Mem. S.A.It. Vol. 84, 1163

Memorie della

Brown dwarfs will never die

Population III brown dwarfs and habitable planets around nearby ultracool dwarfs

E. L. Martín

Centro de Astrobiología (INTA-CSIC), Carretera de Ajalvir km 4, E-28550 Torrejón de Ardoz, Madrid, Spain, e-mail: `ege@cab.inta-csic.es`

Abstract. This paper presents a glimpse on future prospects in brown dwarf research. The advent of space missions such as GAIA, JWST and Euclid, and the new generation of giant ground-based telescopes will bring about a quantum leap in the discovery and characterization of brown dwarfs of various types. It is pointed out here that the longevity of brown dwarfs makes them extremely interesting as relics of the first generation of stars in this Universe (Population III). The advantages and caveats of looking for habitable planets around brown dwarfs is the other topic discussed in this paper.

Key words. Stars: formation – Stars: low.mass, brown dwarfs – Stars: luminosity function, mass function – Cosmology: observations

1. Introduction

Brown dwarfs (BDs) are objects less massive than stars. During their early evolution they may sustain nuclear reactions in their interiors, particularly D-fusion and ^{7}Li fission, both of which take place at temperatures below those needed for H-fusion (3×10^6 K). However, they fail to settle on the H-burning stellar main-sequence because their core becomes degenerate. The mass boundary between stars and BDs was first calculated in the 1960s by two teams, and it is located between 0.09 and 0.07 solar masses for Population II and I chemical mixture, respectively (Kumar 1963a,b; Hayashi & Nakano 1963; Nakano 2003). BDs are a sink of baryonic matter, and thus their density needs to be calculated to estimate their contribution to the dark matter in galaxies (Bahcall 1984).

At first BDs were called Black Dwarfs, but this term was dropped after the thesis work of Jill Tarter in 1975. The word brown becomes colorful when translating into different languages. For example in Mexico BDs become Enanas Café, and in Brazil they are known as Enanas Mulatinhas. Quoting Franca D'Antona, "Brown is Now a Color" (D'Antona 1998). The extremely cool temperatures that are reached by BDs during their evolution have made it necessary to coin two new spectral classes to classify their spectra: the L class (Martín et al. 1997; Kirkpatrick et al. 1999), and the T class (Burgasser et al. 2006). An even cooler spectral class named Y has been suggested but remains controversial (Dupuy & Kraus 2013).

Send offprint requests to: E. L. Martín

The term ultracool dwarf (UCD) is more general than BD because it includes the coolest stars as well as the brown dwarfs. UCD refers to the spectral type of the objects being M7 and later. The choice of M7 is justified by the weakening of the TiO bands caused by the onset of metallic grain condensation in the photospheres of objects cooler than about 2500 K (Tsuji et al. 1996). The boundary between UCDs and red dwarfs coincides with the substellar limit at the age of the Pleiades (120 Myr). Extremely ultracool dwarfs (EUCDs) is a term introduced here to refer to objects with spectral class L5 and later which are too cool to be stars on the main-sequence for the age of the Universe, and thus they must be BDs.

The advent of high spatial resolution imaging techniques at near-infrared wavelengths enabled the search for BDs around nearby low-luminosity very late M dwarfs. Even though the discovery of a faint companion to the dM7 Van Biesbroeck 8 star was not confirmed (Perrier & Mariotti 1987), it attracted considerable attention to this type of objects and paved the way for future discoveries (Stevenson 1991). The first unambiguous BD companion to a star was Gl 229B (Nakajima et al. 1995), which later became the prototype of the T dwarfs. However, it was not the first BD discovered, and possibly no even the first BD companion ever seen.

On March 9, 1990, a faint companion in the pre-main sequence visual binary system UX Tau A,B was identified with the TV camera of the 2.5-meter Isaac Newton Telescope (INT) in La Palma. UX Tau C had already been noticed at Lick Observatory by G. Herbig (see notes on UX Tau A in Jones & Herbig 1979) but no spectrum was taken. The spectrum of UX Tau C obtained at the INT by Magazzù et al. (1991) was classified as M6 spectral type and it showed the presence of a strong lithium neutral resonance line. At the very young age of this multiple system in Taurus, it is likely that UX Tau C is in fact a very young BD companion to UX Tau A. Spectral types of M6.5±0.5 have been derived for both components in the eclipsing BD binary 2M0535-05 located in the Orion star-forming complex (Stassum et al. 2007). At 0.054±0.005 and 0.034±0.003 solar masses, the dynamical masses of both components are well below the substellar limit. It is remarkable that the spectral type of UX Tau C coincides within the error bars with that of 2M0535-05.

Lithium detection in UX Tau C prompted the idea of using this fragile element to test the substellar nature of BD candidates. The lithium test was applied to many BD candidates (Magazzù et al. 1993; Martín et al. 1994) until it finally met with success in the case of the Pleiades late-M dwarfs PPl1, Teide 1 and Calar 3 (Basri et al. 1996; Rebolo et al. 1996) and in the cases of the extreme Hα emitter field UCD PC0025+0447 (Martín et al. 1999), the high proper motion object LP944-20 (Tinney 1998) and the first field L-type dwarf Kelu 1 (Ruiz et al. 1997). Even though the lithium detection of PPl 15 was the first to be reported among the Pleiades BD candidates, its interpretation is complicated by the binarity of this object (Basri & Martín 1999), and the weakness of the lithium line, which suggests that this system could be composed of a stellar mass primary that has depleted lithium and a substellar mass secondary that has preserved it. It is noteworthy that both LP944-20 and UX Tau C had been seen since the 1970s but they remained unrecognized as BDs for about two decades.

The days of the exciting discoveries of the first BDs are long gone, but these objects are still at the forefront of observational astronomy and keep challenging our minds. In this paper I focus on two topics that are likely to bring exciting discoveries in the bright future of these faint sources, namely, Population III BDs and habitable planets around BDs.

2. Population III BDs in the Euclid survey

The fact that BDs and planetary mass objects are copiously forming in the Milky Way even though their masses are more than an order of magnitude lower than the typical Jeans mass strongly suggests that BDs are likely to have formed throughout all the episodes of star-formation in the Universe, notwithstanding the very first generation of stars (Population III). Pop. III stars are thought to have been rather massive, typically between 40 and 300 solar masses (Hokosawa et al. 2011). However, it is found in our own galaxy that regions were massive stars form also produce a high number of BDs (Peña Ramírez et al. 2012; Bouy et al. 2008), possibly by fragmentation and collapse of lightweight molecular cores in filaments triggered by collisions of the primordial star-forming clouds and by shock fronts originated from jets and explosions of massive stars.

Atmosphere models for zero-metallicity BDs show that Rayleigh scattering and molecular hydrogen absorption make the spectral energy distribution to shift toward bluer wavelenghts with respect to the black body emission. For example, Population III EUCDs are predicted to have negative $I - J$ colors in stark contrast with their Population I counterparts (Saumon et al. 1994). Searches for UCDs typically use an (I-J) color criterion of > 3 (Martín et al. 1999; Kendall et al. 2004) or $r - J$ color cut of > 4 (Martín et al. 2013). Searches for Population III BDs will have to use radically different color criteria. It will be extremely important to use as many photometric points as possible to identify such elusive objects.

ESA's Euclid mission main survey plans to reach photometric limits in one optical and 3 near-infrared passbands of 24.5 magnitude (10 sigma) over 15,000 square degrees with diffraction limited image quality (FWHM≤0.18 arcsec at red optical wavelengths). It also plans to obtain slitless low-resolution (R=250) near-infrared spectra.

ESA has selected our team in its second call for Euclid Independent Legacy Scientists. We have demonstrated that using Virtual Observatory (VO) tools with multiwavelength survey data can be efficient to reveal reliable new UCDs (Aberasturi et al. 2011) without the need for follow-up spectroscopy. Our team also has experience with using the maximum reduced proper motion method to select UCDs from large area surveys with high success rate (Phan Bao et al. 2008), and with low-resolution spectroscopic characterization of faint UCDs and ultracool subdwarfs (Lodieu et al. 2010).

Efficient mining of the Euclid survey with the VO will produce several hundred thousands of UCD identifications. From this information the galactic scale height of BDs can be derived as well as the luminosity function in the galactic disk. Thousands of new BD binaries will be resolved providing unprecedented statistics of the binary properties as a function of chemical composition and mass, which are extremely useful to constrain models of BD formation (Duchene & Kraus 2013). Nevertheless, the most exciting prospect will be the identification of the first candidate Population III VLM stars and BDs, which are expected to have a very low density in the solar vicinity (about 10^6 less than the density of Population I dwarfs).

3. Habitable planets around BDs

Due to their very low masses and their small radii, UCDs are arguably the best hosts to detect small planets (Martín et al. 2005; Belu et al. 2013). Follow-up transmission spectroscopy, a very promising technique to characterize the atmospheric constituents of exoplanets (Kaltenegger & Traub 2009; Pallé et al. 2009) and the evaporation of their atmospheres (Murgas et al. 2012), is also more favorable in the case of planets around UCDs.

While it has been pointed out that there is no obvious phenomenon that renders planets around BDs uninhabitable (Barnes et al. 2011), it is also true that for EUCDs the habitable zone is so close to the object that tidal heating and the associated runaway greenhouse effect is a major concern (Barnes et al. 2013). A sweetspot in the search for habitable planets are the VLM stars and the bottom of the main sequence and the most massive BDs. The spectral types of these exoplanet hosts are in the range M6 to L0. Many of these stellar objects are fast rotators, and hence the radial velocity technique is not the best approach to detect habitable rocky planets around them (Rodler et al. 2011). A search for transits around nearby UCDs seems to be the most practical route to find the nearest examples of habitable planets that can be followed up with transit spectroscopy. Such an idea has indeed been suggested as additional surveys for the Kepler and Euclid spacecrafts (Martín 2013).

Acknowledgements. This work has been supported by the Spanish Ministerio de Economia y Competitividad via grant AyA2011-30147-C03-03 . EM is thankful to the College of Arts and Sciences of the University of Florida for a visiting position during part of the time during which this manuscript was written. The members of the ESA independent legacy team on ultracool dwarfs are the following: David Barrado, Hervé Bouy, Nuria Huélamo, Nicolas Lodieu, Basmah Riaz, Johannes Sahlmann and Enrique Solano.

References

Aberasturi M., Solano E., & Martín, E. L. 2011, A&A, 534, L7
Bahcall, J. N. 1984, ApJ, 276, 169
Barnes, R., et al. 2011, in 16th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, eds. C.M. Johns-Krull, M.K. Browning, A.A. West, (ASP, San Francisco), ASP Conf. Ser., 448, 391
Barnes, R. & Heller, R. 2013, AsBio, 13, 279
Basri, G., & Martín, E. L. 1999, AJ, 118, 2460
Basri, G., Marcy, G. W., & Graham, J. R. 1996, ApJ, 458, 600
Belu, A. R., et al. 2013, ApJ, 768, 125
Bouy, H., et al. 2008, A&A, 477, 281
Burgasser, A., et al. 2006, ApJ, 637, 1067
D'Antona, F. 1998, in Brown Dwarfs and Extrasolar Planets, eds. R.R. Rebolo, E.L. Martin, M.R. Zapatero Osorio, ASP Conf. Ser., 134, 545
Duchene, G., & Kraus, A. 2013, ARA&A, 51, 269
Dupuy, T., & Kraus, A. L. 2013, Science Express, in press (arXiv:1309.1422)
Kaltenegger, L., & Traub, W. A. 2009, ApJ, 698, 519
Kendall, T. R., et al. 2004, A&A, 416, L17
Kirkpatrick, J. D., et al. 1999, ApJ, 519, 802
Kumar, S. S. 1963a, ApJ, 137, 1121
Kumar, S. S. 1963b, ApJ, 137, 1126
Hayashi, C., & Nakano, T. 1963, Prog. Theor. Phys., 30, 460
Hokosawa, T., et al. 2011, Science, 334, 1250
Jones, B. F., & Herbig, G. 1979, AJ, 84, 1872
Lodieu, N., et al. 2010, ApJ, 708, L107
Magazzú, A., Martín, E. L., & Rebolo, R. 1991, A&A, 249, 149
Magazzù, A., Martín, E. L., & Rebolo, R. 1993, ApJ, 404, L17
Martín, E. L. 2013, EPJWC, 47, 15003
Martín, E. L., Magazzù, A., & Rebolo, R. 1994, ApJ, 436, 262
Martín, E. L., et al. 1997, A&A, 327, L29
Martín, E. L., Basri, G., & Zapatero Osorio, M. R. 1999, AJ, 118, 1005
Martín, E. L., et al. 1999, AJ, 118, 2466
Martín, E. L., et al. 2005, AN, 326, 1015
Martín, E. L., et al. 2013, A&A, 555, 108
Murgas, F., et al. 2012, A&A, 544, 41
Nakajima, T., et al. 1995, Nature, 378, 463
Nakano, T. 2003, in Brown Dwarfs, ed. E. Martín, (ASP, San Francisco), IAU Symposium, 211, 551
Pallé , E., et al. 2009, Nature, 459, 814
Peña Ramírez, K., et al. 2012, ApJ, 754, 30
Perrier, C. & Mariotti, J.-M. 1987, ApJ, 312, L27
Phan Bao, N., et al. 2008, MNRAS, 383, 831
Rebolo, R., et al. 1996, ApJ, 469, L53
Rodler, F., et al. 2011, A&A, 532, 31
Ruiz, M.T., Leggett, S.K. & Allard, F. 1997, ApJ, 491, L107
Saumon, D., et al. 1994, ApJ, 424, 333
Stassun, K. G., et al. 2007, ApJ, 664, 1154
Stevenson, D. J. 1991, ARA&A, 29, 163
Tinney, C.G. 1998, MNRAS, 296, L42
Tsuji, T., et al. 1996, A&A, 308, L29