Monitoring X-ray Emission from SN 1986J

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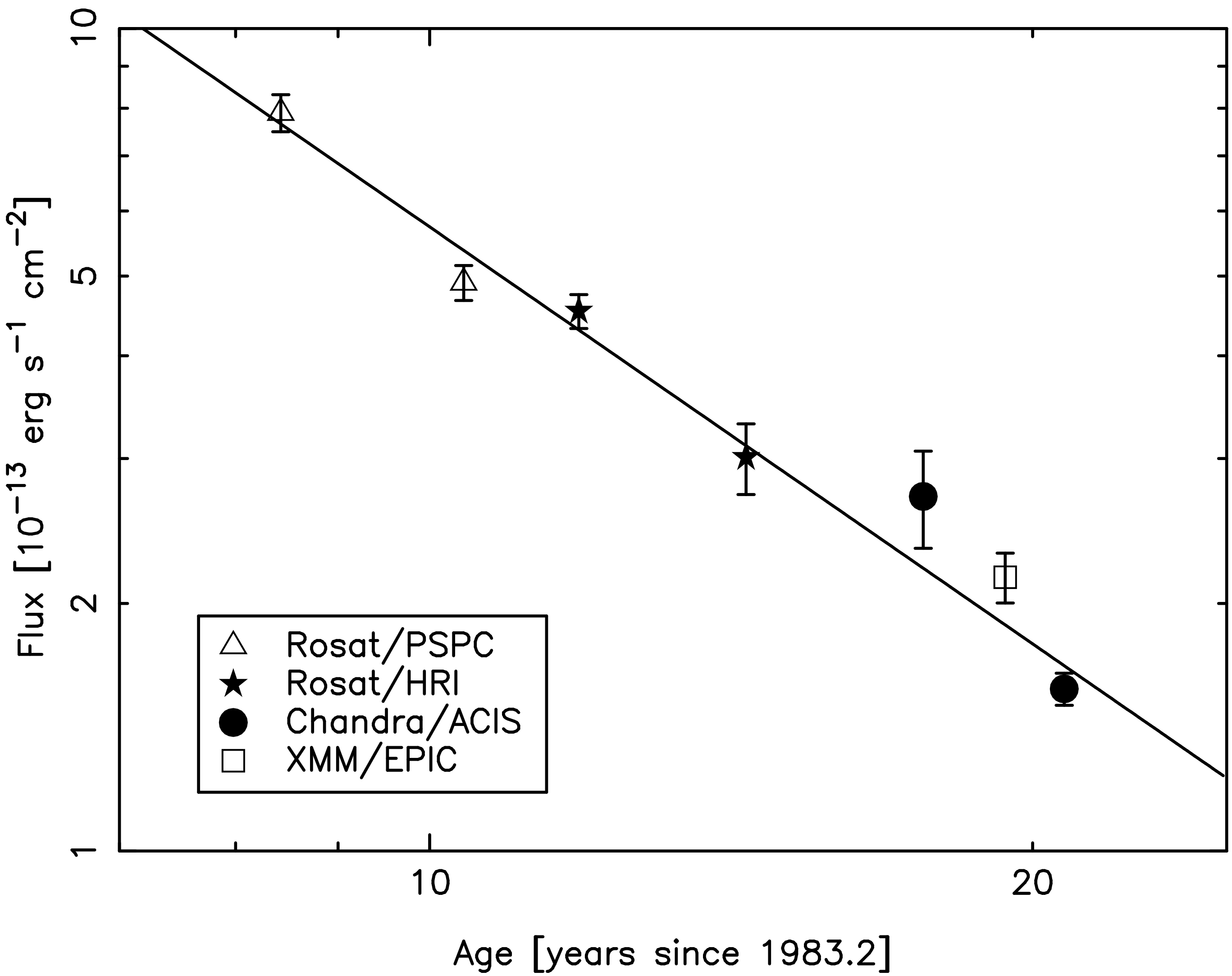
Overview

- SN1986J was an unusual supernova: Type IIn
  (‘n’ = *narrow* optical lines)
- Extremely luminous in X-ray and radio
  ($L_X > 10^{40}$ erg s^{-1}, $L_{\rm radio} > 10^{38}$ erg s^{-1})
  $\Longrightarrow$ circumstellar interaction
- Evolution is not self-similar
  $\Longrightarrow$ massive, clumpy wind?
- Oxygen-poor ejecta
  $\Longrightarrow$ Asymptotic Giant Branch “superwind”? *(Chugai 1997)*

Unabsorbed Flux 0.5-2.5 keV



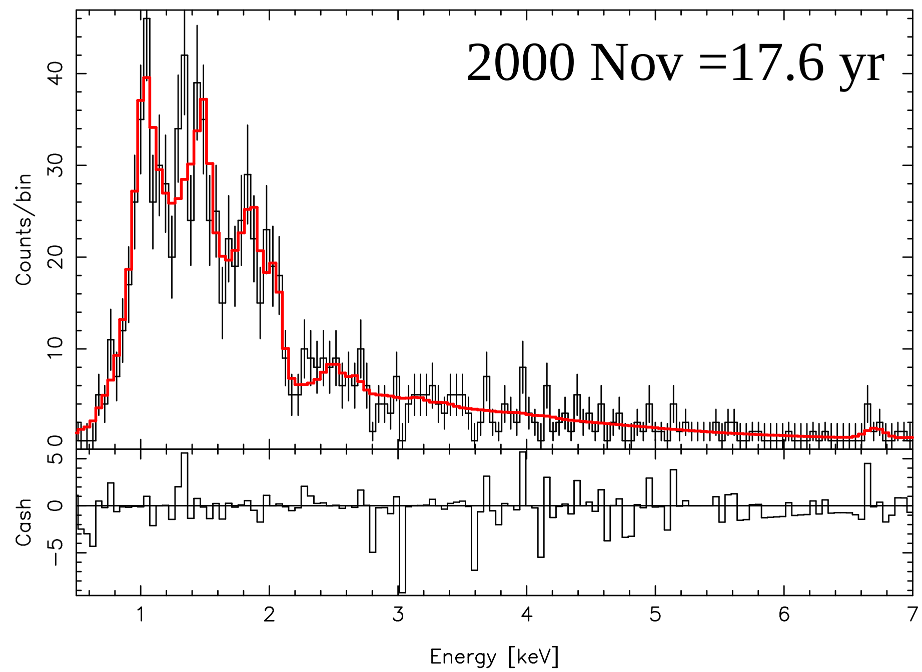
- Rapid decline, $F \propto t^{-(1.7 \pm 0.25)}$, suggests circumstellar medium density profile steeper than $\rho \propto r^{-2}$
- Self-similar model predicts $L_X \propto t^{-\alpha}$, $\alpha \lesssim 1$

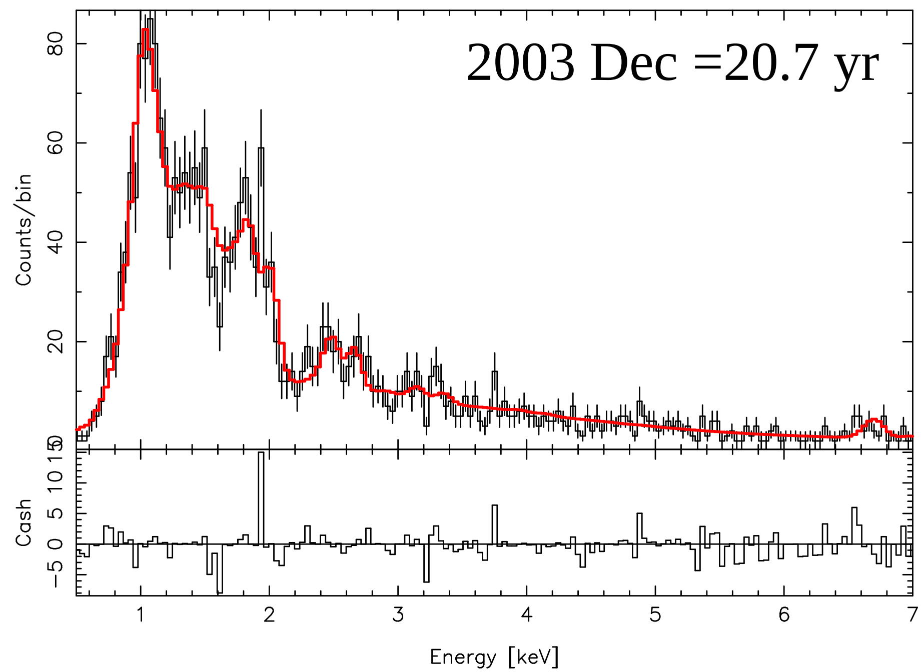
X-ray Spectral Evolution

Chandra/ACIS-S data:

$$\begin{aligned} N_H &= (5.5 \pm 1) \times 10^{21}\ \mathrm{cm}^{-2} \\ T_1 &= 5.5^{+1.7}_{-0.7}\ \mathrm{keV} \\ T_2 &= 1.1 \pm 0.1\ \mathrm{keV} \\ K_2/K_1 &= 0.29 \end{aligned}$$

No significant change in shape (at 90% confidence)





Dynamical constraints:

1. $T_e = \frac{3}{16}\frac{\bar{m}}{k}v_{\rm sh}^2 \implies v_{\rm sh} \approx 2000$ km s^{-1}
2. Recent VLBI gives $R \propto t^{0.71\pm0.11}$
   expansion $v \approx 6000$ km s^{-1} (*Bietenholz, Bartel & Rupen 2002*)

Self-similar model (*Chevalier 1982*)

$$\left.\begin{aligned}\rho_{\rm star} \propto r^{-n}\\ \rho_{\rm wind} \propto r^{-s}\end{aligned}\right\} \implies R_{\rm contact} \propto t^m, \qquad \left(m \equiv \frac{n-3}{n-s}\right)$$

Reconciling T_e and VLBI expansion rate requires $s \lesssim 2$,
but $L_X(t)$ suggests $s > 2$.

Clumpy wind model (*Chugai 1993*)

cloud shock velocity $v_c = v_{\rm sh}/\delta^{1/2}$

Observed T_e suggests cloud density contrast $\delta \sim 10$.

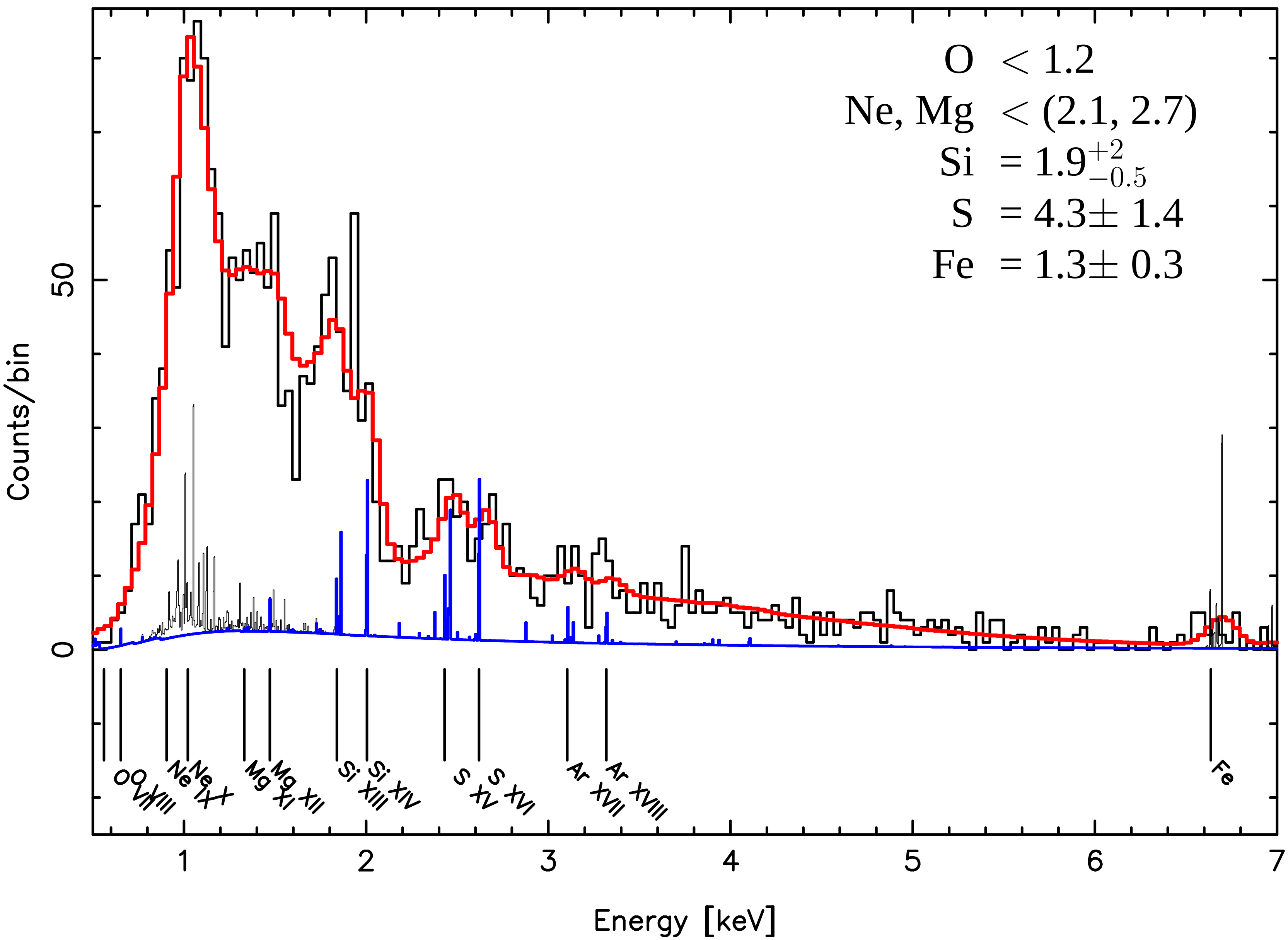
Progenitor Star

(Chugai 1997)

1. Massive, slow wind suggests 8-10 $M_\odot$ progenitor
2. AGB "superwind" phase *(e.g. Heger et al. 1997)*
   - large amplitude pulsations due to helium shell-flashes
   - $\dot{M} \sim 10^{-4}$ $M_\odot$ yr^{-1} for several 10^4 yr
3. O-Ne-Mg core yields electron capture core-collapse supernova *(Nomoto 1987; Nomoto et al. 1997)*
   - core burns to nuclear statistical equilibrium composition during explosion
   - Expect very low oxygen abundance

Chandra/ACIS-S3 (2003 Dec)

Equilibrium ionization fit:



Summary

- Large X-ray, radio luminosity
  $\Longrightarrow$ circumstellar interaction
- Continuing steep decline, $F_X \propto t^{-(1.7\pm0.25)}$
  $\Longrightarrow$ $\rho_{\rm csm}$ steeper than r^{-2}
- Light curve slope, electron temperature and radio expansion
  $\Longrightarrow$ not self-similar
- Electron temperature, $T_e \approx 5.5$ keV
  $\Longrightarrow$ X-ray emission dominated by reverse shocked ejecta
- Abundances
  $\Longrightarrow$ AGB "superwind"?