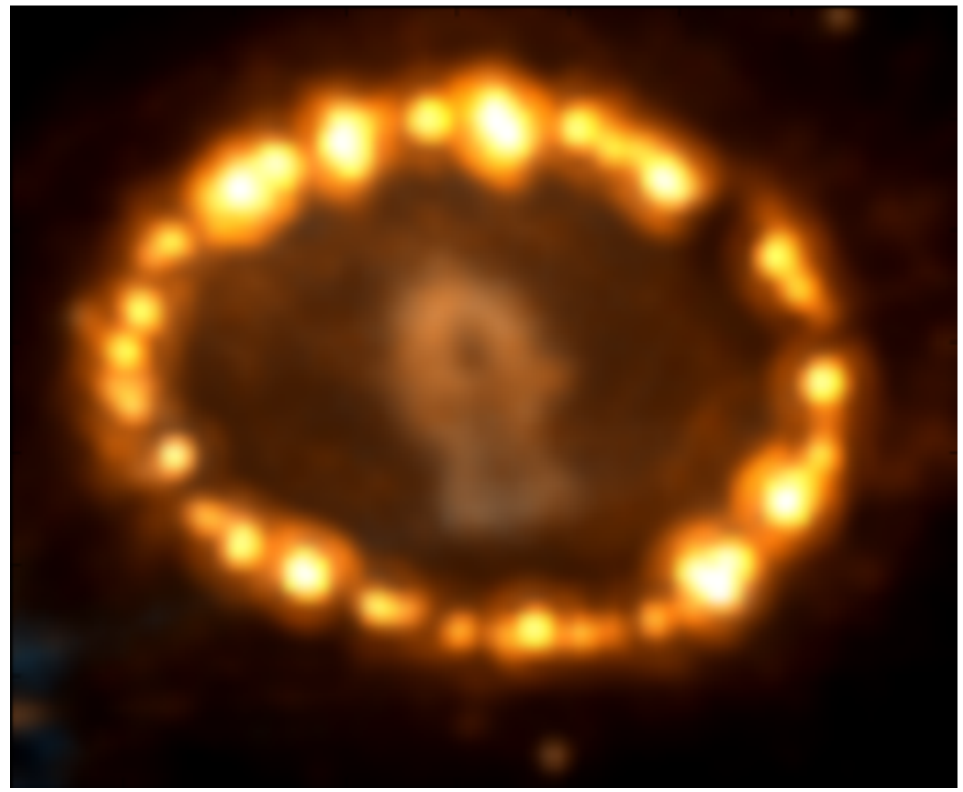
The ejecta of SN 1987A

3D emissivity, time evolution and molecular hydrogen



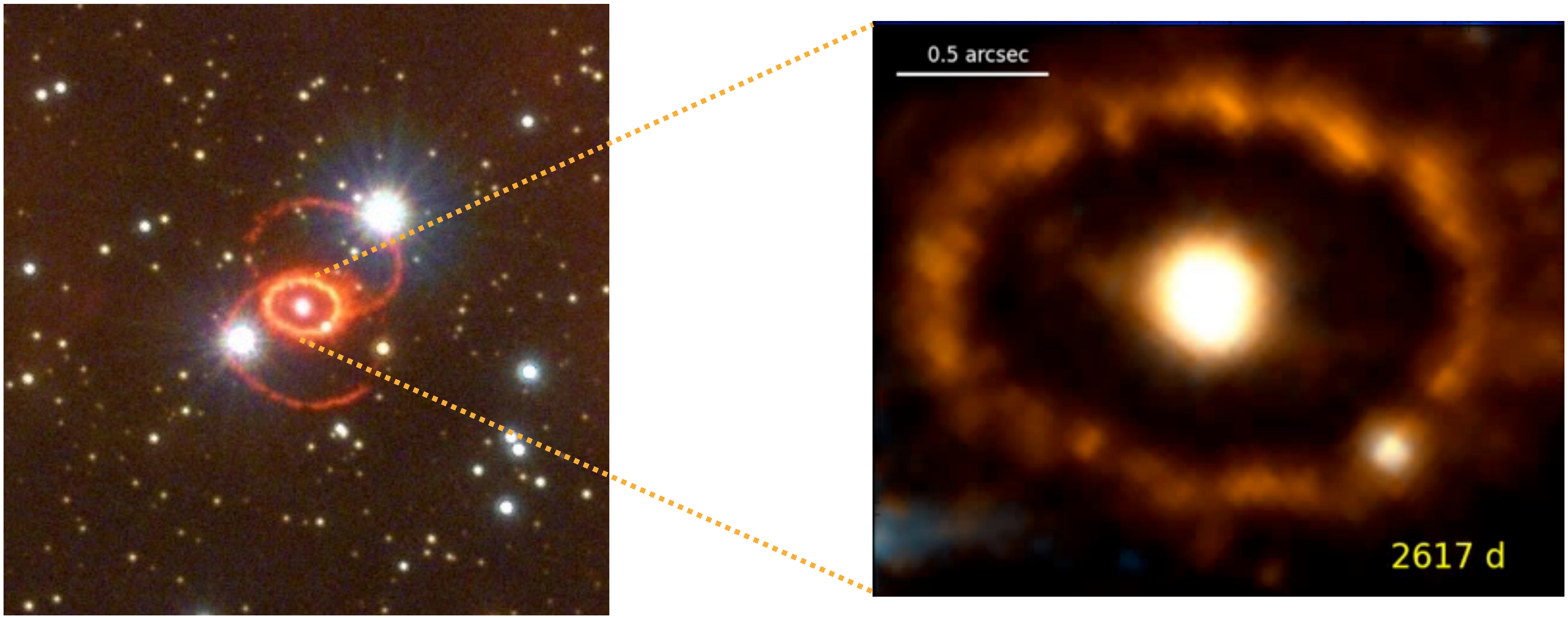
Josefin Larsson

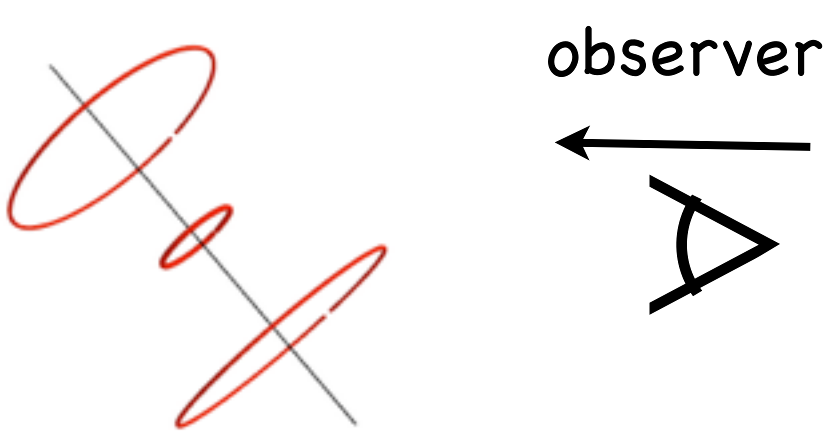
ROYAL INSTITUTE OF TECHNOLOGY & OSKAR KLEIN CENTRE, STOCKHOLM

Claes Fransson, Jason Spyromilio, Bruno Leibundgut,
P. Challis, R. A. Chevalier, K. France, A. Jerkstrand, R. P. Kirshner, P. Lundqvist, M. Matsuura, R. McCray, N. Smith, J. Sollerman, P. Garnavich K. Heng, S. Lawrence, S. Mattila, K. Migotto, G. Sonneborn, F. Taddia & J. C. Wheeler

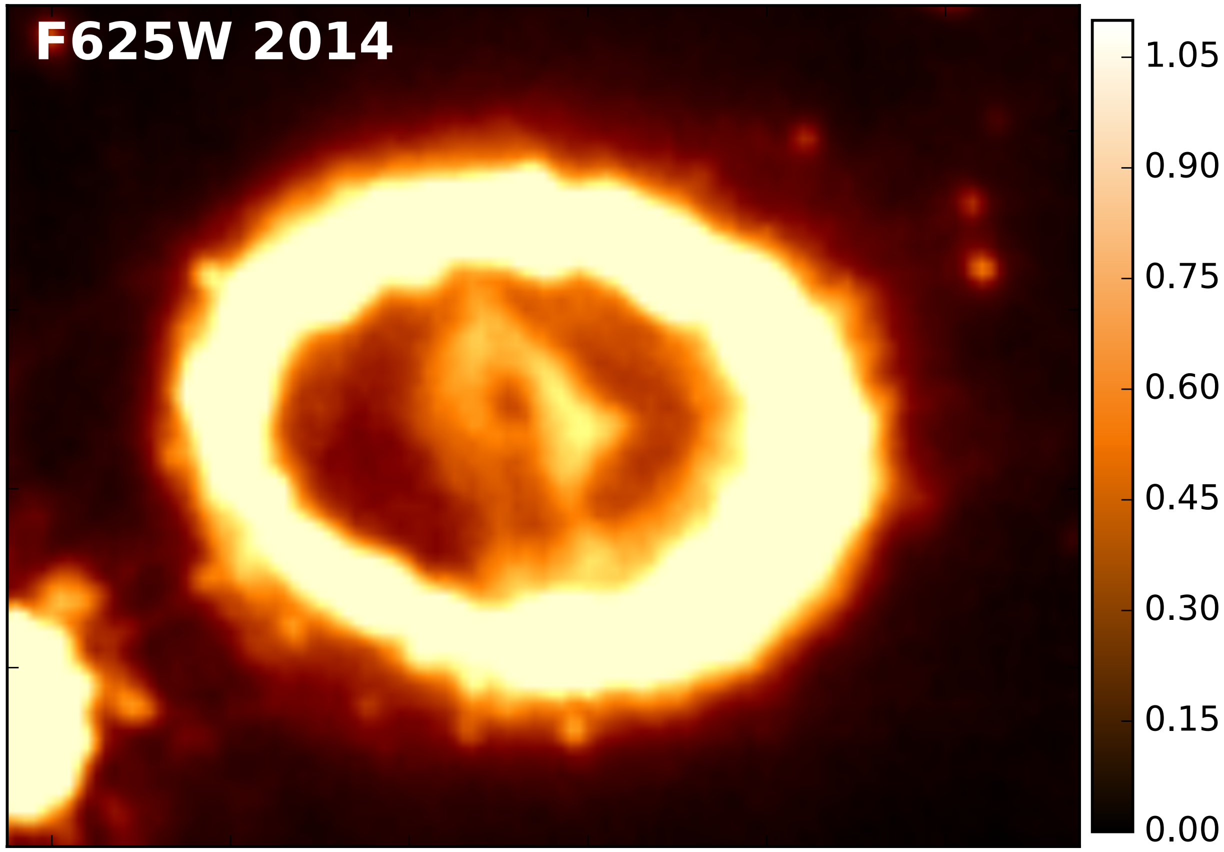
Supernova 1987A

HST Images in F625W+F439W





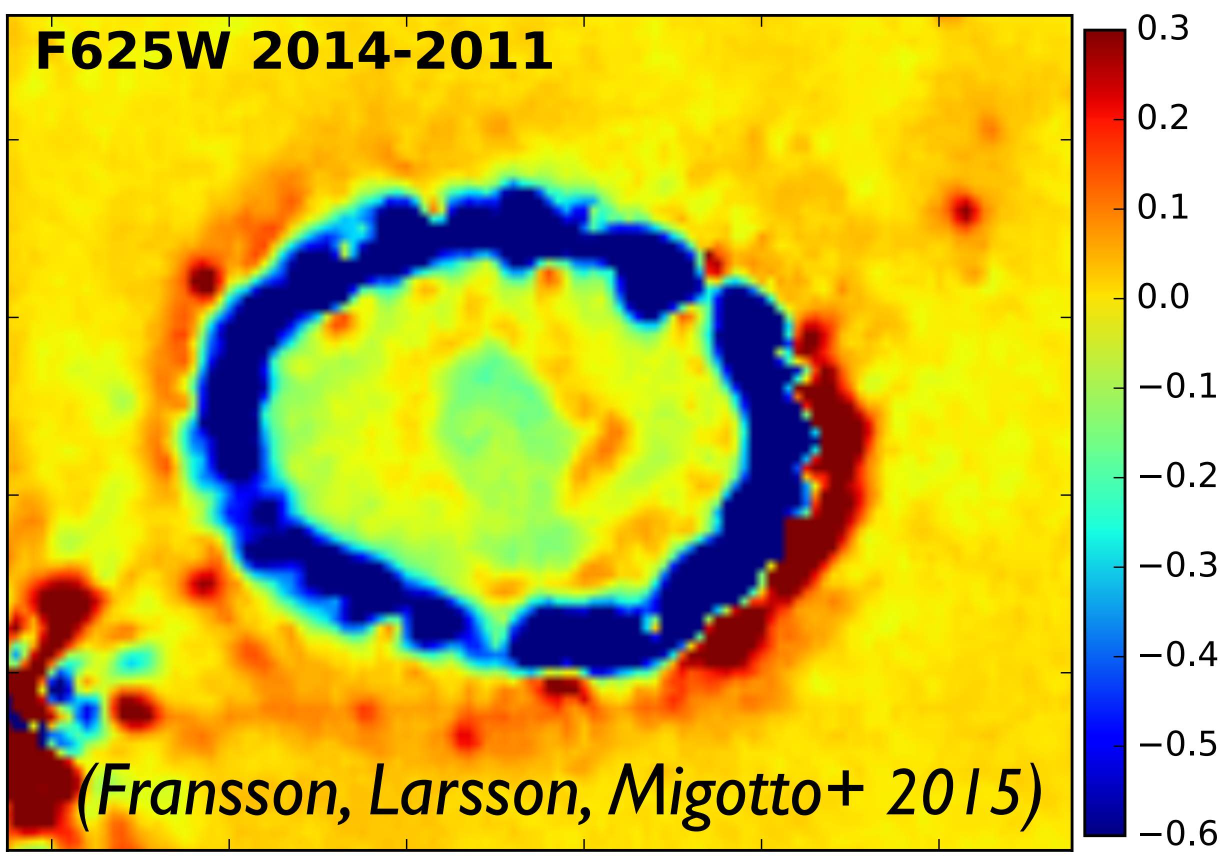
Inclination ~ 45°
Radius of inner ring ~ 0.6 ly (0.8")



Inner ejecta

Still in homologous expansion phase (not interacting with ring).

Directly probes the explosion geometry.



Ring

The ring is fading and new hot-spots are appearing outside.

The blast wave has passed the main ring.

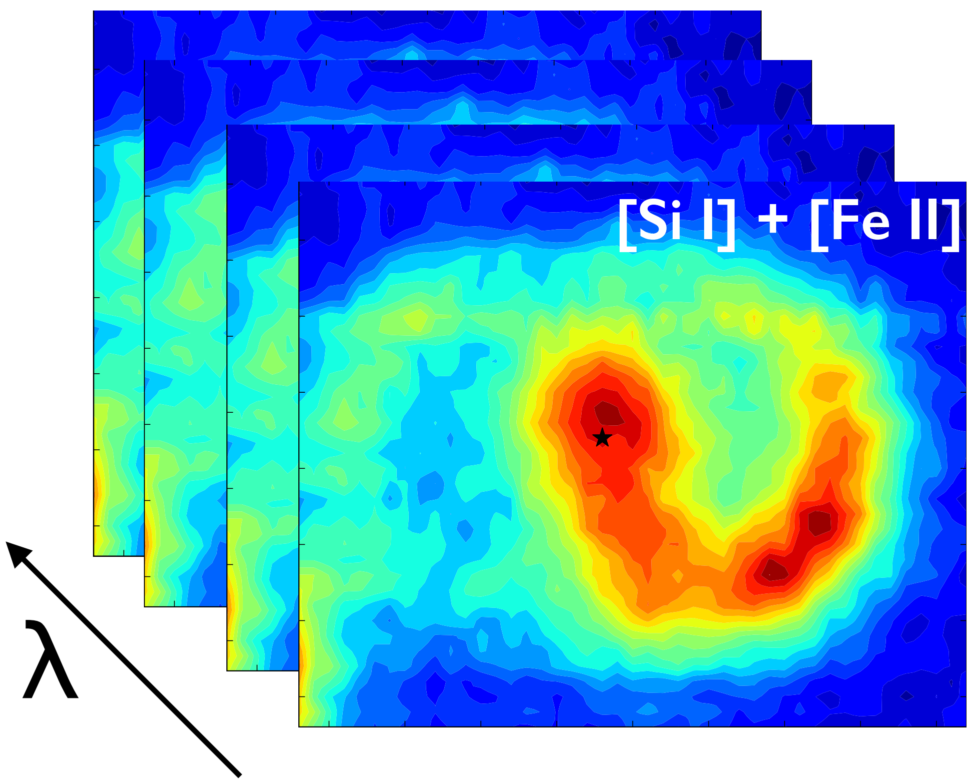
See poster by Katia Migotto.

Mapping the ejecta in 3D

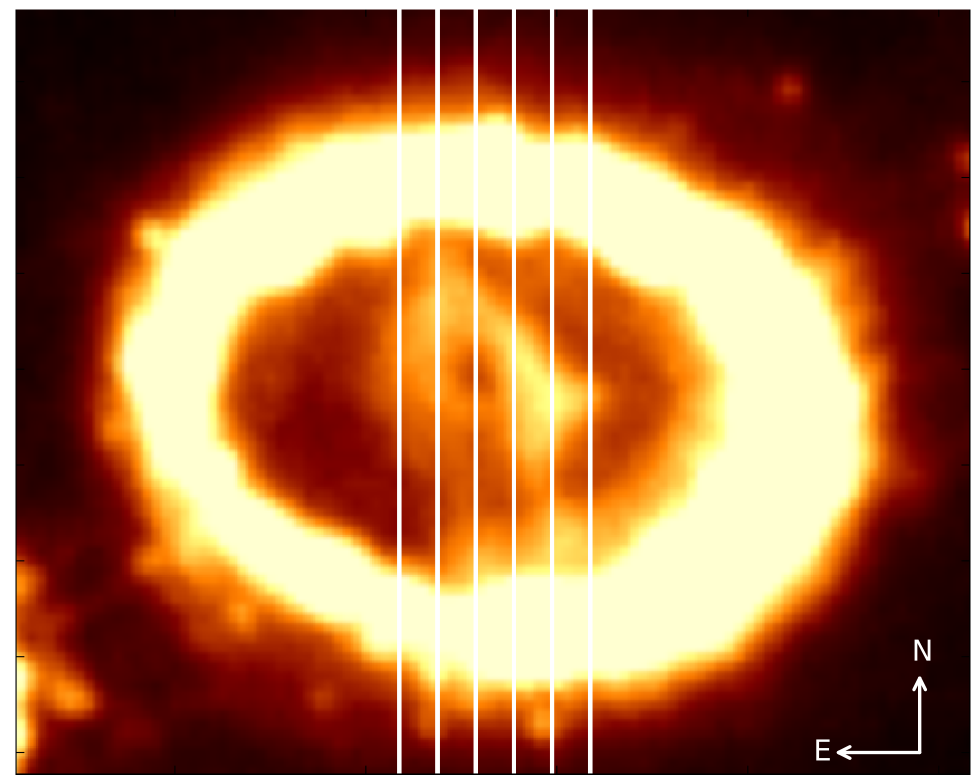
The freely expanding ejecta are described by a simple "Hubble law": $v = r/t$

The combination of imaging and spectra therefore gives 3D information.
(For previous studies see *Kjaer at al. 2010; Larsson et al. 2013*)

New observations at ~10 000 days *(Larsson et al., submitted)*

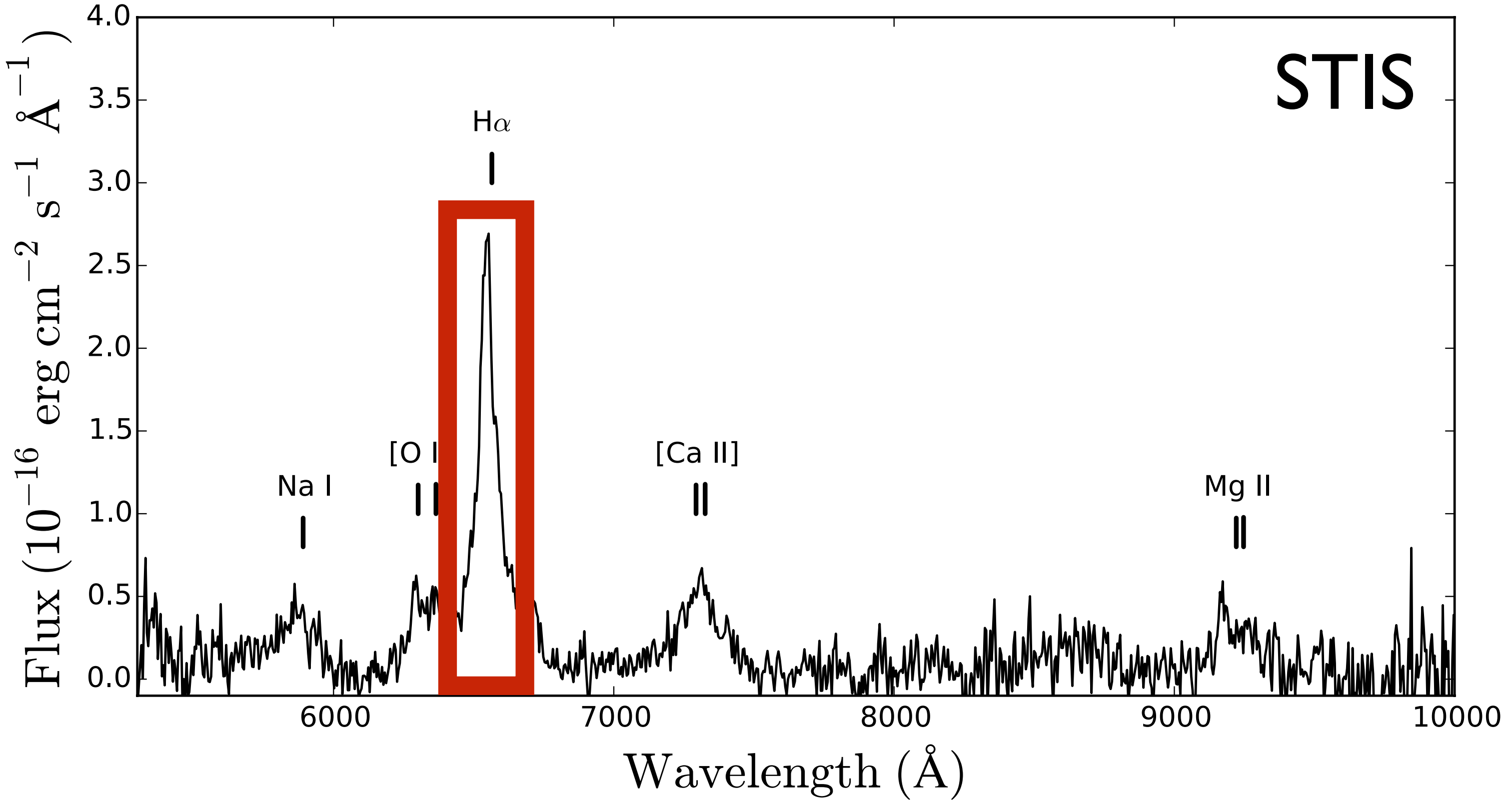


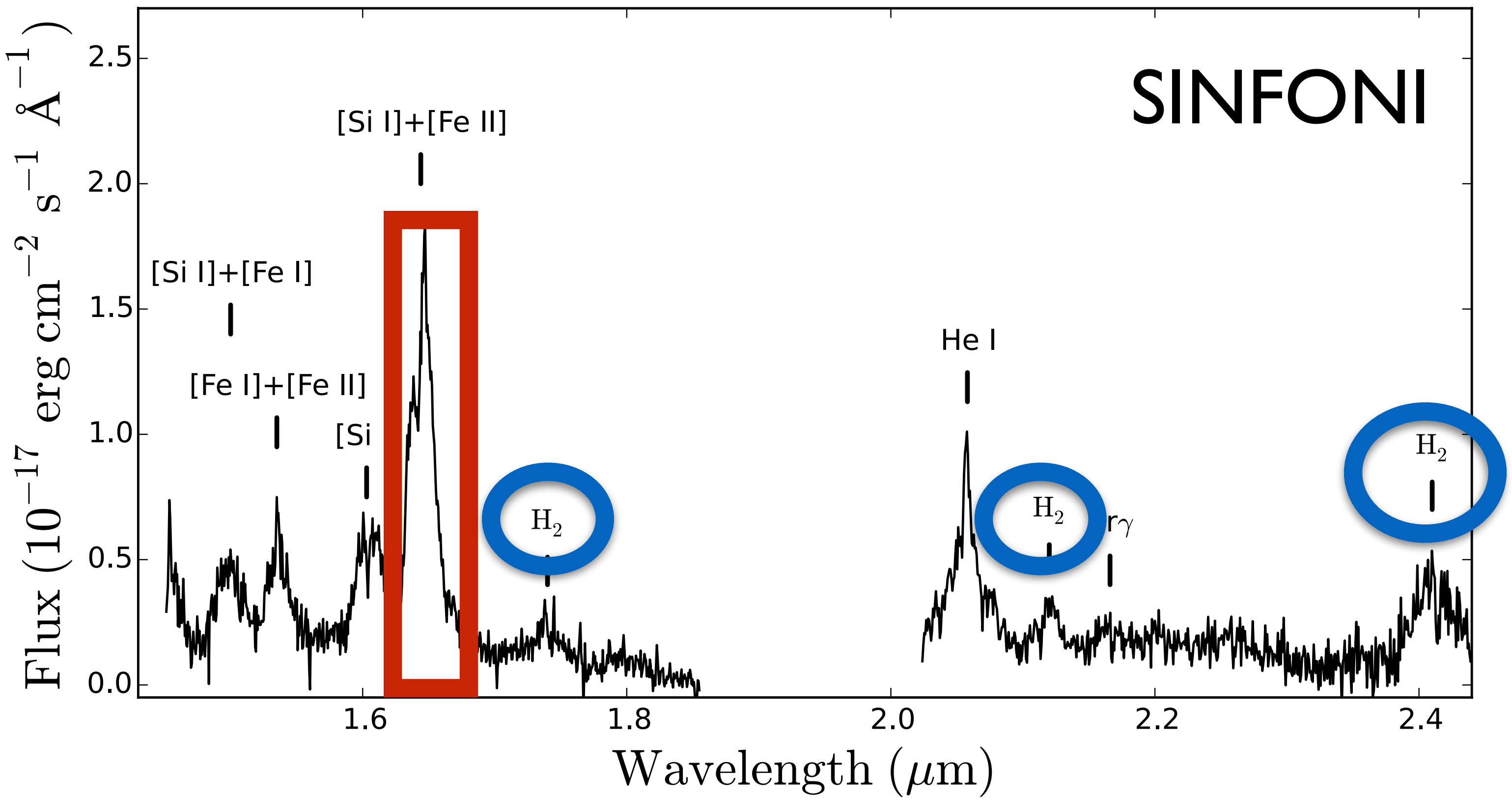
VLT/SINFONI IFU observations (H & K bands).



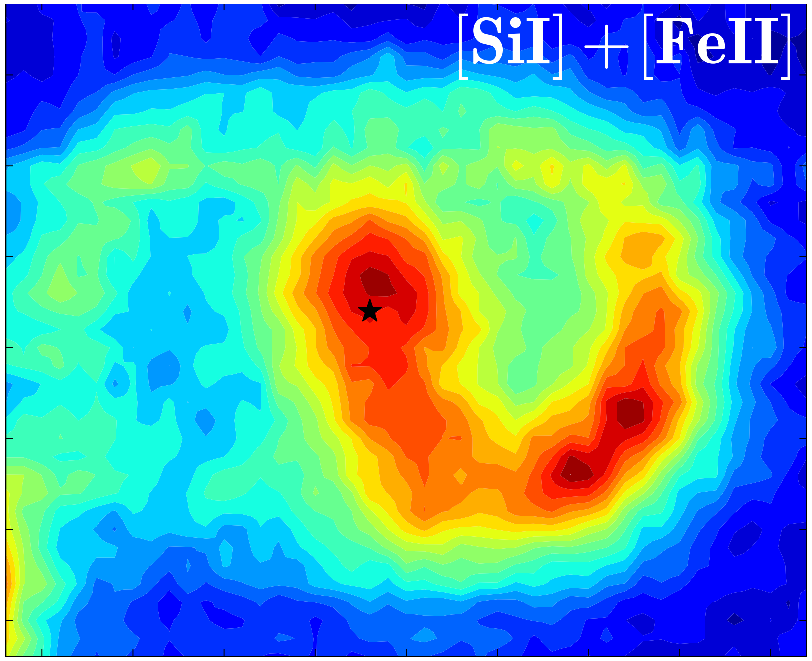
HST images (WFC3/F625W) and spectra (STIS/G750L, 0.1" slits)

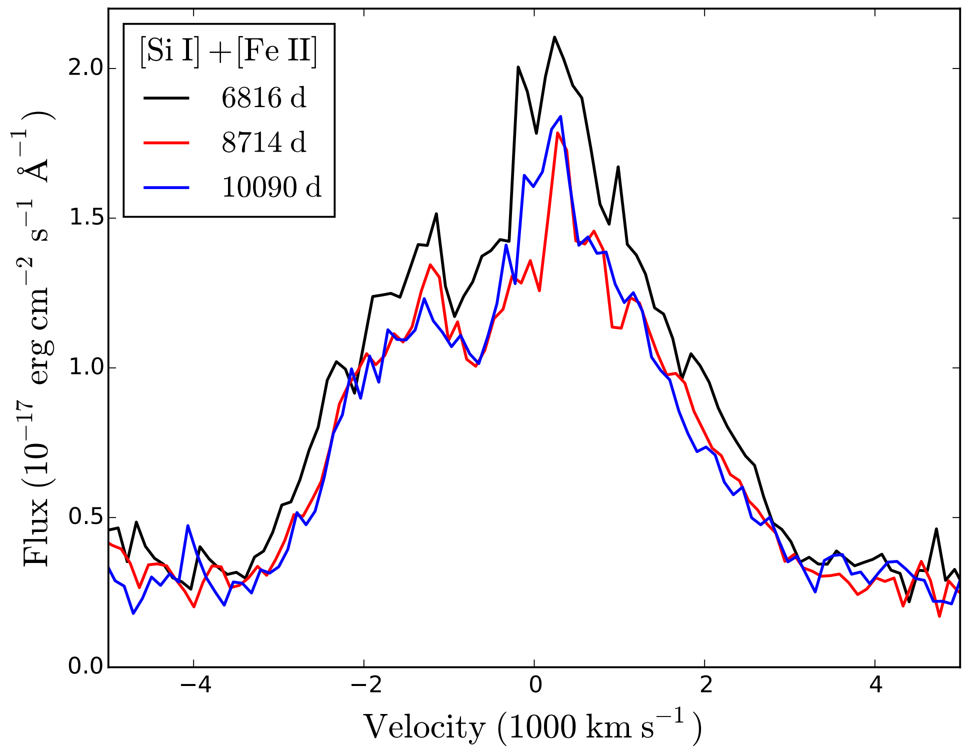
Total spectra





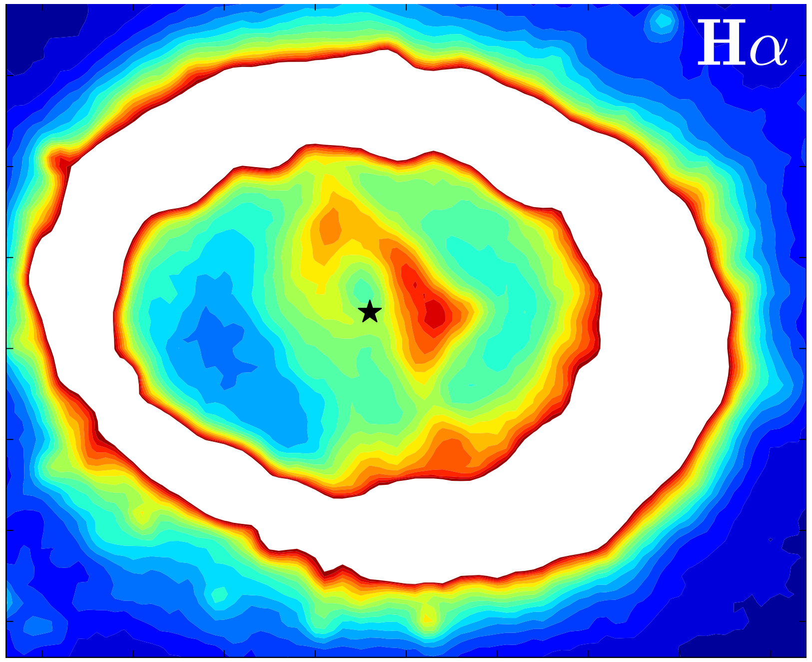
Energy sources

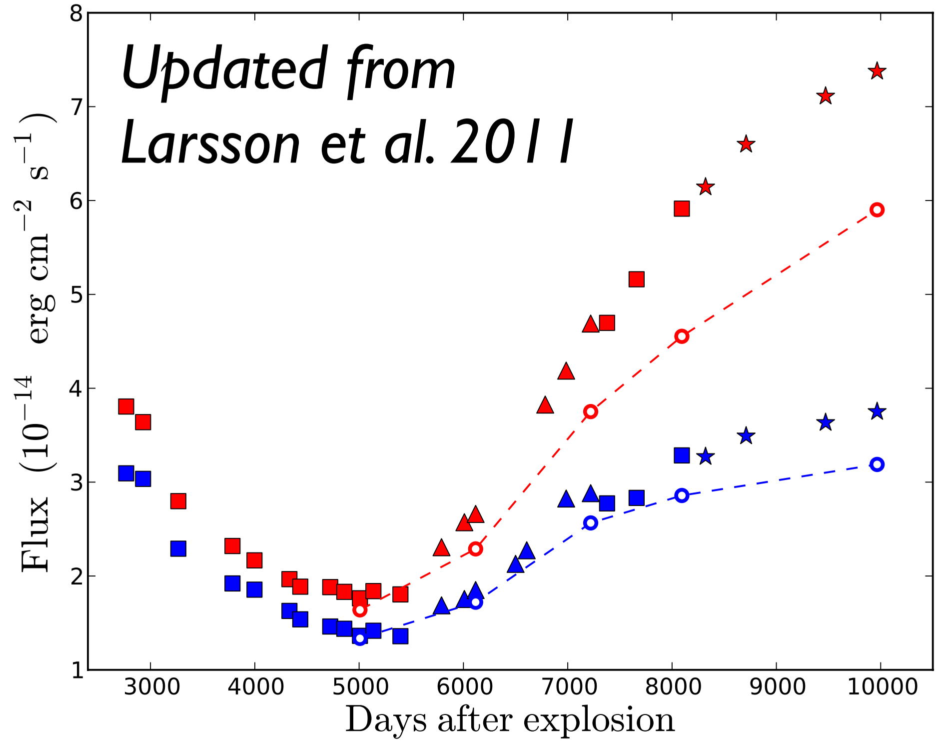




Powered by ^{44}Ti

No significant changes in flux, line profiles or morphology in the last 10 years.

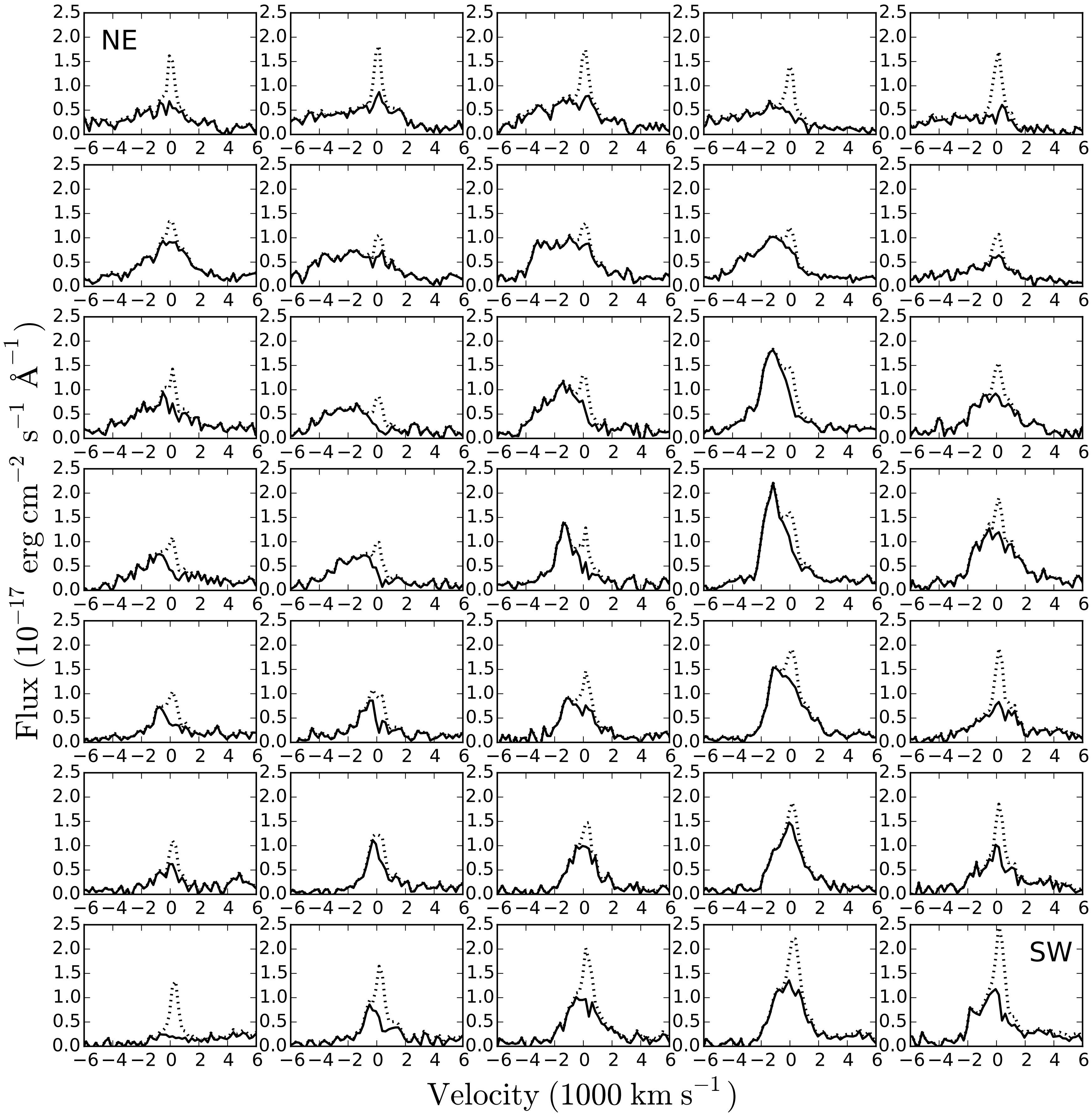


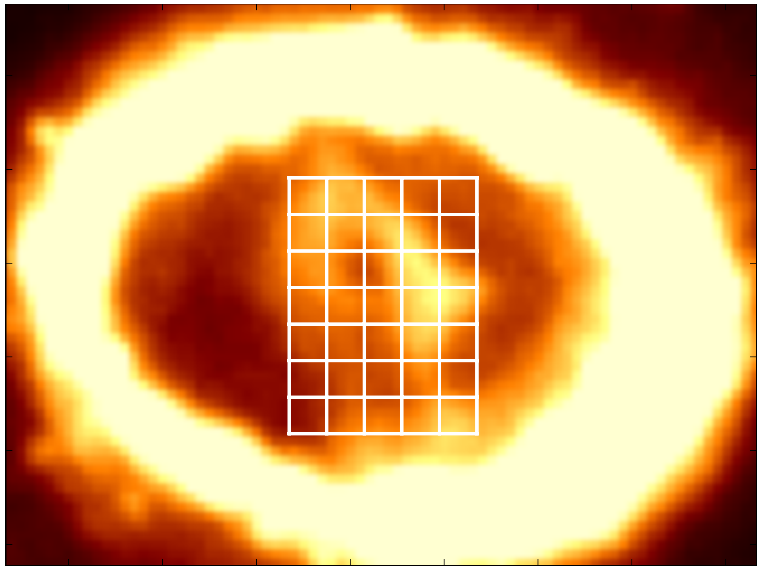


Powered by X-rays from ring.

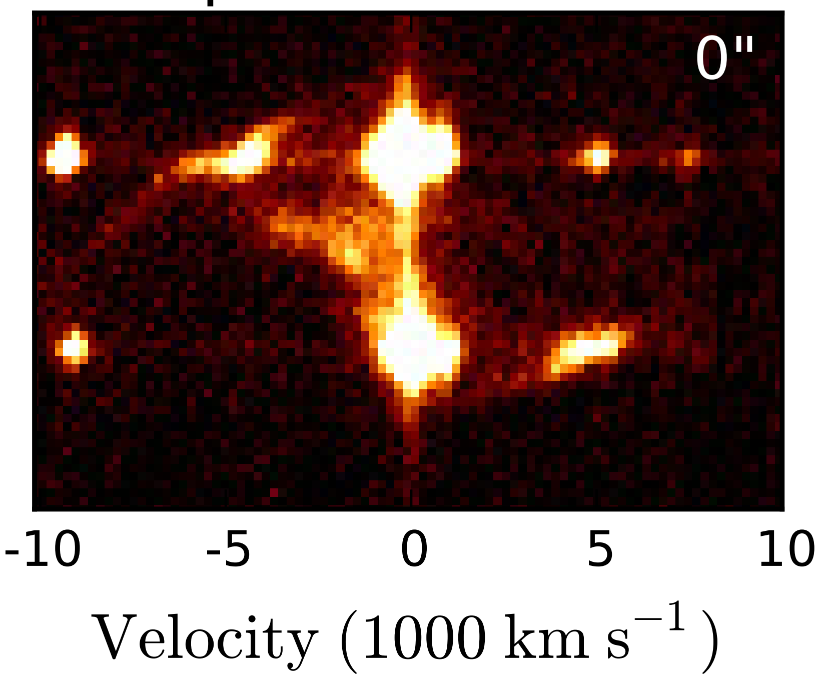
Brightening and change to edge-brightened morphology after ~5000 days.

Hα



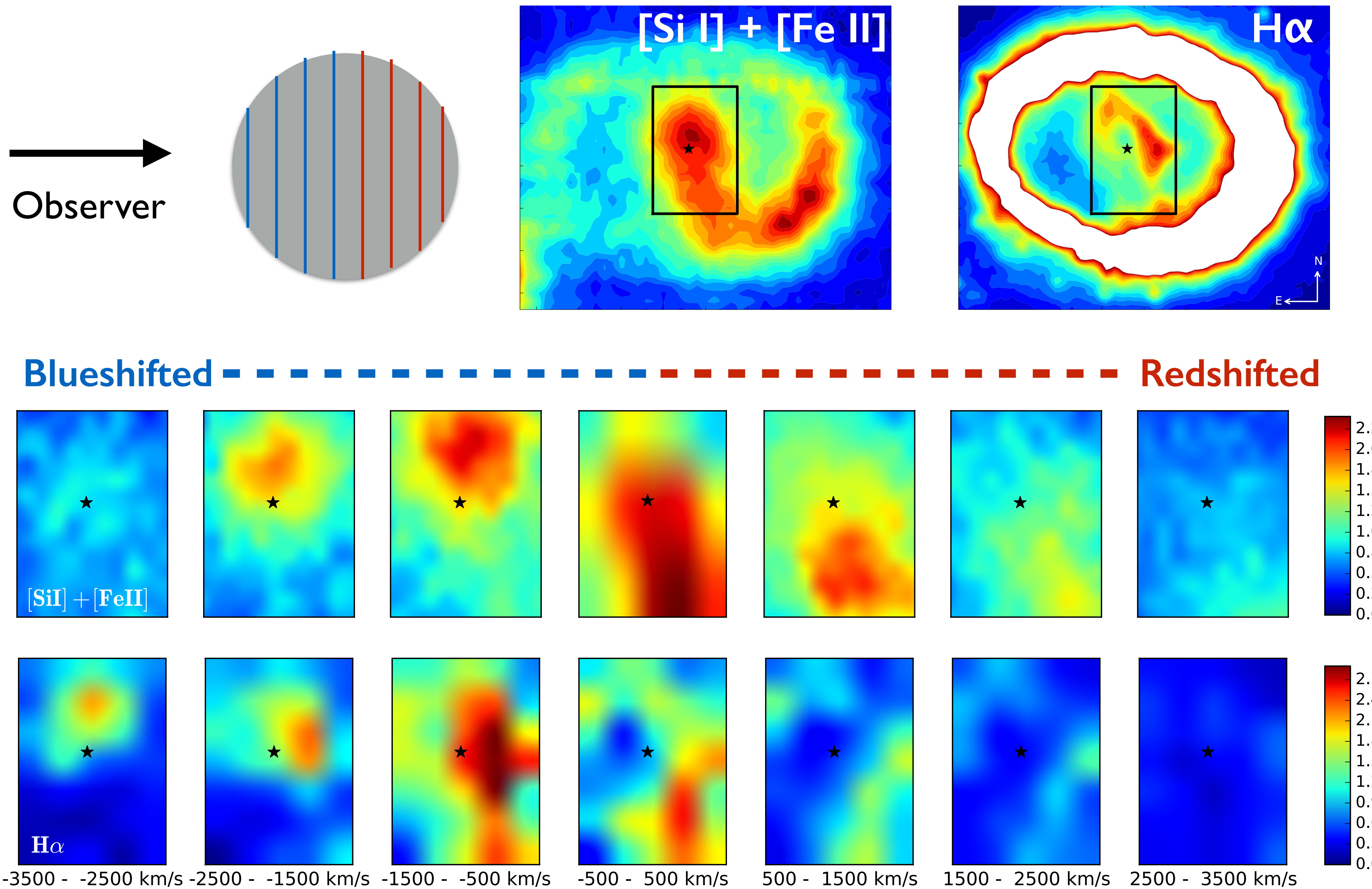


2D spectrum, central slit

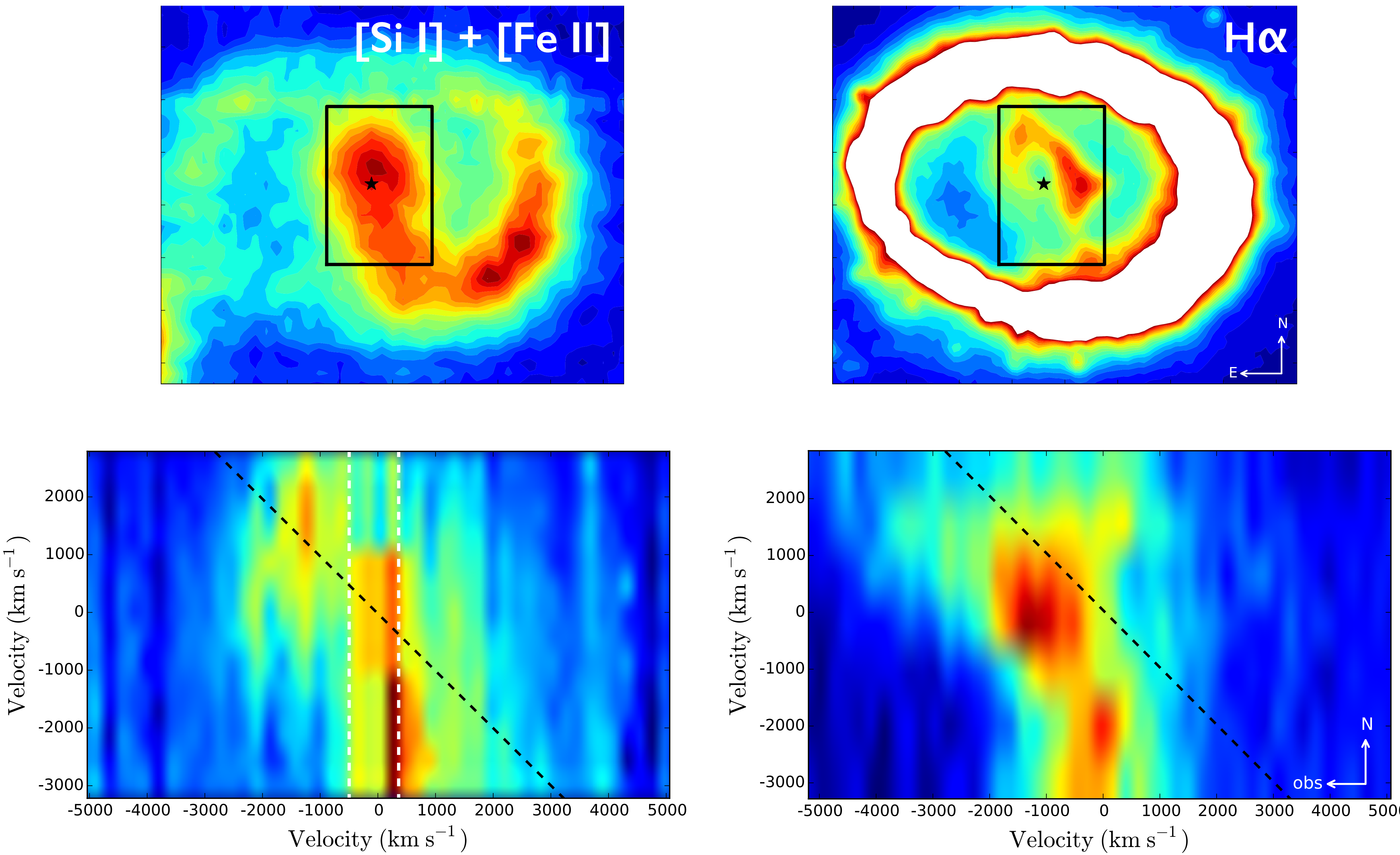


Dotted line shows spectrum before correcting for ring.

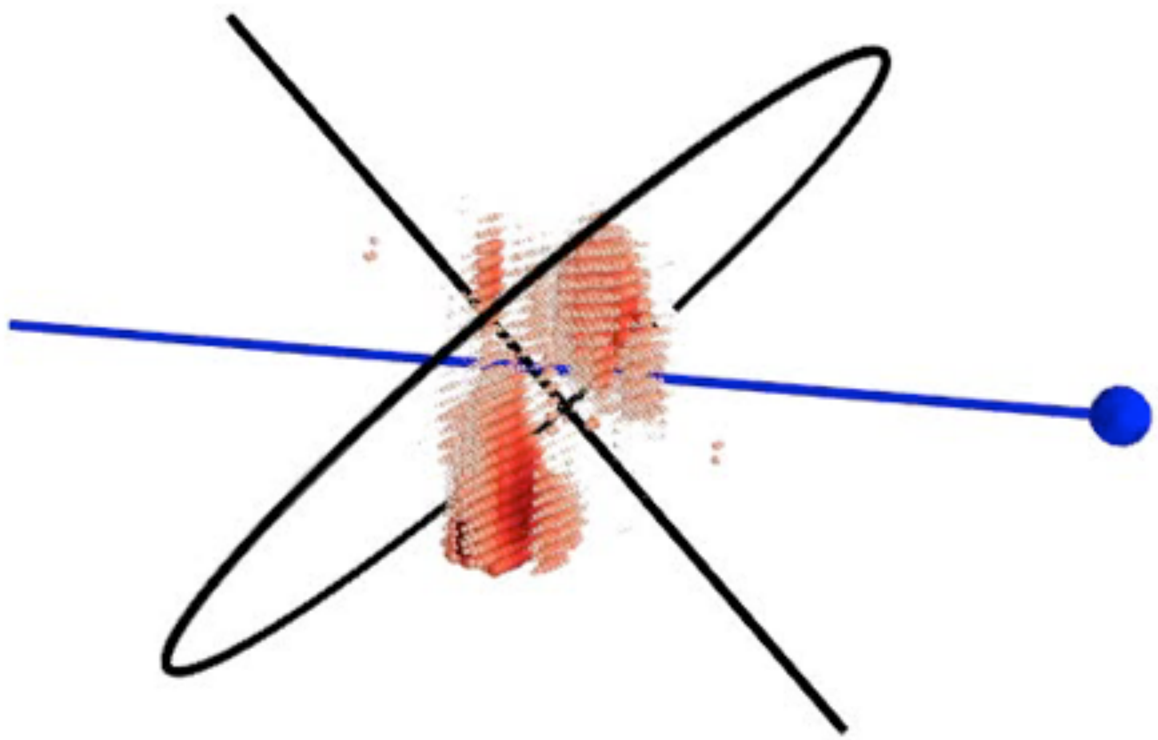
Velocity slices: Hα & [Si I]+[Fe II]



“Sideview”: Hα & [Si I]+[Fe II]



[Si I]+[Fe II] 3D emissivity



● Position of observer

The emission is shown out to 3 500 km/s.

Only emission brighter than 3 times the continuum level is shown.

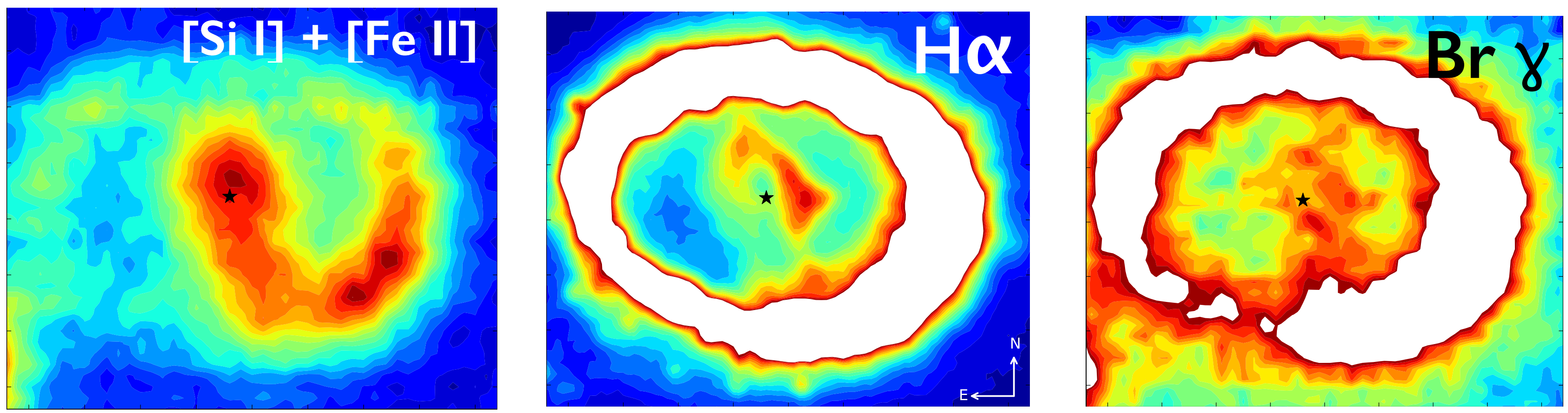
The narrow line from the ring has been removed.

Day 8717

(Larsson et al. 2013)

Dust

Hershel and ALMA have revealed a large amount of dust in the ejecta, estimated to ~0.5 $M_\odot$ *(Matsuura et al. 2011; Indebetouw et al. 2014; Matsuura et al. 2015).*



Different amounts of extinction by dust is unlikely to be the main reason for the different morphologies of Hα and [Si I]+[Fe II]!

- The hole is a natural consequence of the external X-ray illumination. It appears at the same time as the ejecta start brightening.
- If due to dust, the hole should become less prominent with time as the optical depth decreases.
- Brγ also has a low surface-brightness region at the centre.

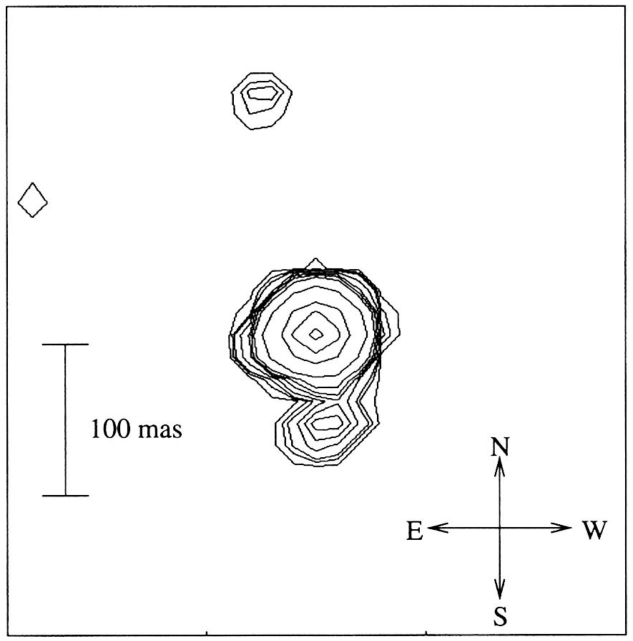
The dust may be in optically thick clumps that affect the optical and NIR in the same way.

Large-scale structure

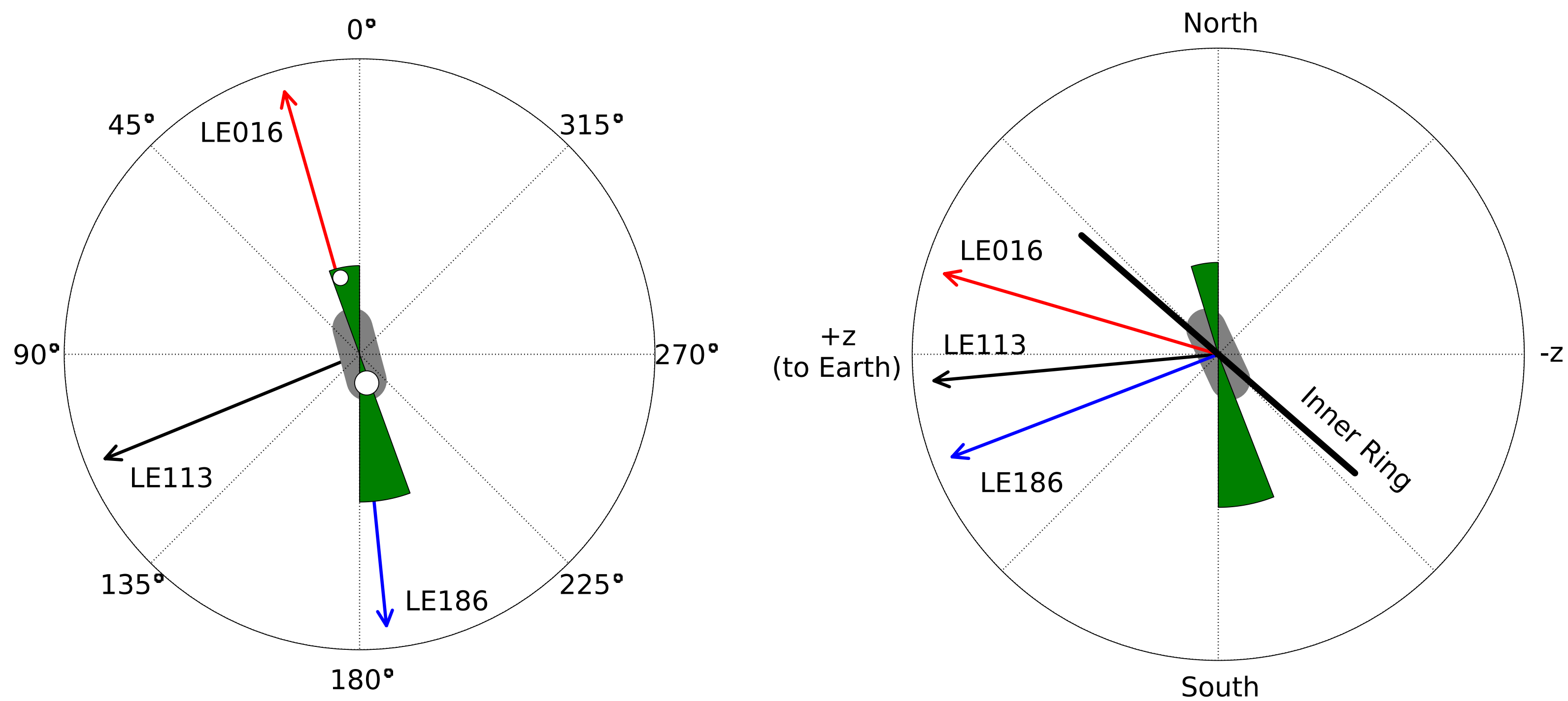
All emission lines show a similar global structure.

Seems that there is a global asymmetry that extends from the inner metal core to the outermost hydrogen layer.

Mystery spots



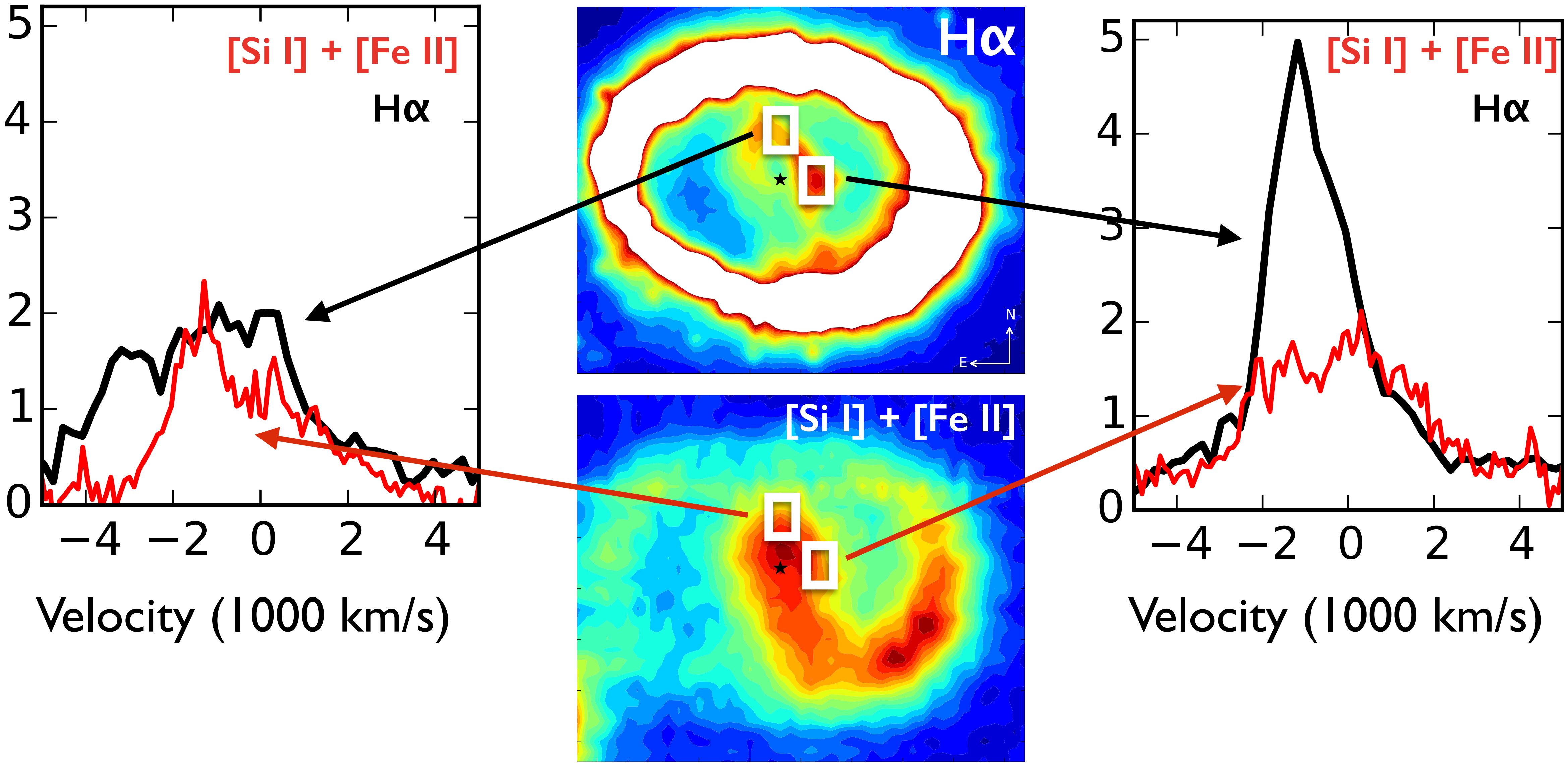
(Meikle et al. 1987, Nisenson et al. 1987, Nisenson & Papaliolios 1999)



Light echo *(Sinnot et al. 2012)*

This symmetry axis is also consistent with polarimetry *(Jeffery 1991)* and first hot-spot in the ring.

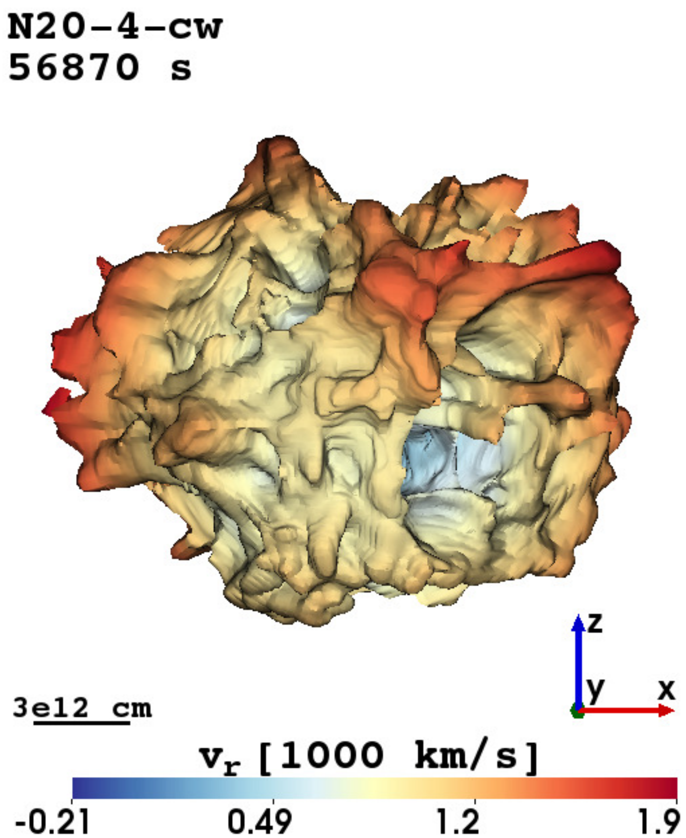
Smaller-scale structures



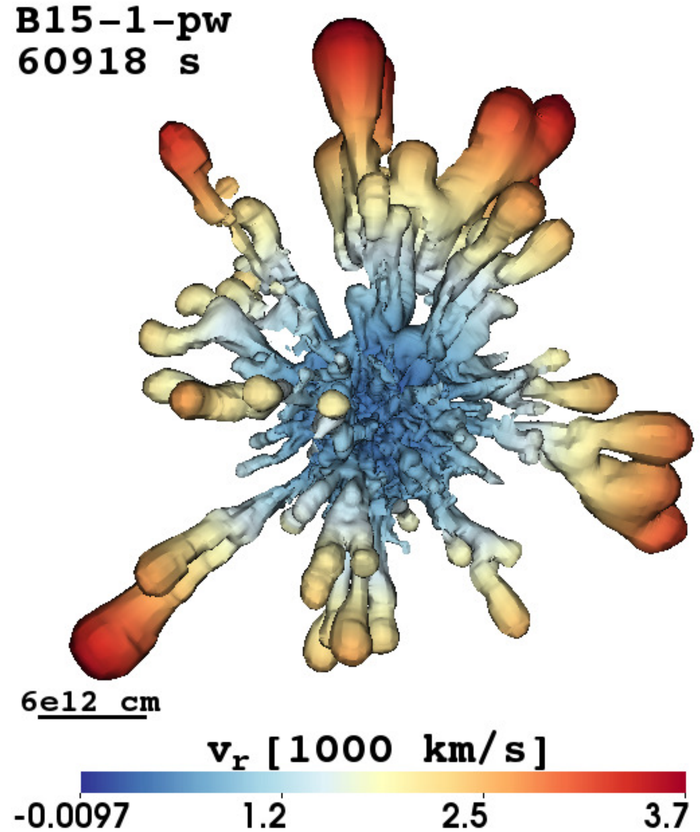
See "clumps" in both images and spectra. Typical size ~1000 km/s.
Differences between different emission lines.

Comparison with explosion models

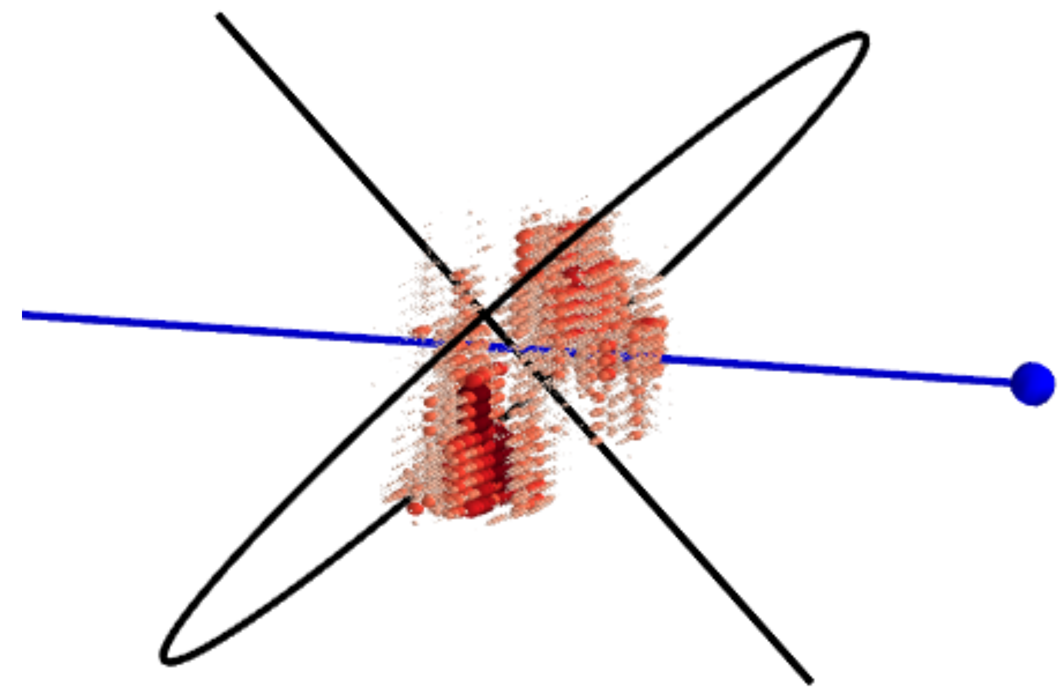
20 M$_\odot$ BSG (~like 87A)



15 M$_\odot$ BSG



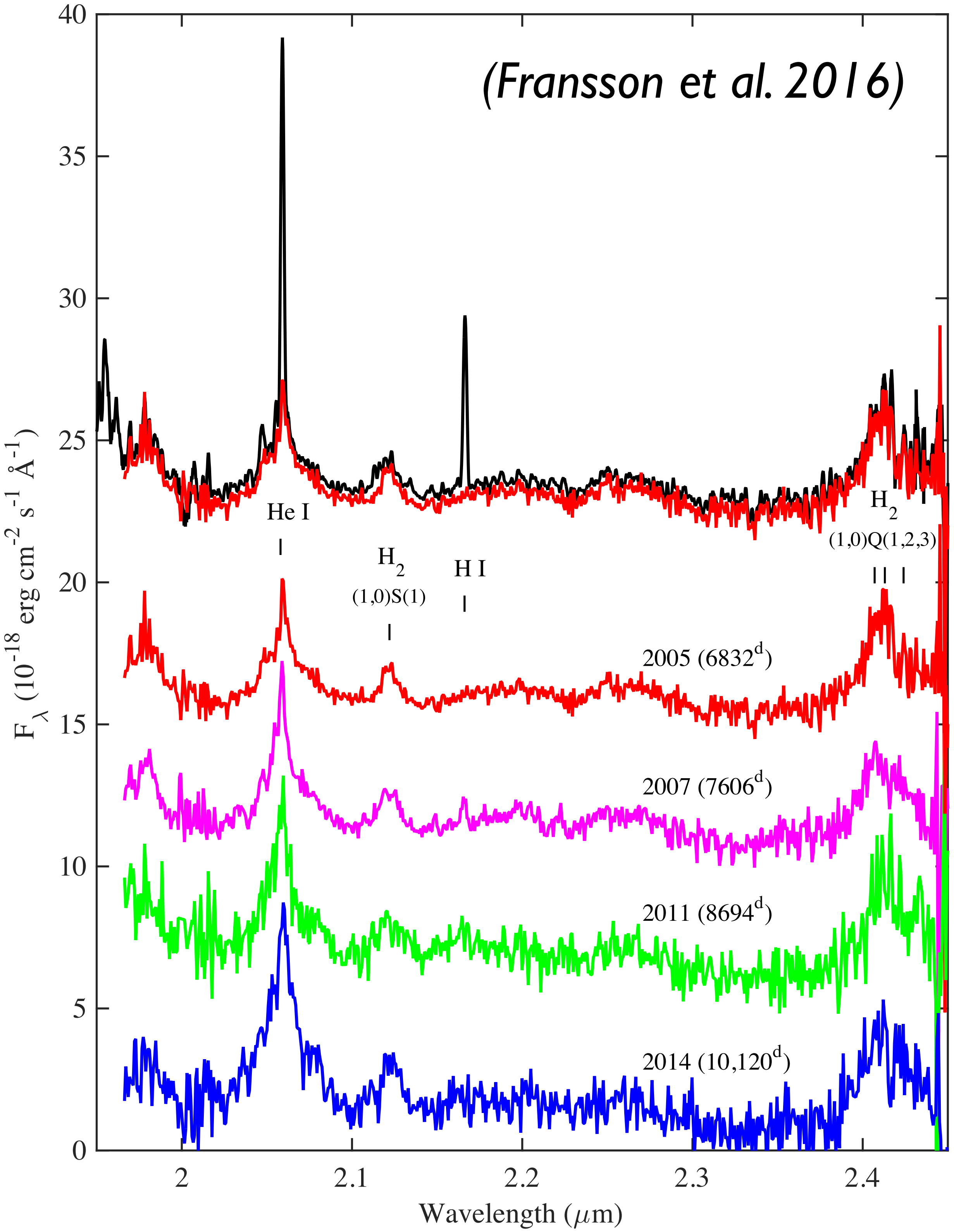
Observations



3D isosurfaces (3%) of Fe/Ni-rich ejecta ~16 hours after explosion for different progenitor models *(Wongwathanarat et al. 2015. See also poster by Gabler et al.)*

The observations have a more prominent large-scale asymmetry than the models. But the models not homologous and not necessarily showing where most Ni is.

Molecular hydrogen

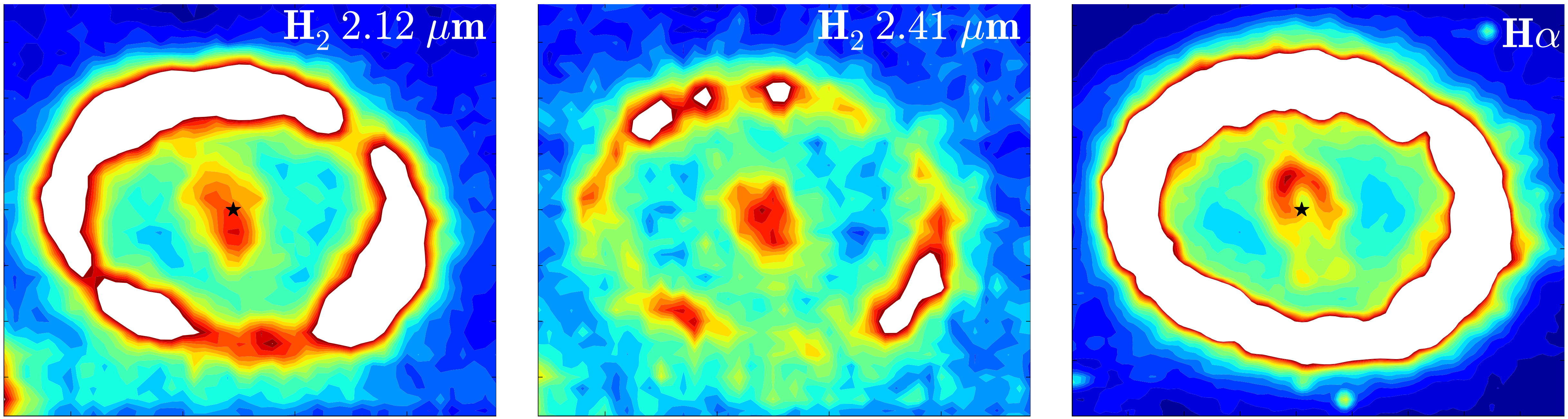


Rovibrational transitions from H_2:
2.12 µm (1,0)S(1)
2.406, 2.413, 2.423 µm (1,0)Q(1-3)

Predicted to form ~600-1000 years after explosion. ~1% of total H abundance *(Culhane & McCray 1995)*.

No significant flux evolution 2005-2014. Likely powered by ^{44}Ti.

Spatial distribution



Images from 2005

(Fransson, Larsson et al. 2016)

The H_2 is concentrated to the core, where it is shielded from X-ray emission from the ring. Mixing of H to < 500 km s^{-1}

Spectral modelling suggests excitation by UV fluorescence (but non-thermal electrons also a possibility).

Conclusions

- The [Si I]+[Fe II] emission is consistent with staying constant in both flux and morphology over the last 10 years. Powered by ^{44}Ti.
- Hα (and many other lines) powered by X-ray emission from the ring.
- The ejecta exhibit a large-scale broken dipole structure that extends from the inner metal core to the outermost hydrogen layer. The distribution is close to the plane of the ring in the north and close to the plane of the sky in the south.
- The ejecta distribution is inhomogeneous, with a number of bright clumps appearing on a scale of $\sim$ 1000 km s^{-1}. On these scales there are also clear differences between different emission lines.
- There is H_2 in the core of the ejecta. This is the first detection of H_2 in a young supernova. The spatial distribution implies mixing of H to low velocities.