Related Objects

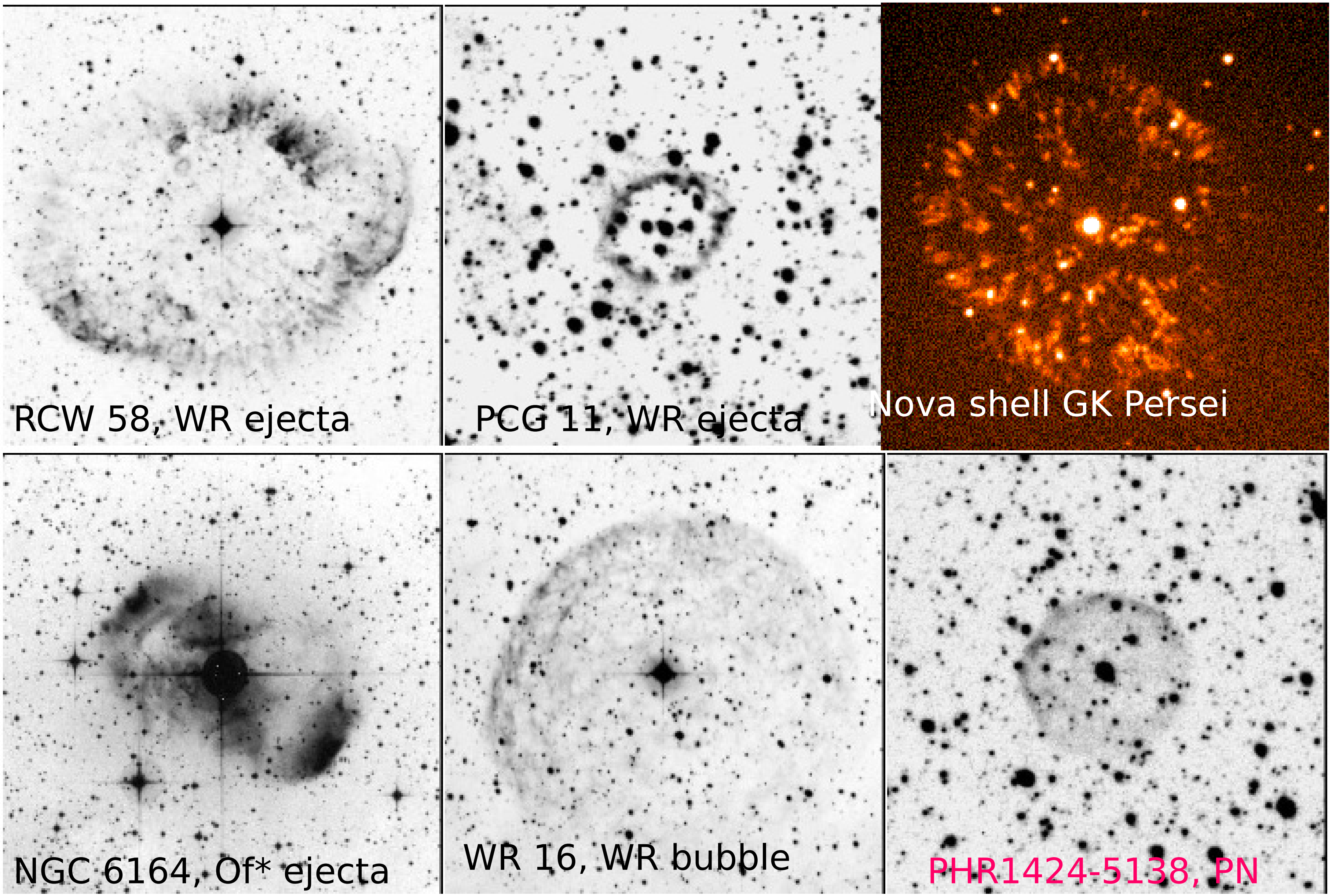
- The intruders
- The relatives
- The friends

- Processes
- Evolution

The Intruders

- PNe are identified through
  - Morphology
  - Diagnostics (warm dust, high excitation lines, ..)
- Hit and miss
  - Before Acker catalogue, >30% of PNe were misclassified
  - Confused with HII regions, galaxies, LBVs, ..
- Worse for post-AGB stars/PPNe

The mimics

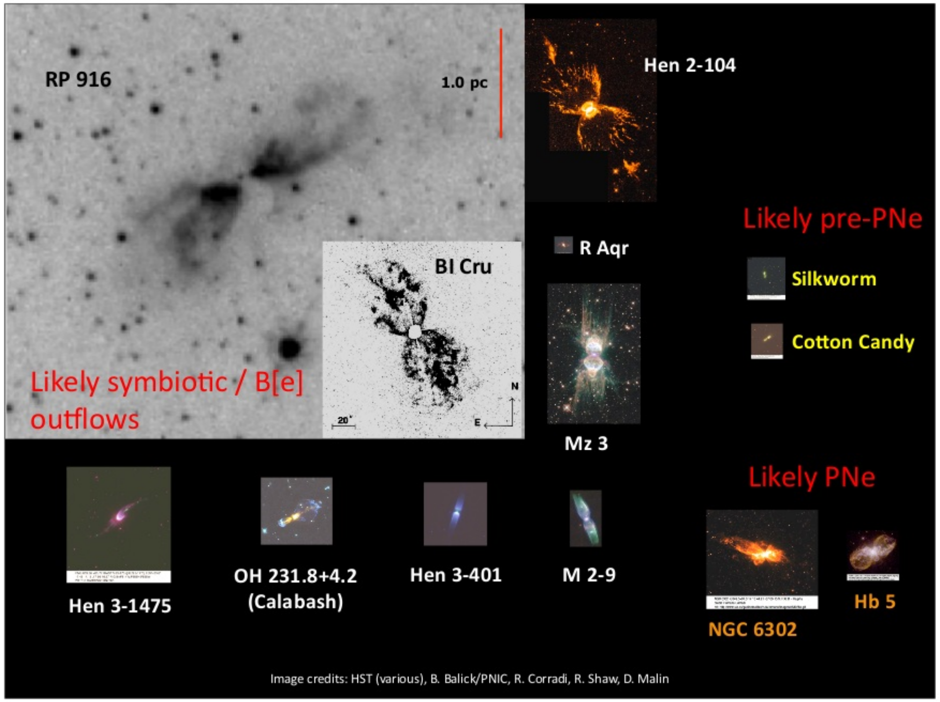

RCW 58, WR ejecta
PCG 11, WR ejecta
Nova shell GK Persei
NGC 6164, Of* ejecta
WR 16, WR bubble
PHR1424-5138, PN

The Relatives

- Symbiotic stars

  Look like APN

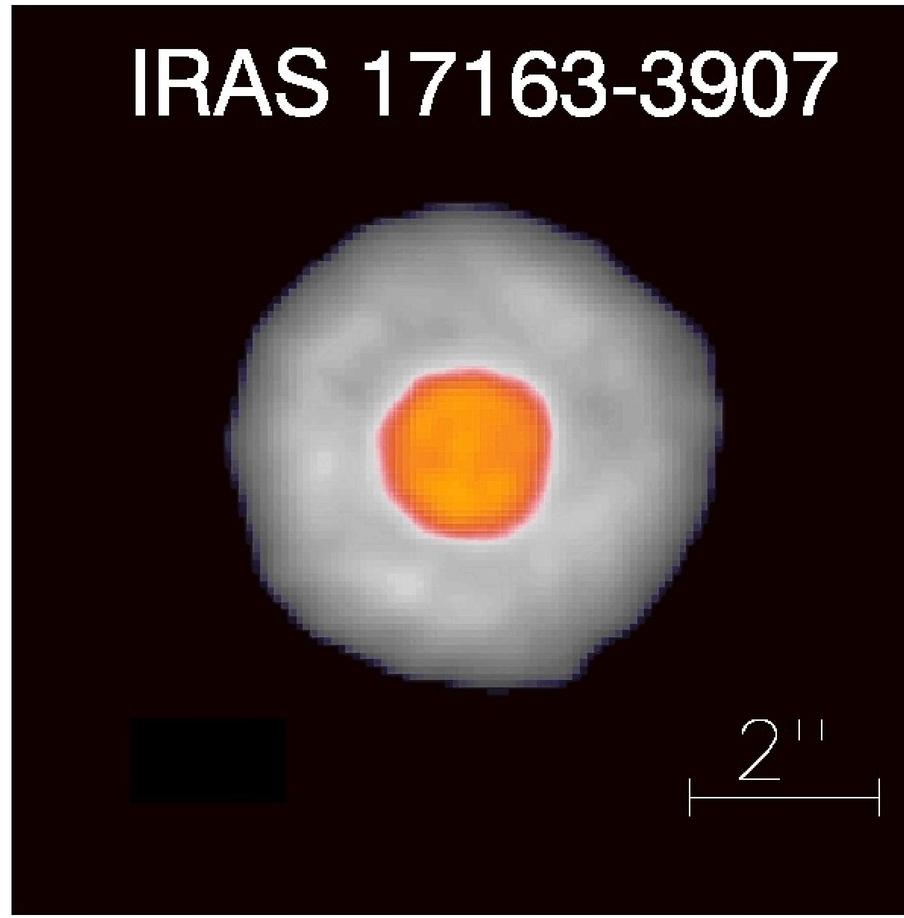
  Evolutionary related
- But not PNe



The Friends: Massive stars

- Yellow supergiant
- Multiple mass loss episodes

Lagadec et al.



What to learn ..

- Extend parameter space for processes
  - Angular momentum, binary interactions, magnetic fields, ..
- Define evolutionary sequences
  - Binary sequences from MS to DD
  - Single star evolution

Example of processes: clumping

- Water masers found in Miras, SR, RSG
- Show clumping
- Clump size ~ stellar radius

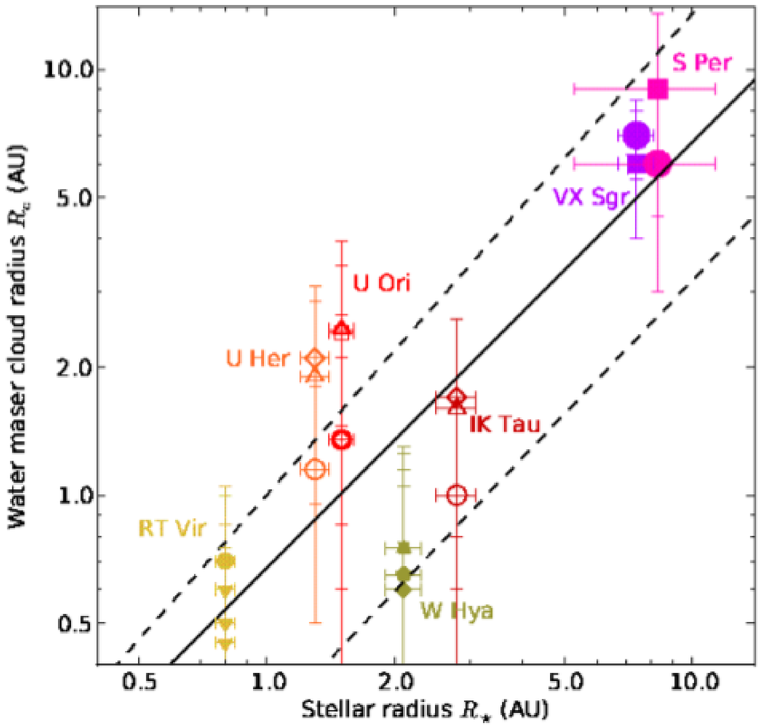
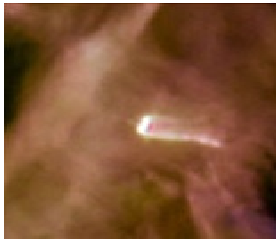


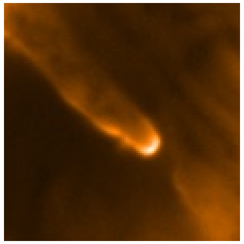
Fig. 62. Water maser cloud radius R_c as a function of $R_\star$. The different epochs are shown by different symbol shapes as in Fig. 44. RSG, Miras and SRb are shown by large, hollow and small symbols, respectively. The solid and dashed lines show the slope of an error-weighted fit to the relationship between R_c and $R_\star$, and the dispersion in the relationship.

Jet formation

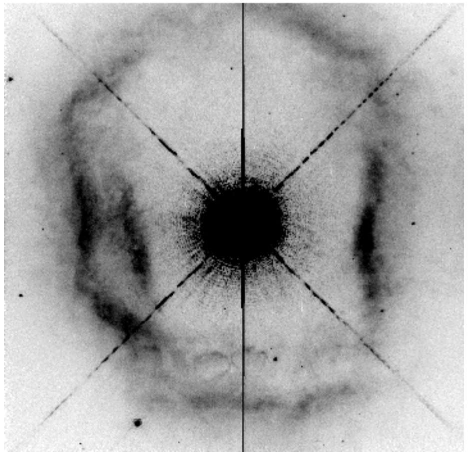
- PPNe very similar to YSO jets
  - Water fountains
  - K3-35
- But very different environments
- Different jet launching mechanisms?
- YSO and PPN jets accretion powered
  - But YSOs do not require binarity
- YSO disks are active
  - PPN disks passive?

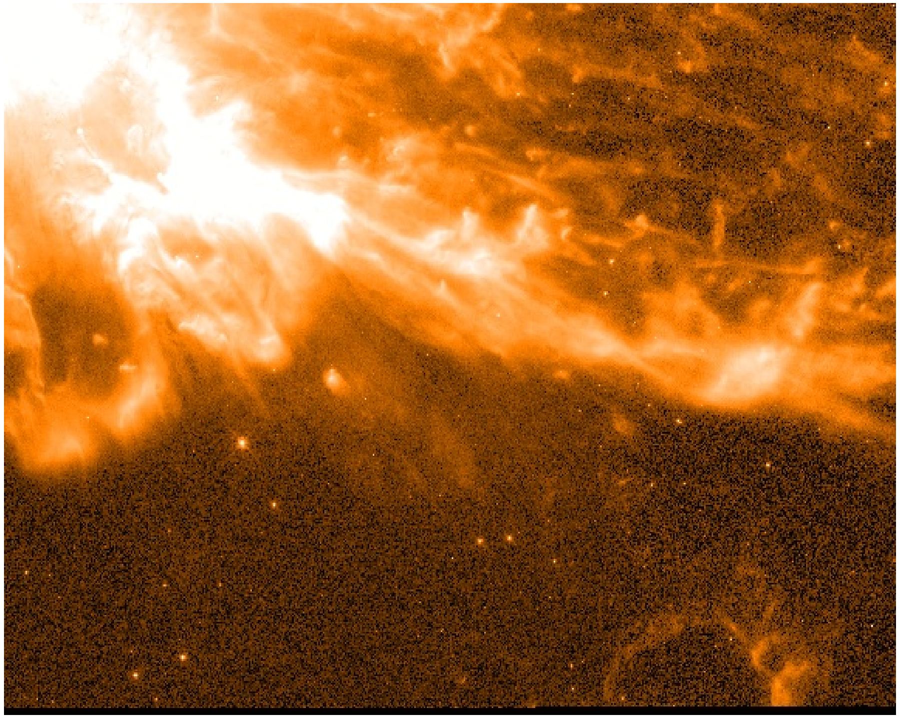
Interacting winds: Massive stars





- AG Car -Nota et al.





Angular momentum

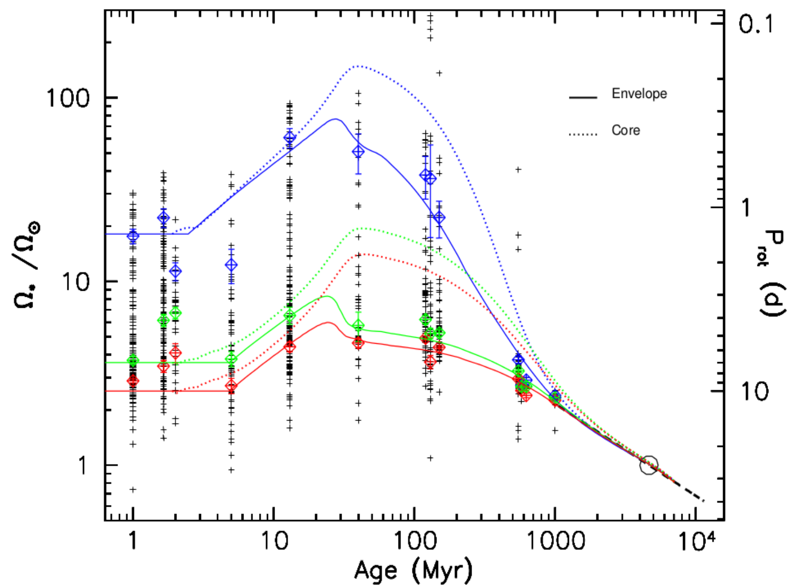
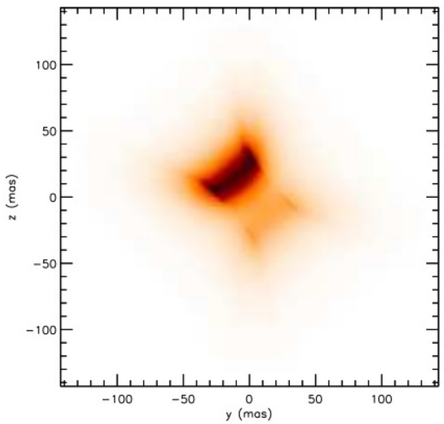


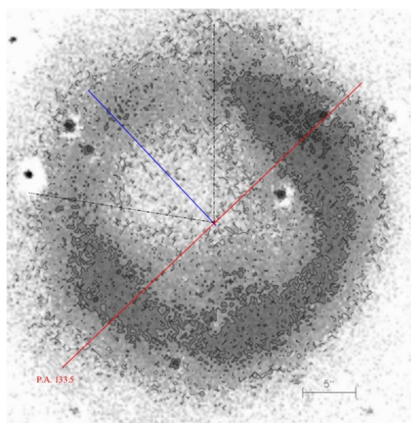
Fig. 3. Angular velocity of the radiative core (dashed lines) and of the convective envelope (solid lines) is shown as a function of time for fast (blue), median (green), and slow (red) rotator models. The angular velocity is scaled to the angular velocity of the present Sun. The blue, red, and green tilted squares and associated error bars represent the 90^{th} percentile, the 25^{th} percentile, and the median, respectively, of the rotational distributions of solar-type stars in star forming regions and young open clusters obtained with the rejection sampling method (see text). The open circle is the angular velocity of the present Sun and the dashed black line illustrates the Skumanich relationship, $\Omega \propto t^{-1/2}$.

Gallier & Bouvier 2013

- Stellar rotation decays as P ~ $t^{0.5}$ after t~10^8 yr
- Low-mass AGB stars: slow rotators
- High-mass stars retain more angular momentum
- Shaping affected?

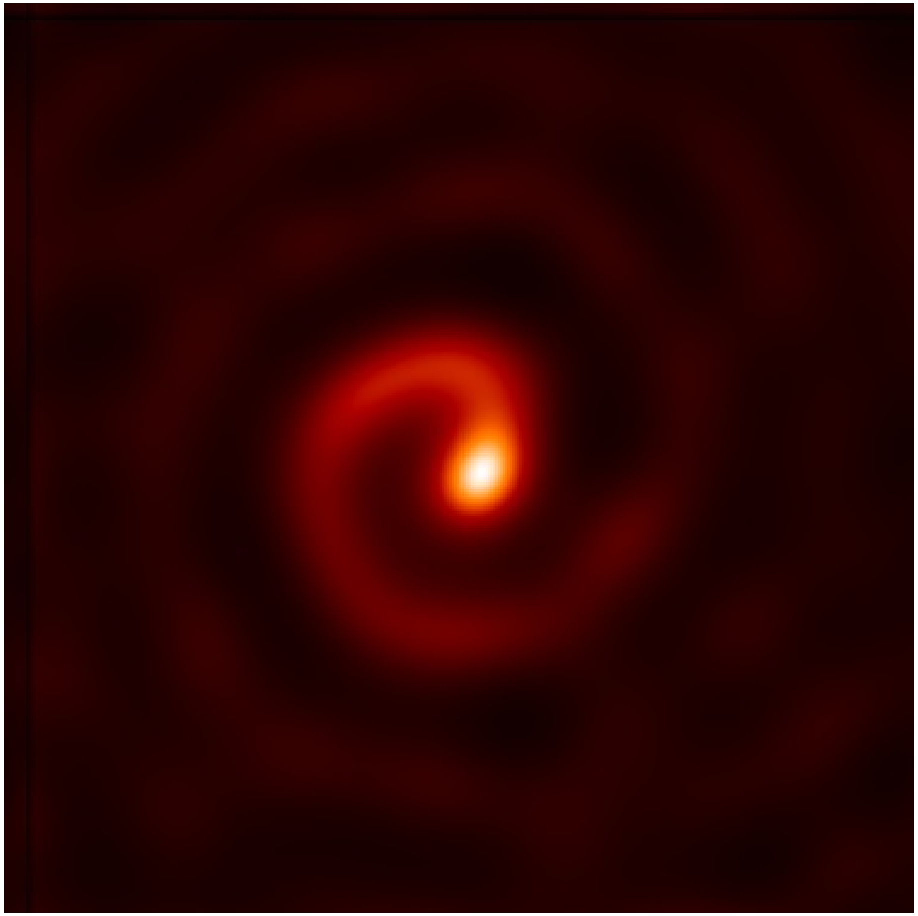
VLTP eruptions





- Same star, different epoch
- Sakurai's Object
  - VLTP bipolar
  - Old PN mildly elliptical
- Same symmetry axis

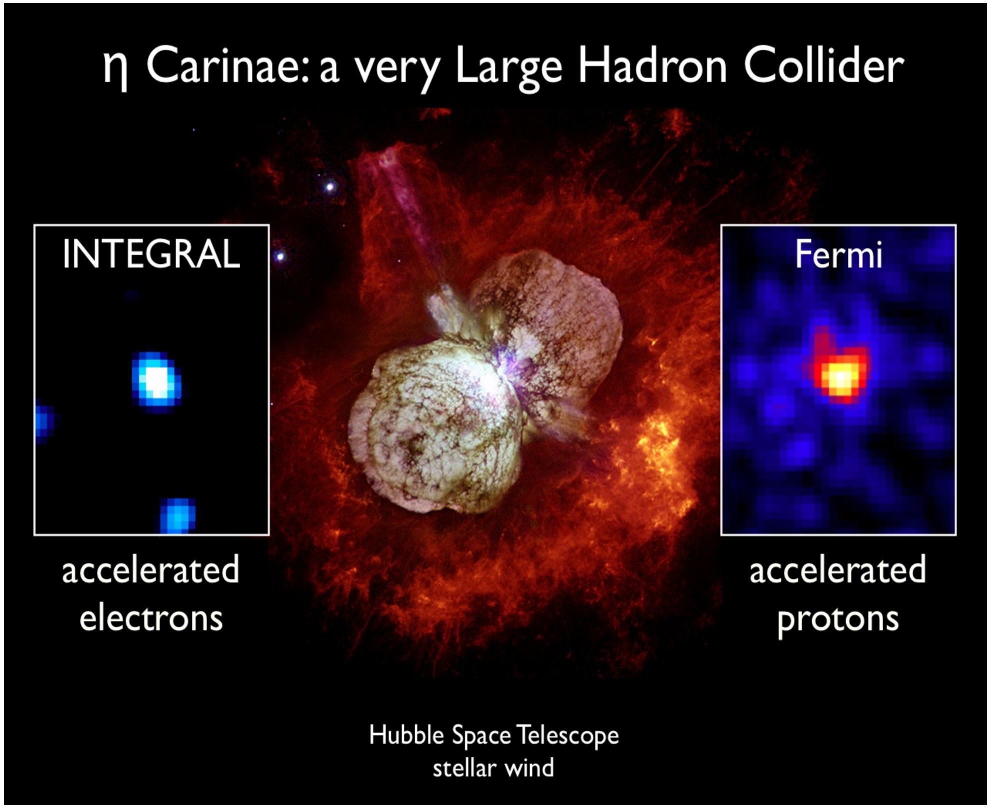
High mass binaries



- WR104
- 8-month binary period
- Dust formation occurs in wind collision region
- Start of spiral

Binaries

- High mass binary
- Periastron-induced activity
- Episodic mass loss



Evolution: Low mass binaries

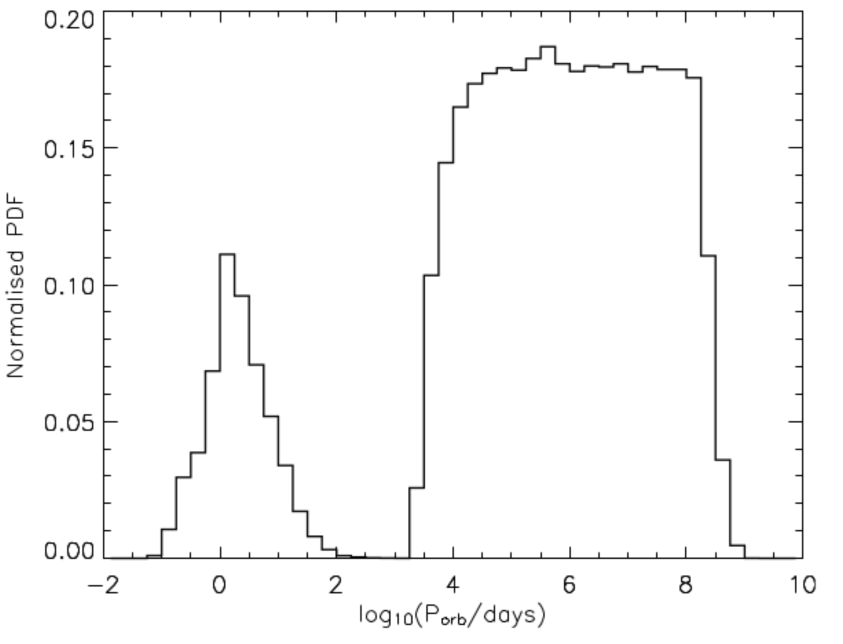
- Distant companions: evolve as two single stars
- Closer companions:
  - Enhanced mass loss
  - Mass transfer

  Symbiotic stars
- Closest: common envelope, interacting binaries

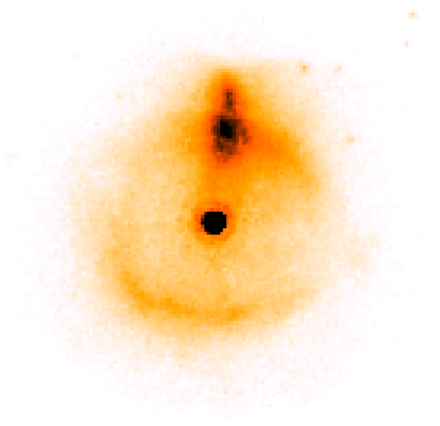
  Novae, CVs, ..

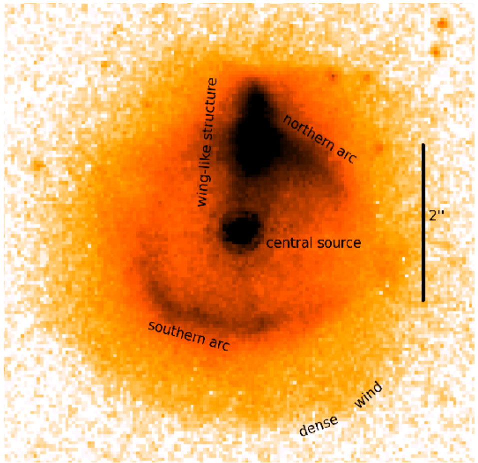
Low mass binaries

- Periods of WD-MS binaries (model)
- More than 75% have evolved as single stars

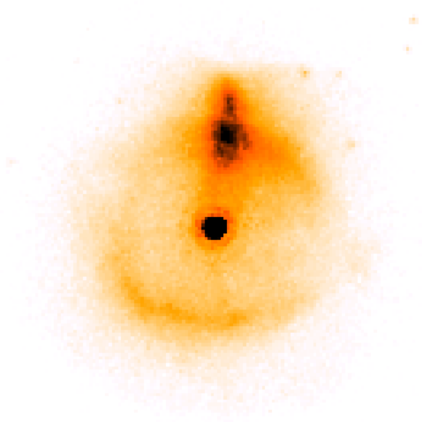


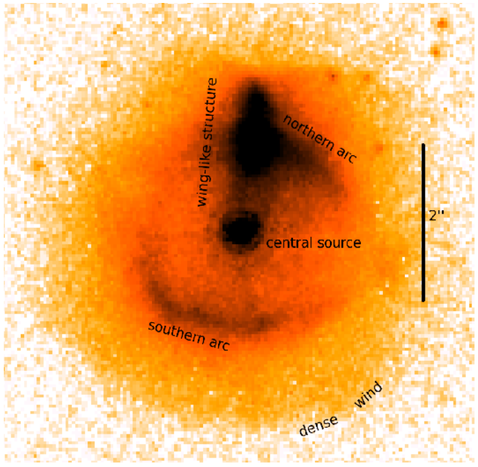
Elliptical binaries





- M2-29: PN with half a torus (Gesicki et al. 2010)
- Hen 2-428: same

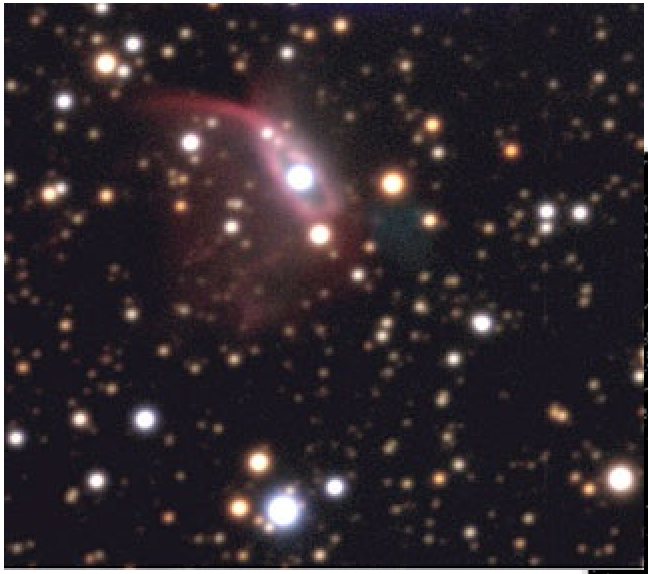




Elliptical binaries

- V417 Cen: Symbiotic star with similar shape (van Winckel 1994)

  Cause: intermittent mass loss on elliptical orbit



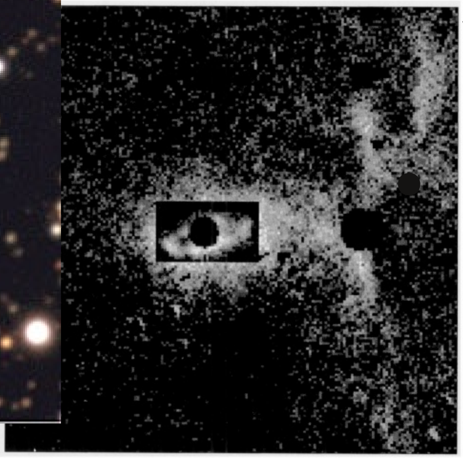
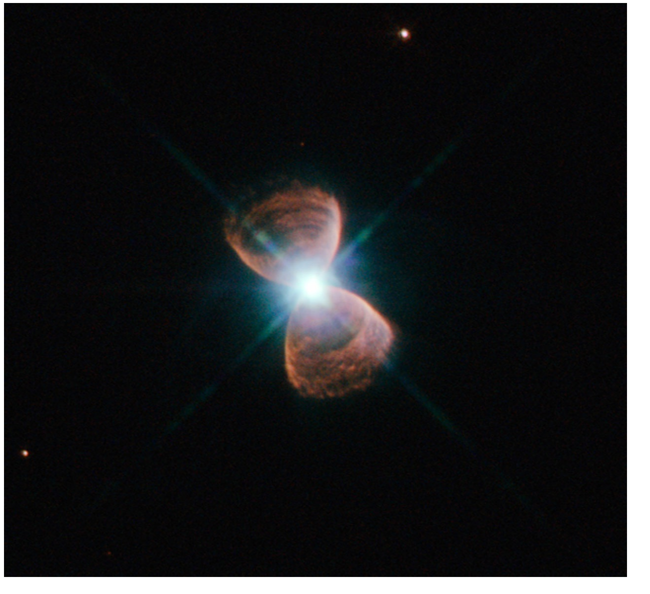


Fig. 6. The coronographic image of V417 Cen. The Hα image is subtracted by a Hα continuum image to show only nebular emission, without the stars in the field. The central box has cut-levels which are different from those of the rest of the image. The field size is 1.′7 × 1.′7, north is up, west to the left

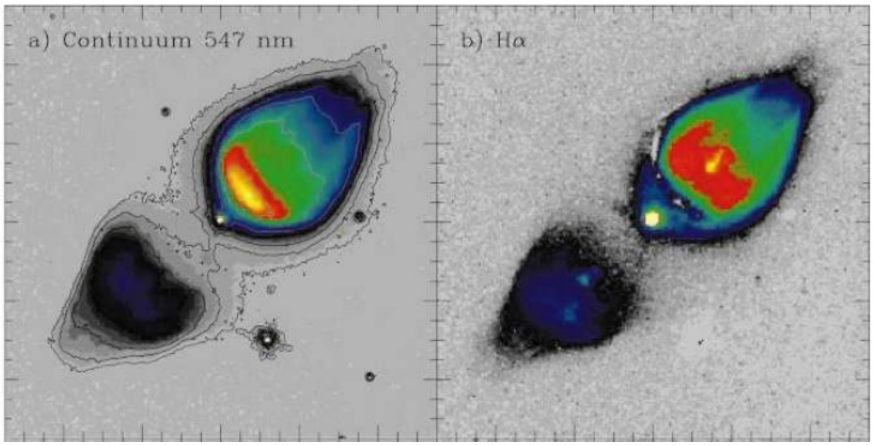
Symbiotic stars

- S-type: RG+WD, P>200 days
- D-type: Mira+WD: P 10-50 yr
- WD: L ~10^3 L_o, H-burning

- Mass transfer
- Flickering
- Pulsations
- Eruptions



Symbiotic post-AGB stars



- M1-92, post-AGB
  - Disk, outflow
  - F2 supergiant + white dwarf

- Spectrum similar to MWC560
- Symbiotic system
  - M4 supergiant + white dwarf
- MWC560 may evolve rapidly into M1-92

Arrieta et al. 2005

Evolution bias

- AGB:

  CE systems skip TP-AGB

- Post-AGB

  Symbiotics: skip this

  - pre-ionized

  CEs evolve very fast

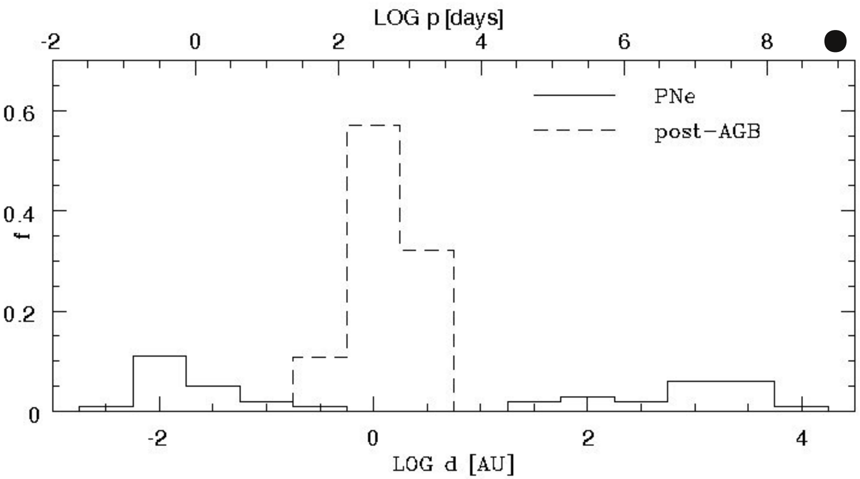
- PNe: Single stars

  low mass: too lazy

  high mass: too fast

- Speed of evolution and starting point for post-AGB/PN phase differs per channel

Binary problem



- Evolutionary sequences should match
  - Binary parameters
  - Morphologies
  - Evolutionary speed
- Solution lies on the

  AGB

PN novae

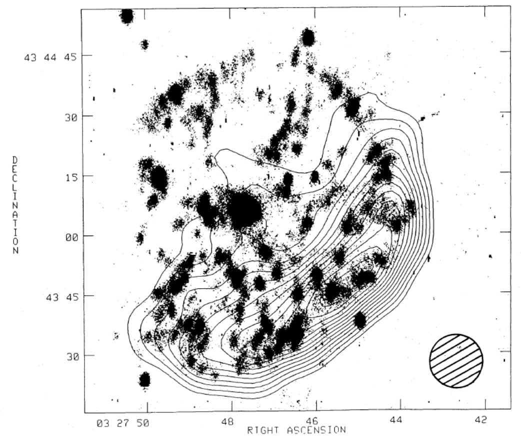
- Two novae observed inside PNe

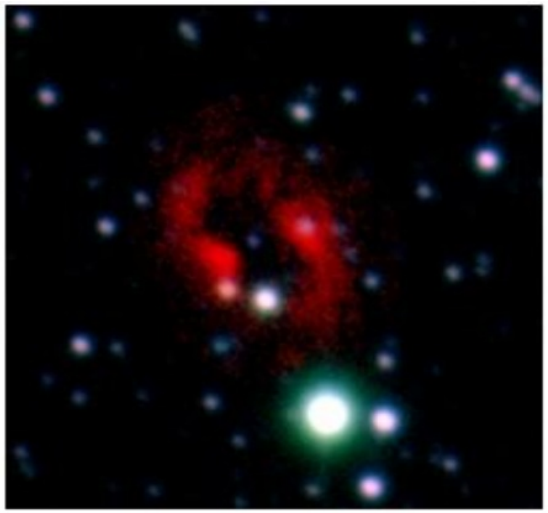
  GK Per

  - 2.00 day period
  - WD +K1 giant

  V458 Vul

  - 98.1 min period
  - WD + pAGB ?





PN novae

- Both novae are at extreme ends of period distribution
- One-off events?
- Triggered by
  - post-AGB mass transfer?
  - Accretion disk?
  - Fall-back?
- Which parameter range is traced by these novae?

This session

- How do massive stellar winds compare to AGB/PNe?
  - Do modeling tools cross-pollinate?
- Do all bipolar nebulae show the same shaping processes?
- Can we identify evolutionary sequences?
- Can we trace the AGB/PNe connection?