The effect of scattering clouds and dust on extrasolar planet emission spectra

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Scattered thermal radiation

Properties like temperature and composition can be derived from secondary eclipse measurements of transiting planets at a range of wavelengths. These spectra consist of a combination of thermal emission from the planet and reflected starlight.

Clouds and haze do not only scatter starlight, they also scatter thermal radiation from the planet itself. Venus is a good example of this: thermal emission from its surface can be seen at the nightside only because the clouds are very scattering, not absorbing. Scattering of thermal radiation is often ignored.

We present spectral calculations for hot exoplanets/cool Brown Dwarfs that include realistic clouds and their scattering behaviour.

Model atmospheres

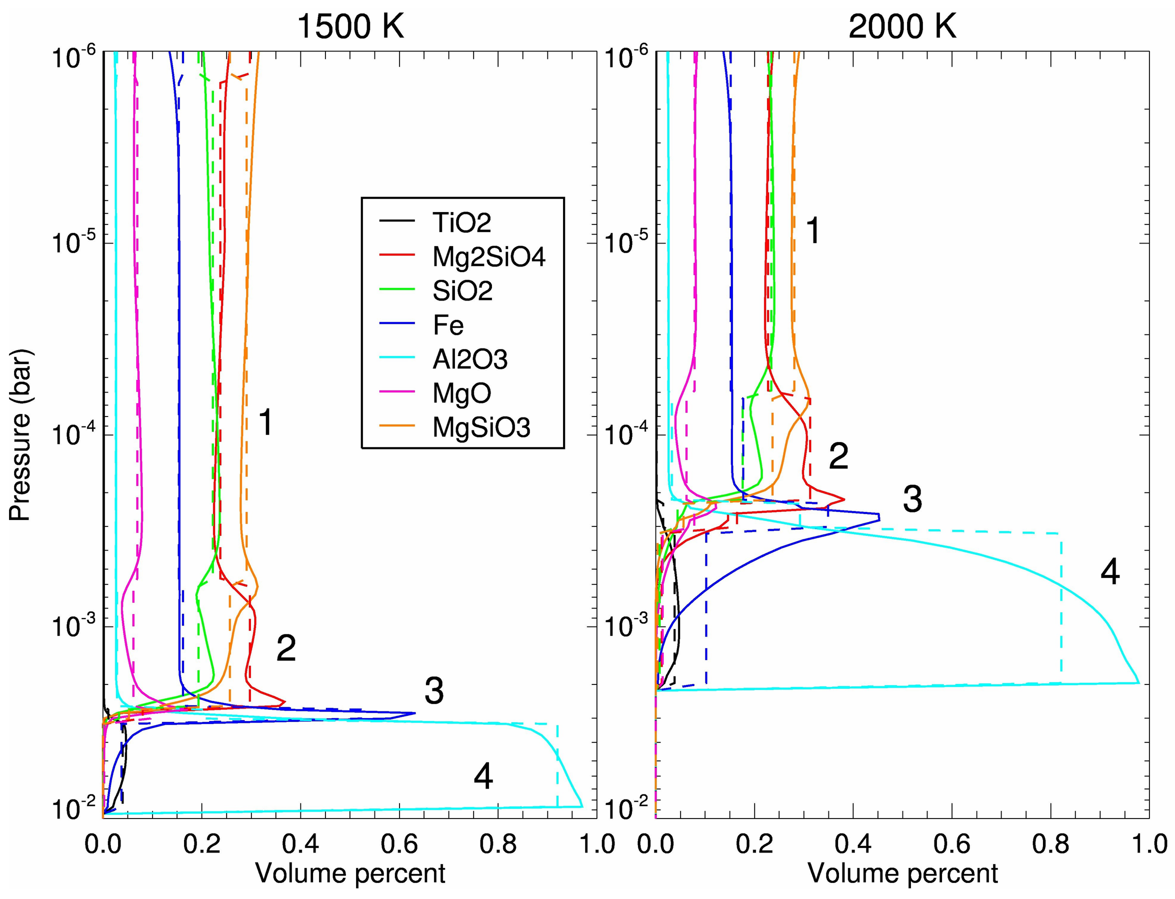
The DRIFT-PHOENIX model is used, which self-consistently calculates temperature, composition and clouds for Brown Dwarf/exoplanet atmospheres.

For ease of calculation, we determine 4 regions in the atmosphere in which we keep particle properties constant. These are based on the particle composition (see figure).

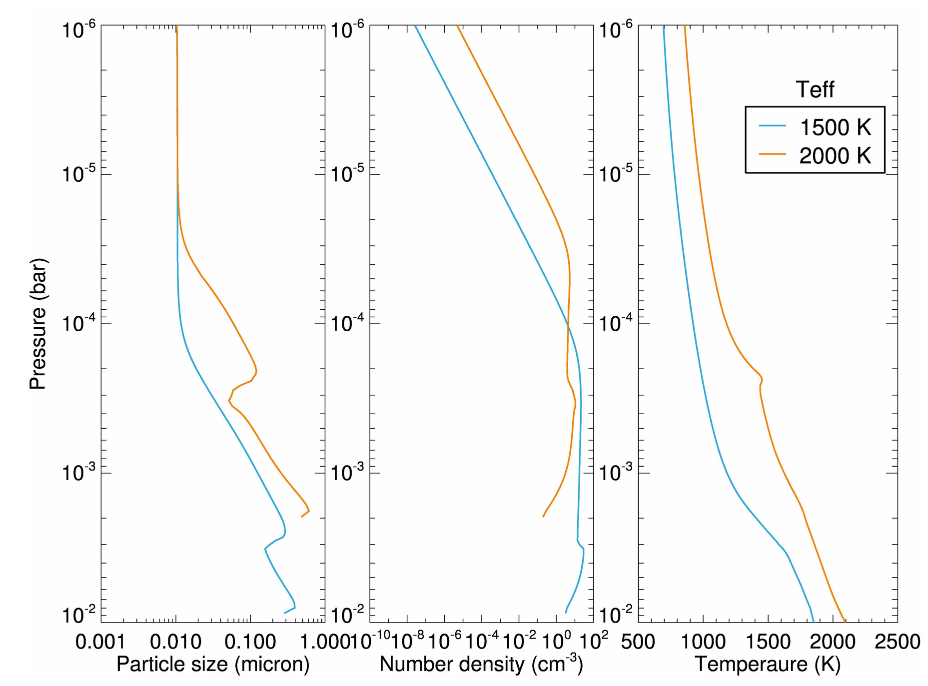
We calculate spectra for 2 cases:

- Teff = 1500 K, log g = 3.0
- Teff = 2000 K, log g = 3.0

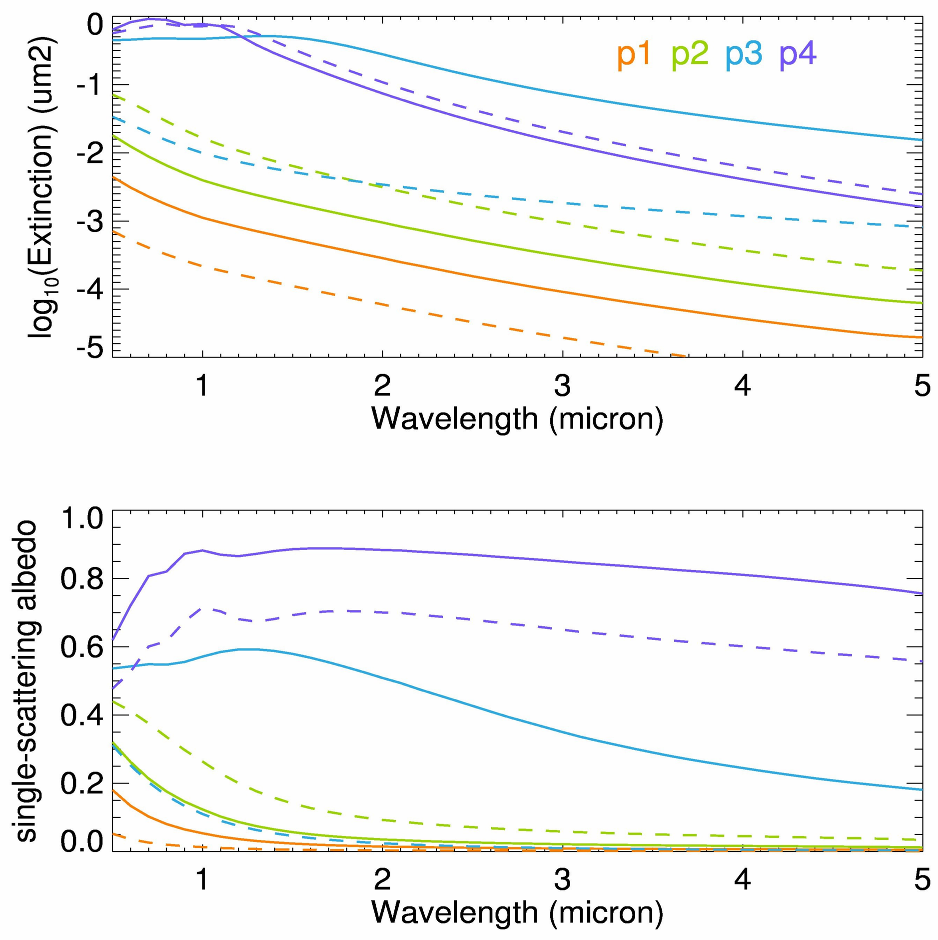
The two atmospheres and cloud properties for the four layers are shown in the figures.



Composition of the cloud particles for the two different cases. The clouds are composed of a mixture of several condensed molecules with indicated mixing ratio. Indicated are the four layers that are used for the calculations and the mean mixing ratios (dashed lines).



Temperatures and mean particle sizes and number densities for the two cases.



Particle properties used in the calculations for the four layers in the atmosphere for the two cases (solid line = 1500 K; dashed line = 2000 K).

Model spectra

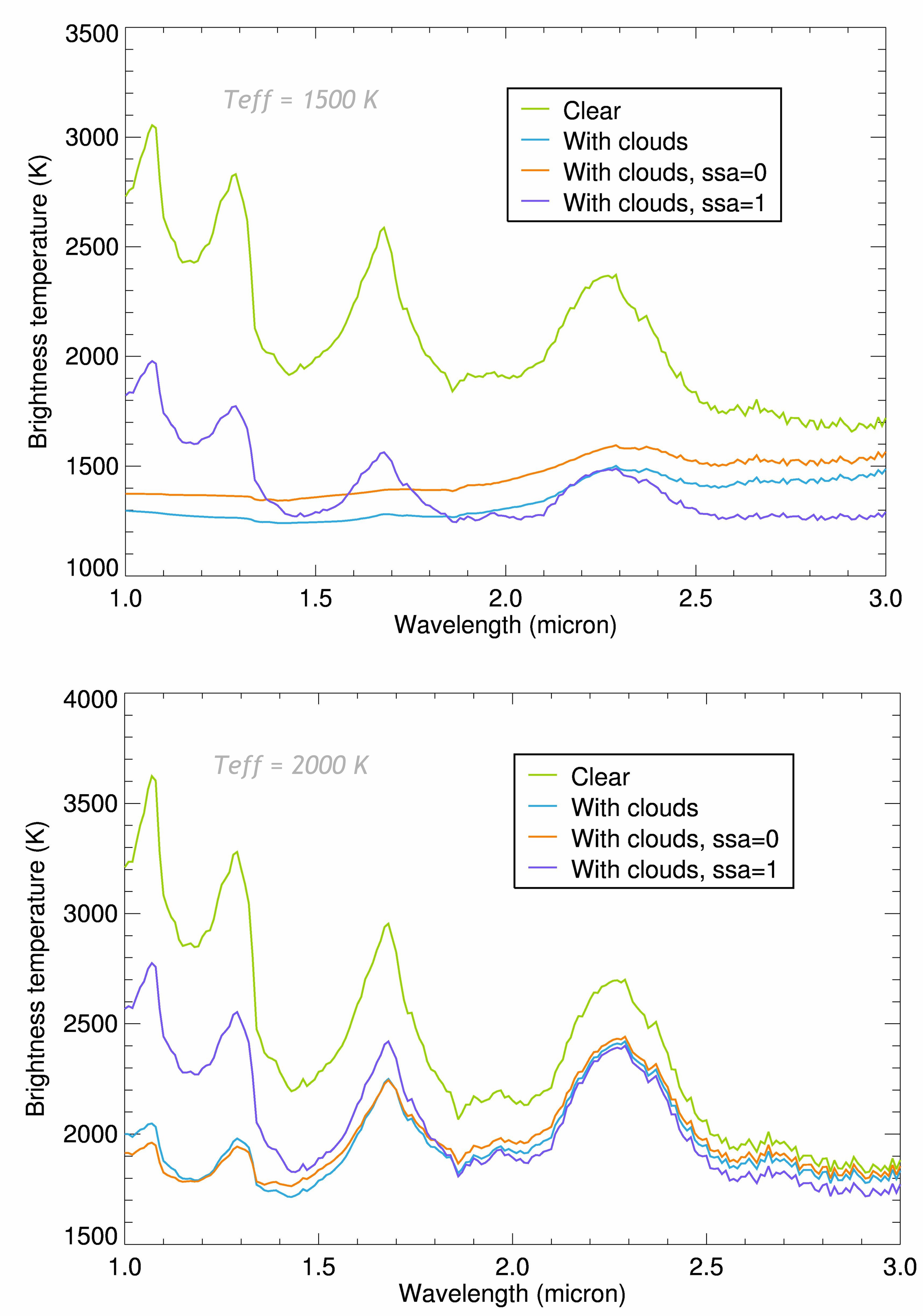
Spectra are calculated using a doubling-adding routine that includes internal sources (Wauben et al., 1994).

The spectra show a large difference between a clear atmosphere (green lines) and the clouds included (blue lines). The difference is larger for the Teff = 1500 K case, since particles are larger and more numerous, resulting in larger optical depths and larger single-scattering albedos.

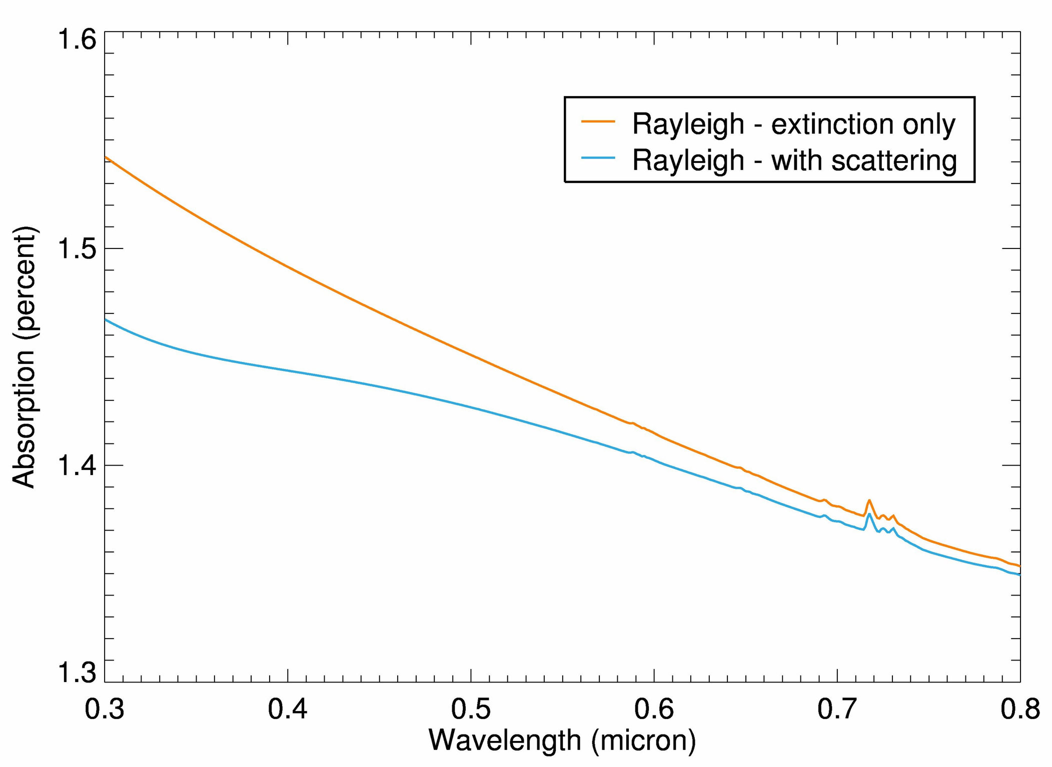
When scattering is ignored (orange lines) and only extinction is taken into account, absorption features are subdued. The effect is not very large in this case, since the upper cloud layers in the DRIFT-PHOENIX atmospheres are small and have low single-scattering albedos. Significant differences are present though. The resulting planet albedo is also small.

Larger particles will result in larger albedos. When the single-scattering albedos of all clouds are set to unity, but optical depth are kept the same (purple lines), large differences are seen: radiances are much higher at short wavelengths and absorption features are much more pronounced. Real large cloud particle will be also more forward-scattering, strengthening this effect.

So, taking into account scattering of thermal radiation can make a large difference in spectral calculations, especially when real clouds are larger than predicted by DRIFT-PHOENIX.



BEWARE: transmitted light can be scattered too!



Transmission spectrum for GJ1214b, with H2 Rayleigh scattering and little absorption by water vapour. The orange line includes Rayleigh scattering optical depths, but assumes the extinction is all absorbing. Blue line shows the same Rayleigh optical depths, but with a contribution from diffuse light due to the Rayleigh scattering.

Example: Rayleigh scattering on GJ1214b by a hydrogen atmosphere.

Scattering allows more starlight to go through than taking into account only extinction. This reduces the apparent radius of the planet and changes the slope of the (transit) transmission spectrum.

Work in progress: taking into account optically thick, forward-scattering clouds in transit measurements.

Conclusions

DRIFT-PHOENIX predicts optically thick clouds of small particles that have a large impact on the spectrum.

The predicted clouds are not very scattering, especially at high altitudes, but a significant difference in spectra can be seen when scattering is ignored, making absorption features more subdued and radiances higher.

Colder temperatures make the scattering effect larger, since optical thickness and particle sizes increase.

Ignoring the scattering behaviour of highly scattering particles will result in massively different spectra. This will also affect heat balance.

Also transit transmission measurements can be seriously affected by scattering of particles.

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