Lecture 2: Inferences from Supernovae Lightcurves and New Surveys

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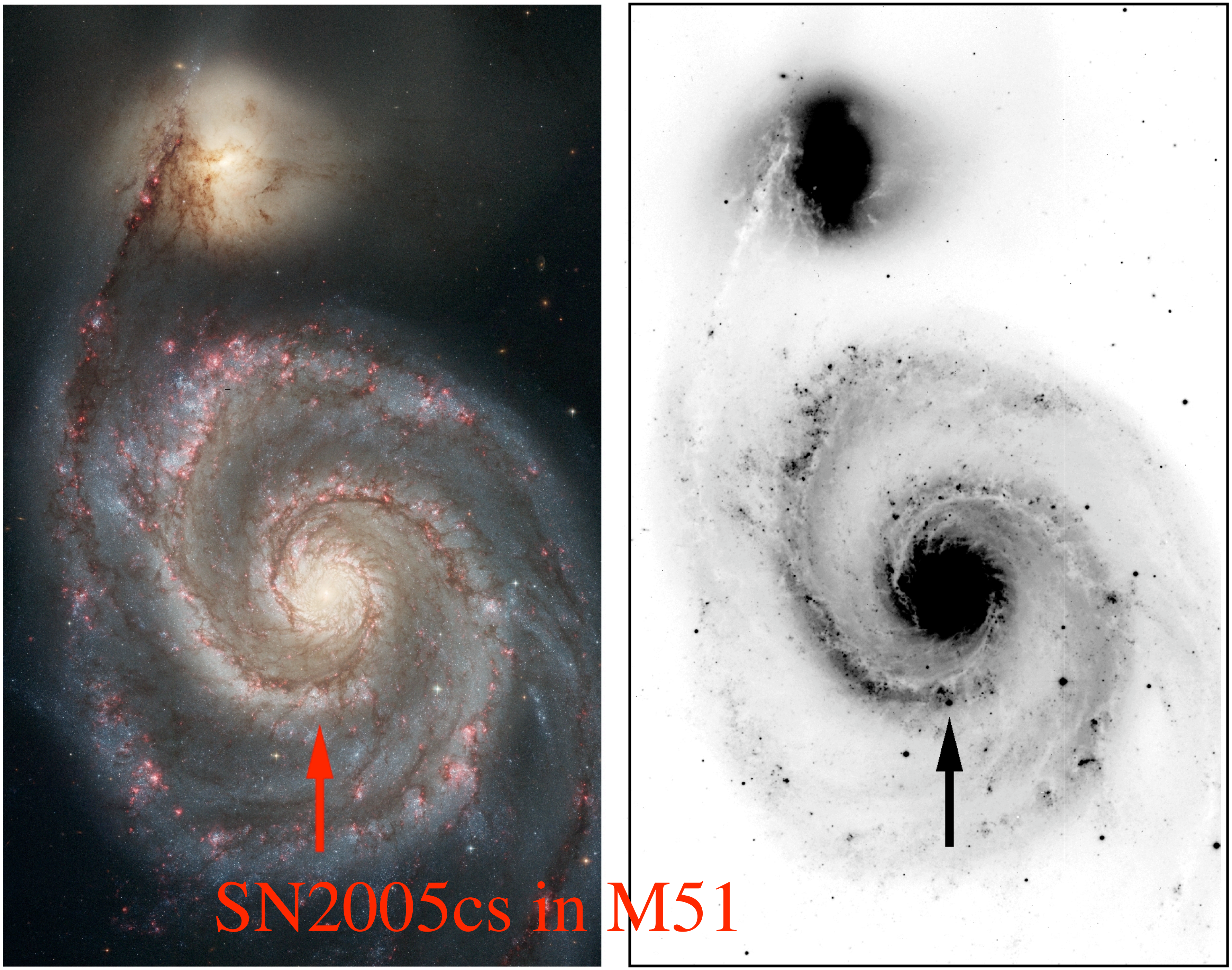
Stars explode once every second in the Universe, often becoming brighter than their home galaxies. Enhanced capabilities to scan the skies now detect about 30 per day, revealing new phenomena!

HW Problem

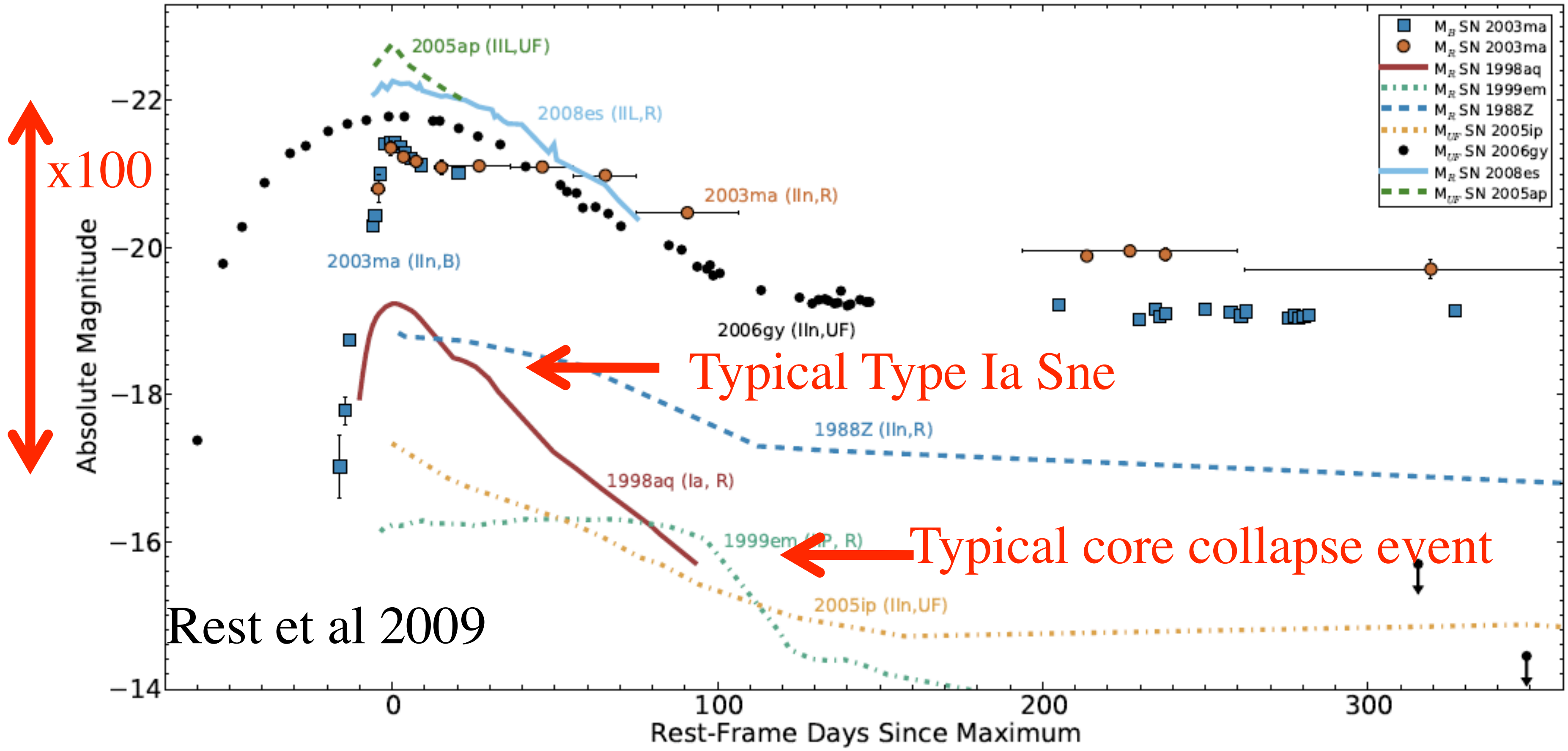
- A typical nuclear energy release is 1 MeV per baryon (10^{18} ergs/gram).
- How small does a 1 $M_{\odot}$ (2×10^{33} grams) object need to be to reach this energy per gram in gravitational binding energy?


SN2005cs in M51

Supernovae Light Curves

The sun was +5, so these are 25 magnitudes brighter=10^{10}

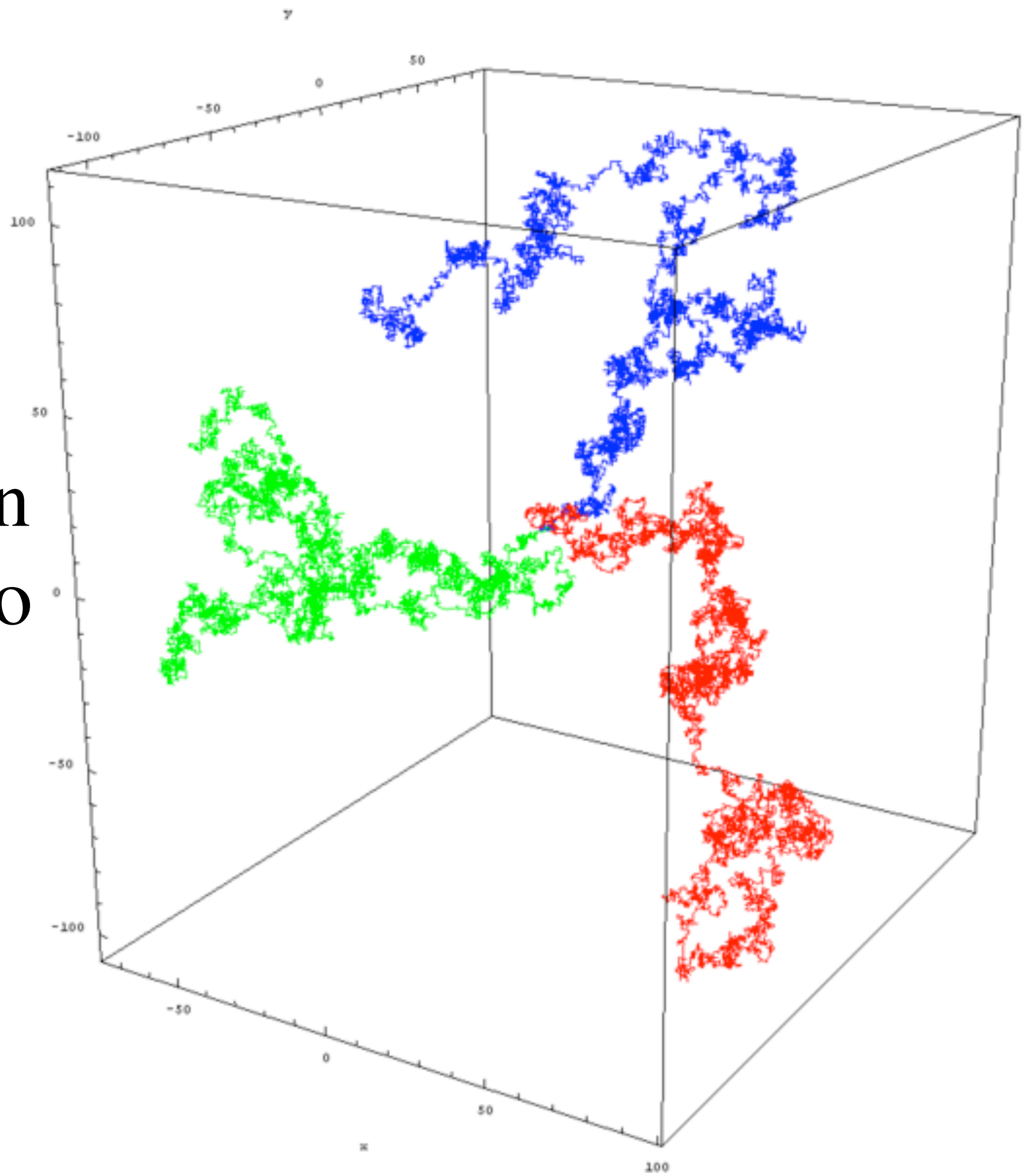
➔ 1 year to emit same energy as the Sun does in 10 Gyr!



HW Problem: Random Walks

A particle has a mean free path= Lambda..

How many scatters, on average, does it take to escape from a box of size R?



Simple Lightcurves

- Consider an ejected mass M that is expanding at v, so R=vt, and has opacity Kappa

$$t_{\rm diff} \sim \frac{N\lambda}{c} \sim \frac{R^2}{\lambda c} \sim \frac{\kappa M}{Rc}$$

- Radiation diffusion time is >R/v=age until a time

$$t_d \approx \left(\frac{\kappa M}{vc}\right)^{1/2} \approx (10 - 20)\ \text{days}$$

- But before then the expansion is adiabatic and since it is radiation-dominated=> $T \approx T_o \left(\frac{R_o}{R}\right)$

Luminosity Estimate

- The luminosity is

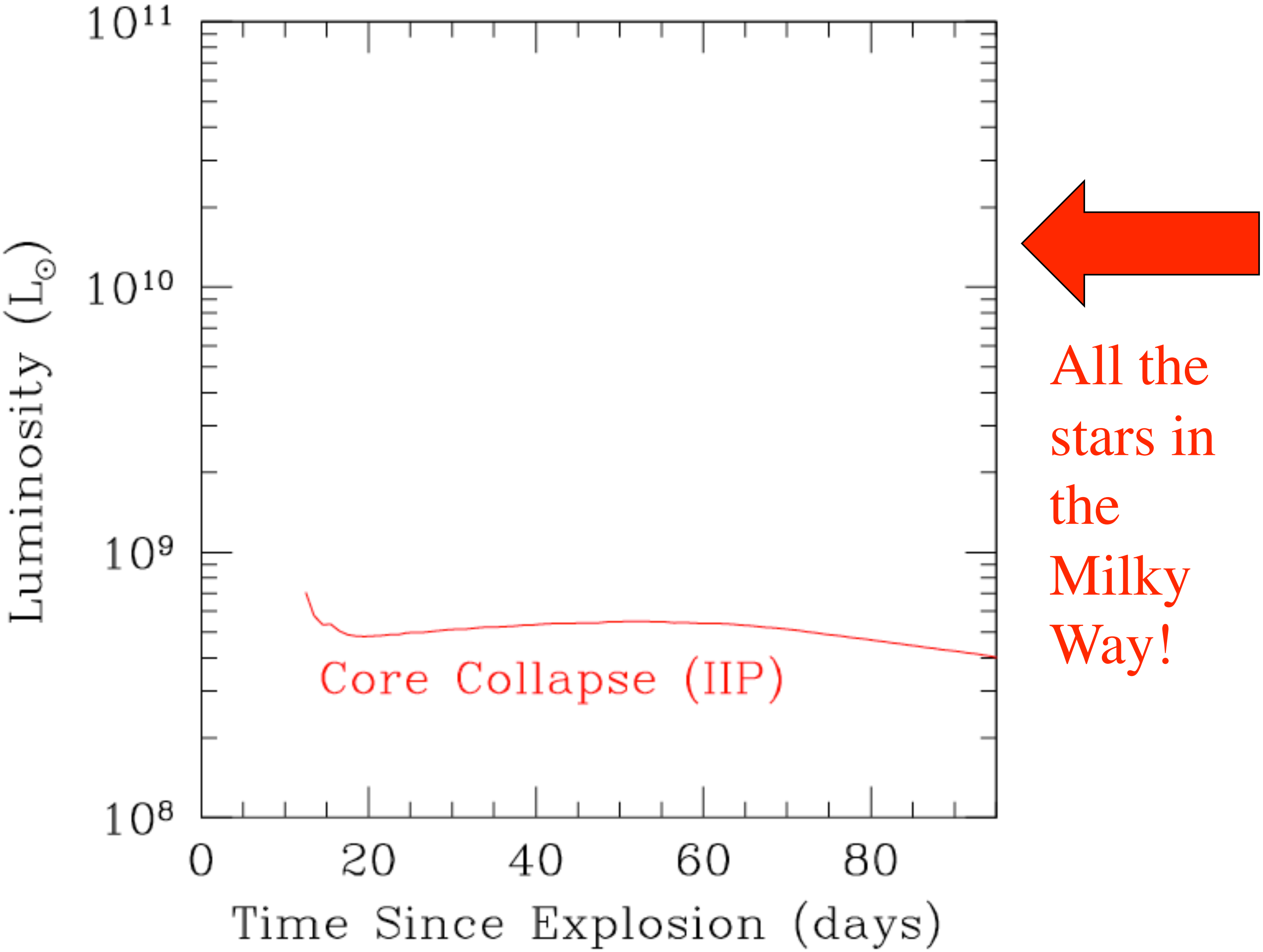
$$L \sim R^2 \frac{c}{\kappa\rho} \frac{d}{dr} aT^4 \sim \frac{R^3 E_{\rm rad}}{t_{\rm diff}}$$

- During the adiabatic phase, T goes like 1/R, giving

$$L \sim \frac{R_o^4 ac T_o^4}{\kappa M} \sim \frac{E_{\rm sn} c R_o}{\kappa M}$$

- An excellent estimate for the peak luminosity of Type IIP SNe (~10^9 $L_\odot$) where R_o is comparable to distance from Earth to Sun for red giants and E_{sn}~ 10^{51} ergs. Inferred mass is $M=10\text{-}20M_\odot$

Theorist Version!



All the stars in the Milky Way!

HW Problem: Radiated Energy

How much of the $E_{sn}=10^{51}$ ergs is radiated?

Why is it such a small fraction?

Where did the energy go?

Core Collapse Outcomes (more in Lecture 4)

- Type IIP SNe: Core Collapse of 10-30 $M_\odot$ objects. Has Hydrogen in it.
- Type Ib SNe: More Massive stars have winds that allow for substantial mass loss, so that the observers see no H, but rather Helium
- Type Ic SNe: Likely even more massive: H and He lost in wind prior to collapse

Observed Fractions of Core-Collapse Supernova Types and Initial Masses of their Single and Binary Progenitor Stars

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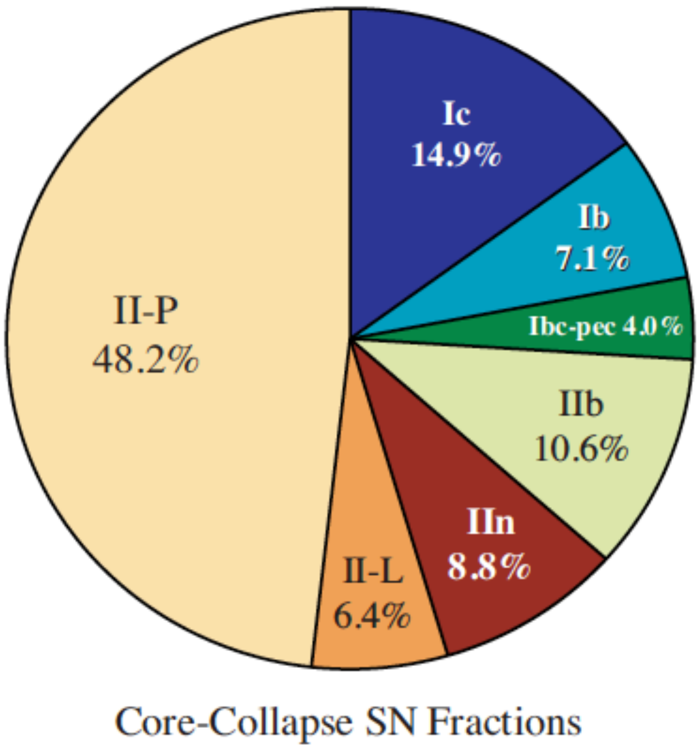
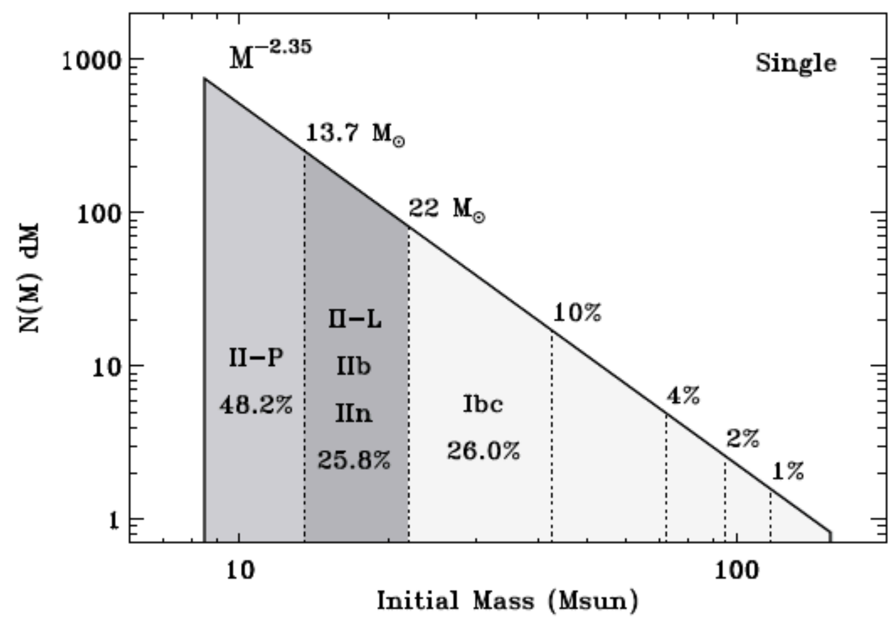


Figure 1. Relative fractions of CCSN types in a volume-limited sample from LOSS. This is slightly different from the fractions quoted in Paper II, in order to better suit the aim of this paper as explained in the text. The main difference is that we exclude SNe in highly inclined galaxies because of extinction effects, and we reorganise the class of SNe Ibc-pec (namely, we moved broad-lined SNe Ic from the "Ibc-pec" category to the "Ic" group).



Type Ia Supernovae: Brighter than a whole galaxy for a month!

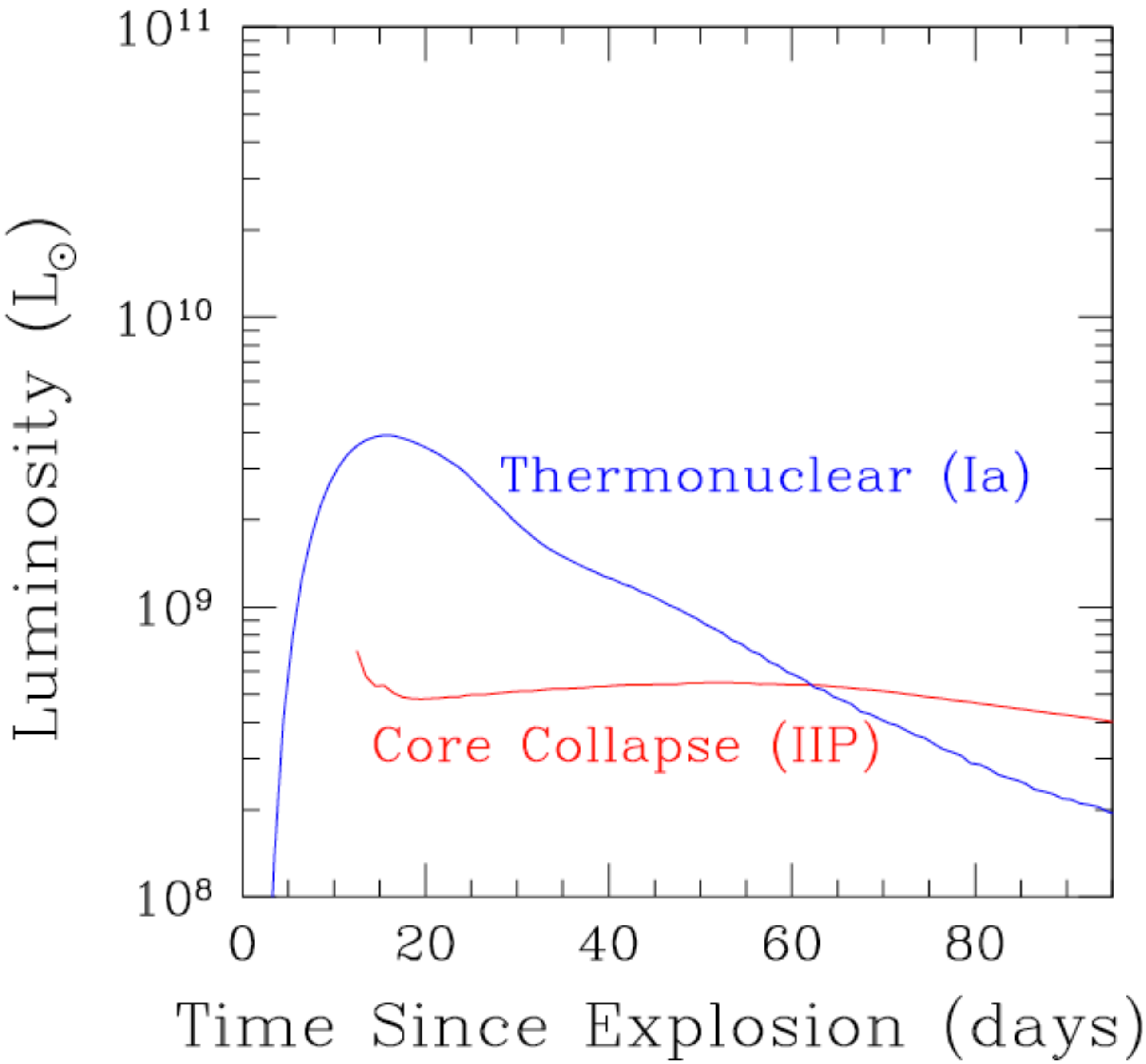
Type Ia Supernovae

- About 1 in 500 white dwarfs seem to explode
- We think this is triggered by new material re-starting Carbon fusion in the core, completely burning the material to ^{56}Ni in ~10 seconds
- The star expands at 10,000 km/sec and is heated by radioactive decay as $^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$
- Over 2/3 of the ^{56}Fe in your body was made this way!

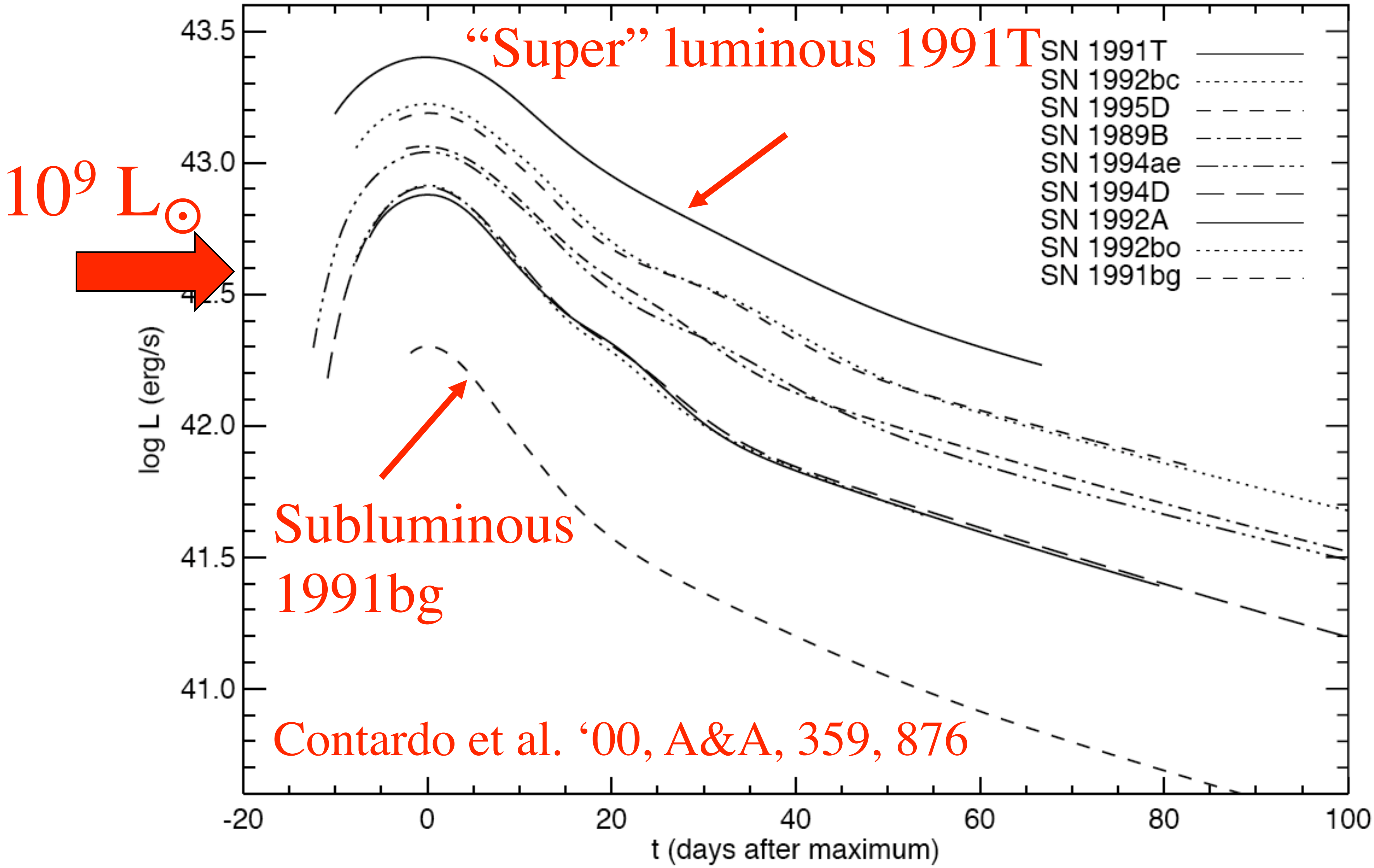
HW Problem: Nuclear Luminosity

- What is the luminosity from the decay of a $M_\odot$ of element 56 if each decay releases 4 MeV and the e-folding decay time is 100 days?

Brighter than Core Collapse



G. Contardo et al.: Epochs of maximum light and bolometric light curves o



Thermonuclear Supernova Lightcurves

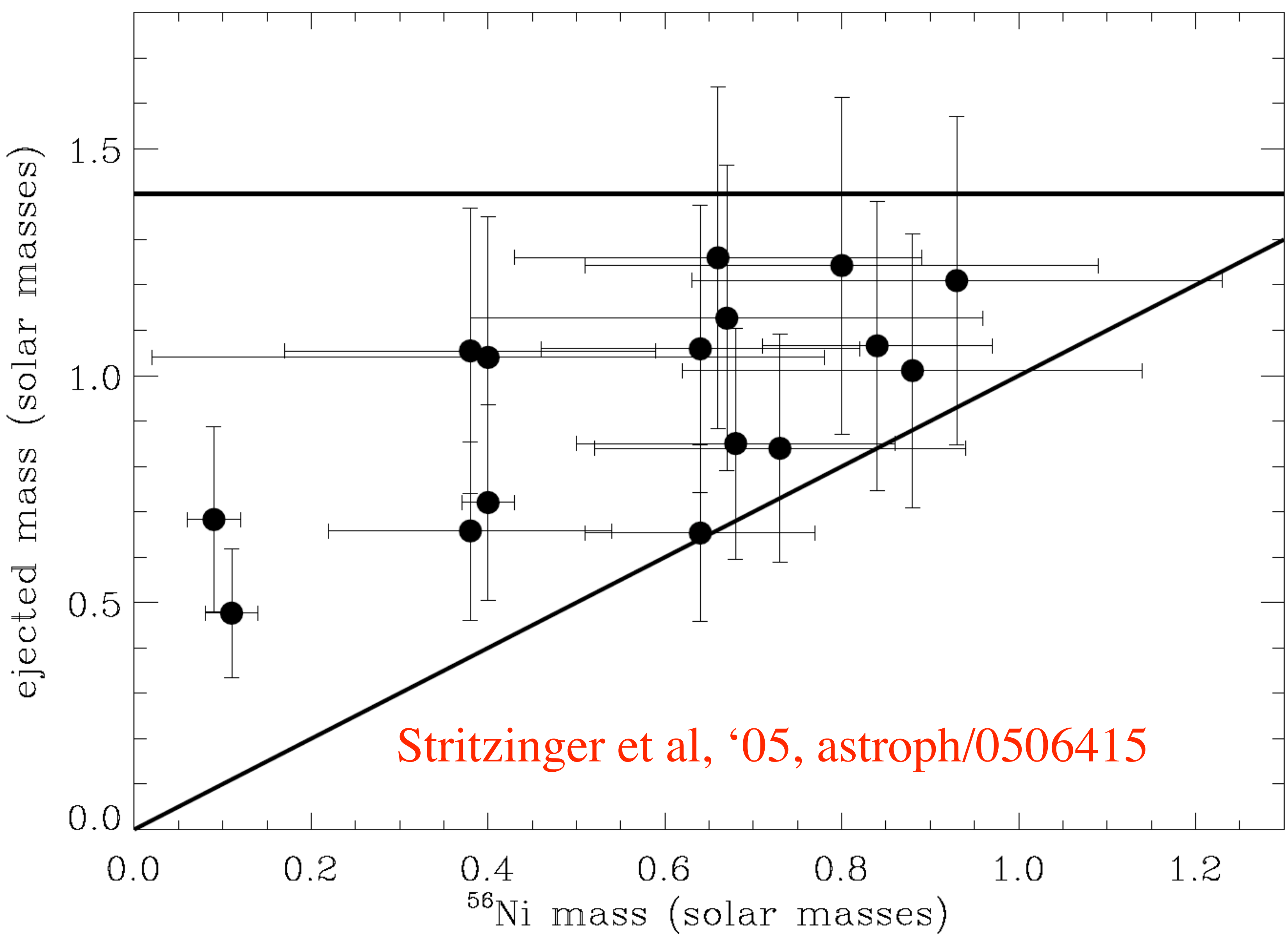
Since R_o is smaller than core collapse by 10^5 these would be very faint events, however… the remnant is heated by the radioactive decay: ^{56}Ni (6.1 d) ⇒ ^{56}Co (78 d) ⇒ ^{56}Fe

• The peak in the light-curve occurs when the radiation diffusion time through the envelope equals the time since explosion. . .

$$\tau_m = \left(\frac{\kappa M_e}{7cv}\right)^{1/2} \approx 20 \text{ days}$$

• The luminosity after peak is set by the radioactive decay heating rate ⇒ can measure the ^{56}Ni mass via the peak luminosity, yielding 0.10-1.3 $M_{\odot}$

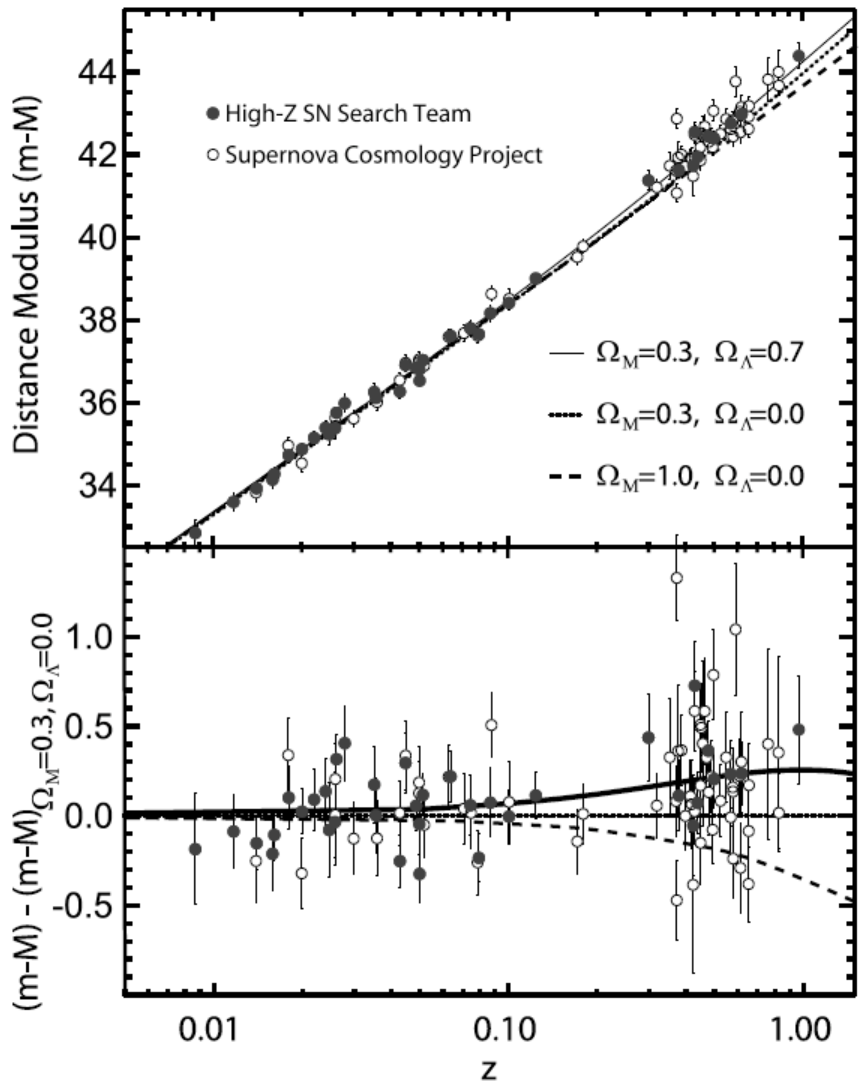
Light Curve Fitting to Measure Ejected and ^{56}Ni Masses

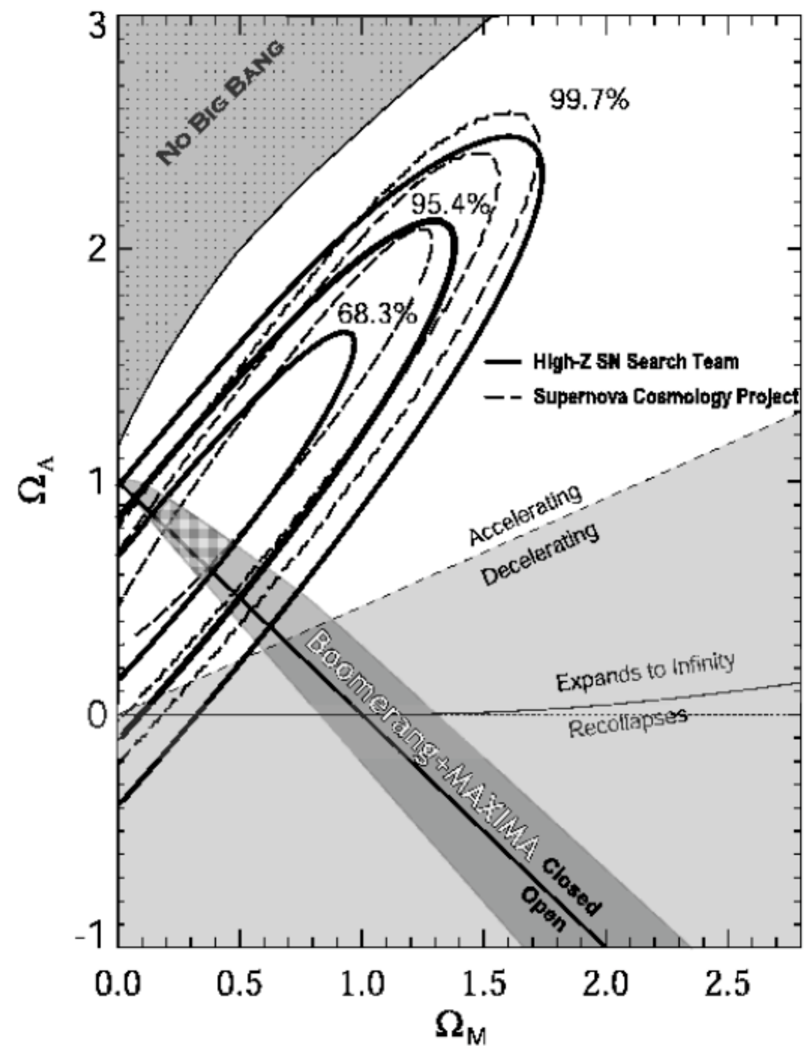


Thermonuclear Outcomes (more in Lecture 3)

- Type Ia SNe: Near complete thermonuclear burn of a 1.0-1.3$M_\odot$ C/O WD.
  - Some very bright events suggest $>M_{ch}$
  - Some faint events suggest $<< M_{ch}$
- ".Ia" Sne: Not firmly established yet, theoretically predicted event from a Helium Detonation

The Universe is Accelerating!!

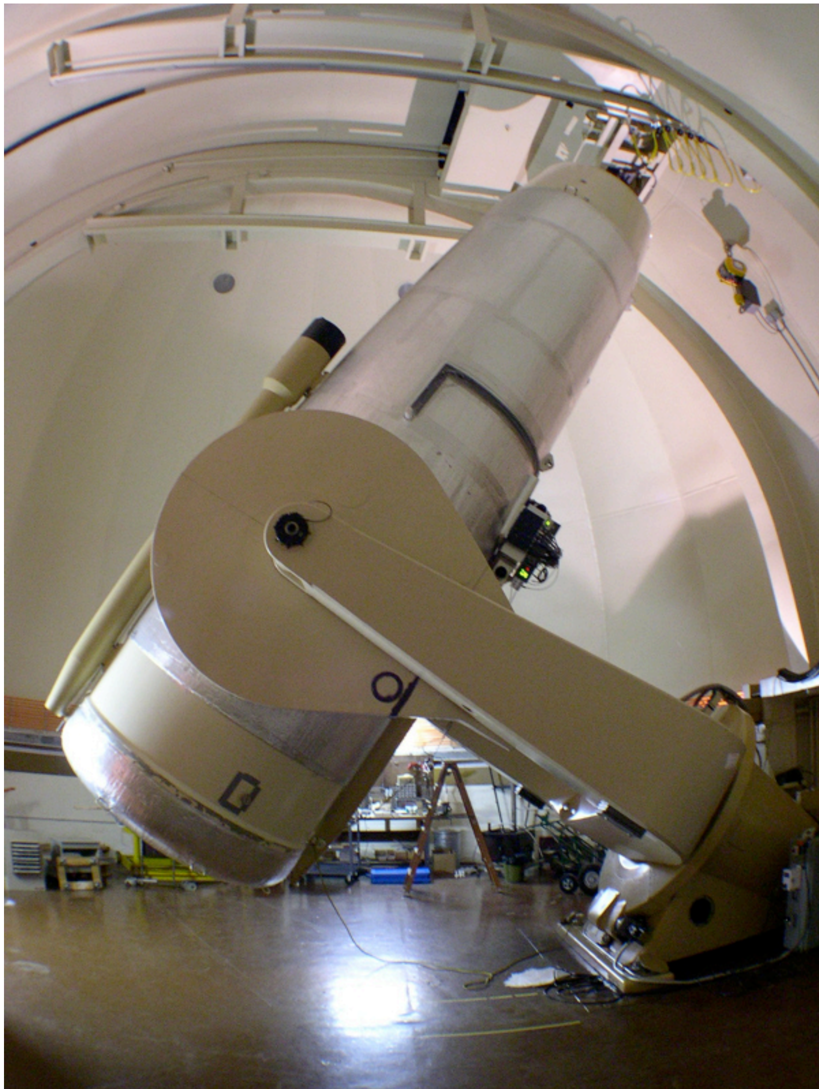




Surveys, Surveys, Surveys!

Completed survey (V=22.5, 260 deg^2)

Medium deep survey (V=24, 50 deg^2)

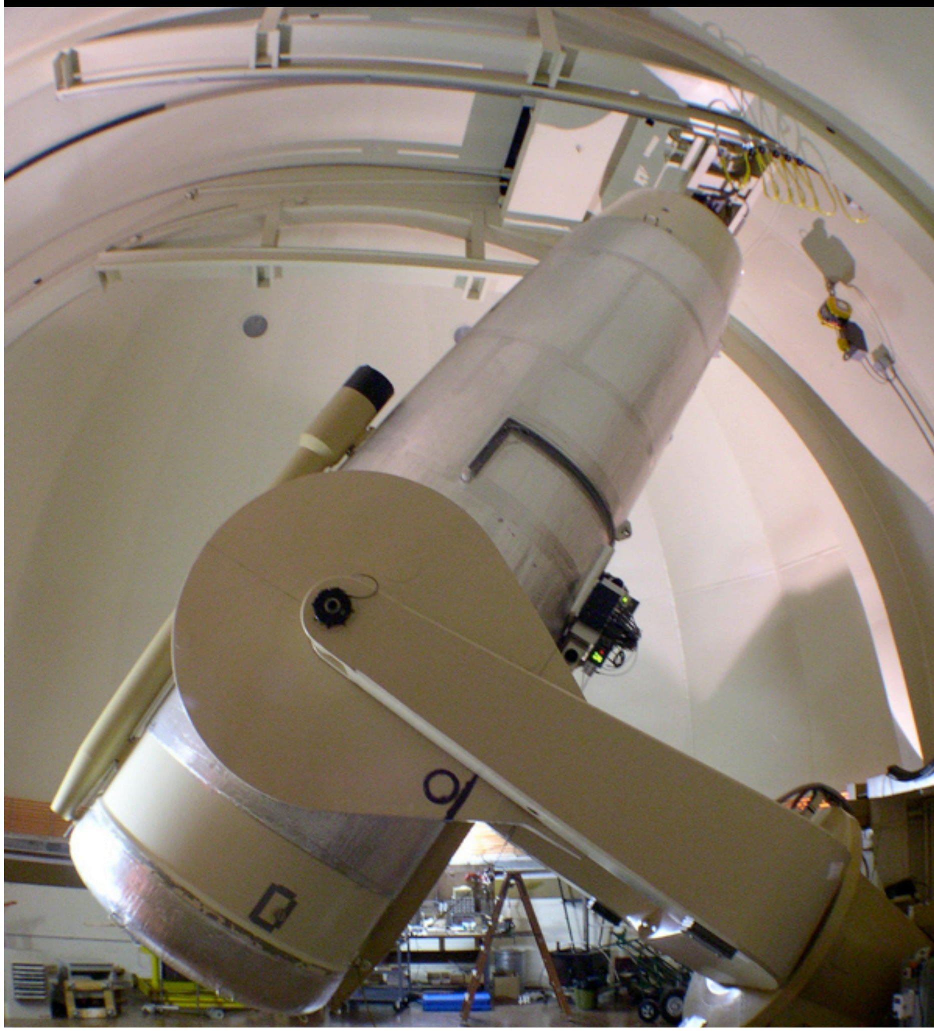


Palomar Transient Factory
('09; R=21, 3000 deg^2, 5d)

ROTSE (V=18,
200 deg^2)

SkyMapper
('10; V=19,
1000 deg^2
every 3-4 d)

Palomar Transient Factory



- A 100 Mega-Pixel CCD camera (CFH12K from CFHT) on the 48 inch Schmidt Telescope at Palomar (near San Diego)

- We now scan 10% of the sky every 5 nights, finding a supernova every 10 minutes.

- We find ~1000 supernovae per year that are tracked by a network of telescopes for photometry and spectroscopy… typing..

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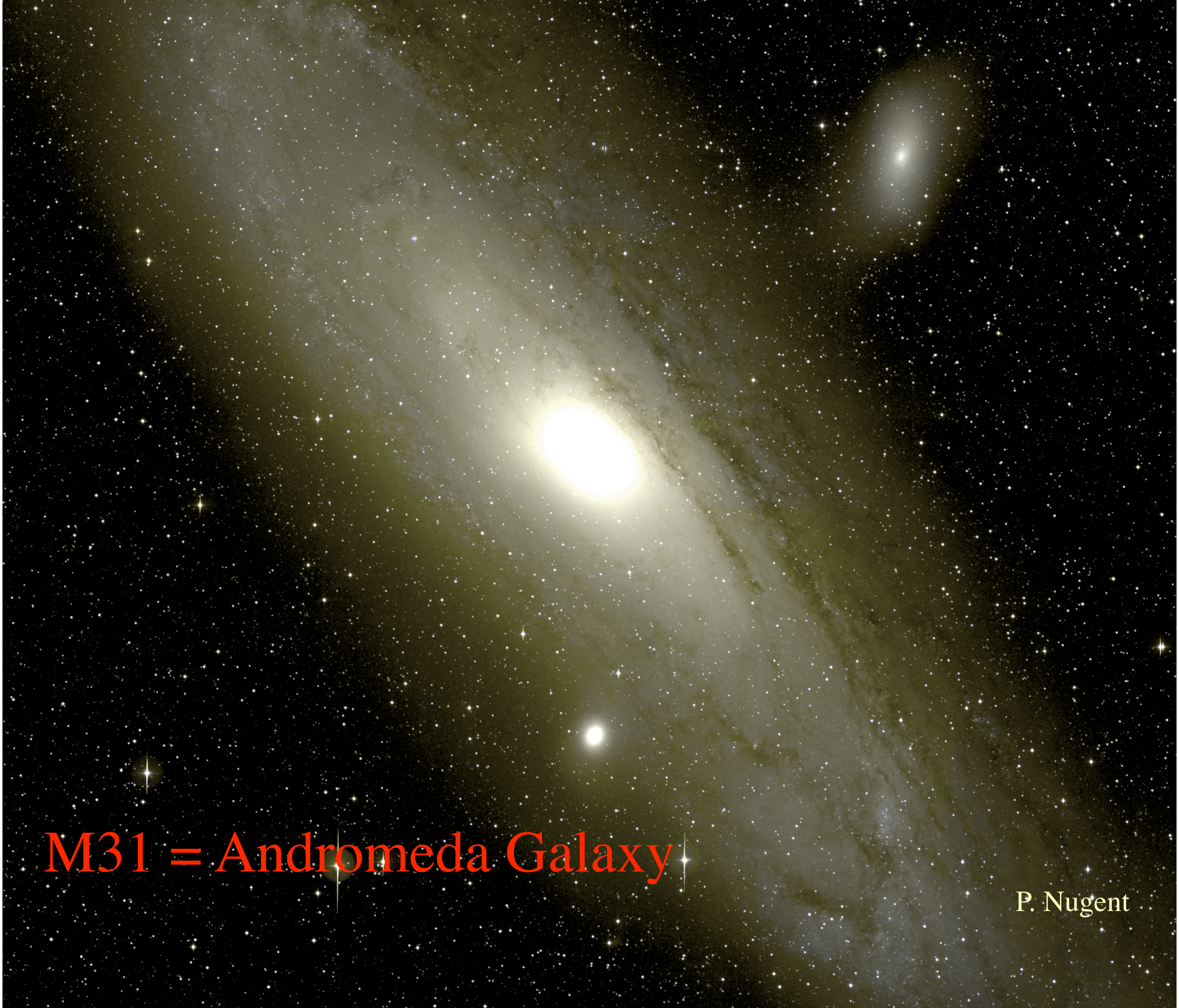
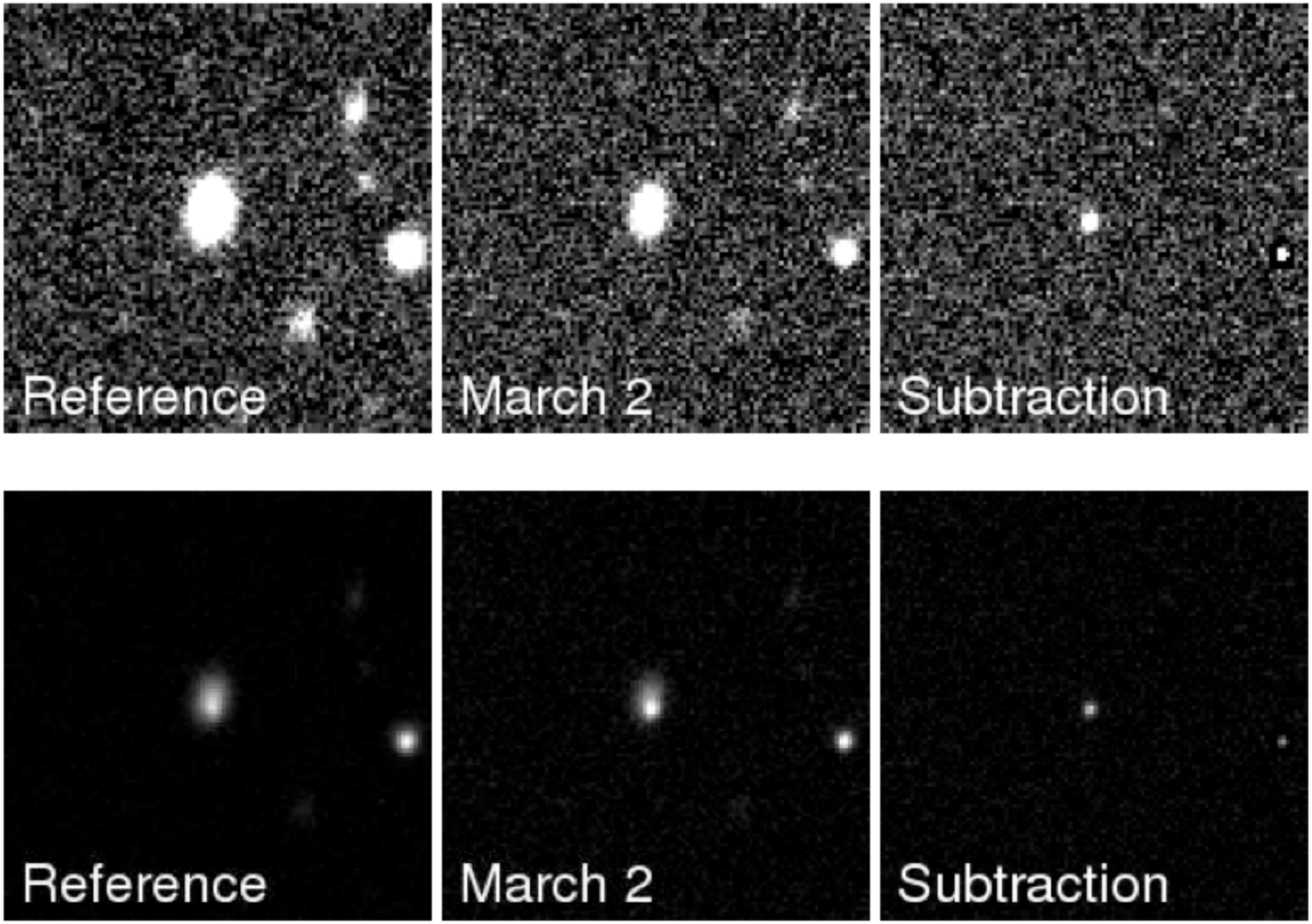
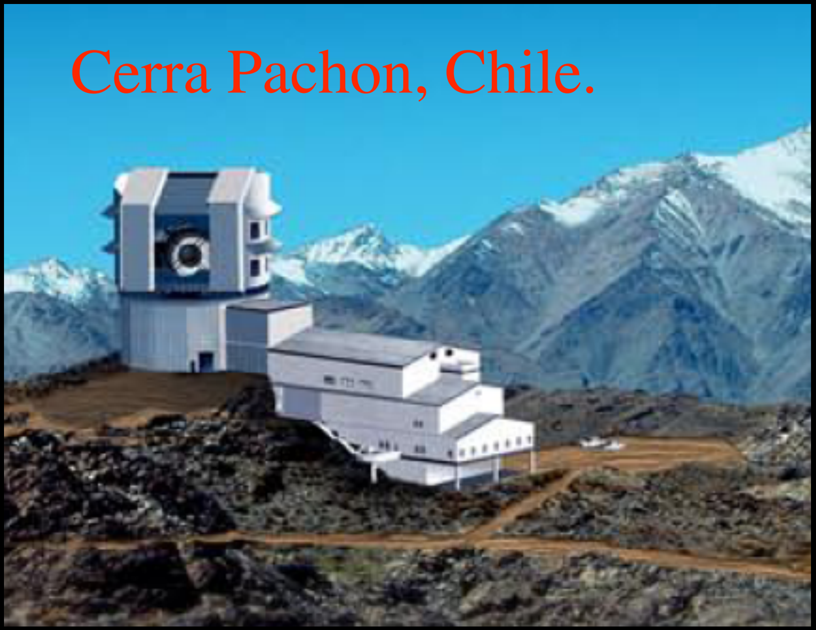

M31 = Andromeda Galaxy
P. Nugent

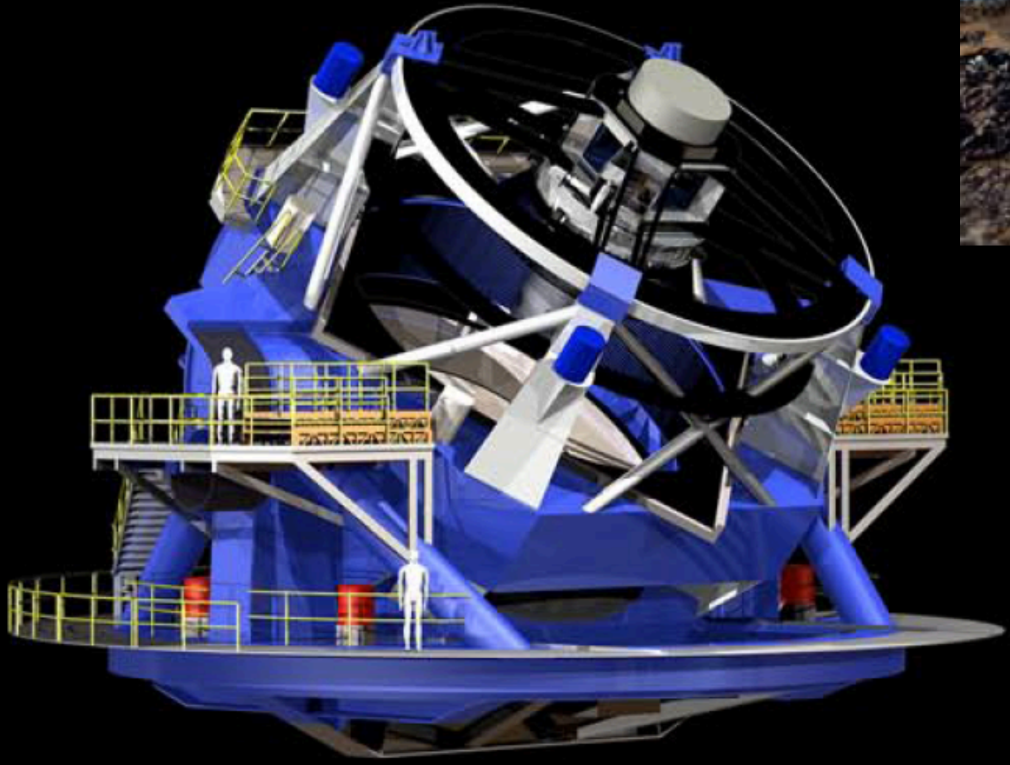
SN2009av – The First PTF Transient Discovery



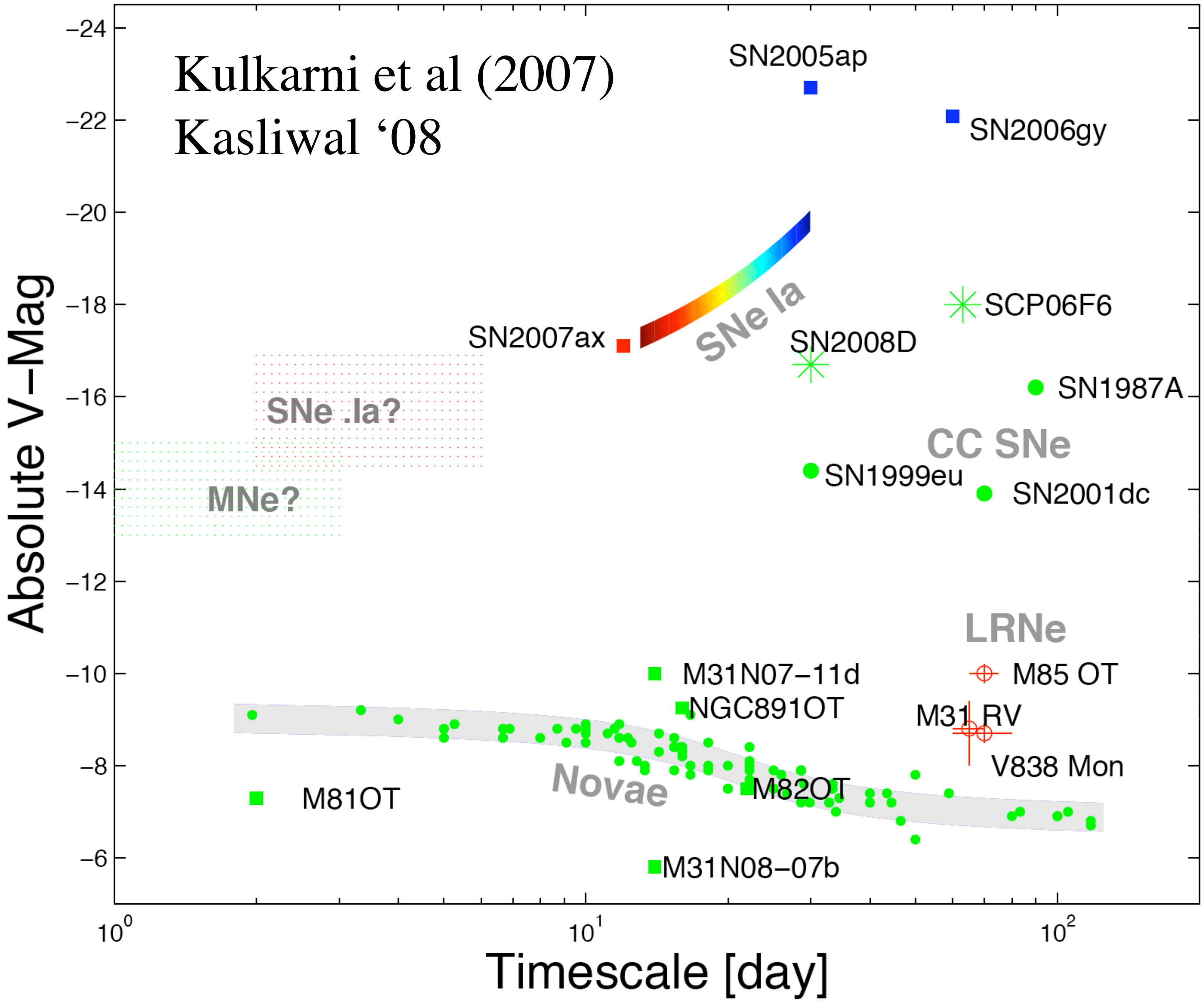
A type Ia supernova caught 8 days before maximum light in a redshift z=0.055 host galaxy

Large Synoptic Survey Telescope (LSST) is a proposed 8.4-meter, 10 deg^2 telescope that will provide V=24 imaging across the entire visible sky over a few nights.





Supernovae and Transients



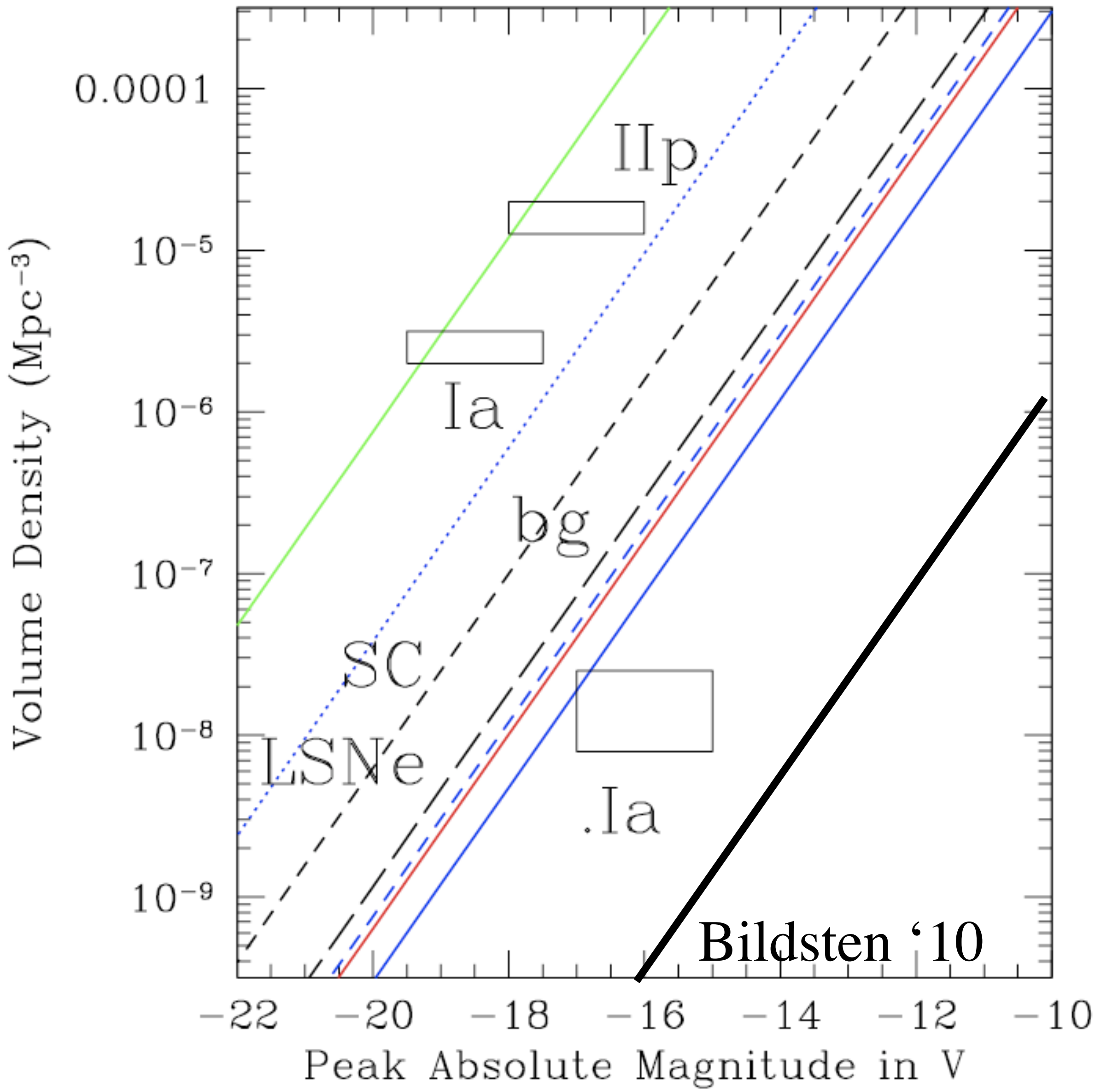
Three Things Matter

- Fraction of the sky that is 'monitored'
  - All sky is 40,000 deg^2, but, of course, not all of the sky is available every night..
- "Depth" of survey.
  - One magnitude is a factor of 2 in brightness, $2^{1/2}$ in distance, $2^{3/2}$ in volume.
- Cadence (frequency of looks) helps to find and followup on 'fast' trending objects, but many last longer than the cadence and are not missed!

Rough Survey Parameters

Survey	SNLS	SDSS	TSS	SKY	PTF	PS1	DES	LSST
Depth	24.3	22.5	18	19	20.5 R	24	25R	24
Omega	4	260	200	1000	2700	50	15	30000
Cad (d)	3	2	1	3-4	5	4	5	3-4
Year	03-08	05-08	now	10-?	now	now	11-	?
z at -18	0.7	0.3	0.04	0.06	0.15	0.6	0.6	0.6

Survey Volumes and Expectations



- The boxes plot the volume rate * duration for Type Ia (30 d), Type IIp (100 d) and .Ia (5 d)
- Densities rough for LSNe, 'Super-Chandra' and Faint Ia (bg)
- Lines show the 1 event per "exposure" line for
  - ROTSE (green)
  - SKYM (blue-dotted)
  - SNLS (dashed)
  - SDSS (long-dashed)
  - PS1 (blue-dashed)
  - PTF (blue-solid)
  - DES (red)
  - LSST (heavy-black)

What to do with 1000 Supernovae??

- Value of luminosity functions for all Sne
  - Nickel mass and total mass distributions for Ia
  - Energies and ejected masses for IIp
  - Faint and Bright Fractions of each/every class
- Probe the Physics of rise times
- Find a few VERY NEARBY events.
- Rates as a function of each galaxy type (delay time distributions)
- Find a FEW of the new ‘odd’ ones.. Something I will emphasize in the next two lectures

End of Lecture Two