Modeling X-ray Emission from Planetary Nebulae

M. Steffen*, D. Schönberner*, A. Warmuth*, A. Schwope*, E. Landi†, M. Perinotto** and N. Bucciantini**

*Astrophysikalisches Institut Potsdam. Potsdam, Germany
†Artep Inc., Ellicott City, MD, USA
**Dipartimento di Astronomia e Scienza dello Spazio, Firenze, Italy

Abstract. Recent observations using the Chandra X-ray Observatory and XXM Newton revealed without doubt diffuse X-ray emission from the shock-heated wind gas in planetary nebula (PN) interiors. Typical properties of the emitting gas are temperatures of a few 10^6 K and electron densities of the order of 100 cm^{-3}. According to current hydrodynamical models, the shocked gas becomes too hot ($T \approx 10^7$–10^8 K) and too tenuous ($n_e \approx 1$ cm^{-3}) to produce the observed X-ray emission. However, the hot gas is confined by the rather cool ($T \approx 10000$K) nebular gas, and thermal heat conduction across the interface between the hot and cool gas becomes important. It changes the contact discontinuity into a more extended transition layer covering the temperature range where the observed X-ray emission is thought to arise. To date, only similarity solutions for the hydrodynamical problem of PN evolution with heat conduction have been derived (Zhekov & Perinotto 1996). We present first results from new numerical simulations of the PN evolution including thermal conduction by electrons. We confront the X-ray luminosities predicted by these models with those derived from XMM/Chandra observations.

FIRST RESULTS

In order to study the effect of electron heat conduction on the properties of Planetary Nebulae, we have compared two sequences of 1D hydrodynamical models, one computed with, the other without heat conduction. Both sequences describe the evolution of a PN with a central star of $M = 0.595\,M_\odot$ over a period of ≈ 10000 years.

Following Spitzer (1962) and Cowie & McKee (1977), heat conduction is treated as a diffusion process, with a diffusion coefficient that depends on electron temperature and density. It turns out that heat conduction is negligible in the relatively cool PN proper. Likewise, the free flowing stellar wind is not affected by heat conduction; it remains cool. However, heat conduction strongly influences the structure of the 'hot bubble' consisting of shocked wind matter: After 5640 years of post-AGB evolution, we find that $T \approx 5\,10^7$ K and $n \approx 0.5$ cm^{-3} are nearly constant inside the 'hot bubble' when heat conduction is ignored, while the temperature falls by 2 orders of magnitude towards its outer edge (the contact discontinuity), and density increases by the same factor (i.e. gas pressure remains uniform), when heat conduction is taken into account. Although uncertain numerically, we estimate that the total mass of the 'hot bubble' is at least a factor 10 larger in the models including heat conduction.

Using the CHIANTI code (e.g. Young et al. 2003), we have computed synthetic X-ray maps and spectra from the hydrodynamical PN models. We find that the X-ray luminosity ($5-28$ Å) increases more than 10 times when including heat conduction. The X-ray luminosities predicted by our hydrodynamical models are, however, still too low by factors $\approx 2--10$ compared with recent observations (see Fig. 1). Possible reasons for this discrepancies are currently under investigation. A faster evolution of the central star, for example, will lead to a more compact 'hot bubble' and presumably to a better match of the X-ray luminosities.

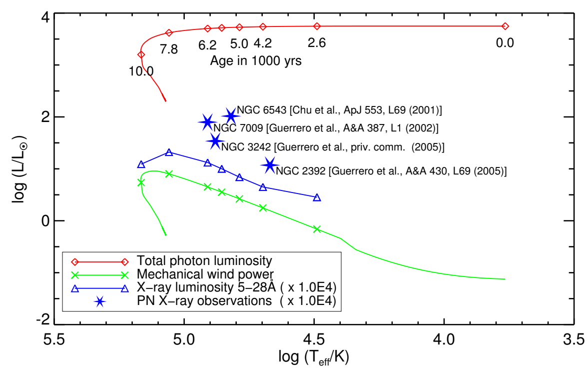

FIGURE 1. Hertzsprung-Russell-Diagram showing the evolutionary track of the central star (diamonds), the corresponding evolution of the wind power $\dot{M}V^2/2$ (crosses), and the X-ray luminosity (between 5 to 28 Å, triangles) for our hydrodynamical model sequence. Stars represent PN X-ray sources observed by XMM/Chandra (Guerrero et al. 2005, priv. comm.); errors due to uncertain distances are eliminated by plotting the observed X-ray luminosity as $L_X = L_{\rm phot}^{\rm model} \times (L_X^{\rm obs}/L_{\rm phot}^{\rm obs})$. All X-ray luminosities are scaled up by a factor 10000.

REFERENCES

Cowie, L.L., & McKee, C.F. 1977, ApJ, 211, 135
Spitzer, L. 1962, Physics of fully ionized gases (Wiley)
Young, P.R., et al. 2003, ApJS, 144, 135
Zhekov, S.A., & Perinotto, M. 1996, A&A 309, 648