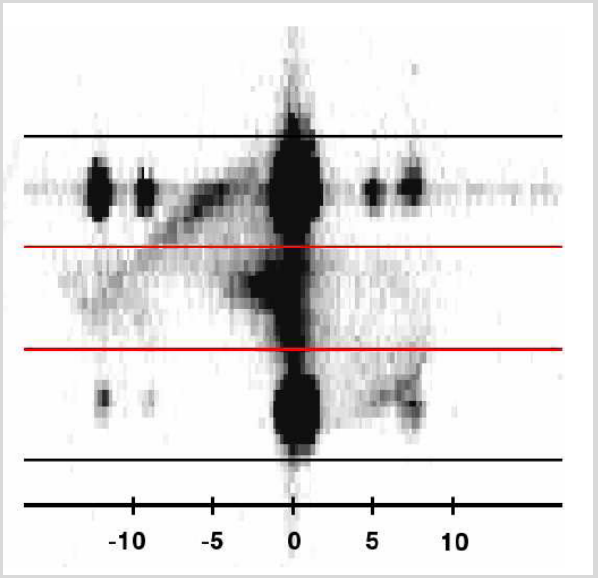
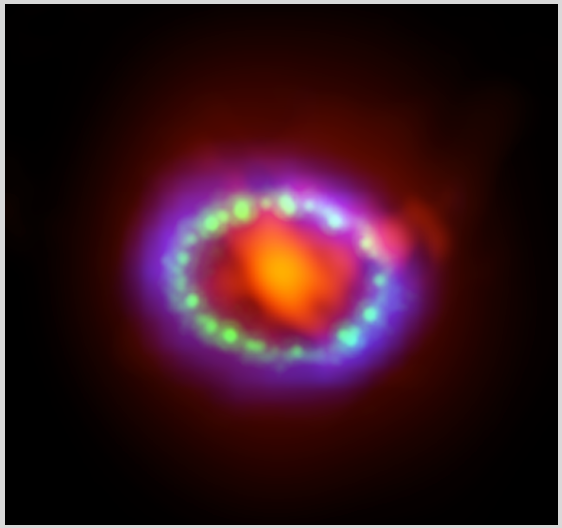
SN 1987A

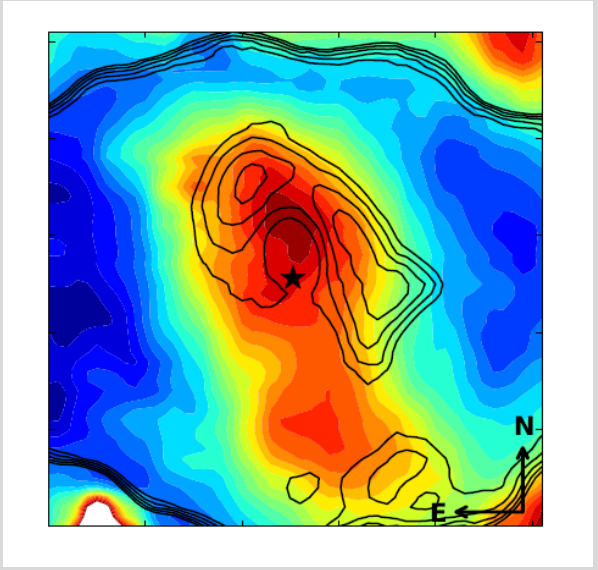


Exciting Physics

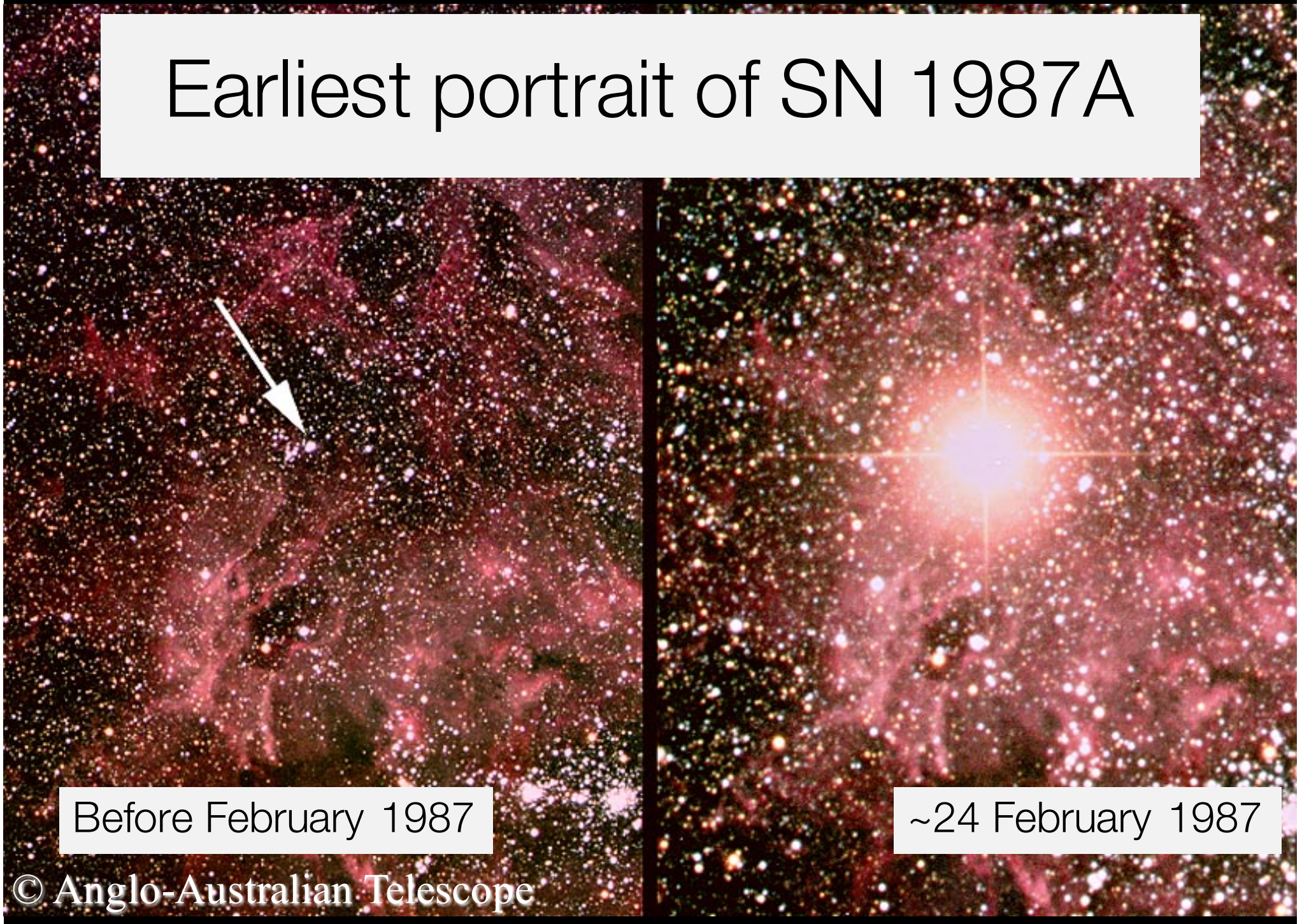


Bruno Leibundgut
(ESO)

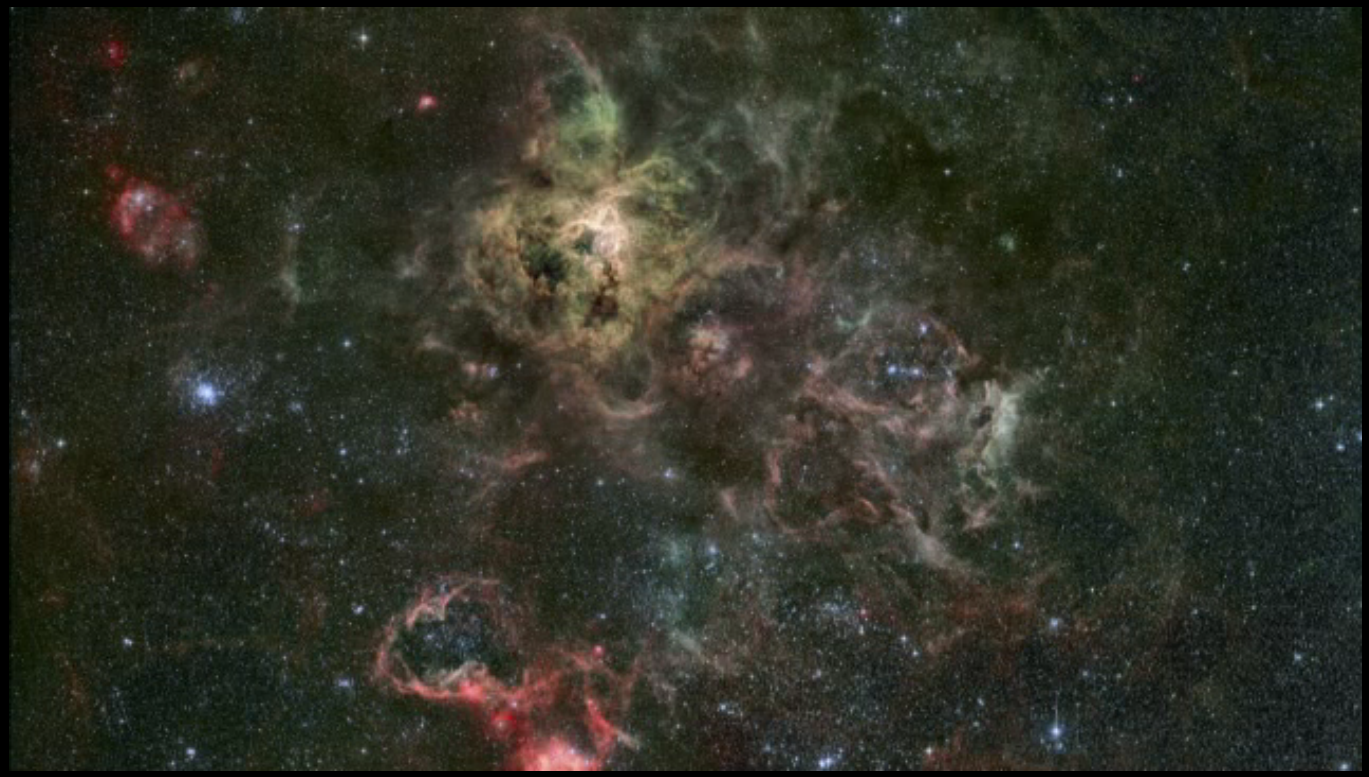
Claes Fransson (Stockholm)
Josefin Larsson (Stockholm)
Katia Migotto (Stockholm)
Anders Jerkstrand (Belfast)
Jason Spyromilio (ESO)



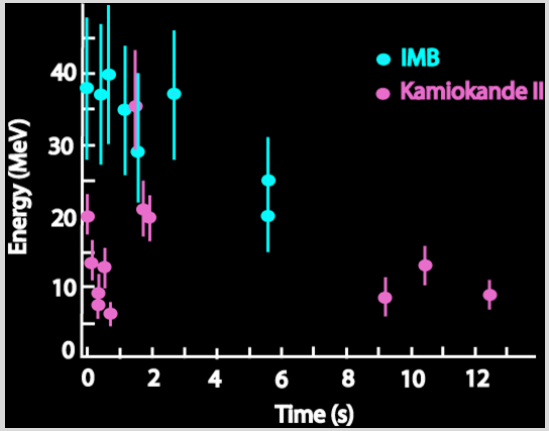
Earliest portrait of SN 1987A



Introducing SN 1987A



Uniqueness of SN 1987A



Neutrino detection

direct evidence of core collapse and formation of a neutron star (or black hole)

Naked-eye supernova after >350 years

detection of X-rays and γ-rays very early

mixing and direct nucleosynthetic products

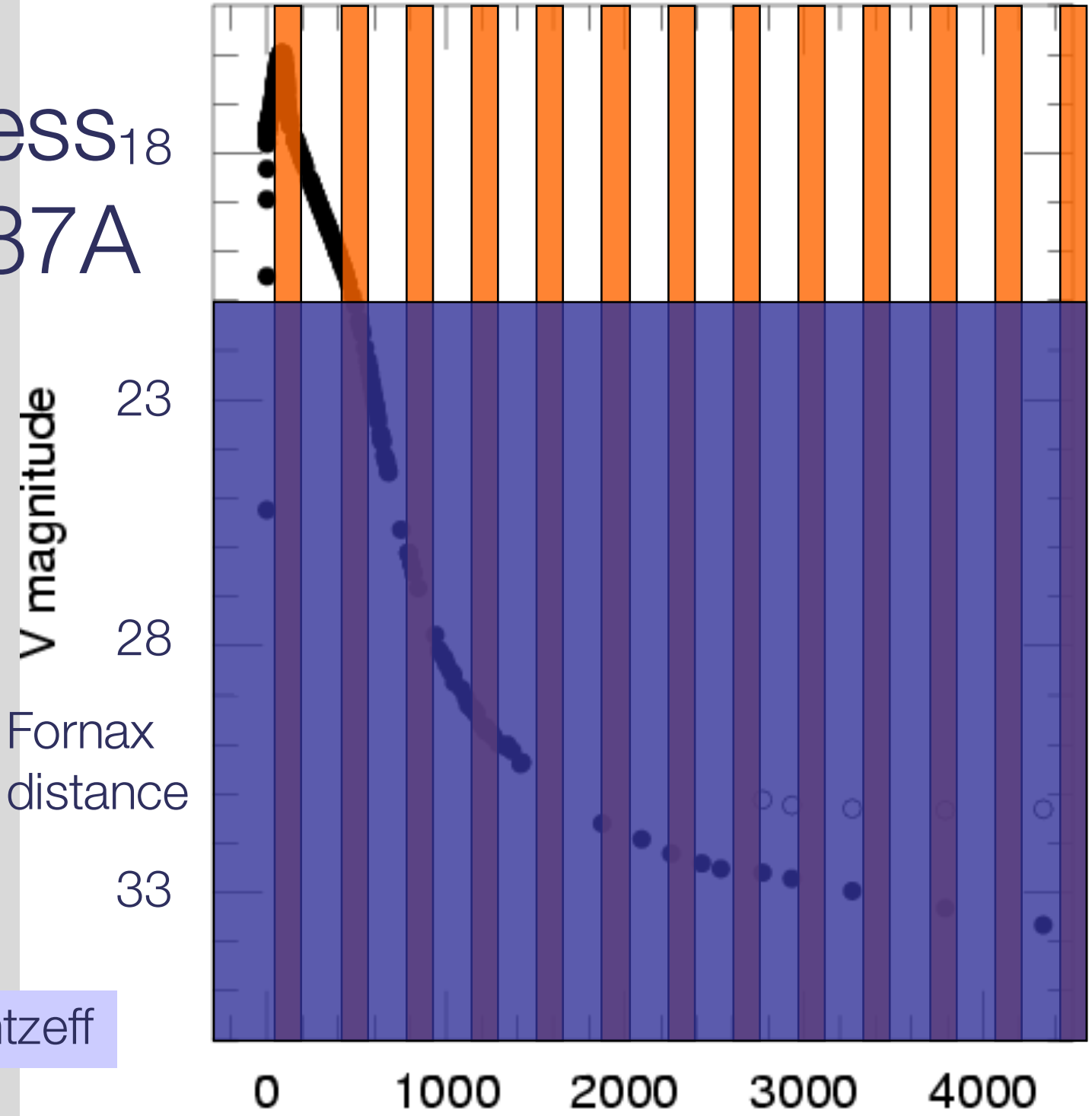
monitoring with HST, VLT, Gemini, Chandra, XMM, ATCA, Herschel, Spitzer, ALMA

Progenitor star observed before explosion

insight into stellar evolutionary channel leading to a supernova

surprise → blue supergiant!

Uniqueness of SN 1987A



Suntzeff

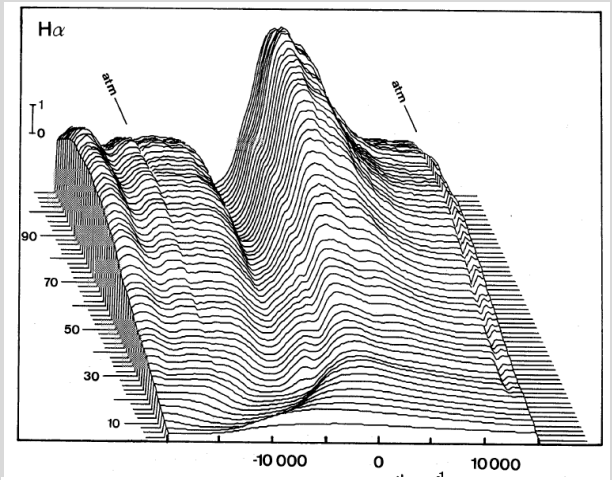
Properties of Sk -69 202

- Luminosity ~ 10^5 $L_\odot$
- Temperature ~ 15 000 K
- Radius ~ 40 $R_\odot$
- About 6 $M_\odot$ in the core (He and beyond)
- Main sequence mass ~20 $M_\odot$

→ early B/late O star

Uniqueness of SN 1987A

- Spatially resolved
  - separate circumstellar environment (rings) from the ashes of the explosion (ejecta)
- Signatures of an asymmetric explosion
  - polarimetry, ‘mystery spot’, spectral line evolution (‘Bochum event’)



Hanuschik & Thimm 1988

The exciting SN 1987A today

(11216 days since explosion – 29 years old)

Fluorescing rings

Shocks

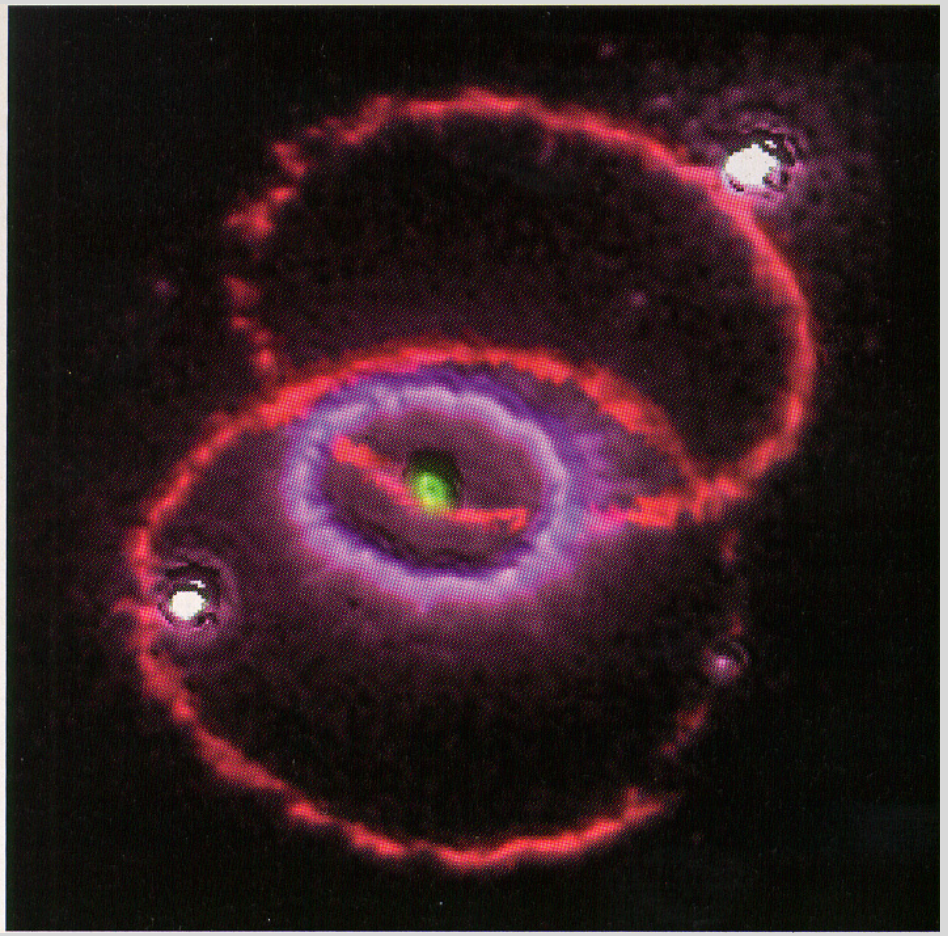
outer ejecta reached the inner ring

Radioactively heated material

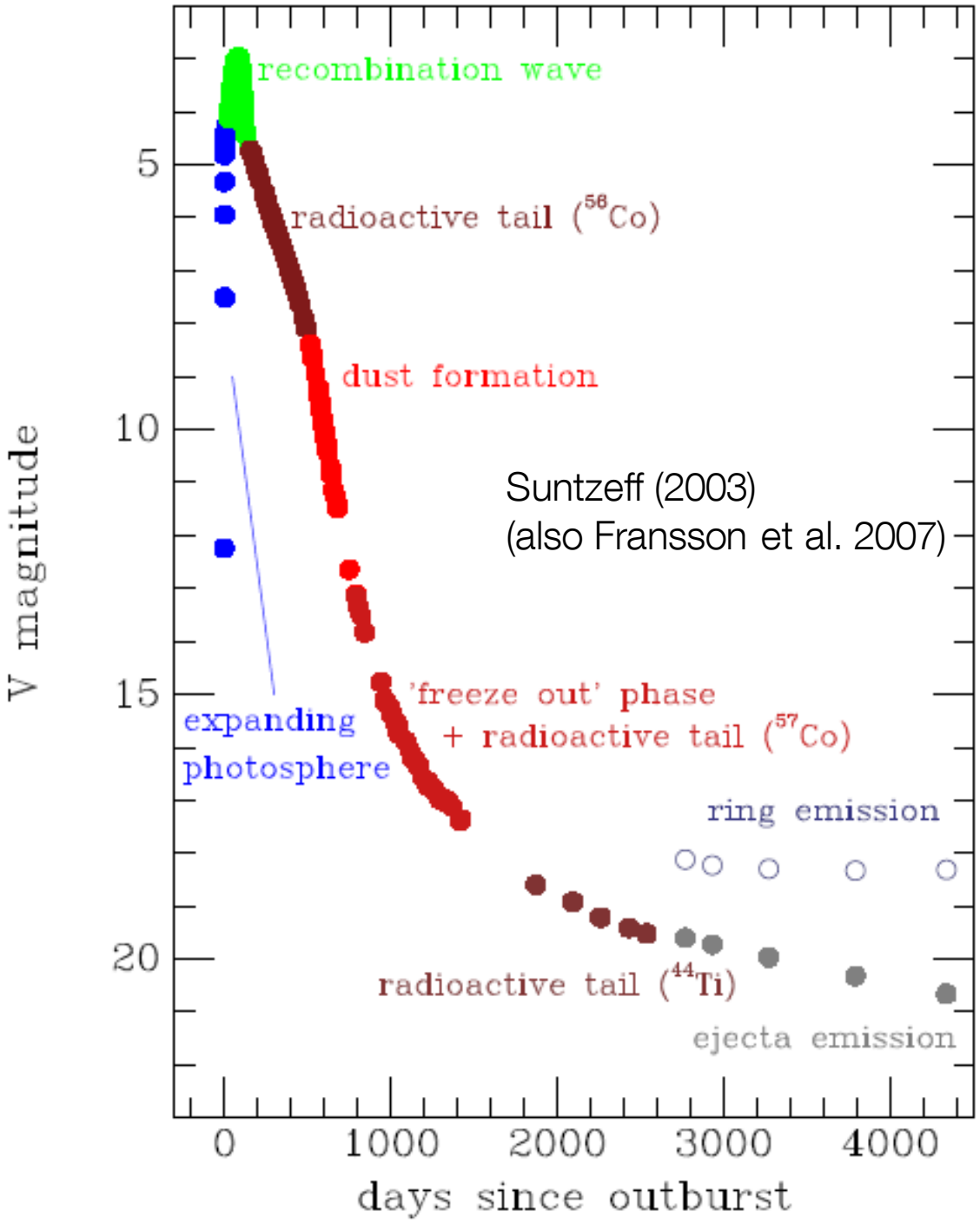
inner ejecta

Dust

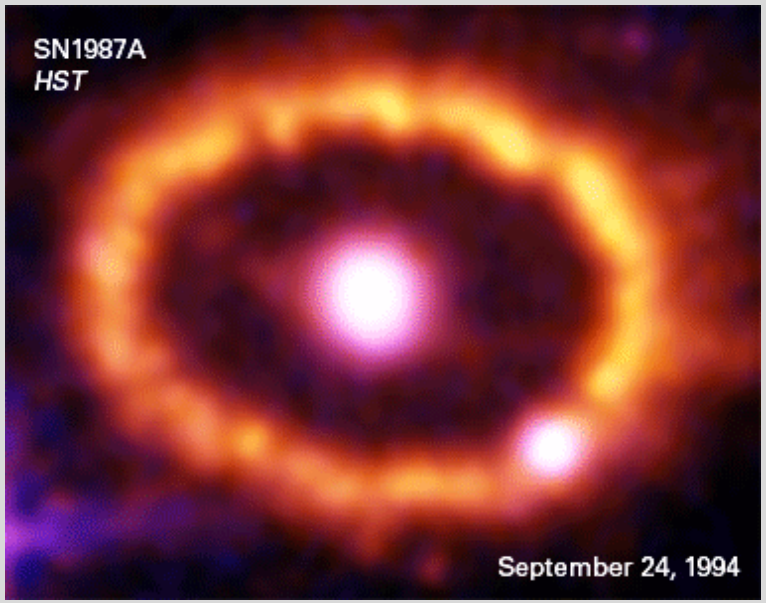
in and around the supernova



Energy escape from a (core-collapse) supernova



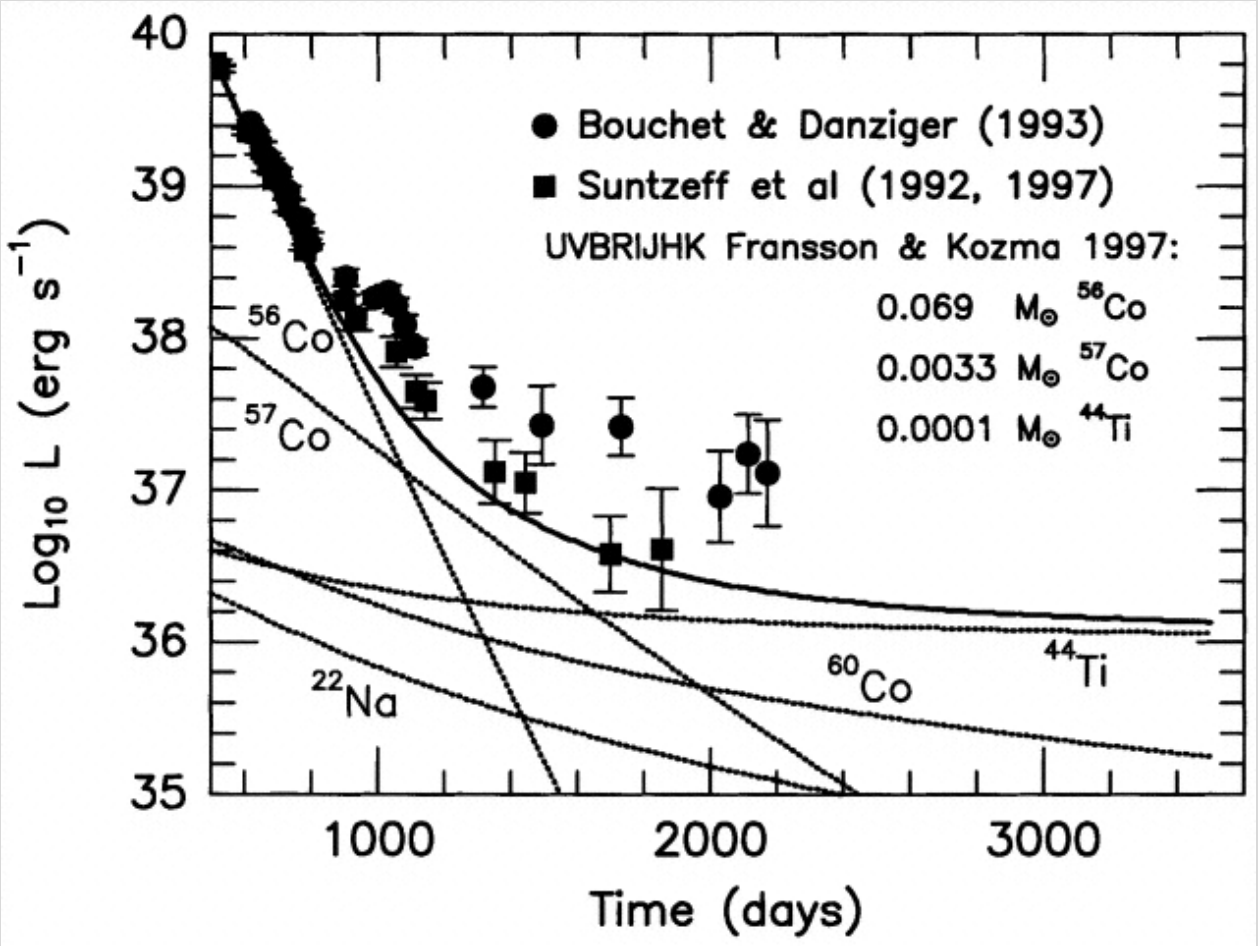
SN 1987A
the best observed supernova ever



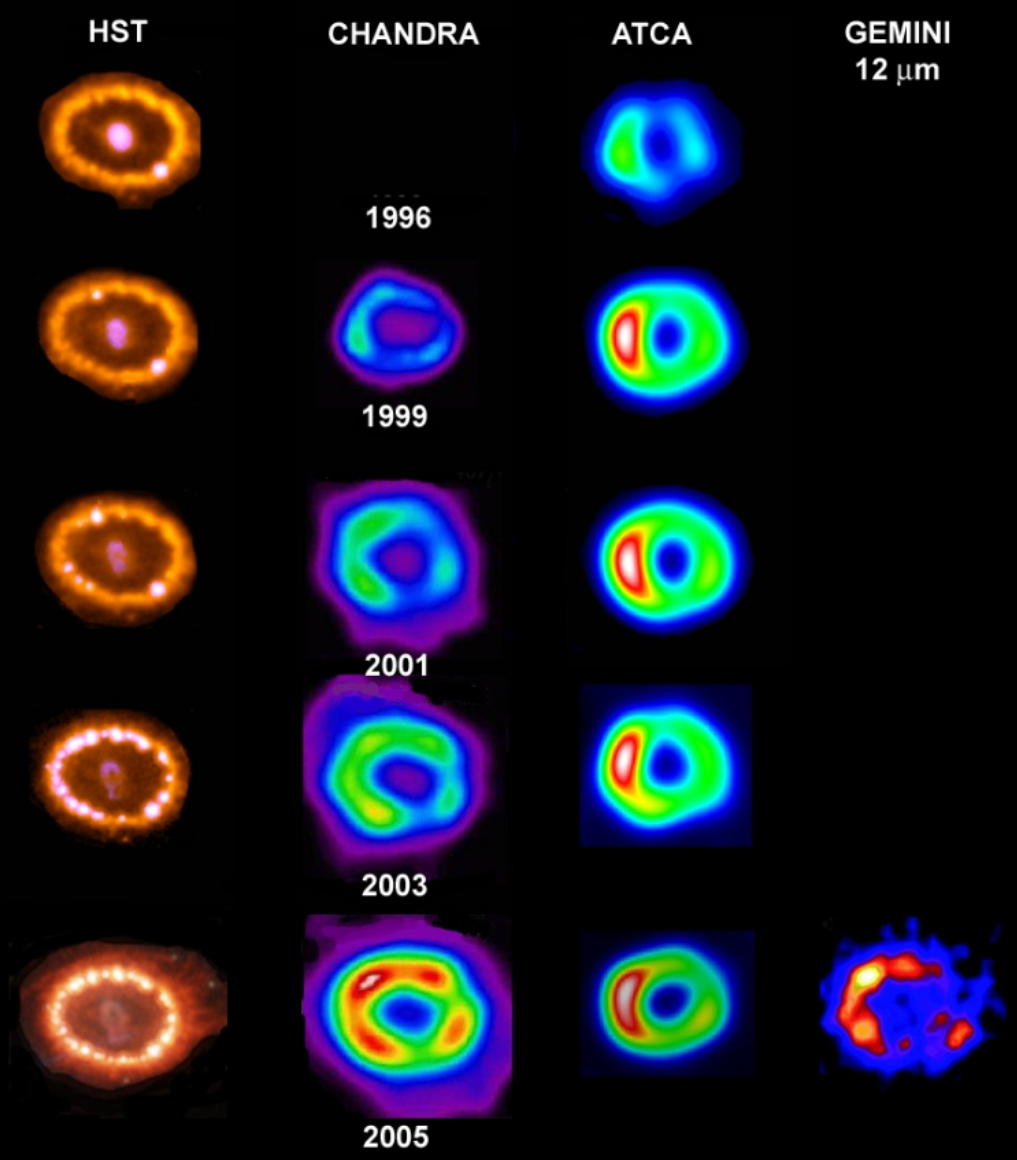
What can drive SN emission at late phases?

Freeze-out

recombination of atoms at long time-scales

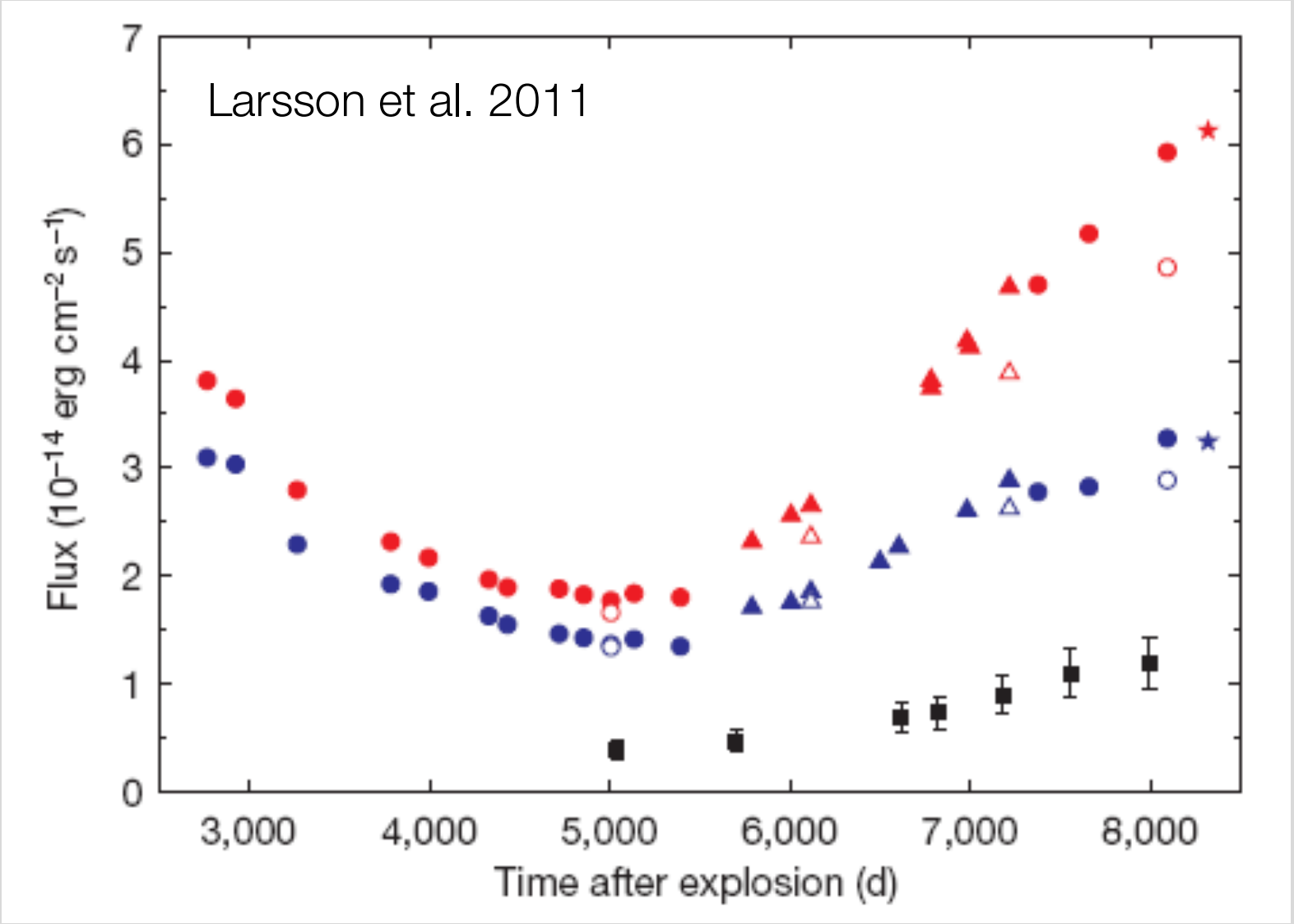


Optical, X-rays and Radio



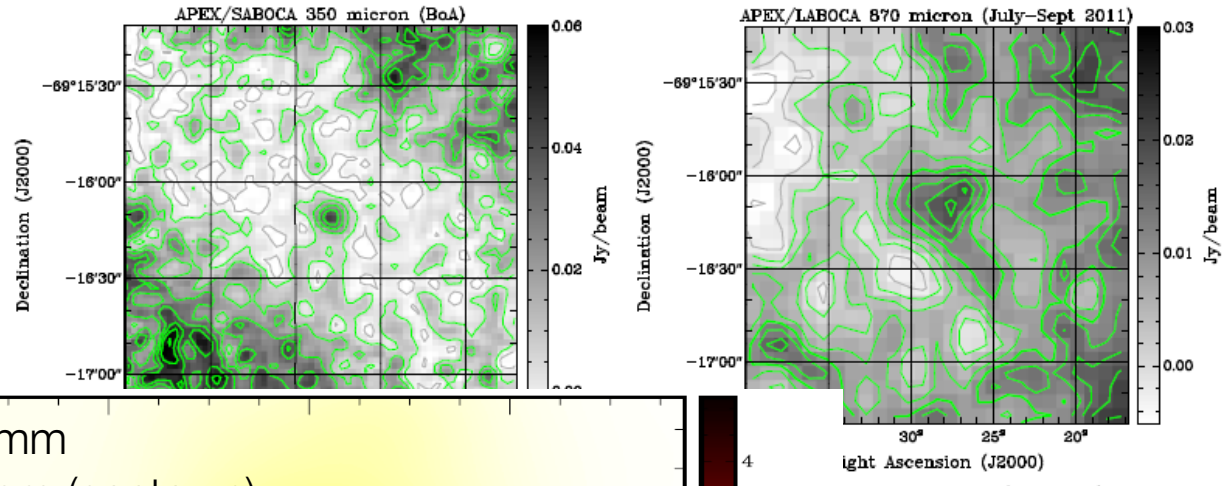
Park et al
Manchester et al

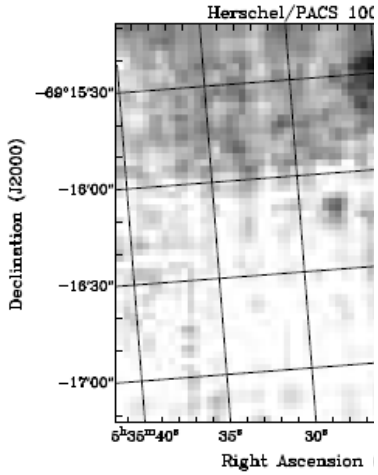
SN 1987A brightening at all wavelengths

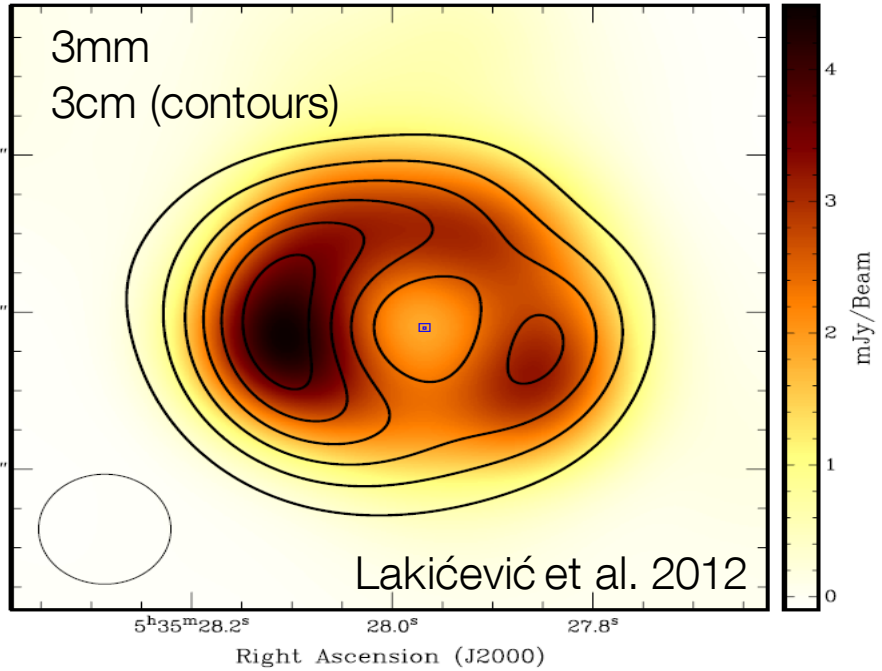


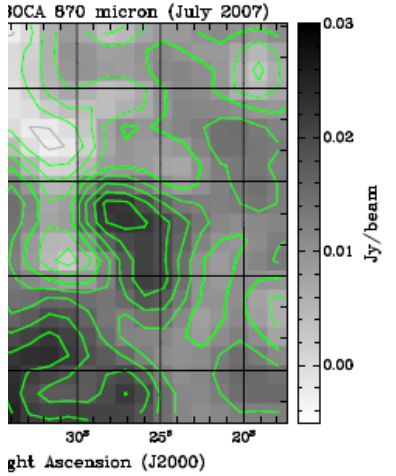
Exciting developments

Lakićević et al. 2012









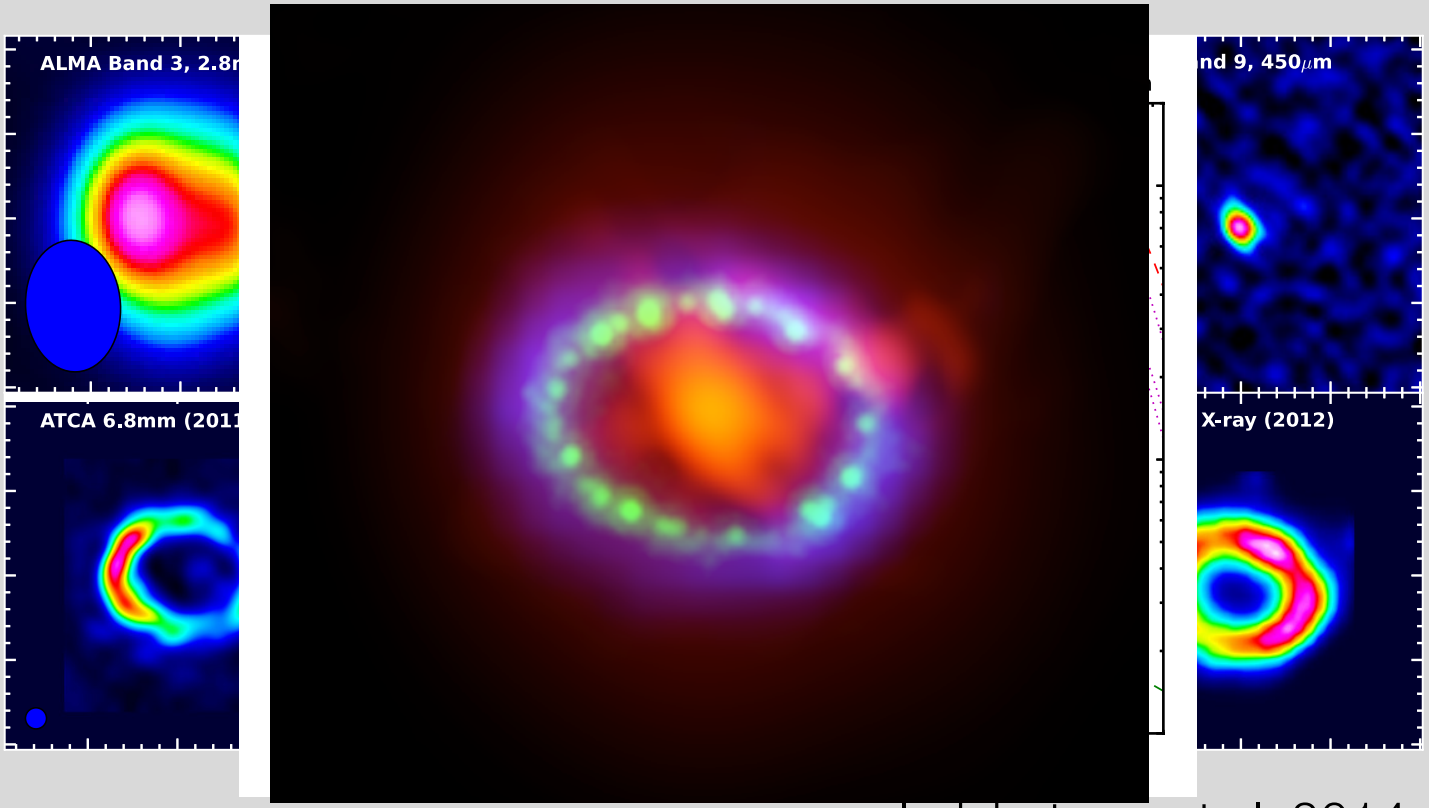
Matsuura et al. 2011

Background subtracted

rschel

Dust in SN 1987A

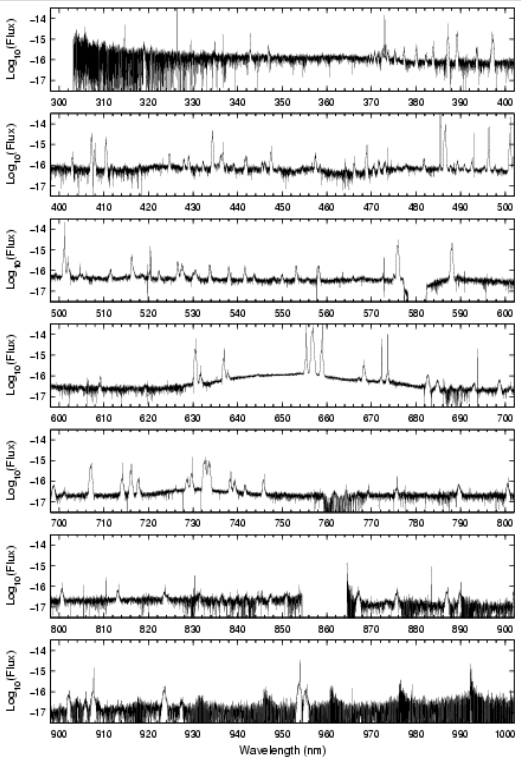
- Synchrotron emission from the ring
- Thermal dust in the inner ejecta



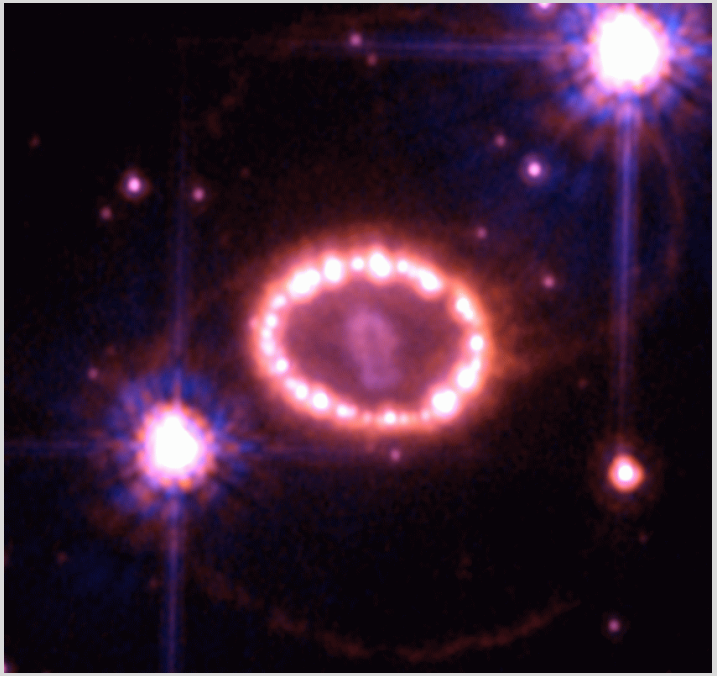
Indebetouw et al. 2014

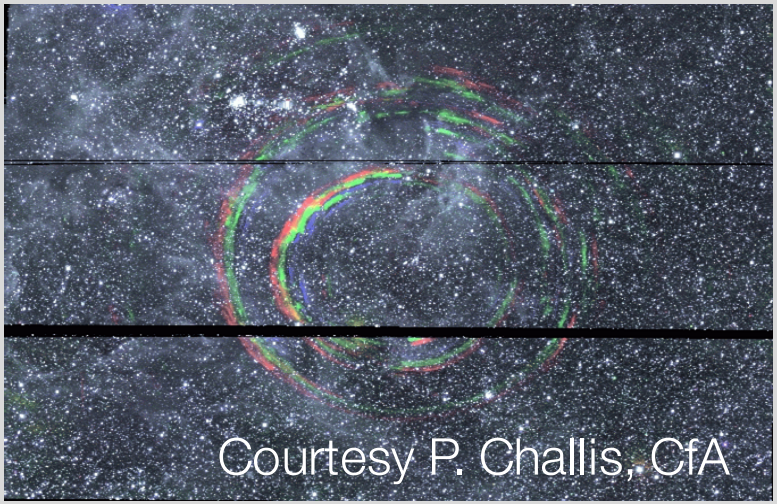
The complex SN 1987A @ 27 years

Combination of several emission sites



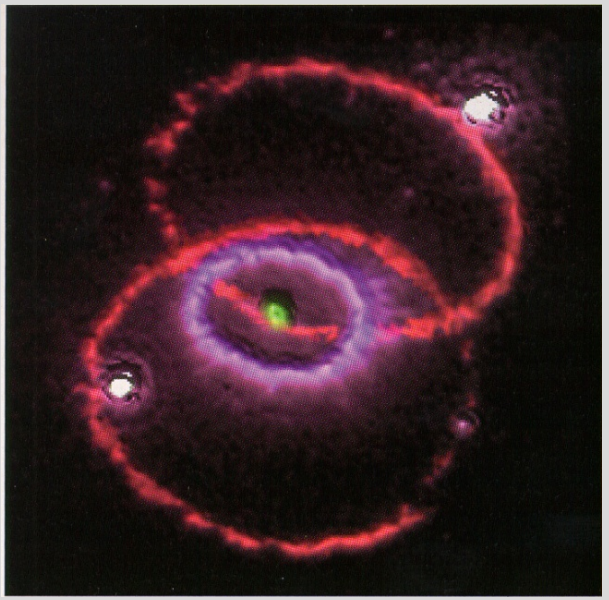
- inner ejecta
- shocked ejecta
- shocked inner ring
- ionised inner ring
- outer rings
- light echoes



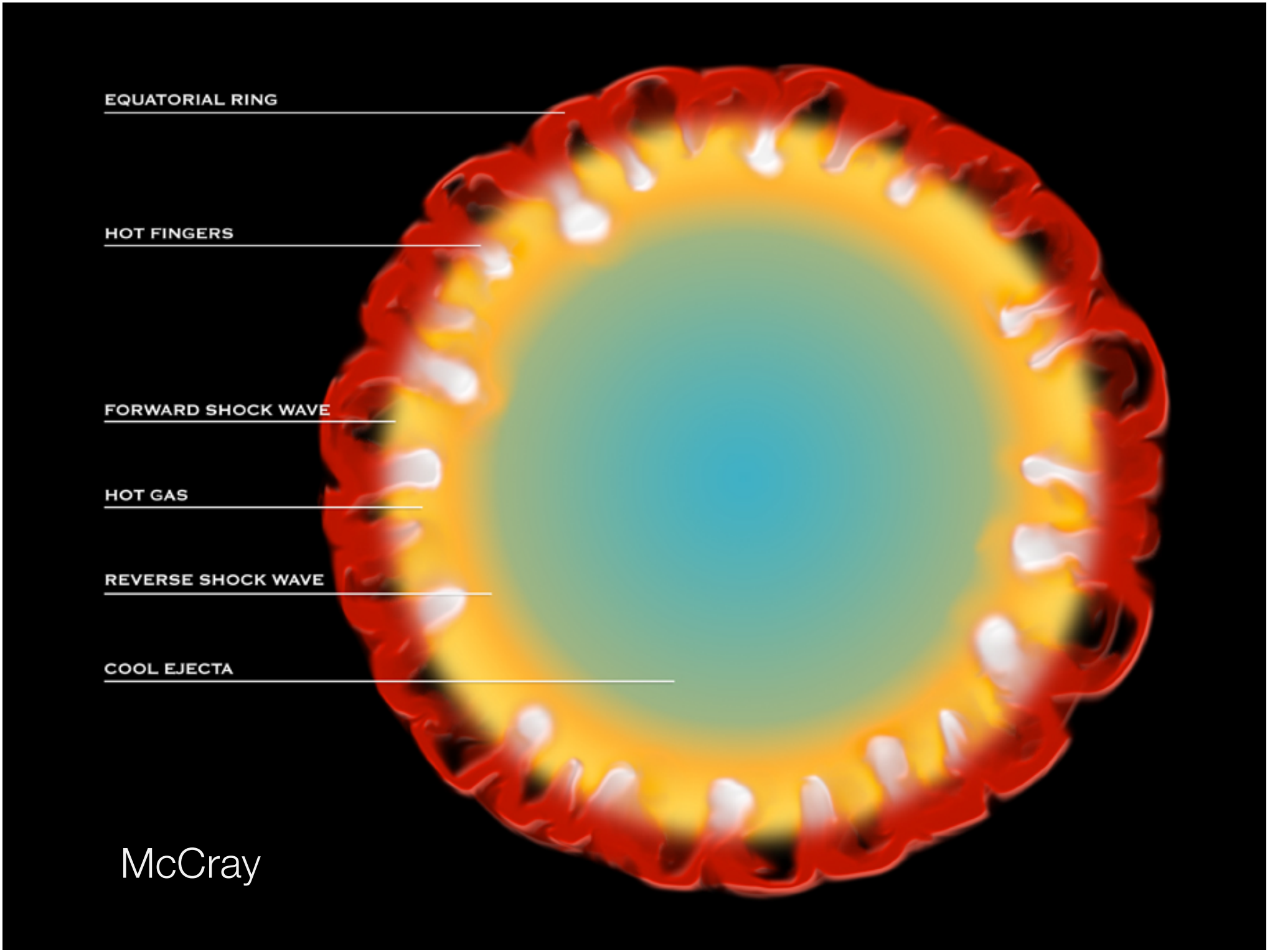


The different emission sites in SN 1987A

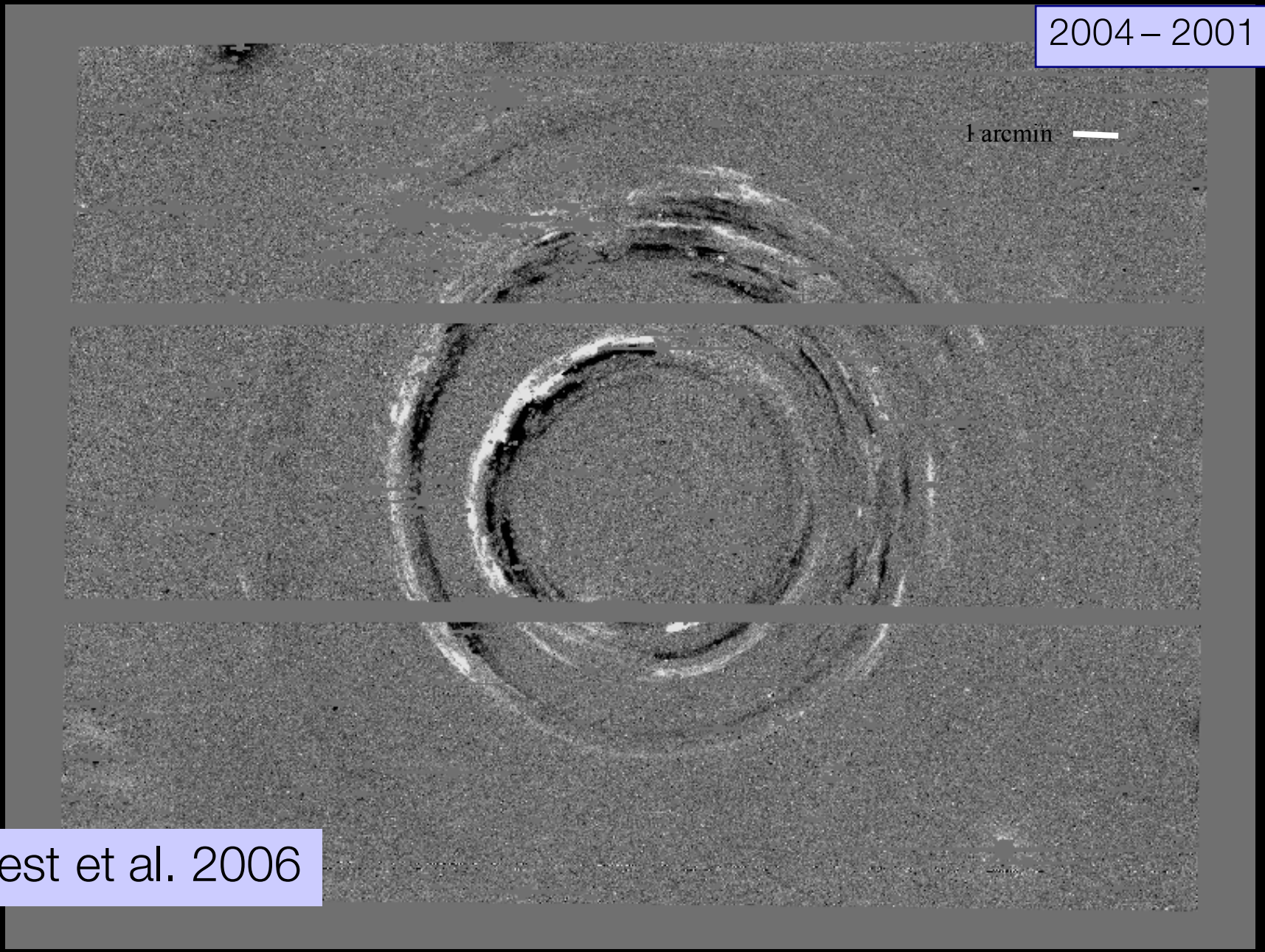
SN ejecta
- radioactively heated material ('inner ejecta')
- X-ray heated ejecta
- dust



Rings
- density enhancements in equatorial (?) plane
- shock physics
  - forward shock (into the ring)
  - reverse shock (into the ejecta)

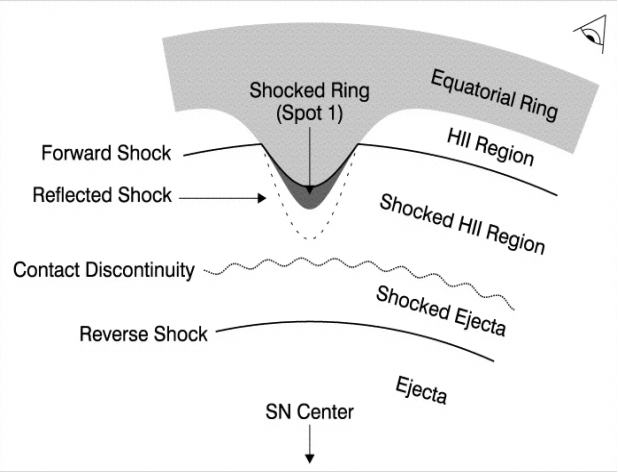

EQUATORIAL RING
HOT FINGERS
FORWARD SHOCK WAVE
HOT GAS
REVERSE SHOCK WAVE
COOL EJECTA
McCray

The hidden SN 1987A



Rest et al. 2006

The ring collision



Dominating at all wavelengths

shock emission increasing for the past 13 years

Emission from the stationary ring

narrow lines (FWHM ≈ 10 km/s)

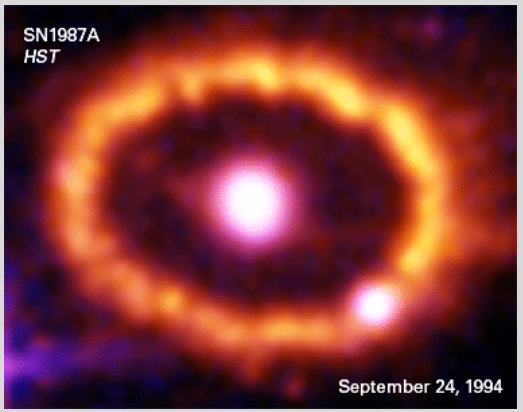
known since 1987 - fading

Shocked ring region (forward shock)

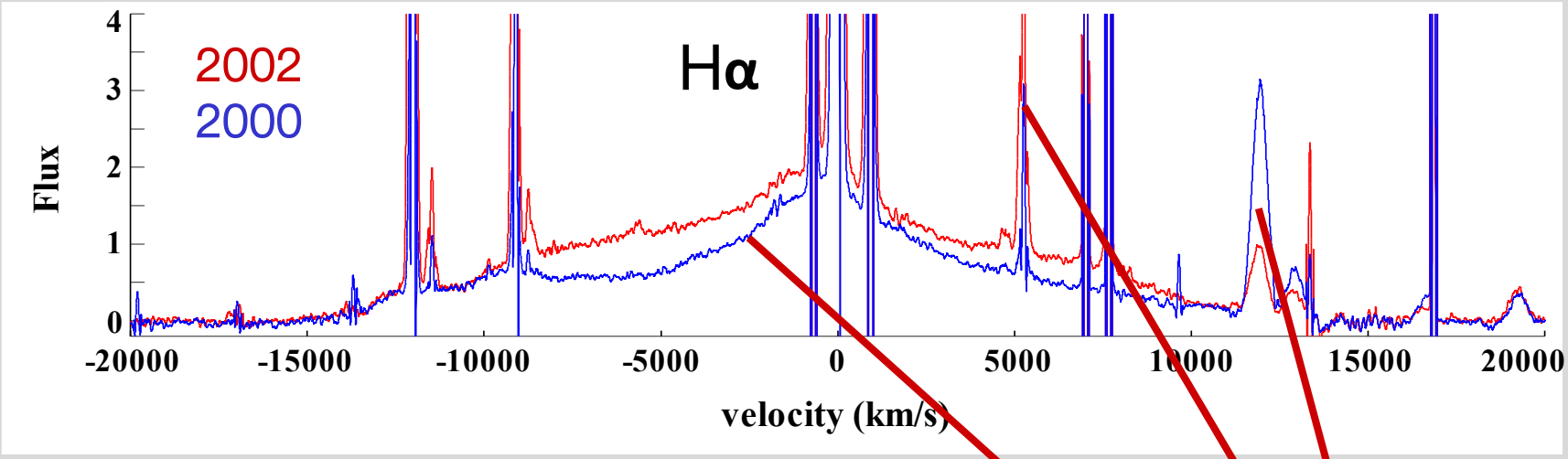
intermediate lines (~300 km/s)

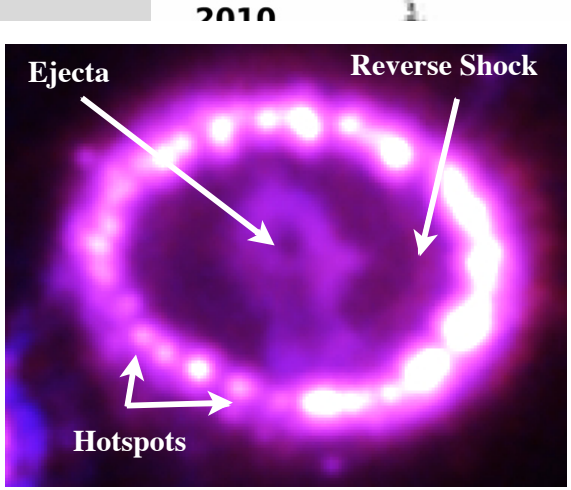
Reverse shock

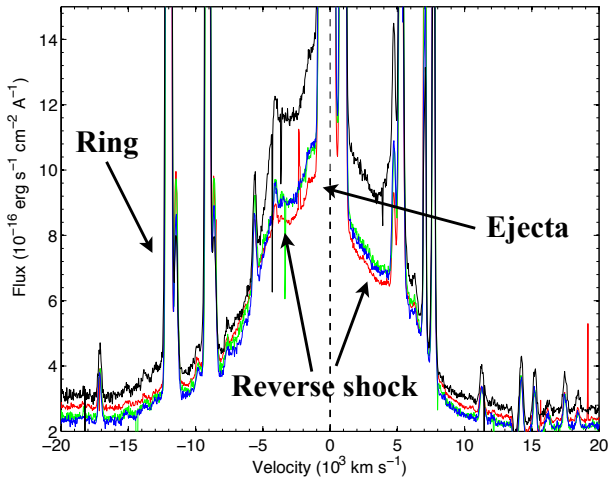
ejecta (>11000 km/s)

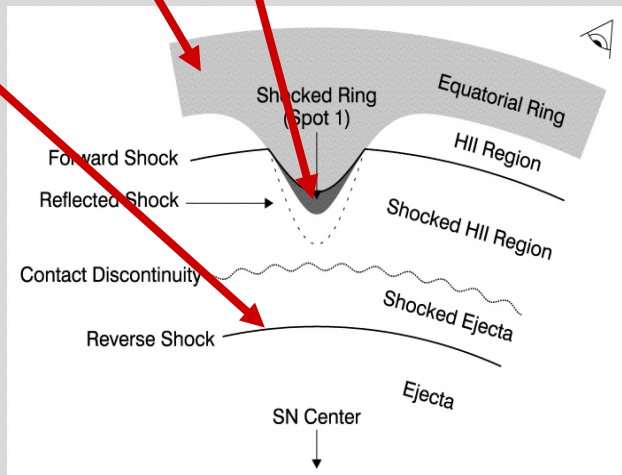


The emission line components





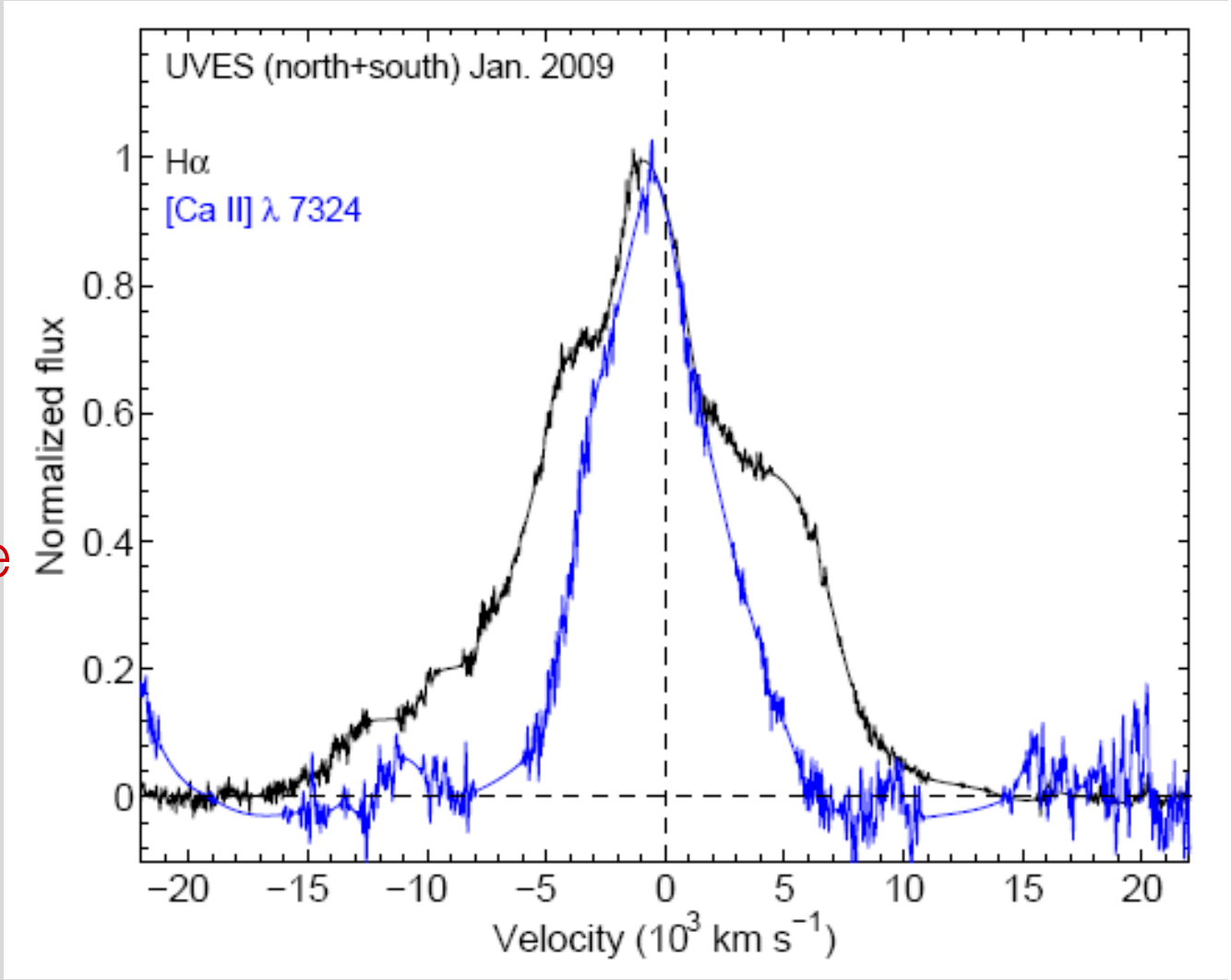




Fransson et al. 2013

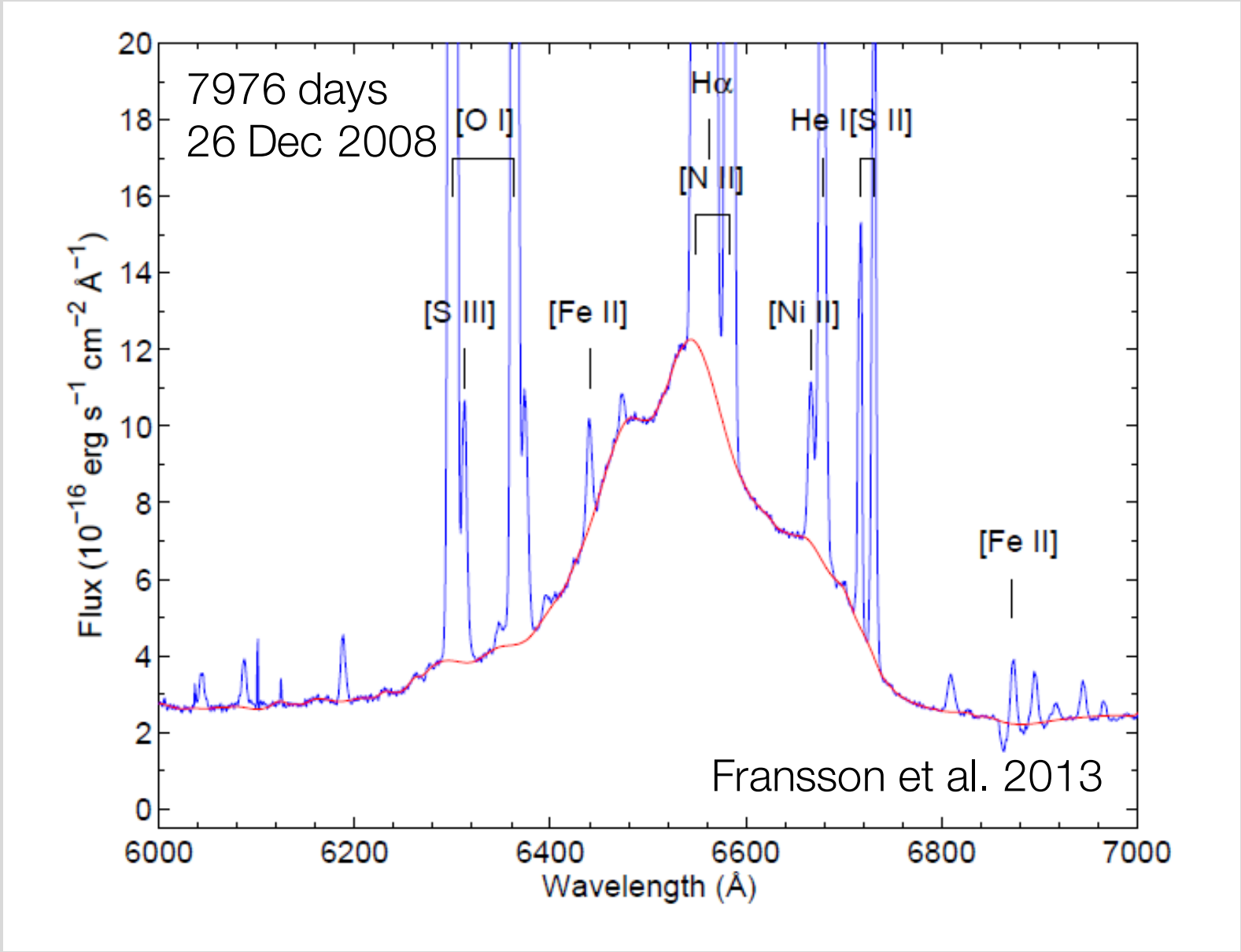
Hydrogen in SN 1987A

- 'Clean Hα'
- Flux increase by
  - 4 to 6 from 2000 to 2007
- v_{max}>11000 km/s
  - larger than possible in equatorial ring
  - anisotropic expansion



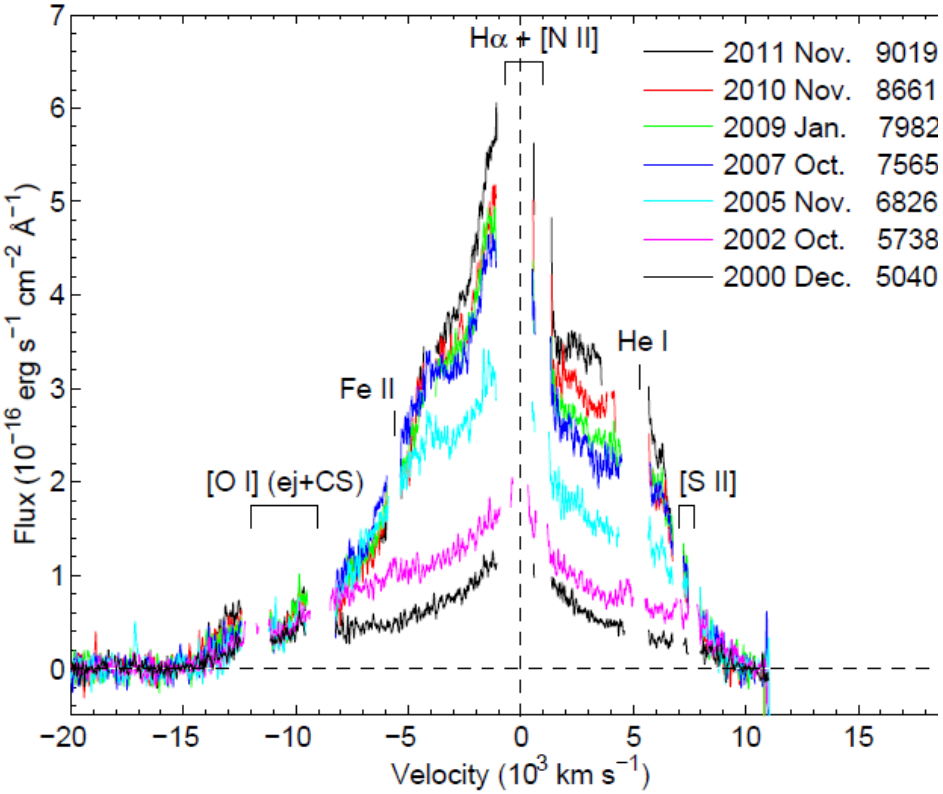
Fransson et al. 2013

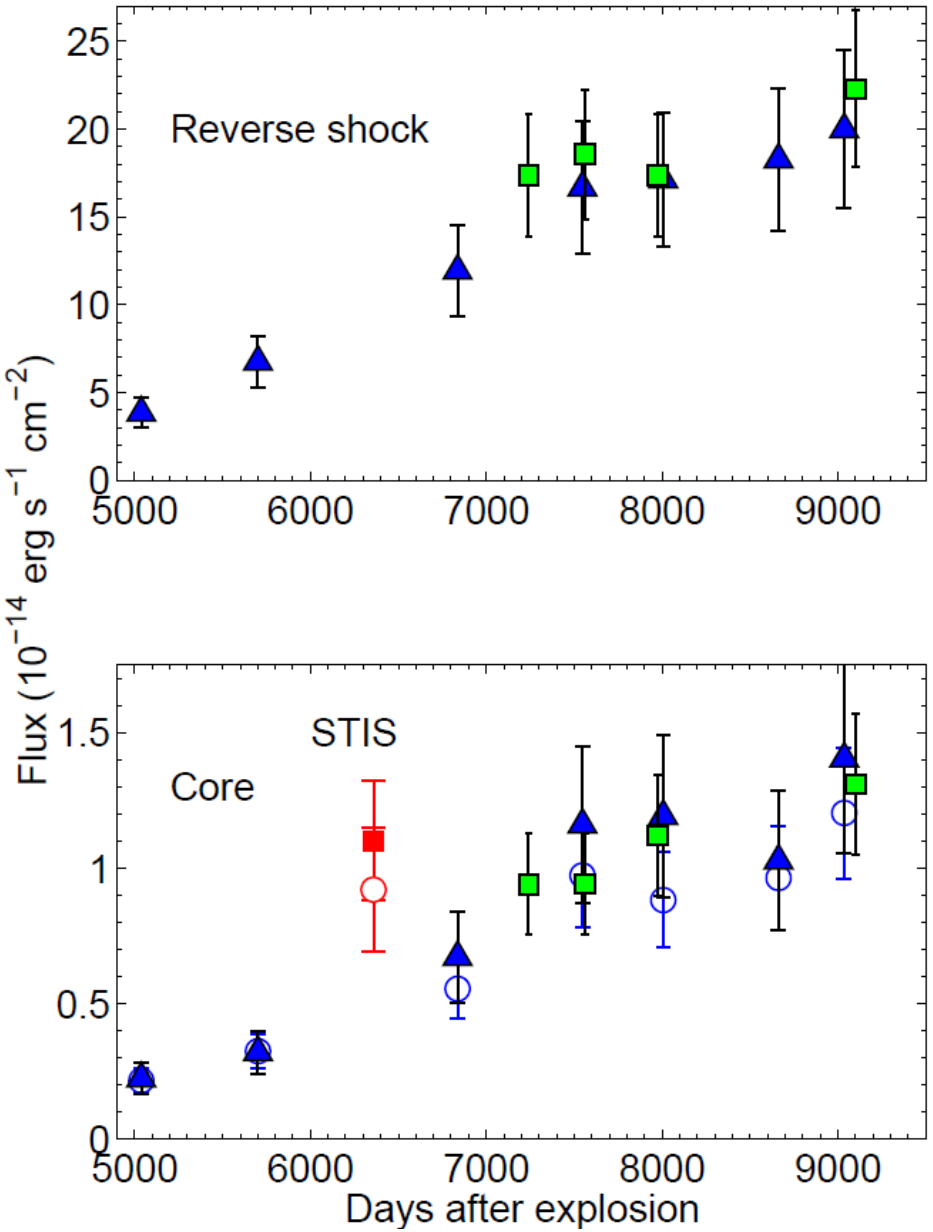
Hα in SN 1987A



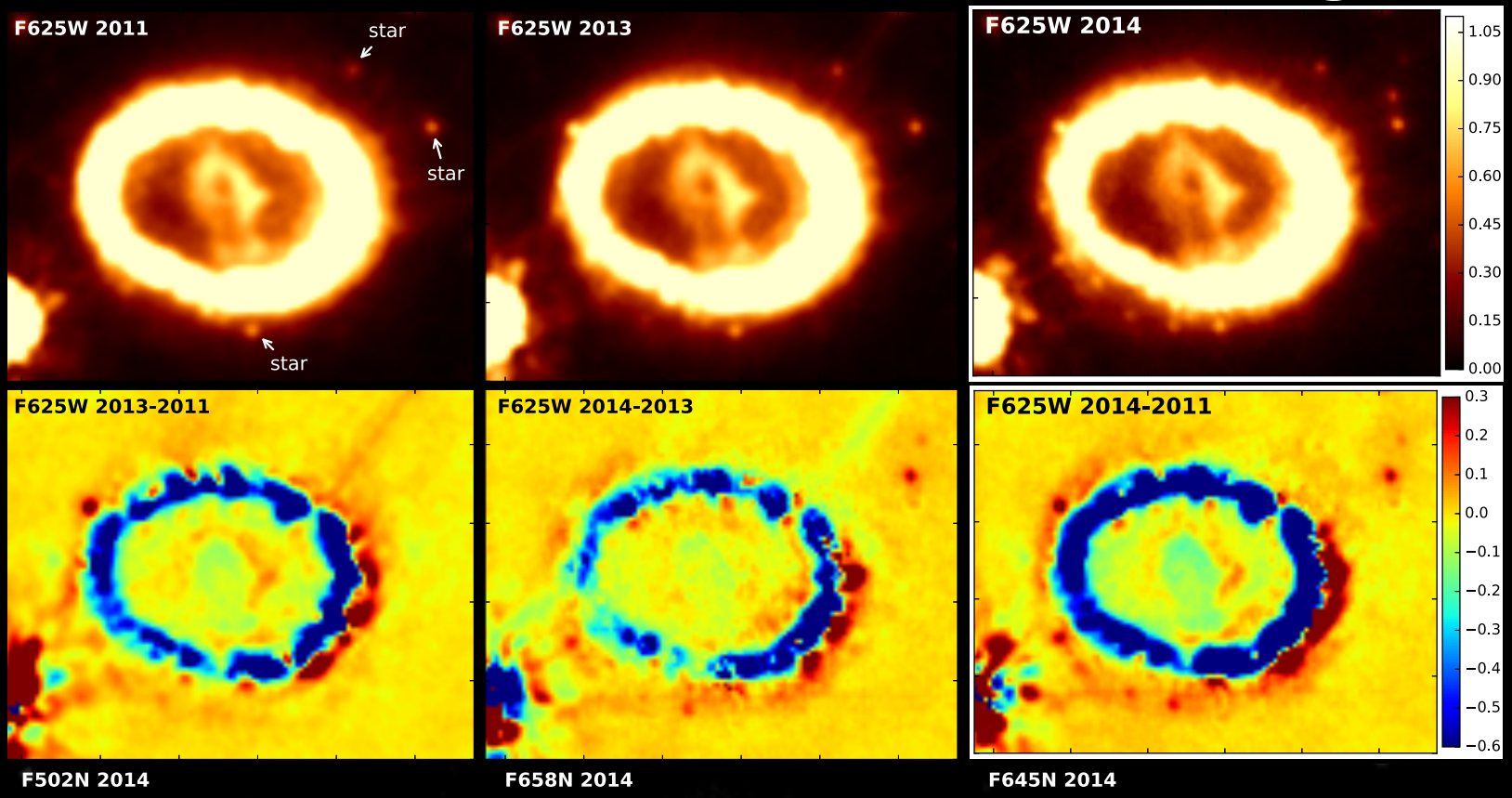
Evolution of Hα

Combination of FORS, UVES and STIS data





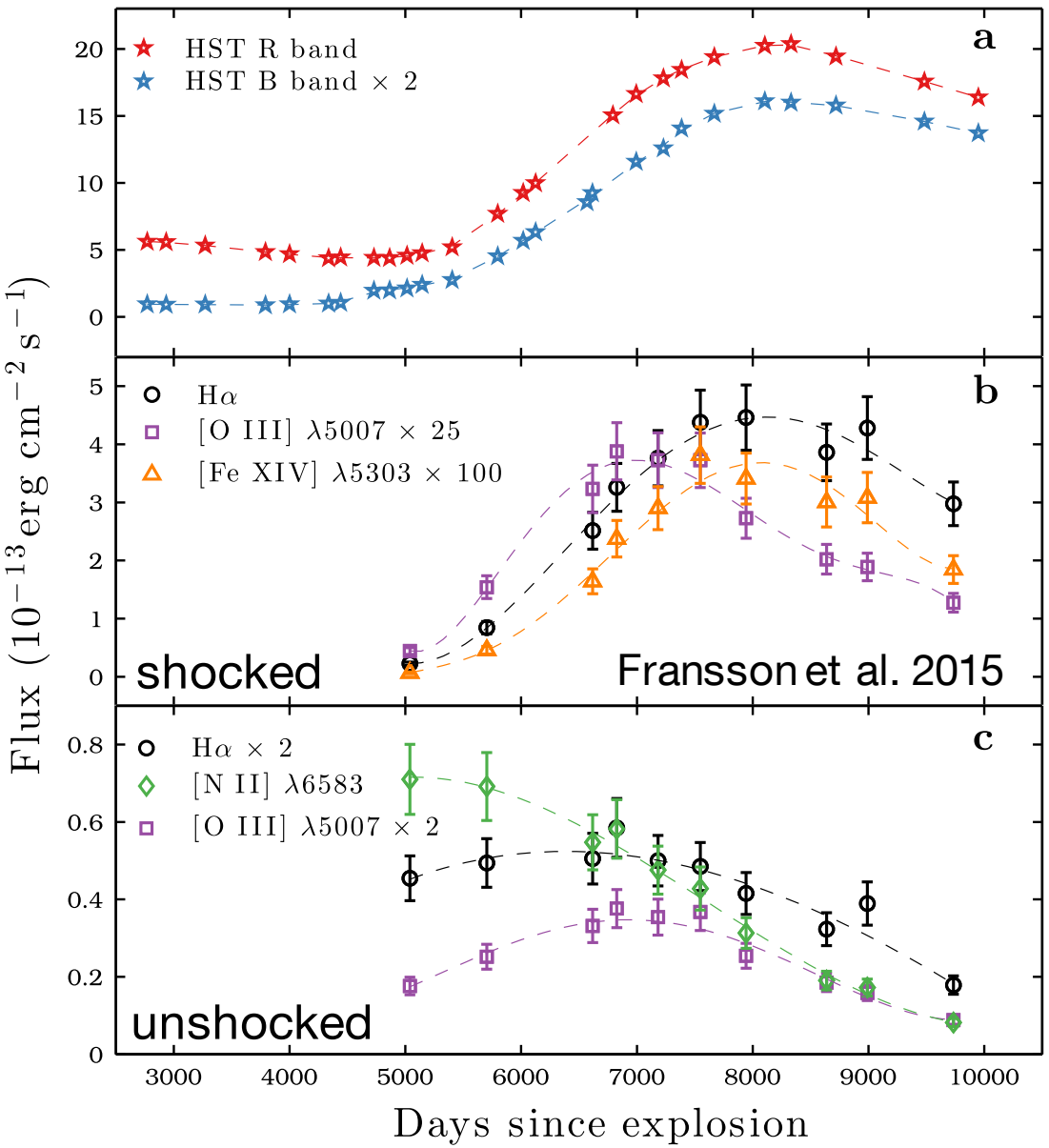
Emission outside the ring



Fransson et al. 2015

Destruction of the ring

- Ring emission has peaked
- Shock is dissolving the ring between 2020 and 2030



How this could look like

Summary

SN 1987A is as interesting as ever

- ring collision is in full swing
  - forward shocks in the ring
  - reverse shock in the debris (outer ejecta)
- shocked material can be analyzed through the X-rays and the coronal lines
  - now heating the inner ejecta as well
- first direct look at an explosion
  - resolved inner ejecta (iron core) are the immediate reflection of the explosion mechanism
  - confirmation of the standing accretion shock instability (SASI) → neutrino convection in the explosion

More to come

- Complete destruction of the ring
- Illuminating the outside
  - beyond the inner ring
- Detailed mapping of the inner ejecta
  - details on explosion mechanics and distribution of synthesized material
  - dust formation
    - where is the dust that formed early on?
    - what is the dust composition?
  - what will be lost due to the external illumination?
- Where is the neutron star?
  - limits uncomfortable for the theory


No sign yet of a neutron star
Collapse to a black hole?

SN 1987A will be the first supernova that we can observe forever.

L. Woltjer