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Brown dwarfs:

disk structure and dust mineralogy

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Abstract. We report on sensitive ground-based measurements of a small sample of young brown dwarf disks. Our detections in the infrared regime, combined with detailed spectral energy distribution modeling, allowed to characterize the structure of brown dwarf disks and infer their dust composition. We also performed submm and mm observations which provided the first mass estimates for brown dwarf disks.

Key words. brown dwarfs – circumstellar disks – mineralogy

1. Introduction

Circumstellar disks play a fundamental role in understanding how stars and planets form (e.g. Shu et al. 1987; Lissauer 1993). The recent identification of near-infrared excess emission towards young brown dwarfs (BDs) provided the first hints that these sub-stellar objects might be surrounded by a disk (e.g. Muench et al. 2001). Further hints came from the detection of few young BDs in ISOCAM images of star-forming regions (Comerón et al. 2000).

These findings set at least two important questions: *Do brown-dwarfs form like stars through accretion via a circumstellar disks? Could BD disks evolve into planetary disks?* To answer such ambitious questions we need to understand the structure of BD disks, their lifetime, dust composition and grain size distribution. In the following sections, we summarize our present knowledge on BD disks and discuss what we expect to learn from our upcoming SPITZER observations.

2. Disk geometry: flared vs flat

The work by Natta & Testi (2001) represents the first attempt to derive properties for BD disks through modeling of their spectral energy distributions (SEDs). The only two ISOCAM measurements indicative of warm dust around three BDs in the Chamaeleon region were interpreted in the frame of passive flaring disks (Chiang & Goldreich 1997), simple scaled-down versions of T Tauri disks. Such models have two main predictions: i) a large mid-

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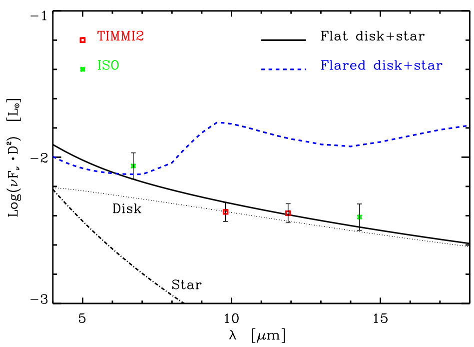

Fig. 1. Modeled SED of a flat and a flared disk compared to the observations. The dot-dashed line indicates the contribution from the star; the dotted line is the flat disk emission. Their sum is the solid line fitting the observations. The dashed line shows the prediction of the flared disk model.

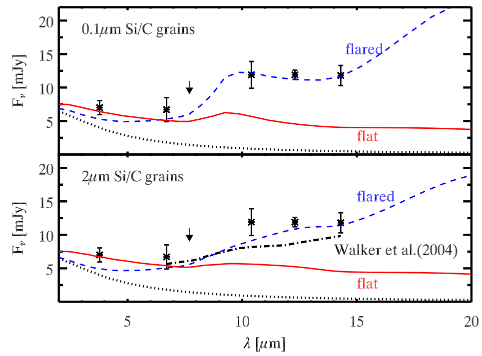

Fig. 2. SED comparison of disk models for Cha Hα1. The upper panel refers to small dust sizes (0.1 μm), the lower panel to larger grains (2 μm). Flared and flat model predictions are compared. The contribution of the BD photosphere (dotted line) is approximated by a black-body model.

and far-infrared excess ii) a prominent silicate emission feature originating from an optically thin heated layer.

To probe the silicate feature, we targeted Cha Hα2 with the TIMMI2 on the 3.6m telescope at La Silla. Our detections, with filters in between the ISOCAM measurements, led to two main conclusions. First, we could role out the existence of the predicted silicate emission feature (see Fig. 1). Second, by modeling the slope of the continuum we could prove that the disk geometry cannot be flared and that a simple flatter dust distribution fits better the observed SED (Apai et al. 2002).

In the same star-forming region, we found recently evidence for a flared disk surrounding the brown dwarf Cha Hα1 (Sterzik et al. 2004). Our T-ReCS Gemini detections also prove the existence of a silicate emission feature dominated by small astronomical grains (Fig. 2), in contrast with the predictions of Walker et al. (2004).

These two examples combined with the results from observations and modeling of other 12 brown dwarf disks (Natta & Testi 2001; Apai et al. 2002; Natta et al. 2002; Pascucci et al. 2004; Mohanty et al. 2004; Apai et al. 2004; Sterzik et al. 2004) show that both flared and flat configurations do occur in a similar statistic.

3. Disk masses

It is widely believed that disk detections prove the star-like formation of BDs and rule out the ejection embryos hypothesis. However, the situation is mode complex: both scenarios will leave circumstellar dust around the BD, but they differ in the amount of the dust and the extension of the disk (e.g. Padoan & Nordlund 2004; Bate et al. 2003). Infrared observations cannot determine the disk mass because the emission is usually optically thick in the infrared regime. In addition, the infrared emission originates from close to the BD, thus preventing infrared excess detections to prove star-like formation.

Measuring the amount of circumstellar dust requires observations at optically thin wavelengths. We used the IRAM-30m and SCUBA/JCMT telescopes to target 9 young and 10 old/field BDs at 1.3 mm and 850 μm. We detected two young BD disks at both wavelengths, one located in the Taurus and the other in the IC348 region (Klein et al. 2003). Using the range of emission coefficients found for T

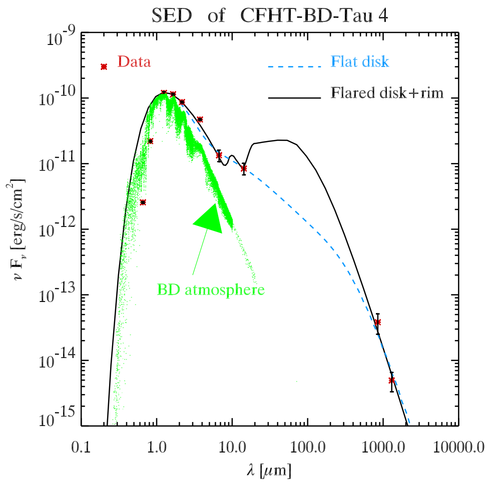

Fig. 3. Comparison of model fits with observations. The measurements are dereddened with a visual extinction of 3 mag (Martín et al. 2001) and are plotted with asterisks. The models that best fit the observations are the flat disk (dashed line) and the flared disk with an inner puffed-up rim (solid line). The atmosphere of a 1 Myr old BD with 3000 K effective temperature is overplotted in dots (Allard et al. 1999).

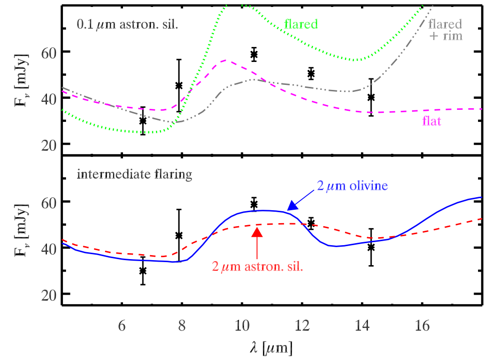

Fig. 4. Flat, flared and intermediate disk models compared to the observed SED of CFH-BD-Tau4. Models in the upper panel use $0.1\,\mu$m astronomical silicate grains. The parameters of all models are given in Pascucci et al. (2004), except for the reduced flaring parameter applied in the lower panel. The lower panel also shows that $2\,\mu$m olivine grains reproduce the observed emission better than $2\,\mu$m astronomical grains.

Tauri disks, we could infer total disk masses of few percent of the BD masses (0.4-6 M_J).

For the object CFHT-BD-Tau4 in Taurus we also retrieved archival ISOCAM measurements and built a more complete SED (Pascucci et al. 2004). We then used different shell and disk geometries to interpret the spectral energy distribution and proved the following: i) the dust must be distributed in a disk-like structure (first evidence for a disk around a BD), ii) the classical flared disk configuration does not reproduce the observed SED iii) a flatter disk geometry fits well our measurements and hints towards the presence of larger grains in the disk (Fig. 3).

4. Grain growth and dust settling

We recently probed the silicate emission of CFHT-BD-Tau4 by deep mid-infrared observations with the T-ReCS Gemini south. We detected emission from the dust in the disk at three wavelengths in between the ISOCAM filters. The SED shows a prominent silicate emission feature which originates from a heated surface layer in the disk. The peak position of the feature and the line to continuum flux ratio clearly show that the emission is dominated by grains about 10 times larger than the $0.1\,\mu$m grains characteristic to the interstellar medium. Fitting the silicate feature and the overall SED requires a two-layer flared disk with reduced scale height (Fig. 4). Larger grains and flatter disk geometry prove that grain growth and dust settling already occurred in the disk of CFHT-BD-Tau4 (Apai et al. 2004). These two processes are the first essential steps which lead to the formation of planets.

5. Disk lifetime

The disk lifetime is also strictly connected to the possibility of forming planets. In our T-ReCS campaign we included an approximately 10 Myr old member of the TW Hya association (Gizis 2002; Mohanty et al. 2003). We detected the faint 2MASS1207-3932 (in the following 2M1207) at two mid-infrared wave-

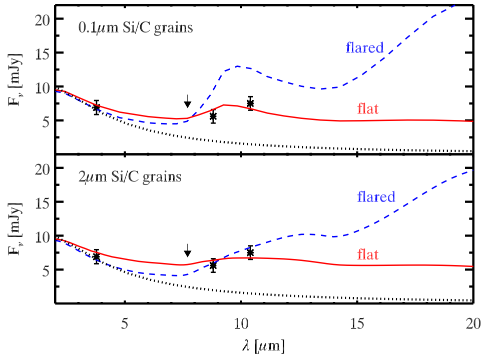

Fig. 5. SED and comparison of disk models for 2M1207. Lines are the same as in Fig. 2.

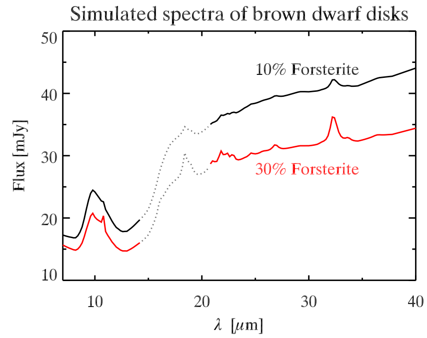

Fig. 6. Simulated mid-infrared spectra for BD disks convolved with a spectral resolution slightly worse (R=50) than IRS-LR. The modeling follows Bouwman et al. (2001) with input parameters typical for BDs and their disks. The most important regimes for dust mineralogy will be covered by the SL1 and LL1 IRS modules (solid lines). The two curves differ in the fraction of the crystalline silicate forsterite and represent the optimistic (upper curve) and pessimistic (lower curve) cases.

lengths and showed that there is a substantial excess probably originating from a circumstellar disk (Sterzik et al. 2004). Such a detection suggests that the lifetime of BD disks might be similar to that of T Tauri disks. Note that the previous L-band measurement from Jayawardhana et al. (2003) is purely photospheric, suggesting that L-band observations become not good tracer for more evolved disks. The SED modeling favors a flatter disk configuration and larger grains which fit well with the older age of the source. Chauvin et al. (2004) very recently discovered a close companion to this BD which is a good candidate for being the first directly imaged giant planet.

6. Conclusions and Future Prospects

The main conclusions of our work can be summarized as follows:

- BD disks show a variety of geometries (flared, intermediate, flat) which seem to be linked to the disk evolution
- masses of BD disks are few percent of the BD masses, in agreement to what is found for T Tauri stars and their disks
- grain growth and dust settling is observed at least in one BD disk
- the lifetime of BD disks appears to be similar to that of T Tauri disks

These conclusions are based on the small sample of objects observable with ground-based facilities. Our upcoming SPITZER spectroscopy of other 17 young BD disks will enable a more complete study on a larger sample. We will cover the wavelength range 8-13 μm and 20-37 μm with the SL1 and LL1 modules, which allow to study the 10 μm feature as well as other dust features like those from crystalline silicates (Fig. 6). The spectroscopy combined with data available from literature will allow us to study dust composition, grain sizes and disk structure for a homogeneous group of young brown dwarf disks.

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