From Giant Planets to Cool Stars
ASP Conference Series, Vol. 212, 2000
C. A. Griffith, and M. S. Marley, eds.

Mid-IR Observations of the Pleiades Brown Dwarfs Teide 1 & Calar 3

K. Leech, B. Altieri, L. Metcalfe

ISO Data Centre, Astrophysics Division, ESA, Villafranca, Spain

E. L. Martín

Dept of Astronomy, Univ of California, Berkeley, USA

R. Rebolo, M. Zapatero Osorio

Instituto de Astrofísica de Canaries, Tenerife, Spain

R. Laureijs, T. Prusti, A. Salama, R. Siebenmorgen

ISO Data Centre, Astrophysics Division, ESA, Villafranca, Spain

P. Claes, N. Trams

Astrophysics Division, ESA, ESTEC, The Netherlands

Abstract. This paper describes observations of the brown dwarfs Teide 1 and Calar 3 made with the European Space Agency's (ESA) Infrared Space Observatory (ISO) in the near- to mid-IR. The aim is to compare the observations against brown dwarf atmosphere models.

Because detection limits were found to be below model predictions neither object was detected. This places stringent limits on models of brown dwarf atmospheres.

Introduction

The European Space Agency's Infrared Space Observatory (ISO) (Kessler et al. 1996) was the first satellite IR observatory. It contained a 60cm diameter telescope and instruments inside a cryogen tank and was operational between November 1995 and May 1998. Due to the low spatial resolution ($\approx 2''$ at best) and sensitivity limits of the instruments, however, it was unsuited to observe any of the faint brown dwarfs discovered as companions to brighter stars (e.g. Gleise 229b).

Just prior to the launch of ISO the first solitary brown dwarfs, Teide 1 (Rebolo et al. 1995) and Calar 3 (Zapatero Osorio, Rebolo, & Martín 1997) were discovered in the Pleiades cluster. They were first considered brown dwarfs due to their extreme spectral type and luminosity. The detection of Lithium in their atmospheres indicates that they are true brown dwarfs (Rebolo et al. 1996). Properties of these objects are given in Table 1, with the photometric values

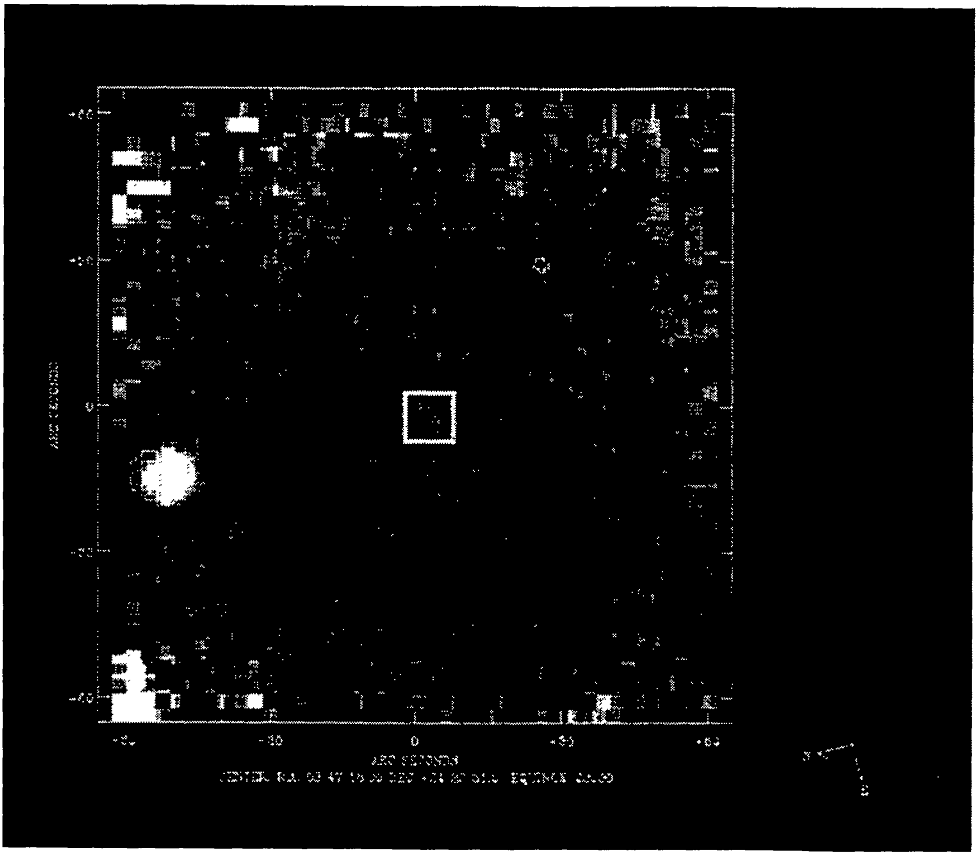

Figure 1. The Teide 1 field observed through the 4–5 μm (LW1) filter. The square box is the region where Teide 1 is expected to be from optical data, and is the correct size for the point spread function.

being the average of data presented in Festin 1998, Zapatero Osorio, Rebolo, & Martín 1997 and Martín et al. *in prep.*

Assuming they are black bodies, their estimated fluxes in the mid-IR range from 100 microJanskies to 1 milliJanskies depending on the wavelength region covered. Given these brightnesses and the solitary nature of the objects, reducing straylight contamination and source confusion, it seemed feasible to observe them with the ISOCAM (Cesarsky et al. 1996) camera onboard ISO. Unfortunately the brown dwarfs were too faint to attempt observations with the other three ISO instruments.

Instrument & Observations

Observations of these two objects were therefore planned with the ISOCAM. This instrument had detectors and filters capable of observing over the 3 to 15 μm wavelength range. Given the low fluxes of these objects, just within the detection limit, it was decided to limit observations to three wideband filters: LW1, 4–5 μm; LW2, 5–8.5 μm; and LW10, 8–15 μm.

Table 1. Object properties

	Teide 1	Calar 3
RA (J2000)	3 47 18	3 51 26
Dec	24 22 31	23 45 20
Mass (M_J)	55 ± 15	55 ± 15
T_{eff}	2600 ± 150	2600 ± 150
I	19.03	18.87
J	16.27	16.19
H	15.55	15.43
K	15.11	14.92

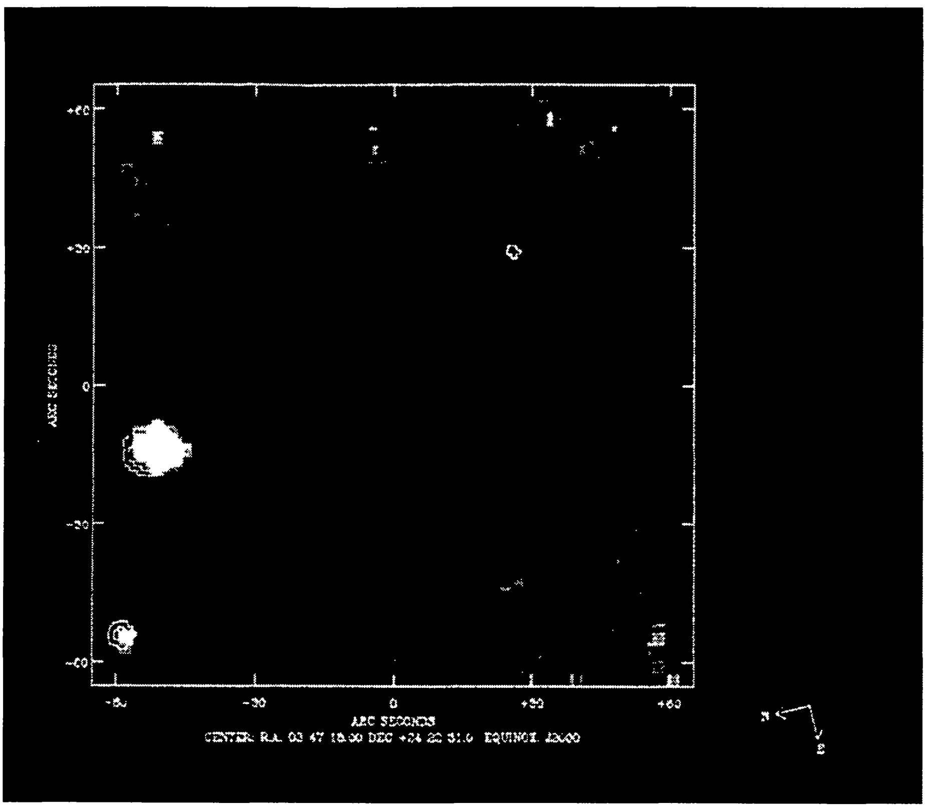

Figure 2. The Teide 1 field observed through the 5–8.5 μm (LW2) filter.

The observing strategy is discussed in Leech et al. (1998). In summary the plan was to break each observation through a filter into several sub-observations. Each sub-observation would be moved slightly with respect to the others (in ISO terminology this is called rastering), the normal way to observe faint sources. Given that Teide 1 was detected before Calar 3, the ISO observations were planned to provide more time for Teide 1 than Calar 3. Both objects were observed in September 1997, with a summary given in Table 2.

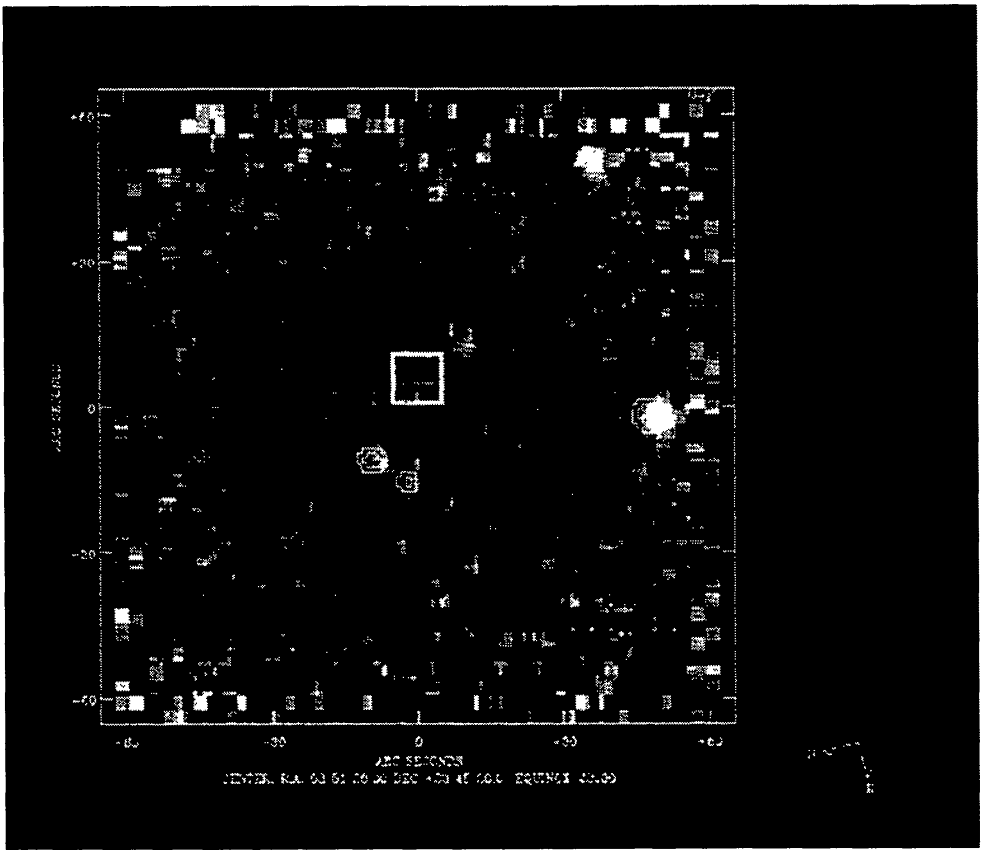

Figure 3. The Calar 3 field observed through the 4–5 μm (LW1) filter, overlaid with a contour plot from the DSS. The square box is the region where Calar 3 is expected to be, of the right size for the point spread function, and the overlay is from the Digital Sky Survey.

Data Reduction and Preliminary Results

Observations were reduced using the CAM Interactive Analysis software (CIA), Ott et al. 1997, using techniques outlined in the CIA documentation, and tools developed for faint source detection by Metcalfe (Altieri et al. 1998).

Preliminary results from the observations indicate our sensitivity was insufficient to detect either object in the mid-IR. The sensitivity limits are shown in Table 2 and the observations are given in Figures 1 to 3 (the LW10 observation of Teide 1 is not shown). Also shown in Figures 1 & 3 is a box where the brown dwarfs should be, based on optical data, of size of the point spread function of the ISO Satellite/ISOCAM filter combination.

In the case of Teide 1 there is unexpected structure in the background, probably from the dust in the Pleiades cluster. It is mainly evident in the longer wavelength data and reduces our sensitivity by increasing the effective noise in the maps. This structure can be seen in Figure 2, although the data reduction method used reduces large-scale structure in order to emphasise point sources.

Table 2. Observation Details and Sensitivity Limits

Object	Filter	Wavelength μm	Total time/sec	3σ Flux μJy
Teide 1	LW1	4 – 5	2700	170
Teide 1	LW2	5 – 8.5	2200	170
Teide 1	LW10	8 – 15	3900	230
Calar 3	LW1	4 – 5	2200	230

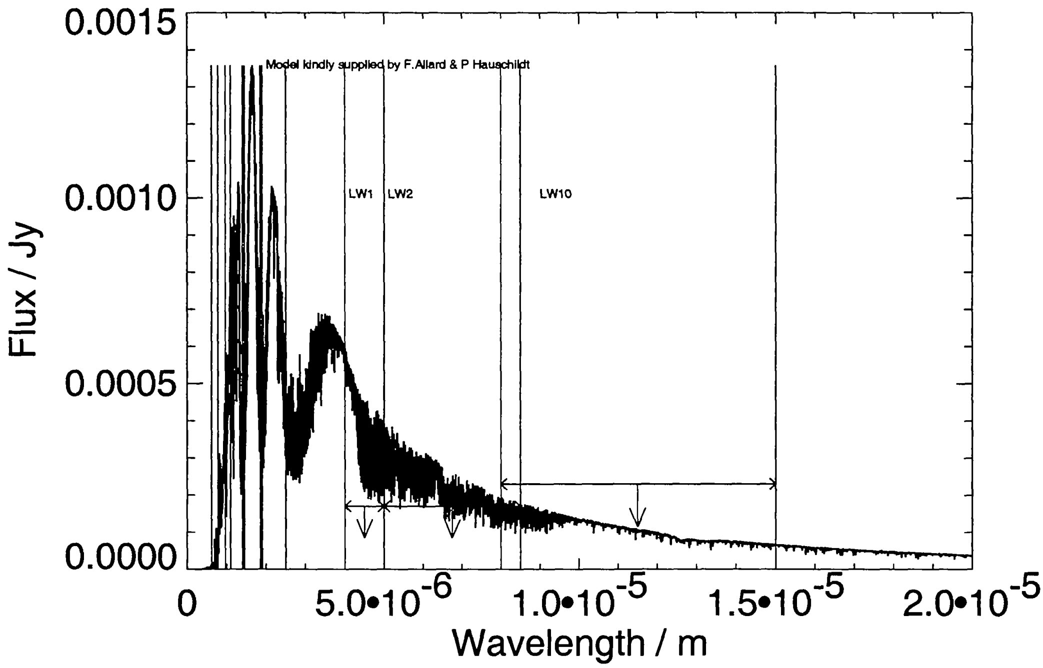

Figure 4. Model spectrum of Teide 1 overlaid with the filter bandpasses and 3σ flux limits from ISO observations.

Comparison with Models

These upper limits can be compared with a dust-free brown dwarf atmosphere model (T_{eff} of 2500K) scaled to the observed J, H and K fluxes of Teide 1 or Calar 3. The upper limits from the observations of Teide 1 through the LW1 and LW2 filters, both 170 μJy, appear inconsistent with predictions (approximately 400 and 200 μJy respectively) from this model. Figure 4 shows the model spectrum overlaid with the various filter bandpasses and respective 3σ flux limits. Models with different temperatures (2300 – 2700K) show similar discrepancies between the model and data from Teide 1.

These observations can also be compared with the predictions of the dusty models of Tsuiji et al. (1996). There is little difference between the fluxes of the dust free and dusty models in the wavelength region of interest for objects with an effective temperature of 2600K. Hence the observed upper limits also appear inconsistent with the dusty models.

Similarly, the upper limit derived for Calar 3 through the LW1 filter of 230 μJy appears inconsistent with the $\approx$400 μJy predictions of the dust free (or dusty) model.

Conclusions

We have successfully imaged the fields containing the two Pleiades brown dwarfs Teide 1 and Calar 3. Unfortunately, neither appears to have been detected, although the field of Teide 1 contains structure which decreased our sensitivity limit from that expected.

The upper limits derived from the observations appear inconsistent with the fluxes predicted from dust free and dusty models. Reddening is unlikely to cause this inconsistency, as it would decrease the near-to-mid IR ratio, rather than increasing it as needed to explain the observations. Accurate models of these objects with varying amounts of dust are needed to try and resolve this apparent paradox.

Acknowledgments. ISO is an ESA project with instruments funded by ESA member states (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

The ISOCAM data presented in this paper was analysed using 'CIA', a joint development by the ESA Astrophysics Division and the ISOCAM Consortium. The ISOCAM Consortium is led by the ISOCAM PI, C. Cesarsky, Direction des Sciences de la Matire, C.E.A., France.

We thank F. Allard and P. Hauschildt for providing us with the BD model.

References

Altieri, B., et al. 1998, ISOCAM Faint Source Report, Issue 1.0, available from http://www.iso.vilspa.esa.es/users/expl_lib/CAM/fs_report.ps.gz

Cesarsky, C., et al. 1996, A&A 315, L32

Festin, L., 1998, A&A 333, 497

Kessler, M. F., et al. 1996, A&A 315, L27

Leech, K. J., et al. 1998, in ASP conf. Ser. Vol. 134, Brown Dwarfs and Extrasolar Planets, ed R. Rebolo, E. L. Martín & M.R. Zapatero Osorio (San Francisco: ASP), 93

Ott, S., et al, 1997, in ASP Conf. Ser. Vol. 125, Astronomical Data Analysis Software and Systems VI, ed. G. Hunt & H.E.Payne, (San Francisco: ASP), 34

Rebolo, R. et al. 1995, Nature, 377, 129.

Rebolo, R. et al. 1996, ApJ 469, L53

Zapatero Osorio, M. R., Rebolo, M. & Martín , E. L. 1997, A&A 317, 164.