Frontiers in time-domain astrophysics

-the intermediate Palomar Transient Factory and the Zwicky Transient Facility

Ariel Goobar
Stockholm University

Oskar Klein centre

Time domain & Breakthroughs

- Variable stars (Cepheids, RR-Lyrae)
  - yardsticks for Local Universe
- Pulsars
  - Tests of GR
- ν's from SN87A, AGNs, GRBs,…
  - physics of compact objects, collapse,..
- Supernovae
  - H_0
  - accelerated expansion

Excitements to come soon (amen!) include:

- Gravitational wave sources (+ EM radiation!)
- Galactic SN neutrinos (+EM)
- Everything we have *not* (yet) thought about!

Transients @ optical wavelengths

Our knowledge/discovery potential is limited by survey parameters:

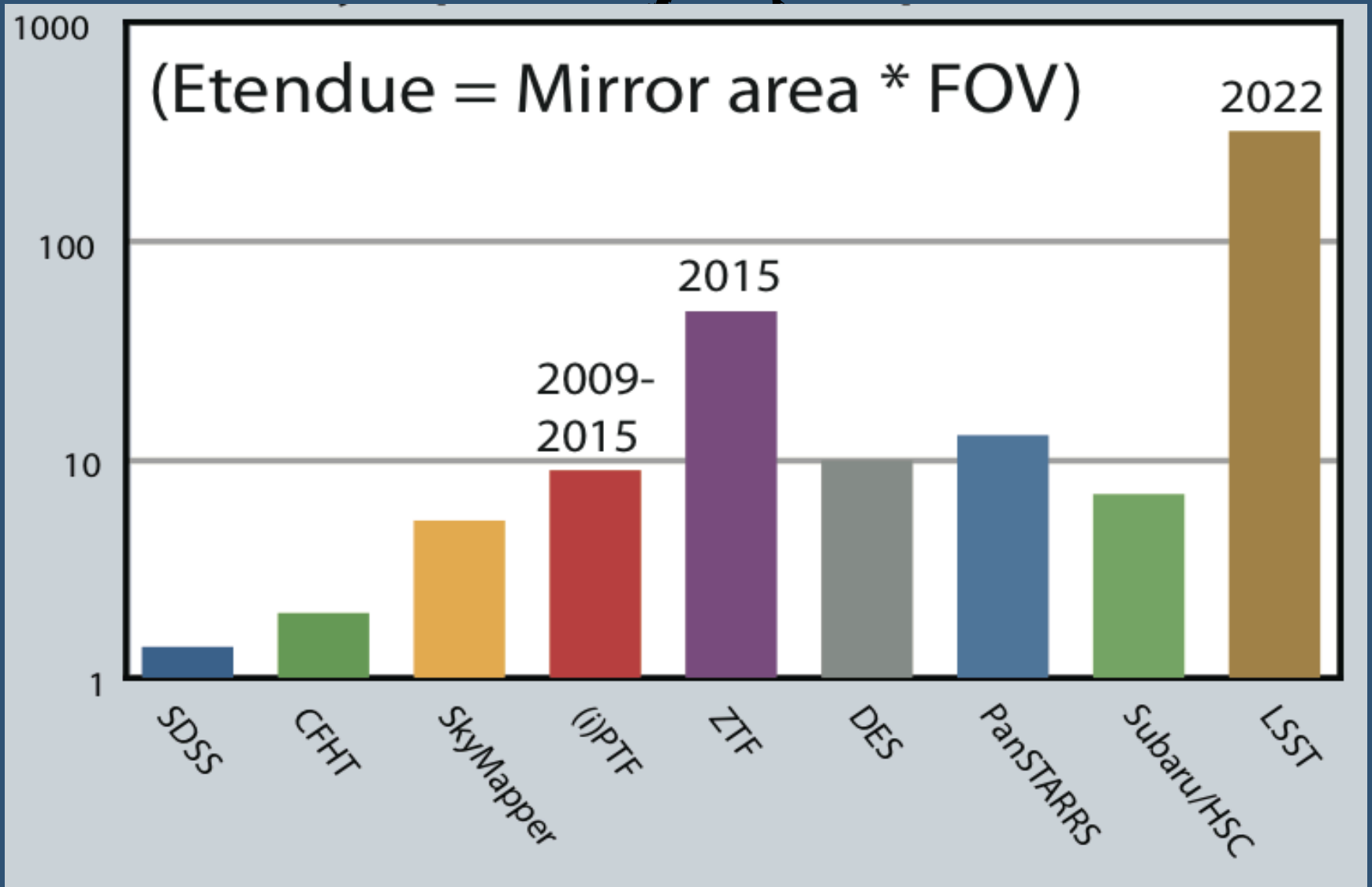
- flux sensitivity
- cadence (how often a field is revisited)
- Wavelength range

-- Surprises may wait around the corner

-- need to push the observational boundaries!

(c.f. supernova cosmology)

Optical Surveys "Survey Speed"



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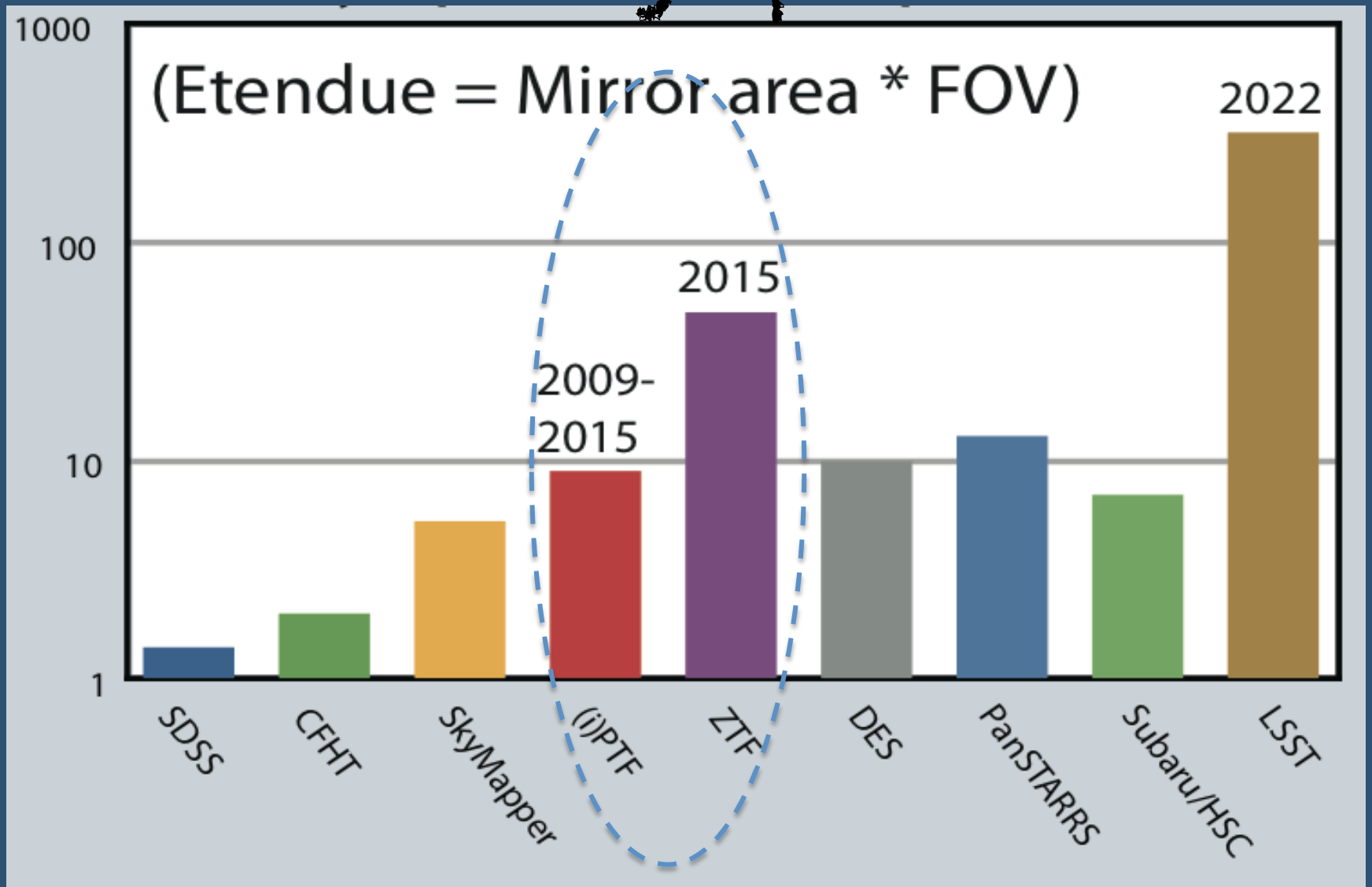
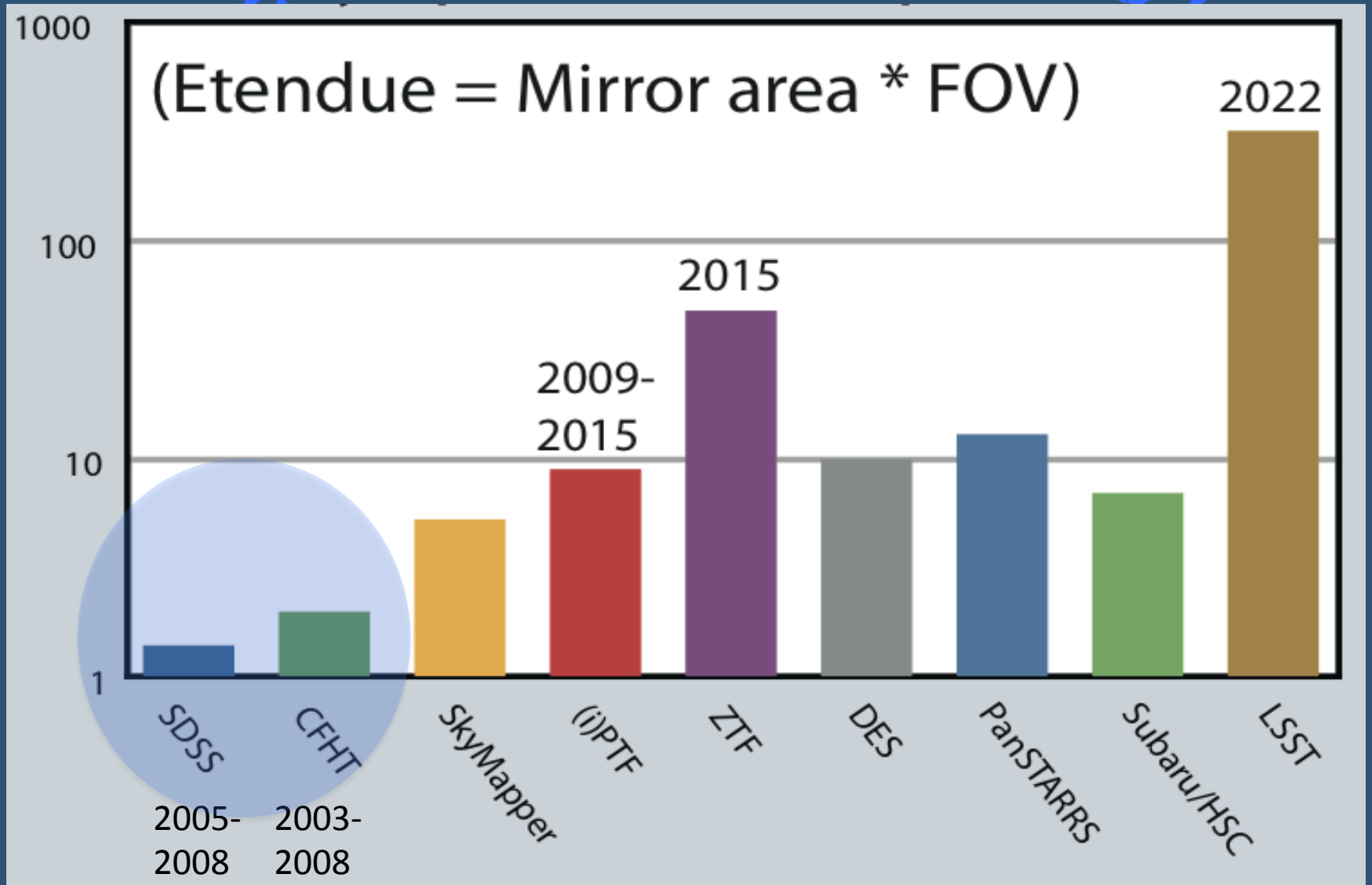
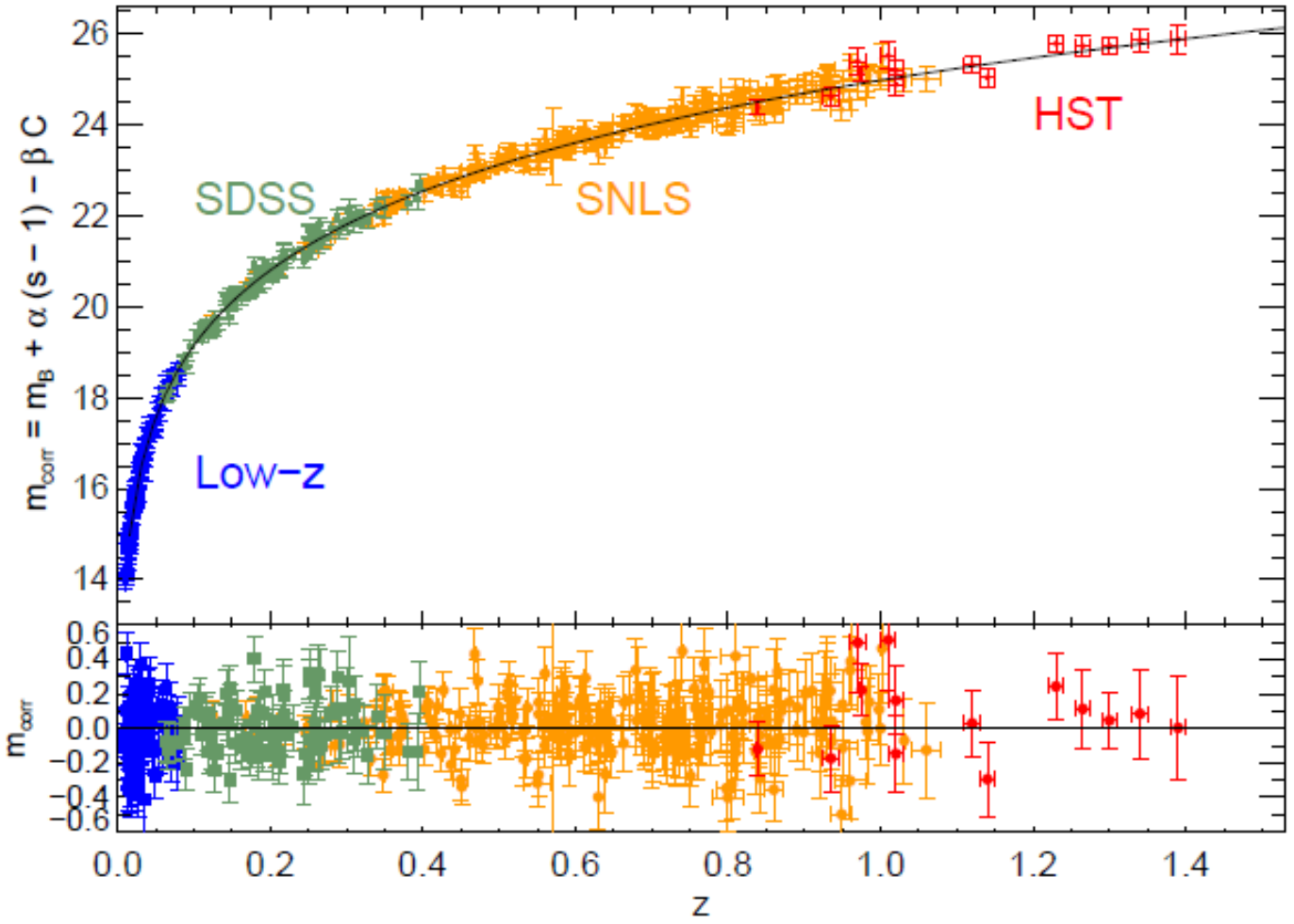


Optical Surveys
Type Ia SN cosmology

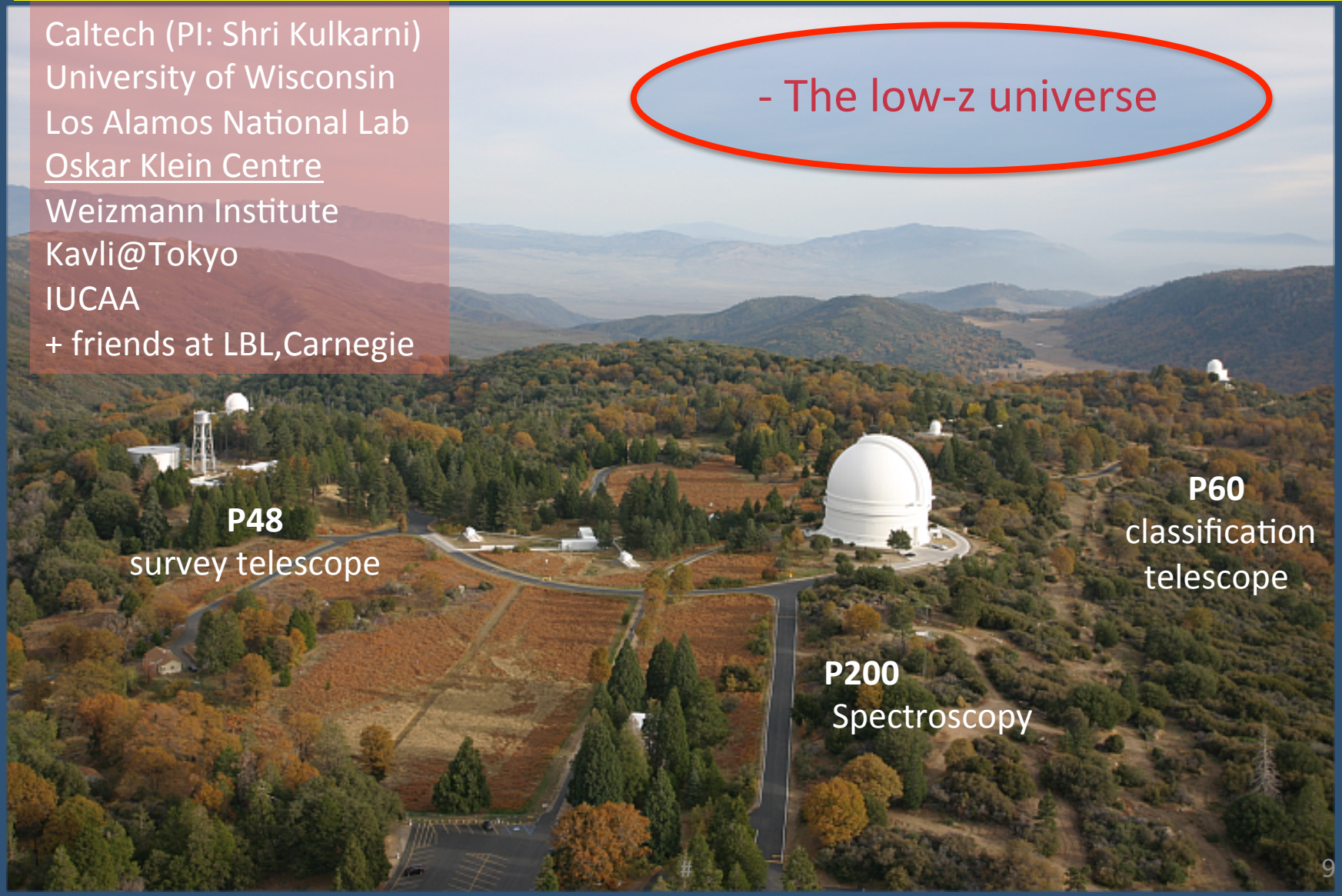


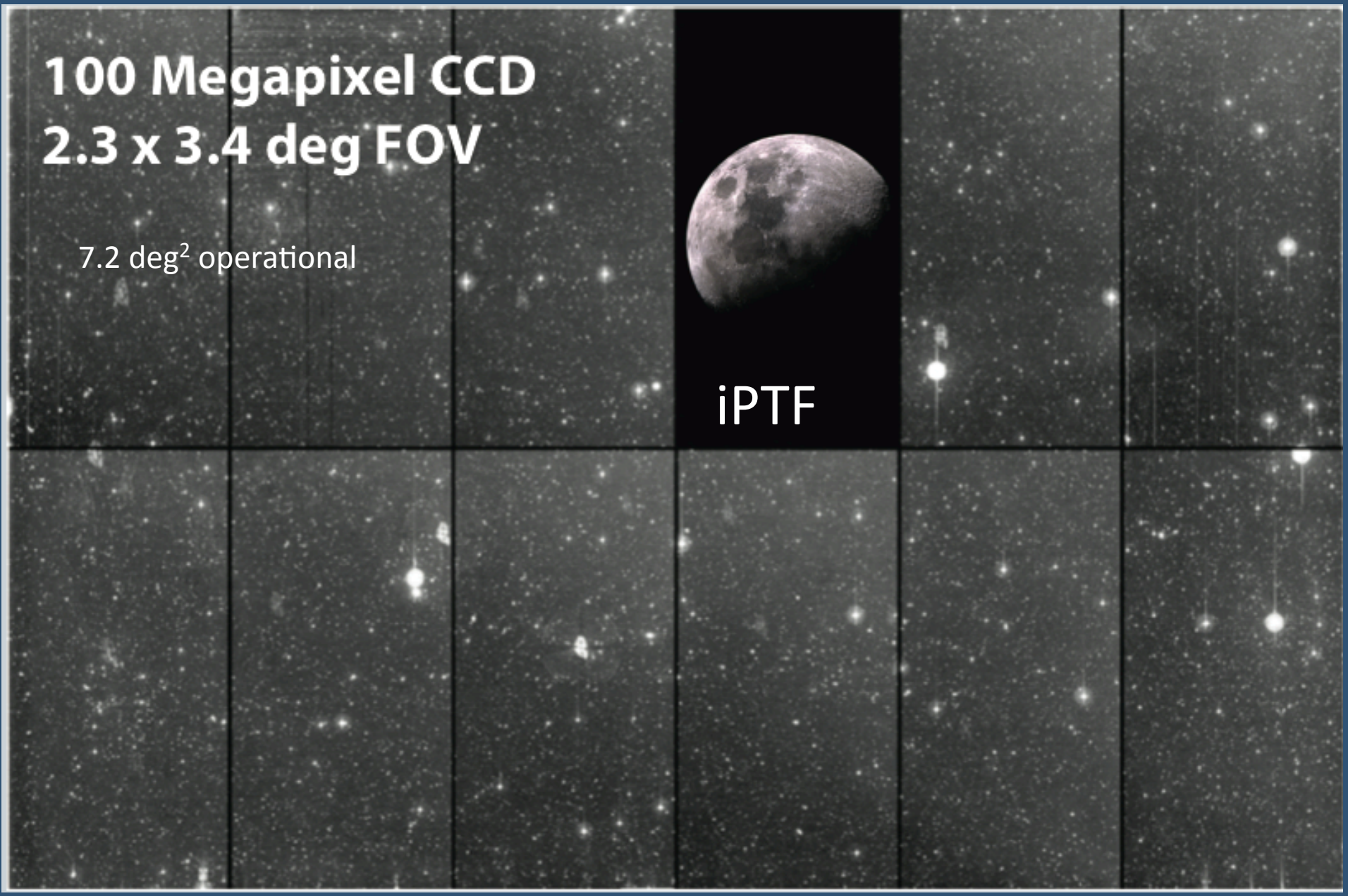
SNe Ia: SDSS 1 yr + SNLS 3 yrs

Conley et al 2011

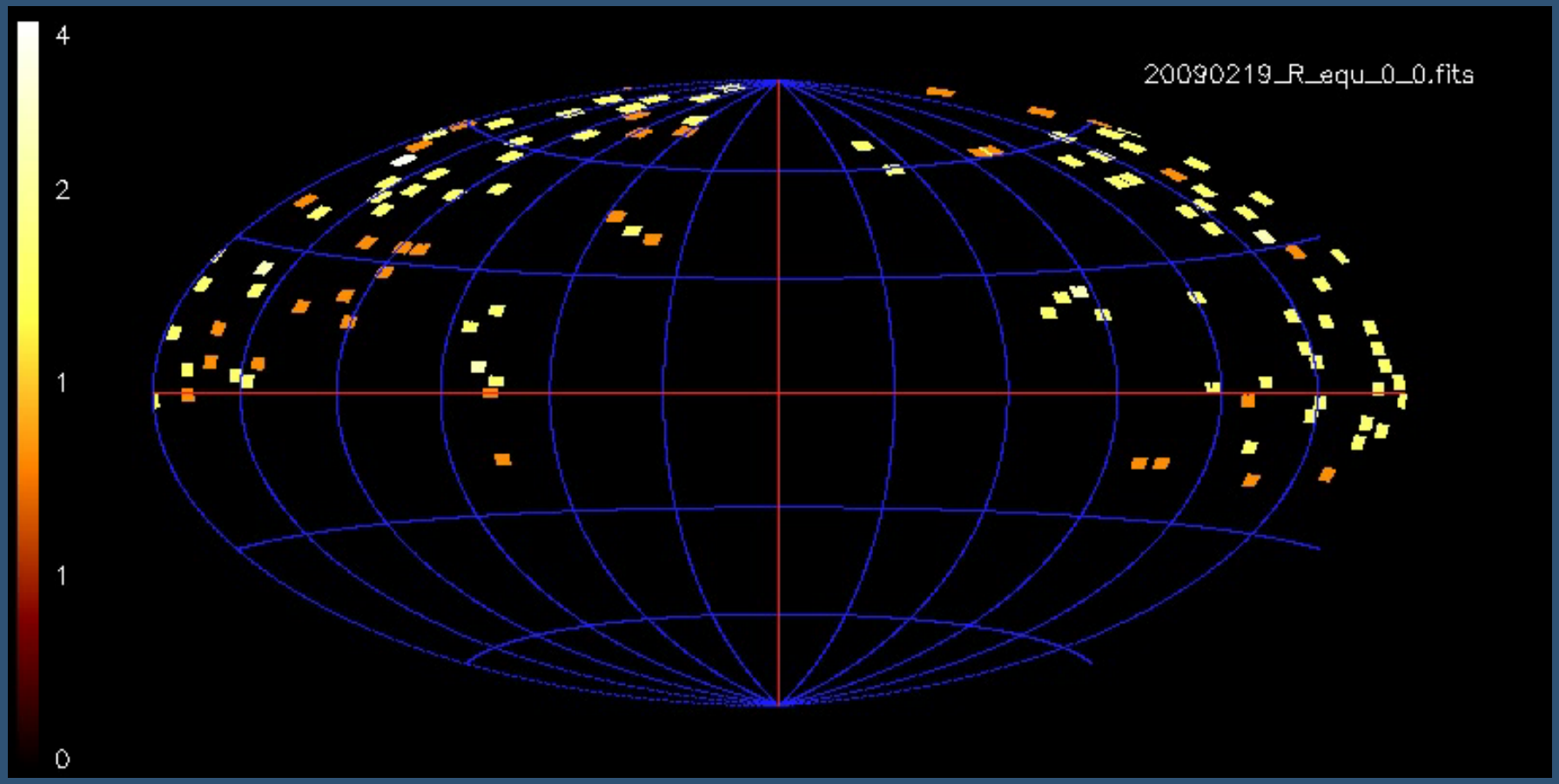


Where do iPTF/ZTF fit in?

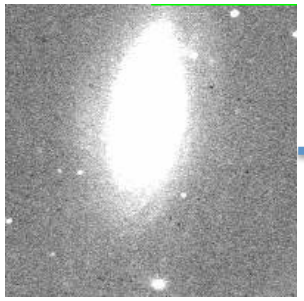



100 Megapixel CCD
2.3 x 3.4 deg FOV
7.2 deg^2 operational
iPTF

(i)PTF Searching the sky



Pipeline Flow Chart



Raw data

(Palomar -> Caltech -> LBL)

processing

3 min

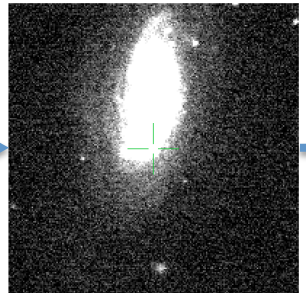
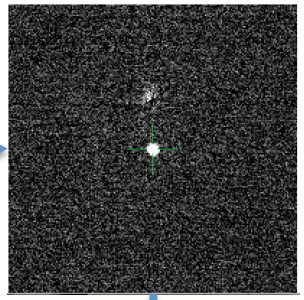
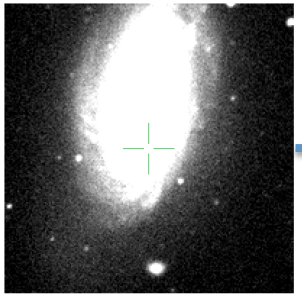


Image Subtraction



1.5 min/ image

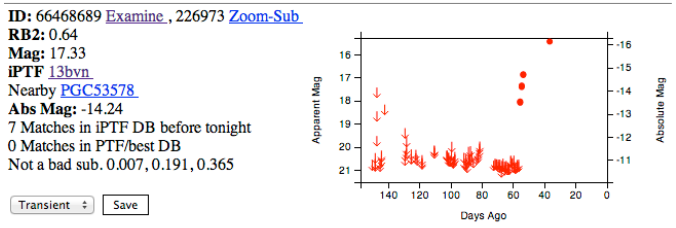


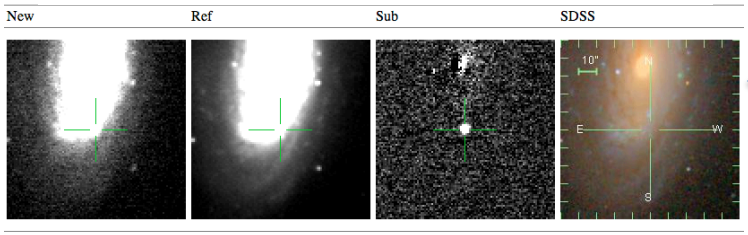
Reference Image

Real-Bogus (reject false alarms)

0.5 min/ image

Load candidates Into database





Scanning Page

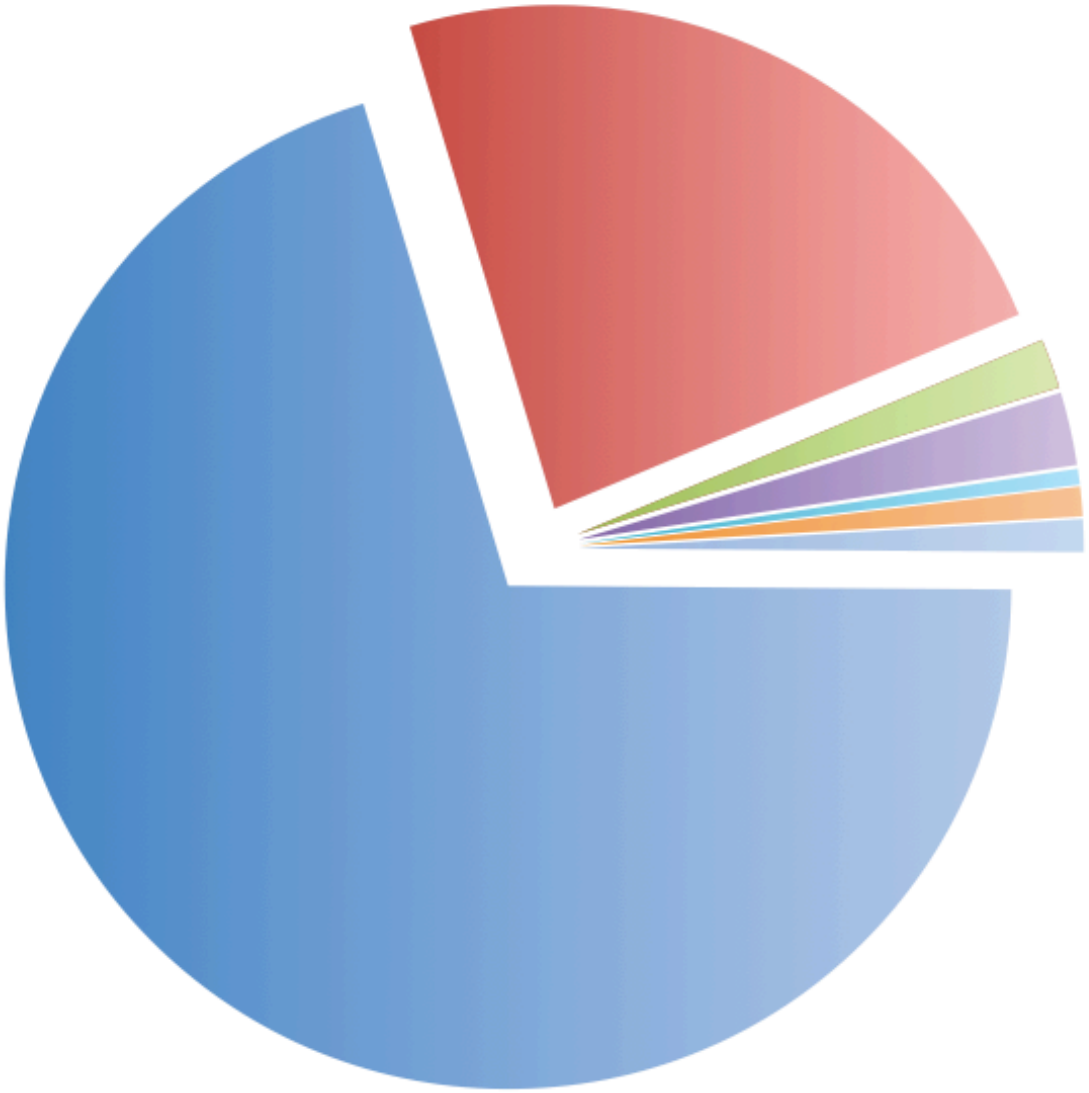
Star/rock Identification

Local galaxy match

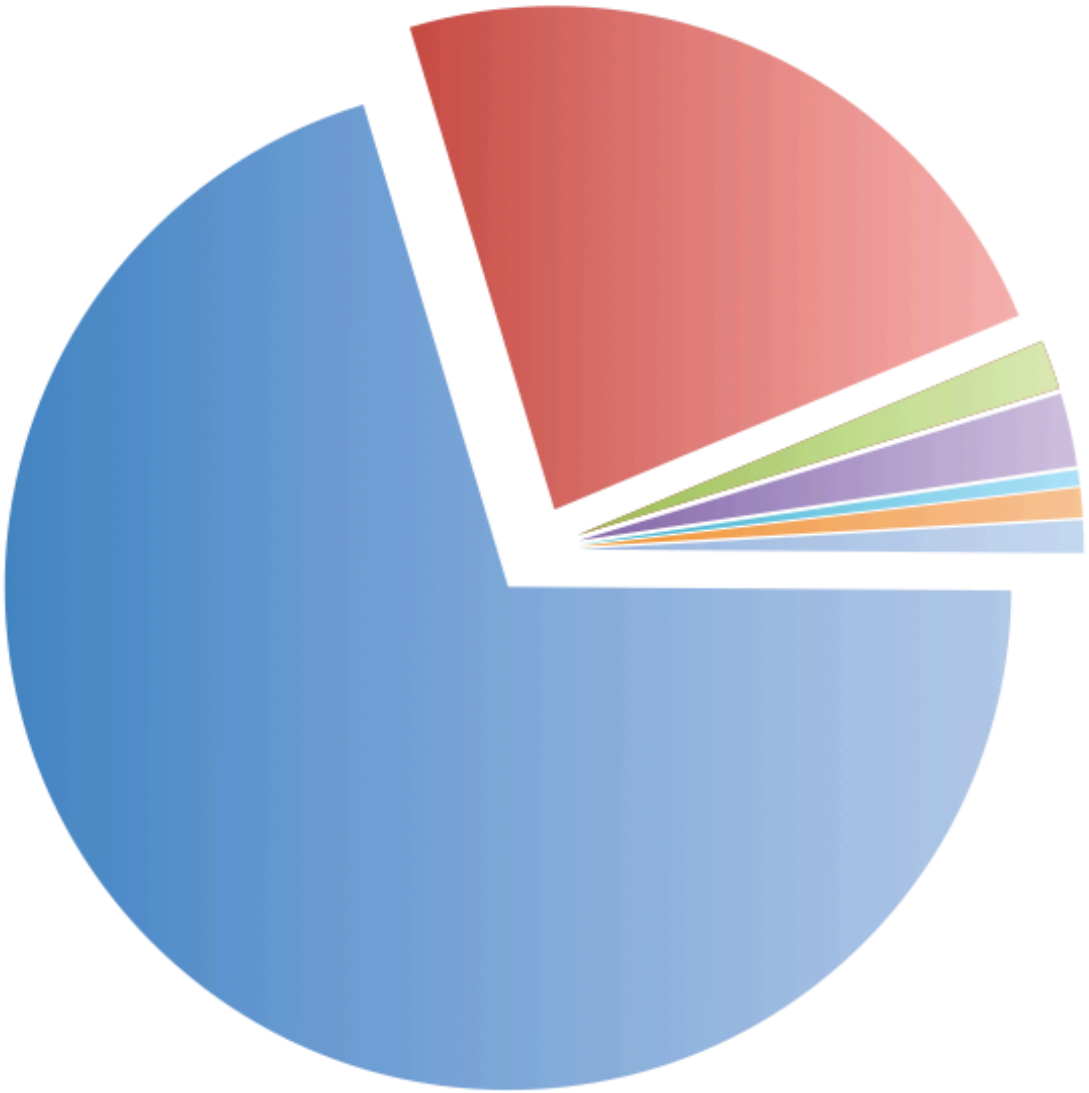
0.5 min/image

Database

COURTESY OF YI CAO & MANSI KASLIWAL



Spectroscopically confirmed PTF/iPTF SNe



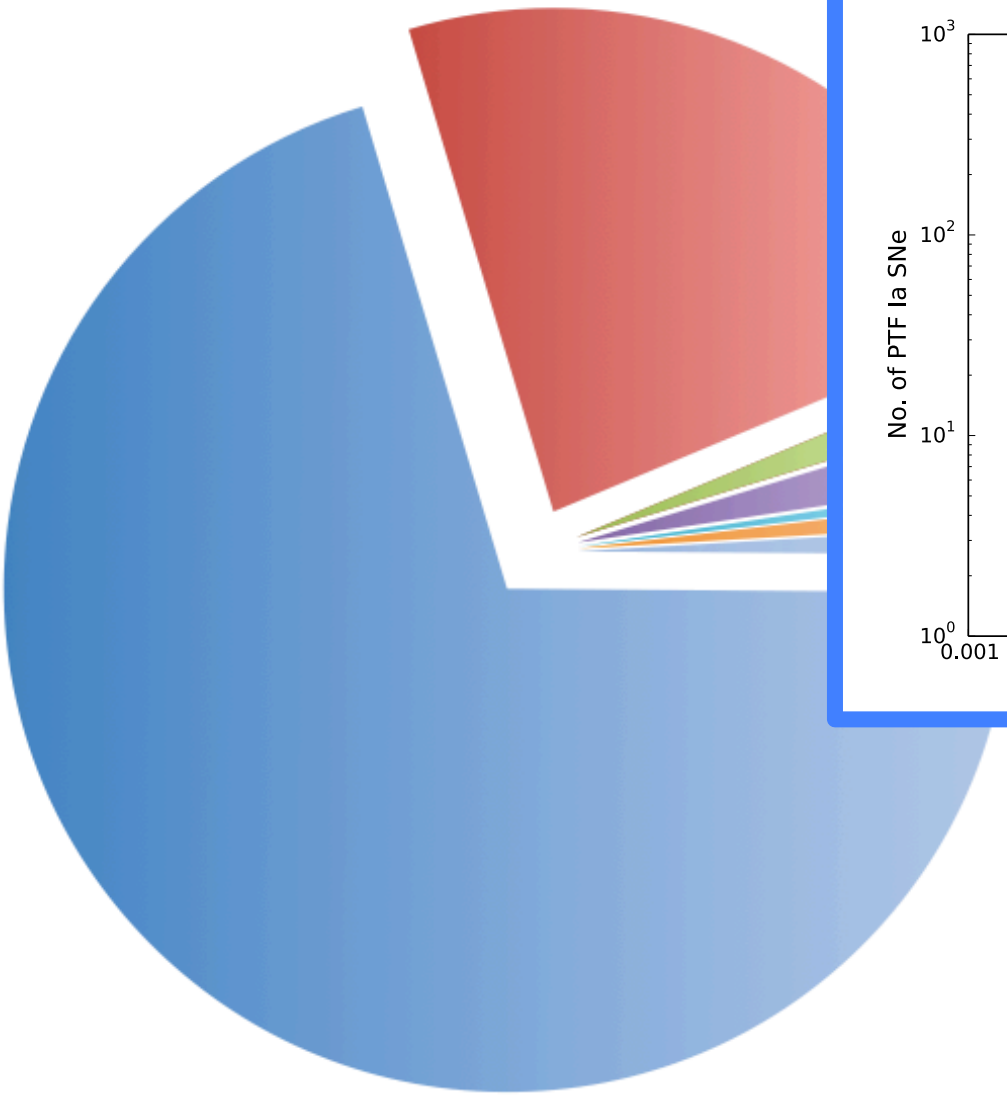
II (469)

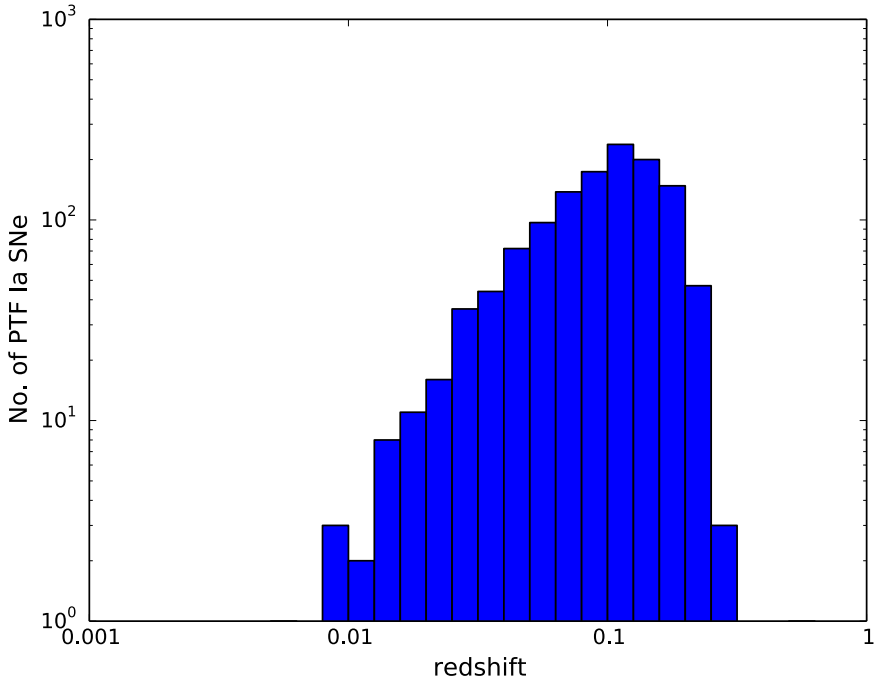
Ib (32)
Ic (47)
Ib/c (10)
Ic-BL (19)
SLSN (21)

Ia (1411)

Total:
1837 (2009-2012)
232 (2013)

Spectroscopically confirmed PTF/iPTF SNe





- Ia (1411)

Total:
1837 (2009-2012)
232 (2013)

iPTF/ZTF and Type Ia SNe


iPTF/ZTF and Type Ia SNe

Cadence & Survey area

- SDSS-II 150 sq.deg every 3-4 days
- SNLS 1 sq.deg every 3-4 days
- iPTF >500 sq.deg, (now) *multiple times/night*

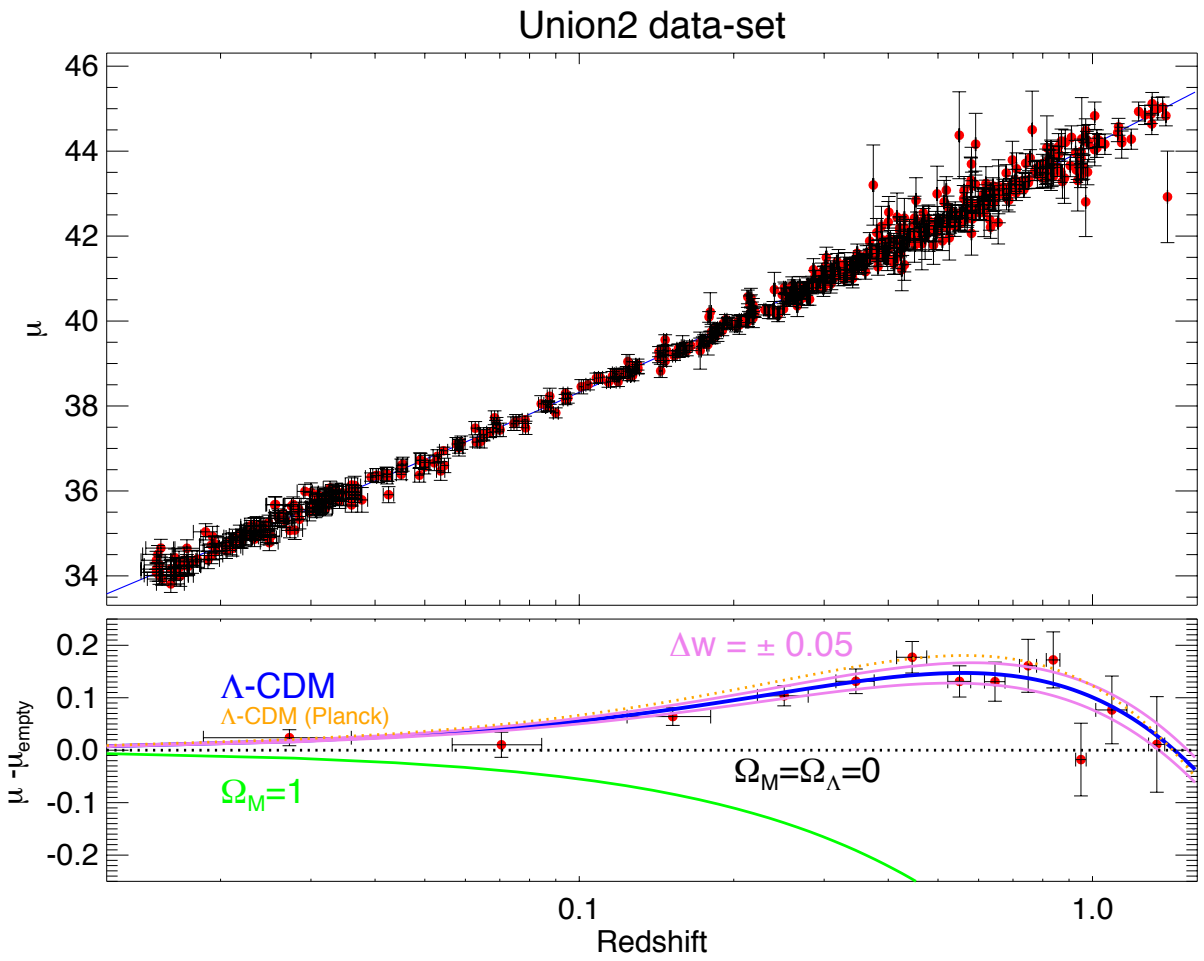
➔ *Ideal for studying the local universe and discovery transients extremely early (=soon after explosion)!*

➔ *Discoveries (<21.5 mag) can be followed by a large number of instruments – difficult for e.g. DES, HSC*

➔ *…in a very wide range of wavelengths*

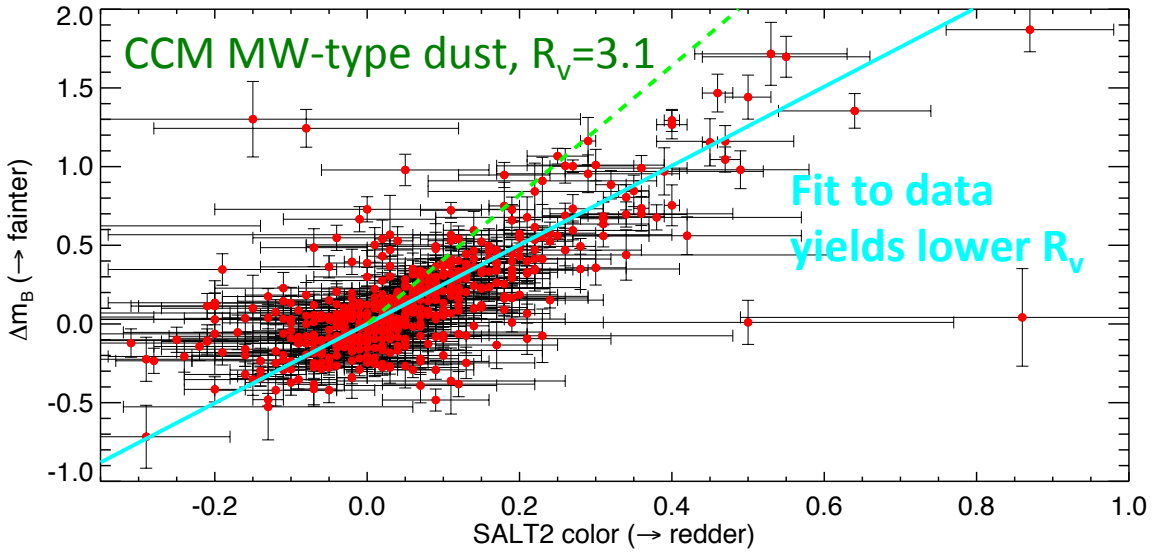
➔ *Host galaxy environment can be studied in depth*

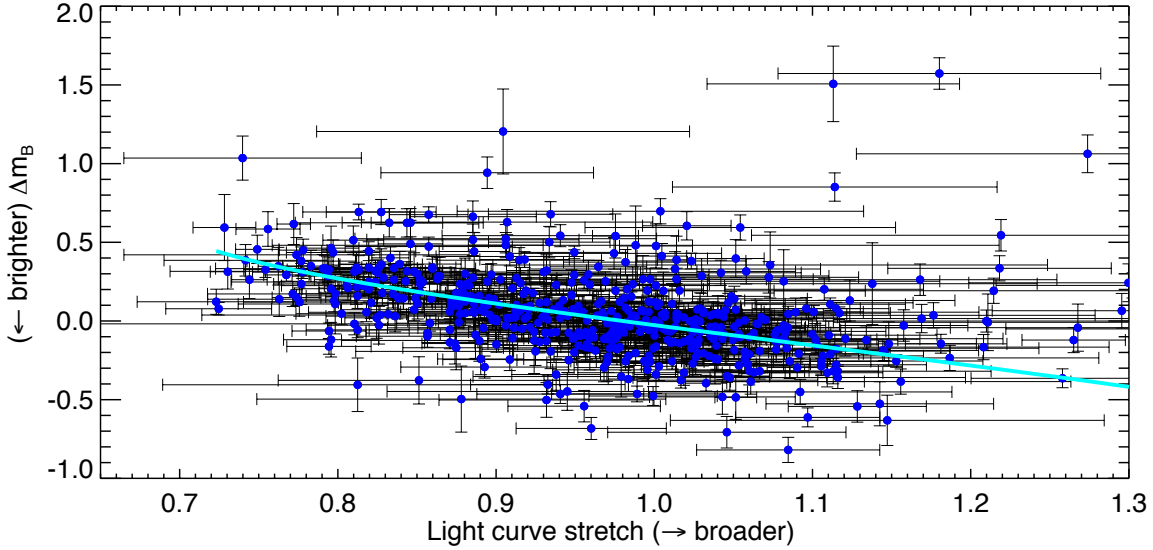
SNIa and the challenge of Dark Energy



Target:
look for deviations from $w \neq -1$,
But requirements on control of systematics are quite brutal.

Applied corrections are large - lack understanding





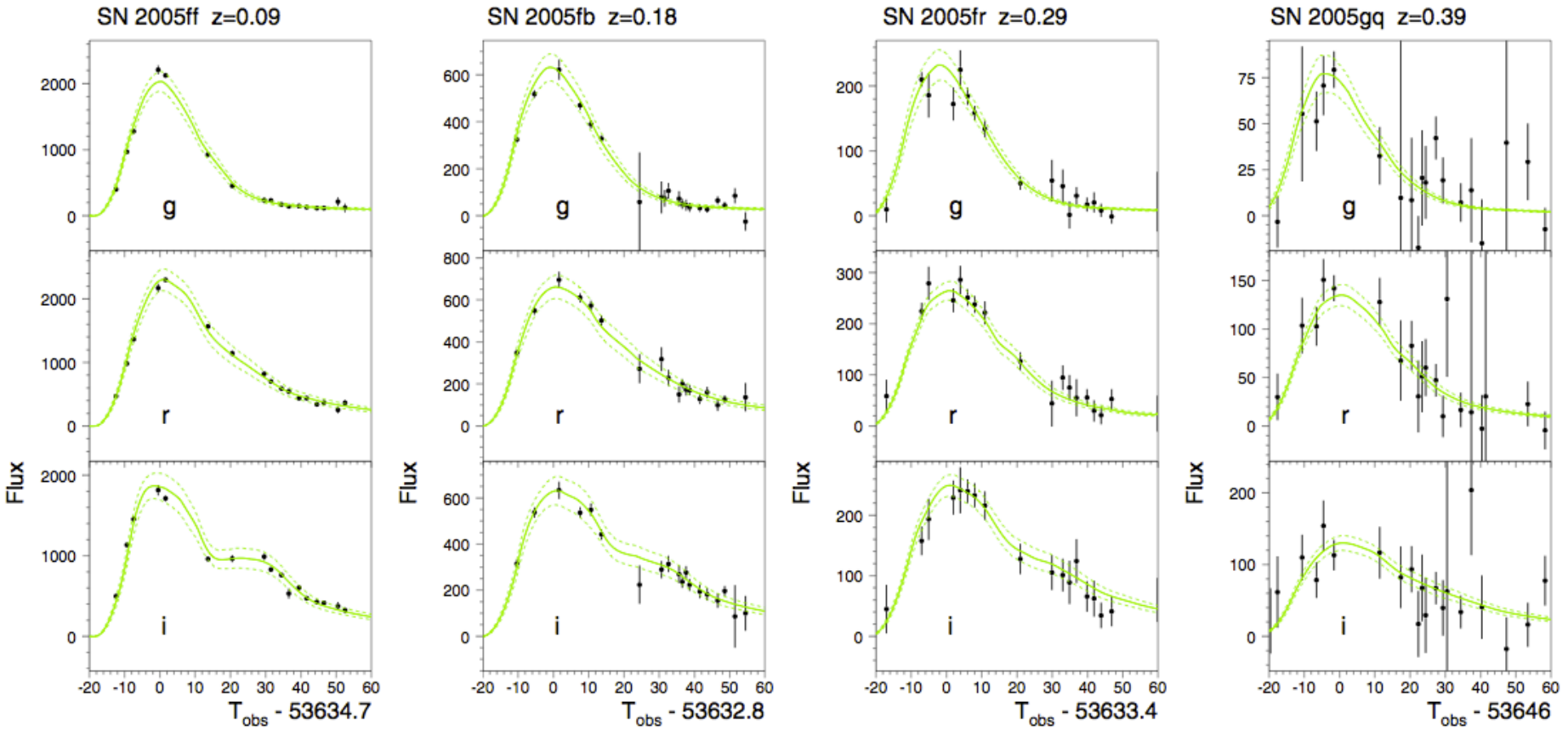
Color-brightness correction particularly bothersome, since large and we should "know better".

Many possible (partial) explanations, e.g.:

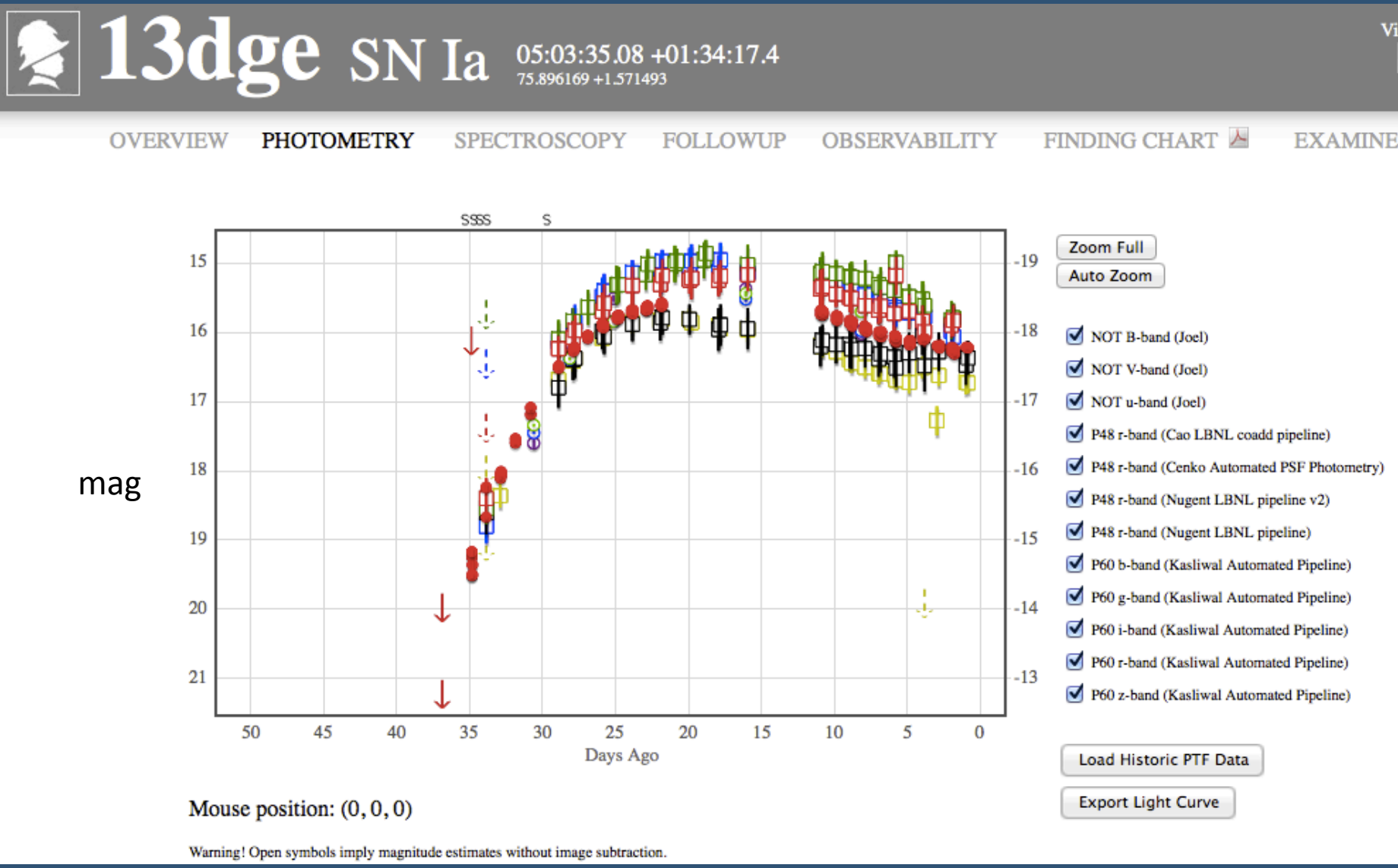
- Statistical bias
- Differences in interstellar dust
- Poorly understood intrinsic color properties
- Dust in circumstellar medium?

AG 2008, Amanullah & AG 2011

SDSS-II cadence and S/N

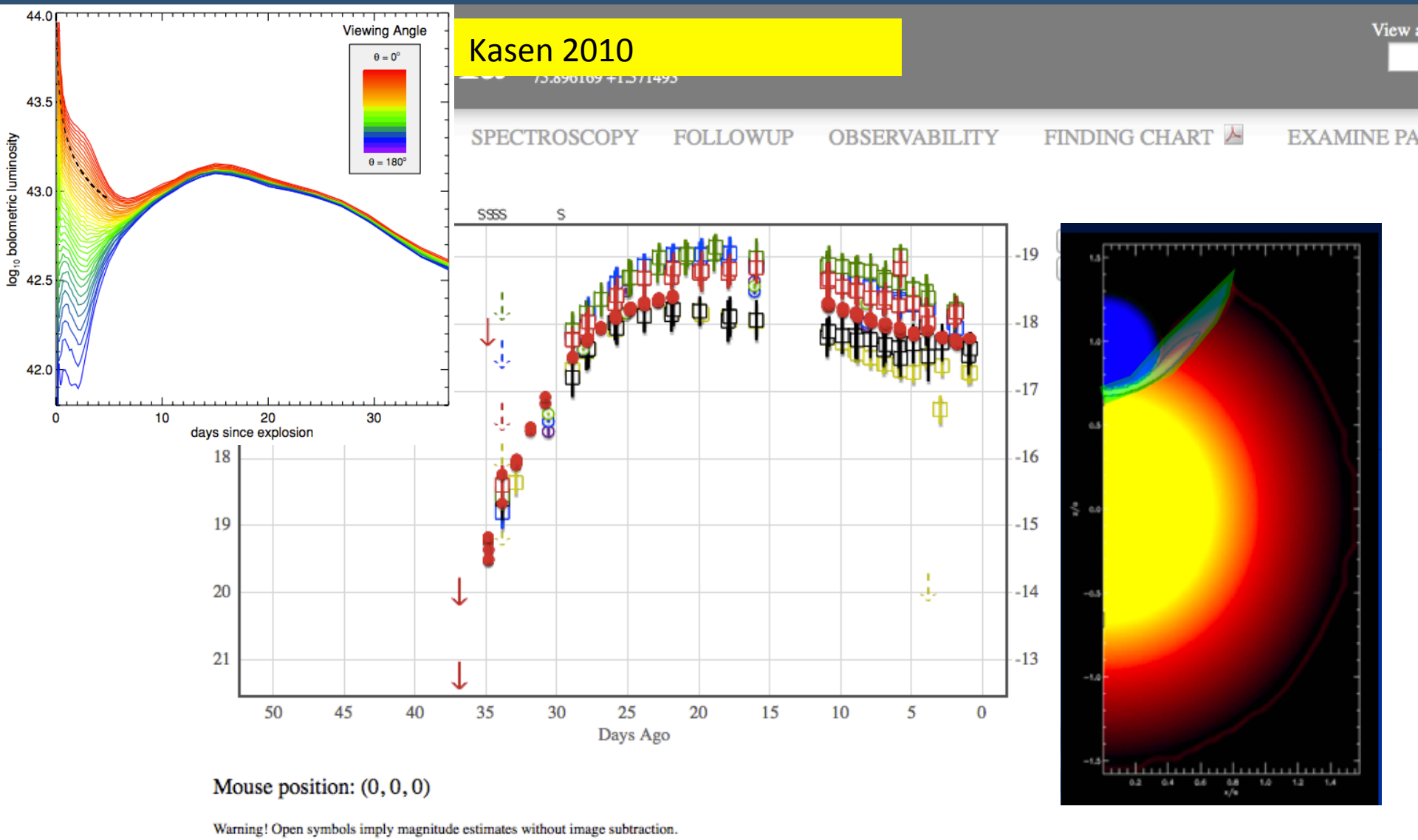


A "typical" iPTF SNIa



Nature of progenitor system

Kasen 2010



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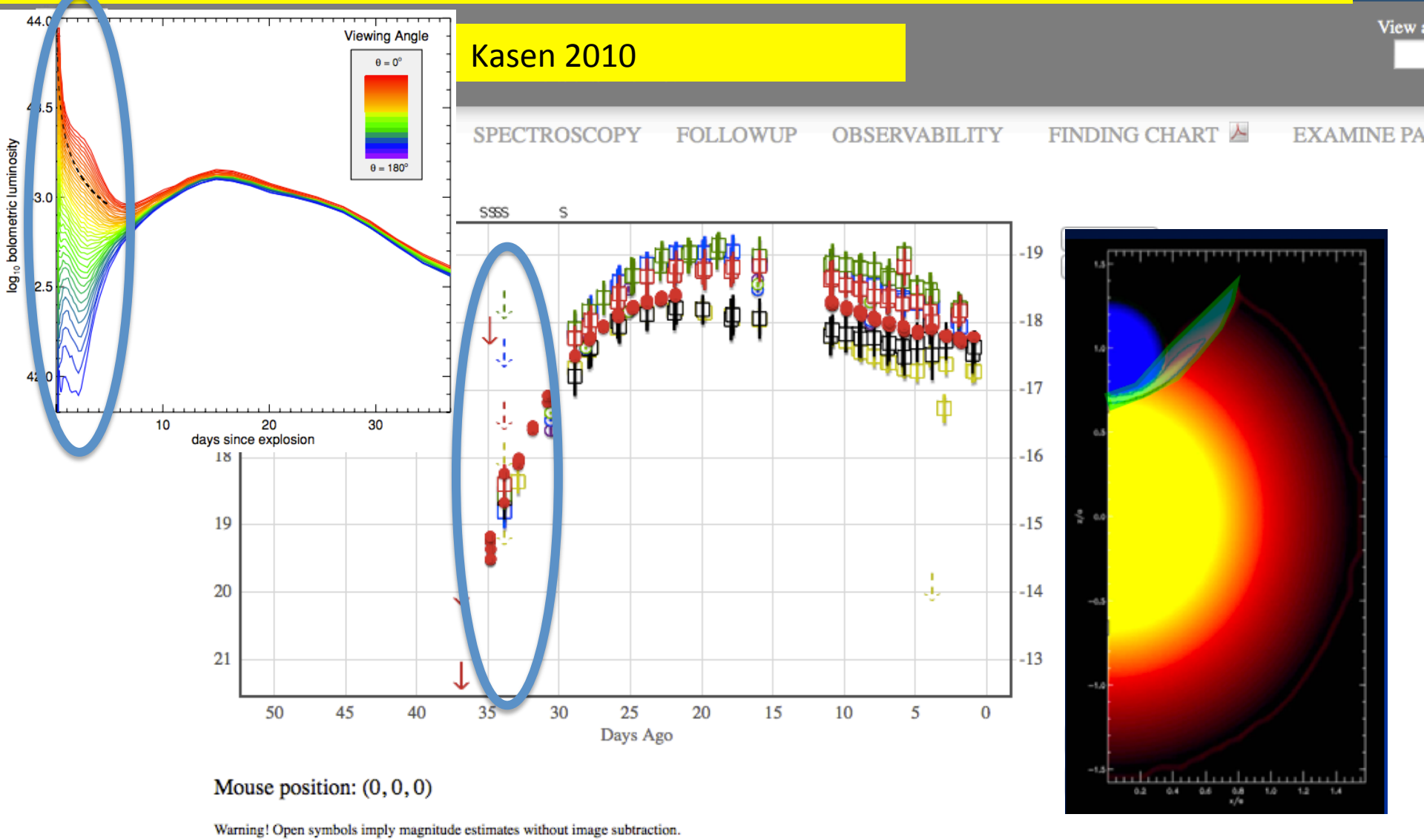
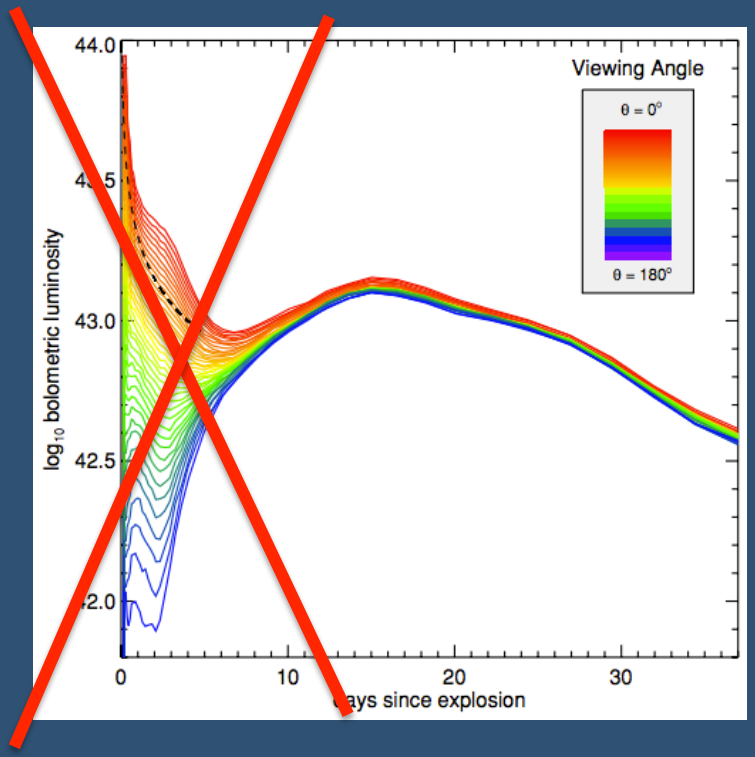
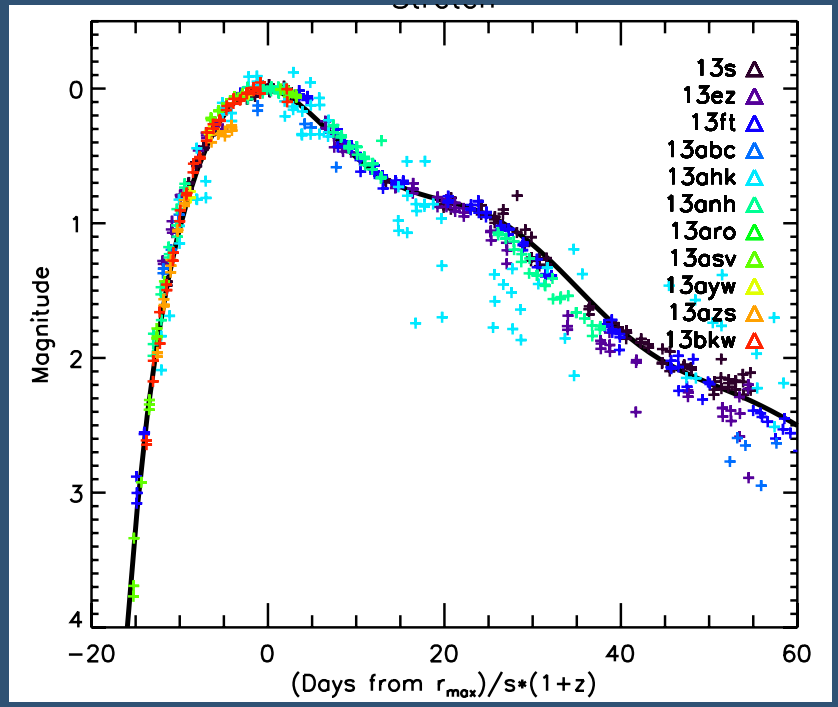
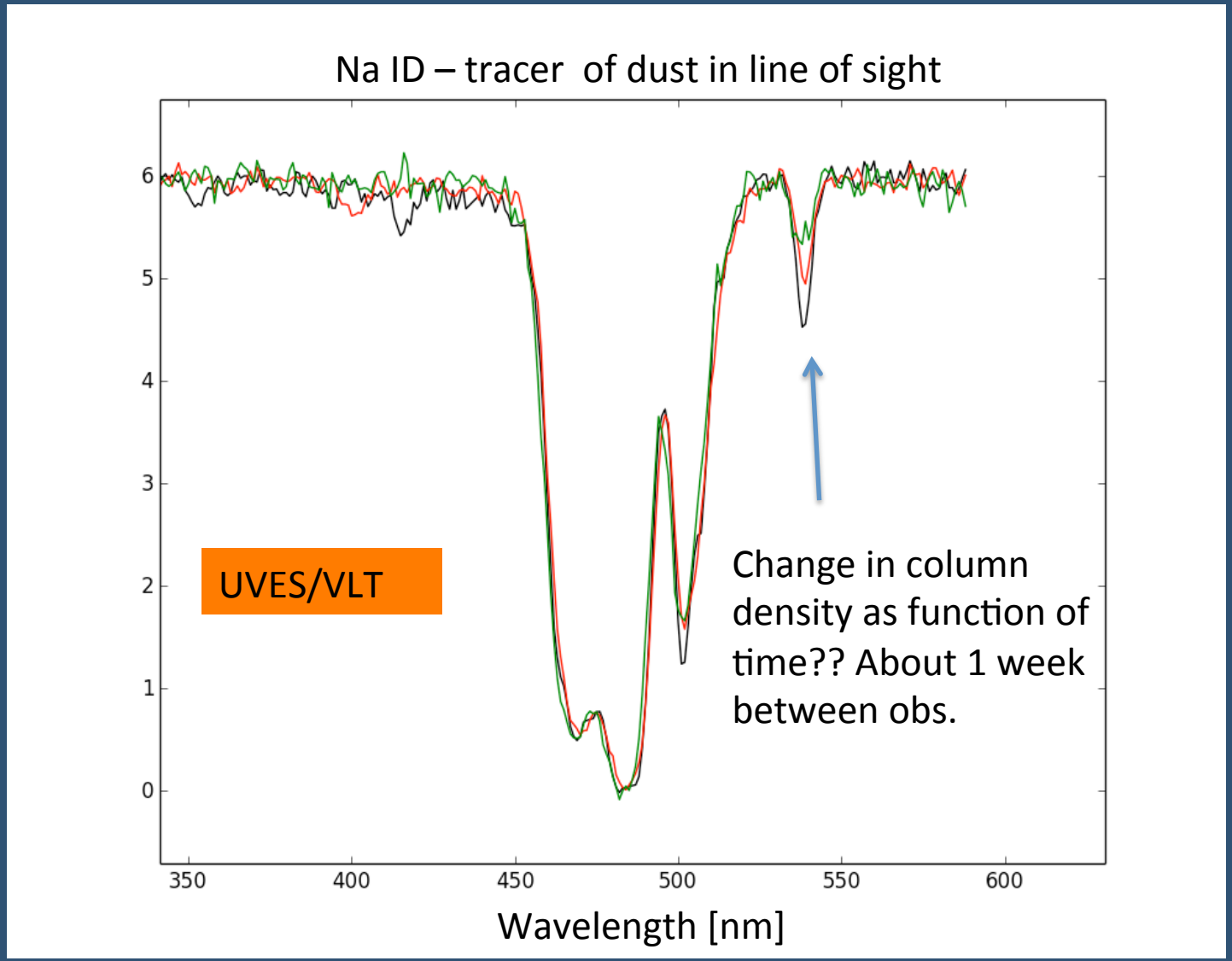


So far, no signs of interaction...





Early discoveries - ideal for detailed spectroscopic follow-up studies



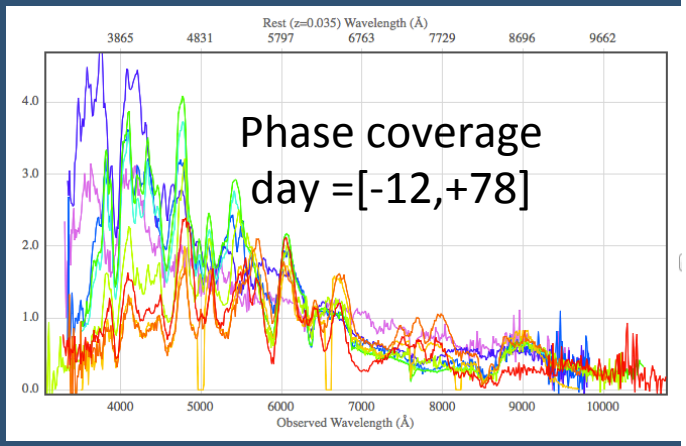
SNIa cosmology work in progress

- **R-band (still optical, but longer than currently used for cosm.)**
  -Hubble diagram up to redshift 0.1
  - high statistics/low(er) systematics?
  - explore local expansion rate ("Hubble bubble")
  - Bounds on anisotropic expansion
  - peculiar velocities and the matter density field
  - path-finder for higher-z surveys targeting longer wavelength

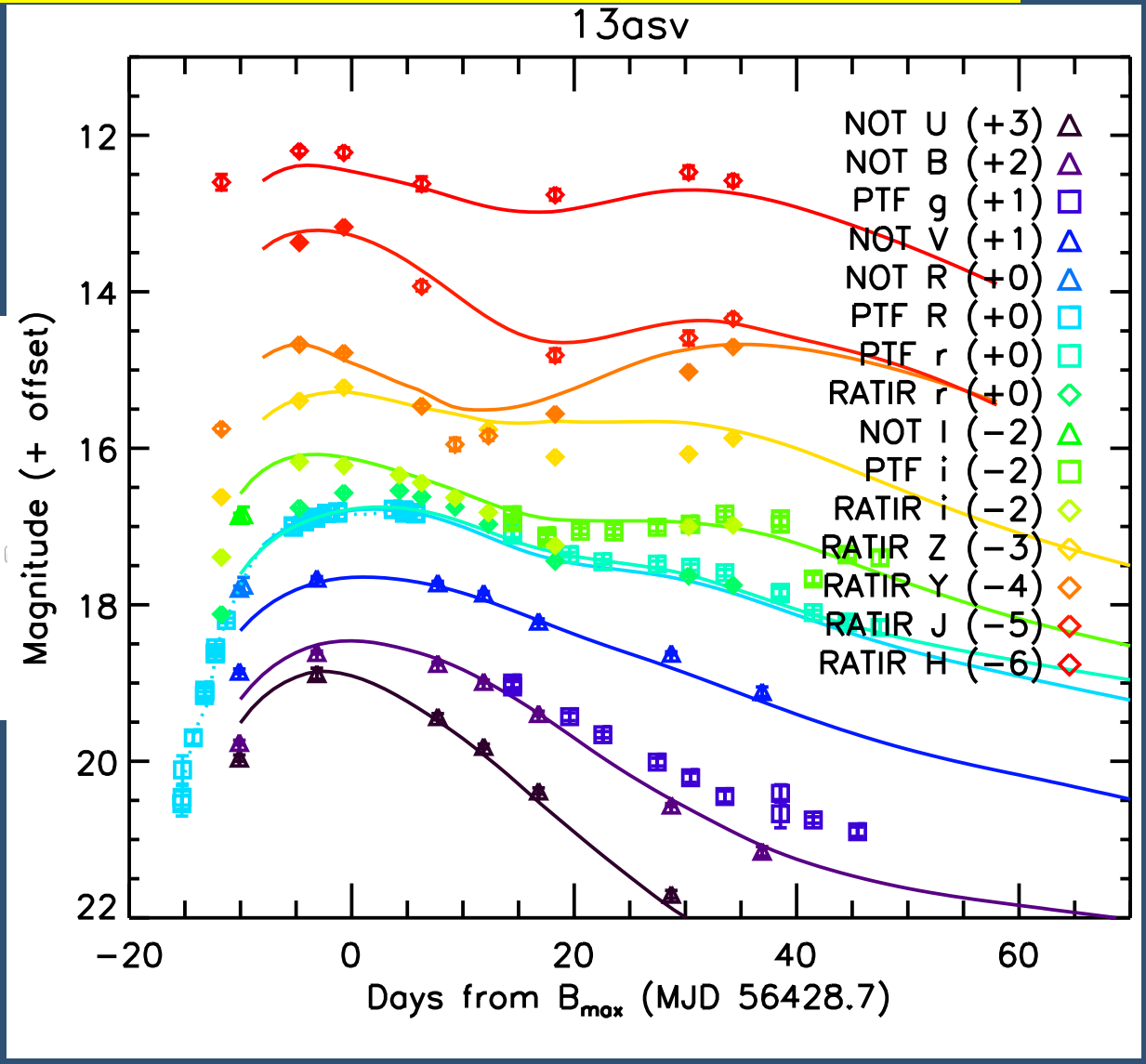
- **Near IR**
  - cosmology without dimming by dust
  - anchoring point for studies of reddening by dust at optical wavelengths

Prel LCs Palomar+NOT+RATIR

(+Swift data not shown)



Best LC has 13-14 epochs in Near-IR

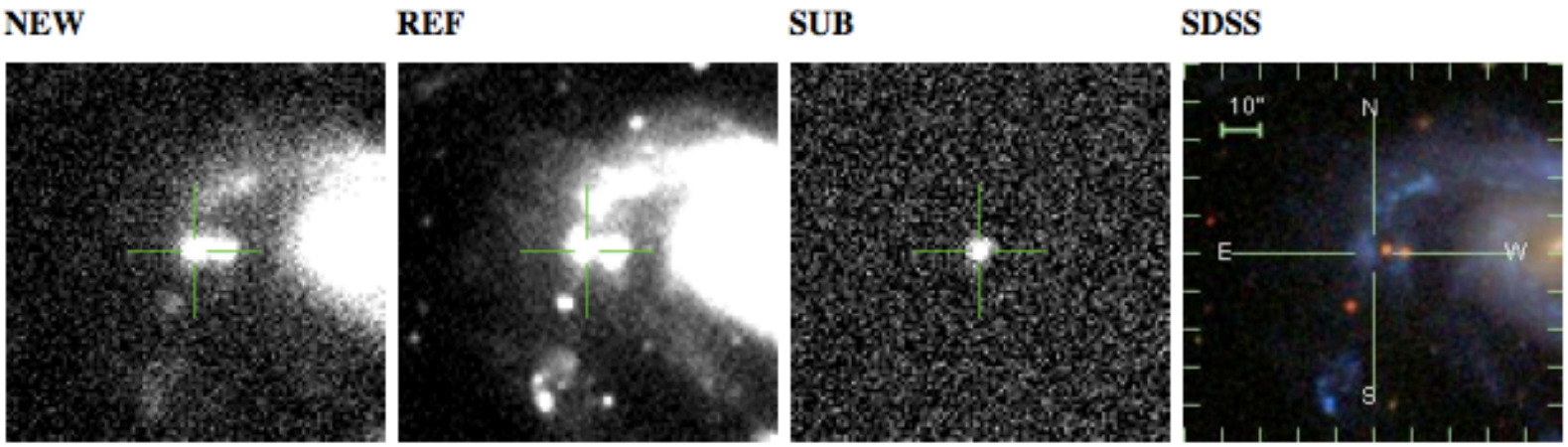


Other explosive events!

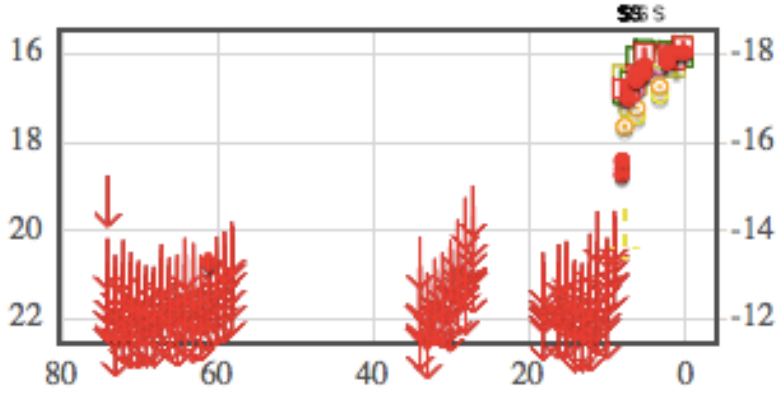
13dqy SN II

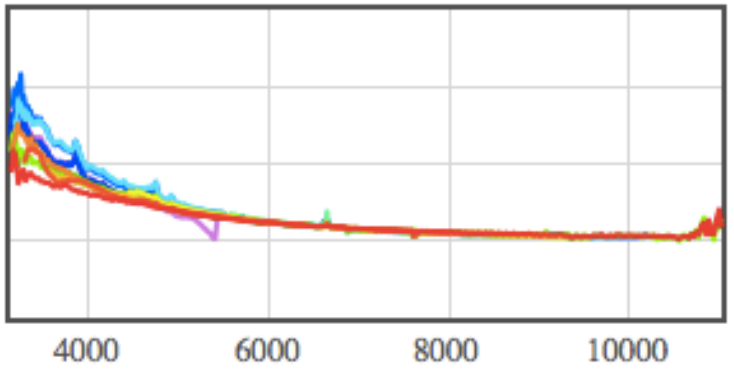
From image to ID within a few hs!

OVERVIEW PHOTOMETRY SPECTROSCOPY FOLLOWUP OBSERVABILIT



First spectrum "just" after explosion!





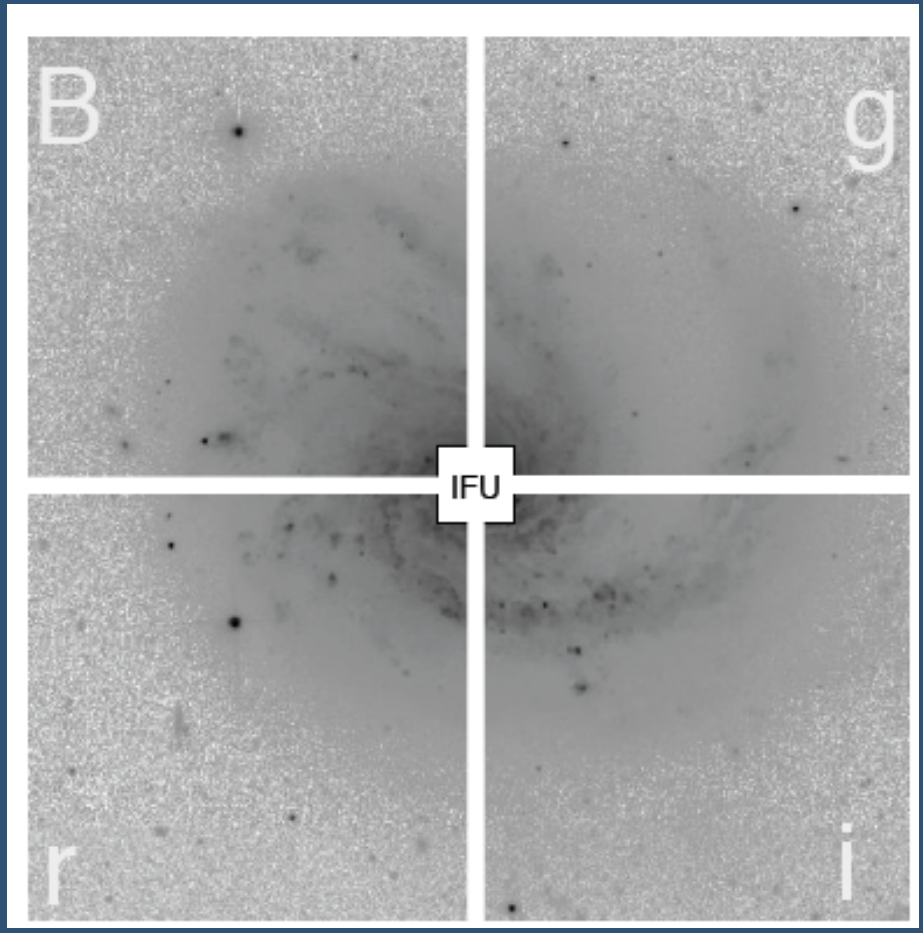
r = 16.0 (0.2 d) | Upload New Photometry

z = 0.011855 | Upload New Spectroscopy
DM (approximate) = 33.51

News:"SED Machine", low resolution spectrum within 30 minutes! (P60)

Spectral range [365- 980] nm,
27" fov w/0.675" resolution
$R=\Delta\lambda/\lambda=100$
6'x6' images

Robotically triggered!

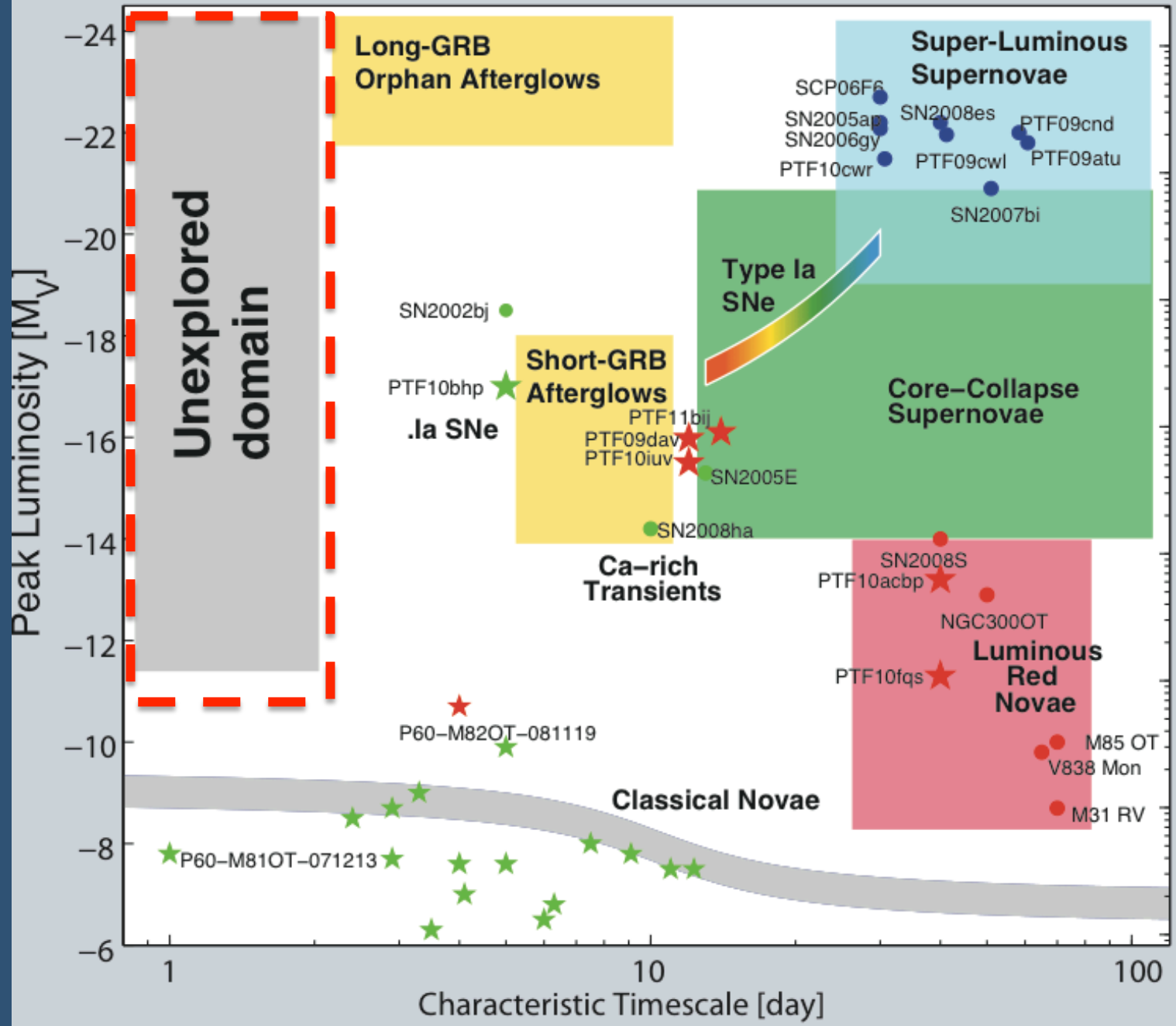


The "New" Transient Universe

Compact mergers and GW

- LIGO & VIRGO are being upgraded, accessible volume for stellar mass compact objects enhanced by > x1000 (2016)
- Rates are very uncertain: 0.2 – 400 yr^{-1}, poor localization (~100 deg^2)
- Merger GWs as “Standard sirens”?
- Properties of EM counter parts are also very uncertain. But! Shorter time scale (a few days), relatively faint and red… fall into the “unexplored domain” box!

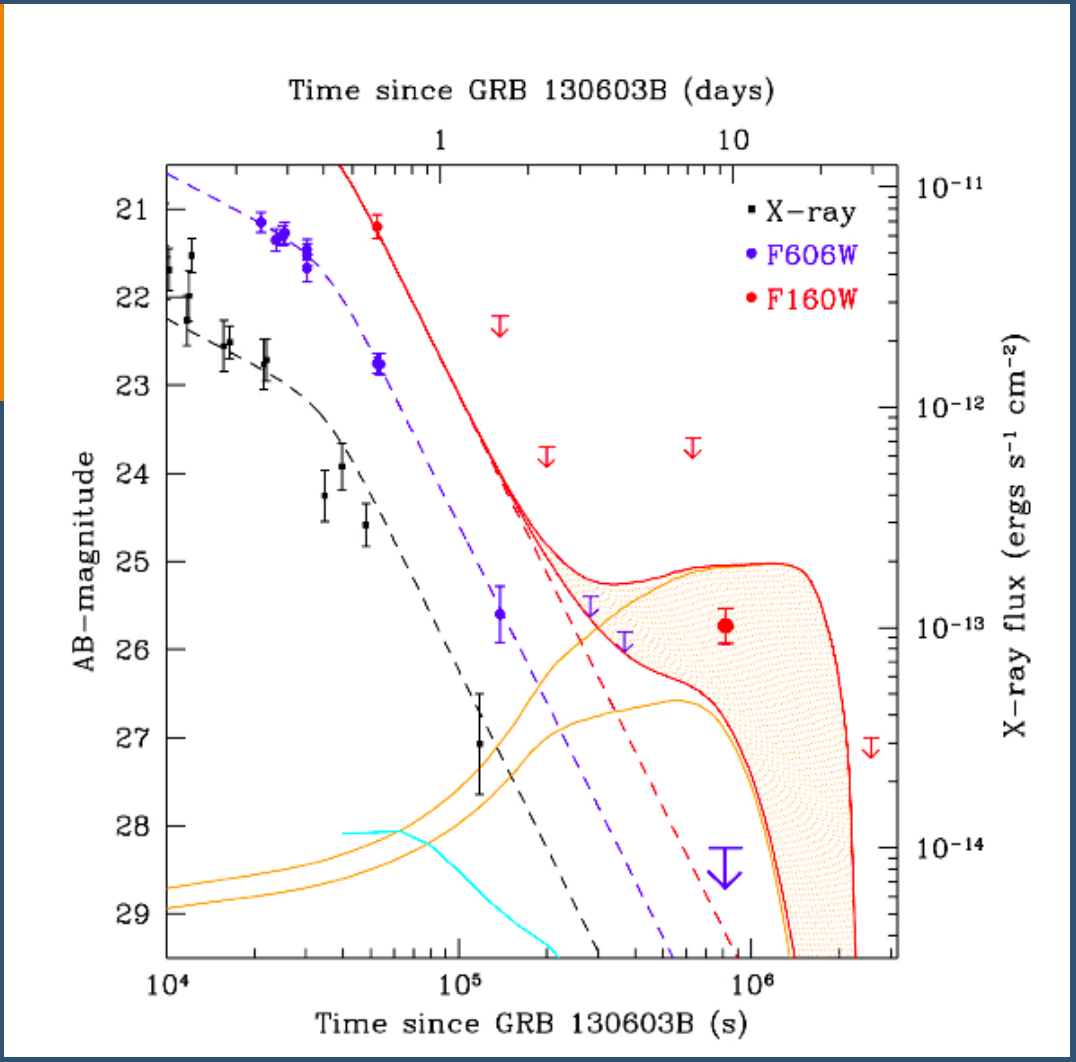
The landscape of optical transients



First candidate?

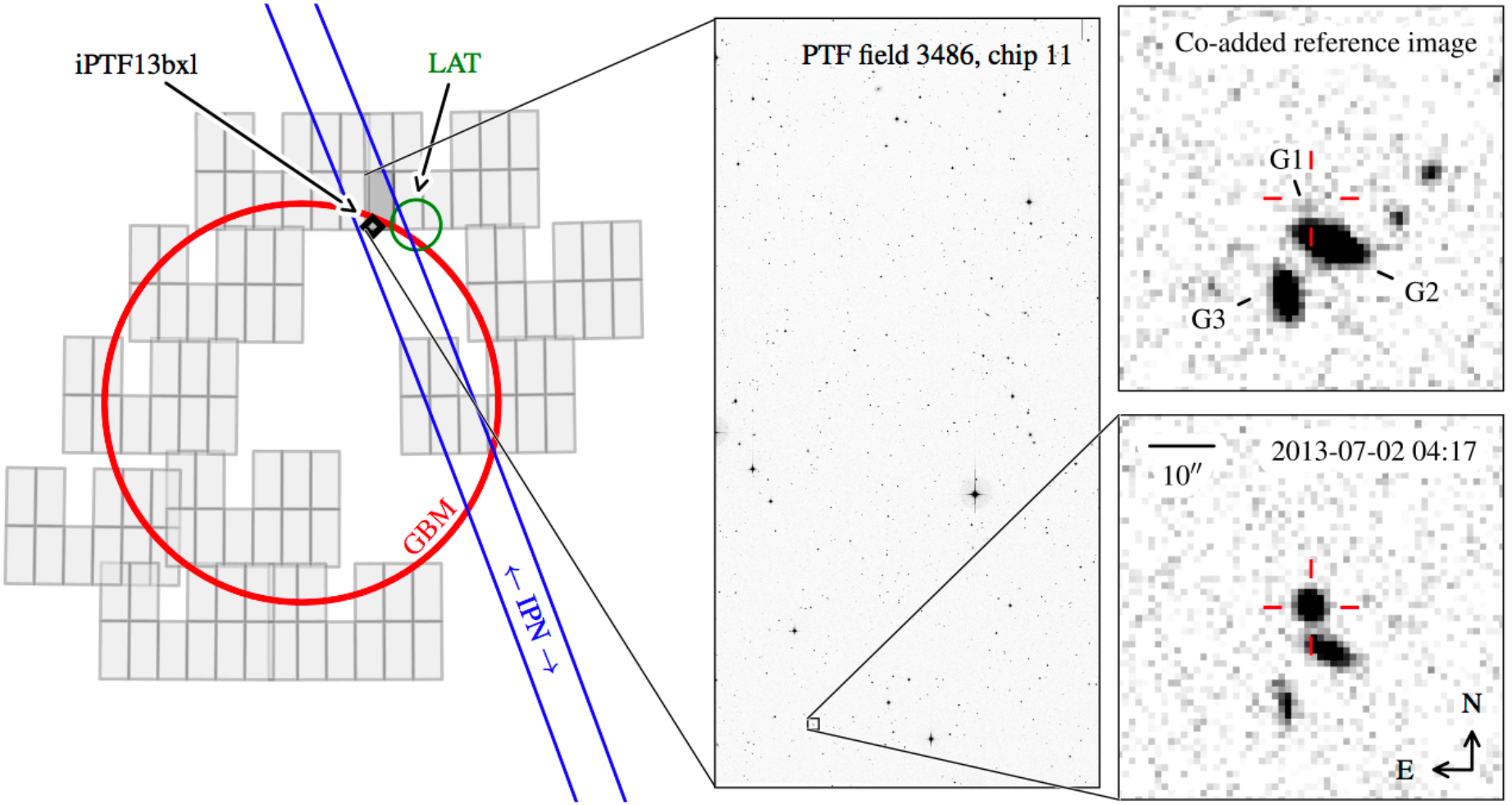
- Association with short GRBs?

  Tanvir et al Nature, 2013



Finding the EM counter-part
Proof of concept (Singer et al 2013)

Discovery & redshift of a GBM GRB in 71 deg^2



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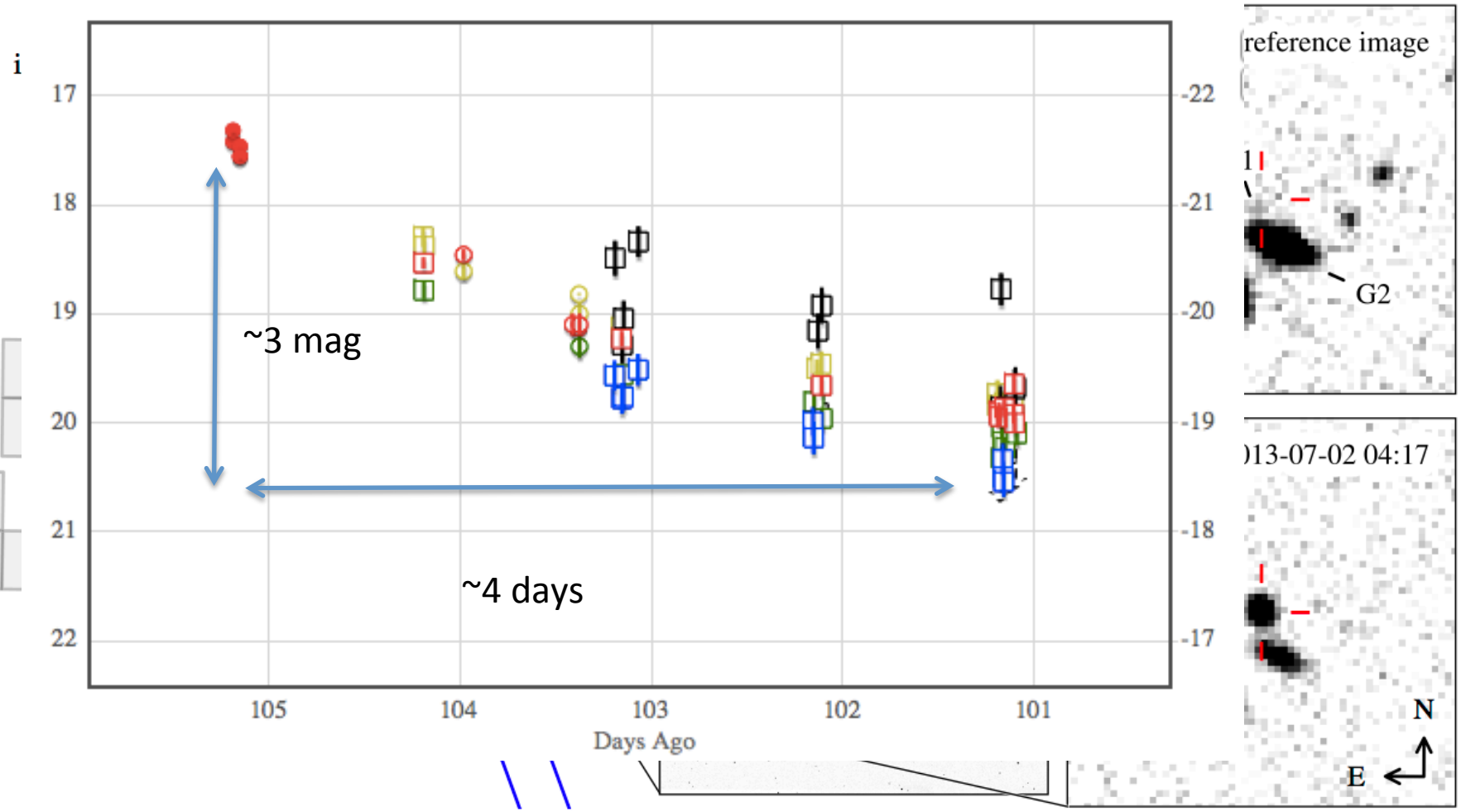
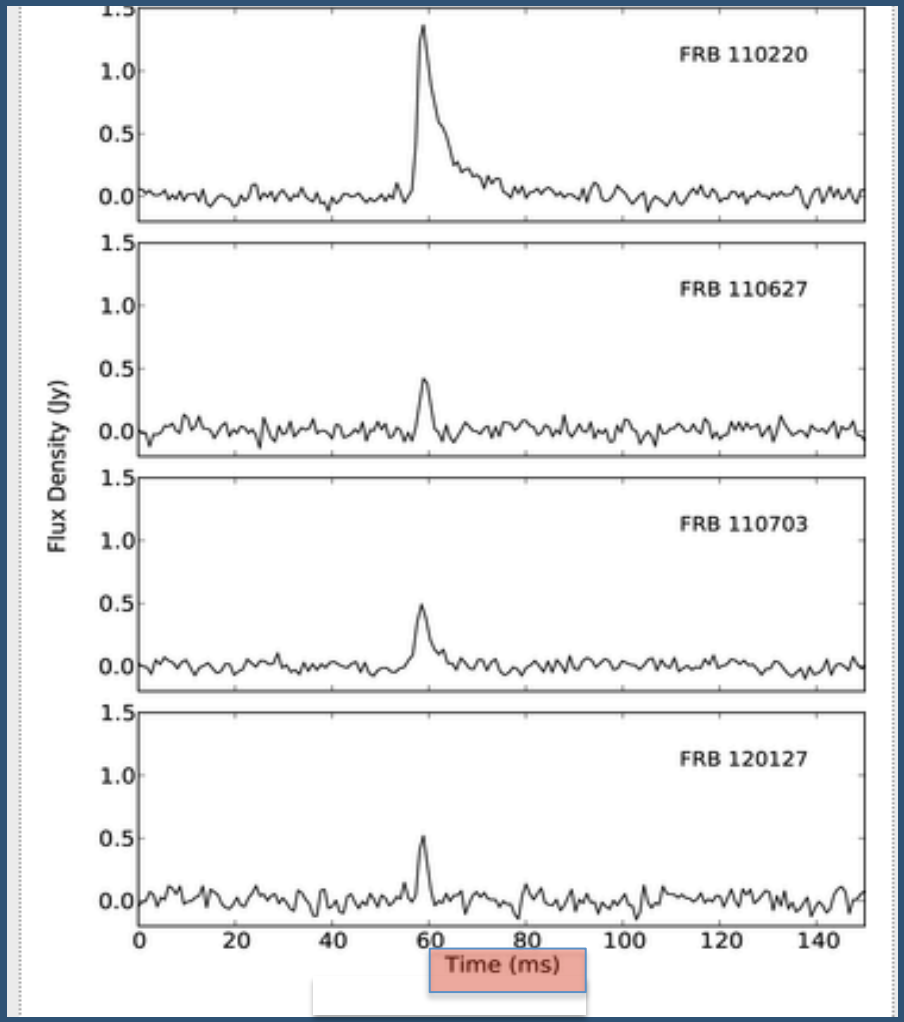


Latest addition: Fast Radio Bursts?



Thornton et al, Science, 2013;
Also Lorimer et al 2007

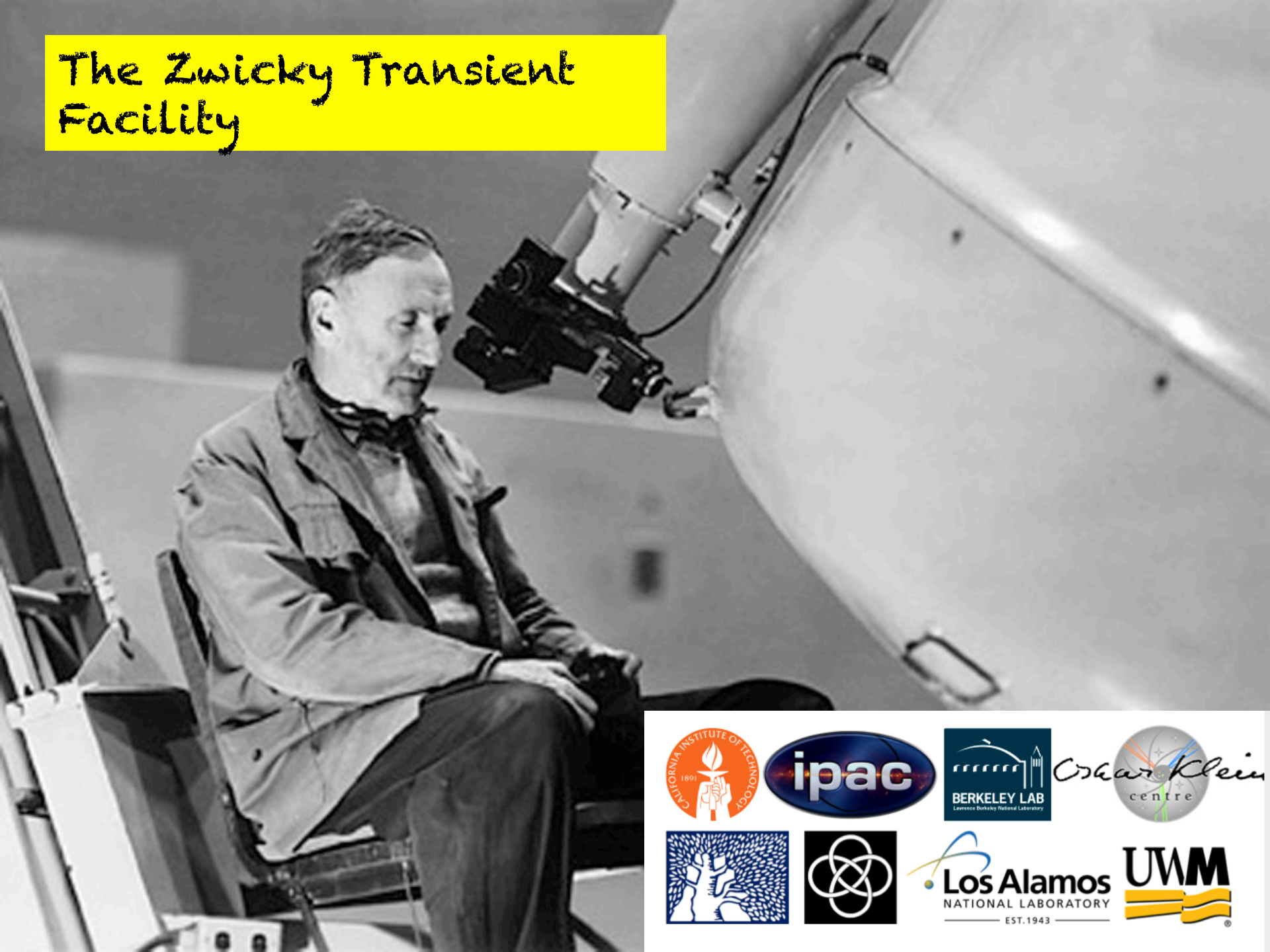
4 bursts at high galactic latitudes, inferred distances from time structure vs arrival time, z=0.45-0.96. Inferred rate: 0.1 Hz.

Suggested origins:

Primordial BH- evaporation??? (Rees 1977)
Core-collapse supernovae?
Merger of compact objects?
Failed GRBs?
Infall into supermassive BHs?

Optical counterpart wanted!

The Zwicky Transient Facility



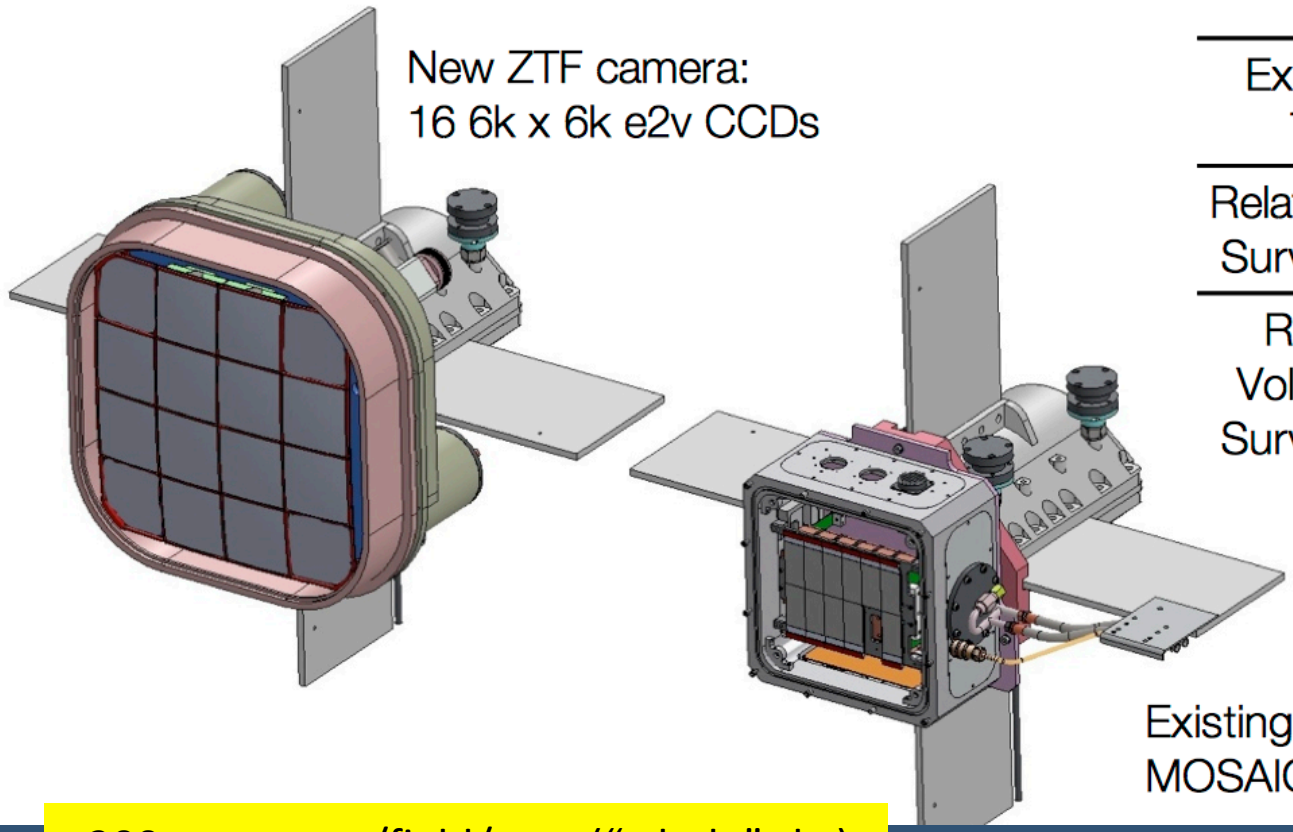
ZTF will survey an order of magnitude faster than PTF.

3800 deg^2/hour ⇒ 3π survey in 8 hours

	PTF	ZTF
Active Area	7.26 deg^2	45 deg^2
Readout Time	36 sec	10 sec
Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**14.7x**
Relative Volumetric Survey Rate	1x	**12.3x**

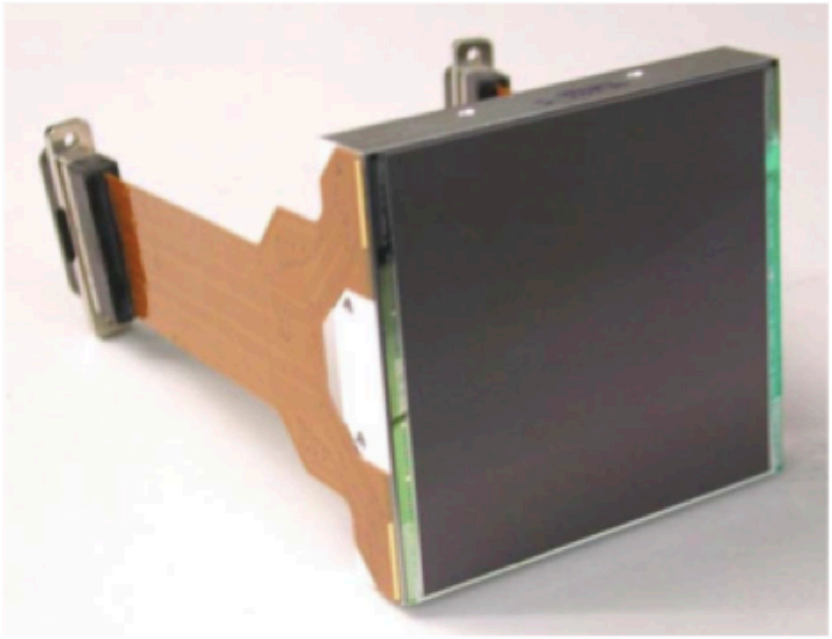
For Type Ia SNe

New ZTF camera:
16 6k x 6k e2v CCDs



Existing PTF camera
MOSAIC 12k

>200 exposures/field/year ("whole" sky)



[CCD231-84 is illustrated here; CCD231-C6 is similar]

e2v	
dimension	9.2 x 9.2 cm
pixels	6.1k x 6.1k
pixel size	15 micron
pixel scale	1”/pixel
outputs	4

~600 Mpixel , 40 x 40 cm^2 focal plane

Summary

- Time domain astrophysics is experiencing a rapid development – FoV+timescale
- Likely to discover new kinds of transients and significantely improve the measurements of known ones, e.g. Type Ia supernovae used in cosmology
- iPTF/ZTF are showing the way: SNe are being discovered within few hours from explosion
- Theorists: think of new tests we should do with time-domain data!

And dont miss part III sometime soon!


Thank you!
I. Arcavi