The X-ray Lightcurves of Young Supernovae, and Implications for the Supernova Progenitors

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Massive stars - SN Progenitors (Older View?)

- Cool Massive Stars (Red Supergiants): Single stars ~ (8)11-30(?) initial mass end their life as Red Supergiants, becoming Type IIP SNe.
- These have dense, low velocity winds (~ 10-50 km/s, 10^{-7}-10^{-4} solar masses/yr).
- Single Massive stars (solar metallicity) > above 30-35 solar masses may explode as Wolf-Rayet stars, forming 1b/c SNe
- These have fast, dense winds (1000-3000 km/s, 10^{-7} to 5×10^{-5} solar masses/yr).
- SN 1987A, had a blue supergiant progenitor, with a wind velocity in the range of 500 km/s, and mass-loss rate < 10^{-8} solar masses/yr

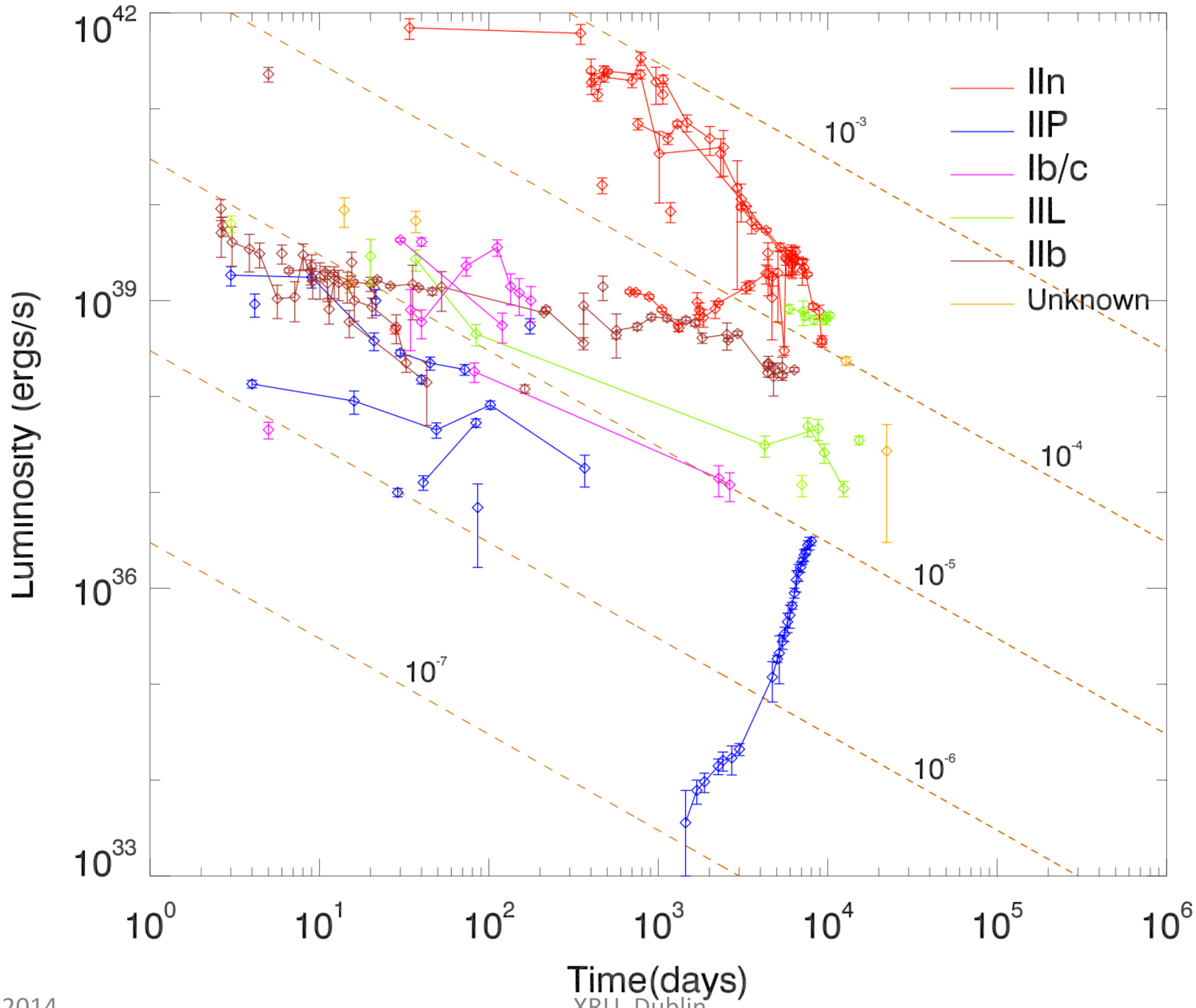
Environments of Massive Stars

- Chevalier (1982) model: X-rays are thermal.
- X-ray emission probes ambient medium.
- Thermal bremsstrahlung ~ ρ_w^2.
- The crucial ingredient is the ambient medium density, which depends on wind velocity and wind mass-loss rate as

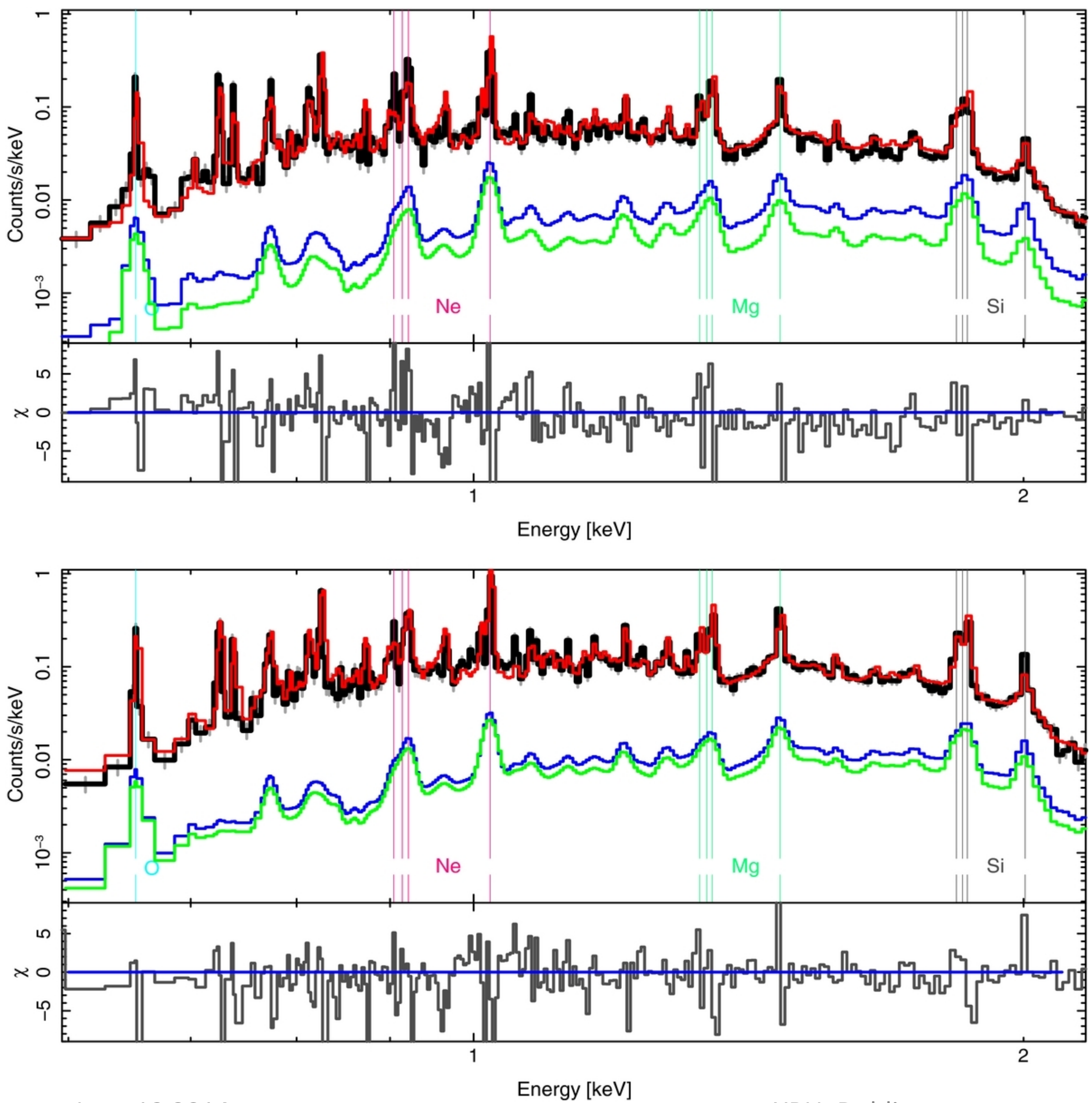
$$\rho_{wind} \propto \frac{\dot{M}}{v_w}$$

- For RSG stars, v_w is low (20 km/s), for W-R stars v_w is ~2000 km/s.
- ⇒ Density much higher around RSG stars.

X-Ray Lightcurves of SNe



D. Dewey et al. 2012 ApJ 752 103 doi:10.1088/0004-637X/752/2/103

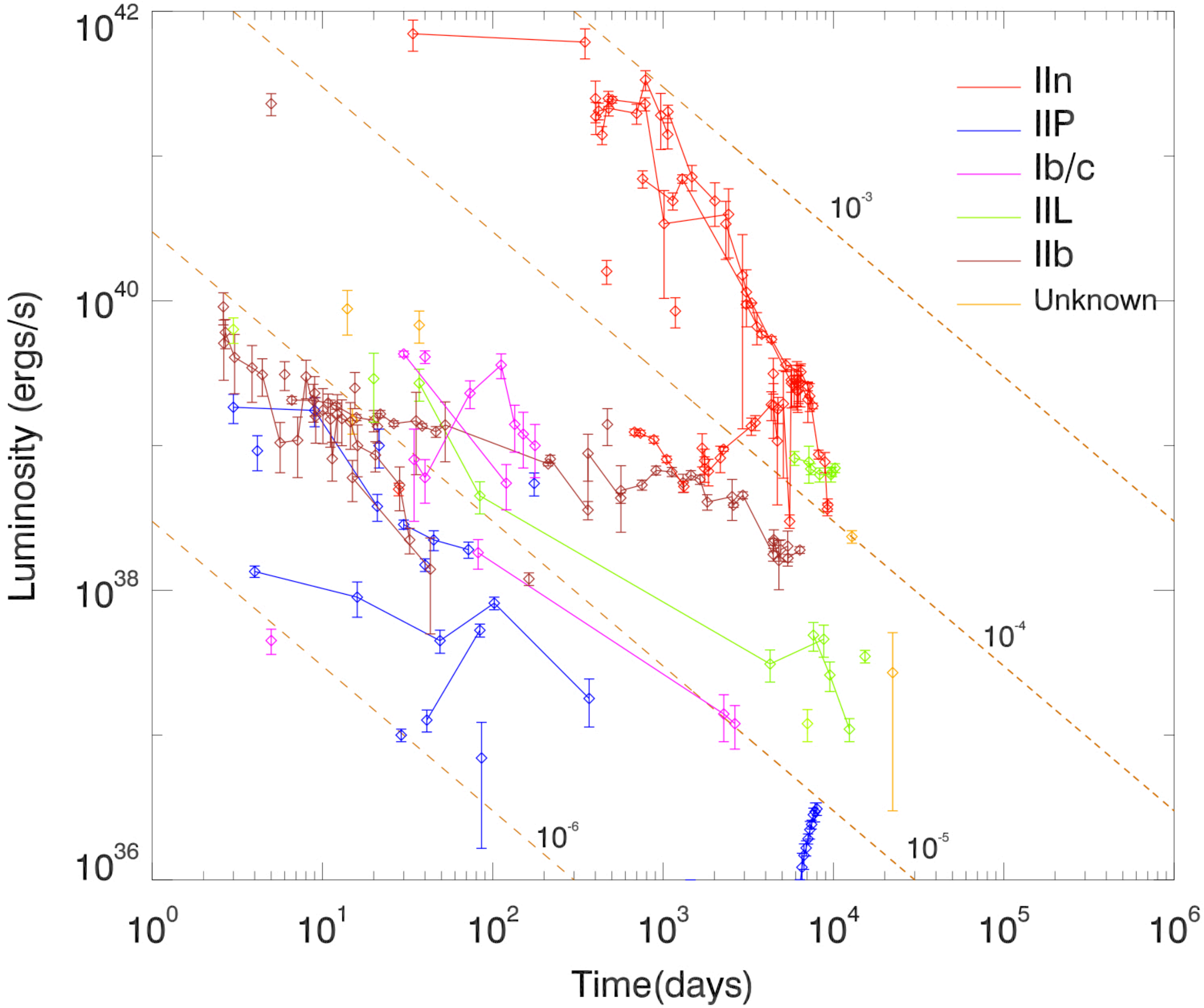


HETG(MEG) spectra and full hydrodynamics-based models. The HETG-07 (top) and HETG-11 (bottom) data (black) are reasonably fit by the total (HII plus nominal clumped-ER) model spectra (red). The HII-shocked-CSM (blue) and the HII-shocked-ejecta (green) components are also shown individually.

(Dewey, Dwarkadas et al. ApJ, 752, 103)

Progenitor BSG: Wind velocity ~500 km/s, Mass-loss rate < 10^{-8} msun/yr.

X-Ray Lightcurves of SNe



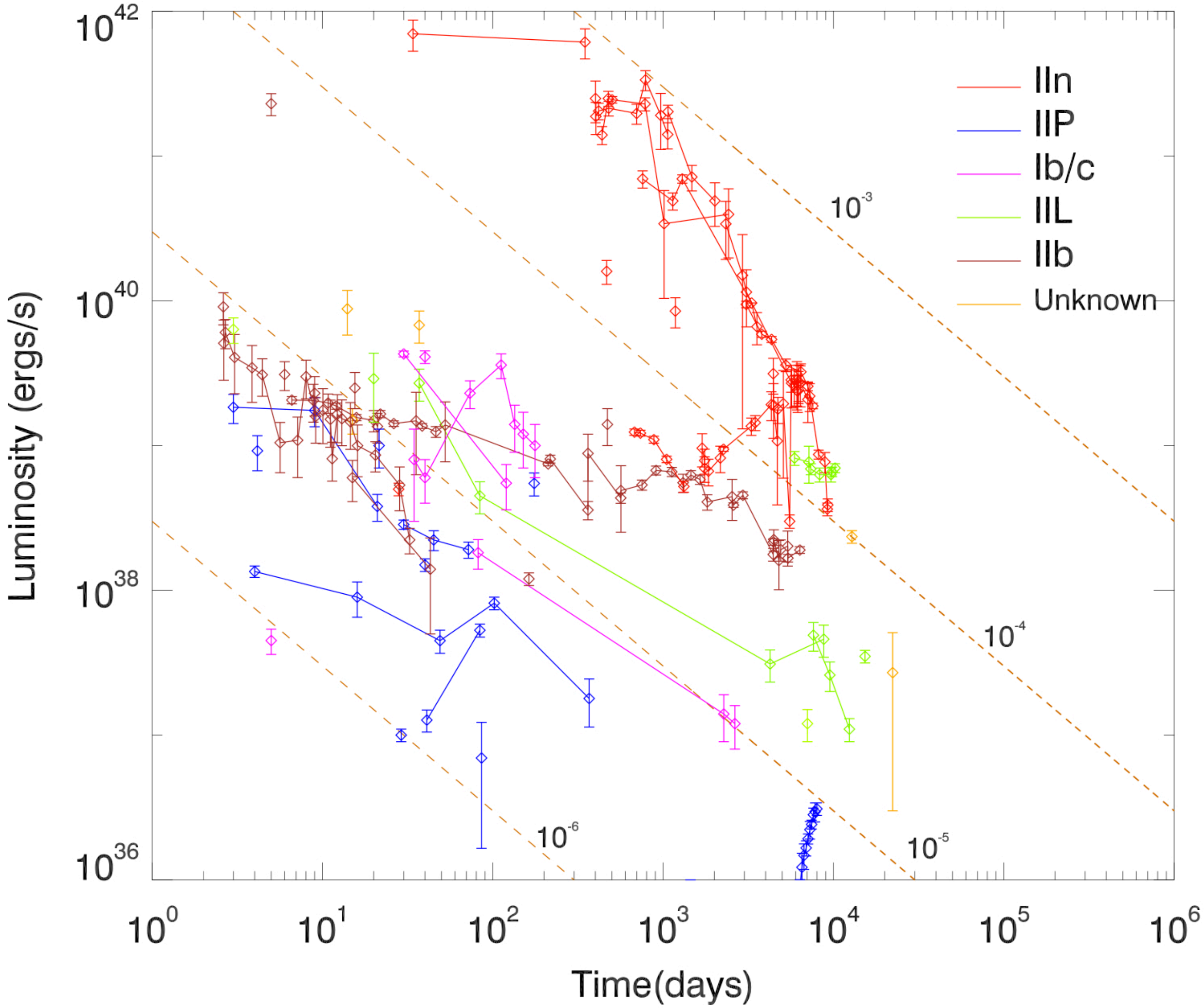
Type IIP SNe

- All IIP luminosities lower than about 3.e39 ergs/s
- But IIPs come from Red supergiants, which should have high mass-loss rates, and low wind velocities, and thus high density medium surrounding it.
- Thermal bremsstrahlung ~ ρ_w^2
- Why are IIP luminosities the lowest amongst all SNe?
- Chevalier, Fransson and Nymark 2006: IIP emission is from Inverse Compton Scattering, not thermal bremsstrahlung.
- But why is bremsstrahlung not important?

Is the Emission for more Luminous IIPs absorbed?

- Detailed calculations (Dwarkadas 2014, MNRAS, 440, 1917) suggest that it is unlikely that the X-ray emission from all high-luminosity Type IIP Sne could be absorbed.
- If not, then our only other option is that perhaps RSG stars with high mass-loss rates don't become Type IIP SNe.

X-Ray Lightcurves of SNe



Maximum Mass of IIP Progenitors

- So it seems that if IIPs with $\dot{M} > 10^{-5}$ are not seen, that's possibly because they really aren't there!
- Geneva mass-loss rate-luminosity relation for RSGs:

$$\dot{M} = 4.7 \times 10^{-6} (L/10^5)^{1.7}$$

- This gives a maximum luminosity of about 1.6 x 10^5 $L_{\odot}$

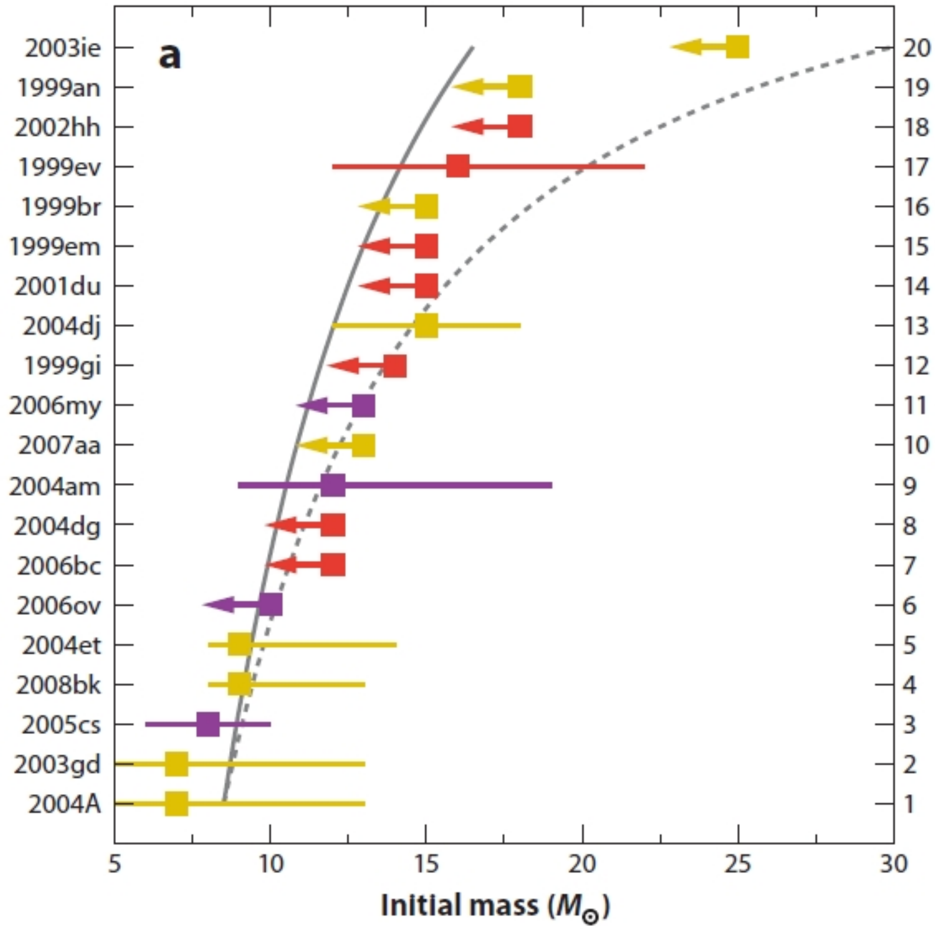
Maximum Mass of IIP Progenitors

- If we then use the mass-luminosity relationship from Mauron and Josselin

$$M \sim 0.14\, L^{0.41}$$

- We get $M_{max} \sim 19\ M_{\odot}$
- RSG Stars with $M > 19\ M_{\odot}$ do NOT become Type IIP SNe.

Maximum Mass of IIP Progenitors



Smartt 2009
ARAA

Finds maximum mass < 16.5 Msun.

Maximum Mass of IIP Progenitors

From our grid of rotating models, the following evolutionary scenarios are possible (Georgy et al., 2012):

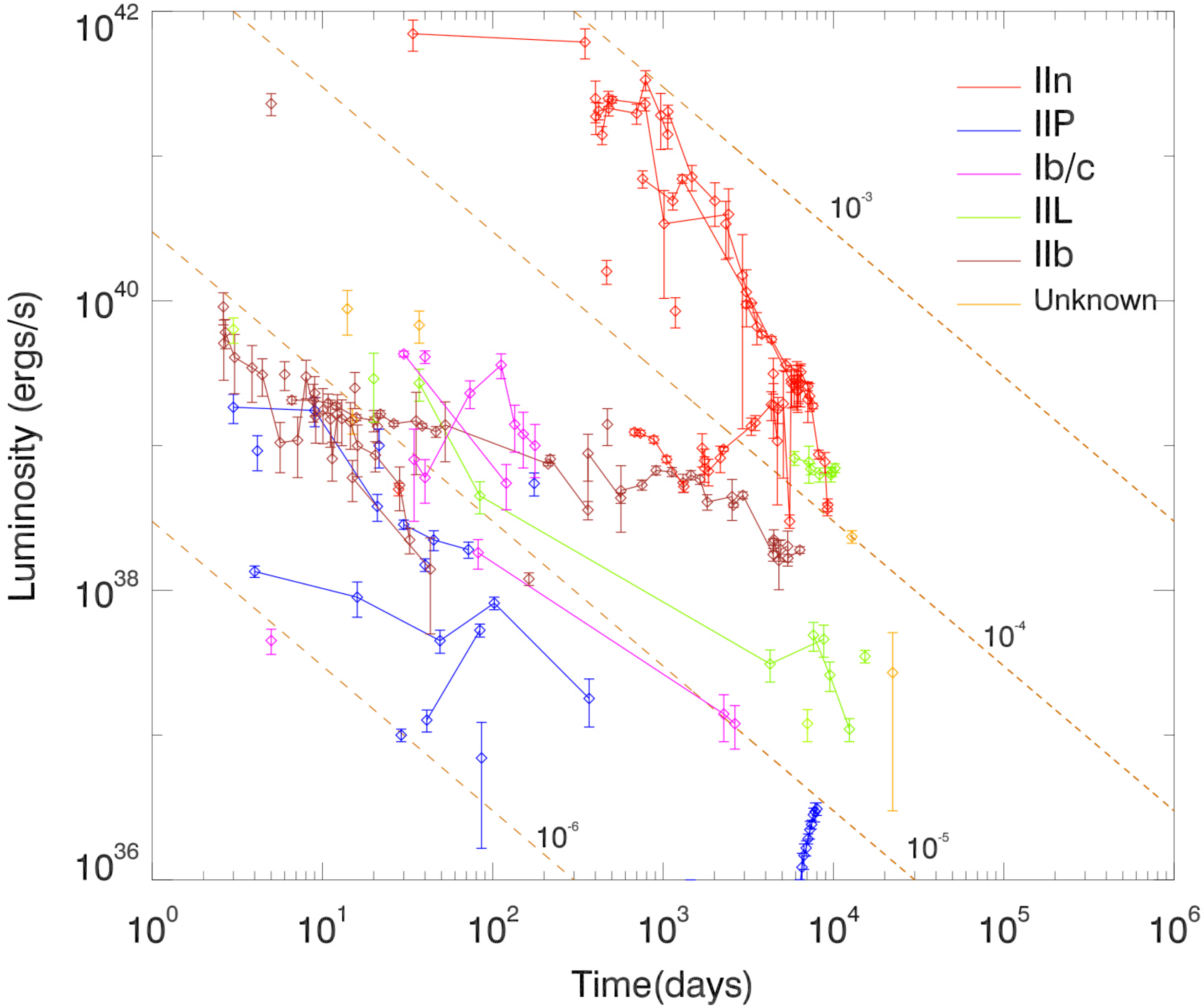
- MS → RSG for star with initial mass $M \lesssim 16.8\,M_\odot$
- MS → RSG → nitrogen rich (WN) Wolf-Rayet star (WR) for star with initial mass $16.8\,M_\odot \lesssim M \lesssim 25.0\,M_\odot$
- MS → Yellow supergiant (YSG) → WN → carbon rich (WC) WR star for star with initial mass $25.8\,M_\odot \lesssim M \lesssim 60.0\,M_\odot$
- MS → WN → WC for star with initial mass $M \gtrsim 60.0\,M_\odot$

Georgy et al 2012

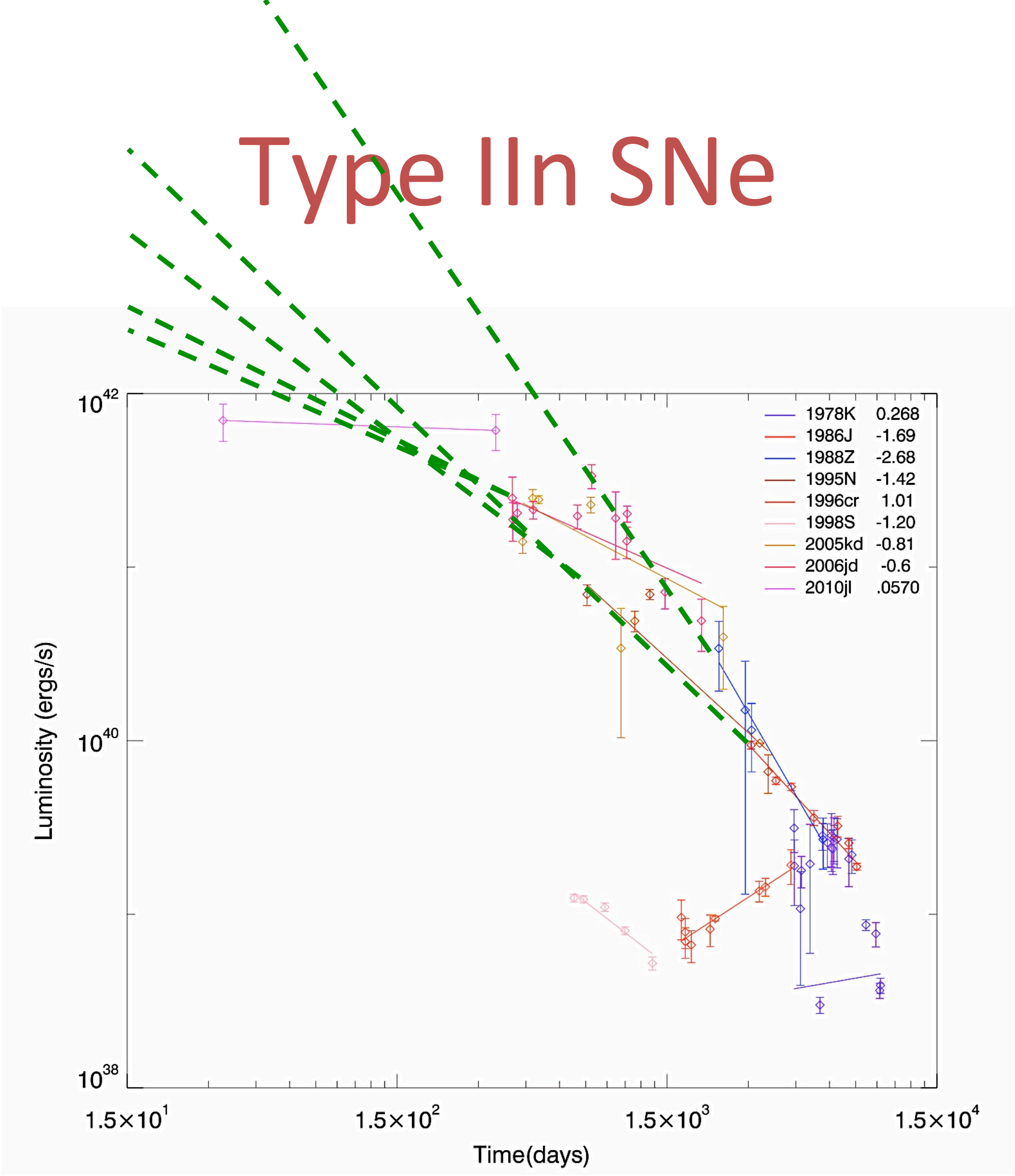
Rotating Stars > 16.8 Msun will not explode as RSGs but becomes W-R stars.

Non-rotating star limit 19 Msun.

X-Ray Lightcurves of SNe

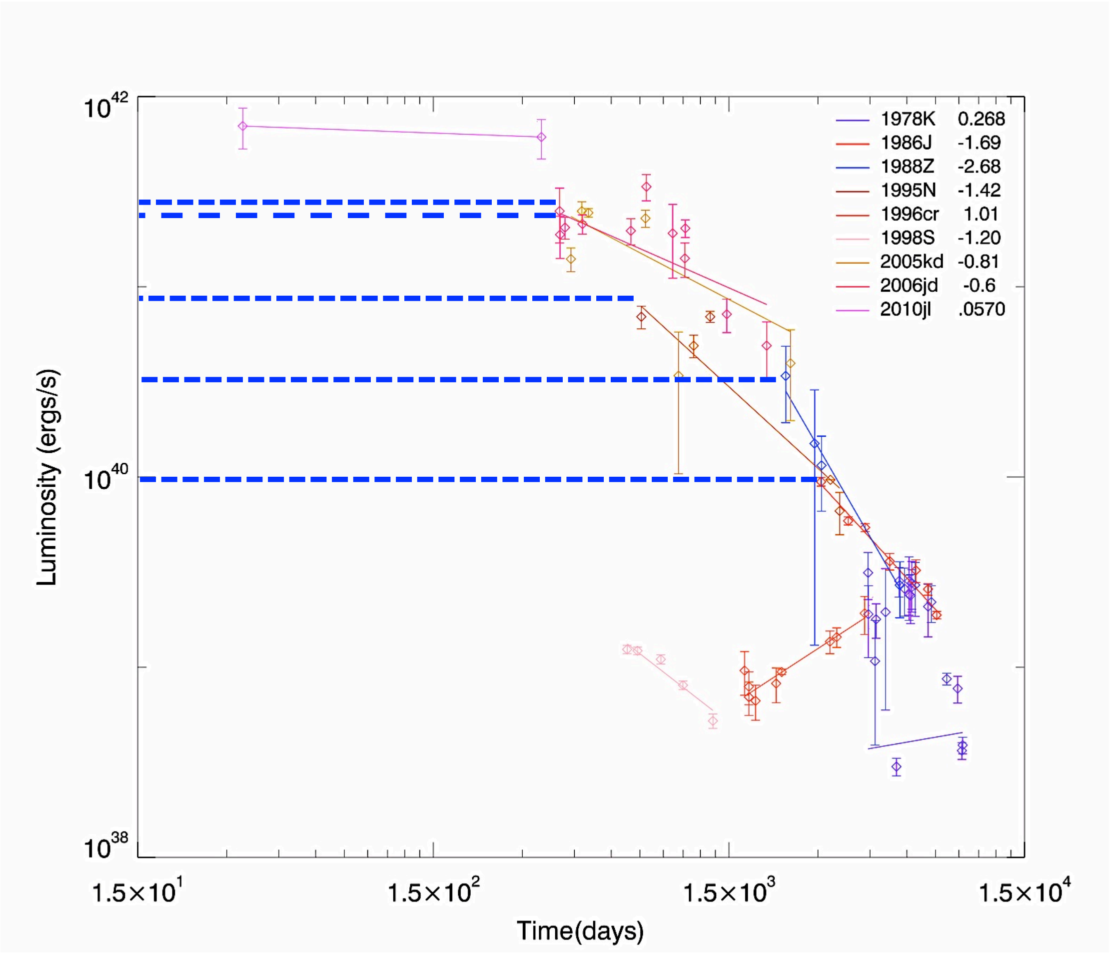


Type IIn SNe



1978K 0.268
1986J -1.69
1988Z -2.68
1995N -1.42
1996cr 1.01
1998S -1.20
2005kd -0.81
2006jd -0.6
2010jl .0570
Luminosity (ergs/s)
10^{42}
10^{40}
10^{38}
1.5×10^{1}
1.5×10^{2}
1.5×10^{3}
1.5×10^{4}
Time(days)

Type IIn SNe



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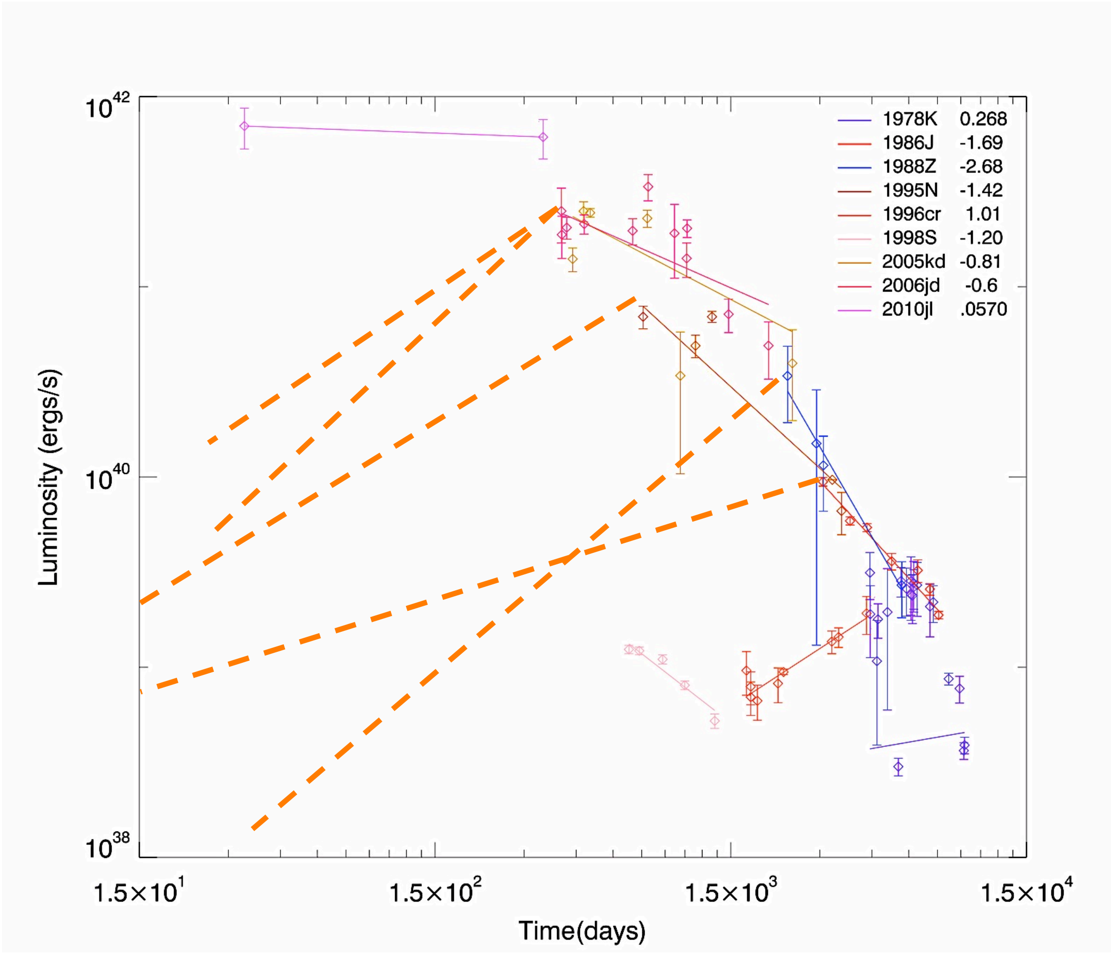
Luminosity (ergs/s)
Time(days)

Type IIn SNe



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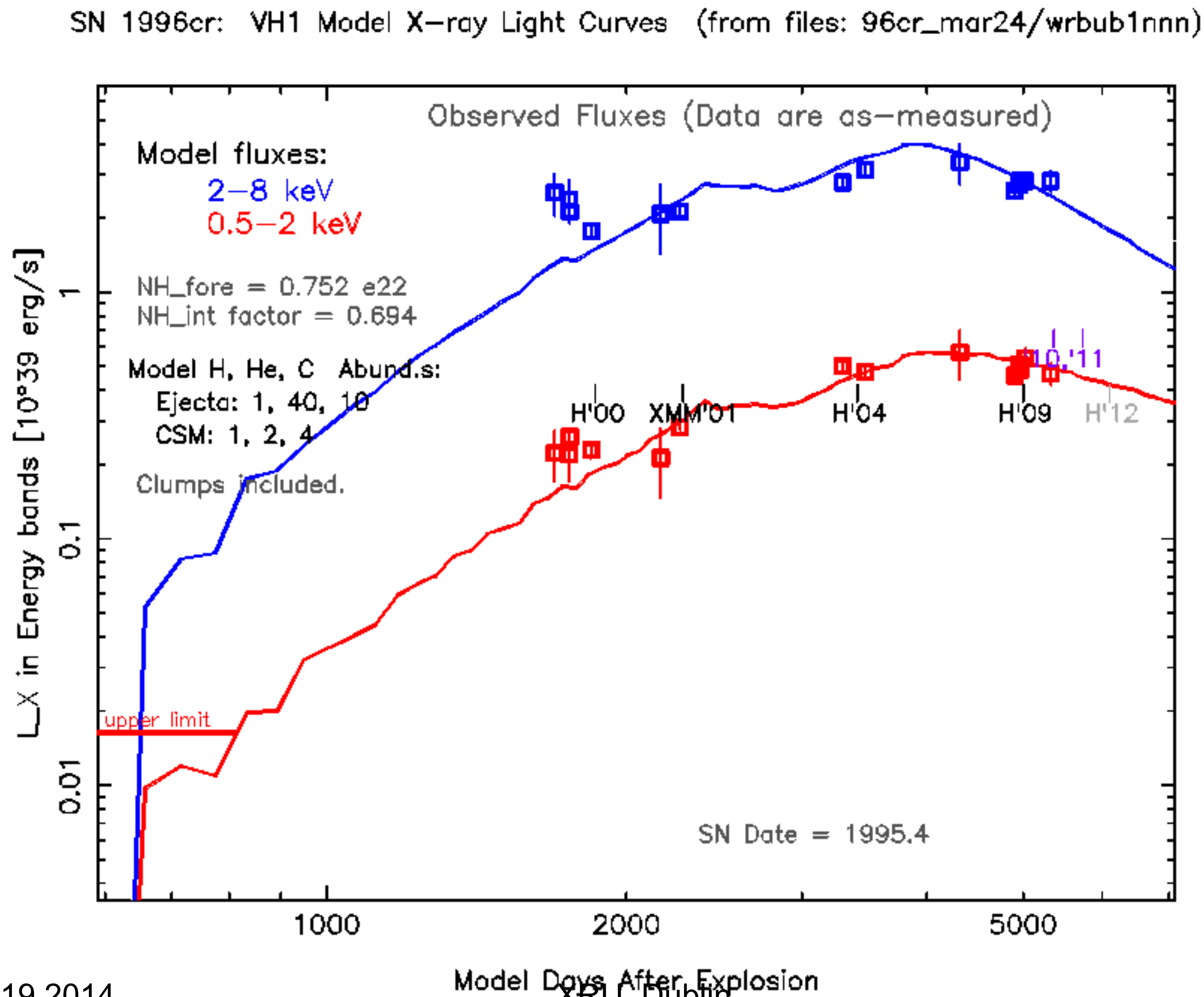
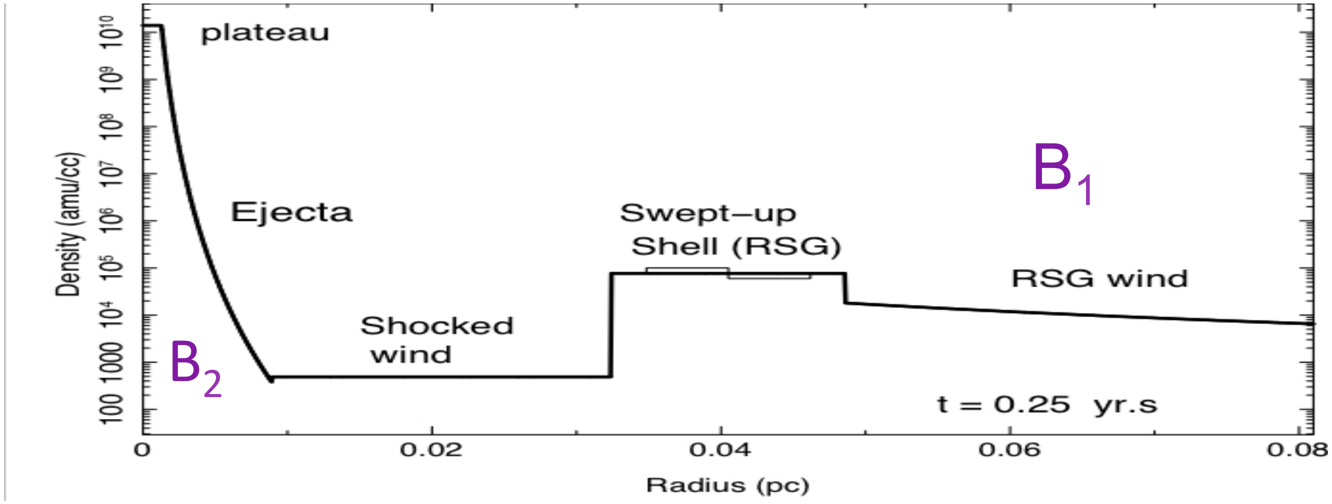
Type IIn SNe

- Show the highest X-ray luminosities
- Show a wide diversity in lightcurves, with steeply decreasing X-ray lightcurves.
- Unlikely to have maintained the high luminosities, or the steeply decreasing X-ray lightcurves, since the time of explosion.
- Therefore, the X-ray luminosity must have been steady, or lower, early on.

1996cr - Comparison with X-Ray data

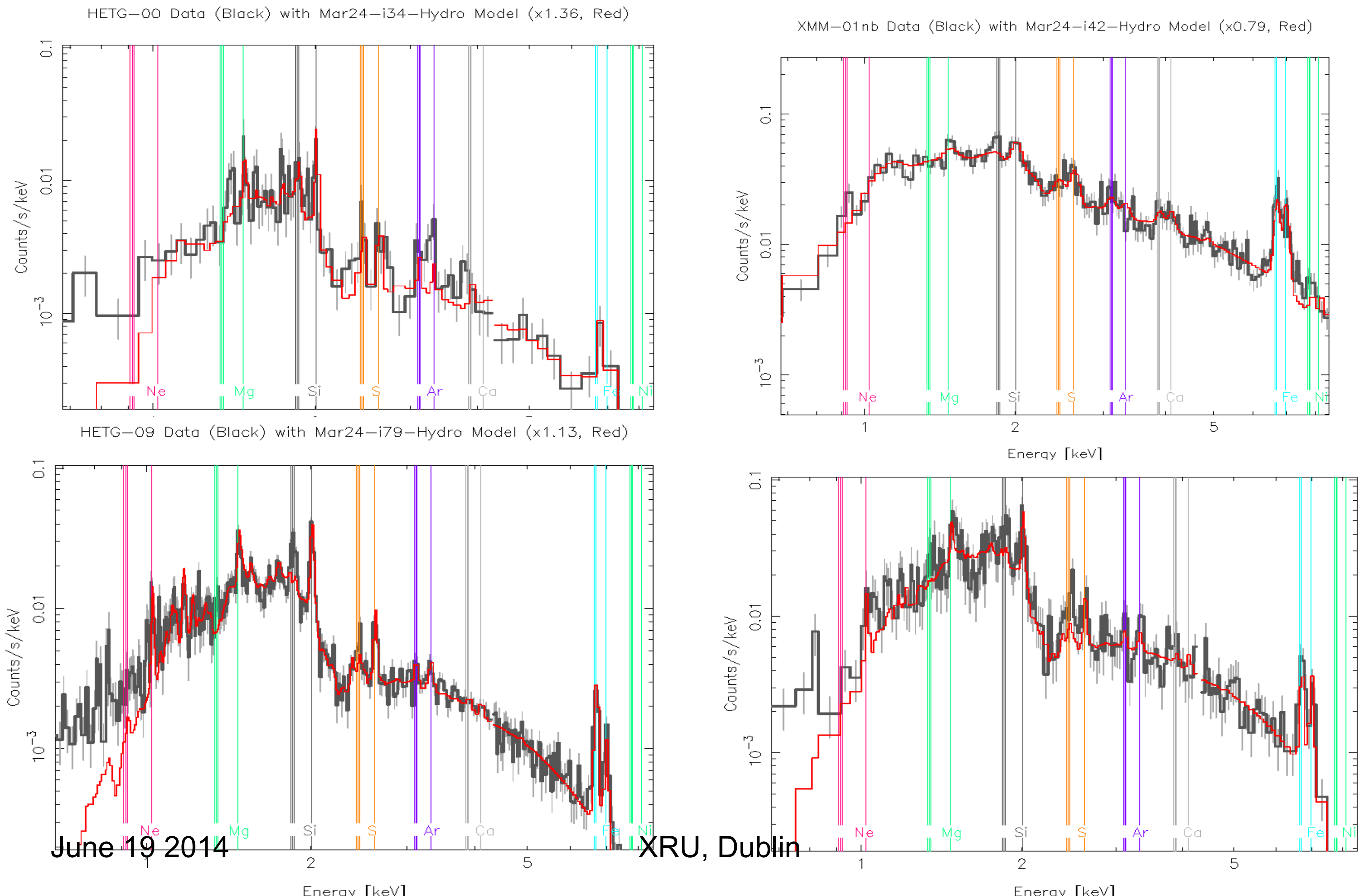


Finding the Progenitor

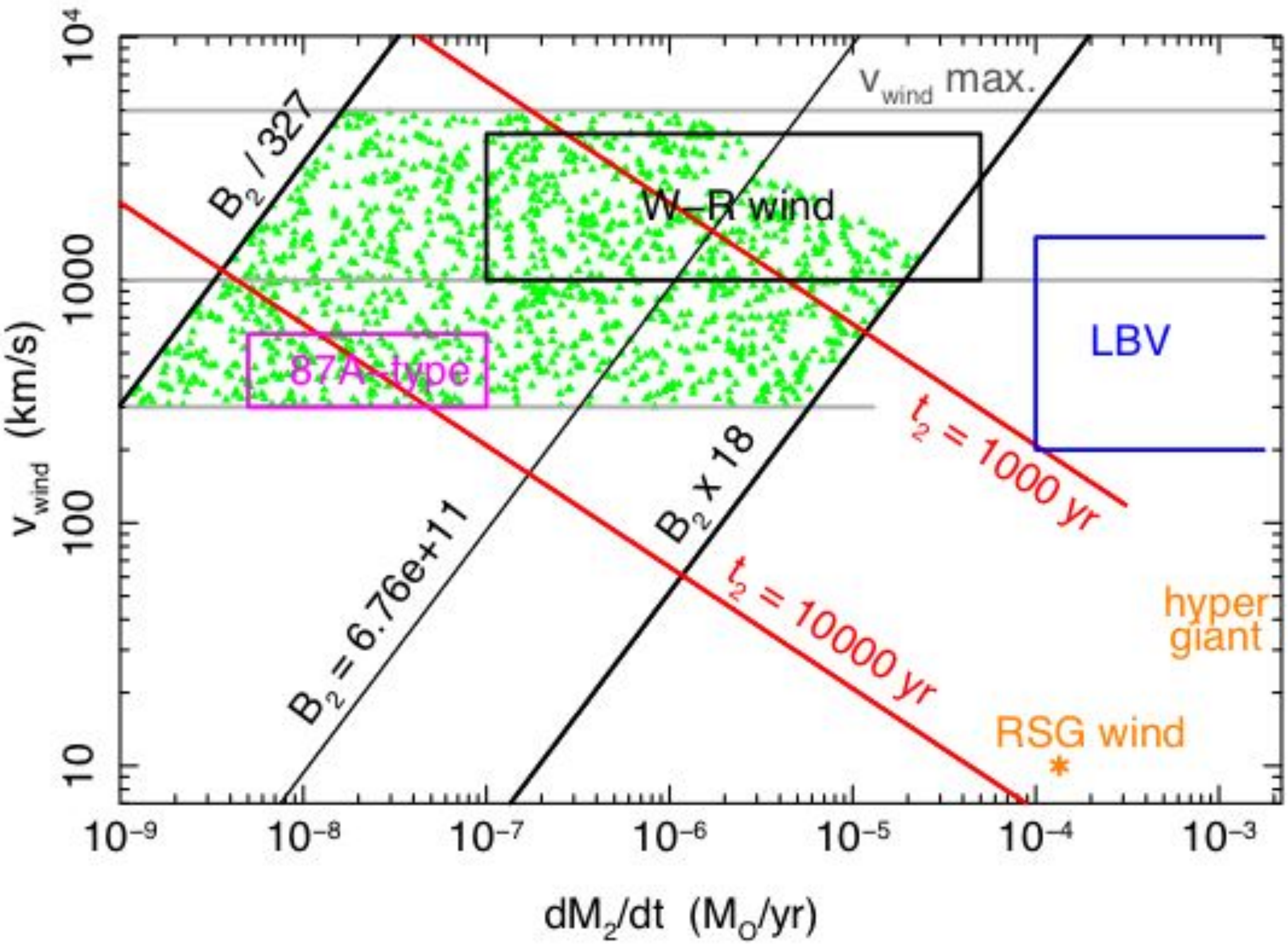


- Surrounding wind density parameter (B_1 = Mdot/v_w) given by assumption that mass in bubble equal to mass of swept-up material.
- Only upper limits on inner wind region density parameter B_2.
- Apply equations for formation of wind bubble by interaction of two winds [R = (L/1.5 B_1)t], L = 0.5 Mdot v_w^2

SN 1996cr (Comparison between Observed and Simulated Spectra)



Closing in on the Progenitor



Type IIn SNe

- What kind of progenitor can give rise to such a high density medium just outside the star?
- Plotted are soft X-ray light curves, hard X-ray emission may be larger earlier on. Where do these energy reserves come from?
- Maybe the X-ray luminosity, and density, were much lower early on, then increased, now decreasing again (like 1996cr?). Makes sense from energy point of view.
- Most IIns seem to evolve in a medium whose density decreases faster than r^{-2}.

Summary

- SN X-ray lightcurves show a wide diversity, spanning 9 orders of magnitude. Can provide valuable insights into SNe progenitors.
- Our understanding of X-ray emission from 87A shows that we can reproduce the X-ray spectra with reasonable accuracy.
- X-ray lightcurves of IIPs appear to indicate a maximum mass-loss rate, and therefore maximum mass of 19 Msun for the progenitor.
- IIns as a class may not have a single progenitor.
- Some IIns must either have much lower density just outside the star, rising, then dropping, if emission is all thermal. Or if the densities are high, as indicated, then the mass-loss rates must be ~10^{-3} Msun/yr or larger, so that Inverse Compton effects dominate.

QUESTIONS & DISCUSSION