Gas Opacity in Circumstellar Disks

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Abstract

We would like to address the question of how an accurate treatment of gas opacity impacts the equilibrium temperature in an innermost dust-free gaseous regions around stars. For this purpose we computed new advanced tables of gas opacity, which include 'two-temperature' Planck means. We test the new opacity on a standard radiation benchmark test and compare the resulting temperature profiles to those obtained with other gas opacity data and 'single-temperature' Planck means. The complicated underlying physics of gas absorption introduces a degeneracy into the equilibrium temperature in optically thin regime. A temporal evolution of the thermal energy needs to be traced in order to resolve the degeneracy. The new set of gas opacities can be used in radiation transport simulations of passive and accretion disks as well as of irradiated planetary atmospheres.

Why Is It Important?

1. Accretion disks:
   - flashlight effect, opening angle, outflow rate, disk life-time [1], [2]
2. Protoplanetary disks:
   - cooling rates, fragmentation, chemistry
   - visibility curves, SED [3, 4], spectral features
3. Irradiated planetary atmospheres.
   - temperature structure, chemistry, evolution

New Gas Opacity

Several different types of averaged opacity are needed in the simulations.

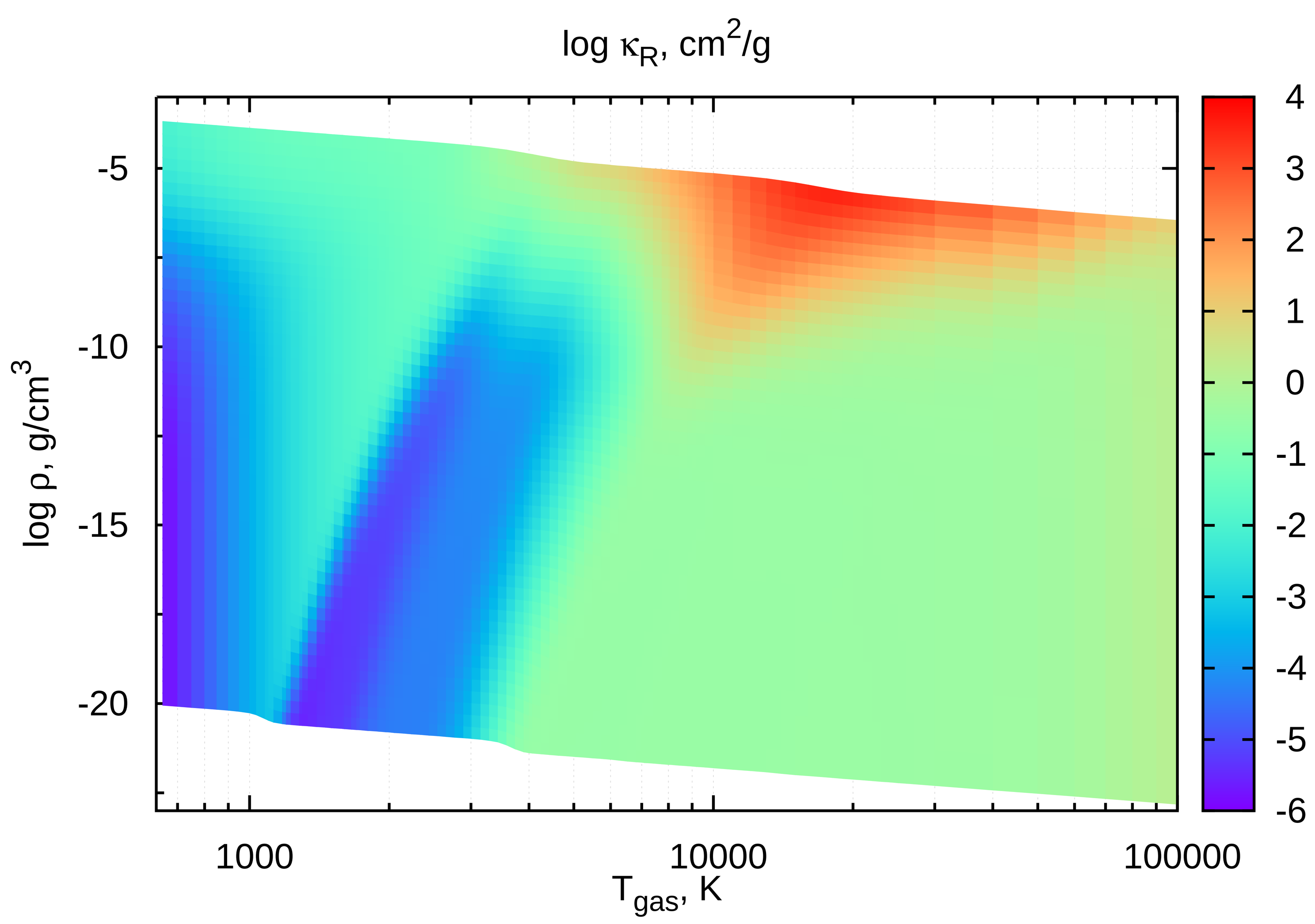

FIGURE 1: Logarithm of Rosseland mean (in colour) versus temperature and logarithm of density. [Me/H] = 0.0

Rosseland average - for optically thick regions.

$$\kappa_R^{-1} = \frac{\int \kappa_\nu^{-1} \partial_T B_\nu d\nu}{\pi^{-1} a c T^3}$$

In optically thin parts, where the gas at $T_{\rm gas} = T$ is irradiated by a star with $T_* > T$ - 'two-temperature' Plank average:

$$\kappa_p(T_*, T) = \frac{\int \kappa_\nu(T) B_\nu(T_*) d\nu}{\pi^{-1} \sigma T_*^4}$$

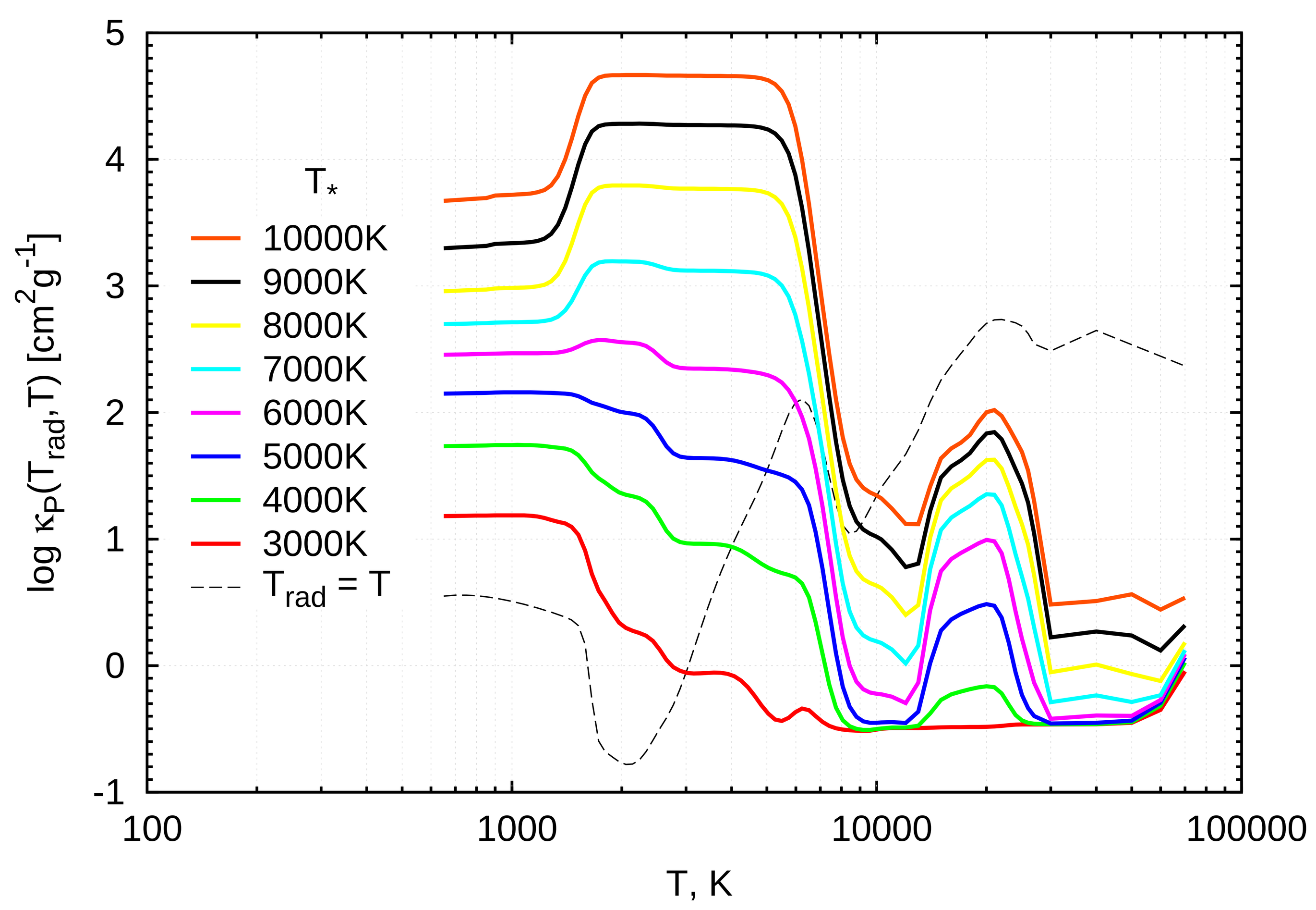

FIGURE 2: 'Two-temperature' Planck mean opacity. Gray dashed line is a 'single-temperature' Planck mean. $\varrho = 10^{-14}$ g cm^3.

We computed the new gas opacity tables making use of the publicly available code 'DFSYNTHE' [5]. The data set comprises Rosseland, Planck and 'two-temperature' Planck means and covers huge parameter space relevant for circumstellar medium (CSM) conditions.

Radiative Equilibrium

We consider a radiative equilibrium in an optically thin gaseous disk. The density set-up is that from a 2D radiative transfer benchmark test [6]. We adopt $T_* = 5777$ K, $R_* = 1 R_\odot$, $0.01 < r < 10$ AU, and set the scaling density to assure the disk remains optically thin in radial direction ($\varrho_{dust} = 0$). The equilibrium solution is then found numerically from

$$a_r T_{\rm eq}^4 = \frac{\kappa_p(T_*, T_{\rm eq})}{\kappa_p(T_{\rm eq})} \frac{F_*(r)}{c}.$$

The non-monotonous behaviour of the mean absorption with the gas temperature and density results in a degeneracy of the solution. Namely, for given ϱ and T_* there are several $T_{\rm eq}$, some of which are stable, others - not.

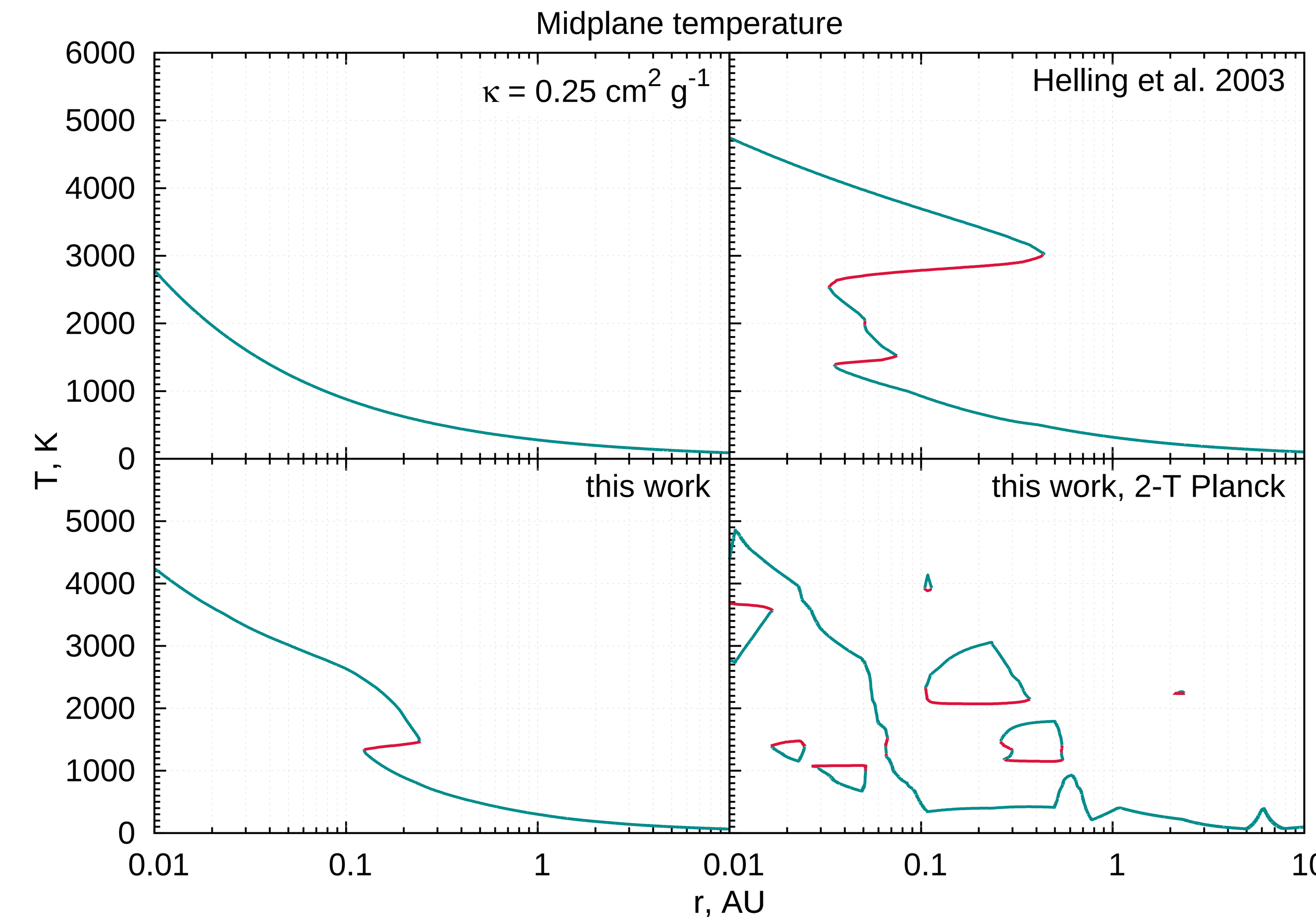

FIGURE 3: Roots for the midplane temperature radial profile in an optically thin regime according to different gas opacity data. The bottom right panel includes the correct 'two-temperature' description, for the rest we used $\kappa_{\rm P}(T_*, T) = \kappa_{\rm P}(T_*)$. The green colour correspond to the stable branches, the unstable ones are given in red.

Thus, the actual value of $T_{\rm eq}$ depends on the heating and cooling history, which within this simplified framework is described by:

$$\partial_t \varepsilon_{\rm th} = \kappa_p(T) c \varepsilon_{\rm r} - 4\sigma T^4 \kappa_p(T) + \kappa_p(T, T_*) F_*(r).$$

Conclusions

- the computed gas opacity set comprises 2-temperature Planck means & covers the parameter range relevant for CSM conditions;
- the complicated nature of gas opacity induces degeneracy to the equilibrium temperature solution in an optically thin limit;
- the new gas opacity data result in a different temperature distribution in the benchmark test;

References

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