HST observations of SN1987A in its early thirties

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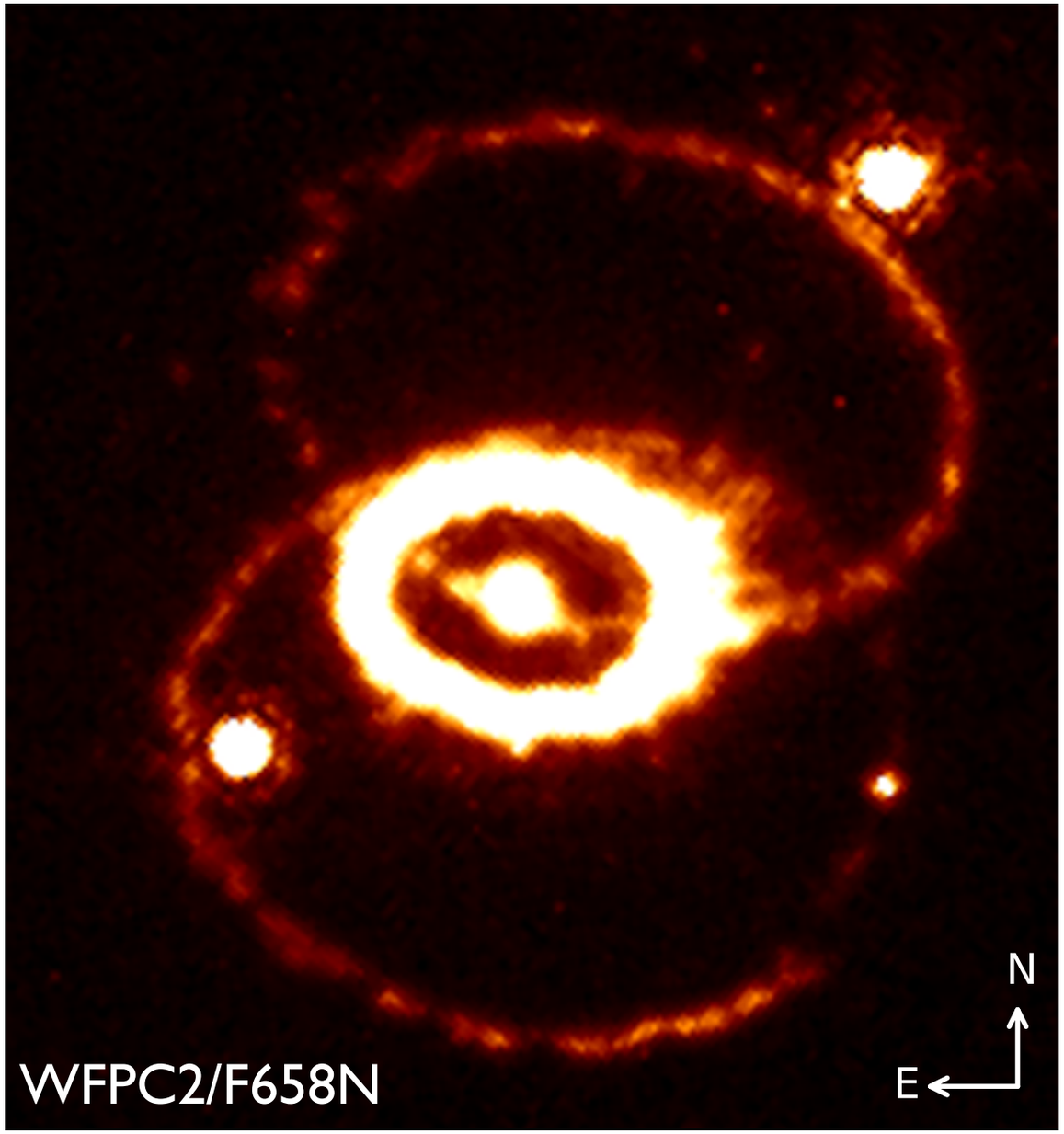
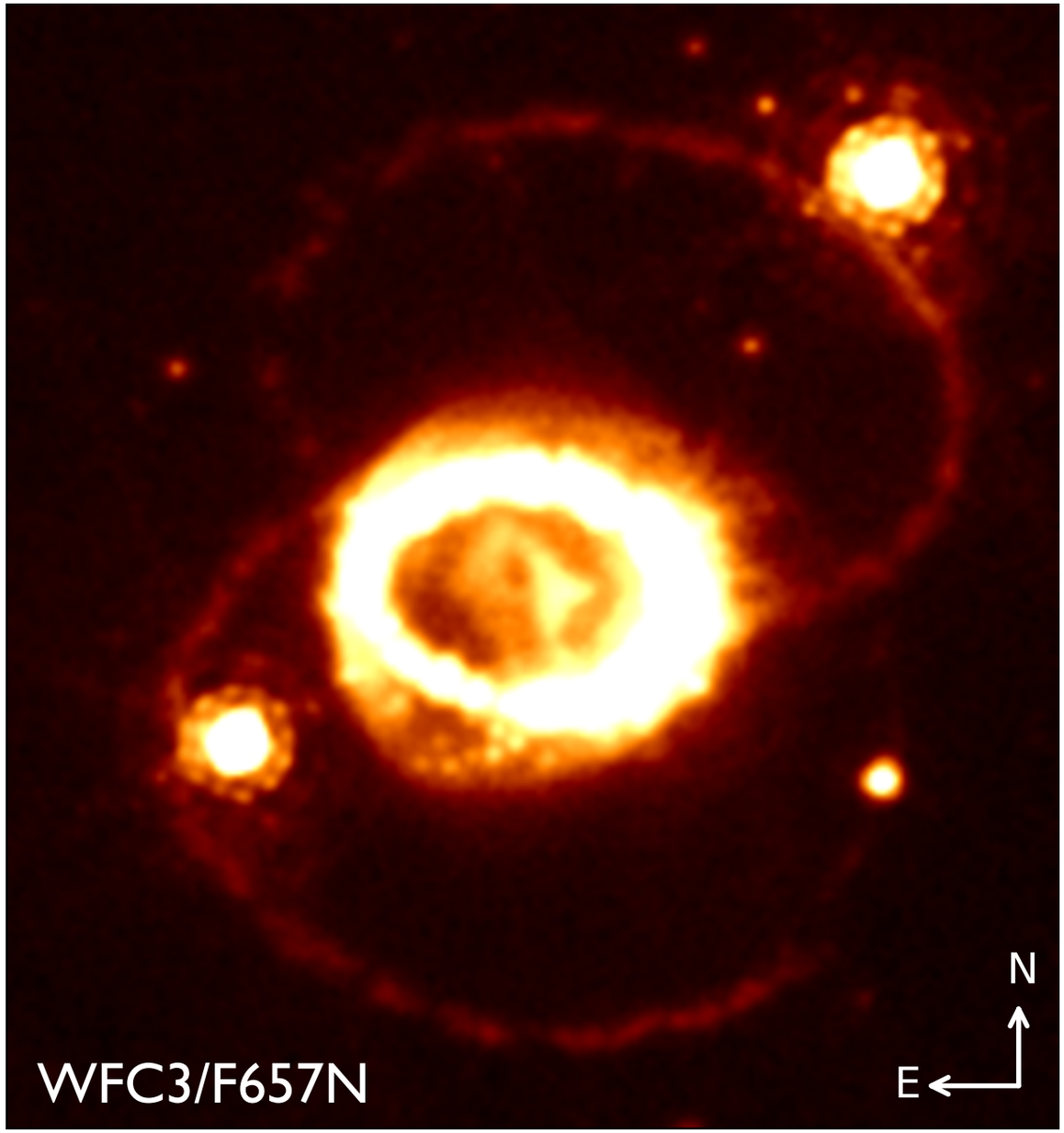
Claes Fransson, Dennis Alp
and many others …

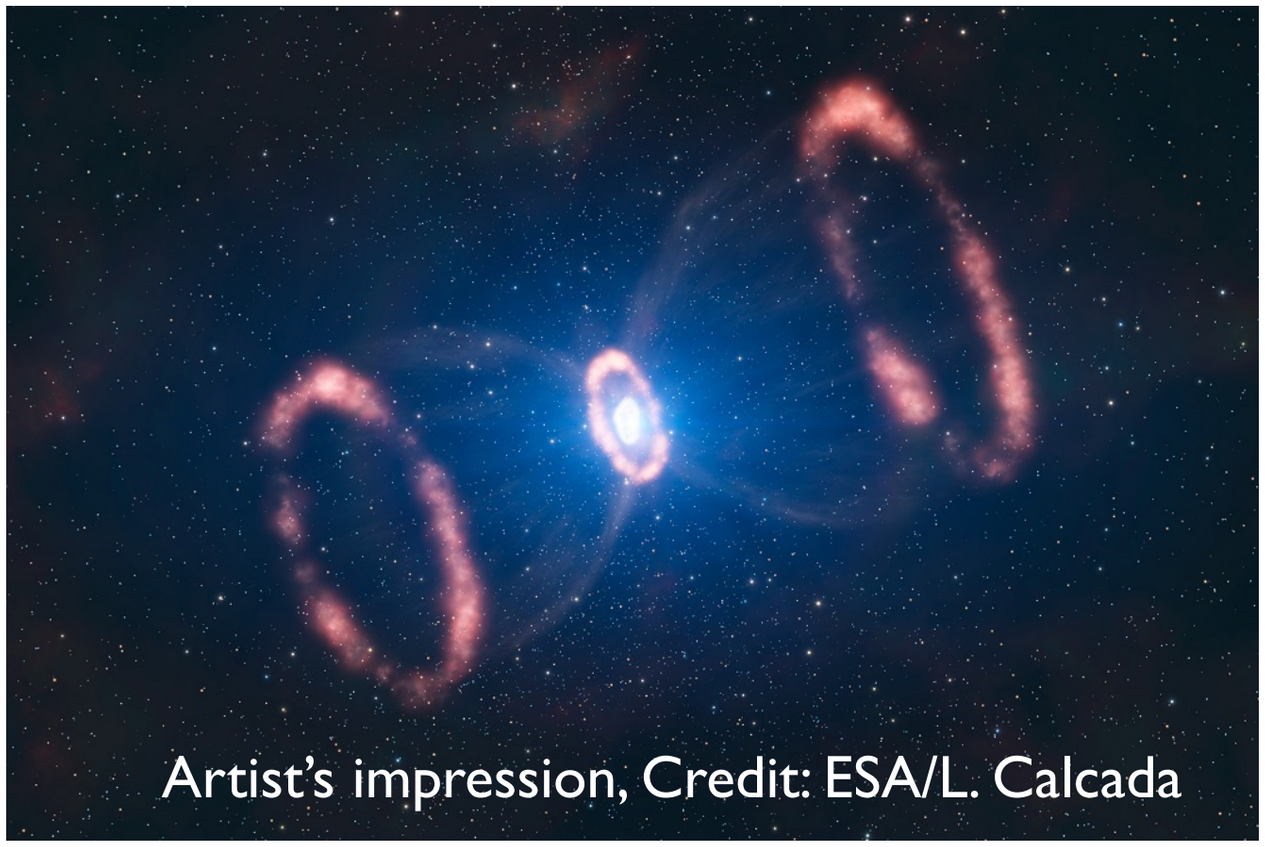
1994
(2500 days)



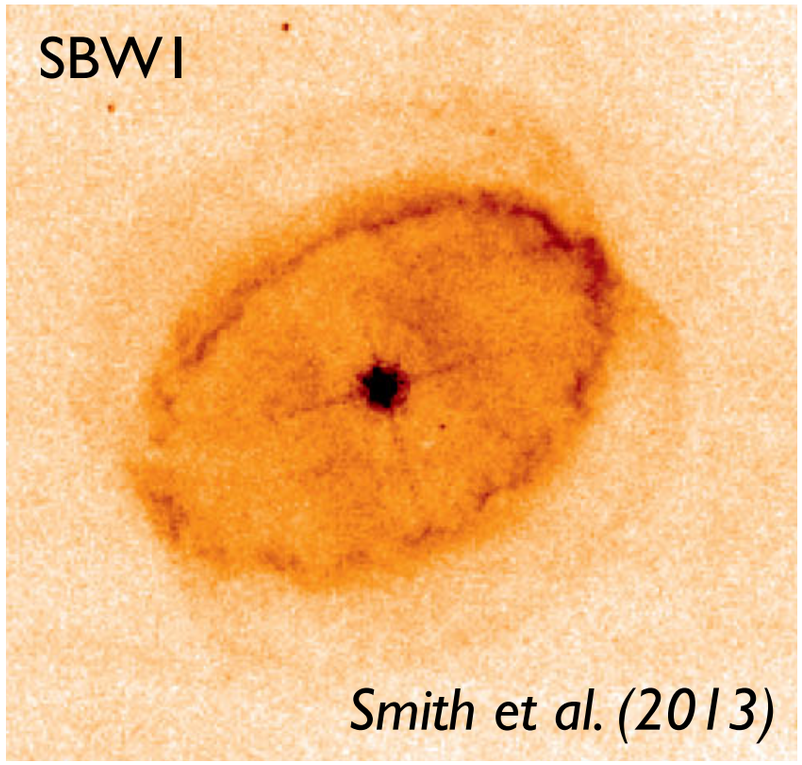
2018
(11,500 days)



Ring nebula and progenitor



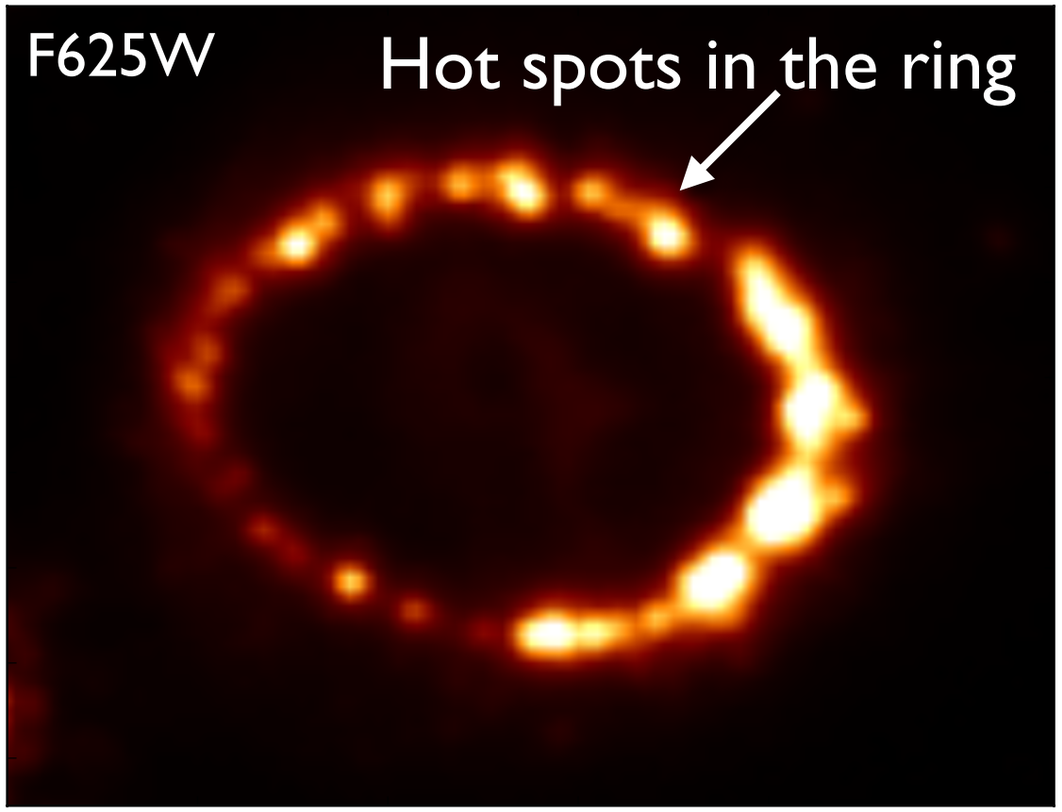
Artist's impression, Credit: ESA/L. Calcada

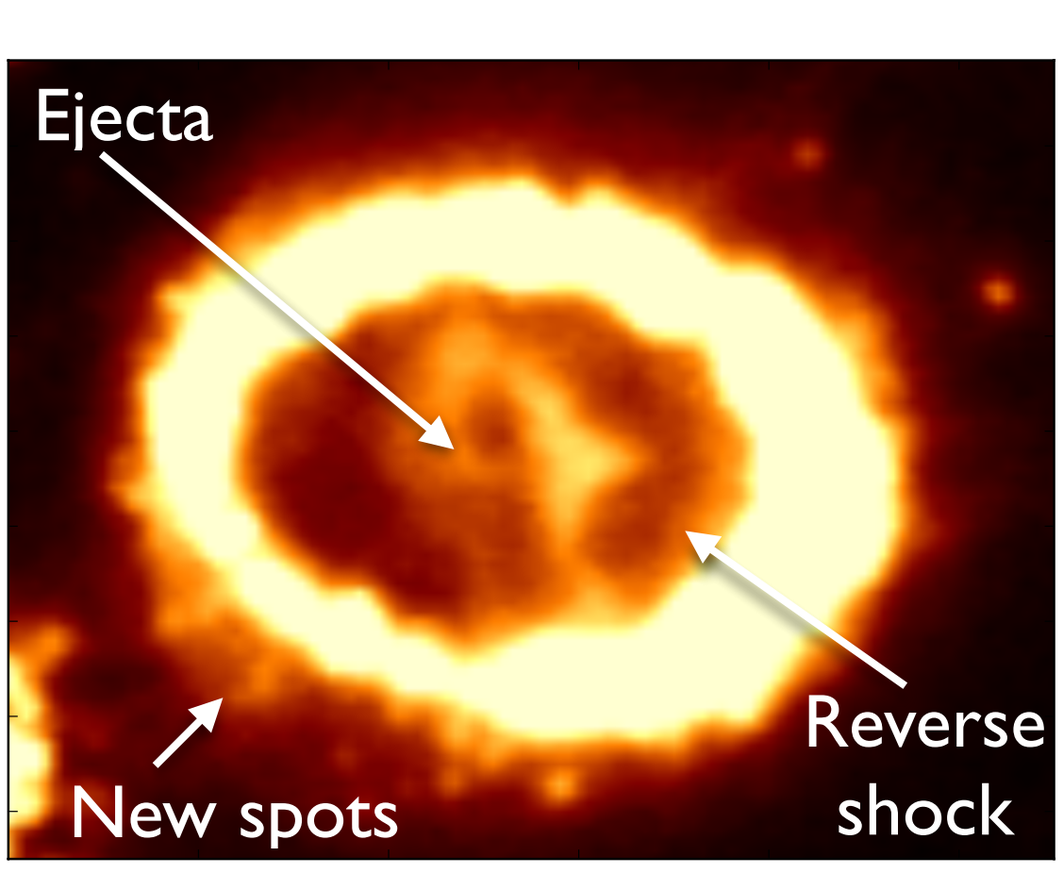


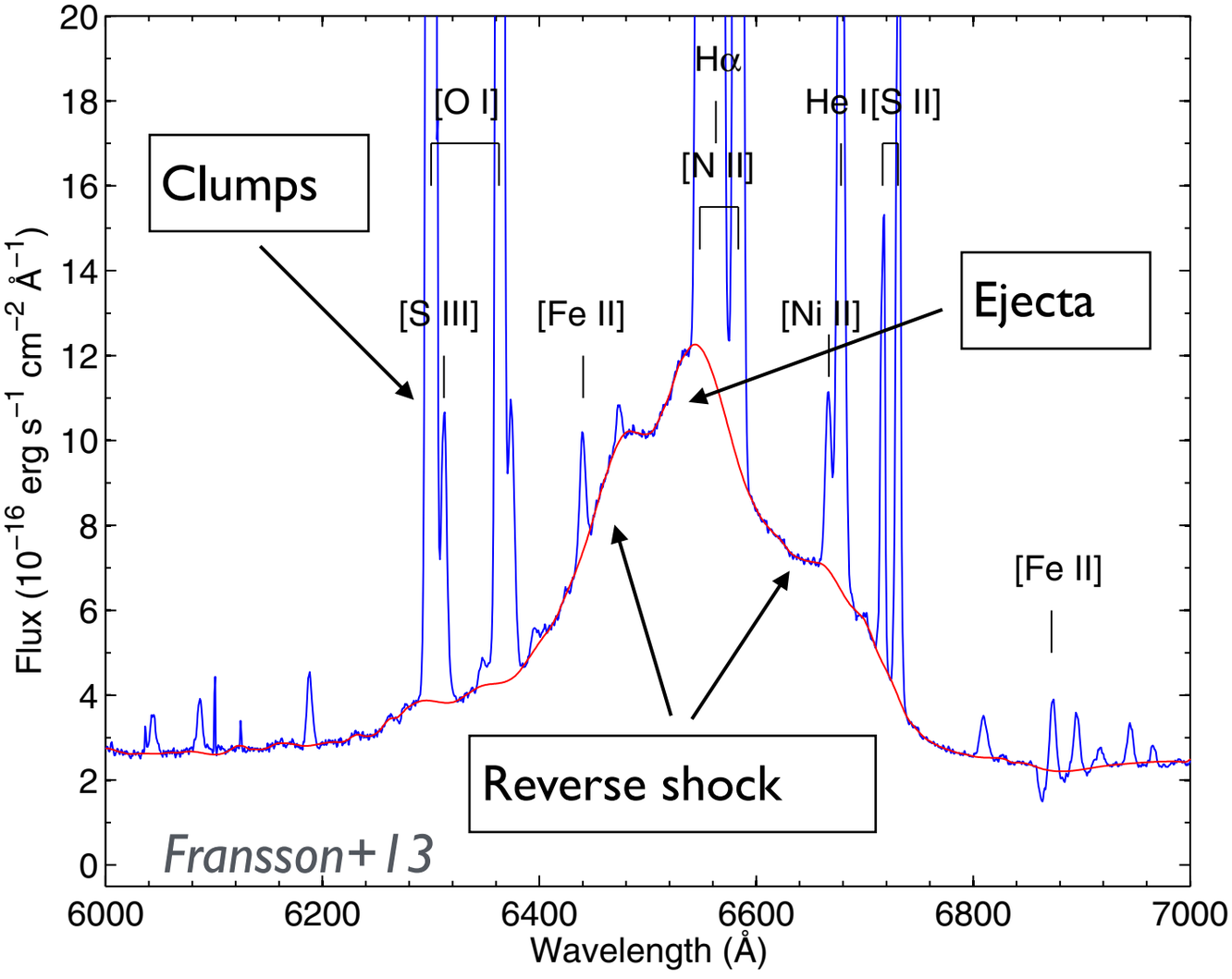
Circular rings inclined by ~ 45°. Kinematic age ~ 20,000 years.

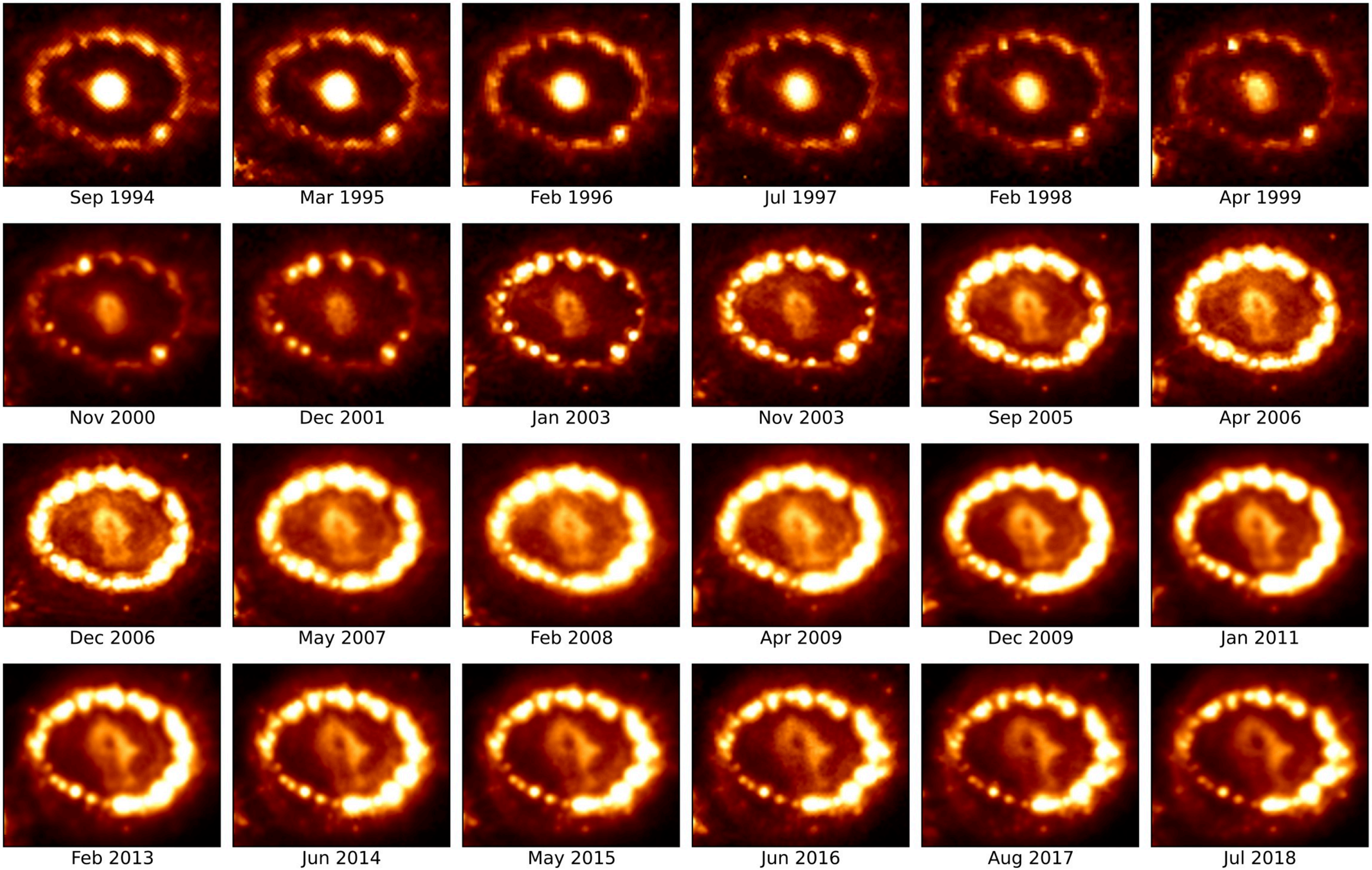
Possible formation scenarios: Interaction of BSG and RSG winds (*Blondin & Lundqvist 1993*), binary merger (*Morris & Podsiadlowski 2009*), photoevaporation of ring emitted by BSG (*Smith+2013*), bipolar jets (*Akashi+2015*).

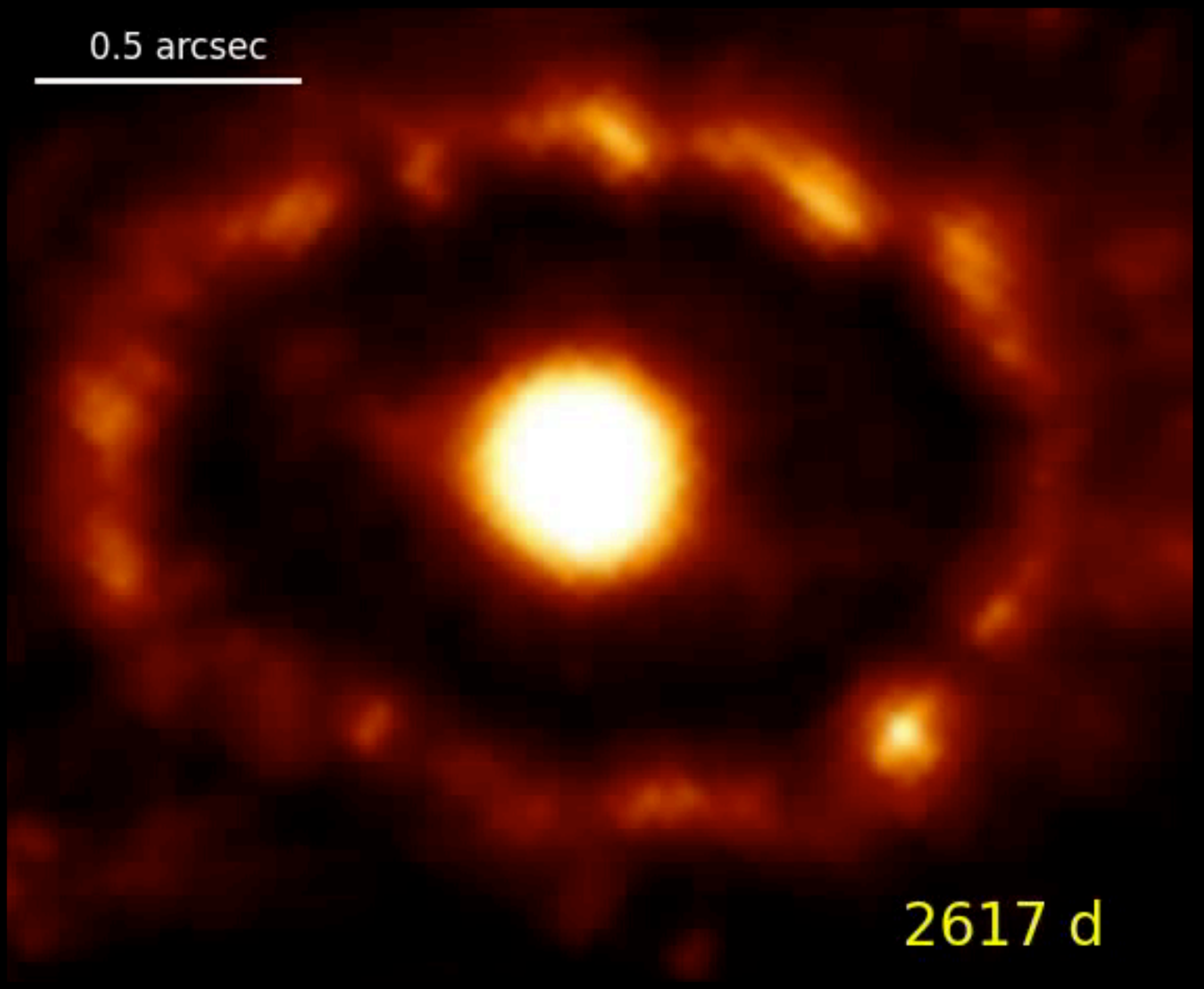
Connected to unusual BSG progenitor [see also poster by Dennis Alp for new constraints on the progenitor].


F625W
Hot spots in the ring

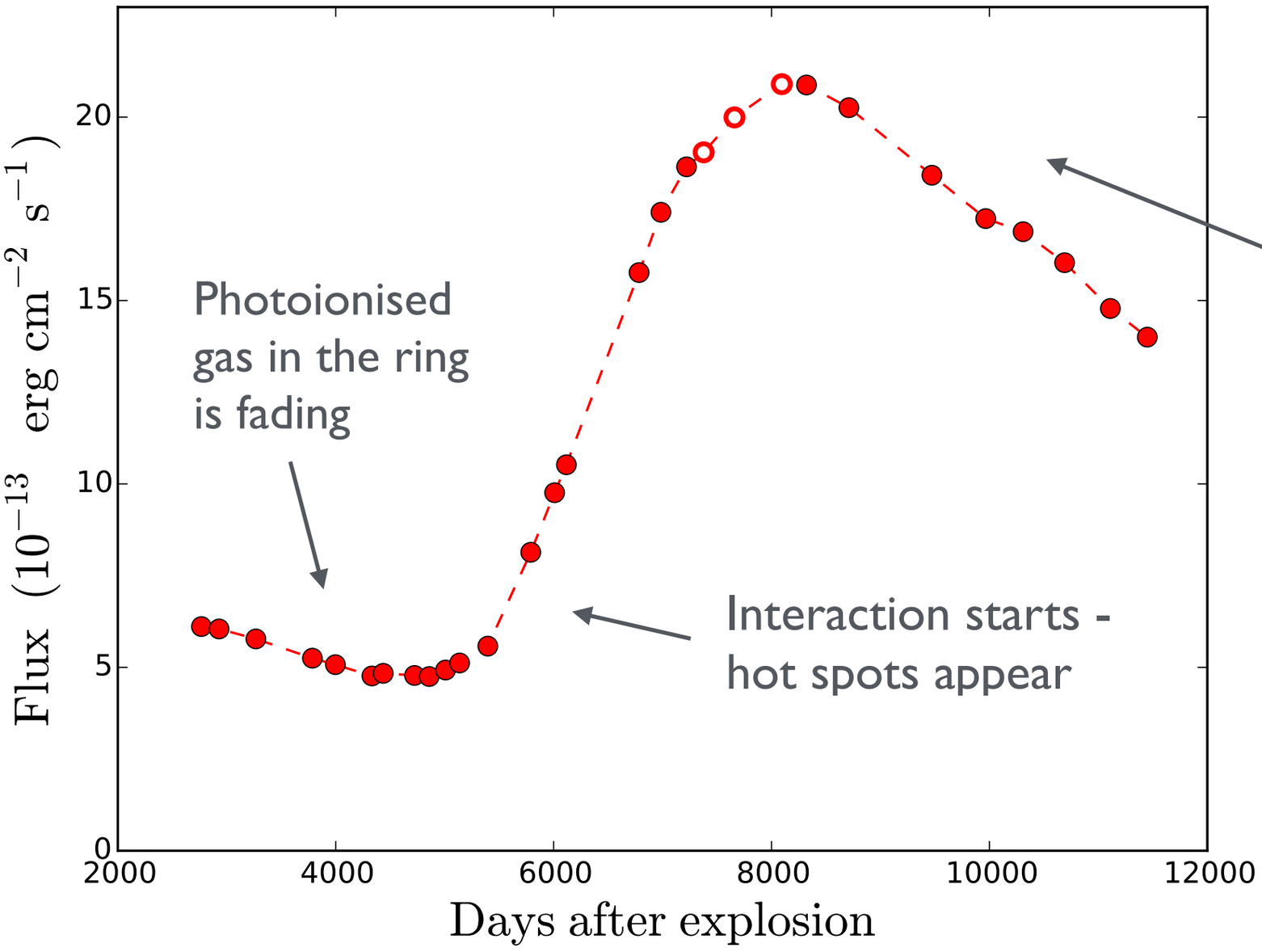

Ejecta
New spots
Reverse shock


Clumps
Ejecta
Reverse shock
[O I]
Hα
[N II]
He I
[S II]
[S III]
[Fe II]
[Ni II]
[Fe II]
Fransson+13
Flux (10^{-16} erg s^{-1} cm^{-2} Å^{-1})
Wavelength (Å)
0
2
4
6
8
10
12
14
16
18
20
6000
6200
6400
6600
6800
7000


Sep 1994
Mar 1995
Feb 1996
Jul 1997
Feb 1998
Apr 1999
Nov 2000
Dec 2001
Jan 2003
Nov 2003
Sep 2005
Apr 2006
Dec 2006
May 2007
Feb 2008
Apr 2009
Dec 2009
Jan 2011
Feb 2013
Jun 2014
May 2015
Jun 2016
Aug 2017
Jul 2018


0.5 arcsec
2617 d

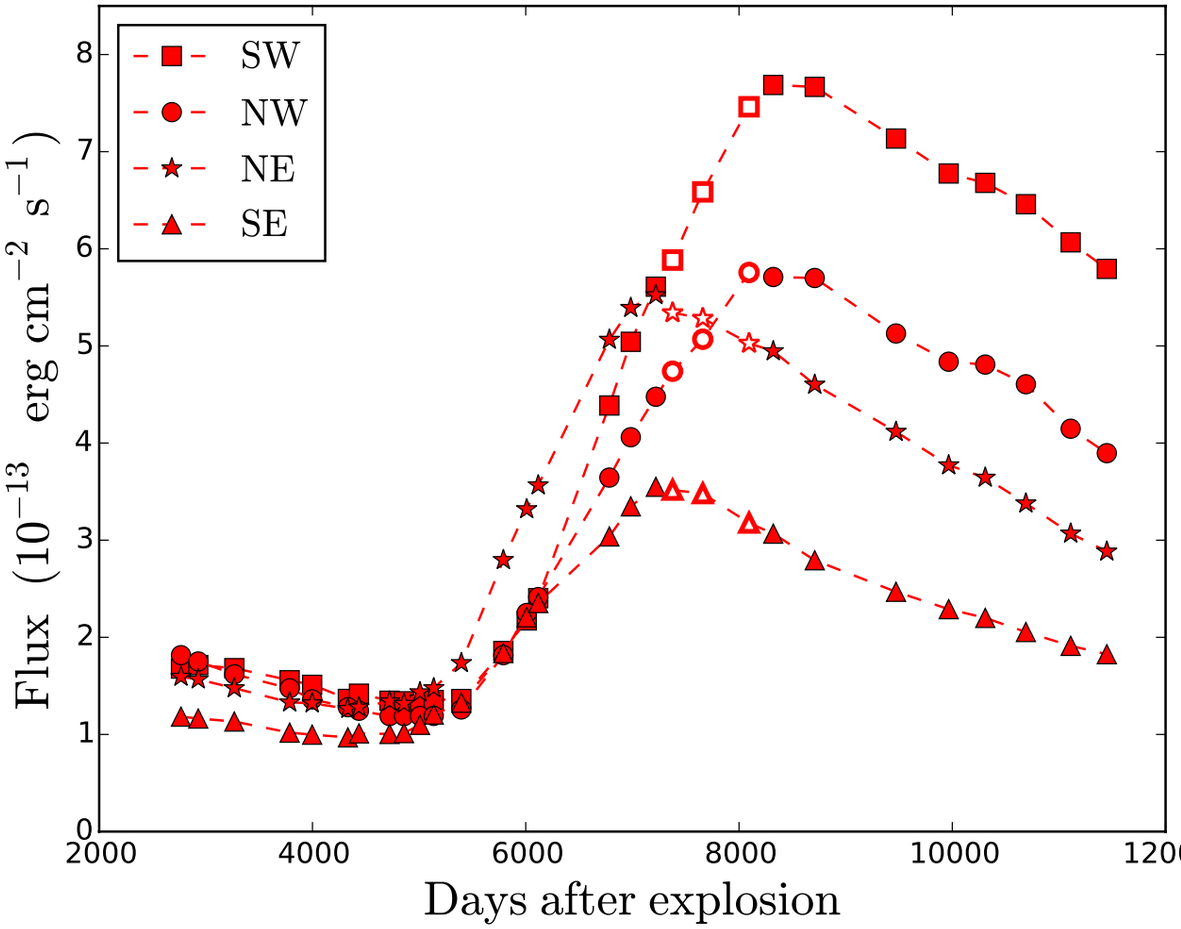
The rise and fall of the ring



The blast wave has left the ring.

The clumps are being destroyed by the shocks.

Fading of the ring is seen also in IR (*Arendt+2016*). Flattening of soft X-ray light curve (*Frank+2016*). Re-acceleration of the shock wave in radio (*Cendes+2018*).



Asymmetries

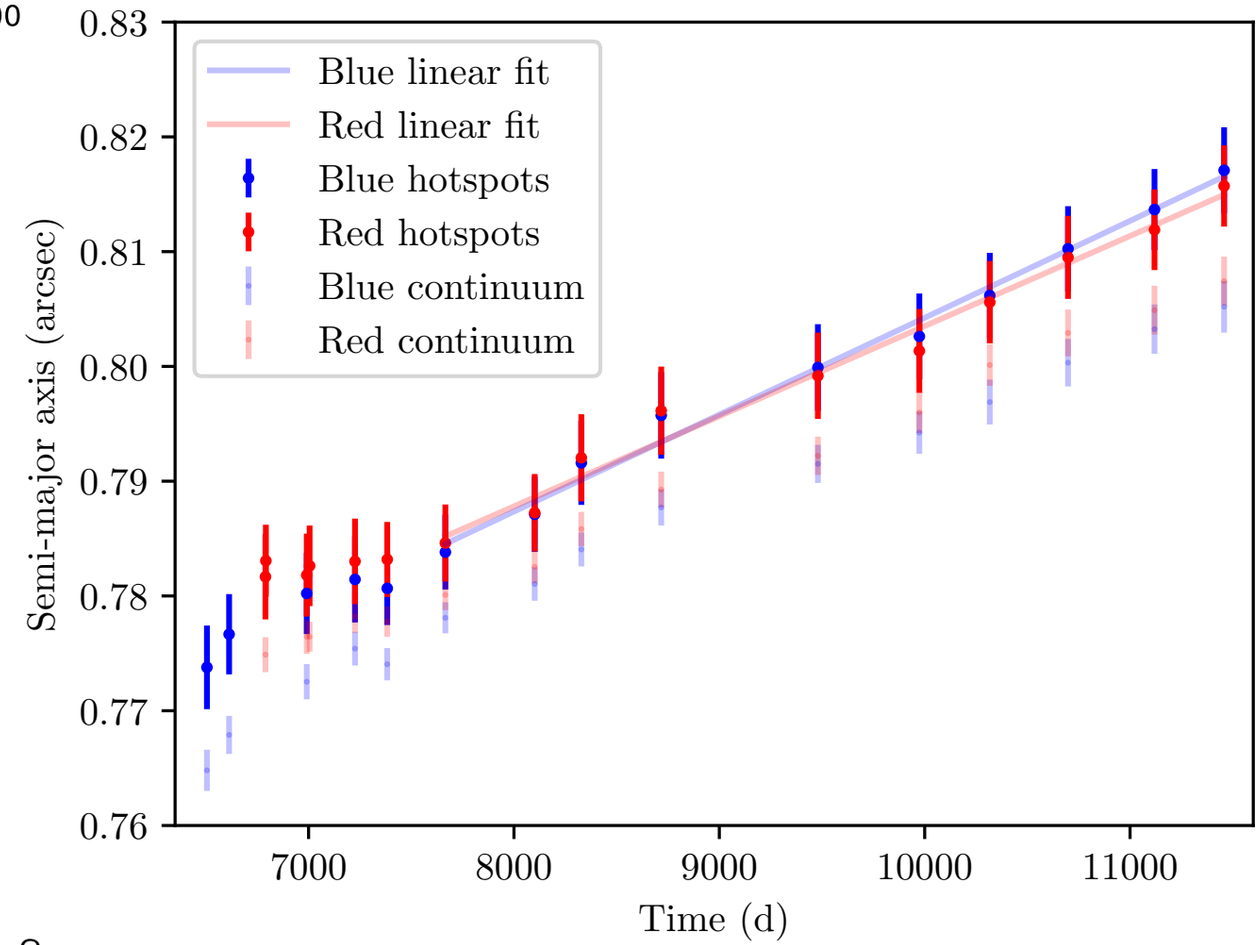
The eastern side peaked earlier.

South-west currently three times brighter than south-east.

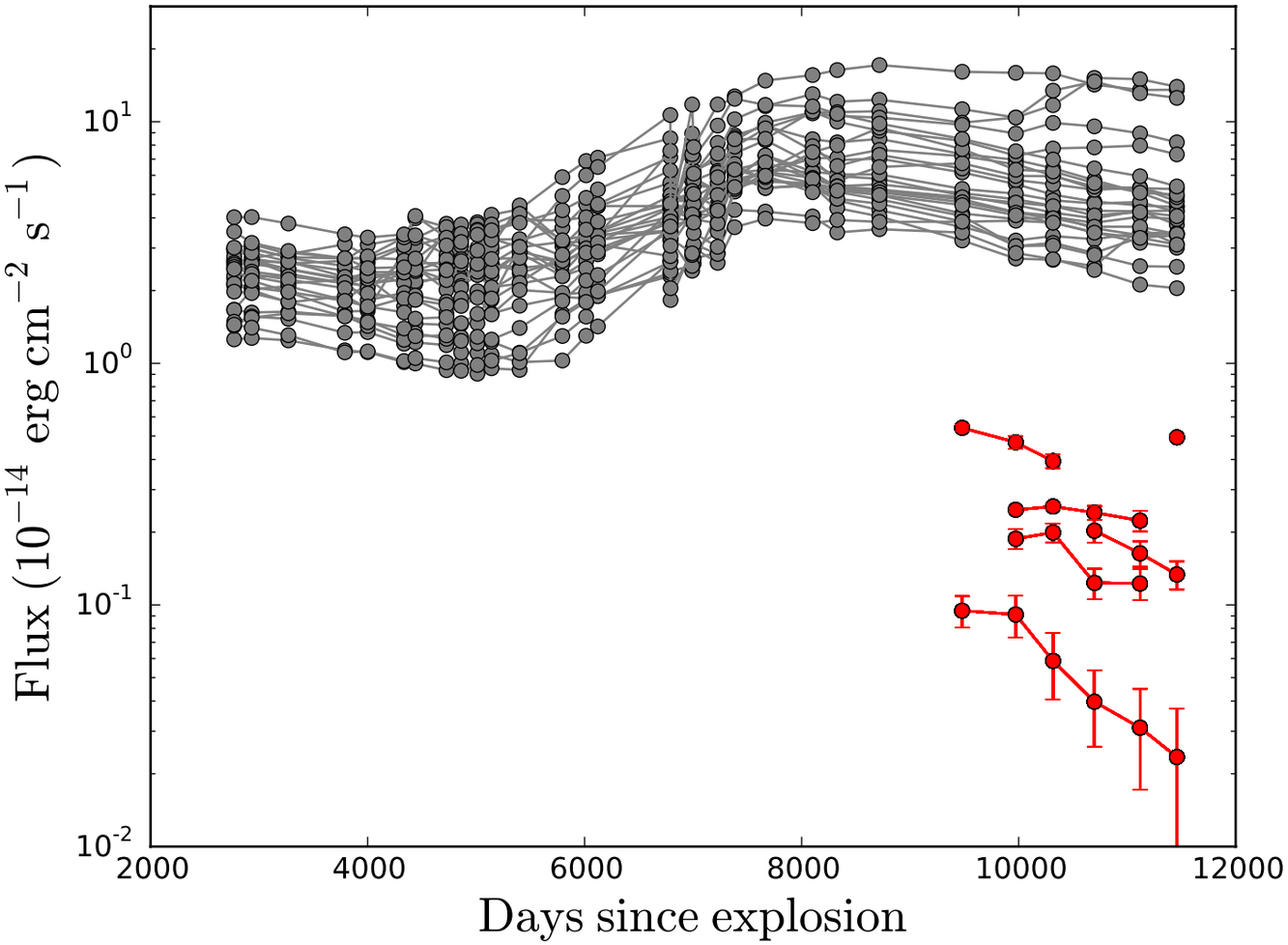
Expansion

The ring expands at 700 km s^{-1}.

Consistent with highest velocities observed in spectra of the hotspots.

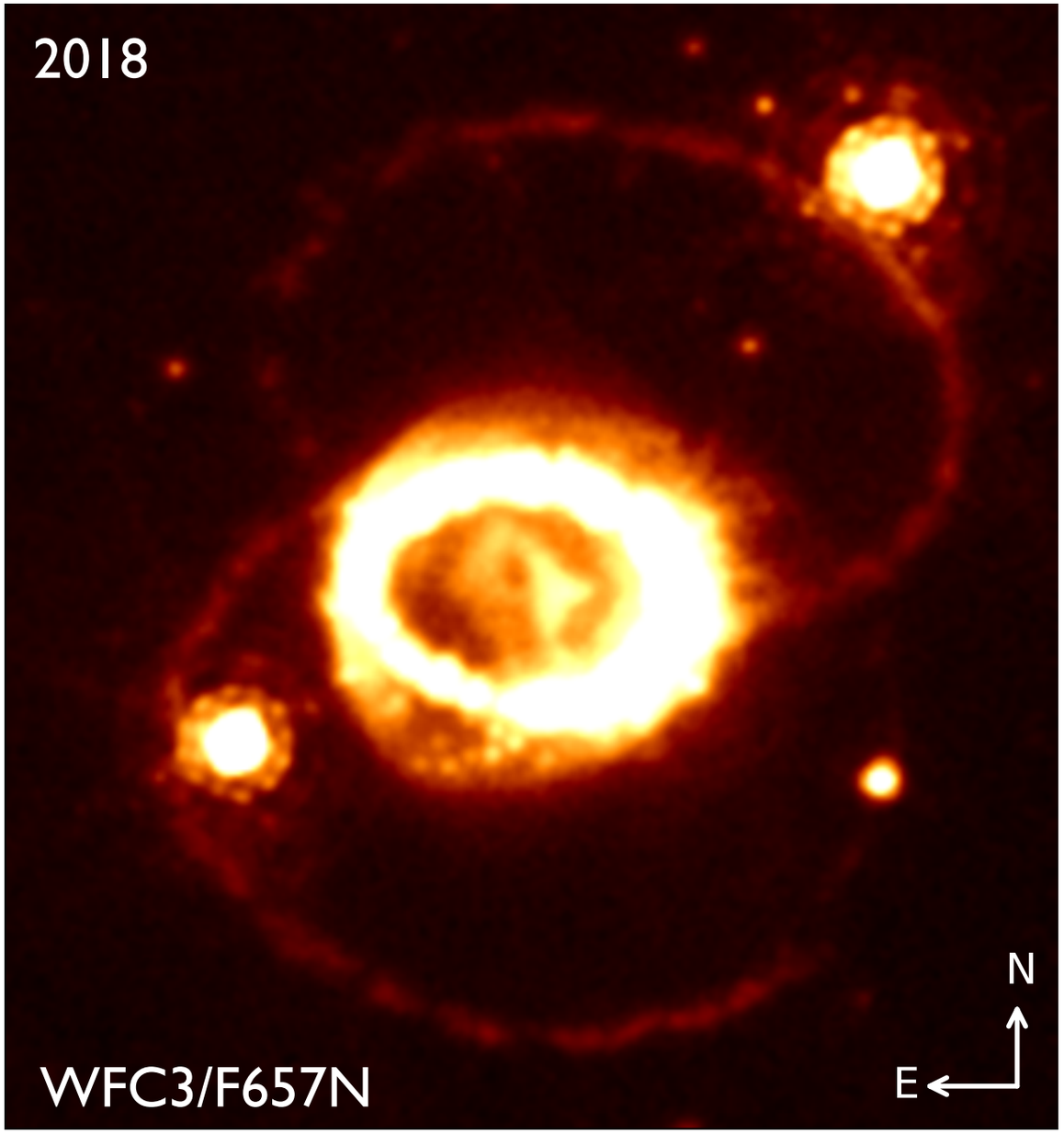


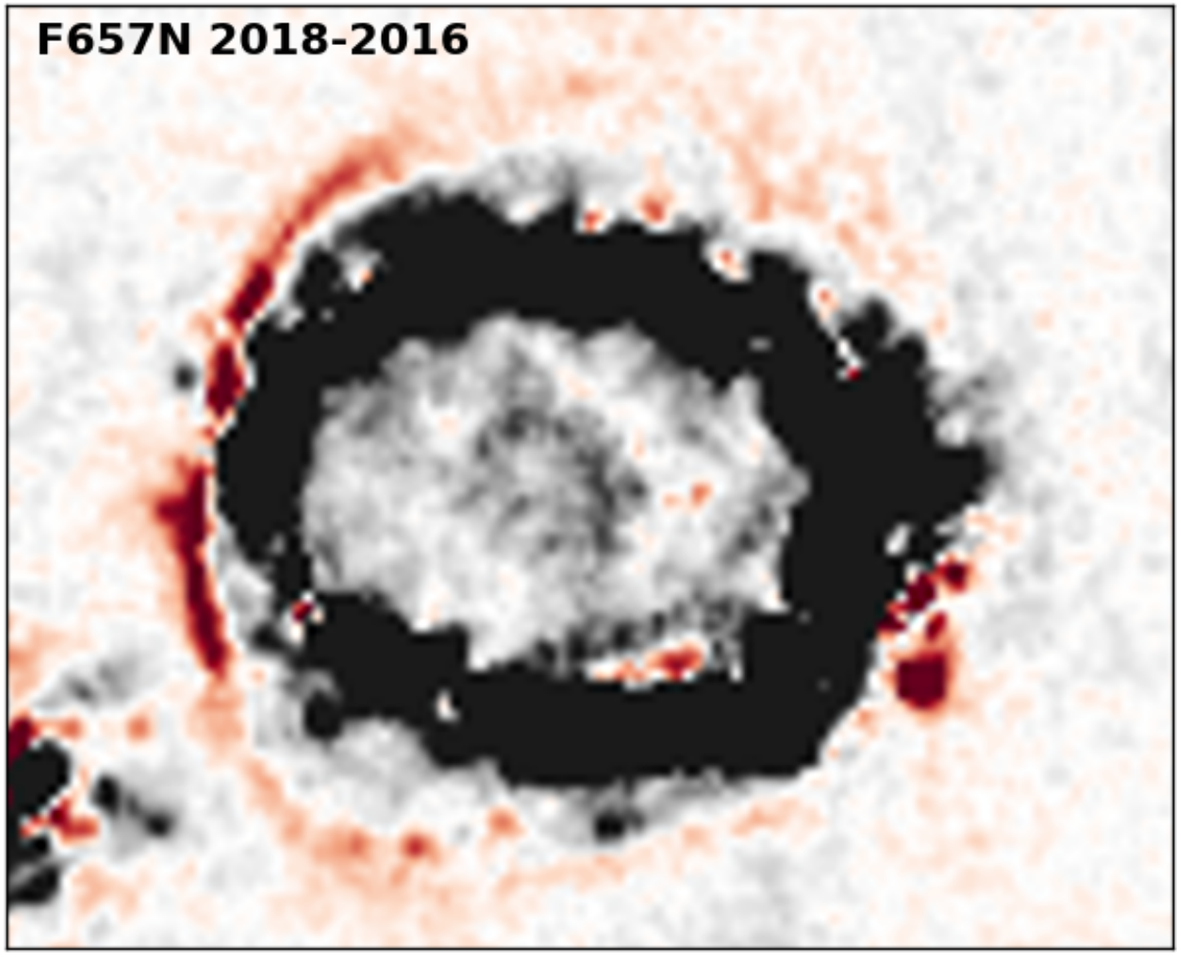
New spots outside the ring



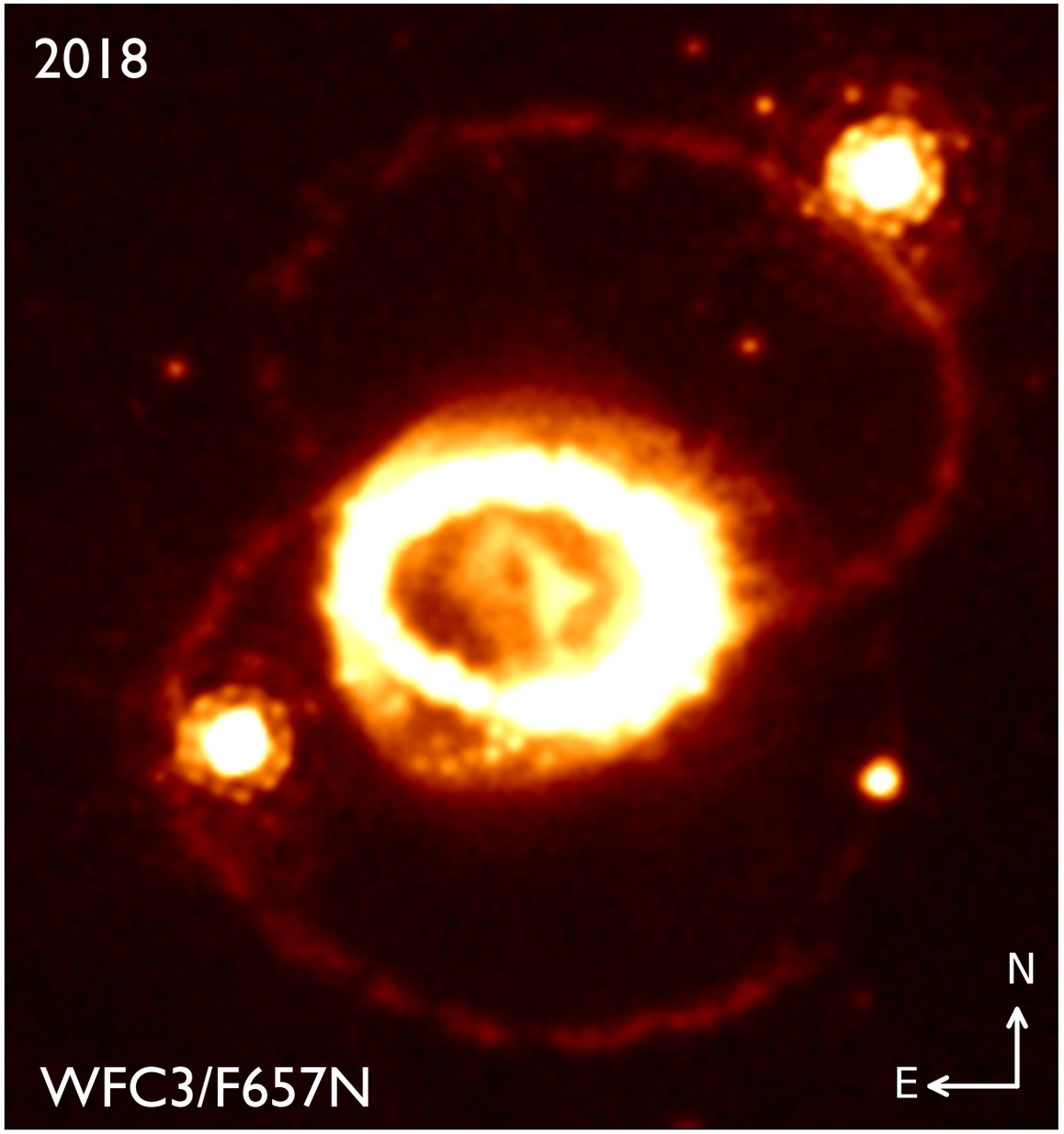
- About a dozen new spots have appeared outside the ring between 2013-2018
- Strong in narrow filters so most likely line emitting
- Peak fluxes one-two orders of magnitude lower than the hotspots in the ring

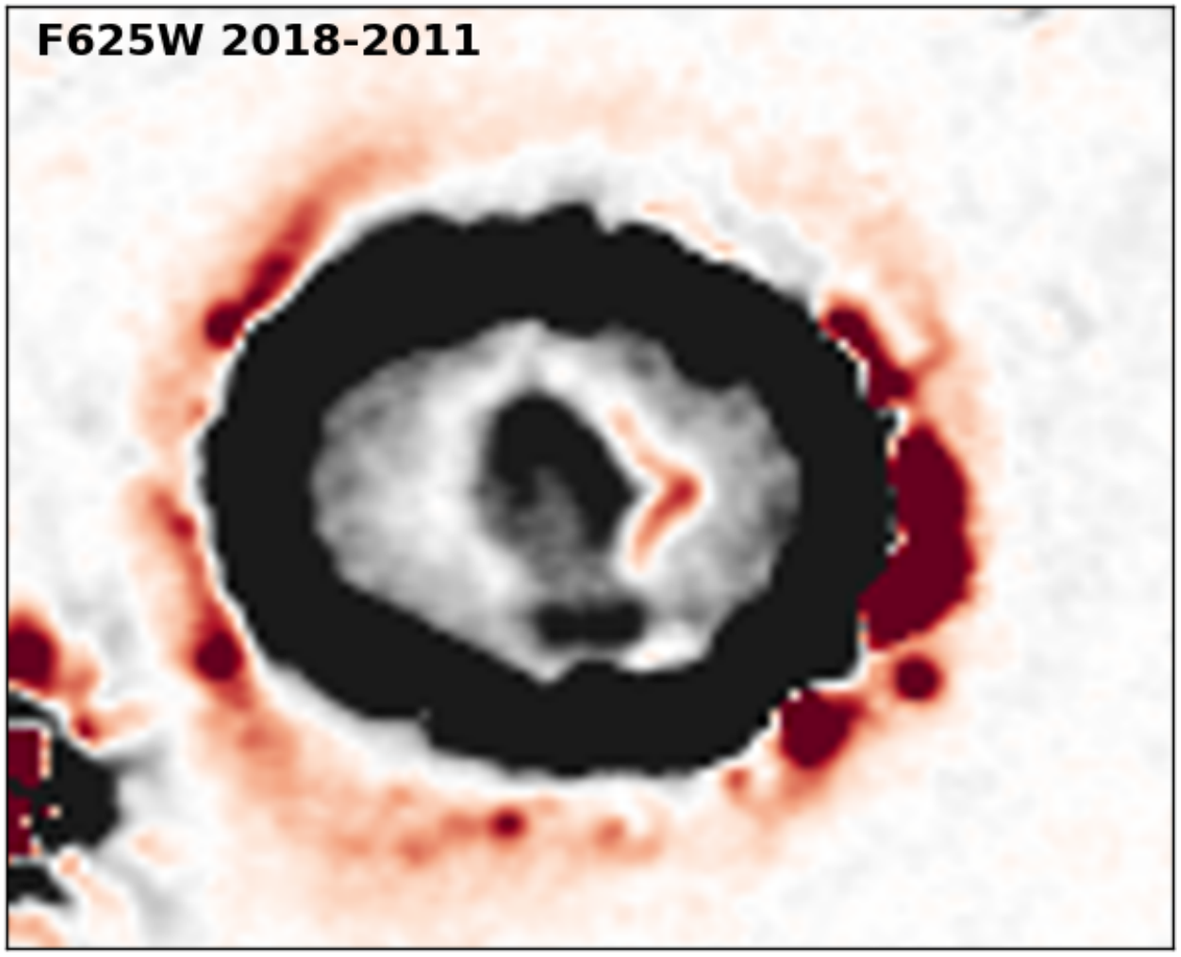
Diffuse emission outside the ring

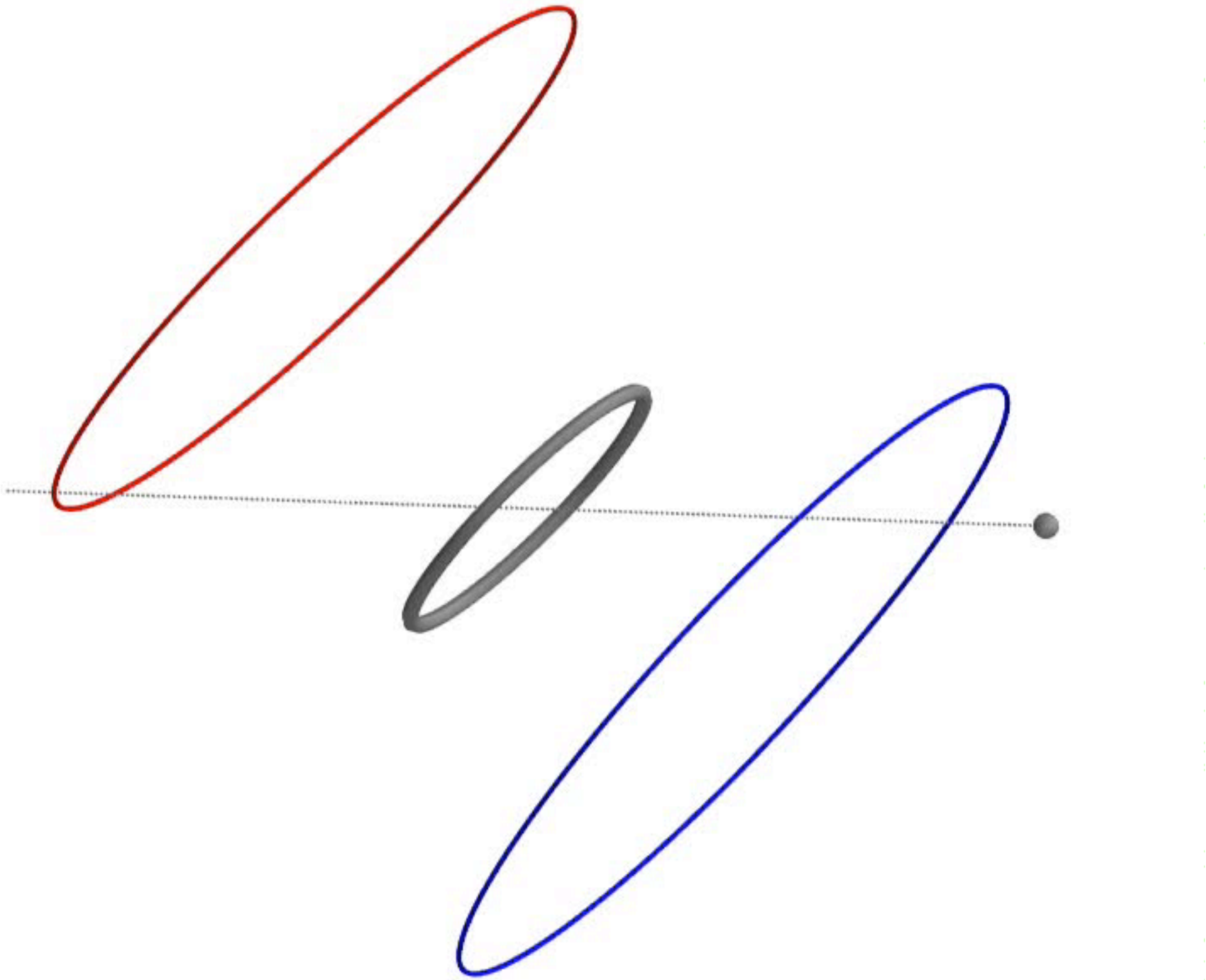


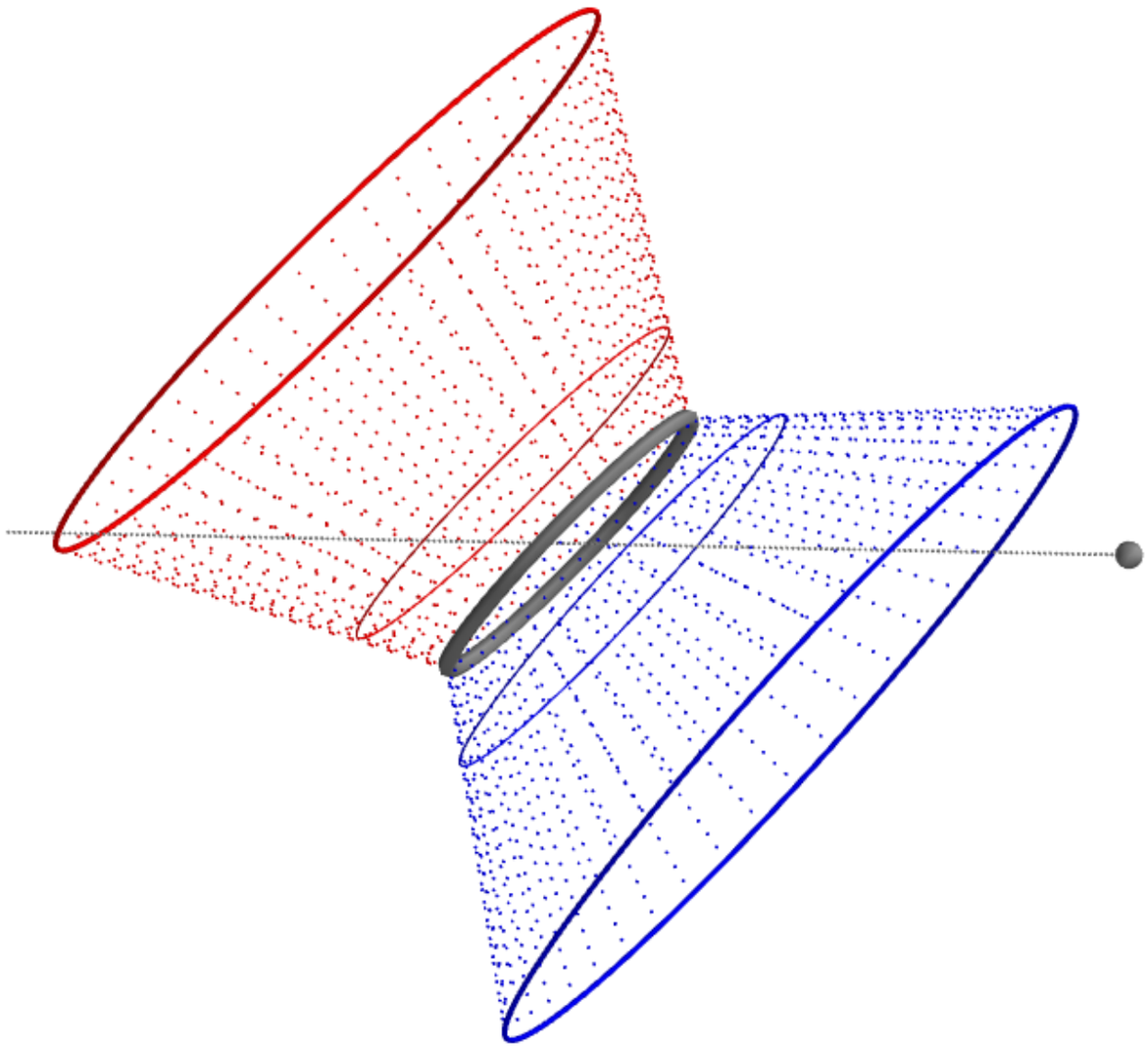


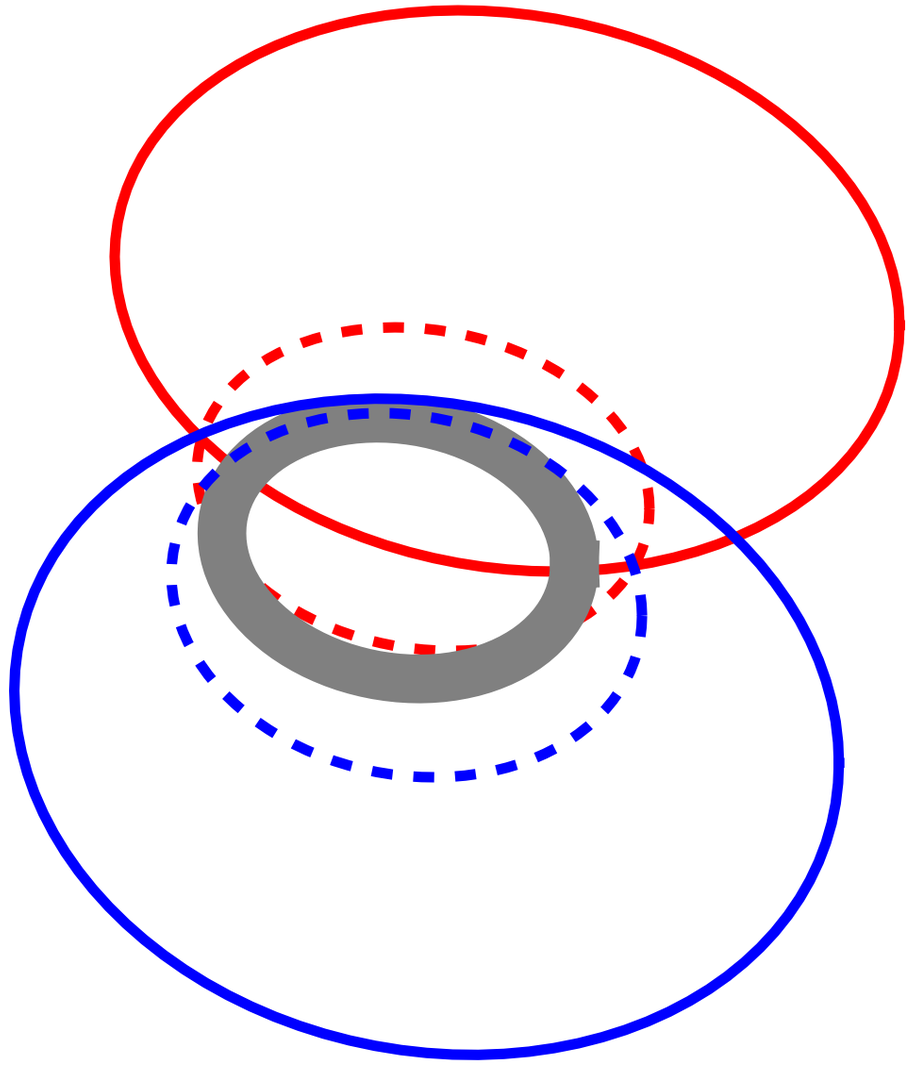
Diffuse emission outside the ring





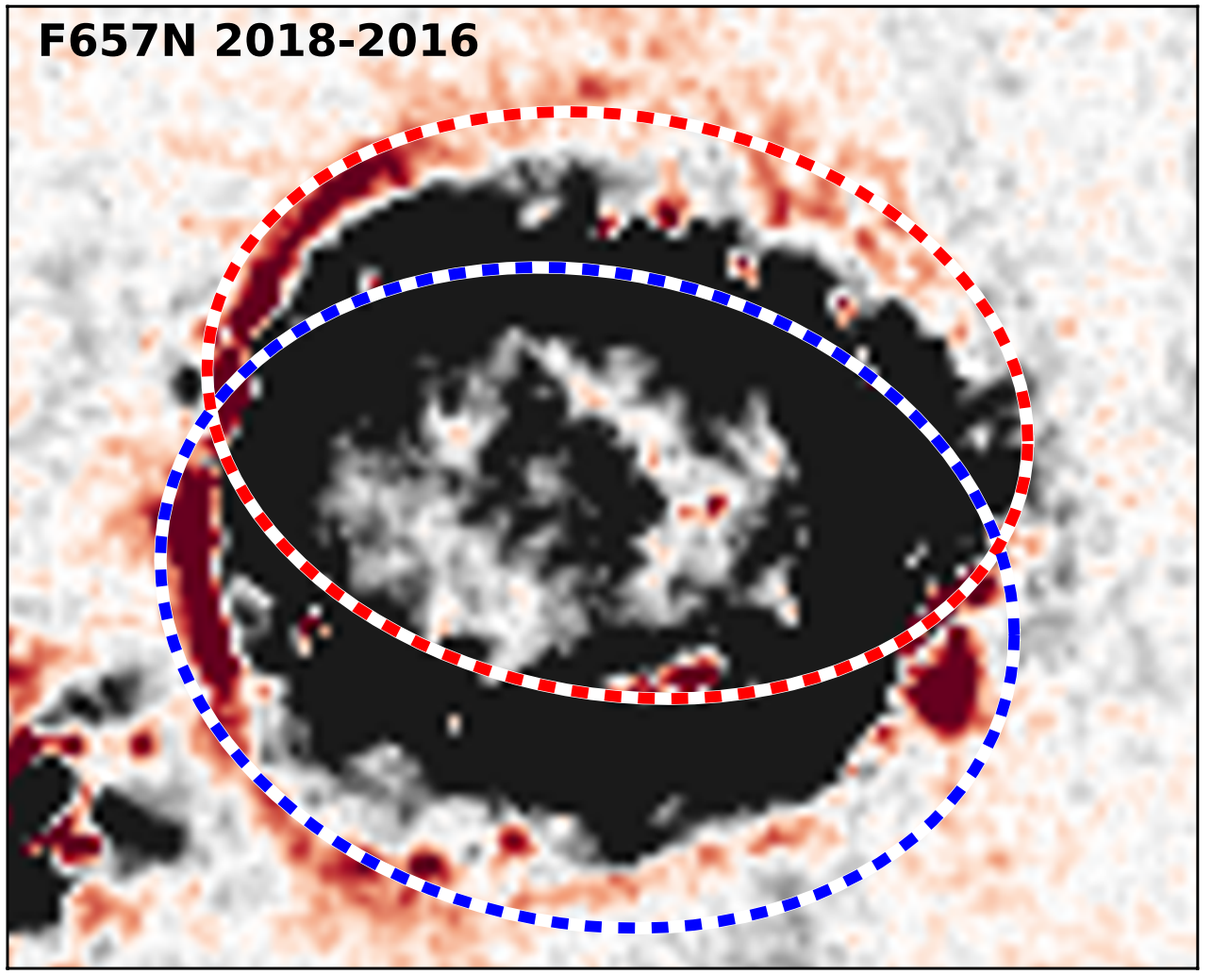


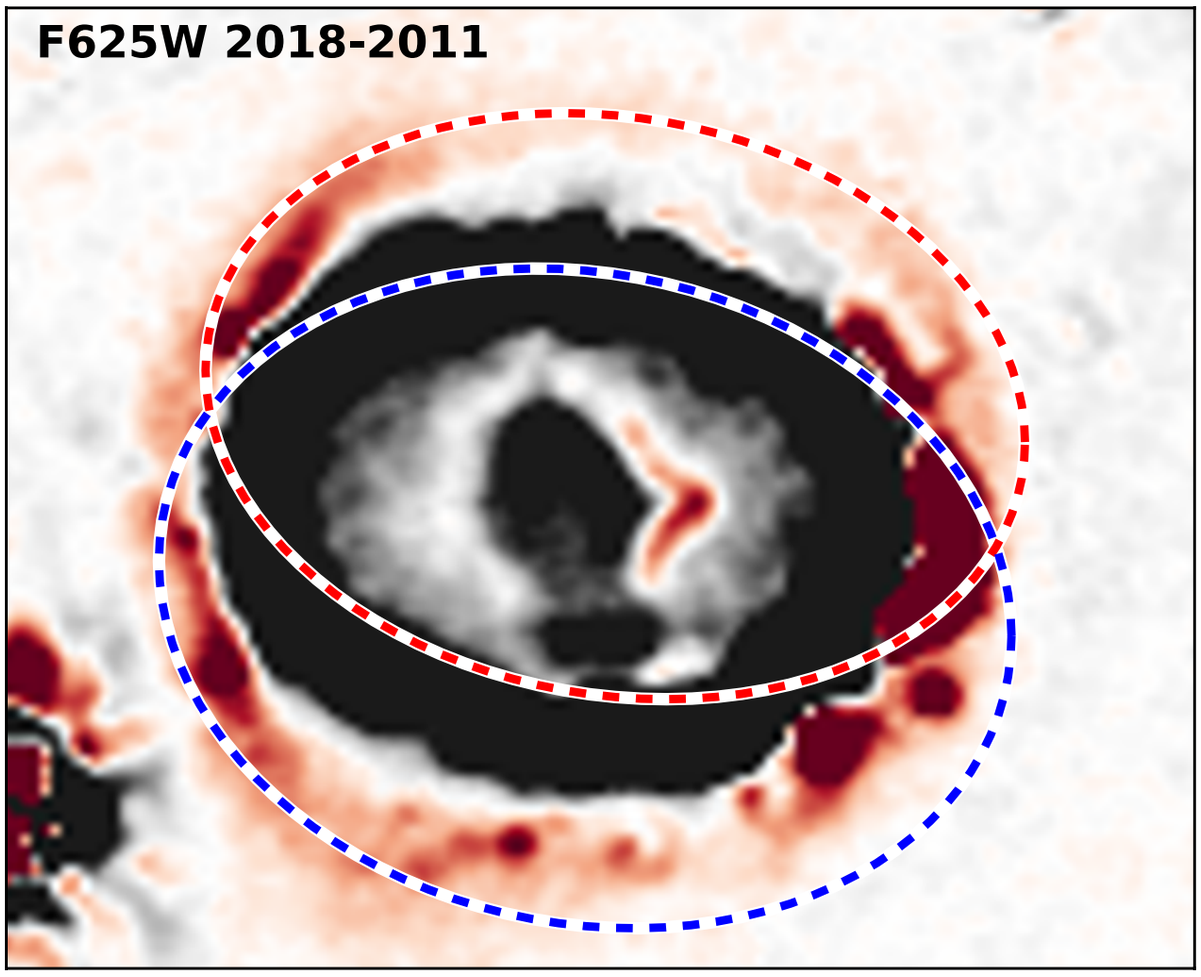




Get new “intermediate” rings (IR) from ejecta interacting with high-latitude material.

Will look like a single ring due to overlap with the equatorial ring in the projection.





Expect deviations from this simple model. Asymmetries, more complex geometry of material connecting rings, interaction at range of velocities…

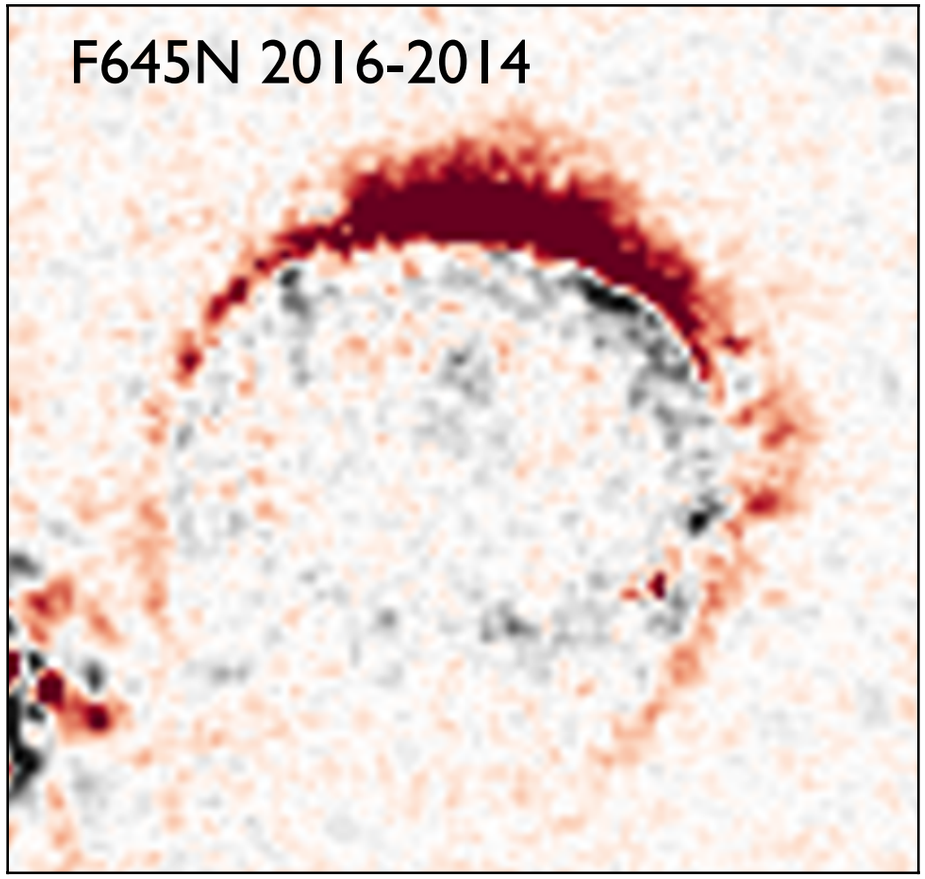
Plausible scenario: Seeing fast ejecta interact with high-latitude material with $n \sim 10^3$ cm^{-3}

- The new spots would be clumps with transmitted shocks (~ 100 km s^{-1})

- The rim of diffuse emission would be the reverse shock. Velocities of ~10,000 km s^{-1} (reverse shock emission seen in spectra at these velocities)

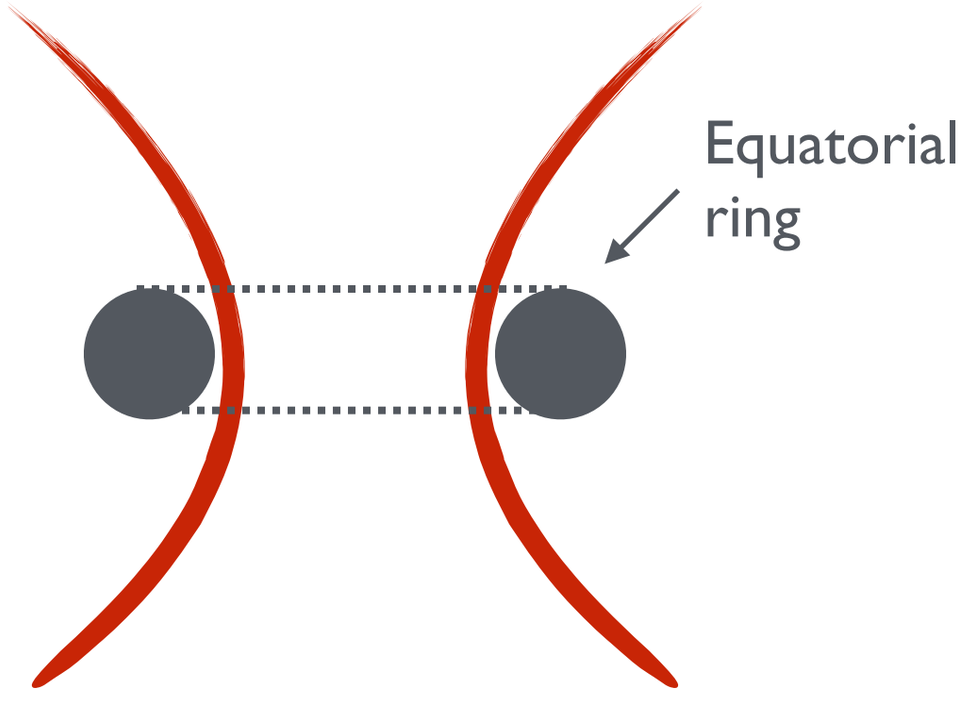
Need spatially resolved spectra to test model. Some information from narrow filters.

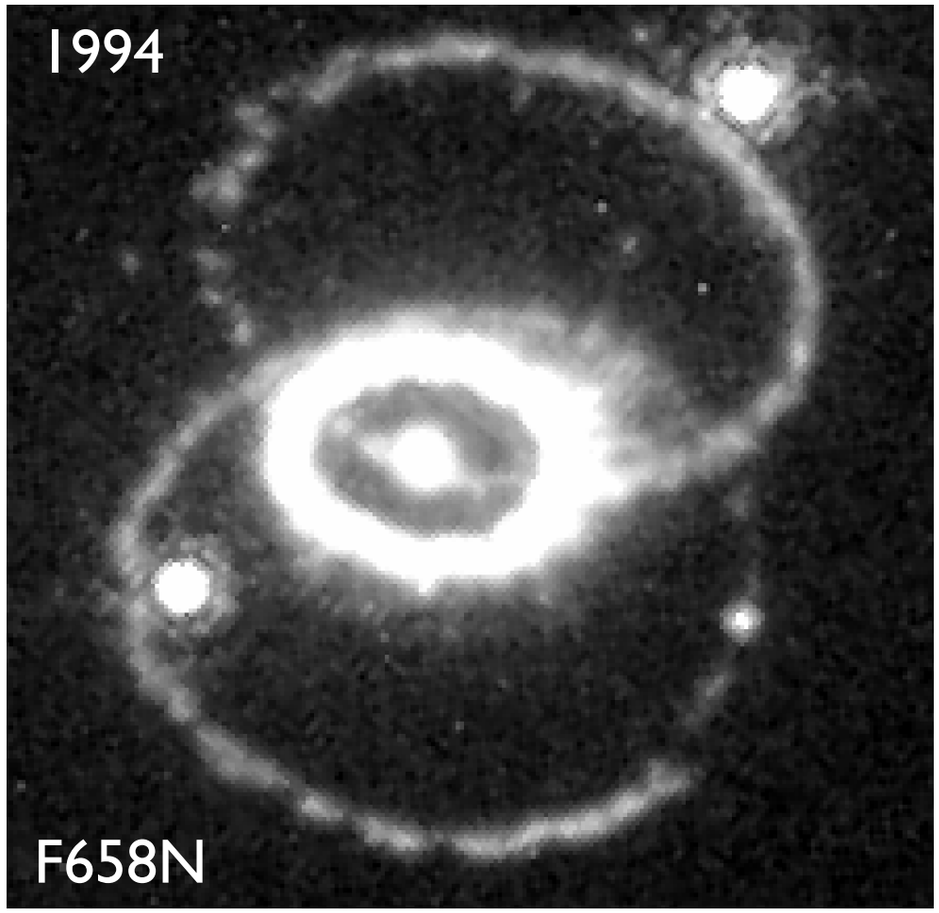
Both IRs blueshifted in north and redshifted in south. Higher blueshift for southern IR.



Probes Hα between -3100 and -7500 km s^{-1}. See also *France et al. (2015)*

Blueshifts higher than expected for simple model with straight lines connecting rings. Implies more curved shape.

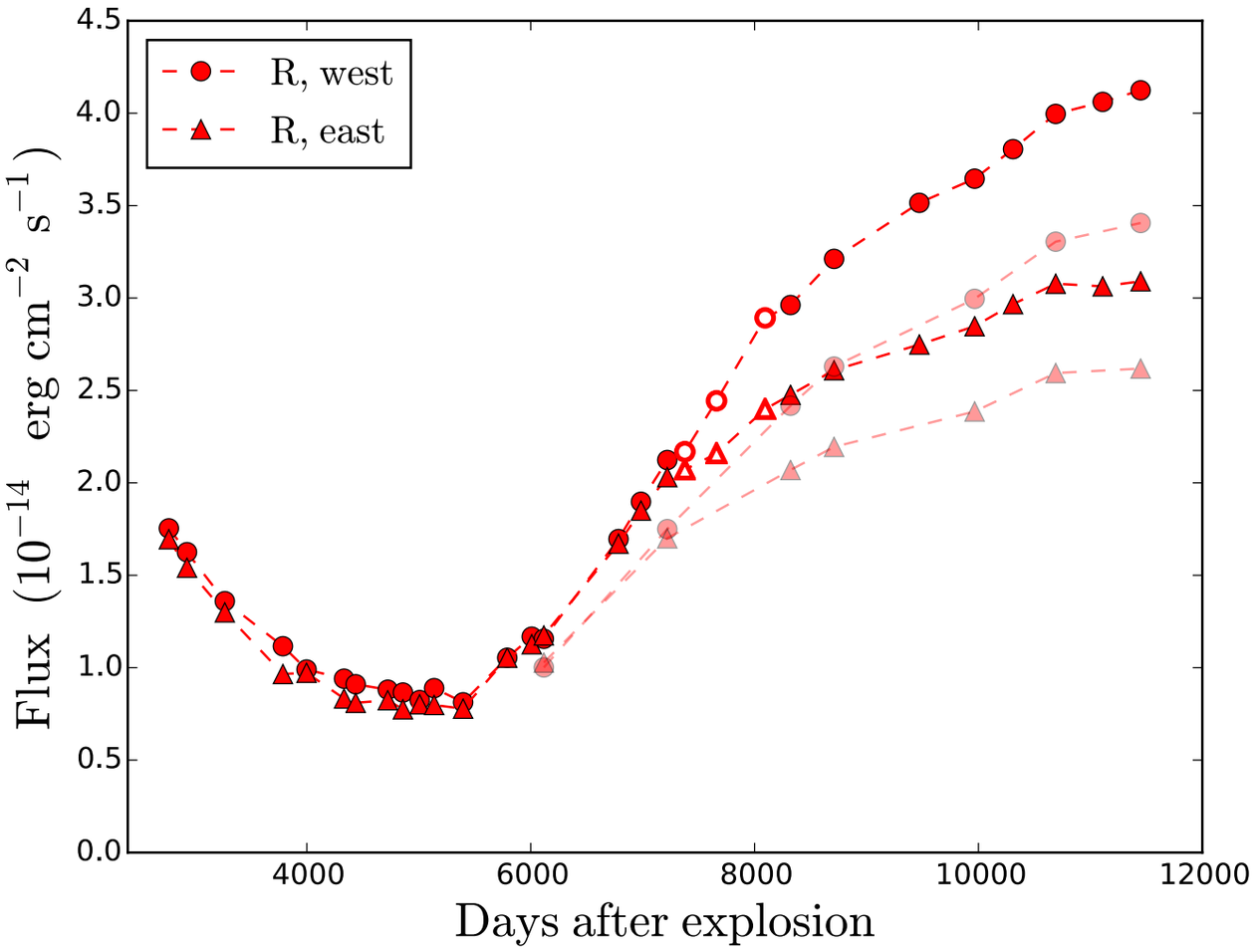




Diffuse emission from photoionised high-latitude material at early times?

Light echoes also suggest that there is material connecting the rings *(Crotts+1995, Sugerman+2005).*

The ejecta



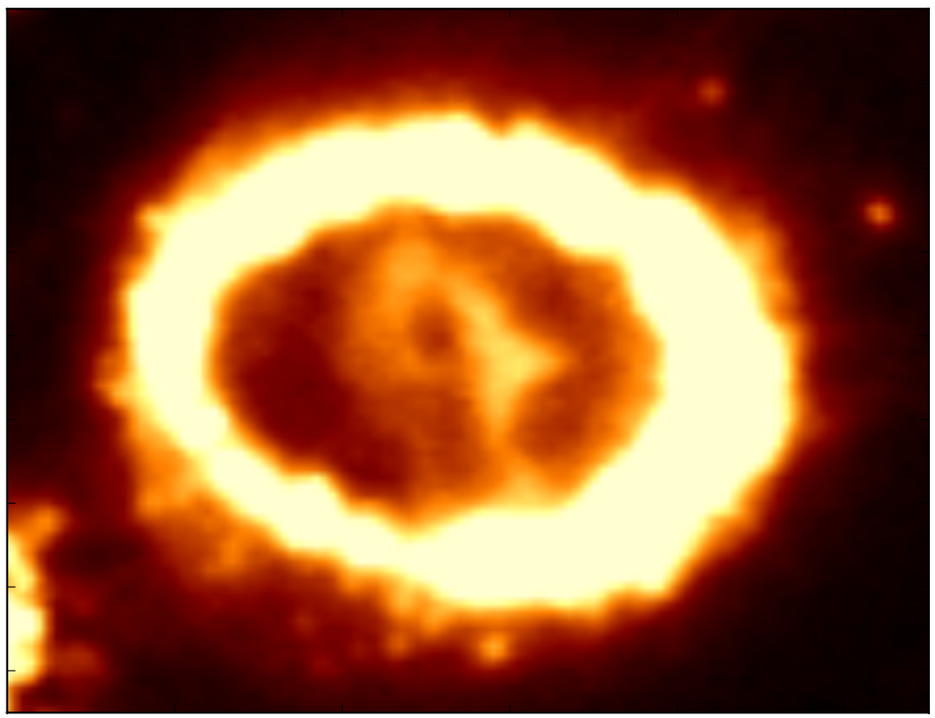
The ejecta fade as expected from radioactive decays until ~ 5000 days.

Brightening thereafter due to heating by X-rays from the ring (*Larsson+2011*).

The flux is now increasing at a slower rate and the western side is significantly brighter.

These trends are in agreement with the evolution of X-ray emission (*Frank+2016*).

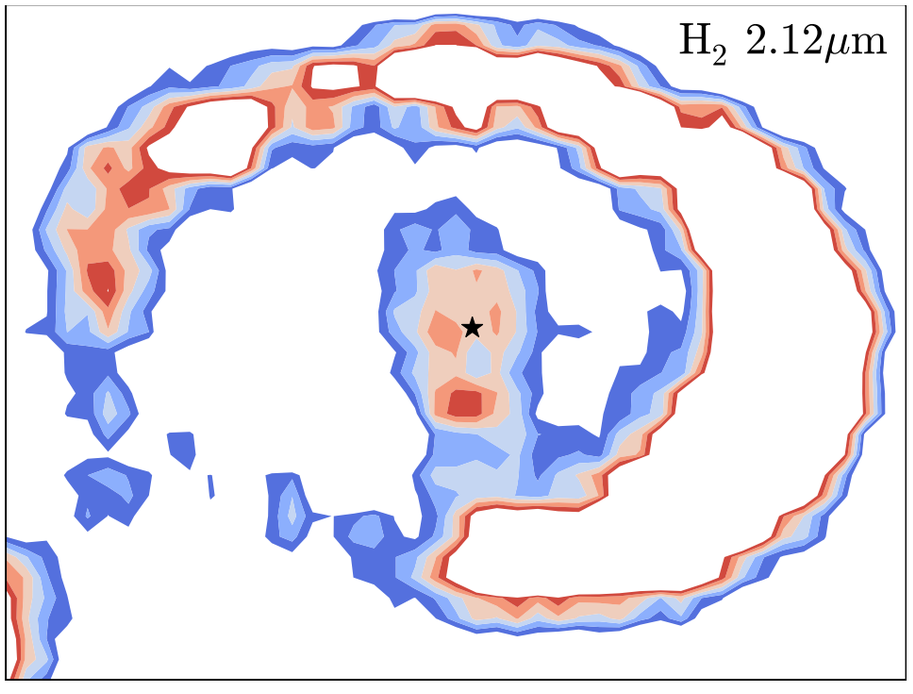
Implications for the morphology

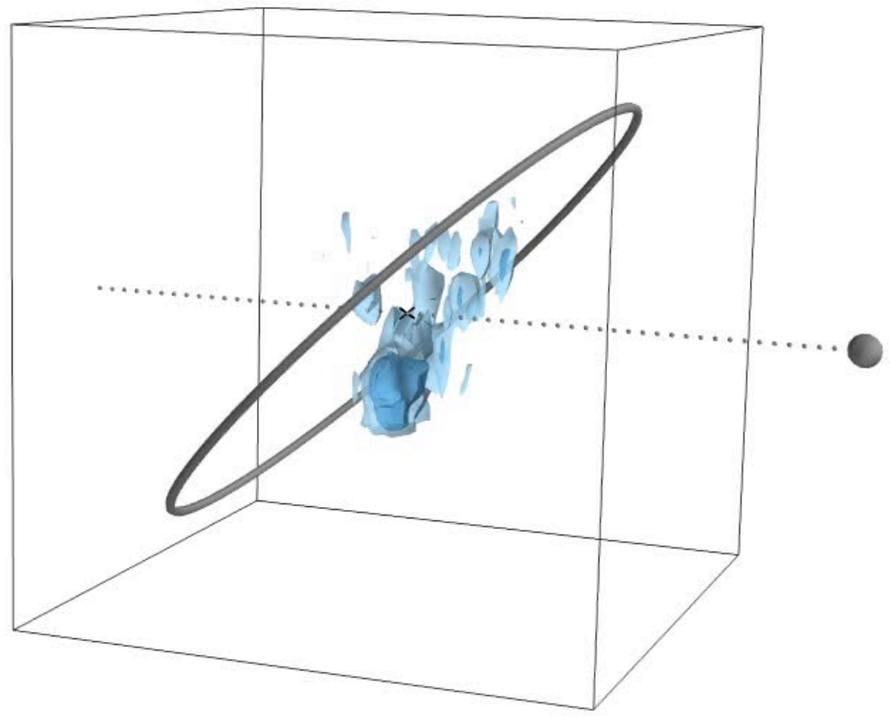


Powering by X-rays explains the edge-brightened morphology of the ejecta (*Larsson+13, Fransson+13*).

Optical emission from ejecta currently dominated by a clump in the west *(Larsson+16)*.

X-rays do not reach the innermost ejecta. Molecules can survive!





H_2 in the ejecta *(Larsson+2019)*

The future of SN 1987A

The optical emission from the ring will continue to fade. Extrapolation shows that it will be gone by ~ 2035.

Expect more emission outside the ring at all wavelengths. Gradually probing the mass-loss history of the progenitor. New insight into the formation of the rings!

The evolution of the emission from the inner ejecta is strongly coupled to the X-ray emission. We will resolve smaller spatial scales as the ejecta expand.

Detection of the compact object?!