Real-Time Data Analysis in Astrophysical Surveys: 2014 and Beyond...

Peter Nugent (LBNL/UCB)

What is a Supernova?
(pl. supernovae)

- "Nova" is Latin for new.

- First used to describe "new" stars that suddenly appeared in the night sky. (The Chinese referred to them as "guest stars".)

- The prefix "super" distinguishes them from "classical novae" which are fainter cousins of supernovae (but I won't get into those in this talk).

- The term supernova was coined by Fritz Zwicky in 1926.

- Supernovae observations by humans have been recorded for the past 2000 years.

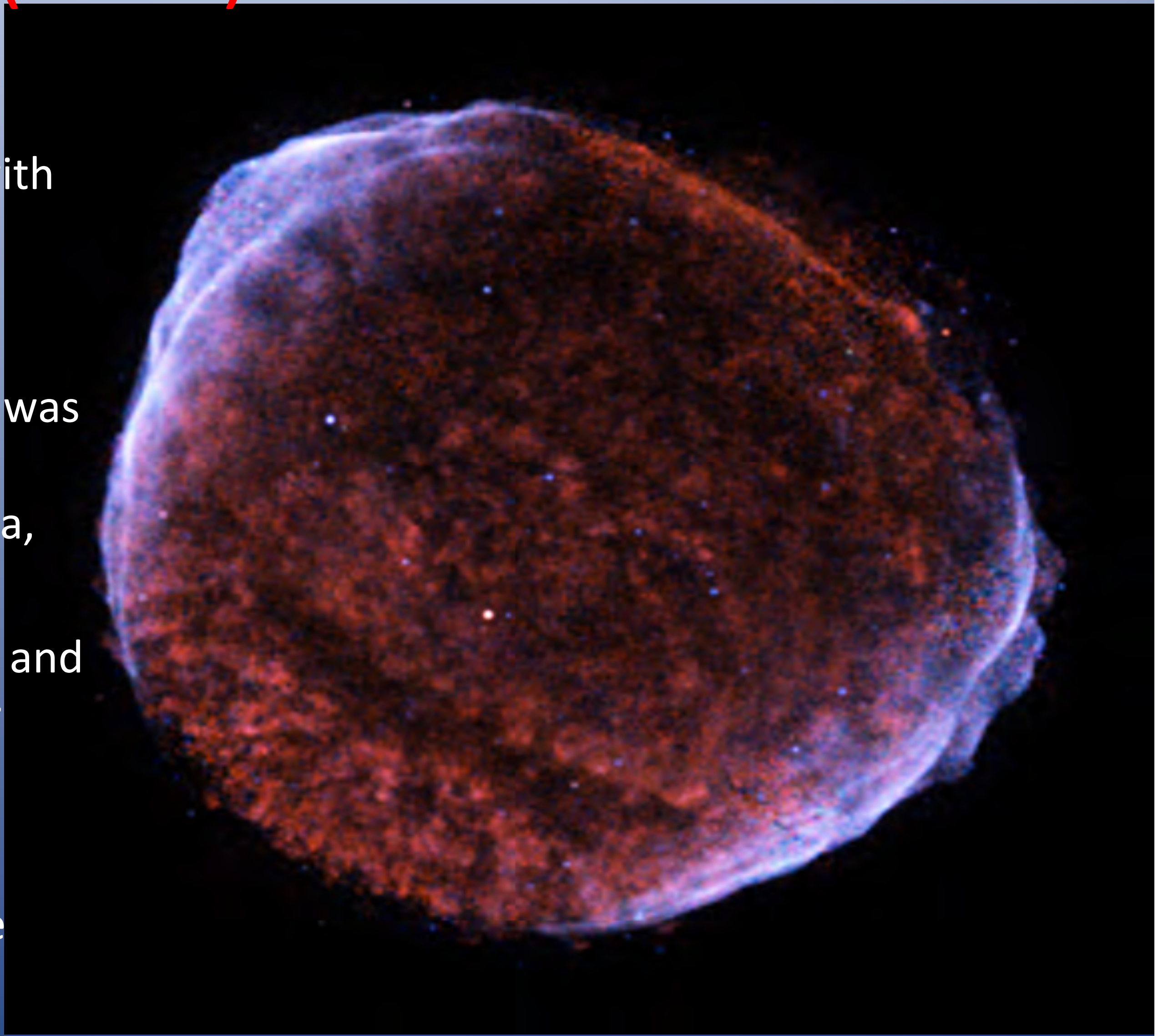
How Frequent are they?

- Somewhere in the universe there is a supernova exploding every second.

- In a galaxy like our Milky Way there is ~1 supernova per century.

- We find around 1-3 new supernova per night these days - most are very distant ~ 1 billion light years away.

Historical SNe (1006)



This is a SN remnant image with the Chandra X-ray satellite telescope.

It came from SN 1006, which was seen by ancient observers in Switzerland, Egypt, Iraq, China, Japan, and North America.

The SN cast shadows at night and was visible during the day for months.

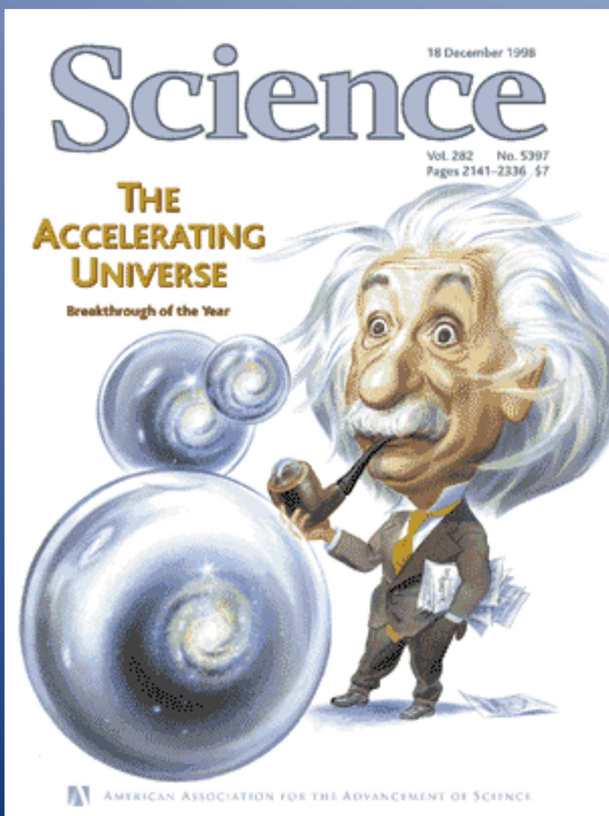
Supernovae are the explosive deaths of some stars.

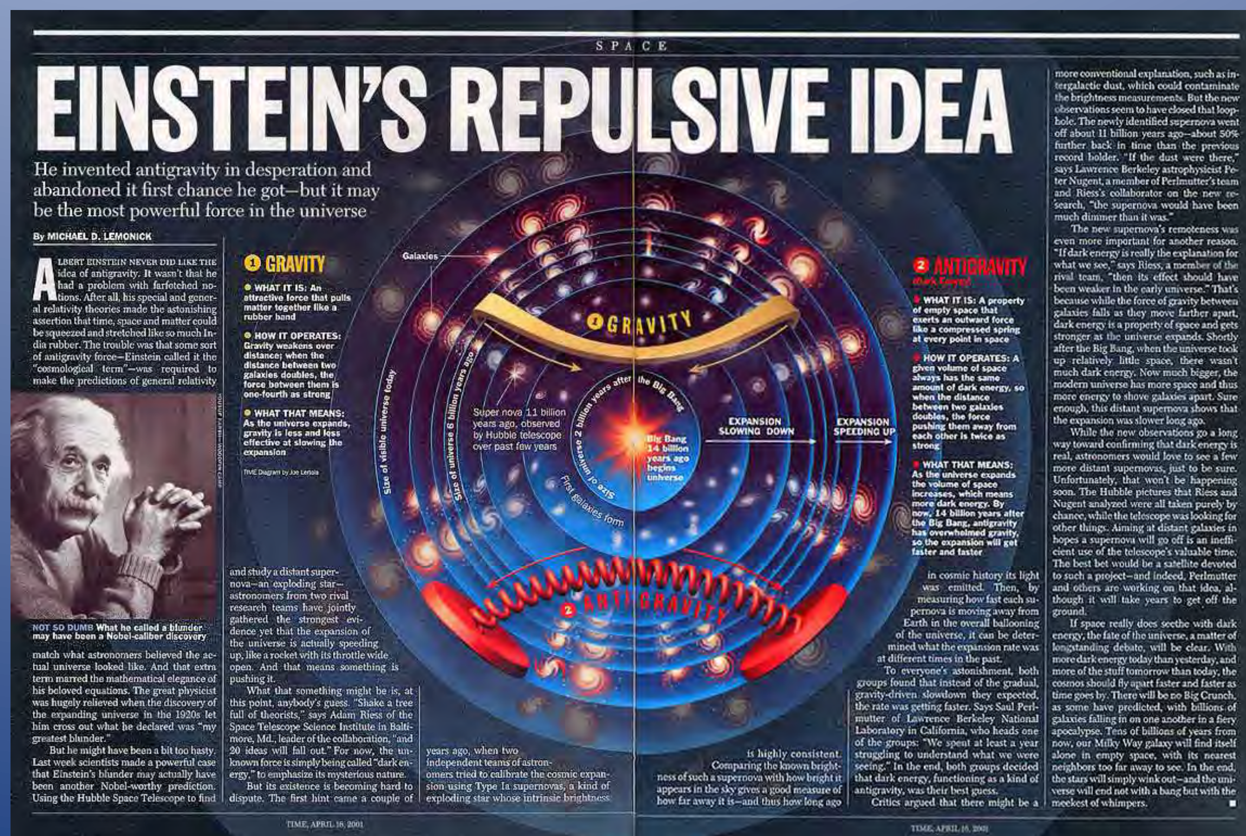
We are star-stuff

Group / Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
			90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

Cosmology

Over the past 15 years the observations of Type Ia supernovae at high redshift have shown that the universe is currently accelerating and that over 2/3 of it is in the form of "dark energy".




SPACE

EINSTEIN'S REPULSIVE IDEA

He invented antigravity in desperation and abandoned it first chance he got—but it may be the most powerful force in the universe

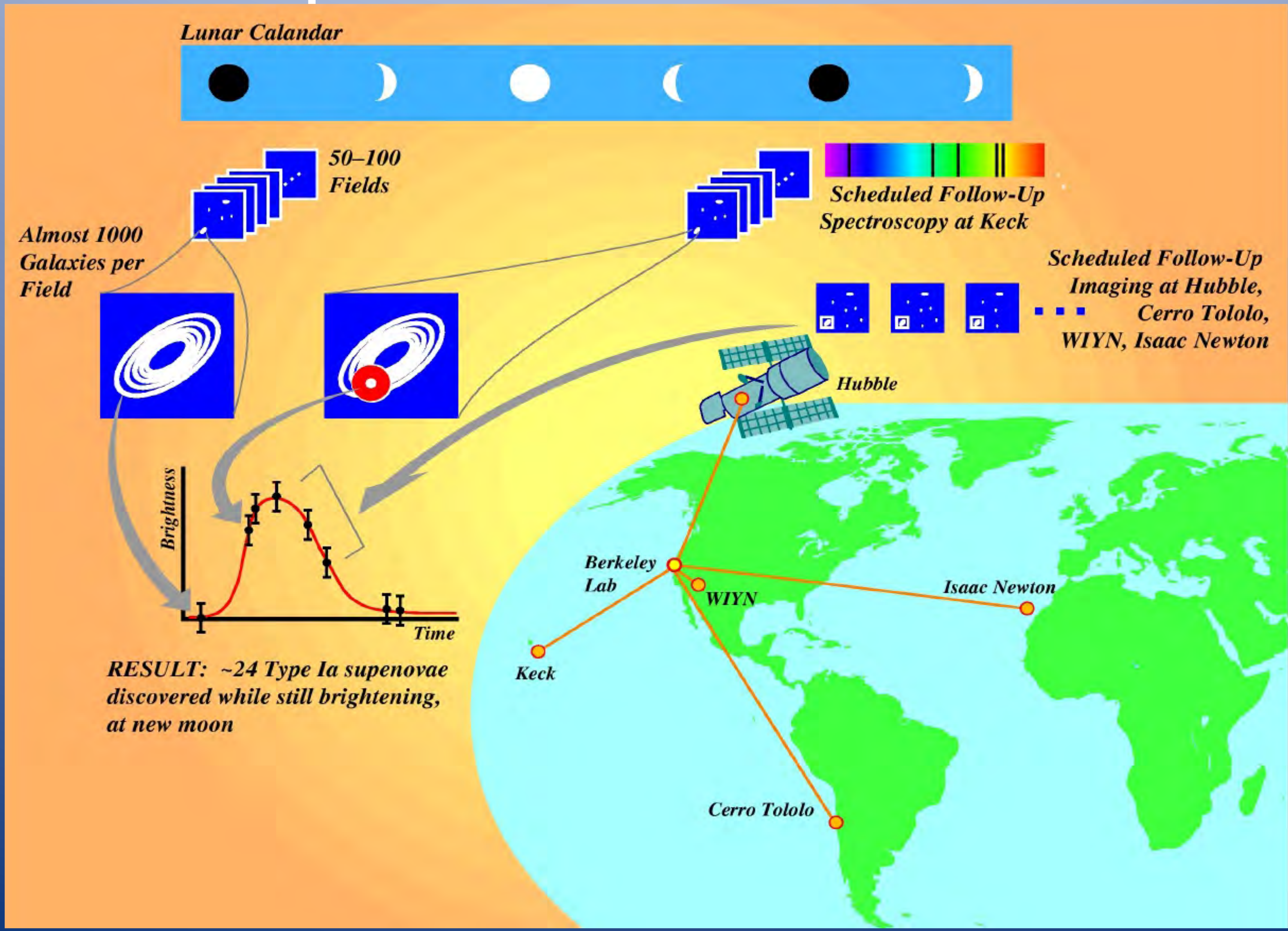
By MICHAEL D. LEMONICK

Supernovae circa 1998

The 4-m Victor Blanco telescope was equipped with 1 (and then 4) 2kX2k ccd's. Exposures were typically 5-10 min long.

We could transfer all the data up on a 56k-baud connection during the night and it would be subtracted within a few hours of dawn – when the connection was good. Often the astronomer would make it back to Berkeley with the tapes before all the data was in...

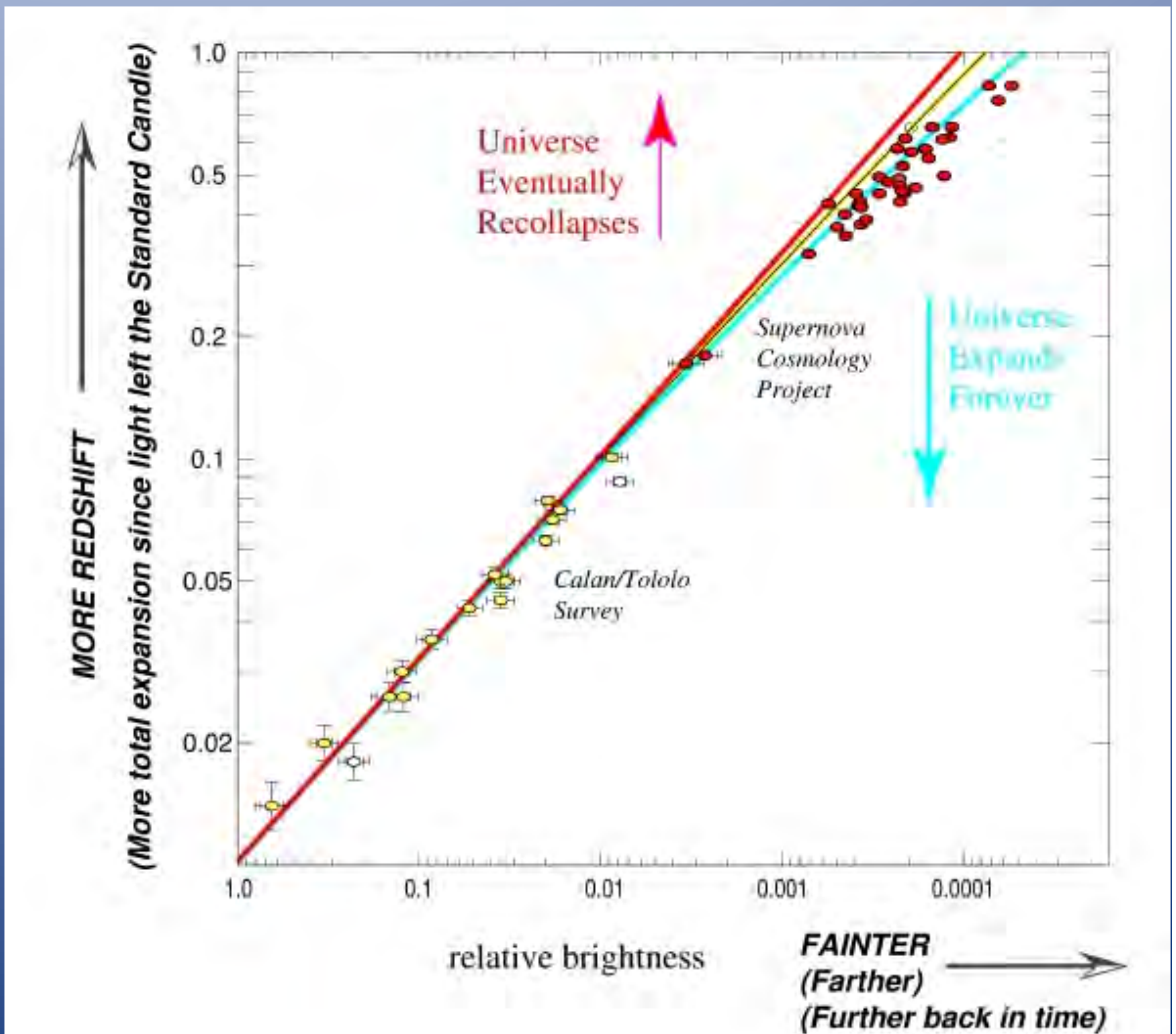
Supernovae circa 1995



Supernovae circa 1998

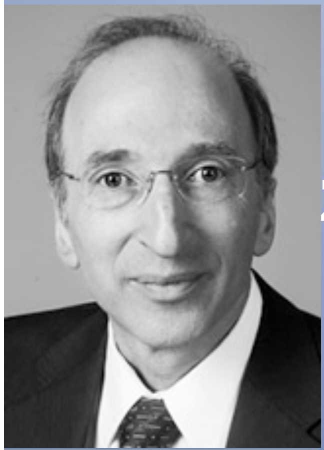
The Calan/Tololo Survey by Hamuy *et al.* pinned the low-z part of the Hubble diagram, while the work of Riess *et al.* and Perlmutter *et al.* got the high-z end.

Turns out it is easier to find them at high redshift than low redshift....

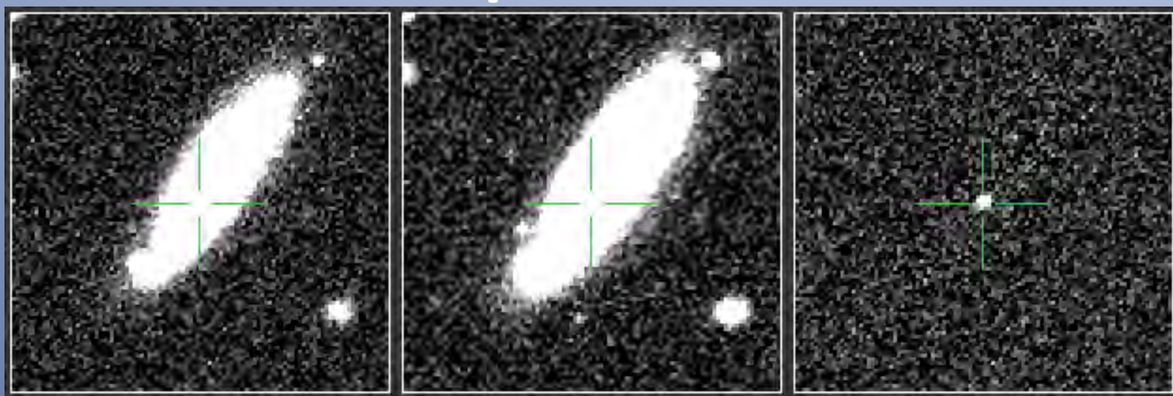


Cosmology

2011 Nobel Prize in Physics

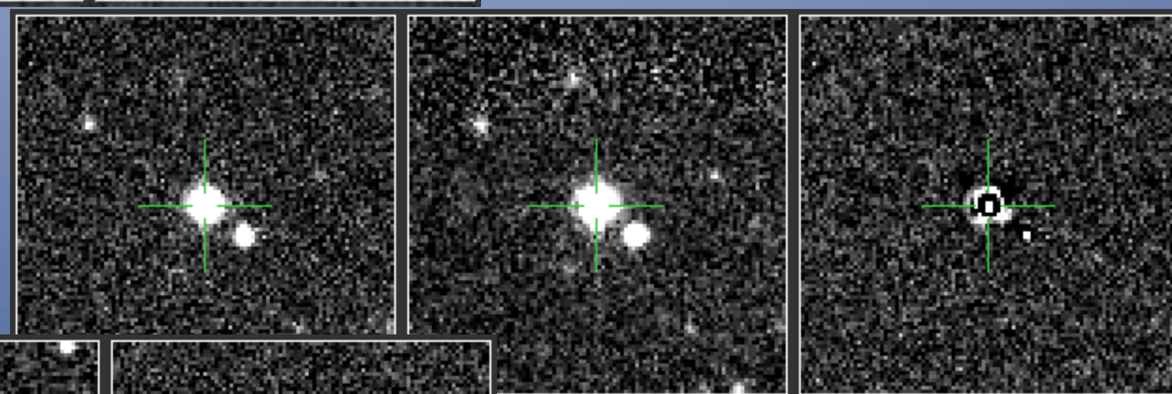


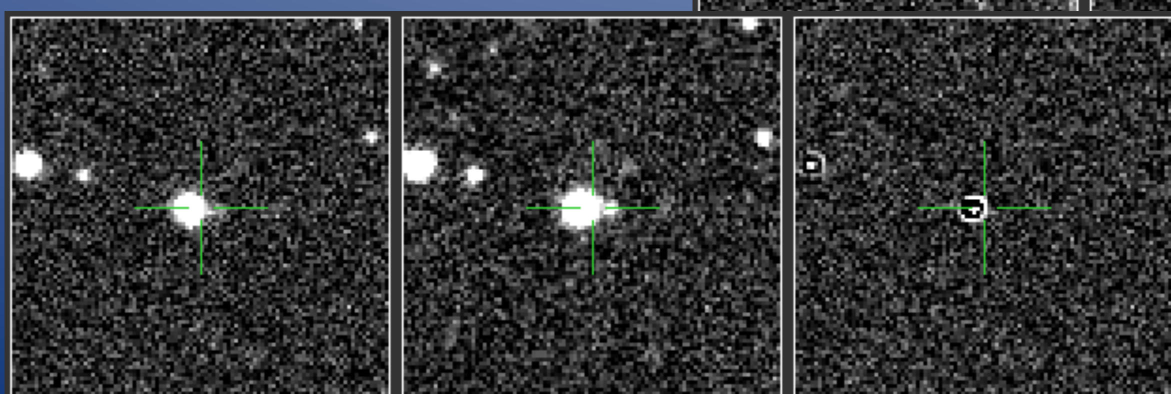
Supernovae circa 1998



Per image we would have ~200 5-σ detections. We would require 2 independent detections.

Typically only 50-200 images taken per night - 4 sq. deg. of sky.





Cuts were made based on shape, motion, etc., and a scanner would have to look at ~5 candidates per image.

Supernovae circa 2000

Pain begins.....

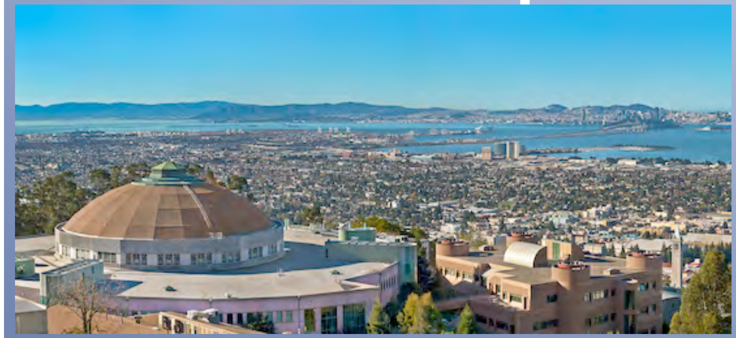
NEAT Search Facilities

Site:	Haleakala	Palomar I	[illegible]
Aperture:	1.2m	1.2[illegible]	[illegible]m
Nights/Month:	18 dark/gray	18 [illegible]	[illegible] dark/gray
Imager Format:	4k × 4k	[illegible]	16k × 24k
Imager Scale:	1.33″/[illegible]	[illegible]/pixel	0.50″/pixel
Field of View:	[illegible]	[illegible]1°×3.4°	2.3°×4.0°
Filters:	[illegible]	open	4 fixed filters
Exposures:	[illegible] sec	3×60 sec	TBD
Read[illegible]:	20 sec	20 sec	TBD
Nig[illegible]:	600□°	800□°	(2000 □°)
Start[illegible]:	Mar 2000	Feb 2001	~Dec 2001
Data ([illegible]ompressed):	12 Gbyte/night	17 Gbyte/night	(28 Gbyte/night)

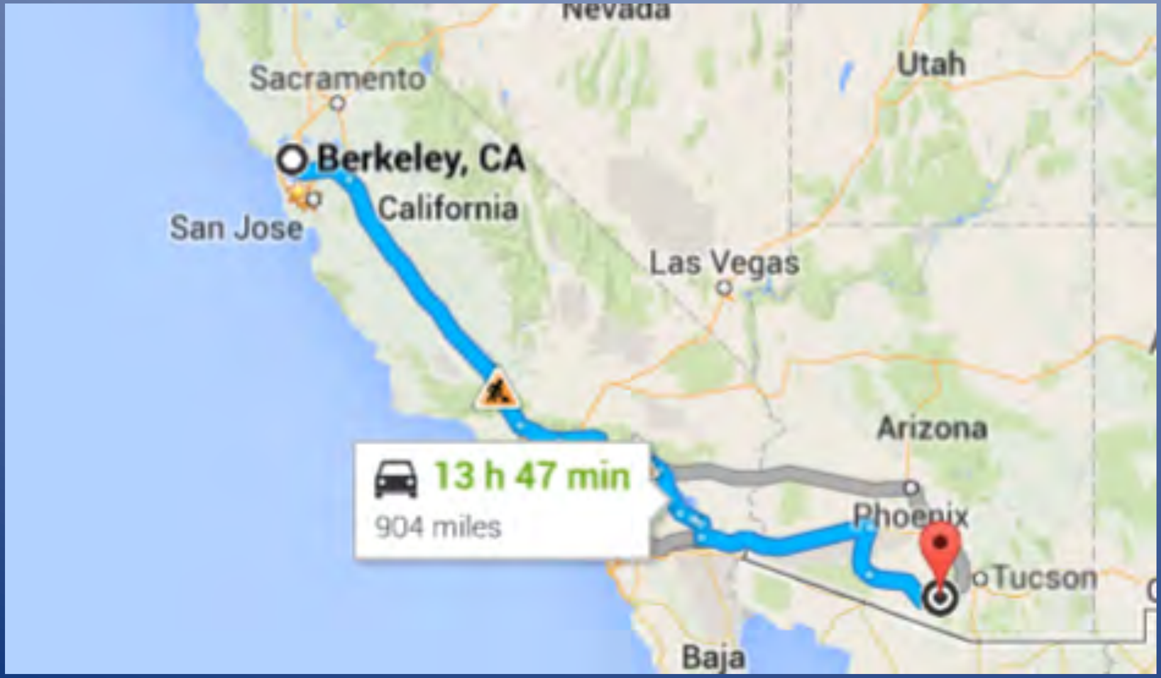
~1000 sq. deg. – 250 X increase in scale per night

EVERY NIGHT !!!

Supernovae circa 2000



FEDEx Networking: Do not underestimate the bandwidth of a station wagon filled with DAT tapes... achieved 200 kB/s



PTF (2009-2012)

- CFH12k camera on the Palomar Oschin Schmidt telescope
  - 7.8 sq deg field of view, 1" pixels
  - 60s exposures with 15-20s readout in r, g and H-alpha
  - First light Nov. 24, 2008.
  - First useful science images on Jan 13th, 2009.

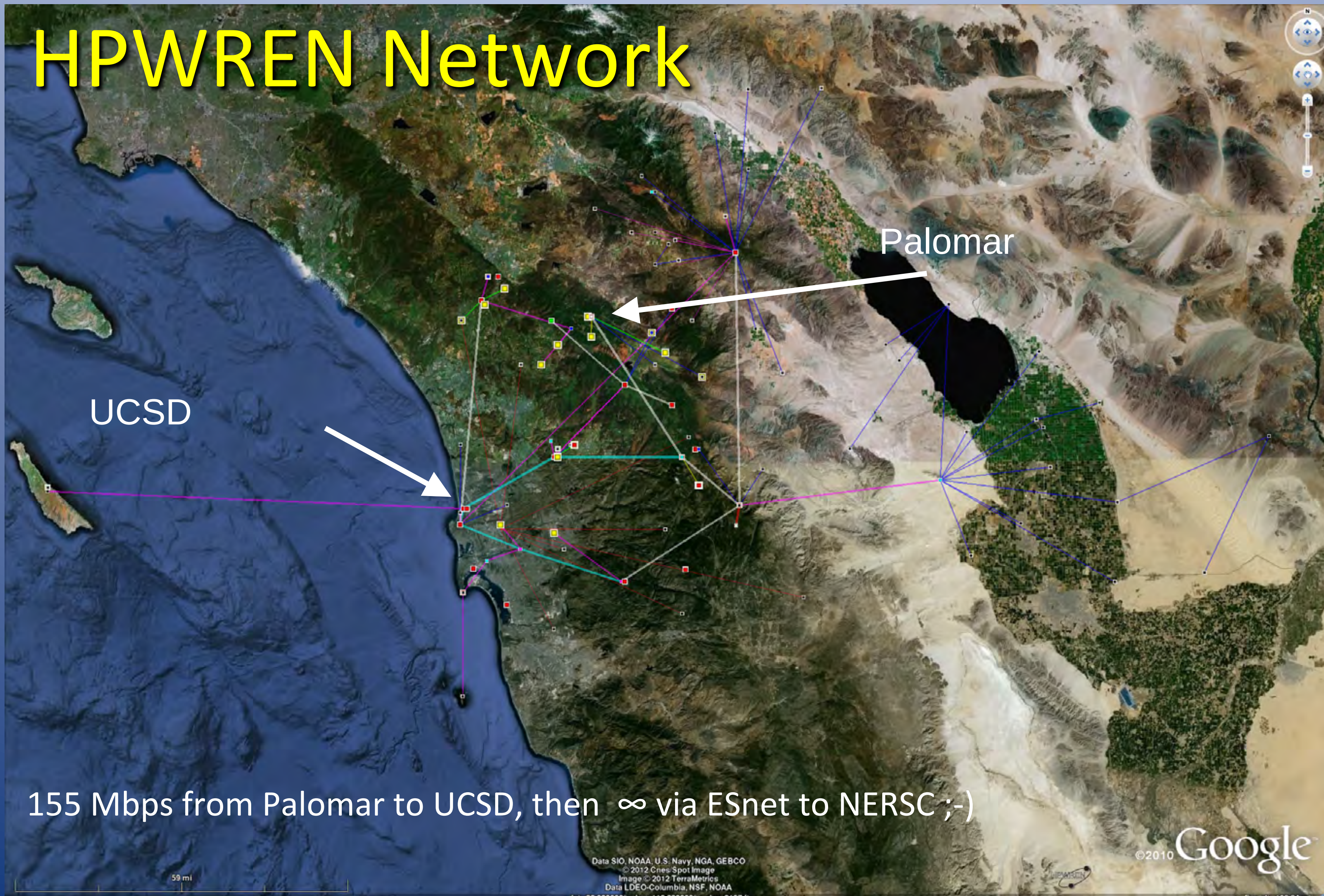
- 2 Cadences (Mar. - Nov.) 2009-2011
  - Nightly (35% of time) on nearby galaxies and clusters (g/r)
  - Every 3 nights (65% of time) on SDSS fields with minimum coverage of 2500 sq deg. (r) to 20th mag 10-sigma
  - H-alpha during bright time (full +/-2 days)

Nov-Feb, minute cadences on select fields.

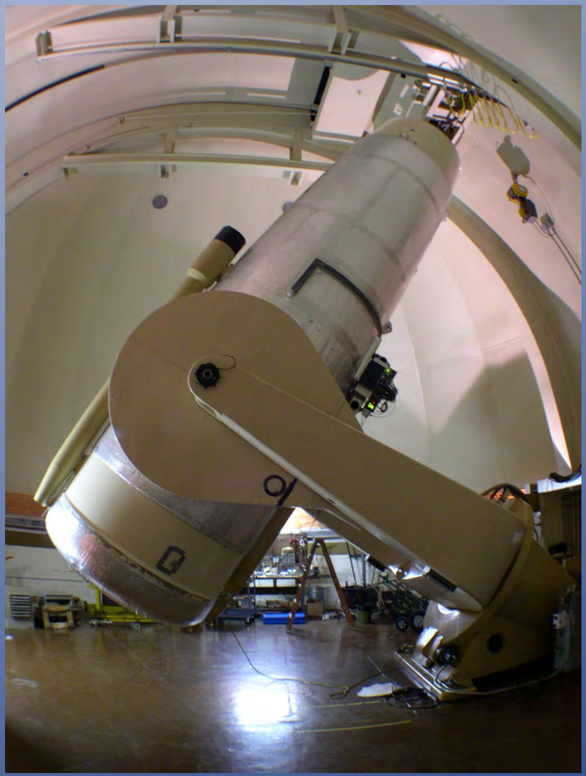
Supernovae circa 2009

Discovery and Follow-up

Instrumentation, system design, first results	Law, Kulkarni, Dekany et al. 2009 PASP 121 1395L
Science plans	Rau, Kulkarni, Law et al. 2009 PASP 121 1334R
2010 survey status	Law et al. 2010 SPIE 7735


HPWREN Network
Palomar
UCSD
155 Mbps from Palomar to UCSD, then ∞ via ESnet to NERSC ;-)
©2010 Google

PTF Camera



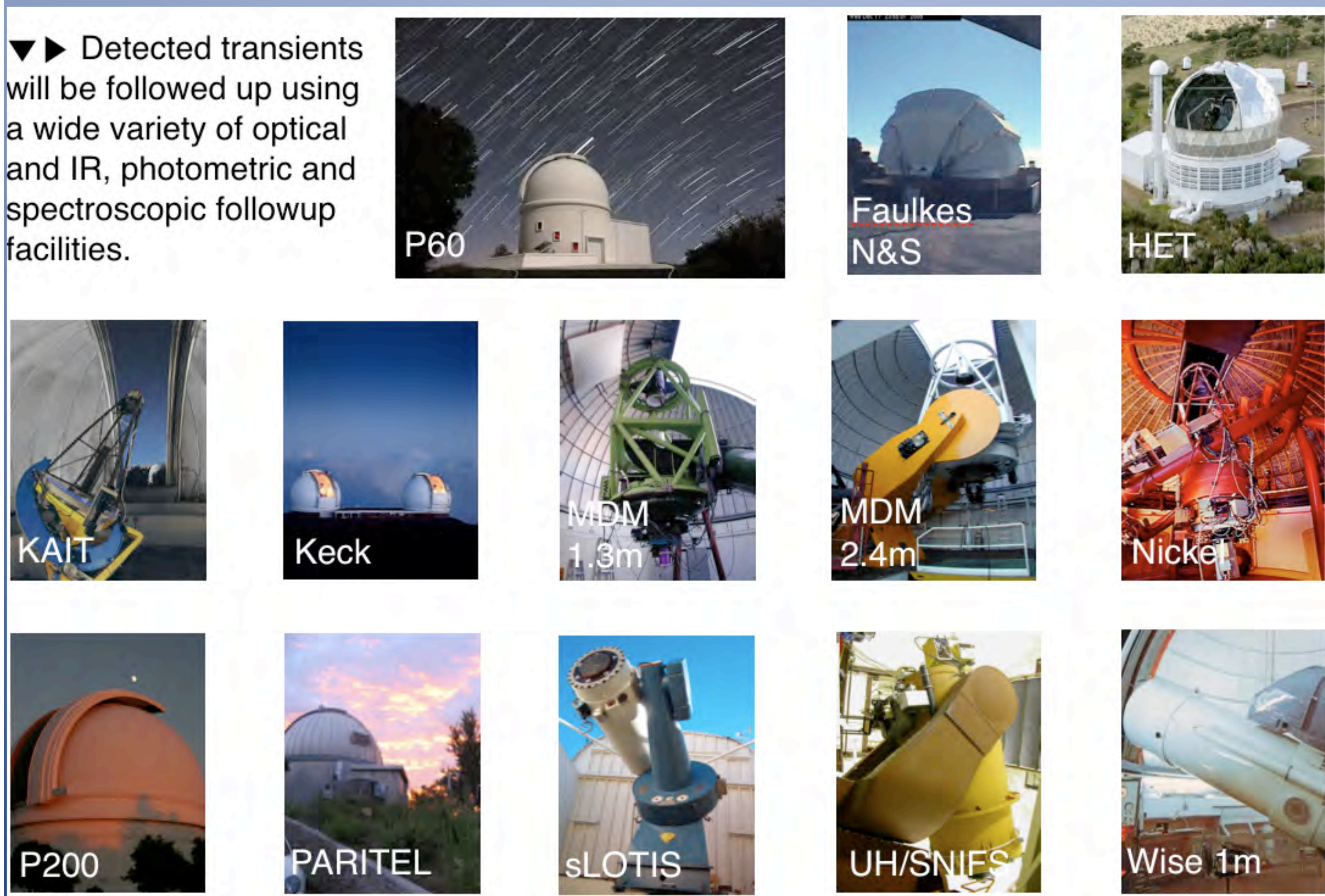
92 Mpixels, 1” resolution, R=21 in 60s

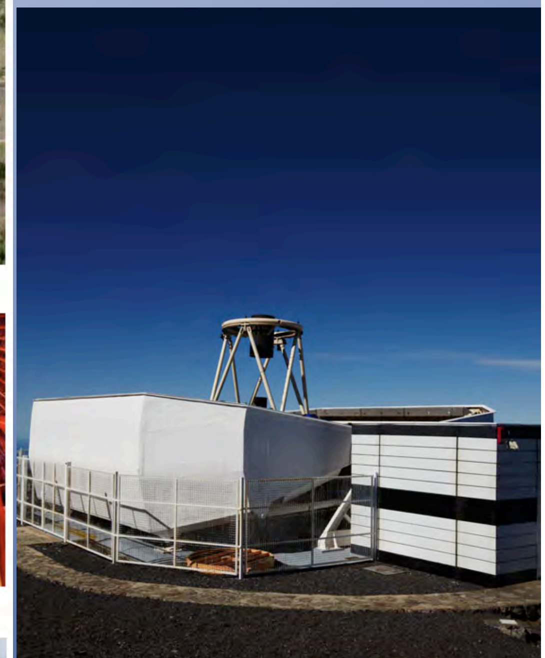
PTF Science

PTF Key Projects	
Various SNe	Dwarf novae
Transients in nearby galaxies	Core collapse SNe
RR Lyrae	Solar system objects
CVs	AGN
AM CVn	Blazars
Galactic dynamics	LIGO & Neutrino transients
Flare stars	Hostless transients
Nearby star kinematics	Orphan GRB afterglows
Type Ia Supernovae	Eclipsing stars and planets
Tidal events	H-alpha ½ sky survey

The power of PTF resides in its diverse science goals and follow-up.

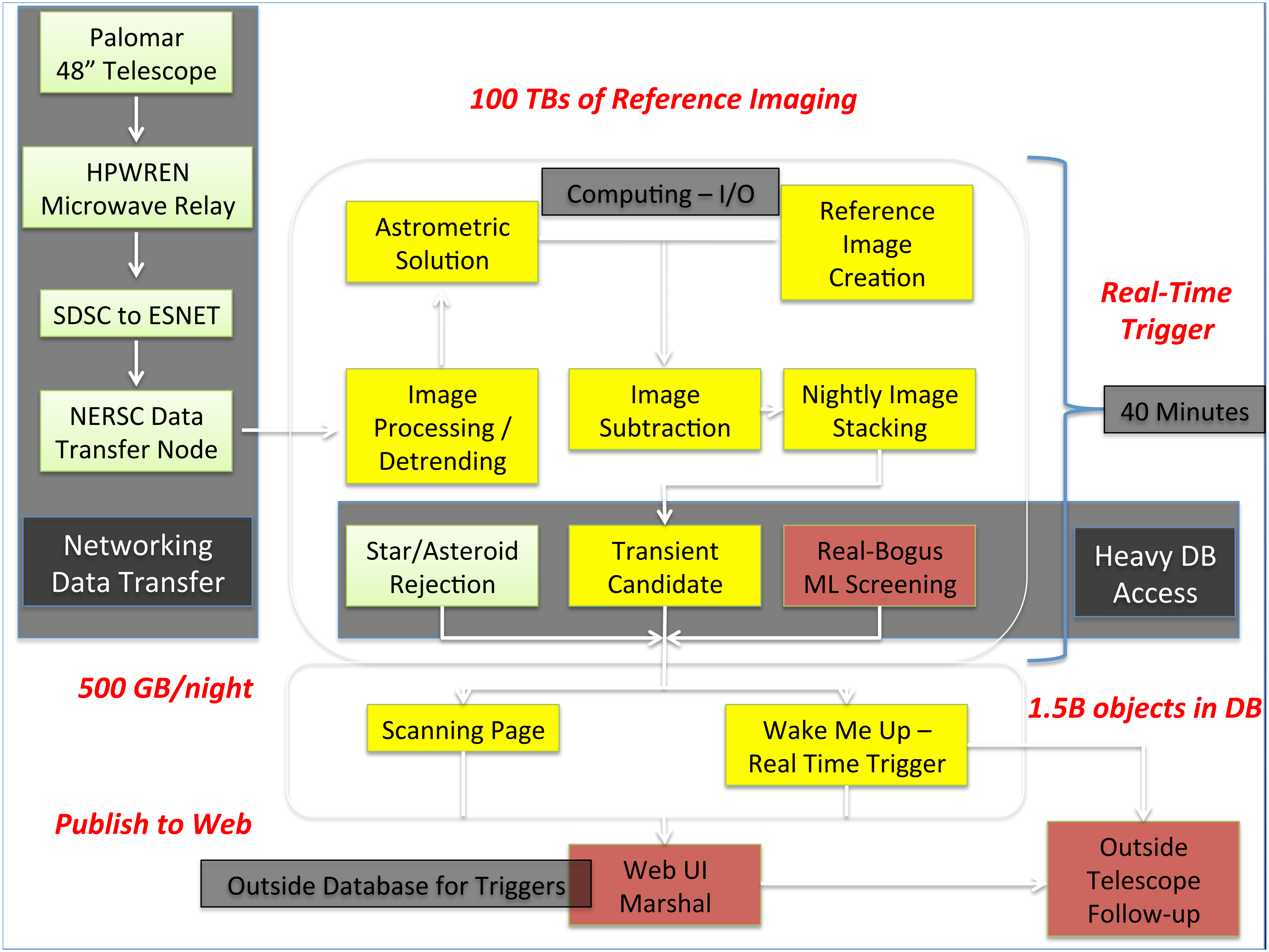
PTF Science



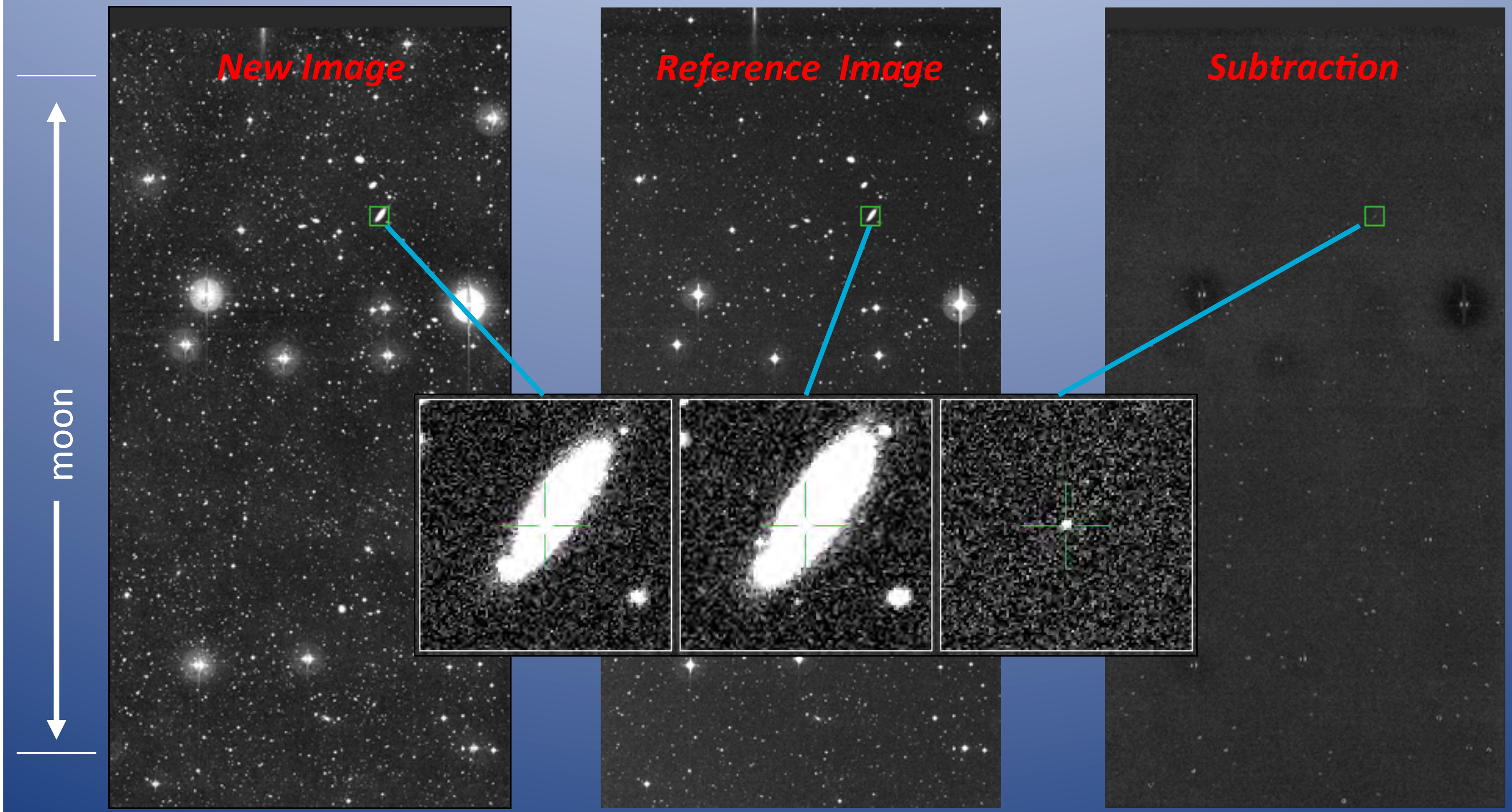


Liverpool Telescope

The power of PTF resides in its diverse science goals and follow-up.


Palomar 48” Telescope
HPWREN Microwave Relay
SDSC to ESNET
NERSC Data Transfer Node
Networking Data Transfer
100 TBs of Reference Imaging
Computing – I/O
Astrometric Solution
Reference Image Creation
Image Processing / Detrending
Image Subtraction
Nightly Image Stacking
Star/Asteroid Rejection
Transient Candidate
Real-Bogus ML Screening
Heavy DB Access
Real-Time Trigger
40 Minutes
500 GB/night
1.5B objects in DB
Scanning Page
Wake Me Up – Real Time Trigger
Publish to Web
Outside Database for Triggers
Web UI Marshal
Outside Telescope Follow-up

Real or Bogus – Machine Learning Analysis



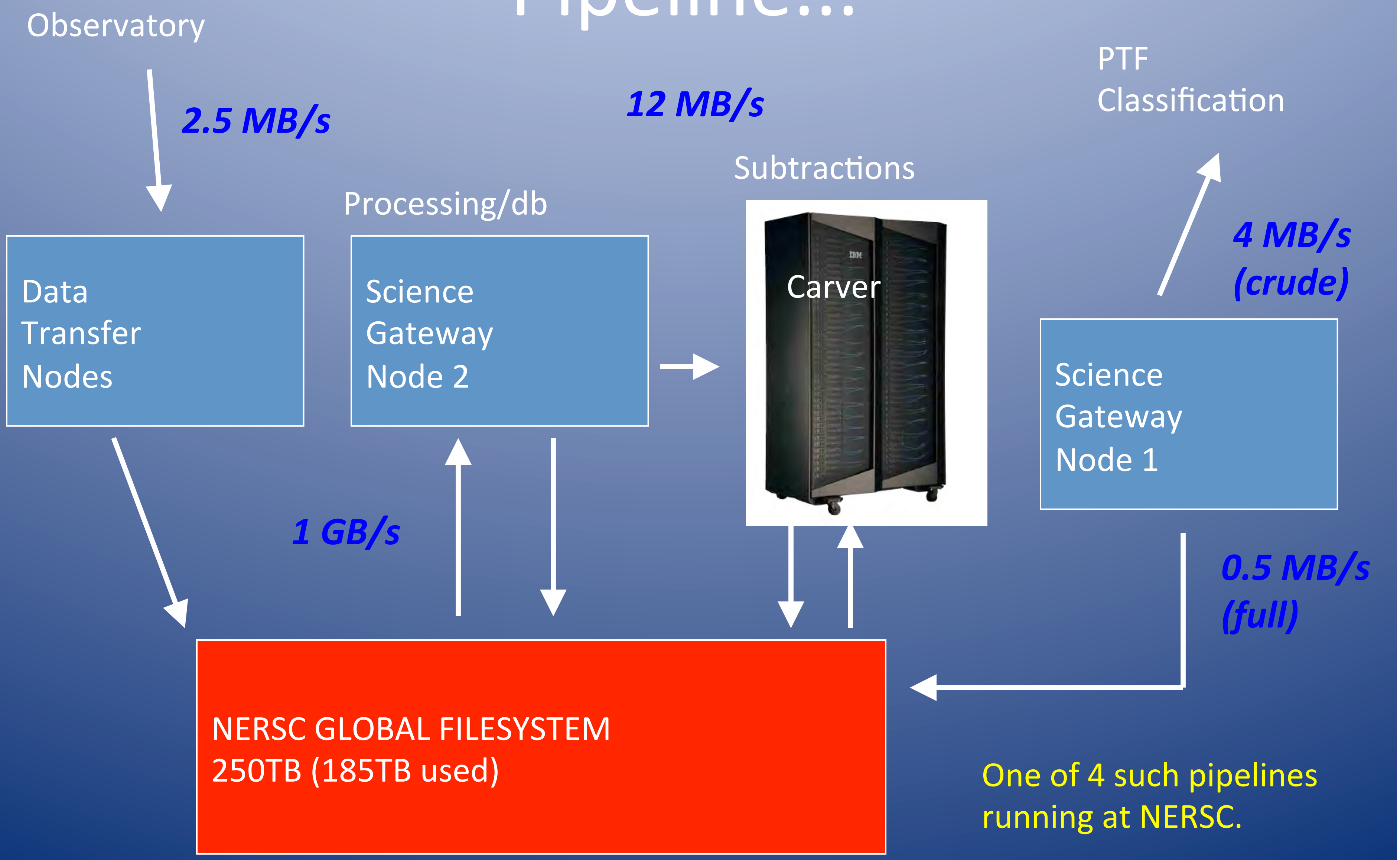
4096 X 2048 CCD images - over 3000 per night – producing 1.5M bogus detections, 50k known astrophysical objects and only 1-2 new astrophysical transients of interest every night. Machine learning is used to wade through this sea of garbage.

PTF Database

	R-band	g-band
images	1.82M	305k
subtractions	1.52M	146k
references	29.2k	6.3k
Candidates	890M	197M
Transients	42945	3120

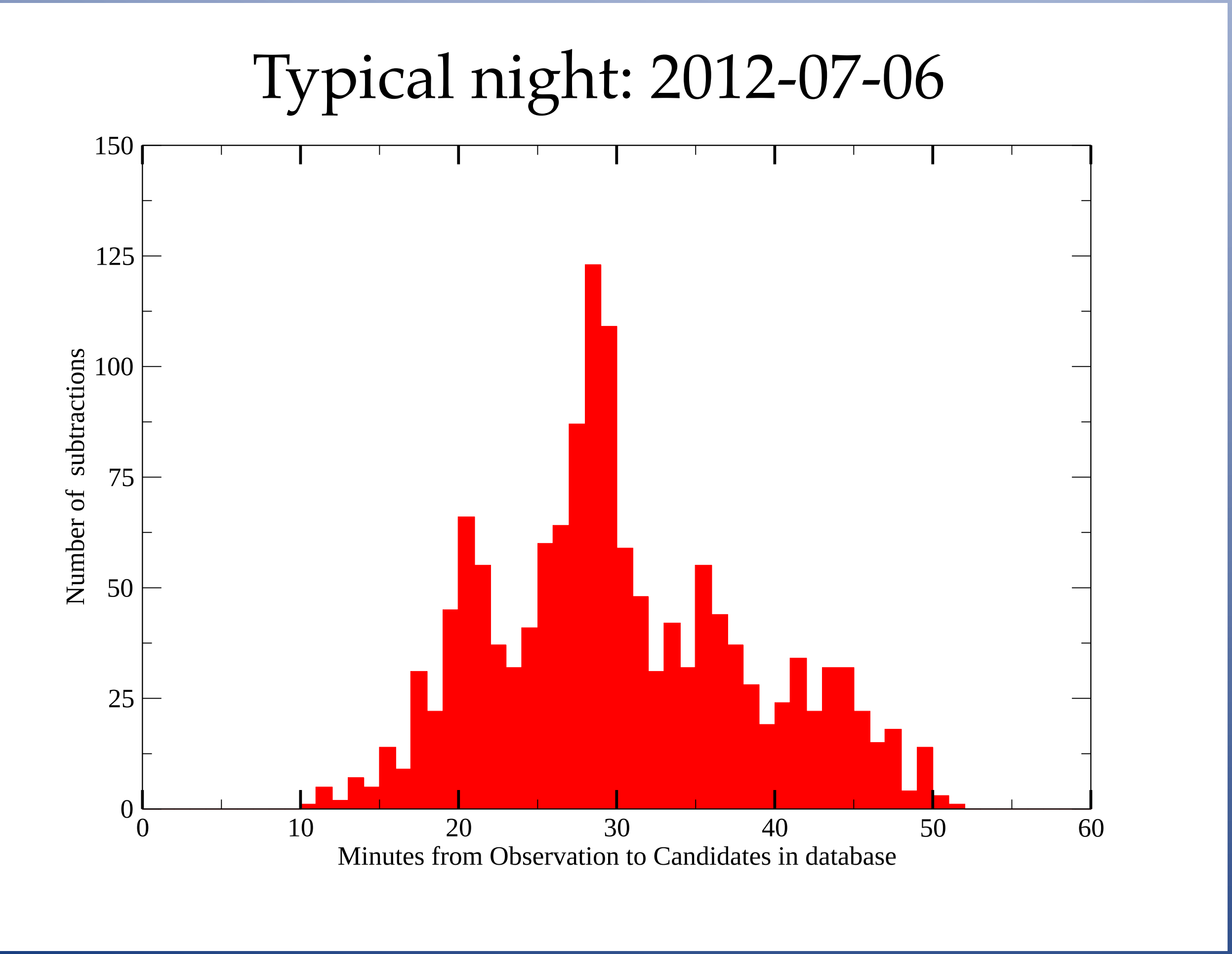
All in 851 nights.
An image is an individual chip (~0.7 sq. deg.)
The database is now 1 TB.

Pipeline...



One of 4 such pipelines running at NERSC.

Turn-around



What does "real-time" subtractions really mean?

For 95% of the nights all images are processed, subtractions are run, candidates are put into the database and the local universe script is run in < 1hr after observation.

Median turn-around is 30m.

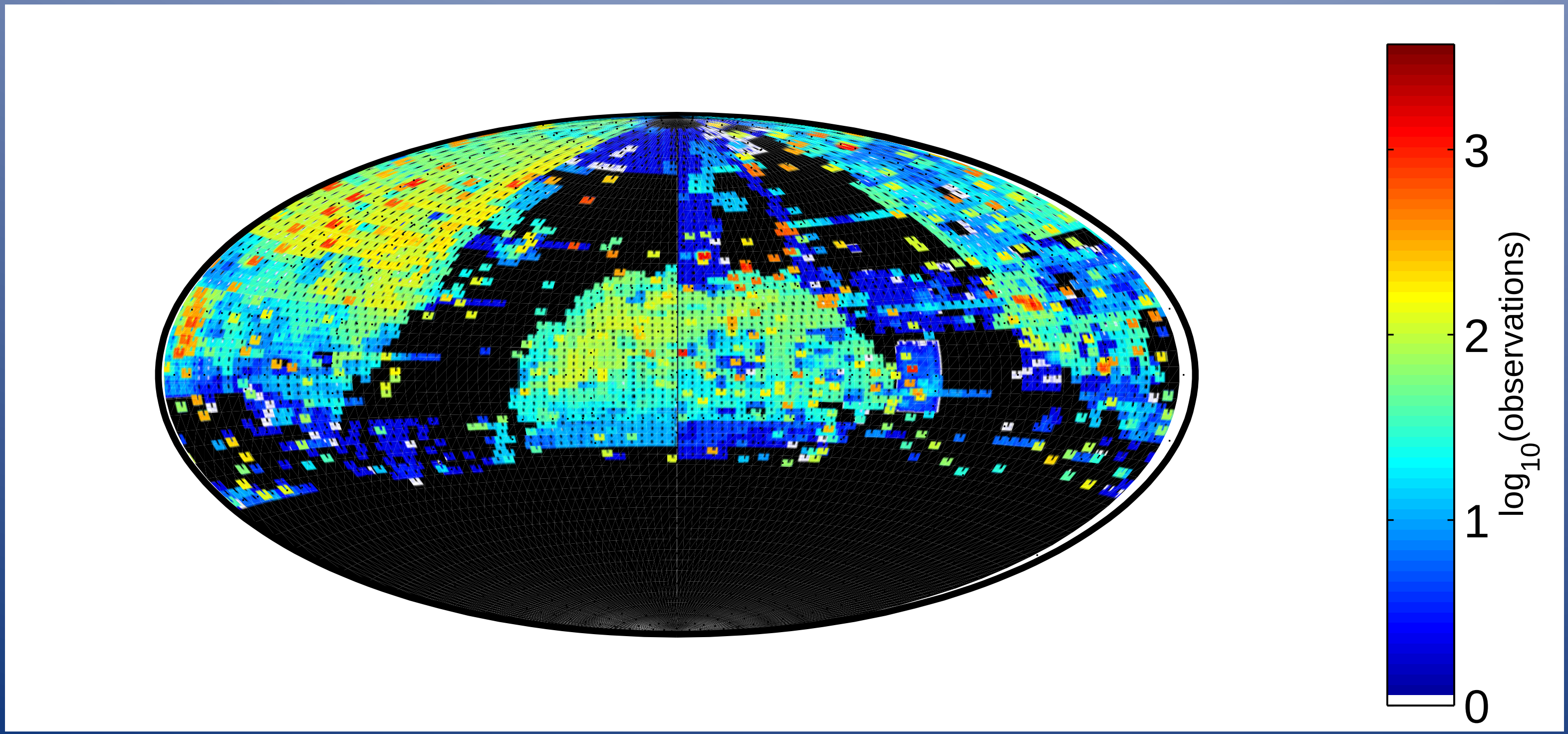
Now forced to be reduced to < 15min due to following discoveries:

PTF Sky Coverage

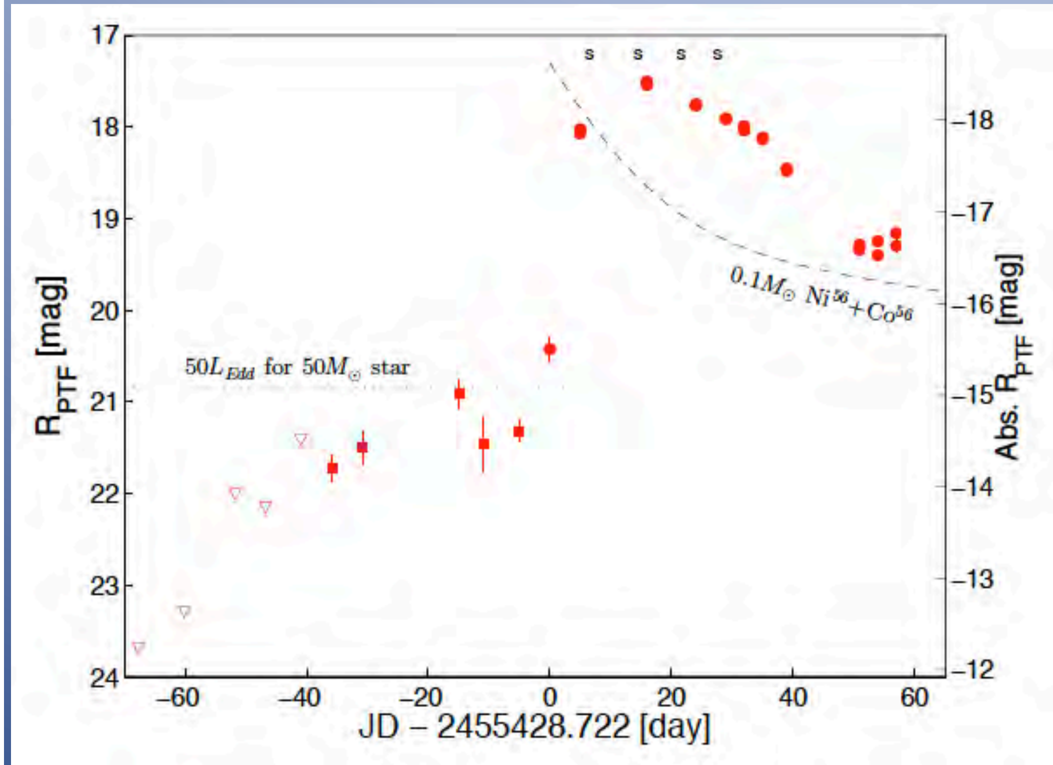
To date:

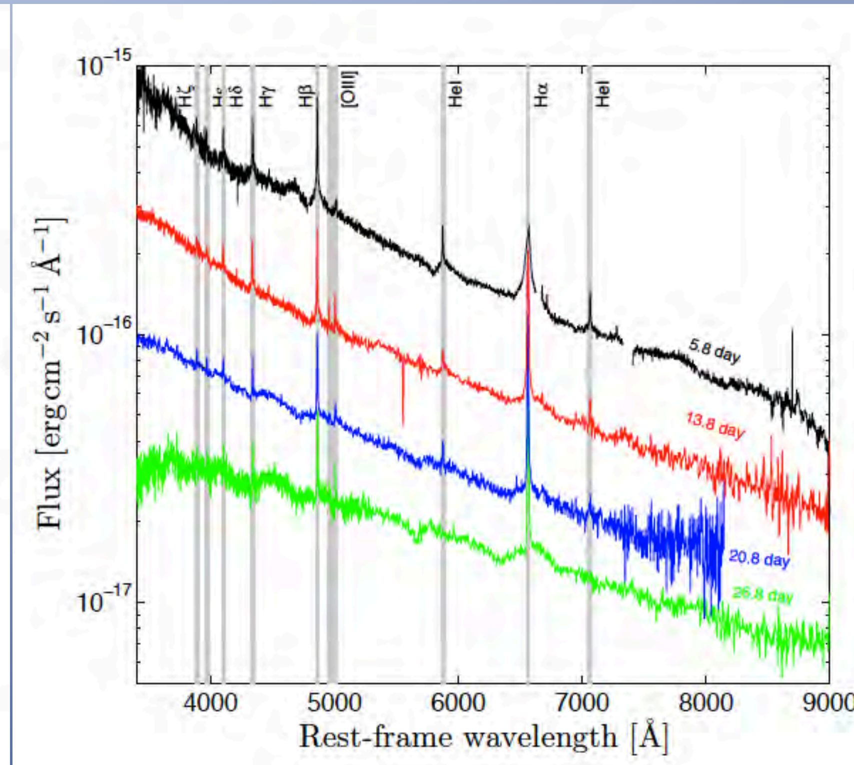
- 2285 Spectroscopically typed supernovae
- 10^5 Galactic Transients
- 10^4 Transients in M31

89 publications, 6 in *Nature* and 2 in *Science*



Pre-Outbursts

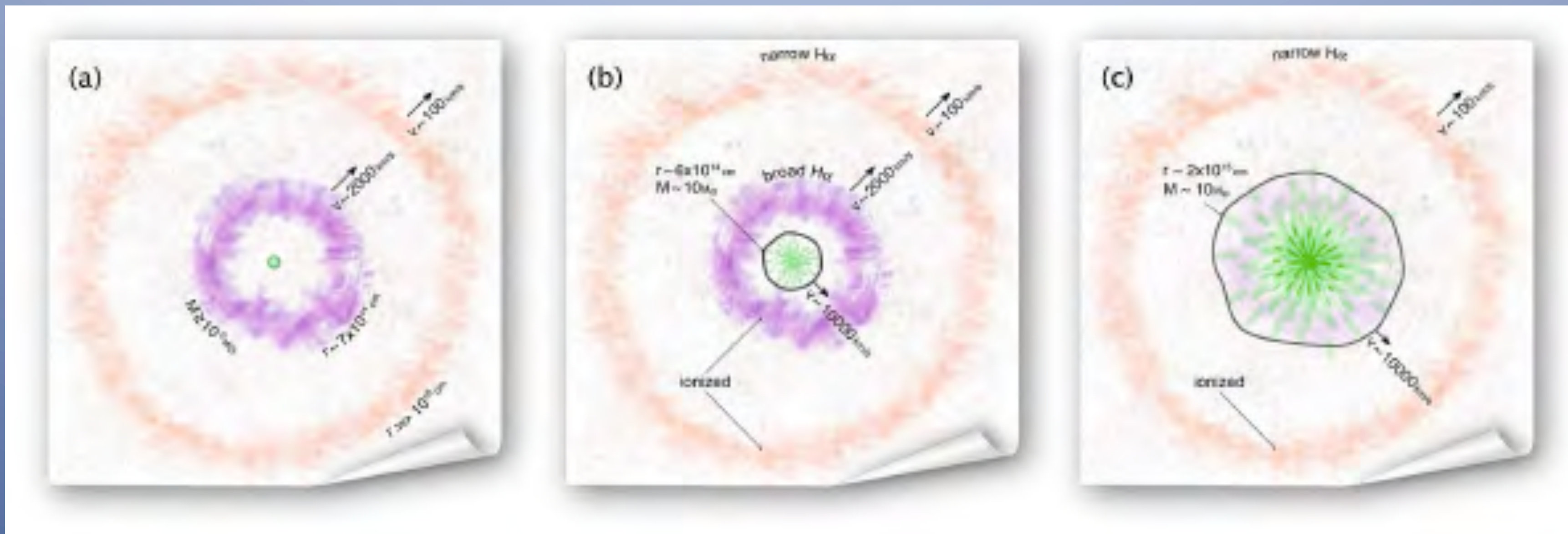




SN 2010mc - Ofek et al. (2013) *Nature &* SN 2011ht – Fraser et al. (2013) *ApJ*

Possible Explanation: Super-Eddington fusion luminosities, shortly prior to core collapse, drive convective motions that in turn excite gravity waves that propagate toward the stellar surface and eject substantial mass.

Pre-Outbursts

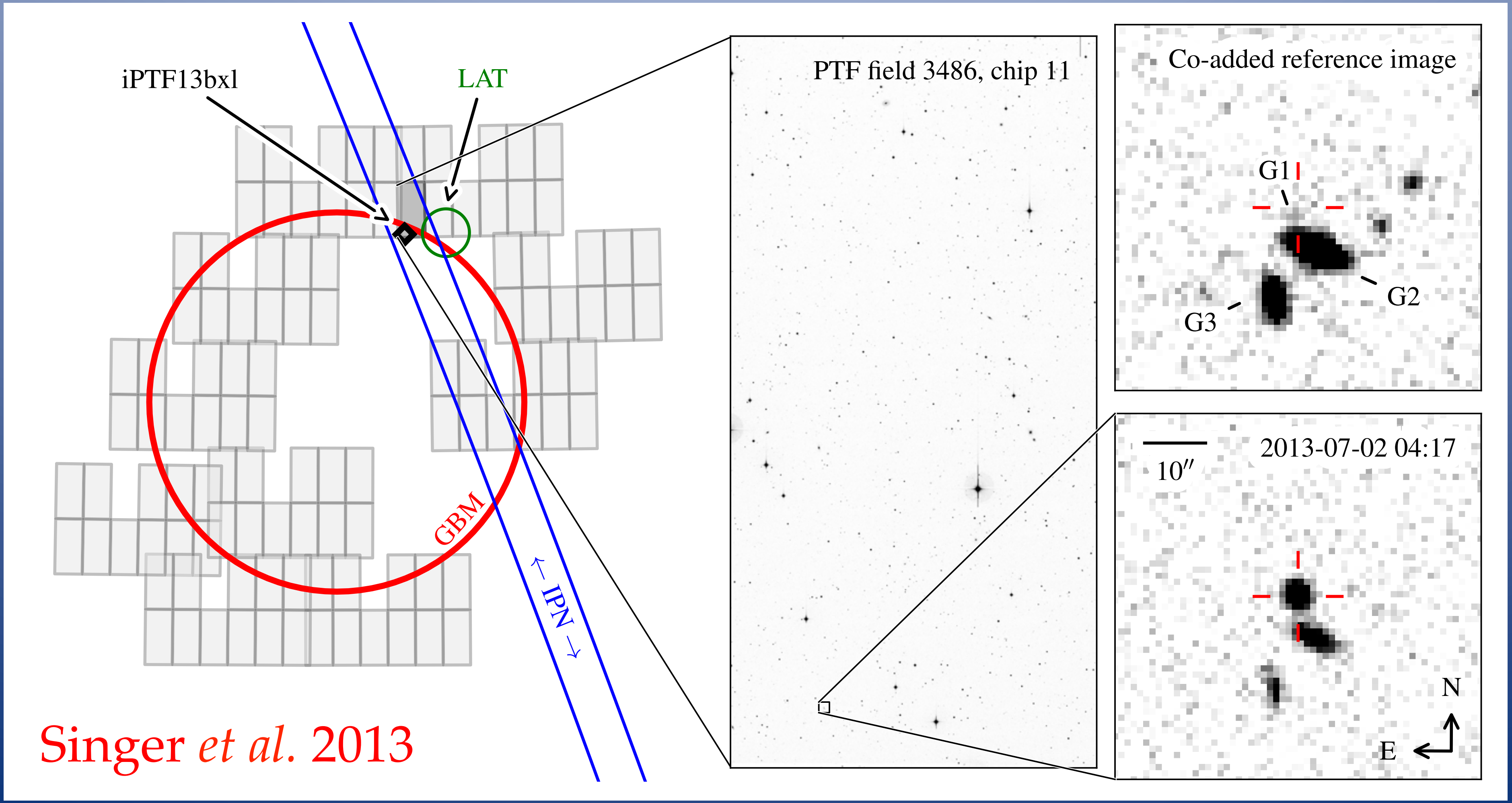


(a) 10^{-2} $M_{\odot}$ ejected one month earlier during pre-outburst ~2000 km/s

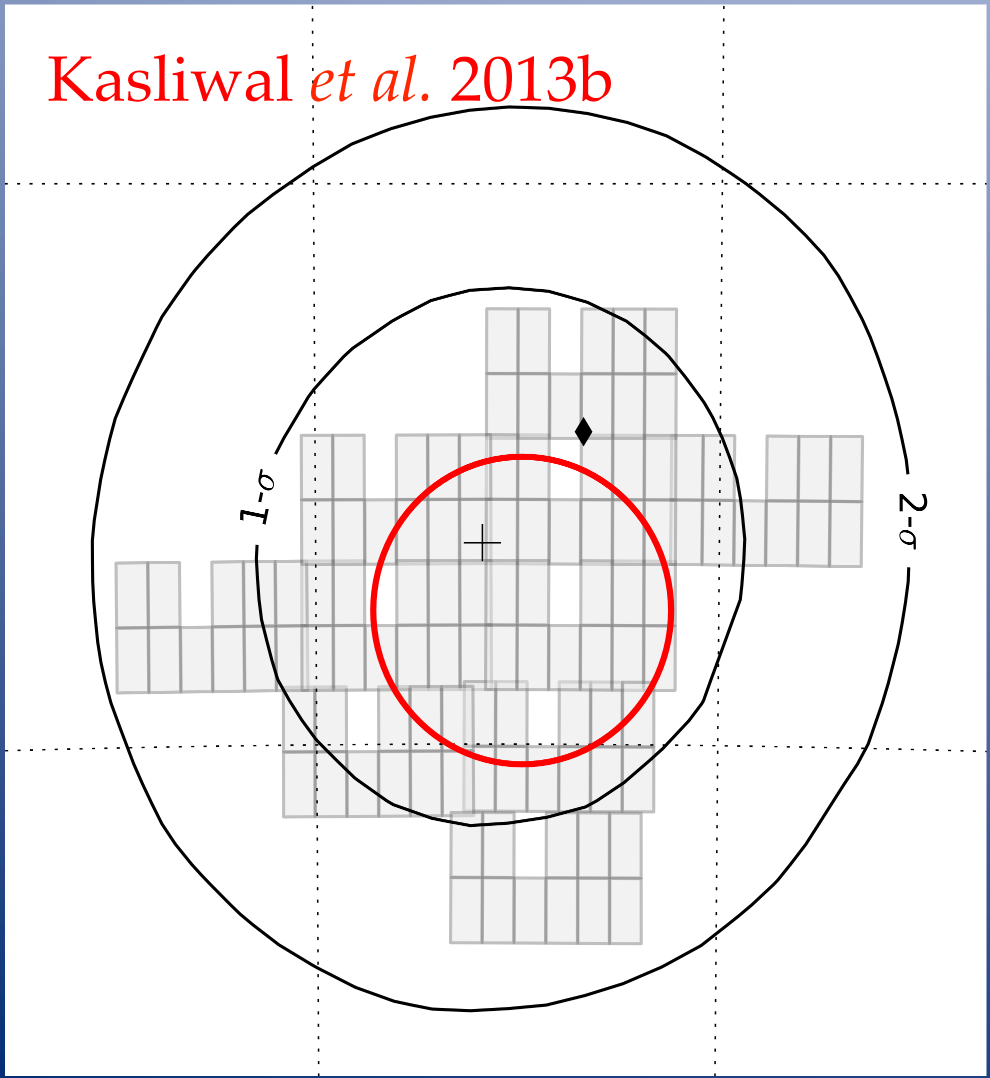
(b) At day ~ 5, the SN shock front (grey line at 10^4 km/s) is ionising the inner and outer shells which produce the broad and narrow H emission seen in the early-time spectra.

(c) At day ~ 20, the SN shock engulfs the inner shell, and the intermediate width Hα vanishes and narrower features appear: pre-pre-outbursts.

Overcoming wide & fast: iPTF13bxl in 71 deg²!



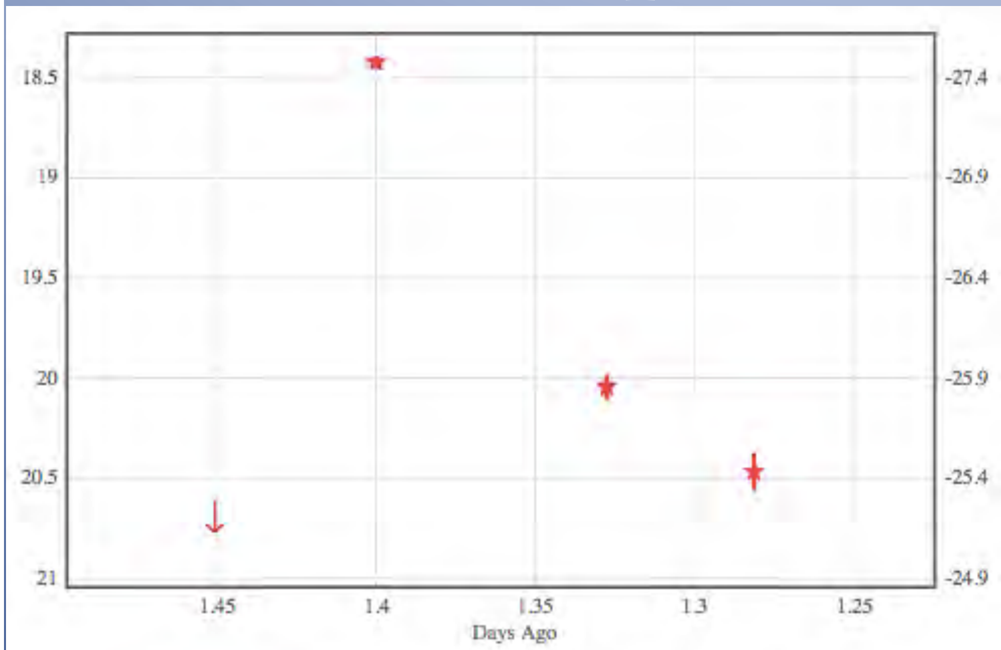
The second Fermi afterglow: iPTF13dsw at z=1.87!

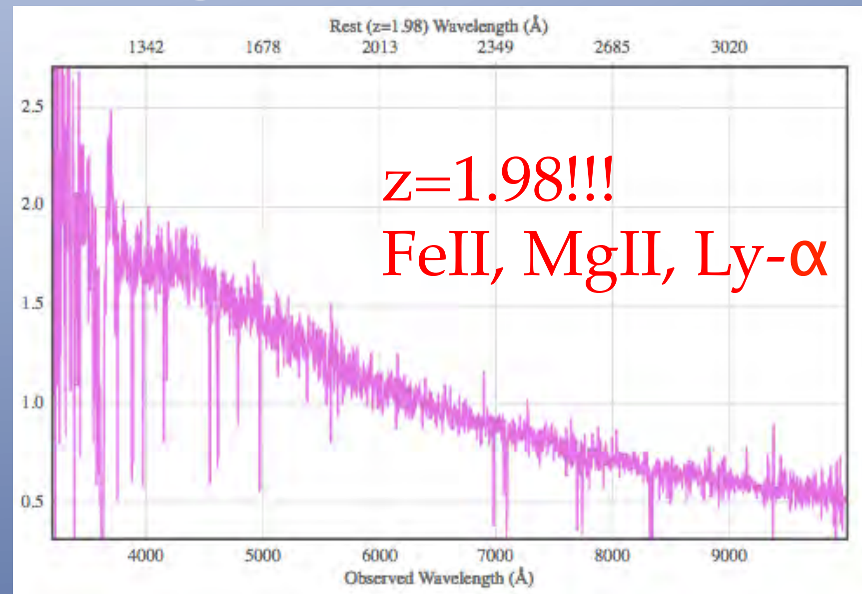


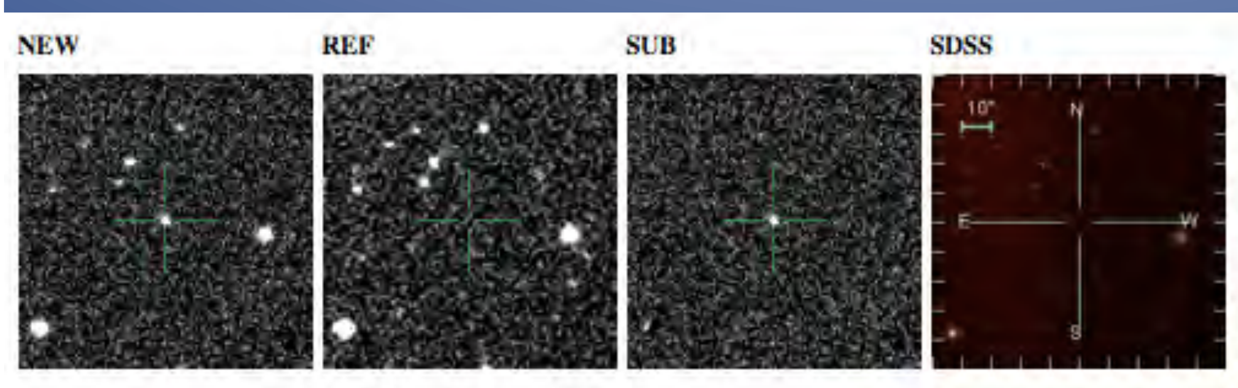
Overcoming
Wide, Fast & Faint

Pinpointing the afterglow
amidst 30,000 candidates

Orphan Afterglow



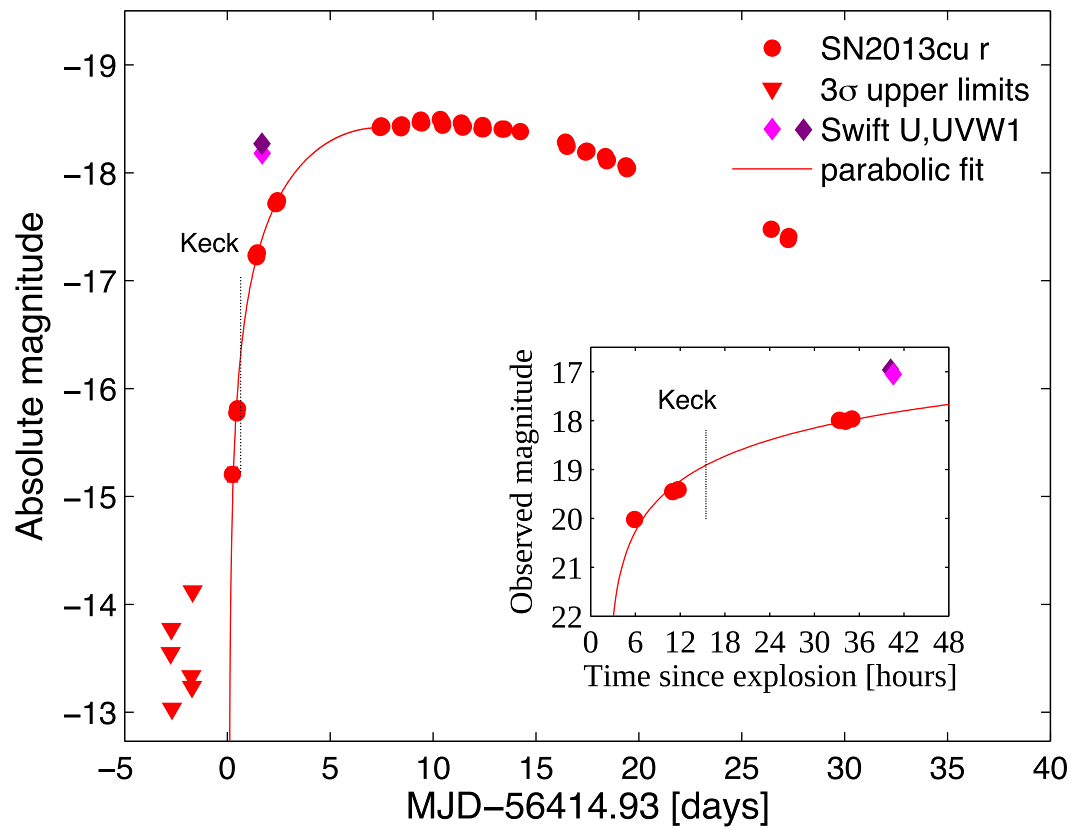




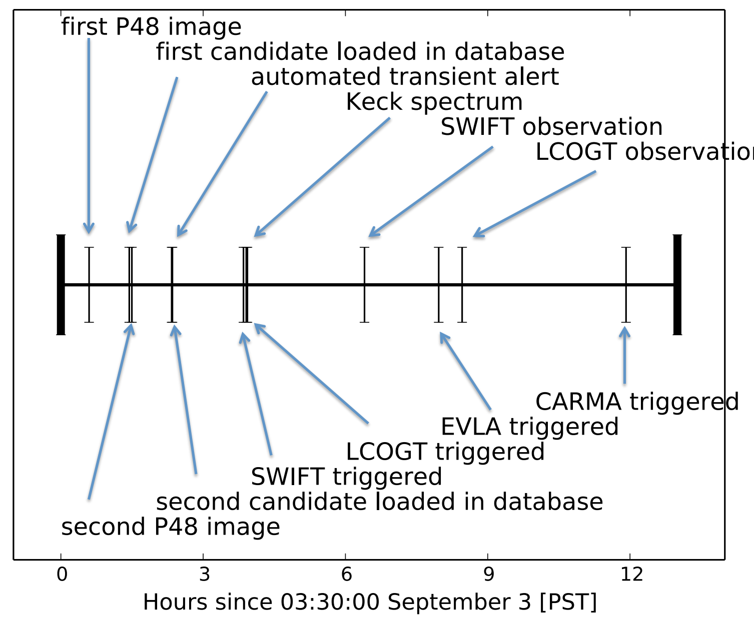
iPTF14yb
Cenko et al. 2014

IPN found a GRB (localization ~200-300 sq. deg.)
~15 min before first detection.....

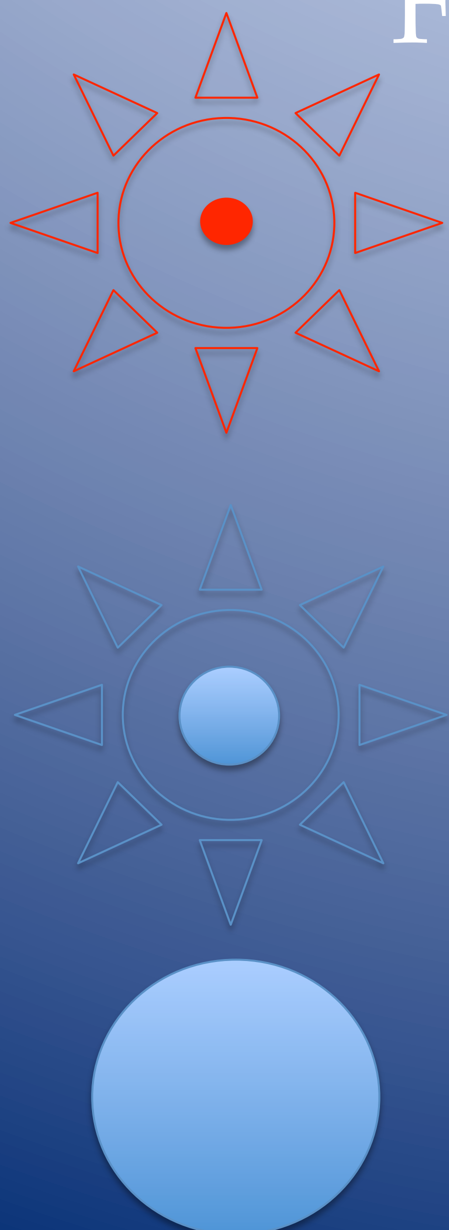
Flash Spectroscopy

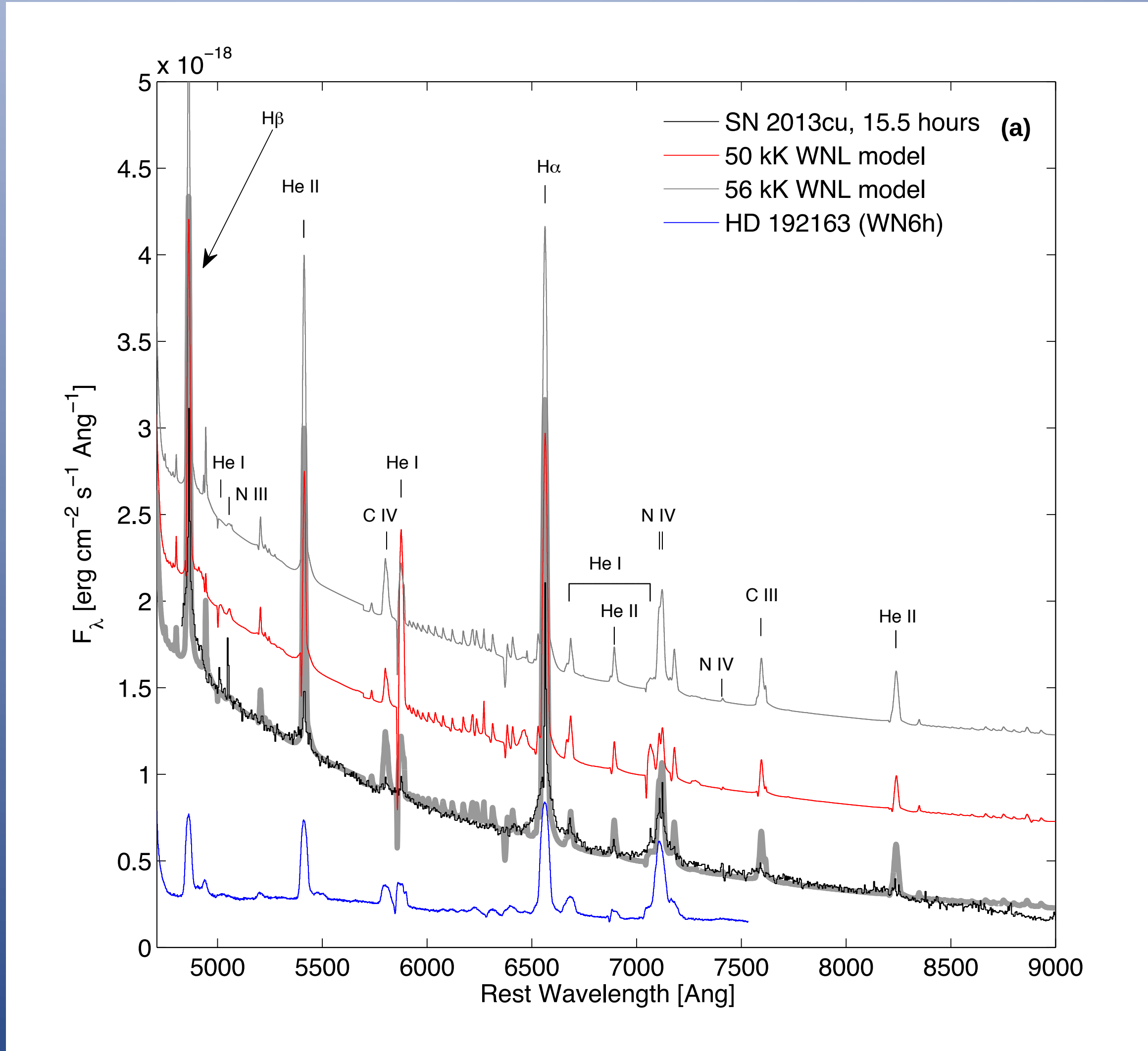


SN2013cu (iPTF13ast)
Gal-Yam et al. (2014) *Nature*

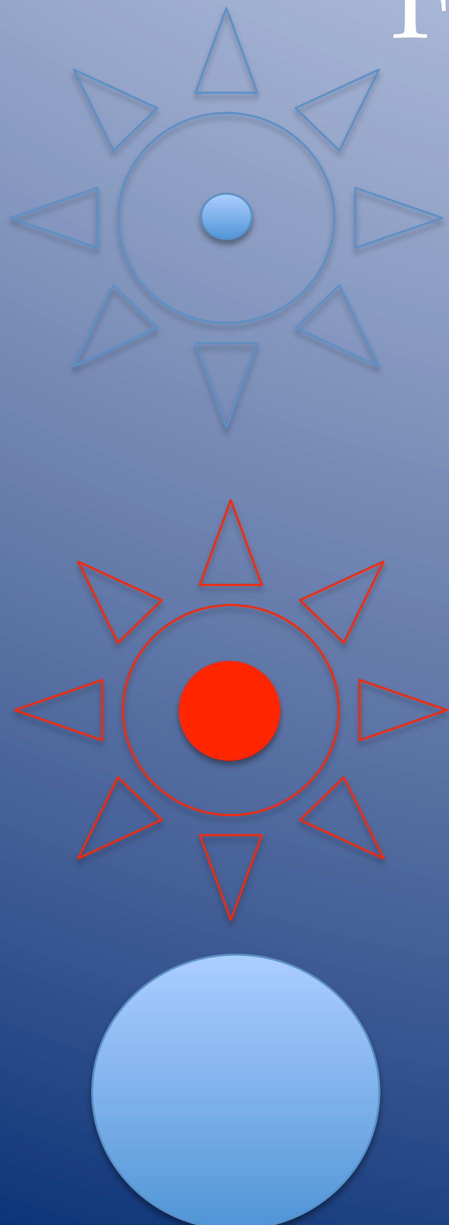


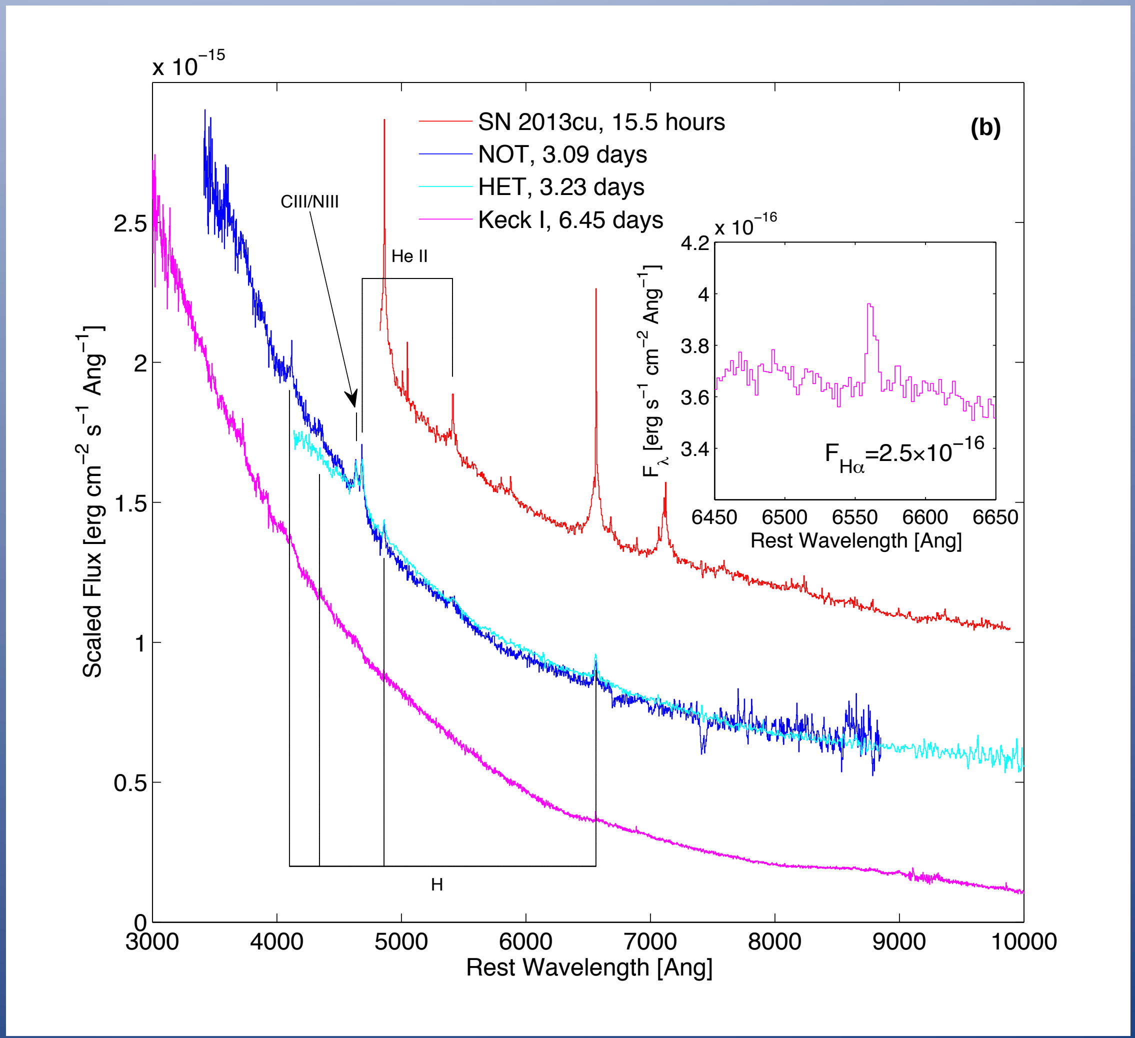
Flash Spectroscopy



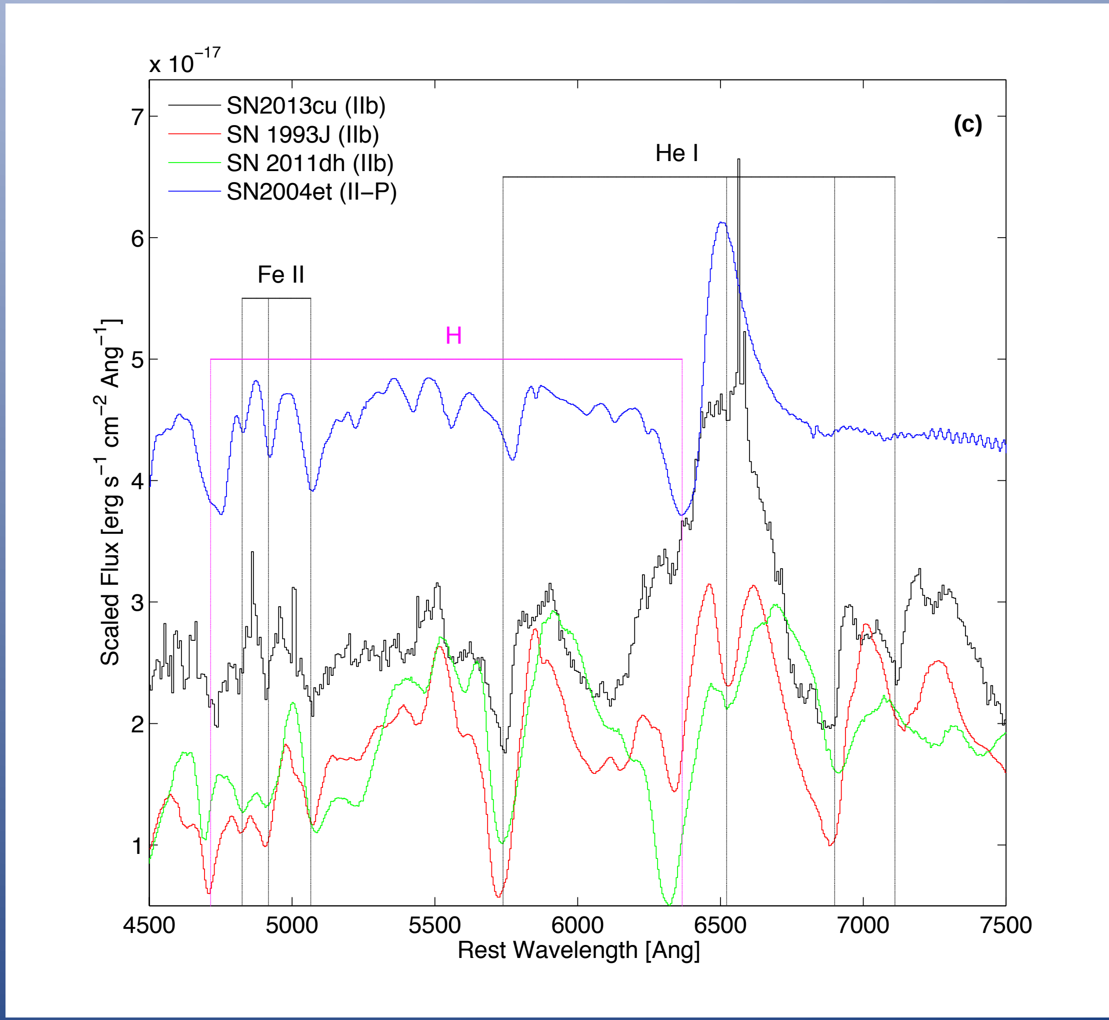


Flash Spectroscopy

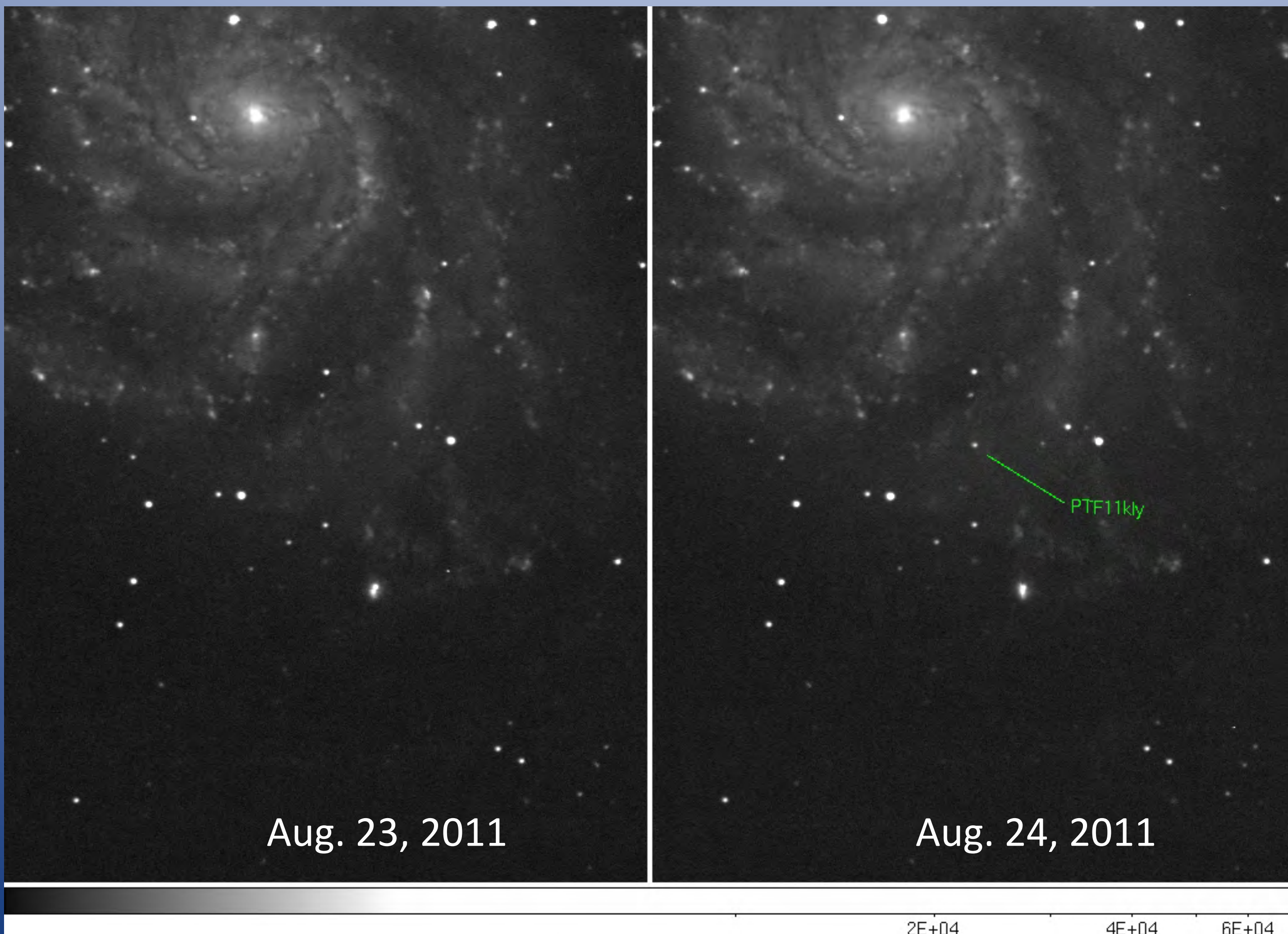




Flash Spectroscopy



PTF11kly (SN 2011fe)



Caught at magnitude ~17.4, ~100,000 times fainter than the eye can see.

20% rise between first 2 detections separated by 1hr

~1/1000 as bright as the SN reached at peak brightness.

Discovery

Young Type Ia Supernova PTF11kly in M101

ATel #3581; *Peter Nugent (LBL/UCB), Mark Sullivan (Oxford), David Bersier (Liverpool John Moores), D.A. Howell (LCOGT/UCSB), Rollin Thomas (LBL), Phil James (Liverpool John Moores)*

on ***24 Aug 2011; 23:47 UT***

Distributed as an Instant Email Notice Supernovae

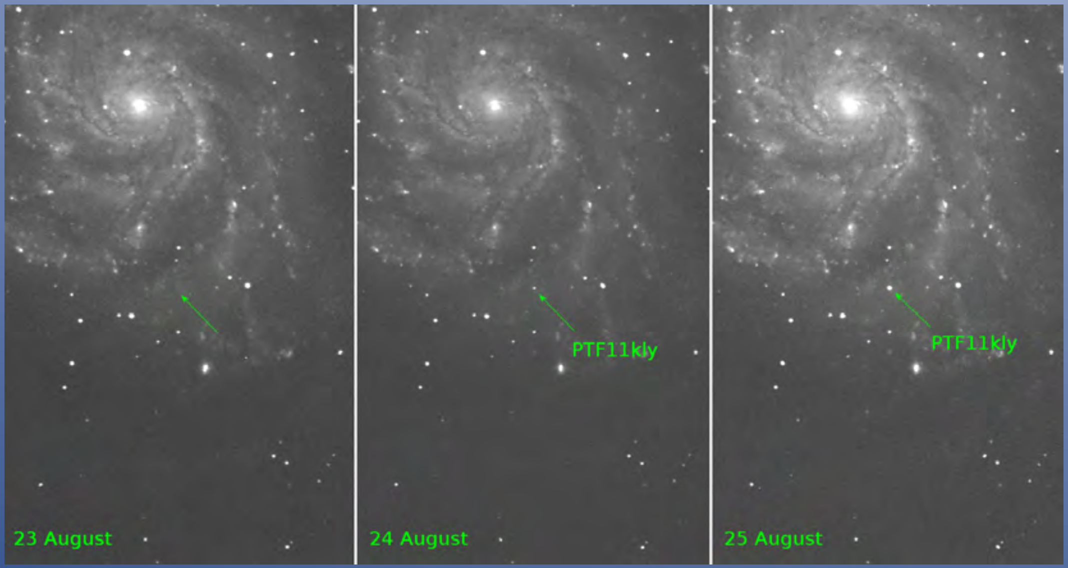
Credential Certification: R. C. Thomas (rcthomas@lbl.gov)

Subjects: Optical, Supernovae

Referred to by ATel #: 3582, 3583, 3584, 3588, 3589, 3590, 3592, 3594, 3597, 3598, 3602, 3605, 3607, 3620, 3623, 3642

The Type Ia supernova science working group of the Palomar Transient Factory (ATEL #1964) reports the discovery of the Type Ia supernova PTF11kly at RA=14:03:05.81, Dec=+54:16:25.4 (J2000) in the host galaxy M101. The supernova was discovered on Aug. 24 UT when it was at magnitude 17.2 in g-band (calibrated with respect to the USNO catalog). There was nothing at this location on Aug 23 UT to a limiting magnitude of 20.6. A preliminary spectrum obtained Aug 24 UT with FRODOSPEC on the Liverpool Telescope indicates that PTF11kly is probably a very young Type Ia supernova: Broad absorption lines (particularly Ca II IR triplet) are visible. The presence of an H-alpha feature is confidently rejected. STIS/UV spectroscopic observations on the Hubble Space Telescope are being triggered by the ToO program "Towards a Physical Understanding of the Diversity of Type Ia Supernovae" (PI: R. Ellis). Given that the supernova should brighten by 6 magnitudes, the strong age constraint, and the fact that the supernova will soon be behind the sun, we strongly encourage additional follow-up of this source at all wavelengths.

SN 2011fe is the closest Type Ia supernova in the last 25 years and the 5th brightest supernova of any type in the last century. It was found by the Palomar Transient Factory, which processes its data at NERSC.



It was caught 11 hours after explosion, and has been followed by almost every professional telescope on earth and in space – could be seen in binoculars.

These observations have led to the best constraints to-date for the progenitors of these supernova, and have added several new wrinkles on how these runaway thermonuclear explosions take place.

Pipeline…

Observatory

2.5 MB/s

Data Transfer Nodes

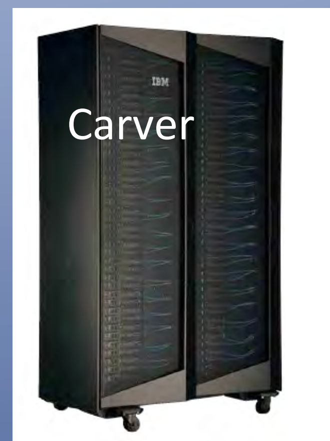
Processing/db

Science Gateway Node 2

1 GB/s

12 MB/s

Subtractions



PTF Classification

4 MB/s (crude)

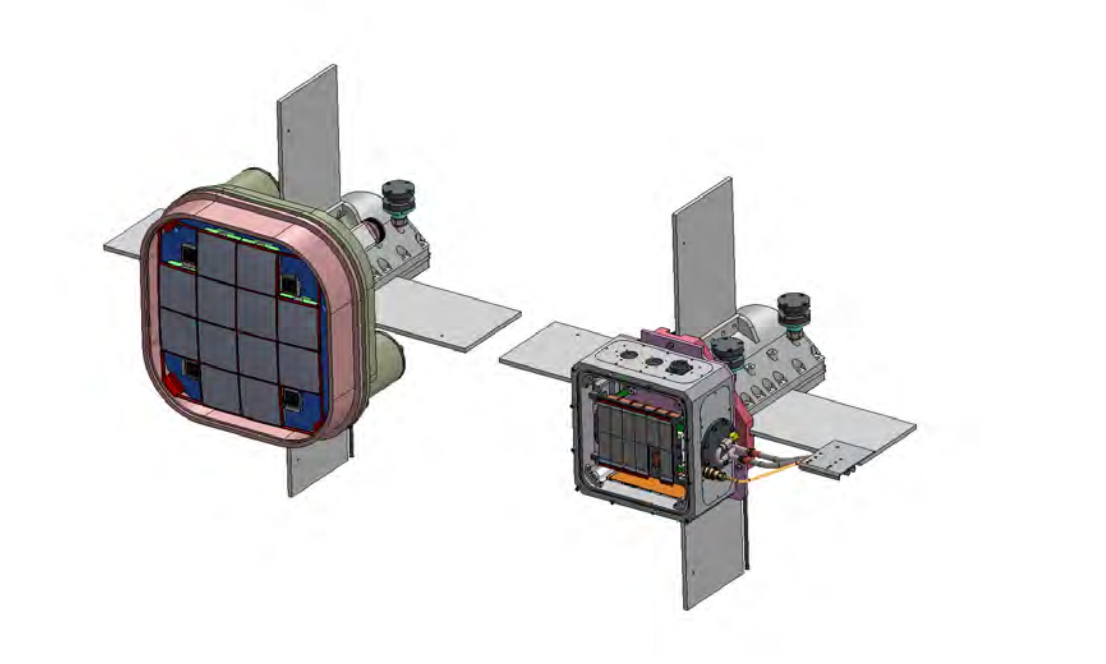
Science Gateway Node 1

0.5 MB/s (full)

NERSC GLOBAL FILESYSTEM
250TB (185TB used)

Trigger new subtractions: output now greater than input ~ 1 TB/night

Future Surveys



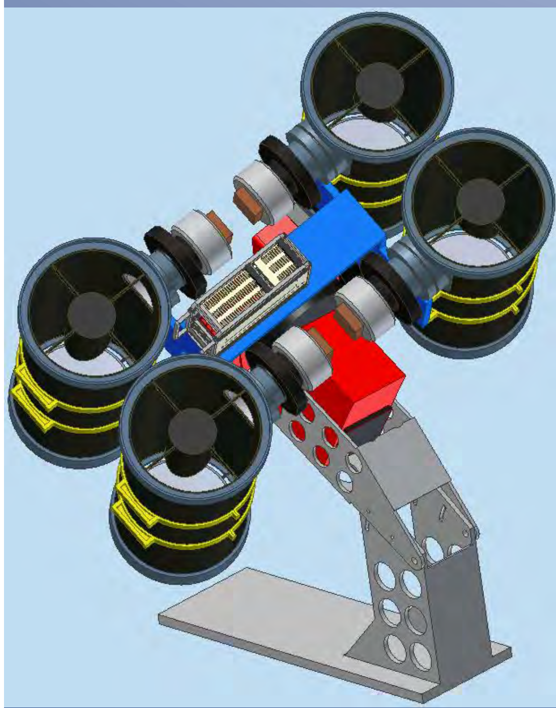
Telescope	AΩ
*i*PTF/PTF	8.7
DES	11.7
ZTF	42.6
LSST	82.2

ZTF (46 deg.^{2}) *i*PTF (7.2deg.^{2})

ZTF will be the largest imager until LSST

ATLAS

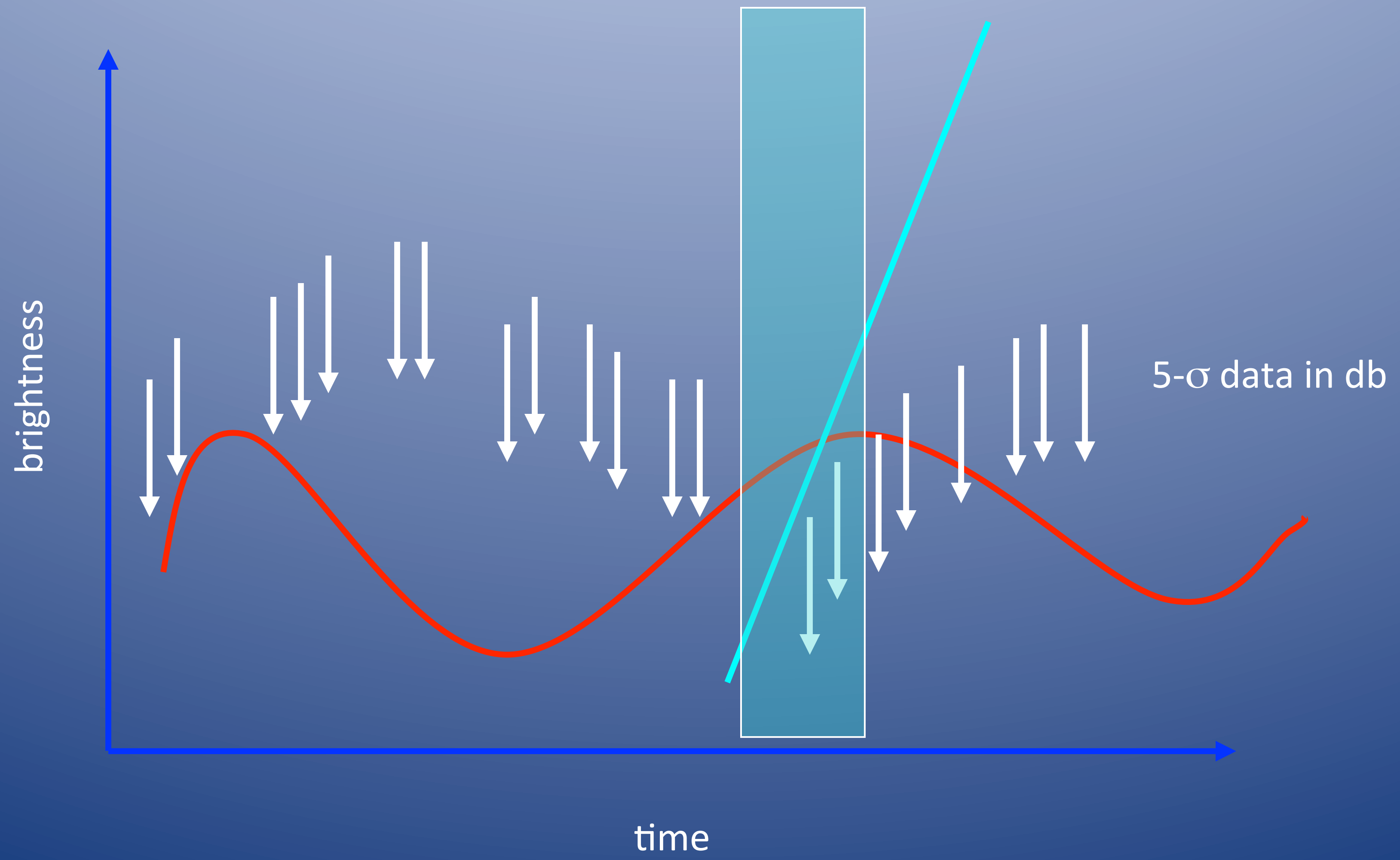
Asteroid Terrestrial-impact Last Alert System Project -



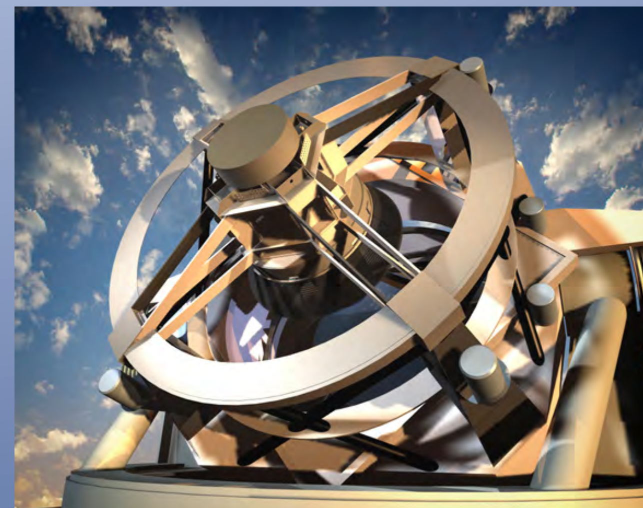
Tunguska – 8Mtons

The Chelyabinsk meteor entered the Earth's atmosphere at around 40,000 mph before breaking into chunks and streaking the sky with fireball and vapor trails. It is estimated to be about 50 feet across with a mass of 10,000 tons. 500 ktons of TNT – 25XHiroshima .

Bottlenecks…crude *vs*. real



Future



LSST - 15TB data/night
Only one 30-m telescope
How many triggers can we handle???

LSST...

Site Roles and their Functions

- Base Facility
  Real-time Processing and Alert Generation, Long-term storage (copy 1)
- Archive Center
  Nightly Reprocessing, Data Release Processing, Long-term Storage (copy 2)
- Data Access Centers (DACs)
  Data Access and User Services
- System Operations Center (SOC)
  System Supervisory Monitoring Control & End User Support/Help Desk

* Co-located DAC: shares infrastructure with Archive Center

** Co-located DAC: shares infrastructure with Base Facility