The role of binarity in [WR] central stars of PNe

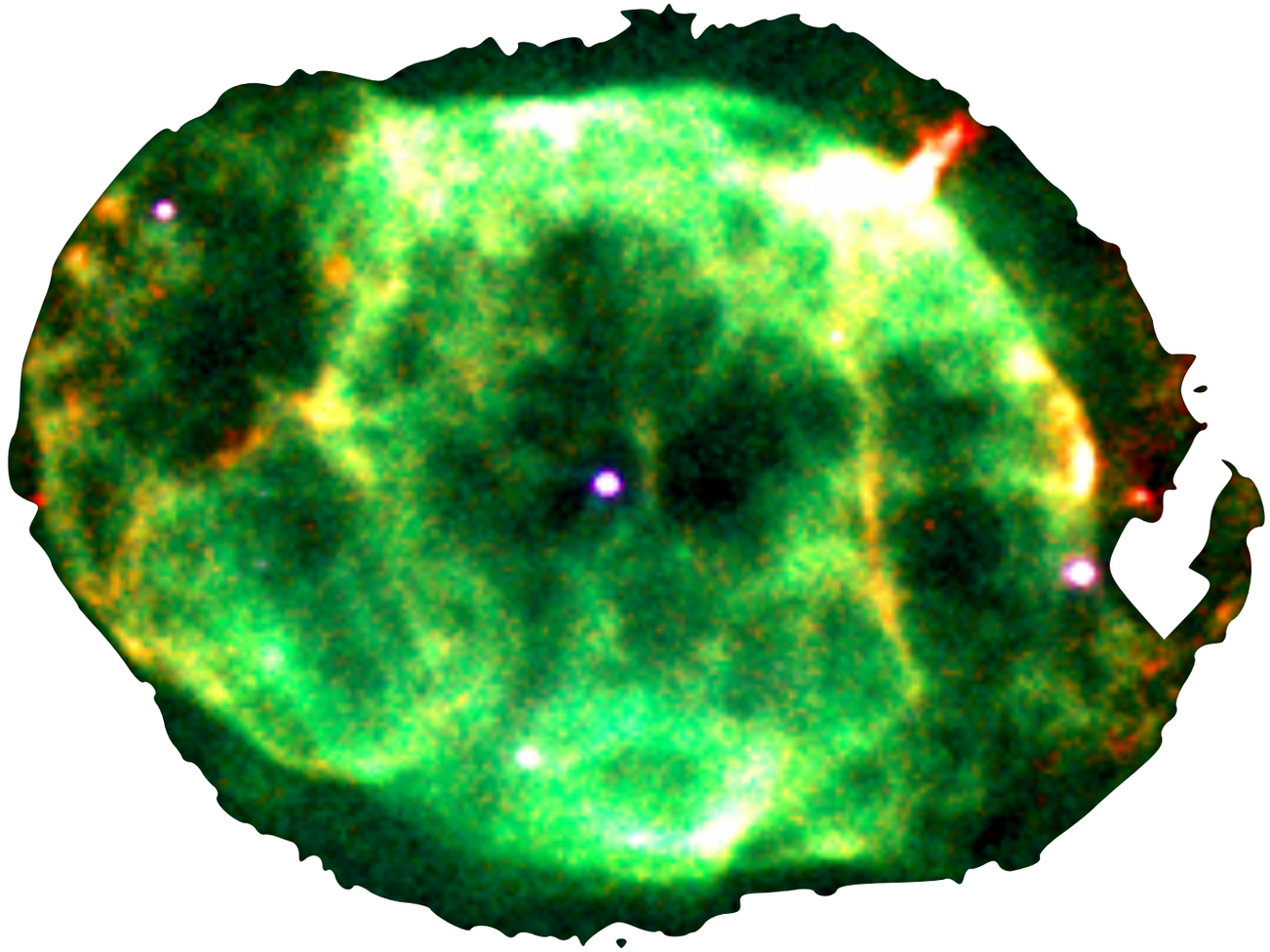
Brent Miszalski
SALT Astronomer
brent@saao.ac.za
http://miszalski.saao.ac.za

National Research Foundation | South African Astronomical Observatory

Tarsocera namaquensis

Judy Schmidt

Outline



- Close binaries in PNe
- Close binary [WR] central stars?
- Wider binaries and dust
- Perspectives

Close binaries

Close binary central stars

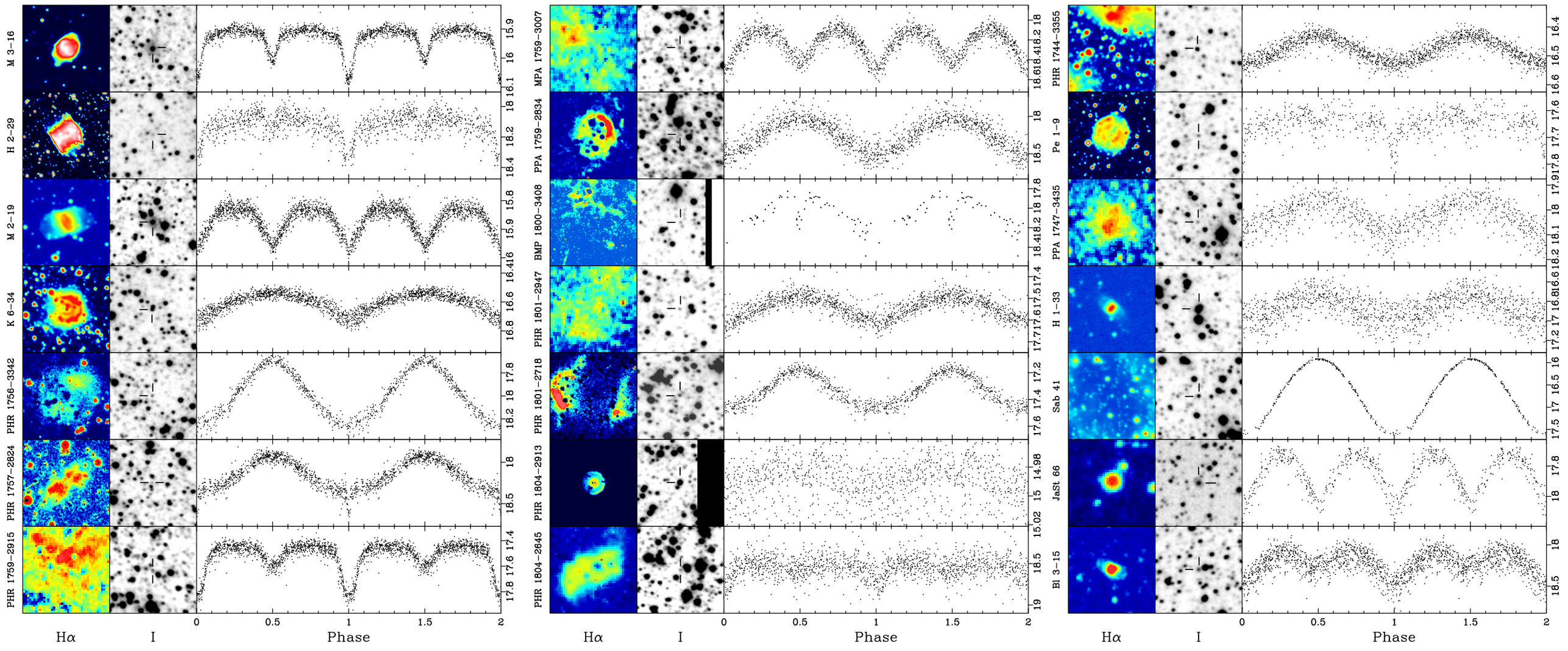
- Currently know of > 40 close binaries (~1 in 5 PNe)
- Orbital periods ~0.1-1.0 day (post common-envelope)
- Most common: WD + MS, but WD + WD also found
- Majority found via (biased) photometric monitoring (irradiation effect, ellipsoidal variation or eclipses)
- RV monitoring best suited to finding WD+WD (often not phot. variable)
- Specific nebular features appear to be strongly tied to binarity
- Can use these trends to guide surveys looking for more precious examples

The OGLE-III sample

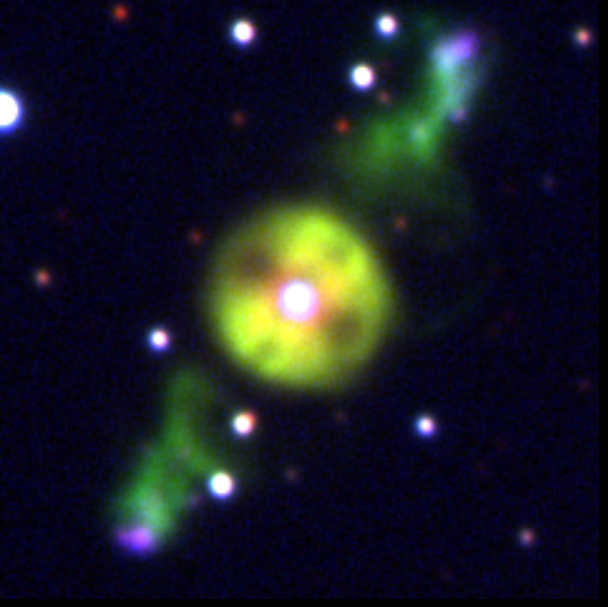
Major result => ~1 in 5 (20%) of PNe have close binary central stars

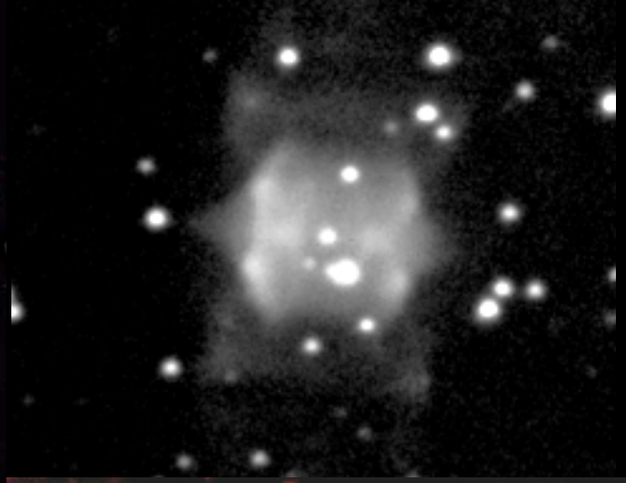
Miszalski et al. 2008

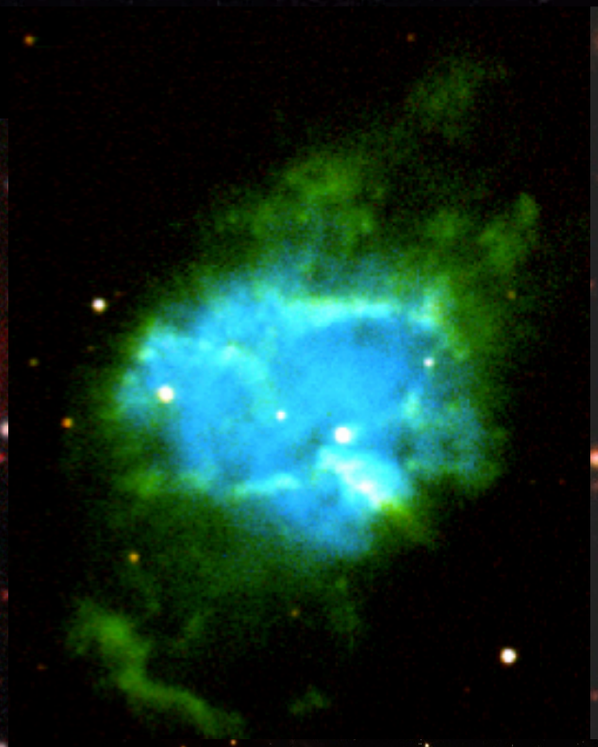
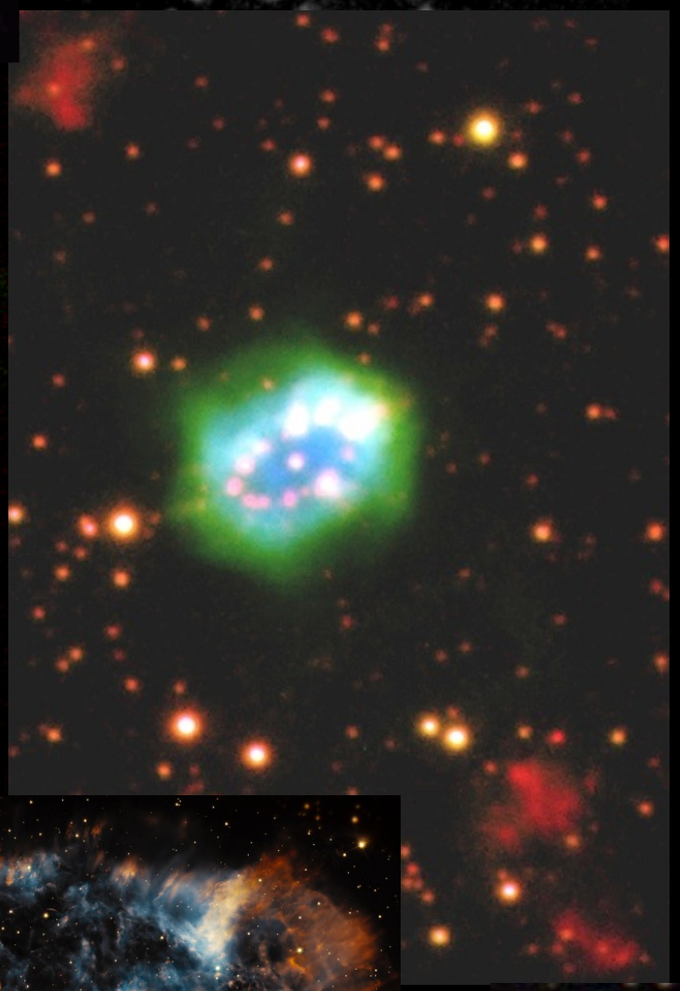
Miszalski et al. 2009a



Agrees with ~10% estimated by Bond (2000) based on a smaller sample






Morphological descriptors of binarity

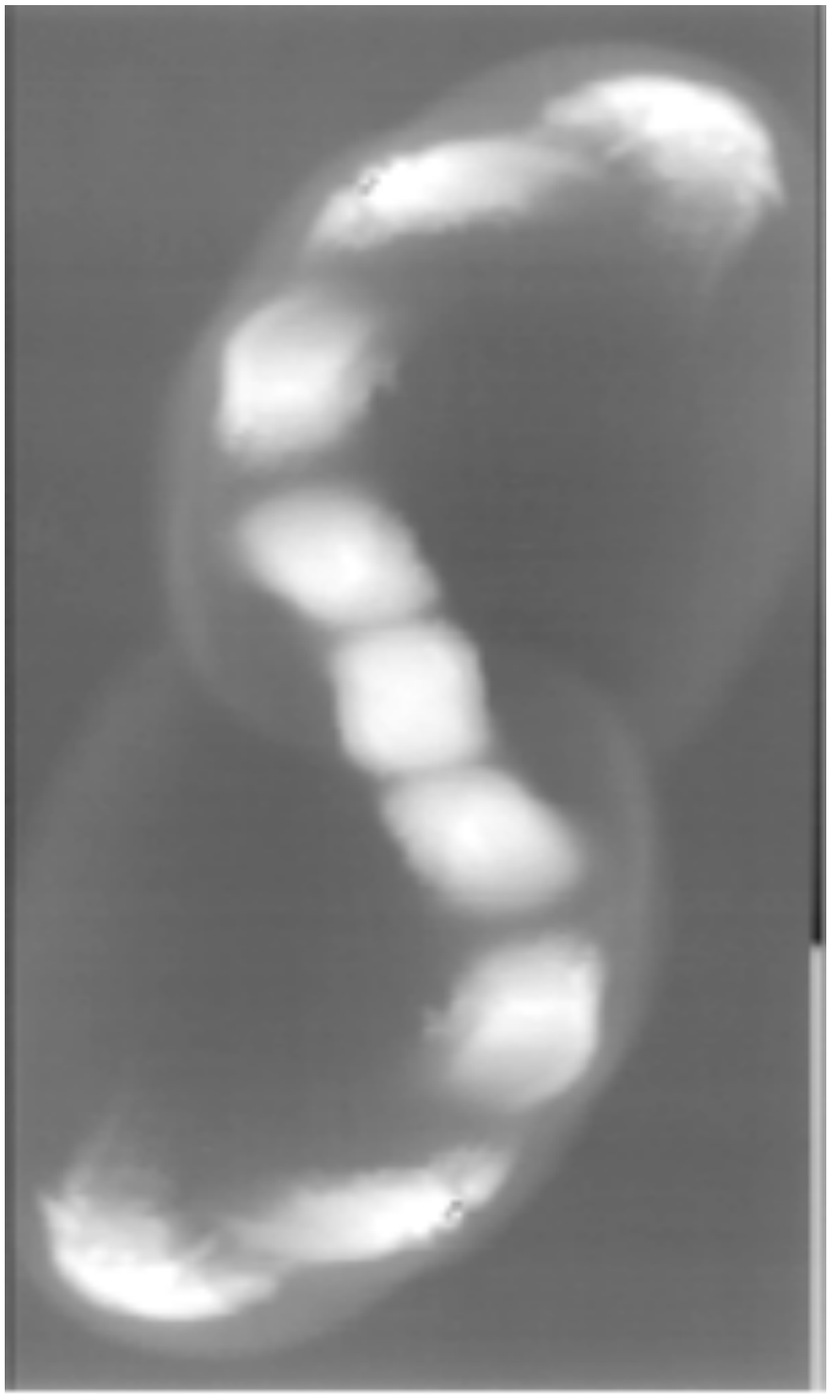
Miszalski et al. 2009b

- Jets (polar outflows)
  - Mostly ejected before main nebula
  - Accretion disk around companion
  - Precession produces S-shaped jets
- Low-ionisation structures
  - Filaments and rings
- Bipolar nebulae (weak dependence)

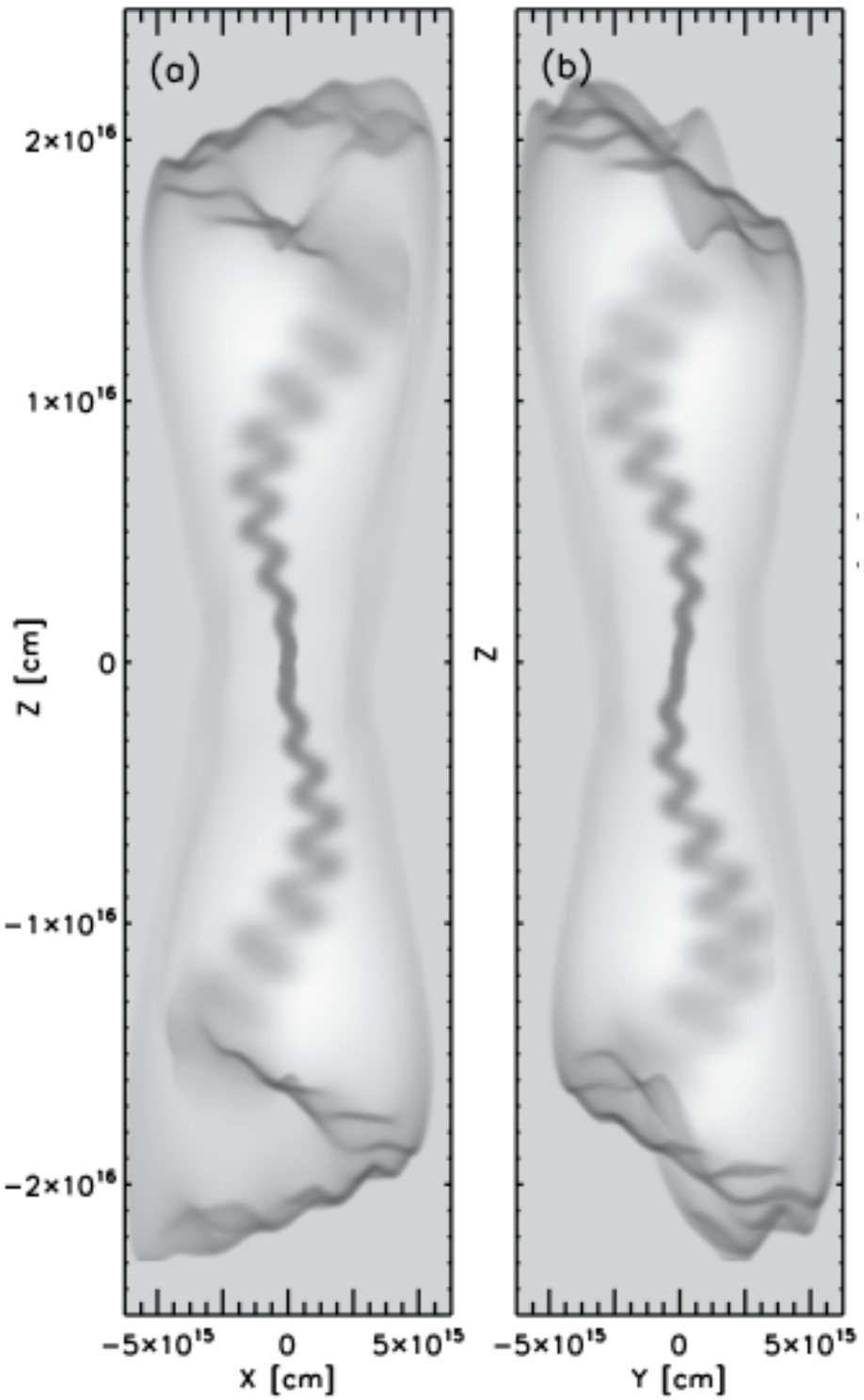
Fleming 1

Boffin, Miszalski+ 2012, *Science*

Jets long **assumed** to be binary driven!



Cliffe+ 1995, 1996

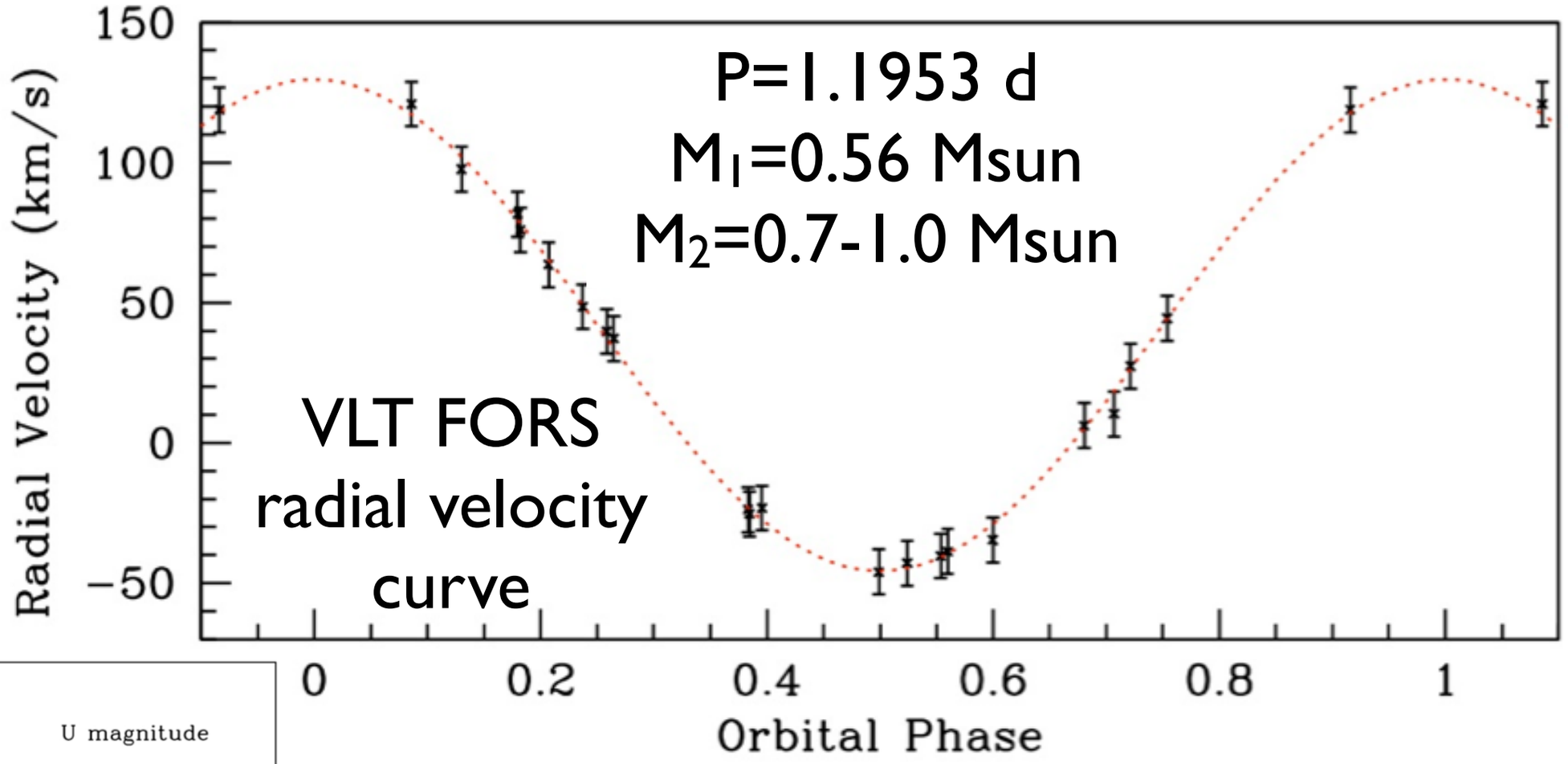


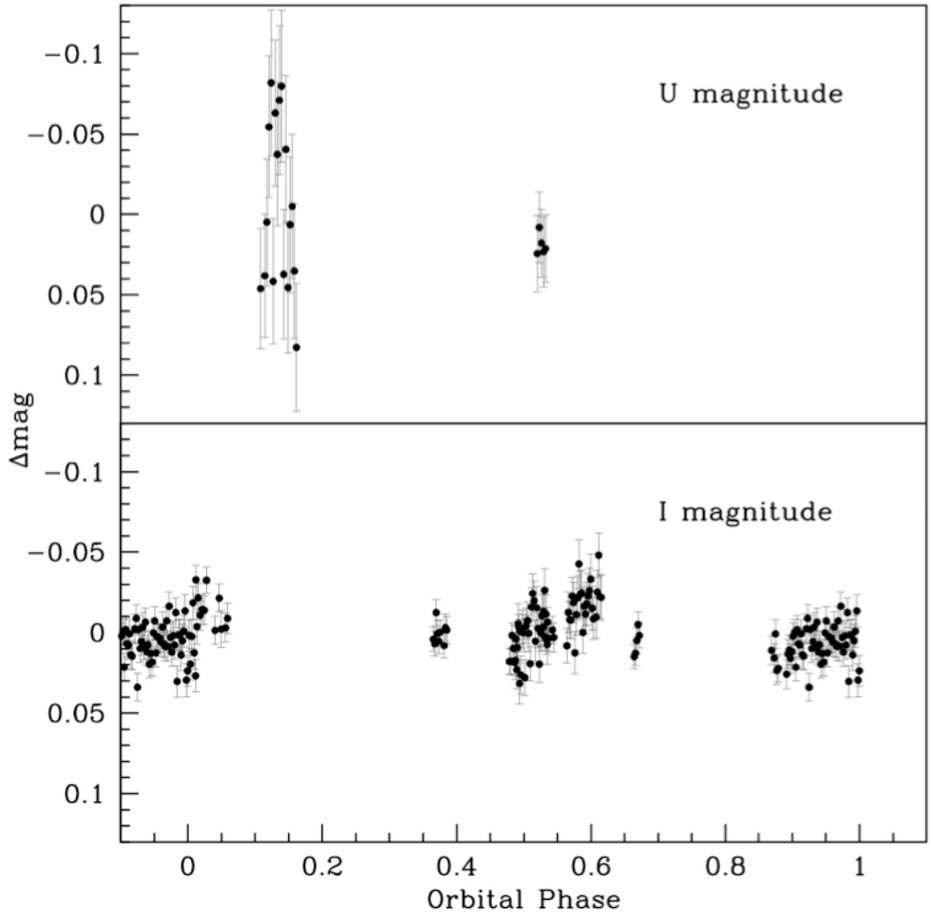
Raga+ 2009

Boffin, Miszalski +2012

Boffin, Miszalski+2012, *Science*

DD central star revealed!





flat lightcurve
=> strong bias against DD systems in photometric surveys

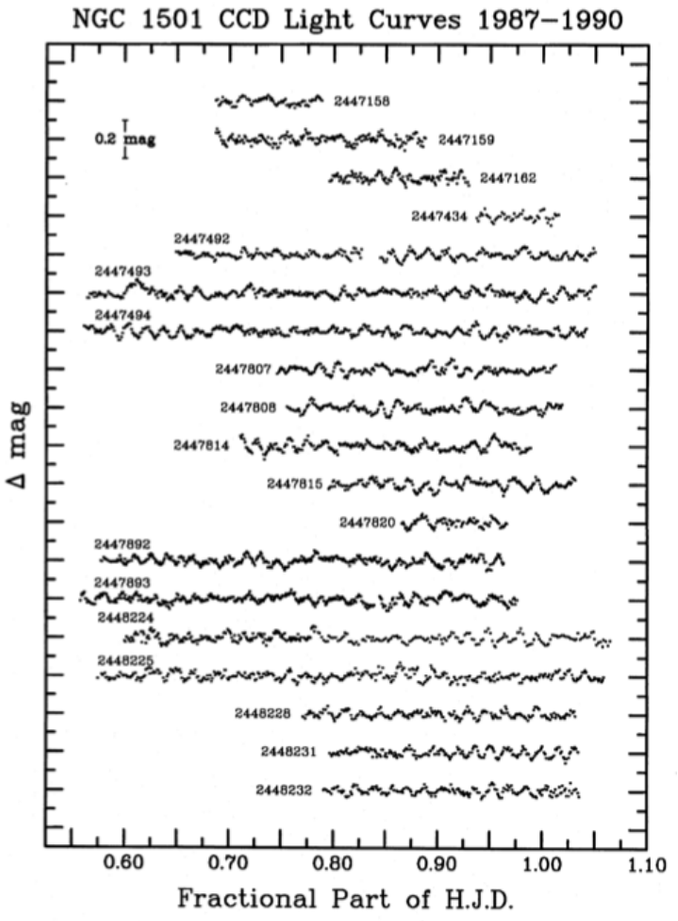
Close binary [WR] central stars?

Variability

- At least 37 H-deficient stars - [WC], PG1159 and O(He) types - were monitored photometrically by Ciardullo & Bond 1996 and Gonzalez-Perez+ 2006

  - Non-radial pulsations, but not strong variability due to binarity

Ciardullo & Bond 1996

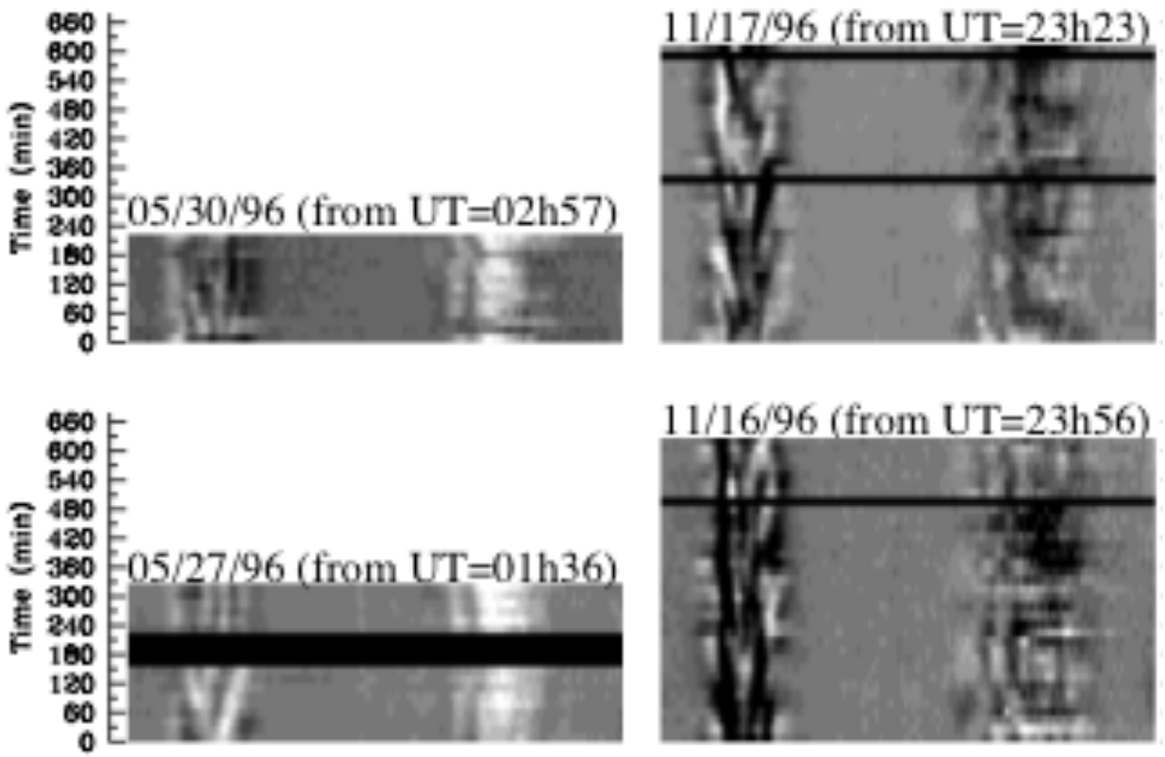


- RV monitoring of some brightest objects (e.g. NGC40) - Grosdidier+ 2000, 2001

  - Turbulent outflows, no apparent periodic motion due to binarity

- Hajduk+2010 - photometric (periodic) and spectral variability in [WC7] PHR0654-1045 - more obs needed

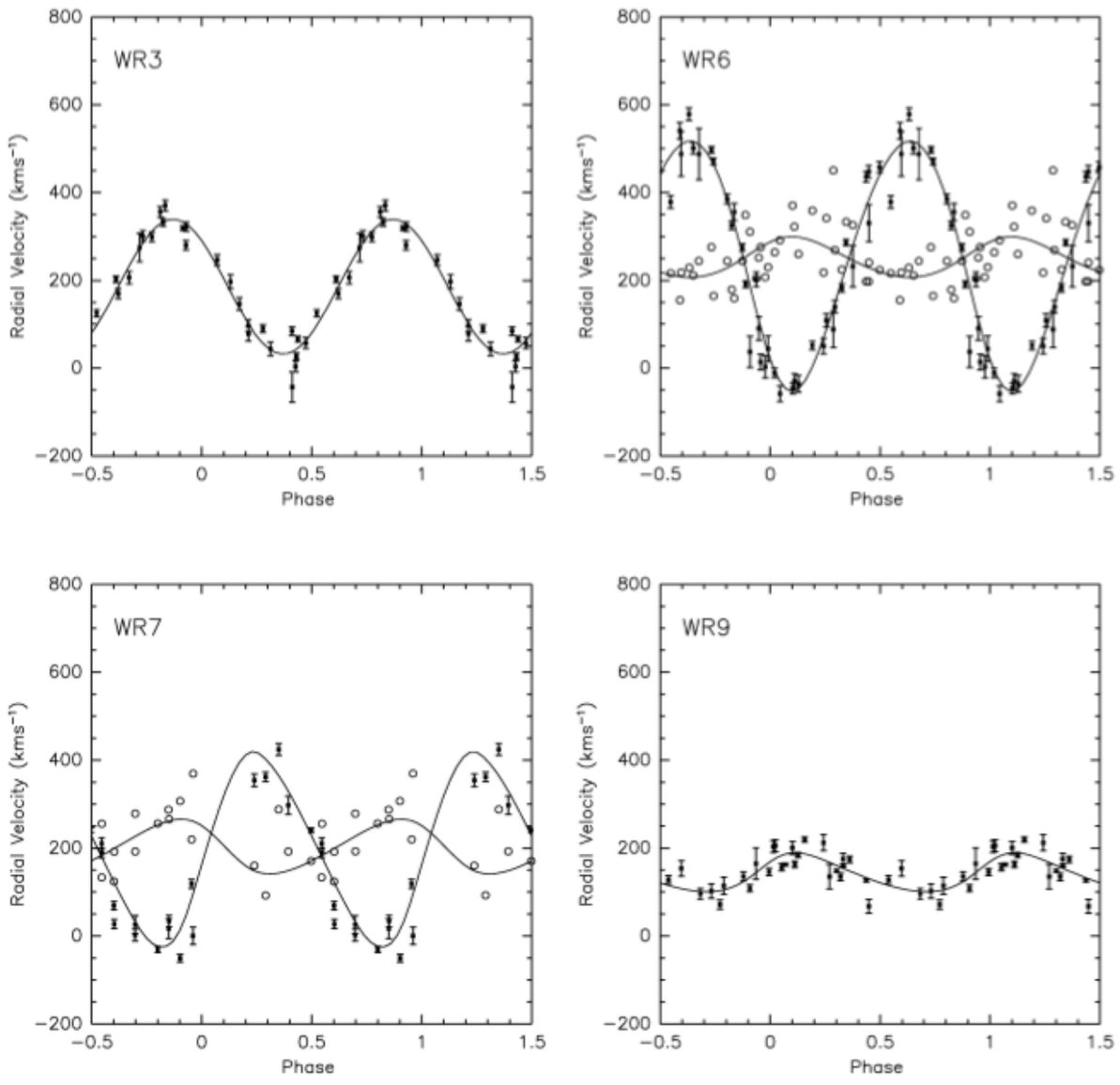
Grosdidier+ 2001



A new approach

- Miszalski+ 2009b noted that many nebulae around [WO] CSPNe are **dominated** by low ionisation structures and jets => likely binaries
- Missing 5-7 binaries (!) from H-def sample monitored photometrically if 1/5 is binary
  - Irradiation effect amplitudes would be very large, easily noticed, given high primary Teff (≥ 100 kK)
  - Companions must be evolved WD or O/B subdwarfs - can only use RV monitoring (Fleming1!)
- PN community have done little RV monitoring, perhaps suspected [WR] too windy to give any useful results

A new approach



Foellmi, Moffat & Guerrero 2003a,b

- Cross-correlation routinely works for massive WR stars
- No reason to expect it won't for [WR] central stars!!!!
- The late Olivier Chesneau inspired us to give it a go during 2013 Nova conference in Cape Town
- RV monitoring of several bright [WR] with SAAO 1.9-m
- SALT RSS monitoring of several fainter [WR] stars
  - PHR0654-1045 and NGC5189 + others ongoing

First results

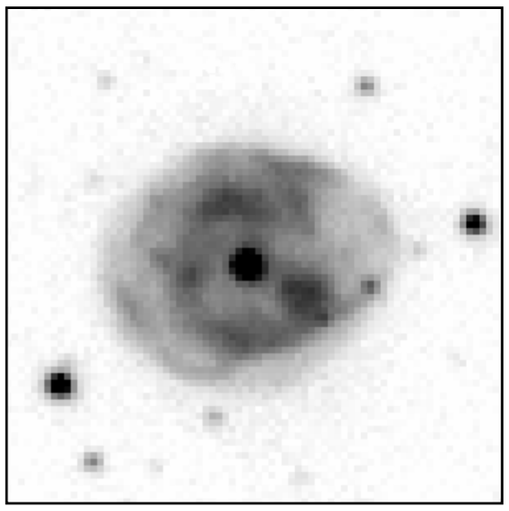
- Published first results in Manick, Miszalski & McBride 2015, MNRAS
- SAAO/UCT MSc thesis of Rajeev Manick (June 2014) - now PhD student @ Leuven
- Aim for S/N > 40 in continuum

- Data analysis: cross correlation following Foellmi, Moffat & Guerrero 2003
- Currently expanding the sample with SALT
- Overall aim: Keplerian masses and radii for [WR] stars to better understand the formation of all observed types

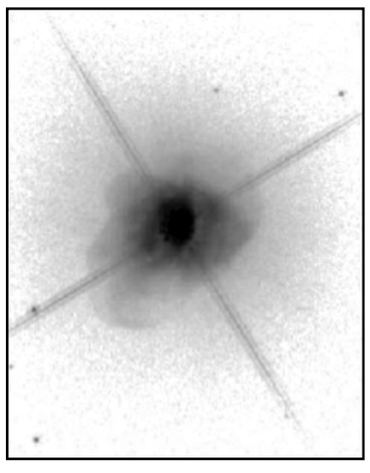
Non-variables

Object	V (mag)	Type	Epochs	Telescope
NGC 5315	14.4	[WC4]	17	SALT *
Hen 2-99	13.3	[WC9]	15	SALT *
PMR 2	13.3	[WC9/10]	7	1.9m
Hen 2-113	11.9	[WC10]	12	1.9m
Hen 3-1333	10.9	[WC10]	7	1.9m

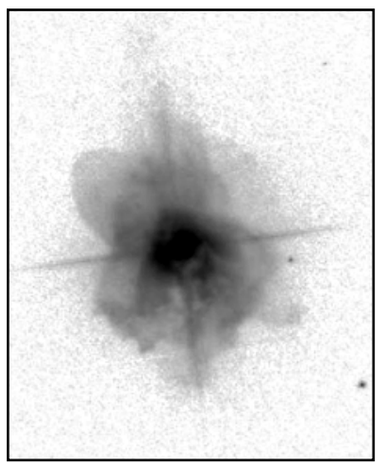
NGC 5315



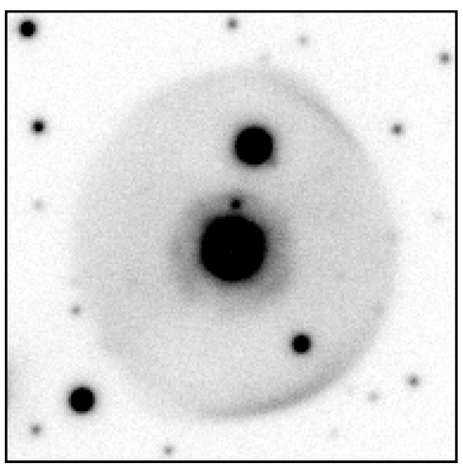
Hen 2-99



Hen 2-113



Hen 3-1333

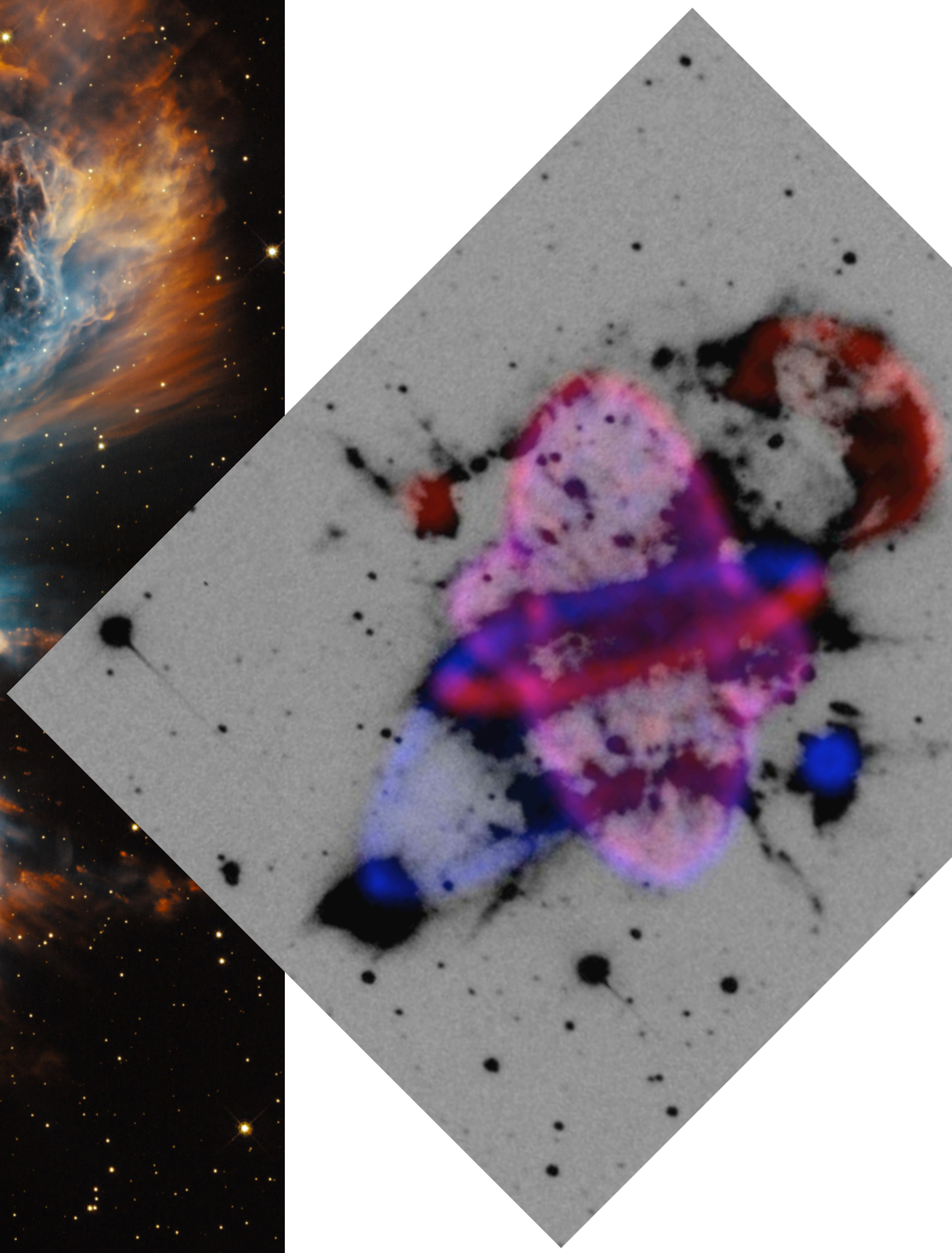


PMR 2

*also observed with SAAO 1.9m (see Manick+2015)

NGC5189

Precessing outflows
Low ionisation filaments
Jets - best candidate!



Sabin+2012

NGC5189

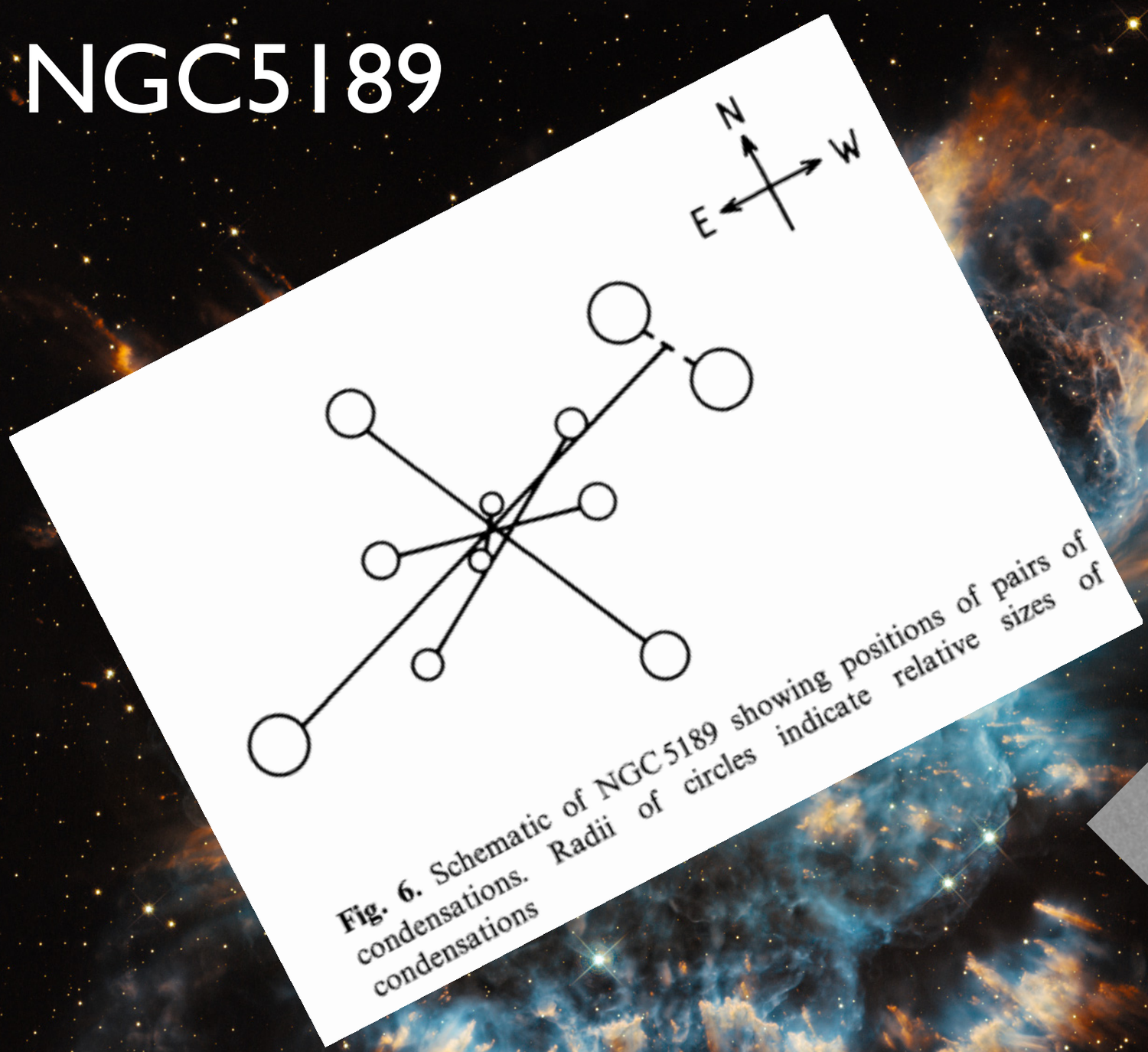
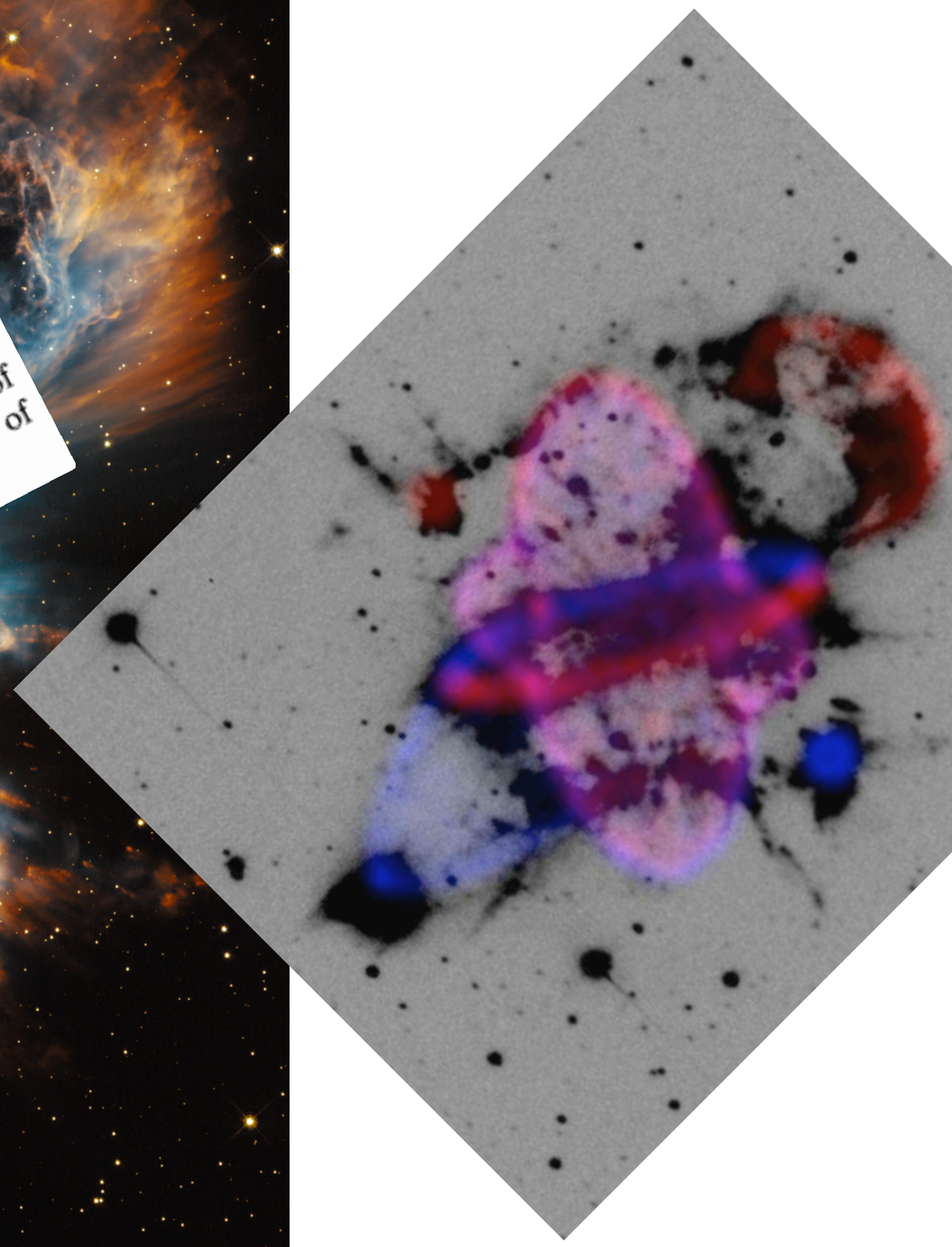


Fig. 6. Schematic of NGC 5189 showing positions of pairs of condensations. Radii of circles indicate relative sizes of condensations

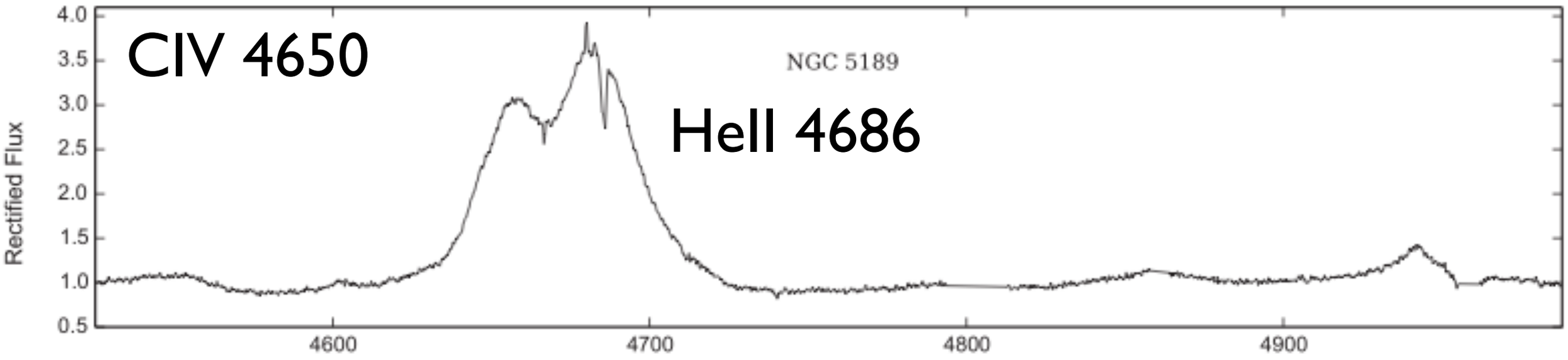
Precessing outflows
Low ionisation filaments
Jets - best candidate!

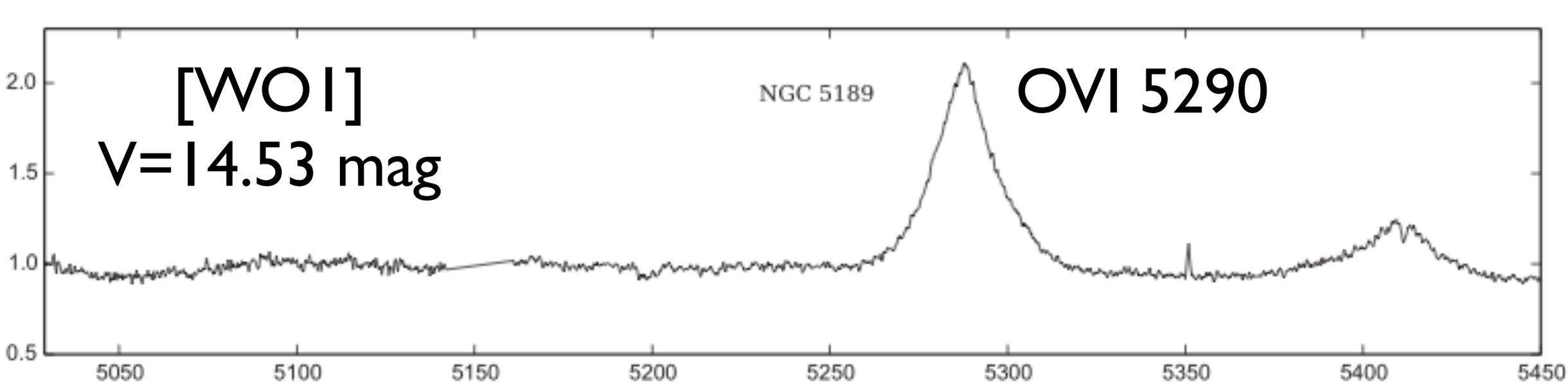


Sabin+2012

3.7d < Porb < 5.2 d
Phillips & Reay (1983)

Representative spectrum; S/N range of all spectra: 45-90





Teff=165 kK

v_∞=2500 km/s

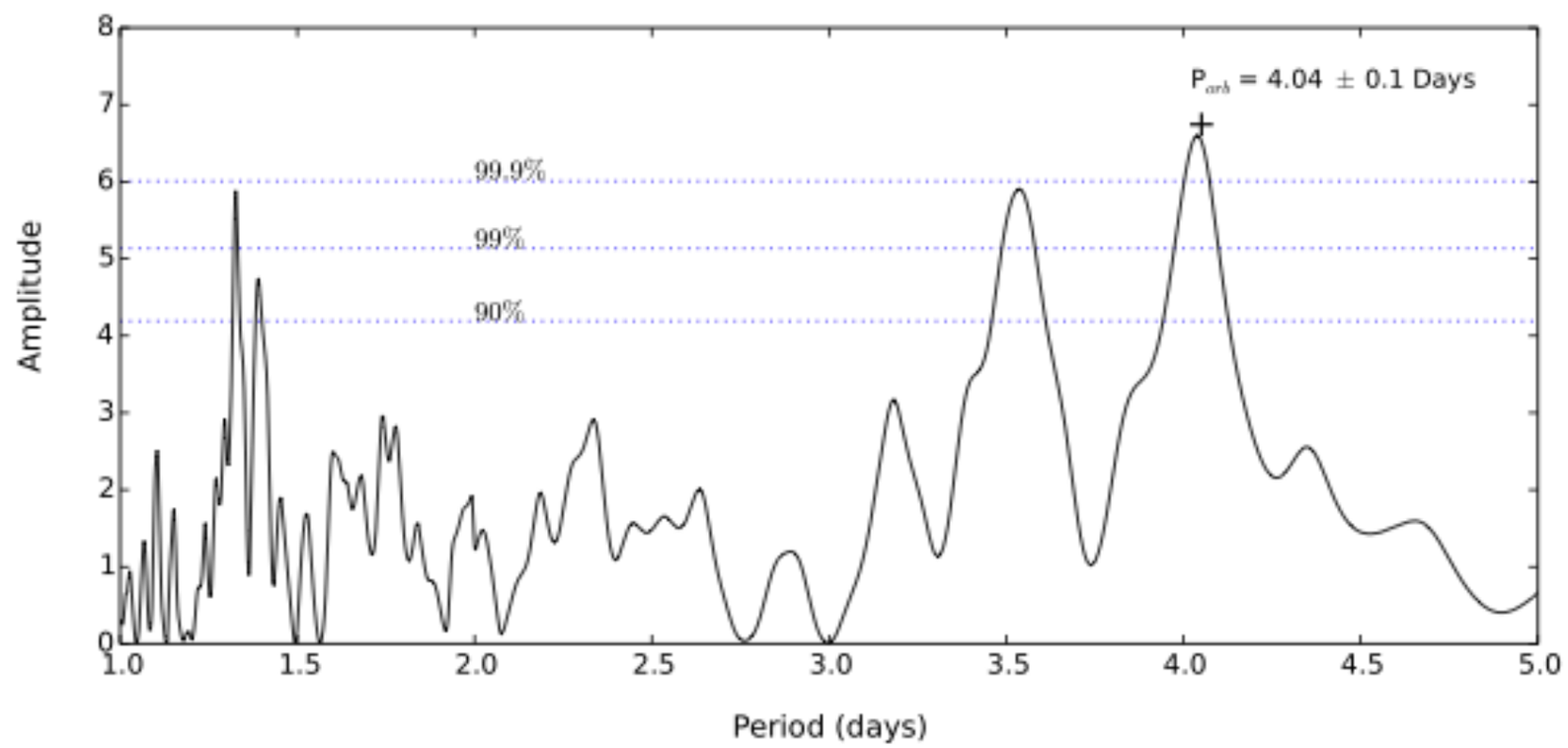
(Keller+2014)

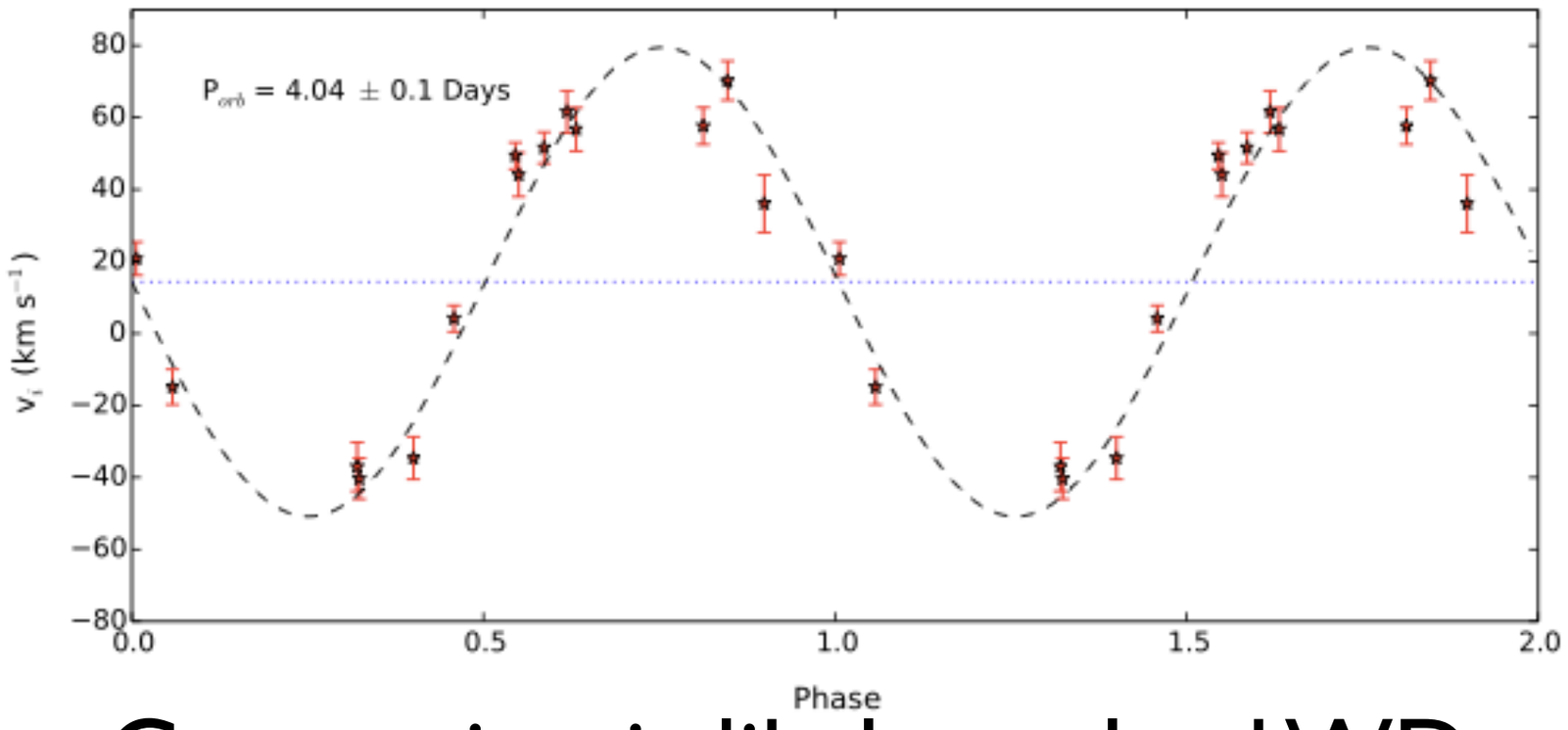
Manick, Miszalski & McBride 2015

P=4.04±0.10 d

Assuming [WO1]=0.6 Msun

Inclination (degrees)	Secondary Mass (Msun)
30	1.56
40	0.99
50	0.74
60	0.61
70	0.54
80	0.51





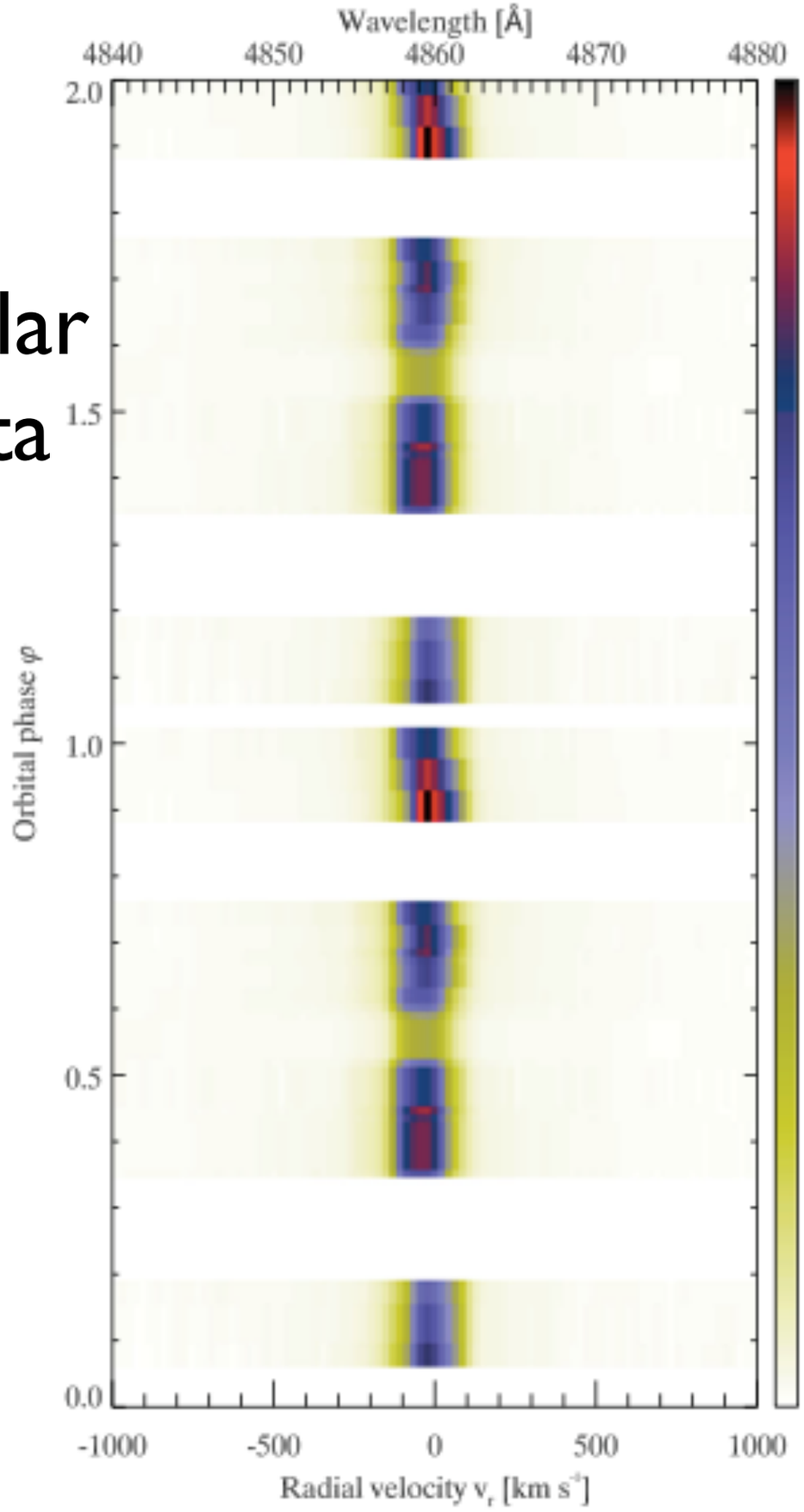
Companion is likely evolved WD

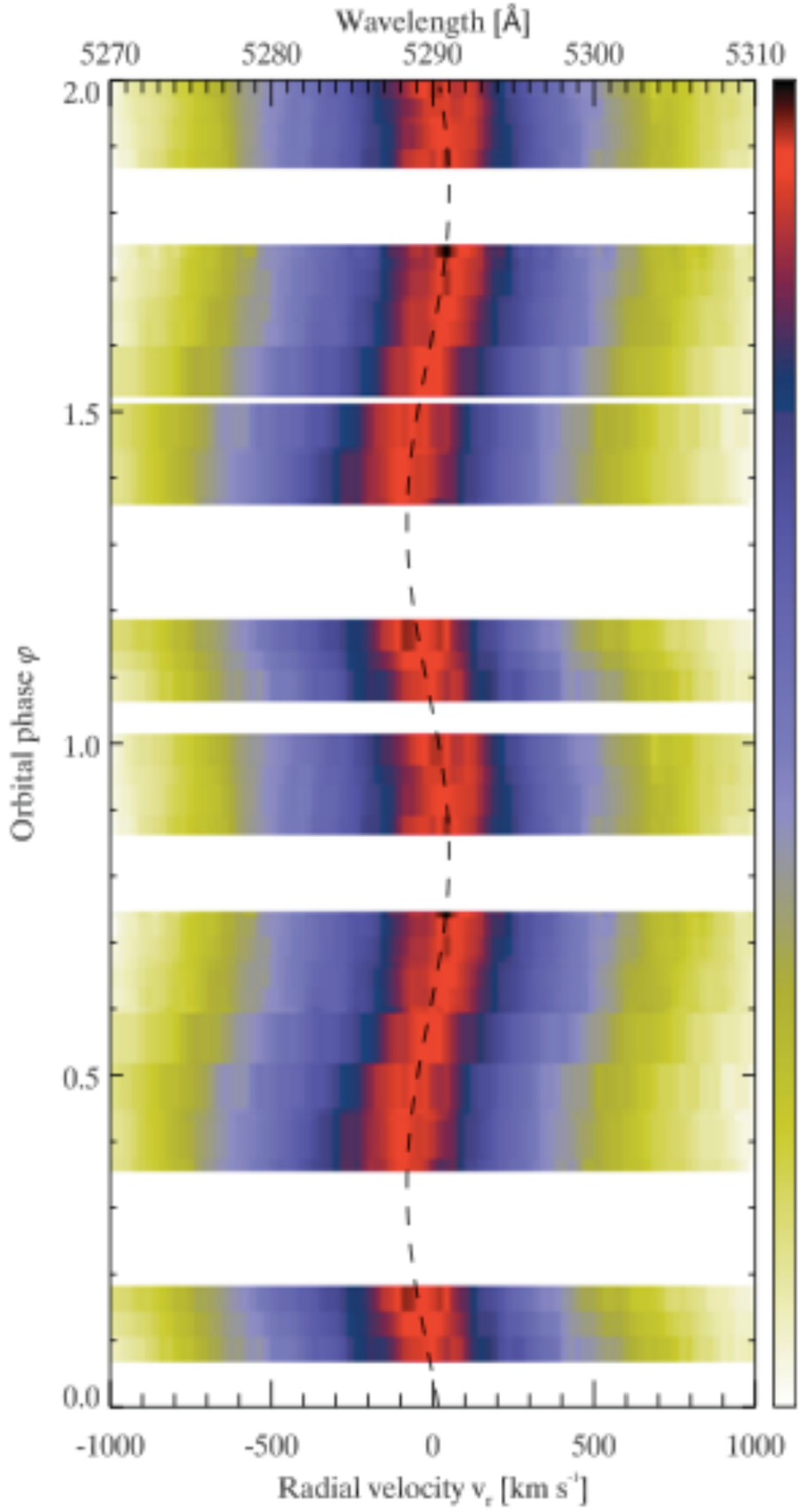
Need inclination (e.g. polarimetry)

Manick, Miszalski & McBride 2015

If you're not convinced…

Nebular Hbeta

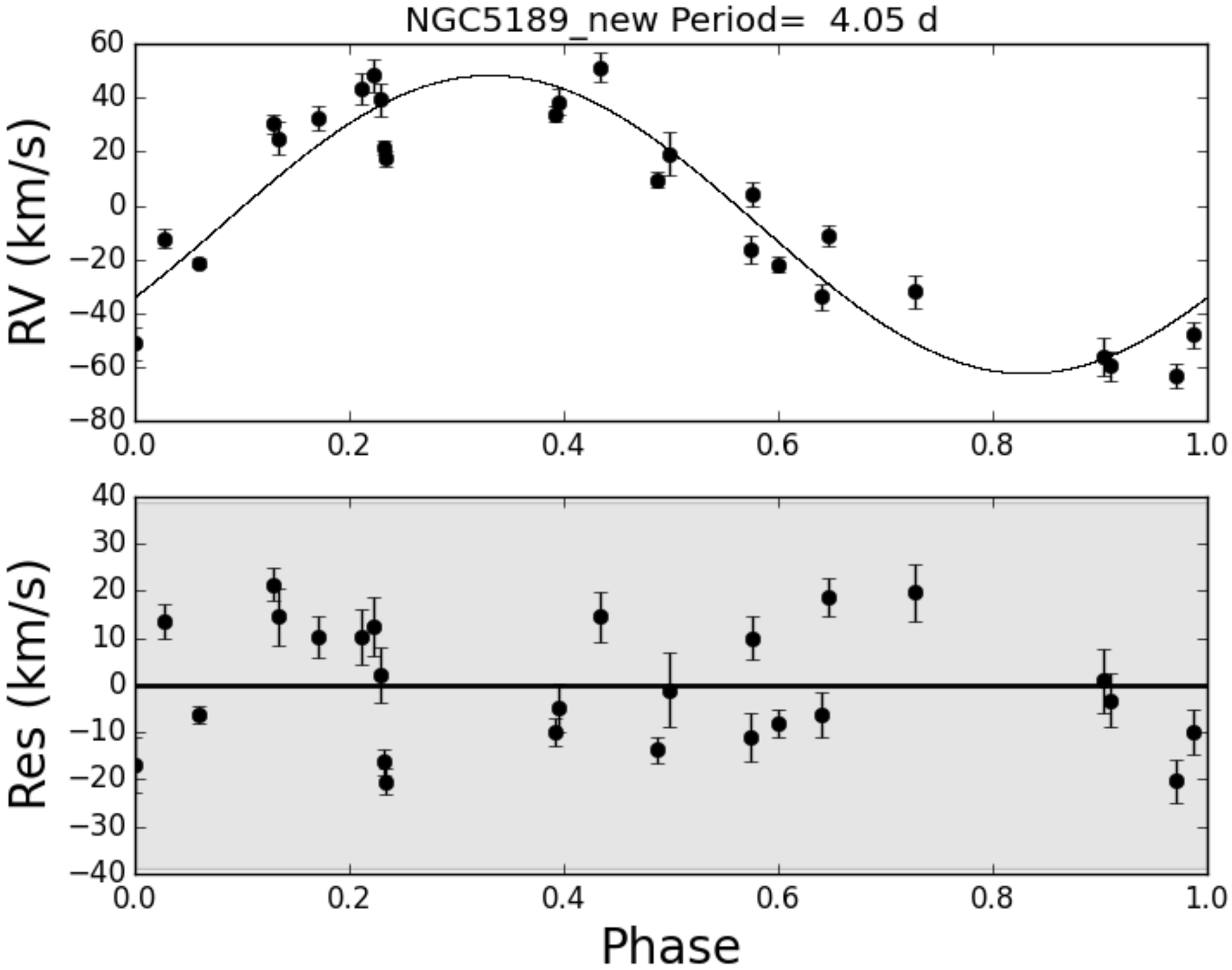




Stellar OVI

if you're STILL not convinced…

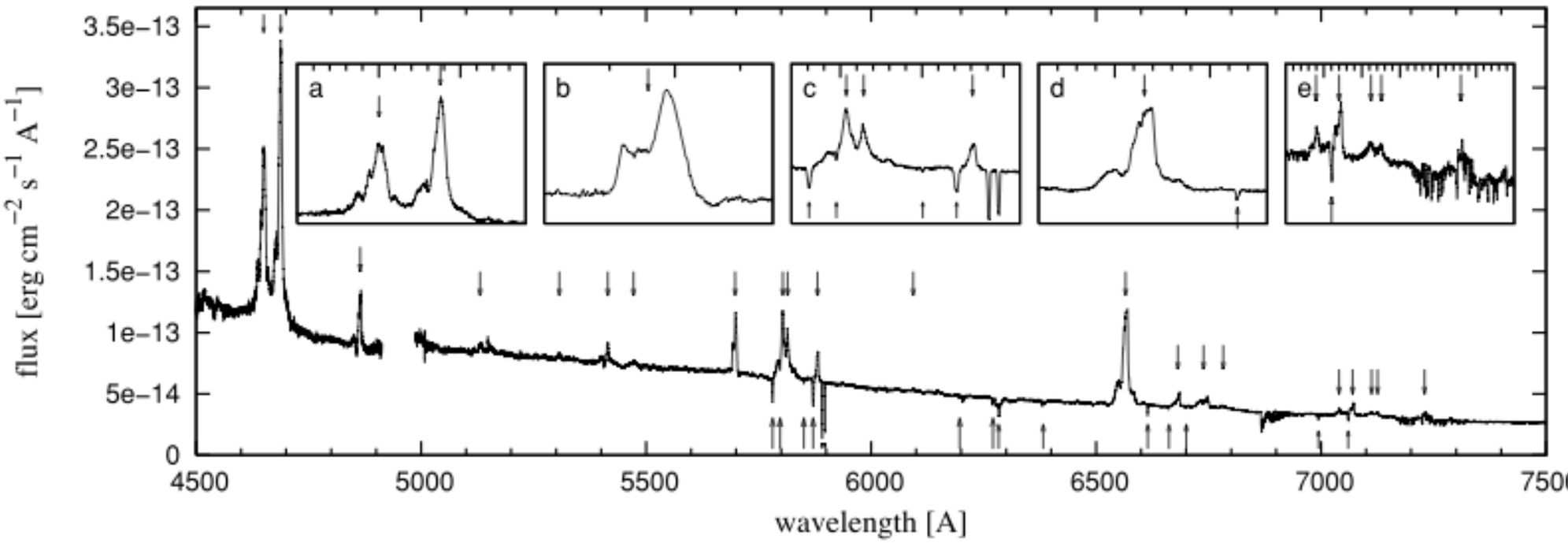
Fit with *more* data - 26 total SALT RSS spectra



PHR0654-1045

[WC7] spectral type

Hajduk+ 2010



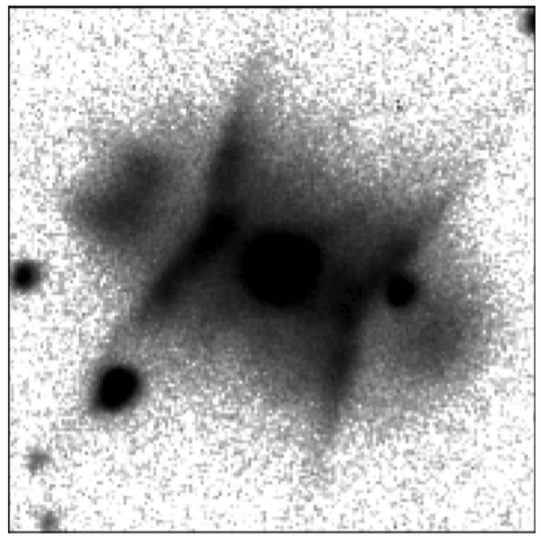


Figure 3. $H\alpha$ image of PN G222.8 − 04.2. Logarithmic intensity scale is applied. The box is 30 arcsec width, North is at the top and East to the left.

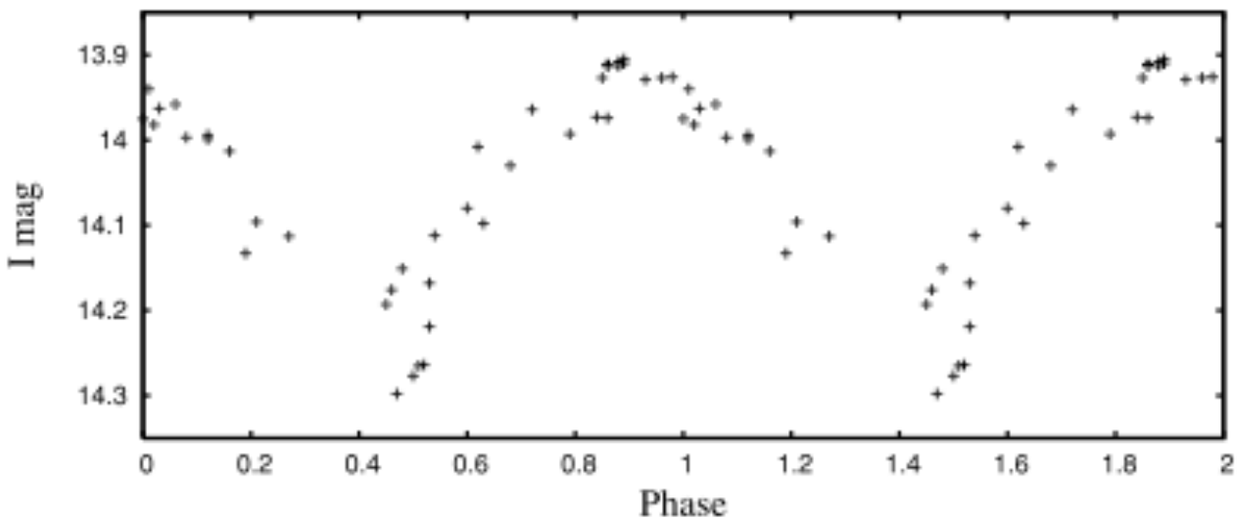


Figure 6. SAAO *I*-band light curve of PN G222.8 − 04.2 phased with the period of 0.63 d.

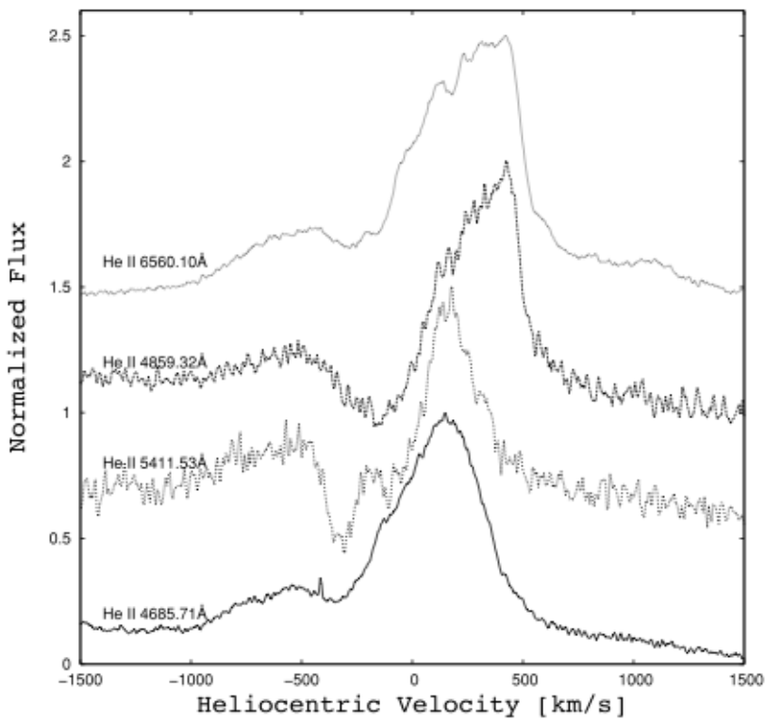
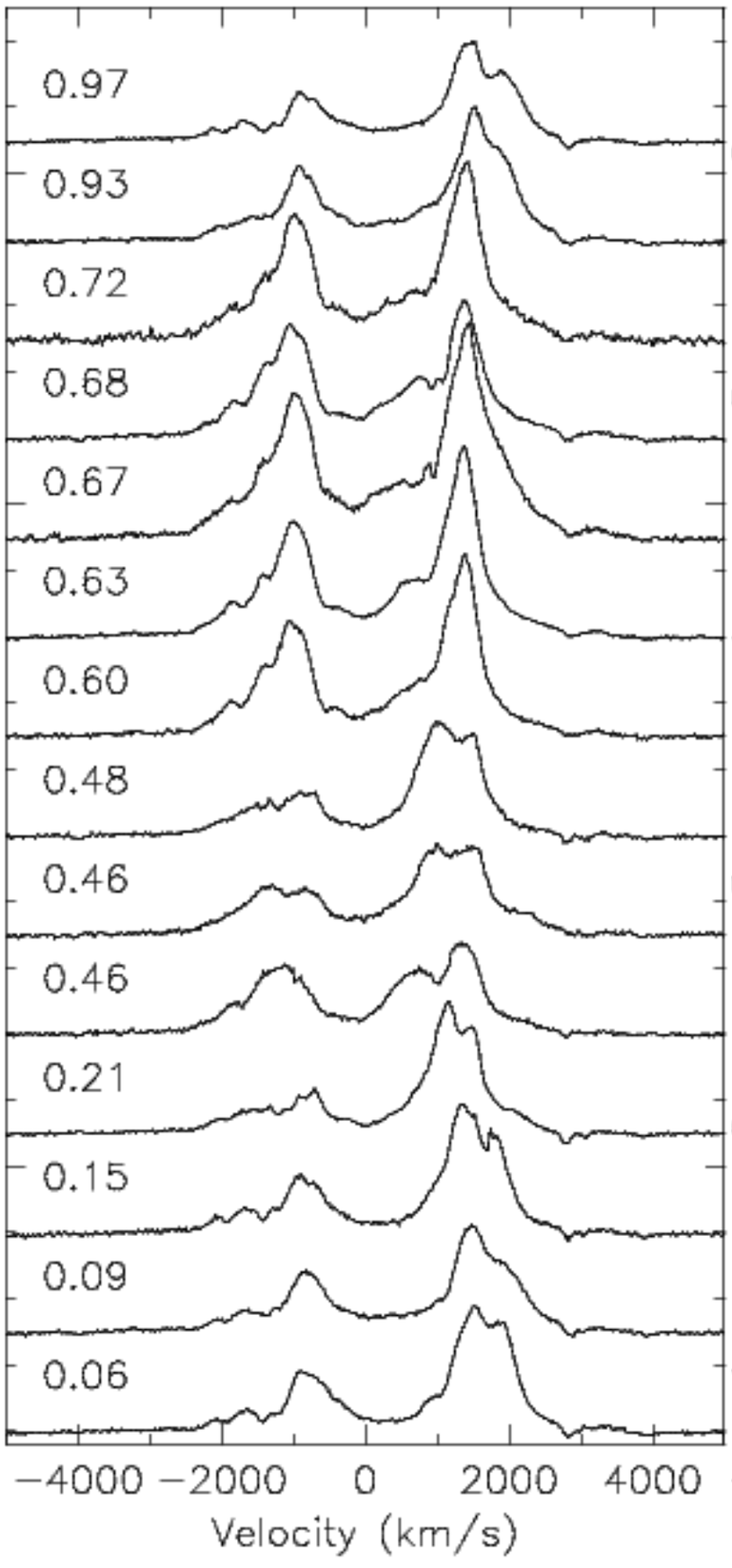


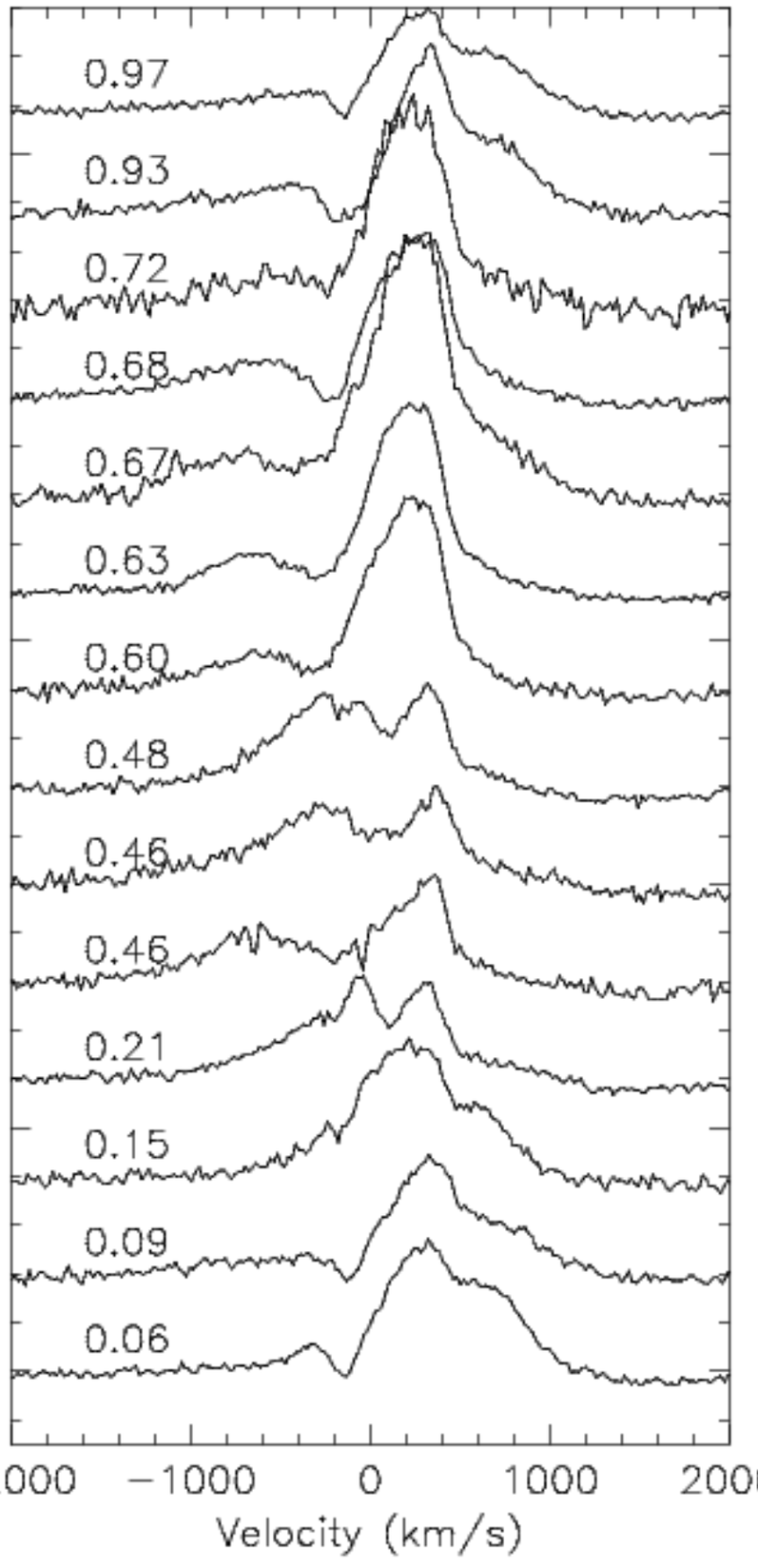
Figure 8. Helium II lines.

14 SALT RSS spectra, 2 Å res (FWHM)

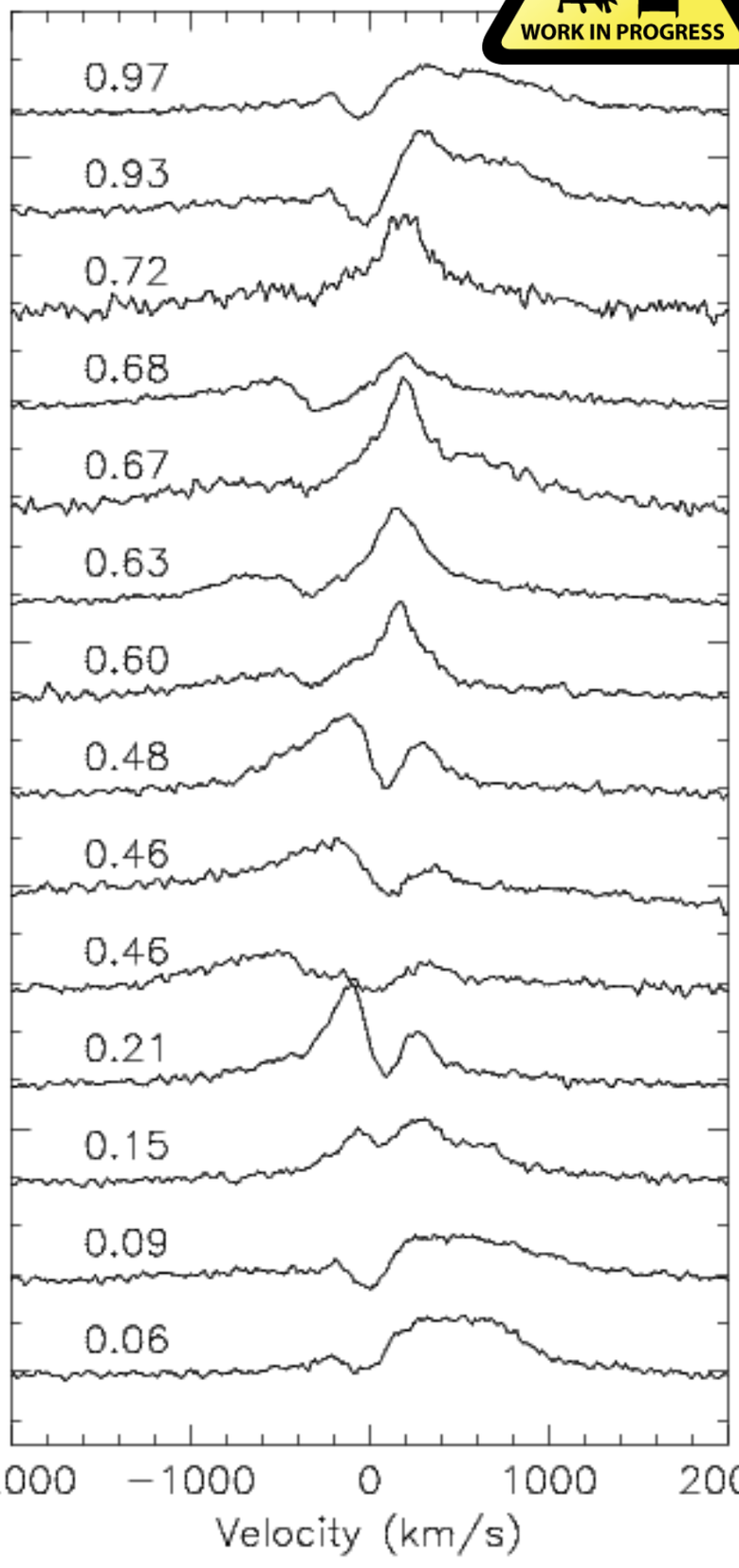
λ4667



HeII 4859



HeII 5412



PHR0654 Period= 1.26 d

RV (km/s)

200
150
100
50
0
−50
−100
−150
−200
−250

0.0
0.2
0.4
0.6
0.8
1.0

Res (km/s)

100
50
0
−50
−100

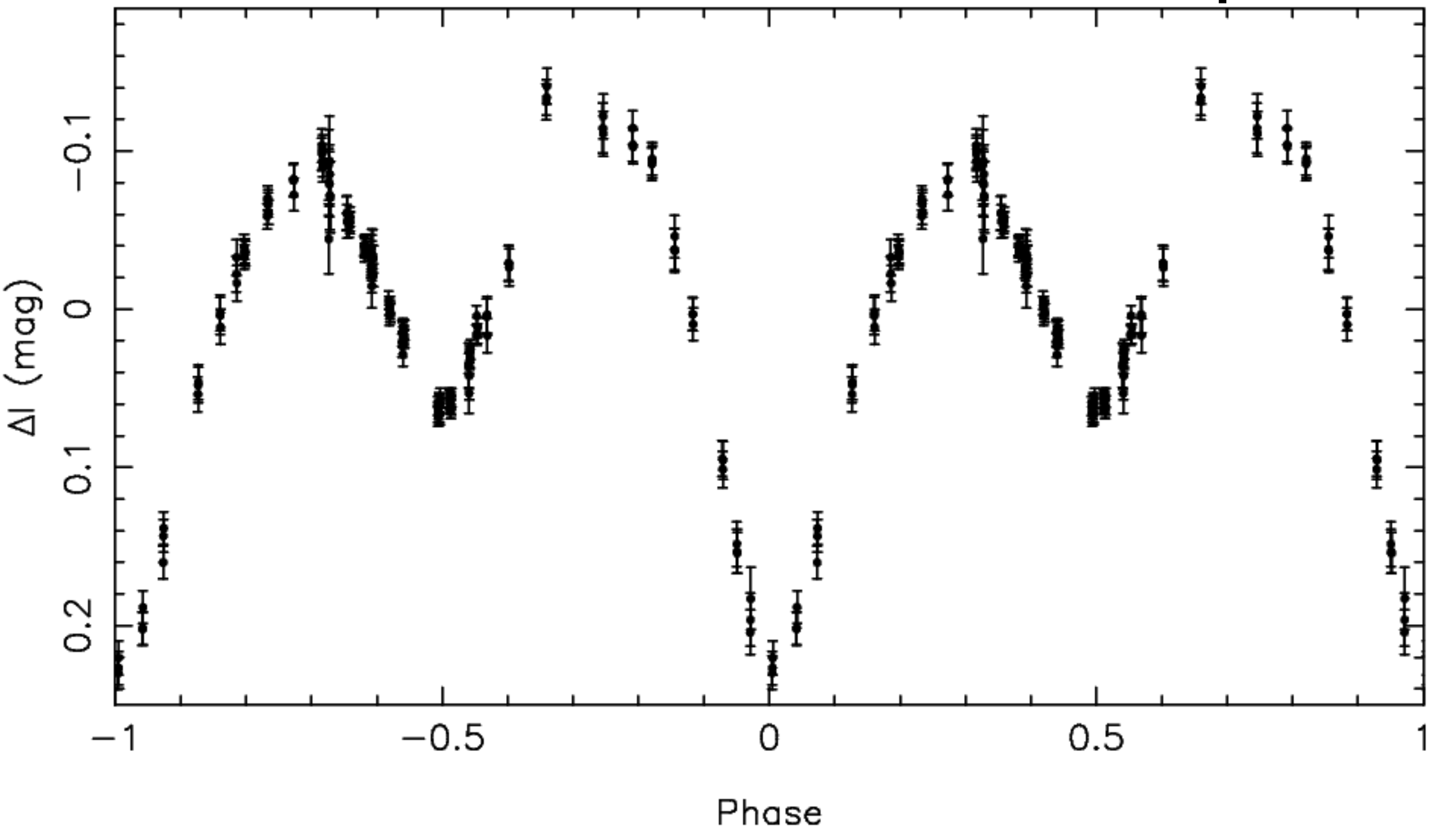
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Phase

ESO NTT lightcurve from Dave Jones and Henri Boffin

P=1.26 days

Ellipsoidal variability or eclipses

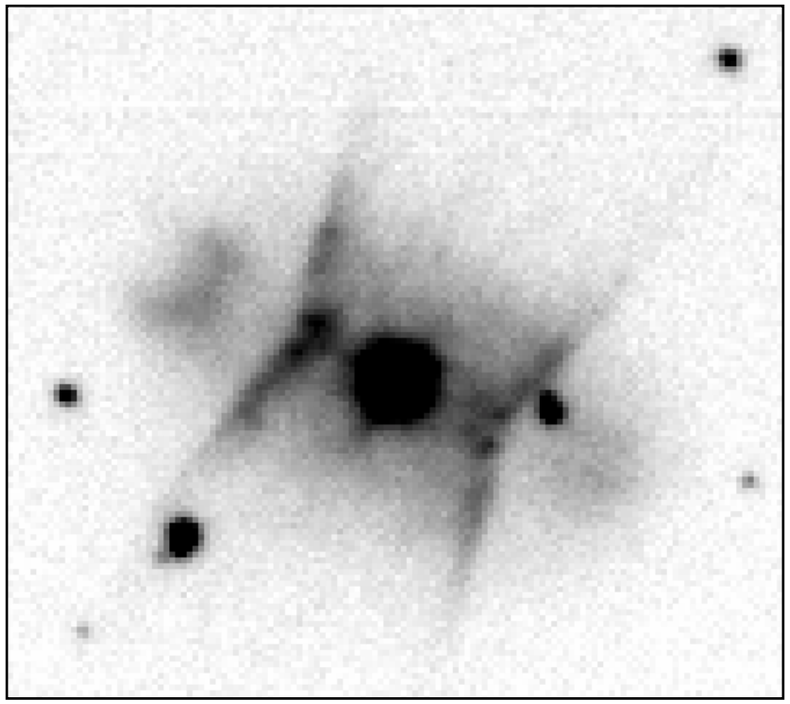


Companion mass

Assuming [WC7]=0.6 Msun

Inclination (degrees)	Secondary Mass (Msun)
30	>6.0
40	4.1±0.50
50	2.7±0.30
60	2.2±0.20
70	1.8±0.07
80	1.7±0.03

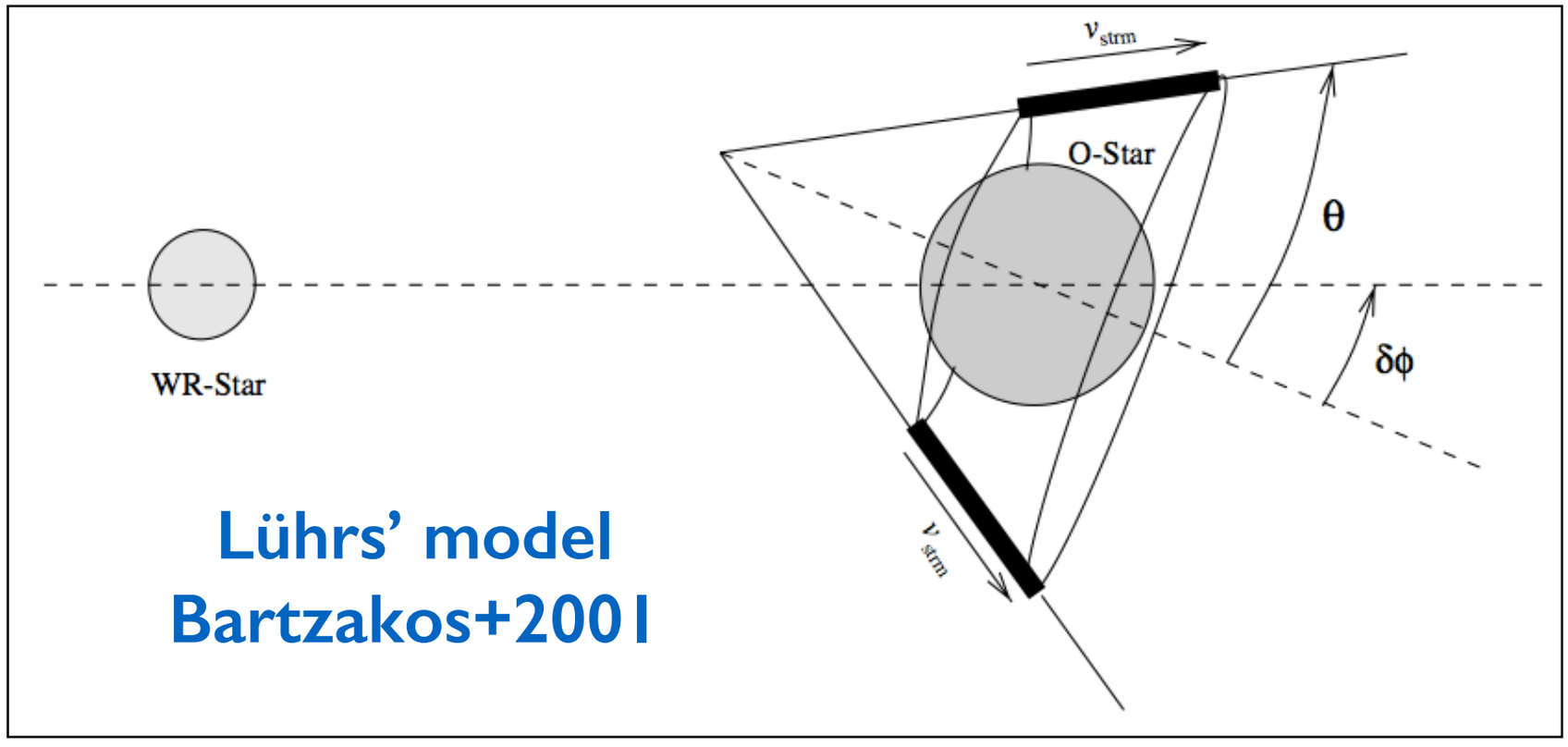
Another [WR] or O/B subdwarf?



Over-estimated amplitude?

Cross-correlation gremlins due to template?

Todo: full RV + lightcurve model

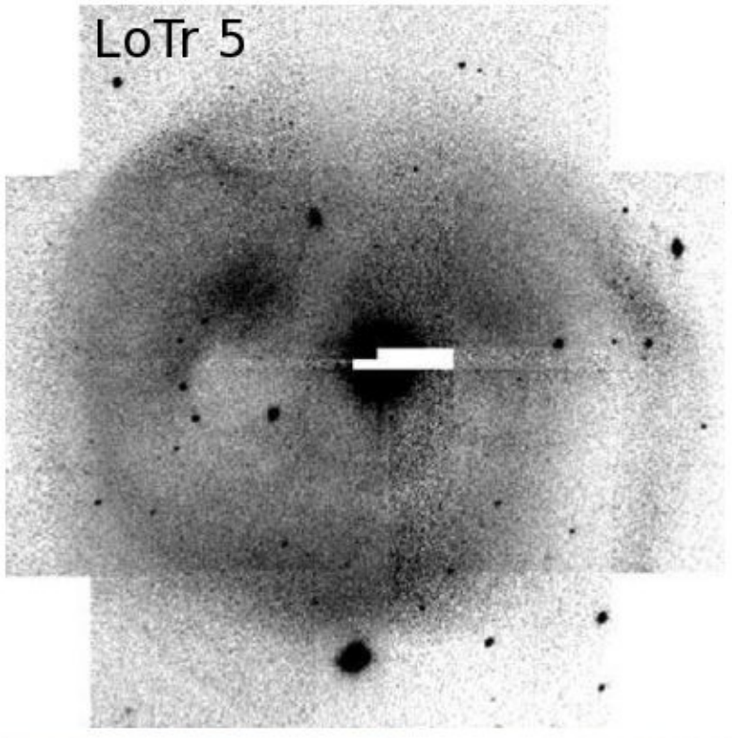


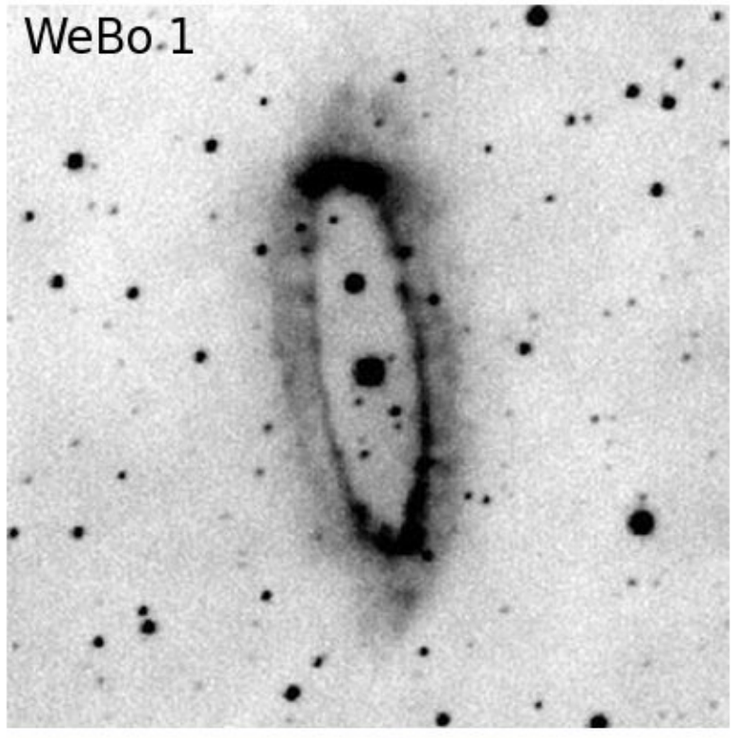
Lührs' model
Bartzakos+2001

Wider binaries and dust

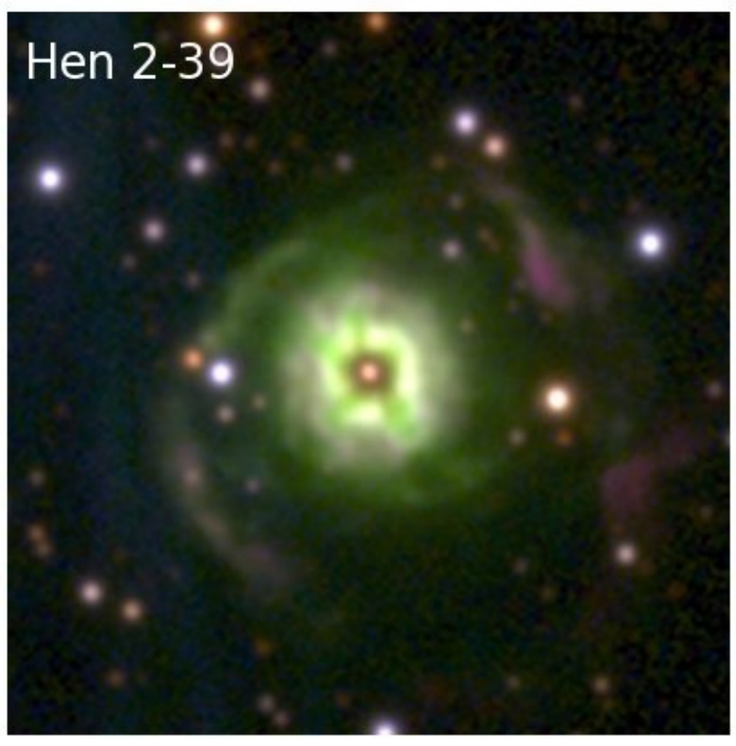
Barium central stars

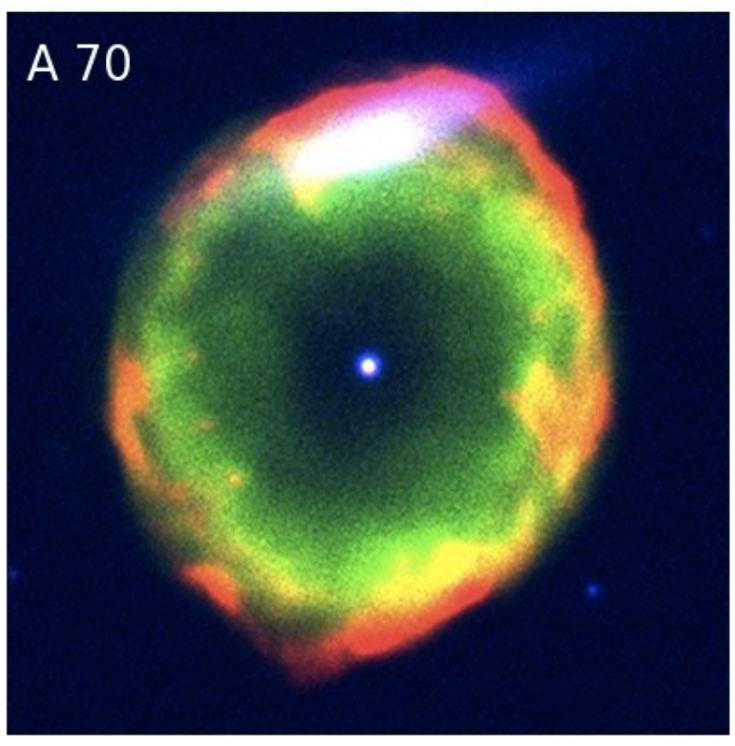
Graham +2004
Van Winckel +2014





Bond+2003
Siegel+2012



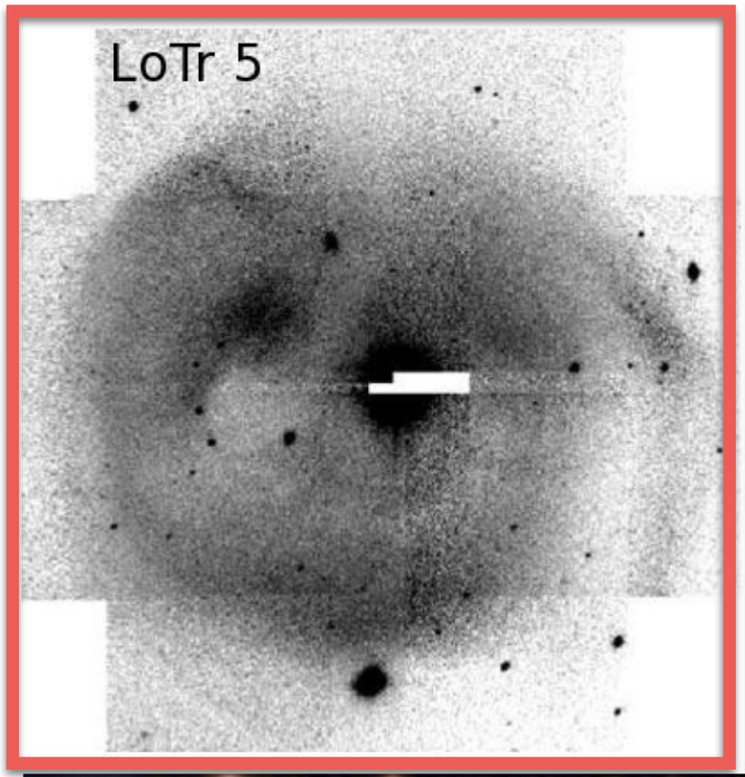


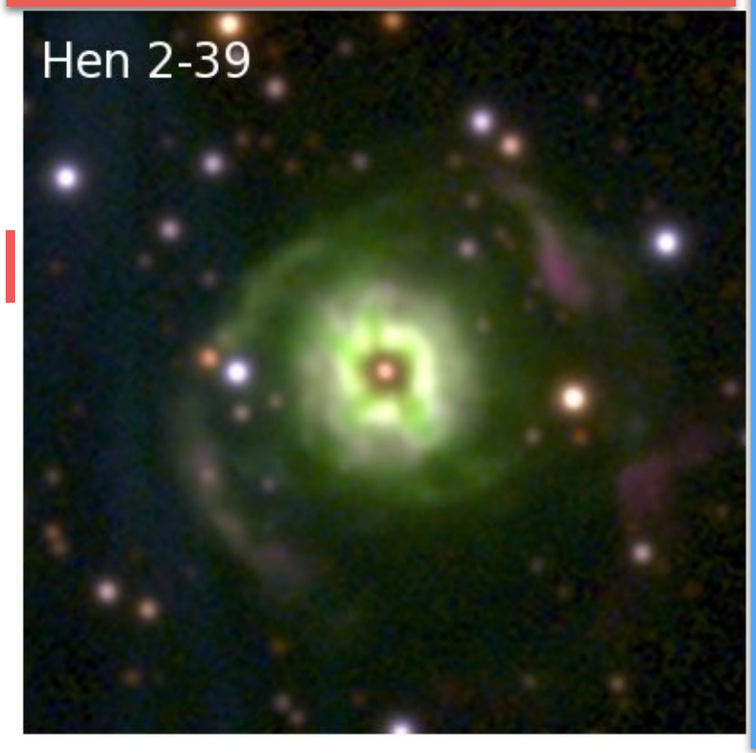
Miszalski+2013 Miszalski+2012

Barium central stars

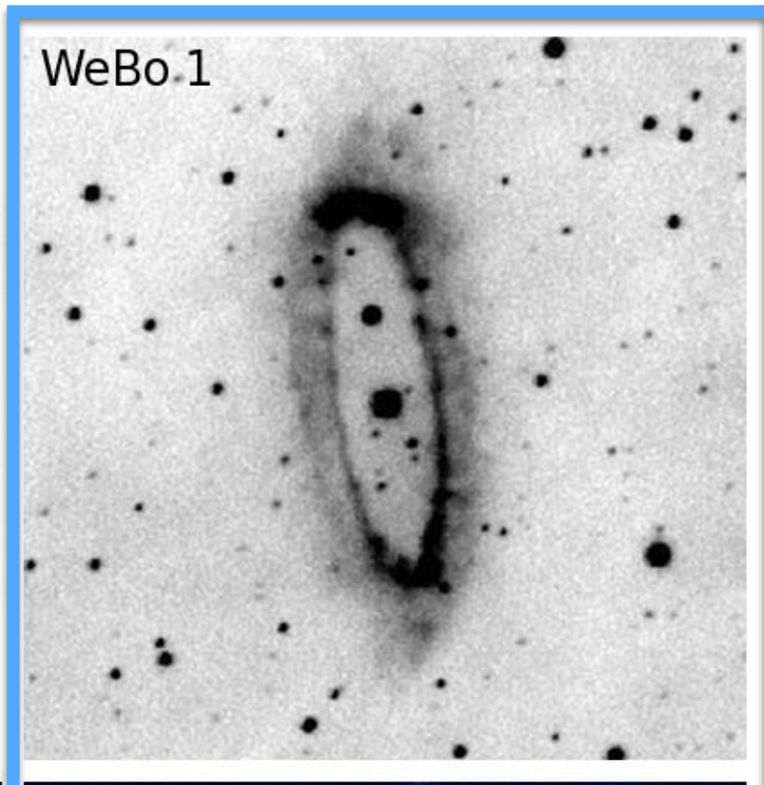
Graham +2004
Van Winckel +2014

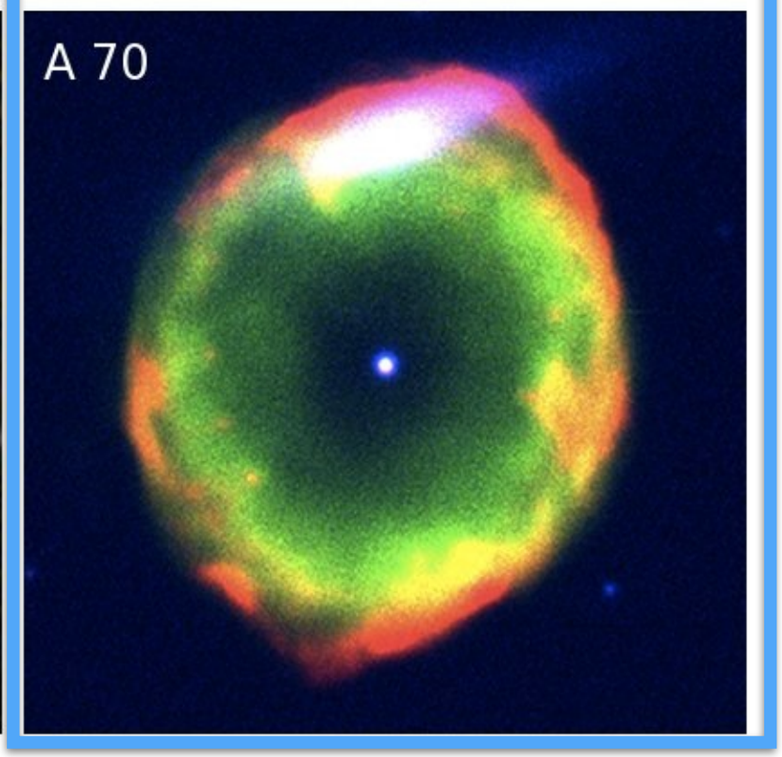
RV orbit in progress (Van Winckel talk on Wednesday)





Miszalski+2013





Miszalski+2012

Bond+2003
Siegel+2012

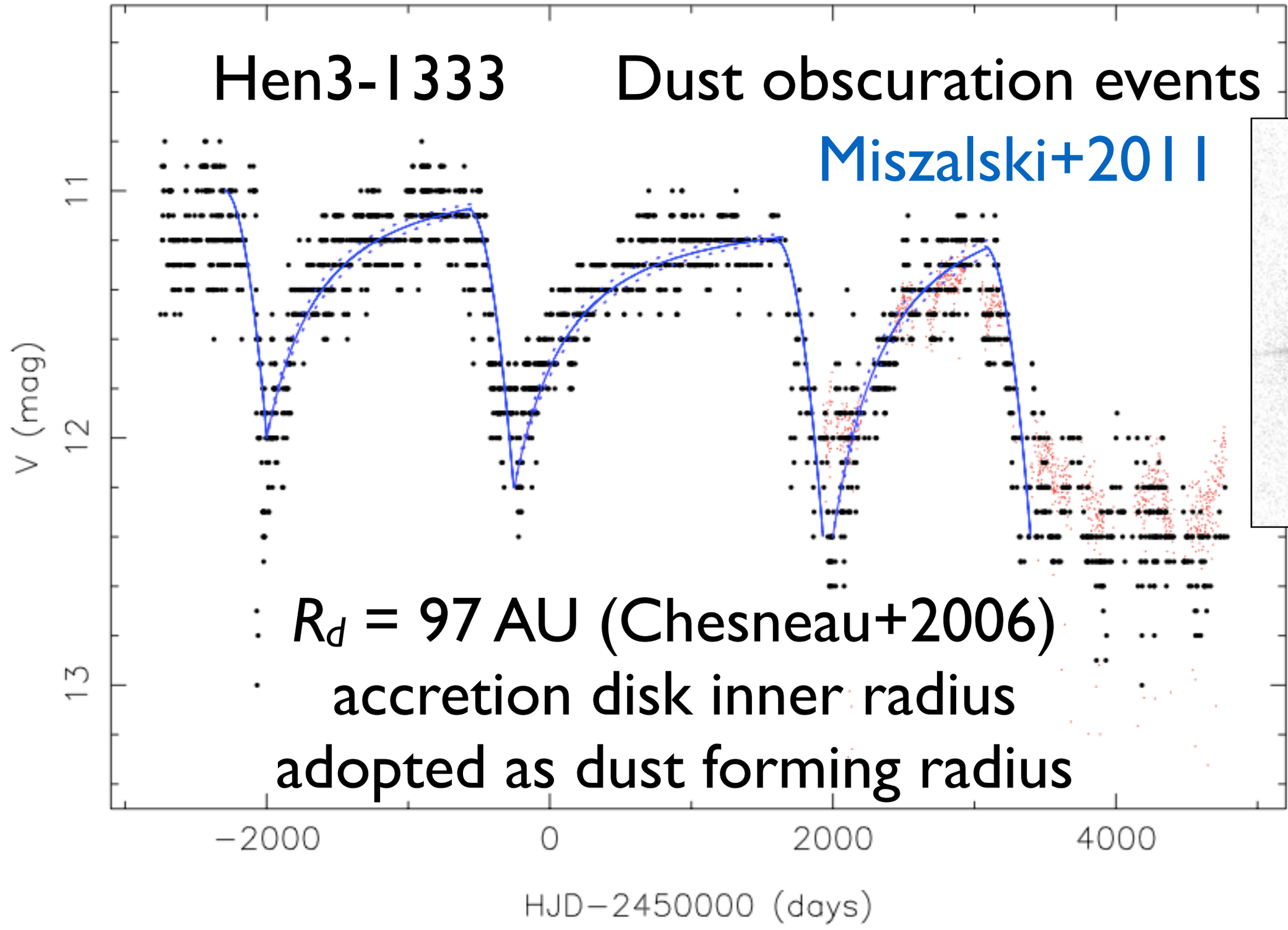
WD companion detected in UV for WeBo1 and A70

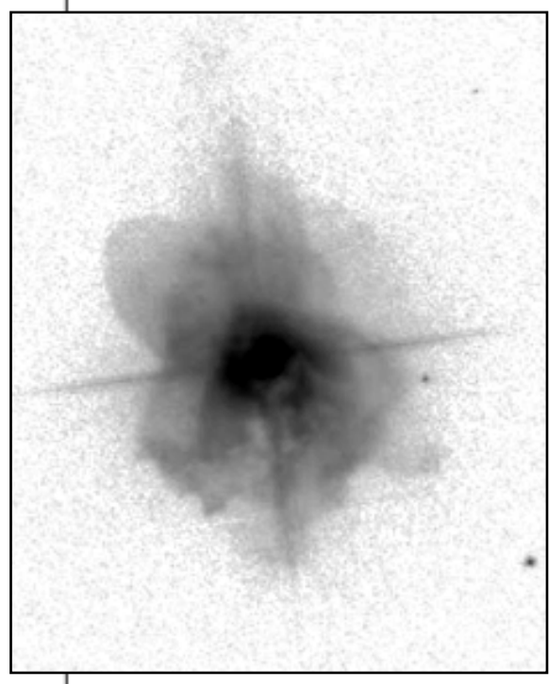
Wider binaries with [WR]?

- No wide [WR] binaries proven yet
- NGC 246 (PG1159) - visual binary? (Ciardullo+1999)
- Hen 3-1333/CPD-56° 8032 - [WC10]
  - Dust disk detected by STIS (De Marco+2002) and VLTI (Chesneau+ 2006)
- Post-AGB disks strongly tied to binarity (Van Winckel+ 2009)
- Dual dust chemistry (C and O dust), also found in numerous [WR]
- Quasi-periodic dust obscuration events (every ~5 yrs)

Hen3-1333 Dust obscuration events

Miszalski+2011





: R_d = 97 AU (Chesneau+2006)
accretion disk inner radius
adopted as dust forming radius

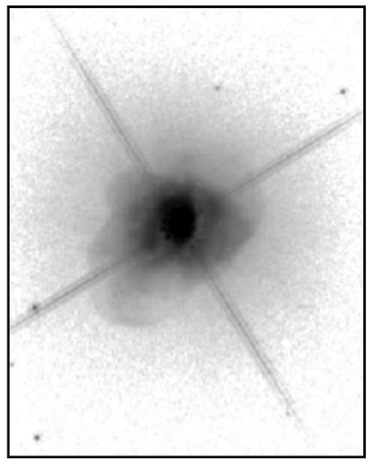
dust forming wide binary?

$$m(t) - m(t_1) = (m(t_0) - m(t_1)) \frac{R_{\rm d}^2}{(R_{\rm d} + v_\infty t)^2}$$

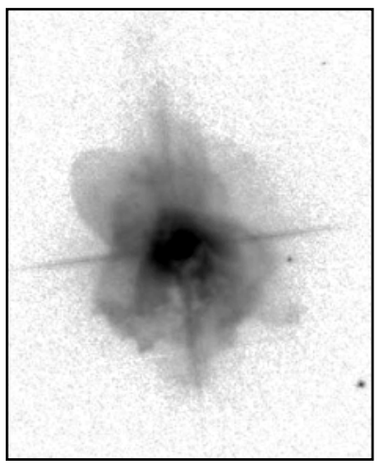
dust grain growth
Goeres & Sedlmayr (1992)

- Teff=30 kK, v_∞=225 km/s (De Marco & Crowther 1998)

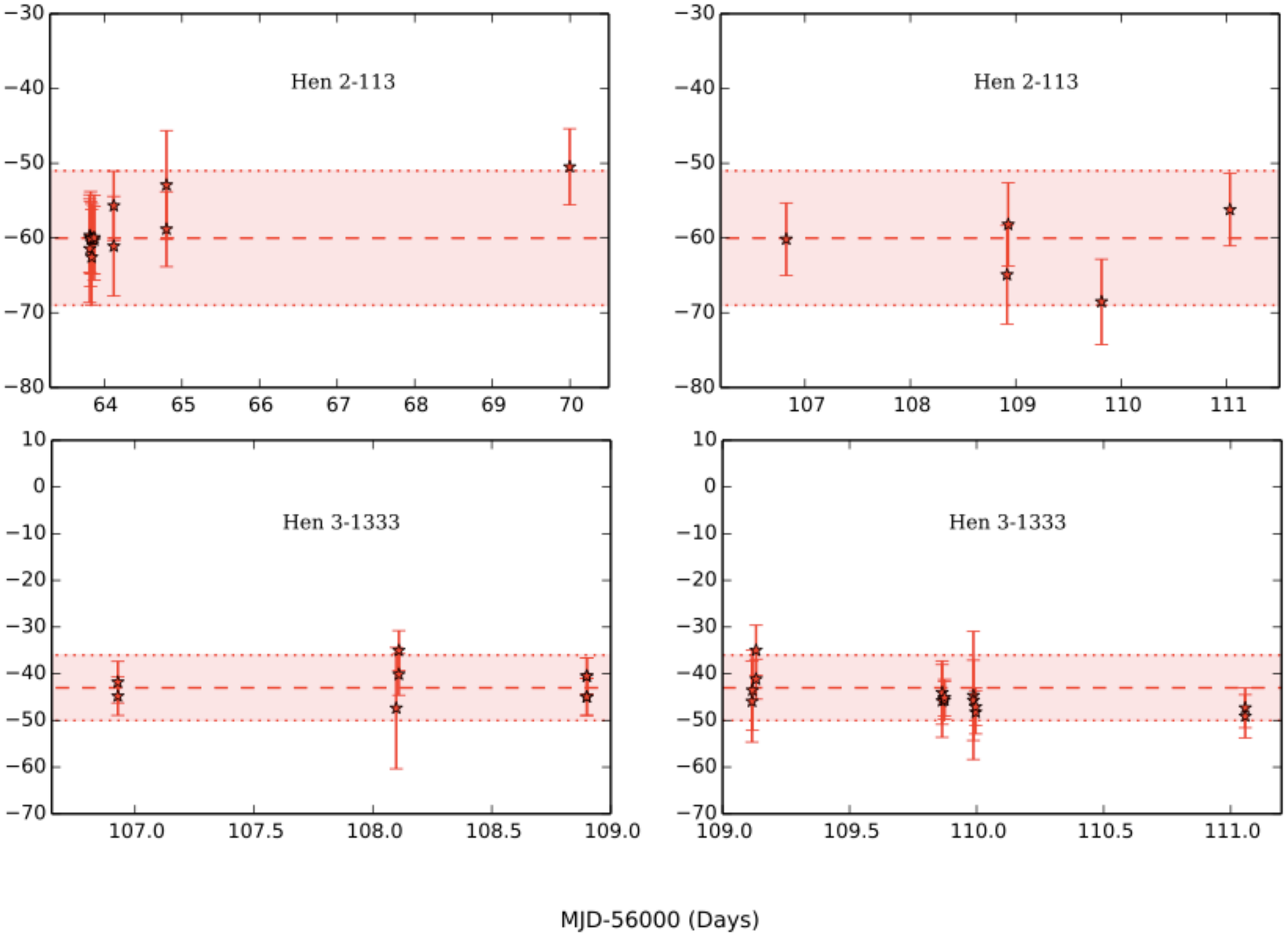
Not close binaries



Hen2-113
12 spectra

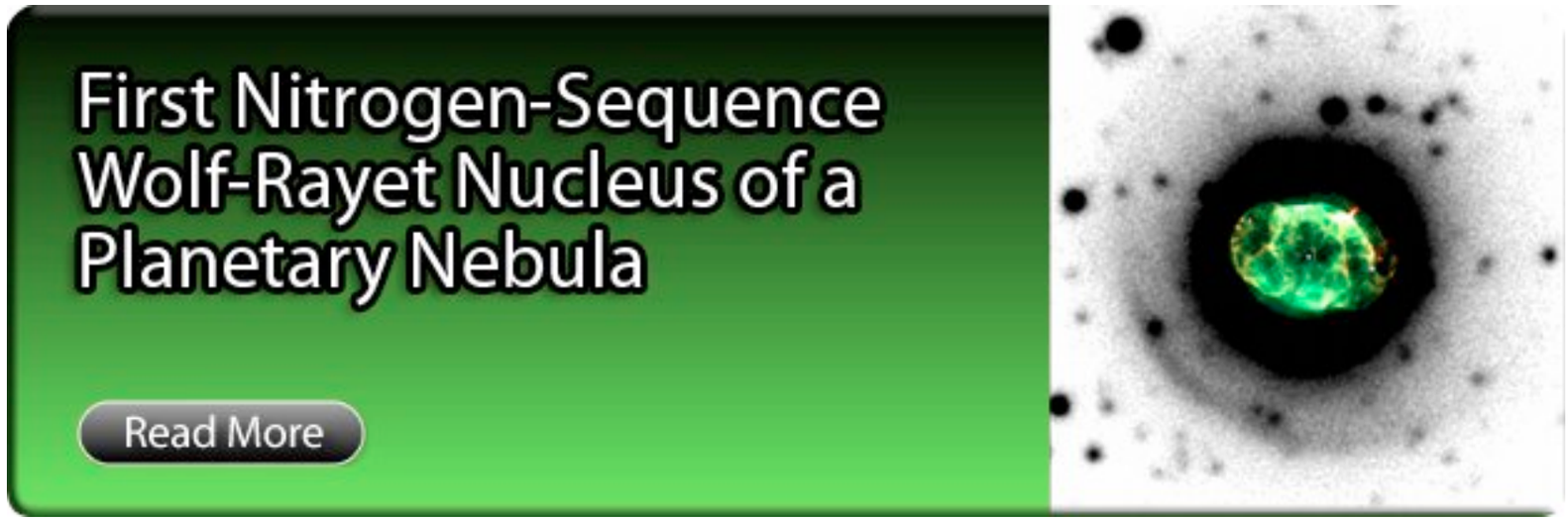


Hen3-1333
7 spectra



Manick, Miszalski & McBride 2015

Perspectives



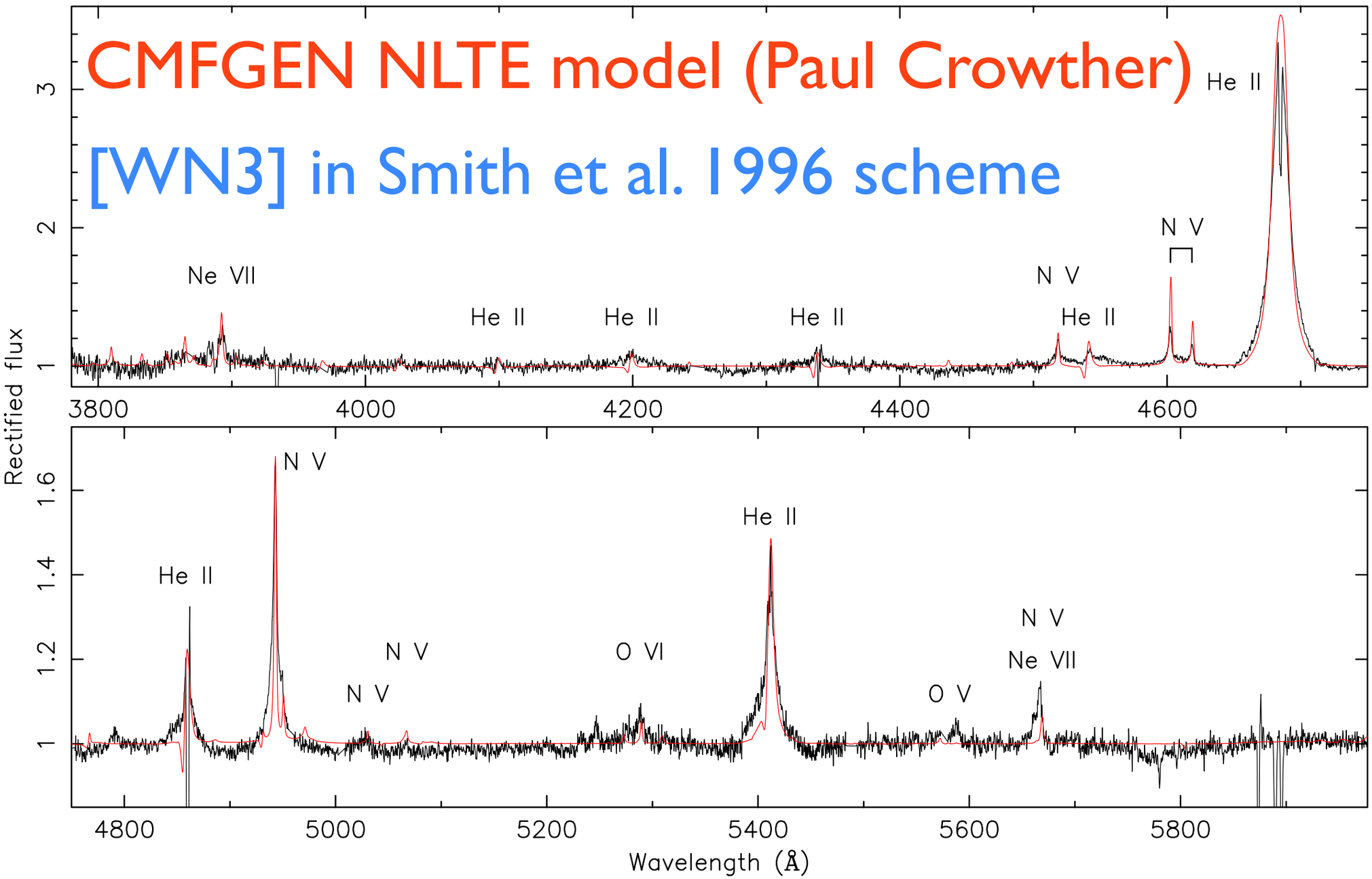
IC 4663
Miszalski+2012

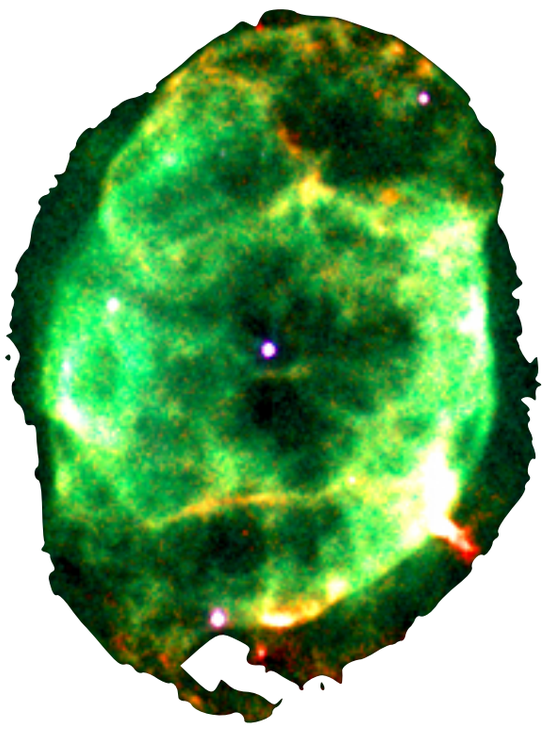
CMFGEN NLTE model (Paul Crowther)

[WN3] in Smith et al. 1996 scheme

He = 95% by mass

T*=140 kK





Atmospheric Composition

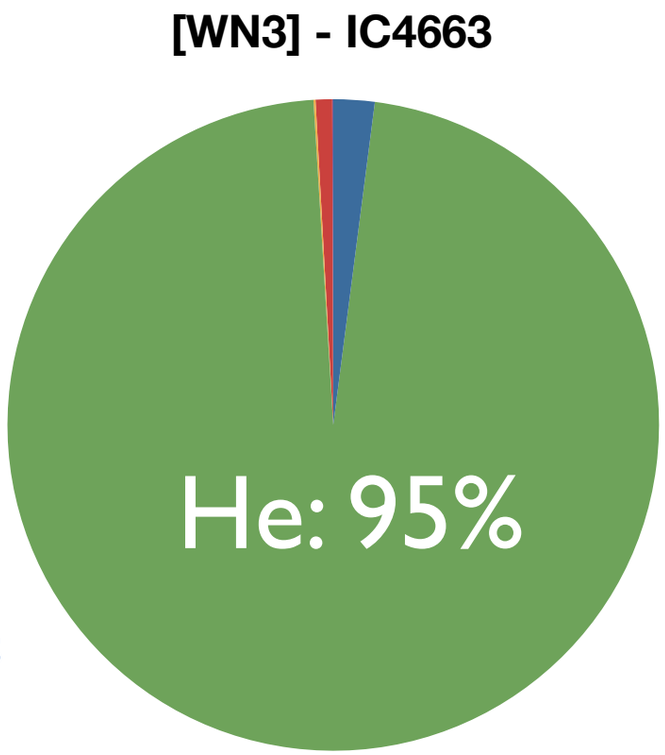
He-rich H-def sequence

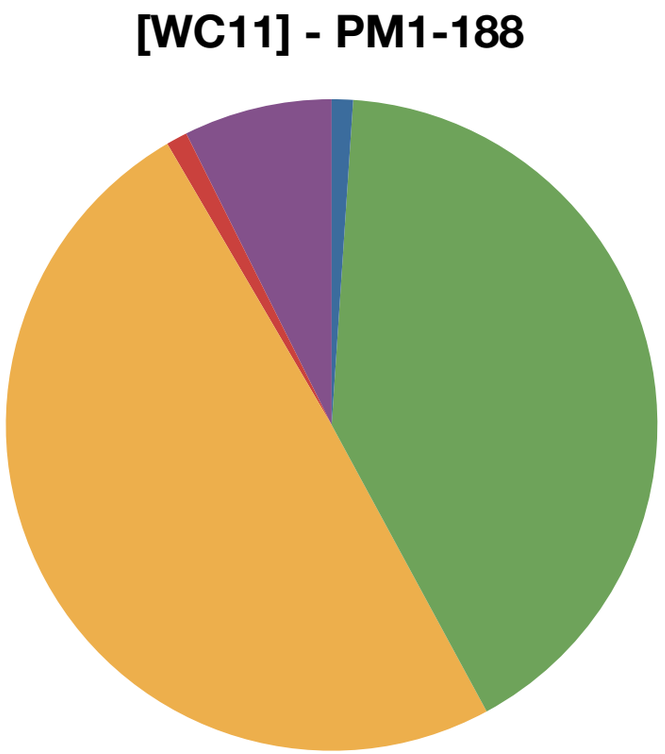
[WN]

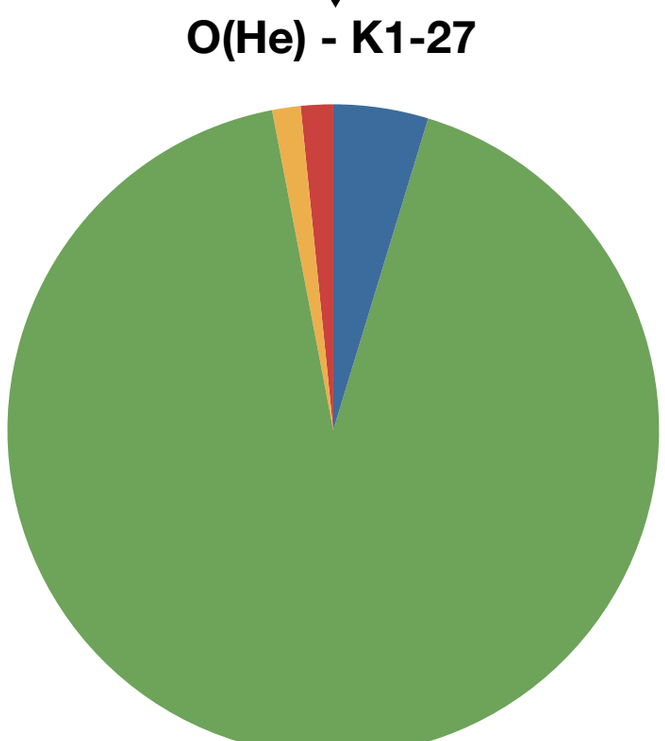
CMFGEN analysis (Crowther)

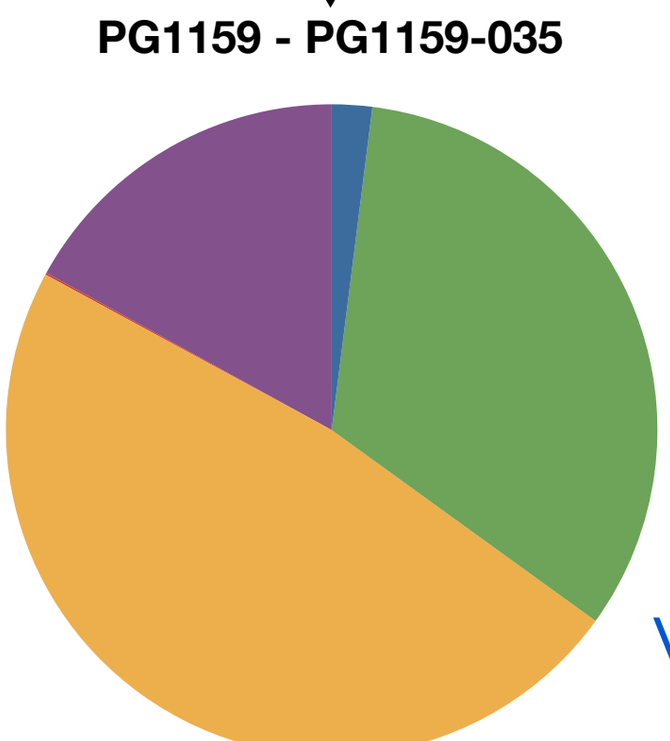
C-rich H-def sequence

[WC]









O(He)

PG1159

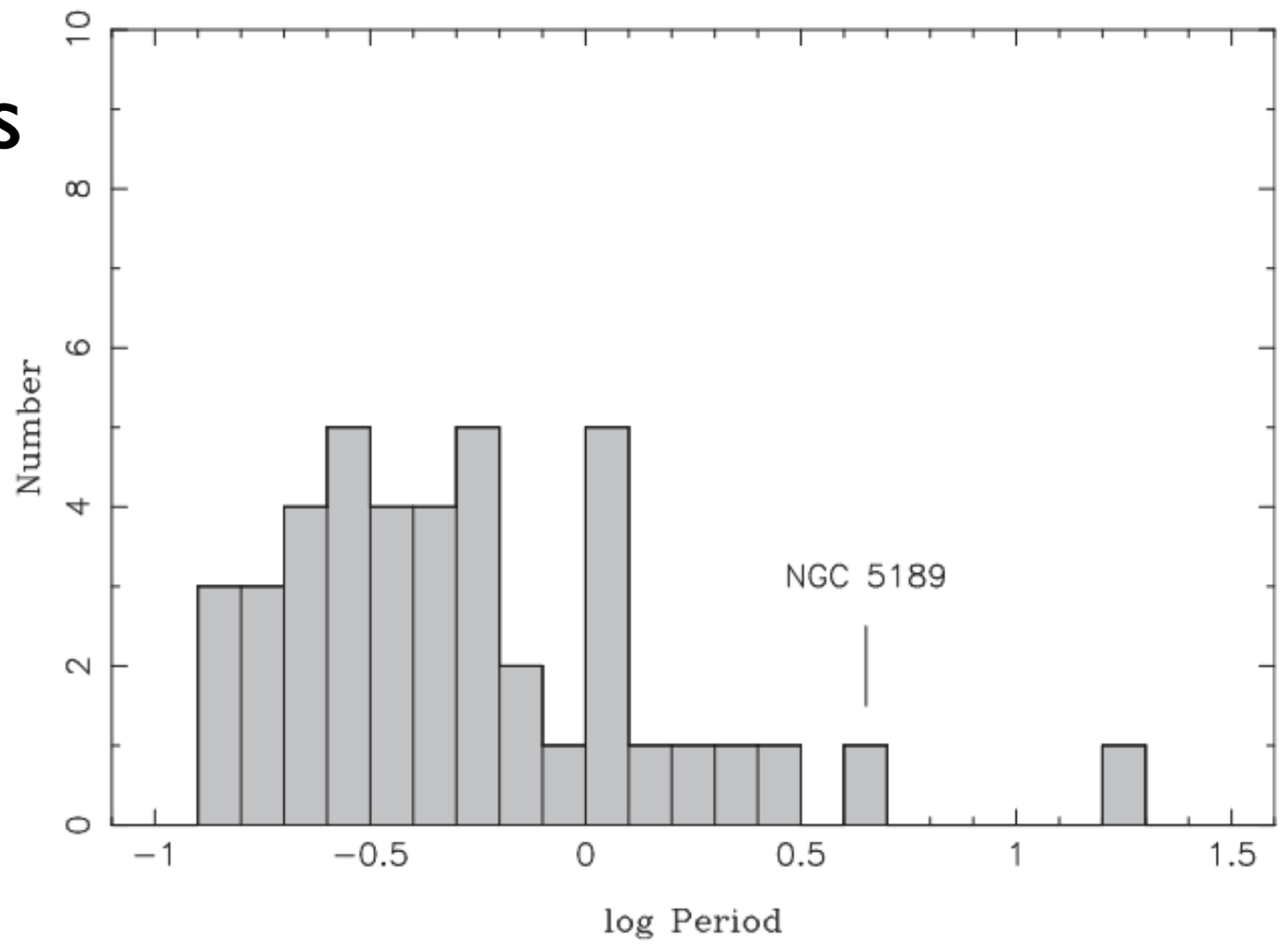
Mass fractions: Werner & Herwig (2006)

Perspectives

- RV survey motivated by He-rich (>90%) [WN] stars
- The LTP/VLTP/AFTP scenarios cannot explain [WN] composition => binary merger? (Zhang & Jeffery 2012)
- As [WC] stars can be in binaries, then [WN] may not necessarily result from mergers (if similar formation)
- Two post-AGB channels: C-rich [WC] → PG1159 and He-rich [WN] →O(He) (Miszalski+2012)
- Binary statistics crucial to help understand if either channel depends on binaries to form (or not)
  - H-envelope stripped by companion? Or not important?
  - Develop binary formation scenarios (De Marco & Soker 2002)

Perspectives

- Larger 4.05 d orbit of NGC5189 suggests [WR] companions could have wider orbits than most post-CE binaries (several days - months) => more space needed for larger [WR] radii?
- These wider orbits can only be reliably found with RV monitoring, even if in orbits of a few days!
- PG1159 stars should also have (wideish) companions
  - Only ONE post-CE PG1159: Nagel+ 2006; Schuh+2009



Looking forward

- Need more binaries to further develop formation scenarios (e.g. De Marco & Soker 2002)
- Target [WN] stars for RV monitoring
- Linear polarimetry to get inclinations of [WR] binaries (?)
- RV+lightcurve modelling of [WC7] binary PHR0654-1045
- Echelle RV monitoring of brightest [WR]
  - Search for wide binaries (Porb=several 100-1000 days)
  - Connect dust disks, dual-dust chemistry and dust obscuration events with binarity
- A simple common formation scenario for [WR] and non-[WR] PNe?

Thank you!

It's possible to prove a binary,
but it's much harder to disprove
(at all separations and companion types)

even worse for a merger…