MODELING AND DISTANCE DETERMINATION OF PLANETARY NEBULAE

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Abstract. At present the lack of a good, generally accepted distance scale is the major limitation in the study of Planetary Nebula (PN) evolution and their distribution. We describe our fully self-consistent method to derive the physical parameters of a PN, including its distance, from a set of observables. For this we calculate various models and search for a best fit of the model predictions to the observables. An accurate determination of the angular diameter is important for a good distance determination. We think that we shall achieve an accuracy of 30% in distance. We estimate the error in stellar temperature at less than 15% and the uncertainty in the abundances at 0.10 dex.

Key words: planetary nebulae – distance determination – photo-ionization modeling

1. The Method

To model a planetary nebula we use our modified version of the photo-ionization code Cloudy 84.06 (Ferland, 1993). For the model we make the following assumptions:

1. The central star has a blackbody spectrum.
2. The nebula is a spherically symmetric, constant density, ionized shell surrounded by a r^{-2}-density, neutral shell
3. The PN-type dust is intermixed with the gas.

Despite its apparent simplicity this model should give reasonable predictions, because our observables are integrated quantities and we are only interested in the mean properties of the nebula.

The above assumptions give the following free parameters: the stellar temperature, the number of hydrogen ionizing photons, the total hydrogen density in the ionized region, the inner radius of the nebula, the dust to gas ratio, the distance to the nebula and the abundances in the nebula. With given values for these input parameters, it is possible to calculate a model for the nebula with Cloudy, predicting the continuum and line fluxes, photometric magnitudes (with line contamination) and the Strömgren radius.

Our objective is to derive from a given set of observables the physical parameters of the PN. Therefore we assume that there exists a unique set of input parameters, for which the resulting model predictions give the best fit to the observables. These input parameters are then considered the best estimate for the physical properties of the PN. To compare the model predictions with the observed quantities we calculate the goodness-of-fit estimator χ^2. This continuous function is minimized by varying all the input parameters of the model, using the algorithm AMOEBA (Press *et al.*, 1988). The observed quantities we need are:

1. The spectrum of the nebula. Usually this is an optical spectrum, but might also be a UV or IR spectrum. The line ratios make it possible to constrain the stellar temperature, the density and the electron temperature in the nebula. They are also needed to determine the abundances.
2. Since we include dust in the model we also want information on the mid- and far-infrared continuum. For this we use the IRAS fluxes.
3. To constrain the emission measure, we need either a radio continuum measurement (e.g. at 6 cm) or the absolute flux value of some hydrogen recombination line (usually Hβ).
4. We also need a very accurate angular diameter of the nebula.

2. Testing the Method

We calculated a model PN at a distance of 3.94 kpc to investigate how well the method could retrieve the physical parameters and distance using the computed "observables". The model is typical of a very young PN with low excitation. When we used the correct value for the computed observables, we could retrieve the physical parameters and the distance within 7.5%, and the luminosity within 15%. When we introduced "measurement" errors on the angular diameter, we found a strong correlation between the distance and the angular size. For our model nebula the dependence is at least quadratic.

3. Conclusions

The method needs further testing to assess the influence of measurement errors on the results. It is already clear that an accurate determination of the angular diameter is important for a good distance determination. We think that we shall achieve an accuracy of 30% in distance and thus an accuracy of 60% in luminosity. We estimate the error in stellar temperature at less than 15% and the uncertainty in the abundances at 0.10 dex.

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