Mid-infrared Observations of Brown Dwarfs and their Disks: First Ground-based Detection

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Abstract

We present the first mid-infrared (MIR) detection of a field brown dwarf (BD) and the first ground-based MIR measurements of a disk around a young BD candidate. We prove the absence of warm dust surrounding the field BD LP 944-20. In the case of the young BD candidate Cha Hα2, we find clear evidence for thermal dust emission from a disk. Surprisingly, the object does not exhibit any silicate feature as previously predicted. We show that the flat spectrum can be explained by an optically thick flat dust disk.
KEYWORDS: *accretion, accretion disks — circumstellar matter — stars: individual (LP 944-20, Cha Hα2) — stars: low-mass, brown dwarfs*

1. Introduction

Brown Dwarfs (BDs) occupy the substellar mass domain. Having masses lower than 75 M_{Jup}, they are unable to burn hydrogen steadily. Although their presence has been already predicted in the sixties by Kumar (1963), their low luminosity delayed their discovery until 1995, when Nakajima et al. (1995) announced the first detection of a BD orbiting the nearby M-dwarf star Gl229A. Recently, the large-scale near-infrared (NIR) surveys 2MASS and DENIS – complemented by optical data – substantially increased the number of known field BDs. Additionally, deep NIR surveys of star-forming regions revealed hundreds of young BD candidates.

In spite of the rapidly growing number of known BDs (Basri, 2000), we do not know if they form like planets or like stars. Proposed scenarios include the straightforward star-like formation via fragmentation and disk accretion (Elmegreen, 1999), the ejection of stellar embryos (Reipurth & Clarke, 2001) from multiple systems and the formation in circumstellar disks like giant planets. The presence of disks and their properties are crucial in distinguishing between the various scenarios: a truncated disk (size of a few AU) would support the ejected stellar embryo hypothesis, a non-truncated one is the sign of stellar-like accretion, while BDs formed like planets should have no dust around them.

In the case of BDs, NIR data are not necessarily a good tracer of disk emission because they are strongly affected by molecular bands of the cool BD atmosphere. Since the emission of warm (100 - 400 K) circumstellar dust peaks around 10 μm, mid-infrared (MIR) excess emission – arising from dust grains close to the star – is the best tool to search for circumstellar disks. The MIR regime is best accessed by space-born telescopes, the last of which was the Infrared Space Observatory (ISO), operating between 1995 - 1998. However, the majority of BDs has been discovered too late to be targeted by ISO.

Up to now, only few BDs with MIR excess are known. These objects, identified in the ISOCAM archive, are located in the Cha I or in the ρ Ophiuchi star-forming regions (Persi et al., 2000; Comerón et al., 1998). Their substellar nature has been deduced from comparing NIR and optical measurements to evolutionary models (Comerón et al., 1998, 2000).

Natta & Testi (2001) proposed a model based on scaled-down disks around pre-main-sequence stars to explain the measured spectral energy distributions (SEDs).

In this paper we present results from our TIMMI2 MIR imaging campaign. Our aim was to detect MIR excess emission and thus to probe the presence of warm circumstellar dust around BDs. We targeted seven very close field BDs of various ages and a young BD candidate in the Cha I star-forming region. Our observations are the first data in the wavelength region of the silicate feature.

2. Observations

We carried out deep MIR observations with the 3.6m/ESO Telescope at La Silla (Chile) using the TIMMI2 camera (Reimann et al., 2000) in 2001 November and December. The targets were seven field BDs and a young BD in the Cha I star-forming region. From the closest field BDs, we selected those which seemed to be the youngest based on their brightness and spectral type.

We used the 9.8 μm filter, where the instrument is the most sensitive, to search for disk emission. In the case of the detected field BD we also complemented the 9.8 μm measurement with 5 and 11.9 μm observations; the BD detected in the Cha I region was also observed at 11.9 μm. We applied long exposure times (typically 2 hrs in each filter) in order to reach the $\sim$10 mJy sensitivity limit of the instrument. Extensive testing of the pointing accuracy shows a typical error not larger than 1.5" towards the Cha I star-forming region. This excludes any confusion with other sources.

3. Results

3.1. Field Brown Dwarfs

Among the seven targeted nearby field BDs, only the object LP 944-20 could be detected. The 3 σ upper limit of the flux density for the other sources is 15 mJy at 9.8 μm. As one of the youngest (475–650 Myr) and closest (5 pc) field BDs (Tinney, 1998), LP 944-20 was the most promising of our targets. Based on its optical spectrum, its spectral type is equal to or later than M9V (Kirkpatrick et al., 1997). Its classification as a BD has been confirmed by the presence of lithium in its photosphere (Tinney, 1998). Excellent atmospheric conditions and a long integration time led to the *first detection of a field BD in the MIR*. The fluxes measured at 5, 9.8 and 11.9 μm are 39 mJy, 24 mJy, and 22 mJy, respectively. These measurements correspond to more than 5 σ detections in each filter. We estimate a photometric error smaller than 15% for each measurement.

3.2. Cha Hα2

In contrast to the older field BDs, we found clear evidence for excess MIR emission in the case of the much younger (2 - 4.5 Myr) BD candidate Cha Hα2. The observed fluxes are 17$\pm$2 and 21$\pm$3 mJy at 9.8 and 11.9 μm, respectively. The object is close to or in the substellar domain, depending on its exact age (Comerón et al., 2000). There is some evidence that Cha Hα2 is actually a close binary with the components in the substellar domain (Neuhäuser et al., 2002).

4. Discussion

4.1. Field Brown Dwarfs

The non-detection of the six field BDs proves the lack of significant amount of warm dust around older field BDs. These data clearly show that the disk dissipation time is below a few 100 Myr, consistent with recent measurements of BDs in the young σ Orionis cluster (Oliveira et al., 2002). Even the detection of the closest target, the 475-650 Myr old LP 944-20, confirms this hypothesis. Compared to a simple blackbody with $T_\star$=2300 K, $R_\star$=0.1 $R_\odot$, D=5 pc (Tinney, 1998), it is clear that our measurements show no MIR excess, but the photospheric flux of the BD itself.

4.2. Disk Models for Cha Hα2

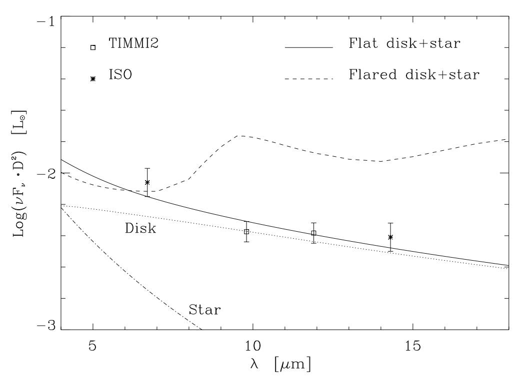

Figure 1: Modelled spectral energy distribution of a flat and a flared disk compared to the observations. Asterisks: ISOCAM measurements at 6.7 and 14.3 μm (20% error bars), while the squares are our TIMMI2 measurements at 9.8 and 11.9 μm (15% error bars).

Modelling the MIR excess emission of Cha Hα2 lead to a surprising result: the SED, plotted in Fig. 1 could be explained by an optically thick, flat disk but not by a T Tauri-like flared one. Fig. 2 shows the schematics of the two different models. A detailed description of the modelling is given in Pascucci et al. (2002).

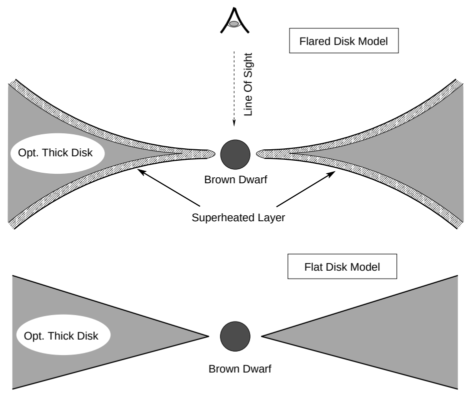

Figure 2: Cross sections of the flared and the flat disk model. The shaded area represents the optically thin superheated layer in the flared disk. This region is the source of the silicate emission feature. The flat disk lacks this disk atmosphere.

5. Summary

Our ground-based measurements represent a new way of probing the properties of disks around BDs, exploring their spectral energy distribution and therefore constraining model prescriptions. We prove the absence of the previously predicted silicate emission feature in the case of the face-on disk around the young BD-candidate Cha Hα2, one of the three known BD-candidates with MIR excess. An optically thick flat disk provides a perfect match to our data. Because no evidence for disks around older field BDs could be detected, disk dissipation times must be shorter than a few 100 Myr. Our results suggest that newborn BDs have disks like young, low-mass stars, but also indicate unexpected differences in their disk geometry. A detailed description of this work can be found in Apai et al. (2002).

References

Apai, D., Pascucci, I., Henning, Th., Sterzik, M. F., Klein, R., Dimitri, S., Günther, E., Stecklum, B., ApJ 573, L115

Basri, G., 2000, ARA&A 38, 485

Comerón, F., Rieke, G. H., Claes, P., Torra, J., Laureijs, R. J., 1998, A&A 335, 522

Comerón, F., Neuhäuser, R., Kaas, A.A., 2000, A&A 359, 269

Elmegreen, B.G., 1999, ApJ, 522, 915

Kirkpatrick, J.D., Henry, T.J., Irwin, M.J., 1997, AJ 113, 1421

Kumar, S.S., 1963, ApJ 137, 1121

Nakajima, T., Oppenheimer, B.R., Kulkarni, S.R., Golimowski, D.A., Matthews, K., Durrance, S.T., 1995, Nature 378, 463

Natta, A., Testi, L., 2001, A&A 376, L22

Neuhäuser, R., Brandner, W., Alves, J., Joergens, V., Comerón, F., 2002, A&A 384, 999

Oliveira, J.M., Jeffries, R.D., Kenyon, M.J., Thompson, S.A., Naylor, T. 2002, A&A 382, L22

Pascucci, I., Apai, D., Semenov, D., Henning, Th., 2003, Comm. Konkoly Obs. 103, proc. of the conf. "Interaction of Stars with their Environment II.", eds. Cs. Kiss et al., p.99

Persi, P., Marenzi, A.R., Olofsson, G., et al., 2000, ApJ 357, 219

Reipurth, G., Clarke, C., 2001, AJ 122, 432

Reimann, H.-G., Linz, H., Wagner, R., Relke, H., Kaeufl, H. U., Dietzsch, E., Sperl, M., Hron, J., 2000, in: "Optical and IR Telescope Instrumentation and Detectors", eds. M. Iye & A.F. Moorwood, ESO, Vol. 4008, 1132

Tinney, C.C. 1998, MNRAS 296, L42