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Memorie della

Brown dwarf parallax programs

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Abstract. Parallaxes are crucial for many brown dwarf topics from the substellar mass function to 3D atmospheric modeling. Here we discuss the current sample of brown dwarfs with parallaxes and the prospects for the near future.

1. Introduction

Distance is a fundamental quantity in Astronomy. The distance of an object combined with its apparent magnitude is used to find its intrinsic absolute luminosity and hence energetic output. Distances are required to convert observed motions into absolute velocities which in turn provide important age and origin indications. Distances are required for most mass determinations and to prove (or disprove) an object's binarity. Distances are often the only way to unravel the degeneracy between effective temperature, chemical composition and surface gravity in spectral observations. The only precise, model independent method, to determine distances to nearby objects is via a trigonometric parallax.

In particular, due to their relatively short observational history, brown dwarf theories are regularly challenged by empirically measured distances. An example of this was the unpredicted blue turn around at the L/T boundary that produces a hump in an absolute magnitude - spectral type plot (Tinney et al. 2003). This pivotal role of distances is especially true in the determination of the substellar mass function where the measured quantity is the density of the tracer sample which is a function of the distance *cubed*. The distances in this case are provided by photometric parallaxes because the samples are too large to contemplate deriving trigonometric parallaxes for the all tracers. Hence the derived mass function is only as good as the photometric parallax calibration. Any errors in the calibration will systematically distort the mass function being derived and dramatically limits any added value we could obtain by increasing sky coverage and tracer sample size.

Brown dwarfs will eventually aid in our understanding of the Galaxy, provide constraints for exoplanet observations and modeling of cool atmospheres. Notwithstanding this potential scientific use, of the 750+ known brown dwarfs less than 90 only have measured trigonometric parallaxes. Here we discuss the current situation, parallax programs nearing completion and areas for improvement.

2. Current Situation

In the dwarfarchive online database as of 2009/10/07 there are 753 known brown dwarfs. Figure 1 shows a equatorial plot of their distribution. The lack of discoveries in the galactic plane is due to the difficulties in obtaining precise photometry in very crowded regions and the higher probability of having contaminant

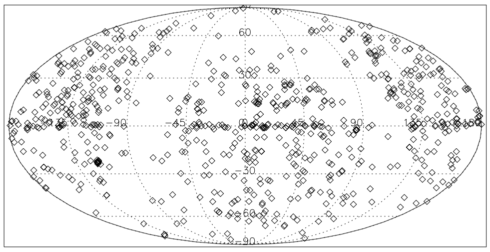

Fig. 1. Equatorial distribution of L and T dwarfs as of 2009/10/07.

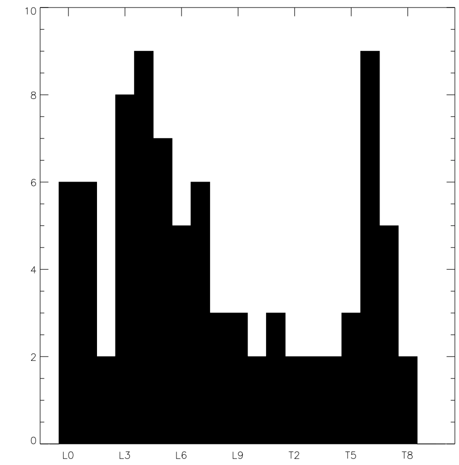

Fig. 2. Distribution in spectral types of all brown dwarfs with parallaxes. The spectral types are those from optical spectra for L dwarfs and from infrared spectra for T dwarfs.

objects (Folkes et al. 2007). Also, in particular along the celestial equator, there are over densities that are due to recent results from the first data releases of the UKIRT Deep Sky Survey (Lawrence et al. 2007; Pinfield et al. 2008; Lodieu et al. 2009).

Of these 753 objects 85 have parallaxes, most of which are measured directly but also a significant fraction inferred from brighter companions. The first L dwarf parallaxes were from the USNO program (Dahn et al. 2002) on the 1.5m Flagstaff telescope and the first T dwarf parallaxes on the 3.5m NTT (Tinney et al 2003). There are still a number of bright L and T dwarfs on the USNO program but nearly all the fainter programs have moved to 4m class telescopes.

Figure 2 shows the distribution of the objects with parallaxes as a function of spectral type. The brighter L dwarfs are reasonably well sampled as these were possible on the large dedicated USNO program. The T dwarfs are primarily either from the USNO program or programs on large, open competition, multi-user telescopes. Both of these programs, USNO because of the prohibitively long exposure times and the multi-user programs with limited time allocations, had to be very selective on their target lists and hence the priority was driven by immediate scientific impact. This is the reason for the better coverage of the T6/T7 bins in comparison to the early T types, as these were the coolest objects discovered in the large optical/infrared surveys of the late 1990s and most interesting scientifically.

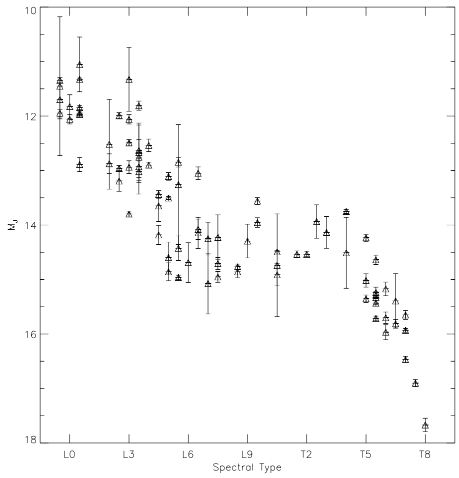

Fig. 3. The absolute magnitude - spectral type correlation for the sample in figure 2.

In Figure 3 we plot absolute magnitudes vs spectral types for all brown dwarfs with parallaxes. While the overall trend is quite evident the details are lost in the combined measuring and intrinsic noise. A 0.5 magnitude combined error is found from a fourth order fit to this data. The intrinsic noise is common to all spectral types and usually due to gradual changes over the main sequence lifetime of a star. For brown dwarfs the spectral type changes significantly with the cooling lifetime and is dominated by the temperature but also small composition and surface gravity differences become important. It is not unreasonable to expect that the intrinsic noise is larger for these objects than stars. This relation is the basis for any photometric parallax calibration and the intrinsic noise can be considered as the limiting factor in using it.

It is possible to find a high order polynomial function to fit the relation in Figure 3 but this can cause systematic biases (e.g. Weis 1996). So we base this discussion on a spline approach. Here we assume we fit cubic spines to sets of 3 adjacent spectral bins to determine values in the middle bin, e.g. M9-L1 and L0-L2 for L0 and L1 values respectively. From Figure 3 taking off the known measuring errors we conservatively estimate the intrinsic scatter to be 0.2 magnitudes in each bin.

Following the rule-of-thumb that systematic errors should be less than 10% of the intrinsic noise we can estimate the number of objects required per bin to attain a fit error of less than 0.02 magnitudes. To do this we have to make a number of assumptions about the calibrating objects:

- Relative $\sigma_\pi < 10\%$ and averages ~5%
- Apparent magnitude errors are negligible
- Extinction is negligible
- The error of the fit improves by a $\sqrt{N - M}$

where N is the number of calibrators and M is the number of parameters. Given these assumptions the average absolute magnitude error will then be 0.11 per object, hence we will require ~30 objects per spline fit, or 10 per spectral bin to achieve a fit error less than 0.02 magnitudes. Considering that we wish to be able to reject outliers we consider 10 objects per spectral bin a minimum. From figure 2 we see that today we do not attain that in any bin.

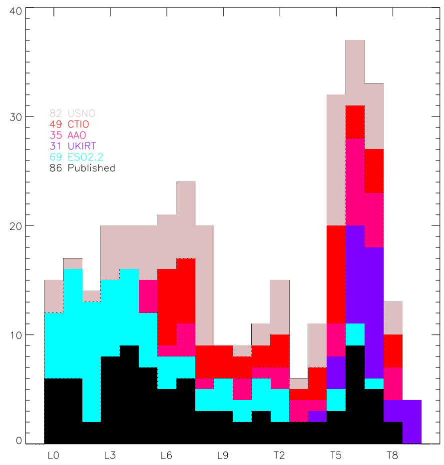

Fig. 4. Distribution in spectral types of brown dwarfs in the various on-going parallax programs as listed in the legend and table 1.

3. Programs in Progress

There are a number of parallax determination programs currently under way that will in part address this short fall. In table 1 we list those programs with more than 20 targets and an expected completion date within a year. In figure 4 we have plotted the combined distribution of these programs and those already published.

There is significant overlap between the various programs, this is quite evident in the later T spectral classes where the number of targets under study per bin exceeds the number of objects currently known. In addition a number of the objects under study will produce a parallax of large error. We have conservatively assumed that the 266 objects in the various programs will produce 160 unique objects with parallaxes of precision better than 10%. We reduce the number of objects per bin by 40% and plot the expected distribution of objects once these parallaxes are published in Figure 5.

In the L0-L8, T2 and T5-T7 spectral types we will have the nominal 10 calibrators per bin. The other bins will require a focused effort. In particular to fill the T8/T9 bins timely exploitation of the deep infrared surveys such as the UKIRT Deep Sky Survey, Canada-France Brown Dwarf survey, the Wide-field Infrared

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

Program PI	Telescope + Detector	Objects under study
Faherty, AMNH USA	CTIO 4m	49 L and T dwarfs
Penna, ON Brazil	ESO 2.2m + WFI	69 L dwarfs
Smart, OATo Italy	UKIRT+WFCAM	31 cool T dwarfs
Tinney, UNSW Australia	AAO 3.9m AAT+WFI/IRIS2	35 L/T dwarfs
Vrba, USNO USA	USNO Flagstaff 1.5m	82 bright L/T dwarfs

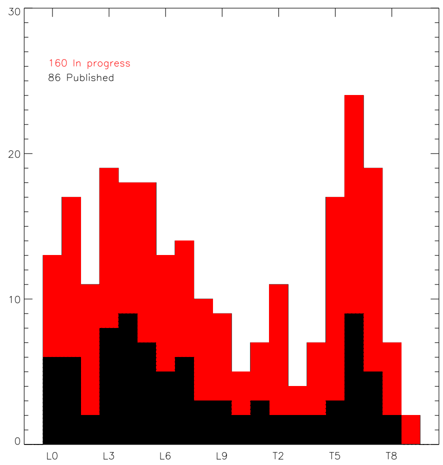

Fig. 5. Current distribution in spectral types of brown dwarfs with parallaxes in black along with the predicted distribution once the programs in Table 1 are completed.

Survey Explorer, and the VISTA Hemisphere Survey is crucial.

We have not discussed here other future sources of brown dwarf parallaxes such as Pan-STARRS or the LSST as parallax results from these are at least three years away and rely on an unproven procedure. The other possible source of parallaxes in the near future are the Gaia/SIM Missions. However in the working bands of these missions brown dwarfs are very faint and only a few will be observable.

4. Conclusions

Our knowledge of brown dwarfs is still in its infancy and future progress requires that we move out of discovery mode into a more focused structured mode. There will soon be enough examples of all L and T spectral classes to have large statistically significant samples for each spectral bin. The determination of precise distances for these objects are long term programs and require large telescopes with collaborative time allocation committees. Without a structured approach we run the risk that the systematic errors will be the limiting factor in spectroscopic and photometric parallax calibrations and any statistical scientific investigations that use them.

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