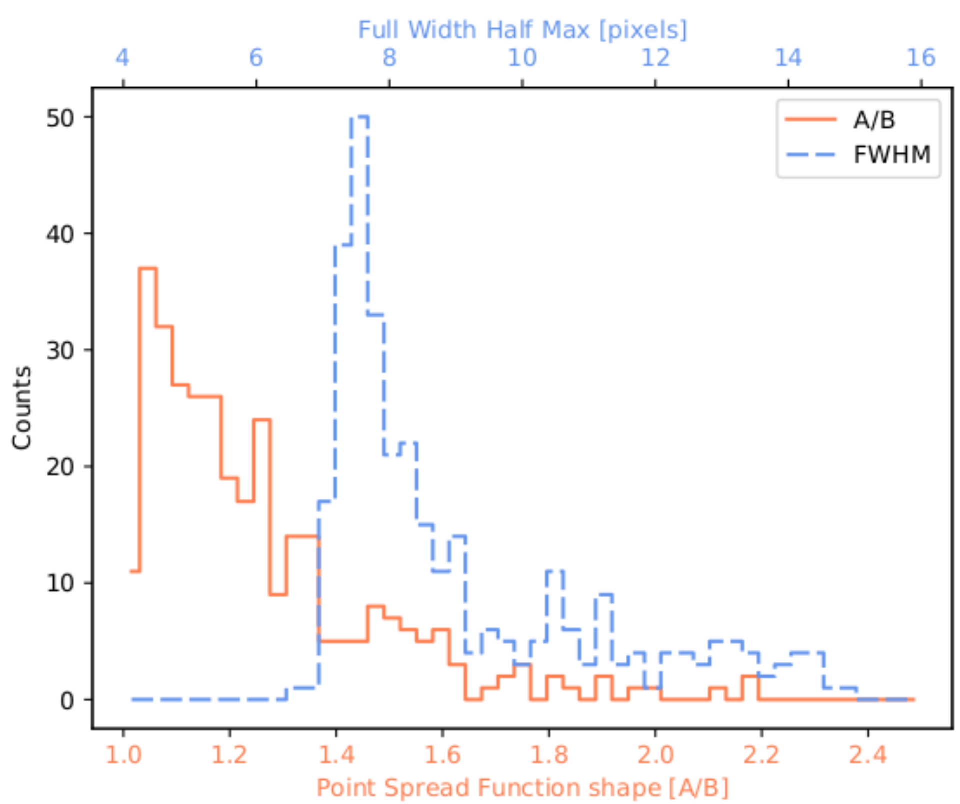
- Based on SEDM and Chimera reduction packages
- Written in python, depending on standard packages including source extractor
- Software is self-documenting and publicly available on the KP84 GitHub

https://github.com/mcoughlin/kp84

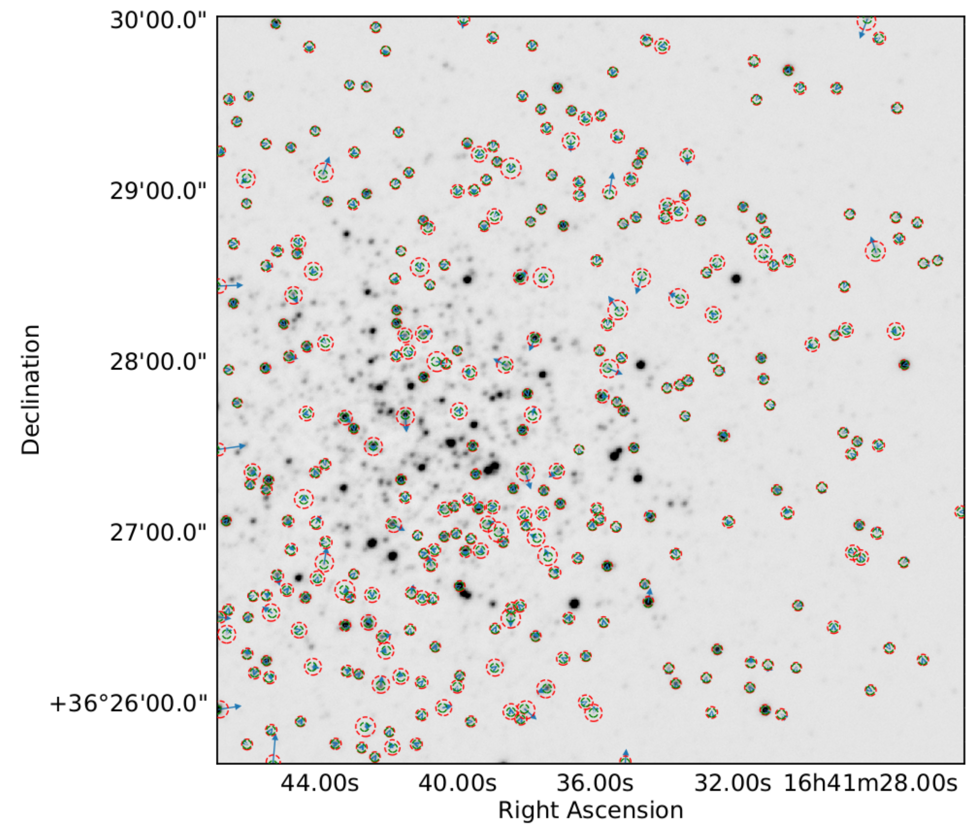
Instrument Performance

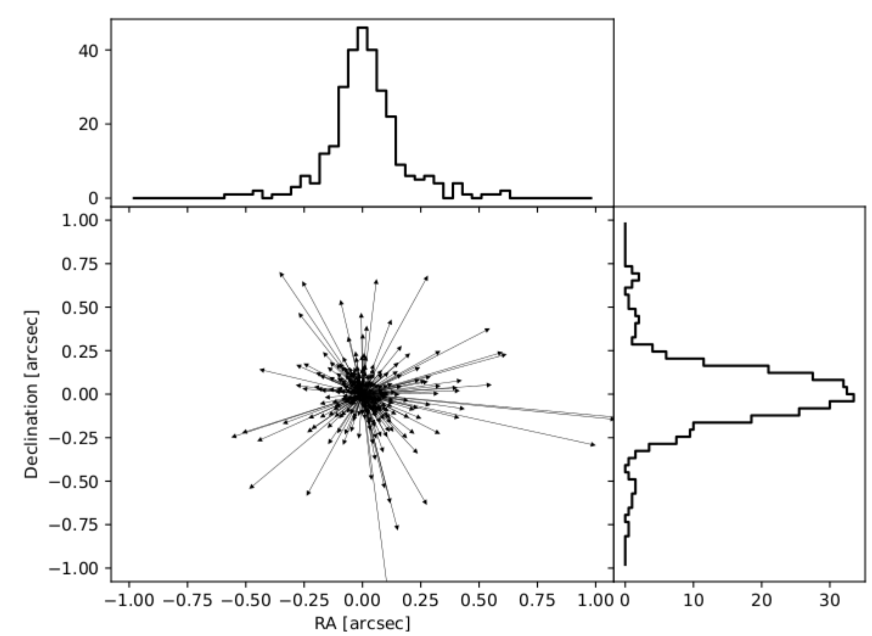
Photometric Performance





Pointing / Distortion





Instrument Sensitivity

Pointing / Distortion

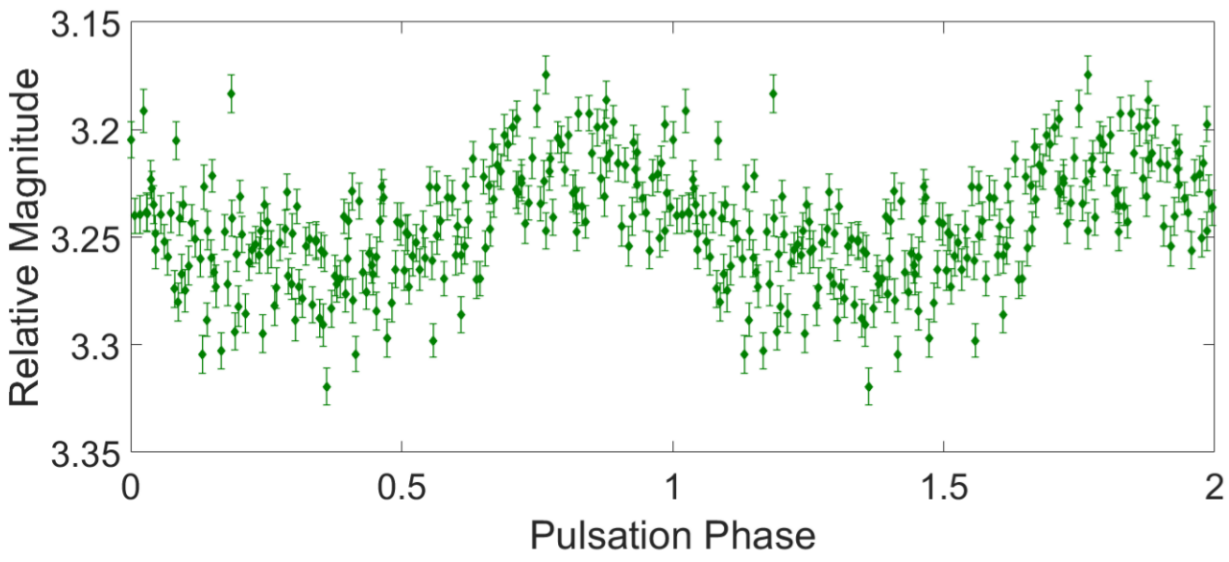
FITS WCS keyword	Value	Standard Deviation	Unit
CD1_1	-7.120×10^{-5}	6×10^{-8}	deg/pix
CD1_2	5.0×10^{-7}	8×10^{-8}	deg/pix
CD2_1	5.3×10^{-7}	6×10^{-8}	deg/pix
CD2_2	7.121×10^{-5}	8×10^{-8}	deg/pix
CRPIX1	512.019	0.003	pix
CRPIX2	512.002	0.002	pix
CCD_ROT	0.423	0.045	deg
PIXEL_SCALE1	0.2563	0.0002	arcsec/pix
PIXEL_SCALE2	0.2563	0.0003	arcsec/pix

Limiting / Zeropoint magnitude

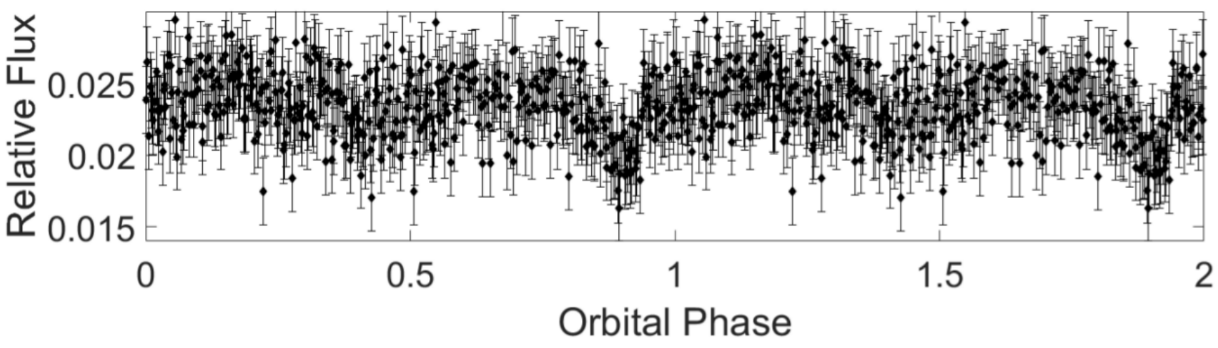
Band	Limiting mag.	$\sigma_{\text{Limiting mag.}}$	Zeropoint mag.
r	23.3	0.31	20.8
g	23.7	0.48	21.3
U	17.5	0.99	17.0
I	16.2	0.49	16.1

Early KPED Results

- PTF1J214022.55+262124.4: period of 4.8 minutes

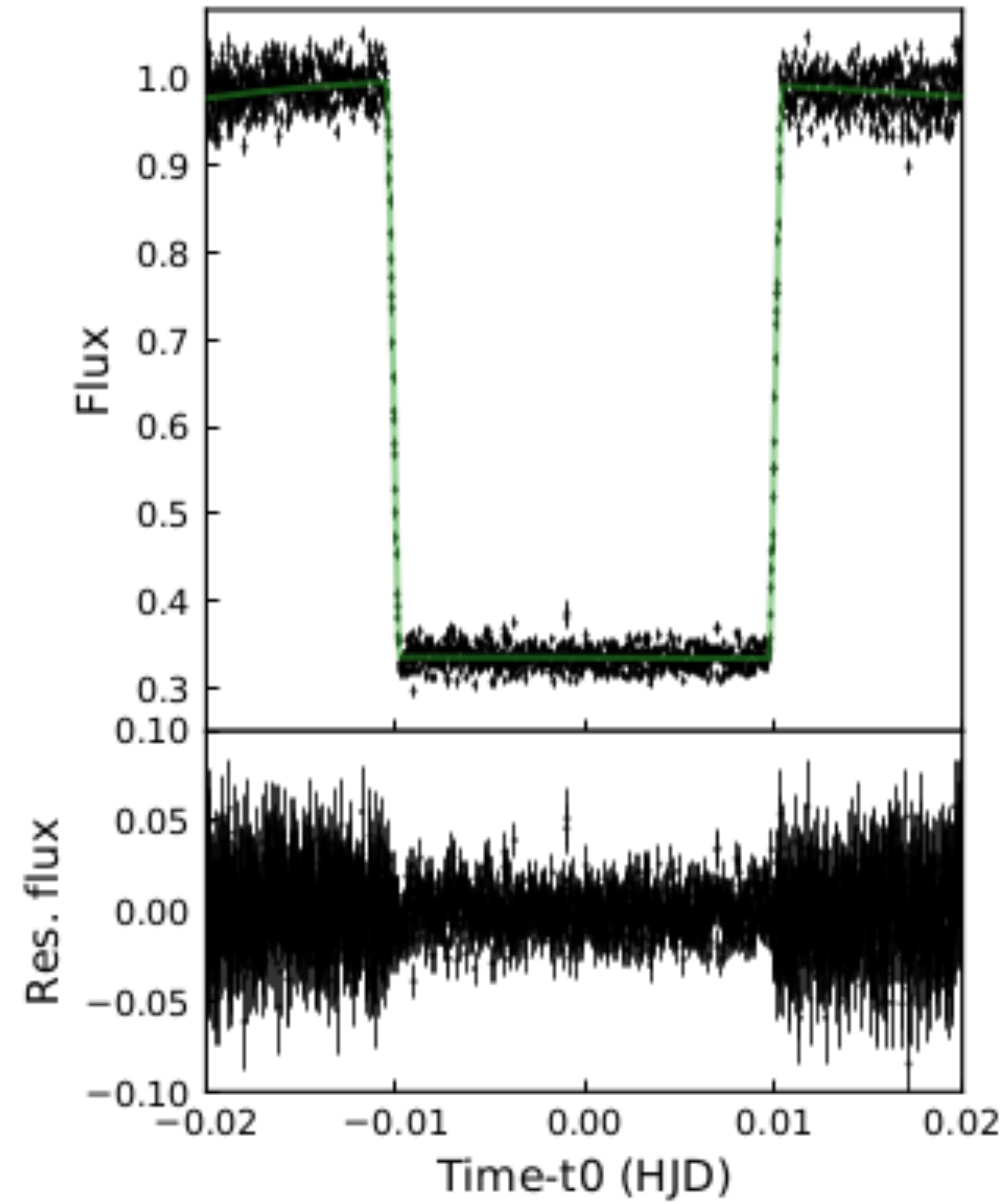


- J0651: period of 12.75 minutes

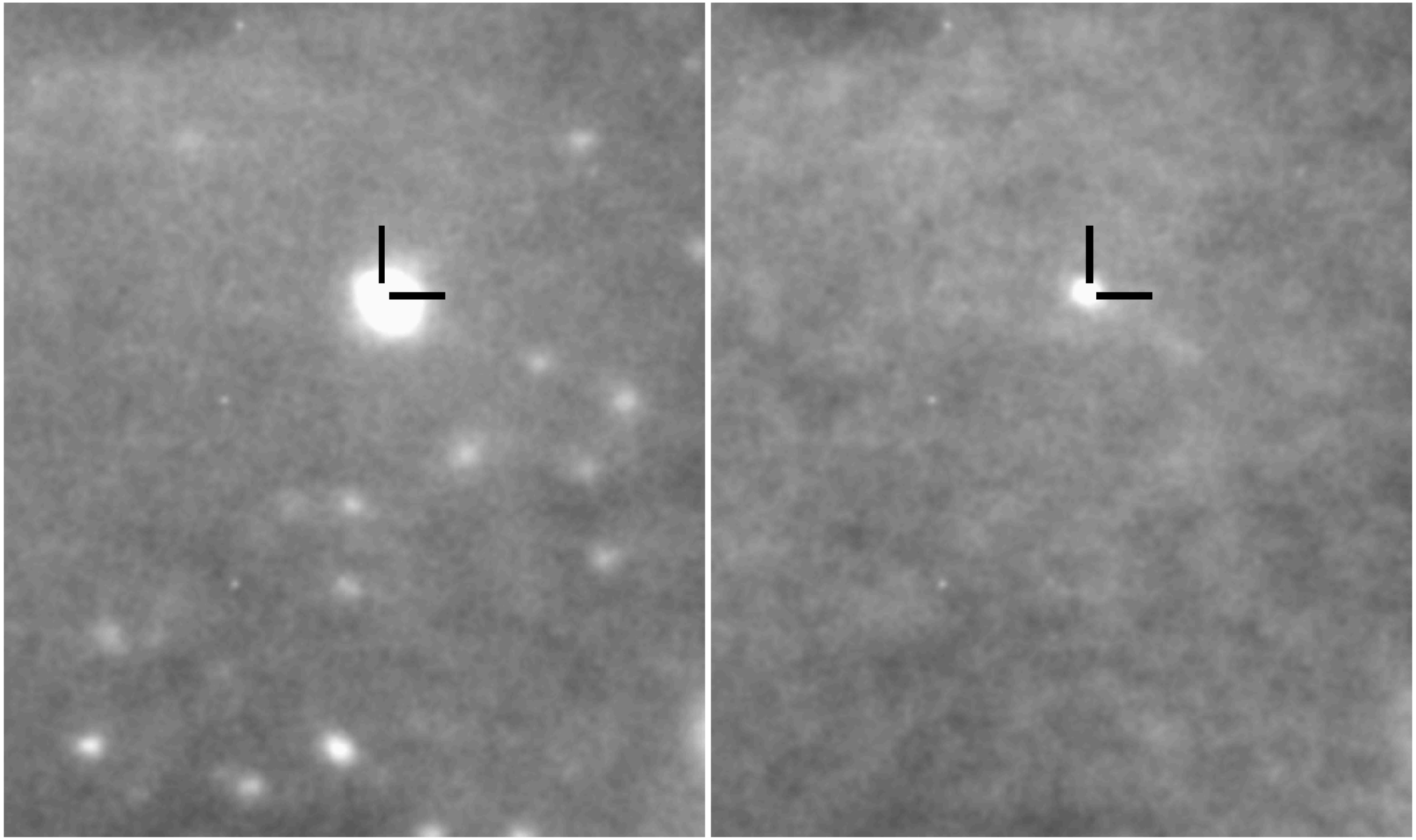


Lightcurve of PTF1J162528.61-003545.8

- PTF1J162528.61-003545.8: an eclipsing white dwarf--red dwarf system (g=16.0) identified by PTF with an orbital period of 7.8 hr.
- Eclipse timing uncertainty: 0.2 s
- Sum of the scaled radii ((R_1+R_2)/a) and the ratio of the radii: 1%



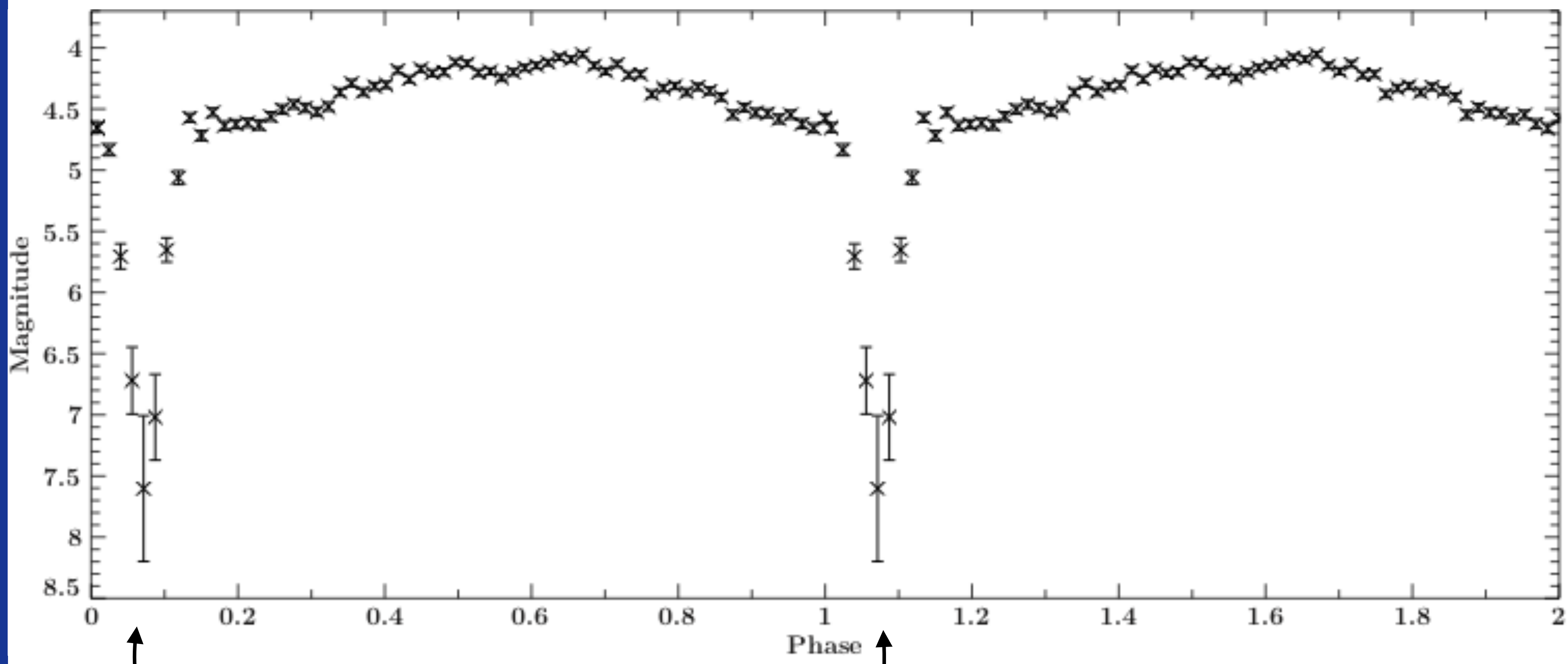
Transient Follow-up



- Example of difference imaging with KPED: ZTF18aalrxas in r-band

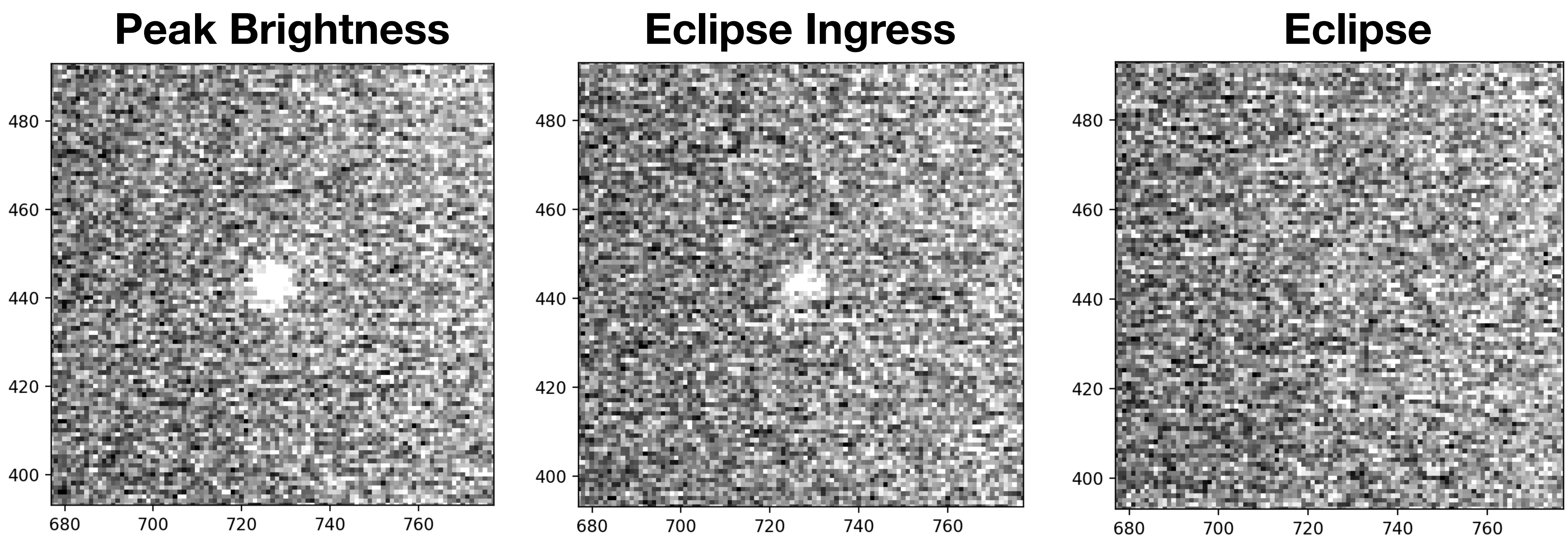
A 7 minute system

- **Folded Lightcurve of the 7 minute binary eclipsing white-dwarf binary from KPED**



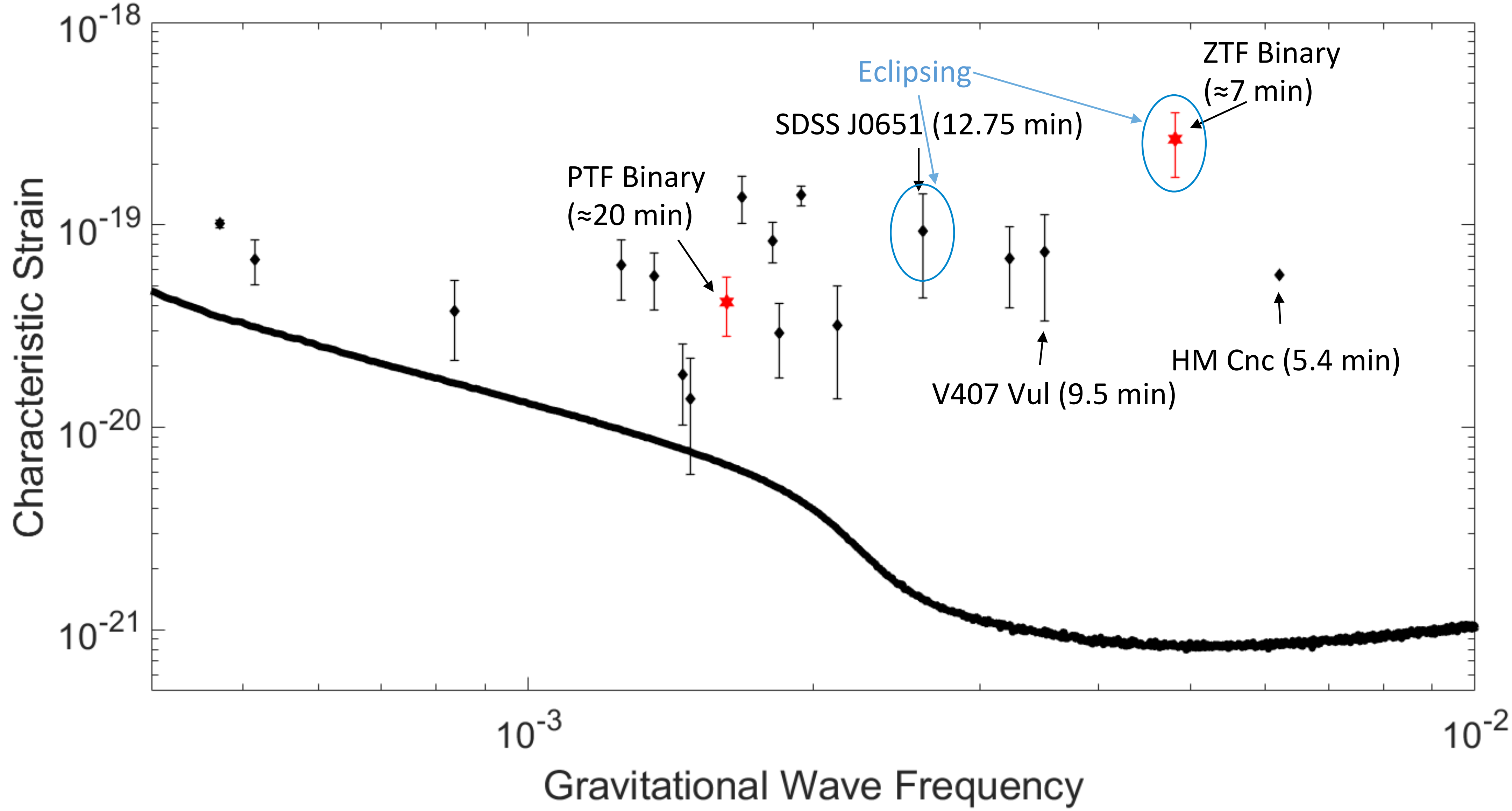
Two eclipses; 7 minute period

A 7 minute system (continued)

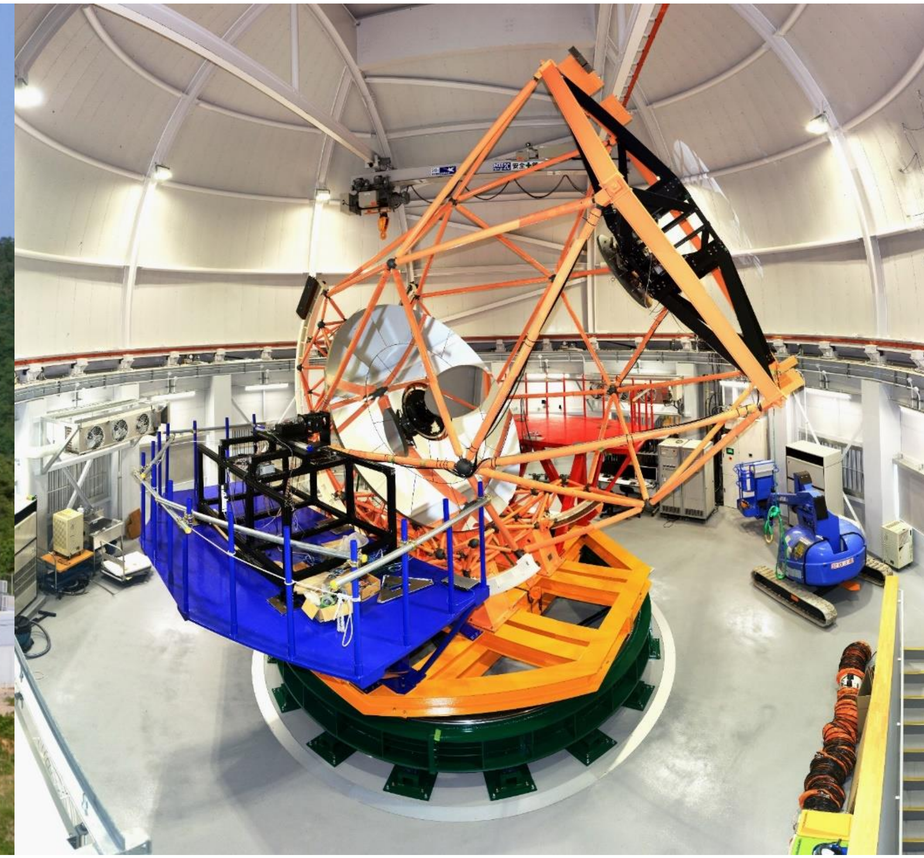


- **Low flux level during the eclipse prioritizes the use of the EMCCD, which is designed for low light level observations**

LISA Verification Binaries



Kyoto 3.8m Seimei Telescope



Keiichi Maeda,
Department of Astronomy, Kyoto University

Overview

A new telescope nearly completed (under fine adjustment):

The diameter = 3.8m.

18 segmented mirrors.

Quick move for ToOs.

First instrument:

Fiber-fed IFU low resolution spectrograph (Kools-IFU). ~19 mag.

Site:

Okayama observatory (western part of Japan).

Operation:

Kyoto U. & NAOJ. 50% University, 50% Japanese astro community.

Aims:

Science (ToO), Education (obs & instrumentation)

Key Science (examples)

- **Transients and ToO observations.**
- Exoplanets.
- Stellar flares and activities.

- Note:
  - High contrast AO camera and high-dispersion spectrograph not ready yet. Transient science is the key in the initial operation phase.

A list of Interests (as usual)

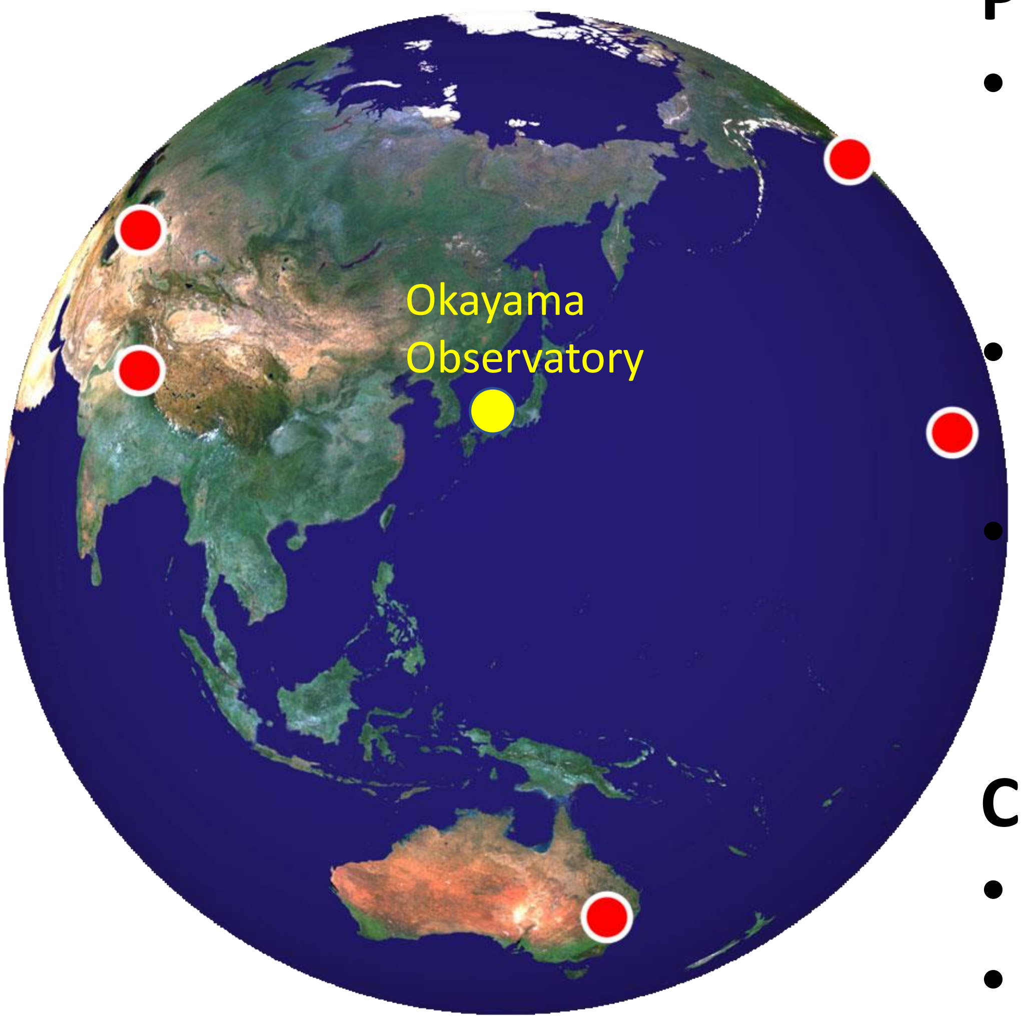
- Gravitational wave counterparts.
- Gamma-ray bursts.
- X-ray binaries.
- Magnetar bursts.
- Supernovae and extragalactic transients.
- Novae.
- Dwarf novae.
- Luminous Red novae.
- Stellar flares.
- Unknown objects and phenomena…..

Maeda responsible for extragalactic transients within the Kyoto University.

Telescope

• Main mirror diameter	3.78m
• F ratio of the main mirror	1.3
• Optical system	Ritchey-Chretien
• Second mirror diameter	1.1m
• Final F ratio	6.0
• Scale at the focus	9.09”/mm
• Focus size	12’φ (w/o correction lense)
	1° φ (with correction lense)

Site: Okayama Observatory



Pros:

- (134.6 deg, +34.6 deg) => Filling the sky coverage for transients.
- Observable night fractions: ~ 50% (best in summar-fall).
- Seeing: 1-1.5” (best in spring & fall).

Cons:

- Bright sky (in optical).
- Altitude = 400m (not typo).

Distribution of mid and large size multi-purpose telescopes

Telescope time & operation

- ~ 50% for Kyoto University.
- ~ 50% for open use (within Japanese community) through NAOJ.
- Public education, outreach, maintenance delivered from the University time and NAOJ time, half-half.
- Also a part of the OISTER collaboration.
- Will start Science run from February 2019.
- The operation in the initial phase (~ 2019) will ne limited in several ways (time, ToO capability, etc).
  - First run: Feb – June 2019.
  - ~ 30 nights for open use, ~ 30 night for the University.
  - Basically visitor mode, but a ToO proposal possible.
  - No ToO allowed across the different time allocations (between the open-use and University).

OISTER collaboration

- Telescope networks within Japan (+ south Africa + Chile).
- Kyoto Telescope can also be activated through the OISTER (i.e., open-use + Kyoto University + OISTER).

Instruments

1. Optical low resolution 2D spectrograph "KOOLS-IFU" (R=800-2,000, Integrated fiber unit of 128 fibers, ϕ=~15arcsec) (1st instrument; almost completed) [Ohta, Matsubayashi]
2. Optical high time-resolution imager and spectrograph (100 images/sec at maximum, R=20 or 150; under construction)
3. Infrared medium resolution spectrograph (R=2,700; under construction)
4. NIR High contrast camera for direct imaging of exoplanets "SEICA" (imager with extreme AO; under construction)

Instruments (continued)

5. Optical high dispersion spectrograph for exoplanet survey (R=~50,000; modifying)
6. Optical multi-color CMOS imager and spectrograph (under construction) [Maeda, Ohta]
7. Infrared imaging polarimeter (designing)
8. Optical high dispersion spectrograph (R=~100,000; applying for a fund)

<u>All of these instruments will be ON anytime, and we will be able to change the instruments very quickly with rotation of the tertiary mirror and move of the fibers.</u>

ToO capability

- Telescope slew speed: 2-3 degree / sec.
- Instrument change: ~ 1 min if it is on the rotator.
- Minimal Elevation: 25~30 deg.
- Kools-IFU: little overhead for acquisition.

- Aiming at a full (?) ToO automation in a few years time scale.
- Limitation in the initial operation: need an on-site observer.

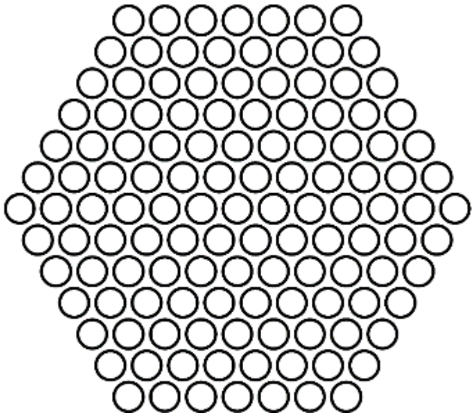
ToO capability - note

- Aiming at a full (?) ToO automation in a few years time scale.
- Limitation in the initial operation: need an on-site observer.
- Several on-site observers related to the transient science.
  - One through the NAOJ budget.
  - Two through the OISTER budget (one from April 2019).
  - One through a Kakenhi Grant budget (PIs: Doi & Maeda) (from Aprial 2019).

Kools-IFU on 3.8m

ファイバー型
可視光面分光装置

Kools-IFU on 3.8m



Grism	VPH-blue	VPH-red	VPH495	VPH683
# of Faibers	127			
FoV for 1 fiber	0.91’’ (diameter)			
FoV for all	14.8’’ (diameter)			
Filling factor	58%			
Wavelength	4000—8900 Å	5800—10200 Å	4300—5900 Å	5800—8000 Å
Resolution	~800	~800	~1200	~2000
Throughput	5.8%	(~6%)	3.4%	(~6%)

Limiting Magnitude w/ Kools-IFU

Glism	VPH-blue	VPH-red	VPH495	VPH683
Magnitude [AB mag]	19.8	19.5	18.6	18.9

Conditions:

- 1800 sec, S/N = 10, $\Delta\lambda$ = 10 Å (low-res) or 4 Å (mid-res) . 1 Å ~ 4 pixels.
- seeing: 1.5" → 95% flux in 7 fibers.
- Background: 19 mag arcsec^{-2}
- 5 pixel summation for the spatial direction.

CMOS multi-band Imager + spectrograph

- Fully funded and under construction (nominal PI: Maeda).
- Operational from 2020 (hopefully).
- Simultaneous observations with 3 arms:
  - Arm 1: g-band.
  - Arm 2: r-band.
  - Arm 3: I or z or y-band.
- Detector = CMOS (for Time Domain).
- ~ 0.3”/pixel, FoV ~ 6 x 11’.

- Future Option: NIR imager+polarimeter (funded: Nagata).
- Future Option: Spectrograph in each arm (fund raising).

Projects for Transients

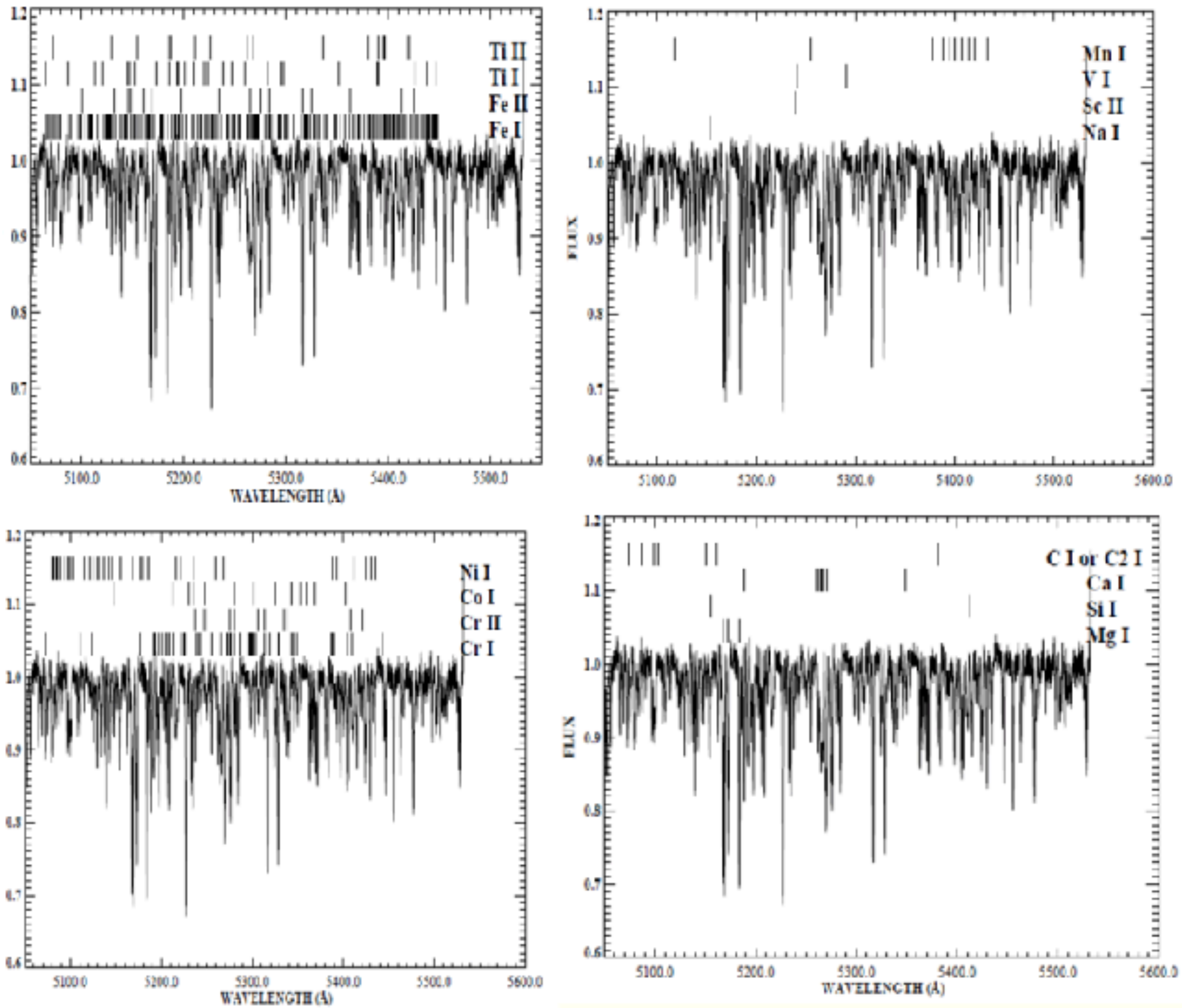
- The transient science will be a collaborative work between Kyoto researchers and other Japanese researchers, but we are open (and seeking) for international collaboration as well.
- Especially, there has been lots of discussion between Kyoto and Tomo-e people (discovery and rapid follow-up), and also with the OISTER project (maximize the resources).

LAMOST-II

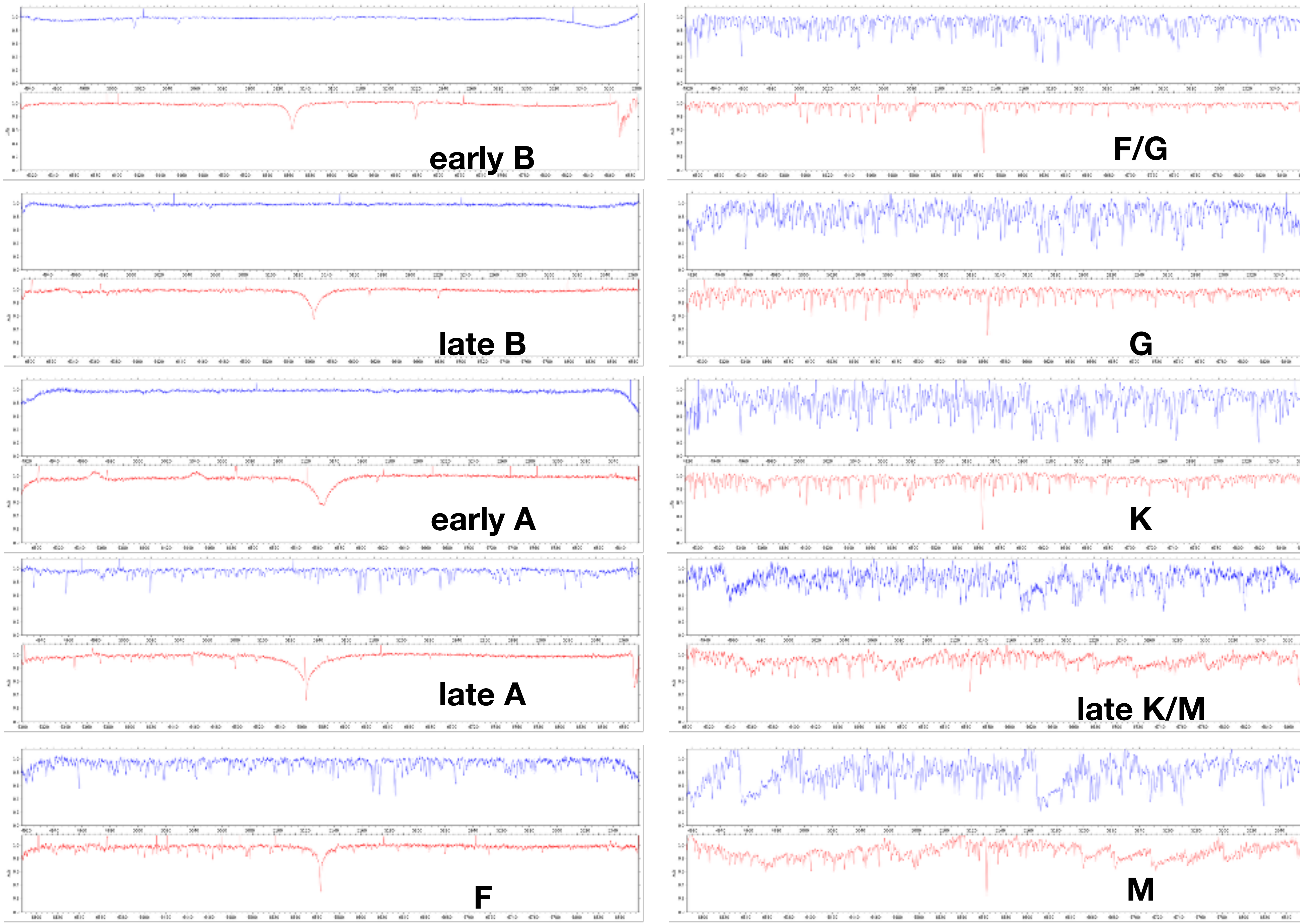
Updated spectrographs

- Gratings are updated and able to switch to R~7500
  - Blue arm: 496-533 nm (Mg Triplet, metal lines)
  - Red arm: 630-680 nm (Halpha, Li)
- With medium-resolution
  - limiting magnitude with 20 min exposure: G<~14 mag (s/n>10)

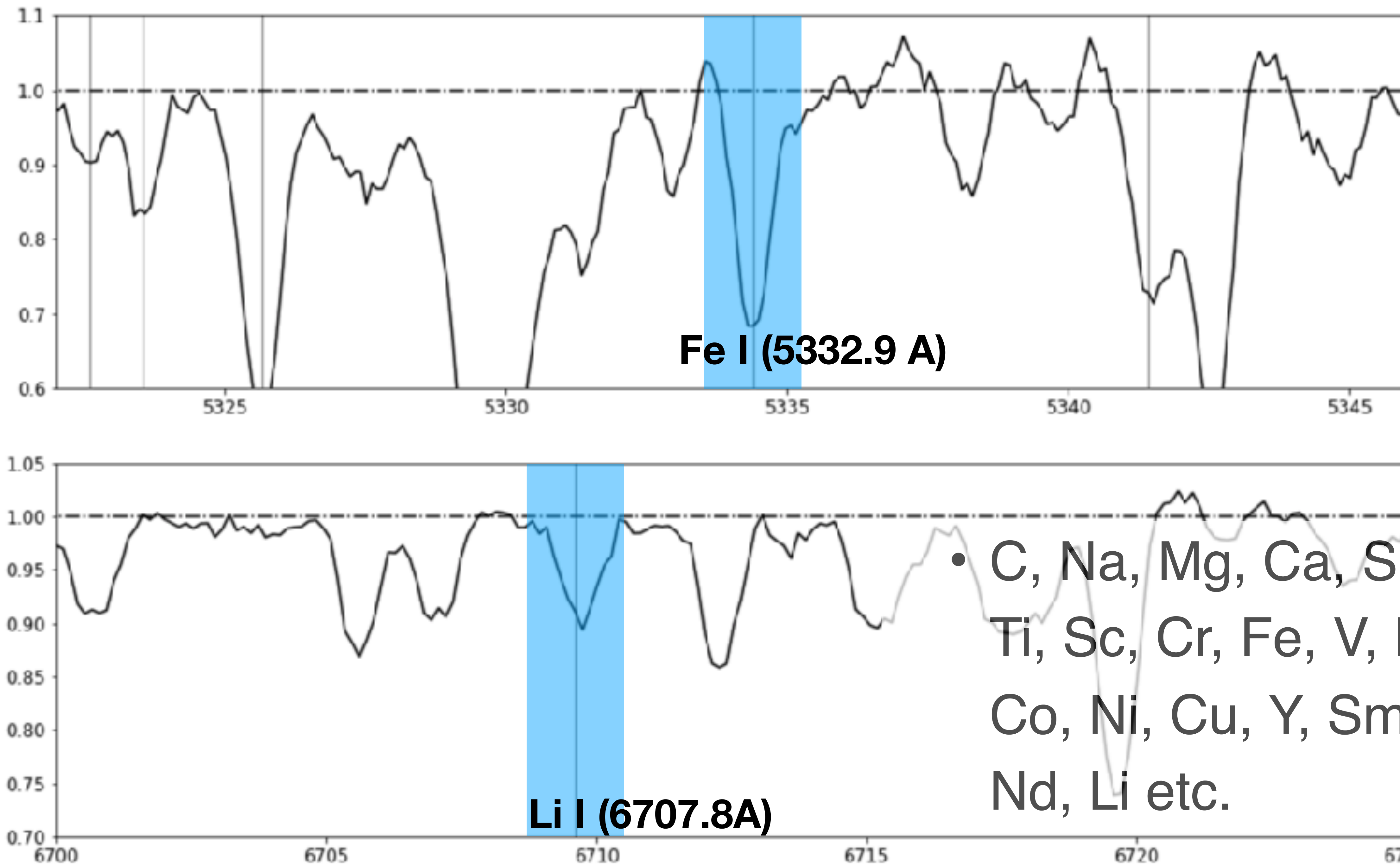
~20 elemental abundances



- C, Na, Mg, Ca, Si, Ti, Sc, Cr, Fe, V, Mn, Co, Ni, Cu, Y, Sm, Nd, Li etc.


early B
late B
early A
late A
F
F/G
G
K
late K/M
M

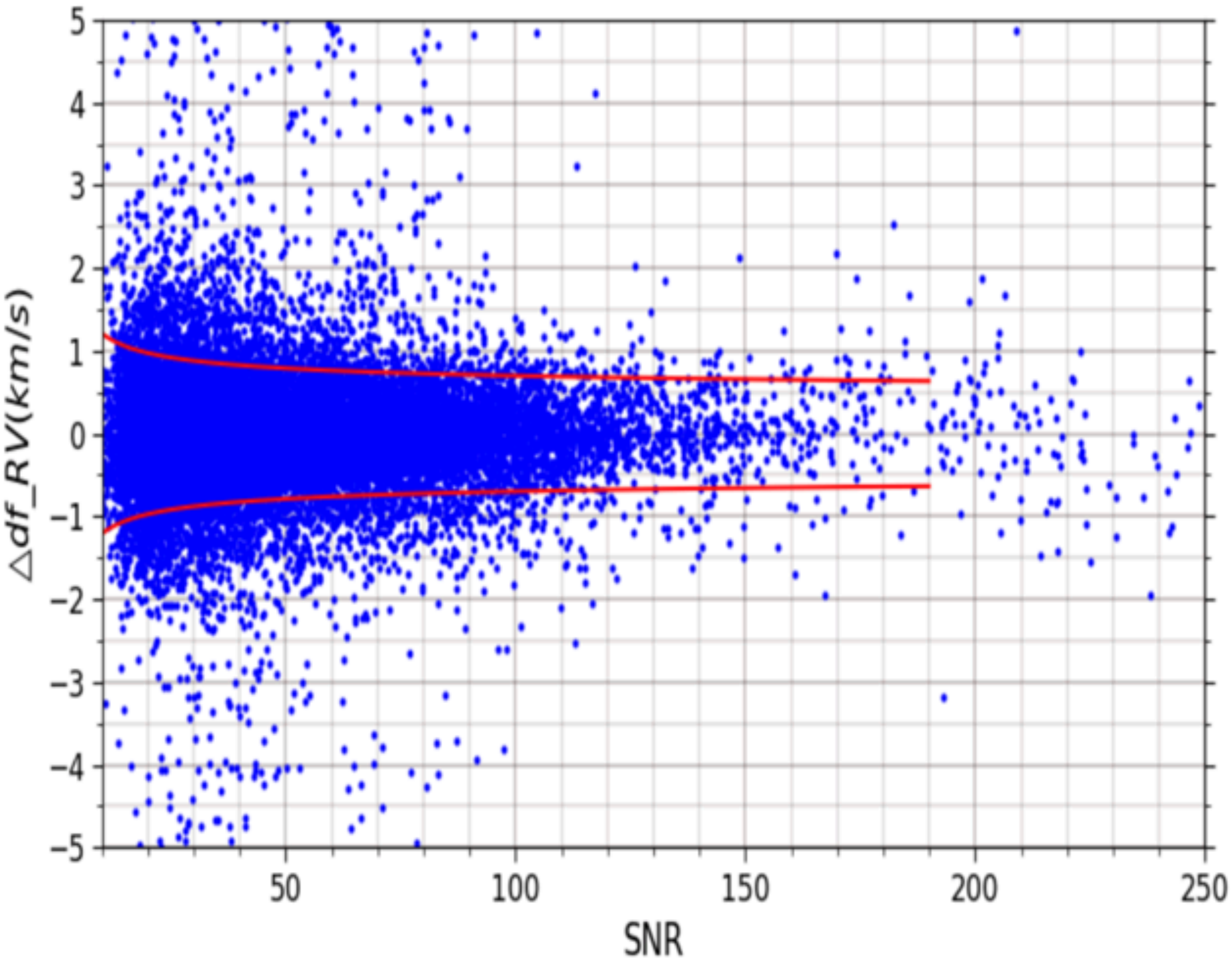
~20 elemental abundances



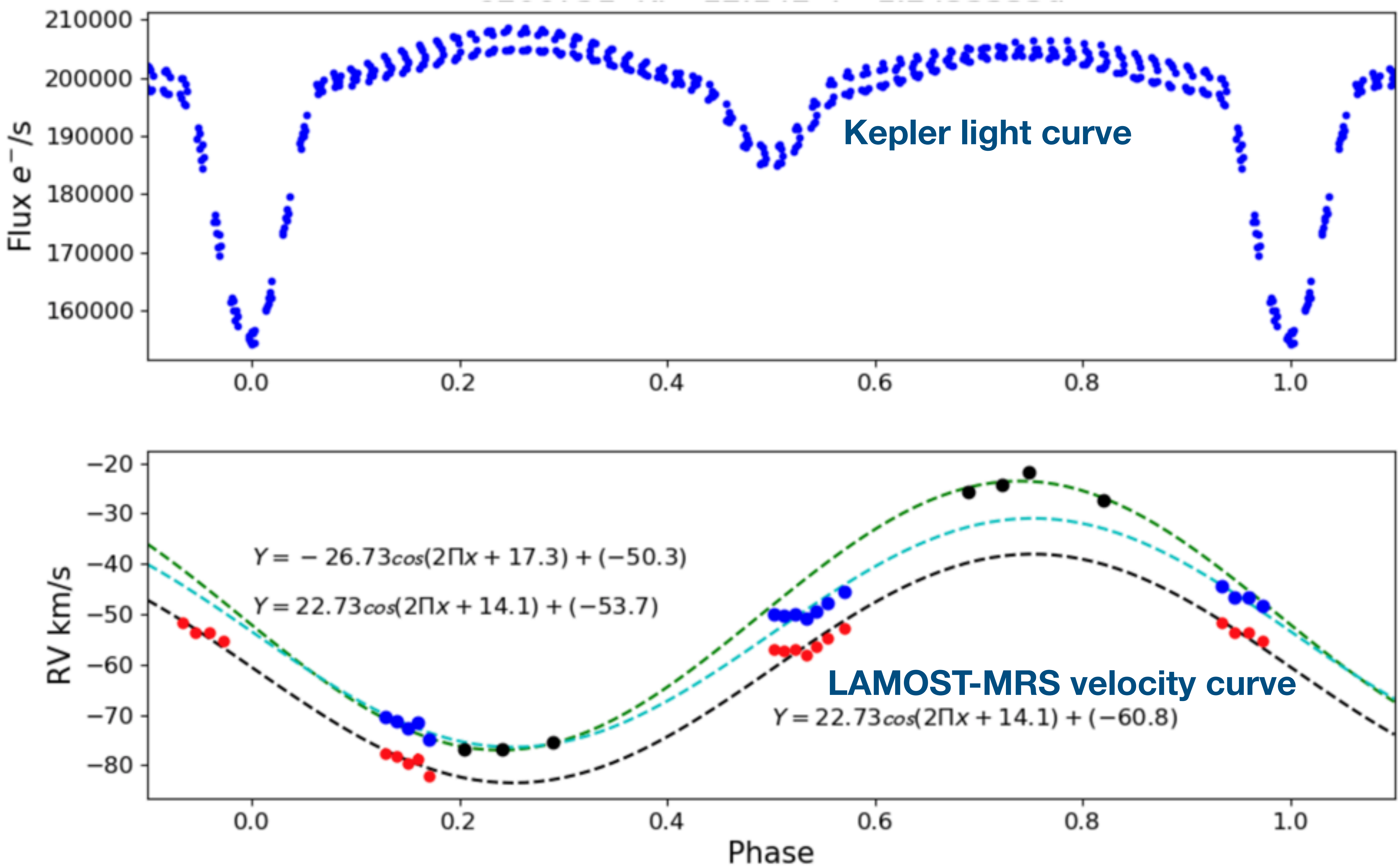
- C, Na, Mg, Ca, Si, Ti, Sc, Cr, Fe, V, Mn, Co, Ni, Cu, Y, Sm, Nd, Li etc.

Radial velocity

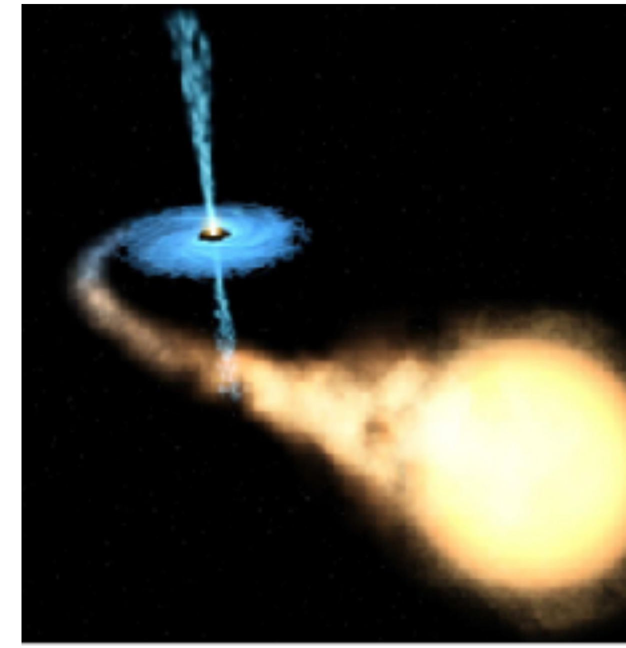
Precision is around 1 km/s



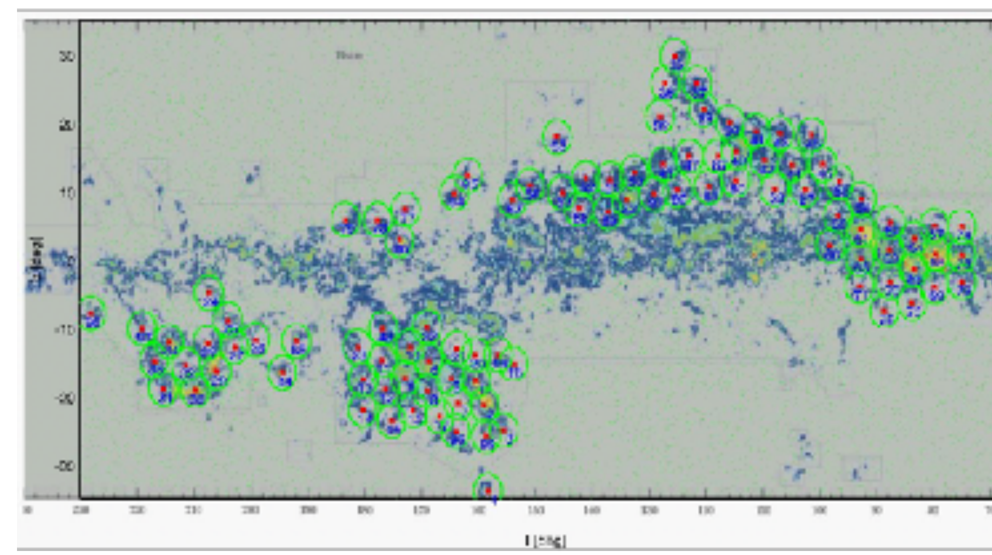
An sample of a Kepler observed eclipsing binary star

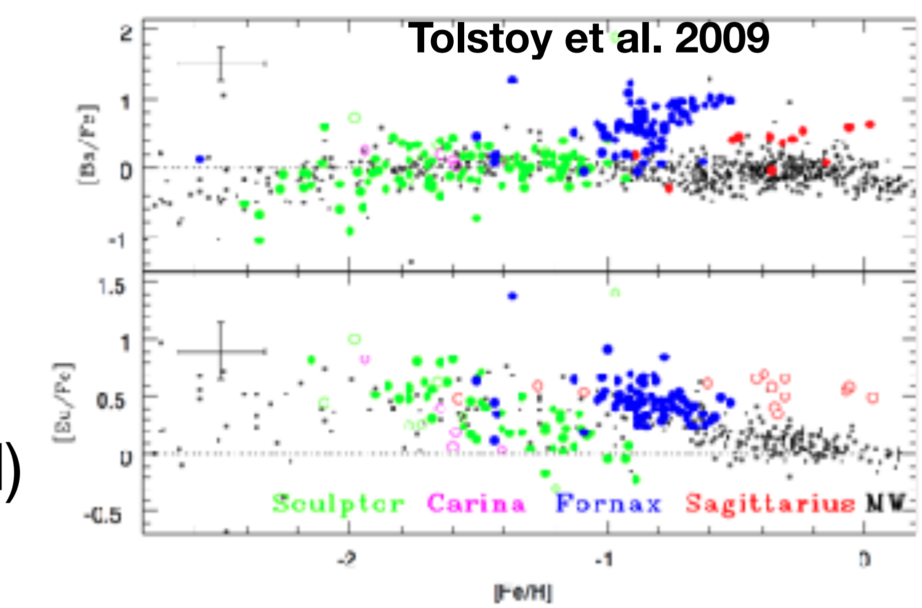


Scientific goals



- Stellar astrophysics (time-domain observations required)
  - Variable stars (pulsation & asteroseismology)
  - Binary stars
  - Pre-Main sequence stars
- Star clusters
- Galactic archeology
- Nebula regions — H II regions, SNR, PNe etc
- Exoplanet host stars (time-domain observations required)

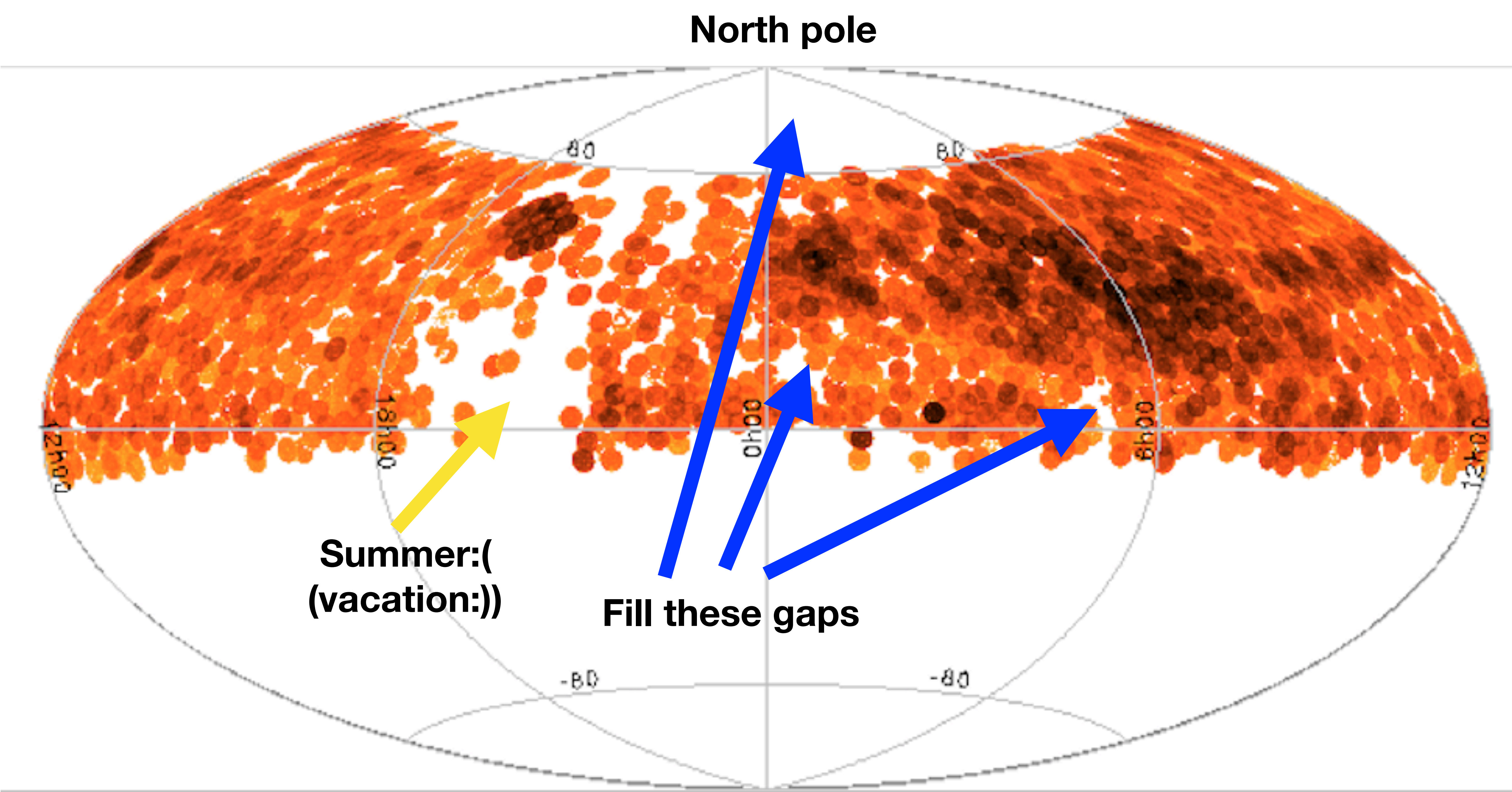




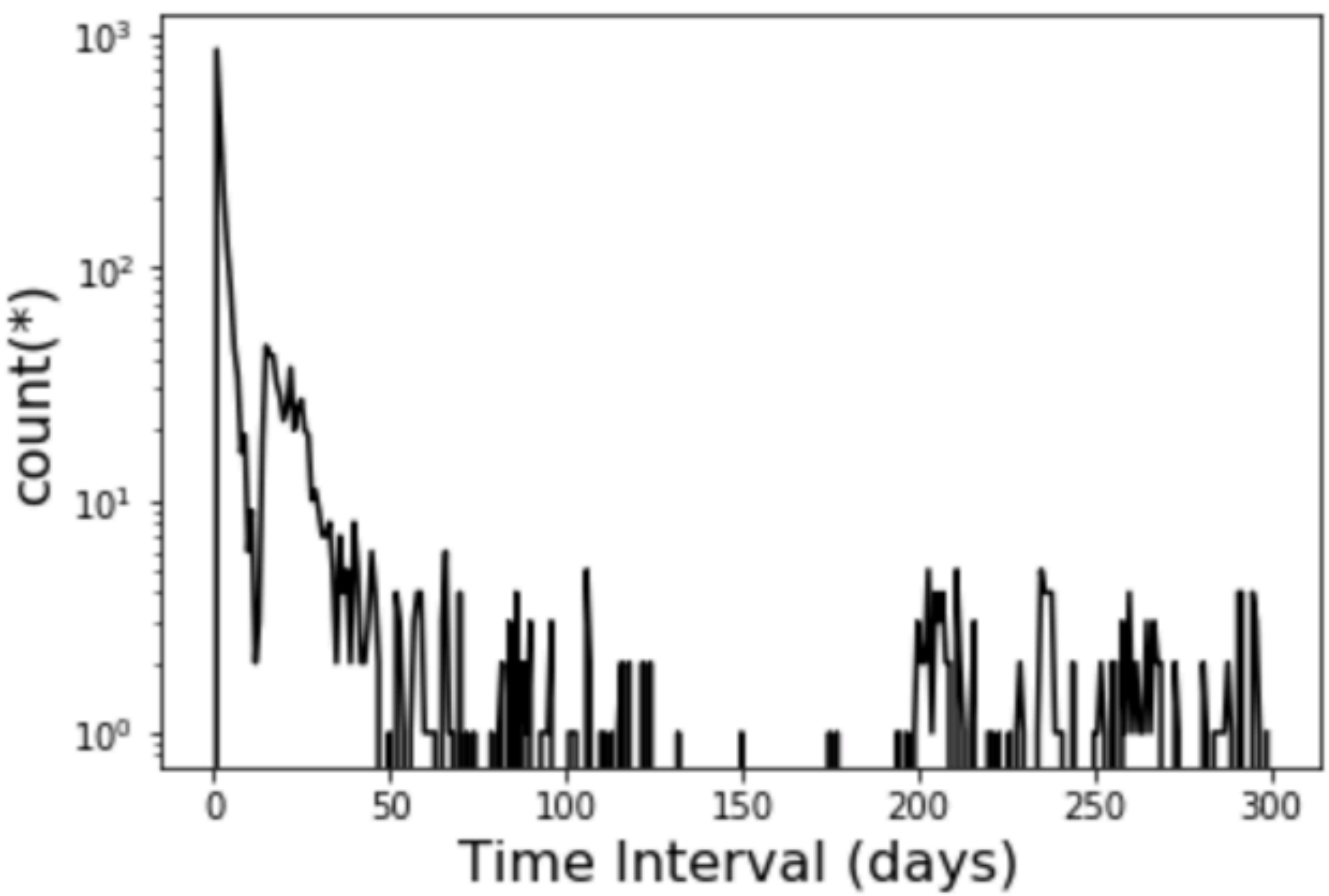
Survey plans

- 5-year survey: Oct 2018-Jun 2023
- Dark/gray nights (14 nights/month): low-res survey same as LAMOST I
- Bright/gray nights (13 nights/month): med-res survey (MRS)
- Expected numbers of spectra
  - low-res: ~3 million more spectra with 1.5h exposure (stars + galaxies + QSOs), r<18
  - med-res: **~200 K stars with time-domain spectra** (20'*n_epoch, <n_epoch>~60), **G<14**
  - med-res: **~2 million stellar spectra** (20'*3 exposure),**G<15**

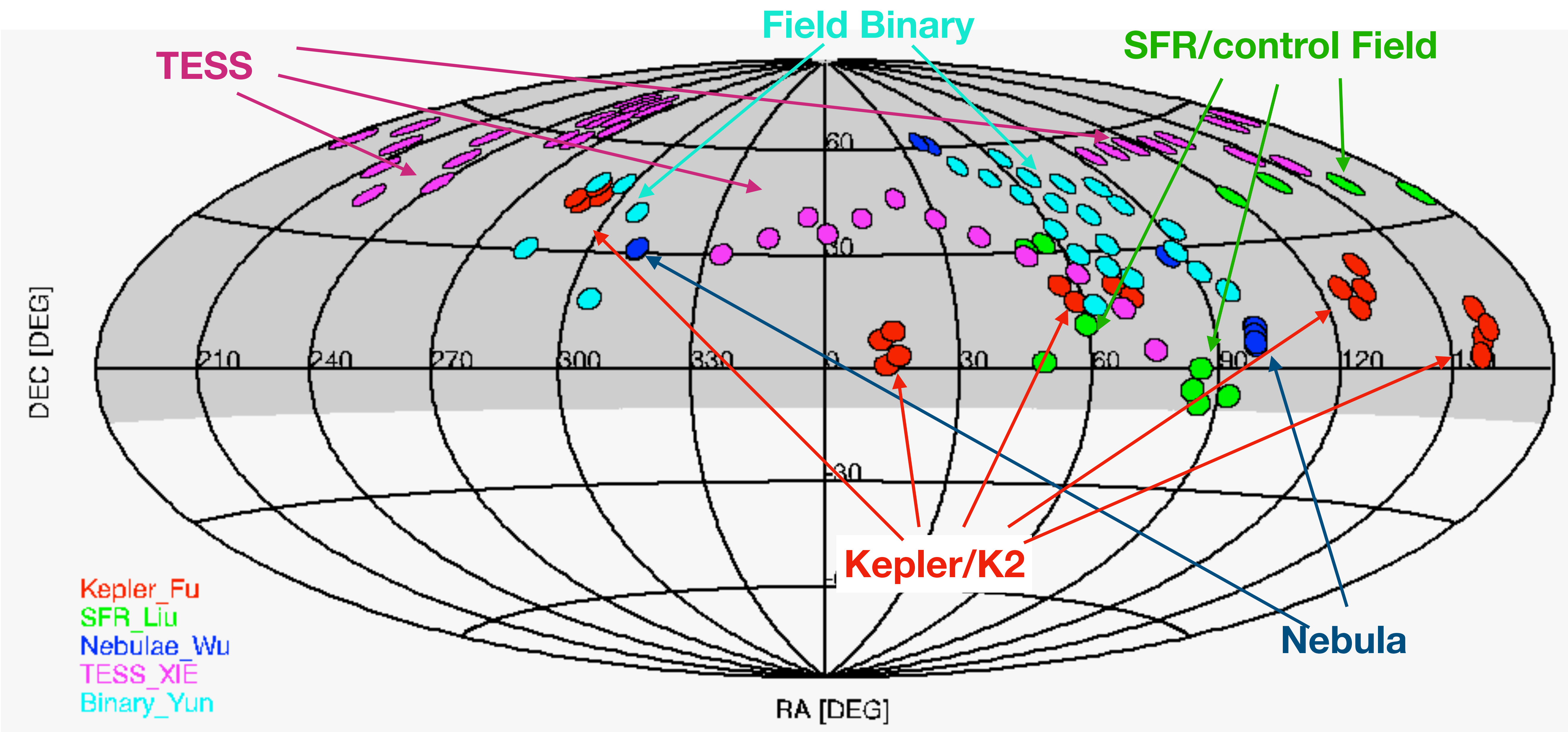
Low-Res survey



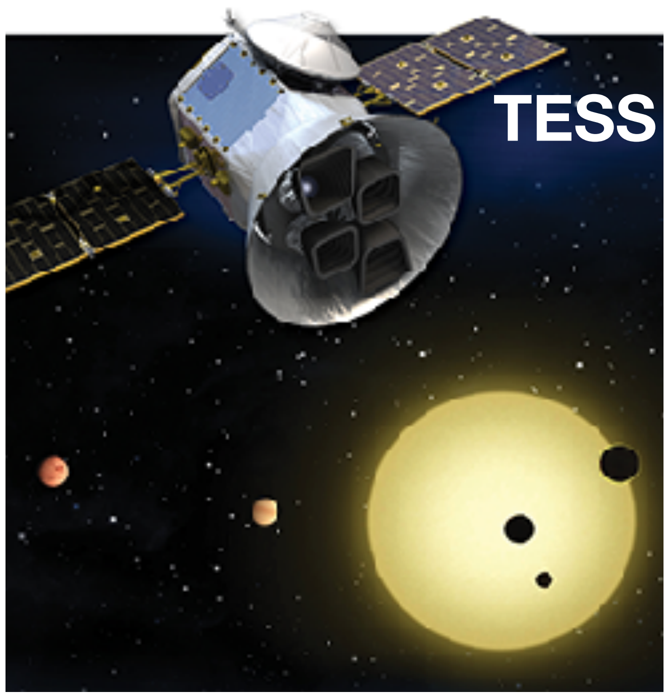
Simulated time-domain observation sample

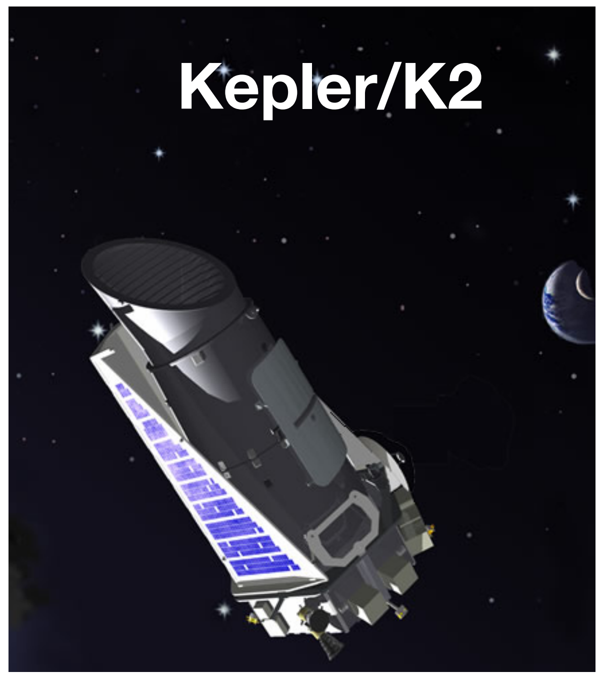


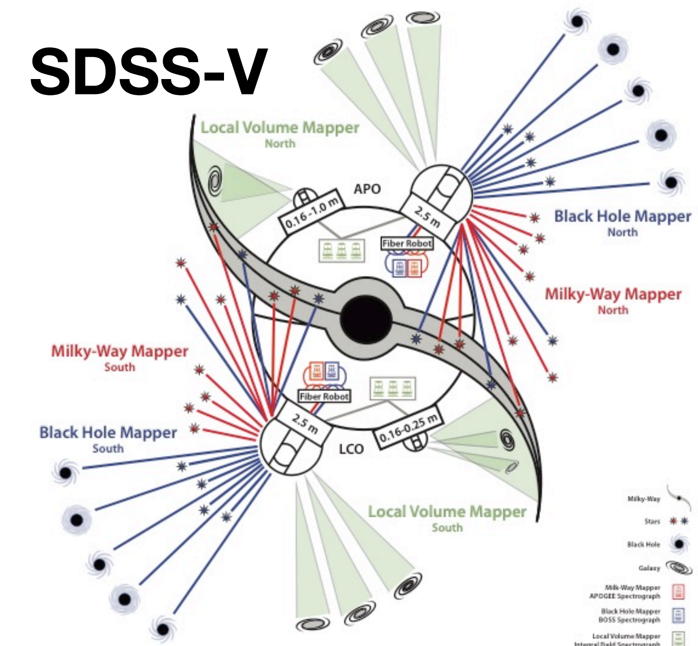
Footprints of time-domain regions



Synergy with other missions

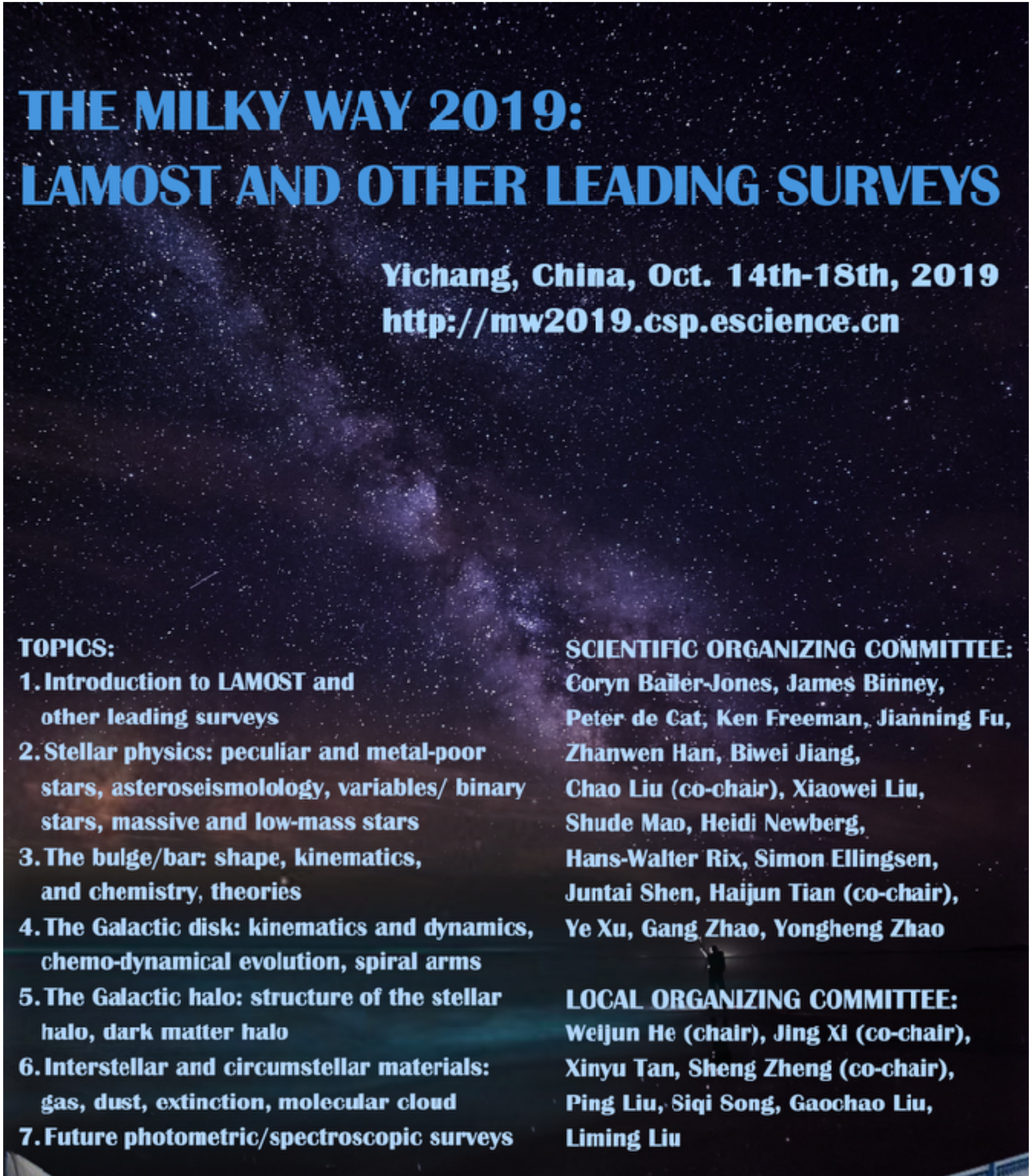






Summary

- LAMOST II = Low-res + Med-res
- LAMOST II ==> Med-res Time-domain survey
- Future products:
    - 200K time-domain med-res stars (G<14)
    - 2 million single-epoch med-res spectra (G<15)
    - ~13 million low-res spectra (inc. LAMOST I) (r<~18)


THE MILKY WAY 2019:
LAMOST AND OTHER LEADING SURVEYS
Yichang, China, Oct. 14th-18th, 2019
http://mw2019.csp.escience.cn
TOPICS:
1. Introduction to LAMOST and other leading surveys
2. Stellar physics: peculiar and metal-poor stars, asteroseismolology, variables/ binary stars, massive and low-mass stars
3. The bulge/bar: shape, kinematics, and chemistry, theories
4. The Galactic disk: kinematics and dynamics, chemo-dynamical evolution, spiral arms
5. The Galactic halo: structure of the stellar halo, dark matter halo
6. Interstellar and circumstellar materials: gas, dust, extinction, molecular cloud
7. Future photometric/spectroscopic surveys
SCIENTIFIC ORGANIZING COMMITTEE:
Coryn Bailer-Jones, James Binney, Peter de Cat, Ken Freeman, Jianning Fu, Zhanwen Han, Biwei Jiang, Chao Liu (co-chair), Xiaowei Liu, Shude Mao, Heidi Newberg, Hans-Walter Rix, Simon Ellingsen, Juntai Shen, Haijun Tian (co-chair), Ye Xu, Gang Zhao, Yongheng Zhao
LOCAL ORGANIZING COMMITTEE:
Weijun He (chair), Jing Xi (co-chair), Xinyu Tan, Sheng Zheng (co-chair), Ping Liu, Siqi Song, Gaochao Liu, Liming Liu

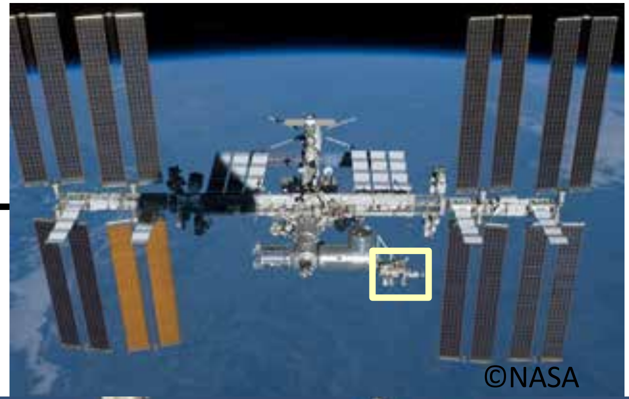
Monitor of All-Sky X-Ray Image (MAXI)
— an X-ray all-sky monitor on the International Space Station —

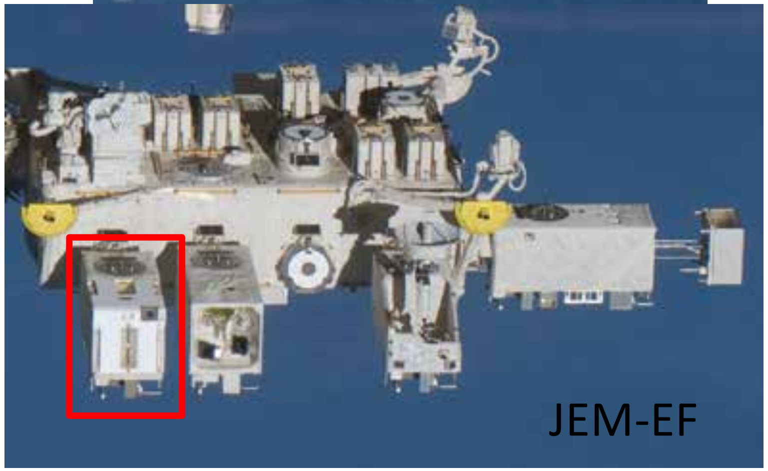
Nobuyuki Kawai (Tokyo Tech)

Time Domain Multimessenger , Nikko, January 2019

Tokyo Tech

1. MAXI mission

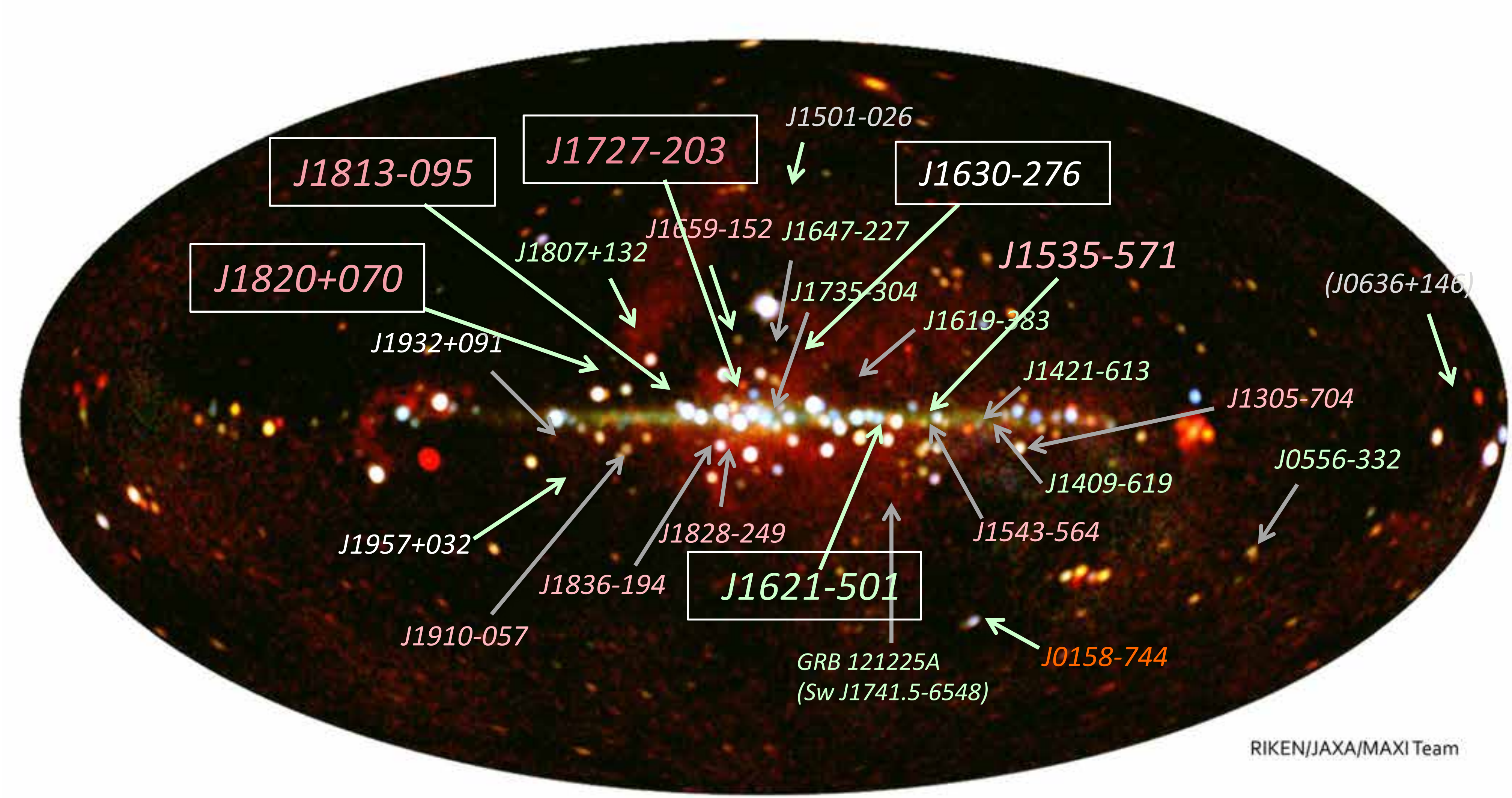




- MAXI (Monitor of All-sky X-ray Image)
- Observation started in August 2009
- Two scientific instruments
  - Gas Slit Camera (GSC) 2-20 keV
  - Solid-state Slit Camera (SSC) 0.7-10 keV
  - GSC has larger effective area and covering sky
- **Large FoV observing whole sky**
  - MAXI can cover entire sky
- **All-time monitoring**
  - Data before the trigger are available
- **Alert system in real-time**
  - Transient events can be searched automatically
  - Real time alert via MAXI mailing lists, 265 subscribers

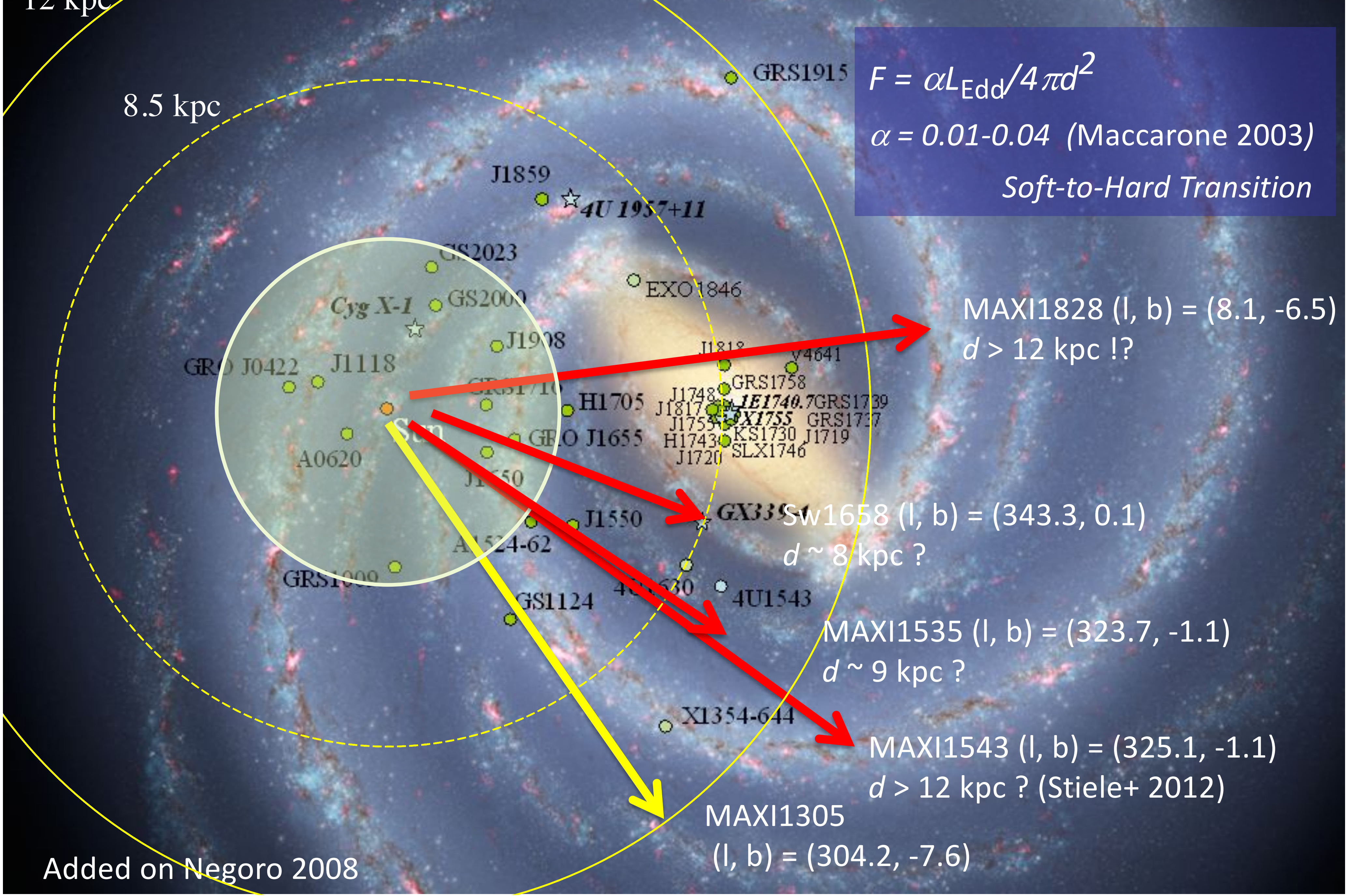
Leading “Time domain astronomy”

20+5 newly discovered X-ray transients
2009 – 2018 (excluding unID short transients)



Total 25 : 10 black holes, 13(-1) neutron stars, 1 white dwarf and 1(+1) unknown.

MAXI watches through the whole Galaxy.



Black Hole Binary — MAXI J1820+070

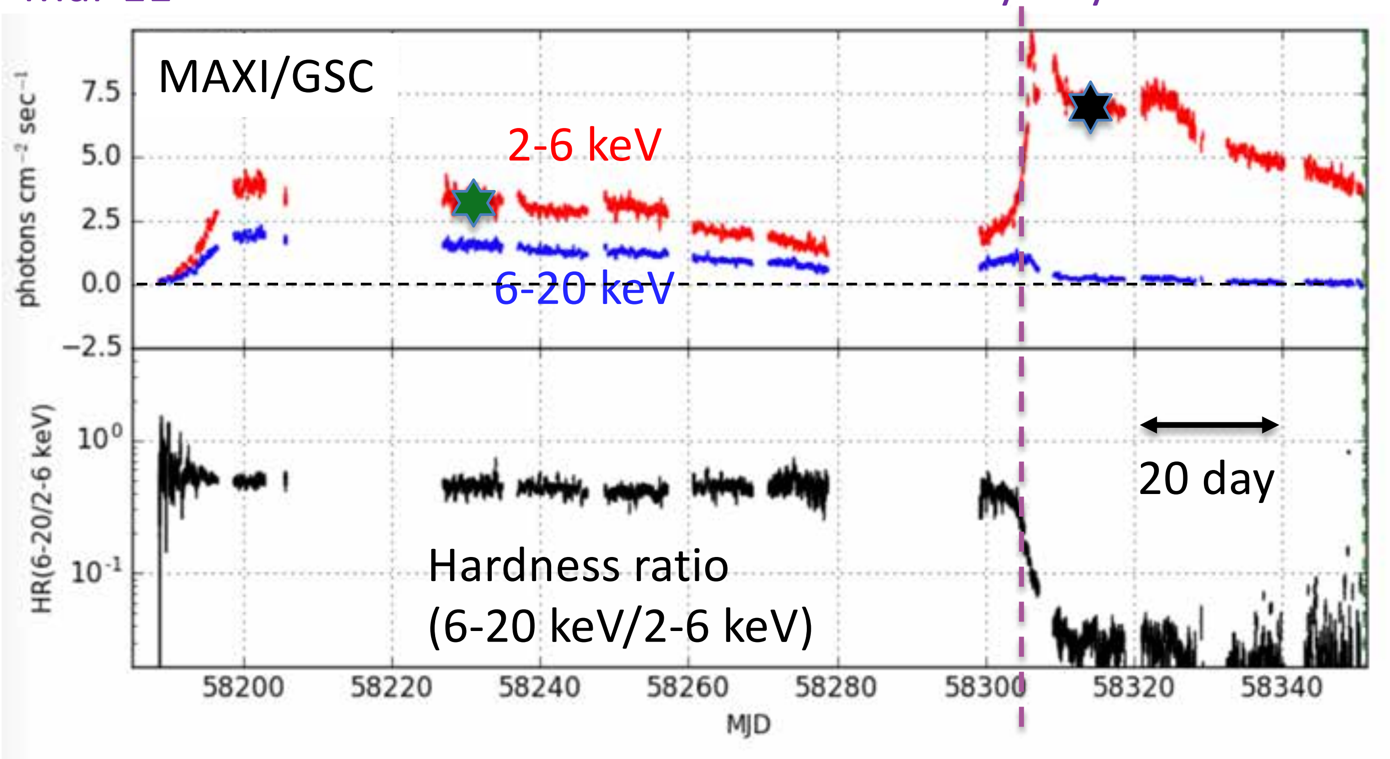
Discovery : March 11, 2018 (Kawamuro+ 2018 ATel #11399)

- Pre-discovery optical detection “ASASSN-18ey” March 5, 2018
- (l, b) = (35.853, 10.160)
- N_H ~1 × 10^{21} /cm^2, Av ~ 0.3
- D = 3 ± 1 kpc (Gandhi+ 2018, GAIA)

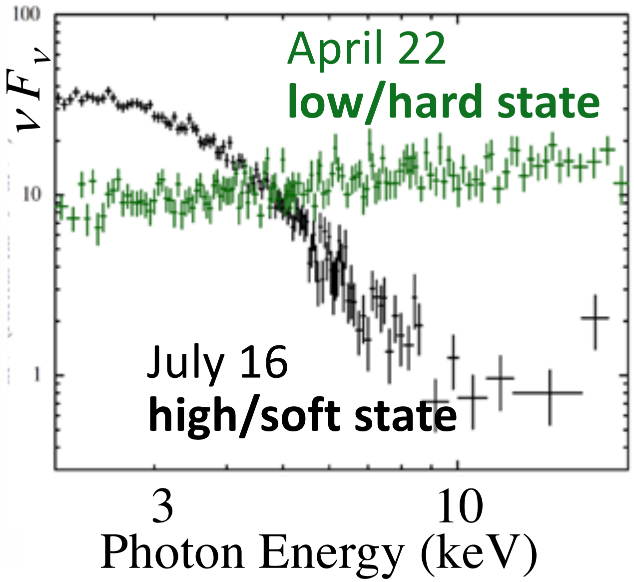
State Transition (T_0+120 days)

Mar 11

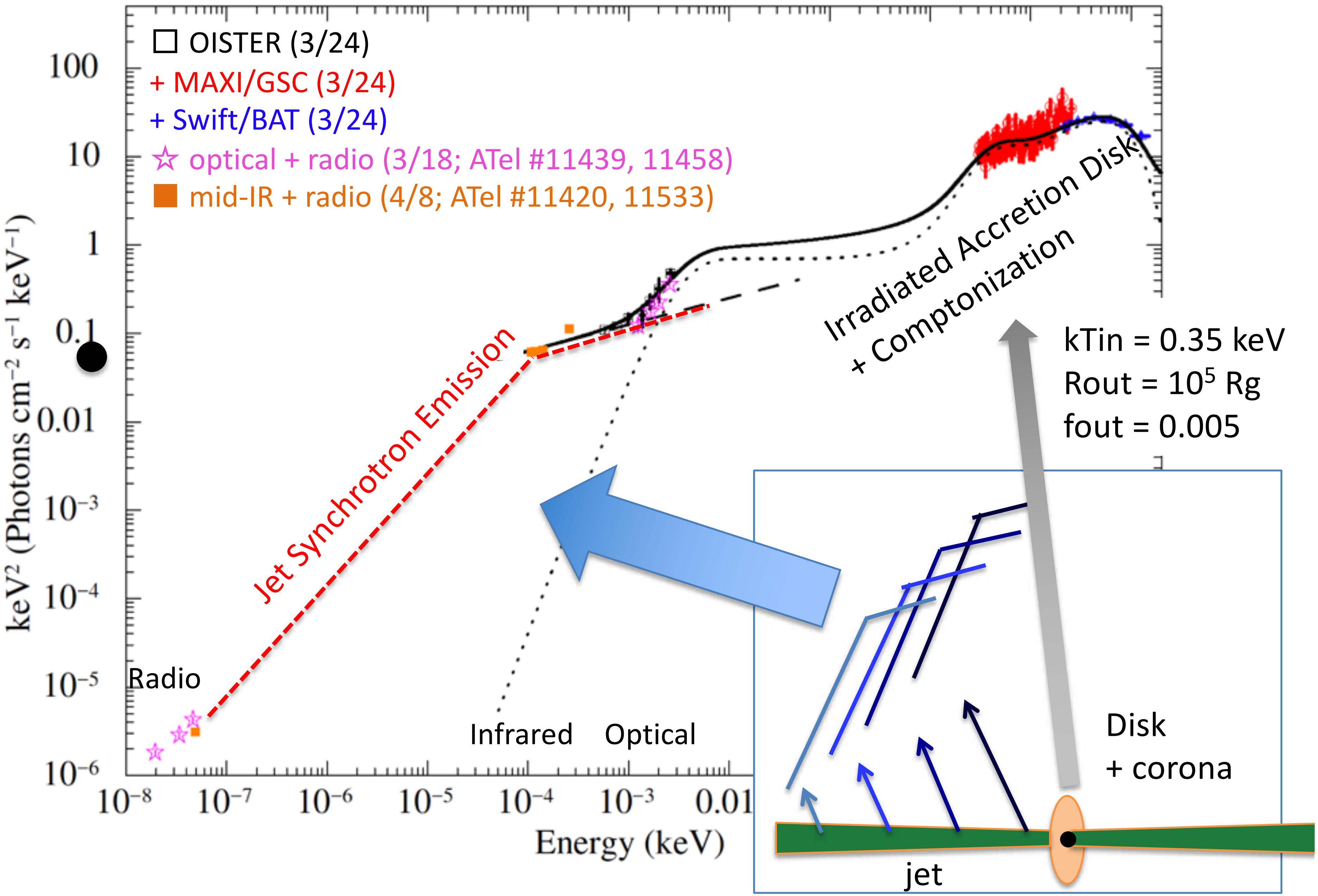
Early July



X-ray Spectrum (MAXI/GSC)

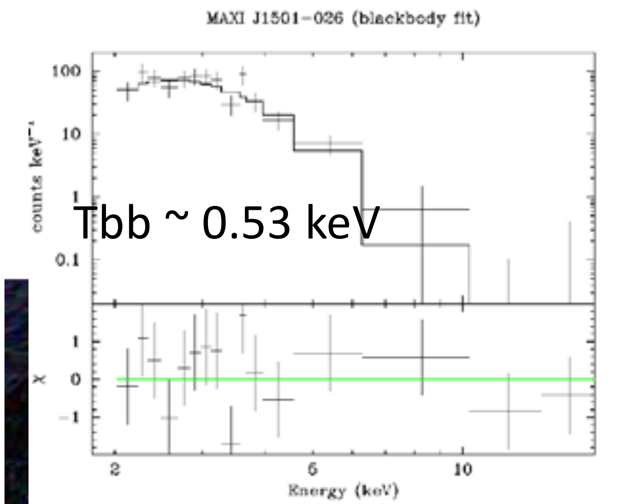


Broadband Spectrum

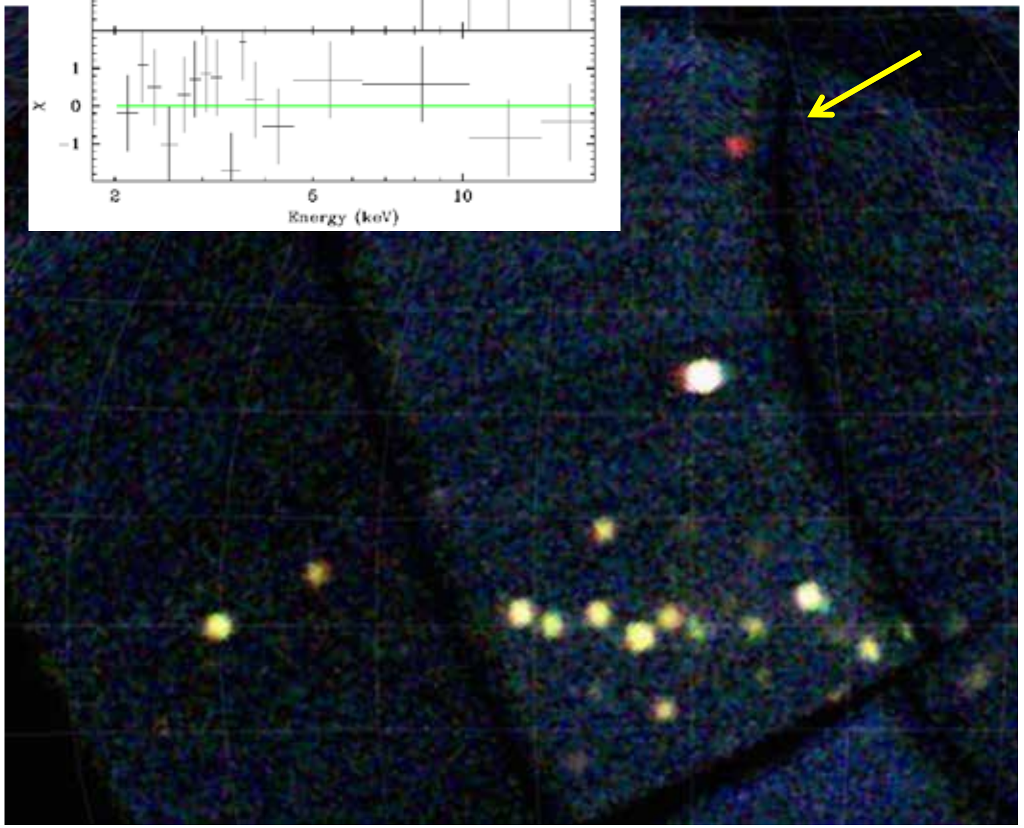


Amazing Transients

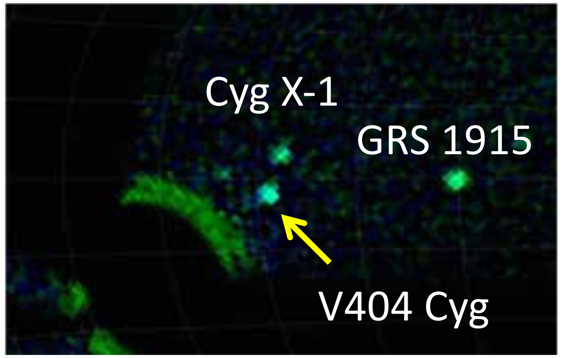
Short, soft X-ray transient MAXI J1501-026 was discovered on 2015 Aug. 26.



Similar properties to MAXI J0157-744 (SSS), but neither X-ray (XRT) nor optical (KWFC) counterpart was detected.



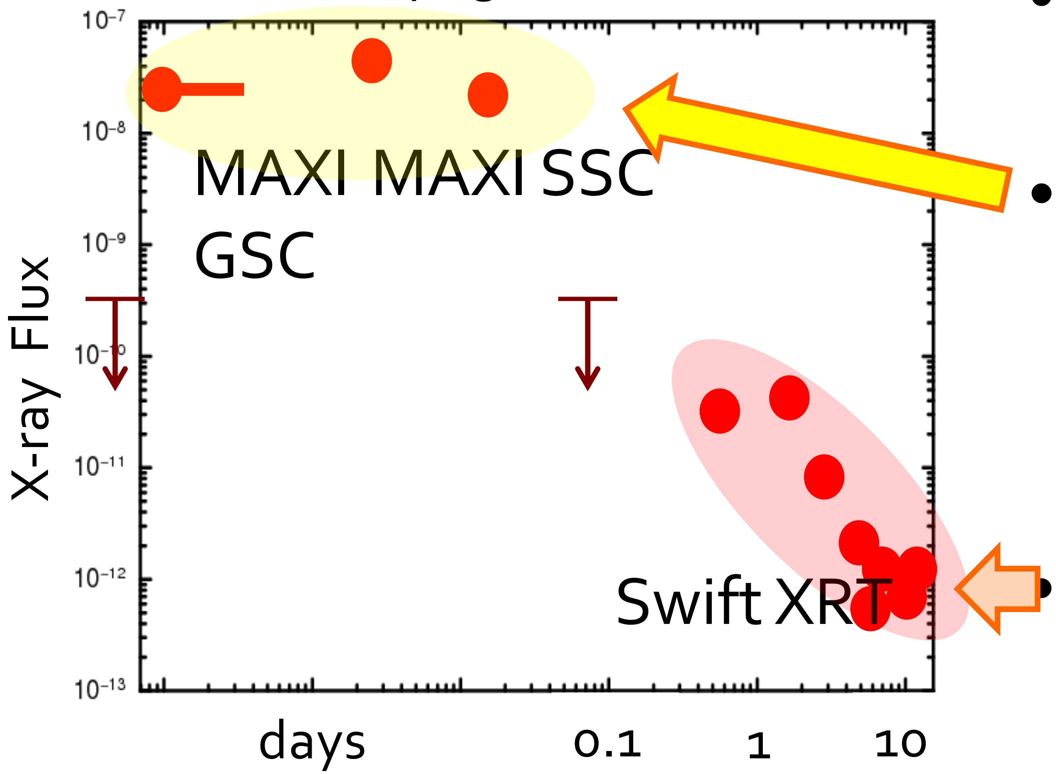
V404 Cyg (GS 2023+338) woke up after 26 years on 2015 June 15. MAXI caught the source with a "degraded" camera ACam 3.



"First signs of renewed activity in V404 Cygni were spotted by the Burst Alert Telescope on NASA's Swift satellite, detecting a sudden burst of gamma rays, and then triggering observations with its X-ray telescope. Soon after, MAXI (Monitor of All-sky X-ray Image), part of the Japanese Experiment Module on the International Space Station, observed an X-ray flare from the same patch of the sky. These first detections triggered a massive campaign of observations from ground-based telescopes and from space-based observatories, to monitor V404 Cygni at many different wavelengths across the electromagnetic spectrum. As part of this worldwide effort, ESA's INTEGRAL gamma-ray observatory started monitoring the out-bursting black hole on 17 June" Taken from INTEGRAL@ESA web site

MAXI J0158-744

X-ray light curve

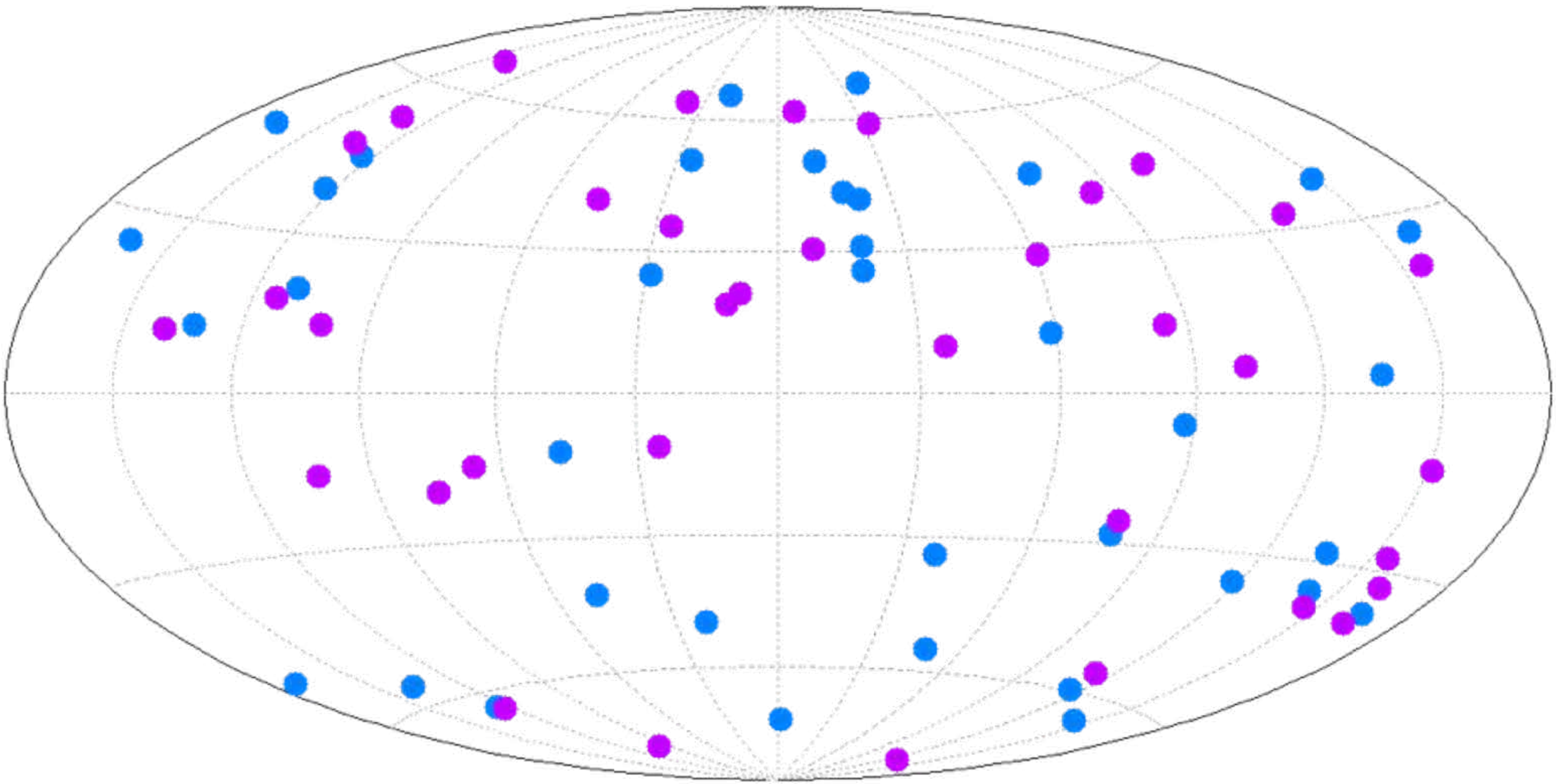


Morii et al. 2013

- Duration ≈ hour
  - (1300 s <ΔT< 1.1 x 10^4 s)
- Extremely luminous
  - 10^{40} erg / s
  - x100 solar mass Eddington luminosity
- supersoft X-ray source at late phase

  → white dwarf
  - classical/recurrent nova?
    - but x10^4 more luminous than known nova X-ray emission
      - (shocked ISM? Li et al. 2012)

MAXI GRBs and transients (2—20 keV)



Serino et al. (2014)

http://maxi.riken.jp/grbs/

●: only MAXI (43)
●: MAXI + other (39 prompt + 7 afterglows)

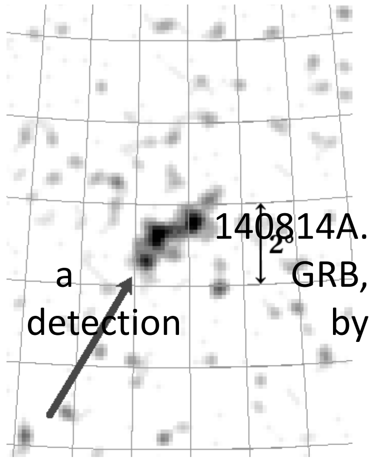
MAXI Unidentified Short Soft Transient (MUSST)

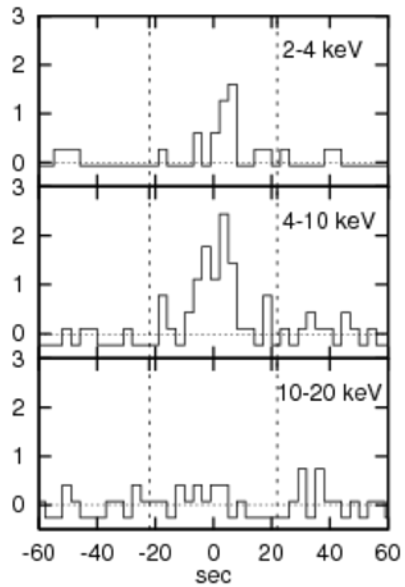
- Detected only in X-ray band (MAXI 2-10 keV) : Soft
  - No detection by Swift/BAT (15-50 keV)
- Fades out before Swift/XRT follow-up at a half day later : Short transient
- No detection by Swift/XRT ends up unidentified
  - MAXI localization (0.3deg) is insufficient for optical follow-ups.
- Rapid X-ray follow-up is desired while it is still bright
  (100 mCrab in 1 minutes, 1 mCrab in 20 minutes).

  ⇒ NICER

8 MUSSTs in 8 years of MAXI

name	l	b	flux [Crab]	reference
GRB 161123A	255.8	-69.6	0.1	Atel #8050
MAXI J1501-026	354.6	+46.8	0.44	Atel #7954
GRB 150428C	139.3	+11.2	0.2	GCN #17772
MAXI J1540-158	351.6	+30.6	0.1	GCN #17568
GRB 140814A	139.9	+66.4	1	GCN #16686
MAXI J0545+043	201.1	-12.6	0.2	ATel #6066
GRB 130407A	26.4	+35.6	4	GCN #14359
MAXI J1631-639	324.4	-10.8	0.12	ATel #3316





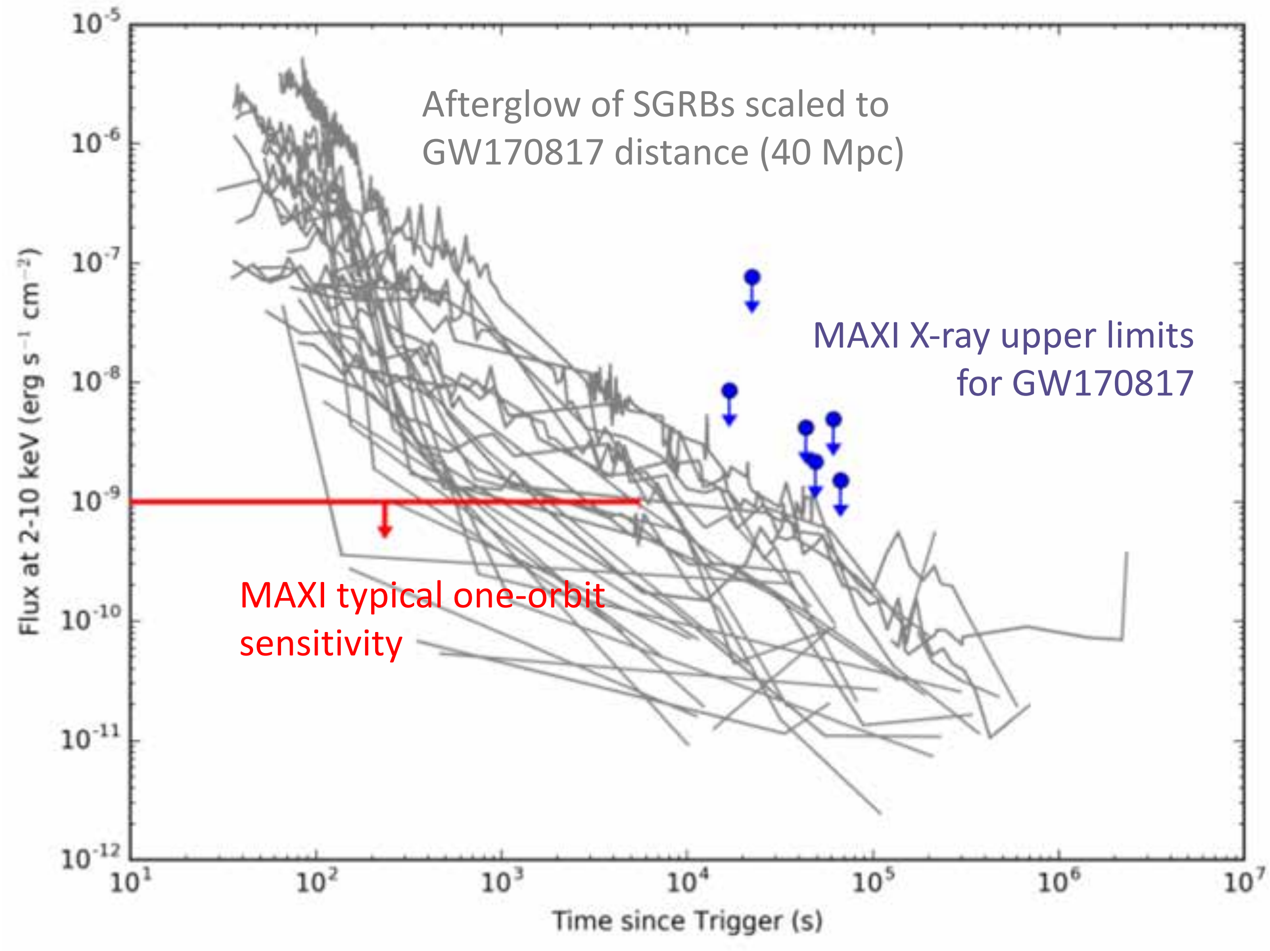
A MUSST, GRB 140814A. Reported as a GRB, but no detection by Swift follow-up. X-ray image at discovery and light curve in the scan. Soft (= no detection in 10-20keV) is a different point from a GRB.

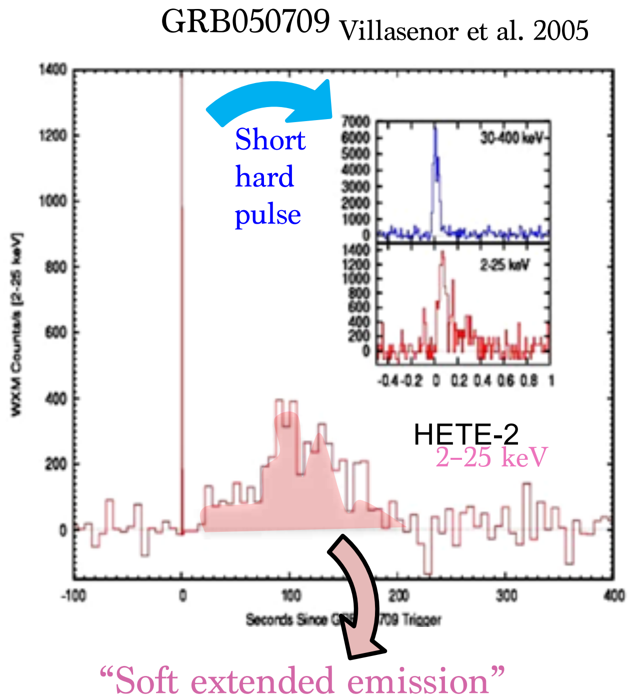
What are these short soft transients?

- gamma-ray bursts with very low E_{peak}
- stellar flares
- igniting classical novae
- tidal disruption events
- low-luminosity GRB w/SN
  (~ SN2006aj/GRB060218)
- SN shock breakout (~ SN2008D)
- very short AGN (blazar) flare
- soft extended emission of short GRBs
  - neutron star merger — GW source (?)
- …

MAXI for GW counterpart search

- MAXI has sensitivity to detect the "extended" X-ray emission and early afterglow of SGRBs, if observation takes place within an orbit (~85% of the whole sky)

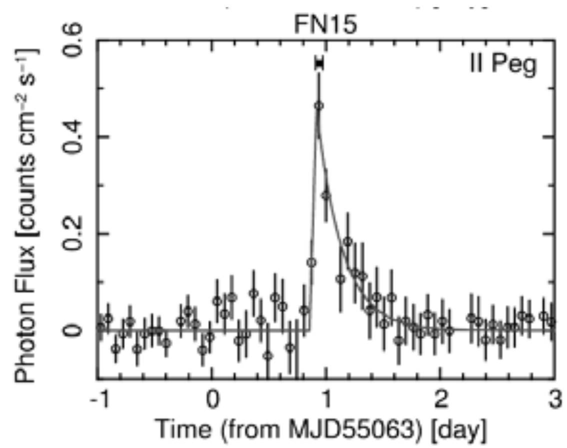




Giant Stellar Flares

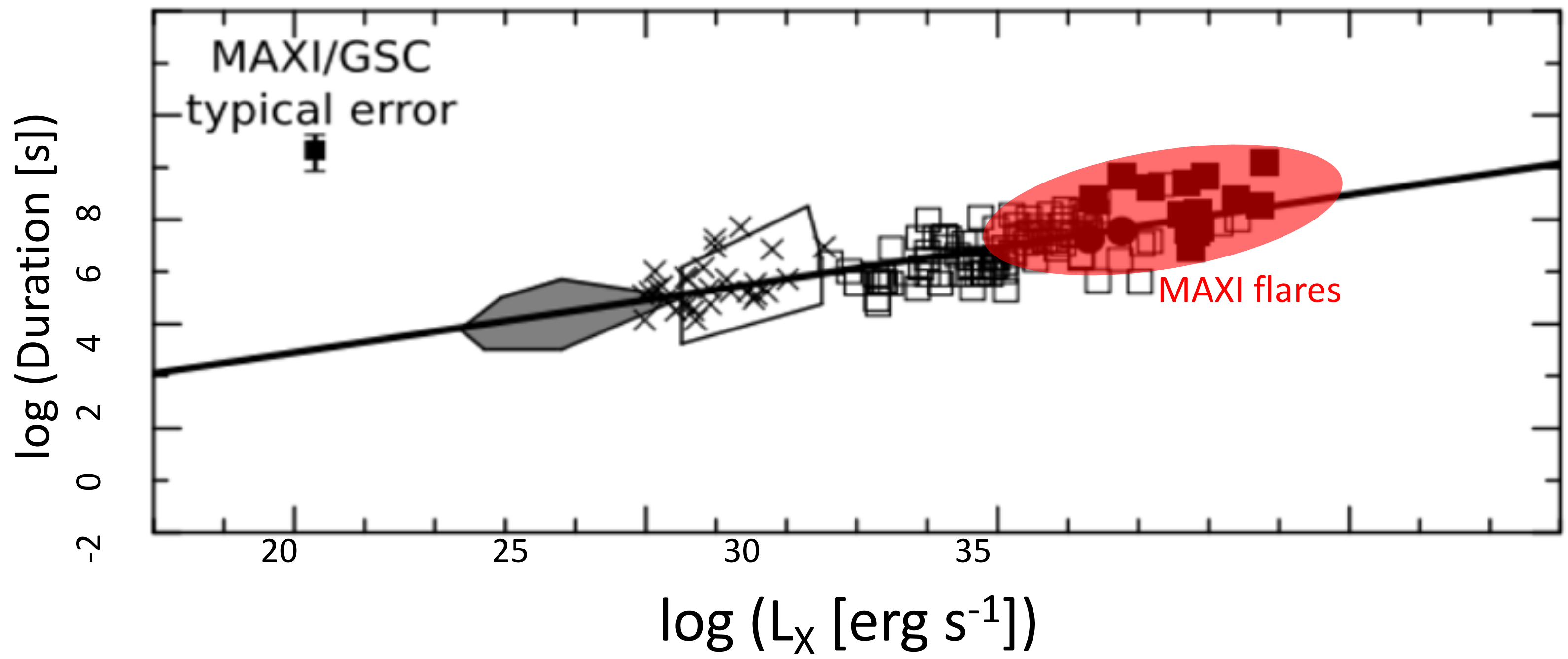
Tsuboi+ 2016

- MAXI detected 23 stellar flares in 2009 Aug - 2011 Aug.
- 2-6 orders of magnitude larger energies were observed in the flares detected with MAXI than those of solar flares.



MAXI giant flare from II Peg

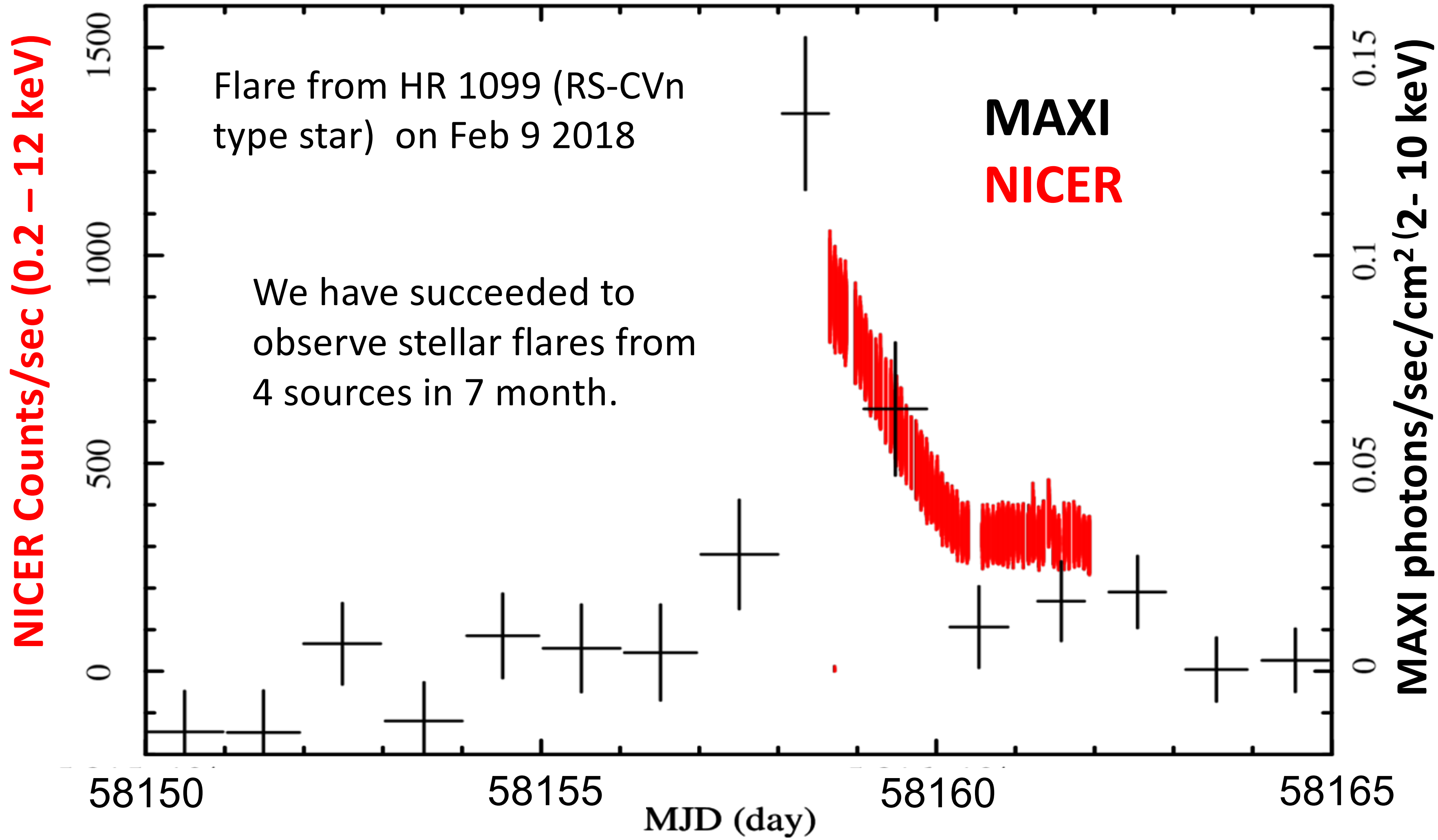
A universal correlation between Lx and duration time was found, which holds from solar micro flares to the MAXI giant flares.



Stellar flare observation by MANGA

- MAXI can discover stellar flares but cannot get high quality data
- NICER cannot discover stellar flares but can get high quality data

The MAXI NICER relationship is quite complementally.

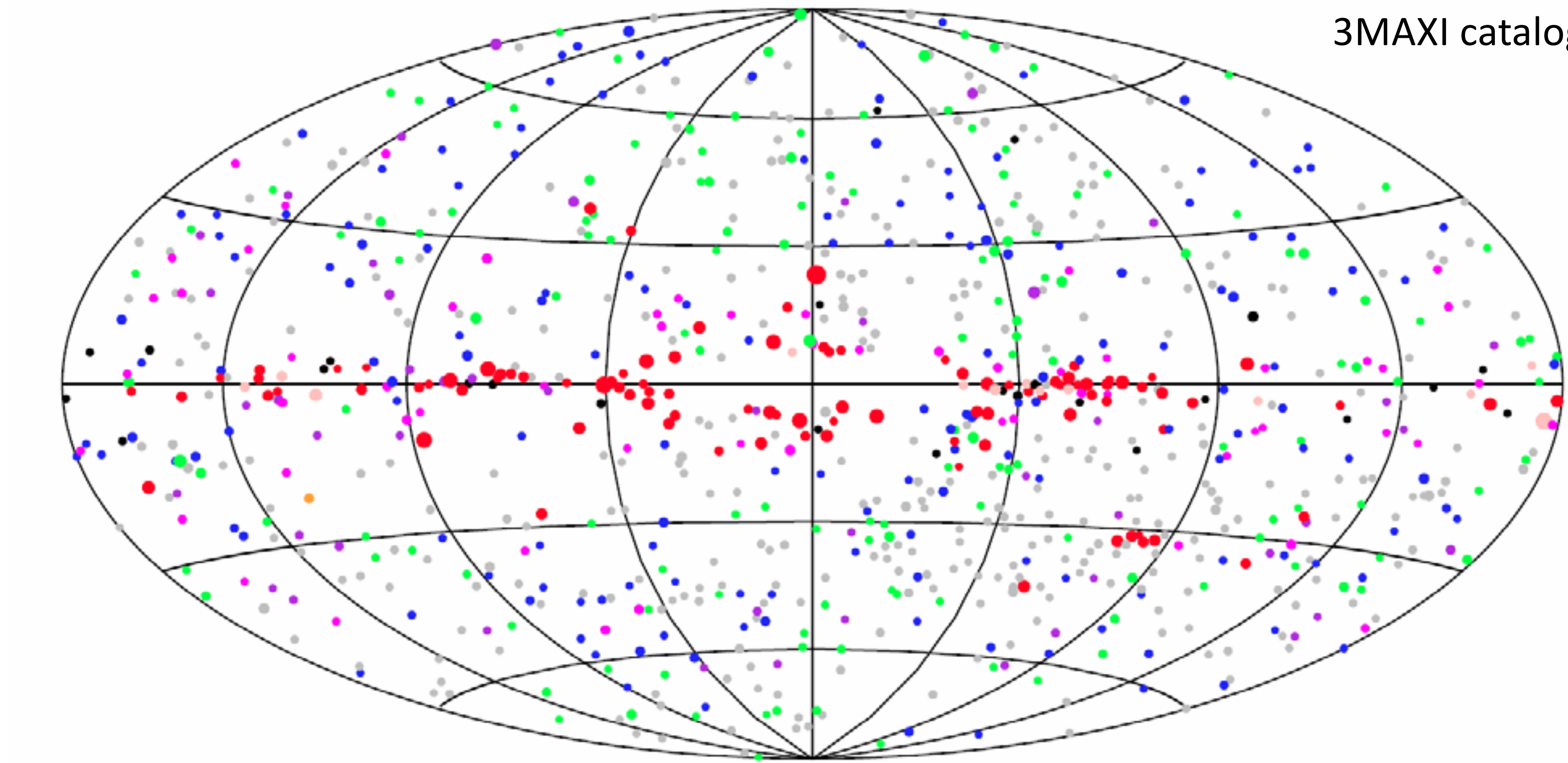


GSC catalog

Hori+ 2018 ApJS 235, 7
Kawamuro+ 2018 ApJS 238, 32

- We have produced new MAXI/GSC source catalogs based on the 7-year data from 2009 August to 2016 July. They will be published in two papers for low (214 sources) and high (682 sources) Galactic latitude regions.
- The sensitivity limit reaches ~0.4 mCrab for half of the whole sky, which is near the source confusion limit of MAXI/GSC.
- The two catalogs contain 896 sources in total, including a significant fraction of new unidentified objects.
- These are the deepest source catalogs covering the 4-10 keV band among all previous and on-going all-sky X-ray missions.
- The merit of 4-10 keV energy range is
  - It is free from the galactic absorption.
  - It is the energy range where blackhole and neutron star binaries emits most of the energy.
- MAXI scans thousands of times for a catalog.
  - It can correctly average the fluxes of variable sources.
  - It can make a variability catalog in one-month time-bin, for example.

GSC catalog



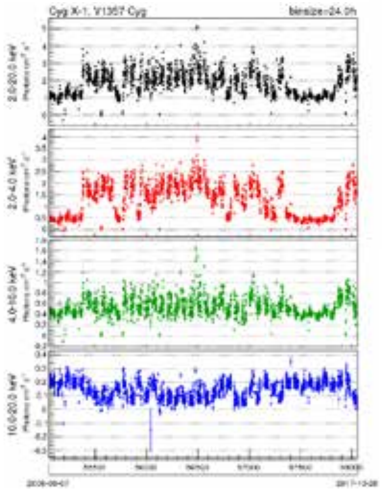
Seyfert **Quasar** **X-ray Binary** **CV** **SNR**

Cluster **Galaxy** **Pulsar** **Star** **Unidentified**

Data distribution

- MAXI data are public at MAXI Web. 403 sources are processed.
- 101 sources of them are processed every 4 hours.
- Ondemand process allows users to extract MAXI data from any sky region in any time period.
- Some contribution pages available.

MAXI HP http://maxi.riken.jp/



Light curve of sources

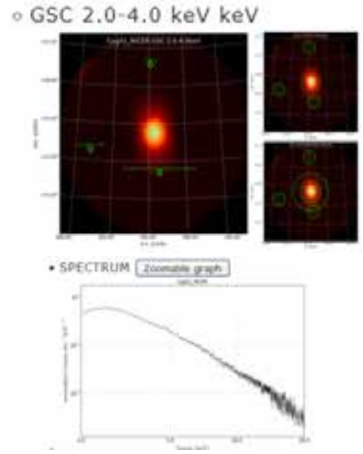
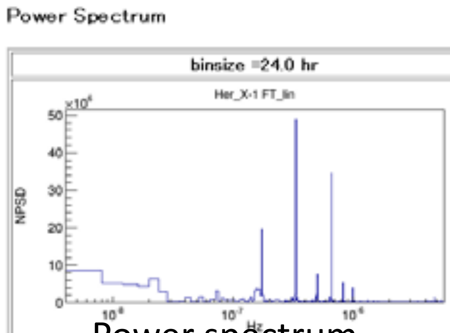
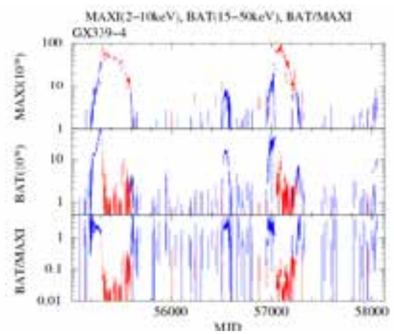


Image and spectrum by ondemand

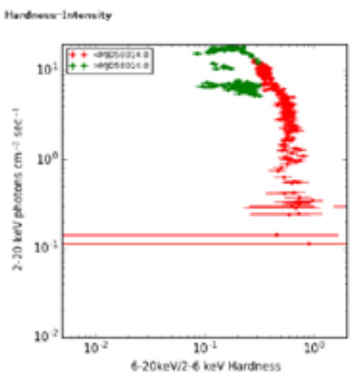
BeXRB monitor @ ESA



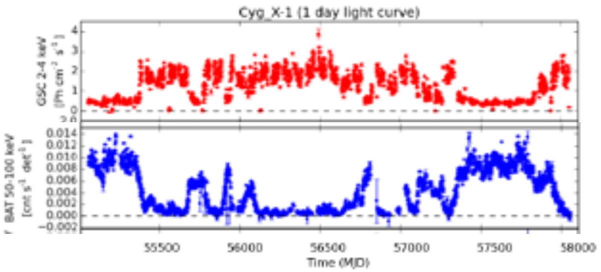
Power spectrum



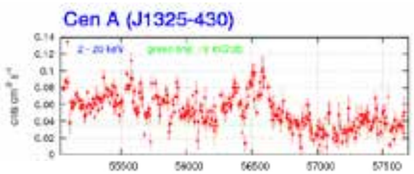
MAXI-BAT Hardness ratio



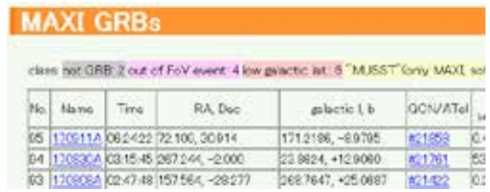
MAXI 1535 monitor



BAT-MAXI transient monitor



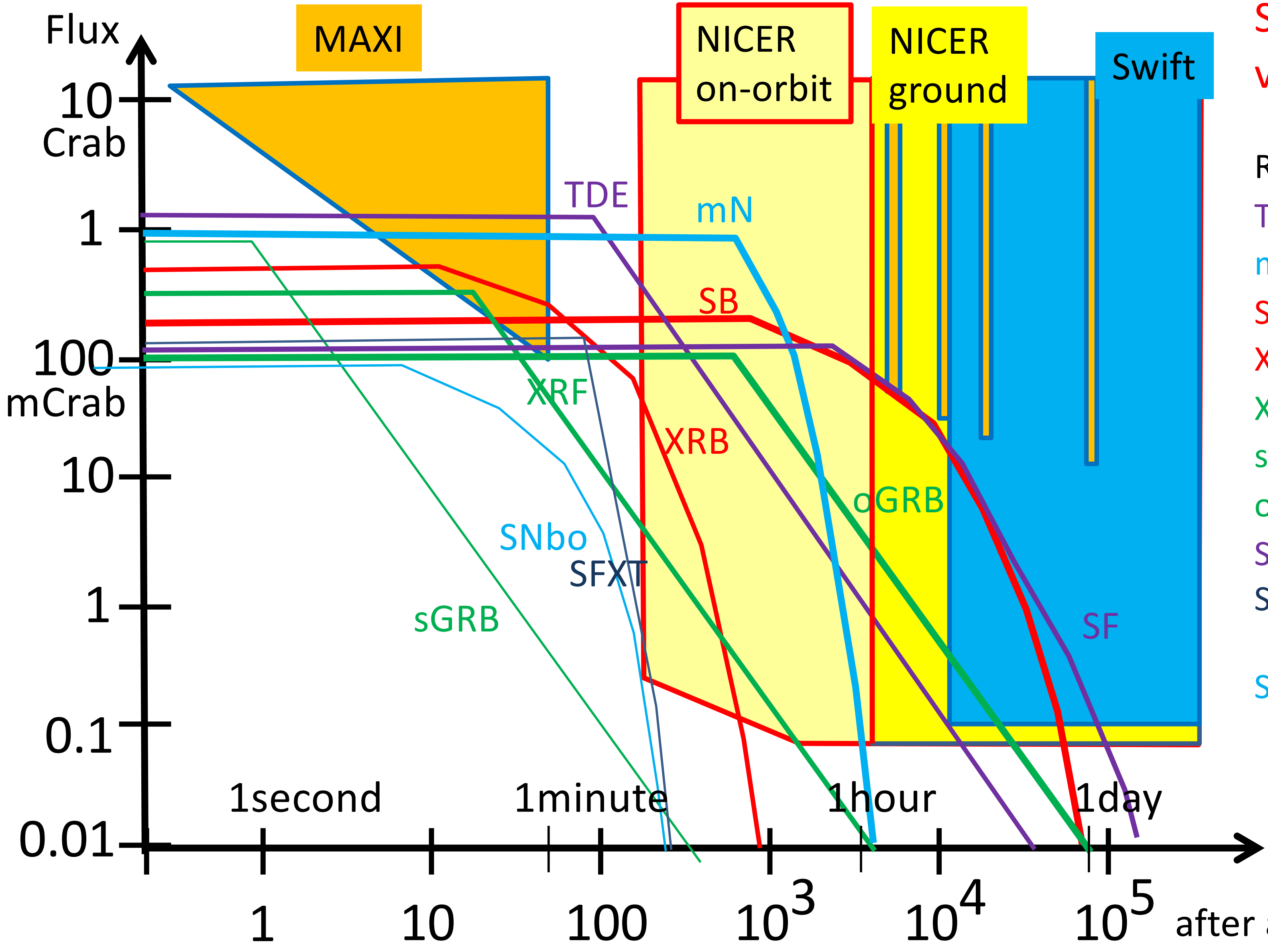
Weekly light curves



MAXI GRB list

Future: Time-domain astronomy of Rapidly decaying objects

Rapidness of follow-up in X-ray and sensitivity



Swift follow up is very effective.

Rapidly decreasing obj.

TDE: as Sw1644

mN: massive Nova

SB: super burst

XRB: X-ray burst

XRF: X-ray flash

sGRB: short GRB

oGRB: orphan GRB

SF: stellar flare

SFXT: super giant fast X-ray transient

SNbo: super nova shock break out

MOA (since 1995)

(Microlensing Observation in Astrophysics)

(New Zealand/Mt. John Observatory, Latitude：44°S, Alt:　1029m)

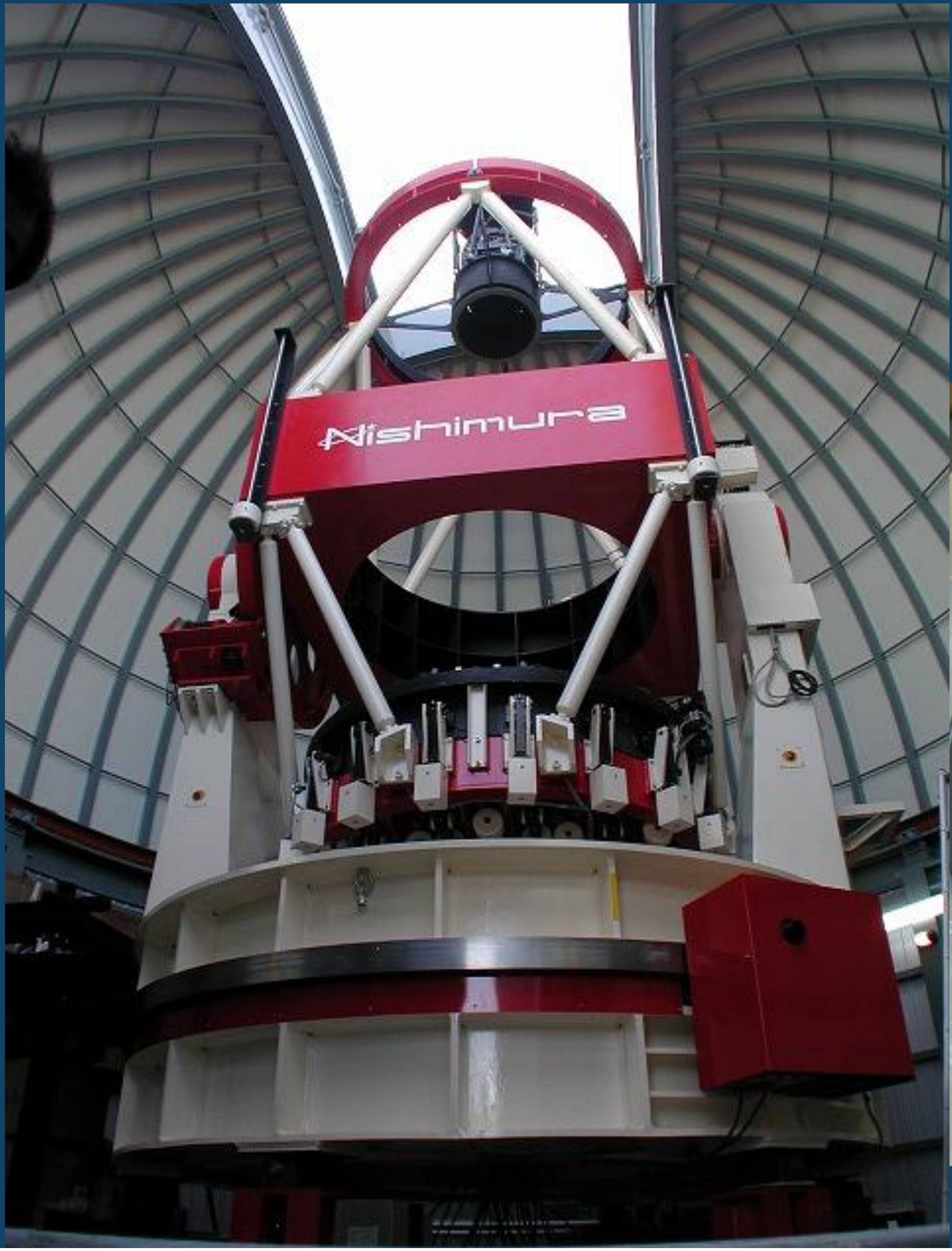
MOA (until ~1500)
(the world largest bird in NZ)

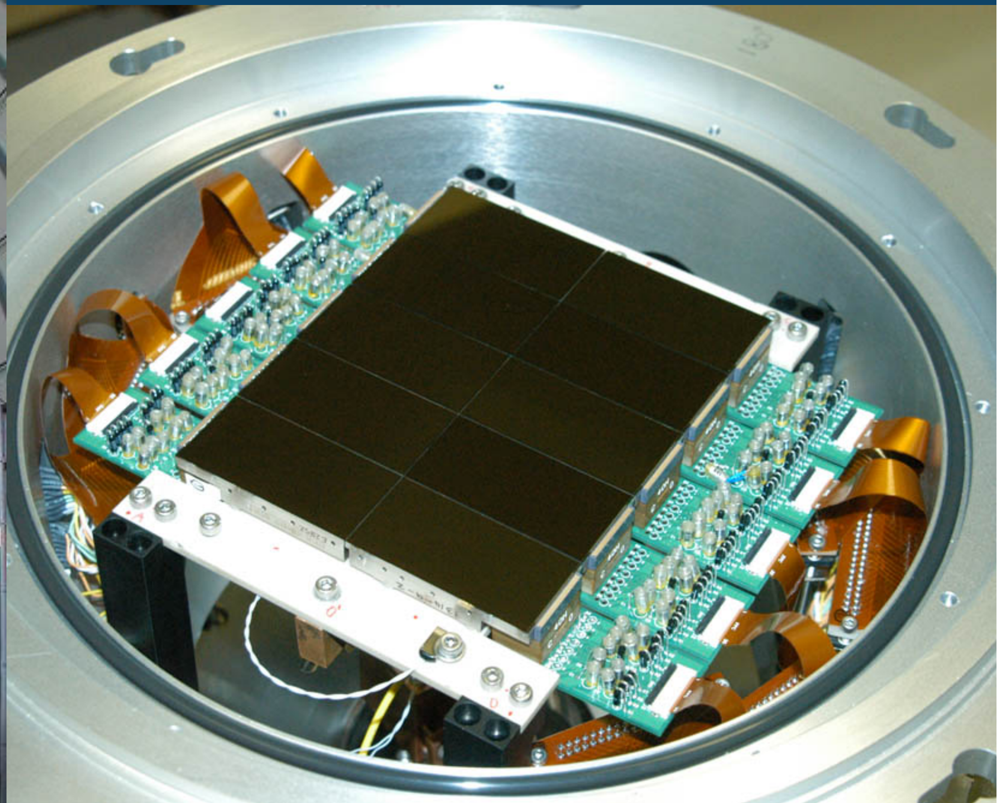
- height:3.5m
- weight:250kg
- can not fly
- Extinct 500 years ago

(Maori ate them)

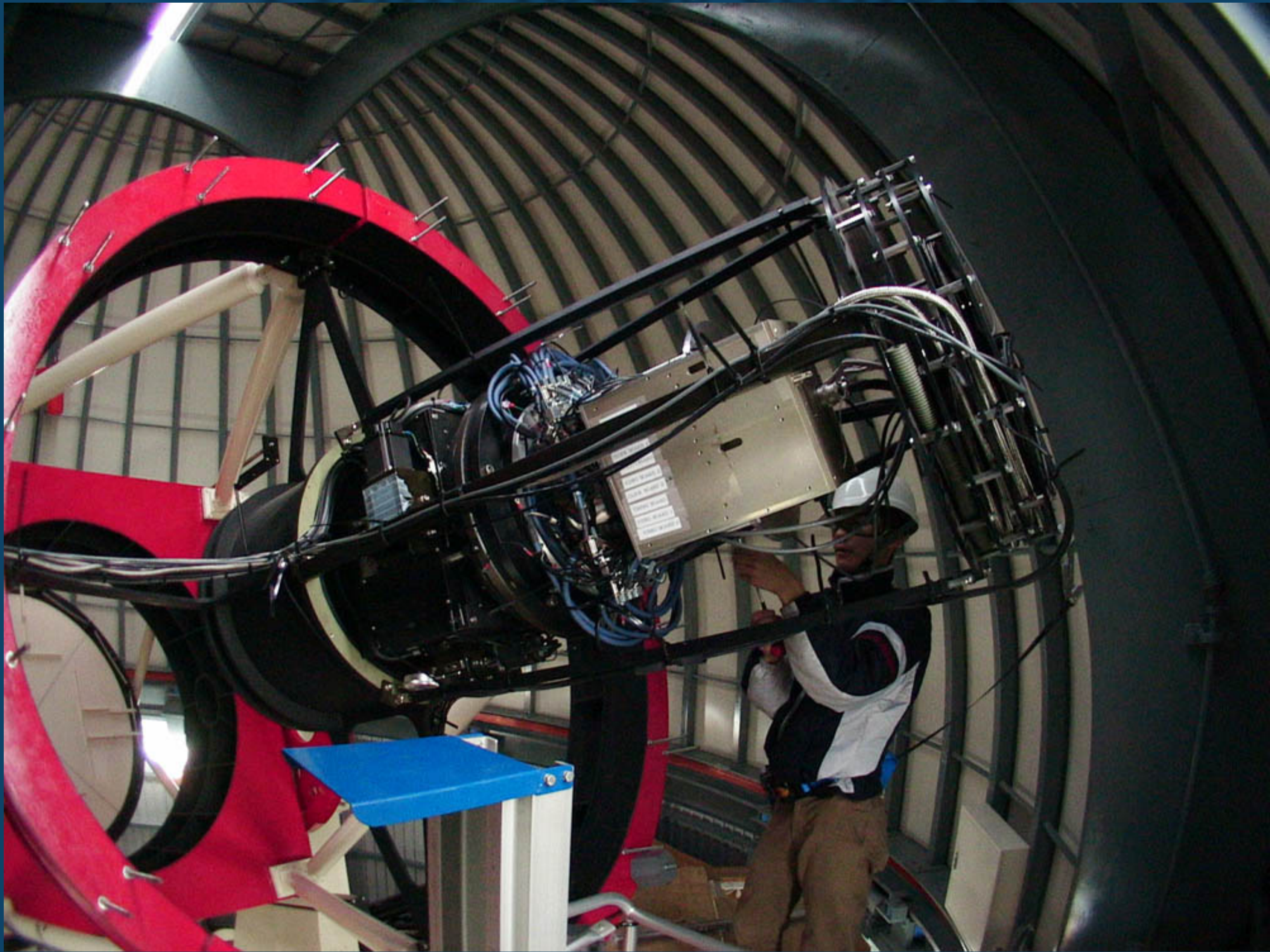
MOA-II 1.8m

Mirror : 1.8m
CCD : 80M pix.(12x15cm)
FOV : 2.2 deg.^{2}
(10 times as full moon)

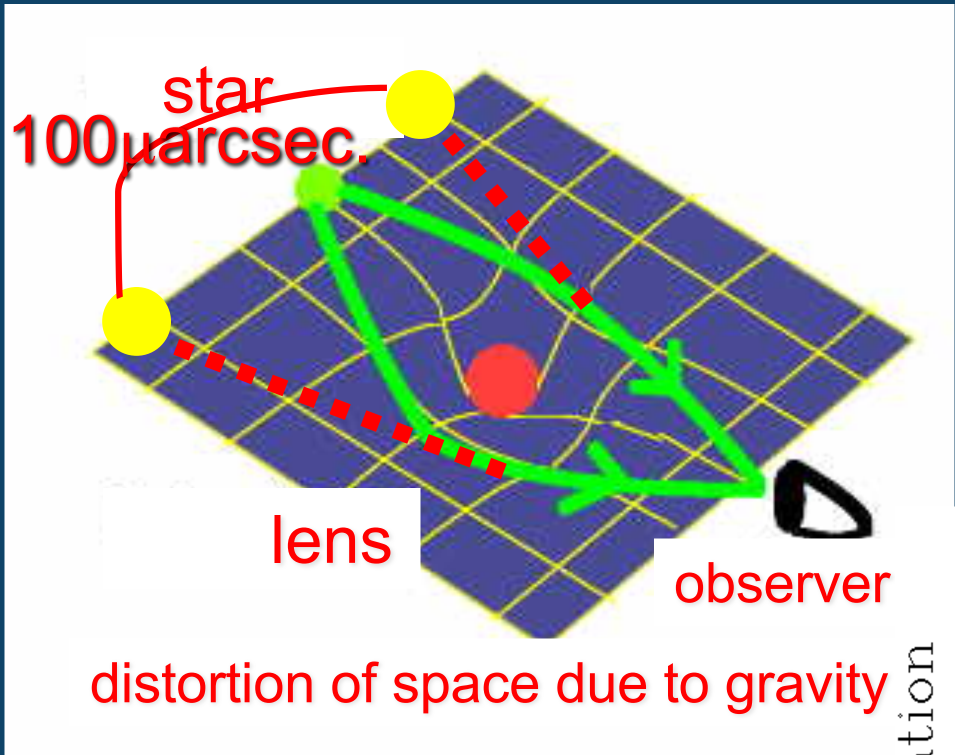




Prime focus camera



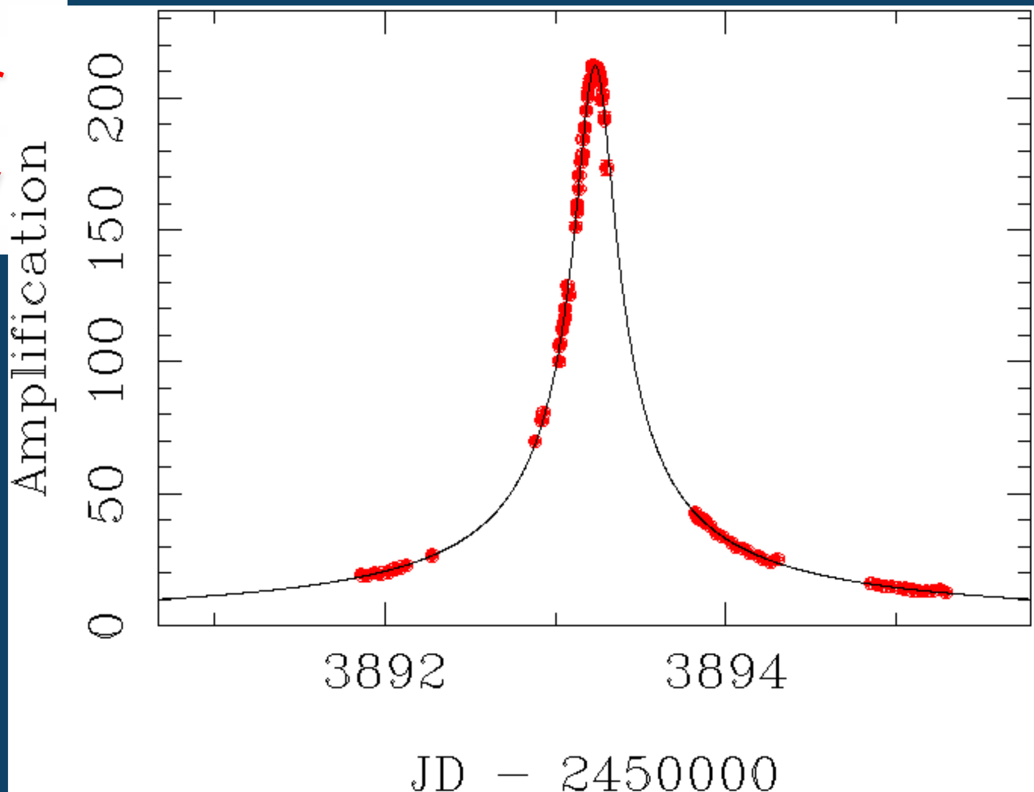
Gravitational Microlensing



✧If a lens is a star, elongation of images is an order of 100μarcsec.

✧Just see a star magnified

✧Einstein predicted 1936, but concluded impossible to observe. Event rate is 1/1M

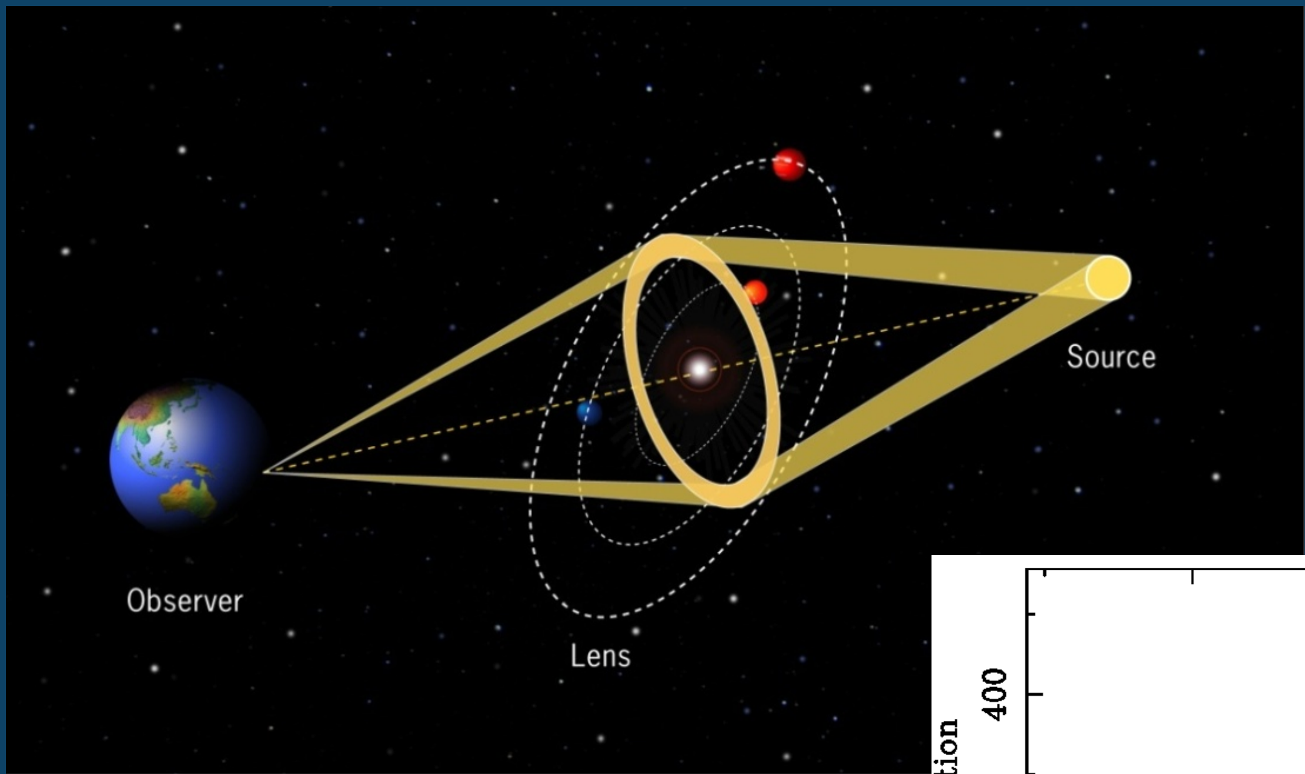


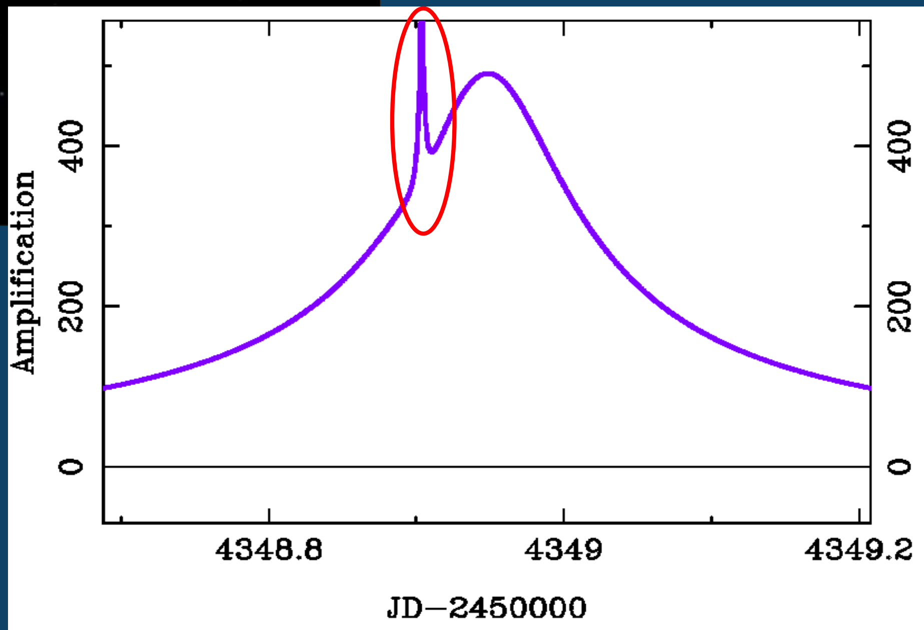
- 1986

Watch Millions stars

Paczynski

planetary microlensing

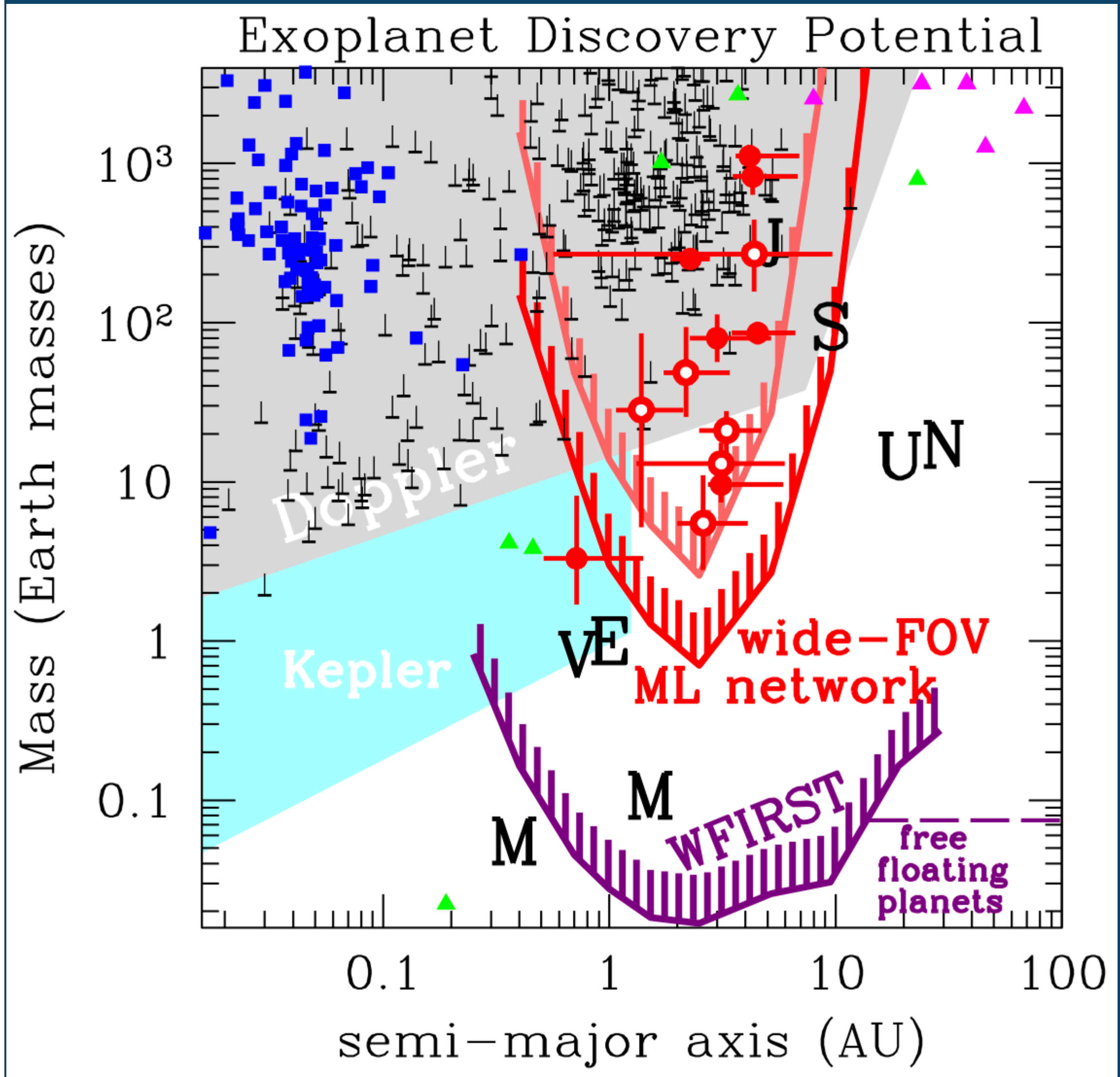




Time scale: $t_p \sim M^{1/2} \sim 1 day (M_J)$

Sensitive to Cold planets outside of snowline ($\sim 3a_{snow}$)

Sensitivity of various methods



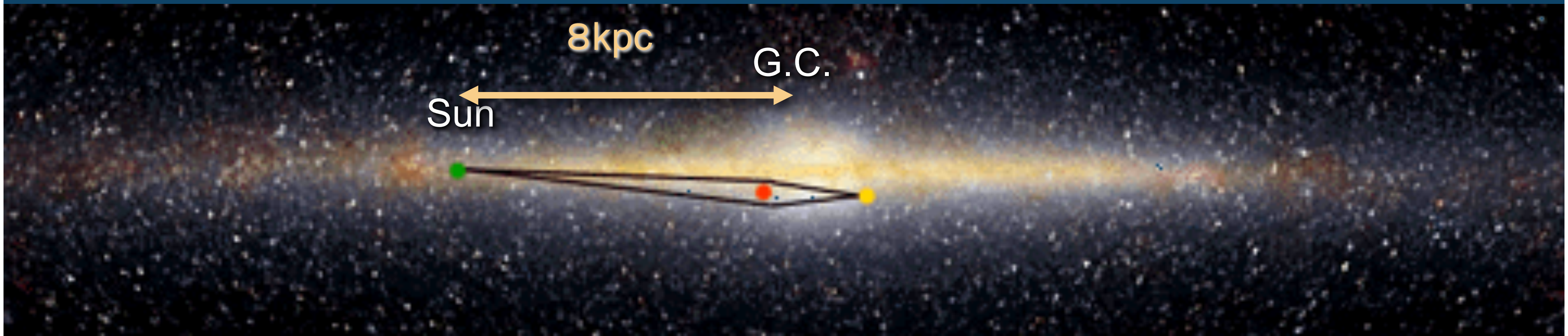
- •RV
- •transit
- •Direct image
- •Microlensing :
  not rely on flux from host

- •1-6 AU : beyond snow line
- •small planet : down to Earth
- •Faint star :M-dwarf, brown dwarf
- •No host : free floating planet
- •Far system: galactic distribution

Survey towards the Galactic Bulge

✧ why ? ➔ Probability:
Microlensing : ~10^{-6} events/yr/star
Planetary event : ~10^{-2}

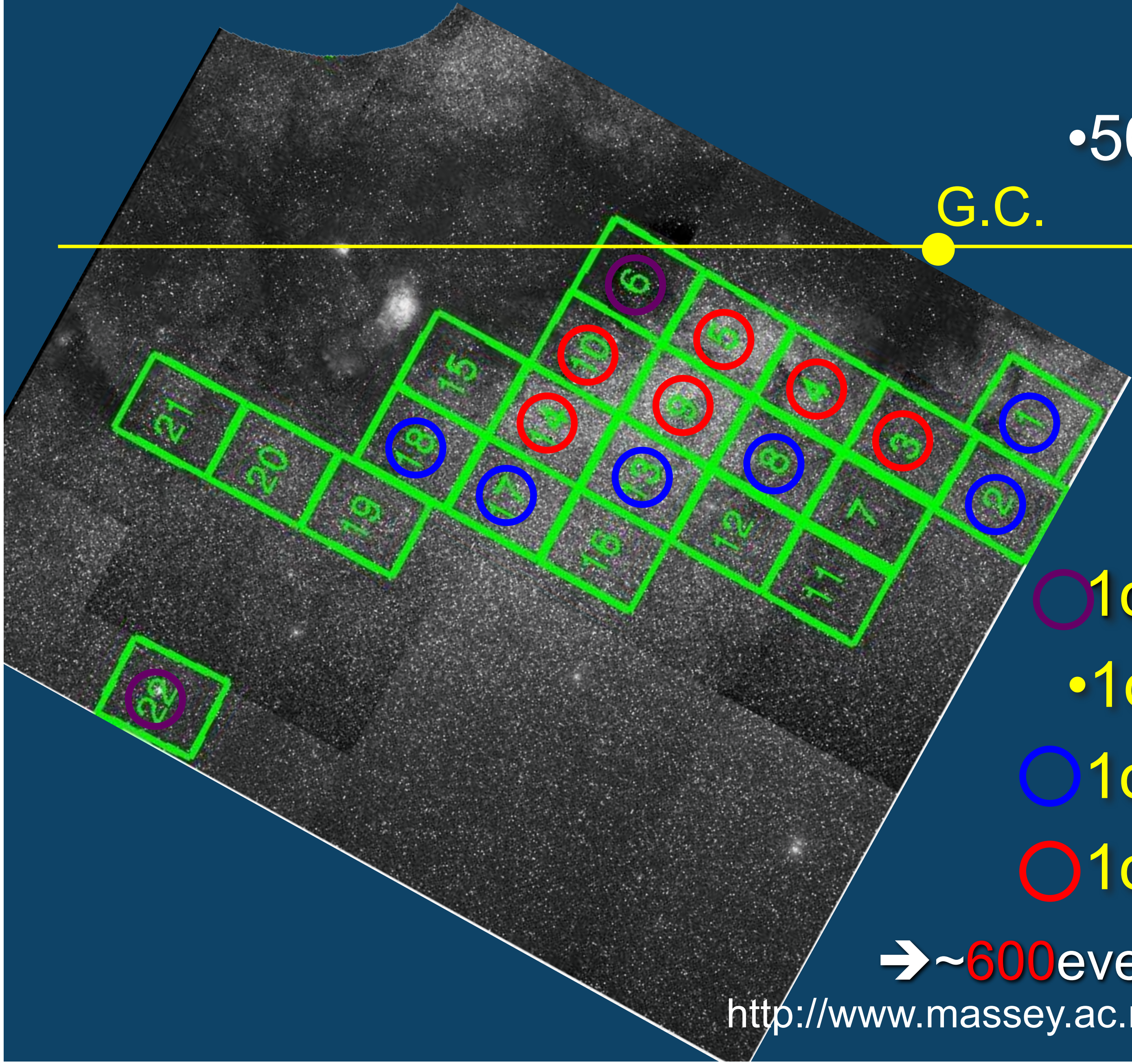
➔ need Wide Field for Many stars



Time scale ~ 30days ($M_{\odot}$)
~ a few days (M_{Jup})
~ hours ($M_{\oplus}$)

➔ need high cadence

Observational fields by MOA



- 50 deg.^{2}(20Mstars)

○1obs./night.(>M_{Jup})

- 1obs./95min.(M_{jup})

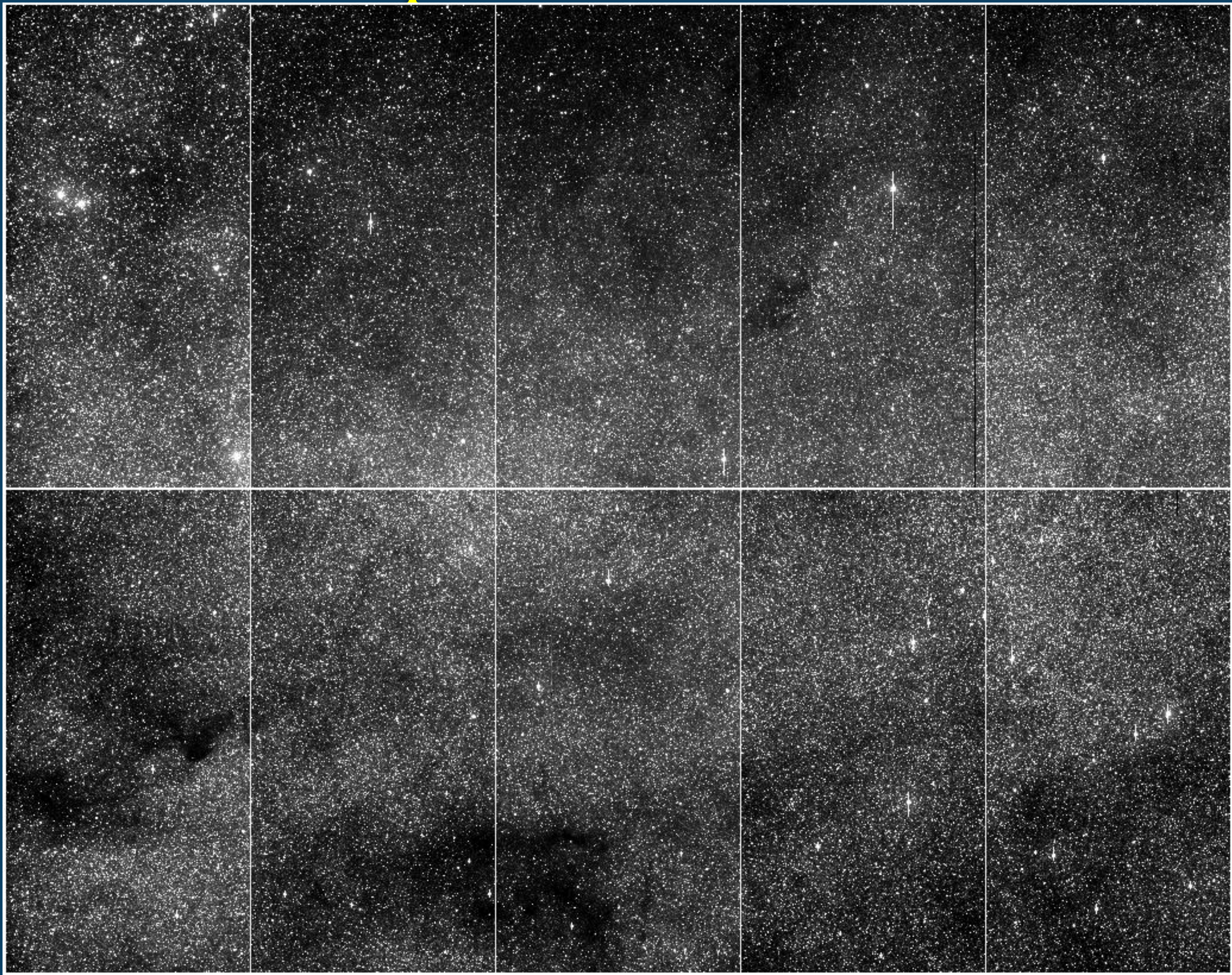
○1obs./47min. (M_{nep})

○1obs./15min. ($M_{\oplus}$)

➔~600events /yr

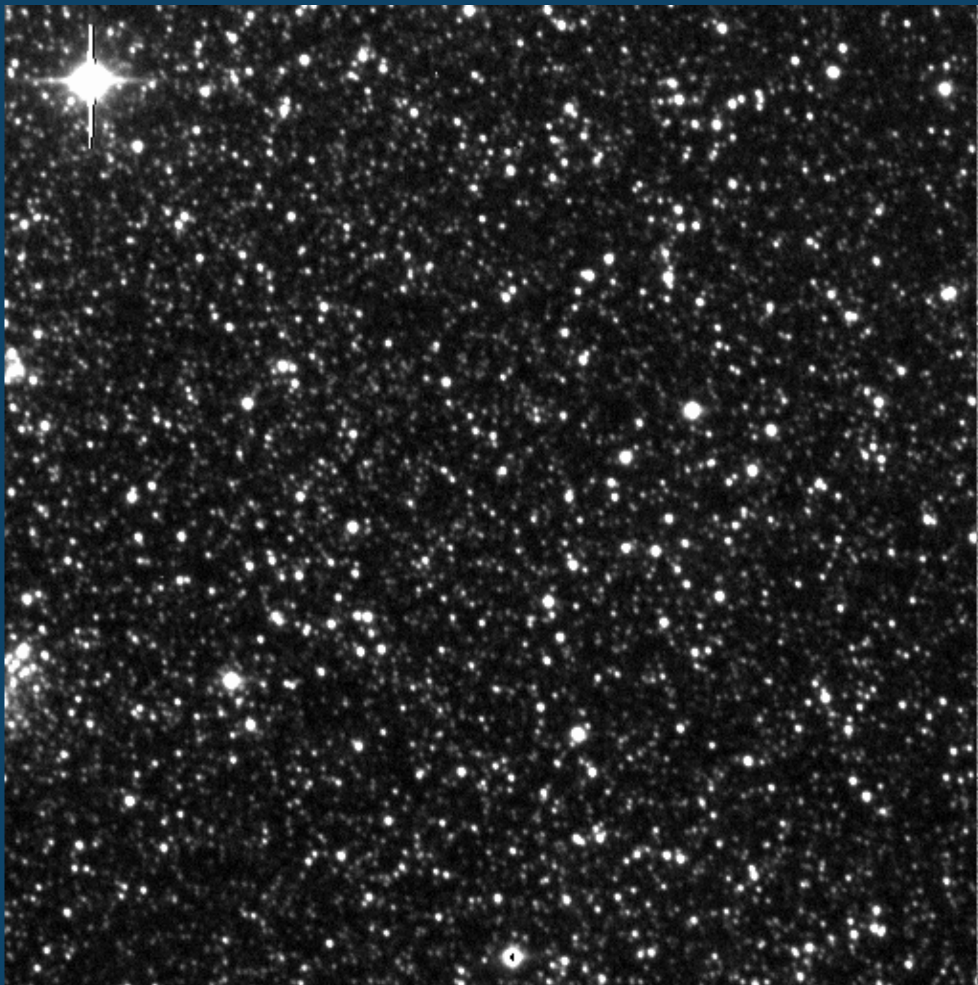
http://www.massey.ac.nz/~iabond/alert/alert.html

An Exposure toward GB

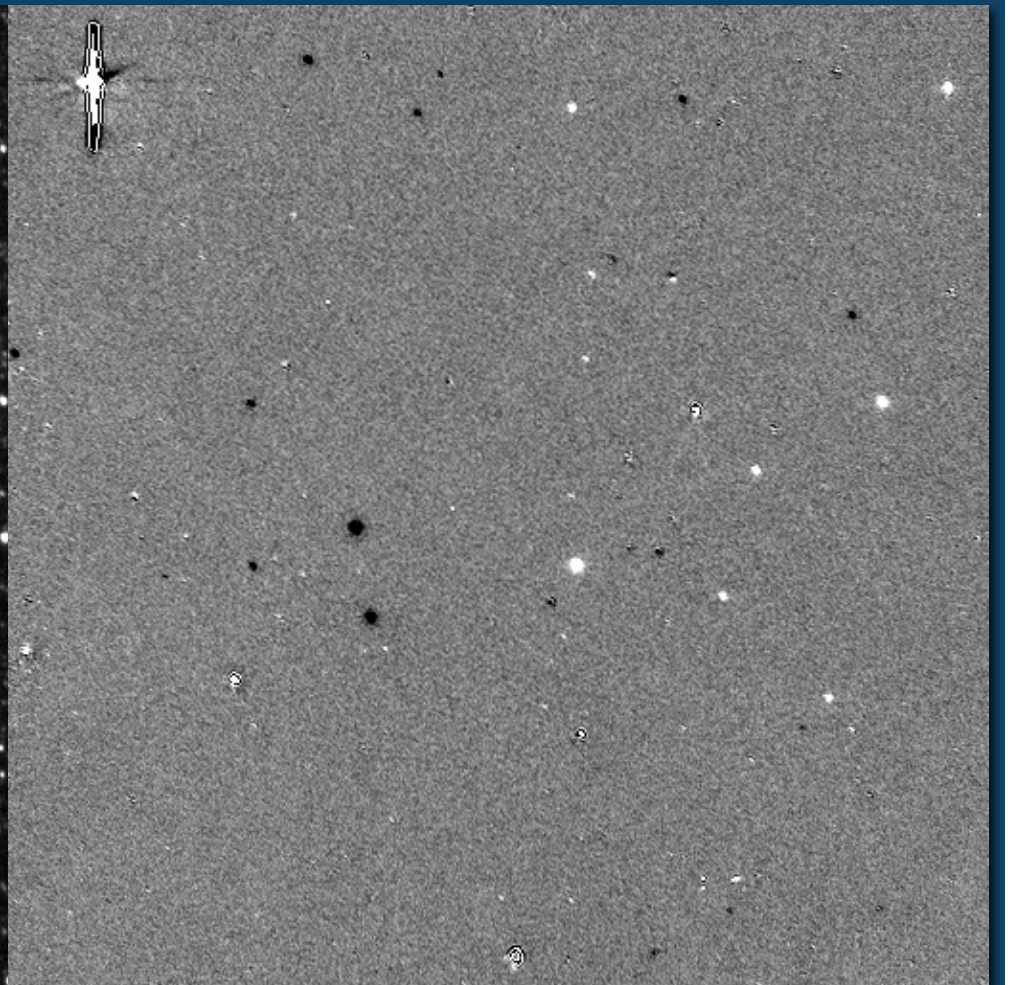


Difference Image Analysis (DIA)

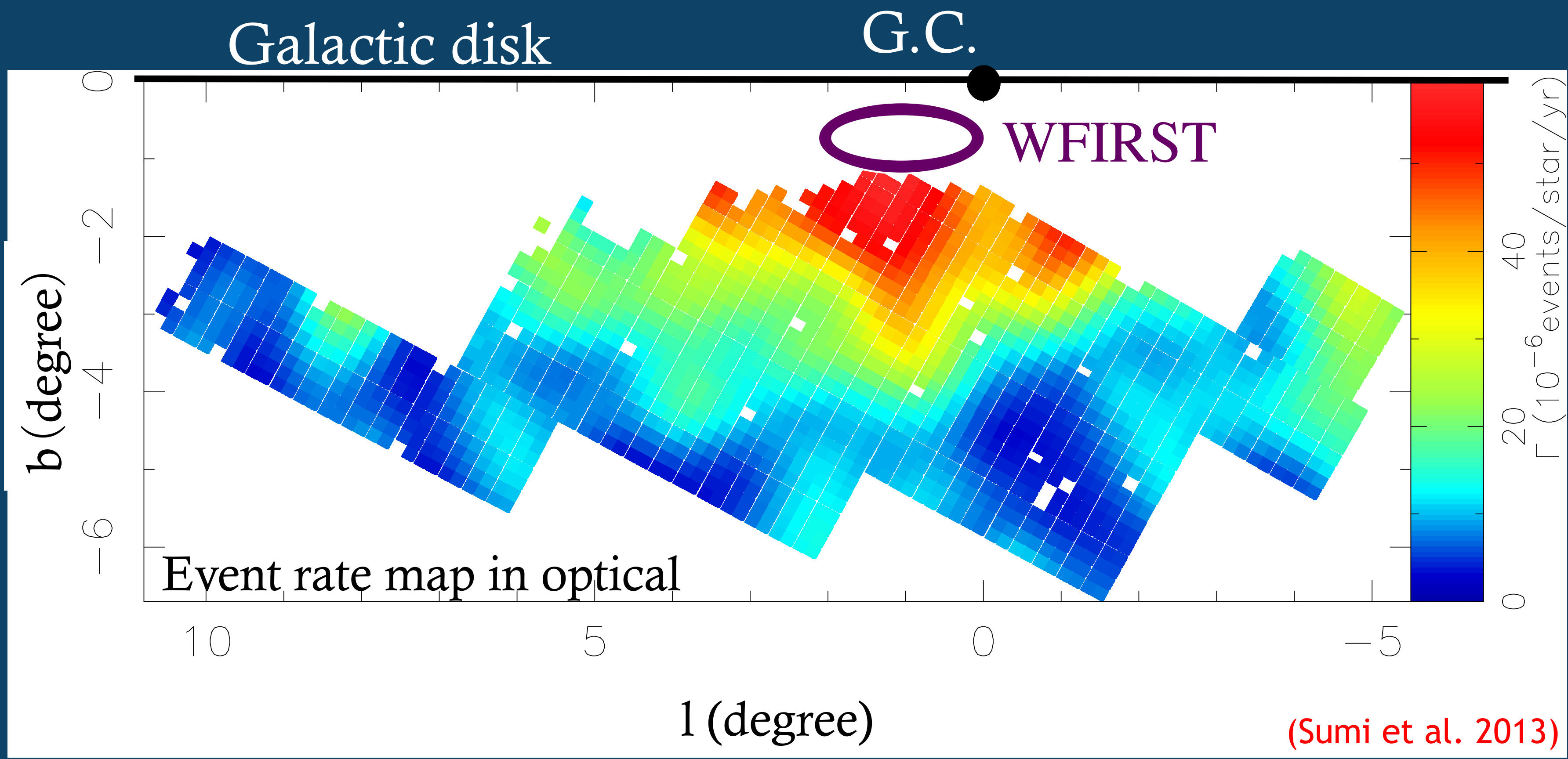
Observed



subtracted



Study the galactic structure & Optimize WFIRST microlensing survey fields by mapping the event rate



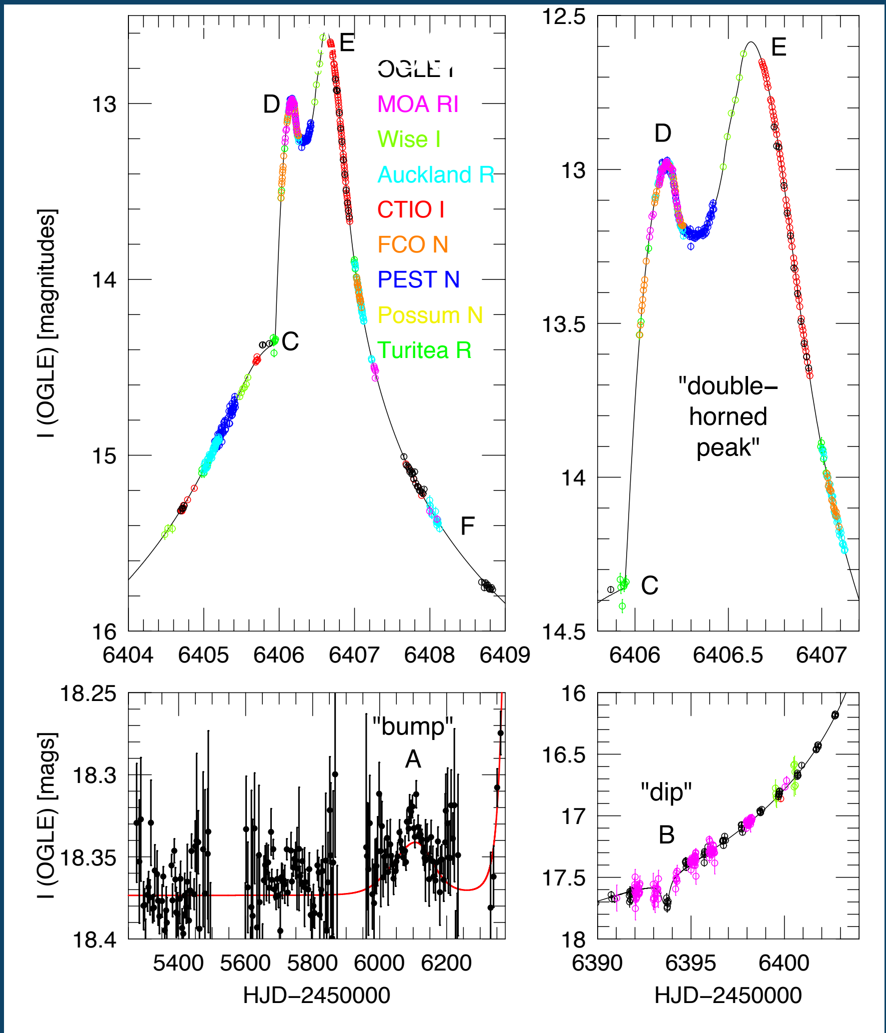
Event rate vary by a factor of 2（peak is at l=1° ）

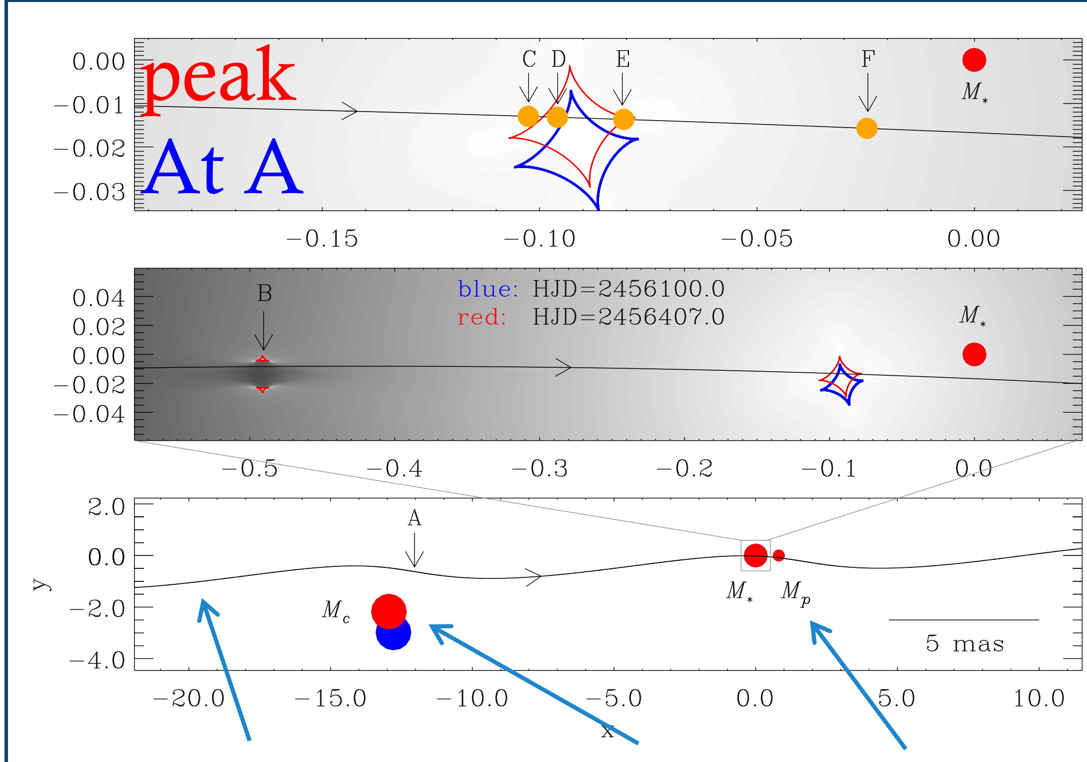
1.7 Earth-mass planet in a binary system

OGLE-2013-BLG-0341/MOA-2013-

Gould+2014

D_l=911.00±0.07kpc
M_c=0.121±0.009$M_\odot$
M_h=0.113±0.009$M_\odot$
M_p=1.66±0.18 M_E
a=0.70±0.02AU





Source trajectory companion Planetary system

Linear approximation of orbit

$\alpha(t)=\alpha_0+d\alpha/dt(t-t_{fix})$

$s(t)=s_0 +ds/dt(t-t_{fix})$

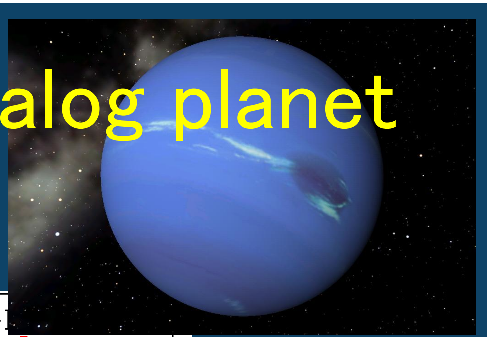
$$\left(\frac{KE}{PE}\right)_\perp = \frac{(r_\perp/AU)^3}{8\pi^2(M/M_\odot)}\left[\left(\frac{1}{s}\frac{ds}{dt}\right)^2+\left(\frac{d\alpha}{dt}\right)^2\right]$$

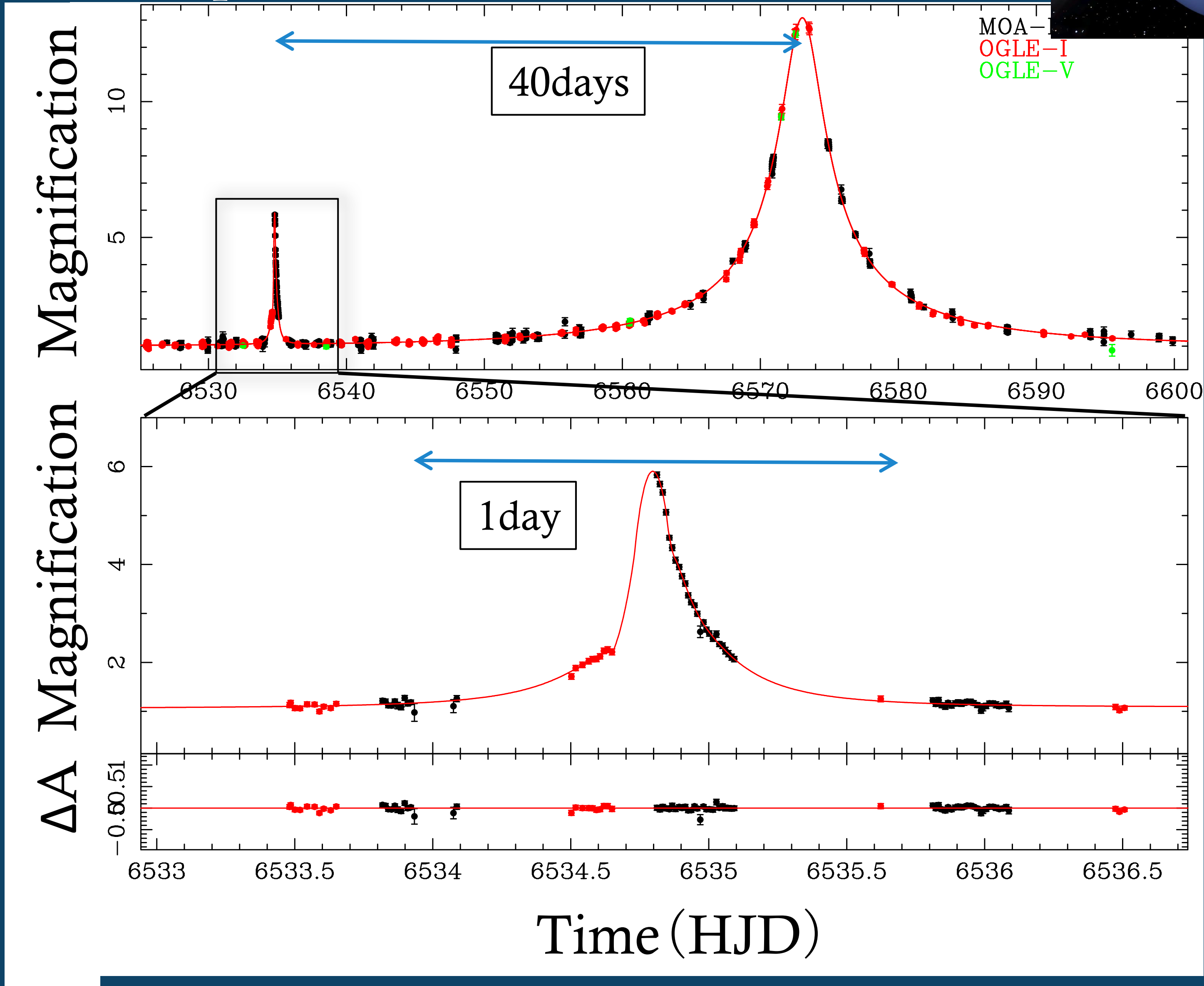
<1 to be bound

MOA-2013-BLG-605: the Neptune analog planet

$q=3x10^{-4}$, $s=2.3$,

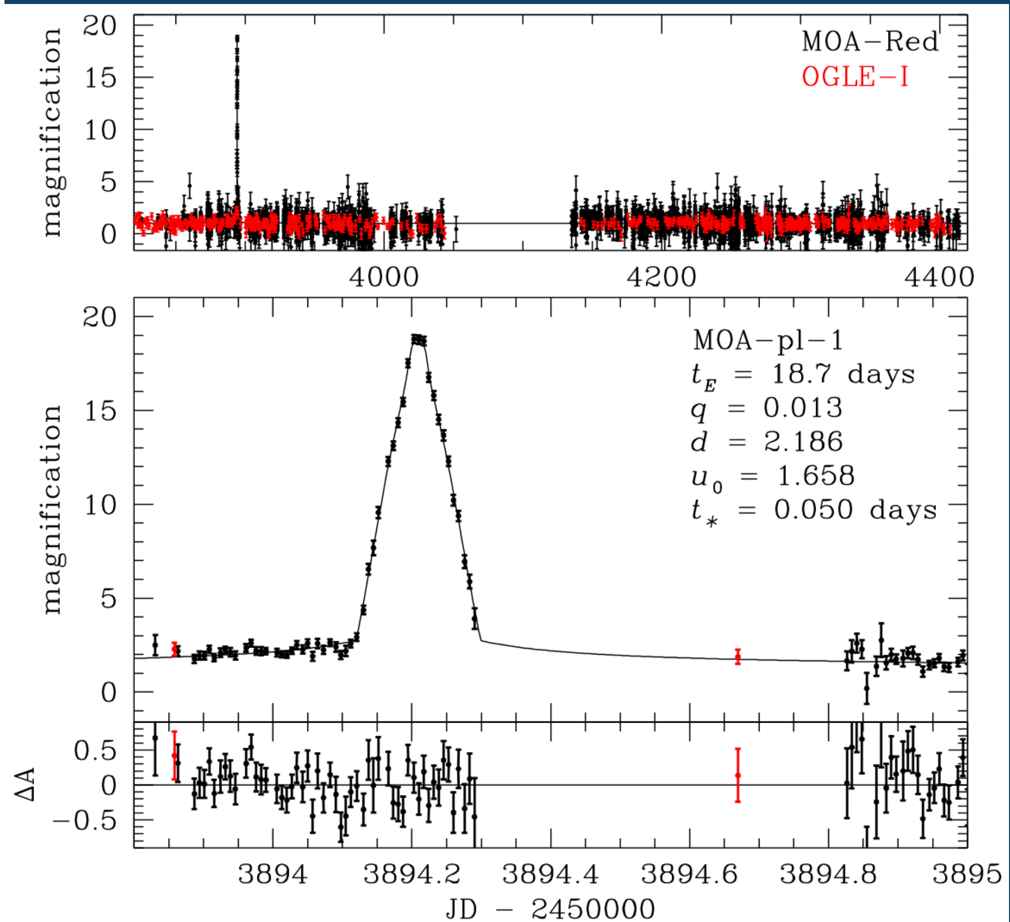
Neptune or super Earth around Brown-dwarf

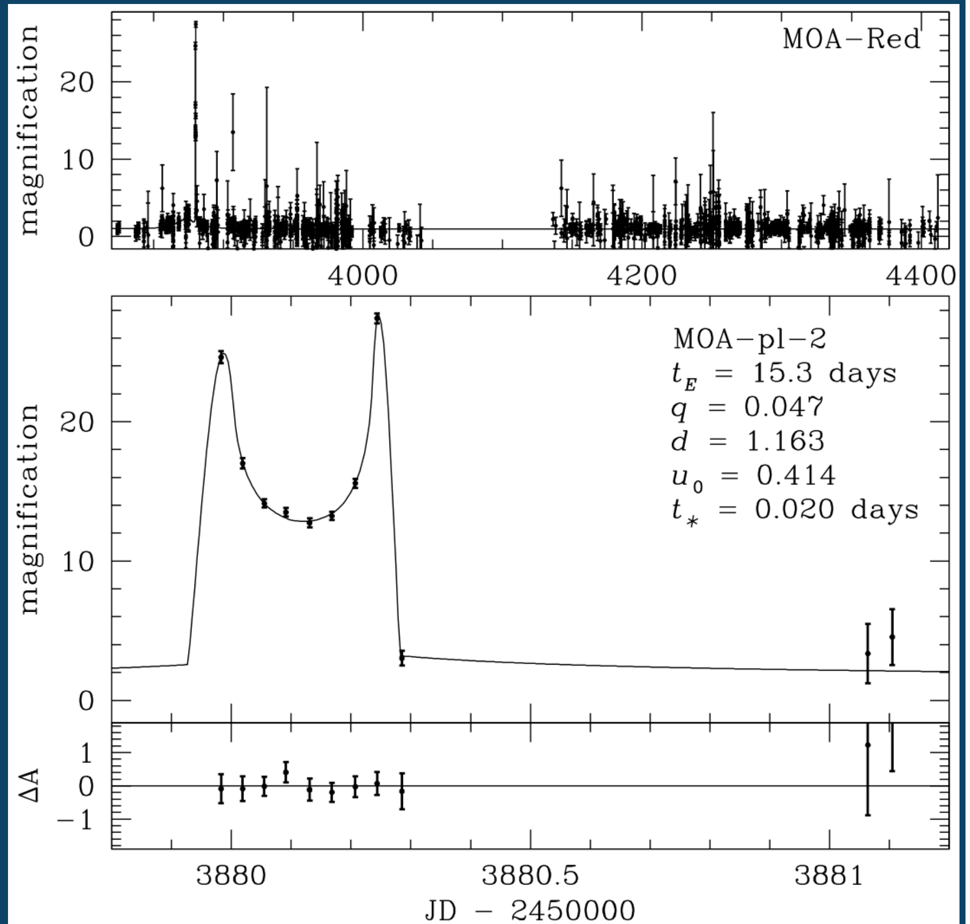


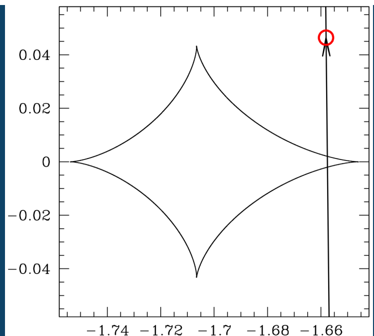


TS+2016

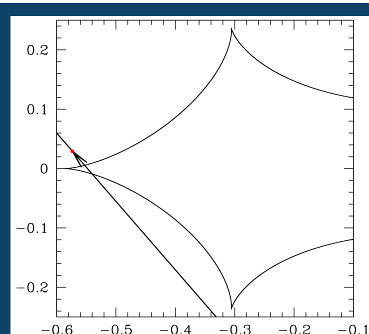
Short Binary Events



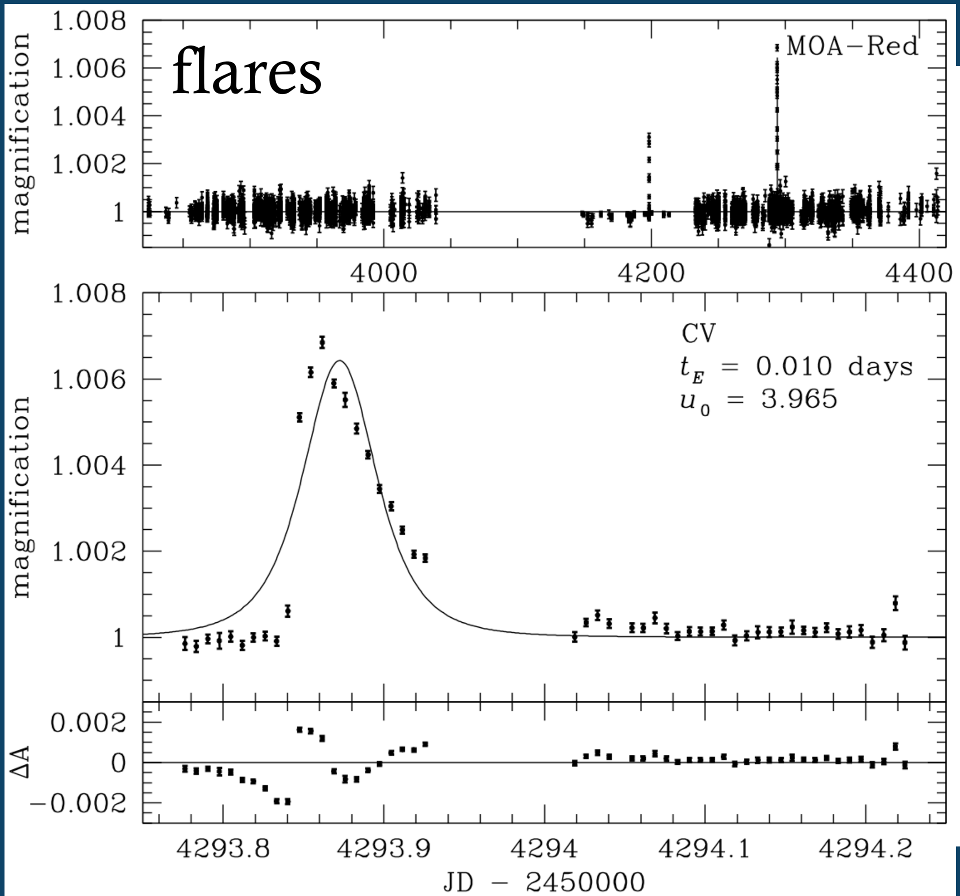


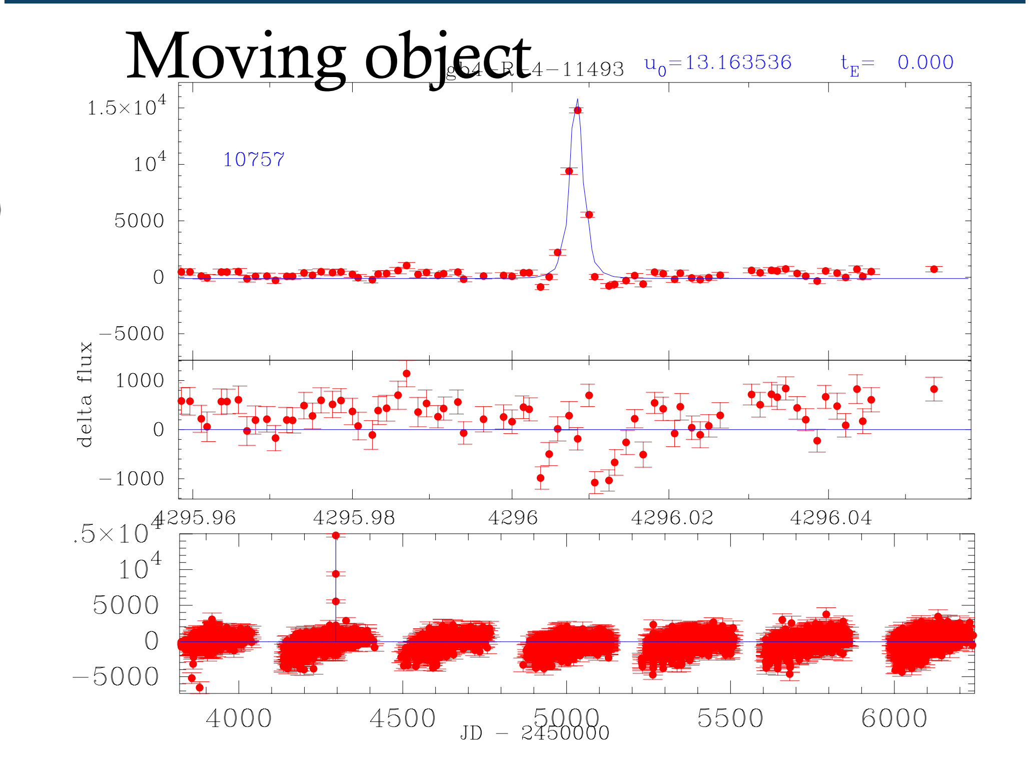


Wide-binaries (d = 2.2, 1.2) with planetary and brown dwarf mass ratios of q = 0.013 and 0.047



Background: CV or moving objects



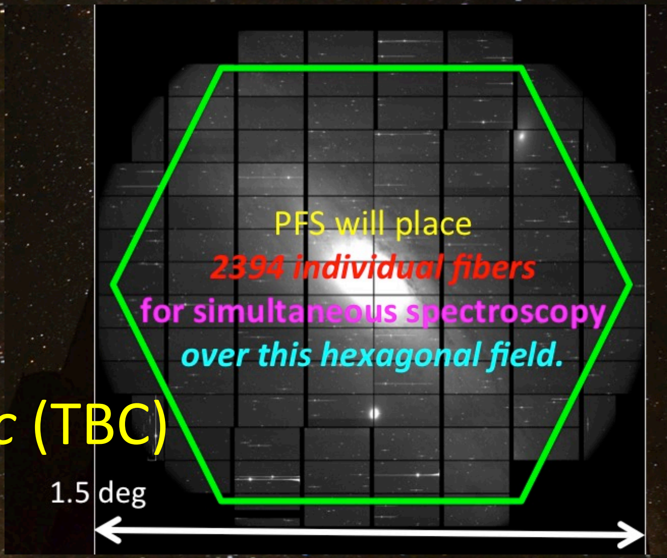


a CV gives a poor microlensing fit, often with low magnification and an unphysically bright source

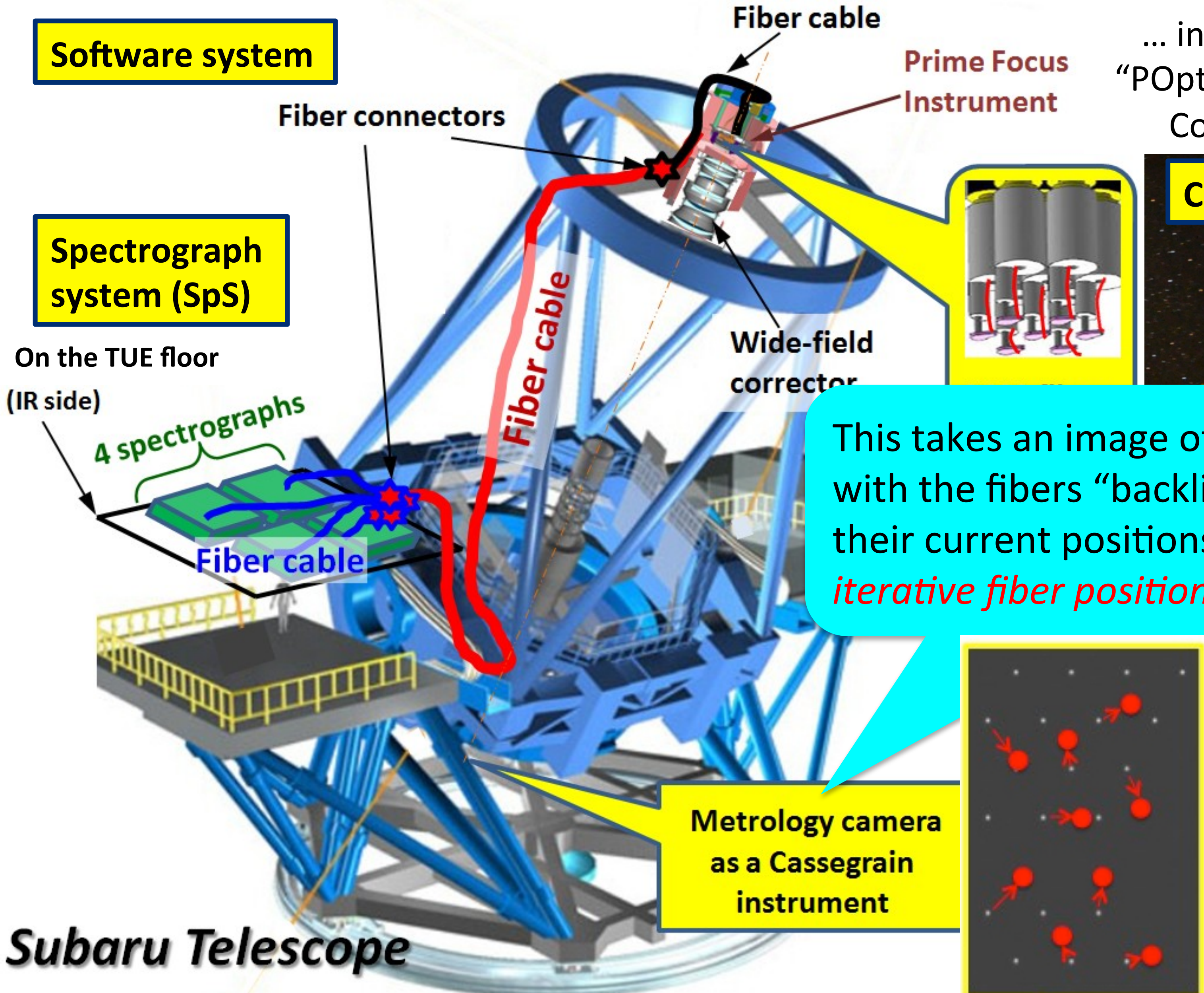
Moving object gives symmetric but unphysical microlensing fit, often with low magnification and an unphysically bright source

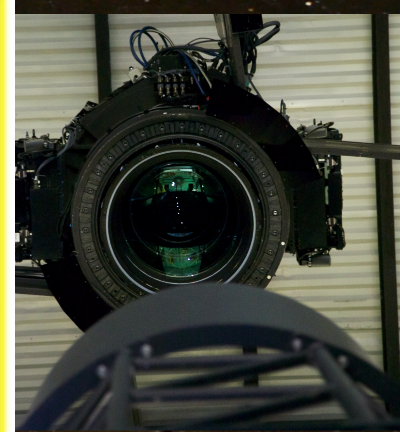
PFS - Fast facts

- Subaru *Prime Focus Spectrograph*:
  The spectroscopy part of the "SuMIRe" project.
  - Wide field: *~1.3 deg* diameter
  - High multiplicity: *2394 fibers*
    - Fiber diameter: ~1.05 arcsec
    - Fiber positioner pitch: ~85 arcsec
    - Minimum fiber separation: ~30 arcsec
  - Quick fiber reconfiguration: *~60-120 sec* (TBC)
    - *Dynamic* survey strategy is allowed.
  - VIS-NIR coverage: *380-1260nm simultaneously*
    - Low resolution mode: ~2.5 A resolution
    - Medium resolution mode (around 800nm): ~1.6 A resolution
- Aiming at start of science operation & survey program in *2021, as a facility instrument on Subaru Telescope.*



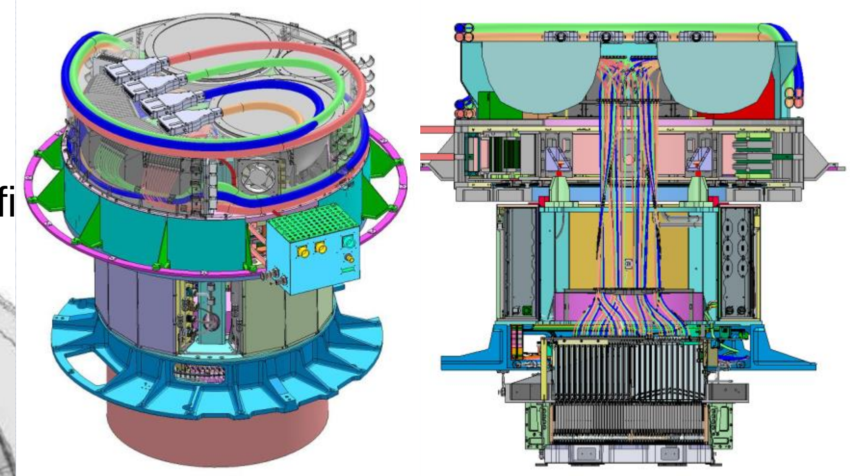
PFS subsystems distribution

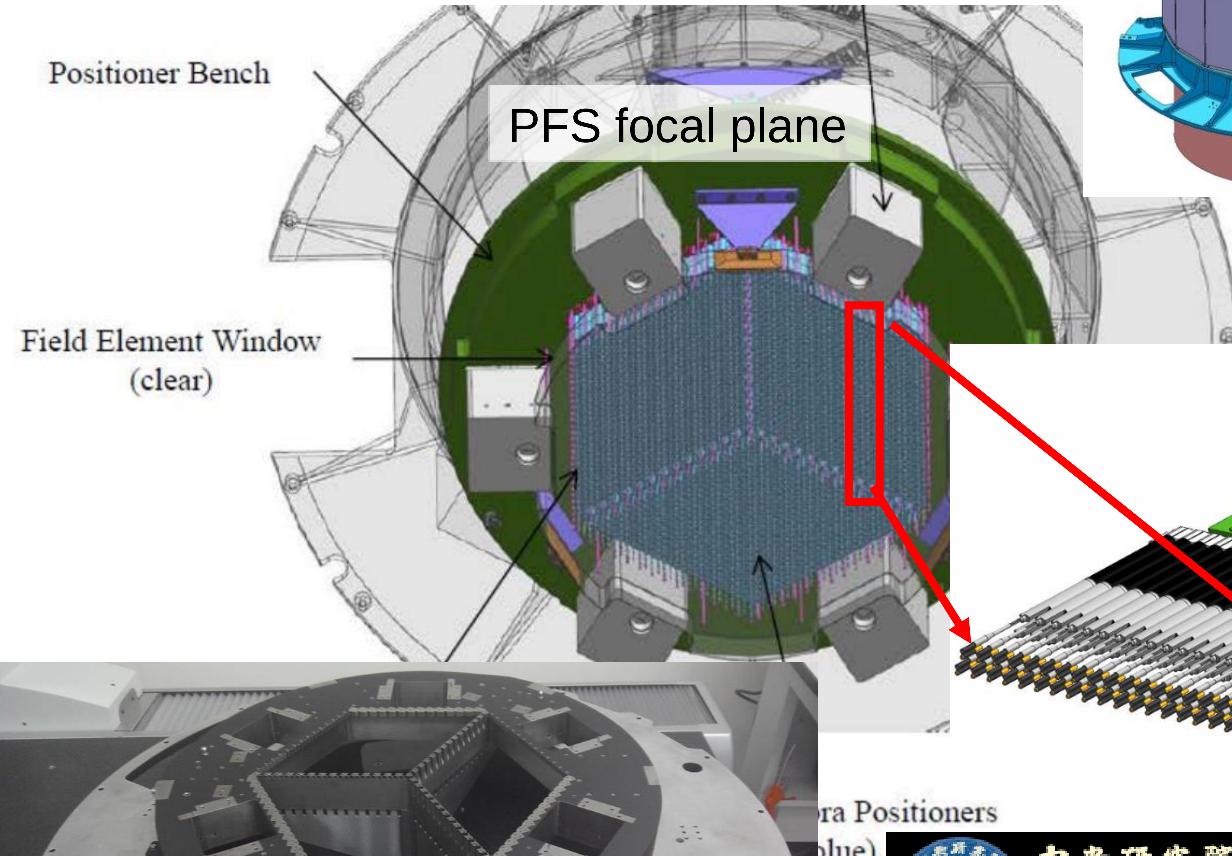




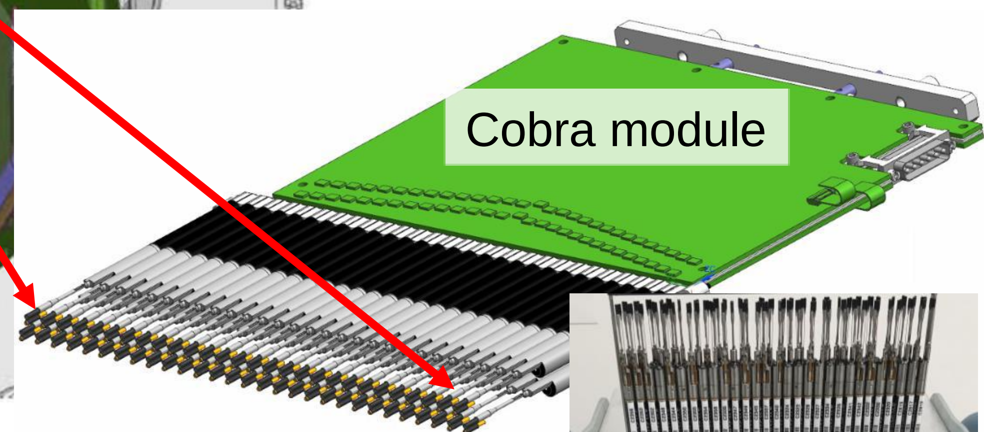
Prime Focus Instrument (PFI)

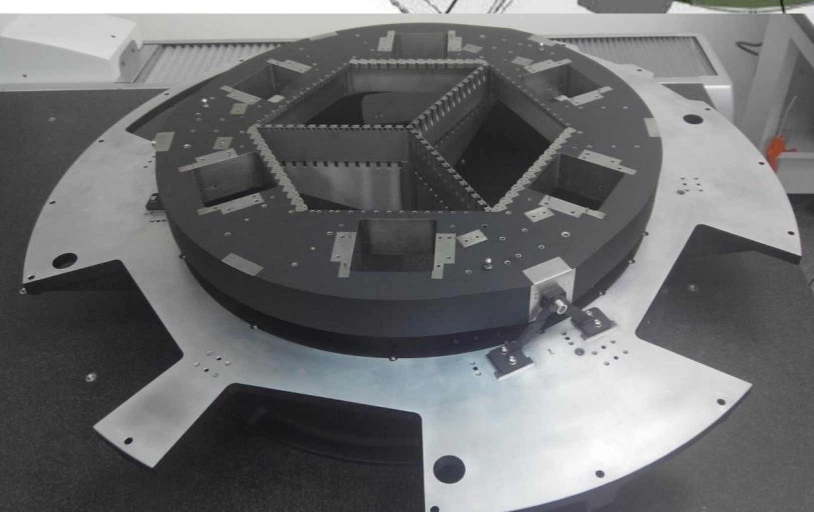
The focal plane will include 42 modules, each with 57 fi
Caltech is building and testing these modules





Each Cobra module includes 57 Cobra assemblies





中央研究院
天文及天文物理研究所
ACADEMIA SINICA
Institute of Astronomy and Astrophysics

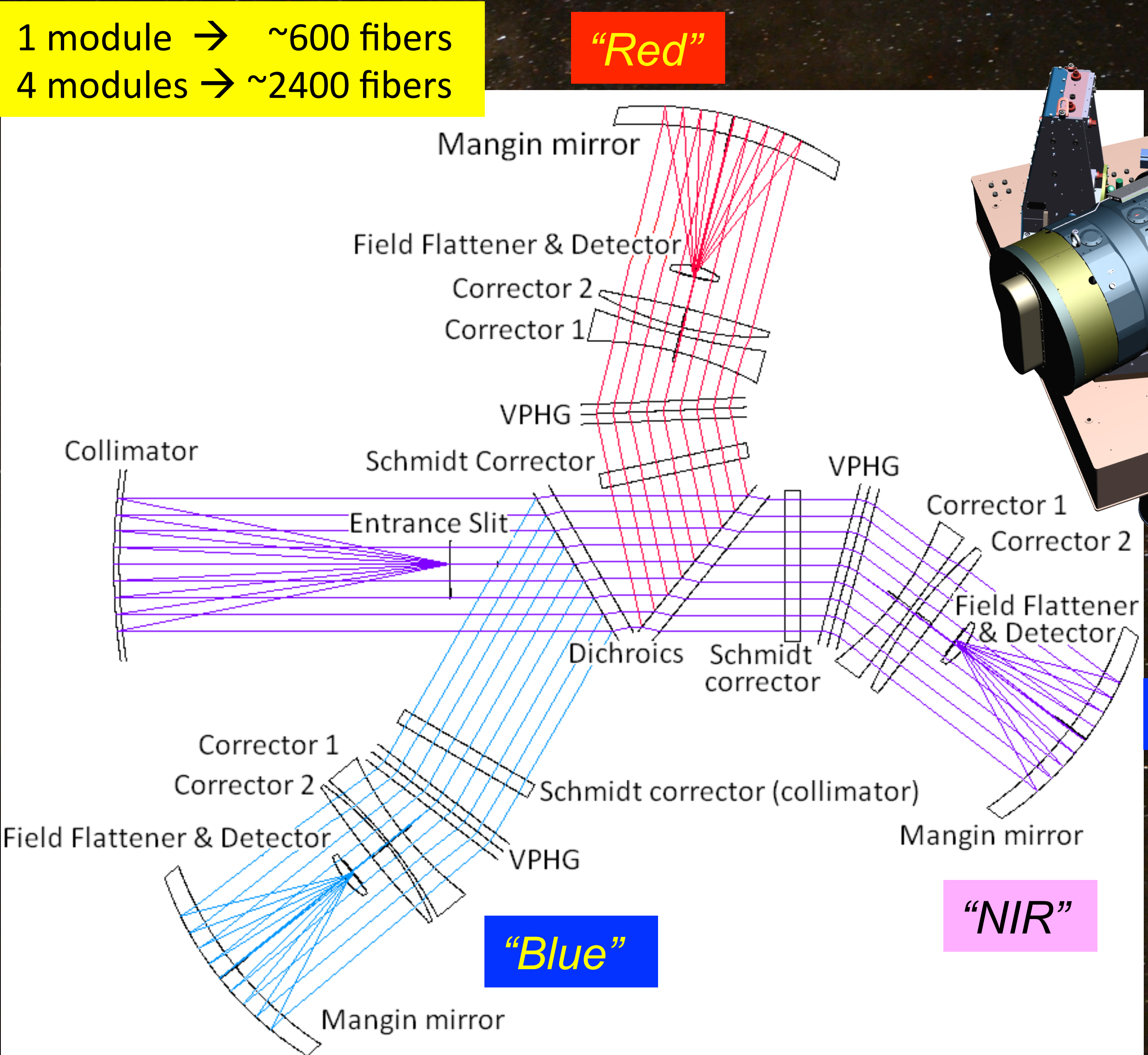
LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

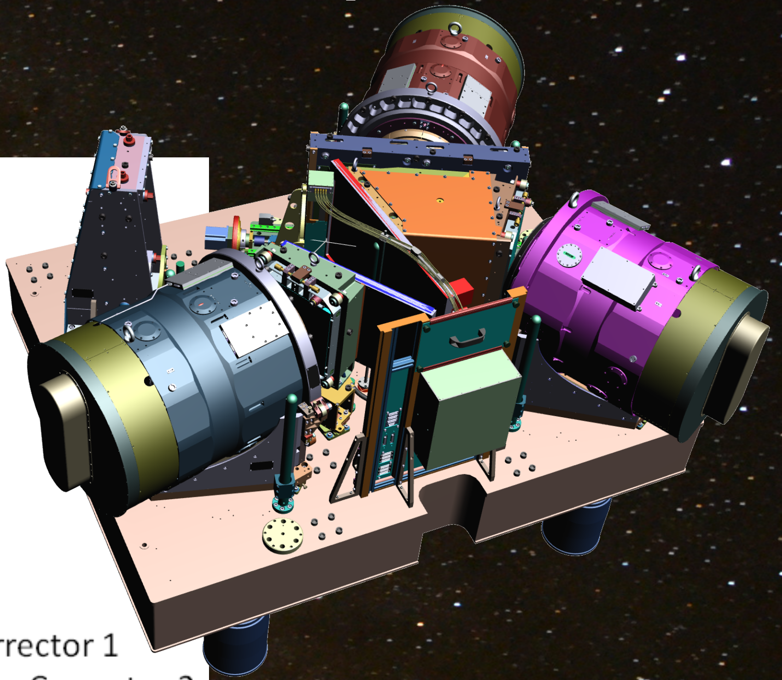
NASA JPL

Caltech

Spectrograph System (SpS)

1 module → ~600 fibers
4 modules → ~2400 fibers





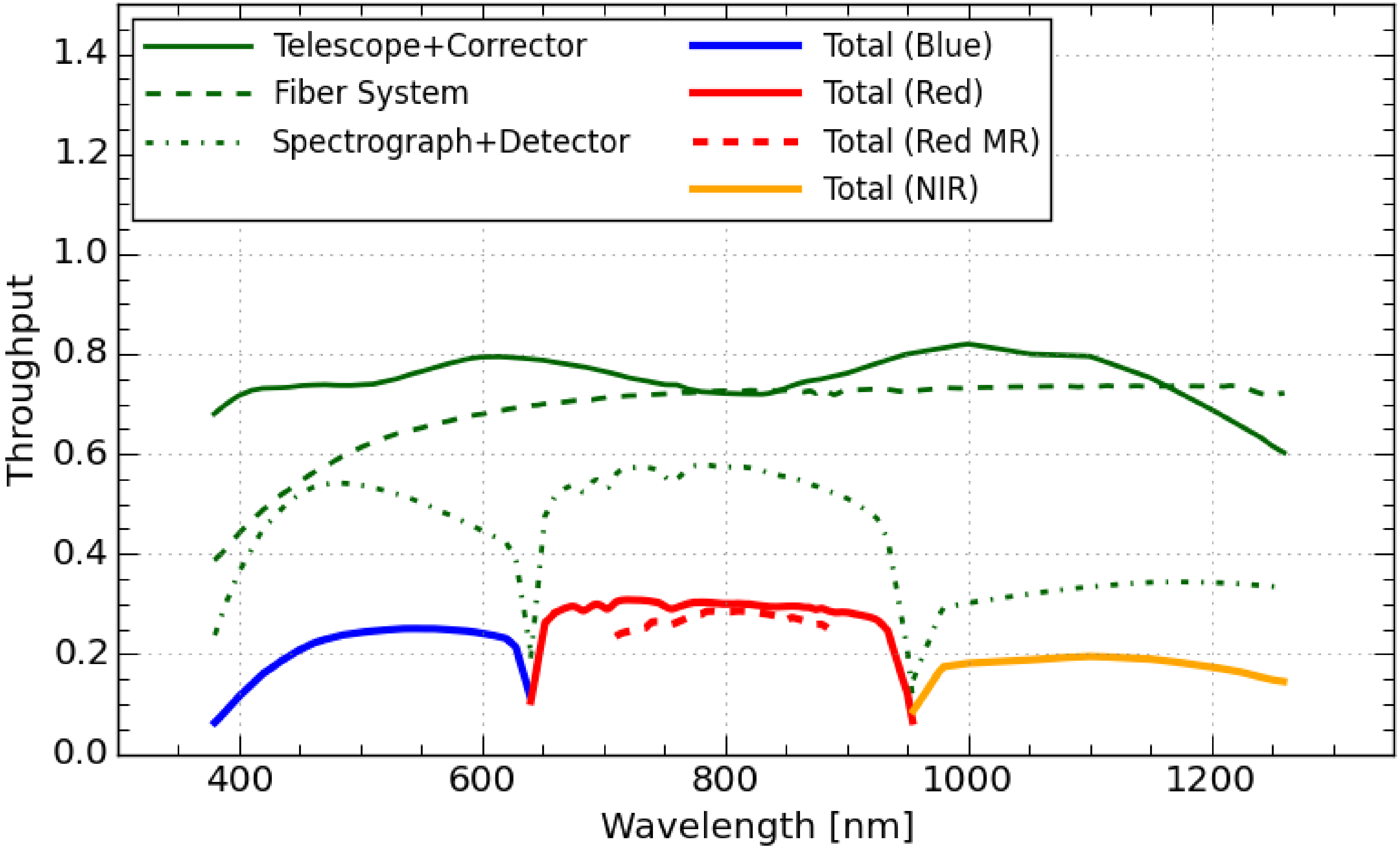
Blue (380-650nm)
Red (630-970nm)
NIR (950-1280nm)

Instrument Parameters

Prime Focus Instrument		
Field of view	~1.38 deg (hexagonal - diameter of circumscribed circle)	
Field of view area	~1.25 deg^2	
Input F number to fiber	2.8	
Fiber core diameter (1)	127 μm (1.12 arcsec at the FoV center, 1.02 arcsec at the edge)	
Positioner pitch	8 mm (90.4 arcsec at the FoV center, 82.4 arcsec at the edge)	
Positioner patrol field	9.5 mm diameter (107.4 arcsec at the FoV center, 97.9 arcsec at the edge)	
Fiber minimum separation (2)	~30 arcsec	
Fiber configuration time	~60-120 sec. [TBC]	
Number of fibers	Science fibers	Fixed fiducial fibers
	2394	96
Fiber density	~2000 deg^{-2} / ~0.6 $arcmin^{-2}$	
Number of A&G camera (3)	6	
Field of view of A&G camera	~5.1 $arcmin^2$ per one camera	
Sensitivity of A&G camera	r'~20.0 AB mag for S/N~30 (100) in 1 (10) sec. exposure	

Spectrograph				
Spectral arms	Blue	Red		NIR
		Low Res.	Mid. Res.	
Spectral coverage	380 - 650 nm	630 - 970 nm	710 - 885 nm	940 - 1260 nm
Dispersion	~0.7 Å/pix	~0.9 Å/pix	~0.4 Å/pix	~0.8 Å/pix
Spectral resolution	~2.1 Å	~2.7 Å	~1.6 Å	~2.4 Å
Resolving power	~2300	~3000	~5000	~4300
Spectrograph throughput (4)	~53% (@500nm)	~57% (@800nm)	~54% (@800nm)	~33% (@1100nm)

Throughput of the system



PFS Expected Performance

Arm		Wavelength range [nm]	Throughput(1)	Resolving Power	Continuum sensitivity(2) [AB mag]		Emission line sensitivity(3) [10^{-17} erg/s/cm^2]	
					mean(4)	representative(5)	mean(4)	representative(5)
Blue		380 - 450	14%	~2300	22.0	22.1 (@415nm)	2.9	2.8 (@415nm)
		450 - 550	24%		22.4	22.5 (@505nm)	1.5	1.4 (@505nm)
		550 - 650	23%		22.1	22.2 (@605nm)	1.5	1.3 (@605nm)
Red	Low Res.	630 - 750	29%	~3000	22.2	22.5 (@680nm)	1.2	1.0 (@680nm)
		750 - 850	30%		22.0	22.4 (@796nm)	1.1	0.9 (@796nm)
		850 - 970	27%		21.6	22.1 (@912nm)	1.2	0.9 (@912nm)
	Mid. Res.	710 - 775	26%	~5000	21.6	21.8 (@741nm)	1.3	1.1 (@741nm)
		775 - 825	28%		21.6	21.8 (@796nm)	1.1	1.0 (@796nm)
		825 - 885	27%		21.5	21.7 (@856nm)	1.2	1.0 (@856nm)
NIR		940 - 1050	17%	~4300	20.9	21.5 (@993nm)	2.0	1.3 (@993nm)
		1050 - 1150	19%		21.0	21.4 (@1100nm)	1.6	1.2 (@1100nm)
		1150 - 1260	17%		20.9	21.3 (@1208nm)	1.5	1.2 (@1208nm)

(1) The total throughput including primary mirror reflectivity, WFC transmission, and PFS instrument. See here. The fiber aperture effect is not included because it depends on seeing condition and object type. The vignetting effect, ~94% at the field center and ~71% at the field edge, is not included either because it depends on the field position. The continuum and emission-line sensitivity information, however, are calculated taking these factors into consideration.

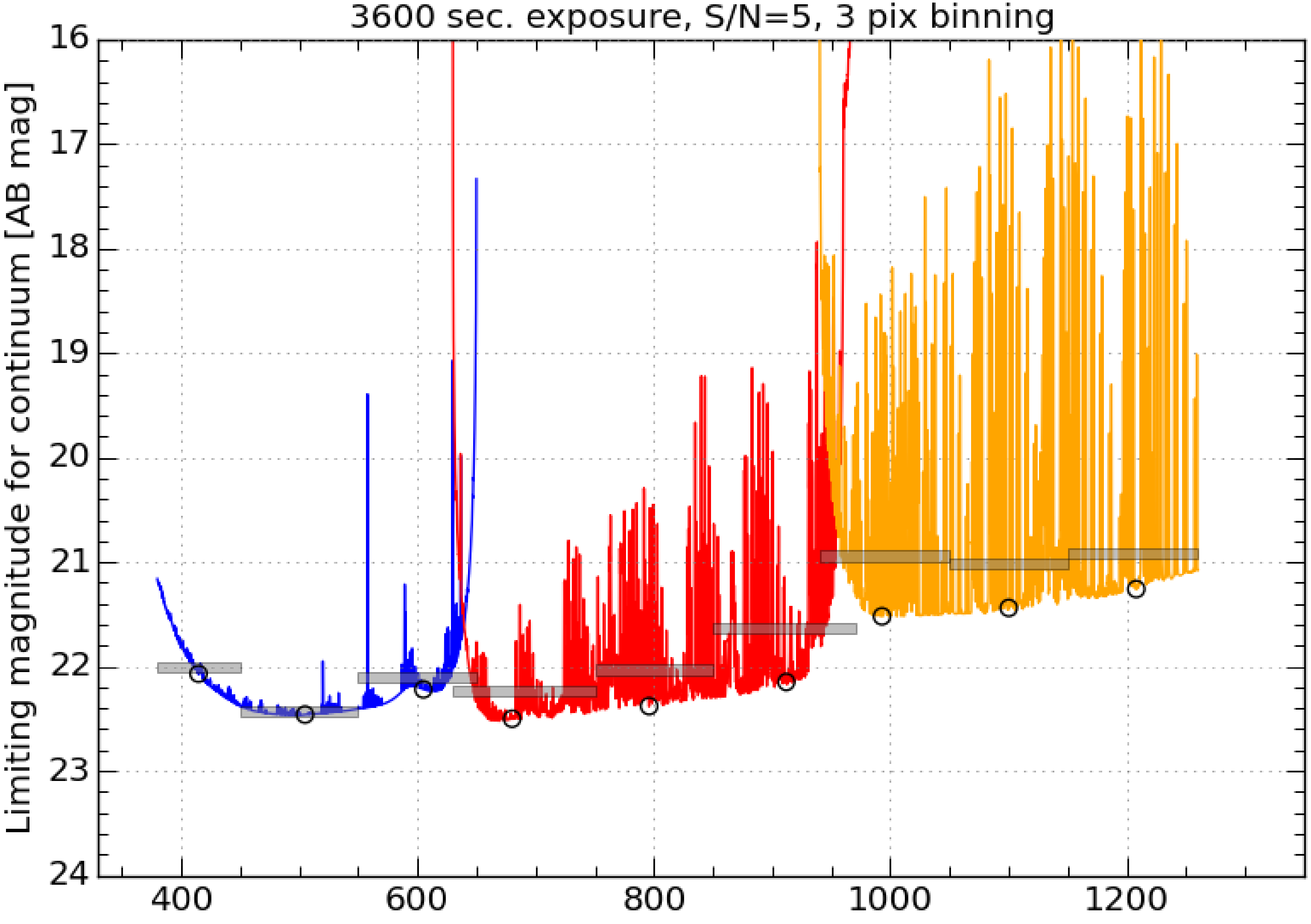
(2) Continuum sensitivity in case of point source, to achieve S/N=5 for 1-hour on-source exposure (8×450 sec.), after 3 pixel binning.

(3) Emission-line sensitivity in case of point source, to achieve S/N=5 for 1-hour on-source exposure (8×450 sec.). Here, the line width is assumed to be σ=70 km/s.

(4) The average limiting magnitude and line flux in the wavelength range. This value may be affected by the sky emission line.

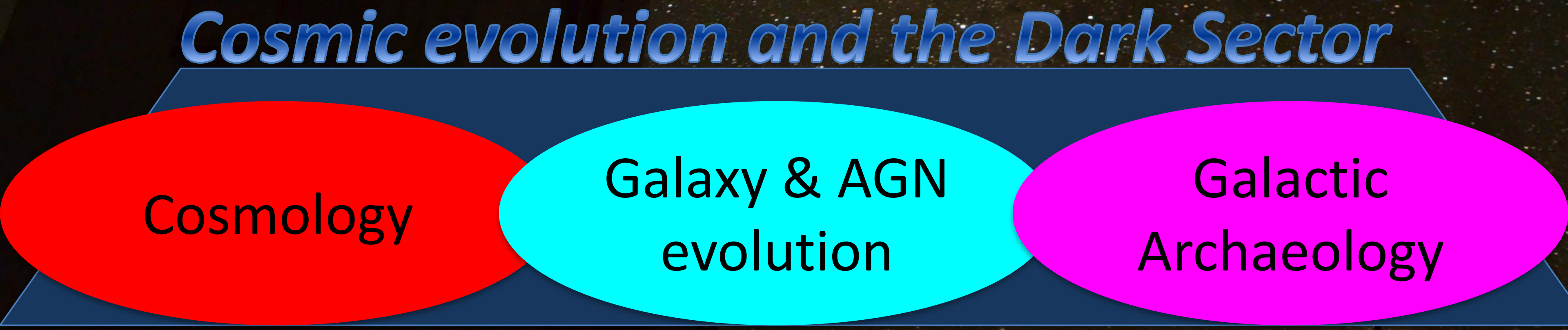
(5) The representative value at the wavelength where the spectrum is not affected by the sky emission line.

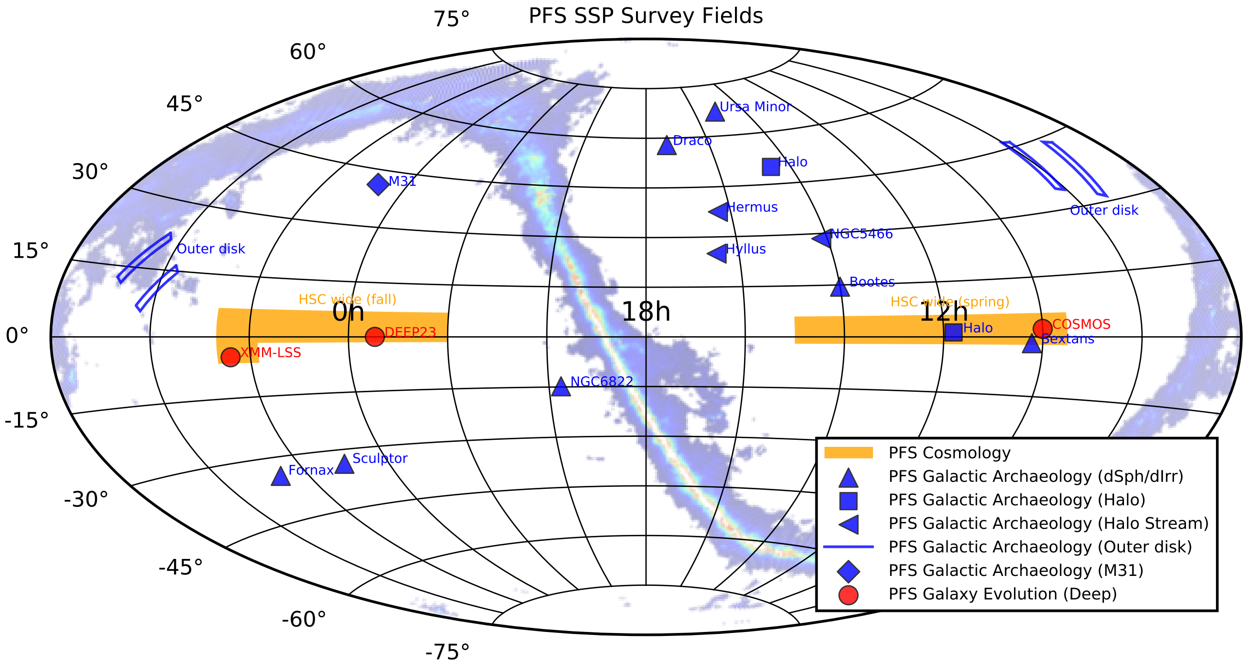
Limiting magnitude for continuum



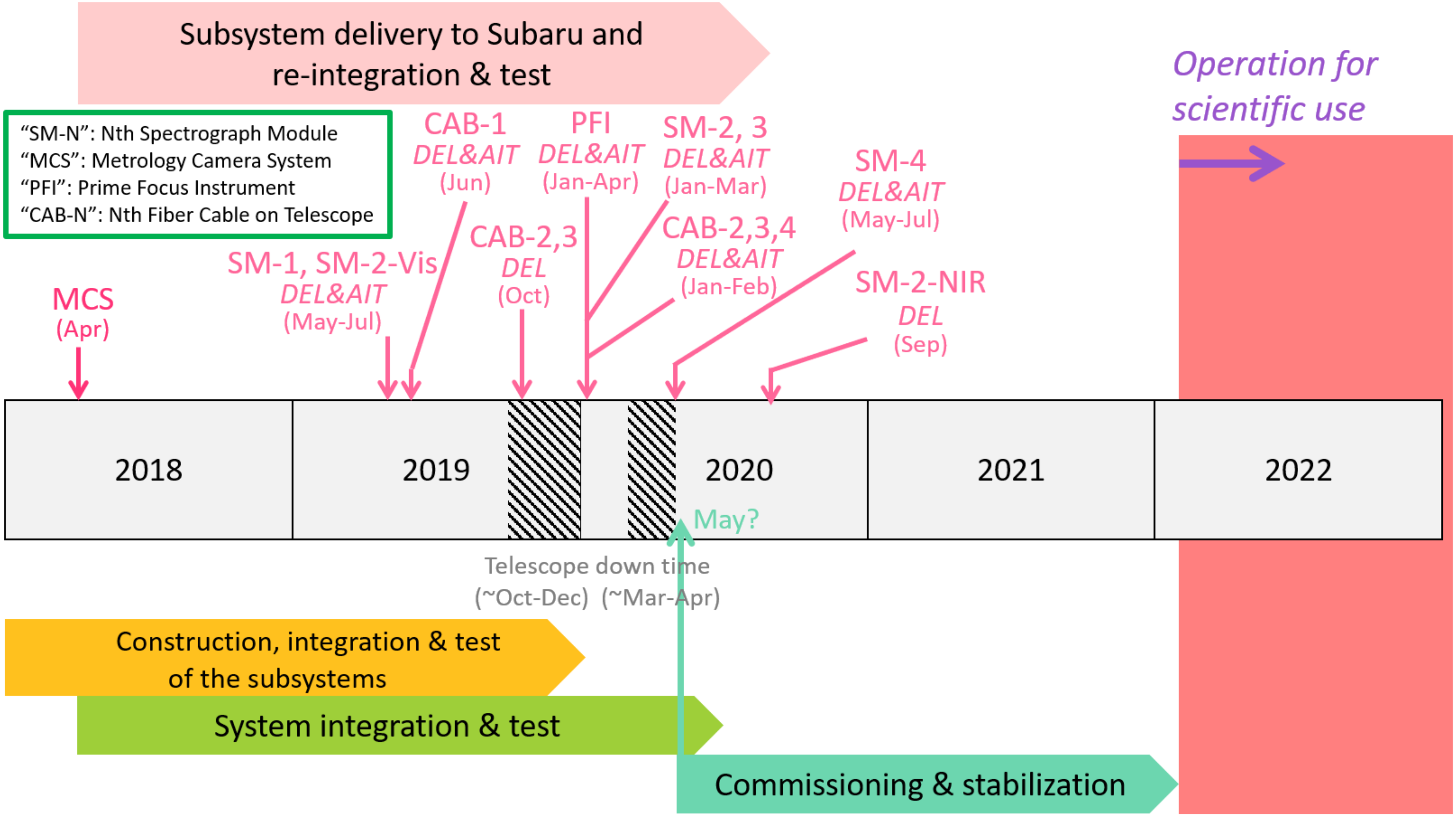
Planning of PFS survey program

- Subaru Strategic Program (SSP): ~300 nights over ~5 years
  - HSC SSP has been progressing since 2014.
    - Continuing out to ~2020(?).
  - PFS SSP: A proposal is in preparation.
    - Timely start after the HSC SSP
    - A survey program with the three "pillars":




PFS SSP Survey Fields
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
0h
18h
12h
Ursa Minor
Draco
Halo
M31
Hermus
NGC5466
Hyllus
Outer disk
Outer disk
Bootes
HSC wide (fall)
HSC wide (spring)
DEEP23
XMM-LSS
COSMOS
Halo
Sextans
NGC6822
Sculptor
Fornax
PFS Cosmology
PFS Galactic Archaeology (dSph/dIrr)
PFS Galactic Archaeology (Halo)
PFS Galactic Archaeology (Halo Stream)
PFS Galactic Archaeology (Outer disk)
PFS Galactic Archaeology (M31)
PFS Galaxy Evolution (Deep)

Timeline



Subsystem delivery to Subaru and re-integration & test
"SM-N": Nth Spectrograph Module
"MCS": Metrology Camera System
"PFI": Prime Focus Instrument
"CAB-N": Nth Fiber Cable on Telescope
CAB-1 DEL&AIT (Jun)
PFI DEL&AIT (Jan-Apr)
SM-2, 3 DEL&AIT (Jan-Mar)
SM-4 DEL&AIT (May-Jul)
Operation for scientific use
CAB-2,3 DEL (Oct)
CAB-2,3,4 DEL&AIT (Jan-Feb)
SM-1, SM-2-Vis DEL&AIT (May-Jul)
MCS (Apr)
SM-2-NIR DEL (Sep)
2018
2019
2020
2021
2022
May?
Telescope down time
(~Oct-Dec) (~Mar-Apr)
Construction, integration & test of the subsystems
System integration & test
Commissioning & stabilization

PRIME Wide FOV
1.8m Telescope at SAAO

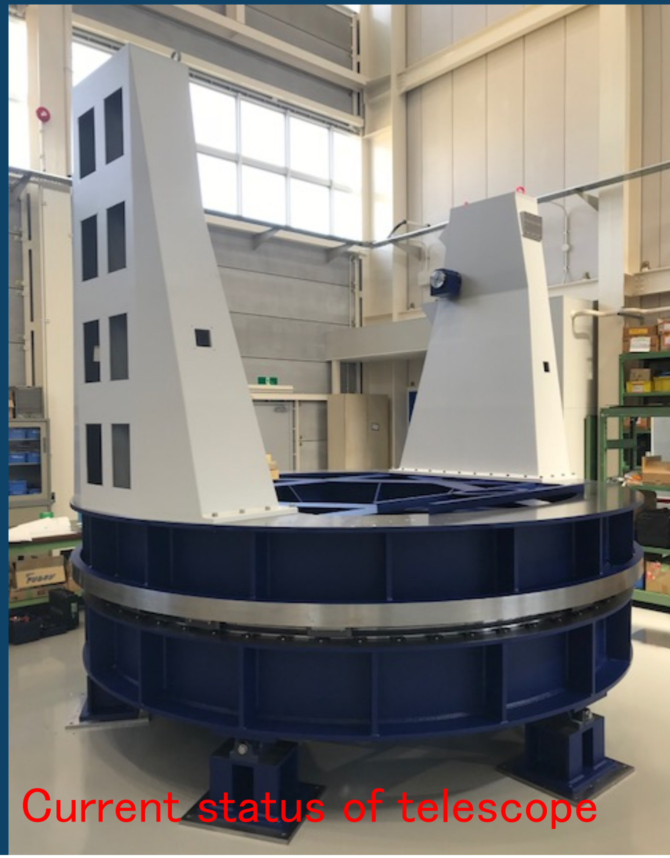
Funded by JSPS

Diameter: 1.8m, (f/2.29)

FOV:1.25deg^2=1.56deg^2(0.5”/pix)

(6xfull moon) World Largest FOV

With H-band Hi-res spectrograph



PRIME (PRime-focus Infrared Mirolensing Experiment)

Objectives:

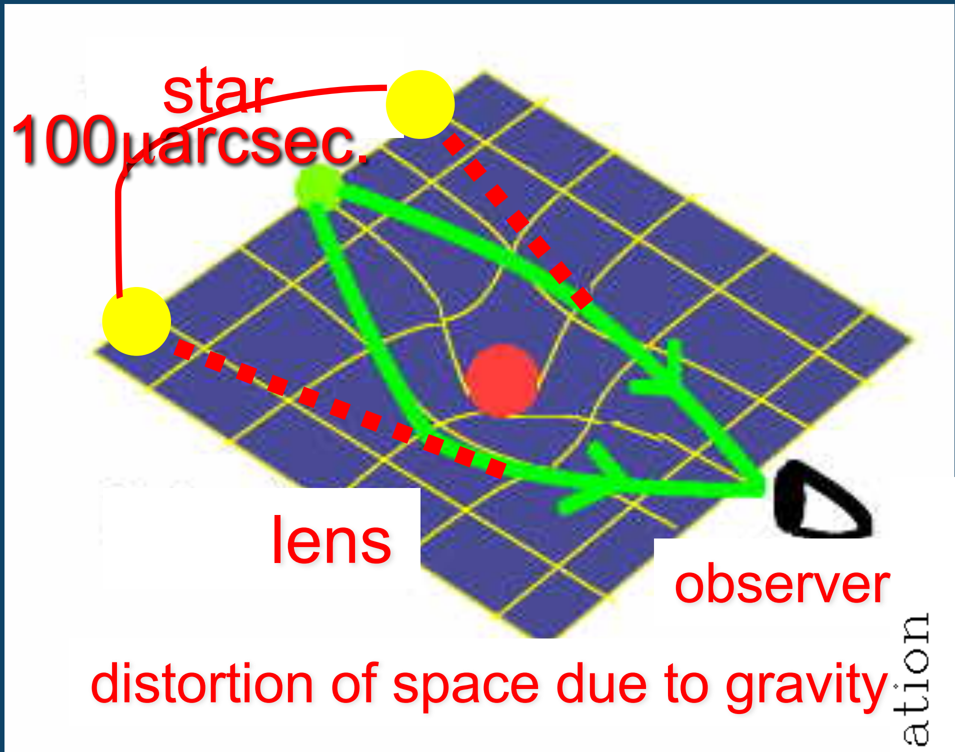
1. Microlensing Exoplanets (～50%)
   - Study low-mass planets outside of snowline
   - Plant frequency in the Galaxy Center
   - WFIRST microlensing survey field optimization
   - Concurrent observations with WFIRST
2. Other sciences (～50%)
   - IR RV survey
   - IR transit
   - Transient GW, GRB, SNe etc.

PRIME collaboration

- **Osaka Univ.:** T Sumi (PI), H. Shibai, T. Matsuo, Naoki Koshimoto Yuki Hirao , M. Nagakane
- **ABC (Astro-Biology Center):** M. Tamura (Director. & U Tokyo)
- **JAXA:** D. Suzuki
- **NASA GSFC:** D. Bennett, R. K. Barry , Alexander Kutyrev,
- **U of Maryland:** Sylvain Veilleux, Drake Deming
- **SAAO:** David Buckley, Ted Williams +

Bond(Massey U), N. Rattenbury (U Auckland), J-P. Beaulieu (IAP), A. Fukui (NAOJ), T. Nagayama (Kagoshima U), N. Matsunaga, Norio Narita (U Tokyo), Yasushi Muraki, Fumio Abe (Nagoya U), Mikio Kurita (Kyoto U), Joachim Wambsganss, Luigi Mancini (U Heidelberg), Eamonn Kerins (U Manchester), David Charbonneau（Harvard、Mearth PI、TESS CoI）、Cullen Blake (Pennsylvania、TESS CoI)

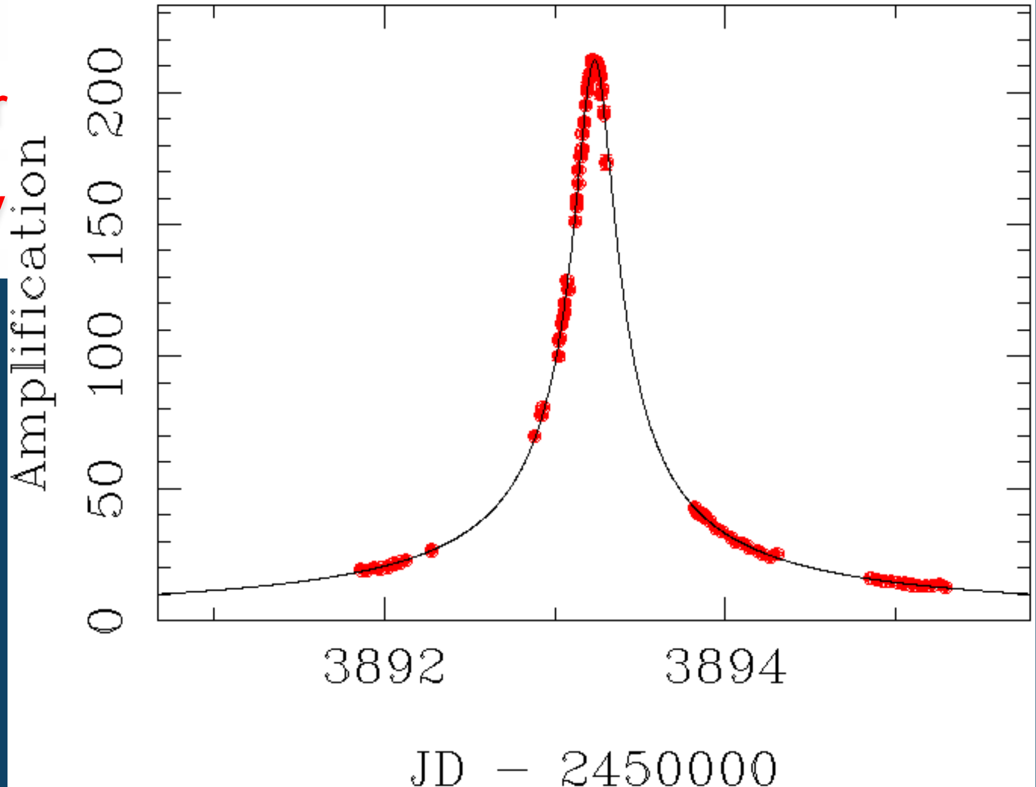
Gravitational Microlensing



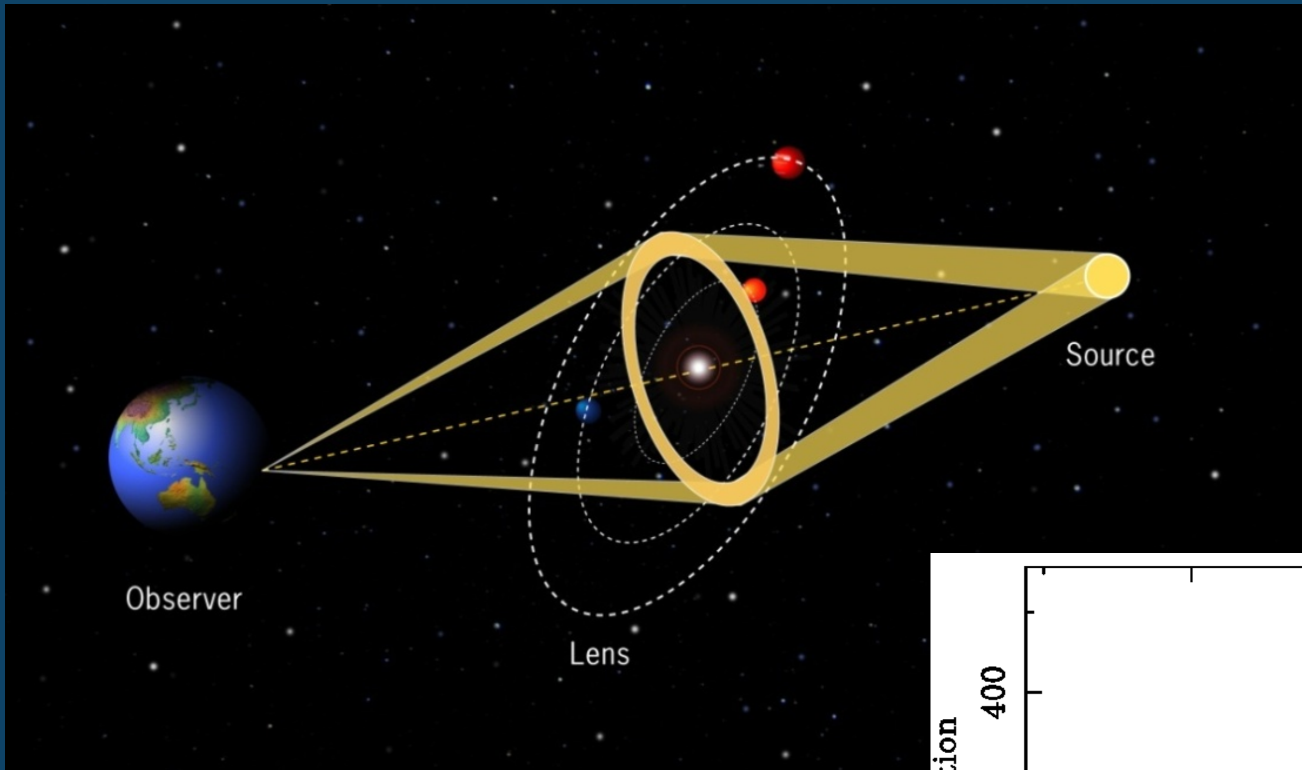
Science, 1936

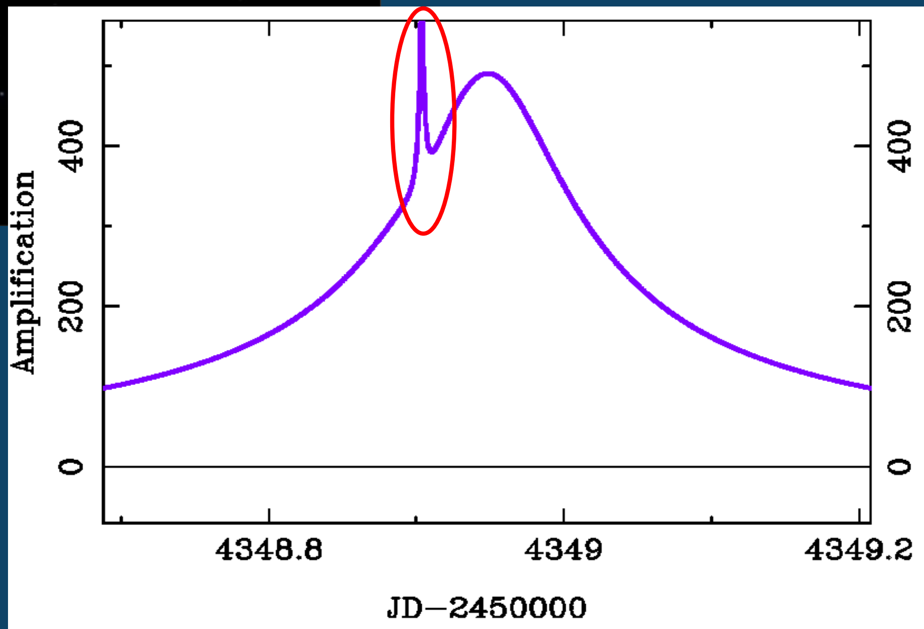
✧If a lens is a star, elongation of images is an order of 100μarcsec.

✧Just see a star magnified



planetary microlensing

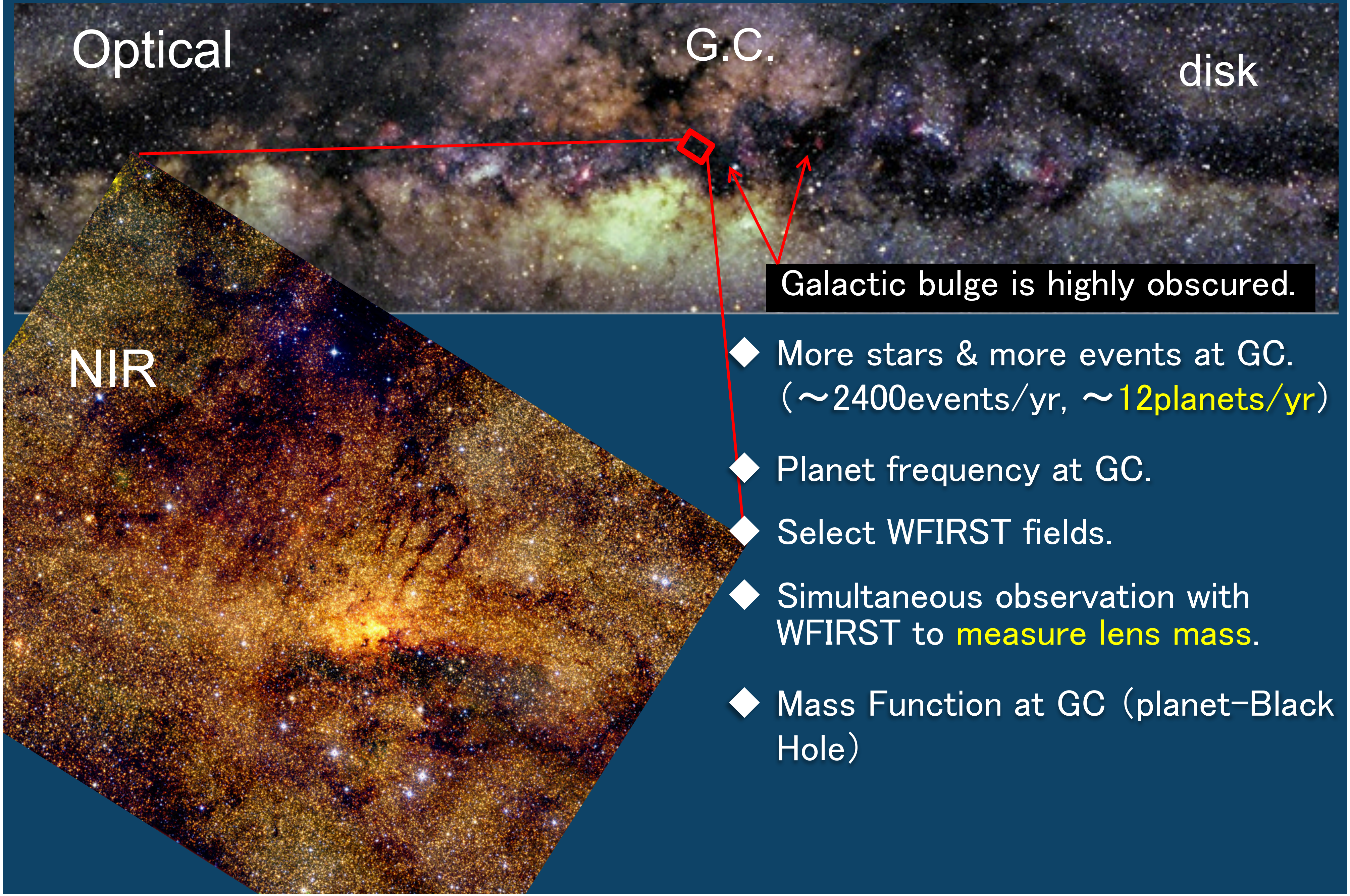




Time scale: $t_p \sim M^{1/2} \sim 1\text{day}(M_J)$
$\sim$a few hours (M_E)

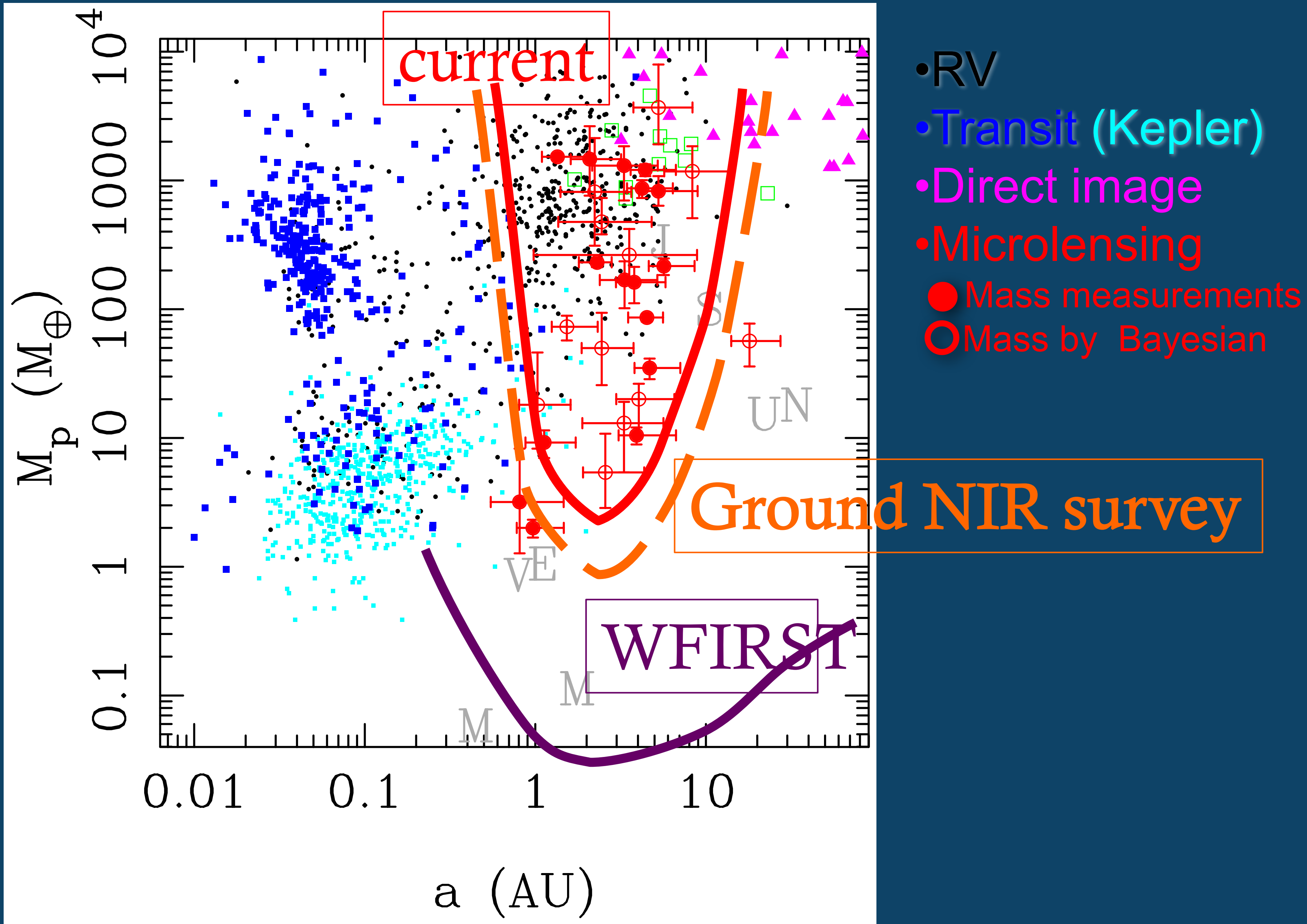
Sensitive to Cold planets outside of snowline ($\sim 3a_{snow}$)

More events & planets in NIR at G.C.



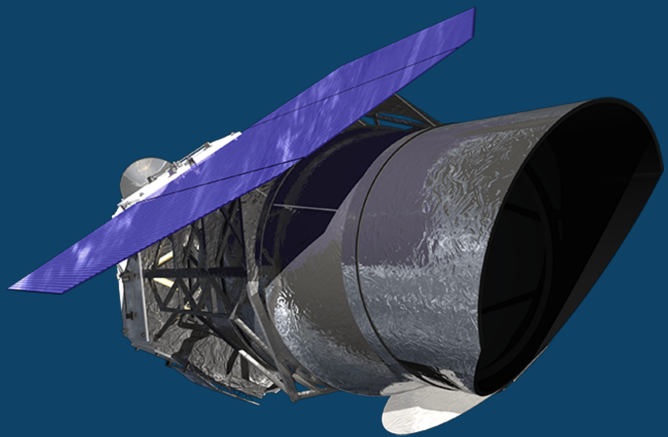
- More stars & more events at GC. (～2400events/yr, ～12planets/yr)
- Planet frequency at GC.
- Select WFIRST fields.
- Simultaneous observation with WFIRST to measure lens mass.
- Mass Function at GC (planet-Black Hole)

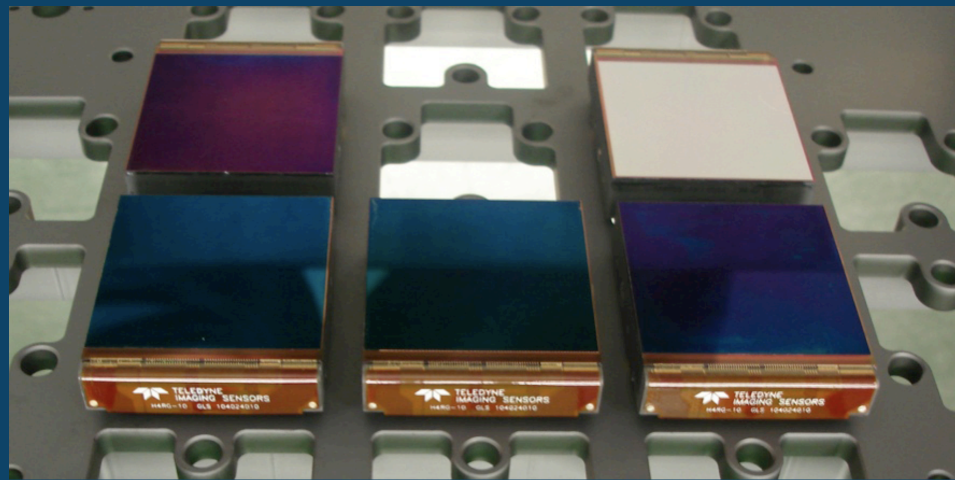
Discovered exoplanets and sensitivity



The World Widest FOV in NIR with World Largest class NIR camera

Loan Four Teledyne HgCdTe 4kx4k H4RG-10 (10μm pitch) from WFIRST team (NASA)





Four H4RG-10 which WFIRST Team owns. (1 chip is dummy)

Diameter:1.8m, f/2.29,

FOV:1.25° x1.25° =1.56deg^2

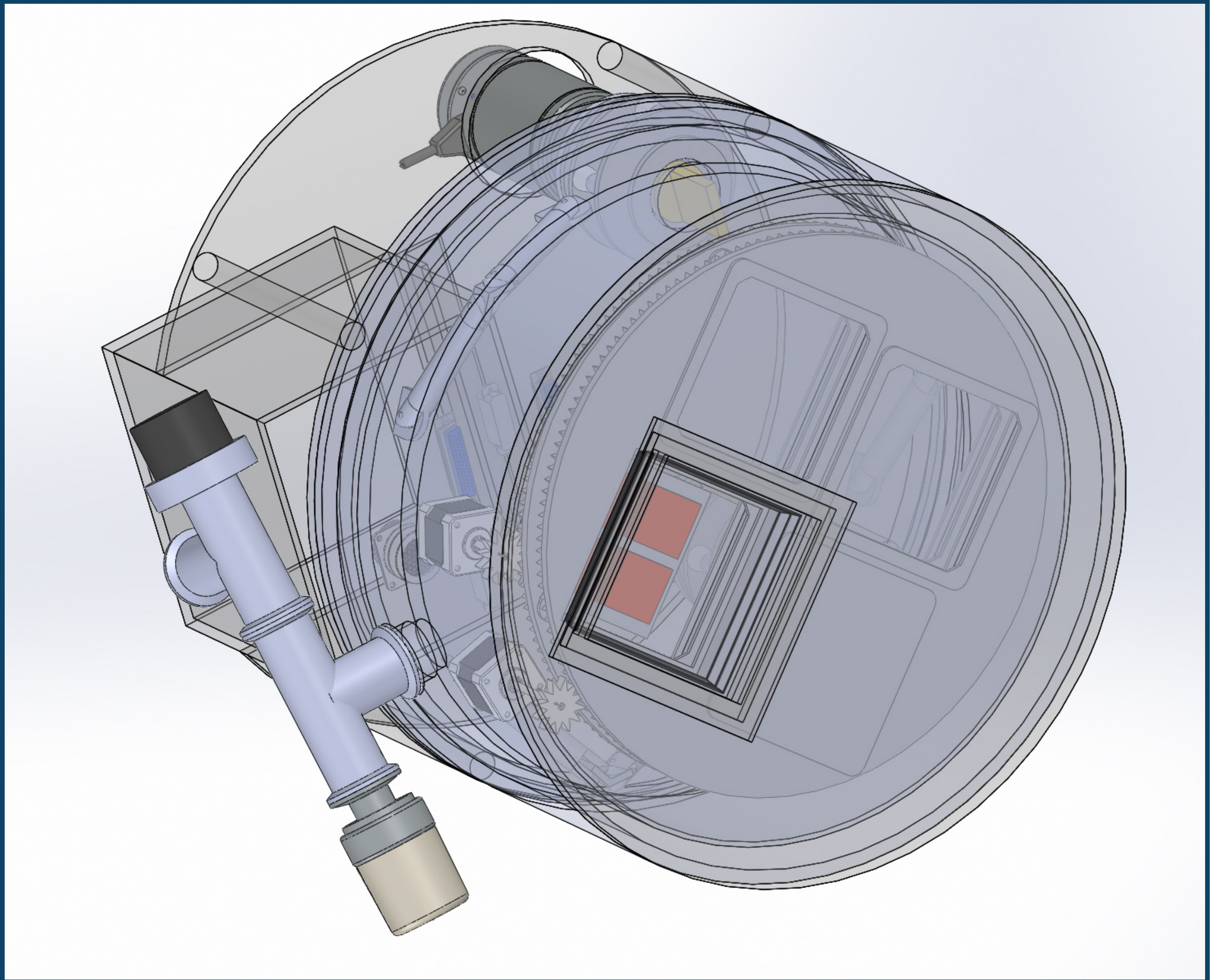
0.5arcsec/pix

Will be Manufactured by University of Meryland @GSFC

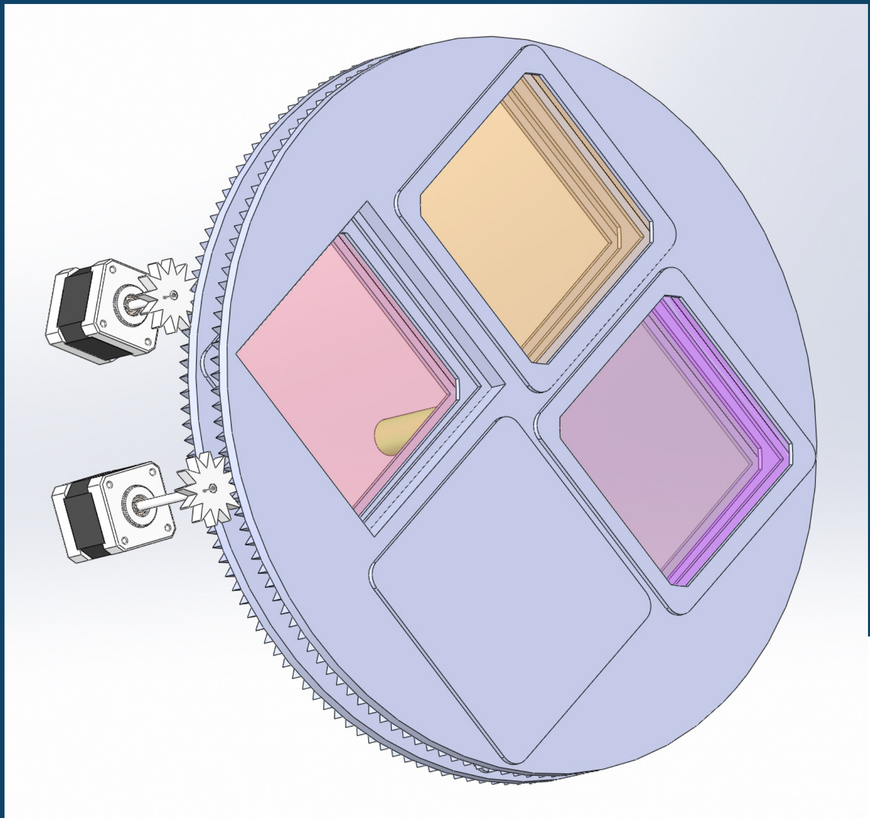
Camera

Alexander Kutyrev（NASA/GSFC,UMD）
Yuki Hirao （Osaka U./GSFC：D2） manufactur@GSFC

- 4 H4RG-10
- 2GTcryocooler
- 2 filter wheels

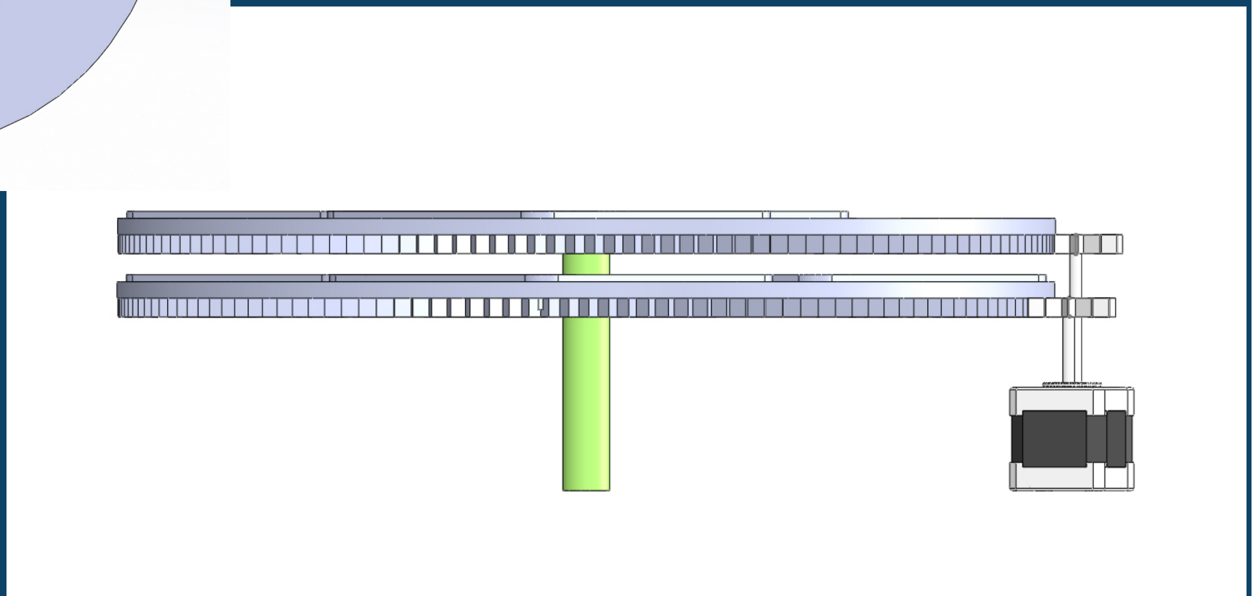


Filter wheels

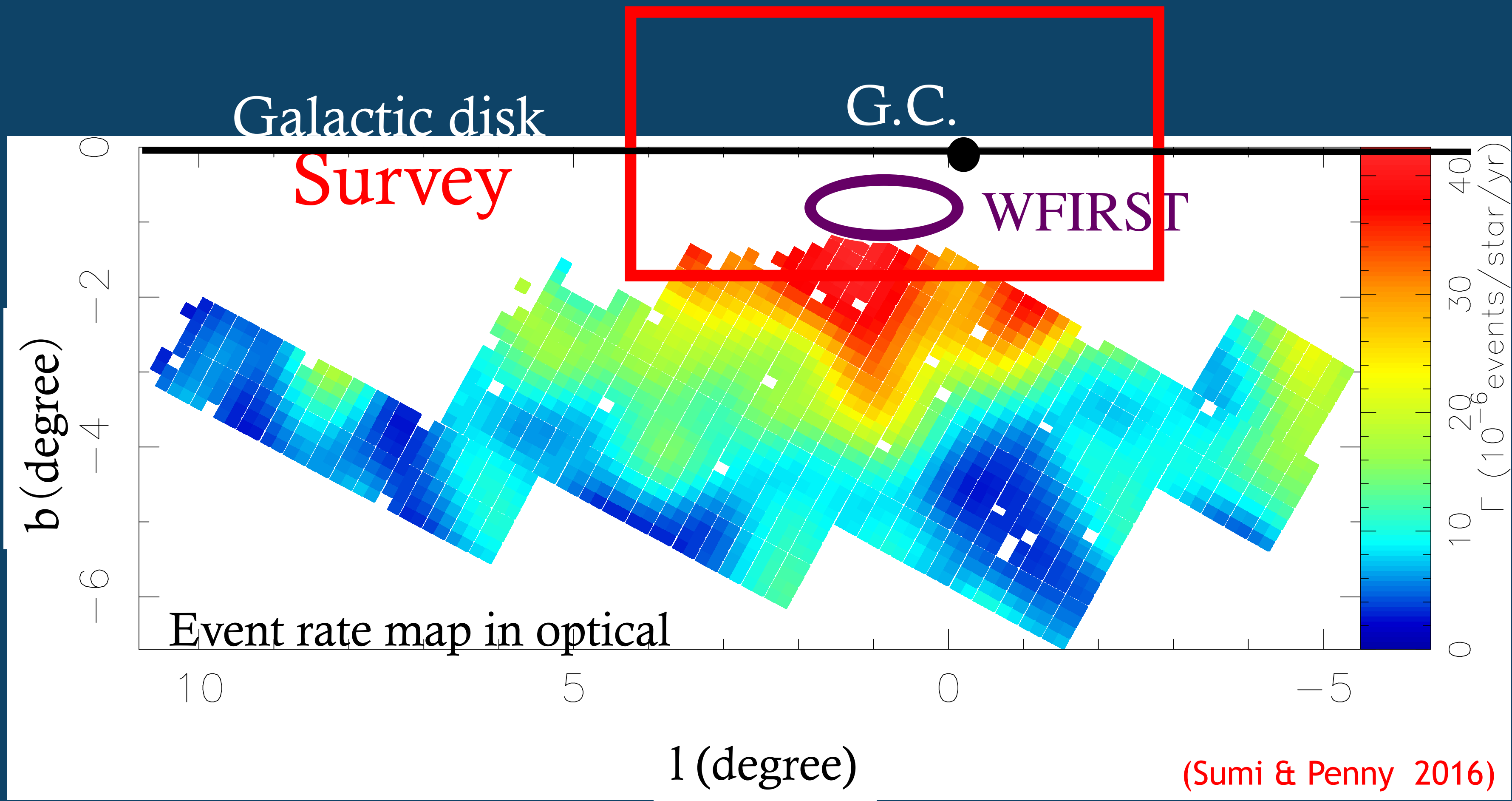


Filter size： 112mm x 112mm

5 filters: z, Y, J, H (Primary),
+Narrow band ([FeII]、Paβ、
HeI etc)

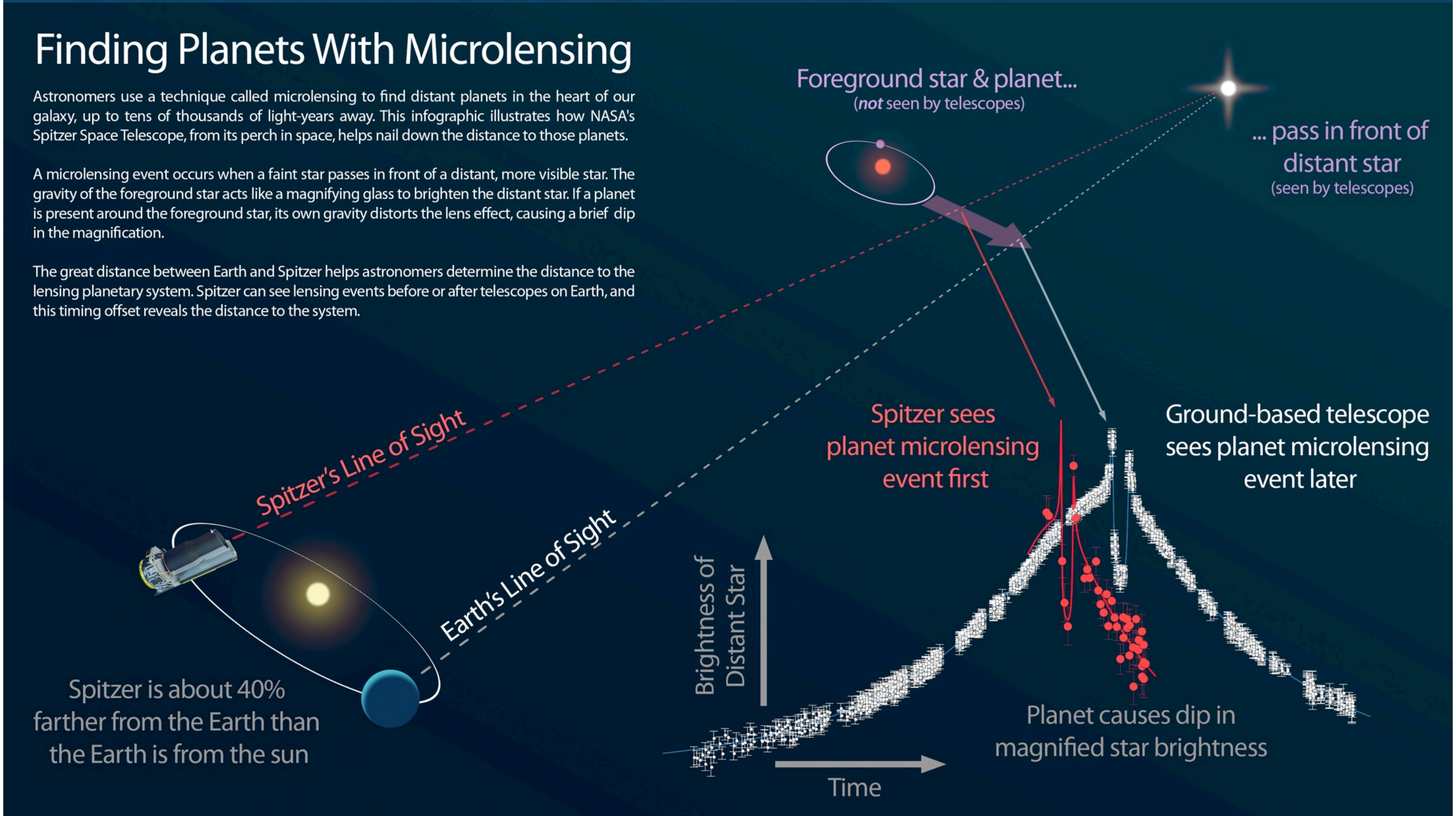


Study the galactic structure & Optimize WFIRST microlensing survey fields by mapping the event rate in NIR



Event rate vary by a factor of 2（peak is at l=1°）

Mass Measurements via Simultaneous WFIRST-Ground obs.



Off-bulge season sciences

- **Transit search for M-dwarfs:**
- Search for habitable planets around M-dwarf which is bright in IR
- Follow-up transit candidates by HAT-South, Mearth projects for select real planets and measure the atmosphere.
- Systematics due to Sunspot and limb darkening is smaller in IR.
- Wide FOV enable us to observe many reference stars for high precision photometry.
- Follow-up TESS candidates. TESS is optical. Need IR for M-dwarfs. Collaborators:

  David Charbonneau（Harvard、Mearth PI、TESS CoI）、
  Cullen Blake (Pennsylvania、TESS CoI)、
  Narita（NAOJ, TESS CoI）、Fukui（Okayama）

- Search for counterparts of high-z GRB, GW etc.
  → ToO observation
- H-band spectrograph: RV for giant planets around M-dwarf.

Schedule

2016 detail design

2017 manufacture

2018 manufacture, construction

2019 install, first light.

2020 observation start

～

2023 create event rate map in the bulge

2025 WFIRST launch,

Concurrent observation start

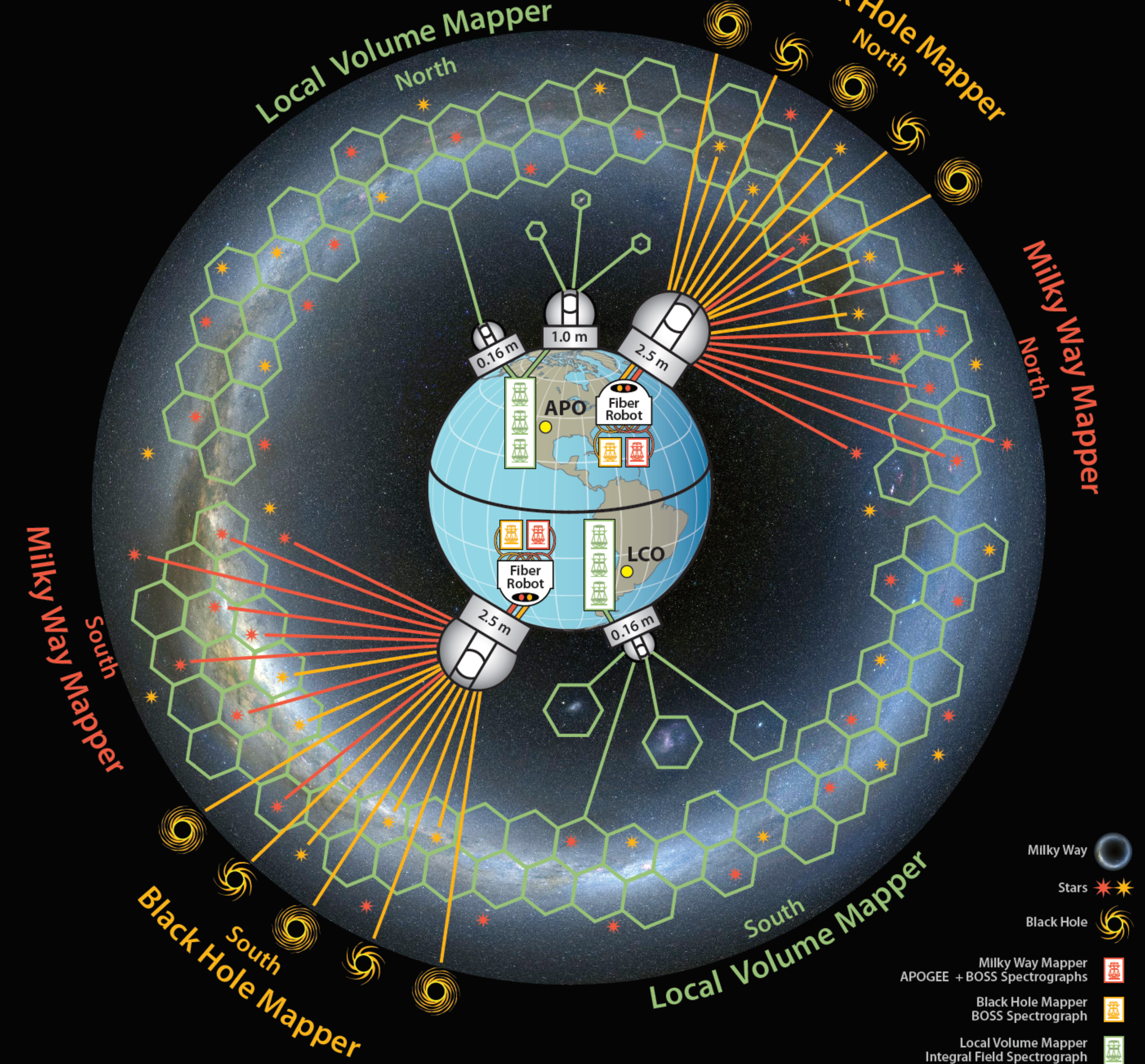
2030 continue to the end of the WFIRST

Summary

- PRIME is first NIR microlensing exoplanet survey
- Detect ～2400 events/yr & ～12 planets/yr down to Earth-mass planet outside of the snowline
- Galactic distribution of exoplanets
- Optimize WFIRST fields
- Simultaneous observation with WFIRST to measure lens mass.
- Mass Function at GC (planet-Black Hole mass)
- Other sciences w/ bulge data
- H-band spectrograph: RV for giant planets around M-dwarf

SDSS-V UPDATE

SDSS-V


Local Volume Mapper
North
Black Hole Mapper
North
Milky Way Mapper
North
1.0 m
0.16 m
2.5 m
APO
Fiber
Robot
LCO
Fiber
Robot
2.5 m
0.16 m
Milky Way Mapper
South
Black Hole Mapper
South
Local Volume Mapper
South
Milky Way
Stars
Black Hole
Milky Way Mapper
APOGEE + BOSS Spectrographs
Black Hole Mapper
BOSS Spectrograph
Local Volume Mapper
Integral Field Spectrograph

SDSS-V's 3 "Mappers"

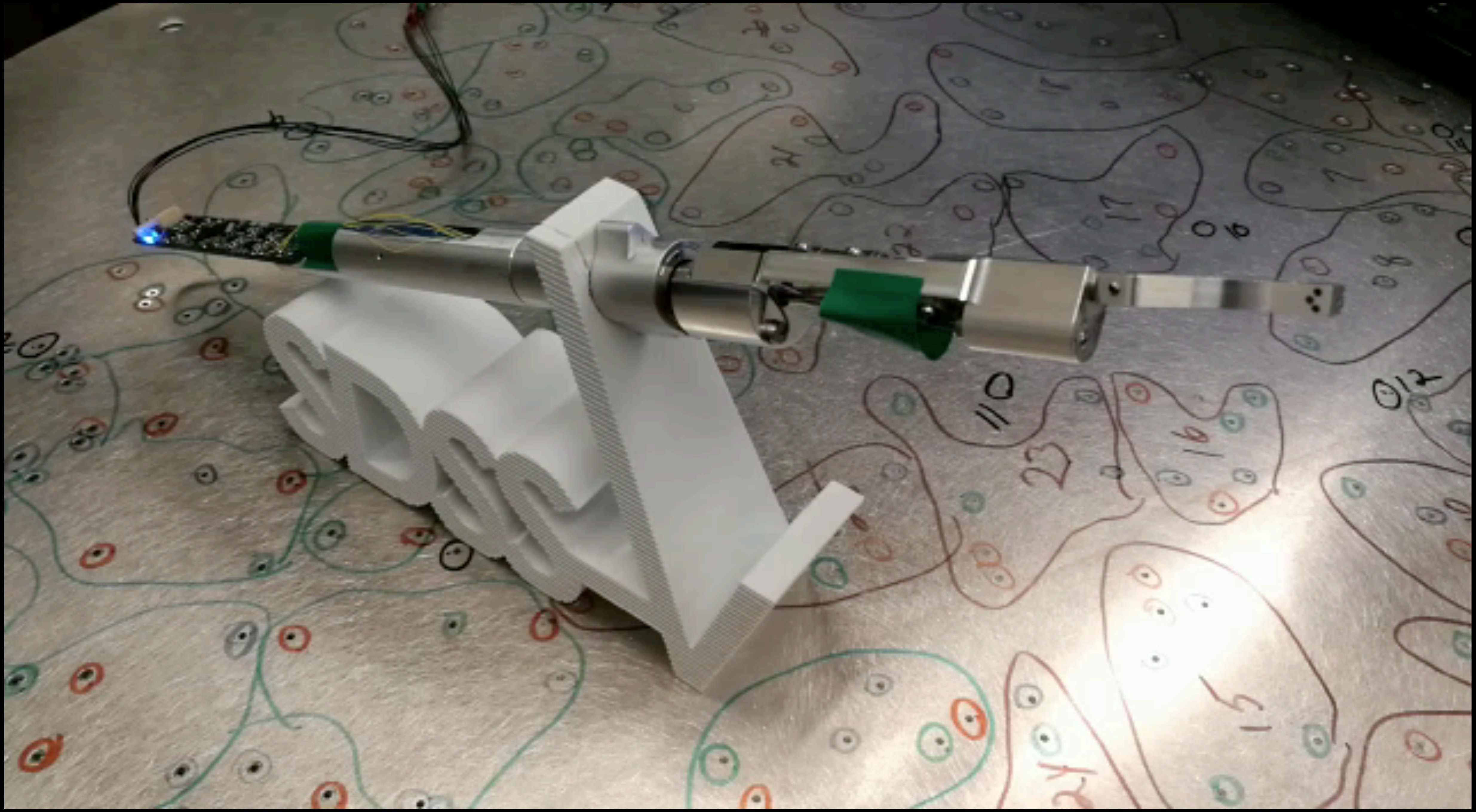
Program	Science Targets	$N_{Objects}$ and/or Sky Area	Primary Spectral Range and Hardware	Primary Science Goals
Milky Way Mapper (MWM)	Stars across the Milky Way	>6M stars; all-sky	IR; APOGEE ($R \sim 22,000$) with fiber-positioning system	Understanding the formation of the Milky Way and the physics of its stars
Black Hole Mapper (BHM)	Primarily supermassive black holes	>400,000 sources; all-sky	Optical; e.g., BOSS ($R \sim 2000$) with fiber-positioning system	Probing black hole growth and mapping the X-ray sky
Local Volume Mapper (LVM)	ISM & stellar populations in the MW, Local Group, and nearby galaxies	>25M contiguous spectra over 3,000 deg^2	Optical; new integral field spectrographs covering 3600-10000Å at $R \sim 4000$	Exploring galaxy formation and regulation by star formation; feedback, enrichment, & ISM physics

Spectroscopic Surveys

Spectroscopic Survey Facilities around the Year 2020								
Survey (facility)	N_{target}	R_{spec}	N_{res}	$\overline{\lambda}[\mu m]$	Ω_{sky}	N_{epoch}	Timeframe	$m_{primary}$
SDSS-V	7×10^6	22,000 2,000	500	1.51-1.7 0.37-1	4π	$4-60$	2020-2024	$m_H \leq 12$ $m_G \leq 18$
Gaia (RVS)	2×10^6	8000	270	0.85-0.87	4π	~ 60	2013-2020	$m_G \leq 12$
Gaia-ESO	0.1×10^6	$17,000$	140	0.55& 0.85	0.02π	~ 1	2013-2018	$m_G \leq 17$
GALAH	0.8×10^6	$28,000$	400	0.40- 0.85	π $\|b\| \geq 10$	~ 1	2015-2020	$m_G \leq 13$
WEAVE	0.8×10^6	$5,000$& $20,000$	1000	0.37-0.9	$\sim \pi$	$\sim 1-2$	2018-2023	$m_G \leq 19$
DESI	8×10^6	$3,000$	5000	0.36-0.98	$\sim \pi$ $\|b\| \geq 25$	$\sim 1-2$	2019-2024	$m_G \leq 19$
LAMOST	8×10^6	$1,800$	4000	0.4-0.9	0.5π	~ 1	2010-2020	$m_G \leq 16$
4MOST	10×10^6	$5,000$& $20,000$	1600& 800	0.4-0.9	1.5π	$1-2$	2023-2028	$m_g \leq 21$ $m_V \leq 16$
APOGEE-1& -2	5×10^5	22,000	300	1.51-1.7	0.5π	~ 4	2011-2019	$m_H \leq 12$
PFS	1×10^6	$3,000$	2400	0.4-1.6	0.05π	1	2018-2021	$m_g \leq 22$
MOONS	2×10^6	$5,000$& $20,000$	1000	0.6-1.8	0.05π	1	2020-2025	$m_g \leq 22$ $m_H \leq 17$

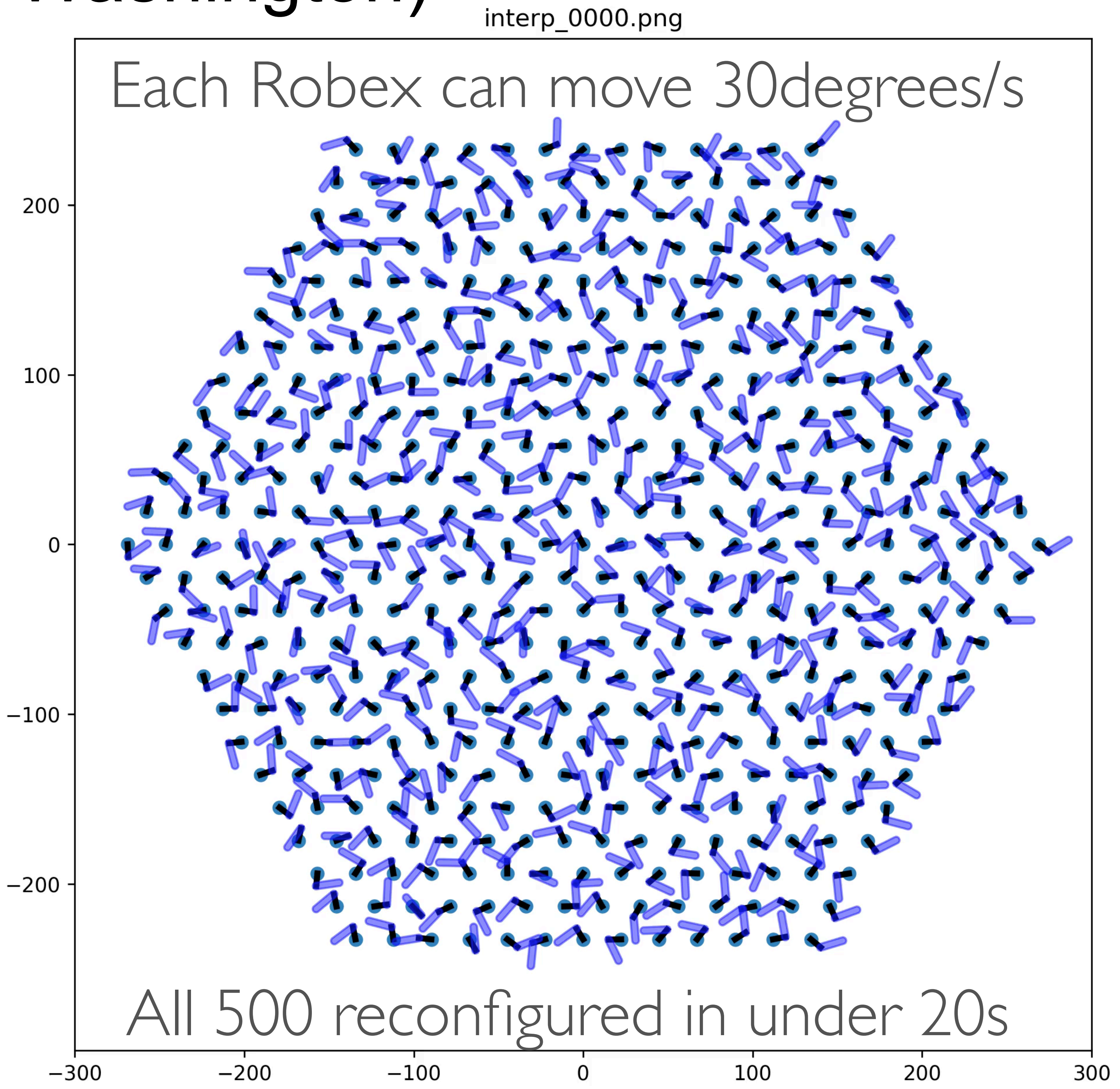
O + IR ; ALL SKY ; TIME DOMAIN!

SDSS-V PROTOTYPE0!

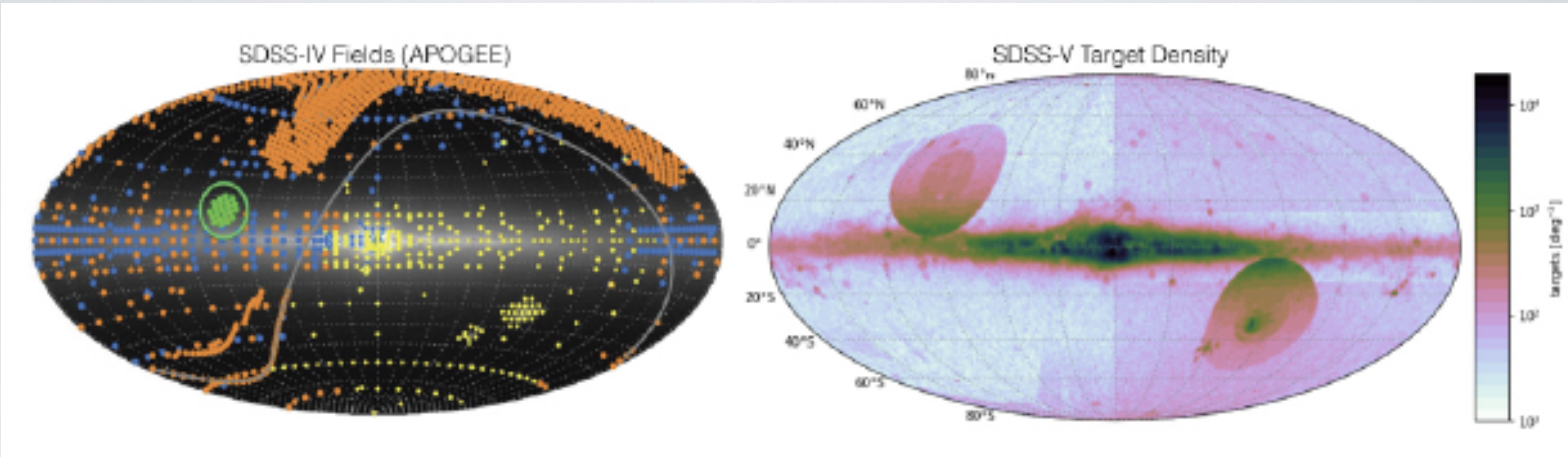


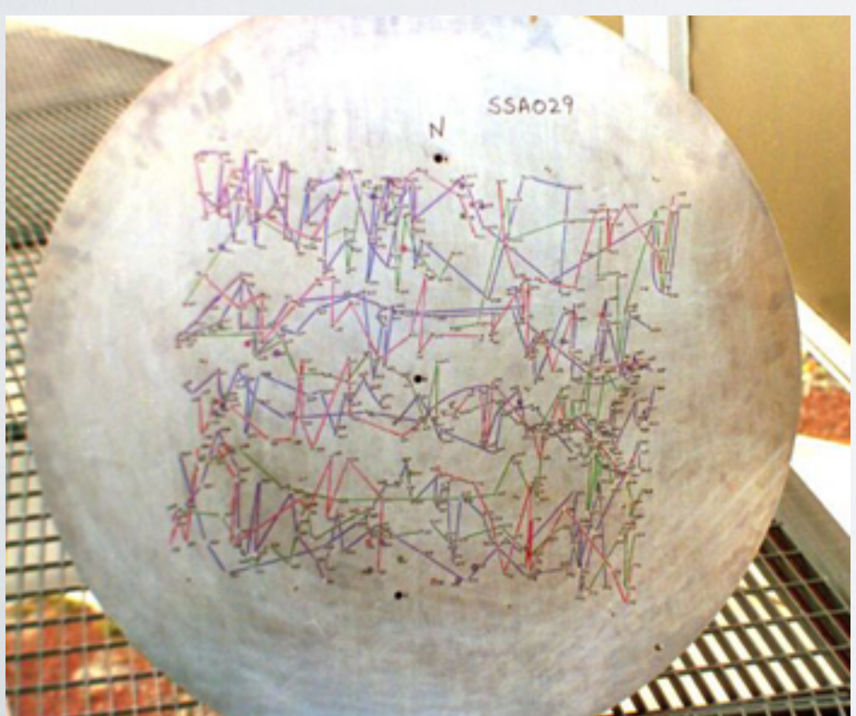
Courtesy J-P Kneib & EPFL Team

Kaiju: A Highly Efficient Collision Avoidance Algorithm for SDSS-V Robotic Fiber Positioners — Conor Sayres (U. Washington)

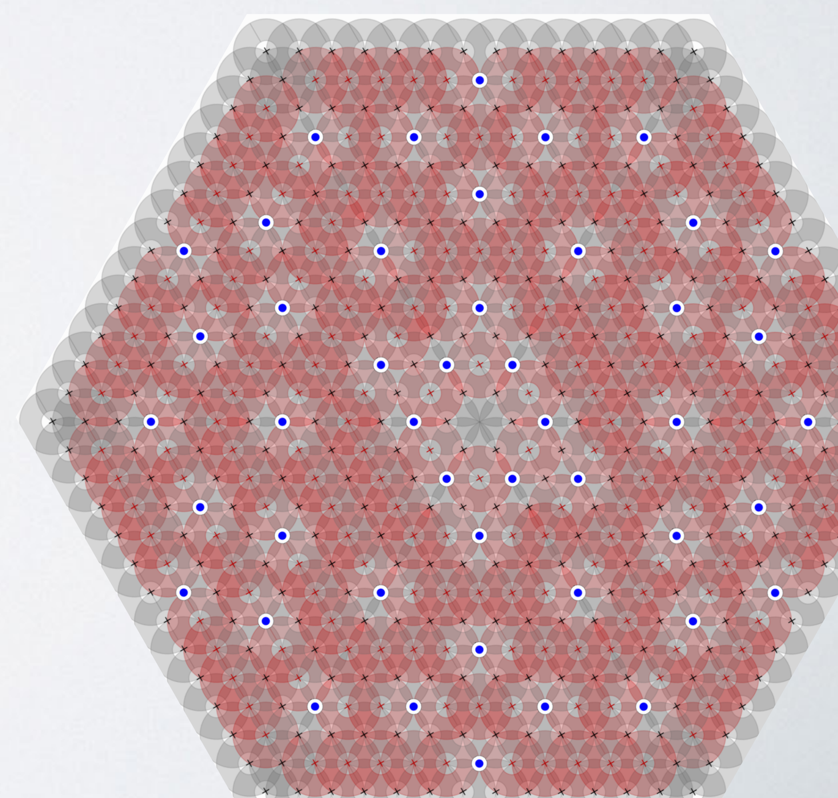


PLATES —> ROBOTS

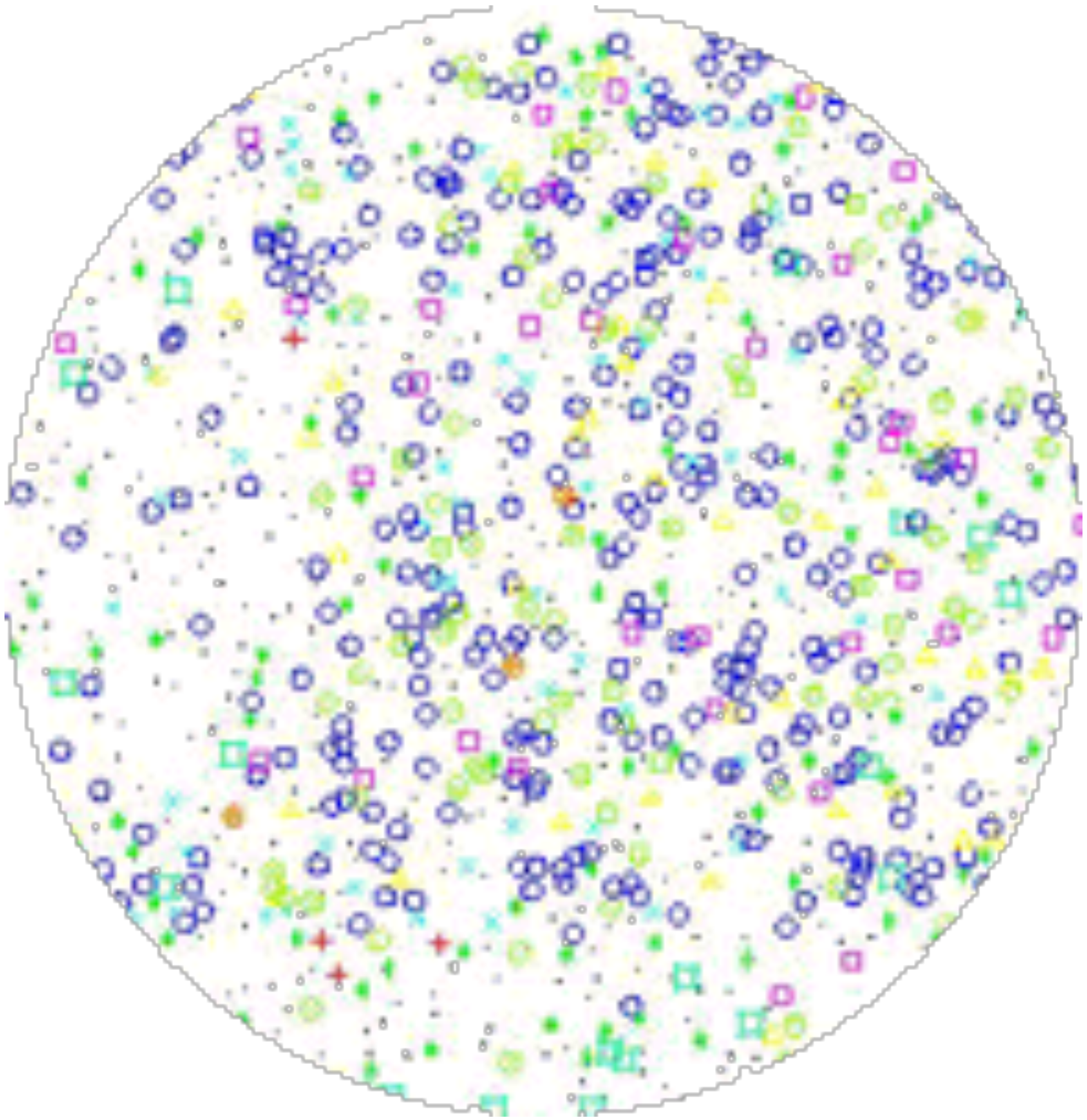


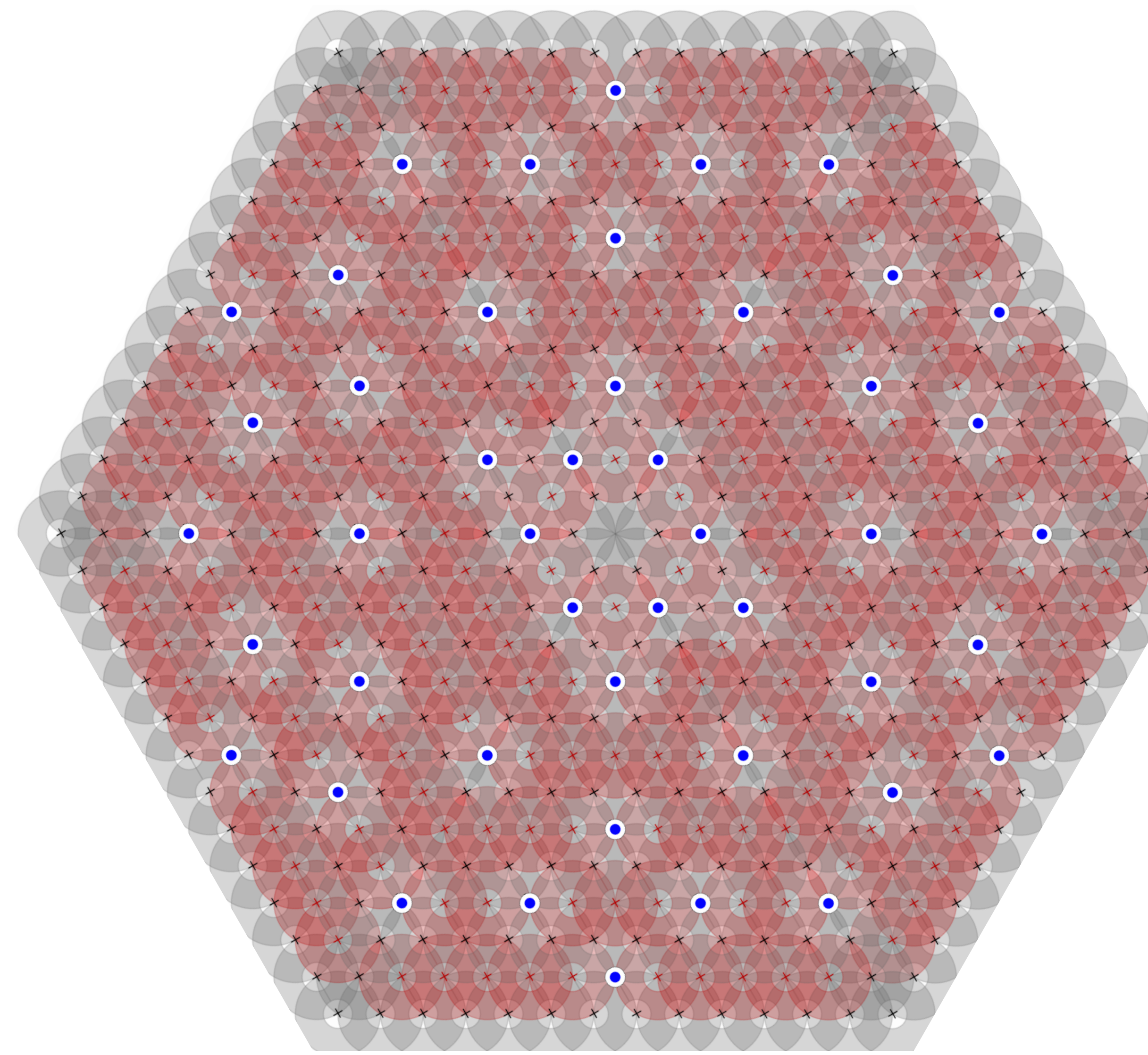


ALL Sky
Dust-Penetrating
Multi-epoch (1-60)
High-quality
spectroscopy



ROBOTIC FIBER POSITIONERS TO FEED SPECTROGRAPHS





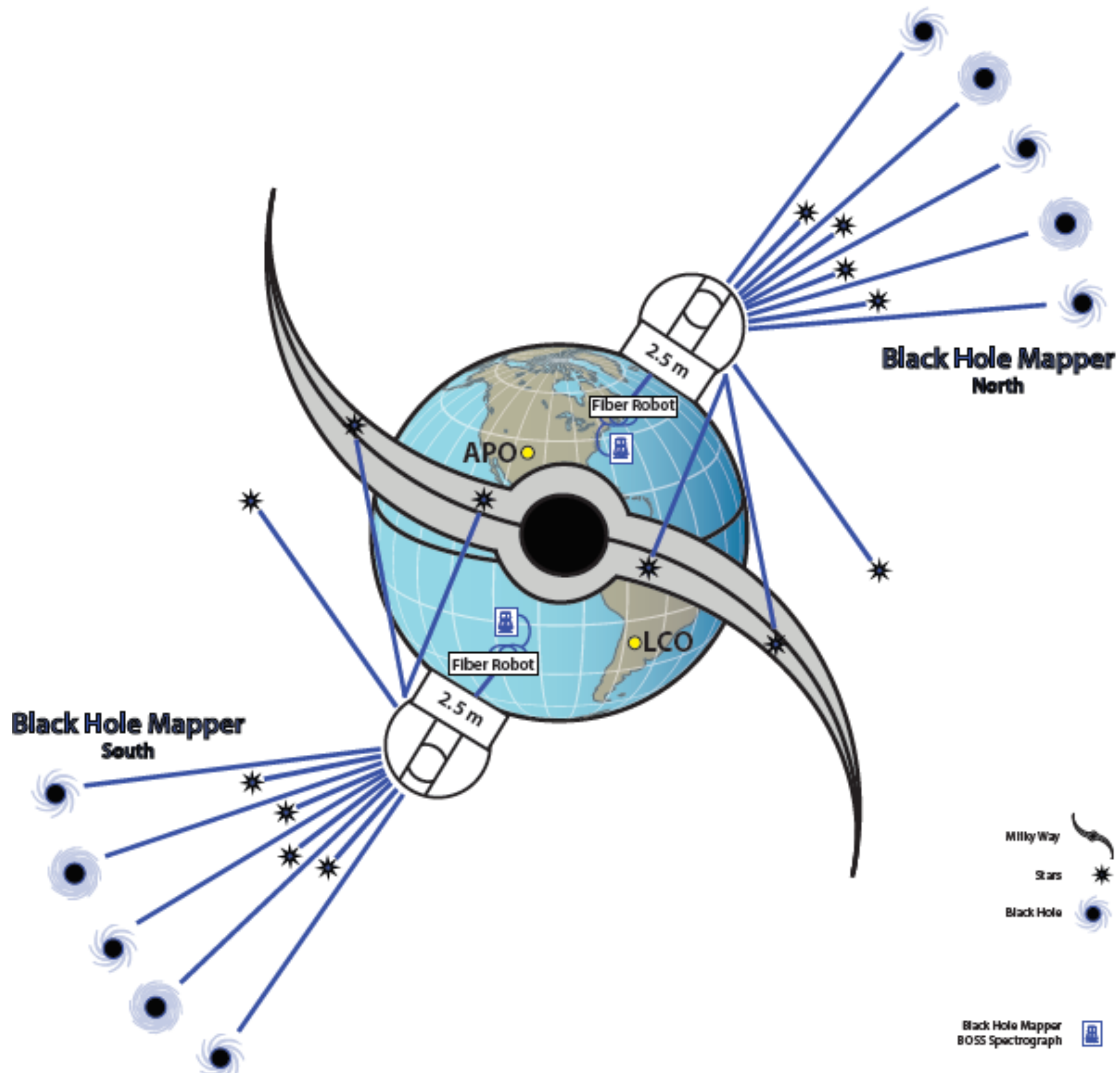
SDSS-V PROTOTYPE1!

- New prototypes tested in December/ January
- Fiber Positioning System successful PDR in November 2018
- Call of Tender for the robots has gone out (today!)

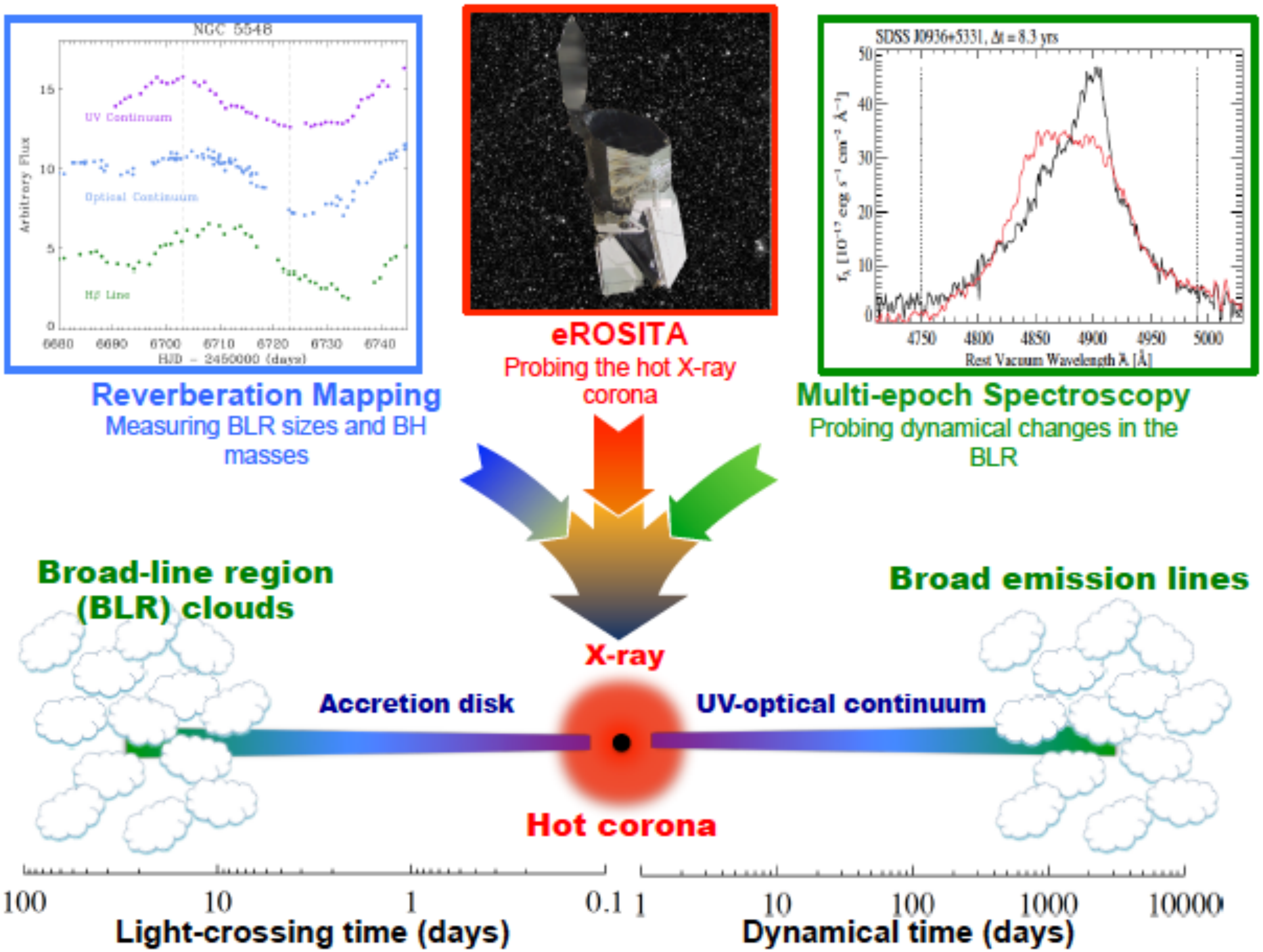
Final design review at the end of Q2!

Ready for "Robot Ridge" in mid-2020 will commission as soon as SDSS-IV completes

BLACK HOLE MAPPER: BHM



BLACK HOLE MAPPER:
UNDERSTANDING BLACK HOLE GROWTH

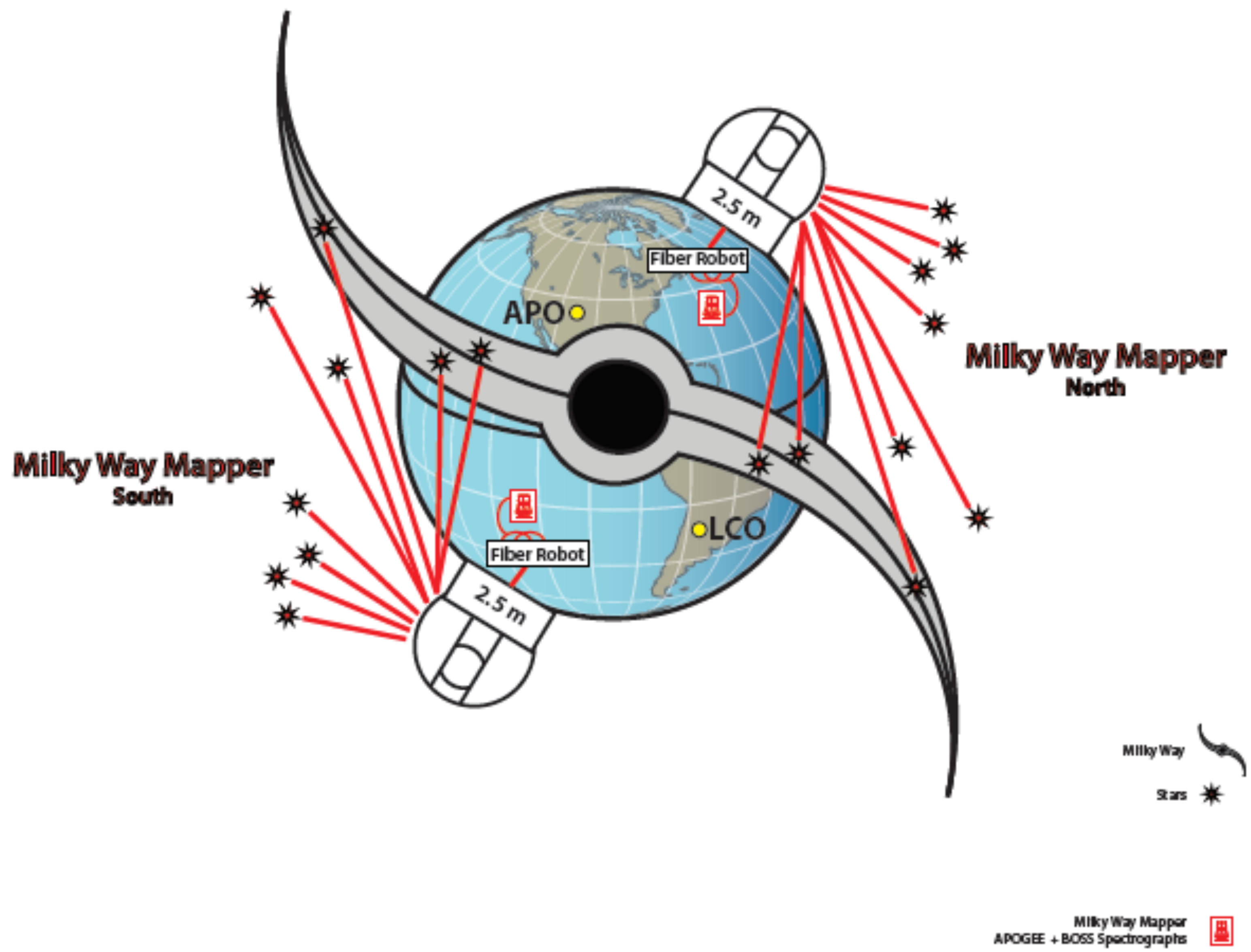


BHM Time-Domain Survey Outline

Spectral time-domain astrophysics of quasars: BH masses, binarity, accretion and events, BLR dynamics, outflows, etc. Broad range of time-sampling/cadence, days to decades.

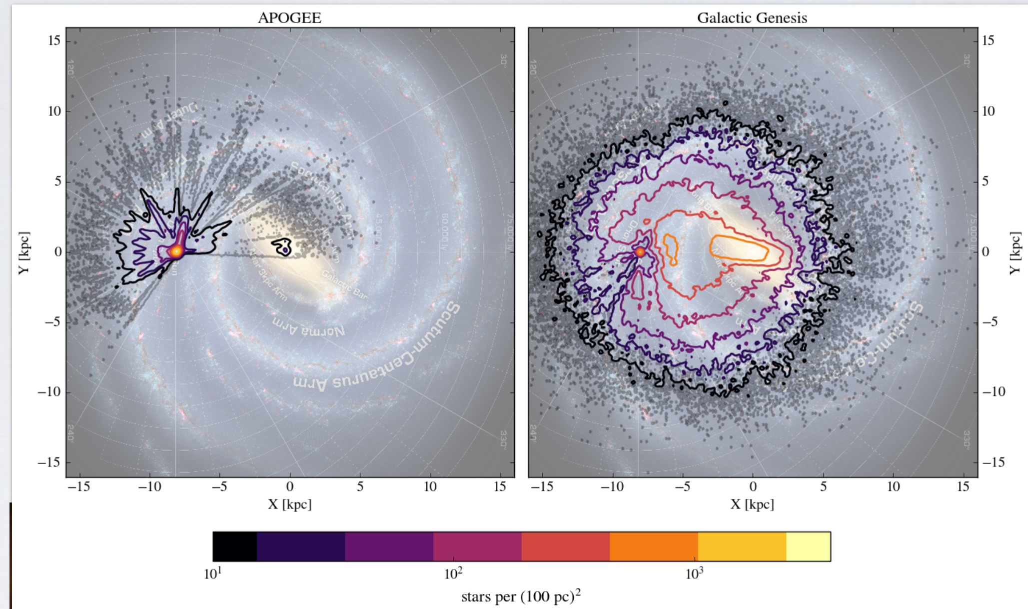
- For >20,000 quasars, 2-3 epochs during AS4 plus earlier-epoch SDSS spectra, sampling ~1-10 year timescales, e.g., transition times of changing look quasars, BAL disappearance and emergence, etc. *(wide/ low-cadence tier; ~3000 deg^2).*
- For >2000 quasars, 12 epochs during ~2 years of AS4, probing down to ~1-month to 1-year timescales, adding unfolding BLR structural and dynamical changes *(medium tier; ~300 deg^2)*.
- Reverberation mapping (RM) for ~1000 quasars in 5 fields, >10^2 epochs, sampling down to days to weeks; lags between continuum and BLR emission yield BH masses; premier RM sample at high L, z. (high-cadence tier; ~30 deg^2)

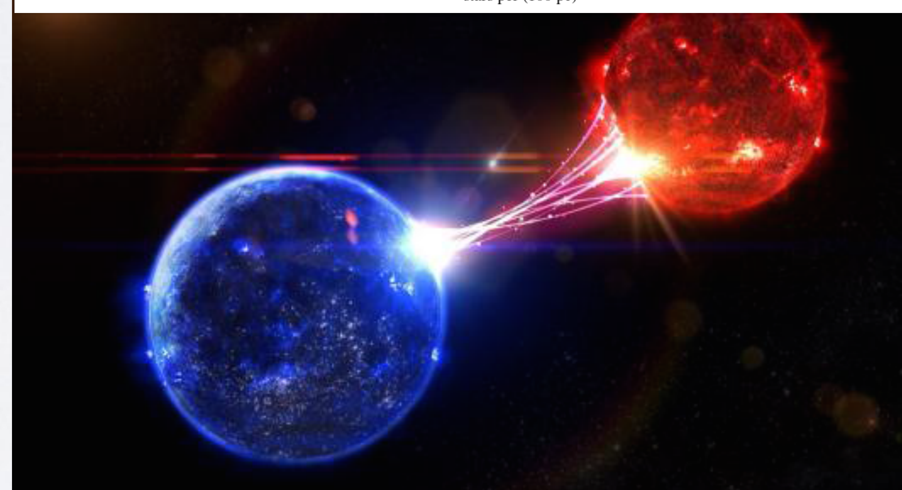
Milky Way Mapper: MWM

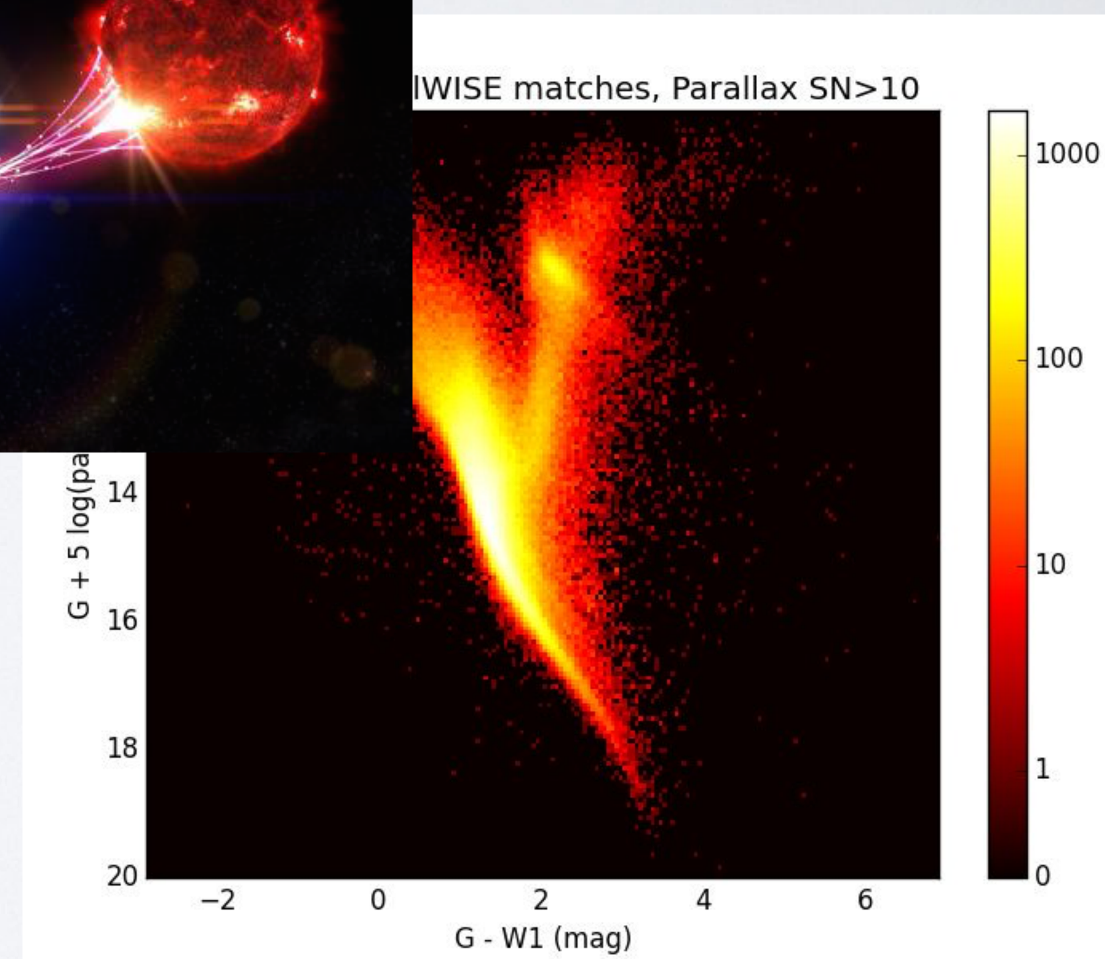


SCIENCE GOALS (GENERAL)

- **1) How did the Milky Way's disk form?**
- **2) How do stars live, evolve, and die (and affect transient/GW universe)?**
- **3) What stars host planets?**
- **4) What IS the stellar multiplicity across the HR diagram? Role of binaries in Stellar Evolution**
- **5) Origin of Supernovae and the heavy elements**



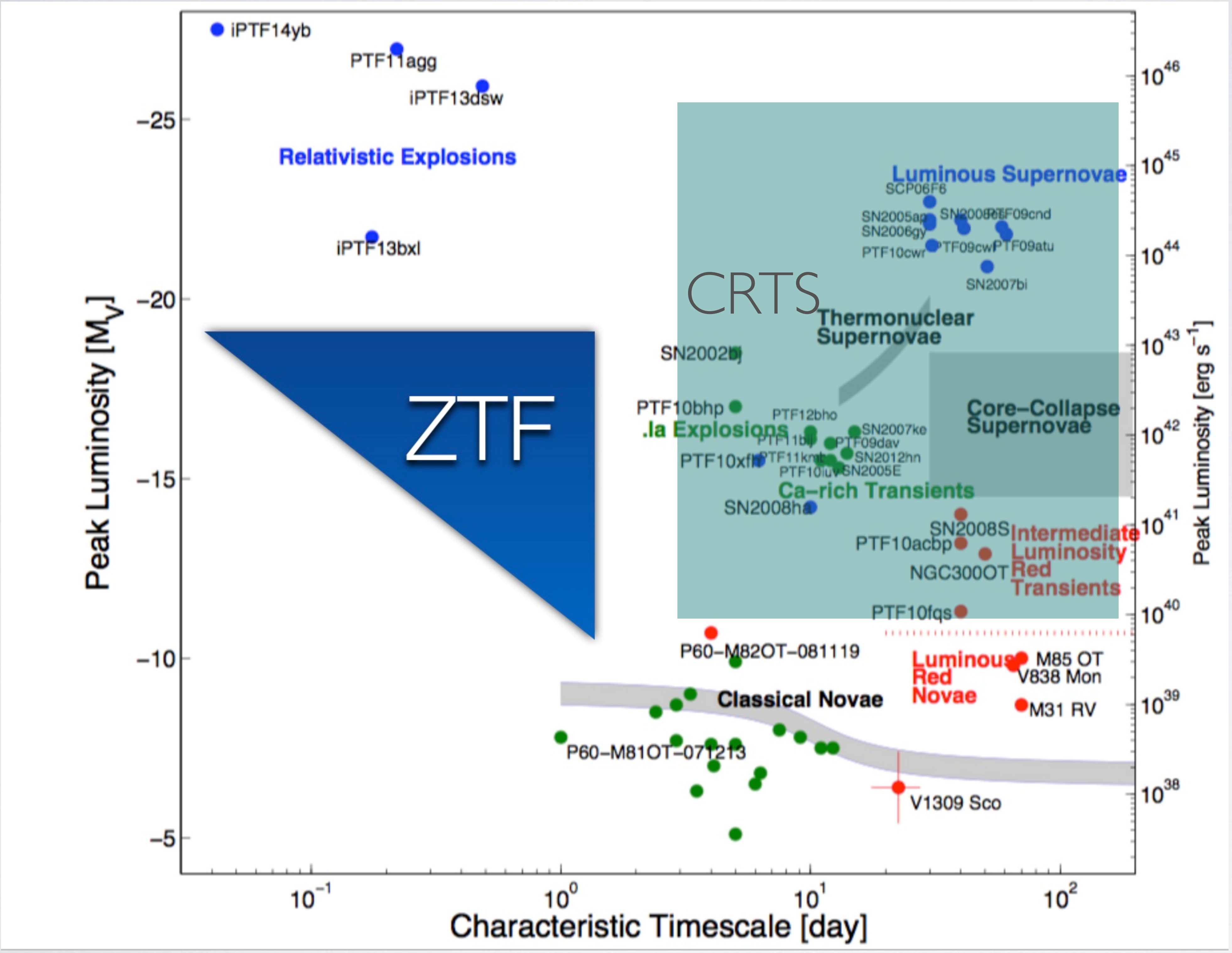




From D. Lang

Galactic Genesis & Stellar Astrophysics Targeting Classes				
Instrument	**Selection**	**$N_{Targets}$**	**N_{Epochs}**	**Comments**
Galactic Genesis Survey: mapping the dusty disk				
APOGEE APOGEE	H<11, $G-H>3.5$ $\|z\| < 200$ pc, H<11, d<5 kpc	4,800,000 125,000	1 1	dust-extinguished disk to complete high-res ISM map
Binaries with Compact Objects: enumerating the populations of binaries with white dwarfs, neutron stars, or black holes, selected by variability				
BOSS BOSS	PTF, ZTF, *Gaia* variability *Gaia* parallaxes	30,000 30,000	3 1	binaries with WDs, NSs, and BHs wide WD+MS/RGB binaries
Solar Neighborhood Census: observing all stars within 100 pc, giving the best probe of low-mass stars, whether in single or binary systems				
APOGEE, BOSS	d<100 pc, $G < 20$, $H < 12$	400,000	2	1000× increase in volume & stars
White Dwarf Chronicle: using white dwarfs and their evolved companions to measure the SFH and age-metallicity relation				
BOSS	$G < 20$	300,000	3	15× increase in sample size
TESS Exoplanet Host Candidates: observing all TESS short-cadence targets in the CVZs				
APOGEE	$H \leq 13.3$	300,000	1–8	all short-cadence targets & planet hosts
Binaries Across the Galaxy: measuring environmental dependence of binary fraction in the disk, bulge, halo, and stellar clusters; probing the brown-dwarf desert beyond solar-type stars				
APOGEE	H<13.4, $N_{Epoch} \geq 6$ by the start of SDSS-V	60,000	6–18	gives orbits with 24–40 epochs for all targets with long APOGEE baselines
Gaia Astrometric Binaries: characterizing rare systems that have good astrometric orbits but limited other information, from *Gaia*'s sample of > 10 million stars				
APOGEE, BOSS	$d < 3$ kpc	200,000	1	rare types of systems
TESS Red Giant Variability: measuring spectroscopic properties for red giants in TESS that have seismic and/or granulation lightcurve signatures				
APOGEE	$H < 12.5$	250,000	1	stars with at least 80 days of TESS observation
Massive, Convective Core Stars: combining dynamic and asteroseismic measurements of binary OBAF stars in the TESS CVZs and characterizing their multiplicity				
APOGEE APOGEE	$H < 12$	200,000 500	2 25	detection of single vs. binary systems >10× increase in current sample size
Young Stellar Objects: quantifying the stellar populations in star-forming regions, including identifying sources of ionizing radiation and characterizing the binary frequency				
APOGEE APOGEE APOGEE APOGEE	$H < 12$, $d < 1$ kpc $H < 12$ $H < 12$, $\|b\| < 2°$ $H < 13$	20,000 3,500 10,000 10,000	12 8 2 2	nearby star-formation regions high-mass star-formation regions massive young stars in the Galactic Plane Central Molecular Zone

TRANSIENTS!



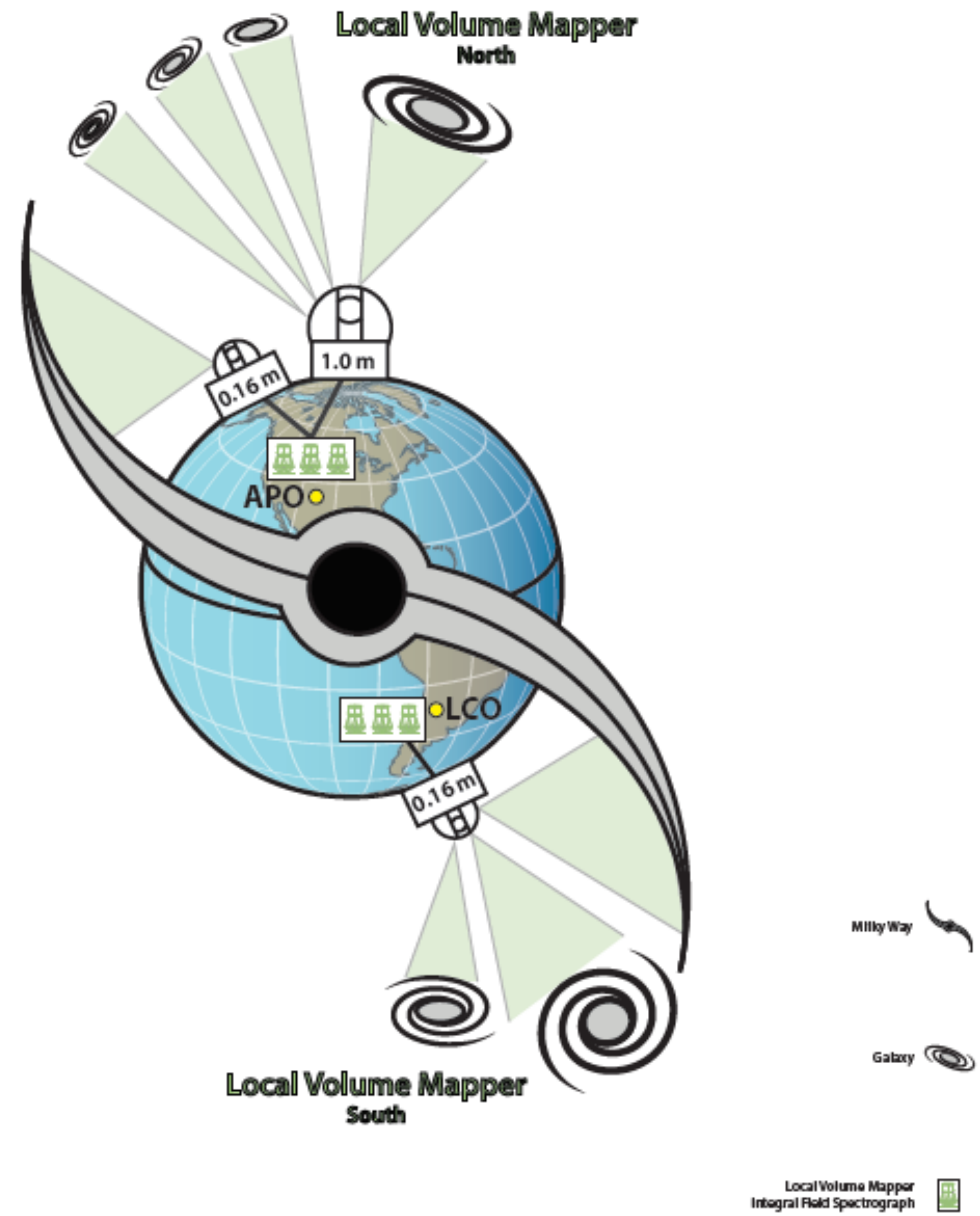
Wouldn't it be nice to settle BASIC questions like: What are Type 1a SNe (and what are they NOT)?

B. Penpraese

Local Volume Mapper: LVM

Using different telescope sizes of and an array of IFU-coupled spectrographs at R~4000 and 3600-10000Å, we survey

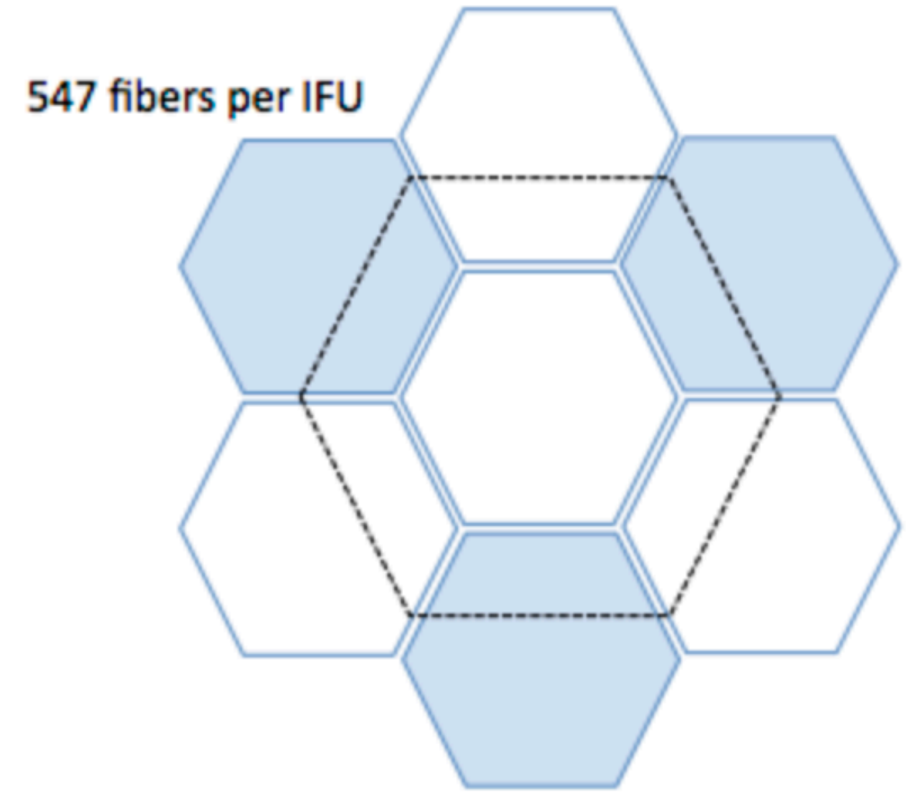
- 2800 sq. deg. in the MW @ 0.1-1 pc resolution,
- 300 sq. deg. in the MW 10x deeper,
- LMC & SMC @ 10 pc resolution,
- M31 & M33 @ 20 pc resolution, and
- 12 nearby galaxies (D≲5 Mpc) @ 50 pc resolution

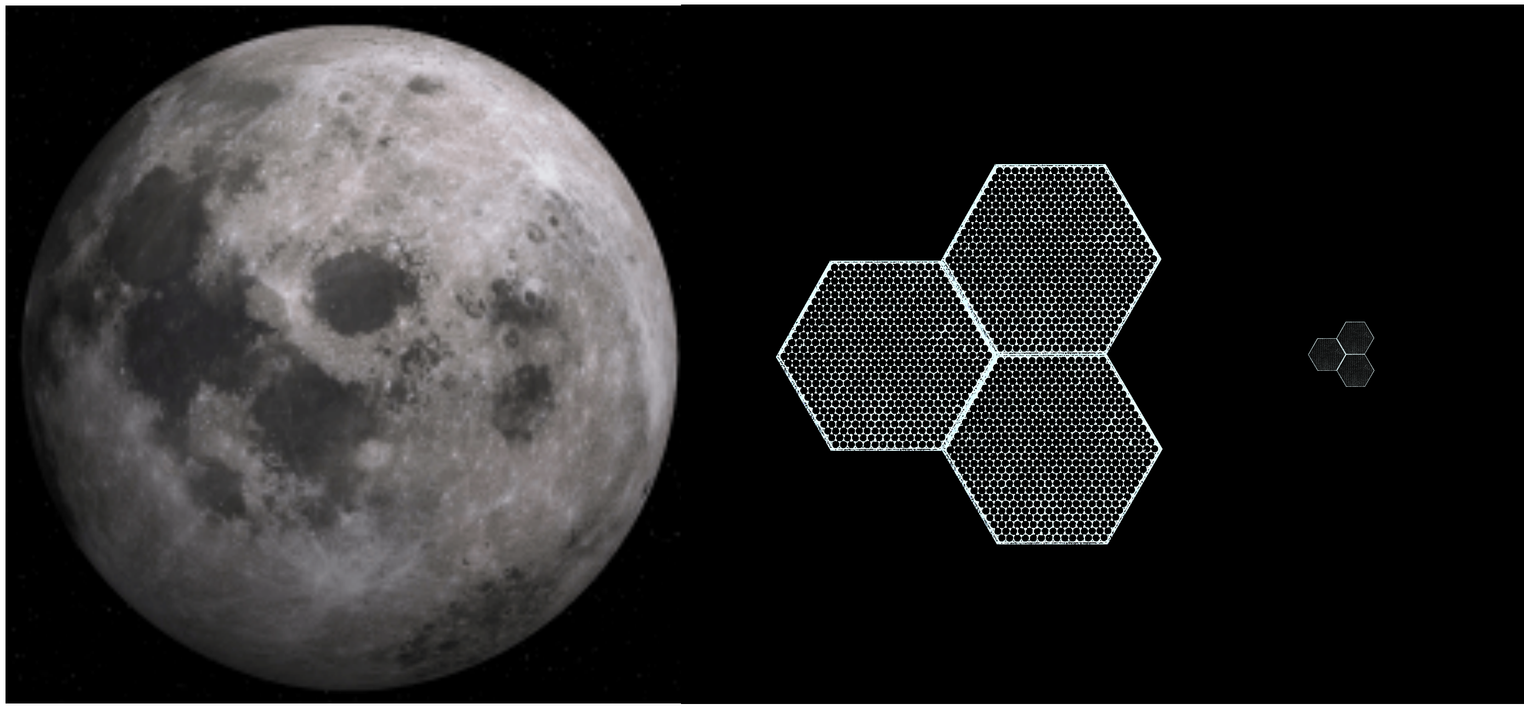


LVM hardware

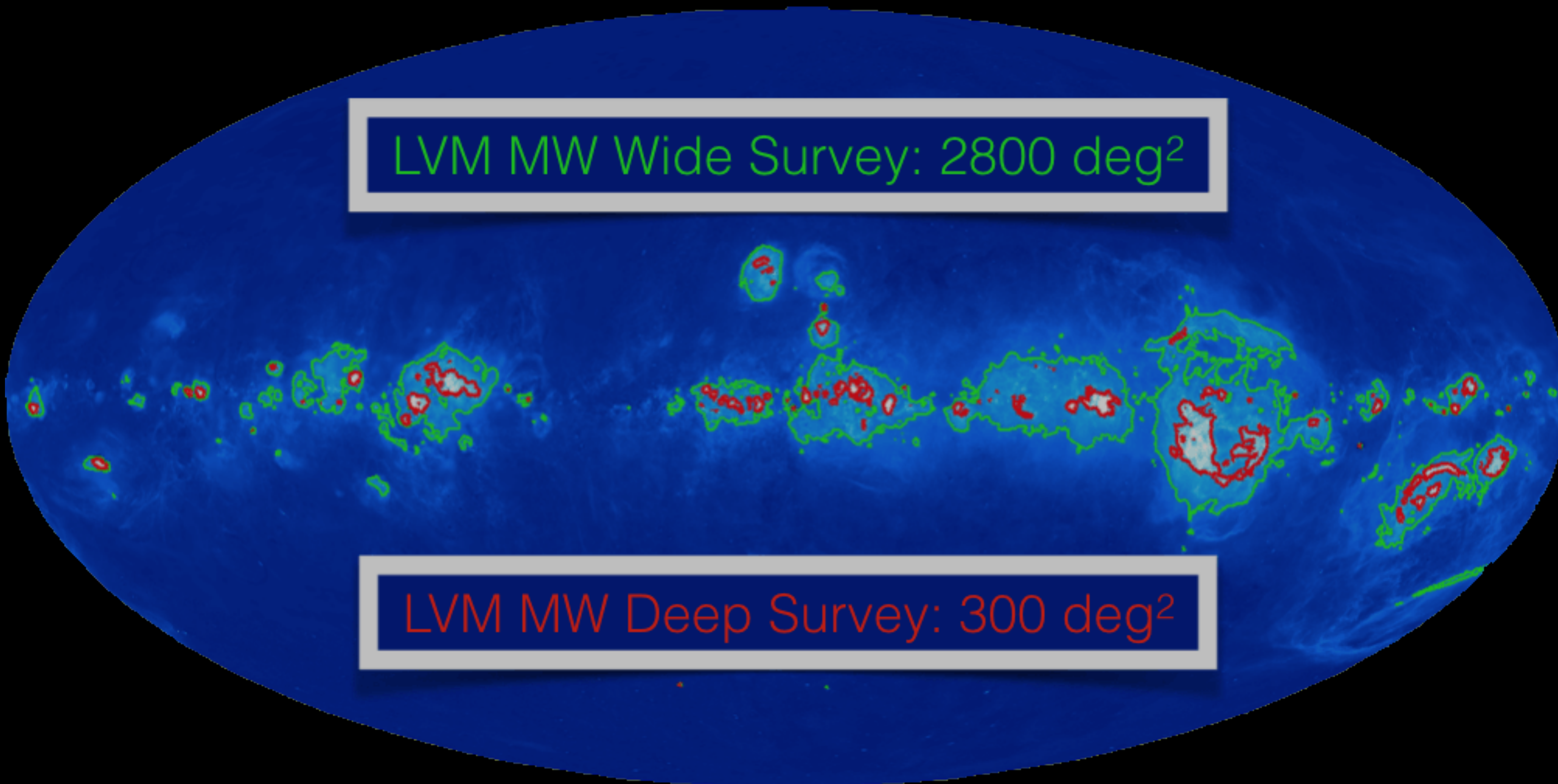
IFU design

- 3 x 547 hexagonal non-abutted lenslet coupled IFUs arrays.
- 309 calibration fibres.
- Based on highly-successful MaNGA design.
- 490 arcmin2 @ 0.16 m
- 12 arcmin2 @ 1 m





OBSERVING GALAXIES AT THE "ENERGY INJECTION SCALE"



Cosmological Zoom-In Observations!

Orion

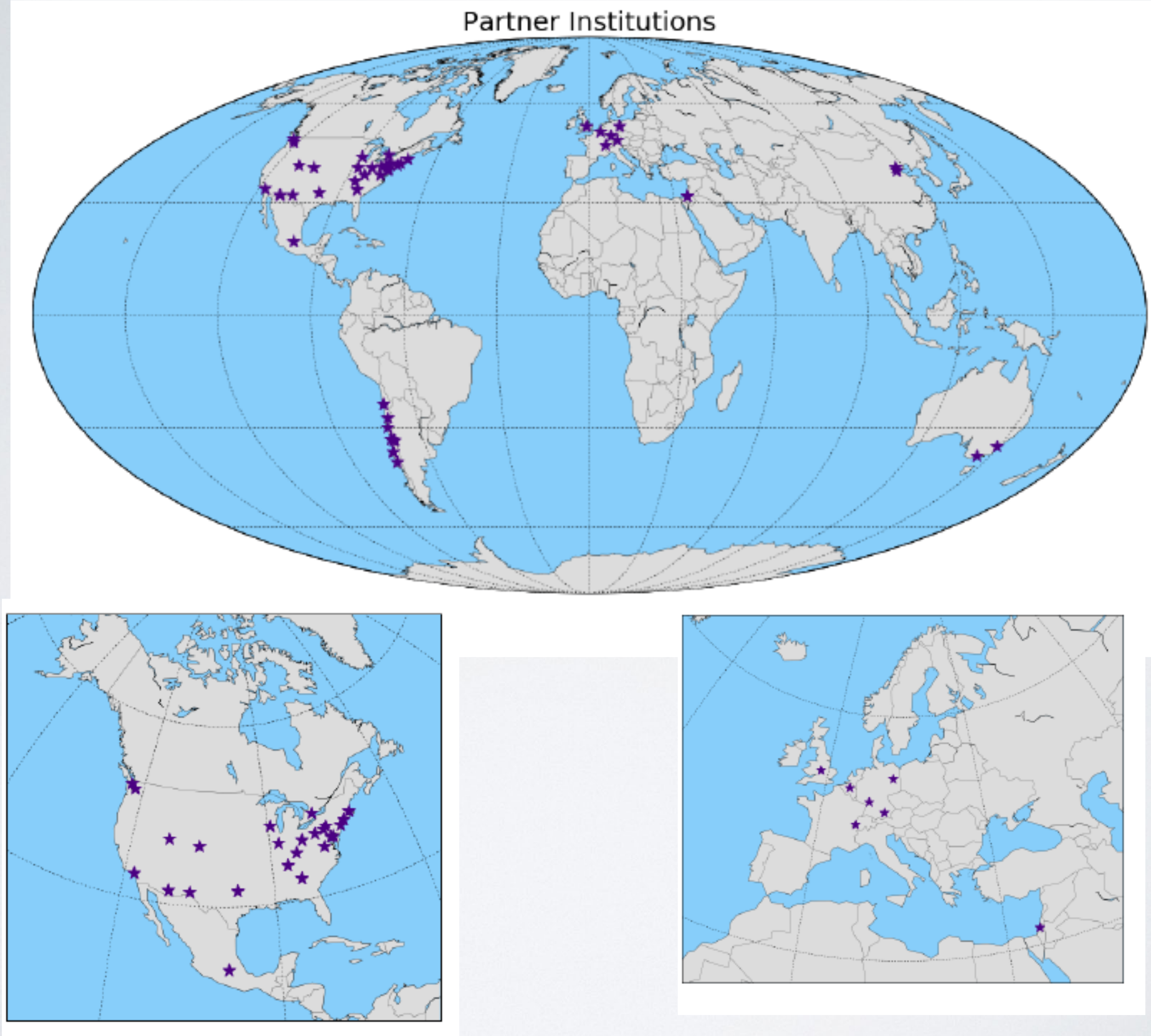
- M42 0.07 pc / spaxel
- APOGEE stars (yellow)
- Combine information from gas and stars to map the interaction between stars and ISM
- Have Teff, L, Z, [X/H], f_{UV}, (age) for each star
- Gas: temperature, density, kinematics, abundances

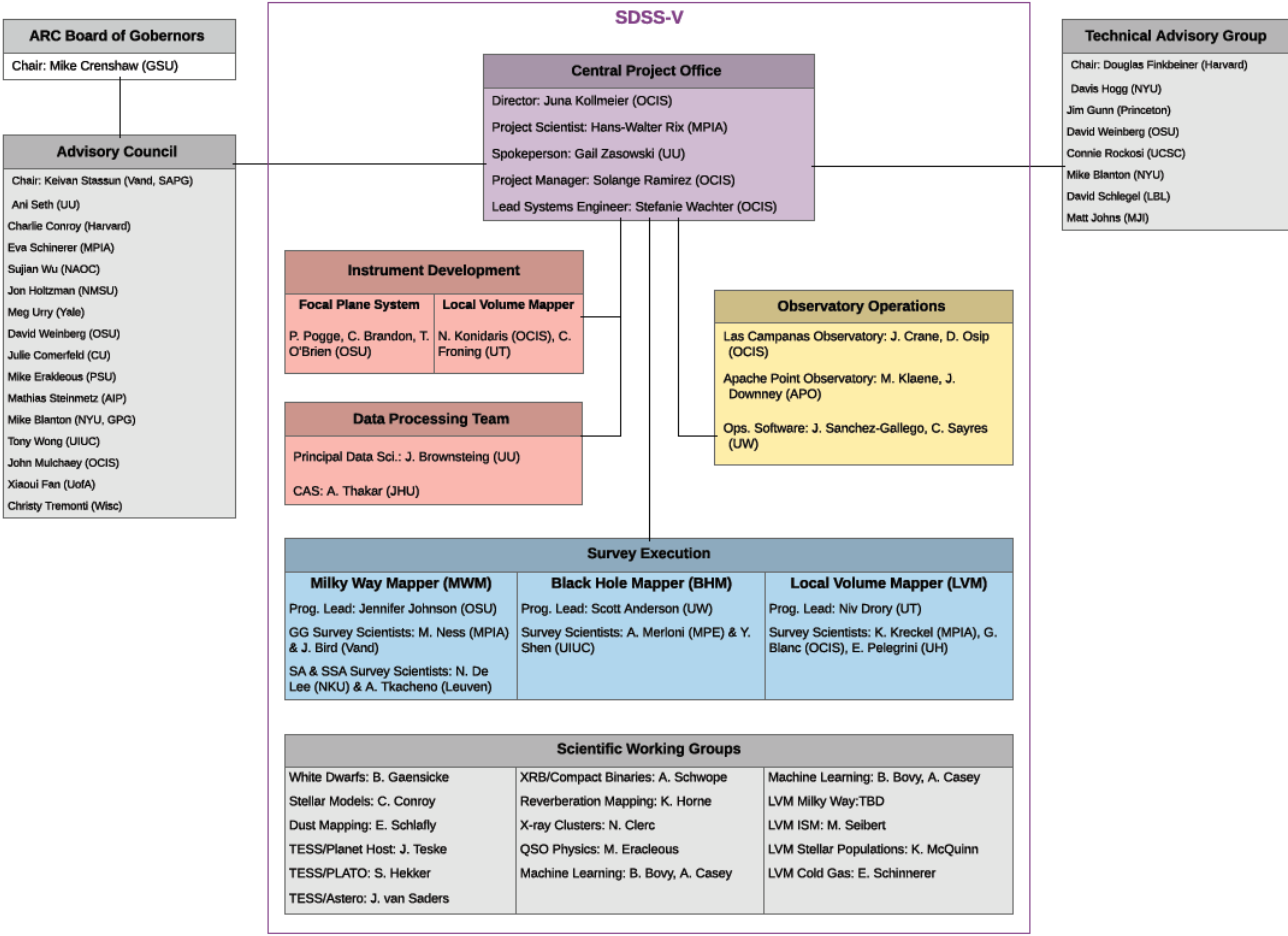
Images: ESO 2.2m

INSTITUTIONAL PARTNERSHIP

GROWTH OF COLLABORATION

SDSS Collaboration Matrix	MOU Signed/Out for Signature	MOU in Draft/Iteration	Prospective Institutions
FULL MEMBERS	CU Boulder Harvard MPE MPIA NMSU OSU NAOC Yale CNTAC	Carnegie Wisconsin STSCI UofA JHU UNAM U of Toronto SAO	NOAO INAF
3 Slot Members	AIP PSU Flatiron UIUC	UVA	Caltech MIT
Individual (1/2) slot Members	University of Washington (2) TCU, TAU (2) Vanderbilt, KIAA, U. Warwick, NYU, KU Leuven, Columbia, U. Penn,York University, University of Victoria, U. Pittsburgh, Georgia State	Monash University EPFL ANU	Oxford St. Andrews Nanjing U. SHAO


Partner Institutions


ARC Board of Gobernors
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Ani Seth (UU)
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SDSS-V
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Project Scientist: Hans-Walter Rix (MPIA)
Spokeperson: Gail Zasowski (UU)
Project Manager: Solange Ramirez (OCIS)
Lead Systems Engineer: Stefanie Wachter (OCIS)
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Local Volume Mapper
N. Konidaris (OCIS), C. Froning (UT)
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CAS: A. Thakar (JHU)
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Apache Point Observatory: M. Klaene, J. Downney (APO)
Ops. Software: J. Sanchez-Gallego, C. Sayres (UW)
Survey Execution
Milky Way Mapper (MWM)
Prog. Lead: Jennifer Johnson (OSU)
GG Survey Scientists: M. Ness (MPIA) & J. Bird (Vand)
SA & SSA Survey Scientists: N. De Lee (NKU) & A. Tkacheno (Leuven)
Black Hole Mapper (BHM)
Prog. Lead: Scott Anderson (UW)
Survey Scientists: A. Merloni (MPE) & Y. Shen (UIUC)
Local Volume Mapper (LVM)
Prog. Lead: Niv Drory (UT)
Survey Scientists: K. Kreckel (MPIA), G. Blanc (OCIS), E. Pelegrini (UH)
Scientific Working Groups
White Dwarfs: B. Gaensicke
Stellar Models: C. Conroy
Dust Mapping: E. Schlafly
TESS/Planet Host: J. Teske
TESS/PLATO: S. Hekker
TESS/Astero: J. van Saders
XRB/Compact Binaries: A. Schwope
Reverberation Mapping: K. Horne
X-ray Clusters: N. Clerc
QSO Physics: M. Eracleous
Machine Learning: B. Bovy, A. Casey
Machine Learning: B. Bovy, A. Casey
LVM Milky Way:TBD
LVM ISM: M. Seibert
LVM Stellar Populations: K. McQuinn
LVM Cold Gas: E. Schinnerer
Technical Advisory Group
Chair: Douglas Finkbeiner (Harvard)
Davis Hogg (NYU)
Jim Gunn (Princeton)
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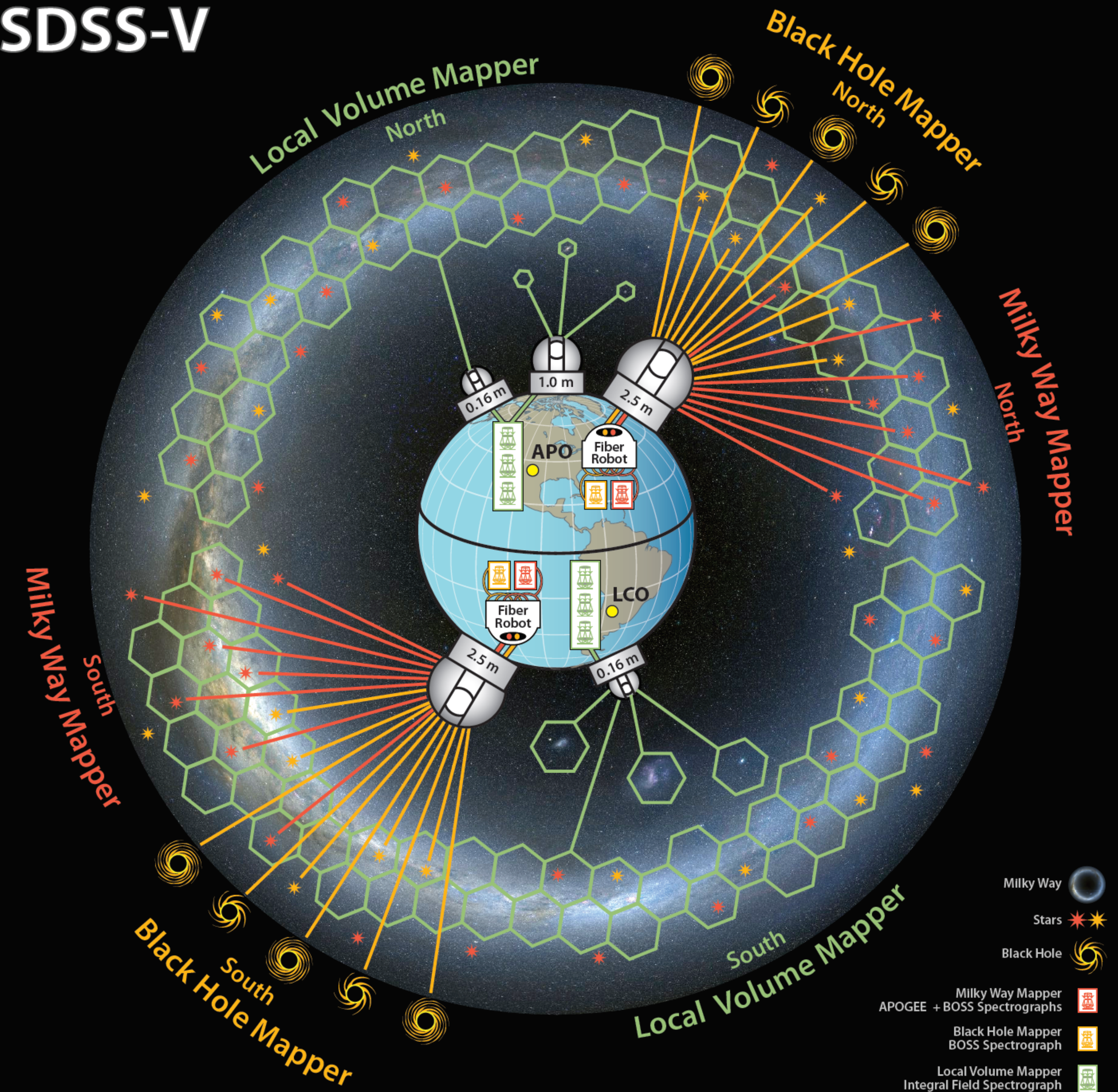
Connie Rockosi (UCSC)
Mike Blanton (NYU)
David Schlegel (LBL)
Matt Johns (MJI)

SDSS-V


Local Volume Mapper
North
Black Hole Mapper
North
Milky Way Mapper
North
Milky Way Mapper
South
Black Hole Mapper
South
Local Volume Mapper
South
0.16 m
1.0 m
2.5 m
APO
Fiber Robot
LCO
Fiber Robot
2.5 m
0.16 m
Milky Way
Stars
Black Hole
Milky Way Mapper
APOGEE + BOSS Spectrographs
Black Hole Mapper
BOSS Spectrograph
Local Volume Mapper
Integral Field Spectrograph

SED Machine

Spectral Energy Distribution Machine

Nick Konidaris
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+1 831 512 4465

Some inspirations

SNIFS

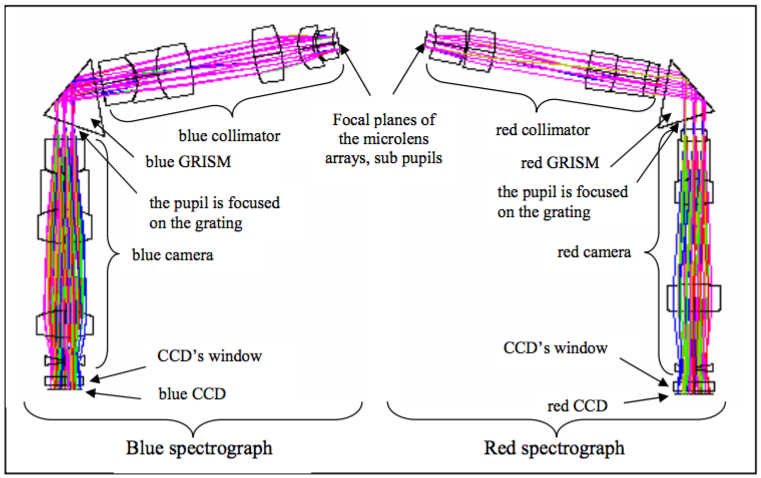
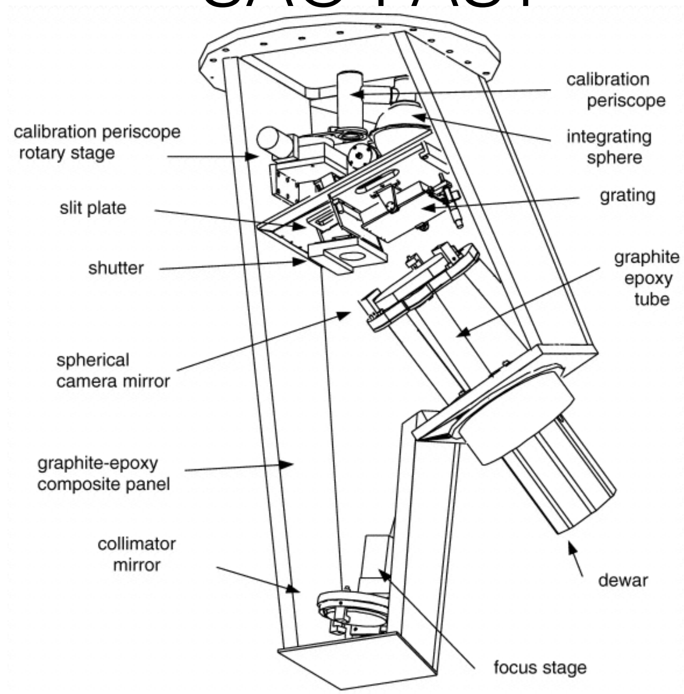


Figure 7: layout of the two spectrographs

Lantz+ (2004)
IFU: 6" x 6" FOV
R~1,000

SAO FAST



Fabricant+ (1998)
Slit / R~1,000

There are two spectrographs that we felt could be combined into one. SNIFS also had a "rainbow camera" with even medium- and narrow-band filters to observe night sky features.

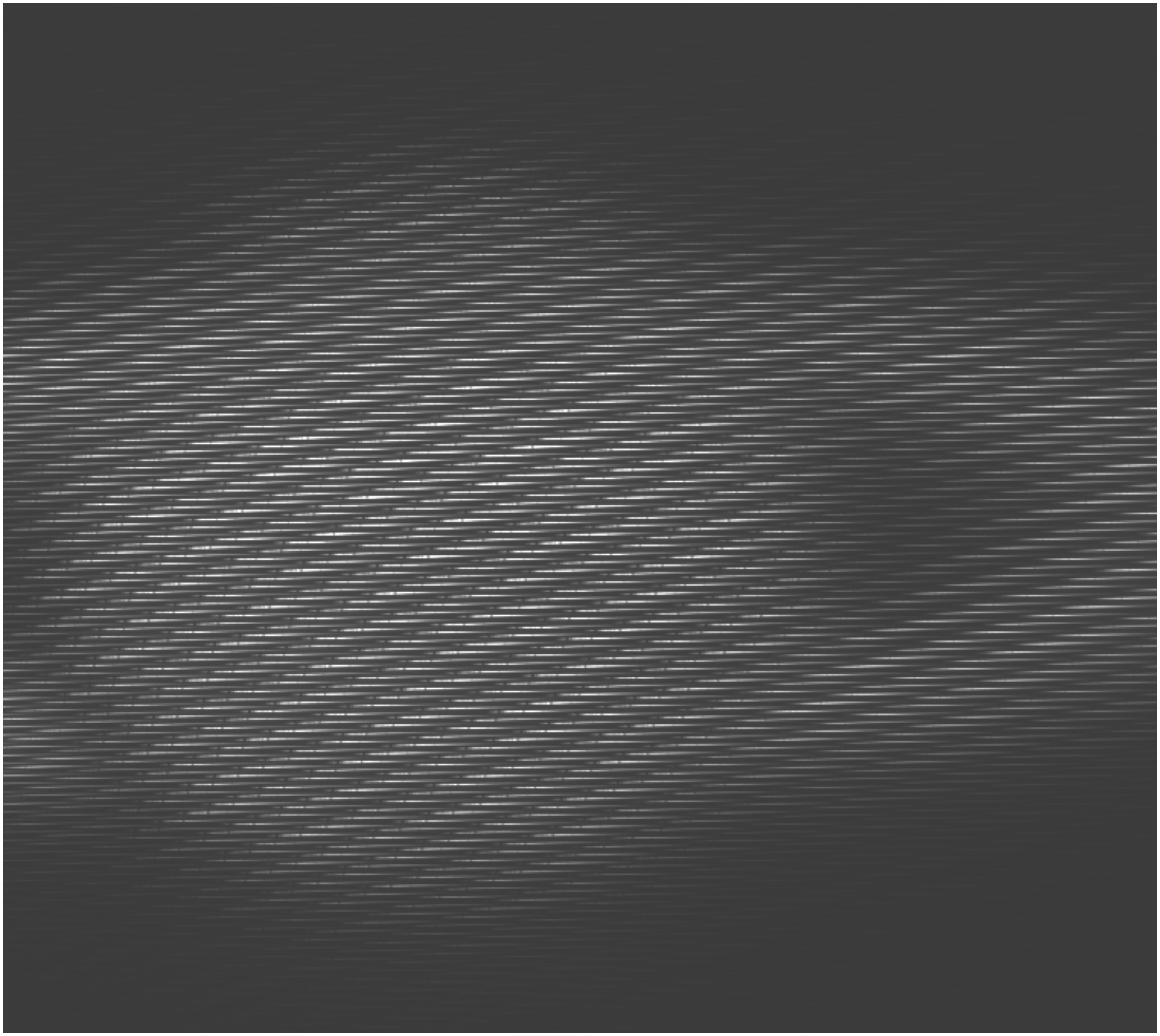
Milestones

- Pasadena Postdoc Retreat: April 2009
- Palomar Retreat: Dec 2009
- ATI Submitted: Nov 2010
- Project start: July 2011: $675 K
- First light on sky: June 2013
- DRP1/DRP2 operational in Jan 2014/May 2015
- Full time operations June 2016

SED Machine is the result of a simple metric

- Maximize the efficiency of taking classification by:
  - Ensuring acquisition efficiency is as high as possible. This is accomplished with a wide-field (30”) integral-field unit.
  - Ensuring the instrument minimizes the time on spectrophotometric standards by simultaneously monitoring in u, g, r, and i and then correcting the resulting spectra for grey absorption.
  - Ensuring the instrument is of the highest possible efficiency.

A spectrum of Saturn taken with SED Machine — demonstrating the enormous field of view of the instrument. Alignment onto the slit is “easy”!



An example from 4 Jan 2019

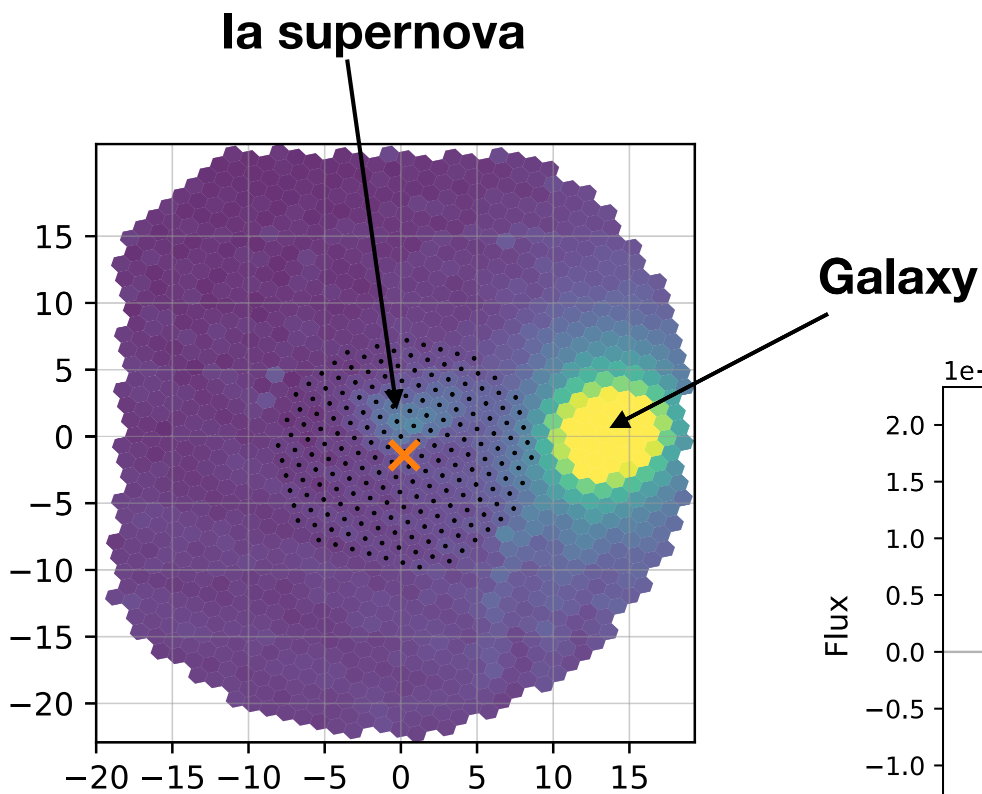


Figure shows the collapsed data cube

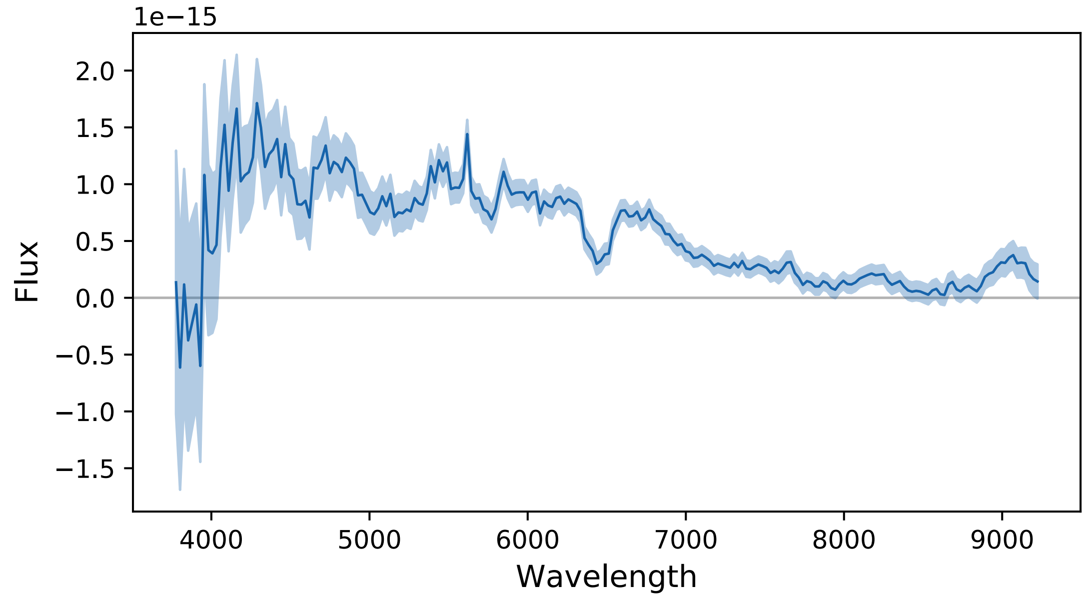
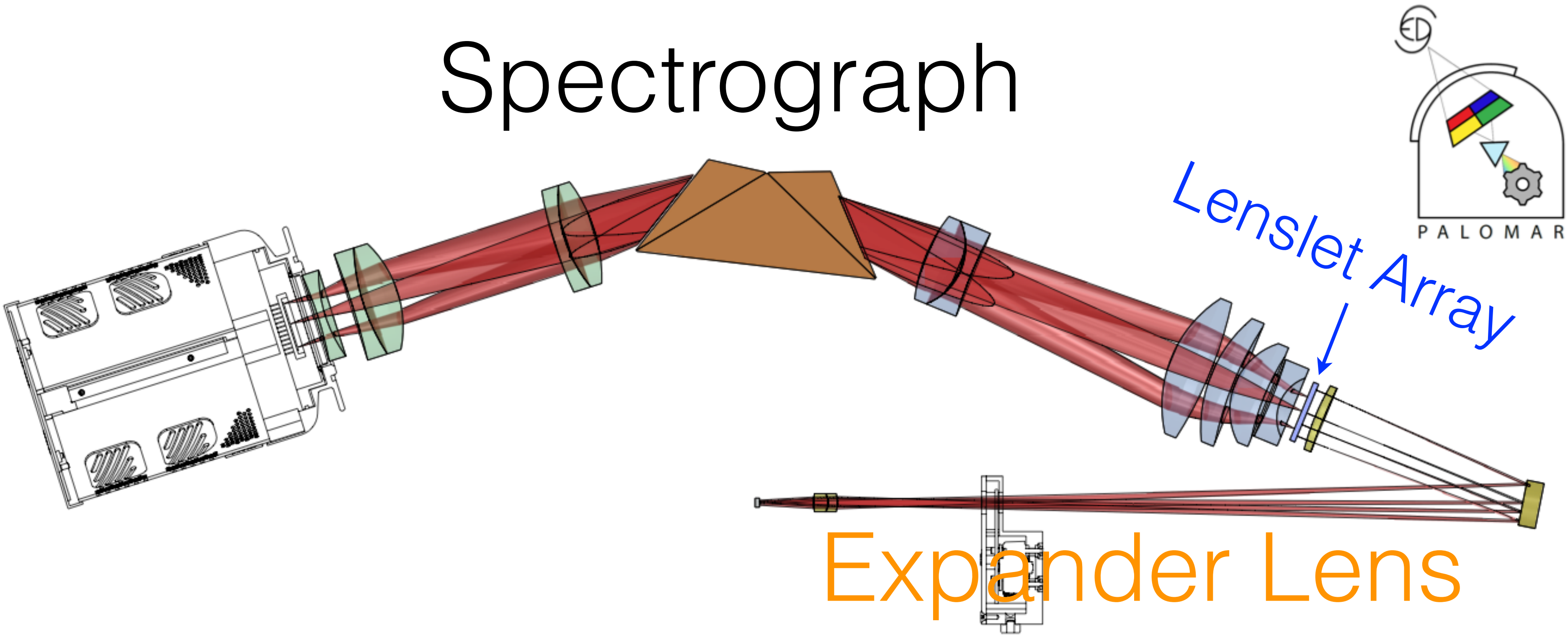


Figure shows sky-subtracted spectrum

Achieved with a lenslet array ("TIGER" style)



Spectrophotometric accuracy- Key metric

- Observe the imaging fields flanking the science fields. Measure the atmospheric zero points. Correct via a bootstrap approach the extinction over the course of the night.

- SNIFS recognized that the medium-band filters were unnecessary so we chose to observe in u-i simultaneously. (This is actually technically hard to achieve without refocus. Excellent work by Sagi Ben-Ami to achieve the design).

Extinction: how to determine?

- Extinction is the main factor that affects the SED Machine's spectrophotometric accuracy. The SNIFS spectrograph inspired us

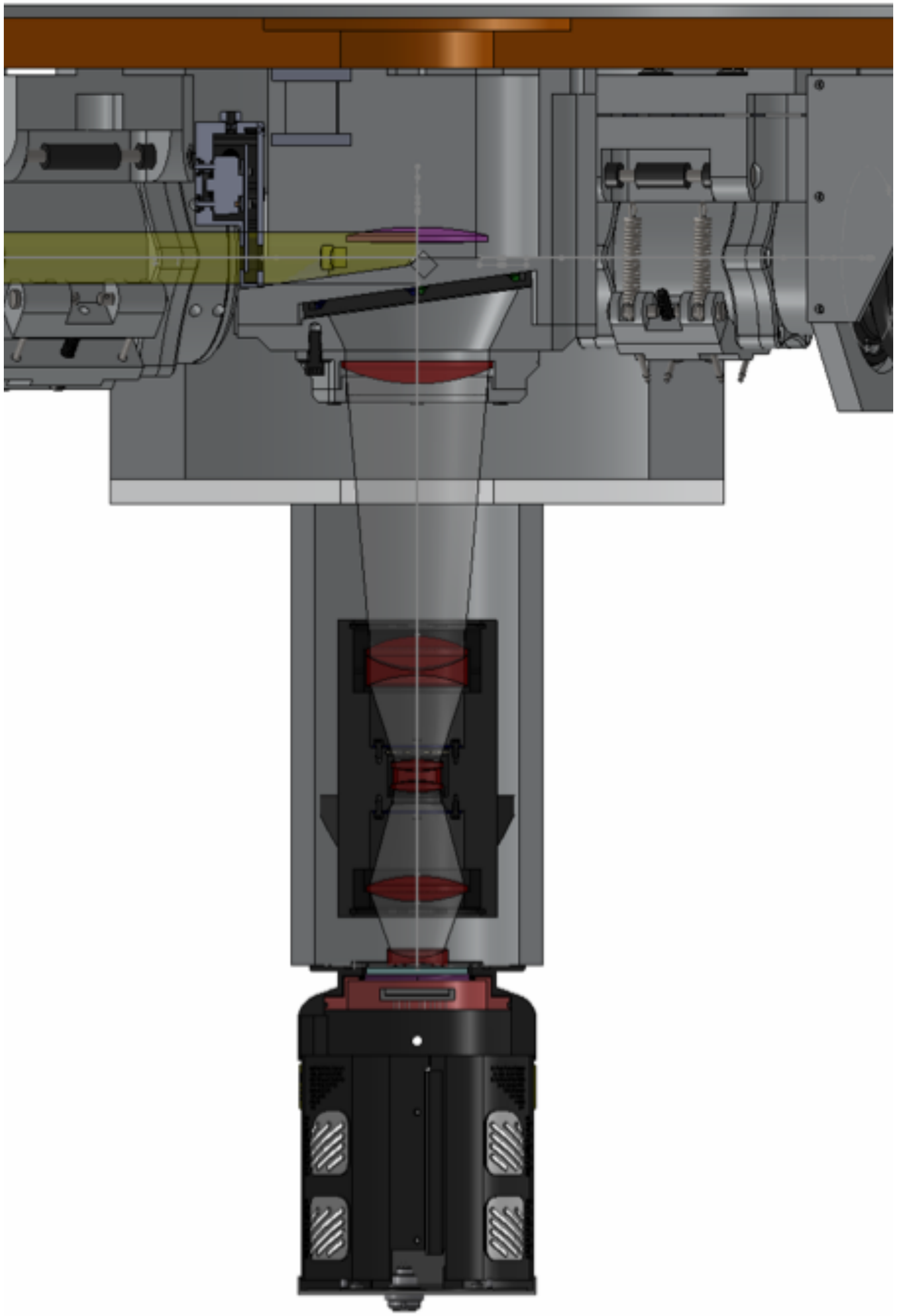
- It is the combination of a variety of physical processes:

$$\text{Rayleigh Scattering} \propto \lambda^{-4}$$

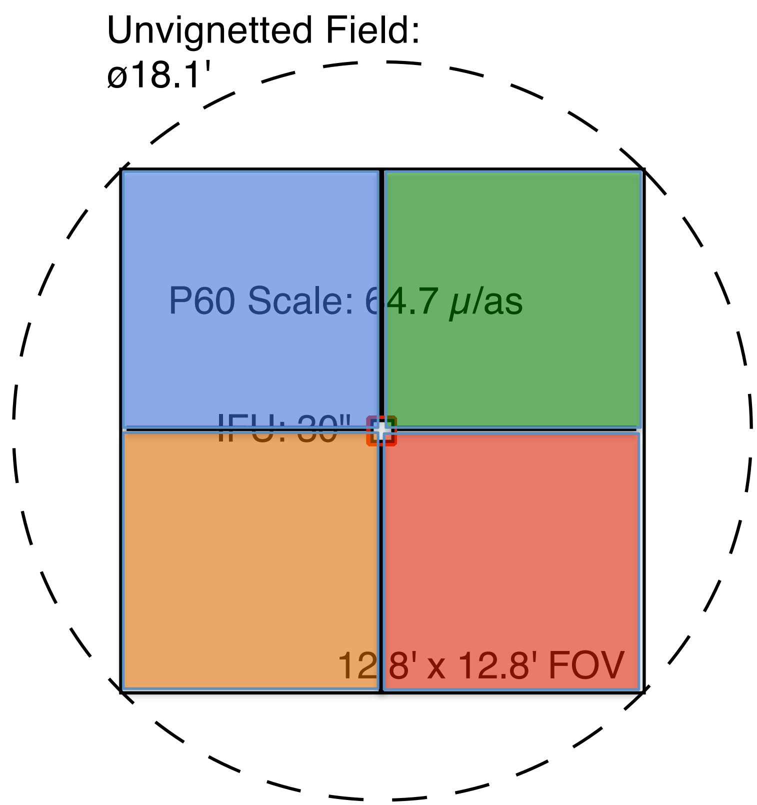
$$\text{Mie Scattering} \propto \lambda^{-1}$$

$$\text{H}_2\text{O Absorption} \propto \lambda^{0}$$

Rainbow Camera



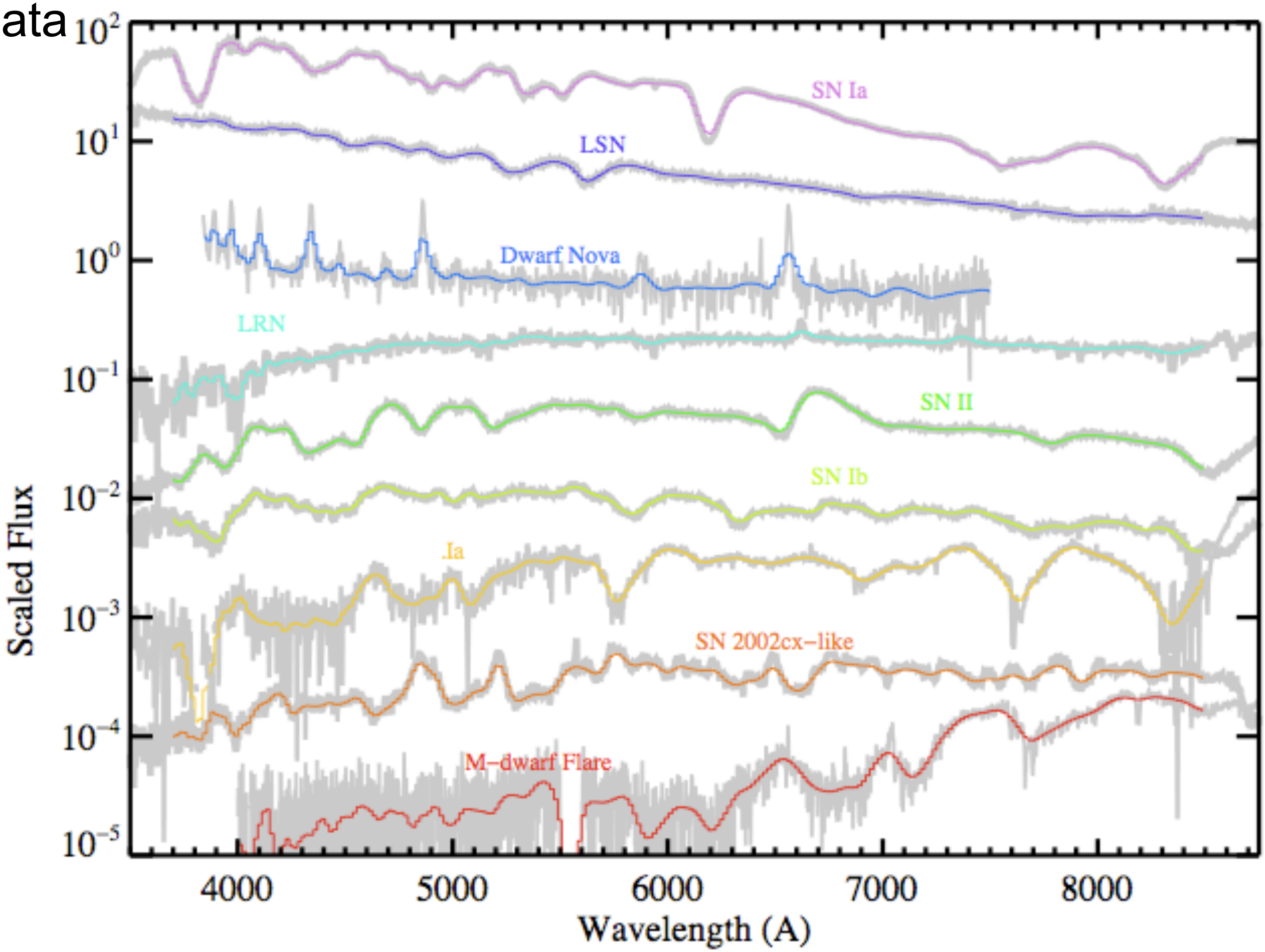
Palomar 60" Focal Plane



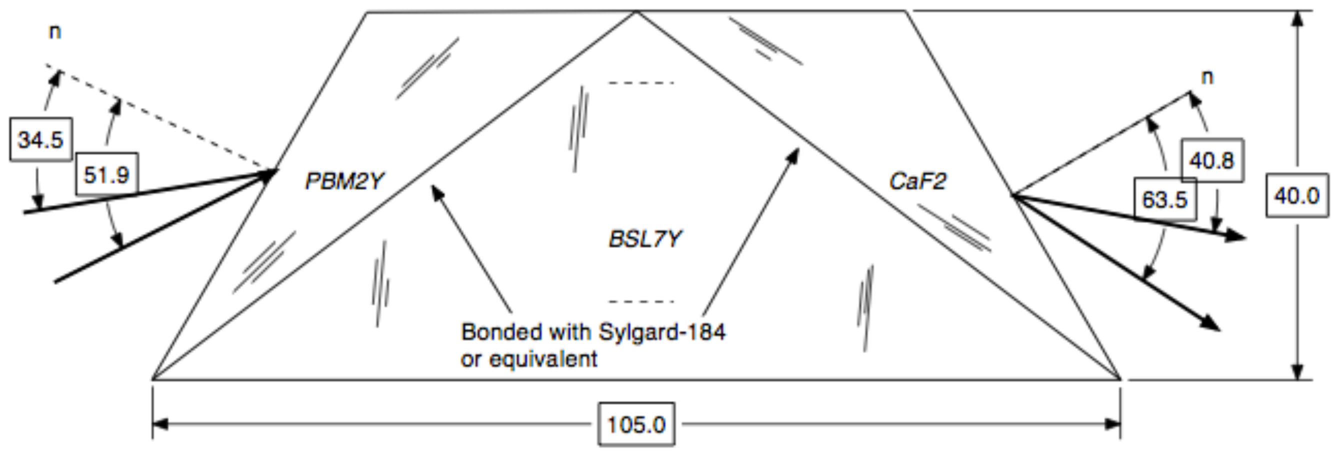
High throughput- Key metric

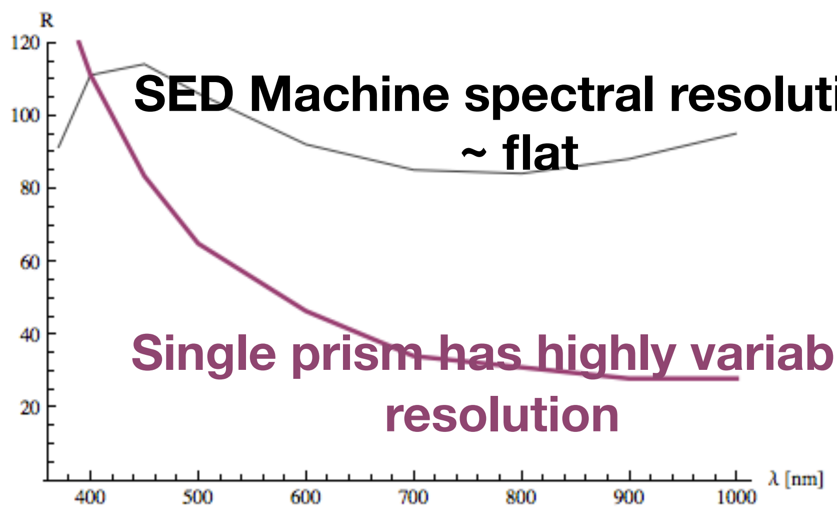
- The instrument is designed to have high throughput from 365 nm - 1 μm.
- A lot of work went into picking a spectral resolution ($R=\lambda/\Delta\lambda=100$) that would allow for efficient classifications.
- Low resolution means high-throughput prism rather than lossy gratings
- (But throughput has never been as good as designed for reasons that have yet to be determined).

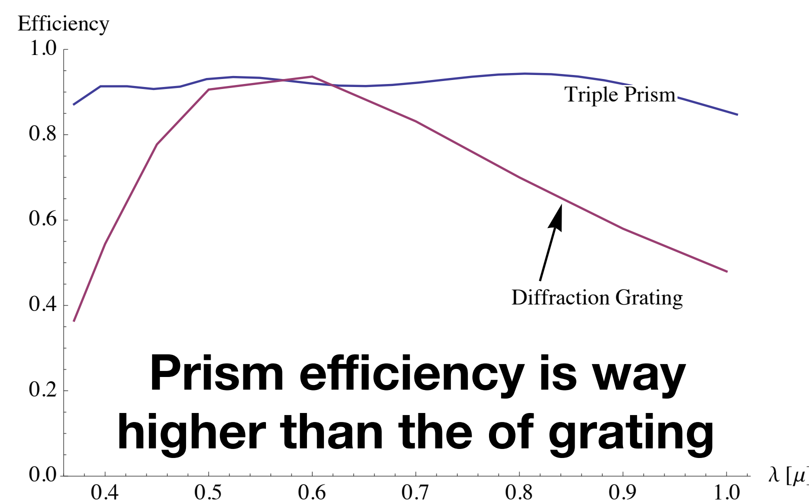
To classify with a single observation, R=100 is sufficient:
data



A lot of work went into designing an elaborate prism for SED Machine.







Results and future

- Pipeline was a journey to finish. Though we had some excellent starts, the first working end-to-end pipeline was written by Nick and finished a year after first light.
- SED Machine has been rebranded to SEDM. Fair because there has been a ton of work on improving the data reduction pipeline!
- SEDM now in routine use.

9 obj/ (good) night

```
Report generated on Thu Sep 29 08:52:01 2016

SEDM DRP run in /scr2/sedmdrp/redux/20160929
Found 15 sp_*.npy files

Object                     Obs Method  Exptime Qual Skysb Airmass
STD-BD+28d4211            obs1 Single    300.0    0    on  1.004
STD-BD+25d4655            obs1 Single    300.0    0    on  1.007
STD-HZ4                   obs1 Single    420.0    0    on  1.098
STD-HZ2                   obs1 Single    300.0    0    on  1.118
STD-HZ2                   obs2 Single    300.0    0    on  1.130
PTF16gox                     -  A / B   2700.0    1    on  1.007
PTF16gmh                     -  A / B   2700.0    1    on  1.071
PTF16gmw                     -  A / B   2100.0    1    on  1.297
PTF16geh                  obs1 Single   1350.0    1    on  1.235
PTF16gqj                     -  A / B   2100.0    1    on  1.051
PTF16gop                     -  A / B   2100.0    1    on  1.393
SolarHD210078             obs1 Single    180.0    1    on  1.417
NGC_884-8                 obs1 Single    300.0    2    on  1.220
NGC_884-16                obs1 Single    420.0    1    on  1.204
NGC_884-12                obs1 Single    300.0    1    on  1.123

Total quality (1-3) science exposure time = 15870.0 s
```

Lessons learned

- The instrument's lack of throughput and no (as far as I know) diagnosis has been made.
- Despite throughput that is at least half of what we designed and hoped for — yet the instrument has been unbelievably useful in early-light spectra and imaging (TDE 14fnl, 14hls, the COW)
- Even underperforming SED Machine is a key tool and more could be used.

What's next?

- Whole idea of SED Machine was to build many copies. What lessons?
  - IFU is essential but lensless probably wrong approach (Carnegie Fellow McGurk has figured out a very low cost way to build slicers)
  - We could benefit from R~1,000 spectral resolution — slicer enables this. (I'd love to discuss this point).
  - Rainbow camera never really got used as intended as far as I know.
  - **MORE are needed**
- Single Planewave 1-m is $730 k, a new SED Machine with slicer is probably $600 k:
  - SED machine next gen + 1m planewave is $1.4 MUSD / m^2
  - DBSP on a new 6.5 m is $3.6 MUSD / m^2
  - The cost of a SED machine + Planewave is within reach for a small department. It's possible to build a farm of followup machines.
- Array v monolithic argument goes back to probably photographic plates — I think the science has changed such that an array of small telescopes is more exciting.

SEDM Performance and DRP

Don Neill

Mickael Rigault

Michael Feeney

Richard Walters

David Hover

Facility instrument on P60

Current performance

- Averaging 1.84 classifications per exposure hour
- New MLA (2018 June 19)
  - Gross throughput similar with new MLA, however:
  - Scattered light greatly reduced
  - Old MLA throughput was artificially boosted by scattered light
- Nearly Doubled Observing Efficiency
  - OLD: ~ 9 objects a night
  - NEW: ~ 16 objects a night with good classifications
    - 20 classified objects current record (20181229: 28 targets, 4 STDs)
  - Single exposure instead of A/B pair needed for scattered light
  - Shorter exposure times
- Fainter limiting magnitude
  - OLD: 18.5
  - NEW: 19.5

Report generated Sat Dec 29 08:48:59 2018

UTStart	Object	Exptime	Air	method	Allocation	Type	Subtype	z	Rlap
1:48:22	STD-GD248	120	1.082	auto_robot_lstep1	2018A-calib	STD			
1:53:19	ZTF18aczbkqp	1200	1.199	auto_robot_lstep1	2018A-BCS	Gal	-	0.0108	11.63
2:15:58	ZTF18acsxkov	2250	1.297	auto_robot_lstep1	2018A-RCF	QUALITY_5			
2:55:22	ZTF18acyocrv	1200	1.556	auto_robot_lstep1	2018A-BCS	Ia	91bg	0.024	6.26
3:18:08	ZTF18aczqtpt	1200	1.075	auto_robot_lstep1	2018A-BCS	NONE			
3:40:26	ZTF18acszayr	2250	1.257	auto_robot_lstep1	2018A-InfantSNe	QUALITY_5			
4:20:02	ZTF18adaimlf	2250	1.034	auto_robot_lstep1	2018A-BCS	Ia	norm	0.736	6.1
5:00:03	SN2018hti	1200	1.075	auto_robot_lstep1	2018A-SLSN	Ic	norm	0.0552	5.82
5:43:13	STD-LB227	120	1.043	auto_robot_lstep1	2018A-calib	STD			
5:49:22	STD-LB227	120	1.045	auto_robot_lstep1	2018A-calib	STD			
5:56:21	STD-LB227	120	1.048	auto_robot_lstep1	2018A-calib	STD			
6:01:09	ZTF18adazblo	2250	1.979	auto_robot_lstep1	2018A-StrippedSNe	Ic	broad	0.6043	5.52
6:40:23	ZTF18aczcumi	2250	1.655	auto_robot_lstep1	2018A-BCS	IIb	-	0.0347	7.57
7:19:33	ZTF18aaflcyp	2250	1.381	auto_robot_lstep1	2018A-BCS	Gal	-	0.0279	17.99
7:59:44	ZTF18acwwowy	1200	1.823	auto_robot_lstep1	2018A-BCS	Ia	norm	0.0515	11.6
8:22:29	ZTF18aczdtgn	2250	1.641	auto_robot_lstep1	2018A-BCS	Ia	91T	0.0685	6.45
9:02:39	ZTF18acybdar	1200	1.515	auto_robot_lstep1	2018A-BCS	Ia	norm	0.0713	9.56
9:25:01	ZTF18acyyefr	2250	2.2	auto_robot_lstep1	2018A-BCS	Gal	-	0.0194	7.04
10:06:12	ZTF18acwwonp	1200	1.61	auto_robot_lstep1	2018A-BCS	Ia	norm	0.0303	19.67
10:28:14	ZTF18abwlupf	2250	1.862	auto_robot_lstep1	2018A-BCS	NONE			
11:08:03	ZTF18acyctqi	2250	1.625	auto_robot_lstep1	2018A-BCS	IIP	-	0.0409	4.72
11:08:03	ZTF18acyctqi	2250	1.625	auto_redo084412_lstep1	2018A-BCS	Ia	norm	0.0789	9.77
11:47:31	ZTF18adalgmc	2250	1.887	auto_robot_lstep1	2018A-RCF	Ia	norm	0.0365	14.76
12:27:08	ZTF18aczemzj	1200	1.693	auto_robot_lstep1	2018A-BCS	Ia	norm	0.0615	13.99
12:49:08	ZTF18acustza	2250	1.892	auto_robot_lstep1	2018A-RCF	Ia	norm	0.7914	6.25
12:49:08	ZTF18acustza	2250	1.892	auto_redo084636_lstep1	2018A-RCF	IIP	-	0.0479	7.52
13:28:57	ZTF18acvilwk	1200	1.727	auto_robot_lstep1	2018A-BCS	Ia	91bg	0.6526	6.38
13:51:24	ZTF18acwyvet	1200	1.467	auto_robot_lstep1	2018A-BCS	Gal	-	0.1625	4.83

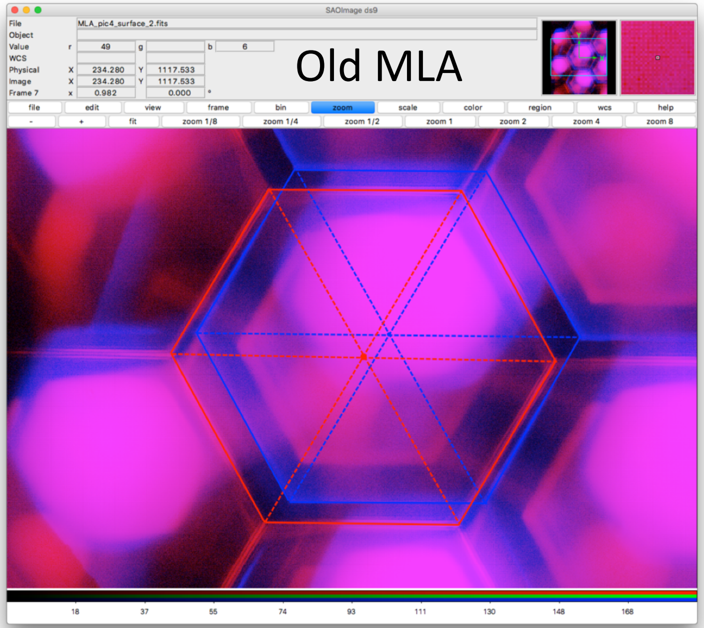
- 20 Redshifts
- 20 Classifications
- 4 STD Stars
- 28 Observations

Current performance

- Fully Automated Pipeline
  - Uses RCAM images to solve IFU WCS
  - PSF-fitting spectrophotometry
  - DAR compensation
  - Real-time uploads to marshal
  - M. Rigault, J. D. Neill, et al. 2019 in prep
- Reliability
  - Airmass limit <= 1.8
  - Hardware Enhancements in progress to remove limit

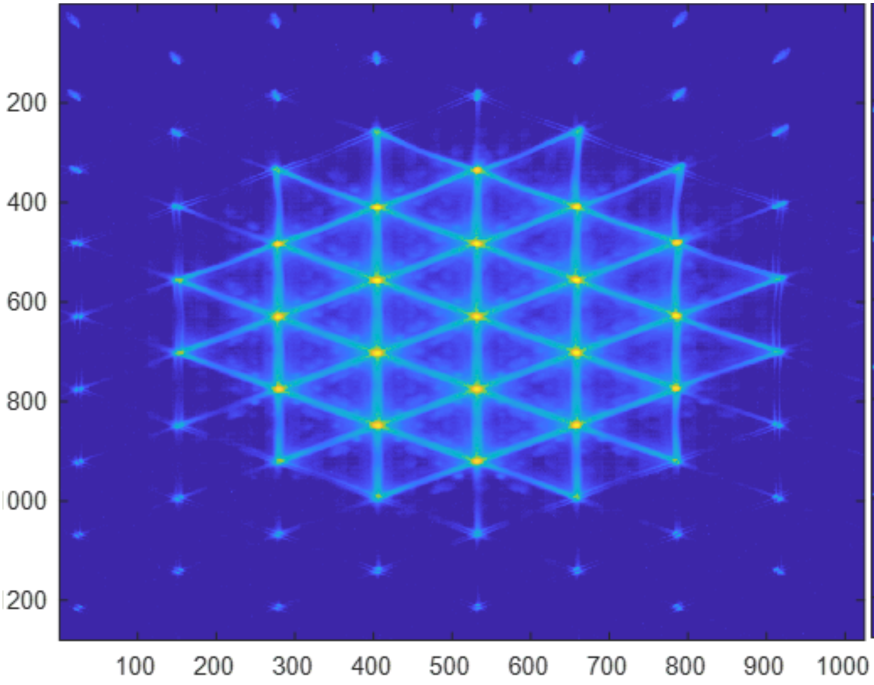
Jenoptic Micro Lens Array (MLA)

- Plano-convex design
  - Removes alignment problems between bi-convex lenslets
- Masked lenslet edges to control scattered light

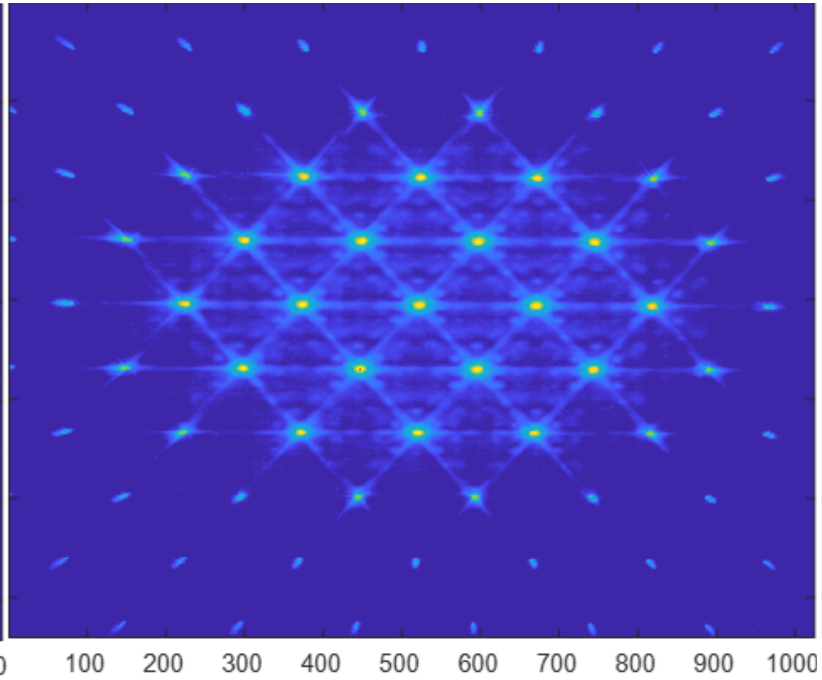


Compare Normalized Image of micro-pupils (log scale)

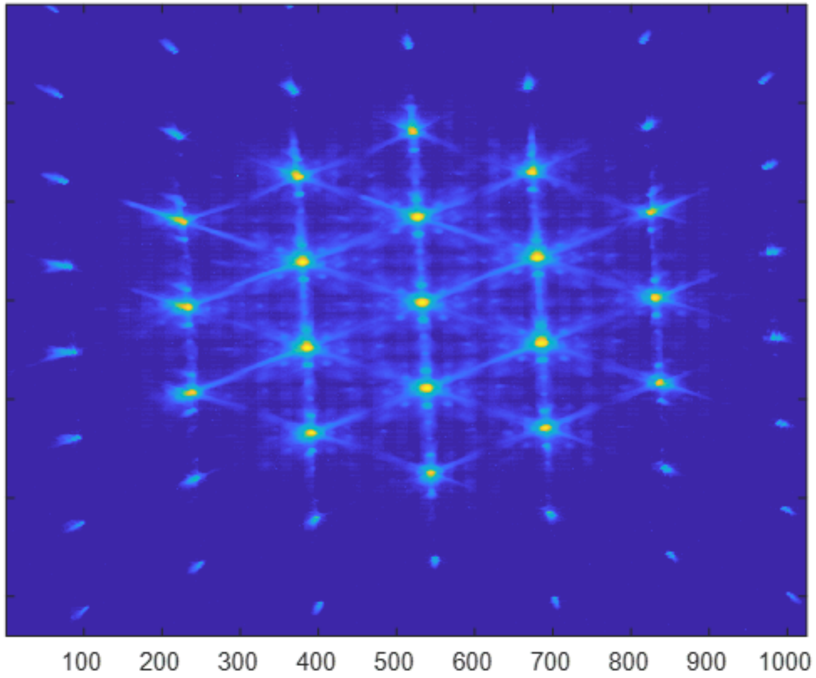
Original MLA



Jenoptic A (520)



Jenoptic D (606)

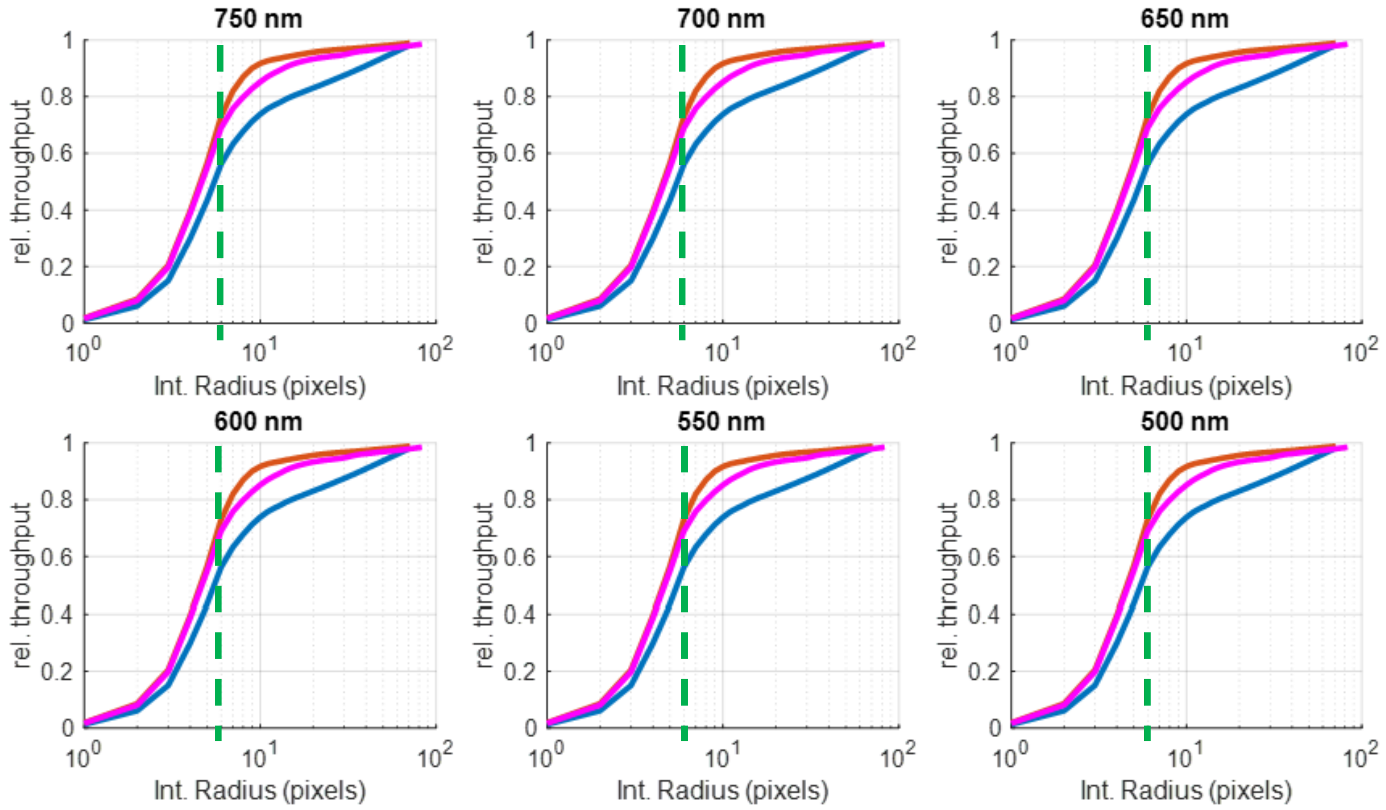


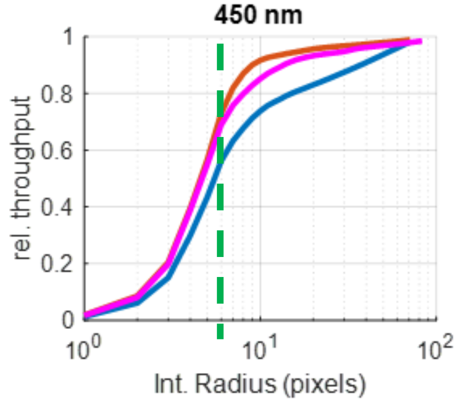
New MLAs have have less power in the “wings”.
Masking cuts throughput but controls light better.

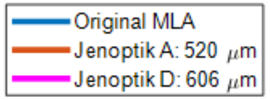
Installed Jenoptic A

D. Hover

Relative Throughput vs Integration Radius







Green dashes indicate current DRP extraction radius

- Integrate detector counts on all centroids, normalized by all detector counts
- New MLAs have shallower diffraction tail (greater than 10 pixels)

Currently Jenoptic A installed

X-axis is for test setup. There is a 3 (Test):1 (SEDM) pixel ratio

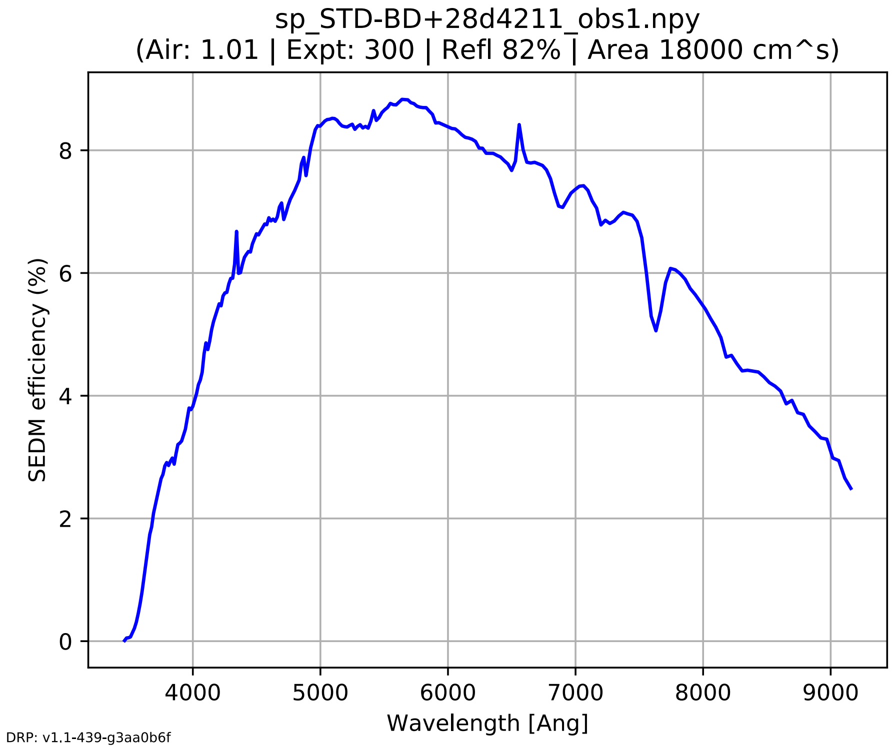
D. Hover

Gross Throughput

Measured for each Standard Star!!

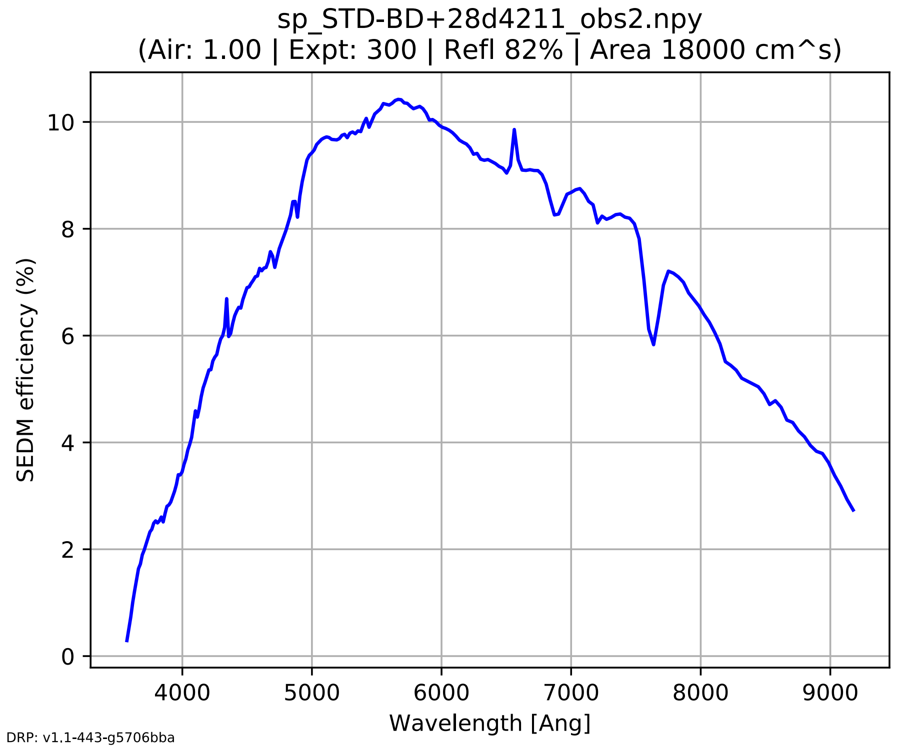
Before new MLA

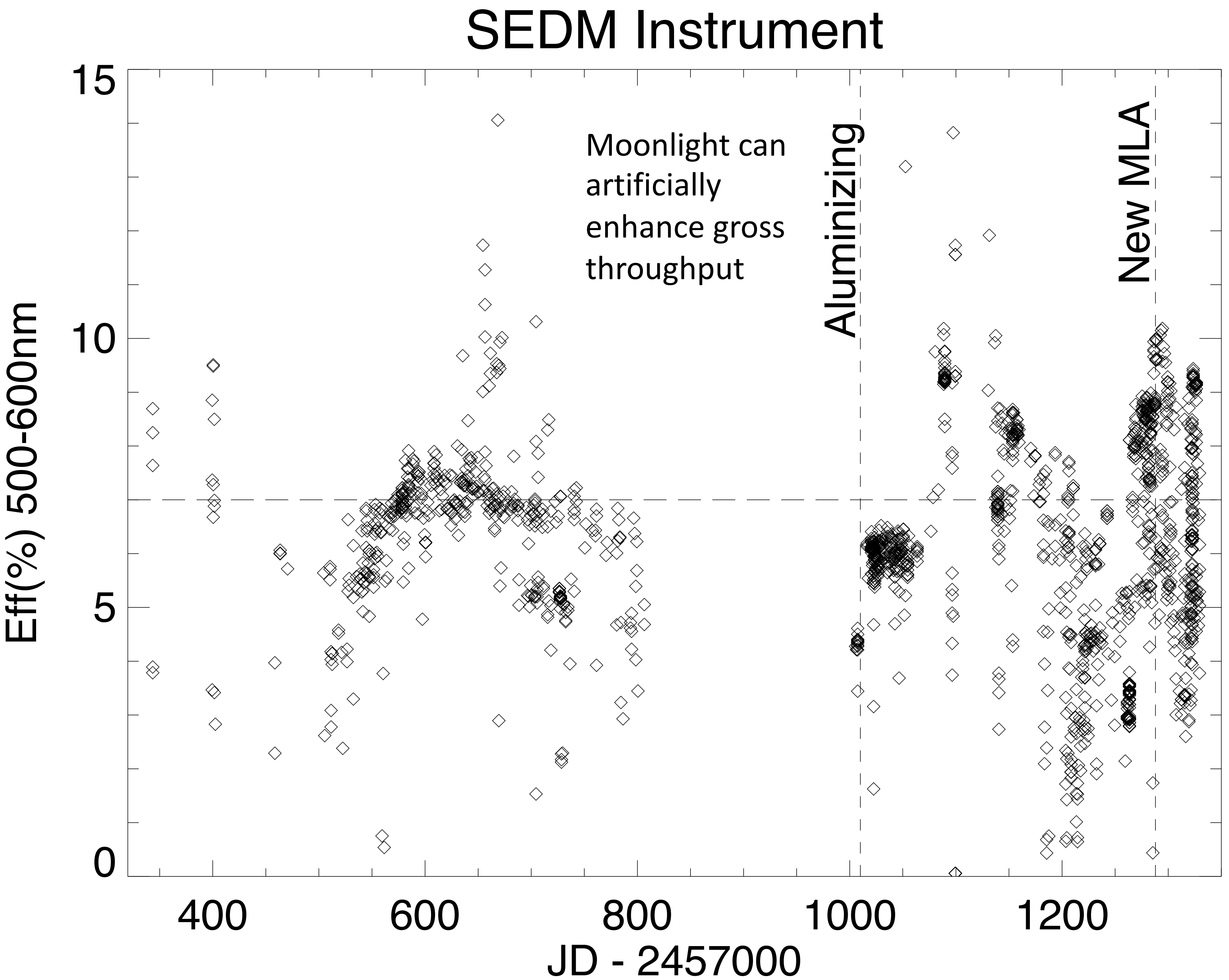
20180617 BD+28d4211



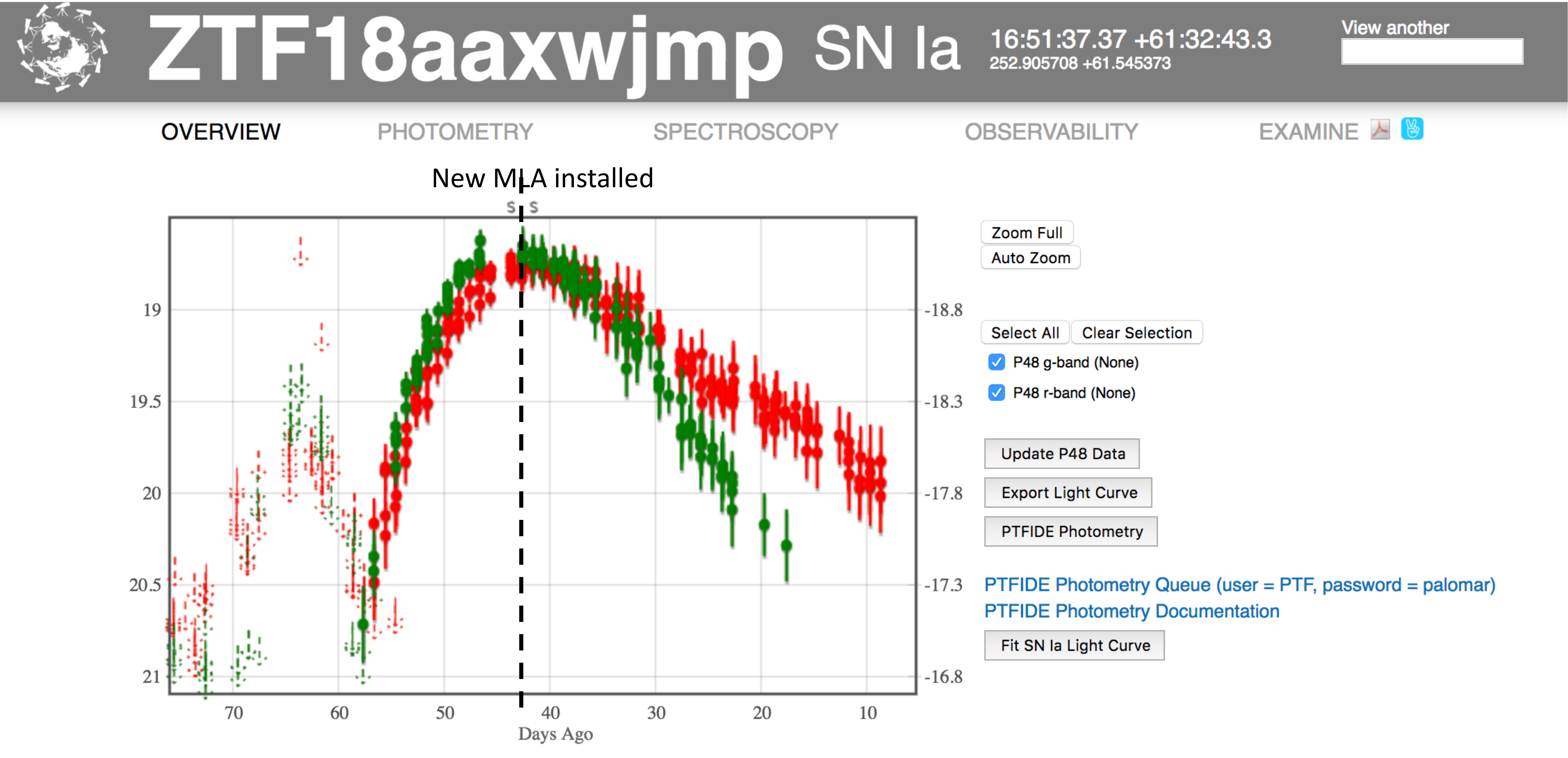
After new MLA

20180619 BD+28d4211





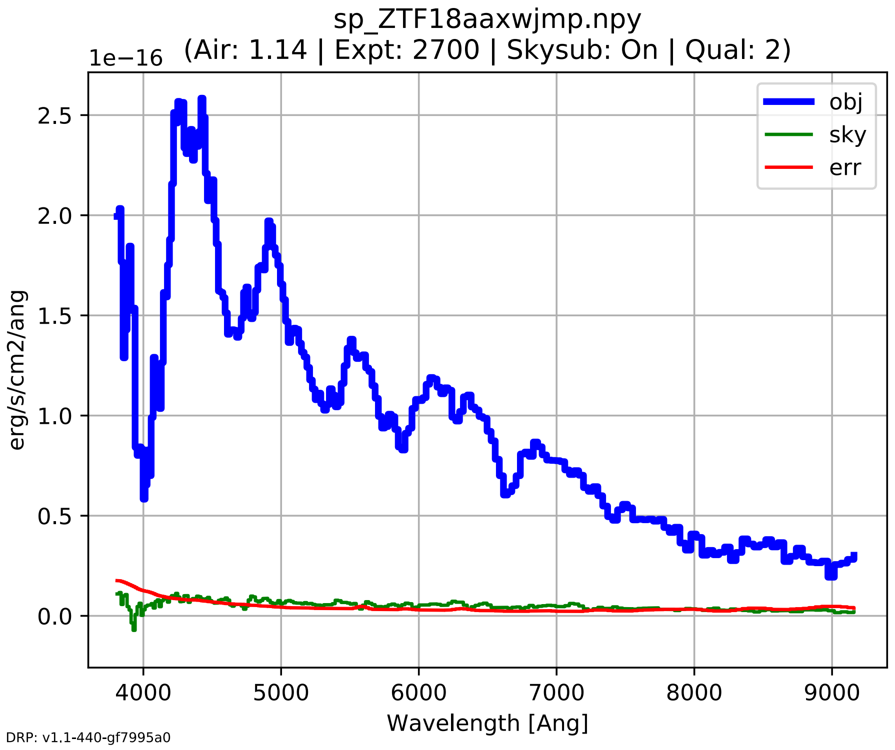
Jenoptic A Installed on 2018 June 19


ZTF18aaxwjmp SN Ia
16:51:37.37 +61:32:43.3
252.905708 +61.545373
View another
OVERVIEW
PHOTOMETRY
SPECTROSCOPY
OBSERVABILITY
EXAMINE
New MLA installed
S
S
19
19.5
20
20.5
21
-18.8
-18.3
-17.8
-17.3
-16.8
70
60
50
40
30
20
10
Days Ago
Zoom Full
Auto Zoom
Select All
Clear Selection
P48 g-band (None)
P48 r-band (None)
Update P48 Data
Export Light Curve
PTFIDE Photometry
PTFIDE Photometry Queue (user = PTF, password = palomar)
PTFIDE Photometry Documentation
Fit SN Ia Light Curve

MLA Upgrade Performance

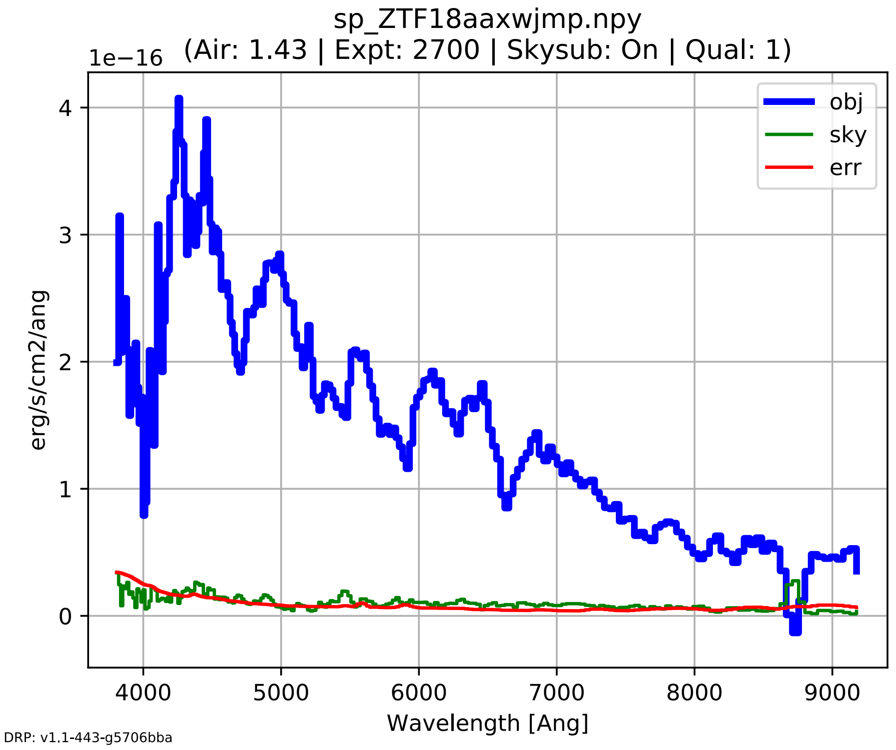
Old MLA: 2018 June 18

A/B pair 18.7 g mag 2700s



New MLA: 2018 June 20

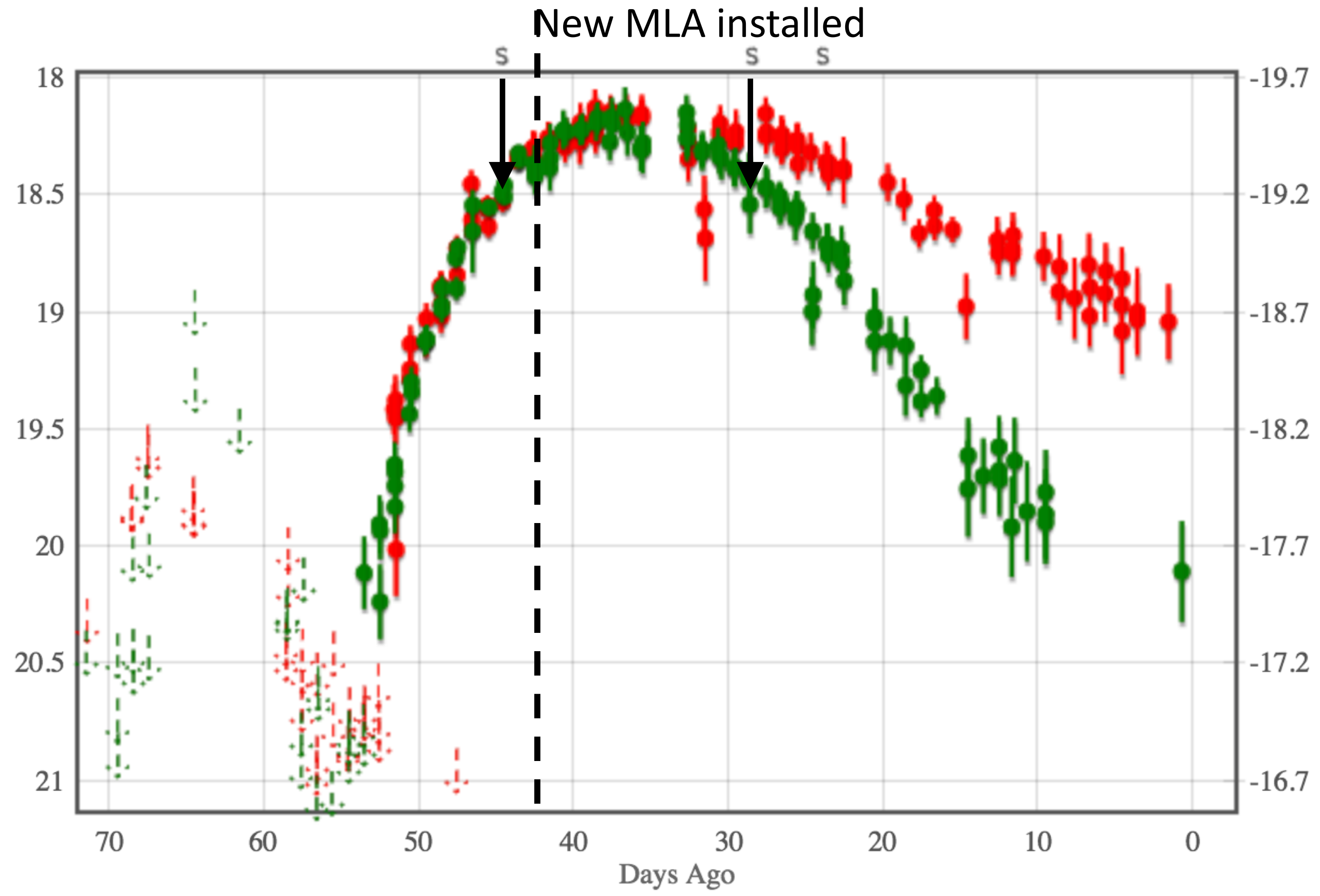
A/B pair 18.7 g mag 2700s



ZTF18aaytovs SN Ia 91T-like

17:45:53.40 +31:42:38.0
266.472504 +31.710562

OVERVIEW PHOTOMETRY SPECTROSCOPY OBSERVABILITY EXAMINE



Zoom Full
Auto Zoom

Select All
Clear Selection

- [x] P48 g-band (None)
- [x] P48 r-band (None)

Update P48 Data
Export Light Curve
PTFIDE Photometry

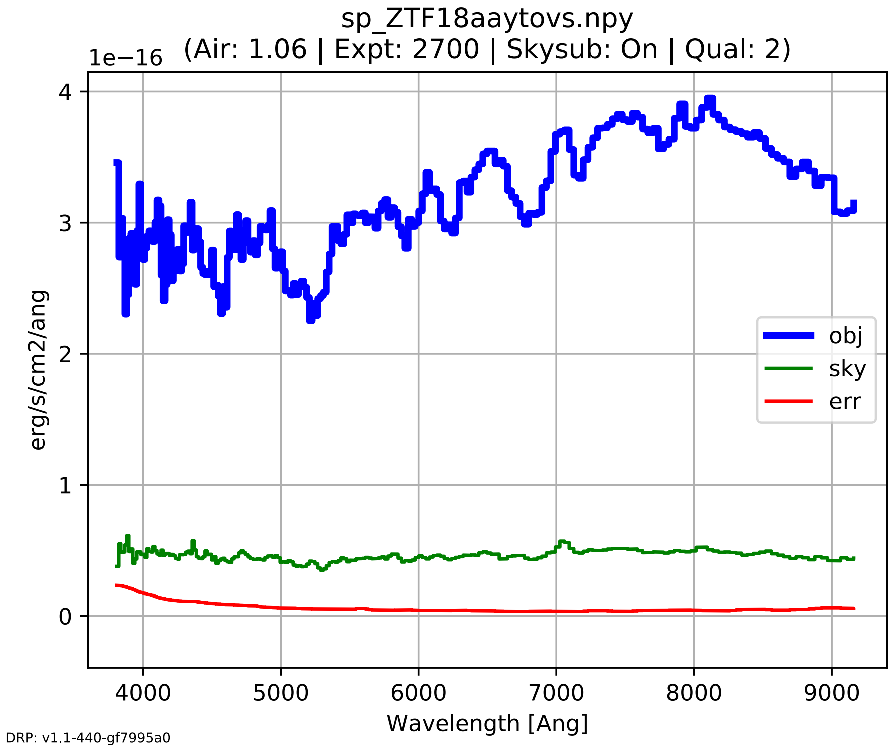
PTFIDE Photometry Queue (user = PTF, password = palomar)
PTFIDE Photometry Documentation

Fit SN Ia Light Curve

MLA Upgrade Performance

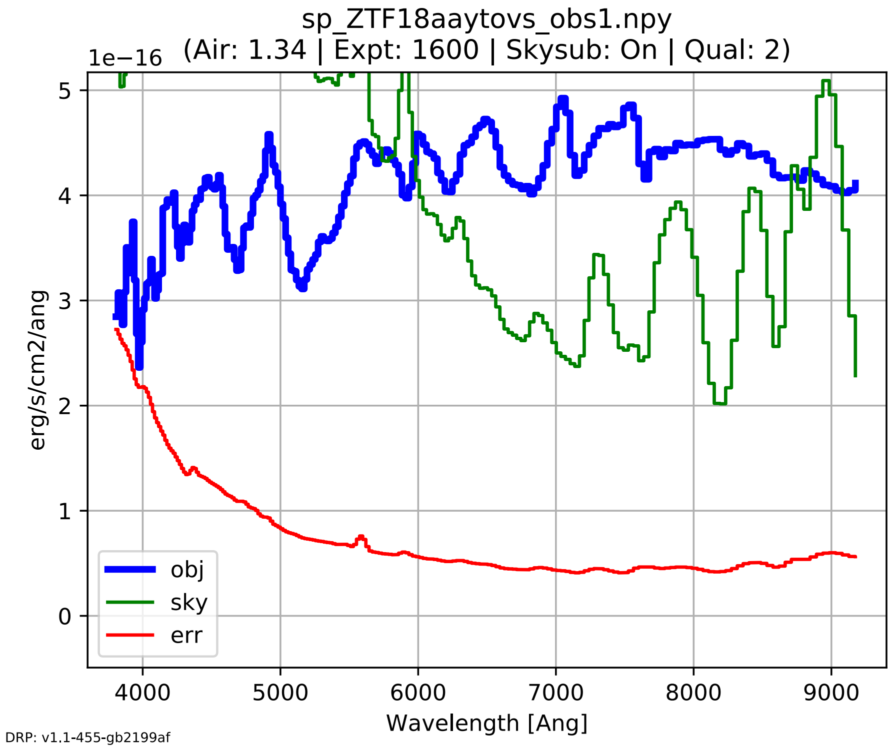
Old MLA: 2018 June 17

A/B pair 18.5 g mag 2700s



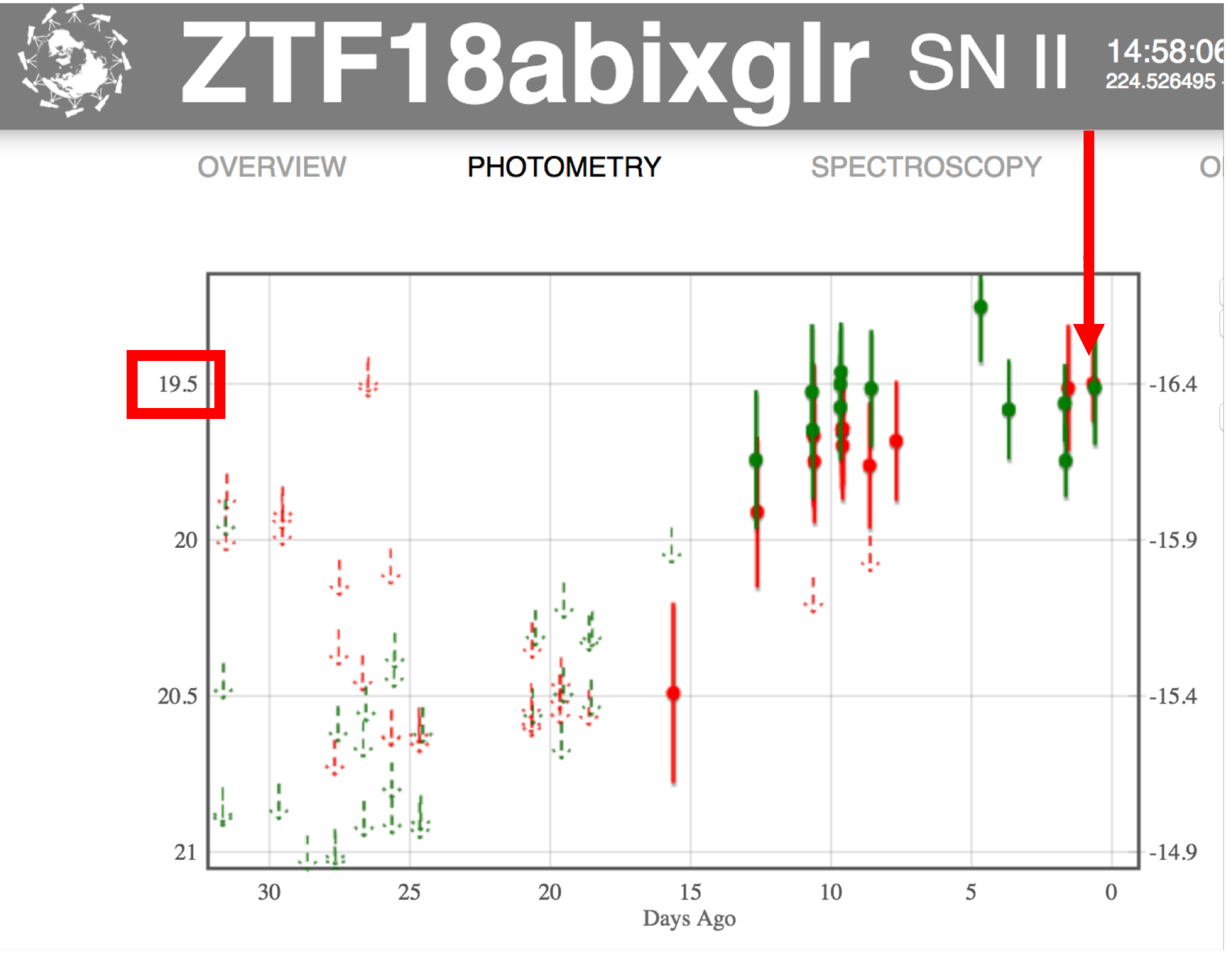
New MLA: 2018 July 03

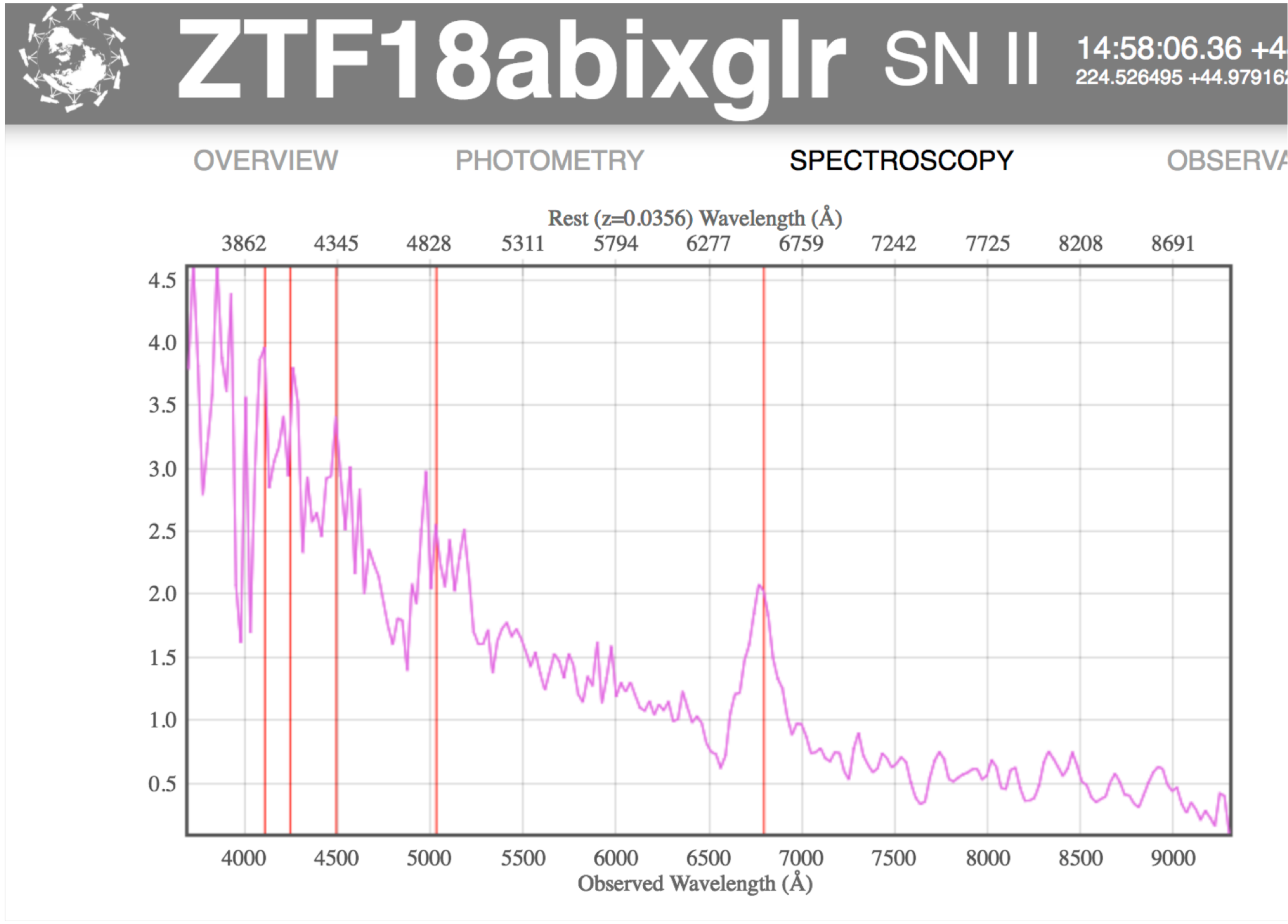
Single 18.5 g mag 1600s



Pushing fainter: ZTF18abixglr at 2430s

(instead of 2700s)



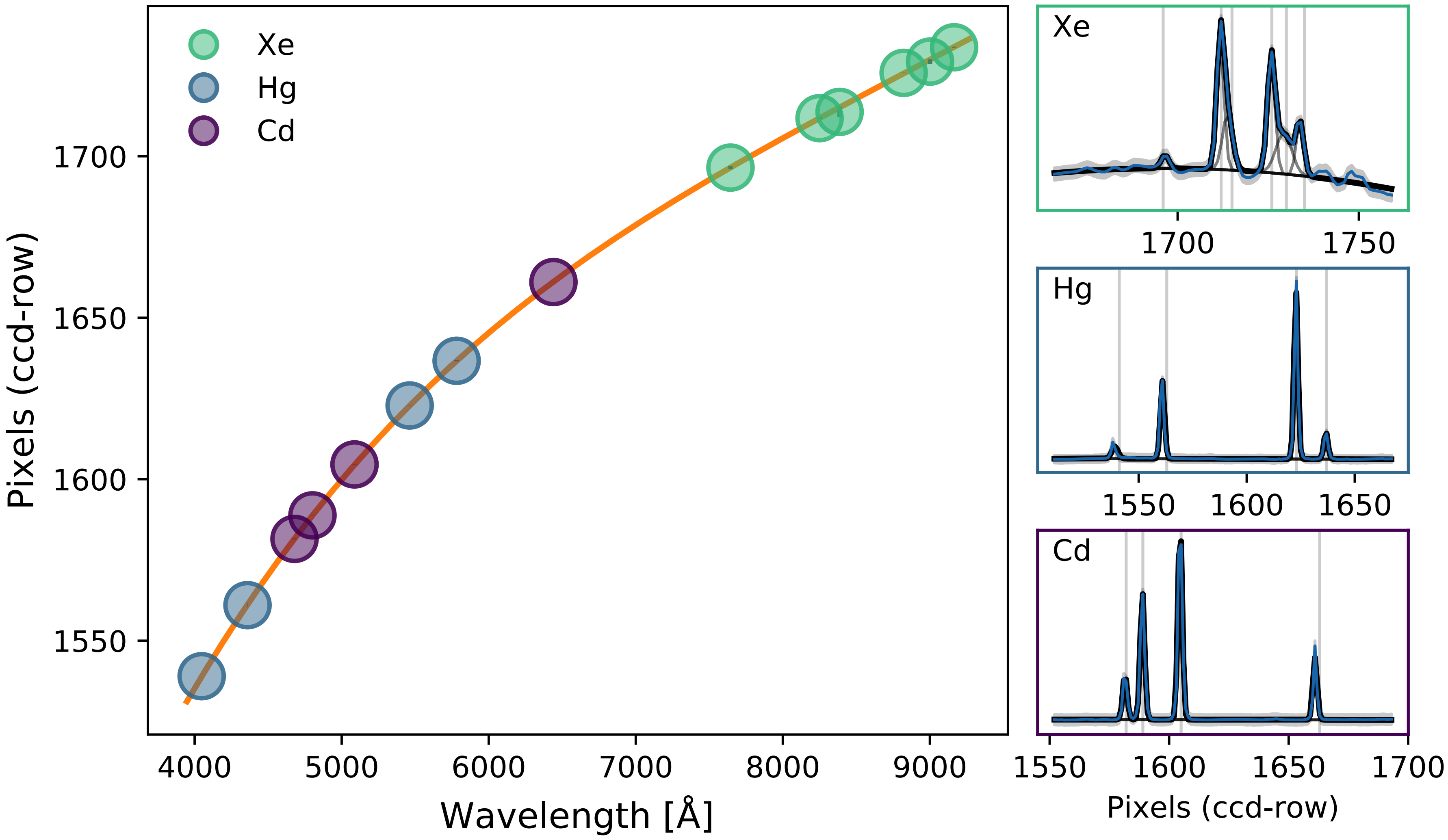


New SEDM Pipeline (pysedm)

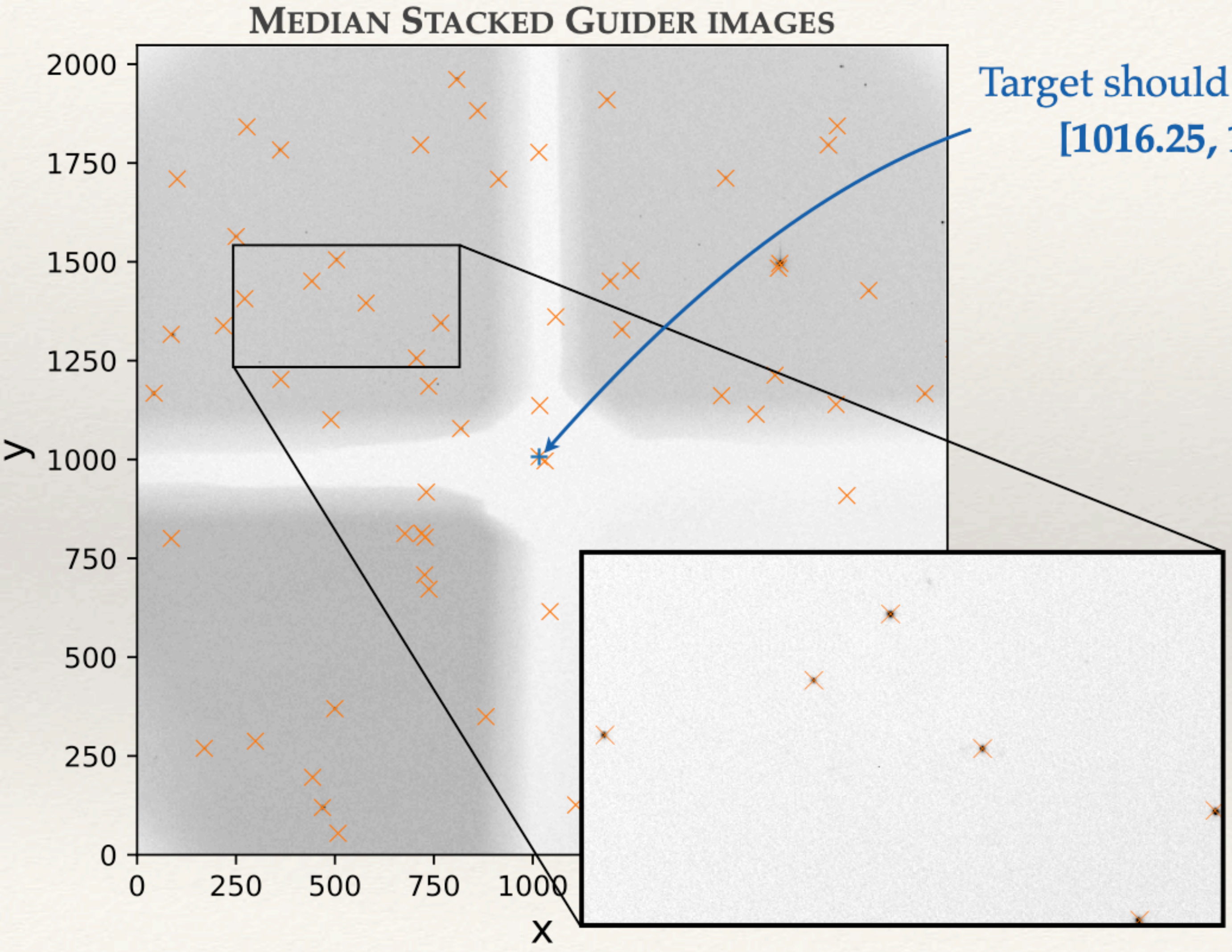
- Better wavelength solution
- Automated extraction location
- Telluric / DAR correction
- PSF extraction instead of aperture
- Integrated with astropy
- Based on SNIFs pipeline
- Github repository (MickaelRigault/pysedm)
- Rigault, Neill, et al. 2019 (in prep, subm. to ZTF pub board)

Wavelength Solution

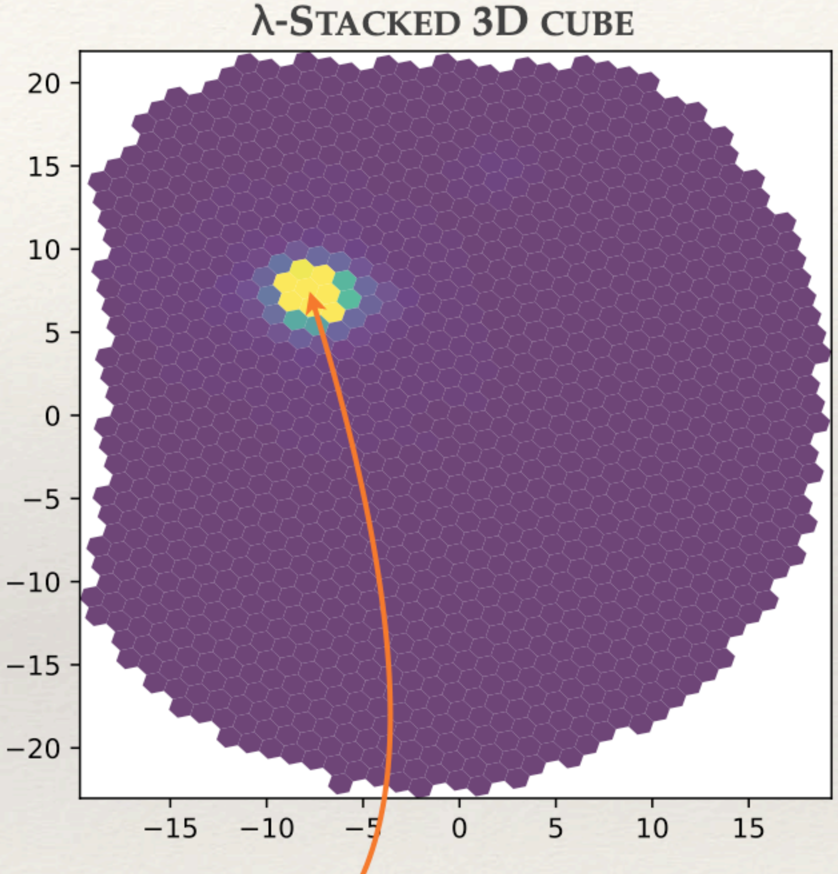
- Deblending
- More lines



Guessing IFU position | *use of guider images*



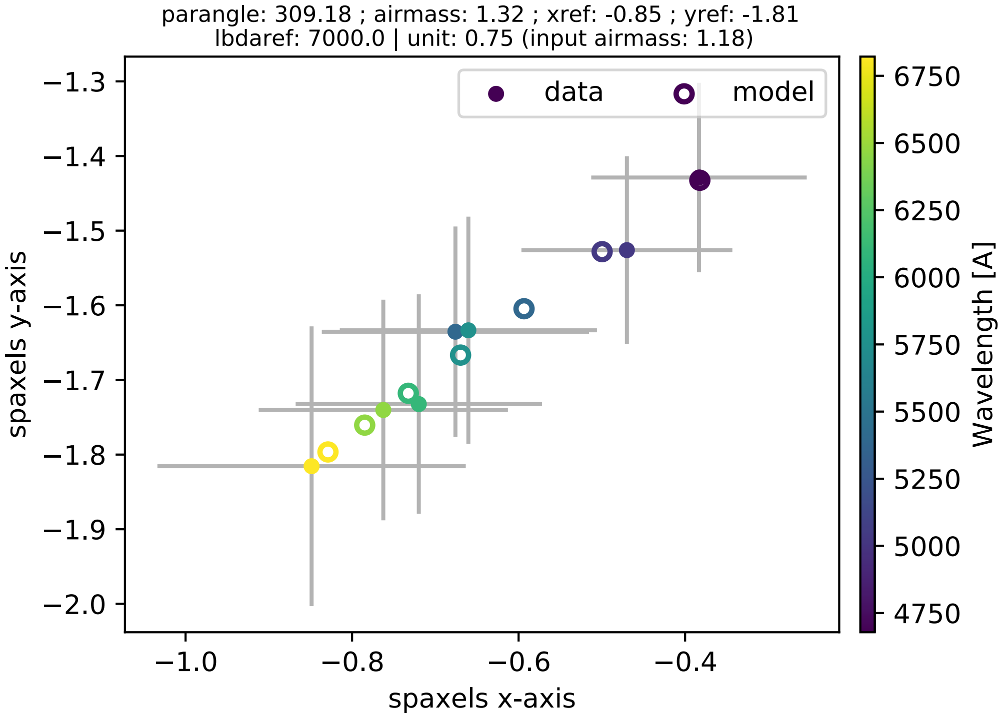
Target should be at pixels:
[1016.25, 1006.86]

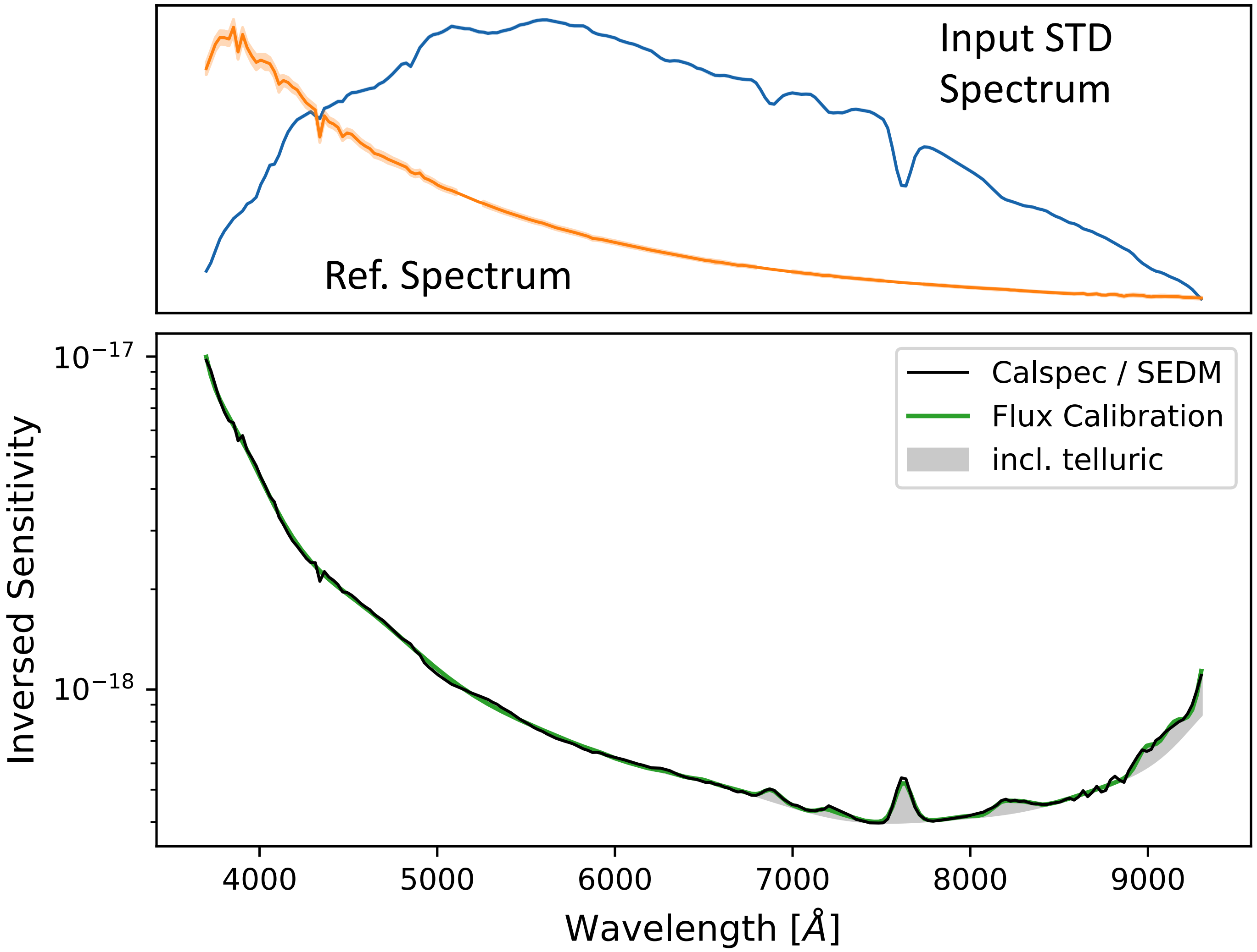


Fitted IFU position:
[-7.64, 7.36]

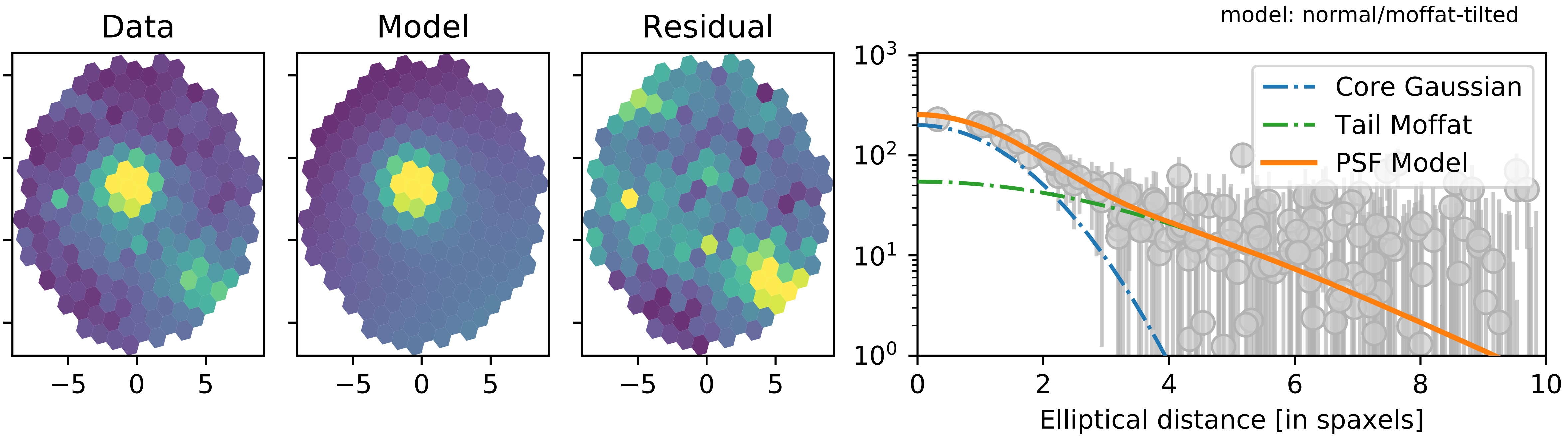
Telluric and DAR Corrections

- Telluric a function of airmass
- DAR fitted from data

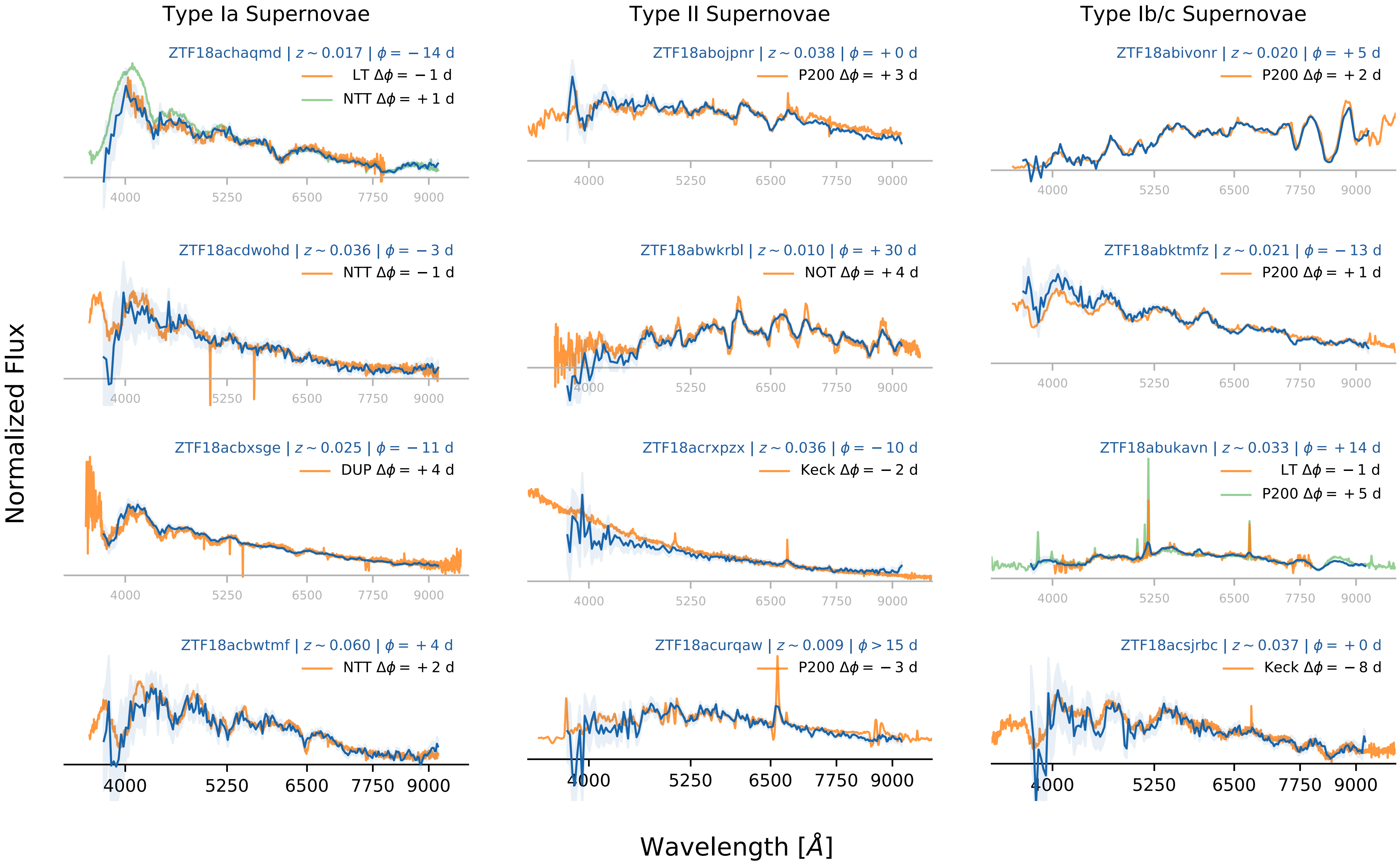




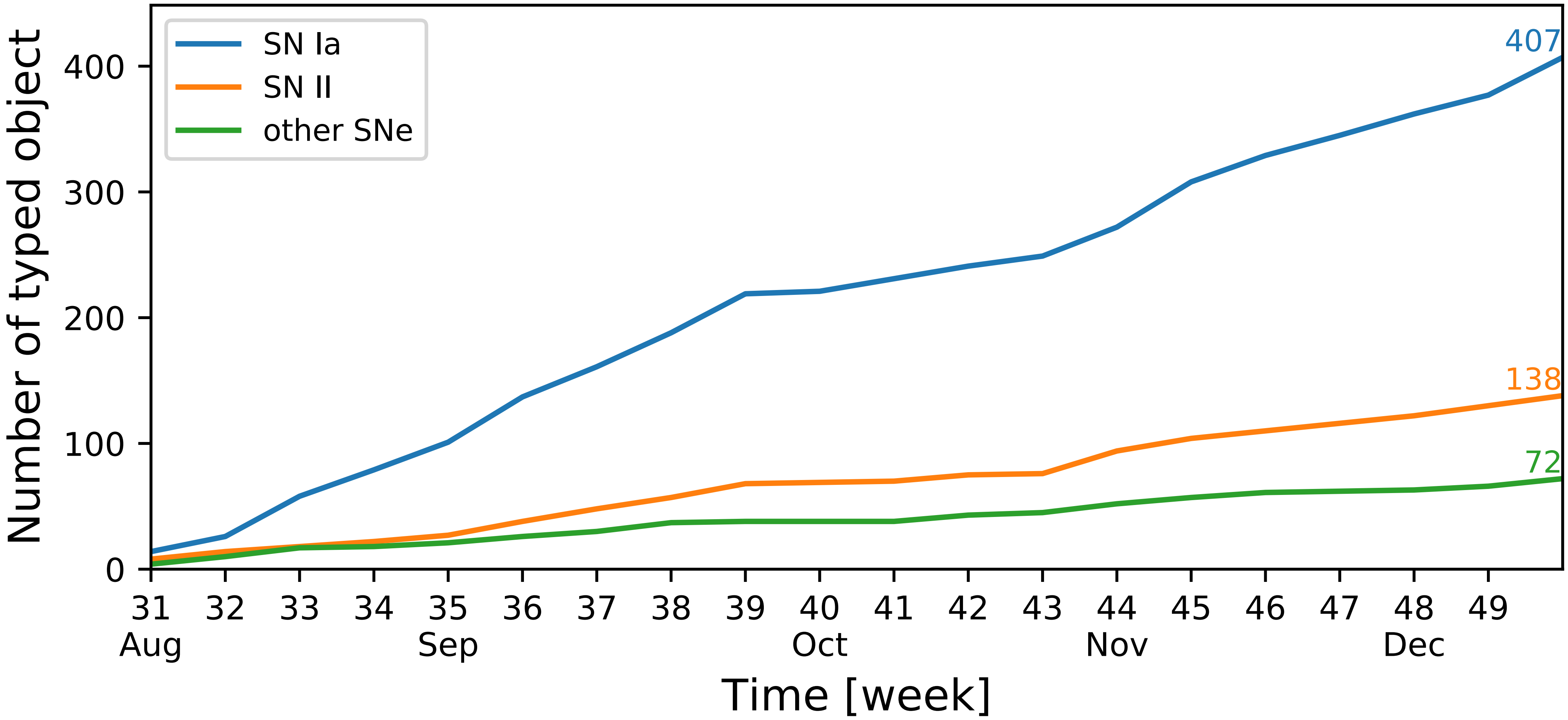
PSF-fitting Spectrophotometry



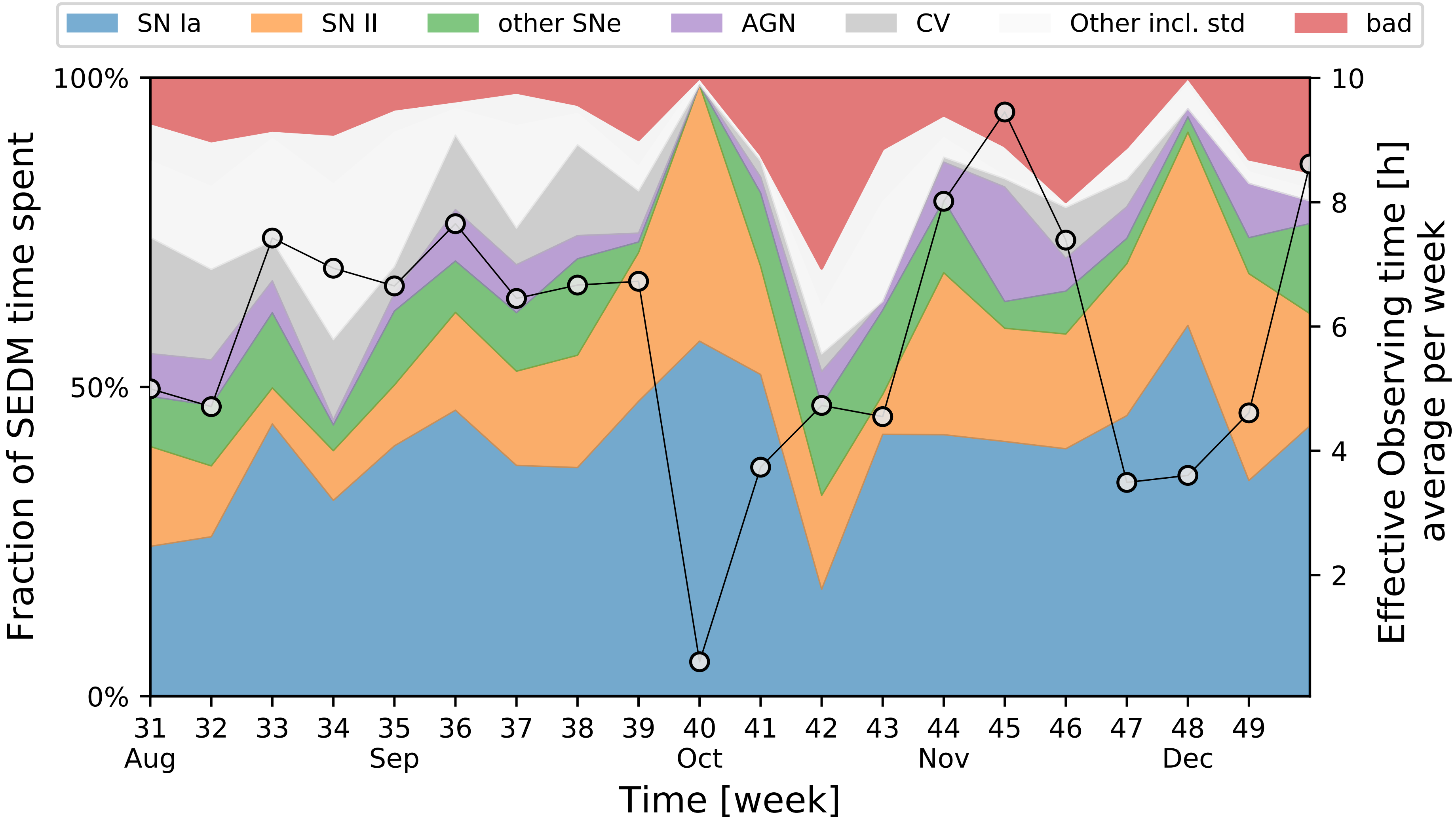
Comparison with other Spectrographs



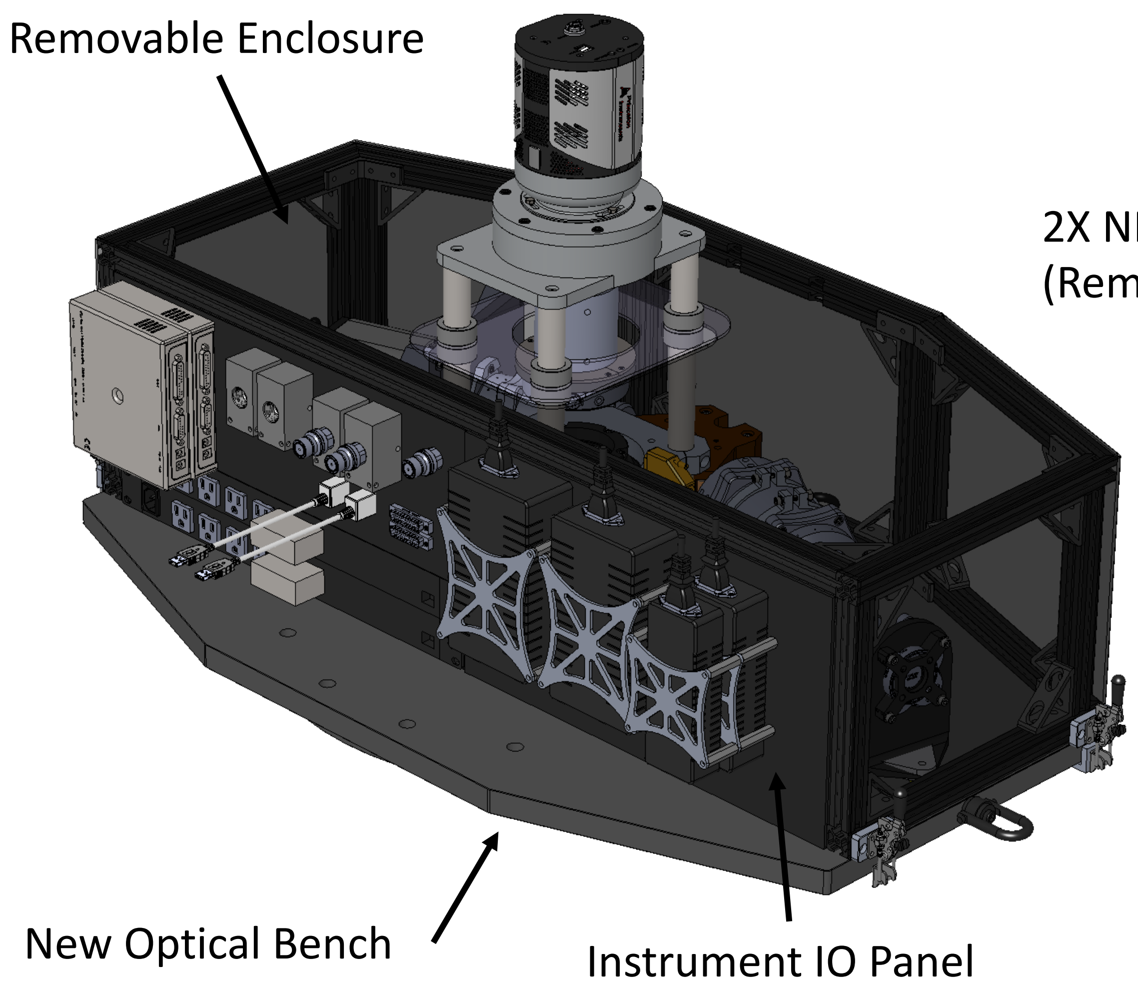
Resulting Classifications

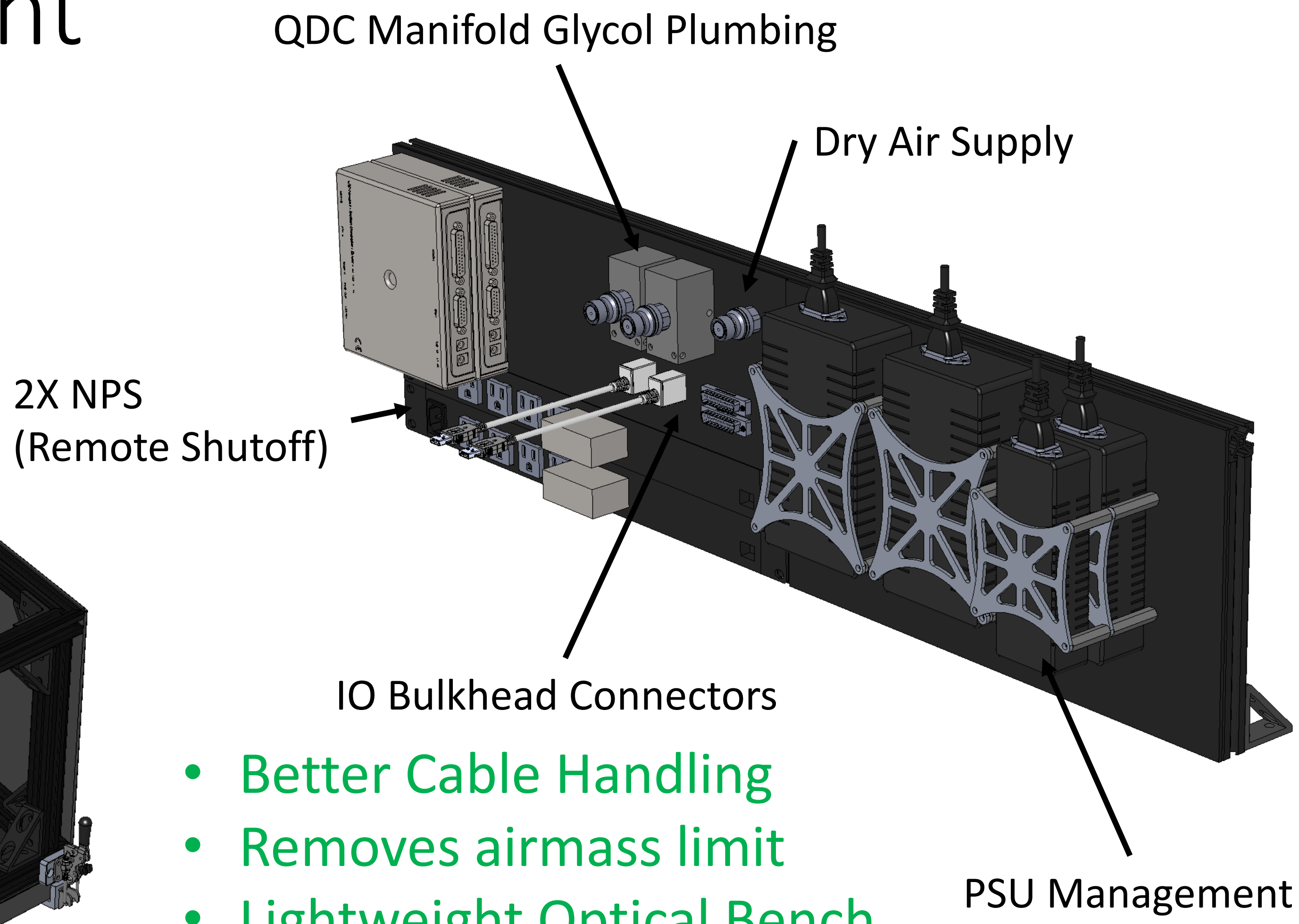


Classifications Distribution / Observing Time



SEDM: Enhancement





- Better Cable Handling
- Removes airmass limit
- Lightweight Optical Bench
- Easier/More Reliable Maintenance

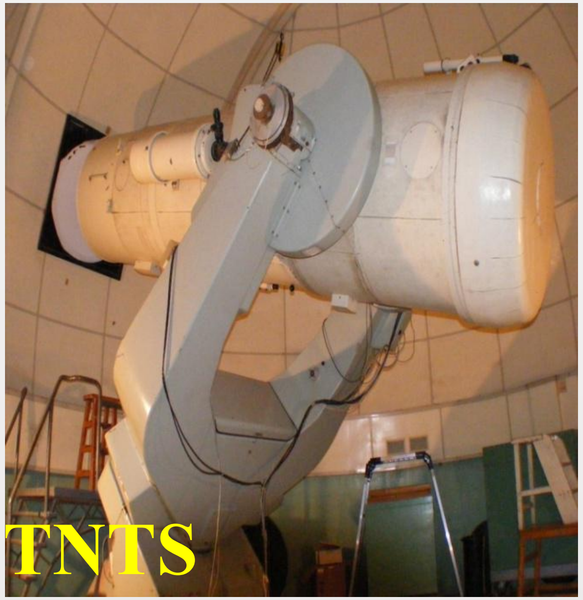
SEDM in production

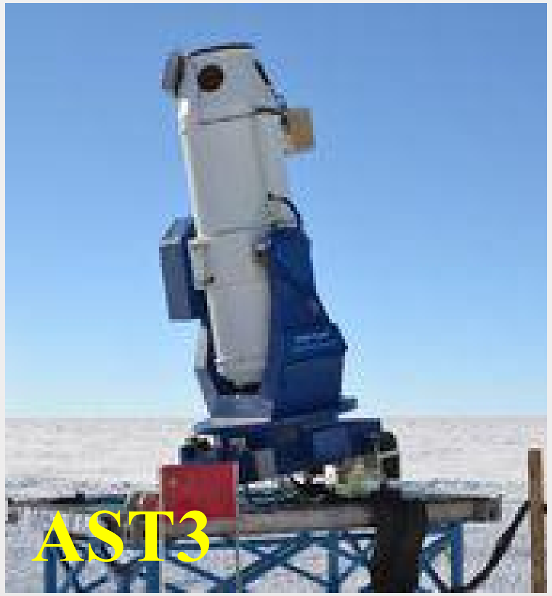
- Documentation
  - www.astro.caltech.edu/sedm
- Current status
  - pharos.caltech.edu/login
- New pipeline
  - github.com/MickaelRigault/pysedm

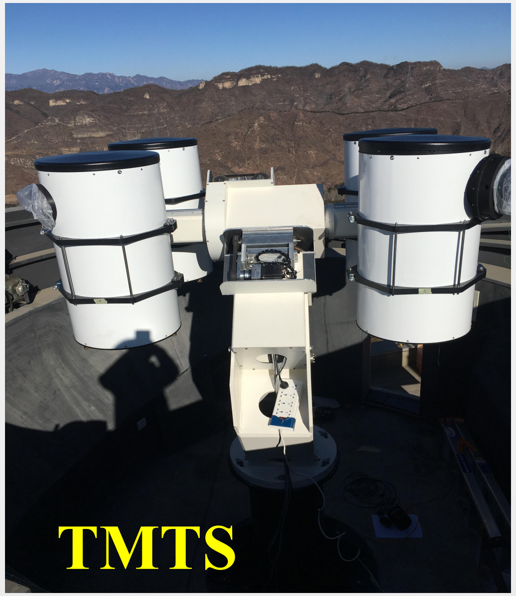
Transient Surveys in China: TNTS, PTSS and TMTS

Xiaofeng Wang
Tsinghua Unviersity

Tinghua-NAOC Transient Survey (TNTS)
Purple Mountain Observatory-Tsinghua Supernova Survey (PTSS)
Tsinghua Multitube Survey Telescopes (TMTS)







- 60/90cm schmidt
- 2.25 square degrees
- 4kx4k CCD
- 1.3 arcsec/pixel
- 20.0 mag (60s-exposure)
- unfilter

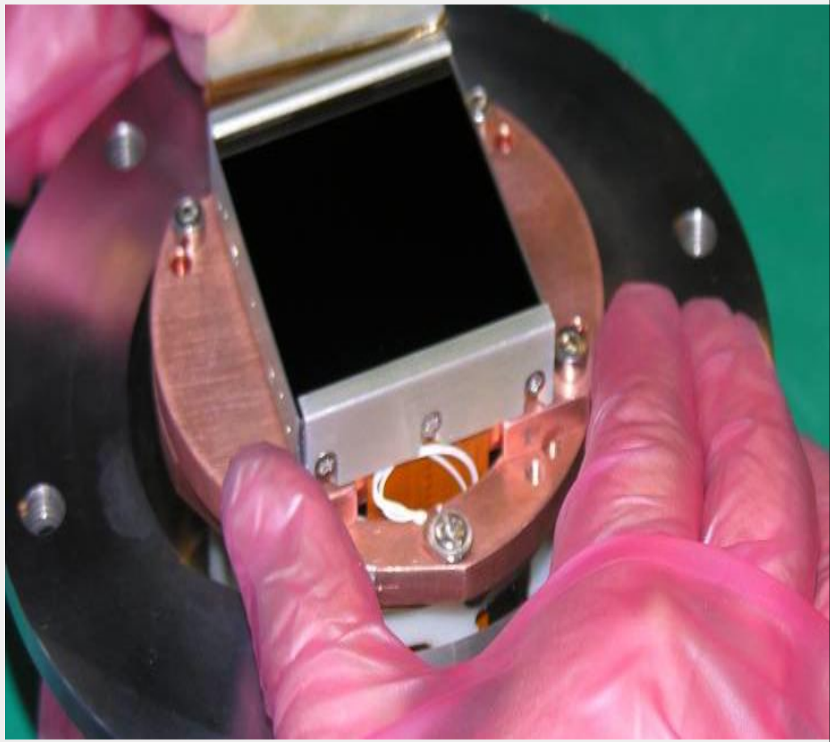
- 104/120cm schmidt
- 9.0 square degrees
- 10kx10k CCD
- 1.0 arcsec/pixel
- 20.5 mag (60s-i/r)

- 50/68cm schmidt
- 4.5 square degrees
- 10kx10k CCD
- 1.0 arcsec/pixel
- 18.5 mag (60s-i/r)

- Aperture: 4x40cm
- 20 square degrees
- Resolution: 1.8”/pixel
- Limited magnitude: 19.0 mag(30s白光)

Tsinghua-NAOC Transient Survey (TNTS)

60/90cm schmidt



Telescope: 60/90 cm f/3 Schmidt

CCD: E2V 4096x4096

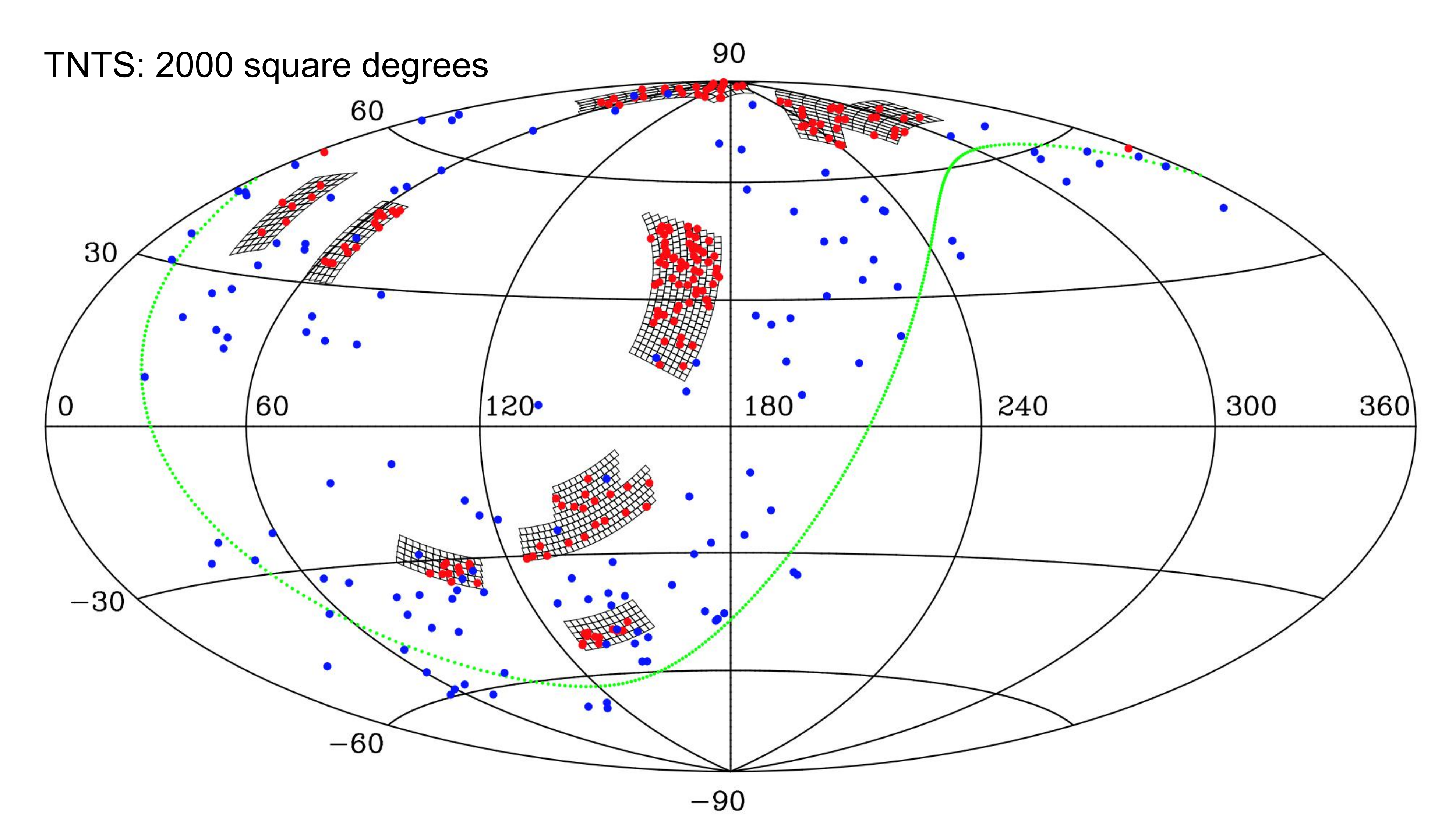
Blue sensitive 12um/pixel

Filters: 15 intermediate bands

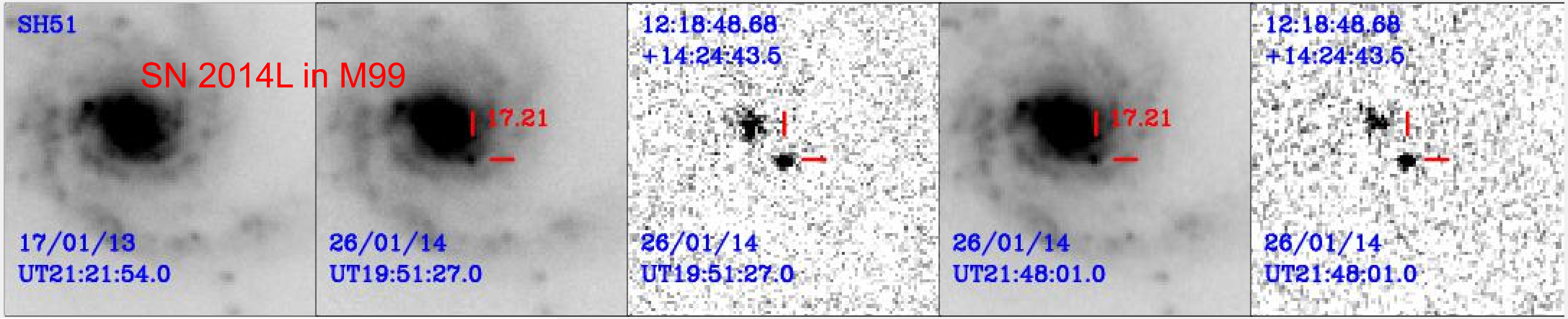
The field of view: 2.45 square degrees

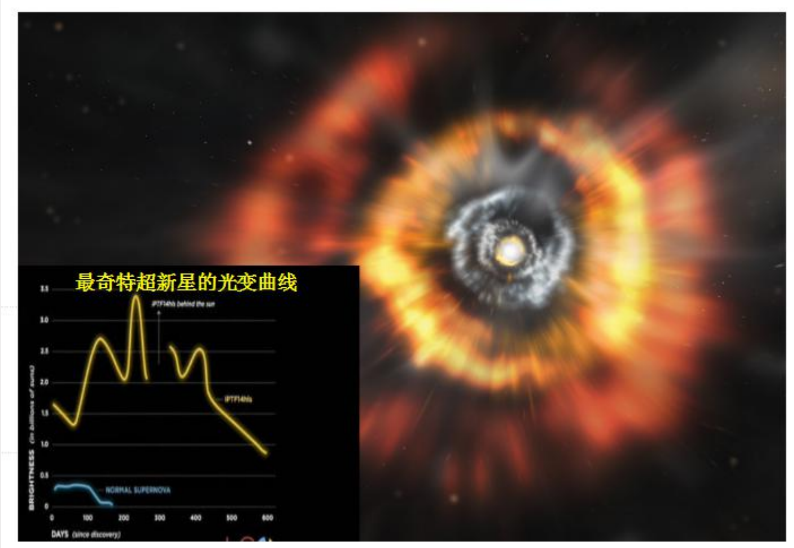
can be upgraded to 20 square degrees

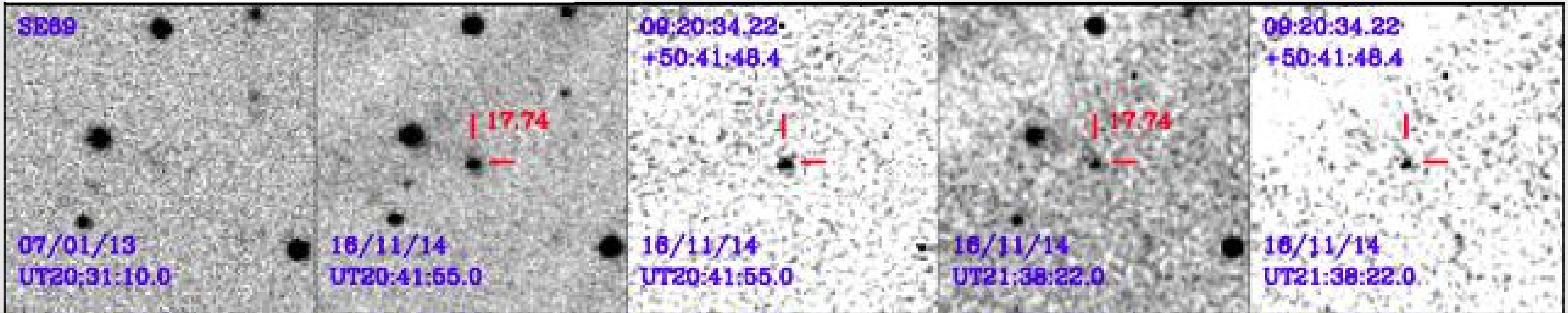
Supernovae discovered by TNTS



SN 2014L in M99



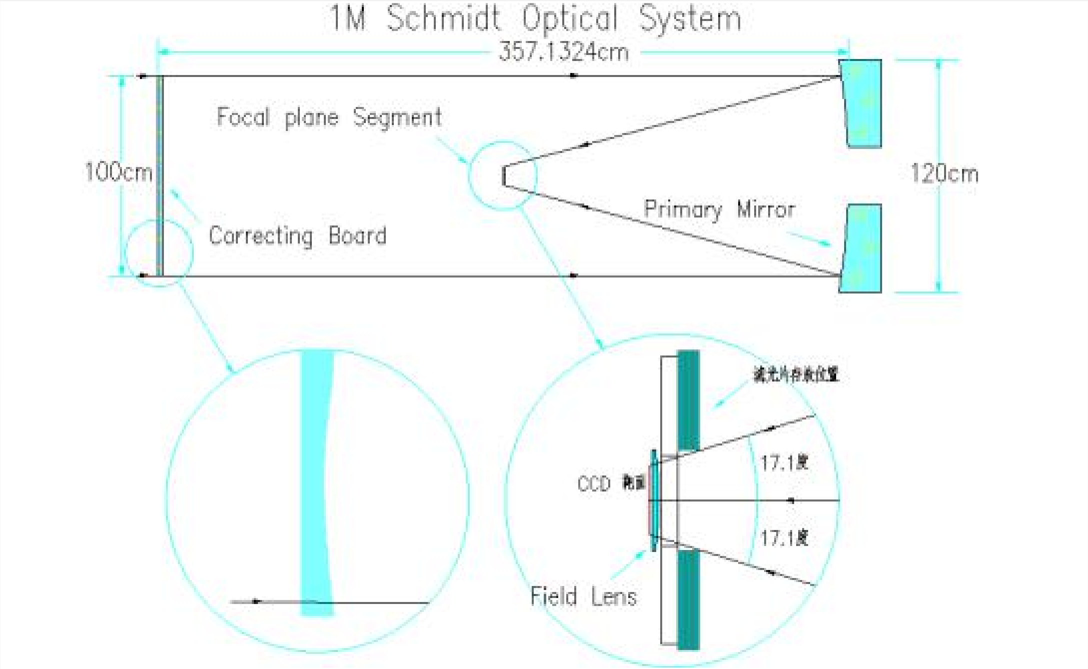


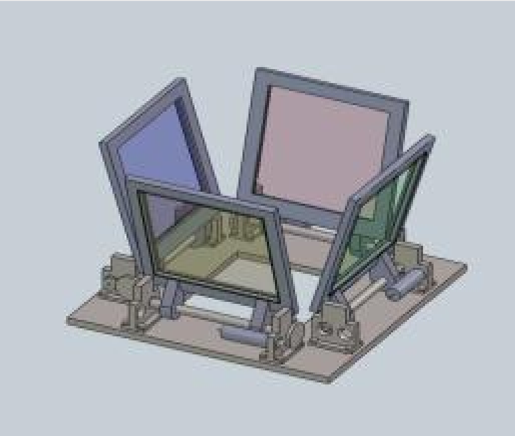


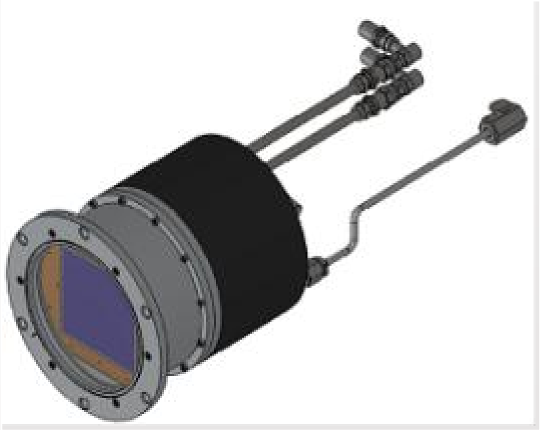
PMO-Tsinghua Supernova Survey (PTSS)

- Location: 118.465° E, 32.737° N
- Sea level: 219m
- Observable night: 194
- Average seeing: θ ~ 2″
- Night Sky Brightness: 22.1 (g), 21.2 (r), 20.4(i)
- Temperature: -20o— +40o
- Wind Velocity: <20 m/s
- Good seeing and sky background

Optical System of CNEOST







- Telescope Parameters
    - Corrector: 1.0m
    - Primary Mirror: 1.2m
    - Focal length: 1.8m
- CCD Camera 1(STA-10K-CCD)
    - CCD像元:10Kx10K
    - pixel size: 9ux9u
    - FOV: 9 Sq.d
    - resolution:1.03"/pxl
- Limited magnitude(3sigma)
    - r~20.5 mag @ 60s
- Filters
    - SDSS: g/r/i/z
    - Bessel: B/V/R/I/V+R
    - Narrow Band: SII/OIII/H_α

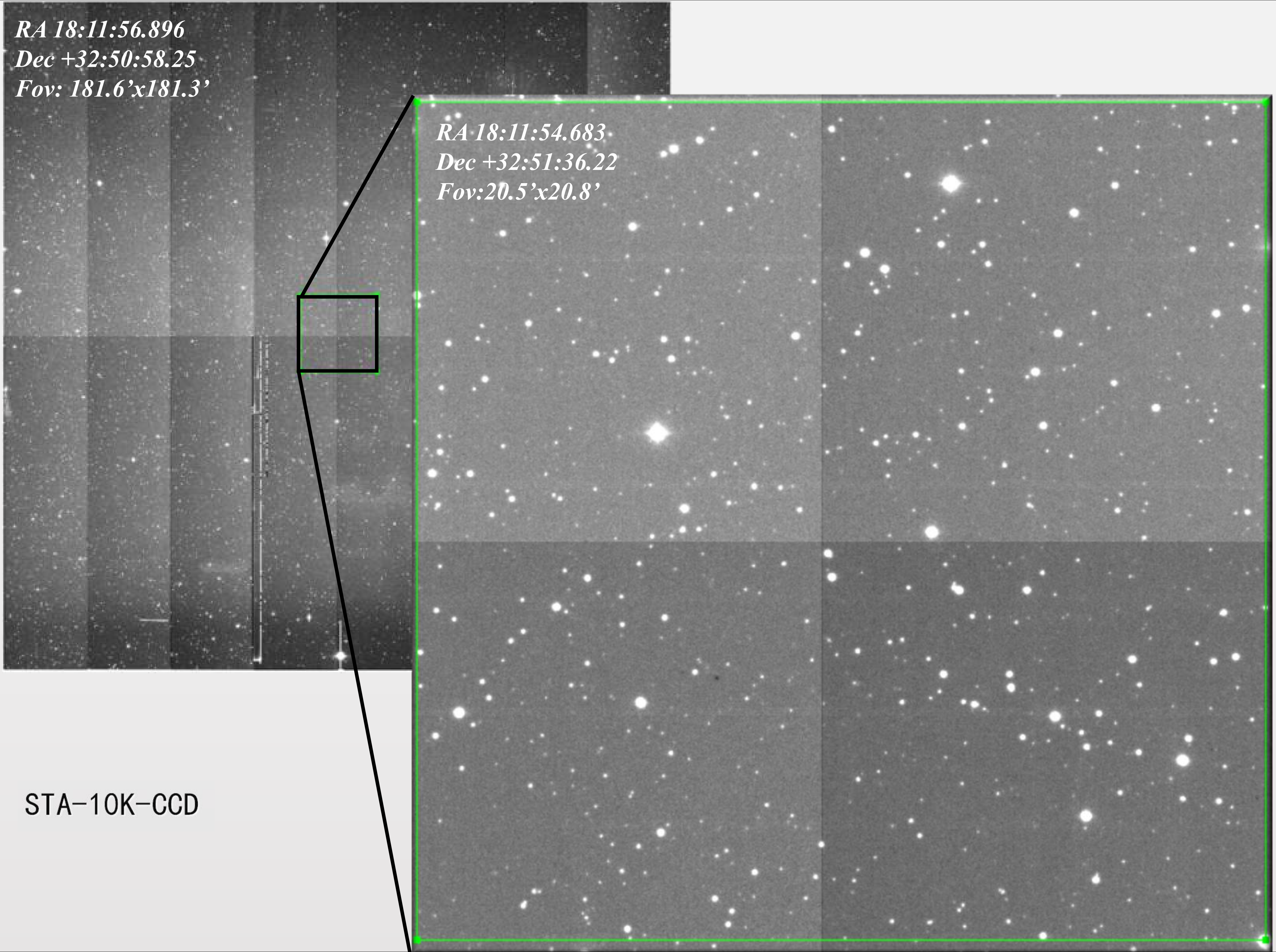
CNEOST观测系统

- 望远镜参数
  - 改正镜：1.0米
  - 主　镜：1.2米
  - 焦　距：1.8米

- CCD相机1(STA-10K-CCD)
  - CCD像元：10Kx10K
  - 像元尺寸：9ux9u
  - 单帧视场：9 Sq.d
  - 分辨率：1.03"/pxl
- CCD相机2(SI-4K-CCD)

- Limited magnitude(3sigma)
  - r~20.5 mag @ 60s

- 滤光片系统
  - SDSS：g/r/i/z
  - Bessel：B/V/R/I/V+R
  - 窄带：SII/OIII/H_α


RA 18:11:56.896
Dec +32:50:58.25
Fov: 181.6’x181.3’
RA 18:11:54.683
Dec +32:51:36.22
Fov:20.5’x20.8’

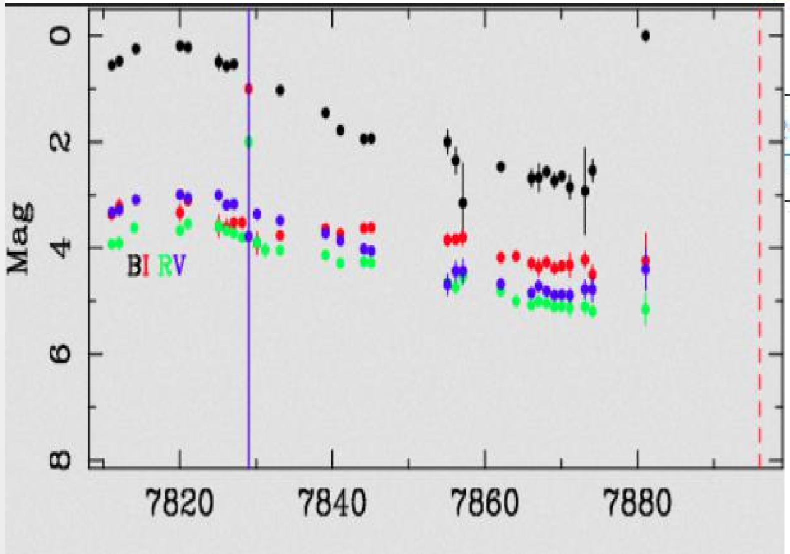
STA-10K-CCD

Database system of PTSS

PTSS Name : PTSS-18kce
Robey Yes Prob: 0.995831
OBS-DATE : 2018-10-26 19:55:14
RA : 09:02:00.40
DEC : +12:21:22.65
Mag : 18.472 +/- 0.067
VIP label : sn
Near source (PPMXL) : 3.8595 arcsec.
Identified by: hanjie

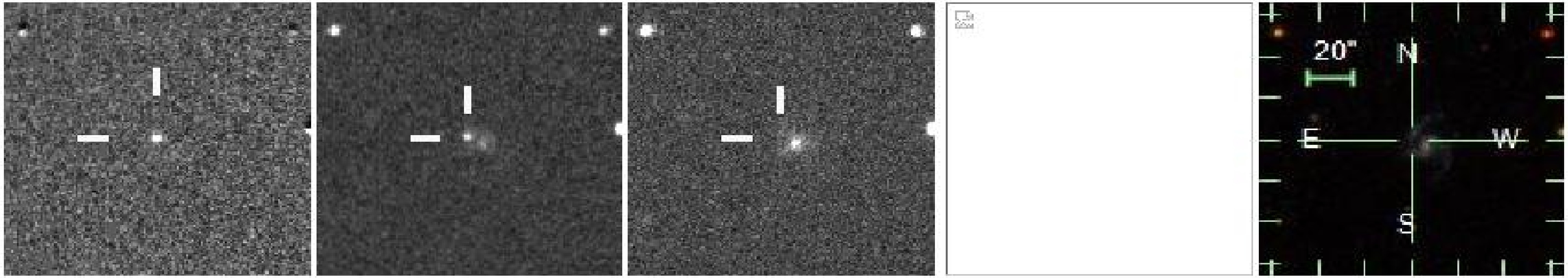
Comments (Time in UT)

comment Push



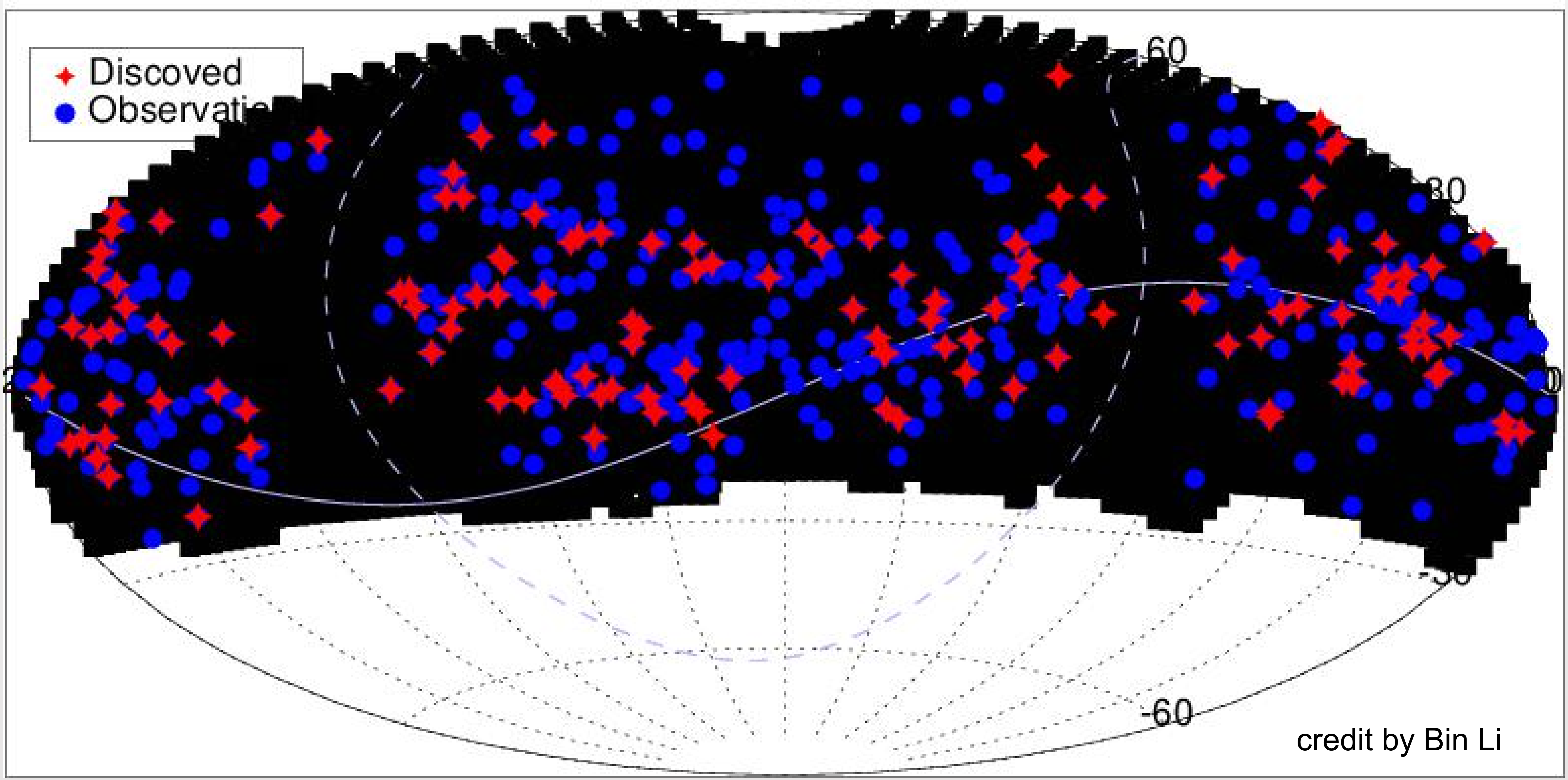
--other PTSS NAME ----------------------------
018-11-09T20:13:49.470 18.3732
'SS-18kce @ 2018-10-26 18.4727

Check: SDSS
Check : MPC
Check : Simbad
Check : NED
Check: AAVSO
Check : Vizier
Check : TNS
Check : PanSTARRS
link : OSC
link : Latest SN

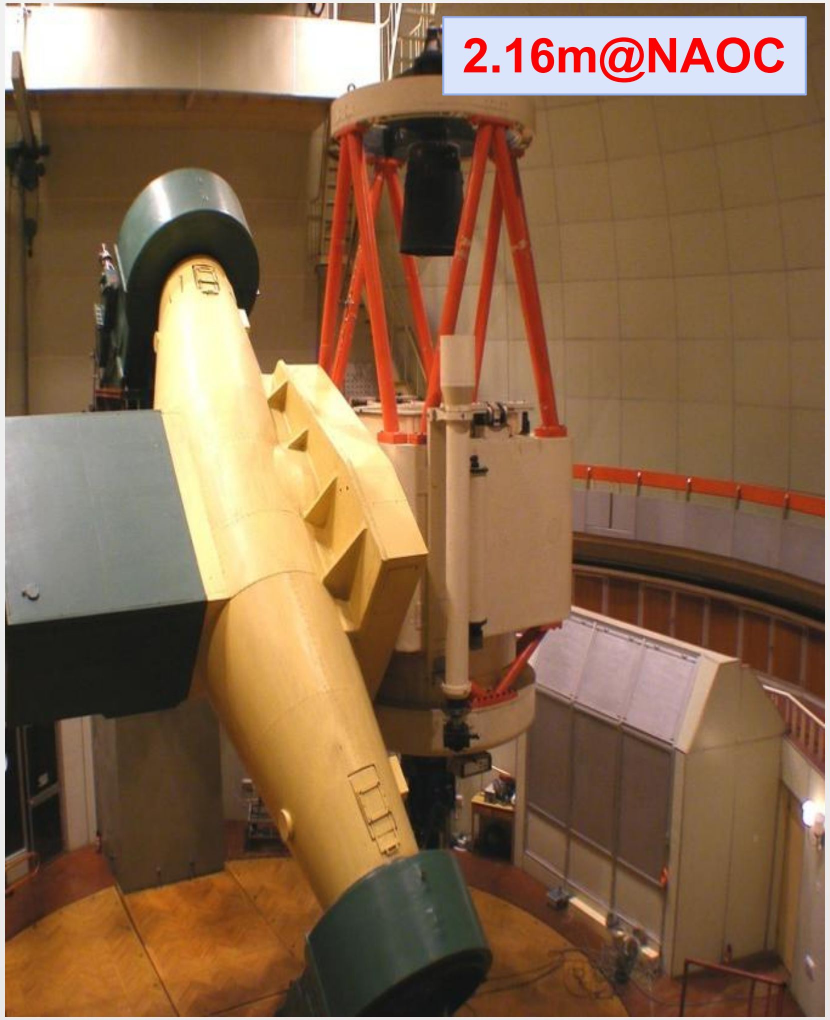


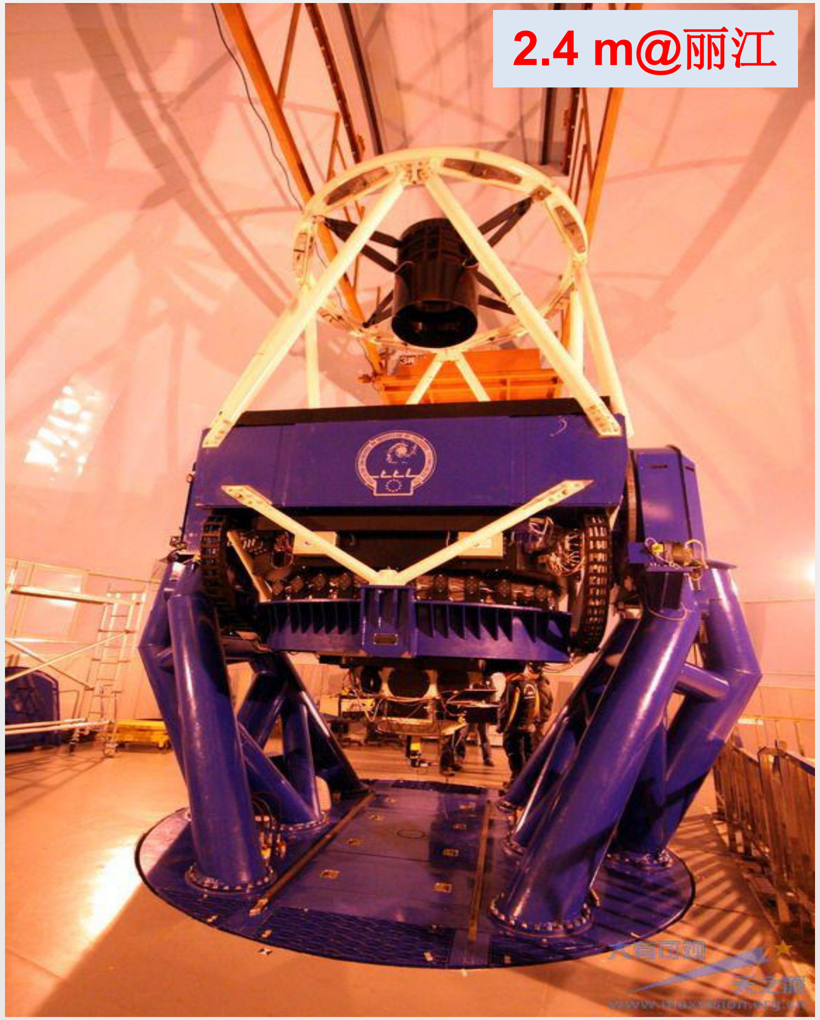
Tempfilename: L20151220_03420_085923+1235_60S_VR_109824.FITS
Fitsname:L20181026_09418_085926+1235_60s_VR_311126.fits
get sub fits get obs fits get temp fits

Supernovae discovered and observed by PTSS



Follow Up Facilities





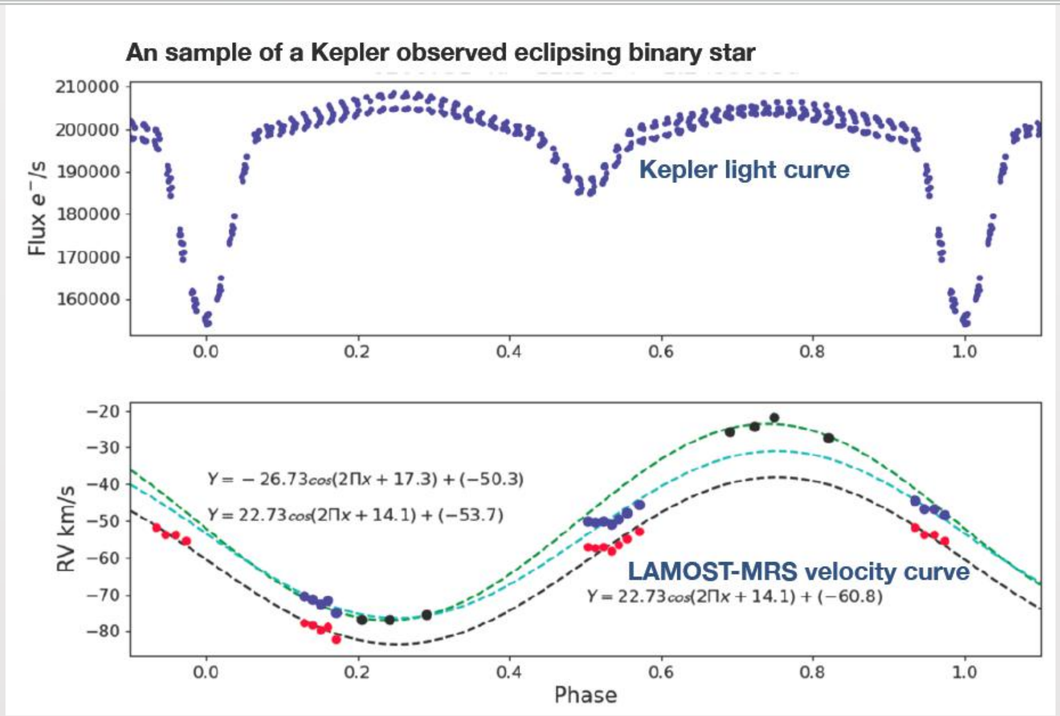
Tsinghua Multi-tube Survey Telescope

- Aperture: 40cm
- FOV: 4x5 square degrees:
- Resolution: 1.8”/pixel
- 4x4K CMOS
- Limited magnitude: 19.0 mag(30s)

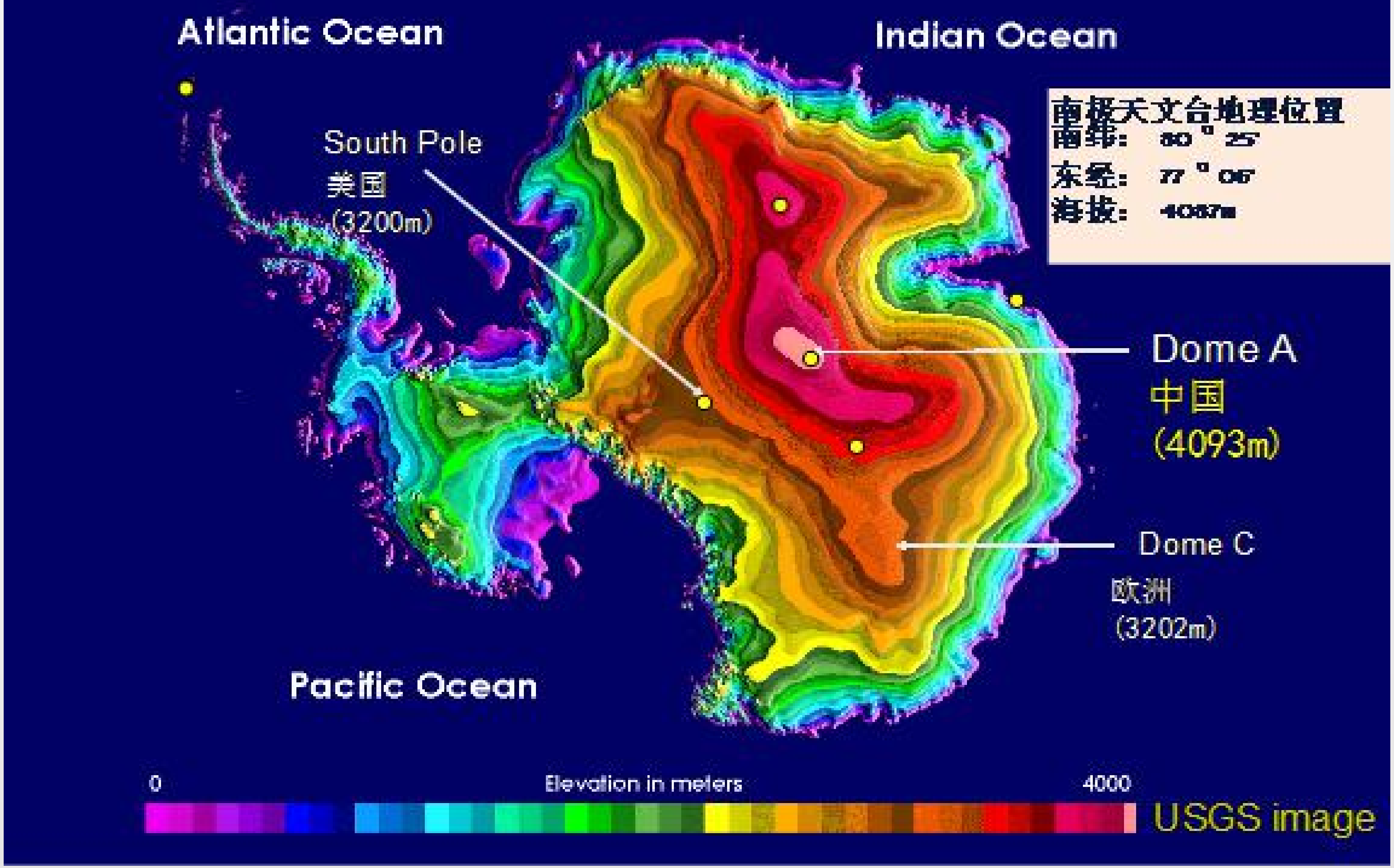
Sciences:
- Supernovae, GRB
- flare stars,compact binary
- AGN, TDE,
- EM counterparts of Gravitational wave

~2500 square degrees/10 hours（4 bands）
~10000 square degrees/10 hours (1 band)

Synergy with Lamost II for Time-domain Sciences

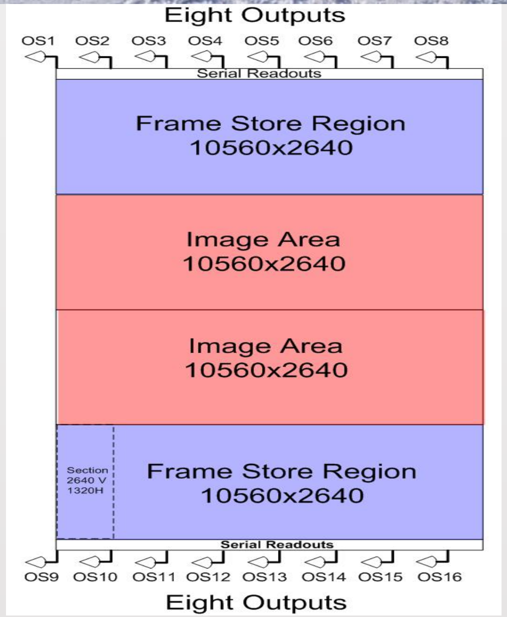


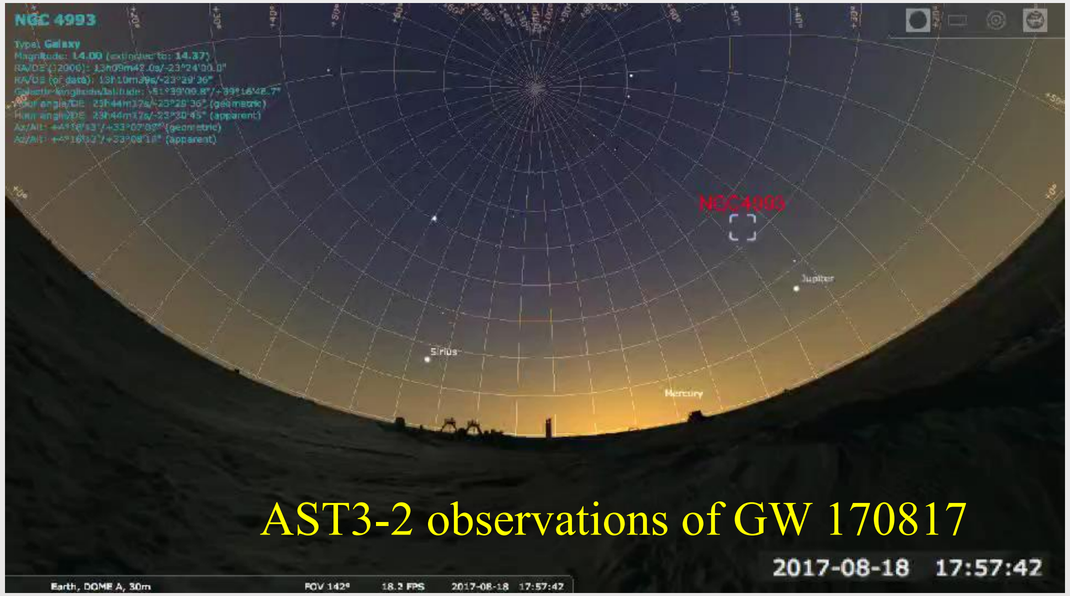
Chinese Antarctic Observatory



Telescopes at Dome A:
Antarctic Survey Telescopes (AST1, AST2, AST-3)

Site: Dome A, Antarctic
Telescope: 50/68cm Schmidt
Detector: 10k*10k STA1600-FT,
9micron/pixel, 1arcsec/pixel,
FOV: 1.46x2.93
No shutter: Frame Transfer CCD.





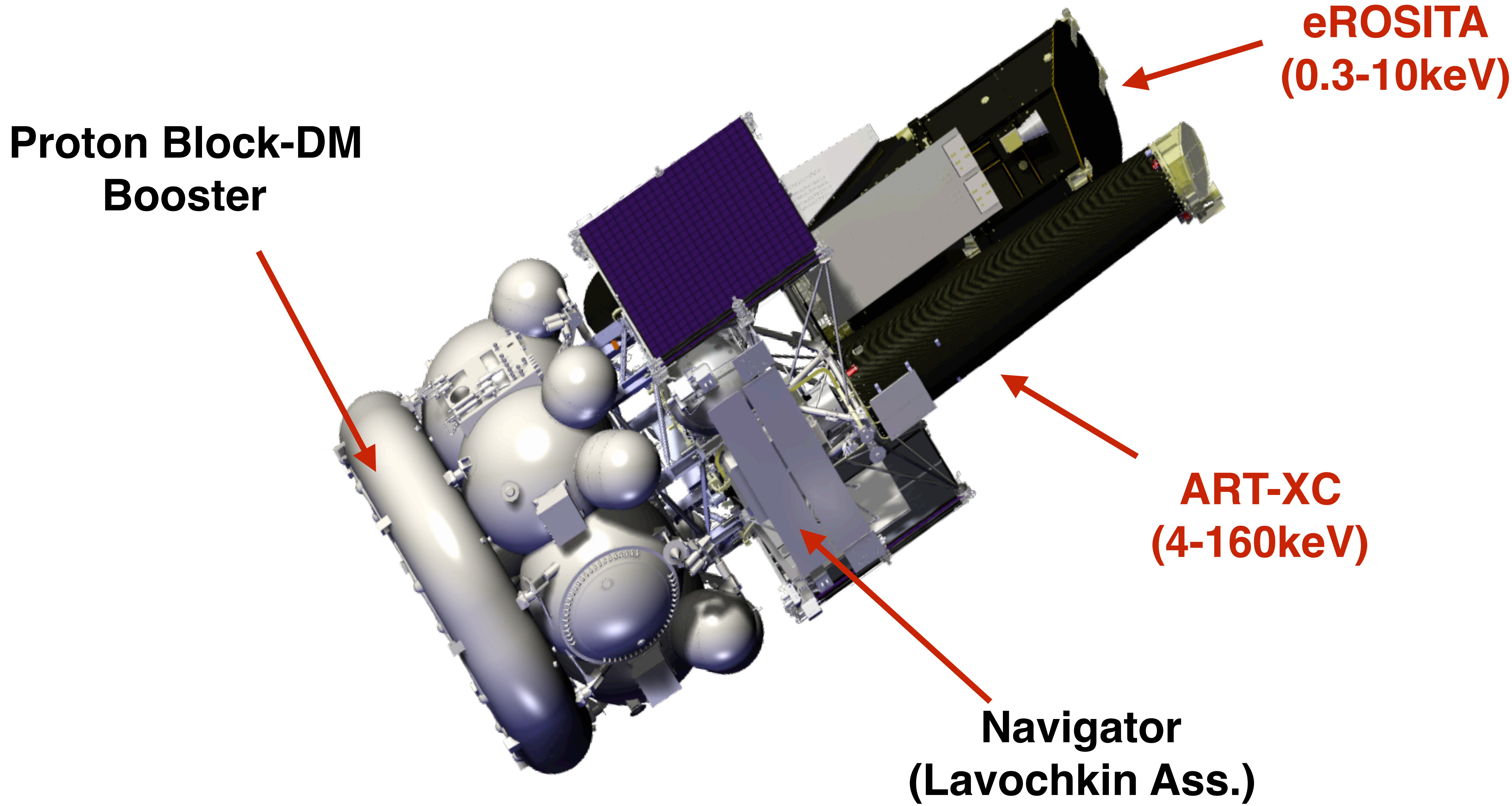
Spectrum-Röntgen-Gamma (SRG)

Overview for TDA-MMS Meeting (2018 Feb 8-10, Tokyo/Nikko)

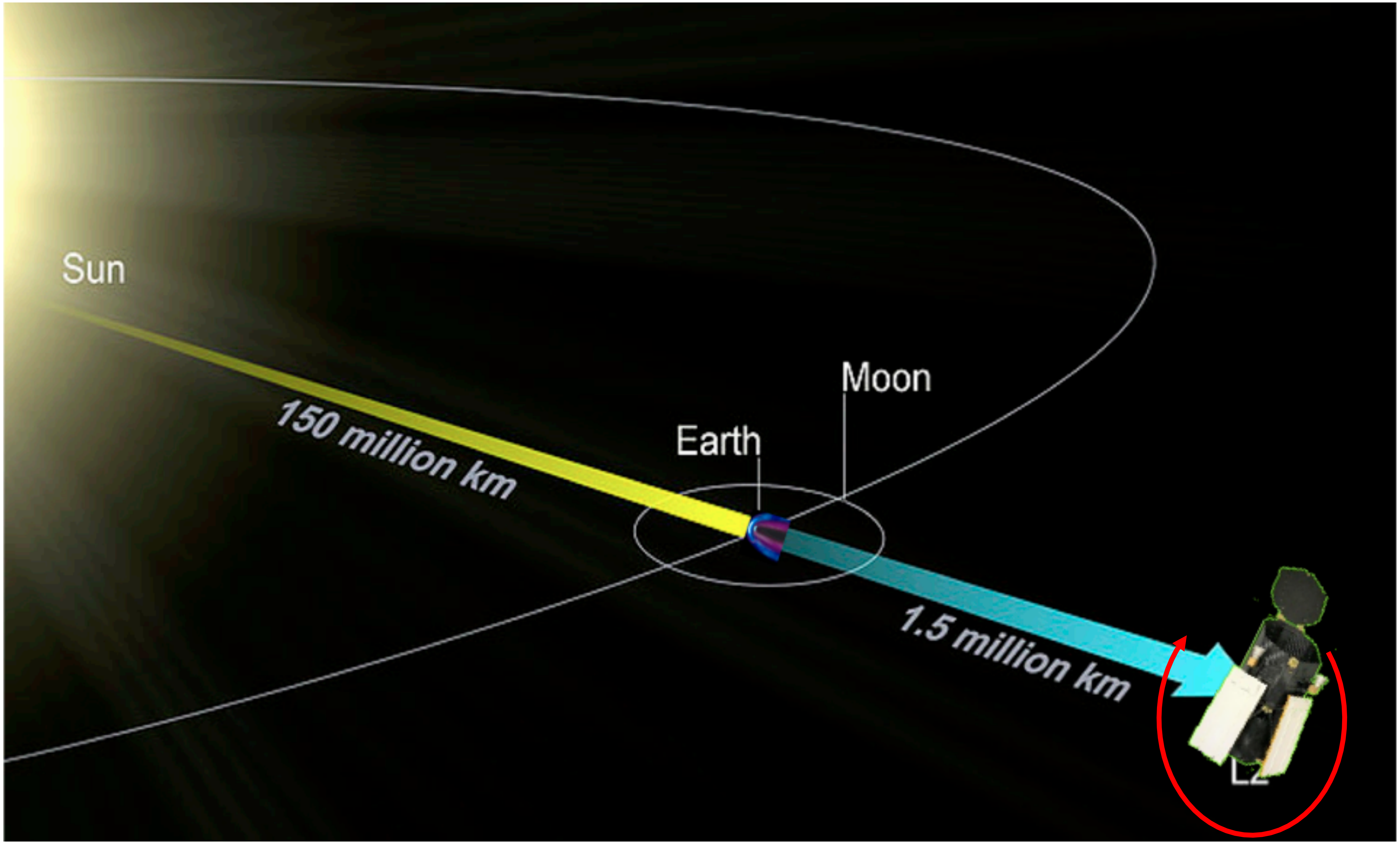
Prepared by Arne Rau (MPE)

SRG: overview

SRG - Russian satellite with two scientific instruments: eROSITA lead by MPE (Germany), and ART-XC lead by IKI (Russia). To be launched from Baykonour in 2019.

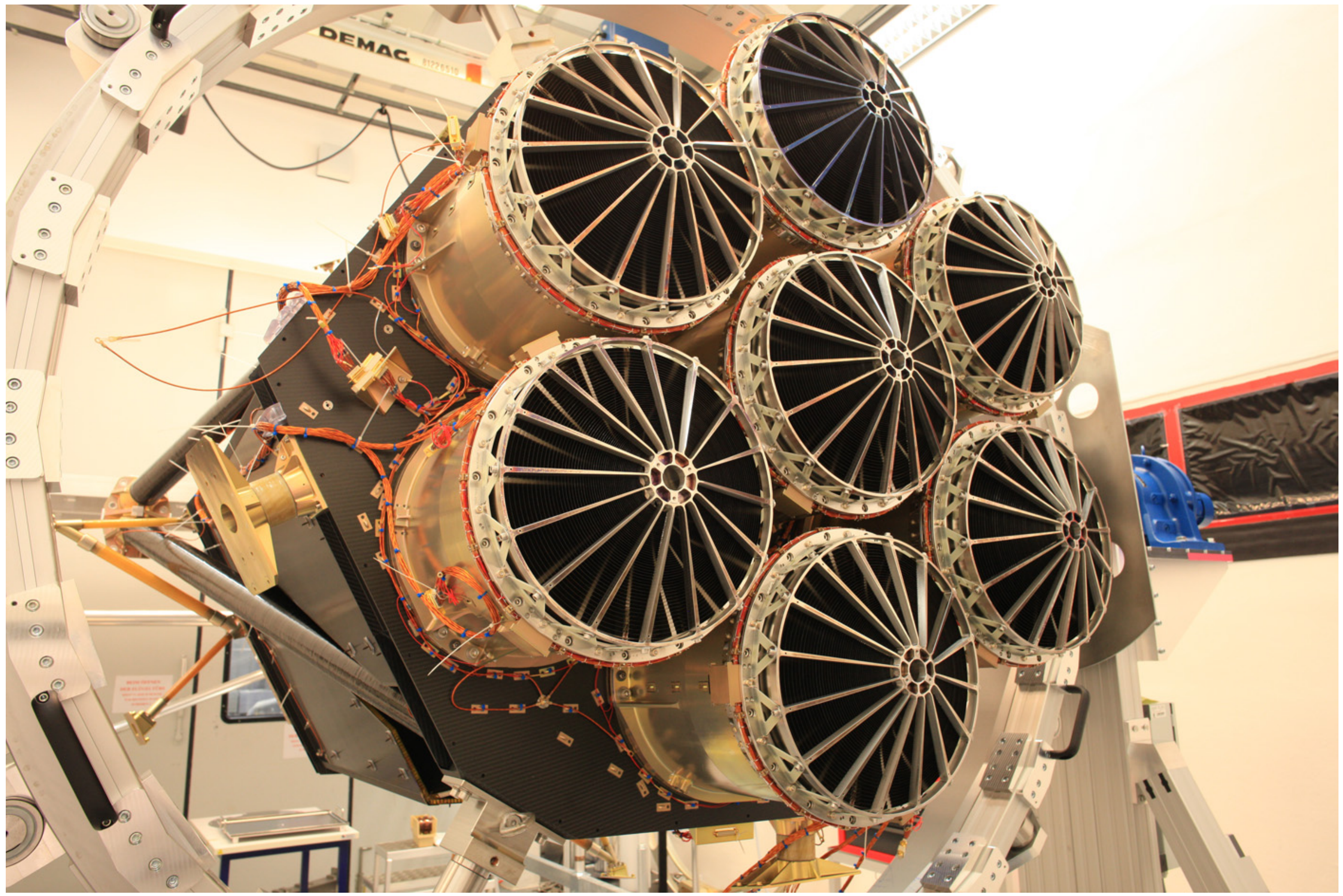


SRG: orbit (L2)



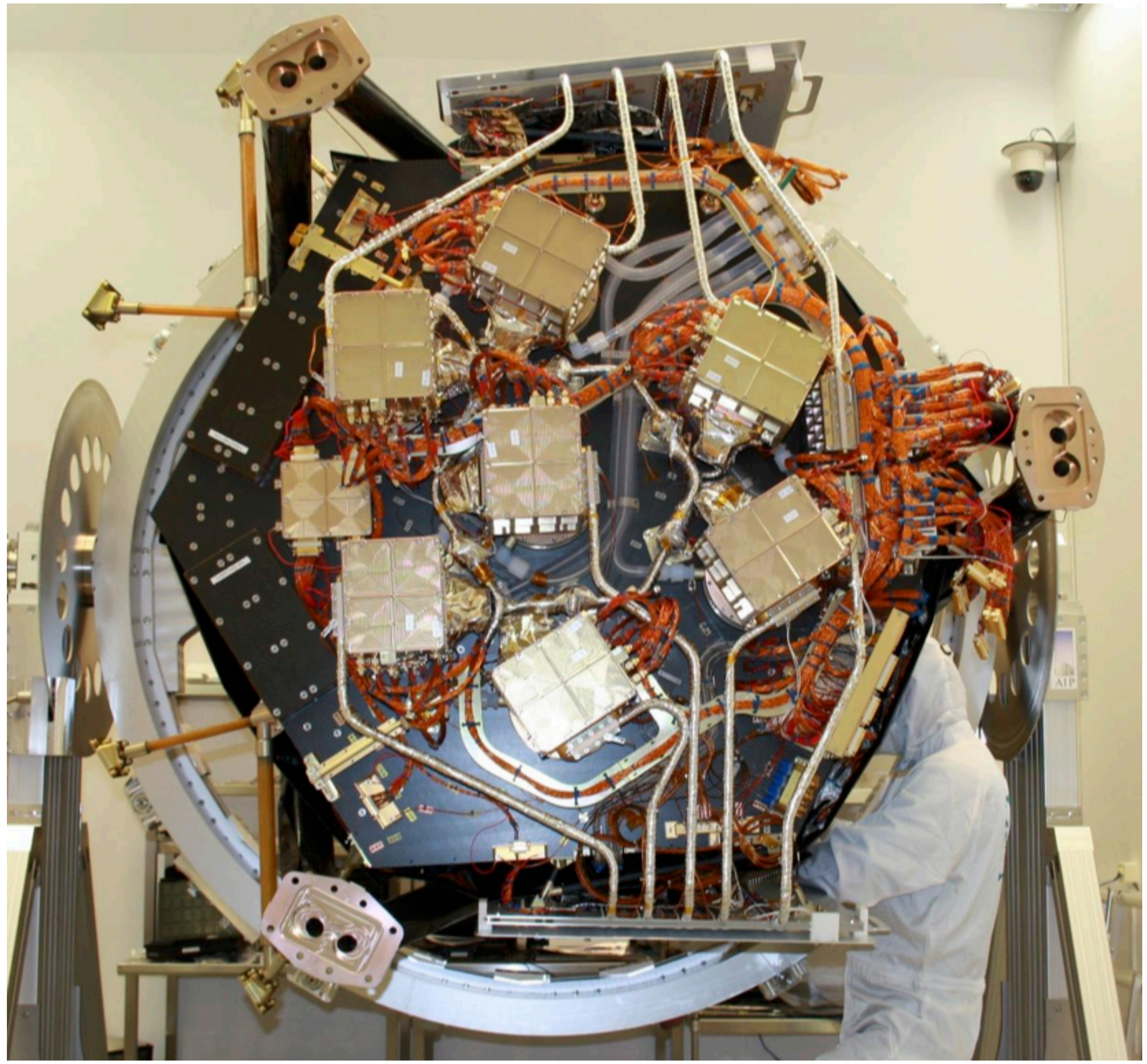
- continuous rotation (4hr) of the satellite
- 4yr survey operation
- 3yr pointed observations

eROSITA: optics



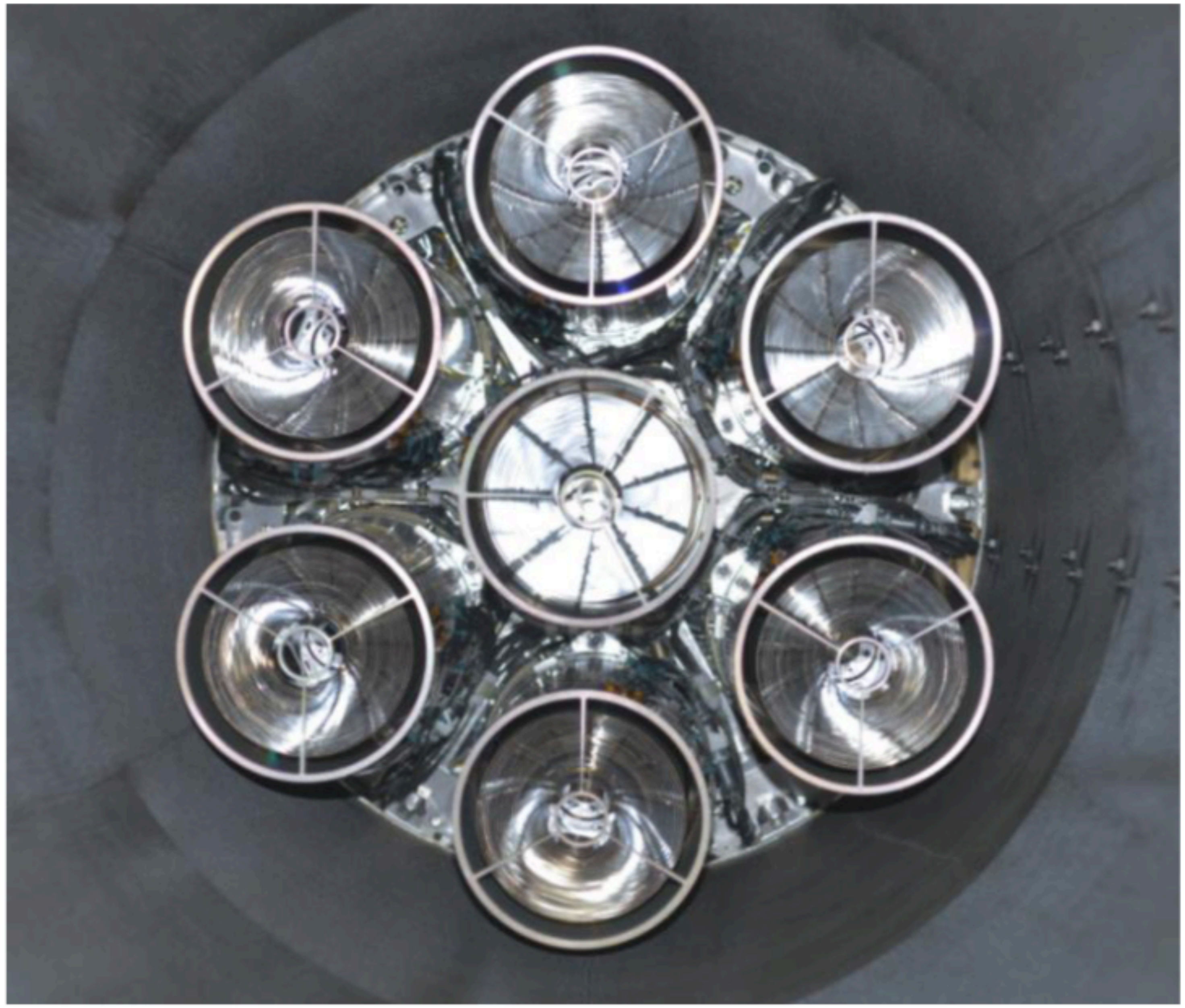
- 7x 54 nested gold-coated nickel mirror shells
- 1.6m focal length
- on-axis HEW ~18”, ~25” survey averaged
- FoV-averaged effective area comparable to XMM on-axis (~1700cm^2 @1keV)
- survey speed 7-8x larger than XMM

eROSITA: camera



- 7 identical framestore pnCCDs
- energy resolution of 77eV at 1.5keV, 136eV at 6.4keV
- time resolution 50ms
- FoV ~1deg^2

ART-XC: optics & camera

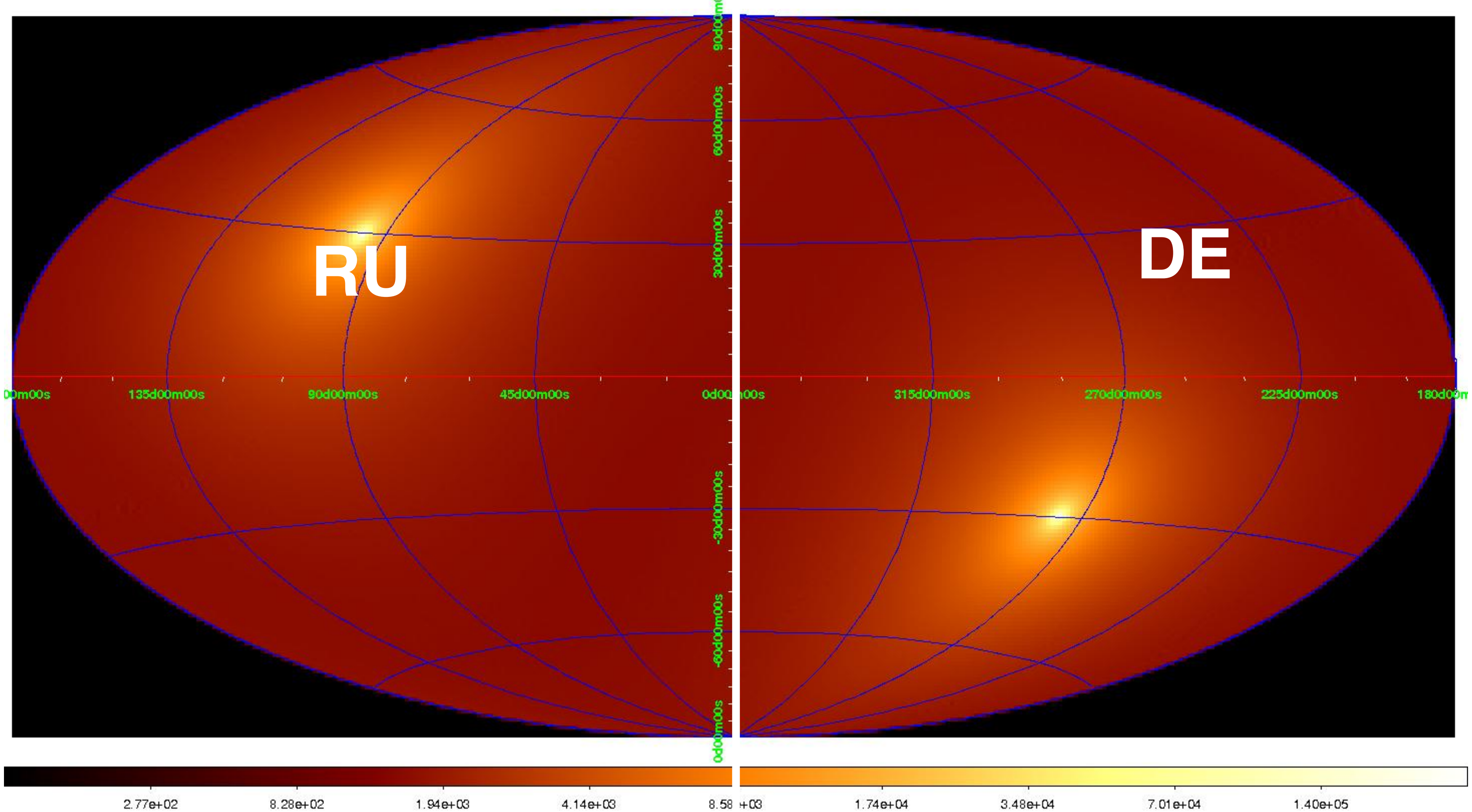


- 7x 28 nested iridium-coated Ni/Co mirror shells
- 2.7m focal length
- on-axis HEW <35”
- 7 identical DSDD CdTe detectors
- FoV ~0.3deg^2

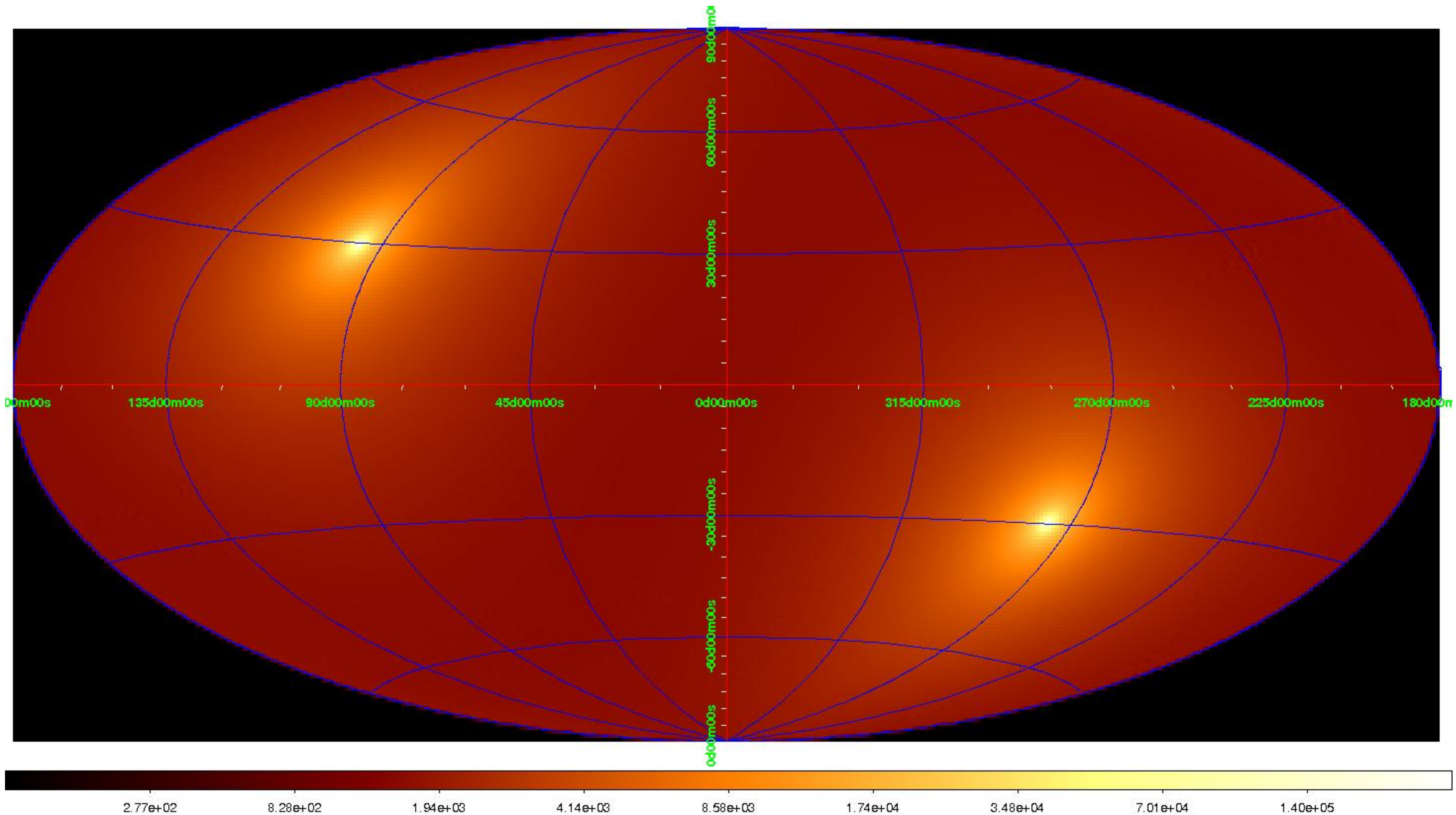
SRG: politics

ART-XC: Russia owns data rights over entire sky
eROSITA: data rights split evenly between Germany (West in Gal. Coord.) and Russia (East). —> 2 separate consortia, little collaboration foreseen at the moment.

eROSITA sky-split



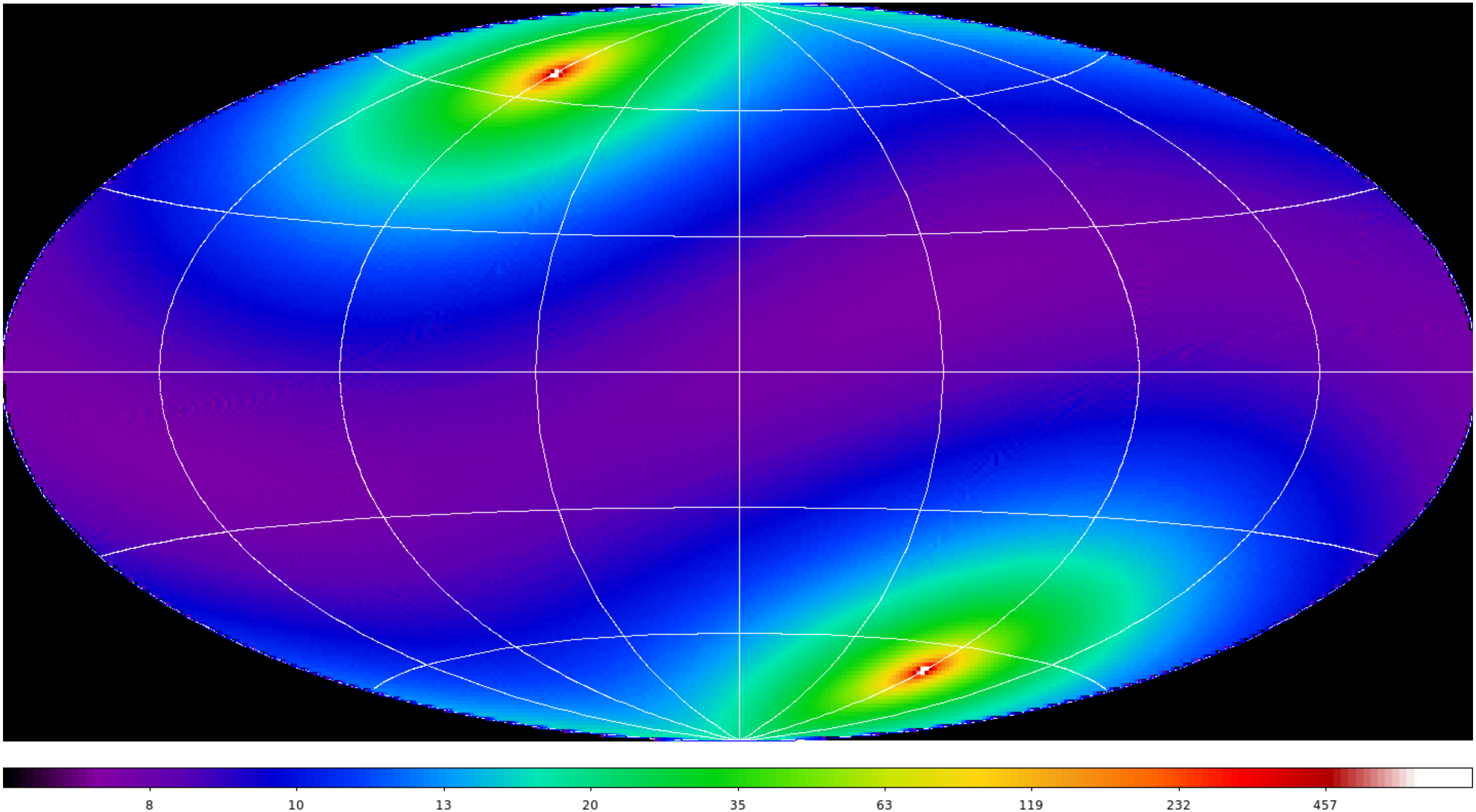
eROSITA: survey strategy



300s **8500s** **140000s**

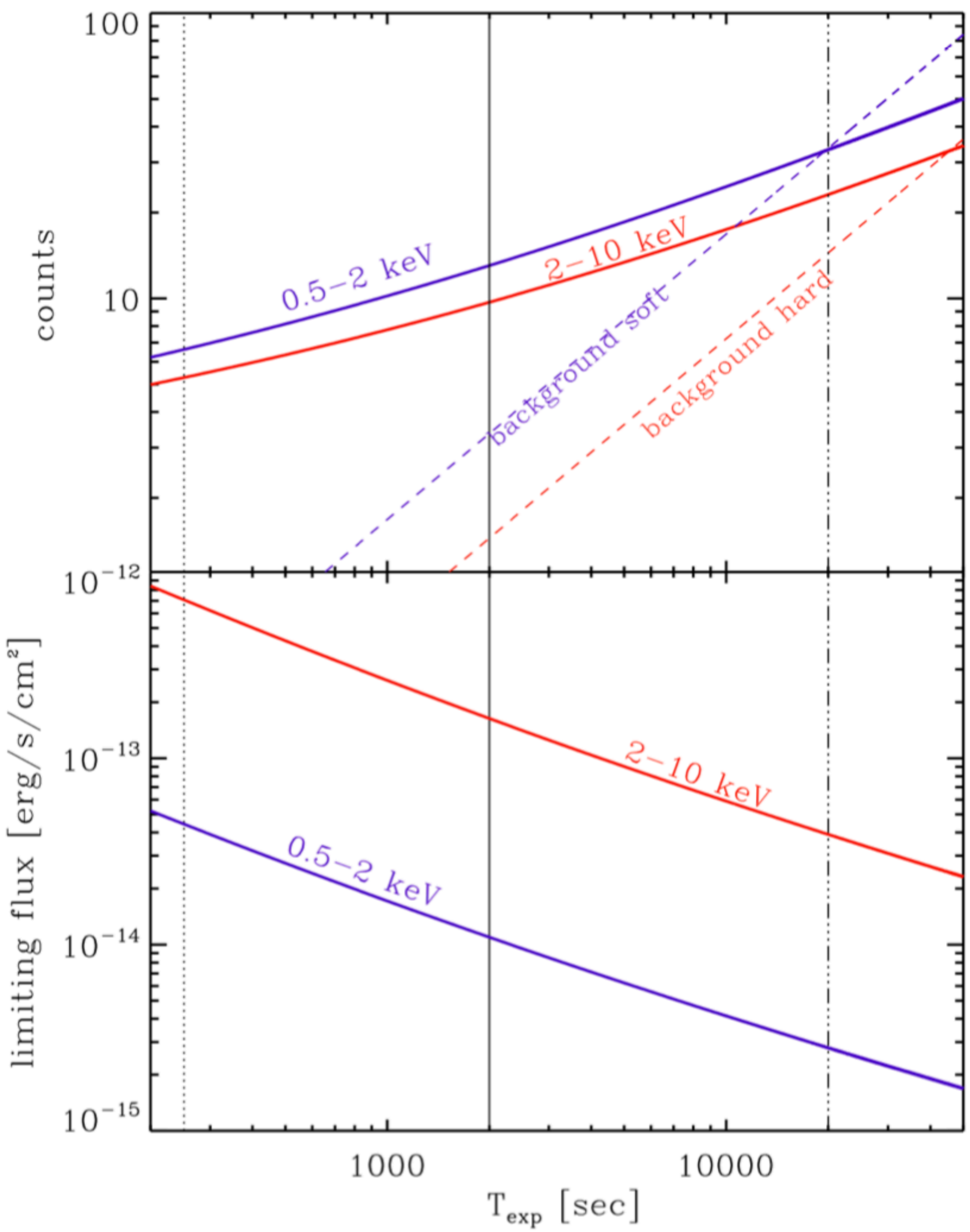
- eRASS: full sky coverage in 1/2yr
- eRASS1,2,..8: together form the 4-yr all-sky survey
- each skyposition covered >6x with 4hr cadence per eRASS

eROSITA: visits at sky position



- 8-500 visits within 4yr
- each visit consists of ~6 subsequent passes with ~40s exposure every 4hrs

eROSITA: sensitivity vs exposure

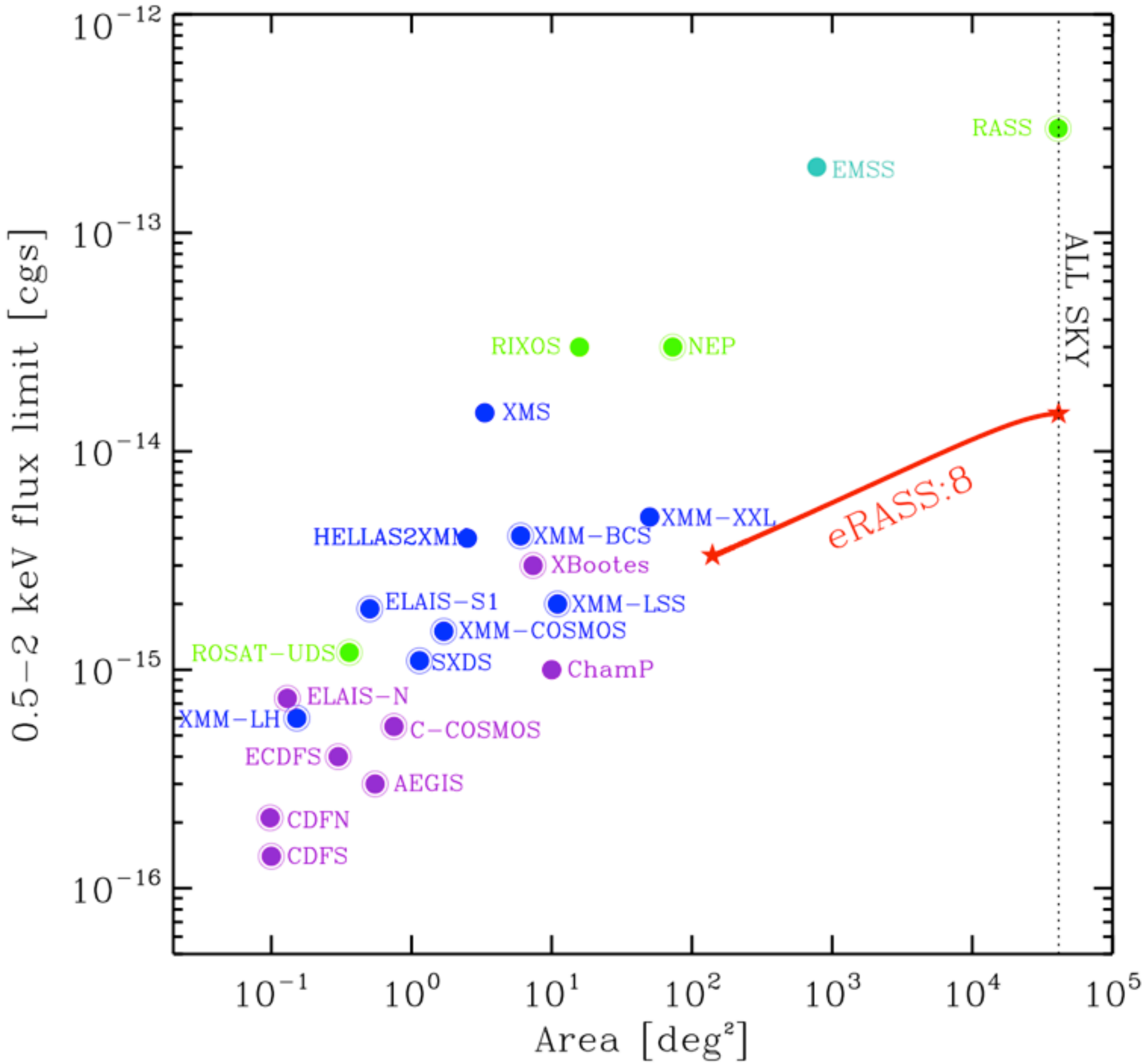


Top panel: Minimum number of net counts needed to securely identify a point source in survey mode as a function of exposure time

Bottom: Sensitivity plot for AGN (power-law with Γ=1.8, N_H=$3x10^{20}$) limiting flux versus exposure time.

Three vertical lines are shown, marking the average exposure times for one all-sky survey (eRASS:1, 6 months; 250 s, dotted) the final 4-years all-sky survey (eRASS:8, ~2 ks, solid) and the 4-years deep exposure at the ecliptic poles (~20 ks, dot-dashed).

eROSITA: sensitivity comparison (4yr)

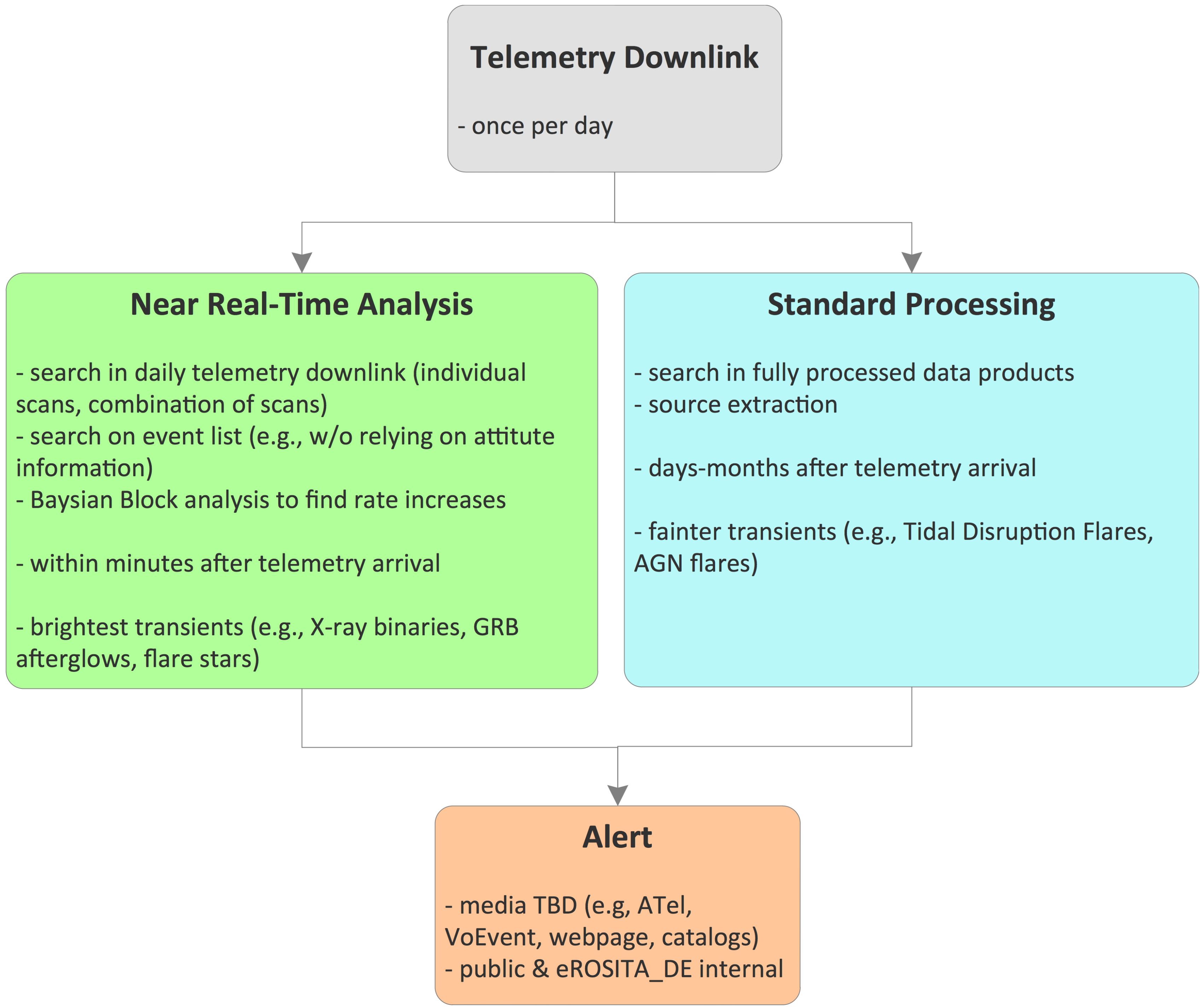


All sky: 10^{-14} [erg/cm^2/s] (0.5-2 keV) (25x ROSAT)

2×10^{-13} [erg/cm^2/s] (2-10 keV) (100x HEAO/RXTE)

eROSITA_DE: transient search plans

Transients and variables will be searched for in all time scales, from <40s to years. (Only in the German part of the sky for the moment. Discussion with Russia ongoing!)



eROSITA_DE: transient alert timeline

<table>
<tr><th>Calibration / PV Phase</th><th>eRASS1</th><th>eRASS2</th><th>eRASS3</th></tr>
<tr><td colspan="4">Manual source vetting.</td></tr>
<tr><td colspan="2">Distribution of man. vetted alerts to interested eROSITA_DE members (e.g., TDA working group, external collaborators) via mailing list and/or internal web page.</td><td colspan="2"></td></tr>
<tr><td colspan="4">Public announcement of exceptional transients via Astronomer's Telegrams, GCNs.</td></tr>
<tr><td colspan="2"></td><td colspan="2">Distribution of semi-automatically generated alerts to interested eROSITA_DE members (e.g., TDA working group, external collaborators) via VOEvent or similar.</td></tr>
<tr><td colspan="2"></td><td colspan="2">Public web page for high significance alerts. Public block-announcement of new events via Astronomer's Telegram.</td></tr>
<tr><td colspan="3"></td><td>Distribution of semi-automatically generated alerts to the public via VOEvent or similar.</td></tr>
<tr><td colspan="3"></td><td>Public web page for semi-automatically generated alerts.</td></tr>
</table>

NRTA system developed at ECAP (J. Wilm's group). NRTA team will involved broader eROSITA_DE community. Efforts will be man power limited, though.

eROSITA_DE: collaboration opportunities

- **Individual External Collaborations** to make proposal for well-define project to Science Working Group Chairs (TDA: A.Rau, J.Wilms)

- **Group External Collaborations** for larger facilities through team-to-team MoUs (e.g., Hyper Supreme Cam, SDSS IV)

More Details can be found in the

eROSITA Science Book: Mapping the Structure of the Energetic Universe
(Merloni et al. 2012)

https://arxiv.org/abs/1209.3114

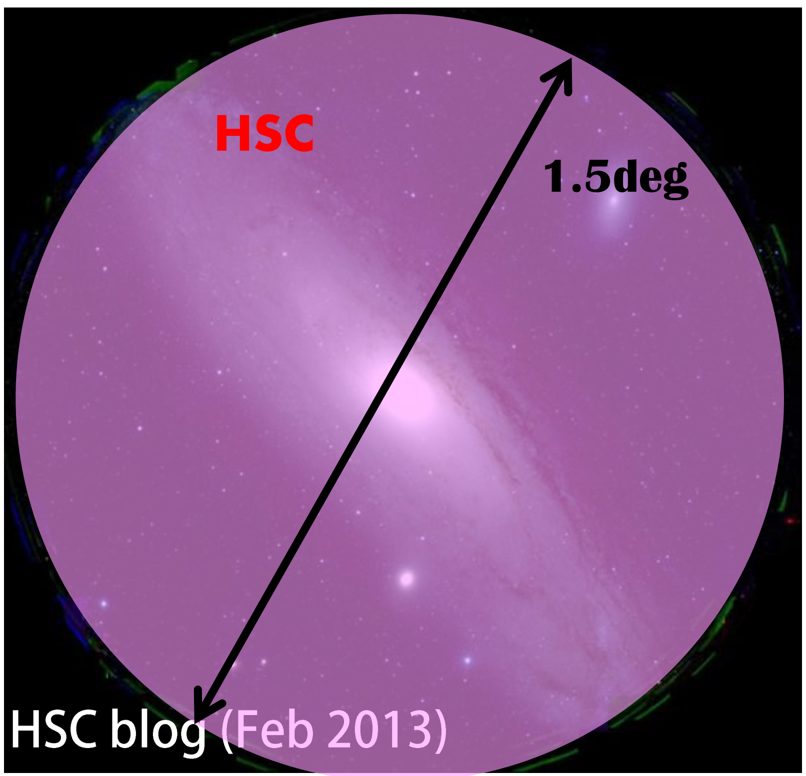
Subaru transient survey

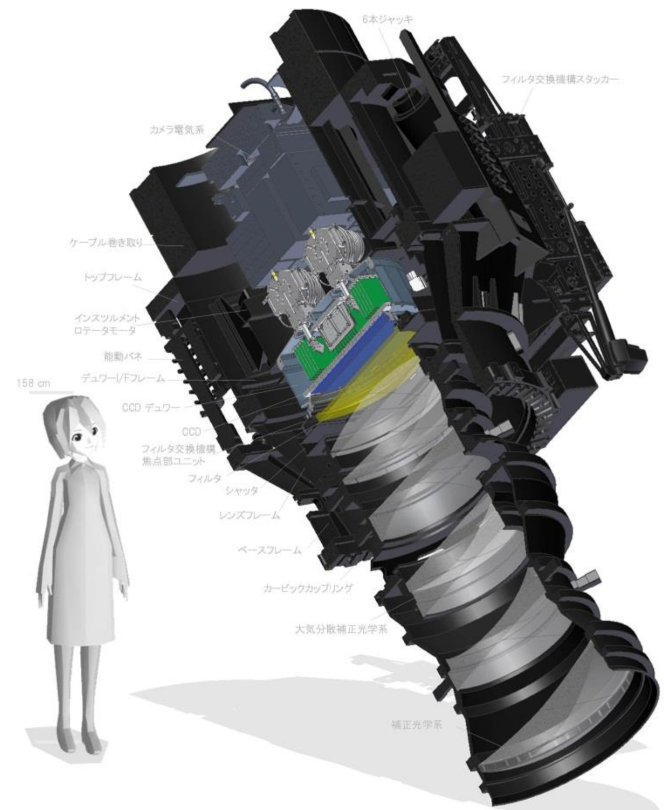
Nozomu Tominaga
(Konan University)

KONAN UNIVERSITY

Subaru/Hyper Suprime Cam

- Hyper Suprime-Cam (HSC)
  - Diameter: 8.2m, FoV: 1.77deg^2, ~900M pixels





HSC instrument parameters

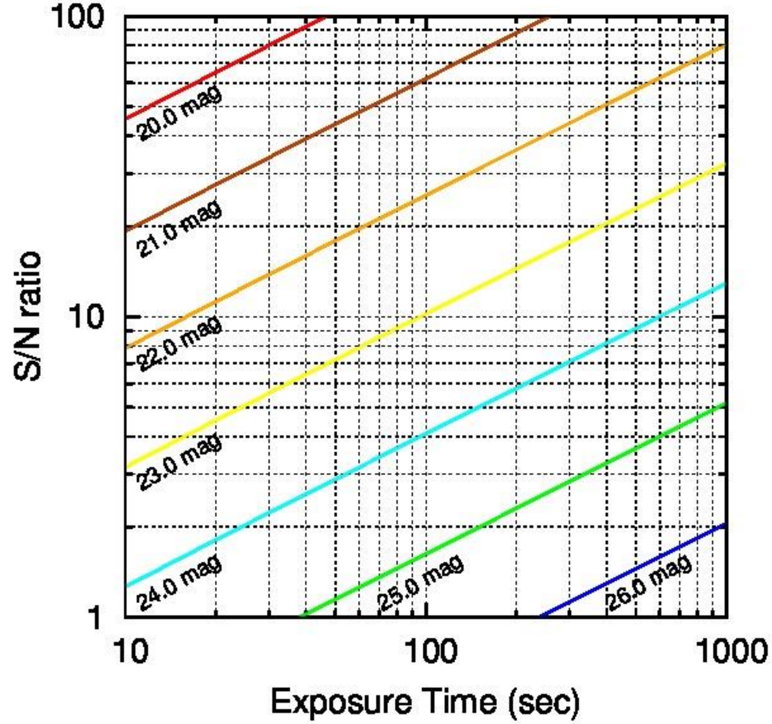
- Number of science CCDs:

  104 chips (4 unavailable chips)
- Overhead time: ~35 sec per exposure
- Number of filters: 6
- Filter exchange: ~30 min

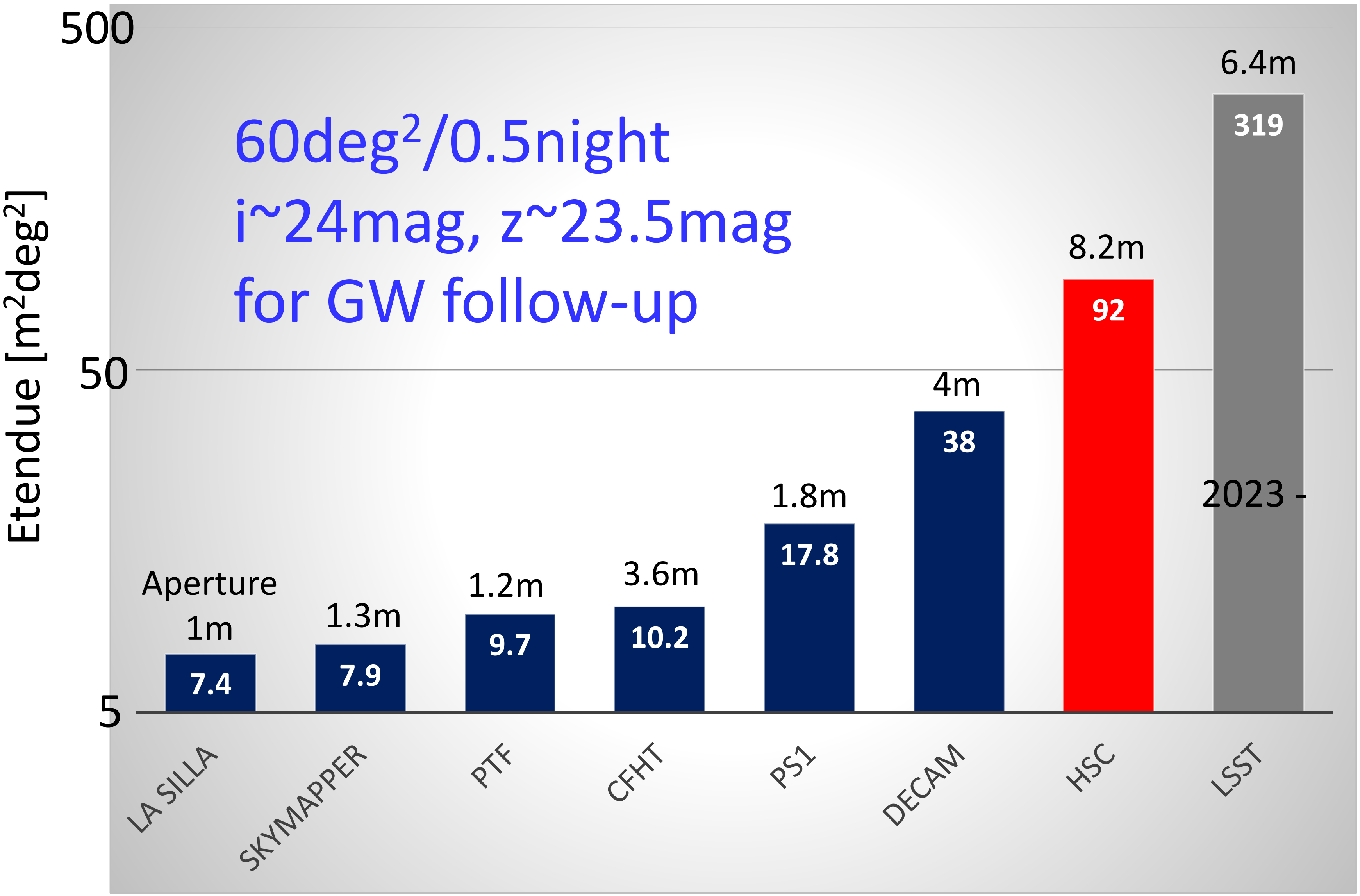
5σ lim. mag.
w/ 1min exp.

g 25.5
r 23.9
i 24.2
z 23.6
Y 22.8

z-band



Etendue of optical telescopes



Available only on gray/dark nights

Schedule for January 2018

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	Jan 01 ○	Jan 02	Jan 03	Jan 04	Jan 05	Jan 06
	Obs FOCAS Obs FOCAS	S17B-002 Kodama MOIRCS		S17B-002 Kodama MOIRCS	S17B-130 Kotani CHARIS+SCExAO	UH-07B Hodapp CHARIS+SCExAO S17B-130 Kotani CHARIS+SCExAO
Jan 07	Jan 08 ◑	Jan 09	Jan 10	Jan 11	Jan 12	Jan 13
UH-07B Hodapp CHARIS+SCExAO Taiken Kikaku (1hr)/Obs HDS	SSP HSC Eng/Queue HSC	SSP HSC S17B-055I Suzuki HSC	Queue HSC	Queue HSC	Queue HSC S17B-055I Suzuki HSC	SSP HSC
Jan 14	Jan 15	Jan 16 ●	Jan 17	Jan 18	Jan 19	Jan 20
UH-18B Tholen HSC	UH-18B Tholen HSC	S17B-116 [ToO] Y. Tanaka HSC SSP HSC	S16B-001I Inoue HSC	S16B-001I Inoue HSC	S16B-001I Inoue HSC	SSP HSC
Jan 21	Jan 22	Jan 23 ◐	Jan 24	Jan 25	Jan 26	Jan 27
S17B-044 Yoshida HSC Queue HSC	Keck Prochaska HSC S17B-055I Suzuki HSC	Eng/Queue HSC SSP HSC	UH-28A Goebel CHARIS+SCExAO S16A-119I Aoki HDS	S17B-093 Currie CHARIS+SCExAO S16A-119I Aoki HDS	S16A-119I Aoki HDS	S16A-119I Aoki HDS Obs IRCS+AO188(LGS)
Jan 28	Jan 29	Jan 30 ○	Jan 31			
Keck Melis COMICS	S17B-092 Takagi IRCS+AO188(LGS)					

Need to submit proposals

- Deadline: early Sep/Mar for A/B semesters

Semester		Proposals			Nights		
		Submitted	Accepted	Ratio	Requested	Awarded	Ratio
S17A	2017/02 - 2017/07	166	42	25%	418.3	82	20%
S17B	2017/08 - 2018/01	135	37	27%	294	69.5	24%
S18A	2018/02 - 2018/07	155	45	29%	347.3	94	27%
S18B	2018/08 - 2019/01	156	50	32%	415.7	84.5	20%
S19A	2019/02 - 2019/07	133	46	35%	354.9	89.5	25%

- HSC is more competitive than the average.

There are 3 kinds of proposals.

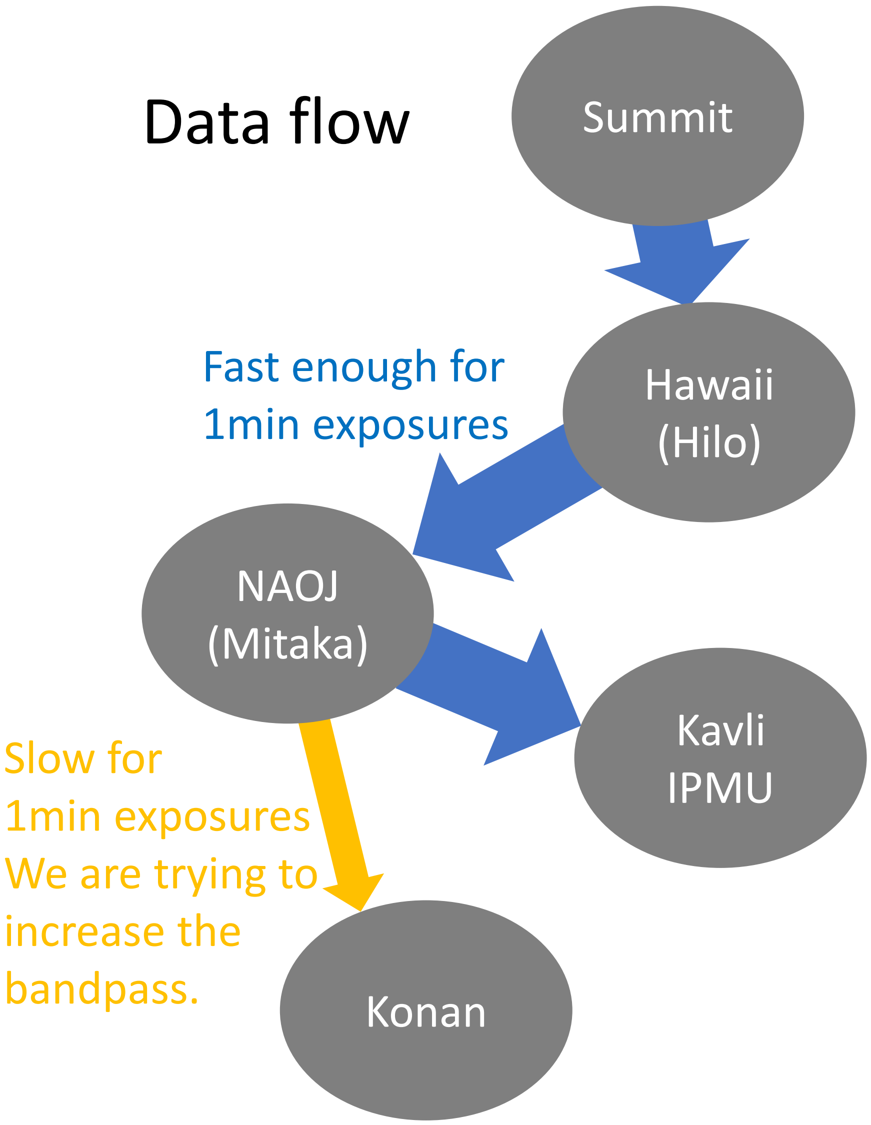
- Openuse: <= 5 nights, 1 semester
- Intensive: <= 40 nights, <= 6 semesters
- SSP: <= 300 nights, <= 10 semesters

Data analysis for transient surveys

Transient finding system

- Naoki Yasuda and NT are working on it.
- Hawaii observatory
  - CPU: 176 cores
  - Storage: 20TB
- Kavli IPMU
  - CPU: 1200 cores
  - Storage: 3.5PB
- Konan University
  - CPU: 488 (+320) cores
  - Storage: 500TB

Data flow



Subaru strategic program (SSP)

COSMOS (Nov 2016 – Apr 2017): several days cadence

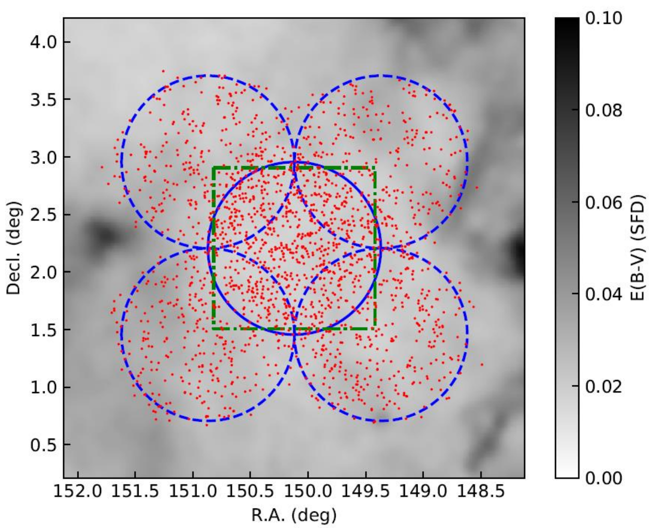
Two layers:

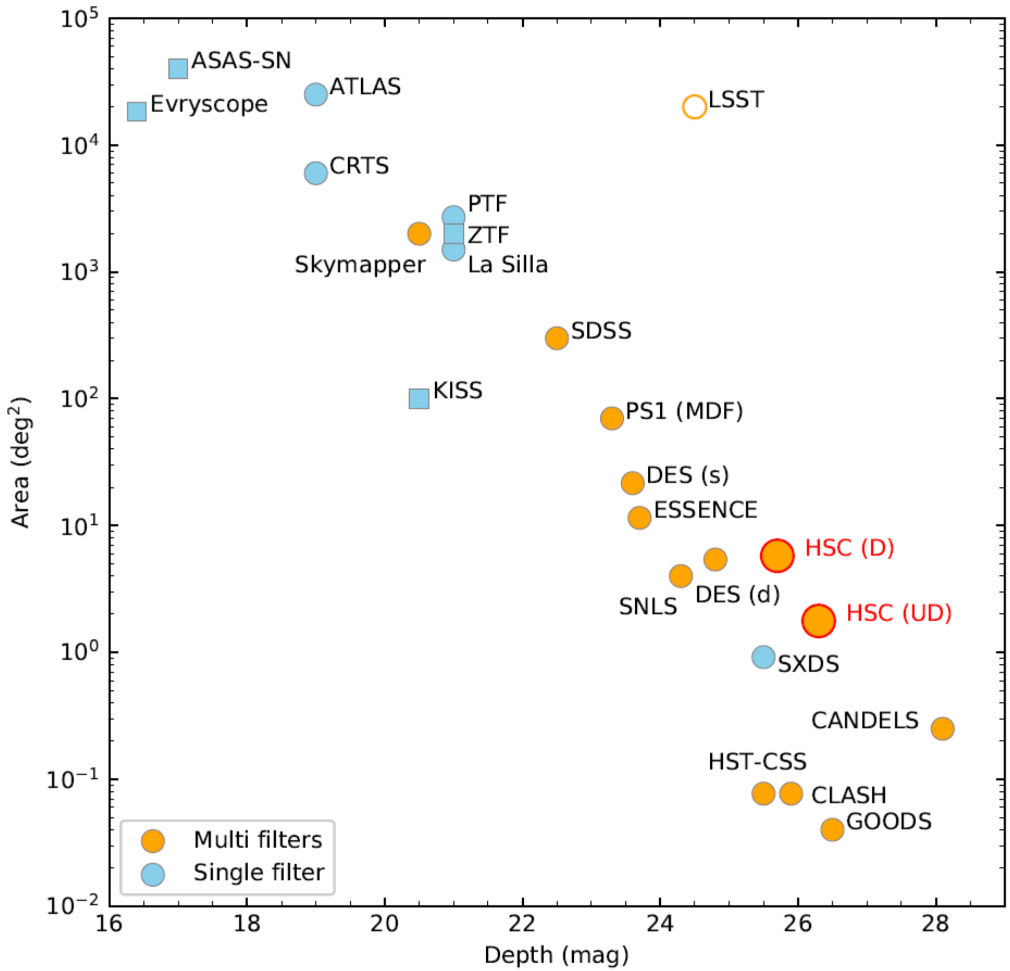
- Deep: Ω=5.8deg^2

  m_{lim}~25.7, 4 months

- Ultradeep: Ω=1.8deg^2

  m_{lim}~26.3, 6 months



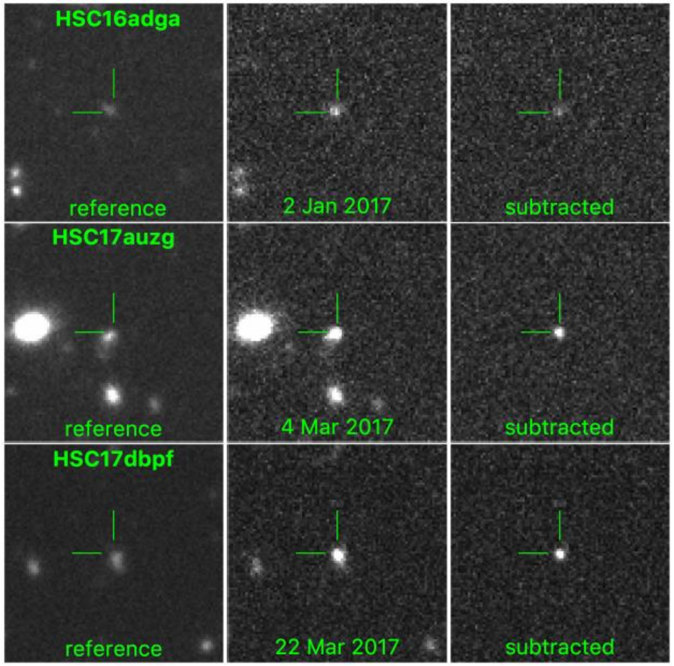


Yasuda + submitted

Pick-up results -SLSNe-

Subaru HIgh-Z sUpernova CAmpaign (SHIZUCA)

Moriya+18 (arXiv:1801.08240)
Curtin+18 (arXiv:1801.08241)



SHIZUCA discovered SLSNe at z=1.9-2.4.

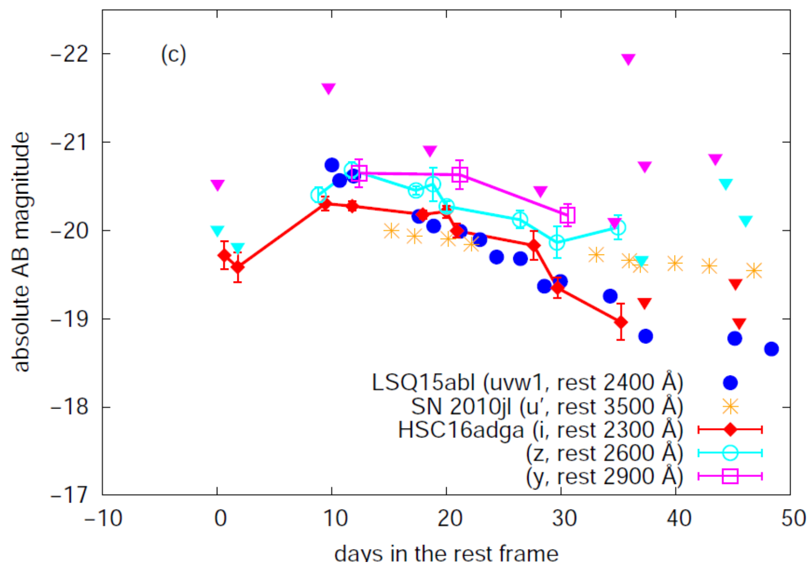
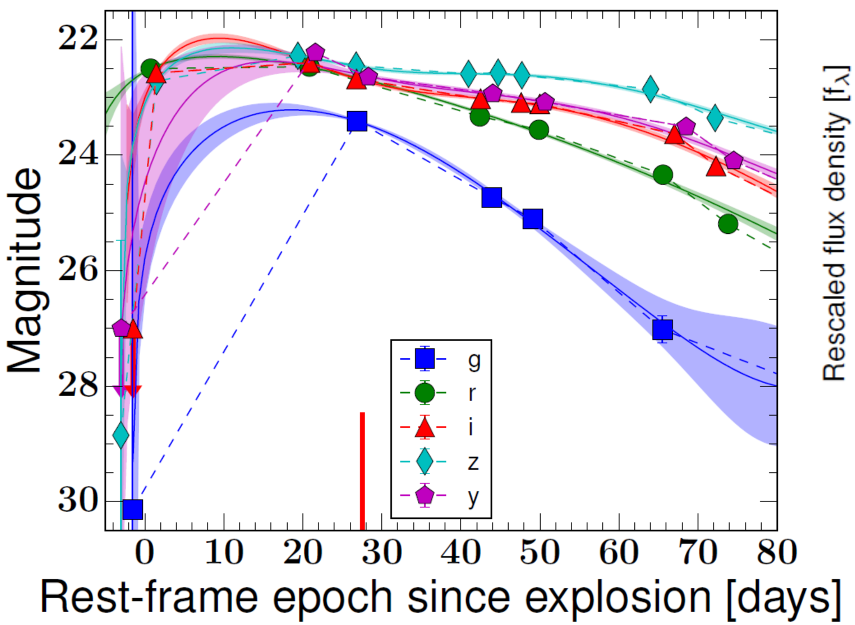


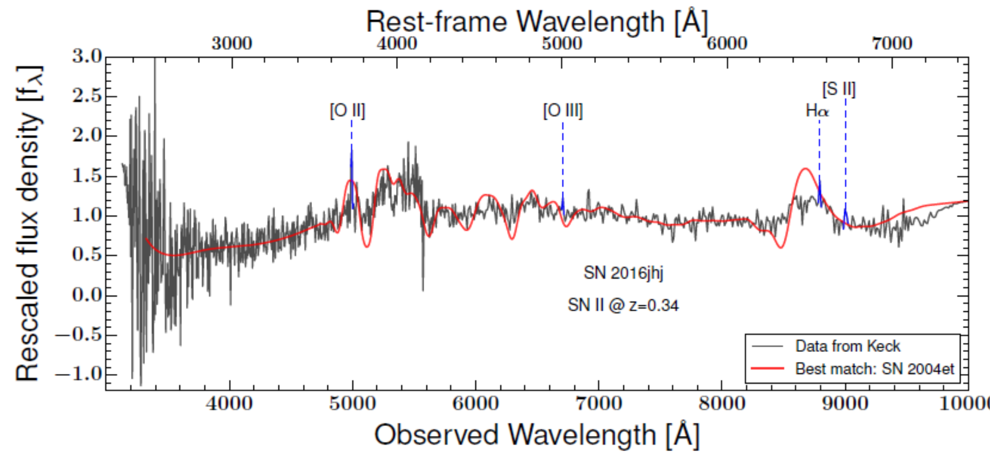
Table 1. List of SNe and SN candidates.

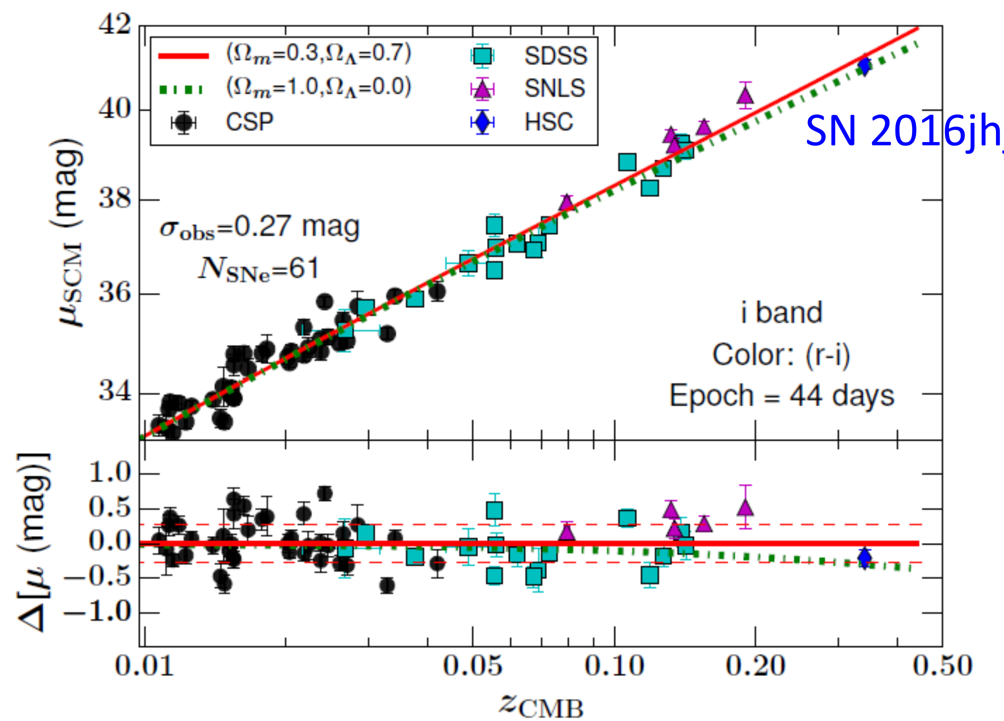
HSC name	IAU name	redshift	host galaxy magnitudes in the HSC filters g	r	i	z	y	Section
HSC16adga	SN 2016jhm	2.399 ± 0.004^a	24.55 ± 0.03	24.42 ± 0.04	24.48 ± 0.06	24.29 ± 0.07	24.20 ± 0.13	3.1
HSC17auzg	SN 2016jhn	1.965 ± 0.004^a	23.88 ± 0.02	23.77 ± 0.02	23.54 ± 0.02	23.41 ± 0.03	23.58 ± 0.06	3.2
HSC17dbpf	SN 2017fei	1.851 ± 0.004^a	24.11 ± 0.02	23.91 ± 0.02	23.67 ± 0.03	23.63 ± 0.04	23.60 ± 0.08	3.3
HSC16apuo	AT 2016jho	$2.8225^{+0.4727\,b}_{-0.7032}$	27.00 ± 0.75	25.31 ± 0.19	25.50 ± 0.35	24.92 ± 0.29	26.10 ± 0.29	4.1
HSC17dsid	AT 2017fej	$4.1974^{+0.0908\,b}_{-0.126}$	27.74 ± 0.34	25.07 ± 0.04	24.83 ± 0.04	24.68 ± 0.05	25.23 ± 0.18	4.2

[a] Spectroscopically confirmed (Curtin et al. 2018).
[b] COSMOS2015 photometric redshift (Laigle et al. 2016).

Pick-up results -IIP cosmology-







SN 2016jhj at z=0.34 extended the Type II supernova Hubble diagram.

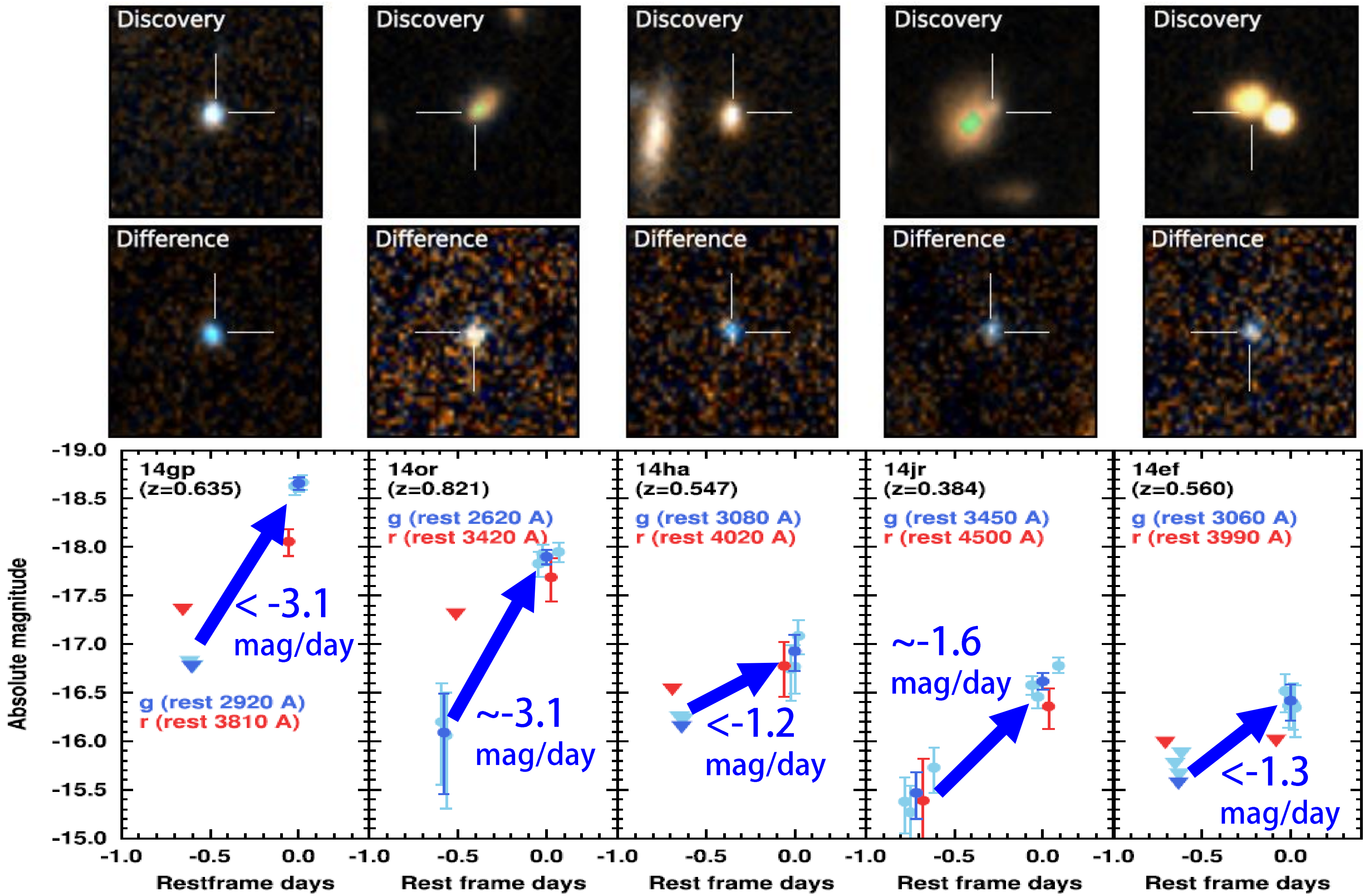
de Jaeger+18 (arXiv:1709.01513)

Openuse program

- Subaru HSC survey optimized for optical transients
  - PI: Nozomu Tominaga
  - Jul 2014 (2 nights): g,r 10min exp., 7 fields, ~1hr cadence
    follow-up at ~1month later
  - Nov 2014 (2 nights): g,r 36min exp., 2 fields, ~1hr cadence
    no follow-up
  - May 2015 (1 night): g,r 6min exp., 13 fields, ~1.5hr cadence
    follow-up cancelled
  - Aug 2015 (1 night): poor weather
  - Mar 2016 (2 x 0.5 nights): poor weather
  - Jun 2018 (4 x 0.5 nights): cancelled
- Multi-band Subaru Survey for Early-phase SNe Ia
  - PI: Jian Jiang
  - Apr 2016 (1.5 nights): g,r 1.5-2min exp., 35 fields, ~1-2hr cadence

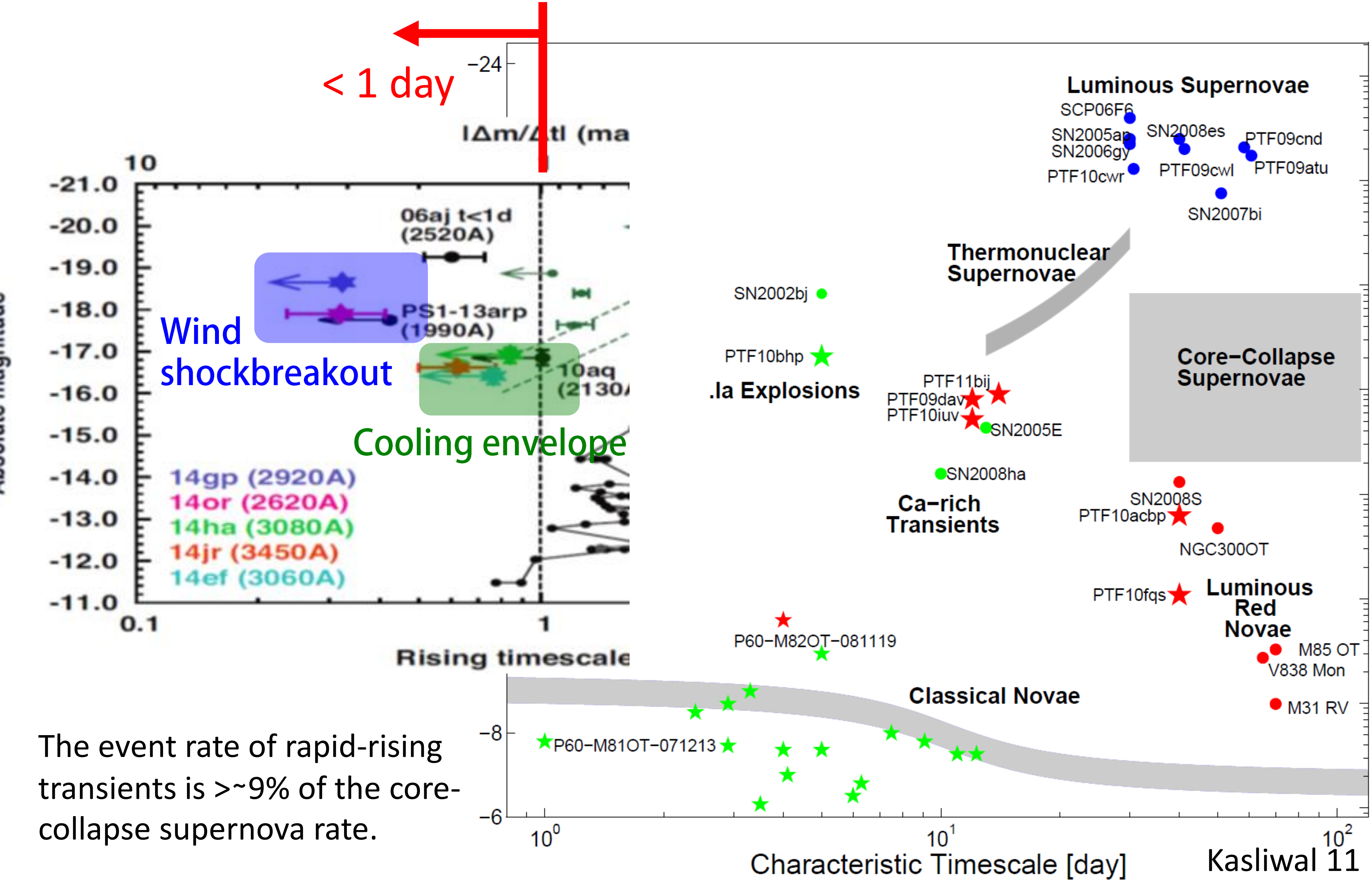
Pick-up results -rapid rising transients-

5 rapid-rising transients were discovered in 2 nights.



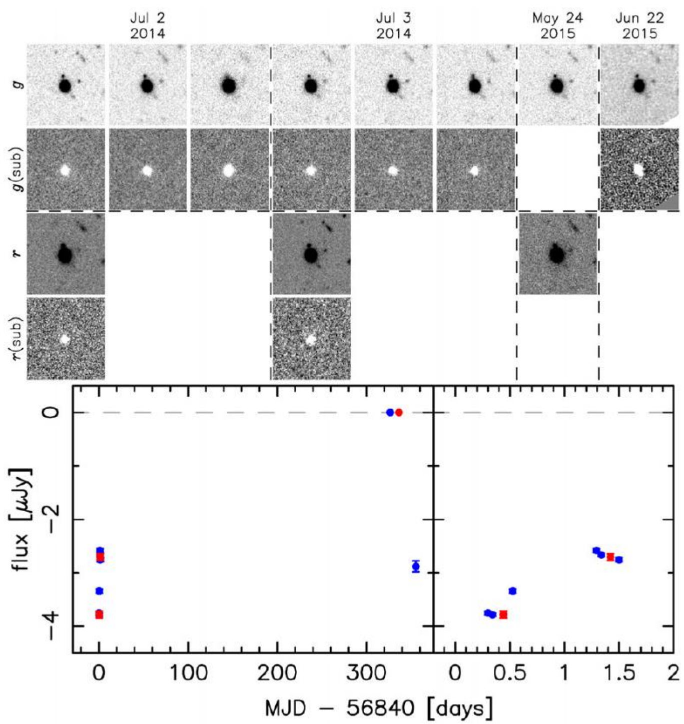
Tanaka, NT+ 16 (arXiv:1601.03261)

Pick-up results -rapid rising transients-



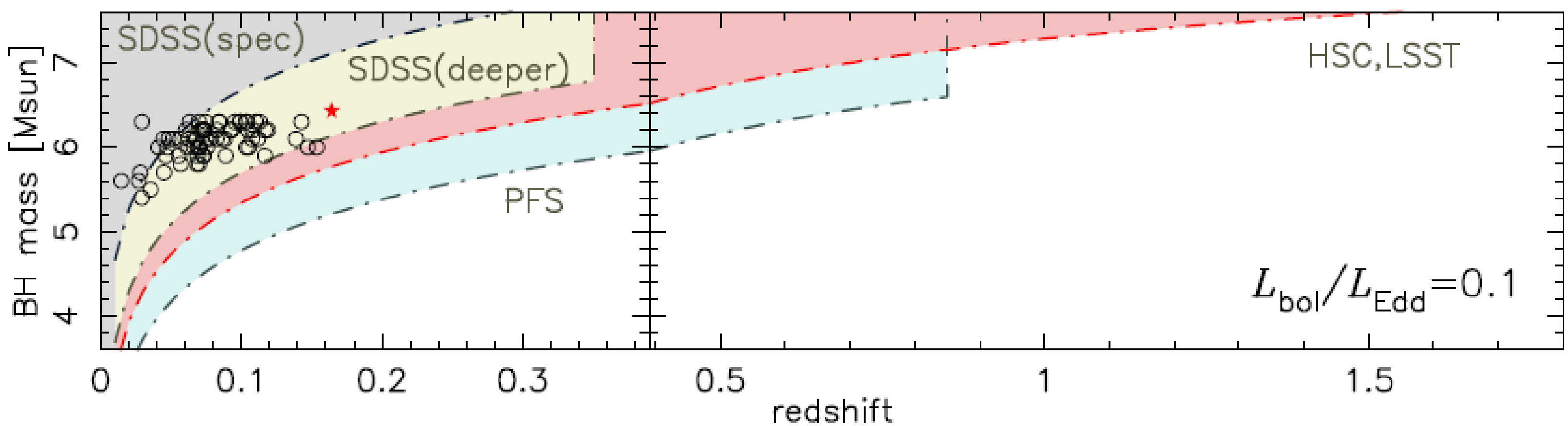
The event rate of rapid-rising transients is >~9% of the core-collapse supernova rate.

Pick-up results -low-mass AGN-



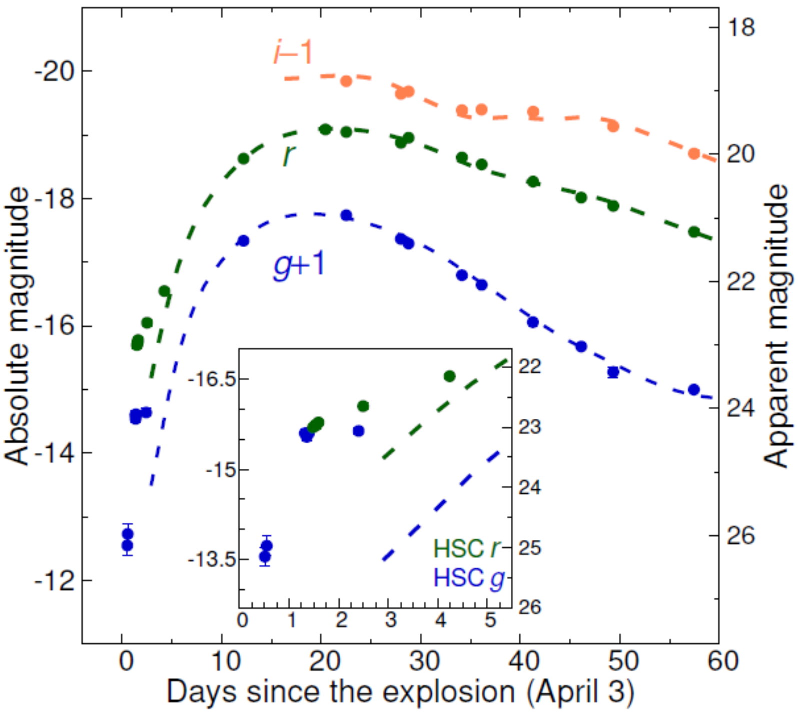
The high-cadence observation enables to select low-mass active black holes (BHs) at galaxy centers. Spectroscopic follow-up observation identify an active 2.7x10^{6}Msun BH at z = 0.164.

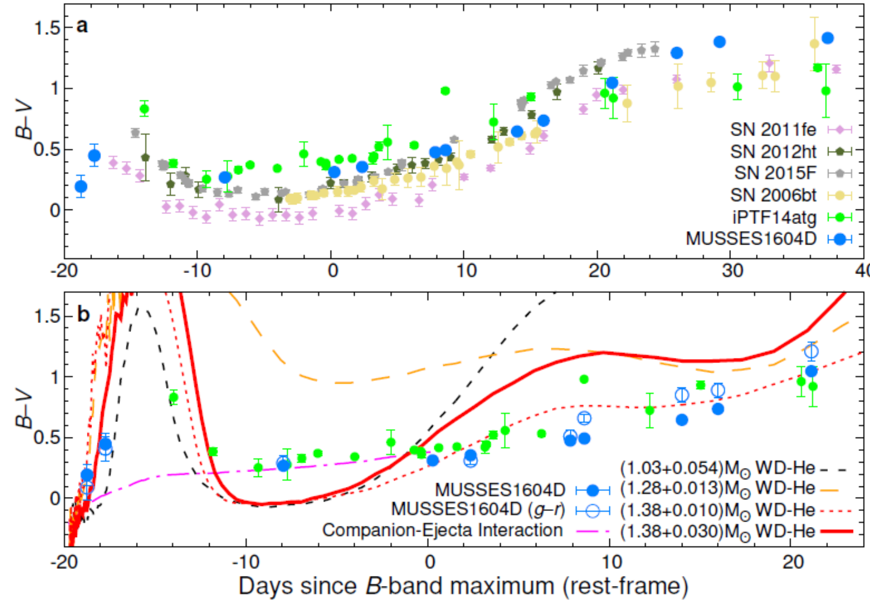
Fig. 5. Detectable BH mass as a function of redshift.
An Eddington ratio of 0.1 is assumed. A variability amplitude of 10% is also assumed.

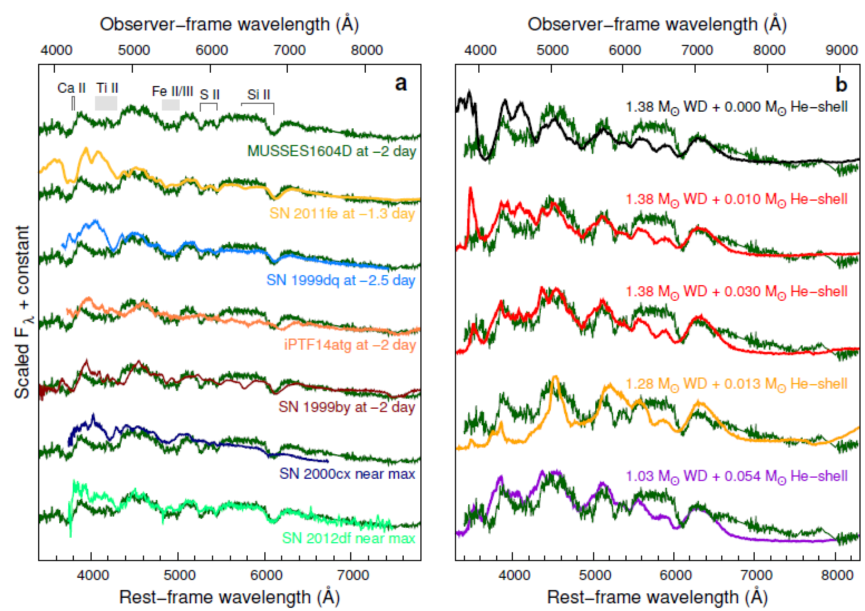


Morokuma+16 (arXiv:1603.02302)

Pick-up results -A hybrid SN Ia-





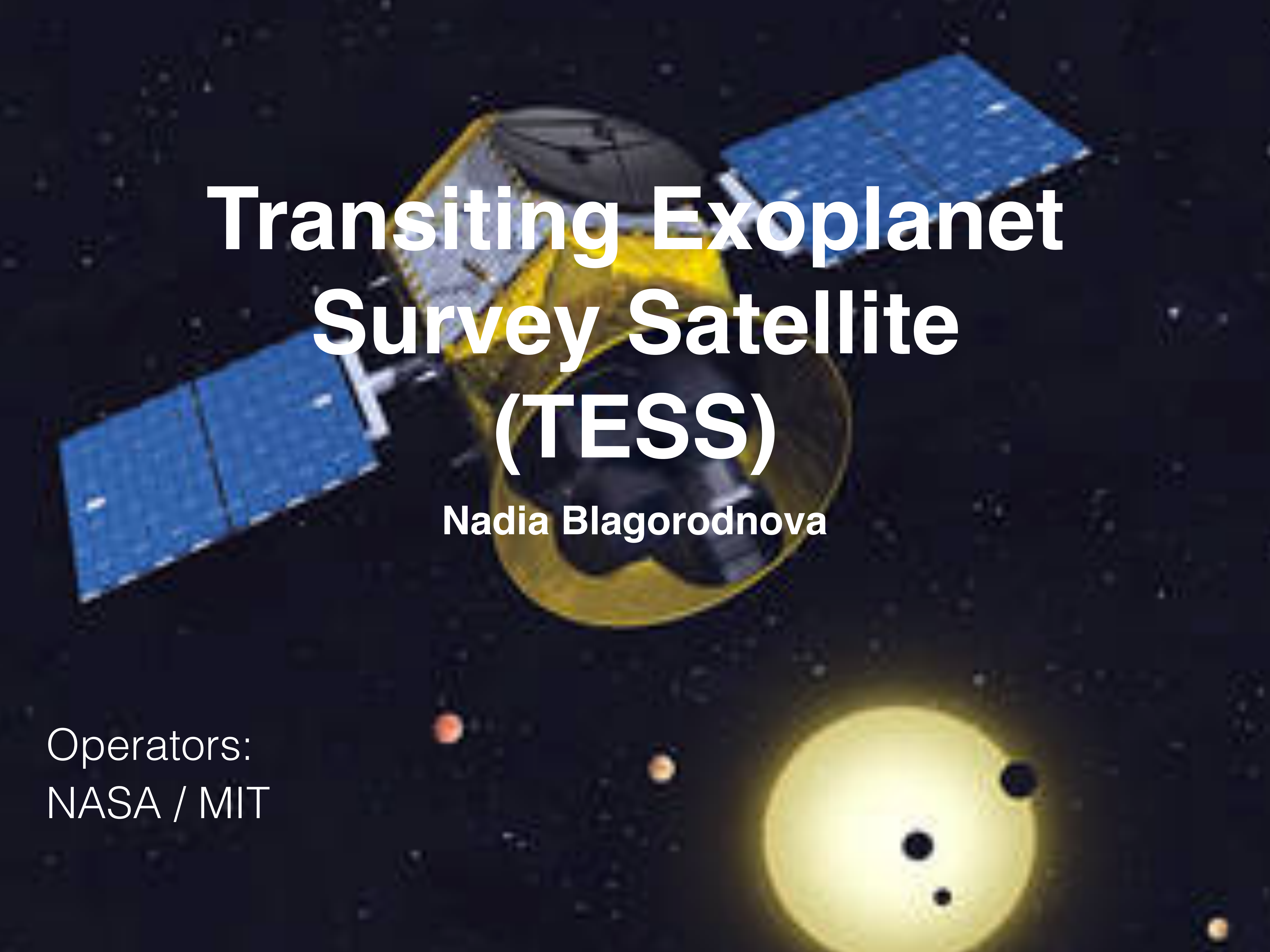


A red optical flash at ~0.5 days after explosion can be explained with a SN explosion triggered by a detonation of a thin helium shell.

Jiang + 17 (arXiv:1710.01824)

Future plan

- HSC-SSP: transient survey in SXDS
  - Aug 2019 – Jan 2020
  - 3 fields in deep (4 month), 1 field in UD (6 month)
  - high-cadence in g-band (18 fields nights)
- Openuse
  - 1hr cadence survey
  - May 1-4, 2019: 4 x 0.5 nights (+GMOS follow-up 2 nights)
  - 30 sec exp. in g (<25.1mag), 60 fields (106deg^2)
    or 1min exp. in g (<25.5mag), 45 fields (80deg^2)
- More future
  - HSC-intensive or HSC-SSP-2 for a transient survey?



Transiting Exoplanet Survey Satellite (TESS)

Nadia Blagorodnova

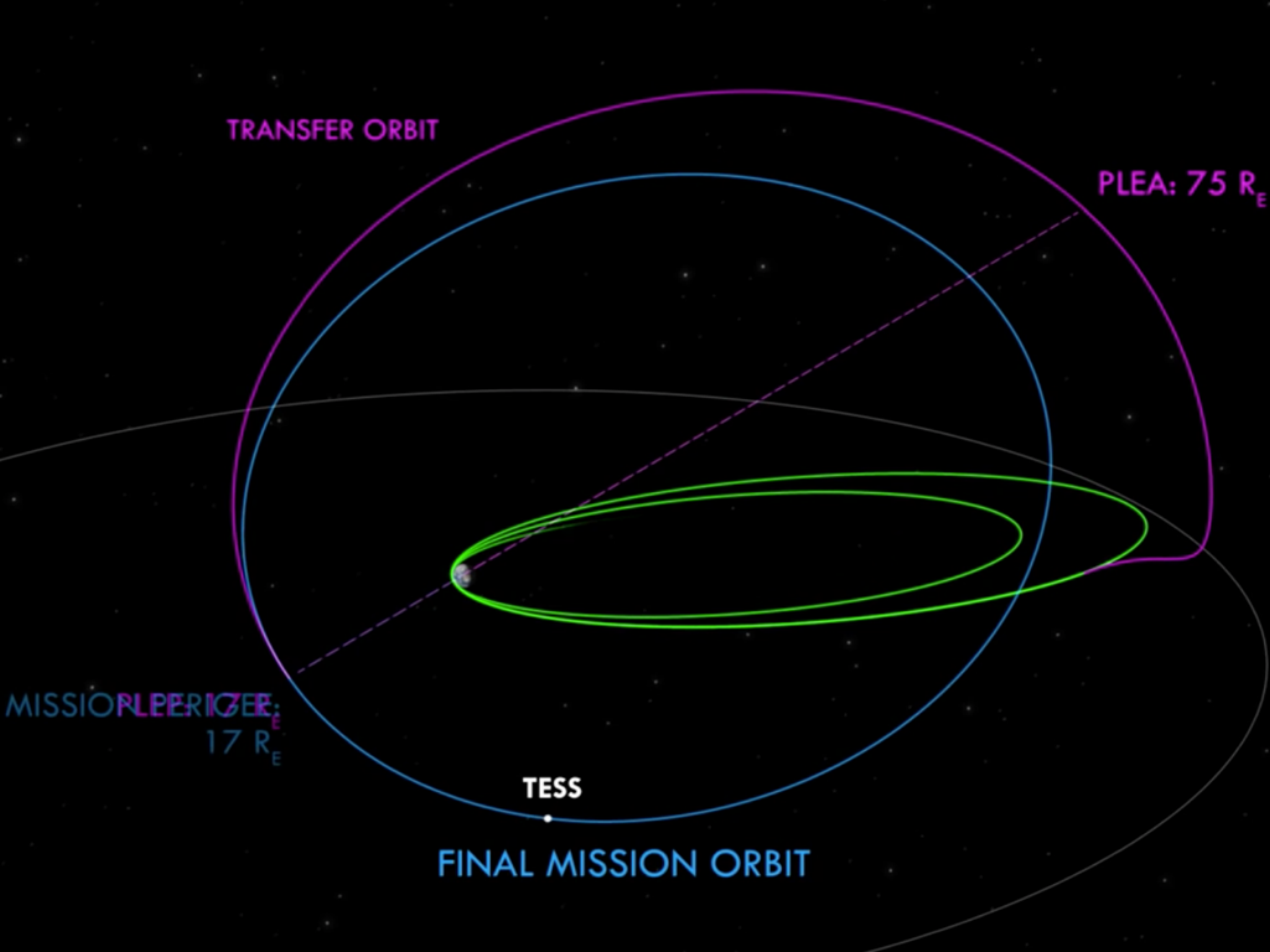
Operators:
NASA / MIT

Mission goals & objectives

- **Detect and characterise exoplanets**
    - **Measure planet mass, size, orbit, density**
- Survey ~200,000 of the brightest stars near the Sun to search for transiting exoplanets.
- Focus on G-, K-, and M-type stars with apparent magnitudes brighter than magnitude 12.
- 1,000 closest red dwarfs
- To discover 20,000 exoplanets (vs. 3,800 known)
    - 500-1000 Earth-sized and super-Earth-sized
- Complement by ground-based follow-up observations on planet candidates

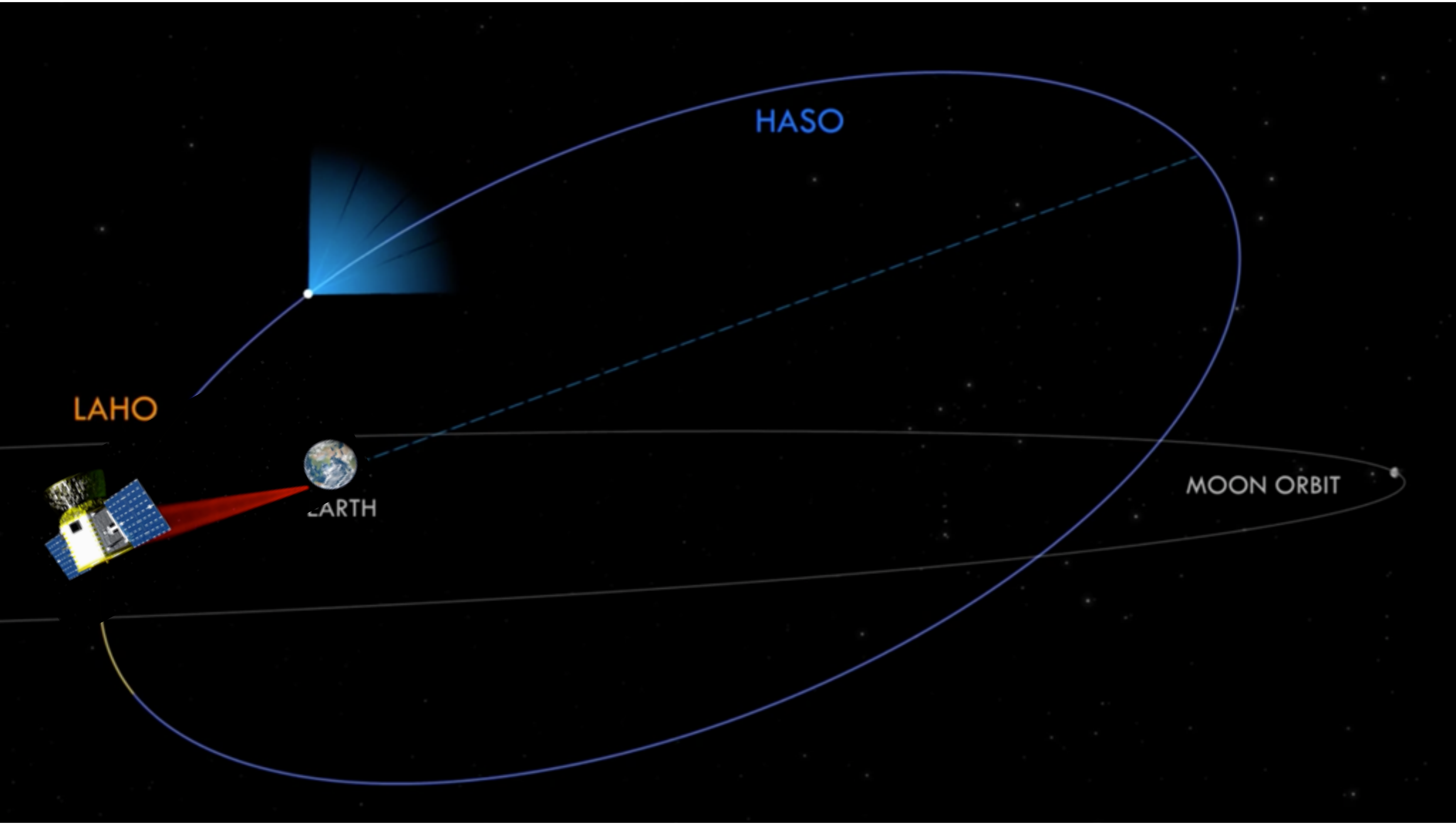
Mission approach

- 2 year mission
- Sky survey divided in 26 different sectors: 24 x 96 degrees across (85% of the sky)
    - Length sector: 27 days (2 orbits)
    - Stare and step. Two-minute cadence on the brightest stars
- TESS stars 30 to 100 times brighter than those the Kepler mission and K2
- TESS sky area 400 times larger than Kepler.
- 20,000 additional objects during the mission through its Guest Investigator program.
- Full-frame images exptime 30min transmitted as well for transient science

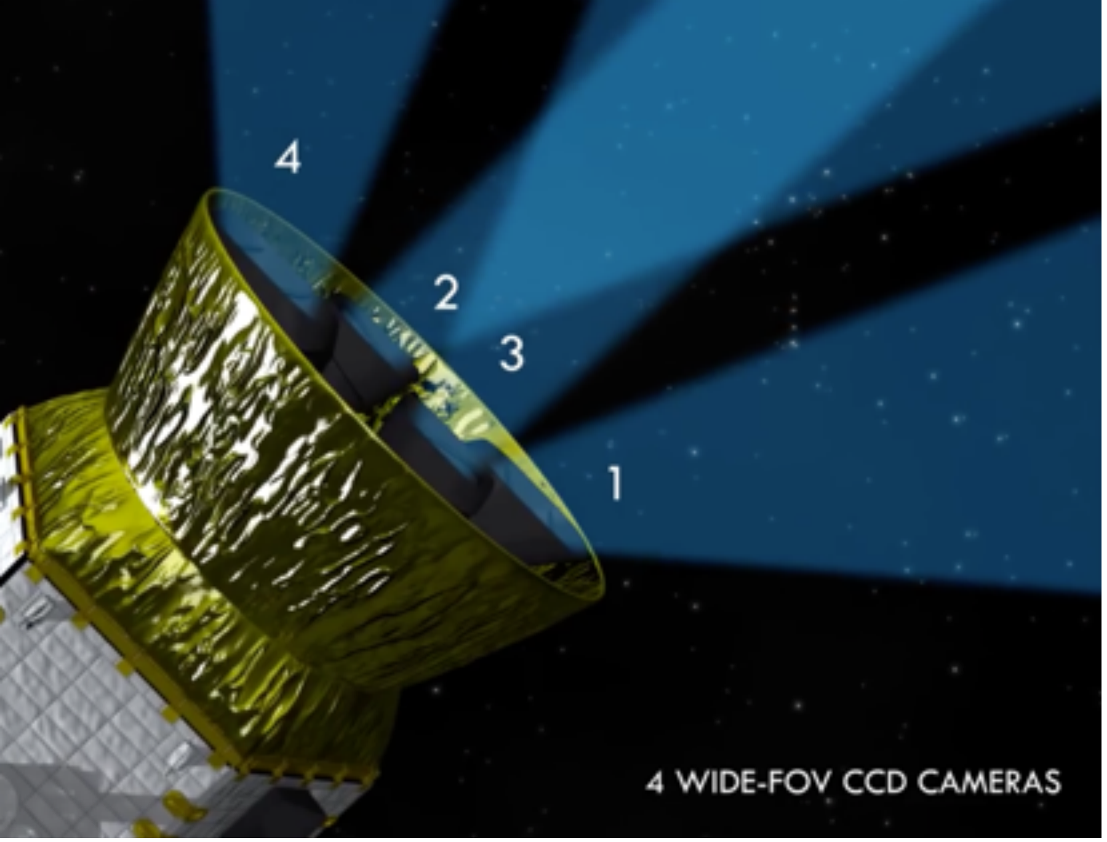


TRANSFER ORBIT
PLEA: 75 R_E
17 R_E
TESS
FINAL MISSION ORBIT

- 3h downlink every 13 days at perigee
- mission orbit period 13.7 days



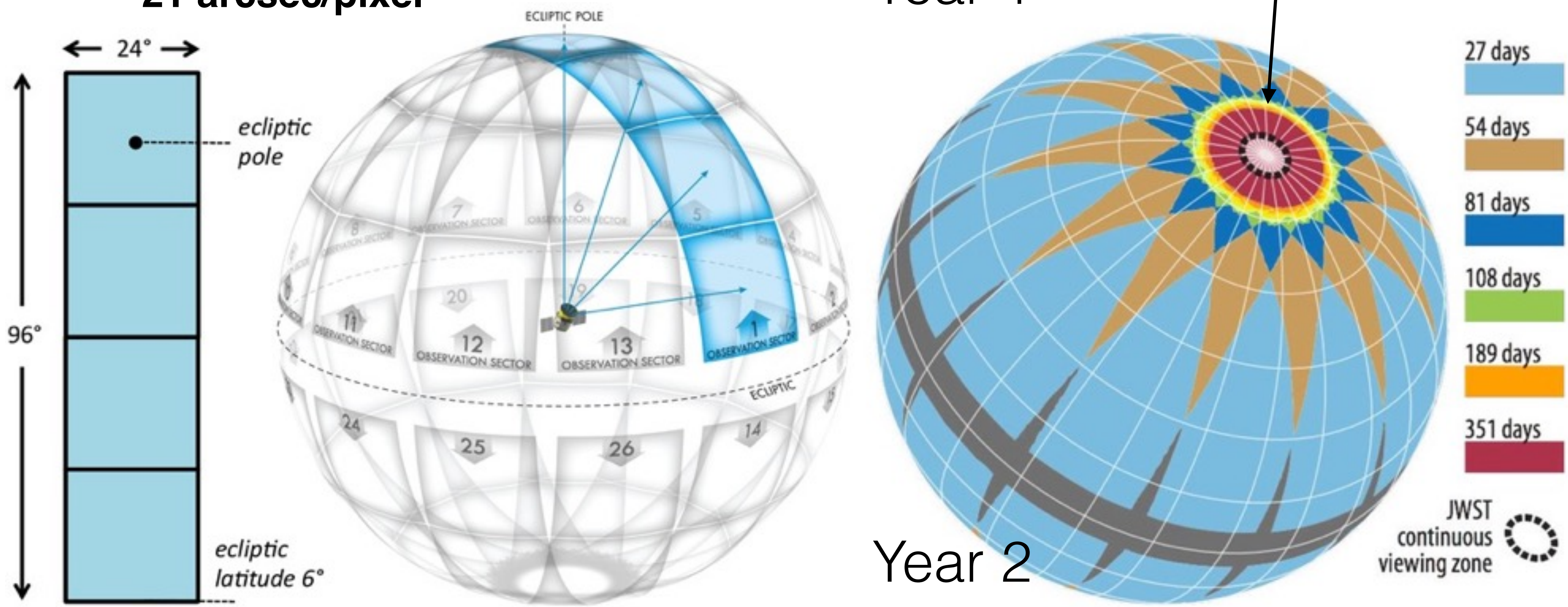
Scanning law



JWST
continuous
viewing zone

6000-10000 Å
21 arcsec/pixel

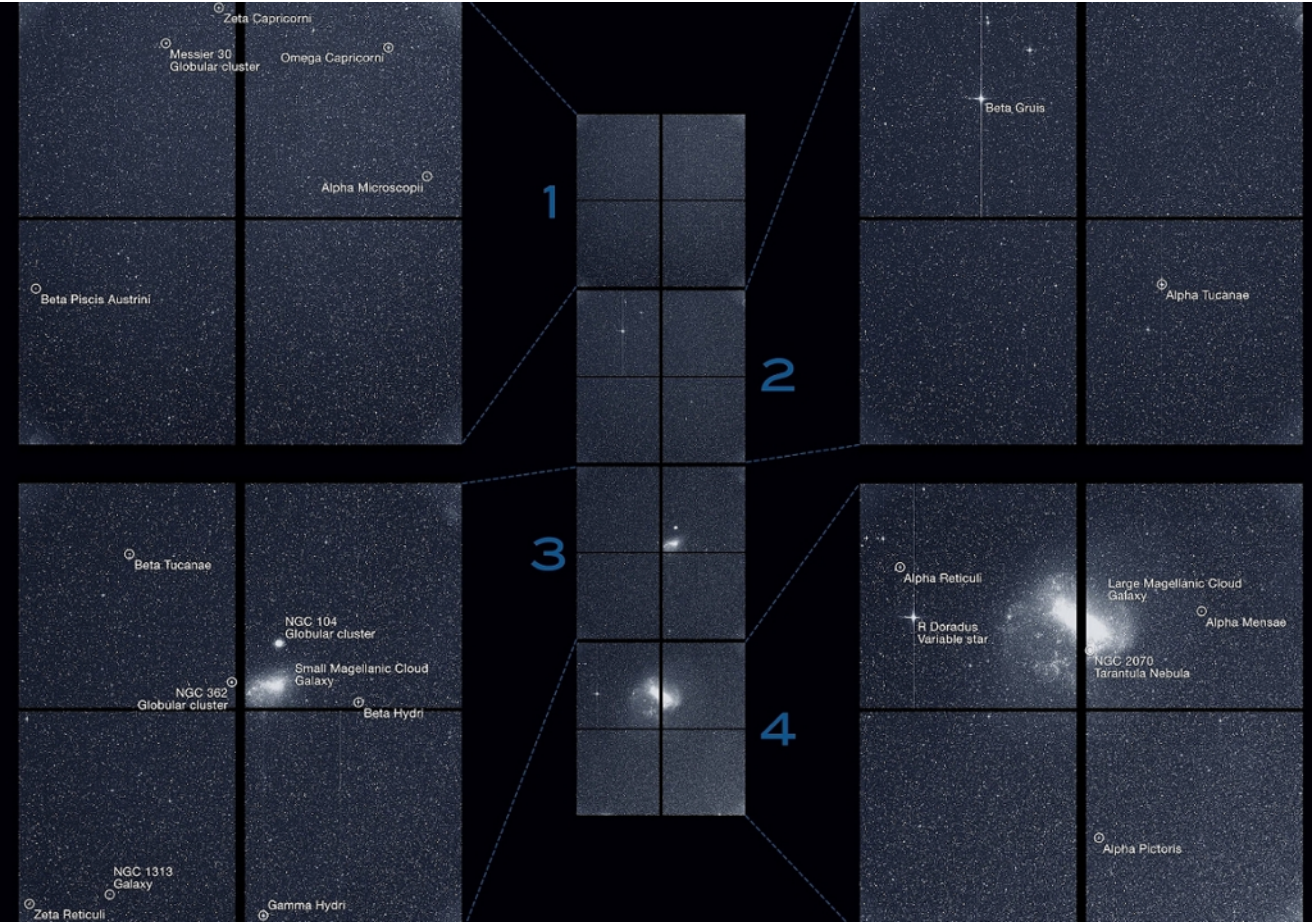
Year 1



Year 2

Mission status

- TESS launched on April 18, 2018
    - SpaceX Falcon 9 rocket.
- Started science operations on July 25, 2018
- The first light image taken on August 7, 2018
- Released publicly on September 17, 2018



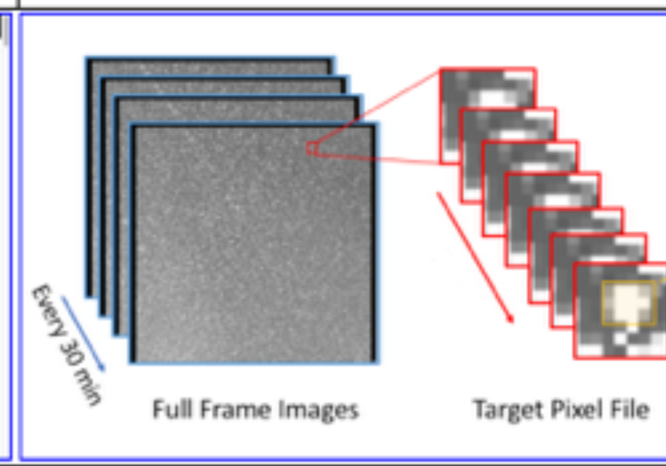
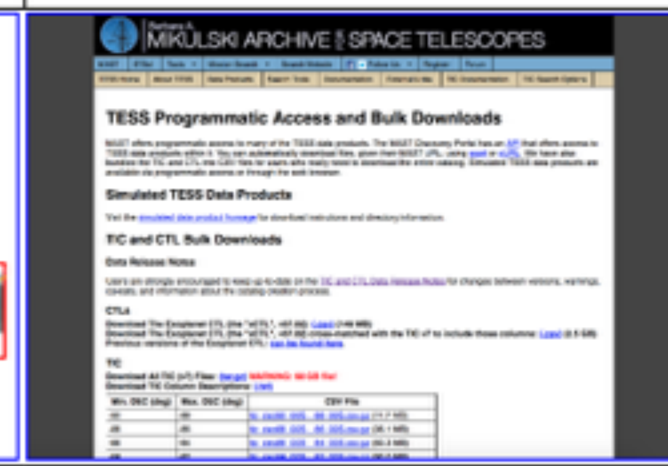
Zeta Capricorni
Messier 30
Globular cluster
Omega Capricorni
Alpha Microscopii
Beta Piscis Austrini
1
Beta Gruis
Alpha Tucanae
2
Beta Tucanae
NGC 104
Globular cluster
Small Magellanic Cloud
Galaxy
NGC 362
Globular cluster
Beta Hydri
NGC 1313
Galaxy
Zeta Reticuli
Gamma Hydri
3
4
Alpha Reticuli
Large Magellanic Cloud
Galaxy
R Doradus
Variable star
Alpha Mensae
NGC 2070
Tarantula Nebula
Alpha Pictoris

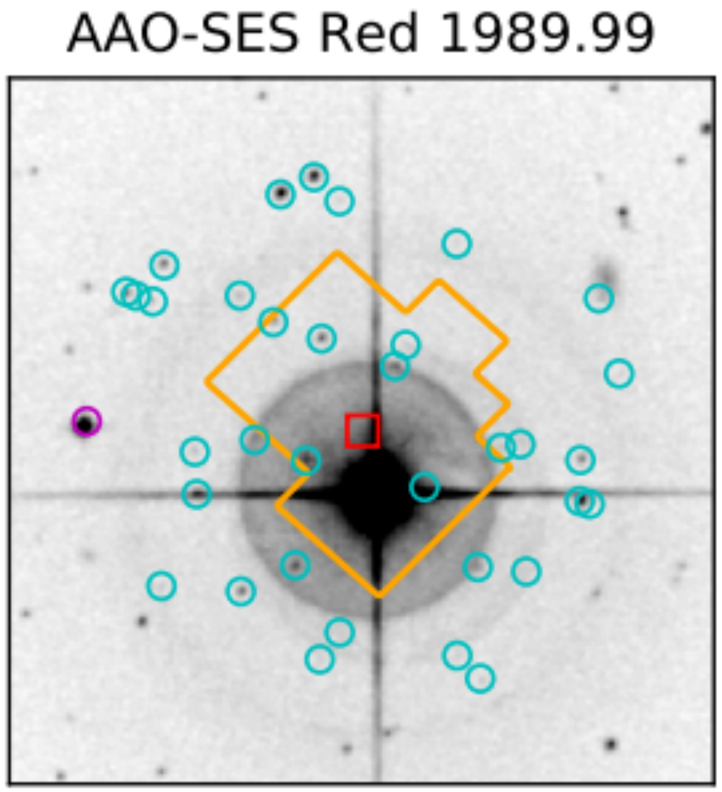
Data format

- Cutouts around 15,000 selected stars (per orbit) are co-added over a 2-minute period and saved on board for downlink
- Full-frame images are co-added over a 30-minute period and saved for downlink.
- The data downlinks will occur every 13.7 days near perigee

Data access

- Data on first 5 sectors is available available at MAST: full frame images, cutouts, pixel light curves…
- Access through Python using the package *lightkurve*

Discovery Portal	Astroquery	TESSCut	Bulk Downloads
			
Cross-mission search across all MAST missions and the Virtual Observatory. Upload source lists, spatial cross-match with MAST, VO, and catalogs. Interactive spectral and light curve plotting, charts, image cutouts, and footprint overlay. Advanced search enables pre-filtering on metadata.	Python package to search for and retrieve data products at MAST. Search for TESS FFIs or two-minute cadence data. Query the TIC or exoCTL catalogs. TESS-specific hints using Astroquery available here.	For users who want to create cutouts from full frame images without having to download the entire field-of-view. Specify central coordinate and size and get back cutouts in target pixel file format.	For users who want to download files in bulk, you may download many types of TESS products in bulk or via URL. This includes the ETE-6 simulated data, TIC and exoCTL catalogs, FFIs, and two-minute cadence data. Visit the Bulk Downloads page for information and access.



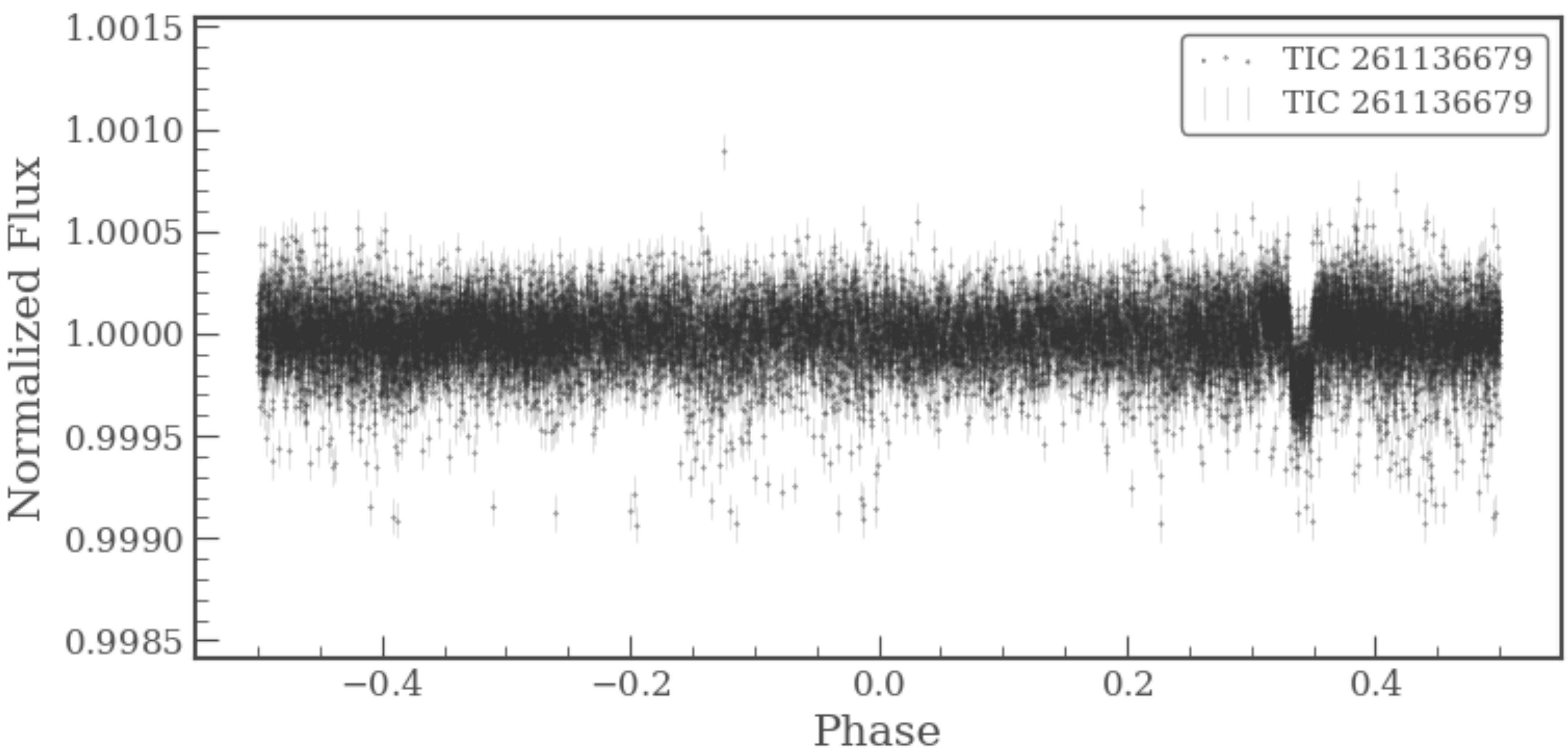
First TESS exoplanet

TESS aperture 6 × 6 pixels

Porb = 6.27 days

Mc = 4.52 ± 0.81 M⊕

Rc = 2.06 ± 0.03 R⊕



Tomo-e Gozen

Image: TNM Image Archives

Tomo-e Gozen: summary

- **Instrument (PI: Shigeyuki Sako, U. Tokyo)**
  - 1m Kiso Schmidt telescope
  - 84 CMOS chips (1k x 2k)
  - 20 deg^2 FOV
  - Imaging with 2 Hz (2 fps)
  - ~17 mag in 0.5 sec exposure
  - 30 TB/night (raw data are deleted in 1 week)

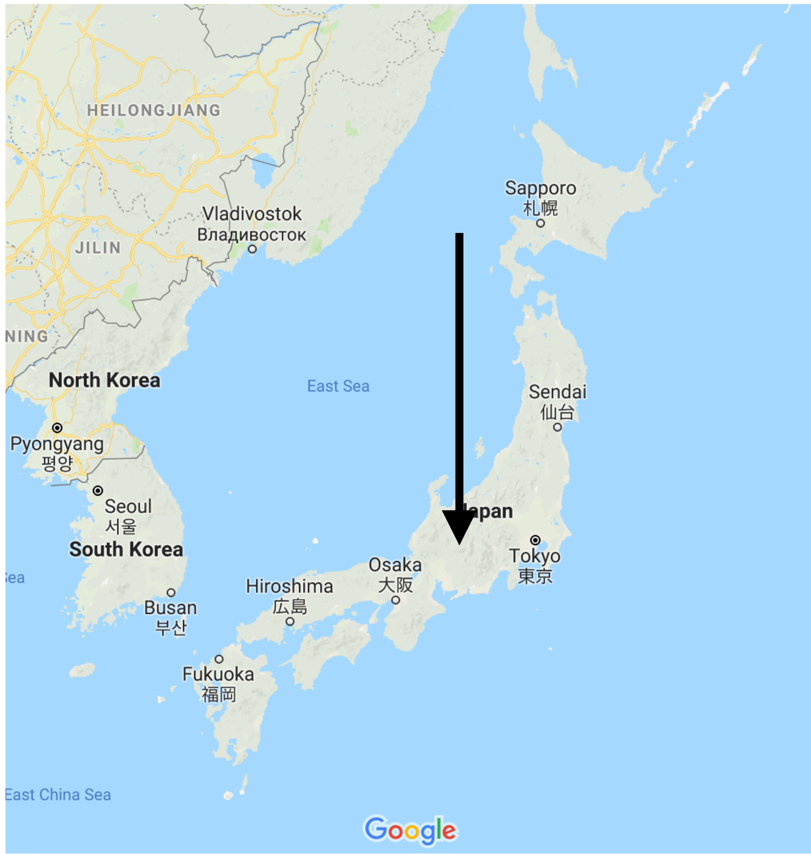
- **Survey (PI: Tomoki Morokuma, U. Tokyo)**
  - 7000 deg^2 - 2 hr cadence - 18 mag (6 sec exposure)
  - No filter
  - 2018 November - (FOV 5 deg^2), 2019 April - (FOV 20 deg^2)

Telescope

http://www.ioa.s.u-tokyo.ac.jp/kisohp/top_e.html

- 1m Kiso Schmidt telescope
  - Operated by U. Tokyo since 1974
  - 9 deg diameter FOV

137.6283,+35.7940 (EL=1130 m)



Camera

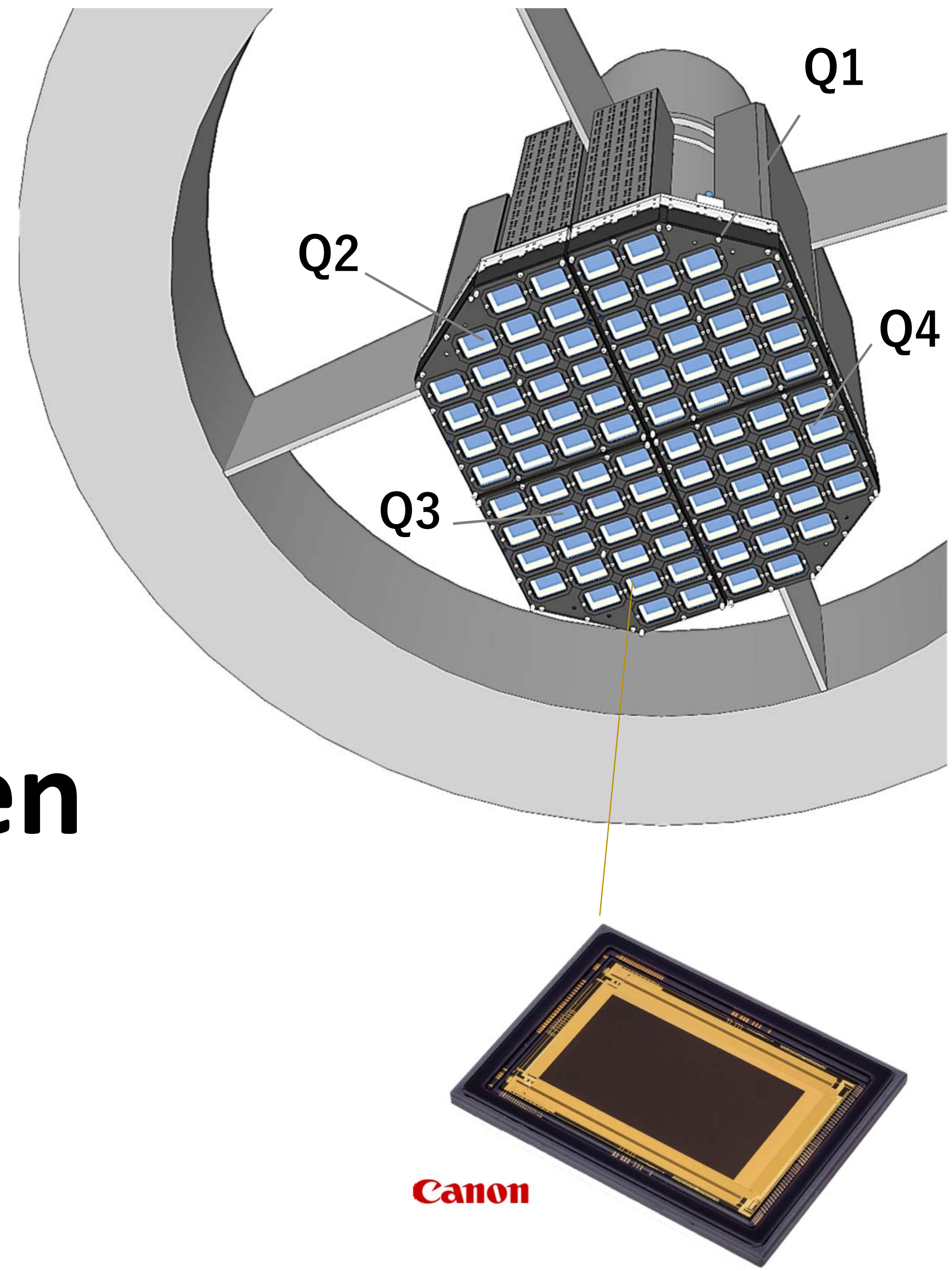
http://www.ioa.s.u-tokyo.ac.jp/tomoe/about.html

Sako et al. 2018, SPIE
Kojima et al. 2018, SPIE
Osawa et al. 2016, SPIE

the first wide-field CMOS camera

The Tomo-e Gozen

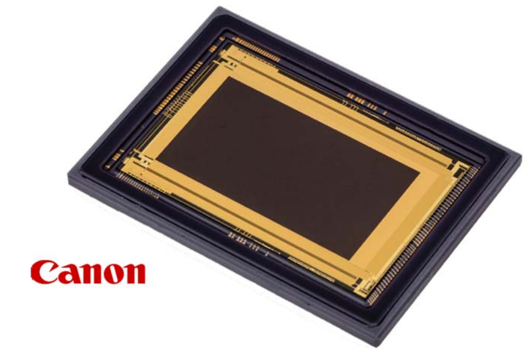
- FoV of 20 deg^2 in ϕ 9 deg
- 84 chips of CMOS, 1k x 2k pixels
- Consecutive frames in 2 fps (max)
- Big movie data of 30 TB/night (max)

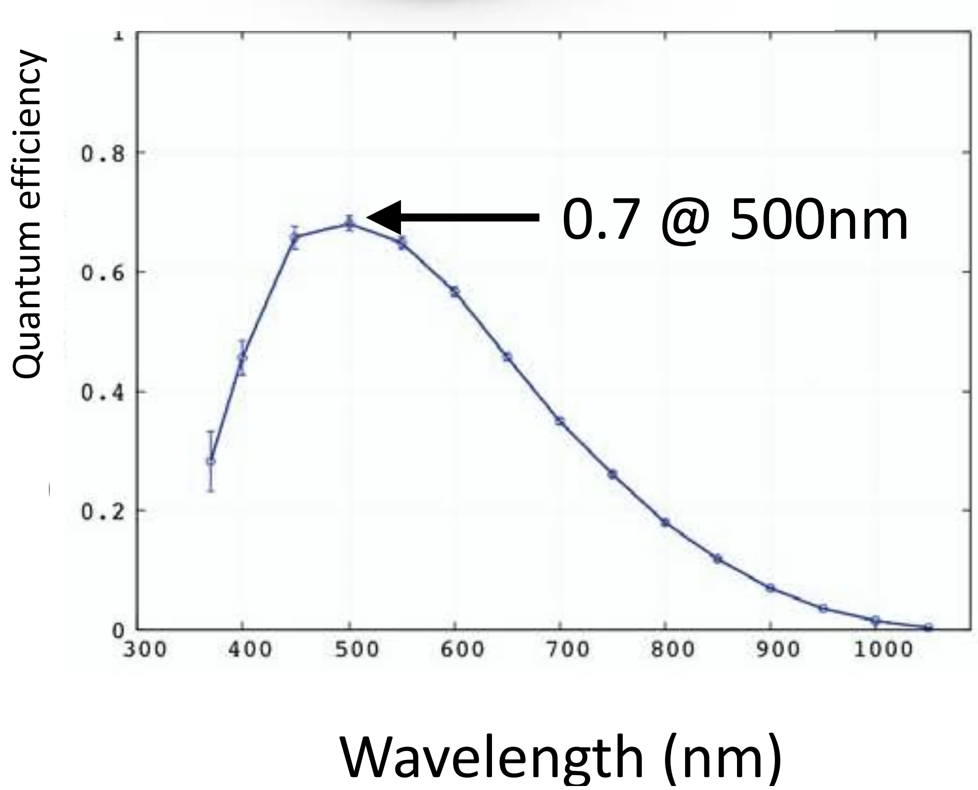


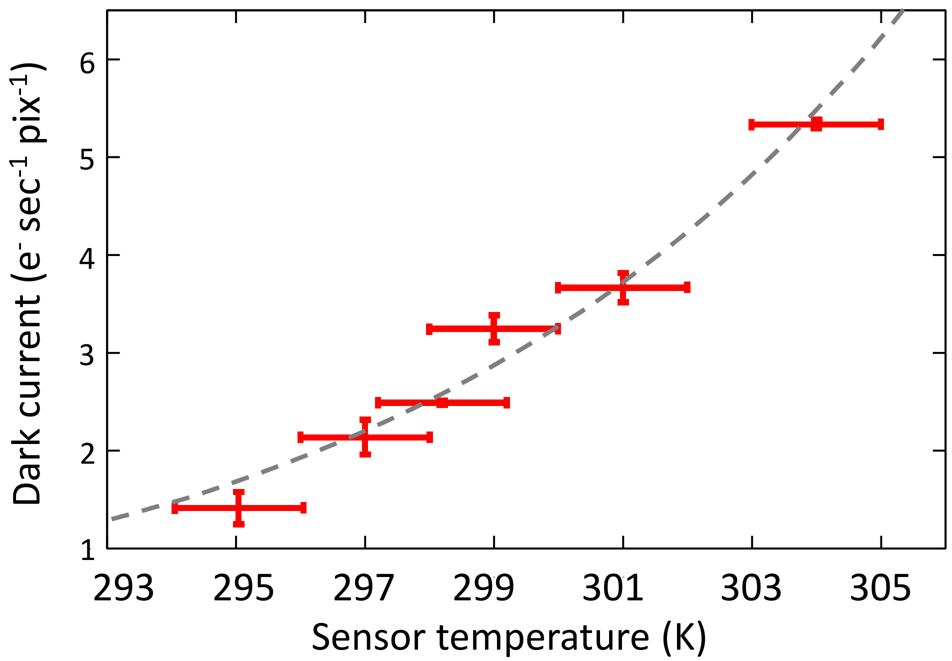
Slide courtesy of Shigeyuki Sako

Sensor

- **Large pixel CMOS sensor by Cannon**
  - 2000 x 1128 pixels, front side illuminated
  - 19 um/pix (= 1.198 arcsec/pix)
  - Sensitive at 370-730 nm
  - Readout noise: 2.0 e^-
  - Dark current: 6e^- sec^{-1} @ 305K
    (sky 50 e^- sec^{-1} pix^{-1} at Kiso)

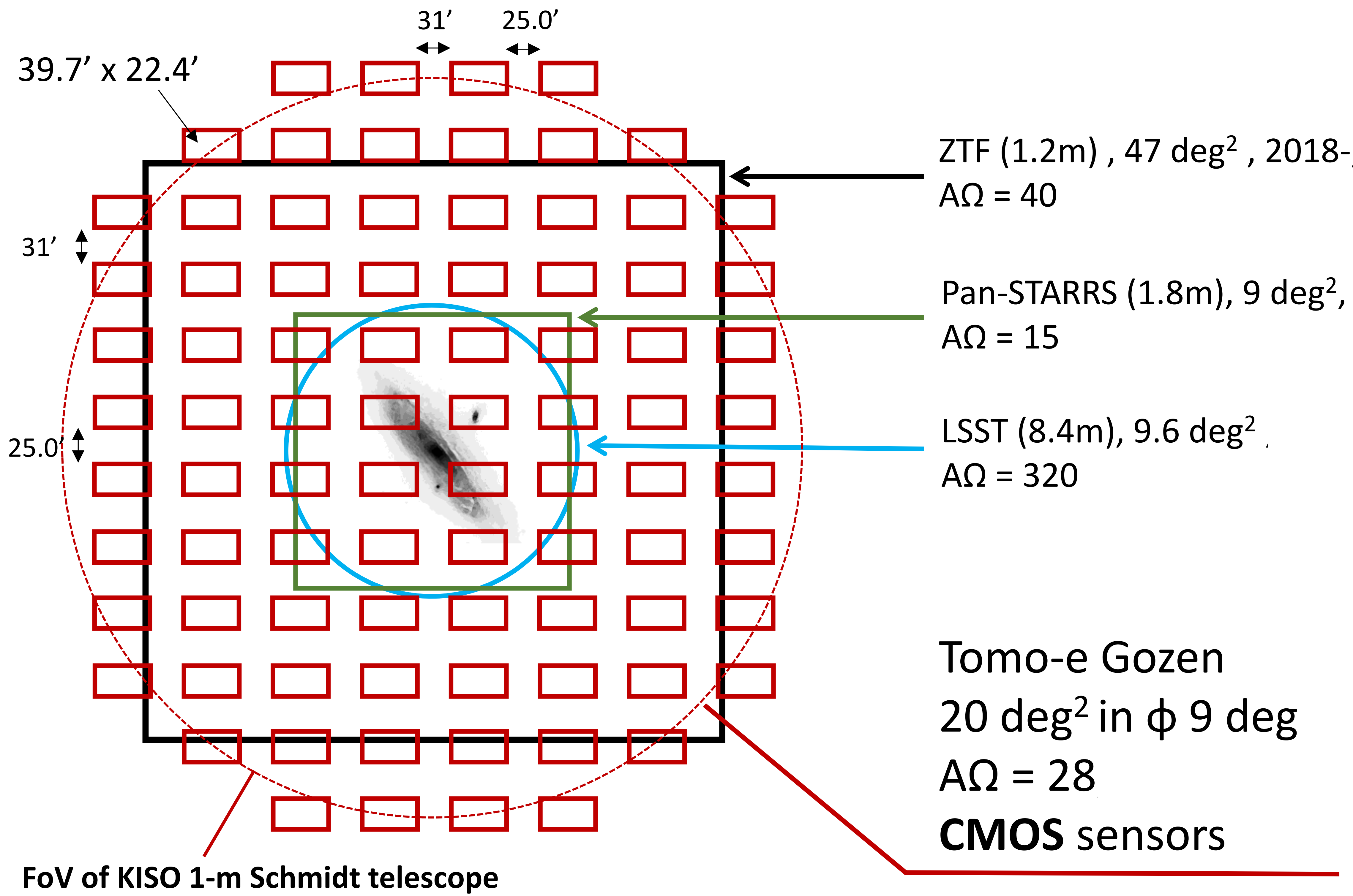






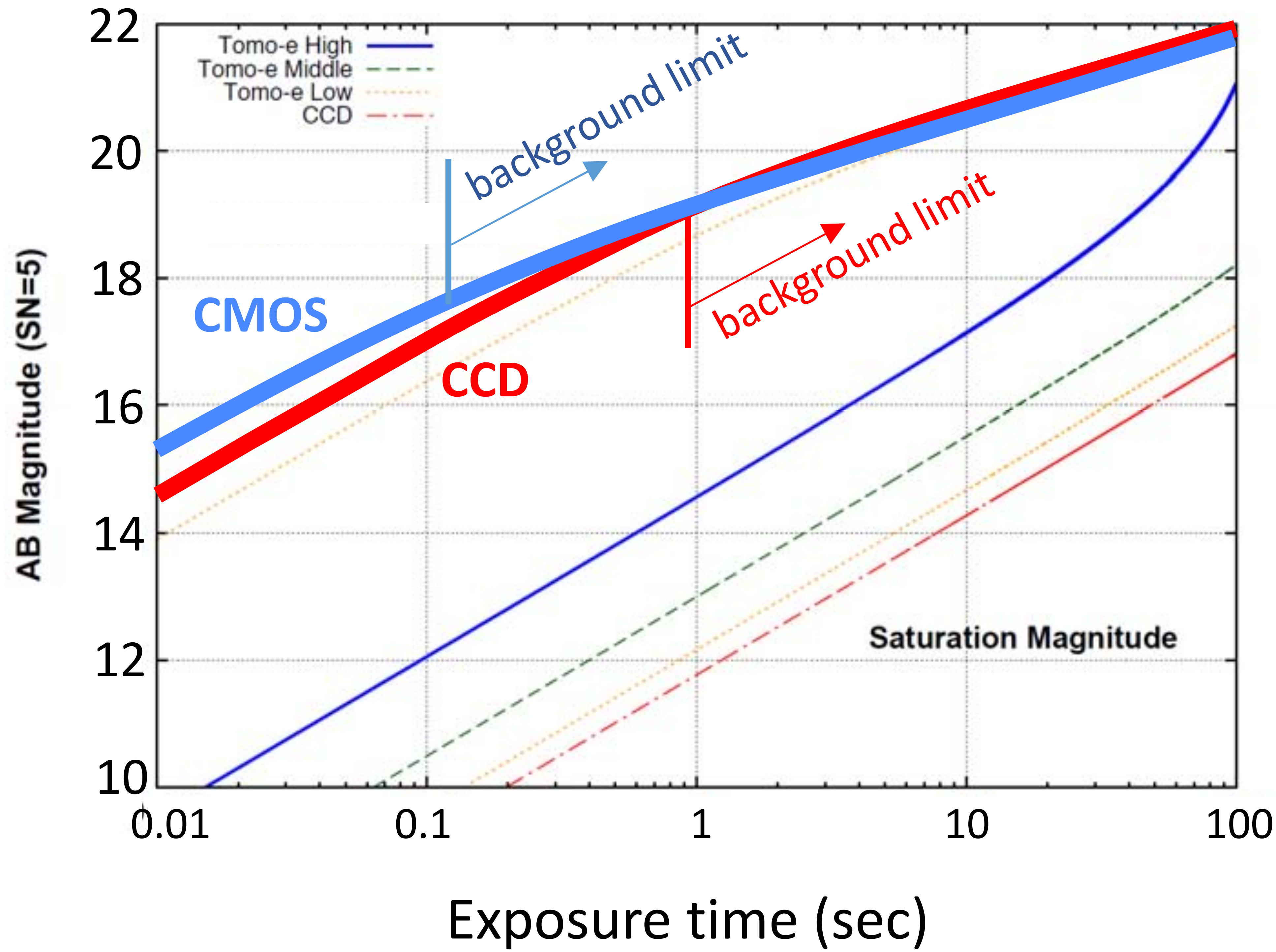
Kojima, Sako, Ohsawa et al. 2018, SPIE

Field of view



Slide courtesy of Shigeyuki Sako

Limiting magnitudes



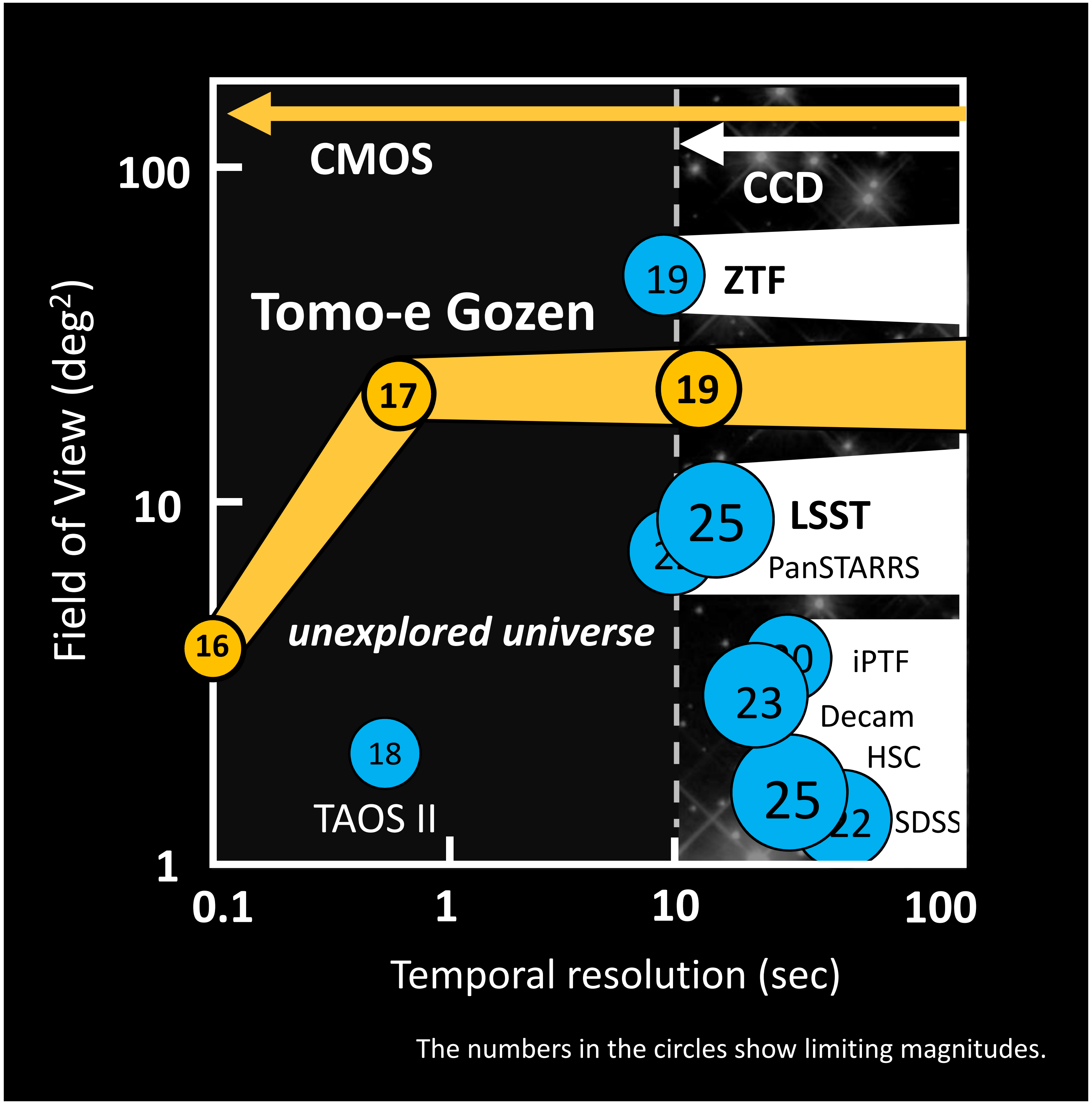
Kojima, Sako, Ohsawa et al. 2018, SPIE

Slide courtesy of Shigeyuki Sako

Transient sky in second timescale

Default observing mode: imaging with 2 Hz (2fps)

- ~17 mag in 0.5 sec
- ~30 TB/night



By Shigeyuki Sako

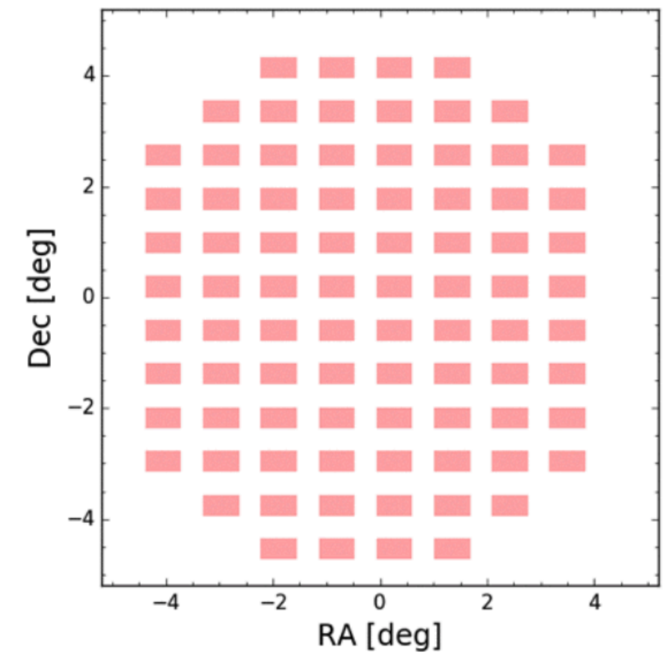
Northern sky transient survey

PI: Tomoki Morokuma

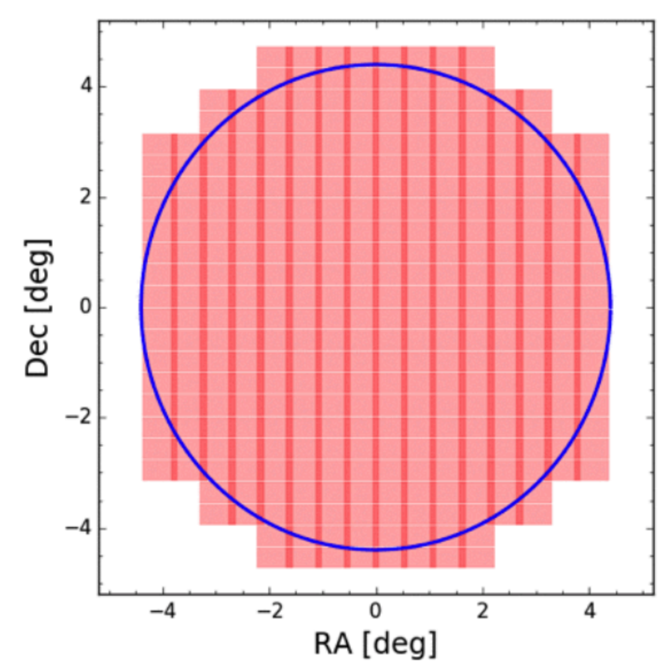
- **Survey plan: 7000 deg^2 - 2hr cadence - 18 mag**
  - 1 "visit" = 60 deg^2 in 1 min
    - 12 x 0.5 sec = 6 sec (~18 mag depth)
    - 2 x 2 dithering (to fill the gap)
  - 2 hr cadence (= 120 visits)
    => ~7000 deg^2 in total (elevation > 40 deg)
  - No filter (effectively g + r)
  - Keep detection information of 2 Hz images

- **Schedule**
  - 2018 November - (Q1, FOV 5 deg^2)
  - 2019 April - (Q1-4, FOV 20 deg^2)

1 exposure

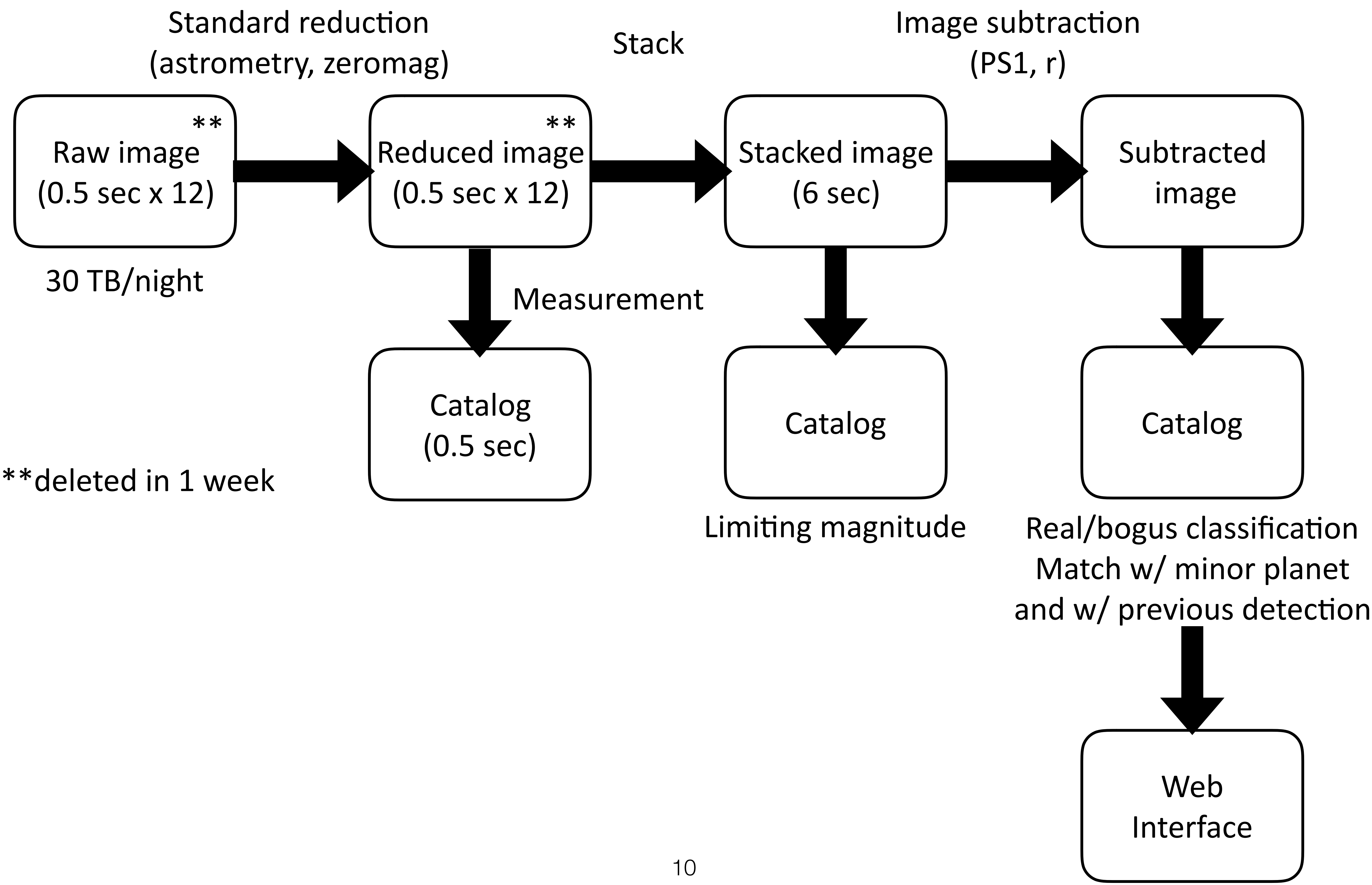


2 x 2 dithering



By Tomoki Morokuma

Data flow


Standard reduction
(astrometry, zeromag)
Stack
Image subtraction
(PS1, r)
**
Raw image
(0.5 sec x 12)
**
Reduced image
(0.5 sec x 12)
Stacked image
(6 sec)
Subtracted
image
30 TB/night
Measurement
Catalog
(0.5 sec)
Catalog
Catalog
**deleted in 1 week
Limiting magnitude
Real/bogus classification
Match w/ minor planet
and w/ previous detection
Web
Interface

Transient detection in the test run

= AT 2018leh (2018-12-31)
= ZTF18adbmrug (2018-12-30)

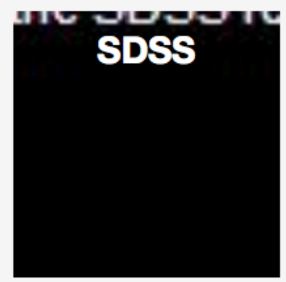
Tomo-e transient server List Object Account Logout

previous

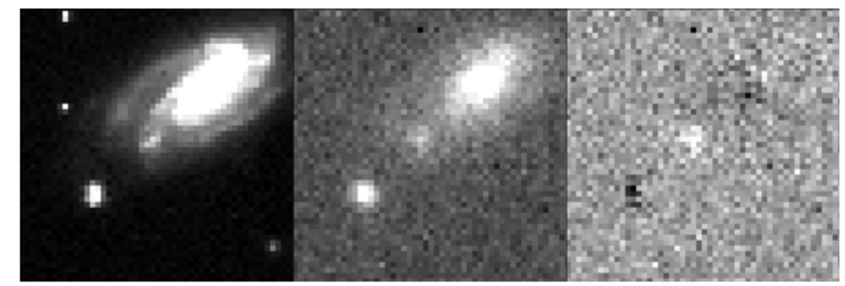
19monv

Transient ID: 220736 Variable_id: 1021301

Number of detections: 3 (paramcand)



ref cr sub



58496.5133 17.74 +- 0.07

2019-01-11

Tags Click a tag for removal Insert tags

No tag assigned.

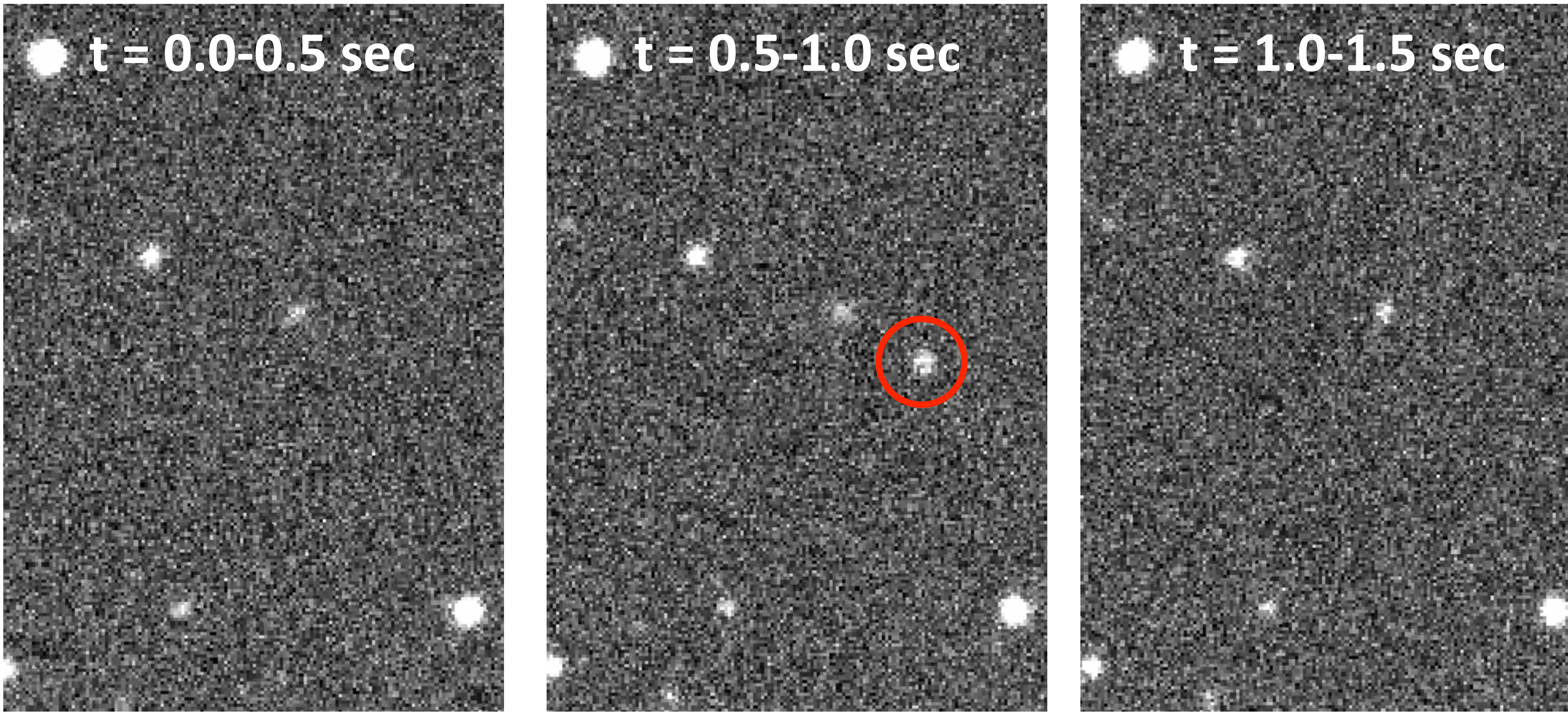
Rapid | Young? | SN | AGN | MP? | Unclear | Bogus | or [ ] submit

SN? | AGN? | Variable?

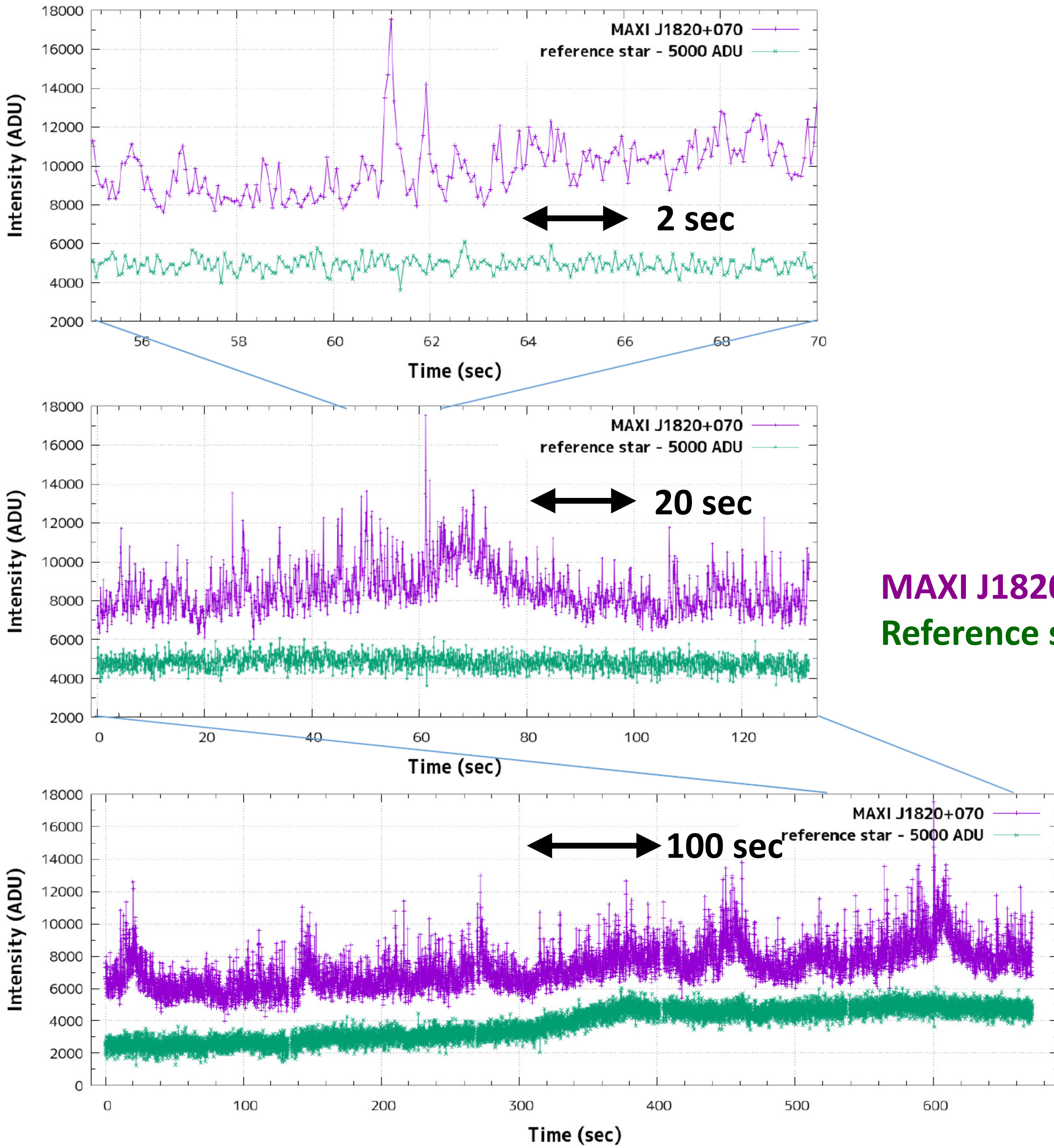
Ra, Dec (Decimal)	Ra, Dec	Detector ID	x,y
61.26379 , 25.26215	04:05:03.31, +25:15:43.8	134	0.00 , 0.00 0.00 , 0.00

Relavant links	SDSS	PS1	TNS	MPChecker	Visibility (local site: 137.6283 35.7942 1130 +9)
fits files	Ref	Sub			

Very rapid transient in 2Hz imaging mode



Rapid variability of X-ray transient (MAXI J1820+070)



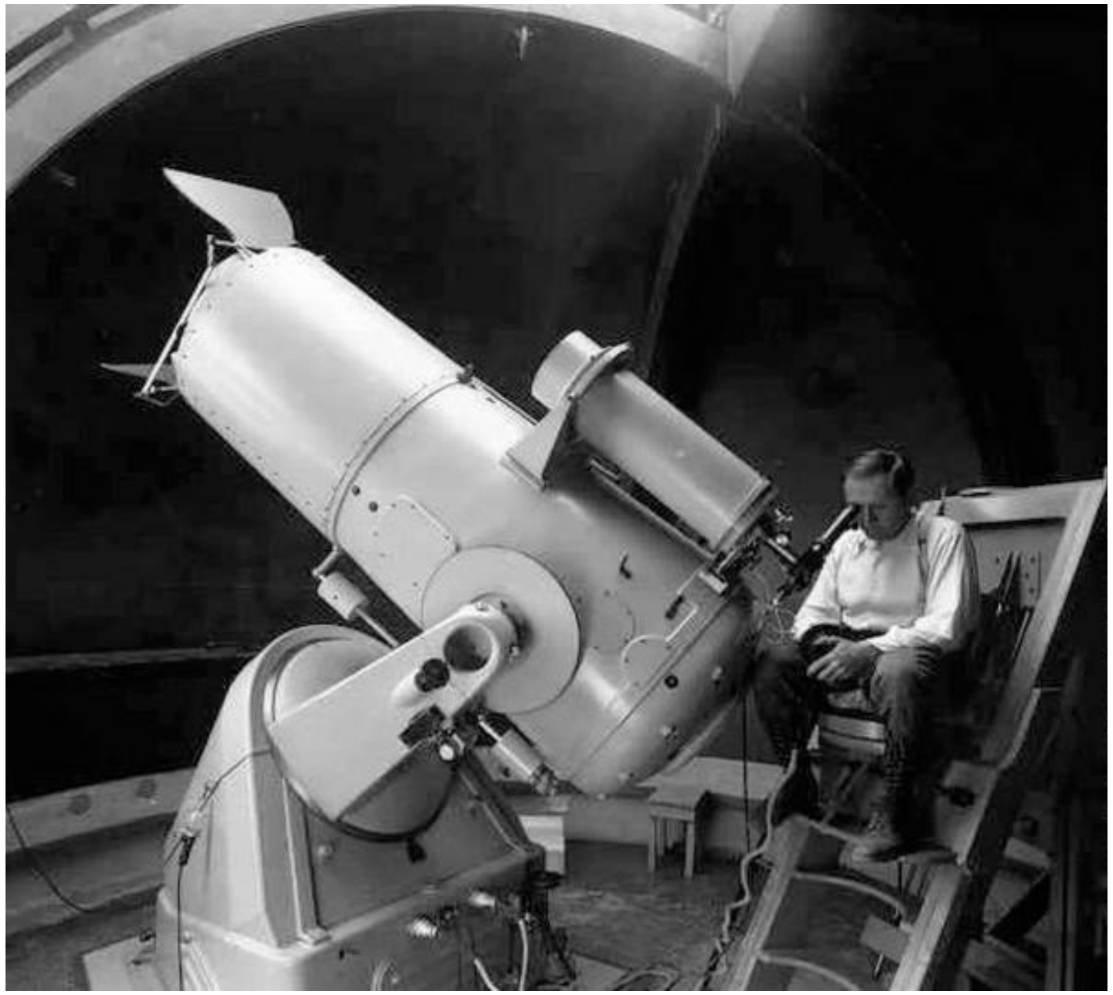
MAXI J1820+070
Reference star

Sako et al. 2018, ATel, 11426

http://www.ioa.s.u-tokyo.ac.jp/tomoe/MAXIJ1820+070/MAXIJ1820+070.html

ZTF Public Surveys

Eric Bellm
Survey Scientist
University of Washington



The ZTF MSIP proposal to the NSF established two major public surveys.

The approved proposal allocated 50% of the P48 time available to the collaboration (40% of the total time) to conduct two public surveys of broad utility:

Northern Sky Survey

Two visits/night (g+r) for asteroid rejection ⇒ 3-day average cadence

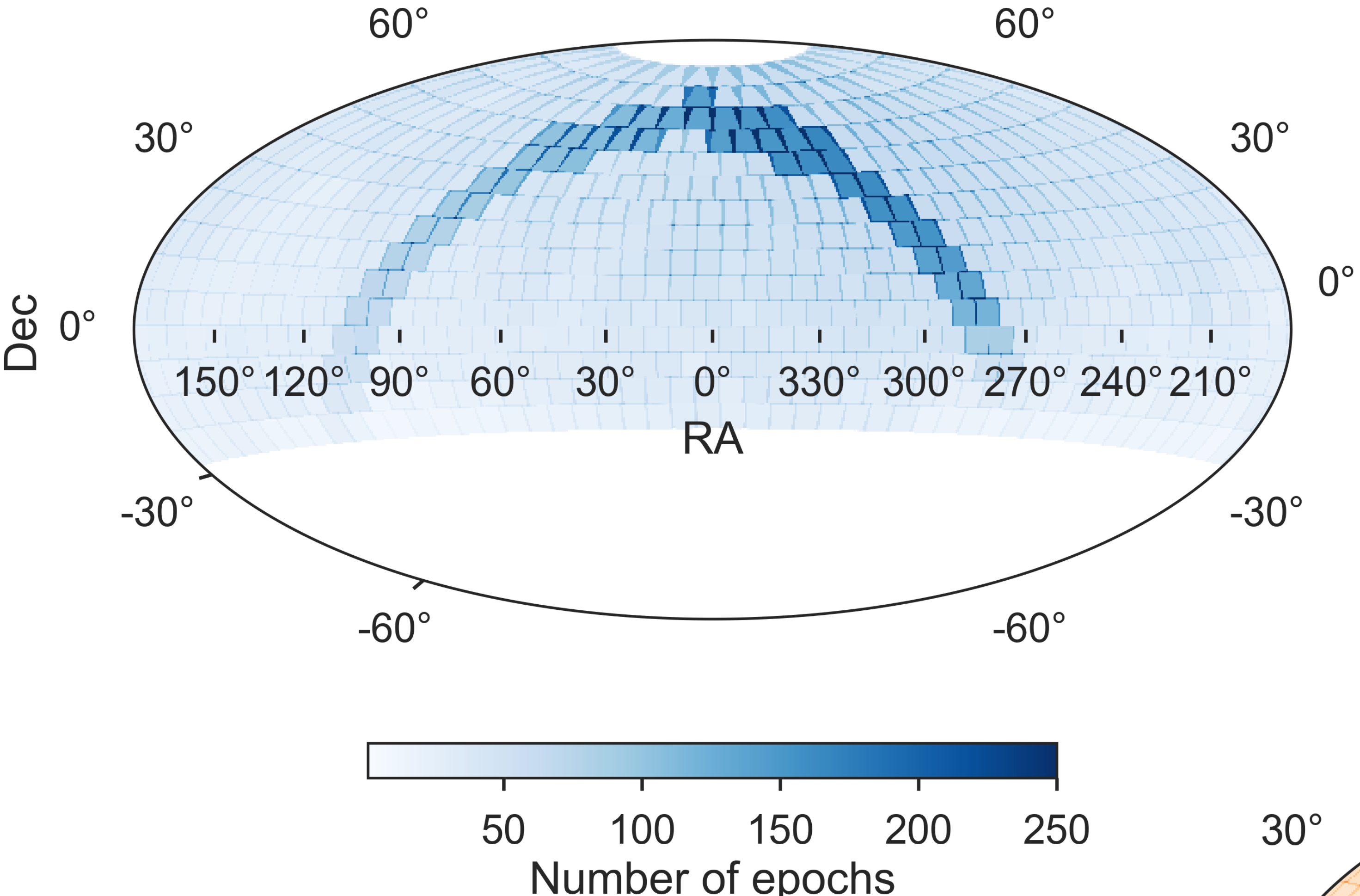
~23,675 deg^2 total footprint; 85% time; 4325 deg^2 average per night

Similar to LSST Wide-Fast-Deep
systematic samples of supernovae, SLSNe, TDE, AGN, variable stars, asteroids…

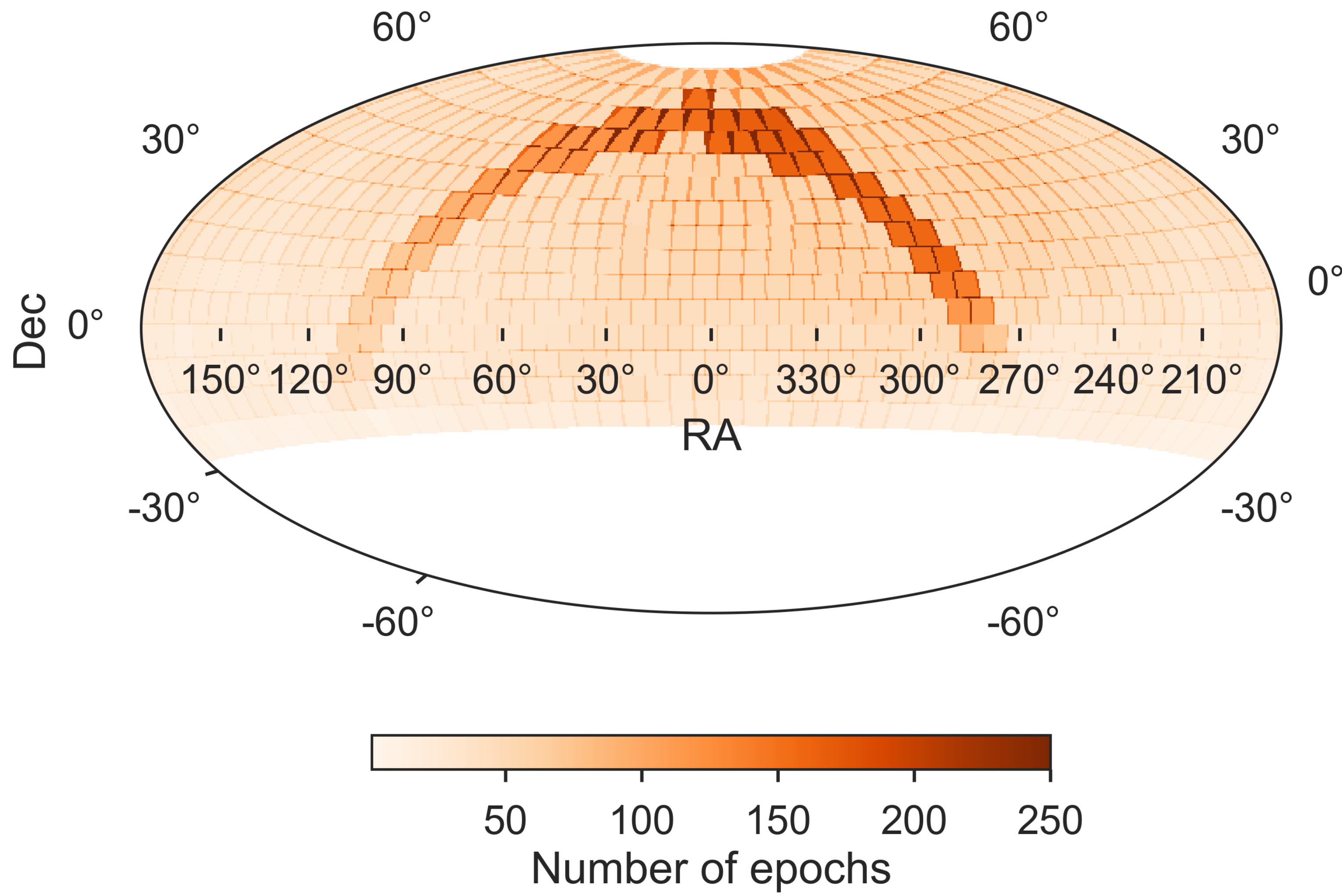
Galactic Plane Survey

Nightly sweep of the Galactic Plane ($|b|<7°$; nightly g+r)
~2800 deg^2 total footprint; 15% time; 1475 deg^2 average per night
rare and exotic variables and binaries, CVs and novae, M-dwarf flares, large-scale gyrochronology, young star outbursts, and more

The ZTF scheduler has delivered the MSIP programs as designed.



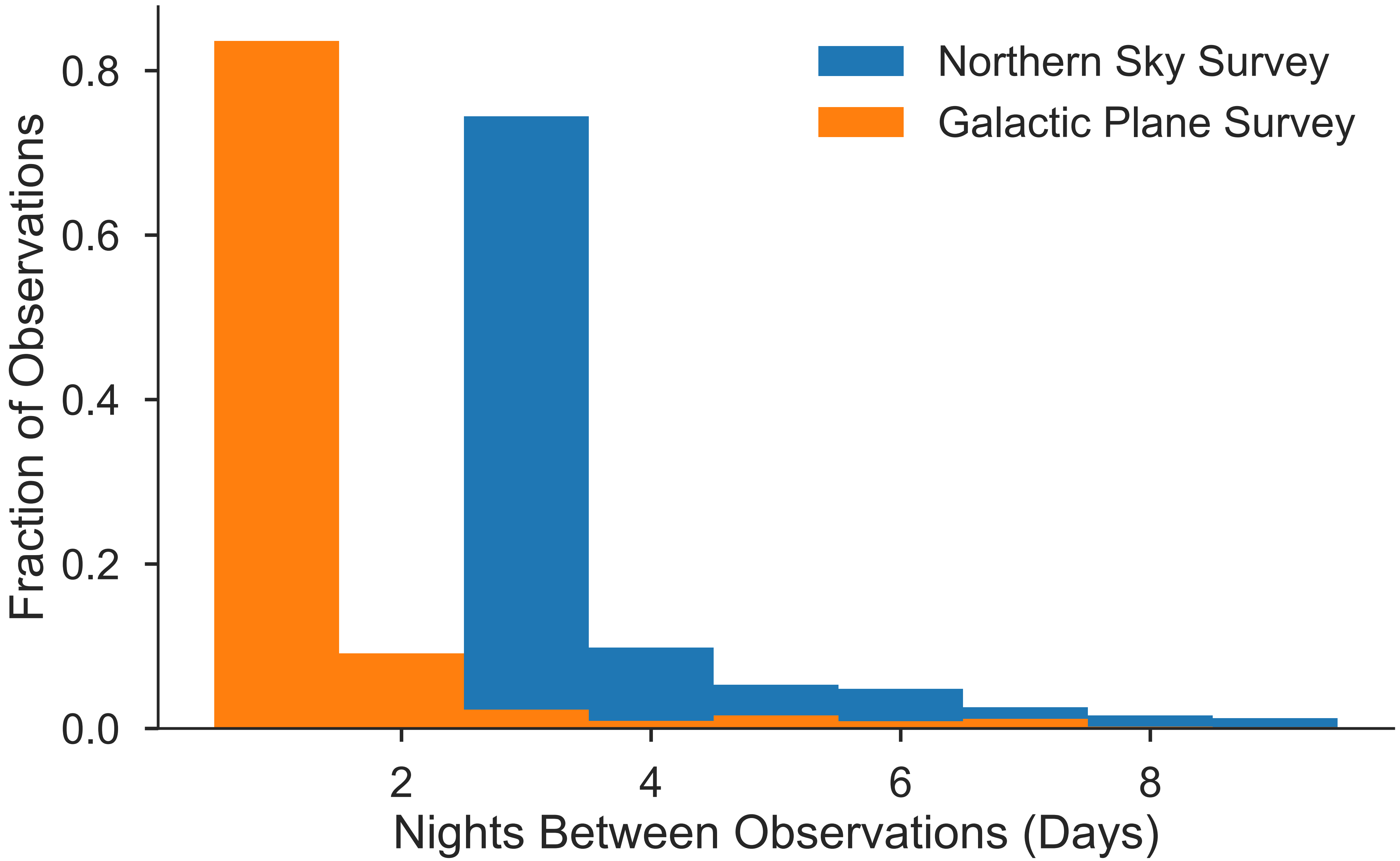
g-band



r-band

Bellm et al., PASP submitted
poster 363.08; zwicky.tf/aw8

The ZTF scheduler has delivered the MSIP programs as designed.

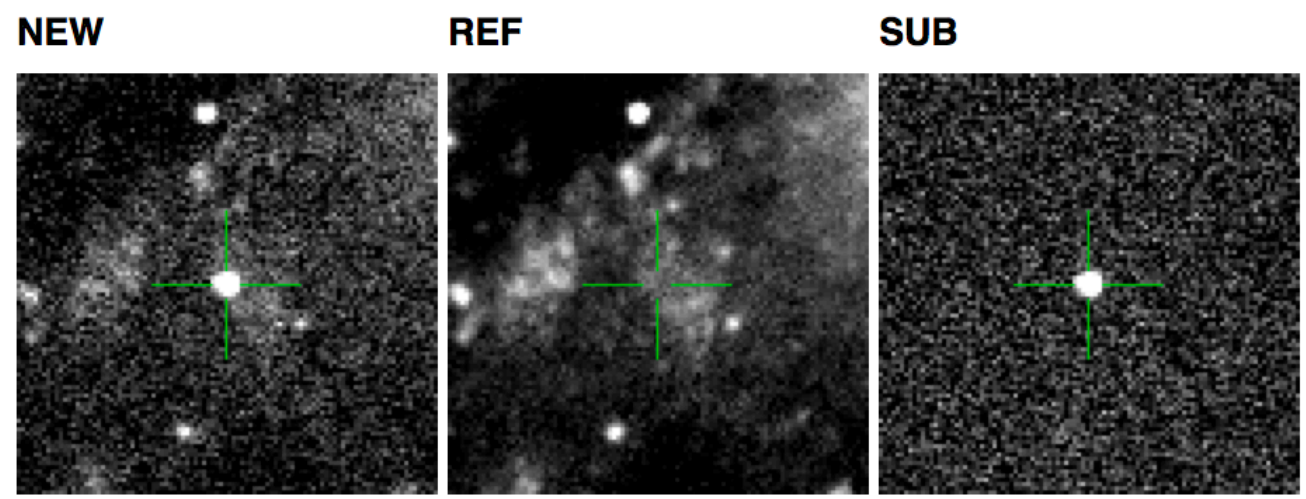


Bellm et al., PASP submitted
poster 363.08; zwicky.tf/aw8

ZTF is providing two main flavors of data products.

Alerts from image differencing

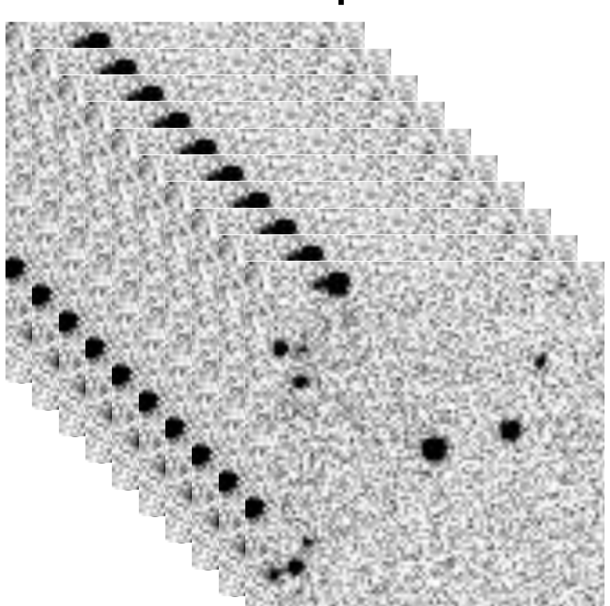
- released in near-real time from public surveys
- filter to find objects of interest for rapid followup
- contains false detections!

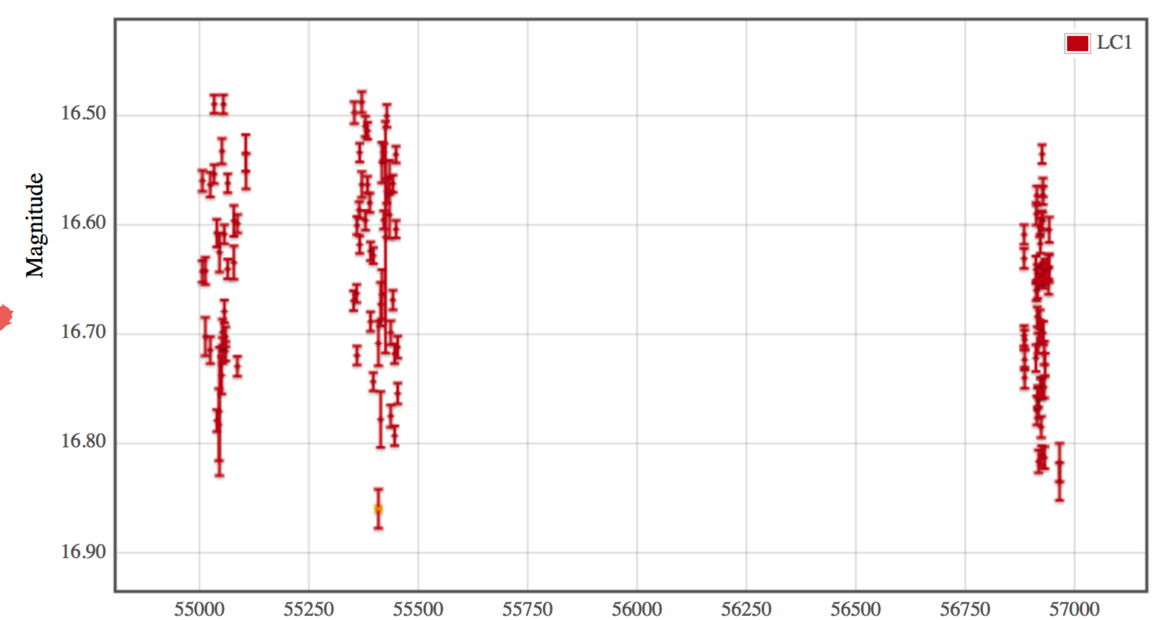


Processed images and catalogs;

PSF **lightcurves** for *all* sources in the images

- released biannually beginning Q2 2019
- more precise for variable stars & AGN





ZTF is prototyping an LSST-like alert stream.

Primary interface is an *alert stream*, not a *batch query*

Real-time, low-latency, naturally distributed & decentralized

All* subtraction candidates are streamed at low latency

ZTF: 1M alerts/night

LSST: 10M alerts/night

Events sent in rich alert packets

position, time, filter, magnitudes, Real/Bogus score, distance to nearest reference source, PSF metrics, solar system counterpart (if applicable), star/galaxy score, PS1 & Gaia crossmatch, number of past detections in the survey, number of past observations; 30 days past history with upper limits; image cutouts

https://github.com/ZwickyTransientFacility/ztf-avro-alert

compare to LSST's Data Products Definition Document: **ls.st/dpdd**

Users find events through classification & filtering systems

send full stream to community brokers: ANTARES, ALeRCE, etc.

planned UW filtering service (compare to LSST's)

Since June 2018 we have been sending real-time alerts from the public surveys to community brokers.

ANTARES

https://antares.noao.edu/

LASAIR

https://lasair.roe.ac.uk/

ALeRCE

Automatic Learning for the Rapid Classification of Events

http://alerce.science/

LCO

https://mars.lco.global/

There is also nightly static archive of the alerts:
https://ztf.uw.edu/alerts/public/

We expect to revise the MSIP surveys after ~18 months.

Modifications to the public surveys will be considered for the second half of ZTF's 3-year survey (late 2019), taking into account lessons learned, results obtained to date, and the broader landscape.

A move to higher cadence on a smaller sky area is likely, but ideas and suggestions are welcome. Public surveys will continue to be aimed at enabling a wide range of science goals.

The ZTF MSIP PI will select the revised public surveys after reviewing these inputs.

ZTF’s public surveys are operating effectively, generating science, and seeding a new ecosystem of community brokers for the LSST era.

Science from ZTF

Lin Yan (Caltech)

The two major ZTF public surveys

- Northern Sky Survey
  - 2 visits/night (g+r) for asteroid rejection, 3-day cadence on average; ~23,675sq deg

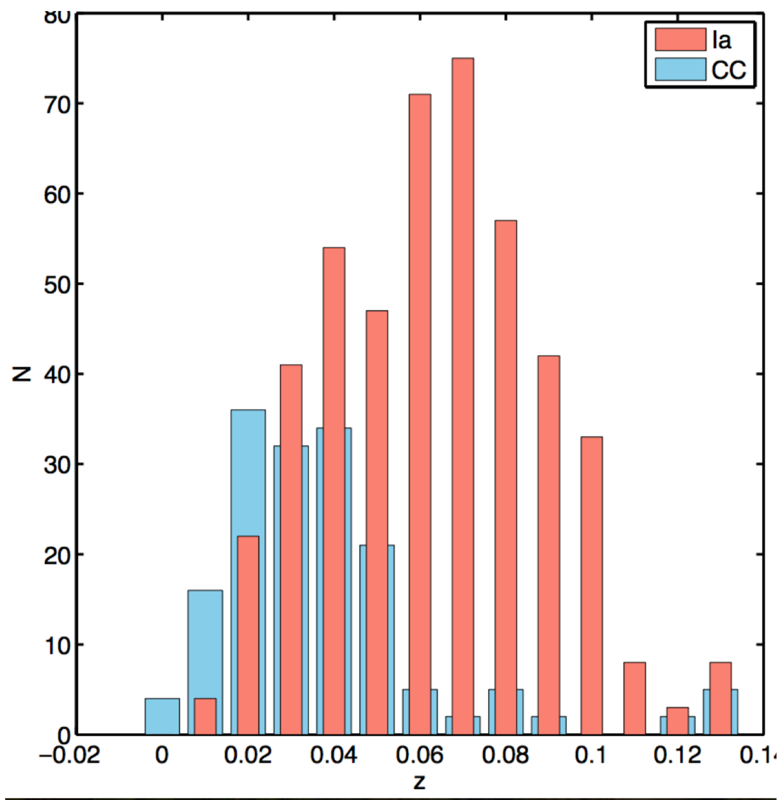
- Galactic Plane Survey
  - Nightly sweep of the Galactic plane (|b|<7; 1 day cadence in g & r), ~ 2800sqdeg

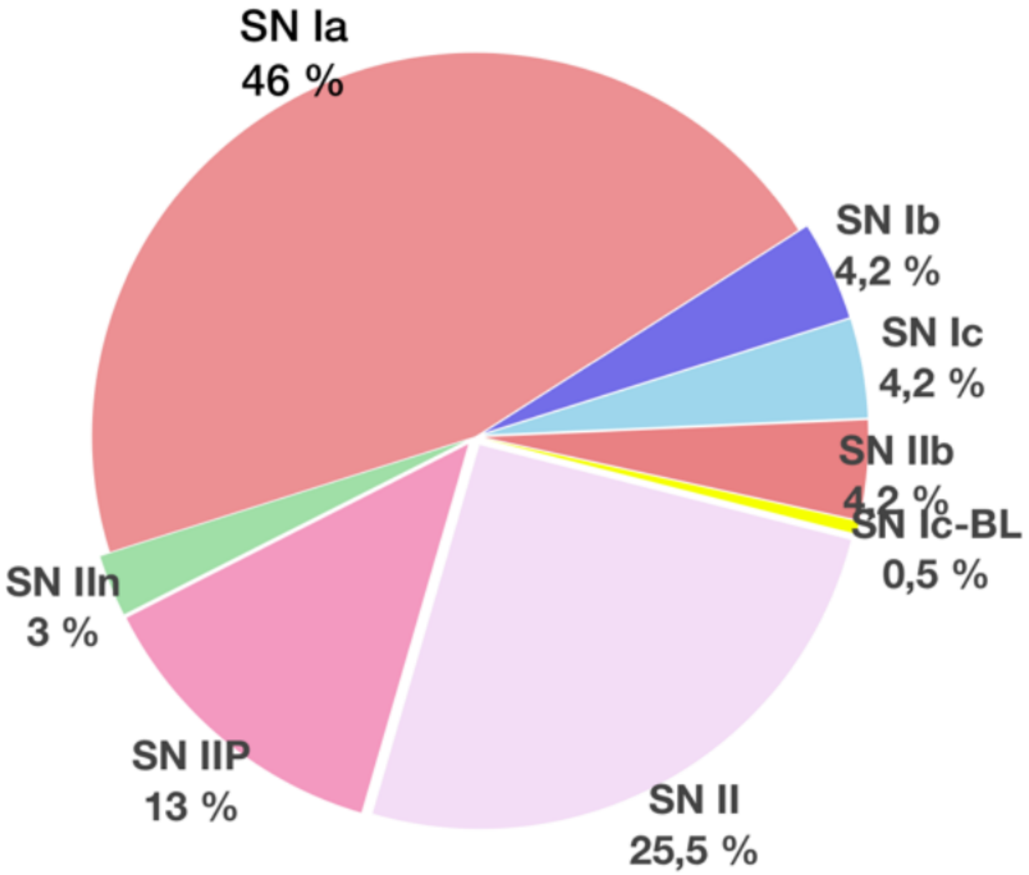
Broad categories:

- ❖ Supernova
- ❖ Nuclear transients – (TDE, AGN)
- ❖ Stellar variables (binary & flaring)
- ❖ Asteroids

Supernova – (1) rates and luminosity functions:

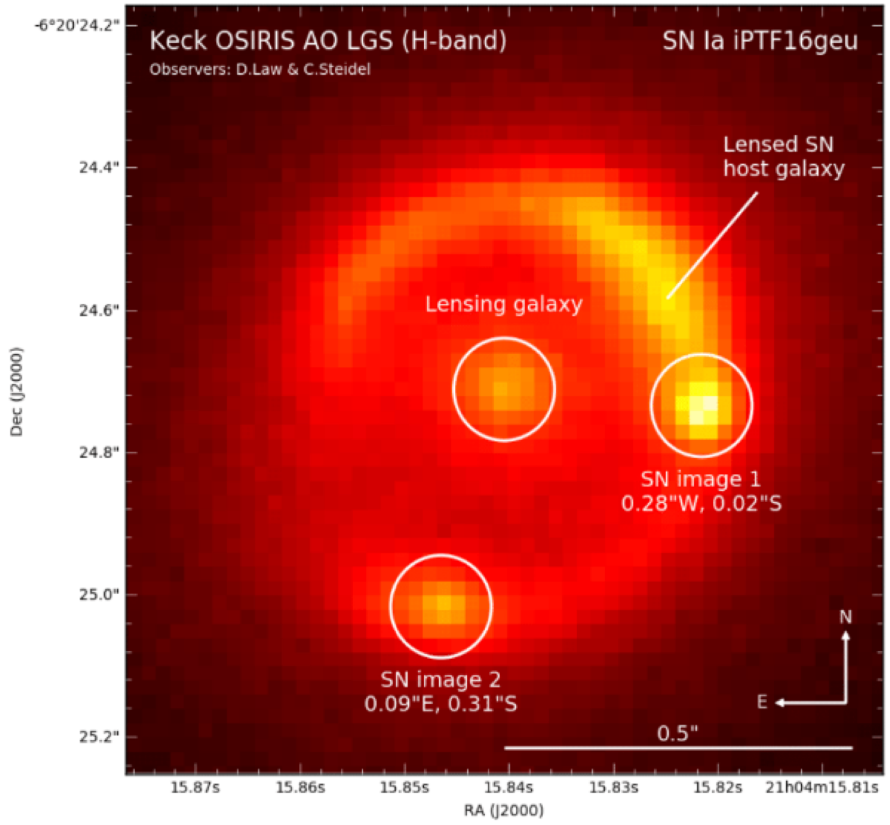
- The ZTF Bright Transient Survey (BTS)
  - All alerts brighter than 18.5mag are spectrally classified, primarily using SEDM on Palomar 60inch
  - Total classified: 622 (477 Ia, 177 ccSN)





Supernova – (2) rare events:

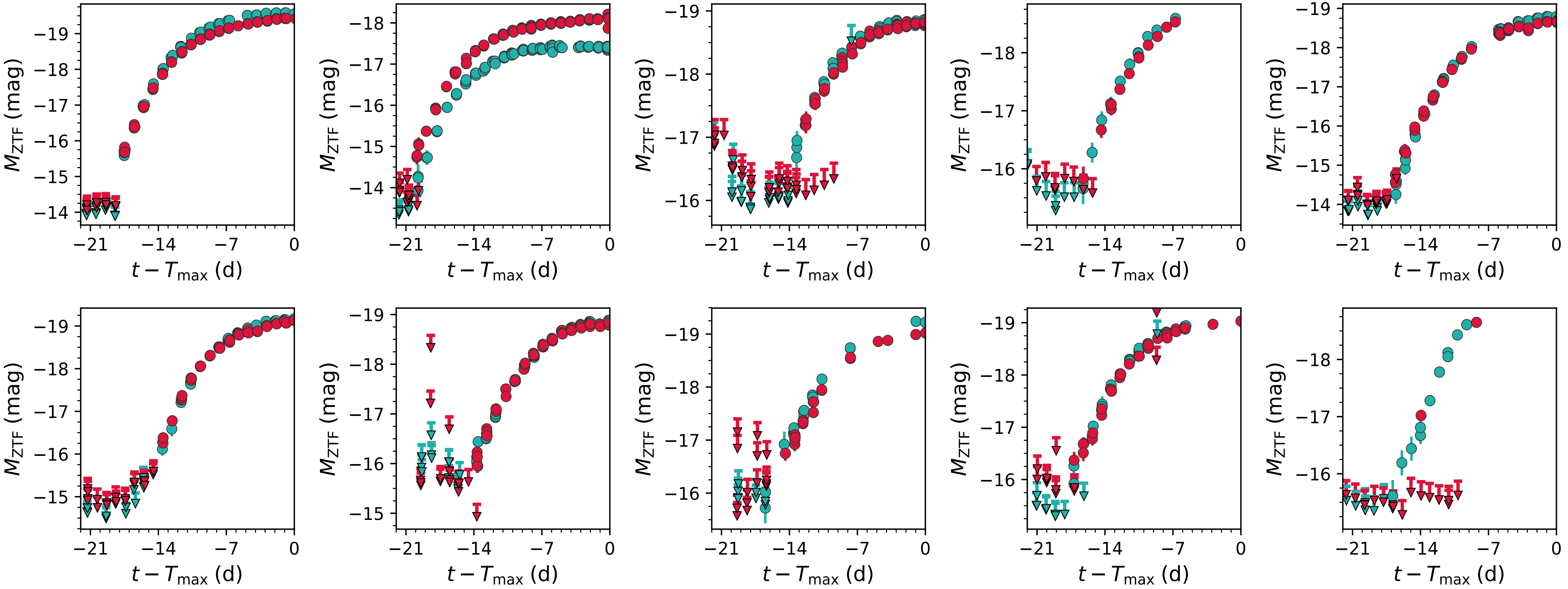
- Fast transients, very luminous (SLSN)
- Ca rich transients at outskirts of galaxies
- Strongly lensed SNe



Goobar et al. 2017

Supernova – (3) Young SN Ia and SN II

ZTF routinely finds young SNe Ia (> 12 in the period from 01 Jun – 15 Sept)

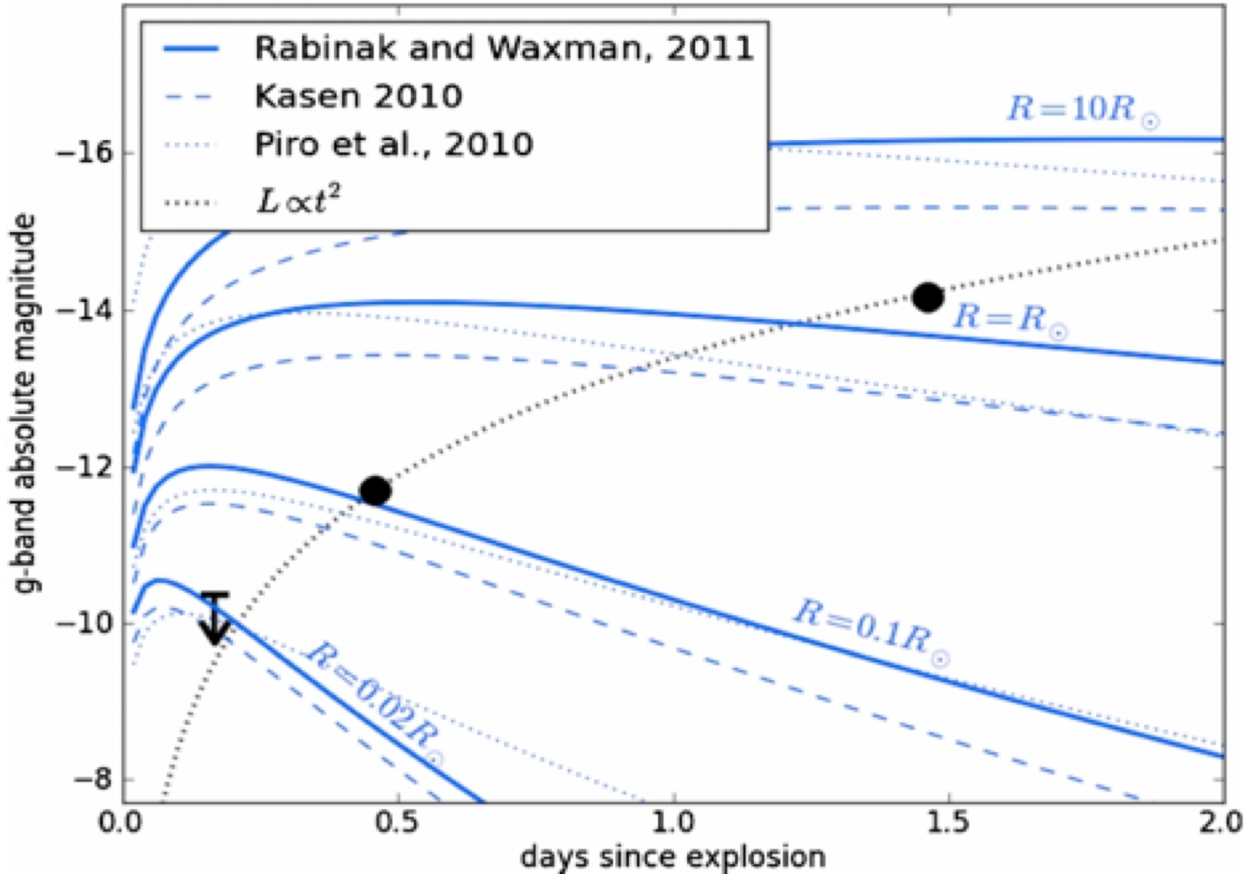


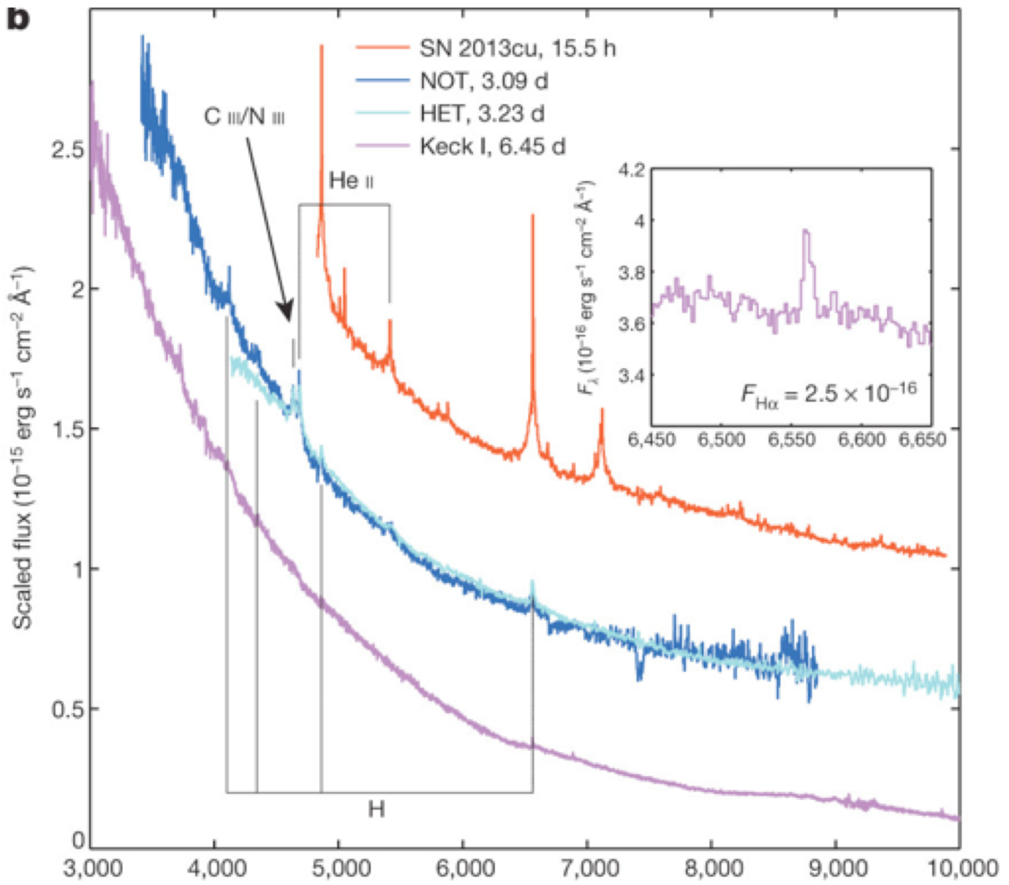
Keck ToO program is particularly important for obtaining early spectra to search for unburned C & velocity of the ejecta

Supernova – (3) Young SN Ia and SN II

understand physics of shock breakout & shock heating; observe progenitor wind

measure progenitor radius and distinguish progenitors

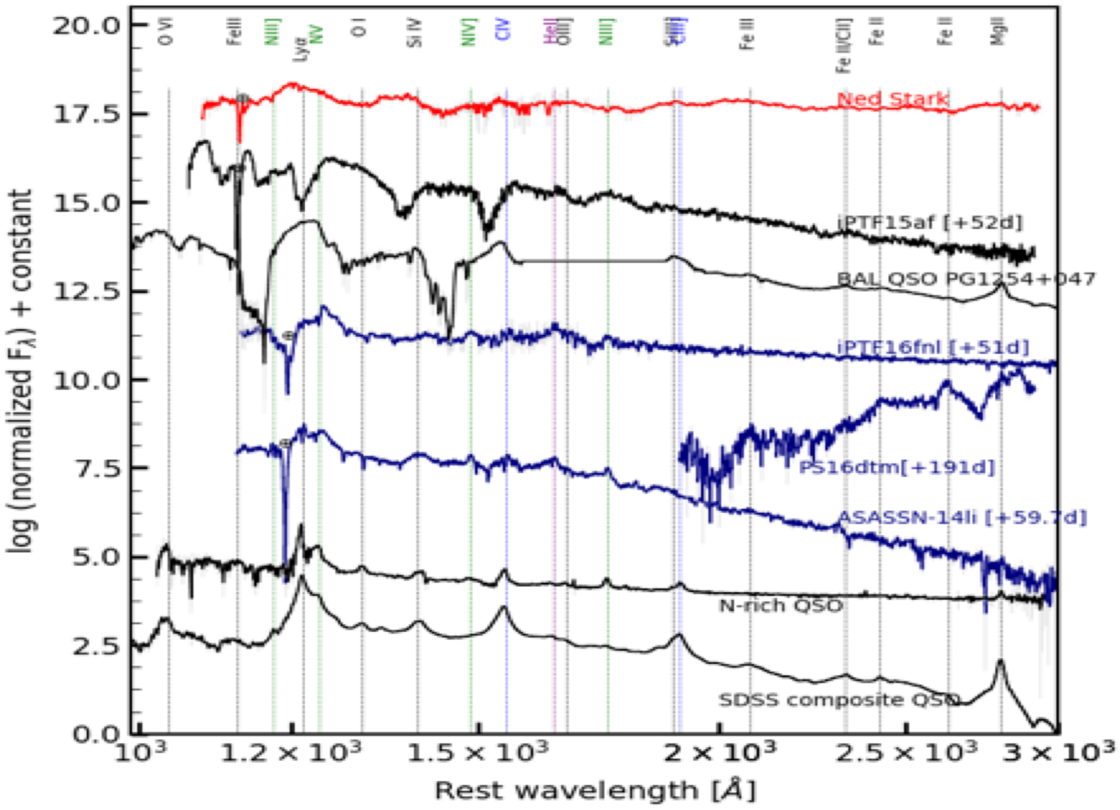


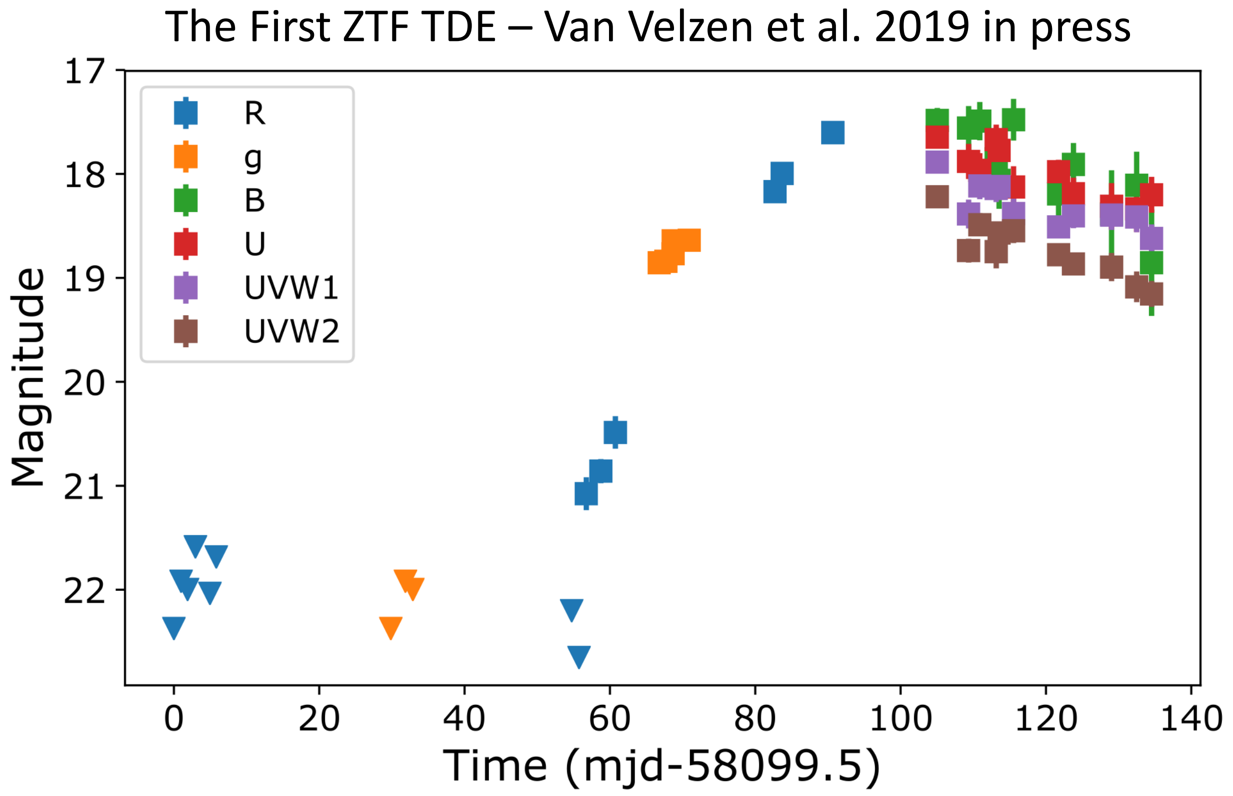


Bloom+ 2011; Gal-Yam+2013

Nuclear Transients

- Tidal Disruption Events

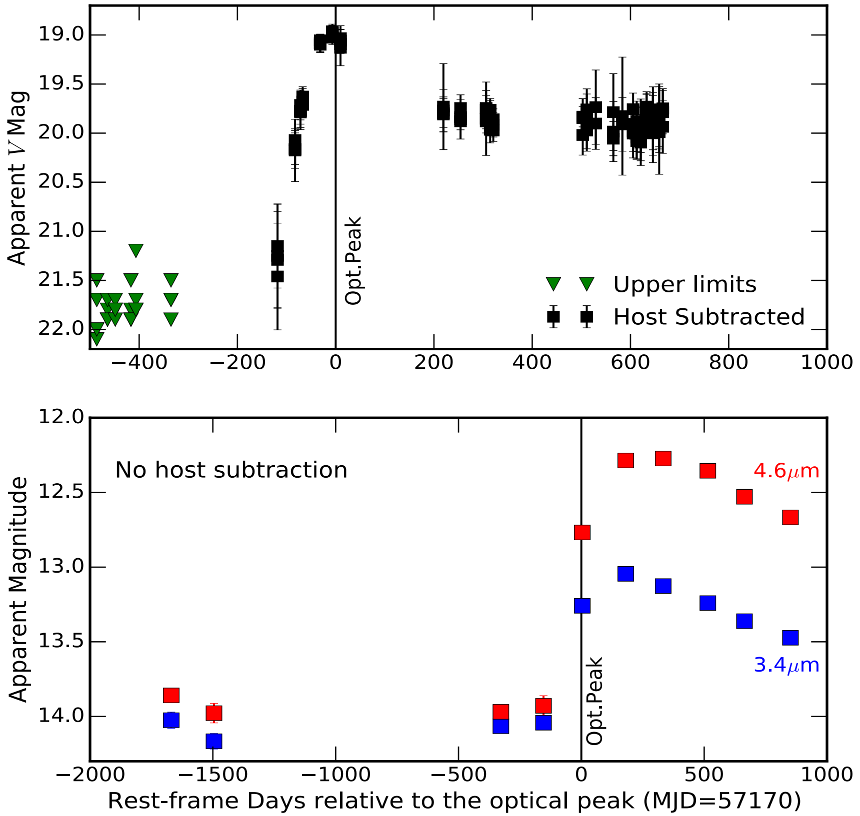


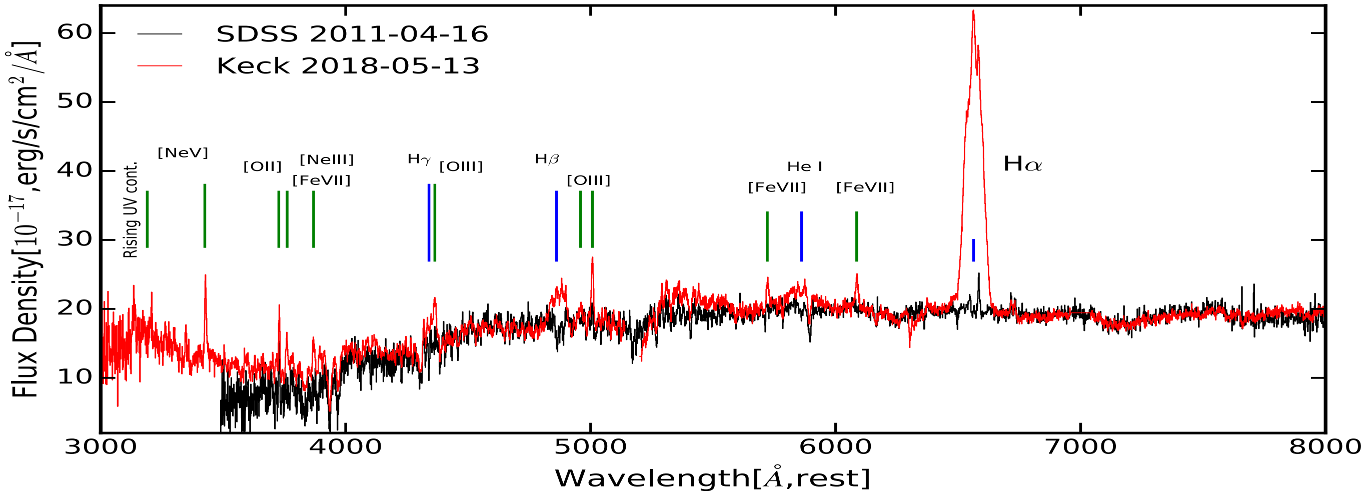


Blagorodnova+ 2019 in press

Changing-Look AGNs

- A rapid “turn-on” of type-I AGN from quiescent state < 200days much longer than the viscous infall time. Challenging the current AGN accretion disk

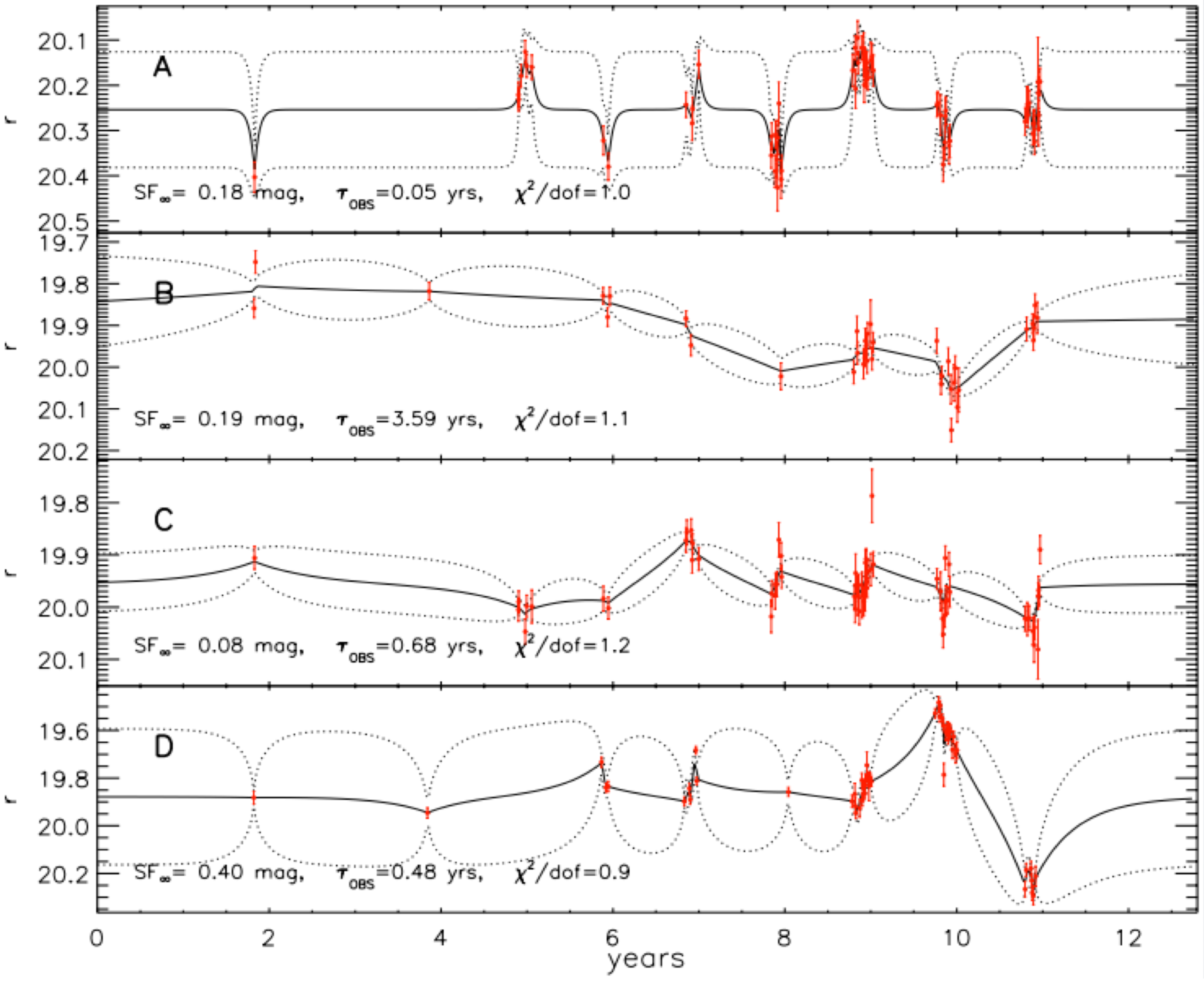




Yan+ 2019 in press

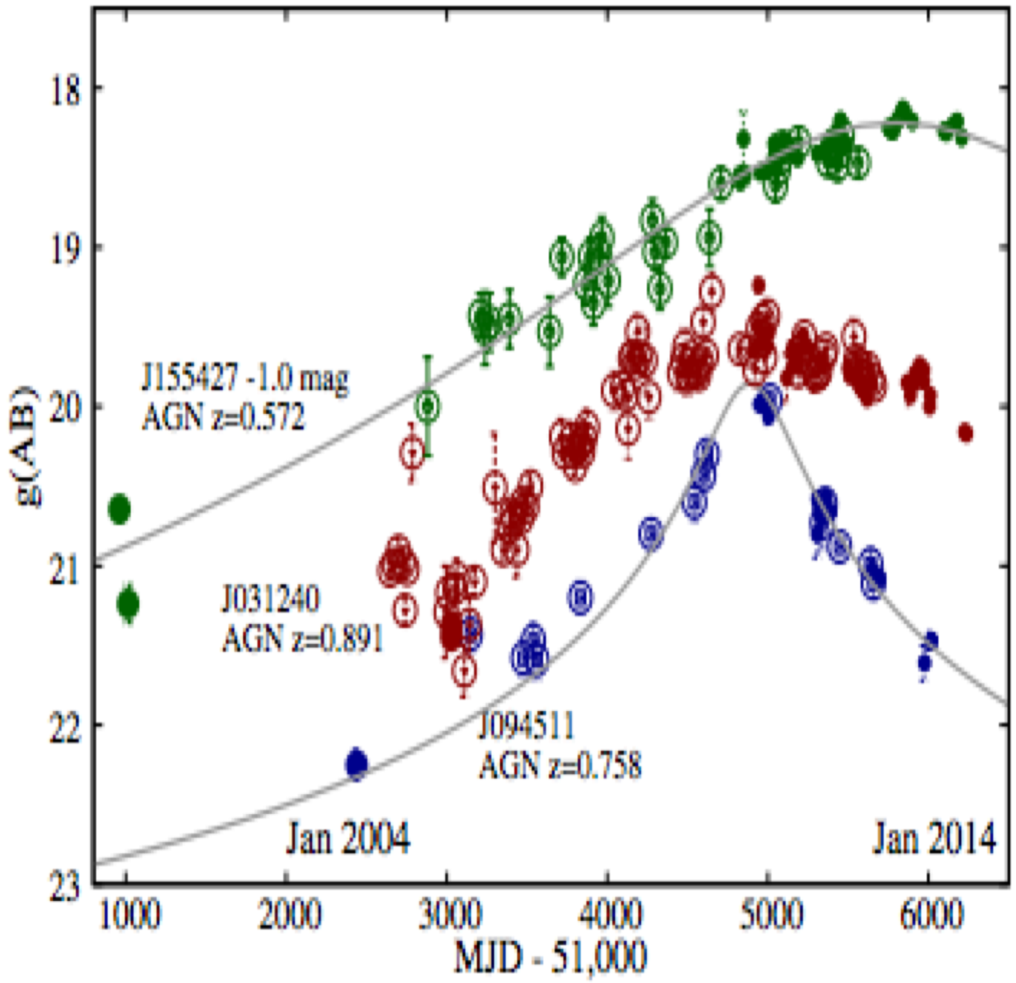
AGN variabilities:

Small amplitude



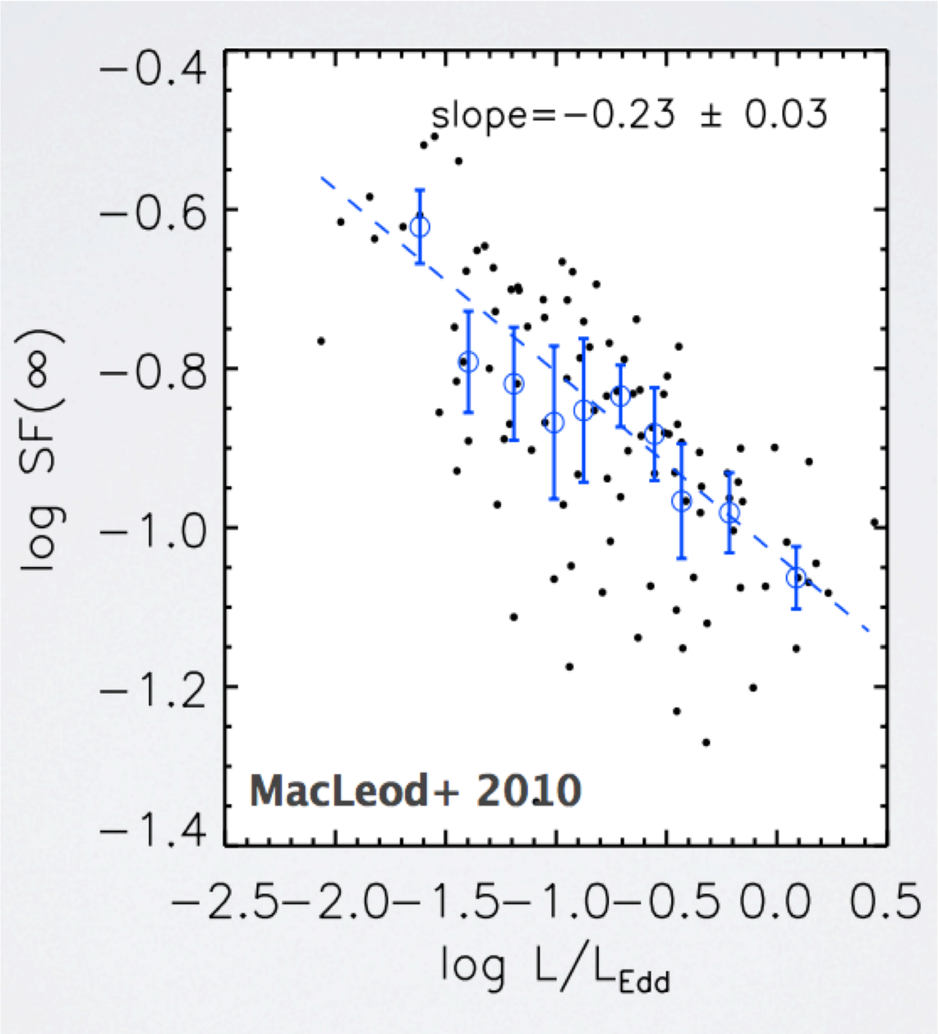
McLeod+ 2010

Large amplitude



Lawrence+ 2016

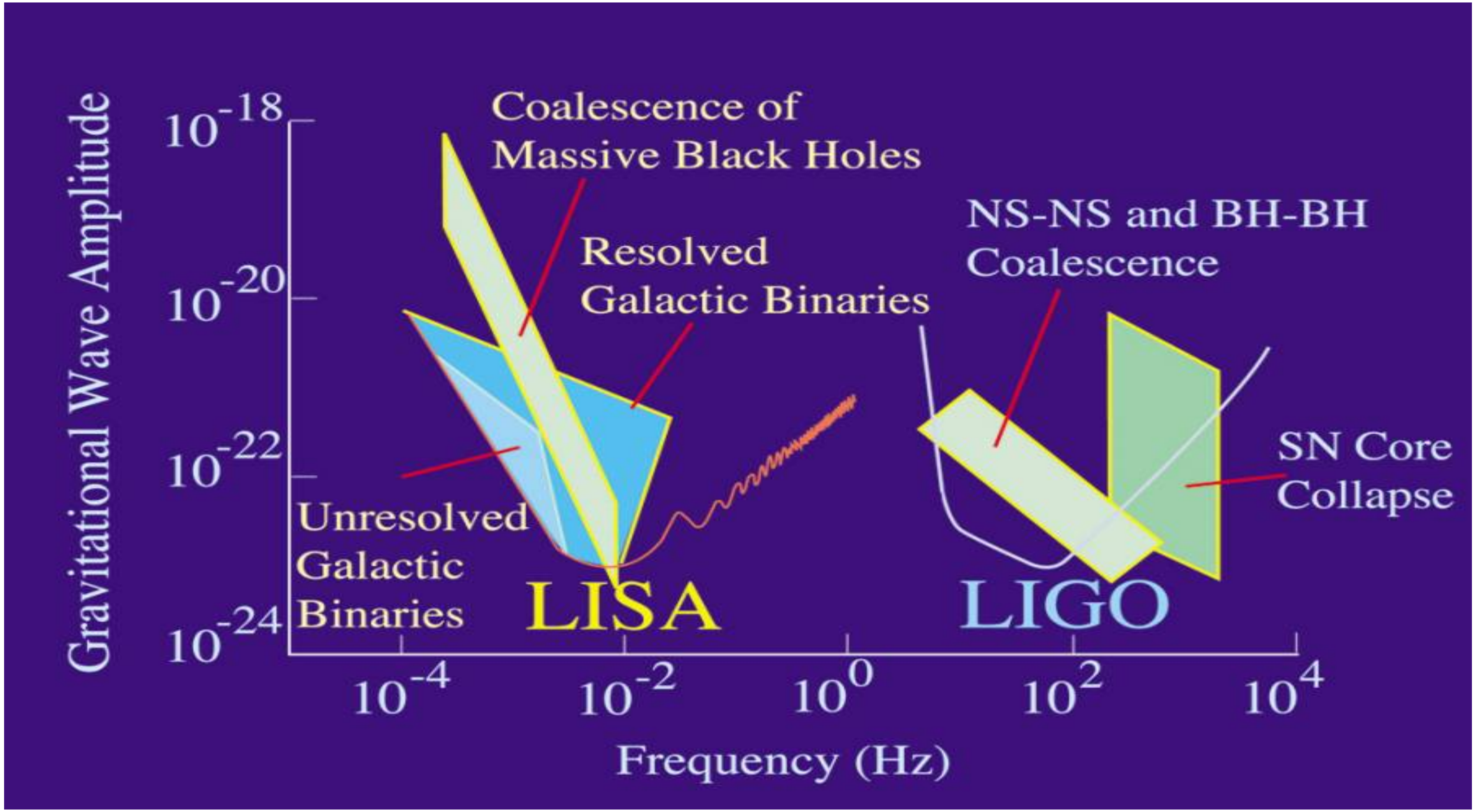
AGN variabilities – accretion physics



Damped Random Walk model –

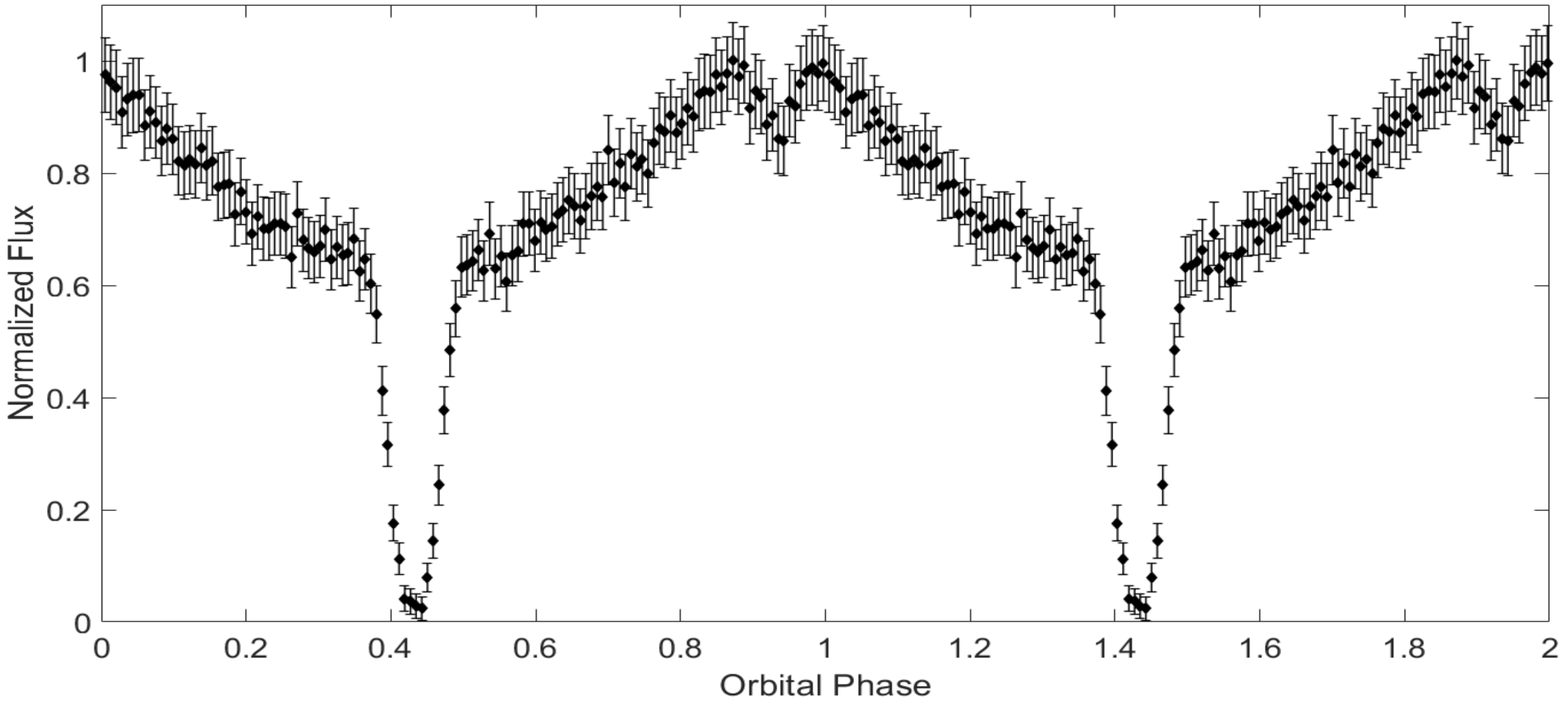
Is Eddington ratio the driver of AGN variability?

Stellar variables – (1) compact binaries



A new ZTF eclisping, double WD system:

6.9 *minutes Orbit*

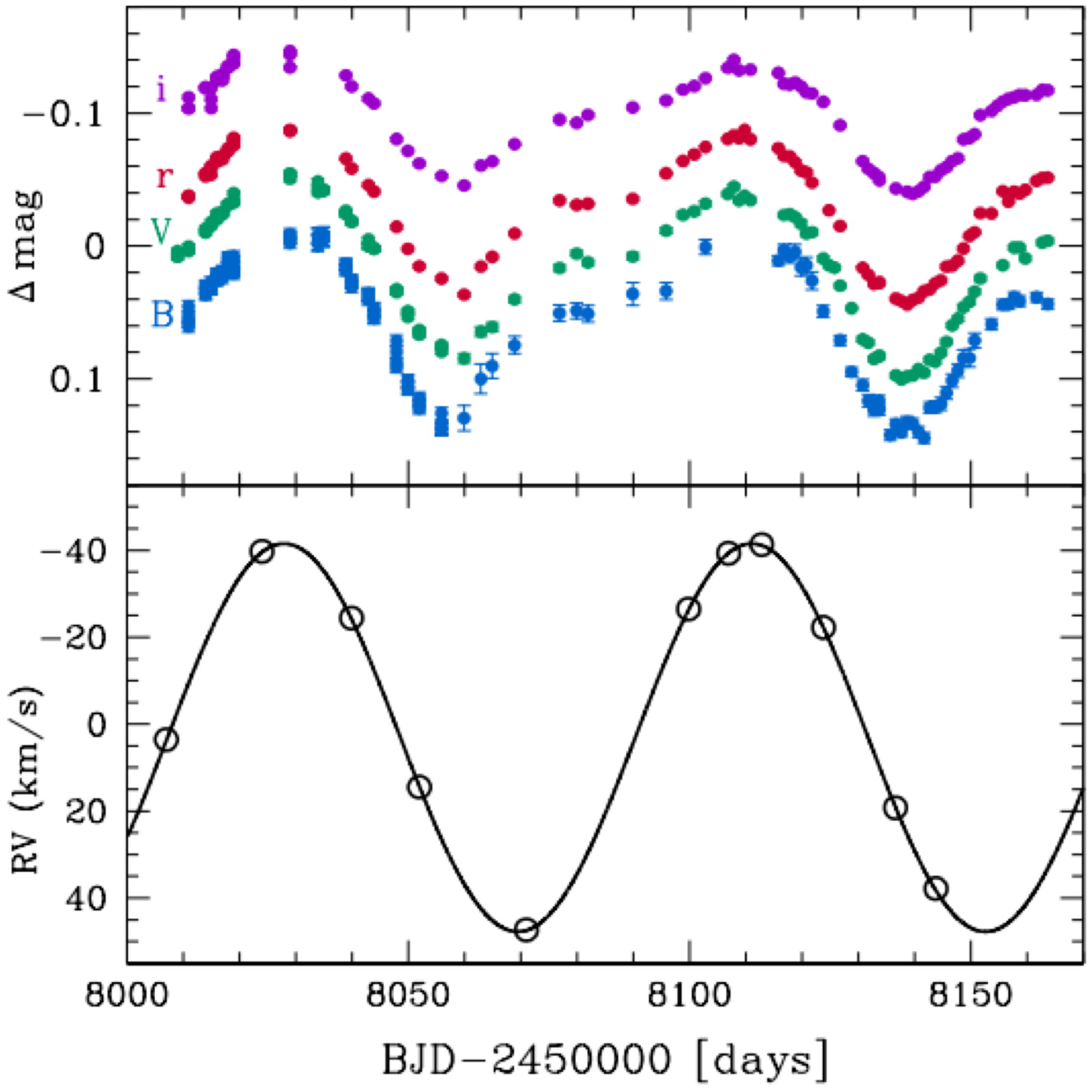


Burdge+ 2019 in prep

Binaries with BH:

- A black-hole (2.5 – 5.8Msun) + a red giant with a period of 83 days

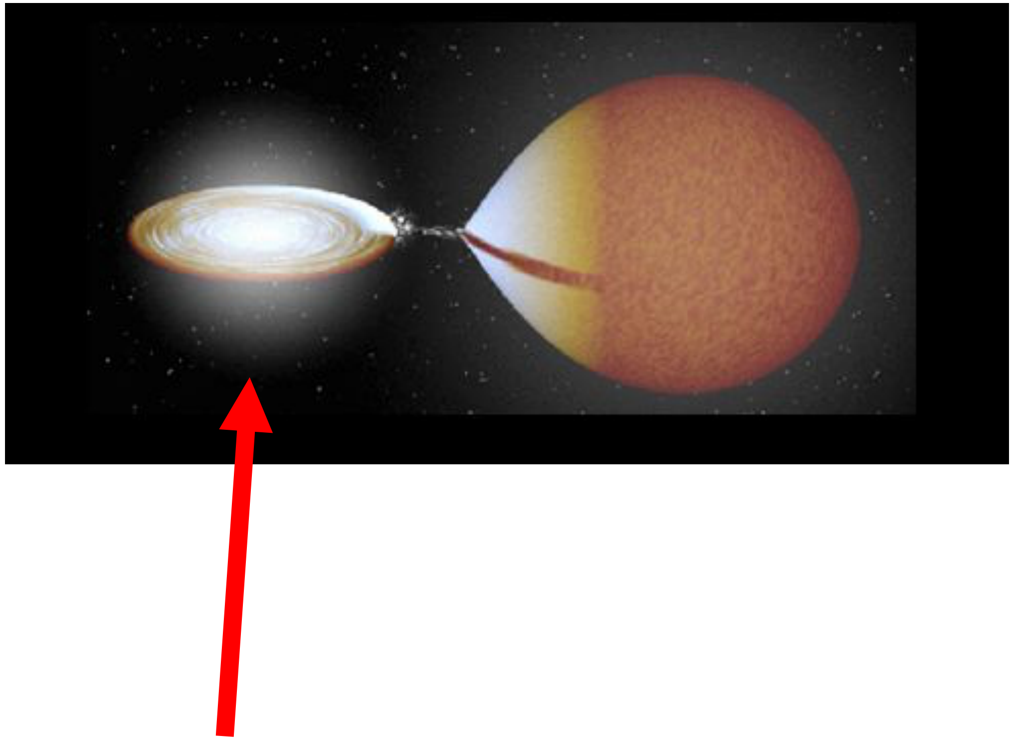
ASAS-SN light curves



Thompson + 2018 Nature

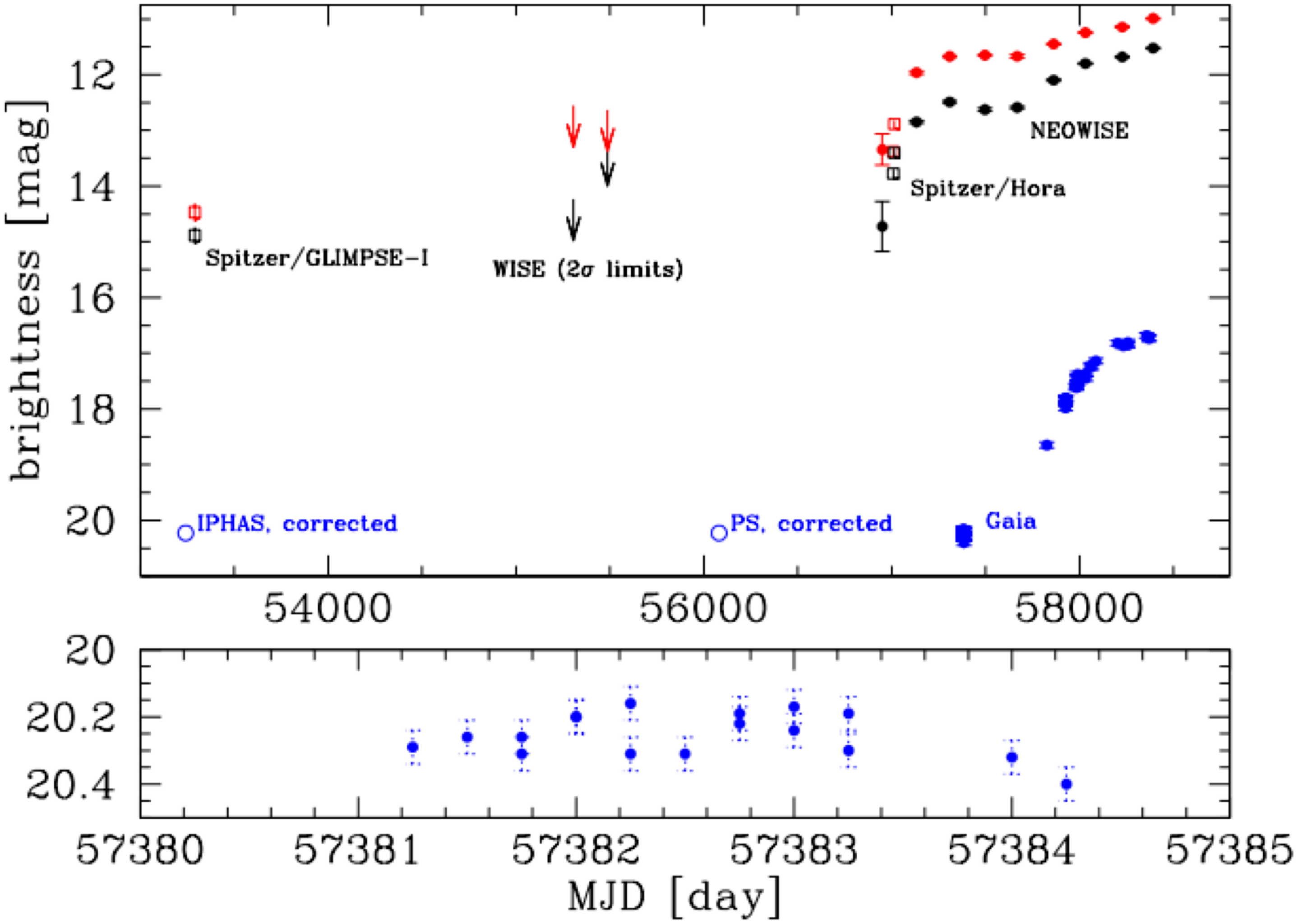
Cataclysmic Variables from ZTF

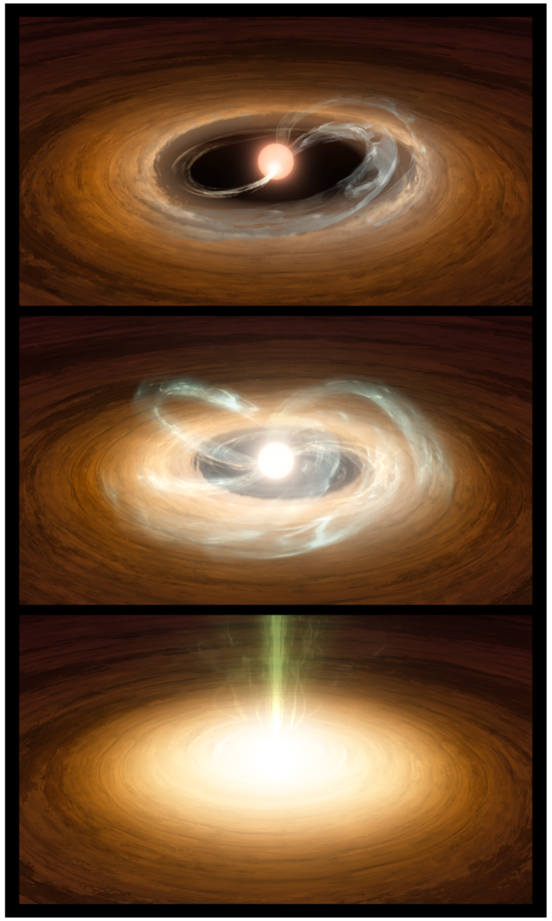
- Paula Szkody (UW) and Jan van Roestal (Caltech) have large programs



Accreting white dwarf

Young stars – FU Orionis (~25 total so far)

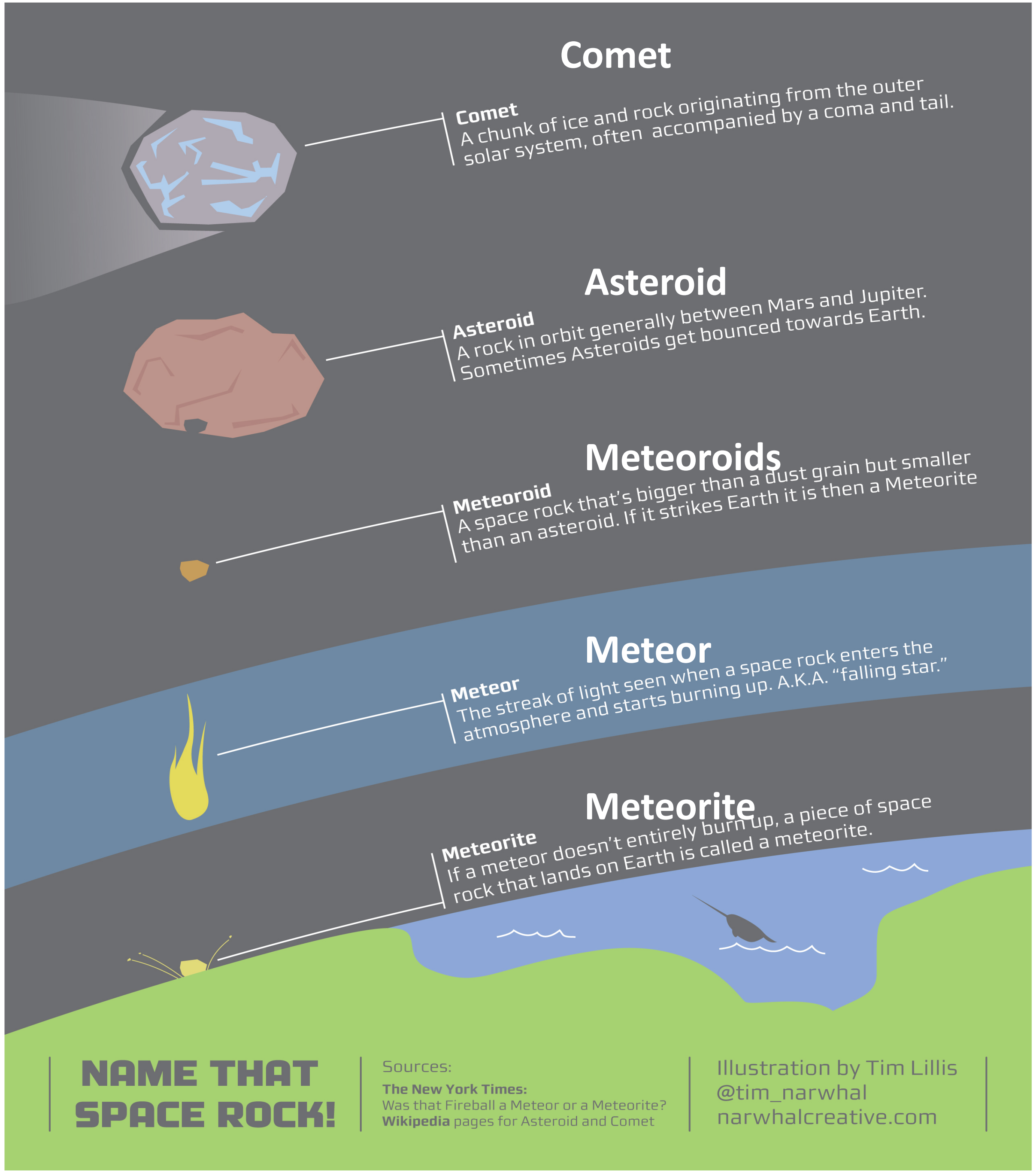




Gaia17bpi, Hillenbrand+ 2018 ApJ

ZTF Solar System Science

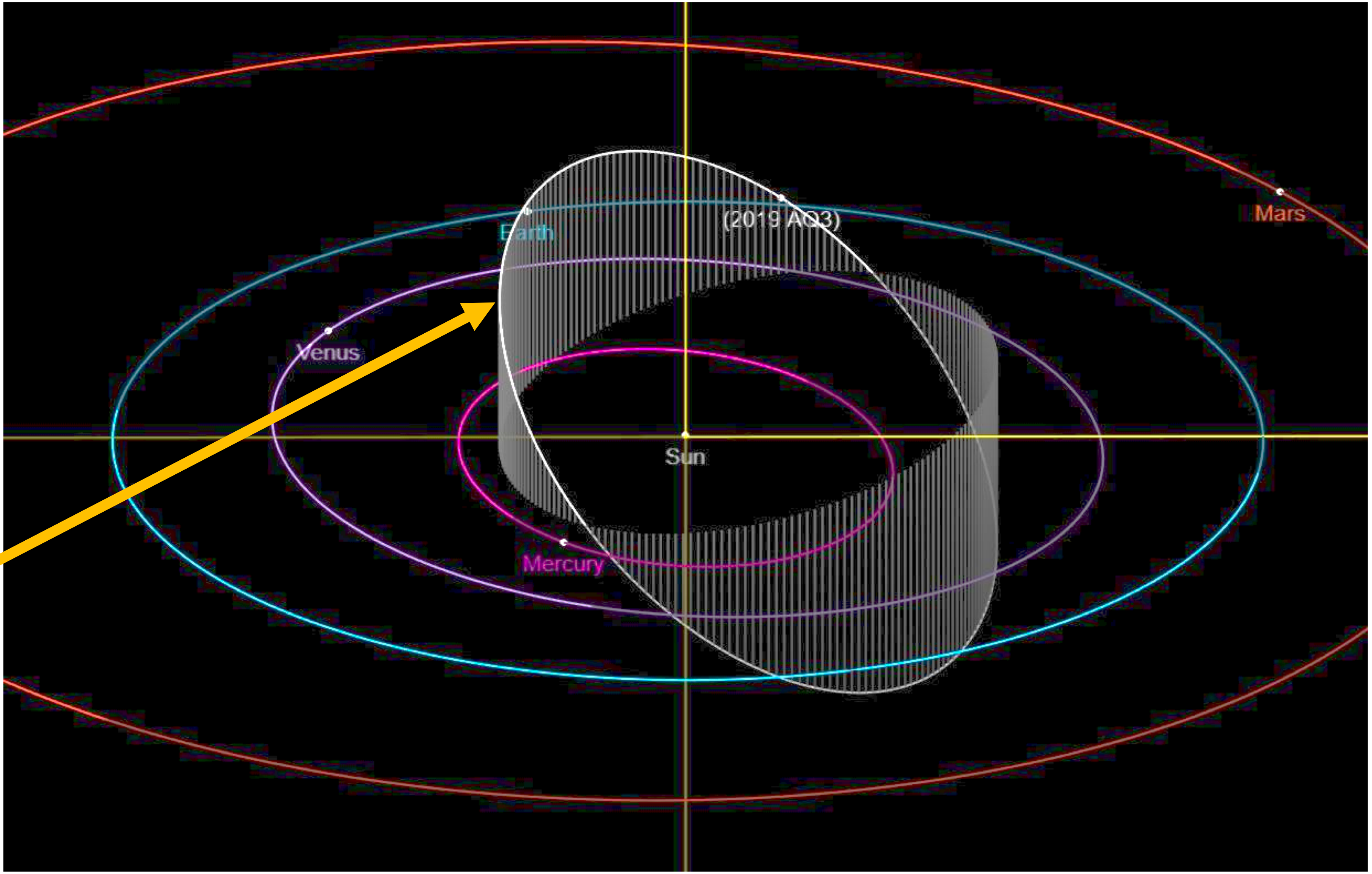
- **Discover**, **characterize**, and **monitor** small bodies in the solar system
- Enable **rapid response** on transient events
- Comets
- Main Belt Asteroids
- Near Earth Asteroids
- Centaurs
- Interstellar objects



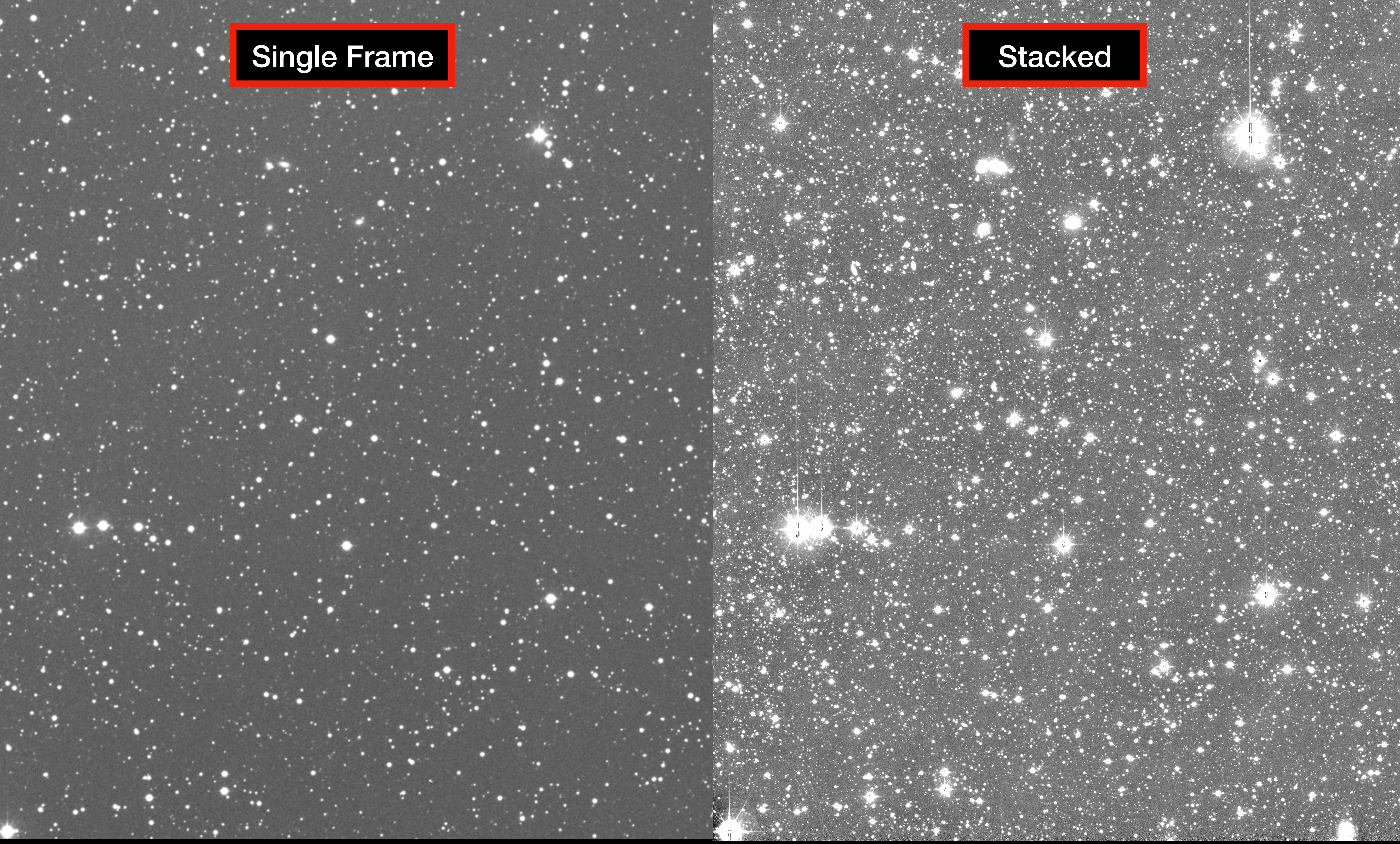
Most recent near Earth asteroid (~10km) from ZTF:

- 2019AQ$_3$

(19mag discovered by ZTF)



NEO 2019AQ$_3$



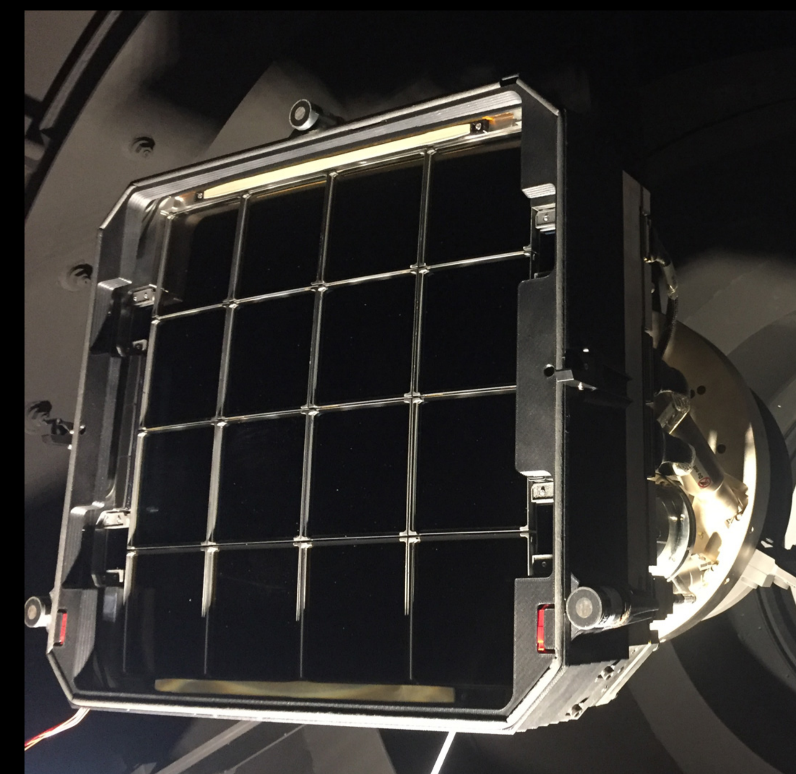
The ZTF Coadd Facility

with P. E. Nugent, Y. Yao, A. Goobar, S. R. Kulkarni

Danny Goldstein
Hubble Fellow (Caltech)

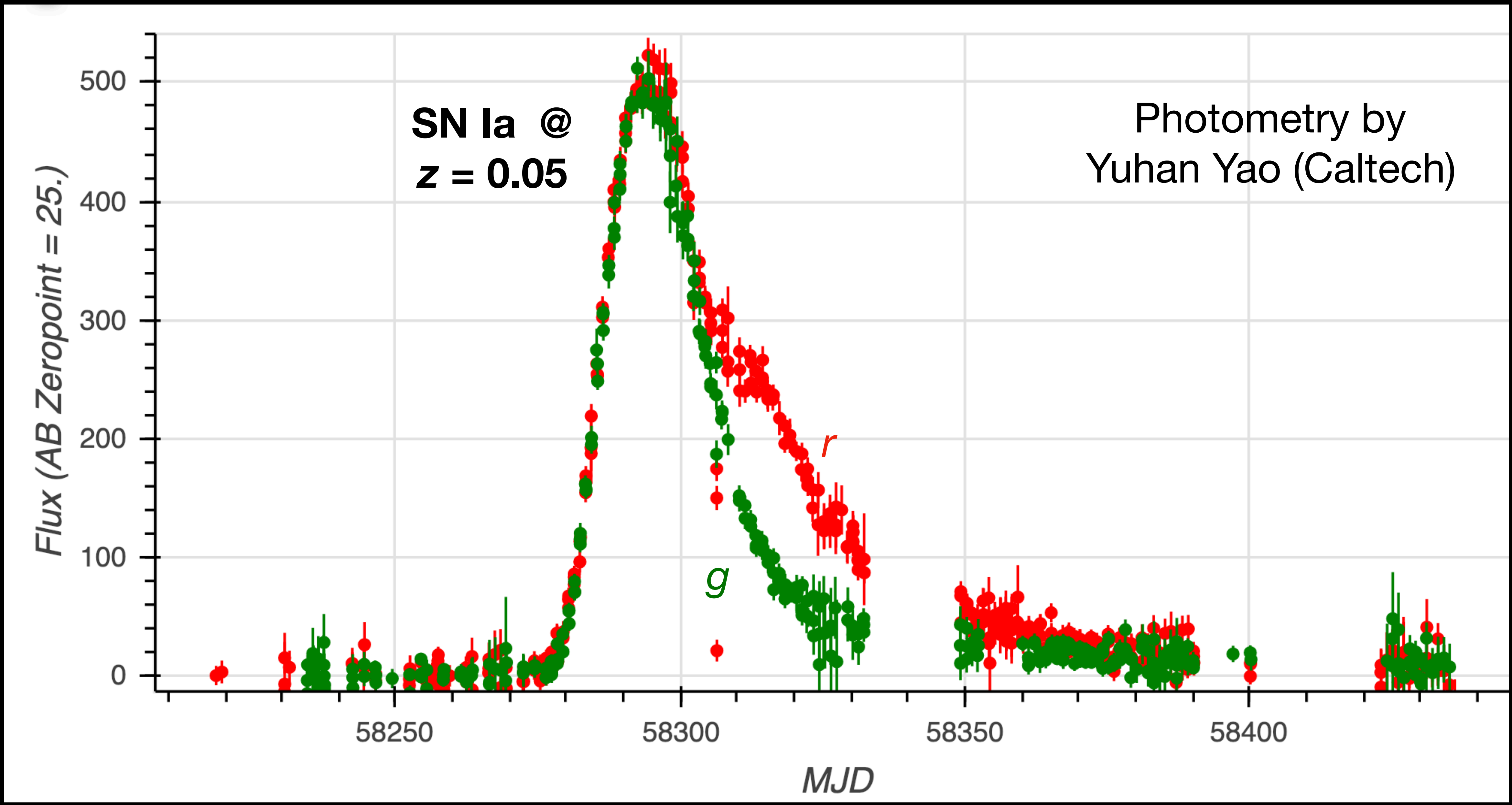
The Zwicky Transient Facility and Partnership Survey

- Optical imager with 47 square degree field of view
- Mounted on 48-inch (1.2m) telescope at Palomar observatory
- 30 second exposures - limiting mag of 20.5 in *g*, *r*
- Partnership ("high-cadence") survey covers 2,000 square degrees of northern sky ***six times per night*** in g, r to 20.5 per visit



See Bellm et al. (2019), Graham et al. (2019)

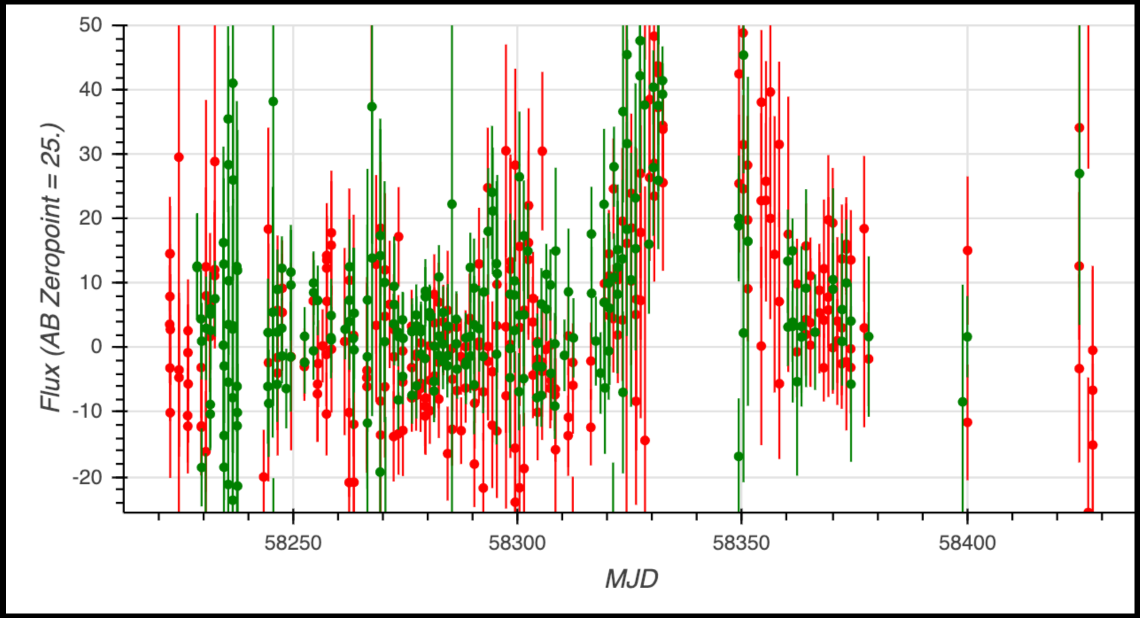
Typical Light Curve from the Partnership Data



Yao et al. (2019, in prep)

The Cost of High Cadence

- ZTF is producing fantastic data, but 6 visits / night is overkill for most science cases.
- Since only objects detected at at least 5 sigma on single-epoch difference images can trigger alerts, fainter transients, which are still present in the data, but not at 5 sigma in single-epoch subtractions, are missed.



This object was not detected by the single-epoch pipeline as none of its individual detections have SNR > 5.

The Cost of High Cadence

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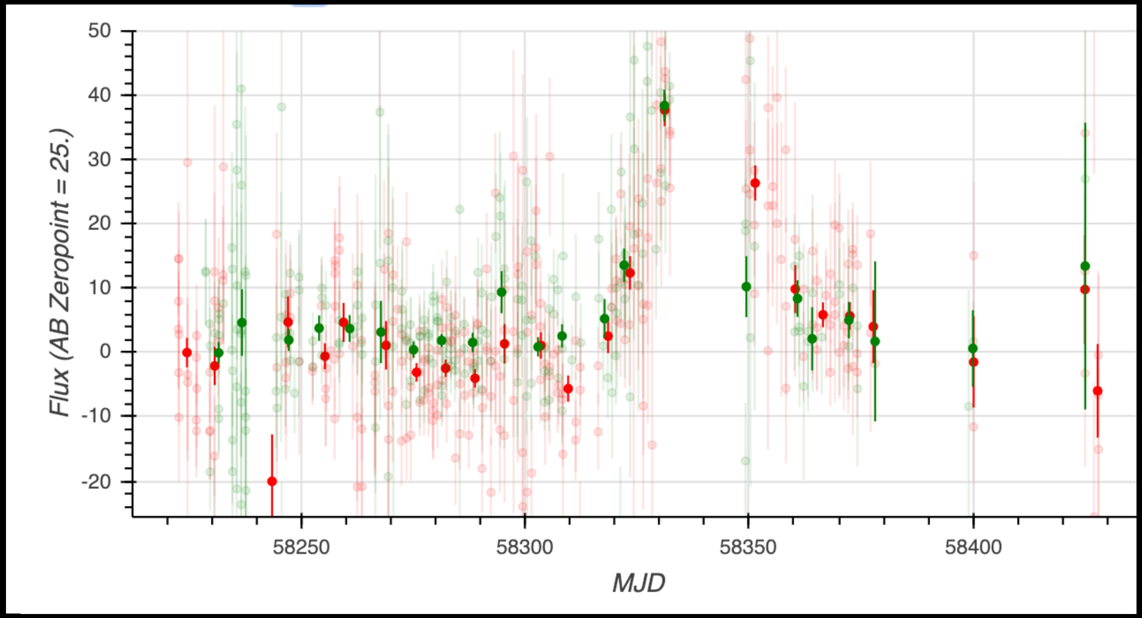
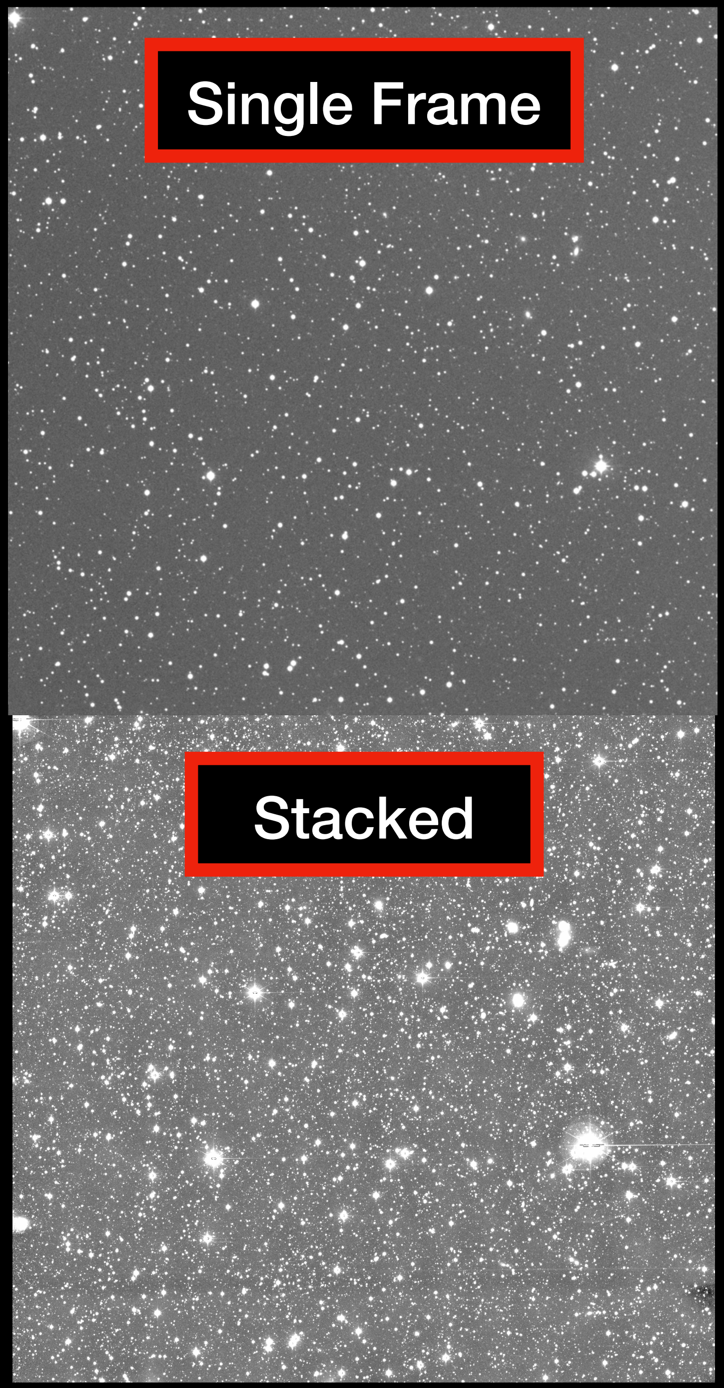
- Since only objects detected at at least 5 sigma on single-epoch difference images can trigger alerts, fainter transients, which are still present in the data, but not at 5 sigma in single-epoch subtractions, are missed.



This object was not detected by the single-epoch pipeline as none of its individual detections have SNR > 5.

Solution: The ZTF Coadd Facility

- The ZTF Coadd Facility is an automated software tool that produces deep subtractions from coadded ZTF science images, increasing the sensitivity of the survey to faint transients.
- The idea is to trade the survey's cadence for depth. The coadded light curves are deeper, but sparser in time.
- Ideally suited to many different science cases where light curves evolve over days or weeks, not hours: supernovae, nuclear transients, stellar variability, microlensing, etc…



Key Takeaway: Increasing the Depth of ZTF

- Using the ZTF coadd facility, the partnership survey is *not* limited to finding transients brighter than *g, r* ~ 20.5 — it can go deeper. When considering what science is possible with ZTF, it is important to keep this key point in mind.
- The actual limiting magnitude of the partnership survey (2000 deg sq) is:

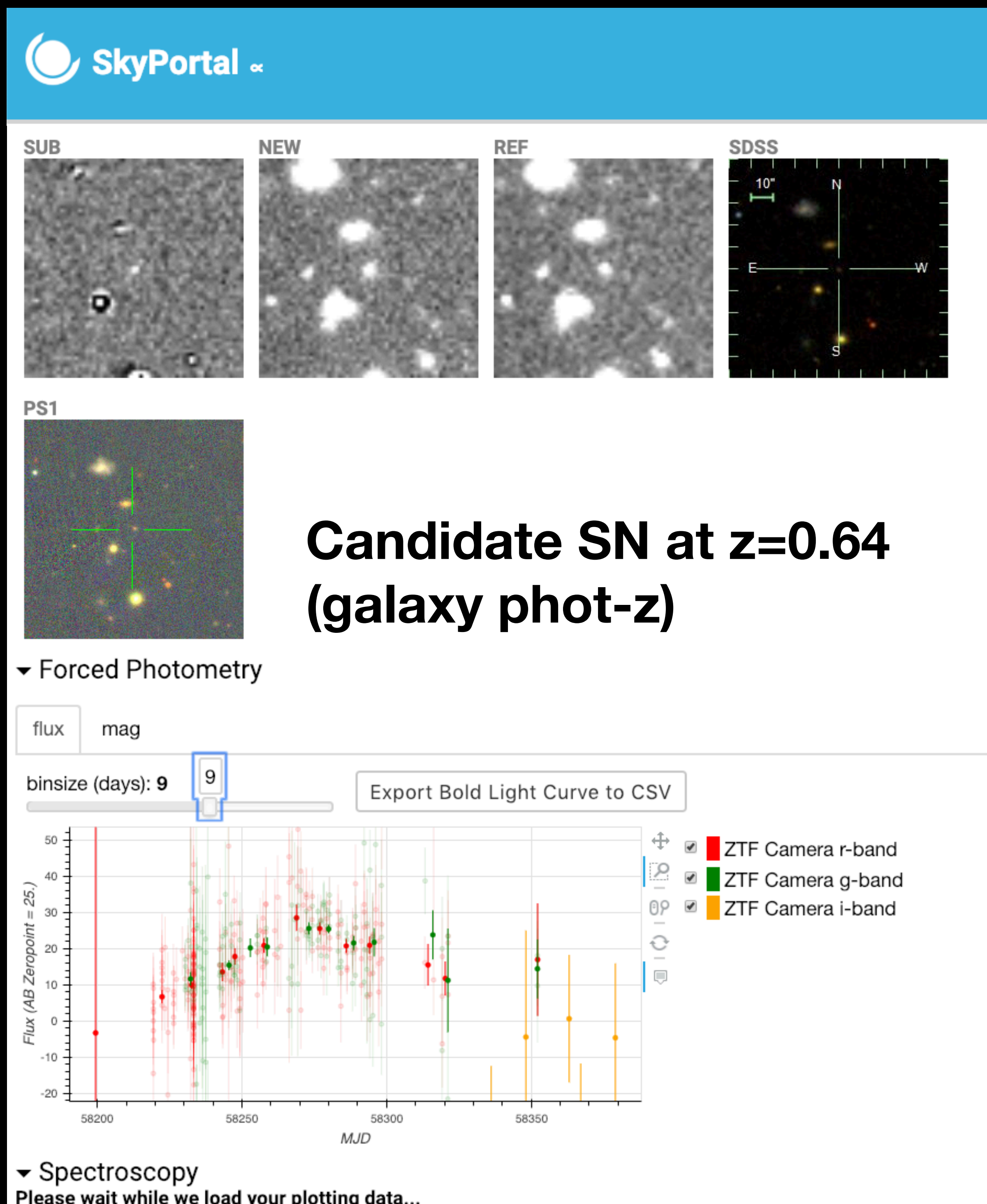
$$m_{\rm lim}(\Delta t) \approx 20.5 + 2.5 \log\left(\sqrt{6\Delta t}\right)$$

where Δt is the effective cadence after coaddition.

$$m_{\rm lim}(1\,{\rm day}) \approx 21.5 \qquad m_{\rm lim}(5\,{\rm days}) \approx 22.4$$

$$m_{\rm lim}(2\,{\rm days}) \approx 21.9 \qquad m_{\rm lim}(10\,{\rm days}) \approx 22.7$$

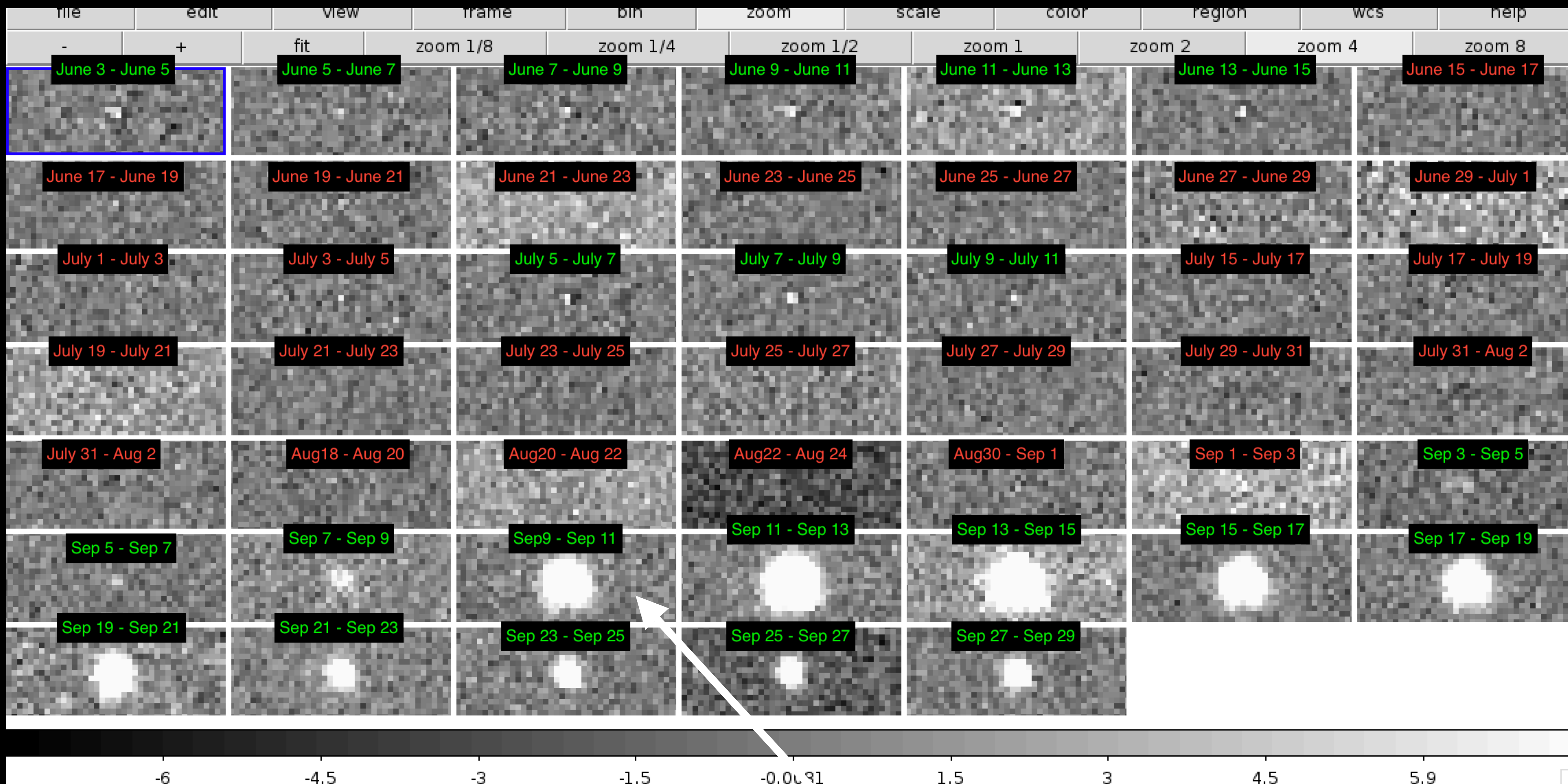
Interface to the Coadd Facility: Skyportal Marshal



- Beautiful interface to coadded data written by expert developers: Stefan van der Walt, Arien Crellin-Quick, and Josh Bloom (Berkeley)
- Enables custom filtering of events based on light curves and contextual information
- Interactive stacking of photometry
- Open source software: http://github.com/skyportal/skyportal

Early Science with the Coadds

Detection of pre-supernova outbursts (*M* ~ -13) from a broad-lined SN Ic progenitor (Ho et al. in prep).

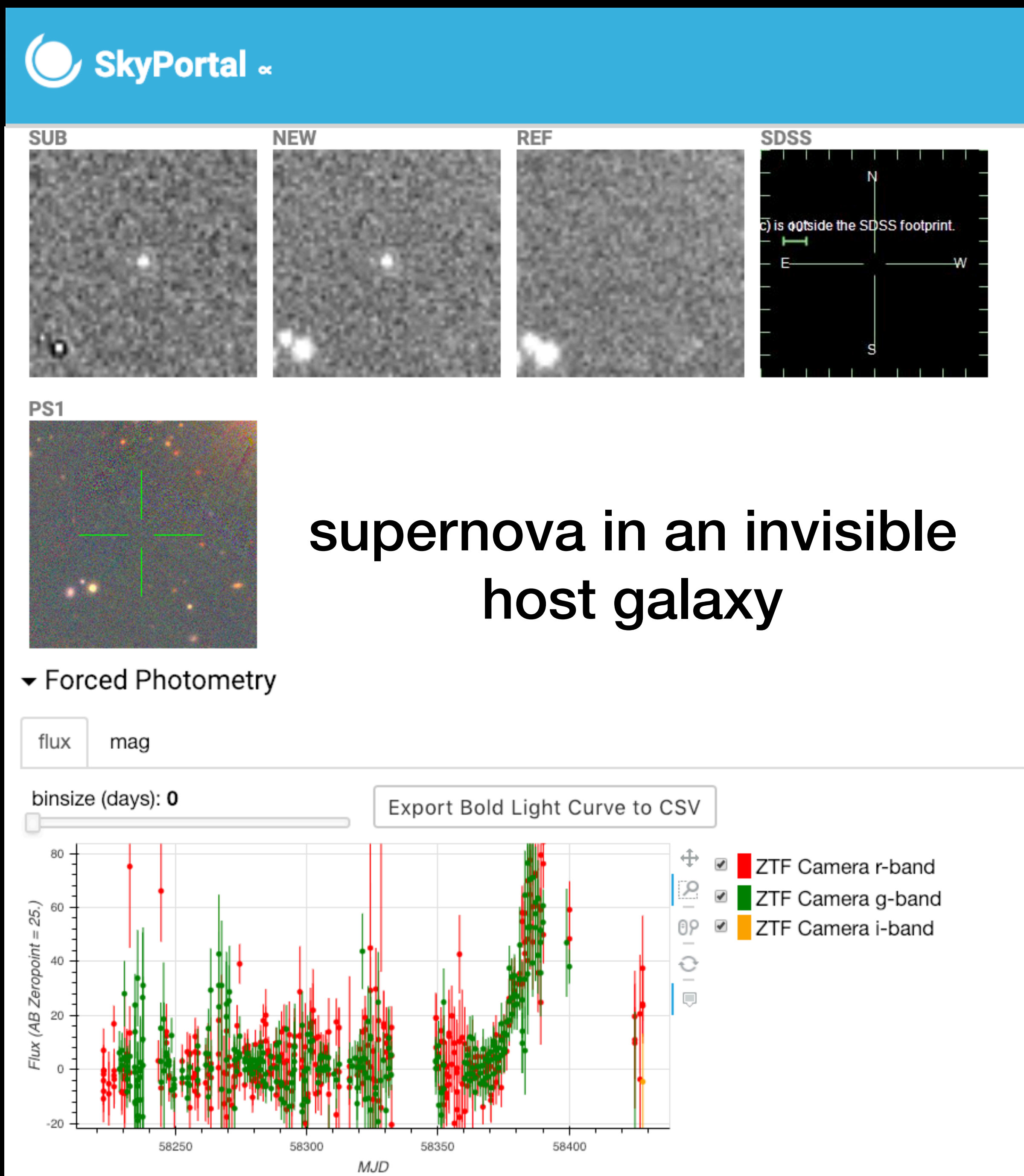


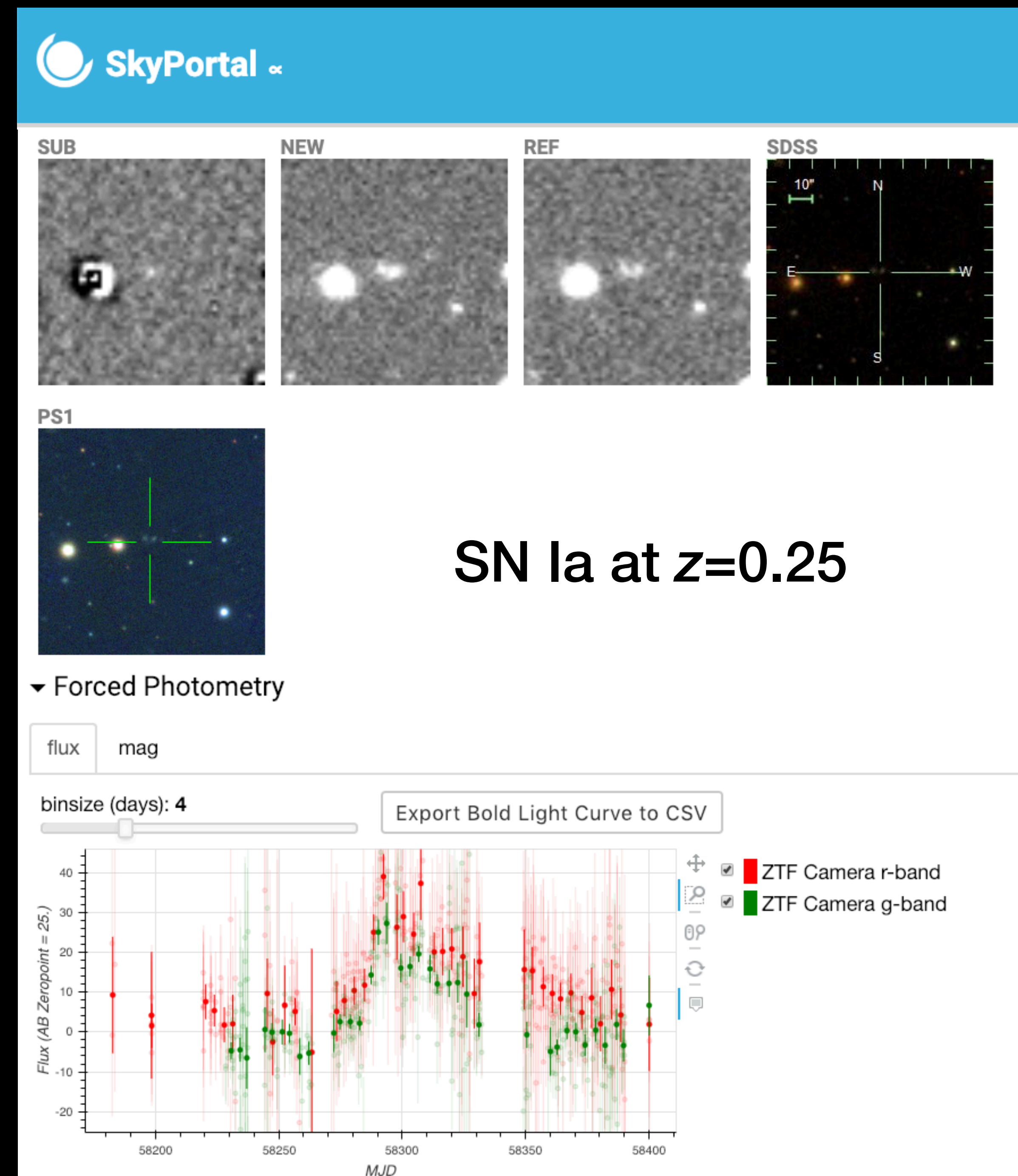
All images show coadd facility subtractions.

Date of first ZTF *single-epoch* detection of the supernova

Early Science with the Coadds

Discovery of faint or high-redshift SNe missed by nominal survey

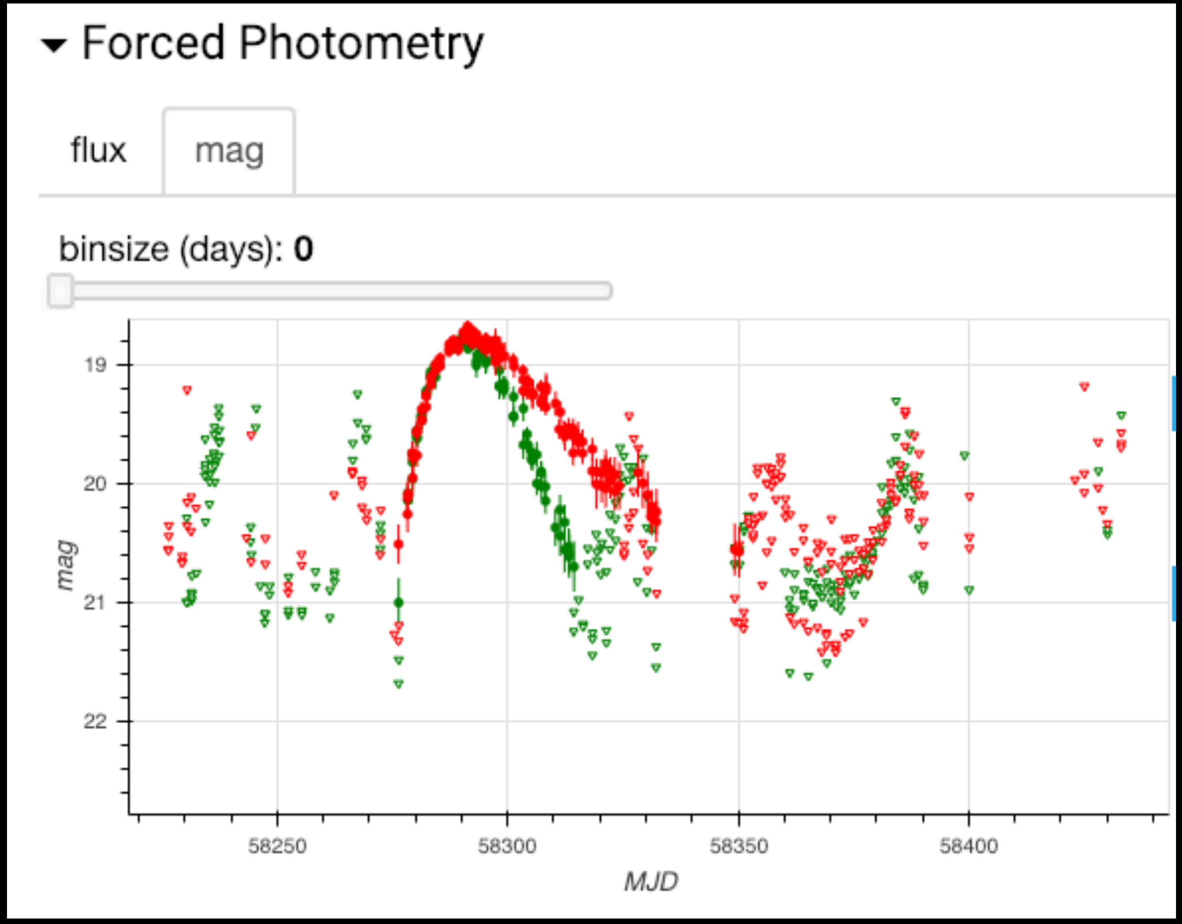




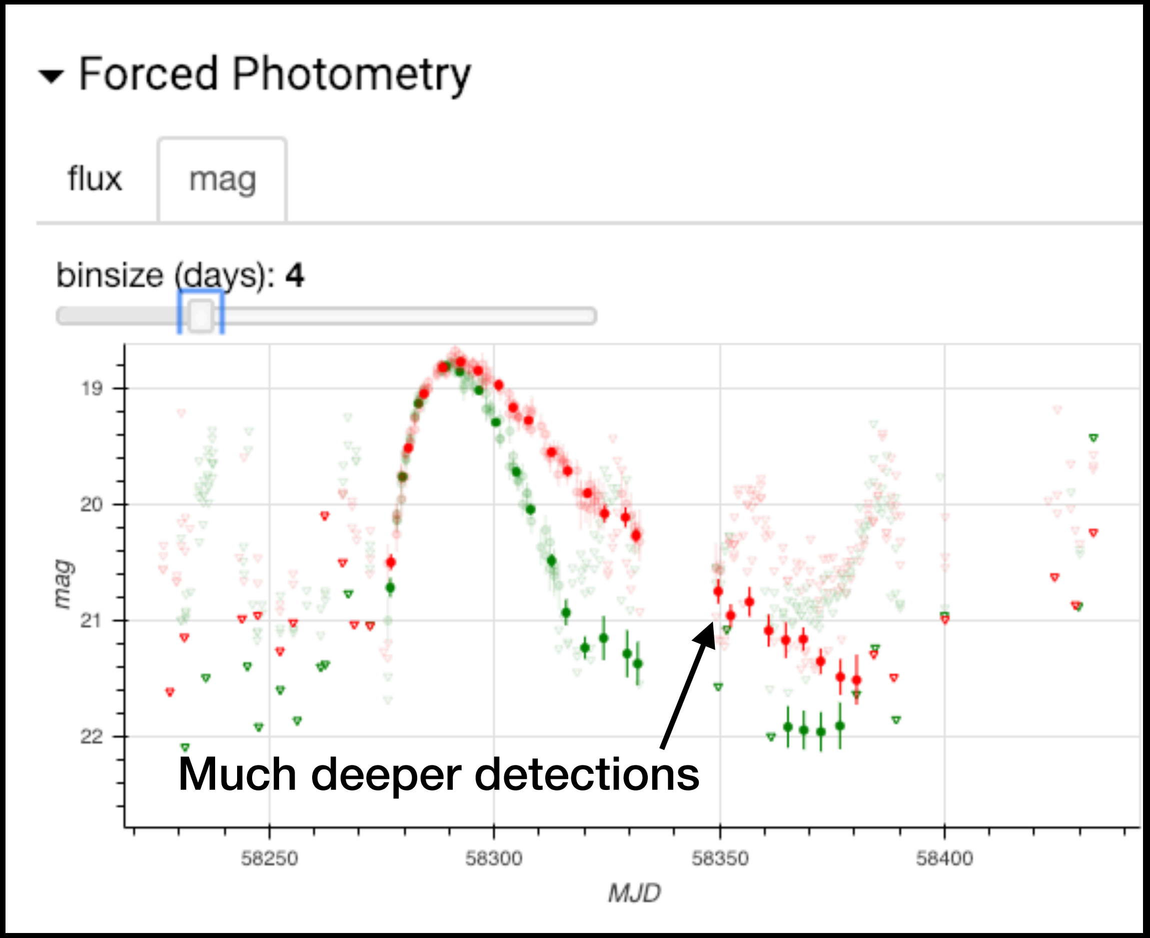
Early Science with the Coadds

Extension of supernova light curves into nebular phase

SN Ia at z=0.07



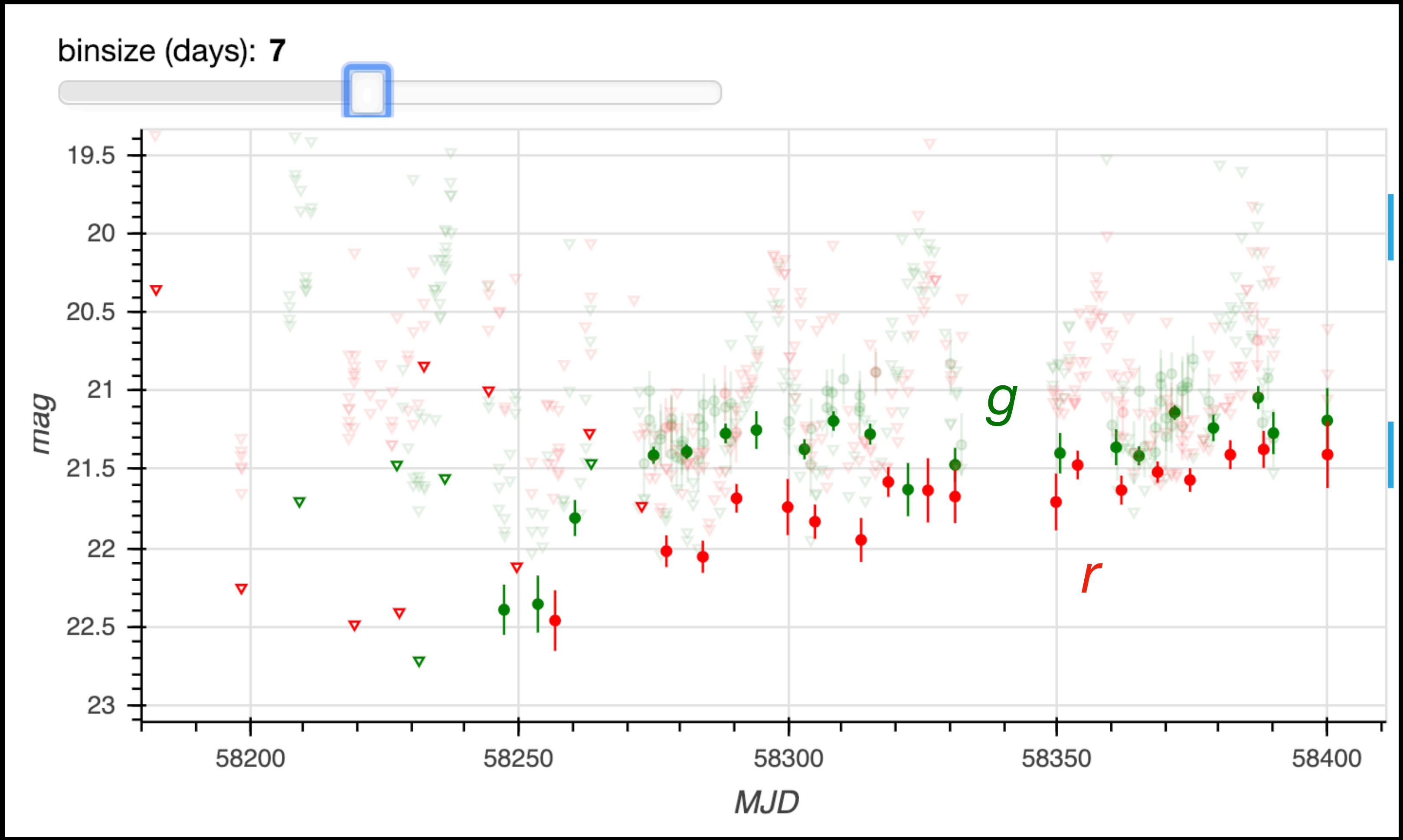
Without Stacking



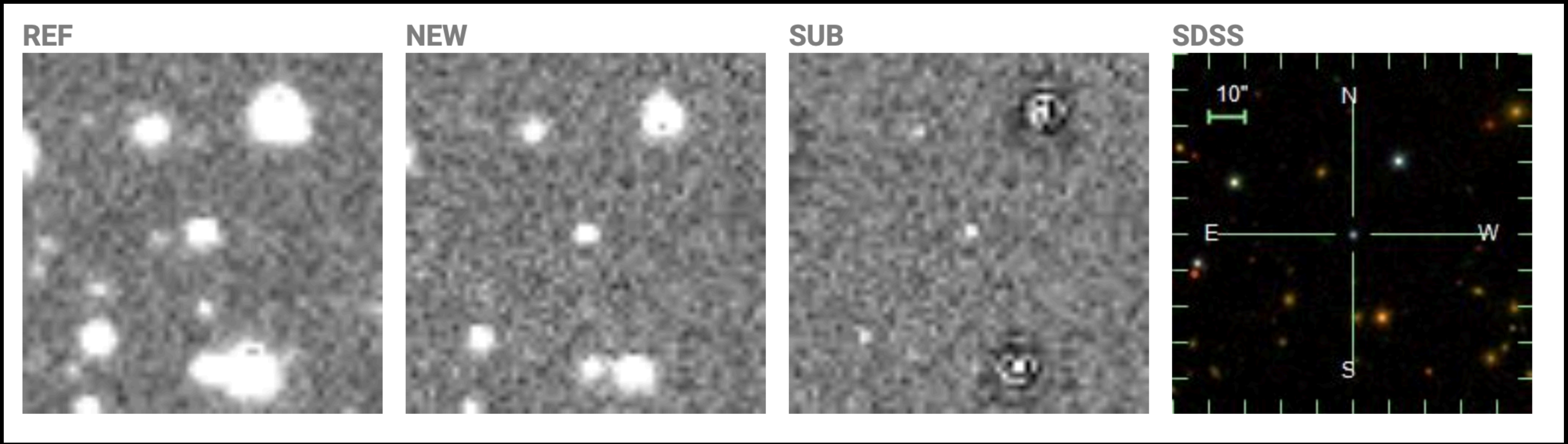
With Stacking

Early Science with the Coadds

Monitoring of faint stellar / AGN variability

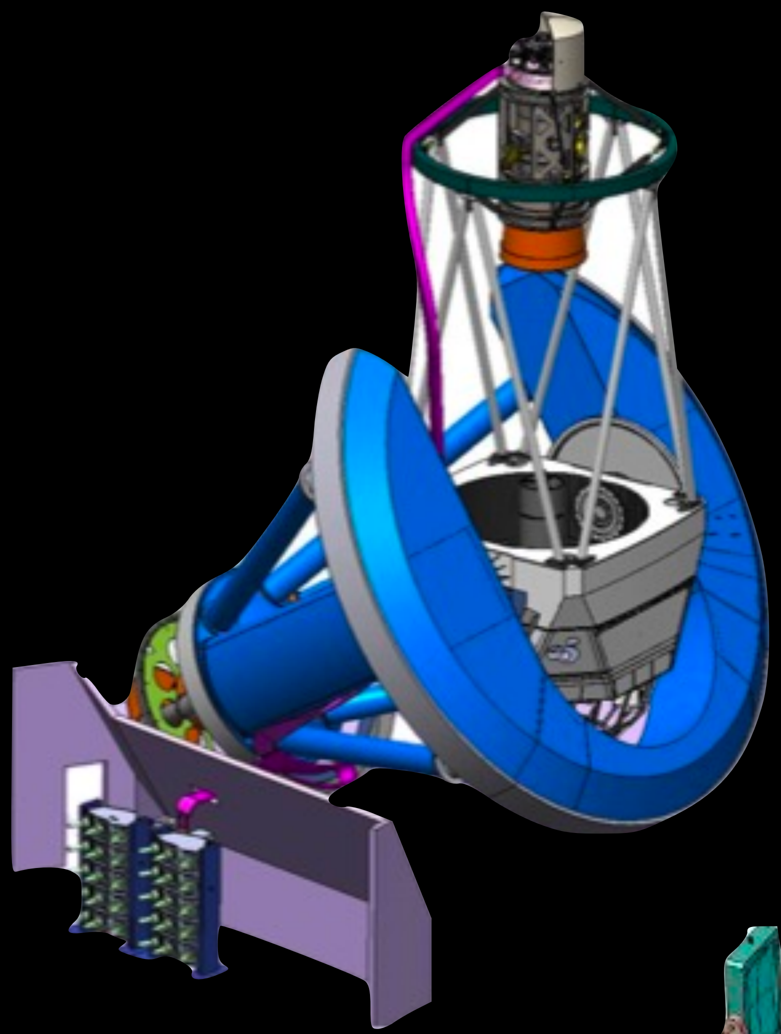


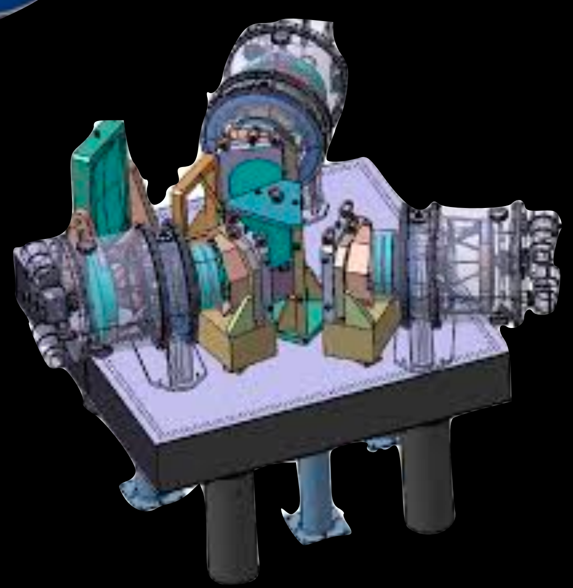
Variability at 21-22 mag

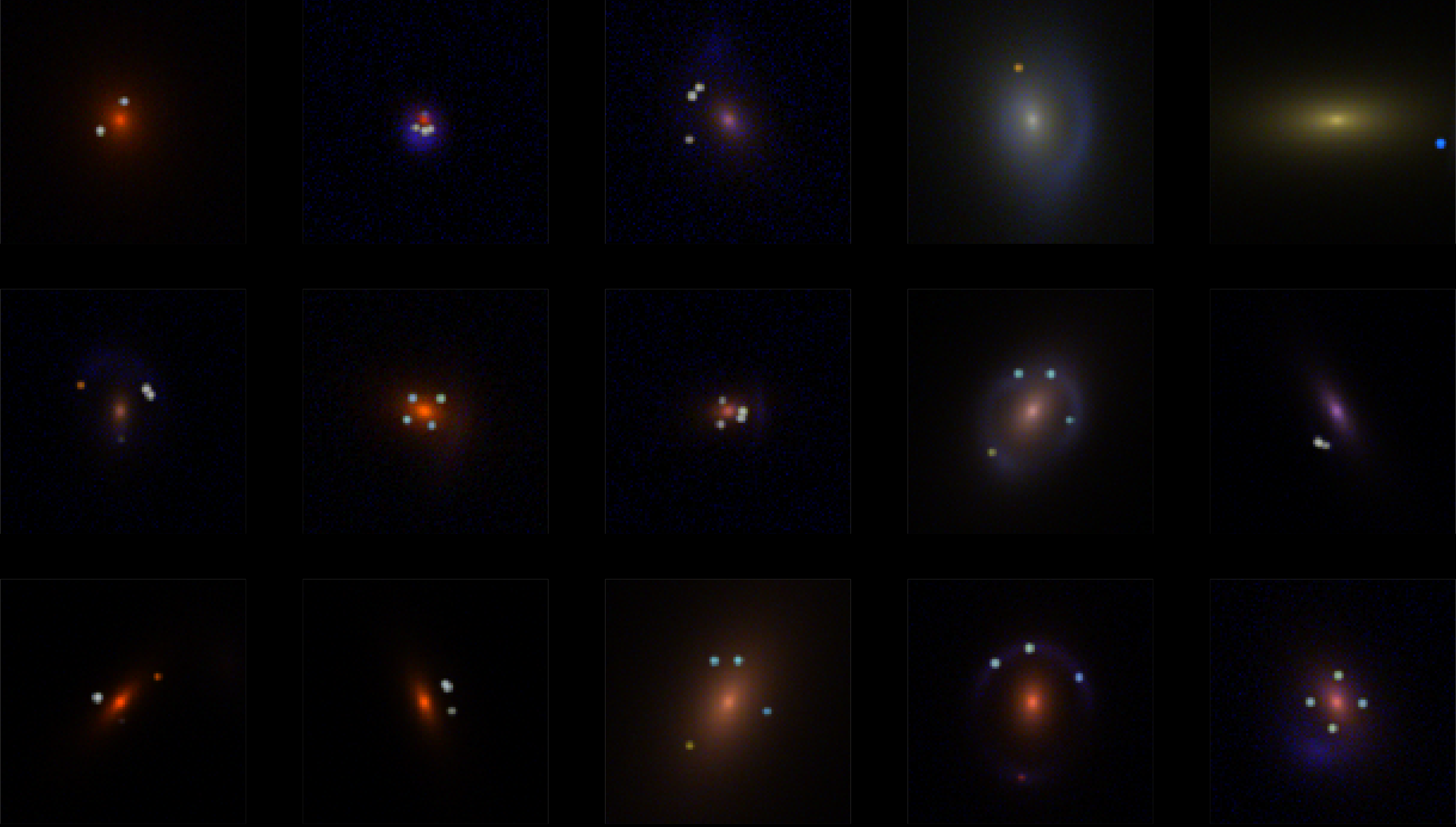


Connection to TDAMMS

- The ZTF Coadd Facility will roughly double the size of the ZTF partnership transient stream
- Most of these new transients are too faint for the facilities performing rapid follow-up of ZTF targets, e.g. SEDM.
- However, some of them will be well-suited for larger MMS facilities, such as DESI, 4MOST, and PFS.
- Need to start thinking now about coordinating with these facilities.

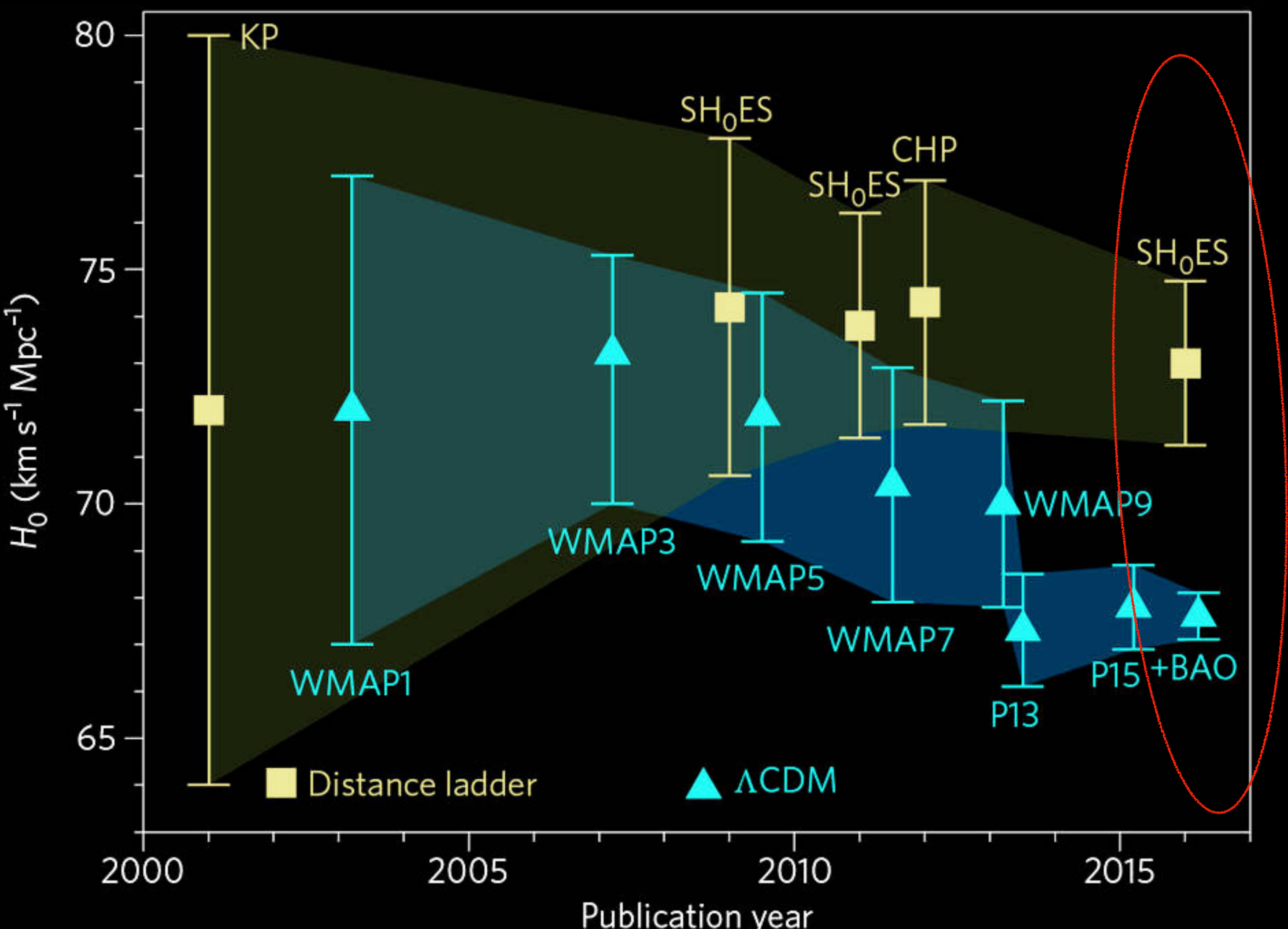






Original Motivation for Coadd Facility: Strongly Lensed SNe

H_0: The Biggest Tension in Cosmology



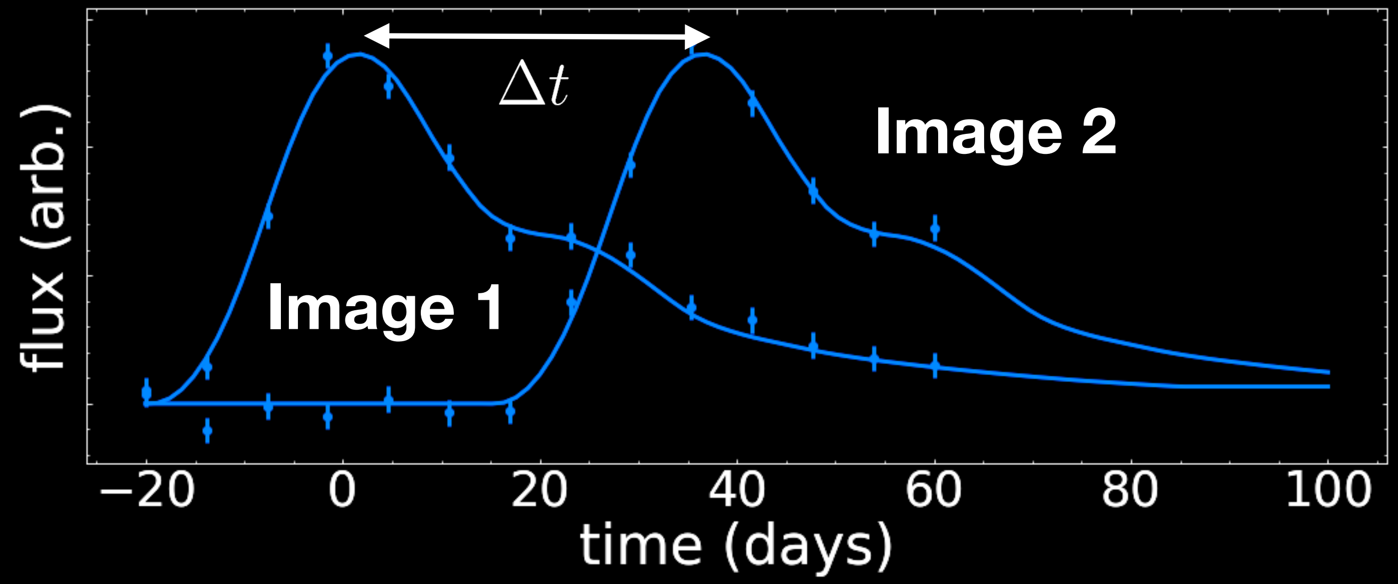
3.4σ

Need H_0 to <1% to resolve tension

Freedman 2017 (Nature Astronomy)

Time Delays: An Independent Route to H_0

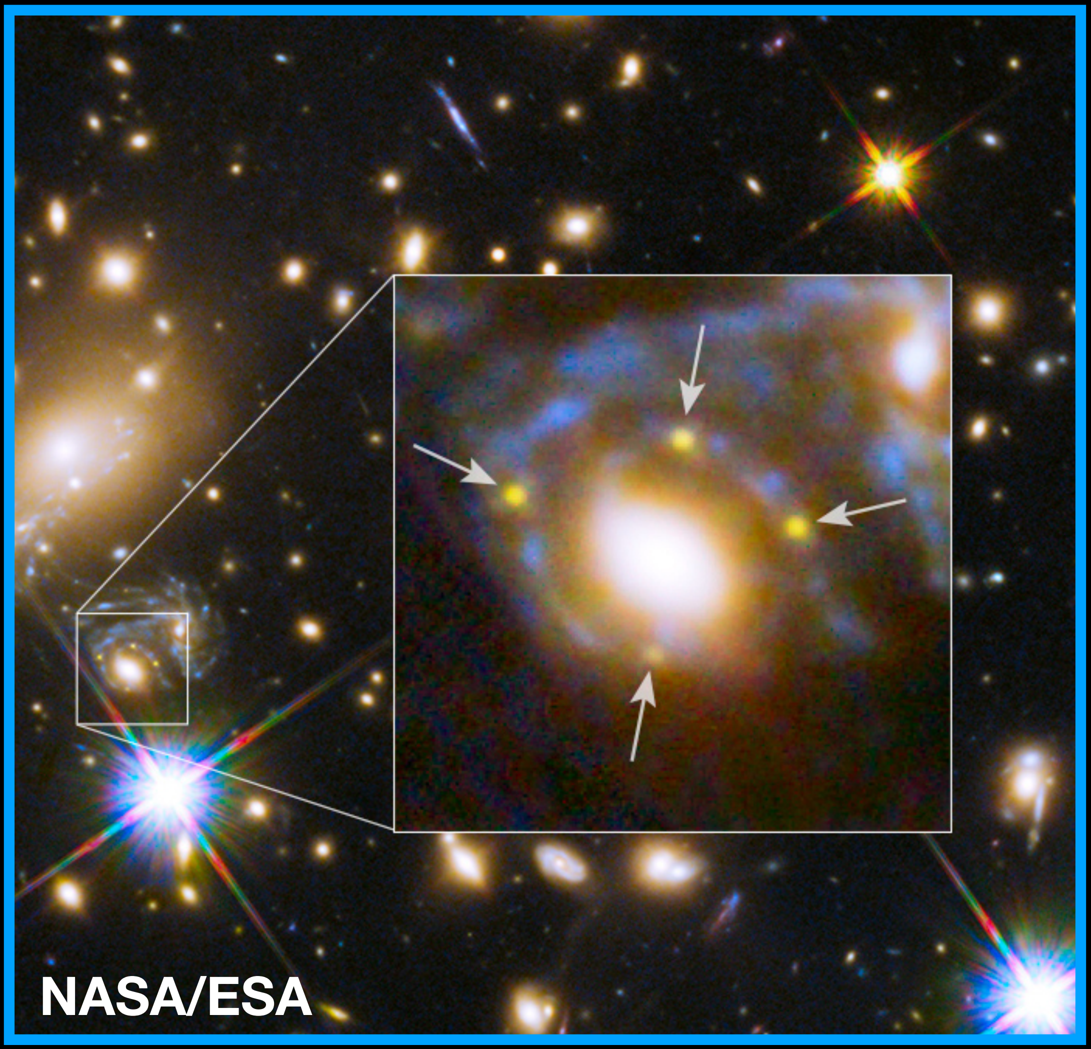
Time delays between multiple images of strongly lensed Type Ia supernovae directly constrain H_0 (Refsdal 1964) and provide leverage on dark energy (Linder 2004, 2011).



$$\Delta t \propto \boxed{\frac{D_l D_s}{D_{ls}}} \propto H_0^{-1} f(w)$$

Triple ratio of distances: a unique cosmology probe

H_0 hasn't been measured well with supernova time delays because only two multiply imaged supernovae have been found.



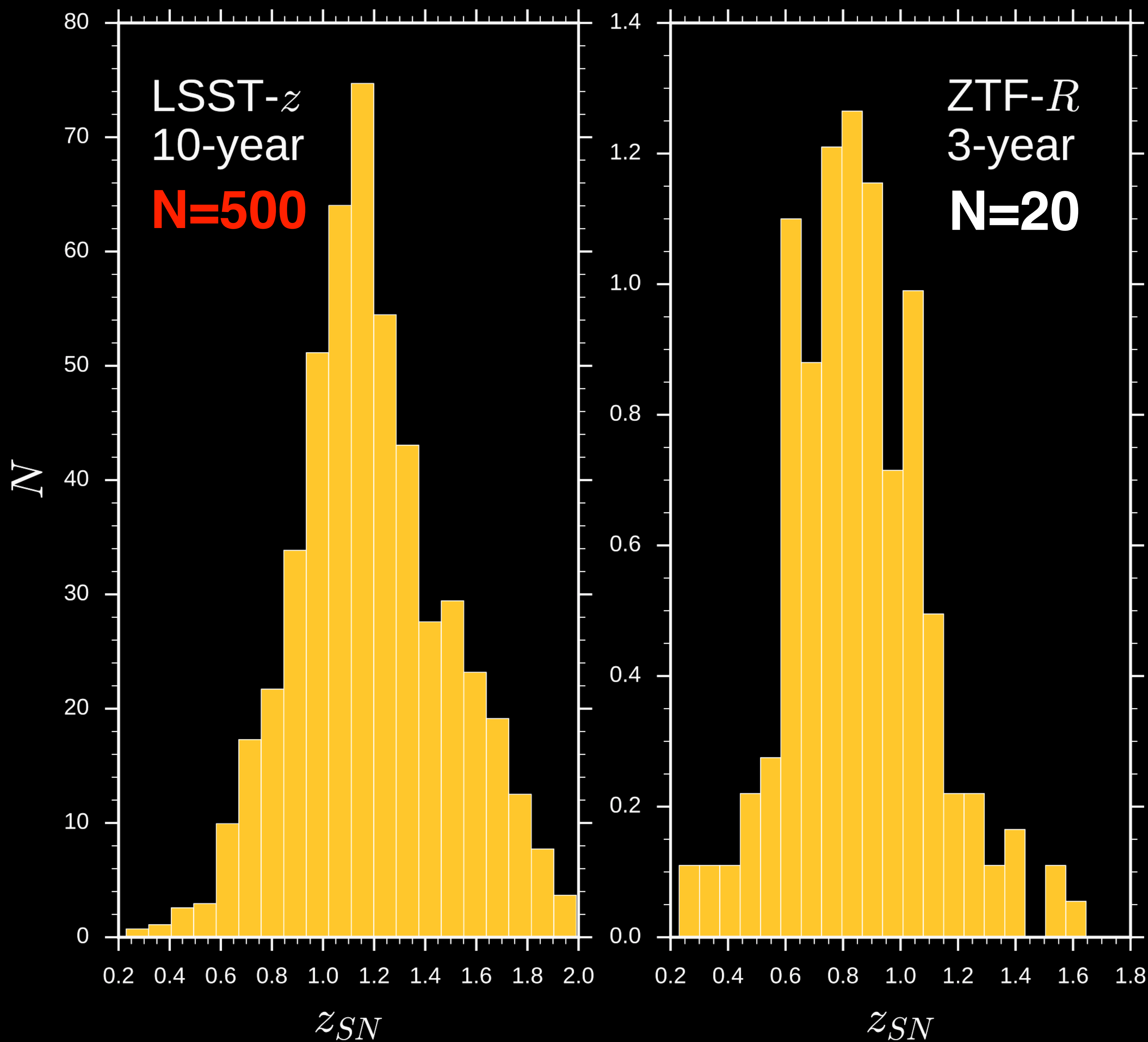
SN "Refsdal" (SN 1987A-like) z=1.49
Kelly et al. 2015 (*Science*)
discovered w/*HST*, μ~ 10,
J~24.2 (AB)

iPTF16geu (SN Ia) z=0.41
Goobar et al. 2017 (*Science*)
discovered w/ P48, μ ~ 52,
i ~ 19 (AB)

HOW TO FIND GRAVITATIONALLY LENSED TYPE Ia SUPERNOVAE

DANIEL A. GOLDSTEIN[1,2] AND PETER E. NUGENT[1,2]

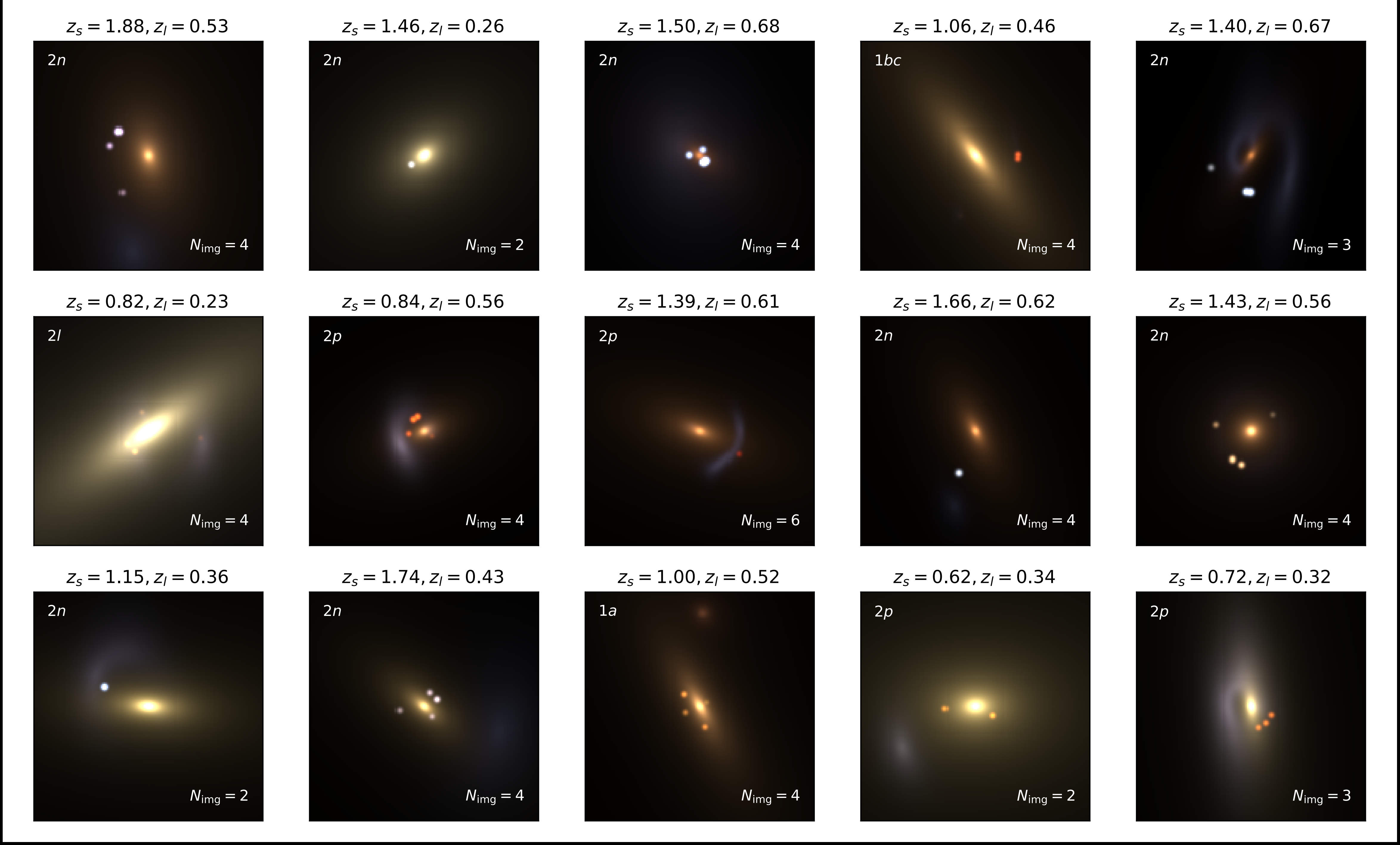
published in ApJL (Jan 2017)



Thanks to new glSN hunting techniques, we are now expecting ~10x as many glSNe from LSST than predictions of Oguri+Marshall (2010), which required resolved images.

Rates and Properties of Strongly Gravitationally Lensed Supernovae and their Host Galaxies in Time-Domain Imaging Surveys

Daniel A. Goldstein,[1,2,3,*] Peter E. Nugent,[2,3] and Ariel Goobar[4]



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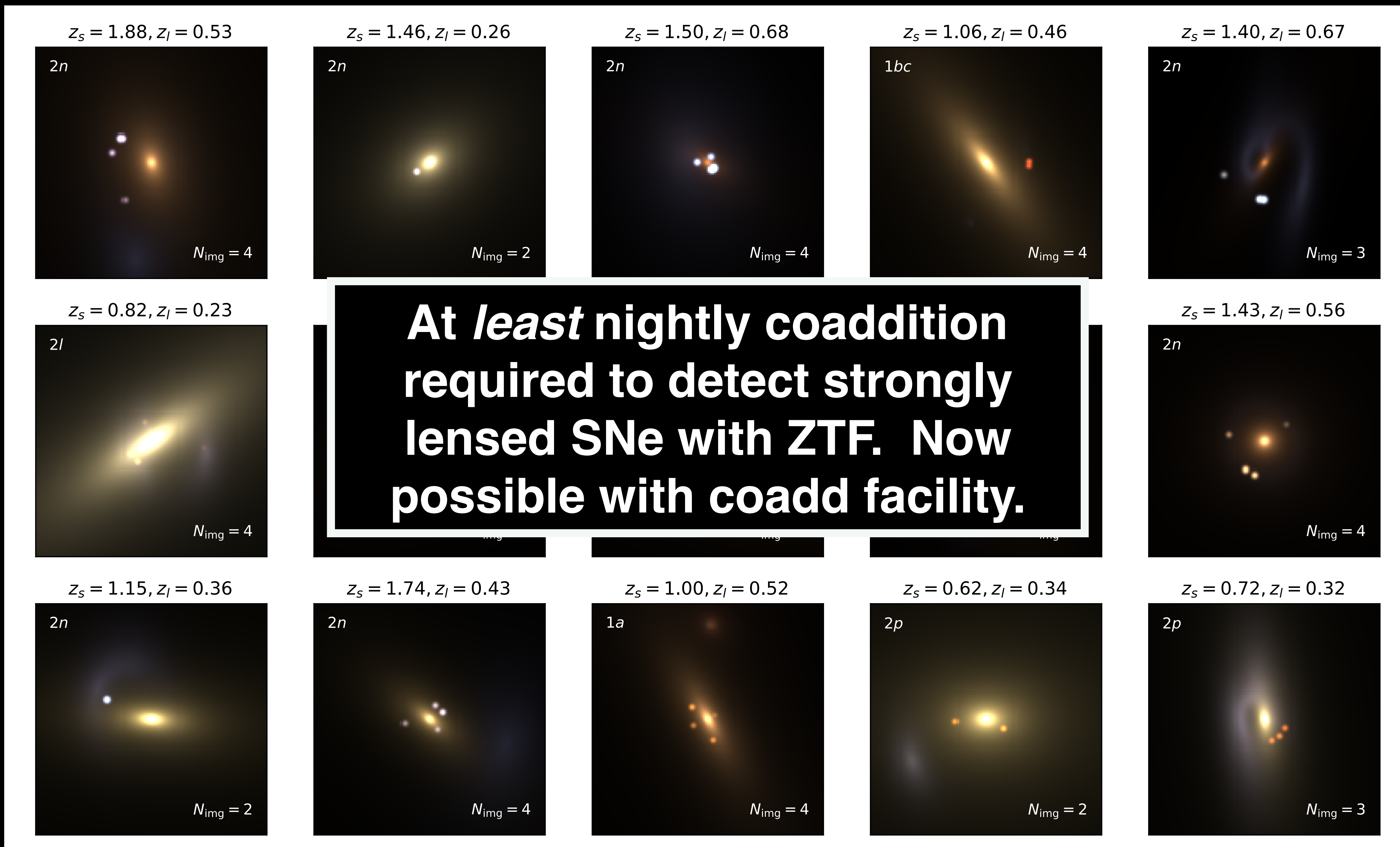

At *least* nightly coaddition required to detect strongly lensed SNe with ZTF. Now possible with coadd facility.

Conclusions and Outlook

- Automated image differencing of coadded wide-field science images is an efficient way to greatly extend the science reach of the current generation of time domain surveys.
- We have implemented a framework for doing this in ZTF, which has been operative for a couple of weeks and produced early science results.
- Using the framework, we can extend the reach of ZTF to ~23rd mag while still maintaining the cadence necessary for many science cases.
- Transients identified by this framework that are too faint for current rapid follow-up resources will be well-suited to future MMS facilities.