Virtual Workshop MAAT@GTC
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Brown dwarfs and planetary mass objects with MAAT@GTC

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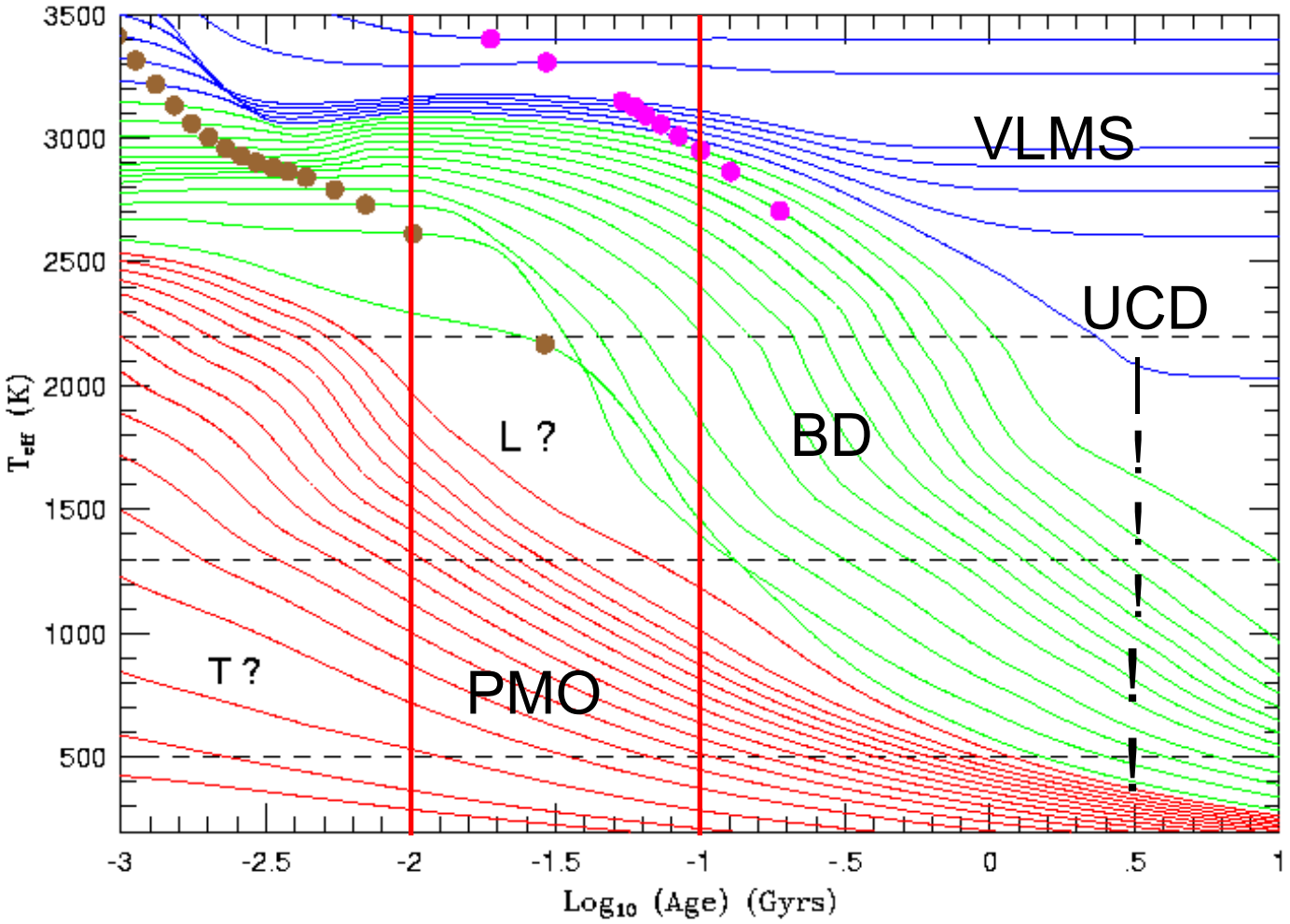
Outline

- Introduction: VLMS, BD, PMO, UCD
- Synergy Euclid-MAAT on Legacy Science of Ultracool Dwarfs (ILS project)
- MAAT spectroscopic follow-up of ultra-cool companions around young stars
- The Substellar Lithium Depletion Boundary in Coma Ber
- Final remarks

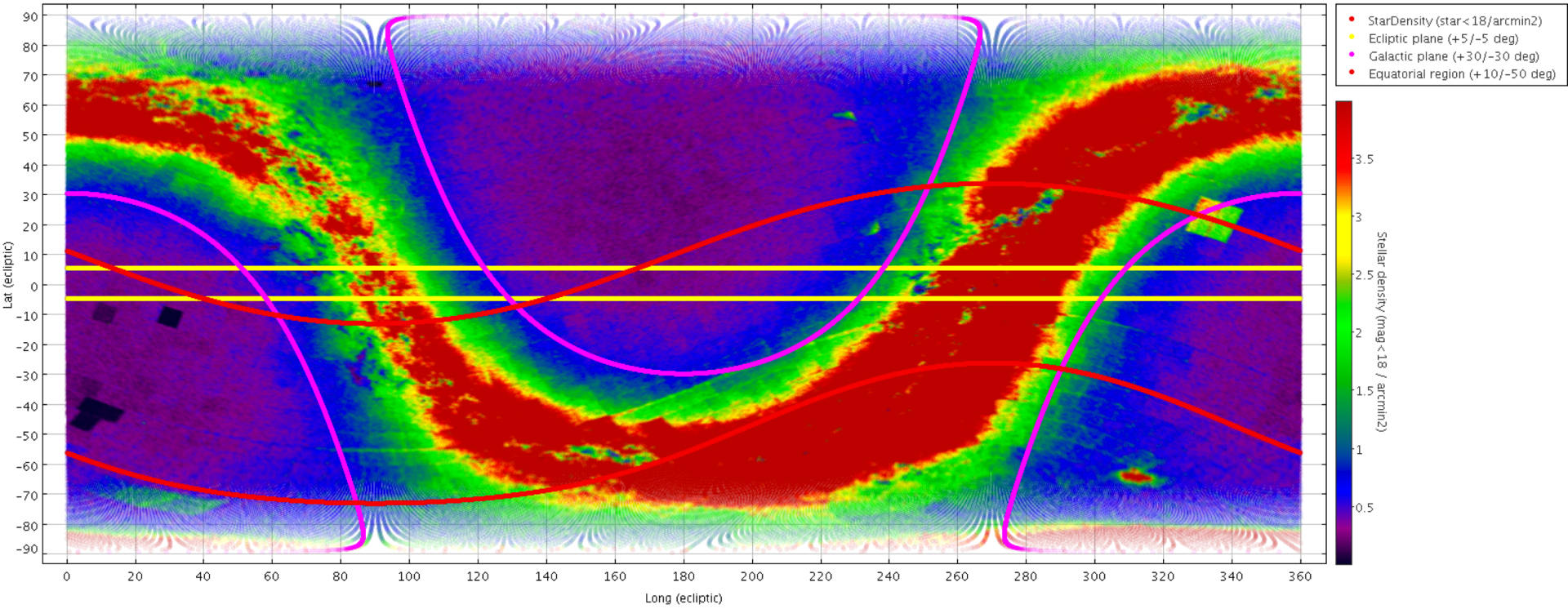
Evolution of substellar objects



Substellar objects cool down and get fainter for ever

Burrows et al. 1997

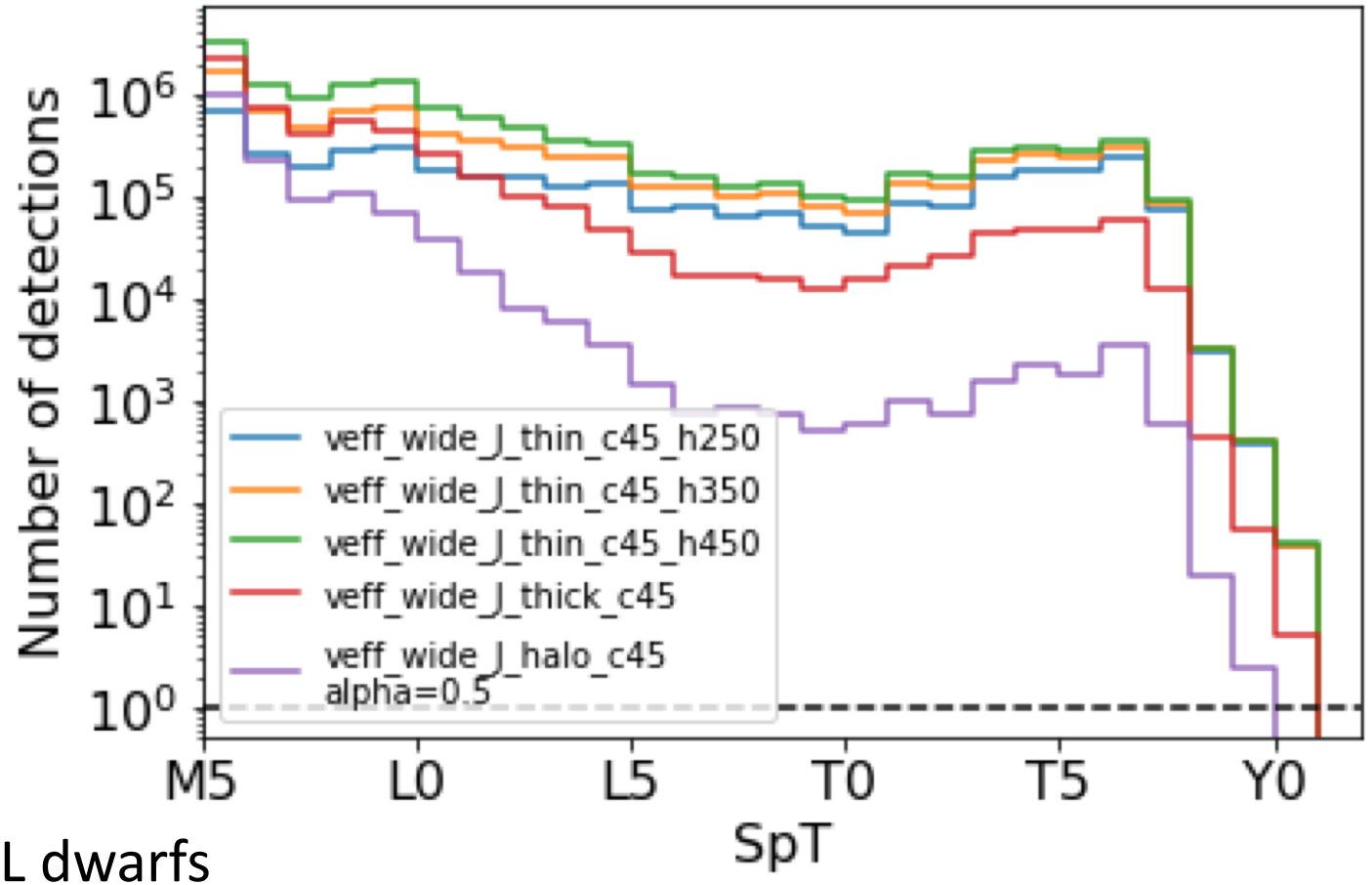
The Independent Legacy Science Project on Ultracool Dwarfs with EUCLID (selected by ESA in 2012)



EUCLID wide survey: ~15.000 deg^2 J_{lim}(Vega)~23, $I+z_{lim}$ (Vega)~24-25
Slitless spectra R~350 1.25—1.80 microns
(Galactic lat) β<30deg (Ecliptic lat) βeta<5deg
EUCLID deep surveys: 40 deg^2 J_{lim}(Vega)~25 P.I. Y. Mellier (IAP)

Simulation Results: Detection Counts by A. Burgasser

Wide Survey J-band



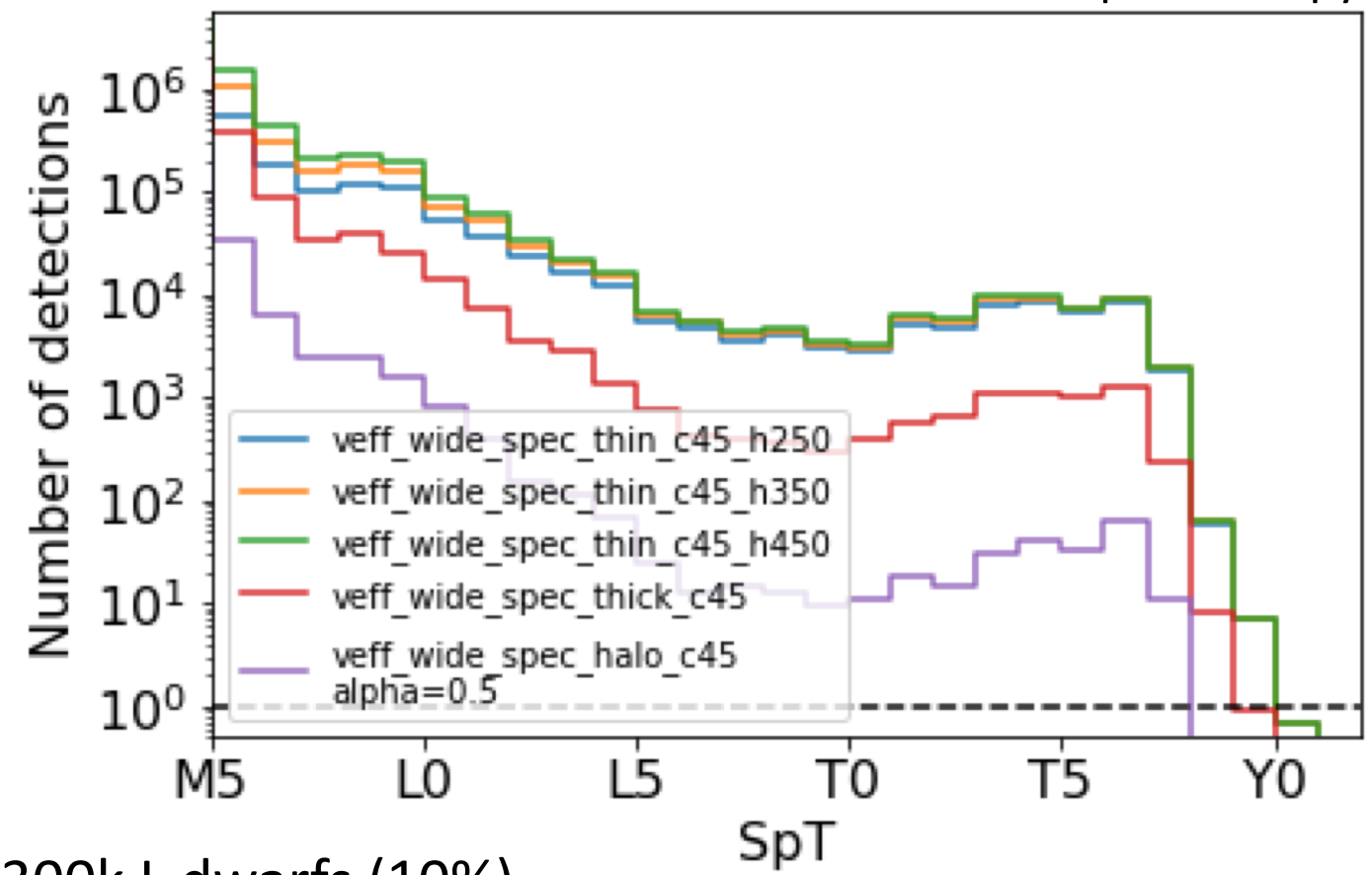
1-2M L dwarfs

0.5-1M T dwarfs

100k sdLs & 10k sdTs

Simulation Results: Detection Counts

Spectroscopy*



100k-300k L dwarfs (10%)

30k T dwarfs (6%)

2500 sdLs, 150 sdTs (2%)

* assumes all sources observed!

CAHA survey proposal

Led by N. Lodieu & M.R. Zapatero Osorio

190 nights over 3 years

Probing the low-mass end of the Initial Mass Function at different ages and metallicities

Methodology and tools

Using Omega2000, we will obtain astrometry and photometry for images covering:

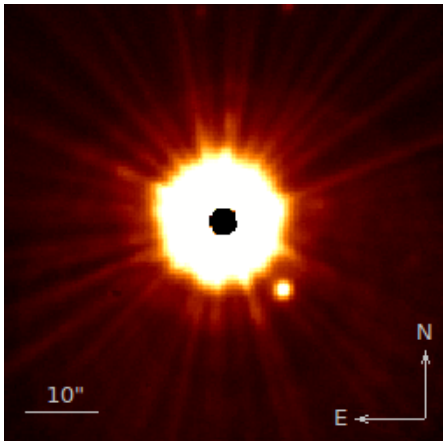
- ~1 deg^2 in the Pleiades: third epoch to be compared to previous Omega2000 frames.
- ~3 deg^2 in Coma Ber: first epoch to be compared with future Euclid data.
- 100 young members of stellar moving groups (~6 deg^2): first epoch to be compared with future Euclid data.
- 100 low-metallicity stars (~6 deg^2): first epoch to be compared with future Euclid data.

Omega2000 *J*-band images (also *H*-band for the Pleiades):

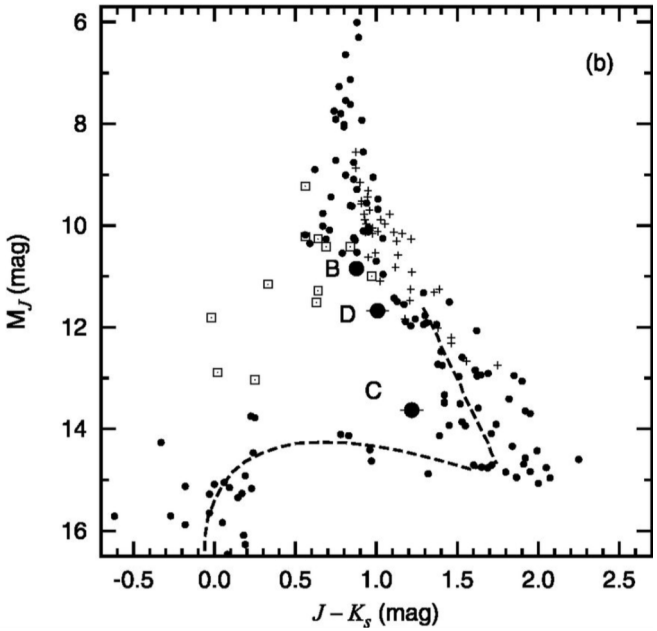
- Limiting Vega magnitude of 23, which is imposed by Euclid.

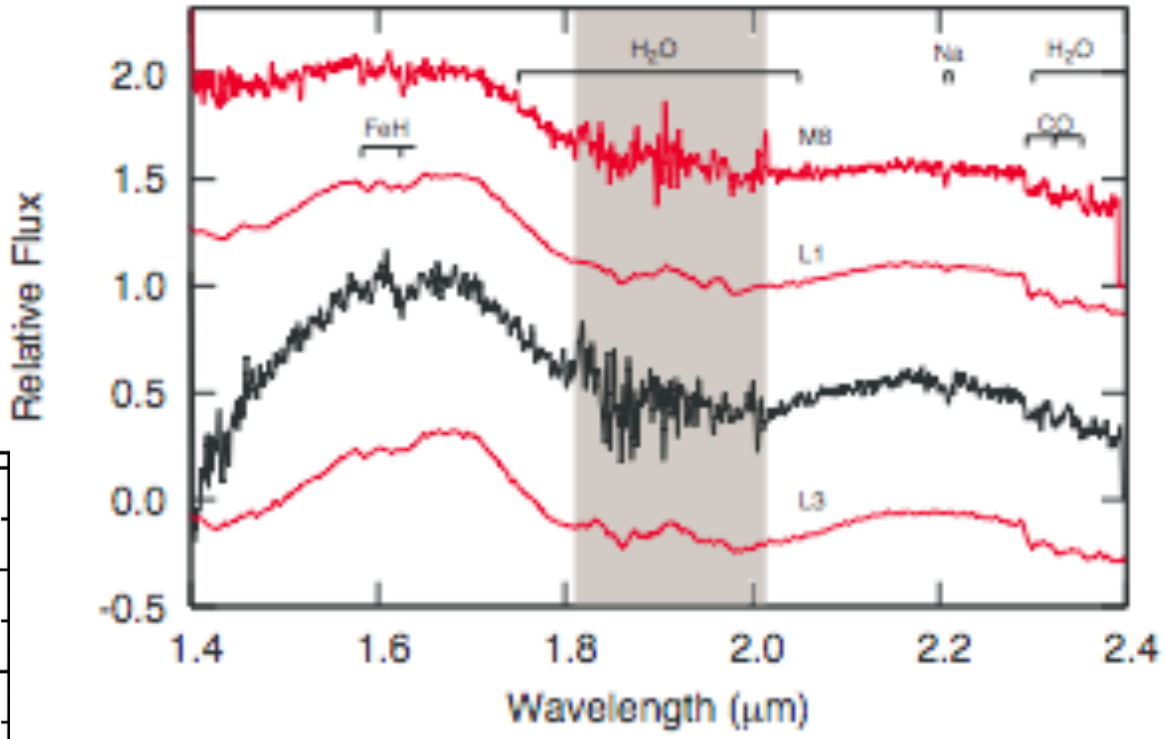
This proposal represents the only opportunity for us to exploit the science that Euclid can deliver in the field of substellar objects (northern hemisphere)

Examples of ultra-cool companions to nearby stars



(Gauza et al. 2012)

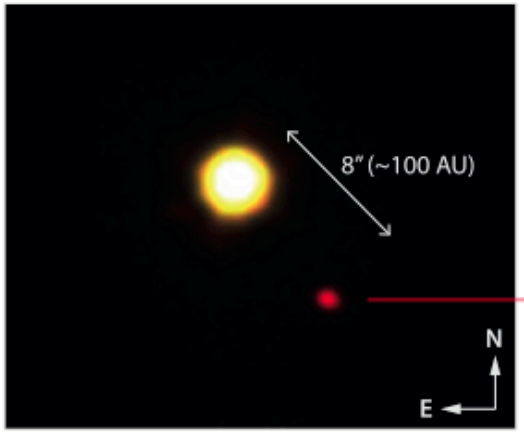


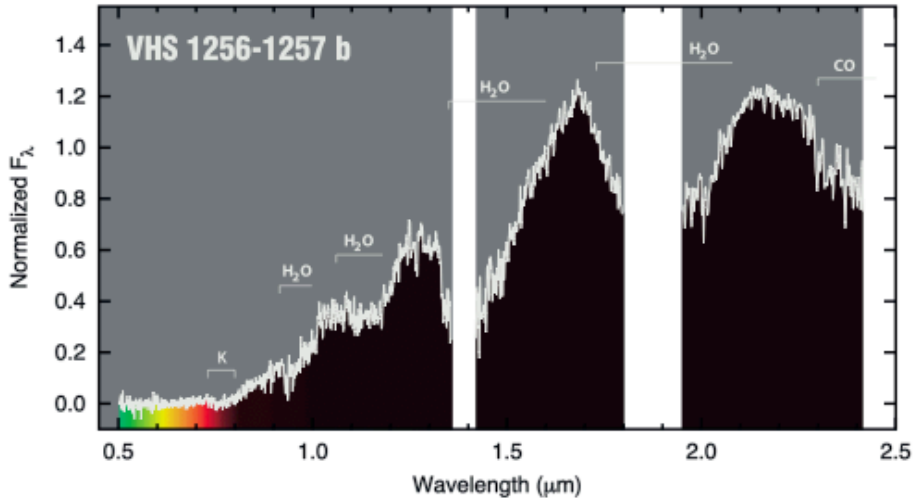


L dwarf companion at 312 AU of slightly metal poor HD221356 triple system (F8+M8+L3)

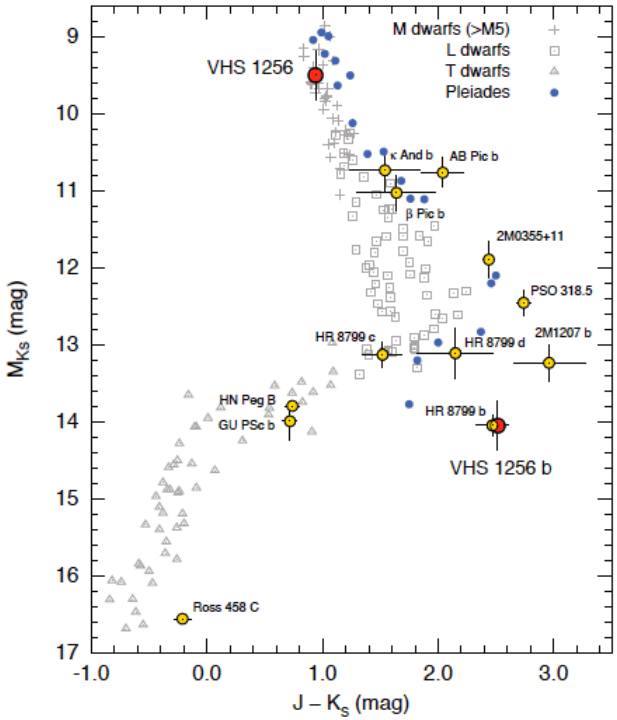
(Gauza et al. 2010)

VHS1256b: wide planetary mass companion





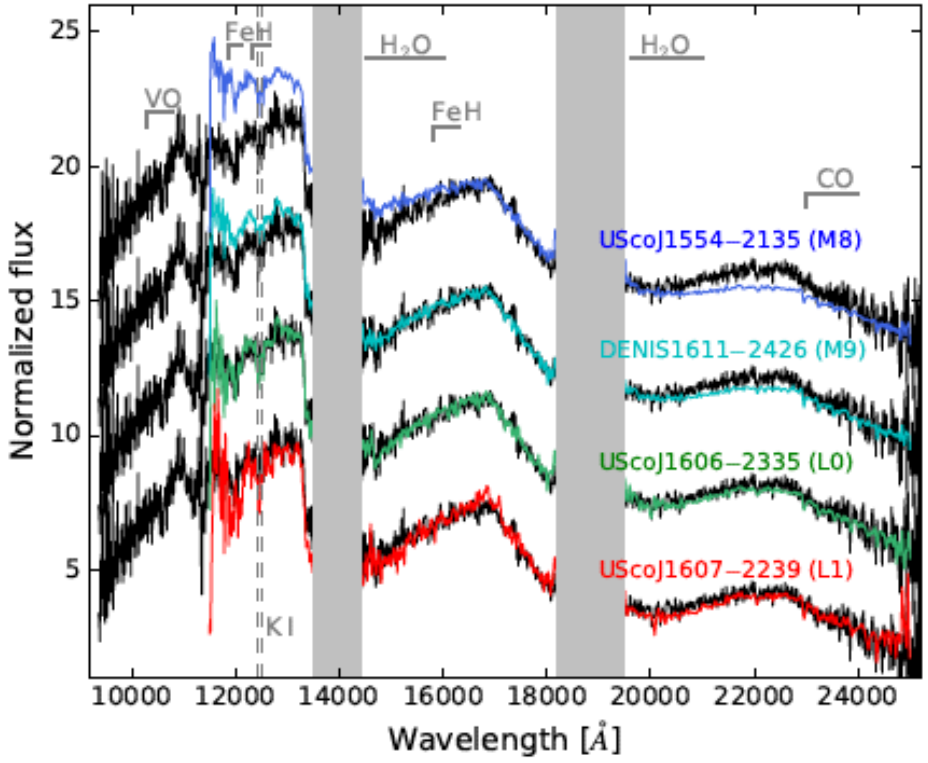
(Gauza et al. 2015)



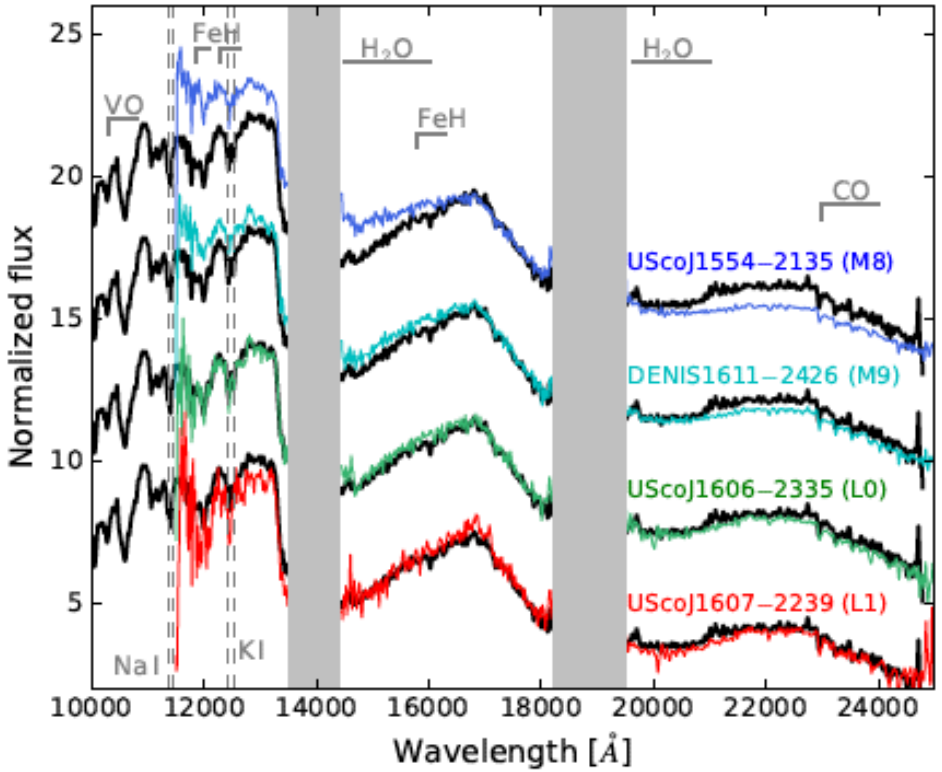
- A very red L7 planetary mass companion at ~100 AU of a young (150-300 Myr) nearby (~13/16.5pc) M7.5 dwarf
- Intermediate aged super-Jupiter with underluminosity and strong flux excesses at near-IR.
- The primary is itself binary (Stone et al. 2016)

Two L dwarf substellar companions in Upper Scorpius.

L0 and L0.5 companion at 2900 and 3500 AU from M2.5 and M3.0 stars



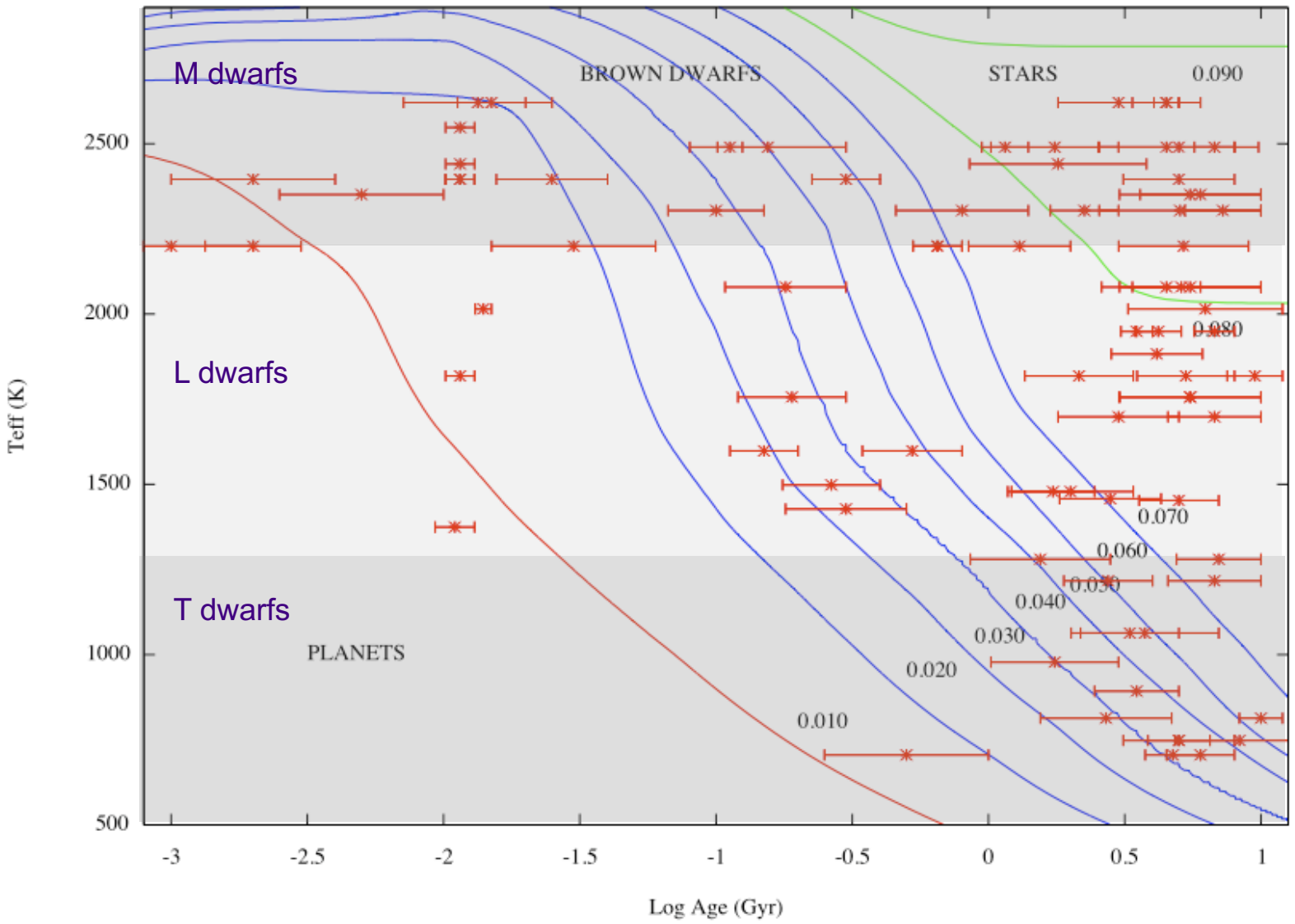
NTT/SOFI NIR spectrum



VLT/X-Shooter NIR spectrum

(Chinchilla et al. 2020)

Wide substellar companions around young stars



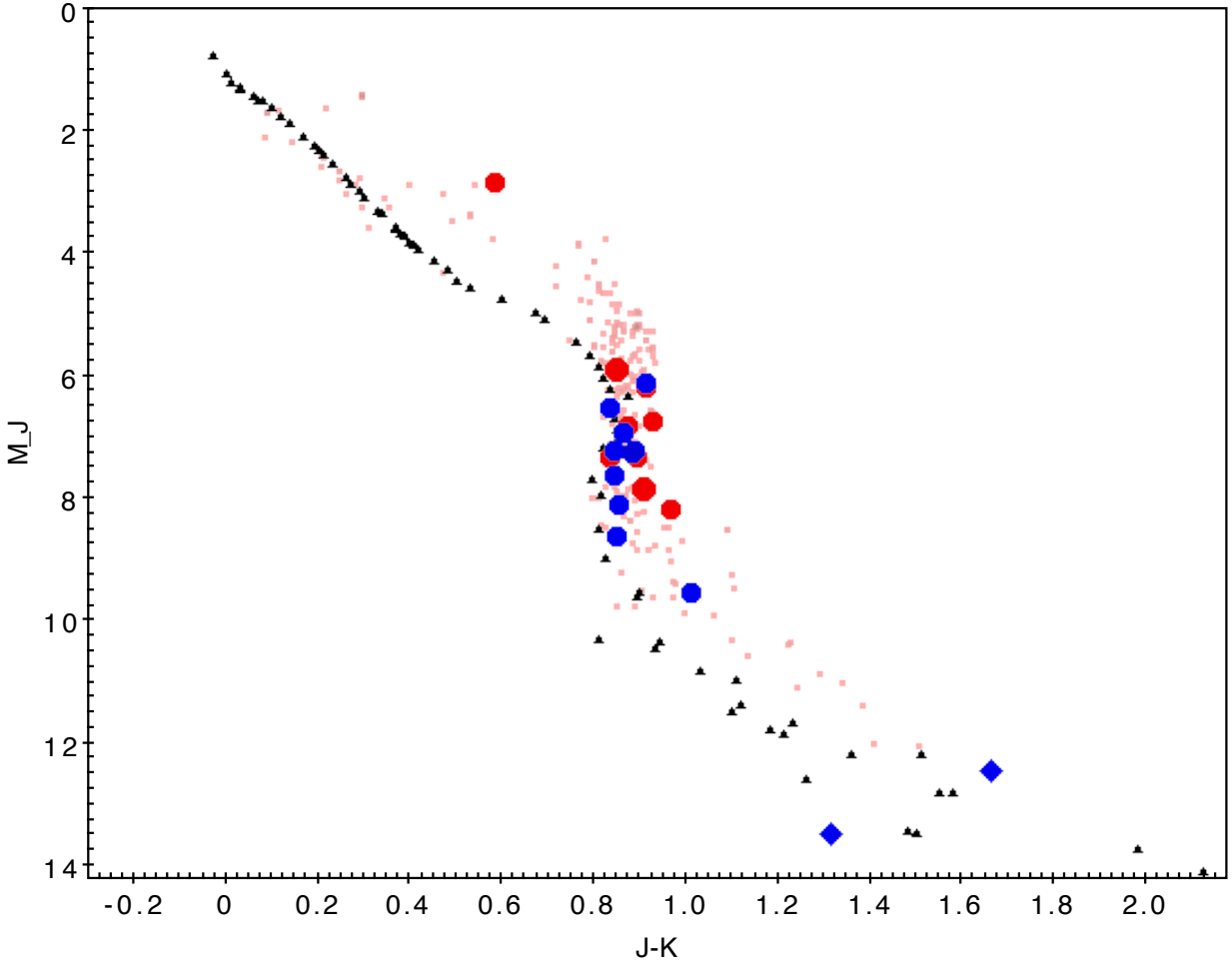
Increasing number of substellar companions are discovered at young ages

YMG: Beta Pictoris

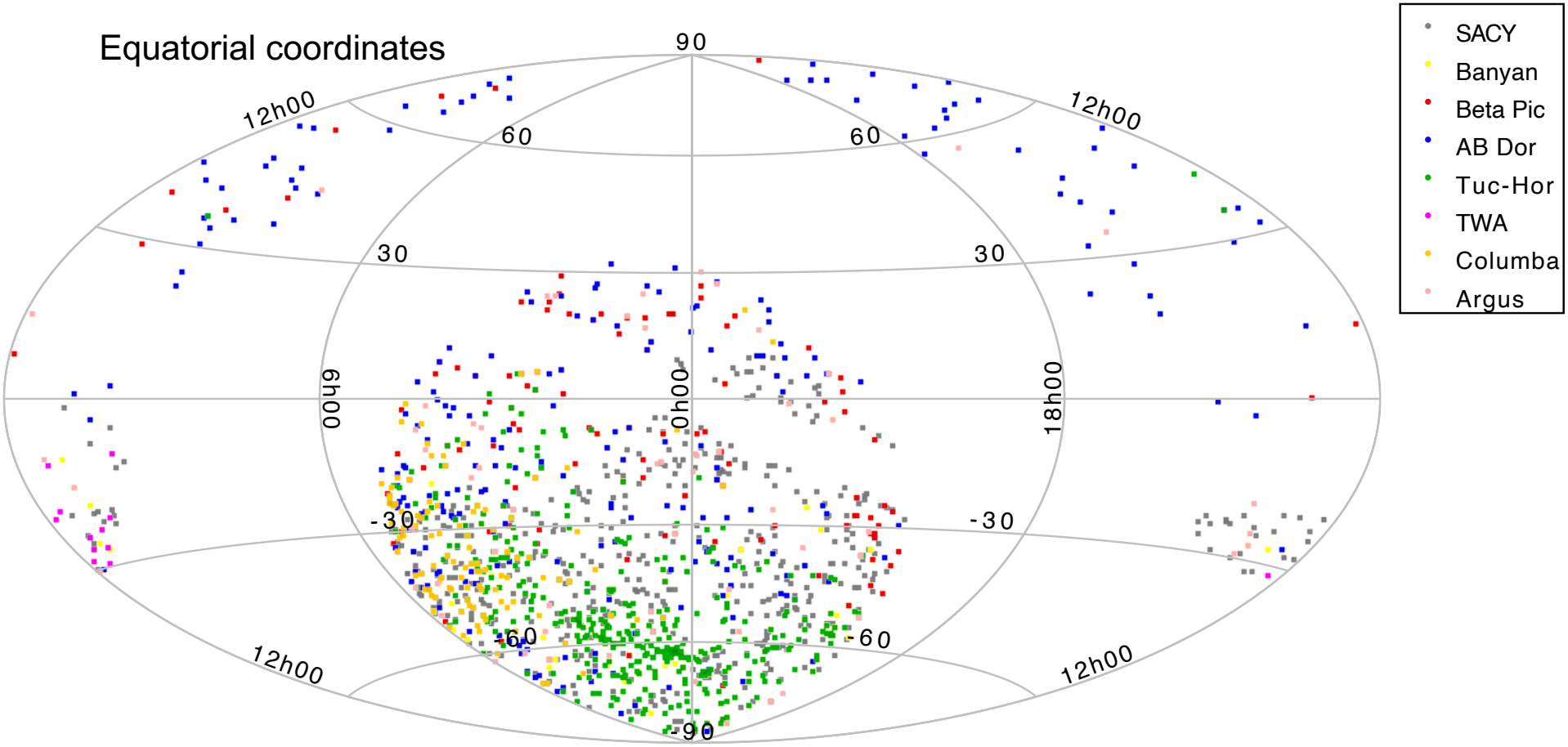
Beta Pic: (Age~25 Myr, d~45 pc)

13 companion candidates of 142 members

Preliminary binarity fraction: ~5-9% (>M5): **~0.7-2%**



Young Nearby Stars in EUCLID

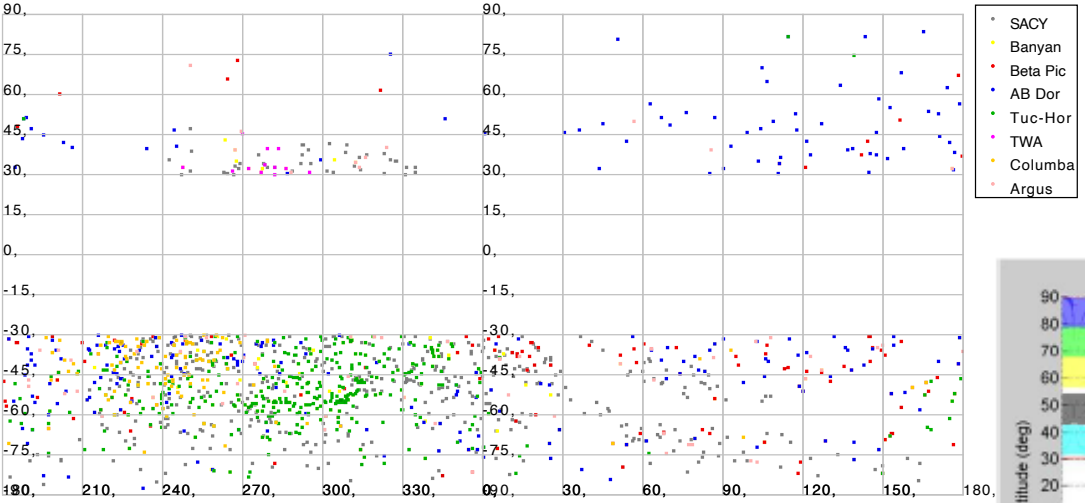


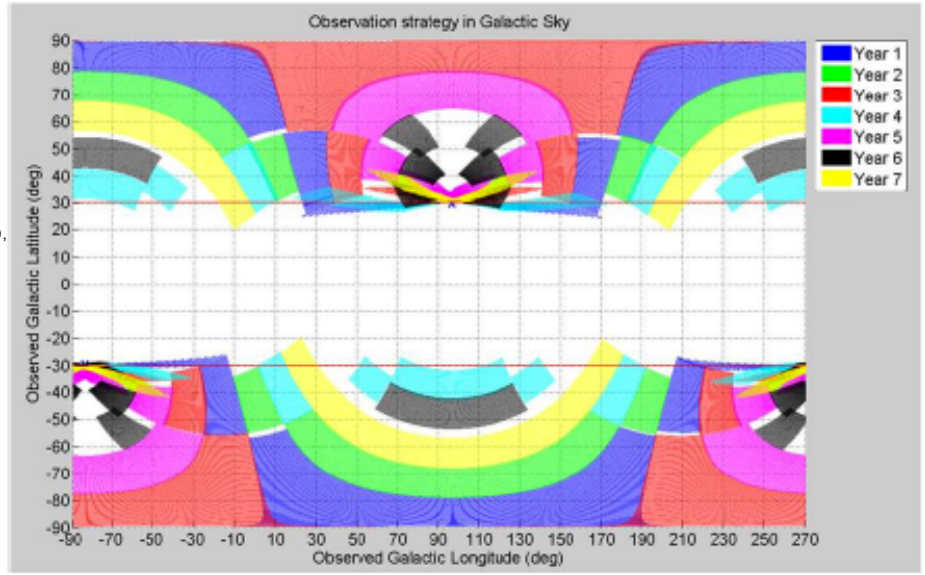
YMGs (AB Dor, Beta Pic, Tuc-Hor, TW Hydrae, Columba, Argus, Eta Cha): 980 stars (~300 ultra-cool dwarfs)

Young nearby stars, SACY (Torres et al. 2006): 577 stars (486 not in YMGs)

Young Nearby Stars in EUCLID

Galactic coordinates





YMGs (AB Dor, Beta Pic, Tuc-Hor, TW Hydrae, Columba, Argus, Eta Cha): 980 stars (~300 ultra-cool dwarfs)

Young nearby stars, SACY (Torres et al. 2006): 577 stars

ILS substellar companions of young stars project for EUCLID (led by V.J.S. Béjar)

Main objectives:

- ✓ Multiplicity fraction of young stars
- ✓ Evolution of binarity with mass and age
- ✓ Dynamical masses of young substellar objects

Expected number of young substellar companions with EUCLID:

- 1-3%: ~10-30 wide companions
- 10-20%: ~30-60 close ultra-cool companions (resolution VIS ~0.2”)

Coma Ber open cluster

- Second closest open cluster to us (87 pc)
- Brown dwarf sequence identified using Pan-STARRS, UKIDSS & GAIA down to L2.5 spectral subclass (about 65 Jupiter masses). J-band limit 18th mag.
- Age estimates ranging from 300 to 1000 Ma in literature (780 Myrs ours)

BDs in Coma Berenices: central area searches

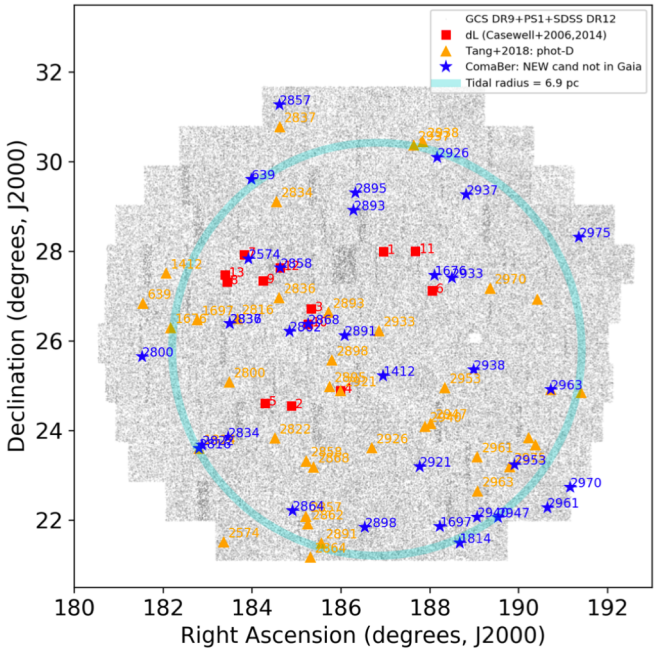
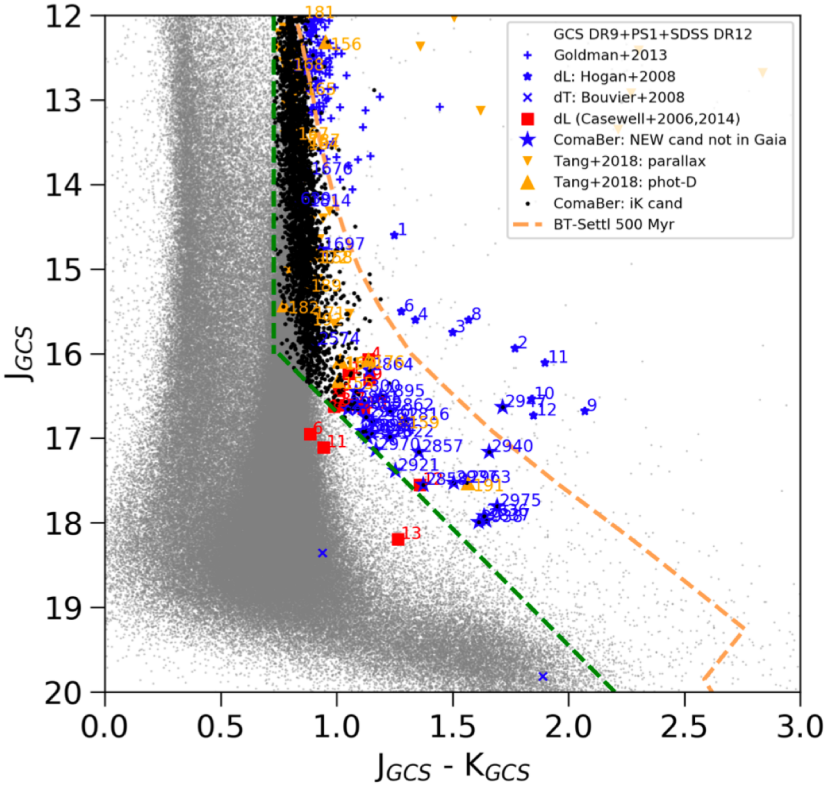


Fig. 1. Coverage of the full cross-matched catalogue with UKIDSS GCS, Pan-STARRS DR1, and SDSS DR12 photometric surveys (small grey dots). Overplotted with red squares, orange triangles, and blue asterisks are member candidates of the Coma Ber cluster from Casewell et al. (2006) and Casewell et al. (2014), Tang et al. (2018), and this study, respectively. **We included the tidal radius of Coma Ber as a large cyan circle (6.9 pc; Tang et al. 2018).**

BDs in Coma Berenices: CM diagram



BDs in Coma Berenices: GTC/OSIRIS follow-up

Table 2. Log of the GTC OSIRIS spectroscopic observations. We list the names of the targets as given in Casewell et al. (2006) and Tang et al. (2018), and this paper, respectively, along with their coordinates, magnitudes, dates of observations, instrumental set-up, weather conditions, and spectral types derived in this work. The last row is a well-known field lithium L dwarf template (Martín et al. 1997, 1999) observed as part of our programme GTC55-19A.

Name	R.A.	Dec	*J*	*G*	Date	Date	SNR
	hh:mm:ss.ss	°:′:″	mag	mag	yyyy-mm-dd	sec	6750-6800 Å
cbd67	12:18:32.71	+27:37:31.3	17.551	22.485	13-04-2018	2×1800	4.9
cbd34	12:23:57.37	+24:53:29.0	15.940	20.140	13-04-2018	2×1500	12.9
cbd34	12:23:57.37	+24:53:29.0	15.940	20.140	13-05-2018	2×1500	7.8
cbd10	12:21:02.46	+26:22:04.2	16.814	21.139	12-04-2018	2×1500	2.0
ComaBer 4	12:35:56.59	+25:21:11.2	17.993	22.928	13-05-2018	2×1800	4.9
ComaBer 5	12:45:25.19	+28:18:16.2	17.801	22.736	13-05-2018	6×1800	7.0
ComaBer 7	12:18:27.25	+31:15:53.3	17.162	>21.36	12-05-2018	2×1500	3.6
T159	12:11:14.90	+23:35:39.9	16.787	22.736	29-04-2018	2×1800	3.9
T191	12:42:53.70	+24:55:07.1	17.530	22.736	29-04-2018	4×1960	4.1
T191	12:42:53.70	+24:55:07.1	17.530	22.736	01-05-2018	2×1960	3.2
T191	12:42:53.70	+24:55:07.1	17.530	22.736	11-05-2018	2×1960	7.6
DENIS1228	12:28:15.20	−15:47:34.2	14.378	—	13-04-2018	2×370	10.1

BDs in Coma Berenices: OSIRIS spectroscopic results

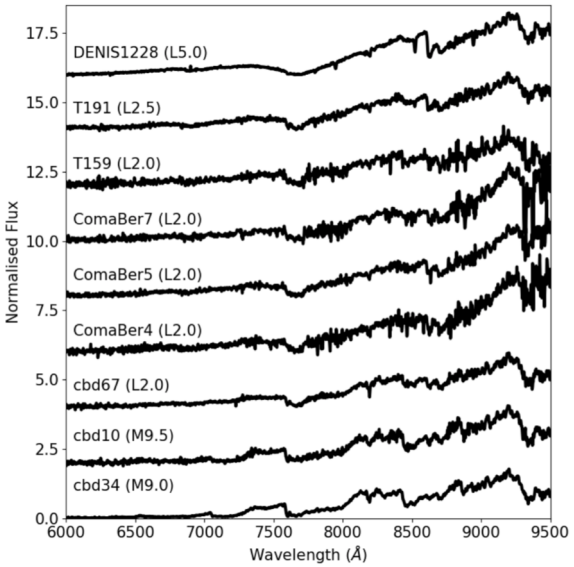


Fig. 4. Subset of GTC/OSIRIS optical spectra of BD candidates in Coma Ber discussed in this paper.

Table 3. Spectral types and radial velocities derived in this work. Spectral types from the literature come from Casewell et al. (2014) and Tang et al. (2018). Targets are ordered from earlier to later spectral subclass.

Name	SpT	SpT	RVs
	Literature	This work	km/s
cbd34	M9	M9.0±0.5	−2±38
cbd10		M9.5±0.5	3±46
cbd67	L1	L2.0±0.5	−18±35
ComaBer 4		L2.0±0.5	16±24
ComaBer 5		L2.0±0.5	2±15
ComaBer 7		L2.0±0.5	62±16
T159	L2	L2.0±0.5	10±21
T191	L4	L2.5±0.5	−1±14

BDs in Coma Berenices: Search for lithium

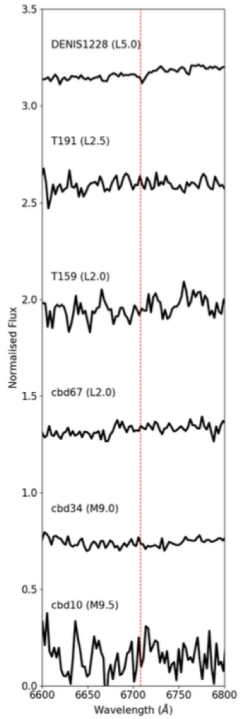


Fig. 6. Zoom on the spectral region around the Li resonance doublet at 6707.8Å for Coma Ber targets selected from Casewell et al. (2006), Casewell et al. (2014), and Tang et al. (2018). The Li I resonance doublet is clearly detected only in the lithium L dwarf, DENIS1228(Martín 1997; Martín et al. 1999), but not in the Coma Ber targets.

SLDB in Coma Berenices

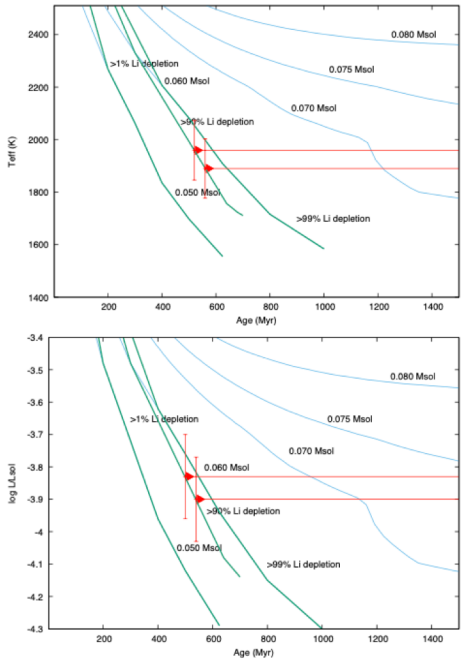


Fig. 7. Evolutionary tracks (effective temperature (Teff) and luminosity) from the models by Baraffe et al. (2015) for VLM stars and BDs as a function of age. Masses and predicted Li depletion factors are labeled. The non detection of Li in the Coma Ber member candidates studied in this work impose lower limits on the cluster age. The limit coming from the L2 candidates is depicted as the upper red triangle and horizontal line, and the limit obtained from the L2.5 object (T191) corresponds to the lower triangle and horizontal line in red colour.

LDB ages for open clusters

Table 5. Basic parameters and Li abundances for confirmed substellar members in Coma Ber.

Name	SpT	$log(L_{bol}/L_{\odot}$	T_{eff} (K)	log N(Li)	Age (Myr)
ComaBer 4	L2.0±0.5	-3.83±0.13	1959 ±113	<2.4	>480
ComaBer 5	L2.0±0.5	-3.83±0.13	1959 ±113	<1.8	>500
T159	L2.0±0.5	-3.83±0.13	1959 ±113	<2.0	>490
T191	L2.5±0.5	-3.90±0.13	1890 ±113	<1.5	>550

Table 6. Li depletion boundary (LDB) in open clusters **older than 20 Myr, ordered by increasing distance.**

Name	d pc	SpT Li	Age (LDB) Myr	Age (Other) Myr	Mass Msun	Ref.
Hyades	47	L4	650±70	570 – 900	0.065	Martín et al. (2018)
Coma Ber	87	>L2.5	>550	300 – 1000	<0.07	This work
Pleiades	130	M6.5	112±5	70 – 160	0.075	Dahm (2015)
IC 2391	146	M5	50±5	30 – 75	0.12	Barrado y Navascués et al. (2004)
IC 2602	152	M5.5	46±6	25 – 70	0.12	Dobbie et al. (2010)
Alpha Per	190	M6.5	85±10	50–70	0.08	Barrado y Navascués et al. (2004)
Blanco 1	207	M7	126±14	150 – 500	0.072	Juarez et al. (2014)
IC 4665	385	M4	28±5	30 – 100	0.24	Manzi et al. (2008)
NGC 2547	430	M4	35±4	20 –80	0.17	Jeffries & Oliveira (2005)

MAAT – Euclid synergies for UCDs

- Euclid wide survey (~15.000 deg^2) will be a unique survey 2 mag deeper (NISP) than VHS/UKIDSS and 3-4 mag deeper (VIS) than Gaia to search for substellar objects. Need sensitive spectroscopic follow-up of substellar candidates.

- Euclid will detect tens of benchmark young WIDE substellar companions. MAAT will allow to properly charaterize their physical properties with age (luminosity,T_{eff}) and carry out RV searches for close binaries.

- Euclid will detect dozens of brown dwarfs in the Coma Berenices open cluster. MAAT can determine the SLDB in the second nearest open cluster.

Euclid Deep north survey contains a handful of UCD candidates detected by Gaia. MAAT could provide spectroscopic characterization ahead of mission launch.