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Parallaxes of L and T dwarfs

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Abstract. We discuss a new program to measure the parallaxes of a number of L and T dwarfs, objects that bridge the gap between M dwarfs and planets. This pilot project tests the feasibility of using large telescopes with infrared detectors to determine parallaxes at the level of milli-arcseconds (mas). First results show that we are able to achieve the required centroiding precision and simulations indicate that when the final observations come in we should be able to achieve our goal of parallaxes with accuracies of 2 mas. The main problems will be focal plane astrometric distortions and stability.

1. Introduction

T and L dwarfs are ultra-cool objects cooler than M dwarfs that bridge the gap between stellar and substellar objects, also known as brown dwarfs. They have spectra dominated by molecular absorption due to water, methane and pressure-induced molecular hydrogen. Methane, which first appears prominently in T dwarfs, is expected to remain an important atmospheric constituent down to the temperature of Jupiter ($\sim 125\,\mathrm{K}$), where it is also prominent in the infrared spectrum. This means these objects provide an important link to extrasolar giant planets. Indeed, nearly ten years ago the announcements of the discoveries of the first brown dwarf and extrasolar planet were made at the same conference. Since then many new discoveries have been made, so the prototype of the T class, the companion to the nearby M dwarf star Gl229 (Nakajima et al. 1995), has been supplemented by the discovery of more than 300 L and T dwarfs. These come primarily from the Sloan Digital Sky Survey (Strauss et al. 1999; Tsvetanov et al. 2000; Leggett et al. 2002; Geballe et al. 2002; Knapp et al. 2004) and from 2MASS (Burgasser et al. 1999, 2000, 2002a, 2002b, 2003a, 2003b).

Model atmosphere analyses indicate temperatures of 2500 K for L dwarfs down to 750 K for lower T dwarfs, although significant uncertainties remain. Absolute luminosities are the most direct route toward an empirical temperature scale for ultra-cool dwarfs (e.g., Vrba et al. 2004). In this paper we discuss an ongoing program to measure the parallaxes and hence distances and absolute luminosities of nine T dwarfs and two L dwarfs.

2. Observational program

In Table 1 we list the targets under observation along with their nominal 2MASS *J* magnitudes (Cutri et al. 2003), spectral types in the Kirkpatrick et al. (1999) and Burgasser et al. (2002) systems, number of observations and range of observational epoch

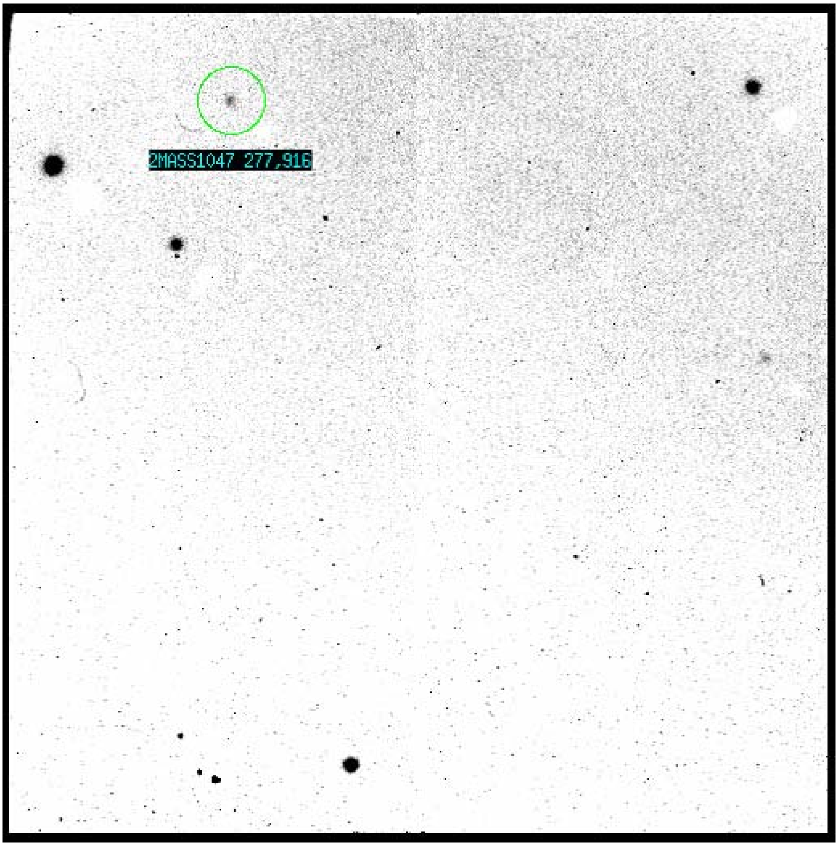


Figure 1. An example field for the object 2MASS1047. The target has a large offset from the center of the CCD to enable sufficient reference stars.

in months. For these faint magnitudes a 3-m class telescope is required, and we have successfully obtained time on the infrared camera, Omega Cass, of the 3.5-m telescope at Calar Alto.

In Fig. 1 we show the field of 2MASS1047. An empty field like this is typical for this program. It forces us to offset the target star from the center in order to maximise

Table 1. Target list

Target	RA	Dec	J	Sp	Number of epochs	Epoch span months
2MASS1021	10:21:09	-03:04:20	16.3	T3	7	11
2MASS1047	10:47:53	+21:24:23	15.8	T6.5	7	11
2MASS1217	12:17:11	-03:11:13	15.9	T7.5	7	13
2MASS1145	11:45:57	+23:17:29	15.4	L1	7	11
2MASS1225	12:25:54	-27:39:47	15.2	T6	6	11
2MASS1237	12:37:39	65:26:15	15.9	T6.5	8	13
SDSS1254	12:54:53	-01:22:47	14.7	T2	8	13
SDSS1346	13:46:46	-00:31:50	15.9	T6	8	13
GL570D	14:57:15	-21:21:50	15.3	T8	6	13
2MASS1507	15:07:47	-16:27:38	12.8	L5	5	13
SDSS1624	16:24:14	00:29:16	15.5	T6	5	13

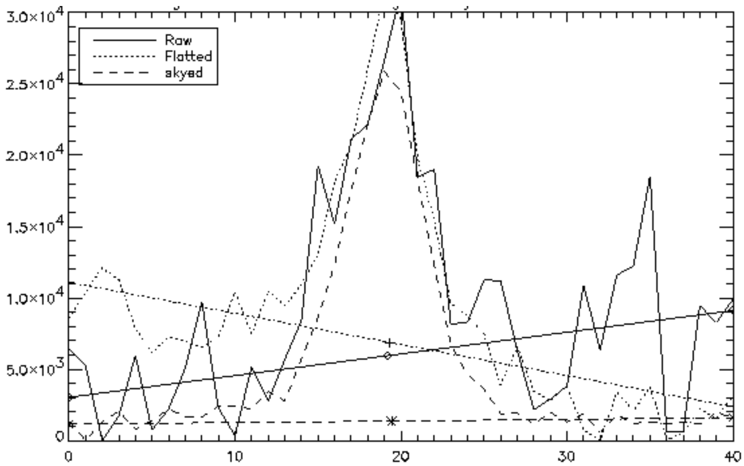


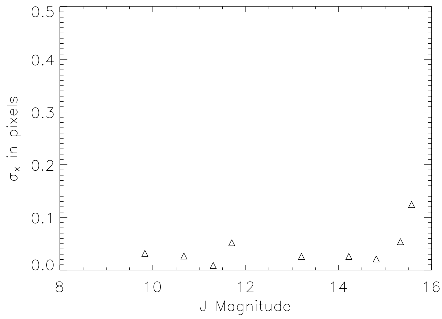
Figure 2. Normalized marginal distributions of a bright star in three phases of calibration as indicated in the legend.

the number of reference stars, and also limits the size of any dither pattern we can employ.

The determination of a parallax in the infrared follows the same process as that of the optical. See, for example, Smart et al. 2003, however, for a number of reasons it should be more precise:
1) The refraction of the atmosphere is lower and varies more slowly so the effects of differential refraction are smaller and probably negligible.
2) The PSFs have smaller FWHM, so in theory can be centred better.
3) The exposure times are in general shorter (of the order of seconds as opposed to minutes), so more observations can be made leading to a higher redundancy.
4) The sky background is always higher, but observations can be made during the period between astronomical and civil twilight leading to observations at marginally higher parallax factors and the possibility to observe when optical observations are not possible.
However, most of these benefits are outweighed by the noisier background and the subsequent necessity to carry out sky subtraction.

In Fig. 2 we show the normalized marginal distributions of a relatively bright star in three phases of calibration: the raw profile, the flattened profile and the sky subtracted profile. To obtain our precision goal we are required to center to at least 0.05 pixels. The centroids from these three distributions vary by over 0.3 pixels using standard weighted moments and 0.2 pixels using 2 dimensional Gaussians.

A number of experiments are being carried out to find the best way to centroid these images. Applying offset images for sky subtraction is the normal procedure, and, as such, we flattened all frames, made $10''$ dithered images and sky subtracted using adjacent frames. In these cleaned images we found positions of all stars using two dimensional Gaussian fitting and then aligned them using a linear transform. From these multiple observations of each star we found positional standard deviations. In Fig. 3 we show two comparisons, one of observations in the same positions (i.e. no offsets) and one of all observations (i.e. including dithered images). The larger standard deviations in the comparison of offset images is indicative of a variable astrometric distortion map, or perhaps because of the lower number of stars in common. Further work is under way to understand these differences.



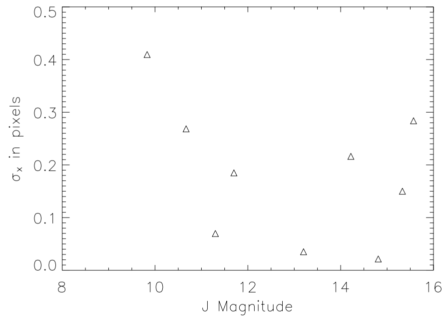


Figure 3. Centroiding sigmas for consecutive observations of the field 2MASS1047. Left panel: detector position always the same. Right panel: dithered positions.

Given that we are able to centroid to within 0.05 pixels we have used simulations (Smart et al. 2001) to see the expected precision with various observational strategies. The best approach is to have a season of intensive observations to sample the parallax ellipse, and then carry out only nominal observations in the following years to sample the proper motion movement. This means the precision of the final parallax, given a fixed number of observations, is a maximum when they are they are distributed in the manner indicated in Fig. 4. This simulation with a centroiding error of 0.05 pixels predicted a final parallax precision of 2 mas.

3. Conclusions

In Fig. 5 we plot absolute magnitudes derived from all published T dwarf distances – 30 distances for 23 objects. The overall trend of a hump in the middle of the range can be clearly seen. However, the details are lost in the noise which is mainly due to inaccurate parallaxes. The results of this project will improve this picture and allow us

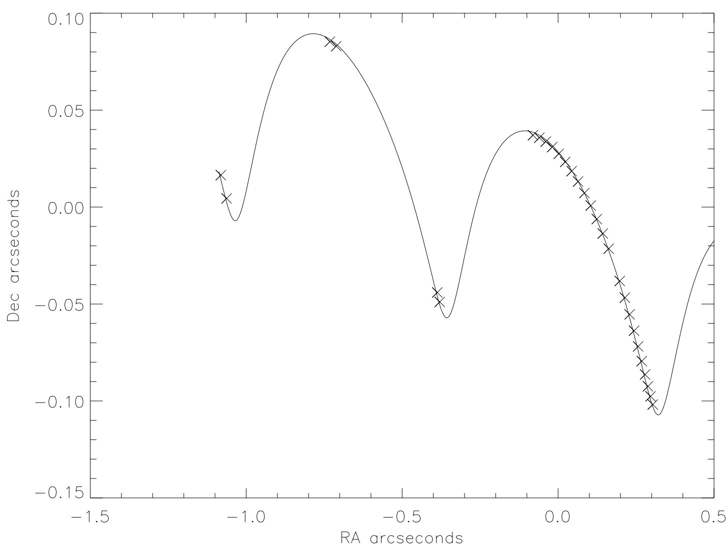


Figure 4. Simulation of the expected motion and observations for a star at RA 12 h and Dec 17°, distance 10 pc and proper motion $1'' \, \mathrm{yr}^{-1}$.

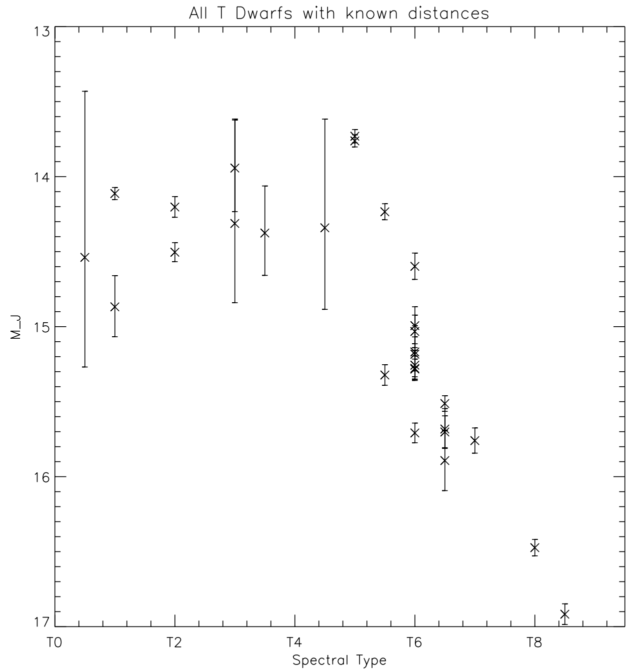


Figure 5. Absolute J magnitudes derived from all known T dwarf distances. 2MASS J magnitudes and spectral types taken from Burgasser (ref).

to distinguish between competing scenarios: cloud disruption (Burgasser et al. 2002a) or a thin dust cloud deep in the photosphere (Tsuji 2002).

The work on T dwarfs has, however, only just begun. While these results will aid the understanding of such features as the L-T transition and the T hump, as more objects are found more issues will present themselves. For example, the differences between T dwarf spectra appear to be relatively subtle. The T8 dwarf Gl570D (Burgasser et al. 2000) must be around 250 K cooler than Gl229B, yet their spectra are similar and bear more resemblance to the reflectance spectra of Jupiter (e.g. **?**) than to L dwarfs (Geballe et al. 2002). Indeed, spectral types may have as much to do with cloud properties as with effective temperatures. Thus absolute luminosities are a key ingredient to a better understanding of T dwarf spectra.

It is also important to point out that for these objects we would be mistaken to wait for the results of the planned space astrometric missions. Gaia (Perryman et al. 2001) will probably not observe any of the T dwarfs, and not many of the L dwarfs, as they are too faint in the magnitude band of the astrometric field. JASMINE (Yamada et al., these proceedings) will observe some of the brighter L and T dwarfs in the Galactic plane, but the number and hence range of properties will be limited. It appears that only dedicated programs such as the present one will provide distances for future objects discovered in the large surveys such as 2MASS, SDSS and UKIDSS.

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