X-ray illumination of the ejecta of Supernova 1987A

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In collaboration with

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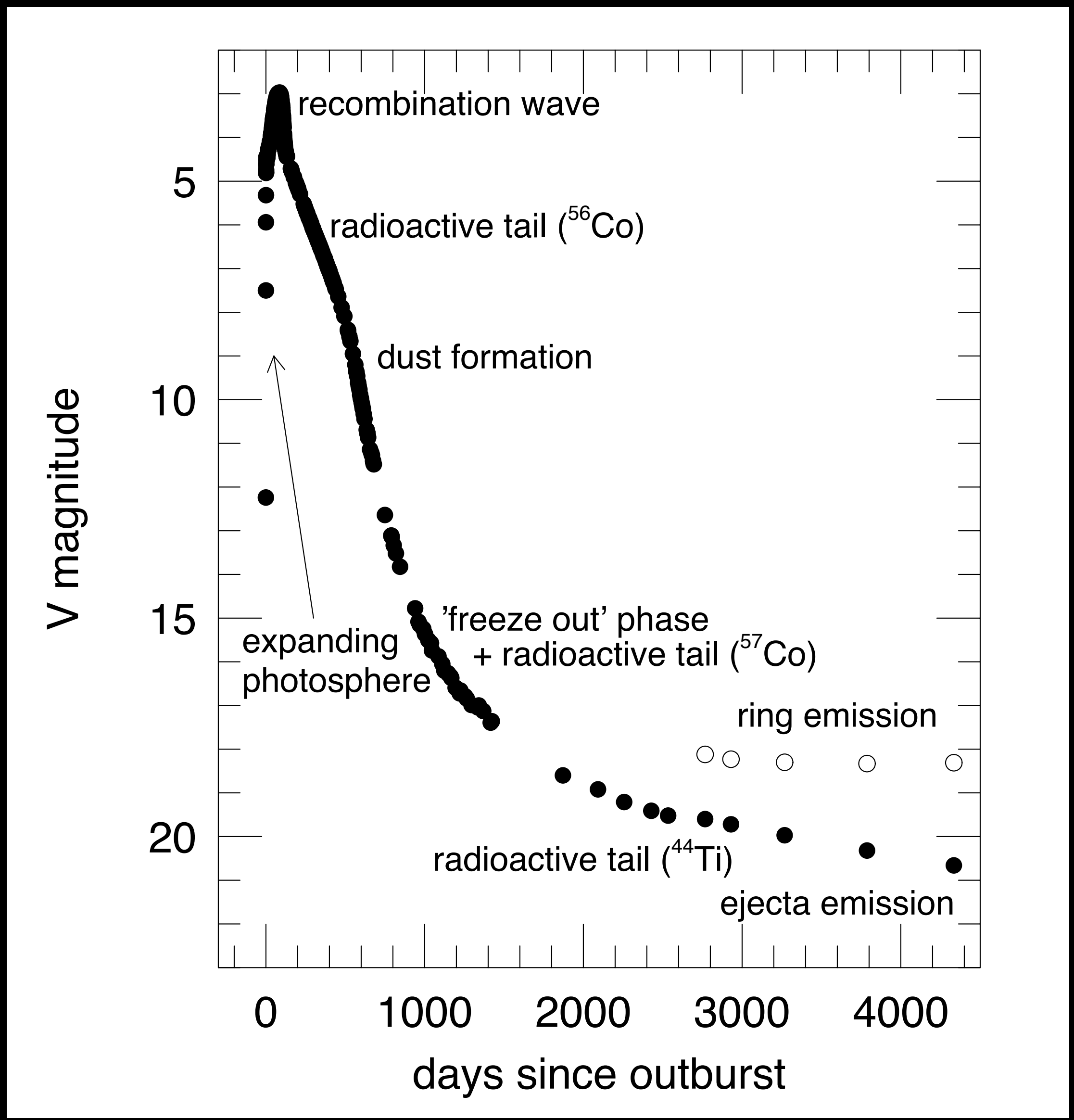
The optical light curve of SN 1987A



Leibundgut & Suntzeff 2003

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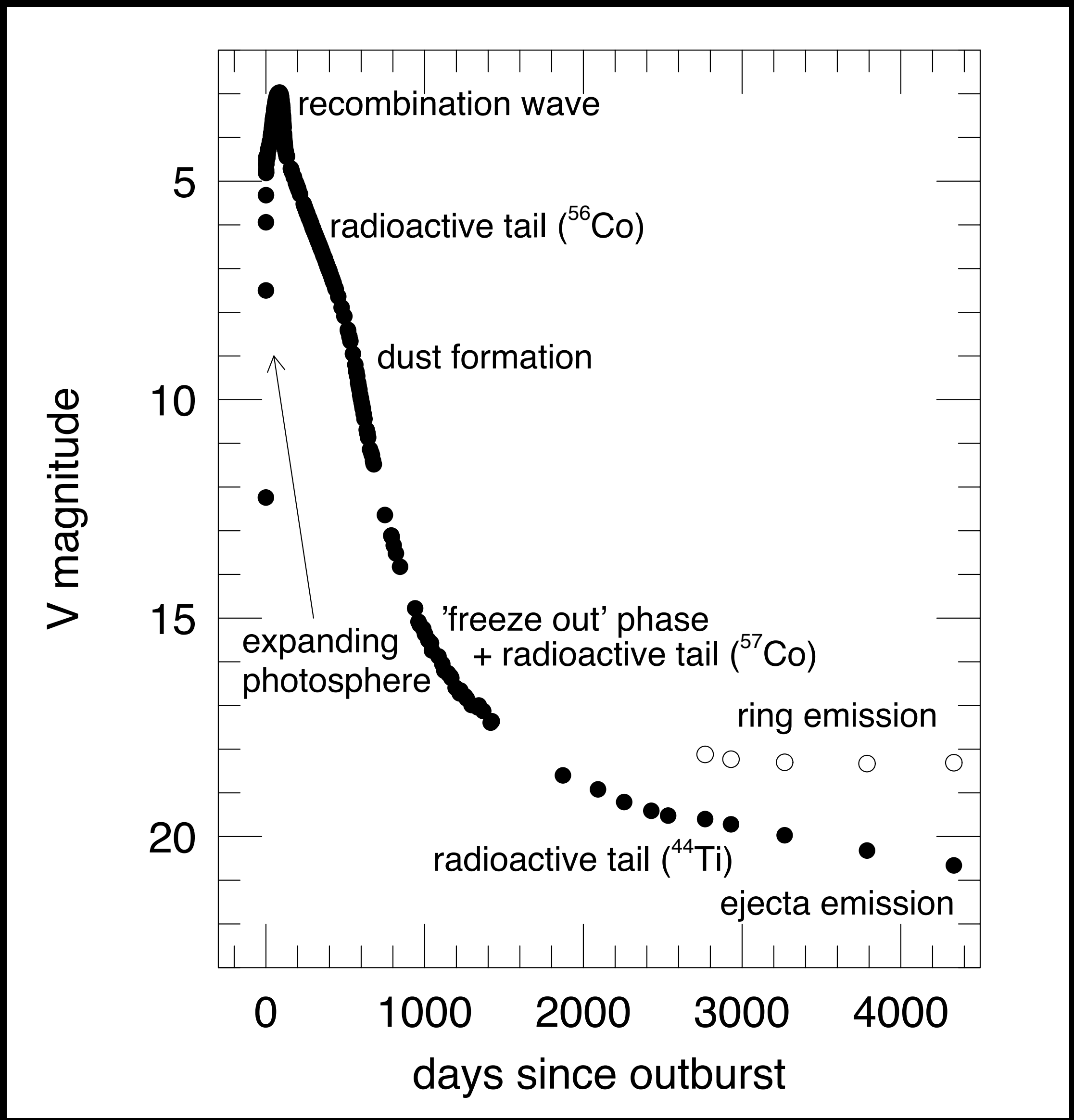


Leibundgut & Suntzeff 2003

At late times a number of different energy sources may be important:

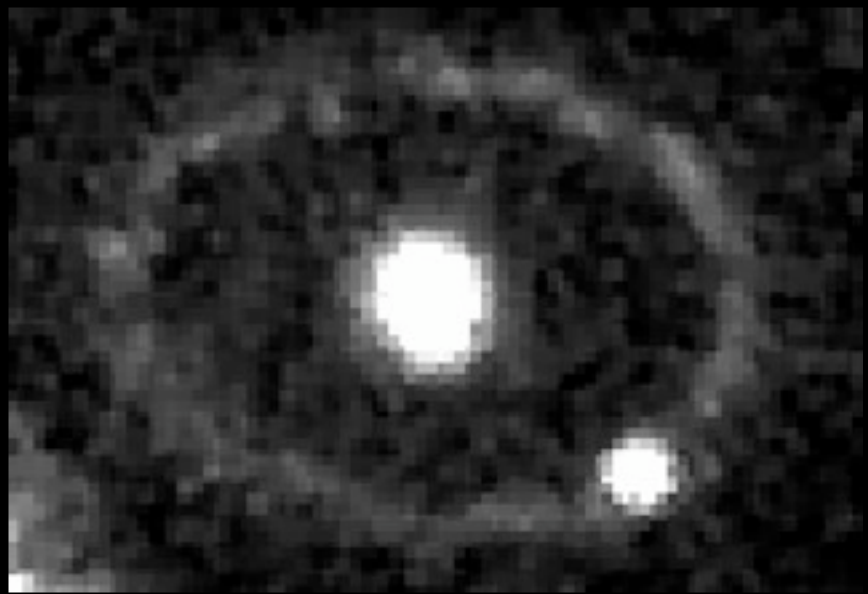
- Radioactive decay
- Interaction with circumstellar medium
- Central compact remnant

We can discriminate between these possibilities by studying the light curve.

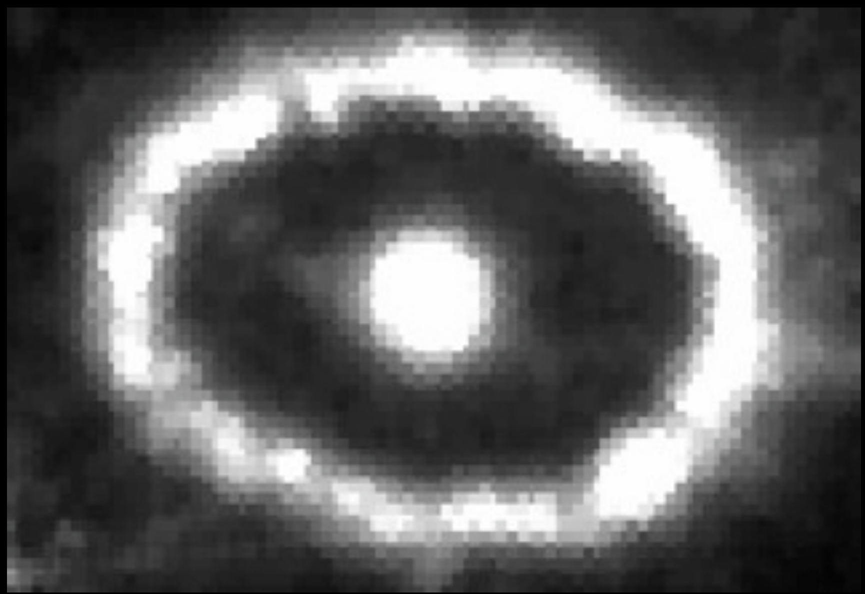
HST imaging

SN 1987A has been regularly monitored by HST since 1994. The most commonly used filters are the broad R- and B-bands.

The B-band is dominated by H and Fe I-II lines
The R-band is dominated by Hα and Ca [II]



B-band



R-band

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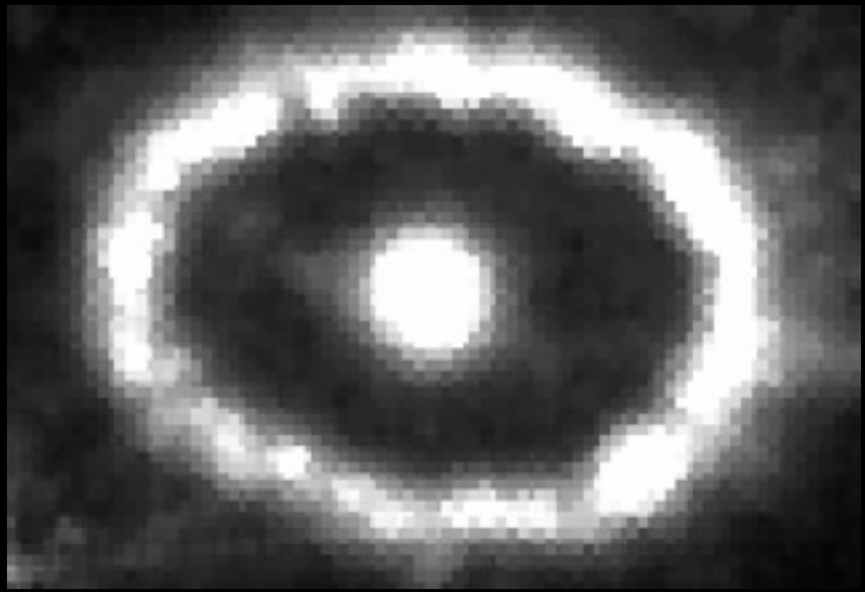

B-band R-band

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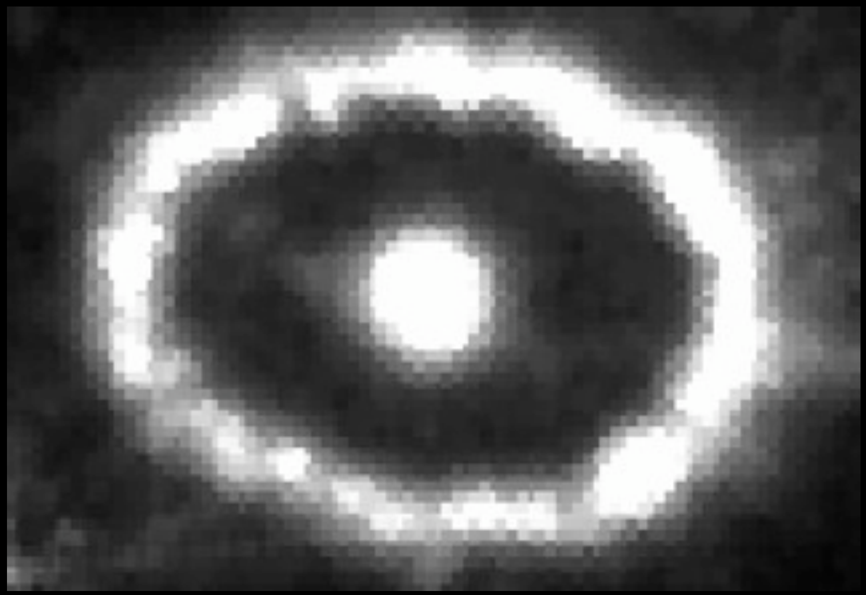

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B-band

R-band

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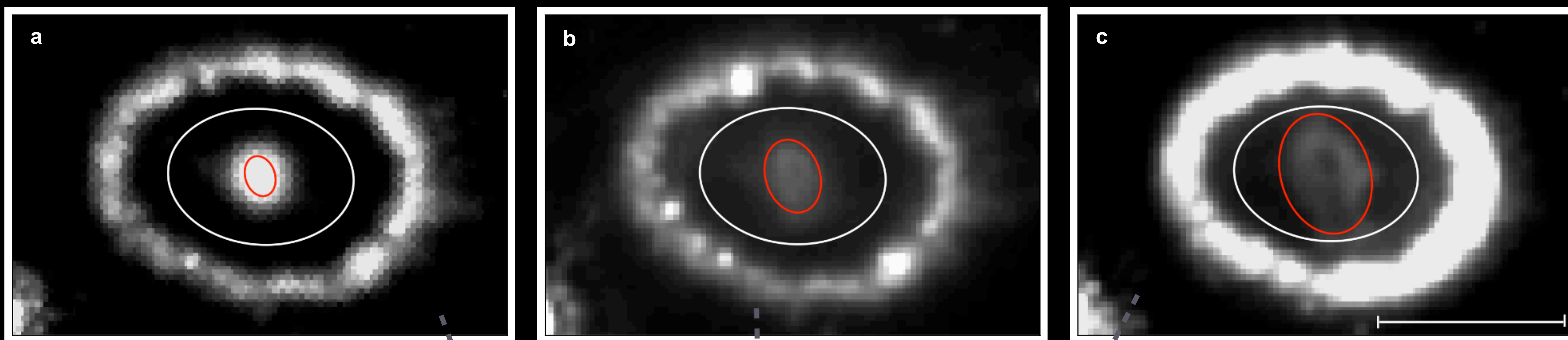
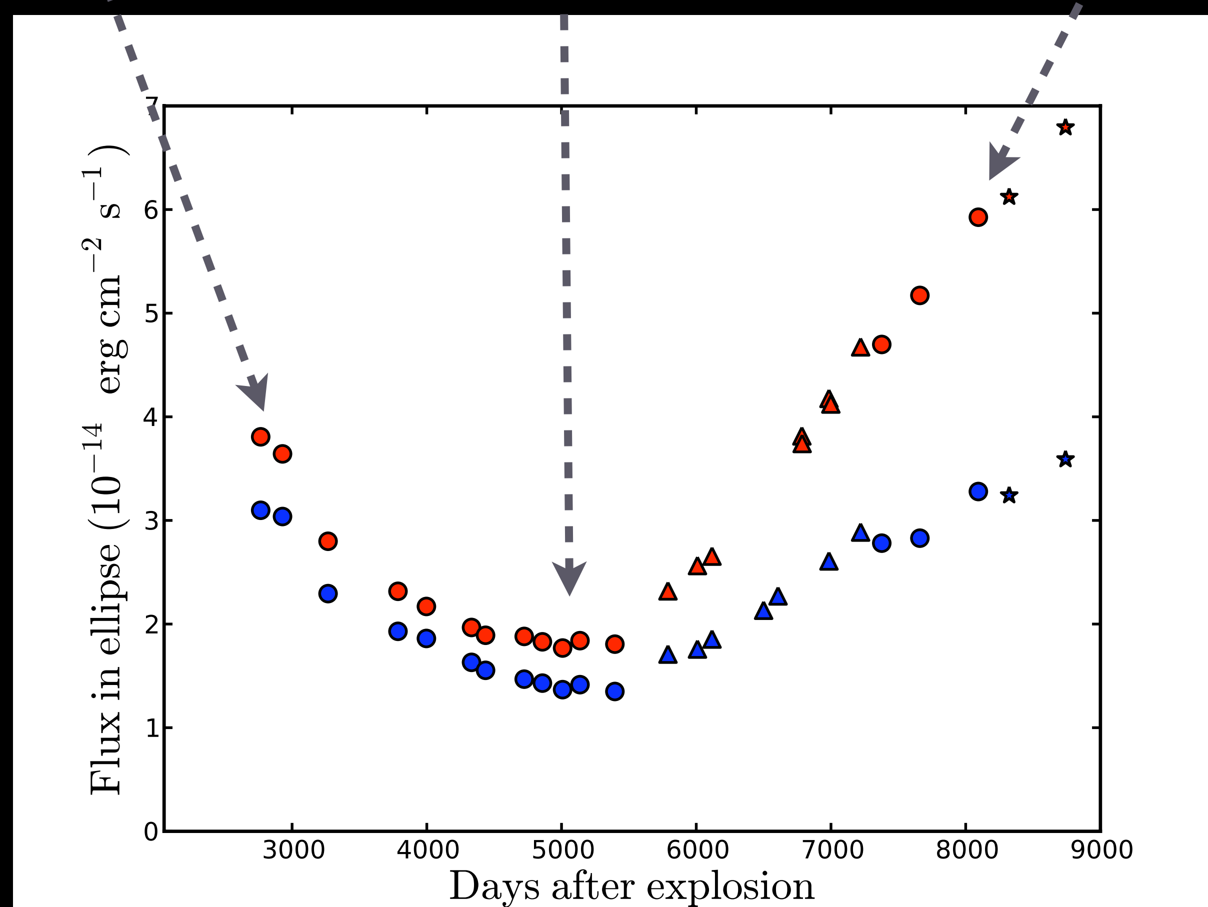
B-band

R-band

The ejecta light curve



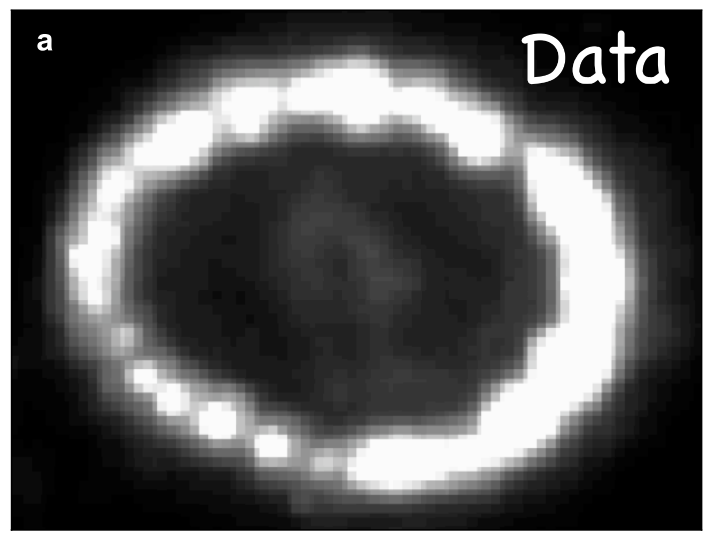


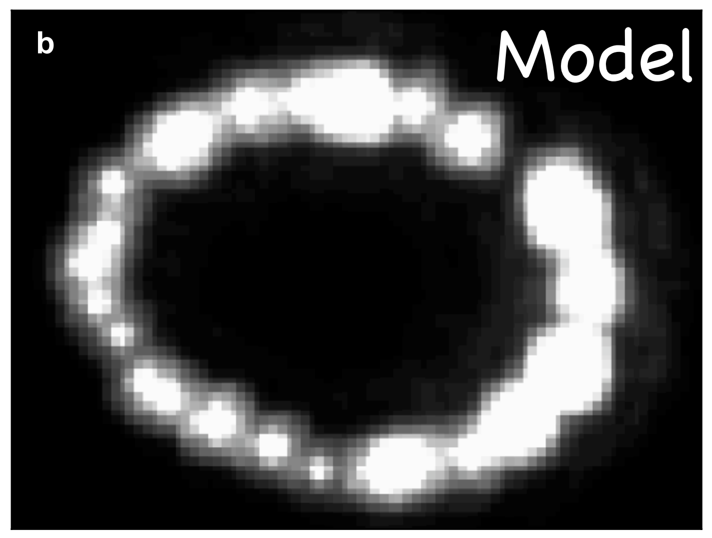
The expanding aperture allows us to follow the same material over time

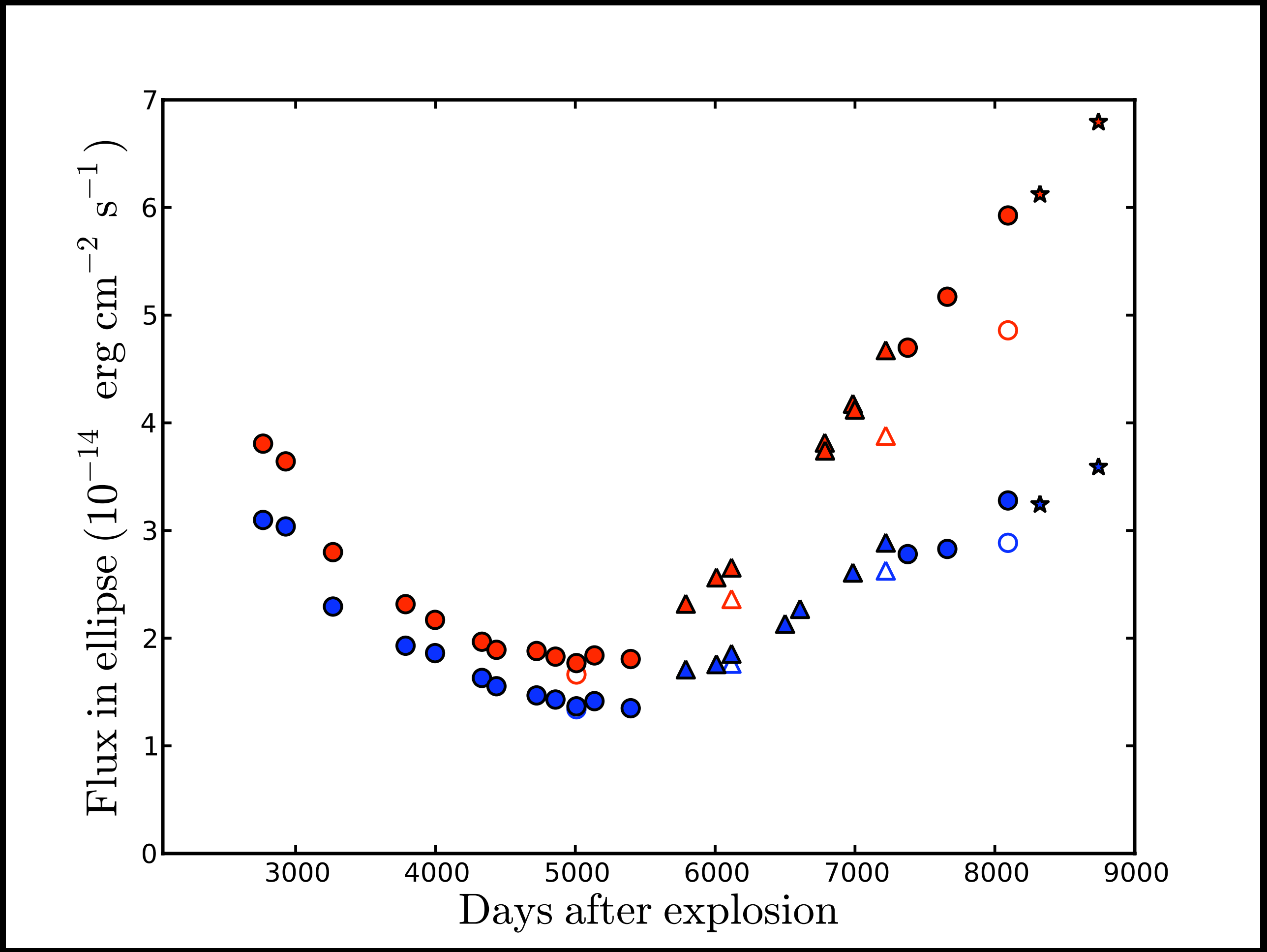
Contamination from the ring

Some of the flux from the brightening ring will spill over into the region where we measure the ejecta brightness.

We can estimate this effect by creating models for the ring.







Open symbols = corrected ejecta fluxes

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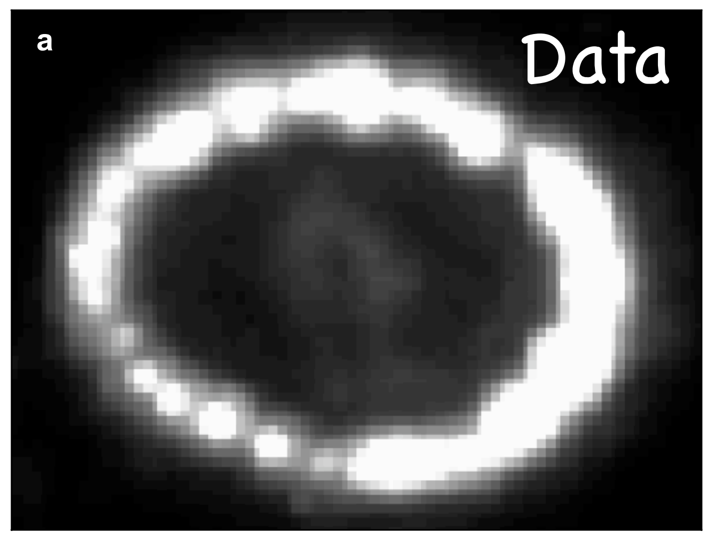
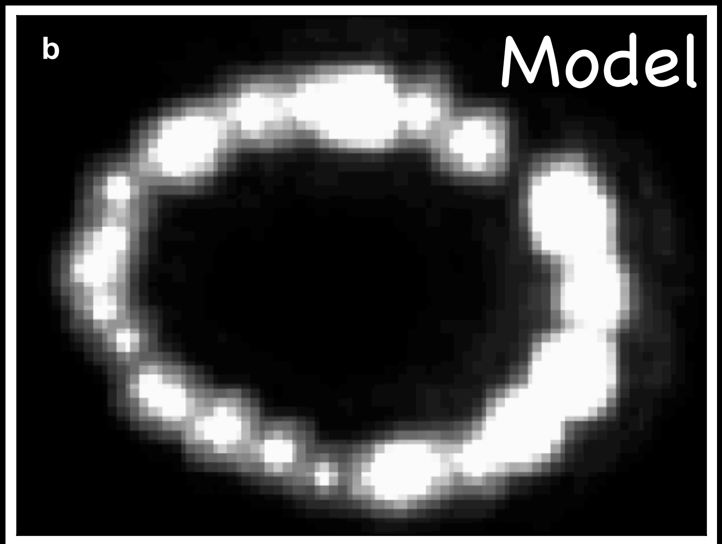
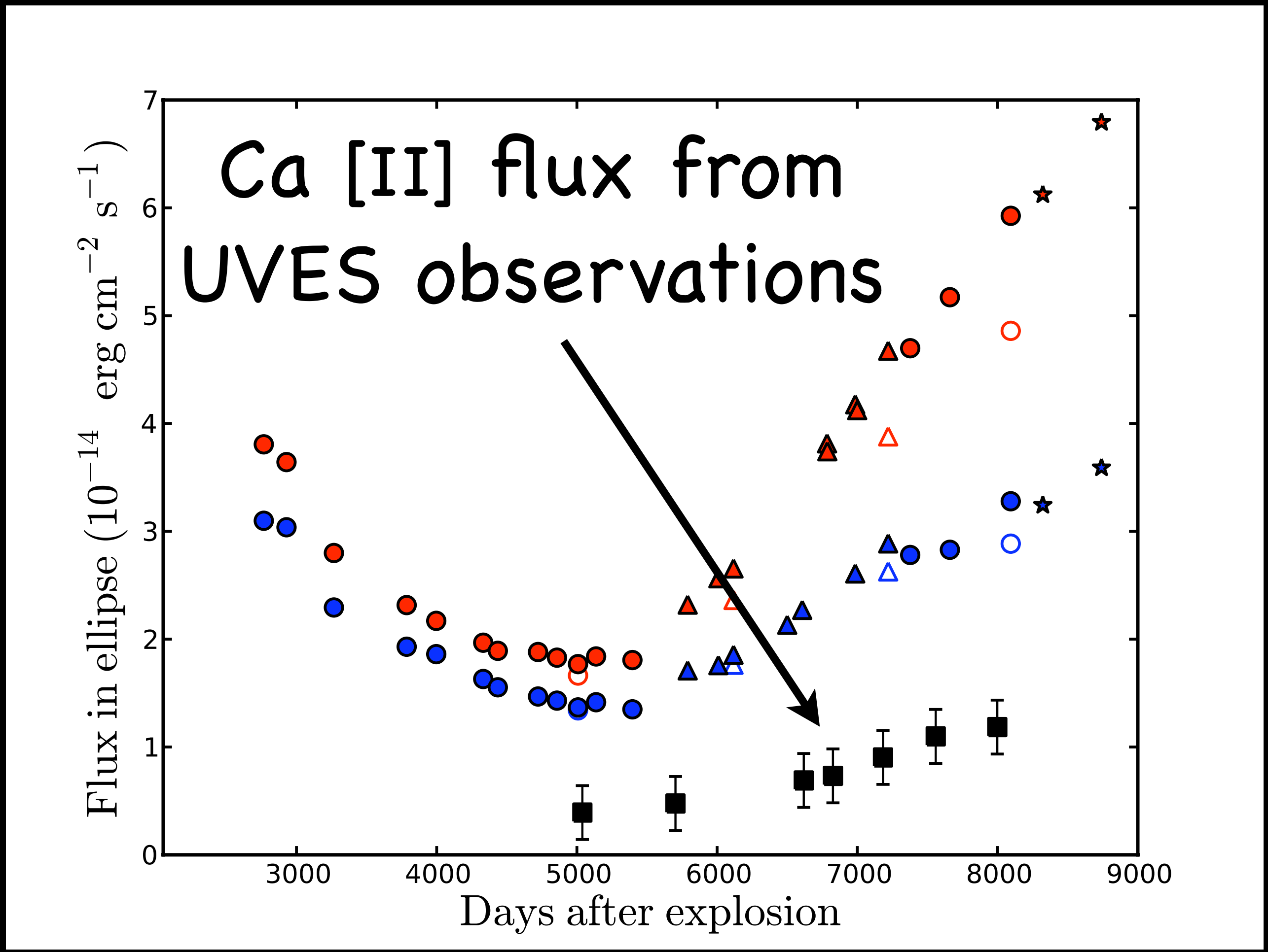
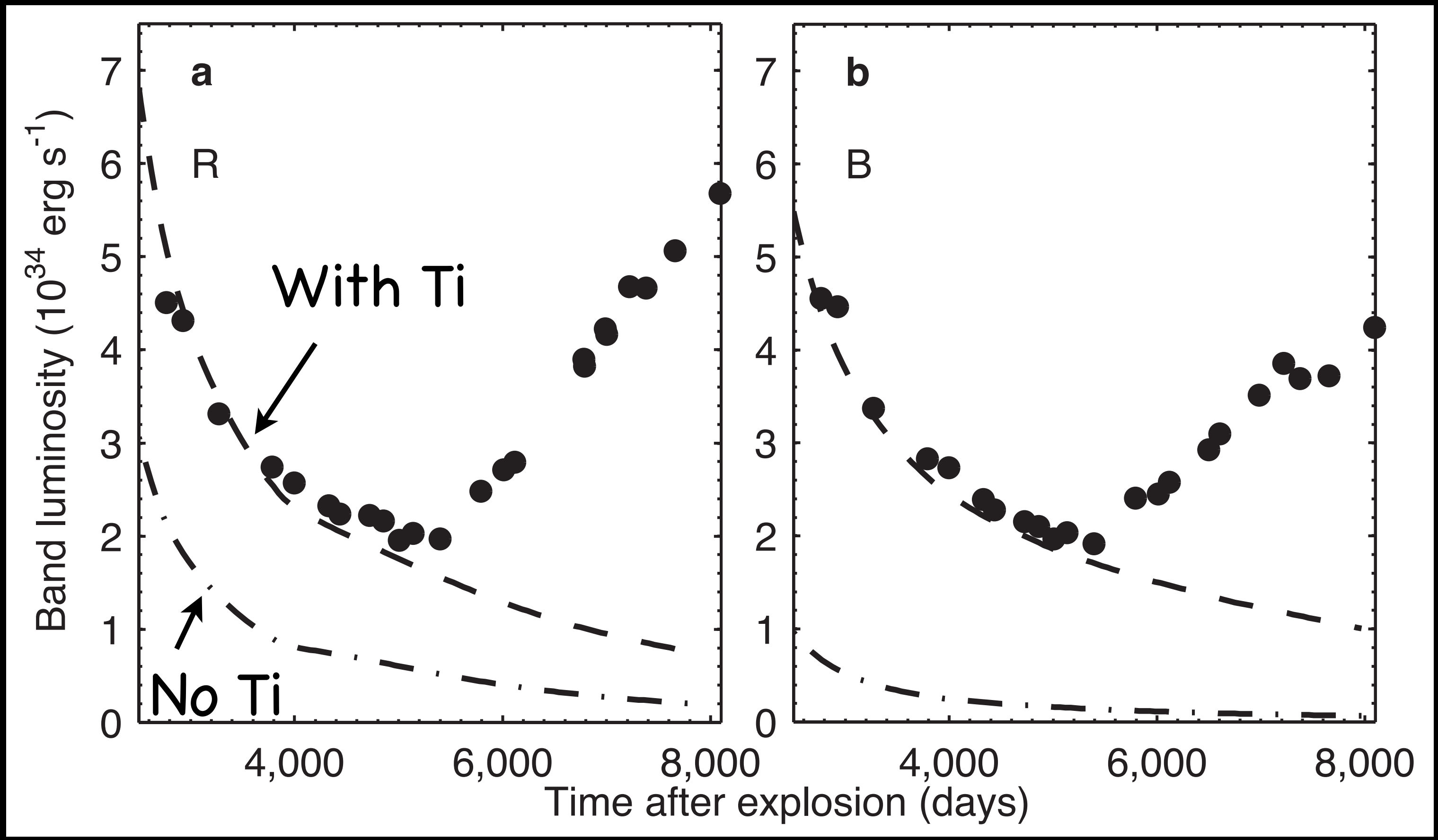






Open symbols = corrected ejecta fluxes

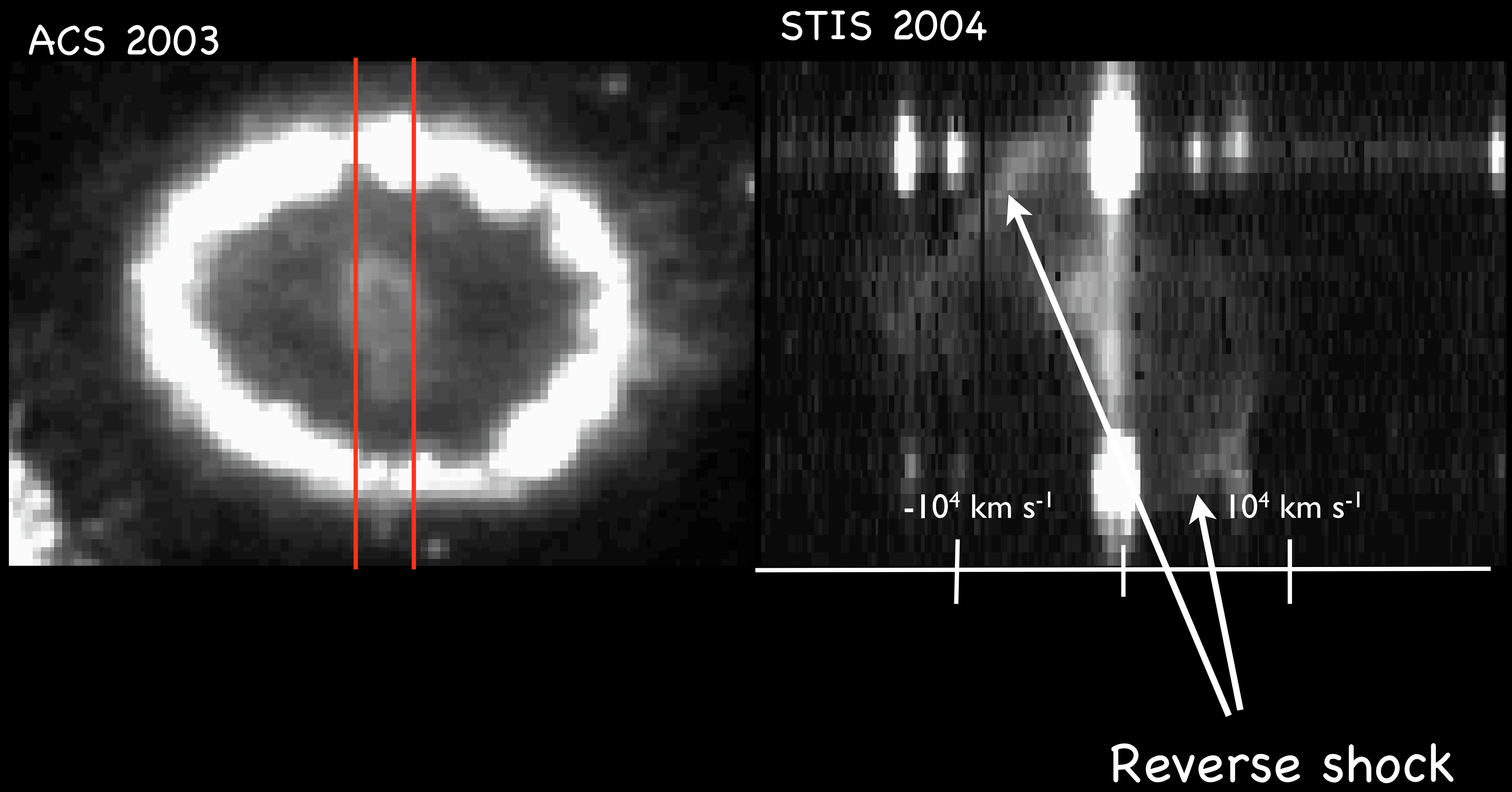
A model for the declining phase



The light curve resulting from radioactive decay was modelled using the code by Kozma & Fransson (1998).

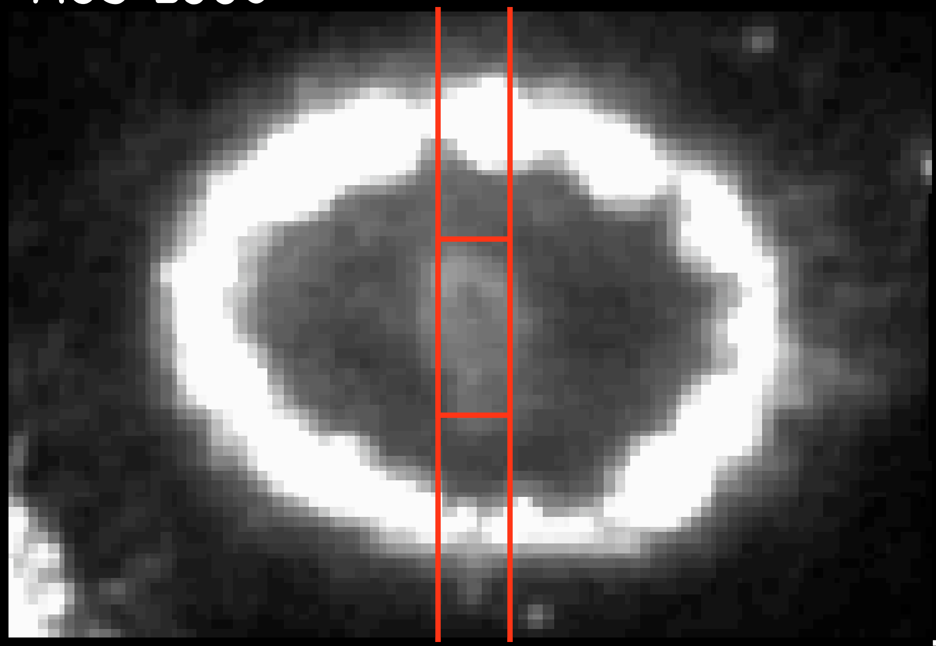
The ^{44}Ti mass used in the model is 1.5 * 10^{-4} M_{sun} (Jerkstrand et al. 2011).

Rising phase - Reverse shock?

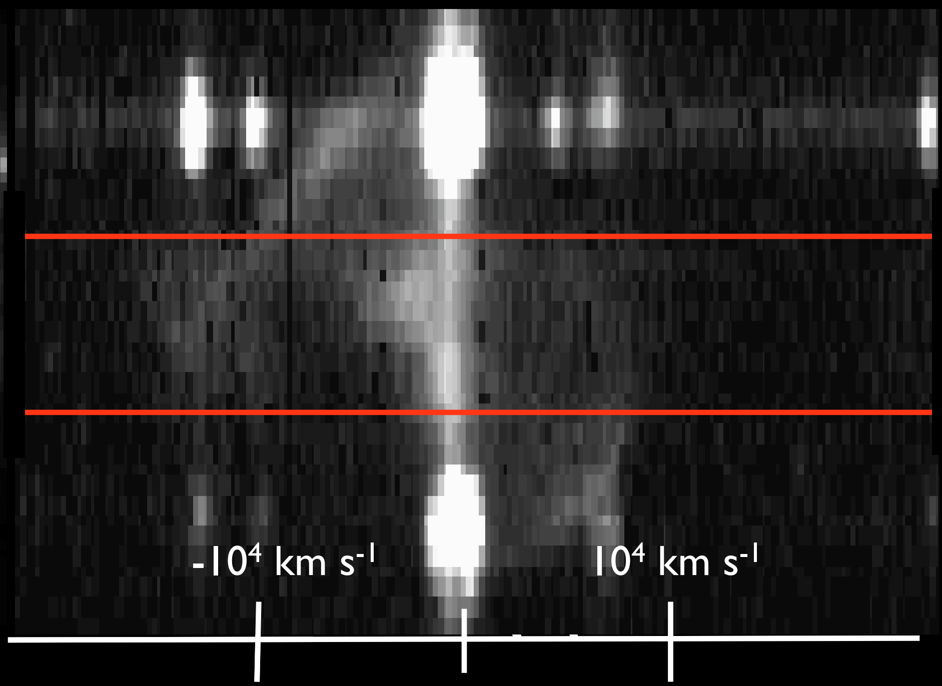


Rising phase - Reverse shock?

ACS 2003



STIS 2004



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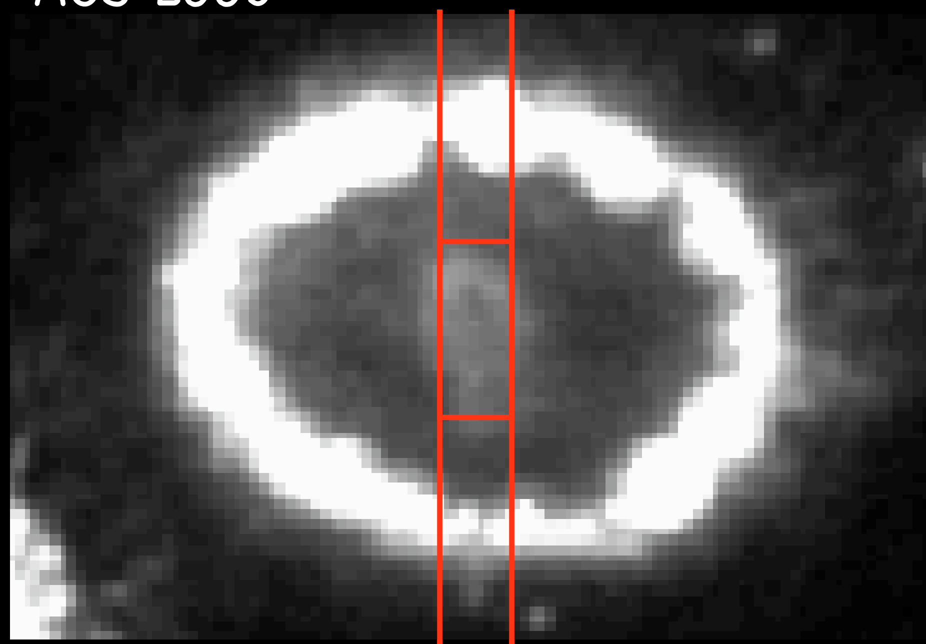

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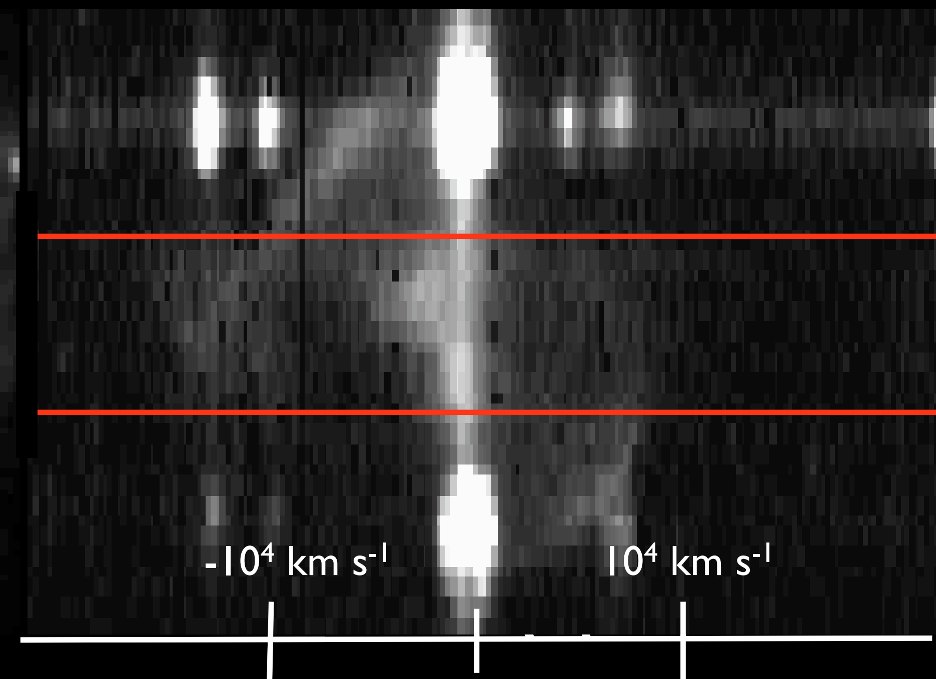
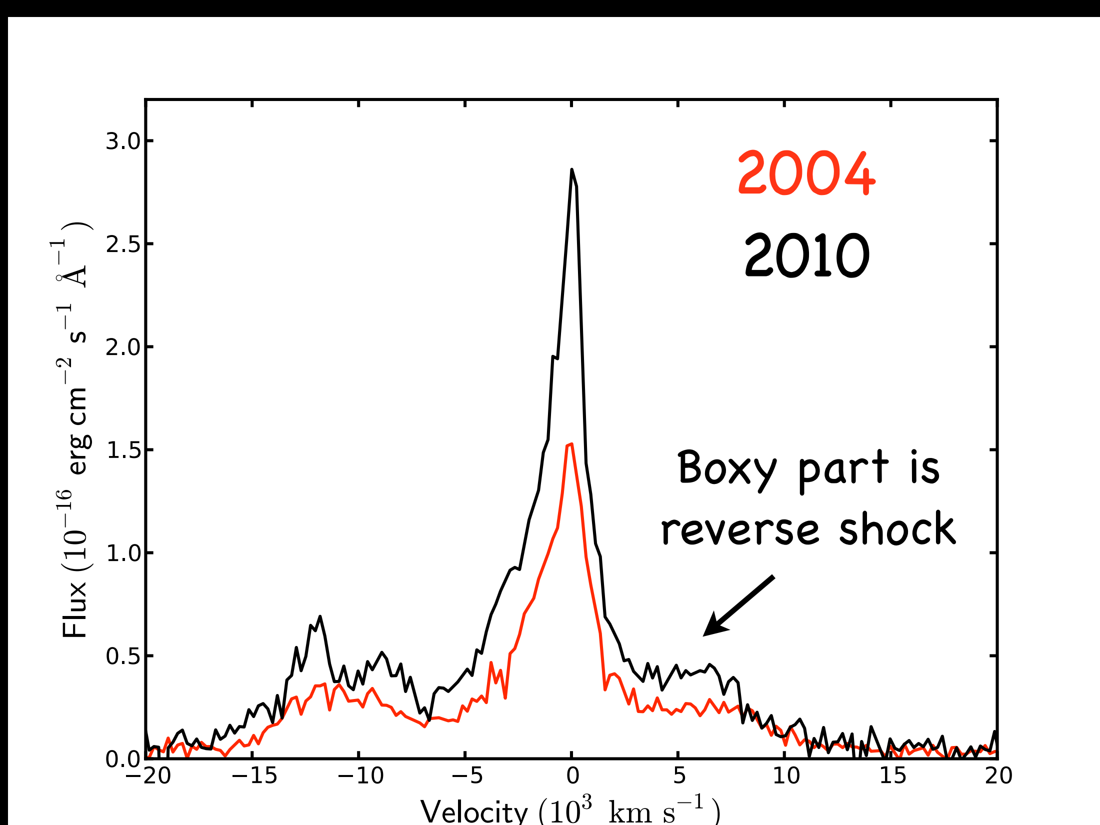


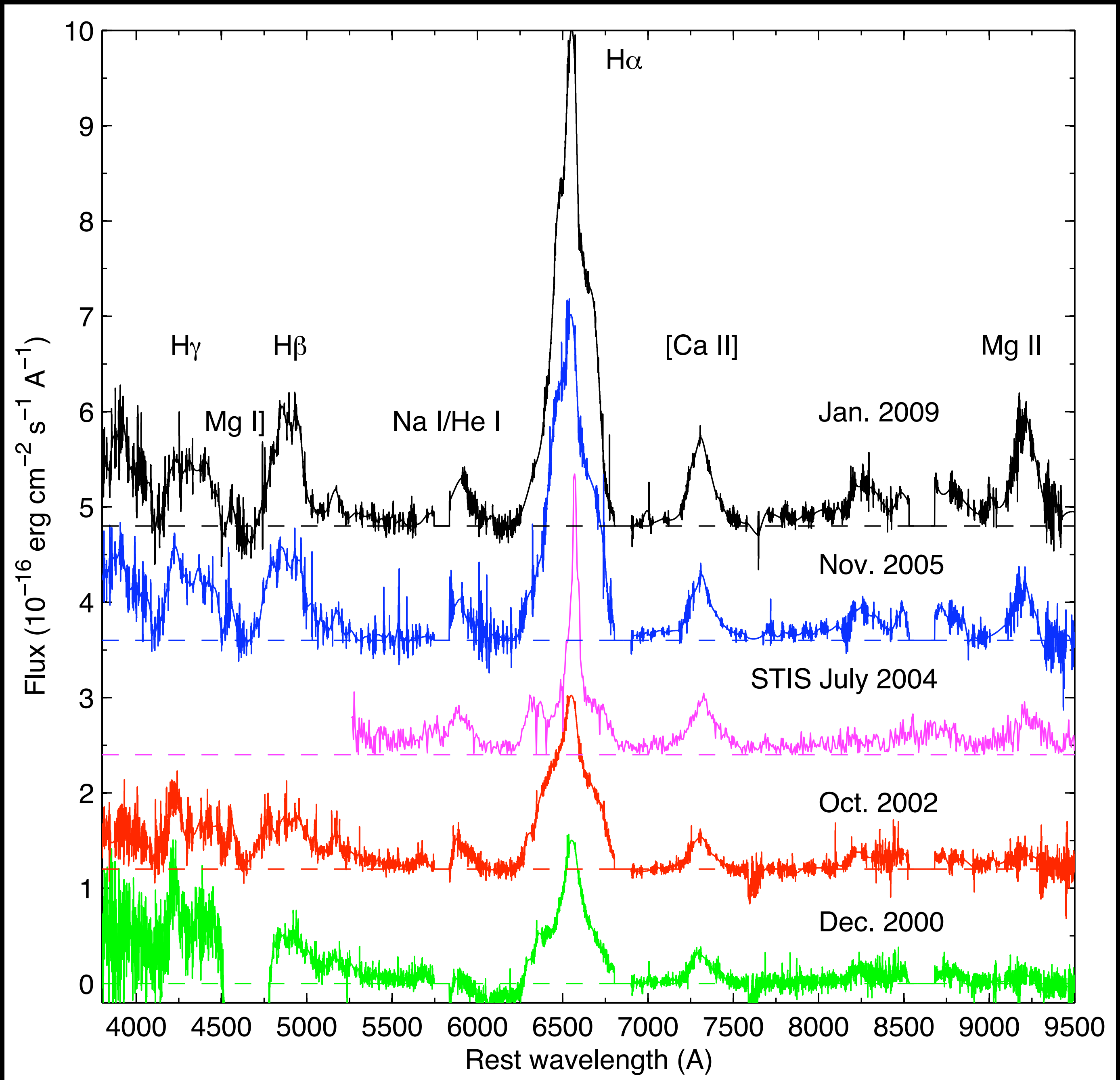


The reverse shock is less than 20% of the the R-band flux.

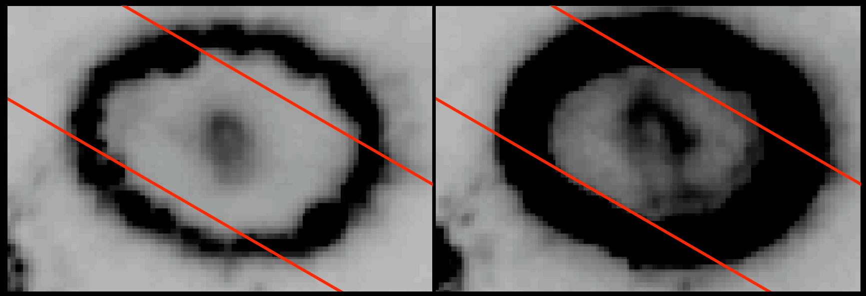
The contribution does not change significantly between 2004 and 2010!

The increase in flux is not due to the reverse shock

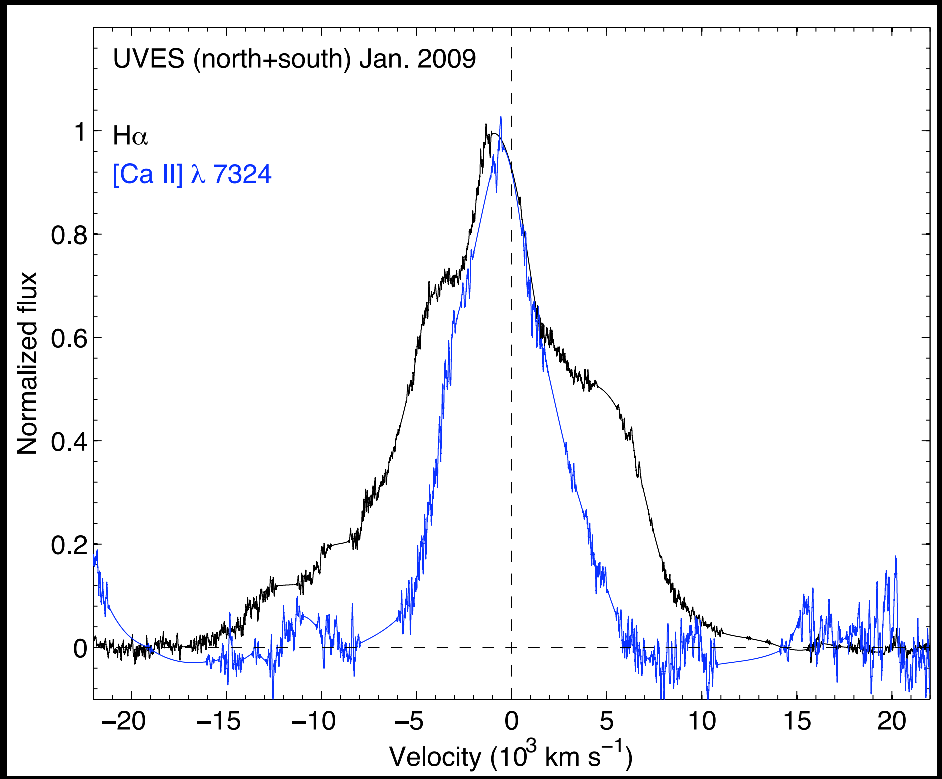
This is supported by UVES observations.



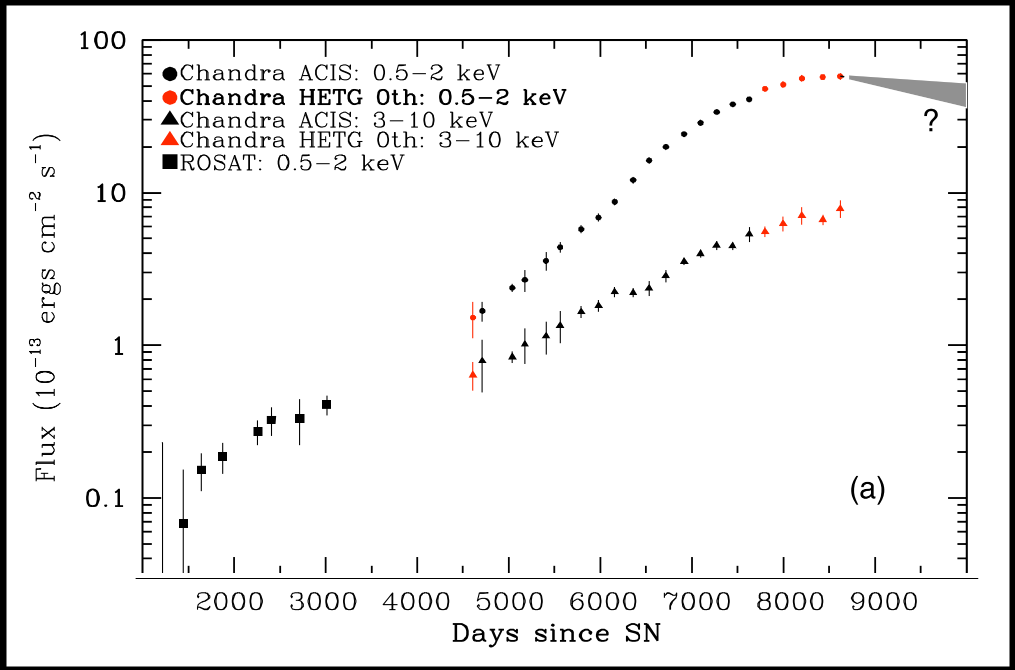
Fransson et al. in prep



The Ca [II] lines do not have a reverse shock component.



Rising phase - X-ray illumination?

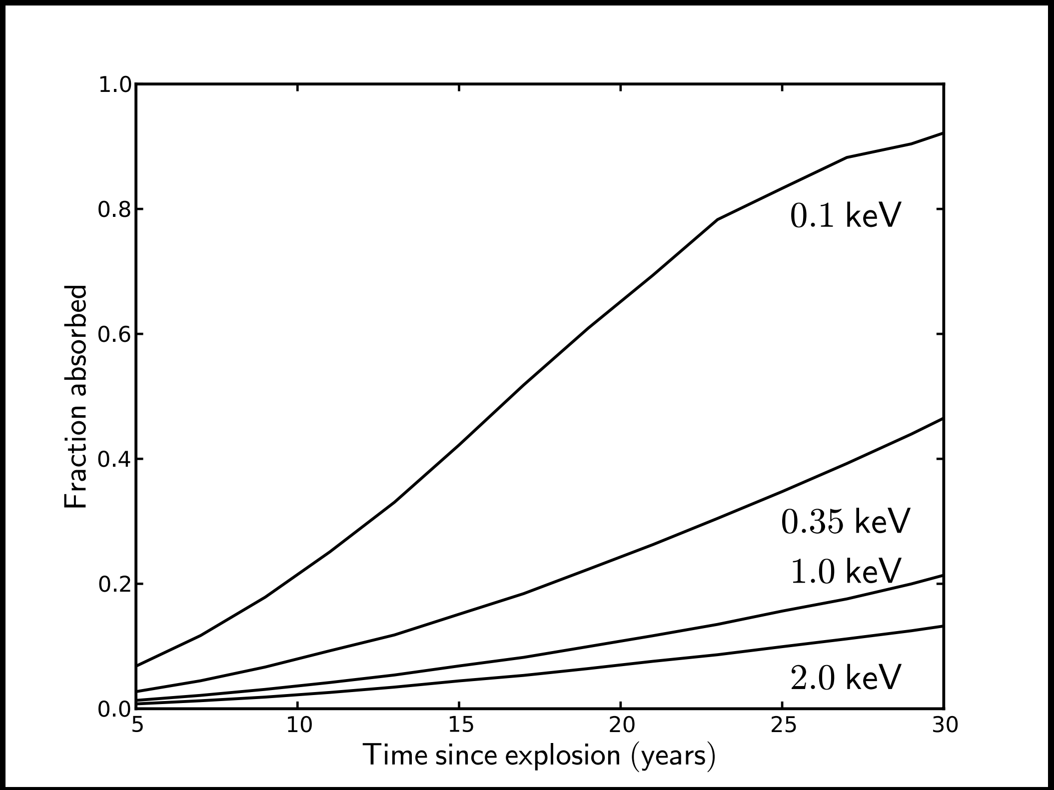


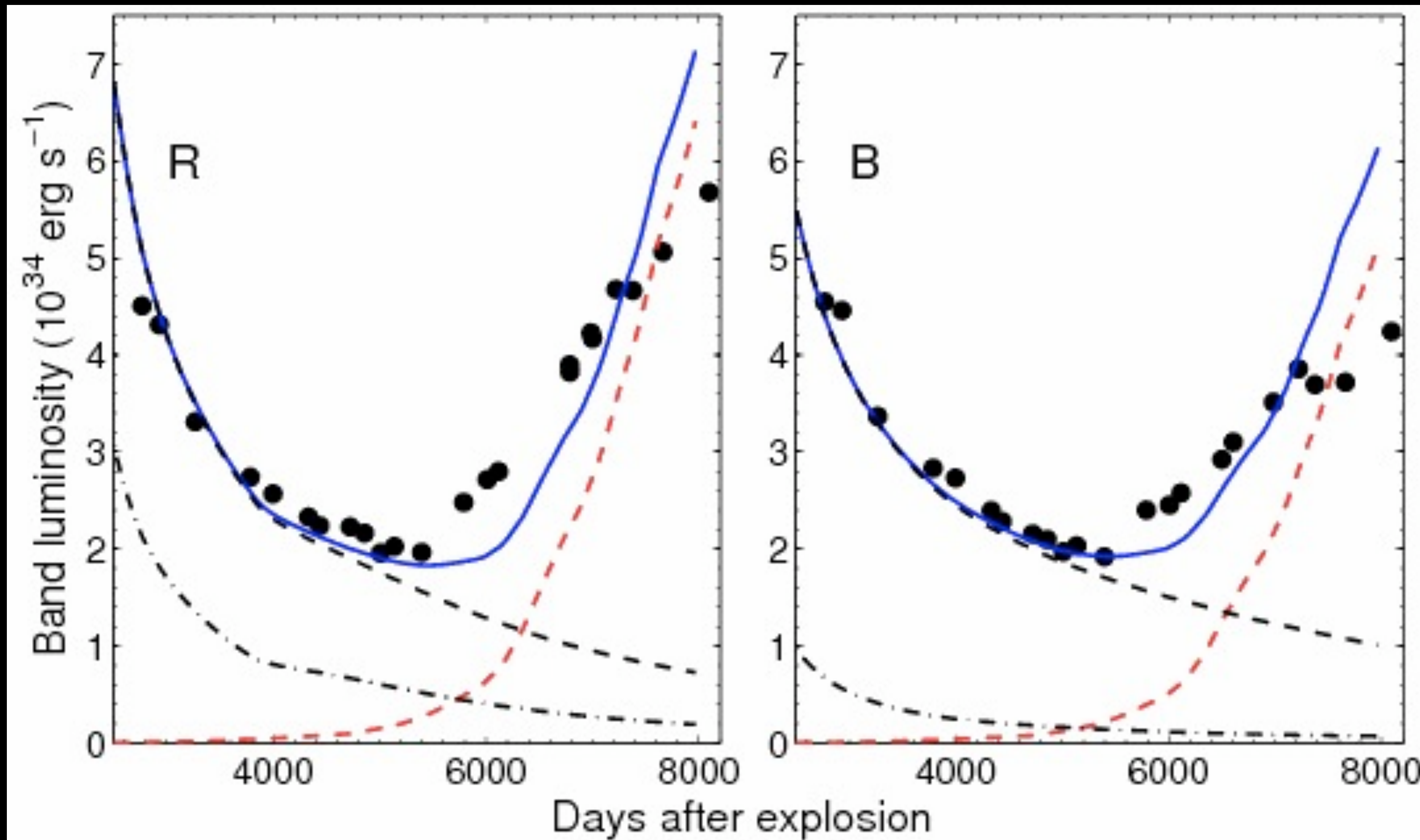
Park et al. 2011

The rising X-ray flux from the ring could be responsible for the brightening of the ejecta.

Model of X-ray absorption by the ejecta:

The absorbed fraction increases with time, due to the increasing solid angle of the ejecta as seen from the ring.





Red lines = observed X-ray flux * fraction absorbed at 0.35 keV * fraction emitted in the R(B) band.

The conversion efficiency from X-ray to optical is 5.0% in the R-band and 3.1% in the B-band. This agrees well with expectations from theoretical calculations.

Other possibilities for increase in flux

1. Pulsar input?

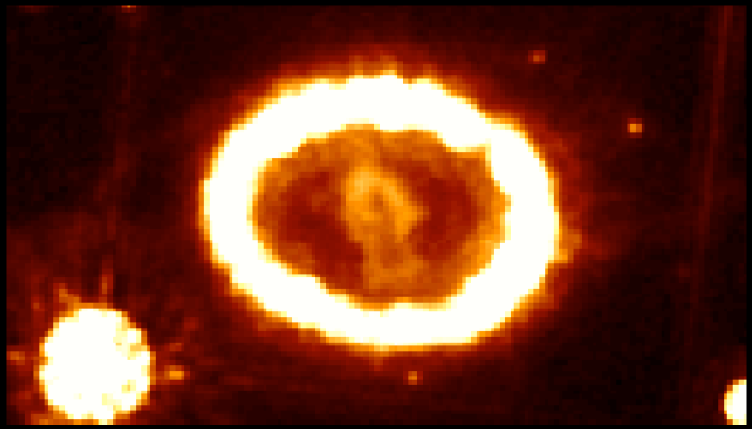
2. Thinning dust?

3. Positron leakage?

Other possibilities for increase in flux

1. **Pulsar input?**

Energy input from a pulsar should be concentrated toward the centre of the ejecta. **It clearly isn't**



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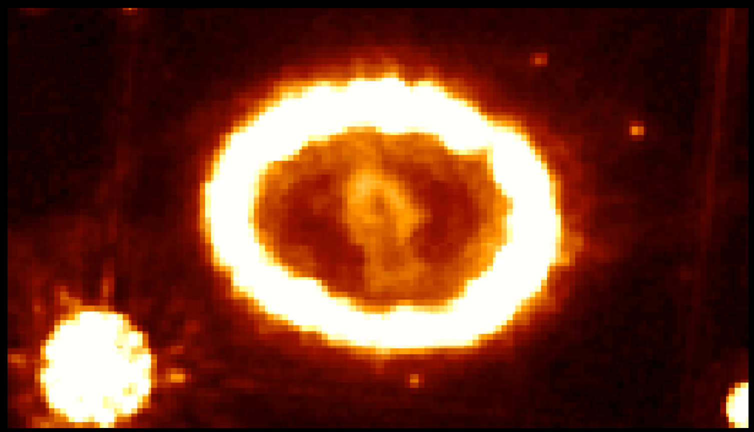
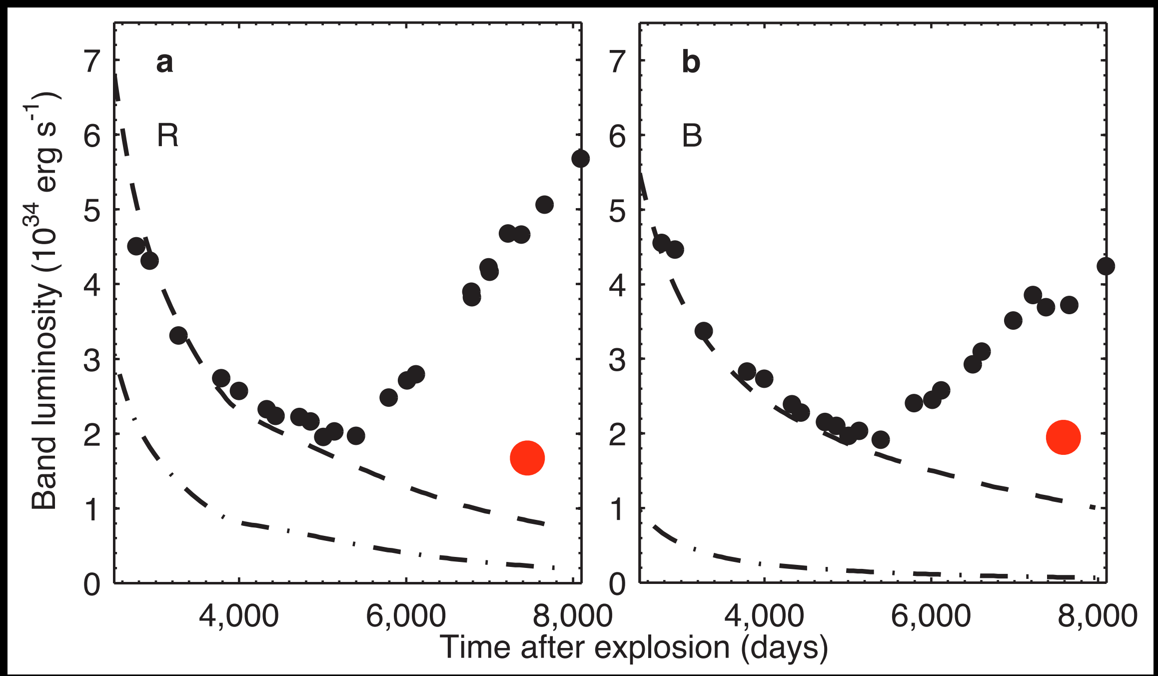


This could only give a factor of 2 compared to the case of pure radioactivity.

3. Positron leakage?



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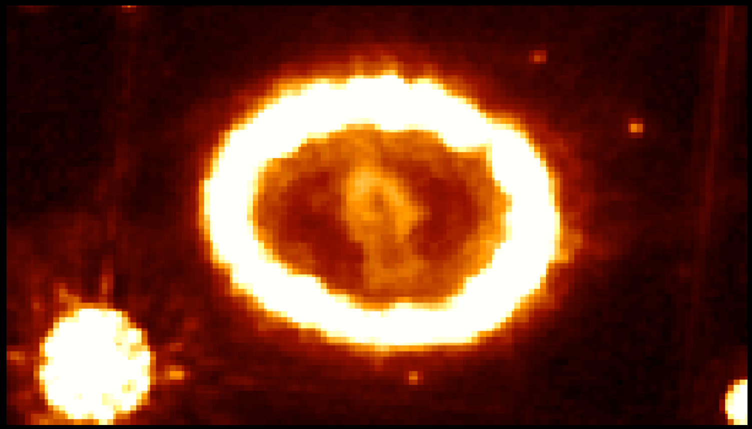
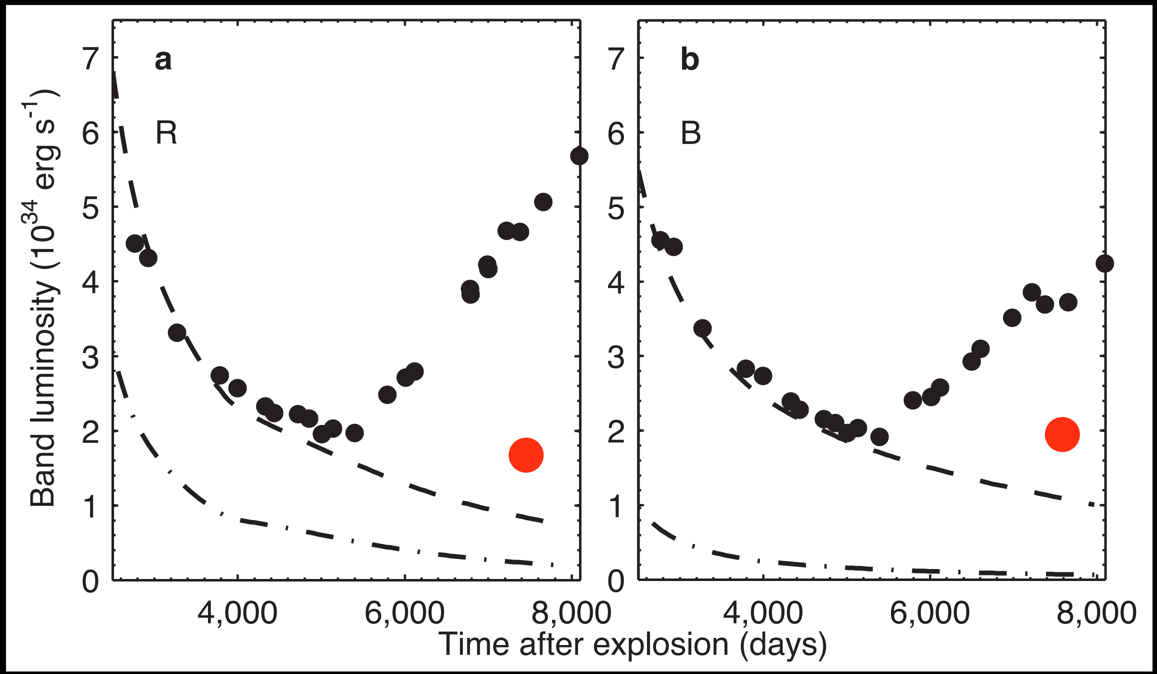


3. Positron leakage?

This effect is also too small.



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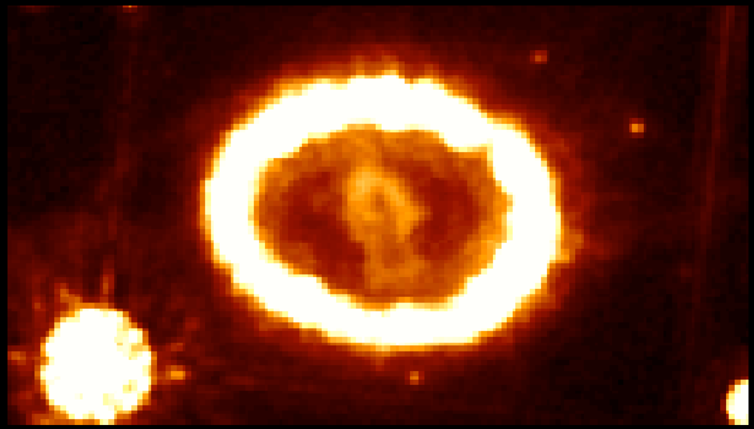

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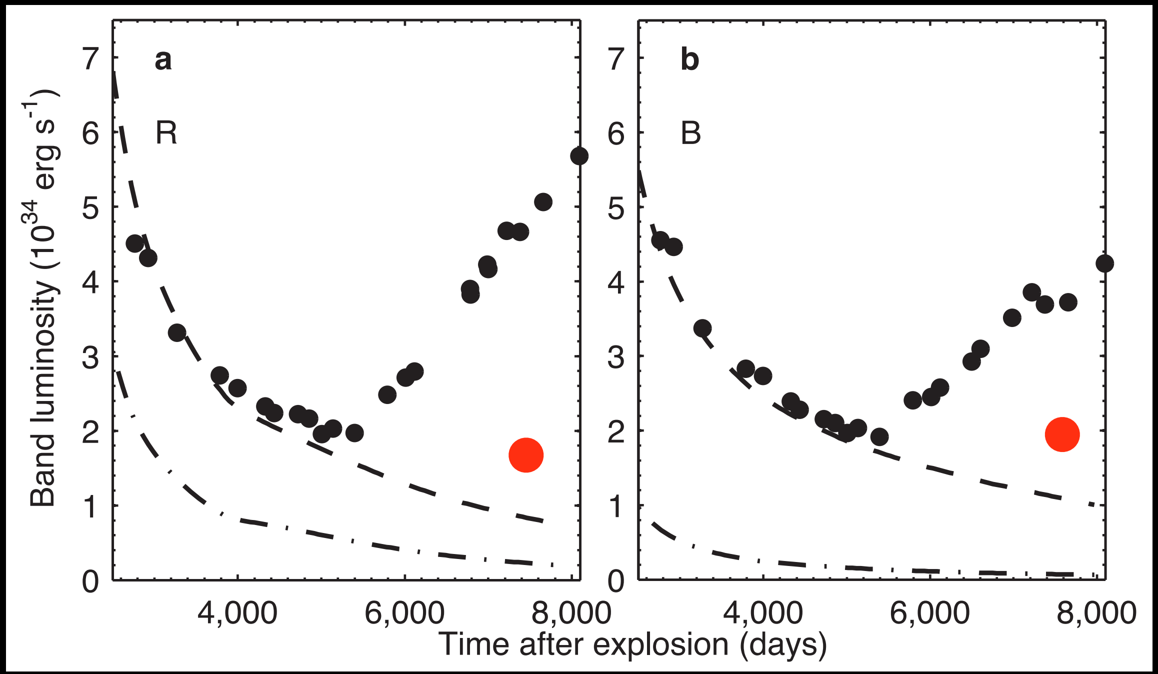


The X-ray illumination is responsible for the brightening

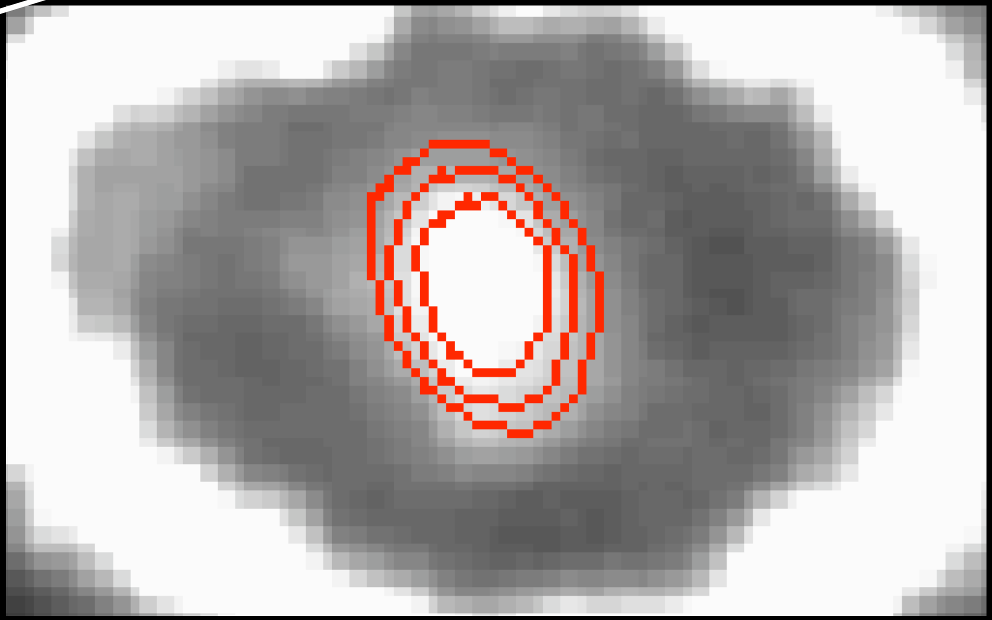
Ejecta morphology

The external X-ray illumination affects the observed morphology of the ejecta.

X-rays became dominant around 2001/2002.

Earlier images give a better idea of the distribution of matter.

Preliminary



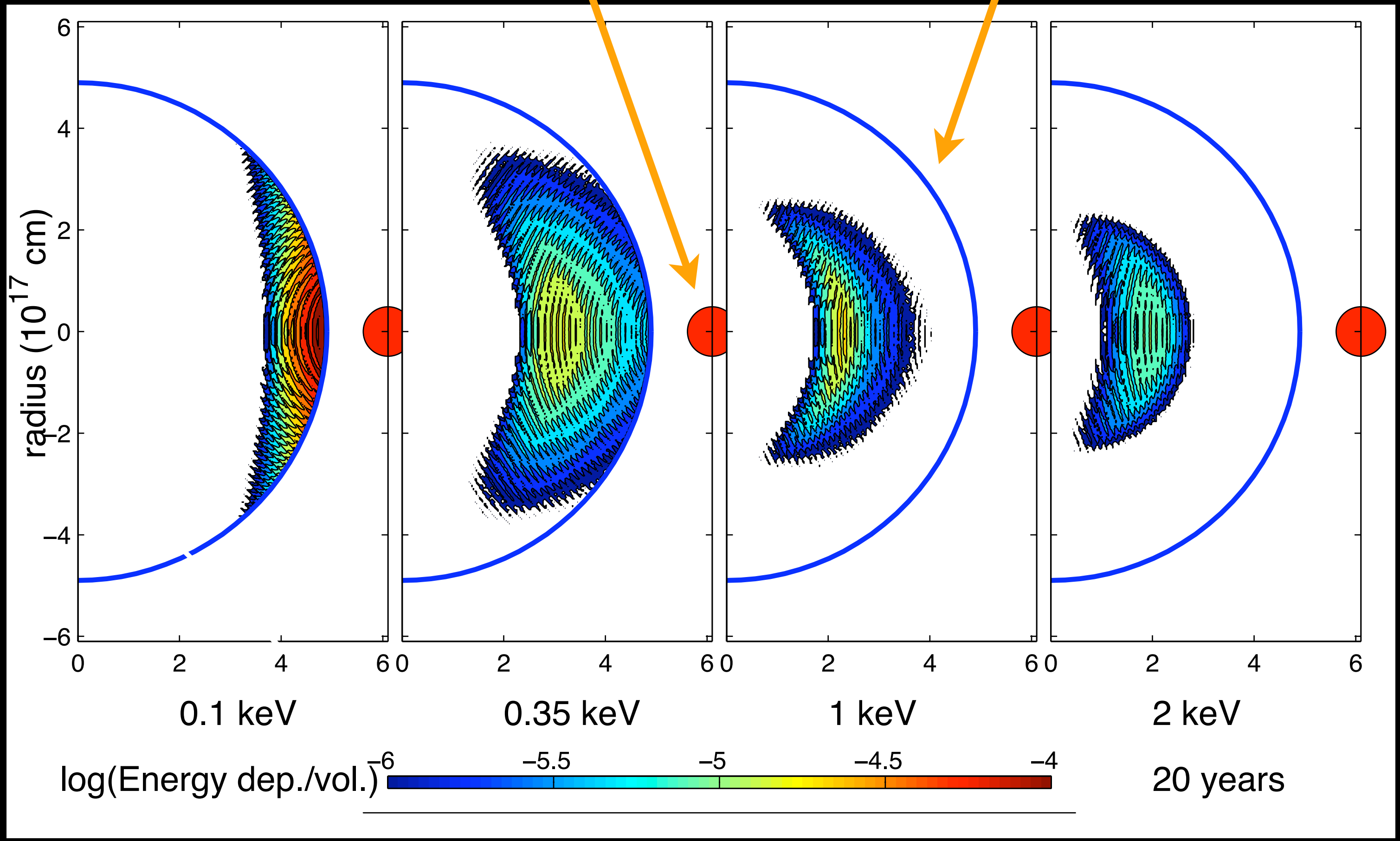
2000
Average b/a = 0.72
Pos. Angle: 13 -23 degrees

X-ray source in ring

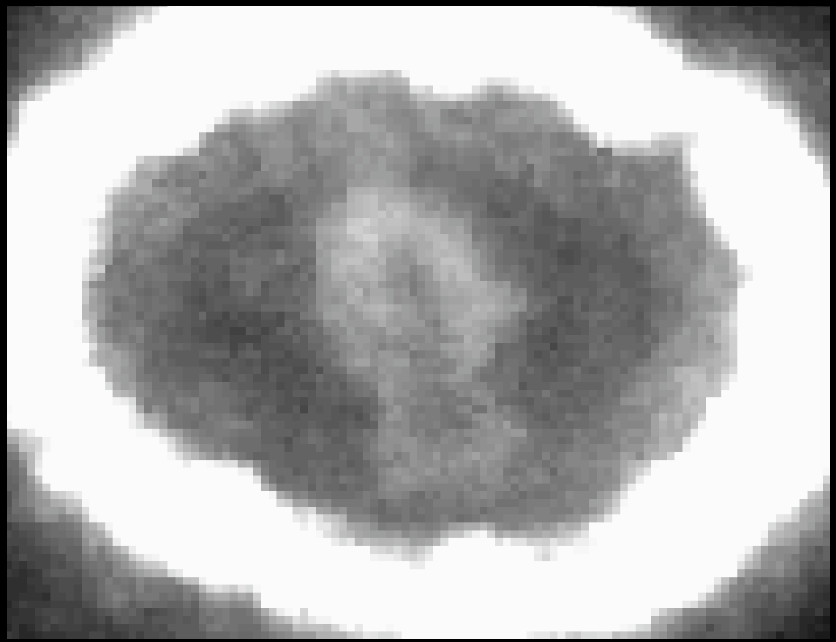
Reverse shock

Energy deposition at 20 years for different X-ray energies.

Note concentration to the plane of the ring.



Fransson et al. in prep

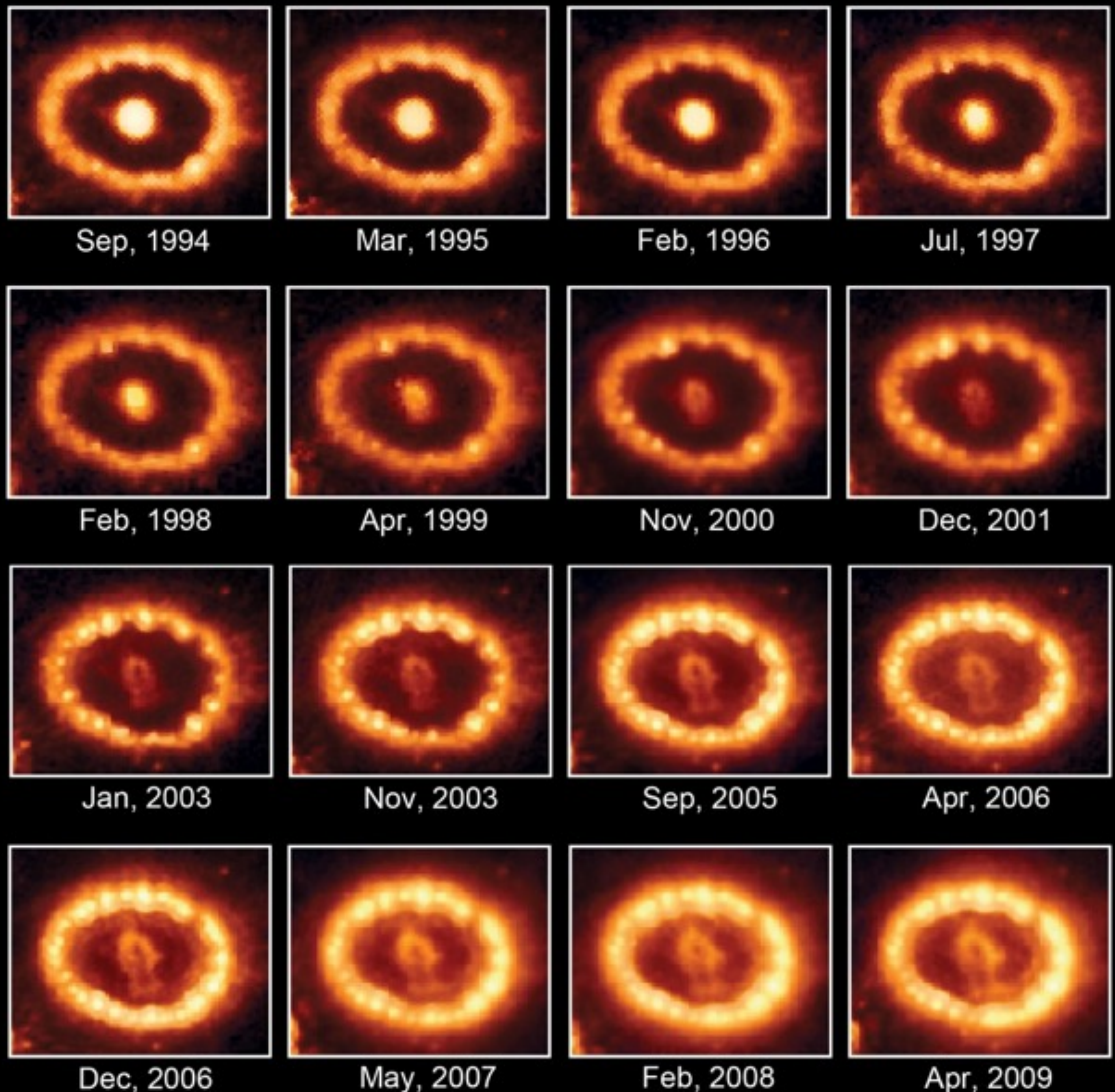


R-band image from 2006

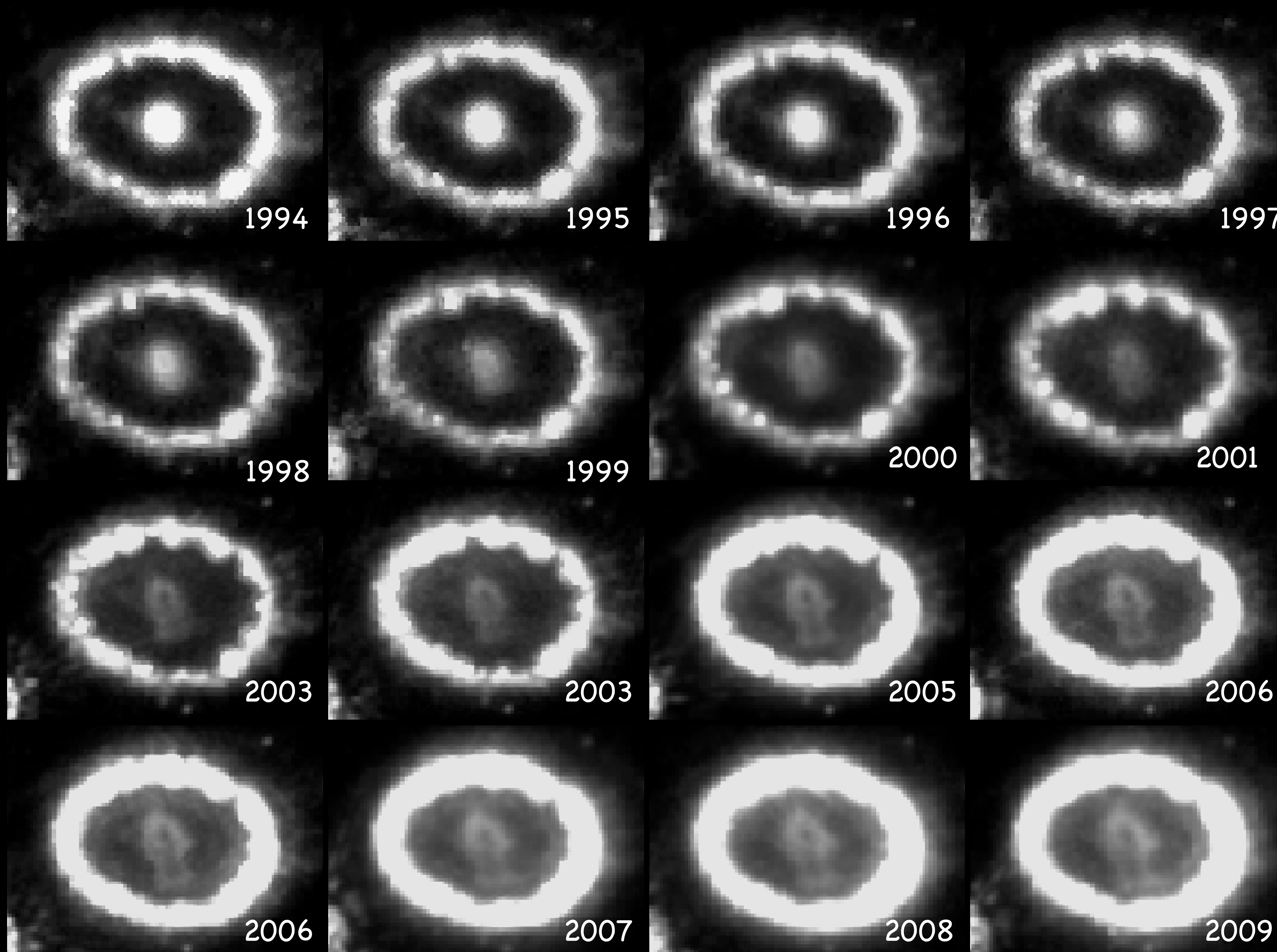
Conclusions

- The late light curve of the ejecta was powered by the radioactive decay of ^{44}Ti up to year 2001 (5000 days after the explosion).
- The rising flux after year 2001 is well explained by X-ray illumination by the ring.
- The powering of the ejecta has shifted from radioactive input to a phase dominated by the kinetic energy of the explosion.
- The X-ray illumination affects the observed morphology of the ejecta.

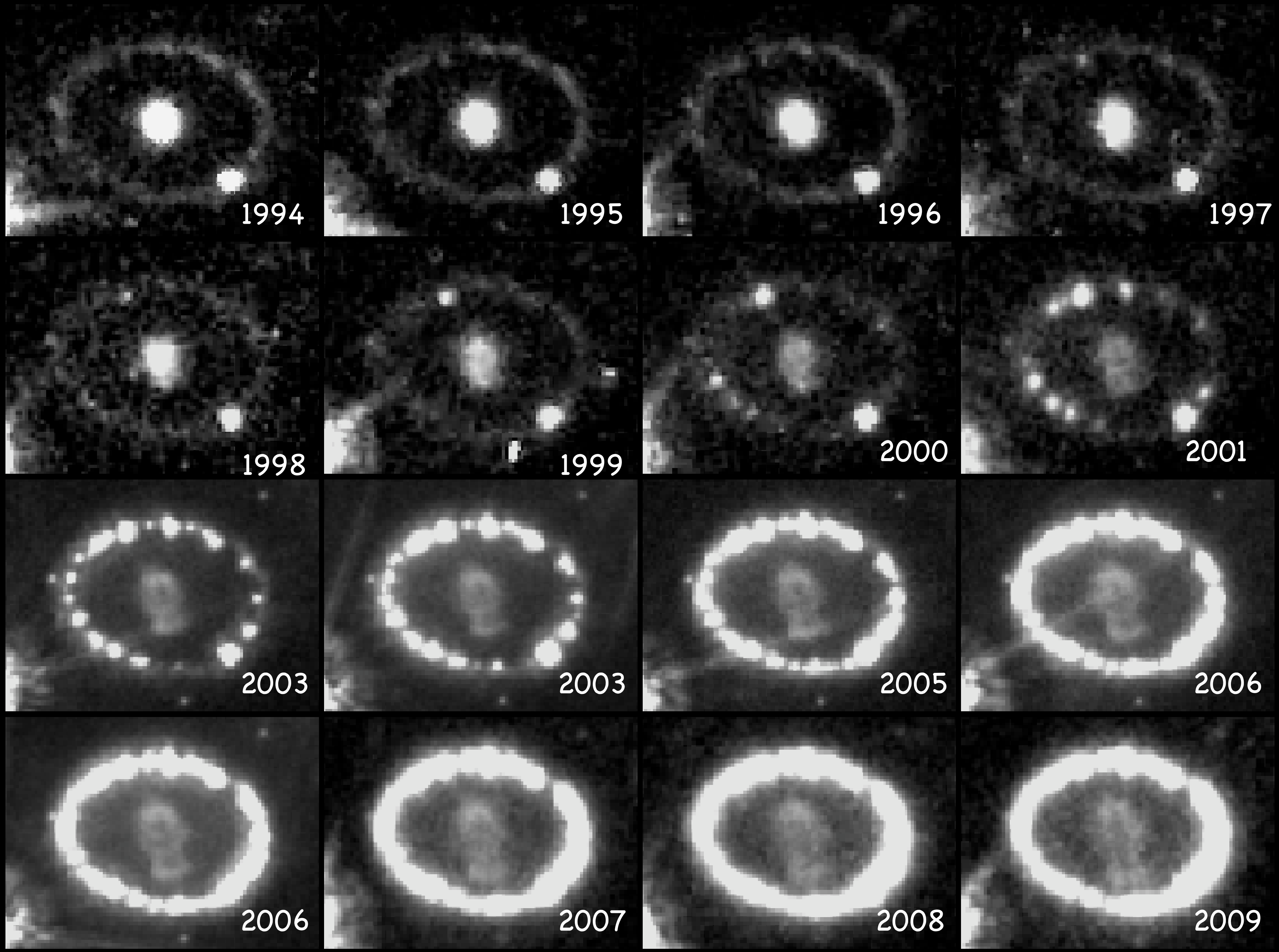
Thanks

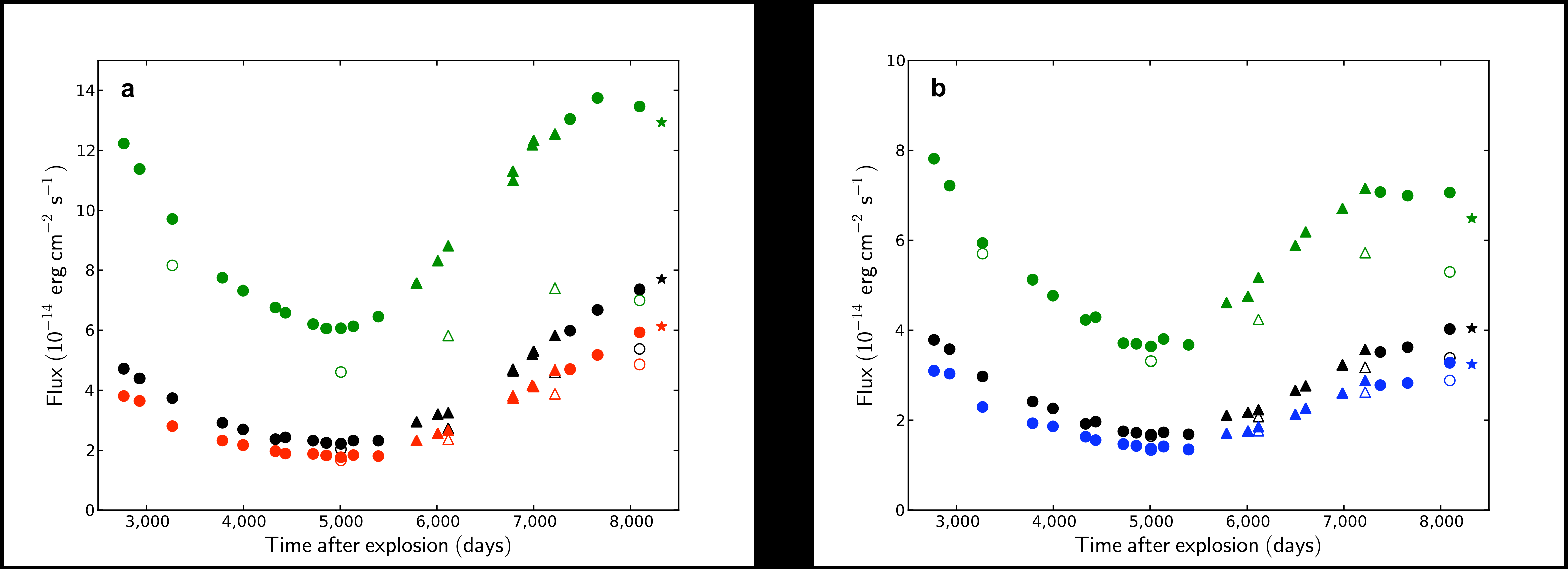

Sep, 1994
Mar, 1995
Feb, 1996
Jul, 1997
Feb, 1998
Apr, 1999
Nov, 2000
Dec, 2001
Jan, 2003
Nov, 2003
Sep, 2005
Apr, 2006
Dec, 2006
May, 2007
Feb, 2008
Apr, 2009

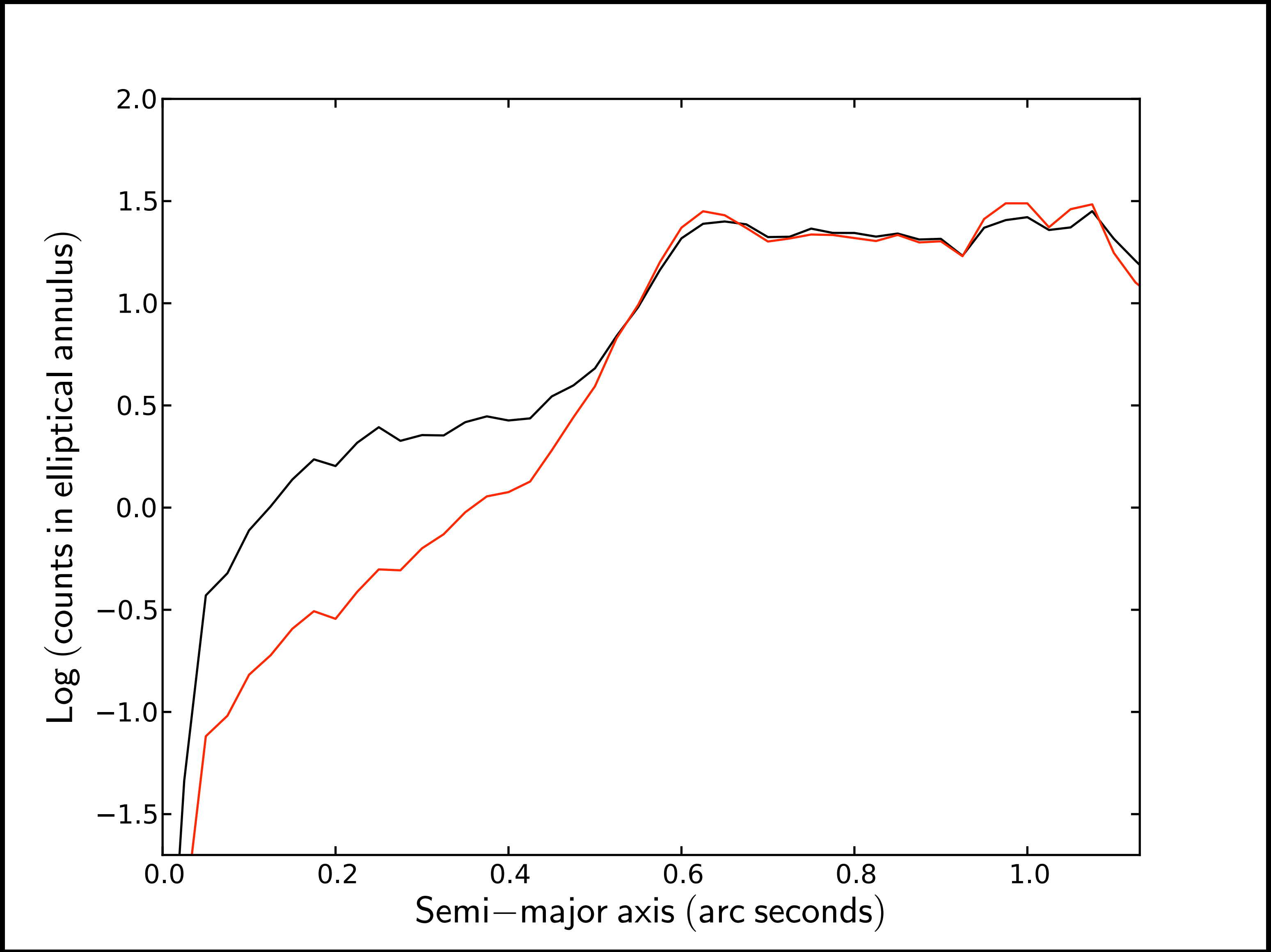
Selection of HST R-band images

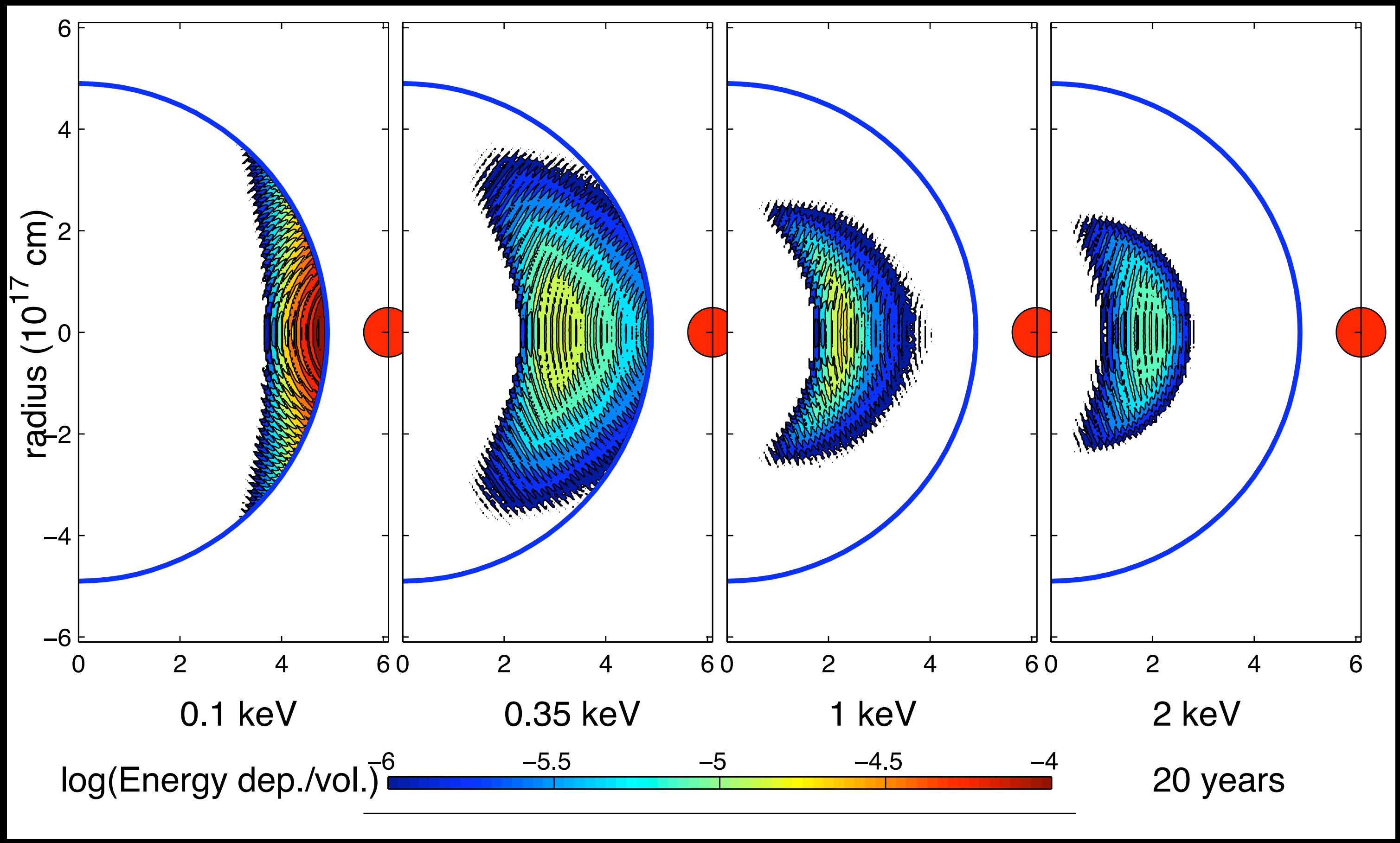


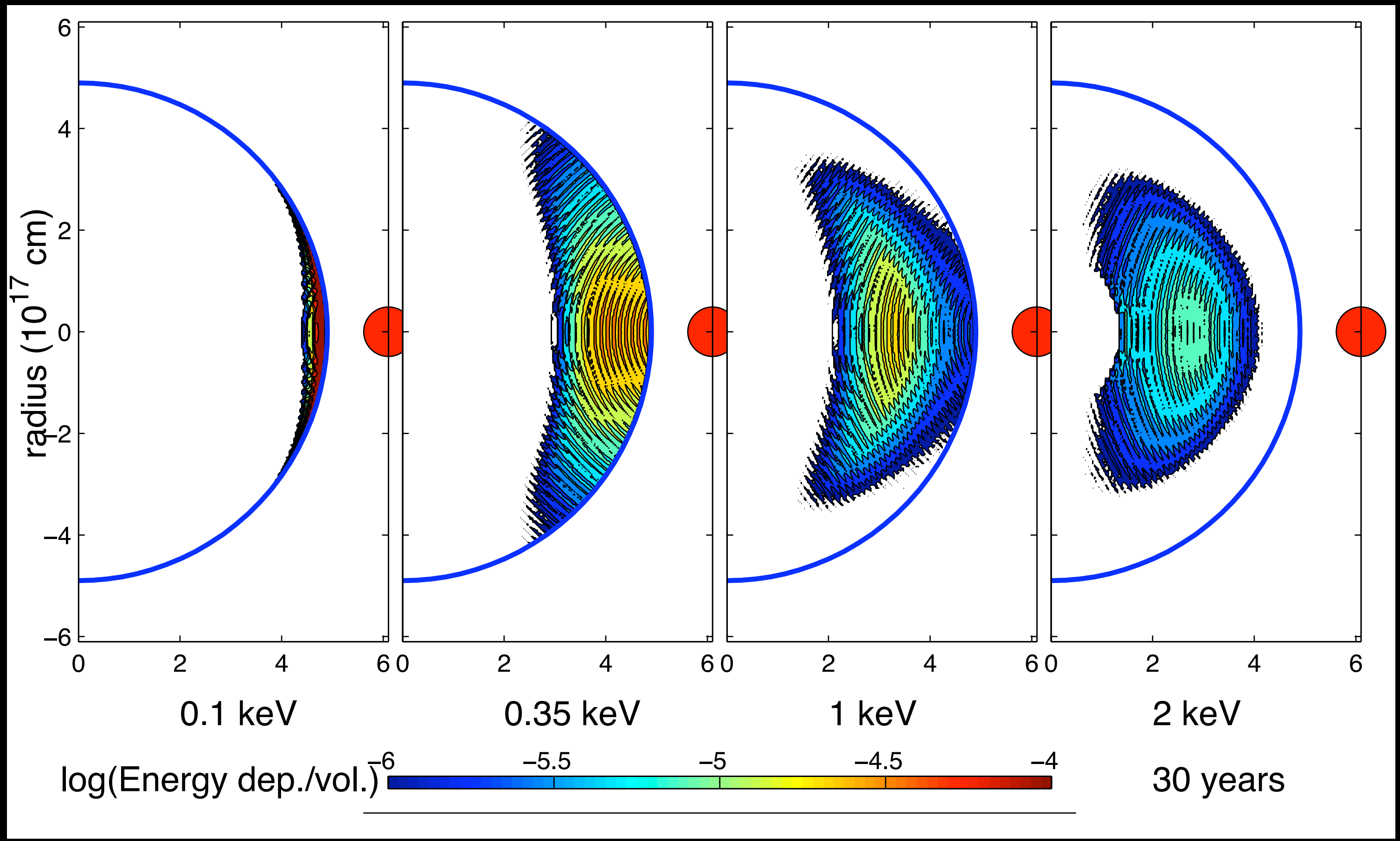
Selection of HST B-band images

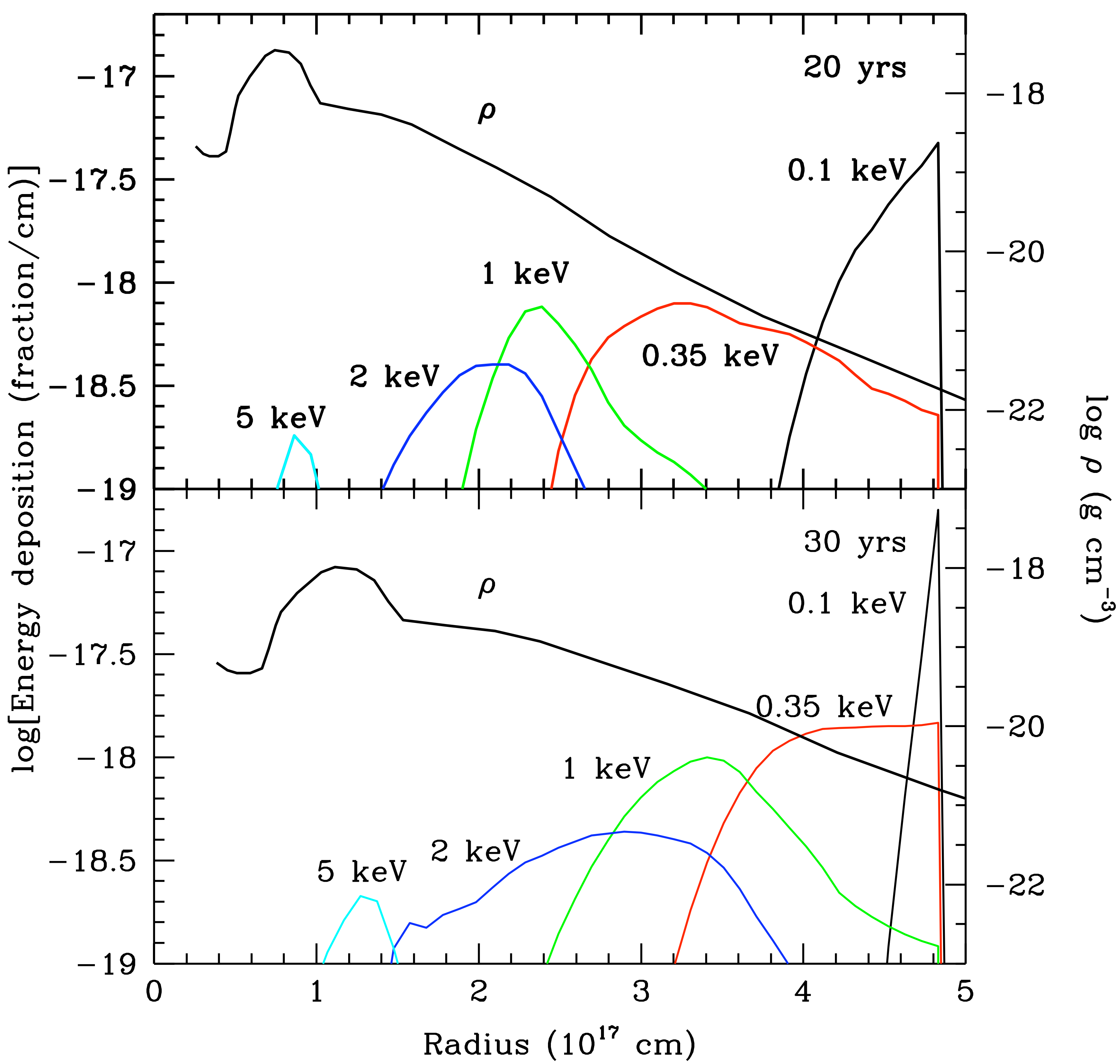



a
b
Flux (10^{-14} erg cm^{-2} s^{-1})
Time after explosion (days)
0
2
4
6
8
10
12
14
3,000
4,000
5,000
6,000
7,000
8,000


2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Log (counts in elliptical annulus)
0.0
0.2
0.4
0.6
0.8
1.0
Semi−major axis (arc seconds)


radius (10^{17} cm)
0.1 keV
0.35 keV
1 keV
2 keV
log(Energy dep./vol.)
−6
−5.5
−5
−4.5
−4
20 years


radius (10^{17} cm)
0.1 keV
0.35 keV
1 keV
2 keV
log(Energy dep./vol.)
−6
−5.5
−5
−4.5
−4
30 years



20 yrs
ρ
0.1 keV
1 keV
0.35 keV
2 keV
5 keV
30 yrs
ρ
0.1 keV
0.35 keV
1 keV
2 keV
5 keV
log[Energy deposition (fraction/cm)]
log ρ (g cm⁻³)
Radius (10¹⁷ cm)
−17
−17.5
−18
−18.5
−19
−18
−20
−22
0
1
2
3
4
5