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L/T dwarfs that Gaia will see

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Abstract. We examine known L and T dwarfs to identify which ones Gaia will be able to detect and we estimate the incompleteness of that sample to predict the expected total number of L and T dwarfs that will be observed by Gaia. We find that of the 1281 dwarfarchives L/T dwarfs only 283 are brighter than Gaia magnitude G=20 and 537 than G=21. The spectral range covered is dominated by L0 to L4 objects at G=20 and extends more significantly to L6 for G=21. We find that the extension of the limiting magnitude from Gaia G=20 to 21 will not have a large impact on the range of L and T spectral sub-classes directly observed.

Key words. Brown dwarfs – Stars: low-mass – Astrometry – Parallaxes – Proper motions – Surveys

1. Introduction

The Gaia mission will revolutionised many areas of Astronomy and the study of brown dwarfs is no exception. Estimates of the number of L and T dwarfs that will be directly observed by Gaia has varied from over 50000 (Perryman et al. 2001), to a few thousands (Sarro et al. 2013) and less than 400 (Smart et al. 2008). Too maximize the exploitation of the Gaia results this number needs to be clarified and objects that will be directly observed need to be observationally parameterised fully.

The compendium of L/T dwarfs at www.dwarfarchives.org (hereafter dwarfarchives) lists 1281 objects (last update 6 November 2012). The bright ones were discovered in the first large infrared surveys such as 2MASS (Epchtein et al. 1999) or DENIS (Skrutskie et al. 2006) and the large optical spectroscopic SDSS survey (York et al. 2000). In Figure 1 we plot the distribution of the dwarfarchives sample objects in galactic coordinates. There is no physical reason for the distribution of nearby BDs not to be uniform and the observed under density in the plane is due to the fact that the majority of these objects were found using photometric selection criteria which in the plane suffers from large contamination and confusion problems.

In this contribution we will use the dwarfarchives sample to estimate the expected numbers of L/T dwarfs that will be observed by Gaia. We consider only L/T dwarfs but note that we expect **many** young late M type brown dwarfs also to be observed by Gaia. We also note that not all early L dwarfs will strictly be "brown dwarfs", for example a L3 object could be an old hydrogen burning object or young brown dwarf. This sample will therefore allow us to look at brown dwarfs and the lightest stars allowing us to study both populations above and below the hydrogen burning limit (e.g. Dieterich et al. 2014). Many brown dwarfs will also be indirectly detected

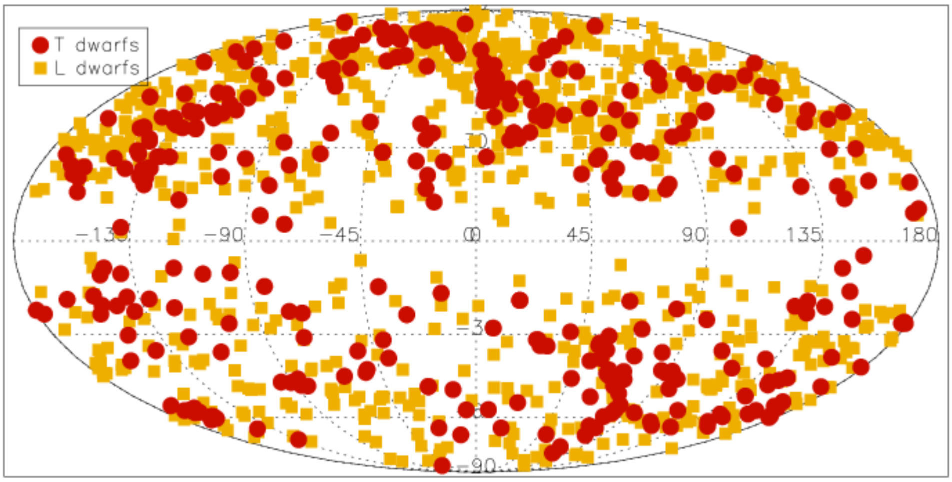

Fig. 1. The distribution of Brown Dwarfs in the online compendium at dwarfarchives.

Table 1. The transform from J to G

SpT	r-i	i-J	G-r	G-J
L0	2,64	4,23	-2,38	4,49
L1	2,56	4,45	-2,27	4,74
L2	2,5	4,64	-2,18	4,96
L3	2,34	4,84	-1,94	5,24
L4	2,38	5,06	-2	5,44
L5	2	5,21	-1,47	5,74
L6	2,79	5,27	-2,61	5,45
L7	2,31	5,91	-1,9	6,32
L8	2,19	6,11	-1,73	6,57
L9	2,33	6,04	-1,93	6,44
T0	2,43	5,76	-2,07	6,12
T1	1,47	6,59	-0,83	7,23
T2	1,8	7,38	-1,21	7,97
T3	1,16	6,75	-0,52	7,39
T4	1,04	7,35	-0,42	7,97

Note 1. r-i and i-J from Hawley et al. (2002), G-r from Jordi (2012), G-J from combination of the first 3 columns.

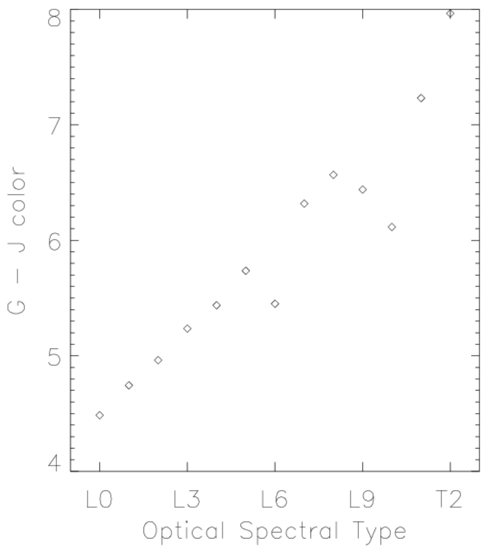

Fig. 2. The relationship of Gaia G magnitude and 2MASS J magnitude to spectral types.

from Gaia observations as members of binary systems (e.g. see Sozzetti 2014) but these are not addressed here.

2. Gaia magnitudes of L/T dwarfs

To evaluate the expected BD content of Gaia we have estimated a G magnitude for each dwarfarchives entry was done using a 3 step process:

1) We attained 2MASS J magnitudes for all dwarfarchives objects along with the dwarfarchives optical spectral type - unless not present in which case we used the infrared spectral type. If the object was too faint for 2MASS then it is probably fainter than G=20 the baseline limit for Gaia.
2) Adopting the average SDSS and 2MASS color difference by spectral type from Table 3 of Hawley et al. (2002) and the color transformations between Gaia photometry and the SDSS system from Jordi (2012) we found a G-J transformation vs spectral type shown in Figure 2 and listed in Table 1.
3) Combining 1 and 2 we estimated a G band magnitude for all dwarf archive objects.

The non-monotonic nature of the transformation in Figure 2 is partially due to small number statistics in the SDSS to 2MASS transformation and also to physical effects such as the J band hump at the L/T boundary. The Gaia to SDSS transformations were based on main sequence stars in the color range g-r =-0.5, 7.0 which covers BD colors. Due to the different spectral energy difference between M dwarfs and BDs we expect there to be a systematic difference but less than 0.1 magnitudes extrapolating the difference between M giants and dwarfs in the transformation construction.

Using this transformation and the published J 2MASS magnitudes we find that of the 1281 dwarfarchives objects 287 objects have G < 20 and 547 have G < 21. Given the volume being examined increases by a factor of 4 in when moving from G=20 to 21 is another indication that the dwarfarchives sample is not complete probably partially because of the limit in the 2MASS J magnitude The spectral type distribution of these objects is shown in Figure 3. It is evident that the BDs observed by Gaia will be predominantly early L dwarfs and even to G=21 the number of observable BDs with spectral types later than L4 is less than 50. There are only two T dwarfs visible to Gaia which are both in binary systems, Epsilon Indi Ba and WISEP J180026.60+013453.1A.

In Table 1 we list the brightest 30 L/T dwarfs visible to Gaia and in Table 2 we list all objects later than L5. The tables contain: discovery name, position, 2MASS J magnitude, estimated Gaia G magnitude, estimated distance using the 2MASS J magnitude - spectral type relation in Marocco et al (2010) , and the spectral type. We note that all the later-than-L5 BDs observable by Gaia, being the brightest examples in their spectral bins, are already the targets of ongoing ground based parallax programs (e.g. Smart et al. 2013; Dupuy & Liu 2012; Faherty et al. 2012). The expectation is that these programs will find parallaxes and proper motions with better than 1mas precisions, i.e. comparable to the expected final precision of Gaia in the G=19-21 magnitude bin where the majority of these objects are.

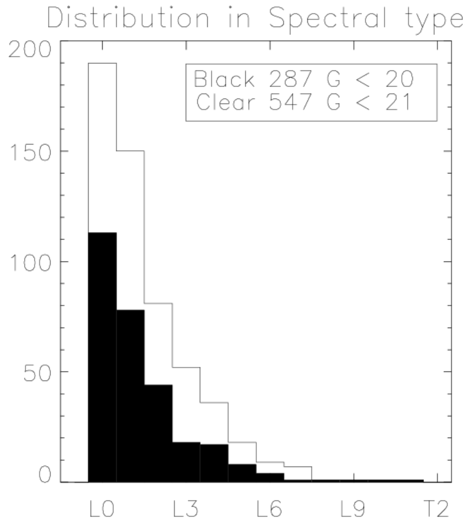

Fig. 3. The distribution of BDs observable by Gaia as a function of spectral type. The black histogram is all objects to G=20 and the clear histogram to G=21.

3. Incompleteness of the dwarfarchives sample

It is evident from Figure 1 that the dwarfarchives sample is incomplete in the plane. The SDSS DR7 was searched comprehensively in Schmidt et al. (2010) for L dwarfs. The SDSS survey had a limiting magnitude of fainter than 21 in z so fainter than the G=20 limit for these red objects. If we assume that the sample found by Schmidt was complete

Table 2. The 30 brightest in the Gaia G band L/T dwarfs from the dwarfarchives sample

Discovery Name	RA hours	Dec Degrees	J mag	G mag	d pc	SpT
G 239-25	14.70604134	66.05549622	11.51	16.00	9.42	L0.0
2MASSI J0746425+200032	7.77848911	20.00891685	11.76	16.37	10.27	L0.5
2MASS J17312974+2721233	17.52492714	27.35647202	12.09	16.58	12.28	L0.0
2MASS J03140344+1603056	3.23428893	16.05155563	12.53	17.01	14.74	L0.0
LSR 0602+3910	6.04179192	39.18310928	12.30	17.04	11.08	L1.0
2MASS J23515044-2537367	23.86401176	-25.62686157	12.47	17.09	14.46	L0.5
DENIS-P J0652197-253450	6.87215900	-25.58071899	12.76	17.24	16.43	L0.0
2MASSW J1555157-095605	15.92103577	-9.93486118	12.56	17.30	13.67	L1.0
2MASSW J1645221-131951	16.75614166	-13.33100033	12.45	17.30	12.26	L1.5
2MASS J09111297+7401081	9.18693638	74.01891327	12.92	17.41	17.96	L0.0
GJ 1048B	2.59998059	-23.52236176	12.69	17.43	17.75	L1.0
2MASSW J1300425+191235	13.01181984	19.20983315	12.72	17.46	14.61	L1.0
2MASSW J1439284+192915	14.65787792	19.48747253	12.76	17.50	14.44	L1.0
SSSPM J0829-1309	8.47616386	-13.15551758	12.80	17.55	13.60	L1.0
2MASS J09211410-2104446	9.35391712	-21.07905579	12.78	17.63	15.07	L1.5
2MASS J02284243+1639329	2.47845459	16.65916634	13.17	17.65	19.19	L0.0
2MASS J12212770+0257198	12.35769463	2.95549989	13.17	17.65	19.86	L0.0
SDSS J104842.84+011158.5	10.81189156	1.19944406	12.92	17.67	15.21	L1.0
2MASSW 1421314+182740	14.35873604	18.46132660	13.23	17.72	20.08	L0.0
SSSPM J0829-1309	8.47616386	-13.15550041	12.80	17.77	12.92	L2.0
2MASSW J1155395-372735	11.92764473	-37.45972061	12.81	17.77	13.68	L2.0
2MASSI J1807159+501531	18.12109184	50.25877762	12.93	17.79	15.16	L1.5
2MASSW J0036159+182110	0.60449171	18.35288811	12.47	17.80	9.74	L3.5
WISEP J190648.47+401106.8	19.11346436	40.18522263	13.08	17.82	16.23	L1.0
2MASSW J1108307+683017	11.14189148	68.50469208	13.12	17.87	15.84	L1.0
DENIS J0006579-643654	0.11608330	-64.61499786	13.39	17.87	22.07	L0.0
WISEP J180026.60+013453.1A	10.82192039	-53.31946564	11.22	17.89	1.85	T0.5
DENIS-P J1756561-480509	17.94894409	-48.08601761	13.41	17.89	22.38	L0.0
2MASSI J1045240-014957	10.75666714	-1.83266699	13.16	17.90	16.70	L1.0
2MASS J09532126-1014205	9.88924122	-10.23904610	13.47	17.95	22.19	L0.0

to the Gaia limit and that the distribution of nearby L dwarf is homogenous in the whole sky we can estimate how many objects there should be in the Gaia sample. Accordingly we find that the sample is about a factor of 2 too small so we expect to find around 500 to G < 20. Extrapolating this estimate to G < 21, just based on the four-fold increase in volume and assuming a flat luminosity function in the L dwarf range, we expect Gaia to find 2000.

These "missing" L dwarfs will be mainly early than L4 because these are the objects that overlap the most in color space with the numerous M dwarfs. In particular we do not expect to find any very late L or T objects unless they are in binary systems with bright primary stars or early L dwarfs like WISEP J180026.60+013453.1 which have not been resolved from the ground.

4. The Gaia L/T list

The L and T dwarfs visible to Gaia will be a important sample for brown dwarf studies over the next few years. While the precision of parallaxes from the ground will be competitive with Gaia the mission will provide homogenous astrometric parameters and photometric

Table 3. All objects later than L5 visible to Gaia from dwarfarchives assuming a magnitude limit of G=21

Discovery Name	RA hours	Dec Degrees	J mag	G mag	d pc	SpT
2MASSI J1315309-264951	13.25859451	-26.83091736	15.19	20.79	24.87	L5.5
2MASS J17502484-0016151	17.84023476	-0.27086499	13.29	18.89	11.27	L5.5
2MASS J22551861-5713056	22.92183876	-57.21823883	14.08	19.68	16.03	L5.5
2MASSI J1010148-040649	10.17077827	-4.11386108	15.51	20.96	16.37	L6.0
SDSS J133148.92-011651.4	13.53026104	-1.28055596	15.46	20.91	17.69	L6.0
ULAS J141623.94+134836.3	14.27335739	13.80731773	13.15	18.60	6.77	L6.0
2MASSW J1515008+484742	15.25023079	48.79488754	14.11	19.56	9.13	L6.0
2MASS J20025073-0521524	20.04742432	-5.36455584	15.32	20.77	15.16	L6.0
2MASS J21481633+4003594	21.80453682	40.06650162	14.15	19.60	7.88	L6.0
2MASS J21481633+4003594	21.80453682	40.06650162	14.15	19.60	7.88	L6.0
2MASS J21522609+0937575	21.87391472	9.63263893	15.19	20.64	14.26	L6.0
2MASSI J0439010-235308	4.65028048	-23.88563919	14.41	20.29	10.52	L6.5
DENIS-P J0205.4-1159	2.09150004	-11.99155617	14.59	20.91	11.03	L7.0
2MASS J09153413+0422045	9.25948048	4.36791706	14.55	20.87	10.93	L7.0
2MASS J21265916+7617440	21.44976616	76.29555511	14.34	20.65	10.97	L7.0
SDSSp J042348.57-041403.5	4.39682770	-4.23430586	14.47	20.91	10.55	L7.5
WISE J104915.57531906.1A	10.82192039	-53.31946564	11.53	17.98	2.45	L7.5
WISEP J180026.60+013453.1A[1]	18.00738907	1.58141696	14.30	20.74	9.01	L7.5
DENIS-P J225210.73-173013.4	22.86964798	-17.50372124	14.31	20.76	10.11	L7.5
DENIS-P J0255-4700	2.91765833	-47.01413727	13.25	19.81	5.29	L8.0
LSR 1610-0040	16.17472267	-0.68138897	12.91	19.35	5.05	L9.0
WISEP J180026.60+013453.1B[1]	10.82192039	-53.31946564	11.22	17.89	1.85	T0.5
ϵ Indi Ba	22.06958961	-56.78269577	12.29	19.52	2.96	T1.0

Note 2. [1] Note the WISE J104915.57531906.1 (Luhman 16) system was not in Dwarfarchives but was added in the preparation of this article.

sampling that will not be matched from the ground in the foreseeable future. This dataset will allow us to examine the correlations between physical parameters such as mass, age and composition with luminosity and spectral indicators that, if calibrated, will allow us to break the degeneracy between these physical parameters. Having the ability to determine ages for these objects from spectra will make them very powerful chronometers for the study of our Galaxy.

To complement the Gaia results we will require medium to high resolution spectra of all the Gaia candidates. This is the goal of the programs discussed in Marocco (2014) and Caballero (2014) to make a spectroscopic census of Gaia brown dwarfs. To aid in that endeavor we have put the list of 547 L/T dwarfs brighter than G=21 online and linked in the home page of the meeting web page: gaiabds.oato.inaf.it. This list also includes links to spectral observations found in various observatory archives. As more spectroscopic observations become available, more L/T dwarfs are found and improvements to the various magnitude transformations are produced this list will be updated.

5. Conclusions

Extrapolating the dwarfarchives sample we predict that approximately 500 L/T dwarfs will be visible to Gaia at the G=20 limit, this number will quadruple if Gaia is extended to G=21. Extending the Gaia survey to G=21 does not increase significantly the L/T spectral range sampled. To aid the collection of high and medium resolution spectra for the Gaia sample we have made the list of known L/T dwarfs public and will continue to update as more objects are discovered and the transformations to Gaia magnitudes improve.

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