



Progenitor and environment of the peculiar red nova V838 Mon

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Light echo of
V838 Mon (HST)

V838 Mon (N Mon 2002) is a representative of a new class of astrophysical objects, red novae known since 1988.

Members of this class are V1006/7 in M31, V4332 Sgr, V838 Mon, possible member V1148 Sgr, and two red novae in another galaxies M85 OT 2006-1 and M99 PTF10fqs.

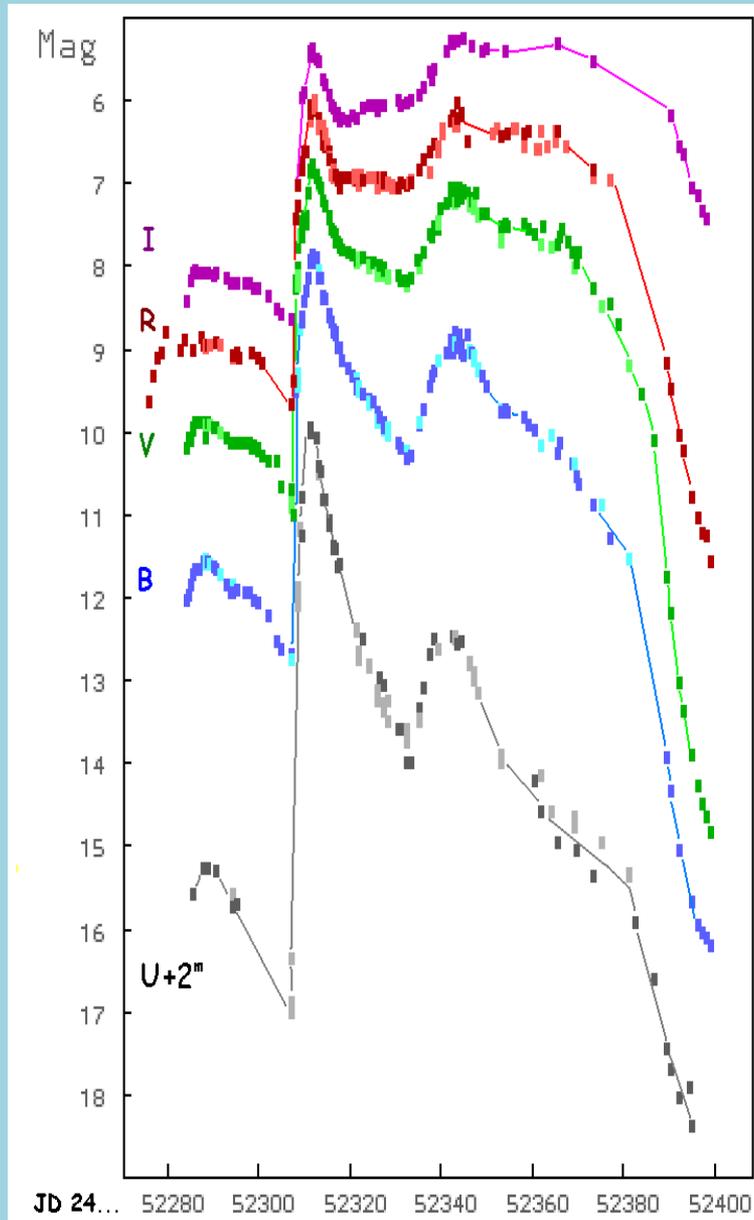
Detailed investigation of V838 Mon revealed cardinal differences between peculiar red and classical novae.

In their outbursts, red novae turn into red K-M type supergiants and do not pass a nebular stage. In an explosion of a red nova, several solar masses of the matter is erupted into space whereas a classical nova throws out ten thousand times less.

The remnant of the V838 Mon is a star of the oxygen branch of cool stars. It is an L-M supergiant while the remnant of a classical nova is a cataclysmic system.

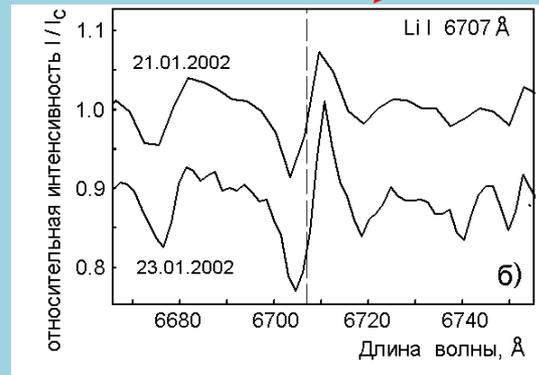
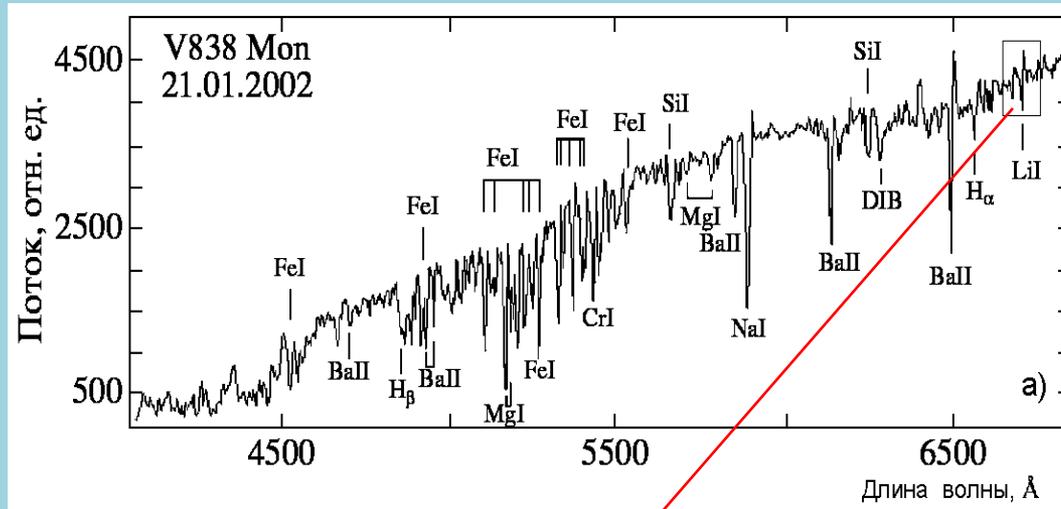
We report the results of multicolor CCD photometry, medium resolution spectroscopy of V838 Mon along with archival photographic photometry of its progenitor.

The light curve of V838 Mon in the outburst from January to May 2002



The light curve shows several peaks in maximum. There is a brightness decrease before the main maximum. We explain these peaks as shock waves coming out to the surface.

The spectrum of V838 Mon in the outburst corresponds to type K0I

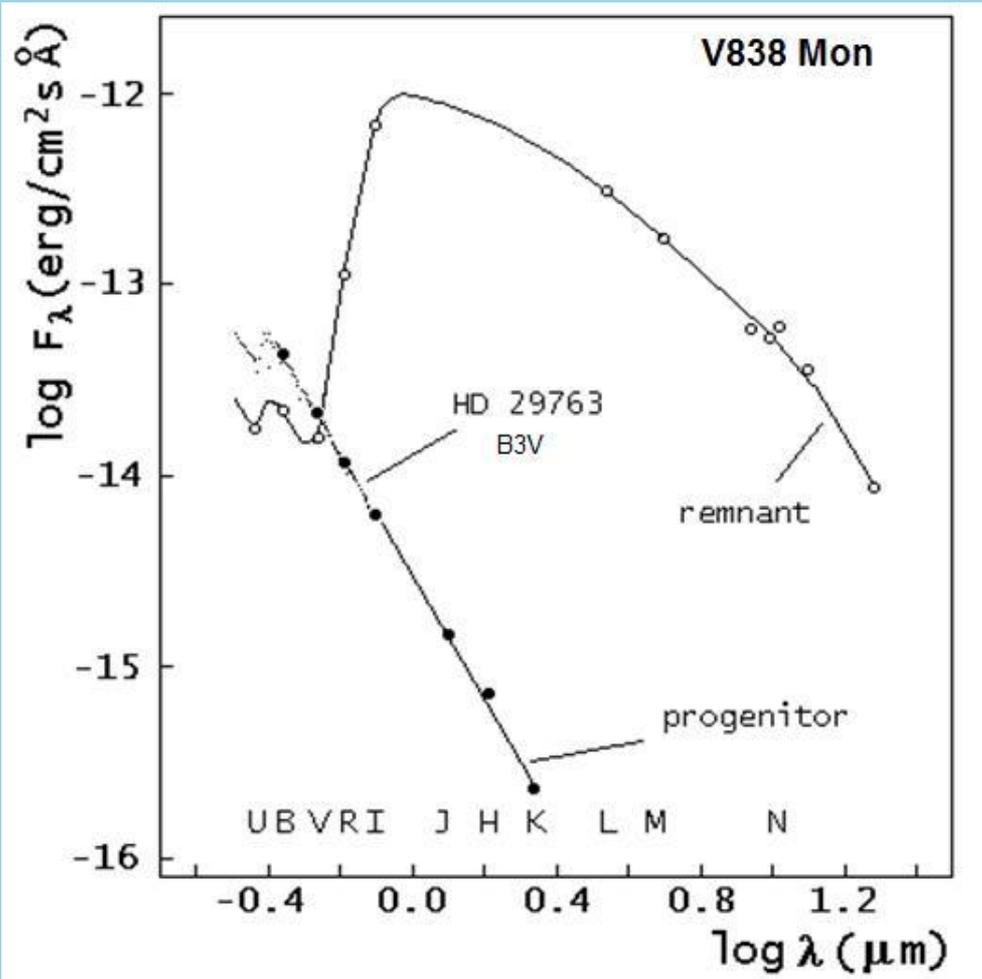


Li I 6707 Å line

Spectral analysis showed that the star with a chemical abundance close to solar one had exploded.

The comparison of the spectral energy distributions of the progenitor and the remnant with the energy distribution of B3V star.

Reddening $E(B-V)=0.77$ was taken into account



Progenitor is definitely a blue star with $(B-V)_0 = -0.17$. It did not show considerable variability over 66 years (from 1928 to 1994). After the outburst, the energy distribution is two-component, containing the B3 component and a IR component, L-type supergiant.

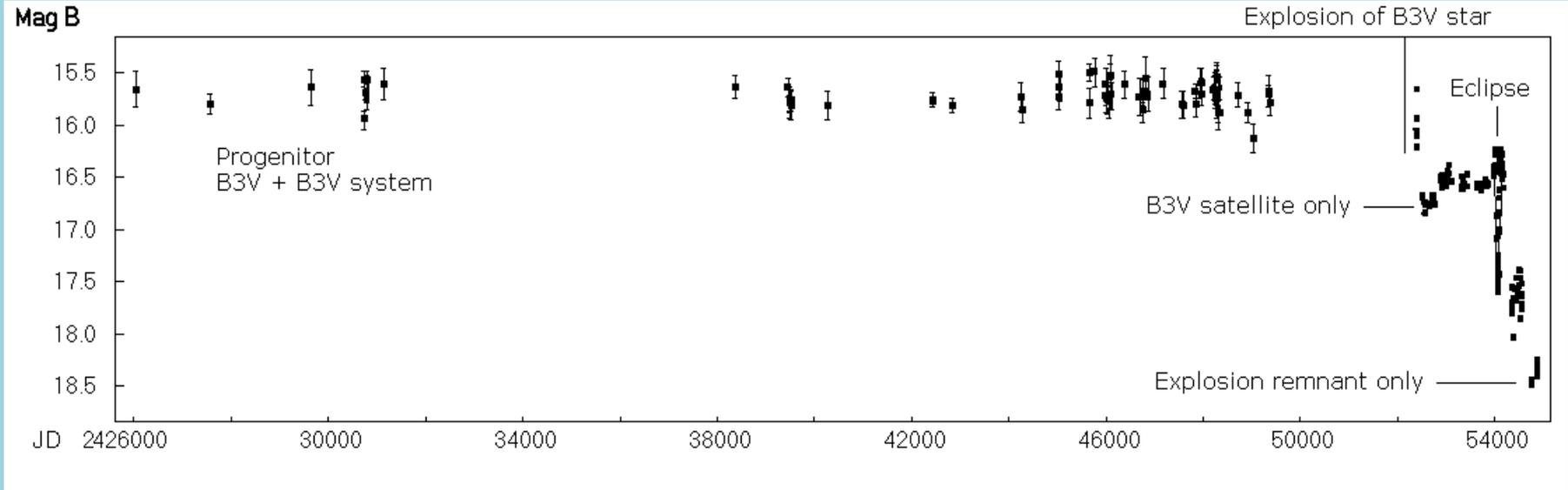
**Before outburst: B3V + B3V
After outburst: B3V + sg(L-M)**

The exploded B3V star was brighter than its blue companion before the outburst by a factor of 1.36 ± 0.03 and their colors were indistinguishable within photometric uncertainties.

We showed that, before the outburst, the star that later exploded had the same spectrum as its companion and mimicked its blue companion .

Summary brightness:	15.27 V,	15.87 B	$B-V=0.60$
B3V component:	16.21 V,	16.79 B	$B-V=0.58$
B3V exploded:	15.86 V,	16.48 B	$B-V=0.62$

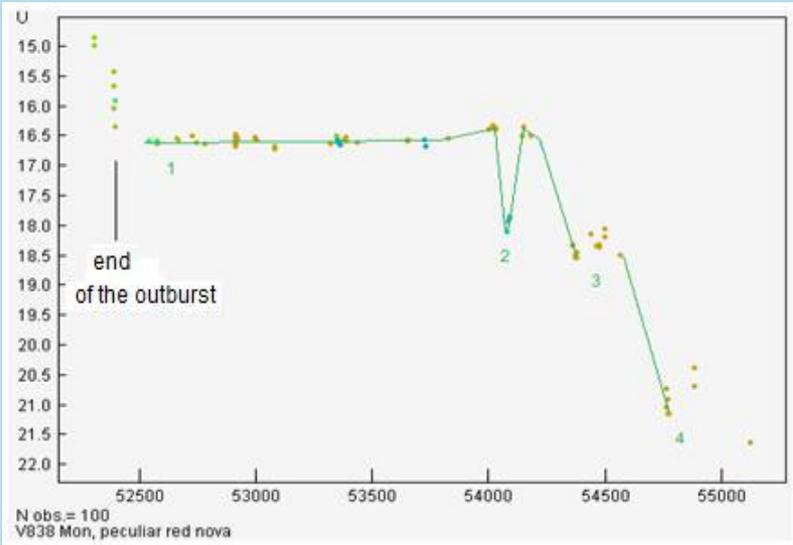
The photometric history of V838 Mon



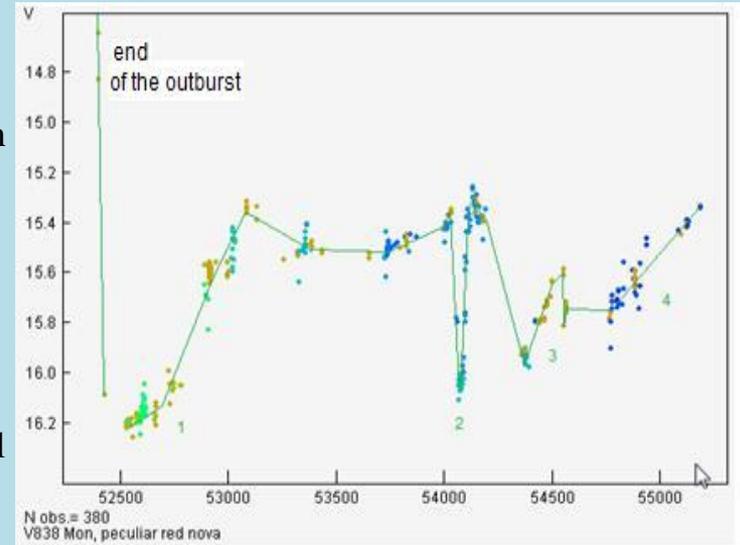
We should mention the importance of Moscow and Sonneberg archival photographic plates for understanding the progenitor's nature. During 66 years the system's brightness was constant. After the outburst, we see photometric indications of a close approach and a collision of two components: first, brightening due to appearance of emission-line spectrum, then, an eclipse of B star observed for 70 days.

Post-outburst evolution.

B3V companion's eclipse-like event happened in December 2006 and lasted 70 days. We explained this feature as a formation of a temporal short-lived accretion disc around the hot companion.



1 – B3V companion
2 – B3V eclipse
3 – B3V through a cloudy structure of remnant envelope
4 – B3V radiation disappeared completely, the cool companion is seen only

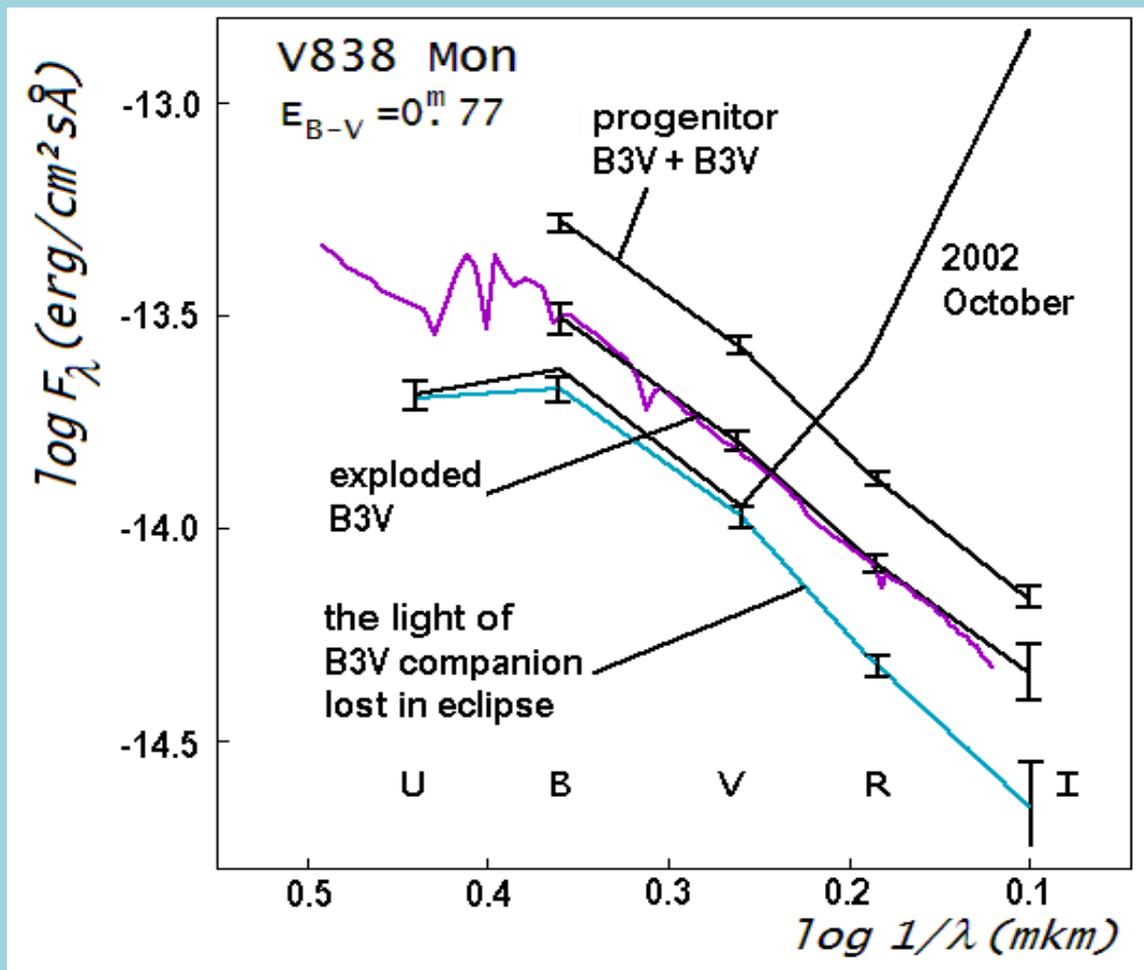


In the next observation season the hot star got into upper layers of the cool star envelope. It faded and fast variations appeared due to passing through a cloudy structure. In October 2008, the hot star completely disappeared from the energy distribution, together with the emission-line spectrum.

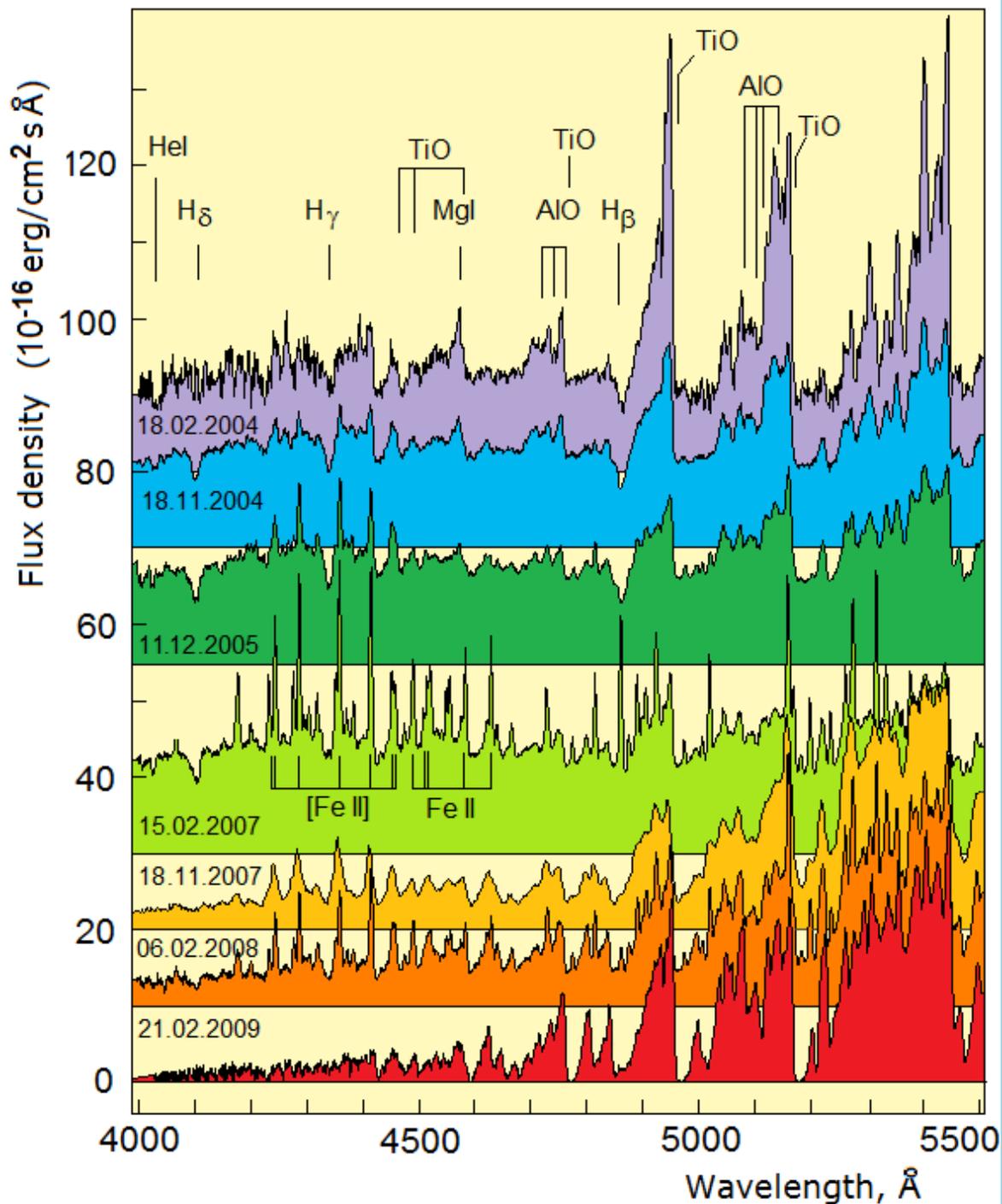
The estimation of SED of the exploded companion using the light of the secondary companion lost in the eclipse.

From top to bottom:

- progenitor, the binary system of two B3V stars (black line);
- exploded brighter B3V star before the outburst fitted by HD 29763 (B3V, violet line);
- binary combined light after the outburst, in October 2002 (with *IR* excess) (black line);
- B3V companion's SED disappeared in the eclipse-like event in December 2006 (blue line)



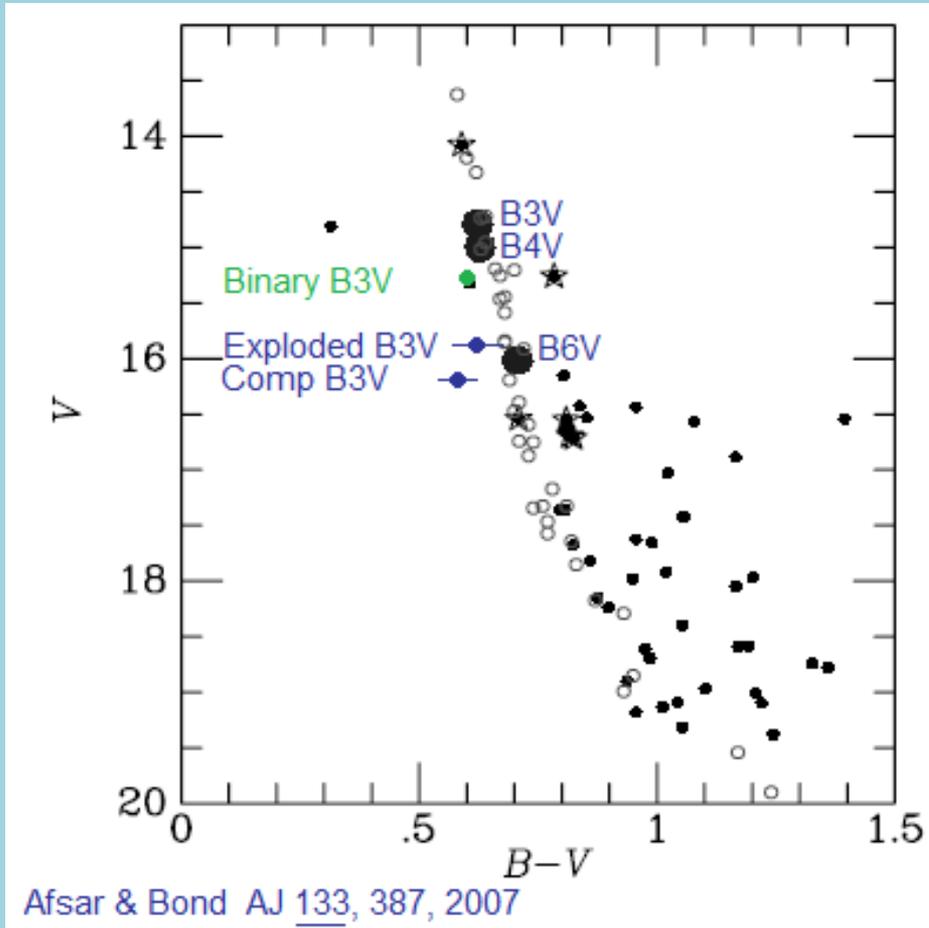
Using a loss of the hot star light in the eclipse, its SED was estimated in all ranges of spectrum from *U* to *I* bands. Subtracting this distribution from the system's combined light before the outburst, we obtained the energy distribution of the exploded star before its outburst in the bands from *B* to *I*.



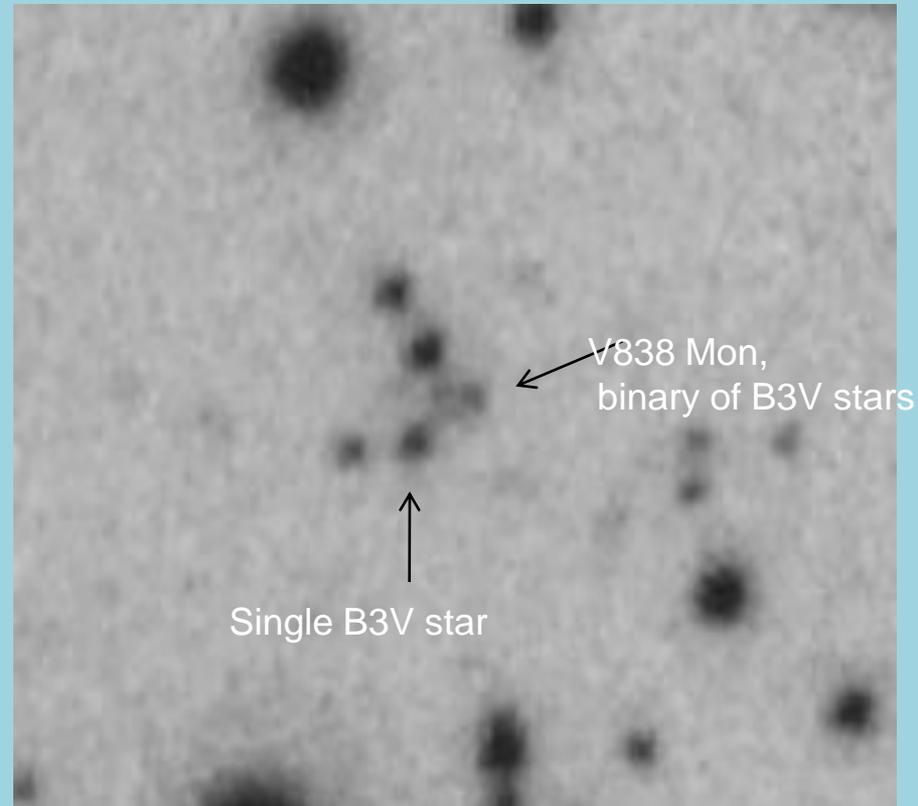
Evolution of two-component spectra of explosion remnant (BTA/SCORPIO).

Here, the spectroscopic history of the approach and engulf of the hot B3V component by the expanding cool remnant is presented. In the blue region there is B3V star continuum with hydrogen and helium absorption lines. To the right, an absorption molecular spectrum of the cool supergiant is seen. The strongest bands on the right side are titanium oxide bands. We observed how emission spectrum of ionized gas increased its intensity. In 2009, neither the hot companion nor the emission spectrum are seen. The residual intensity at minimum of the TiO bands is zero. Thus, the hot companion plunged into the expanding remnant of the outburst.

V838 Mon is a member of a cluster of B stars



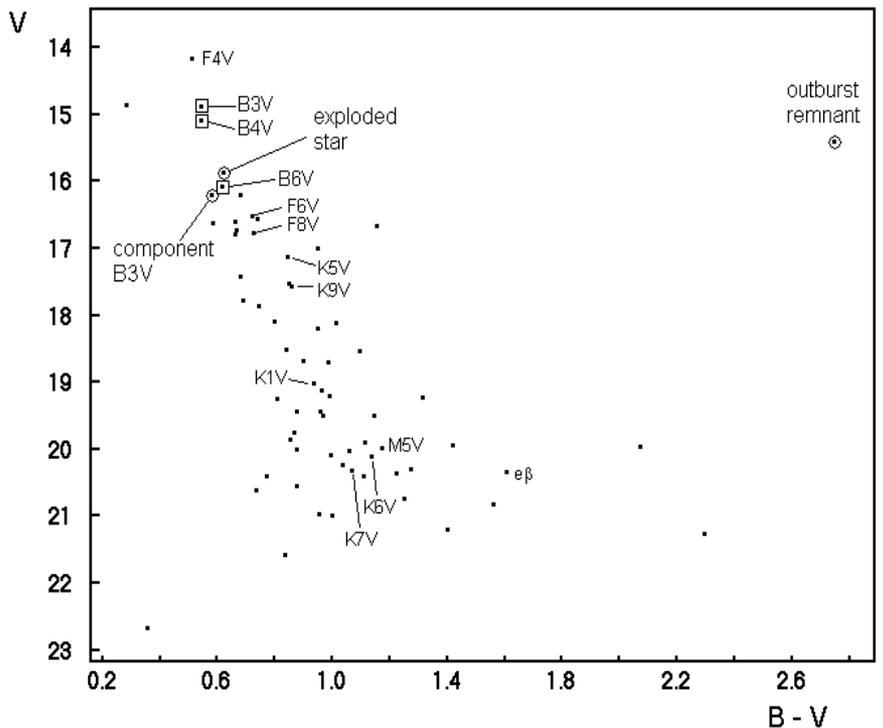
Location of V838 Mon components in C-M diagram. Both components have the same color excesses equal to cluster's color excess, but components themselves were stars of lower luminosities for their B3V spectral type: the exploded component was fainter by 0.97 mag, and the remain one - by 1.32 mag.



Progenitor of V838 Mon.

Photo was taken on 28.02.1943 at 40-cm astrograph in Sonneberg Observatory (Germany).

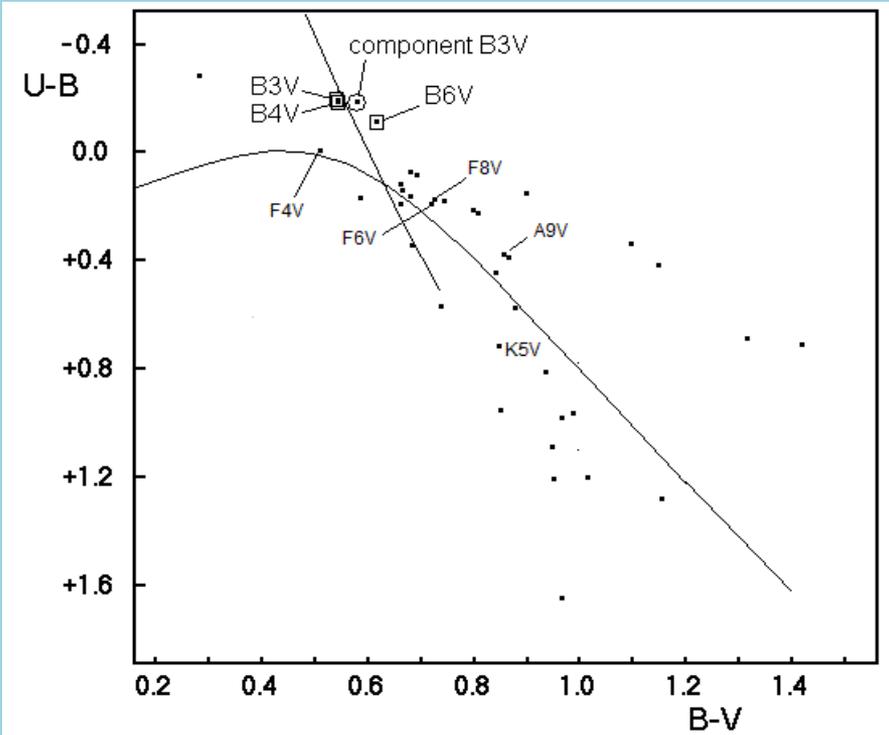
The binary B3V star looks fainter than the single B3V one.



C-M diagram for V838 Mon components, stars which are members of V838 Mon cluster and stars in the vicinity of V838 Mon within the limits of the nebula which the light echo crossed.

Points are our observations, some of them have spectra taken on BTA/SCORPIO.

Squares are stars of the Afsar & Bond's cluster. Circles are components of V838 Mon.

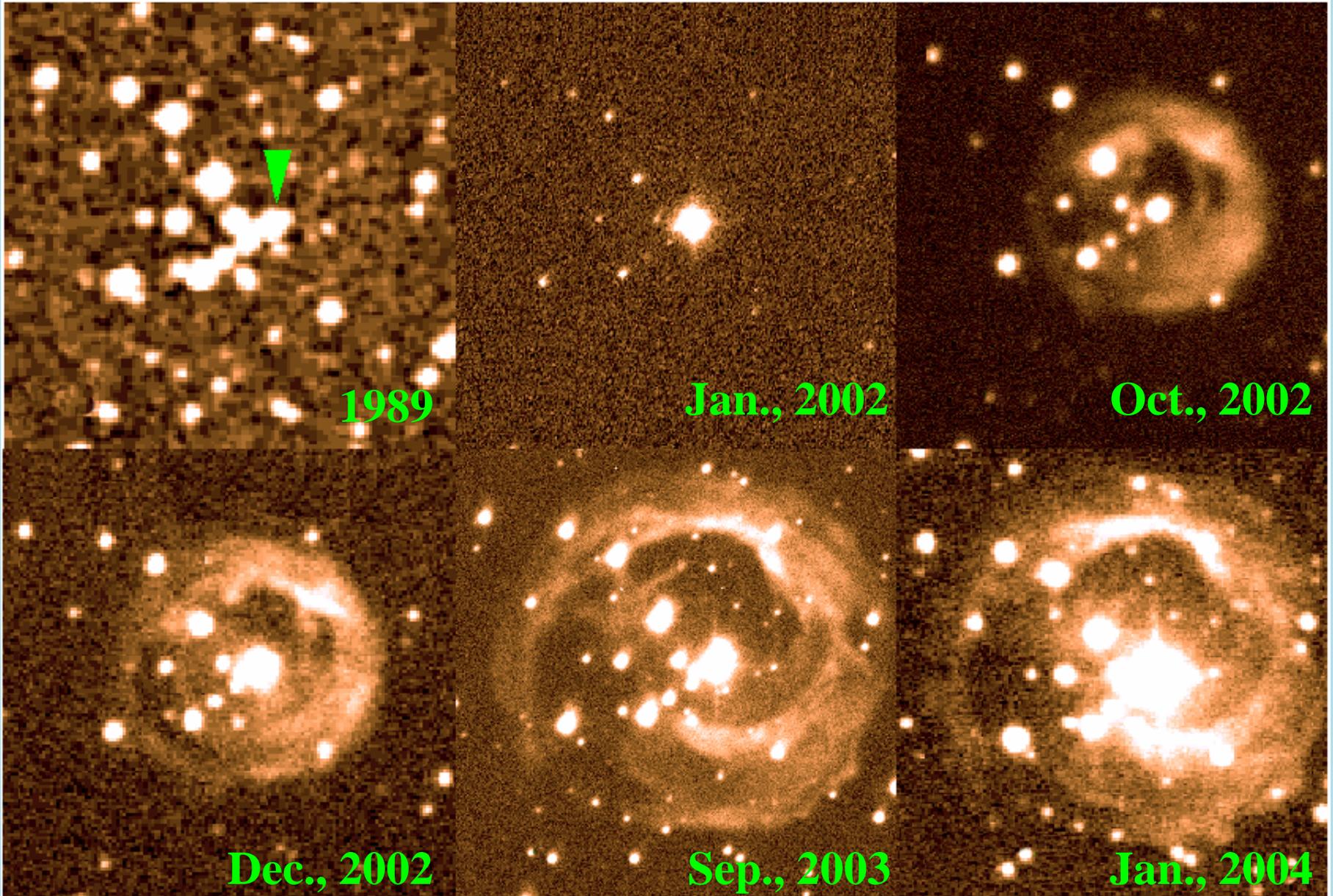


Two-color diagram ($U-B$)-($B-V$) for V838 Mon vicinity in the limits of the nebula .

Squares are stars of the Afsar & Bond's cluster. Circle is the location of B3V companion of the V838 Mon system. Straight line is C-C diagram for normal main sequence stars with reddening coefficient $E(B - V) = 0.77$.

Curved line is the same diagram without reddening.

The light echo of V838 Mon with 1m Zeiss SAO RAN



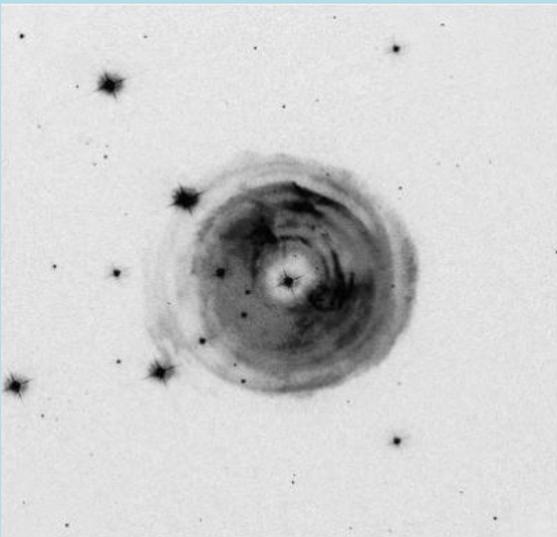
The light echo of V838 Mon

Arcs and central cavity are seen in the first HST image.

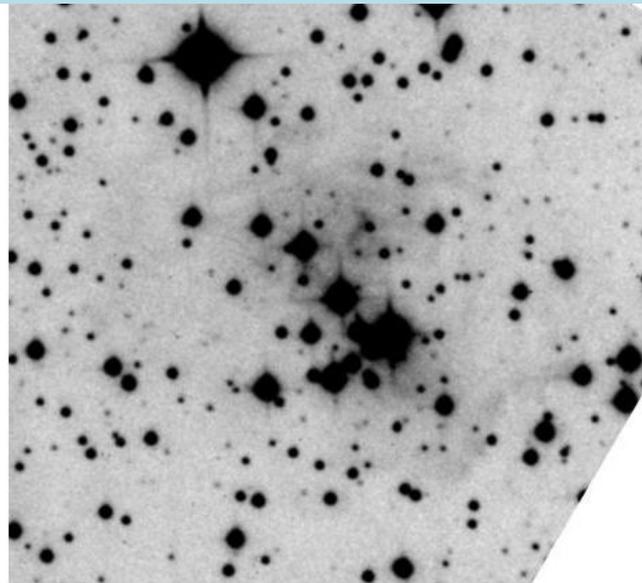
The other images of the light echo were taken with SAO RAS 1m Zeiss telescope in 2007, 2008 and in 2009. Boundary of the echo is still visible in the images of 2007 and 2008.

In the end of 2009 the faint echo in 30" to the north of V838 Mon is visible only.

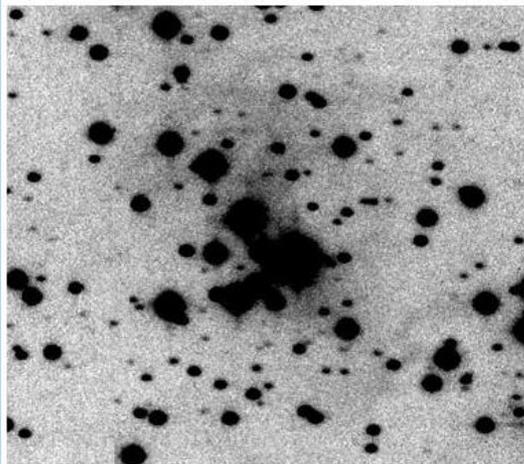
Inner unlit cavity in the first HST images was observed due to V838 Mon location exactly on a remote boundary of a thick dust layer. The distant part of light ellipsoid turned out to be in clear of dust void. Just after the outburst, the light ellipsoid is very narrow, and we see its surface under very small angle. This is why sections of any objects by this ellipsoid look like arcs due to effect of projection.



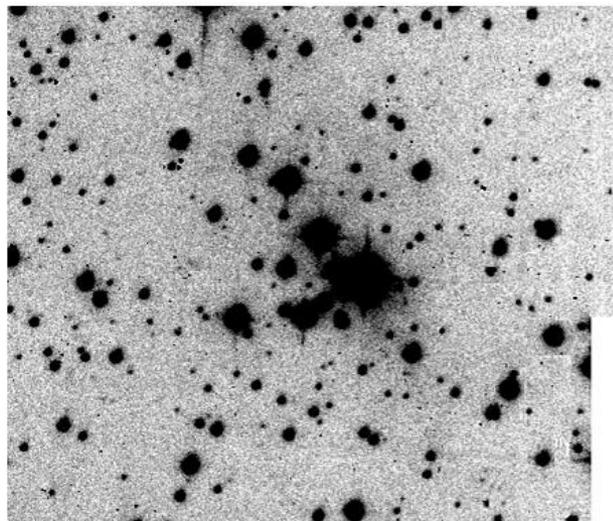
30.04.2002 HST



14.02.2007 SAO 1 m Zeiss telescope

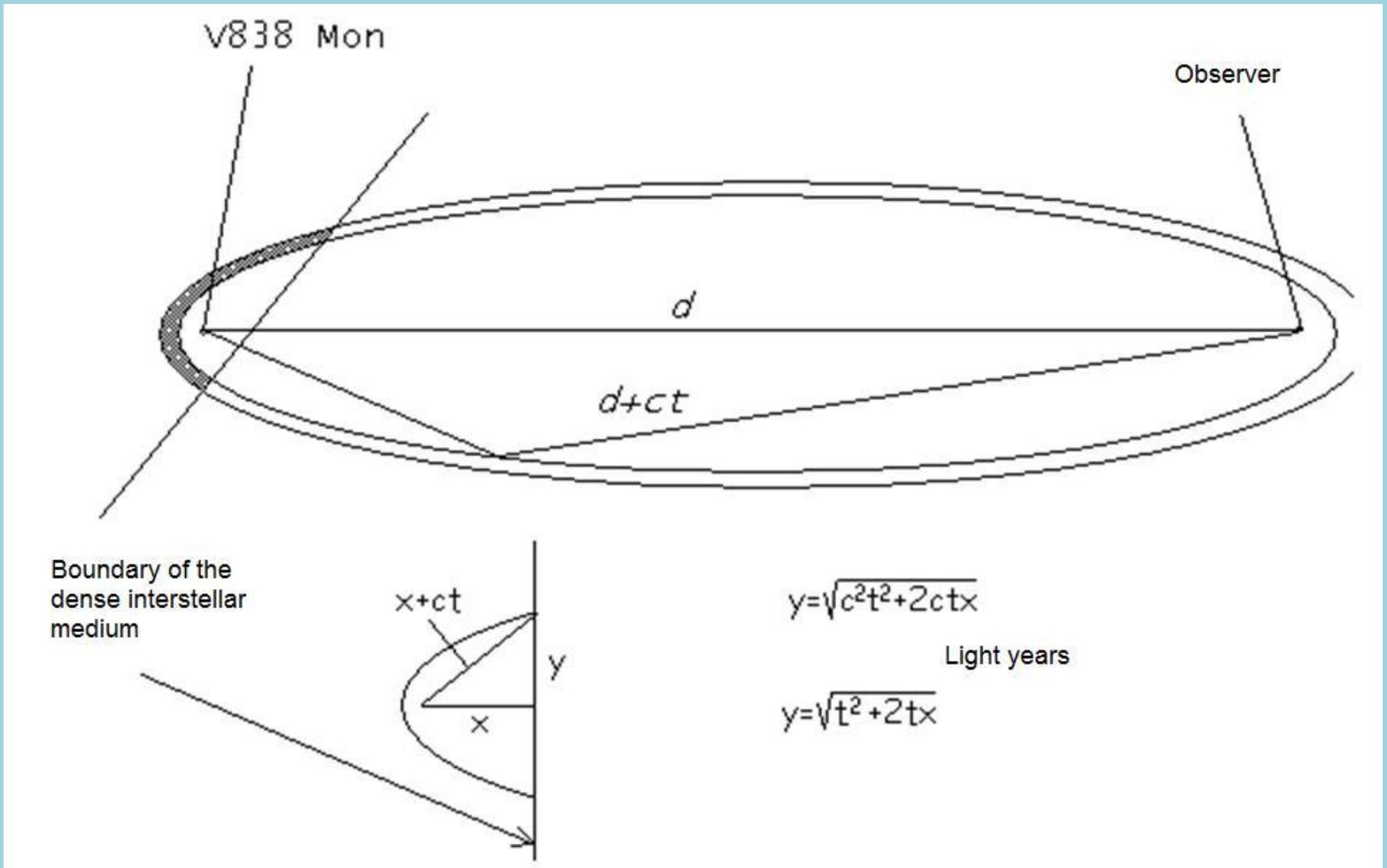


12.01.2008 SAO 1 m Zeiss telescope



21.10.2009 SAO 1 m Zeiss telescope

Model of light echo



Light echo V838 Mon expansion in four directions

Superluminal part is marked.

1 - part of the expansion along the nebula frontal surface

2 - expansion along side walls of nebula

Points - our observations

H - Hubble

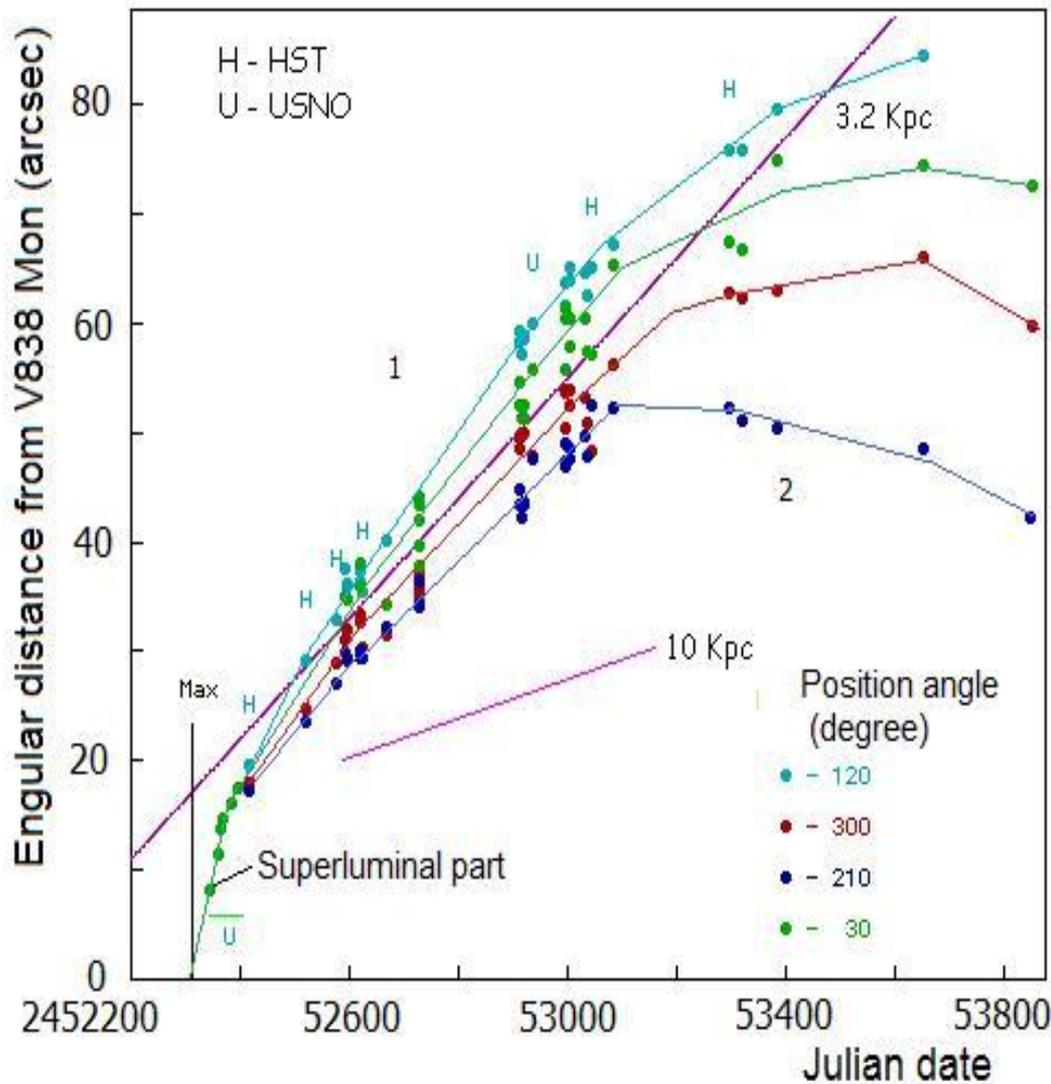
U - USNO

Max - time of V838 Mon brightness maximum

The distance from the star to echo external boundary changes with time.

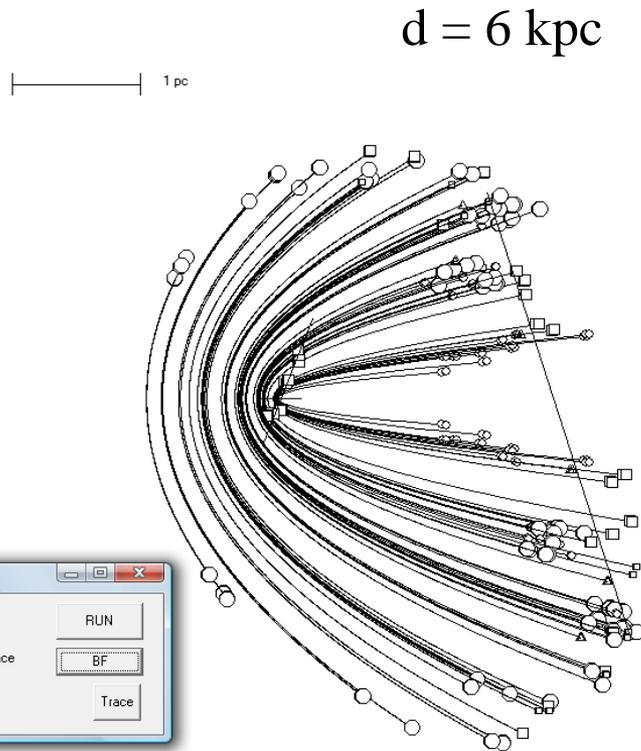
Straight violet lines (asymptotes) approximate this dependence.

Asymptotes were calculated for two distances from the star to the observer: 3.2 and 10 kpc.



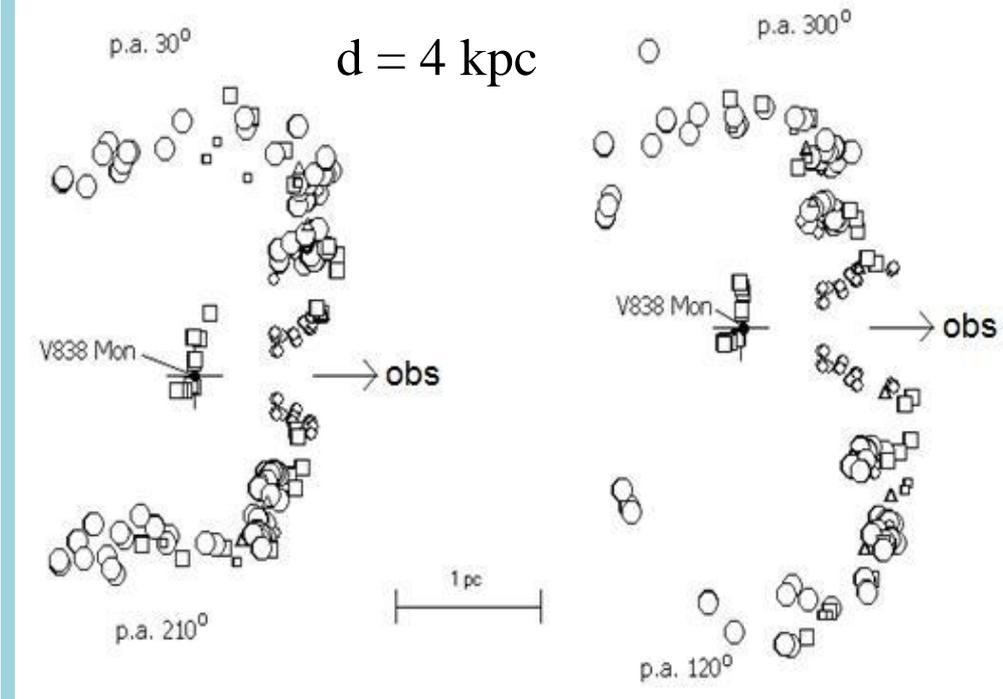
The dependence of distance from the star to the echo external boundary on time is demonstrated.

Models of the gas and dust nebula constructed on the basis of expanding light ellipsoid



The frontal boundary of the nebula is inclined to the surface that is perpendicular to the line of sight by 15° .

The distance $d = 5 \pm 1 \text{ kpc}$ determined by us using the light echo is in agreement to that distance which was determined for normal stars for cluster of B stars.



Two planes of section of the nebula. They come across the line of sight under different position angles.

Squares are Hubble observations.

Big circles are our observations.

The direction to observer and the location of red nova are marked.

Squares near the star fix remote boundary of dust layer which the red nova is located.

Evidences of early age of the red nova V838 Mon:

Abundance of the exploded star is close to the solar one
(not evolved star of Zero Age Main Sequence).

Remnant belongs to oxygen branch of cool stars (TiO, VO, AlO in the spectrum).

Litium is present in flash spectrum.

Components before the outburst are underluminous stars.

Membership of V838 Mon components to the B star cluster.

Connection of B star cluster with gas and dust nebula.

Hypotheses: flash in dwarf binary with ‘cool’ degenerated dwarf, flash in AGB stage, classical nova without nebular stage, star merging, Thorne – Zytkov like event, swallowing down planets.

Our hypothesis is a flash in PMS stage:

Thermonuclear explosion of hydrogen in the center of a hot pre-main-sequence star which radiates due to gravitational contraction.

At that time the main part of stellar mass is exposed to push for the radial and almost adiabatic expansion and cools down as a result. When the radiation and shock wave of the explosion come out to the star surface, its area turns out to be so large that it cannot be heated up to high temperature, and that is why the late K-M spectrum of the star reflects its low temperature.

Such behavior of the red novae phenomenon cannot be confirmed by the evolutionary calculations because these calculations represent the sequences of static equilibrium models. The dynamic calculations are needed for the confirmation.

Thank you

