Frontiers in time-domain astrophysics

-the intermediate Palomar Transient Factory (iPTF) and the Zwicky Transient Facility (ZTF)

Aríel Goobar
Stockholm University

Oskar Klein centre

Time domain & Breakthroughs

- Variable stars (Cepheids, RR-Lyrae)
  - yardsticks for Local Universe
- Pulsars
  - Tests of General Relativity
- Multi-wavelength measurements of AGNs, GRBs,…, ν's from SN87A
  - physics of compact objects, collapse into neutron stars & black holes
- Supernovae
  - Hubble constant, H_0
  - accelerated expansion

Exciting detections in the future (amen!) include:

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

Transients @ optical wavelengths

Our knowledge/discovery potential is limited by survey parameters:

- flux sensitivity
- cadence (how often a region of sky is revisited)
- Wavelength range

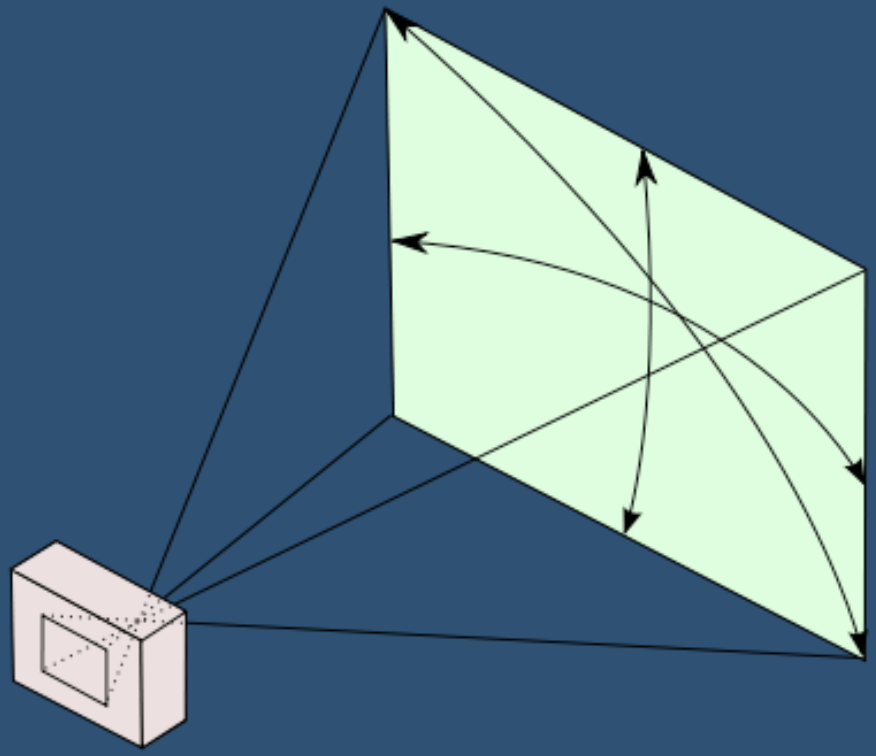
-- Surprises may wait around the corner

-- need to push the observational boundaries!

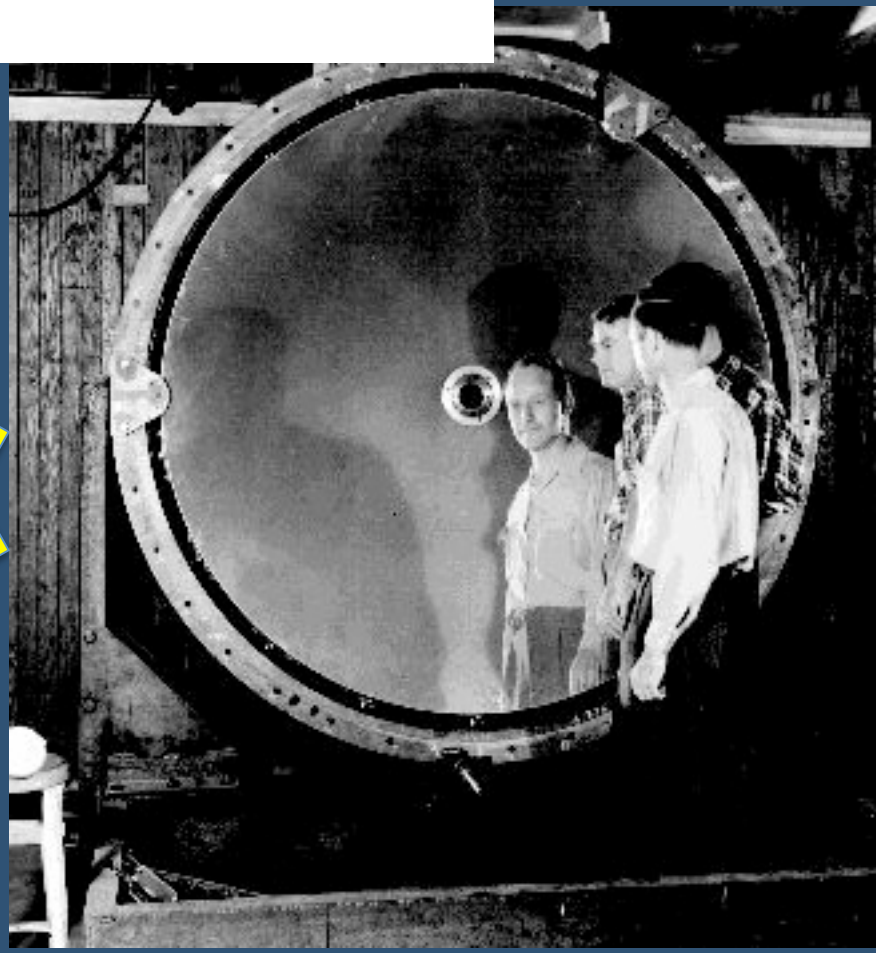
(c.f. supernova cosmology)

Optical Surveys "Survey Speed"

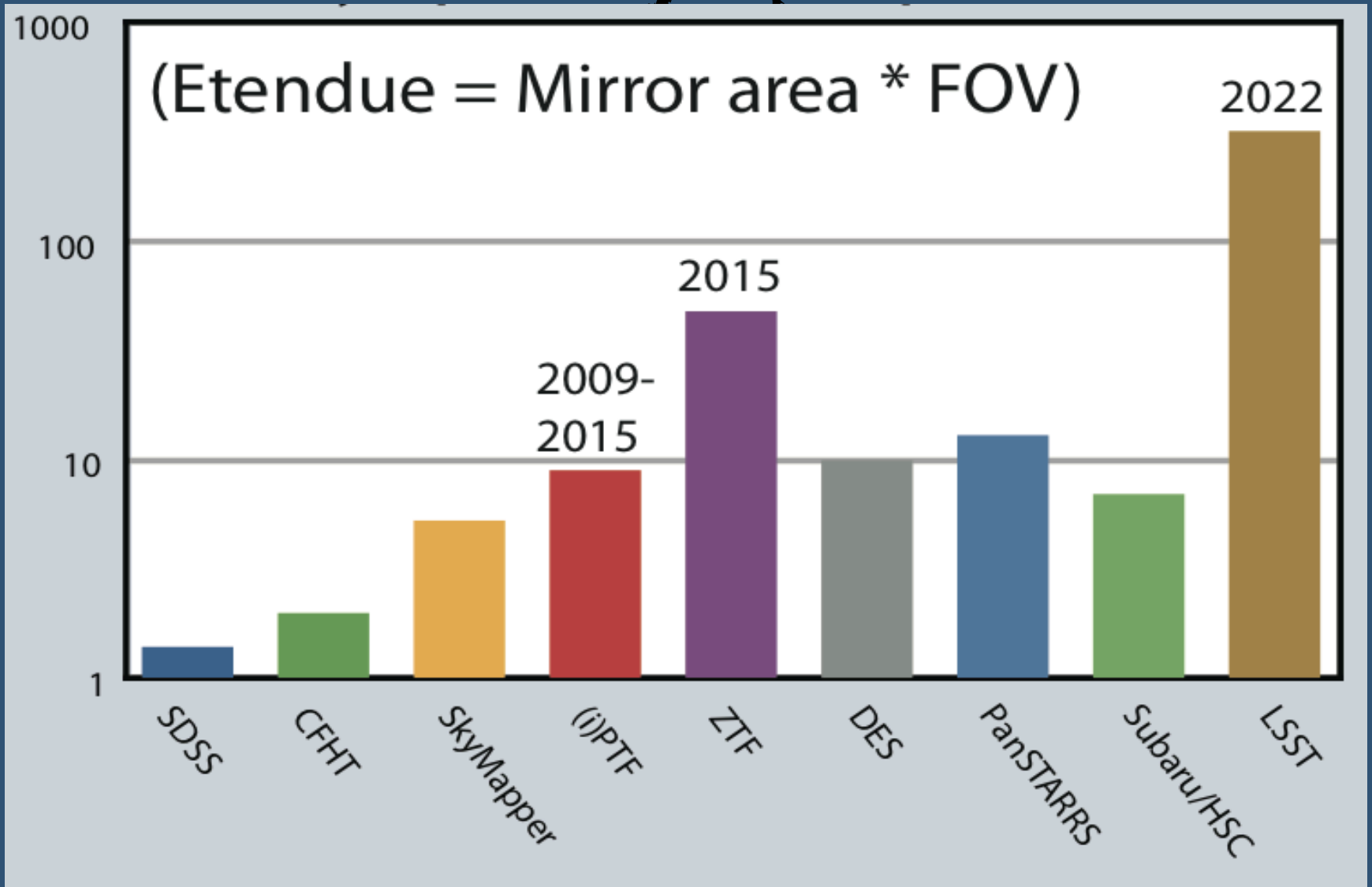
(Etendue = Mirror area * FOV)



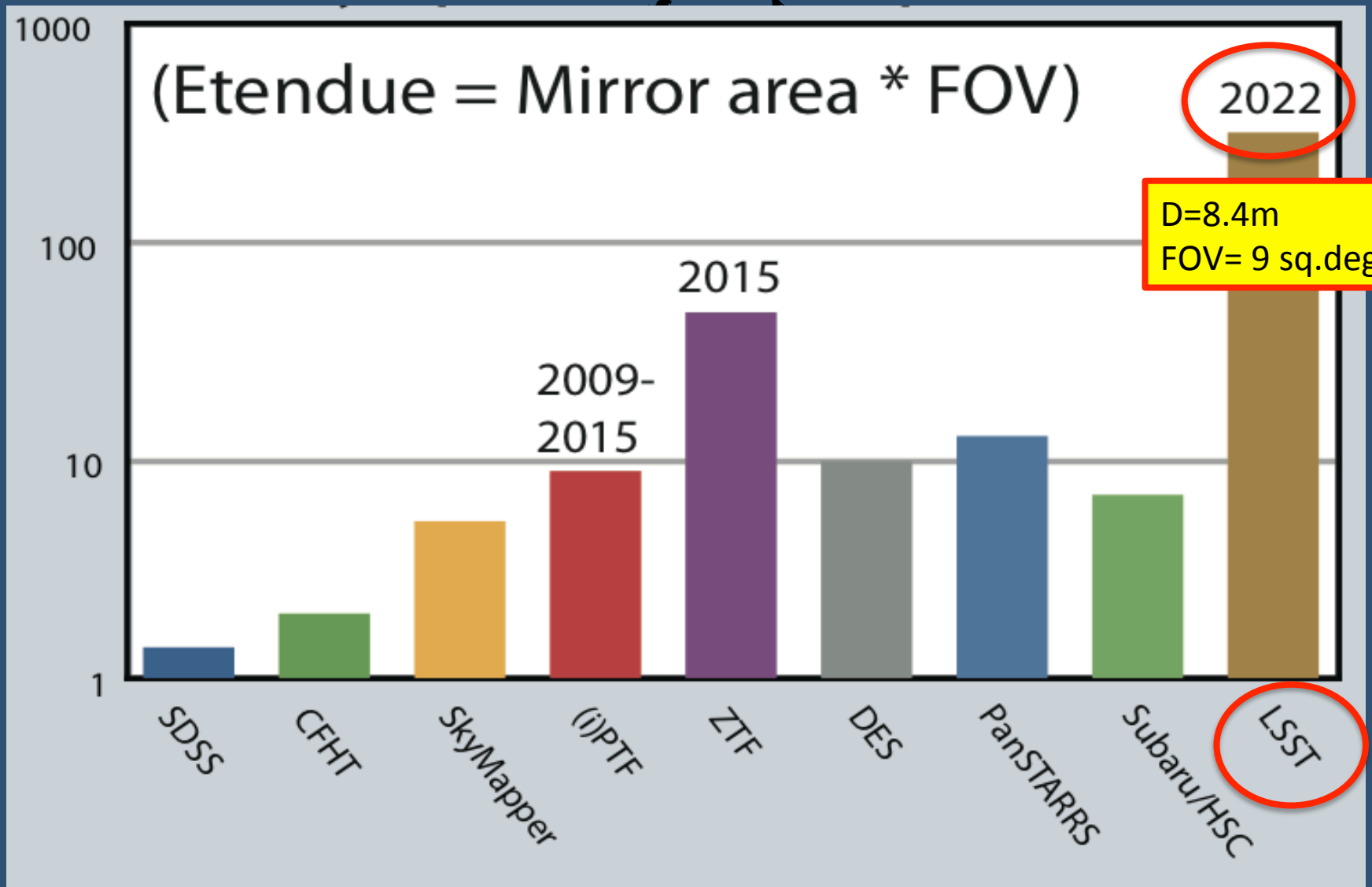
X



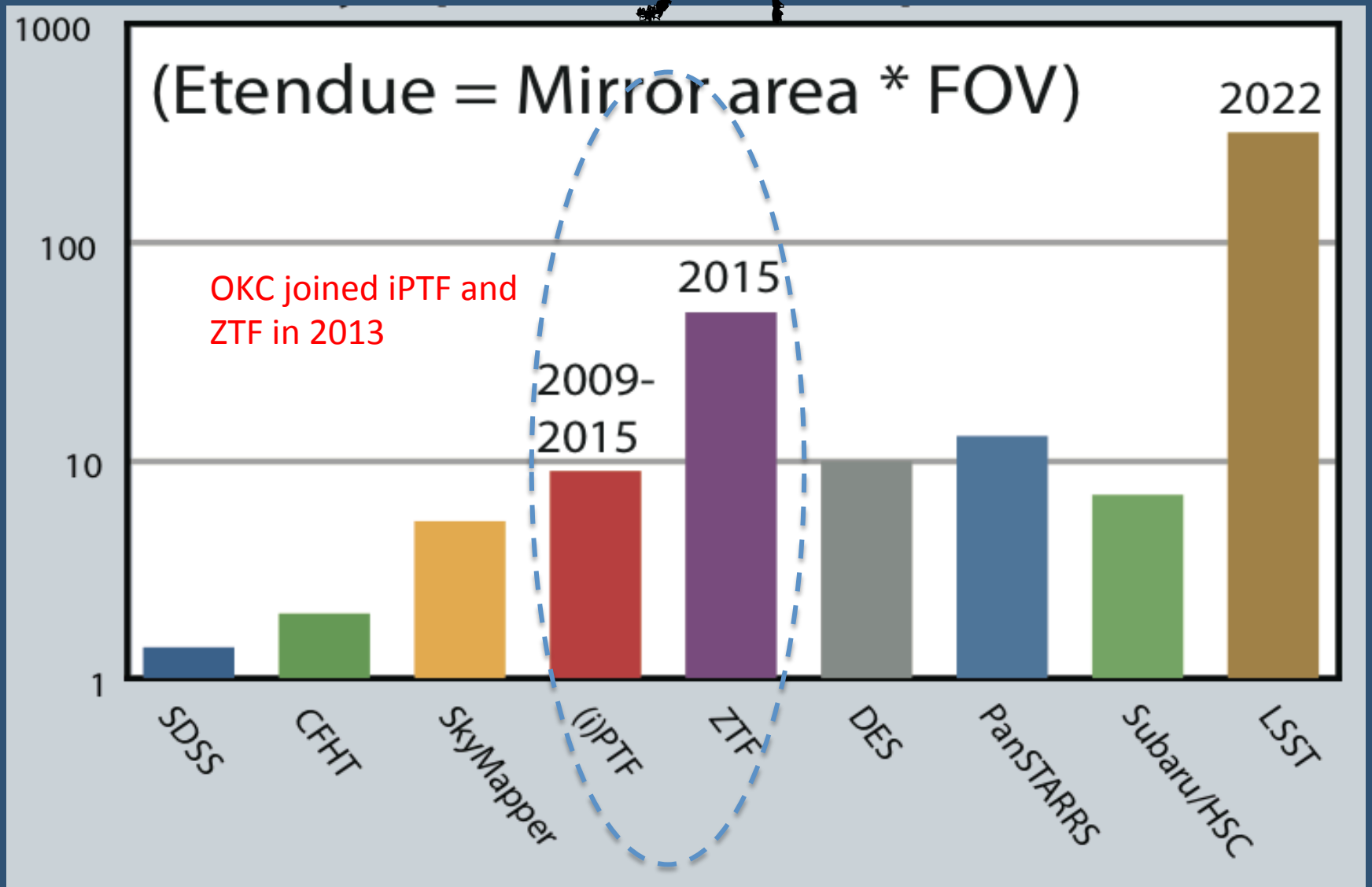
Optical Surveys "Survey Speed"



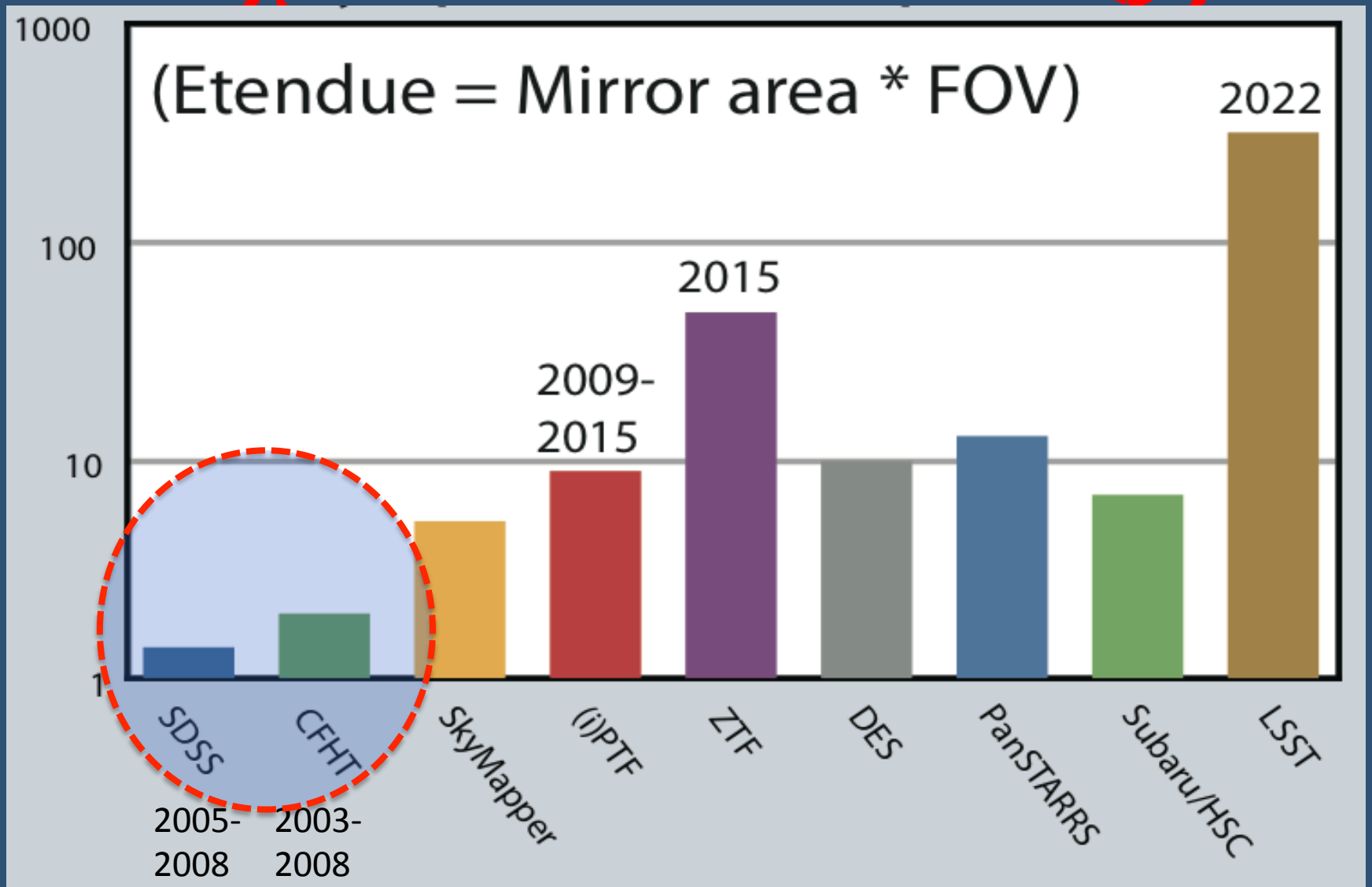
Optical Surveys "Survey Speed"



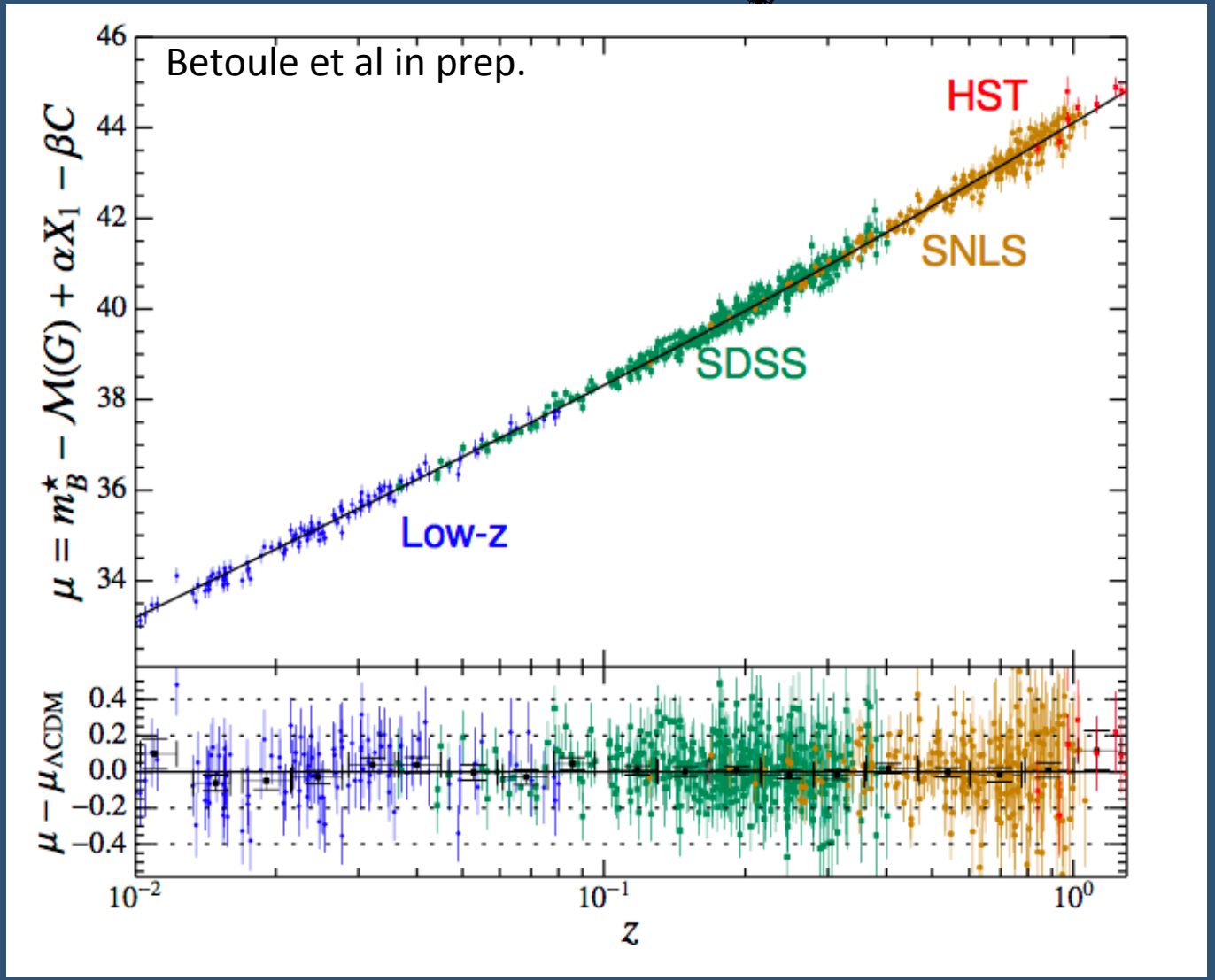
Optical Surveys "Survey Speed"



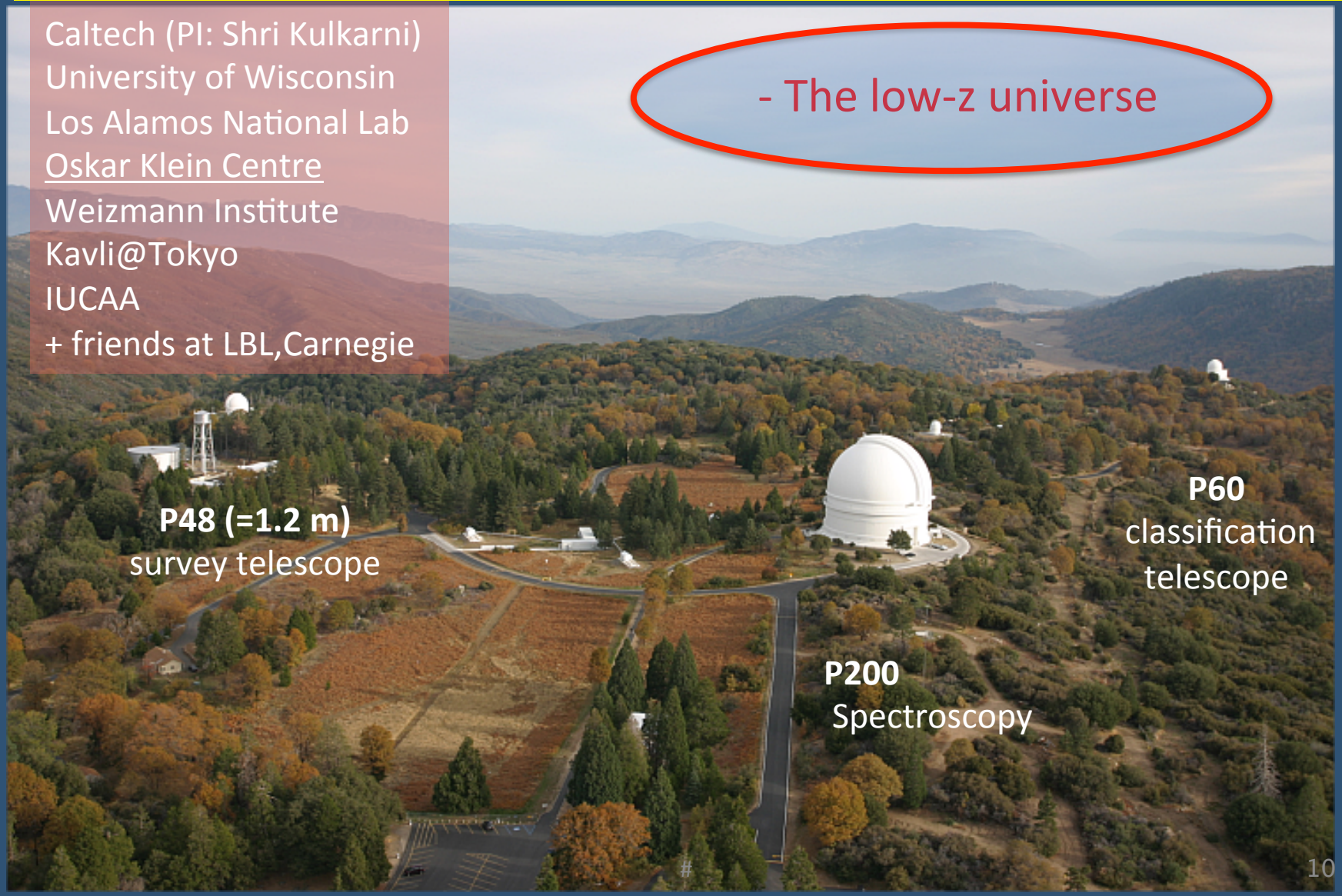
Optical Surveys
Type Ia SN cosmology

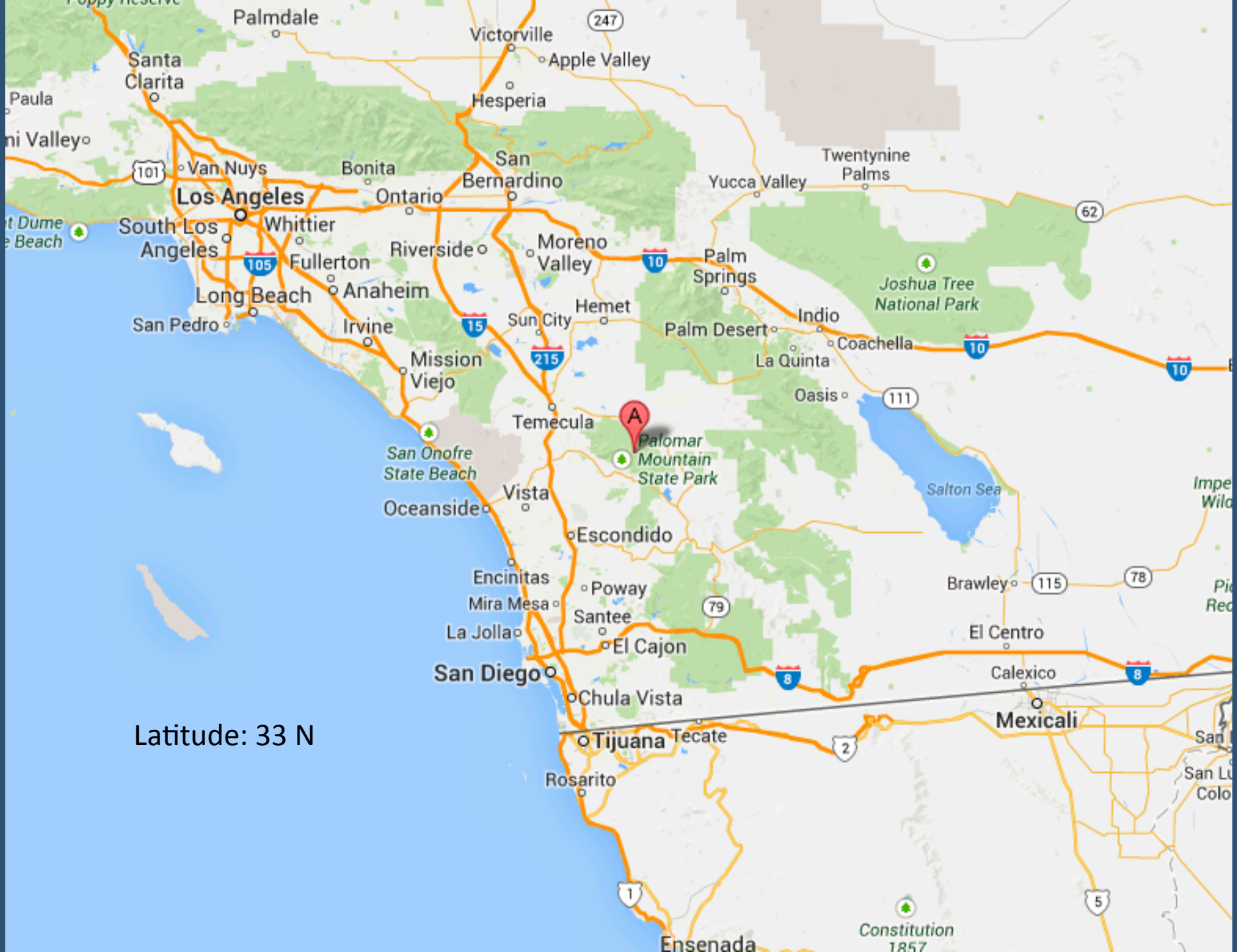


SNe Ia: SDSS 3 yr + SNLS 3 yrs



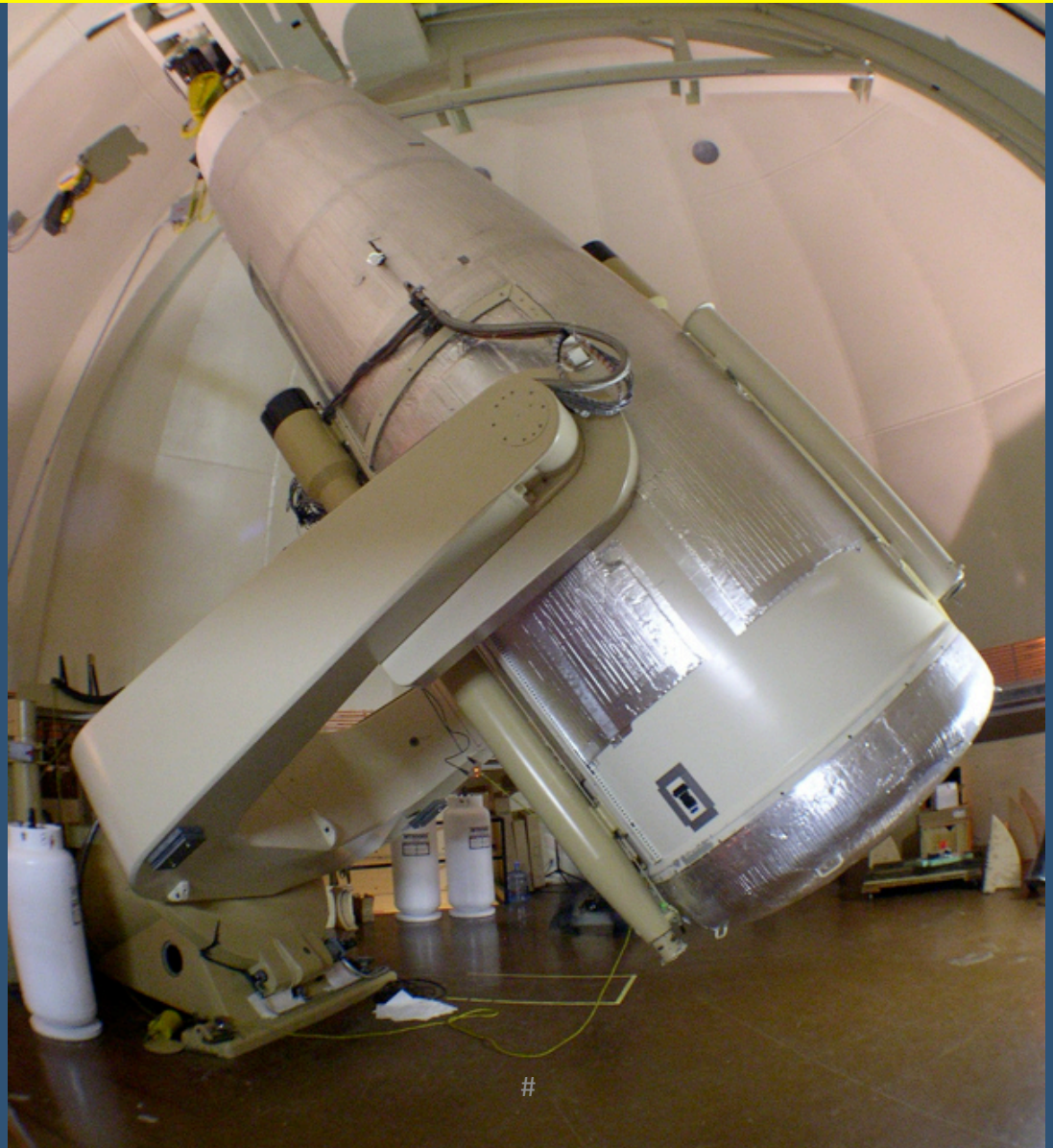
Where do iPTF/ZTF fit in?

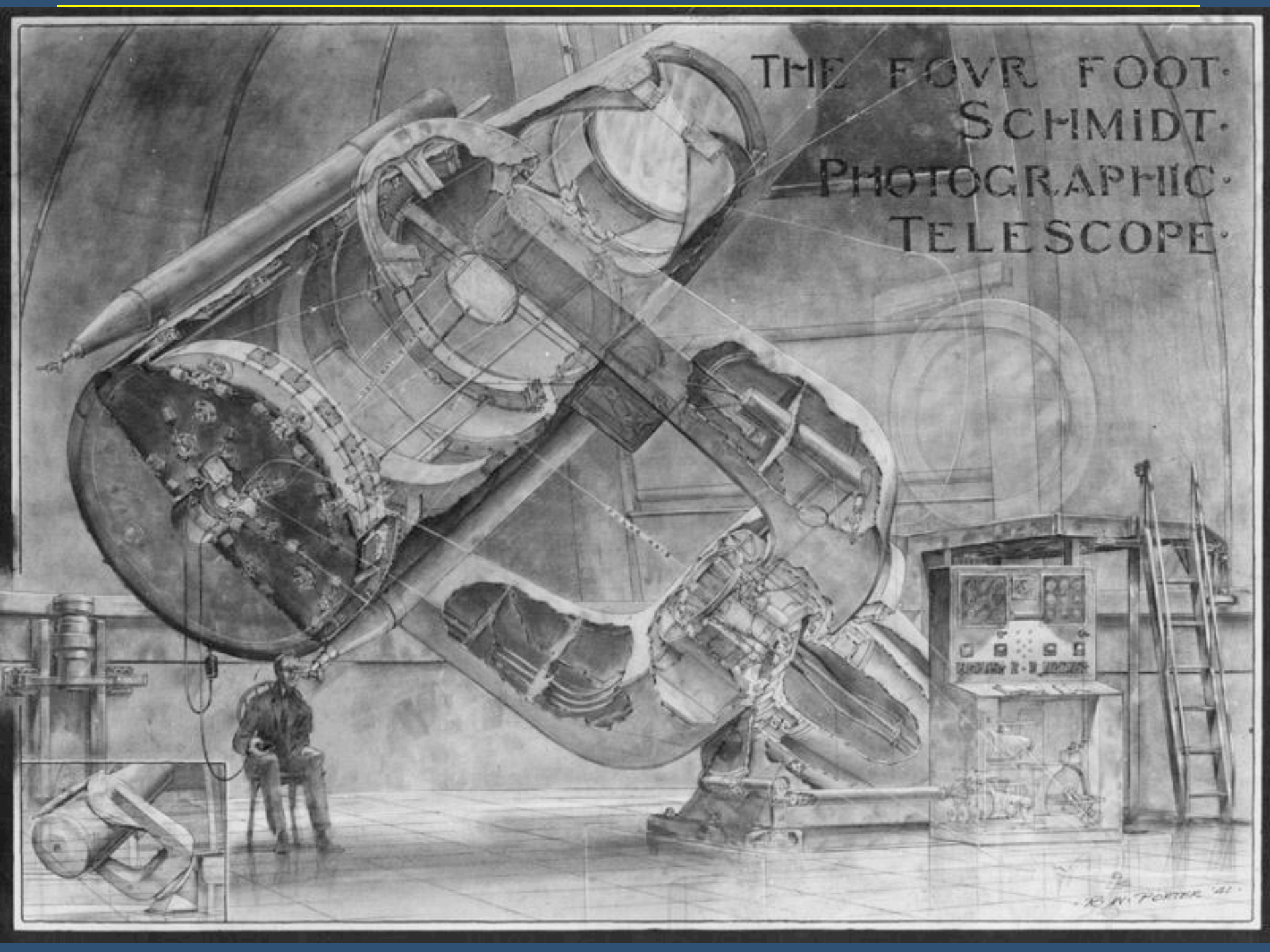


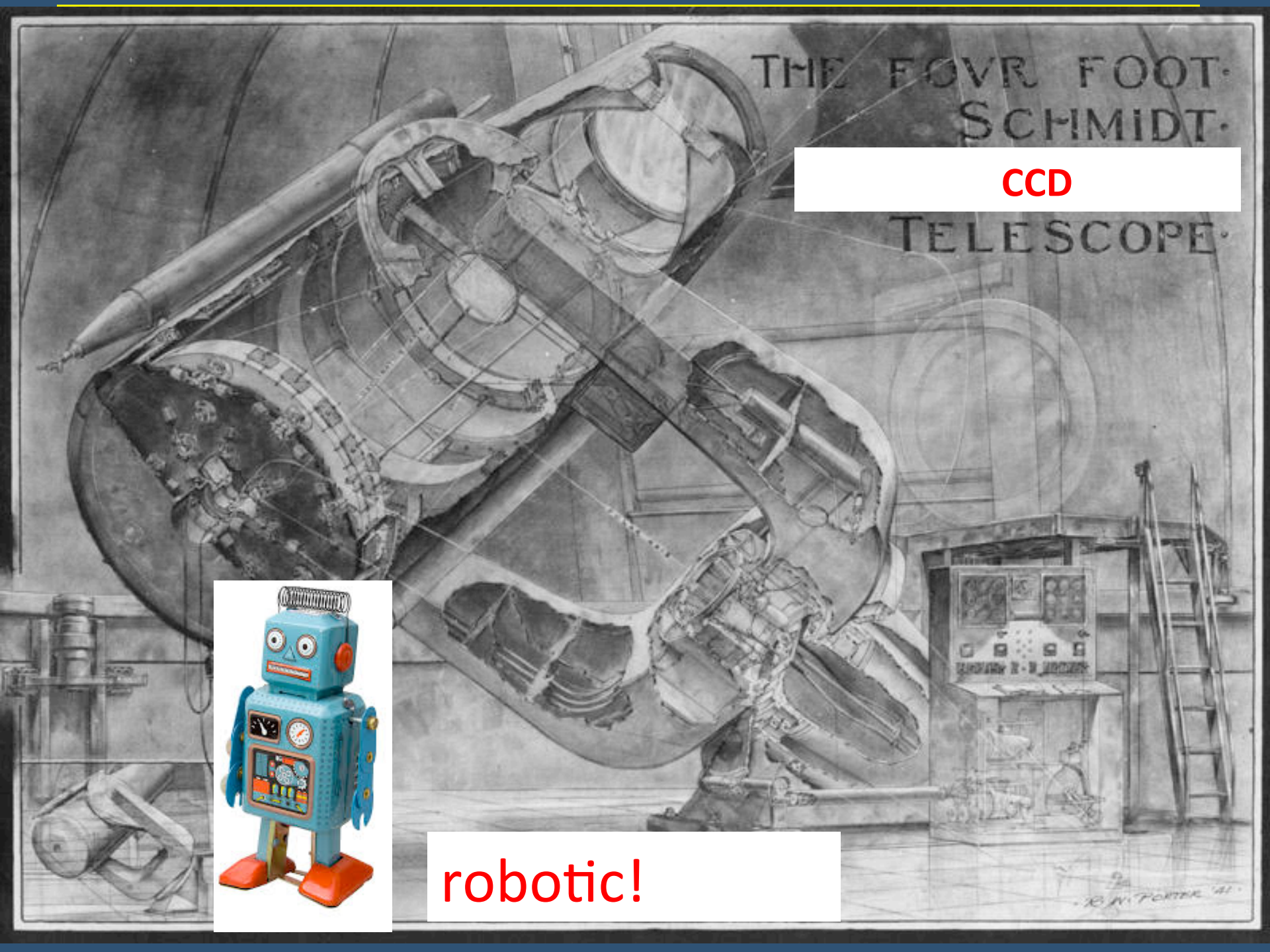


Latitude: 33 N

The 48-inch telescope



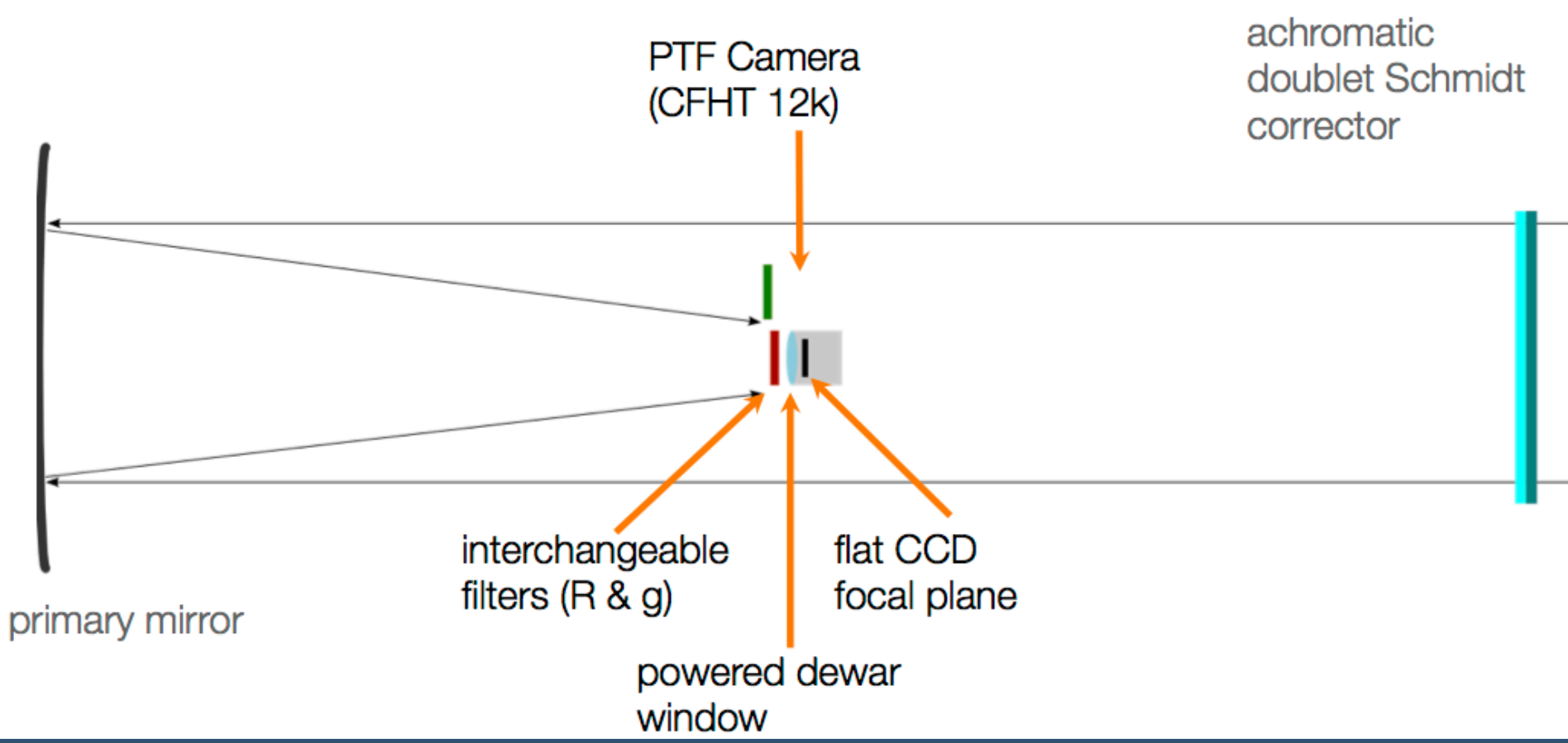

THE FOVR FOOT·
SCHMIDT·
PHOTOGRAPHIC·
TELESCOPE·



CCD

robotic!

Inside the tube



The 12X(2Kx4K) CCDs

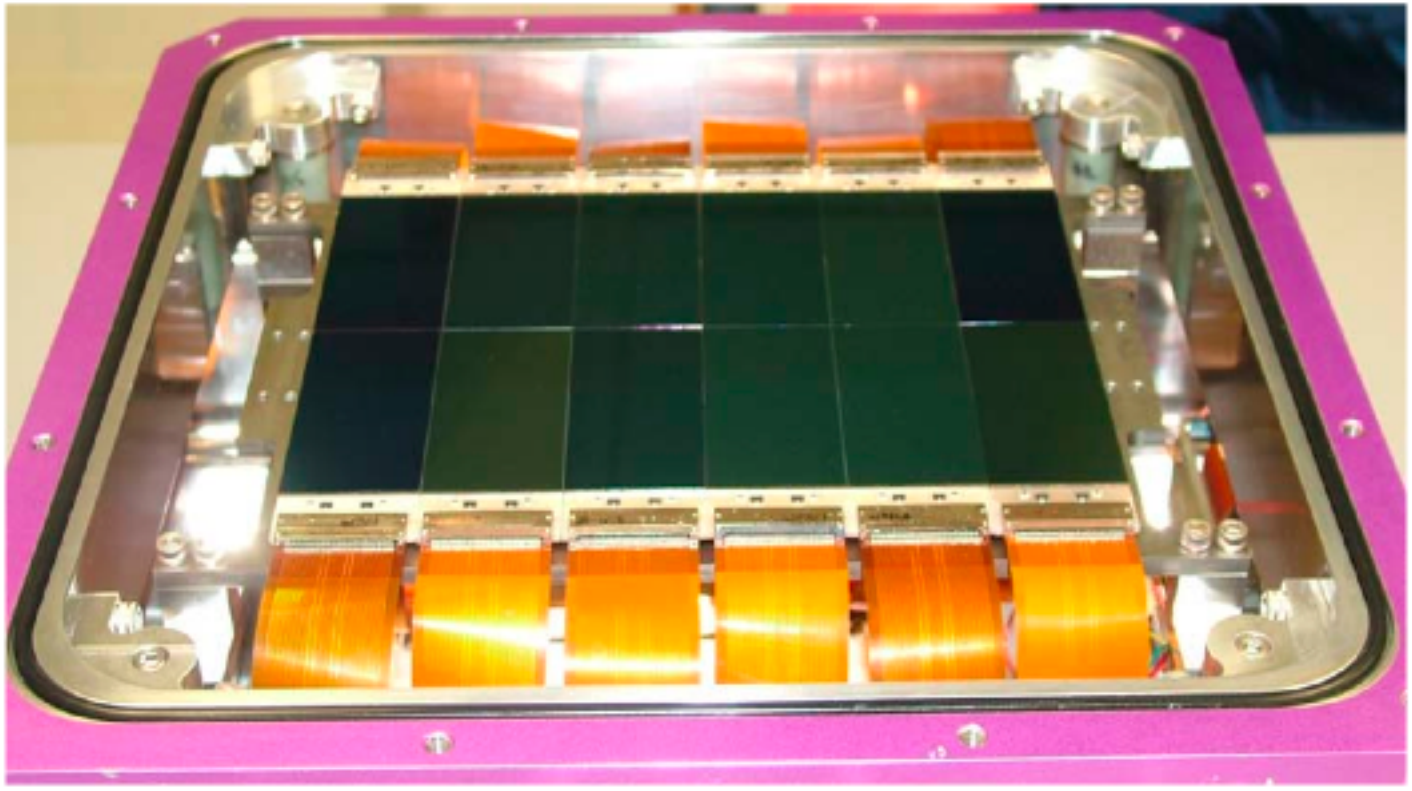
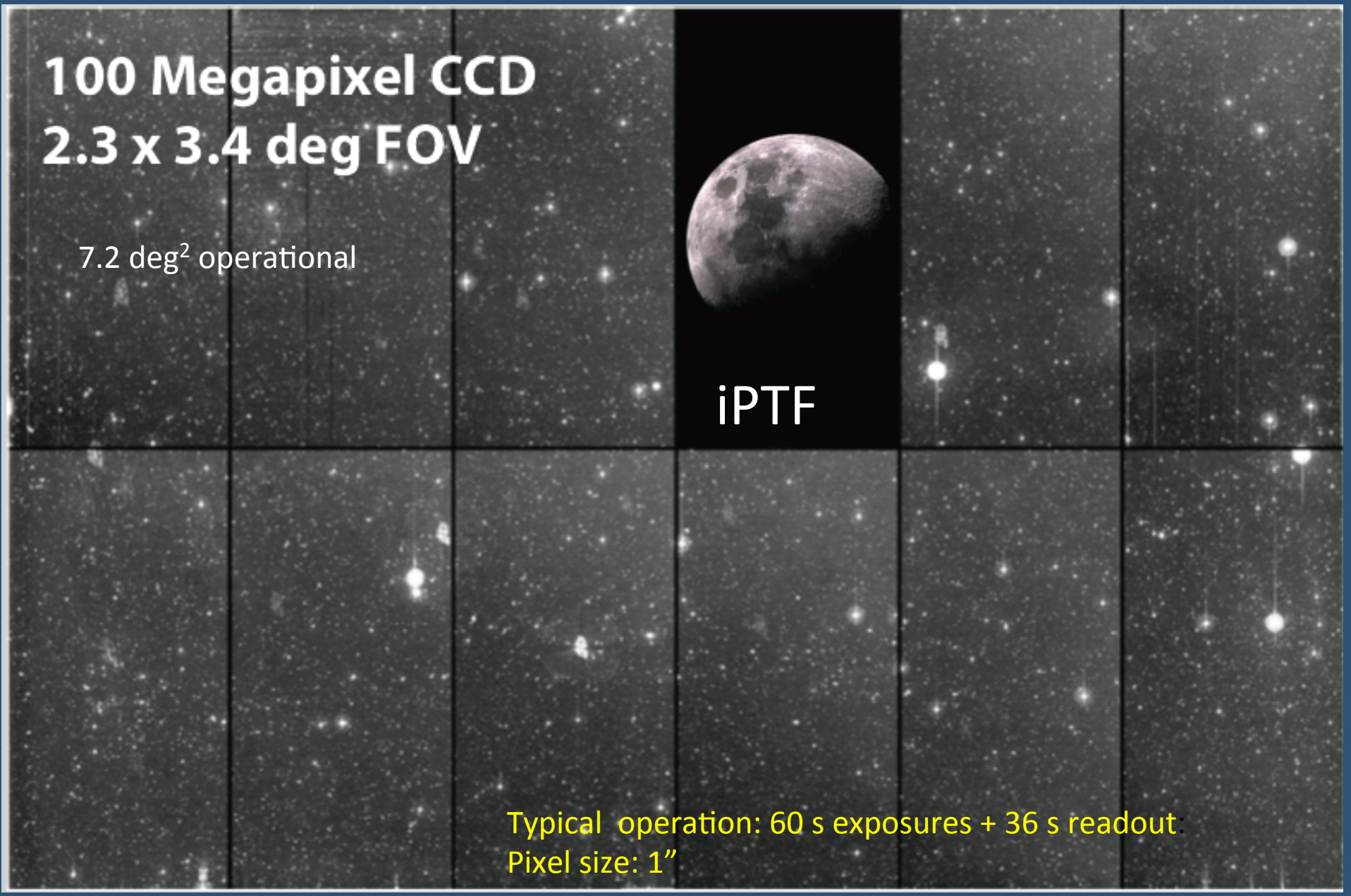


Fig. 1: The Mosaic camera focal plane inside the dewar with front plate and window removed.


100 Megapixel CCD
2.3 x 3.4 deg FOV
7.2 deg^2 operational
iPTF
Typical operation: 60 s exposures + 36 s readout
Pixel size: 1”

(i)PTF Searching the sky

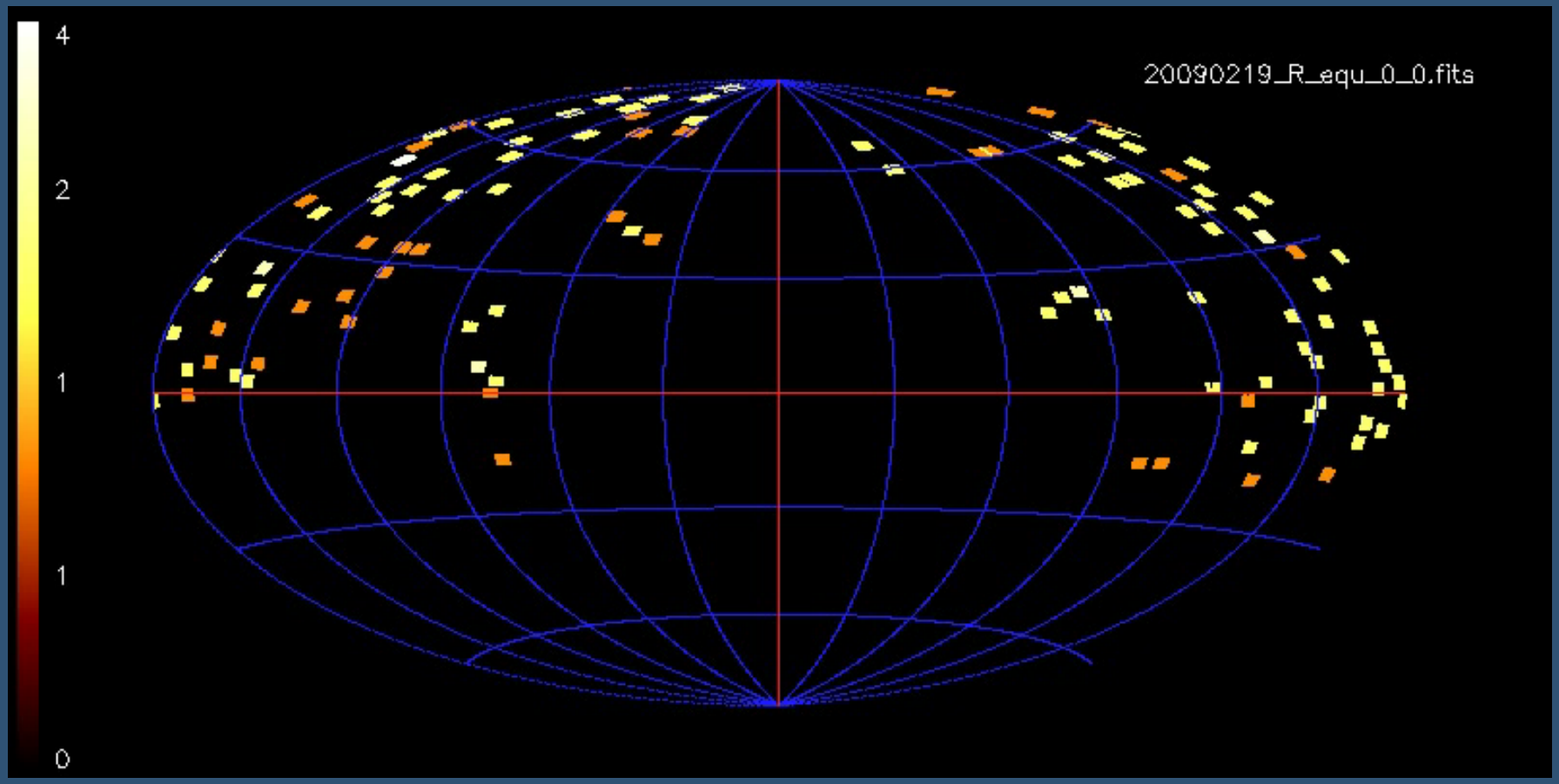
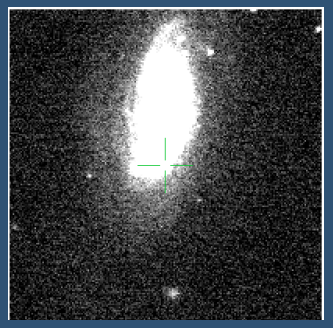
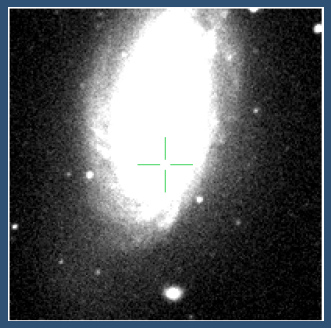


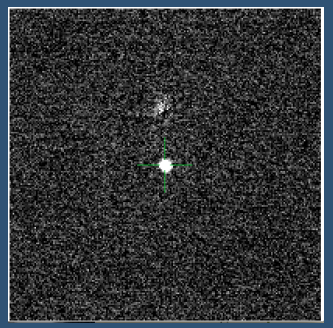
Image Subtraction



Processed new mage

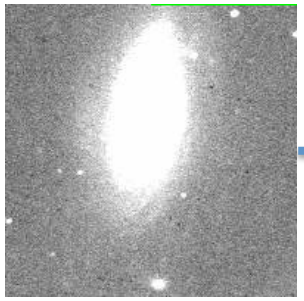


Reference image
from previous visits



Subtraction image

Pipeline Flow Chart



Raw data

(Palomar -> Caltech -> LBL)

processing

3 min

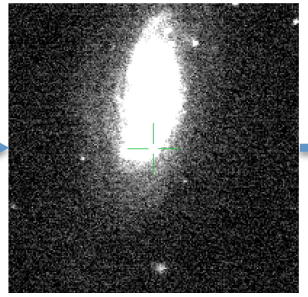
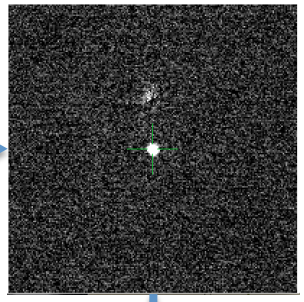
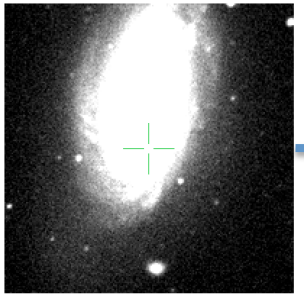


Image Subtraction



1.5 min/ image



Reference Image

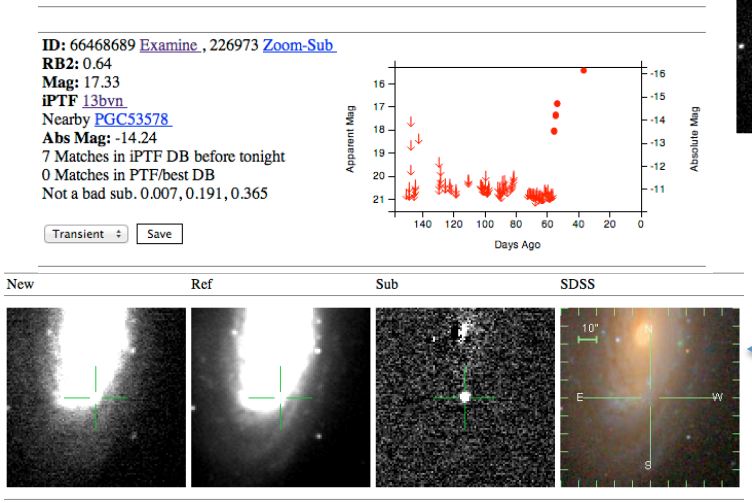
Real-Bogus (reject false alarms) 0.5 min/ image

Load candidates Into database

Database

Star/rock Identification
Local galaxy match

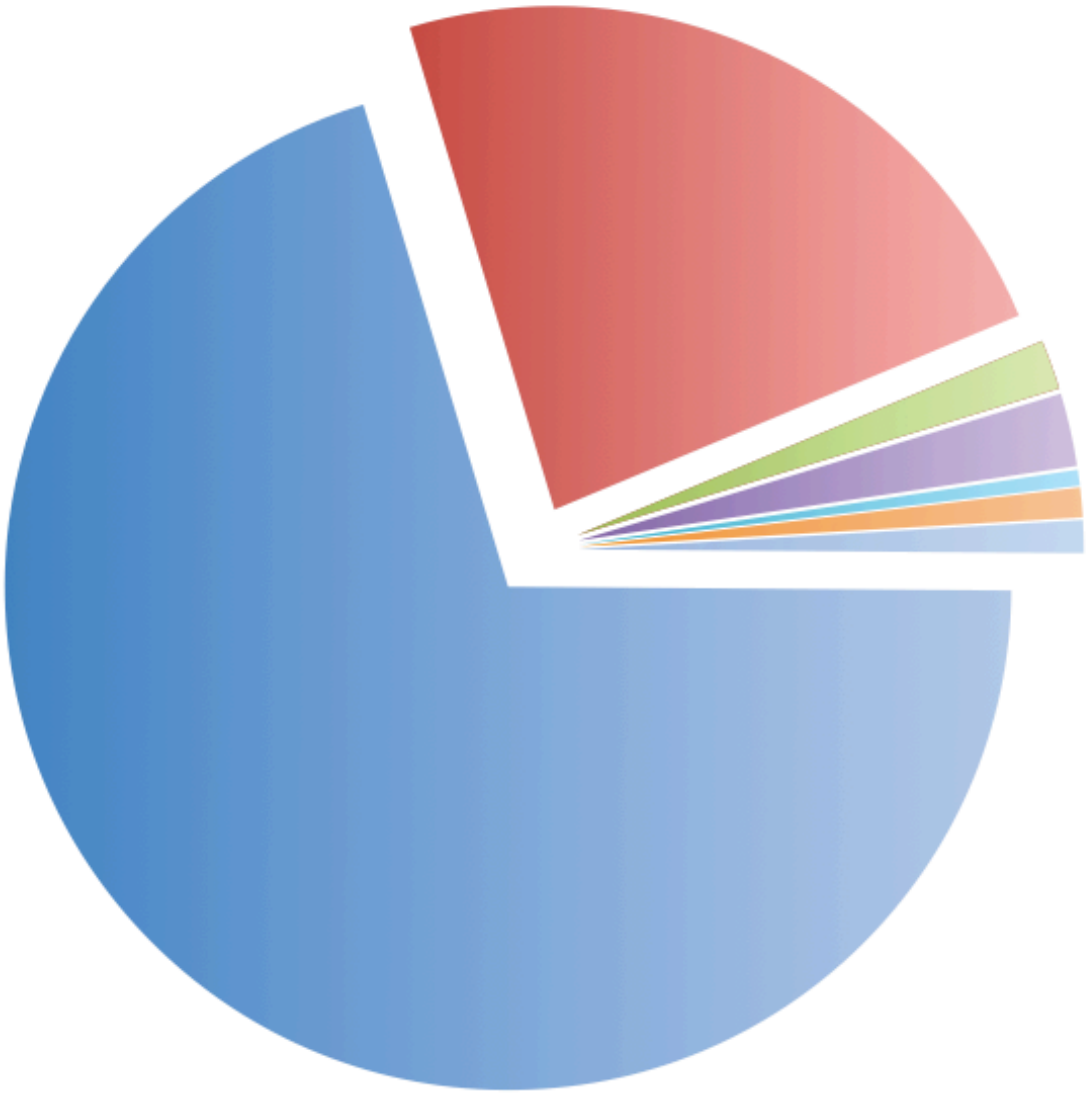
0.5 min/image



Scanning Page: human screening mainly in Israel and Stockholm

COURTESY OF YI CAO & MANSI KASLIWAL

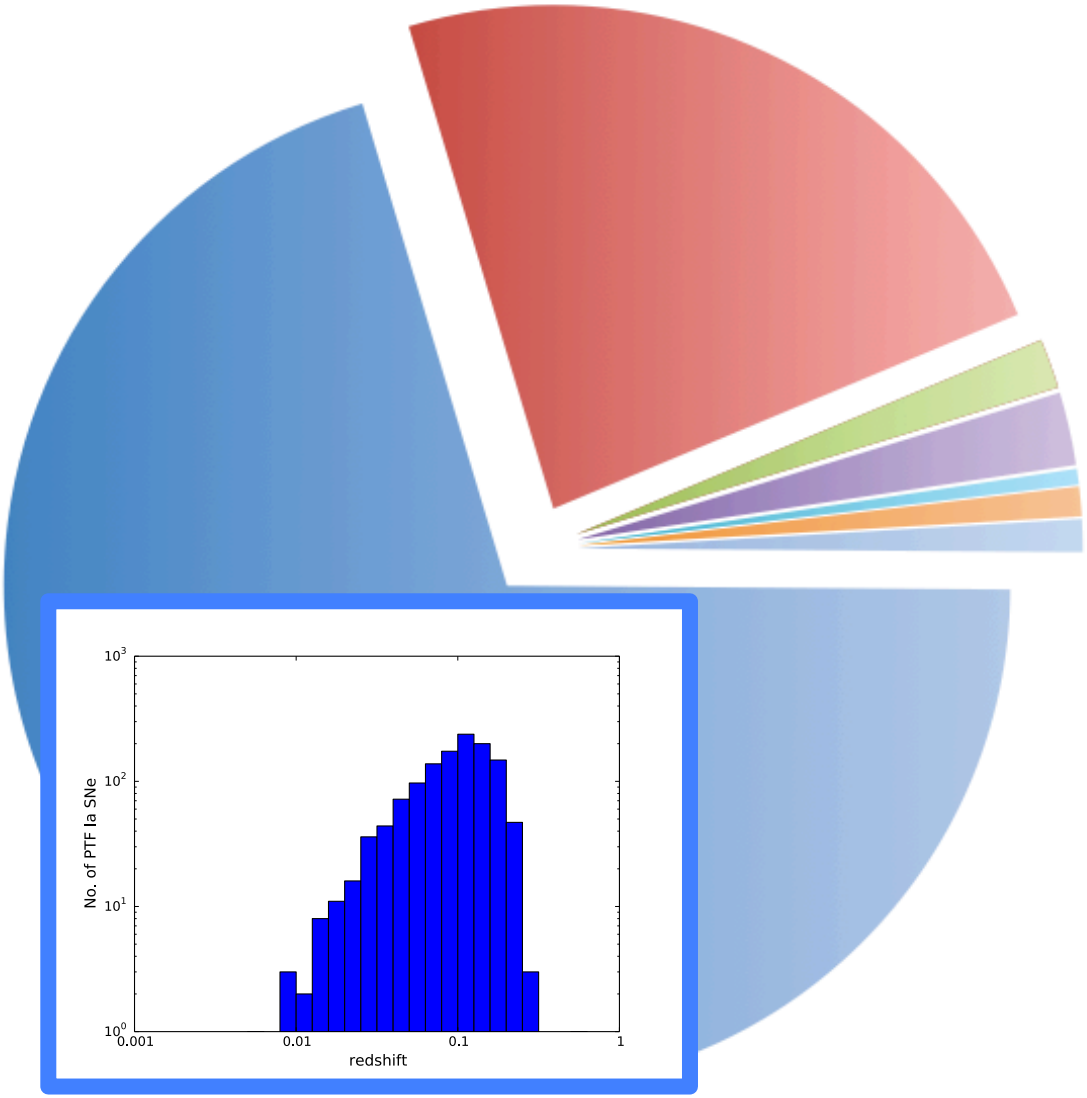
Spectroscopically confirmed PTF/iPTF SNe (October 2013)



- 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



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- Ia (1411)

Total:
1837 (2009-2012)
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Present Time: 16 Dec 2013; 20:03 UT

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iPTF Type Ia SN Discovery Report 20131009

ATel #5465; *Y. Cao (Caltech), P. E. Nugent (LBL), A. Goobar, J. Johansson (OKC), A. Waszczak (Caltech), P. Vreeswijk, A. De Cia, O. Yaron (Weizmann), J. Van Roestel (Radboud)*
on 12 Oct 2013; 07:06 UT
Credential Certification: Yi Cao (ycao@astro.caltech.edu)

Subjects: Optical, Supernovae

The iPTF (ATel #4807) reports discovery of following new Type Ia SNe:

Name | RA (J2000) | Dec (J2000) | Discovery | Mag | Redshift | Type | Spec. | Phase | Instrument | Notes

PTF13dnh | 22 38 33.14 | +12 02 23.4 | Sep 26.17 | 17.7 | 0.04 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dni | 02 05 22.13 | +23 23 16.5 | Sep 26.28 | 19.3 | 0.12 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dnj | 02 00 40.90 | +17 17 05.7 | Sep 26.27 | 20.1 | 0.066 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dnr | 02 05 17.99 | +00 05 55.5 | Sep 28.28 | 20.0 | 0.07 | SN Ia | Oct 04 | | P200+DBSP | CSS130930:020518+000556 (ATel #5456)

PTF13dnw | 02 33 20.99 | +26 59 53.2 | Sep 28.45 | 20.3 | 0.17 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dok | 23 20 48.54 | +02 55 09.8 | Sep 30.20 | 20.6 | 0.07 | SN Ia | Oct 04 | | P200+DBSP |

PTF13don | 23 44 51.30 | +01 41 45.8 | Sep 30.26 | 20.3 | 0.2 | SN Ia | Oct 05 | | P200+DBSP |

PTF13dpz | 23 11 36.58 | -01 00 26.1 | Oct 03.17 | 20.2 | 0.10 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dqa | 01 34 35.69 | -00 51 03.9 | Oct 03.20 | 20.6 | 0.16 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dqc | 02 28 36.90 | +33 02 13.1 | Oct 03.41 | 20.6 | 0.076 | SN Ia | Oct 04 | | P200+DBSP |

PTF13dqj | 01 24 57.49 | +31 34 04.6 | Oct 03.40 | 20.6 | 0.098 | SN Ia | Oct 04 | | P200+DBSP |

The classification spectra are available through WISeREP (Yaron & Gal-Yam 2012).

Related
5659 Supernovae from CRTS
5590 Spectroscopic Classification of CRTS Supernovae
5465 iPTF Type Ia SN Discovery Report 20131009
5456 Classification of Supernovae from CRTS
5437 CRTS Supernova Candidates
5187 CRTS SN Candidates
4733 CRTS Supernova Candidates

OKC participation

- Astronomy: Jesper Sollerman, Claes Fransson, Christoffer Fremling, Francesco Taddia, Katia Migotto. (core-collapse SNe)
- Fysikum: AG, Rahman Amaullah, Giorgos Leloudas, Joel Johansson, Raphael Ferretti, Semeli Papadogiannakis, Tanja Petrushevska (Type Ia SNe)
- KTH: Josefin Larsson (GRBs)

+ other people working in related topics
M.Kromer, S.Rosswog,P.Lundqvist,S.Larsson,…

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*

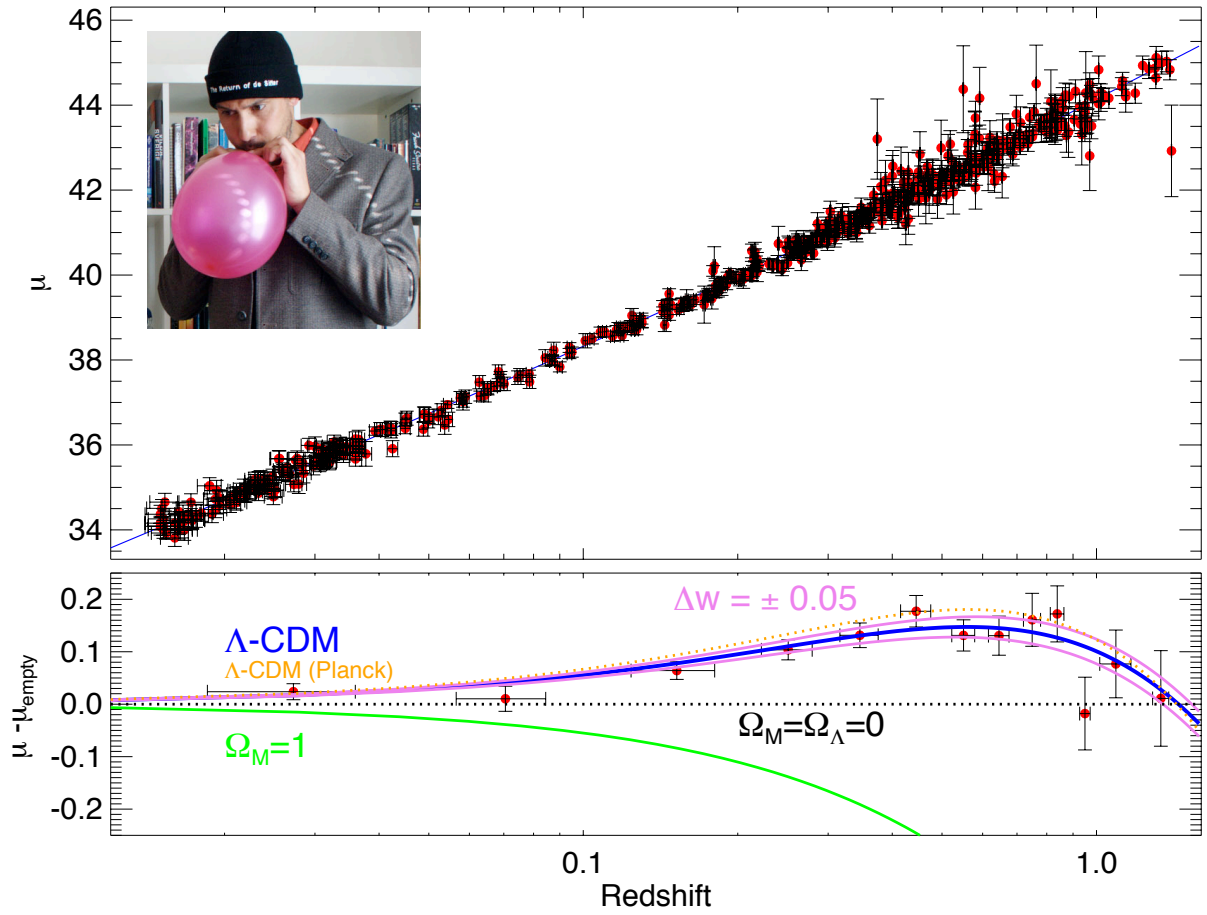
➔ *Ideal for studying the local universe. Discovery of transients extremely early (=soon after explosion)!*

➔ *Discoveries (<21.5 mag) can be followed by a large number of instruments – difficult/impossible for surveys with 4-8 m class telescopes prior to ELT era.*

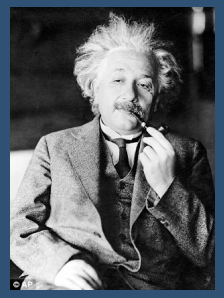
➔ *…in a very wide range of wavelengths*

➔ *Host galaxy environment can be studied in depth*

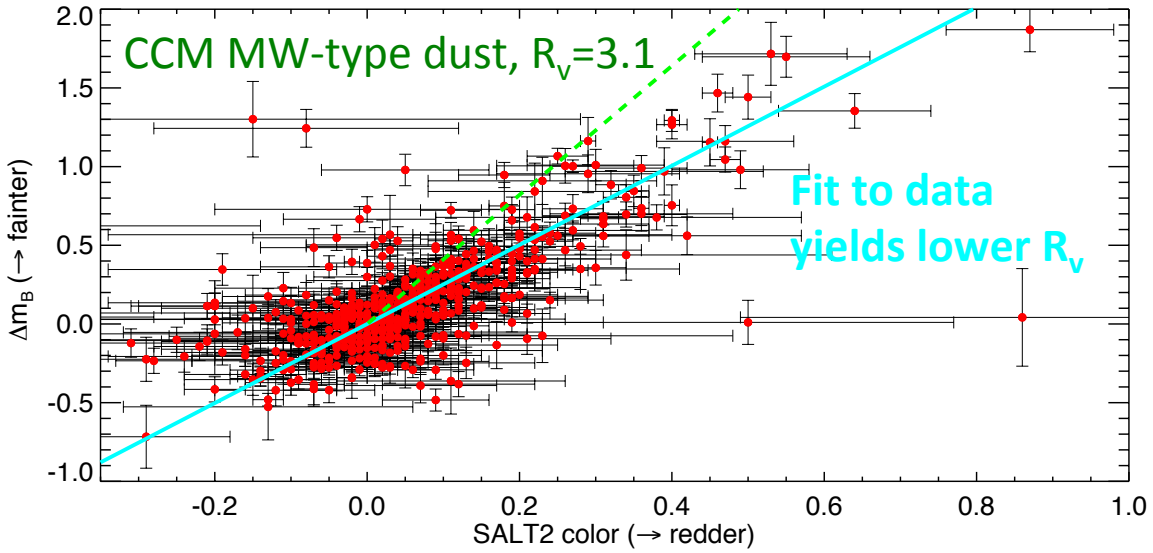
SNIa and the challenge of Dark Energy

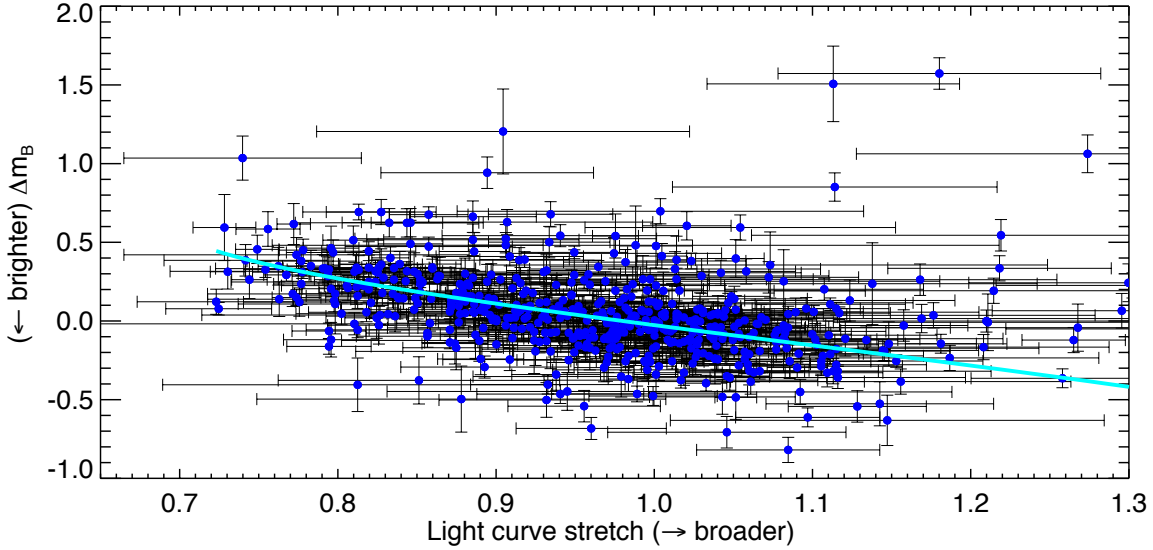


Frontier in cosmology:
Einstein's CC or not?
How to tell? look for deviations from w≠-1,
But requirements on control of systematics are quite brutal.



Applied corrections are large - lack understanding



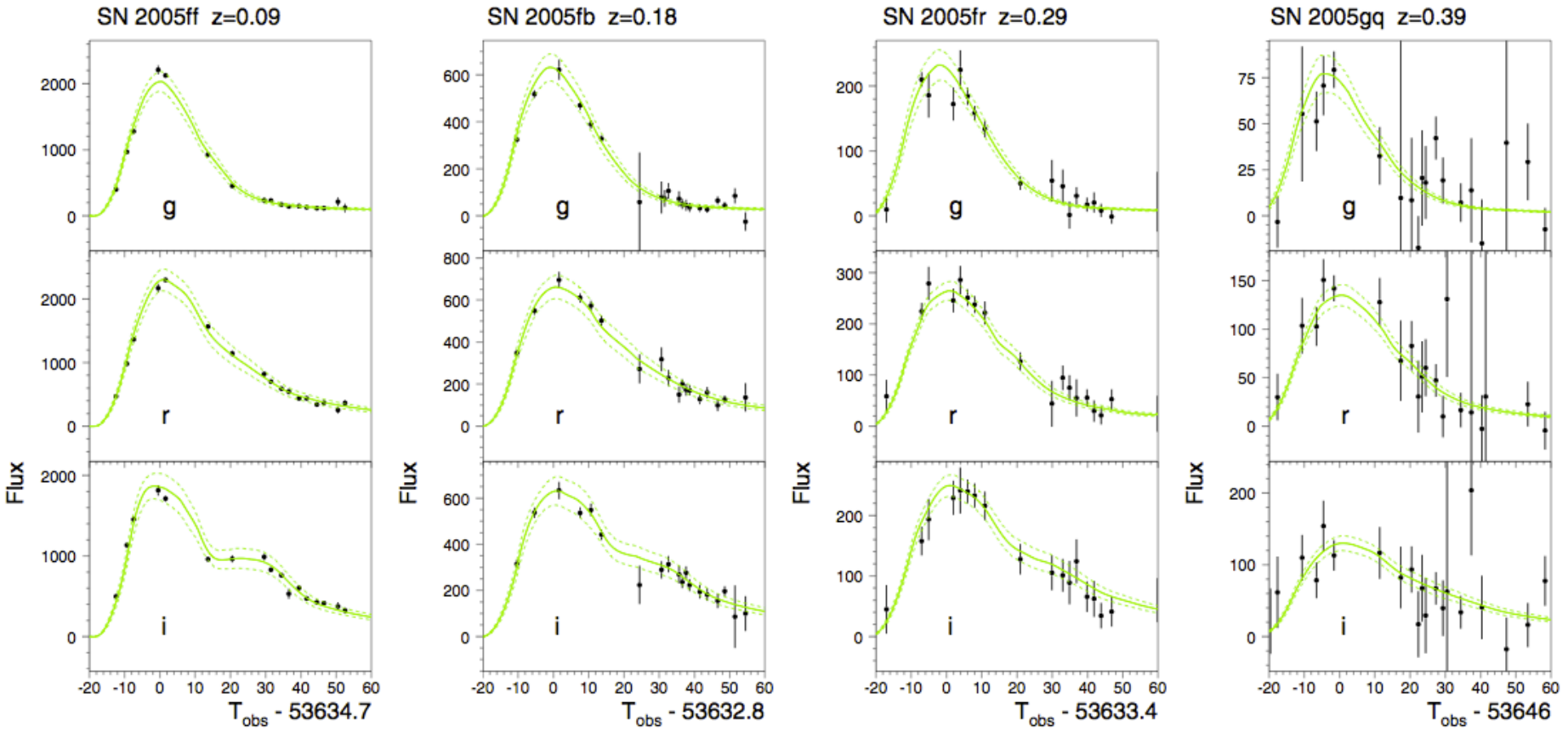


Color-brightness correction particularly bothersome, since large and we should "know better".

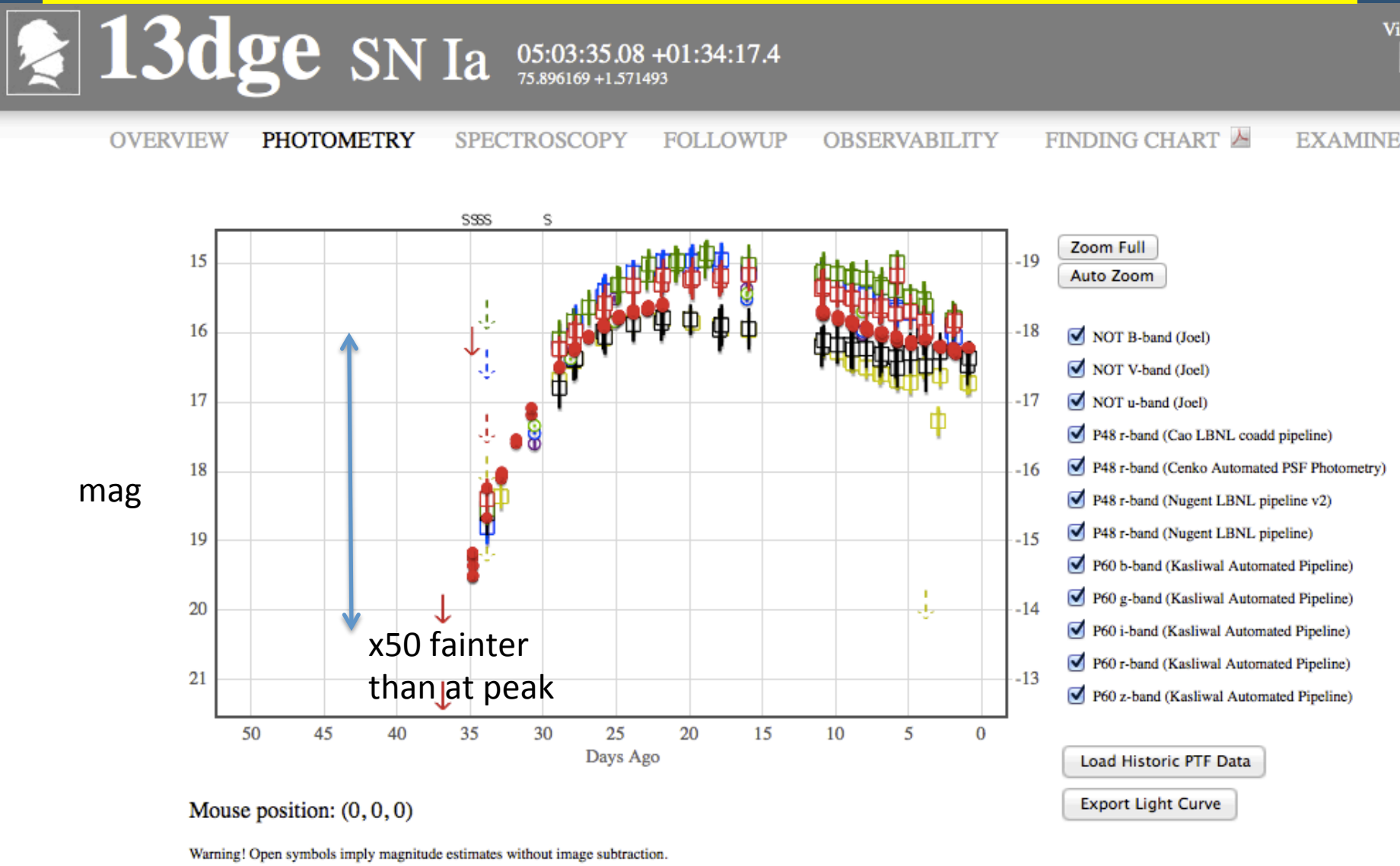
Many possible (partial) explanations, e.g.:

- 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

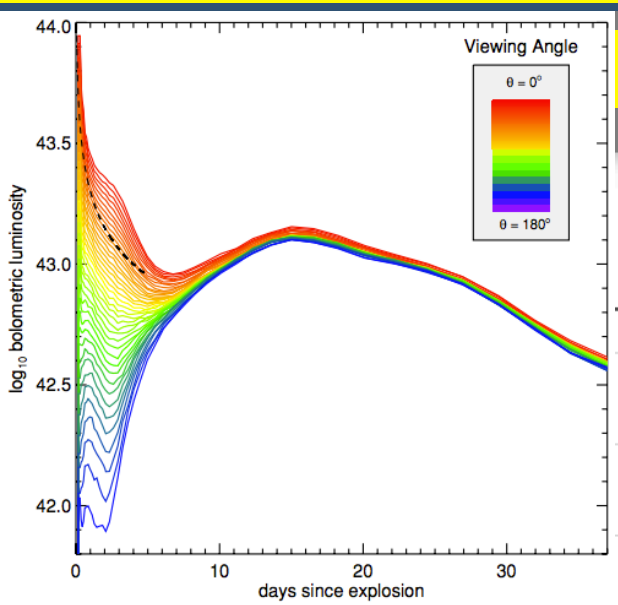


A "good" iPTF SNIa

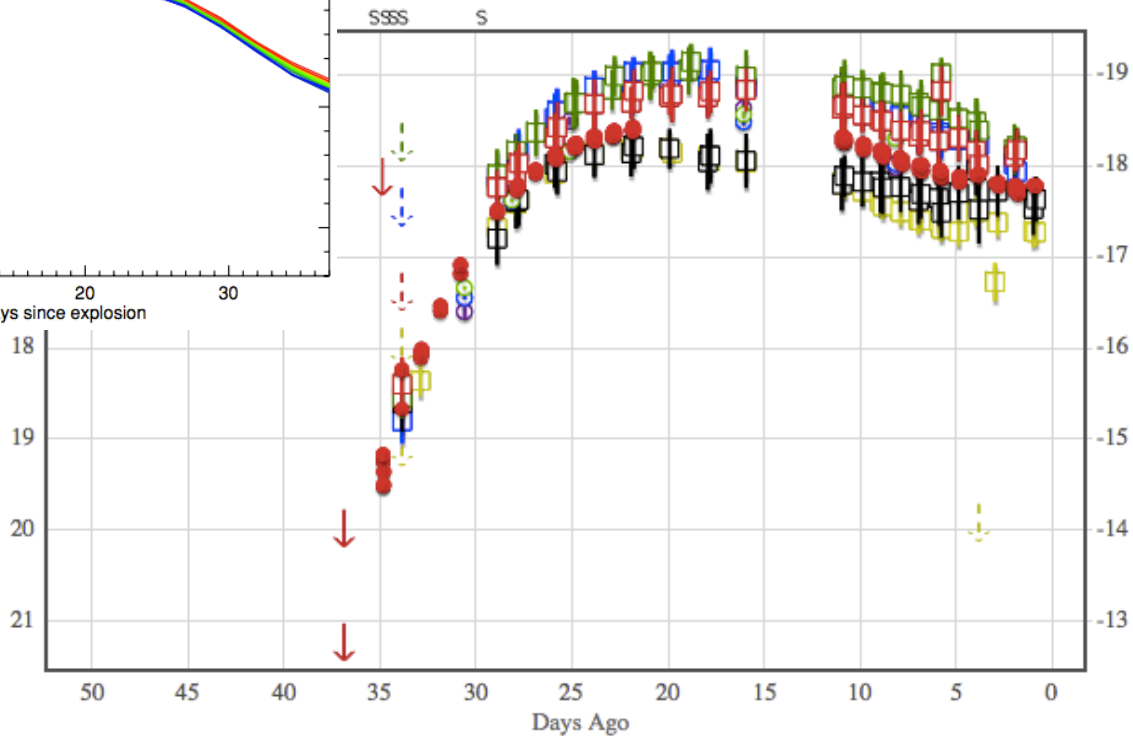


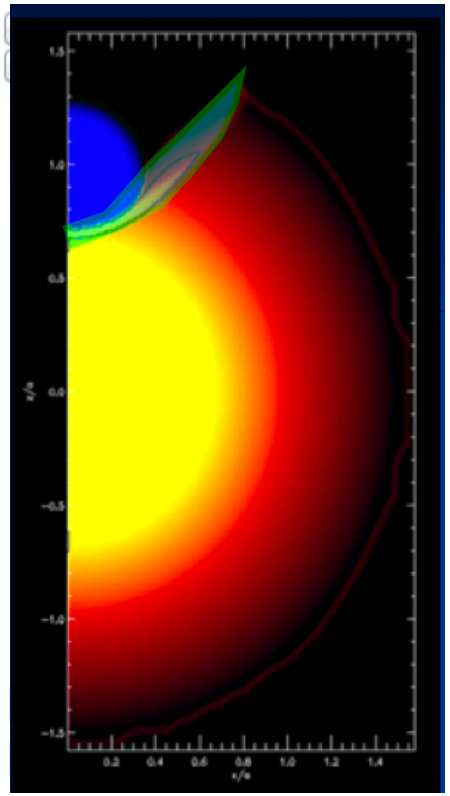
Nature of progenitor system

Kasen 2010 (Model!)



SPECTROSCOPY FOLLOWUP OBSERVABILITY FINDING CHART EXAMINE PA



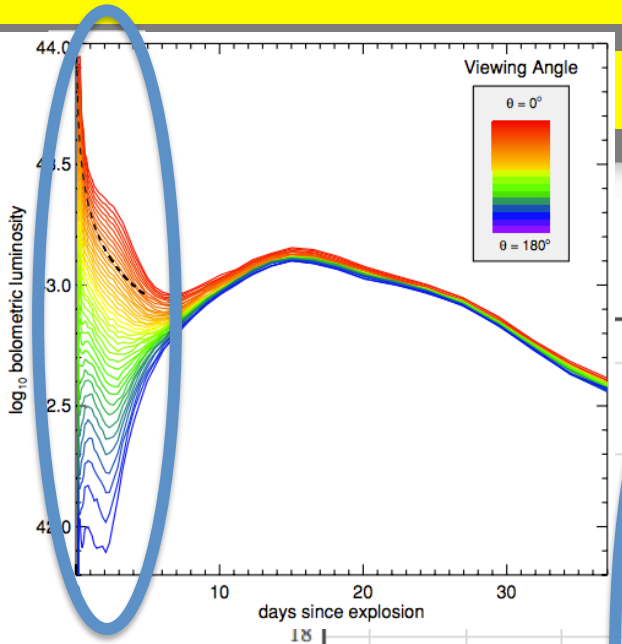


Mouse position: (0, 0, 0)

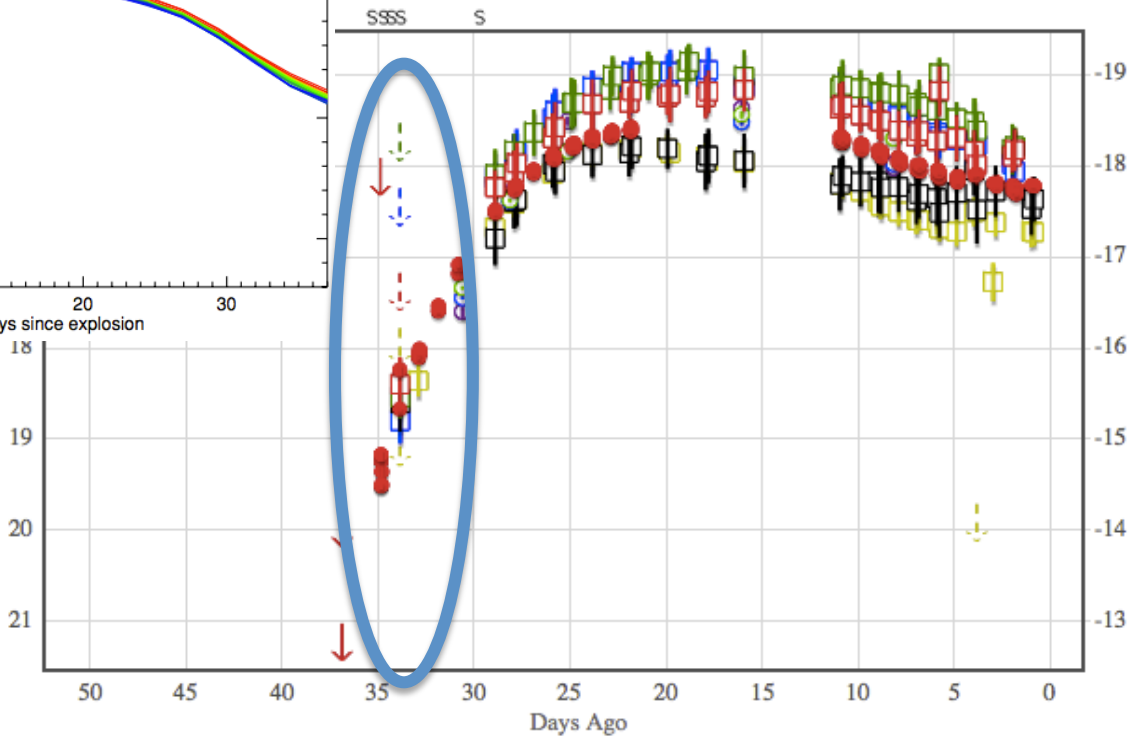
Warning! Open symbols imply magnitude estimates without image subtraction.

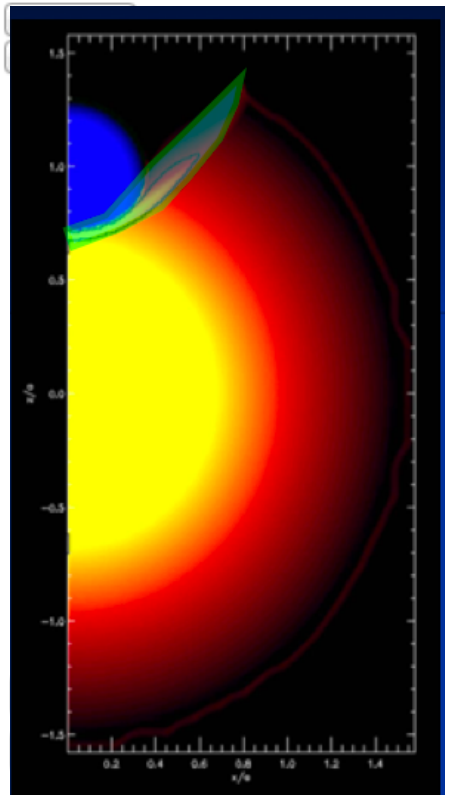
Nature of progenitor system

Kasen 2010 (Model!)



SPECTROSCOPY FOLLOWUP OBSERVABILITY FINDING CHART EXAMINE PA

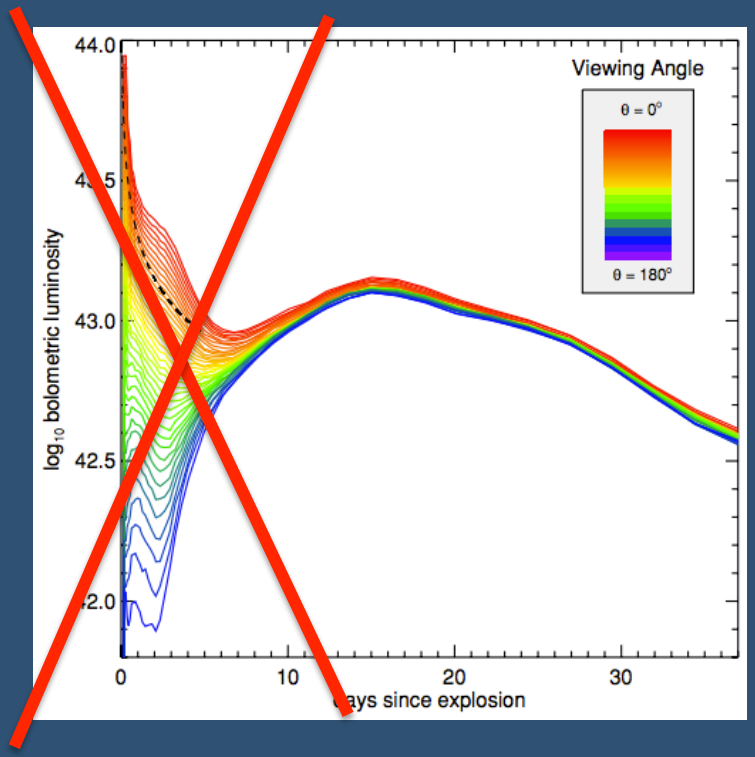


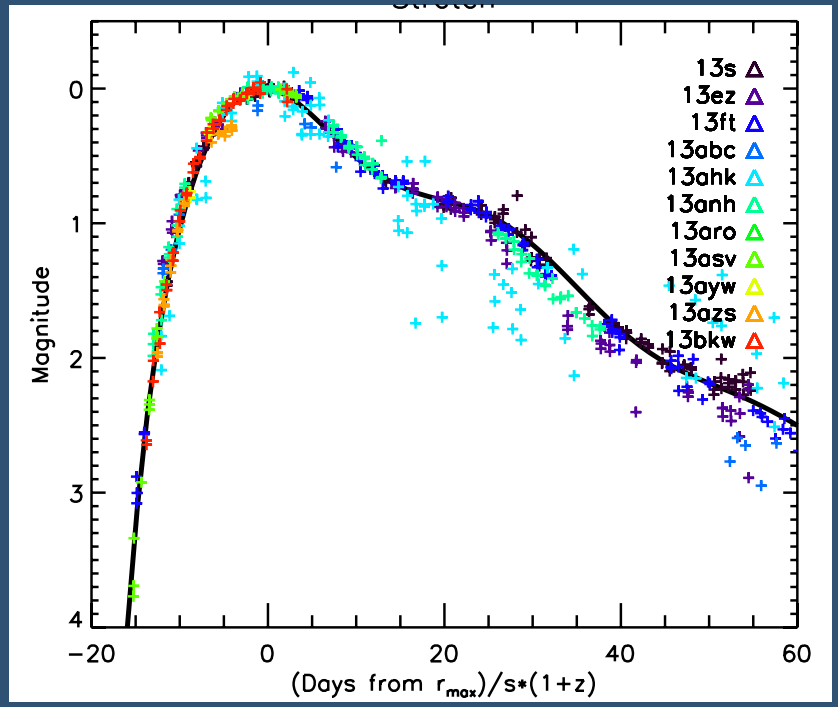


Mouse position: (0, 0, 0)

Warning! Open symbols imply magnitude estimates without image subtraction.

So far, no signs of interaction...





SNIa cosmology work in progress

- Build Hubble diagram at longer wavelengths 0.6 - 1.6 microns where systematic uncertainties from dimming by dust are smaller (IR from other facilities)
- Use wide wavelength coverage to study wavelength dependence of extinction by dust – key for precision cosmology
- Explore local expansion rate – to be compared with global value measured by Planck 2013
  - bounds on anisotropic expansion
  - peculiar velocities and the matter density field
  - path-finder for LSST and higher-z surveys targeting longer wavelength (mainly from space)

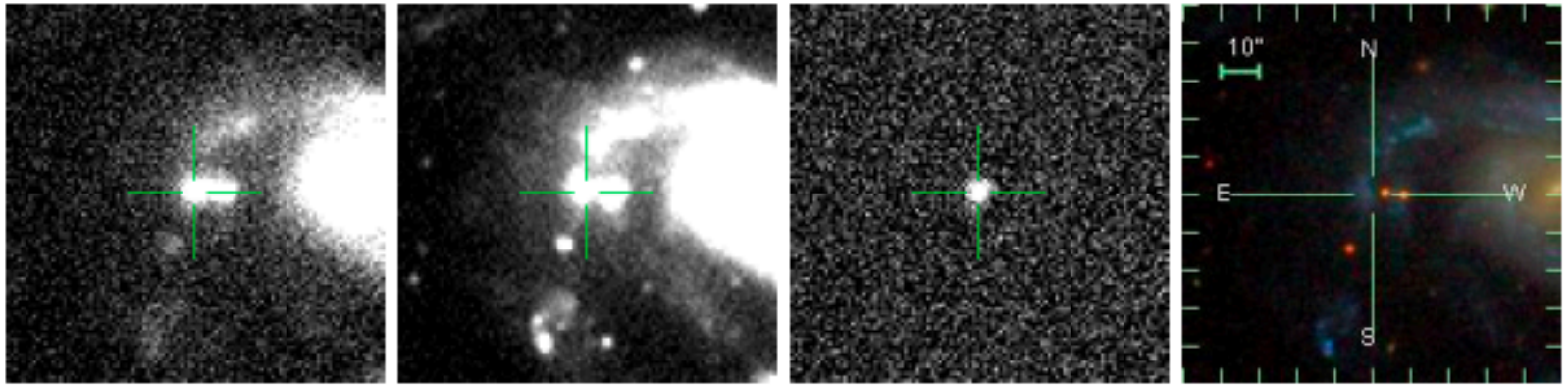

Other explosive events!

13dqy SN II

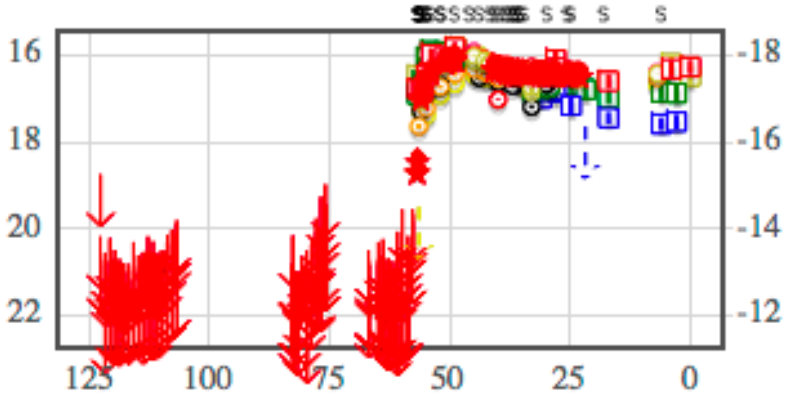
From image to ID within a few hs!

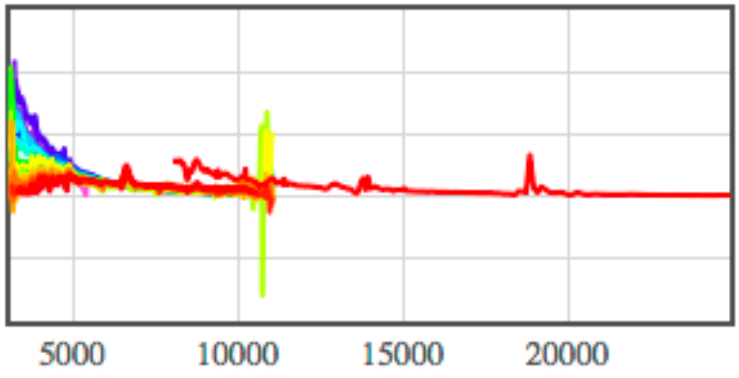
OVERVIEW PHOTOMETRY SPECTROSCOPY FOLLOWUP OBSERVABILITY

NEW REF SUB SDSS



First spectrum "just" after explosion!





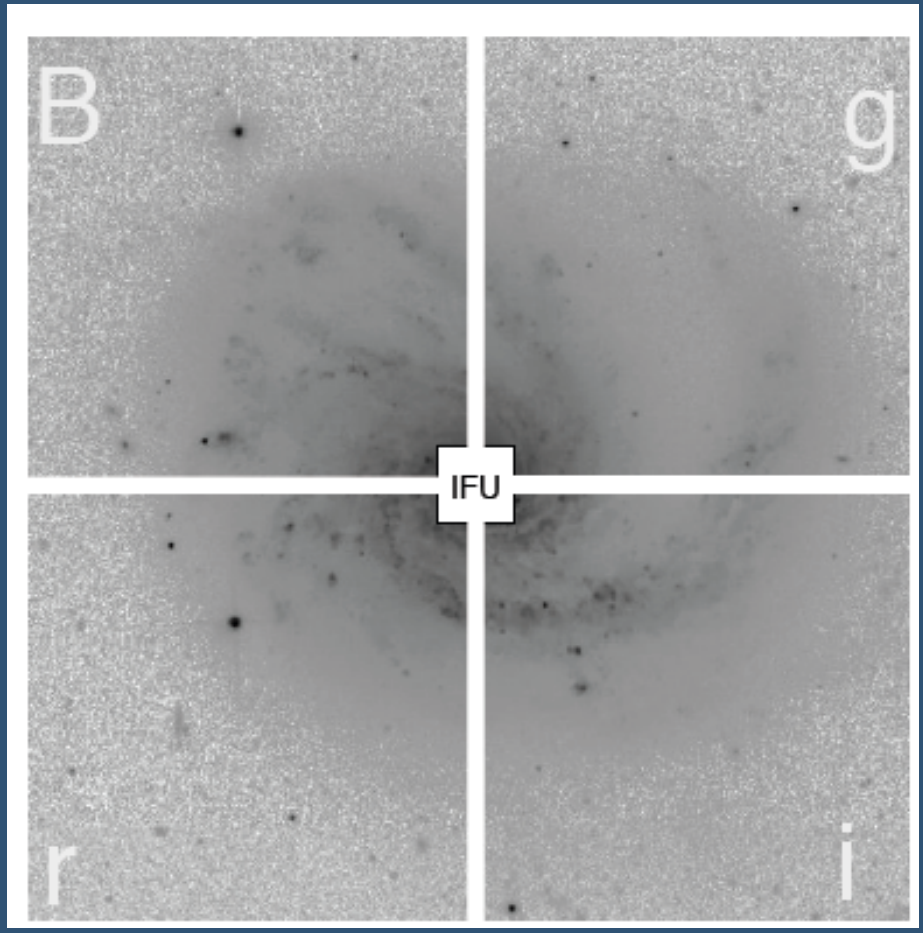
r = 16.5 (22.8 d) | Upload New Photometry

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

News:"SED Machine", low resolution spectrum within 30 minutes(!) from Palomar 60 inch

Spectral range [365- 980] nm,
27" fov w/0.675" resolution
R=Δλ/λ=100
6'x6' images

Robotically triggered!

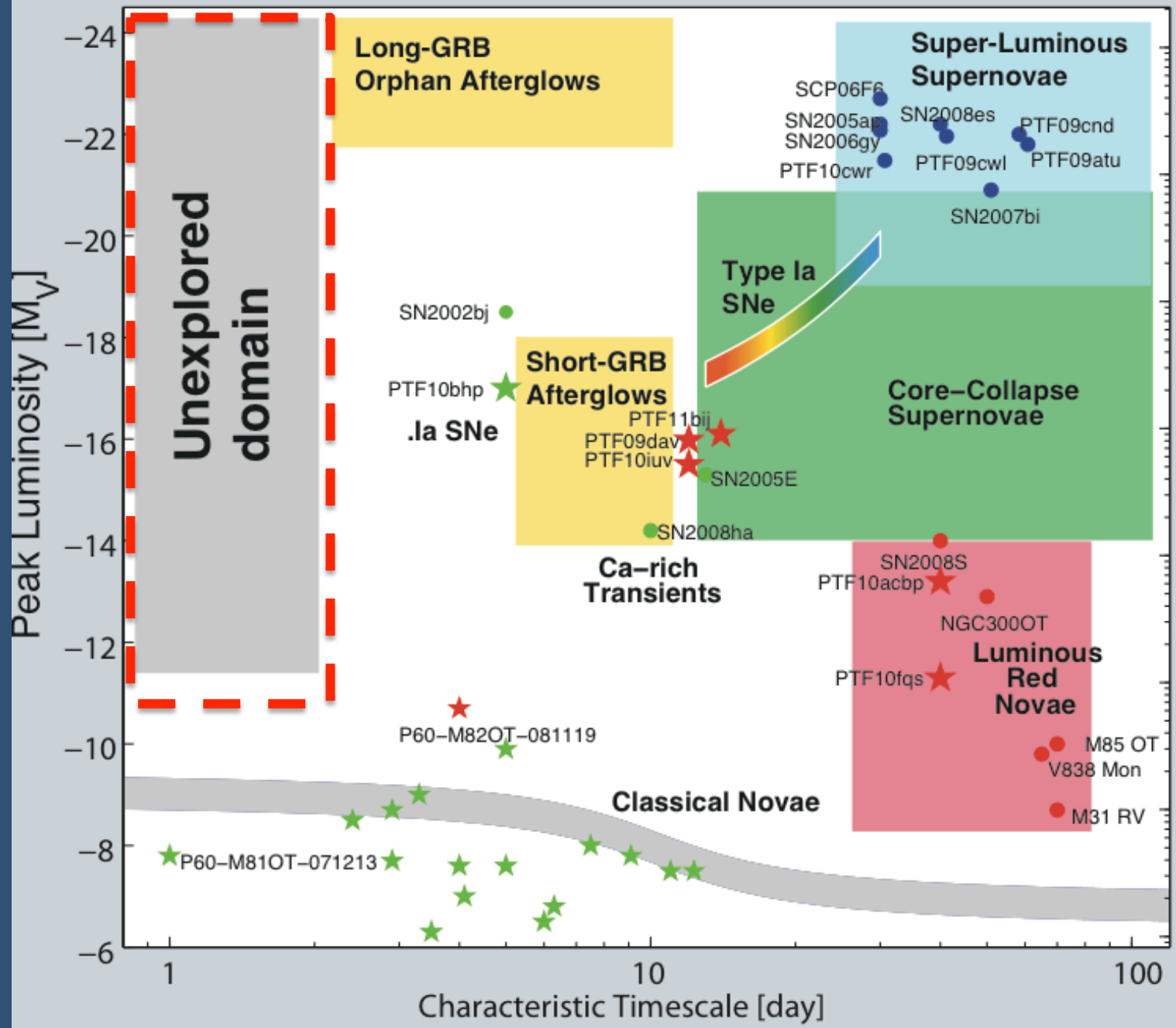


The "New" Transient Universe

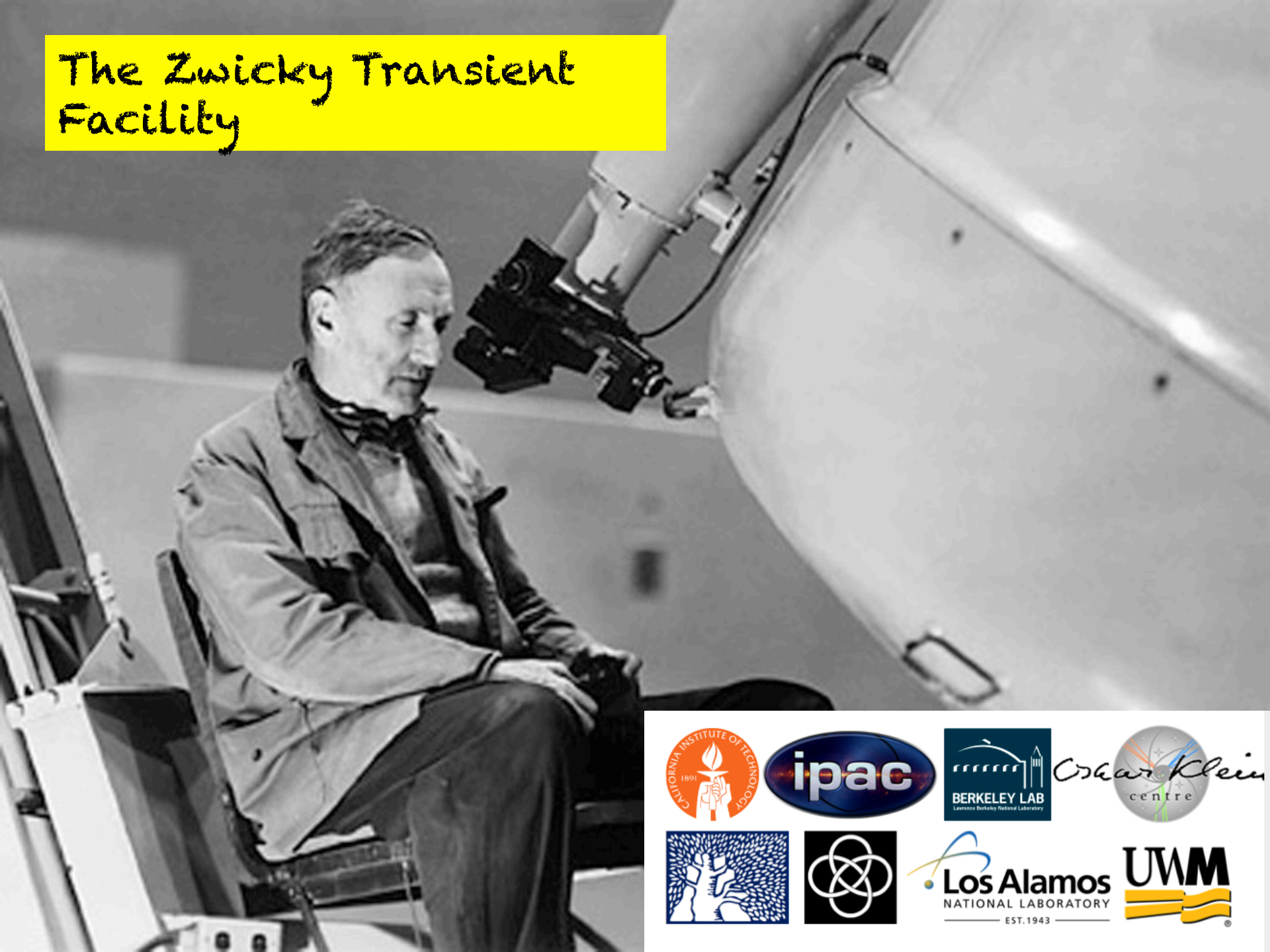
Compact mergers and GW

- 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!

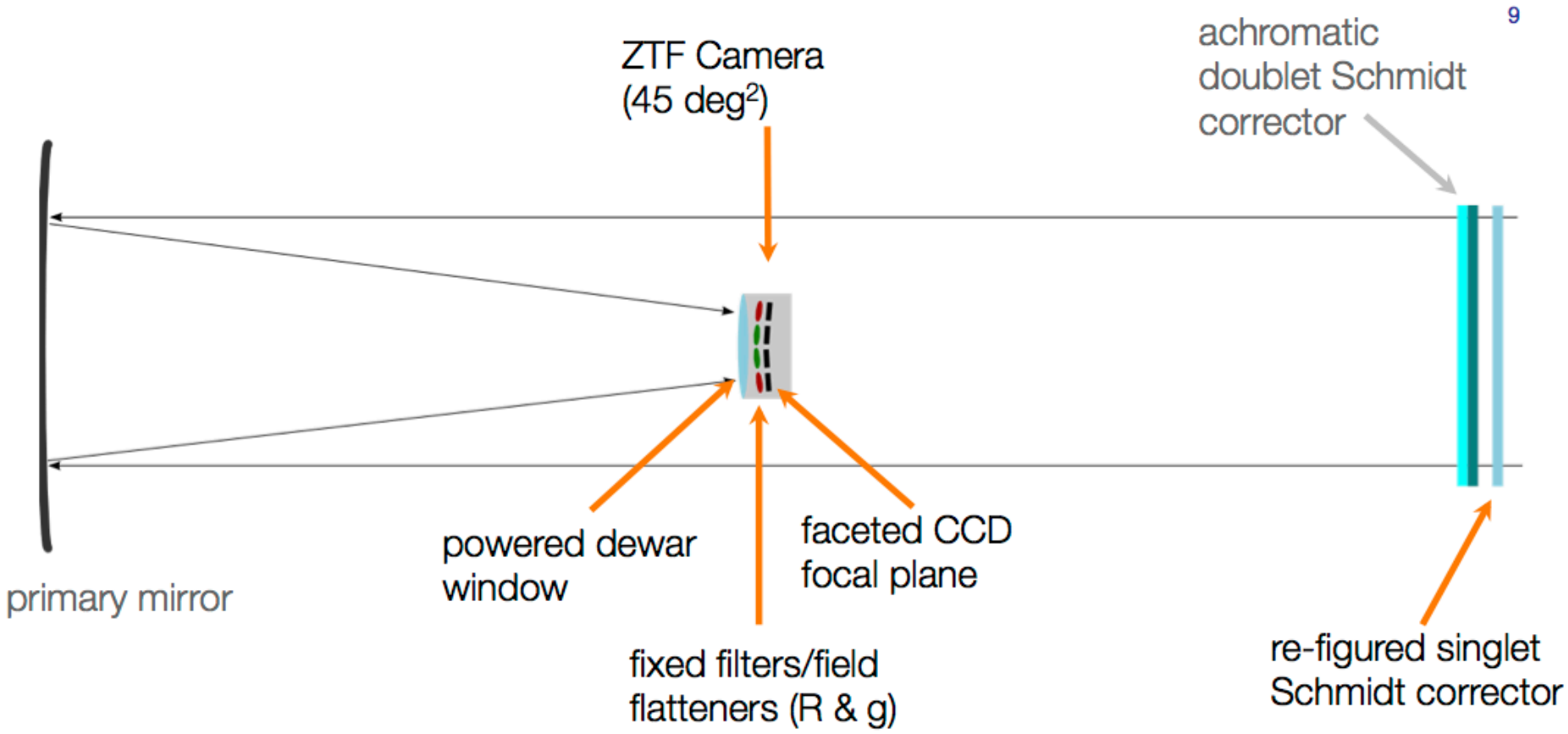
The landscape of optical transients



The Zwicky Transient Facility



New optics enable ZTF's unprecedented field of view.

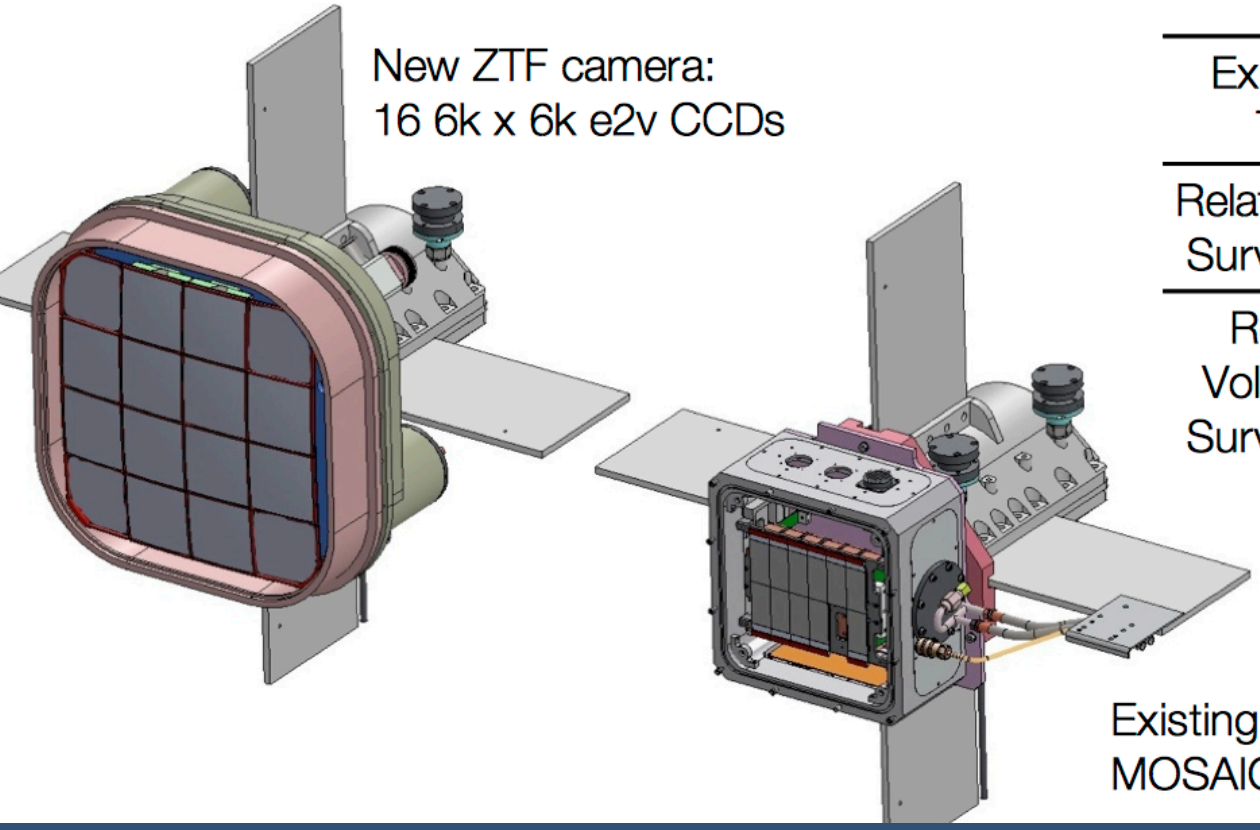


Courtesy of R.Dekany

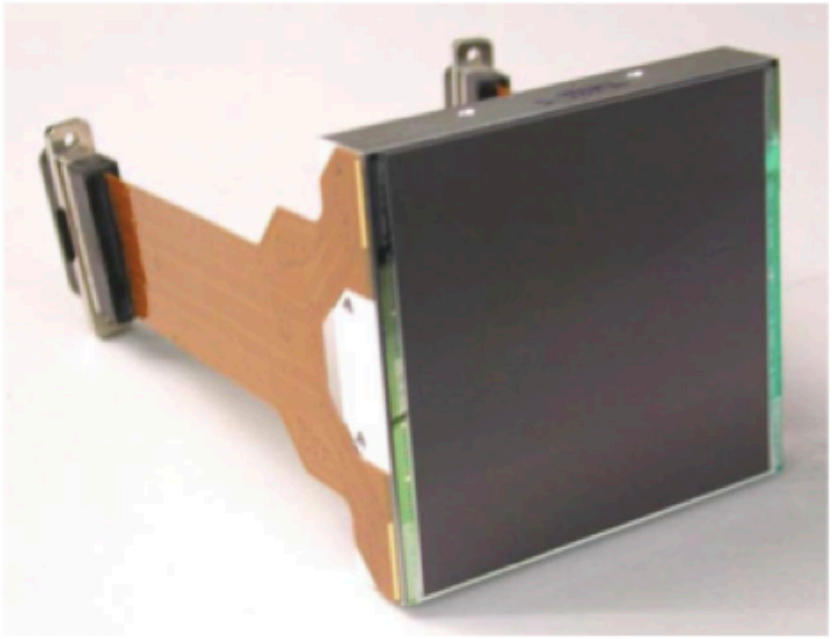
ZTF will survey an order of magnitude faster than PTF.

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**



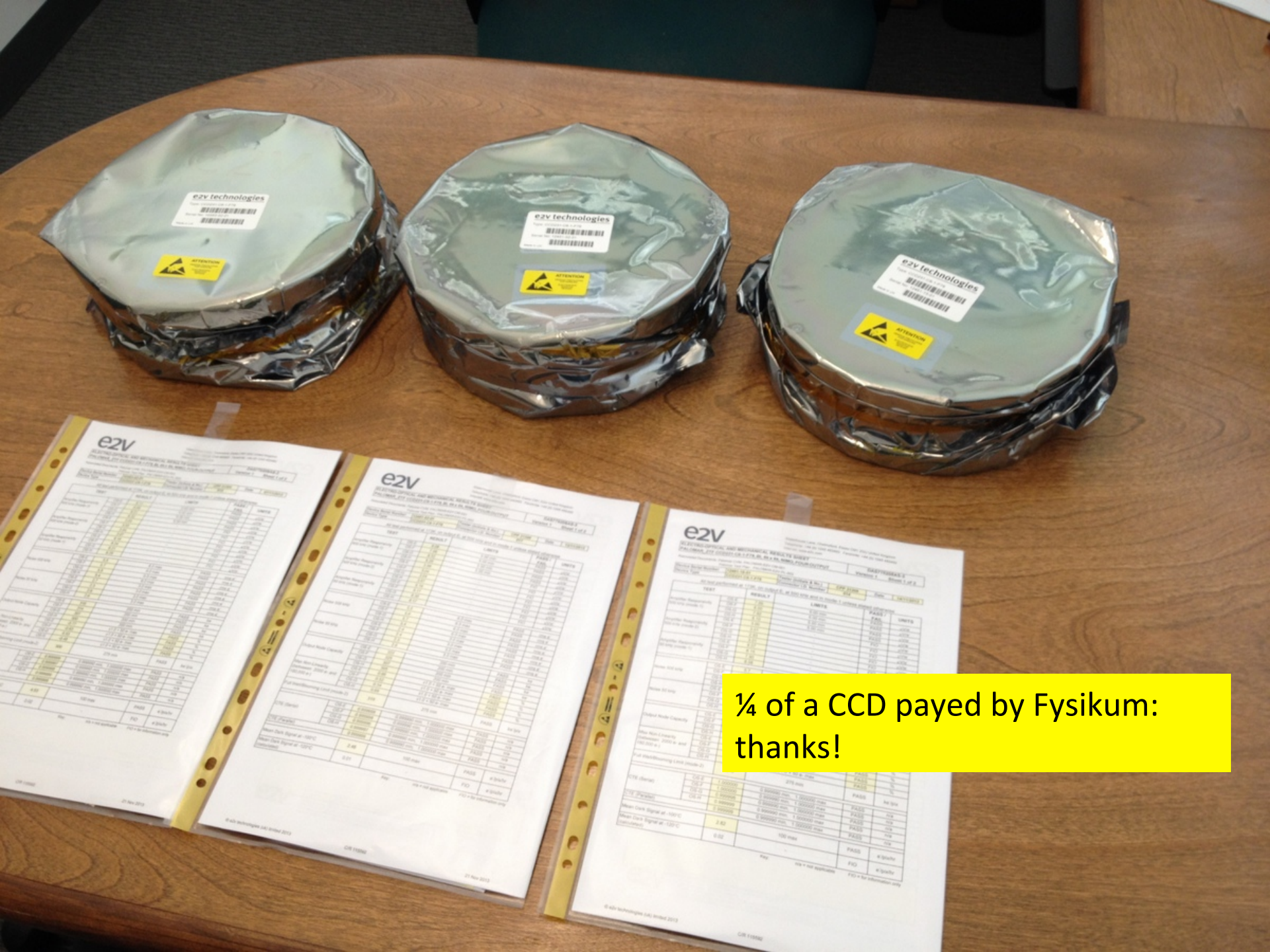
>200 exposures/field/year ("whole" sky)

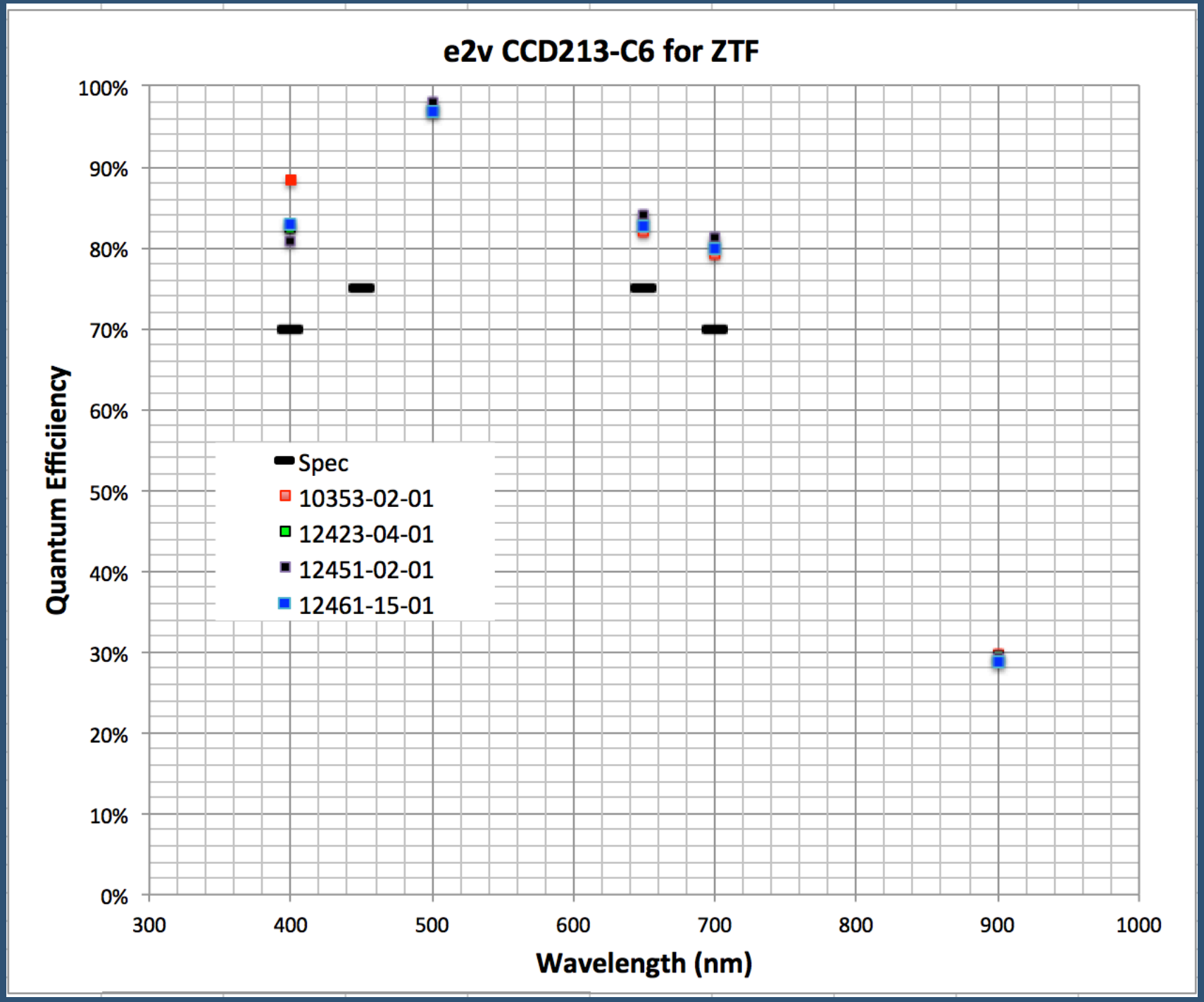


[CCD231-84 is illustrated here; CCD231-C6 is similar]

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


e2v technologies
e2v
¼ of a CCD payed by Fysikum: thanks!


e2v CCD213-C6 for ZTF
Quantum Efficiiency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
400
500
600
700
800
900
1000
Wavelength (nm)
Spec
10353-02-01
12423-04-01
12451-02-01
12461-15-01

Summary

- Time domain astrophysics is experiencing a rapid development – FoV+timescale
- OKC has taken a major step in become a leading institution in this field by taking part in iPTF/ ZTF: transients discovered soon after explosion
- Likely to discover new kinds of transients and significantely improve the measurements of known ones, e.g. Type Ia supernovae used in cosmology and the origins of core collapse SNe.
- Should inspire new tests of fundamental physics using novel time-domain data!


Thank you!
I. Arcavi

16-CCD Budget Overview

Task Name		
ZTFC Full WBS Draft v0_9_3	**37,833 hrs**	$7,350,786
Management	**4,718 hrs**	**$629,386**
Systems Engineering	**2,428 hrs**	**$290,212**
Camera	**19,909 hrs**	**$5,024,196**
Exposure Shutter	**2,388 hrs**	**$300,940**
Filter Exchanger Future Option	**80 hrs**	**$13,120**
Camera Control Software	**2,964 hrs**	**$287,514**
Observatory Infrastructure	**3,362 hrs**	**$621,598**
Commissioning	**1,984 hrs**	**$183,818**

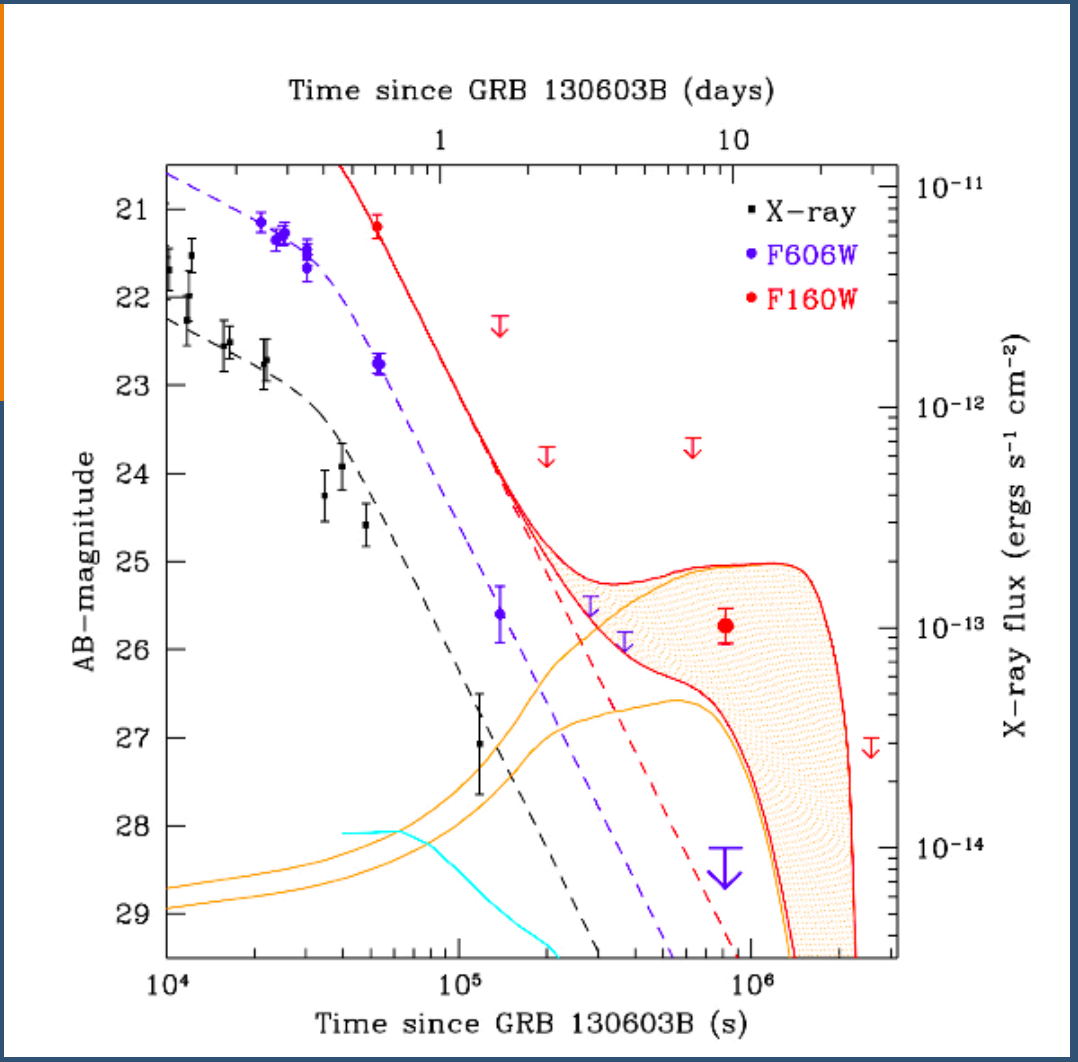
Total budget w/ 30% contingency (ex-CCDs)= $8.95M

CCD's = 16 x 120 k = $1.942 M -> Total $11 M

First candidate?

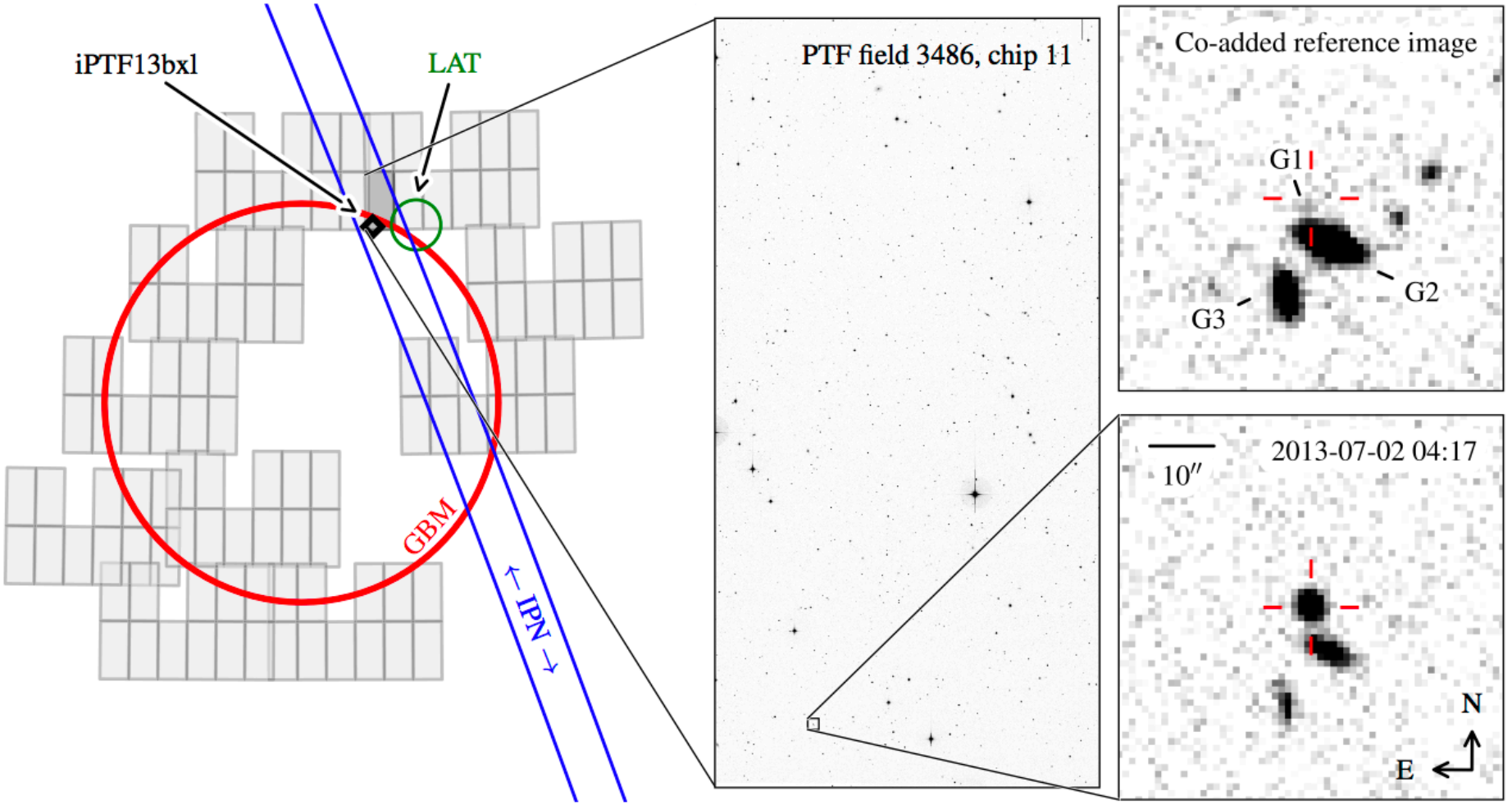
- Association with short GRBs?

  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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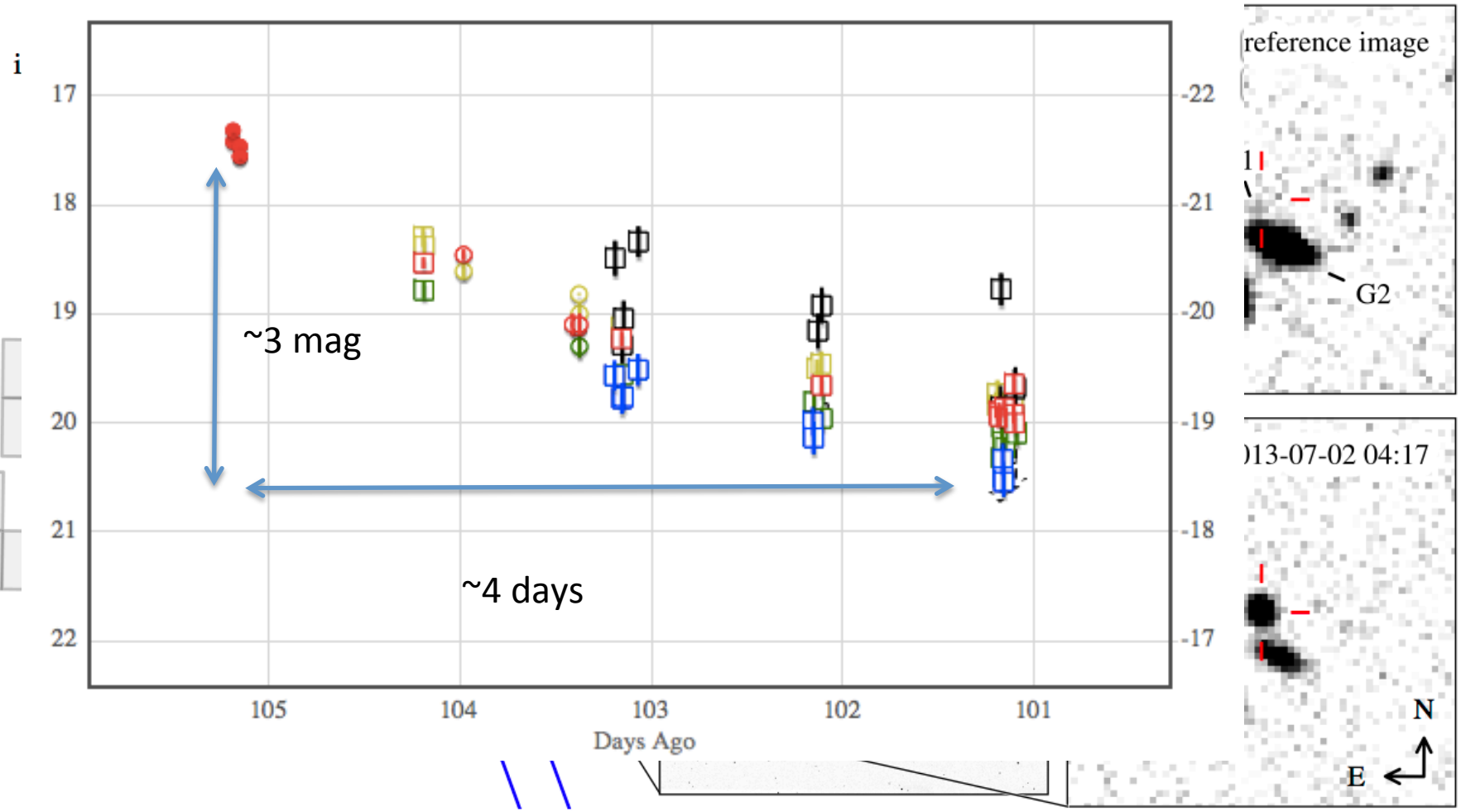

Early discoveries - ideal for detailed spectroscopic follow-up studies