INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: C**

Period AOT39 (April 2019 – September 2019) **Submit using: www.tng.iac.es/submit.html**

1. Title

Using GRIS-U/DOLORES for Efficient Classification of L/M Dwarfs

2. Abstract

We propose a pilot program to test the feasibility of using the GRIS-U with DOLORES to obtain quality spectra of ultracool objects. This is part of an international effort to generate a spectral database of new brown dwarfs being discovered in the *Gaia* data releases. The spectra will provide spectral types and indices. We expect there to be ∼400 new L dwarfs found in *Gaia* and to completely exploit this sample we require at least spectral classification of all of them. If this pilot program is successful, e.g. we are able to obtain sufficiently precise spectral types and indices, we will propose to observe the hotter, brighter M9/L0 objects. The GRIS-U/DOLORES combination is nominally significantly more efficient that larger telescopes for the determination of basic spectral types. These observations are required to map the stellar to sub-stellar boundary and characterise the luminosity function in this region.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	**DOLOR.+MOS**	**NICS**	**HARPS-N**	**GIANO-B**	**ROSS**	**REMIR**
2						

3b. Observing modes

TNG:		**Visitor**	**X**	**Service**		**ToO**
REM:		**Rapid Response**		**Queuing**		**ToO**

4a. Preferred months

first choice: second choice:

4b. Other scheduling constraints (use also box 14)

5a. Past and future of the project

a) Hours already awarded to the project:

b) Hours foreseen to complete the project:
(not including this request)

6. Principal investigator

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7. Co-investigators (name and institution)

W. J. Cooper, INAF - Osservatorio Astrofisico di Torino, University of Hertfordshire
A. Sozzetti, INAF - Osservatorio Astrofisico di Torino
H. R. A. Jones, University of Hertfordshire

8. Status of the project

Telescope	Instrument	Date	Hours	Notes
GTC	OSRIS	2015	20	PI Caballero
GTC	OSRIS	2015	20	PI Marocco
VLT	XSHOOTER	2016	20	PI Beamin
IRTF	SPEX	2017	24	PI Smart
Palomar	TripleSpec	2017/2018	32	PI Mamajek
Blanco	ACRONIS	2017	24	PI Beamin

Description

This is part of a larger project that is in it's 3rd year and has observed mainly medium resolution spectra of later than L2 objects on the telescopes listed above. Observations of selected targets have been published, a larger publication with a catalog of results, will be submitted this year.

Publications

For the TNG this is a new program. Results from the other telescope/instrument combinations have been used in the following publications:

Smart, R. L., et al., 2018 MNRAS 481, Parallaxes of Southern Extremely Cool objects III: 118 L and T dwarfs.
Mamajek, E. E., et al., 2018 RNAAS 2, WISE J064336.71-022315.4: A Thick-disk L8 Brown Dwarf Discovered by Gaia DR2 at 13.9 pc.
Smart, R. L., et al., 2017 MNRAS 469, The Gaia ultracool dwarf sample - I. Known L and T dwarfs and the first Gaia data release.
Marocco, F., et al., 2017 MNRAS 470, Ultracool dwarf benchmarks with Gaia primaries.
Faherty, J. K., et al., 2018 arXiv A Late-type L Dwarf at 11 pc Hiding in the Galactic Plane Characterized Using Gaia DR2.

9a. If this proposal is a part of a PhD thesis, write here the name of the student, the thesis title and briefly describe the relevance of these observations for the thesis goals.

W. J. Cooper, *Characterisation of the stellar-substellar boundary using ultra cool dwarfs in Gaia.* The spectroscopic data from this proposal combined with the *Gaia* astrometric data and survey photometric data will form the fundamental observational dataset for the thesis of Mr Cooper.

9b. Is this, or a similar application submitted to other time allocation committees (e.g. ESO, TNG-CAT, ITP)? If yes, please specify which and explain if and why the proposals should be considered complementary.

Related proposals have been submitted to comparable and larger telescopes for higher resolution spectra of the cooler L dwarf candidates discovered in the *Gaia* second data release.

10. Description of the programme (max. 3 pages, including references, tables, and figures.)

A) Scientific rationale L type dwarfs are a mixture of young planetary mass objects, ultra-cool sub-stellar objects that do not burn hydrogen, and, the lowest mass hydrogen-fusing stars. They have spectra dominated by dust absorption and broad molecular absorption bands mainly due to water and methane. These objects are the link between the lowest mass stars and giant planets, sharing characteristics with both - e.g. like planets they do not fuse hydrogen, but like stars they probably form directly from clouds and emit their own light, generated by slow gravitational collapse. L dwarfs are extremely long lived and from their birth they are continually cooling, hence their luminosity and spectral type are a strong function of age. For example, a 0.05 solar mass object starts its life as a late M dwarf, from ∼0.1 to 1 Gyr it transverses the L dwarf sequence and then continues into the T types. While an evolving spectral type complicates our understanding of these objects, if we find a way to calibrate age indicators these objects have the potential to become accurate Galactic chronometers. In addition, L dwarfs have significant overlap in colour space with directly imaged planets [A10] - increased understanding in the atmospheres of the L dwarfs can be applied to the recently discovered exoplanets, with the advantage of not having contamination from the parent star.

The ESA *Gaia* mission is observing objects as diverse as minor planets, stars, galaxies out to QSOs and had its first data release in 2016. *Gaia* is measuring the parallaxes of all celestial objects down to G = 20.7 (complete to 20.3) finding their distance which has historically been one of the most difficult parameters to determine. Following *Gaia*'s first data release in 2016, we identified 322 known L and T dwarfs. Now, with the second released available, including full parallax solutions for 1.3 billion sources, it is possible to search for previously unknown nearby L dwarfs using astrometric data alone. Reyle [R18] have published an initial foray into this discovery space, identifying 679 as-yet unconfirmed L dwarf candidates. Our investigation has also uncovered hundreds of promising candidates, including an L7 at 11 pc deep in the Galactic plane confirmed in our first semester of observations [F18]. We estimate in the final *Gaia* catalog there will be over 1000 [S17] and of these ∼400 will be new. The current sample of early L dwarfs with precise distances ($\sigma\pi/\pi < 0.1$) is less than 200 so *Gaia* will provide a factor of 5 increase.

To fully characterize the physical properties of these new objects we would need high-resolution spectroscopy, but that would require inordinate amounts of time on large telescopes. In addition, while the high-resolution spectroscopy will allow us to make an in-depth characterisation of these objects higher resolution will not be possible for more distant fainter targets. As one of our main goals is to characterise the properties of this spectral range to then apply that characterisation to the more distant sample medium/low resolution spectra are more appropriate. The medium resolution spectra is being carried out on other telescopes as described in section 8. Here we propose to use the efficient GRIS-U/DOLORES combination to obtain low resolution spectra of some M9/L0 candidates. Combined with the other programs we will build a large comprehensive low and mid-resolution spectral library of L dwarfs with *Gaia* parallaxes and proper motions that will be the gold standard for studies of this spectral region.

The science goals for this program are very broad: from the characterisation of the stellar-substellar boundary (Figure 1), through the search for age indicators and the identification of peculiar objects (Figure 2), to an examination of the evolution of the Galactic velocity dispersion. Here we only have space to discuss one goal in detail: **What is the dominant formation process of LT dwarfs**? How does metallicity, environment and other interactions, come into play? Is there a low-mass cutoff to star formation? One fundamental constraint for these questions is the predicted source densities in the Solar Neighbourhood (Figure 3). *Gaia* is critical to this work, as the availability of precise distances of a volume limited sample will allow us to accurately assess Malmquist, Eddington, and Lutz-Kelker biases that plague current statistical studies. This proposal will provide a homogeneously spectral sample that will allow us to measure the influence of spectral typing errors, hidden binaries, and peculiarities arising from surface gravity, metallicity and other effects in quantifying the local population. To remove any possible biases we require a volume complete sample which means at a minimum spectral typing of all objects L0 and later in the Gaia dataset.

B) Scientific aim To compile a large sample of late L dwarf spectra that provide at a minimum spectral types and indices. We will obtain spectral types, via comparison with templates and obtain spectral indexes that will allow us to identify signatures of youth (red excess, weaker alkali lines etc.) or luminosity excess, signature of similar spectral types binaries, given the accurate distances provided by *Gaia*, or spectral signatures of binarity of different types (L+T). Finally it is important to note that the results of this project, in addition to our more comprehensive campaign, will provide science quality, flux calibrated spectre to be publicly available to the community. They will also be included as templates in the Virtual Observatory SED analyzer (VOSA; [B08], [B12], http://svo2.cab.inta-csic.es/theory/vosa/).

Figure 1: A luminosity – radius diagram reproduced from [D14]. The radius has a minimum (∼L2.5) at the onset of core electron degeneracy. The gap (L1–L3) is due to the rapid evolution of field objects in this parameter space. A volume-complete sample is required to confirm and locate both the minimum and the gap width, both of which are fundamental constraints on model predictions. *Gaia* will provide the volume complete sample and this spectral program will provide the physical properties (luminosity, Teff, log g, metallicity) from models, empirical trends, and direct use of the Stefan-Boltzmann law.

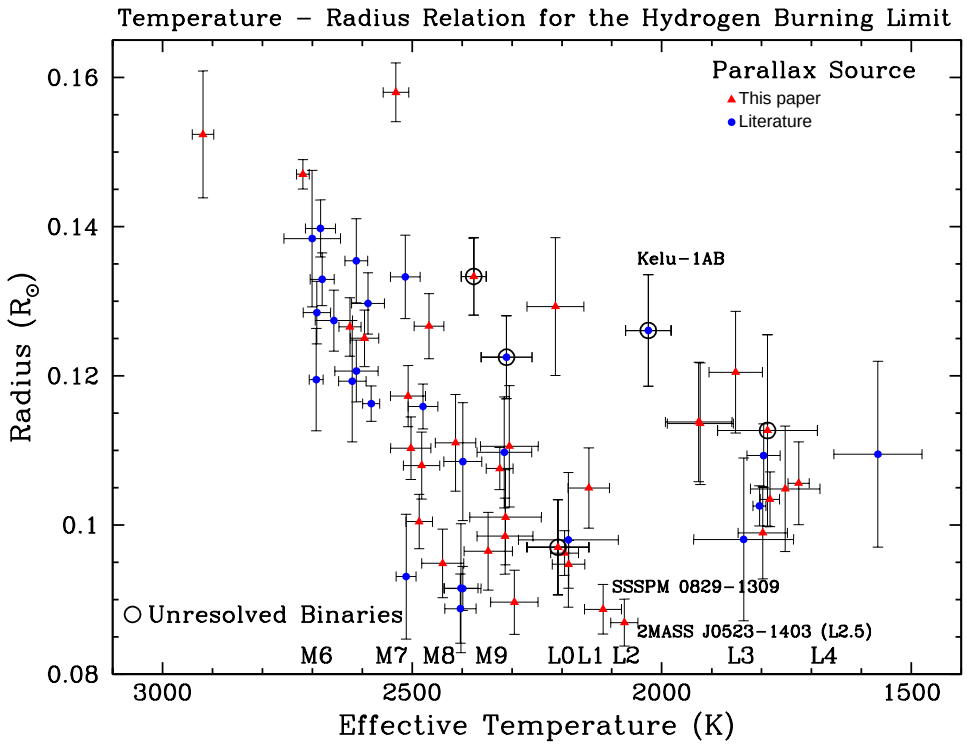
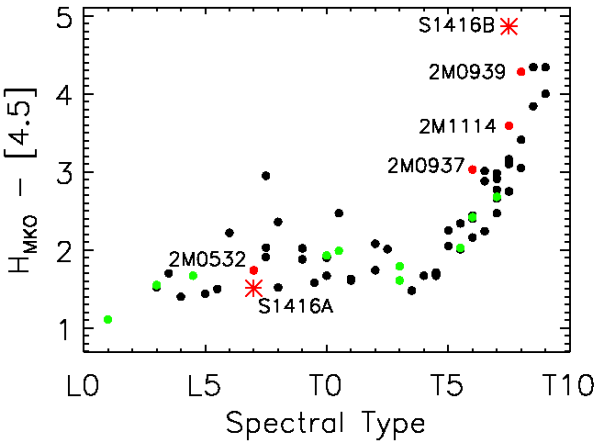


Figure 2: The Promise of Peculiar Objects *Left:* Spitzer IRAC colours as a function of spectral type for LT dwarfs [B10]. Green dots are binaries, red dots are metal poor objects, the red asterisks are the SDSS J1416+13AB L and T components. One component appears old and the other young, one is very red and the other is average. A hypothesis for these contradicting properties is that the secondary is binary but proving this requires both astrometry and spectroscopy. *Right:* The spectrum of ULAS J222711004547 (red) and its de-reddened version (green) compared to the L7 standard 2MASS J0103320+193536 (black) [M14]. The spectrum has been de-reddened assuming various atmospheric grain distributions, a distance and spectra allow us to remove some of the proposed solutions.



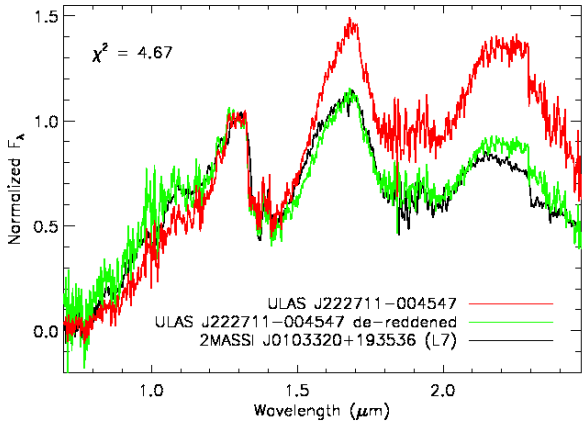


Figure 3: Fundamental Physical and Theoretical Relations: Source density predictions as a function of L spectral type for three different forms of the assumed mass function (α=1.0, 0.0 and -1.0 where dN/dM = M$^{\alpha}$) [adapted from M17]. The error bars are the Poisson noise for the predicted *Gaia* L dwarf sample and the grey region represents the constraints of current data.

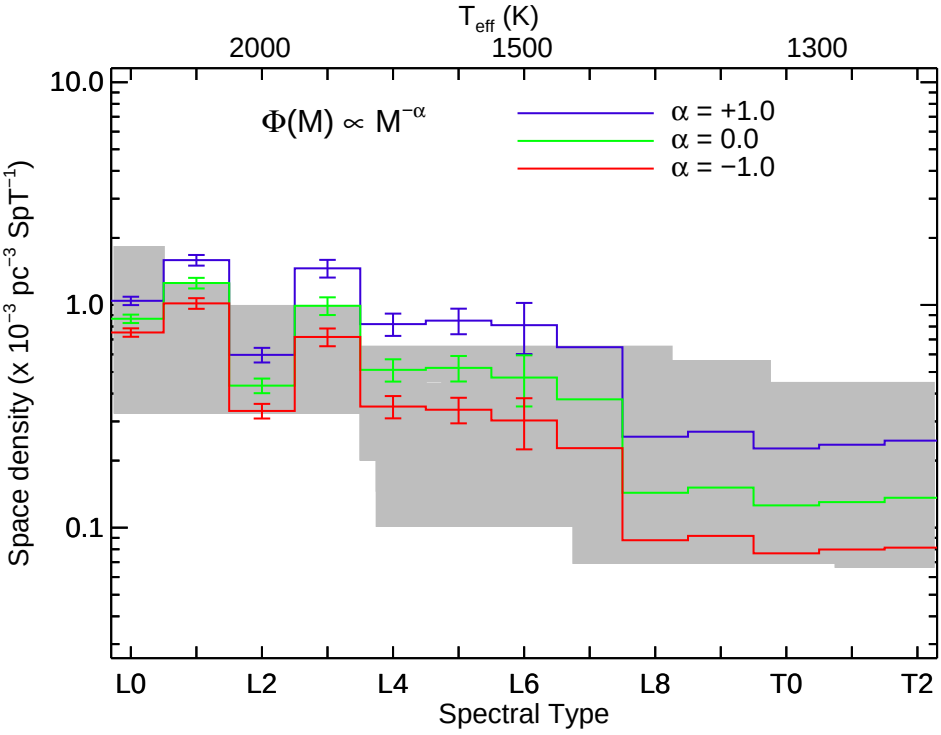
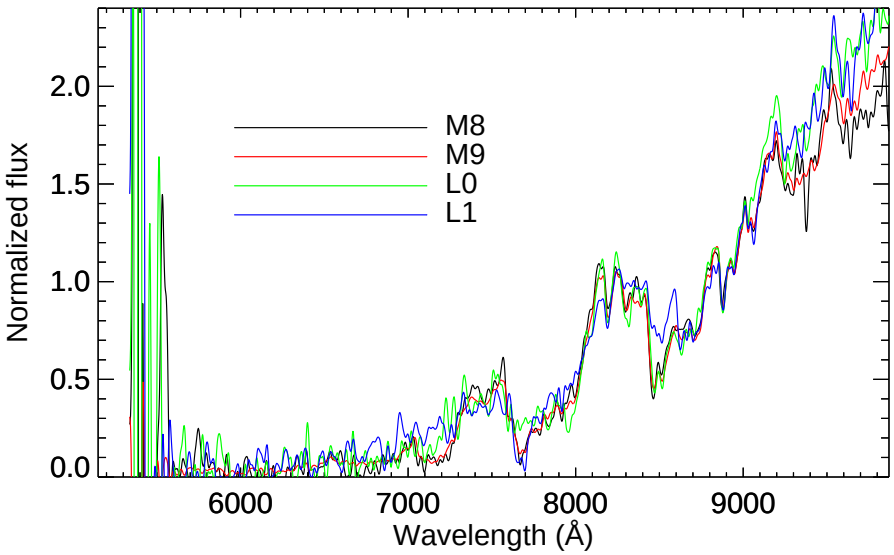


Figure 4: Xshooter spectra of M8 to L1 dwarfs smoothed down to the resolution of GRIS-U. The spectral features at 7700, 8400, 9200, and 9550Å are different between the four targets. The final spectral type will be derived from χ^2 fitting to standards and experience with spectra of similar resolution has shown we can reach our precision goal of ± 1 spectral type.



References: [A10] Allers+ 2010 ApJ 715; [A12] Allard+ 2012 RSPTA 370; [B08] Bayo+ 2008 A&A 492; [B09] Bochanksi+ 2009, PASP, 121; [B10] Burningham+ 2010 MNRAS 404; [B12] Bayo+ 2012 A&A 457; [B14] Beamin+ 2014 MmSAI 85; [B15a] Baraffe+ 2015 A&A 577; [B15b] Beamin+ 2015 ATEL 8244; [B16] Burgasser+ 2016, ApJ, 820; [B17] Beamin+ 2017 RMxAC 49; [D14] Dieterich+ 2014 AJ 147; [F18] Faherty+ 2018, arXiv 18050.1573; [M14] Marocco+ 2014 MNRAS 439; [M17] Marocco+ 2017 MNRAS 470; [R18] Reyle 2018, arXiv:1809.08244; [S13] Sarro+ 2016 A&A 550; [S17] Smart+ 2017 MNRAS 469.

11. List of targets (note that the absence of a proper object list and information may weaken the proposal)

Name	α	δ	Epoch	Mag.	Time	Additional Information
J1829+2600	277 23 14.72	26 00 41.89	J2000	J14.9	1140s	
J1933+2405	293 22 24.65	24 05 57.12	J2000	J14.7	680s	
J1817+1017	274 17 23.89	10 17 32.32	J2000	J14.9	880s	
J1836+0315	279 02 44.56	03 15 25.24	J2000	J14.8	680s	
J1856+0000	284 00 37.16	00 00 46.01	J2000	J14.9	880s	
J1932+0957	293 02 17.82	09 57 33.07	J2000	J14.2	420s	
J1933+1808	293 22 04.44	18 08 59.19	J2000	J14.6	680s	
J1935+2301	293 50 08.70	23 01 59.54	J2000	J14.9	1140s	
J1949+1713	297 22 24.34	17 13 01.33	J2000	J14.3	420s	

12. Observational strategy and justification of requested time, including overheads.

The observation of high resolution spectra is significantly more time consuming so we are applying to larger telescopes and observing later than L2 candidates where, in addition to spectral types and indices, we also obtain radial velocities and metallicity indicators. For most of our science goals the spectral types and indices are sufficient and we are proposing to use the GRIS-U/DOLORES combination because it appears to be much more efficient.

We have calculated exposure times using the Dolores/LR-R ETC; assuming the default values for airmass ($z = 1$), FWHM ($= 1$"), and dark sky (days from new moon $= 0$). Using SDSS-z magnitudes and aiming for a signal to noise ratio of 20 (to be consistent with the rest of our spectral archive, achieving 5% radial velocity measurements and sensitivity enough for quality spectral typing) we have the exposure times listed above, assuming overheads of 10 minutes. Our large UCD sample has $15.6 <$SDSS-z< 19.4, corresponding to individual exposure times of $72s < t < 1.5h$ so we are choosing to focus on a middle range, exposure times an average (from target list) of 4x190s $\rightarrow$ SDSS-z $\approx 17 \rightarrow$ 2MASS J ≈ 14.5. This will allow us to observe at least 4 targets within the 2 hour requested timeframe at a ratio of 2 targets per standard. One objective of this pilot proposal will be to allow us to calculate more accurate exposure time estimates on this new instrument for ultracool objects. The high throughput of GRIS-U should allow us more efficient readings, leading to a larger target observation rate.

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
1	Dolores	1x1	none	none	GRIS-U	2hr	

14a. Moonlight constraints

Max. # of days from new moon 14

14b. Scheduling constraints, special requirements and other remarks
(please include justification of constraints in 14a)

We are interested in the optical spectral end tending towards the infrared, where sky/moon brightness reduces and becomes less relevant.

15. Observational background of the applicants

Name of the observer(s) at TNG:

Experience of the observer(s) with the requested TNG instrument(s)

Experience of the observer(s) with other telescopes/instruments

FGG-INAF complies with the Spanish law for sensible data management (LOPD). Please read the page www.tng.iac.es/info/lopd/lopd-aot.html