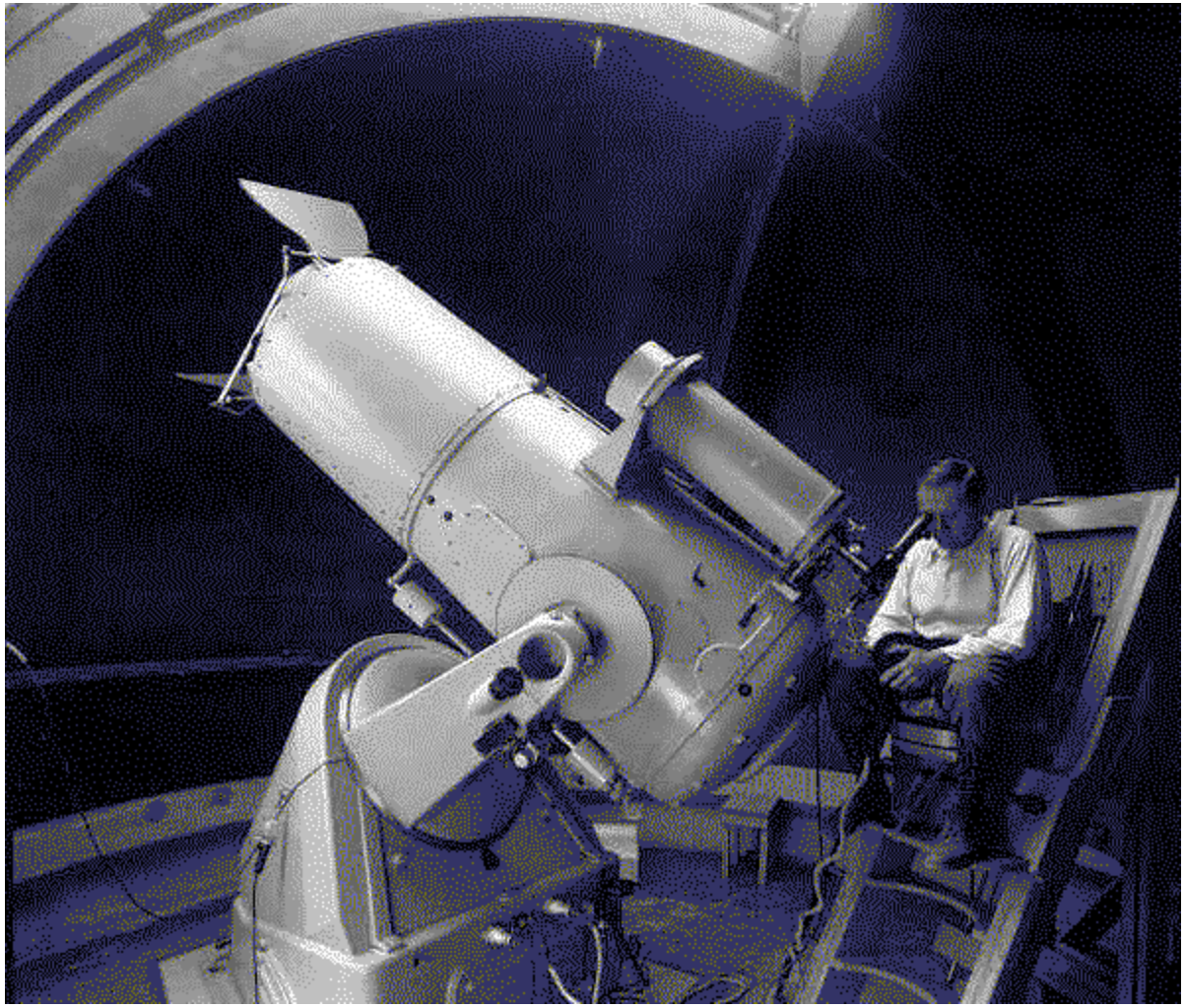
# Bumps, Burps & Booms in the Skies

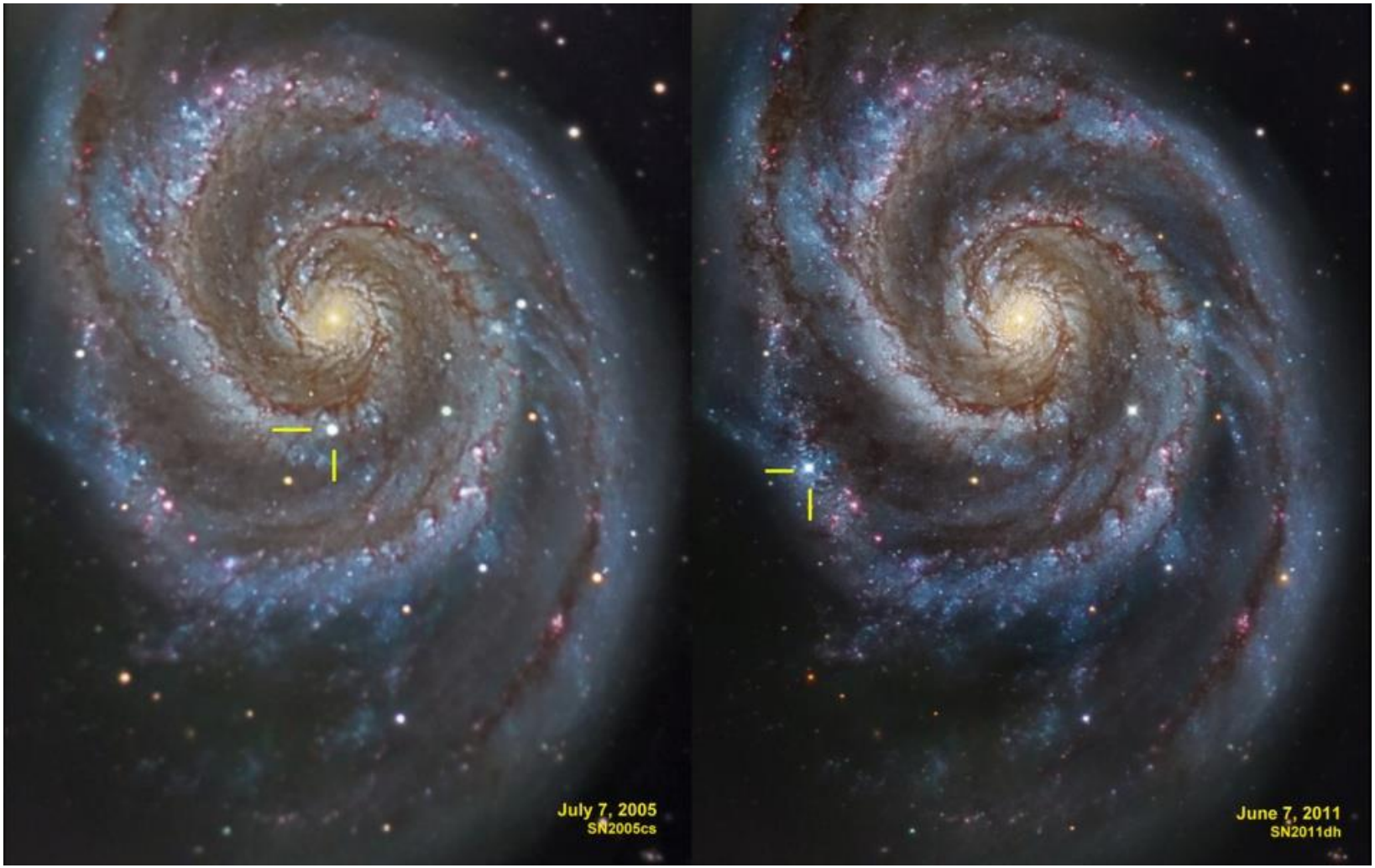

Source: APOD, NASA

# The Palomar Observatory

# Fritz Zwicky (1889-1974)

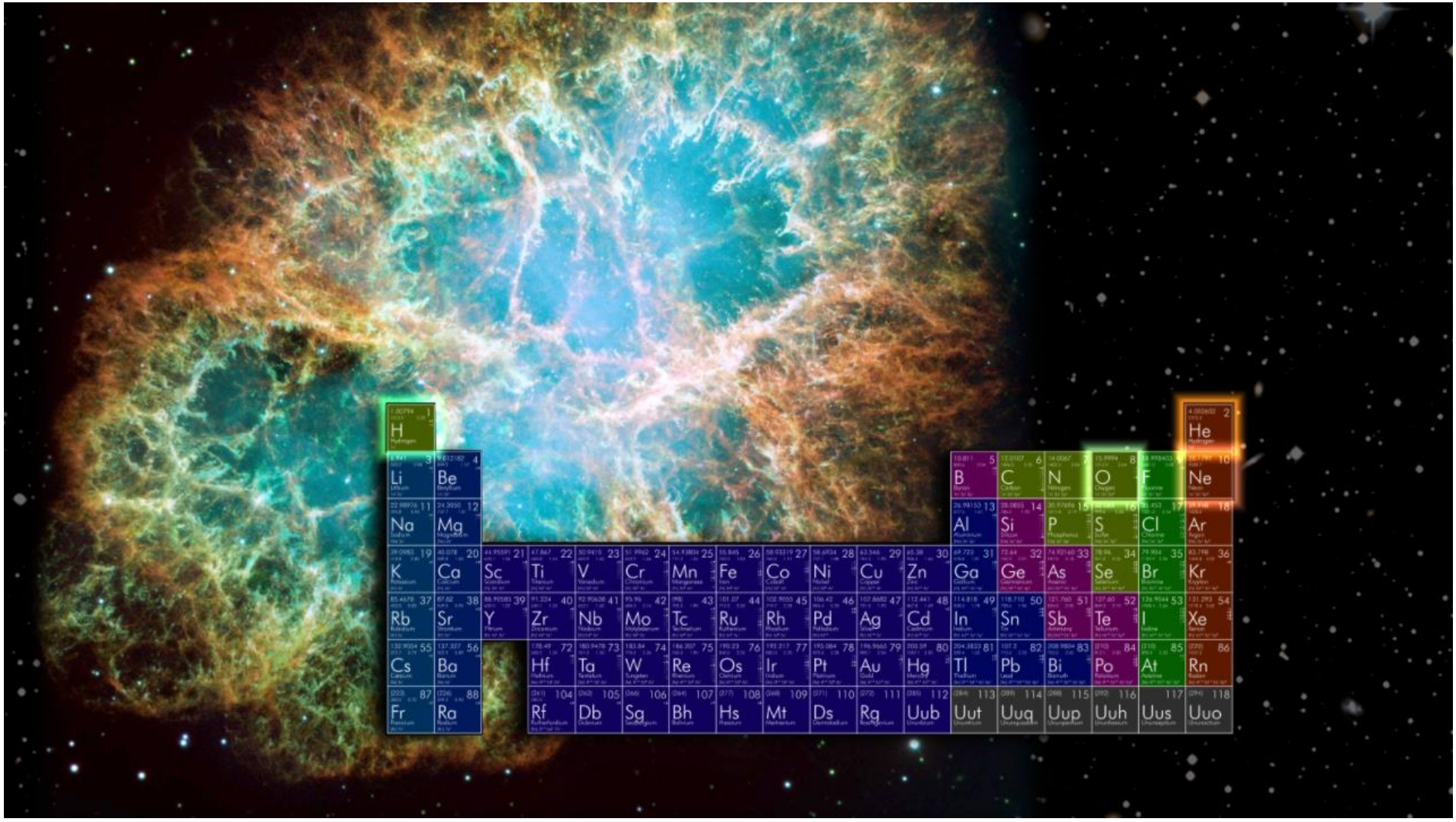


# A Star Dies: A Supernova is born




Astronomy Picture of the Day (NASA)

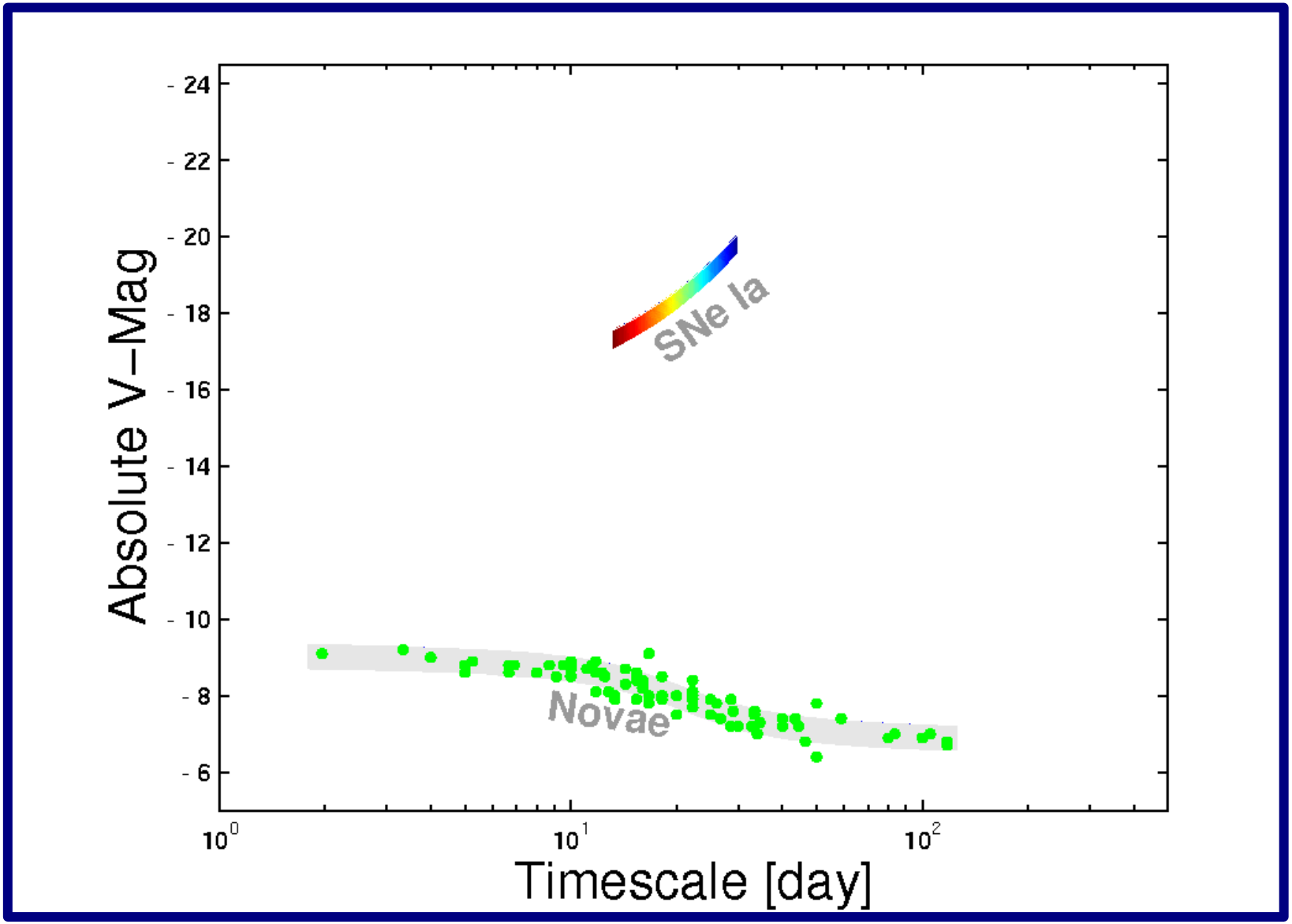
# “Metals”=Stellar Ashes




Credit: NASA

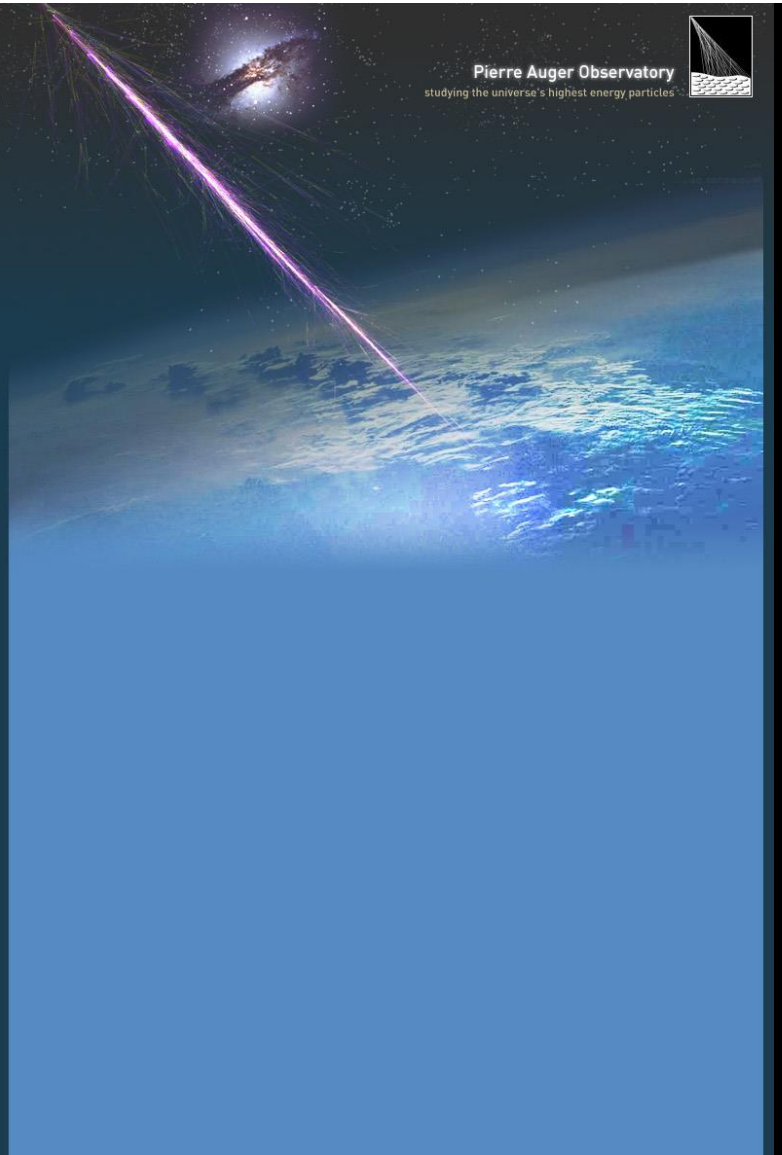
# II. GO AND FIND NEW AND WEIRD STUFF
# (“PHASE SPACE EXPLORATION”)

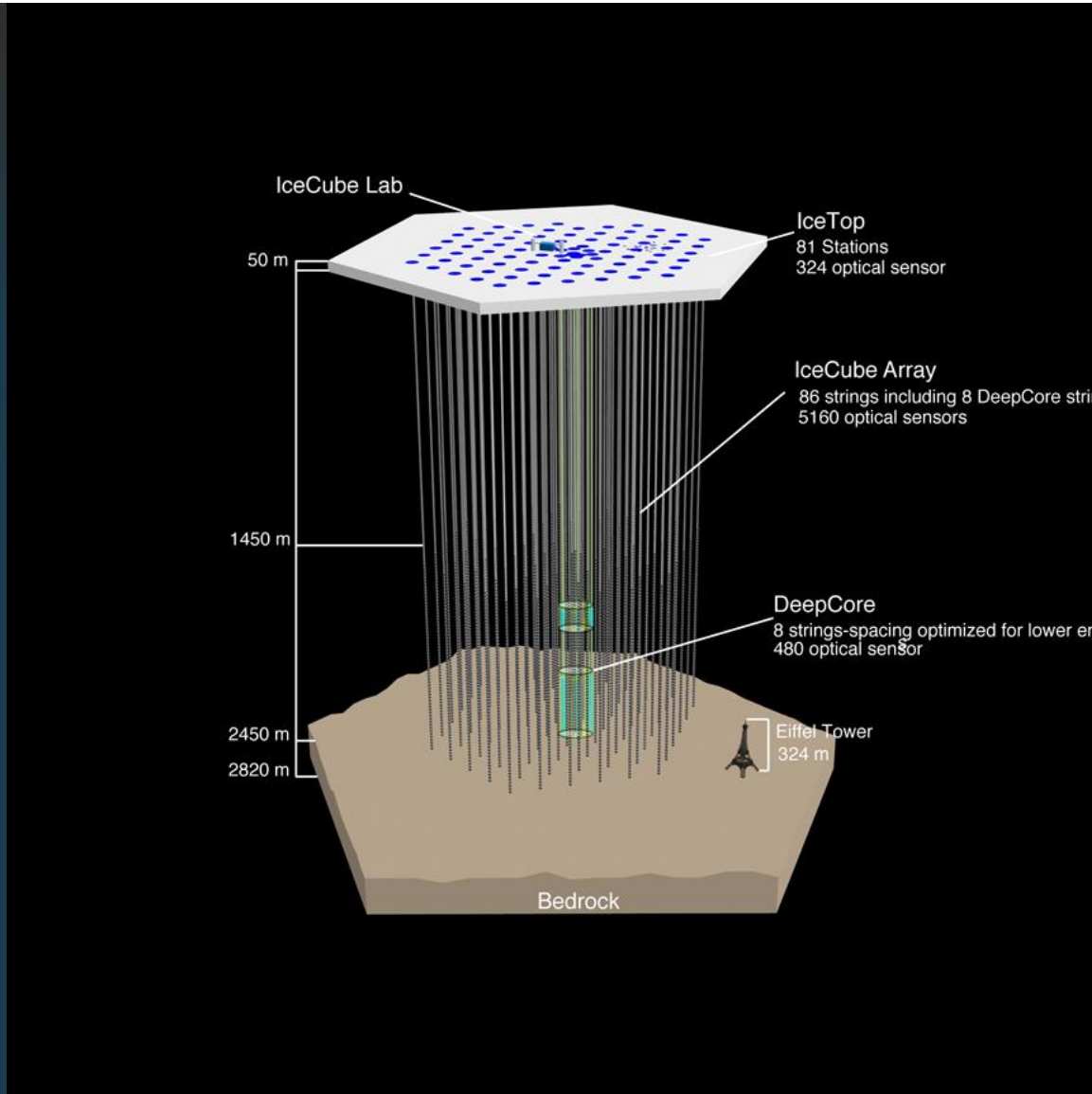
# “Phase Space”


Absolute V–Mag
- 24
- 22
- 20
- 18
- 16
- 14
- 12
- 10
- 8
- 6
SNe Ia
Novae
$10^0$
$10^1$
$10^2$
Timescale [day]

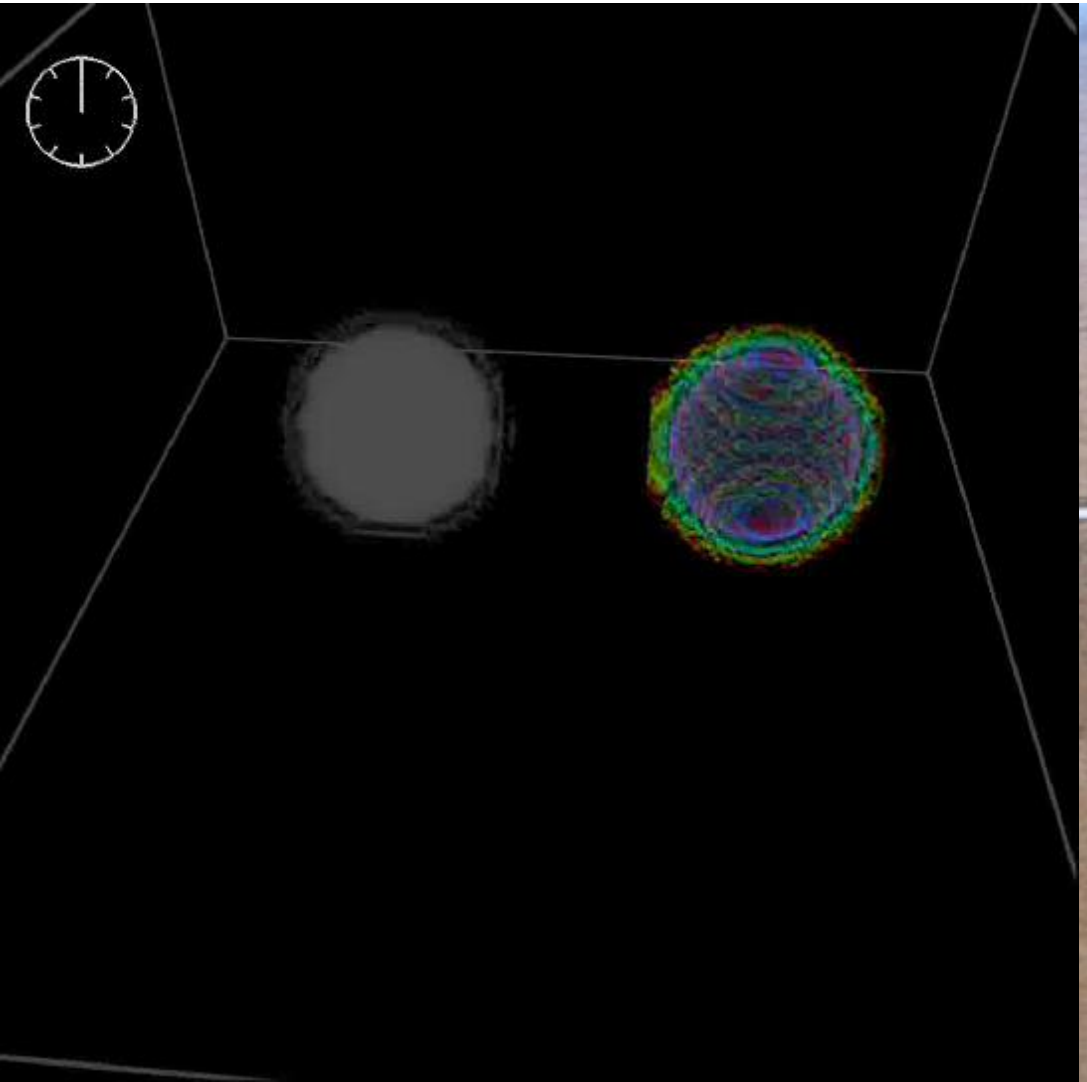
# III. FRONTIER AREAS OF ASTRONOMY & PHYSICS

# Frontier Area: Energetic Particles

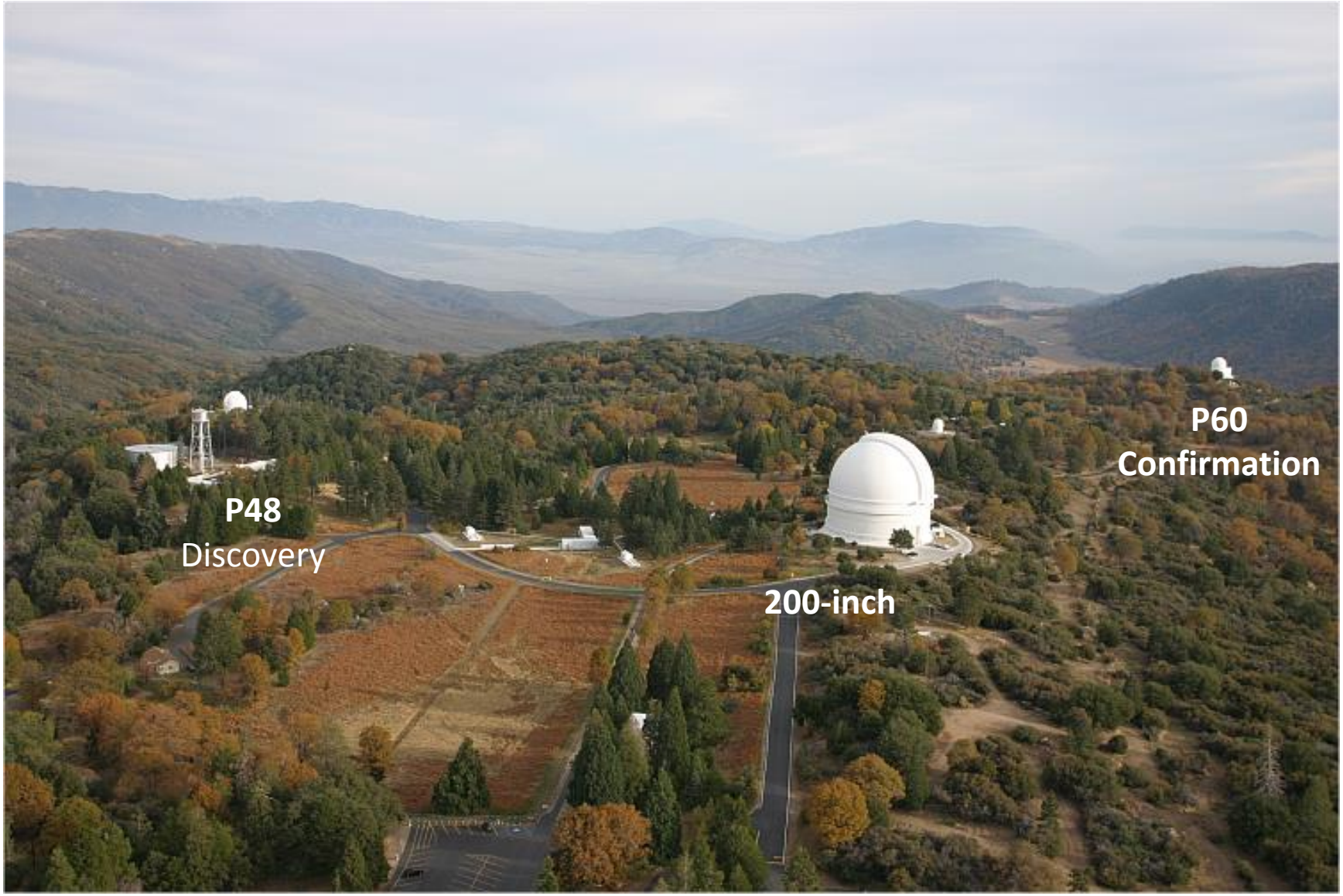


# Frontier Area: Gravitational Waves



# The Palomar Transient Factory (Systematic Exploration of the Skies)


P48
Discovery
200-inch
P60
Confirmation

Credit: UCSB

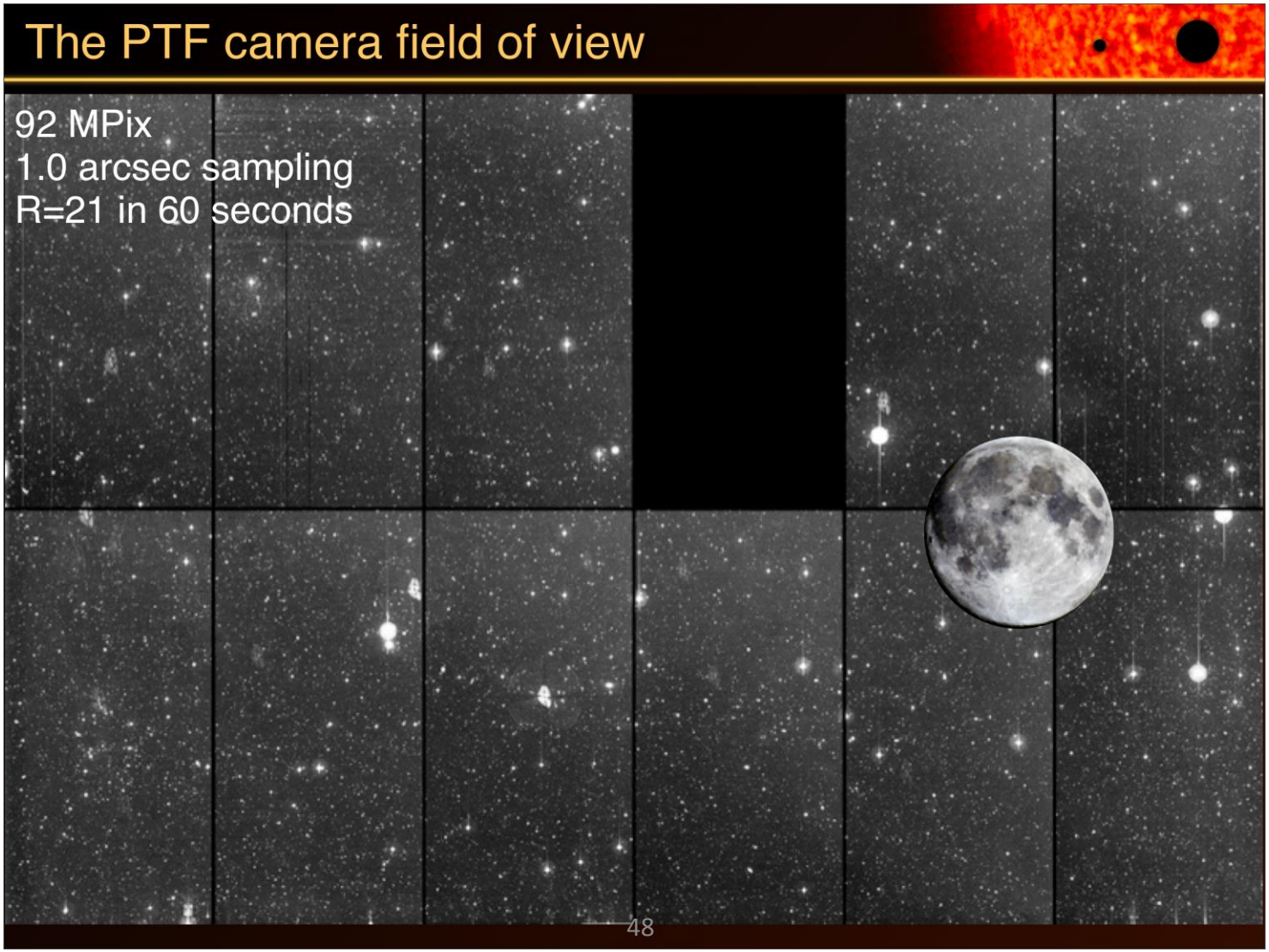
Santa Barbara Independent WHO. WHAT. NOW.

Paul Wellman

Wayne Rosing at Las Cumbres Observatory Global Telescope Network.

# Google Mastermind Turns to the Stars

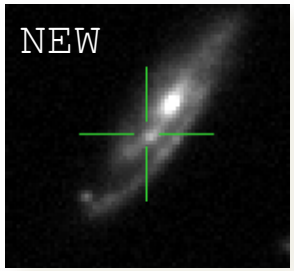
# Hardware

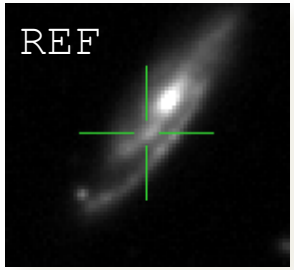

The PTF camera field of view
92 MPix
1.0 arcsec sampling
R=21 in 60 seconds

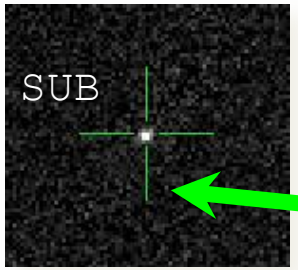
# Gray-ware

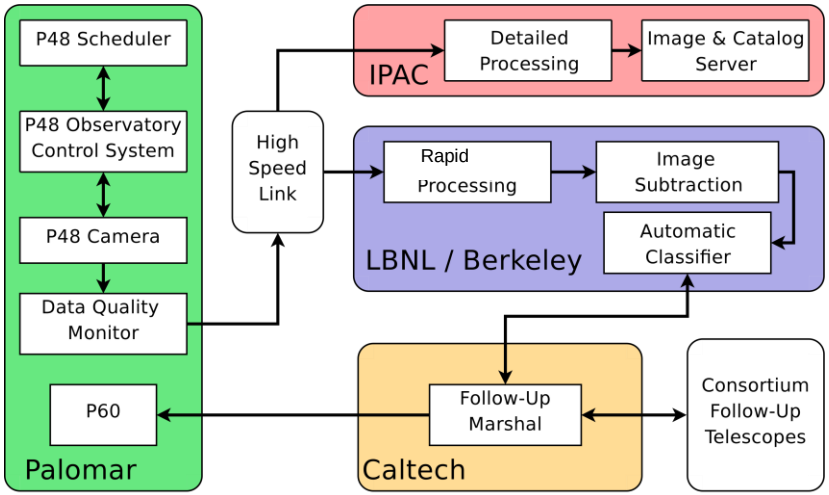

PI:
Shri Kulkarni
Project Scientist:
Nicholas Law
ipac
BERKELEY LAB
LCOGT.net
WEIZMANN INSTITUTE OF SCIENCE
Software Lead
Robert Quimby
COO Hardware
Richard Dekany
Robot Wrangler
Eran Ofek
LBNL Pipeline
Peter Nugent
IPAC Pipeline
Jason Surace
Machine Learning
Josh Bloom

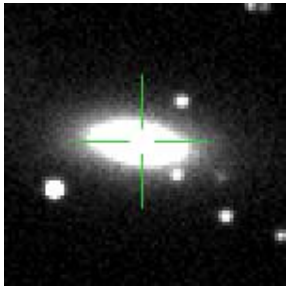
# Software, software & more software

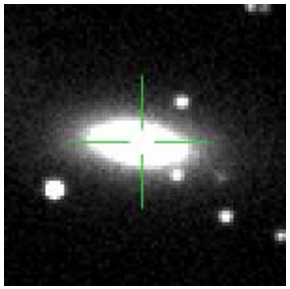


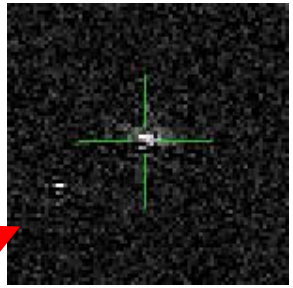







Time from exposure to candidates in the subtraction database: **20 - 40 minutes**

Supernova, good!

Subtraction artifacts, bad!

# IPAC images & catalogue pipeline

Lead by J. Surace

★ Data products:

Reduced images

~100TB per year

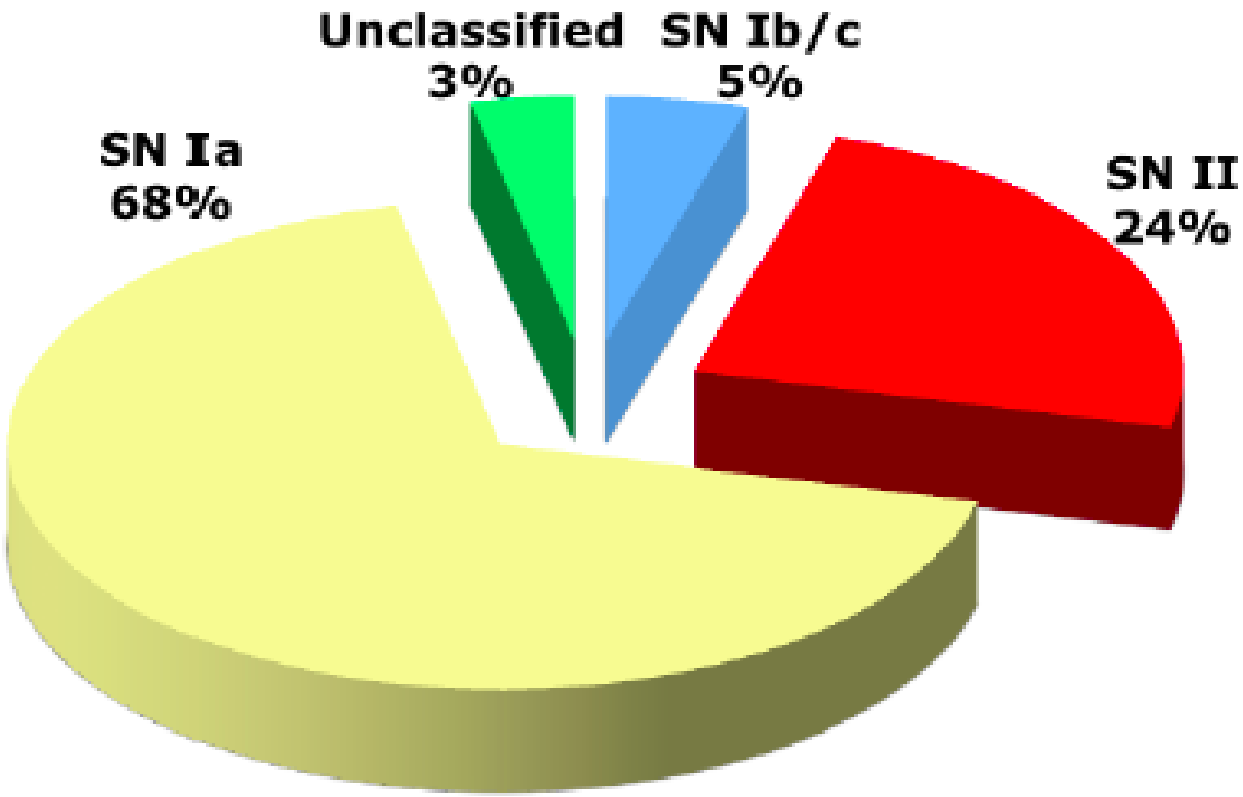
Catalogue

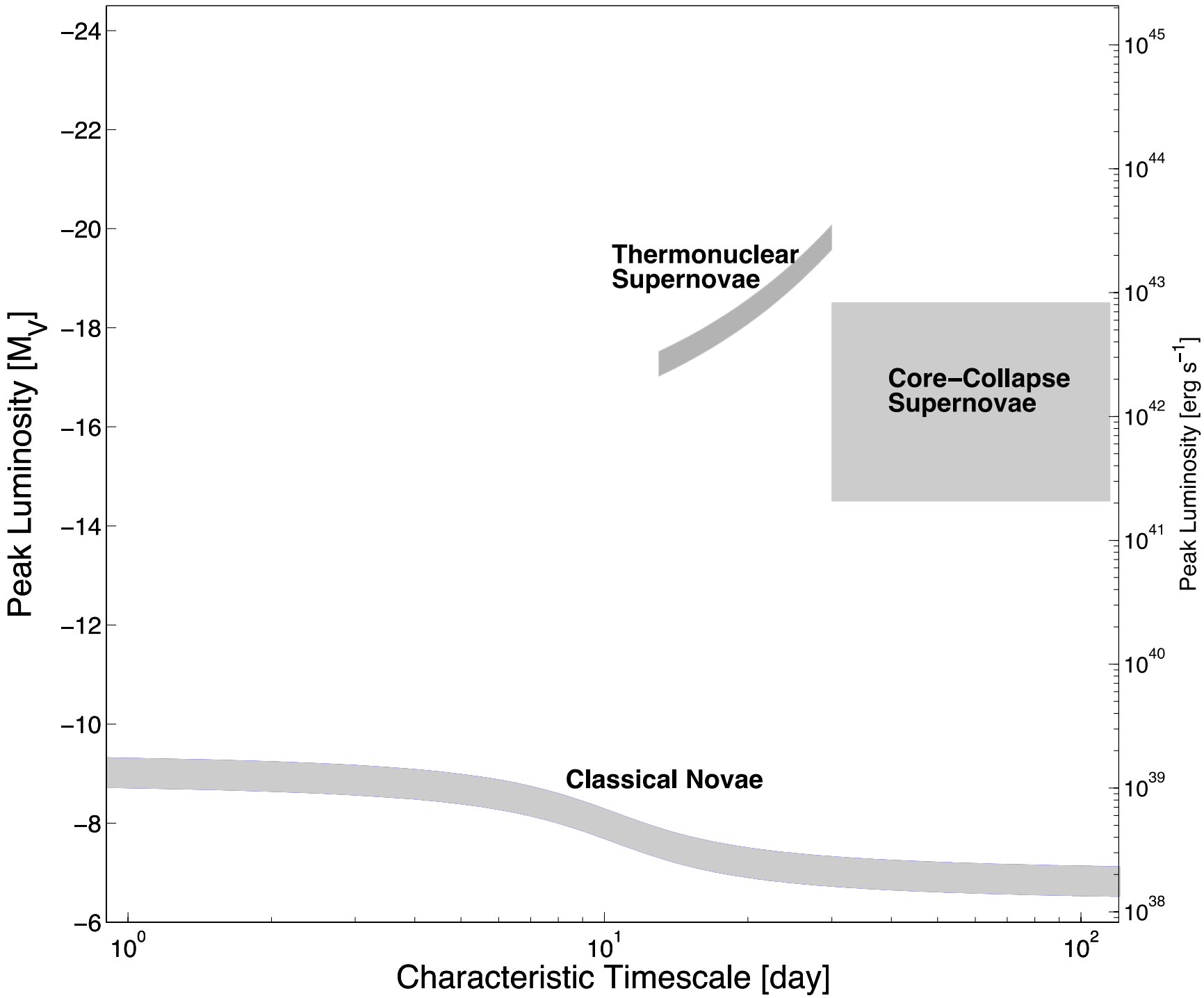
~$10^{12}$ sources per year (10 TB)

# An Explosion of Explosions

# PTF haul (to date)

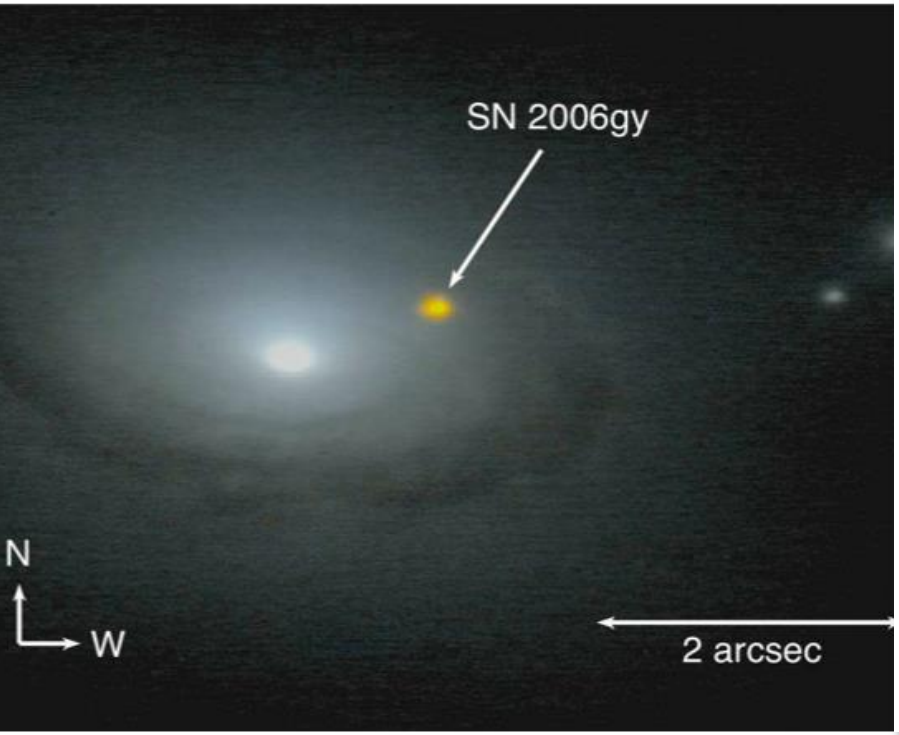
2234

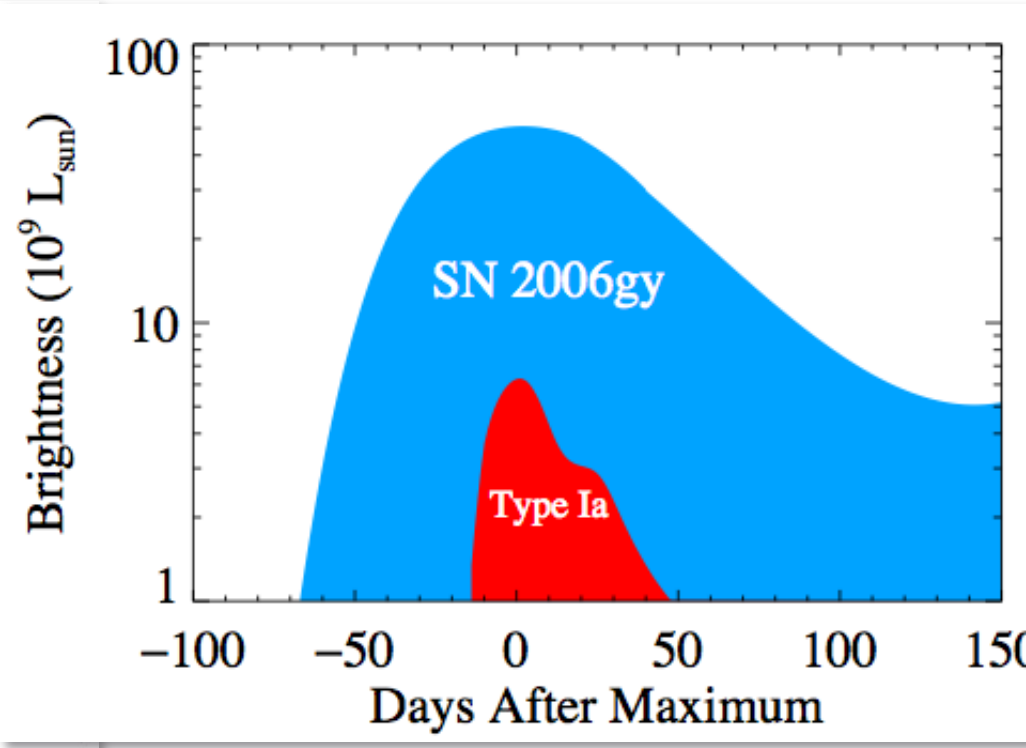





Kasliwal 2011 (PhDT)

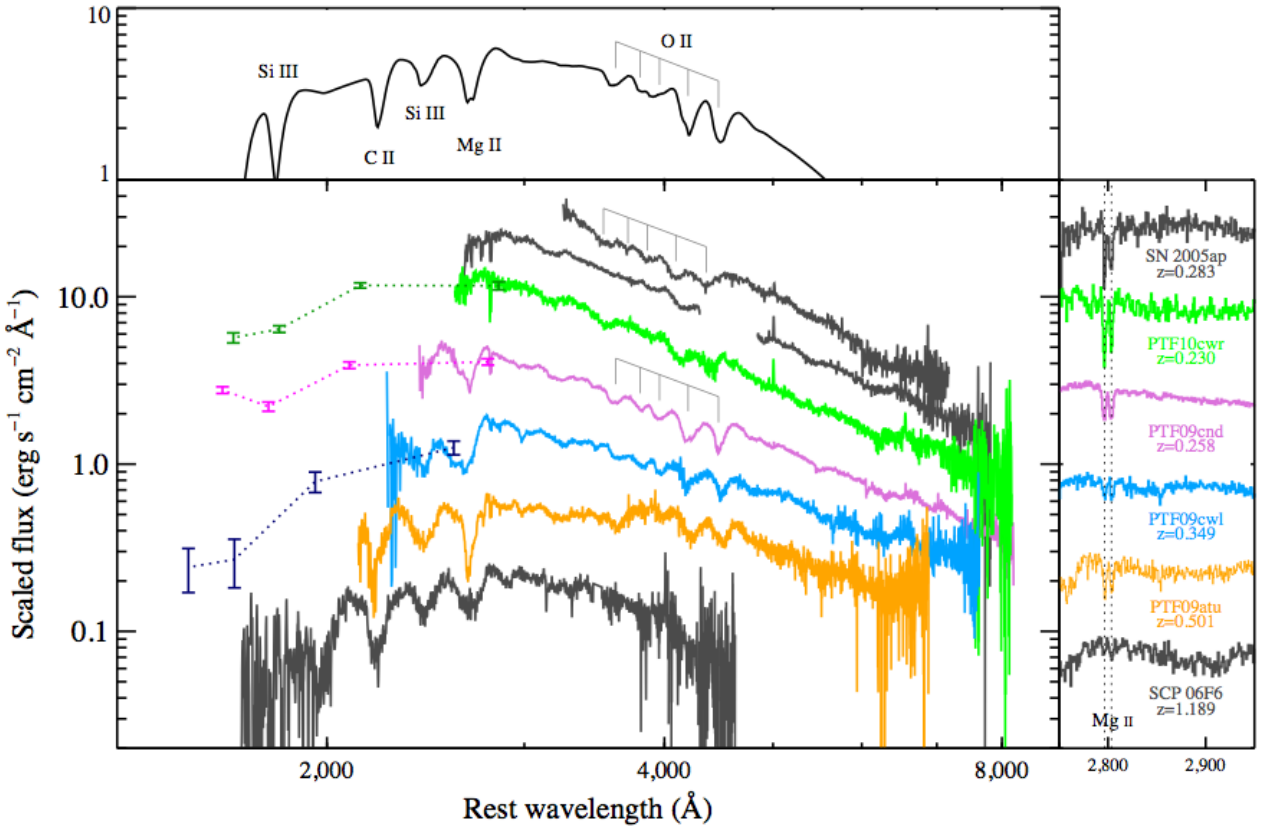
# Super-Luminous Supernovae (Hydrogen)



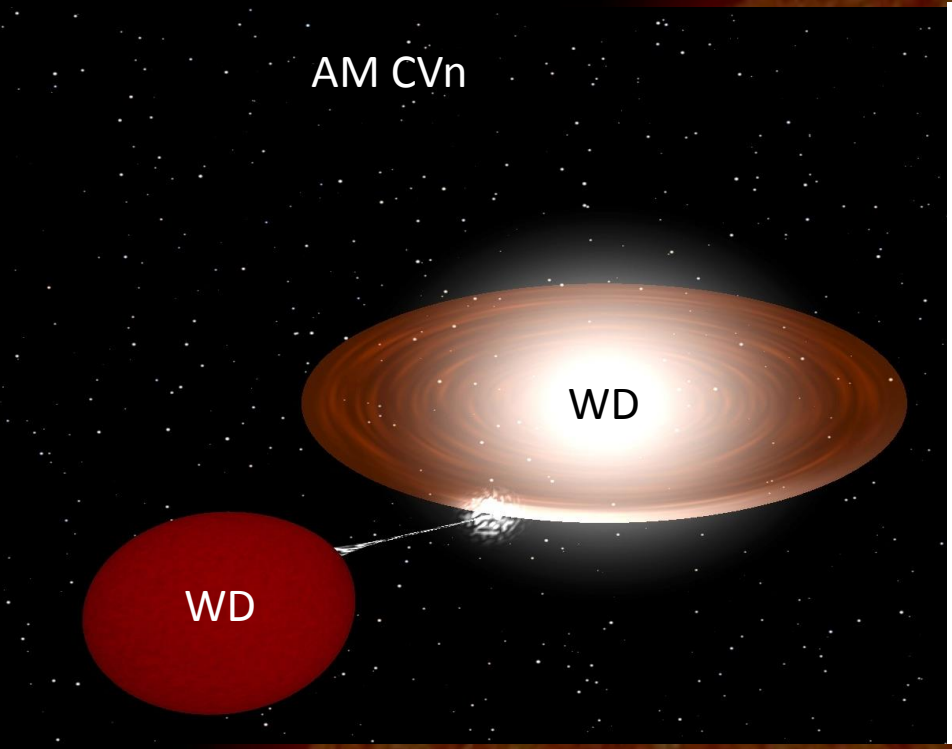



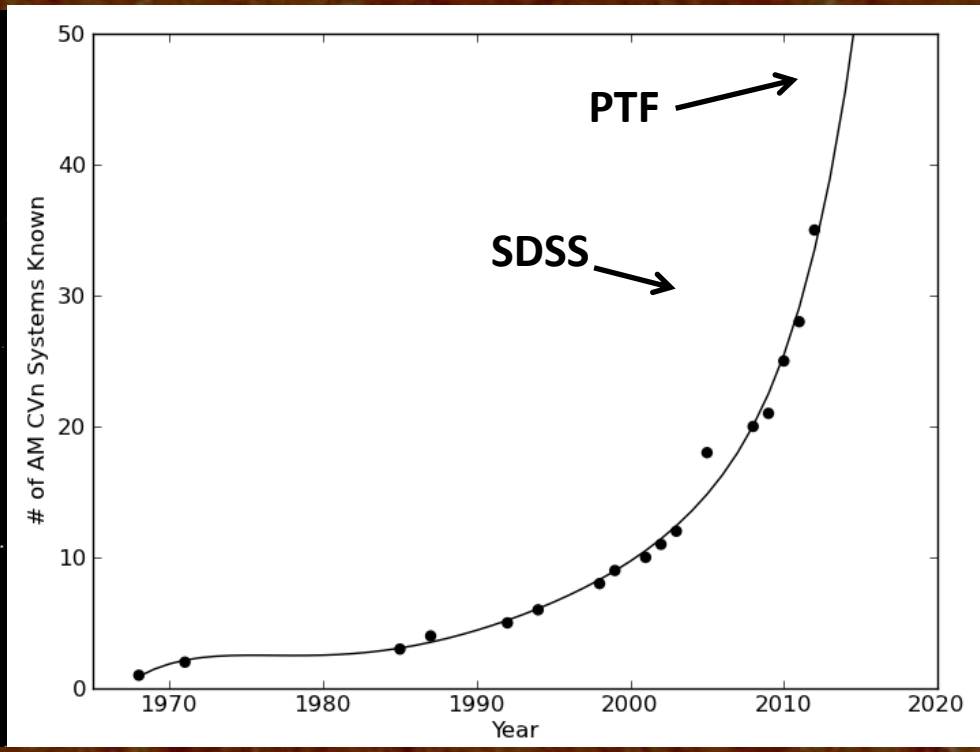

R. Quimby

# Superluminal Supernovae (no Hydrogen)

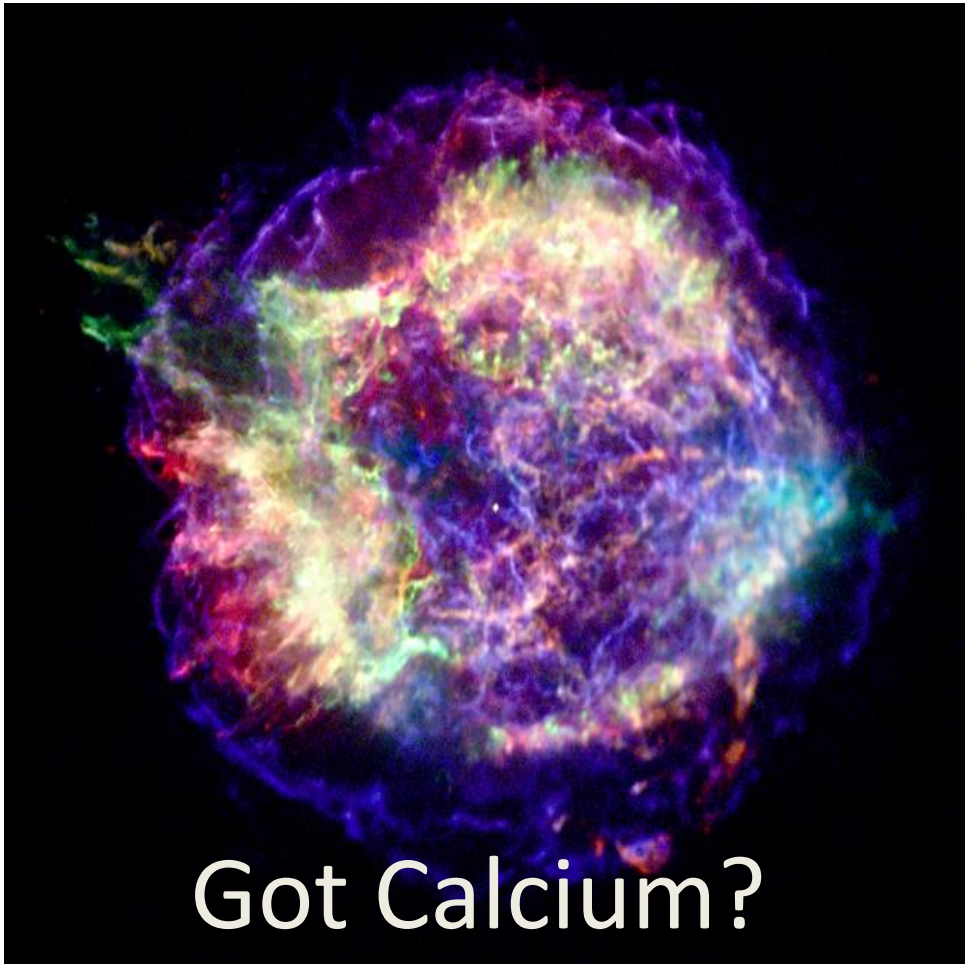


# Double White Dwarfs (AM CVn)

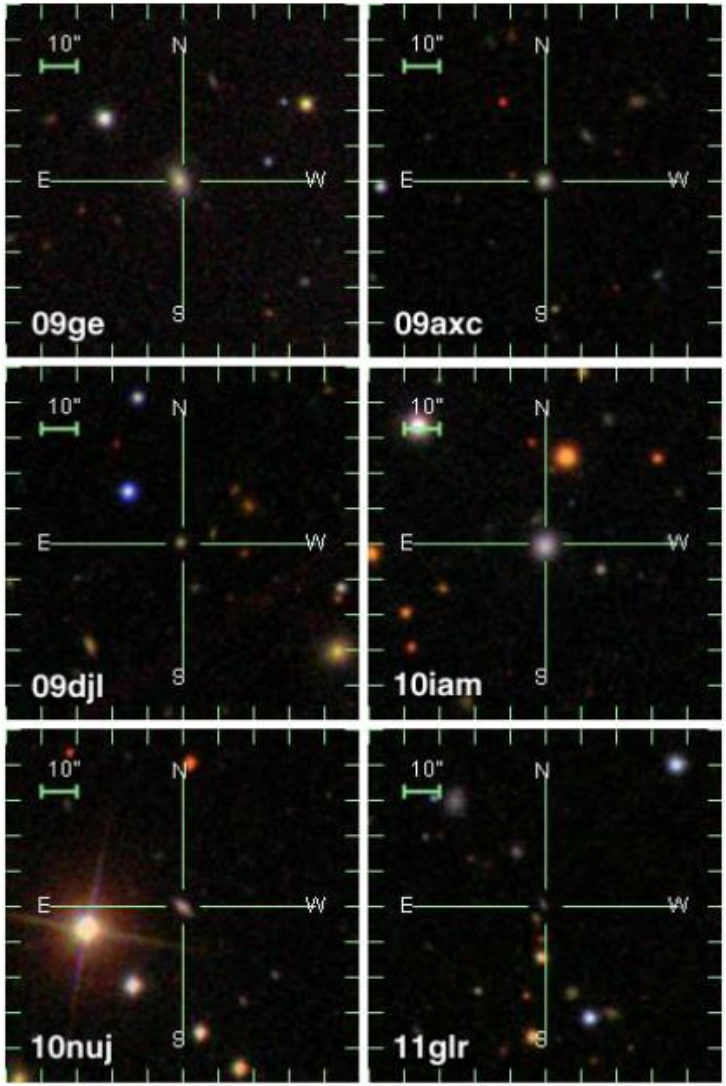


# Weird Outcomes: Carbon Stars, Calcium Ashes, Thermonuclear Explosions



# A sequence of H→He TDF

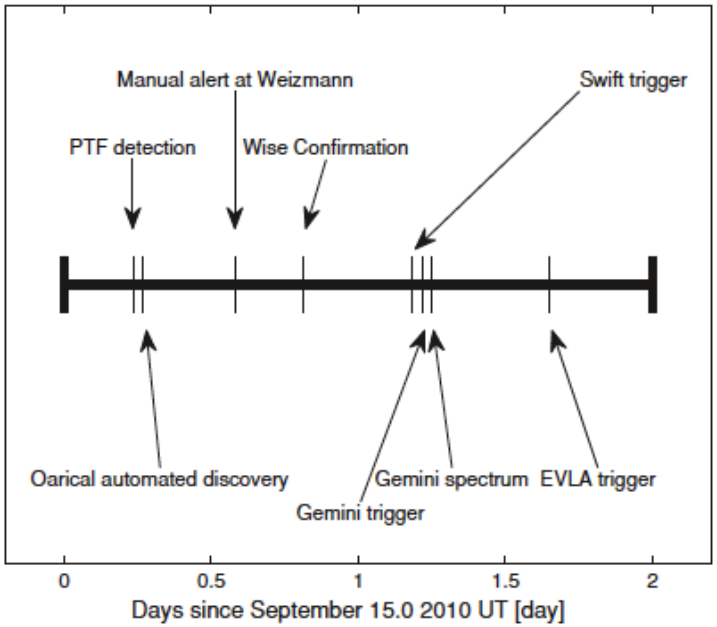


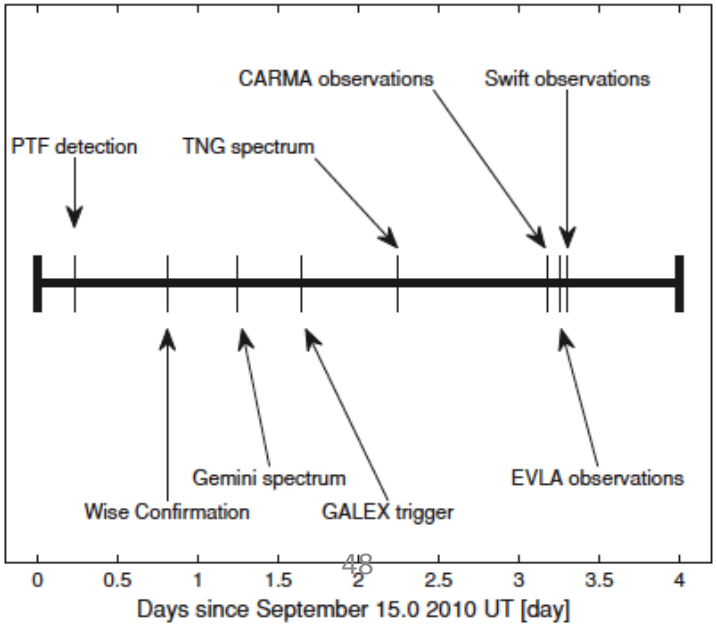

Arcavi et al.
(submitted)

PS1-10jh
Gezari et al.

# ON TO LOW LATENCY (SAME NIGHT)

# Rapid Response: PTF10vdl (dry run)




Led by A. Gal-Yam

# PTF11kly: A nearby Ia Explosion (Rosetta Stone)

Nugent et al
Li et al.

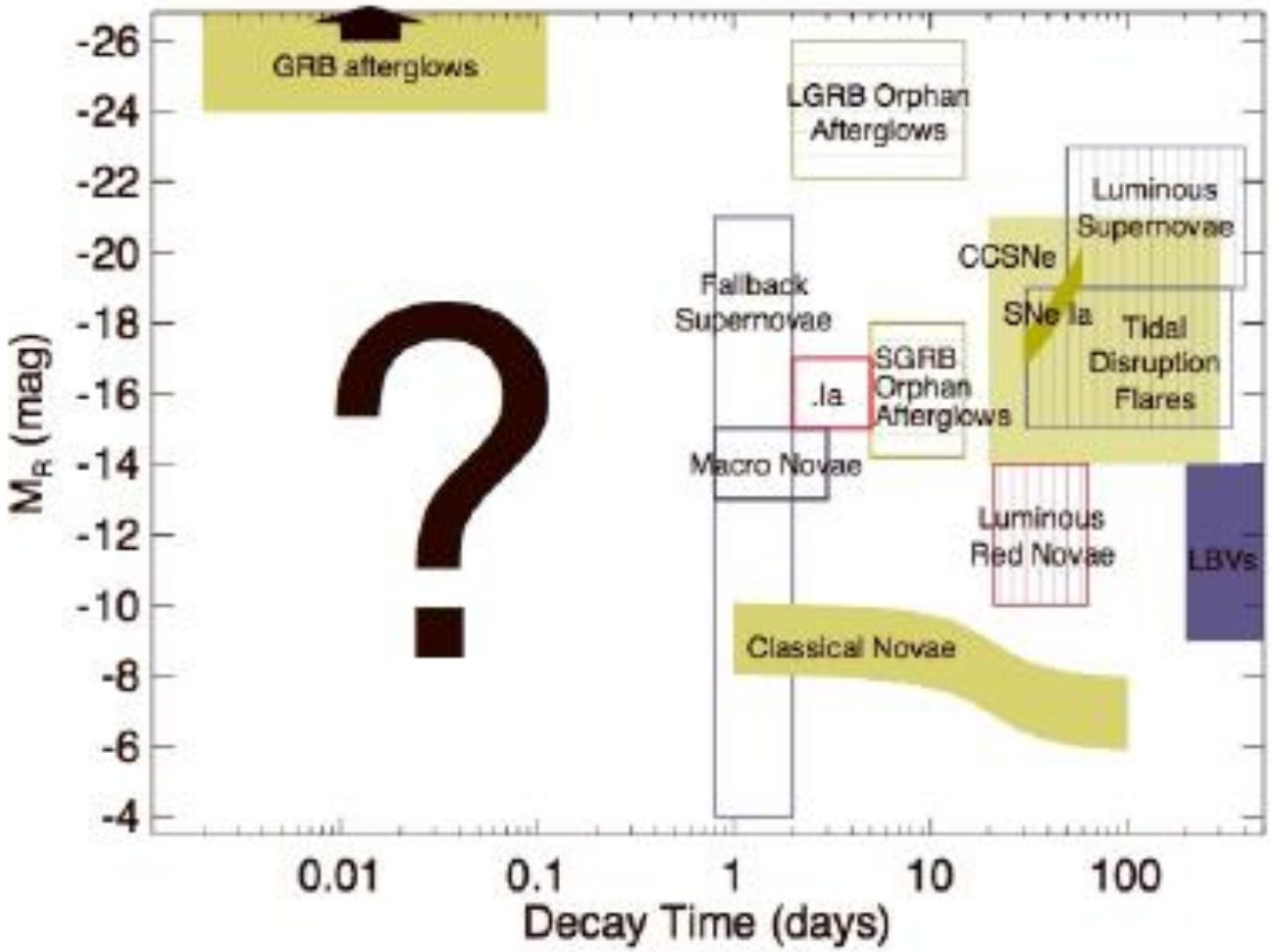
# A Supernova


Source: PTF Collaboration

# What next?

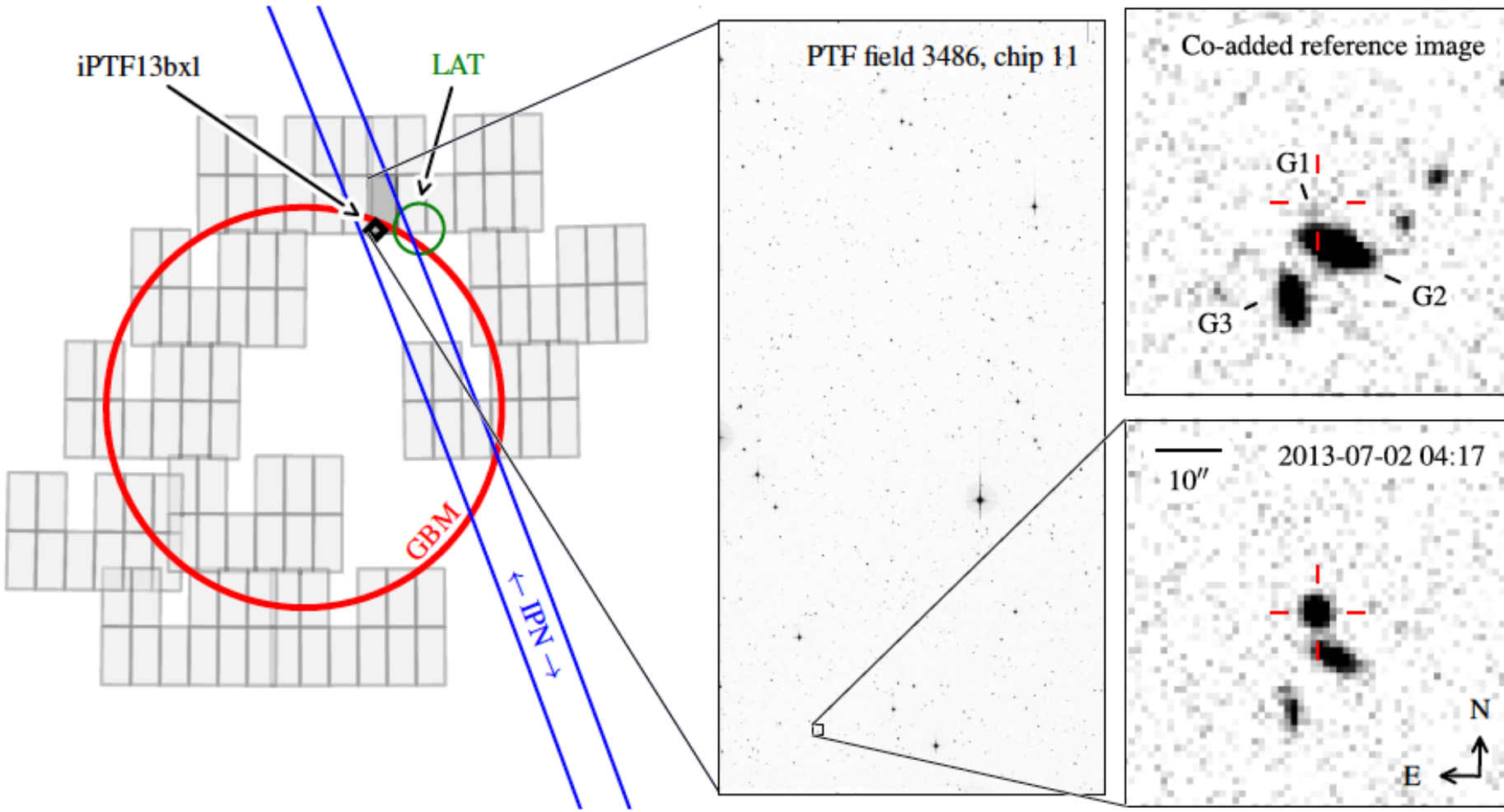
S. R. Kulkarni

# Short timescale is terra incognito



# DEMONSTRATION: HOW TO FIND A NEEDLE IN THE HAYSTACK?

Singer et al.




re 1. P48 imaging of GRB 130702A and discovery of iPTF13bxl. The left panel illustrates the γ-ray localizations (red circle: 1-σ GBM; green circle: LAT

# UT 2013 July 2

- 00:05 Fermi GBM trigger (394416326)
- 01:05 position refined by human (GBM group)
- 03:08 Sun sets at Palomar
- 04:17 PTF starts observations
- (10 fields, 2x60-s per field; 72 square degrees)
- RB2>0.1 yielded 4214 "candidates"
- 44 were known asteroids
- 1744 were coincident with stars (r<21)
- Insisting on 2 frame detection, nix on hot pixels, columns
- led to 43 viable candidates
- Human inspection reduced this to 7 excellent candidates
- iPTF13bxh core of a bright galaxy
- IPTF13bxu "
- iPTF13bxr known quasar (SDSS J145359.72+091543.3)
- iPTF13bxt was close to a star in SDSS
- LEAVING
- iPTFbxj (RB2=0.49), iPTFbxl(RB2=0.86) and iPTFbxk (RB2=0.83)
- SUN ROSE in California

# UT 2013 July 3

- 00:50 Swift observations for iPTF13bxl requested
  - X-ray source detected
- 04:10 Robotic observations of these candidates at P60
  - iPTFbxl showed decline relative to first P48 observation (!)
- 04:24 Spectral observations on the Palomar 200-inch
  - Spectrum is featureless (!!)
- 08:24 Announced iPTF13bxl as afterglow (ATEL, GCN)
- 17:34 LAT localization (3.2 square degrees)
- 19:03 IPN announces annulus of width 0.9 degrees
- 23:17 Magellan observations led to z=0.145

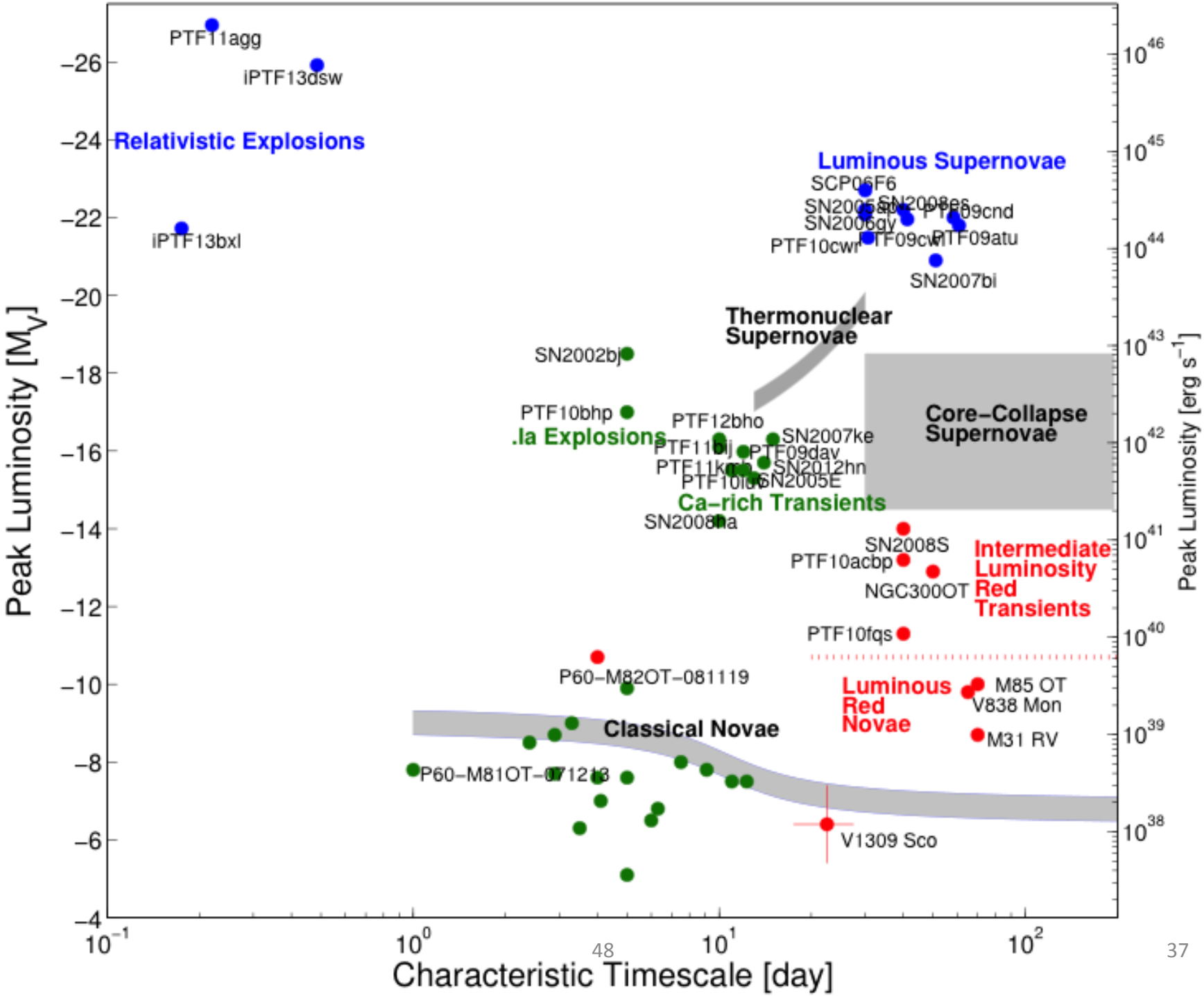
# Not a fluke!

M. M. Kasliwal (Carnegie Observatories/Princeton), L. P. Singer (Caltech) and S. B. Cenko (NASA/GSFC) report on behalf of the intermediate Palomar Transient Factory (iPTF) collaboration:

Starting 2013-10-12 05:26 UT, we imaged about 70 deg^2 in the vicinity of the localization of the Fermi-GBM trigger 403206457 with the Palomar 48-inch Oschin telescope (P48). Sifting through **10,816** candidate variable sources in the GBM error circle using standard iPTF vetting procedures including Palomar 60-inch follow-up, we identify iPTF13dsw as a possible optical afterglow candidate:

RA(J2000) = 02h 10m 06.38s
DEC(J2000) = -04d 24' 40.3”

Light Curve: R=19.7mag @ 05:26 UT (P48), R=20.2mag @ 08:07 UT (P60)


Peak Luminosity [$M_V$]
Peak Luminosity [erg s$^{-1}$]
Characteristic Timescale [day]
PTF11agg
iPTF13dsw
Relativistic Explosions
iPTF13bxl
Luminous Supernovae
SCP06F6
SN2006gy
PTF09cnd
PTF09atu
PTF10cwr
SN2007bi
Thermonuclear Supernovae
SN2002bj
PTF10bhp
.Ia Explosions
PTF12bho
SN2007ke
PTF09dav
SN2012hn
SN2005E
Ca–rich Transients
SN2008ha
Core–Collapse Supernovae
SN2008S
PTF10acbp
NGC300OT
Intermediate Luminosity Red Transients
PTF10fqs
P60–M82OT–081119
Luminous Red Novae
M85 OT
V838 Mon
M31 RV
Classical Novae
V1309 Sco

# Automating the discovery of the Universe

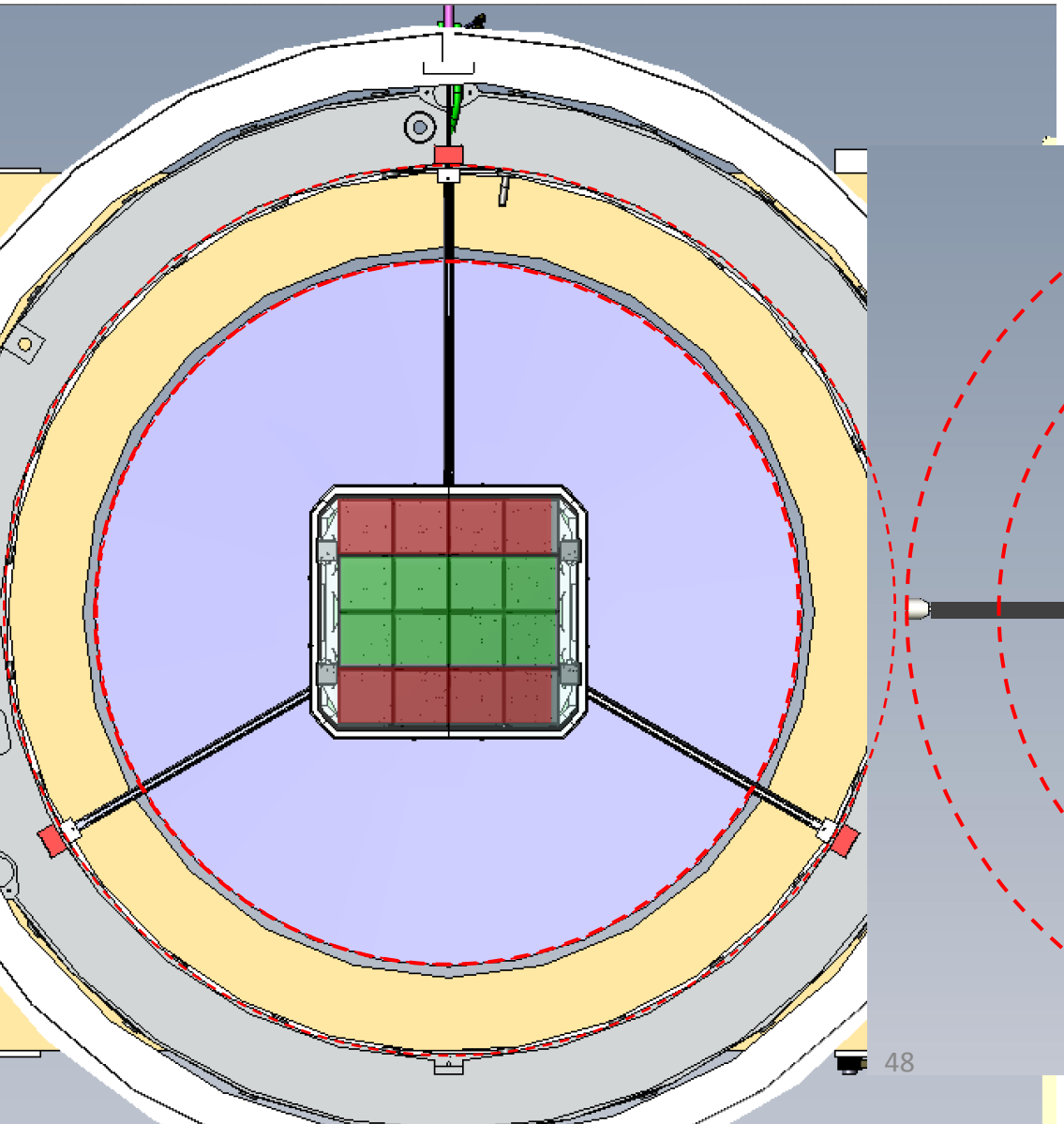
S. R. Kulkarni

Caltech Optical Observatories

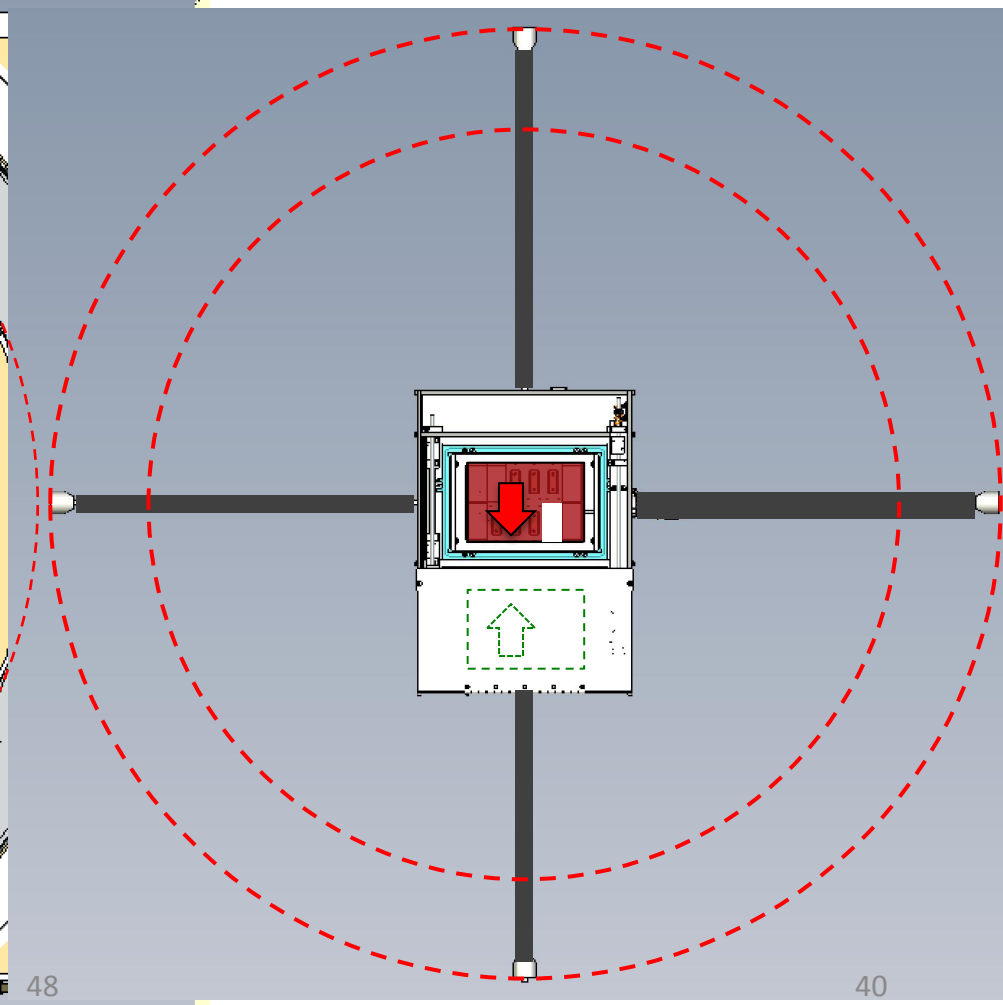
PALOMAR TRANSIENT FACTORY

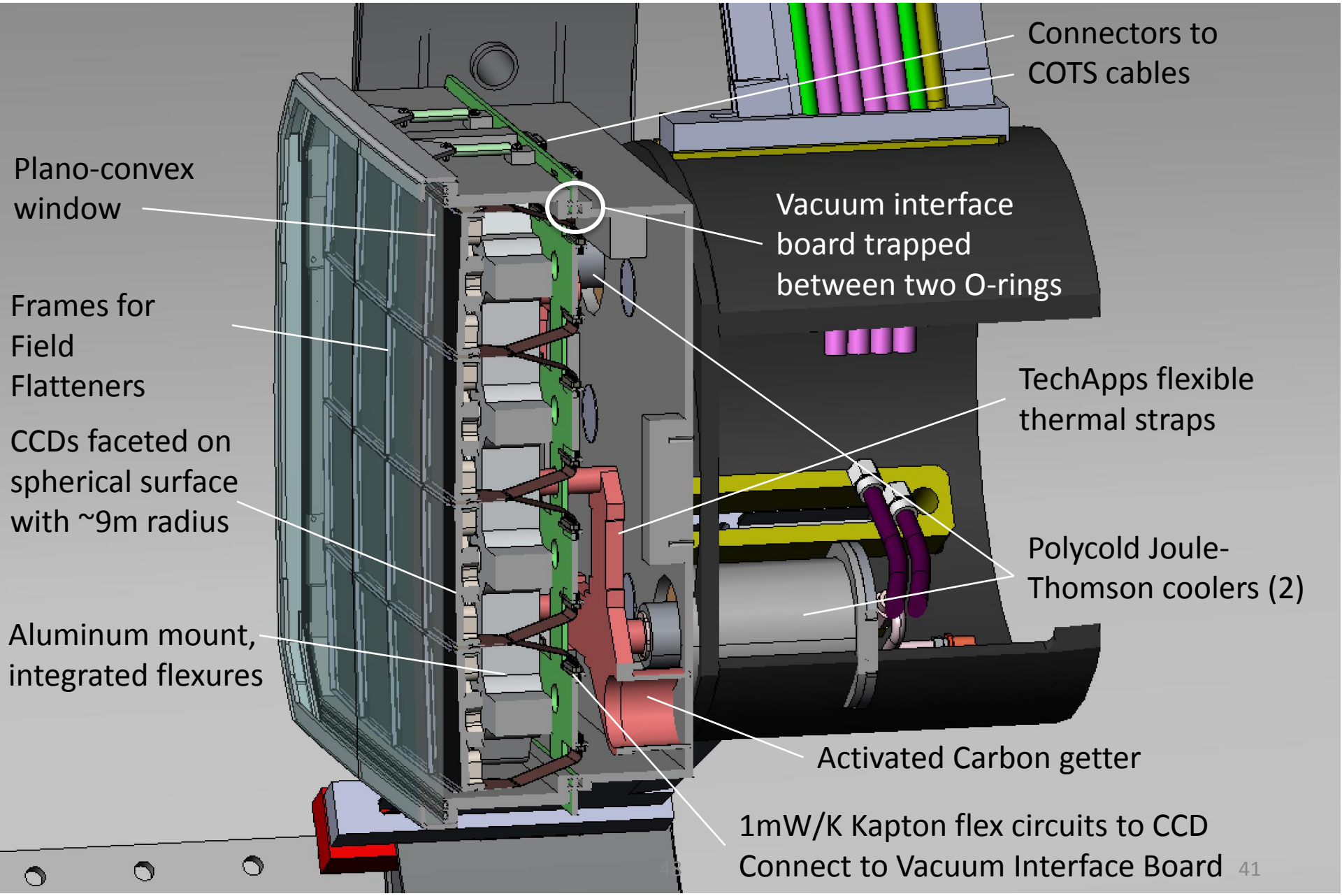
# Zwicky Transient Facility

ZTF



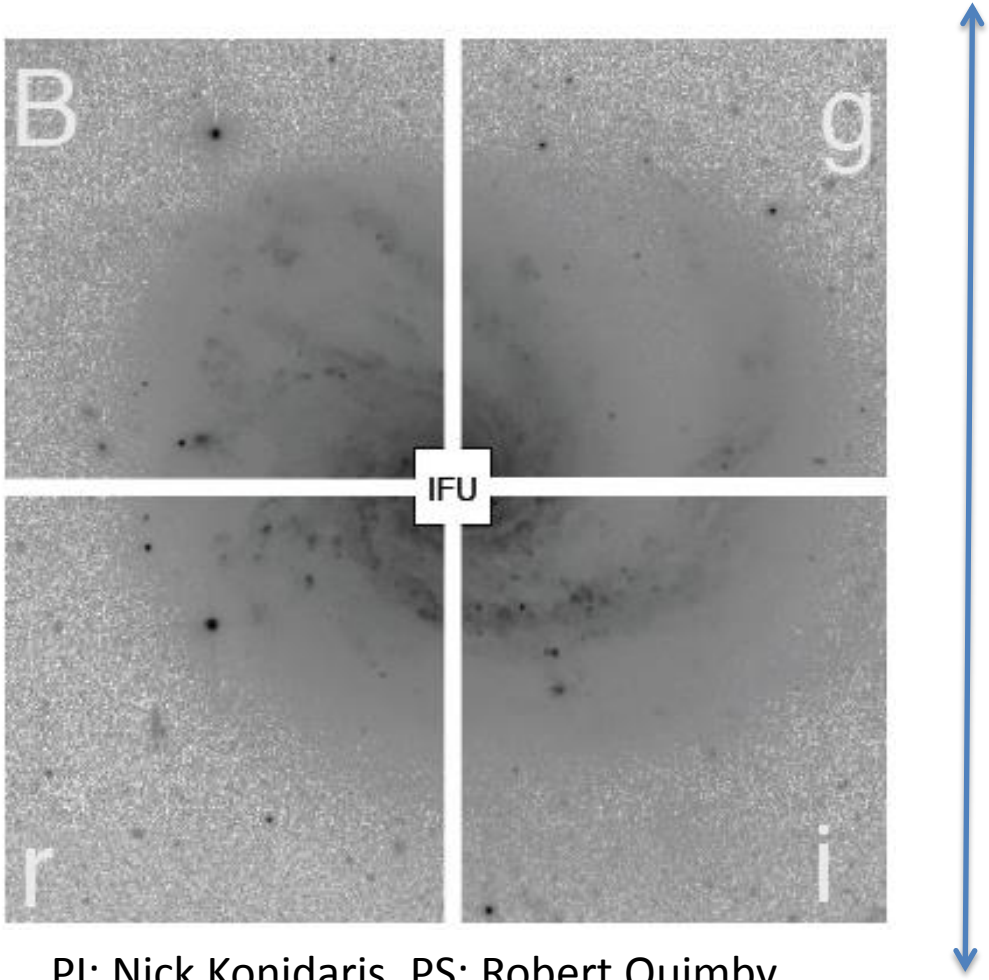
PTF




Connectors to COTS cables
Plano-convex window
Vacuum interface board trapped between two O-rings
Frames for Field Flatteners
TechApps flexible thermal straps
CCDs faceted on spherical surface with ~9m radius
Polycold Joule-Thomson coolers (2)
Aluminum mount, integrated flexures
Activated Carbon getter
1mW/K Kapton flex circuits to CCD Connect to Vacuum Interface Board

# The SED Machine

30 arcsec




7 arcminute

PI: Nick Konidaris, PS: Robert Quimby
In collaboration with NCU-Taiwan


Robo-AO
January 22nd, 2013 3:05 - 7:37 UTC

# Tools in development

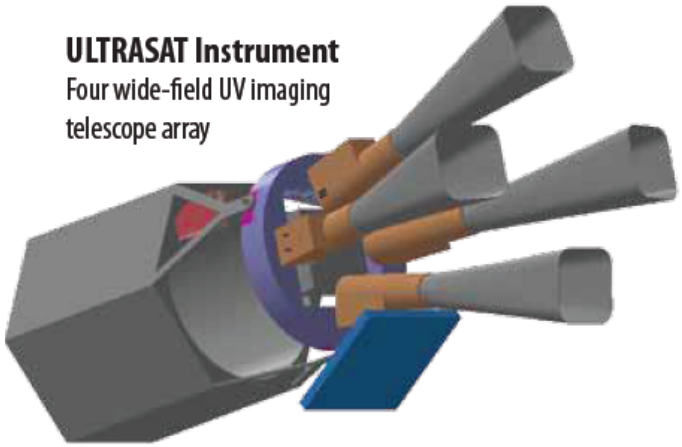
- Robotic spectroscopy
  - “Spectrum on demand” [hardware]
  - Machine Learning (ML) classification of spectra
- Continued improvement of ML classification of transient candidates
- Development of automated “alert” system

## ULTRASAT addresses NASA Strategic Goals:

| NASA Important Questions | ULTRASAT Compelling Science Objectives |
|---|---|
| **SSE-3: How do the lives of massive stars end?** | **Massive Stellar Death (SSE-3*)**—Early UV photometry of a sample of ~300 new supernovae will determine the radii and surface composition of their progenitor stars, and thus the deceased progenitor star pre-explosion nature: cool red supergiant (~500 Sun Radius $R_\odot$), hot blue supergiant (~50 $R_\odot$), or a compact Wolf-Rayet star (~5 $R_\odot$). ULTRASAT will identify mass-loss signatures to constrain pre-explosion evolution. |
| **GCT-3: How do black holes grow, radiate, and influence their surroundings?** | **Tidal Disruption Events (TDEs)**—ULTRASAT will achieve the first robust measurement of the TDE rate, probing galactic structure models (spherical vs. triaxial) and studying TDE physics, by identifying >100 TDEs per year. |
| **What mechanisms are at work when SNe produce GRBs?** | **Gamma Ray Burst Afterglows (GRBAs)**— ULTRASAT will identify ~10 GRB UV afterglows per year and an expected similar number of orphan GRB afterglows. Detection of even a single orphan GRB will confirm the GRB jet model; the normal/orphan ratio will constrain jet structure and thus true GRB energy. |

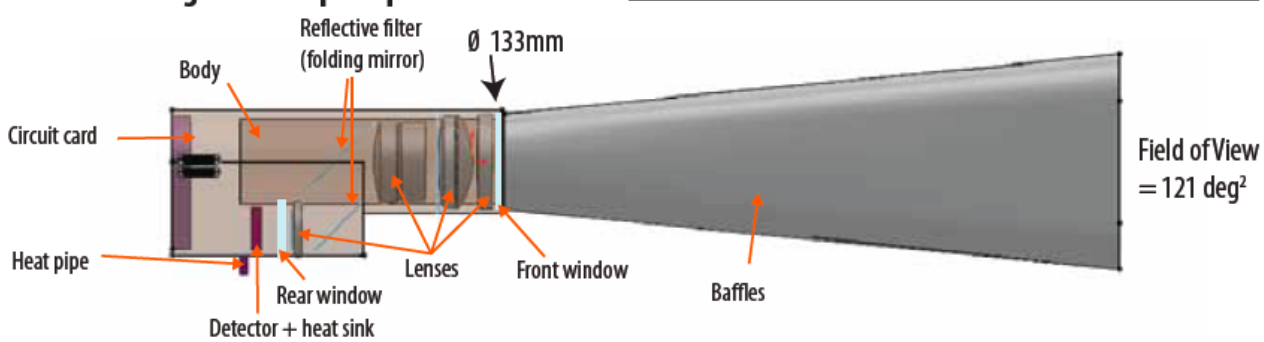
### ULTRASAT Instrument

Four wide-field UV imaging telescope array



| Science Payload Key Facts | |
|---|---|
| Payload type | 4 telescopes |
| Mass (kg) | 91 |
| Field of View | > 484 deg² |
| Band of Operation | 200 – 240 nm |
| Sensor type | Fully depleted p-channel CCD |
| Sensor format | 4128 x 4114 pixels, binned |
| Readout Noise | < 5 e- rms |
| Net Throughput (Optics, CCD) | > 30 % |
| Pixel Scale | 19.3″ |
| Point Source Detection | 21 mag (AB), 5 σ |
| Data / day (compressed) | < 2 GB |
| Young SNe | >100 |
| Transient alerts distribution | < 30 min |

### Single Telescope Exploded View

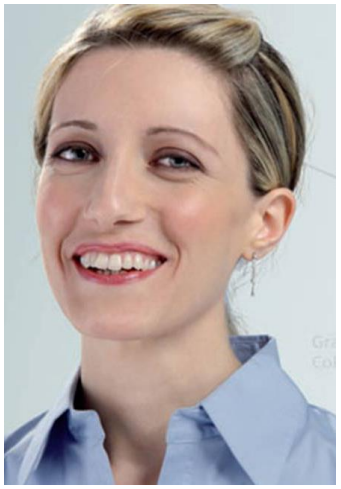


# ZTF Grayware

Iair Arcavi

Eric Bellm

Yi Cao



Alessandra Corsi

Mansi Kasliwal

David Levitan

Gina Duggan

Branimir Sesar

Daniel Perley

Adam Waszczak

http://www.ptf.caltech.edu/

48