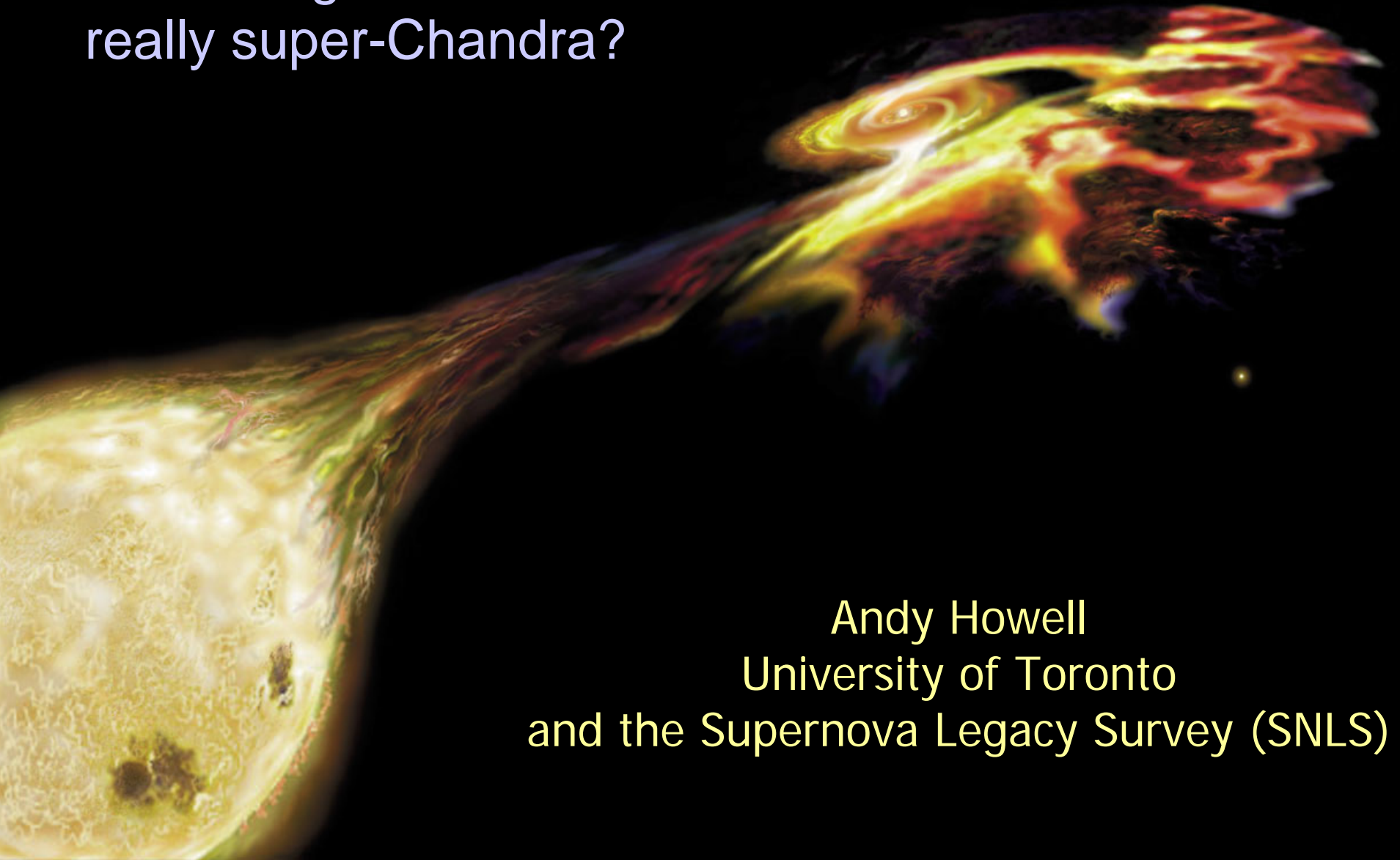


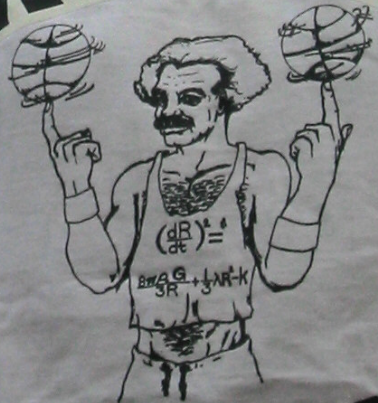
Is the brightest SN Ia
really super-Chandra?



Andy Howell
University of Toronto
and the Supernova Legacy Survey (SNLS)



ROCHE



LOBE TROTTERS

The Chandrasekhar limit



Theoretically a white dwarf should not exceed 1.4 solar masses (the Chandrasekhar limit)

Limit of electron degeneracy pressure (Pauli exclusion principle – can't pack electrons any tighter)

1.4 solar masses for the nonrotating case





Host

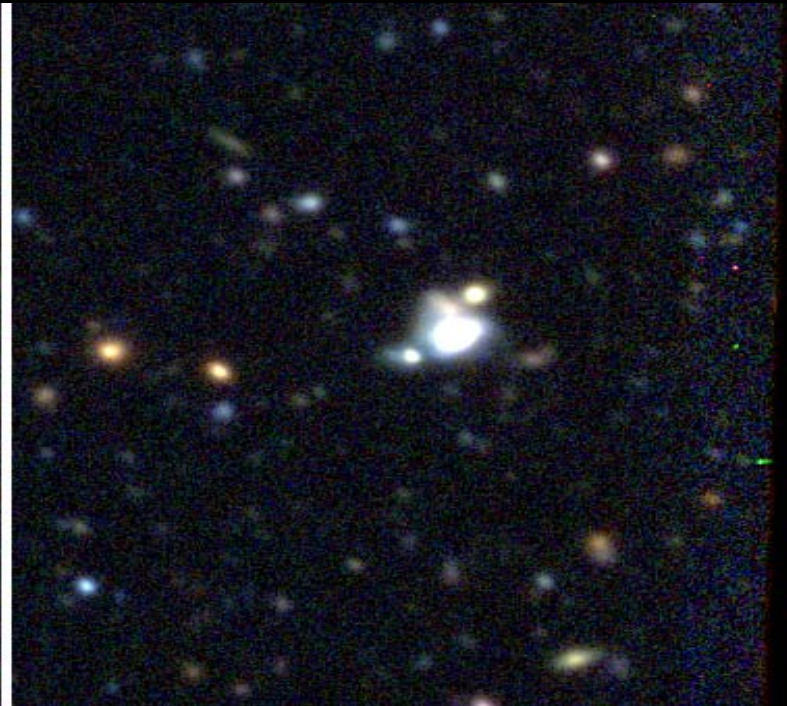
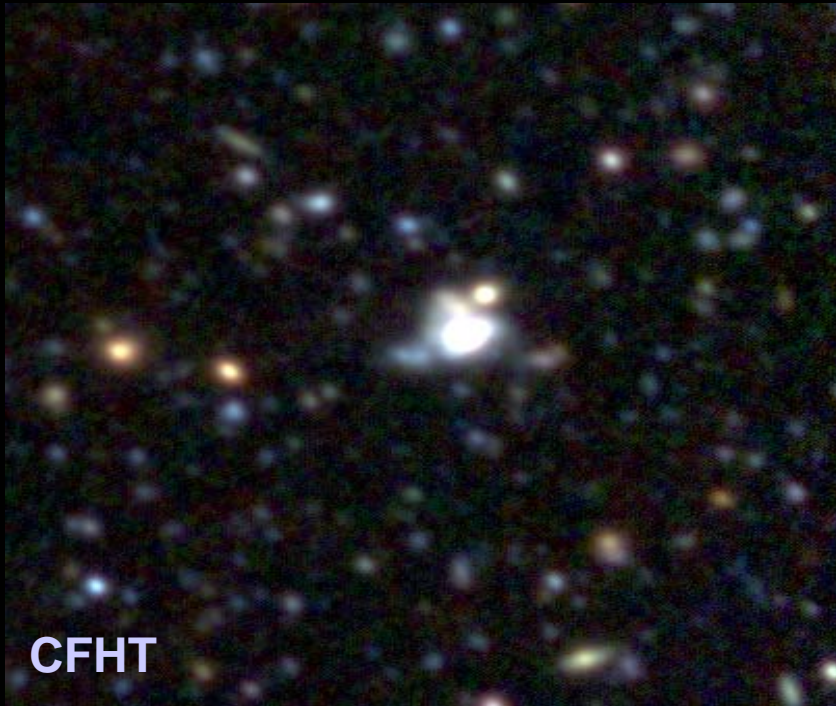
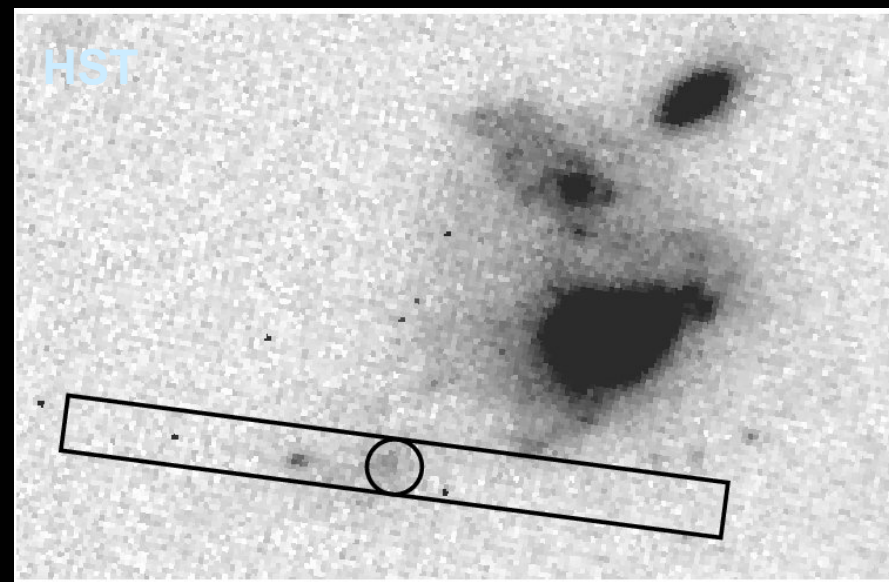
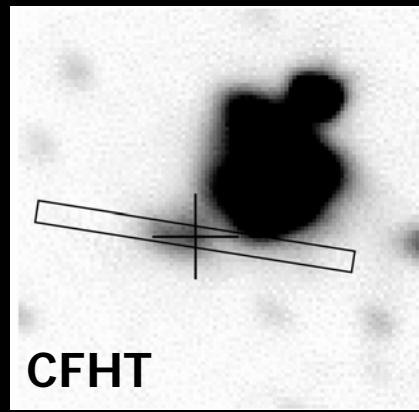
$z = 0.2440$

From PEGASE 2
fits to host ugriz
photometry:

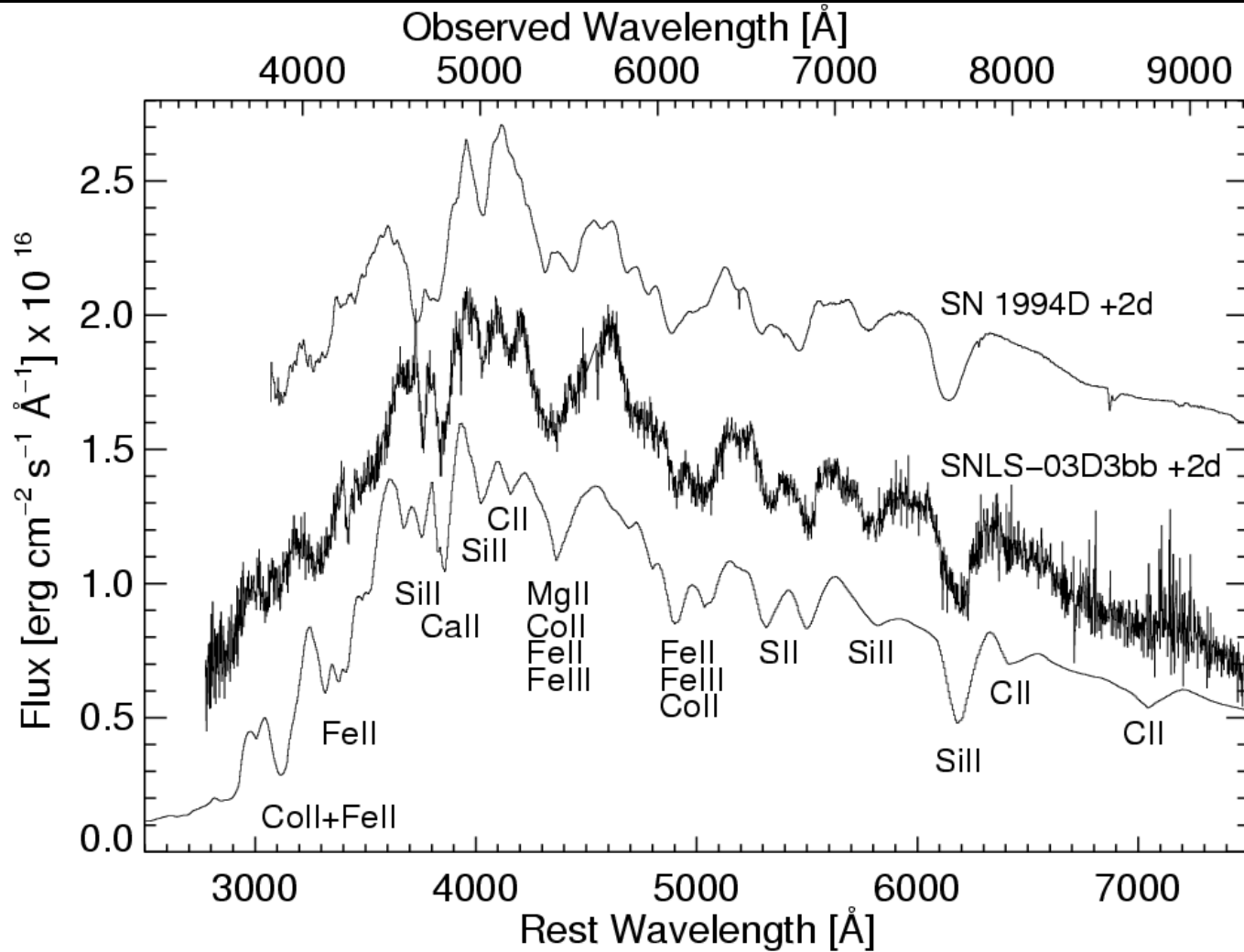
$$\log M_{gal} = 8.93^{+0.81}_{-0.50}$$

$$SFR = 1.26^{+0.02}_{-1} M_{\odot} \text{ yr}^{-1}$$

→ Formally implies host age of 0.7 Gyr, though highly uncertain



Keck + 2d spectrum



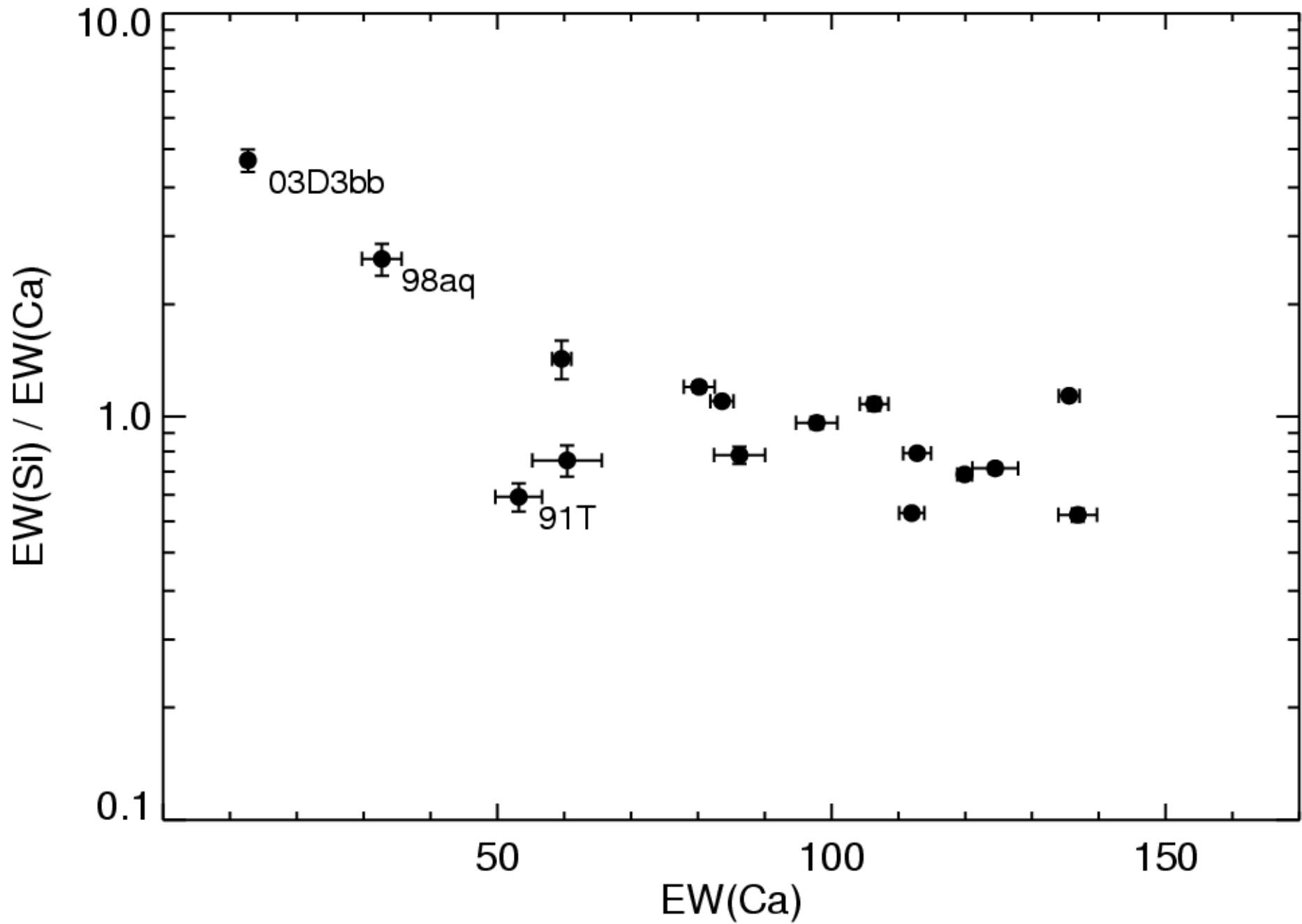
Type Ia

Not like SN 1991T

Low velocities

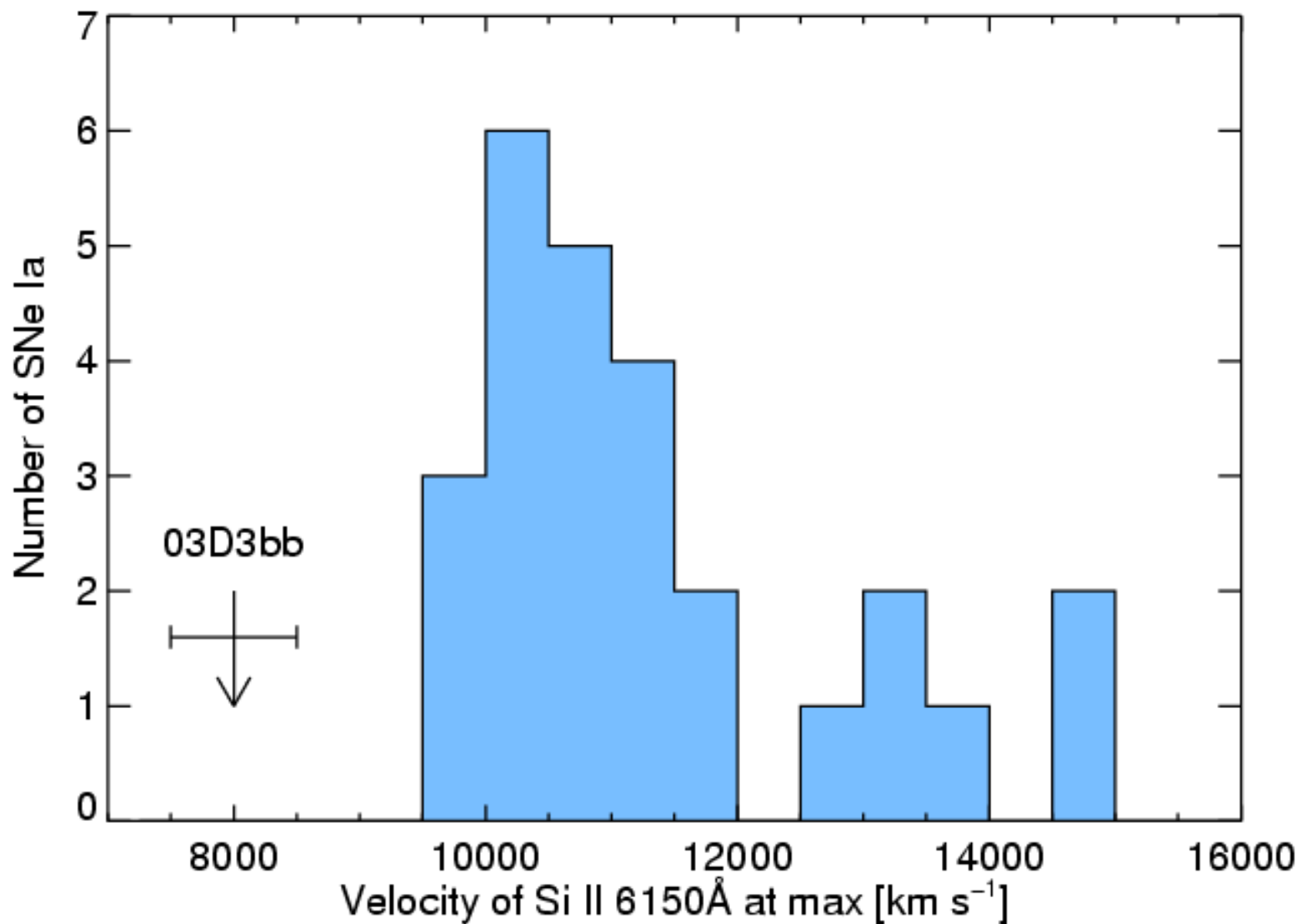
Little Ca compared to S, Si

CII after max

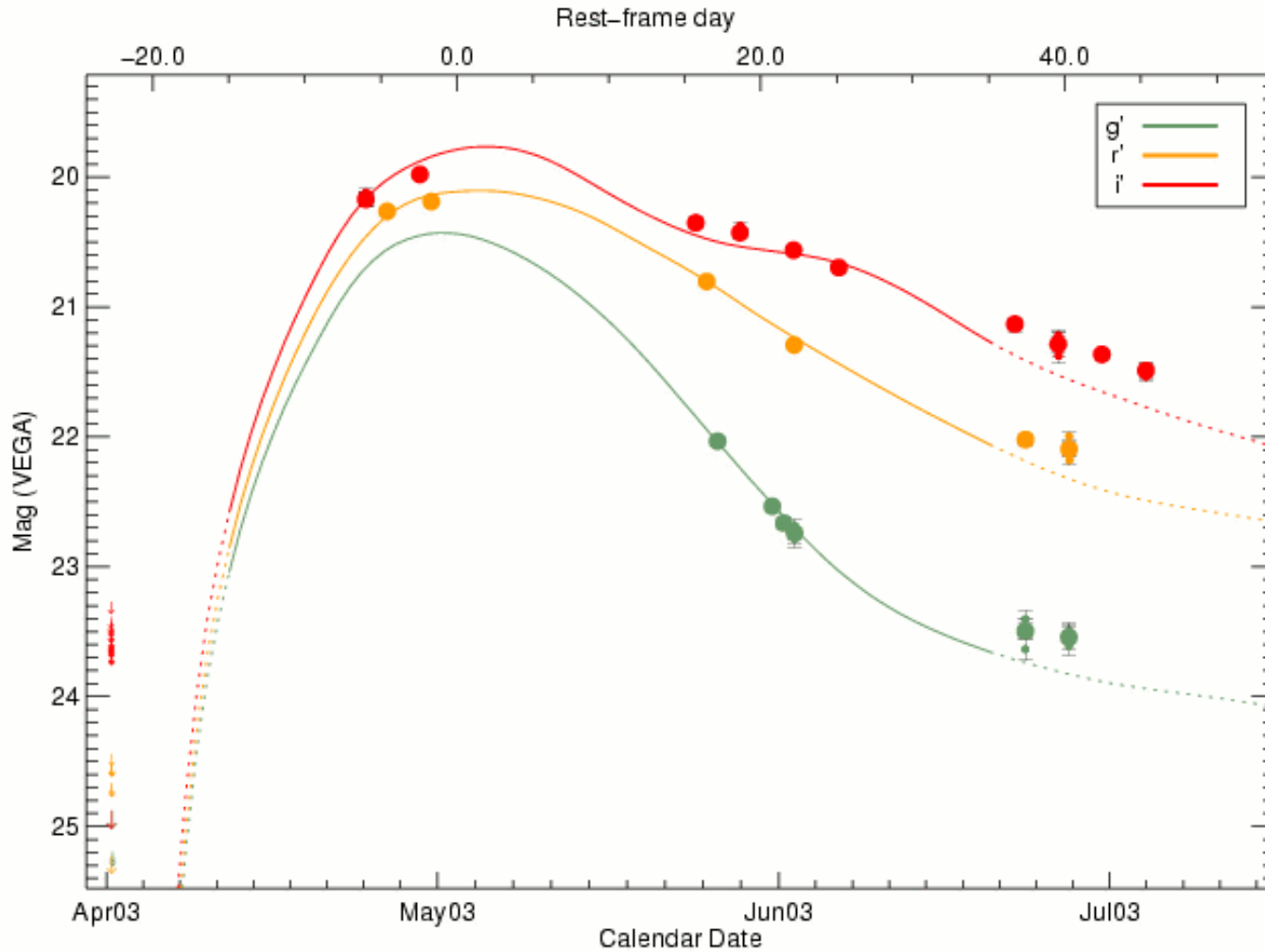


Si II velocity

Low-z data from Benetti et al. 2005



Lightcurve



$V = 20.5 \pm 0.06$

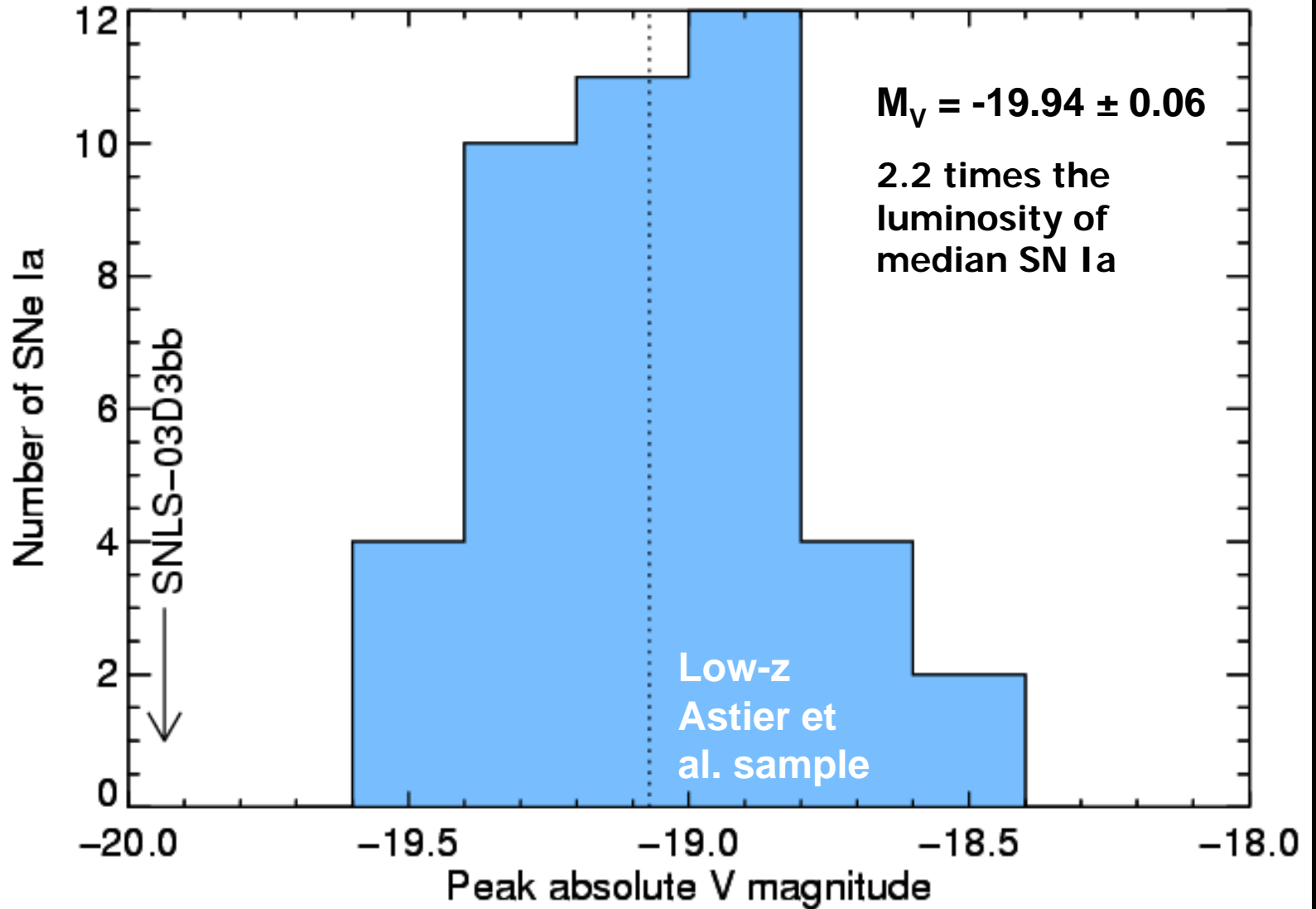
$M_V = -19.94 \pm 0.06$

Use only r, i fit

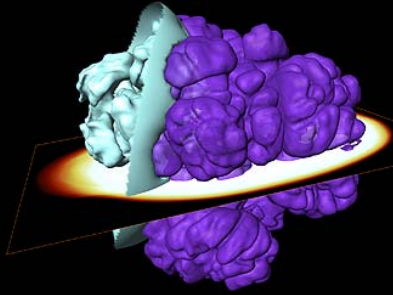
$s = 1.13$

Sparse LC
from early
days of survey

V magnitude distribution



SN Ia power source



Energy to unbind star (kinetic energy): Fusion

Carbon and Oxygen burn to Nuclear Statistical Equilibrium, producing Iron-peak elements (Ni, Co, Fe) in the densest regions.

In less dense regions burning stops at intermediate mass elements (S, Si, Mg, Ca).

Energy to power lightcurve:

$^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$ decay

Converted to nickels,

1SN = 12 nonillion dollars ($\$12 \times 10^{30}$)

\$14 nonillion Canadian



^{56}Ni mass

Arnett's rule: Luminosity at maximum is proportional to spontaneous energy deposition by radioactive decay.

$$M_{\text{Ni}} = \frac{L_{\text{bol}}}{\alpha \dot{S}(t_r)}$$

α : ratio of bolometric to radioactivity luminosities, near unity. Conservatively use 1.2 (Nugent et al. 1996)

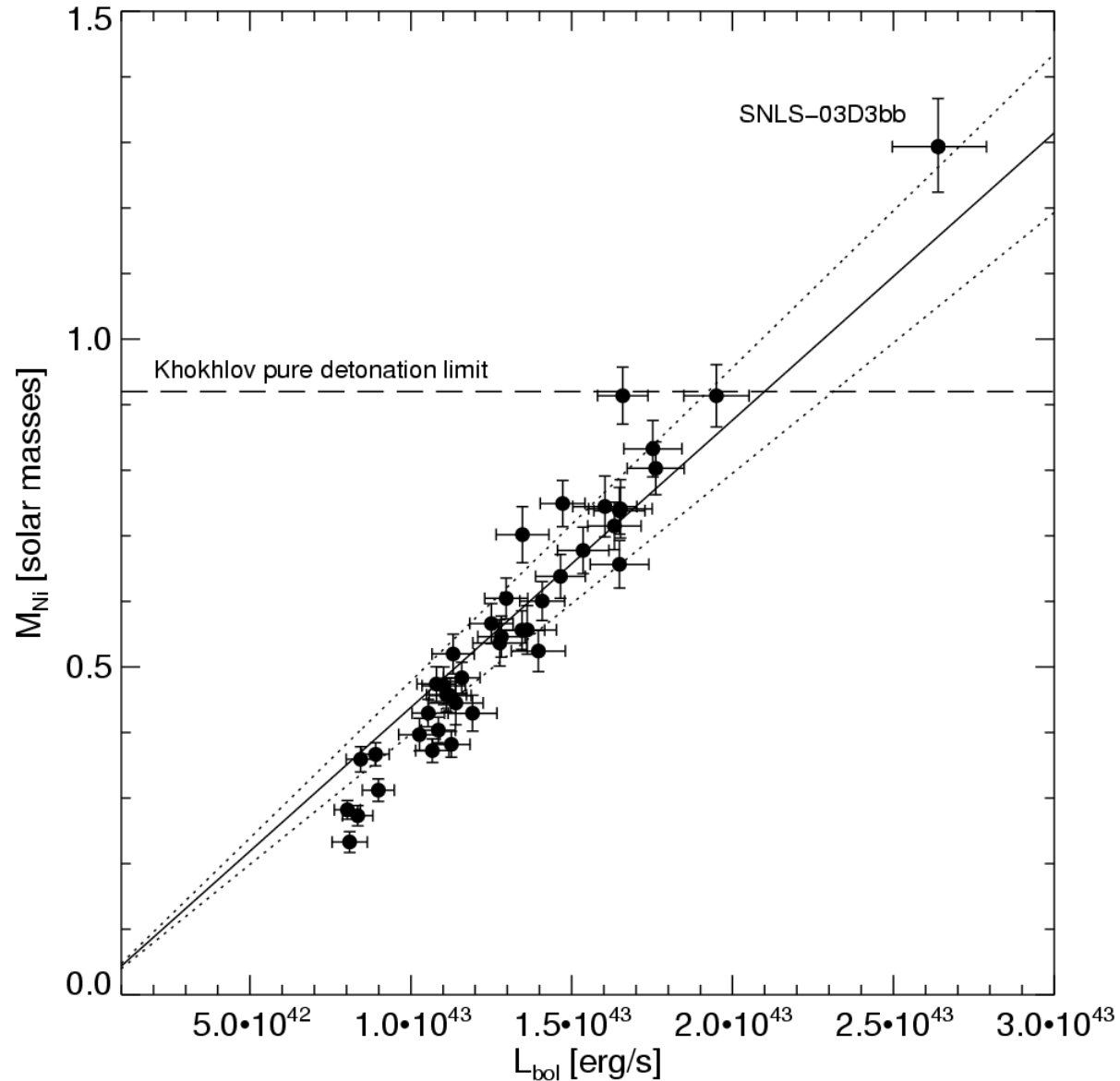
S : energy per second per solar mass from radioactive decay

$$\dot{S} = 6.31 \times 10^{43} e^{-t_r/8.8} \\ + 1.43 \times 10^{43} e^{-t_r/111}$$

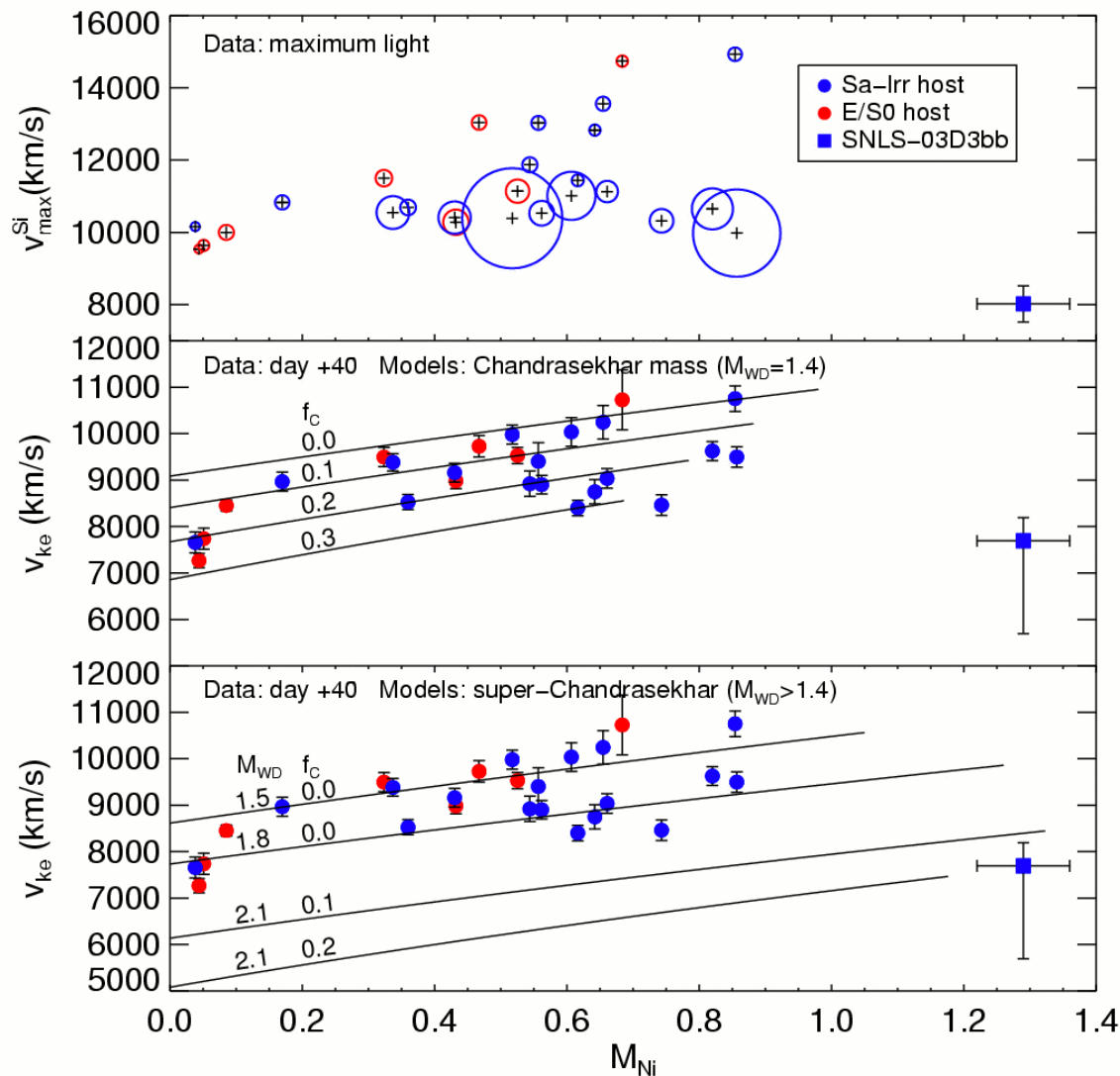
$$\rightarrow M_{\text{Ni}} = 1.29 \pm 0.07 M_{\odot}$$

If 40% is non- ^{56}Ni

$$\rightarrow M_{\text{WD}} \sim 2.1 M_{\odot}$$



Velocity from kinetic energy



KE is nuclear energy
minus binding energy

$$v_{ke} = \sqrt{\frac{2(E_n - E_b)}{M_{WD}}}$$

3 kinds of elements: Fe-peak,
IME, unburned C/O

Energy from burning to Fe peak:

$$E_{Fe} = 1.55 \times 10^{51} \text{ erg s}^{-1} M_{\odot}^{-1}$$

Burning to Si produces 76%
as much

$$E_n = E_{Fe} M_{WD} (f_{Fe} + 0.76 f_{IME})$$

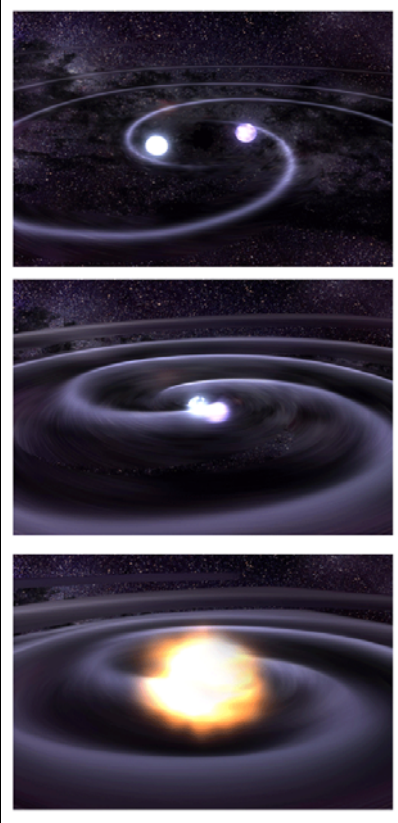
^{56}Ni is 70% of Fe-peak elements:

$$M_{Ni} = 0.7 M_{WD} f_{Fe}$$

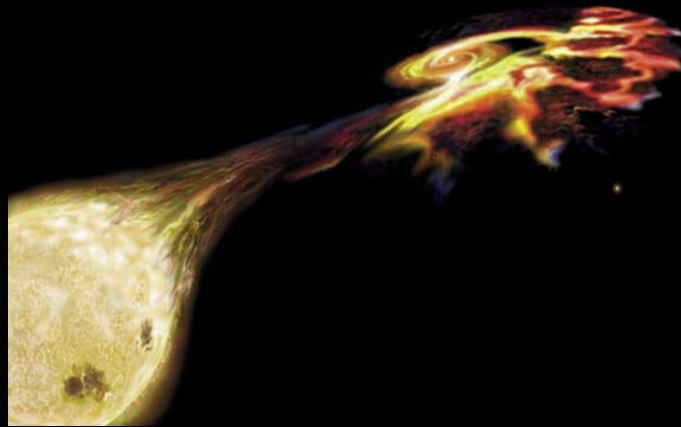
Binding energy (Yoon & Langer
2005)

- 1.4 M_{\odot} WD: 0.5e51 erg
- 2.0 M_{\odot} WD: 1.3e51 erg

Possible Explanations



- Double degenerate model: merger of two massive WDs can produce super-Chandra product.

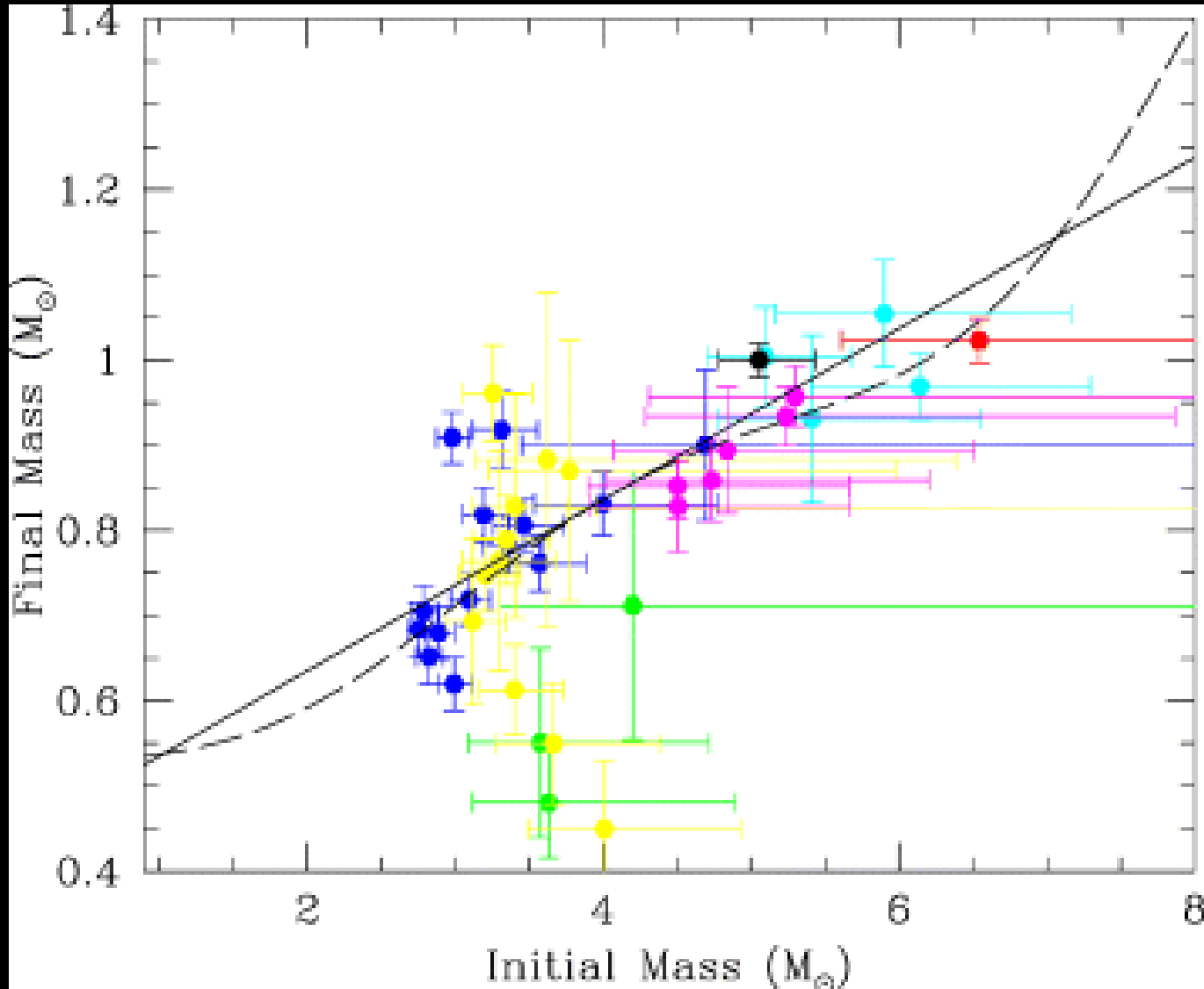


- Single degenerate model: rapid rotation could support 2 solar mass WD according to Yoon & Langer 2005. Requires differential rotation.

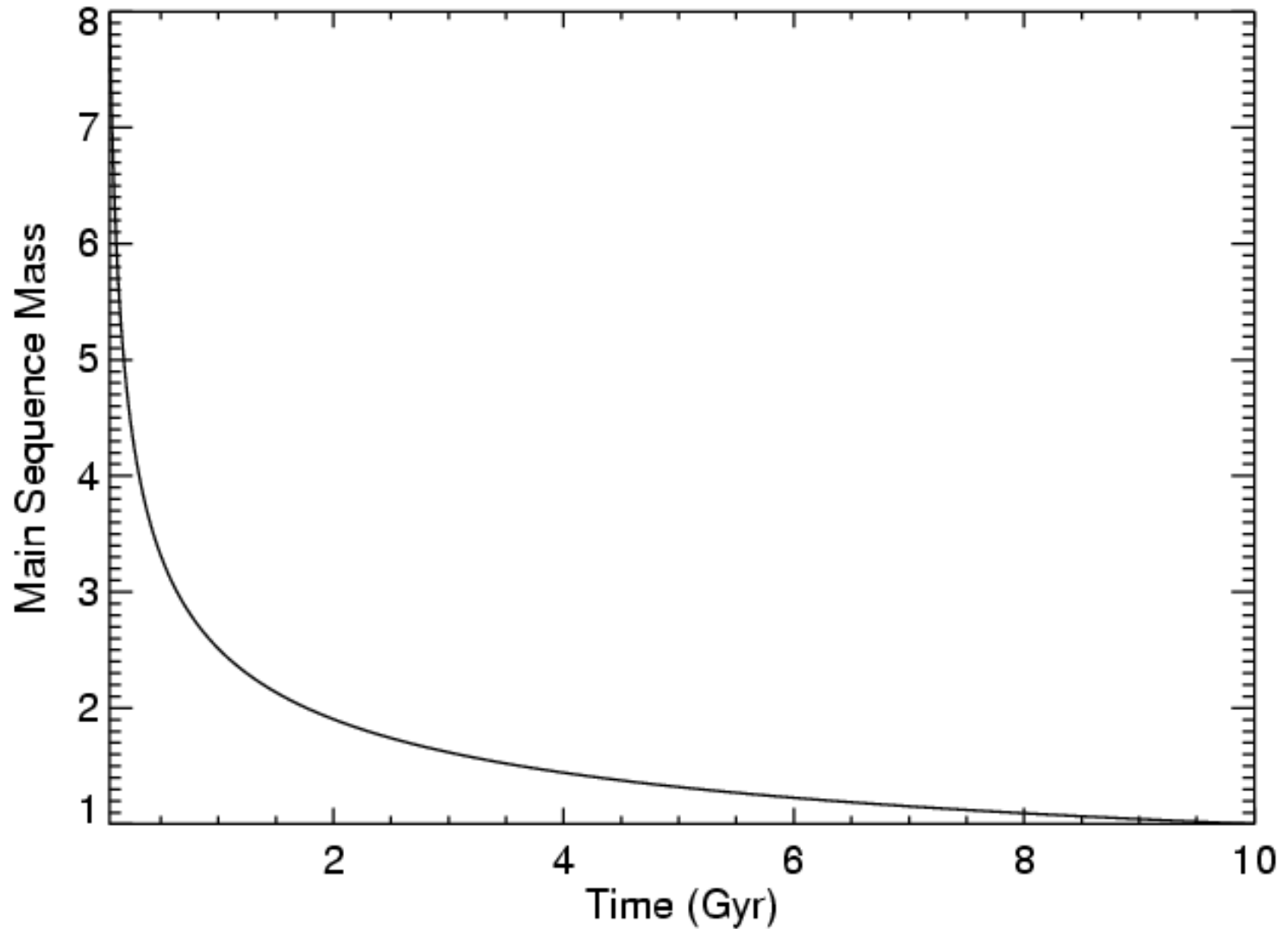
Common envelope merger: Livio & Riess (2003). WD merges with AGB star during common envelope phase.

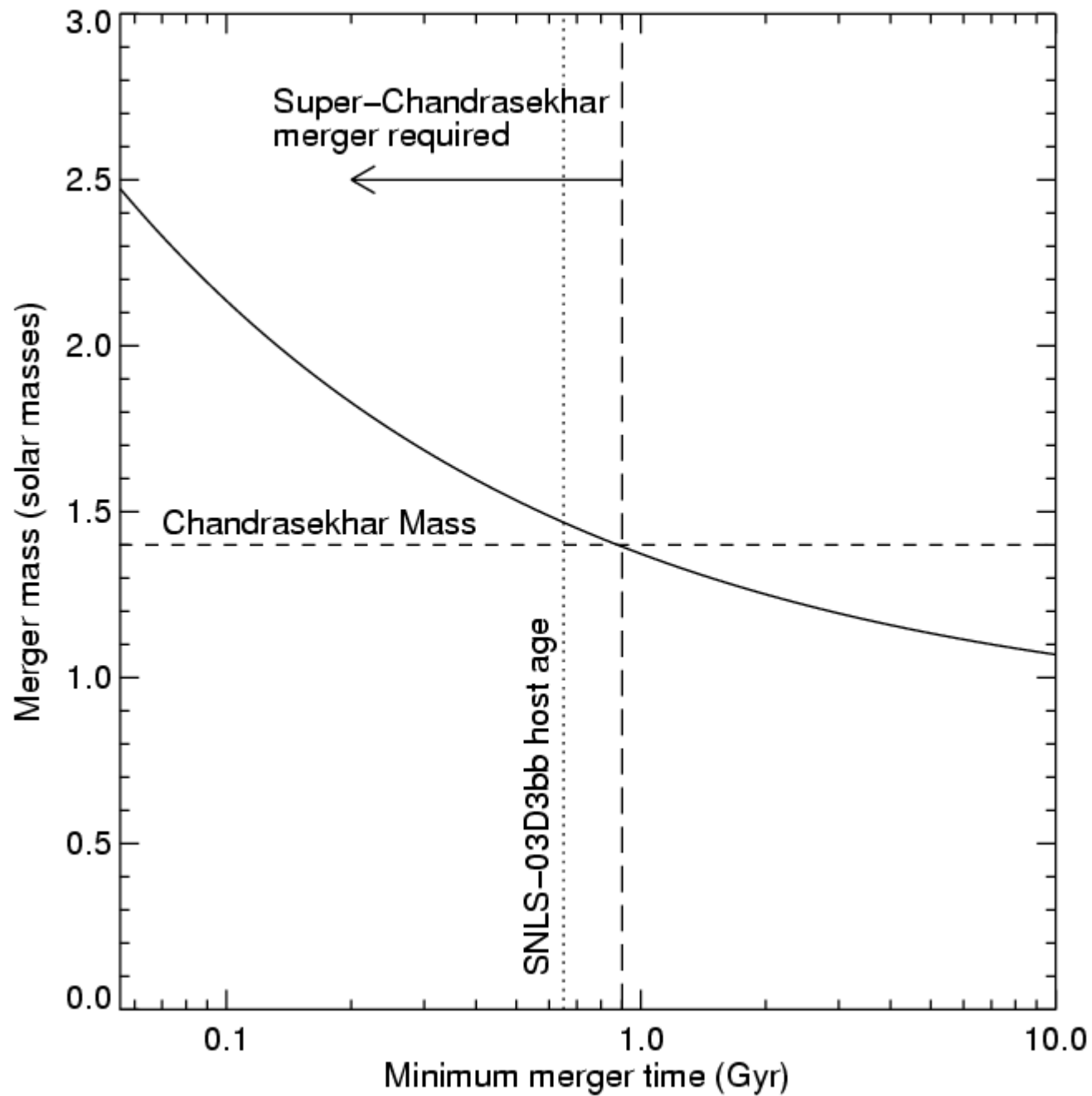
What mass WD does a star make?

Ferrario et al. 2005

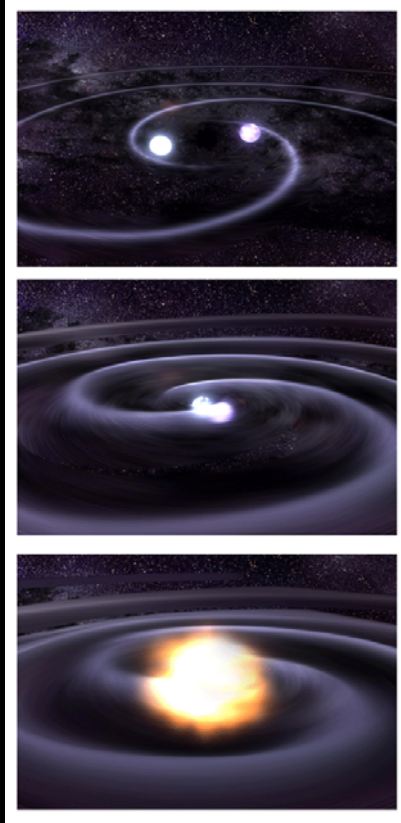


Time to evolve off main sequence

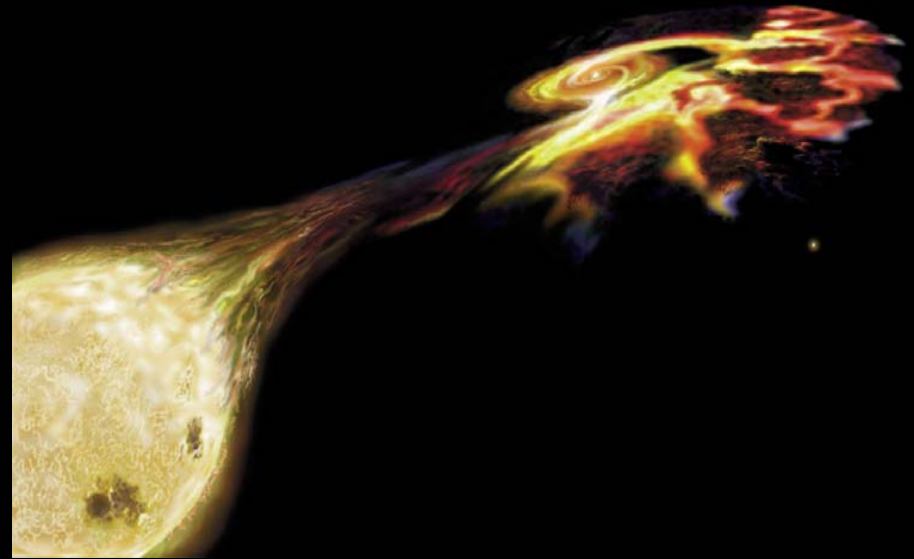




Population effects

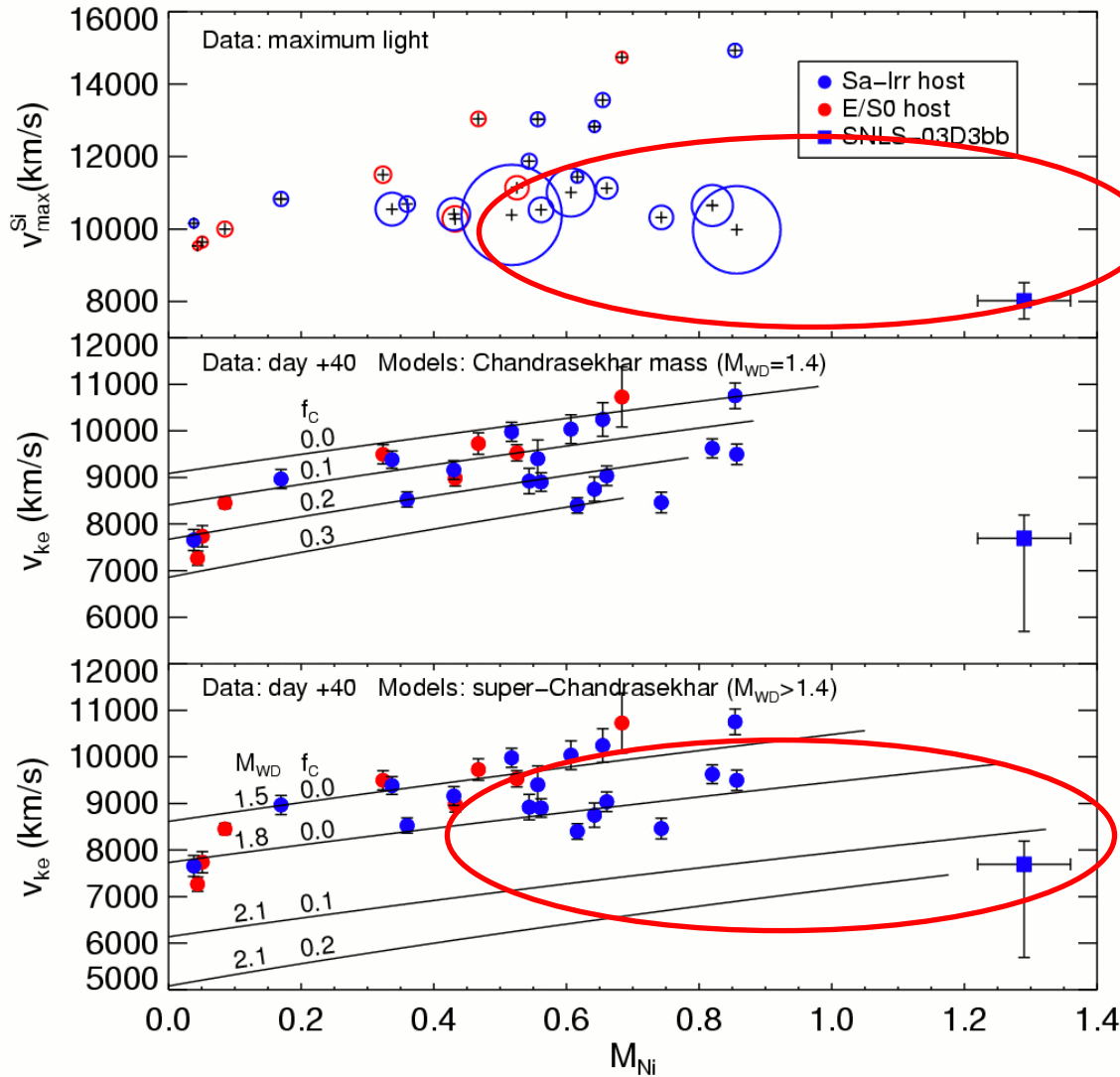


- Double degenerate model: In young population only massive WDs exist – before 0.9 Gyr merger must be super-Chandra.



- Single degenerate model: In young pop, massive WDs, massive stars exist → easier to get super-Chandra.

How rare?



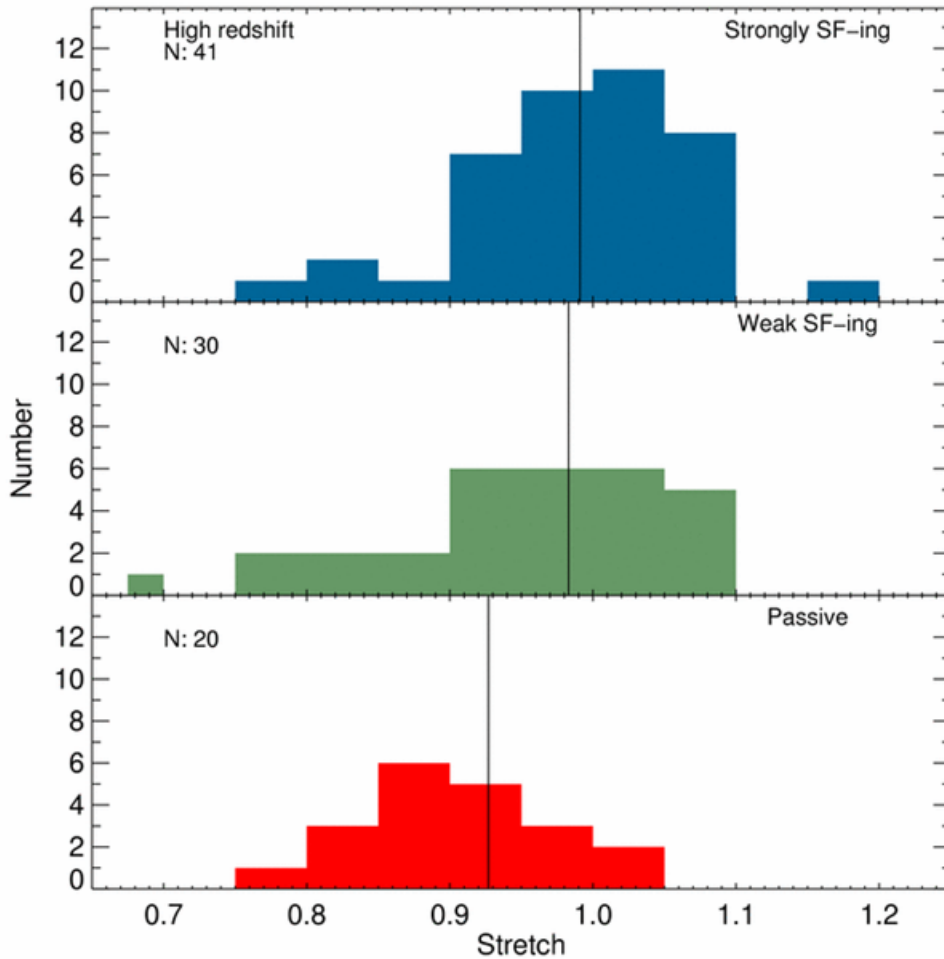
Population of SNe Ia that are bright, low velocity, spiral hosts

Related to SNLS-03D3bb?

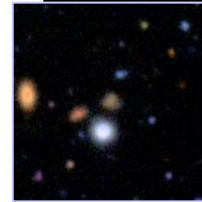
Super-Chandra, but lower level?

SN properties as a function of SFR

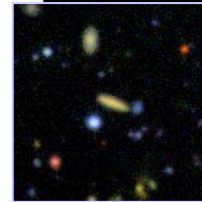
Sullivan et al. 2006.



Younger environments produce brighter SNe (Sullivan et al. 2006, Howell et al. 2001, Hamuy et al. 1996)



Explanation unknown in Chandra model



Expected in super-Chandra model



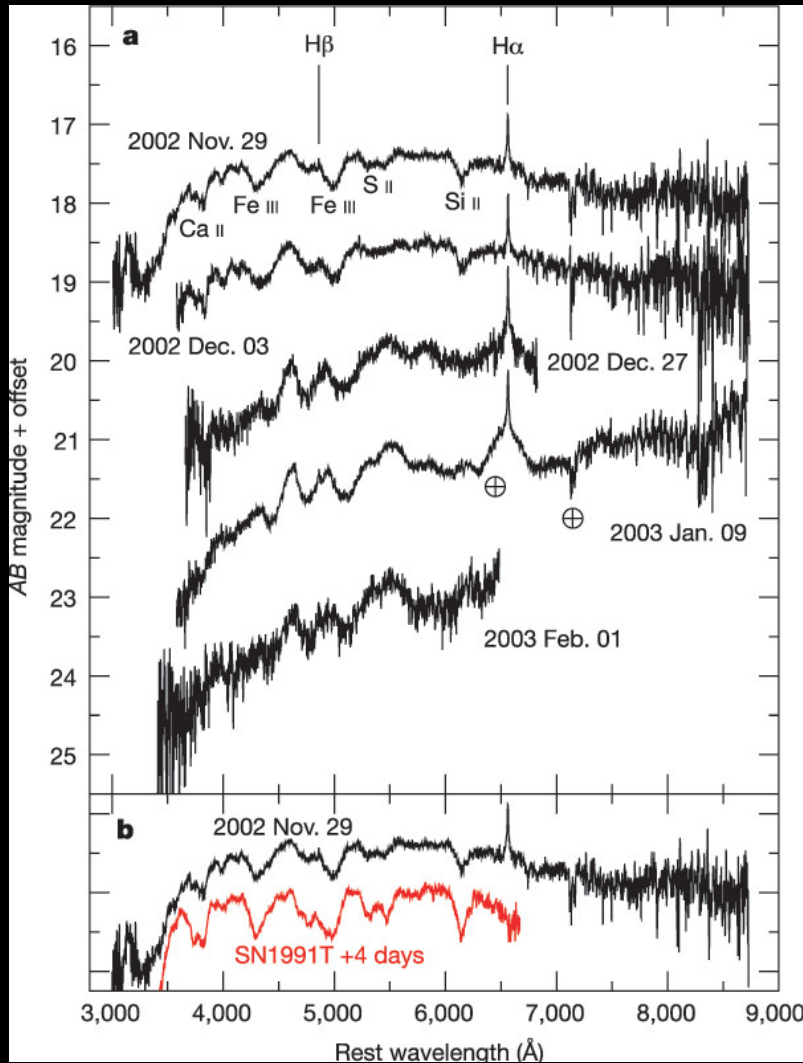
Alternatives

Interaction

Asphericity

Extreme departures from Arnett's rule

Interaction

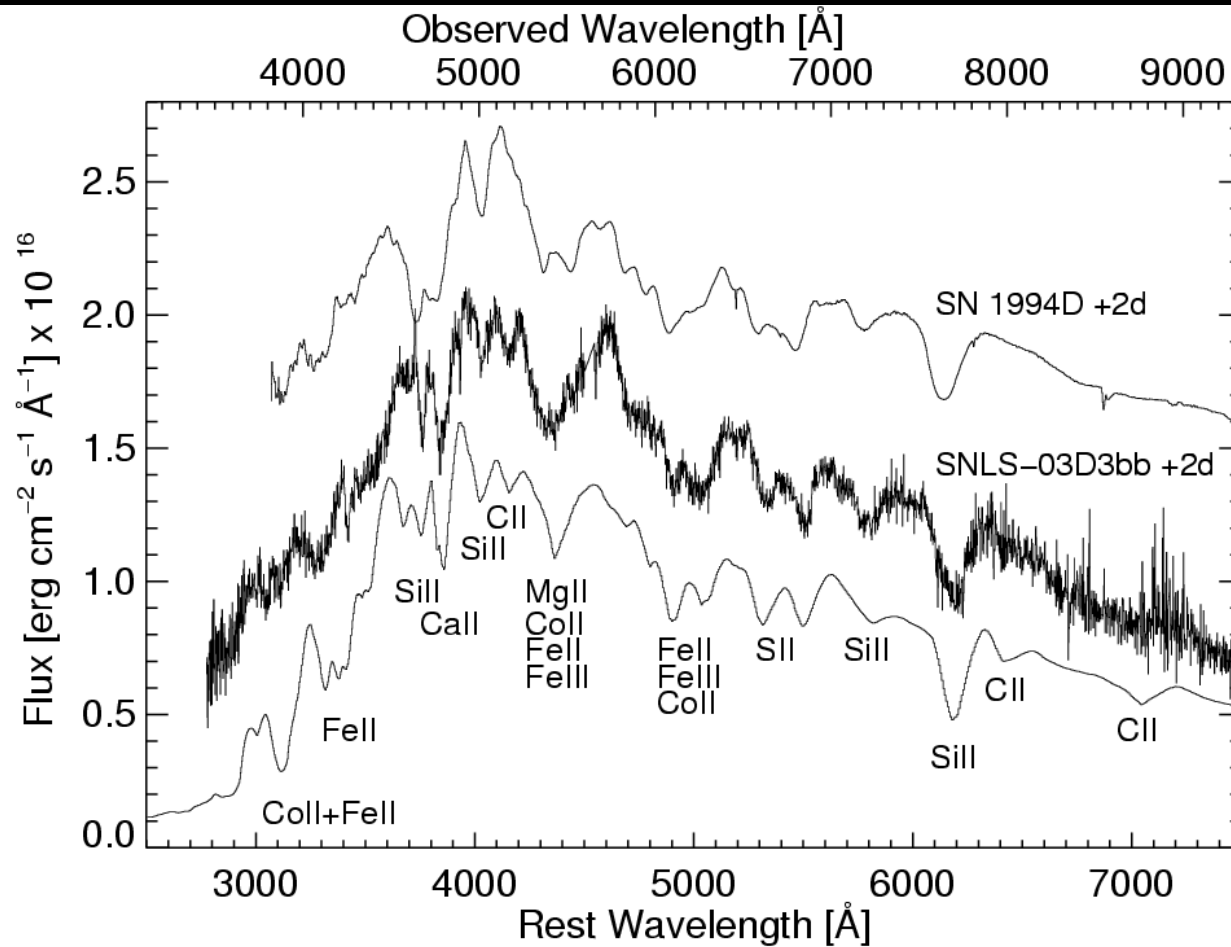


SN 2002ic was about as luminous as SNLS-03D3bb, but because of interaction with CSM

Features like 1991T, but diluted from continuum

Narrow Hydrogen

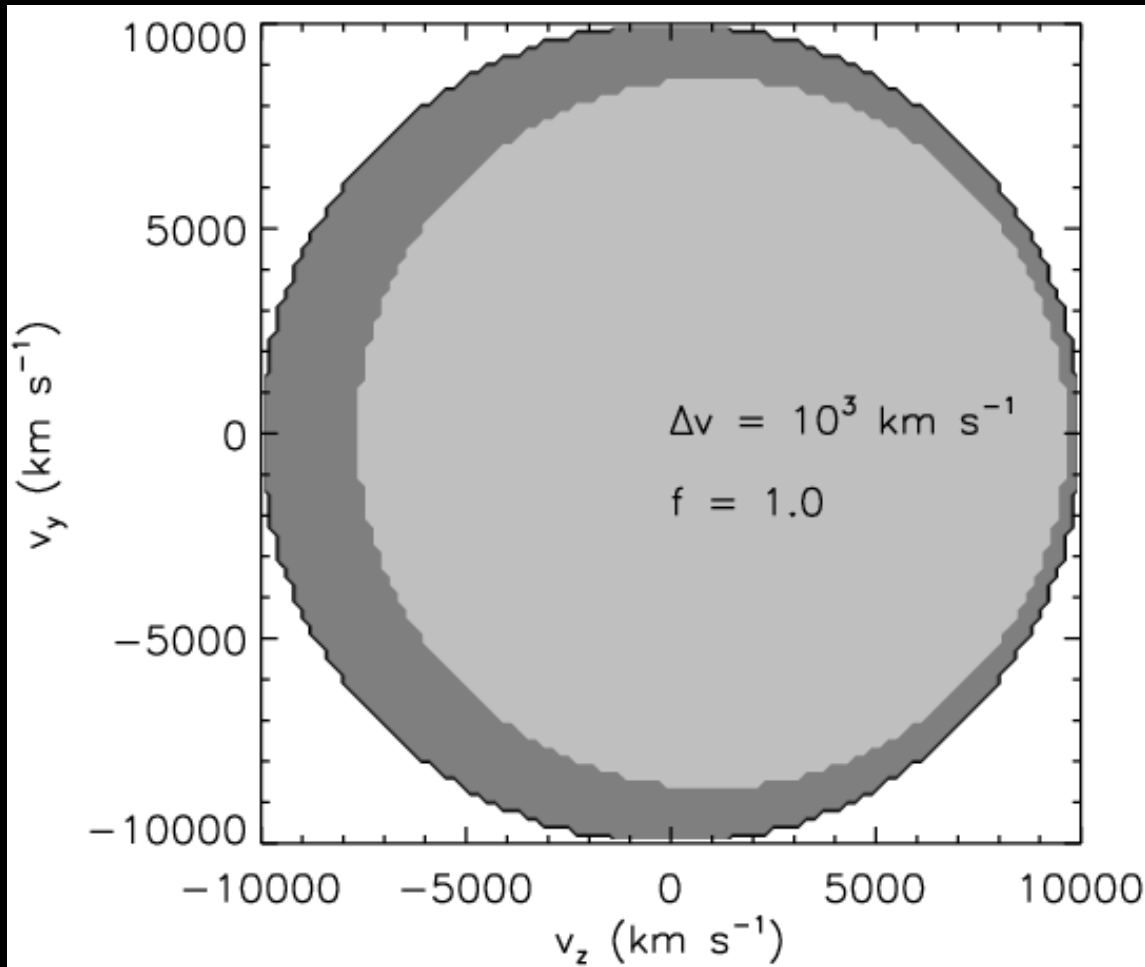
SNLS-03D3bb – no evidence for interaction



Need as much or more interaction as SN 2002ic, yet none seen

Does not explain velocity, other oddities in spectrum

Asphericity: off-center Ni blob



Hillebrandt, Sim, &
Röpke, astro-ph 0702344

Not a simulation.

Arbitrary velocity shift of
 $0.89 M_{\odot}$ of ^{56}Ni

Can reproduce L for
preferred viewing angle

Requires extreme opacity:
cross section of 0.1 cm^2
 g^{-1}

Does not reproduce
spectrum or velocity

Asphericity

SNe this extreme are rare – 1 in $\sim >300$

→ small solid angle for increased luminosity

Can't be achieved by normal clumps, need jet or beam?

Jet or beam would have increased, not decreased velocities

Does not explain why brighter SNe Ia are found in young populations

Extreme departures from Arnett

Assumption that energy from decay equals luminosity at max (Arnett's rule) thought to be good to ~20% (Leibundgut talk, Jeffery et al. 2007, Höflich & Khokhlov 1996, Branch 1992).

Must be wrong by 70% to get $M_{\text{Ni}}=0.9$

We conservatively assume it is wrong by 20% ($\alpha=1.2$) to get $M_{\text{Ni}}=1.3$; $\alpha=1$ gives $M_{\text{Ni}}=1.6$

Large amounts of Ni will decrease α , since some gamma rays escape

Conclusions

- $M_V = -19.94 \pm 0.06$, brightest SN Ia ever observed, Arnett's law implies $\sim 1.3 M_{\odot} {}^{56}\text{Ni}$.
- If $\sim 40\%$ of elements are non- ${}^{56}\text{Ni}$, $M_{\text{WD}} \sim 2.1 M_{\odot}$
- Low velocity *opposite* of expectation from Chandra model, but consistent with super-Chandra
- Young population consistent with super-Chandra.
- Spectrum has more IMEs than SN 1991T
- CII near maximum implies the presence of unburned material deep in the SN. Explosion could have been more efficient.
- ➔ Meets every expectation of super-Chandra model. Simplest explanation.

- SNLS-03D3bb does not follow stretch-luminosity relationship (it is too bright by 4.4 sigma).
- SNLS-03D3bb was thrown out of Astier et al. (2006), but less extreme examples could be in data set.
- Is this SN an oddball or the tip of the iceberg – grad student Bryce Croll investigating.