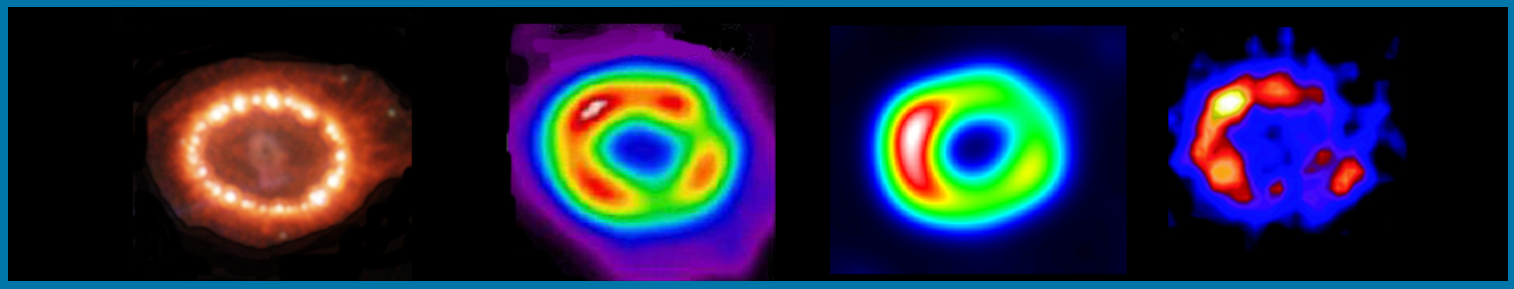
SN1987A: THE X-RAY REMNANT AT AGE 25 YEARS

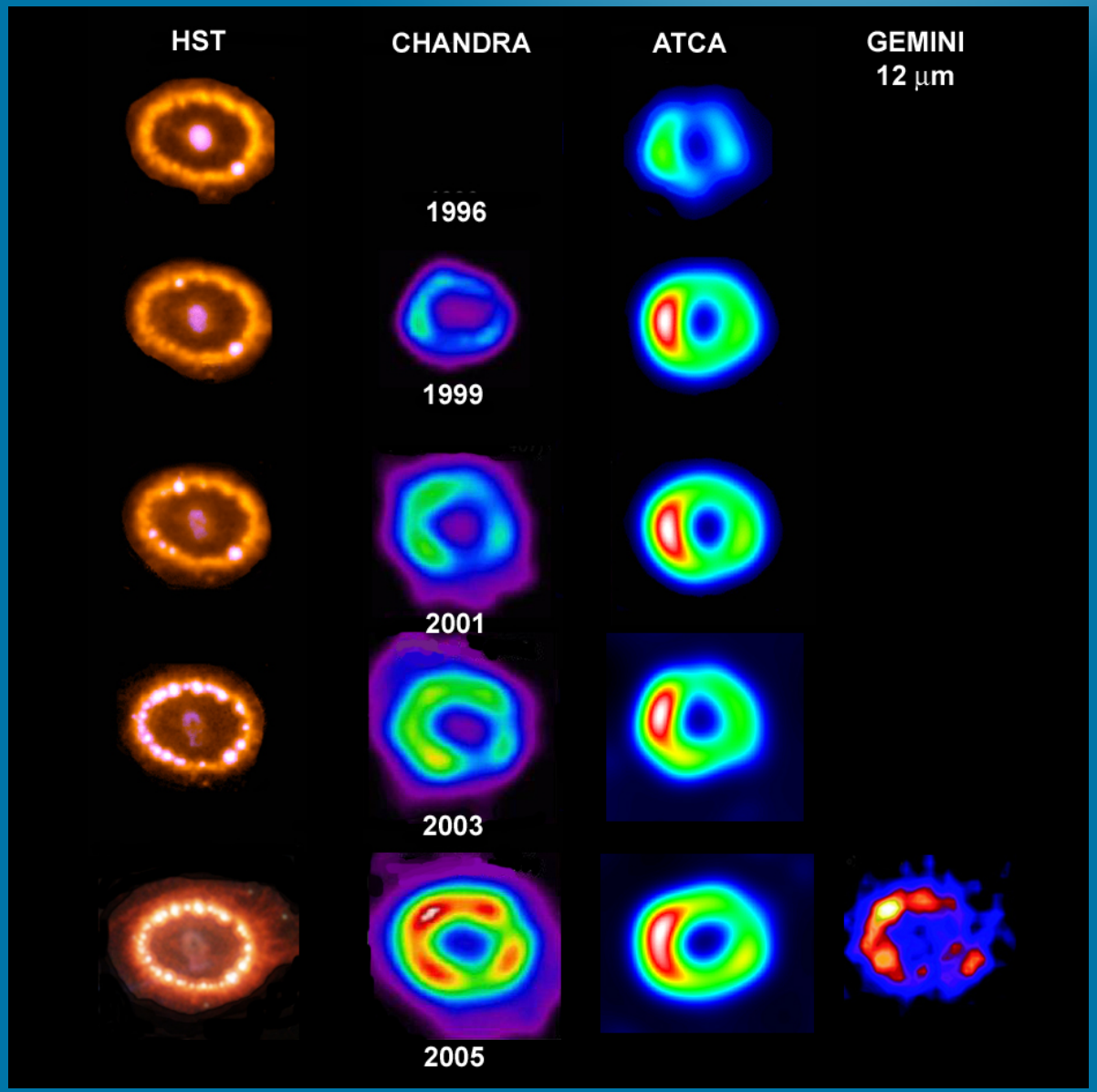
David Burrows (PSU), Sangwook Park (UT-Arlington), Eveline Helder (PSU), Dick McCray (U. Colorado), Svet Zhekov (SRI, Sofia), Dan Dewey (MIT), Judith Racusin (NASA/GSFC), Eli Dwek (NASA/GSFC), Bryan Gaensler (U. Sydney)

SN 1987A was unique

- First naked-eye SN since 1604 (Kepler)
- Known distance: (51.4 ± 1.2) kpc (Panagia+99)
- Known type: Type II-P core-collapse (neutrino burst)
- Known explosion date/time: 23 Feb, 1987 at 07:36 UT
- Known progenitor: Sk -69 202, B3I (blue supergiant)
- Observations cover the electromagnetic spectrum + neutrinos

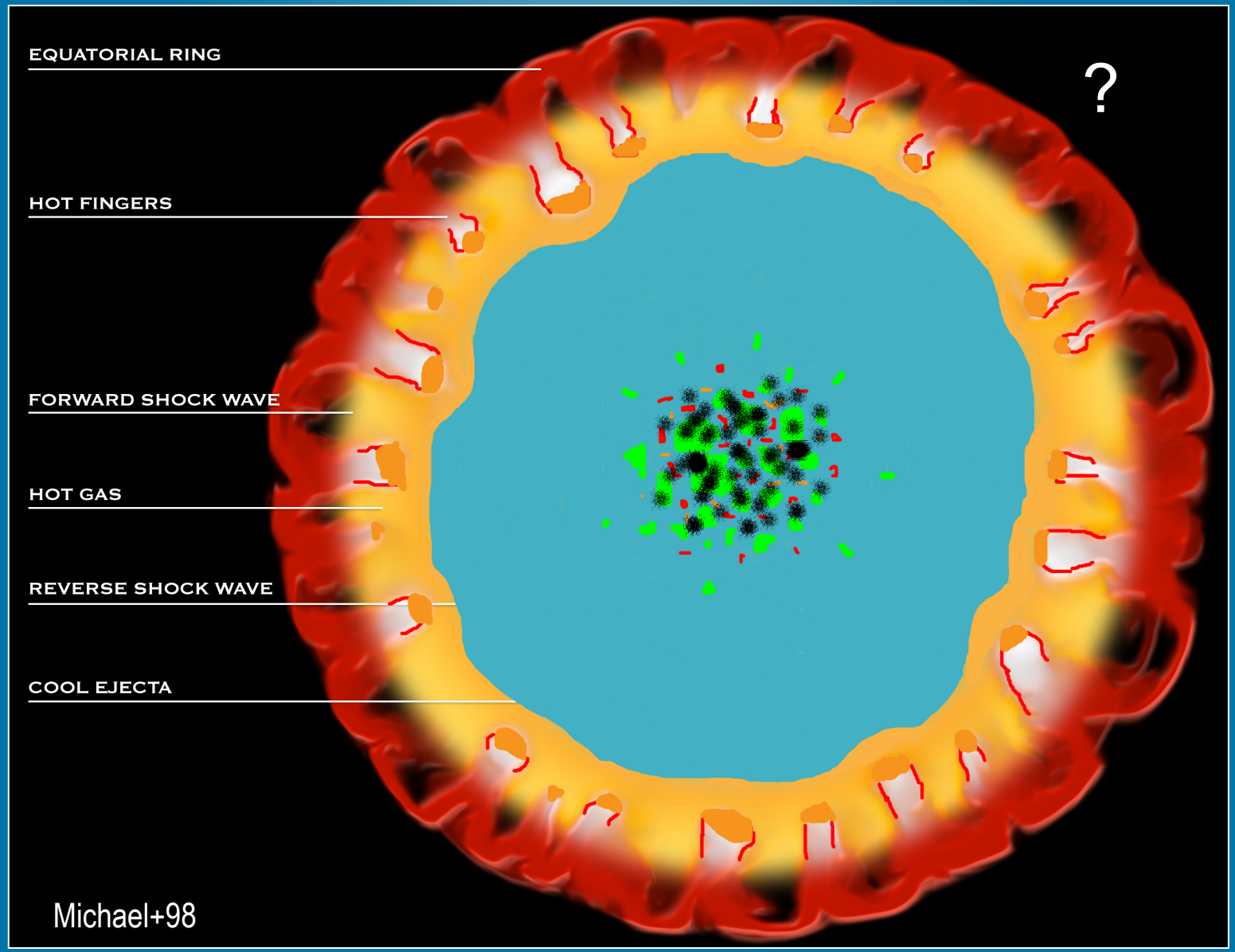


SN 1987A evolution

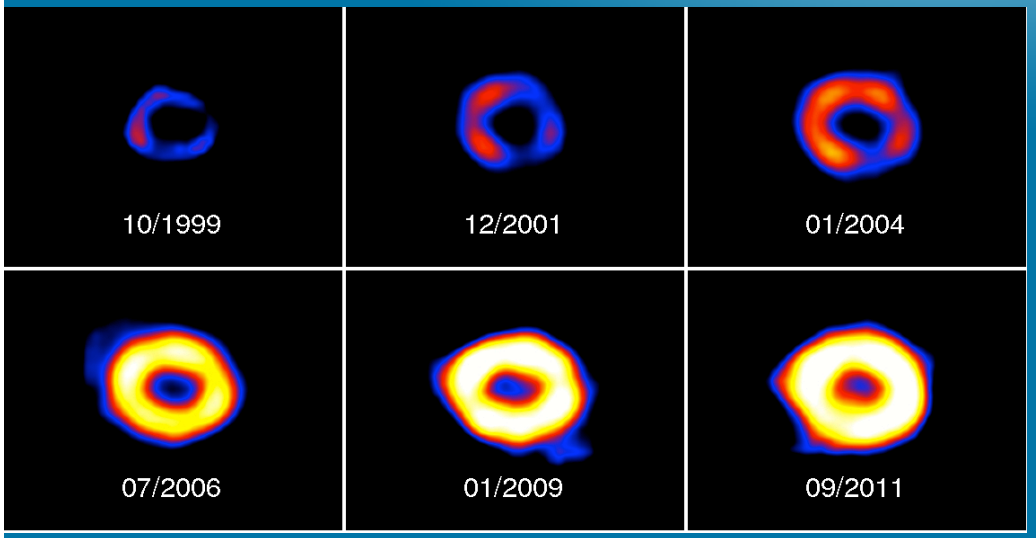


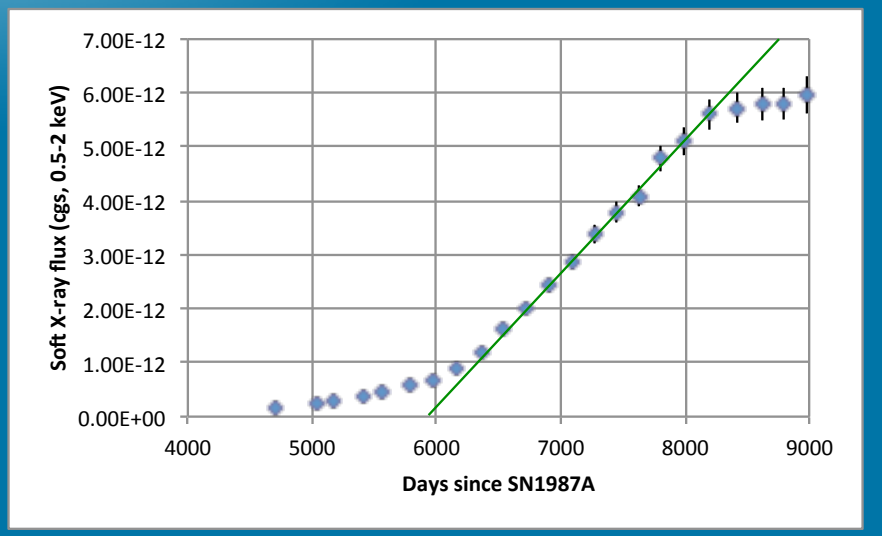
- Radio/X-ray emission began ~ 1200 d after explosion

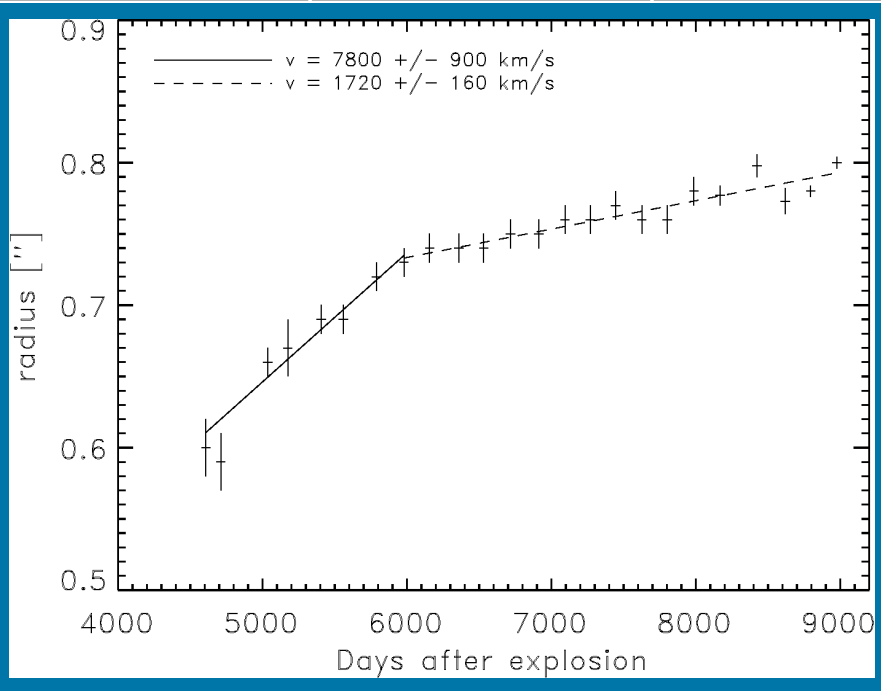
Cartoon of inferred structure (SAO/CXC)



X-ray evolution (Chandra)



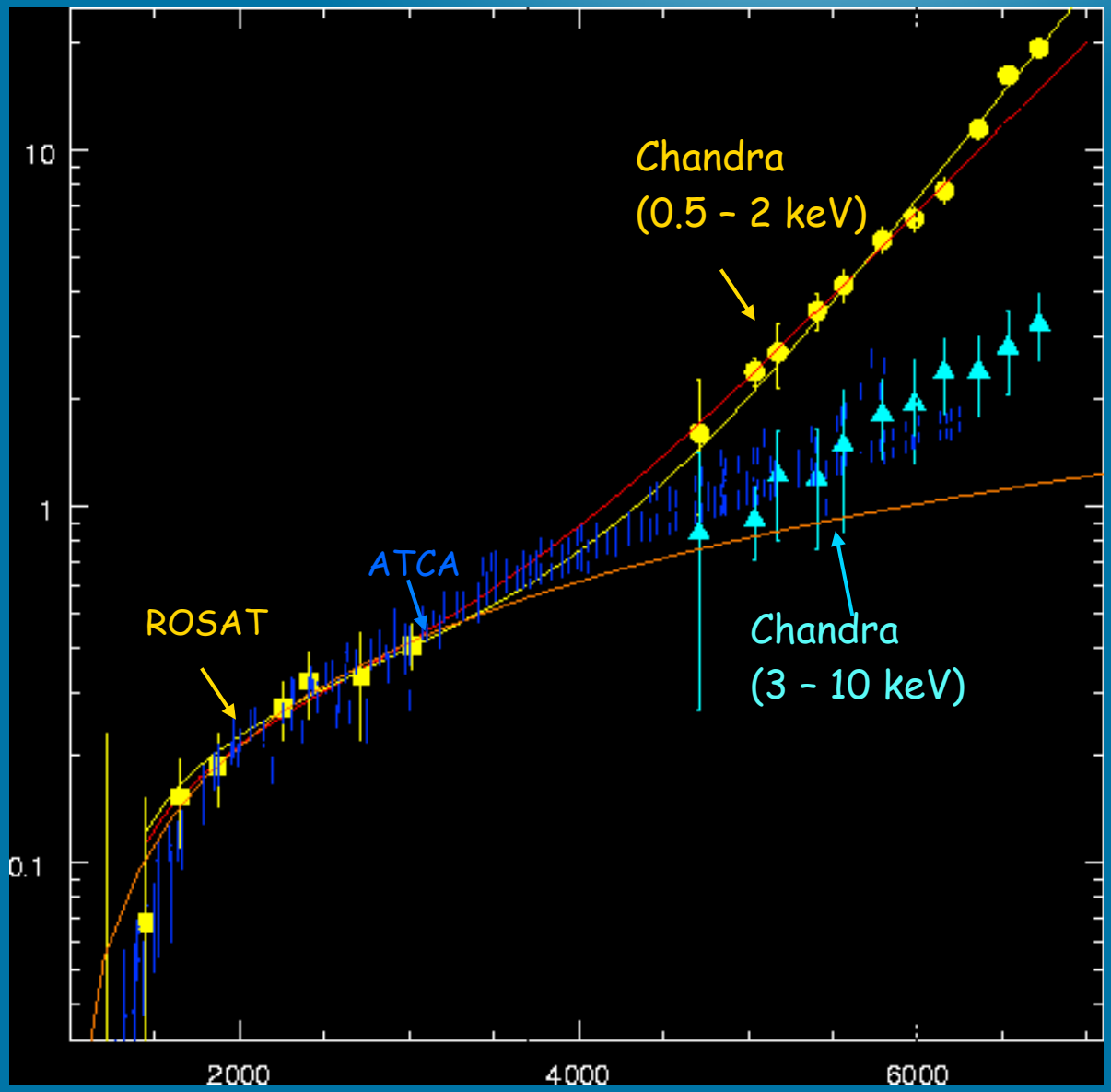




- Upturn in the light curve ~ day 6500
- Linear increase from 6500 – 8500 (Dec 2004 – June 2010)
- Nearly constant since June 2010
- Expansion rate slowed ~ day 6000 (Aug 2003)

Burrows+2000, Park+02,04,05,06,11, Zhekov+05,06,09,10, etc.

X-ray and Radio light curves

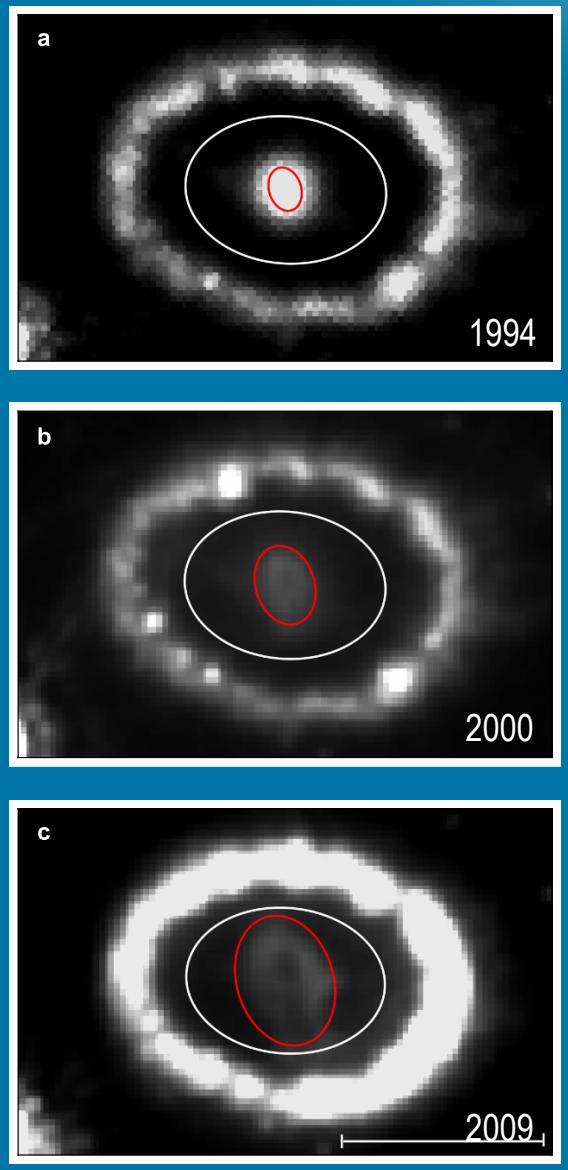


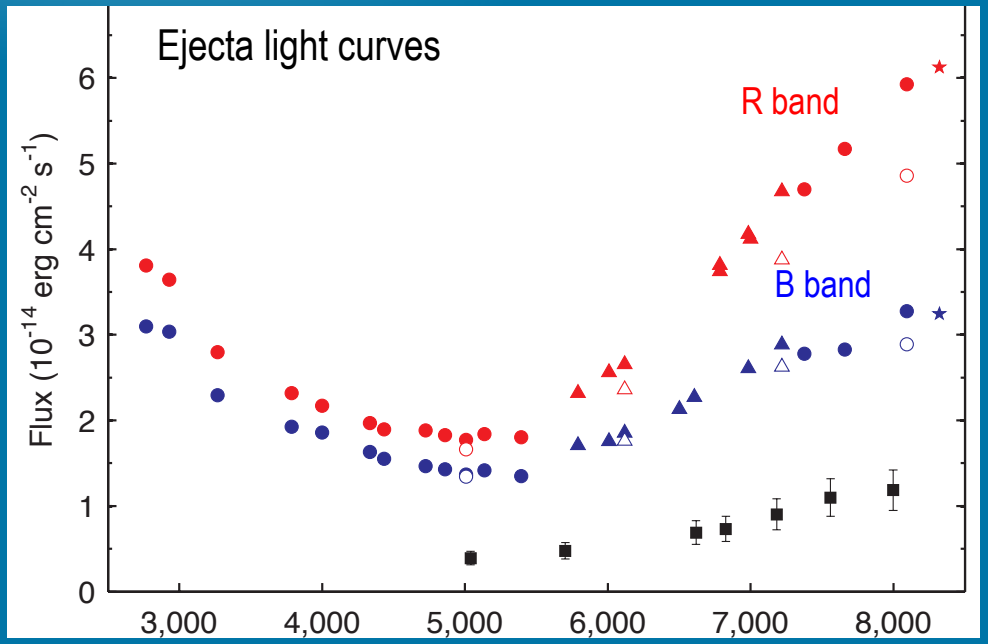
Soft X-ray light curve is linear before day 3000, can be fitted by interaction with exponential density profile for over a decade after day 3000.

Hard X-ray light curve tracks ATCA radio LC, roughly exponential.

Ratio of hard X-ray/Radio is nearly constant. Both dominated by shock in relatively low density gas ($n \sim 100$).

Optical evolution

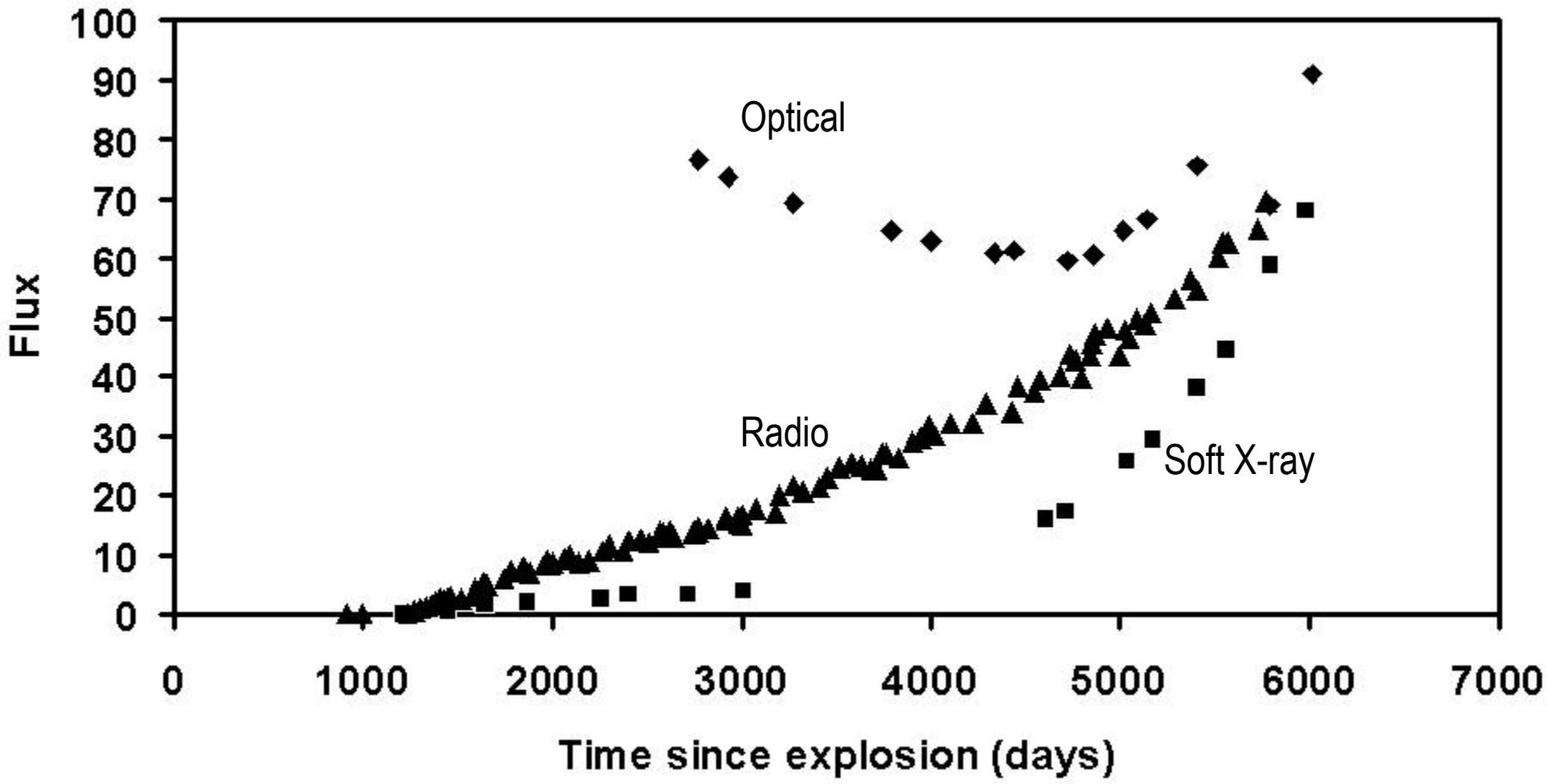




- Ejecta light curve before day 4500 dominated by radioactive decay of ^{44}Ti
- After day 5000, dominated by absorption of X-rays from shocked inner ring

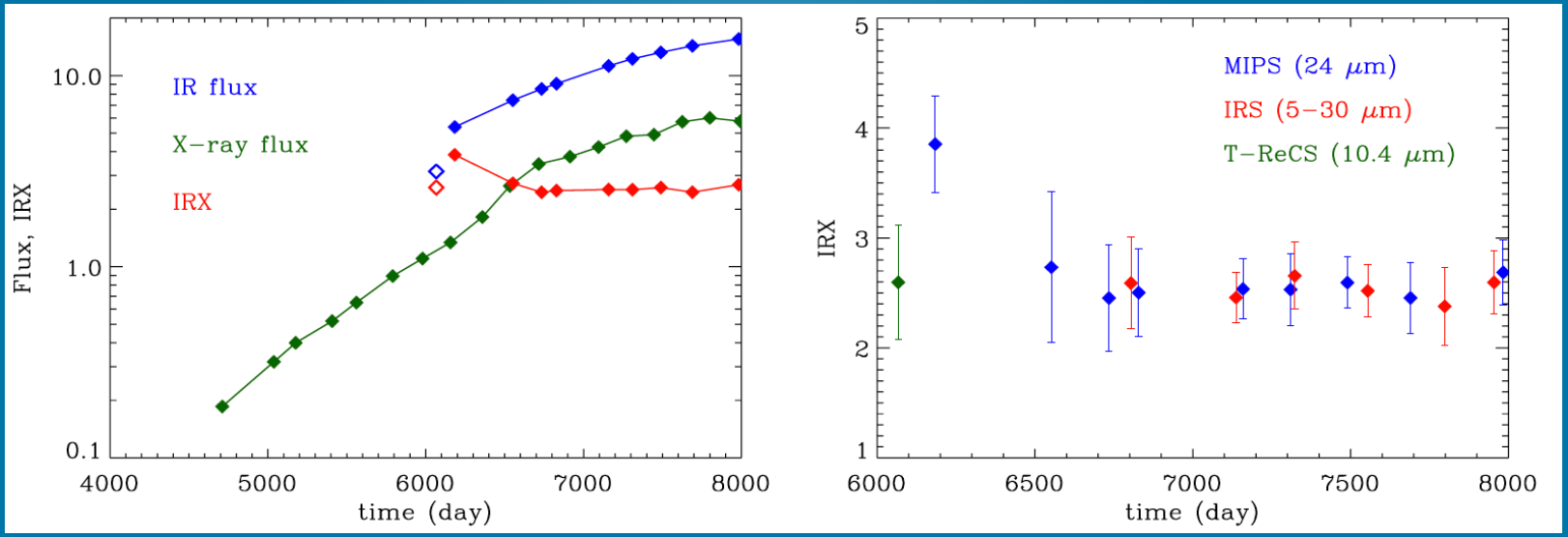
Larsson+11

Radio/Optical/X-ray light curves



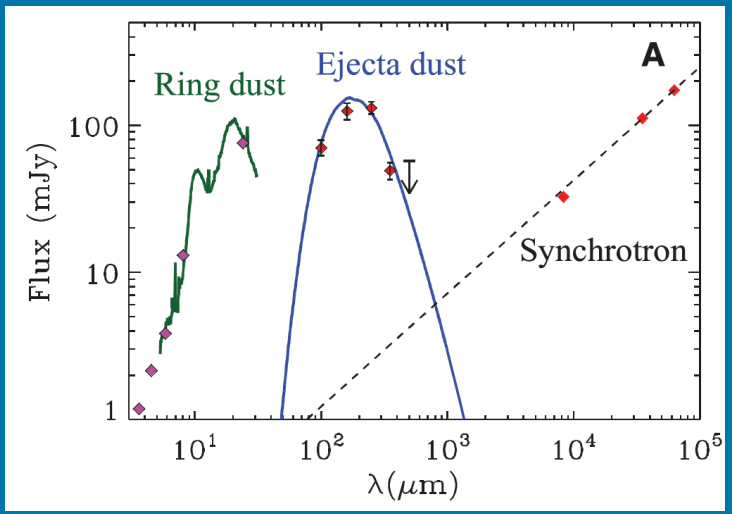
IR evolution

Dwek+10

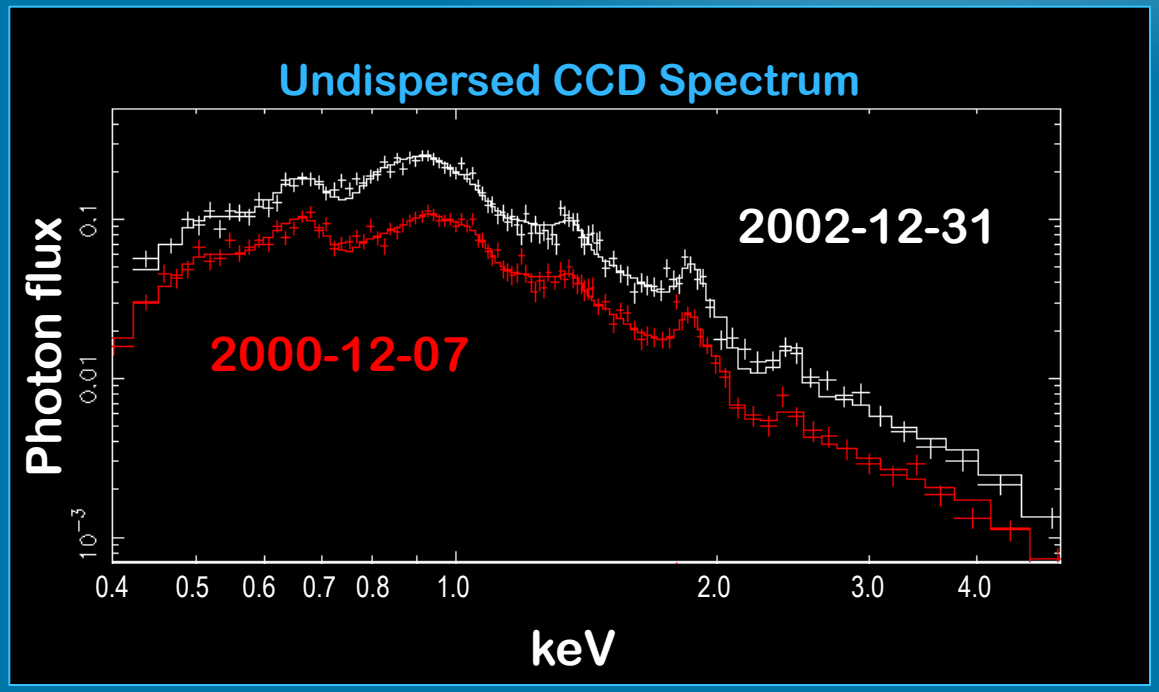


- Mid-IR flux (Spitzer) tracks X-ray flux, suggesting that mid-IR arises in silicate dust heated to 180K by collisions with shocked X-ray emitting gas in the inner ring [Dwek+10]. Inefficient dust formation in the ring.
- Far IR emission (Herschel) appears to be from 20K dust in the ejecta [Matsuura+11]. Efficient dust formation in ejecta.

Matsuura+11

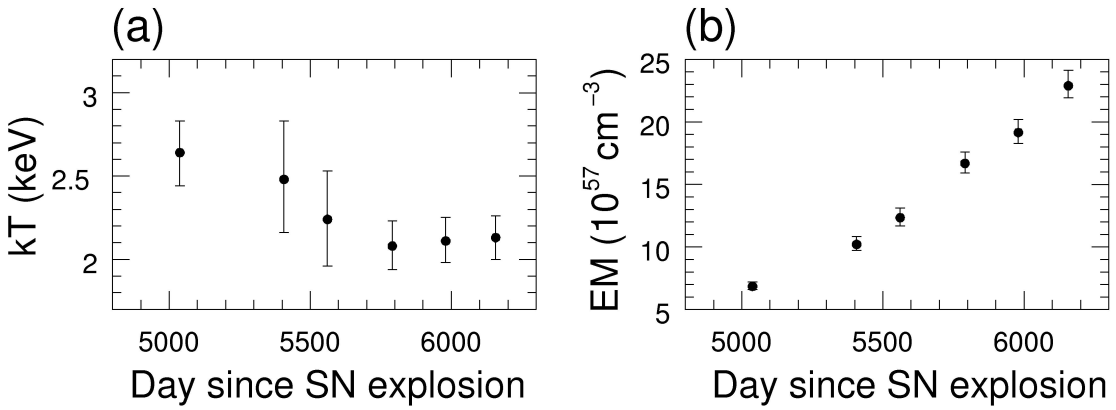


Early X-ray spectra

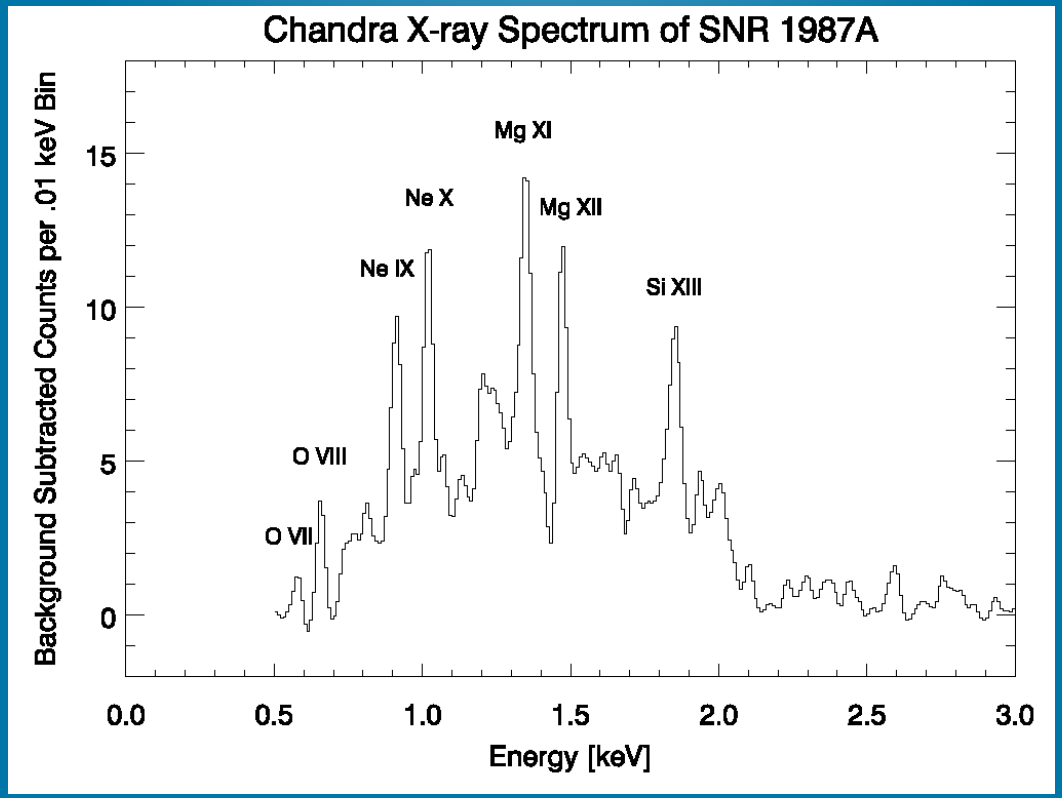


Single Temperature Fit

$N_H = 1.7 \times 10^{21}$ cm^{-2}
kT = 2.2-2.5 keV
$n_e t = 3.3 \times 10^{10}$ cm^{-3} s
Low abundances (0.1-0.5)
$n_e = 160 \sim 230$ cm^{-3}
=> ***Shocked CSM***

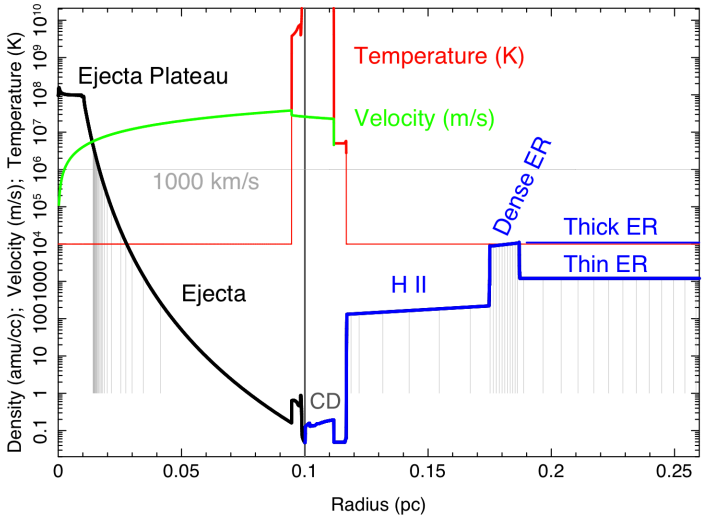


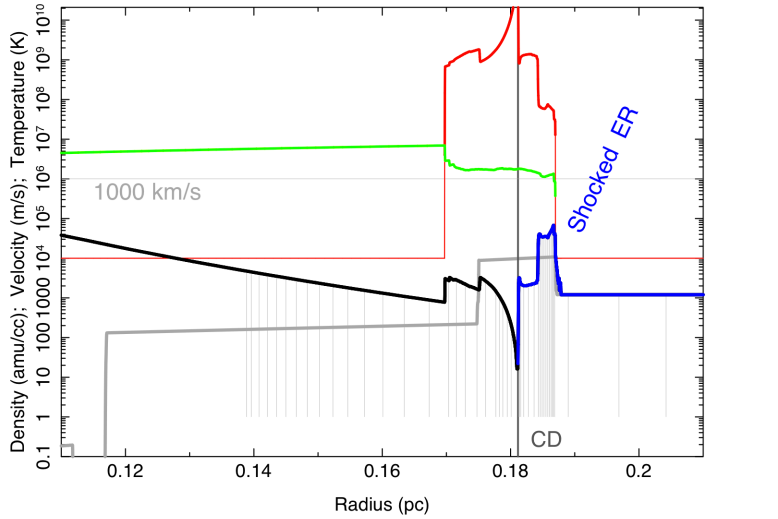
High resolution X-ray spectroscopy

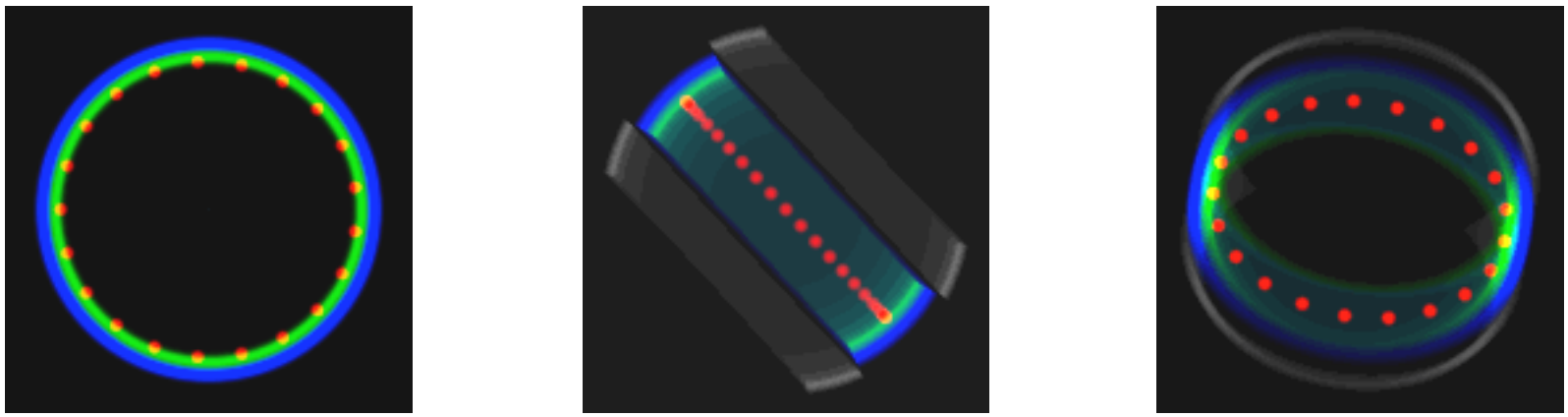


- Line widths are narrower than expected for measured temperature
  - ⇒ Bulk gas velocities are slower than expected: ~300 – 600 km/s
  - ⇒ X-ray emitting gas has been shocked by both forward and reverse shocks [Zhekov +04, Zhekov+09]
- Very broad component => fast shock in HII region out of equatorial plane (Dewey+12)

Physical model based on high-res spec.





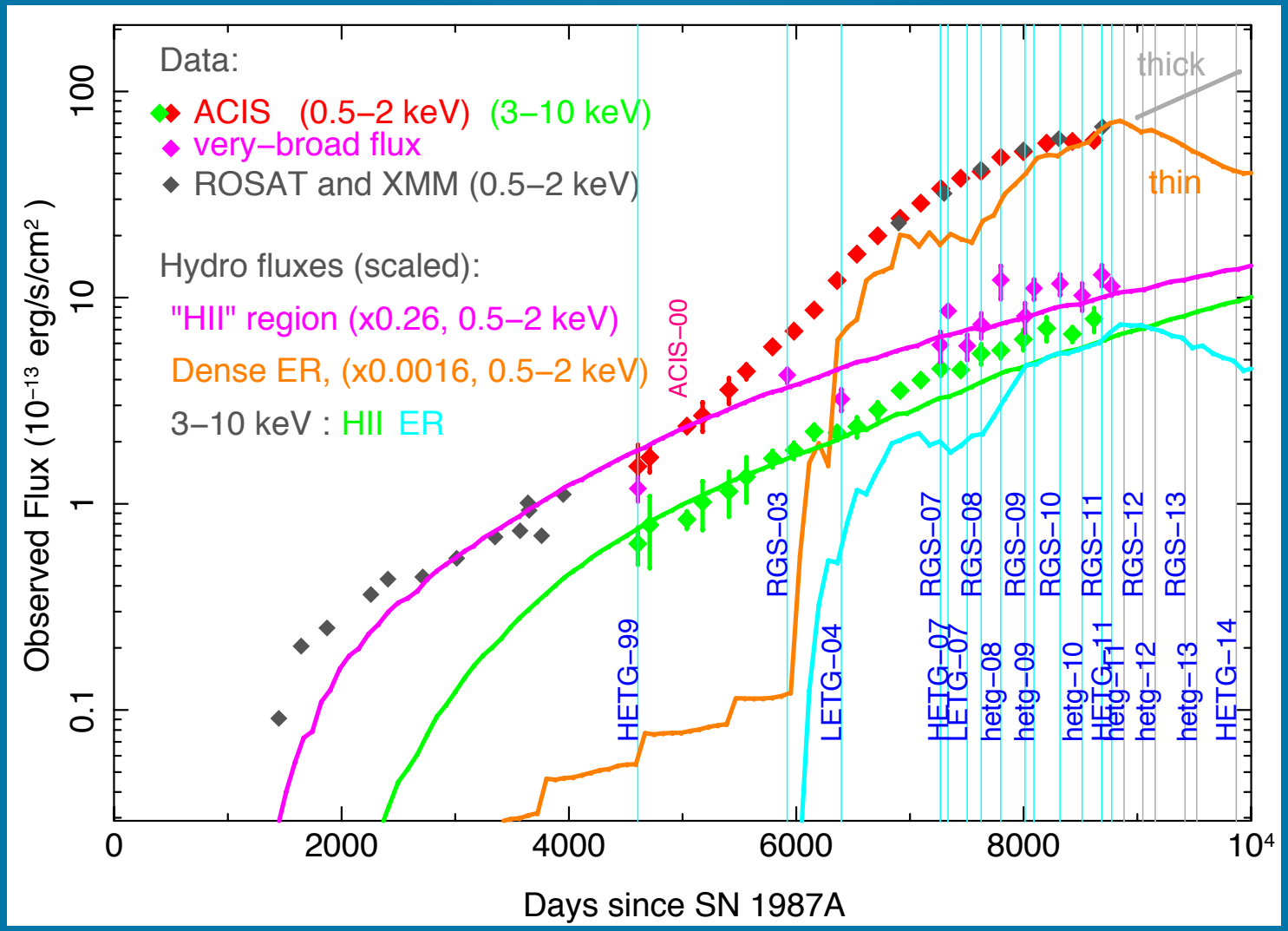


Emission components: Shocked HII Reverse-shocked ejecta Shocked ring High-latitude 8.6 GHz

Dewey+12

The Future of SN1987A

- Has the shock passed through the entire inner ring?



Dewey+12

Summary

- Chandra observations of SN 1987A:
  - Expansion of the X-ray remnant at ~ 1700 km/s
  - Multiple spectral components that can be fit with a combination of shocked equatorial ring, shocked HII, and reverse shocked ejecta
  - No sign yet of a compact remnant (NS or pulsar)
  - Leveling off of the X-ray flux may signal a decrease in the ring density – have we reached the limit of the inner ring? What lies beyond it?
  - ALMA will be able to resolve the remnant – should provide very interesting data in next year or two