Optical & Radio Transients

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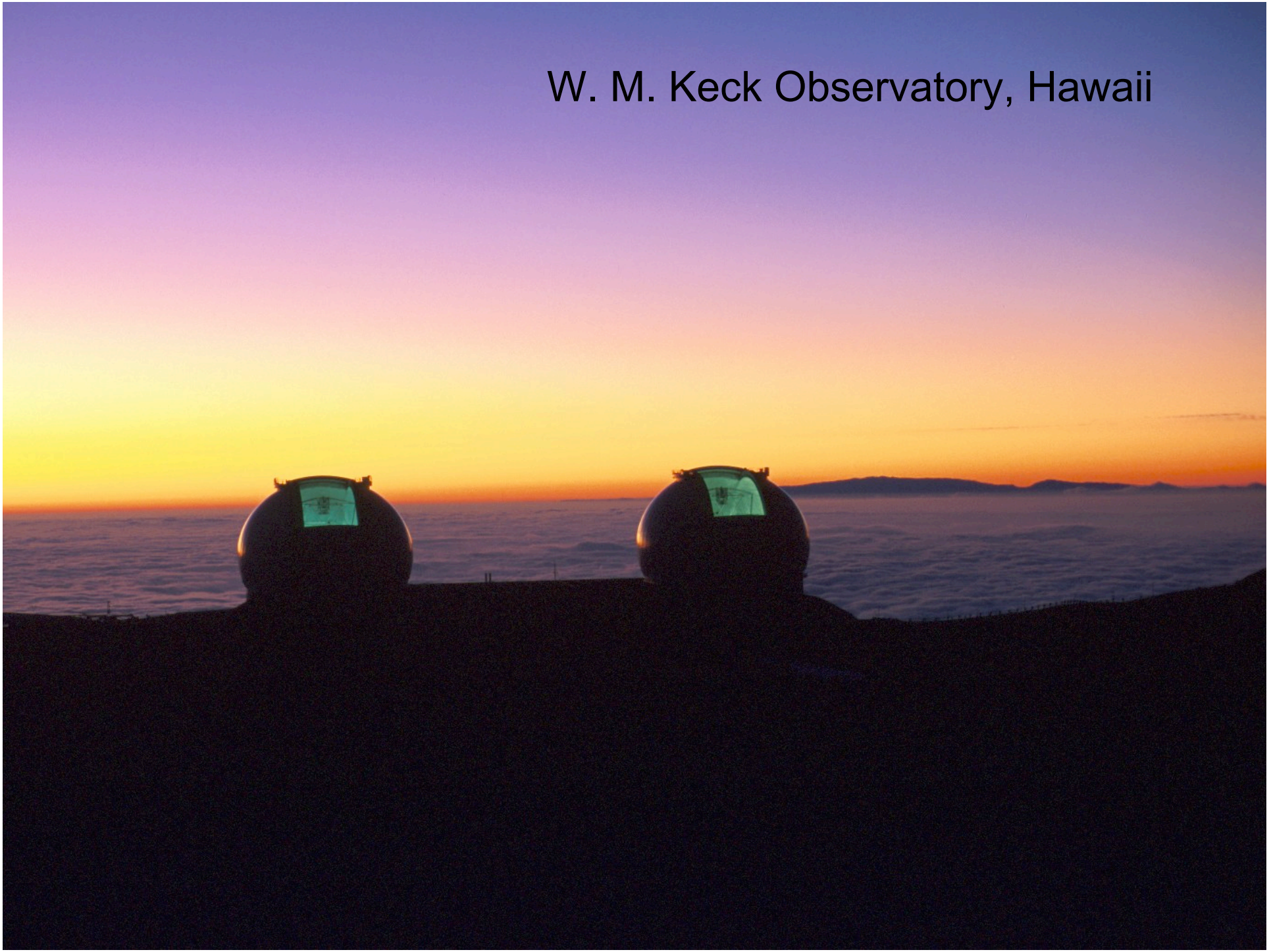
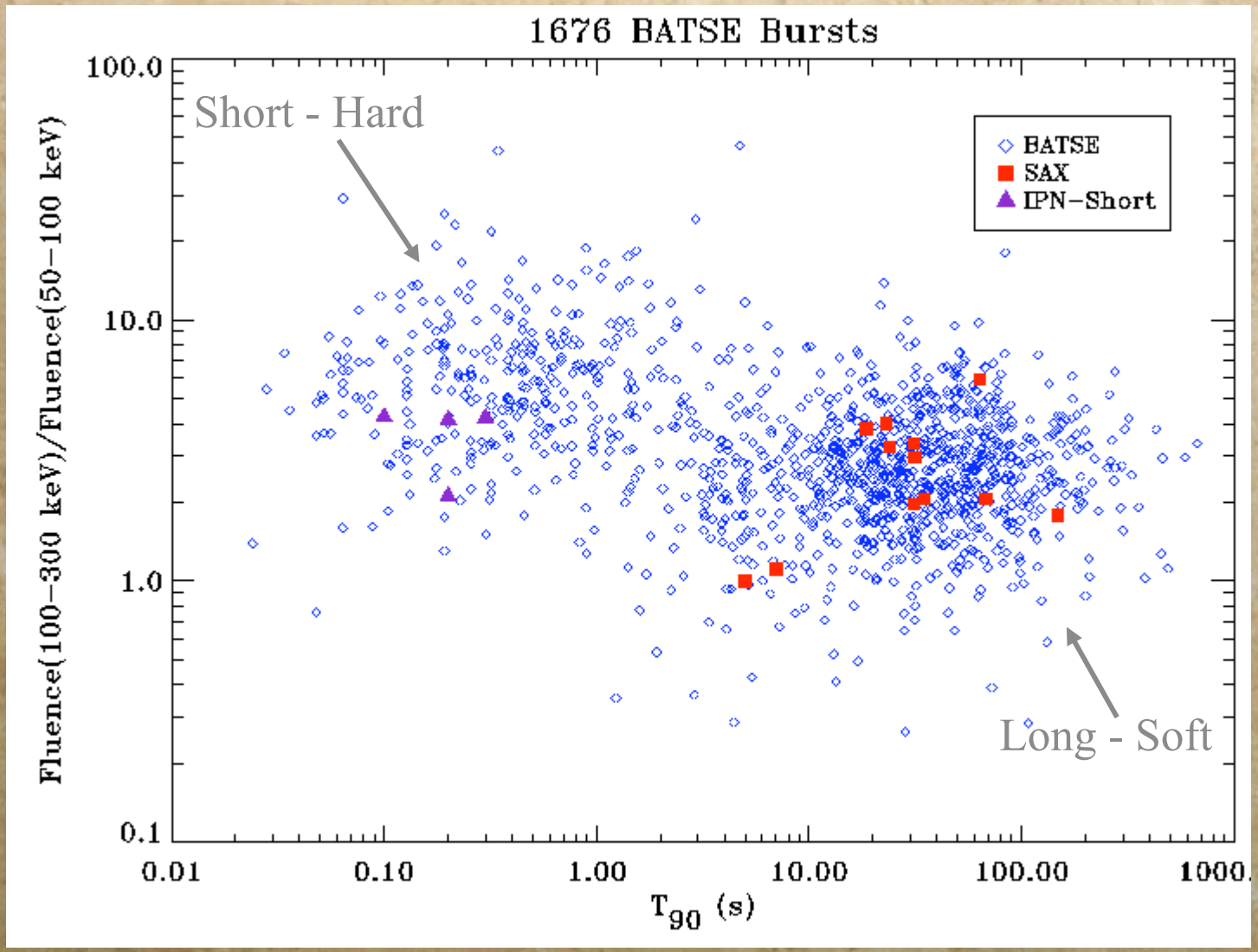
California Institute of Technology
Director, Caltech Optical Observatories
Chairman, Space Interferometry Mission


W. M. Keck Observatory, Hawaii

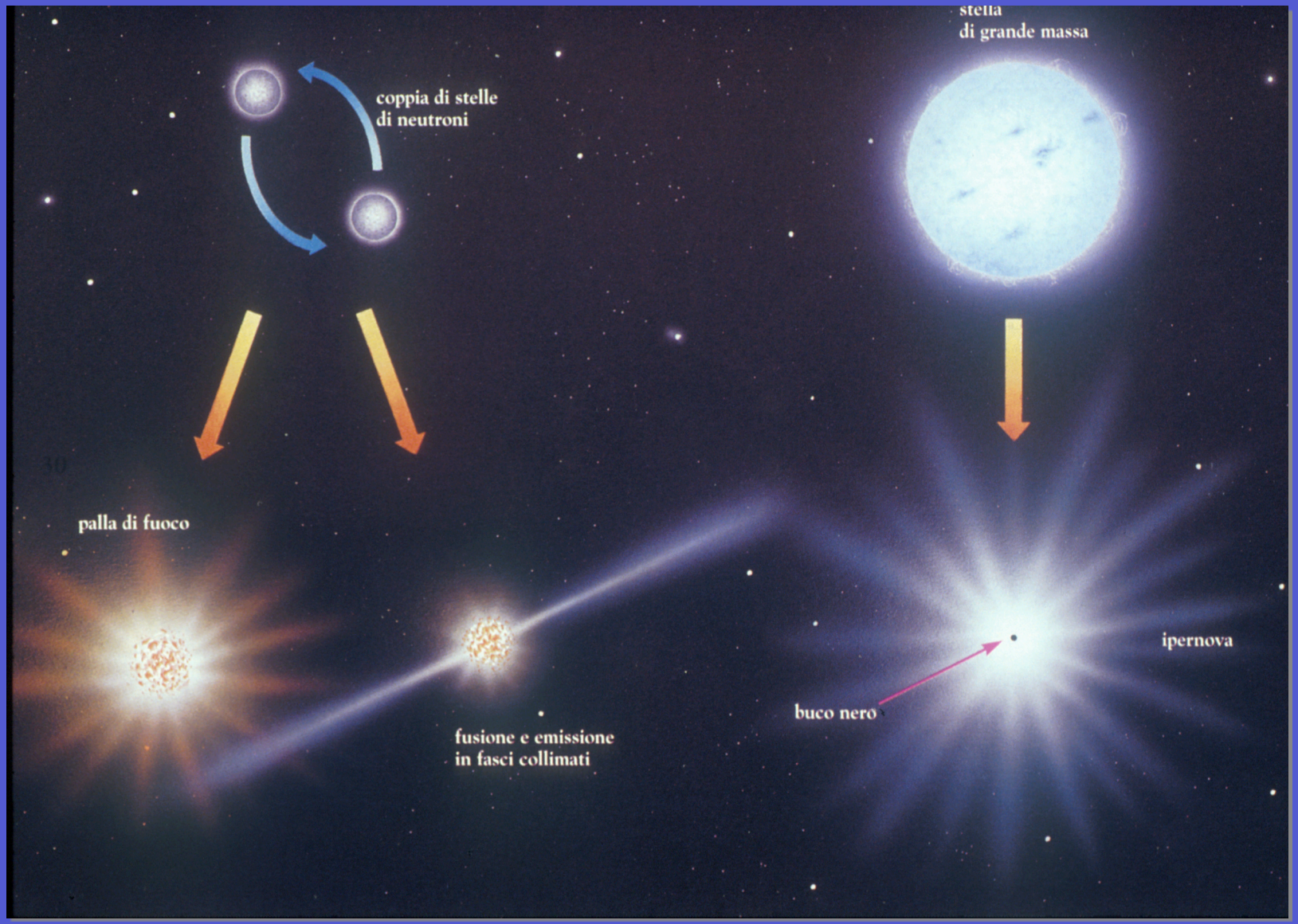
Taking the Measure of the Universe…
Planets, Parallaxes & More

Space Interferometry Mission, PlanetQuest

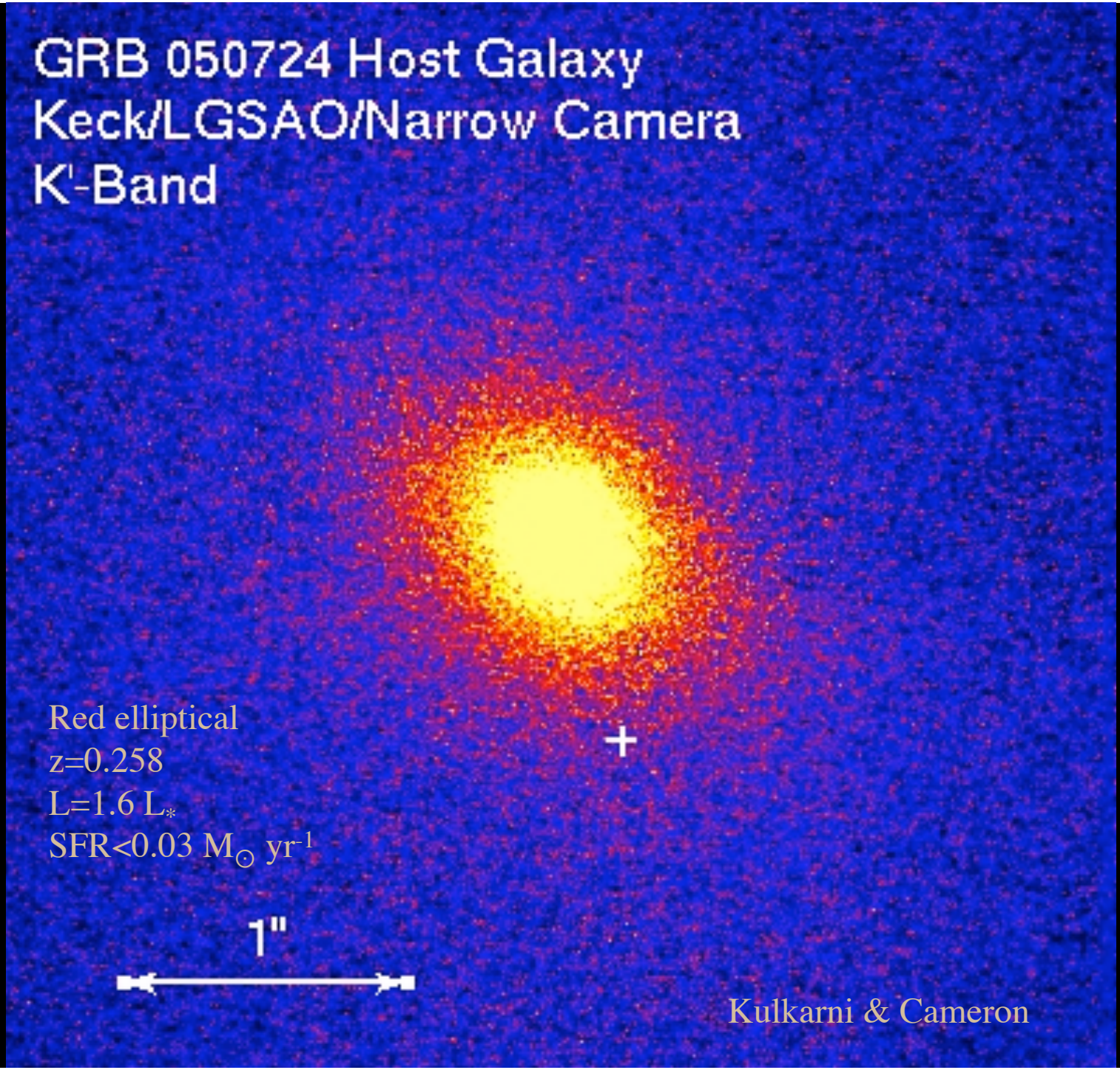
Two classes of GRBs



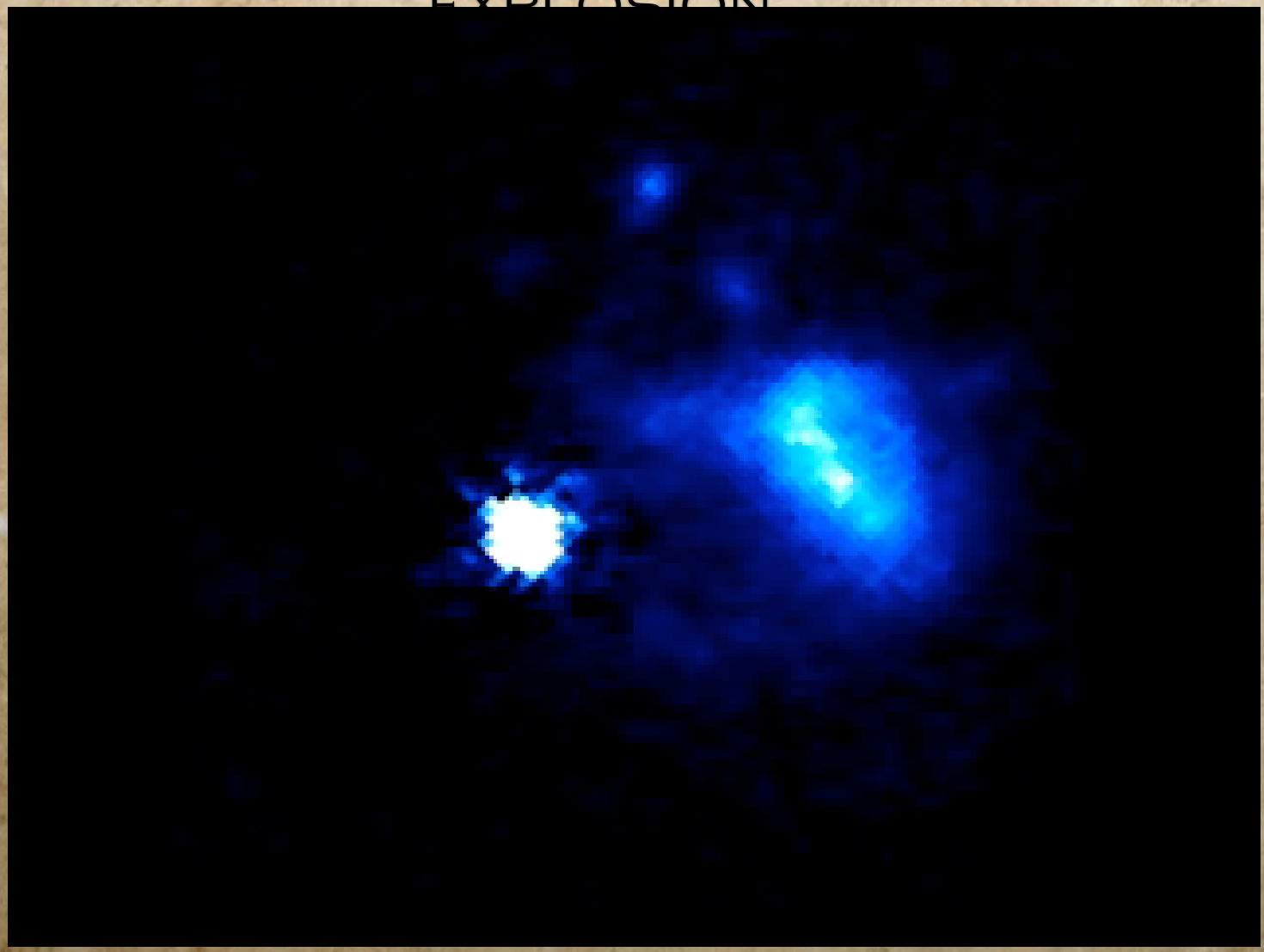
Popular Models



Keck Laser Guide Star AO


GRB 050724 Host Galaxy
Keck/LGSAO/Narrow Camera
K'-Band
Red elliptical
z=0.258
L=1.6 L*
SFR<0.03 M⊙ yr-1
1"
Kulkarni & Cameron

HST imaging & search for supernova explosion



Fox et al. 2005

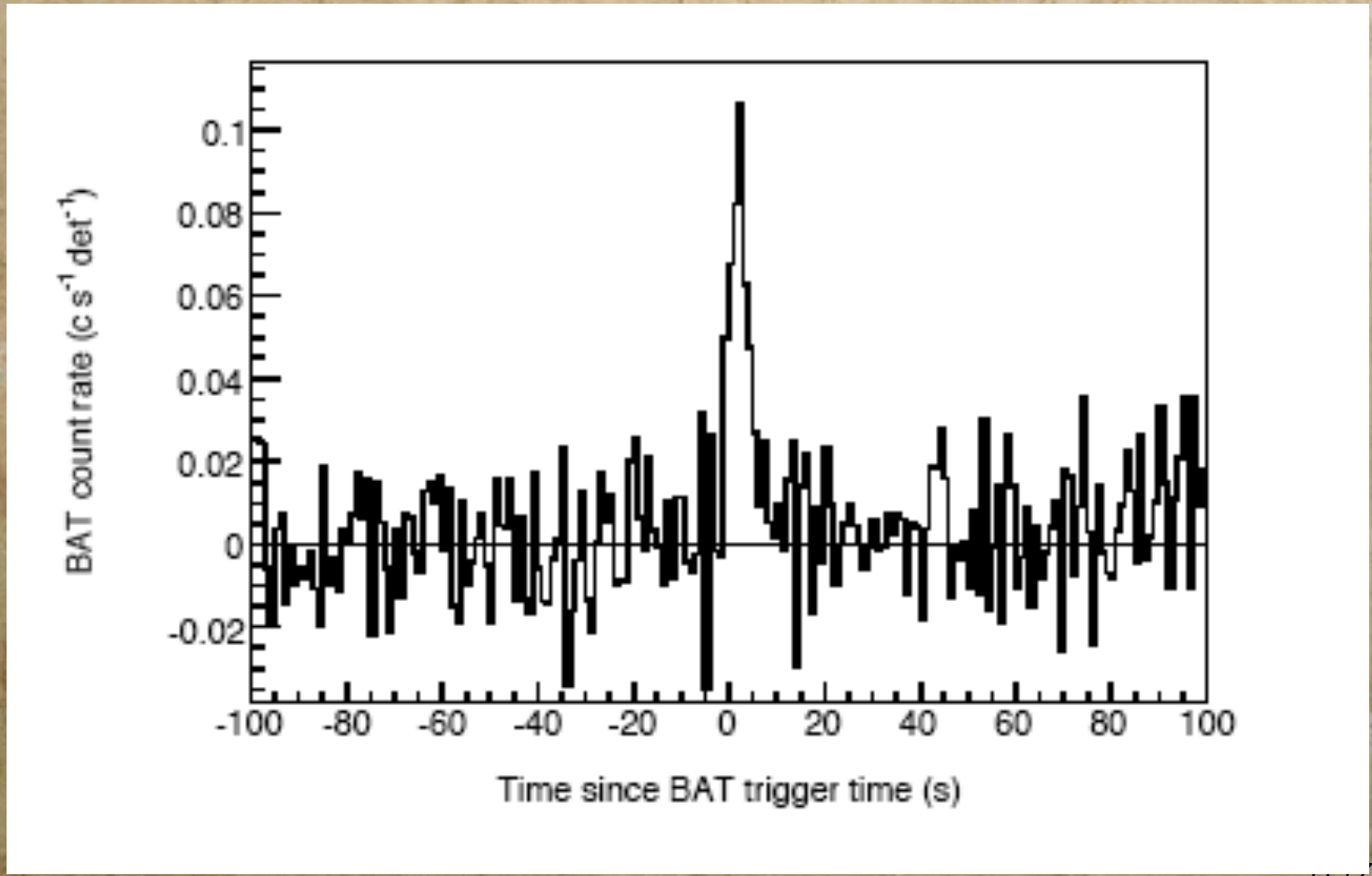

75th Anniversary Astronomical Debate
April 22nd, 1995
GALACTIC
GRBs are
Shapley & Curtis 1920 - 1995 Lamb & Paczyński

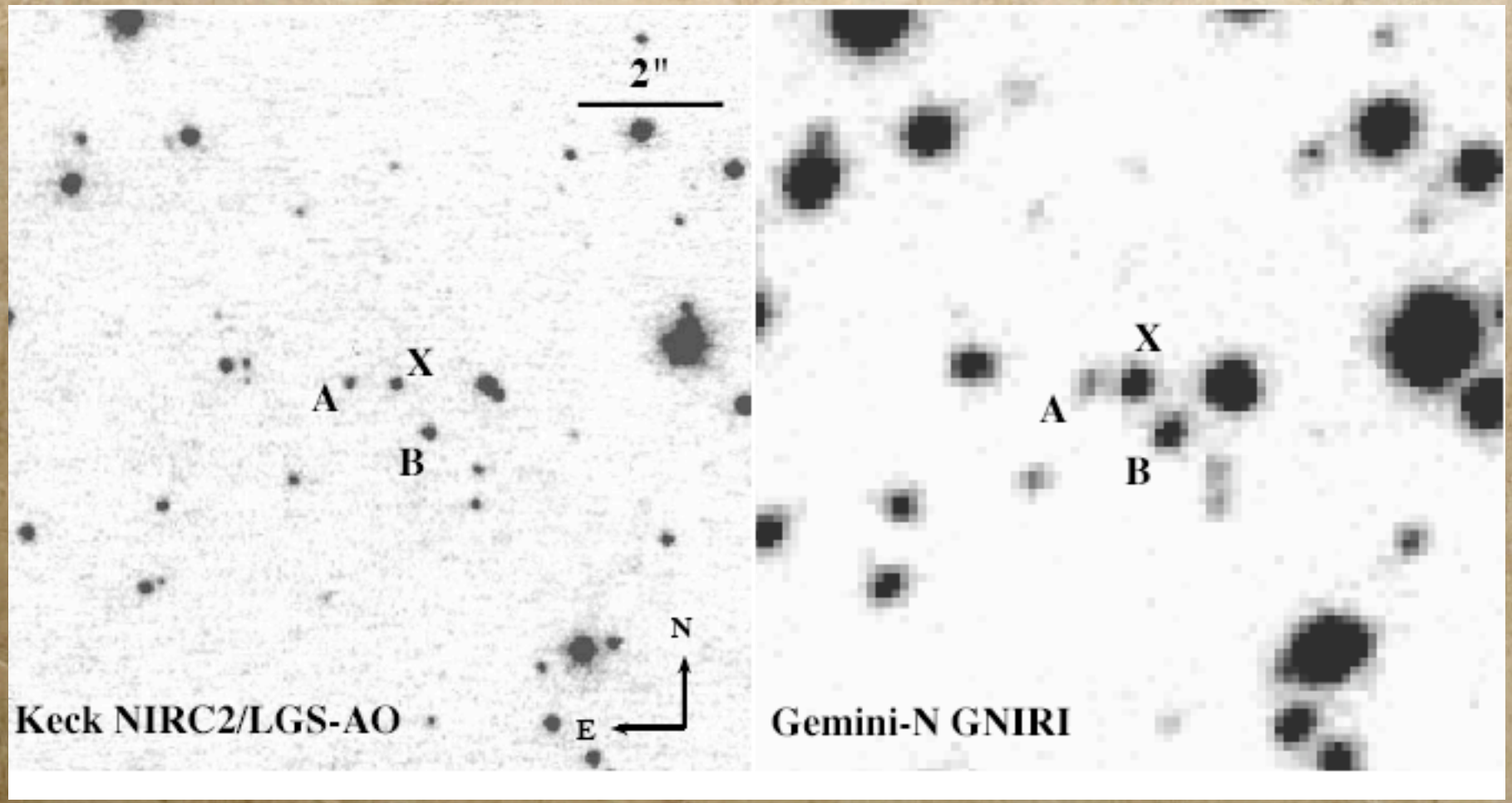

75th Anniversary Astronomical Debate
April 22nd, 1995
COSMOLOGICAL
GRBs are
Shapley & Curtis 1920 - 1995 Lamb & Paczyński


75th Anniversary Astronomical Debate
April 22nd, 1995
OTHER!
GRBs are
Shapley & Curtis 1920 - 1995 Lamb & Paczyński

GRB 070610

(*The Meek Shall Inherit the Skies*)



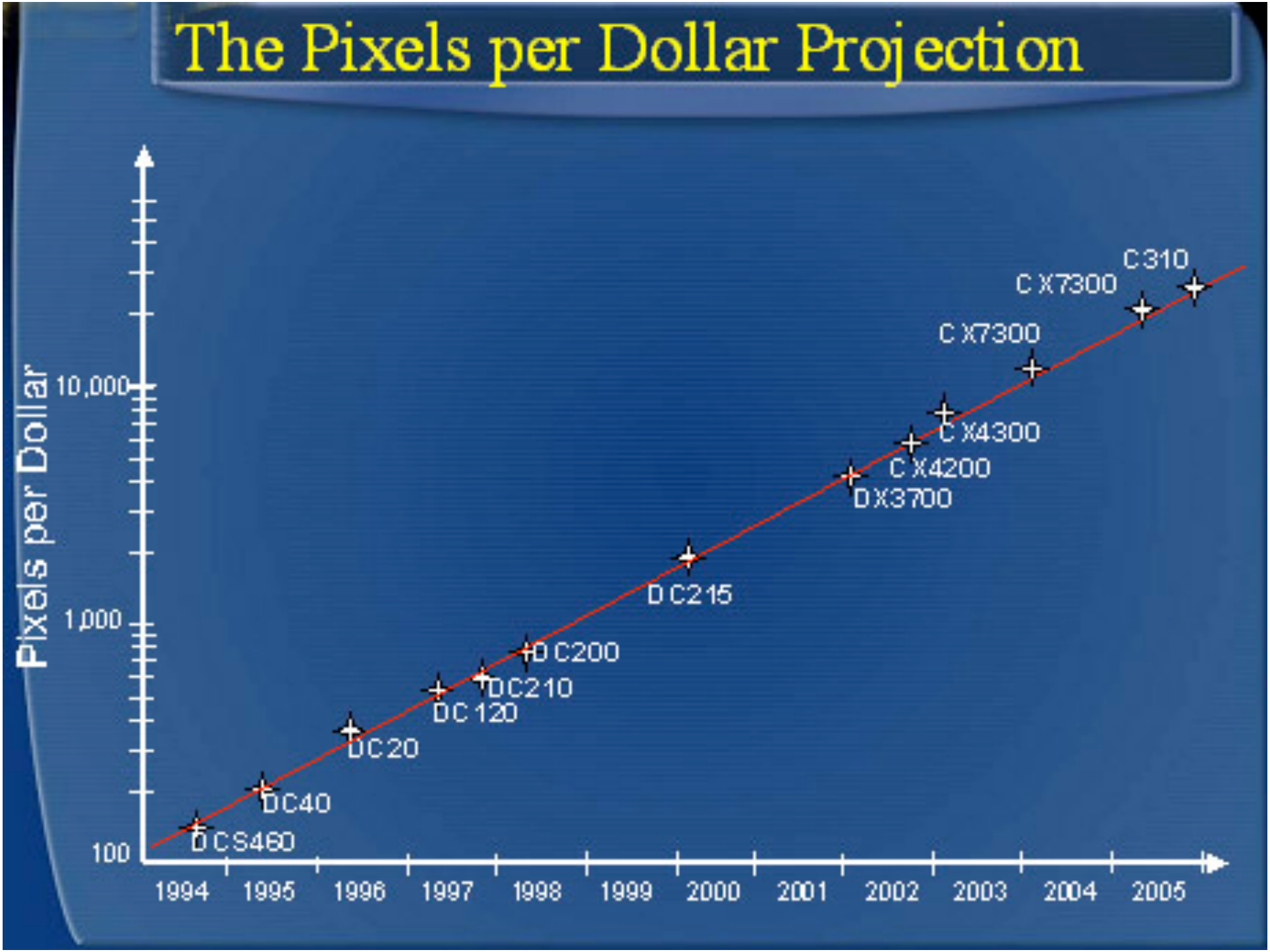

2"
X
A
B
N
E
Keck NIRC2/LGS-AO
X
A
B
Gemini-N GNIRI

Lessons Learnt

- Ambitious and rapid multi-wavelength effort is the key to rapid progress
- There is tremendous open phase
  - "What is not forbidden exists"

The New Wild West: Transients

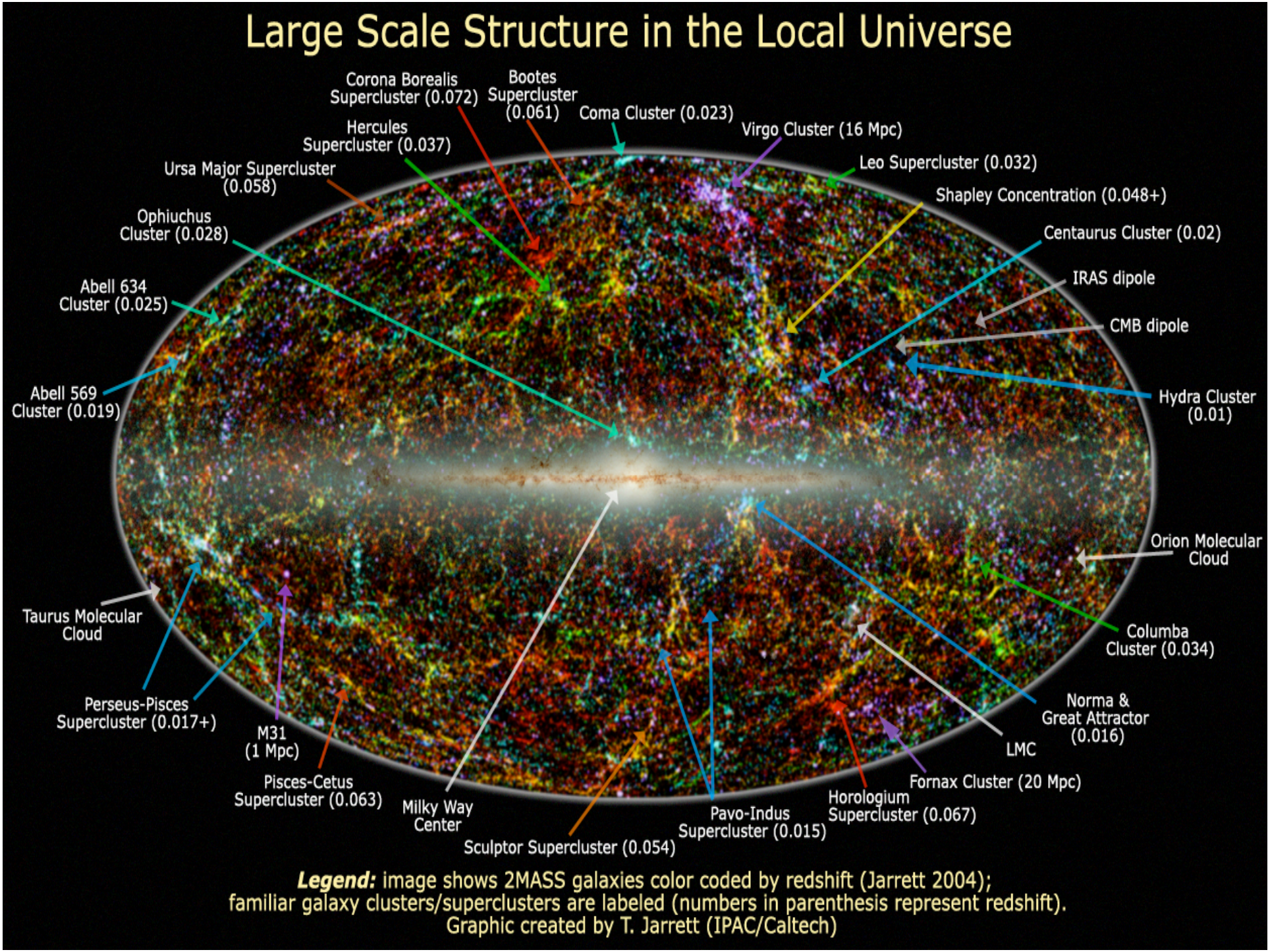
I. Optical Searches


The Pixels per Dollar Projection
Pixels per Dollar
10,000
1,000
100
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
DCS460
DC40
DC20
DC120
DC210
DC200
DC215
DX3700
CX4200
CX4300
CX7300
CX7300
CX7300
C310

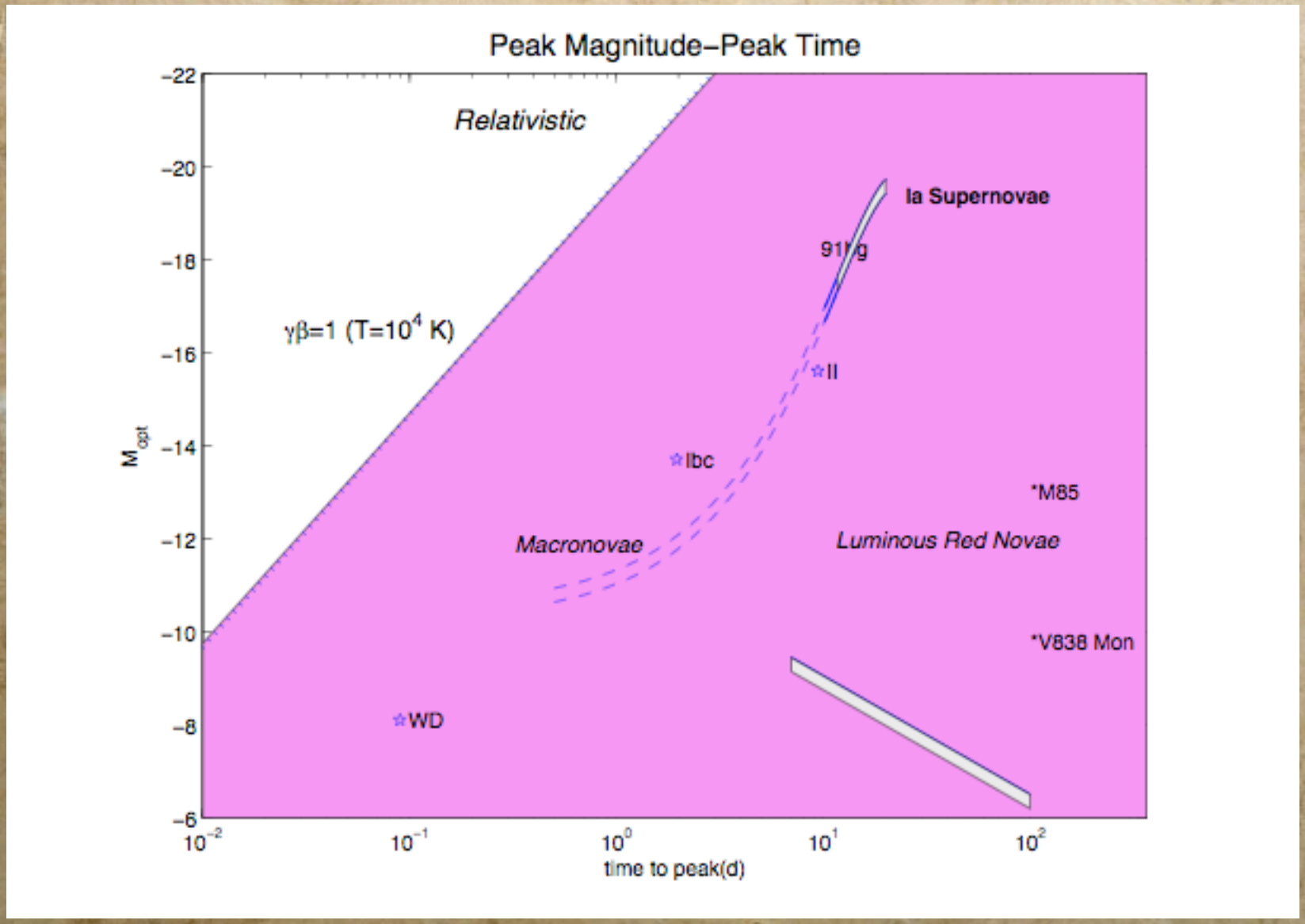
Transients in the Local Universe

An Emerging Field

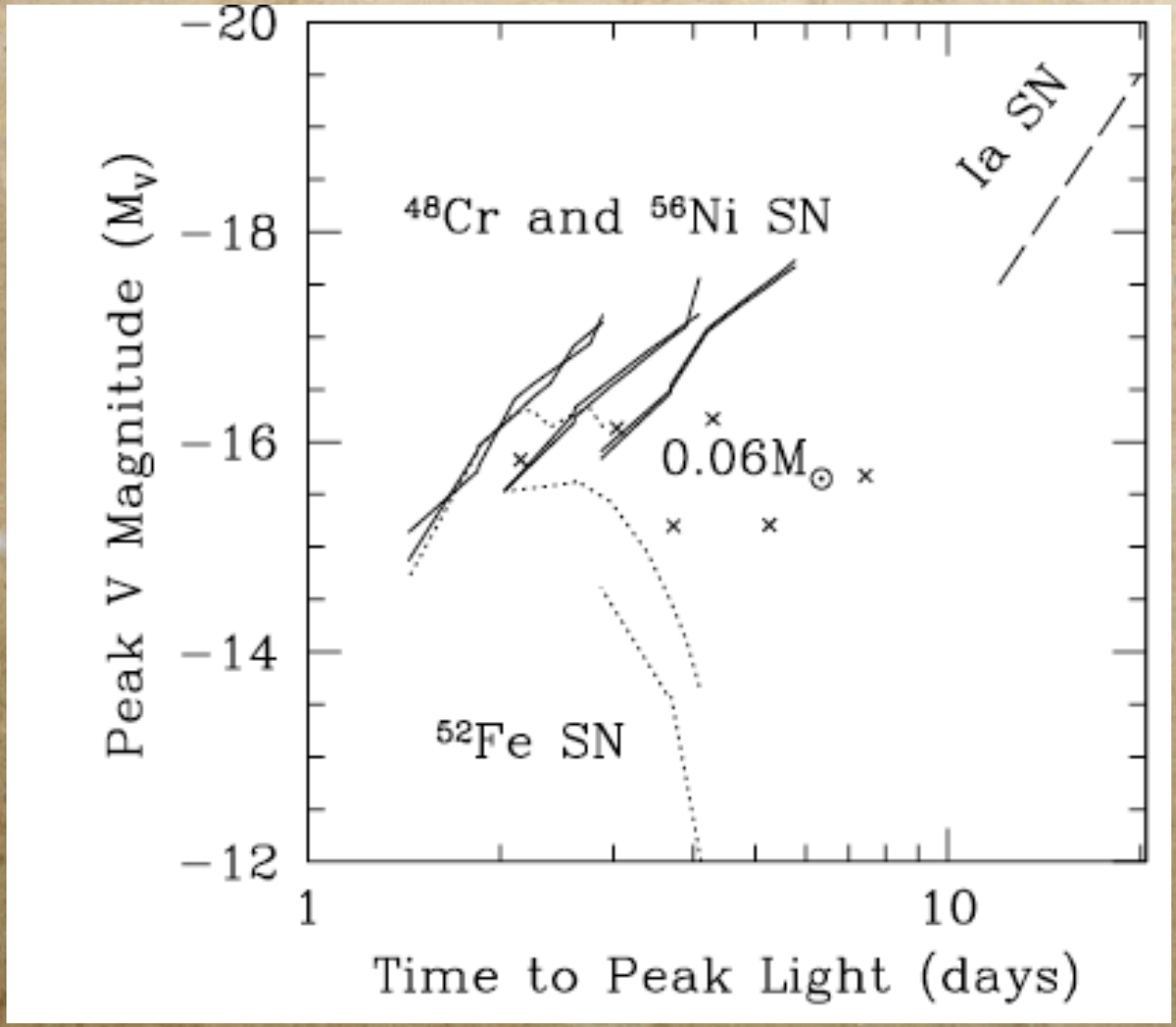
- Ultra-high energy cosmic rays
  - GZK cutoff (proton-pion)
- TeV Sources
  - Pair production on CMB photons
- GW Sources (100 Hz band)
  - Enahanced LIGO (2009)
  - Advanced LIGO (2013)
- Transients in the Nova-Supernova Gap


Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02)
Abell 634 Cluster (0.025)
IRAS dipole
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Orion Molecular Cloud
Taurus Molecular Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
Norma & Great Attractor (0.016)
M31 (1 Mpc)
LMC
Pisces-Cetus Supercluster (0.063)
Fornax Cluster (20 Mpc)
Milky Way Center
Horologium Supercluster (0.067)
Pavo-Indus Supercluster (0.015)
Sculptor Supercluster (0.054)
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004);
familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).
Graphic created by T. Jarrett (IPAC/Caltech)

Focus: Objects in the Nova-Supernova Gap



Helium Flashes (0.1Ia Supernovae)



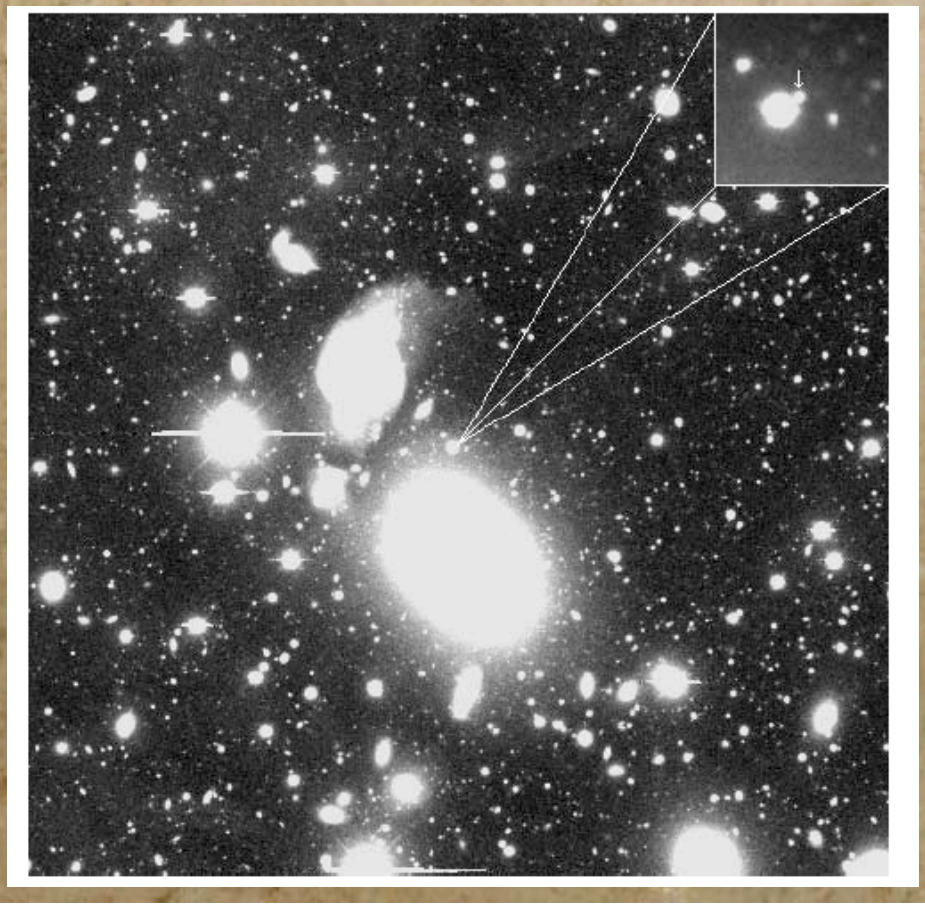
Bildsten et al. 2007

Finding Fast Transients ain't easy

THE DEEP LENS SURVEY TRANSIENT SEARCH. I. SHORT TIMESCALE AND ASTROMETRIC VARIABILITY

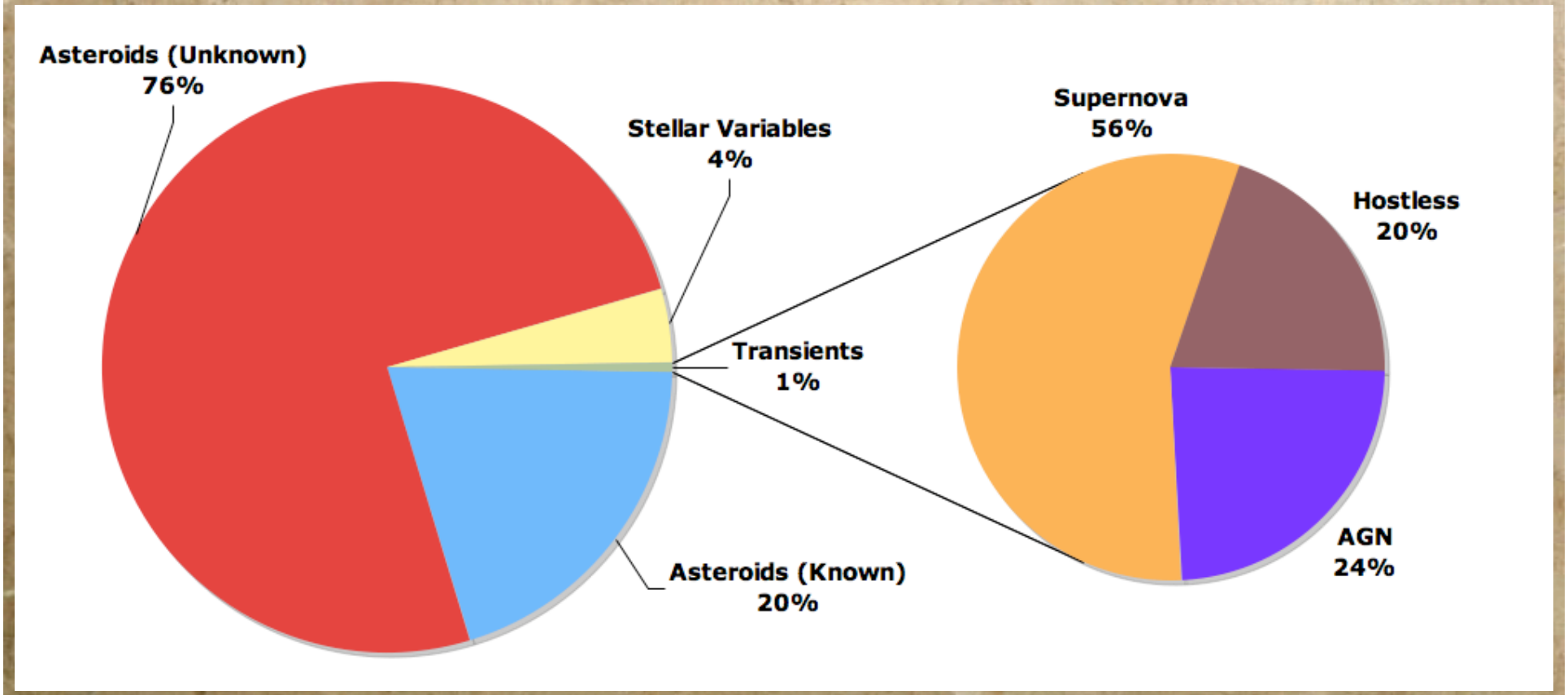
A. C. Becker,[1,2,3] D. M. Wittman,[1,4] P. C. Boeshaar,[4,5] A. Clocchiatti,[6] I. P. Dell'Antonio,[7] D. A. Frail,[8] J. Halpern,[9] V. E. Margoniner,[1,4] D. Norman,[10] J. A. Tyson,[1,4] and R. A. Schommer[11]

Received 2004 March 4; accepted 2004 April 19



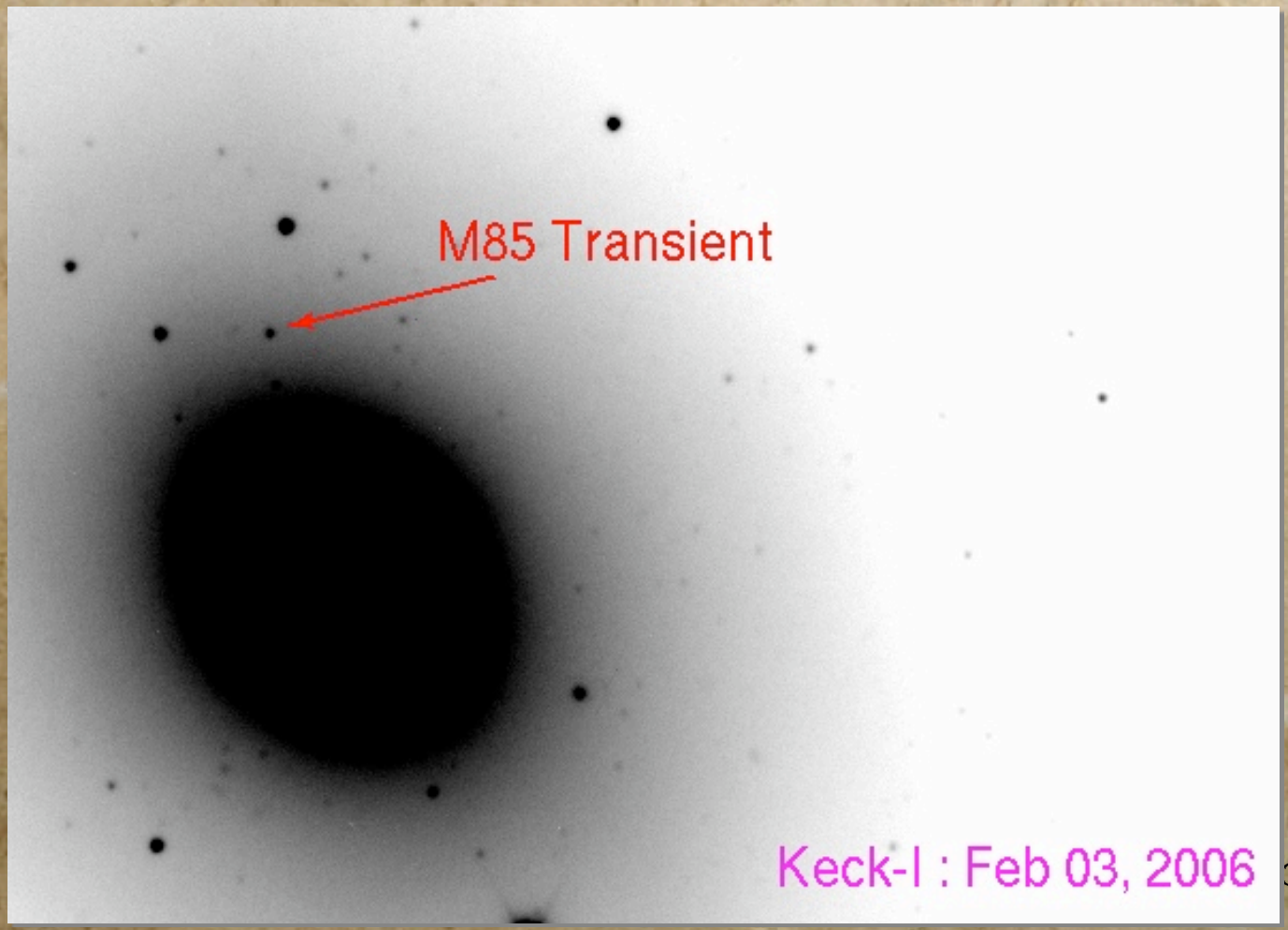
Kulkarni & Rau

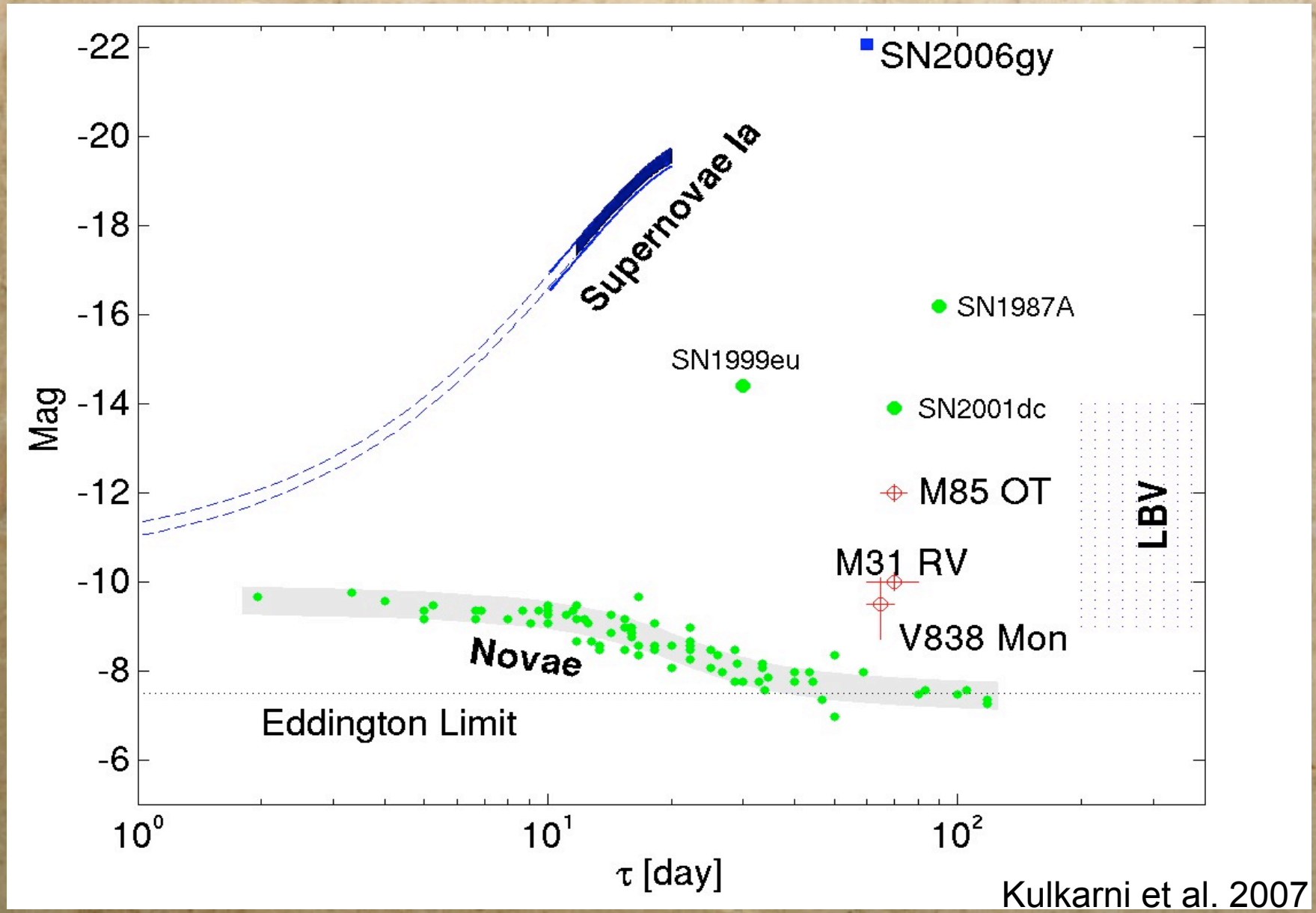
No dearth of Slow Transients either!



Kasliwal

M85 OT2006-1: A Refreshing Start!

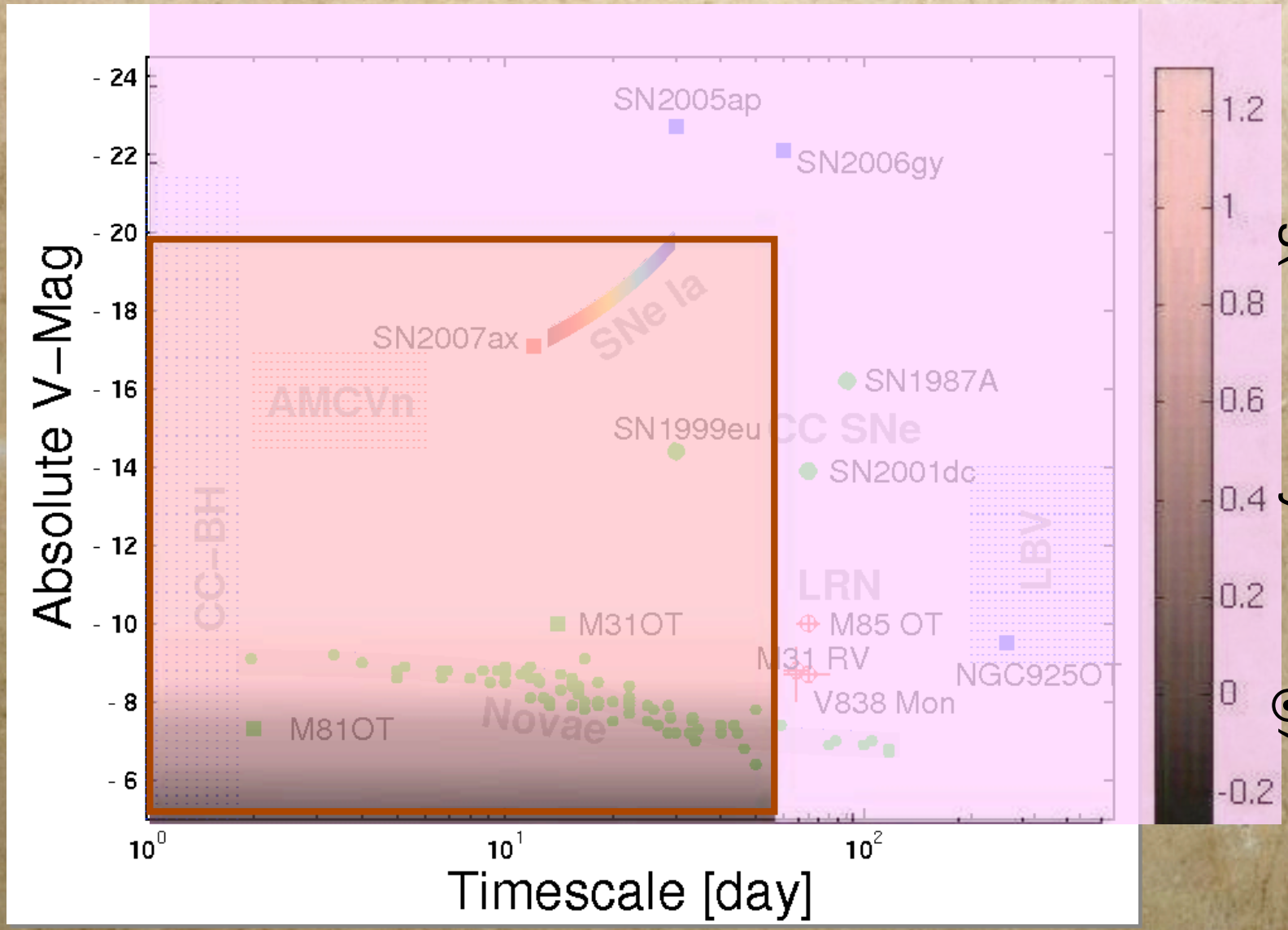




Kulkarni et al. 2007

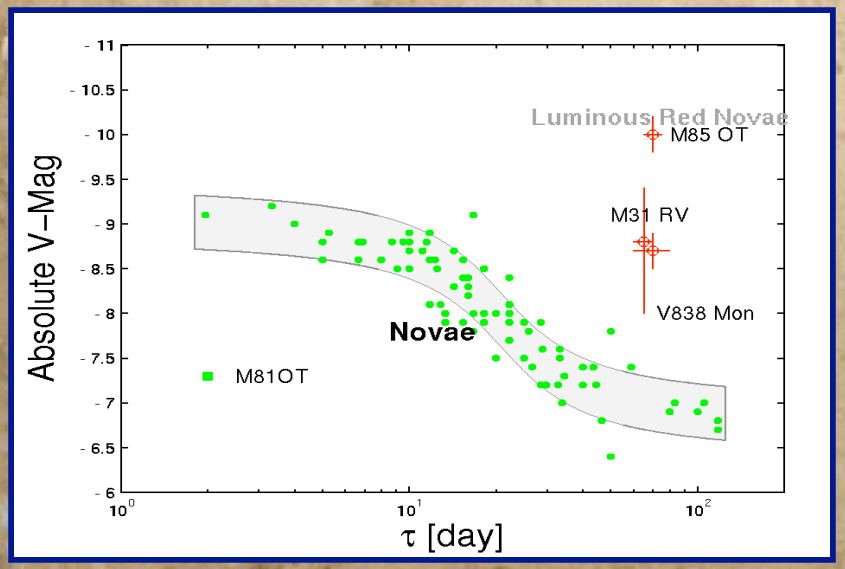
"It's somewhere between a nova and a supernova
... probably a pretty good nova."

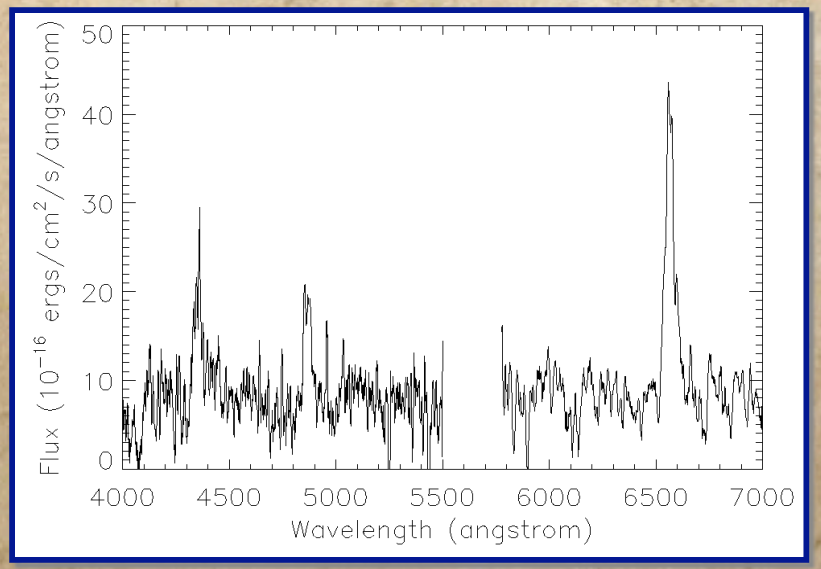
P60-FasTING



Kasliwal

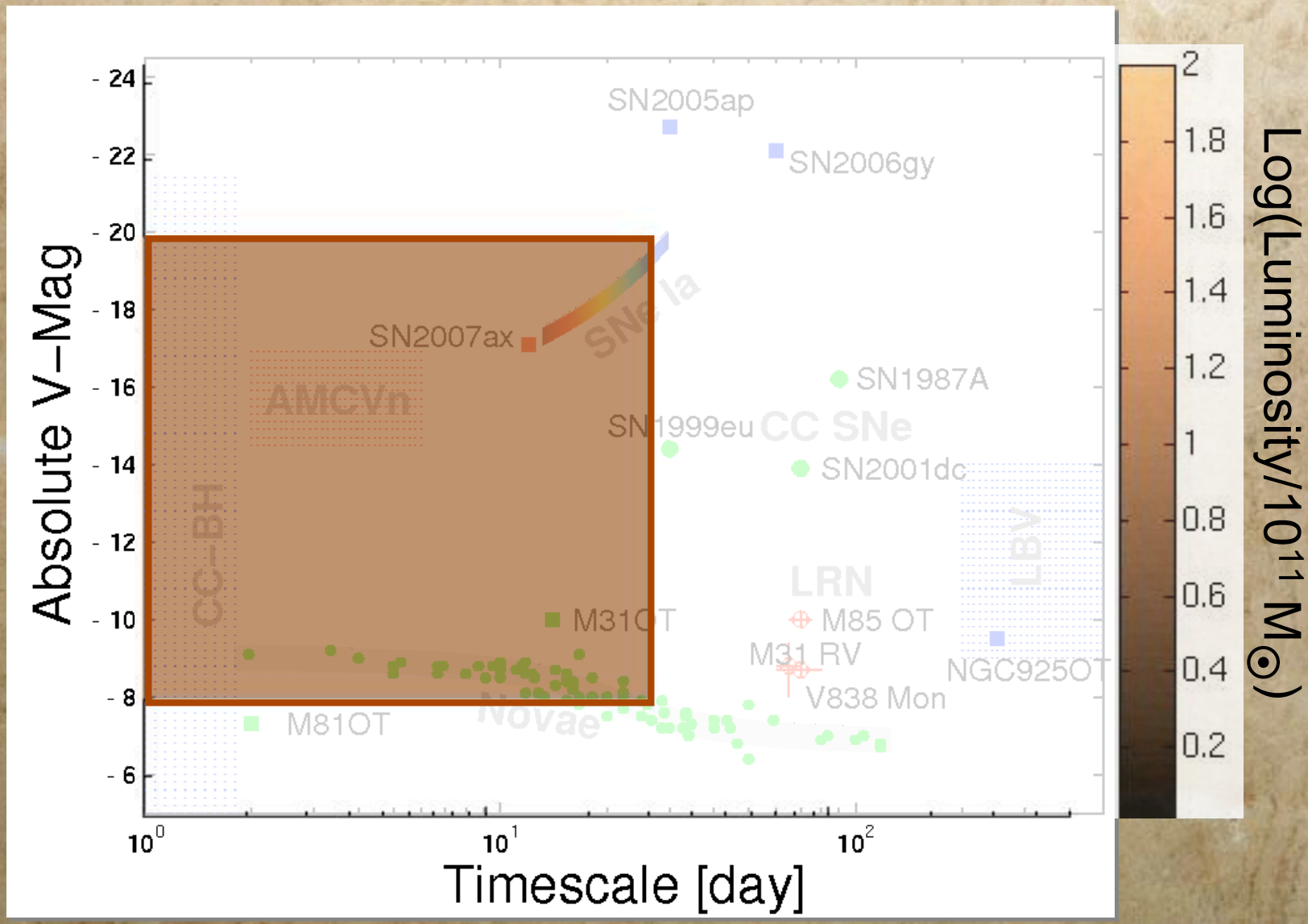
M81OT : A Peculiar Nova



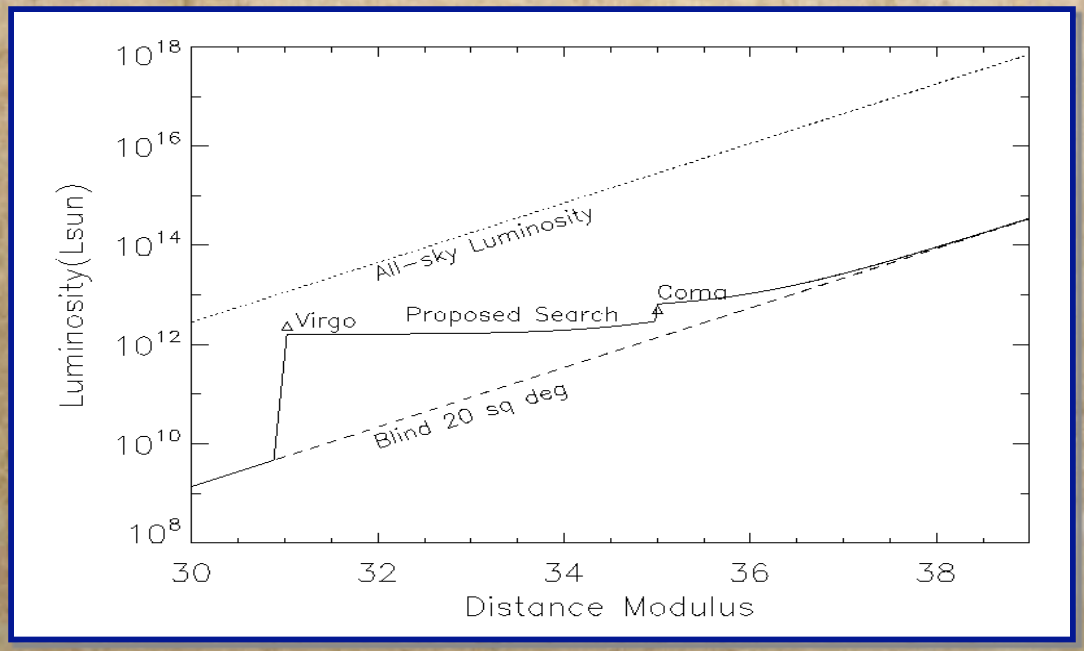


- A clear deviant from the nova relation
- Discovery of nova in M83 (starburst)
- Discovery of new LBVs
  - *Are these progenitors of pair production SNe?*

CFHT-COVET

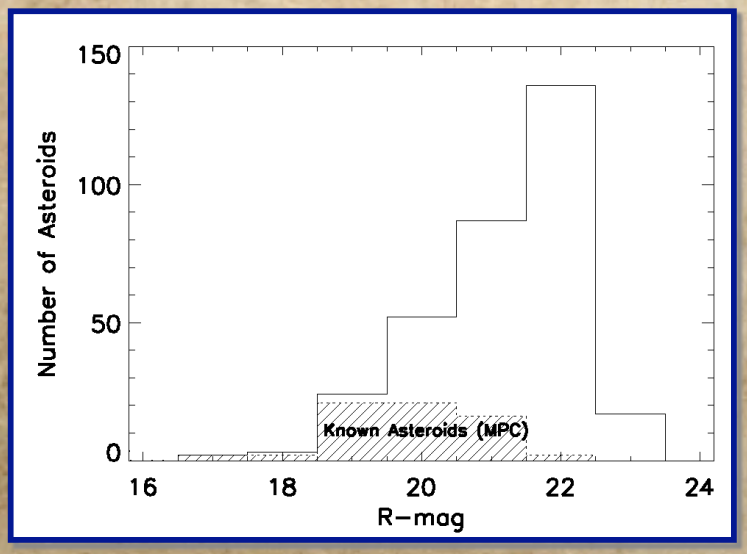

Absolute V−Mag
Timescale [day]
Log(Luminosity/10^11 M⊙)
SN2005ap
SN2006gy
SN2007ax
SNe Ia
AMCVn
SN1987A
SN1999eu
CC SNe
SN2001dc
CC−BH
LBV
LRN
M31OT
M85 OT
M31 RV
NGC925OT
V838 Mon
M81OT
Novae

COMA & VIRGO EXPLORATION FOR TRANSIENTS



- CFHT : 3.6M + MEGACAM: 1 SQ DEG FOV @ 0.18"/PIX
- R-BAND, 60S X 2, DAILY CADENCE, DEPTH R~22
- WHY VIRGO? 25% OF UNIVERSE'S LIGHT @16 MPC IS IN VIRGO!
- PILOT PROJECT (2008): 7 SQ DEG; LARGE PROPOSAL (3 YRS) : 20 SQ DEG
- PILOT PROJECT DISCOVERIES:
  - 7 TRANSIENTS (6 LIKELY SUPERNOVAE) WITH DATA ON 7 NIGHTS ONLY.
- REALTIME REDUCTION PIPELINE : <30MIN

Lessons Learned



- Asteroids : Must be filtered out (Kinetic Signature)
- Galactic M-dwarfs are Pests (Blue, Rapid, Halpha)
- Most "Hostless" transients are Dwarf Novae (Color)
  - *1% are unidentified and new Galactic explosive transients*
  - *1% are entirely unknown*
- Extragalactic Supernovae dominate at faint magnitudes
- AGN not negligible

Key : Robust real-time pipeline and well-defined prompt multiband follow-up strategy

Need a catalog of the local universe

The Palomar Transient Factory


N. Law (Project Scientist)

A. Rau (Book Scientist)

E. Ofek (Cadence Scientist)

R. Quimby (Pipeline Scientist)

IPAC (Archive Center)

P. Nugent (Fast Pipeline)

J. Bloom (Classification & Alert Scientist)

D. Fox (P60 and Followup Scientist)

S. Kulkarni (Principal Investigator)

Palomar Transient Factory

A full end-to-end facility dedicated for transients

Triple cadence surveys

- 1-day cadence
  - AM CVn
  - Peculiar events in nearby galaxies
- 3-day cadence
  - AGN burping & bleating
- 9-day cadence
  - Supernovae

Science Goals

- Supernovae: core collapse
  - Anonymous (lower metalicity) host galaxies
  - Systematic study of Ib and Ic supernovae
  - Rare types of supernovae (IIn, underluminous)
- Supernovae: Ia
  - Cosmology (luminosity function at z=0)
- Catch supernovae at very early times

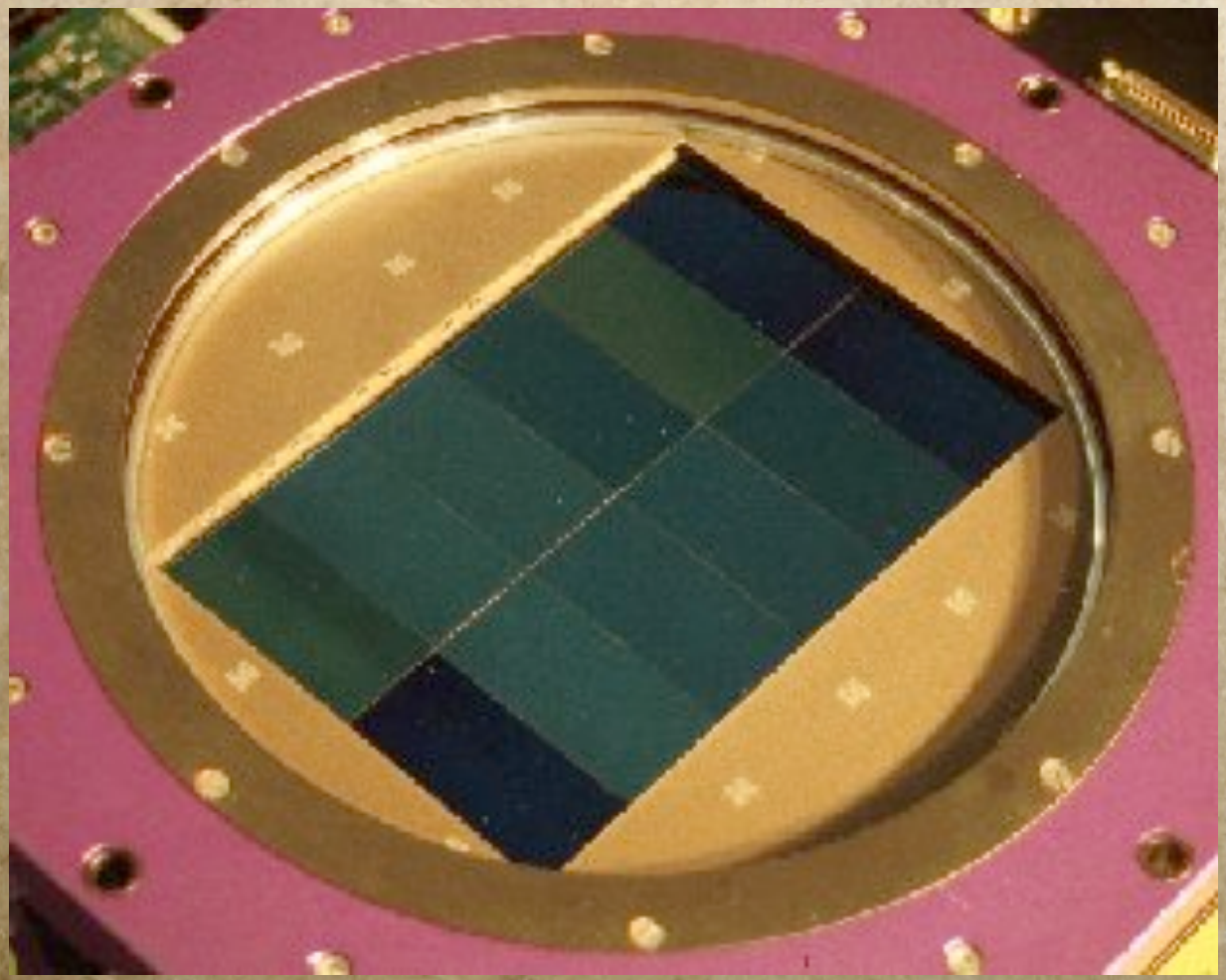
Science Goals

- Transients in nearby galaxies
  - Novae
  - Luminous red novae
  - LBV outbursts
  - Other events (AIC, coalescence, CE, 0.1Ia)
- Nuclear Black Holes:
  - blazing
  - burping
  - tidal events

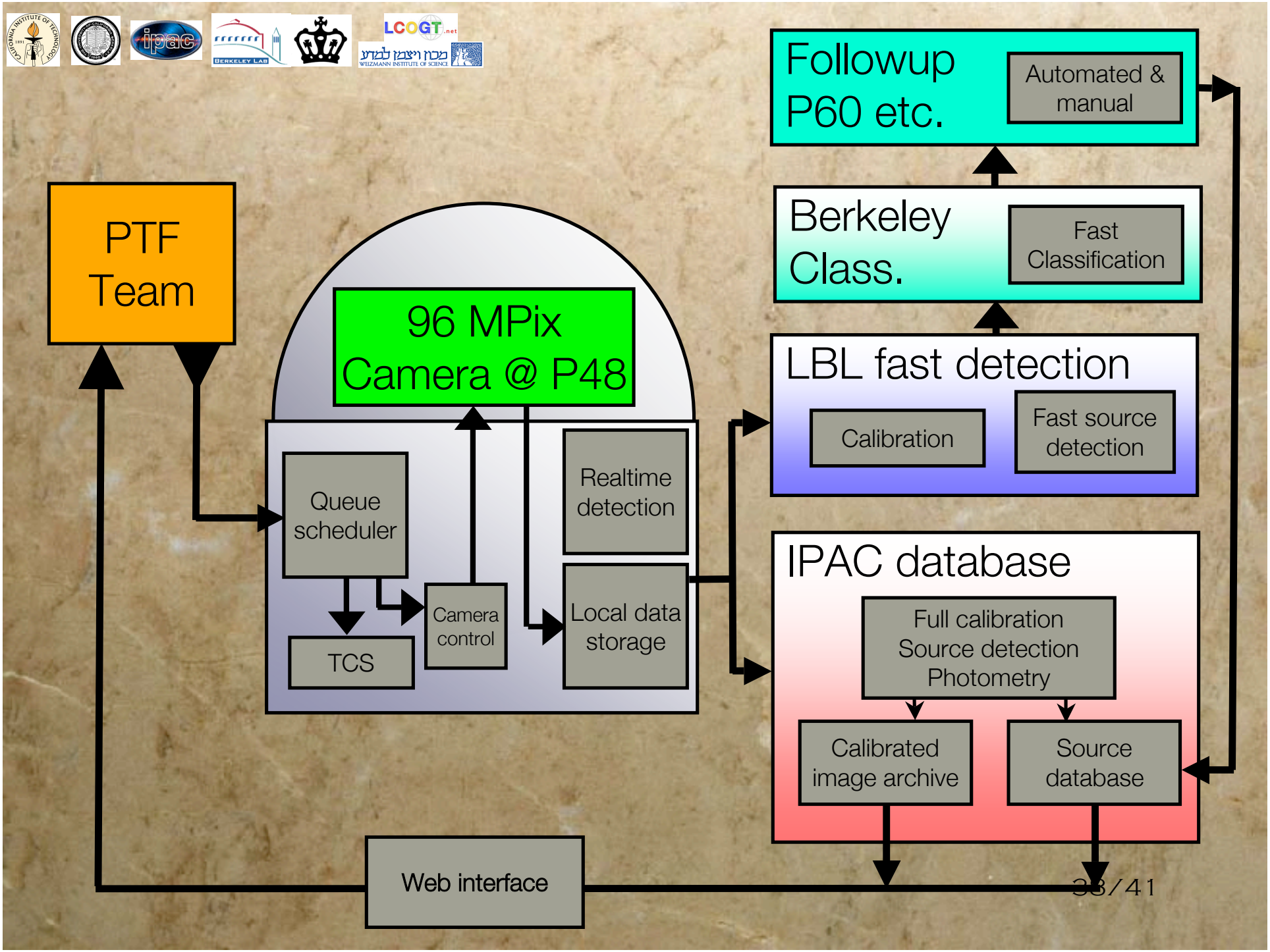
Science Goals

- Galactic Transients:
  - AM CVn
  - Hibernating CVs (and dwarf novae)
  - Flare stars
  - Pre-main sequence stars
  - Planetary Transits

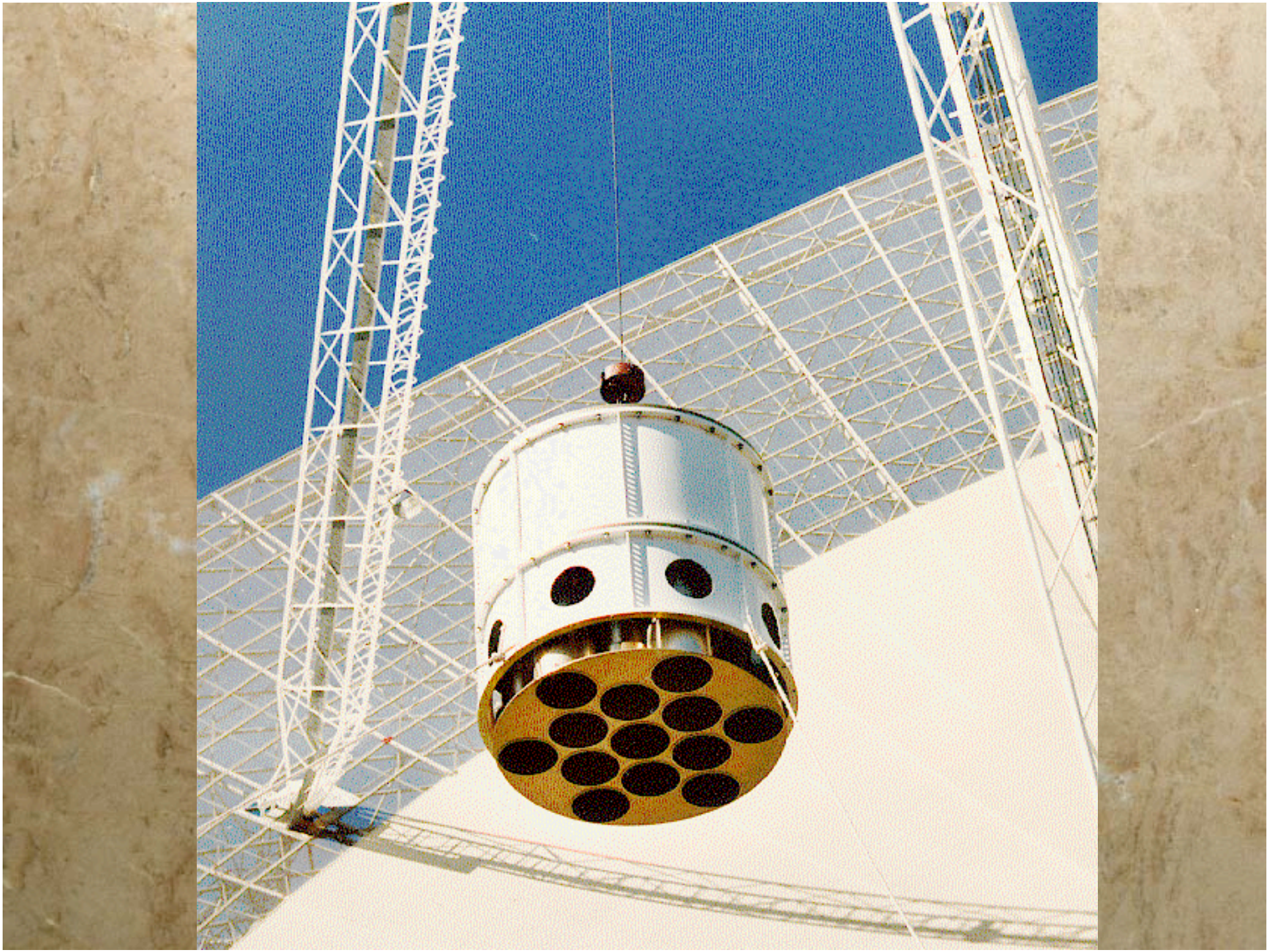
CFH12K Detector

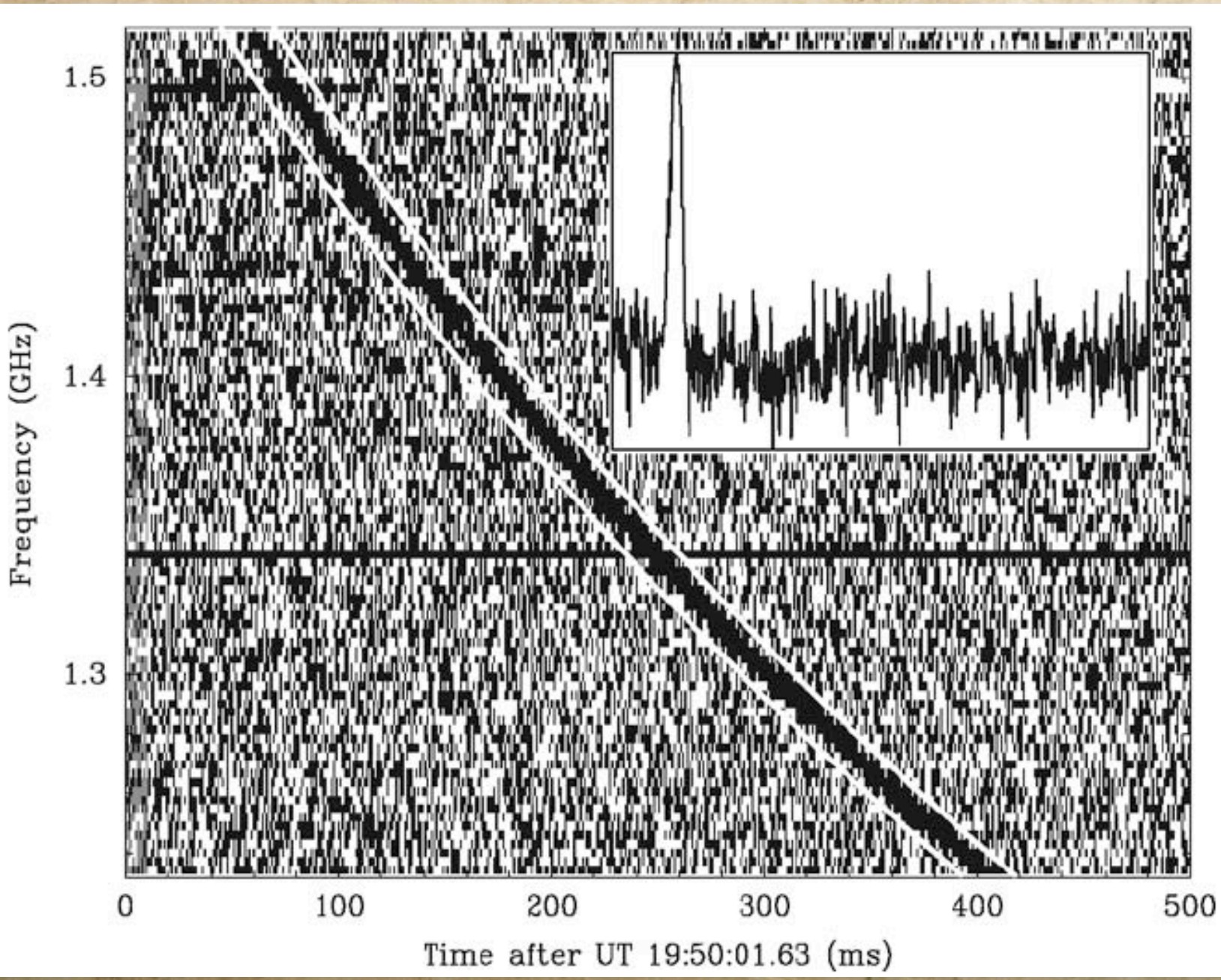


At Caltech now ….


PTF Team
96 MPix Camera @ P48
Queue scheduler
TCS
Camera control
Realtime detection
Local data storage
Followup P60 etc.
Automated & manual
Berkeley Class.
Fast Classification
LBL fast detection
Calibration
Fast source detection
IPAC database
Full calibration
Source detection
Photometry
Calibrated image archive
Source database
Web interface

II. Highly Multiplexed Imaging at Radio Wavelengths

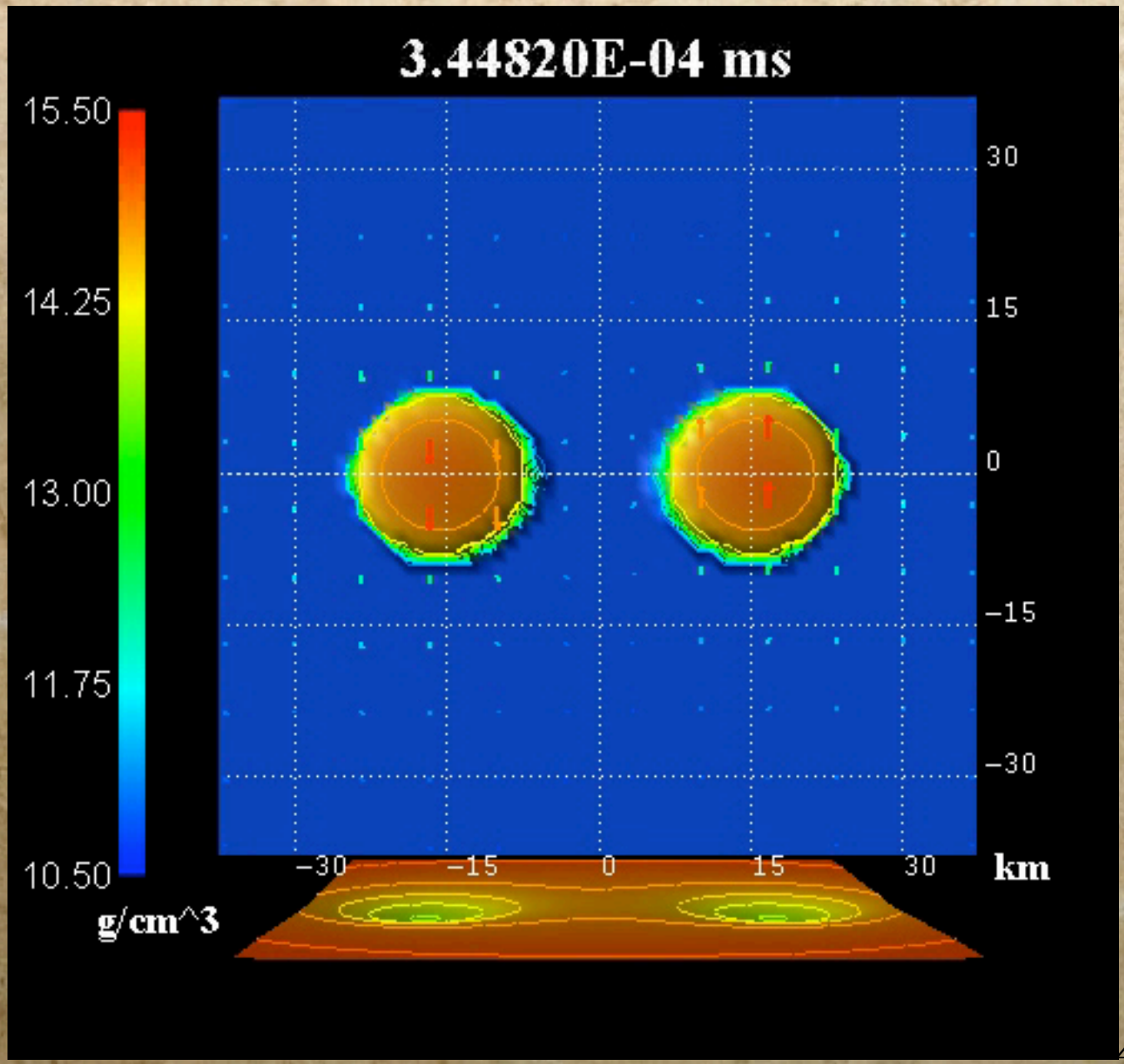



1.5
1.4
1.3
Frequency (GHz)
0
100
200
300
400
500
Time after UT 19:50:01.63 (ms)

Sparkers cannot come from cataclysmic events

Class	Type	Φ $\mathrm{Gpc^{-3}\,yr^{-1}}$	Ref
LSB (low)	BC	100–1800	[1,2]
LSB (high)	Obs	1	[1]
	BC	100–550	[1]
SHB	Obs	> 10	[3]
	BC	$< 10^5$	[3]
SGR	Obs	$< 1.5 \times 10^4$	[4]
In-spiral	Th	3×10^3	[5]
Core Collapse	Obs	3×10^5	[6,7]
Sparkers	Obs	$73–2.7 \times 10^5$	[8]

III. New Messengers

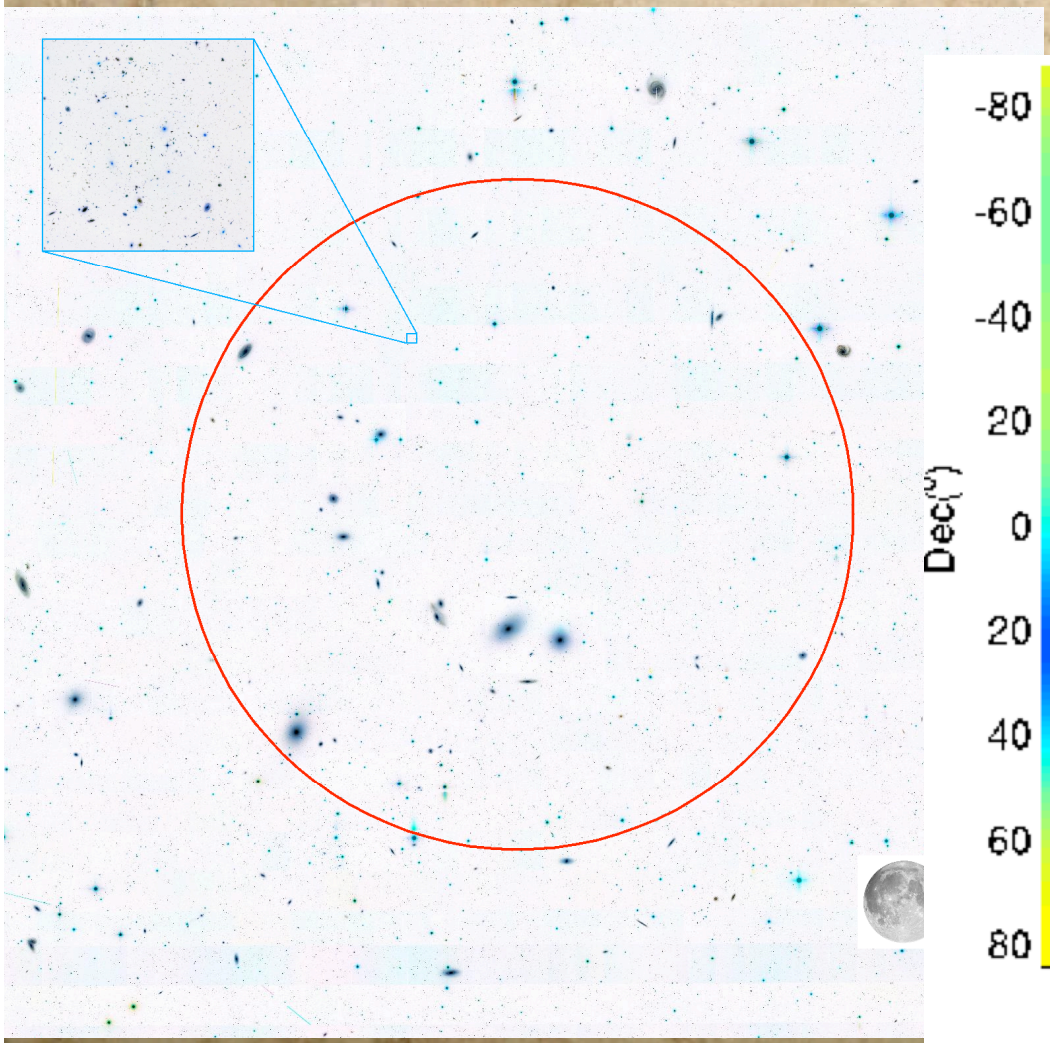

3.44820E-04 ms
15.50
14.25
13.00
11.75
10.50
g/cm^3
30
15
0
−15
−30
−30
−15
0
15
30
km

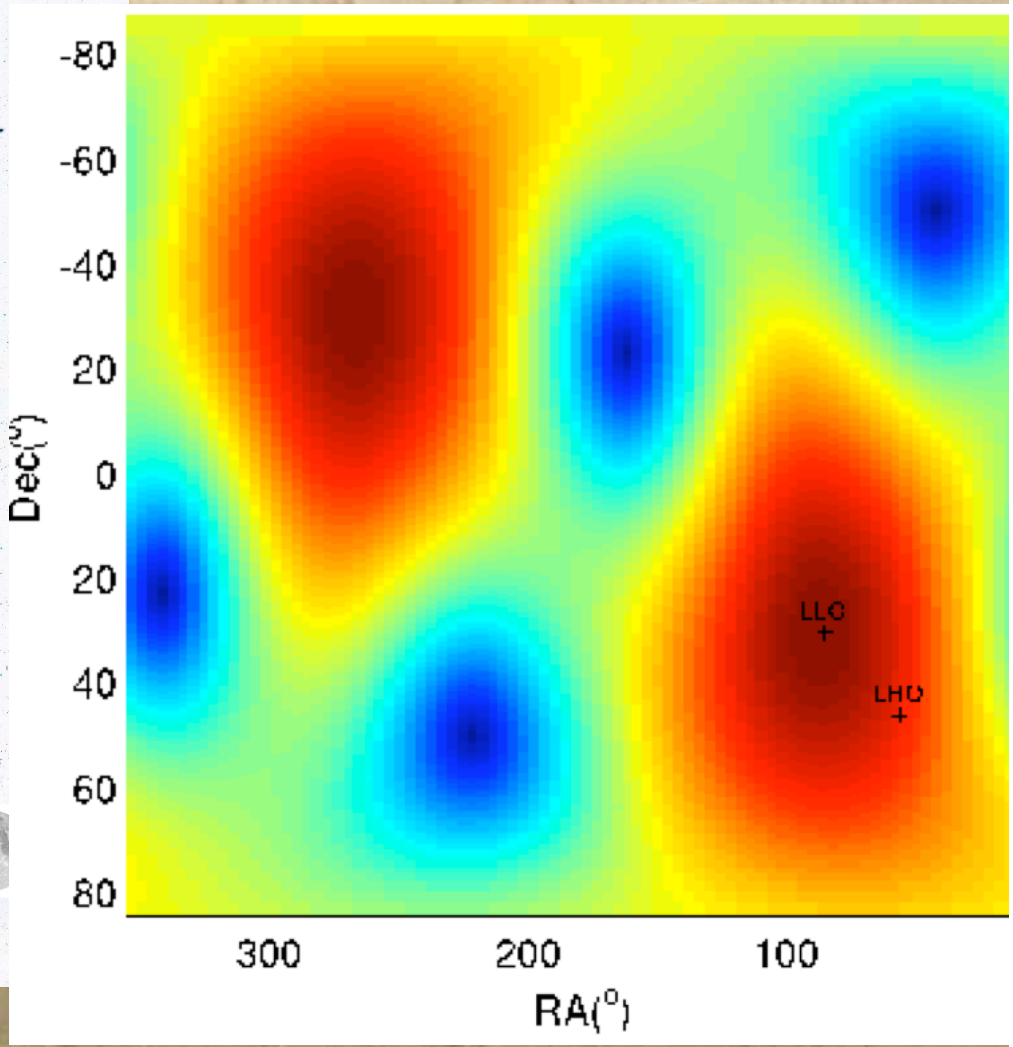
Macronova Model

- Parameters: M_{ejecta} & $v=\beta c$
- Composition
  - Free Neutrons
  - Radioactive Nickel
  - Neutron Rich Material (non-radioactive)
- Injection of energy essential for macronova to shine and be detectable

Li & Paczynski (1998)
Kulkarni (2005)

Gravitational Wave Observatories




-80
-60
-40
20
0
20
40
60
80
Dec(°)
LLO
LHO
300
200
100
RA(°)


End

What do you know?

RUMSFELD

‘‘Reports that say that something that has not happened is always interesting to me...

The message is that there are known knowns, there are things we know that we know.

There are known unknowns, that is to say there are things that we now know we don’t know.

But there are also unknown unknowns, there are things we do not know we don’t know and each year we discover a few more of the unknown unknowns.’’

Mr. Donald Rumsfeld, Department of Defense new briefing

In Summary:
There really are many "Unknown Unknowns" in the sky