CTIO Dark Energy Camera Capabilities & Surveys Summary

Time Domain Astronomy in the Era of Massively Multiplexed Spectroscopy

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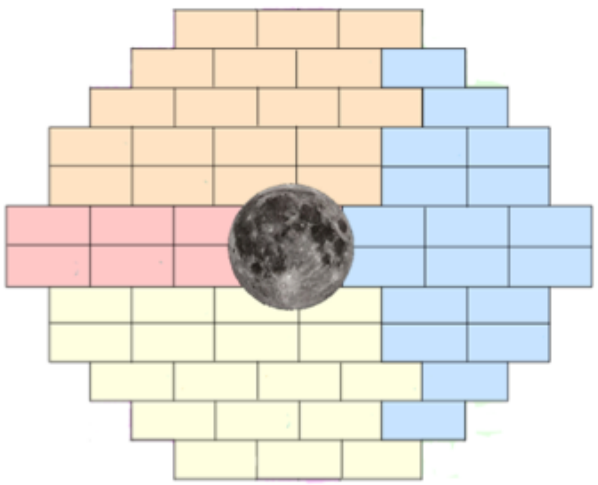
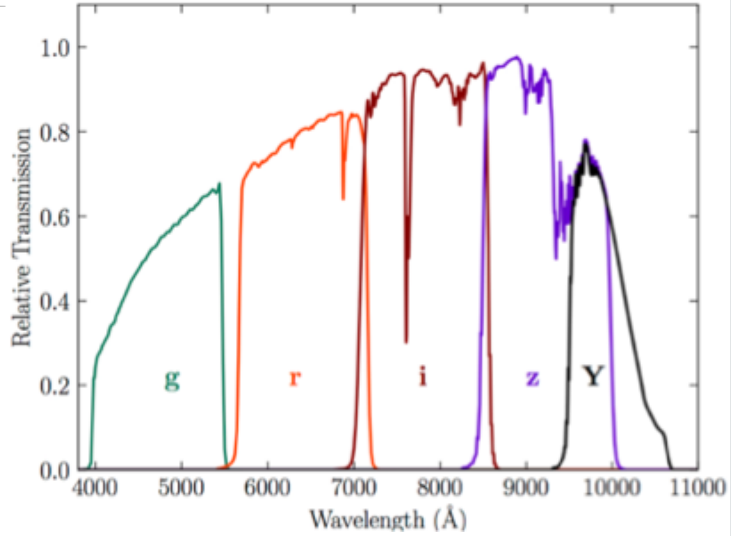
The CTIO Blanco 4-meter Telescope & The Dark Energy Camera

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.)**

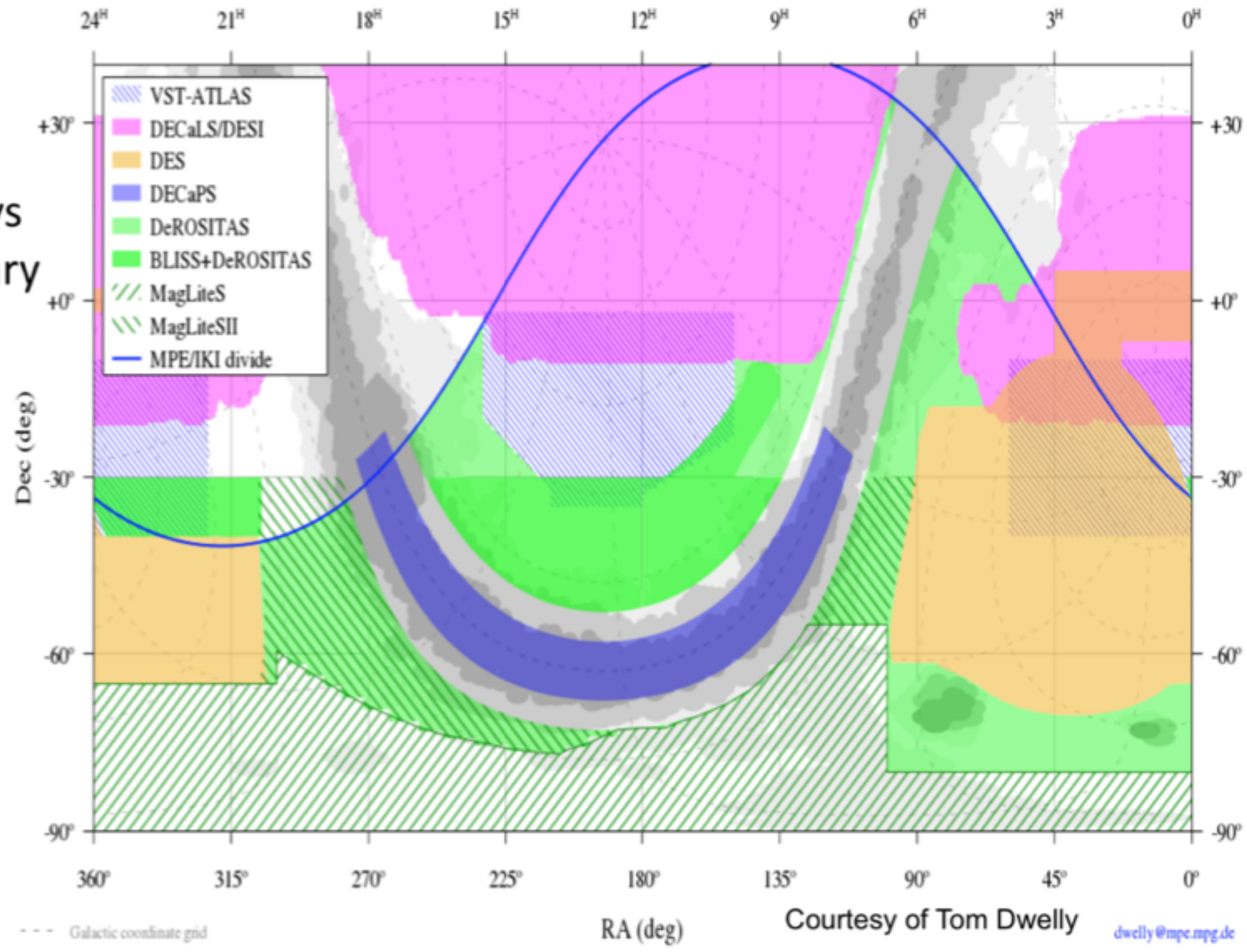




Existing and Planned Surveys

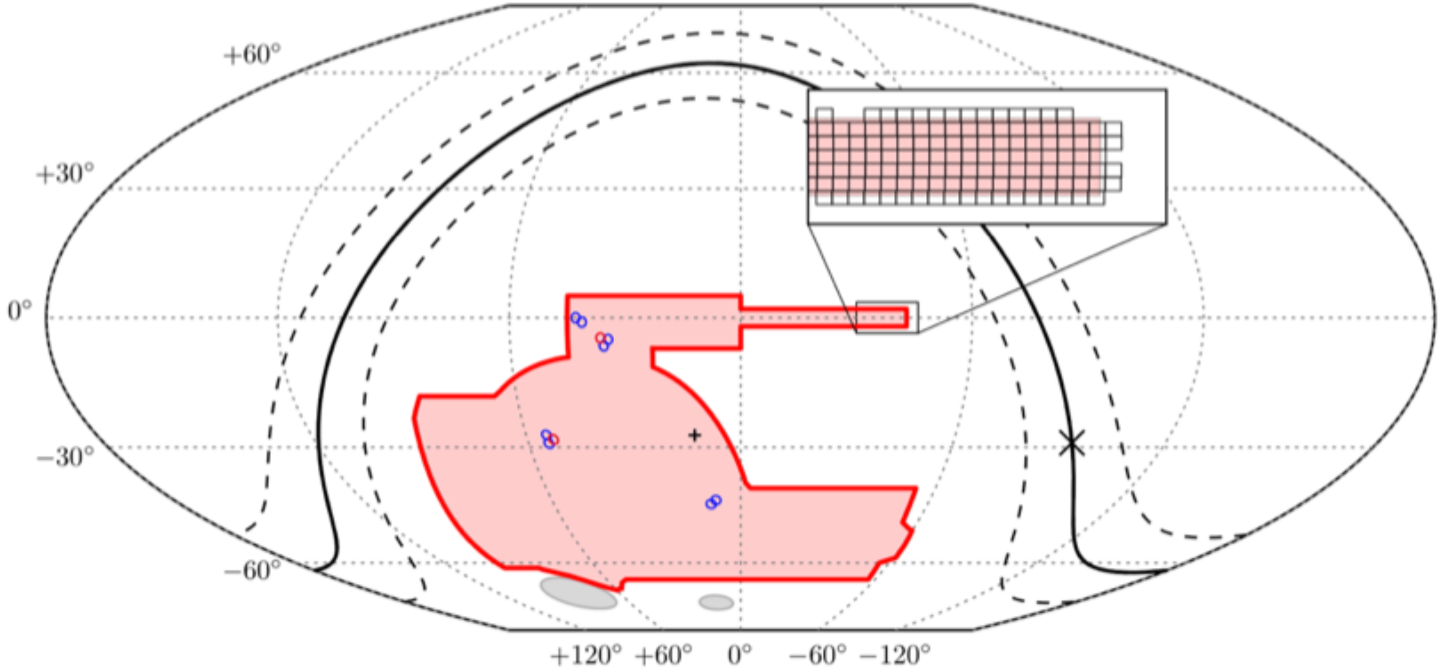
The vast majority of DECam time has been devoted to “non-time-domain” imaging surveys

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

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

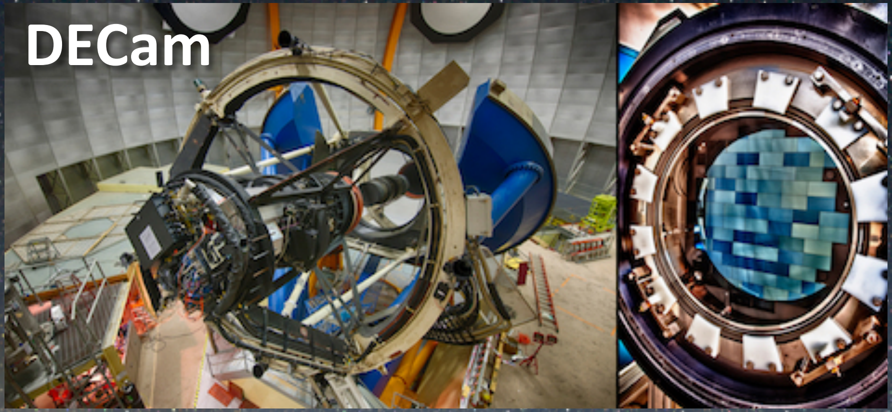
Marco Battaglieri (SAC co-chair),[1] Alberto Belloni (Coordinator),[2] Aaron Chou (WG2 Convener),[3] Priscilla Cushman (Coordinator),[4] Bertrand Echenard (WG3 Convener),[5]

- *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.**

<u>NOAO</u> – 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).

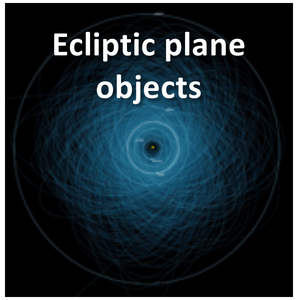
The ongoing PALS: DOE DECam Microlensing Survey could deliver constraints within the year

- 3 fields: Bulge, LMC, SMC
- 32 nights over 2-years
- First light February 2018
- Could place the tightest and most direct constraints 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



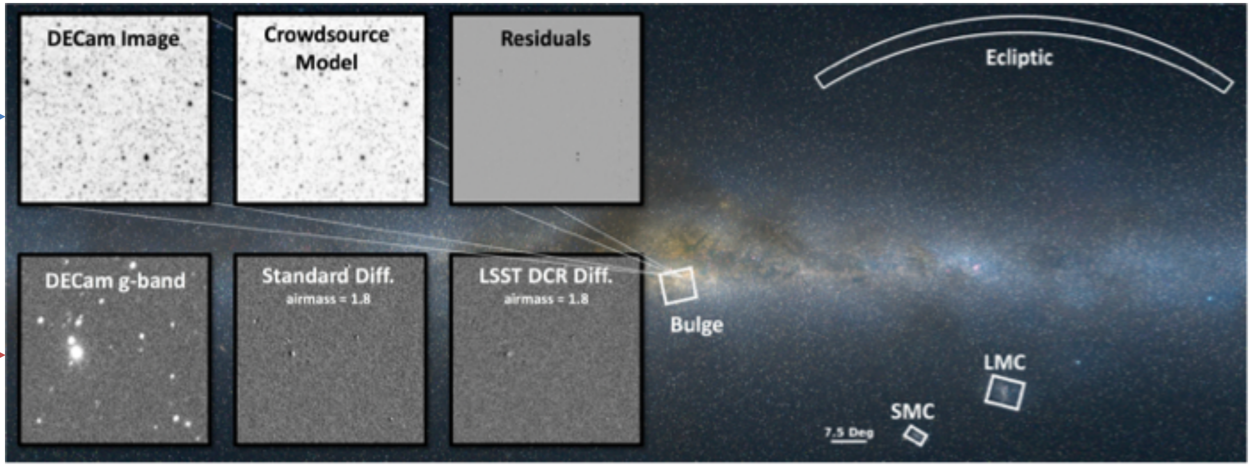
LLNL has an LDRD funded and NOAO awarded DECam black hole microlensing pilot survey

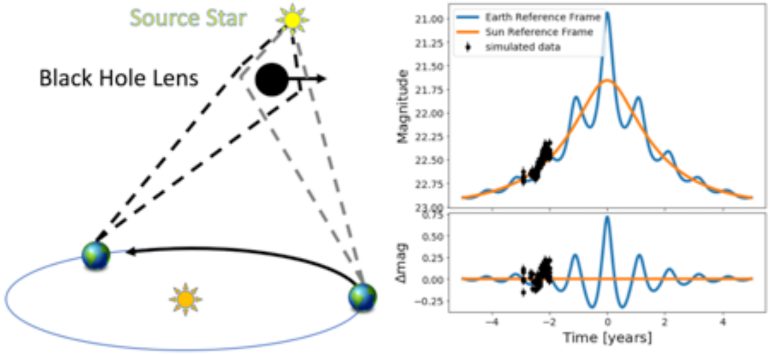
- Ongoing 32 night – two year DECam survey as LSST precursor
- Proposal submitted to extend current DECam black hole dark matter survey
  - *Grow survey 98 nights per year for the next three years; LSST precursor*
  - Add shorter time cadence aspect which will:
    - Detect free floating black holes 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



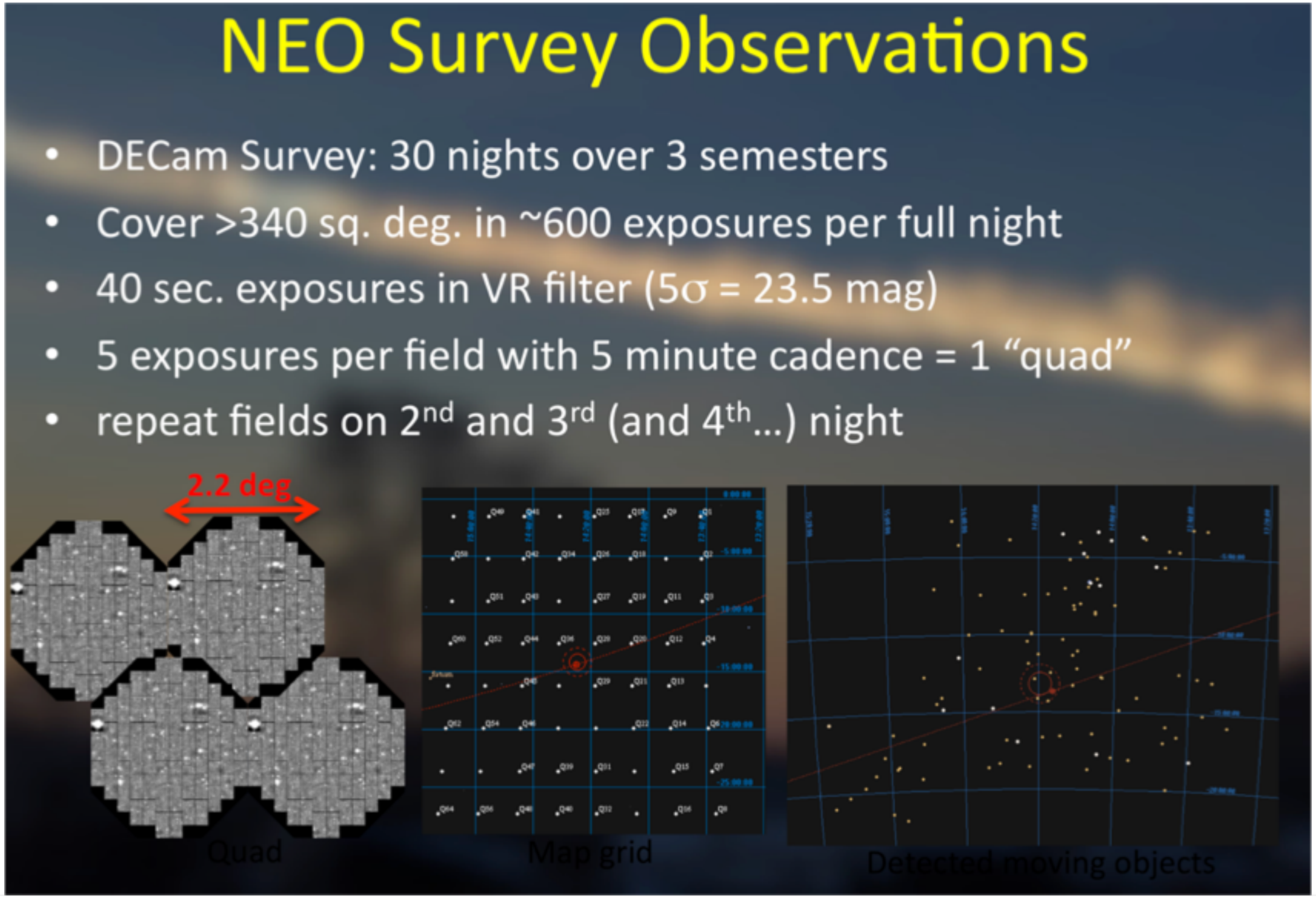
Crowdsource dense field photometry

LSST DM Stack Difference Imaging





The DECam NEO Survey of Near Earth Asteroids



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
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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]
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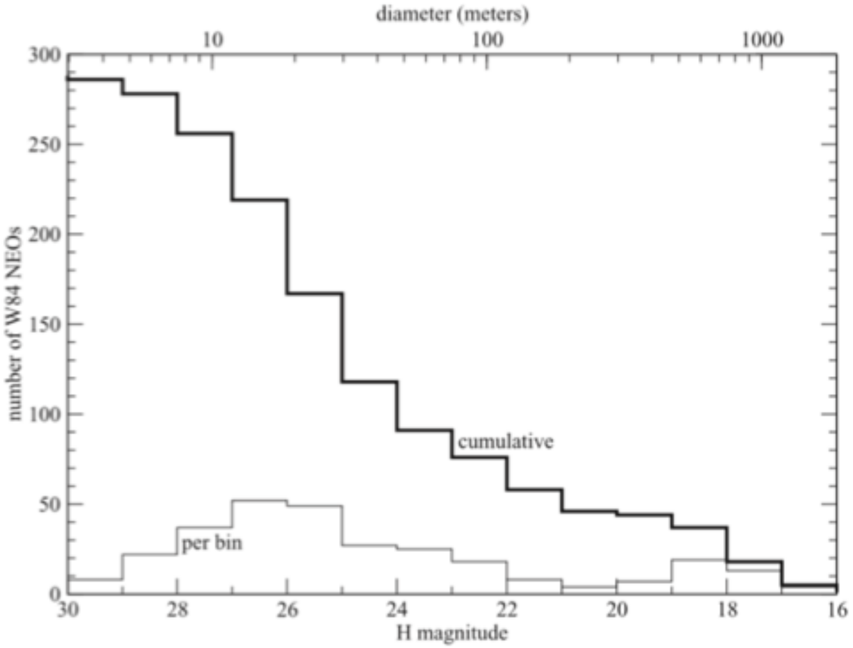
[2] South African Astronomical Observatory P.O. Box 9 7935 Observatory, South Africa
[3] University of the Western Cape Bellville Cape Town 7535, South Africa
[4] National Optical Astronomy Observatory 950 N. Cherry Avenue Tucson, AZ 85719, USA
[5] Cerro Tololo Inter-American Observatory National Optical 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

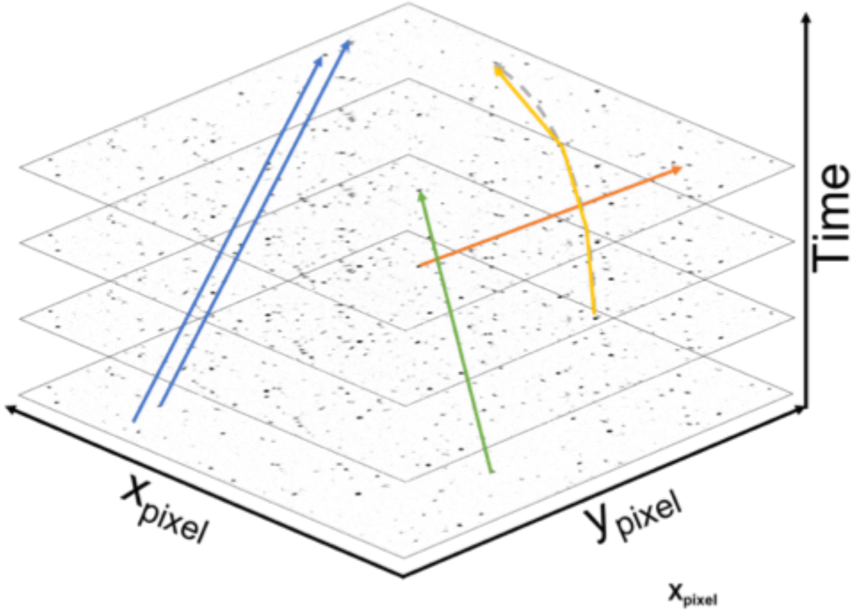
Abstract

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.

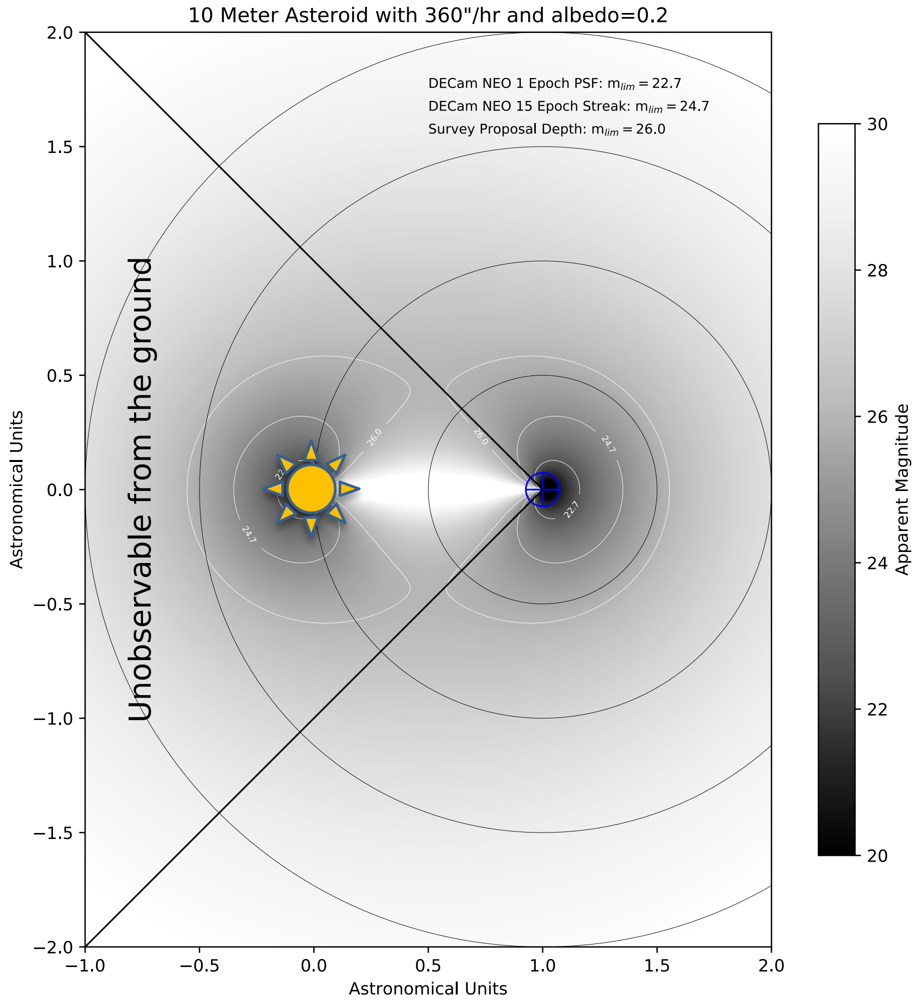


There is room for NEO survey improvement through algorithms and atypical survey strategy

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



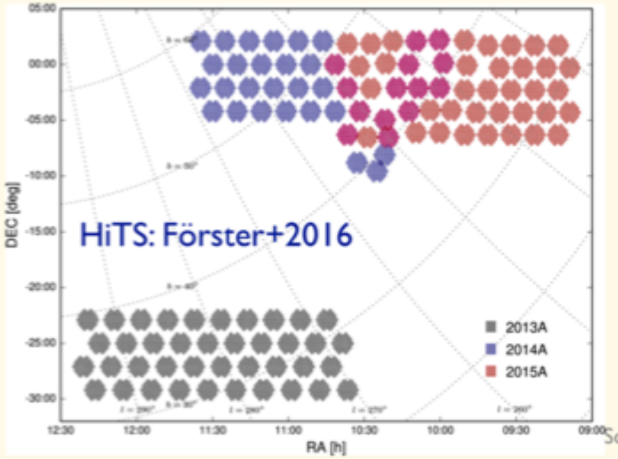
Observing strategy changes can make NEO Trojans and other potentially hazardous asteroids more observable from ground-based telescopes.



DECam searches for RR Lyrae stars

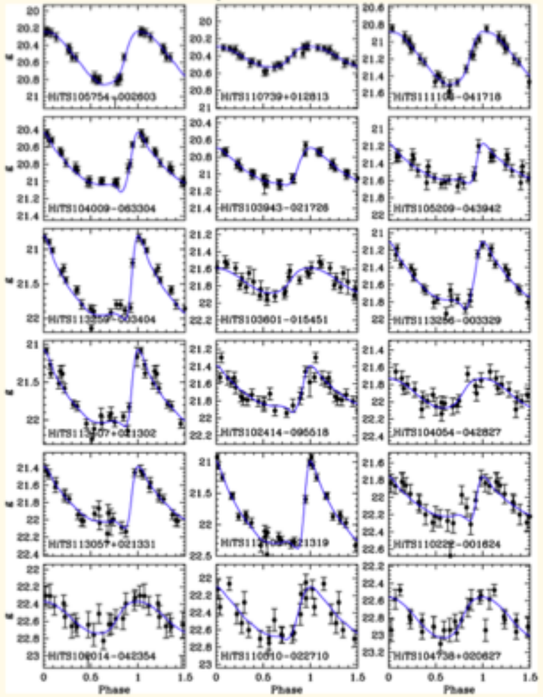
Searching for outer halo RR Lyrae stars

- DECam's FOV makes mapping large areas efficient
- Started with archival data from the HiTS supernova survey (Förster+2016)
- ~20-30 epochs per field
- Have been awarded 7 nights (3 in 2017B, 4 in 2018A) via NOAO/CNTAC proposals (PIs: Carlin, Muñoz)

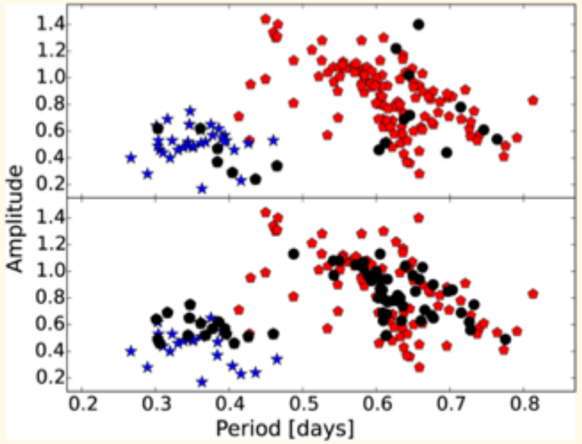


Science Workshop, Tucson, AZ, May 2018

Full HiTS (2014) results (Medina+2018, ApJ, 855, 43):



173 RR Lyrae stars, including 18 at d > 90 kpc



Medina+2018, ApJ, 855, 43

J. Carlin; DECam Community Science Workshop, Tucson, AZ, May 2018

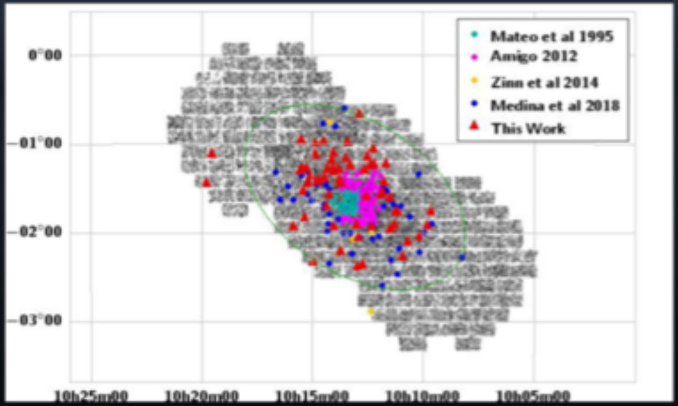
DECam searches for dwarf Cepheid stars

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



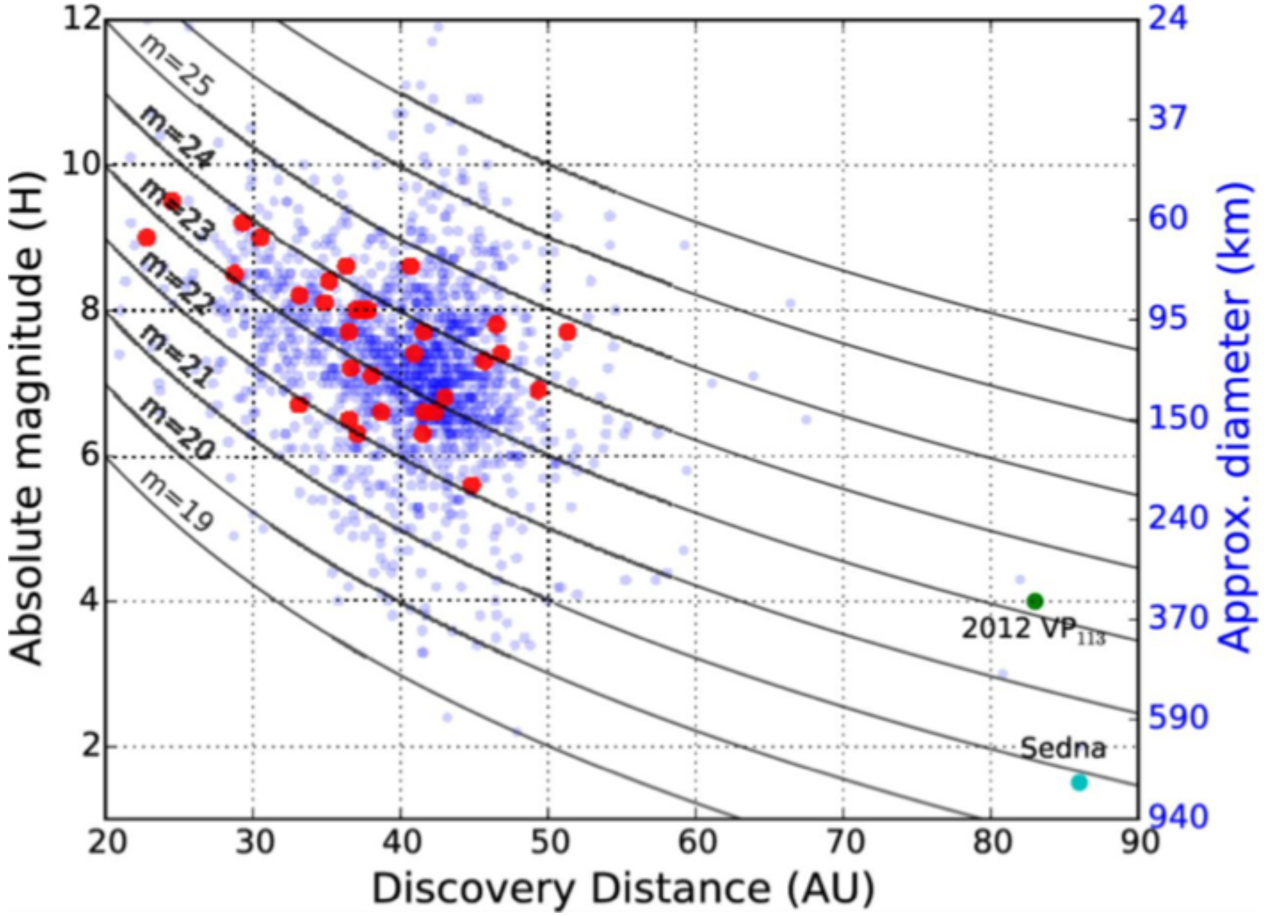
Tidal radius = 83.2 arcmin (Roderick et al 2017)

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

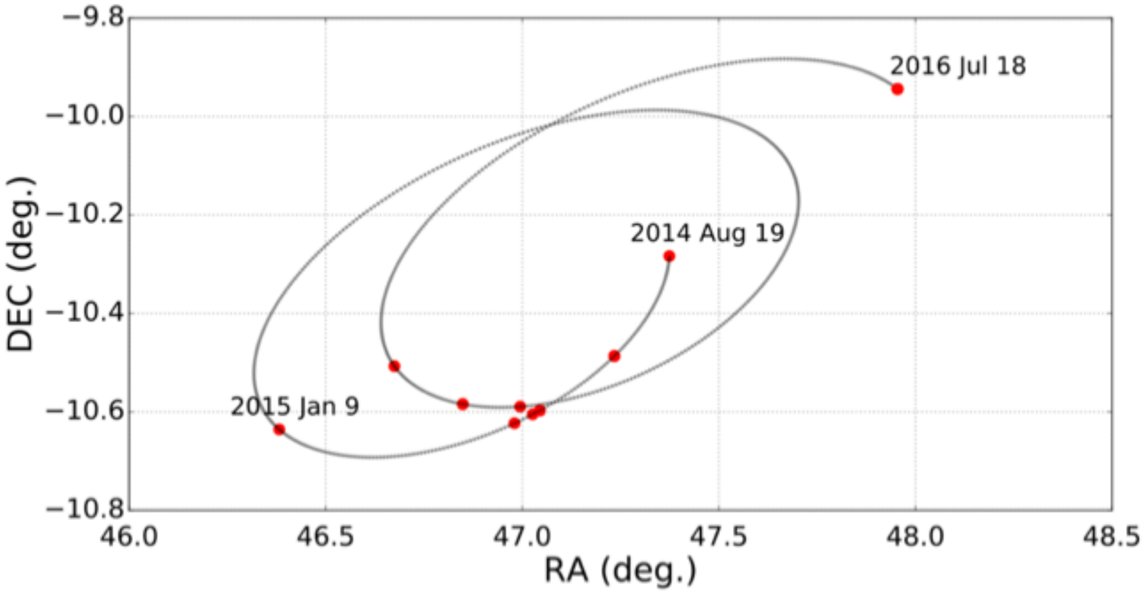
DECam Community Science Workshop 2018 18

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)*.

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