THE CIRCUMSTELLAR RING OF SN 1987A

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IN COLLABORATION WITH VLT AND SAINTS (PI: R. KIRSHNER) TEAMS

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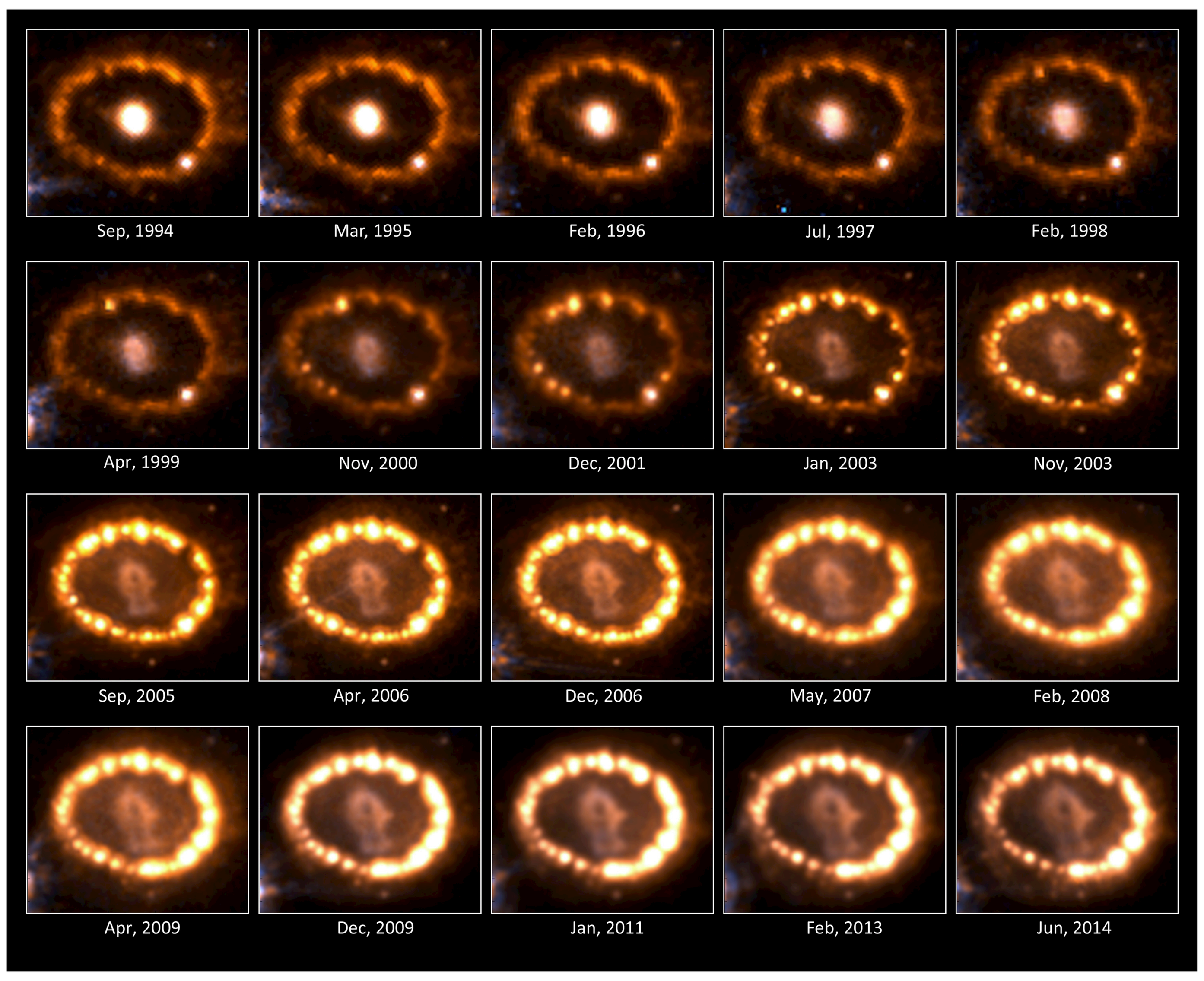
ABSTRACT

The circumstellar ring of supernova 1987A first became visible a few months after the explosion due to photoionisation by the supernova flash. From 1995 hotspots appeared in the ring and their brightness increased nearly exponentially as a result of interaction with the supernova blast wave. Imaging and spectroscopic observations with the Hubble Space Telescope and the Very Large Telescope now show that both the shocked and the unshocked emission components from the ring have been decreasing since $\sim$ 2009. In addition, the most recent images reveal the brightening of new spots outside the ring. These observations indicate that the hotspots are being dissolved by the shocks and that the blast wave is now expanding and interacting with dense clumps beyond the ring. Based on the currently observed decay we predict that the ring will be destroyed by $\sim$ 2025, while the blast wave will reveal the distribution of gas as it expands outside the ring, thus tracing the mass-loss history of the supernova progenitor.

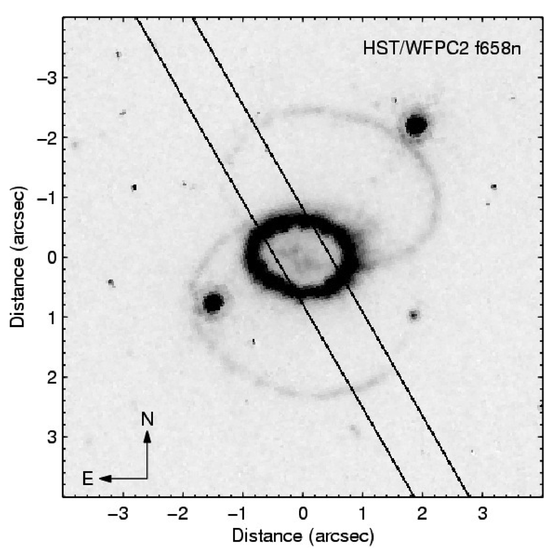
THE CIRCUMSTELLAR RING



HST image composite (Fransson et al 2015, ApJL, 806, L19) showing the time evolution of the structure of the inner circumstellar ring of SN 1987A. Initially photoionized by EUV and soft X-ray emission from the SN explosion, it subsequently faded as the gas cooled and recombined.

In 1998 hotspots began to brighten around the ring. The spots are a result of the interaction between the SN ejecta and the circumstellar ring.

VLT/UVES OBSERVATIONS



The 0.8" slit is placed with PA= 30° as shown in the figure (Gröningsson et al 2008, A&A, 479, 761).

With atmospheric seeing better than 0.8" it is possible to spatially resolve the emission from the north and south of the ring.

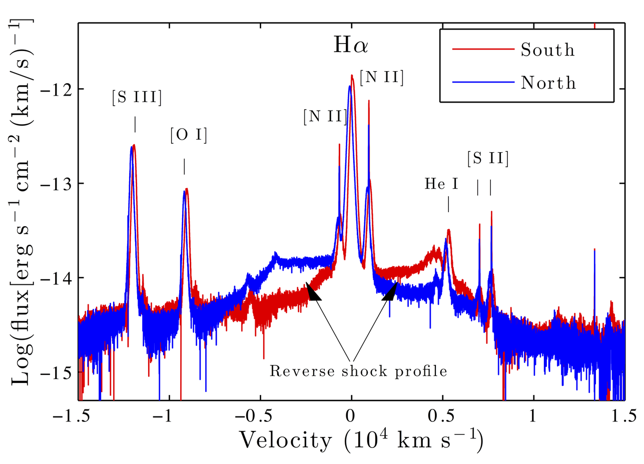
The high resolution spectra also allow us to clearly see a narrow and a broader intermediate components, arising from the unshocked and shocked gas, respectively.

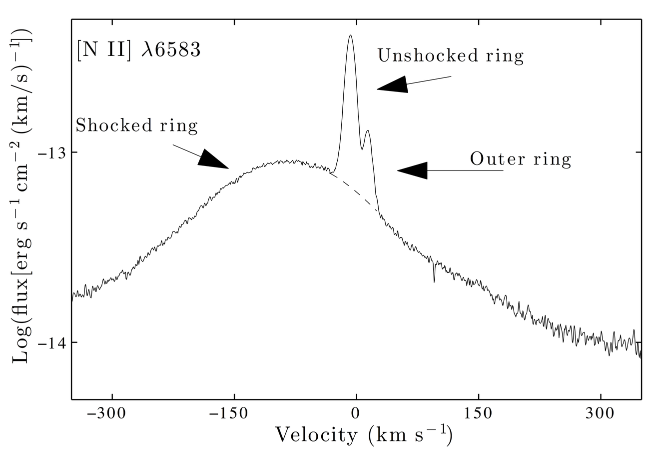
LINE COMPONENTS

Due to the inclination of the ring relative to the line of sight, the spectrum from the northern part of the ring is blueshifted, whereas the spectrum from the southern part is redshifted.

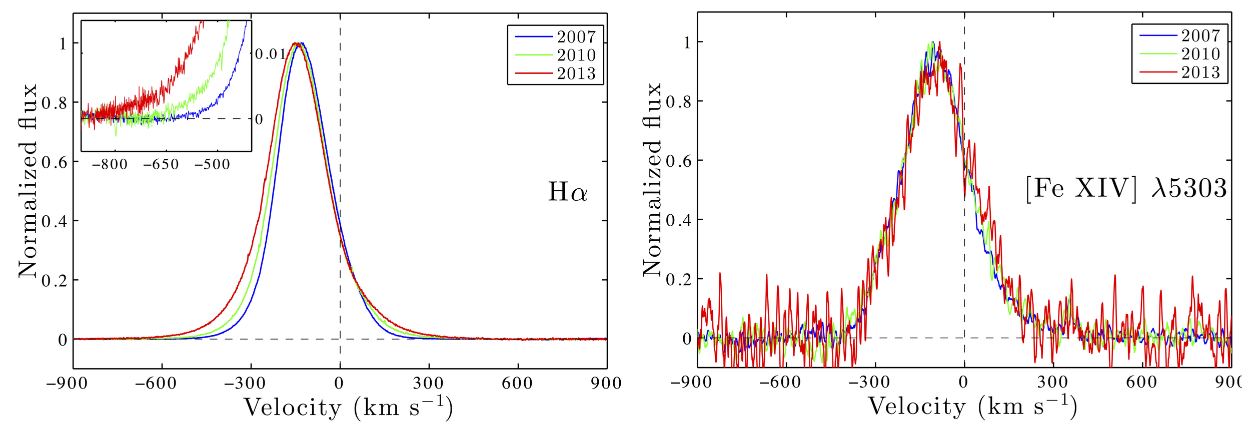
The reverse shock profile of the Hα line is clearly seen in the figure to the left as a broad line component ($\sim 10^4$ km s^{-1}).

The figure to the right shows the shocked ($\sim$ hundreds of km s^{-1}) and unshocked ($\sim$ tens of km s^{-1}) profiles of the [N II] λ6583 line from the northern part of the ring.





EVOLUTION OF SHOCKED RING PROFILES

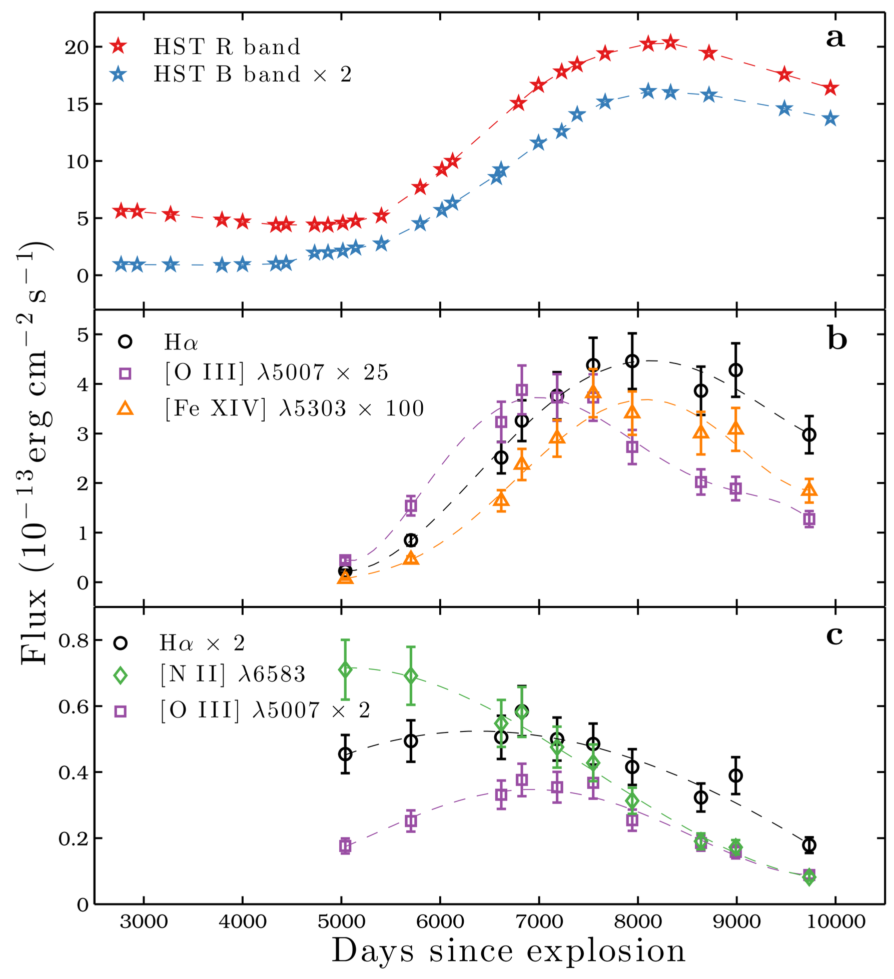


Profiles of Hα and [Fe XIV] λ5303 lines from the northern part of the ring.

The Hα profile shows increasing maximum blue velocity due to shocks with higher velocity becoming radiative, since the cooling time is proportional to the shock velocity as $t_{cool} \propto v_{shock}^{3.4}$ years (Gröningsson et al 2006, A&A, 456, 581).

The [Fe XIV] λ 5303 profile remains constant, as this line comes from the hot gas immediately behind the shock.

LIGHT CURVES



Panel **a** in the figure to the left (Fransson et al 2015) shows the light curves from HST R and B bands, where the fluxes were obtained by placing a 0.8" slit on the image in the same position as the UVES observations. The fluxes are seen to decrease until $\sim$ 5000 days, followed an increase which continues until $\sim$ 8000 days. Since then, a new decrease in the fluxes has been observed.

Panel **b** shows the light curves of the intermediate components of Hα and [O II] λ5007 and [Fe XIV] λ5303 from the ring.

Panel **c** shows fluxes from the narrow (unshocked) components of Hα, [O II] λ5007 and [N II] λ6583.

A clear decline is seen in all UVES fluxes, approximately following the decline in the HST light curves. The fading shocked component is explained by the decrease in the area of radiative shocks, as well as shock velocities becoming higher than the threshold for radiative cooling due to increase in pressure. The narrow emission, in turn, is replaced by soft X-rays as shocked low-density gas is non-radiative. The decline in the fluxes from both shocked and unshocked lines indicate the ongoing destruction of the circumstellar ring

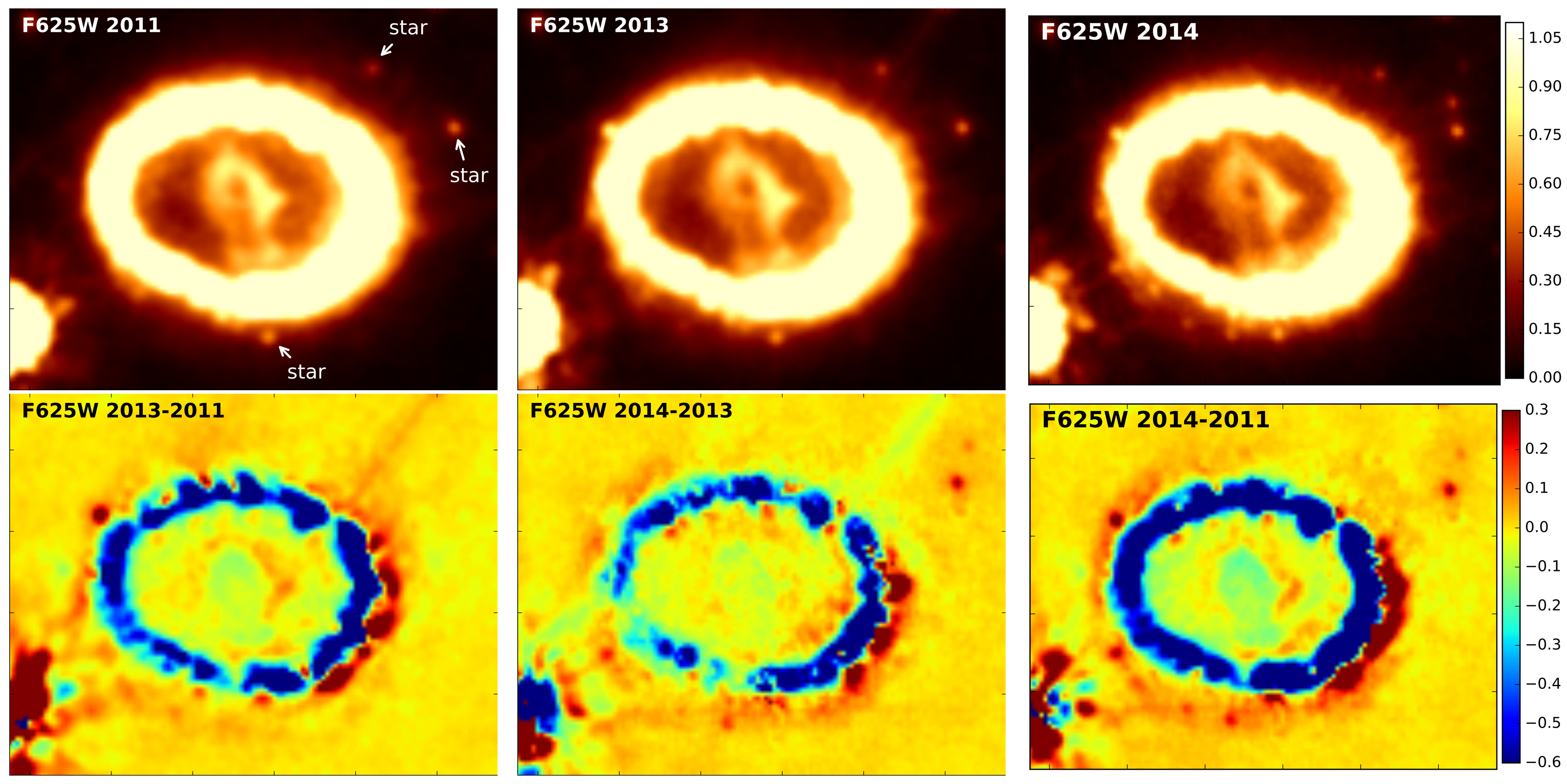
NEW HOTSPOTS

In the figure below, the first row shows narrow band images obtained with the HST/WTC3 in 2011, 2013 and 2014, respectively, of Hα emission (Fransson et al 2015).

The second row is a series of subtractions, clearly showing changes in the fluxes from different regions.

The images show the decrease in emission from the circumstellar ring. In addition, faint new hotspots and diffuse emission have appeared outside the circumstellar ring.

The new spots could be an indication that the shock is now propagating beyond the ring.



CONCLUSION

- We observe an increase in the maximum velocity of the shocked profiles of certain lines from the ring, caused by shocks with higher velocities becoming radiative as they cool.
- Fluxes from shocked and unshocked line components have been decreasing , suggesting the ring is being disintegrated by the shocks. Extrapolating the light curves, we expect the circumstellar ring to be destroyed by $\sim$ 2025.
- New hot spots are brightening up outside the ring, indicating the blast wave may now be expanding beyond the ring. In this case, the distribution of gas outside the ring will be revealed and the mass-loss history of the progenitor traced.