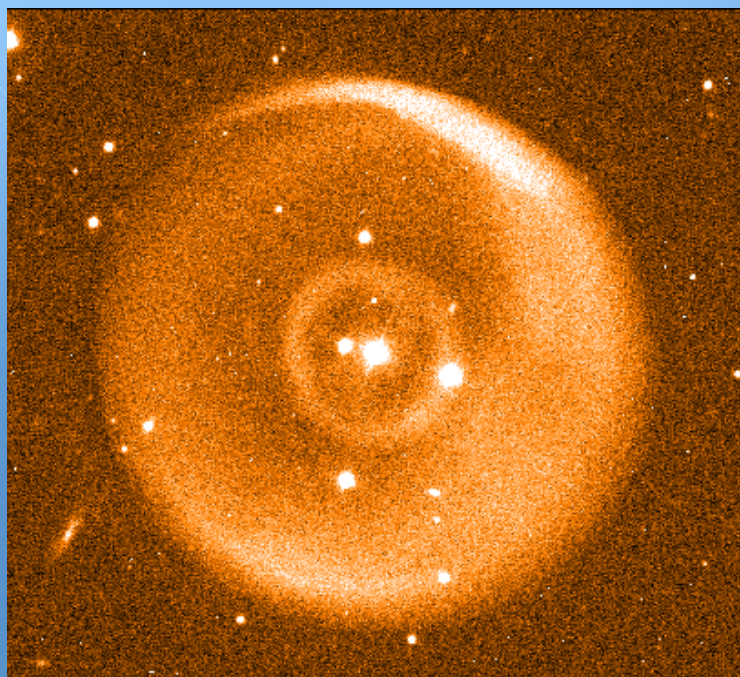


## Giant and Dwarfs:

### The Binary Central Stars of PN LoTr 1



Amy Tyndall

Henri Boffin (ESO)

Dave Jones (ESO)

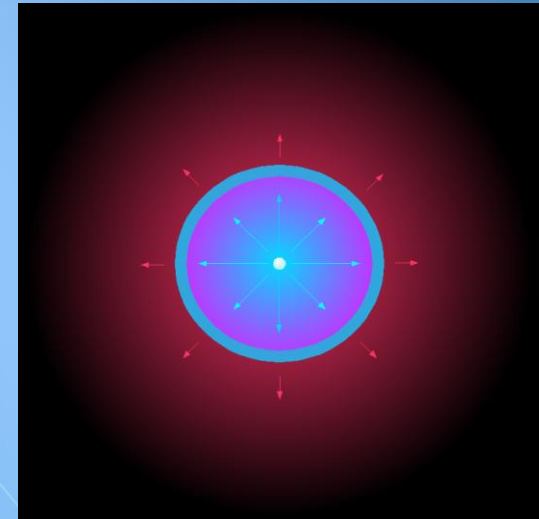
## Contents

- Introduction
- PNe and intermediate-period binary systems
- Stellar photometry and spectroscopy of LoTr 1
- Nebular spectroscopy of LoTr 1, Abell 70, and WeBo 1
- Summary



## PNe and Binary Systems

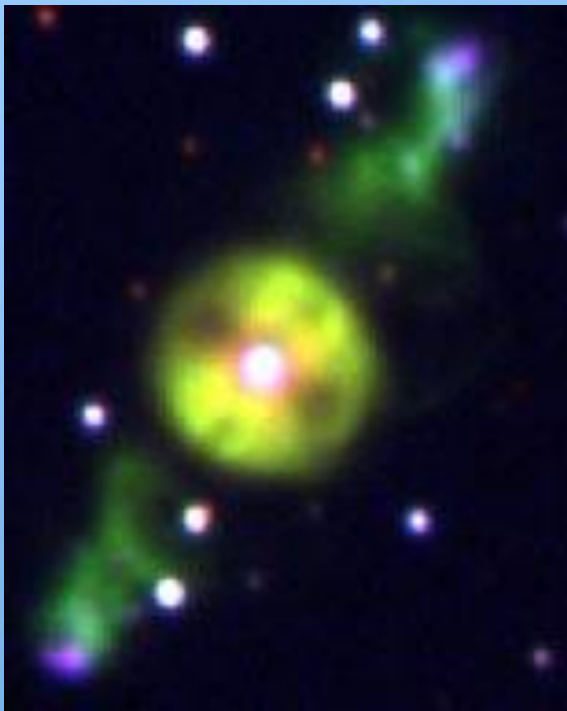
- Ionised shell of gas emitted at end of star's life
- Formed as Red Giant ---> White Dwarf
- $0.5M_{\odot} < M_{\odot} < 8M_{\odot}$



Abell 39

- PNe are shaped by a 'snow-plow' process (Kwok et al. 1978)
- Inherently isotropic winds – spherical PNe
- Disc-like circumstellar envelope -- axisymmetric winds form pair of expanding bubbles to create bipolar shapes

- Need heavy anisotropy to create asphericity
- Binaries!



ETHOS 1

(Miszalski et al., 2011)



'The Necklace', PN G054.2-03.4

(Corradi et al., 2011)



## The 'Abell-35 Group'... Or is it?

- All binaries, with a cool component (rapidly-rotating G/K-type giant), and a hot component (optically-faint white dwarf).
- All show evidence of enhanced Ba II abundances. (*McClure et al. 1983*)
- Cool components are rapid rotators -- rotation periods of a few days.



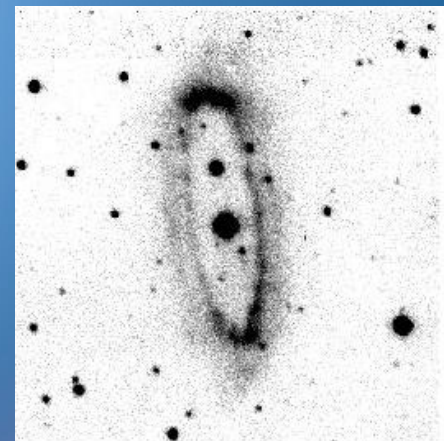
Abell 35



LoTr 5



Abell 70



WeBo 1

- BUT! A35... Not a true PN! (*Ziegler et al. 2012*)

## PN Mimics

- A35 central star – low mass, low luminosity. Ejected matter and surrounding PN dissipated in time taken to evolve off AGB.
- Therefore, A35 actually a low-mass HII region possessing AGB-Manqué star (direct EHB  $\rightarrow$  WD phase). (Ziegler *et al.* 2012)
- K 1-6 – similar morphology to A35, but is highly-evolved stratified PN (Frew *et al.* 2011)
- Need to ensure other mimics aren't misclassified as PN!

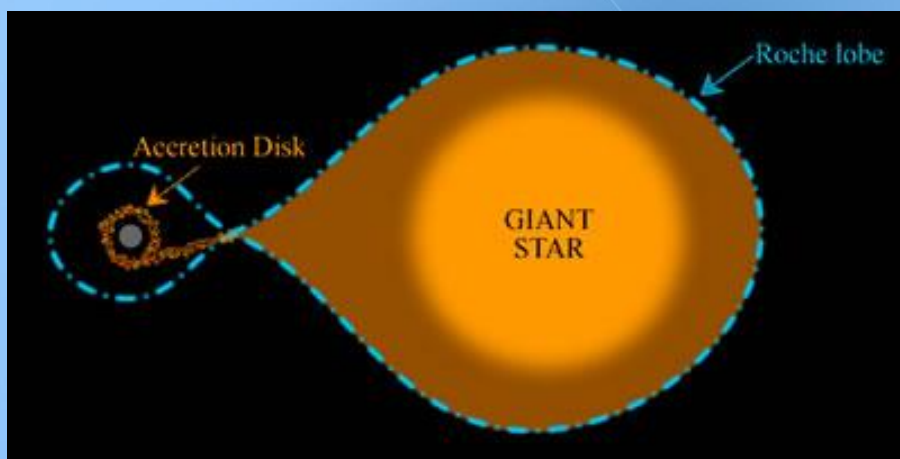


Abell 35

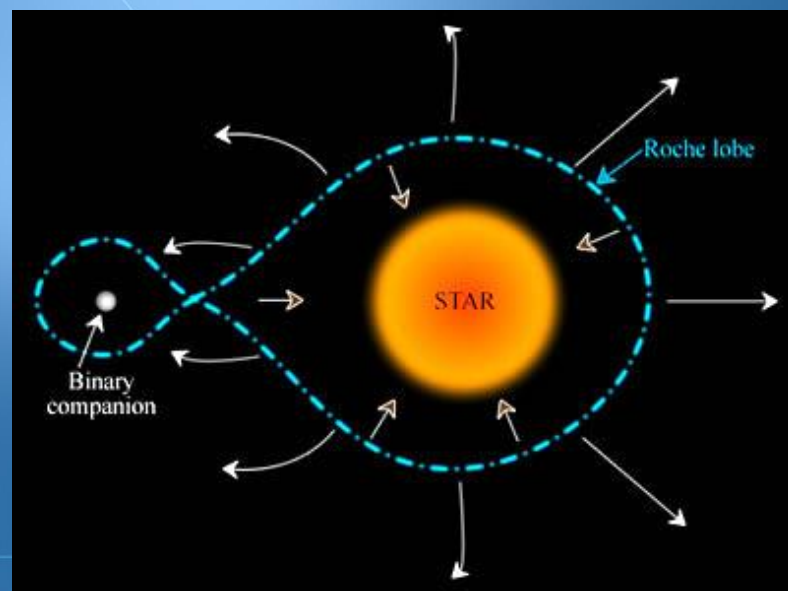


K 1-6

- Wind-accretion scenario for formation -- Star polluted on main sequence by AGB-companion wind, contaminated with s-process elements during thermally pulsing AGB phase...  
\*\* BARIUM STAR! \*\* (Boffin & Jorissen, 1988)
- Common envelope phase on tip of AGB – weakly bound envelope. Progenitor evolves to WD, companion evolves through giant phase and remains polluted.



Close binaries



Wider binaries

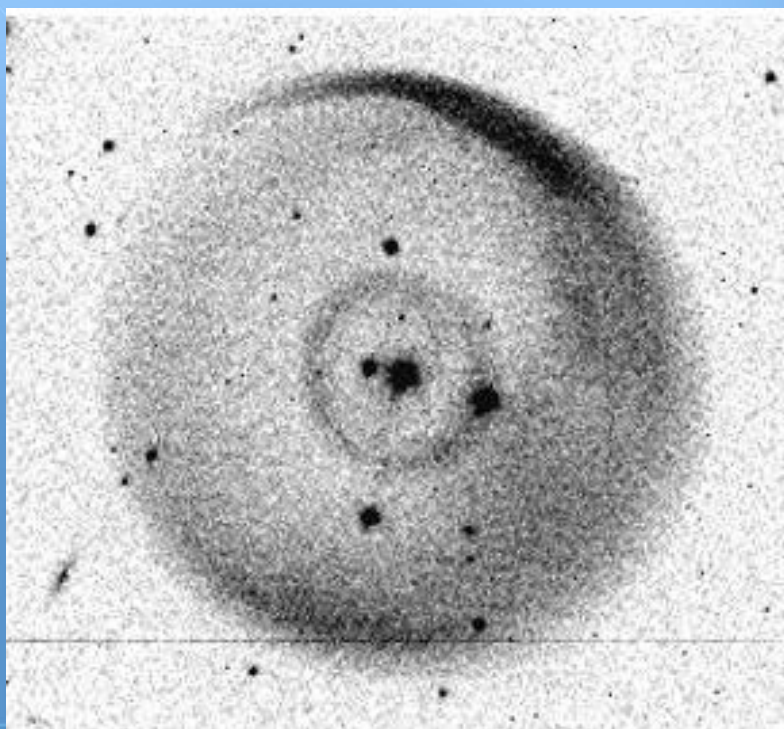
- Accretion of angular momentum – rapid rotator



# LoTr 1

Why pick LoTr 1?

- Believed to have intermediate-period binary at centre with a cool component
- Want to prove the binary nature of LoTr 1, and look for Ba II

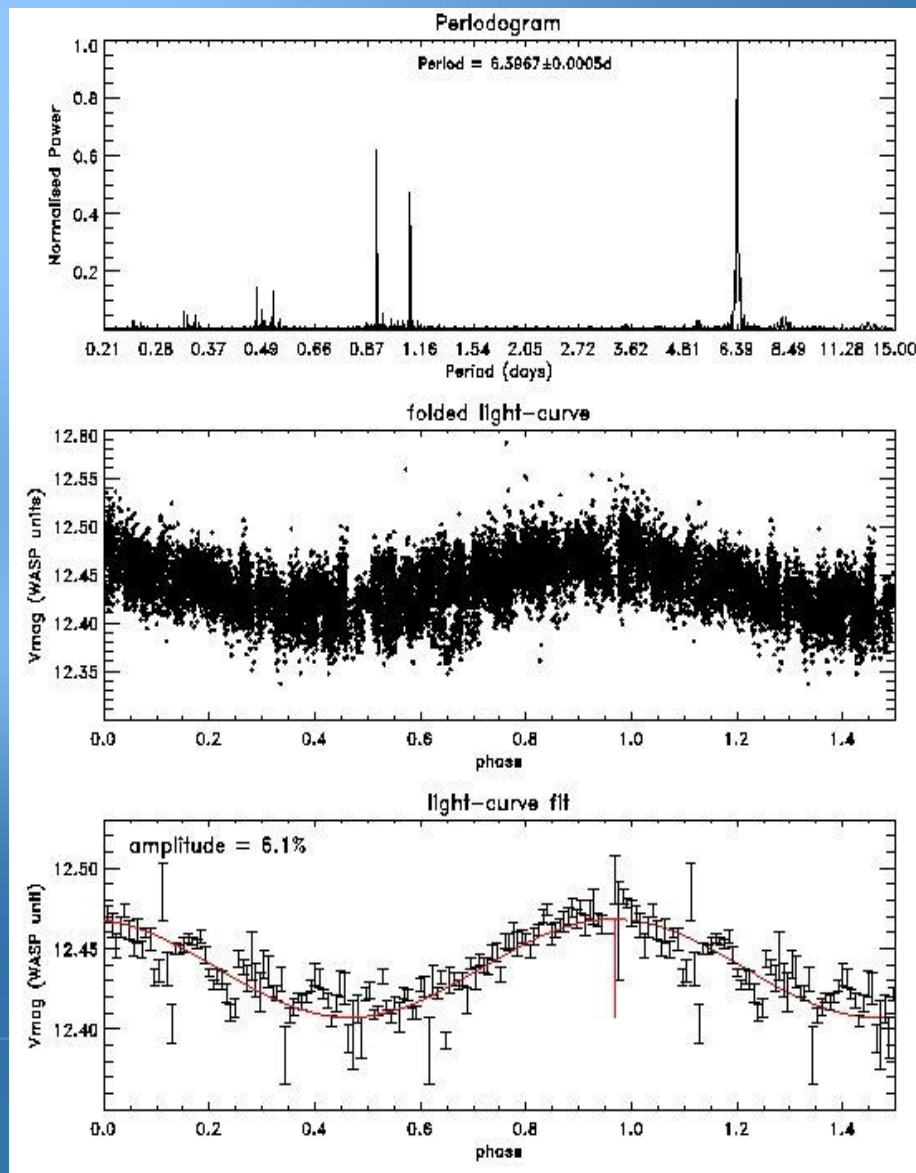


LoTr 1

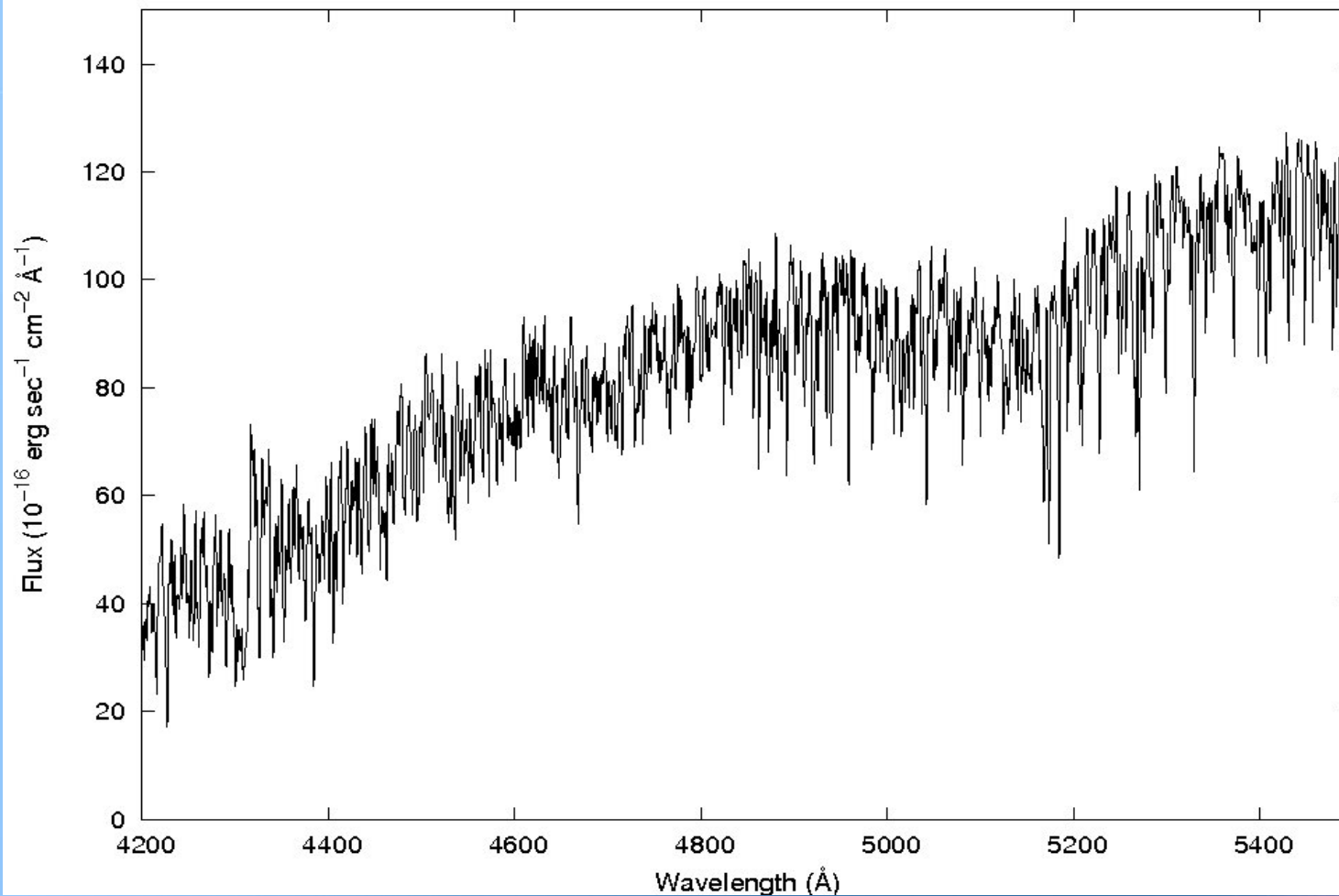
NTT-EMMI, [OIII]5007Å, 1800s



- WASP photometry:  $P = 6.4$  days,  $= 0.061$  mag  
(Jones et al., APN V conference proceedings, 2011)
- Spots on a cool star ... signature of a rapid-rotator  
(De Marco, 2006)



# Spectroscopy



VLT-FORS2

K1-III giant

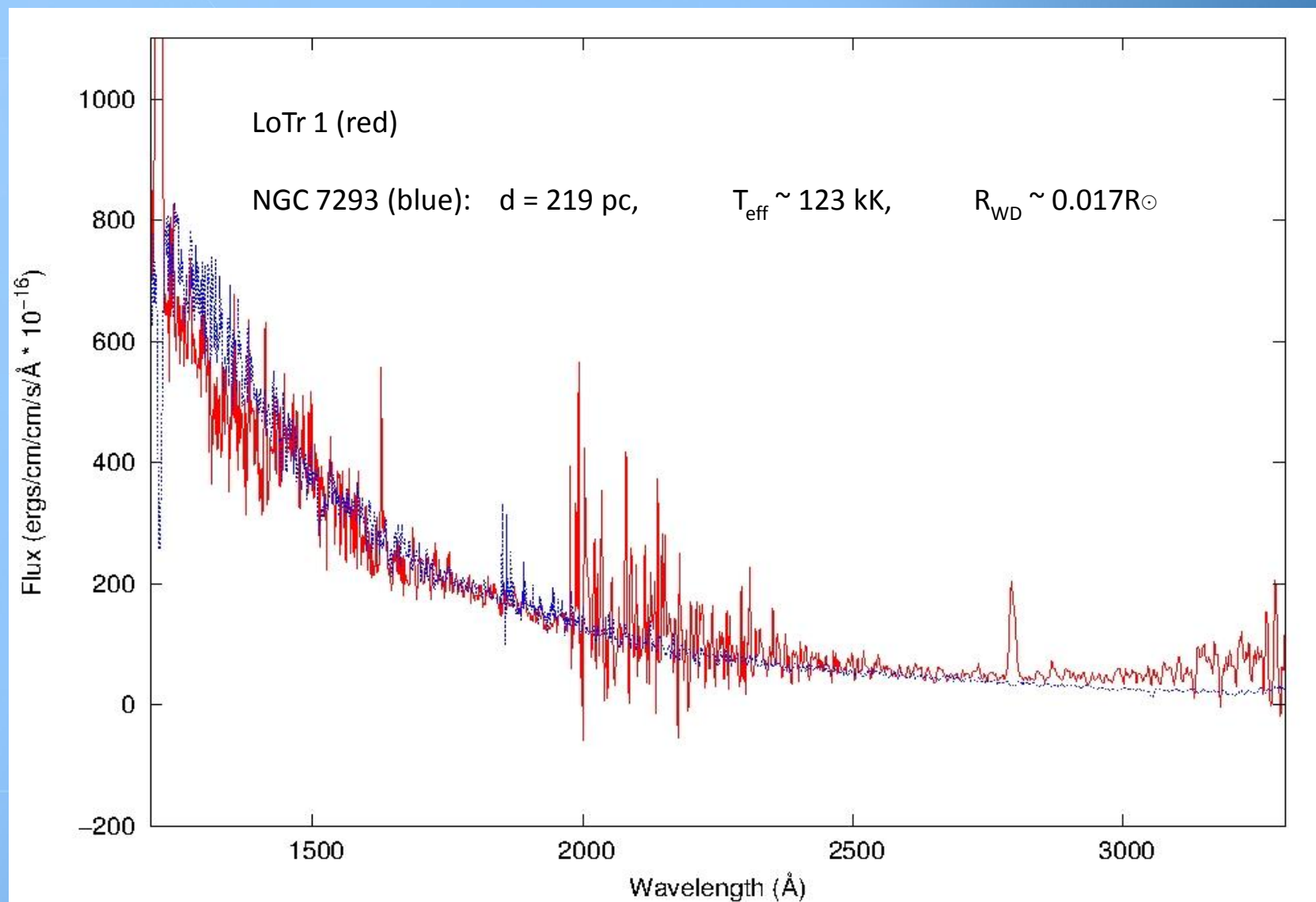
$d = 1.9$  kpc

- Cross-correlation of FORS2 spectrum with synthetic spectrum.

-- RV  $\sim 0$  km/s w.r.t nebular lines... Wide binary orbit

- IUE observations -- strong UV continuum

Hot, unresolved companion  
(Bond et al. 1993)





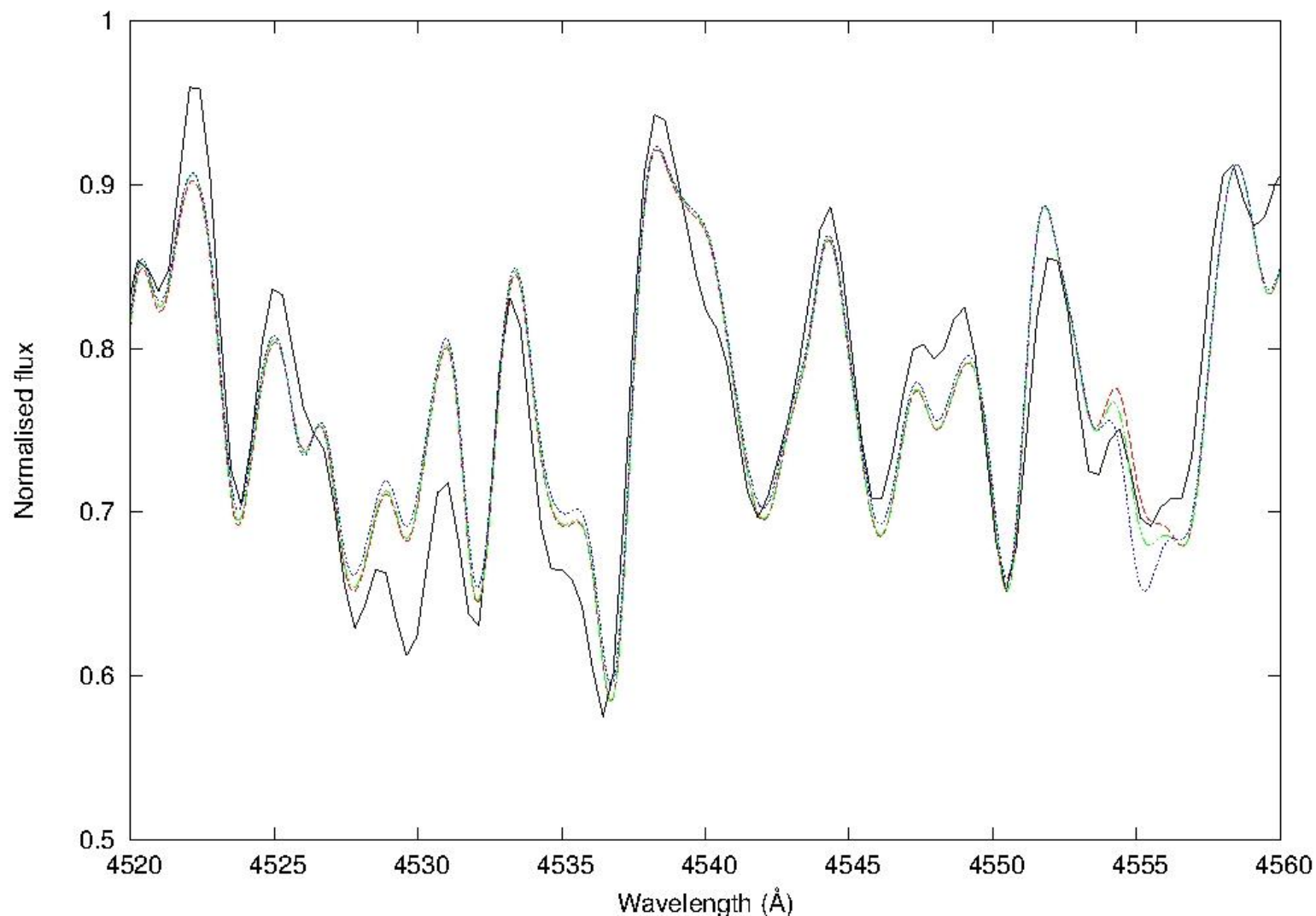
FORS2 + synthetic

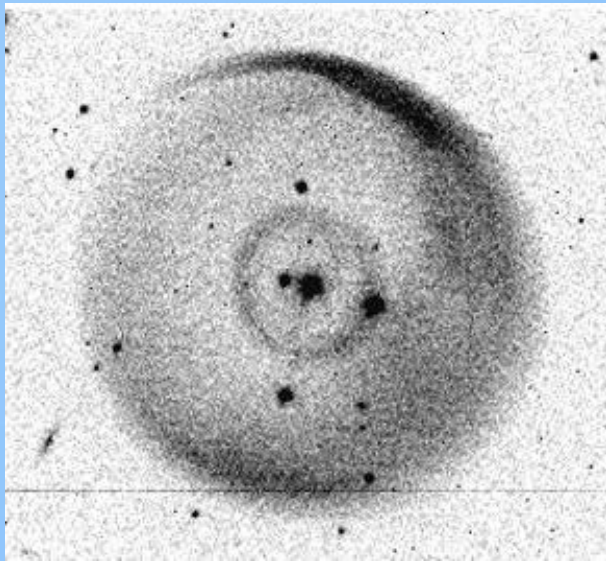
FORS2/LoTr1  
**black**

Solar abundances  
**red**

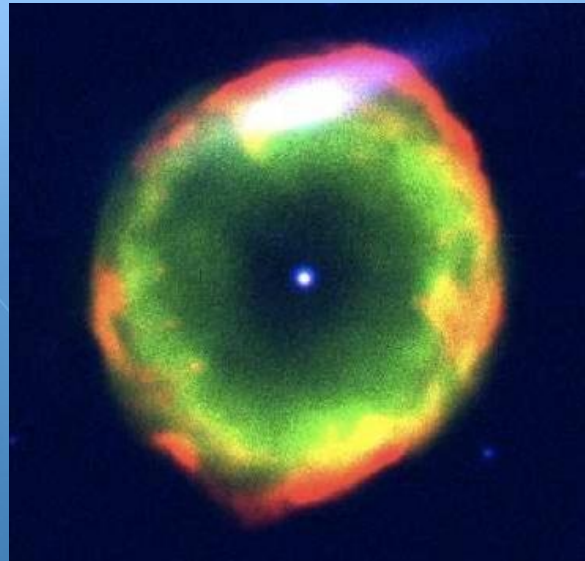
$[Ba/Fe] = 0.2$   
**green**

$[Ba/Fe] = 0.5$   
**blue**

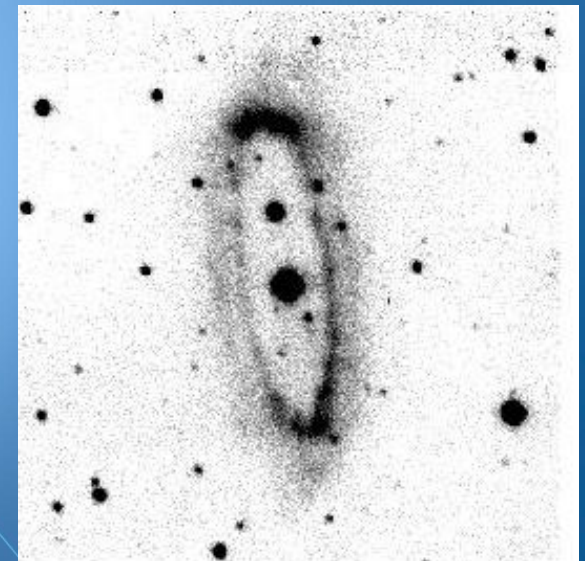




LoTr 1



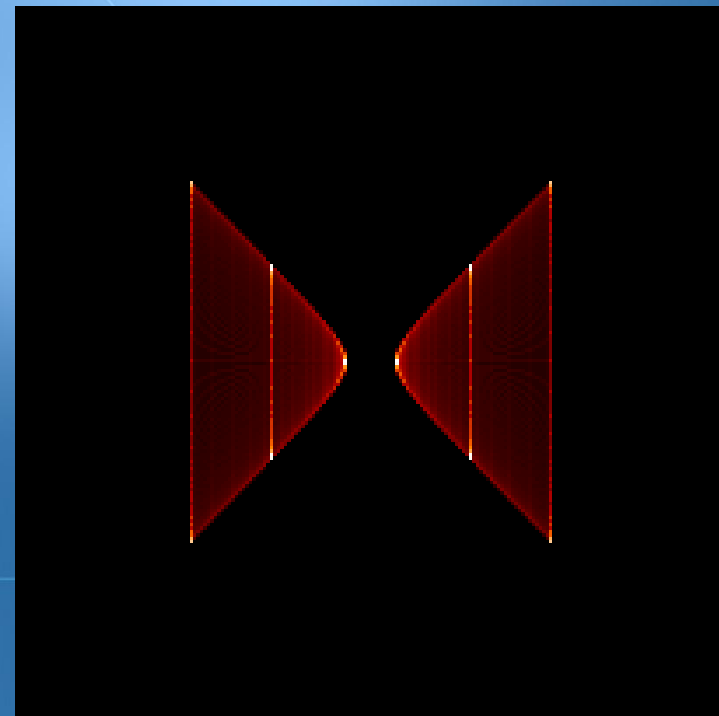
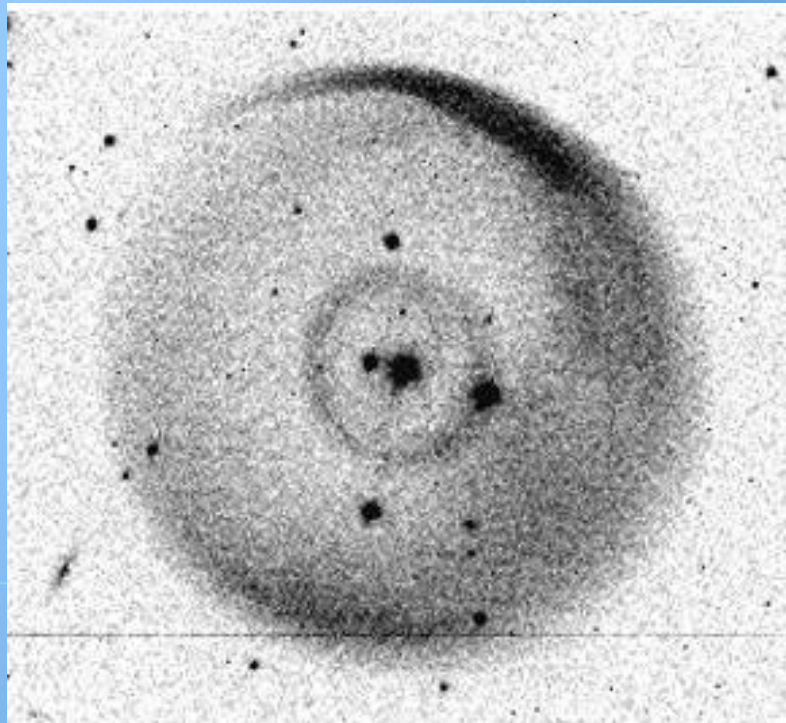
Abell 70



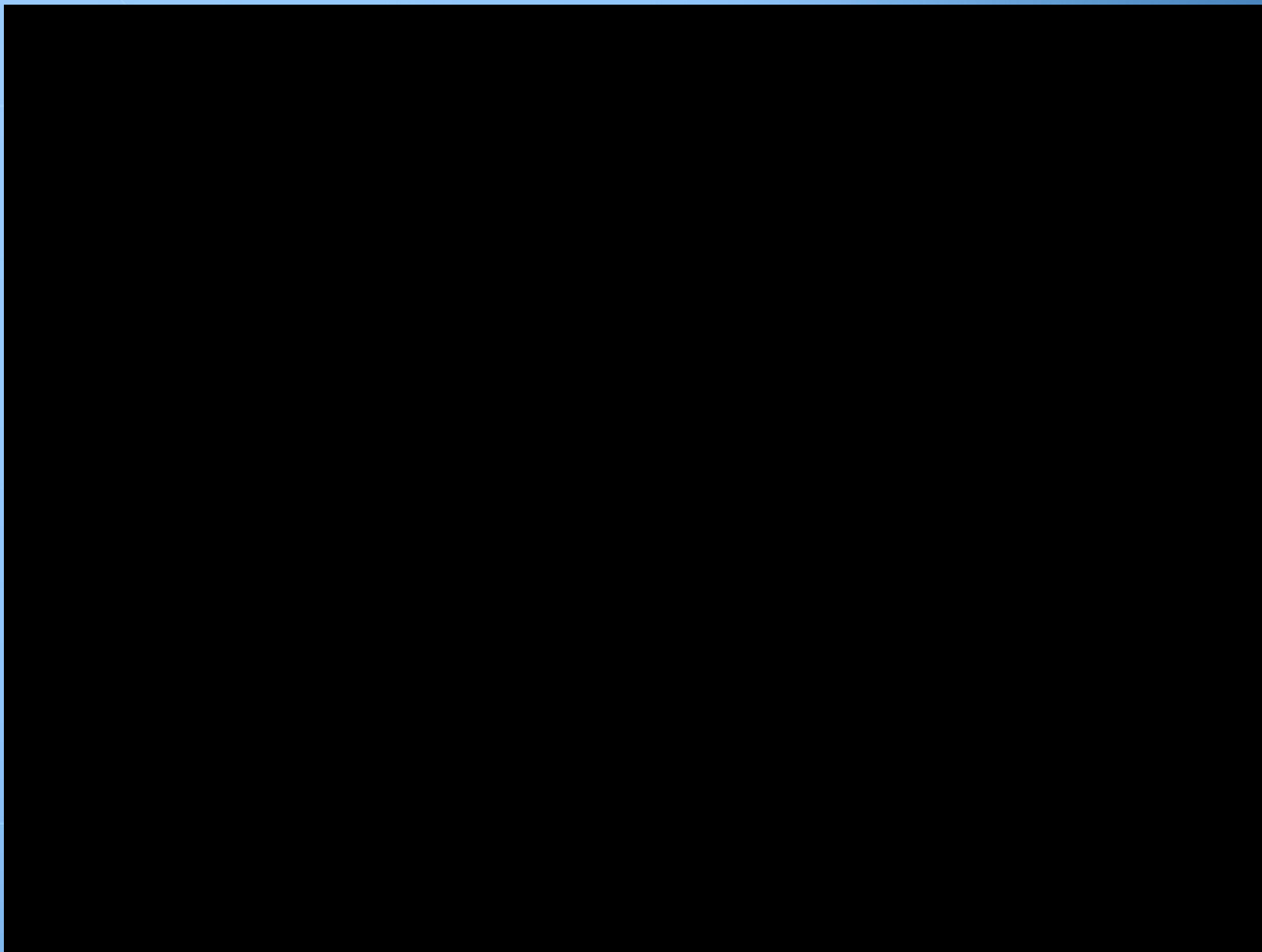
WeBo 1

Degeneracy between PN inclination and morphology – need nebular spectroscopy to complete the picture

e.g. A bipolar nebula viewed perpendicular to symmetry axis appears spherical

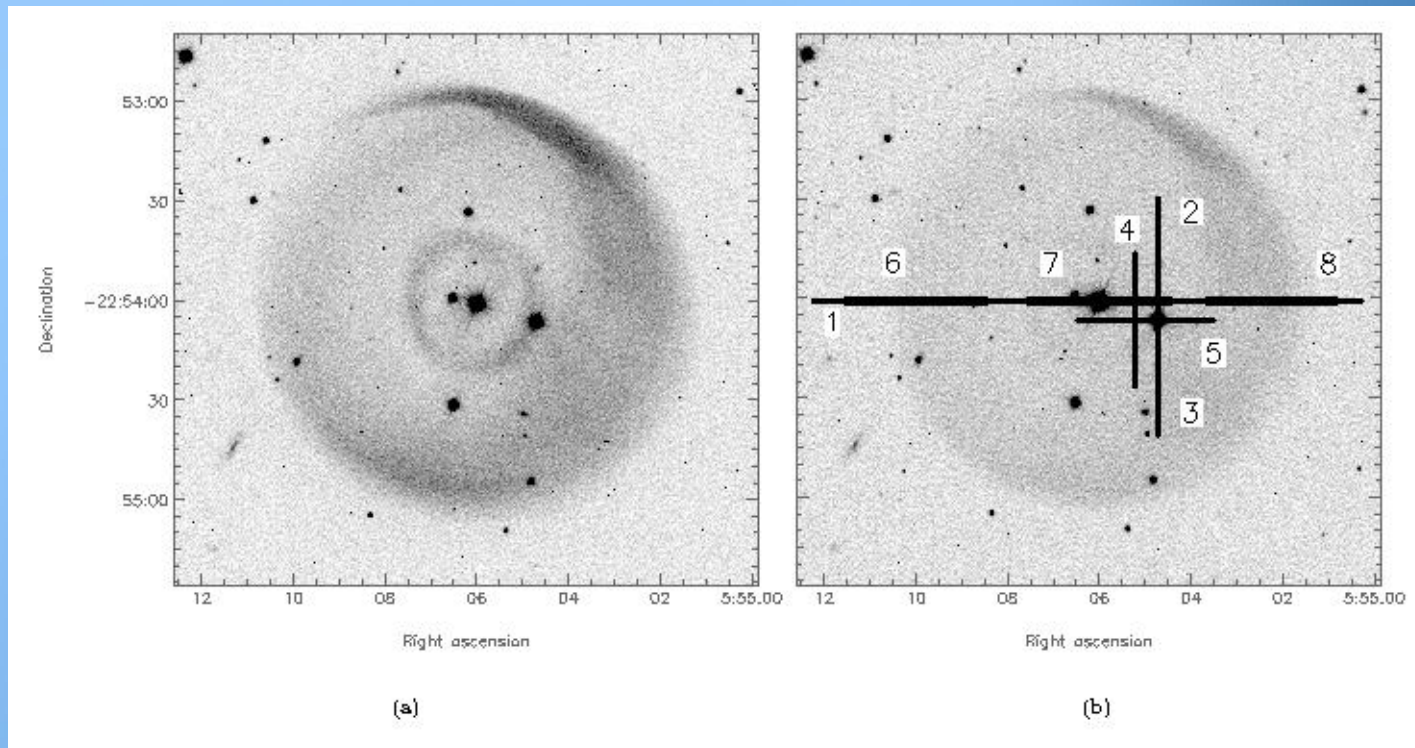






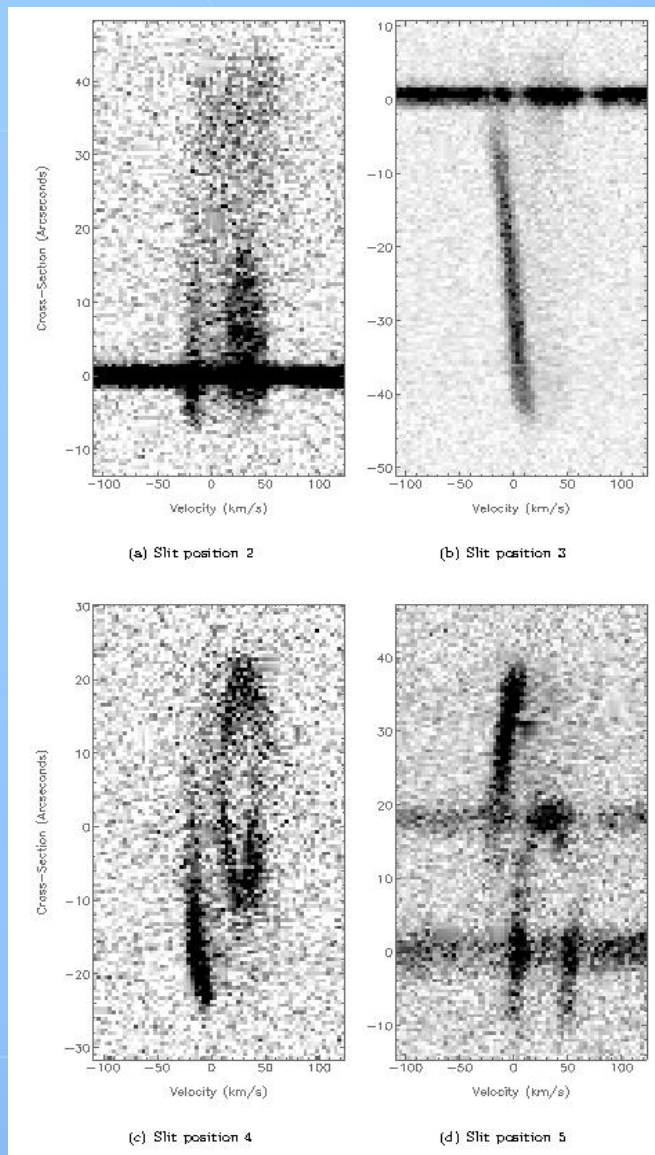
Nebular:

- AAT-UCLES
- NTT-EMMI
- [OIII]5007 Å emission

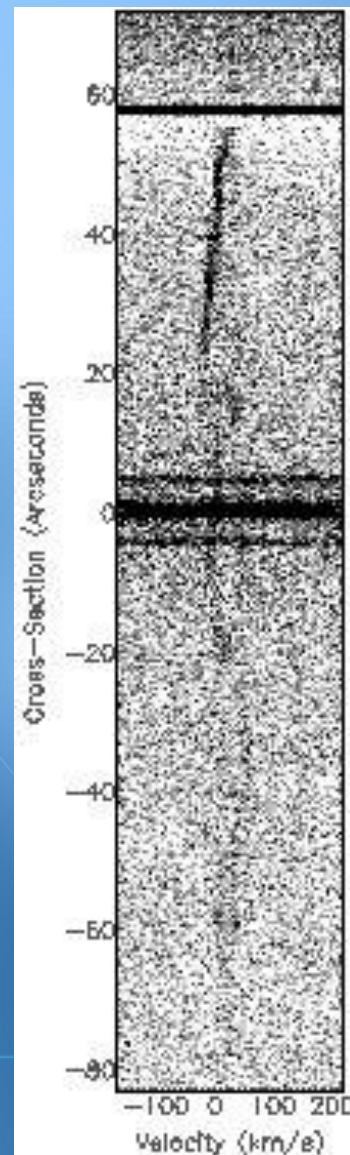


$$t_{\text{outer}} = 27,000 \pm 11,000 \text{ years}$$

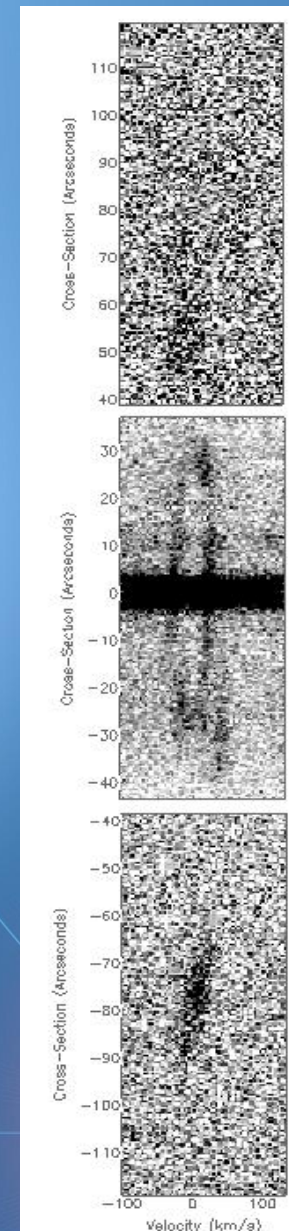
$$t_{\text{inner}} = 8,500 \pm 4,000 \text{ years}$$



AAT-UCLES



NTT-EMMI

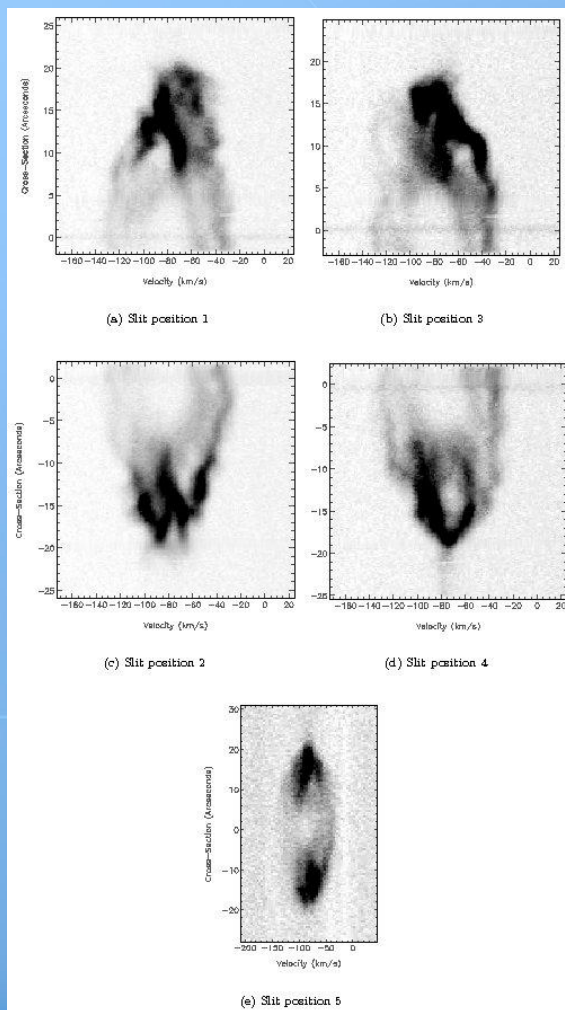
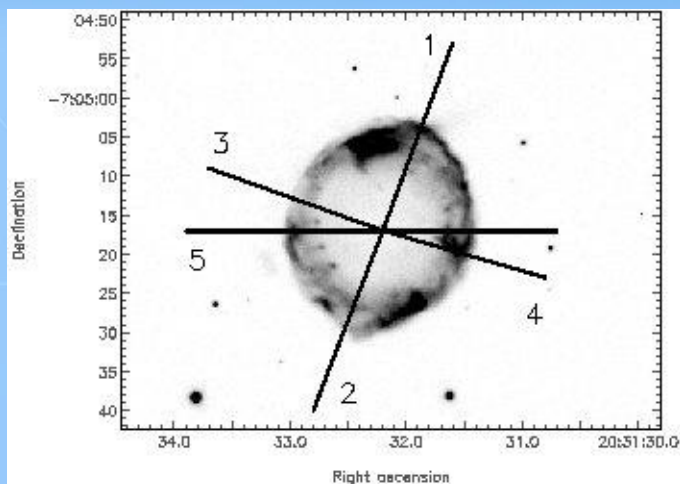


AAT-UCLES



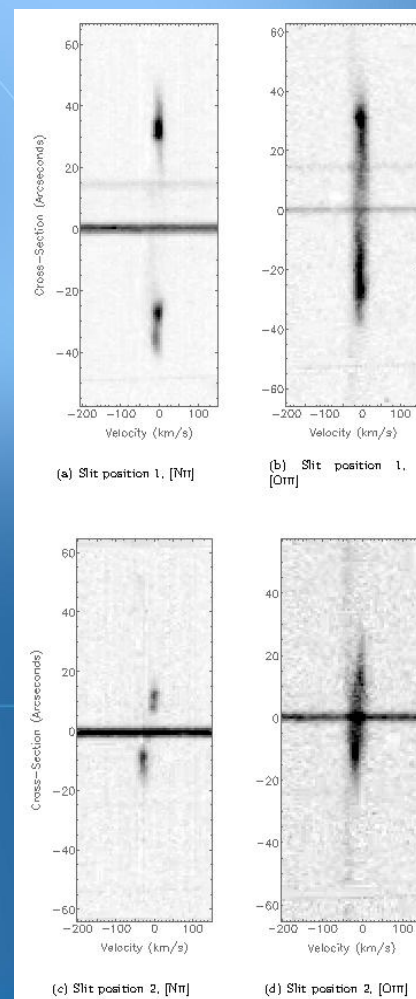
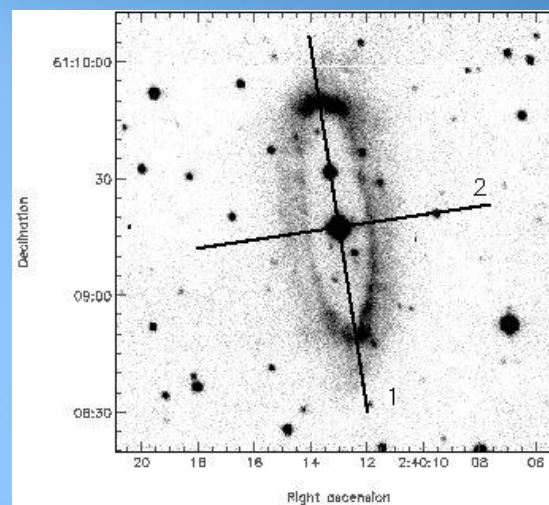
A70: Central star study by Miszalski et al. (2011)

Image = Ha+[NII] (VLT-FORS2), Spectra = [OIII] (VLT-UVES and SPM-MES)



WeBo 1: Cetral star study by Bond et al. (2003)

Image = Ha+[NII] (INT-WFC), Spectra = [NII] and [OIII] (SPM-MES)



# Summary

- LoTr 1 is an intermediate-period binary
  - Rapidly-rotating K1-III giant (of order 6 days)
  - Hot WD companion
  - No evidence of over-abundance of s-process elements (specifically Ba II)
  
- Double-shelled morphology, age =  $27,000 \pm 11,000$  years
  - Different morphology to A70 and WeBo1, but similar stellar system
    - **Similar evolution, but different mass-transfer rate/process to A70 and WeBo 1?**
  - Wind-accretion process possibly responsible for both Ba II over-abundance and ring-like morphology?
    - **Rings common in close-binaries, so high mass transfer rate also responsible here?**
  - Amount of mass transferred must either have been smaller (i.e. not enough accretion onto companion), or occurred too early (before Ba II production)
    - **Second scenario more likely as high mass-transfer rate required for spin-up to the observed rapid rotation.**

Thank You!



Gracias!

