

Central Stars of Planetary Nebulae

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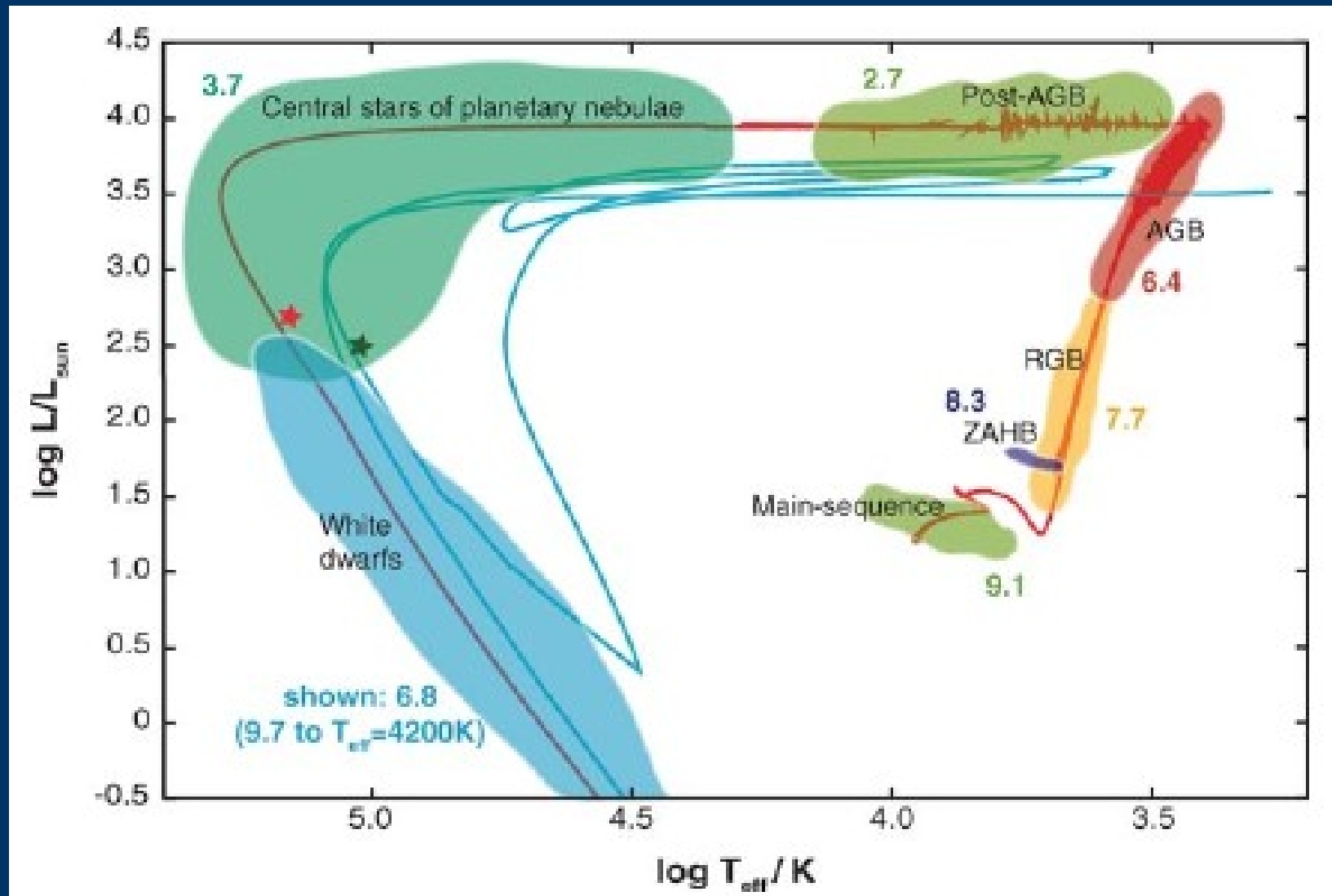
Overview

- Origins of planetary nebulae (PNe) and their central stars
- Properties
- Instabilities



HST/B. Balick

Evolution Off the Main Sequence

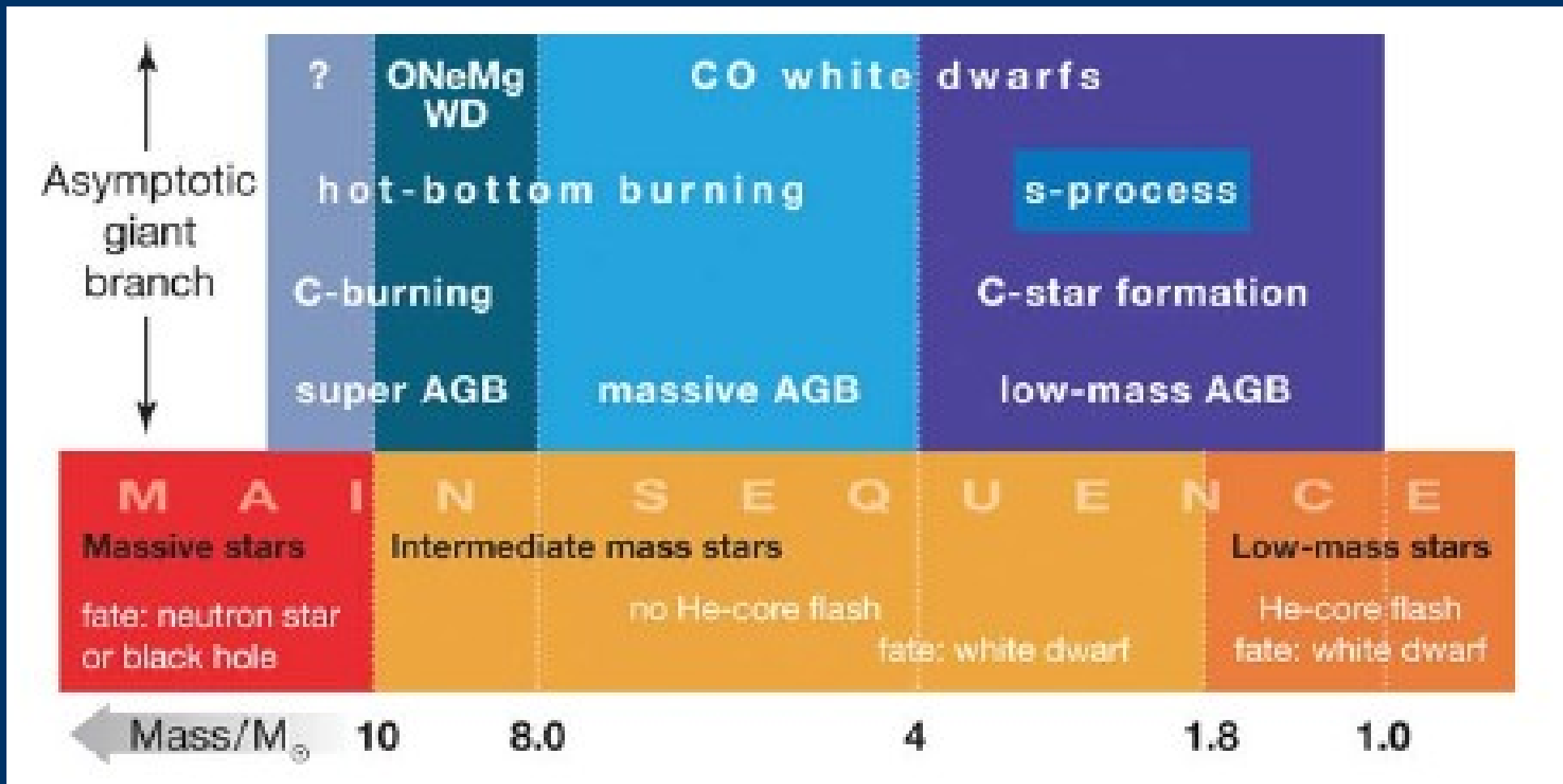


Herwig (2005)

Evolution Off the Main Sequence

- Post-AGB
 - ~1,000 yr
 - Mass loss rates $\sim 10^{-4} M_{\odot}/\text{yr}$
 - PN Central Star
 - ~10,000 yr
 - Creation of planetary nebula
 - White Dwarf
 - Cooling sequence
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End Points for Various Masses



Herwig (2005)

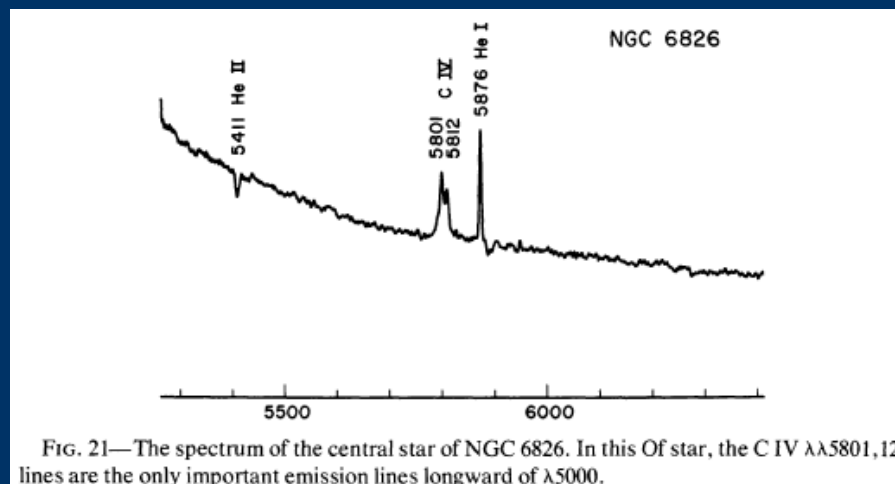
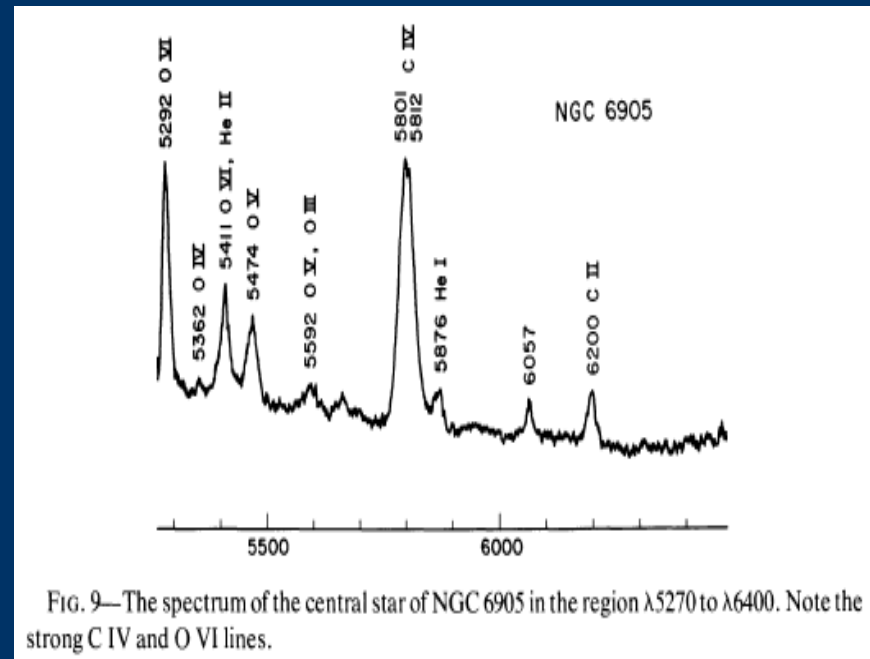
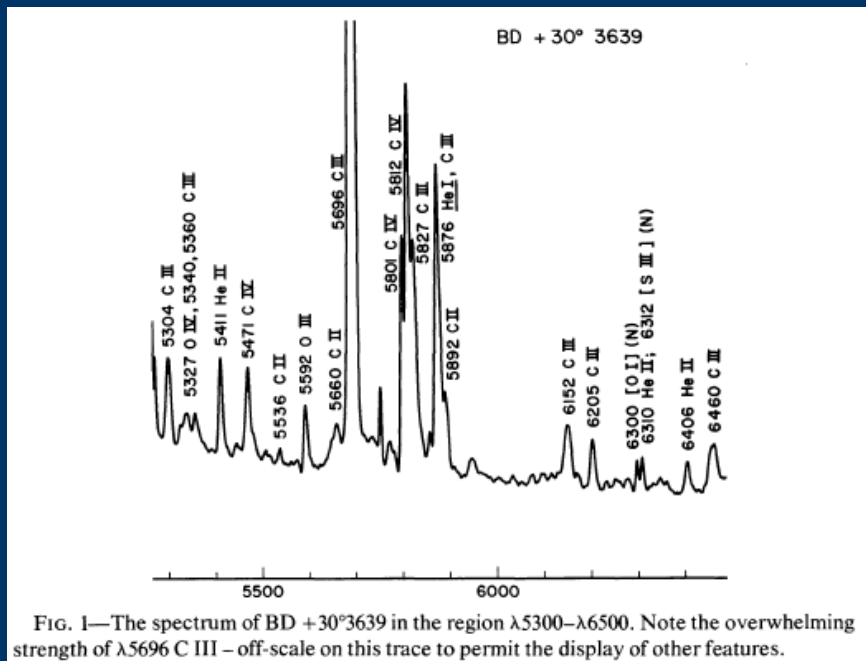
Properties of the Central Stars

- Temperatures $\sim 50,000 - 100,000$ K
 - From luminosities or nebular line flux ($H\beta$)
 - Luminosities $10 - 10^4 L_{\odot}$
 - Mass loss rate $\sim -10 - -7 \log(M_{\odot}/\text{yr})$
 - Rotation rates $\sim 0.1-1$ km/s
 - Angular momentum transported to nebula
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Classification of Central Stars

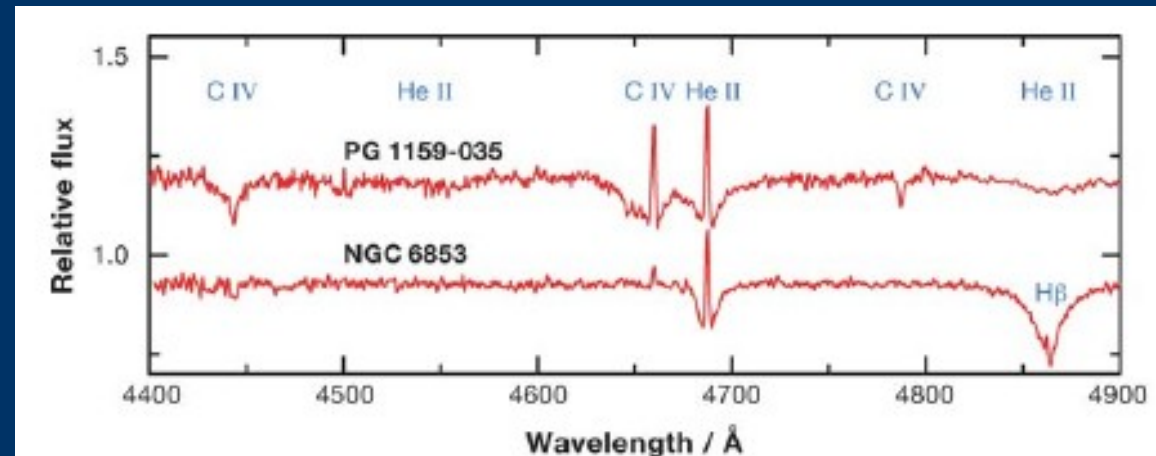
- Absorption-line O
 - Similar to O3 stars
 - Normal H/He ratios
 - Of
 - Several subgroups
 - Wolf-Rayet
 - WC and WN stars, most with broad lines
 - O VI
 - Continuous
 - PG1159
 - DOV
-
-

Classification of Central Stars



Variability – PG1159 Stars

- Also known as variable PN nuclei or GW Viriginis stars
- Hot $\sim 10^5$ K
- Periods of 10 to 30 min
- Hydrogen deficient spectra
 - Strong He and C with O
 - Looks like AGB Intershell



Variability – PG1159 Stars

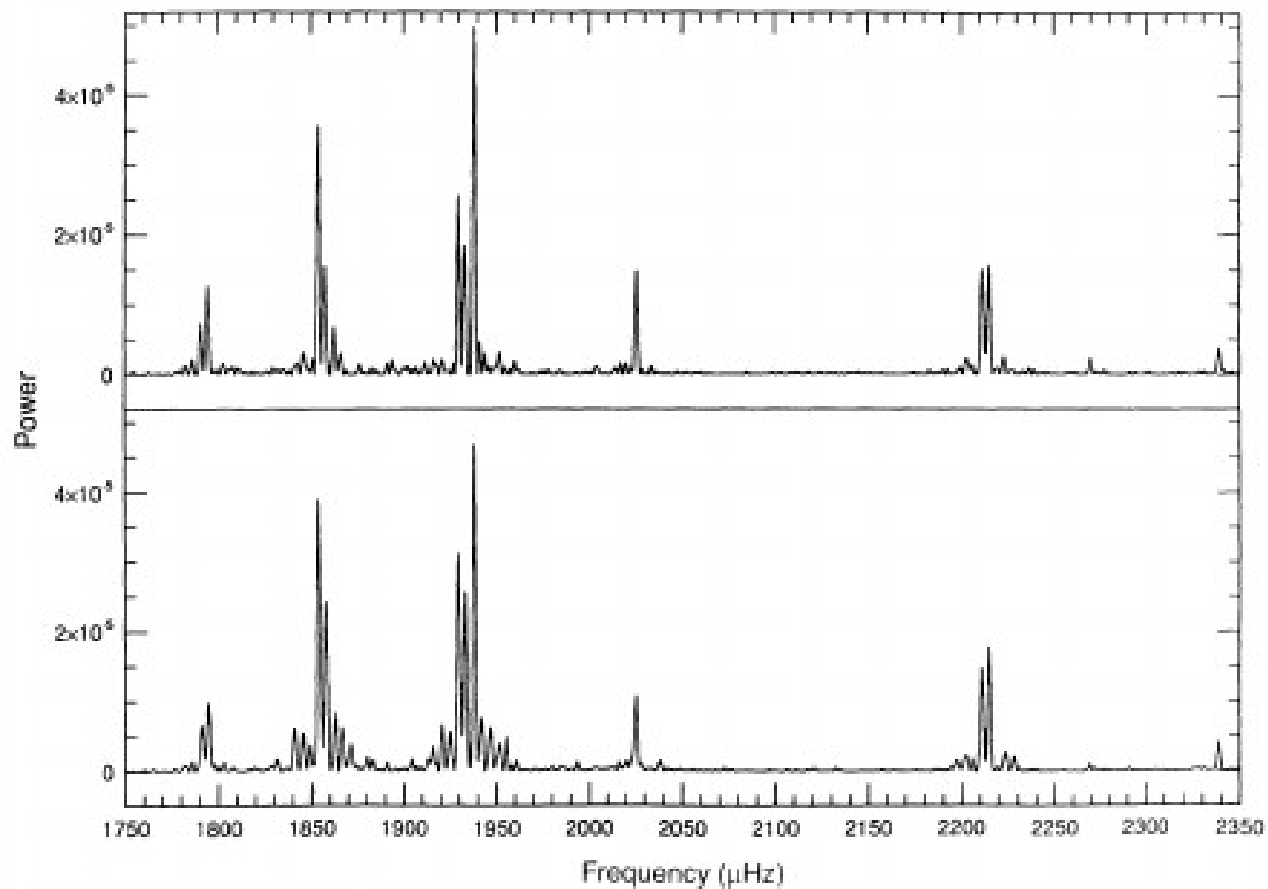


FIG. 2.—Power spectra obtained when the light curve was divided into two equal halves and processed separately. Except for small sidelobe effects arising from differing data gaps, the spectra are the same.

Variability – PG1159 Stars

- Pulsations consistent with non-radial g-modes
 - Driving by ionization zones of C and O
 - Opacity effect
 - Sensitive to exact mixture
 - Period change $\sim -10^{-11}$
 - Implies 1 Myr evolutionary timescale
 - Origins – (Very) Late Thermal Pulse of WD
 - AGB \rightarrow H rich WD \rightarrow AGB \rightarrow PG1159 \rightarrow WD
 - Requires H envelope to get mixed with He envelope
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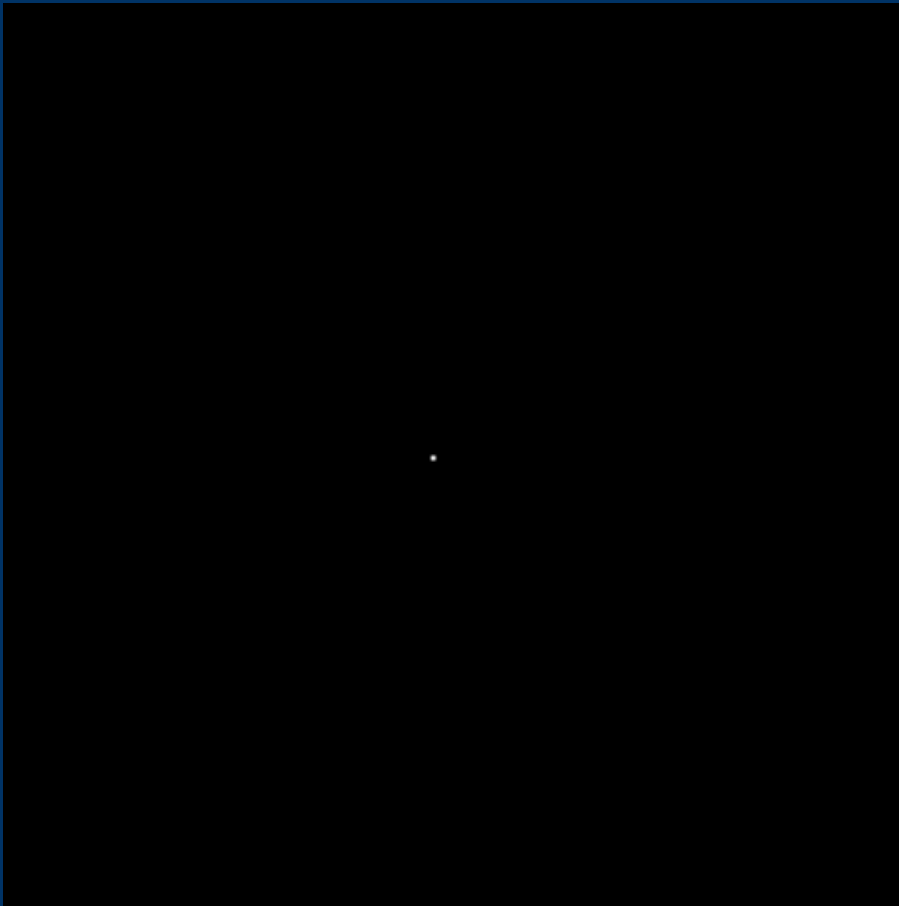
Variability – DOV Stars

- Similar to PG1159 stars
- Periods 2-3 times shorter
 - Smaller radii
- Cooler

- Evolved PG1159 stars



Ultimate Fate

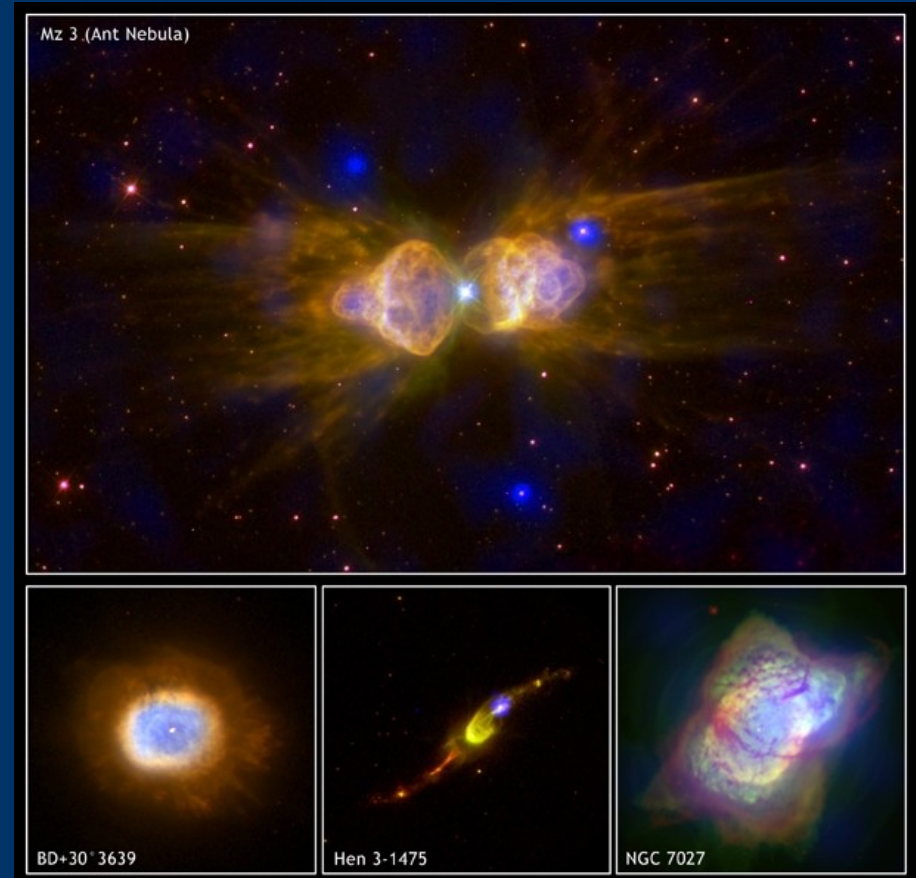


- Cool to white dwarf cooling track
- Reach $\sim 4,000$ K after 10^{10} yr
- Become MACHOS



References

- Aller, L. 1977, JRASC, 71, 67
- Gautschy, A. & Saio, H. 1996. ARA&A, 34, 551
- Herwig, F. 2005. ARA&A, 43, 435
- Kaler, J. 1985. ARA&A, 23, 89
- Winget, D. et al. 1991, ApJ, 378, 326



X-ray: J.Kastner et al.; Optical/IR: BD +30 & Hen 3: J.P.Harrington; NGC 7027: J.Westphal & W.Latter; Mz 3: B.Balick