CCI - ITP Application form
Deadline: February 28, 2015

WHEN YOU SAVE YOUR APPLICATION GIVE IT YOUR FAMILY NAME AND VERSION NUMBER IN CASE YOU NEED TO REPLACE AN EARLIER VERSION BEFORE THE DEADLINE

For the 2015 call of the CCI International Time programme the following amount of time is available per annum (maximum 4 semesters):

- Liverpool Telescope, MERCATOR, WHT, TNG & INT each: 15 nights in the usual distribution of dark/grey/ bright time;
- GTC & STELLA: 80 hours each in the usual distribution of dark/grey/ bright time.

Please complete this proposal form and return it as a pdf to:

cci@iac.es

before midnight your time on Saturday February 28th, 2015.

So that your request has greater possibility of being considered, please, bear in mind the following points when preparing and submitting your proposal:

- The inclusion of simultaneous observations on two or more telescopes that complement each other is possible, but depends on an agreement being reached with the telescope schedulers. The CCI does not schedule the ITP time.
- The proposals must be "international" in nature with the participation of astronomers of several countries (see the attached call for proposals for exact details – Annex I).
- The maximum number of characters specified for each section and the total page limit of 10 A4 sides, plus references, and that a font size equivalent to Helvetica 12 is used.
- If you are not well familiarized with any of the Telescope Installations on which you wish to request time, have you contacted the person responsible for it to ensure that the technical requirements of your proposal are feasible?
- The observing programmes should concentrate on a single large-scale astronomical research project that would benefit from the use of more than one facility and/or propose observations on two or more telescopes that complement each other (in exceptional cases a proposal that requests time on only one telescope will be considered).
- Bear in mind that the CCI does not schedule the observing time; this is done by the corresponding technical committees of each telescope or group of telescopes.
- Under the terms of the International Treaty, if your project is selected, and with the agreement of the Instituto de Astrofísica de Canarias, “any Spanish astronomical institution shall have the right to join the programme if it wishes” (although this is a very rare occurrence).
- A proposal can contain requests for up to 2 years (semesters 2015B – 2017A) on any/all of the telescopes included in the programme.

Annual brief progress reports on the reduction of data and any publications should be sent to the CCI by the successful applicants and on completion of the programme, reduction of the data and publications not later than three years after the final period of observing time for publication in the CCI Annual Report:- cci@iac.es

When your proposal has been received by the CCI Secretariat you will receive an e-mail with confirmation and your reference number for the evaluation process.

Observing Period: 2015B, 2016A/B, 2017A

Principal Researcher; Please, fill in all the information.

Family Name: Marocco

Name: Federico

Degree: PhD

Present position: Post-doctoral Research Assistant

(e.g. Undergraduate, Post-graduate, Post-doctoral Researcher, Technician, Experienced Researcher, etc)

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(If the contact person is different from the PI please provide the same information for this person.)

Family Name:

Name:

Degree:

Present position:

(e.g. Undergraduate, Post-graduate, Post-doctoral Researcher, Technician, Experienced Researcher, etc)

Institute:

Address:

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DATA FOR THE PROPOSAL

Title: L dwarf benchmarks with *Gaia*

Scientific field: brown dwarfs, sub-stellar objects, multiple systems

Abstract: We aim to characterize a large sample of L dwarfs in wide binary systems. These benchmark systems are crucial to test and improve atmospheric models, and to calibrate accurately the relation between observable properties and atmospheric parameters of sub-stellar objects. In order to do that we propose to follow-up 136 multiple system candidates, complementing the astrometric information provided by *Gaia* with photometry and spectroscopy obtained via this project. If awarded the time, we will: confirm companionship for 39 high proper motion brown dwarf companions using common proper motion criteria; confirm companionship for 55 low proper motion brown dwarf companions using common radial velocity criteria; characterize all of the confirmed systems, therefore achieving an accurate and precise calibration of the correlations between observable properties and atmospheric parameters of sub-stellar objects. The observed sample will allow us to characterize the local sub-stellar population, constrain the sub-stellar initial mass function and formation history, and will therefore aid in the understanding of the evolution of our Galaxy. With the first data release from *Gaia* scheduled for one year from now, it is crucial to begin this campaign in semester 2015B, to be ready to promptly exploit the *Gaia* data. This proposal is part of a large collaborative effort aimed at understanding the fundamental processes that govern the formation of sub-stellar objects, and represents the expansion of an ongoing filler program on the GTC.

OBSERVING TIME REQUESTED

	Dark	Grey	Bright	Preferred period
GTC (80 hours bright)			60hours	
Instrumentation & comments	OSIRIS R300R and R2500I, 20h per semester in 2015B and 2016A, 10h per semester in 2016B and 2017A.			
STELLA (80 hours bright)				
Instrumentation & comments				
LT (15 Nts)				
Instrumentation & comments				
MERCATOR (15 Nts)		12Nts		
Instrumentation & comments	HERMES, HRF mode, 3 nights per semester.			
WHT (15 Nts)		6Nts		
Instrumentation & comments	LIRIS, imaging mode, 2 nights per semester in 2015B and 2016A, 1 night per semester in 2016B and 2017A.			
TNG (15 Nts)				
Instrumentation & comments				
INT (15 Nts bright)				
Instrumentation & comments				

(use additional pages if necessary but do not include any other information in this table)

SCIENTIFIC JUSTIFICATION:

Background: L dwarfs are a mixture of ultra-cool sub-stellar objects that do not burn hydrogen, and the lowest mass hydrogen fusing stars. While hydrogen-burning L dwarfs stabilize on the stellar main-sequence after approximately 1Gyr, their sub-stellar counterparts continuously cool down (since they lack an internal source of energy) and evolve towards later spectral types. Their atmospheric parameters are a strong function of age. This is illustrated in Figure 1, where the three very different objects indicated: a 7 Myr 9 Jupiter mass planet, a 90 Myr 30 Jupiter mass brown dwarf and an 8 Gyr 80 Jupiter mass low-mass star, are all spectral type L4-L5. The degeneracy between mass and age in the L spectral range does not affect higher mass objects [1].

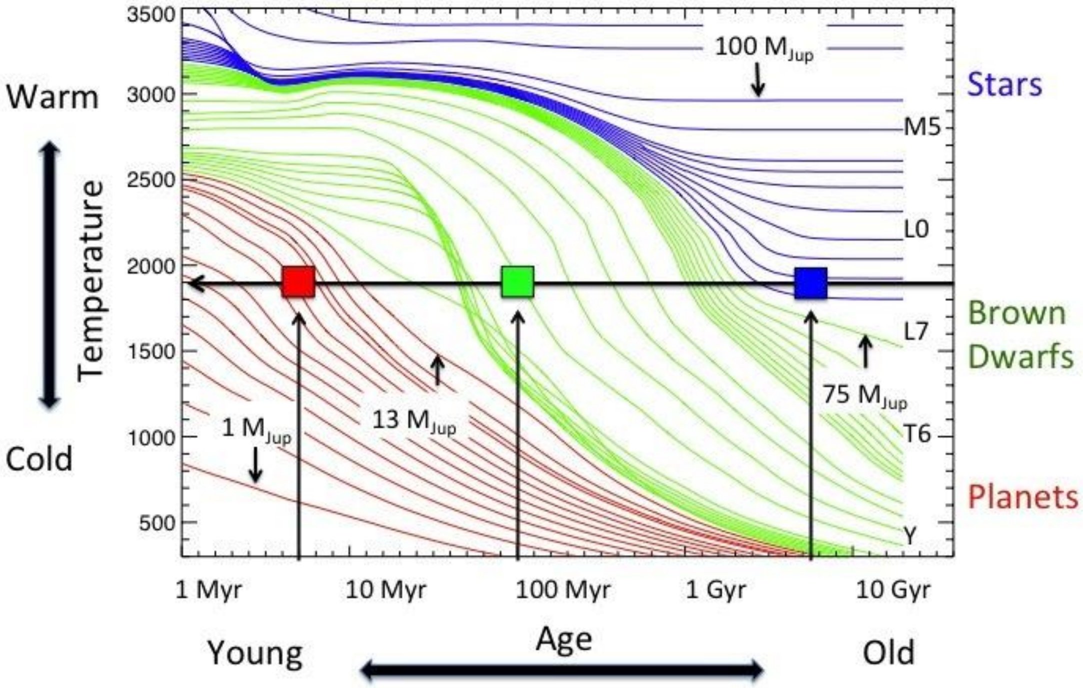

Figure 1: The evolution of effective temperature with time for stellar and sub-stellar objects of different masses. The corresponding spectral type scale is plotted on the right-hand side for reference. The three very different objects indicated: a 7 Myr 9 Jupiter mass planet, a 90 Myr 30 Jupiter mass brown dwarf and an 8 Gyr 80 Jupiter mass low-mass star, are all spectral type L4-L5.

Measuring directly the mass of a celestial body is possible only if the object is part of a multiple system, or via micro-lensing events. But so far the census of L dwarfs with measured masses is very limited [2].

Similarly age indicators are poorly calibrated, and therefore scarcely reliable, especially at old, field-like ages (i.e. > 1 Gyr). The spectra of L dwarfs are characterized by strong alkali absorption lines, as well as by broad molecular absorption bands (primarily due to water, hydrides, and methane). A number of these features have been shown to be sensitive to metallicity and surface gravity (both proxies for age), but the majority of studies have been so far purely qualitative [3,4], and the quantitative attempts to calibrate these age indicators suffer from large scatter and limited sample size [5,6,7].

The cooling tracks shown in Figure 1 are sensitive to the chemical composition of the photosphere, further complicating the scenario. The metallicity in fact influences the total opacity by quenching/enhancing the formation of complex molecules and dust grains, all key factors in shaping the observed spectra of sub-stellar objects. Although a number of absorption features are known to be sensitive to the total metallicity [4,8] no robust calibration has so far been developed to determine the abundances of sub-stellar objects.

Motivation: The way forward to achieve more accurate, precise and robust calibrations is to study large samples of benchmark systems, i.e. multiple systems formed by stellar objects hosting sub-stellar companions [9]. Age and chemical composition inferred from the main sequence stars constrain the atmospheric properties of their sub-stellar companions, and allow for the calibration of the spectroscopic atmospheric parameter indicators. While a few benchmark systems have already been found and characterized [10,11] their number remains limited, and the parameter space is therefore largely under-sampled. With this proposal we aim at characterizing a large sample of wide binaries and multiple systems, to fully populate the range of atmospheric parameter space for ultra-cool dwarfs (UCDs), including in particular the population with outlier properties, since the sensitivity of spectroscopic variations to atmospheric properties will be clearest when the range in these properties is greatest.

The ESA cornerstone mission *Gaia* launched on December 19th 2013 will revolutionise astronomy observing objects as diverse as minor planets, stars, galaxies out to QSOs and impacting almost all areas of study, including of course sub-stellar astrophysics. Many of the problems that have plagued the identification of benchmark systems, binaries, peculiar objects, moving group candidates, space density distributions, effective temperatures, luminosities and relations to spectral types will indeed be removed. Regarding the identification of benchmark systems, *Gaia* will greatly increase the size of the UCD population for which atmospheric parameters can be obtained, by providing measurements for a large number of primary stars. Having such a large pool of potential primaries is fundamental, since the fraction of stars with L dwarfs as wide companions could be as low as ∼0.33% [10]. *Gaia* will allow us to whittle down these systems into a large sample with outlier properties that will reveal the nature of UCDs in rare parameter space (e.g. high and low metallicity). In order to access this population however, it is crucial to identify benchmarks out to greater distance (∼100 pc). While nearby systems can be pinpointed using common proper motion criteria, for the most distant benchmarks their typically low proper motion would not provide strong enough constraints on the physical association of the system (since chance alignment contamination increases with decreasing proper motion). These associations have to be confirmed via common radial velocity instead.

Once discovered, benchmark systems need to be characterized via detailed spectroscopic studies of both the primary stars and their sub-stellar companions. While *Gaia* will provide (in addition to astrometry) radial velocity and atmospheric parameters estimate for the primaries, many UCDs are too faint to be observed by the ESA satellite. Even those UCDs that are bright enough to be astrometrically observed by *Gaia*, will be too faint for the Radial Velocity Spectrometer. The RVS and the Red Photometer therefore will not allow the determination of radial velocities, spectral indices, and metallicity and age indicators necessary to fully exploit these benchmarks. Measuring such quantities require higher resolution spectra.

Objectives: Here we propose to pursue the identification and characterization of a sample of 136 benchmark system candidates, complementing the *Gaia* data with spectroscopy, photometry, and astrometry. The list of proposed targets can be split in two sub-samples that will be addressed separately.

One sub-sample consists of 105 UCD candidates with potentially associated stellar primaries. Our sample of candidate companions represents an initial selection, including primaries from a number of catalogues of photometric or spectroscopic estimated metallicity (e.g. [12,13,14]). We cross-matched the list of stars with unusual metallicity values (i.e. either high or low metallicity) with L dwarf candidates, photometrically selected combining the SDSS with the UKIDSS LAS and GCS, to identify possible pairings. Binaries (and multiple systems) were identified imposing a maximum matching radius of 3 minutes of arc. For each system we used the spectrophotometric distance for the primary to calculate the absolute magnitudes of the companions. We then imposed colour – magnitude cuts, based on the colours and magnitudes of known L dwarfs (see e.g. [15]) to remove contamination from reddened stars, background galaxies, and quasars. Although our selection method rules out much contamination, producing a candidate list that is rich with genuine systems, observational confirmation is still an important requirement in order to reject spurious associations. In Figure 2 we compare the separation distribution for our benchmark candidates to the separation distribution of confirmed systems obtained in [11]. Our sample is clearly incomplete for projected physical separations s < 1000 AU, since we are probing out to a further distance than [9] (close systems become unresolved at large distance). Also surveys like SDSS and UKIDSS are known to have problems at cataloguing sources near bright stars (SDSS in particular). Some close companions will therefore be lost due to search algorithm issues. On the other hand the distribution at intermediate separations shows a slowly declining trend, demonstrating that the number of spurious pairs is limited. If we were dominated by

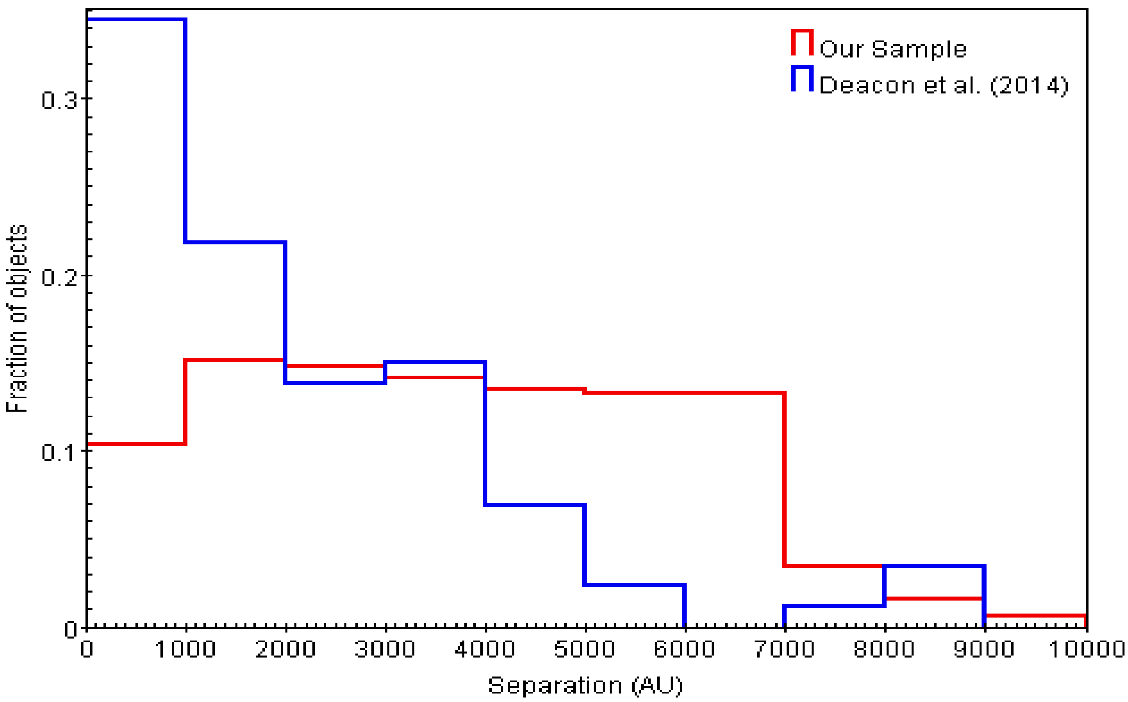

Figure 2: The separation distribution for our candidate benchmark systems (red histogram) compared to the separation distribution of the confirmed benchmarks from Deacon et al. (2014, blue histogram)

contamination one would indeed expect the number of systems to increase ∝ s^2. At separations s > 7000 AU the number of systems drops, since we lose objects due to the separation limit adopted for the initial cross-match. The systems identified here have been missed by previous efforts (e.g. using Pan-STARRS 1 data [11]) either because they lacked the depth provided by UKIDSS, or because they focused on high proper motion systems only. Our selection yields a sample of more than 500 potential systems, almost 400 of which are observable from the Observatorio del Roque de Los Muchachos. The 105 systems proposed here are the ones whose primaries have photometrically estimated metallicity with relative uncertainty < 30%, and with either high or low metallicity (i.e. [Fe/H] > +0.3 or [Fe/H] < -0.3). We chose these systems because they populate regions of the parameter space that have so far remained unexplored.

Using the colours of known L dwarfs and published transformations [16,17] we estimated the G magnitude for our 105 UCDs, and found that 11 of them are bright enough to be visible by *Gaia*. The astrometric confirmation of the physical association of these systems will therefore be provided by *Gaia*. Here we propose to use OSIRIS on the GTC to obtain high signal-to-noise ratio spectra of these 11 L dwarf candidates, to measure their spectral type, radial velocity (RV), spectral indices, and absorption lines equivalent width. We propose to use HERMES on the Mercator telescope to observe their main-sequence primaries and allow for an accurate measurement of their parameters (abundances, surface gravity, and rotational velocity). These would constrain the age and atmospheric parameters of the ultra-cool companions. We would use the OSIRIS spectra of the UCDs to identify spectral indicators (the equivalent width of absorption lines, spectral indices, etc.) that correlate with the inferred parameters by comparing the various systems characterized. Moreover as these objects are so close, the perspective acceleration will change both the parallax and the proper motion over the time frame of the mission. These small changes lead to “astrometric” radial velocities with errors of 10-20km/s. The more precise values found in this project will therefore act as a quality check of the *Gaia* results and in fact can be used as constraints to improve the *Gaia* astrometric solutions.

Of the 94 L dwarf candidates too faint to be visible to *Gaia*, 39 are potentially associated with high proper motion stars (i.e. proper motion ≥ 50 mas/yr, with proper motions taken from the PPMXL catalogue [18]). Here we propose to use LIRIS on the WHT to obtain J band imaging follow-up for these 39 UCDs, to measure their proper motion (PM). Combining our measured PMs with the astrometric information for the primary star (provided by *Gaia*) we will be able to confirm the association of these systems, and if confirmed they would be “promoted” into our spectroscopic follow-up queue.

Finally, the remaining 55 UCD candidates are associated with low PM stars (i.e. PM < 50 mas/yr). Common PM criteria would not be sufficient to unambiguously confirm these associations (since chance alignment contamination is high for low PM), so common radial velocity would be used instead. We would use LIRIS on the WHT or OSIRIS on the GTC (depending on the object brightness) to obtain low-resolution spectra for these 55 UCDs. These spectra are needed to confirm the ultra-cool nature of the objects and estimate their spectrophotometric distance. These would constrain the companionship of our candidate benchmark systems, removing contaminating background objects. The systems that pass this further selection will be “promoted” for intermediate resolution follow-up.

The other sub-sample consists of 31 spectroscopically confirmed, bright L dwarfs that are visible to *Gaia*, with their potentially associated primaries. We identified the stellar companions following the same procedure described above. Following the same reasoning applied to the previous sub-sample, here we propose to use OSIRIS on the GTC to obtain high signal-to-noise ratio spectra of these 31 UCD candidates, and to use HERMES on the Mercator telescope to observe their main-sequence primaries. While *Gaia* will provide atmospheric parameter estimates for these objects, the higher resolution and wider wavelength coverage offered by HERMES will yield more precise abundance measurements, allowing a detailed modelling of the dust properties in the photosphere of the UCD companions. Since 9 of the stellar primaries have already been fully characterized by RAVE [14], only 22 would need to be observed with HERMES.

Our initial sample targets crucial parameter space using currently available survey and catalogue data, and we are in the process of implementing a plan to expand our sample further by including photometrically selected primaries, and as the LAMOST spectroscopic catalogue grows in size and into the M dwarf regime. Moreover, the first data release from *Gaia*, expected for summer 2016, will allow us to further expand our selection and refine the list of L dwarfs that will be visible to the ESA satellite. The *Gaia* first release (DR1) will either contain the Tycho2 – *Gaia* astrometric solution (TGASS, [19]) or the Hundred Thousand Proper Motion catalogue, with positions and colours of other Gaia targets. Either way the search for brown dwarf benchmark systems will be completely revamped. The new proper motions will include all nearby primaries where the brown dwarf companions are sufficiently bright for characterization. The all sky colours and positions combined with ground based surveys will allow the identification of the complete sample of *Gaia* L dwarfs, which can then be searched for possible benchmark systems. The Torino and Madrid group are part of the pre-publication scientific validation of all the *Gaia* releases including TGASS and DR1, working both in the data dissemination and the Ultra-Cool Dwarfs work packages, so will be uniquely placed to immediately produce benchmark candidate lists. In light of this we propose to extend our program for 4 semesters (2015B, 2016A/B, and 2017A) to allow for flexibility in our sample selection. The first two semester of observations will cover exclusively the current target list, while in the third and fourth semester we will start complementing the sample with the new systems discovered. In this way our sample is fully exploiting *Gaia* to establish a benchmark population that will reveal UCD atmosphere physics across the full sub-stellar parameter space. The correlations derived from our benchmark systems would then be applied to the entire population of L dwarfs, to study the properties of the solar neighbourhood population at the stellar – sub-stellar boundary.

Given the wide range of brightness covered by our sample (from very bright main sequence stars to extremely faint ultra-cool dwarfs), and the diversity of the follow-up observations required, we need an ample variety of facilities to complete our project. The ITP represents therefore a unique opportunity to carry out this observing campaign.

LIST OF PRINCIPAL TARGETS

This list is a sub-sample of our full list of 136 systems. The list is continuously expanded as the LAMOST Galactic Anticentre survey progresses, and will be greatly incremented and refined by the first *Gaia* data release (expected for the end of semester 2016A).

Name	R.A. (hh:mm:ss.ss)	Dec. (dd:mm:ss.s)	V (mag)	J (mag)
TYC 594-874-1	00:05:32.46	07:40:51.0	10.946	9.878
J0005+0740	00:05:33.35	07:40:34.5	…	17.870
BD+05 87	00:39:12.71	06:34:50.9	10.382	9.412
J0039+0634	00:39:19.59	06:34:50.9	…	18.190
J0301+3540	03:01:03.14	35:40:51.1	…	14.610
TYC 2351-535-1	03:01:13.25	35:38:47.4	11.087	10.004
BD+48 957	03:36:30.69	49:14:14.3	9.345	8.257
J0336+4916	03:36:39.02	49:16:20.7	…	17.480
TYC 1807-235-1	03:45:06.34	27:53:19.4	10.170	9.152
J0345+2753	03:45:08.62	27:53:29.5	…	18.390
J0401+2212	04:01:12.62	22:12:24.1	…	17.190
TYC 1262-291-1	04:01:17.10	22:14:57.4	11.253	9.679
HD 282075	04:25:52.55	33:29:01.4	10.431	9.117
J0425+3330	04:25:58.37	33:30:15.5	…	16.260
J0531-0400	05:31:58.49	-04:00:38.9	…	15.870
HD 294215	05:31:59.01	-03:57:45.4	10.218	9.369
TYC 1888-1441-1	06:41:46.23	27:33:30.4	10.770	9.633
	…	…	…	…
J2356+1940	23:56:25.08	19:40:25.9	…	15.810

Technical feasibility (per telescope)

Mercator/HERMES: we would use HERMES in HRF mode to observe 33 main sequence stars. We require a signal-to-noise ratio (SNR) of 80-100 to allow for robust parameters determination (abundances, surface gravity, radial and rotational velocity). Given the typical brightness of our targets (7.5 < V < 12) and using the online ETC for the Mercator telescope, we estimate a total observing time of 6 nights, including overheads. Since our objects are evenly spread across the right ascension range, we would need blocks of three nights, one per semester in 2015B and 2016A, separated by at least ~4 months. We request two extra block of 3 nights in 2016B and 2017A to allow for the follow-up of primaries in systems that will be confirmed through our LIRIS imaging and spectroscopy campaign.

WHT/LIRIS: we would observe 39 UCD candidates in imaging mode, in J band. We require a SNR of 50 to robustly determine the centroid for the target and nearby reference stars, for accurate astrometric calibration. Given the typical brightness of our targets in the J band (14.5 < J < 19) and using the LIRIS Imaging mode ETC available online we require approximately 2 nights to observe all of them, including overheads. We would observe 33 UCD candidates in spectroscopy mode, using the LR_ZJ grism. We require a SNR of 20 to allow for the measurement of the spectral indices required for spectral typing. Given the typical brightness of our targets in the J band (14.5 < J < 17) and using the LIRIS Spectroscopy mode ETC available online we require approximately 2 nights to observe all of them. The total time needed on WHT/LIRIS is therefore 4 nights. Since our objects are evenly spread across the right ascension range, we would need 2 nights per semester in 2015B and 2016A. We request another 1 night per semester in 2016B and 2017A to follow-up additional targets that will be identified exploiting the *Gaia* DR1 and the expansion of the LAMOST Galactic Anticentre Survey.

GTC/OSIRIS: we would observe 42 object in R2500I mode and 22 in R300R mode. We require a SNR of at least 30-40 for the R2500I targets to allow for a robust fit to the absorption lines and accurate determination of the molecular absorption bands heads, in order to measure precise radial velocities (down to a precision of a few km/s). Given the typical brightness of our targets in the SDSS z band (roughly corresponding to the wavelength coverage of the R2500I grism) which is typically between 16 < z < 19, and using the OSIRIS ETC provided online, we would need a total of 36 hours to observe all of our targets, including overheads. We request SNR of at least 20 for the R300R targets to allow for the measurement of the spectral indices required for spectral typing. Using the OSIRIS ETC provided online, we estimate we need a total of 4 hours to observe the 22 R300R targets. The total time requested on the GTC is therefore 40 hours. Since our objects are evenly spread across the right ascension range, we would need 20 hours per semester in 2015B and 2016A. We request another 10 hours per semester in 2016B and 2017A to allow for the follow-up of UCDs in systems that will be confirmed through our LIRIS imaging and spectroscopy campaign, and for additional targets that will be identified exploiting the *Gaia* DR1 and the expansion of the LAMOST Galactic Anticentre Survey.

Any additional relevant information, including results from previous ITP awards.

Our team includes individuals with ample expertise in observation, reduction and analysis of OSIRIS, HERMES, and LIRIS data, as well as experts in modelling and characterization of stellar and sub-stellar atmospheres.

The spectra for the L dwarfs visible by *Gaia* obtained here will contribute to the expansion of MAIA, a large database of spectra of ultra-cool dwarfs maintained by J. A. Caballero.

J. A. Caballero has been awarded 20h on GTC/OSIRIS in semester 2015A in filler mode (106-GC54-15A), to obtain high signal-to-noise ratio low-resolution optical spectroscopy of the brightest L dwarfs that are visible to *Gaia*. The current proposal represents and extension to that one.

References:

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[11] Deacon et al. 2014, ApJ, 792, 119

[12] Ammons et al. 2006, ApJ, 638, 1004

[13] Yuan et al. 2015, MNRAS, 448, 855

[14] Kordopatis et al. 2013, MNRAS, 436, 3231

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[16] Jordi et al. 2010, A&A, 523, 48

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[19] Michalik et al. 2015, A&A, 574, A115