The dust disk around HR 4049: Another Brick in the Wall.

C. Dominik — University of Amsterdam
C.P. Dullemond — MPIA Garching
J. Cami — NASA Ames
H. v. Winckel — University Leuven

Introduction

Introduction

HR 4049 is a post-AGB star which attracts attention because of a long list of very special properties:

1. HR 4049 is a spectroscopic binary star.
2. The elemental abundances show a depletion pattern typical for gas with refractory dust removed: HR 4049 is accreting gas as a result of gas-dust separation. The iron depletion is extreme: $sim 10^{-5}$.
3. HR 4049 has a strong IR excess which contains about 30% of the stellar luminosity.
4. The gas in the vicinity of the star is oxygen-rich, with some of the most extreme isotopic abundances measured so far (Cami and Yamamura 2001)

We present the Spectral Energy Distribution of HR 4049 based on literature data and new continuum measurements at 850 μm. The SED shows variable absorption in the UV, and a large IR excess, both caused by circumstellar dust. The shape of the IR excess from 1 μm all the way down to 850 μm can be nearly perfectly fitted with a single blackbody function at $T \approx 1150$ K or alternatively with a sum of blackbodies in a narrow temperature range. We present two possible scenario's for explaining the shape and the intensity of the IR excess. The first scenario involves large grains ($a \geq 1$ mm) that each radiate like a blackbody. The second scenario argues that the blackbody radiation is due to a very optically thick circumbinary disk.

Large grains in a disk?

Can a collection of large grains be responsible for the blackbody shape of the excess emission?

Required disk structure

Using the equation of thermal equilibrium of dust grains, we can translate the limits imposed on the temperature from Eqs. (**??**) and (**??**) into limits on the distance of the dust grains from the central star :

$$T_d = \left(\frac{1}{2}\frac{R_*}{R}\right)^{1/2} T_* , \qquad (1)$$

Using a stellar effective temperature $T_\star$ of 7500 K and an effective radius $R_\star$ of 47 $R_\odot$ (**?**), we find that the dust grains must be between 3.5 and 8 AU from the star. Considering optical depth effects, the outer limit would go down to 6.2 AU. According to Eq. (**??**) the same optical depth would require the disk height to reach $2H = 1.7R$. Therefore, the large grins must be distributed in a narrow distance range, but out to large heights over the midplan of the system.

Dust grains in a gas-rich disk

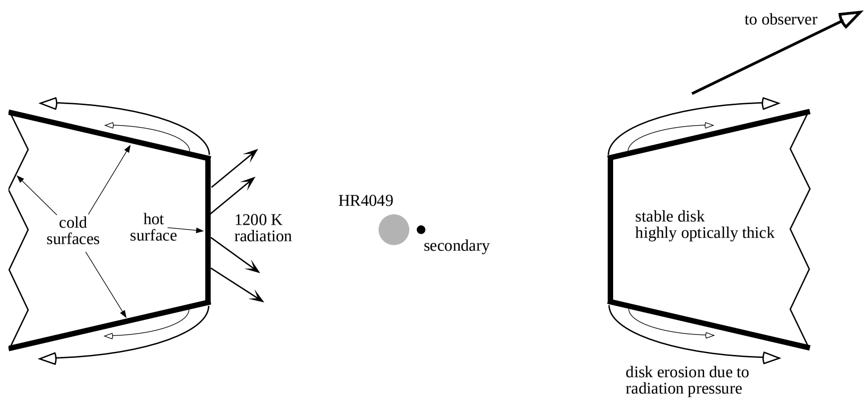
If the disk were gas-rich, the same hydrostatic pressure which is required to hold up the vertical height would also act in the radial direction, attempting to spread the disk in this direction. Another concern is grain settling. The settling time for grains is a gas-rich disk is approximately 150 yr for 1 mm dust grains. Grain settling would half the disk height in this time scale.

Dust grains in a gas-poor disk

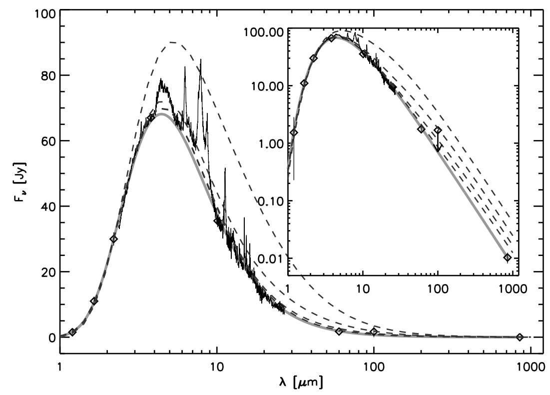
The other possibility is that the disk is gas-poor. It would then be a structure resembling the asteroid belt in the solar system, where dust is produced in collisions between large bodies. However, such a disk cannot keep the required large inclination distribution. The disk must have an optical depth of order one in the radial direction. Since the disk is higher than its radial extent the vertical optical depth will be of order one. Therefore, a dust grain moving on an inclined orbit will experience at least two collisions during each orbit.

The collisions between grains will either destroy the grains or dissipate energy, which leads to a rapid flattening of the disk.

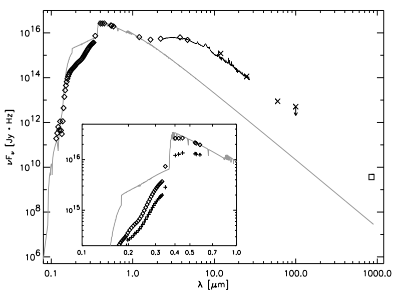
The Wall Model



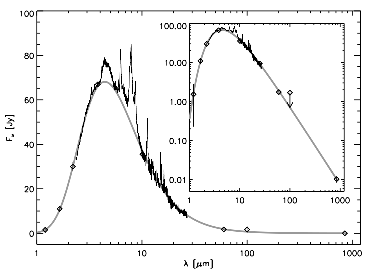
We propose a new model for the circumstellar environment of HR 4049. In this model, the IR excess originates in a massive (several tenth of a solar mass) gas-rich disks around the binary system, at a distance of about 10 AU. The radial optical depth in the disk is in excess of 10^4, so that the sided of the torus not facing the star are very cool and invisible at mm wavelength. The radiative transfer calculations below show that for such high optical depth, the spectrum emerging from the disk is indeed close to a blackbody.



The Infrared Excess of HR4049 is a perfect Blackbody



The SED of HR 4049 at photometric maximum. The diamonds show IUE measurements, optical and near-IR photometry; these measurements are de-reddened using $E(B-V) = 0.1$. IRAS observations at 12, 25, 60 and 100 μm are shown as crosses. Note that the 100 μm point is only an upper limit. The continuum measurement at 850 μm based on the new SCUBA observations is represented as the square. The ISO-SWS spectrum between 2.3 and 27 μm is plotted as the solid black line. The thick grey line shows a Kurucz model for the star with parameters $T_{\rm eff} = 7500$K, $\log g = 1$ and $[Fe/H] = -4.5$. This Kurucz model is scaled to match the SED at photometric maximum at 580 nm. The inset shows the SED at photometric maximum (diamonds) and photometric minimum (+) at UV and optical wavelengths, revealing (variable) extinction from circumstellar dust.



The IR-excess of HR 4049. The Kurucz model is subtracted from the SED shown in Fig. **??**. Errors on the near-IR photometry points, the IRAS measurements and the SCUBA point are indicated, but are generally smaller than the symbol size. Note that the "photometric" points at 3.8 μm and 10 μm were derived from the ISO spectrum (see text for more details). The prominent features in the ISO-SWS spectrum are mainly due to PAHs, nano-diamonds, and CO_2 (see Paper I). The thick grey line shows a single blackbody at a temperature of 1150 K. The inset shows that this single temperature blackbody provides a perfect fit to the entire continuum, including the 60 μm and 850 μm measurements.