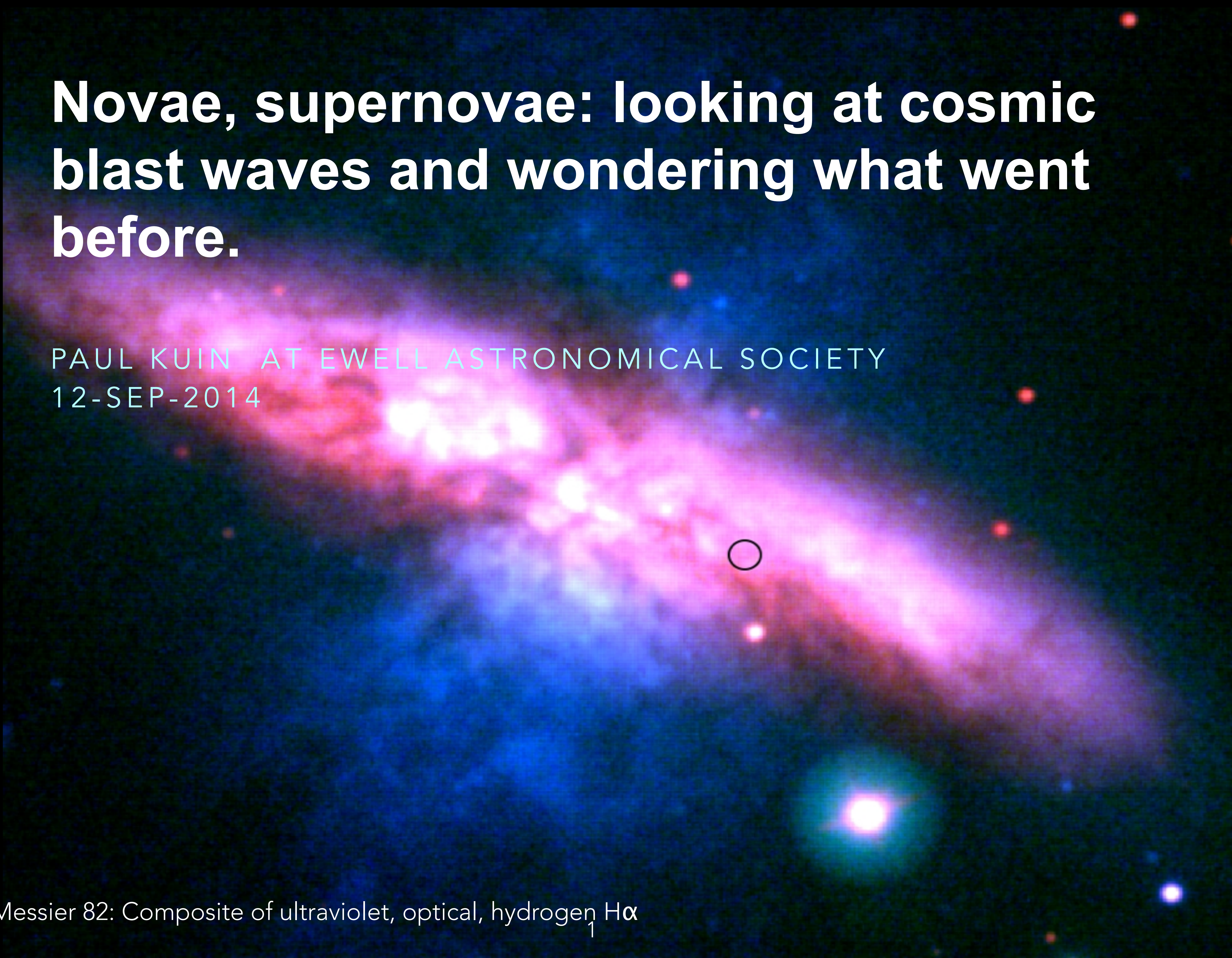
Novae, supernovae: looking at cosmic blast waves and wondering what went before.

PAUL KUIN AT EWELL ASTRONOMICAL SOCIETY
12-SEP-2014



Messier 82: Composite of ultraviolet, optical, hydrogen Hα

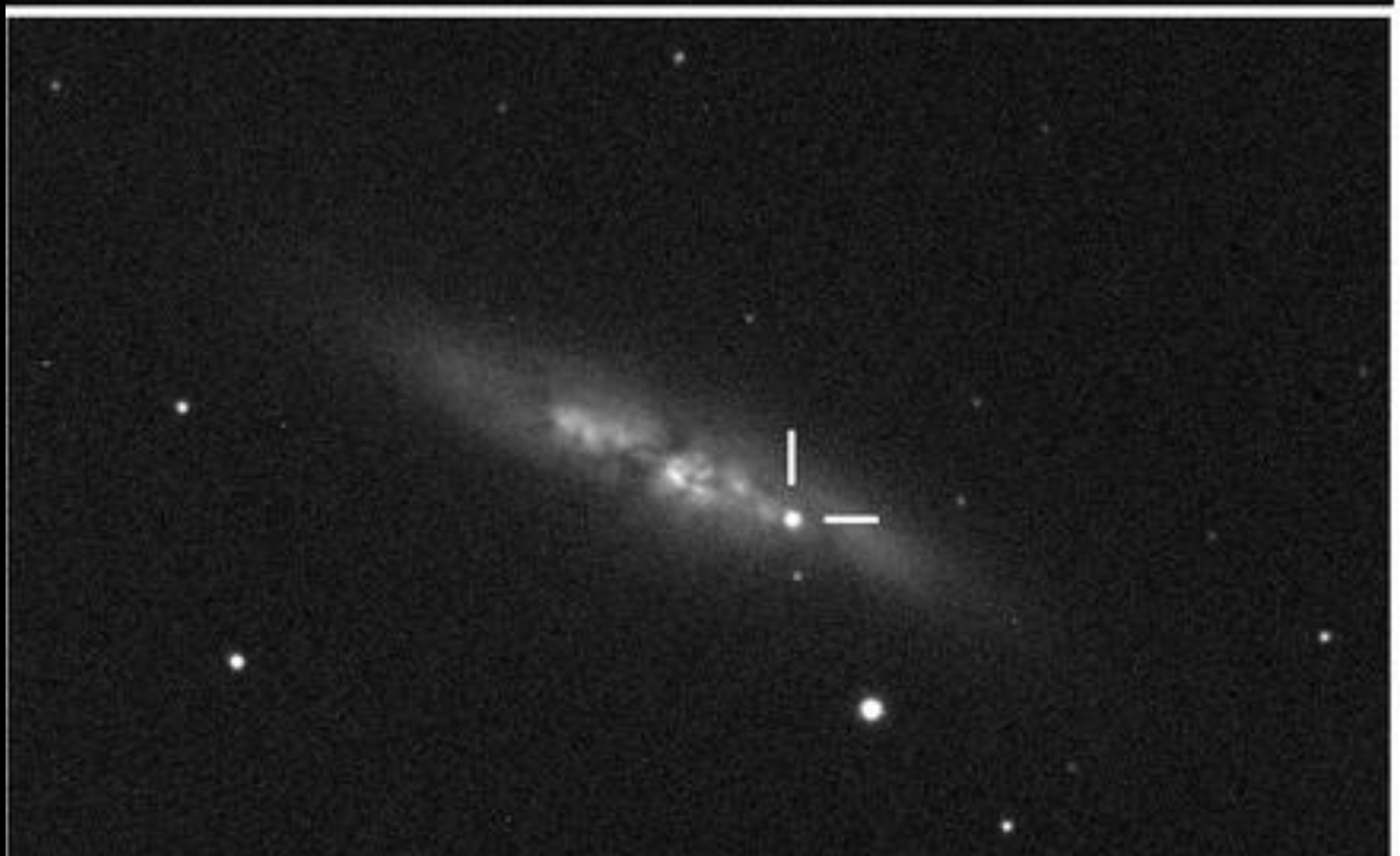
What I intend to talk about (in no particular order):

- discovery of novae and supernovae
- how they relate to normal stars
- why they are important
- the beauty of the aftermath
- observations with instruments of the Swift satellite
- the importance of the observations in gamma rays
- modelling the explosion: the devil is in the details
- interstellar extinction by dust
- progress made!

Discovery

- Often a nova is discovered by experienced sky observers who note a difference in the sky
- Dedicated robotic telescopes take daily or weekly images which are (semi-)automatically processed
- After a burst of gamma rays from a nova causes the Swift BAT instrument to see it light up in gamma rays - only for very bright ones.
- example : SN 2014 J discovered accidentally, and one discovery from the MASTER robotic telescope network.

10 december 2013

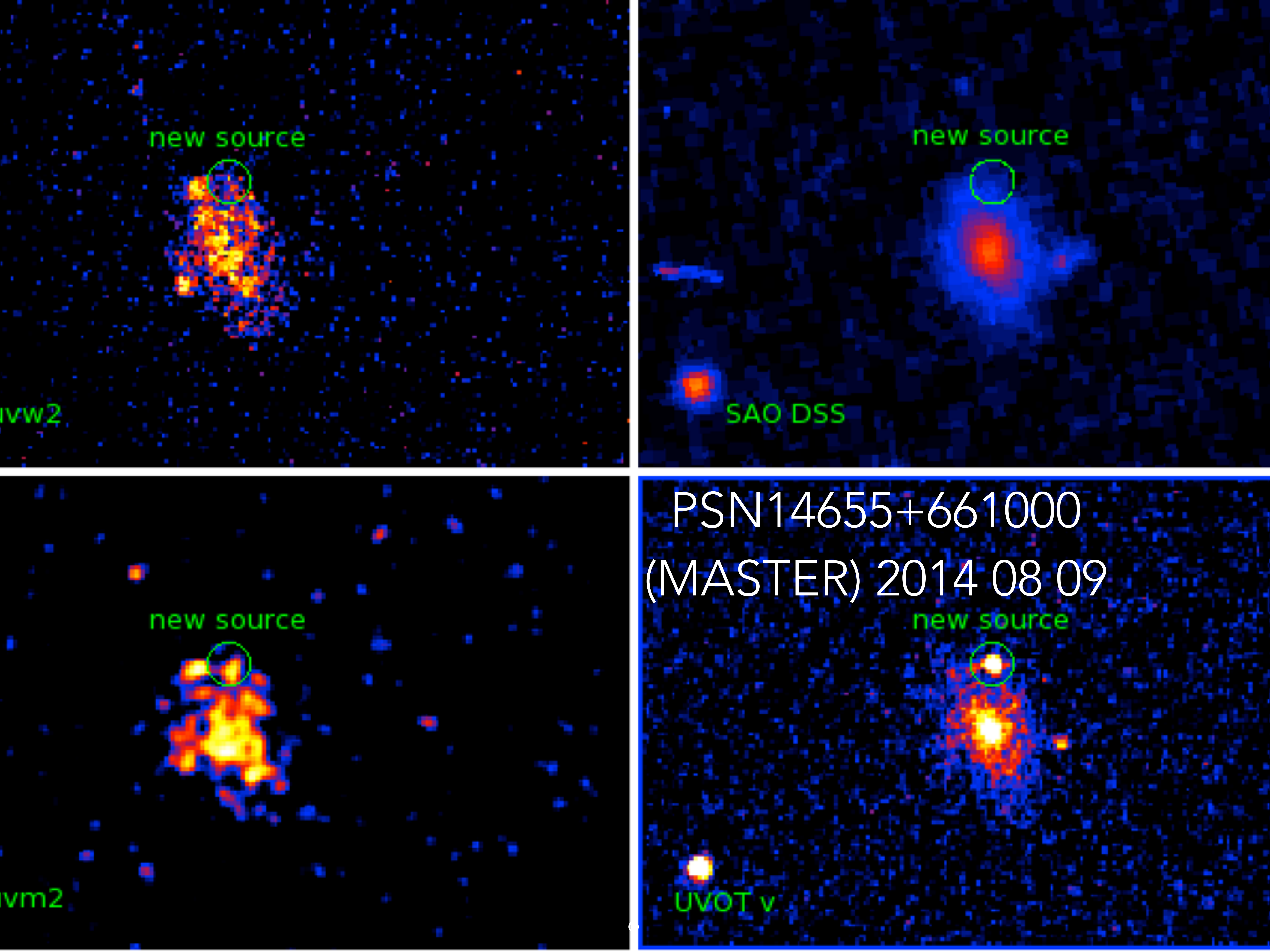


21 January 2014

Steve Fossey, Ben Cooke, Guy Pollack,
Matthew Wilde, Thomas Wright, UCL

A NEW STAR WHERE THERE WAS NONE BEFORE. THE DISCOVERY BY STEVE FOSSEY AND STUDENTS ON 21 JANUARY AT 19:20 GMT.

ADAM BLOCK, MT. LEMMON SKYCENTER, U. ARIZONA


new source
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THE RELATION TO NORMAL STARS

- Calculations of the internal structure of normal stars was started by Eddington around 1924. Structure of normal stars maintained by radiation pressure.
- White dwarfs explained as a degenerate gas (the Fermi exclusion principle) providing the pressure.
- Neutron stars explained. Only atomic forces can withstand the pressure. (Chandrasekhar) Mass limit, then black hole.
- computers allowed the calculation of evolution of the star, taking knowledge of nuclear reactions, and turbulence into account. Giant and supergiant stars explained.
- In binary systems an additional effect proved important: when one star evolved to a giant its radius grows and thus can loose mass to its companion. The distance between the stars also changes with loss of orbital momentum.

MOVIE: THE RELATION OF NOVAE AND SUPERNOVAE TO THE EVOLUTION OF MASSIVE NORMAL STARS

MOVIE RECAP:

- We have a binary star system, with relatively massive stars
- normal stars with different mass
- the heavier star evolves faster
- once it becomes older its nuclear composition changes
- the core gets hotter and its radius expands
- mass is lost to the companion which gets heavier
- the star goes supernova and leaves behind a neutron star

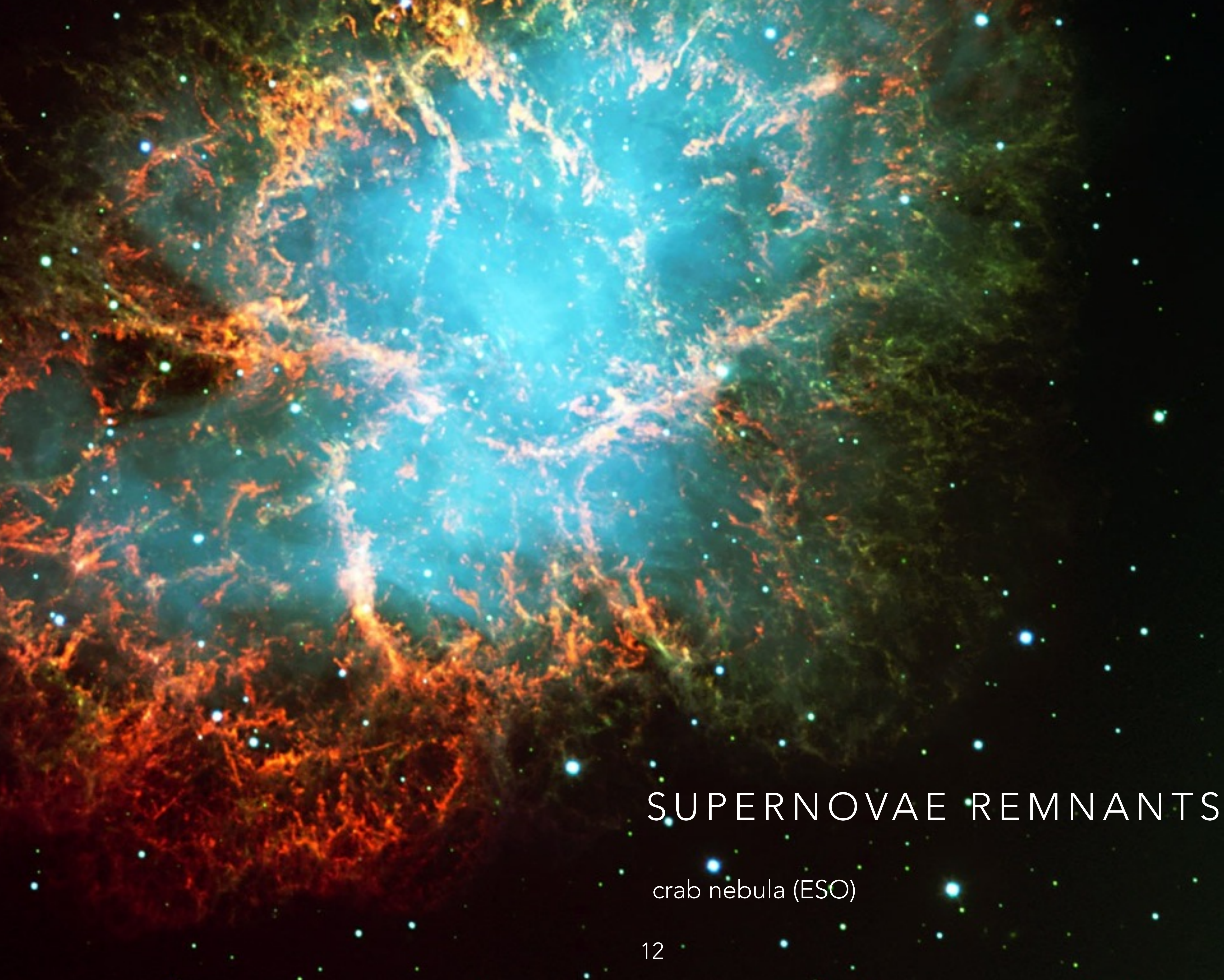
Lighter stars do it differently

- The first star evolves into a white dwarf
- The second star evolves and transfers mass - Hydrogen
- The transferred mass accumulates on the white dwarf
- When enough hydrogen is present on the WD surface the bottom stars nuclear burning in milli-second causing a blast of radiation : we get a Nova

The Importance of Novae and Supernovae

- Most matter is just in the form of hydrogen
- Novae and supernovae create and eject heavier elements into space.
- They also stir up the space around them, causing nebulae to form and light up and are helping bring about the formation of new stars with their planets
- They are a laboratory to gain a better understanding of nature

Next : Remnants are Beautiful



SUPERNOVAE REMNANTS

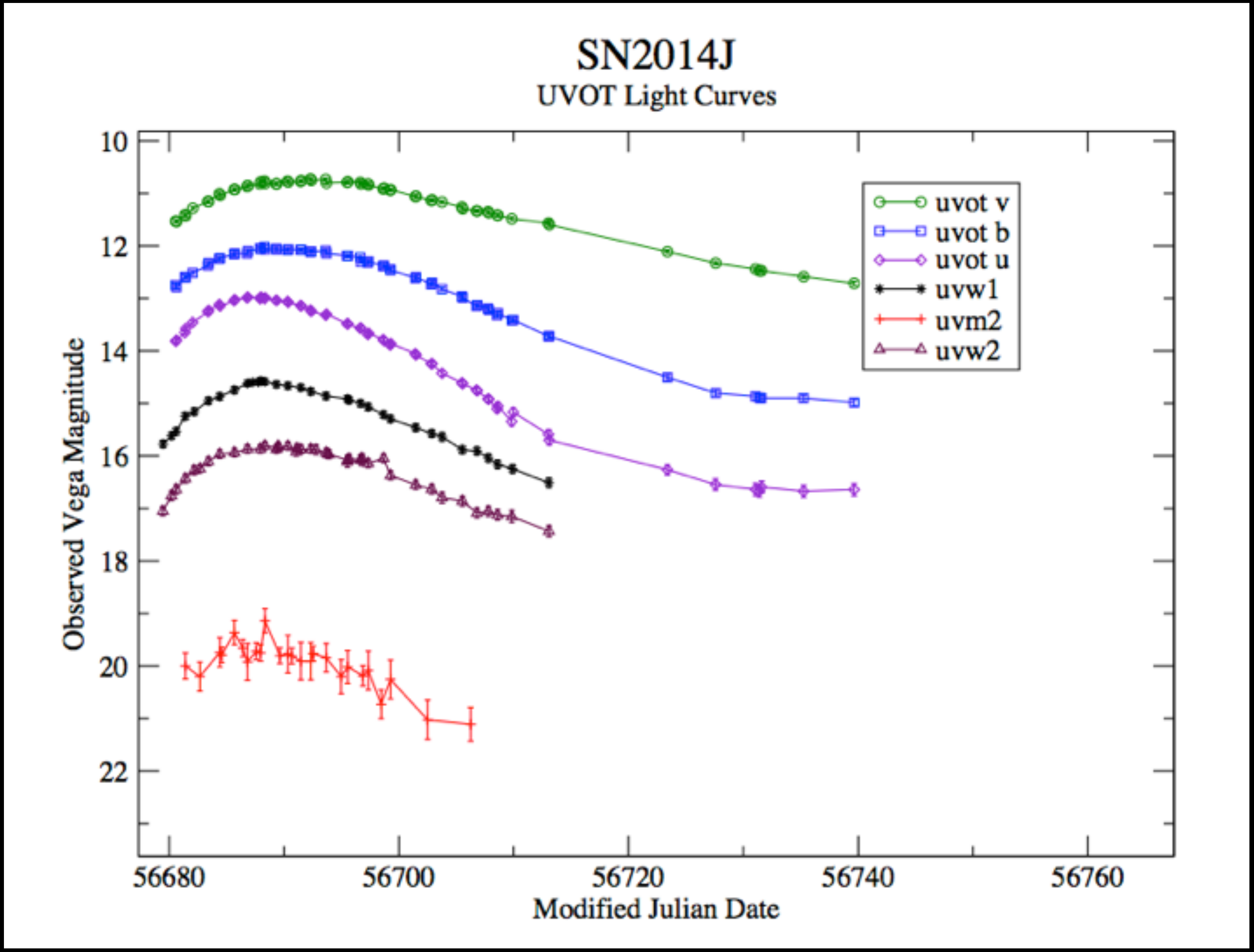
crab nebula (ESO)

SWIFT DISCOVERS SN REMNANT IN X-RAYS:

GALACTIC SUPERNOVA REMNANTS ARE SOME TIMES BEHIND DUST CLOUDS.

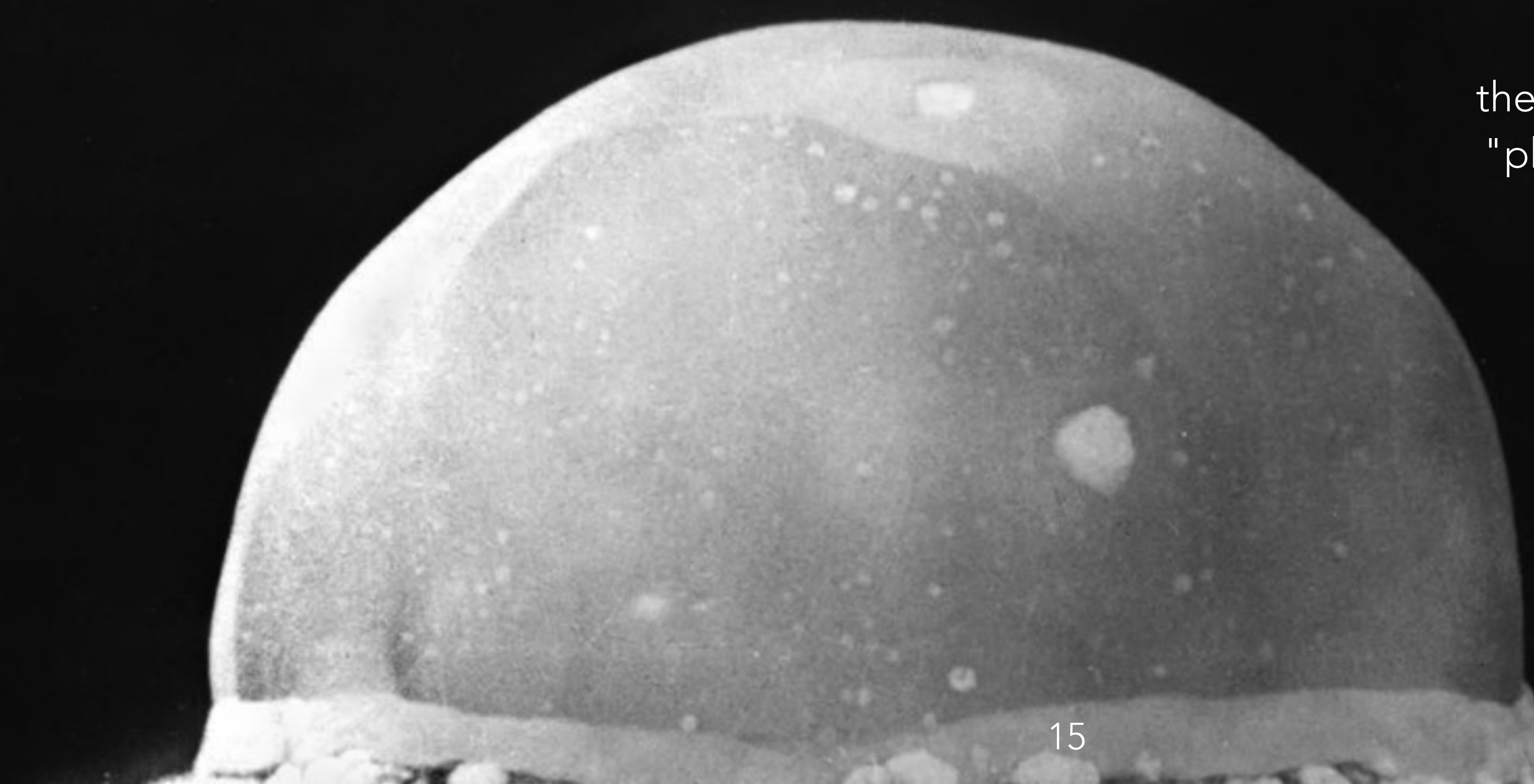
G306.3 -0.9: A NEWLY DISCOVERED YOUNG GALACTIC SUPERNOVA REMNANT. SHOWN IS A COMPOSITE OF X-RAY (BLUE), IR (GREEN), MICROWAVE (RED) -- CHANDRA OBS., SPITZER OBS., ATCA.

SUPERNOVA BRIGHTNESS OVER TIME



LIGHT CURVES - PLOTTING THE SUPERNOVA BRIGHTNESS OVER TIME

The brightness comes from the size of the blast:
the "photosphere"
the point where light escapes from the blast

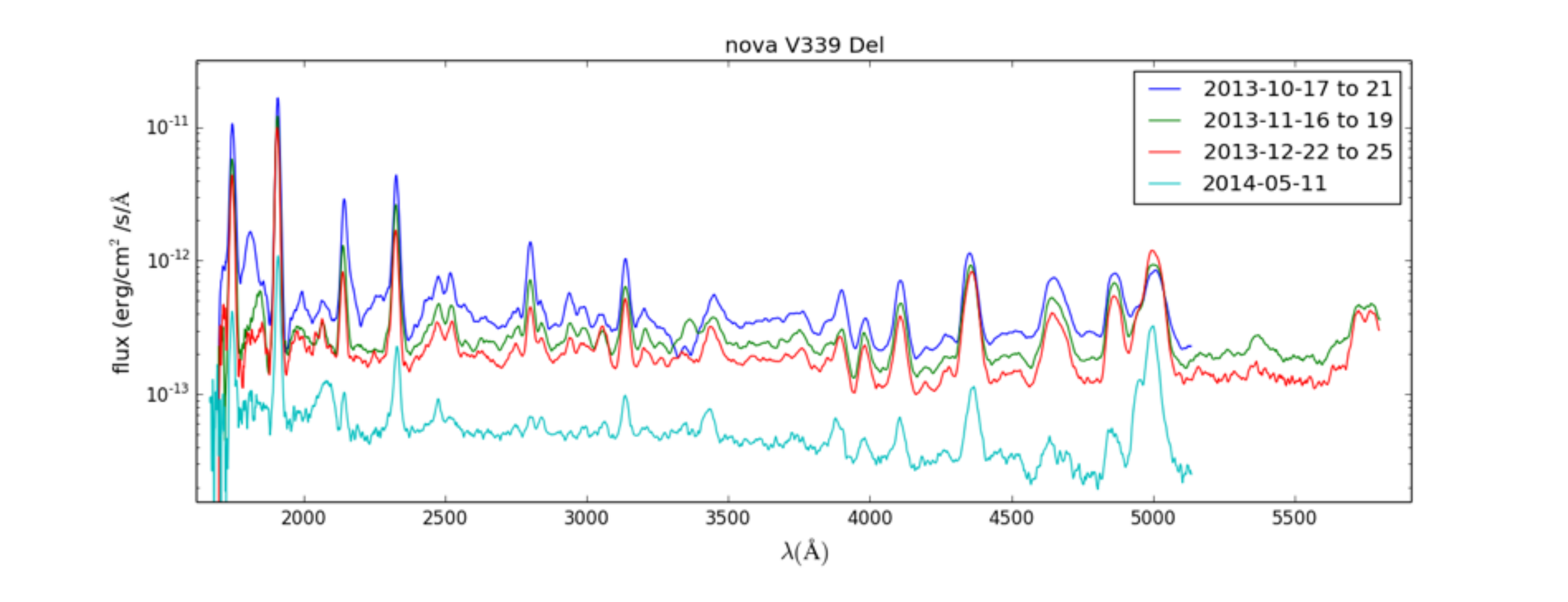


the Trinity nuclear bomb explosion "photosphere" milli seconds after the start.

Swift observations of Novae

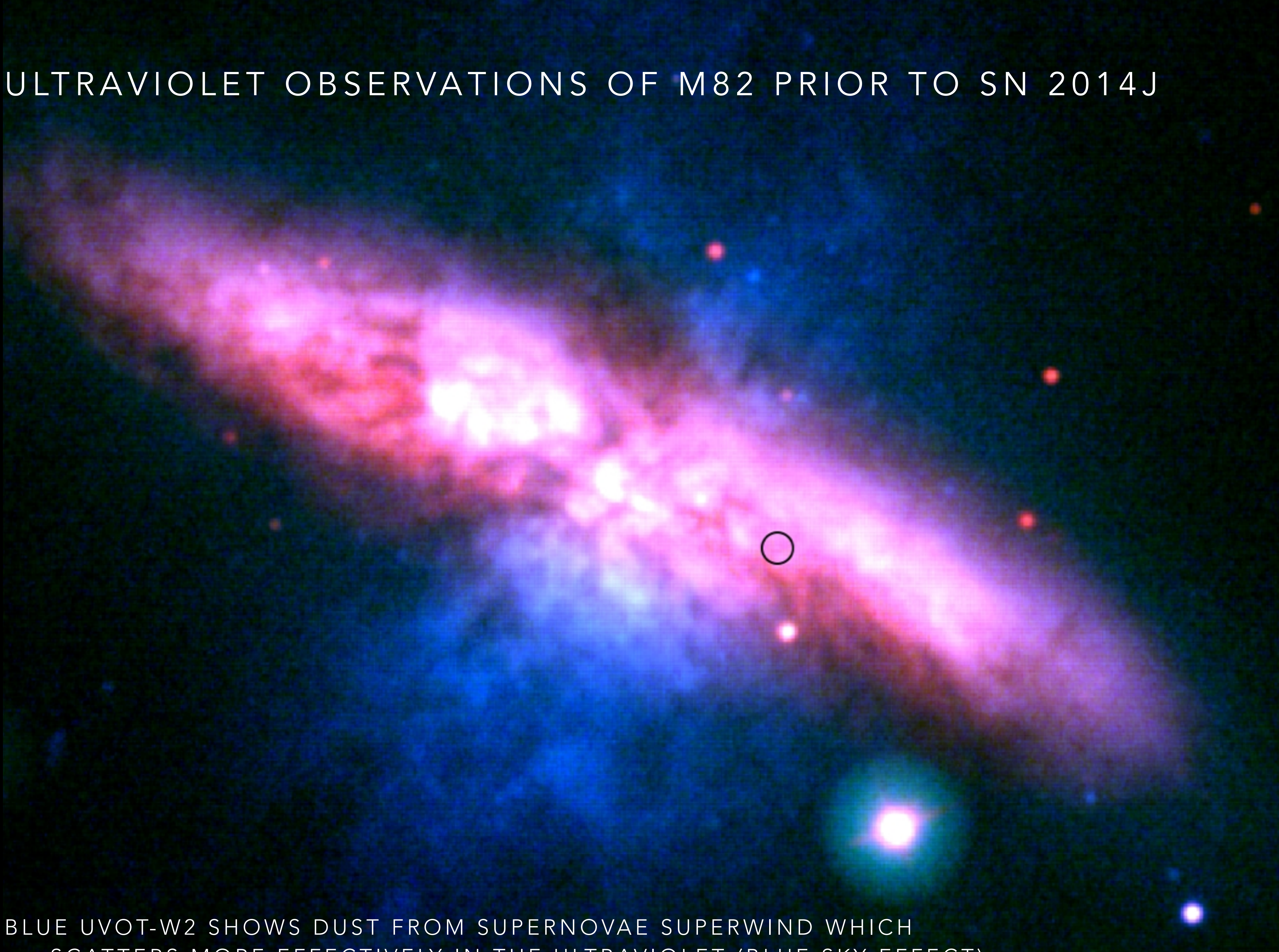
- X-ray brightness over time
- X-ray spectrum
- ultraviolet brightness (~22nd to ~10th magnitude)
- ultraviolet-optical low resolution spectra
- Example: V339 Del (Nova del 2013, August 14)
- V1369 Cen (Nova Cen 2013, December 2)
- RS Oph (most recent 2006)
- T Pyx (most recent 2011)

Swift uvot nova spectrum



- Bright lines from low-density shell
- Twice ionised nitrogen, oxigen carbon signature
- Also hydrogen, magnesium, and neon
- line width indicates large velocities

ULTRAVIOLET OBSERVATIONS OF M82 PRIOR TO SN 2014J



BLUE UVOT-W2 SHOWS DUST FROM SUPERNOVAE SUPERWIND WHICH
SCATTERS MORE EFFECTIVELY IN THE ULTRAVIOLET (BLUE SKY EFFECT)
GREEN SDSS-G FROM STAR LIGHT
RED IS FROM H-ALPHA FROM YOUNG STARS
BLACK CIRCLE IS WHERE THE SUPERNOVA APPEARED MID-JAN 2014

SN 2014J MAIN RESULTS

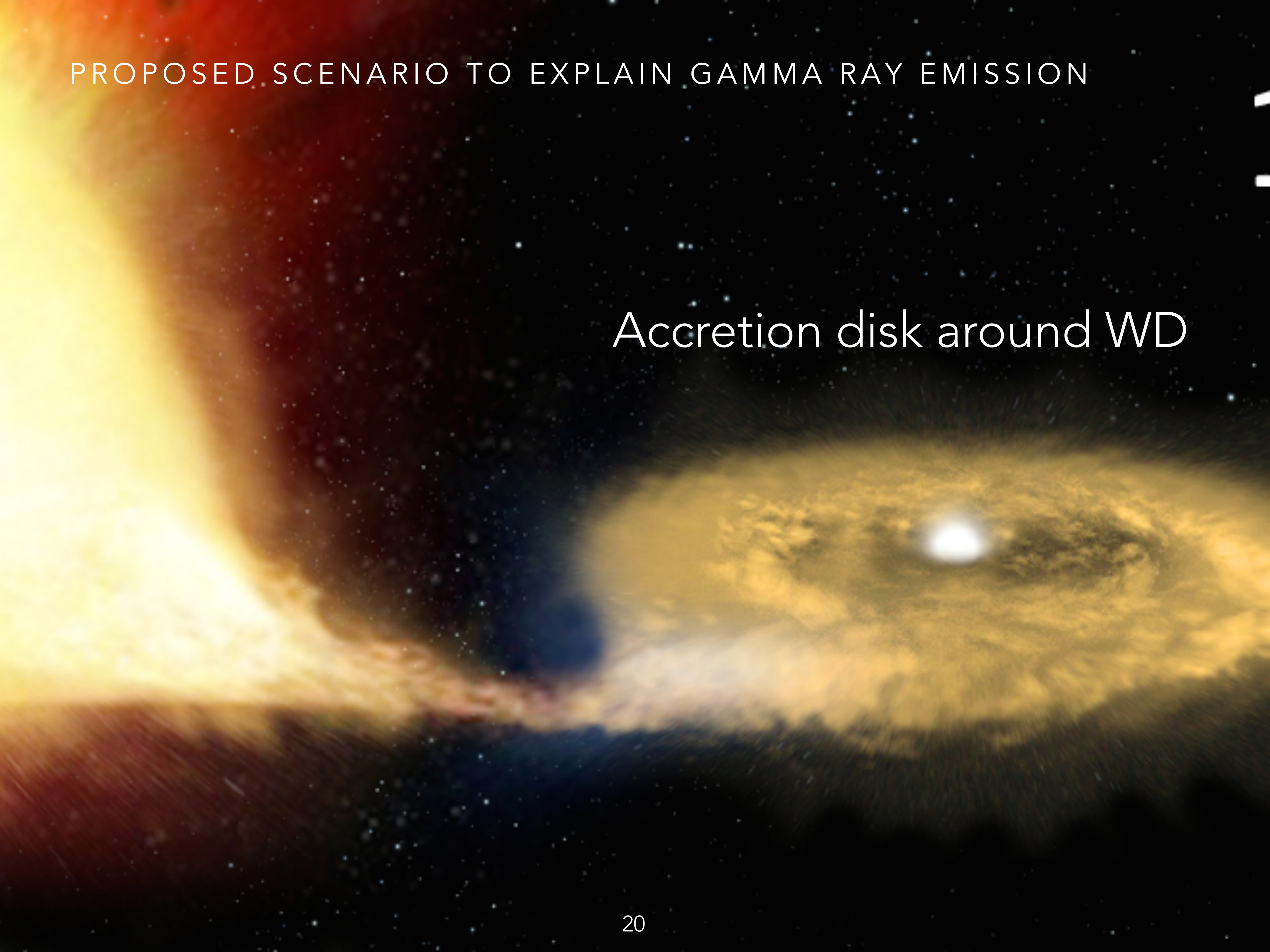
- Early gamma-ray emission

models predict that radioactive Nickel created in the explosive nuclear burning **core** should become visible weeks after the explosion. Its decays produces heat that powers the luminosity at later time.

Not so, gamma rays from the ^{56}Ni decay were observed just 15 days after the explosion. They are not from the core of the progenitor star. Best alternative: Explosive burning of accreted matter on the surface (6 artists impressions from ESA)

- High extinction is not close in to the SN

PROPOSED SCENARIO TO EXPLAIN GAMMA RAY EMISSION



Somehow the matter piles up on the equator

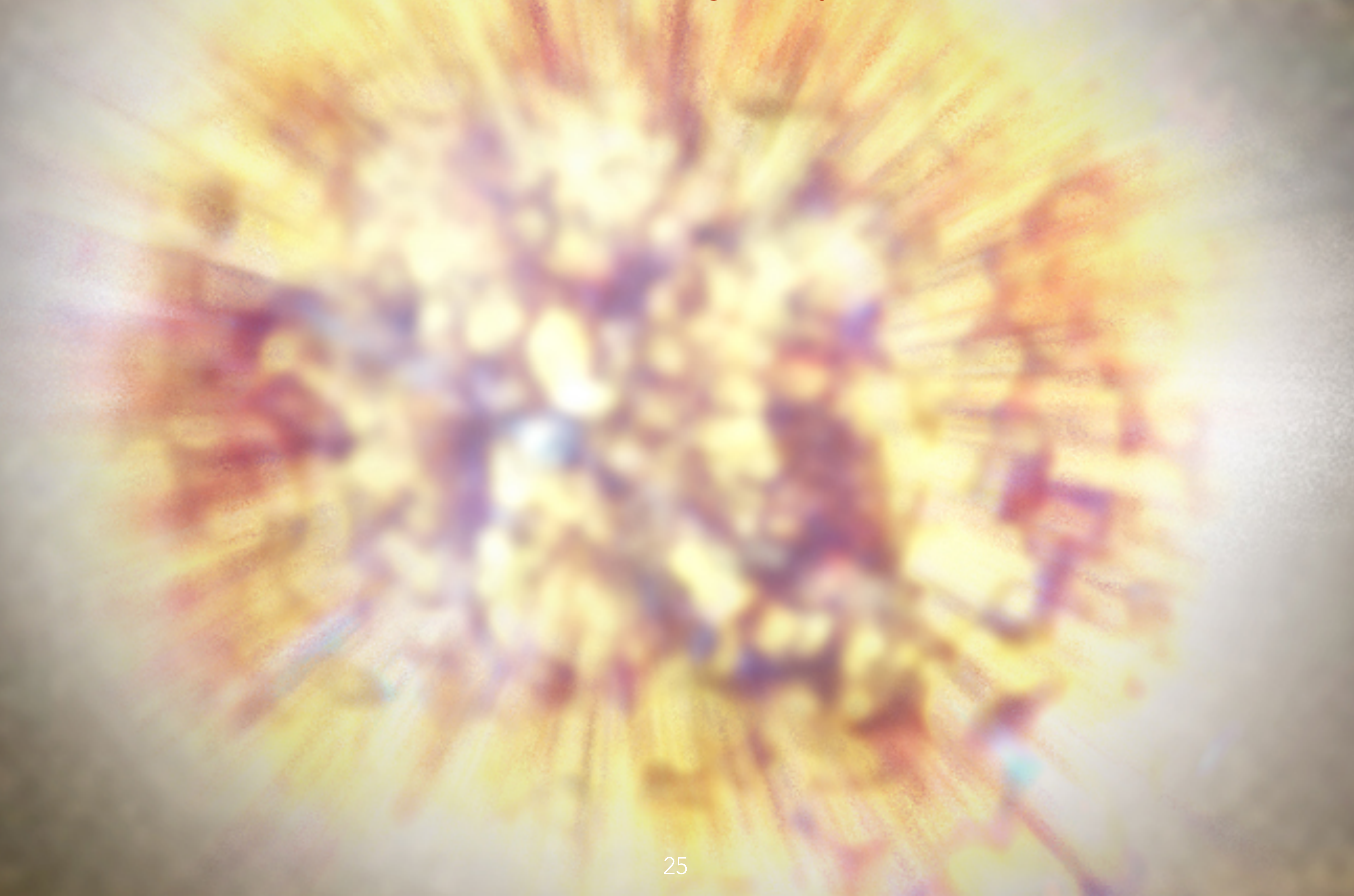
Ignition of nuclear burning

In milli-second most is burned and explodes outward

Action = reaction: a strong shock moved to the center

KABOOM!! We have a SN

The star blows apart, leaving only the core as a NS



SN2014J result:
High extinction is not happening in close to the SN

- colours (comparing brightness in two colour bands) can be used to infer how much extinction there was between the SN and us.
- SN2014J is of type 1a (There is lots of hydrogen in the spectrum of the SN ejecta).
- compare colours and/or spectrum to nearby SN1a in M101: SN2011fe, which had negligible extinction.

COMPARE SN2014J OBSERVATIONS TO SN2011FE

- The bluest filters is where the extinction is highest.
- SN2011fe had nearly no extinction (reddening) dashed line.
- Dotted line: SN2011fe spectrum modified with the SN2014J extinction show both SN2014J spectra can so be made to match. (also adjusted to match overall speed of evolution).
- from Amanullah et al.

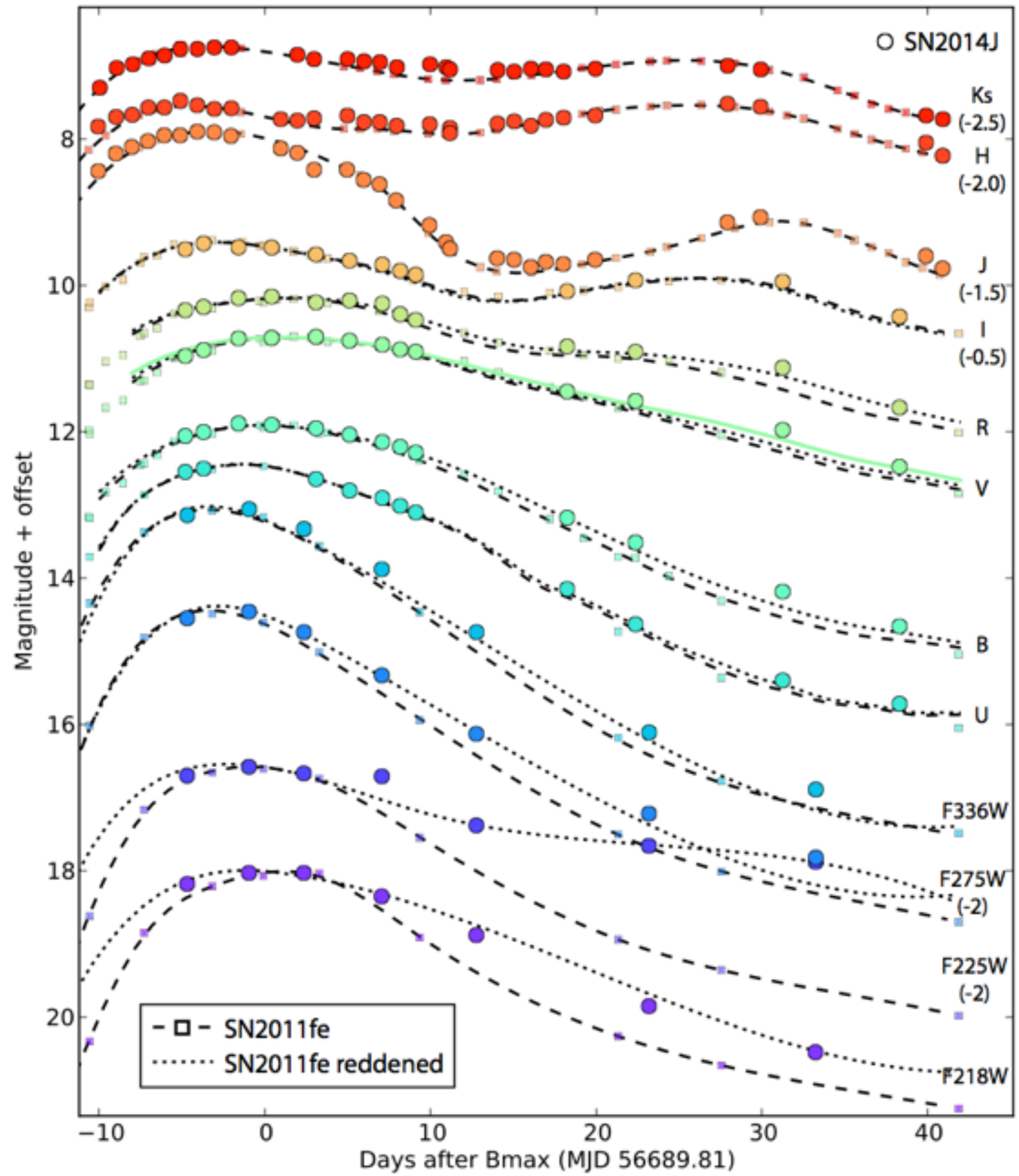
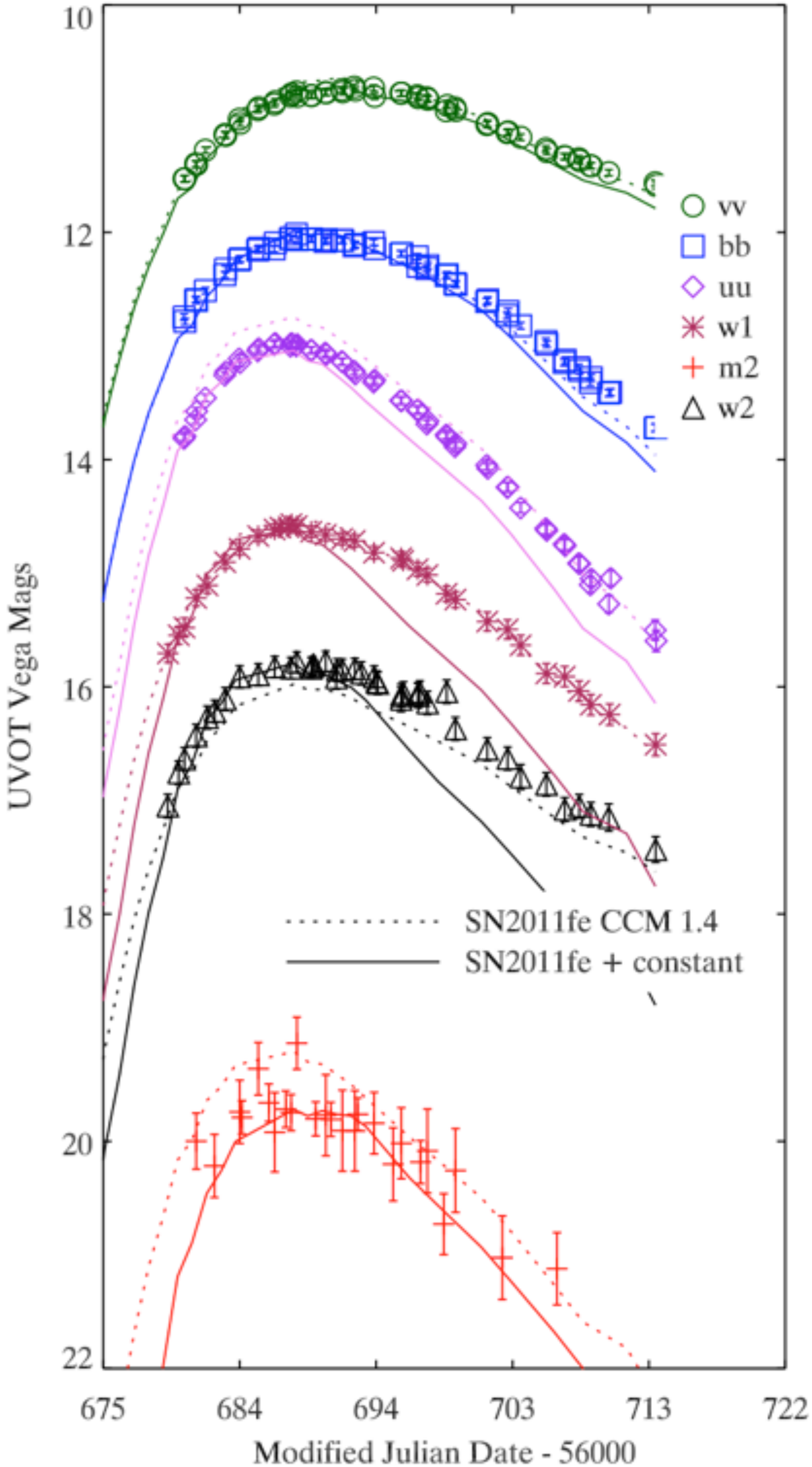


Fig. 1.— Lightcurves for all passbands used in this analysis. For *V*-band we also over plot (solid, green line) the fitted model from SNooPy. The black lines are fits to synthetic photometry of SN 2011fe spectra (dashed) and spectra reddened with the best fit FTZ model to SN 2014J.



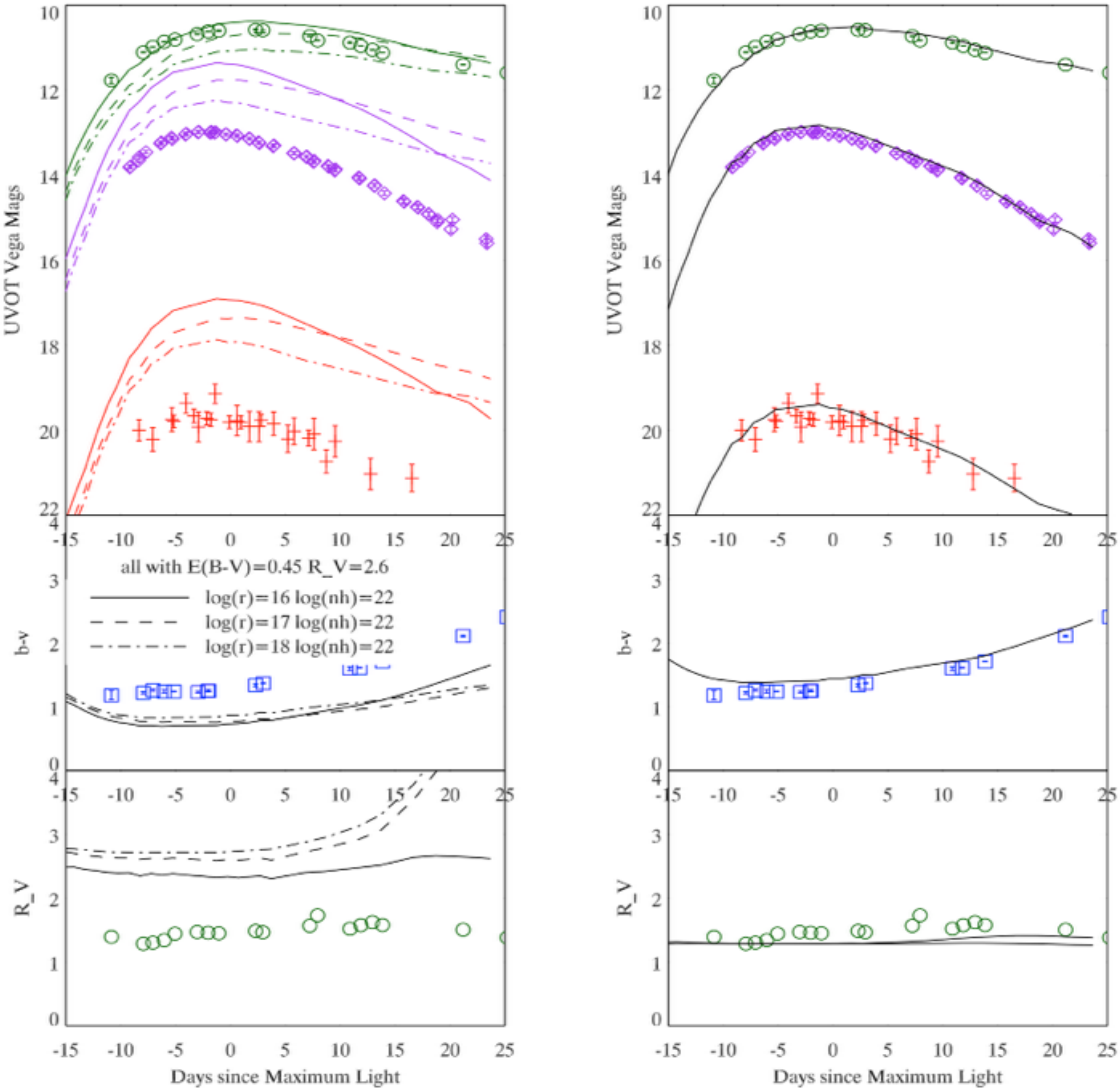
SWIFT UVOT LIGHT CURVES COMPARED TO THE REDDENED SN2011FE. ACTUAL MAGNITUDESARE SHOWN, SO THE BLUEST COLOUR UVW2 IS FAINTEST (=HIGHEST MAG NUMBER).

HERE R_V=1.4 WAS BEST FIT.

Figure 1. UVOT light curves of SN2014J given in observed Vega magnitudes versus time. The reddening naturally separates the curves with no arbitrary offsets needed. We overplot the spectrophotometric light curves for SN 2011fe (based on bolometric spectra from Pereira et al. 2013) without extinction (but offset to match the peak magnitudes). We also plot spectrophotometric light curves for SN 2011fe after reddening with a CCM extinction law with E(B-V)=1.4 and R_V=1.4 and correcting only for the difference in distance moduli.

SN2014J result:
High extinction is not happening in close to the SN

- the equation $A_V = R_V * E(B-V)$ shows the relation between extinction in magnitudes A_V and the reddening in the (B-V) colour (the excess E). Here R_V is a number, usually 3.1. For SN2014J, it is lower, with a value around 2, which gives a steeper extinction law for different colours, with more extinction in the blue.
- Why is the extinction different ? Dust properties ? Smaller dust particles could give a steeper extinction law. The physics of scattering tells us so.
- The spectral evolution complicates things more: The relative brightness of different colours over time depends on the location dusty clouds that scatter the light once it reaches them.



LEFT:
E(B-V)=0.45
R_V = 2.6

RIGHT:
E(B-V)=1.4
R_V=1.1

Figure 5. Left: The SN2014J photometry, B-V color and R_V are compared to models with the SN 2011fe series modified by circumstellar dust at different radius values and a foreground reddening of E(B-V)=0.45 and R_V=2.6 as suggested by Foley et al. (2014). Right: The SN2014J photometry, B-V color and R_V are compared to a model with SN 2011fe reddened with a Cardelli law with E(B-V)=1.4 and R_V=1.1.

Where is the cloud in the galaxy

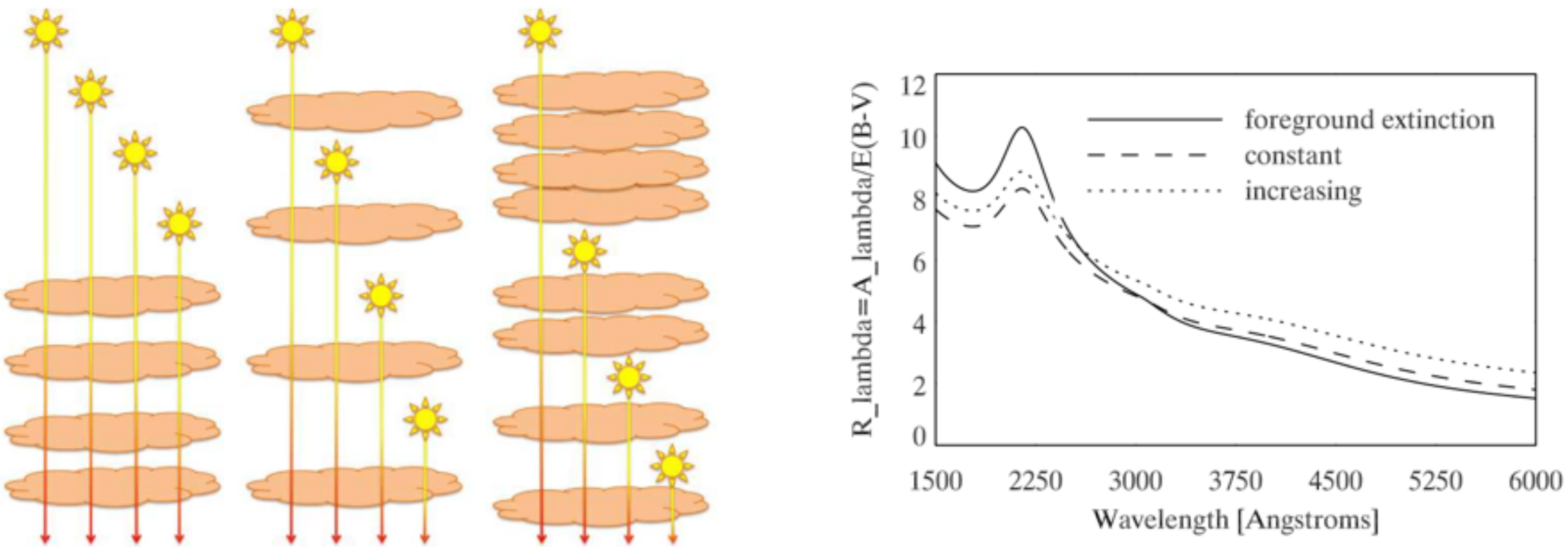


Figure 6. Left: Different distributions of dust clouds with respect to the stars. Most extragalactic extinction determinations are calculated as a foreground sheet in front of the stellar content. Other configurations with the dust mixed within the stellar content, resulting in different amounts of reddening to different stellar populations is more likely.
Right: Inferred reddening laws from the three scenarios presented at the left. The resulting R_V values are 1.82, 2.12, 2.69. Mixing the stars and dust results in an increase in the effective R_V.

So, if we look at the combined star light of M82 to determine the extinction law, RV will be higher since the clouds will be between the M82 stars. - another piece of the puzzle.

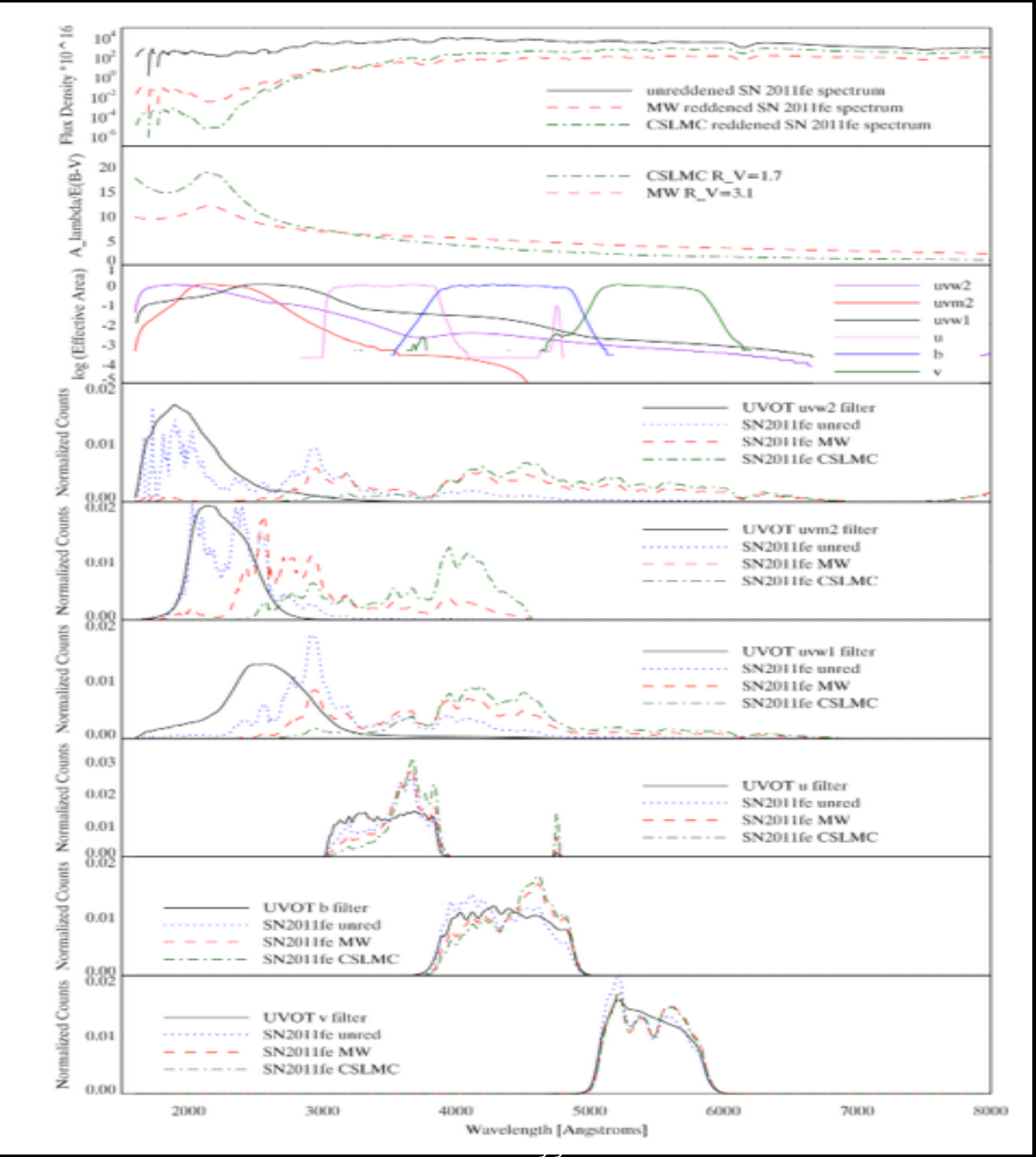
What we have learnt from type 1a SN 2014J

- Reddening: absorption was far from SN: interstellar
- Gamma rays: nuclear processed elements were found early

What did we infer from that?

- The progenitor star of the type 1a SN did not recently eject much matter in shells or a wind. Why? If it was previously a recurrent nova, how long between the last eruptions ?
- The nuclear material from the centre of the explosion could not cause the gamma rays in time.
- Material on the surface of the progenitor at its equator is (perhaps) what started the explosion.
- question: does the matter fall and accrete on White Dwarf stars in novae systems also in a ring around the equator and how do we find out if it does ?

INSTRUMENTAL EFFECTS : RED LEAK



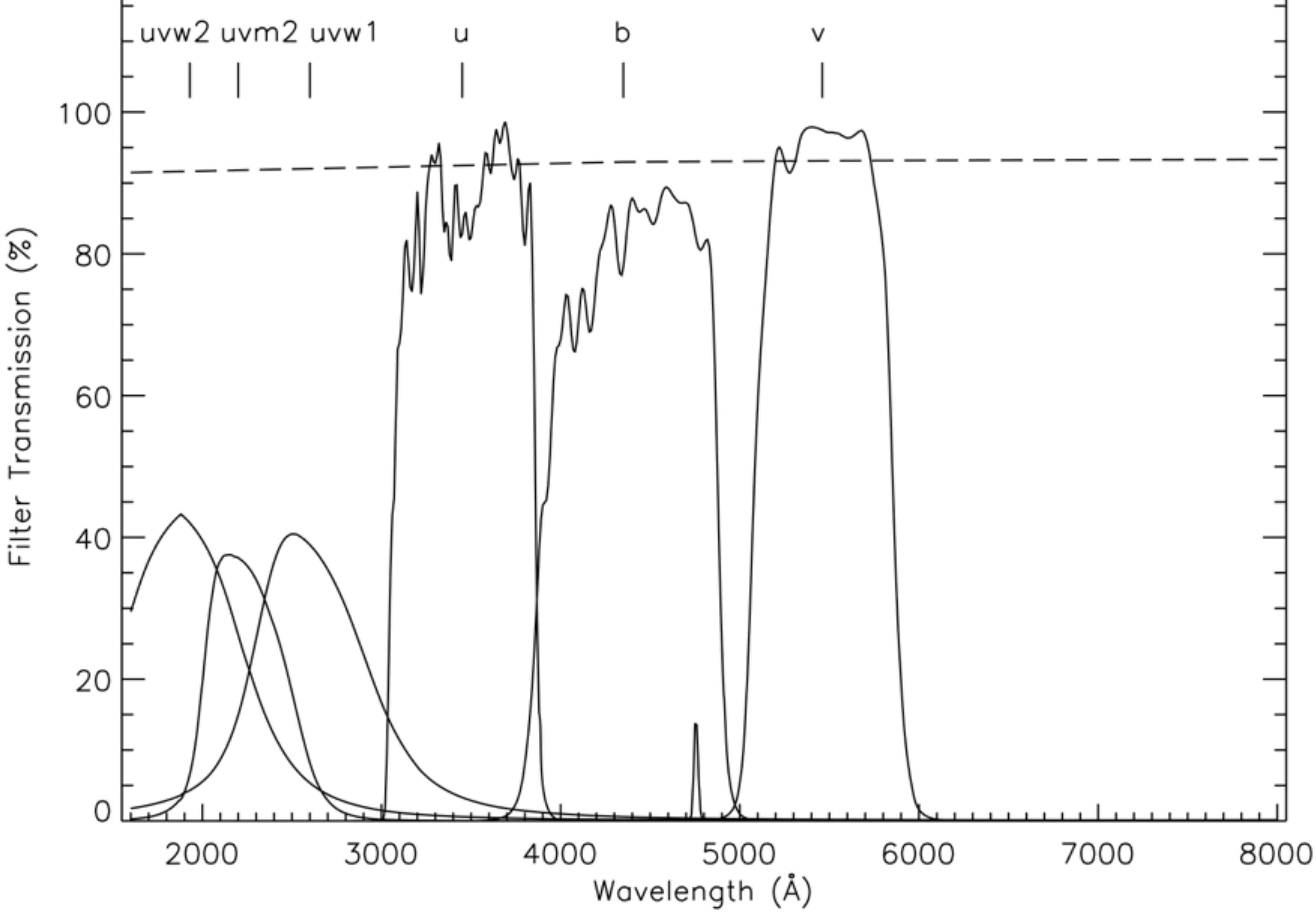


Figure 2. Filter transmission curves for the UVOT filters as measured in the laboratory. The *white* filter transmission curve is given by the dashed line; the identities of the other filters are indicated on the plot. The extra peak at