SBS 1150+599A / PN G 135.9+55.9

The most metal-poor PN and its binary central star

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Warning: Work in progress

Results (status: beginning of 2004) published in Tovmassian, Napiwotzki, Richer, Stasińska, Fullerton & Rauch 2004, ApJ 616, 485

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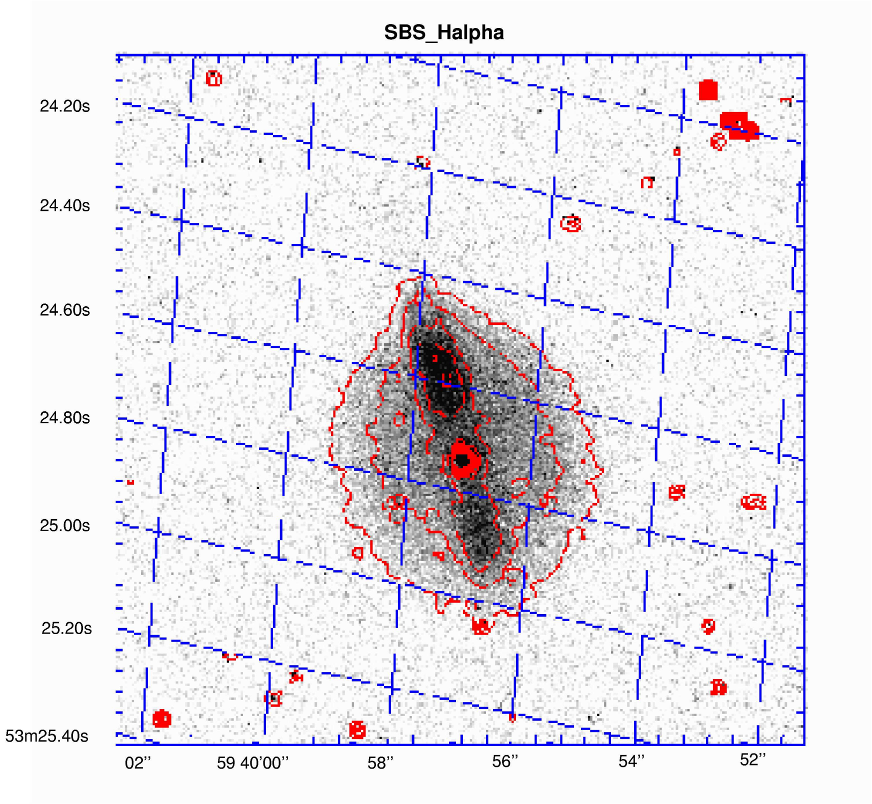
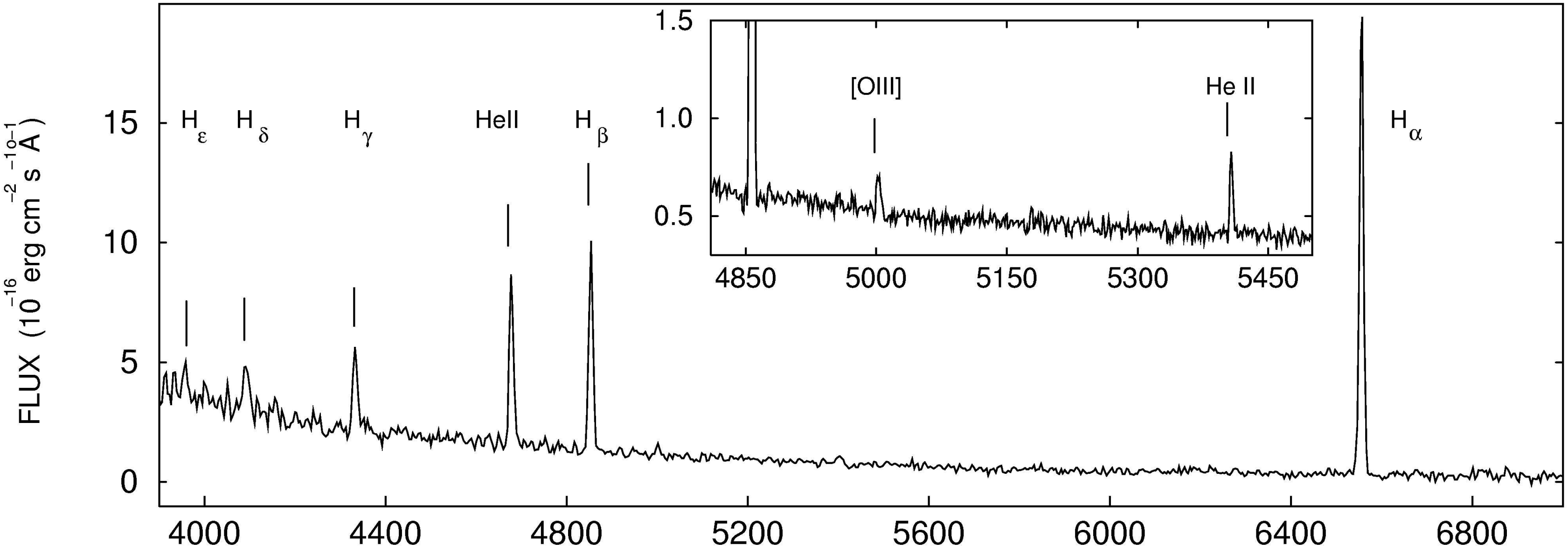


Hα (HST)

Discovered by the **S**econd **B**yurakan **S**urvey
Classification:
cataclysmic variable!

Tovmassian et al. 2001:
extremely oxygen poor
planetary nebula

PN spectrum



FLUX (10^-16 erg cm^-2 s^-1 A^-1)
15
10
5
0
4000
4400
4800
5200
5600
6000
6400
6800
Hε
Hδ
Hγ
HeII
Hβ
Hα
1.5
1.0
0.5
[OIII]
He II
4850
5000
5150
5300
5450

PN metal abundances

Very high excitation PN: only [O III], [Ne III] and [Ne V] observed so far

Tovmassian et al. 2001: O/H $\approx$ 1/500 solar
upper limit: O/H $<$ 1/100

Richer et al. 2002: O/H $<$ 1/50, Ne/O = 0.5 (solar: 1/7)

Jacoby et al. 2002: O/H $\approx$ 1/500 solar, limit: O/H $<$ 1/100
but Ne/O = $2 \ldots 4$

Péquignot & Tsamis 2005: O/H $\approx$ 1/13 solar
Ne/O $\approx$ 1/7

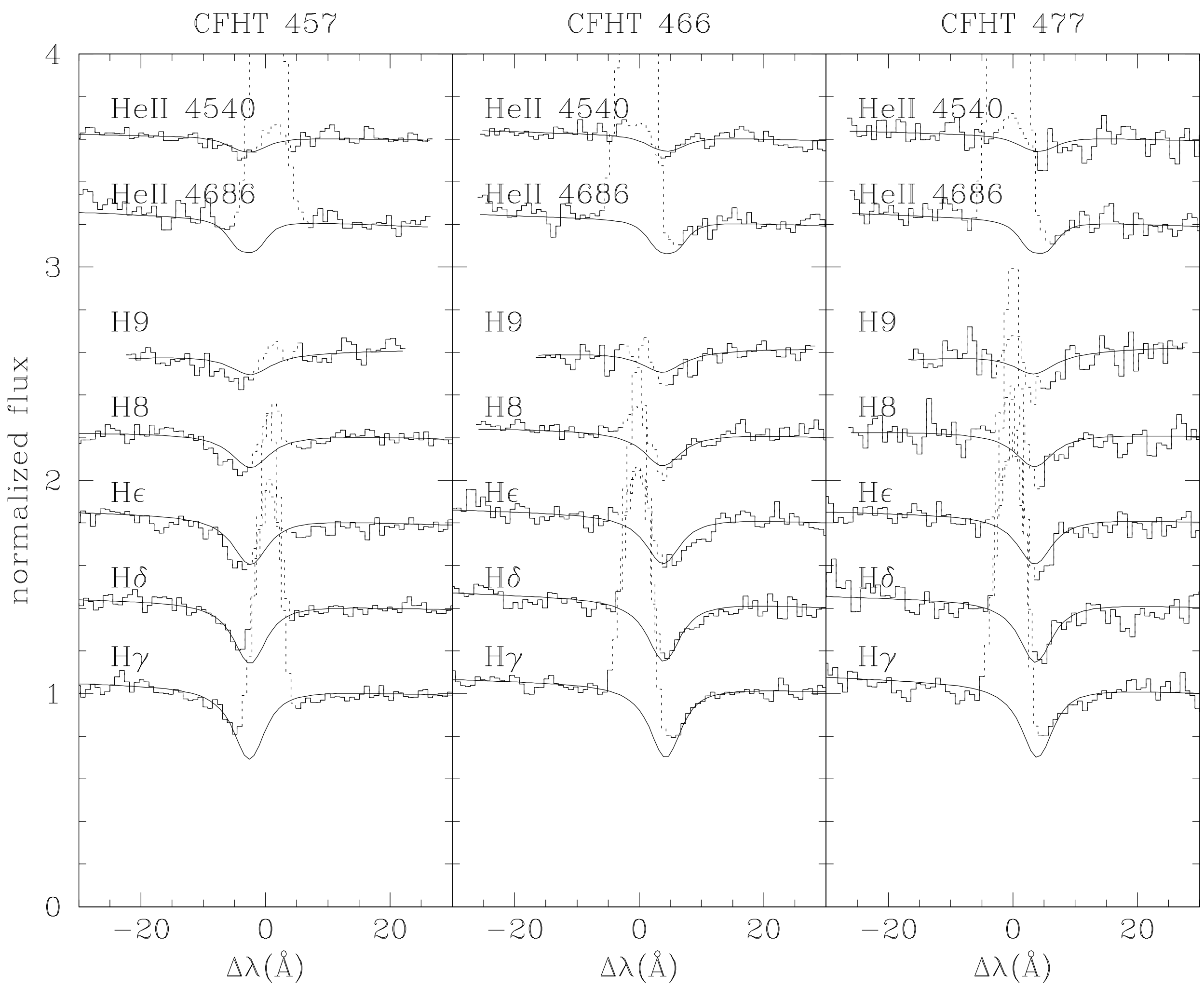
SBS 1150+599 is very metal-poor!

Evidence for pop. II nature

SBS 1150+599A fulfils three criteria for membership in the Galactic halo population

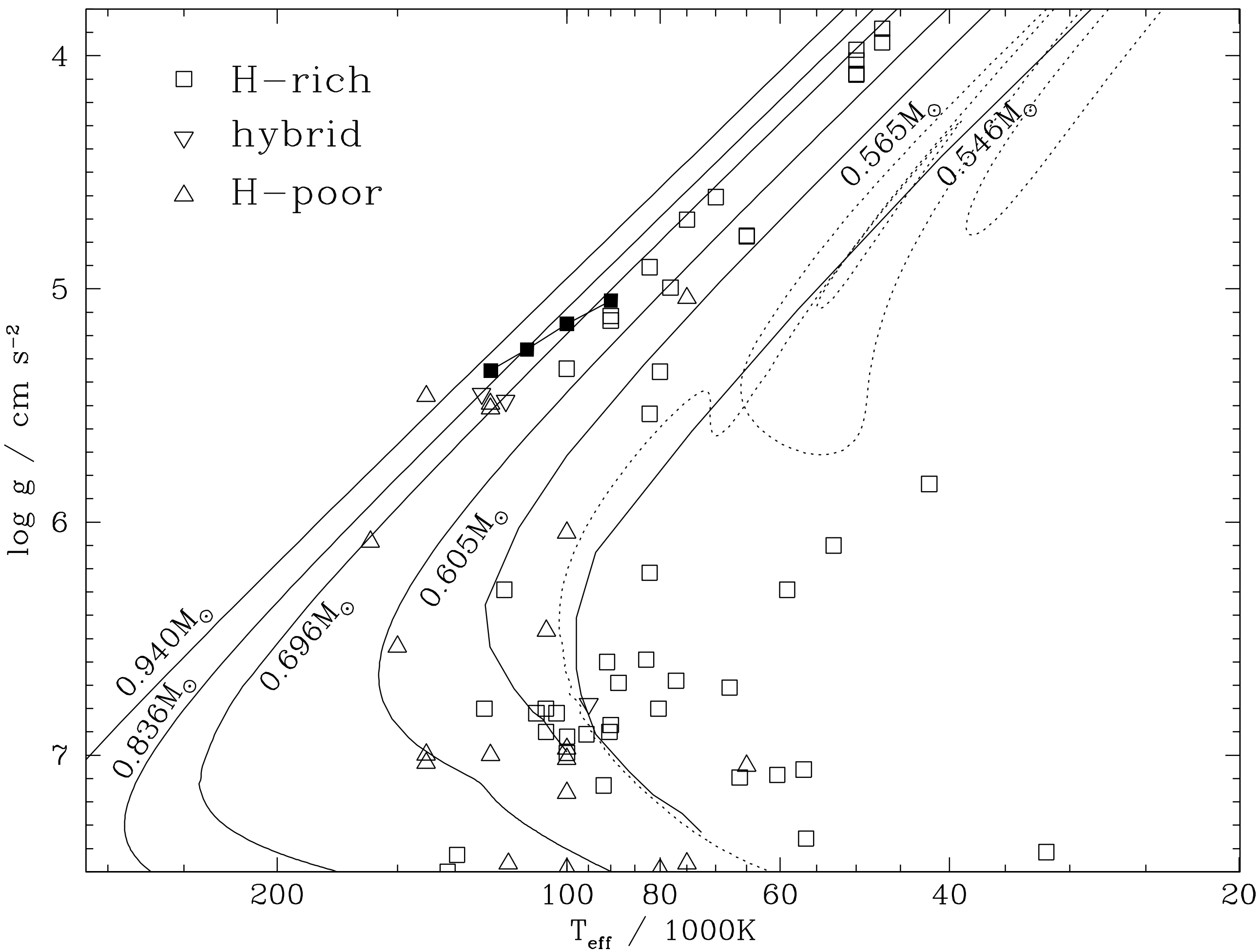
- very low metal abundance
- very large distance from the Galactic plane:
  $z \approx 15$ kpc
- Very high RV:
  Hel. RV = -193 km/s (Richer et al. 2003)

CFHT spectroscopy May 2003



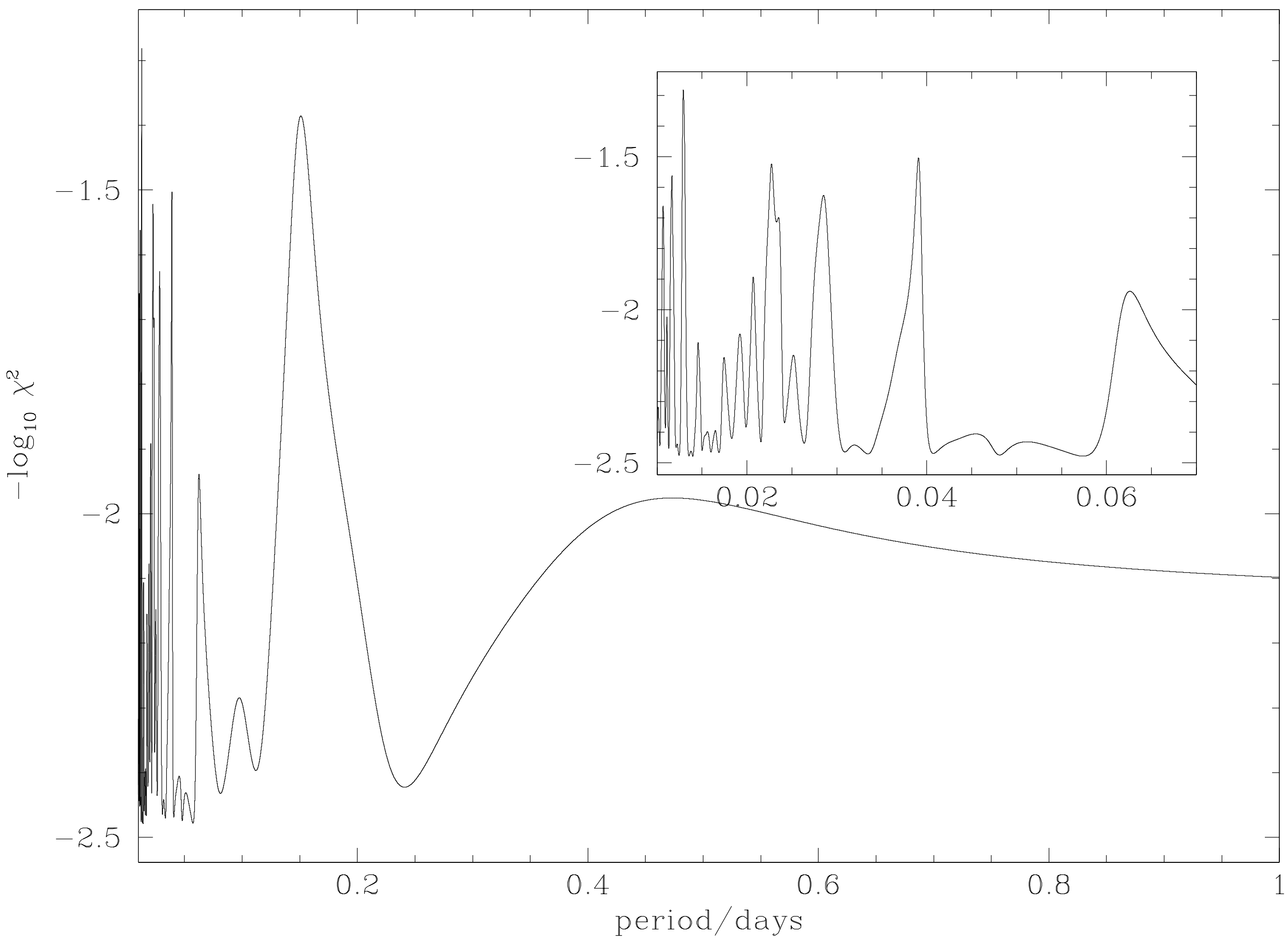
$T_{\rm eff} = 120\,000$ K, $\log g = 5.35$, $\log {\rm He/H} = -1.0$

Comparison with evolutionary tracks



but: pop. II object $\rightarrow M \approx 0.55 M_\odot$

Spectroscopic orbital period:



possible periods: 0.039 d, 0.063 d, 0.151 d

(0.94 h), (1.5 h), (3.6 h)

Nature of the companion

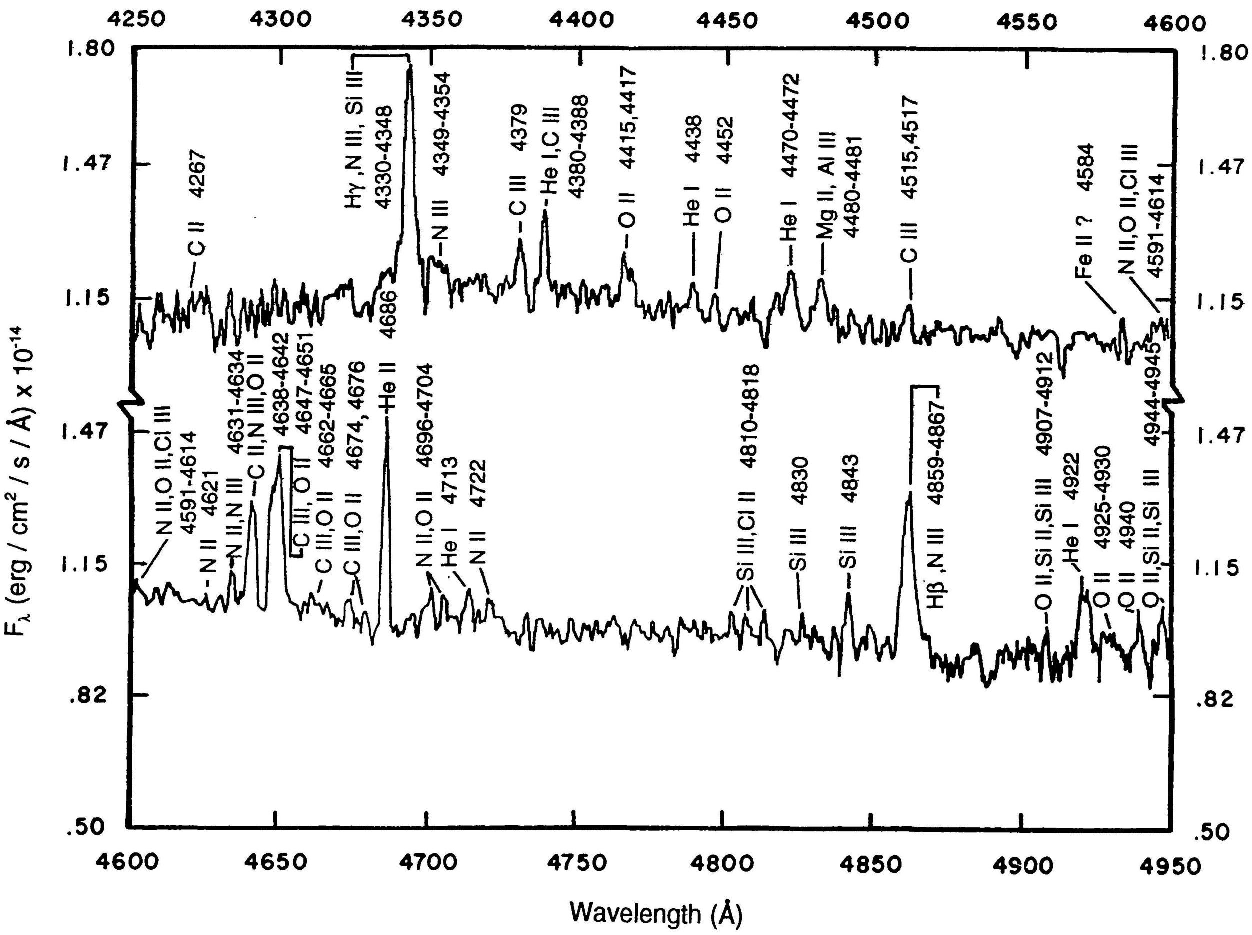
main sequence star?

Reference system: BE UMa

CSPN+KV system (Liebert et al. 1994; Ferguson et al. 1994):

- $T_{\rm eff}(\rm CSPN) = 105\,000$ K
- $0.4 M_\odot$ main sequence companion
- orbital period: 2.29 days
- spectacular reflection effect
  - re-processing of CSPN radiation on the illuminated hemisphere of the cool companion
  - heating of the companion's photosphere
  - causes photometric variation
  - forest of emission lines

Reference system: BE UMa



Nature of the companion

main sequence star?

- We (Tovmassian et al. 2004) argued that the absence of emission lines from the hot, illuminated hemisphere of the companion provides strong evidence against a main sequence star
- Péquignot & Tsamis (2005) object that no emission lines are visible, because of high ionisation

compact object?

white dwarf, neutron star

New observations

April 2004: Photometric observations at San Pedro Mártir/Mexico

- four hours differential photometry
- show photometric variability
- run too short to determine nature of variability and periodicity

May 2004: Spectroscopic observations with HET/USA

- two series of shorter exposures (15 min) to overcome problems with orbital smearing
- additional RV points
- supports $P \approx 4$ h

Latest observations

The plan: near-simultaneous observations in January 2005

- Two half-nights spectroscopy at Keck I/USA
- Three nights four-channel photometry at Calar Alto/Spain
- One night single-channel photometry at San Pedro Mártir/Mexico

Latest observations

The plan: near-simultaneous observations in January 2005

- Two half-nights spectroscopy at Keck I/USA

  ☹ poor weather, no observations

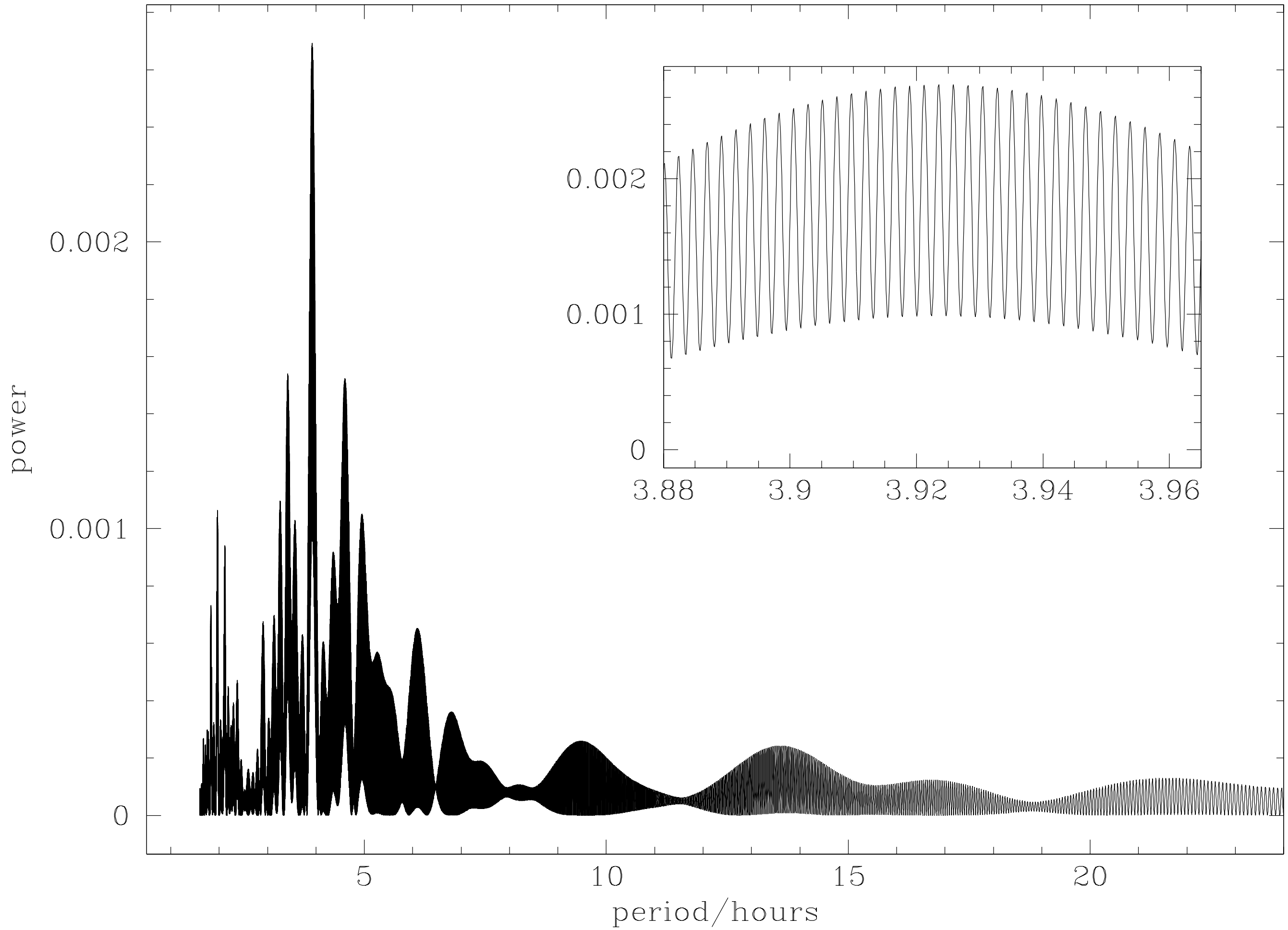
- Three nights four-channel photometry at Calar Alto/Spain

  ☺ good to perfect conditions

- One night photometry at San Pedro Mártir/Mexico

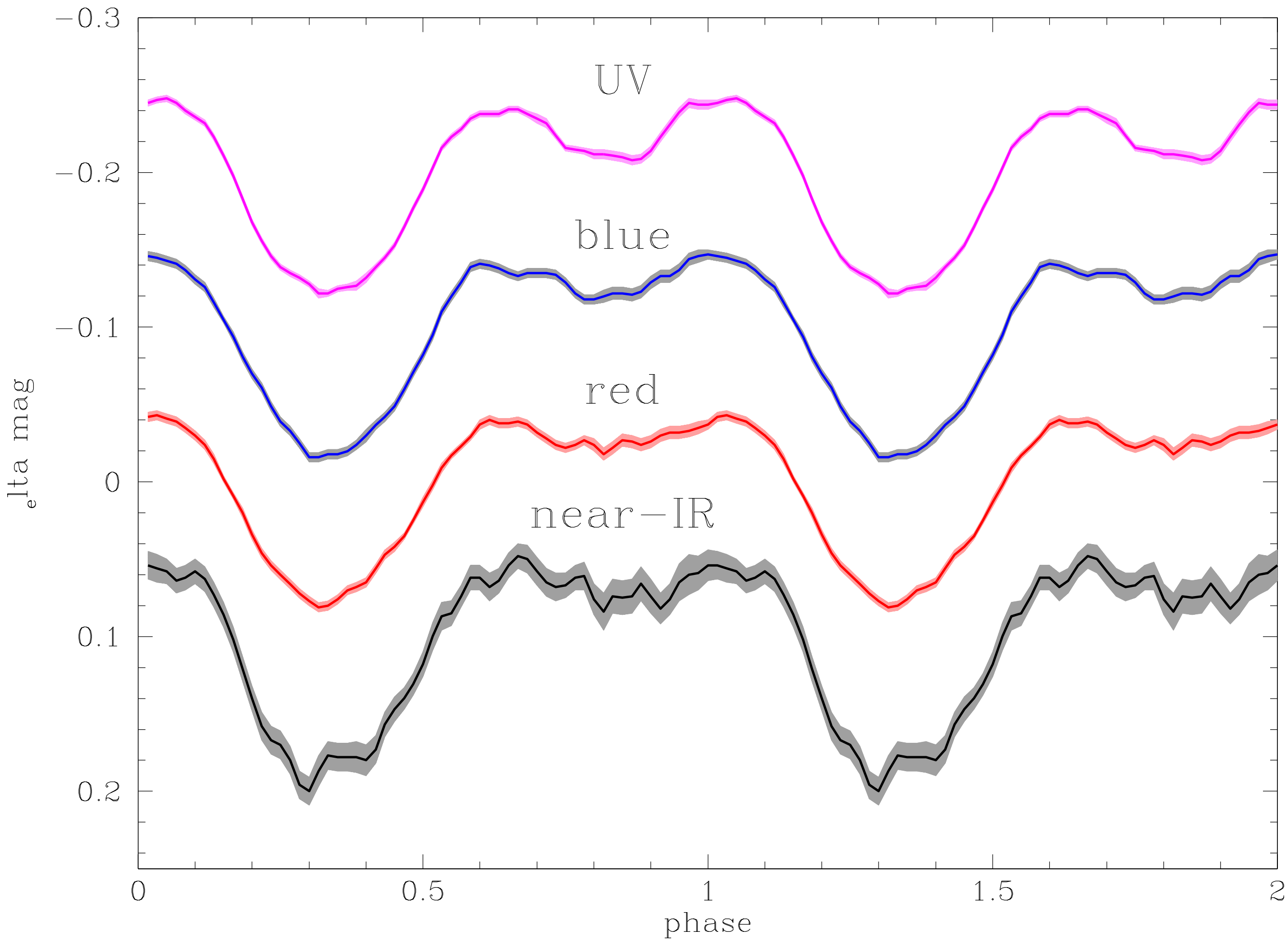
  ☺ good conditions

Photometric orbital period



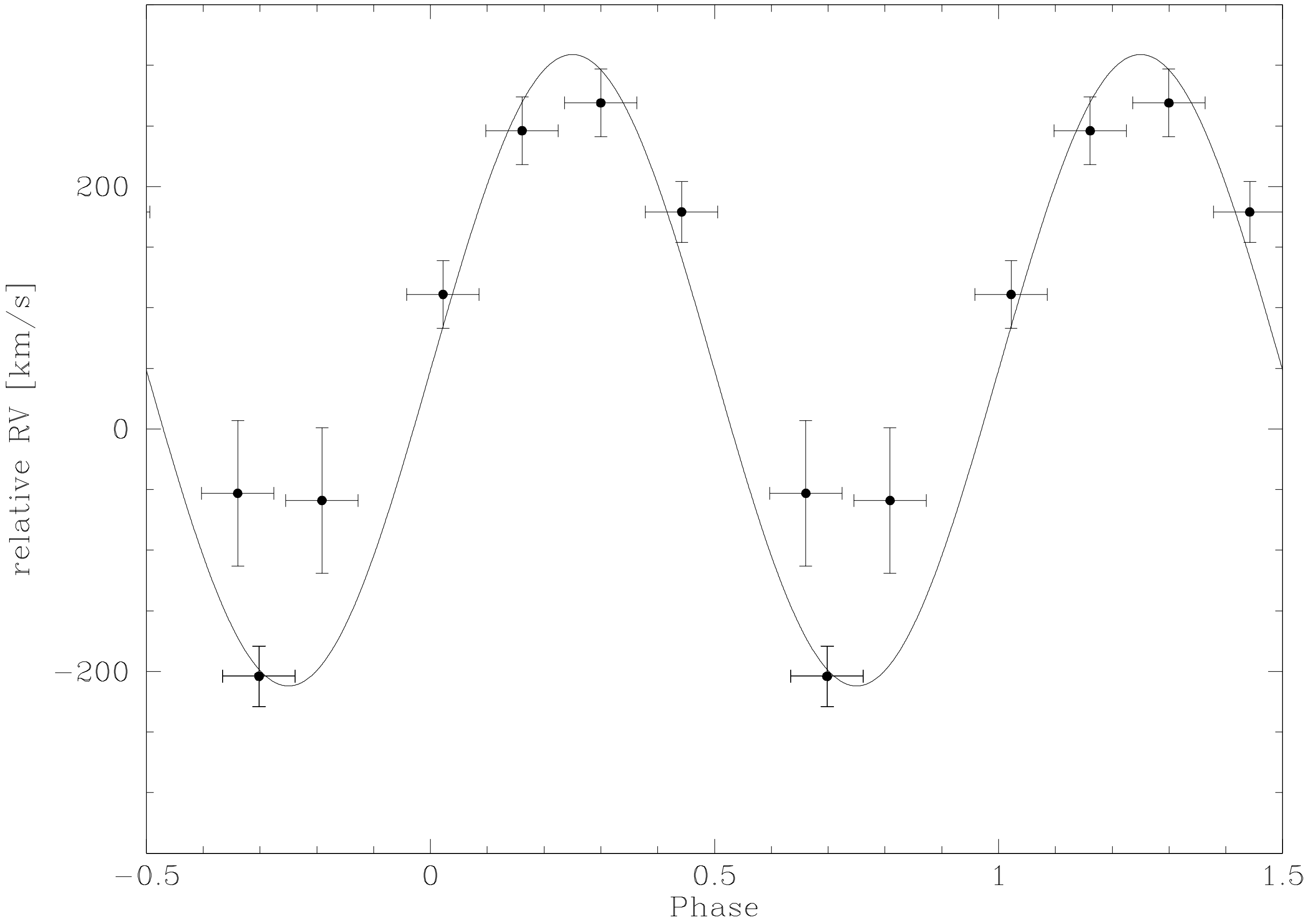
period: 3.92 h

BUSCA light curve



period:

RV curve

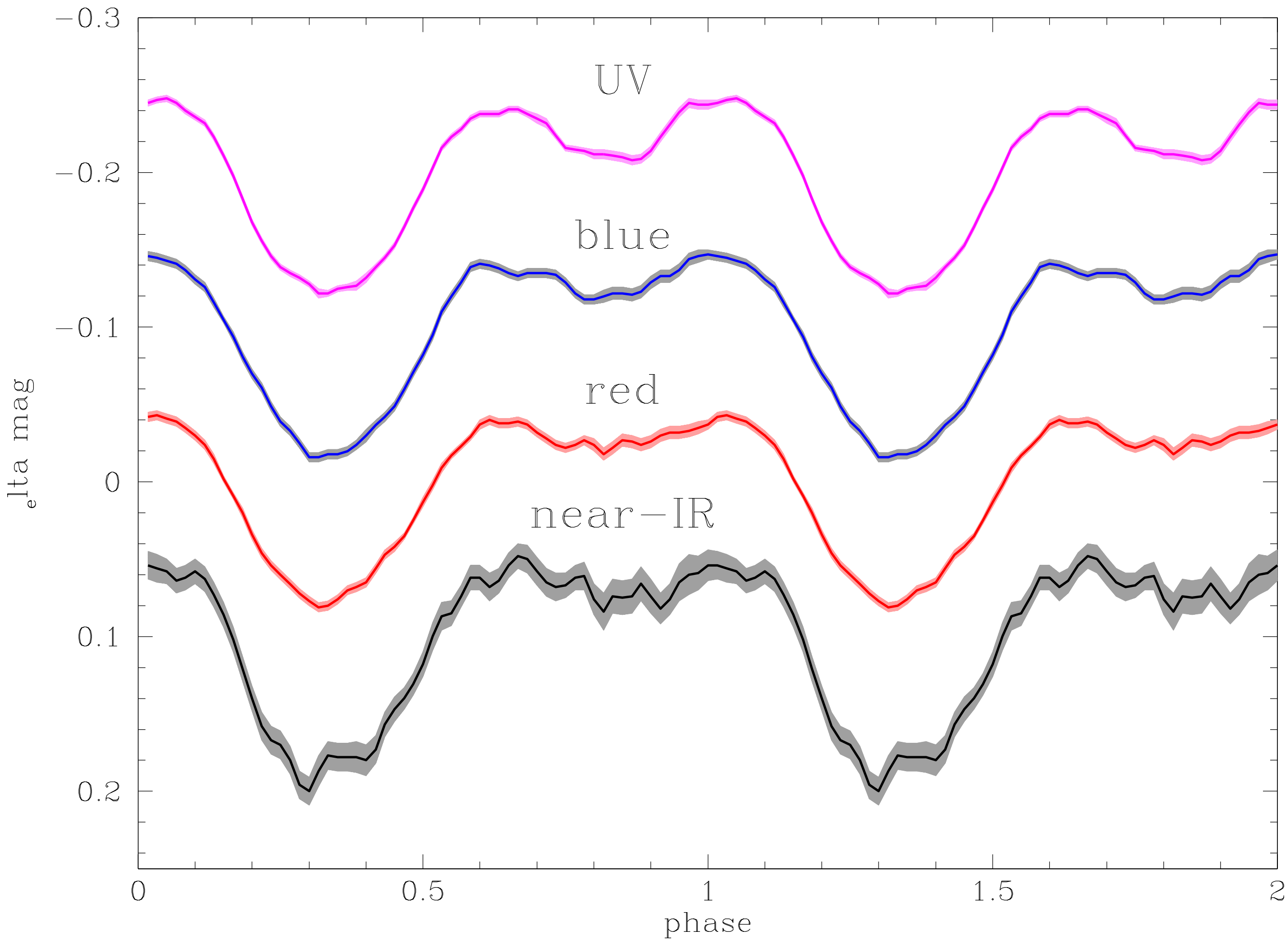


amplitude: 260 km/s

RV curve

- amplitude: 260 km/s
- $\rightarrow$ mass function (includes $\sin^3 i$ term)
- $\rightarrow$ lower limit on companion mass for $i = 90^\circ$
- adopt $M(\mathrm{CSPN}) = 0.55 M_\odot$
- $\rightarrow M(\mathrm{companion}) \geq 0.83 M_\odot$

BUSCA light curve



period:

Light curve of a CSPN+main sequence binary

Effects in a system with a main sequence companion:

- eclipses
  (unless $i < 60^\circ$)

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  re-processing of CSPN radiation on the illuminated hemisphere of the cool companion

Light curve of a CSPN+main sequence binary

Effects in a system with a main sequence companion:

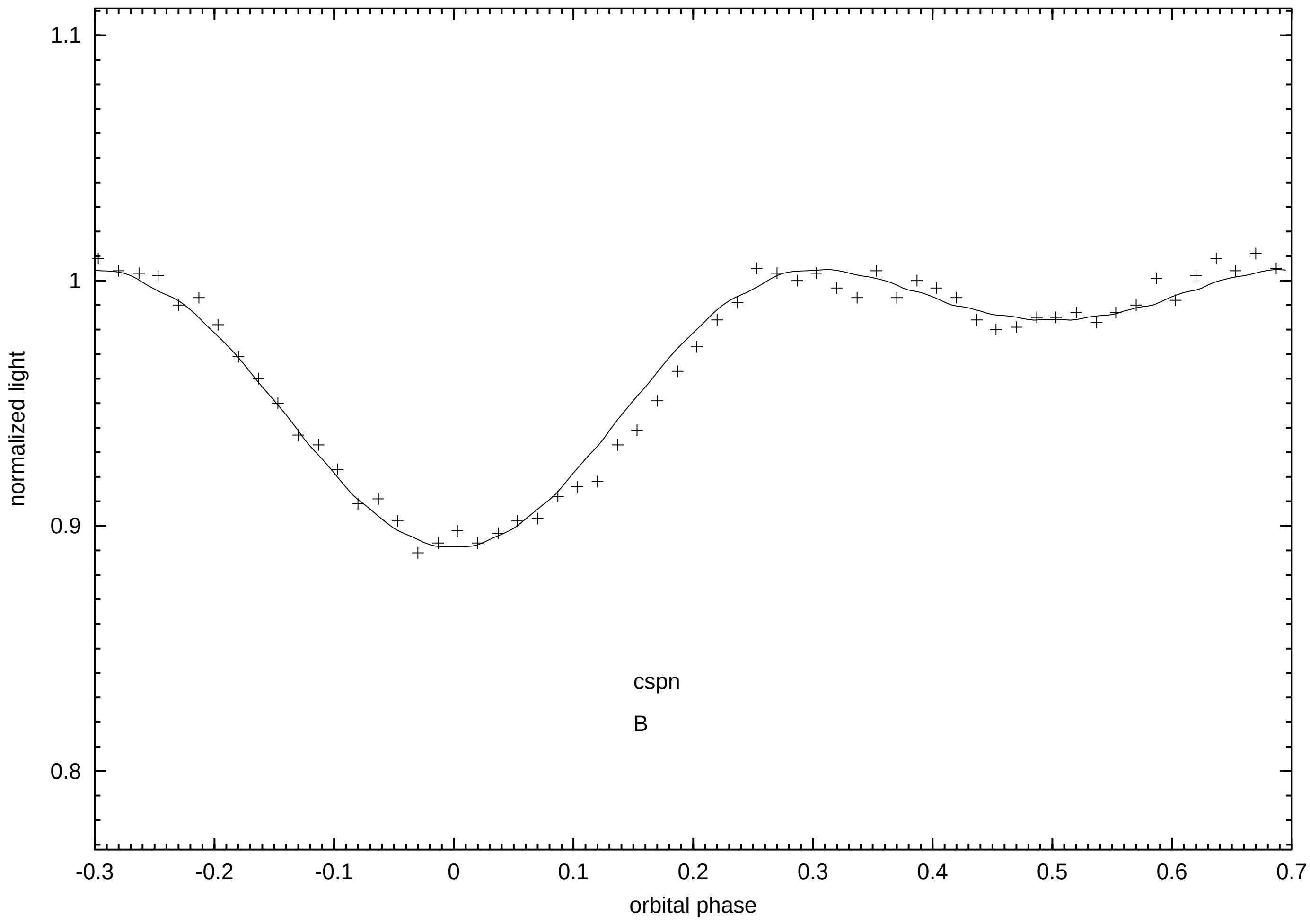
- eclipses
  (unless $i < 60°$)
- reflection effect
  re-processing of CSPN radiation on the illuminated hemisphere of the cool companion
- ellipsoidal variation
  deviation from spherical symmetry caused by gravitational pull of companion

Light curve of a CSPN+main sequence binary

Fitting the light curve

- no acceptable fit with a $R = 0.5 R_\odot$ main sequence companion possible
- R as free parameter yields $R = 0.18$

Best light curve fit



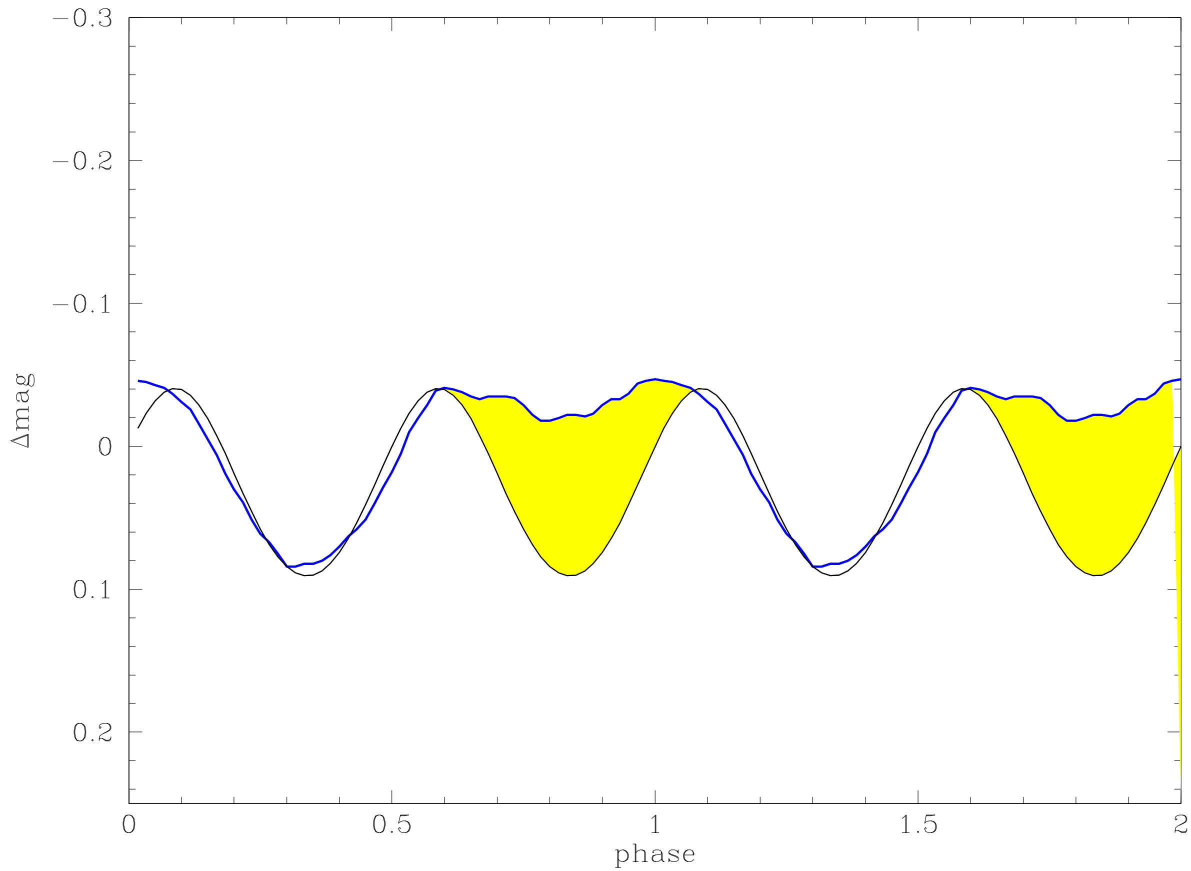
Light curve of a CSPN+main sequence binary

Fitting the light curve

- no acceptable fit with a $R = 0.5R_\odot$ main sequence companion possible
- R as free parameter yields $R = 0.18$
- orbital inclination $i = 40°$
  $\rightarrow M(\mathrm{companion}) = 1.8M_\odot$
- $\rightarrow$ main sequence companion can be ruled out
- companion must be a compact, evolved star
  (pre-) white dwarf, neutron star

How to explain the light curve?

Light curve could be explained by ellipsoidal variation caused by the deformed CSPN . . .



How to explain the light curve?

Light curve could be explained by ellipsoidal variation caused by the deformed CSPN . . .
. . . plus additional – phase dependent – source of light:

- hot spot on the CSPN
  could be caused by (particle-)irradiation
  from a neutron star companion
- hot disk-like structure around the WD/NS companion
  accretion from a CSPN wind?
  relict from the common envelope phase?

What do we know?

- SBS 1150+599A is the hot (120 000 K) central star of a PN
- close binary system, $P = 3.92$ h
- minimum companion mass $M = 0.83 M_\odot$
- main sequence companion can be ruled out
- companion must be a compact evolved companion, i.e. white dwarf or neutron star
- gravitational waves will cause merging of the system in 1 Gyr
- Minimum system mass ($0.55 M_\odot + 0.83 M_\odot$) close to Chandrasekhar limit $\rightarrow$ supernova type Ia progenitor?

Future work

Phased spectroscopic and photometric observations

- will allow to distinguish models and determine the nature of this binary system
- analysis of the light curve to constrain, e.g.,
  - inclination i,
  - radius of CSPN,
  - mass of companion

PNe as tool

- SPY (ESO Supernovae Ia progenitor survey): survey of 1000 white dwarfs for double degenerates (white dwarf + white dwarf binaries)
- about 100 double degenerates discovered
- formed in a common envelope phase
- provides, e.g., mass and period distributions
- Additional information from a PNe:
  - constraints on the CE time scales
  - PN morphology constraints CE geometry
  - chemistry (initial + nuclear processing)