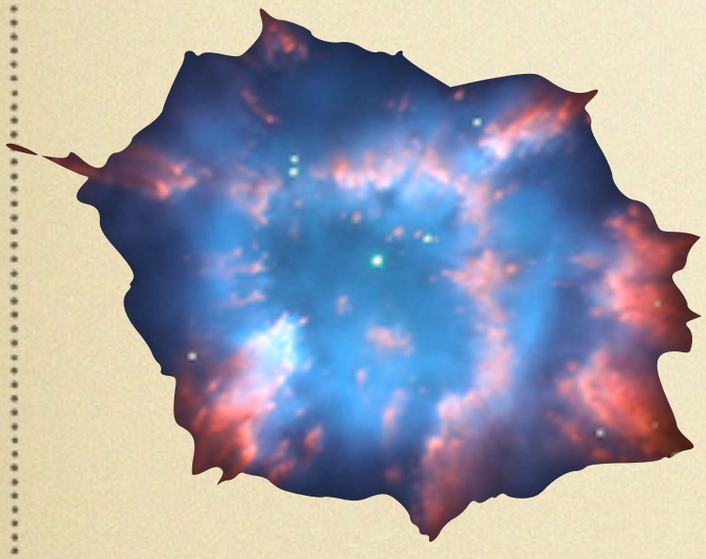
Binary central stars of planetary nebulae



Brent Miszalski
SALT Postdoctoral Fellow

National Research Foundation | South African Astronomical Observatory

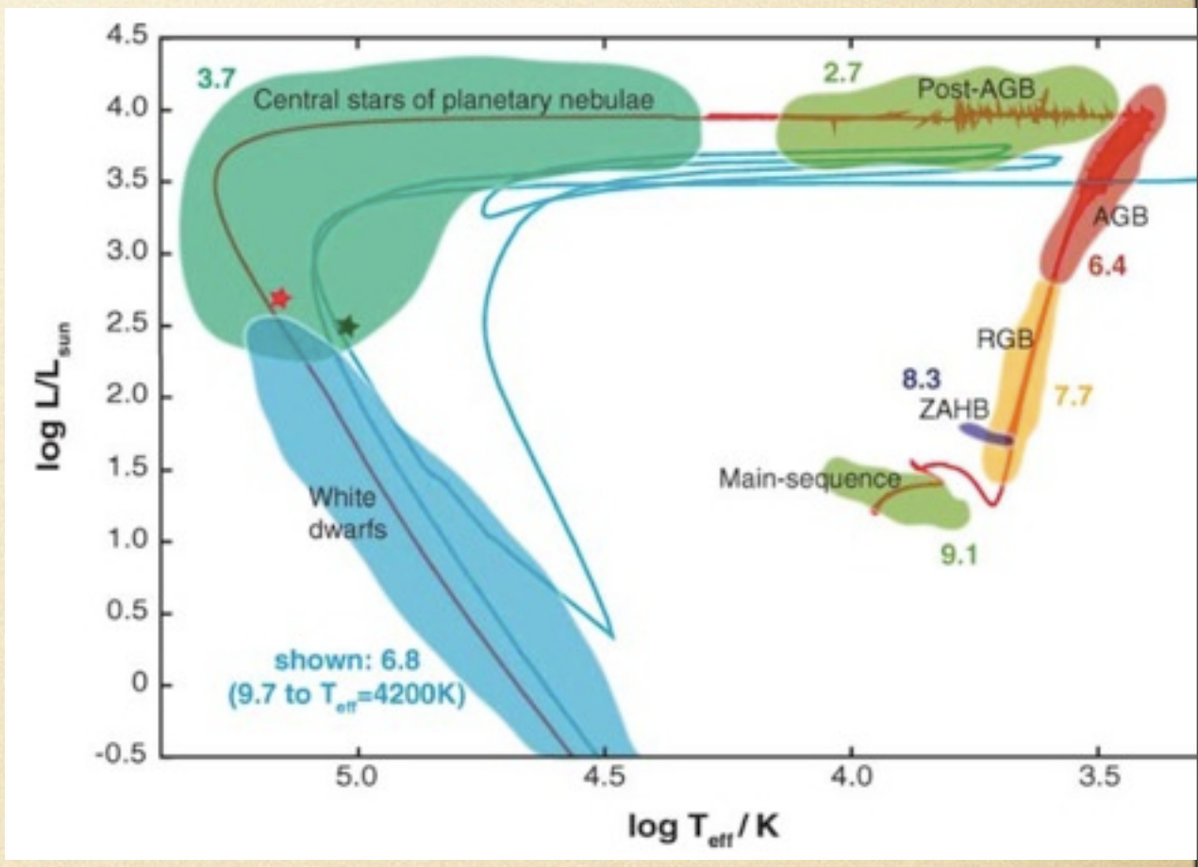
Overview

- A little background
- The contribution of close binaries so far
- In search of intermediate period binaries
- Projects with VVV and VPHAS+

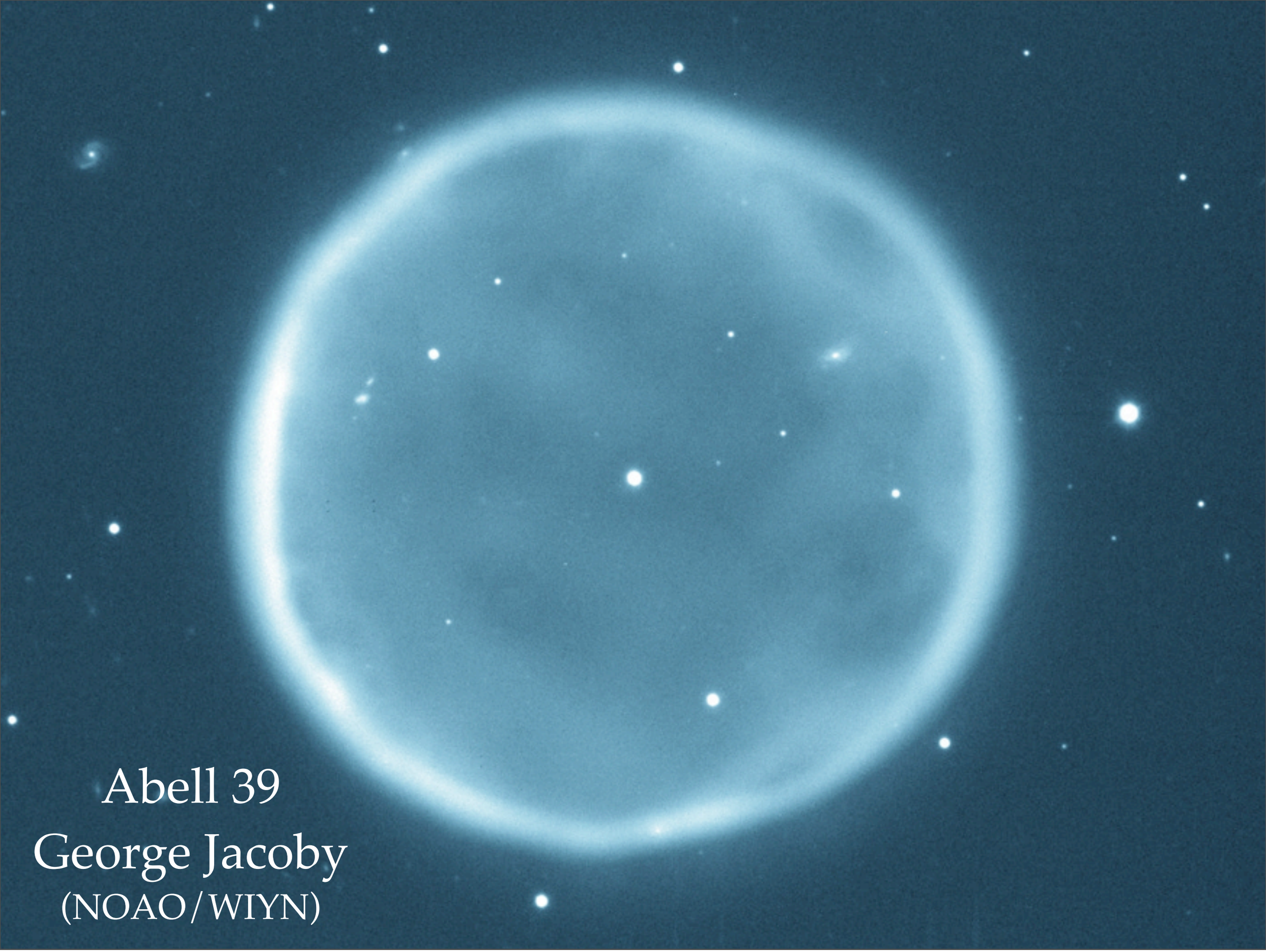
Planetary Nebulae (simple definition)

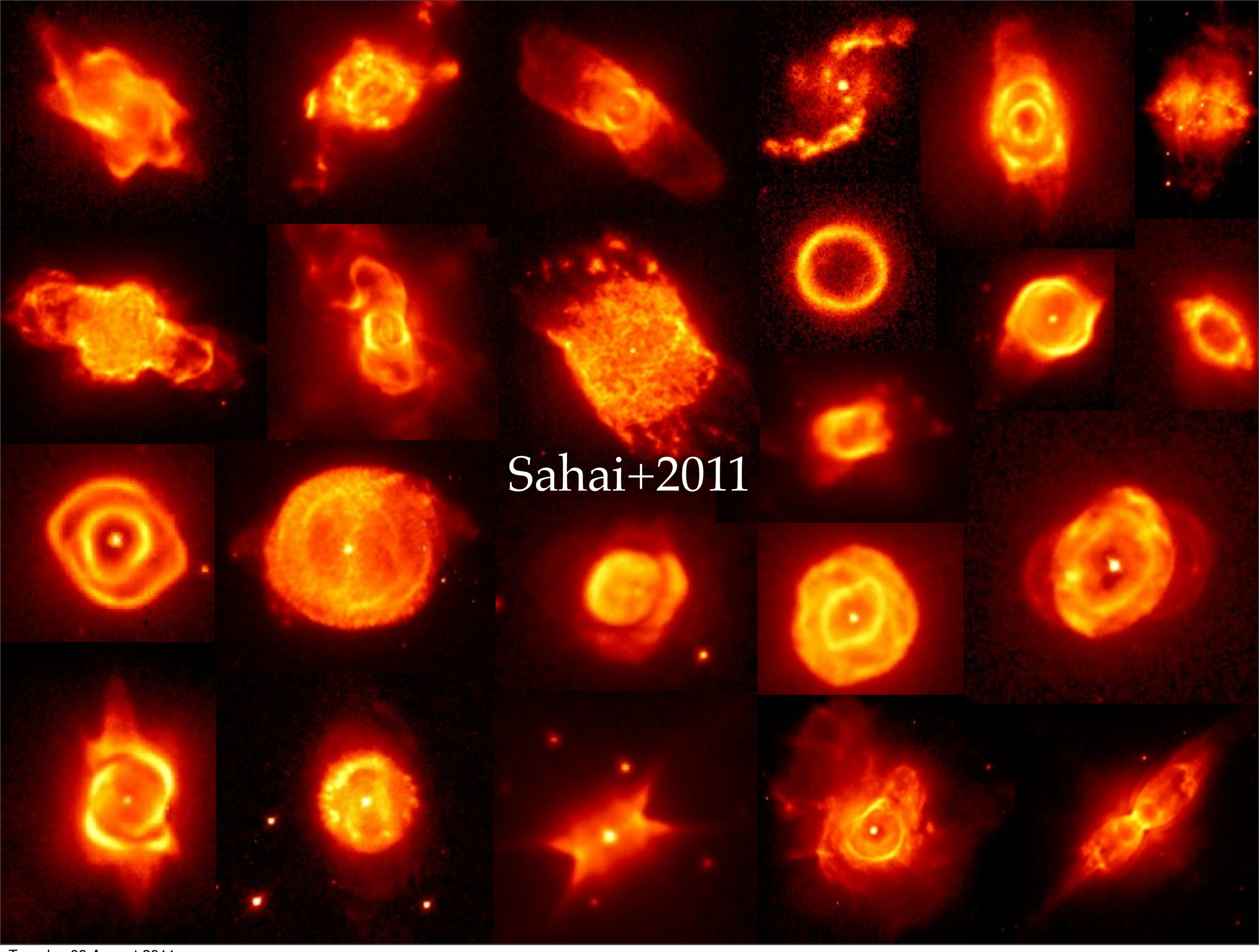
- "A PN is a star that ejects some material while evolving from the red giant to the white dwarf stage" (Lutz 1993)

- "An ionised shell ejected at the end of the AGB phase, either by a single star, or as part of a common-envelope ejection" (Frew 2008)

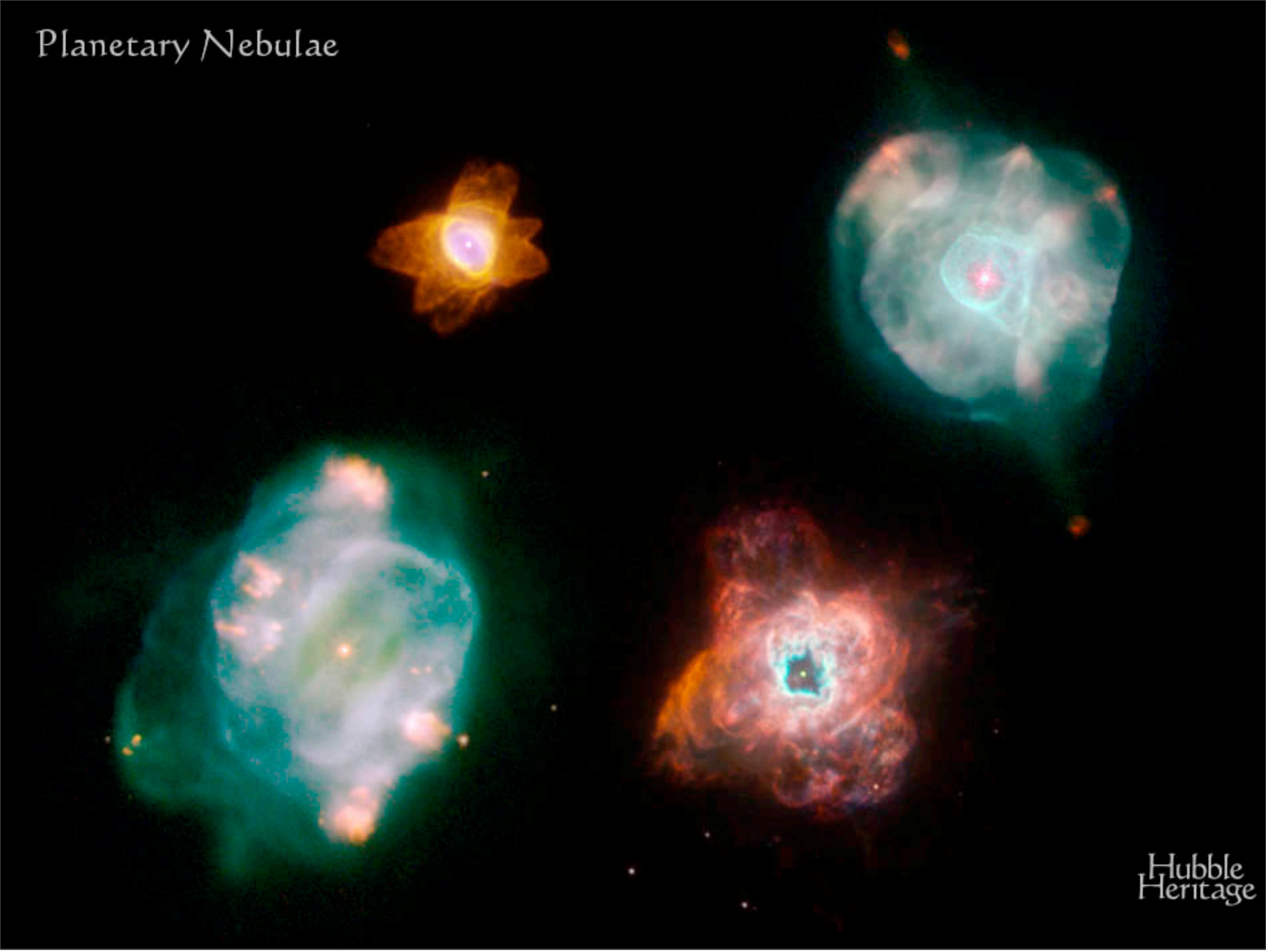


Herwig 2005

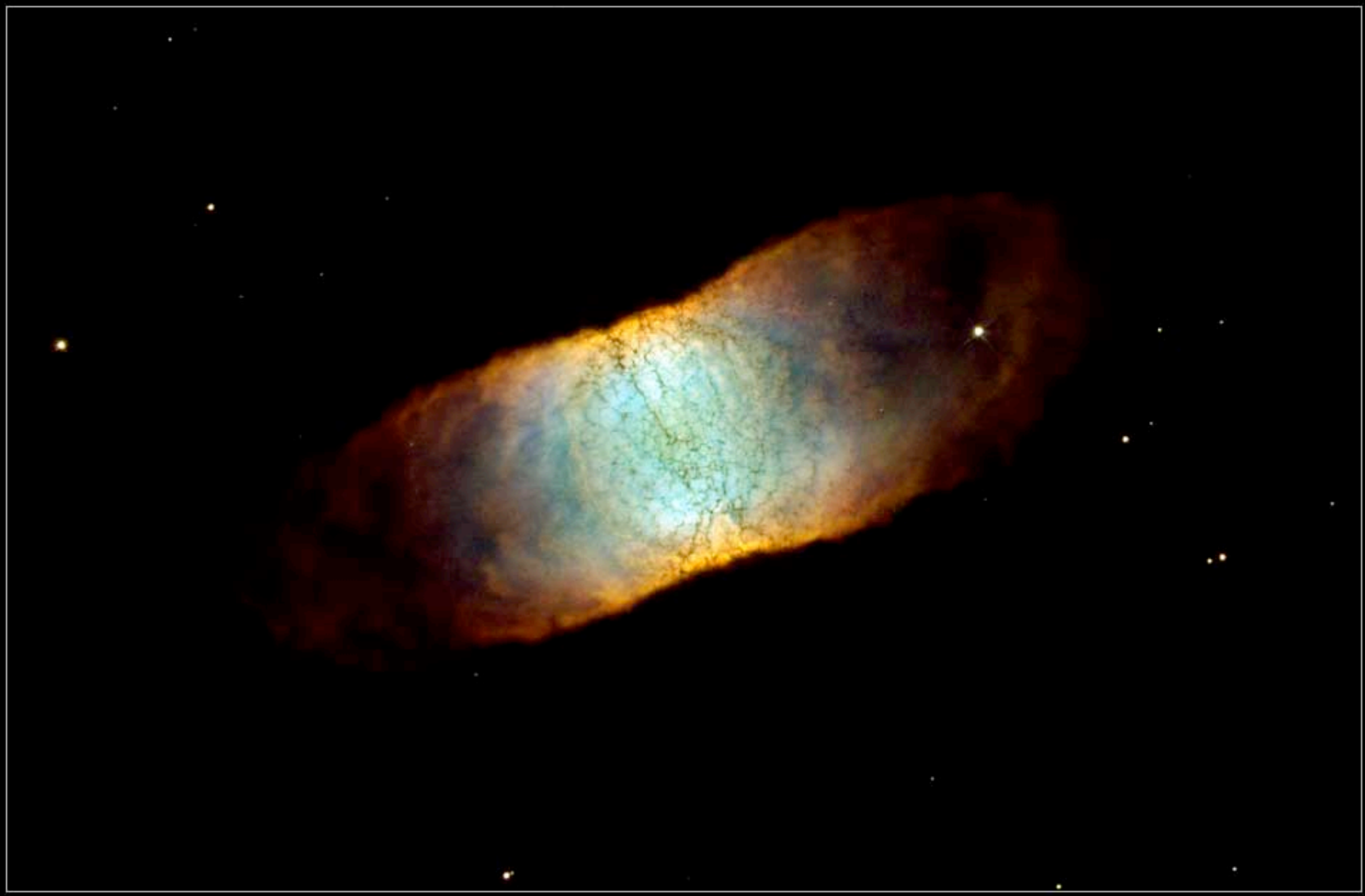

Abell 39
George Jacoby
(NOAO/WIYN)


Sahai+2011

Planetary Nebulae



Planetary Nebula IC 4406



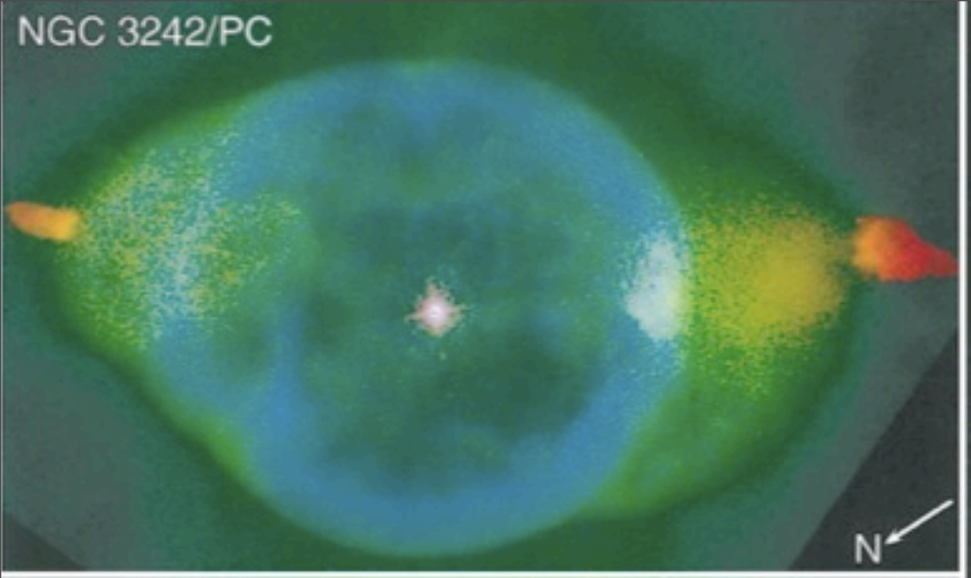
Hubble Heritage

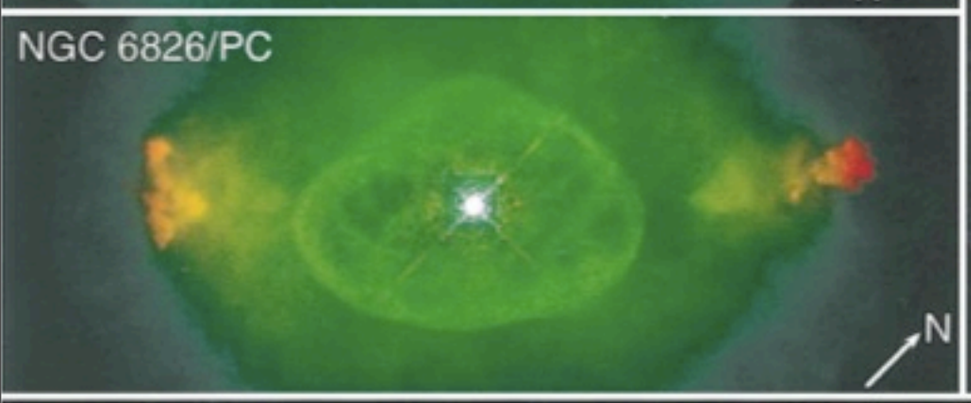
Planetary Nebula NGC 2818

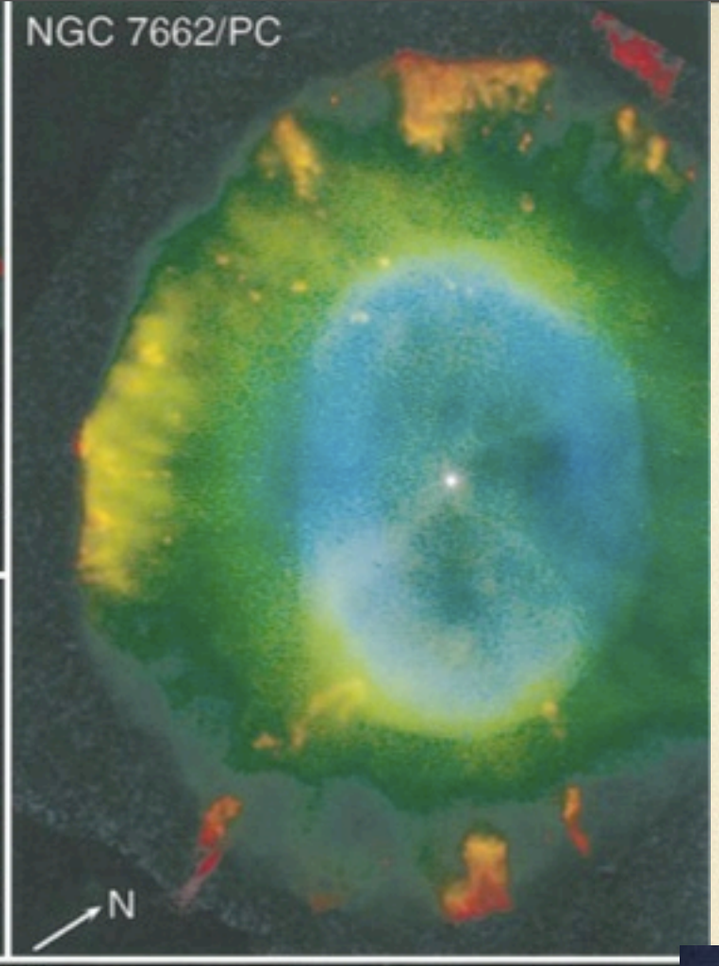
Hubble Heritage

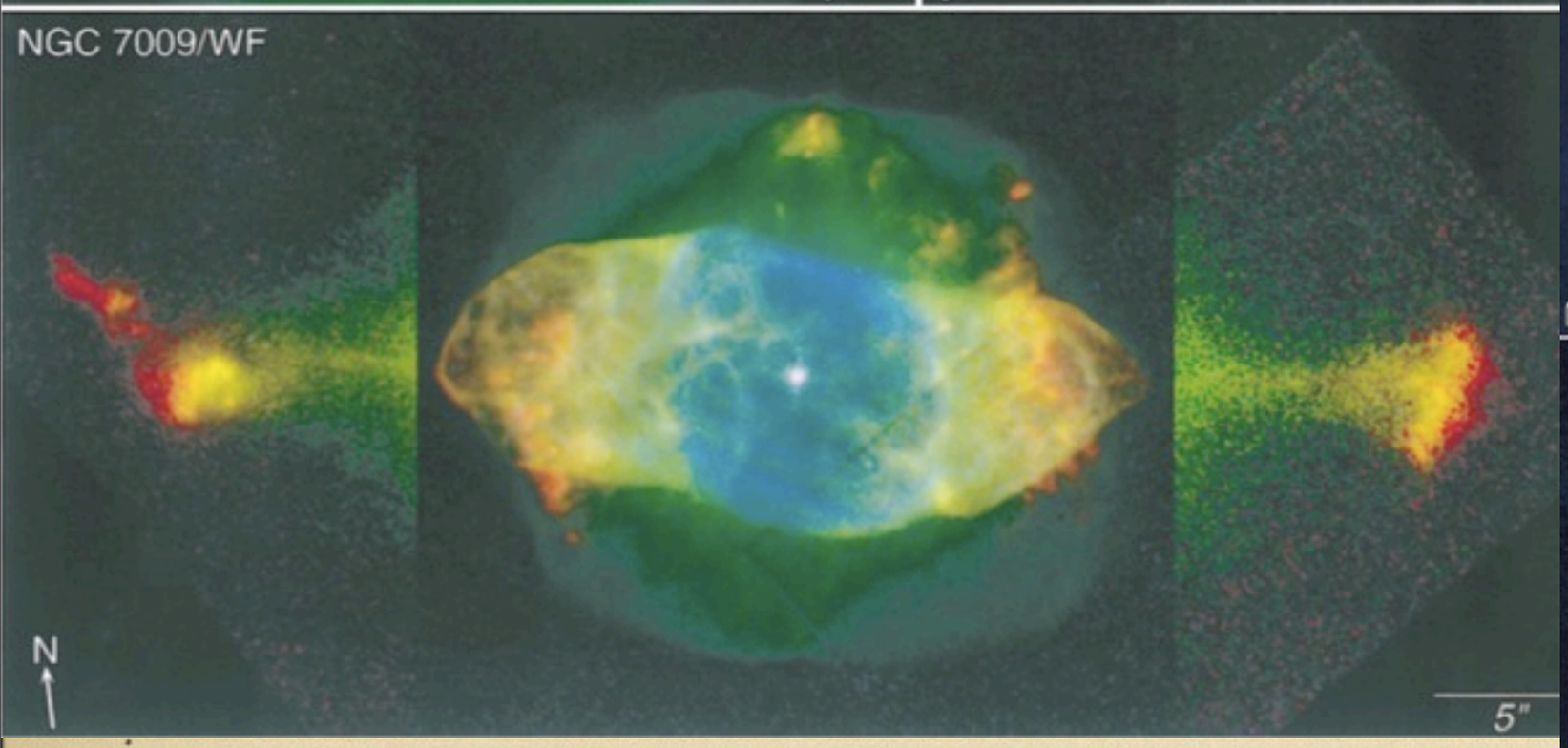
Hubble Heritage Gallery Planetary Nebulae

Tuesday 09 August 2011



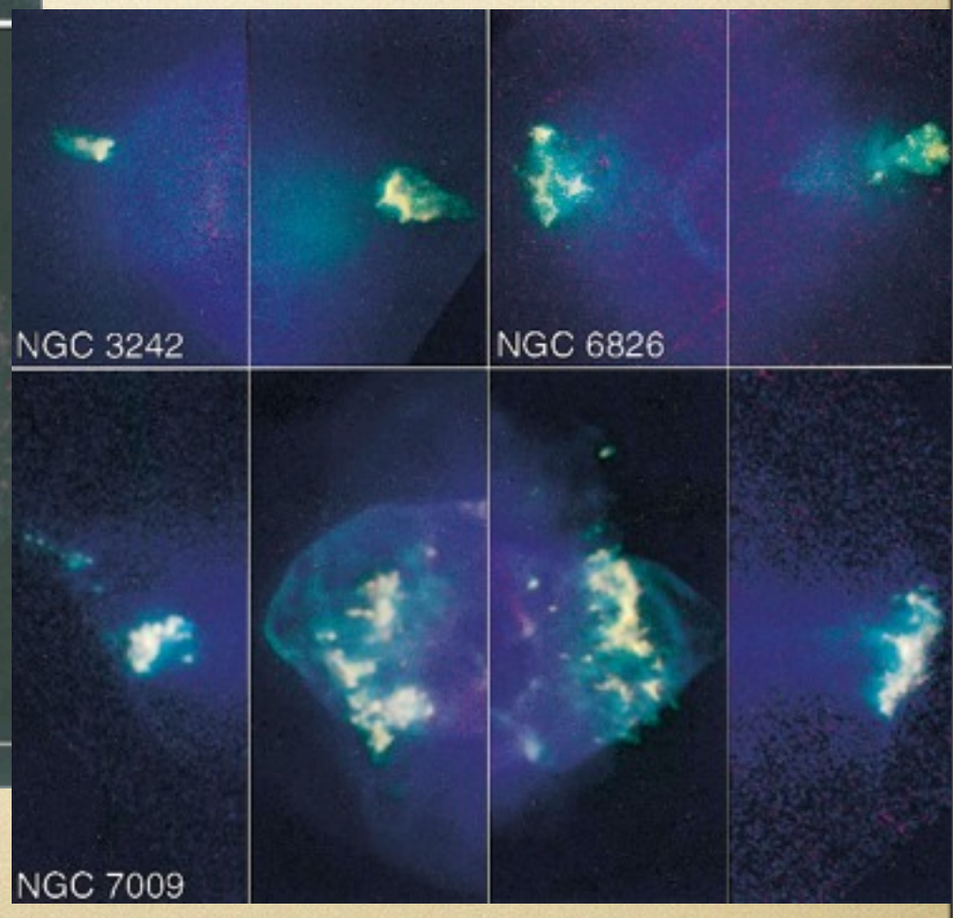






Balick et al. 1998

Microstructures & Jets



How are PNe shaped?

- A protracted debate with no apparent consensus
  - Balick & Frank 2002, ARA&A, 40, 439
- Interacting stellar winds (ISW) can explain some
  - Assumes density contrast (e.g. dusty torus)
- Rapid rotation and Magnetic fields?
  - Models can work but require strong fields that aren't detected and don't last long enough
  - An often fiery debate...

Can we ignore magnetic fields in studies of PN formation, shaping and interaction with the ISM?

Noam Soker 2005

Department of Physics, Technion–Israel Institute of Technology, Haifa 32000, Israel;
soker@physics.technion.ac.il

ABSTRACT

Yes. [1]

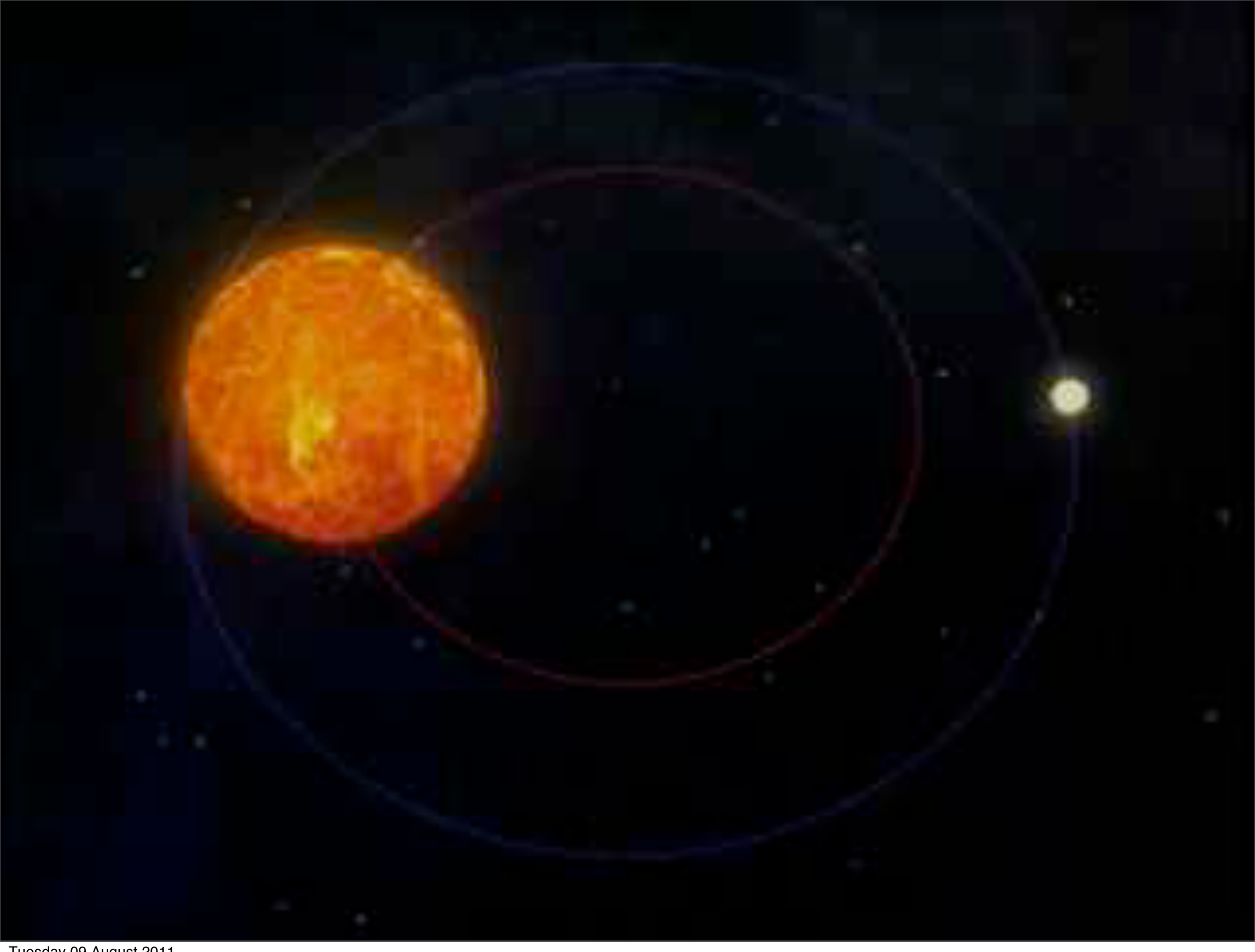
see also Soker 2006

1. Introduction

In a quest for better understanding the shaping mechanism of planetary nebulae (PNs) I published many papers in the past (e.g., Soker 2004a) all of which came to the same conclusion: For the formation of non-spherical PNs a companion is required, wether stellar or substellar. This results from the basic assumption that angular momentum is a conserved physics quantity. As trivial as this may sound, some published models for the shaping of PNs seem to have ignored this basic physical law. Most recently I discussed this in a paper that was accepted by astro-ph (Soker 2005b), but was rejected by MNRAS and the ApJ. Both referees (a third referee in ApJ can be ignored for a non-scientific report) were either

BINARIES

- Are the `natural' solution to the problem
- Predicted by theory (e.g. common-envelope evolution)
  - However, observational evidence has been `weak'
- Jets and collimated outflows
  - Accretion disks in close binaries (Soker & Livio 1994)
  - Common-envelope dynamo (Nordhaus+ 2006, 2007)
- Explains strong density contrast between equatorial (orbital) plane and polar direction
  - Pre-requisite for dust disk formation? (e.g. Van Winckel+ 2009)



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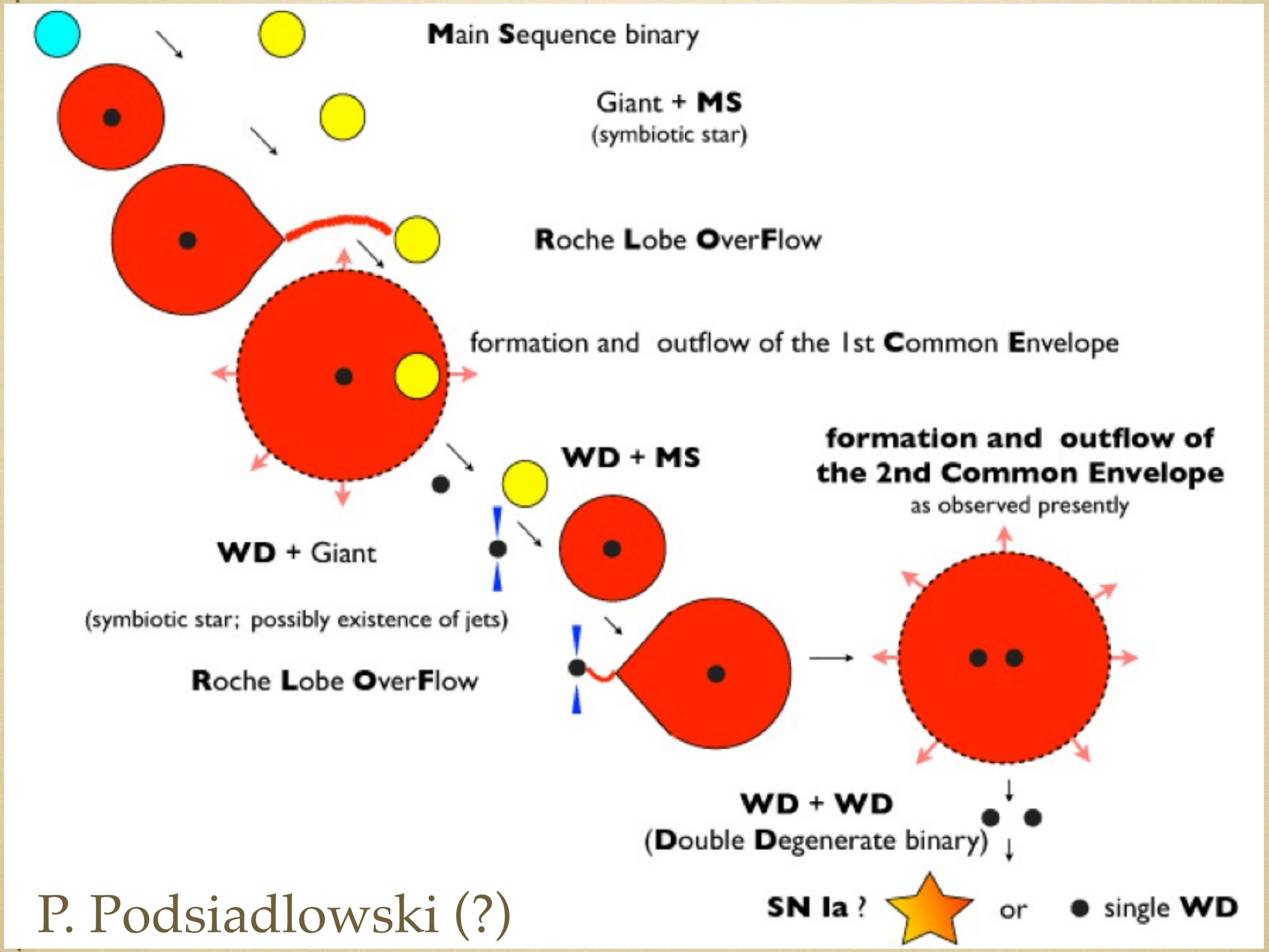


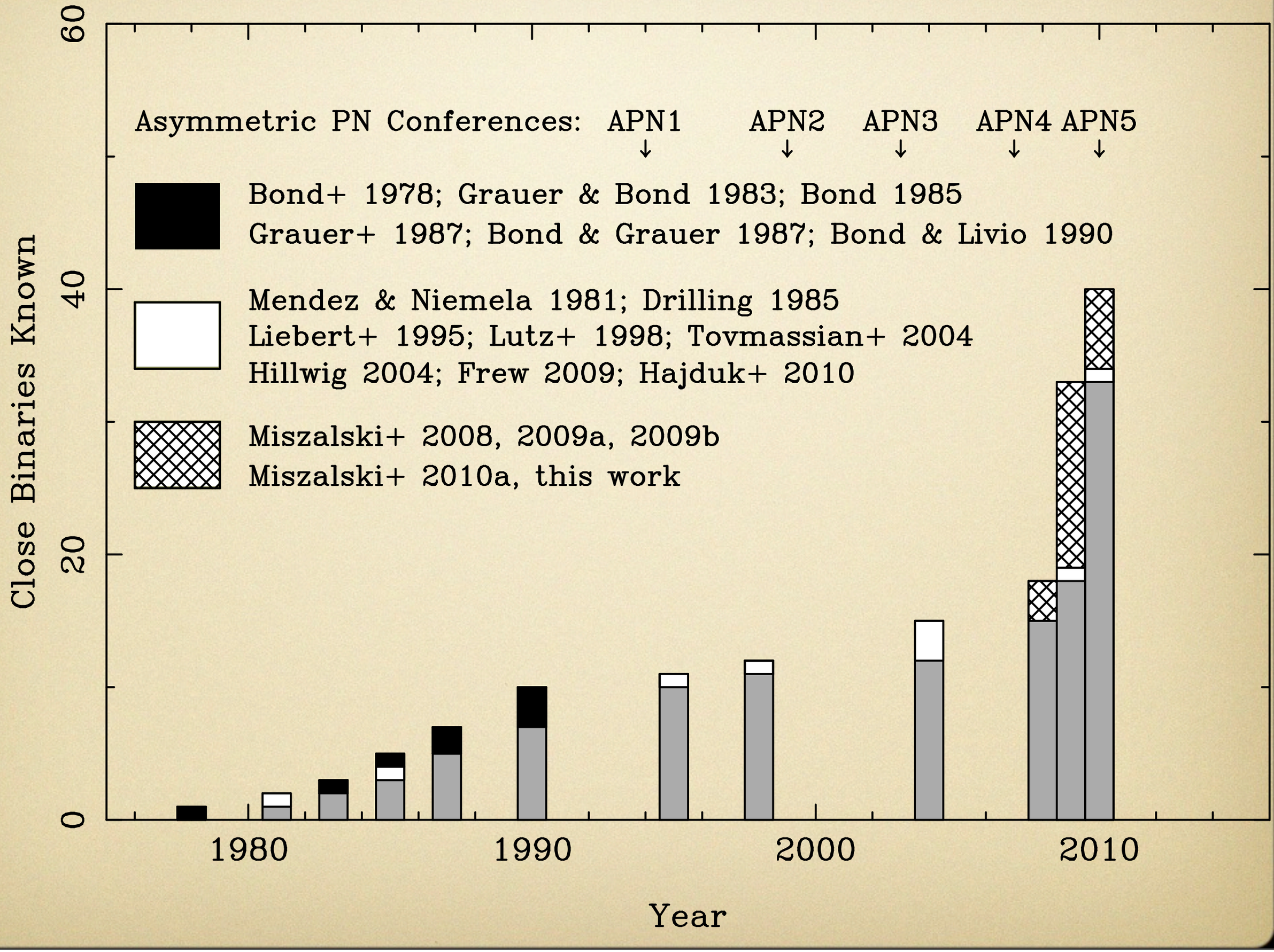
P. Podsiadlowski (?)

fresh out of the oven

- The NEBULA is the actual common-envelope (CE)
- Age < 10^4 yrs guarantees freshness of the binary
- No significant angular momentum loss after termination of CE phase => pristine periods
- Period distribution used in *parameterised* models of CE
- Homogeneous sample of post-AGB post-CE binaries useful to better understand CE (De Marco+ 2011)
- Progenitors of Cataclysmic Variables (10^7-10^8 yr before)

Show me the binaries

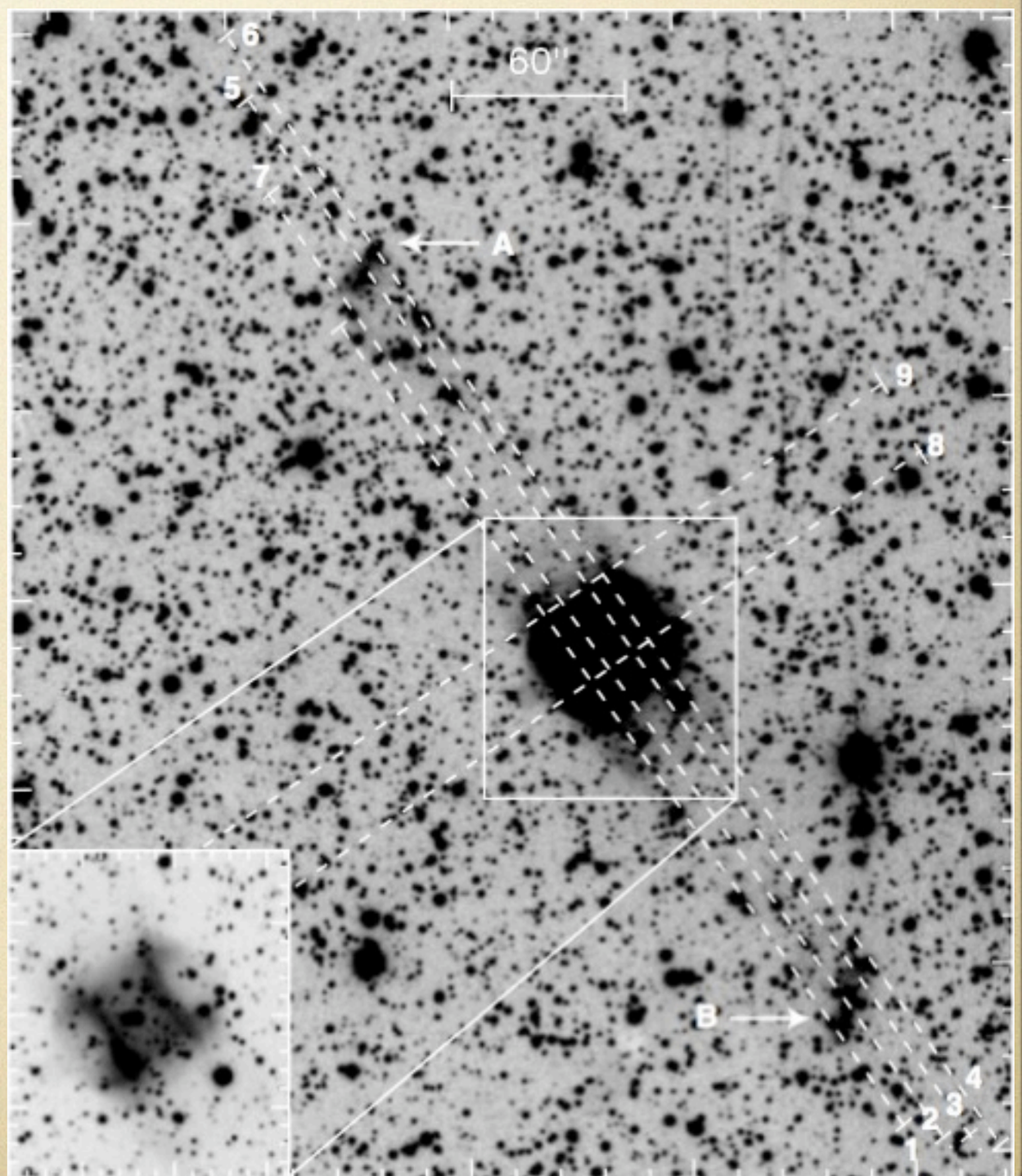
Miszalski+ 2011, Asymmetric Planetary Nebulae V



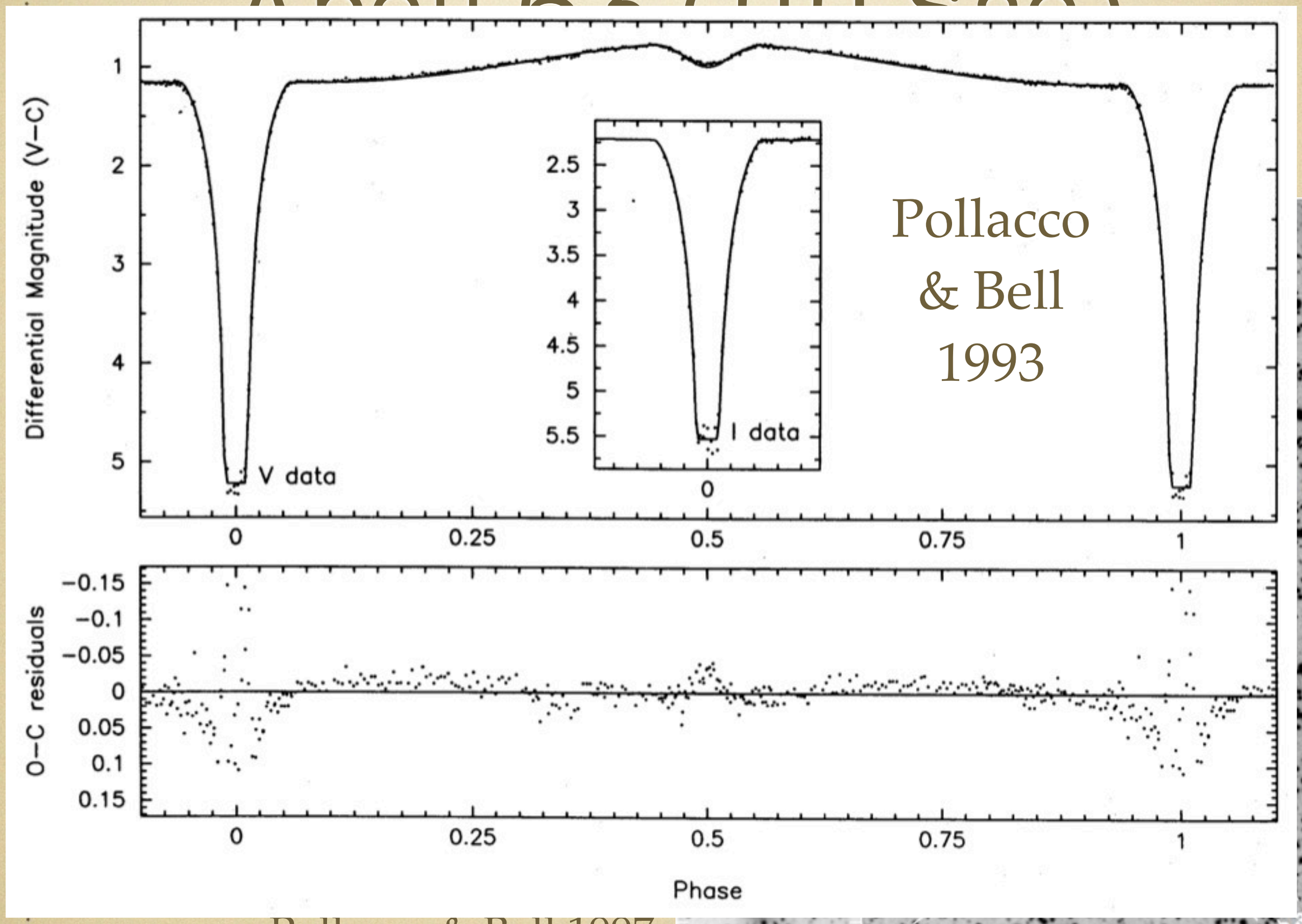
Abell 63 (UU Sge)
The first close binary

- Bond (1976)
- Photographic plates showed 14.7-16.0 mag variation
- White dwarf eclipsed by M4V every 0.46 days
- Strong irradiation effect

Pollacco & Bell 1997

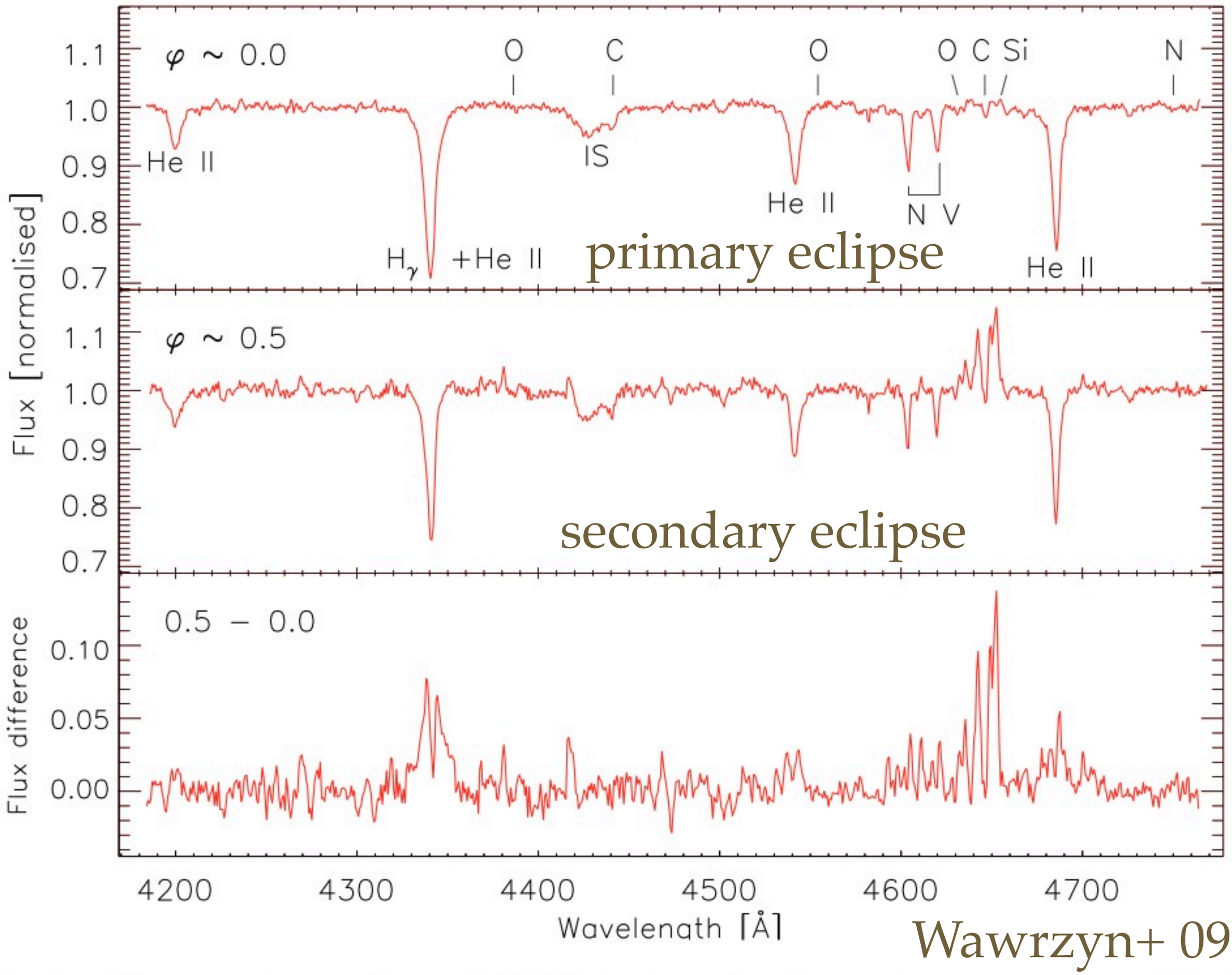


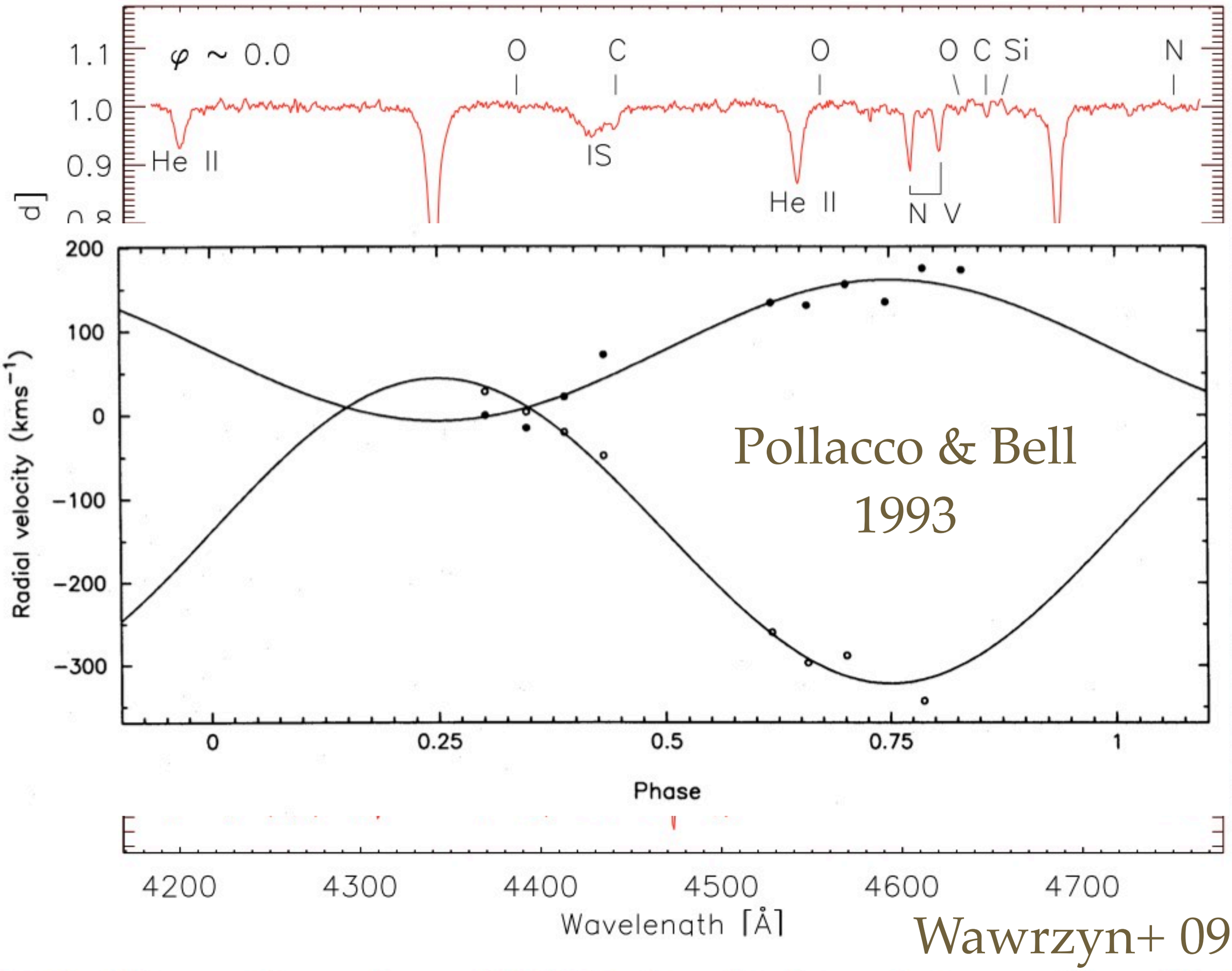
Abell 6Z (JHK Sgr)



Pollacco & Bell 1993

Pollacco & Bell 1997

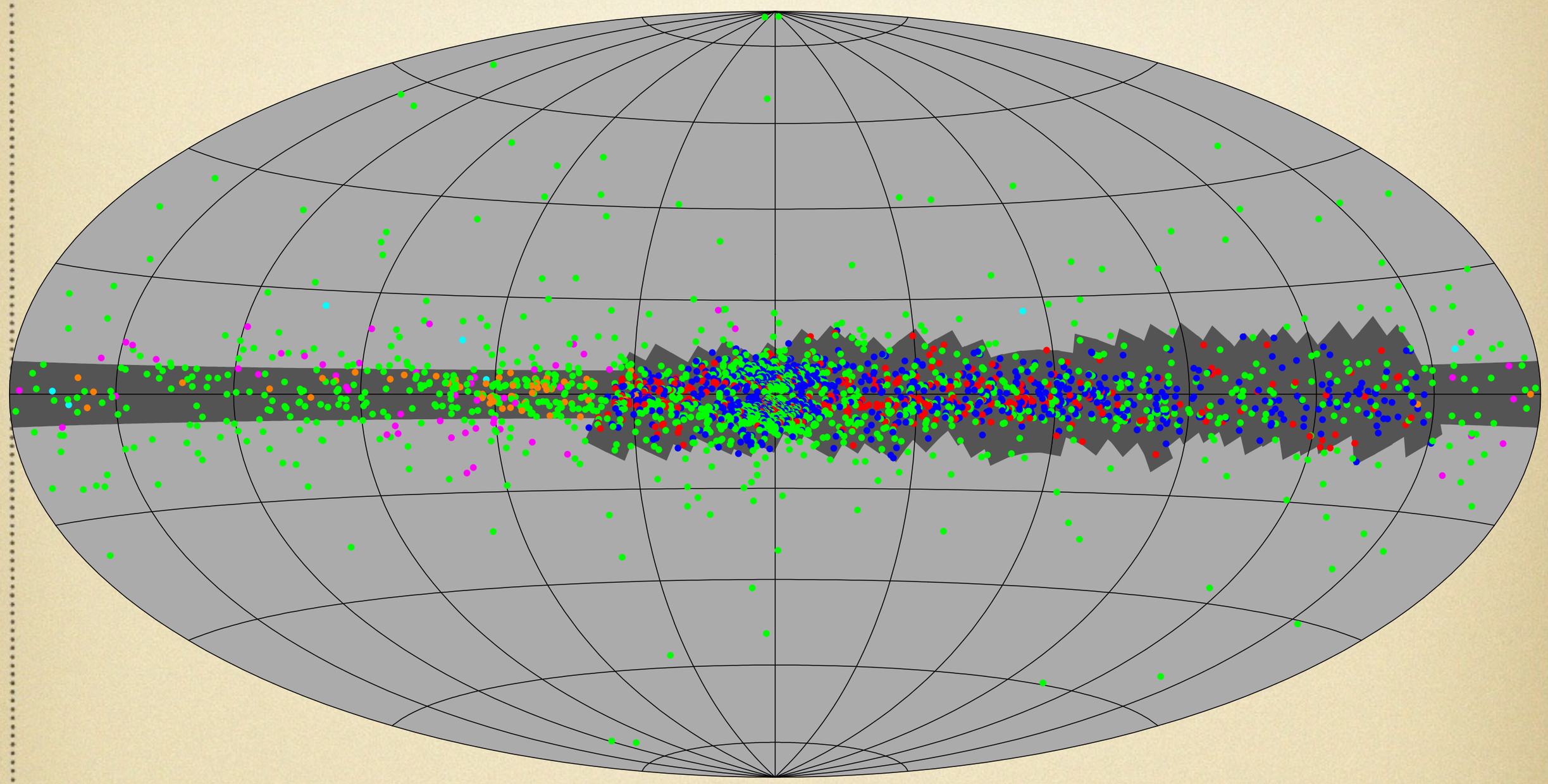

φ ~ 0.0
O
C
O
O C Si
N
He II
IS
He II
N V
Hγ +He II
He II
primary eclipse
φ ~ 0.5
secondary eclipse
0.5 − 0.0
Flux [normalised]
Flux difference
Wavelenath [Å]
4200
4300
4400
4500
4600
4700
Wawrzyn+ 09


φ ~ 0.0
O
C
O
O C Si
N
He II
IS
He II
N V
1.1
1.0
0.9
d]
200
100
0
−100
−200
−300
Radial velocity (kms⁻¹)
0
0.25
0.5
0.75
1
Phase
4200
4300
4400
4500
4600
4700
Wavelength [Å]
Pollacco & Bell
1993
Wawrzyn+ 09

How to find them?

- Periodic photometric variability (most < 1 day)
  - Most common and successful method (e.g. I-band)
- Spectroscopy
  - Periodic radial velocity variability (~100-200 km/s)
    - Radial velocity shifts of irradiated emission lines
    - Composite spectra
- Photometry
  - Near-infrared or mid-infrared excess

A grand challenge, <2850 PNe known!



IPHAS Viironen+ (2009)

Deep Sky Hunters Jacoby+ (2010)

Known (various)

MASH-I Parker+ (2006)

MASH-II Miszalski+ (2008)

ETHOS Miszalski+ in prep

PLAnetary Nebula Binaries

PLAN-B is a collaboration to look for binaries in the central stars of planetary nebulae, their progenitors and progeny. We are testing the hypothesis is that binarity is a dominant mechanism to form and shape planetary nebulae, an assertion that is backed by theory. With these pages we coordinate our projects.

Click for more information about the PN binary problem

Community portal: the PLAN-BBlog

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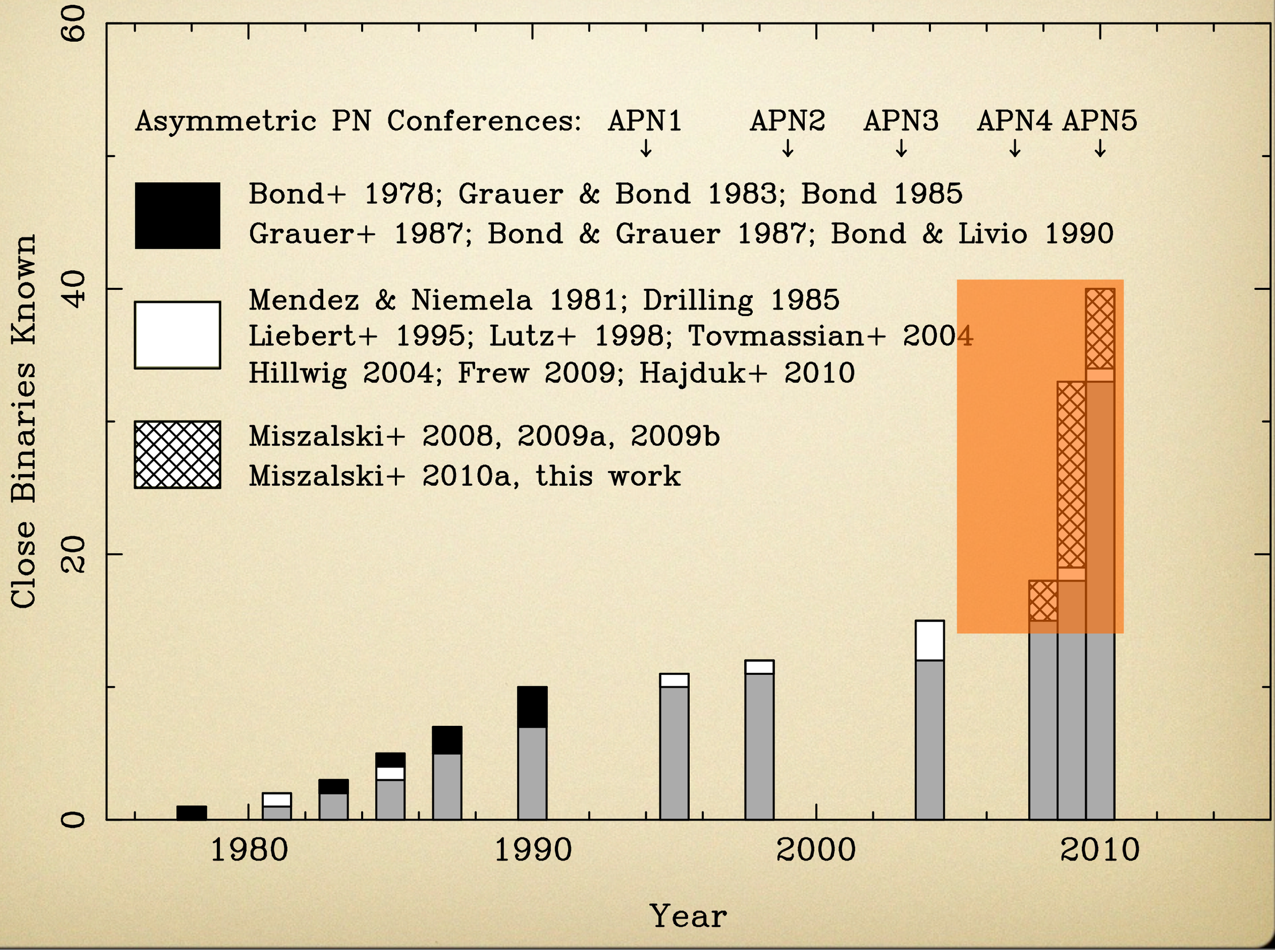
Publications

www.wiyn.org/planb/

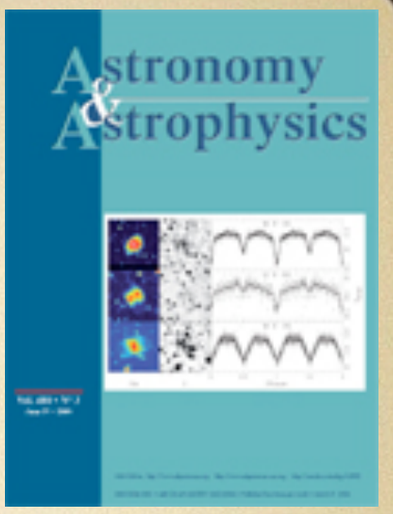
Team Members: LOGIN HERE

Miszalski+ 2011, Asymmetric Planetary Nebulae V

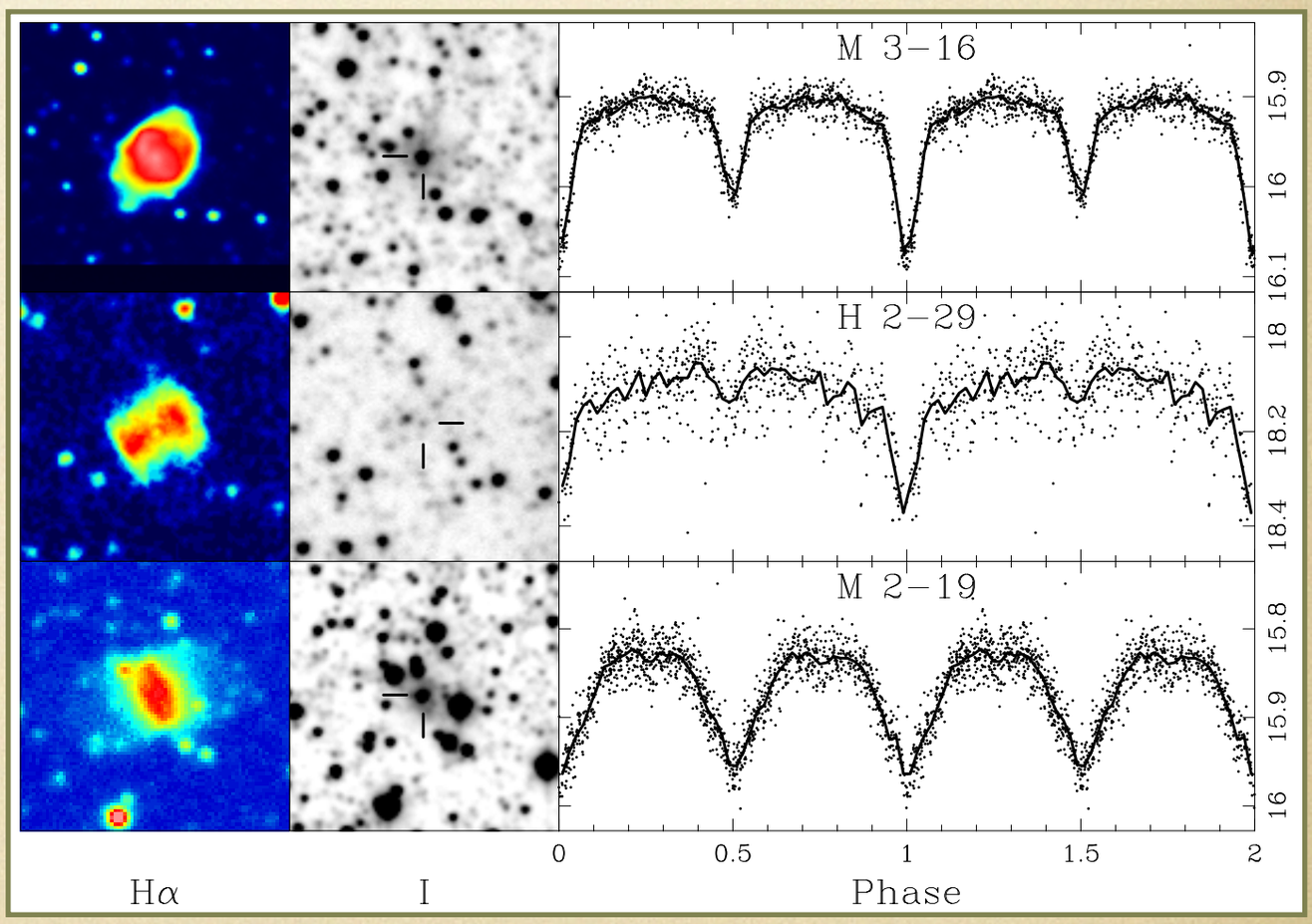


The turn of the tide

Miszalski+ 2008

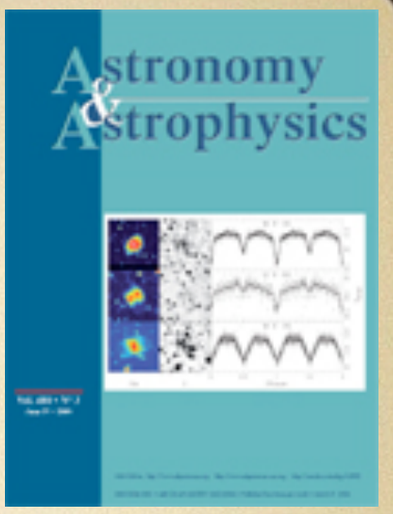


- Microlensing surveys allow variability studies on a massive scale
- Cadence often high enough to detect short periods
- Fainter MASH-I/II PNe more suitable



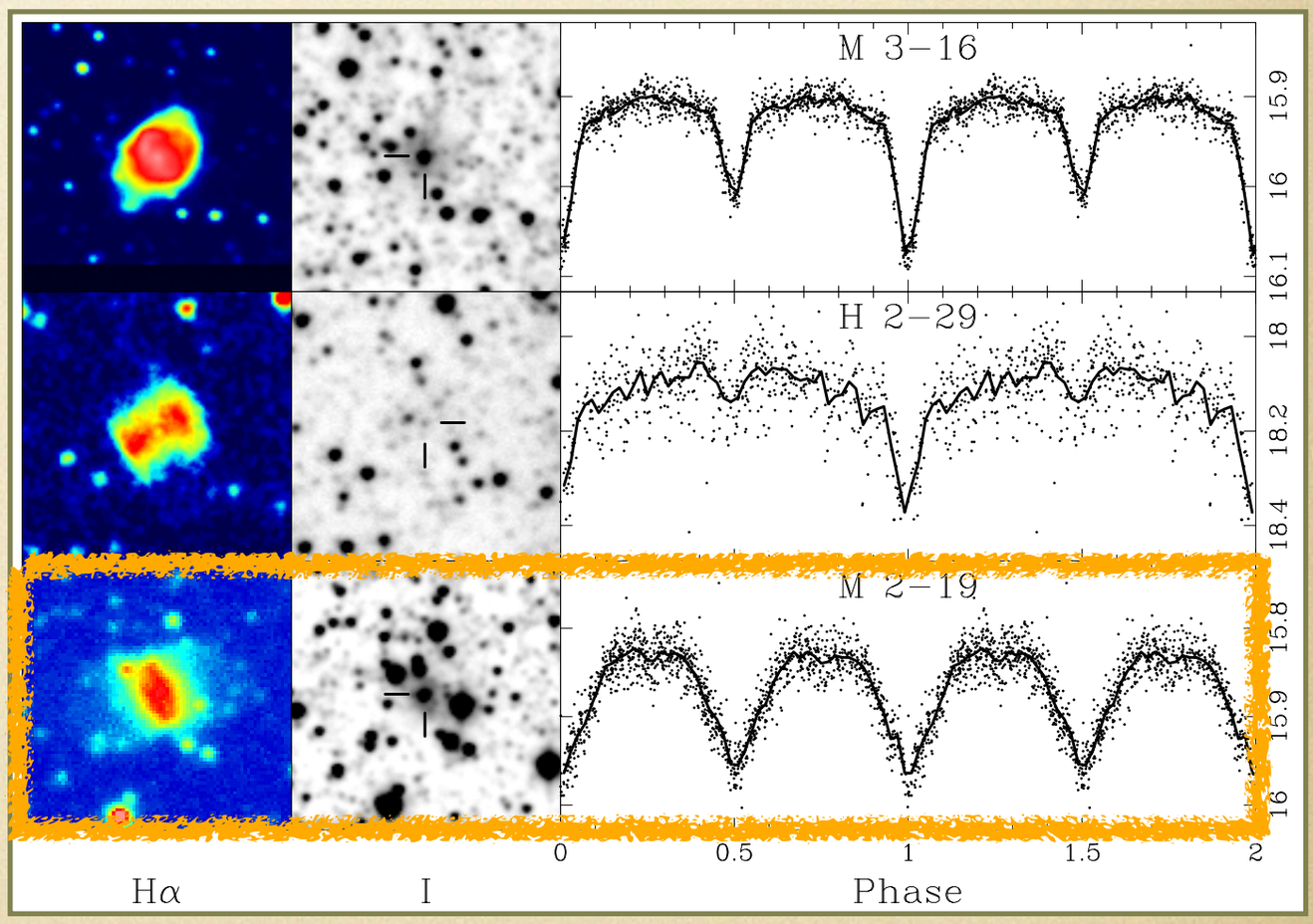
The turn of the tide

Miszalski+ 2008

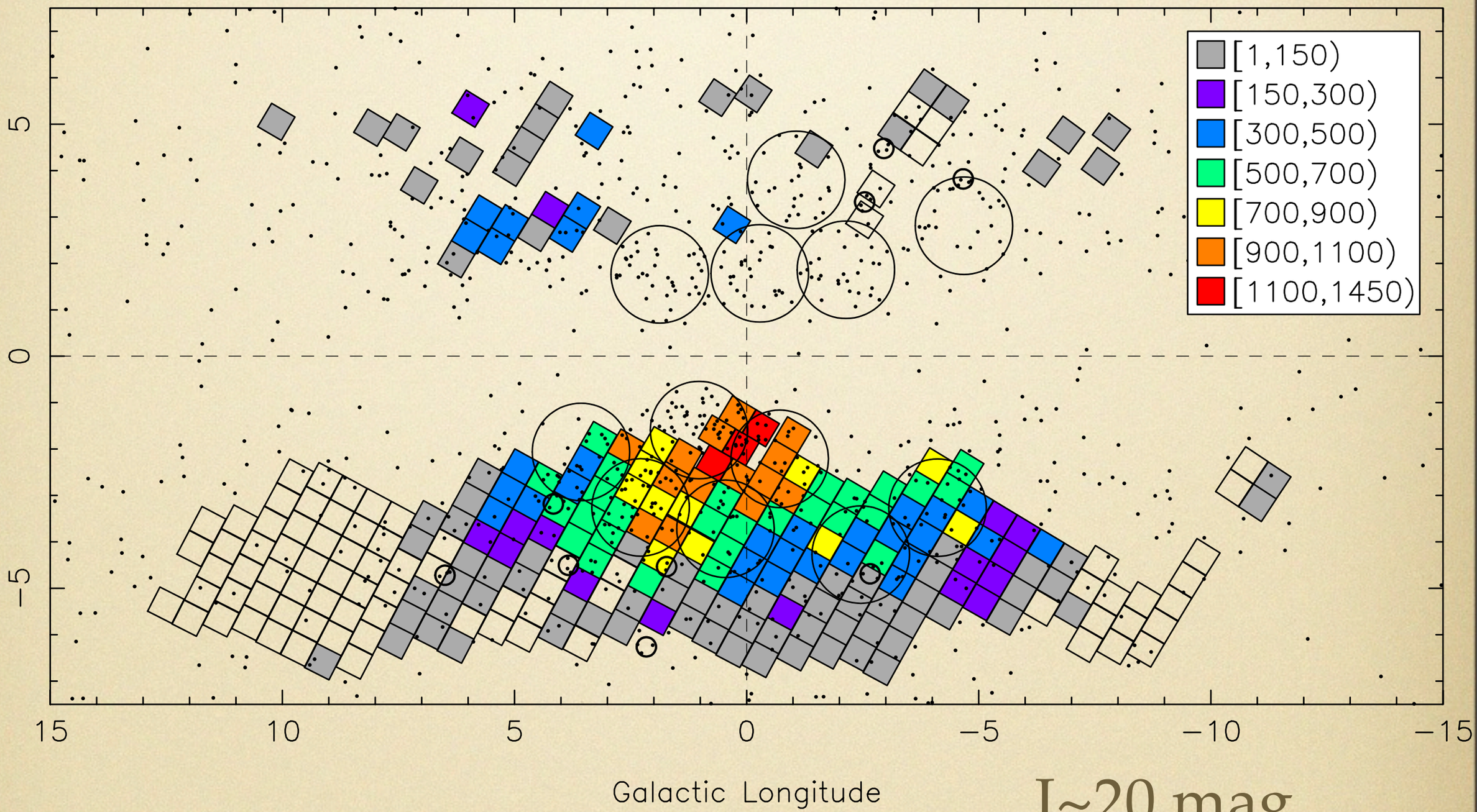


- Microlensing surveys allow variability studies on a massive scale
- Cadence often high enough to detect short periods
- Fainter MASH-I/II PNe more suitable

M2-19 - first canonical bipolar with period < 1 day



OGLE-III Bulge fields



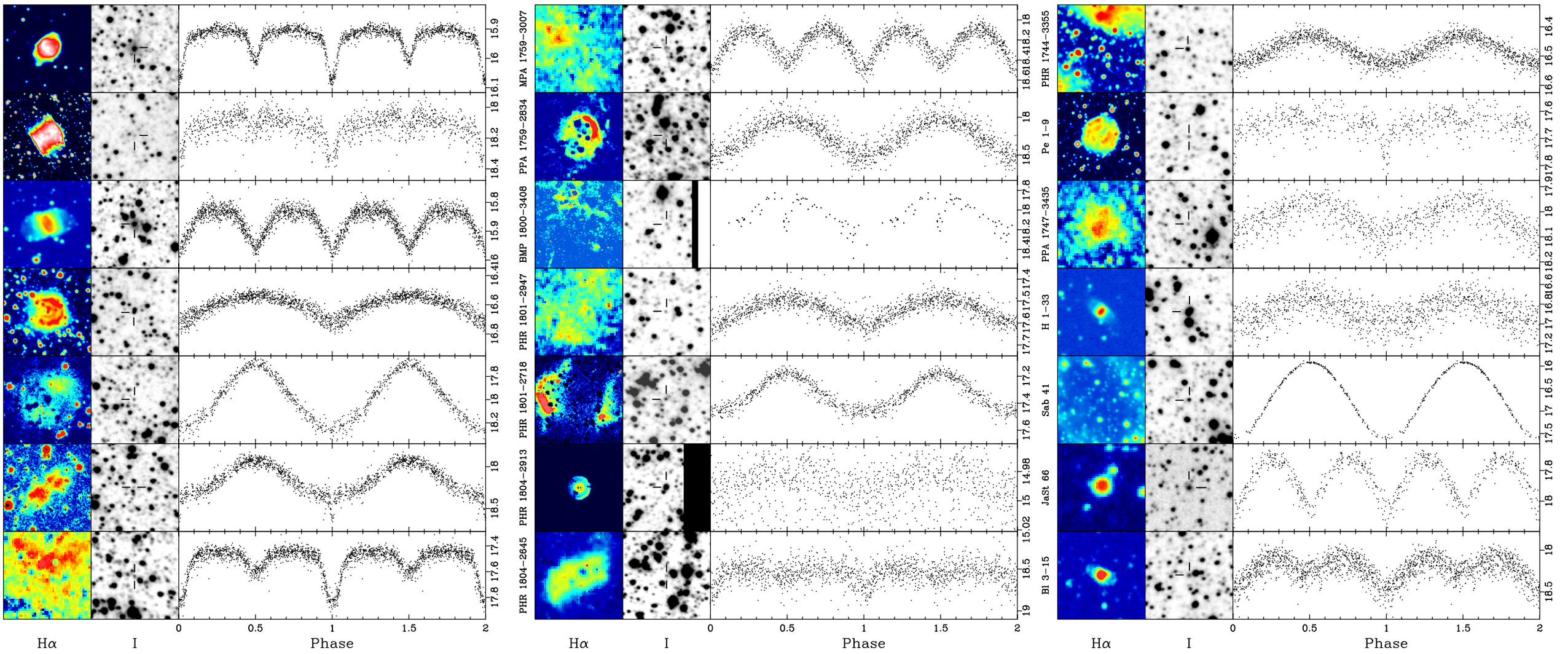
I~20 mag

AAT 2dF / AAOmega ○ VLT FLAMES

The OGLE Sample

Miszalski+ 2009a

Close binary fraction: 17±5%



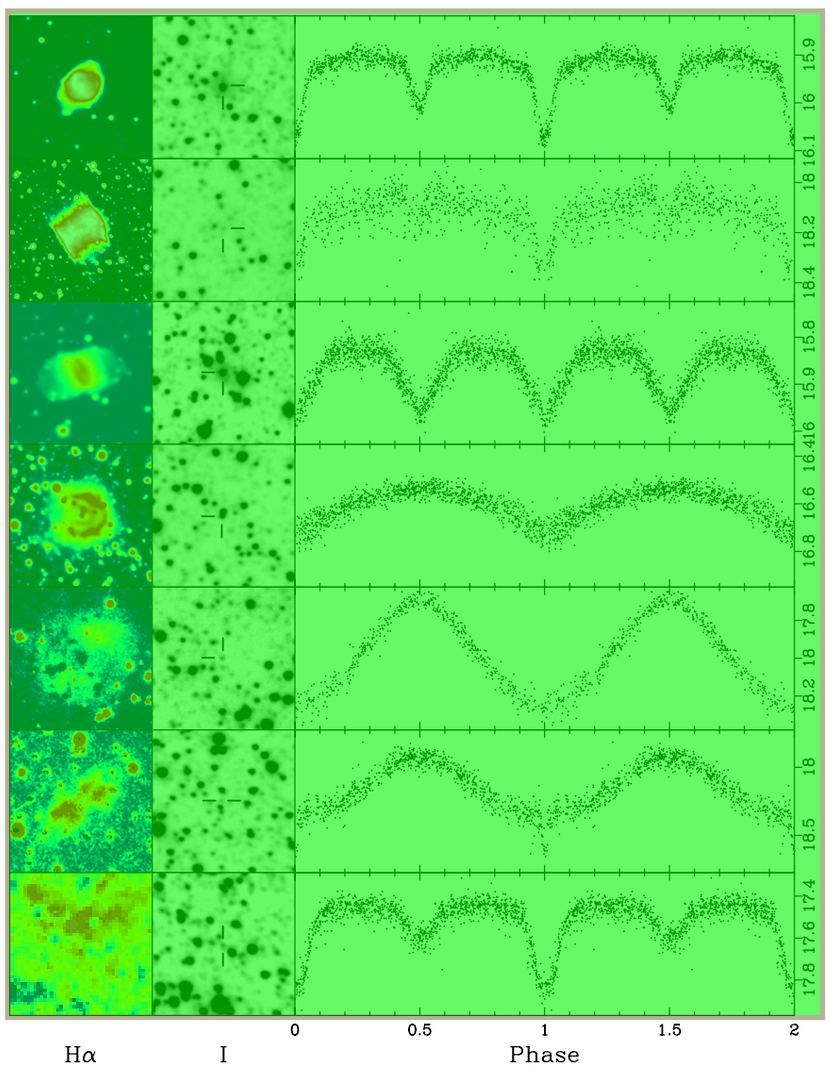
60% are MASH-I / MASH-II PNe

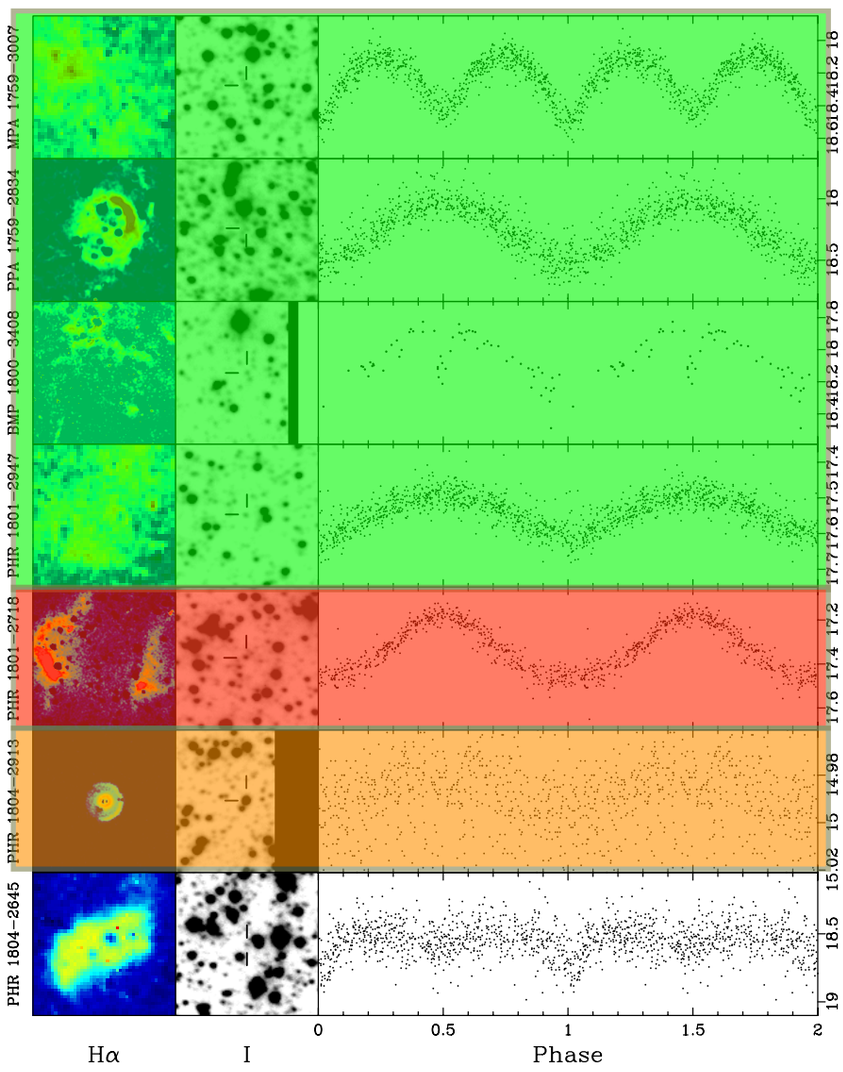
The OGLE Sample

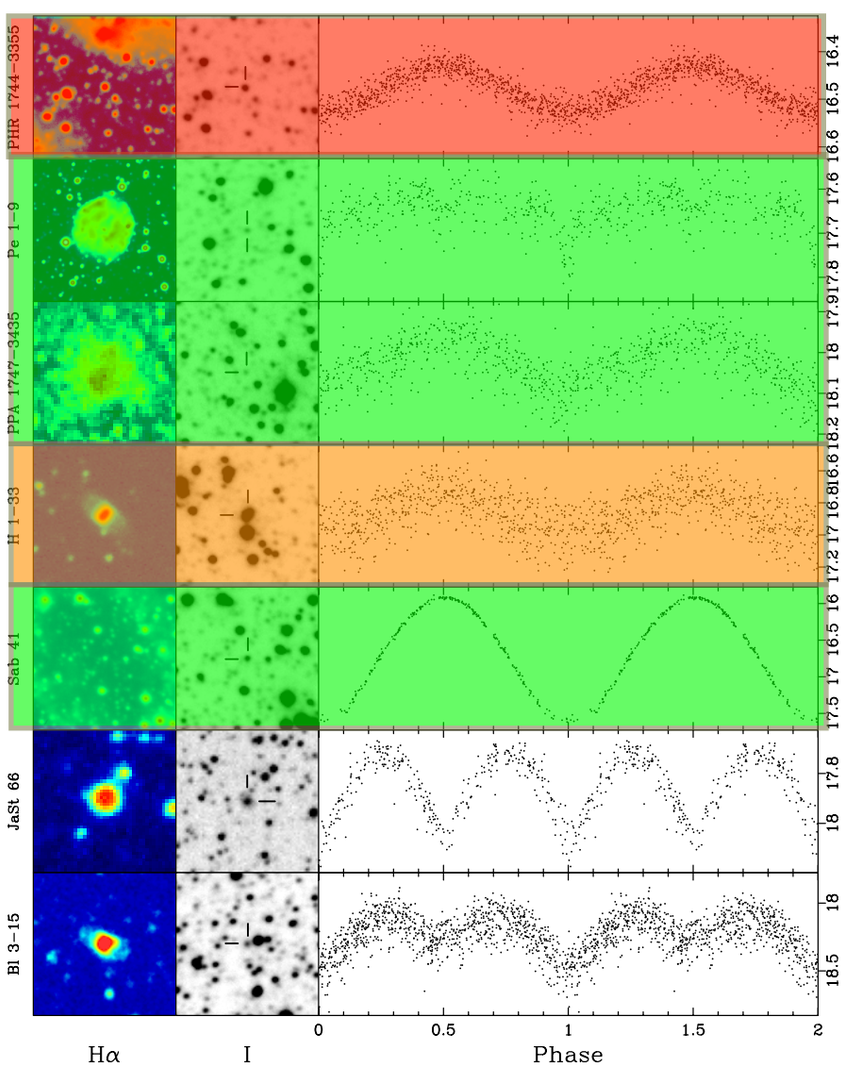
Miszalski+ 2009a

Close binary fraction: 17±5%

CSPN status: confirmed, likely, non-confirmed

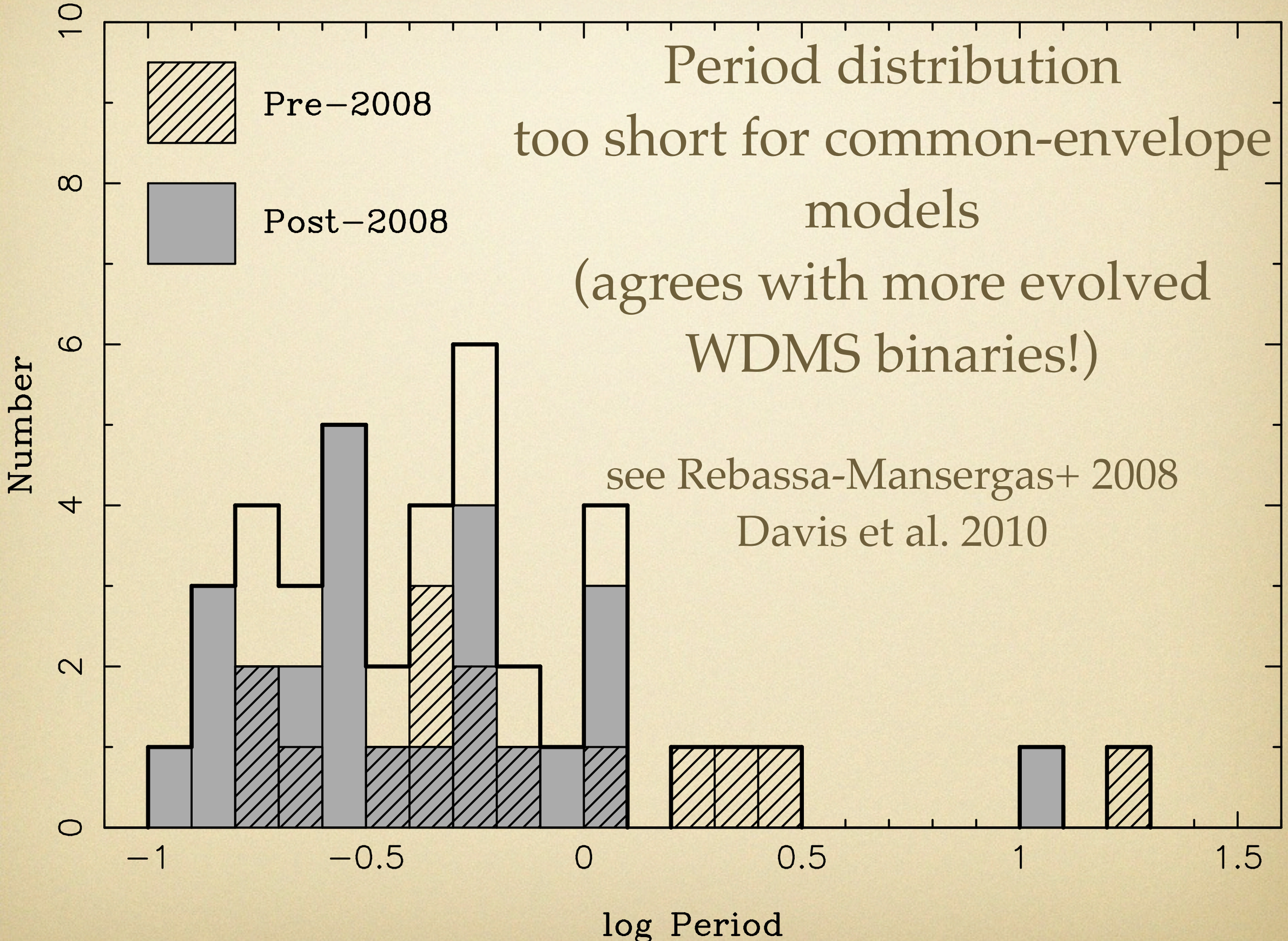






60% are MASH-I / MASH-II PNe

Miszalski+ 2009a, 2011



Period distribution
too short for common-envelope models
(agrees with more evolved WDMS binaries!)

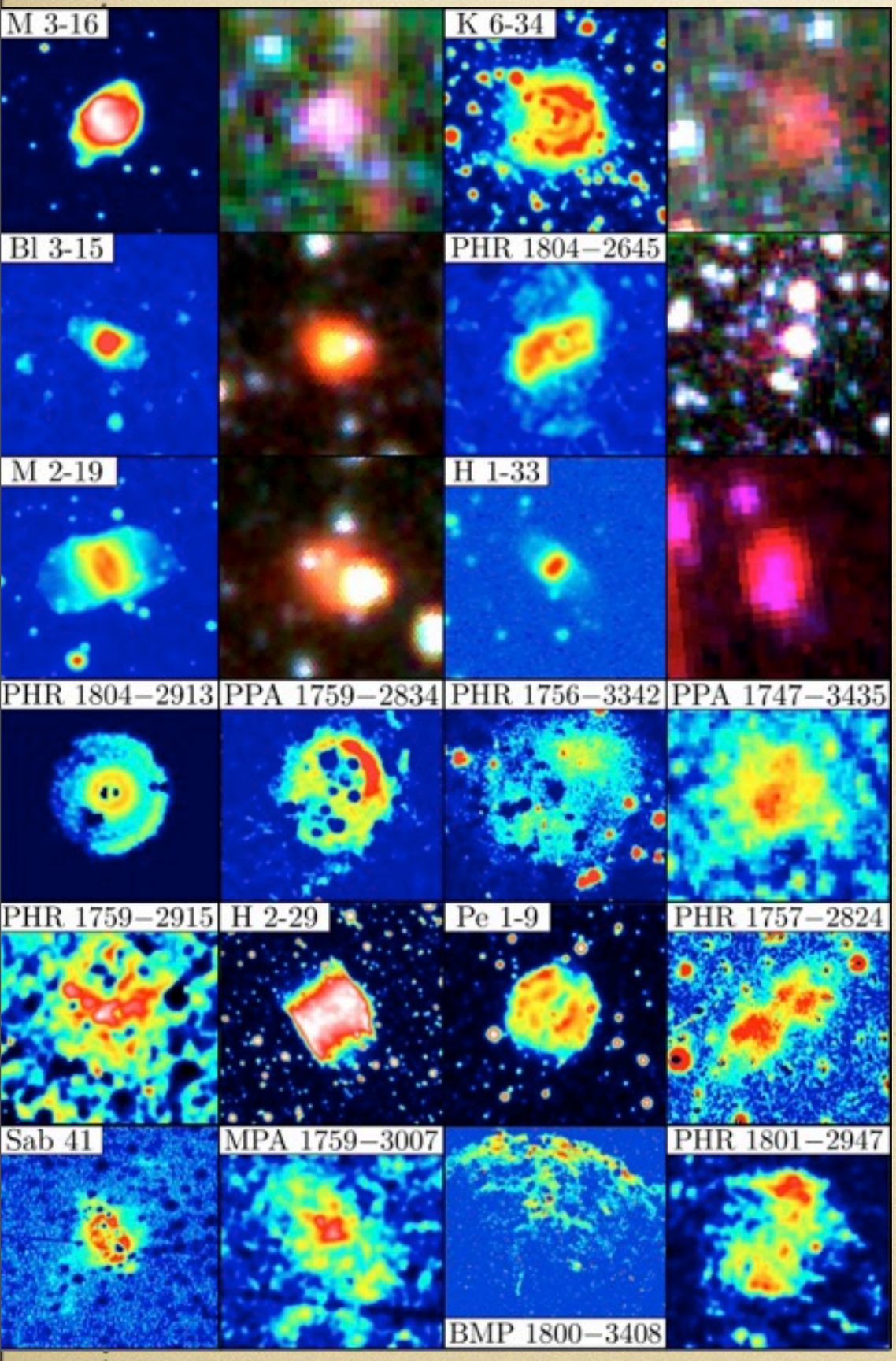
see Rebassa-Mansergas+ 2008
Davis et al. 2010

Morphological Traits of Post-CE PNe

- Needed to identify new binaries and understand what morphological features ARE SHAPED by binaries
- No clear trends in pre-OGLE sample (Bond & Livio 1990)
- Traits deduced from OGLE sample (Miszalski et al. 2009b)
  - Bipolar PNe
  - Low-ionisation filaments (particularly in rings)
  - Jets and collimated outflows (!!)

Morphologies

Miszalski+ 2009b

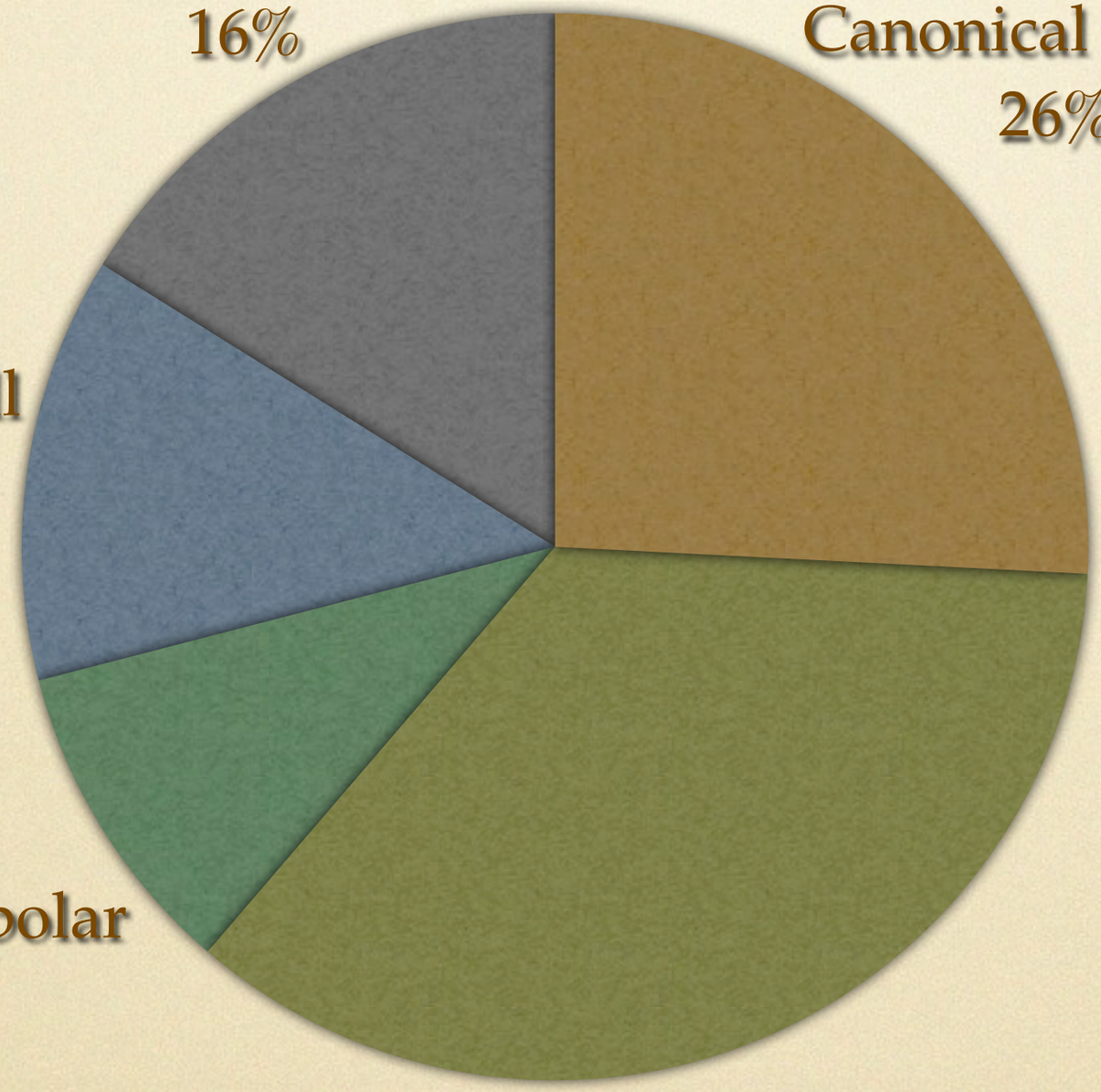


K6-34 H2-29

M2-19 Pe1-9

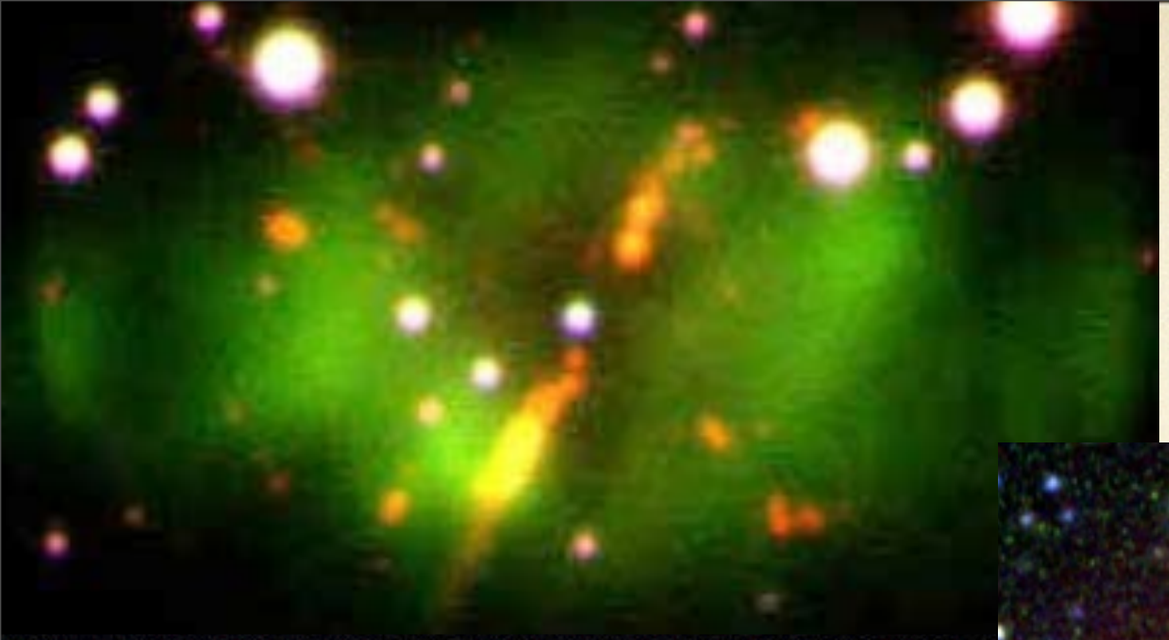
General shapes of 30 Post-CE PNe

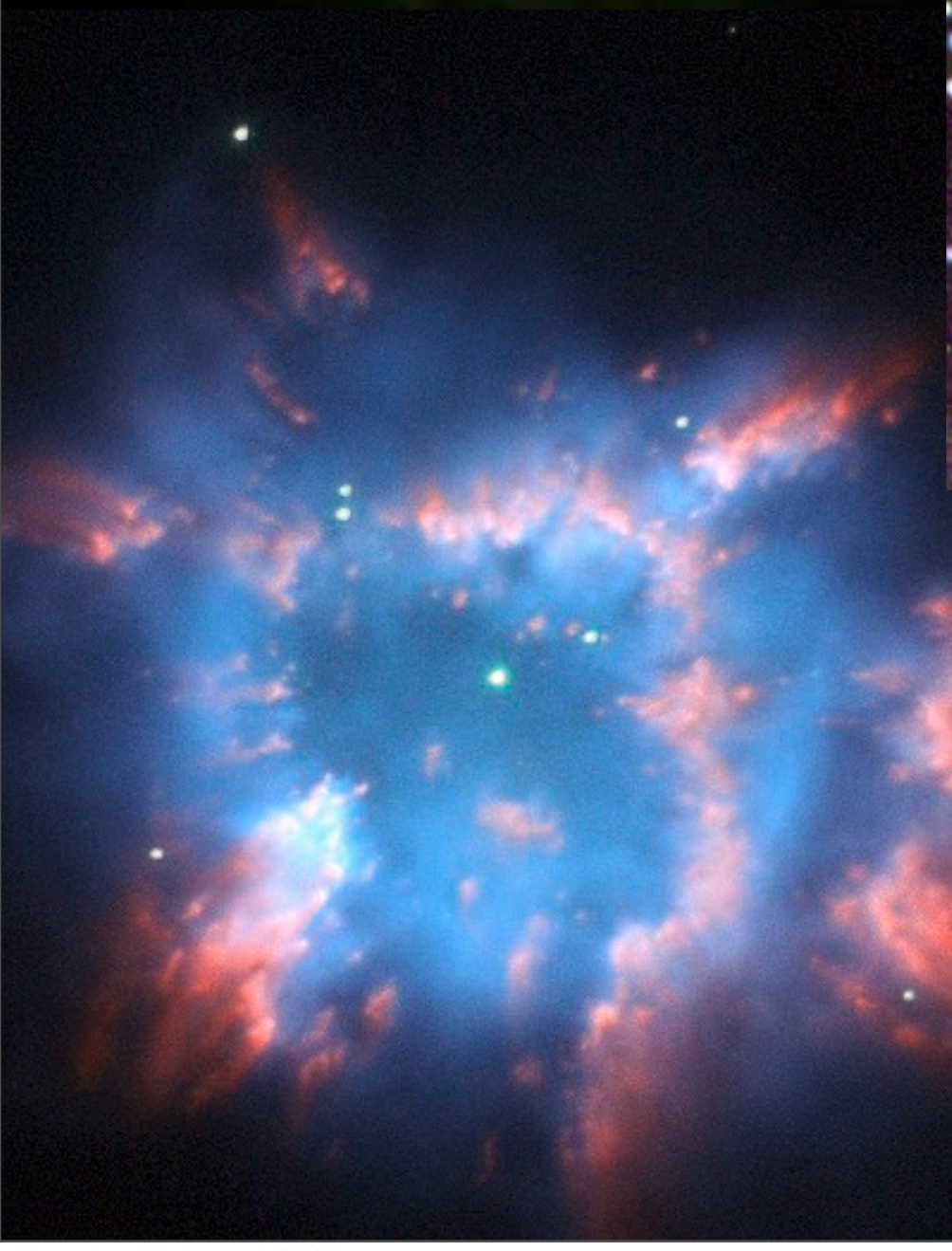
Miszalski+ 2009b

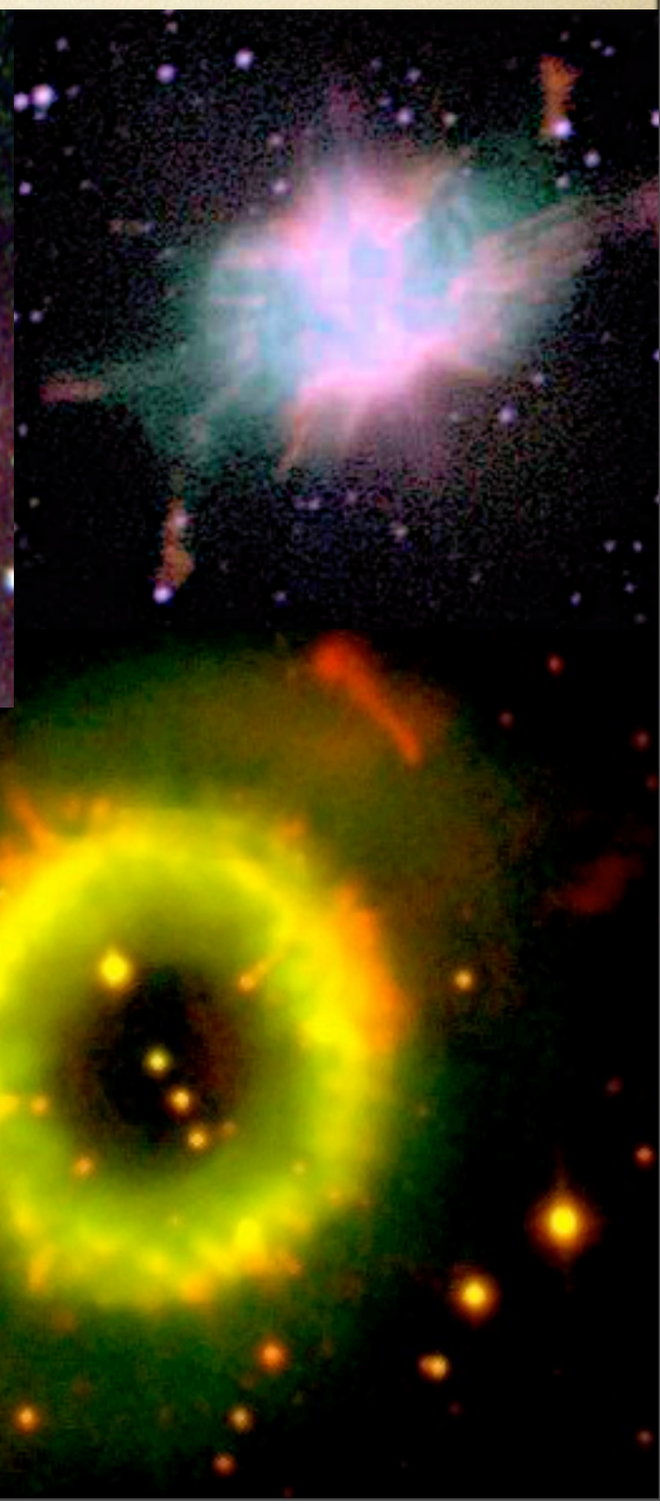


~60% bipolar fraction is plausible

Low-ionisation filaments







Rings

One ring to rule them all, ***one ring to find them****,*
One ring to bring them all and in the darkness bind them.

THE ASTRONOMICAL JOURNAL, 134:846–859, 2007 August

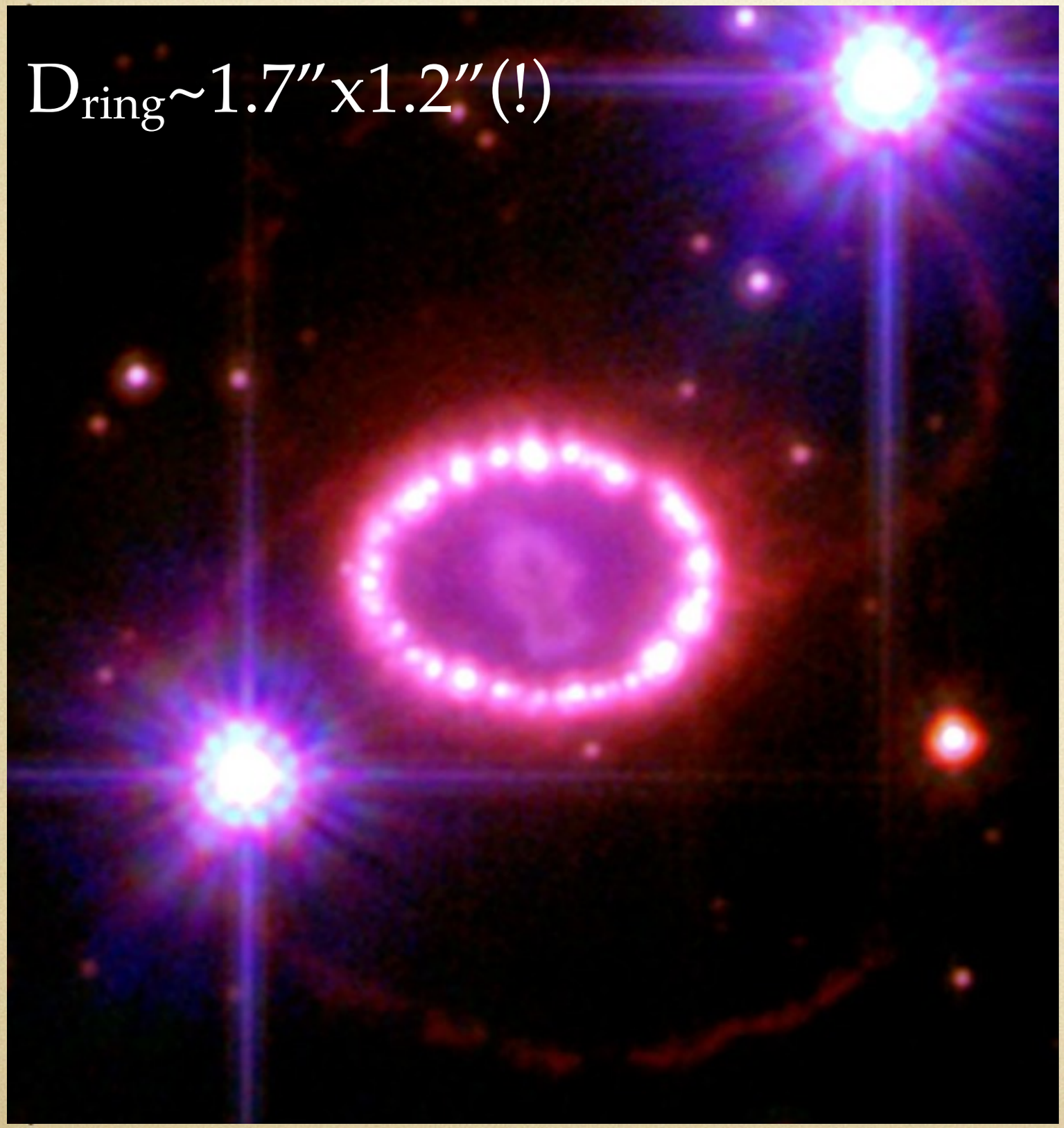
AND IN THE DARKNESS BIND THEM: EQUATORIAL RINGS, B[e] SUPERGIANTS, AND THE WAISTS OF BIPOLAR NEBULAE[1]

NATHAN SMITH,[2,3,4,5] JOHN BALLY,[3,5] AND JOSH WALAWENDER[3,5,6]

Received 2007 February 13; accepted 2007 March 30

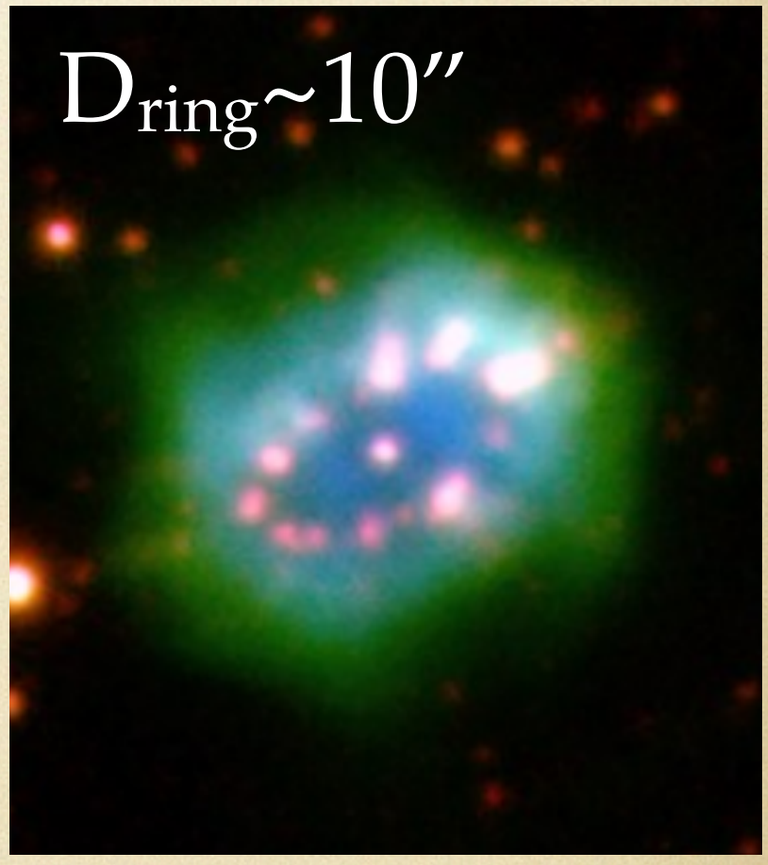
One ring to rule them all, ***one ring to find them,***
One ring to bring them all and in the darkness bind them.

SN1987A



The Necklace

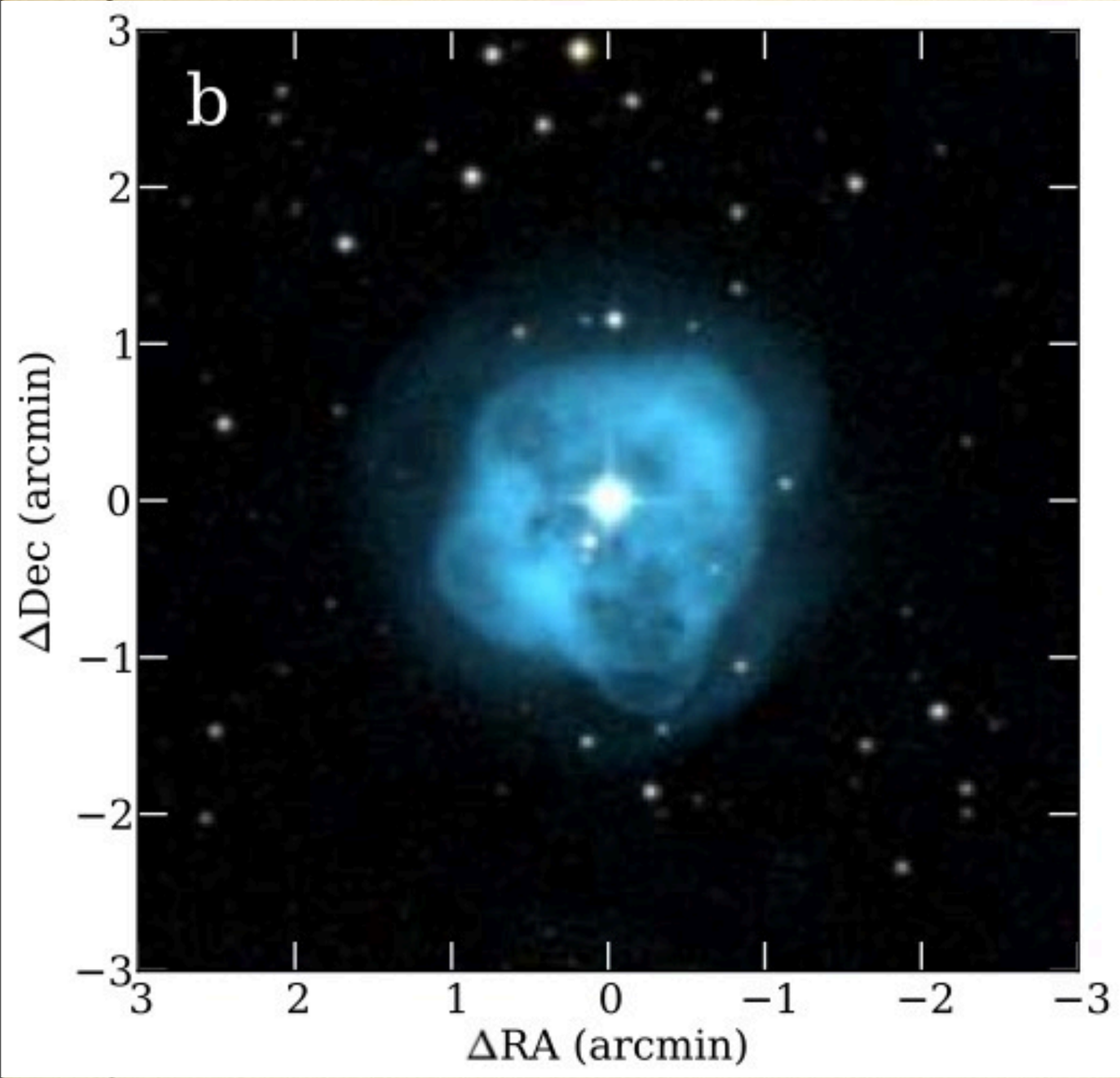
Corradi, Sabin, Miszalski+2011



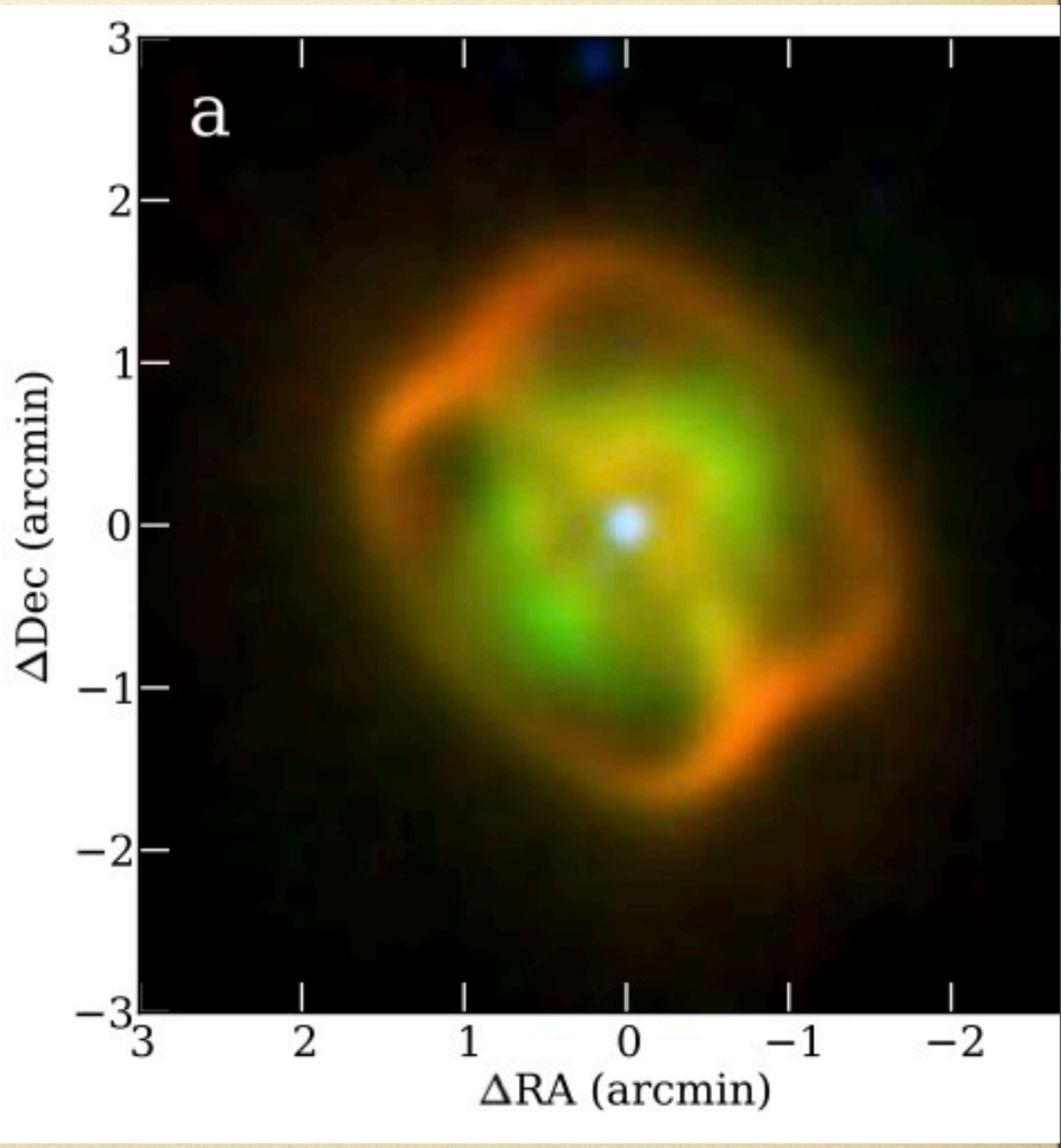
IPHAS DISCOVERY

NGC 1514

OPTICAL (SSS)



MID-INFRARED (WISE)

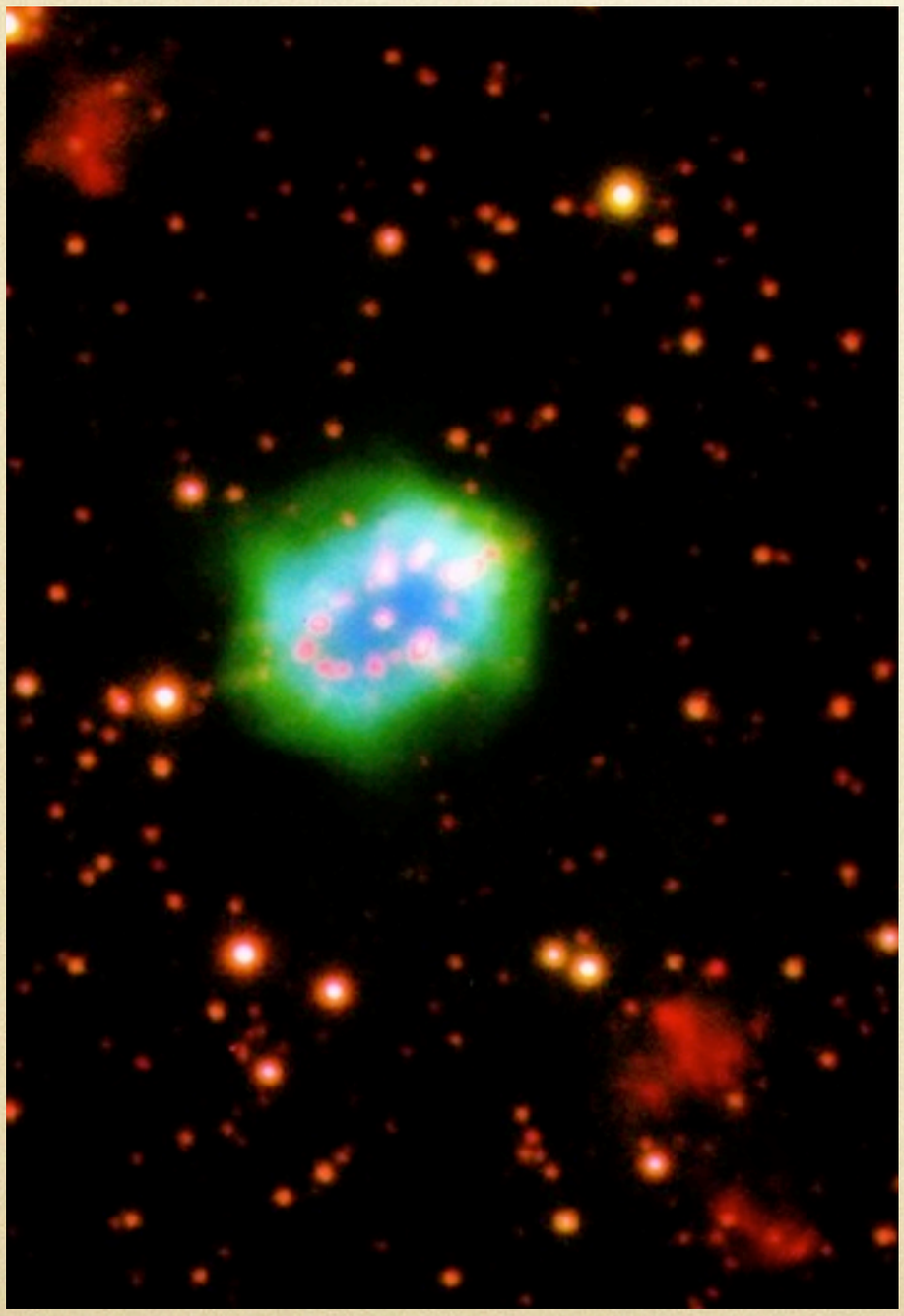


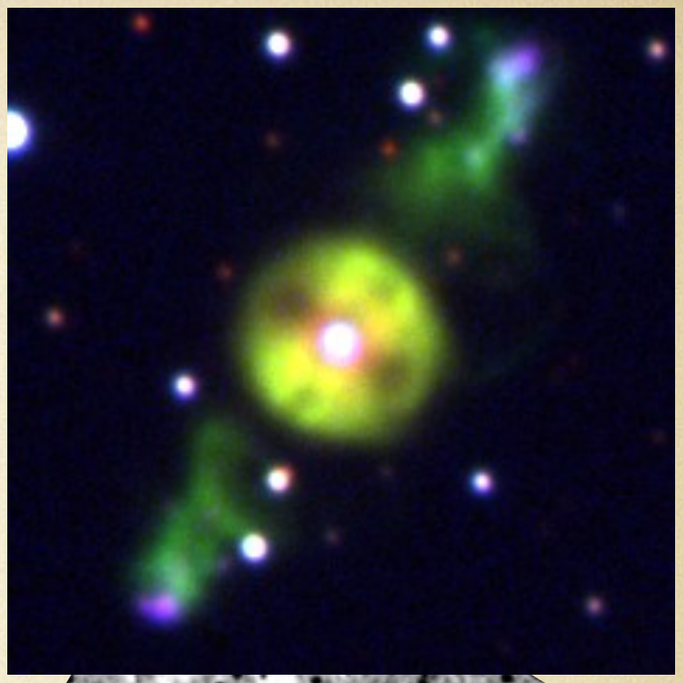
Wide binary (Kohoutek 1967)

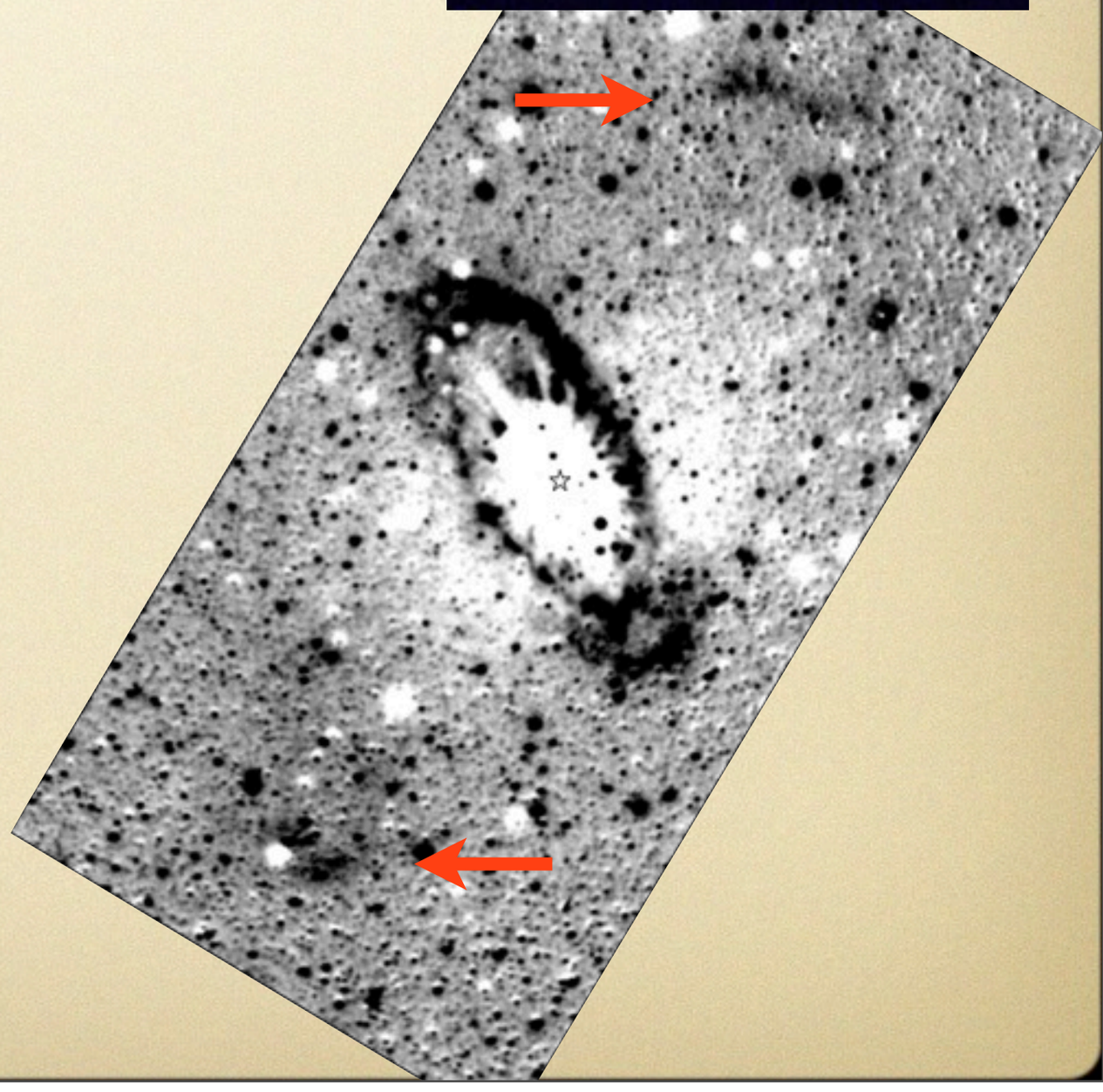
Ressler et al. 2010

Jets

Strong indicator!

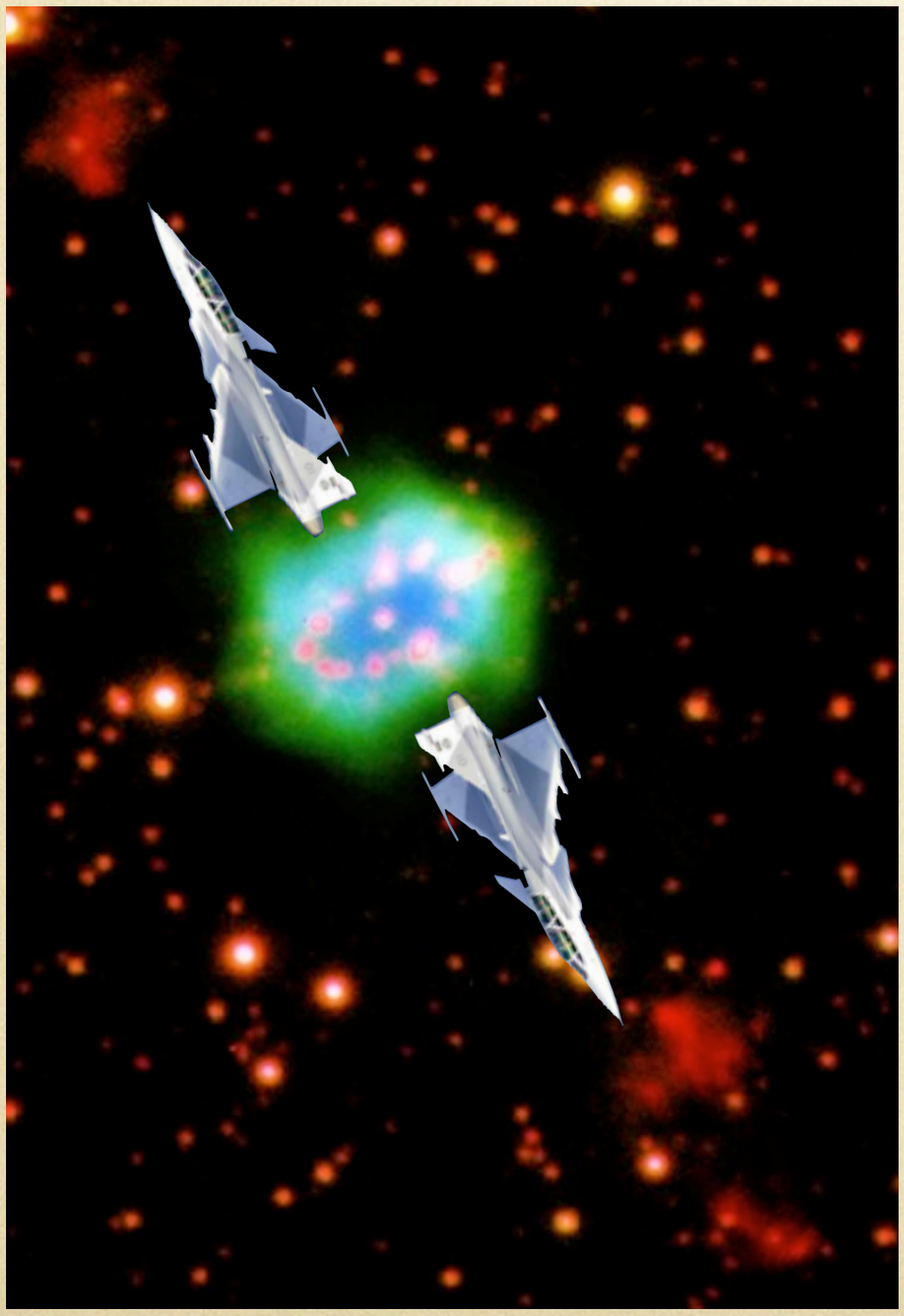


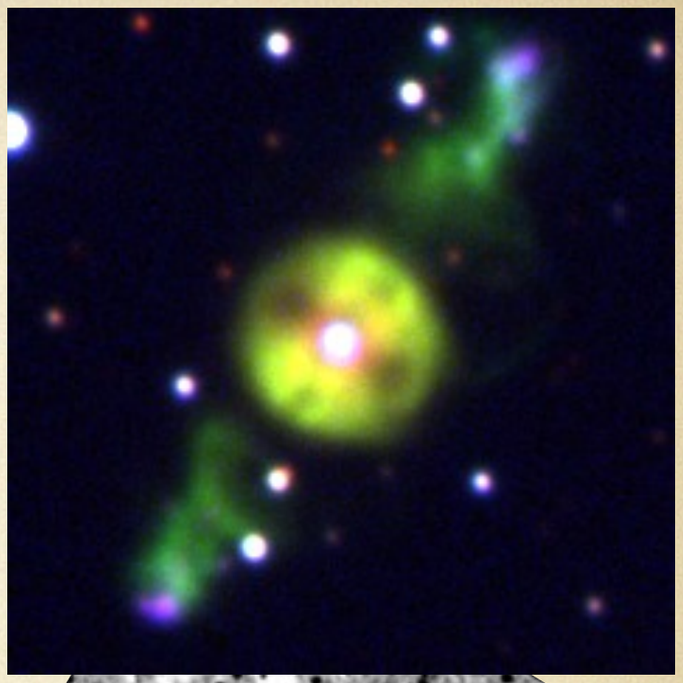


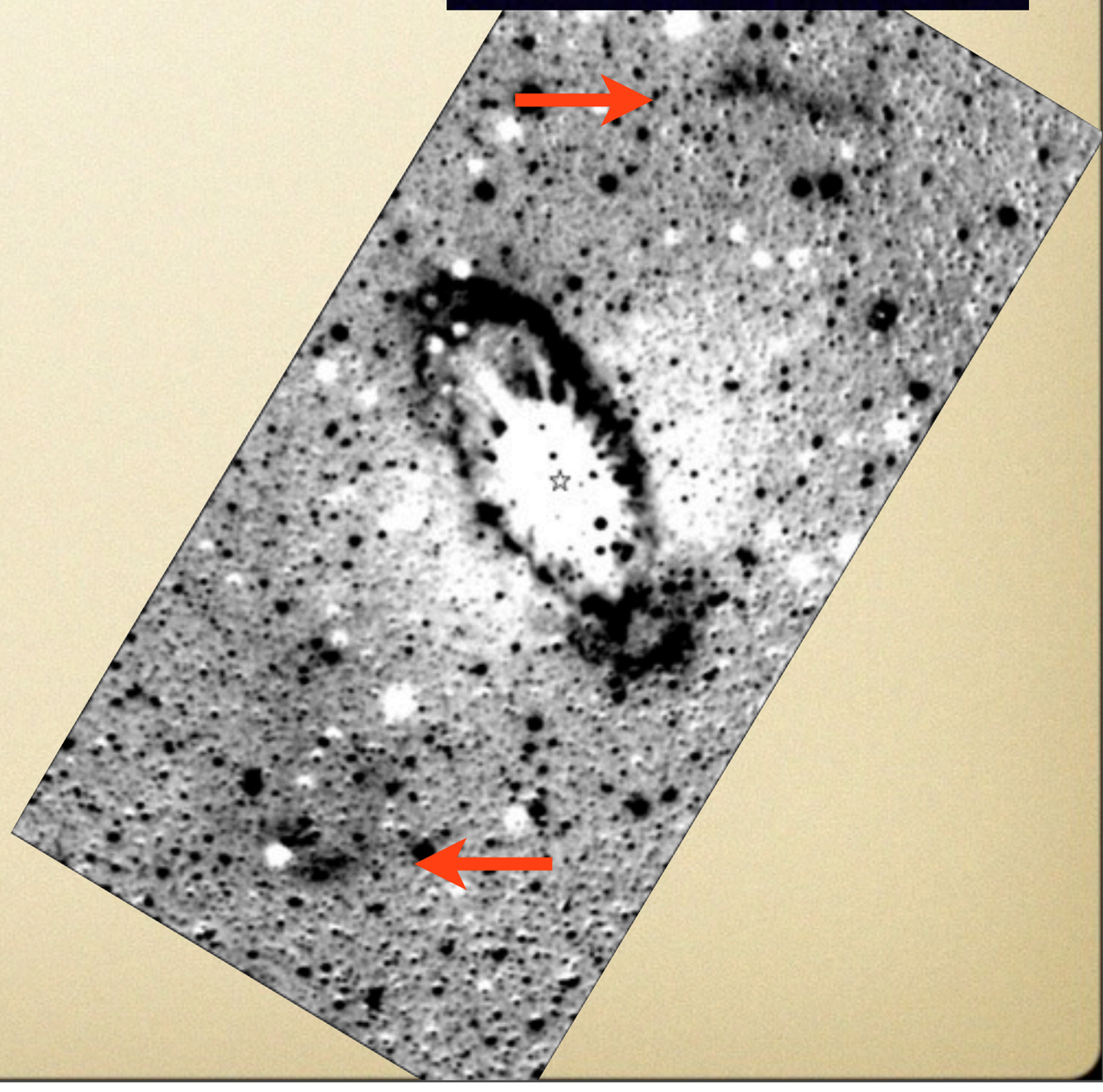


Jets

Strong indicator!

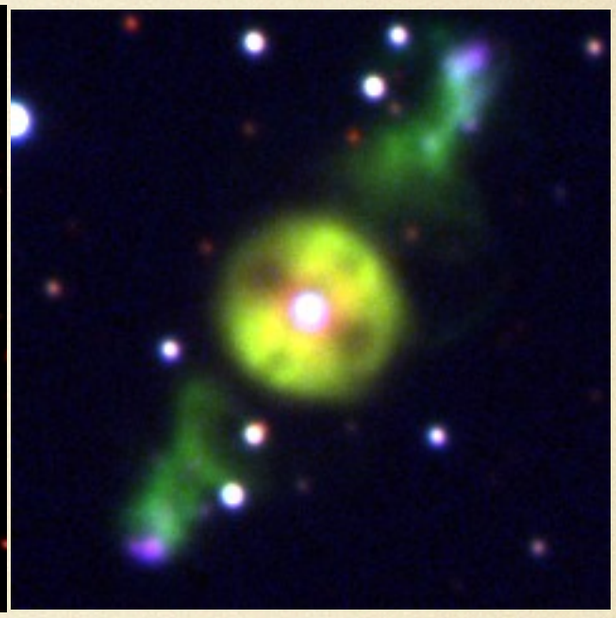
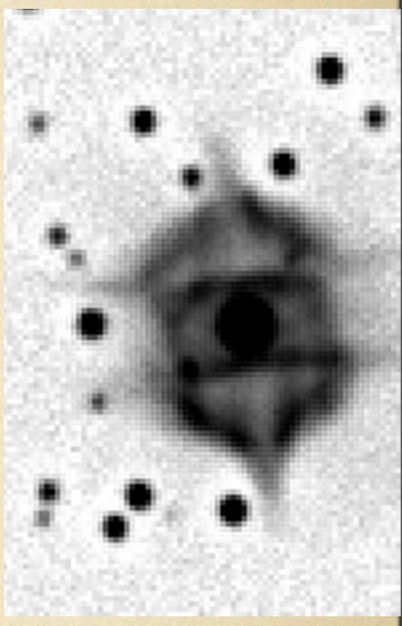


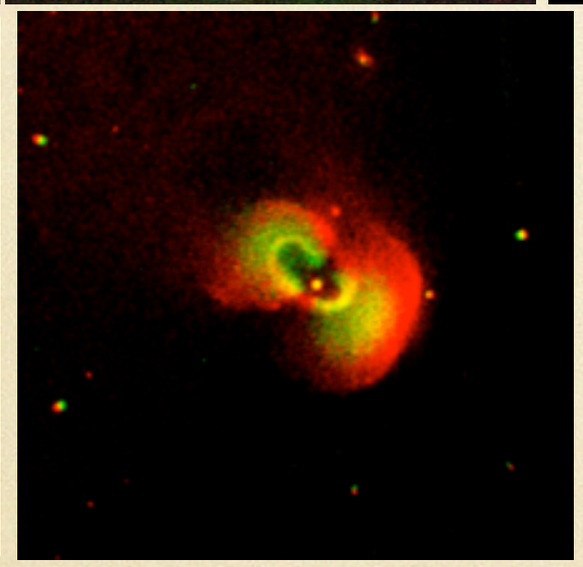




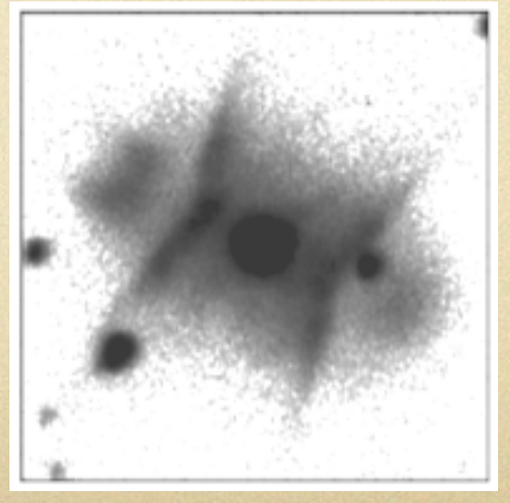
close binaries found since OGLE





+ more
in preparation



How did we find them?

- **Team:** B. Miszalski, R. Corradi, D. Jones, H. Boffin, M. Santander-Garcia, P. Rodriguez-Gil
- Select PNe that fit Miszalski et al. (2009b) traits for post-CE nebulae
- Time series-photometry and some spectroscopy
- A mix of small (Mercator 1.2m, SAAO 1.9m, INT) and large (VLT, Gemini South, WHT) telescopes
- Identify and develop cutting-edge methods to find new binaries over traditional, less-rapid methods

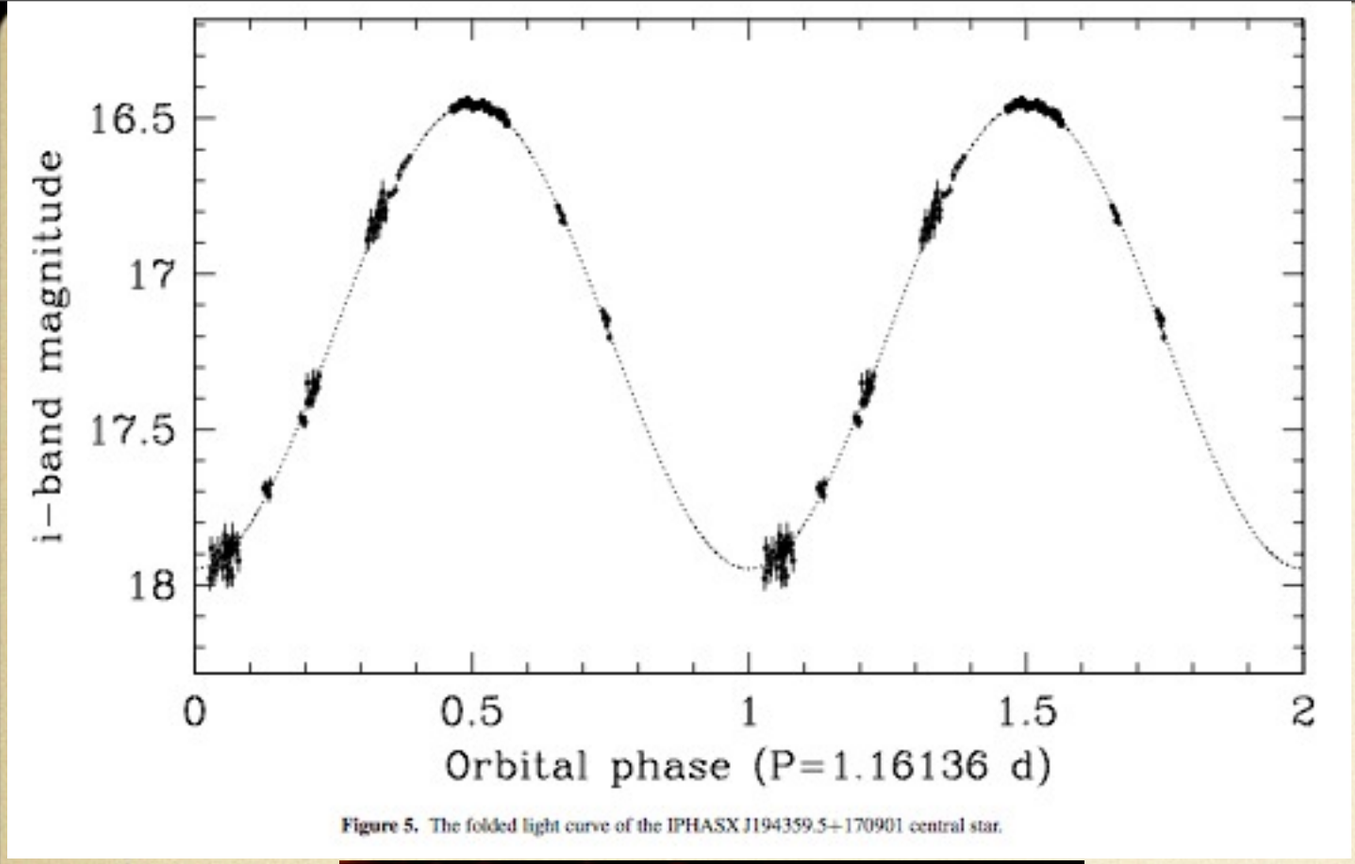
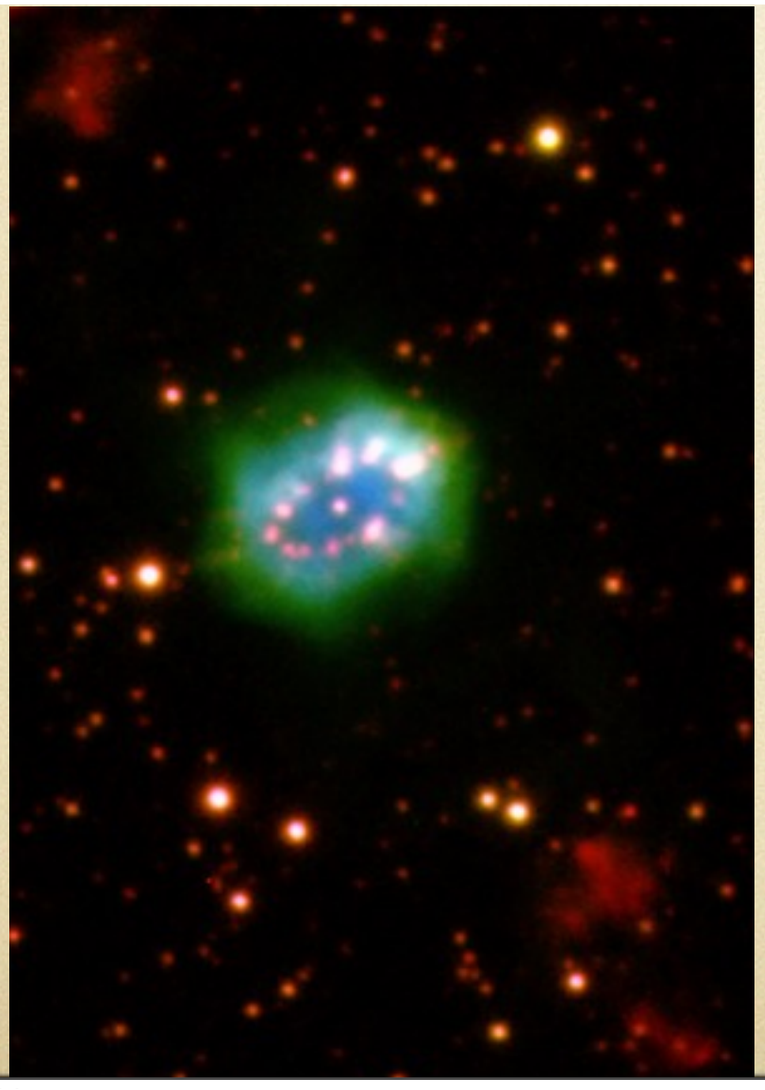


Figure 5. The folded light curve of the IPHASX J194359.5+170901 central star.



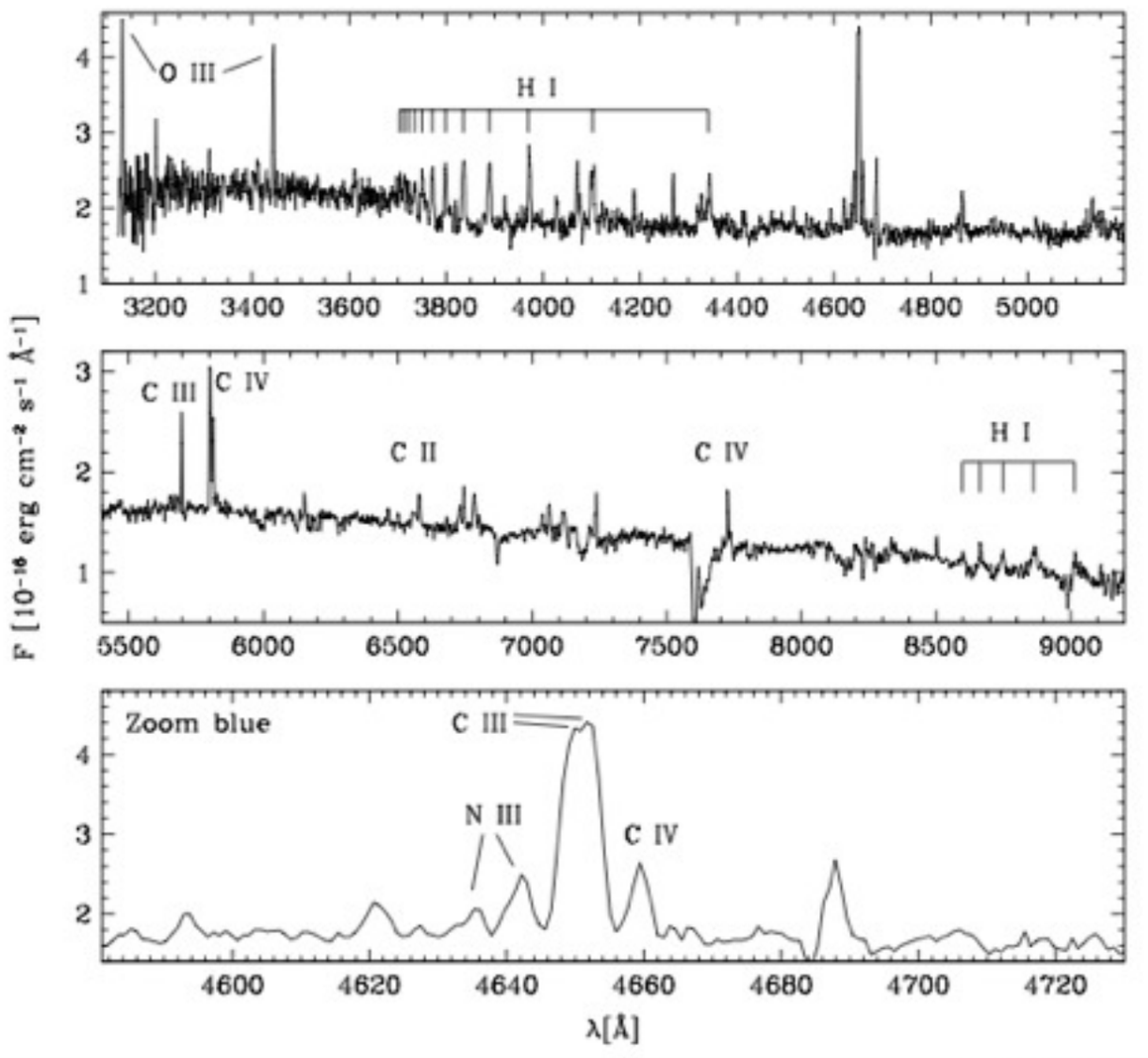
The Necklace

Corradi, Sabin, Miszalski+ 2011

P=1.16136 days

0.75 mag amplitude!

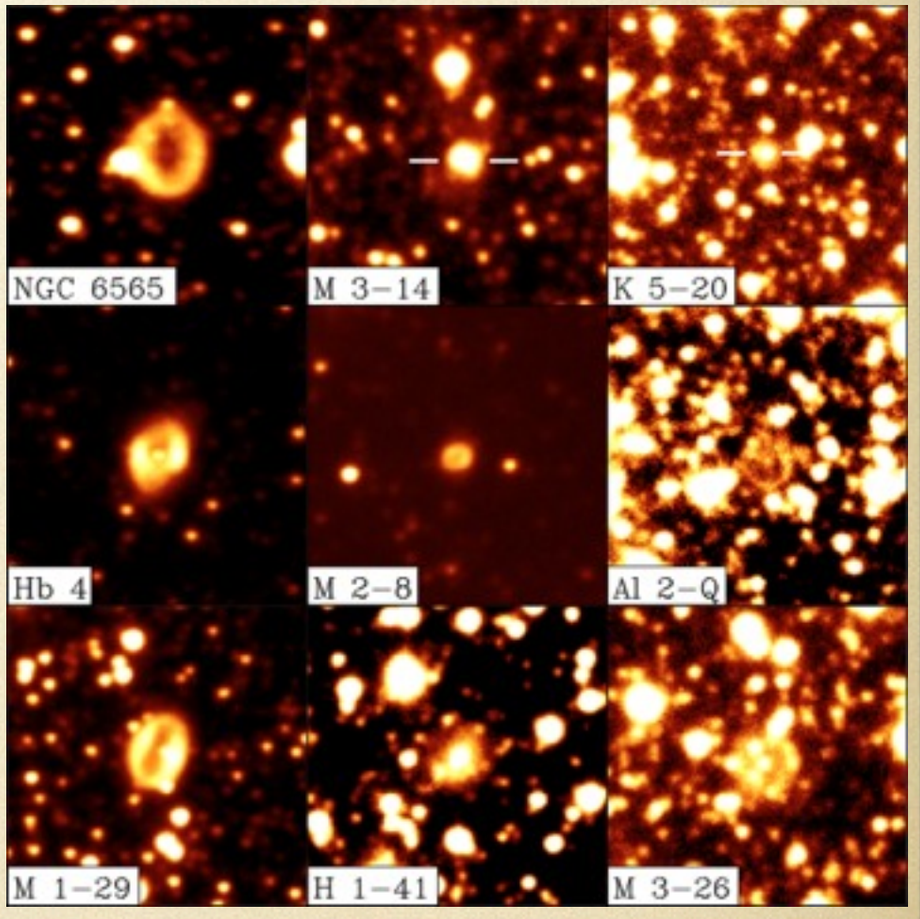
WD T_{eff} > 100 kK



Choice of filter

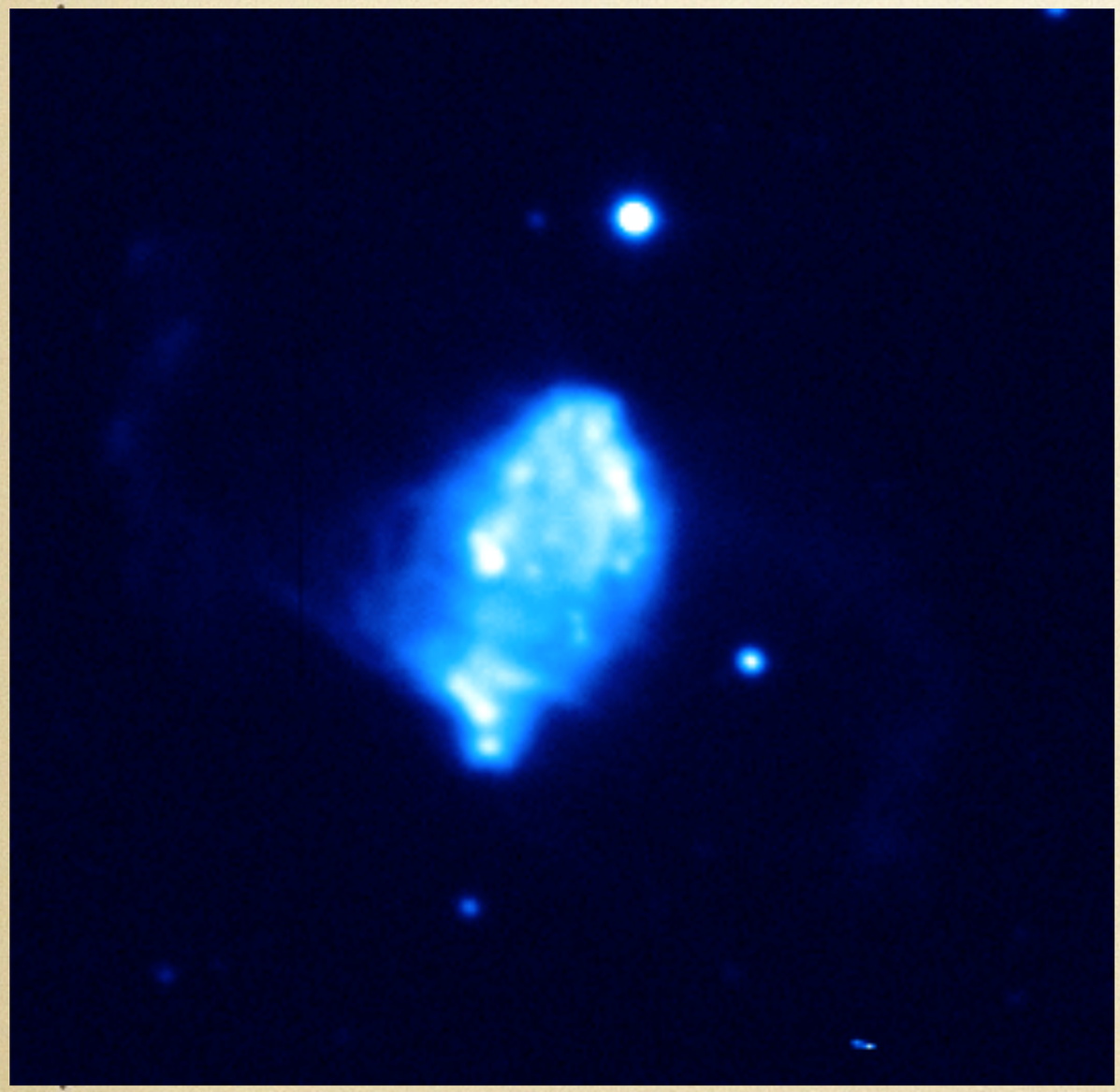
- Nebula can totally obscure CSPN and render photometry useless
- I-band often used but is susceptible to [SIII] contamination
- Stromgren y is a good compromise (λ_0=547 nm, W_0=23 nm)
- Best solution: narrow-band filter slightly off blue nebular lines, e.g. Hbeta-continuum, [OII]-continuum? (CSPN are hot blue stars)
- Some nebula continuum remains

OGLE-III I-band
Miszalski+ 2009a

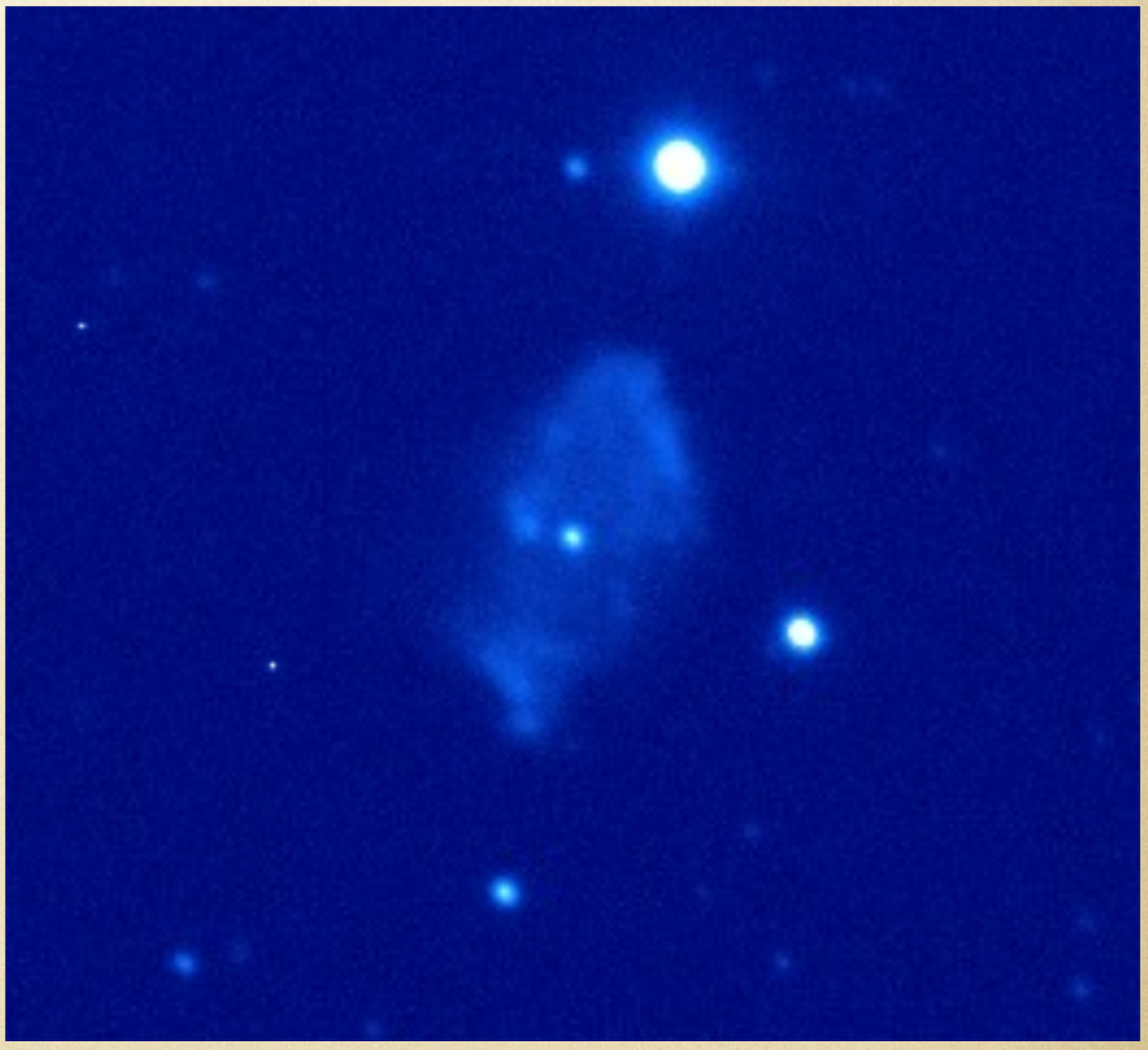


Example: NGC6309

Halpha on-band



Halpha off-band



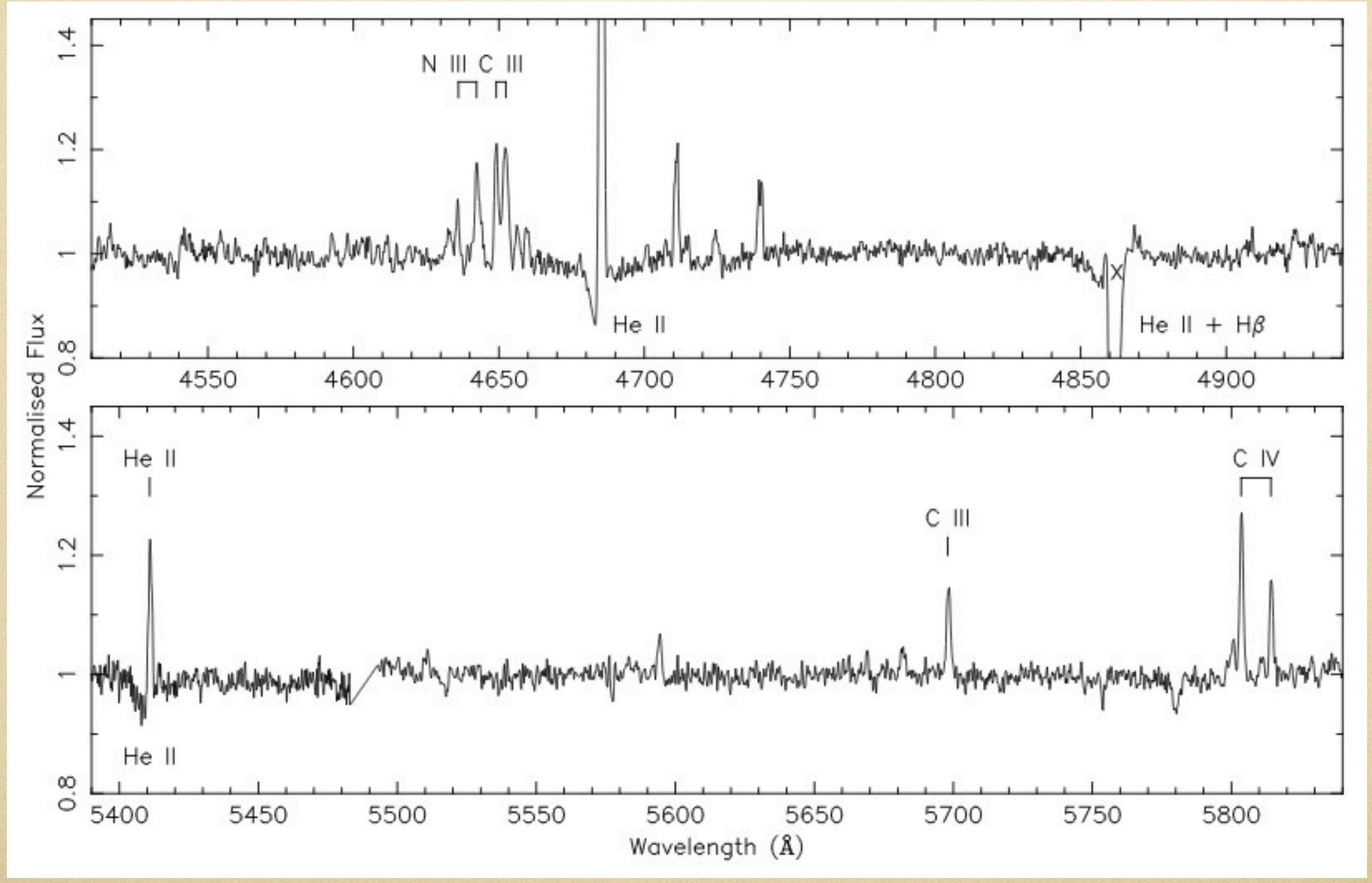
NGC 6326

GMOS spectrum	RV_{hel} (km/s)
Nebula	-1
CIII/NIII (Secondary)	158
HeII 5412 (Primary)	-50

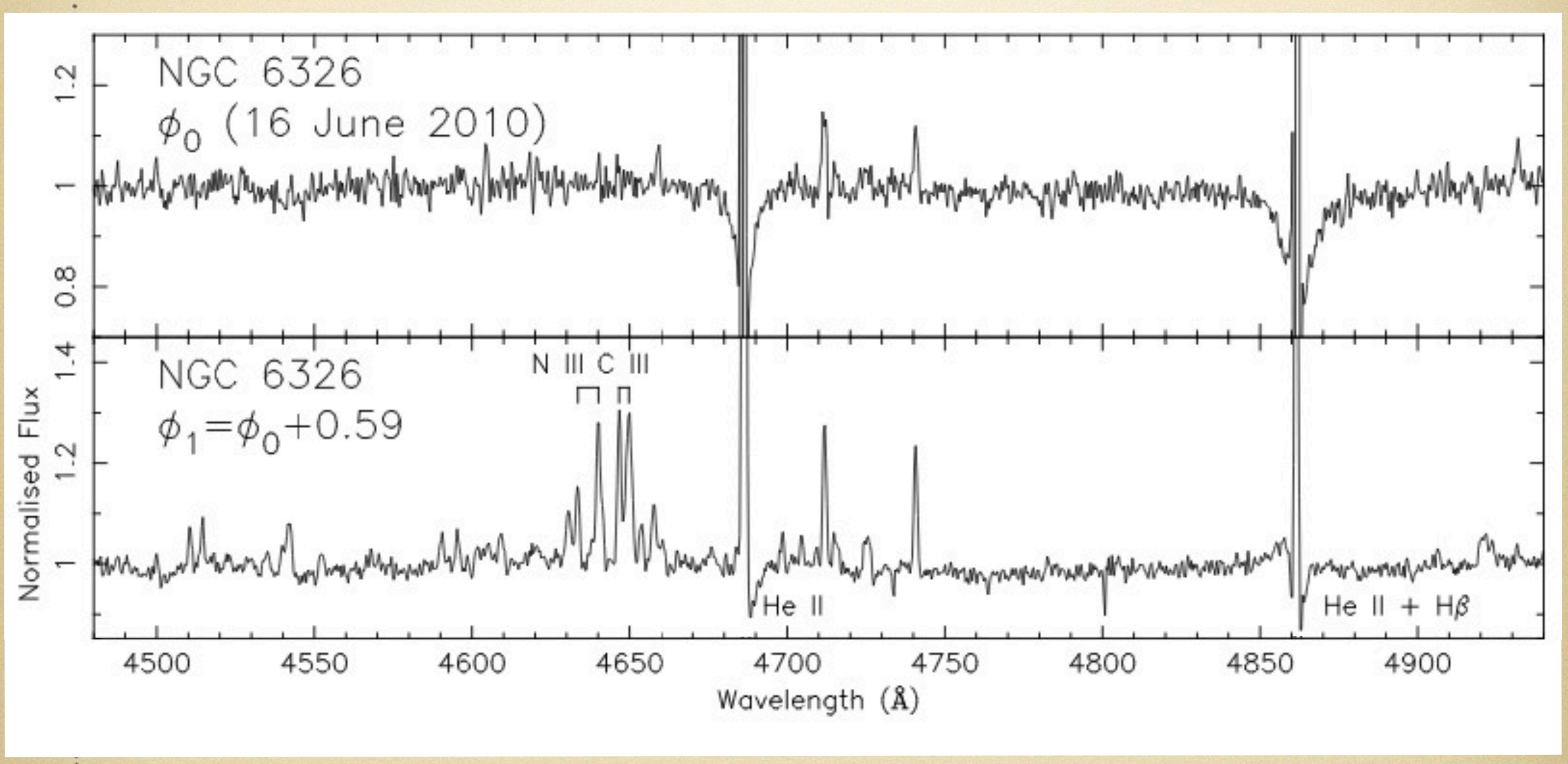
HST image [NII] [OIII]

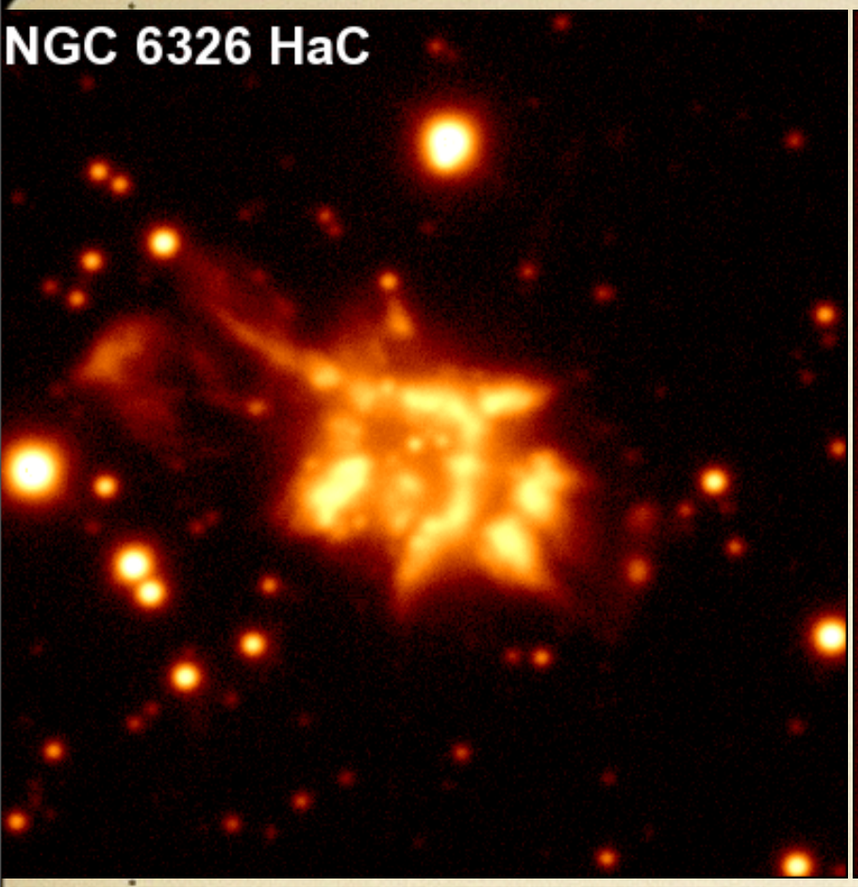
GMOS spectrum

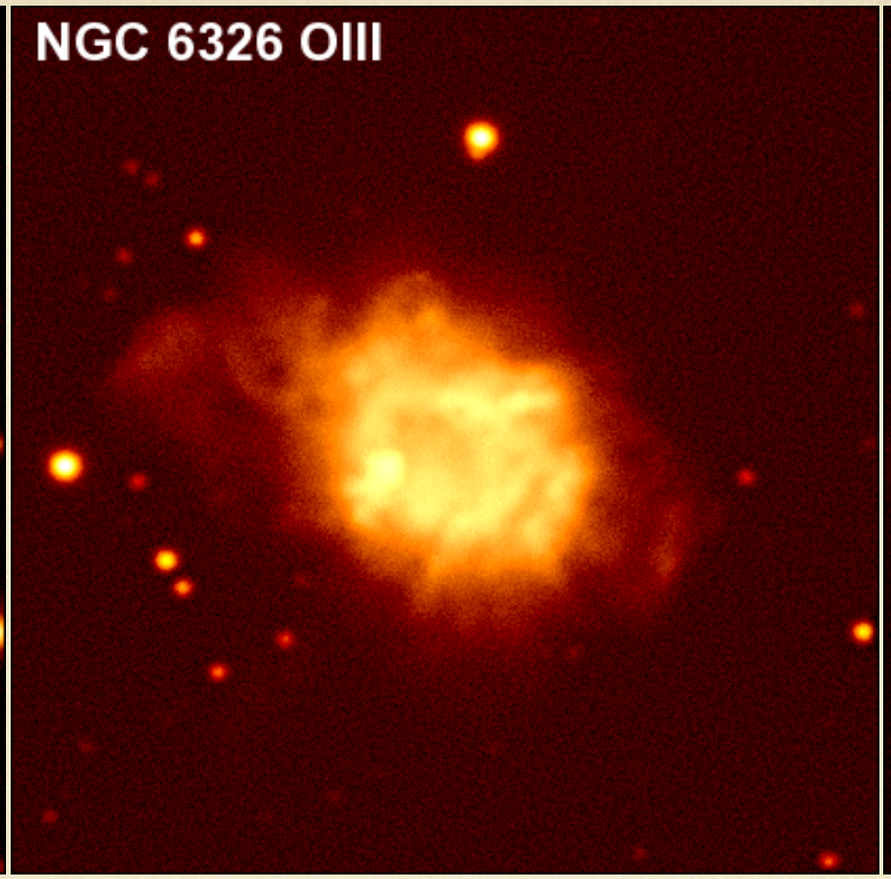
Miszalski et al. 2011, **arXiv:1105.5731**

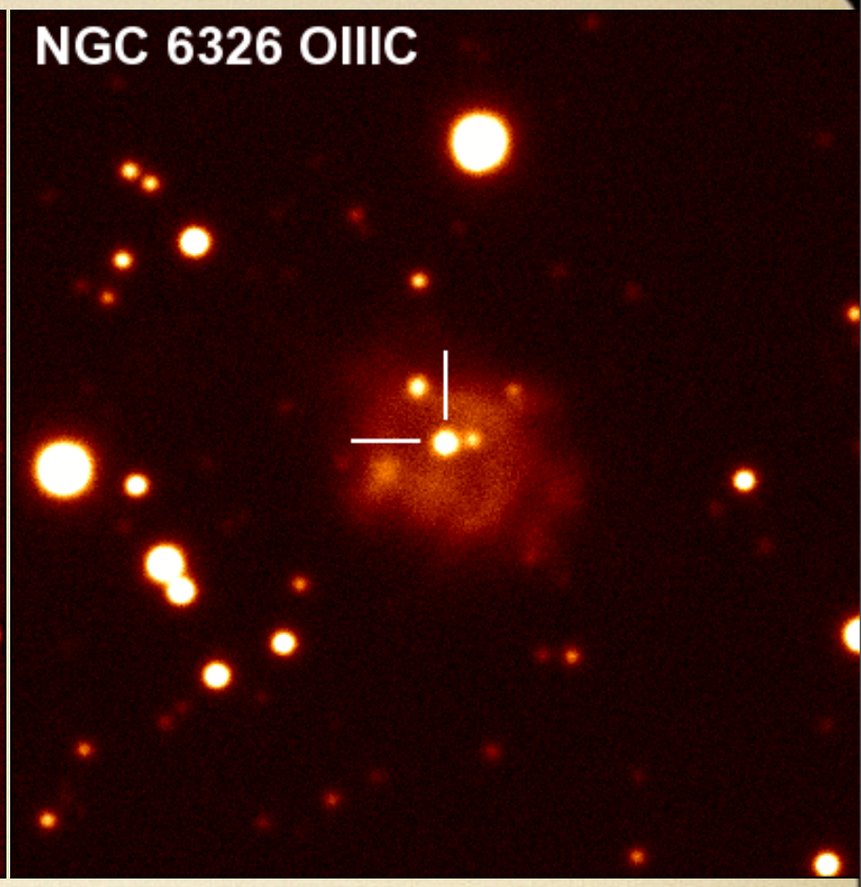


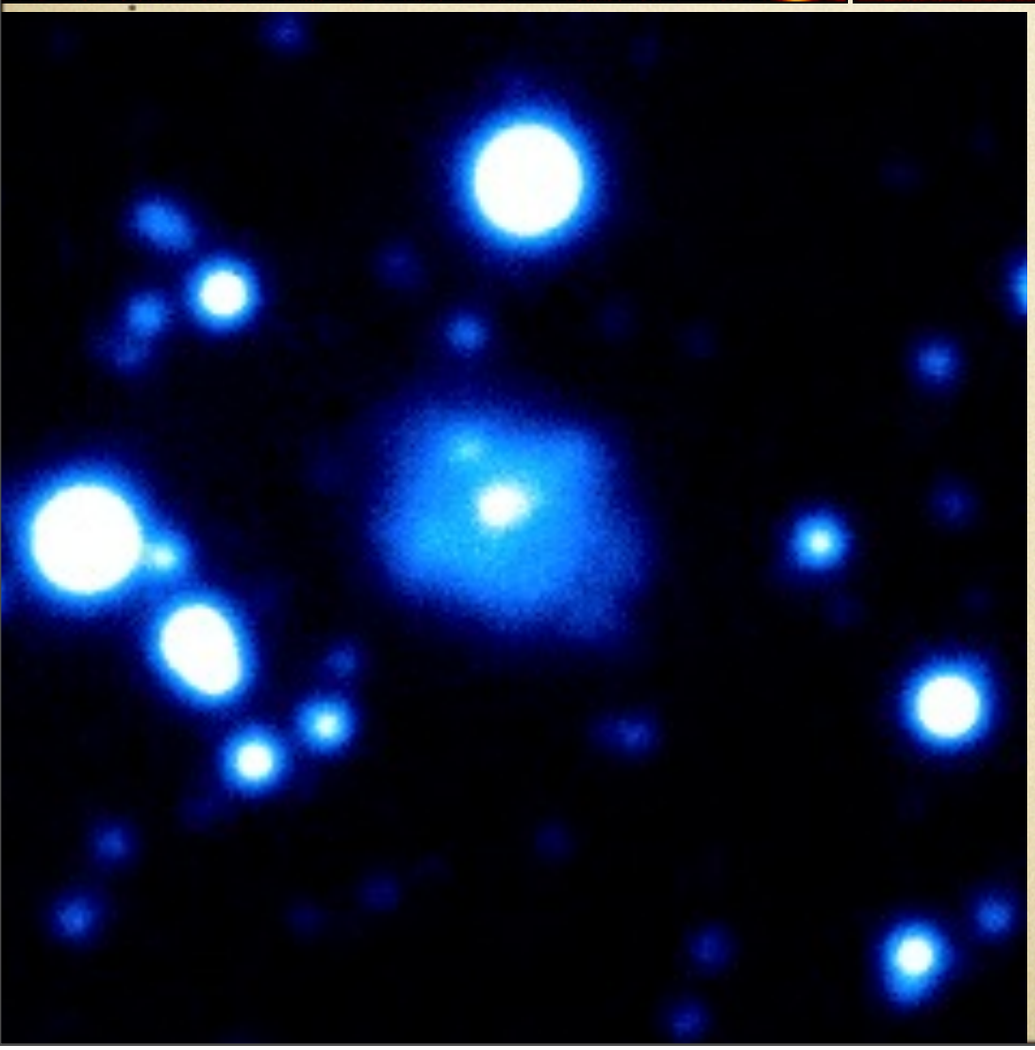
VLT FORS2 spectra must be a binary!











GMOS images

Miszalski et al. 2011

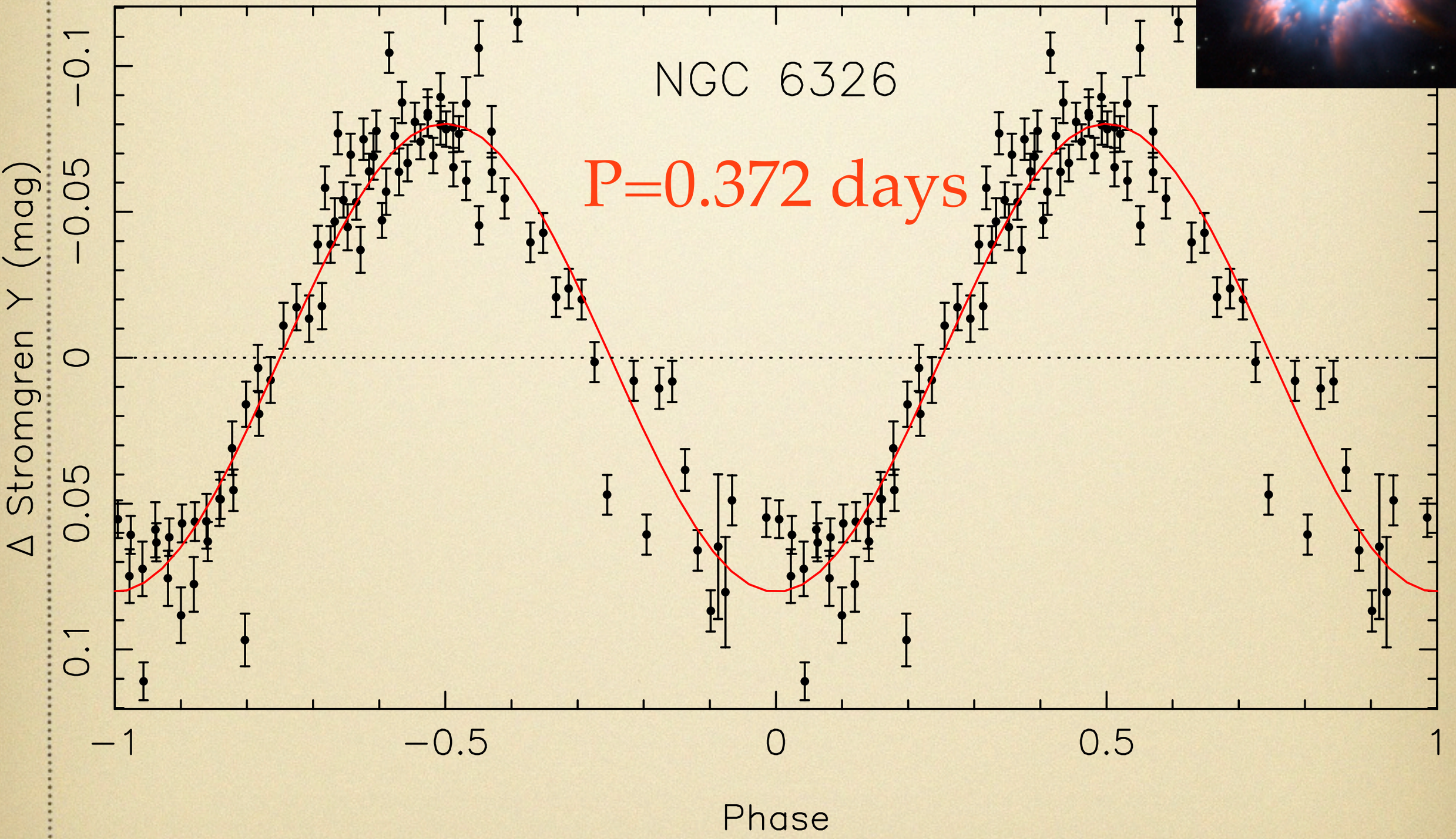
SAAO CCD

1.9m

Strömgren *y* 600s

exposure

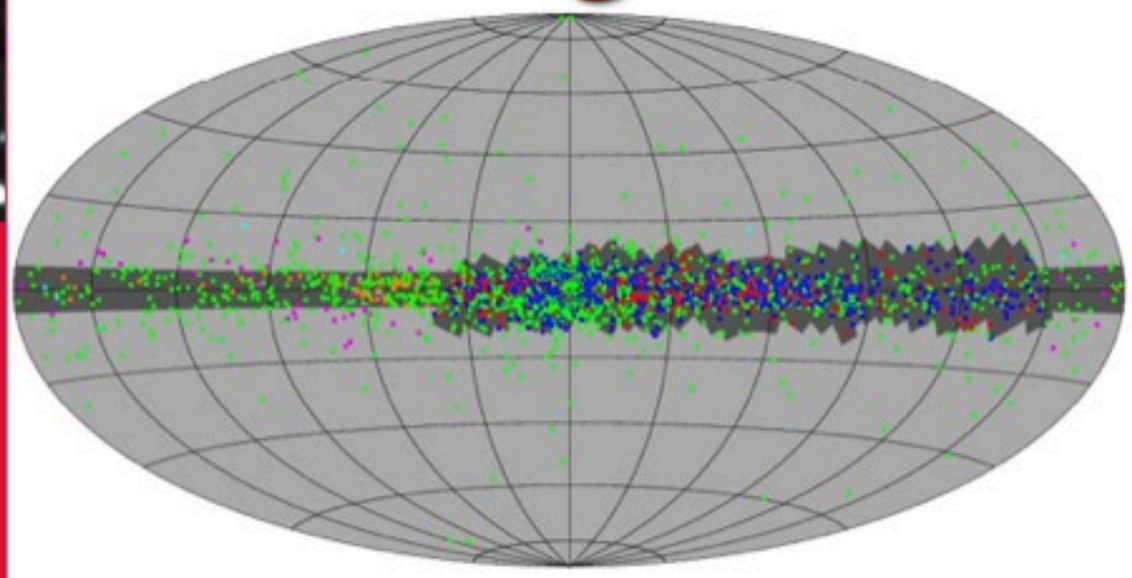
SAAO 1.9m lightcurve; Strömgren *y*



David Jones (ESO Chile); Miszalski et al. 2011

HOME
DATABASE
DB DOCS

Planetary Nebulae



For assistance in using the database of PNe within the SHS, please see the documentation.

Separate Items

Name(s) verbose SUBMIT

SHS field(s) SUBMIT

Coords (J2000) Radius 4 arcmin SUBMIT

Coords (J2000)
(name,ra dec) Browse... Radius 4 arcmin SUBMIT

Database Query

RA	eq_r/15 > 7 and eq_r/15 < 15
DEC	eq_d > -30
L	gal_l >= 350 OR gal_l <= 10
B	gal_b >= -5 AND gal_b <= 5
Size	maj <= 35
PreCheck	
Comment	comment~'lovely'
Name	name~'^A[0-9]'
FirstObs	firstobs is NULL

Output gallery FS . FIELDS STARALT 09 February 2011 La Palma NoPNe 30
Catalogue ALL
Regions none known green mash red mash2 yellow r 5 w 1
Type TLP
Order By RA ASC DESC

SUBMIT

Online database
of all Galactic PNe

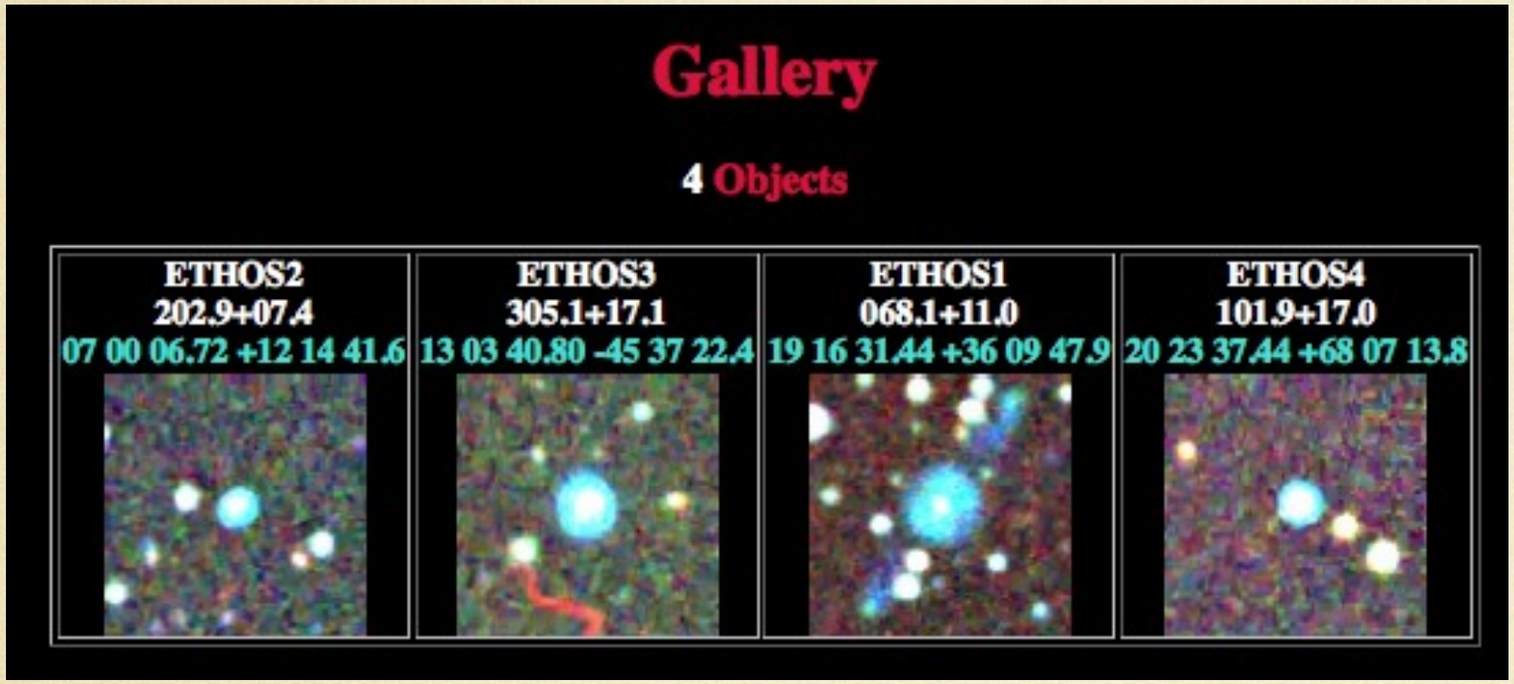
under development

Miszalski

Acker
Parker
Oschenbein

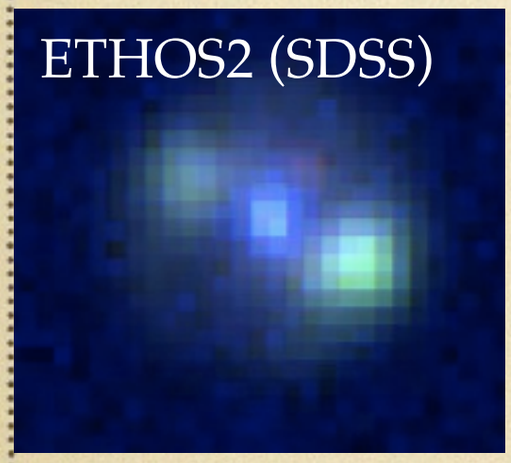
hosted by CDS

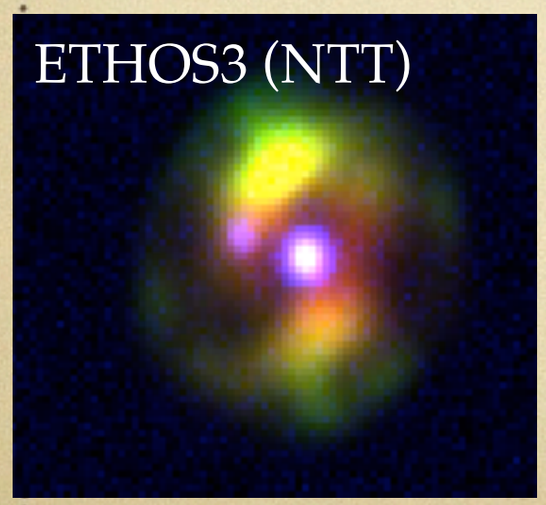
Extremely Turquoise Halo Object Survey

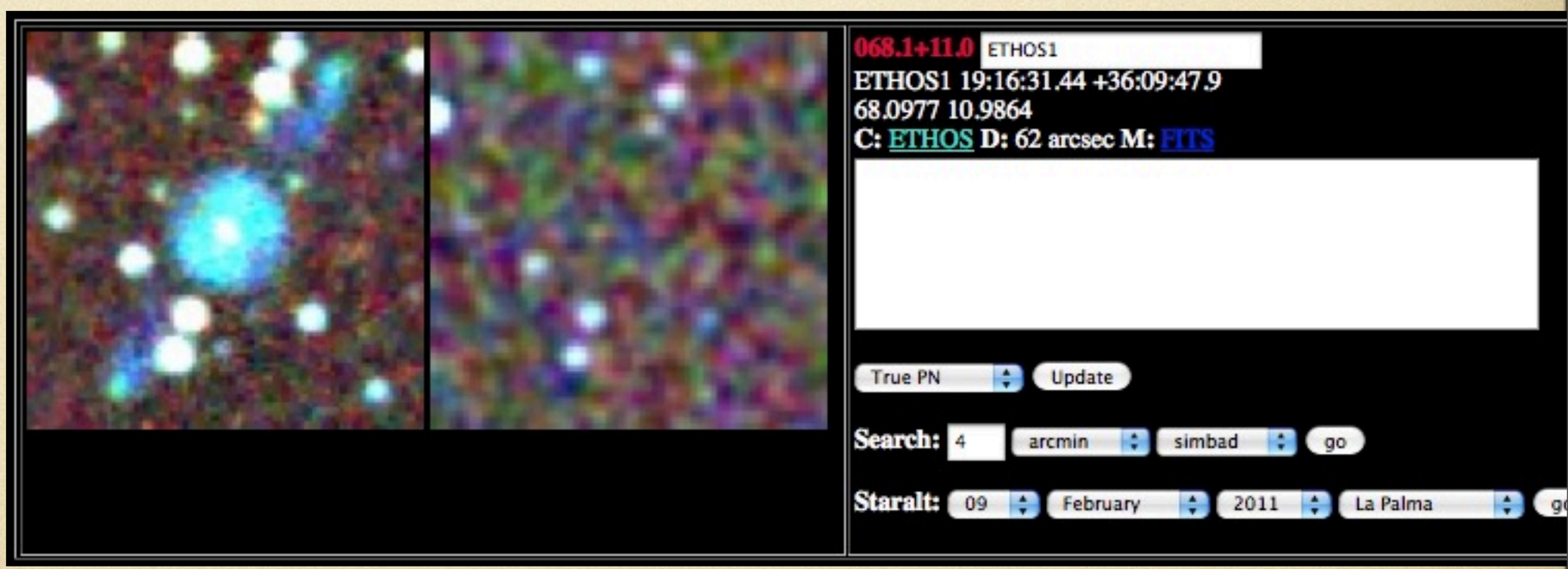


Miszalski et al. (in prep)

SuperCOSMOS Science Archive selected PNe!







Extremely Turquoise Halo Object Survey

SuperCOSMOS Science Archive

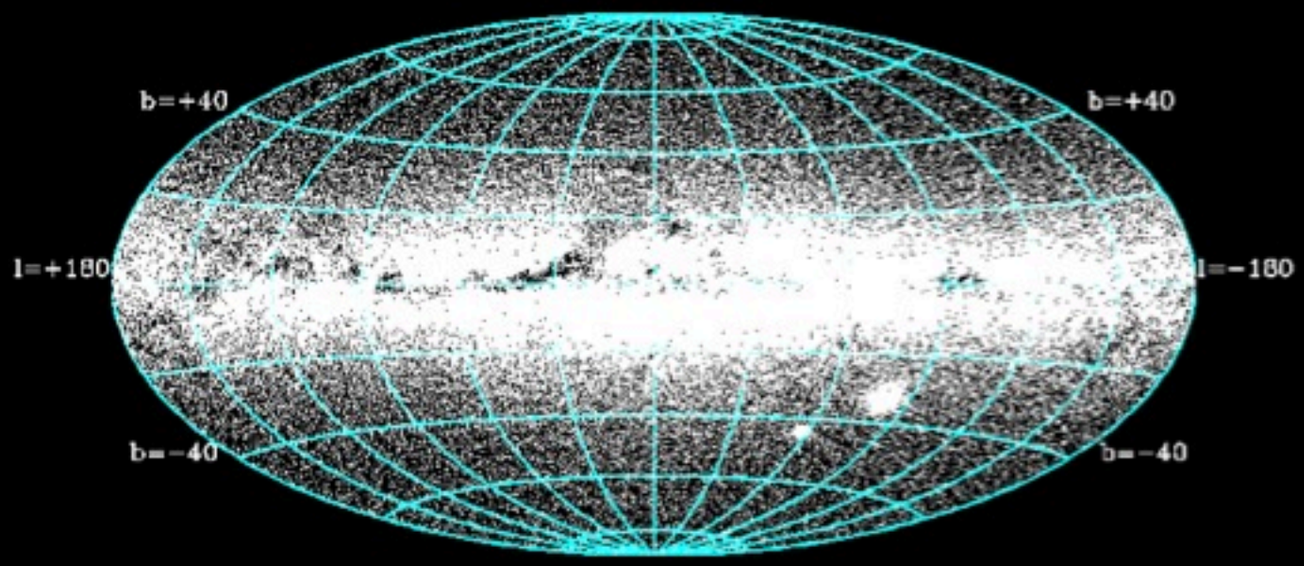
IFA ROE

SSA - SuperCOSMOS Science Archive

LATEST NEWS: A new database of ~200 plates in the single survey field no. 287 has been included in the SSA - for more details click on F287 here or in the navigation bar below left.

The SuperCOSMOS Science archive holds the object catalogue data extracted from scans of photographic Schmidt survey plates.

At around 4 terabytes in size, the database contains nearly 6.4 billion individual object detections which are merged into just under 1.9 billion multi-colour, multi-epoch sources and covers the whole sky in three wavebands (BRI), with one colour (R) represented at two epochs.



Access to the data has previously been made available through the SuperCOSMOS Sky Survey pages. The SSA is based on the same underlying data but it is housed in a relational database (Microsoft SQL Server 2008). This platform allows users more power and control over how they can access the data.

A short description of the SSA database structure and content is given in the Data Overview, for full details see the Schema Browser.

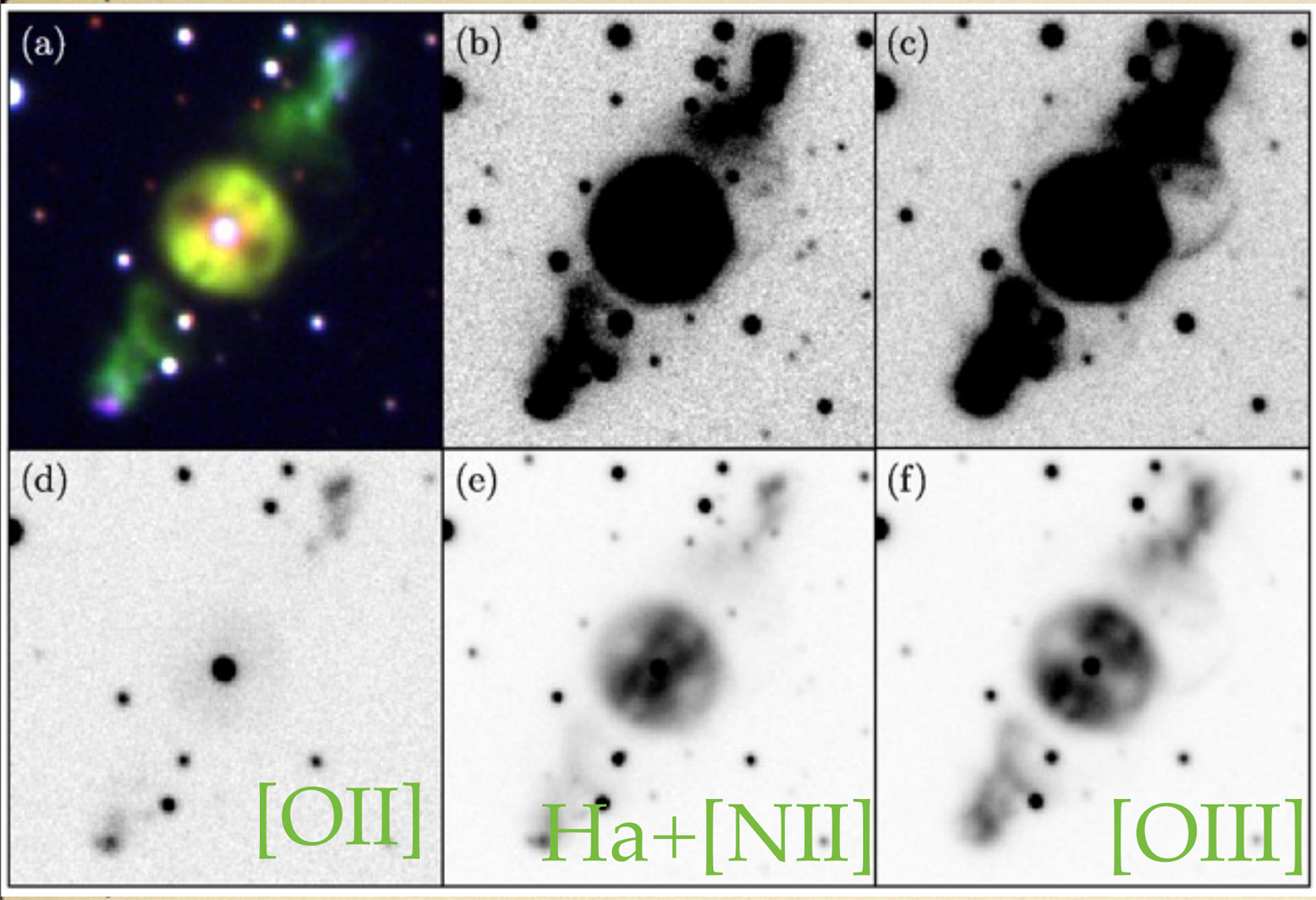
Users wishing to access the data should first read the general introductory notes under Data Access.

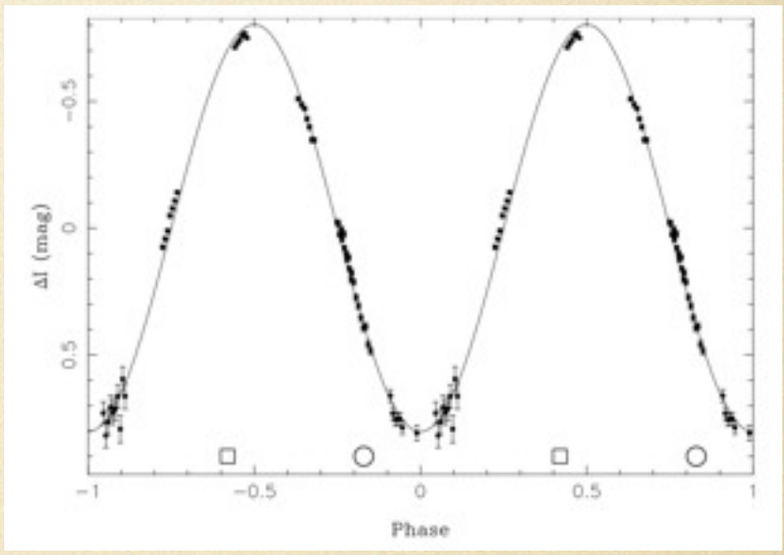
WFAU, Institute for Astronomy,
Royal Observatory, Blackford Hill
Edinburgh, EH9 3HJ, UK
Tel +44 131 668 8356 (office)
or +44 131 668 8100 (switchboard)

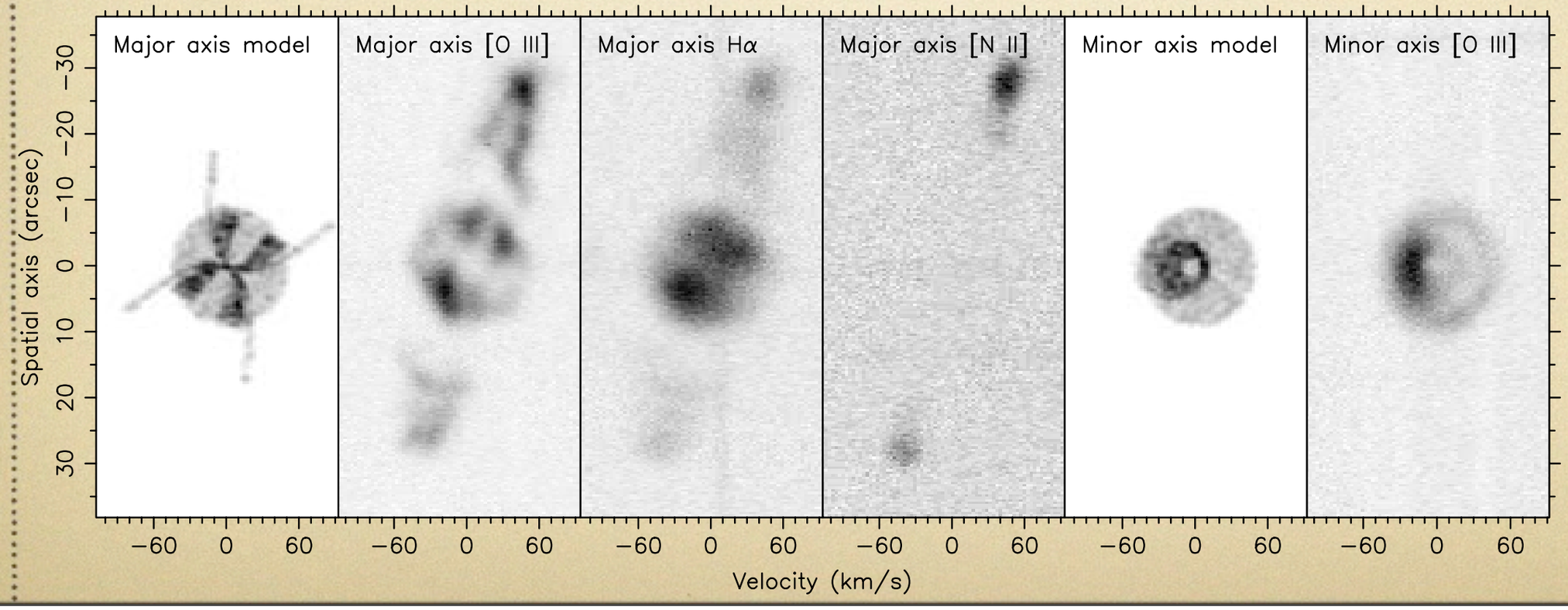
nan@roe.ac.uk
12/1/2011

ETHOS 1

Miszalski, Corradi, Boffin+ 2011







jets ~120 km/s

Jets ejected before main nebula

Name	T_{nebula} (yrs/kpc)	T_{jets} (yrs/kpc)	Reference
Abell 63	3500	5200	Mitchell+ 2007
Necklace	1100	2350	Corradi+2011
ETHOS 1	900	1750	Miszalski+2011

Jets in PNe

- Probably ejected by temporary (wobbly) accretion disk (during RLOF?)
- Ejection before main nebula
- No evidence *(yet?)* for ongoing accretion in PNe (no flickering)
- General lack of strong collimation, supporting precession
- jet speeds of 100-300 km/s common
- Excellent signposts to find new binaries!

Intermediate periods?

close binaries

Miszalski+09

De Marco+08

post-agb stars

Van Winckel (2003)

PNe??????????

HST resolved

Ciardullo+ 1999

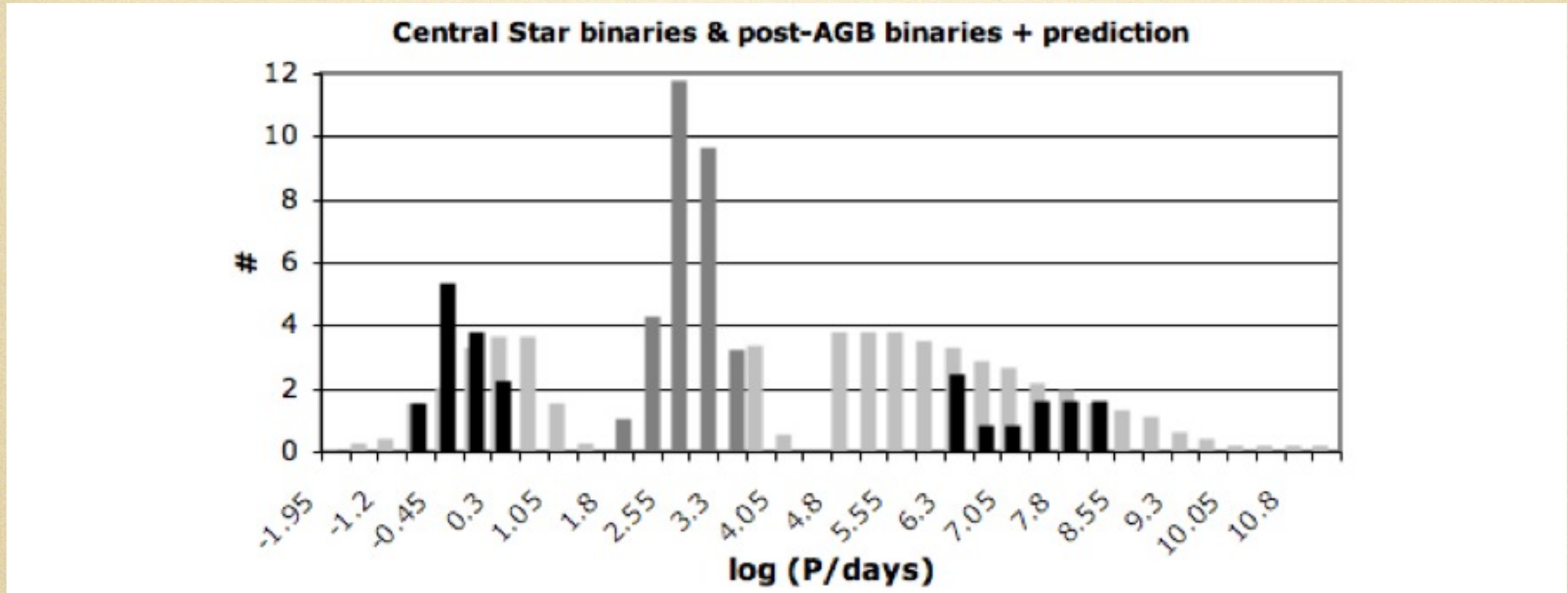
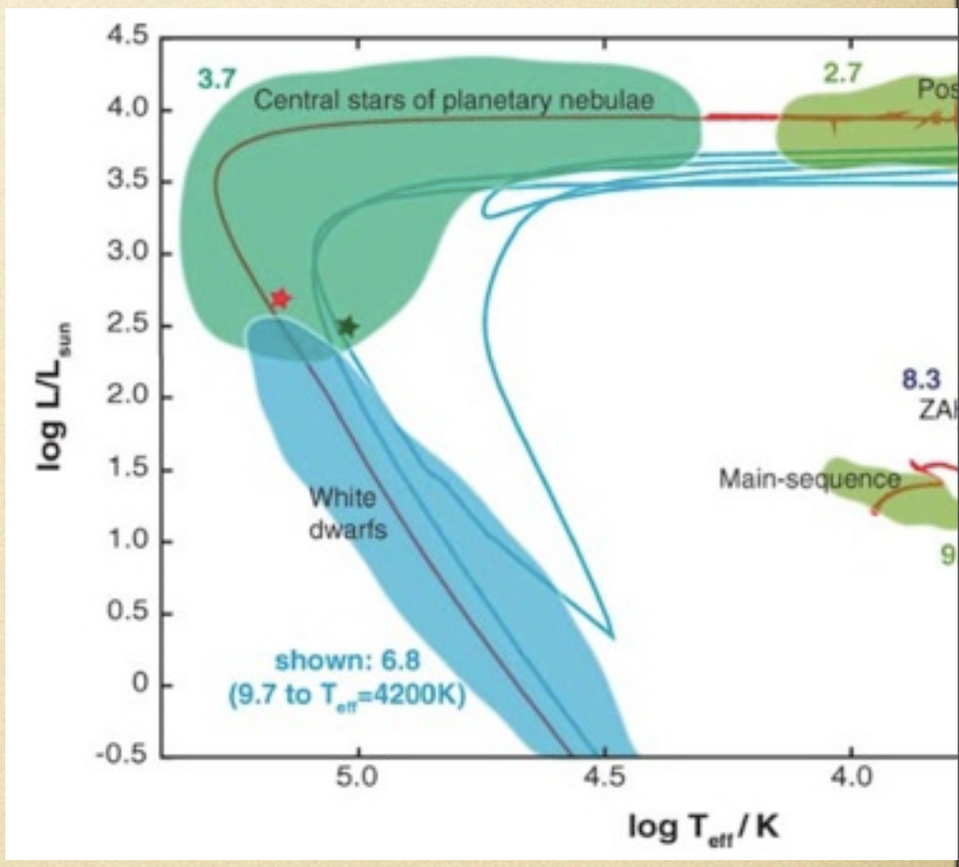


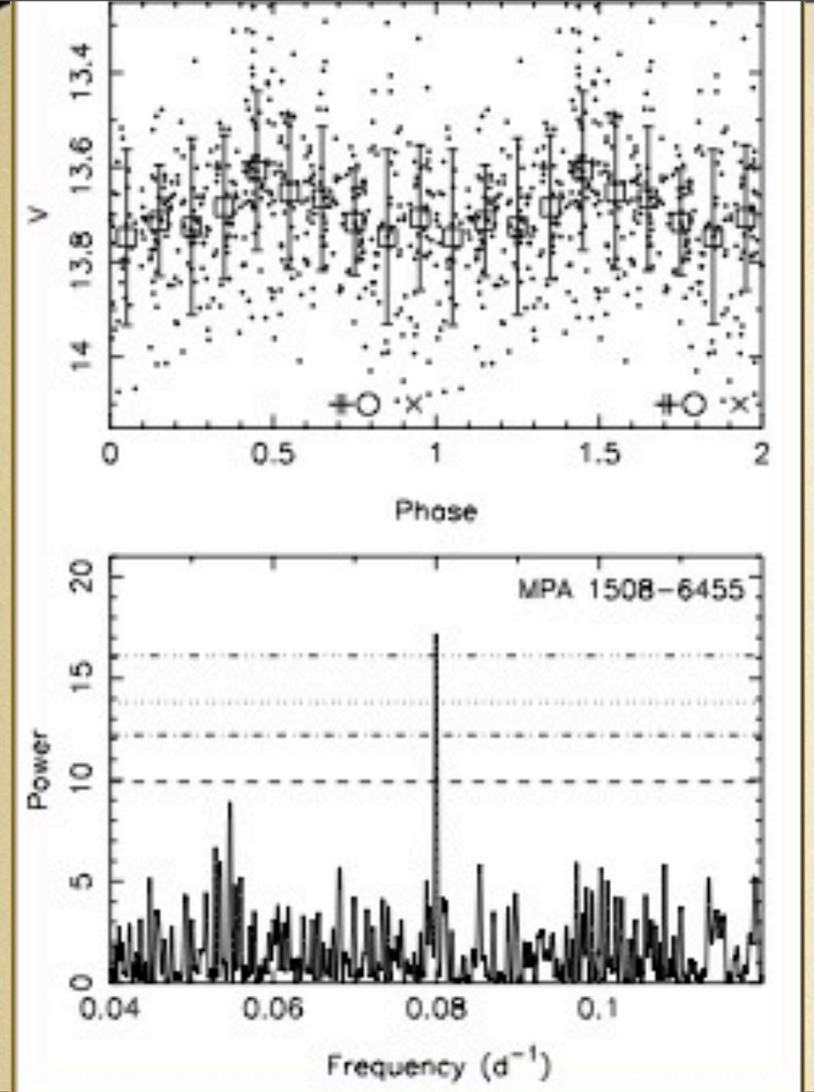
Figure 6. The central star of PN binary period distribution (black/burgondy), plotted along with the post-AGB binary period distribution (dark grey/dark orange) and compared with a preliminary prediction by Moe and De Marco (in preparation; light grey/blue).

De Marco, Farihi & Nordhaus 2009

How to find longer period binaries

- Subgiants and giants need more space in their orbit => longer periods
- Huge range in M_V in from -2 to +7 mag!
- Composite spectra can be found
  - Giants in most systems can be detected
  - Sub-giant or even MS in fainter systems

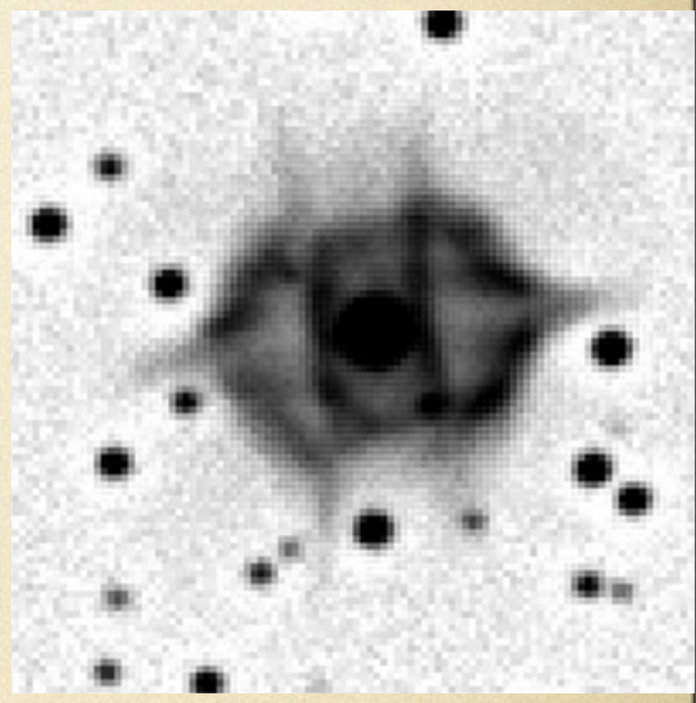


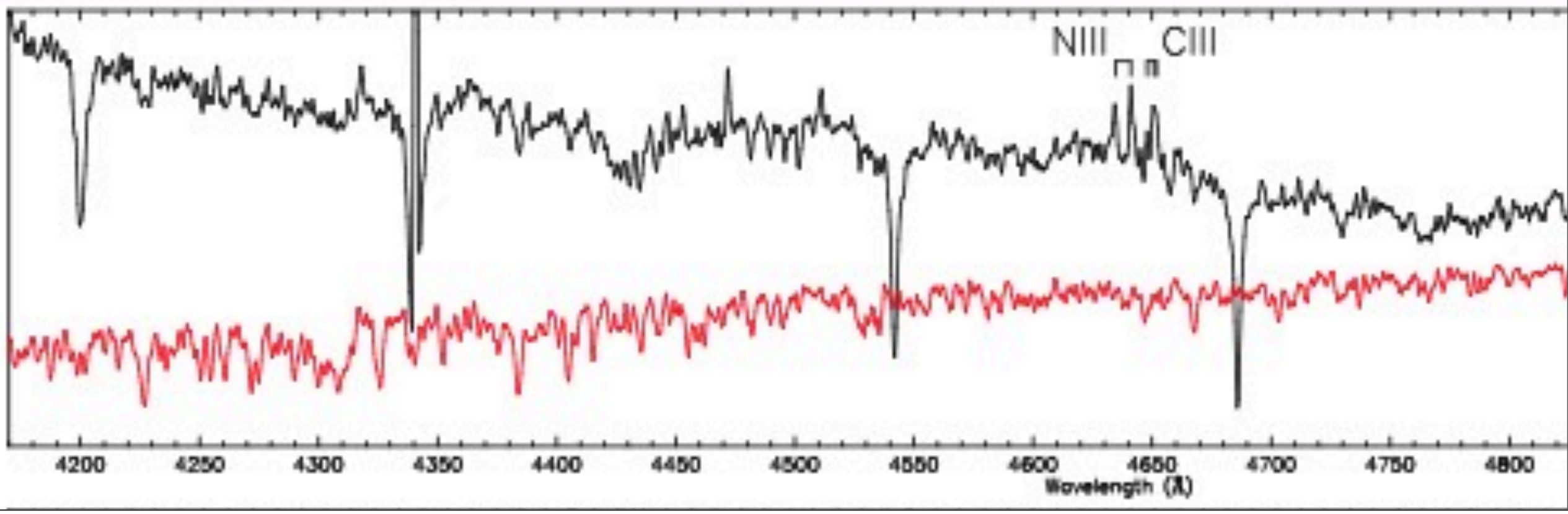


MPA1508-6455

ASAS lightcurve => P=12.5 d

Primary	**Secondary**
T~40kK	K giant
log g~4	
Mv~-1	





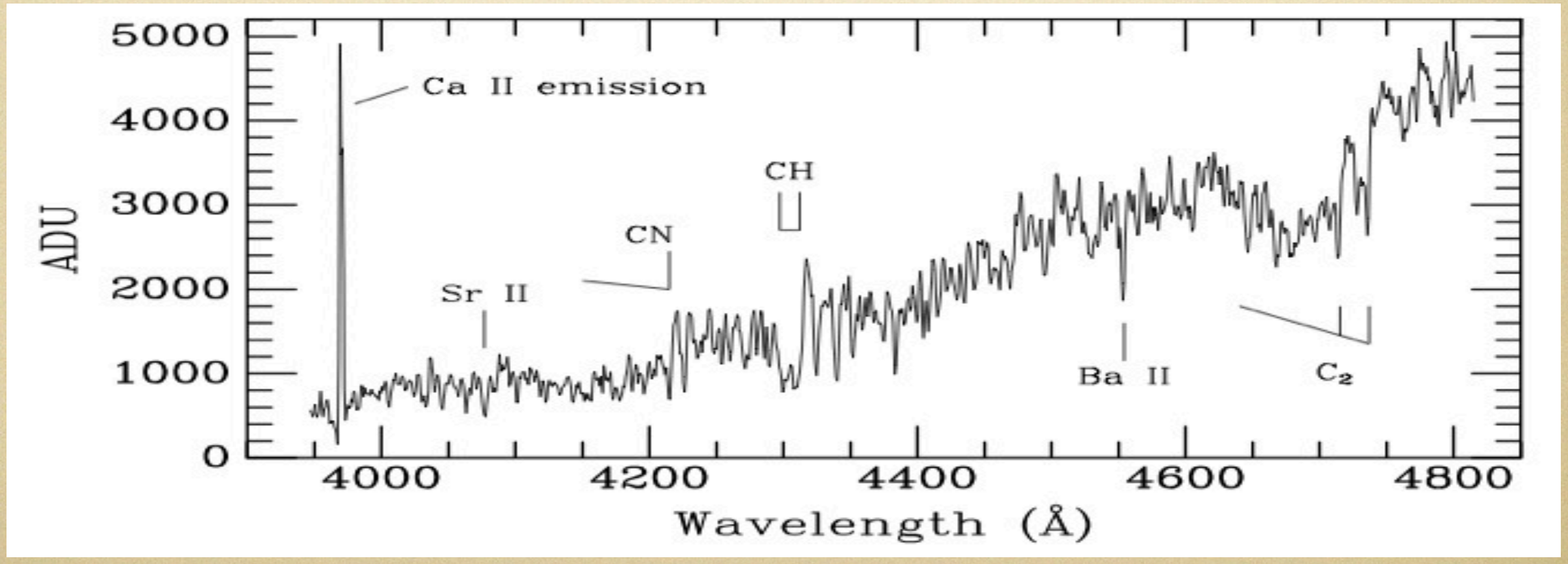
Barium central stars

- Barium stars: peculiar s-process enriched giants with white dwarf companions
- During AGB thermal pulses of primary dredge-up s-process and carbon rich material
- Wind accretion **pollutes** the companion, that then evolves to giant phase
- Left with WD, enriched companion and, **if lucky**, a planetary nebula from the WD

WeBo 1

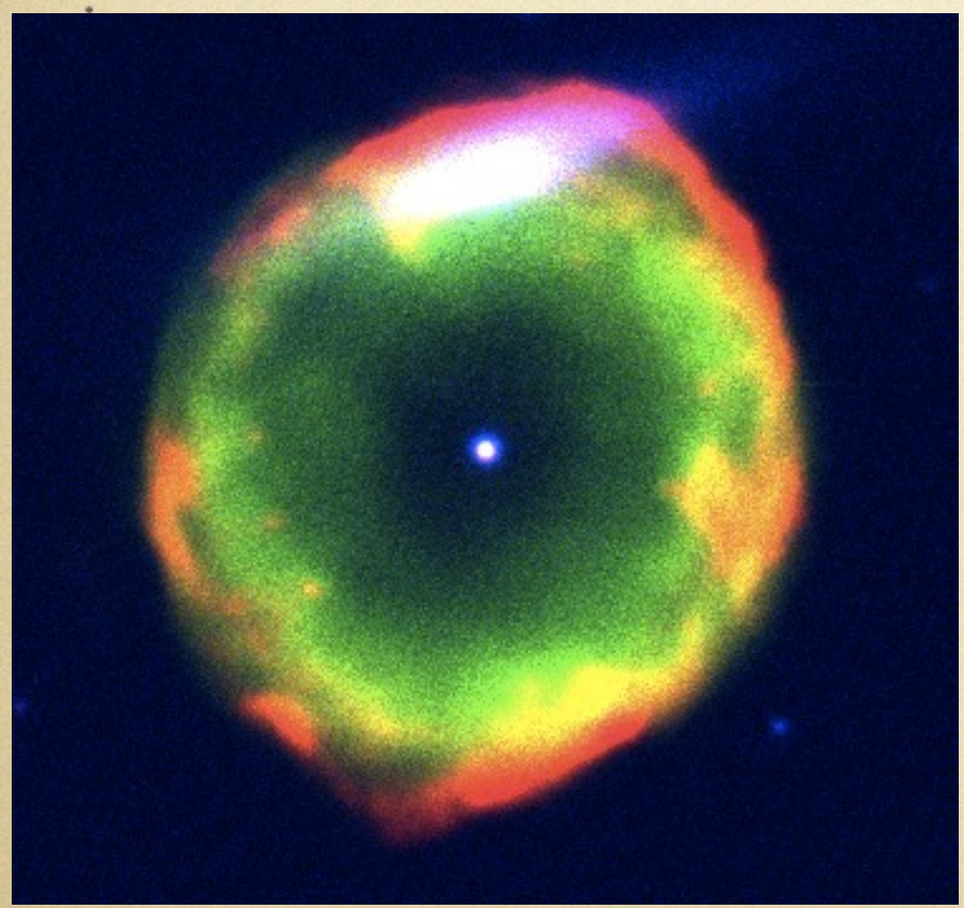
(Bond, Pollacco & Webbink+2003)

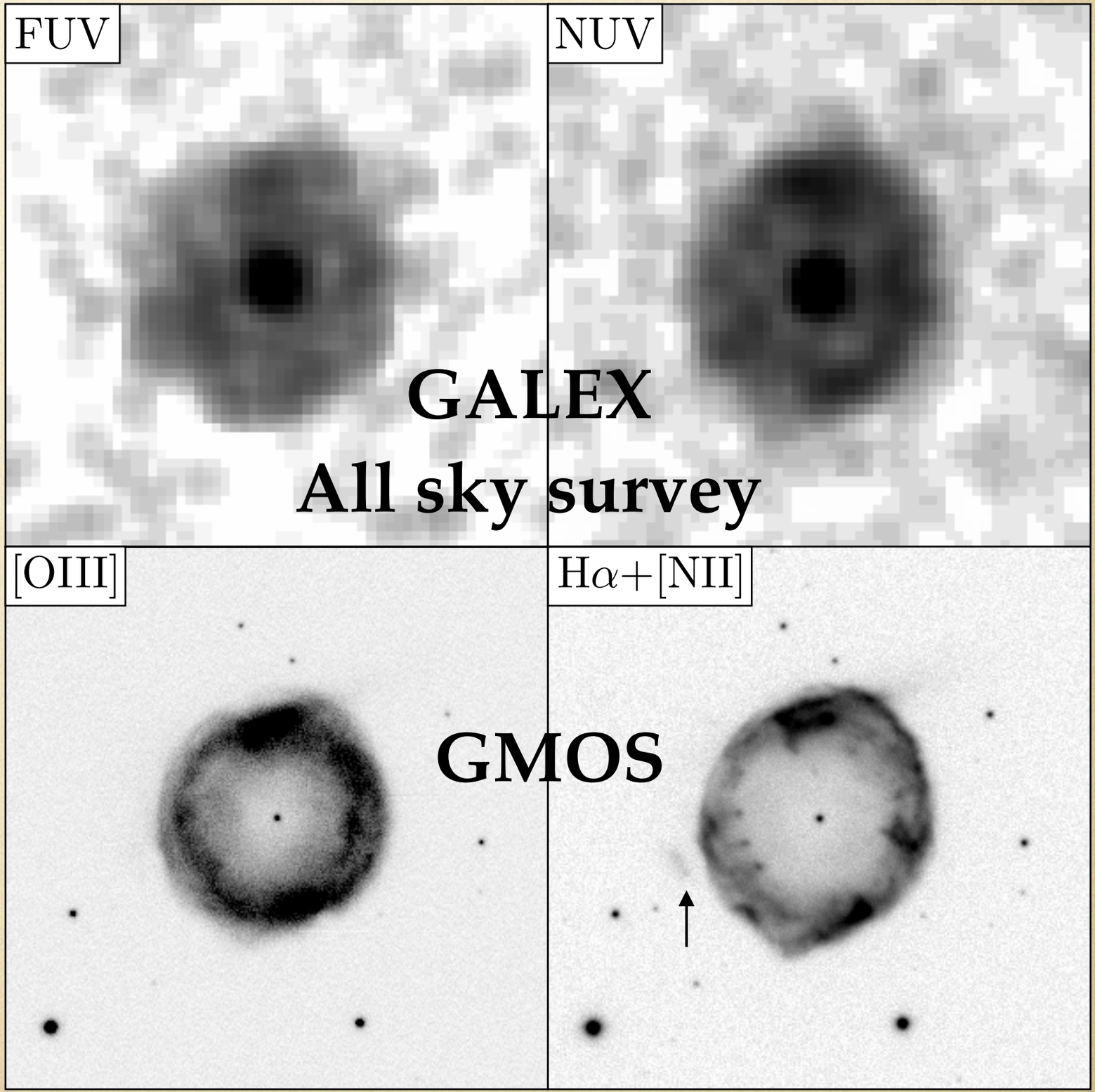
- K0III: p Ba5 ; chromospheric emission
- 4.7 day rotation period; sin i ~ 90 km/s
- Only four others: Abell 35, LoTr 1, LoTr 5 and...



Abell 70 (PN G038.1-25.4)

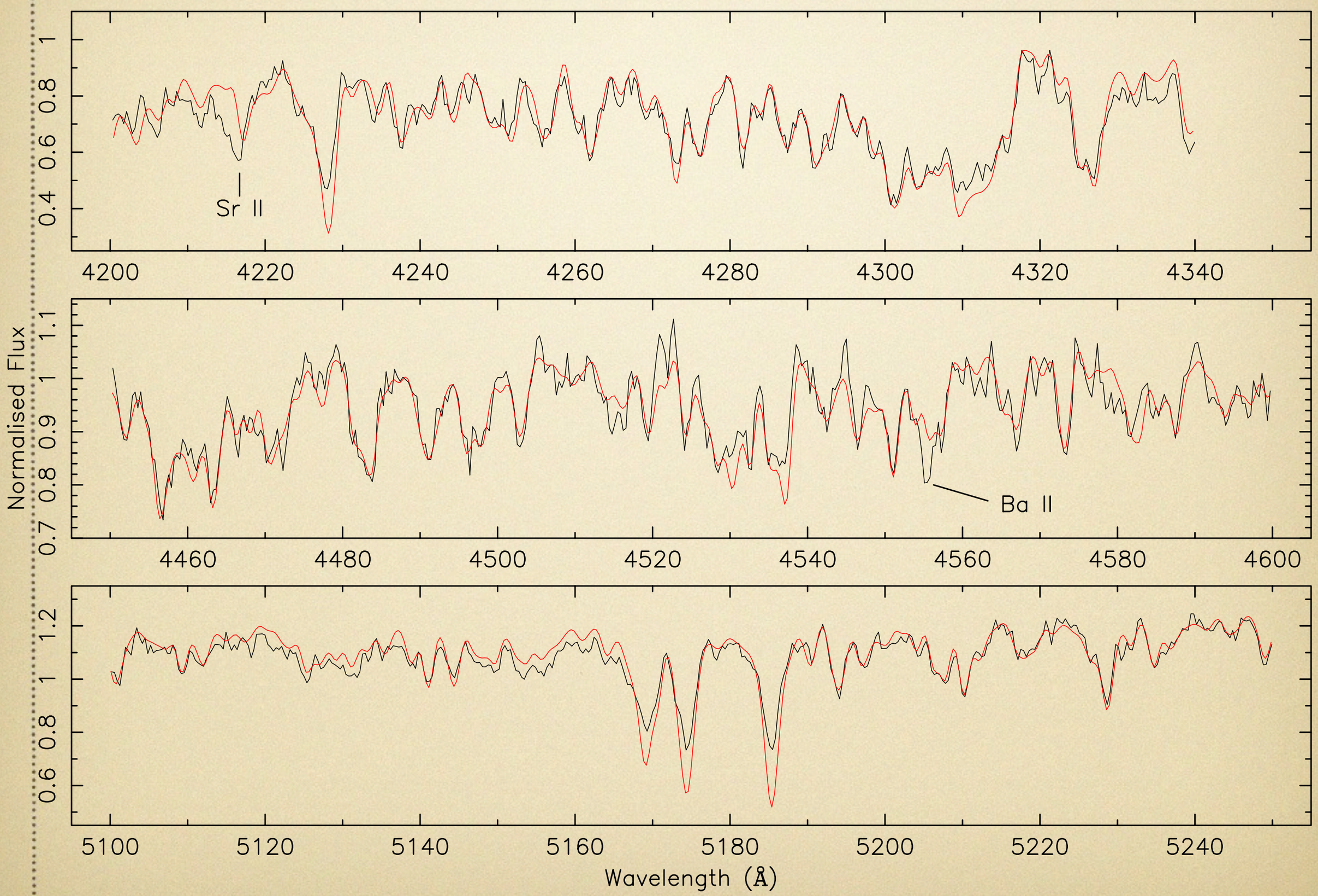
Miszalski, Boffin et al. MNRAS, submitted



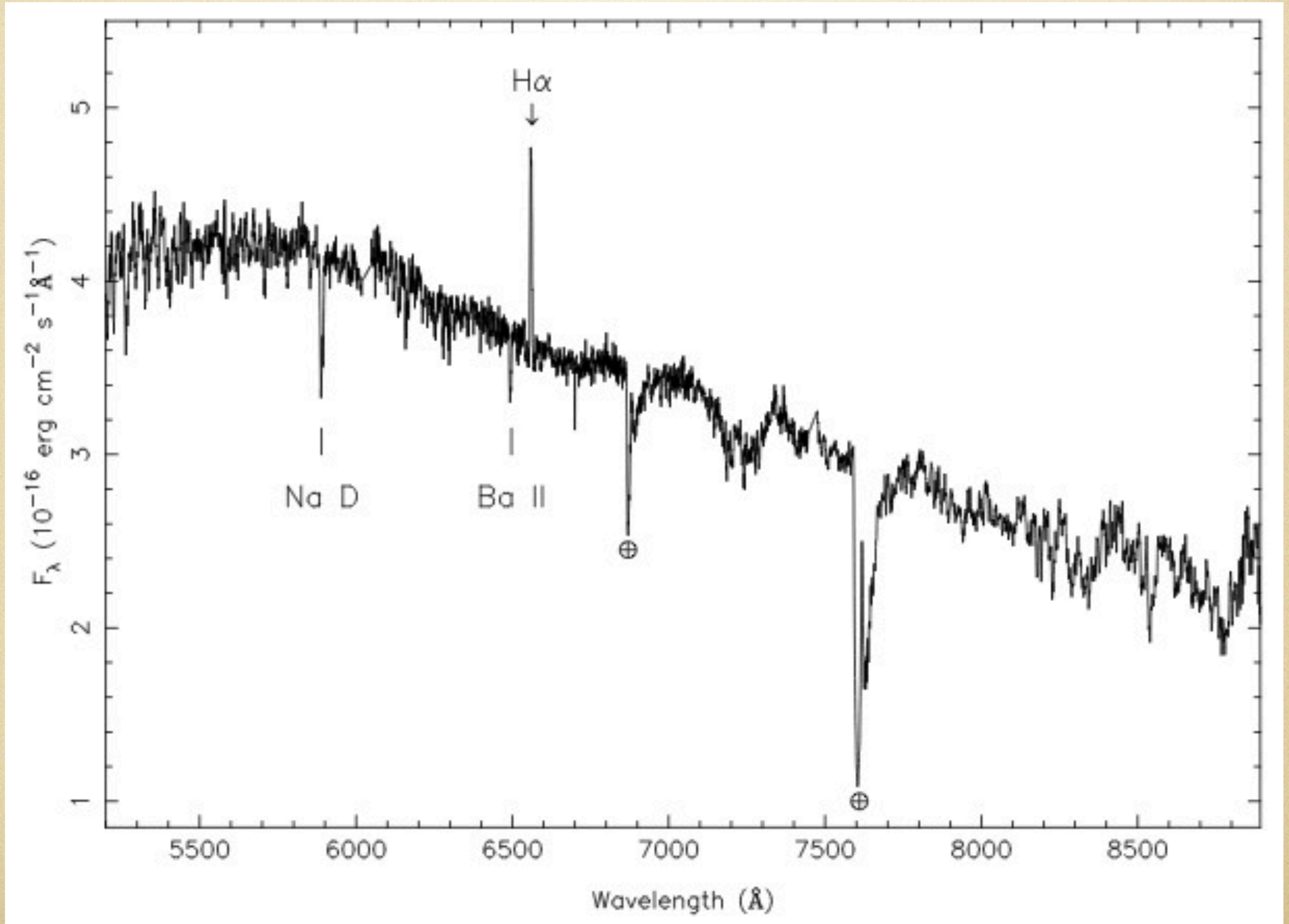


Abell 70 (VLT FORS)

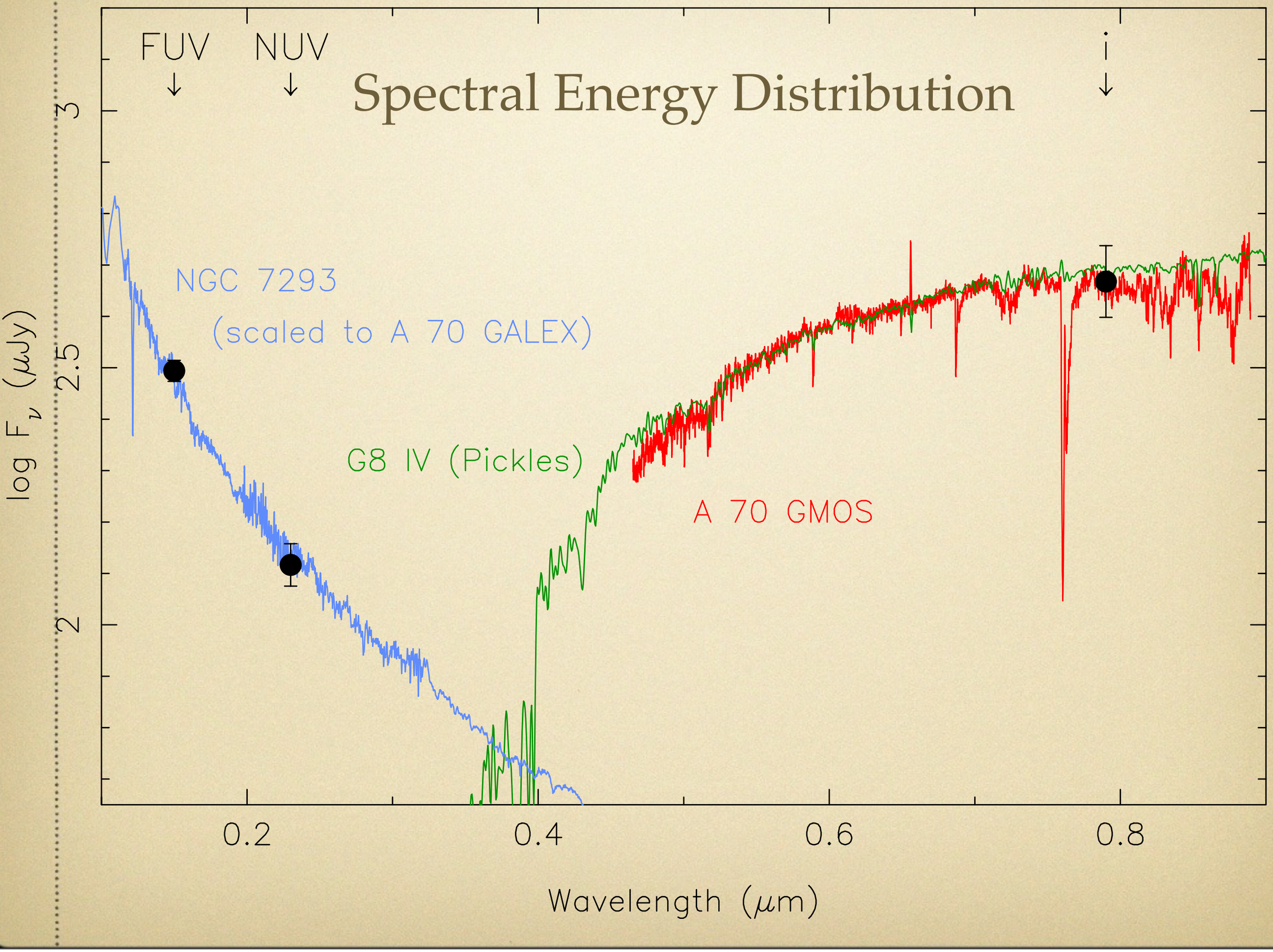
HD24616 (G8IV / V, UVESPOP)



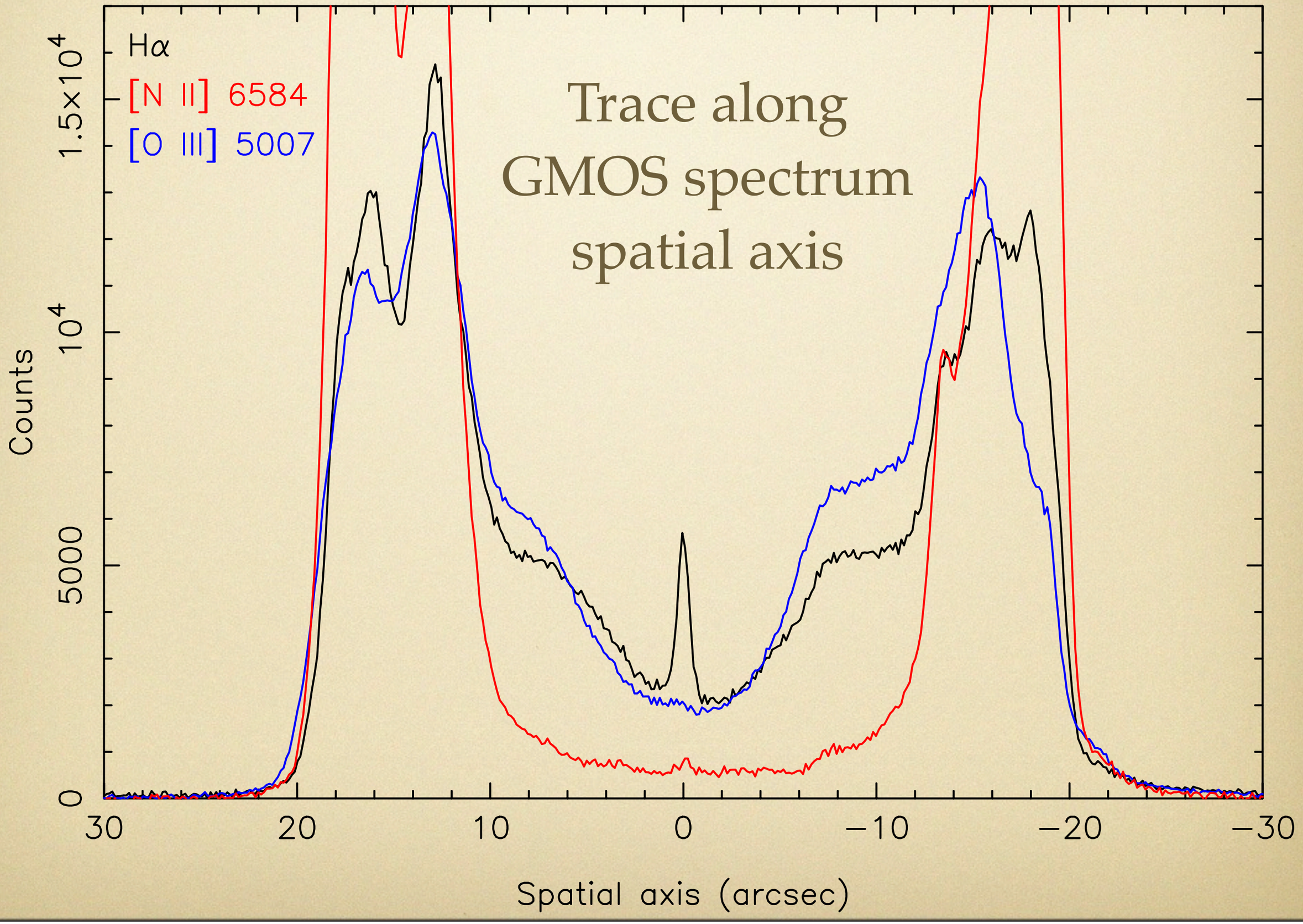
Abell 70 (GMOS)



Spectral Energy Distribution



Chromospheric Emission

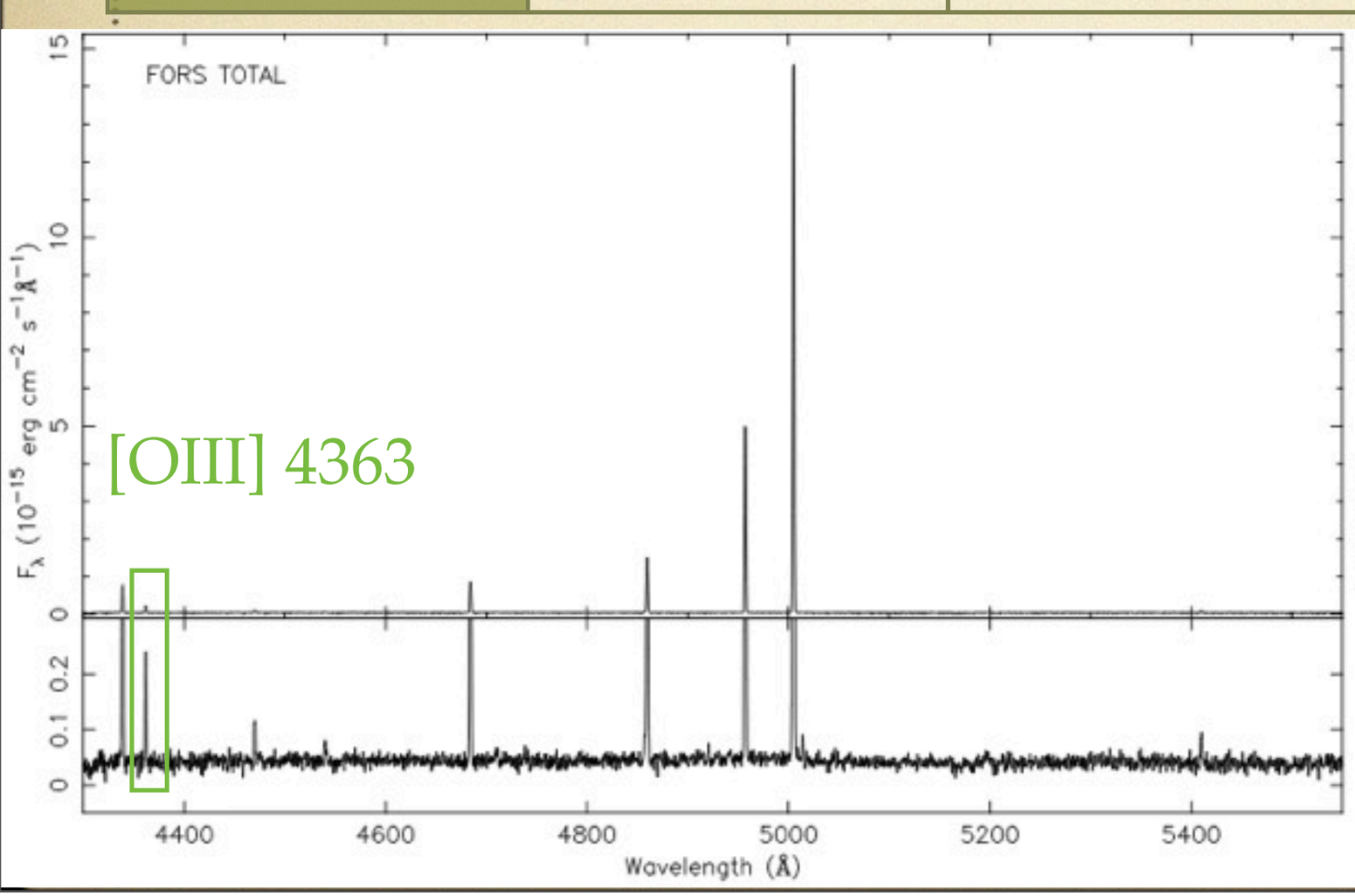


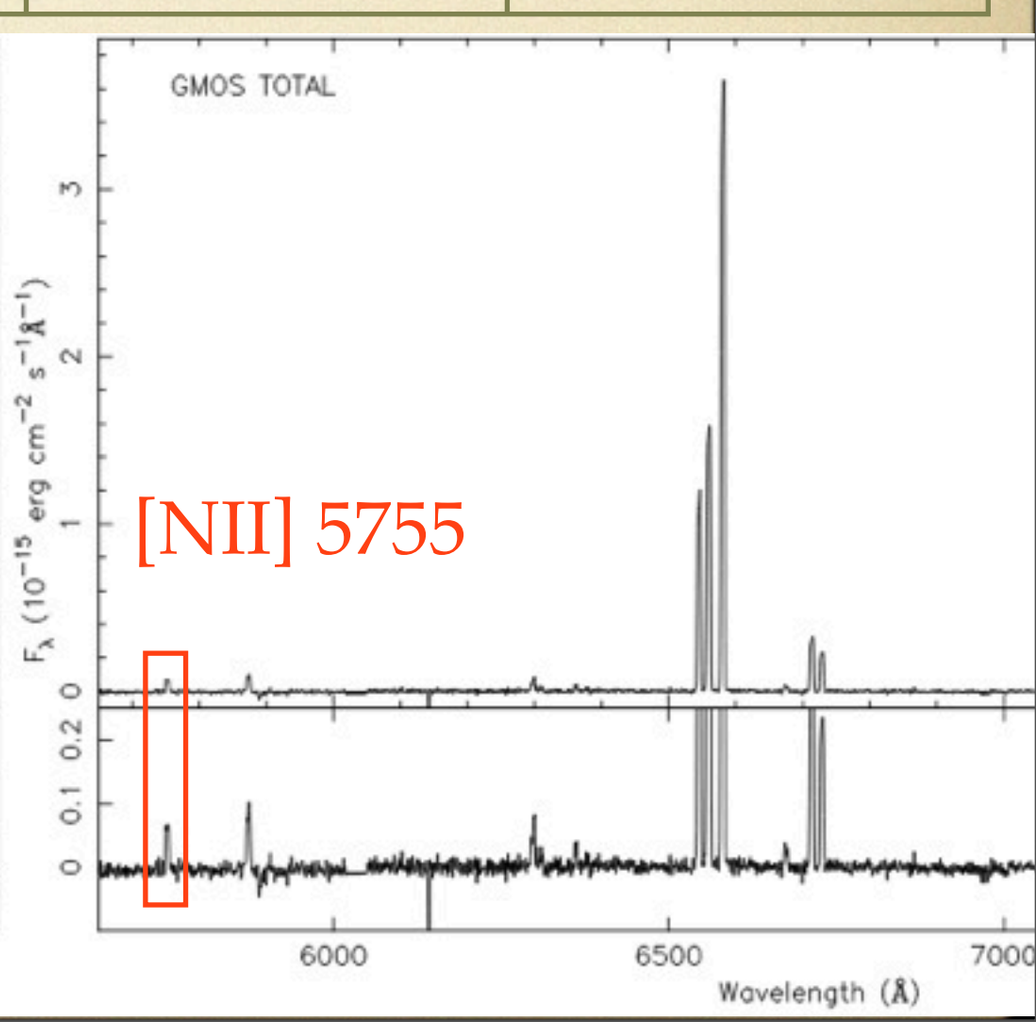
Radial velocities

Vneb=72.3±2.8 km/s

	MJD	Vhelio (km/s)	
GMOS	54944.83	-92.7±1.7	
FORS 2009	55026.40	-66.7±17.9	bad S/N
FORS 2010A	55364.41	-68.6±7.9	**consistent with no orbital motion above 8 km/s**
FORS2010B	55366.4	-69.6±8.0	

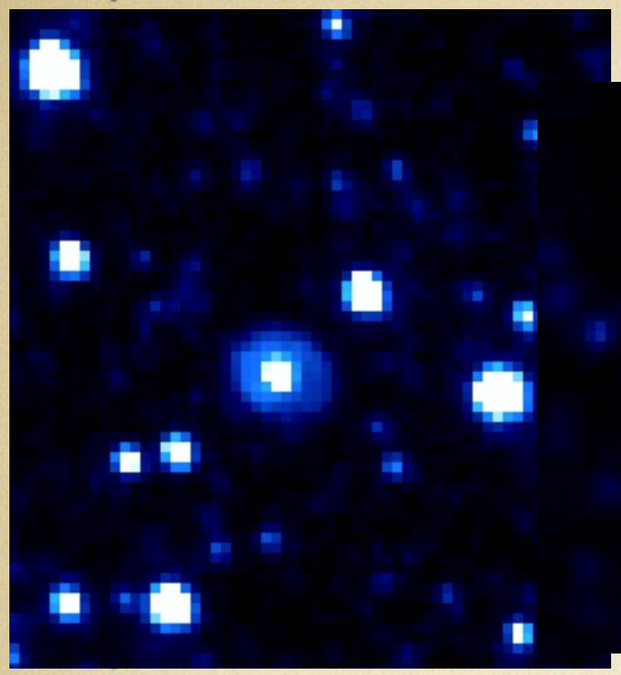
	Abell 70	Type I	non-Type I	Solar
Te(NII) [K]	12400+- 200			
Te(OIII) [K]	13200+- 200			
He	**11.28**	**11.11**	11.05	10.93
N	8.68	8.72	8.14	7.78
O	8.43	8.65	8.69	8.66
N/O	**0.25**	**0.07**	-0.55	-0.88



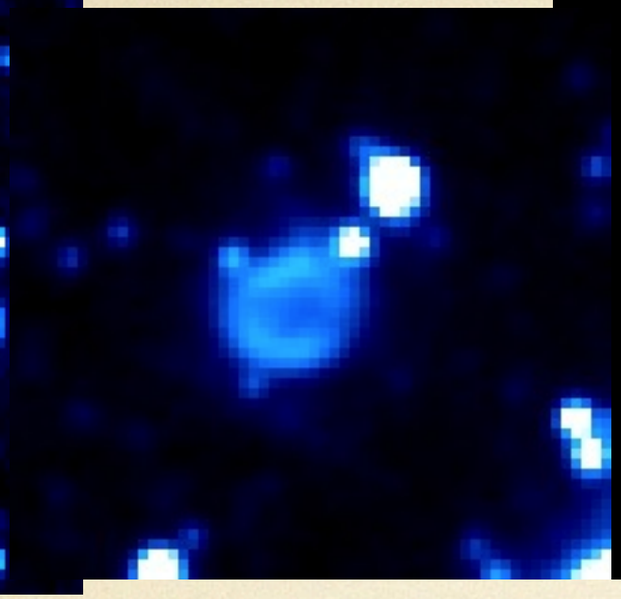


VVV and PNe

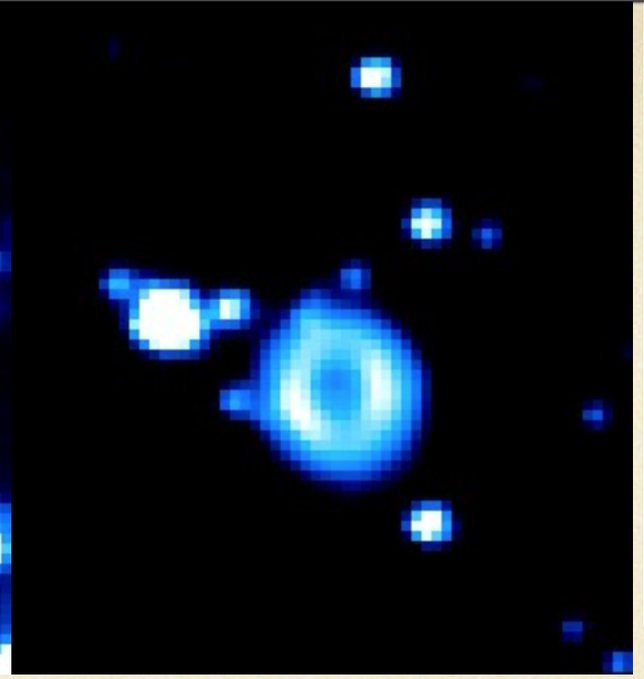
- Ks lightcurves!! (as survey progresses)
- Flag Ks variables for small telescope followup
- Nebula morphology
- Central star magnitudes with VPHAS+ => NIR excess to white dwarfs (wider binaries)
- Unusual or individual object followup



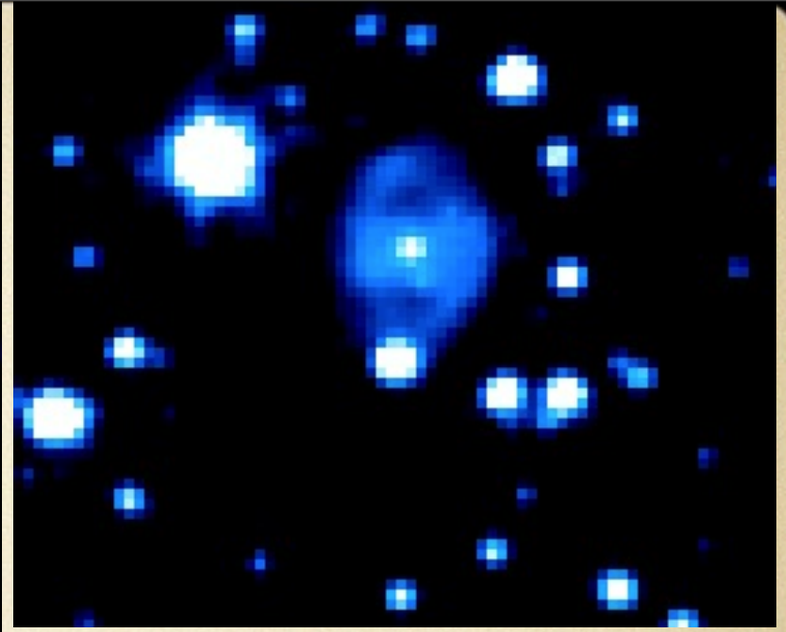
H2-17



Hen2-81



Hb6

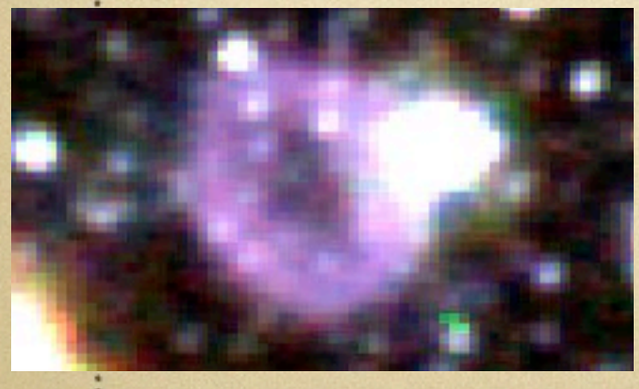


PHR1801-2522

Hen2-85

VVV Ks images

NGC6565



M2-30

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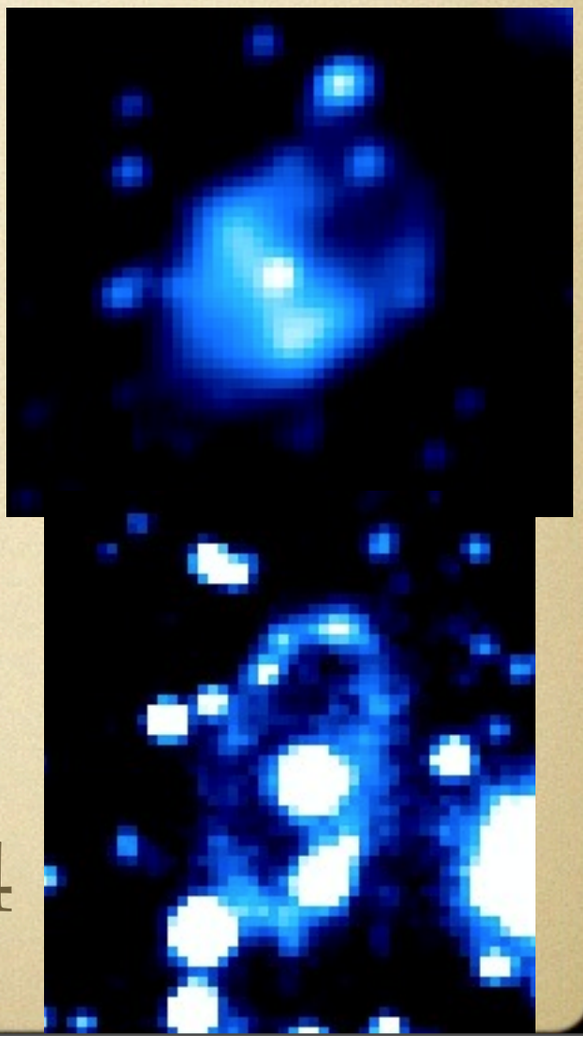
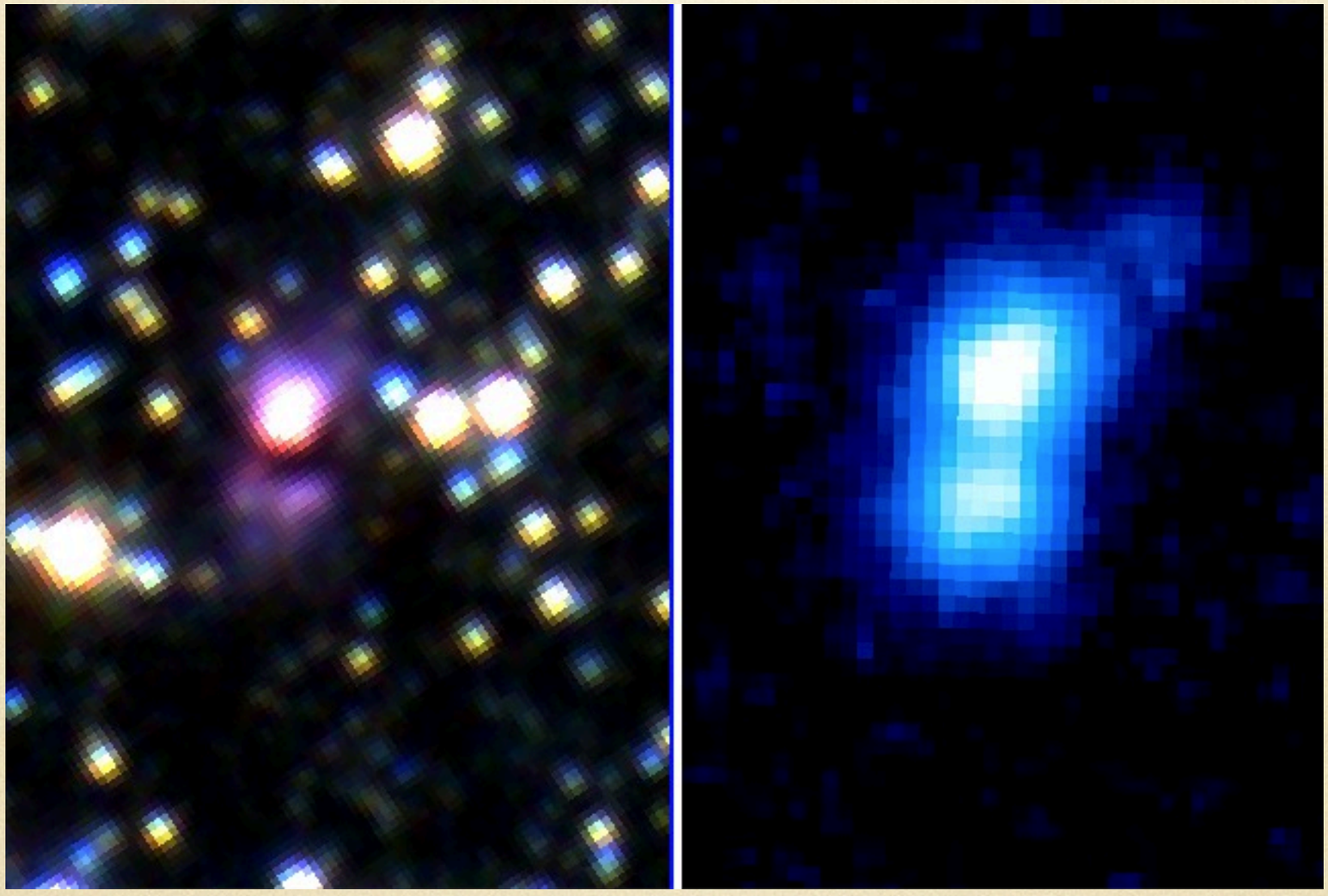


MPA1729-3513

VVV



Halpha

highly obscured torus

Recent onset of ionisation?

VPHAS+

- Superior resolution over photographic SuperCOSMOS Halpha Survey
- Limited scope for new PN discoveries (SHS already thoroughly searched for new PN)
- May reveal more SN1987A rings (e.g. Necklace)
- Will provide excellent resource to ID **blue** central stars => needed to revise binary fraction estimates in conjunction with OGLE-III/IV and VVV results