Formation and X-ray Emission of Born-Again Planetary Nebulae

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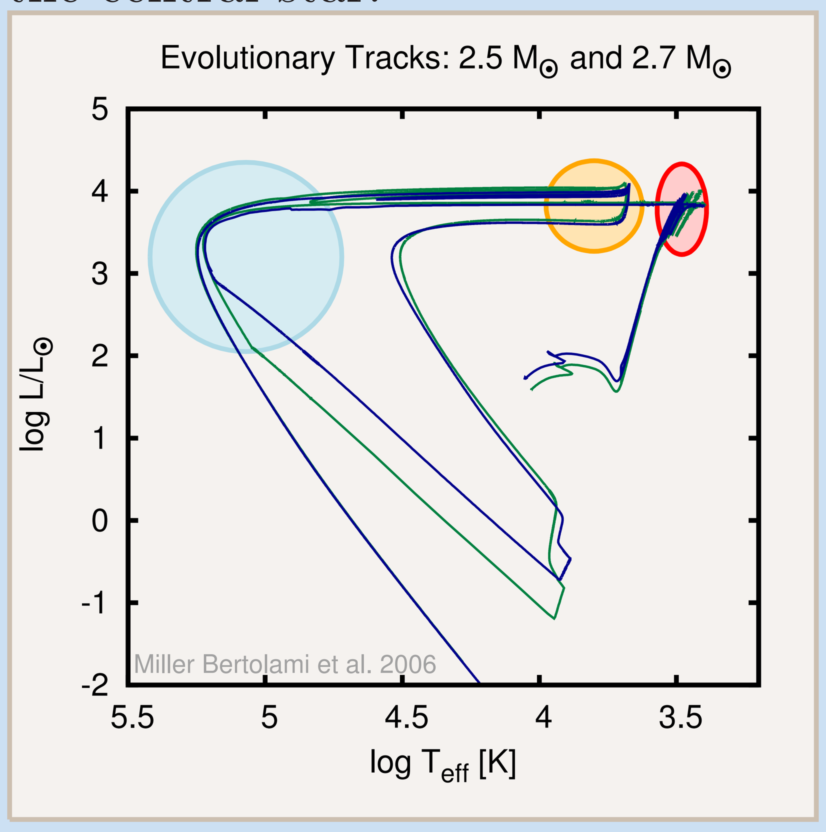
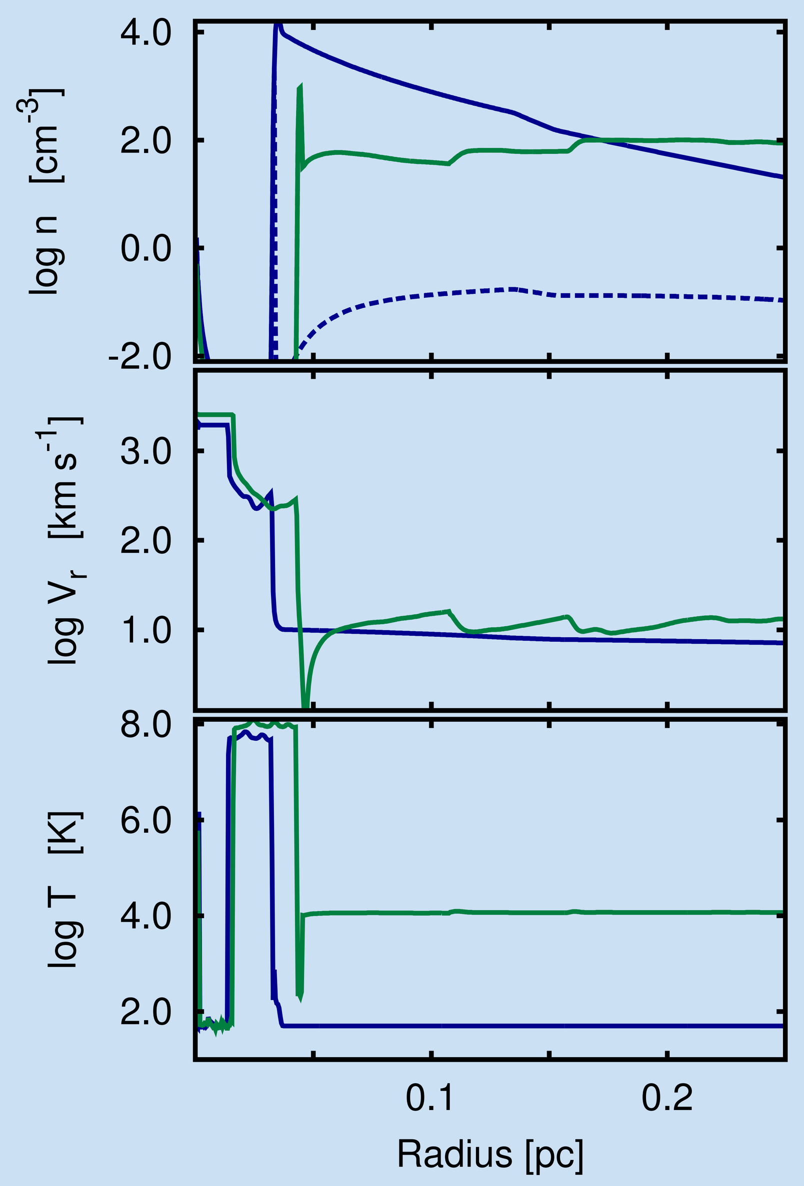
Outline

Some central stars of planetary nebulae experience a final thermal pulse after having arrived at the white dwarf stage and pass through a giant phase before returning to the white dwarf cooling track. The morphology, kinematics and X-ray emission of the resulting "born-again" PNe depend on the stellar evolution and mass-loss history of the central star.



1D Models

We model the interaction between the final fast wind and the material ejected during the VLTP. The density, ionized density, radial velocity and temperature about 1000 yrs after the onset of the final fast wind stage are shown for the two different stellar models.



The $2.5M_\odot$ model produces a photoionized nebula with a typical density around 100 cm^{-3}, with an inner hot shocked bubble produced by the fast wind.

The $2.7M_\odot$ model produces a small-radius hot, shocked wind bubble surrounded by expanding ($V_r \sim 10$ km s^{-1}) neutral gas.

Acknowledgements

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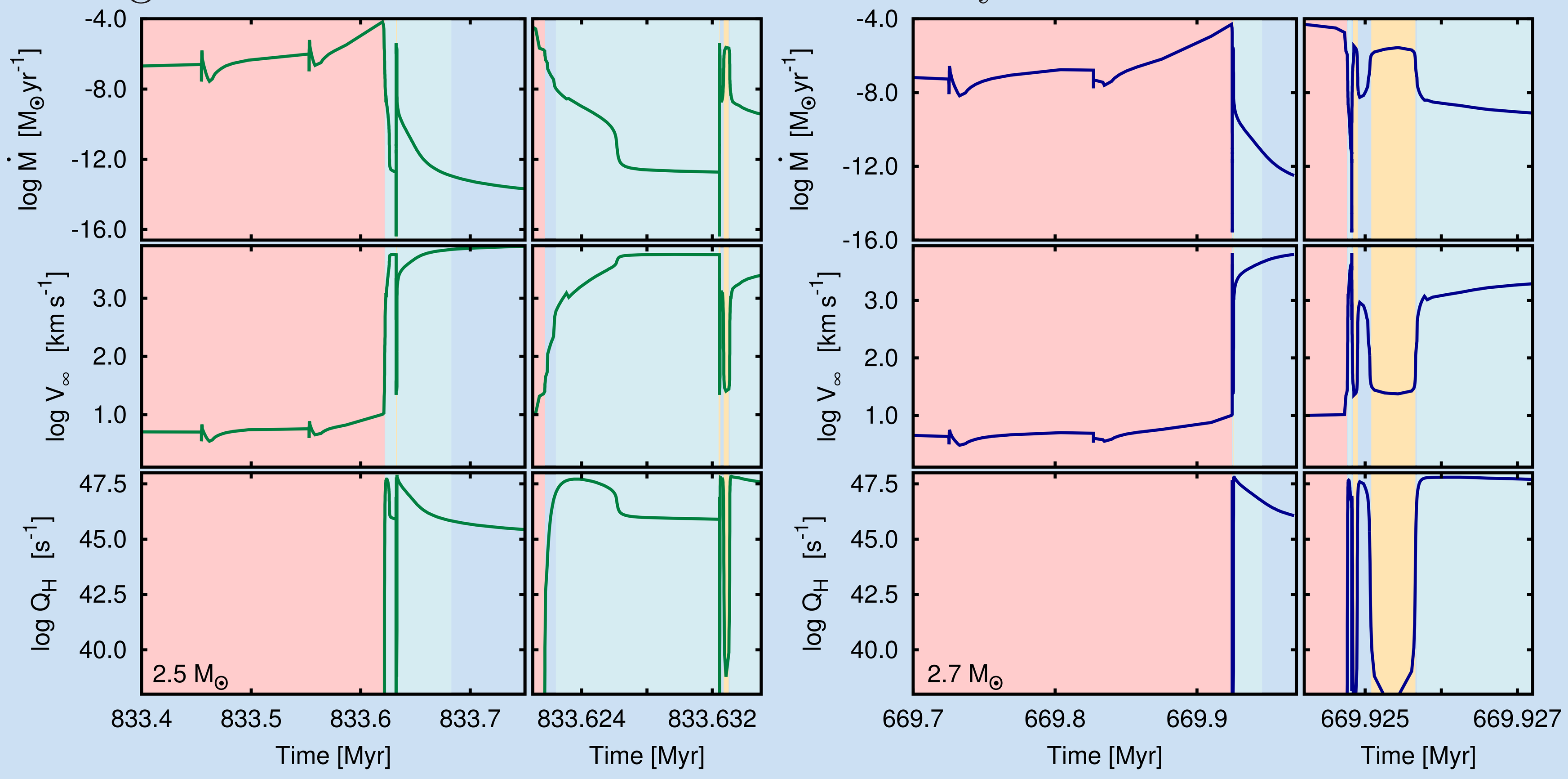
Mass-loss History and Ionizing Photon Rate

Beginning with the final pulses of the AGB superwind, we follow the mass-loss history of the star as it evolves from the AGB to become a planetary nebula central star, then undergoes a very late thermal pulse, with a corresponding rise in the mass-loss rate, before returning to the white-dwarf cooling branch on a timescale as short as 100 years.



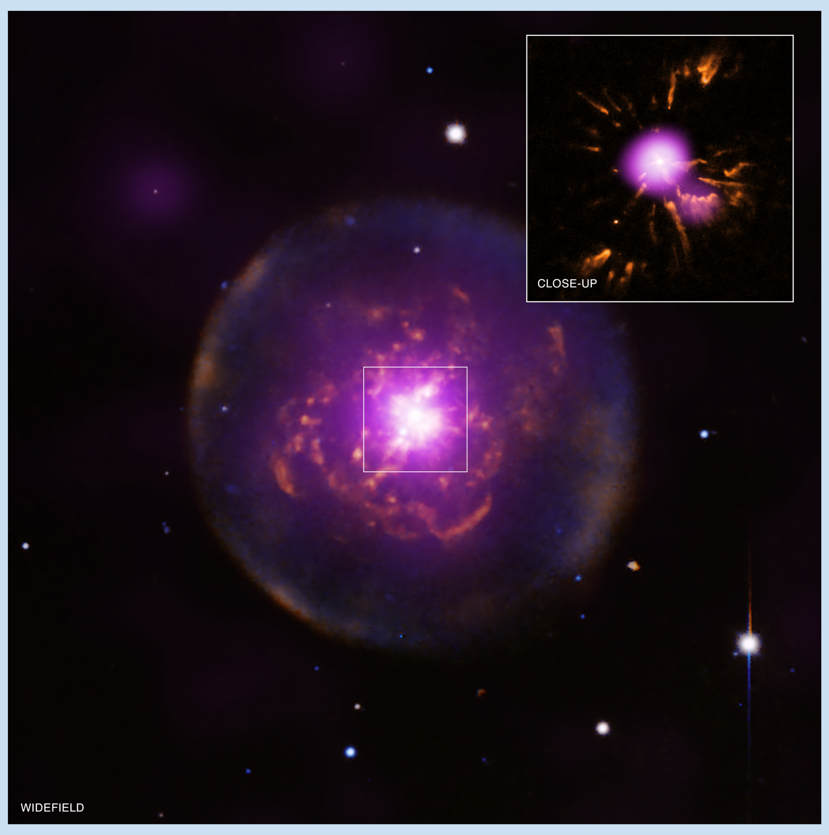
Mass-loss rates and stellar wind velocities were found using:

AGB Superwind: Verbena et al. 2011,

Cool Giant Winds: Schröder & Cuntz 2005,

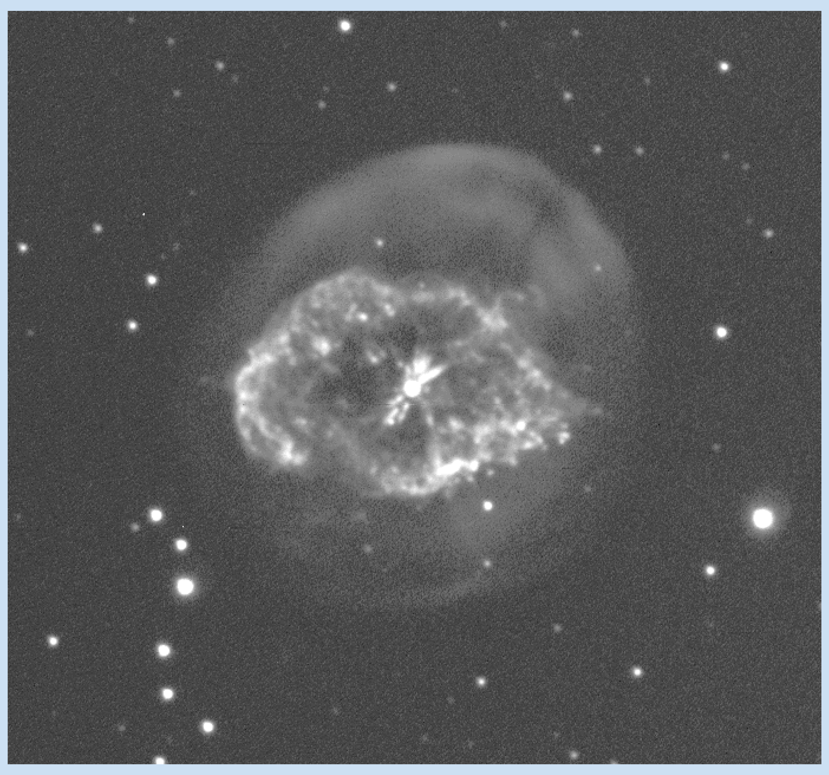
Hot Star Winds: Kudritzki et al. 1989; Pauldrach et al. 2004.

Born-Again PN A30



Guerrero et al. 2012

Born-Again PN A78

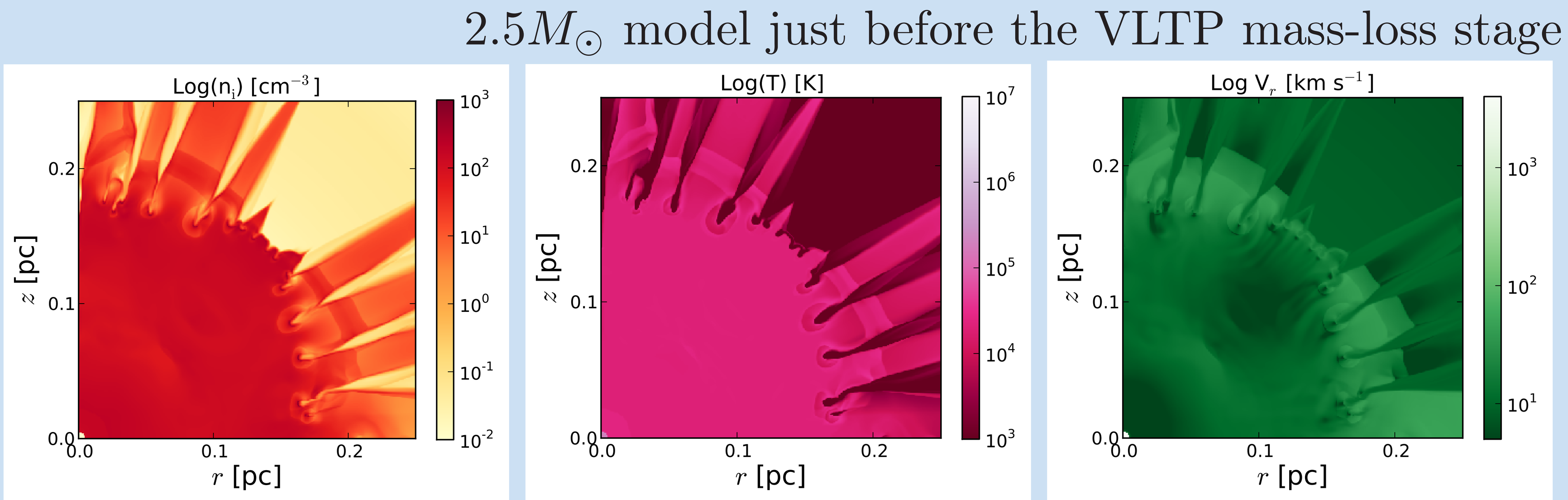


Jacoby 1979

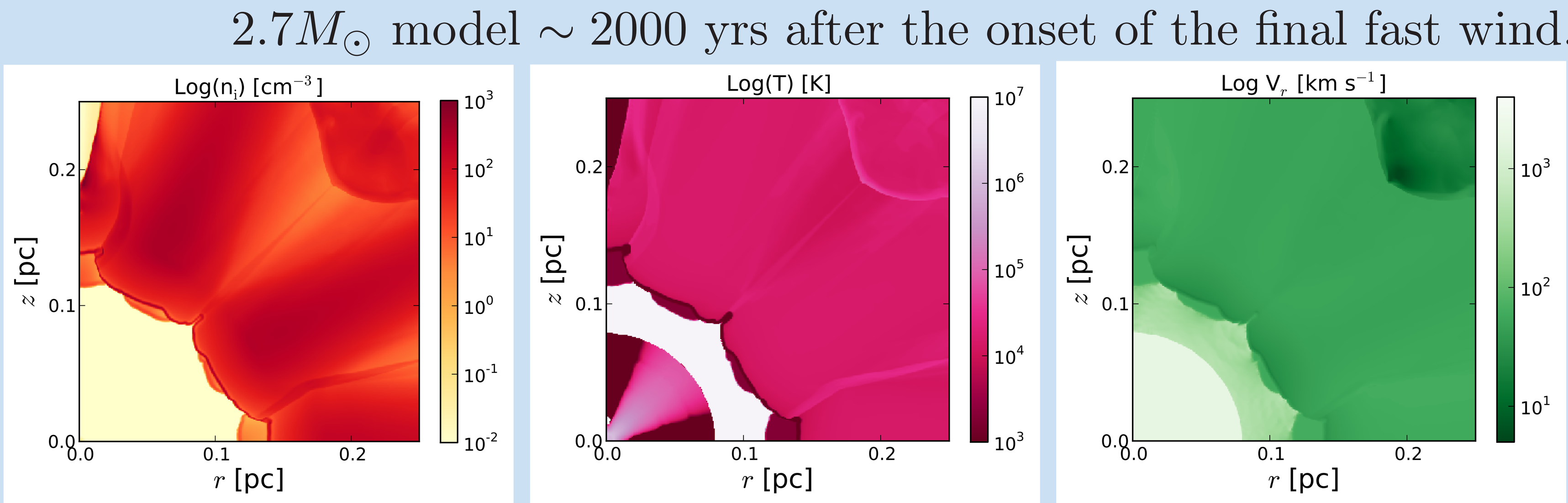
2D Models

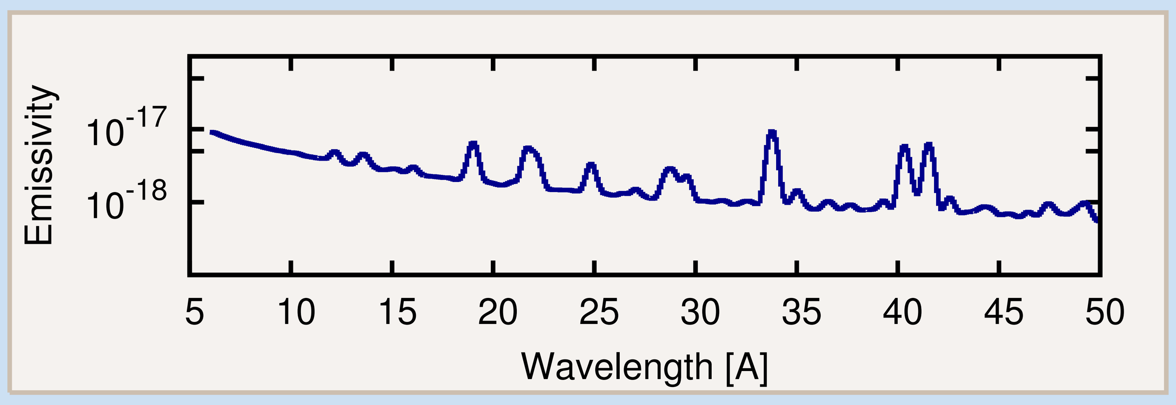
Hydrodynamic, ionization and cooling instabilities break up the dense swept-up shell.

$2.5M_\odot$ model just before the VLTP mass-loss stage



$2.7M_\odot$ model ~ 2000 yrs after the onset of the final fast wind.

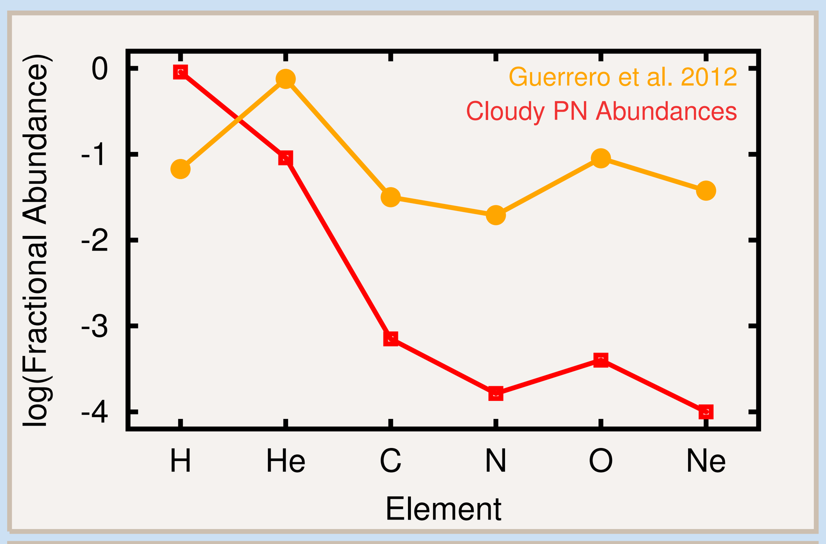


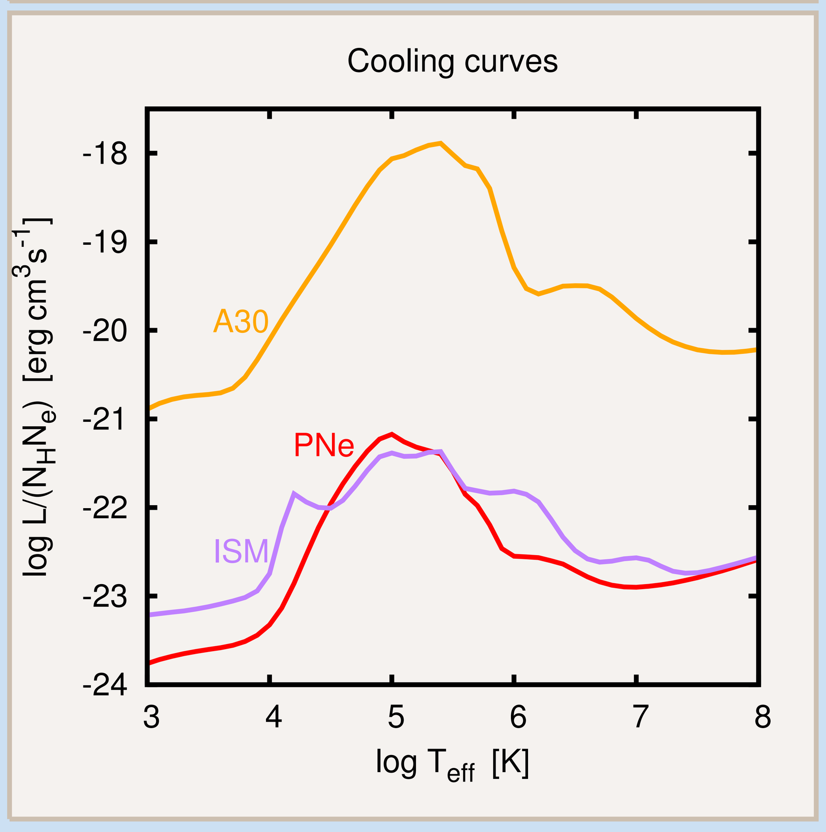


Intrinsic X-ray spectrum calculated with the *CHIANTI* code for the $2.7M_\odot$ 2D simulation.

Abundances

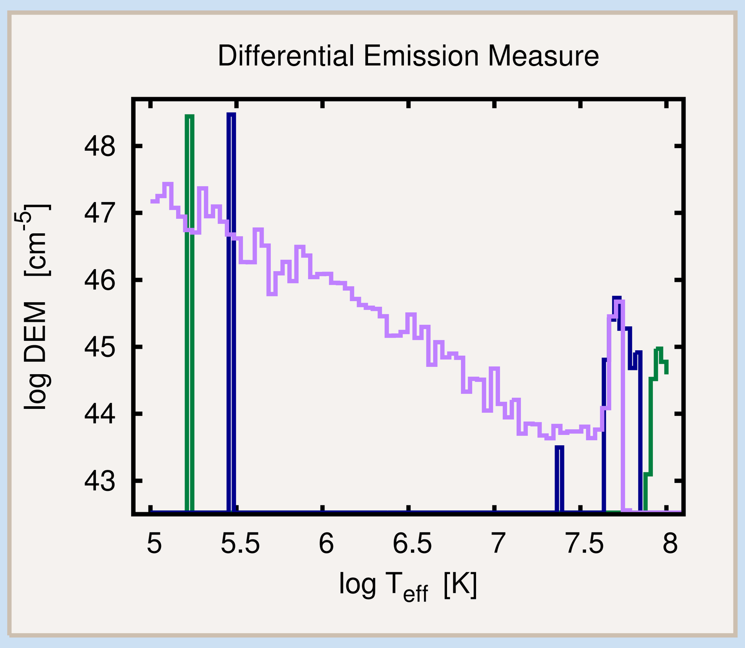
We take into account the evolving chemical abundances of the material expelled from the post-AGB star in the radiative cooling rate.





DEM

In 1D, hot gas at $\sim 10^8$ K in both models dominates the spectrum. In 2D, there is a broader spread of temperatures, but $\sim 10^8$ K gas dominates the spectrum.



Summary

The results are very sensitive to the detailed mass-loss history of the central object. 1D models do not capture the formation of structures due to instabilities. Processes such as thermal conduction should be included to reduce the temperature of the hot bubble. Very high numerical resolution is required to study the region closest to the star.

References:

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