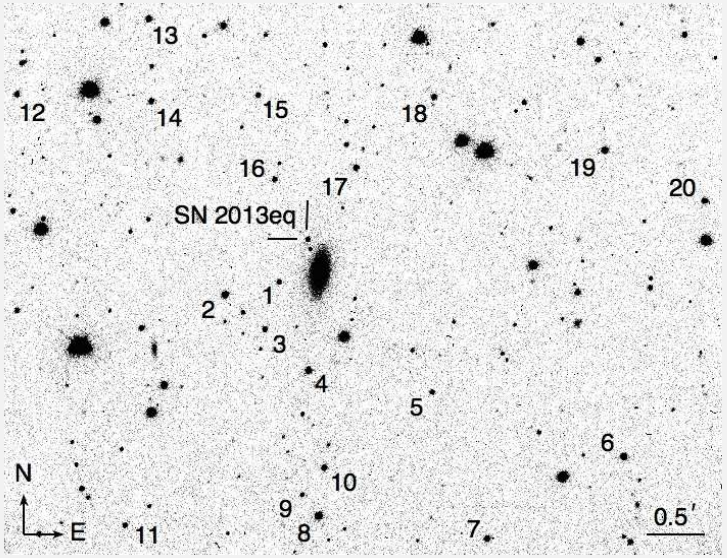
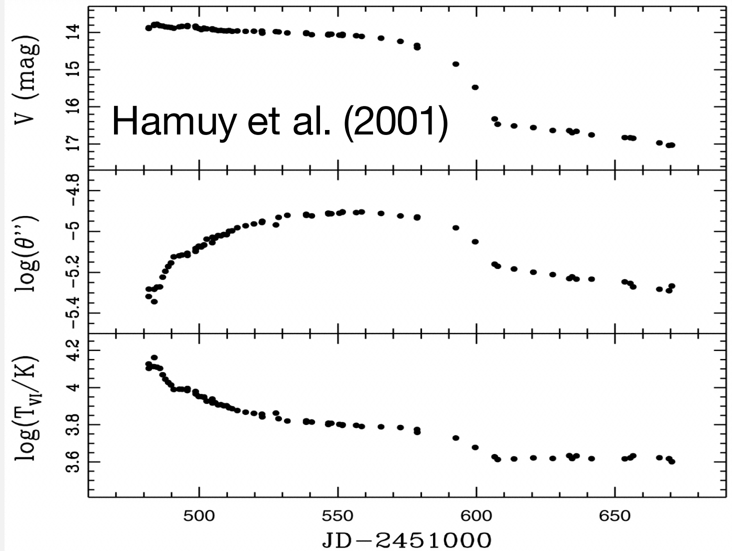




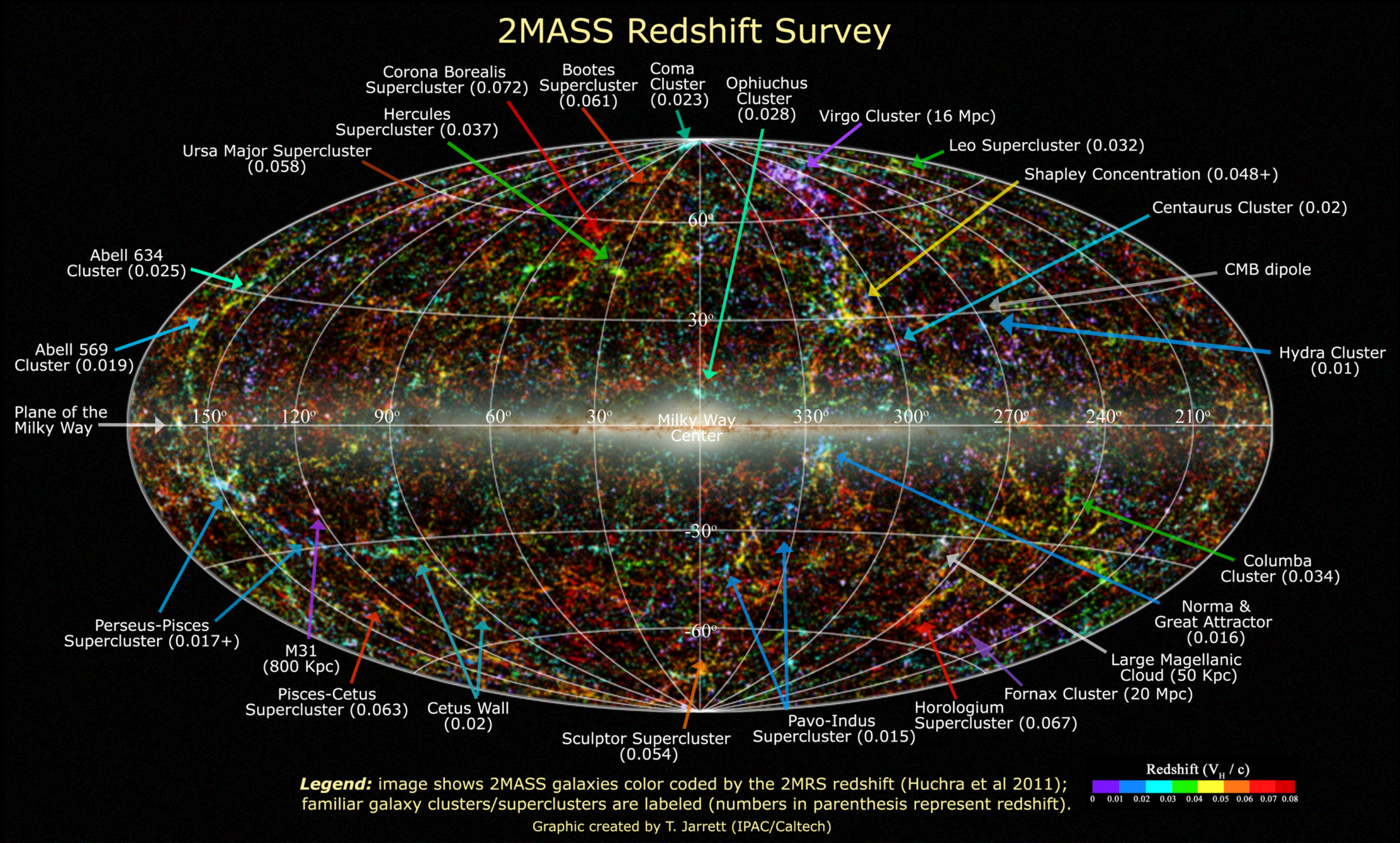
The distance to the Type IIP SN 2013eq

Elisabeth Gall (QUB/MPA), Rubina Kotak (QUB),
Bruno Leibundgut (ESO),
Stefan Taubenberger (ESO/MPA),
Wolfgang Hillebrandt (MPA),
Markus Kromer (Stockholm)

arXiv:1603.04730

Extragalactic Distances

Required for a 3D picture of the (local) universe



Extragalactic Distances

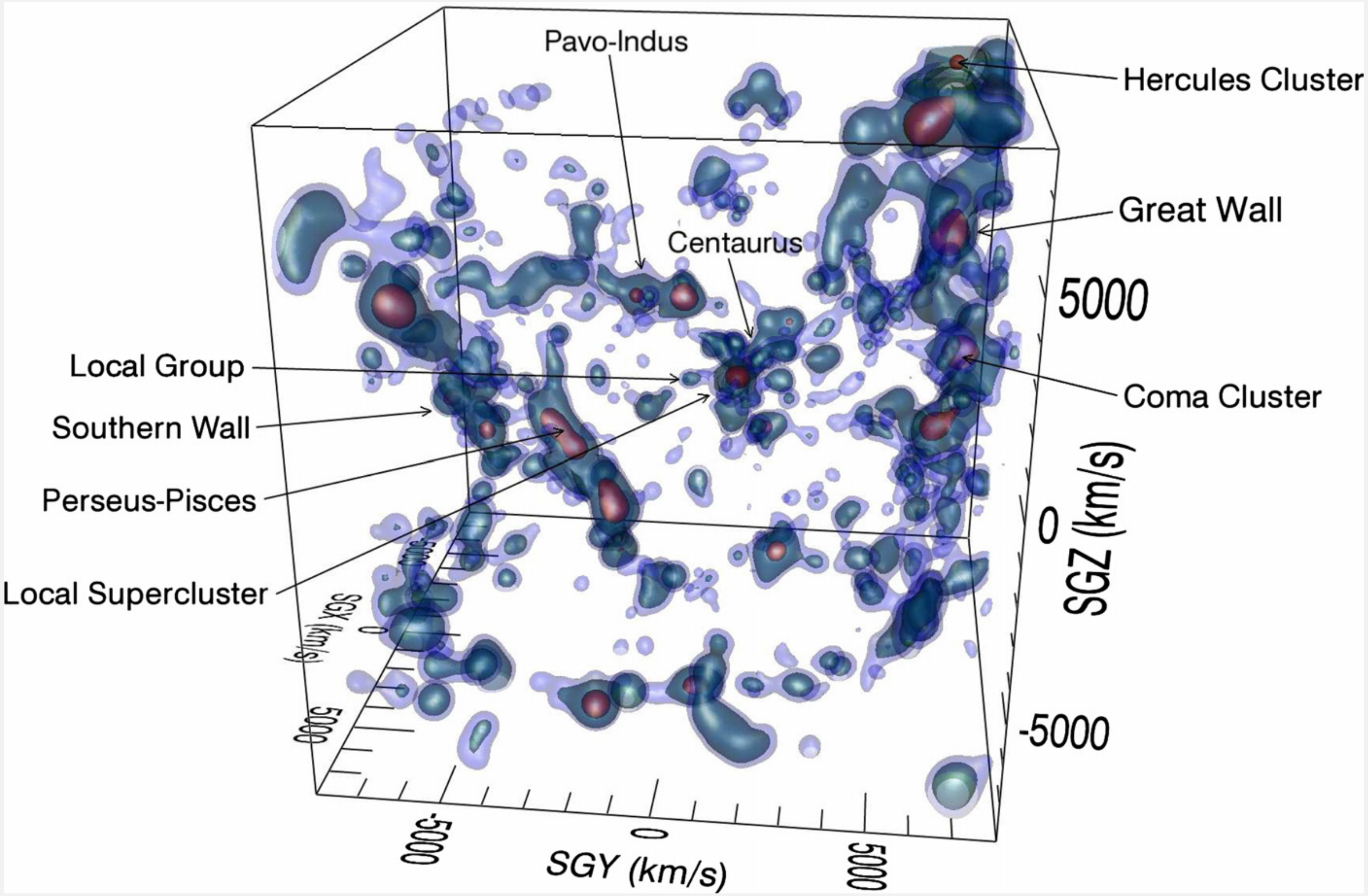


Figure 8. Perspective view of the V8k catalog after correction for incompleteness and represented by three layers of isodensity contours. The region in the vicinity of the Virgo Cluster now appears considerably diminished in importance. The dominant structures are the Great Wall and the Perseus–Pisces chain, with the Pavo–Indus feature of significance.

Extragalactic Distances

- Many different methods
  - Galaxies
    - Mostly statistical
    - Secular evolution, e.g. mergers
    - Baryonic acoustic oscillations
  - Supernovae
    - Excellent distance indicators
    - Three main methods
      - (Standard) luminosity, aka 'standard candle'
      - Expanding photosphere method
      - Angular size of a known feature

Expanding Photosphere Method

- Modification of Baade-Wesselink method for variable stars
- Assumes
  - Sharp photosphere → thermal equilibrium
  - Spherical symmetry → radial velocity
  - Free expansion

Expanding Photosphere Method

$$\theta = \frac{R}{D} = \sqrt{\frac{f_\lambda}{\zeta_\lambda^2 \pi B_\Lambda(T)}}; \; R = v(t - t_0) + R_0; \; D_A = \frac{v}{\theta}(t - t_0)$$

- R from radial velocity
  - Requires lines formed close to the photosphere
- D from the surface brightness of the black body
  - Deviation from black body due to line opacities
  - Encompassed in the dilution factor ζ^2

Expanding Photosphere Method

- Measures an angular size distance
  - Not important in the local universe
  - Interesting for cosmological applications
  - Mostly for H_0
- Cosmology
  - Include time dilation
  - Metric theories of gravity imply

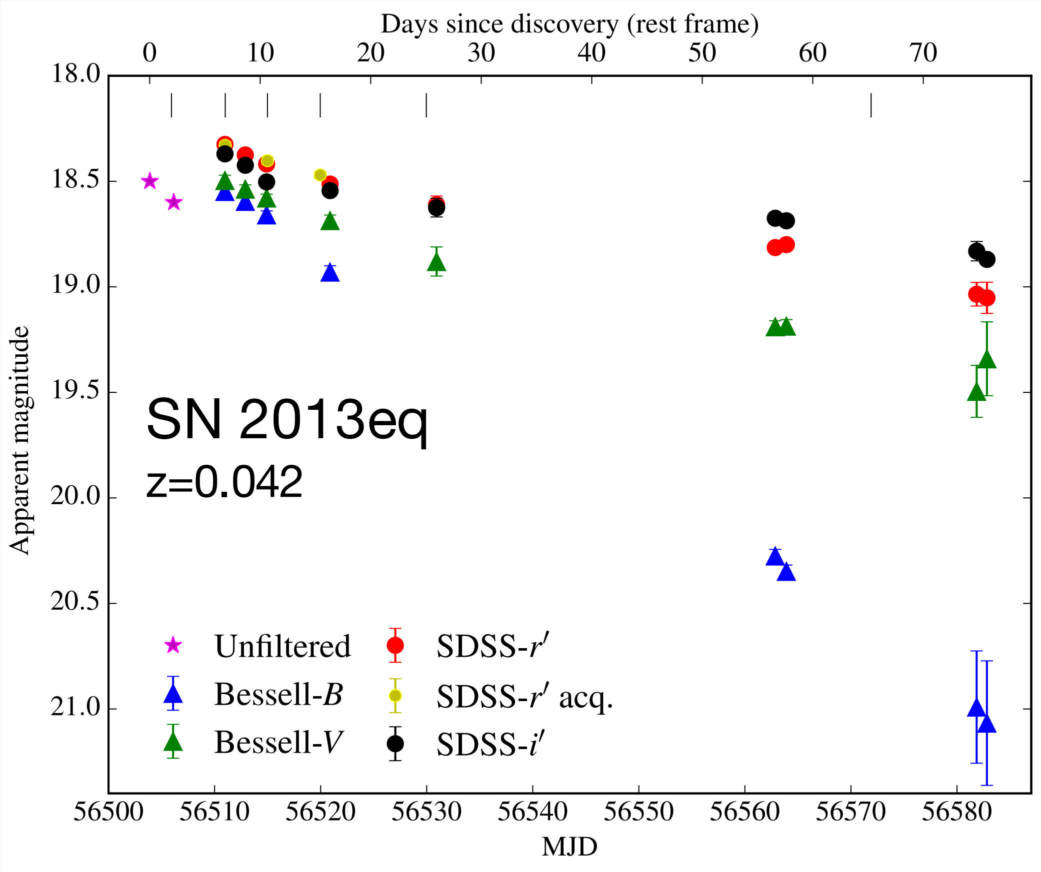
$$D_L = (1+z)^2 D_A$$

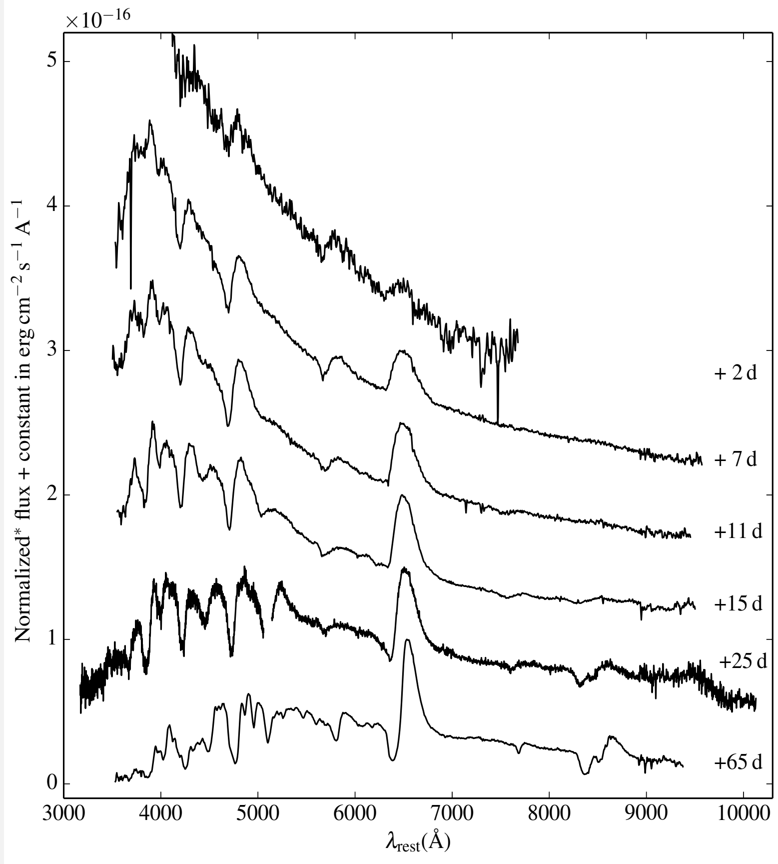
z	$\frac{D_L}{D_A}$
0.1	1.21
0.15	1.32
0.2	1.44
0.25	1.56
0.3	1.69
0.35	1.82

Expanding Photosphere Method

- Principle difficulties
  - Explosion geometry/spherical symmetry
  - Uniform dilution factors?
    - Develop tailored spectra for each supernova → Spectral-fitting Expanding Atmosphere Method (SEAM) – see Christian Vogl's talk on Friday
  - Absorption
- Observational difficulties
  - Multiple epochs
  - Spectroscopy to detect faint lines
  - Photometry

SN 2013eq

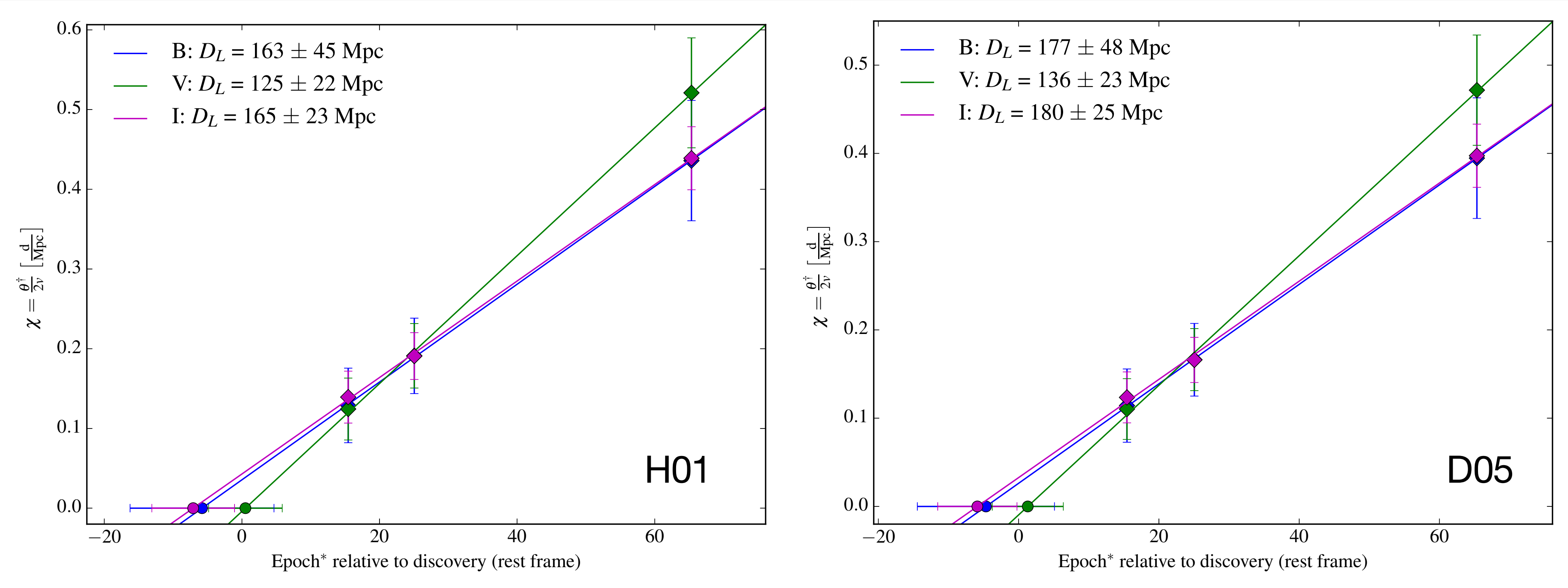




Gall et al. 2016

SN 2013eq

- Two different dilution factors applied
  - Hamuy et al. 2001 (H01)
  - Dessart & Hillier 2005 (D05)
    - Both give a good distance to SN 1999em, e.g. Jones et al. (2009)



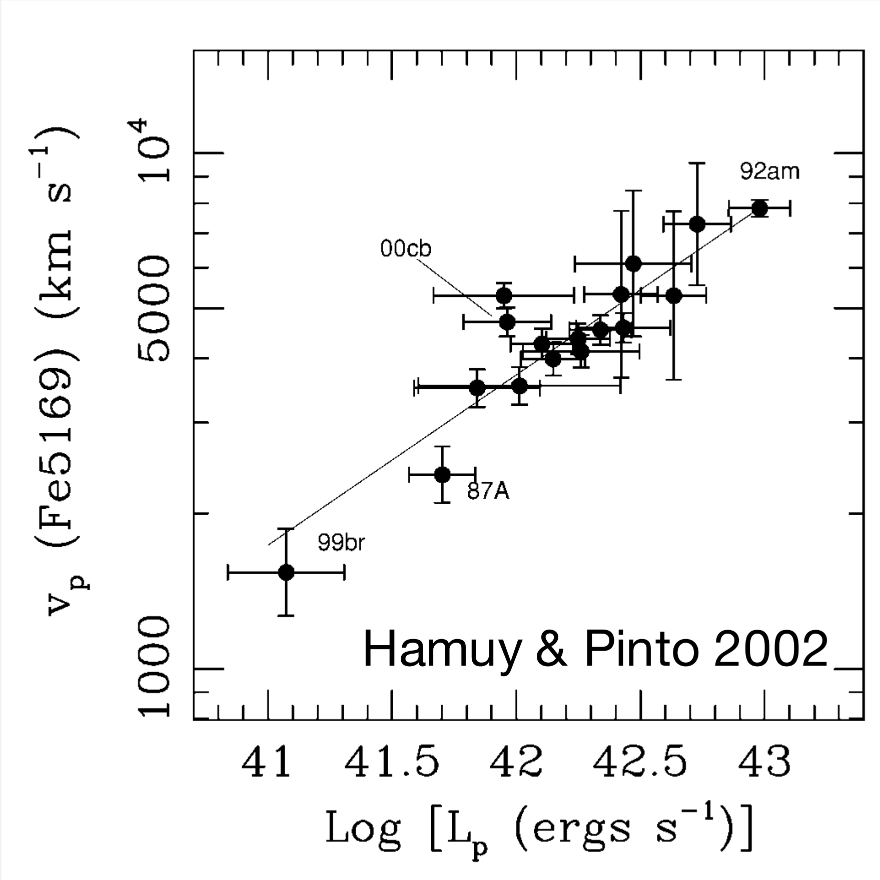
Standardizable Candle Method

Introduced by Hamuy & Pinto (2002)

- Normalised luminosity during the plateau phase of SNe IIP
- Normally at 50 days after explosion

Used widely for SNe IIP

- Nugent et al. 2006
- Poznanski et al. 2009
- Olivares et al. 2010
- Maguire et al. 2010
- Polshaw et al. 2015



Standardizable Candle Method

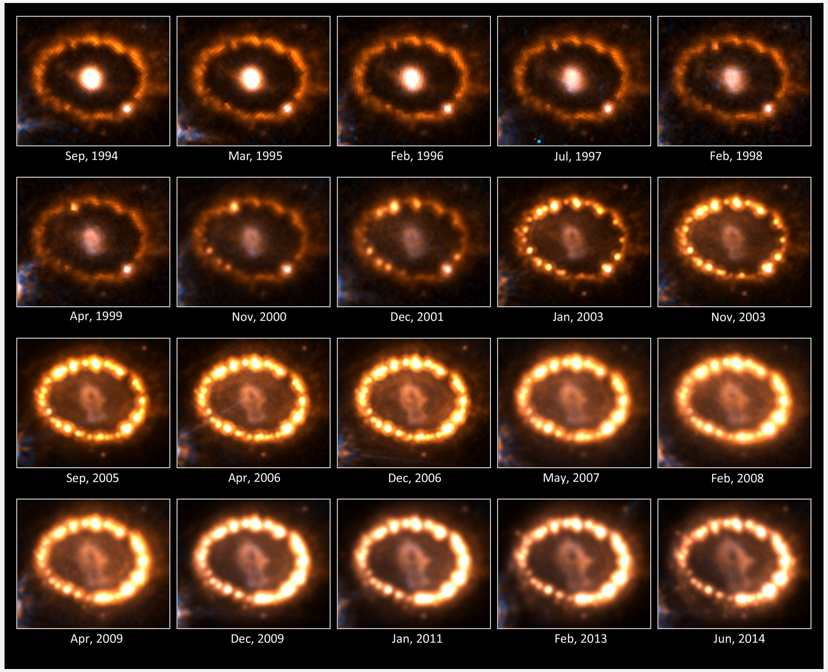
- Straightforward simple method
  - Only few observations required
- Issues
  - Need to know explosion time
    - Often not too obvious from observational data
  - Measurement during a ’faint’ epoch
    - Plateau and not maximum
  - Spectroscopy often difficult
    - Faint phase and faint lines
    - Attempts to use prominent hydrogen lines

Distance to SN 2013eq

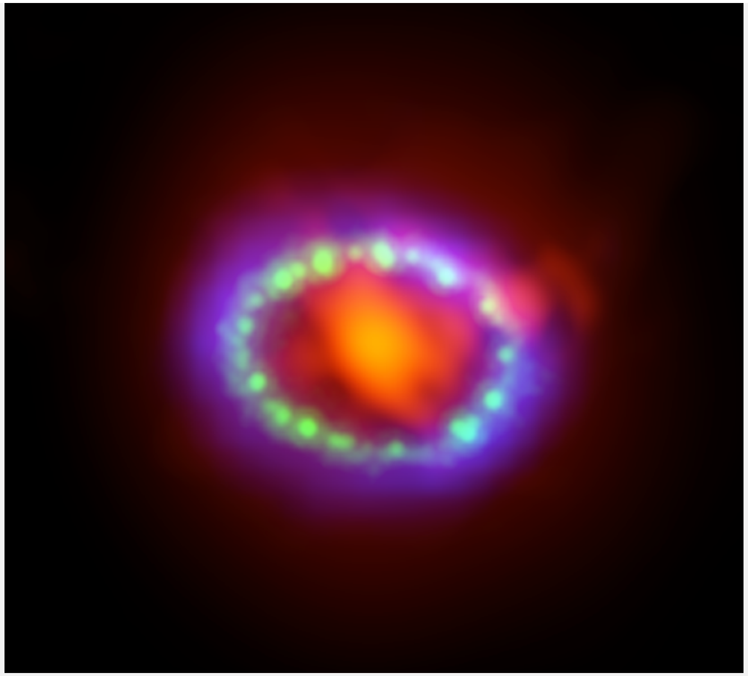
- Use EPM and CSM to measure distance to same supernova
- EPM provides explosion date to be used by CSM

Dilution Factor	Filter	D_L Mpc	Averaged D_L Mpc	t_0 days*	Average t_0 days*	Average t_0 mjd
H01	B	169 ± 37	156 ± 15	8.3 ± 2.6	6.3 ± 0.9	56497.4 ± 1.0
	V	127 ± 19		1.0 ± 0.9		
	I	171 ± 15		9.5 ± 0.5		
D05	B	183 ± 40	169 ± 16	6.9 ± 2.4	5.0 ± 0.9	56498.7 ± 0.9
	V	139 ± 20		0.0 ± 0.8		
	I	185 ± 17		8.0 ± 0.4		

Dilution Factor	t_0 mjd	V_{50}^* mag	I_{50}^* mag	v_{50} km s^{-1}	μ mag	D_L Mpc
H01	56497.4 ± 1.0	19.05 ± 0.04	18.33 ± 0.03	5078 ± 422	36.14 ± 0.23	169 ± 18
D05	56498.7 ± 0.9	19.06 ± 0.04	18.33 ± 0.03	4961 ± 413	36.10 ± 0.22	166 ± 17



Fransson et al. 2015


Indebetouw et al. 2014

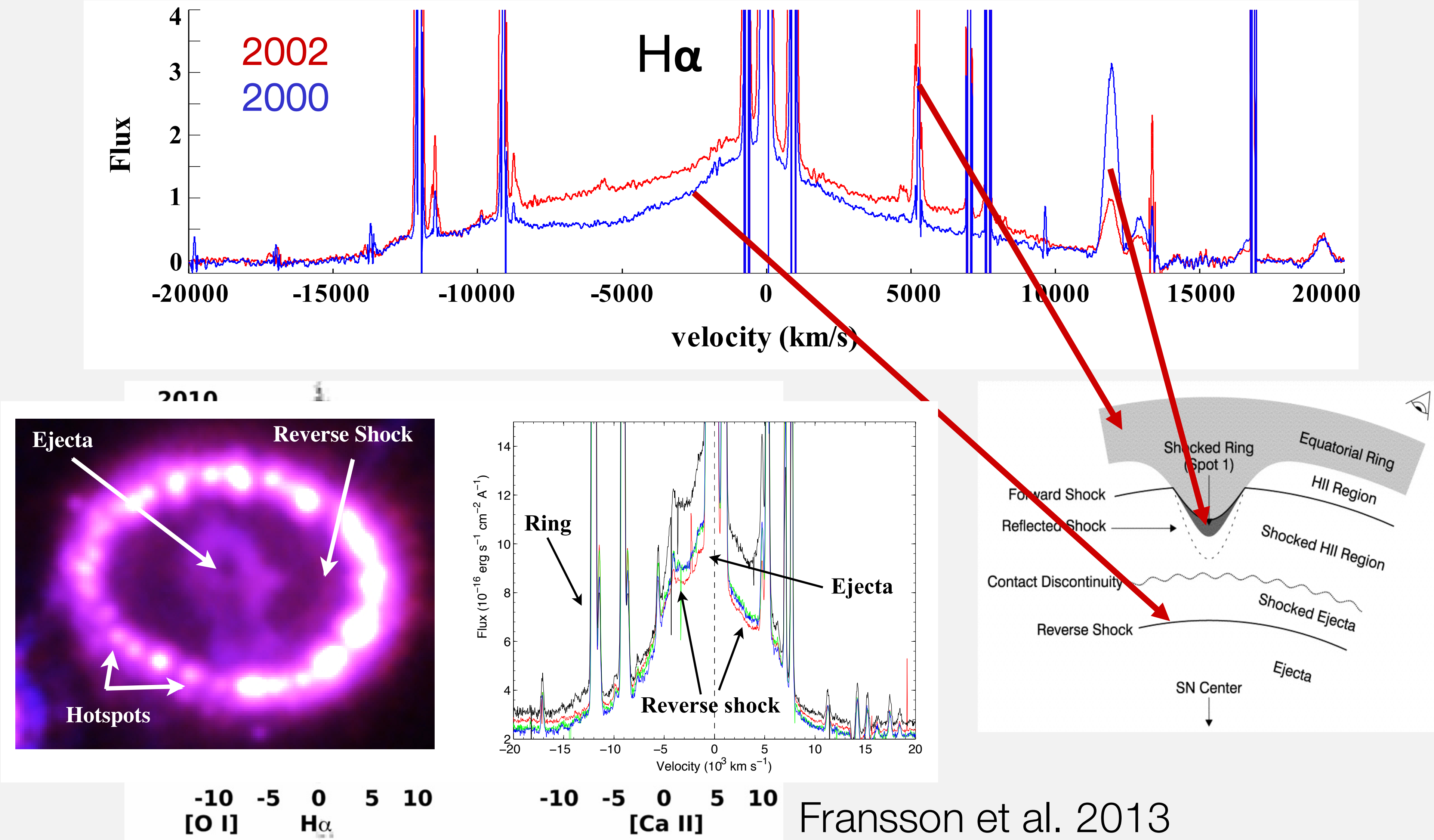
SN 1987A – recent news

Claes Fransson (Stockholm)

Josefin Larsson (Stockholm)

Jason Spyromilio (ESO)

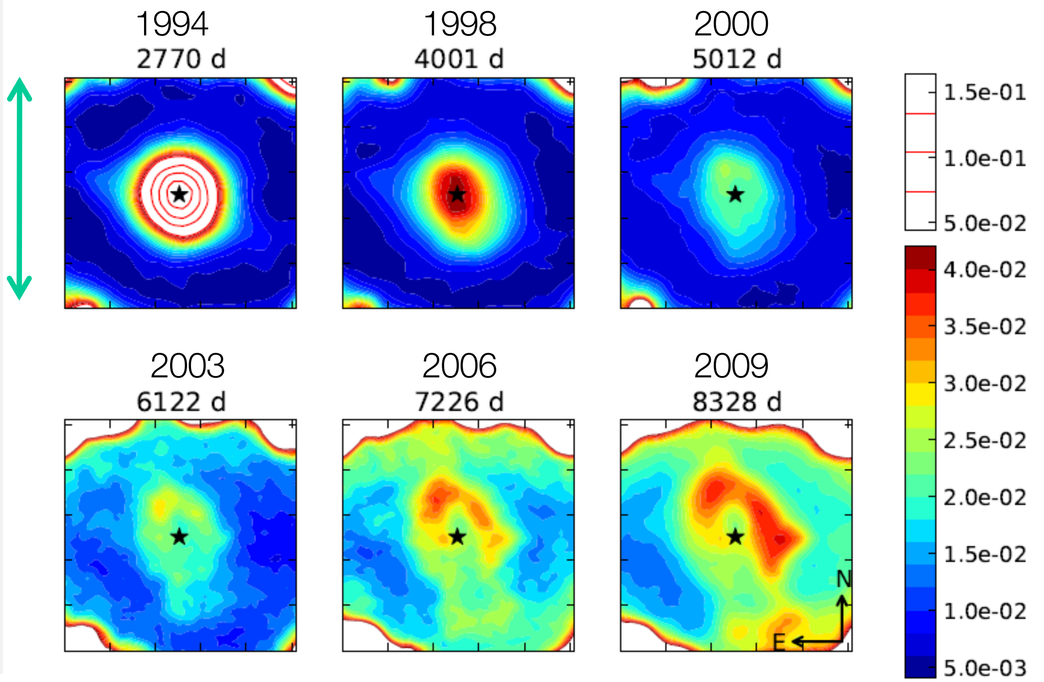
The emission line components



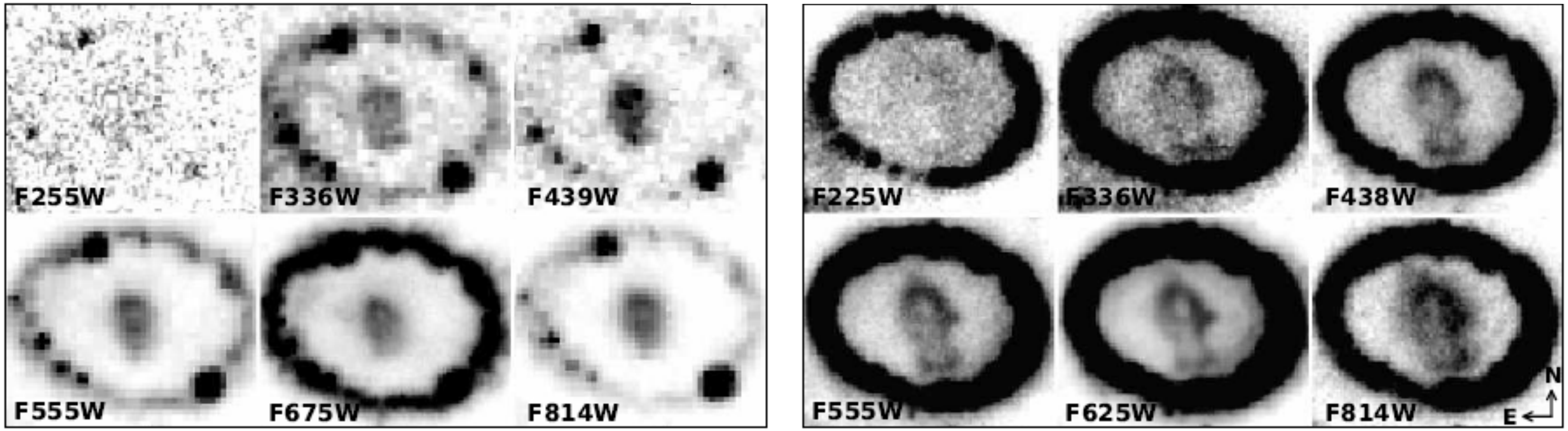
Fransson et al. 2013

Evolution of the inner ejecta

Clear change in morphology at optical wavelengths



Larsson et al. 2013

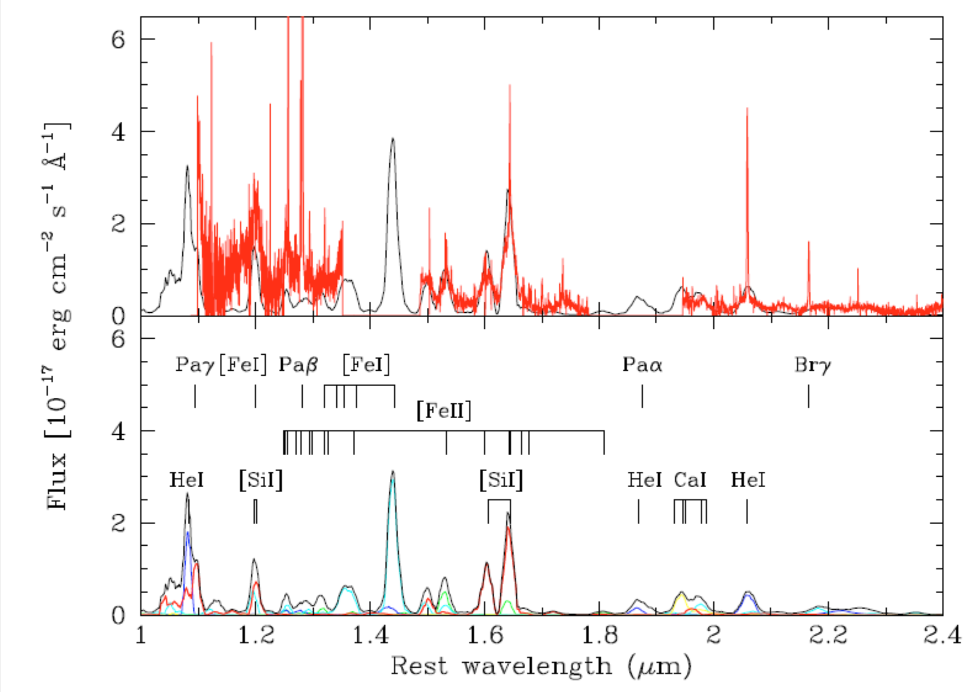


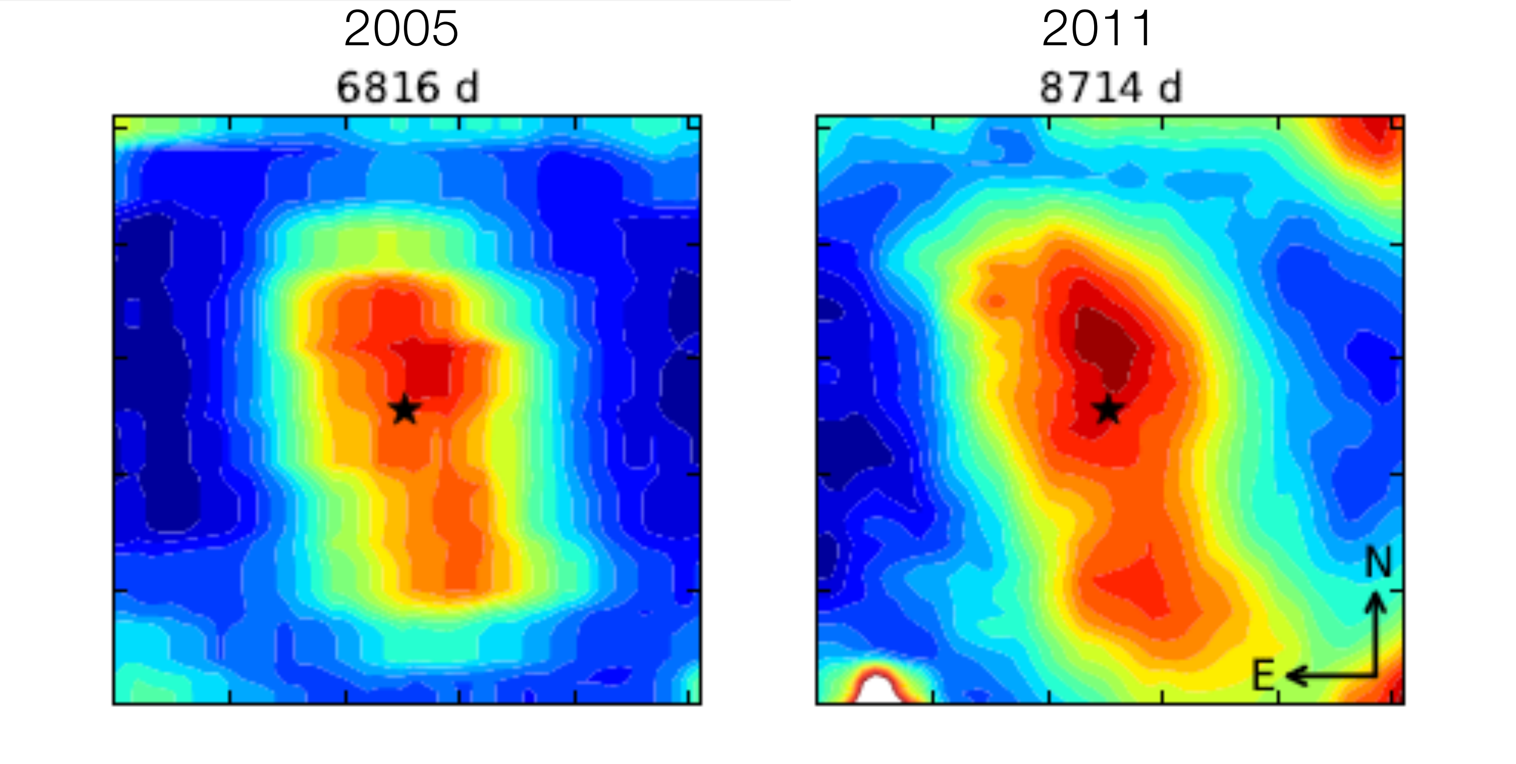
13 Nov 2000

12 Dec 2009

IR observations

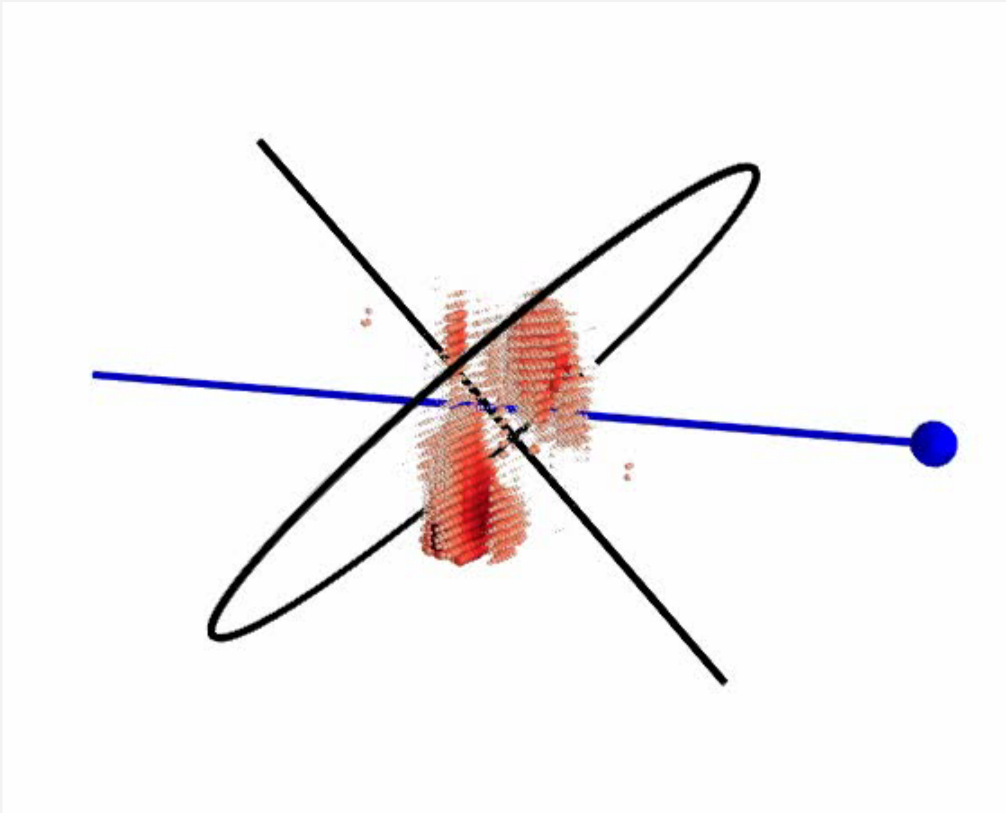
[Si I]/[Fe II] 1.644μm emission





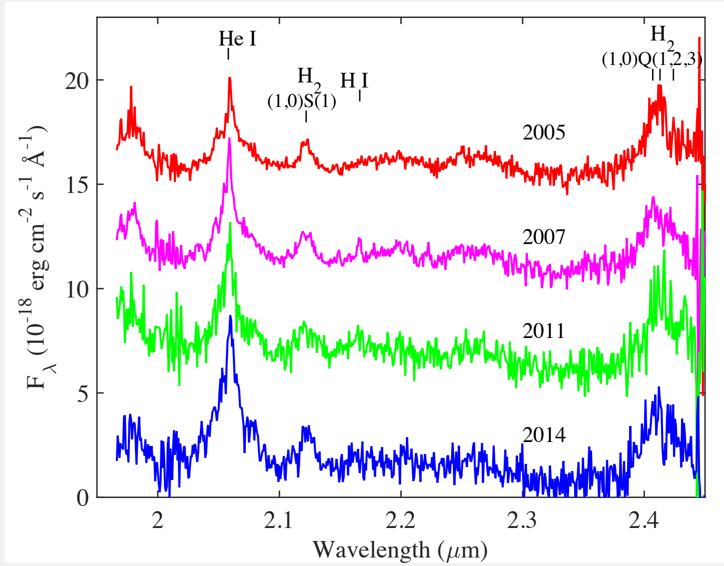
3-dimensional picture

- Derived from [Si I]+[Fe II] 1.644μm emission
- Emission in the plane of the equatorial ring
- Clumpy distribution
- Extending out to ~4500 km s^{-1}



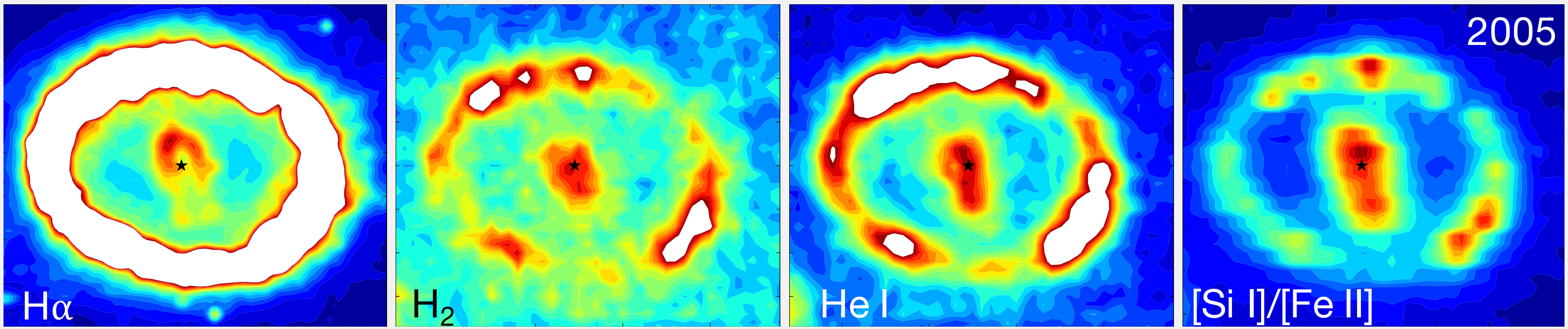
Larsson et al. 2013

Inner ejecta

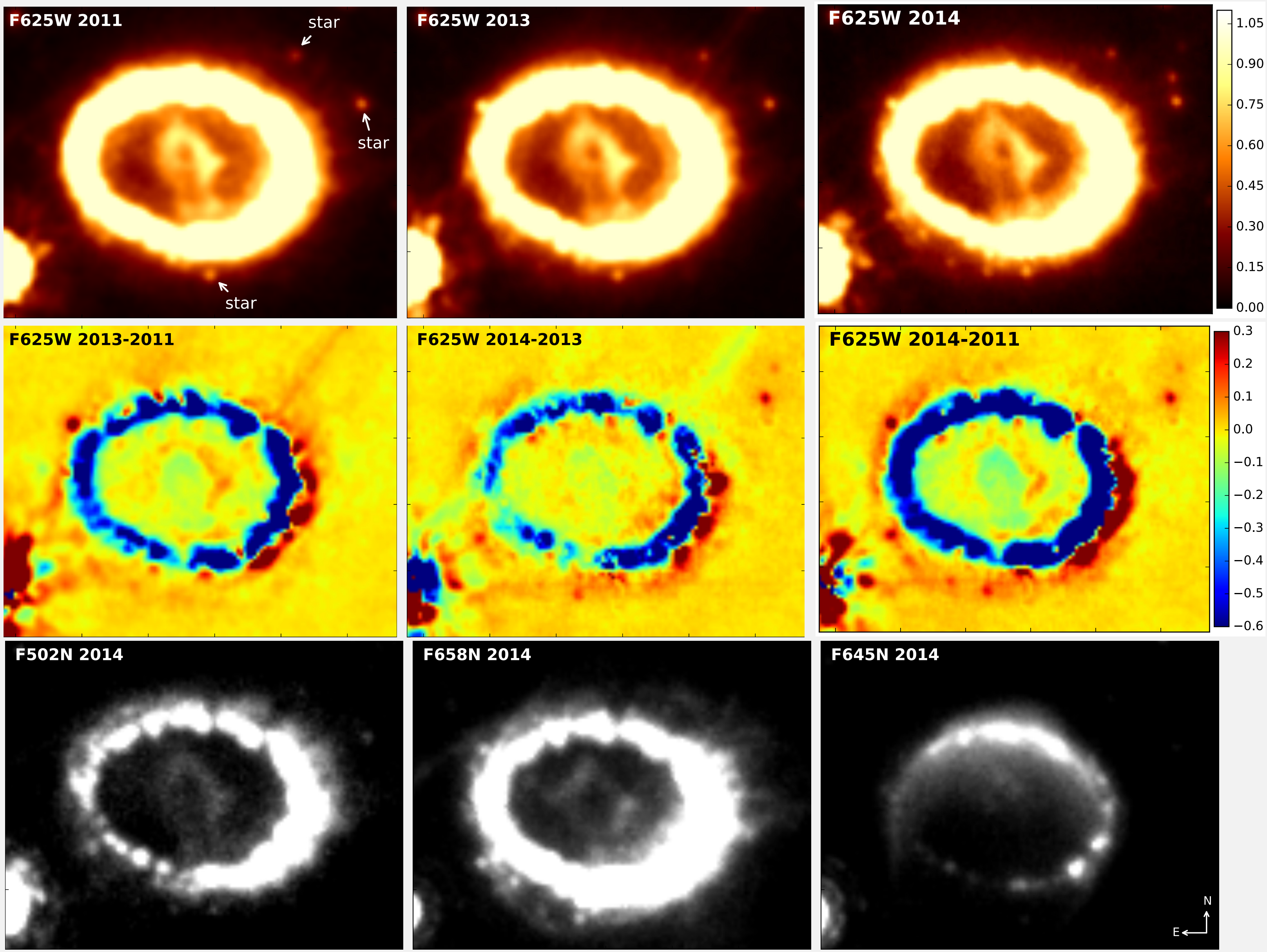


- Complicated region with emission from
  - Cold dust (mm, ALMA; SiO, CO)
  - Infrared emission lines (μm, SINFONI; He, H_2, Si/Fe)
  - Optical emission lines (nm, HST; H)
- Different spatial distributions

Fransson et al., subm.



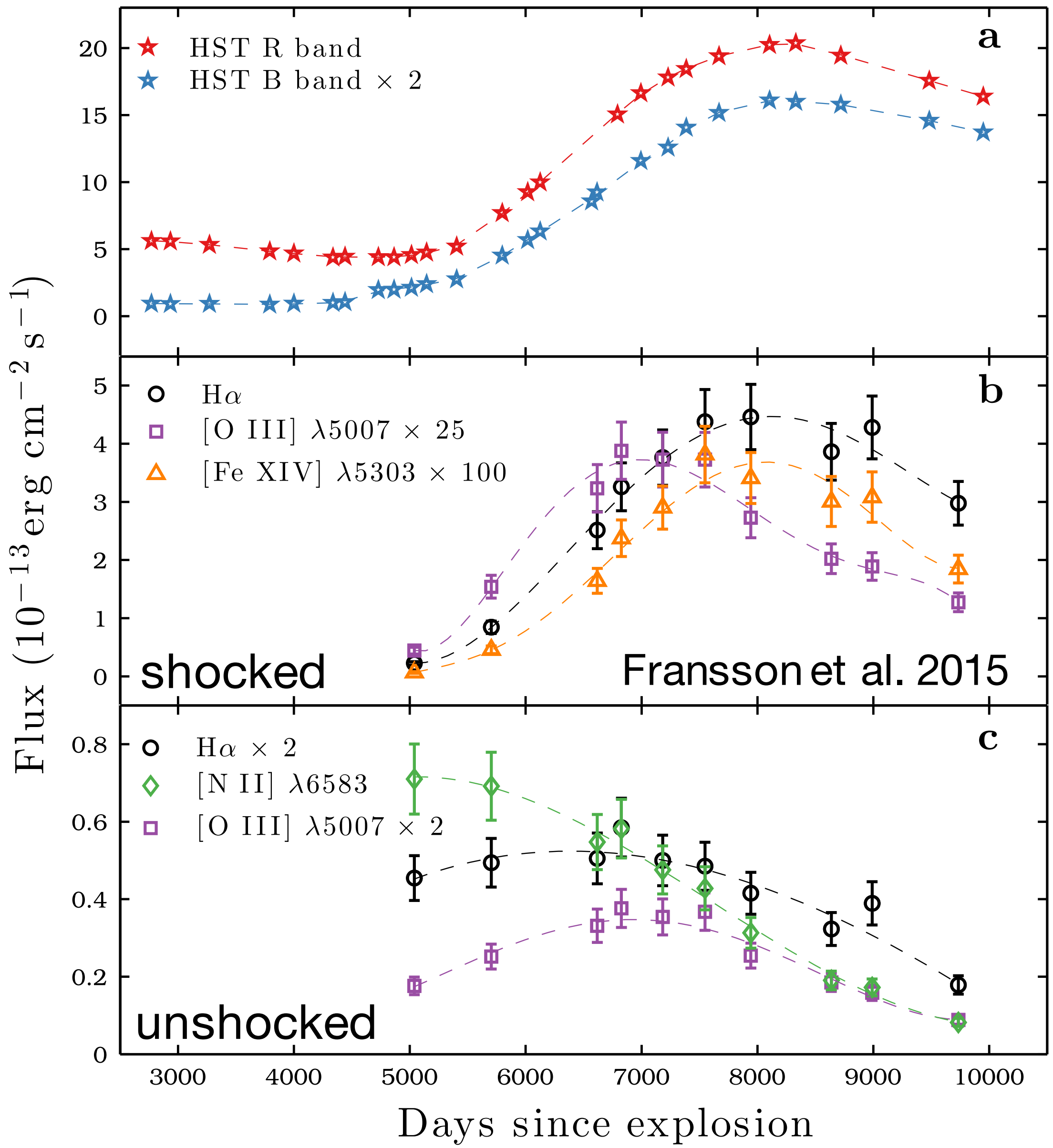
Emission outside the ring



Fransson et al. 2015

Destruction of the ring

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



SN 1987A – the supernova that keeps giving

- Asymmetric explosion
- Molecule and dust formation in the inner ejecta
- Ionisation of the inner ejecta (Hα) by the ring emission
- Ring destruction has started