Investigating the X-Ray Emission from Type IIn Supernovae

Vikram Dwarkadas

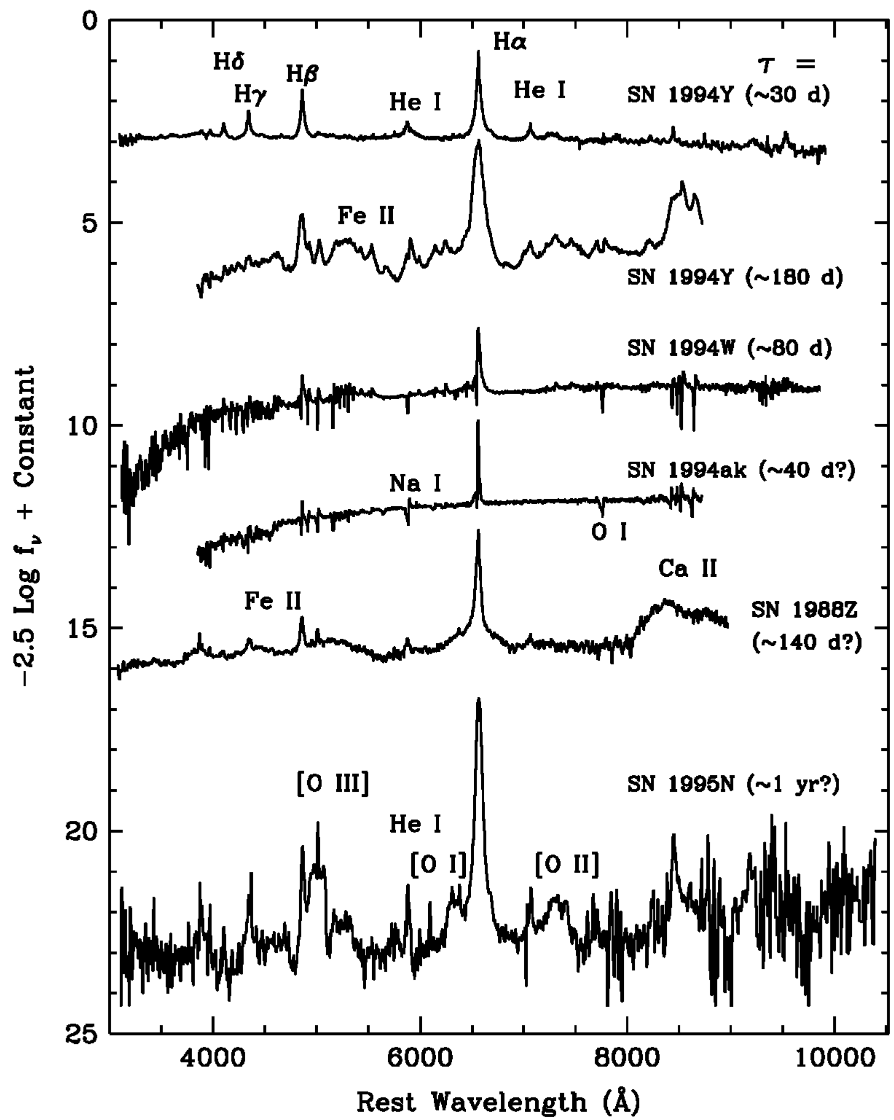
University of Chicago

We gratefully acknowledge support from NASA ADAP grant# NNX14AR63G

June 6 2017

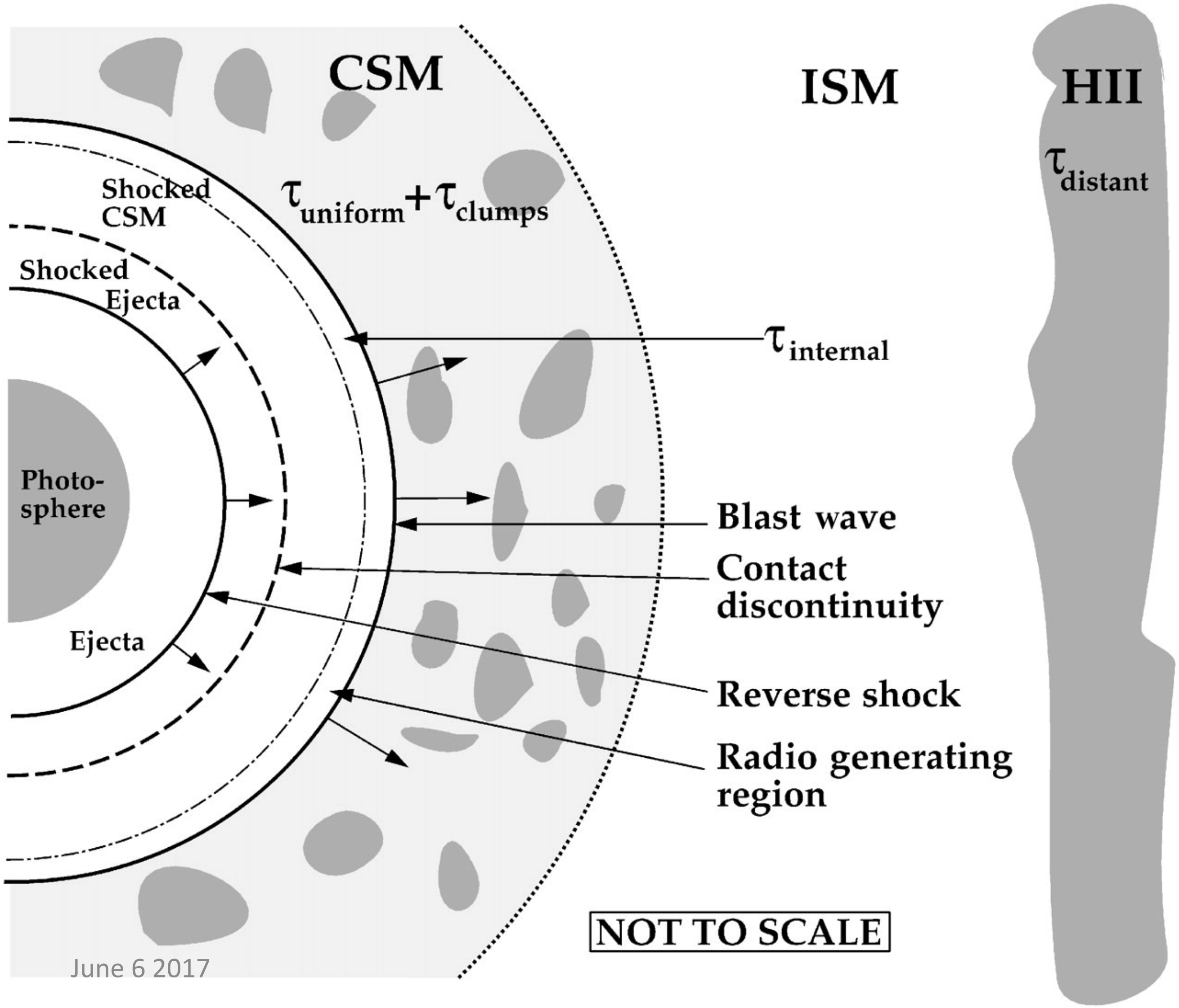
Type IIn SNe

- Subclass first suggested by Schlegel (1990)
- `n' for narrow lines, on a broad base.
- Narrow lines presumed to arise in surrounding medium, represent ambient (wind) velocity.
- Usually (but not always) show high X-ray. Larger diversity in radio.
- Probably evolve in high density medium.



Spectra of several Type IIn SNe (Alex Fillipenko, 2001, AIPC).

SN Interaction with Circumstellar Medium

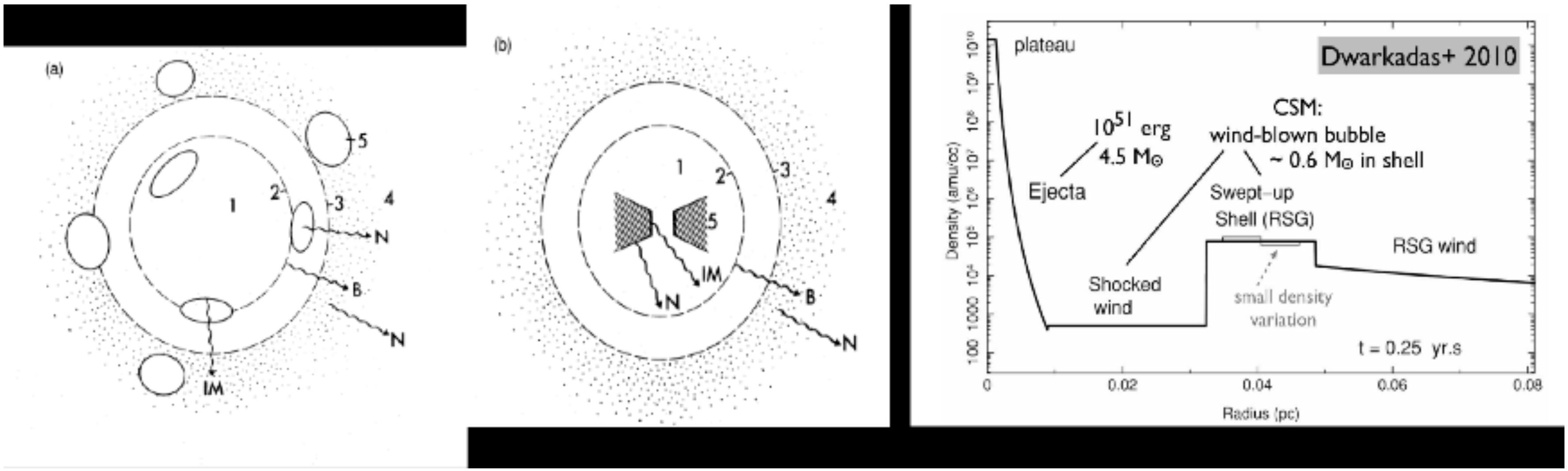


SN shocks evolve in the ambient medium. For a core-collapse SN, this medium is formed by mass-loss from the progenitor star.

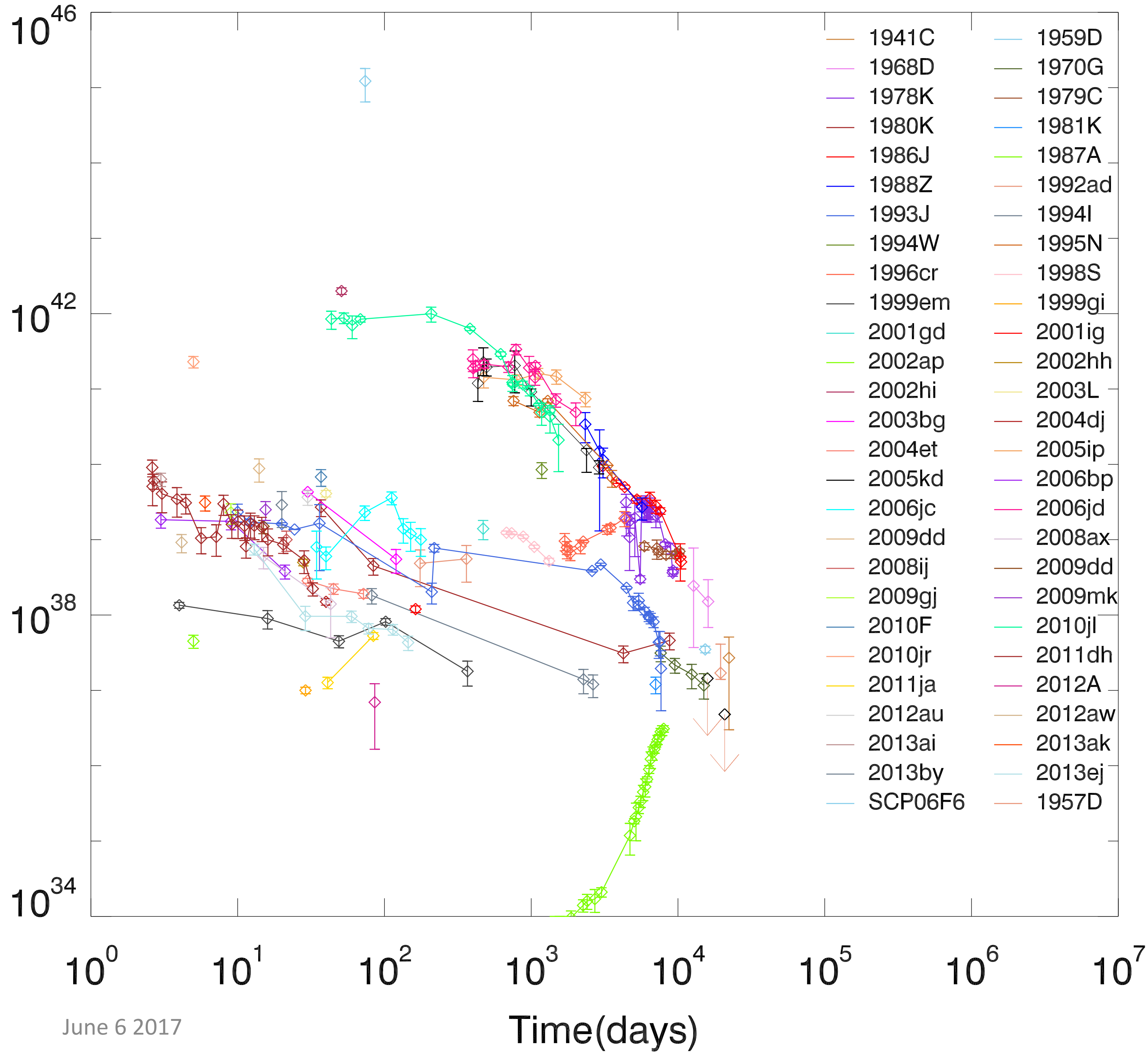
If the mass-loss rate is high and velocity low, the surrounding density may be very high, leading to strong circumstellar interaction.

Weiler et al ARAA, 2002

Models for formation of Type IIns

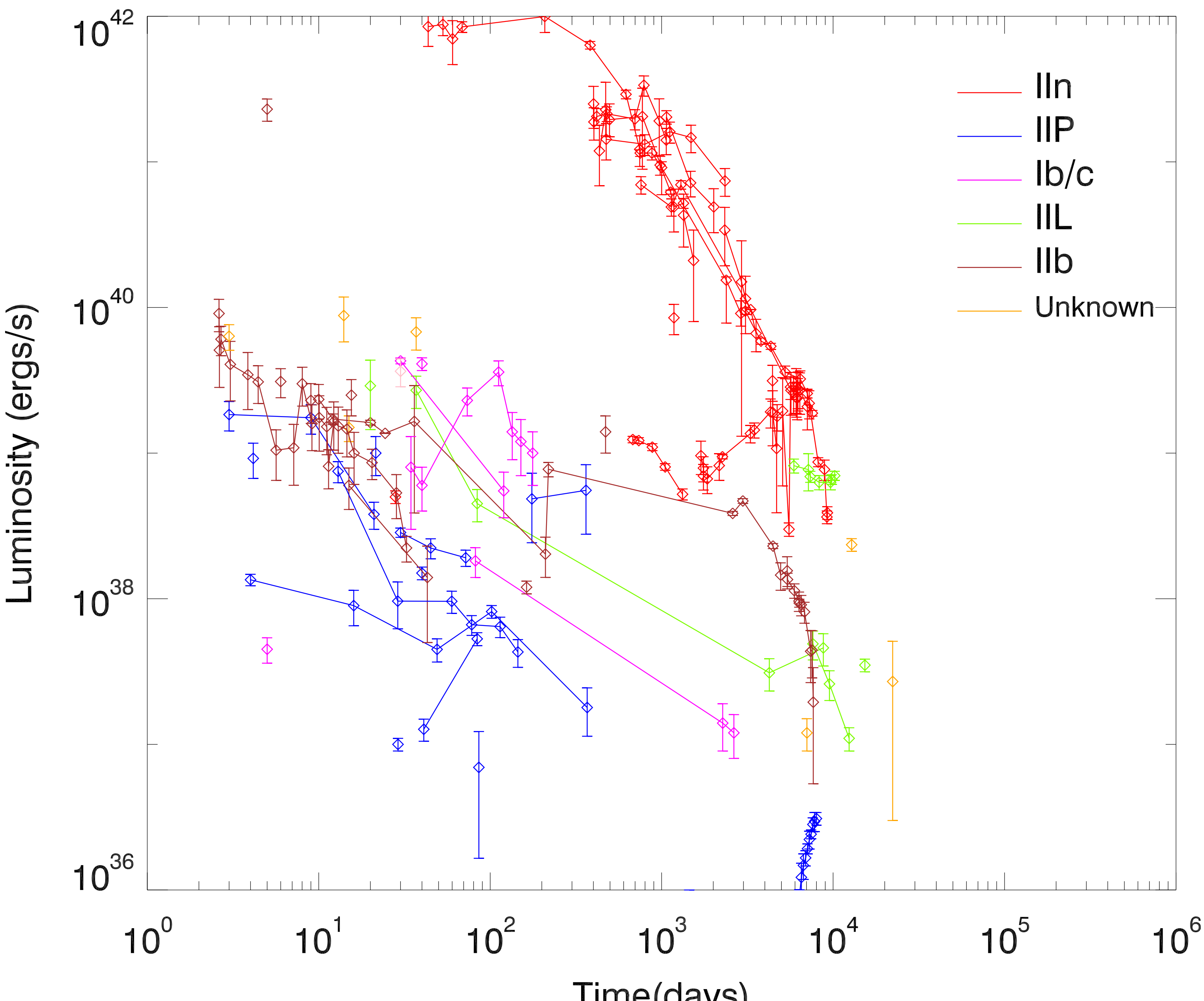


Models for the formation of narrow (N) and intermediate (IM) velocity lines in IIns (Chugai & Danziger 1994, Dwarkadas et al 2010). From L-R (a) Interaction of SN shock wave with a clumpy medium (b) Interaction with a dense equatorial wind and (c) Expansion into a wind bubble and dense shell (SN 1996cr). Narrow lines arise from shocks in denser components.



X-Ray Lightcurves of most observed X-Ray Sne

Note: Light curves publicly available, see poster G02.



X-Ray Lightcurves of most observed X-Ray SNe, removing the brightest and dimmest. Grouped by type. Note IIns form the brightest class.

X-Ray Emission/Atomic Processes

Continuum emission – thermal bremsstrahlung:

$$F_\nu \sim \frac{n_e n_H V}{4\pi D^2} T^{1/2} g(E,T)\, e^{-E/kT}$$

Proportional to n^2, can be used to determine density profile

Line emission:

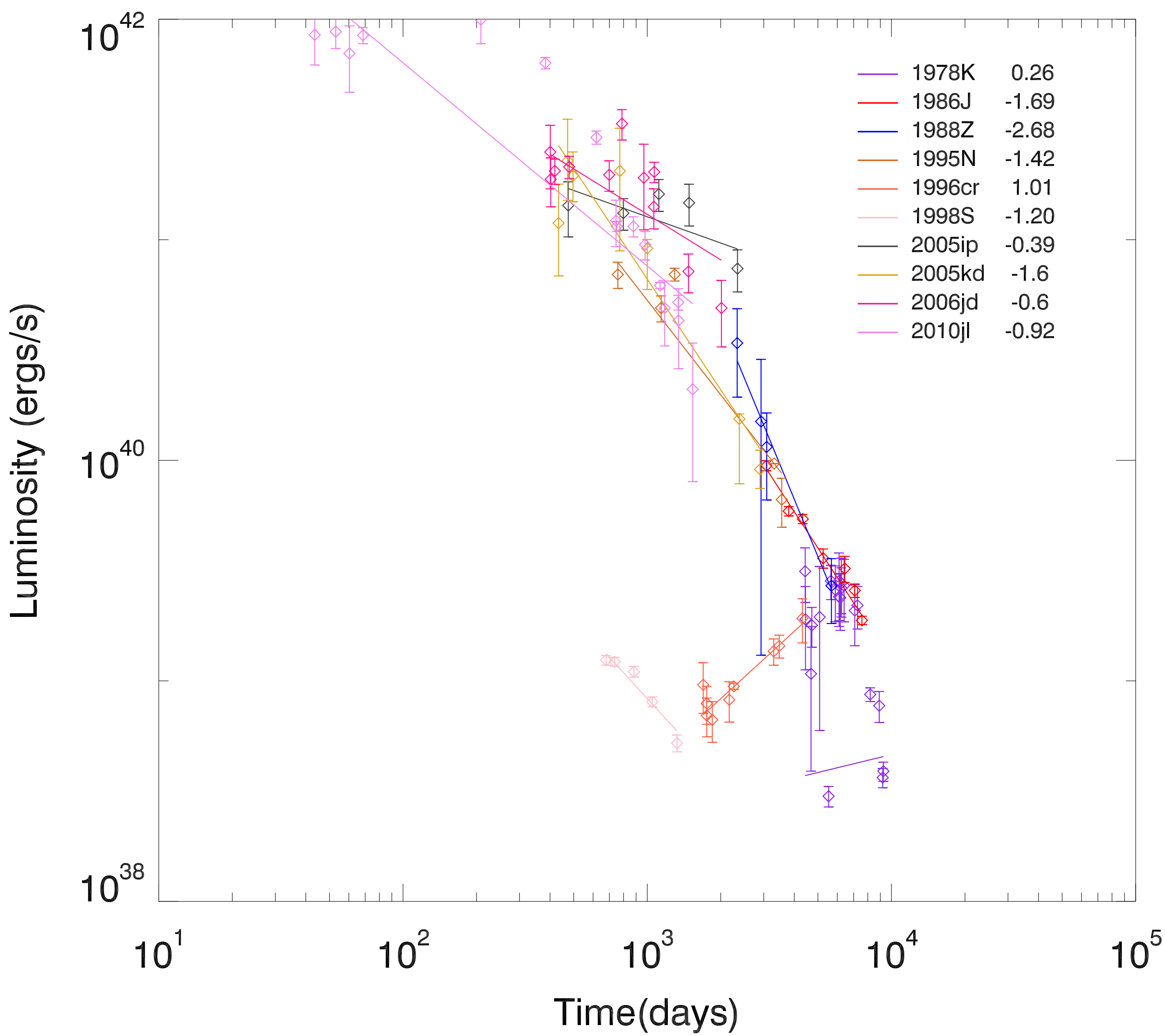
$$F^a_{Z,i} \sim \frac{n_e n_H V}{4\pi D^2} \left(\frac{n_Z}{n_H}\right) \left(\frac{n_{Z,i}}{n_Z}\right) \epsilon_a(T, E_{ex})$$

Abundance of element Z

Ionization fraction of ion i

X-Ray Luminosity

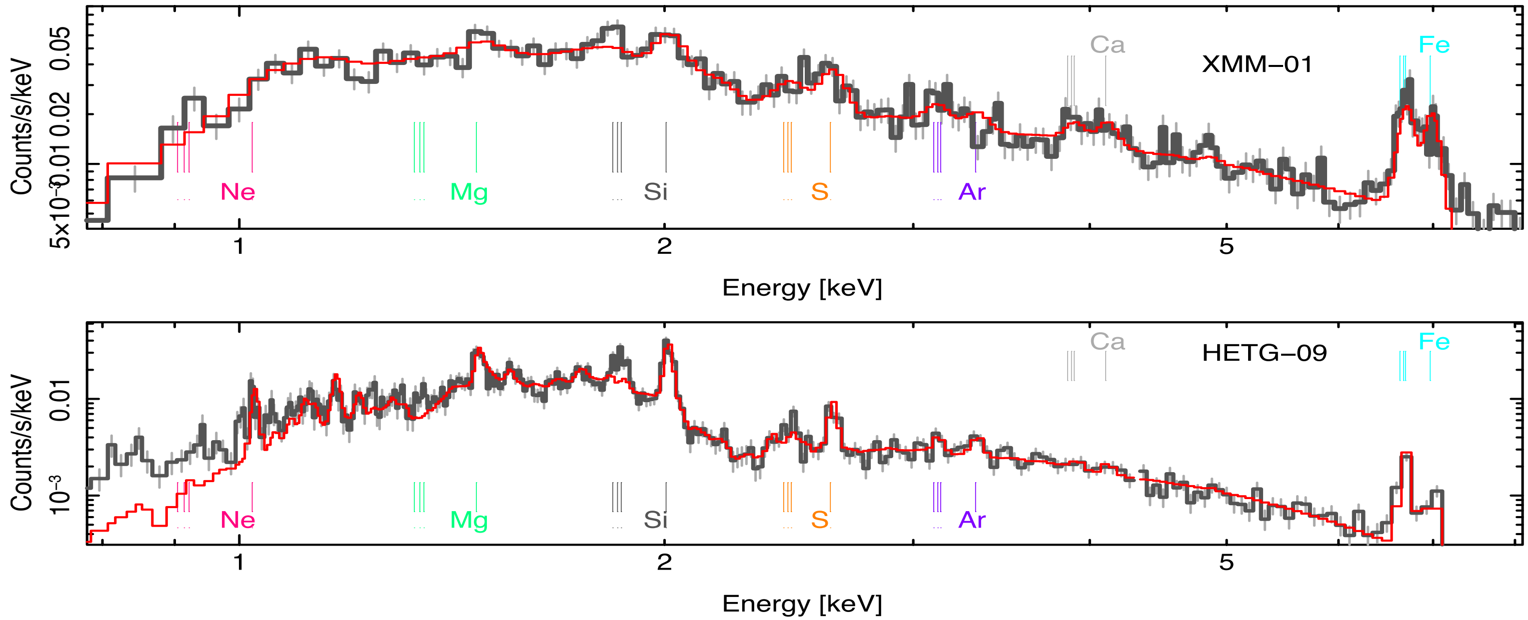
- X-ray luminosity $L_x \approx n_e^2 \lambda V$
  - Where n_e = electron number density
  - λ is the cooling function
  - V is the volume of emitting region
- Using Chevalier self-similar solution, thin shell, $\rho_{ej} \approx r^{-n}$, $\rho_w \approx r^{-s}$, s=2 – constant parameter wind
- Wind medium, constant properties, $L_x \approx t^{-1}$
- If $s \neq 2$, then $L_x \approx t^{-(12-7s+2ns-3n)/(n-s)}$



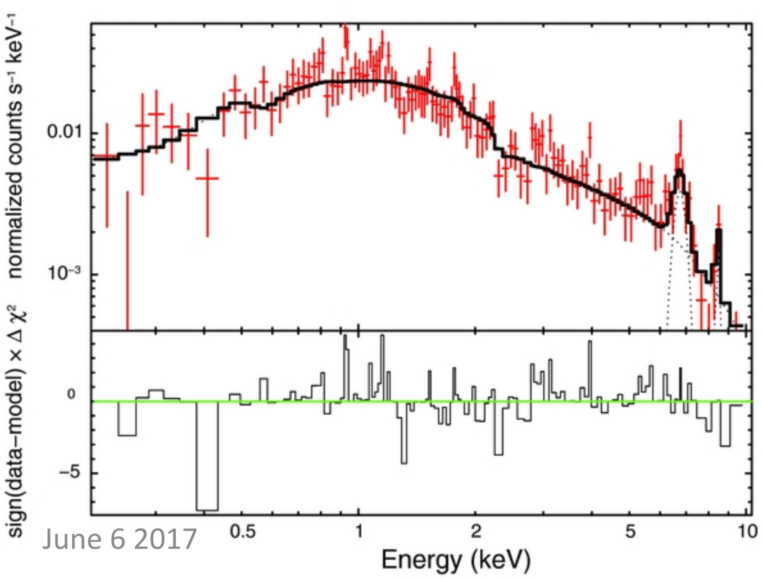
Power-law ($L=Kt^{-\alpha}$) fits to the X-Ray Lightcurves of Type IIn SNe. Note that the slopes deviate strongly from -1, suggesting a wind medium with mass-loss rate, velocity, or both, changing with time.

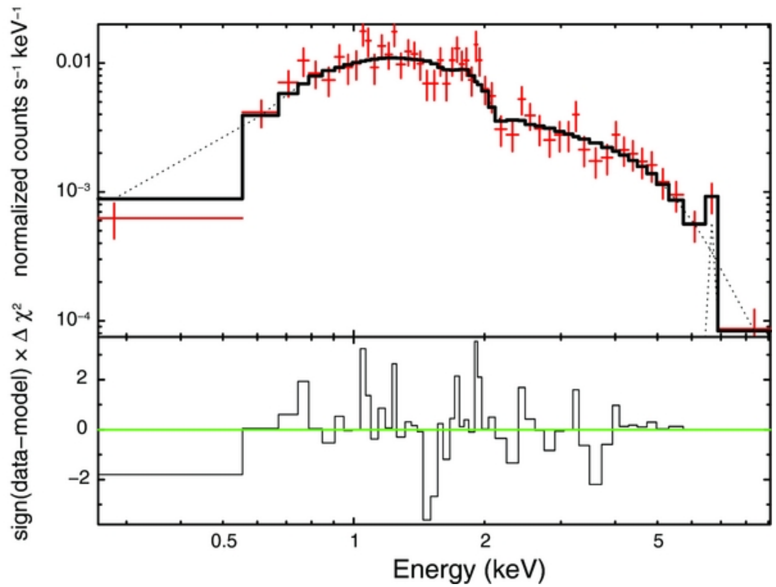
Caveat: X-ray emission measured only in a small waveband (Chandra, XMM)

X-Ray Spectra of Type IIn Supernovae



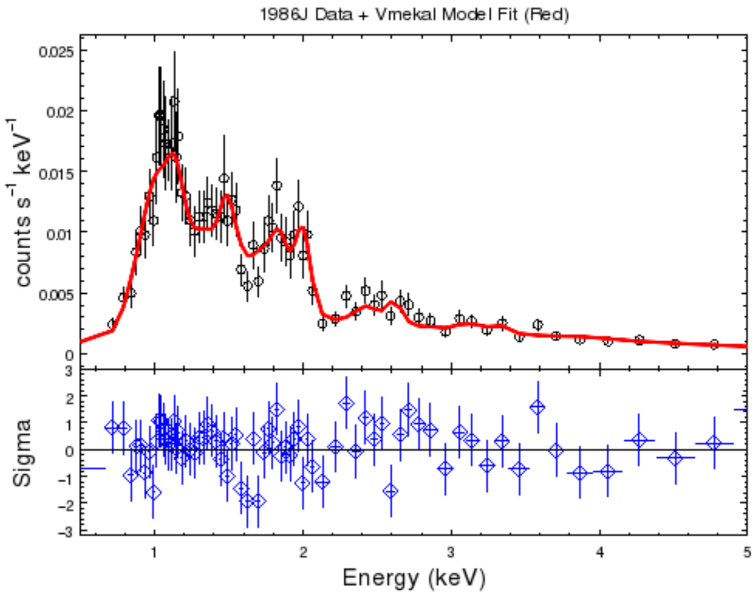
SN 1996cr: Top: 2001. Bottom: 2009 Dwarkadas et al 2010., MNRAS, 407, 812

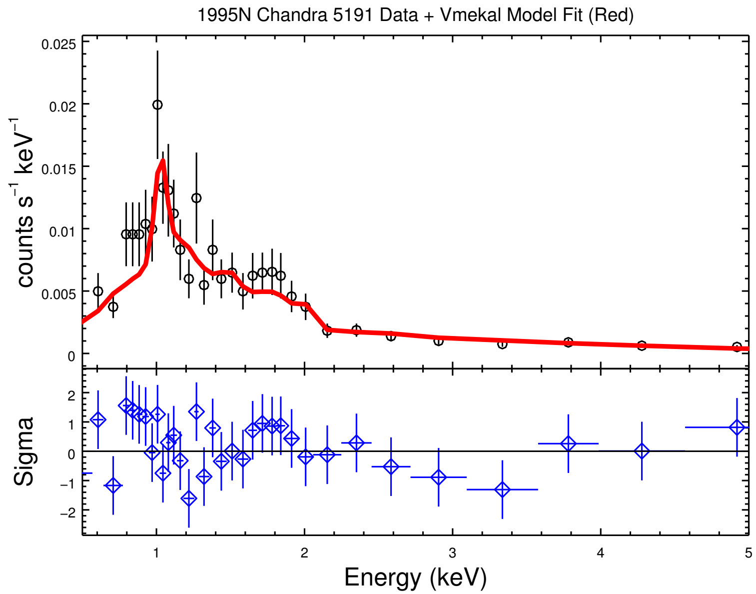




SN 2006jd. Chandra et al 2012. Left: XMM Right: Chandra. Both in 2009.

Spectra of Type IIn Supernovae



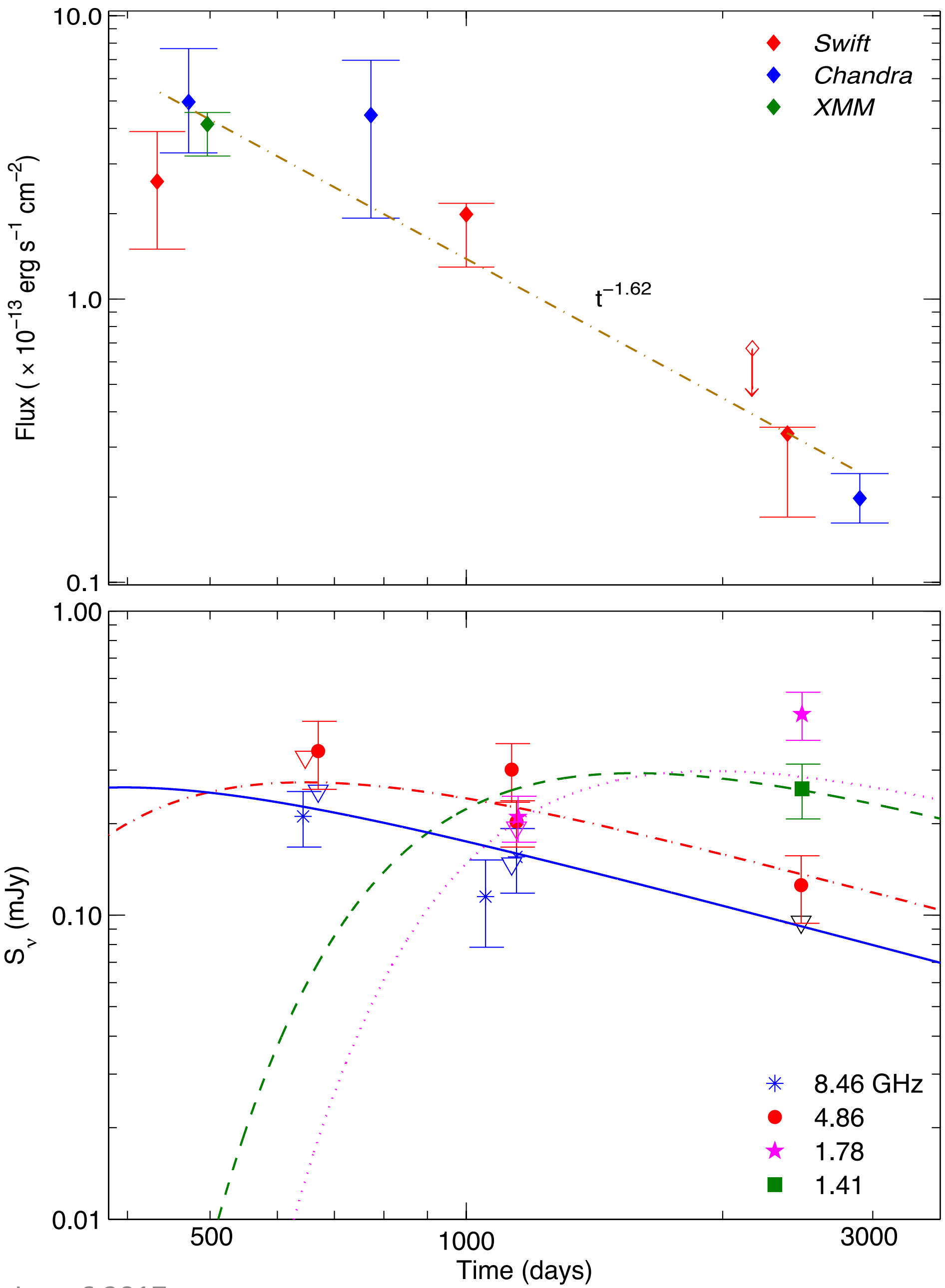


SN 1986J: Chandra ID 4613, Year 2003
Spectrum is definitely thermal, shows lines of Fe, Si, S, Ar, Mg.
(Dwarkadas et al., in prep)

SN 1995N: Chandra 5191, March 2004
Ne and Si abundances above solar.

Observed spectra of type IIn SNe are all thermal!

(Caveat: We rarely have spectra in first year [2010jl])



SN 2005kd X-Ray and Radio

(Dwarkadas et al 2016, MNRAS, 462, 1101)

Emission is thermal. Implies mass loss rate > 2 x 10^{-3} $M_{\odot}$/yr for 10 km/s wind.

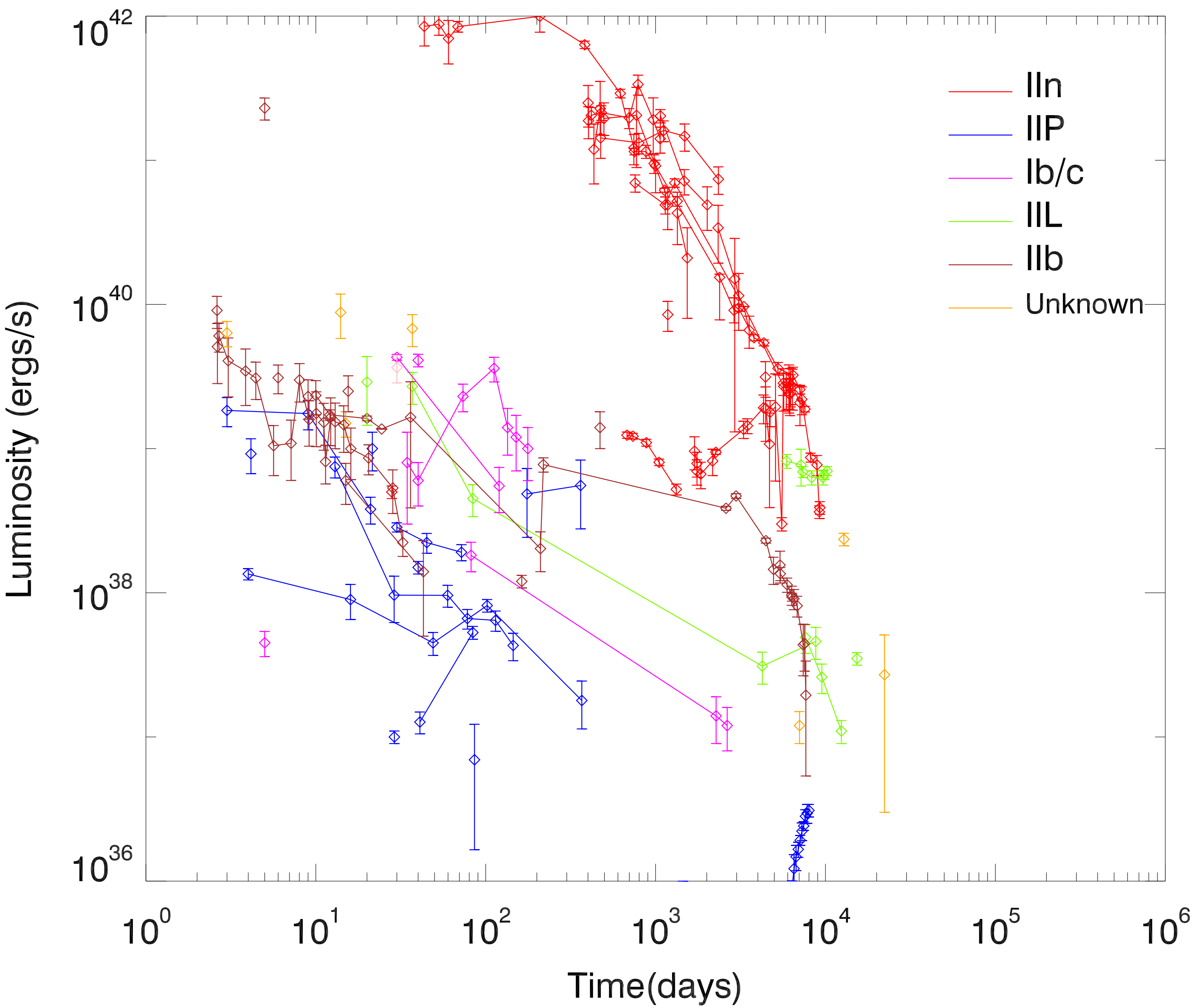
(See poster #G03)

X-Ray Properties of Type IIn SNe

- Show the highest X-ray luminosities amongst all SN types, but with considerable range.
- Show a wide diversity in lightcurves, with steeply decreasing X-ray lightcurves, but one that is increasing.
- Early spectra often show temperatures outside Chandra, XMM range (> 10 keV). In some cases can be fit by 2-Temperature spectrum
- Column densities often > 10^{21} cm^{-2} for first few years.
- Often show excess of Fe, Si, S, Mg (α-elements) in spectra.

X-Ray Properties of Type IIn SNe

- As a class probably have multiple progenitors; the `n’ presumably has more to do with surrounding medium.
- Simply from the energetics, it is unlikely that IIns 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. Exemplified by 2010jl.



X-Ray Lightcurves of most observed X-Ray SNe, removing the brightest and dimmest. Grouped by type. Note IIns form the brightest class.

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.
- The X-ray luminosity is probably steady early in the evolution, then decreasing. Makes sense from energy point of view.
- Most IIns seem to evolve in a medium whose density decreases faster than r^{-2}.
- Derived mass-loss rates higher than those for most SN progenitors (RSGs, Wolf-Rayet stars, hypergiants, blue supergiants). Indicative of mass ejections, as in LBVs. Problem for the stellar evolution models.

Questions & Discussion