B[e] Star CI Cam: Eighteen Years of Research

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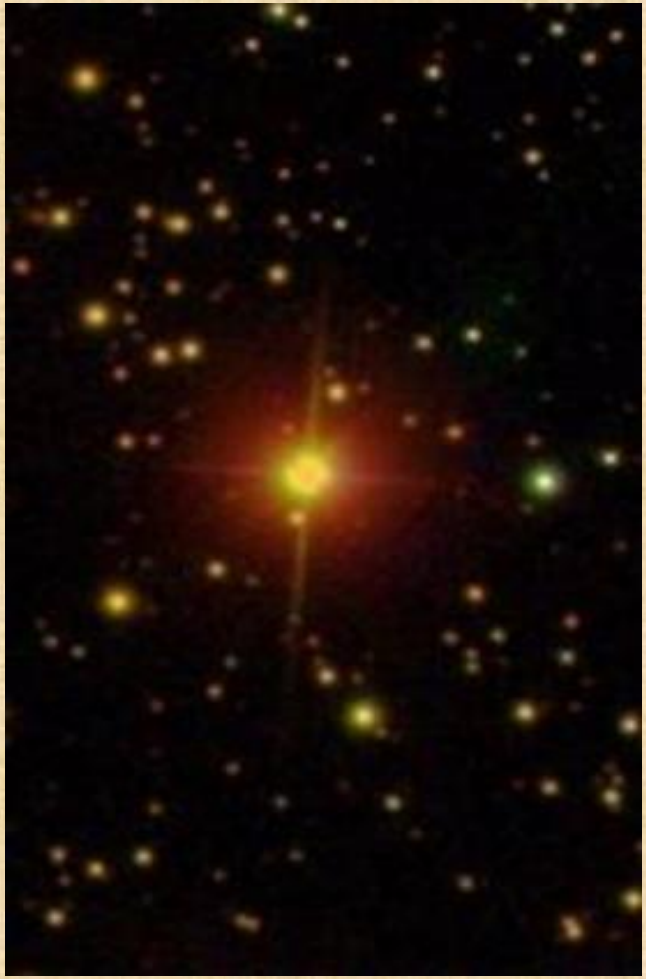
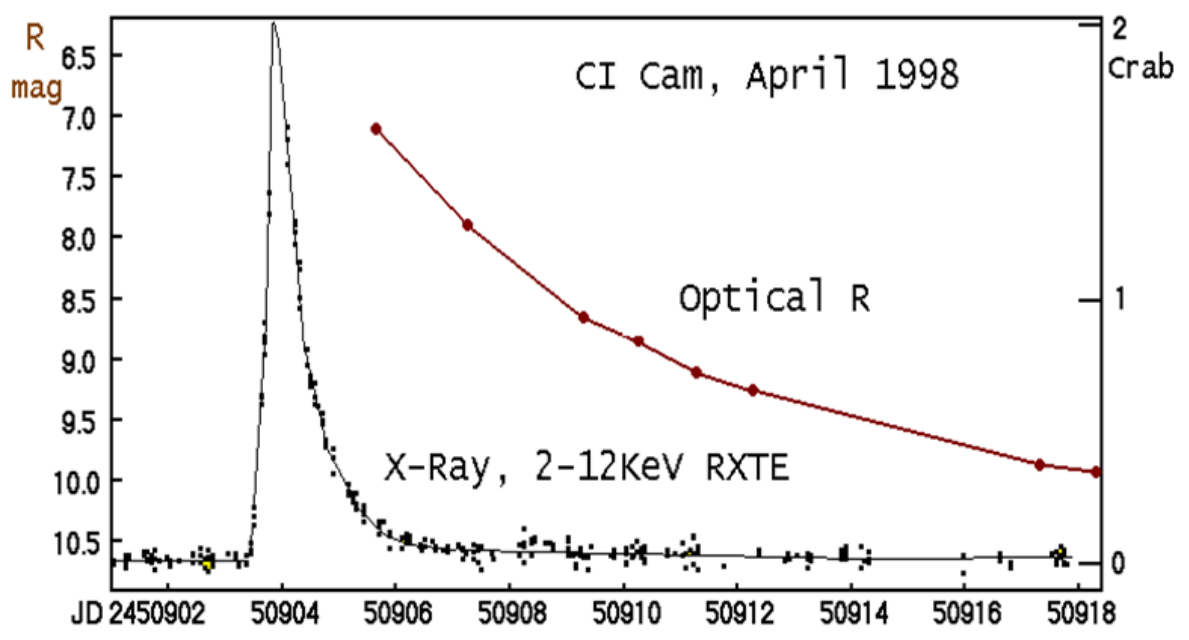


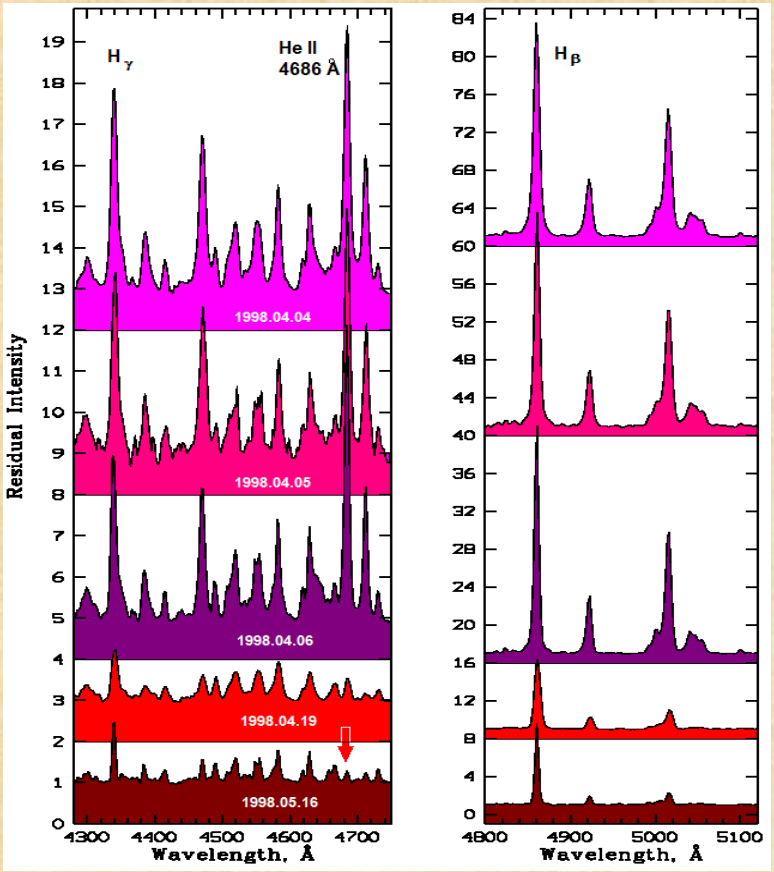
CI Cam. SDSS image



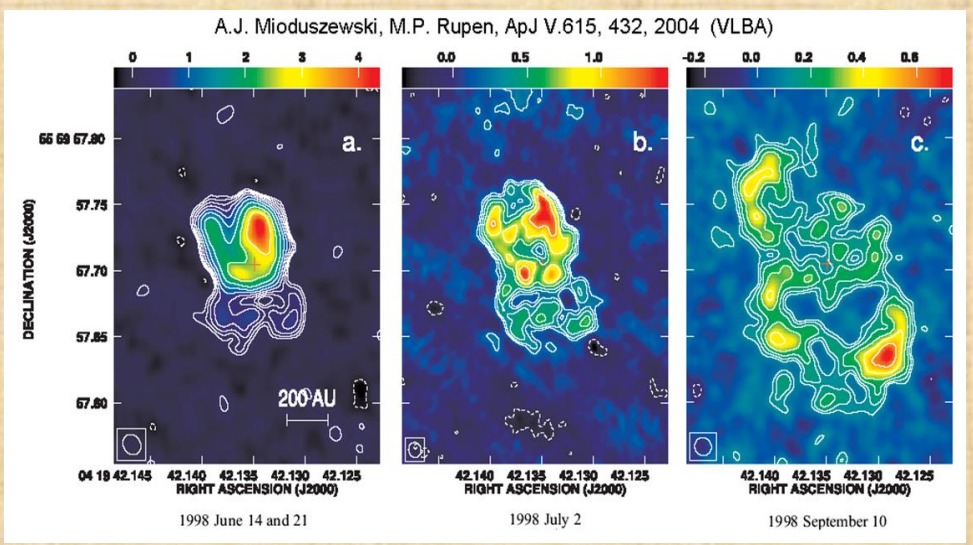
Strong outburst in γ-, X-ray, optical and radio waves occurred on 1998 April 1.

CI Cam in the 1998 outburst

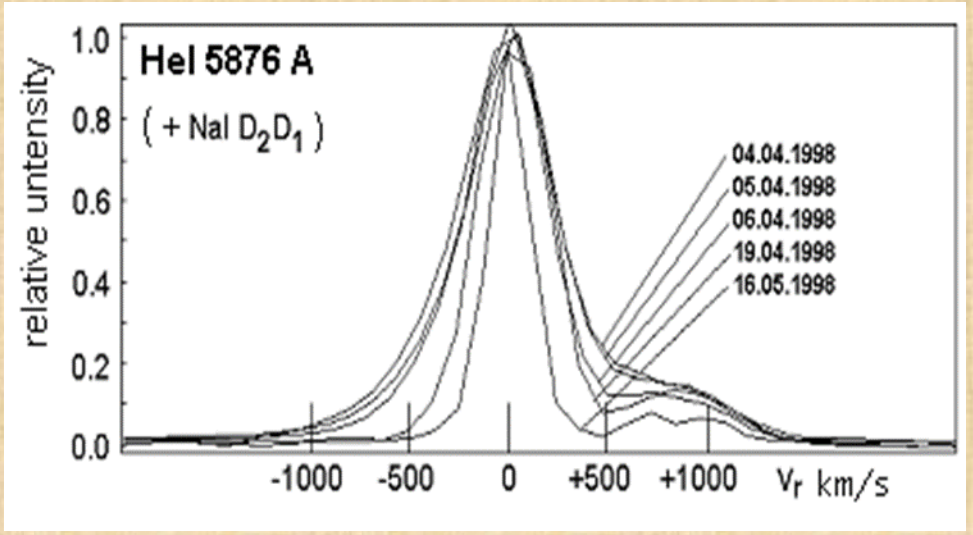
Thermonuclear explosion of hydrogen accumulated on the surface of a *white dwarf* (Orlandini et al., 2000; Ishida et al., 2004). Peculiar Classical Nova: exploded in the dense medium (therefore it was strong in γ rays), hydrogen accumulated from the disk and wind, open burning on the surface (soft X rays), massive and hot companion.



BTA/SP124 spectra taken during the outburst decay between April 4 and May 19, 1998. Strong brightening of He II 4686 Å emission is visible in the outburst.

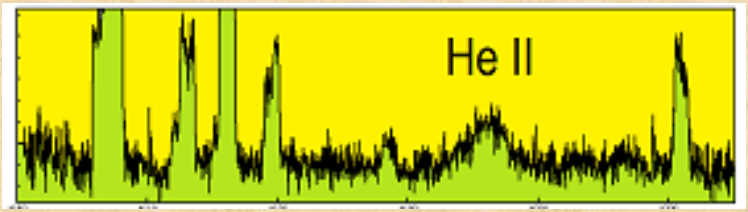


VLA radio intrferometry
CI Cam's radio remnant, "a shock ploughing into a dense circumstellar medium"



The ejecta with the velocity of 1200 km/s were seen as broadening of the line profiles and wide wings (BTA/SP124)

Russian 6-m telescope with the NES echelle spectrograph is pointed to CI Cam to monitor rapid changes in spectral lines on 2012 Jan 6.



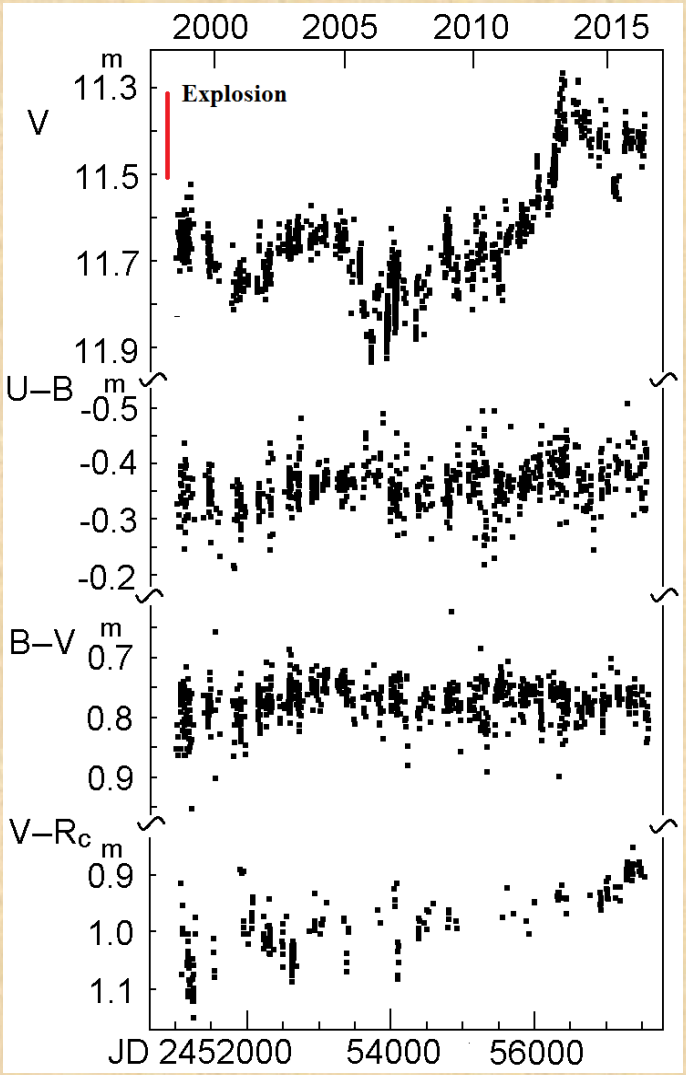
He II 4686 A line in this night

Observations of CI Cam since April 1998:

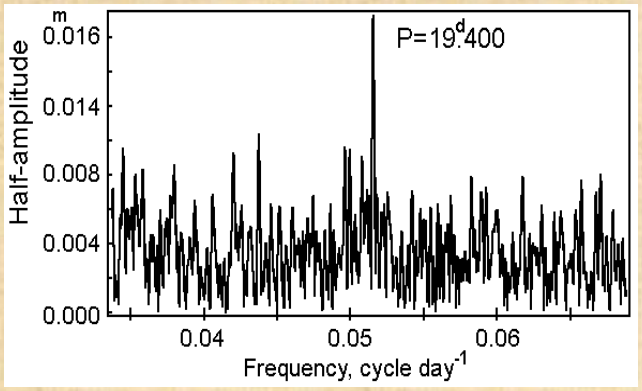
- Photoelectric and CCD UBVR photometry, 586 nights;
- Optical monitoring in the V band, 5 seasons, 69 nights;
- Medium resolution optical spectroscopy, R=350-1000, 198 spectra;
- High resolution optical spectroscopy, R=13000-60000, 30 spectra;
- Spectral high resolution monitoring, R=60000, 1 night, 35 spectra.

CI Cam: UBVRc photometry

The white dwarf is detected.
Its 19.4 day orbital period is present.

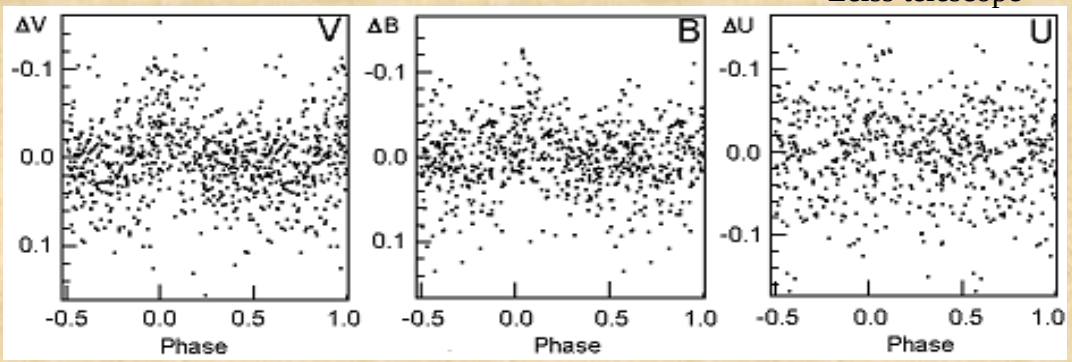


Light and color curves of CI Cam after the 1998 outburst (586 nights).
The star became brighter by 0.4 mag since 2009.

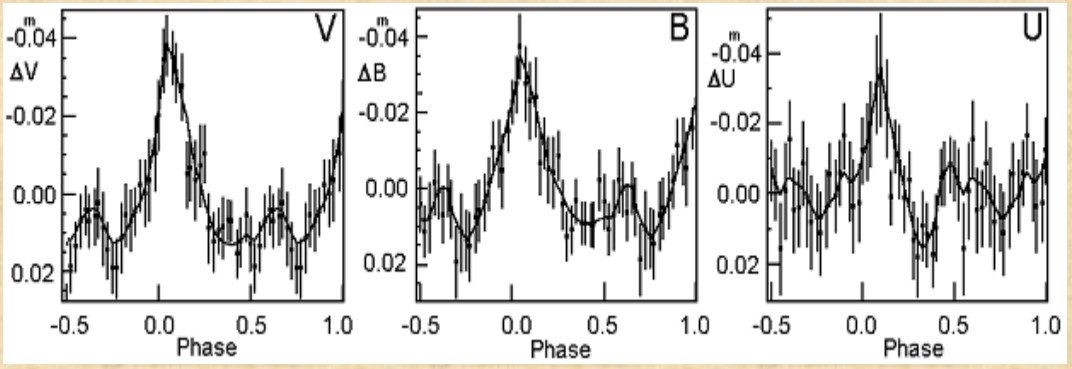


Deeming periodogram calculated for residuals in the V band when the main trend eliminated shows periodical variations with P=19.40±0.03 day

SAI Crimean Station 60 cm Zeiss telescope



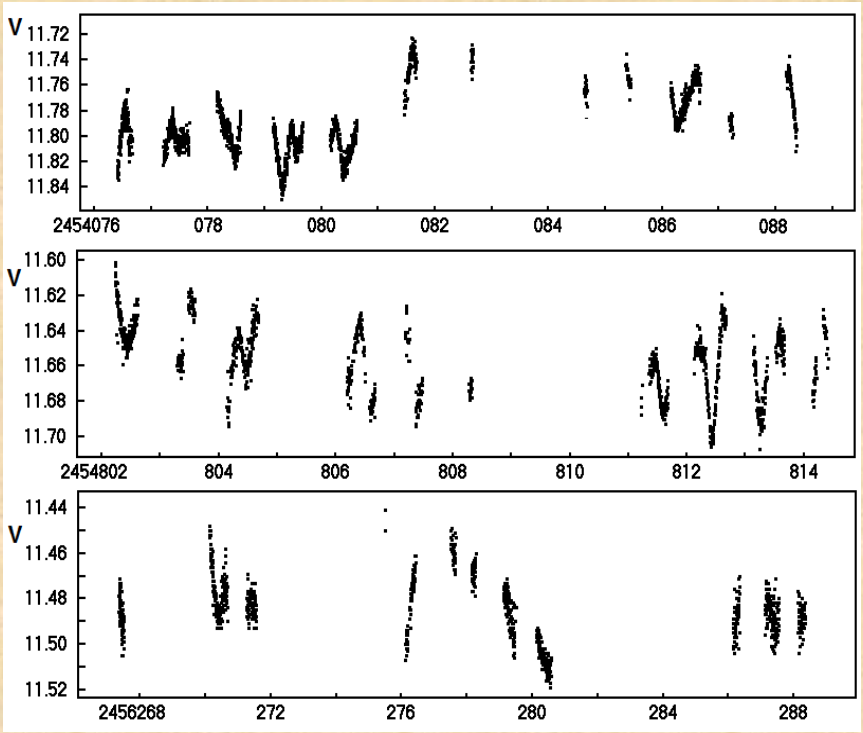
Light curves for residuals plotted versus phase and calculated for nightly averaged observations with the period of 19.40 days.



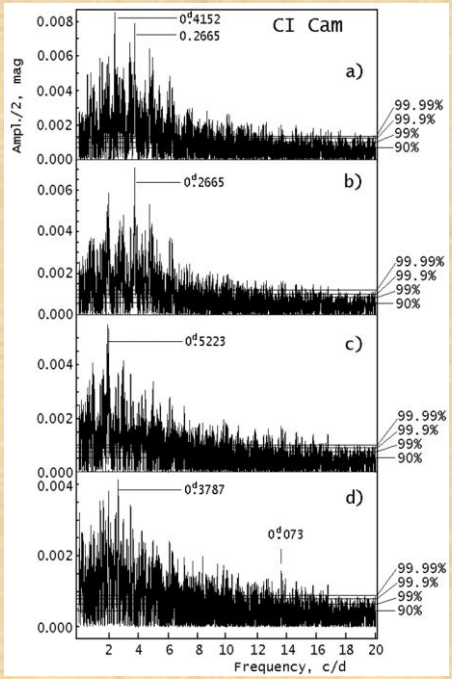
Averaged phased light curves with the period of 19.40 days.
The full amplitude of orbital variations amounts to 0.046 mag.

CI Cam: photometric monitoring

Double-mode pulsations. 3:2 resonance.

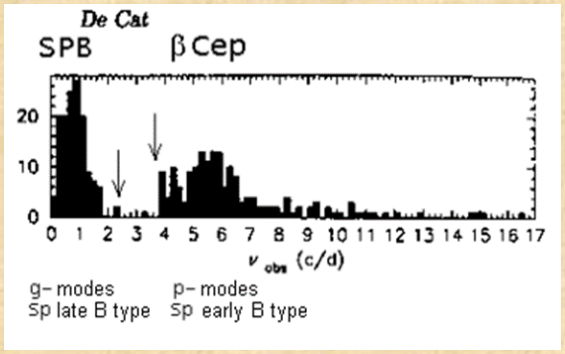


Fragments of light curves taken in the course of monitoring. Top: December 2006, middle: December 2008 (both in optical low state). Bottom: December 2012 (in optical high state).

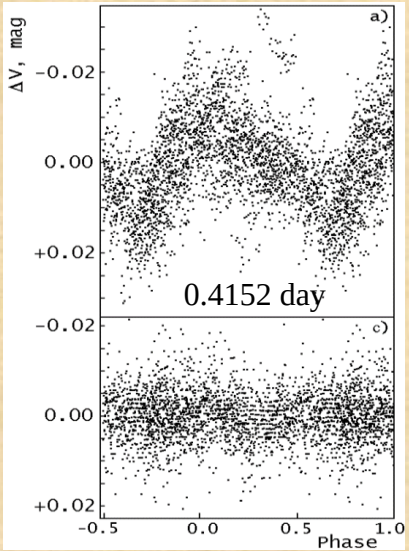


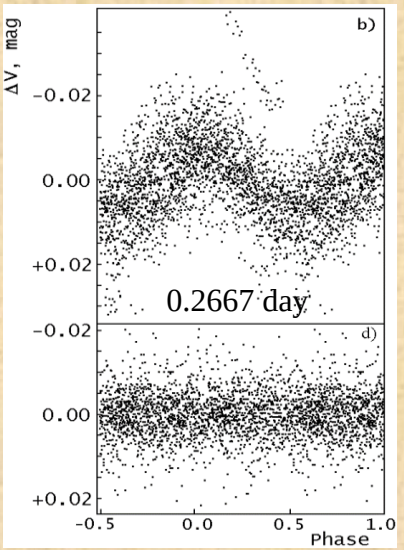
Fourier transform and decomposition of components with the Deeming method.

50 cm Maksutov meniscus telescope of the SAI Crimean station used for monitoring of CI Cam



The distribution of frequencies of gravity and pressure modes in pulsating B-type stars (De Cat, 2001) , and dominant frequencies of CI Cam (two arrows). The star is not a super-giant.



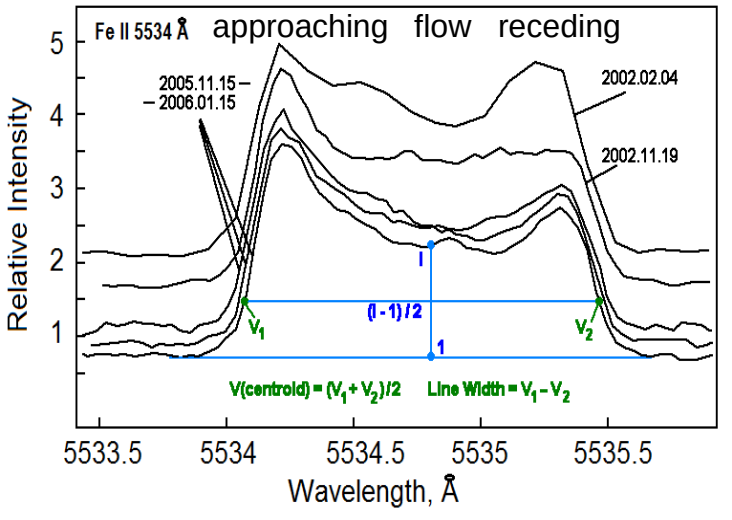


Main components extracted from CI Cam light curve (top). Check star GSC 3723.0080 with the same periods (bottom).

CI Cam: line profiles

The majority have rectangular shape with a full width about 75 km/s.

Non-Keplerian wind equatorial disk

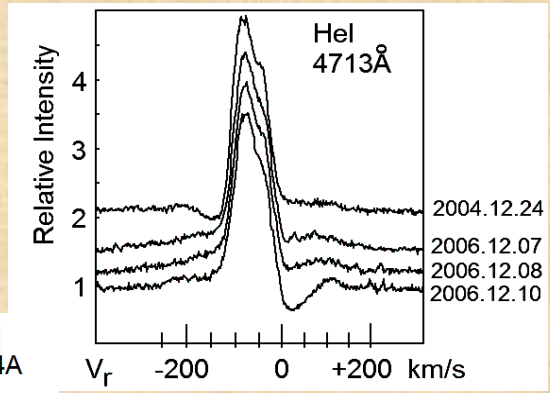


Structure of Fe II lines in the BTA/NES spectra of CI Cam (the profiles are superimposed for a better view). Figure demonstrates the method used to estimate radial velocities and widths of wind lines. The accuracy of echelle velocities is ~1 km/s using BTA/NES, CFHT/ESPaDOnS, McDonald Smith 2.7 m and Struve 2.1 m with Echelle spectrograph, and ~2 km/s with the 2.1 m San Pedro Martir telescope and REOSC spectrograph.

Russian 6 m BTA telescope, NES

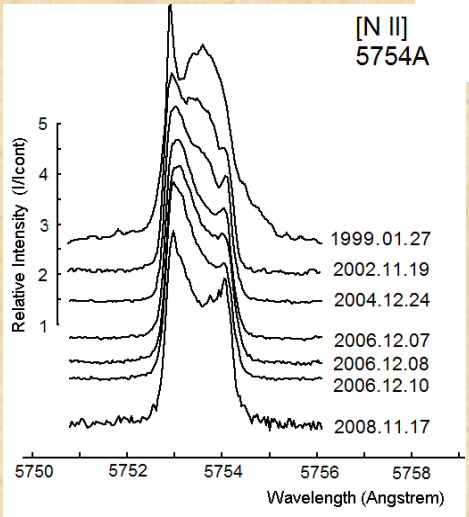
McDonald Smith 2.7 m telescope, cs2

Canada-France-Hawaii 3.6 m telescope, ESPaDOnS



Rapid night-to-night variations in He I 4713Å line. The absorption components are changing from time to time, what we think to be due to pulsation waves.

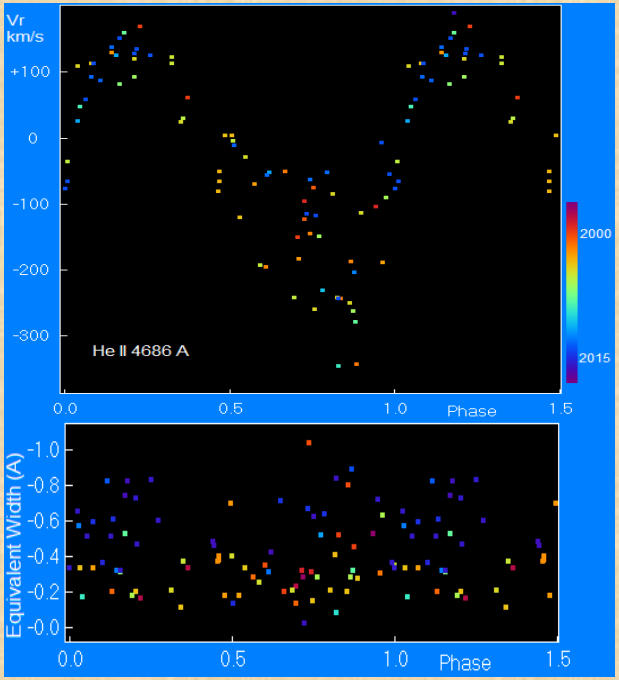
2.1 m telescope San Pedro Mortir, REOSC



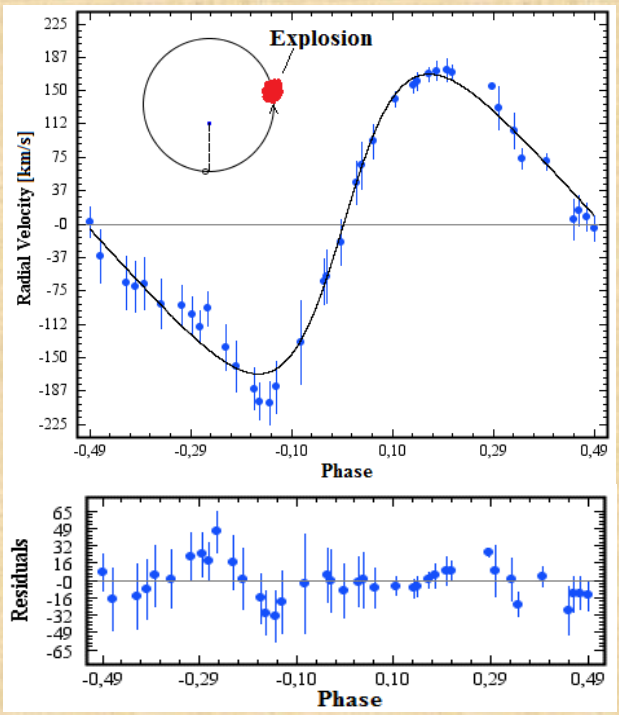
Slow variations of [N II] 5754 Å forbidden line profile after the 1998 outburst (the profiles are superimposed for a better view).

CI Cam: medium resolution spectroscopy

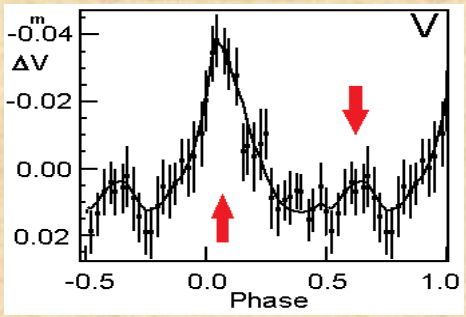
The orbital period can be seen in the shifts of the He II 4686 Å emission line.



The most reliable radial velocities and equivalent widths plotted versus phase of 19.400 day period. Colors show dependence on time. There is a high dispersion of velocities before the periastron.



The best solution of the average velocity curve taken with the *Console* package (S. Meschiari, et al., 2009, PASP V.121, 1016).



The star becomes brighter in the nodes when the orbit crosses the equatorial disk.

New mean orbital elements:

T_0=JD 2453751.2

P(orb)=19.400 ± 0.030 day

K = 169 km/s

$a \cdot sin(i)$ = 0.6 a.e.

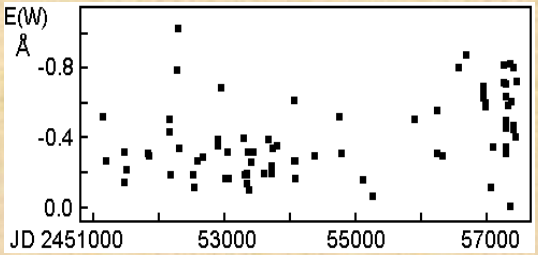
e = 0.27

periastron longitude ω = 270°

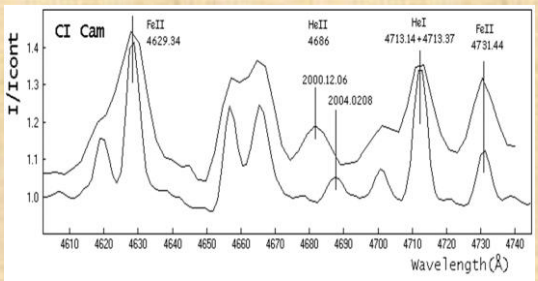
mean anomaly M = 358°

f(M) = 59 $M_\odot$ [!]

1 m Zeiss telescope of SAO RAS having been mostly used with UAGS spectrograph for medium resolution spectroscopy.



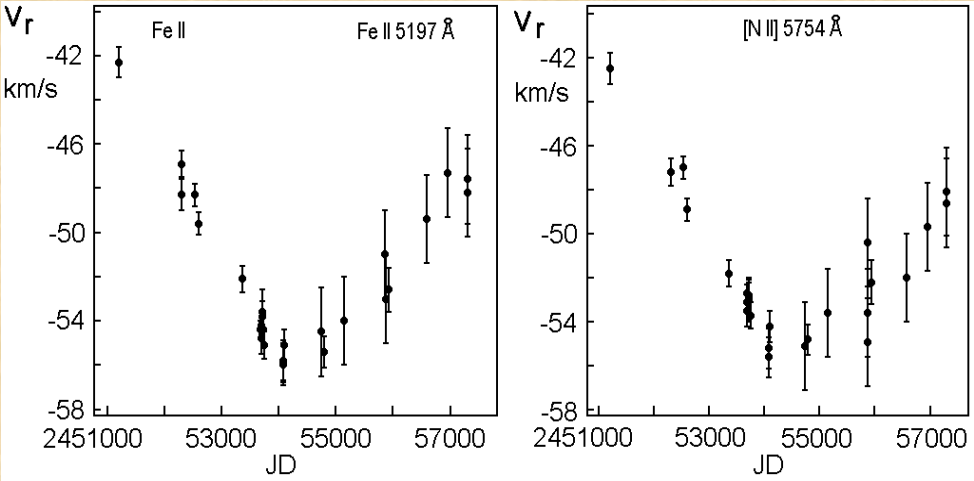
Equivalent widths of He II 4686 Å plotted versus time.



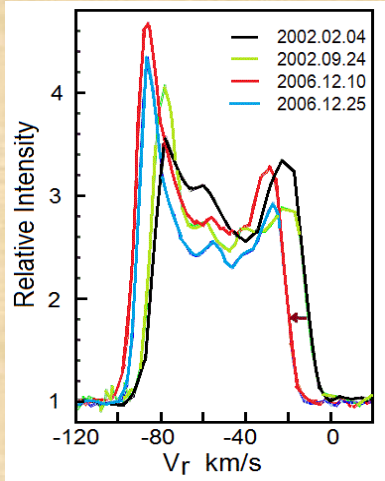
Large Doppler shifts with the 19.4 day period can be seen even in low-resolution spectra.

CI Cam: high resolution spectroscopy.

Acceleration of the surrounding nebula seen in emission lines. Third component.

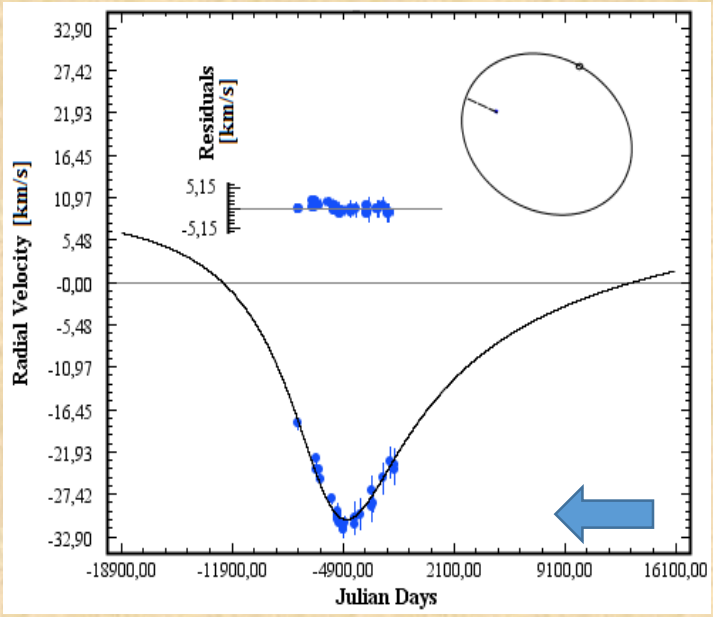


Radial velocity curves of Fe II emission lines (left) and of the forbidden line of [N II] 5754 Å (right)



The shift of the Fe II 5534Å line profile for 4 years

Russian 6 m telescope BTA with the Nasmyth Echelle Spectrograph



One of *Console* solutions with P=220 yr (80000 days)

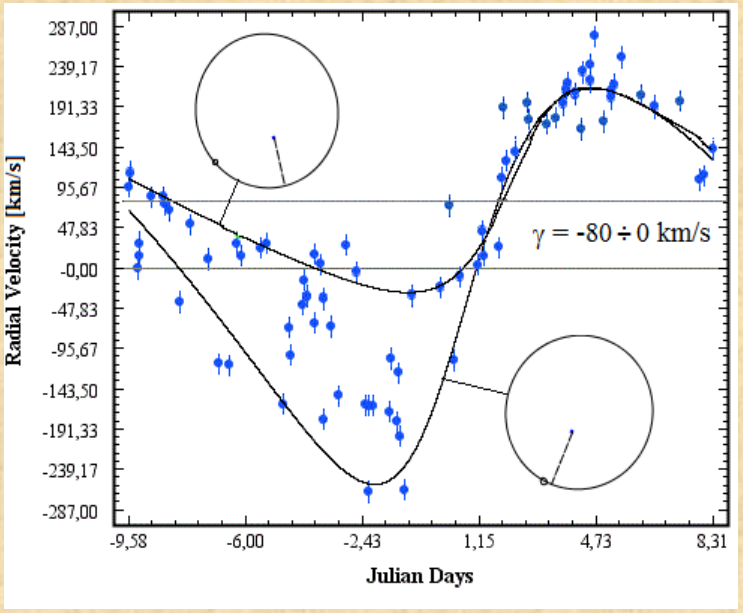
For the velocity curve of nebular lines, γ-velocity is not known. The γ-velocity of He II 4686Å varies between -80 and 0 km/s, being equal to -24 km/s for the averaged velocity curve. The coordinated solutions for nebular lines exist for P>160 years.

e =0.47 – 0.70

γ = -25 ÷ +5 km/s

Periastron longitudes 161-183°.

This solution is taken with the values e=0.62, p.l.=158°, s·sin(i) = 80 a.e. (the way along the line of sight).



Extreme *Console* orbital solutions with P=19.400 days

CI Cam: What do we know?

● Triple system: B4 III-V[e] + WD + invisible massive star. Distance 1.1 – 1.7 kpc.
● 1998 April outburst was an explosion of hydrogen accumulated on the surface of the white dwarf from the circumstellar wind nebula surrounding B type star. The contribution of the exploded WD in the common light in the peak of outburst was a few units of 10^{38} erg/s what is typical of classical novae.
● Star has brightened after 2009 getting maximum in 2012, and turned to an active state with the stronger He II 4686Å emission.
● B type star was a double mode pulsator with 3:2 resonance in a quiet state. It is not a supergiant.
● WD moves around the B type star on an elliptical orbit with the period of 19.40 day. This period is present in the photometry. The B type star is surrounded by a gaseous disk, and the system becomes brighter twice in the period in the nodes of the orbit when the WD passes through the plane of this disc. The shape of the radial velocity curve has changed in the active state.
● Majority of permitted and forbidden lines in the spectrum associated with gaseous surroundings of the B type star are shifting in the range of 14 km/s. If the interpretation of this shift as the orbital motion of the B star along with its surrounding nebula is true, there has to be a third invisible massive companion with the orbital period more than 160 years.
● Velocity curve of the nebula suggests that the B star with the WD companion passed through periastron and had an approach with the invisible star in 2009. Both the active state and the changes of the orbital velocity curve shape may be explained by the approach.

Thanks for attention