Formation of Planetary Nebulae: Mass Loss Mechanisms

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JPL-Caltech/
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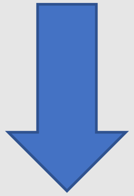
- PN is a cloud composed of ionized gas ejected from a low- to intermediate-mass star at the end of its stellar lifetime
- Characteristic glow caused by ionizing UV radiation from central star
    - Requires temperature of ~30,000K and at least 100 particles/cm^3



Where does all that gas come from?
Stellar winds, pulsation

Stellar Winds

- Radiation pressure from star imparts momentum on condensed dust particles in the stellar atmosphere
- Friction causes the dust to drag gases along with it as it is pushed away from the star

Model mass loss due to winds using Reimers' formula:

$$\dot{M} = -4 \times 10^{-13}\,\eta \left(\frac{L_* R_*}{M_*}\right)\ \mathrm{M}_\odot\,\mathrm{yr}^{-1},\ \ \eta \sim 1$$

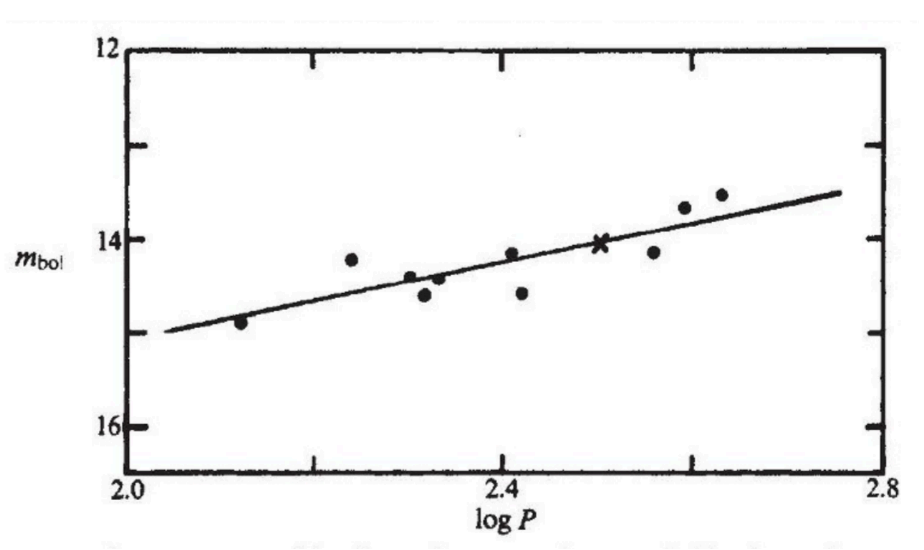
Assume that mass loss rate is proportional to luminosity (more radiation pressure), and inversely proportional to M/R (surface gravity is M/R^2). AGB stars have large radii (several hundred solar radii) but are not significantly more massive than the Sun. Low surface gravity!

Luminosity increases (see HRD), and mass decreases. Increasing mass loss rate!

Pulsation

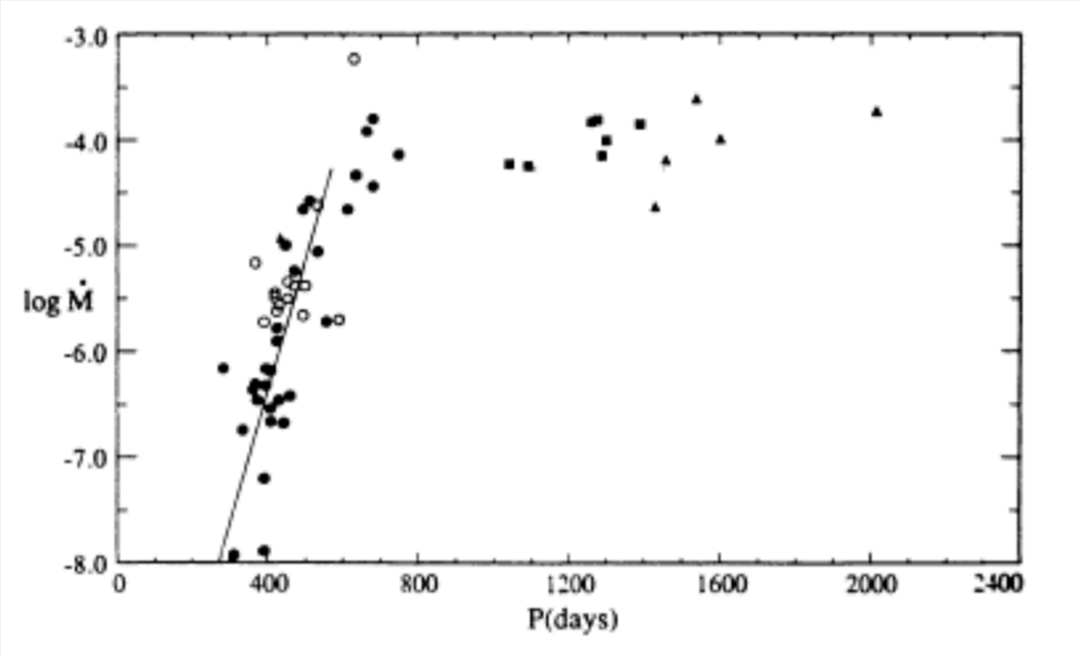
- Late-stage AGB stars are called thermally pulsate
  - Unstable shell burning causes helium shell flashes, and causes the star to expand and contract as it attempts to maintain equilibrium
- Produces shock waves that levitates material—increases the density of material in the stellar atmosphere.

$$\dot{M} = 4\pi r^2 \rho v$$



Glass, I.S., Evans, T.L. 1981, Nature, 291, 303

Period of pulsation also related to luminosity!



Vassiliadis, E., Wood, P.R. 1993, ApJ, 413, 641

- For stars with M >= 2.5 solar masses:

$$\log \dot{M}\ [\mathrm{M}_\odot\,\mathrm{yr}^{-1}] = -11.4 + 0.0125\left(P\ [\mathrm{days}] - 100\left(\frac{M_*}{M_\odot} - 2.5\right)\right)$$

- For stars with M <= 2.5 solar masses:

$$\log \dot{M}\ [\mathrm{M}_\odot\,\mathrm{yr}^{-1}] = -11.4 + 0.0123\,P\ [\mathrm{days}]$$