Mem. S.A.It. Vol. 85, 752

Memorie della

Gaia and the luminosity and mass functions of field brown dwarfs

C. Reylé

Institut UTINAM, CNRS UMR 6213, Observatoire des Sciences de l'Univers THETA Franche-Comté-Bourgogne, Université de Franche Comté, Observatoire de Besançon, BP 1615, 25010 Besançon Cedex, France, e-mail: celine@obs-besancon.fr

Abstract. Thanks to recent and ongoing large scale surveys, thousands of brown dwarfs have been discovered in the last decade. Large and homogeneous samples can be used to constrain the field brown-dwarf luminosity function and mass function. In this paper I will review the studies of field brown dwarf luminosity and mass functions obtained from complete and well defined samples. The uncertainties remain quite large and the comparison with the brown dwarf mass function in star clusters is puzzling. I wiil discuss how Gaia can bring important clues on that topics.

Key words. Stars: low-mass, brown dwarfs – Stars: luminosity function, mass function – Galaxy: stellar content

1. Introduction

Five decades have passed since Kumar (1963) proposed the first theoretical existence of brown dwarfs, but their first observational discoveries is still quite recent. The first discoveries of brown dwarfs were made by Nakajima et al. (1995) around the nearby star Gliese 229 and by Stauffer et al. (1994) and Rebolo et al. (1995) in the Pleiades. Delfosse et al. (1997); Ruiz et al. (1997) and Kirkpatrick et al. (1997) found the first field brown dwarfs. Since then, several hundreds of field brown dwarfs have been identified, most of them thanks to large-scale optical and near-infrared imaging surveys because they can be identified by their red optical minus near-infrared colours. Most of them have been found in the DEep Near-Infrared Survey of the Southern Sky (DENIS, Epchtein et al. 1997), the Two-Micron All-Sky Survey (2MASS, Skrutskie et al. 2006) and in the Sloan Digital Sky Survey (SDSS, York et al. 2000).

The new generation of large-area surveys uses deeper images: the UKIRT Infrared Deep Sky Survey (UKIDSS, Lawrence et al. 2007), the Canada-France-Brown-Dwarf Survey (CFBDS, Delorme et al. 2008), and the Wide-field Infrared Survey Explorer (WISE, Wright 2008). As a consequence, the number of known brown dwarfs increases and new types of rarer and fainter brown dwarfs are detected. To date 1300 L,T,Y dwarfs have been detected in the local Galactic field. With that large number of identified brown dwarfs, it becomes possible to define uniform and well-characterised samples of substellar objects to investigate their mass and luminosity functions.

Knowing these functions is essential in several studies. In terms of Galactic studies, it gives clues on the baryonic content of the

Galaxy and contributes to determine the evolution of the Galaxy mass (our Galaxy probably counts several 10^{10} of brown dwarfs, hundreds of them in the Solar neighbourhood!). In terms of stellar physics studies, it gives constraints on stellar and substellar formation theories (can a single log-normal function fit the mass function from field stars to brown dwarfs?). To validate these assumptions, it is first necessary to refine the field brown dwarf luminosity and mass functions.

In this paper I will review the recent observational efforts to characterize the low-mass end luminosity and mass functions and discuss how Gaia data will help, or not, to improve these determinations.

2. The field brown dwarf luminosity function

An initial estimate of the local space density of late T dwarfs has been made by Burgasser (2002), from a sample of 14 T-dwarfs. Allen et al. (2005) used these results combined with data compiled from a volume-limited sample of late M and L dwarfs (Cruz et al. 2003) to compute a luminosity function. Recently, a detailed investigation on a volume-limited sample of field late-M and L dwarfs has been performed by Cruz et al. (2007). A similar empirical investigation of field T-dwarfs has been presented by Metchev et al. (2008). Still the number of objects in their sample is relatively small (46 L-dwarfs and 15 T-dwarfs, respectively) and the field brown dwarf luminosity-function remains poorly constrained. Thus further efforts were needed to measure the space density of brown dwarfs.

Halfway through the CFBDS survey Reylé et al. (2010) drew a complete and well defined sample of 102 L and 7 dwarfs over 780 deg^2. Very recently Kirkpatrick et al. (2012) used a sample of 148 T6 to >Y1 dwarfs from WISE, Day-Jones et al. (2013) 63 L4-T1.5 over 495 deg^2 from the UKIDSS Large Area Survey DR7, and Burningham et al. (2013) 78 T6-T8.5 over 2270 deg^2 from the UKIDSS Large Area Survey DR8. The space densites are summarized in Table 1.

Several steps still have to be handled carefully before deriving the space density. It is necessary to correct for contamination and uncompleteness. Absolute magnitude versus colour or spectral type relations have to be assumed to estimate a distance for each object. Such relations can be obtained from brown dwarf sample with measured parallaxe. However they show a significant scatter (see Fig. 16 and 25 in Dupuy & Liu 2012). These result in quite large uncertainties as well as discrepancies between authors, as seen in Table 1.

3. Towards the field brown dwarf mass function

The work is even more complicated when one wants to go from the luminosity function to the mass function. The main difficulty comes from the age degeneracy found in the mass-luminosity relation of brown dwarfs (see e.g. Fig. 2 in Jeffries 2012). Furthermore, the luminosity function at the low mass end is highly dependant on binarity corrections (Reid et al. 2002) whereas the binarity rate is poorly known.

First estimates of the substellar mass function have been obtained in the L-dwarf domain: Reid et al. (1999) with $1 < \alpha < 2$, Burgasser (2002) $0.5 < \alpha < 1$, Allen et al. (2005) $\alpha < 0.3 \pm 0.6$. Recently, Metchev et al. (2008) derived a T dwarf space density that was mostly consistent with $\alpha = 0$ and the comparison of the observed number of T4-T8.5 dwarfs by Pinfield et al. (2008) favoured $\alpha < 0$. The analysis of brown dwarfs found in the Large Area Survey (LAS) of UKIDSS and teh CFBDS also suggests that the substellar mass function is declining at lower masses (Burningham et al. 2010; Reylé et al. 2010; Burningham et al. 2013).

In order to estimate the mass function, the authors compare the field brown dwarf luminosity function to model loci taken from simulations that predict the observed luminosity function based on evolutionary models with an assumed value for the initial mass function $\Psi(M) = dN/dM \propto M^{-\alpha}$. Burgasser (2007) performed simulations assuming different mass functions. The comparison between

Table 1. Comparison of the brown dwarf space densities ρ (10^{-3} objects pc^{-3}) obtained from different studies: (1) Cruz et al.(2007), (2) Metchev et al.(2008), (3) Reyle et al.(2010, (4) Kirpatrick et al.(2012), (5)Day-Jones et al.(2013), (6) Burningham et al.(2013)

Spectral type	(1)	(2)	(3)	(4)	(5)	(6).
L3.5-L8	2.2 ± 0.4	–		–	–	–
L5-L9.5	–	–	$2.0^{+0.8}_{-0.7}$	–	–	–
L7-T0.5	–	–	–	–	0.29 ± 0.05	–
T0-T5.5	–	$2.3^{+0.9}_{-0.9}$	$1.4^{+0.3}_{-0.2}$	–	–	–
T1-T4.5	–	–	–	–	0.23 ± 0.09	–
T6-T7.5	–	–	–	2.0 ± 0.2	–	1.3 ± 0.3
T6-T8	–	$4.7^{+3.1}_{-2.8}$	$5.3^{+3.1}_{-2.2}$	–	–	4.4 ± 0.3
T8.5-T/Y	–	–	$8.3^{+9.0}_{-5.1}$	–	–	$> 3.4 \pm 1.8$
T8-Y1	–	–	–	> 4.9	–	–

different luminosity functions and these simulations is shown in Fig. 1. It suggests that the best agreement is obtained with a flat mass function ($\alpha = 0$) or even a decreasing mass function. Note that the values often disagree for early T-dwarfs. However, the physics at the L/T transition is difficult to model, not only due to the cooling of the atmosphere but also to the clearing of the atmosphere that needs to model properly the hydrodynamics and the clouds formation (Freytag et al. 2010), making the timescales uncertain. If confirmed, this low value would back Burgasser (2007) suggestion that the L/T transition occurs rapidly.

Surprisingly, these results are not consistent with the substellar mass function in young open clusters showing $\alpha \simeq 0.6$ (see Bayo et al. 2011; Alves de Oliveira 2013, and references therein). This discrepancy is still not understood and must be reproduced and explained by any successful star formation theory, although this difference should be taken with caution as the results might not be mature enough.

4. How can Gaia help, or not?

The brown dwarf census usually follows a two-step process: candidates are first found in large photometric surveys and extensive spectroscopic follow-ups are performed to determine spectral types and remove contaminants. Parallaxes are needed to determine luminosities and the space density. However those are difficult to obtain for large samples and empirical relations between magnitude and spectral type are often used to estimate distances. Obviously Gaia will give an unprecedented homogeneous sample of L-dwarfs with precise measured distances. A preliminary estimate of the number of ultra-cool dwarfs has been obtained by Sarro et al. (2013). See also Smart (2014) in this volume. The field brown dwarfs are of different ages, ranging from 0 to 10 Gyr but individual masses cannot be estimated due to the age-dependent mass-luminosity relation making difficult the construction the mass function. Statistical simulations of the expected luminosity function are needed. They assume various mass functions, birthrate, evolutionary models, and binarity. The construction of the field brown dwarfs luminosity and mass functions is thus heavily model-dependent! In particular masses are probably not well-predicted by the luminosities given by the current evolutionary models. Gaia will be very helpful in obtaining masses for benchmark brown dwarfs in binaries with known age.

On the observational side the T-dwarf (and now Y-dwarf) census is vastly improving thanks to WISE. Significant efforts are still needed to measure precise trigonometric parallaxes for very faint objects and to understand

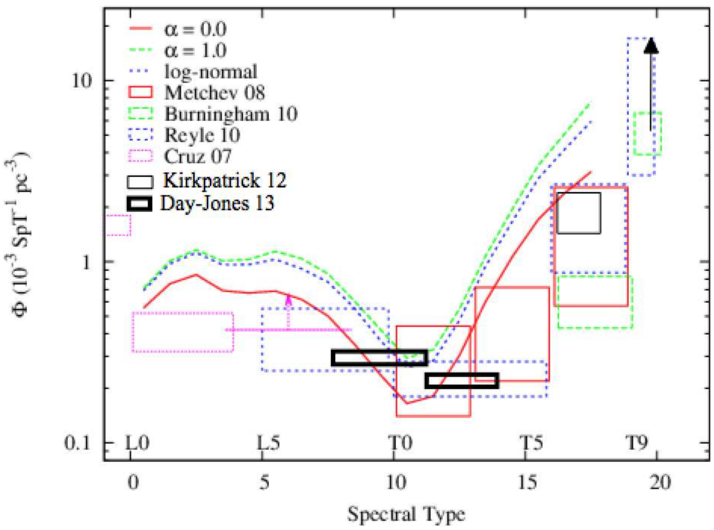

Fig. 1. Comparison of the brown dwarf space densities ρ (10^{-3} objects pc^{-3}) obtained by Burgasser (2007) from simulations assuming different mass functions: $\Psi(M) = dN/dM \propto M^{-\alpha}$ with observed luminosity functions (see references in the text). Adapted from Jeffries (2012)

their physics. These efforts must be pursued as the sensibility of Gaia will not allow to probe the coolest brown dwarfs.

References

Allen, P. R., Koerner, D. W., Reid, I. N., & Trilling, D. E. 2005, ApJ, 625, 385
Alves de Oliveira, C. 2013, MmSAI, 84, 905
Bayo, A., Barrado, D., Stauffer, J., et al. 2011, A&A, 536, A63
Burgasser, A. J. 2002, Ph.D. Thesis, California Institute of Technology
Burgasser, A. J. 2007, ApJ, 659, 655
Burningham, B., Pinfield, D. J., Lucas, P. W., et al. 2010, MNRAS, 406, 1885
Burningham, B., Cardoso, C. V., Smith, L., et al. 2013, MNRAS, 433, 457
Cruz, K. L., et al. 2003, AJ, 126, 2421
Cruz, K. L., Reid, I. N., Kirkpatrick, J. D., et al. 2007, AJ, 133, 439
Day-Jones, A. C., Marocco, F., Pinfield, D. J., et al. 2013, MNRAS, 430, 1171
Delfosse, X., Tinney, C. G., Forveille, T., et al. 1997, A&A, 327, L25
Delorme, P., Willott, C. J., Forveille, T., et al. 2008, A&A, 484, 469
Dupuy, T. J., & Liu, M. C. 2012, ApJS, 201, 19
Epchtein, N., de Batz, B., Capoani, L., et al. 1997, The Messenger, 87, 27
Freytag, B., et al. 2010, A&A, 513, A19
Jeffries, R. D. 2012, EAS Publications Series, 57, 45
Kirkpatrick, J. D., Beichman, C. A., & Skrutskie, M. F. 1997, ApJ, 476, 311
Kirkpatrick, J. D., Gelino, C. R., Cushing, M. C., et al. 2012, ApJ, 753, 156
Kumar, S. S. 1963, ApJ, 137, 1121
Lawrence, A., Warren, S. J., Almaini, O., et al. 2007, MNRAS, 379, 1599
Metchev, S. A., et al. 2008, ApJ, 676, 1281
Nakajima, T., Oppenheimer, B. R., Kulkarni, S. R., et al. 1995, Nature, 378, 463
Pinfield, D. J., Burningham, B., Tamura, M., et al. 2008, MNRAS, 390, 304
Rebolo, R., Zapatero Osorio, M. R., & Martín, E. L. 1995, Nature, 377, 129
Reid, I. N., Kirkpatrick, J. D., Liebert, J., et al. 1999, ApJ, 521, 613
Reid, I. N., Gizis, J. E., & Hawley, S. L. 2002, AJ, 124, 2721
Reylé, C., Delorme, P., Willott, C. J., et al. 2010, A&A, 522, A112

Ruiz, M. T., Leggett, S. K., & Allard, F. 1997, ApJ, 491, L107
Sarro, L. M., Berihuete, A., Carrión, C., et al. 2013, A&A, 550, A44
Smart, R. 2014, MmSAI, 85, 649
Stauffer, J. R., Liebert, J., Giampapa, M., et al. 1994, AJ, 108, 160
Skrutskie, M. F., Cutri, R. M., Stiening, R., et al. 2006, AJ, 131, 1163
Wright, E. L. 2008, EAS Publications Series, 33, 57
York, D. G., Adelman, J., Anderson, J. E., Jr., et al. 2000, AJ, 120, 1579