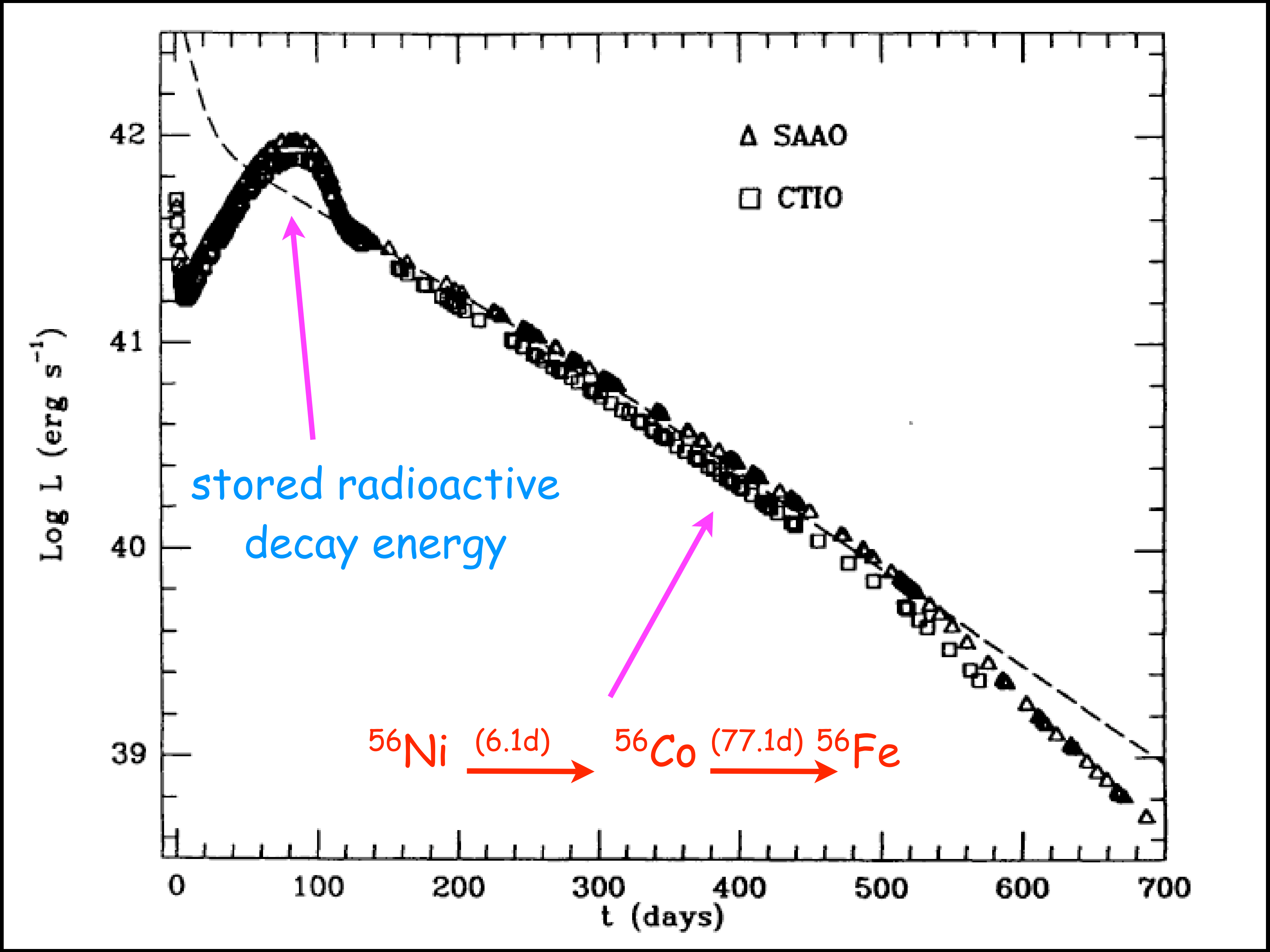
Dust-Gas interaction in SNR 1987A

Eli Dwek

Goddard Space Flight Center

How old were you when this issue of Time appeared?

Phase I: SN energetic powered by the decay of radioactive elements



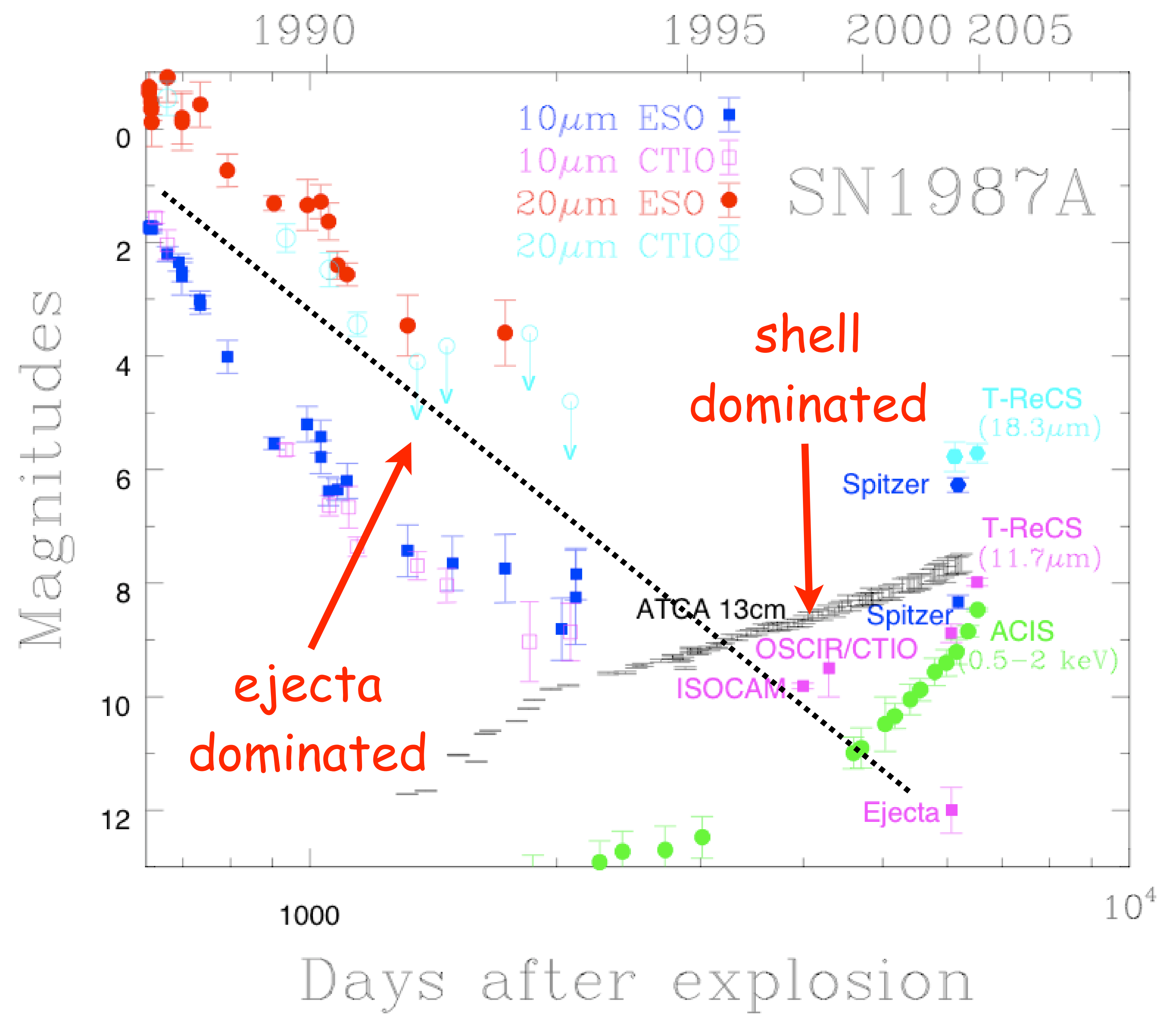
stored radioactive decay energy

^{56}Ni $\xrightarrow{(6.1d)}$ ^{56}Co $\xrightarrow{(77.1d)}$ ^{56}Fe

Aspen Conference on SN1987A: 20 Years After - Eli Dwek

The evolution of SN 1987A: From SN to SNR

(Bouchet et al 2006)



shell dominated

ejecta dominated

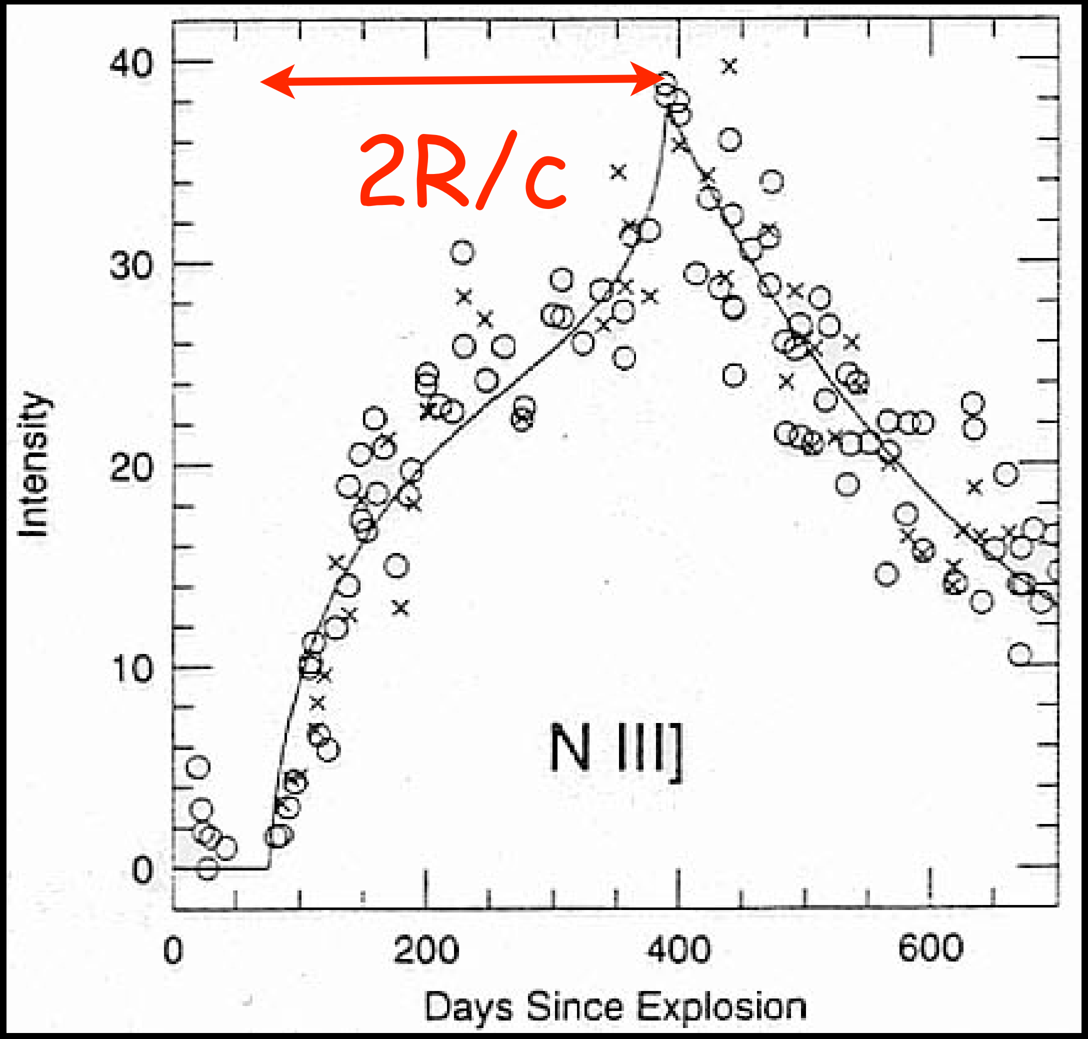
The Circumstellar Ring Around SN1987A

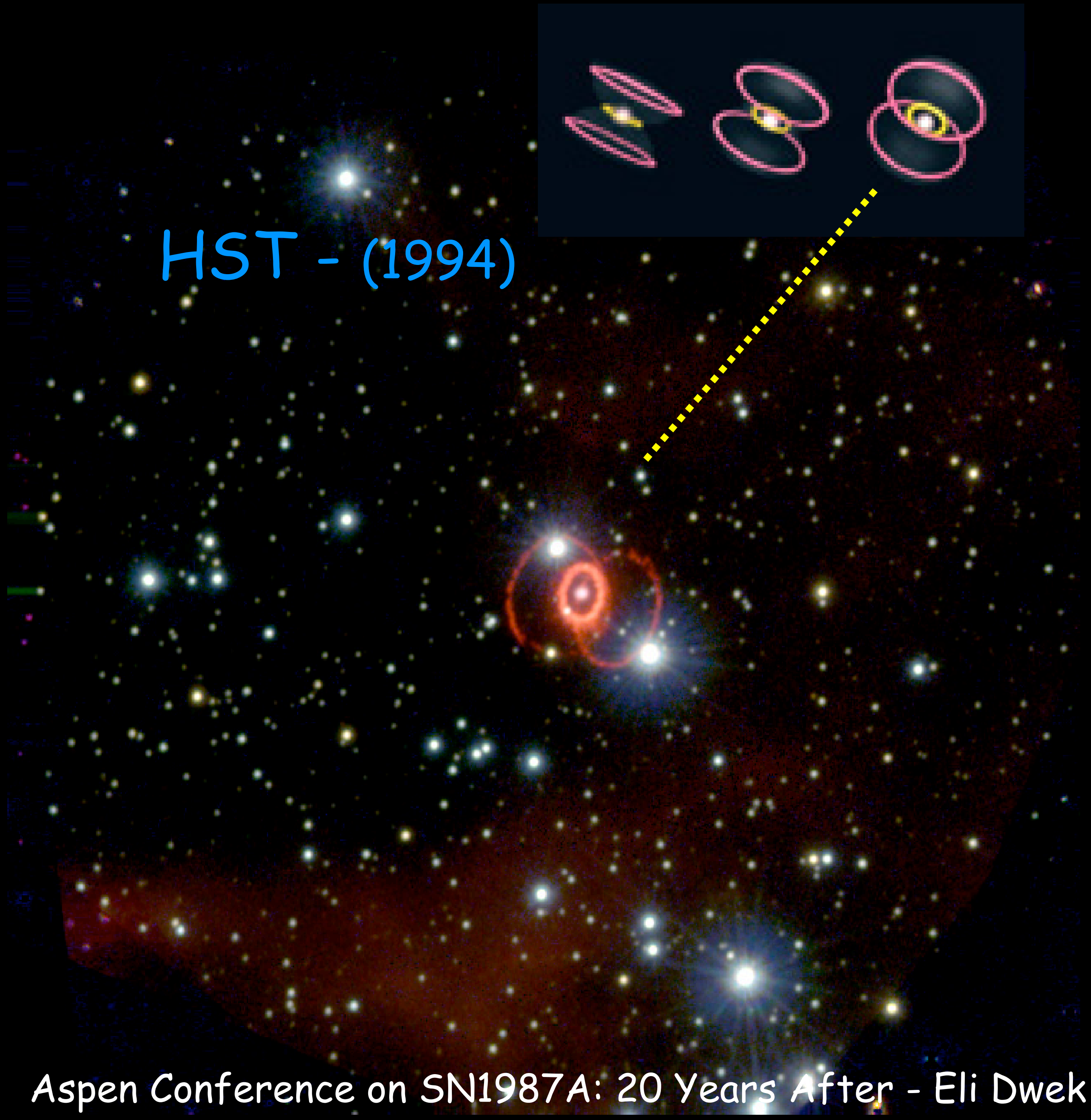
delayed signal

Earth

direct signal

(Sonneborn et al. 1994)





HST - (1994)

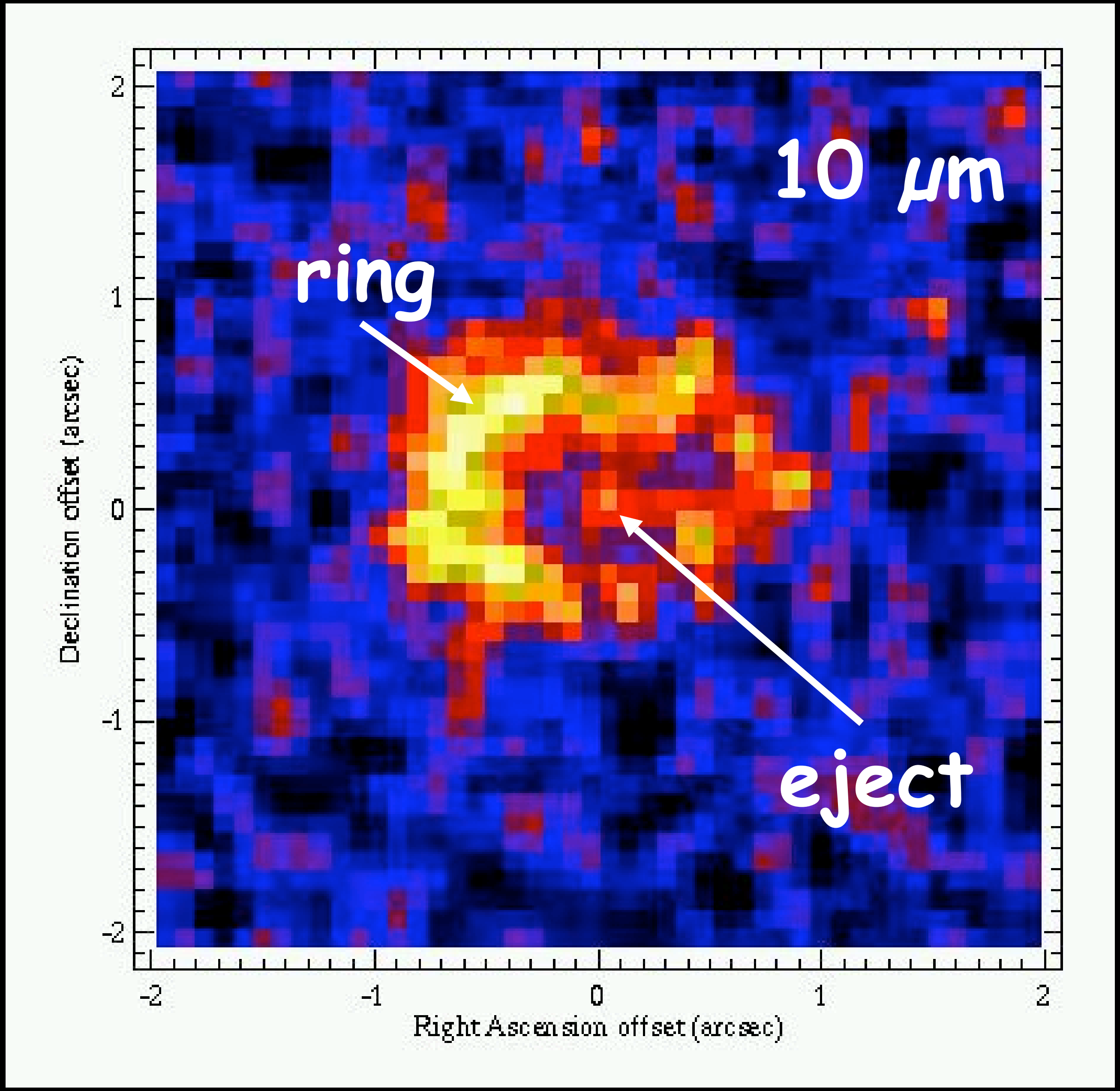
The infrared evolution of SN 1987A

T-ReCS instrument

on the Gemini South 8m telescope

(Bouchet et al. 2004)

Day 6067



Ring emission

Shock-heated dust

T≈ 180±15

$M \approx (0.1\text{-}1) \times 10^{-5}\ M_{sun}$

Ejecta emission

Hot dust

T≈ 100±10

$M \approx (0.1\text{-}2) \times 10^{-3}\ M_{sun}$

Ejecta is more likely Line emission from

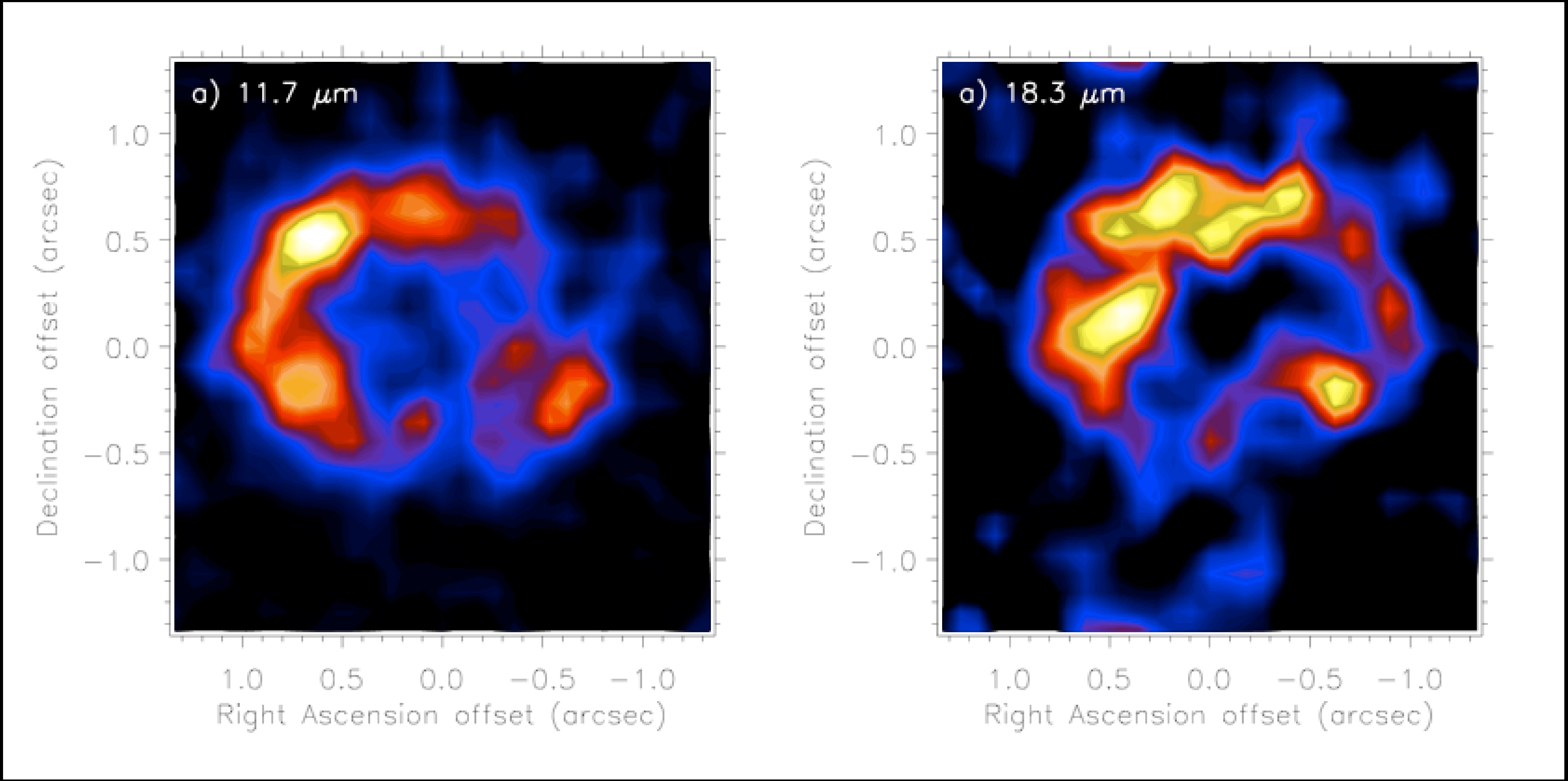
Ar III (8.99 μm)

S IV (10.51 μm)

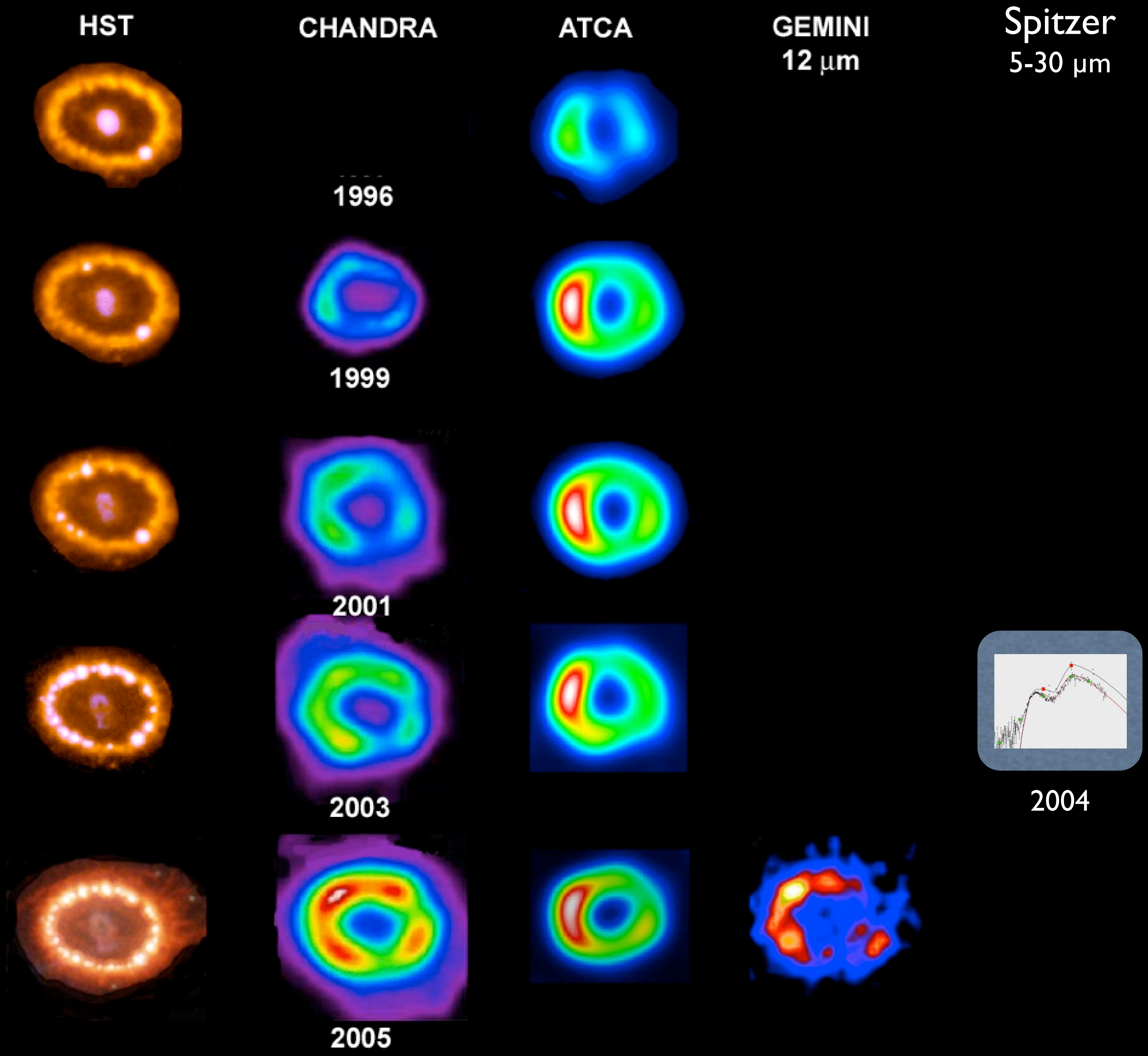
Ne II (12.81 μm)

T-ReCS observations of SN 1987A (day 6526)

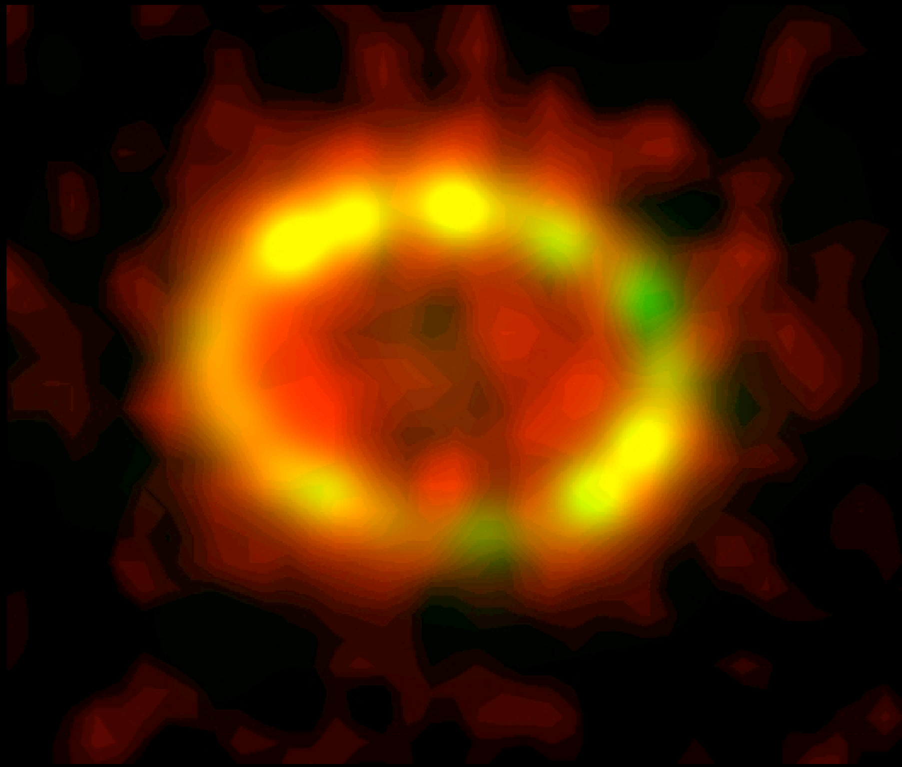
IR emission dominated by the equatorial ring



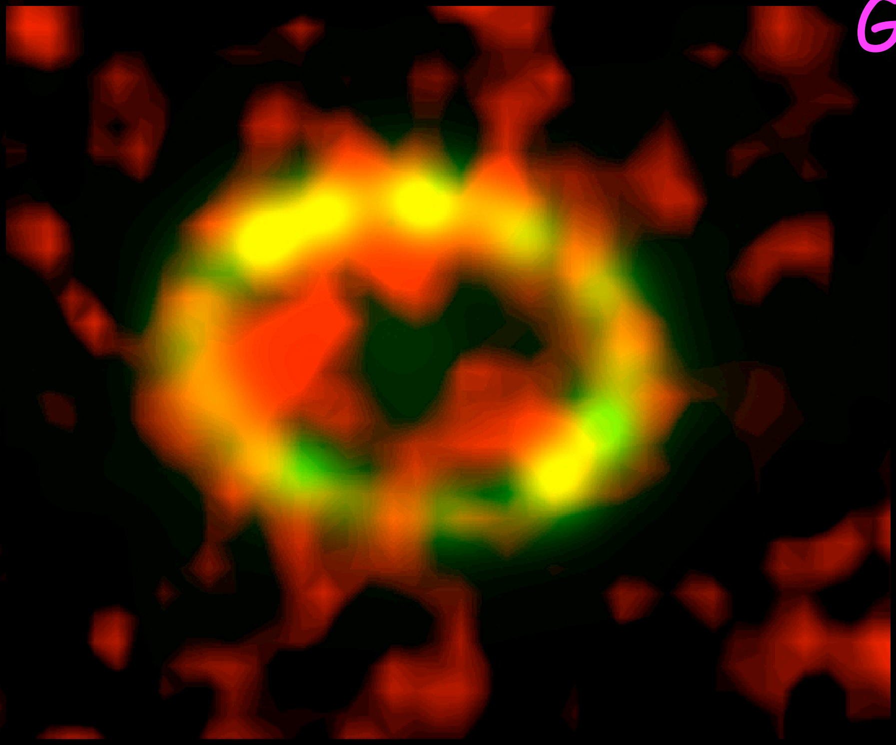
Multiwavelength Evolution of the Equatorial Ring



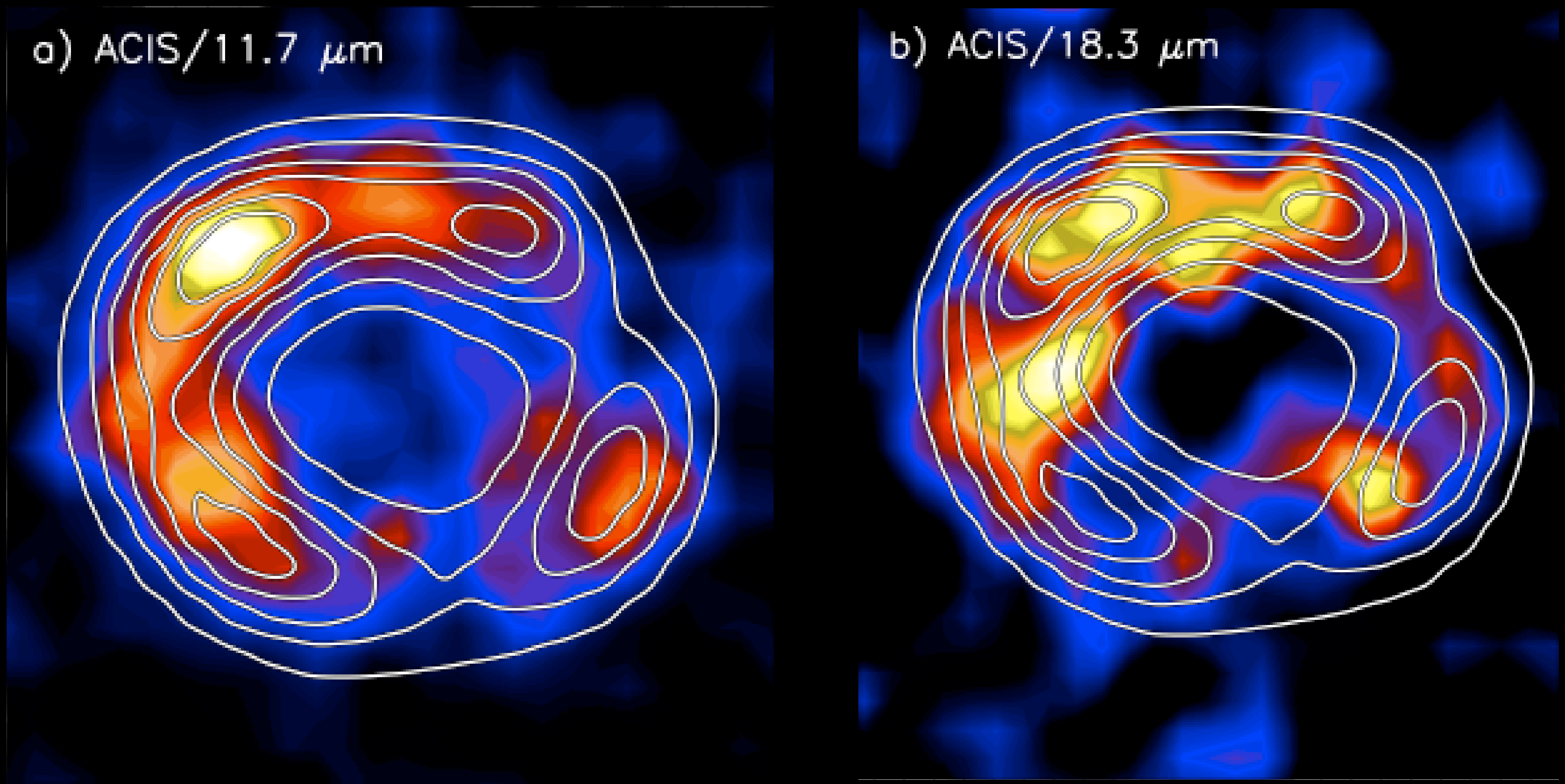
T-ReCS 11.7 μm + HST



T-ReCS 18.3 μm + HST



Good spatial correlation between T-ReCS, Chandra, and HST observations



- What heats the dust?

Radiation?

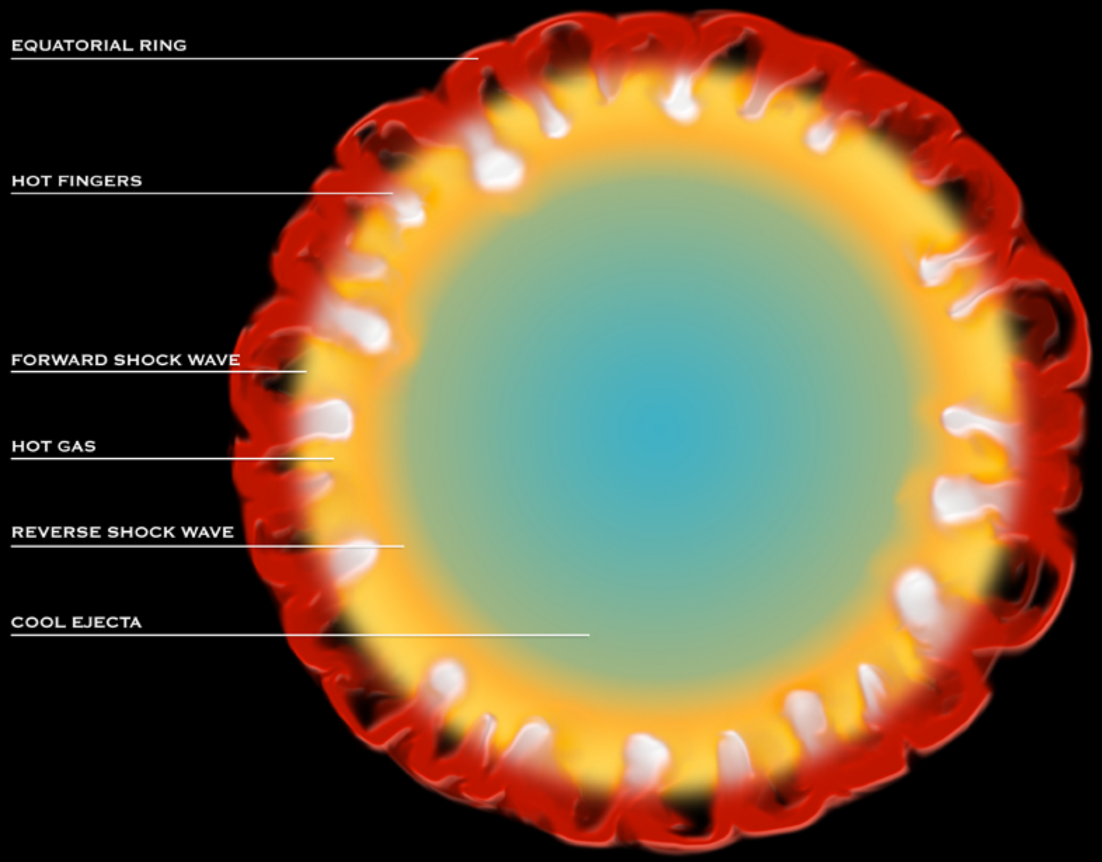
Collisions?

- Where is the dust?

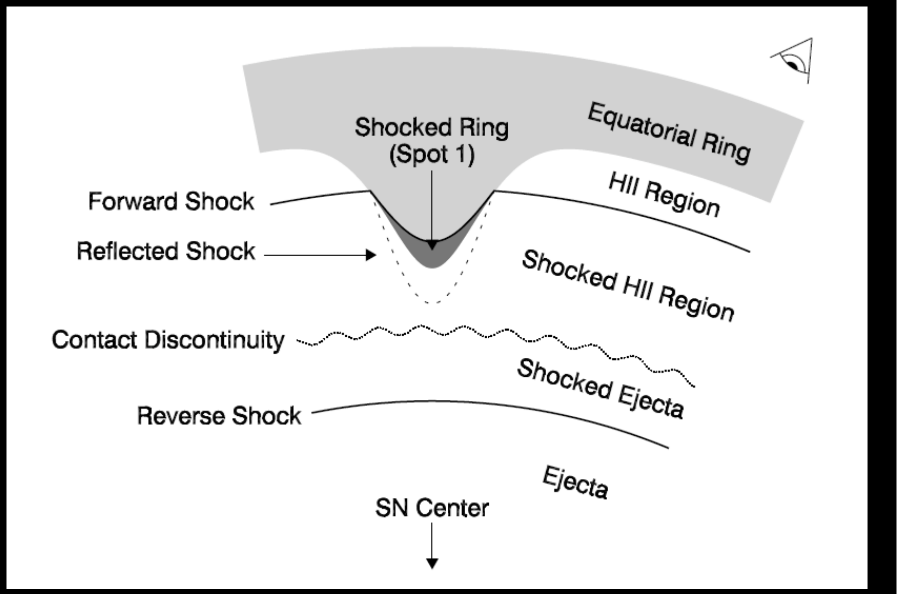
Dense knots?

X-ray gas?

The complex interaction of the blast wave with the equatorial ring



- Hubble (STIS) (Pun et al.)
  - preshock
    - $n_0 \approx 3\text{x}10^4$ cm^{-3}
  - postshock
    - $n_e \approx 10^6$ cm^{-3}
    - vs ≈ 135 and 250 km/s
- Chandra (Park et al. 2006)
  - kT ≈ 2 - 3 keV
  - $n_e t \approx 2\text{x}10^{11}$ cm^{-3}
- T-ReCS (Bouchet et al.)
  - $T_{dust} \approx 170$ K
  - $n_e \approx 300\text{–}1400$ cm^{-3}



Pun et al. 2002

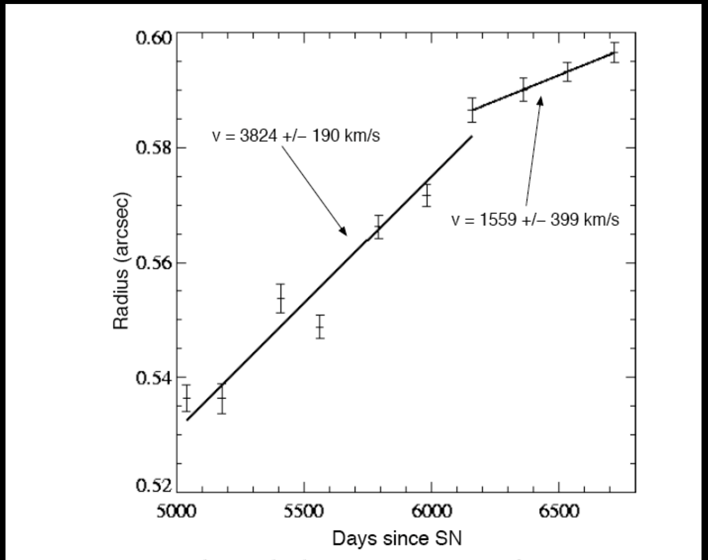
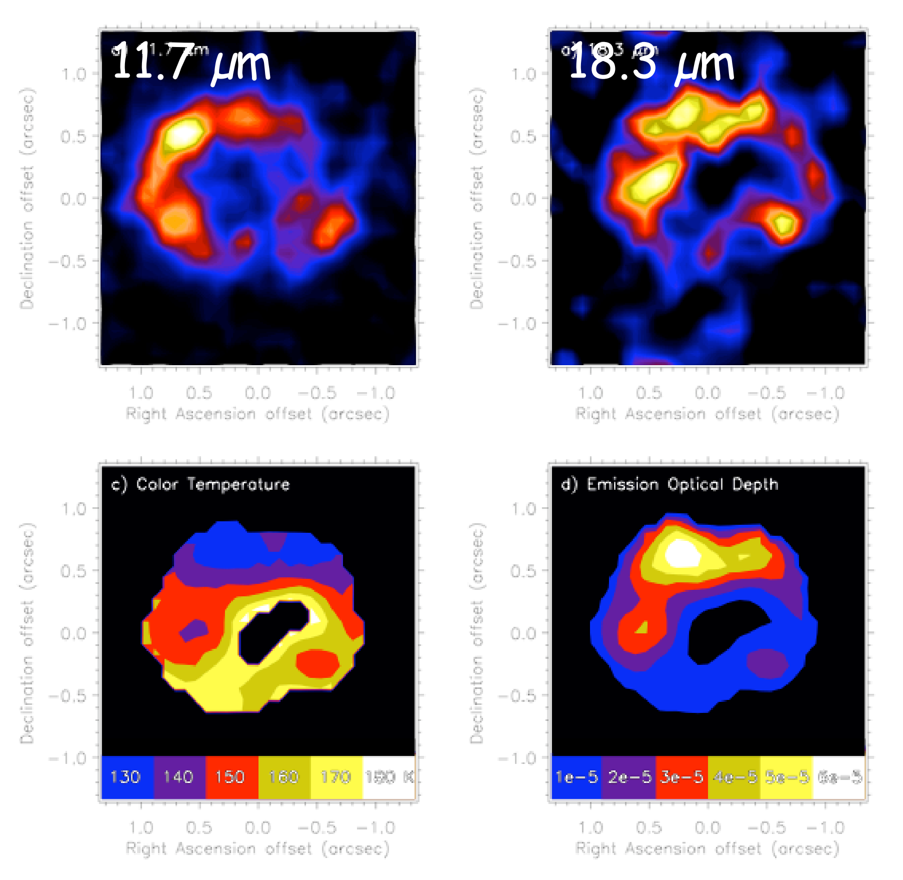


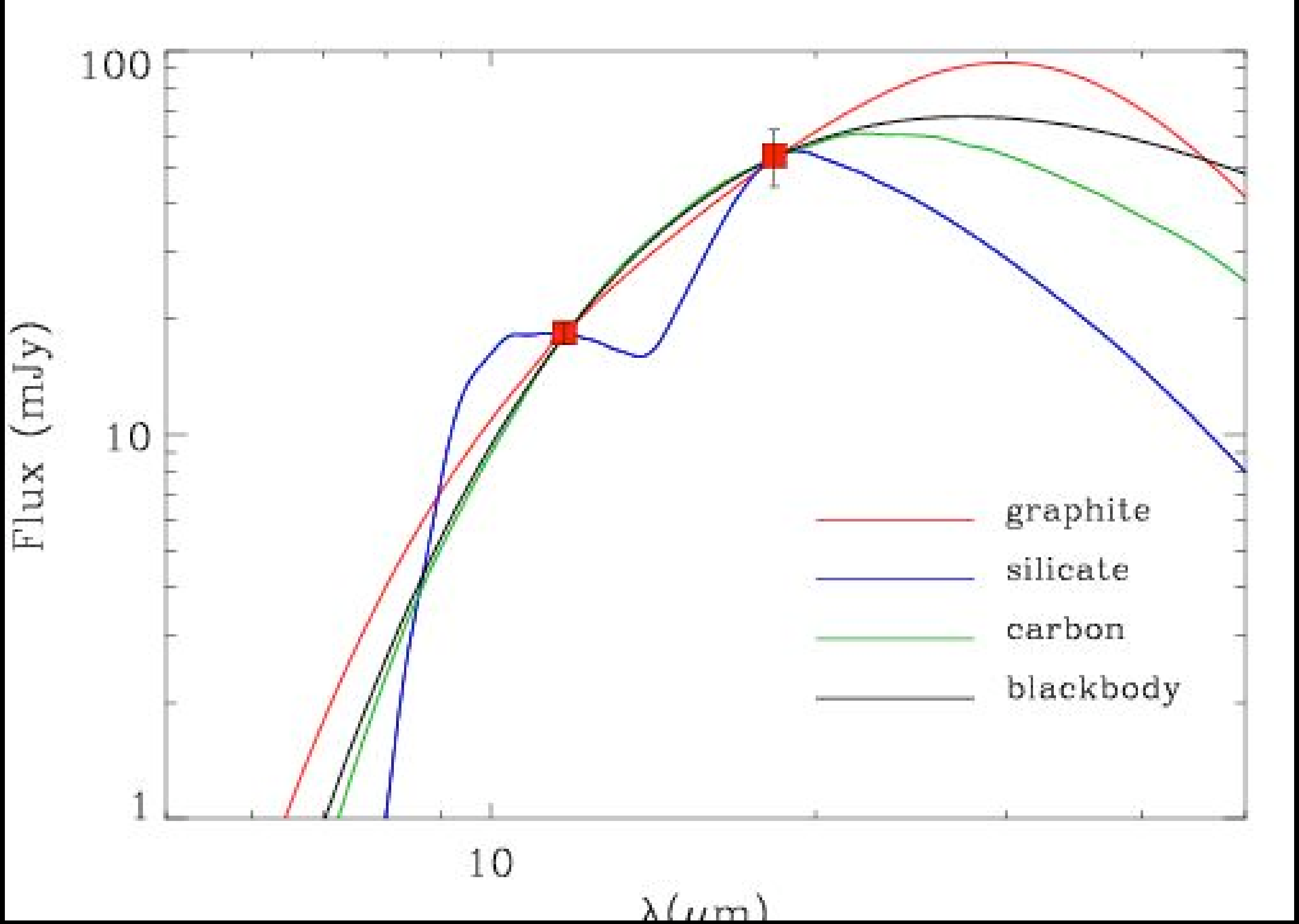
Figure 5. The radial expansion rate of SNR 1987A.

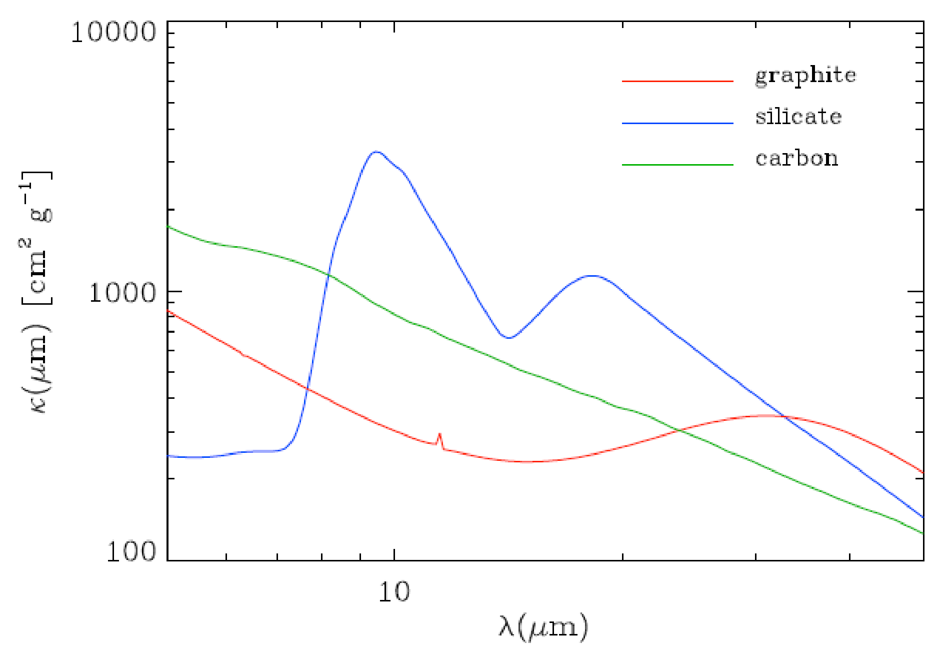
Park et al. 2002

Shock-heated circumstellar dust



T-ReCS observations resolve the ring, but with only two wavelengths, cannot provide constraints on dust composition



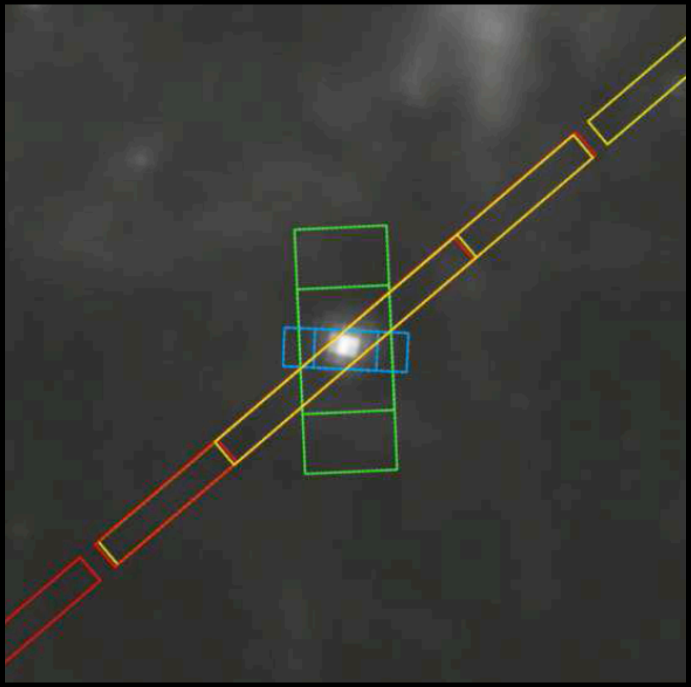


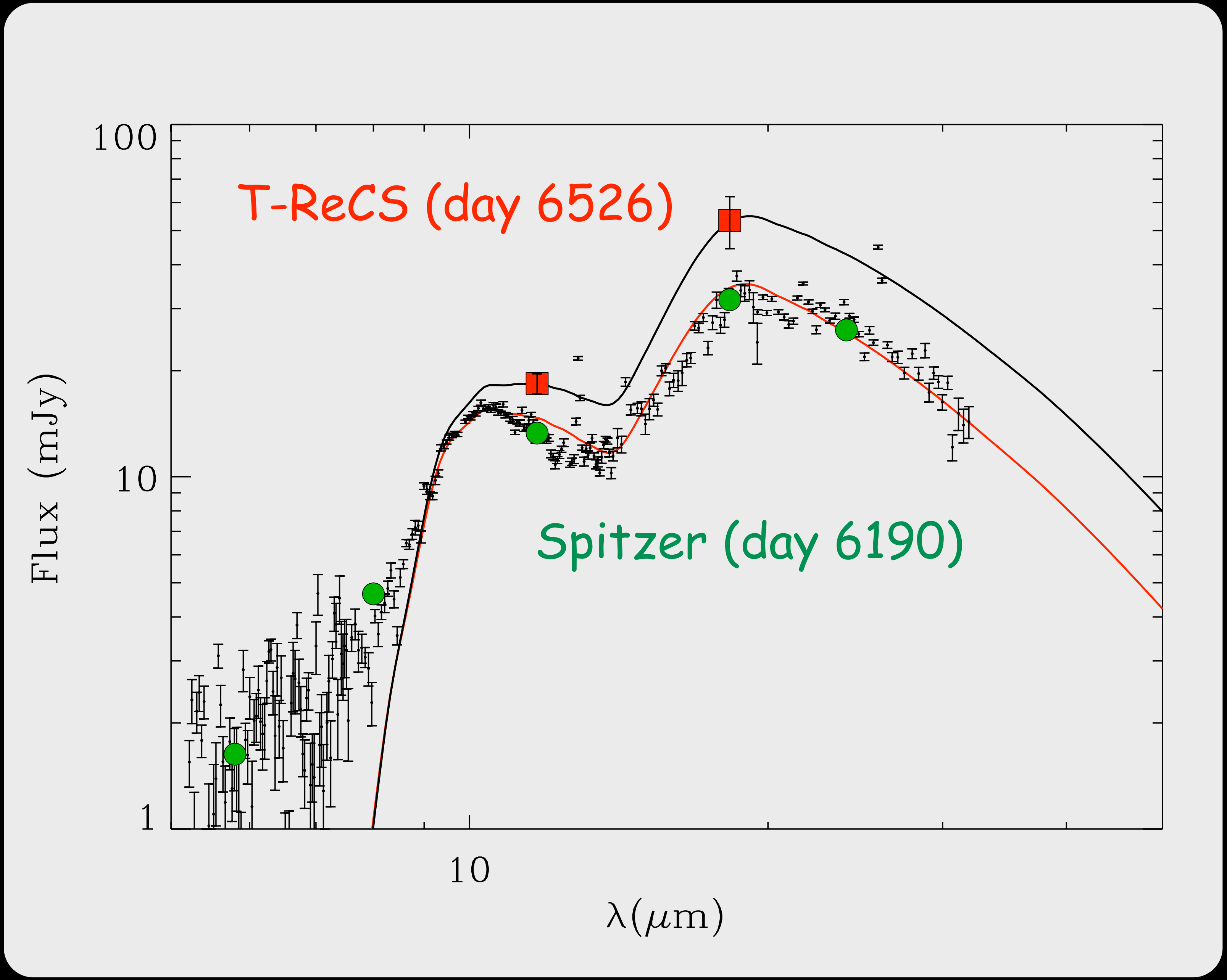
Shock-heated circumstellar dust

Spitzer – MIPS 24 μm (day 6184)
IRAC 3.6–8 μm (day 6130)
IRS 12–37 μm (day 6190)

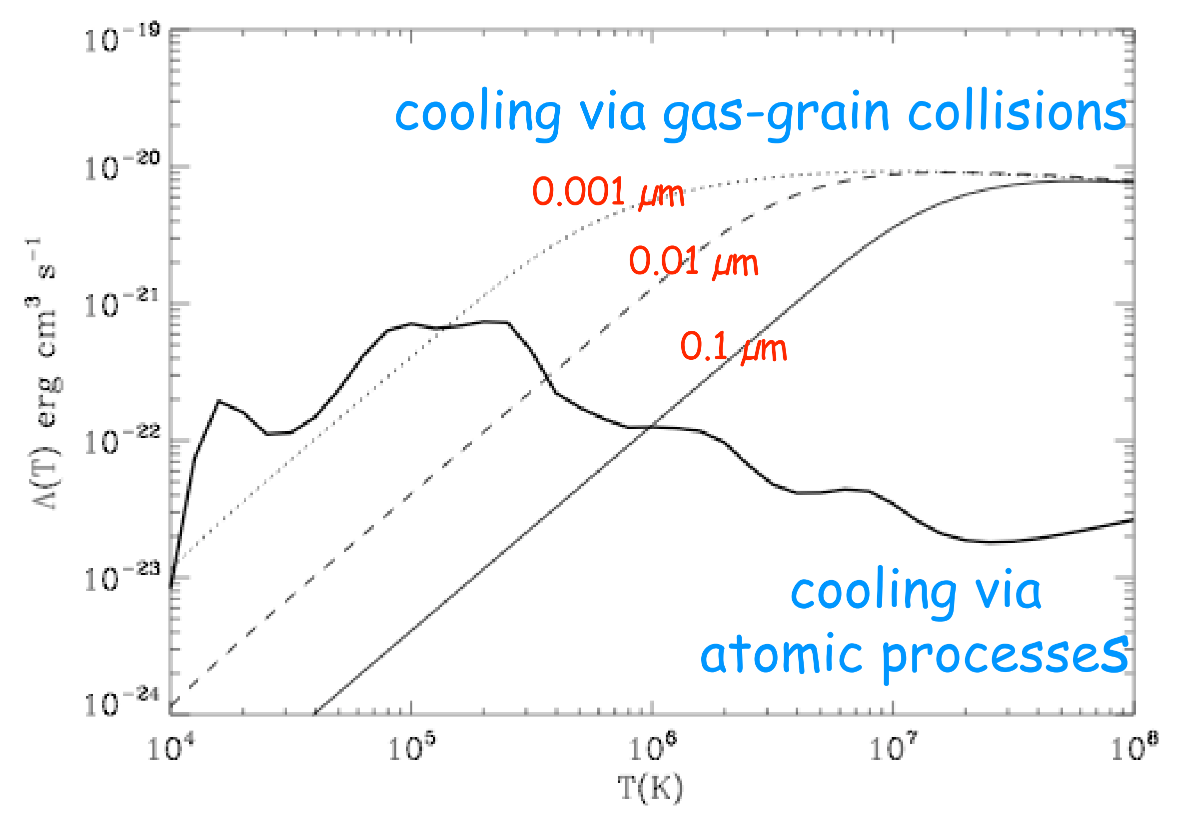
Shock-heated silicate dust
$T_{dust} \approx 170$ K
$M_{dust} \approx 3\times10^{-6}\ M_{sun}$

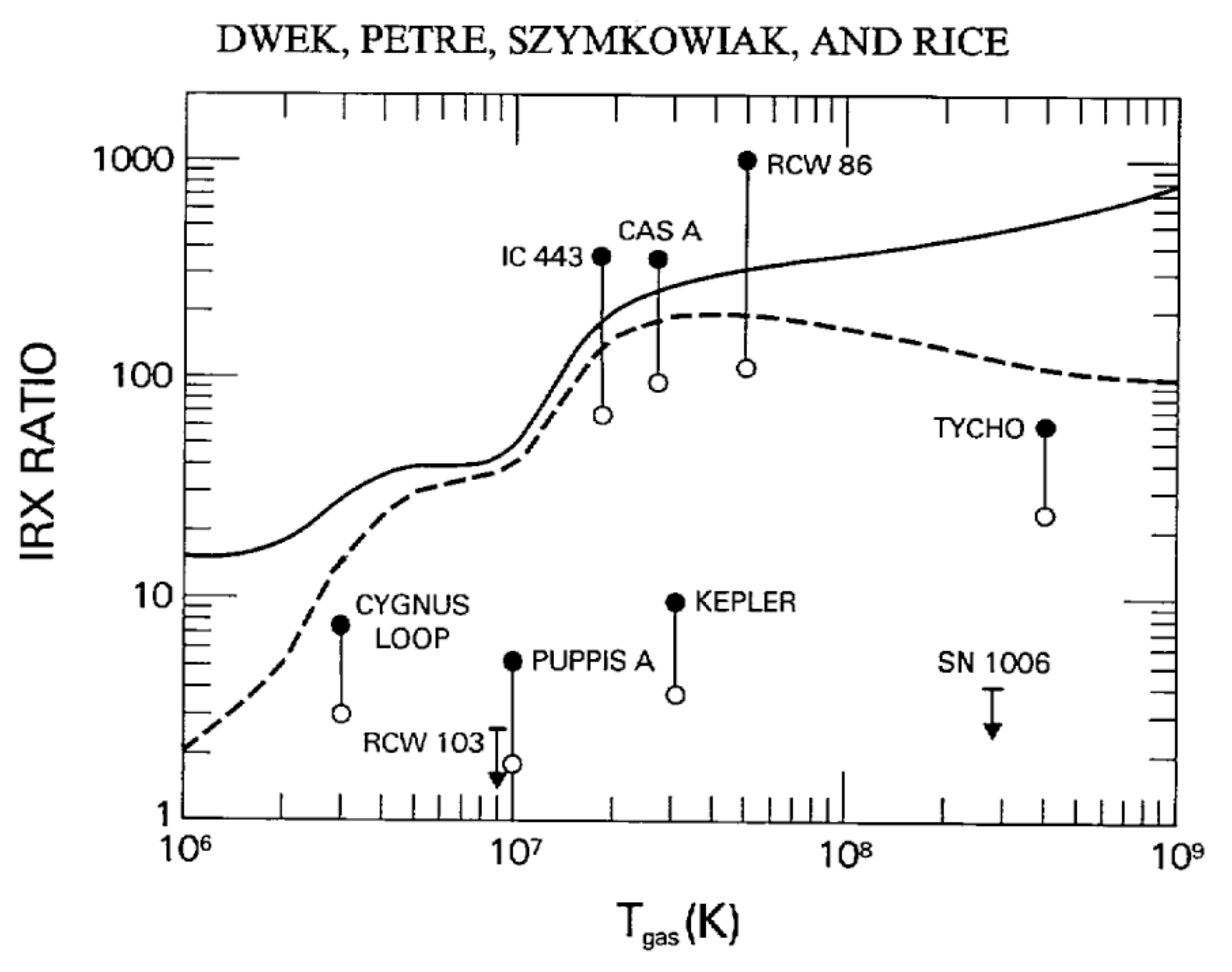
Spitzer observations
day 6190
(Gehrz, Polomski)





The cooling rate of a dusty plasma





- ✦ The IR-to-X ray flux ratio is a measure of the relative importance of the two mechanisms in the cooling of a dusty plasma

- ✦ At $T_{gas} \approx 2\times10^7$ K IRX ≈ 100 for a plasma with a typical dust-to-gas mass ratio (≈ 1%)

For SN 1987A IRX≈ 1 !
dust is severly depleted
in the shocked gas

Why is the IRX = L_{IR}/L_X Ratio so low?

- Inefficient dust production in the wind by the progenitor star
- Grain destruction by the SN shock wave

The importance of SN1987A

- IR diagnostic of dusty X-ray emitting plasmas
  - dust is collisionally-heated by the gas
  - above $T_{gas} \approx 10^6$ K, excellent n_{gas} diagnostic
  - studies of ion-electron temperature equilibration
- Study the dual role of SNe as dust sources and dust sinks
  - SNe may be the most important sources of interstellar dust ($\approx 1\ M_{sun}$/SN)
  - Reverse shocks and SNR are the most important destroyers of dust

Collisional Heating of Dust

$$\boxed{H = \pi a^2\, n\, v\, E_{dep}}$$

$$v \propto T_g^{1/2}$$

electrons stopped

$$E_{dep} \propto kT_g$$

$$H \sim a^2\, n\, T_g^{3/2}$$

electrons whiz through

$$dE/dx \sim E^{-1/2}$$

$$E_{dep} \sim aT_g^{-1/2}$$

$$H \sim a^3\, n$$

$$\boxed{L = \pi a^2\, \sigma T_d^4\, \langle Q \rangle}$$

$$\langle Q \rangle \propto a\, T_d^{\beta}$$

$$L \sim a^3\, T_d^{4+\beta}$$

$$L = H$$

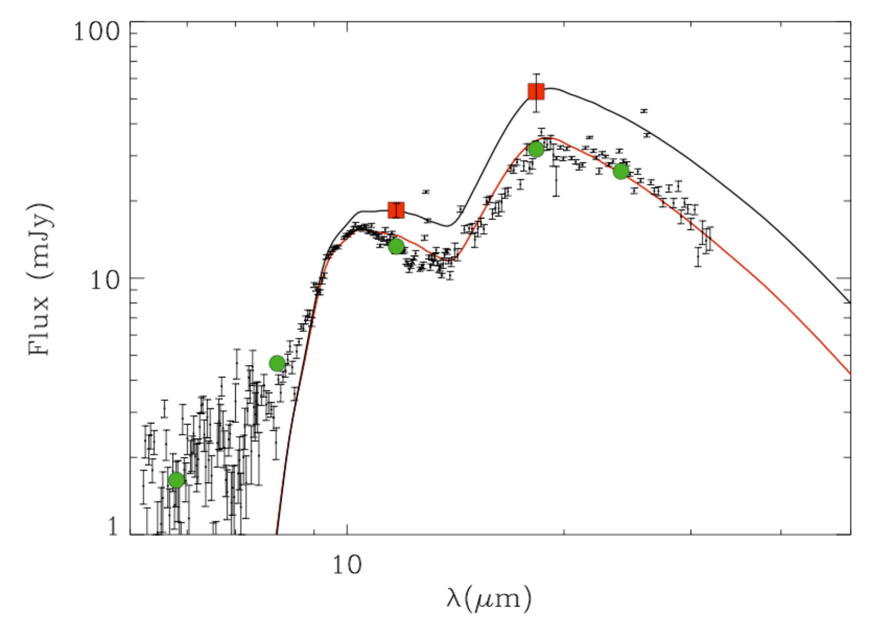
$$T_d \sim \frac{n}{a}\, T_g^{\gamma}$$

electrons stopped

$$T_d \sim n^{1/4+\beta}$$

electrons whiz through

An infrared diagnostic of a dusty X-ray emitting plasma



Spitzer observations can be fit with a silicate dust spectrum radiating at a dust temperature:

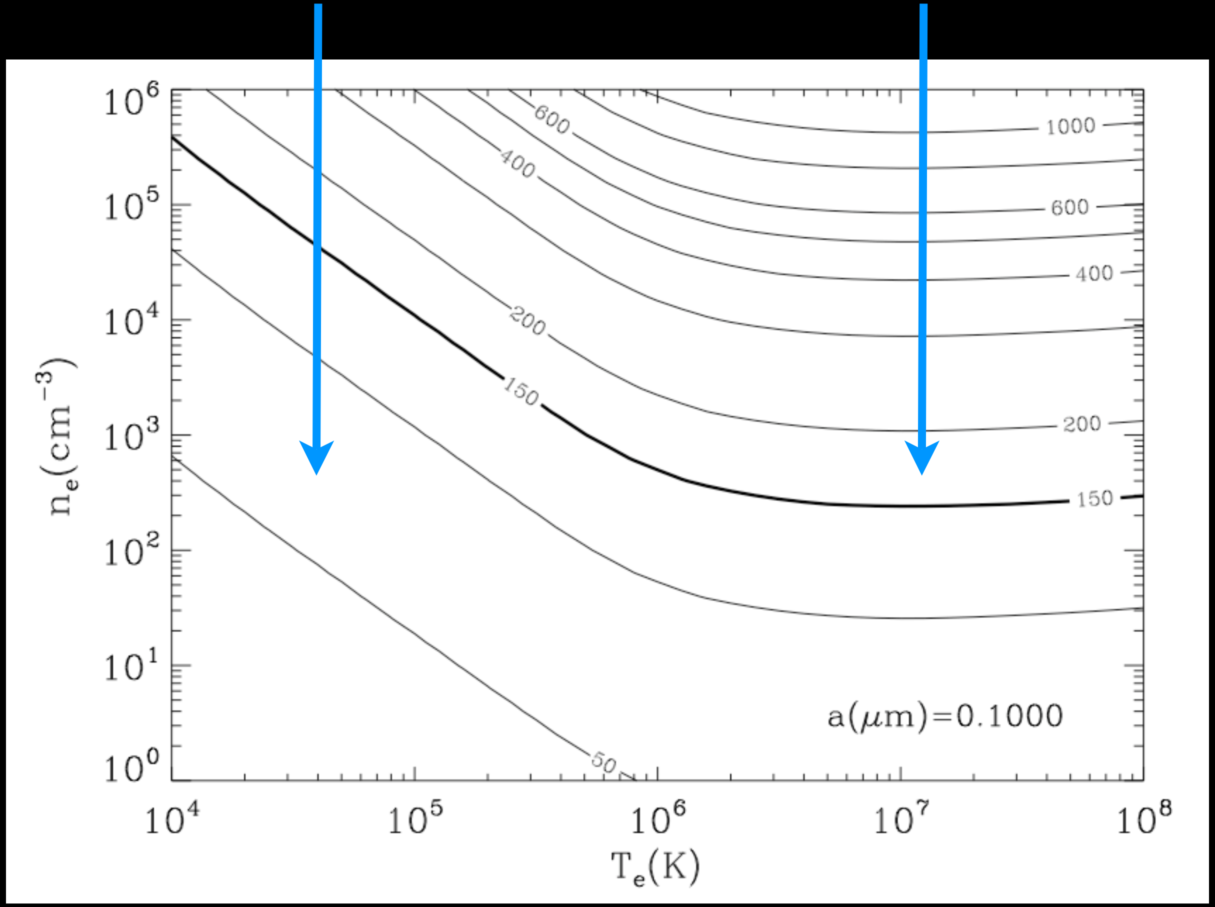
$T_{dust} \approx 160 \pm 15$ K

The mass of radiating dust is

$M_{dust} \approx 3 \times 10^{-6}\ M_{sun}$

electrons stopped in the dust

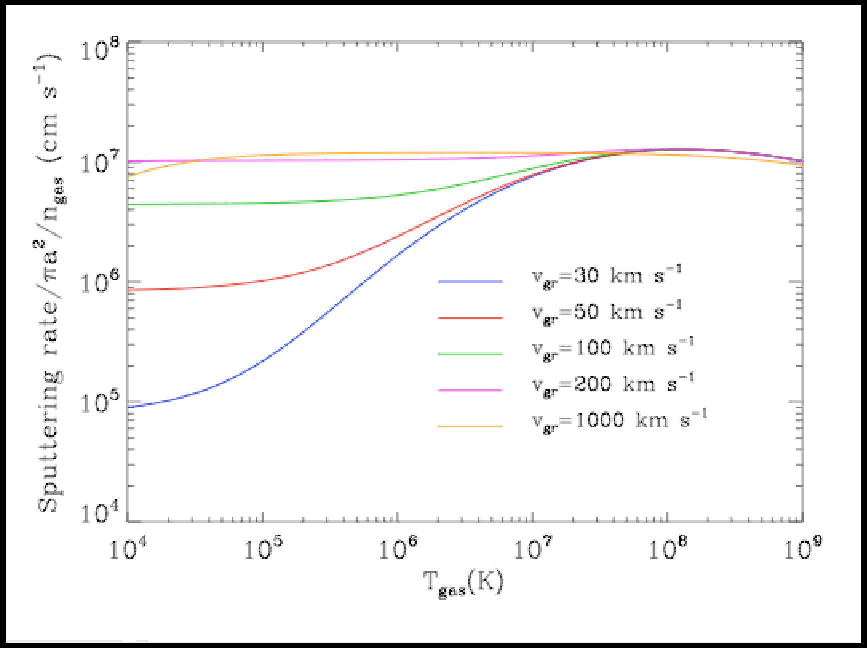
dust transparent to electrons $dE/dx \sim E^{-0.5}$



The dust is collisionally heated by the X-ray emitting plasma. At $T_{gas} \geq 2 \times 10^6$ K, the dust temperature provides an excellent measure of gas density, giving:

$n_e \approx 300\text{-}1400\ cm^{-3}$

Grain destruction lifetime



$$\boxed{\tau_{sput} = 3 \times 10^5 \frac{a(\mu m)}{n(cm^{-3})} \quad yr}$$

Dust needs to be destroyed on a dynamical timescale

$$\tau_{sput} \approx 1 \;\; yr$$

$$a(\text{Å}) = \frac{n(cm^{-3})}{30} \qquad n \approx 300 - 1400 \;\; cm^{-3}$$

$$\boxed{a \approx 10 - 50 \;\; \text{Å}}$$

The dual role of SNe in the evolution of dust

- They are potentially the most important source of interstellar dust
  - ≈ 1 M_{sun} per SN
- They destroy dust in the ISM during the remnant phase of their evolution
  - ≈ 1 - 10 M_{sun} per SNR
  - destruction by reverse shock can also be important

Conclusions

- We are witnessing the interaction of the SN blast wave with the dust in the ER
- The dust is composed of pure silicates
  - O-rich mass loss
- Dust is collisionally-heated to $T_{dust} \approx 180$ K
  - small dust particles transparent to electrons
  - X-ray gas density ≈ 800 cm^{-3} remained constant for 900 d
- IR to X-ray flux ratio is low and evolving
  - grain destruction by sputtering $a \lesssim 50$ Å
- Interaction of the reverse shock with the ejecta will reveal the SN-condensed dust
- SNe are important producers and destroyers of dust