Modelling the Cloudy Atmospheres of Cool Stars

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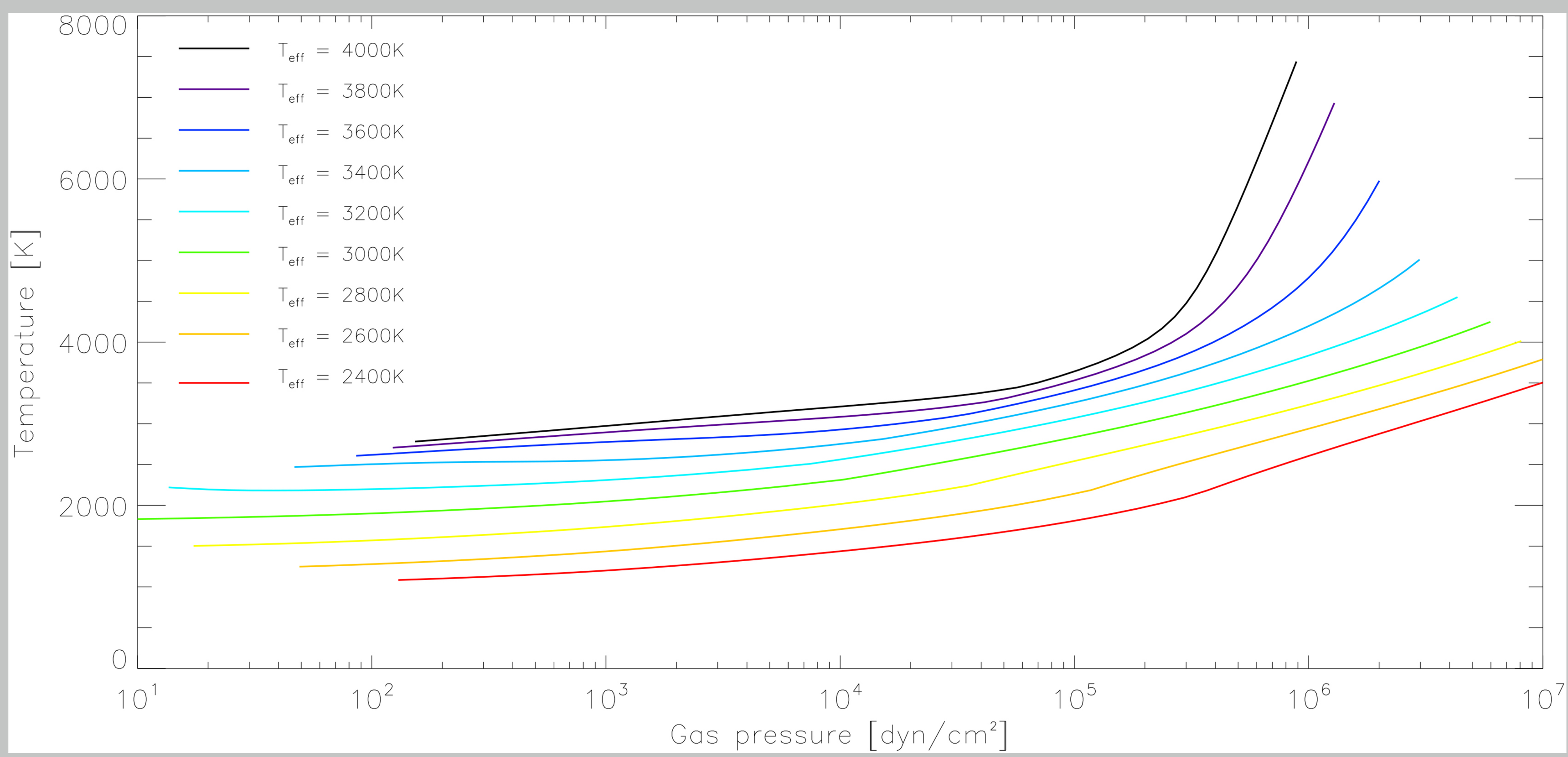
Introduction

M-dwarfs, small and cool stars on the main sequence, are particularly interesting when it comes to searching for new exoplanets as they are very common and their smaller sizes makes detection easier. Unfortunately, their low temperatures cause clouds to form in the upper layers of their atmospheres which makes them difficult to model. And since the biggest uncertainties of the properties of an exoplanet come from the uncertainties in the fundamental parameters of its host star, it is therefore crucial that the stellar models linking the observations of a star to its fundamental properties are determined as precisely as possible.

M-dwarfs were originally thought to be cloud free, but observations have revealed weaker molecular line absorptions than predicted by cloud free stellar atmospheres models (T. Tsuji et al., 1996). This is consistent with the formation of dust that strongly influences the local element abundances and thereby the spectra. In agreement with this, recent modelling of cool stellar atmospheres with clouds demonstrates that it is necessary to include dust formation when modelling the atmospheres of objects that have effective temperatures below 2700K (S. Witte et al., 2009).

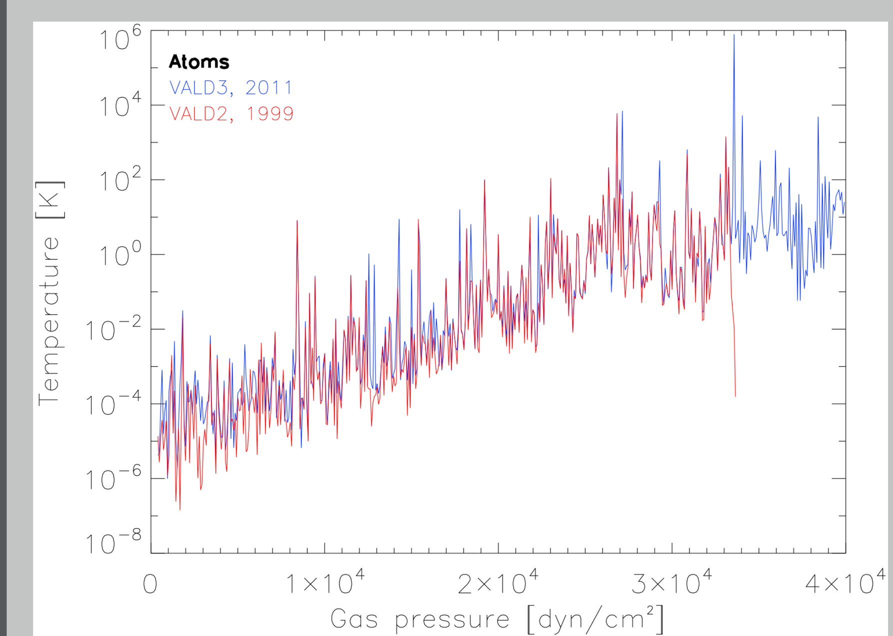
MARCS: Modelling stellar atmospheres since the 70's

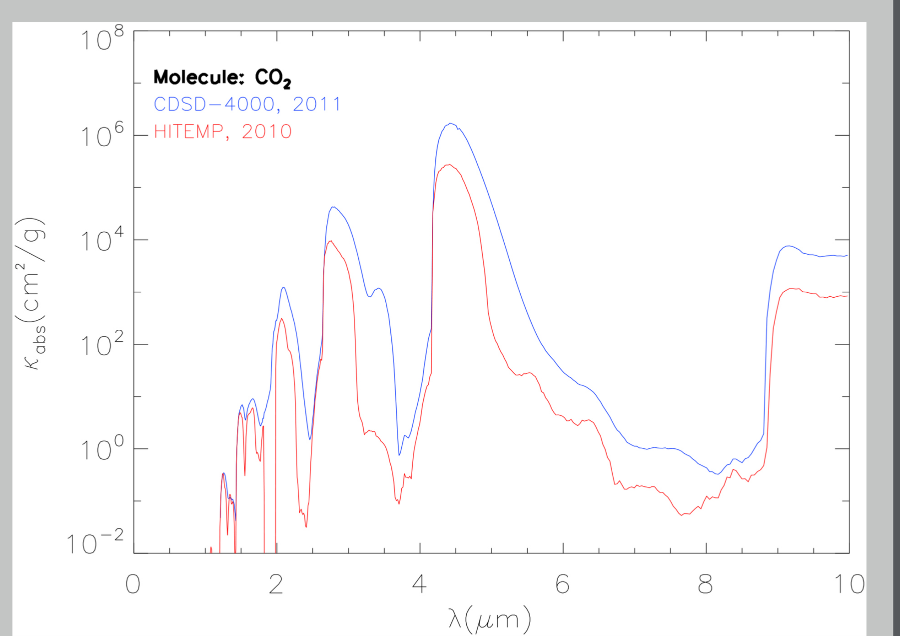
MARCS is the Scandinavian code for modelling stellar atmospheres (B. Gustafsson et al., 1975, 2008). It was introduced in 1975 and today it provides consistent solutions of the radiative transfer and the atmosphere structure and chemistry for stellar atmospheres of late A-type to early M-type stars. For MARCS to model late type M-dwarfs properly cloud formation needs to be included.



Temperature versus gas pressure for a range of stellar atmospheres modelled by MARCS.

The past few years have seen an explosion in the available line list data for both atoms and molecules. We have updated the atomic line database from VALD-2 to VALD-3 (F. Kupka et al., 2011) and updated or included new line data for the molecules CaH, CH_4, CN, CO, CO_2, CS, FeH, H_2O, HCN, MgH, OH, SiO, TiH and TiO.

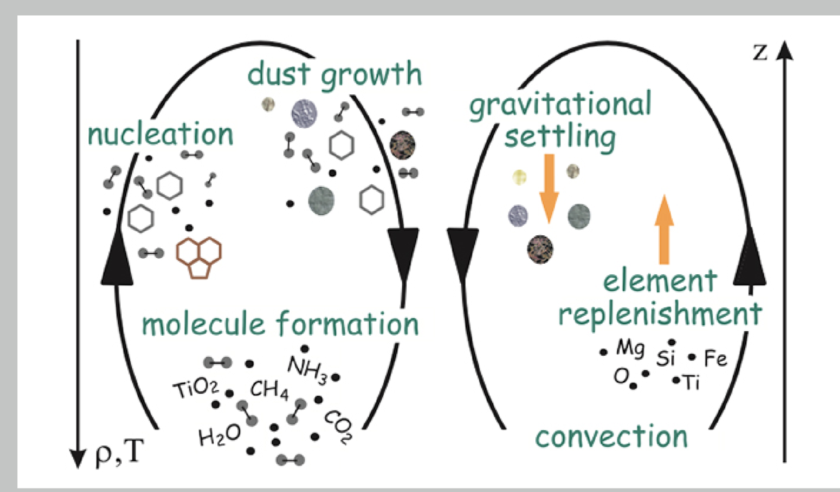




Comparison of old and new data for the atomic lines and the lines for the molecule CO_2.

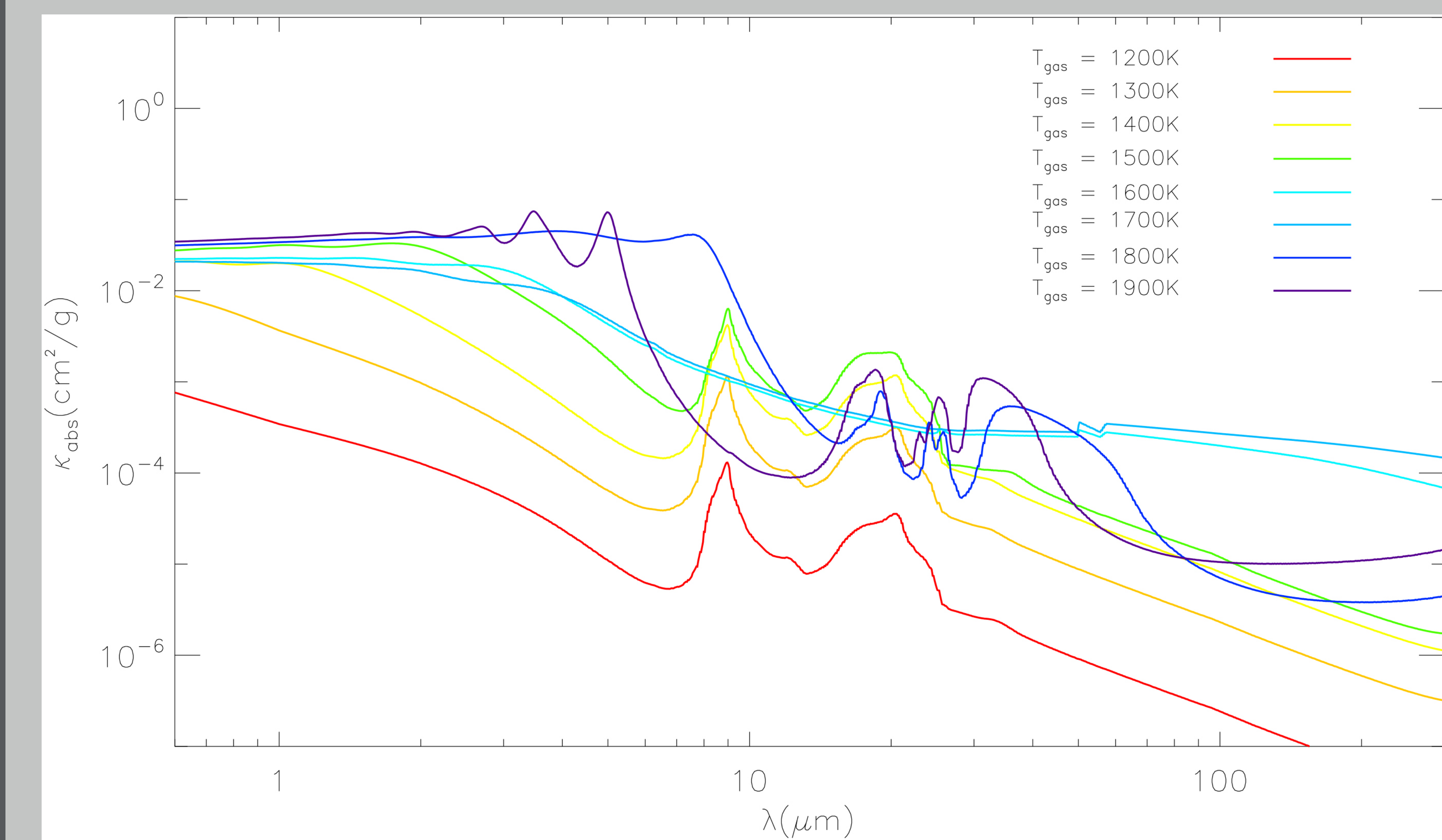
DRIFT: A quasi-static cloud model

The DRIFT code models clouds in cool atmospheres using non-equilibrium dust formation and drift (C. Helling et al., 2008). The illustration on the right describes the life cycle of the dust from atoms to molecules to seed particles to mixed grains and back to atoms again. Convection makes sure that the elements of the upper layers are replenished.



Given a stellar atmosphere with height-dependent temperature, pressure, convection velocity etc., DRIFT calculates the clouds that will form. Because of the high temperatures these clouds consist, not of water as we are used to here on Earth, but of mixed metallic dust grains composed of many small islands of different solid condensates such as TiO_2, Fe, Mg_2SiO_4 and Al_2O_3.

DRIFT provides information about the average sizes, composition and distribution of the dust grains in the clouds. From this the absorption and extinction as a function of wavelength can be calculated for each layer, and this is exactly what MARCS needs to know in order to calculate how the stellar atmosphere reacts to the increased opacity of the cloud layers.

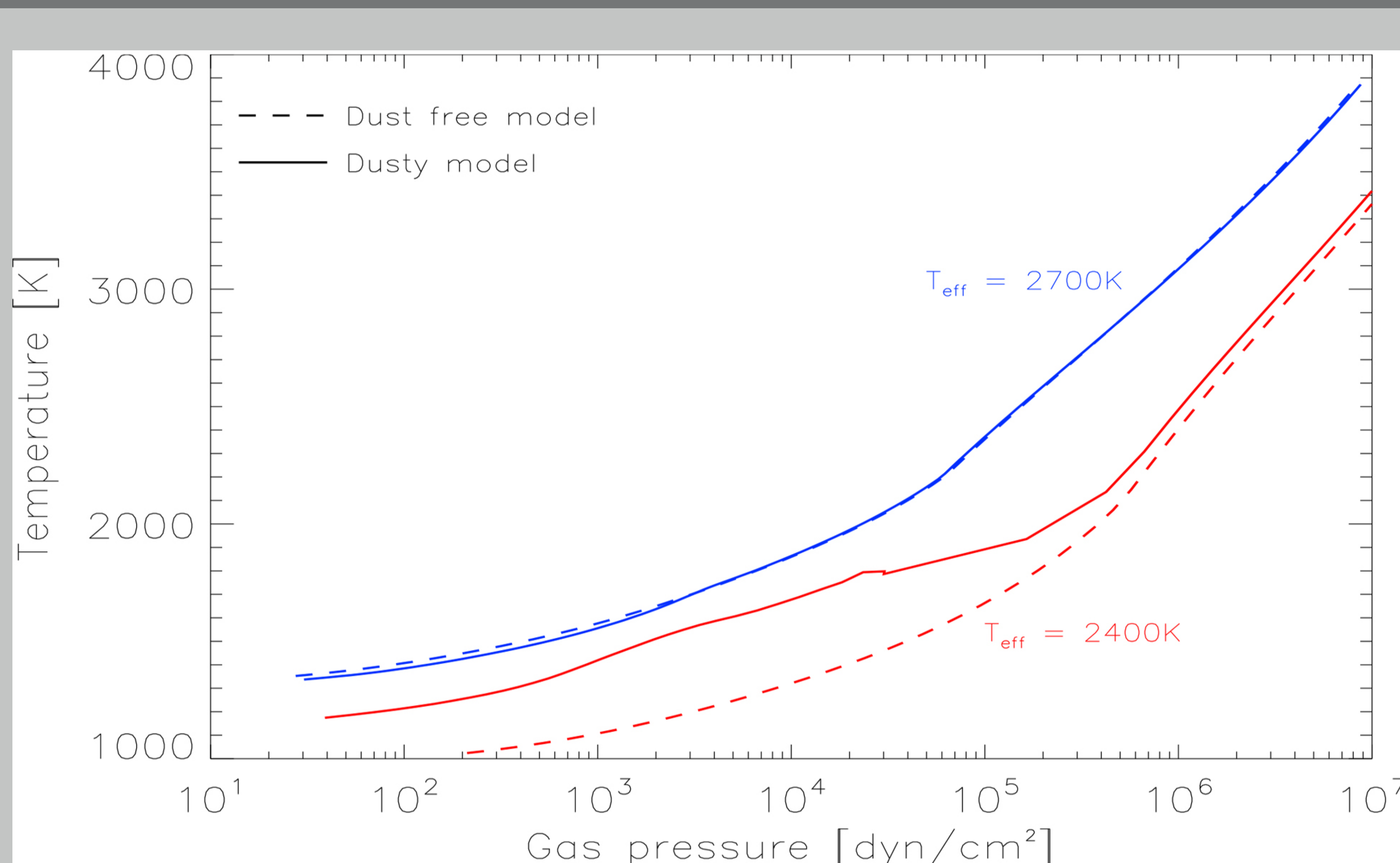


Absorption as a function of wavelength for different layers of an M-dwarf with T_{eff} = 2000K.

MARCS and DRIFT: Modelling cloudy stellar atmospheres

To create a stellar model atmosphere with clouds we start with a dust free model atmosphere. We use DRIFT to calculate its cloud layer and then MARCS to calculate the corresponding opacities and adjust the model atmosphere. An increase in opacity may typically cause the temperature to rise, so when we again use DRIFT to calculate the new cloud layer of the adjusted model, fewer clouds will form. The result is typically a decrease in opacity and temperature. We continue to run MARCS and DRIFT in turn until the model has converged.

The figure on the right shows dust free and dusty models at two effective temperatures. At $T_{eff} = 2700$K the stellar atmosphere is so warm that cloud formation can barely take place. Interestingly enough, the dusty model is slightly cooler than the dust free model. This is because the decrease in the molecular opacity (caused by the depleted element abundances) has a larger effect than the increase in the dust opacity. At $T_{eff} = 2400$K we see a large heating of the outer layers due to the increased opacity from the clouds. Note that the temperature of some of the layers increases by several hundred Kelvin - dust formation can have a big effect on a stellar atmosphere!



Comparison of dust free and dusty stellar atmosphere models.

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