A Giant Step: from Milli- to Micro-arcsecond Astrometry
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L and T dwarfs in Gaia/SIM

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Abstract. We discuss the role of distances for understanding brown dwarfs and estimate the contribution expected by Gaia. We show that Gaia will only observe 25% of L and T dwarfs within 50pc which, at a conservative estimate, amounts to less than 400 objects. We discuss how Gaia results will nevertheless aid the ground-based programs providing reliable, bias free constraints for the calculation of parallaxes in an absolute system. We list the current ground-based programs underway and the possibilities for future all sky survey programs.

Keywords. stars: low-mass, brown dwarfs, stars: distances

1. Introduction

The first brown dwarf, GD 165B, was found almost 20 years ago as a red companion to the white dwarf GD 165 (Becklin & Zuckerman 1988) . At first this object was considered an anomaly but after the discovery of similar objects it was realized that spectral types beyond M were required to classify them, hence the introduction of L and T spectral types (see Kirkpatrick 2005 for review). These objects from around mid-L are not massive enough to burn hydrogen so for simplicity we shall call them brown dwarfs. Since GD 165B over 600 brown dwarfs have been discovered primarily in the large infrared surveys and the Sloan survey. These objects form the link between stars and planets, they will probably prove to be more common than stars and are extremely long lived hence provide insights into the history of our Galaxy.

For those objects in the solar neighborhood the determination of useful parallaxes, e.g. with relative errors less than 10%, is within the range of ground-based programs; indeed over 40 are already determined to this precision. Here we discuss the importance of their distance determination, the contributions of the Gaia and SIM missions and the future for ground-based programs.

2. Distances for brown dwarfs

Since brown dwarfs are fundamentally different to stars, it is useful to examine why their distances are important. The atmospheres of these objects are very complex, being dominated by methane, clouds and dust. The spectral types, especially for T dwarfs, are more indications of the cloud and dust processes in their atmospheres rather than indications of changing in their effective temperature. From their birth these objects are continually cooling hence their luminosity and spectral type are a strong function of age. For example, a .05 $M_{\odot}$ objects starts its life as a late M dwarf, from .1 to 1 Gyr it transverses the L dwarf spectral types and then continues into the late T types.

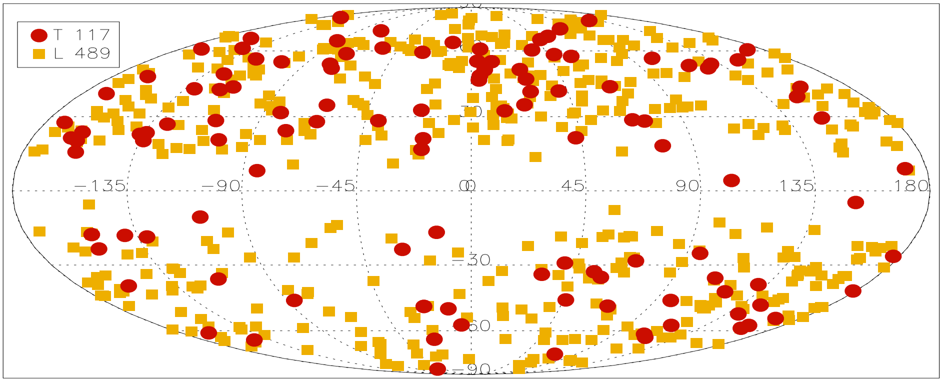

Figure 1. The distribution of known L and T dwarfs in galactic coordinates.

Finally, as with stars, the physical properties of brown dwarfs also depend on chemical composition.

The distance, in combination with a given apparent magnitude, directly provides a luminosity. Since the colors are not good indicators of the luminosity, large numbers of these distances are needed to calculate a statistically significant luminosity function. With a distance estimate under-luminous objects can be identified as possible sub-dwarfs e.g. not part of the local neighborhood but of another galactic component. When we understand better the evolution of these objects, the fact that they visibly change with time will be an important tool in understanding the history of our Galaxy. Finally distances, proper motions and luminosity also allow us to isolate binary systems that are particularly interesting for mass and age determinations.

3. Gaia/SIM and currently known L/T dwarfs

In the online compendium of L and T dwarfs (www.dwarfarchive.org) as of 5 October 2007 there are 606 L/T objects whose galactic distribution is shown in Fig. 1. Recent work by Metchev *et al.* (2007) in the SDSS footprint implies that this sample is 50% complete outside of the galactic plane. Extrapolating the area of the sky examined to the whole sky we can conservatively estimate that this sample is at least 25% of the L and bright T dwarfs within 50pc.

Using i,z' apparent magnitudes when available, or the J/K to i/z' relations for these stars from Hawley *et al.* (2002) when not, we can estimate Gaia G magnitudes using internal transformations (Jordi private communication). Using the spectral type to absolute magnitude relation in Hawley *et al.* (2002) we have calculated the spectro-photometric distances of each object. In Fig. 2 we plot the distribution of the 493 objects within 50pcs in bins of 5 parsecs.

If we assume the limiting magnitude of Gaia is $G = 20$ only the objects shaded as black on the histrogram in Fig. 2 will be observed by Gaia. Hence of the 606 currently known L and T dwarfs Gaia will observe less than 100. In conjunction with the estimated completeness, this implies that in total Gaia will observe less than 400 objects directly and most of those at its limiting magnitude. Gaia will also indirectly observe many other L and T dwarfs that are members of binary systems with a brighter companion, but the number of expected objects observed this way is currently not possible to estimate.

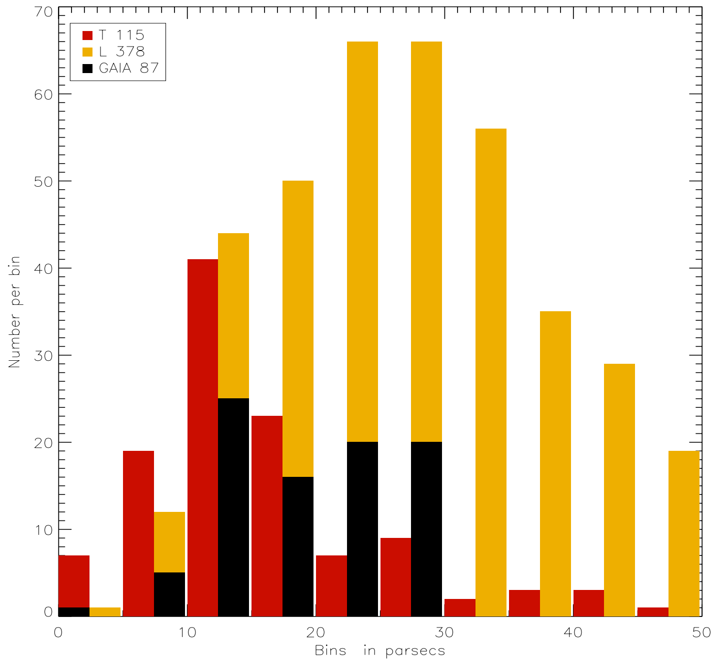

Figure 2. The distribution of L and T dwarf photometric distances within 50pcs. In the legend is shown the color code of the different objects as well as the total number of objects. Gaia will observe the objects distributed in the black histrogram, e.g. only 87 of the total 493 known objects.

While SIM and JWST will go fainter, the investment of observing time will probably only be made for those extremely interesting candidates such as binary systems.

4. The future from the ground

While Gaia will not observe many of these objects directly the observations of anonymous reference stars will help ground-based observations immensely. The two biggest sources of error in ground-based observations are the correction from relative to absolute parallaxes and the calibration of instrumental effects. Gaia will provide data for the anonymous reference stars with a higher precision that will be possible from the ground, hence an application of a full adjustment with constraints will allow us to approach the limit given by random errors. Simulations have shown that given 20 reference stars with Gaia parallaxes, proper motions and a nominal CCD measuring error of 4mas, a precision of better than 1mas is possible after just 30 observations spread over 2.5 years. Sub-mas precisions have also been obtained from the ground Harris *et al.* (2005) and the expectation is that the constraints from Gaia will allow a comparable increase in the accuracy. Given this it is not unrealistic that ground-based parallaxes will be able to provide distances with precisions of 1% for a statistically significant sample of these objects. Having the parameters of the reference stars with such high precision will allow a shortening of the observational campaign and also the ability to calibrate instrumental variations should they occur during the campaign. Gaia parallaxes will allow us to find absolute parallaxes without having to rely on photometric distances, that are prone to

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Table 1. Current programs to determine distances of L and T dwarfs.

Program PI	**Telescope + Detector**	**Objects under study**
Ducourant, OB France	ESO NTT + SUSI2	10 ultracool TW Hydrae members
Faherty, AMNH USA	1.3m Cerro Tololo+ANDICAM	30 bright L and T dwarfs
Penna, ON Brazil	ESO 2.2m + WFI	80 L dwarfs
Röser, ARI Germany	Calar Alto 3.5m + Omega2000	10 ultracool (>sdM7) subdwarfs
Smart, OATo Itlay	TNG+NICS, UKIRT+WFCAM	20 peculiar or very cool T dwarfs
Tinney, UNSW Australia	AAO 3.9m AAT+WFI	30 bright L dwarfs
Tinney, UNSW Australia	AAO 3.9m AAT+IRIS2	15 T-dwarfs

errors in adopted absorptions, or spectroscopic distances, which are both time consuming and also prone to systematic errors.

Currently there are 7 active programs known to the authors which are attempting to find distances of L and T dwarfs, these are listed in table 1. The formerly largest program, that of the USNO, was stopped because of problems with the IR camera, in any case to observed objects fainter than Gaia will require a larger telescope than used in that program. This is where access to 4m class telescopes with IR detectors will play an important role. Working in the IR has three advantages over optical: the seeing is better, the differential reddening correction is smaller and the observations are quicker so we can make more observations per visit thus reducing random errors. Finally, future sky survey programs, PanSTARRS - LSST - SKYMAPPER, offer the possibility to determine parallaxes of these objects to a reasonable precision as a matter of routine.

5. Conclusions

Gaia will observe less than 400 L and T dwarfs and all of those within 50pcs. Distances of fainter objects within the 50pc and all objects outside this limit will not be observed. Parallaxes for the fainter objects can be determined from the ground and dedicated programs are already underway. The results of Gaia will be fundamental for these programs, as they will allow a high precision control of the instrument and provide constraints to directly find absolute parallaxes without the necessity to resort to galactic models or photometric parallaxes.

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