Proceedings of 12th Cambridge Workshop on Cool Stars, Stellar Systems, & The Sun, 2003 University of Colorado.

Dynamic Modelling of the Outer Atmosphere of α Tau

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Abstract. Using one-dimensional radiation-hydrodynamics simulations a model of the outer atmosphere of α Tau is created. The reaction of the model to acoustic waves is explored. It is found that high frequency waves are radiatively damped out in the photosphere. The lower frequency waves above the Hydrodynamic acoustic cutoff frequency do produce some chromospheric heating.

1. Introduction

Static one-dimensional plane-parallel modelling of α Tau (K5 III) (McMurry 1999) can fit the collisionally excited uv emission lines produced in the chromosphere very well, but do not predict the fluorescent uv emission lines, especially those of molecules, with any accuracy (McMurry, et al. 1999). The fluorescent lines of CO require material at 2000K and material at at least 5000K in close proximity to be produced in the observed flux ratios (McMurry and Jordan 2000). One means to create such conditions is at the front of acoustic-type shock waves running through the atmosphere. This prompted the study of acoustic waves travelling through the outer atmosphere of α Tau.

This modelling was done with no preconceived ideas as to whether or not acoustic shocks are able to provide the observed chromospheric heating in giant stars, or to produce the observed stellar wind, but keeping in mind that these were possible outcomes of the simulations. This paper presents preliminary results from the simulations, the main one being the radiative damping of acoustic waves taking place in the photosphere. There is much work still to be done before a more complete study of acoustic waves in a 1d plane-parallel model of α Tau can be presented.

2. Modelling Technique

The simulations use the code of Carlsson and Stein (1997). This solves the equations of radiative-hydrodynamics on a one-dimensional, plane-parallel model. The equations consist of the hydrodynamic equations of mass, momentum and energy conservation, the equation of radiative transfer, and the rate equations for atomic transitions. The continuum transitions of important elements are

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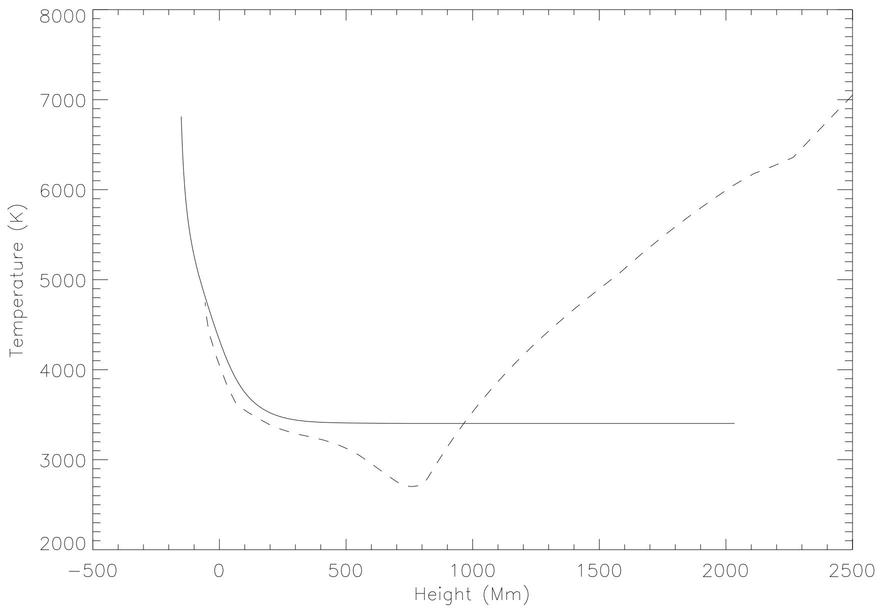

Figure 1. Temperature against atmospheric height for the initial state of the dynamic model (solid line) and the static model (dashed line).

included in the simulations but only the line and continuum transitions of hydrogen are calculated in detail in current runs with this model. The adaptive grid of Dorfi and Drury (1987) is used to concentrate grid points where they are needed, eg on shock fronts.

The model was created by taking a radiative equilibrium model created with the Uppsala Stellar Atmospheres (MARCS) code. This model was then extended upwards at constant temperature, using the temperature of the highest point in the radiative equilibrium model. This is compared to the static 1-d model of α Tau which reproduces the observed collisionally excited chromospheric emission lines in figure 1.

3. Radiative Damping

The most important discovery from these simulations so far is the radiative damping of acoustic waves in the photosphere. The damping behaves like viscous damping, in that the damping rate appears to be proportional to frequency. Figures 2 and 3 show the propogation of waves with two frequencies; one with a period of 40000 s is not damped out in the photosphere and survives to form shocks in the chromosphere. The other has a period of 10000 s and is damped out in the photosphere. These are also shown in movies accompanying this paper. Within the photosphere, the waves are damped out in a certain number of wavelengths. For longer period waves, these wavelengths do not fit in the photosphere, and the waves can escape. For shorter period waves, these wavelengths

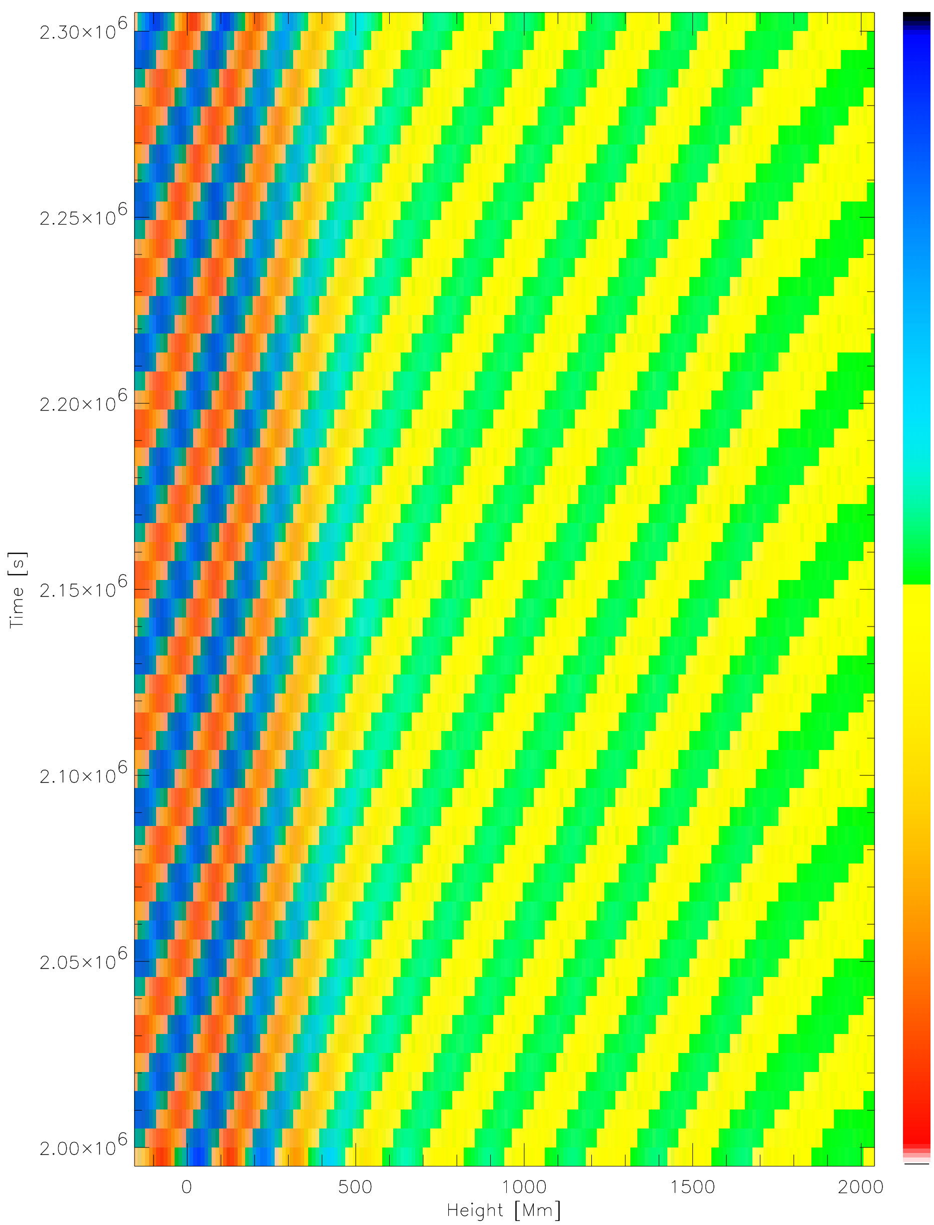

Figure 2. Wave propogation of waves of period 40000 s, showing square root of the acoustic flux in colour with height horizontally and time vertically.

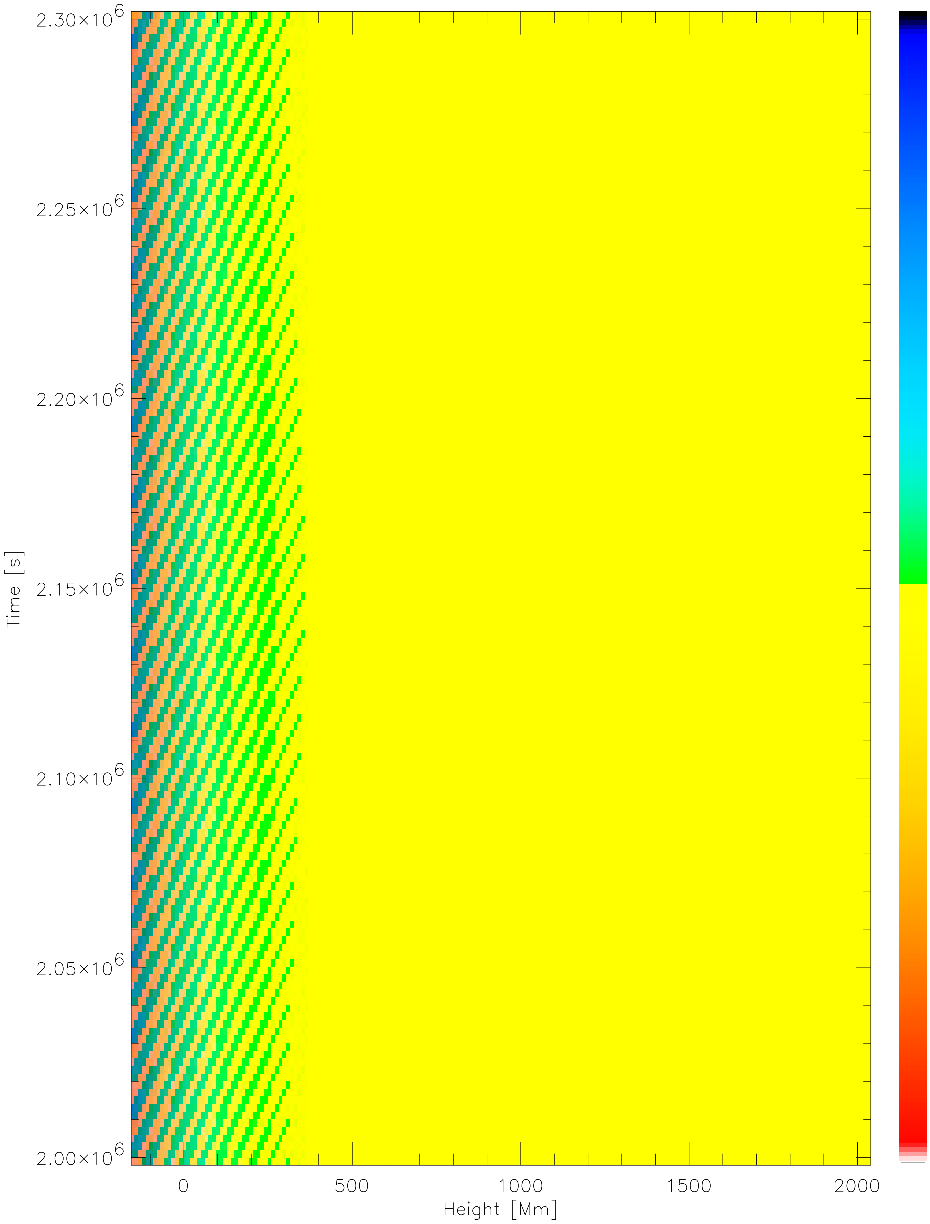

Figure 3. Wave propogation of radiatively damped waves of period 10000 s, showing square root of the acoustic flux in colour with height horizontally and time vertically. The velocity scale is the same as that used in figure 2.

do fit in the photosphere and the waves are damped out. There are high velocity waves visible in the movie of the 10000 s waves, which are probably radiative dispersion waves. For the 40000 s waves, it can be seen that the wave speed increases towards the top of the model.

The radiative cooling time in the region where the damping occurs is at least an order of magnitude less than the wave periods invesitigated. Thus in the compressed parts of the wave, any of the energy that can be converted to radiation by collisions will be. On each compression a certain propotion of the energy is lost. This indicates that waves with a period of more than an order of magnitude less than 10000 s may be able to get through the photosphere.

4. Chromospheric Heating

It is currently an open question as to whether chromospheric heating in cool stars requires magentic effects or if acoustic shock waves are sufficient. Energy balance calculations suggest that high frequency acoustic waves would be required. If these waves are damped in the photosphere, then the ability of acoustic shocks to heat the chromosphere is much reduced. In these simulations some heating is observed, see figure 4 and the accompanying movies. However, until further models covering a larger height can be made, nothing certain can be said, as the observed heating may be due to the numerical upper boundary condition.

5. Conclusions

Initial results from simulations of acoustic waves in the outer atmosphere of α Tau show that acoustic waves are radiatively damped in the photosphere, with more damping of higher frequency waves. This is important for theories that the chromospheres of cool stars are heated by high frequency acoustic shock waves. We do see some evidence that acoustic waves that are not damped can provide some of the chromospheric heating when they become shocks.

References

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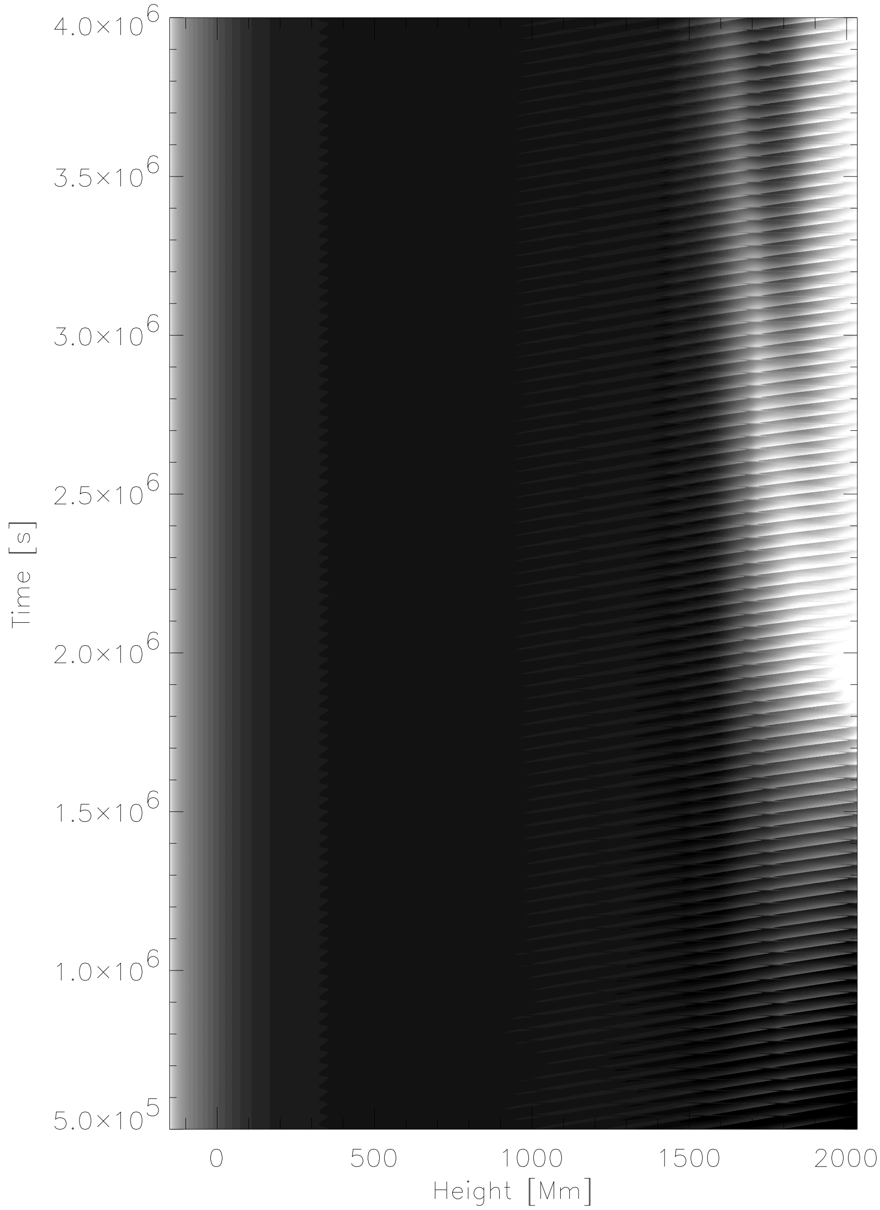

Figure 4. Temperature changes produced by waves of period 40000 s, with height horizontally and time vertically. Higher temperatures are brighter.