Putting Radiation Hydrodynamics into a Detailed Model Atmosphere Calculation

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Abstract. To improve radiation-hydrodynamics calculations from grey transport, then to multi-group transport, and finally to spectrally-resolved radiation transport, requires resources that greatly exceed today’s computer capabilities. However, it is possible to combine a grey radiation-hydrodynamics code with a non-grey model-atmosphere code to obtain more realistic results. In this presentation we describe our current work to combine the atmosphere code PHOENIX and the radiation hydrodynamics code TITAN. We use PHOENIX to tabulate the material functions such as the equation of state and the mean opacities. TITAN can then solve a radiation-hydrodynamics problem such as a shock in an atmosphere for which the initial structure is provided by PHOENIX. The resulting atmospheric snapshots can then be fed back into PHOENIX to calculate high-resolution spectra including a full NLTE treatment. Our goal is to apply this method to obtain high-quality spectra of Mira variables as a function of phase.

1. Introduction

In order to calculate phenomena such as shocks traveling through, or pulsations of, an atmosphere it is necessary to treat time-dependent radiation-hydrodynamics. If these phenomena produce emission lines or other highly non-grey properties, it is necessary to do a detailed radiative transfer calculations as well. Depending on the problem, it may be possible to separate these tasks. However, for highest realism it is desirable to solve the problem with a time-dependent spectrally-resolved radiation-hydrodynamics calculation. The latter requires huge amounts of computer resources, which only now are becoming available. As an intermediate step we propose a consistent coupling of a radiation-hydrodynamics code and an atmosphere code. This example deals specifically with TITAN (Gehmeyr & Mihalas 1994) and PHOENIX (Hauschildt & Baron 1999) and our current efforts to combine the two.

2. The Method

We decided to adjust TITAN to accommodate our goals. This decision is based on the design of TITAN and the encouragement of TITAN’s authors to do so.
Figure 1. The two material functions, the equation of state (the left panel showing the adiabatic gradient $\gamma$ as an example) and the mean opacities (the right panel showing the Rosseland mean opacity as an example) that have been calculated using PHOENIX and will be used as input to TITAN.

2.1. The atmospheric calculations by PHOENIX

PHOENIX is used to calculate the necessary input data such as material functions and starting structures. We have tabulated the mean molecular weight, the adiabatic gradient, the Rosseland mean opacity, and Planck mean opacity as a function of gas temperature and gas density over a wide range of atmospheric conditions. Two examples are shown in Fig. 1 where we plot the adiabatic gradient and the Rosseland mean opacity.

We also used PHOENIX to calculate a grid of spherically symmetric cool giant atmospheres. This is an update to the grid described in Hauschildt et al. (1999) which includes the improved physics described in Allard et al. (2001). In short, it includes the latest opacity sources and treats condensation inside the photosphere (see also Schweitzer et al. 2003, in preparation, for the giant grid). These static atmosphere structures will be used as initial structures for TITAN.

2.2. The radiation-hydrodynamics calculations by TITAN

As mentioned we have made several modifications to TITAN. As an initial structure it takes the atmosphere structure calculated by PHOENIX to map the starting temperature and density run. The opacity-routine has been modified to read in the opacity table generated by PHOENIX and the equation of state has been modified to read in the equation of state table produced by PHOENIX. Titan then calculates the time-dependent evolution of a shock. For all desired time steps, the atmosphere structures will be saved and used as input for a spectrum synthesis by PHOENIX as described in the next paragraph.

2.3. The spectroscopic calculations by PHOENIX

The next step is to use PHOENIX to calculate detailed high-resolution non–LTE spectra from the time steps calculated by TITAN. PHOENIX will take atmosphere structures that contain shocks and use them to calculate the radiation field emerging from these structures. Any iterations will only be performed to solve the non–LTE problem; the temperature structure will be kept fixed.
3. Conclusions and Outlook

The advantage of our approach is the consistency in the data used. We use the same opacity data and equation of state data throughout the entire calculation. However, within TITAN there are still interpolations required to obtain the material functions tabulated by PHOENIX. Also, the tabulation was done for the LTE case. Therefore, no non-LTE effects that alter the material functions are accounted for.

We plan to apply this strategy to the shocked atmospheres of Miras, and because the expansion velocities of their envelopes are small, it is possible to neglect the velocity field as a first approximation. However, PHOENIX is capable of treating an expanding atmosphere. The only complication that has to be addressed is the non-monotonic velocity field present in a shocked atmosphere.

Another improvement that can be made is to use multi-group radiative transfer instead of a grey treatment. PHOENIX can not only calculate grey mean opacities but also opacities for the multi-group treatment.

As an even further improvement, we plan to couple the two codes even closer. It is foreseeable that either TITAN could call PHOENIX as a subroutine to do the radiative transport, or that PHOENIX could call TITAN as a subroutine to do the hydrodynamics. Then there are no interpolations required and non-LTE effects can be taken into account naturally. The computing resources required to perform such a calculation are huge but are becoming available now.

Currently no results are available. The purpose of this contribution was to present our strategy to calculate shocked photospheres of Mira variables. We will be presenting actual calculations in the near future.

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References

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