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IONIZATION MODELS FOR AXI-SYMMETRICAL OBJECTS OR JETS

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RESUMEN

Cuando tomamos un espectro de objetos nebulares, obtenemos información de una banda muy delgada de la imagen. Debemos, entonces, usar modelos para predecir lo que debe verse en esta banda delgada. Presentamos un nuevo esquema para acoplar un código de fotoionización con simulaciones hidrodinámicas 2D y predecir la emisión de objetos axisimétricos, fotoionizados o excitados por colisiones

ABSTRACT

When we obtain a slit spectrum from nebulous objects, we take a narrow pencil through the image. We must, then, use the model to predict the emission from this pencil beam and compare it with the relevant observations. We present a new scheme for modeling or coupling the photoionization code with 2D hydrodynamic simulation to predict the emission of axi-symmetric photoionized objects or shocked excited objects such as jets or PN halos.

Key Words: **HYDRODYNAMICS — PLANETARY NEBULAE: INDIVIDUAL (NGC 6543, NGC 6826) — STARS: WINDS, OUTFLOWS**

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1. INTRODUCTION

Spectral line intensities of planetary nebulae (PNe), H II regions, and Seyfert galaxies are often best understood by a photoionized modeling procedure. Roughly speaking, there are two approaches to photoionization (PI) modeling: 1) one dimensional (plane-parallel or spherically symmetric) models, such as those of Cloudy and other codes (see Ferland 1995), and 2) a 3-D approach, as carried out by Bassgen et al. (1990) and Gruenwald et al. (1997). Nebular objects are not spherically symmetric and one uses a long slit spectrograph or an echelle slit entrance (e.g., $2 \times 4''$) to observe a small portion of the object. Thus, one must use the 3-D or axisymmetric modeling procedure.

The hydrodynamic simulations, such as those of Mellema (1993) and Frank (1992), are useful for the study of shaping of nebular objects or monochromatic images in strategically important diagnostic lines, [N II], [O III], etc. Although gasdynamic simulations include the PI aspect, it is not fully useful for the spectral data analysis. Thus, it would be valuable to develop a modeling procedure which predicts both spectral intensities and monochromatic images.

A fairly large fraction of nebular objects show bilateral symmetries, bipolar conic or torus in AGN or elliptical or bipolar in PNe. We present an axi-symmetric modeling procedure, coupling method of the PI calculation with a two dimensional hydrodynamic simulation which may have an application to the (shock excited) jet or halo emission study.

2. IONIZATION MODEL

Shock treatments including ionization, e.g., Dopita & Sutherland (1996), are useful for a study of emission in jets or halo filaments. The jet or halo may be aligned radially from the center, (1) core H II region (PI region) + outer halo (shocked heated H II region or partially ionized), or (2) H II region (PI) + jets or FLIERs (shocked outer region). Thus, either PI or hydrodynamics alone would not be sufficient to explain these ionized structures. Both recent (core) and older (outer) ejection, e.g., of post-AGB, must be treated correctly by taking PI and shock excitation into account.

Hyung (1994) and Hyung & Aller (1996) described how to construct an axi-symmetrical pure PI model for PNe, following 4 steps: (1) calculation of more than two appropriate PI models; (2) assignment of the above 1-D PI models to an idealized axi-symmetric model geometry, i.e., latitude angles to each composite shell model; (3) transformation of the spherical geometry into Cartesian coordinates; and (4) Euler angle rotation, $X' = AX$. This rotation is necessary to consider not only the slit entrance size, but the cross-section along the line of sight involving the geometry. Here, we propose a new method to model the emission of halo or jets by coupling a PI model with the hydrodynamics. Note that the 2-D hydro code and the axisymmetric PI

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TABLE 1

PREDICTED INTENSITIES[a]

	MCW[b]	$I_{\rm pred}$
[O III] 4363	28.1	30.52
4959	518.0	582.0
5007	1528	1676
$T_{\rm [O\,III]}$ (K)	14 700	15 200

[a]Simulation result at $t = 2000$ yr with:
$\dot{M}_{\rm slow} = 10^{-6}$ $M_\odot$ yr^{-1}; $V_{\rm r}$(slow) $= 5$ km s^{-1};
$\dot{M}_{\rm fast} = 10^{-7}$ $M_\odot$ yr^{-1}; $V_{\rm r}$(fast) $= 2000$ km s^{-1}.

[b]Observations by Middlemass, Clegg, & Walsh (1989).

code must be fully-coupled.

The faint halos of NGC 6543 and NGC 6826 are known to be hotter than the core H II region. The hot fast stellar wind may have escaped beyond the central nebula and has shocked the filamentary halo. By coupling Euderink and Mellema's spherical (r, θ) Roe-solver code with Hyung's PI code, we simulated the halo emission of NGC 6543. Table 1 shows the result at a hydrodynamic time, $t = 2000$ yrs. The hydrodynamic simulation produces a shock heating and density enhancement; and the PI part of our code predicts the [O III] intensities and 4363/5007 ratio, fairly correctly. Here, we use the abundances derived for the core H II region by Hyung et al. (2000). Apparently, there are no O abundance enhancement in the halo of NGC 6543, contrary to previous studies.

3. DISCUSSION

Since one often selects only a tiny fraction of the entire nebula in observations, one does not need to worry about the whole geometry. Thus, one can limit the calculation region within a specific part. For a toroidal ring type object, we may choose a lower latitude zone of spherical shell in our model, e.g., equatorial shell with $-5^\circ < \theta < 5^\circ$, while for a collimated structure such a jet or shock heated filaments in halo, we may choose a polar conic zone with a relatively small opening angle, e.g., $\theta > 80^\circ$. As mentioned above, in PN NGC 6543, the O abundance of the halo region may be not different from that of the core region. The same may be largely true for PN or stellar jets or HH objects. In studying the *HST* monochromatic images or emission of jets or HH objects, one must not modify abundances to fit the emission until various other important factors, such as shocks and geometries, are fully examined. In summary, a spherical 2-D axi-symmetric ionization modeling scheme would be useful in studying the spectra of Bipolar PNe, Jets, AGN conic NLR and toroidal BLR, or axi-symmetric objects.

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