**Short Visit Grant ☒ or Exchange Visit Grant ☐**

*(please tick the relevant box)*

# Scientific Report

**Scientific report (one single document in WORD or PDF file) should be submitted online within one month of the event. It should not exceed eight A4 pages.**

***Proposal Title:*** Brown Dwarfs within Gaia

***Application Reference N°:*** 6043

## 1) Purpose of the visit

This report is related to the visit to the University of Hertfordshire from the 21st to the 31st October 2013.

We planed to discuss about the impacts of Gaia in the detection and characterization of multiple BD systems, and discuss how to integrate Gaia with the current ground based and space large surveys (e.g, 2MASS, UKIDSS, VISTA, WISE) and smaller dedicated surveys like targeted parallax and spectroscopic programs (e.g. NPARSEC [1], X-shooter follow up of L/T BDs [2]).

Based on this study we predict that Gaia will observe 500 companions to faint bown dwarfs within 100pc, these will form the defacto benchmark sample for understanding brown dwarfs for the next 20 years.

[1] Smart+ 2013 MNRAS in press, NPARSEC: NTT Parallaxes of Southern Extremely Cool objects. Goals, targets, procedures and first results.

[2] Day-Jones+ 2013 MNRAS 430, The sub-stellar birth rate from UKIDSS

## 2) Description of the work carried out during the visit

During the visit we have preformed an initial compilation of the current data available for brown dwarfs.

Our base source was SIMBAD [1]. SIMBAD is a database that lists most of the objects that have been published. We complemented this initial listing with the objects within DwarfArchives, [2] a known database of brown dwarfs, that were not crossmatched within a 1arcmin radius. These databases are constructed based on the keywords provided by the authors of the articles that study them, for that reason the information provided for each source is not homogeneous. The photometry provided is also not in an homogeneous system, although most of the objects will have photometry taken with one of two systems: 2MASS and MKO.

Our initial selection was for all objects that were tagged within SIMBAD as brown dwarfs, brown dwarf candidates or that had spectral types later that L0. Completing these table with the objects that were part of the DwarfArchives and not recovered with SIMBAD we compiled a total of 4829 objects that satisfied the initial criteria.

Due to the uncertainty of the brown dwarf state of M dwarfs, we have made a cut on these objects, and only M dwarfs later than M6 were considered. The cut on the M dwarfs and spurious classifications left us with 3170 objects with spectral types later than M6 classified as brown dwarfs and brown dwarf candidates.

The sample was distributed in 1404 M dwarfs, 1305 L dwarfs, 442 T dwarfs and 19 Y dwarfs.

Figure 1 shows the distribution of these objects in the sky.

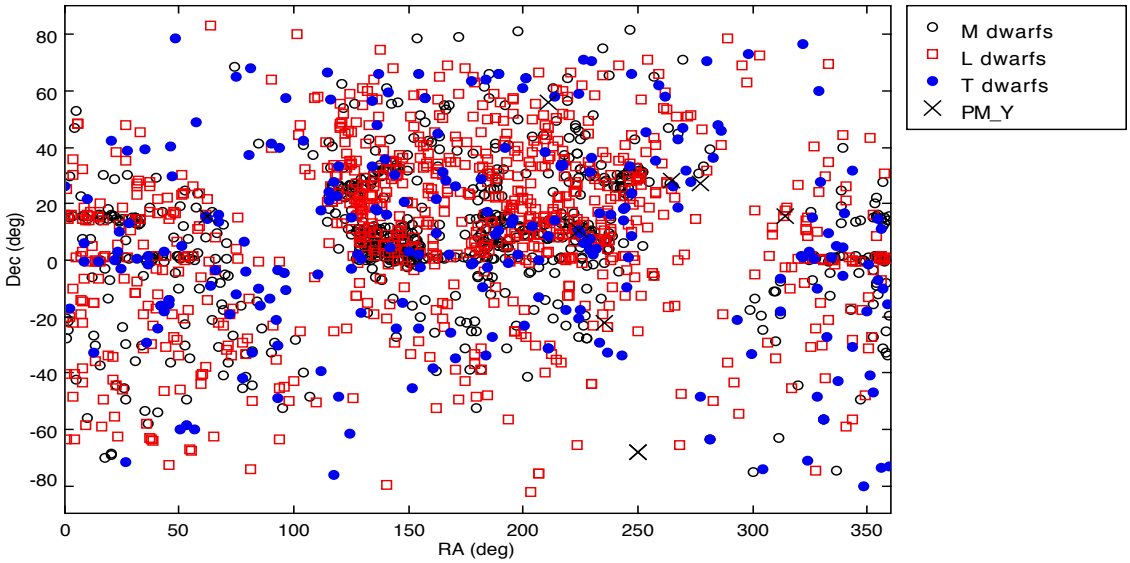


Figure 1: Distribution of known dwarfs in the sky. M dwarfs later than M6 are identified by the black open circles, L dwarfs with red open squares, T dwarfs with blue circles, and Y dwarfs with black crosses (this description will be kept for all plots).

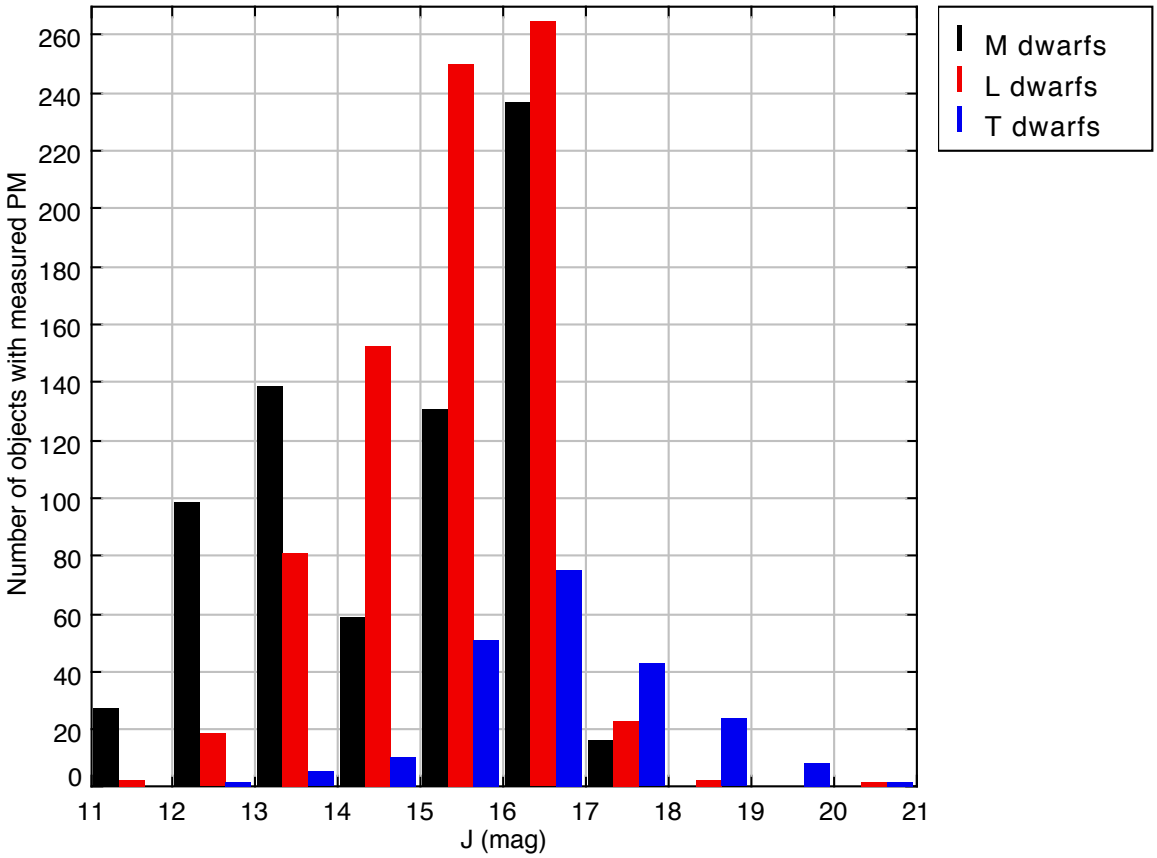


Figure 2: Histogram showing the population of brown dwarfs with measured proper motions separated by spectral types. The histogram peaks around J~16 because it corresponds to the limit of 2MASS. For fainter magnitudes the kinematics studies are focused on T dwarfs, and we are missing information for the L and M dwarf populations.

Using this sample we have investigated their kinematic properties. The kinematic properties we are interested in this project are the distance and proper motions. They are derived by the determination of acurate positions and by their follow up variation with time. The determination of parallaxes is time consuming, and for the brown dwarf population only a very small portion of the objects have measured parallaxes (in this compilation 93 objects).

The Gaia mission will provide kinematic information for ~1 billion stars throughout our Galaxy, but of these only a very small fraction will be direct observations of brown dwarfs (expected less than 1000, [3]). Due to its magnitude limit, Gaia will not be able to detect any T dwarfs (except the 2 closest systems). For most brown dwarfs, expecially the cooler and less luminous, this kinematic information needs to be provided by infrared observations, but for the M and L dwarf population Gaia will be revolutionary. As we can see in Figure 2 the number of objects with measured proper motions is significantly larger than distances, and this number will increase with the release of the results from the ongoing infrared large surveys.

In this project we intended to do a census of the known brown dwarfs, and their kinematic properties. In here we present the main results.

[1] This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.
[2] This research has benefitted from the M, L, T, and Y dwarf compendium housed at DwarfArchives.org.
[3] Sarro, L. M., et al. 2013, A&A, 550, A44

### 3) Description of the main results obtained

Investigating the distribution of the brown dwarfs in colour space we can identify that different spectral types objects distribute themselves differently, particularly T dwarfs have distinct red colours in the infrared (see Figure 3).

In a similar way that we can differenciate different spectral properties of brown dwarfs by plotting them in colour-colour space, we can identify diferent kinematic populations by plotting the objects reduced proper motion for each spectral type.

In the solar neighbourhood we are dominated by stars from the thin-disk, about 97% of the objects will be from that population. The other 3% of stelar objects will be from the thick-disk and halo. The population distribution of brown dwarfs is expected to be similar.

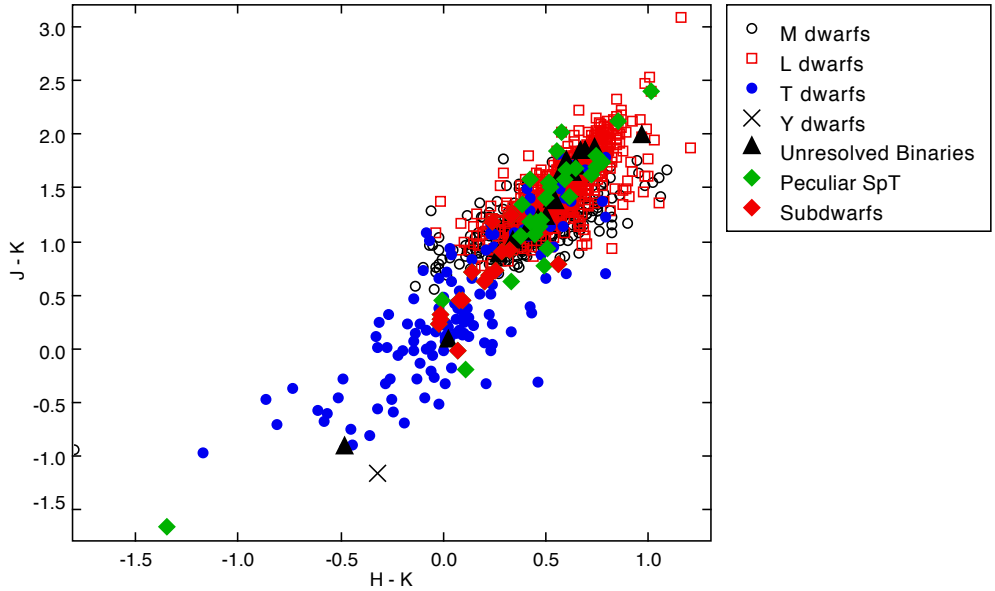


Figure 3: Distribution of brown dwarfs in H-K, J-K colour space. Aditionally to the different spectral type objects we also show the known unresolved binaries (black triangles) and objects that are known subdwarfs or that have peculiar spectral types (red and green diamonds). There are 1602 dwarfs represented in this plot.

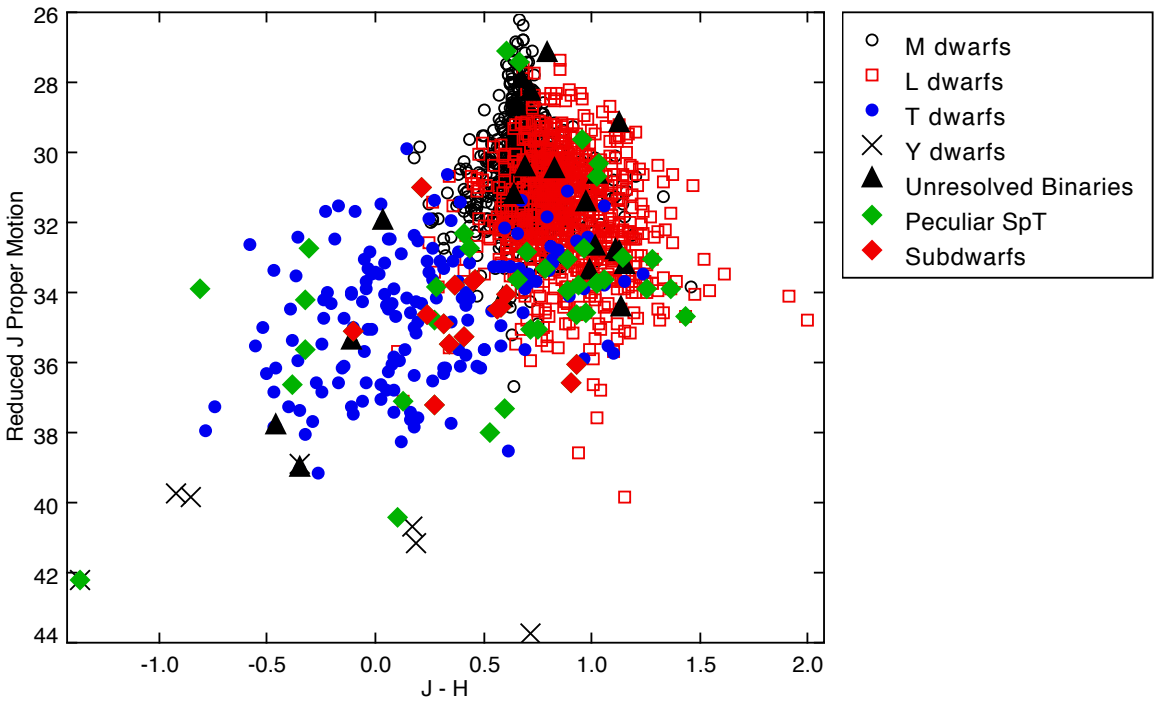


Figure 4: Distribution of brown dwarfs with measured proper motions in J-H reduced proper motion space. L and M subdwarfs clearly show a distinct population to the majority of other L and M dwarfs. There are 1696 dwarfs represented in this plot.

The populations from the thick-disk and halo are expected to show different kinematic properties, they are moving faster then their thick-disk analogues and are expected to have a more metal poor composition. As it is visible in Figure 3, the known M and L subdwarfs show on average an higher reduced proper motion than the rest of the M and L population.

Gaia will provide unprecendent accurate proper motions and distances for the brown dwarfs that it will detect. As it can be visible from Figure 5, the population of known brown dwarfs with accurate proper motions and distances is very sparse.

Kinematic information will also allow the detection of new subdwarfs, that as can be seen from Figure 4 are a very small population.

Another key information provided by kinematics is the identification of wide brown dwarf binaries benchmarks (stellar primary and brown dwarf companion).

Around 10% to 20% of the ultra-cool dwarf population is found to be in close binaries. But only 2% to 3% of ultra-cool dwarfs would are found in wide binaries. These systems are rare, but the current statistics of the occurrence of this type of wide binaries does not support the existence of a brown dwarf desert as implied by other detection techniques sensitive to closer in separations [4].

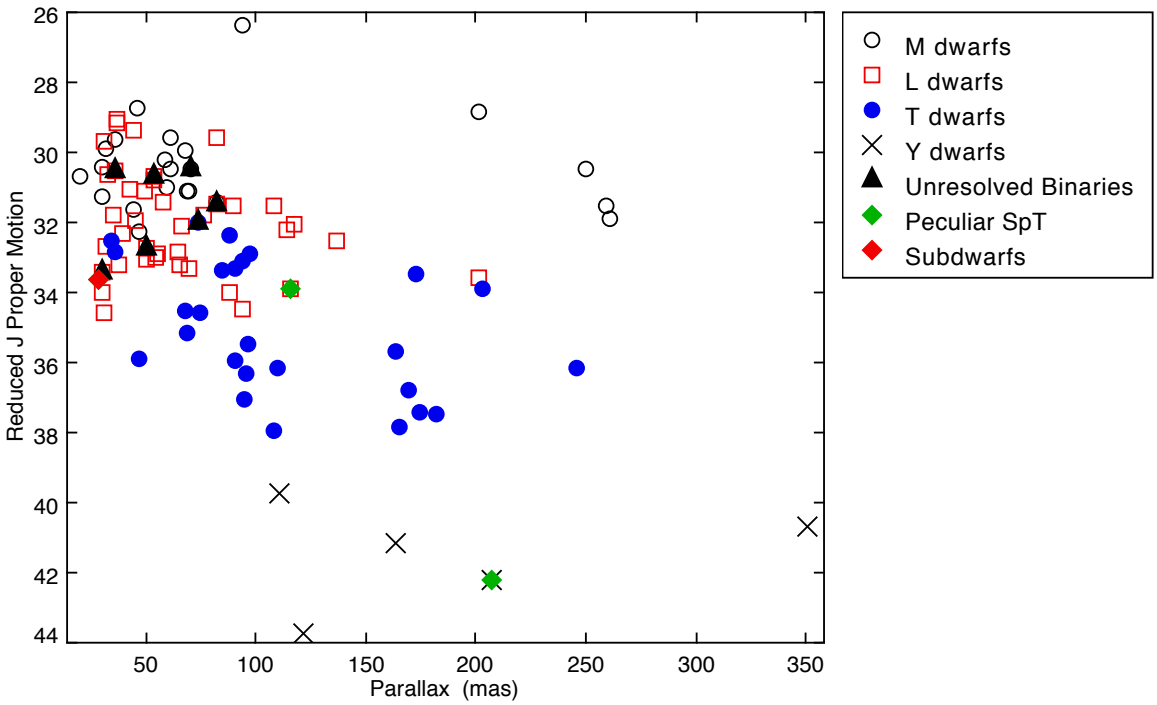


Figure 5: Distribution of brown dwarfs with measured proper motions and parallaxes. Due to their intrinsic faintness Y and late T spectral types are limited to a smaller volume of sky where they can be detected. This plot represents only 93 brown dwarfs.

Currently there are around 50 detected wide binary star ultra-cool dwarf systems, and the majority orbits M dwarfs (see [5] for a review on ultra-cool dwarf wide binary systems).

With the combined results from UKIDSS–LAS, VISTA-VHS and Pan-STARRS we will have access in the next year to an infrared whole-sky complete database of deep multi-wavelength observations. This will unravel a new population of nearby brown dwarfs.

We expect to be sensitive to brown dwarfs within 100pc, this has to do with the limitation of deriving precise proper motions for far away systems and survey magnitude limites. Within this volume of the sky, Gaia should be able to retrieve (virtually) 100% of the stellar and M dwarf population.

For the brown dwarf population we can estimate an expected number of sources by extrapolation of the current field space densities to the areas covered by the infrared surveys named previously. For L0–T5.5 dwarfs [6],[7] we would expect ~17000 objects and for the spectral range between T6-T9 [8] we expect ~3500 brown dwarfs.

These numbers imply that there is a population of ~500 wide binaries composed by a stellar object and a brown dwarf within 100pc of the Earth that has not been unraveled yet. And to which we will be sensitive combining the information from the deep infrared surveys and Gaia. We expect to retrieve a significant portion of the wide binary

population (>70%). This will mean that we expect to have around 300 new wide benchmark binary systems.

The use of Simbad and Dwarf Archives provides a great starting point for the construction of a global database of brown dwarfs. But with the expected large number of new brown dwarfs an effort to use a more standardized classification method should be attempted. Statistic studies preformed with this sample would suffer from significant biases.

[4] Gizis, J. E., et al. 2001, ApJ, 551, L163
[5] Faherty, J. K., et al. 2010, AJ, 139, 176
[6] Cruz, K. L., et al. 2007, AJ, 133, 439
[7] Metchev, S. A., et al. 2008, ApJ, 676, 1281
[8] Burningham, B., et al. 2010, MNRAS, 406, 1885

**4) Future collaboration with host institution (if applicable)**

Recently the host institution in collaboration with the visitor have detected two halo / thick-disk T dwarfs published under on the article "A deep WISE search for very late type objects and the discovery of two halo/thick-disk T dwarfs: WISE 0013+0634 and WISE 0833+0052". This preliminary study is intended to prepare the arrival of Gaia, and to help on the detection of new T subdwarfs.

***5)*** **Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)***

This report and the tables produced to achieve these results will be published under the IPERCOOL webapge: http://ipercool.oato.inaf.it/. And can be accessed freely.

**6) Other comments (if any)**