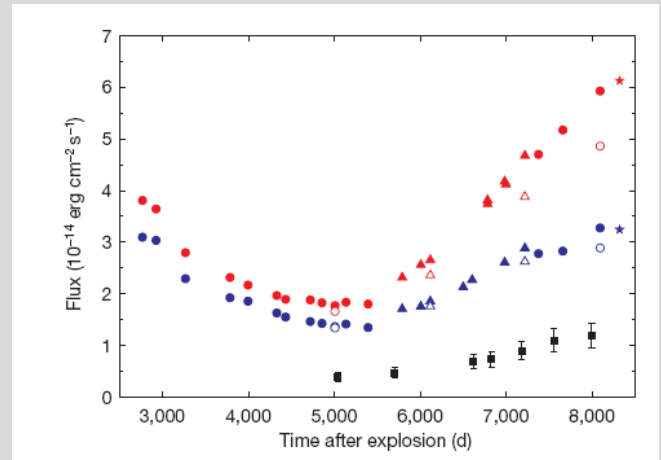


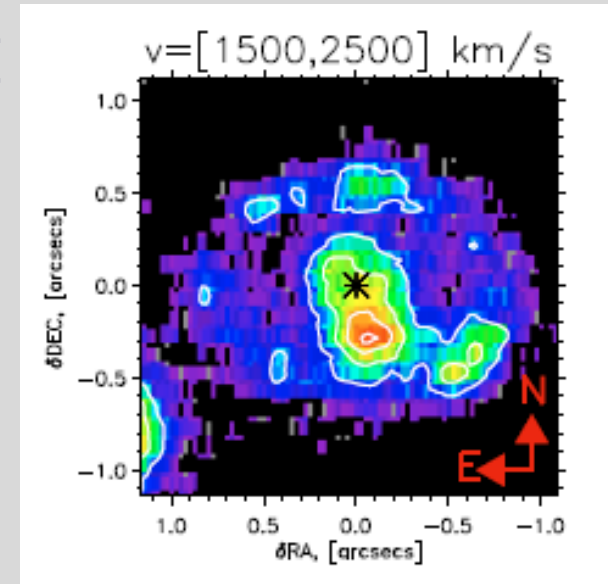
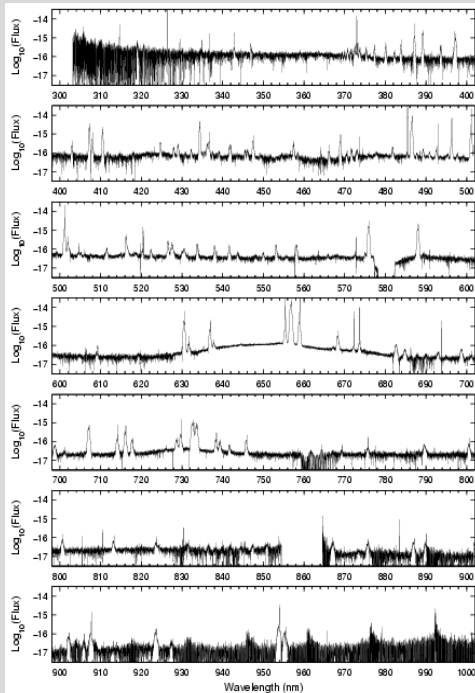


# SN 1987A

the excitement continues



Bruno Leibundgut  
ESO



# SN 1987A – a great collaboration

- Monitoring over the past two and a half decades

Claes Fransson (Stockholm)

Bob Kirshner (CfA) → SINS and SAINTS (HST)

Jason Spyromilio (ESO)

Karina Kjær (Augsburg), Per Gröningsson  
(Stockholm), Anders Jerkstrand (Stockholm)

# The exciting SN 1987A today

(9167 days since explosion)

Fluorescing rings

Shocks

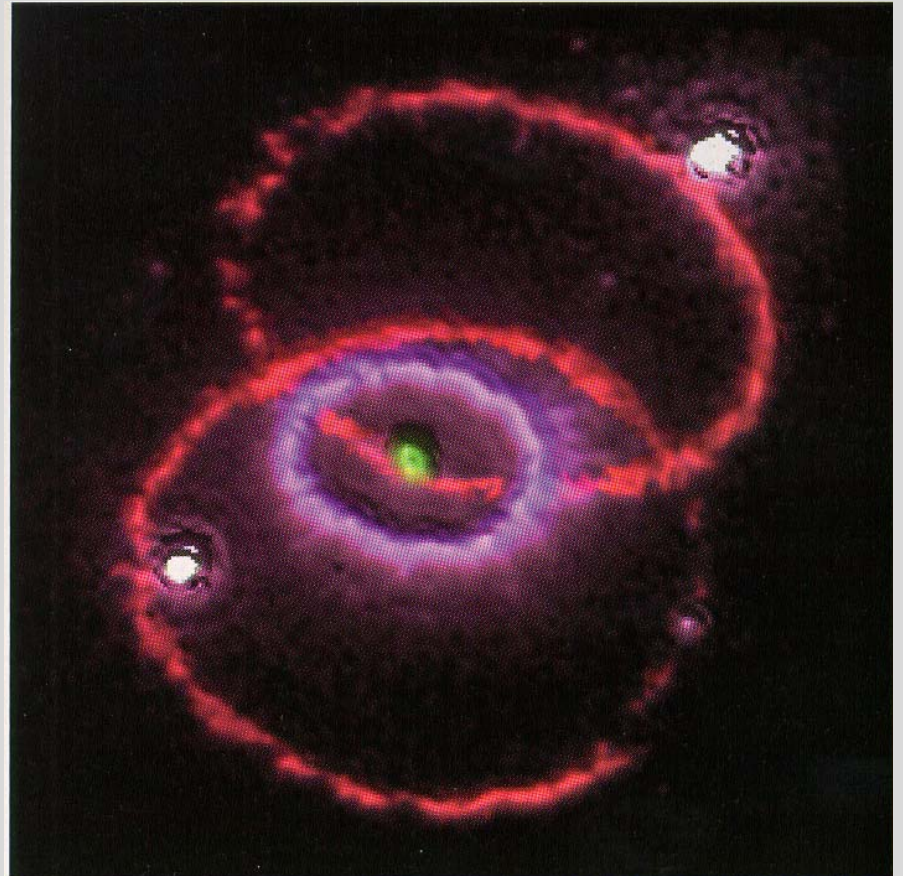
outer ejecta reached  
the inner ring

Radioactively heated  
material

inner ejecta

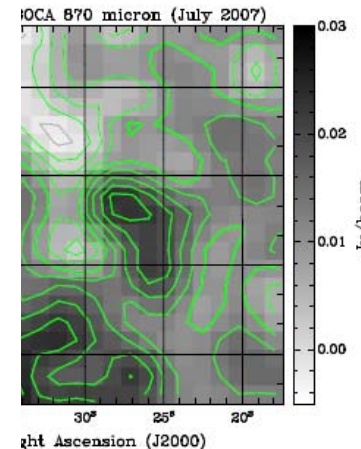
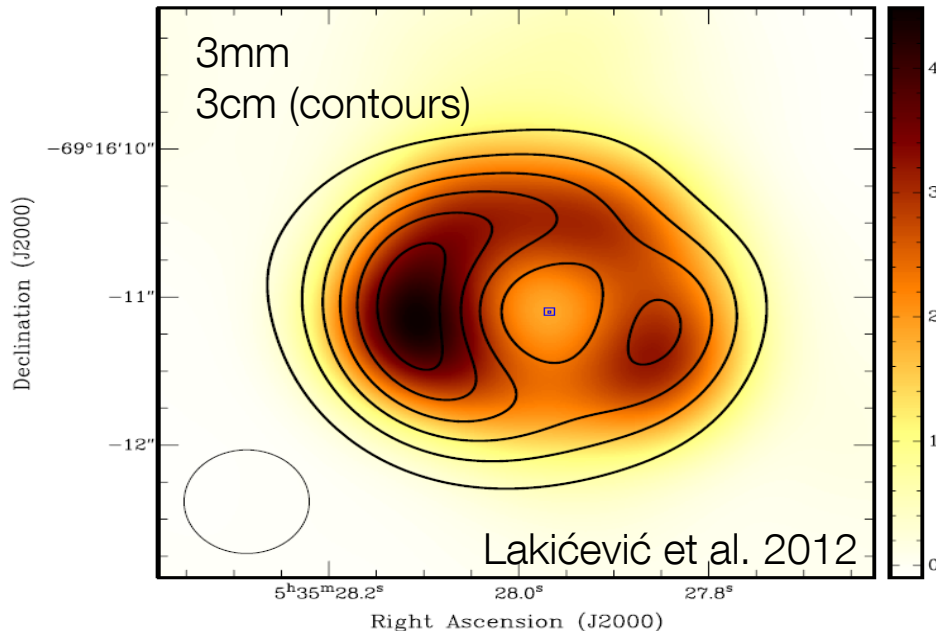
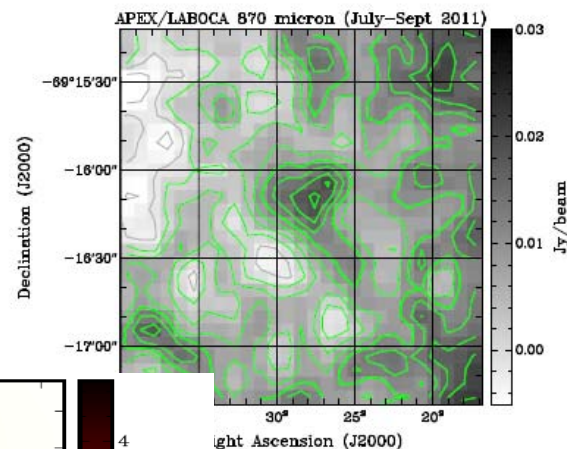
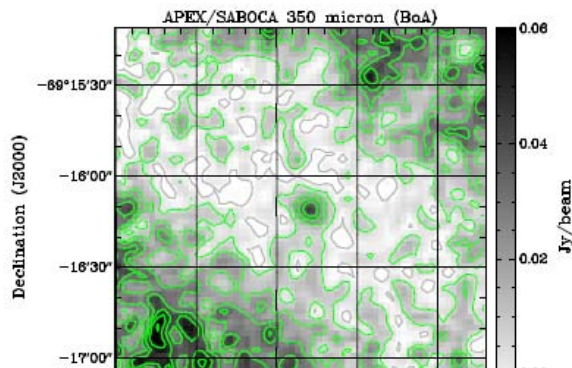
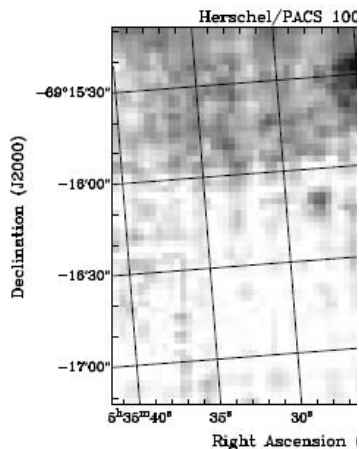
Dust

in and around the supernova



# Exciting developments 2011/12

Lakićević et al. 2012



Matsuura et al. 2011

Background subtracted

Herschel

# Dust - where is it?

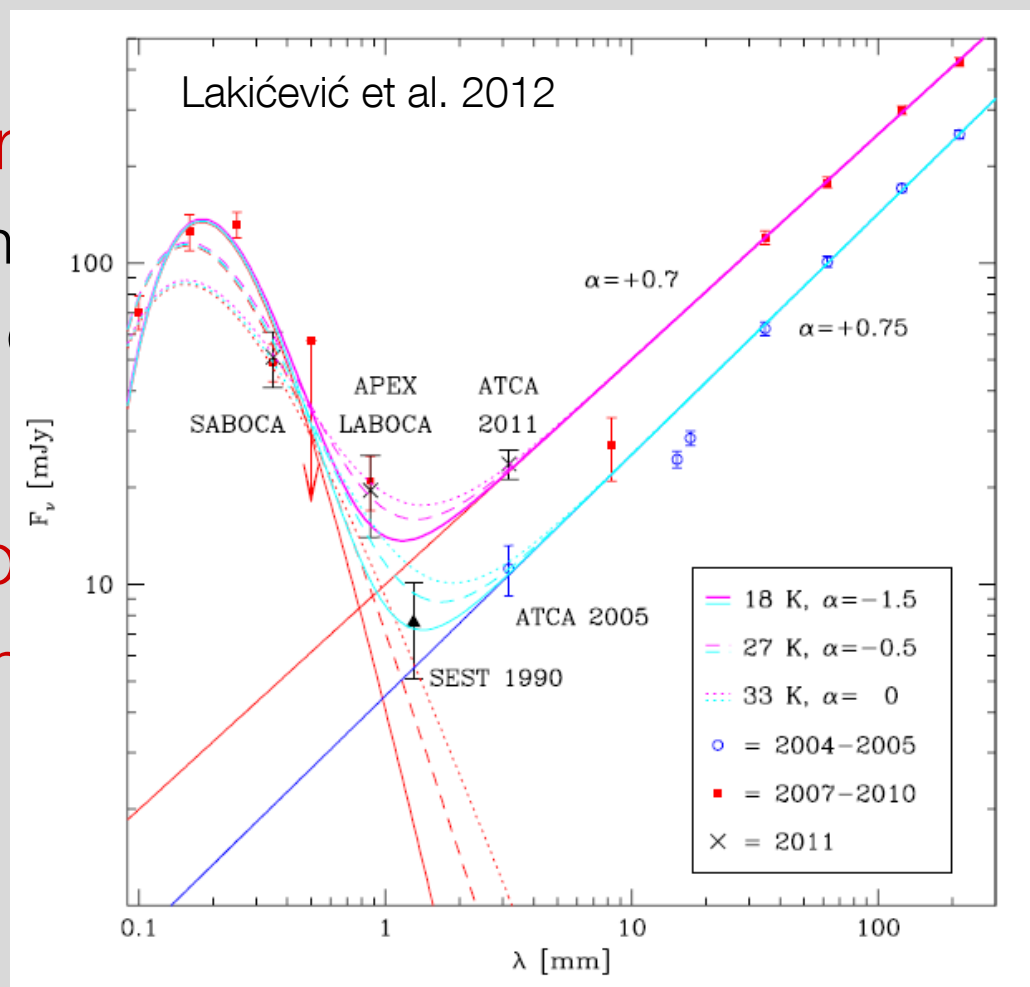
- Herschel fluxes indicate cold dust ( $\sim 20\text{K}$ )

- $\sim 0.5 M_{\odot}$  dust in

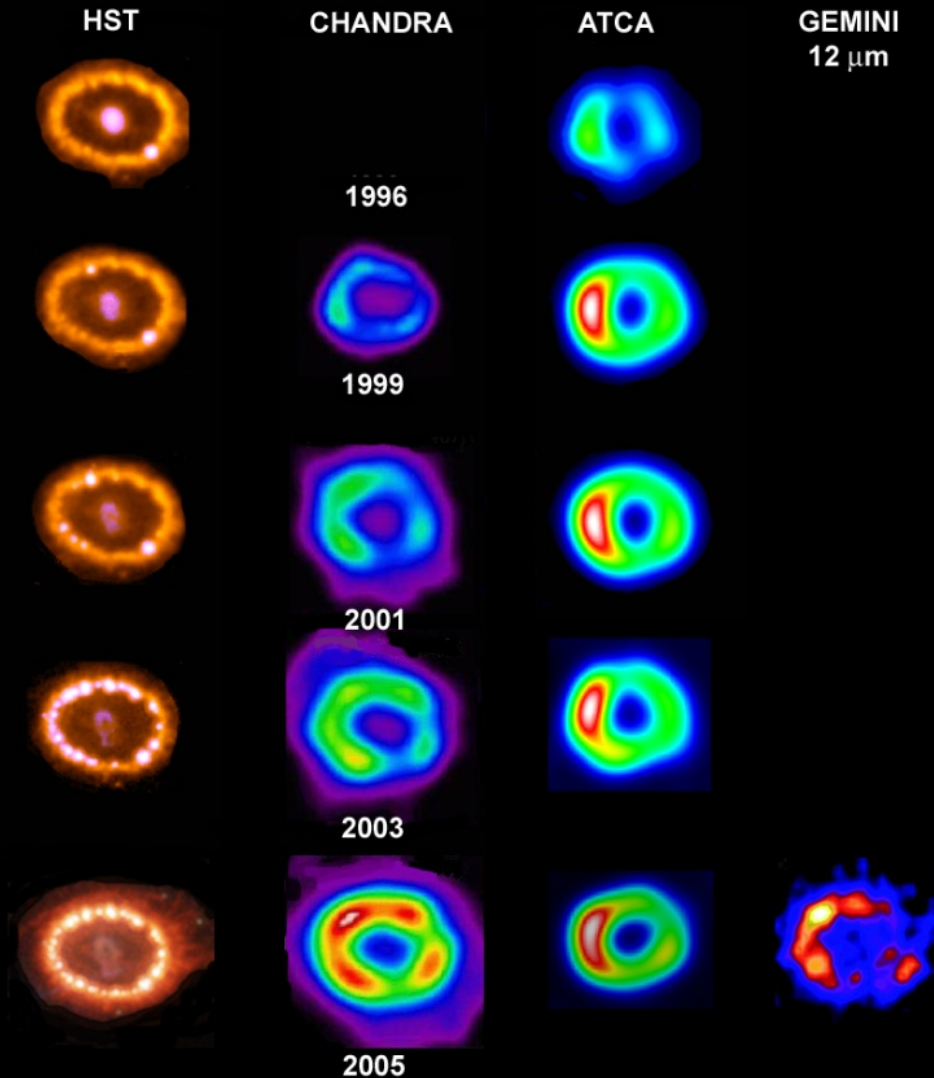
- strongly dependent
    - location in the

- IR/radio SED

- dust – black body
  - synchrotron emission

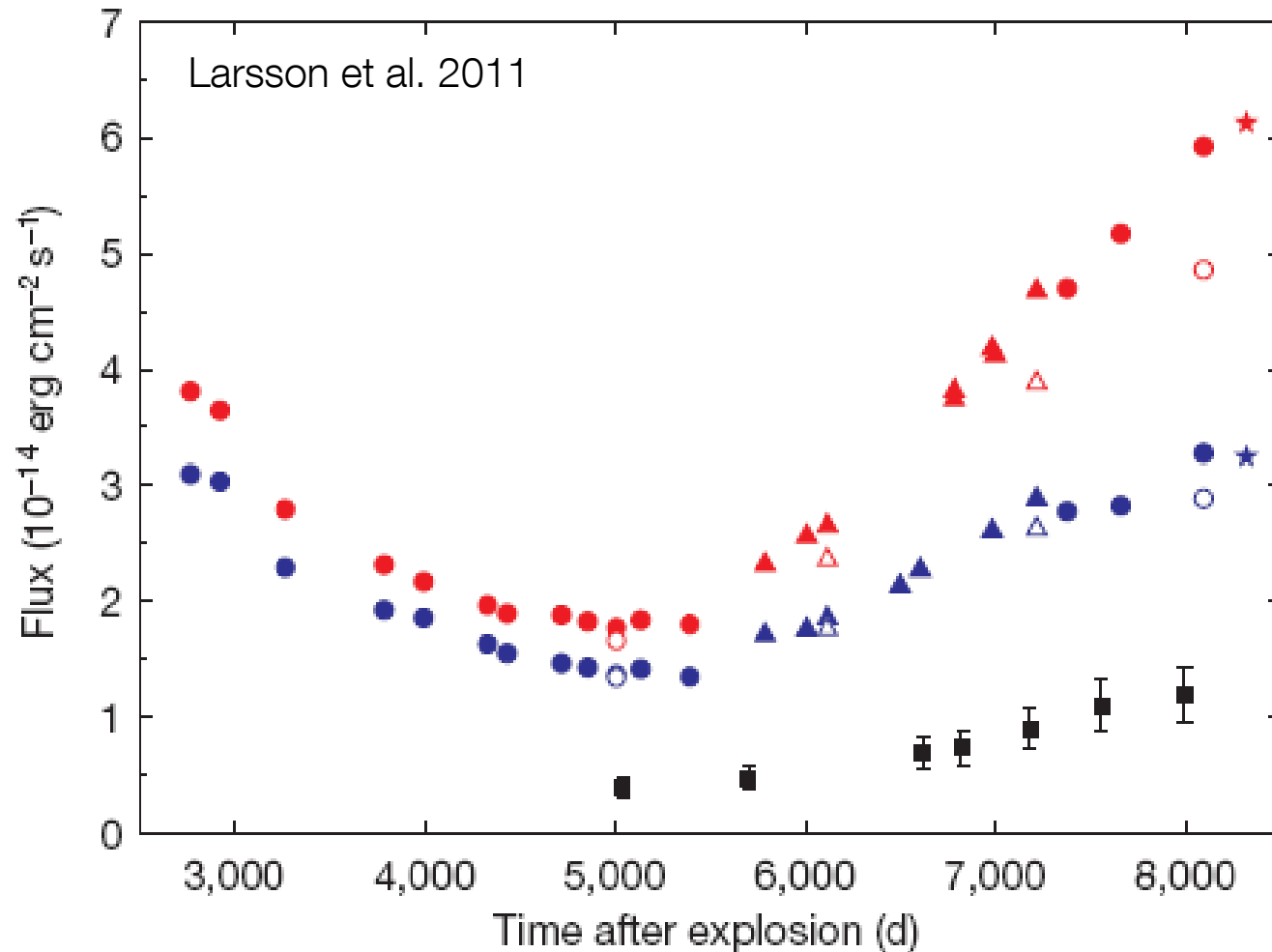


# Optical, X-rays and Radio



Park et al  
Manchester et al

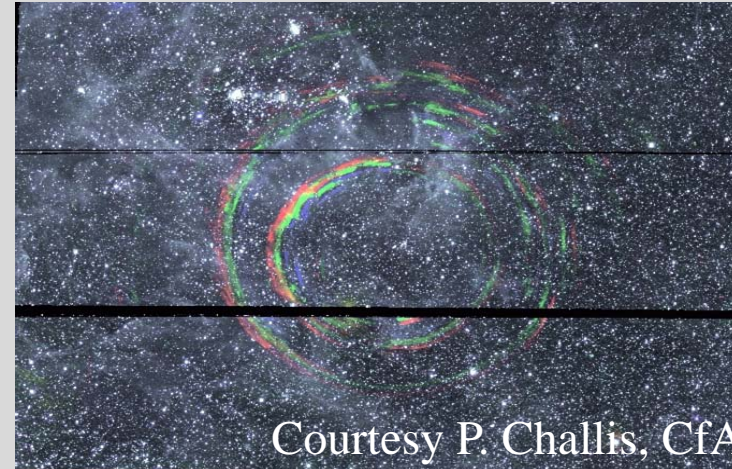
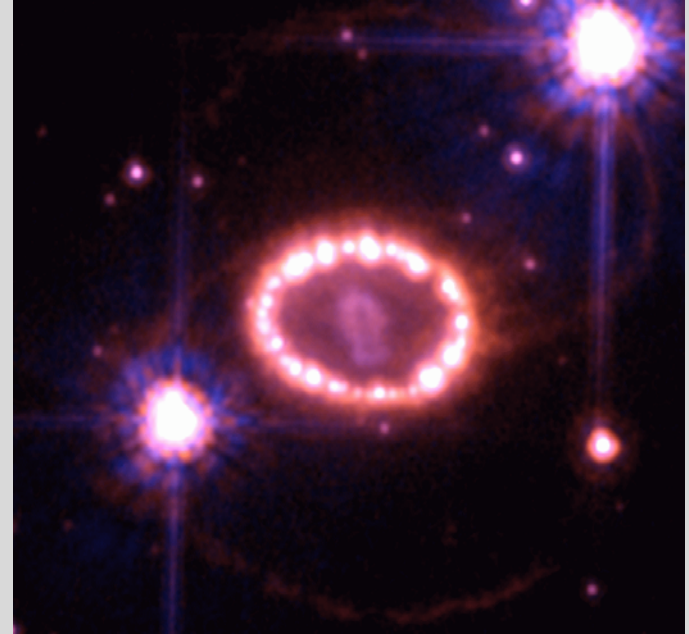
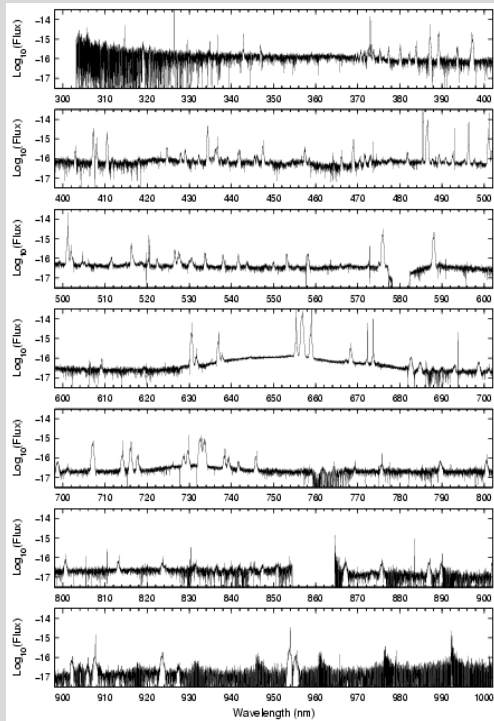
# SN 1987A is brightening at all wavelengths



# The complex SN 1987A @ 25 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)
  - dust?

# The ring collision

Dominating at all wavelengths

shock emission increasing for the past 10 years

Emission from the stationary ring

narrow lines (FWHM  $\approx$  10 km/s)

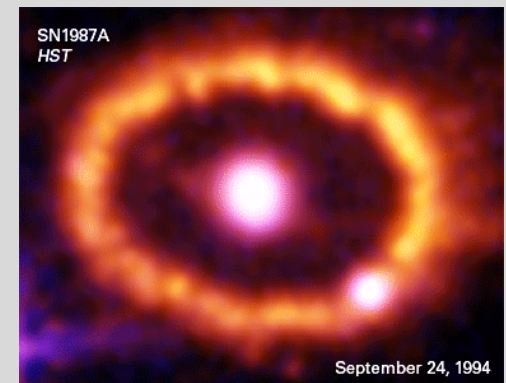
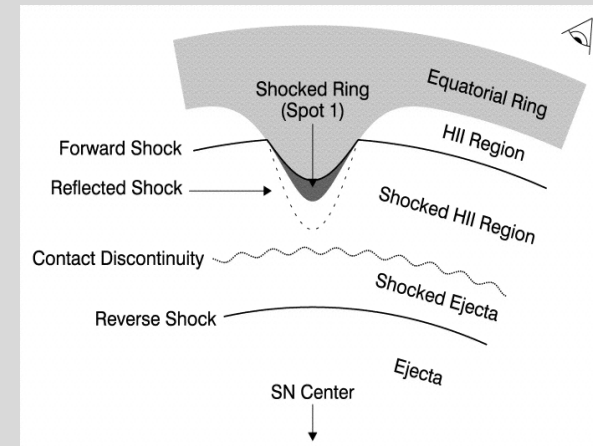
known since 1987 - fading

Shocked ring region (forward shock)

intermediate lines ( $\sim$ 300 km/s)

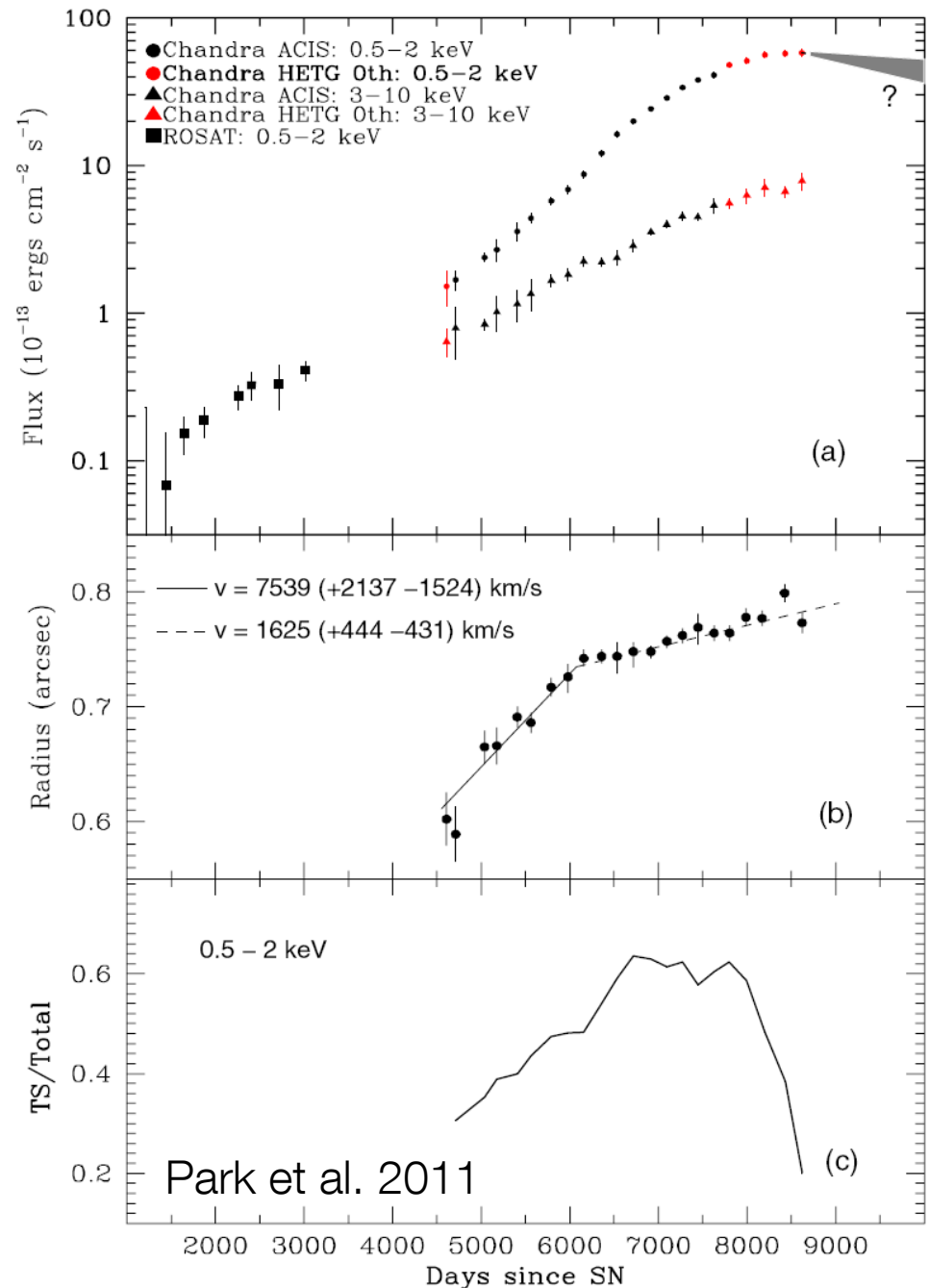
Reverse shock

ejecta ( $\sim$ 15000 km/s)



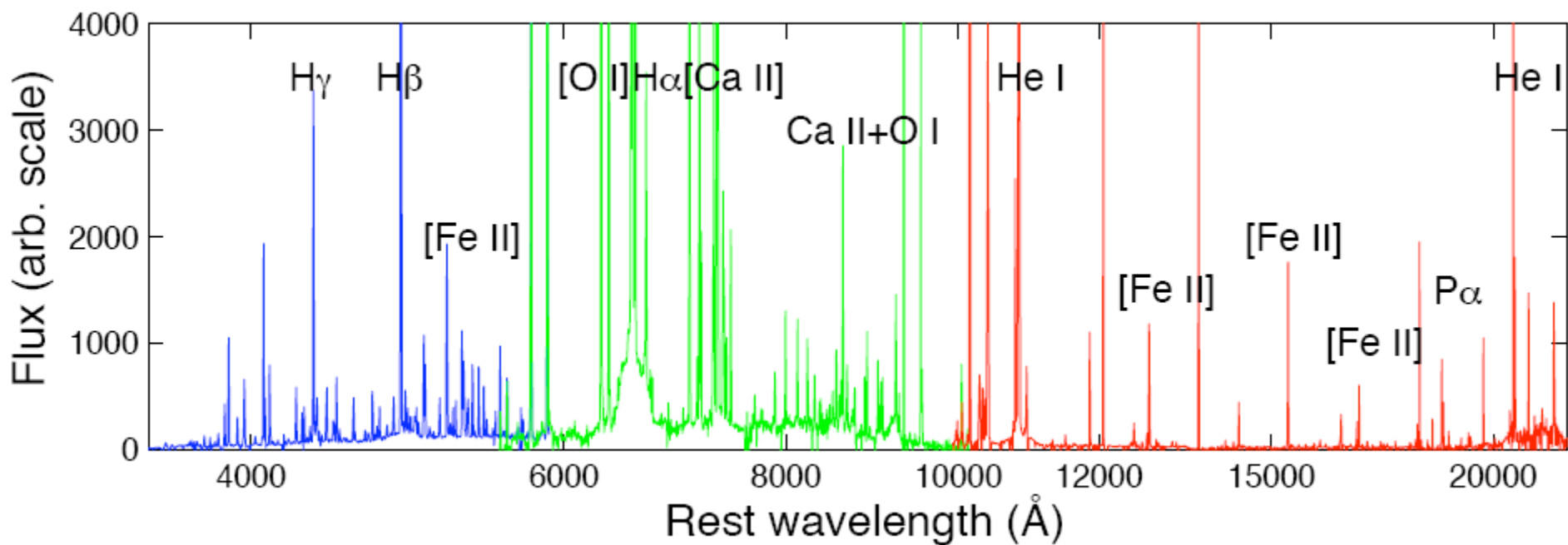
# New phase in the X-rays?

- Turnover of the soft X-rays
- signature of decreasing density structure?

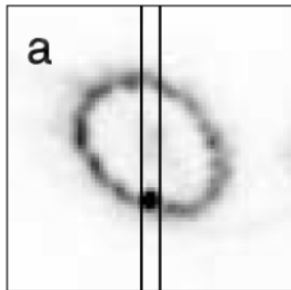
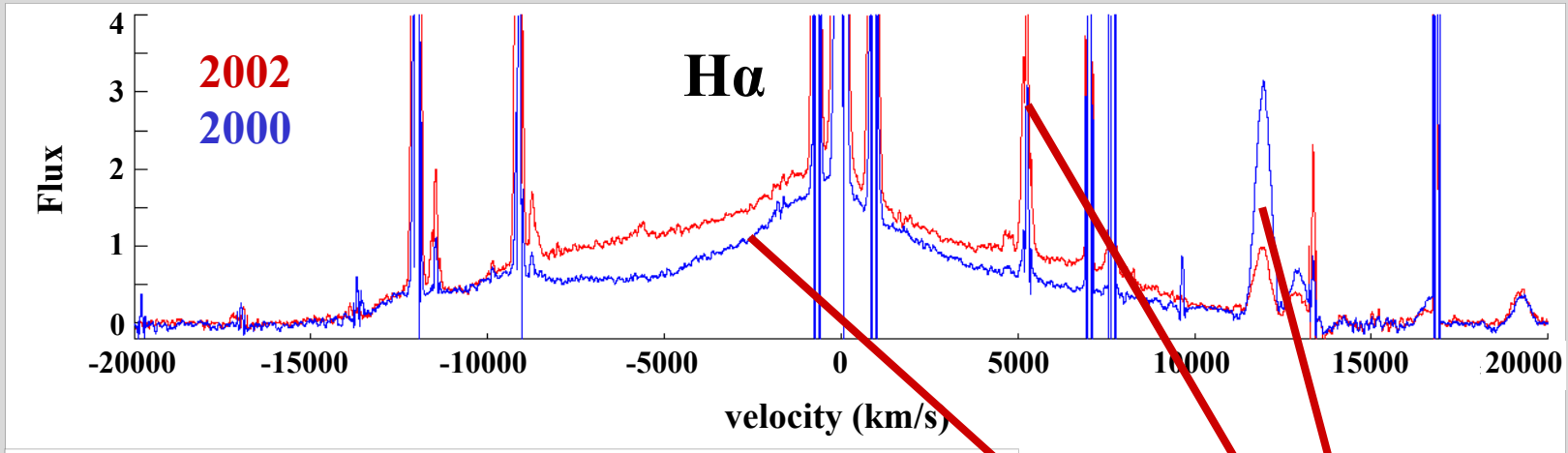


# Emission line components

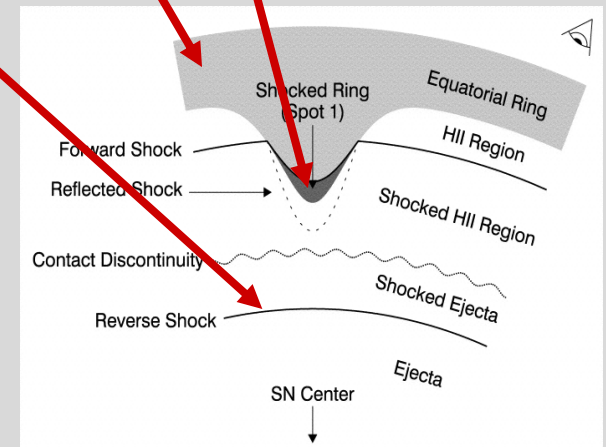
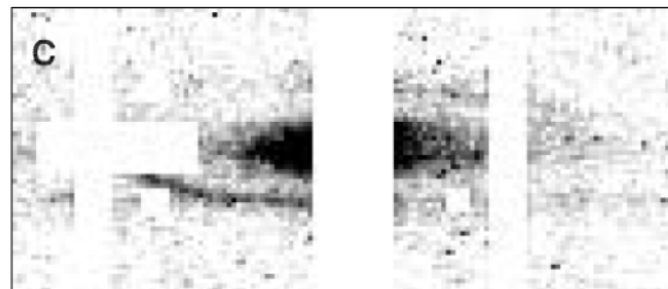
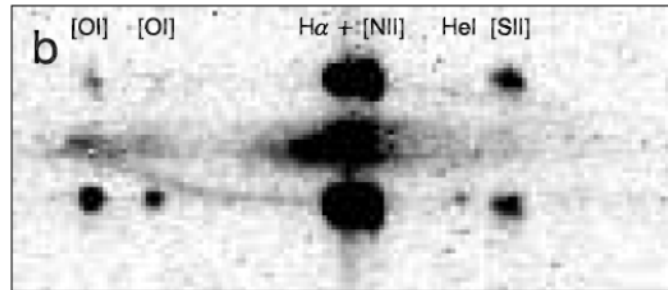
- SN 1987A in Dec 2010
  - Xshooter



# The emission line components



Velocity [1000 km s<sup>-1</sup>]



Michael et al. HST/STIS  
1999

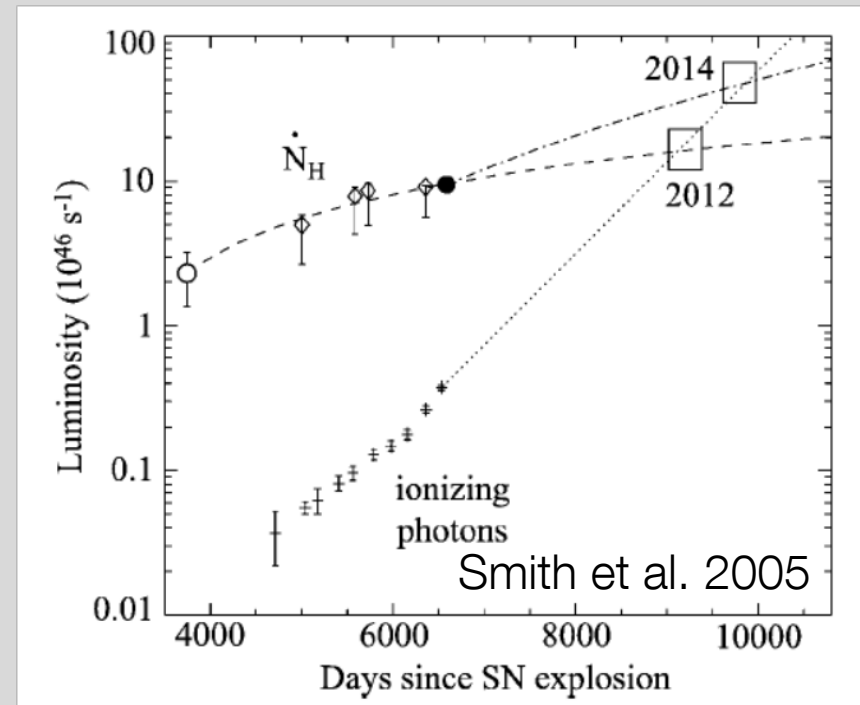
# Reverse shock

Forward shock is ionizing the ejecta

At some point all H atoms will be ionized  
before they reach the reverse shock and the  
emission will turn off

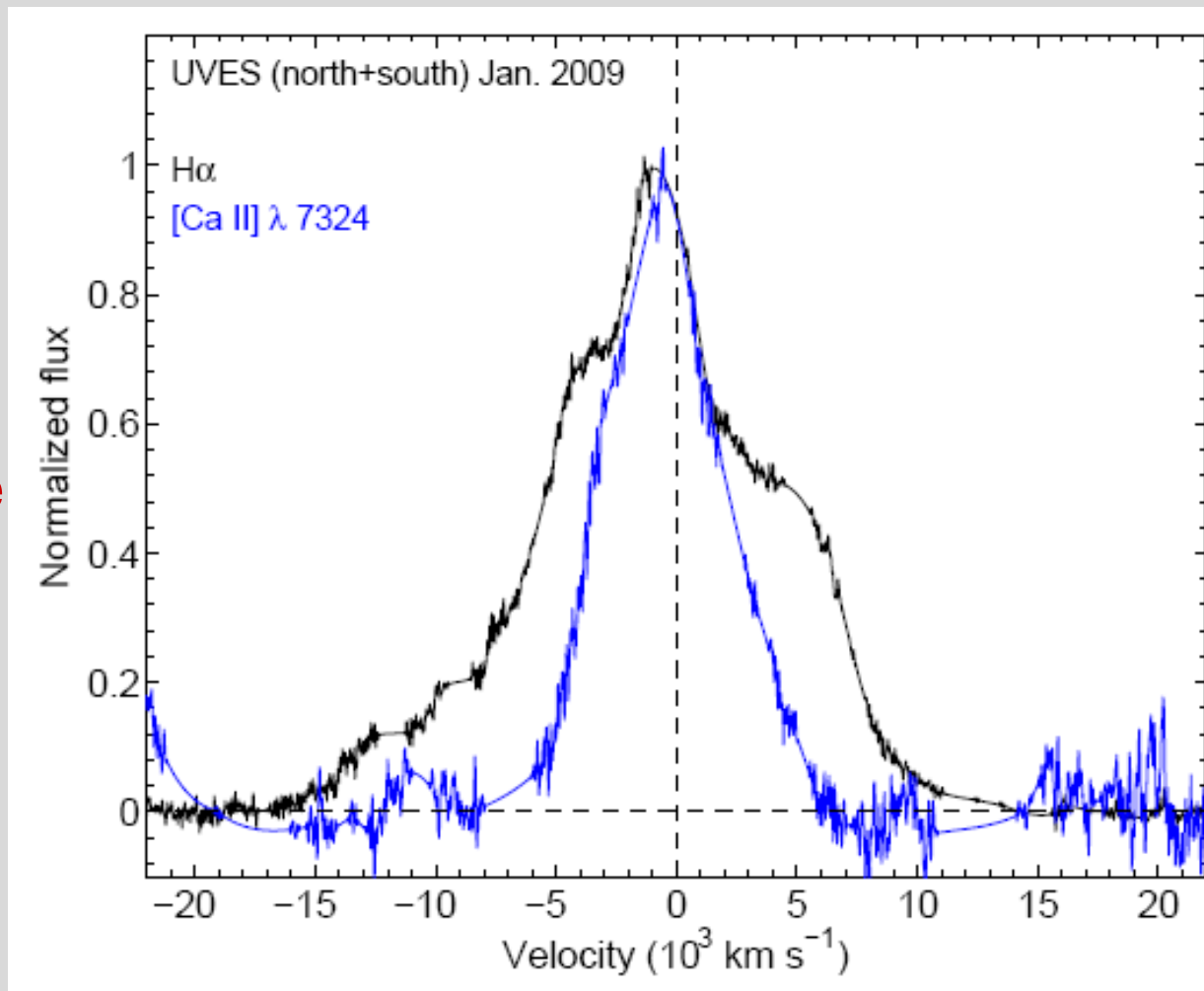
X-rays give the amount  
of ionizing photons

Monitoring the  $H\alpha$   
emission will tell



# Hydrogen in SN 1987A

- ‘Clean H $\alpha$ ’
- Flux increase by  $\sim 3.5$  from 2000 to 2009
- $v_{\max} > 11000$  km/s  
larger than possible  
in equatorial ring  
anisotropic  
expansion
- ejecta brightened
- asymmetry  
indicates dust



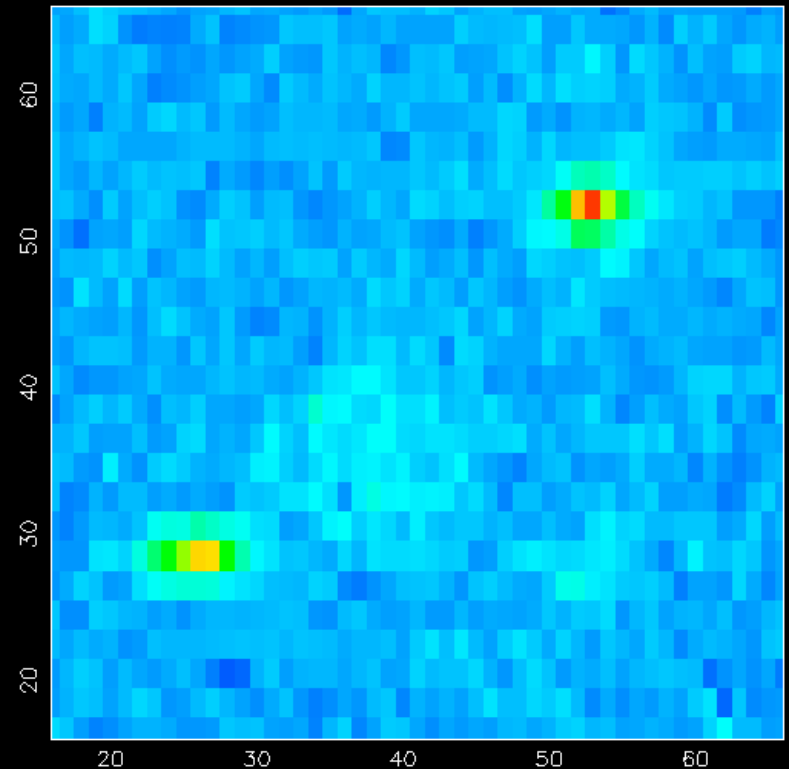
# Spatially resolved infrared spectroscopy

separate ring from  
ejecta

trace the ring in  
individual lines

get spectra from  
separate regions

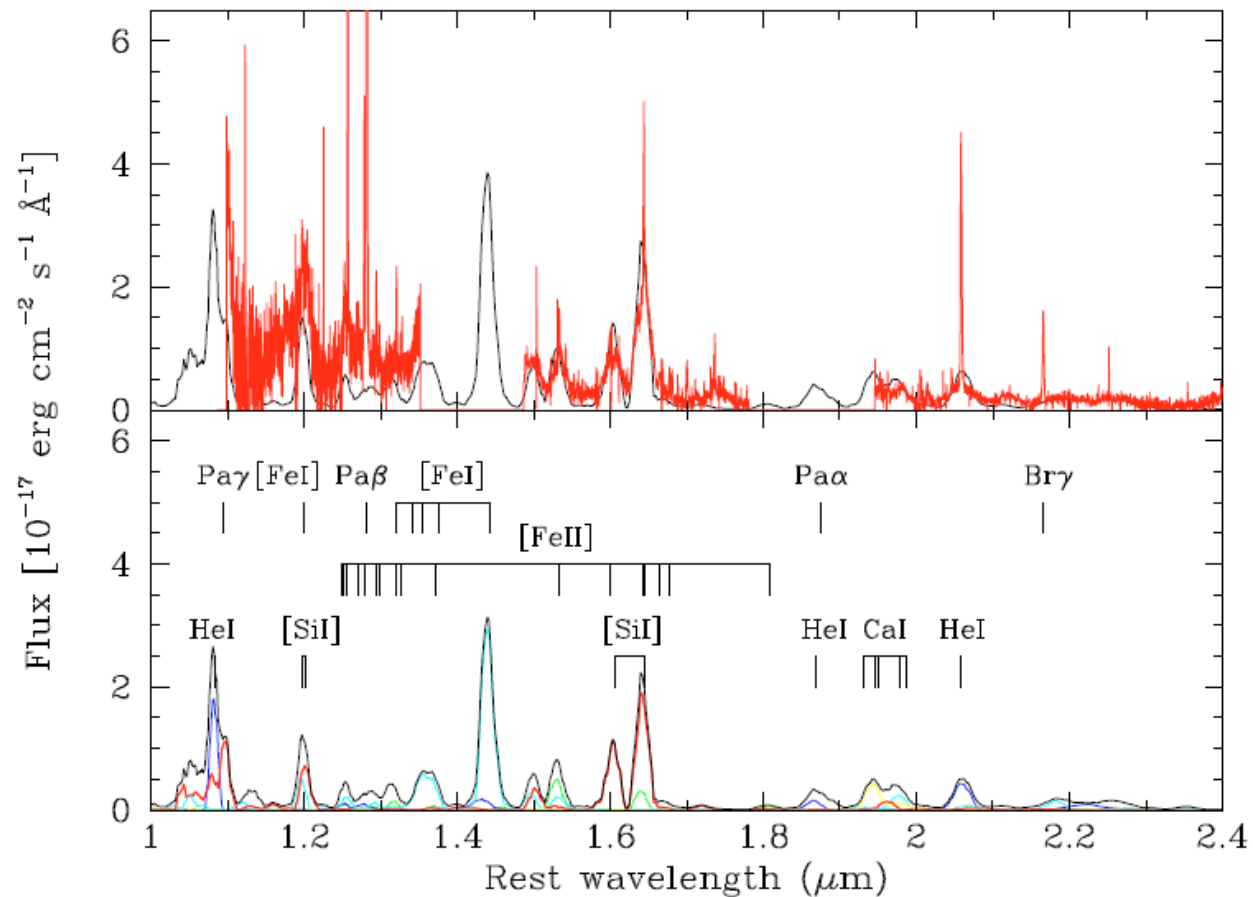
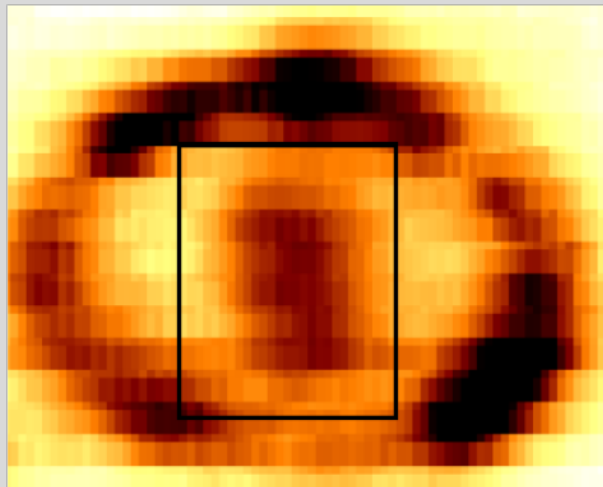
photometry of selected  
regions





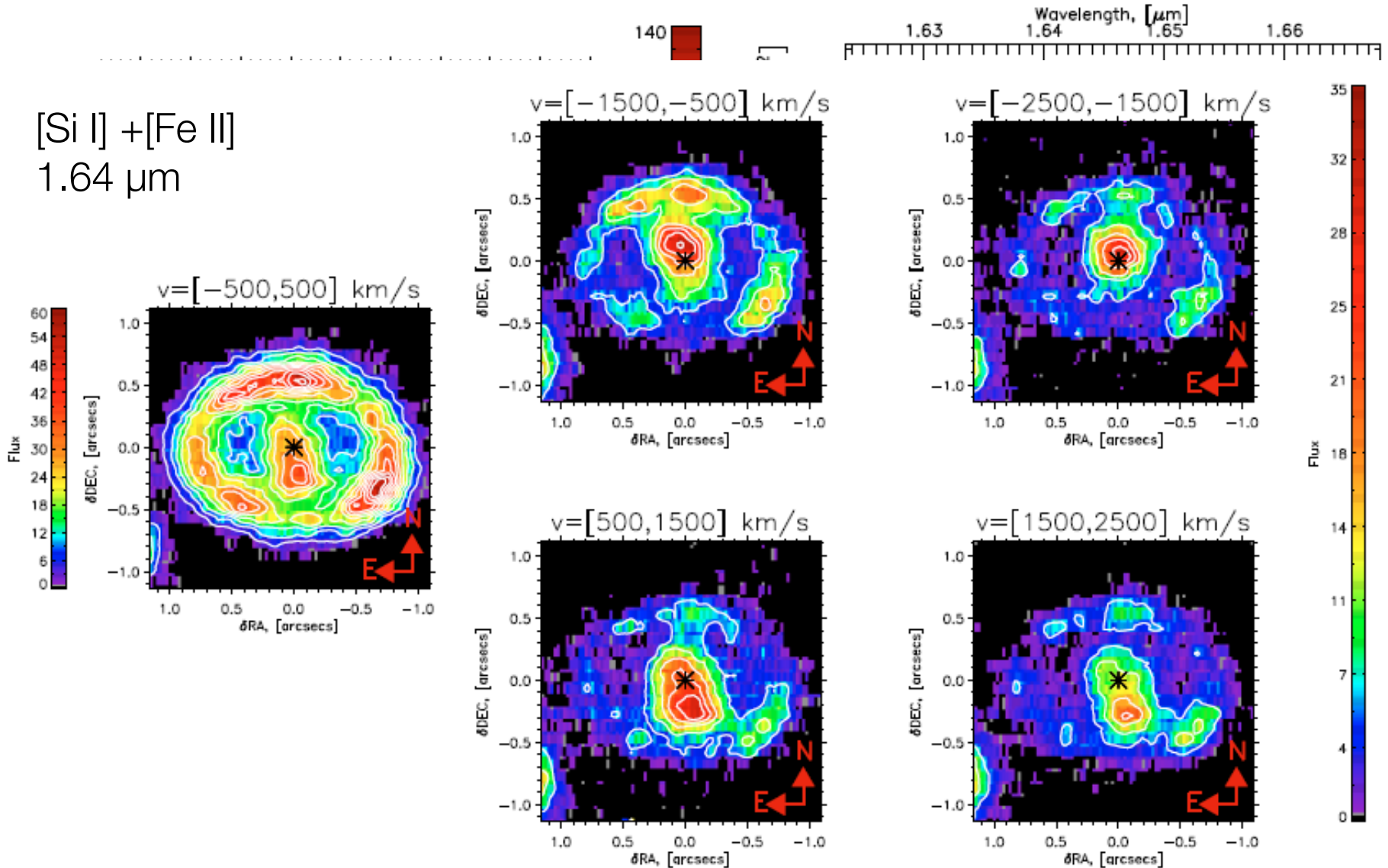
# Ejecta resolved

Ground-based near-IR data show spatially resolved ejecta



# Asymmetry in the ejecta

[Si I] + [Fe II]  
1.64  $\mu\text{m}$



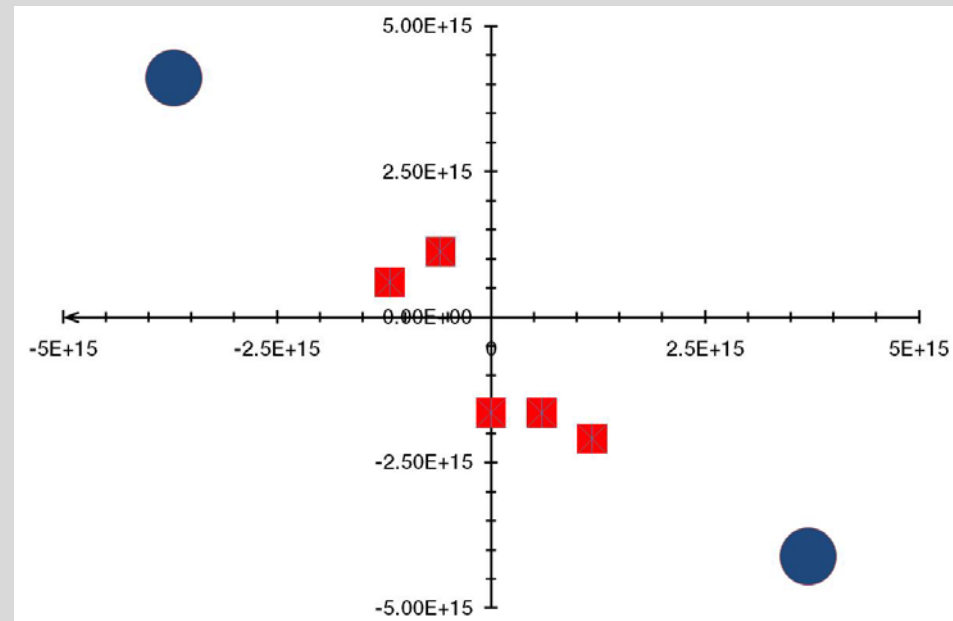
# Ejecta kinematics

Southern part is redshifted, northern ejecta are blueshifted

Expansion velocity roughly 3000 to 4000 km/s

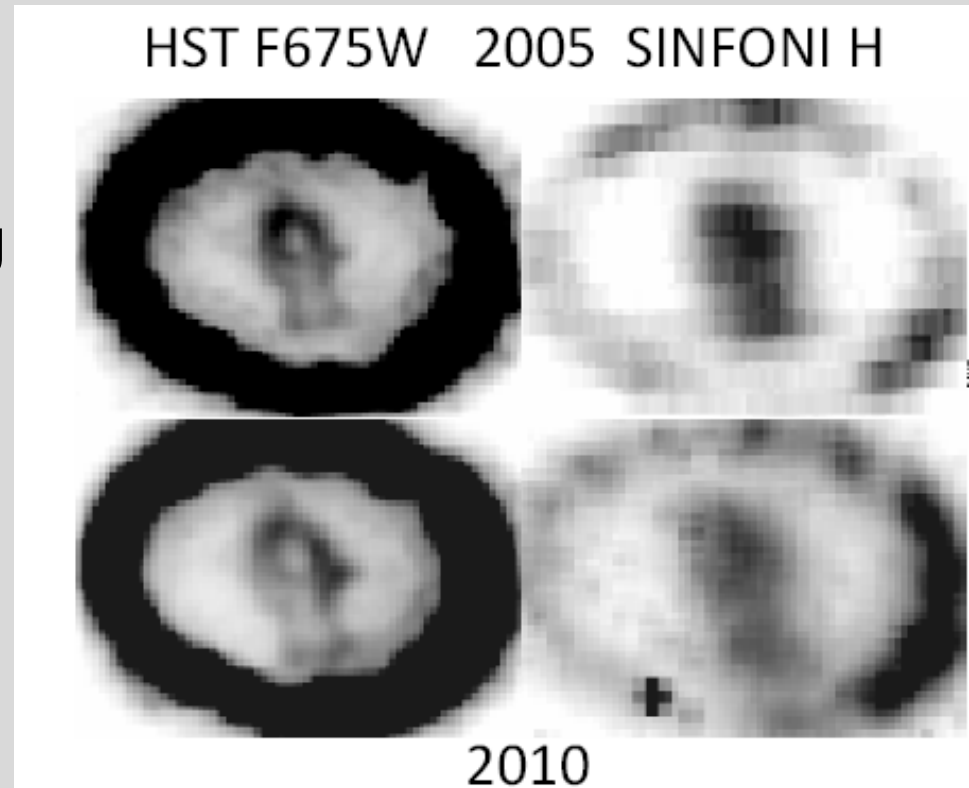
This is the same orientation  
as the inner ring!

Ejecta lies in the  
same plane as the  
ring!



# The inner ejecta

- Comparison optical vs. IR
  - optical
    - heated by X-rays
  - IR
    - radioactive heating



# Summary

SN 1987A is as interesting as ever

ring collision is in full swing

forward shocks in/past(?) the ring

reverse shock in the debris (outer ejecta)

heating of the inner ejecta

first direct look at the inner parts of an explosion

resolved inner ejecta are the immediate result 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
- Disappearance of the reverse shock
- Illuminating the outside
  - beyond the inner ring
- Detailed mapping of the inner ejecta
  - details on explosion mechanics and distribution of synthesized material
  - dust formation
    - ALMA!
- Where is the neutron star?