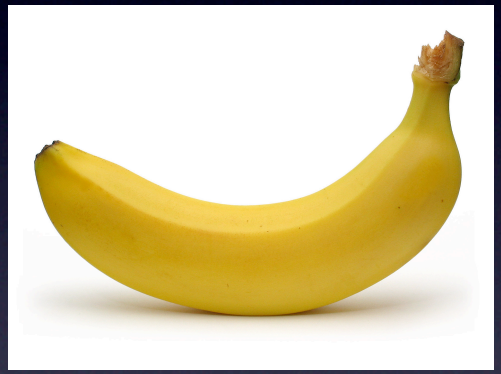
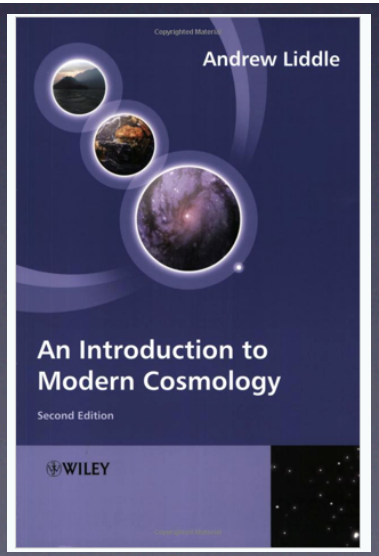
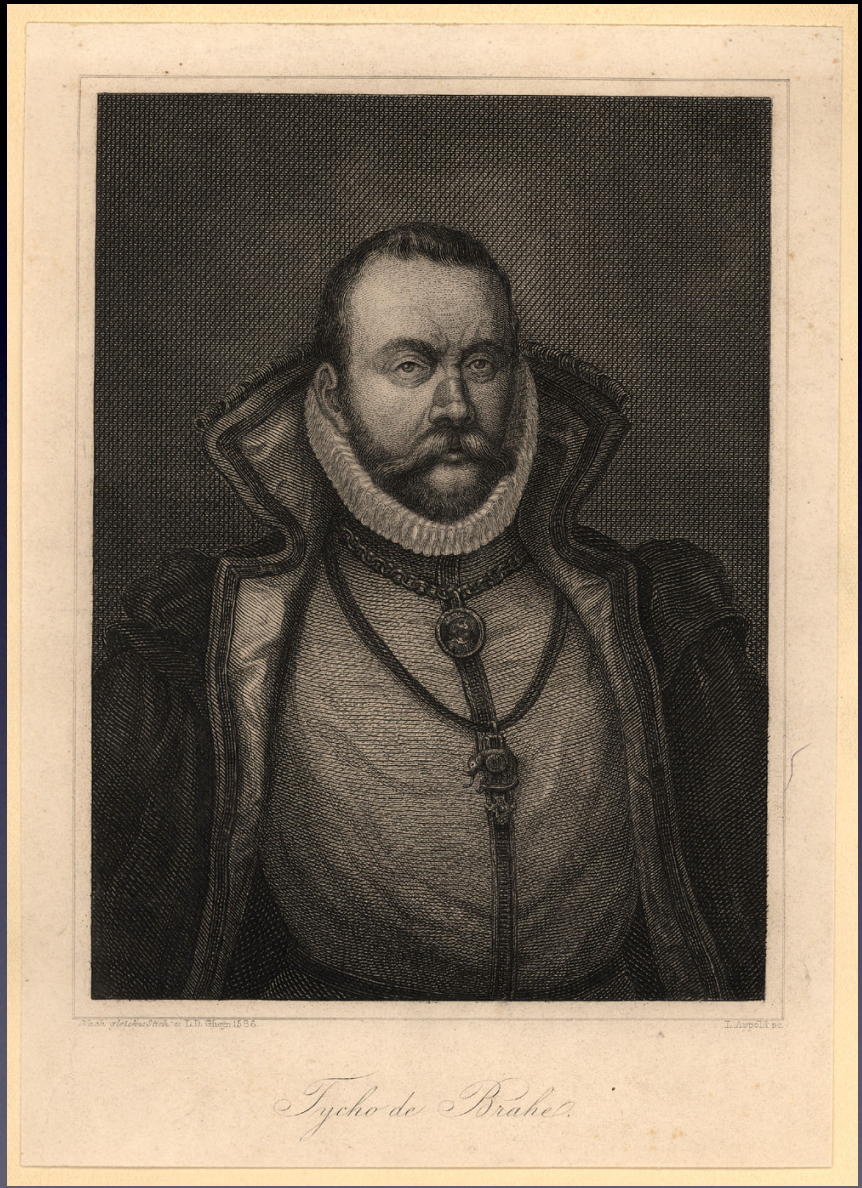
The Transient Universe – current and future surveys

S.J. Smartt
Queen's University Belfast

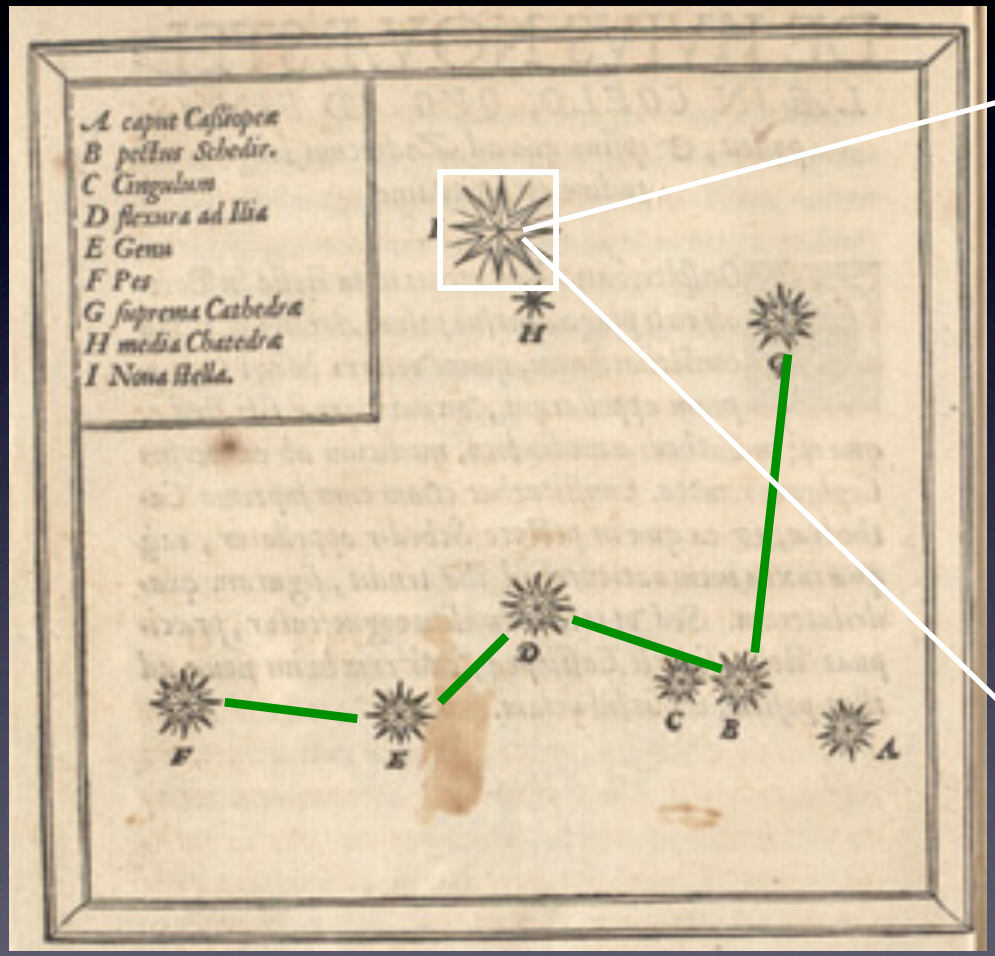


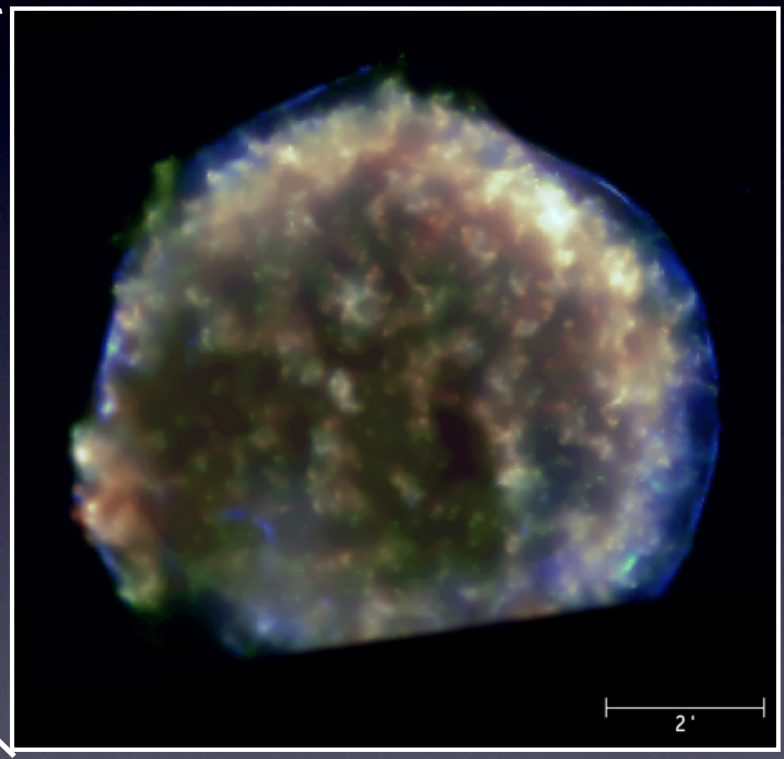

Andrew Liddle
An Introduction to
Modern Cosmology
Second Edition
WILEY

Tycho Brahe 1546-1601



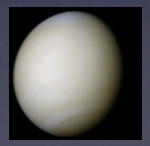
“Stella nova” of 1572





Historical Supernovae

Supernova Remnant	Year	Peak Visual mag
Kepler	1604	-3
Tycho	1572	-4
3C58	1181	-1
Crab	1054	-4
SN1006	1006	-9



Venus = -4.5

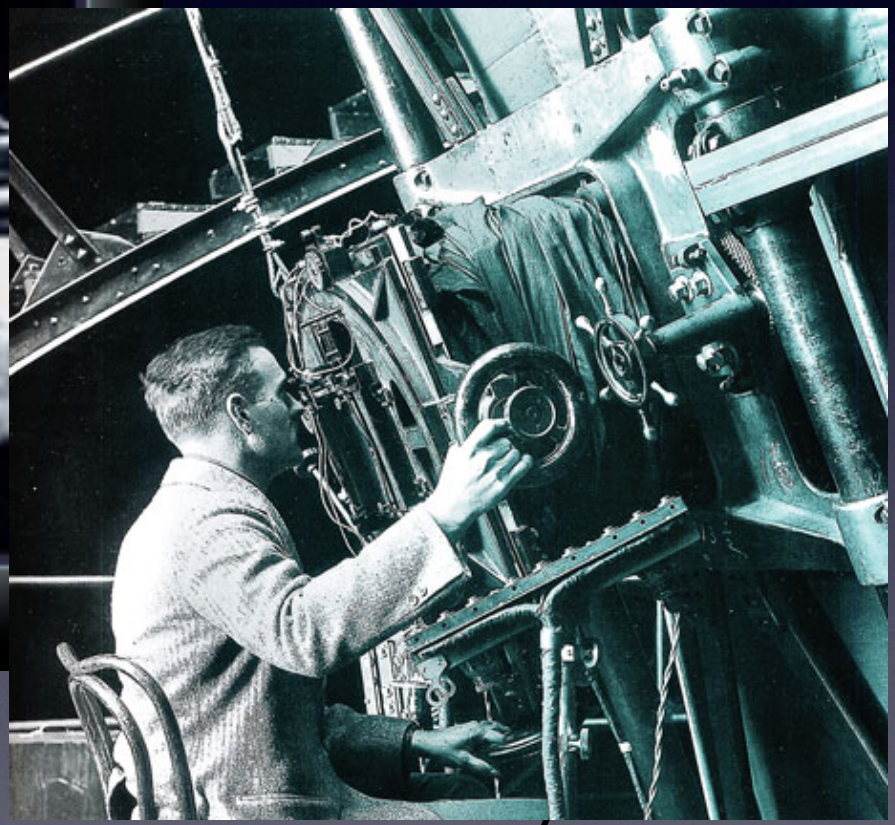
Crescent Moon = -9

"Nova" in the Andromeda galaxy

1885: Isaac Ward, Belfast (19th Aug)

Ernst Hartwig, Tartu (20th Aug)

Next one fom Ireland ? Dave Rahenny, Dublin 2010



“Super”-nova

Fritz Zwicky 1898-1974,
Swiss/Bulgarian

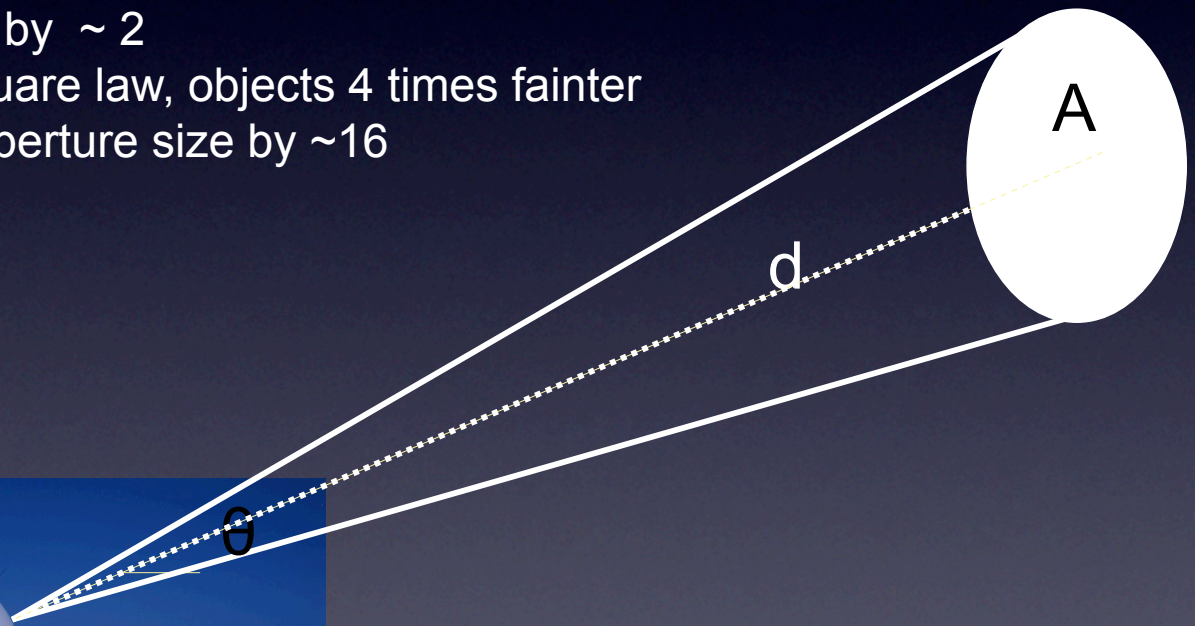
“Nova” in Andromeda = 2×10^9 times solar luminosity
= 10^4 times most luminous stars and galactic novae

Baade & Zwicky (1934) : core-collapse in massive star, gravitational energy release, neutron star formed, source of high energy cosmic rays

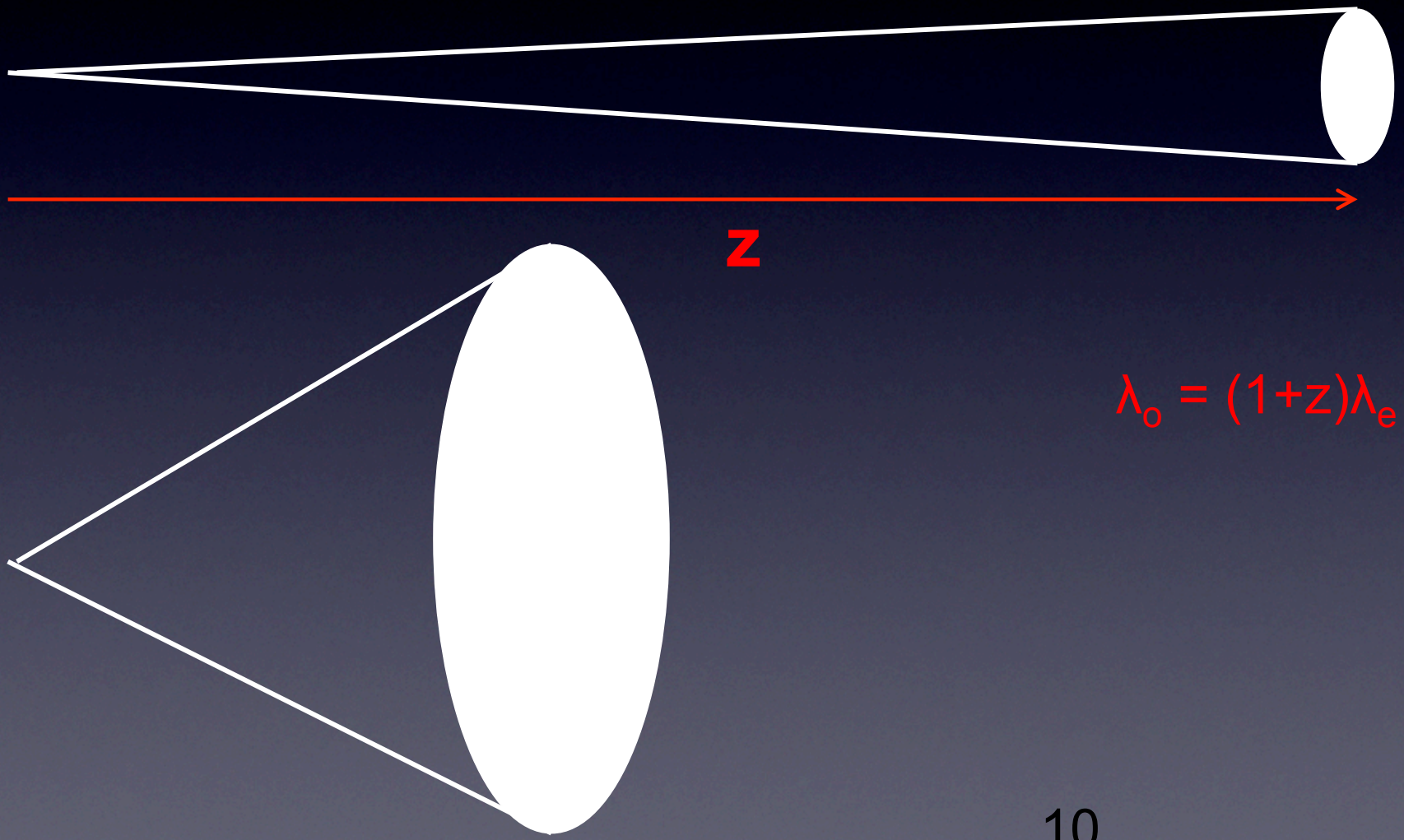
Surveying the Universe

Volume surveyed ≈ $Ad \approx (d)(d^2 \tan^2(\theta/2)) \approx d^3$

How to increase *Volume* by a factor 10 ?
- increase d by ~ 2
- inverse square law, objects 4 times fainter
- increase aperture size by ~16

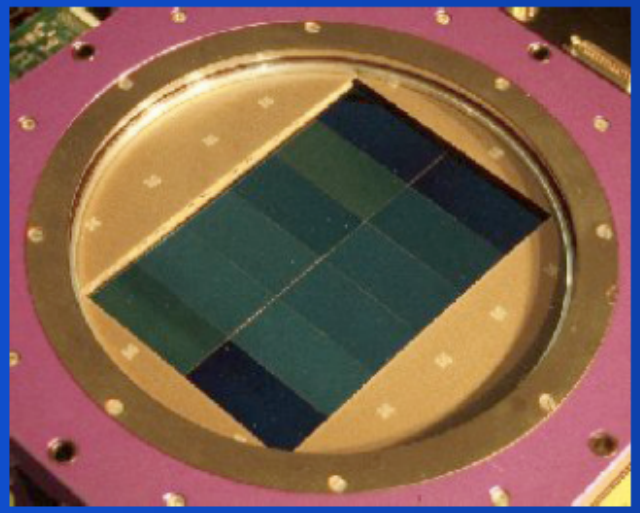


Equivalent Volumes – depth or area ?



$\lambda_o = (1+z)\lambda_e$

Palomar Transient Factory



- 1.2m Palomar Schmidt : 7 square degree camera
- Large pixels – 1 arcsec pixels, 2 arcsec image quality
- Shallow, wide and fast – dedicated follow-up

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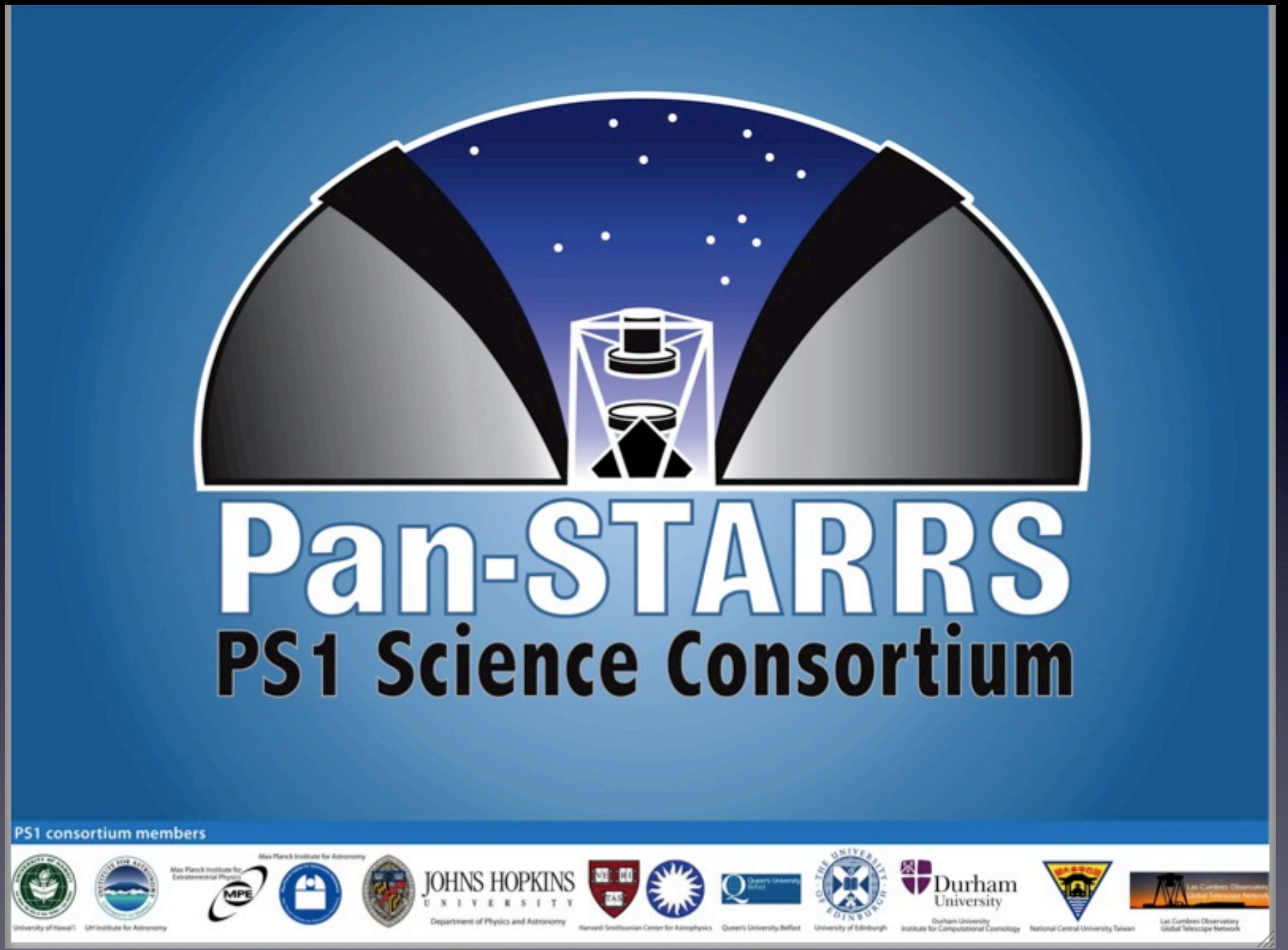
WEIZMANN INSTITUTE OF SCIENCE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Max Planck Institute for Astronomy
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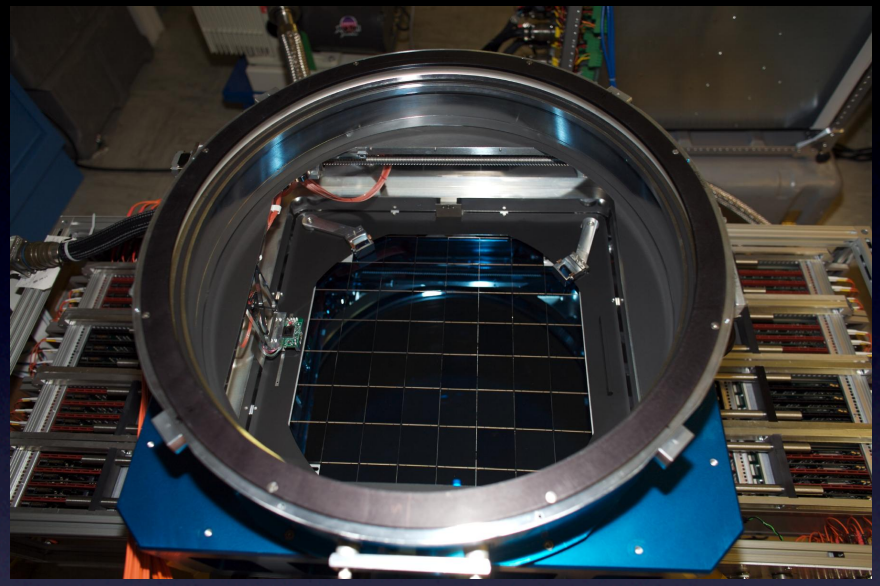
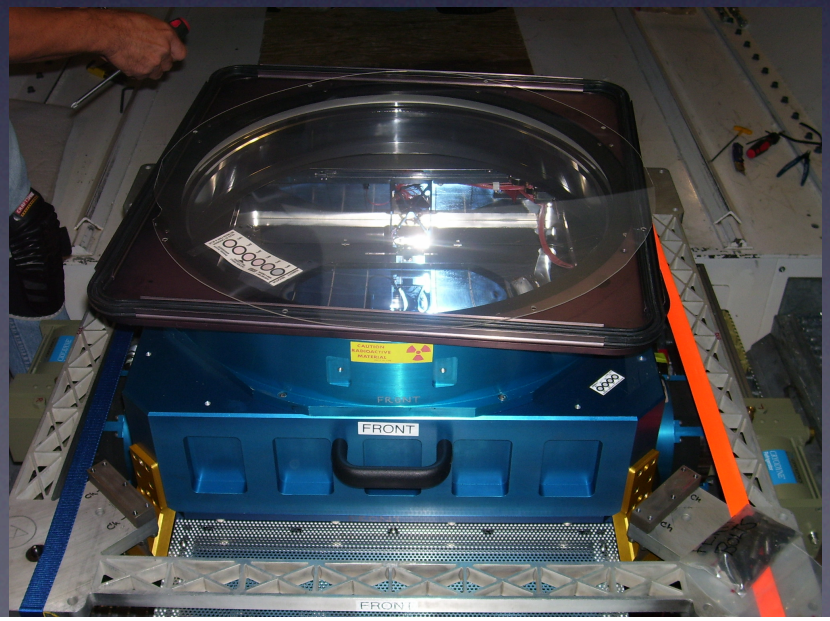
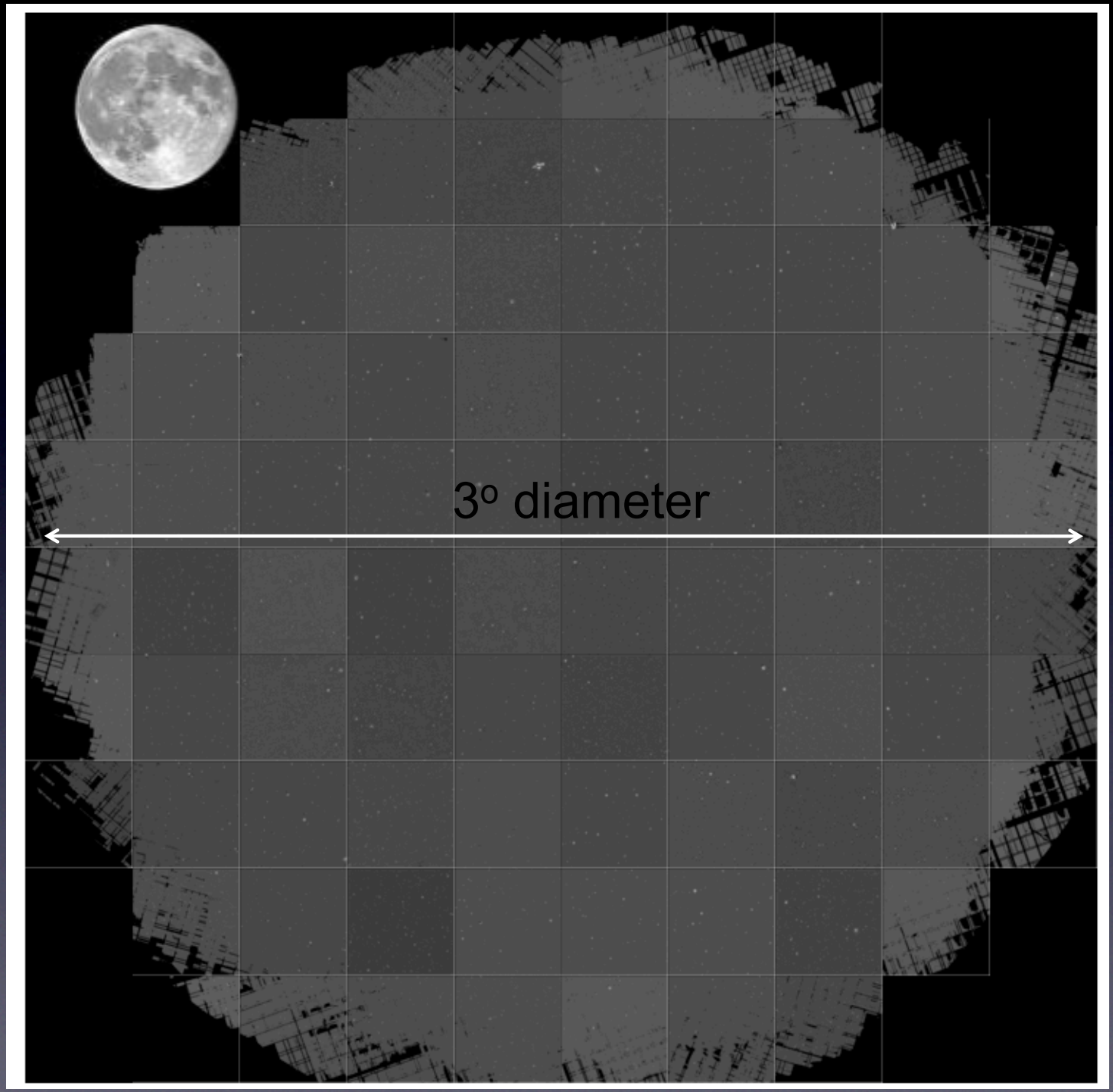
Durham University
Durham University Institute for Computational Cosmology
National Central University, Taiwan
Las Cumbres Observatory Global Telescope Network

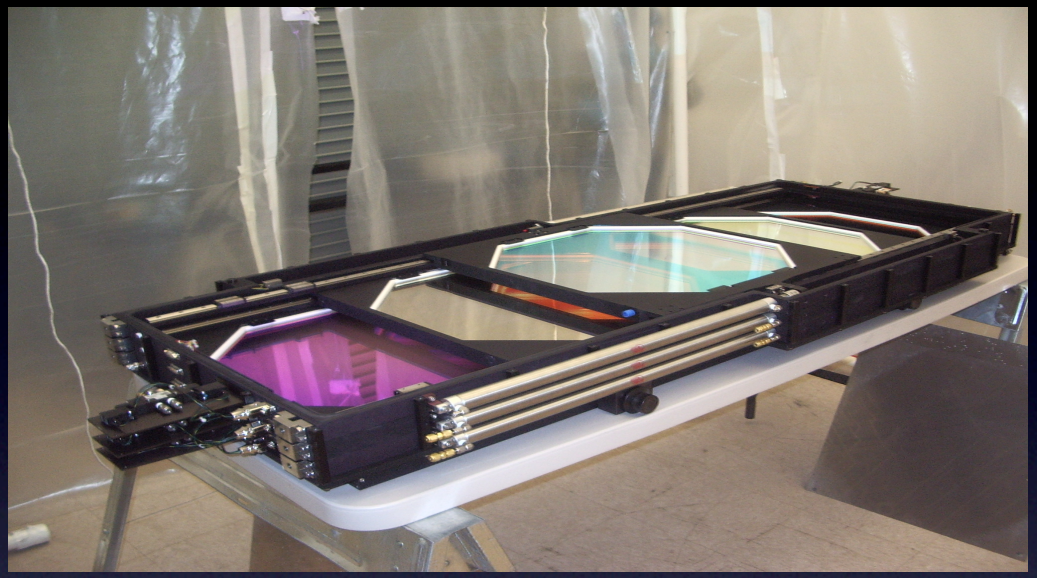
GigaPixel Camera 1



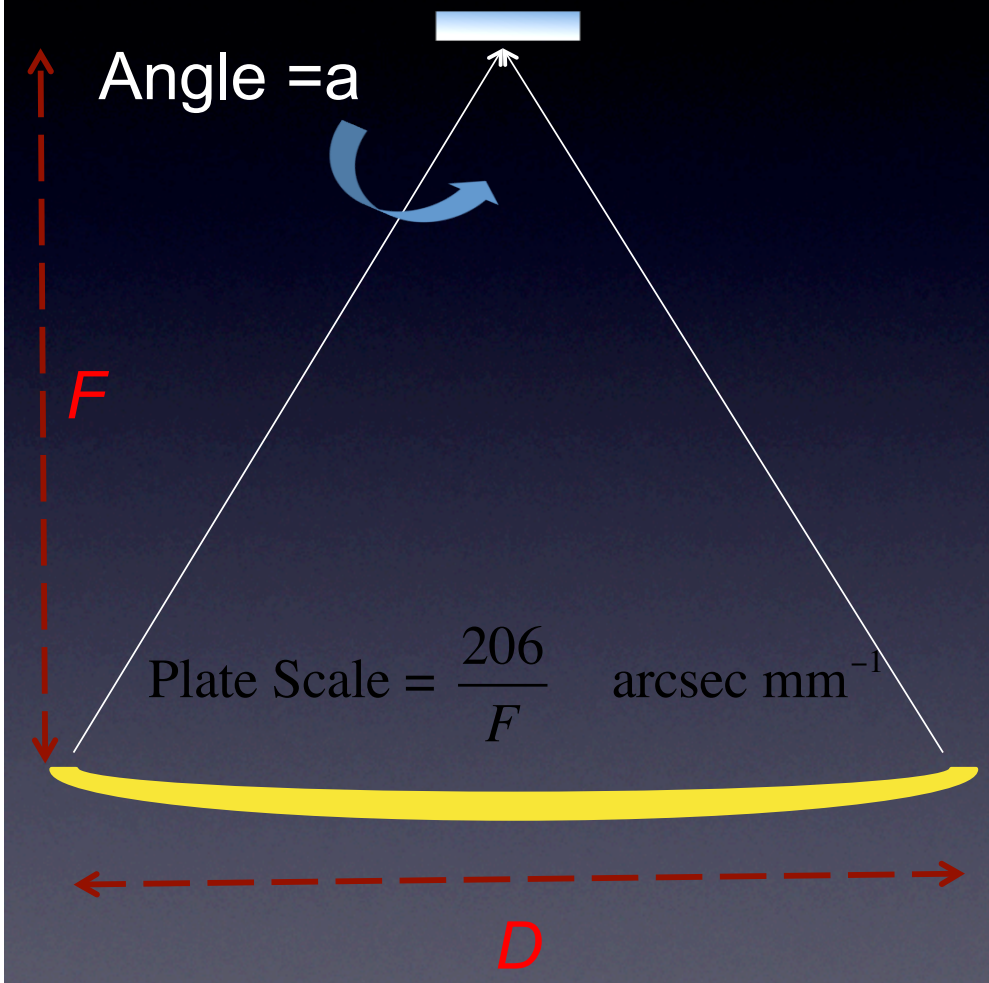


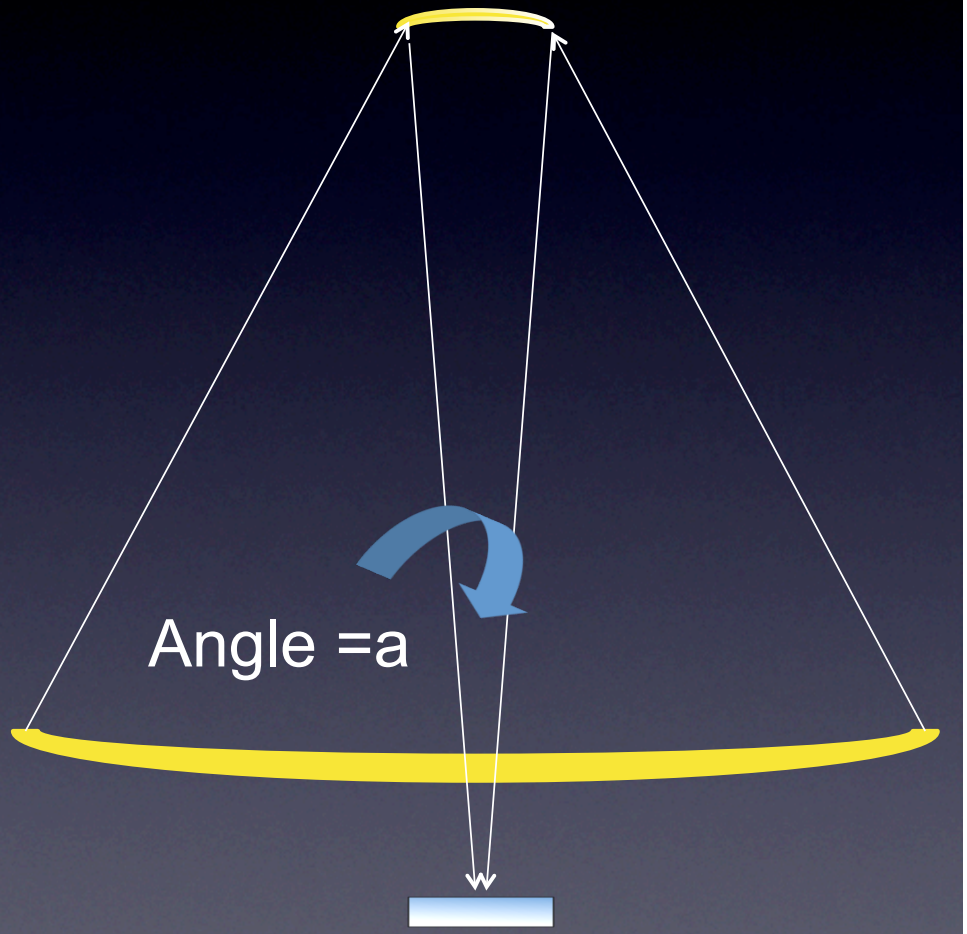

3o diameter

Optical design



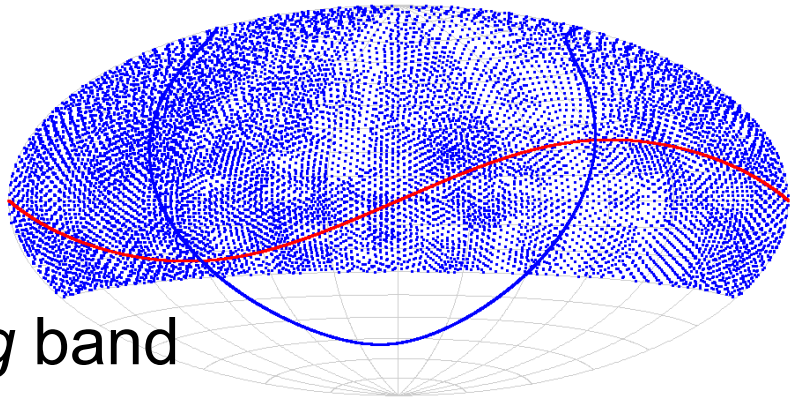
D = diameter of primary mirror
F = focal length
f = F/D = focal ratio



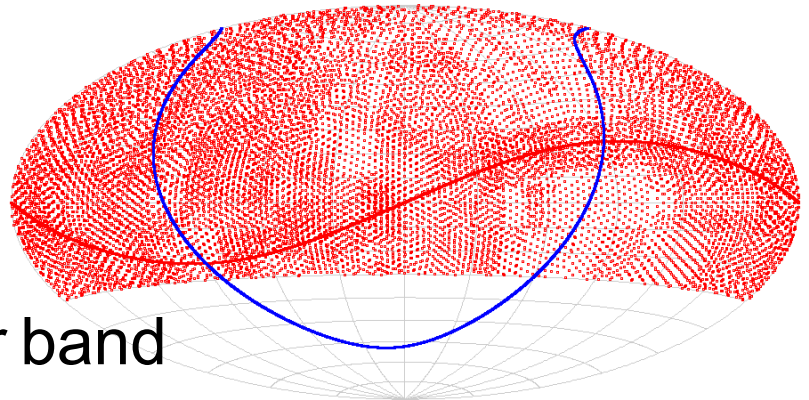


Focal length = 2F , but plate scale is half
Therefore 4 times more pixels !

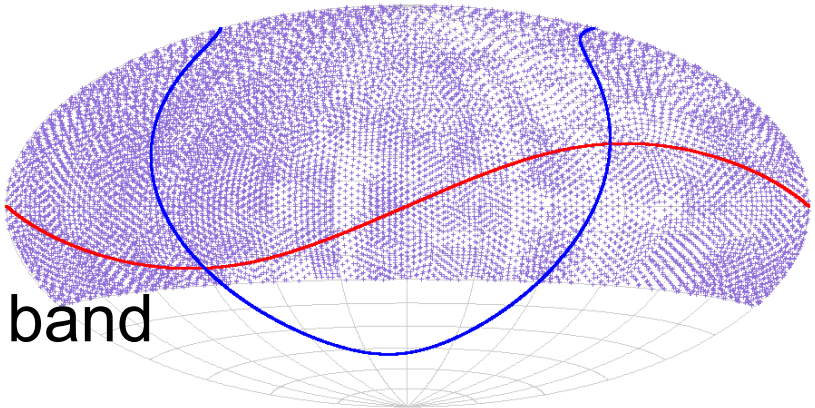
3pi sky coverage to Jan 1, 2012



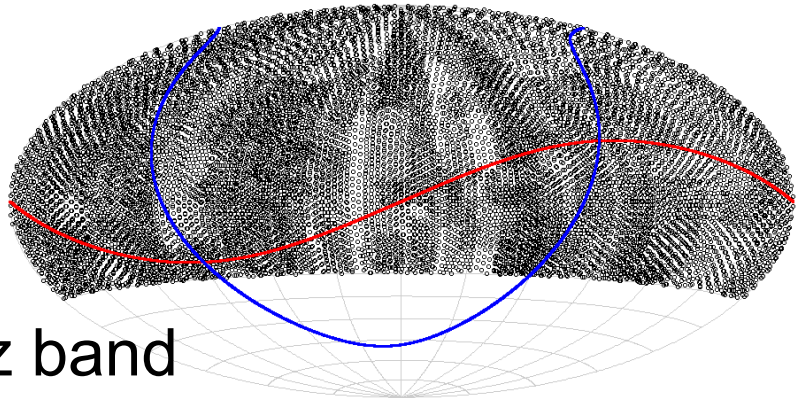
g band



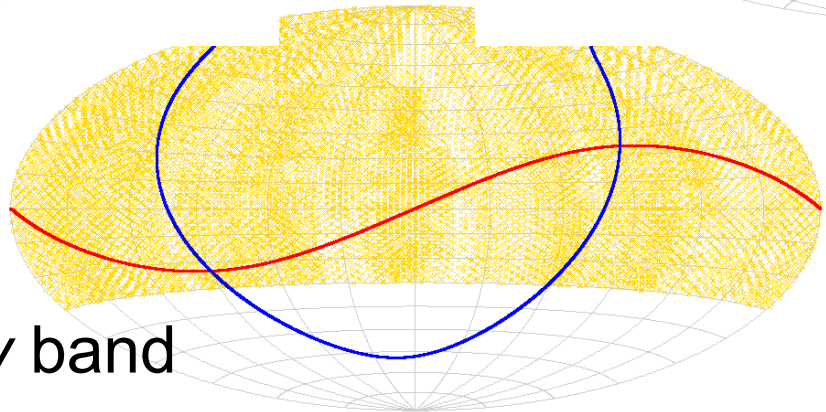
r band



i band



z band



y band

From : Ken Chambers, PS1 Director, Jan 2012

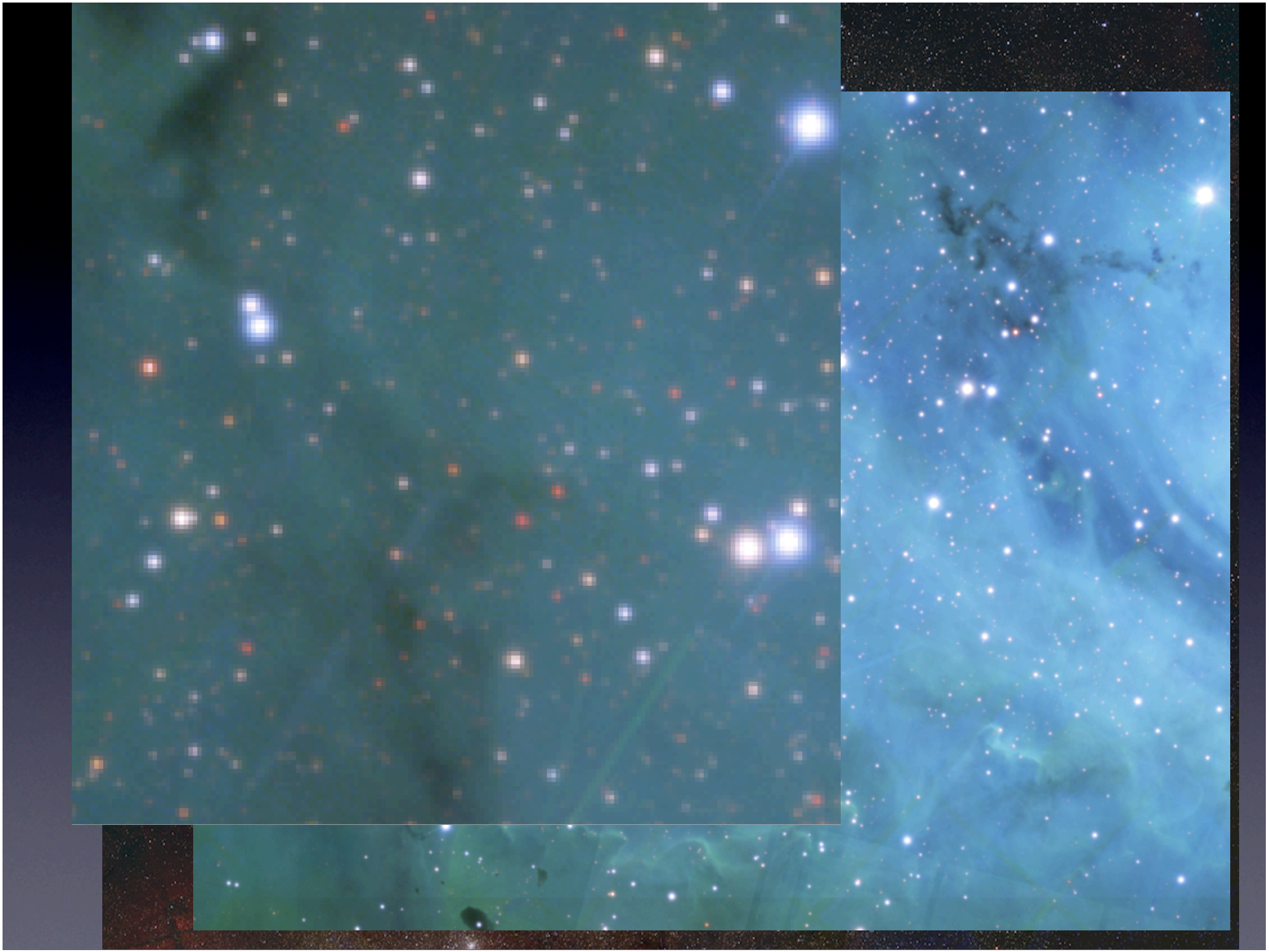
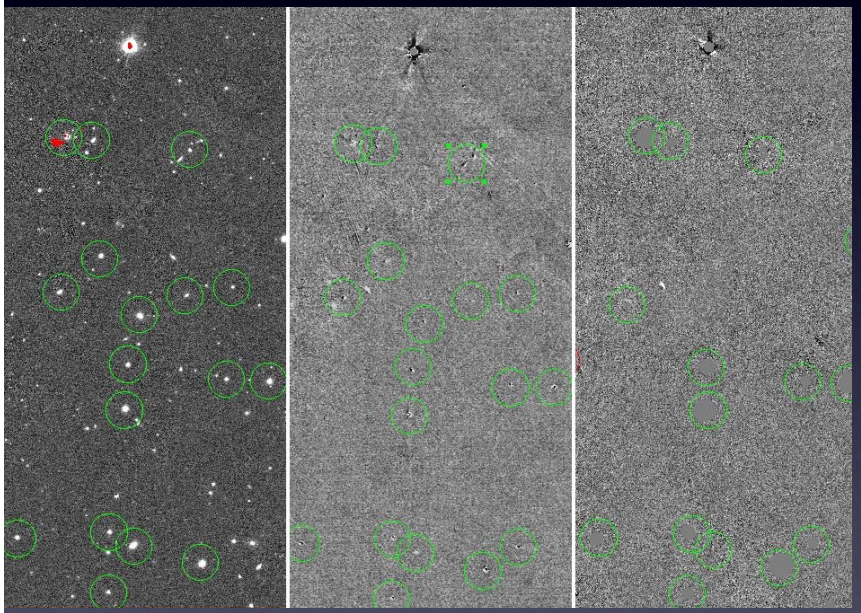
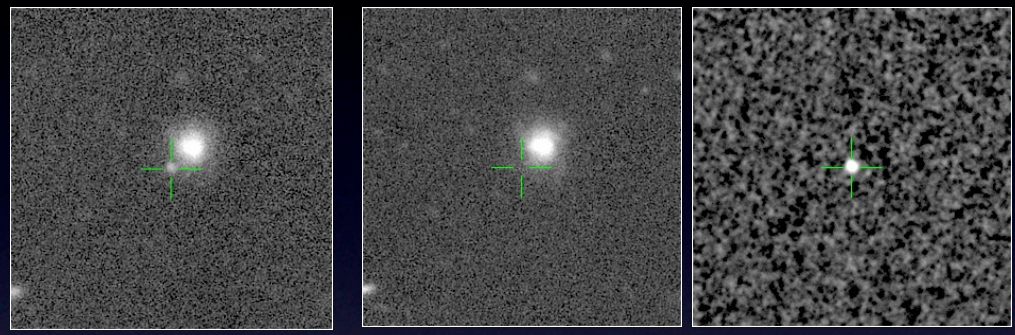


Image Subtraction

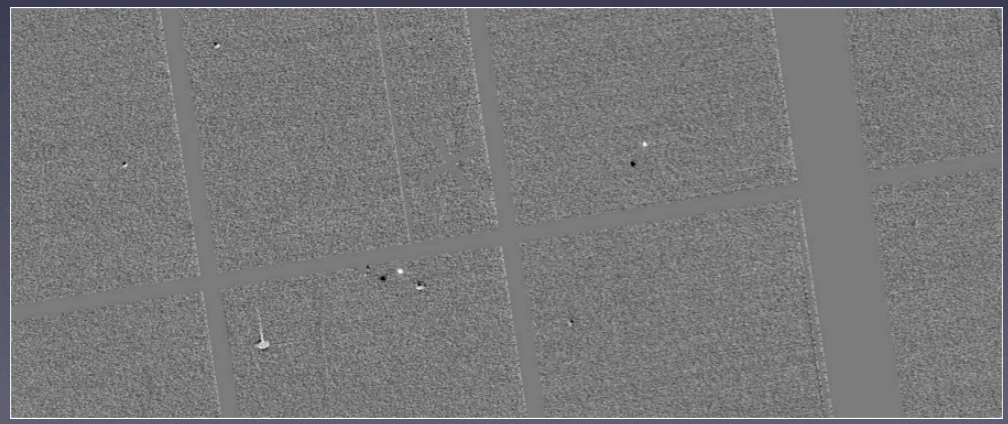


Supernova type Ic, z=0.116

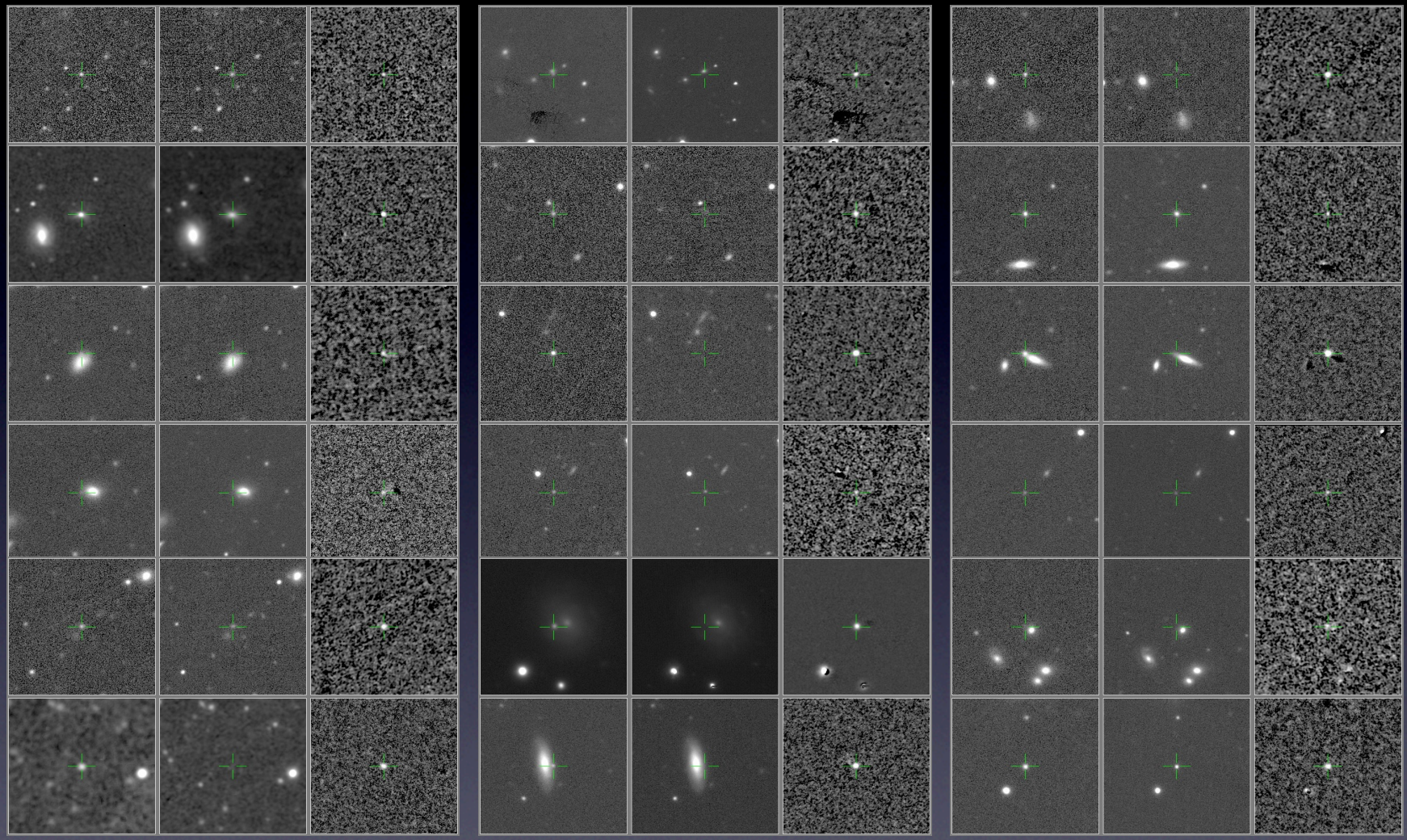
Target **Reference** **Difference**



Moving objects



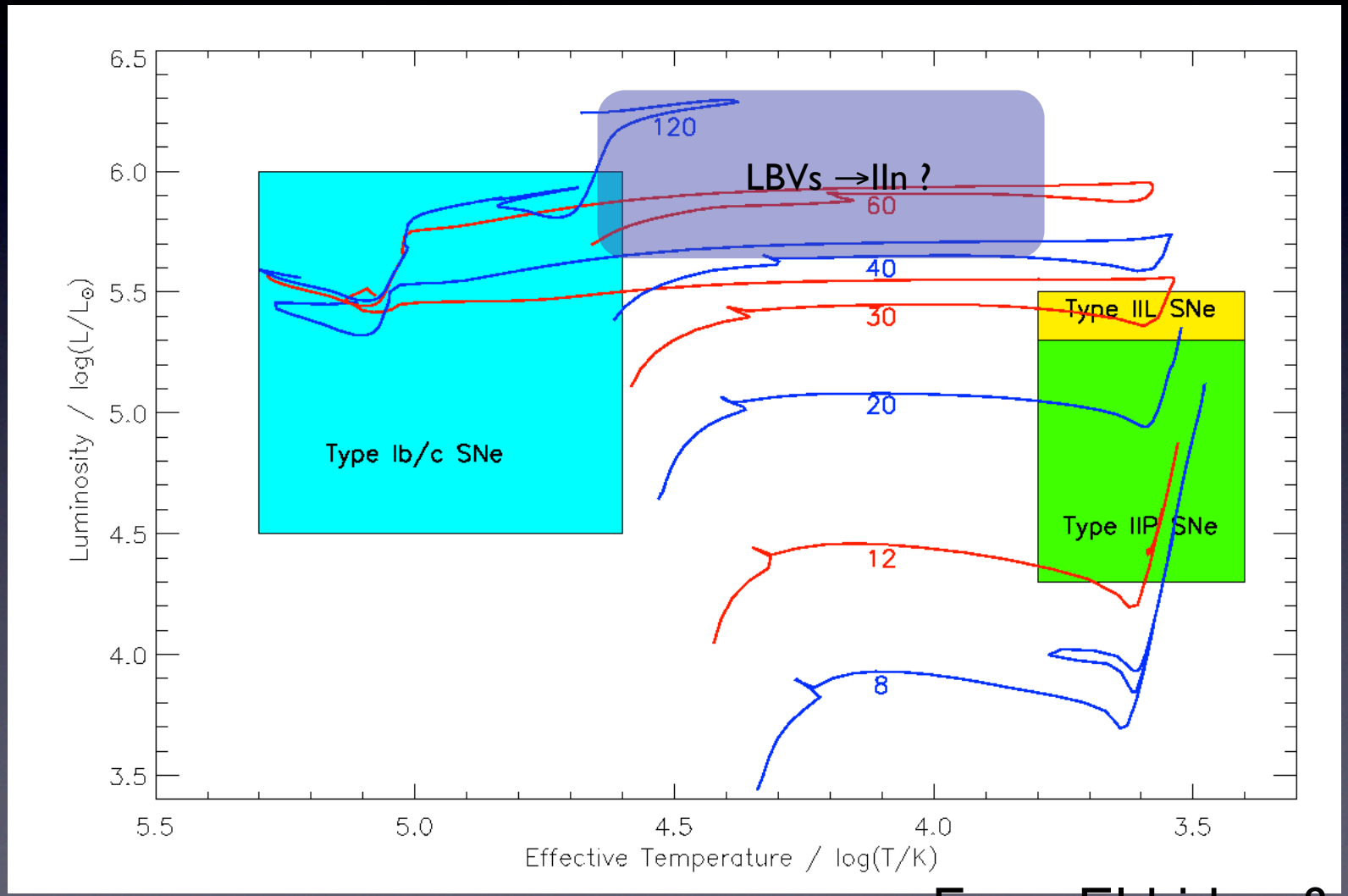
~3x10^3 *transients,* ~300 spectroscopically Confirmed SNe



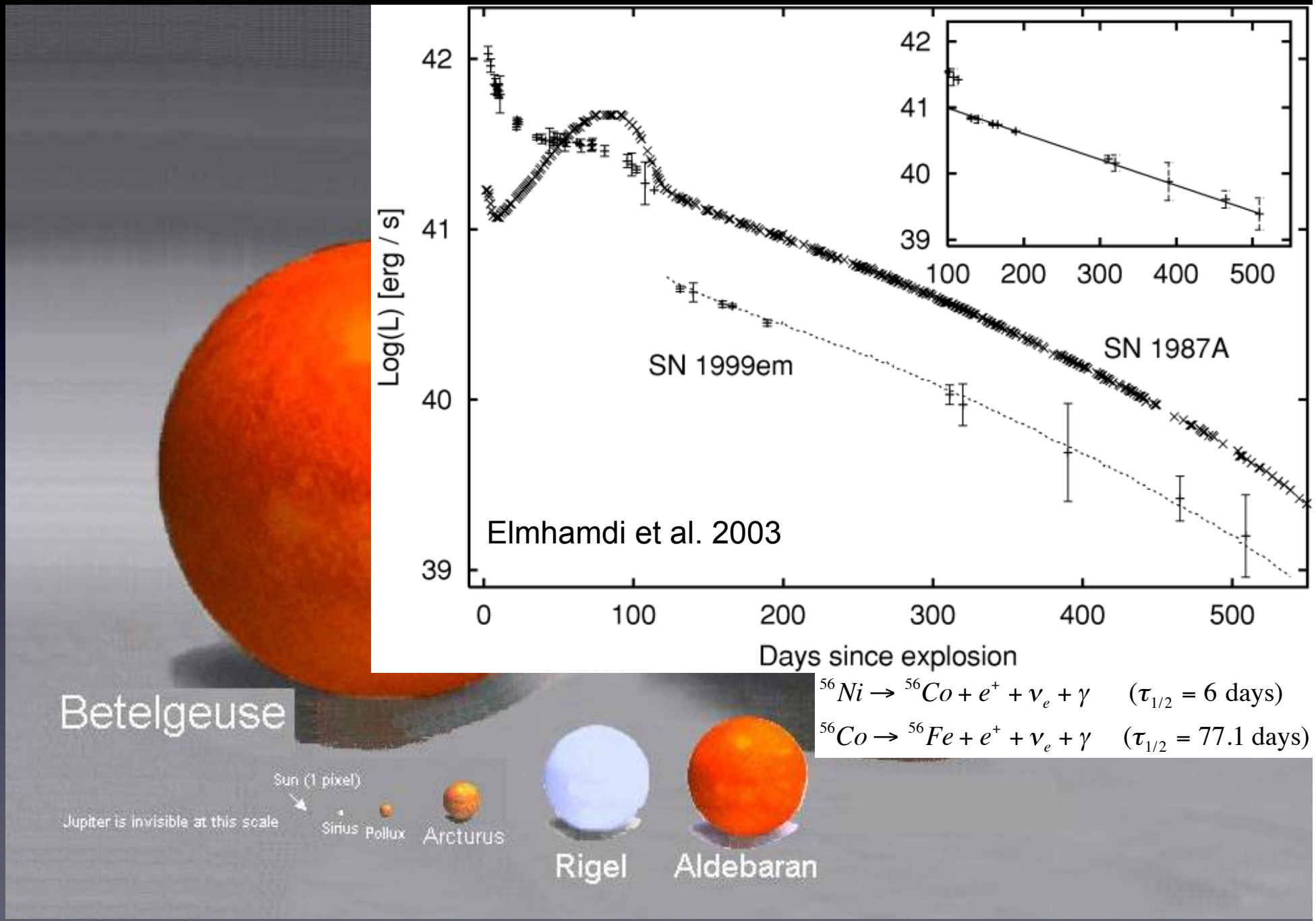
Photpipe team :Huber, Rest, Narayan, Stubbs, Wood-Vasey, Chornock, Foley, Berger, Rodney ++

QUB Team :Smartt,Smith, Kotak, McCrum, Fraser , Magil, Valenti, Botticella, Pastorello, Young

Theory HRD - STARS code



From Eldridge & Tout 04

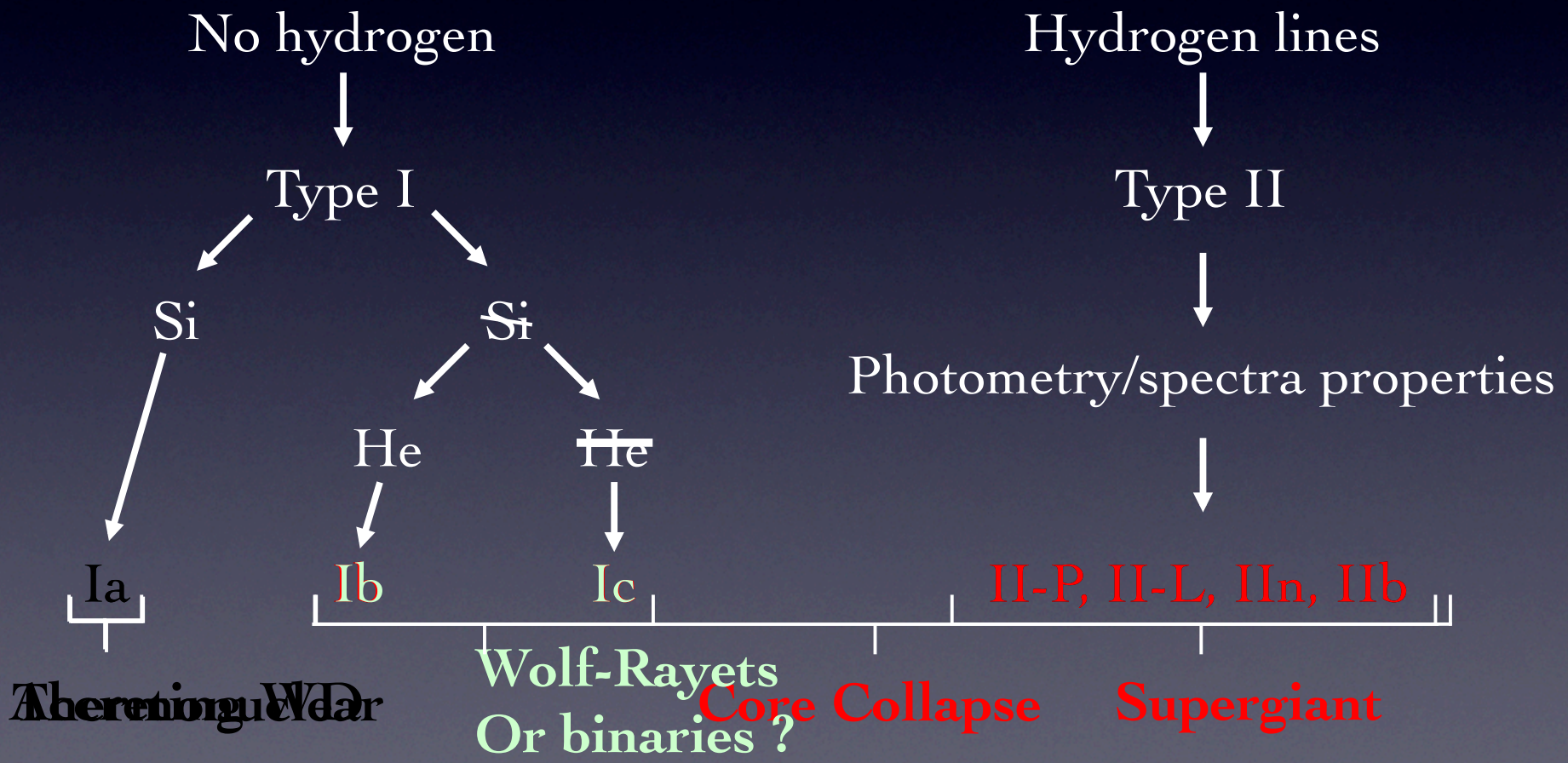


$^{56}Ni \rightarrow {}^{56}Co + e^{+} + \nu_e + \gamma \quad (\tau_{1/2} = 6 \text{ days})$

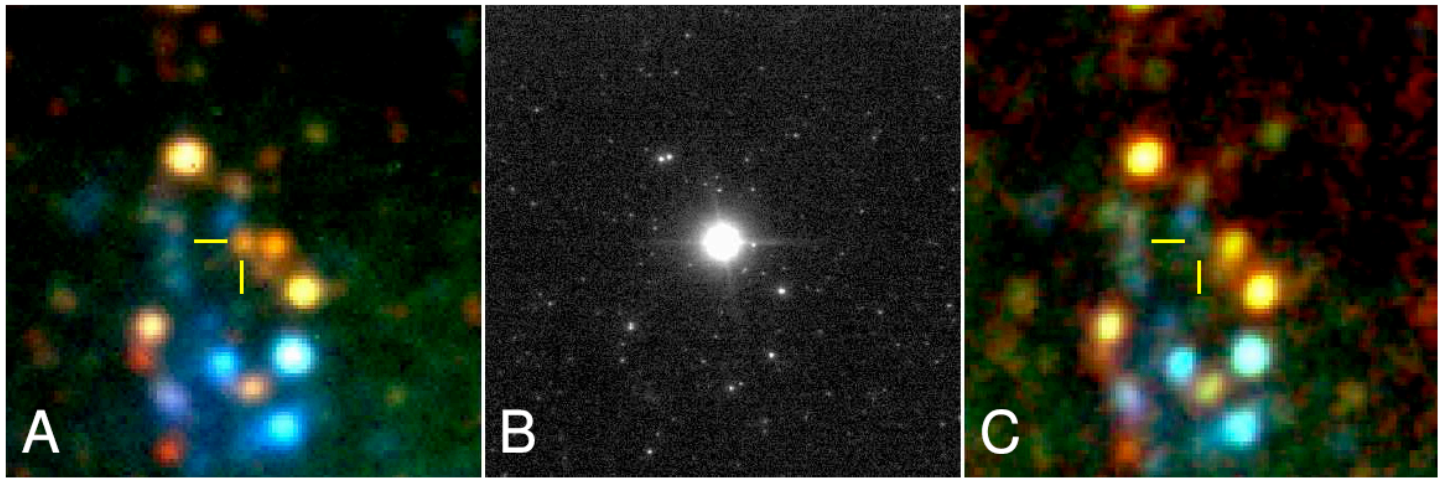
$^{56}Co \rightarrow {}^{56}Fe + e^{+} + \nu_e + \gamma \quad (\tau_{1/2} = 77.1 \text{ days})$

Supernova types

Supernovae are classified by their optical spectra



SN2008bk : red supergiant disappears



Mattila, Maund, Smartt et al in prep.

Maund & Smartt 2009, Science

Smartt 2009, Annual Rev. Astron & Astrophys.

Transients : parameter space

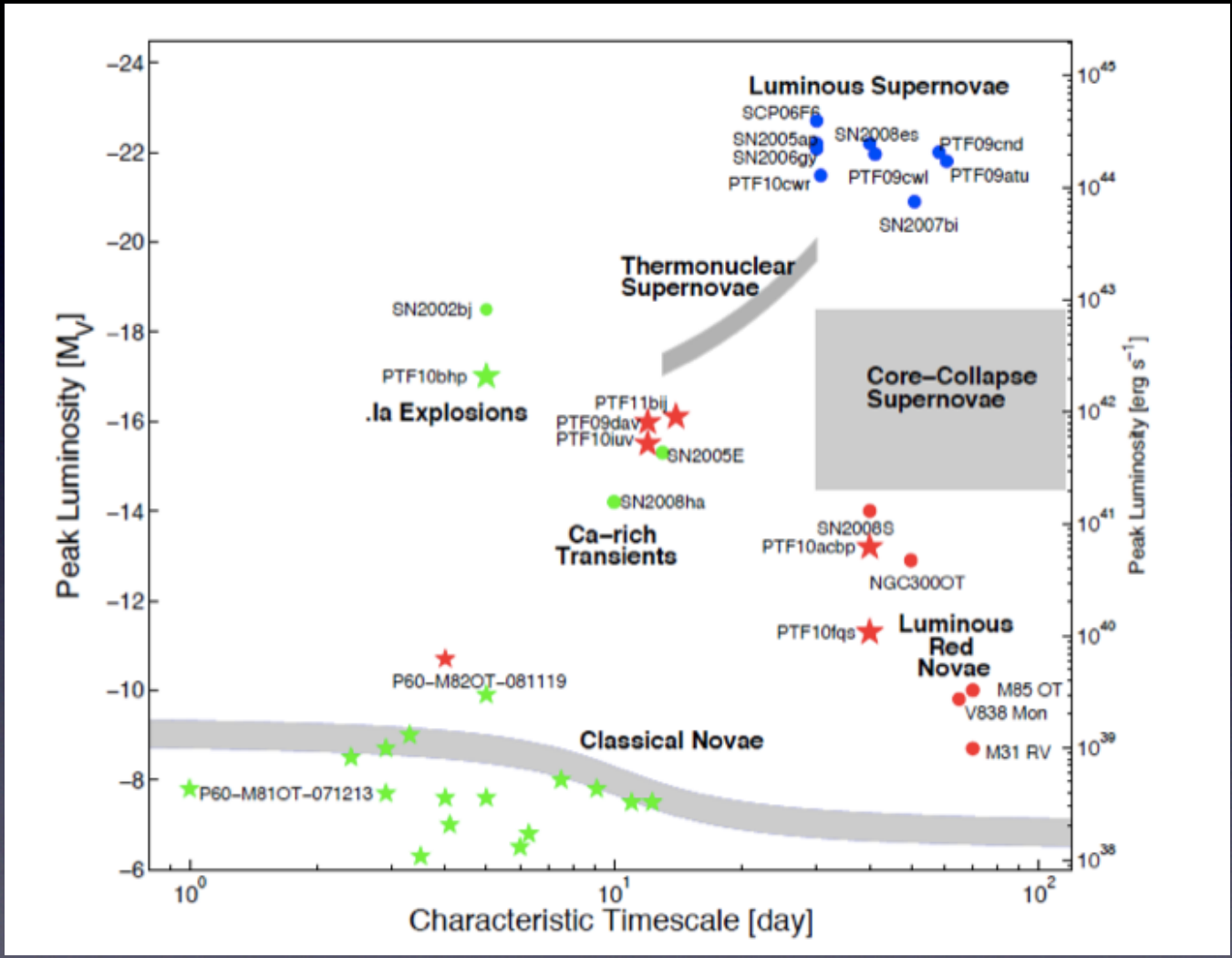
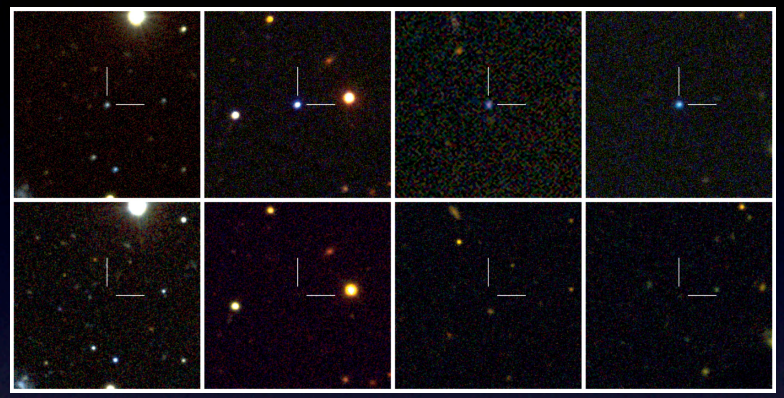
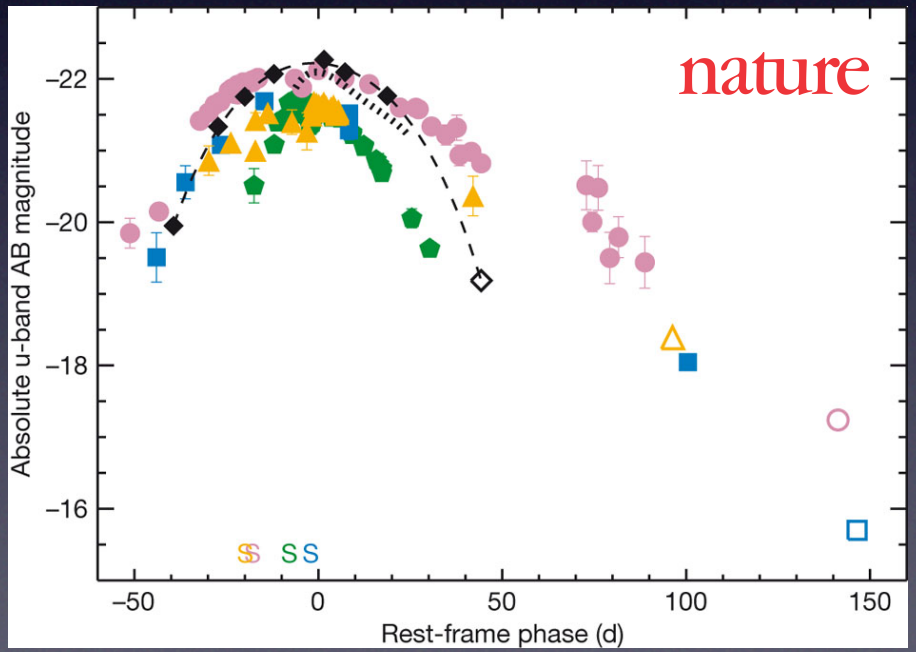


Image credit : Shri Kulkarni, CalTech

Superluminous stellar explosions

Palomar Transient Factory

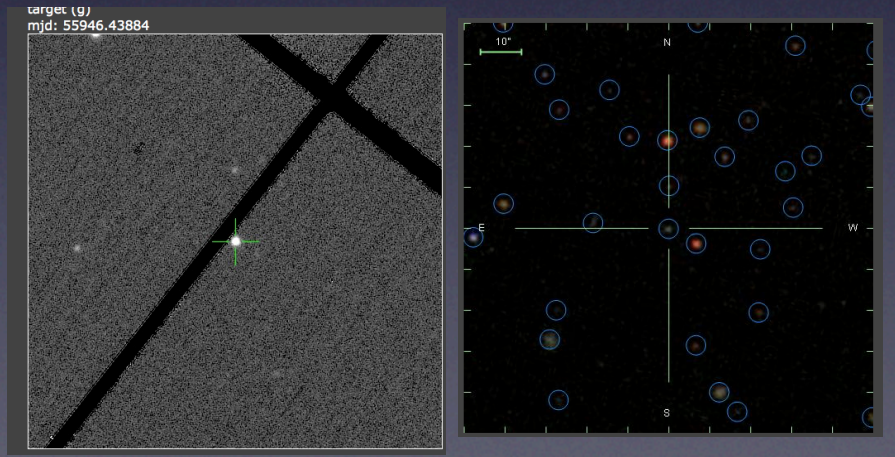




RM Quimby *et al*. *Nature* 2011

Pan-STARRs1 probing redshift ranges 0.1 – 1.5

- Z = 0.1 – 0.3 in the 3Pi survey
- SN2010gx, PS1-11xk, PS1-12fo, + two other candidates
- Z= 0.5 – 1.5 in the MD fields



Pastorello et al. 2010, Chomiuk et al. 2011, Beger et al. 2012

^{56}Ni powered luminoisty is unphysical

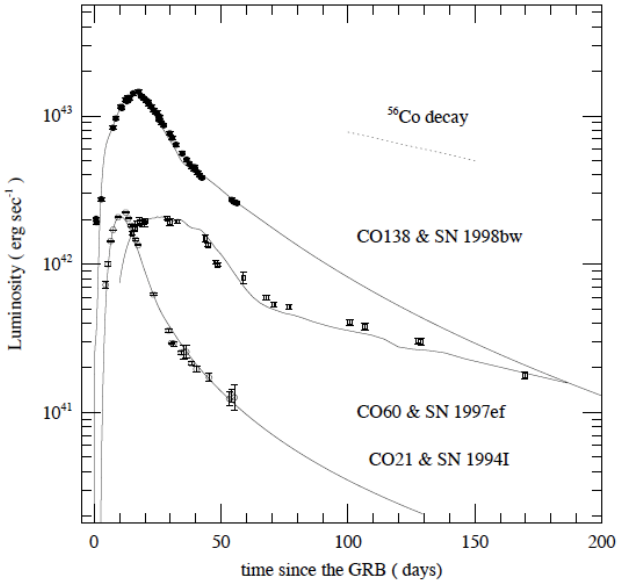
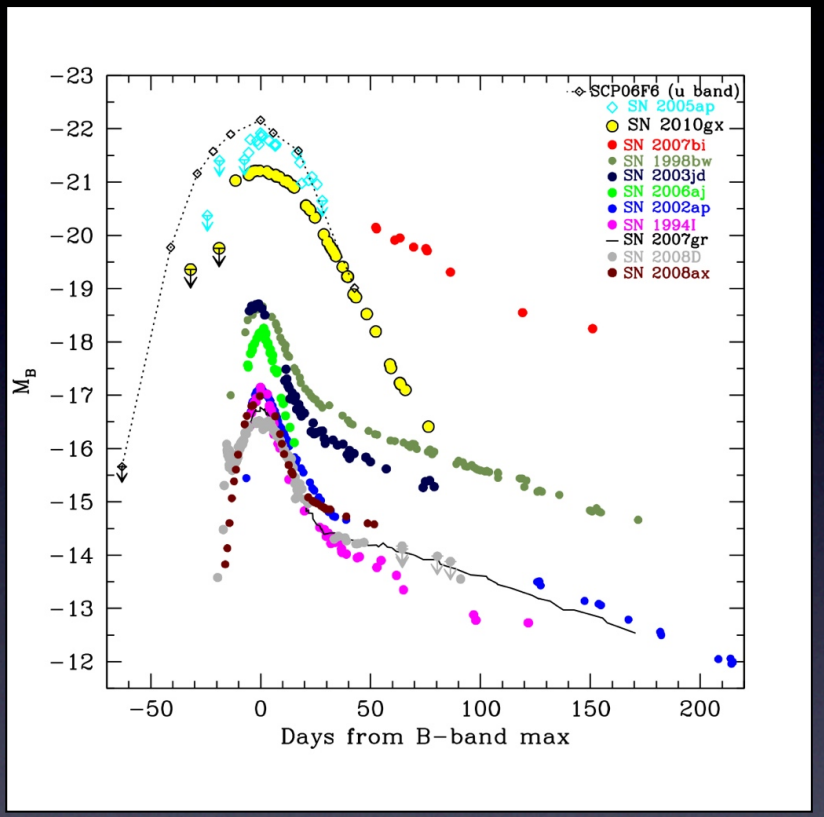


Figure 1: The bolometric light curve of model CO138 ($M_{\rm CO} = 13.8M_\odot$, $E_{\rm exp} = 3 \times 10^{52}$ ergs, $M_{56} = 0.7M_\odot$) compared with the observations of SN1998bw. The time of the core collapse is set at the detection of the

Iwamoto et al. (1998)

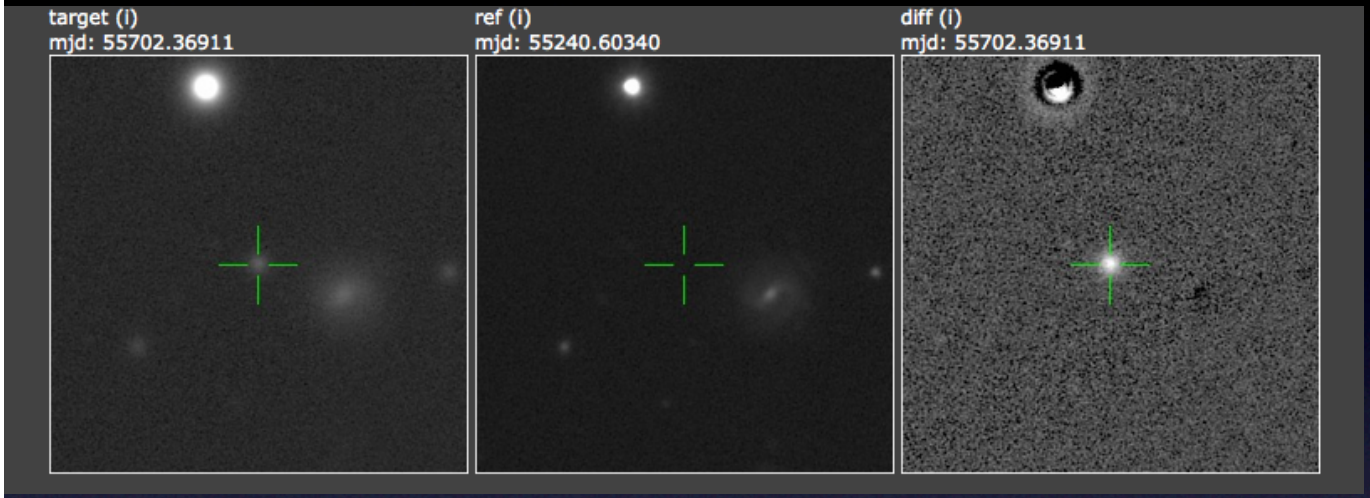


Scaling relations ("Arnett's law") means

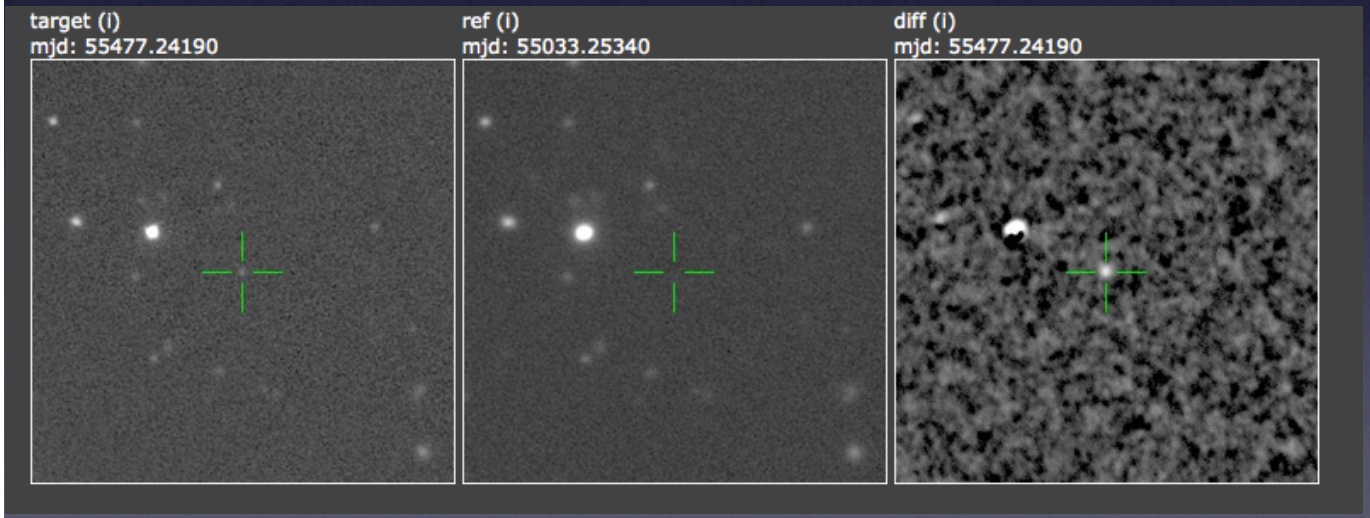
$M_{Ni} > M_{ej}$

Pastorello et al. 2010, Chomiuk et al. 2011

Search for Orphans



- PS1-11zd
- Type Ia, z=0.1 ; same as “host”
- Offset by ~25kpc

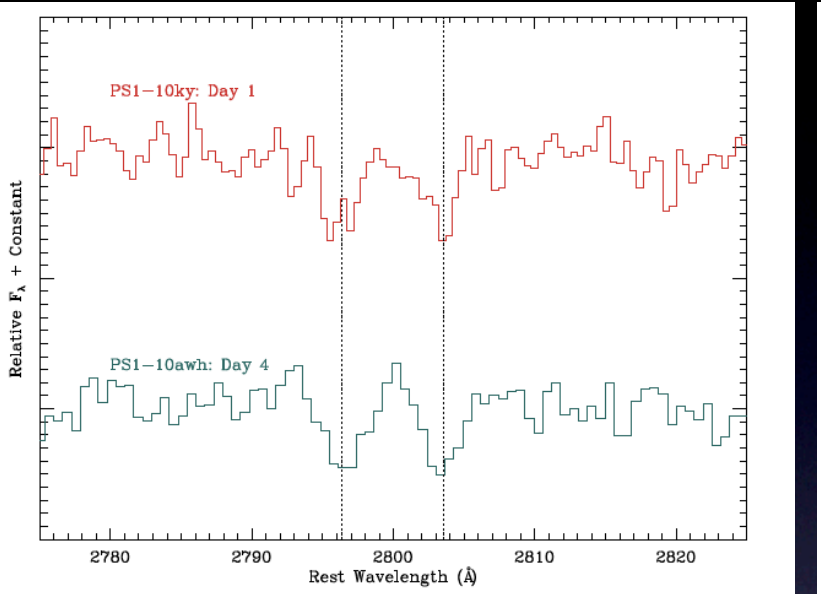


- PS1-10awh
- Type I SN at z=0.9
- No obvious host – even in deep stacks

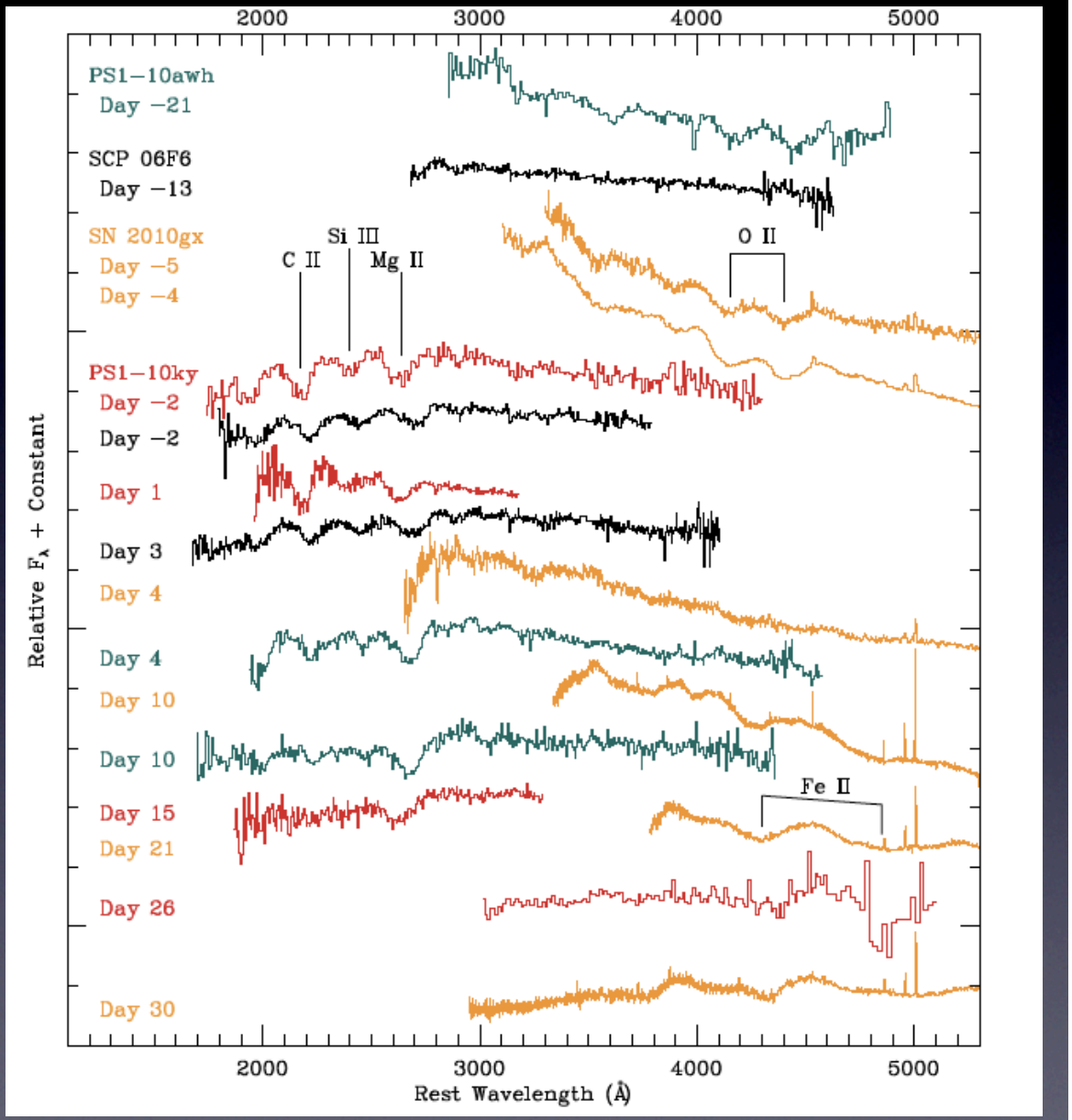
>3.5” from any catalogued star or galaxy, to *r* ≈ *23.5*

254 orphans from 1.25yr

Two "ultra-luminous" SNe at $z \approx 0.9$



- Mg II ISM host absorption
  - PS1-10awh : $z = 0.9084$
  - PS1-10ky : $z = 0.9558$
- Host galaxies undetected
  - $z_{P1} > 25^m$
  - $M_B > -18^m$ or $L_{gal} < 0.05 L\star$

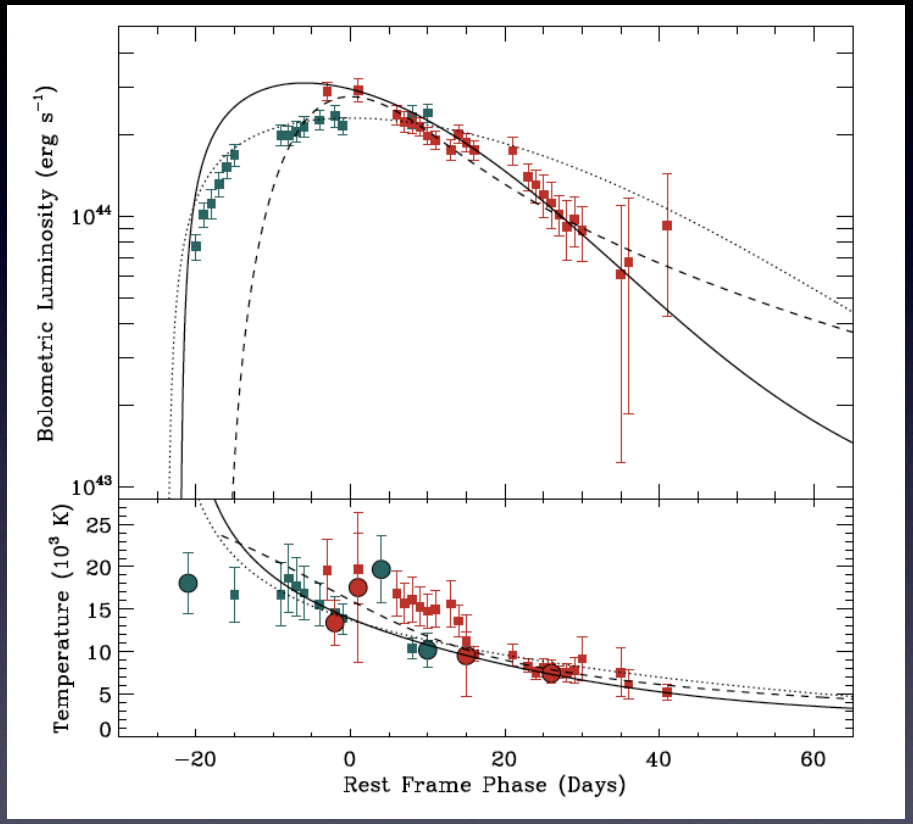


Chomiuk et al. 2011, ApJ

Magnetar Powered lightcurve?

- If NS formed spinning at P = 2-20 ms ; with B ~ 10^{14} G
- Rapid spin down powers extra energy in expanding SN
- If diffusion time is similar to spin down time :

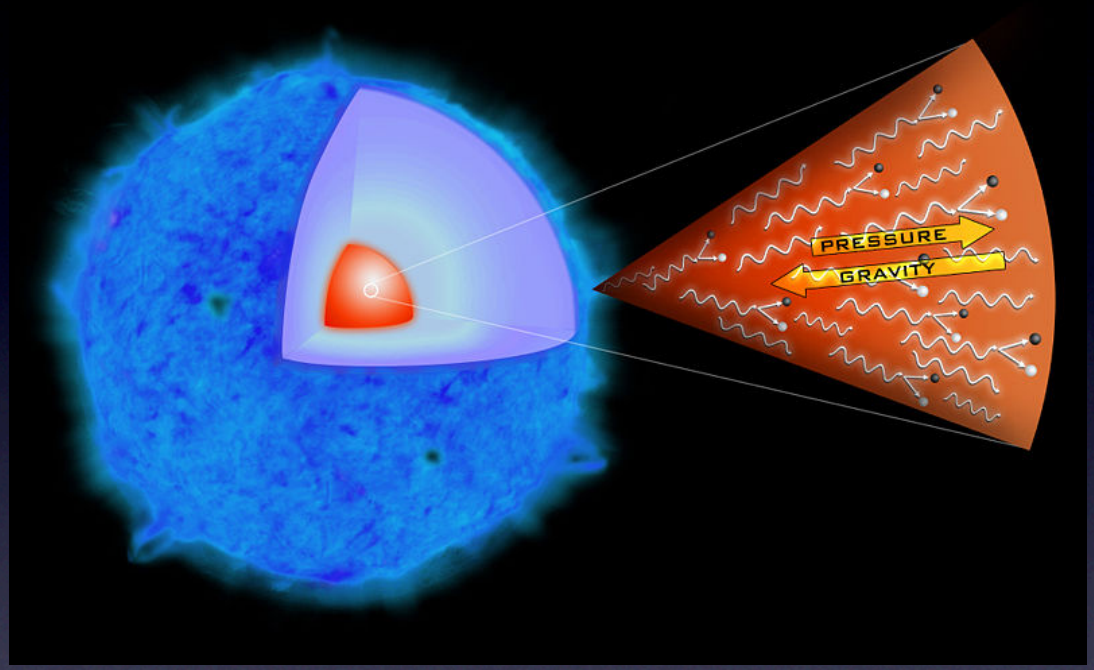
$$L_{peak} \sim \frac{E_p t_p}{t_d^2}$$



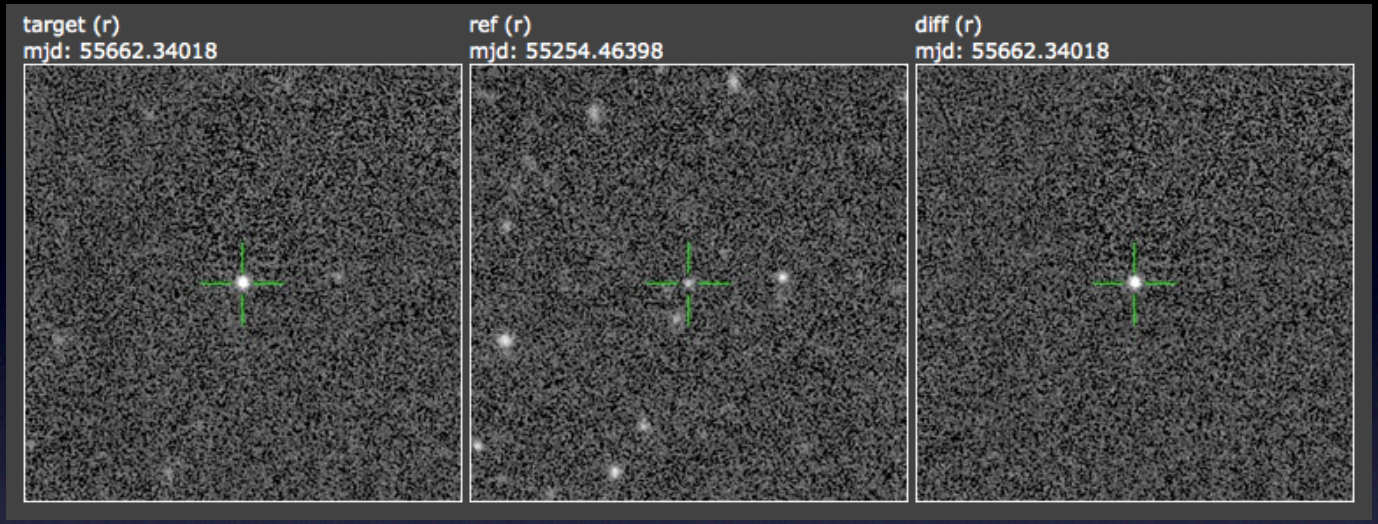
Kasen & Bildsten 2010
Chomiuk et al. 2011

Pair Instability Supernovae

- “Pair instabilty SN” in which core is destroyed in CO thermonuclear runaway
- T ~ 10^9 : e^- e^+ production and thermal pressure decrease
- Thermonuclear runaway in ~60$M_\odot$ CO core
- Was this the mechanism ?

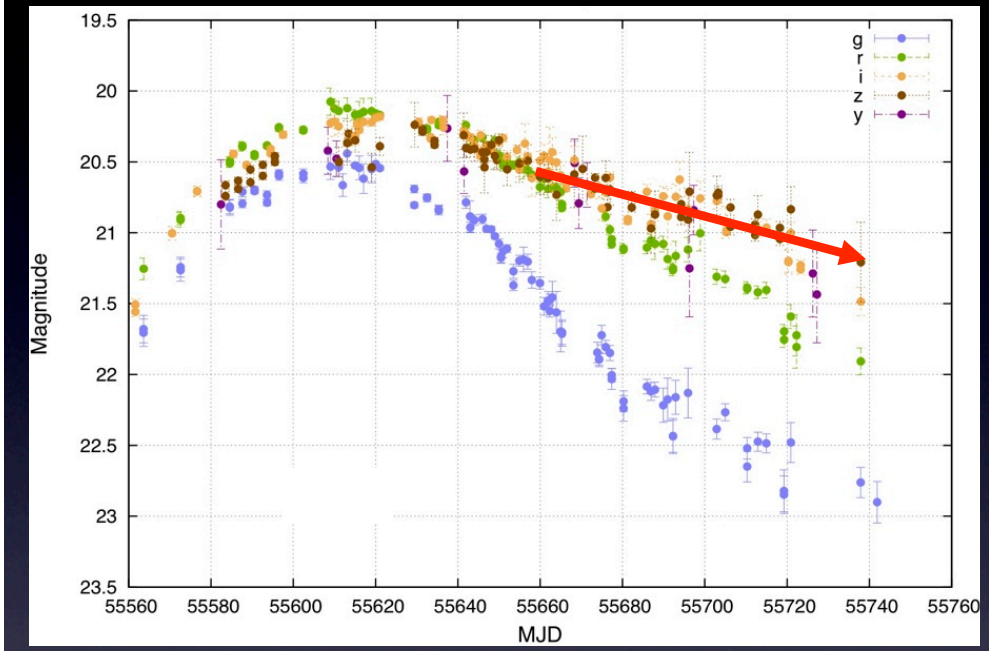


Pair-Instability SN at *z=0.5?*

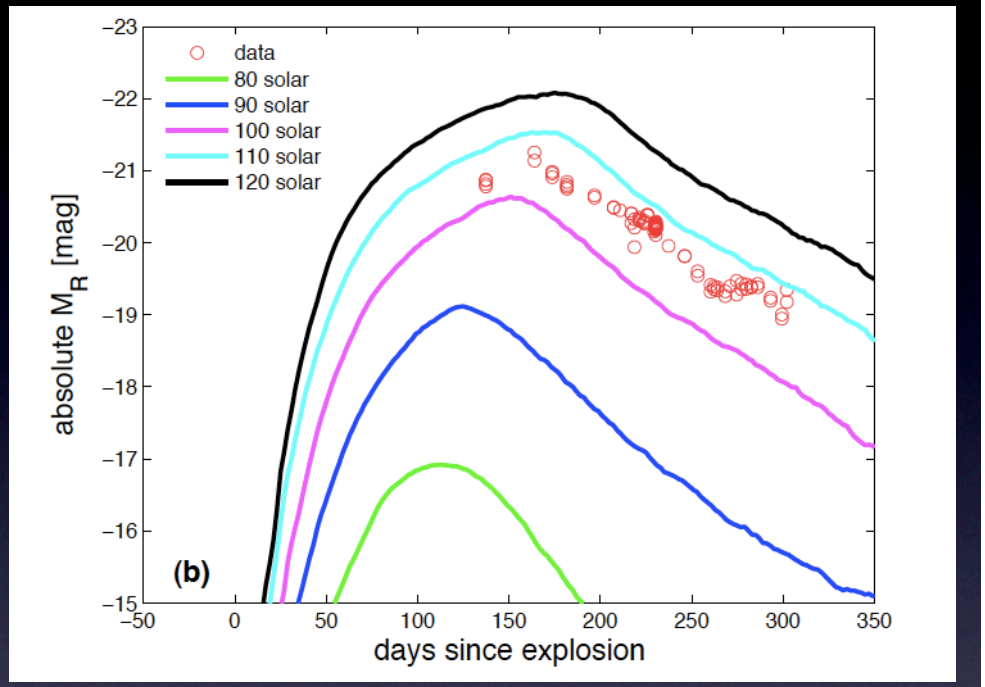


- PS1-11ap (MD05) : *z = 0.524*
- Discovered on first image of MD05 observing season in Jan 2011 ; -50 days before peak.
- Unresolved host :
  - r = 23.6 ±0.16 observed
  - z = 23.7 ±0.0.3 observed ; M_r*(rest)* = -18.7
- Kotak et al. 2011, in prep.

Pair-instability SN ?



Kotak et al. 2011, in prep.

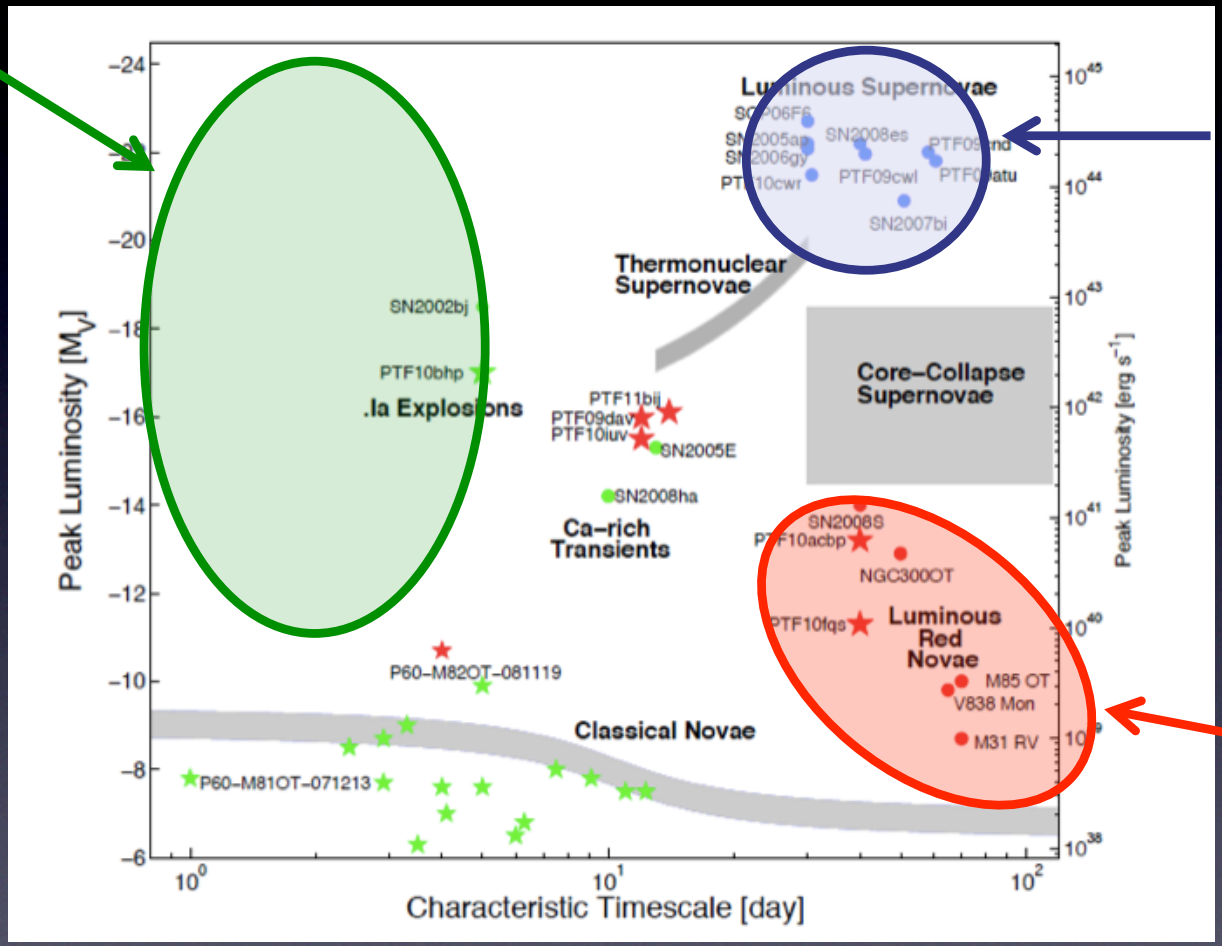


Young et al. 2010, Gal-Yam 2009

- Rise time : 1^m in 40 days (rest frame)
- Decay : ~1 mag per 100 day approximately fits i, z, y
- Rest frame $r \approx$ observed z_{P1}
- $M_r \approx -21.4$

Transients : the future

the unknown



the bright

the faint

What are the limits of physical explosions and transients ?

Image credit : Shri Kulkarni, CalTech

Current

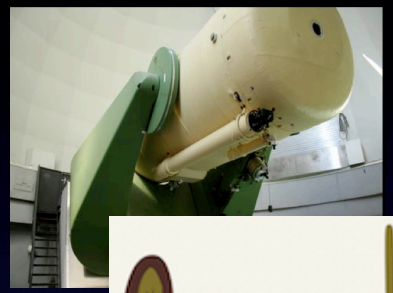
10 square degree cameras + 1-2m telescopes

PS1 – high-z SNe (dedicated 4-8m follow-up)

PTF – low-z SNe (“factory” follow-up built in)

Catalina Sky Survey – 0.5 – 1m telescopes (~7 sq degree FOV), specialises in solar system but also stationary transients

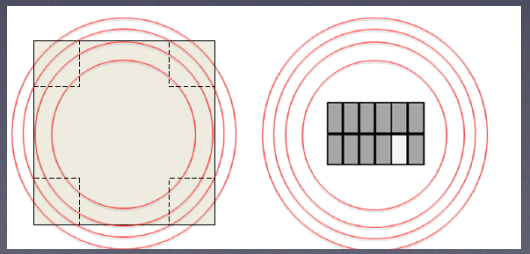
NG Transient Surveys



Pesstro

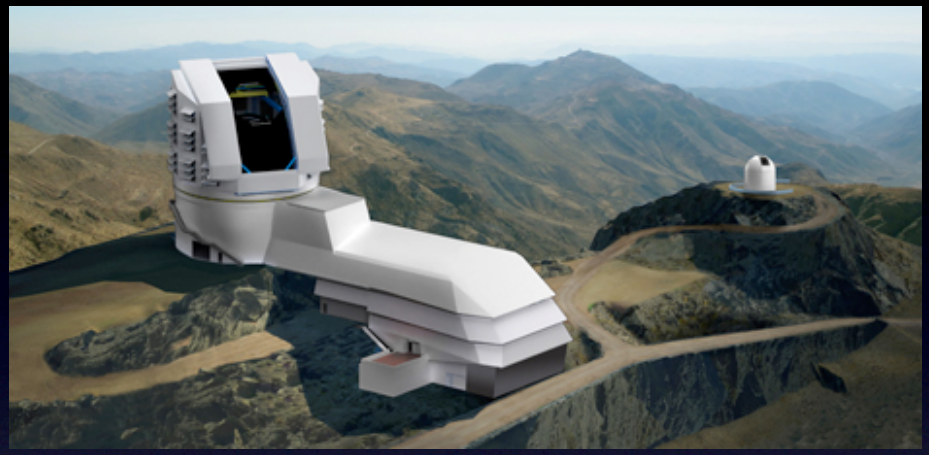
La Silla QUEST + SkyMapper (~10 sq deg. Cameras) + PESSTO (90N per year on ESO NTT)

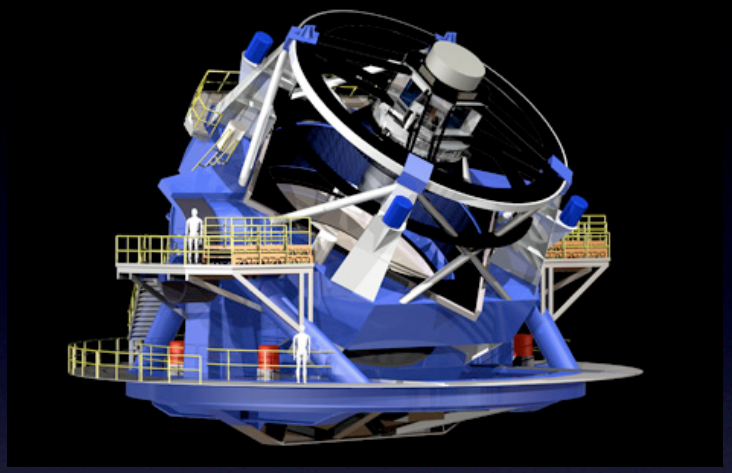
PS1 x 2 = PS1 (2014)



NG-PTF (2015) : 30 sq degree

LSST





- Large Synoptic Survey Telescope – construction due to start 2013/14
- Start Survey ~2020
- 6m telescope + 10 square degree field
- Surveys down to ~24.5^{m} ; 15000 dq degree every 3N