The field brown dwarf luminosity and mass functions

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50 years of brown dwarfs

1963 theoretical prediction of the existence of brown dwarfs

1994 observational discoveries
90s : few discoveries and observational properties still relatively unexplored

Last decade : discovery of 100s of brown dwarfs (most of them in DENIS, 2MASS and SDSS)

New generation of large-area surveys going deeper (UKIDSS, CFBDS, WISE): large number of known brown dwarfs, new types of brown dwarfs detected

To date 1300 L,T,Y dwarfs in the local Galactic field

Towards a complete census

With that large number of identified brown dwarfs, it becomes possible to define uniform and well-characterised samples

Used to investigate the substellar luminosity and mass functions

The knowledge of these functions is essential:

- in terms of Galactic studies, it gives clues on the baryonic content of the Galaxy (probably counts several 10^{10} BDs, 100s in the Solar neighbourhood)
- in terms of stellar physics studies, it gives constraints on stellar and substellar formation theories (does a single log-normal function fit the mass function from field stars to brown dwarfs?)

To validate these assumptions it is necessary to first refine the **field brown dwarf LF**

Outline

The CFBDS as an illustration: a complete and homogeneous sample to derive the space density of field BDs

Recent observational efforts to characterize the low-mass end luminosity function…

…and the mass function

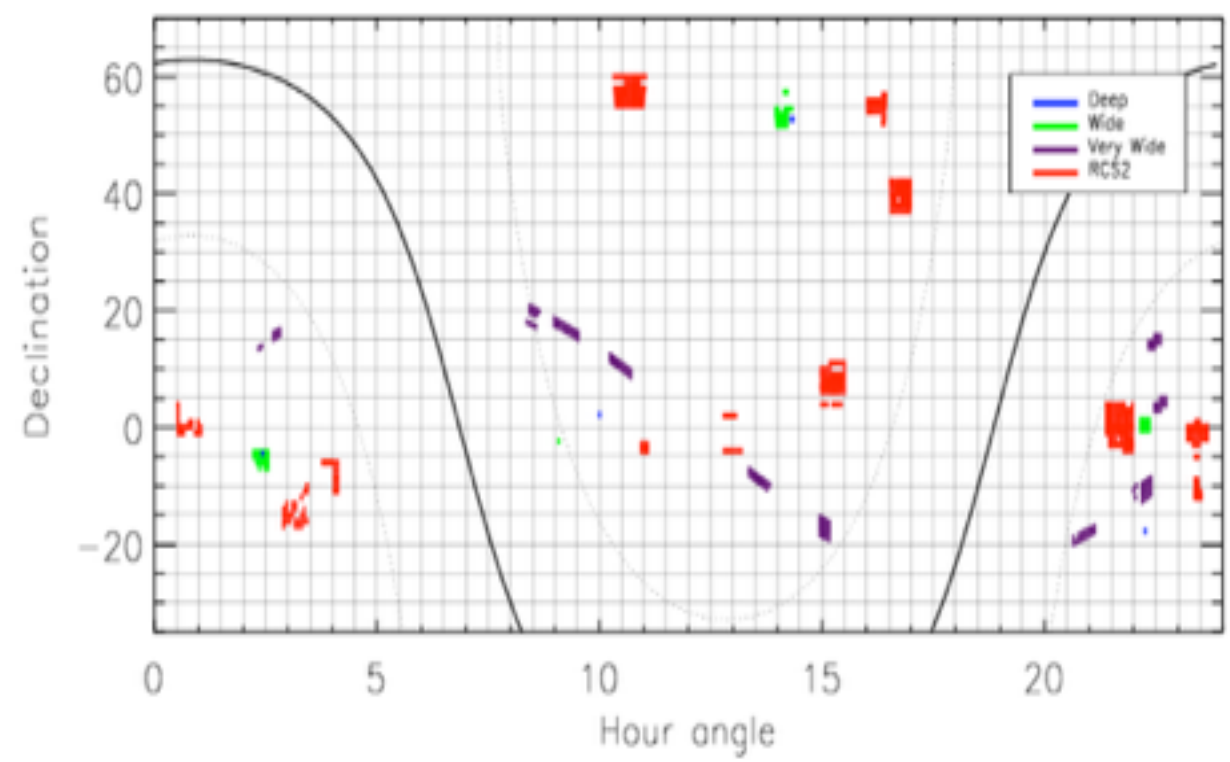
How Gaia can (or not) help?

The Canada France BD Survey

CFBDS is a wide-field survey for cool brown dwarfs conducted with the MegaCam camera on the Canada-France-Hawaii Telescope.

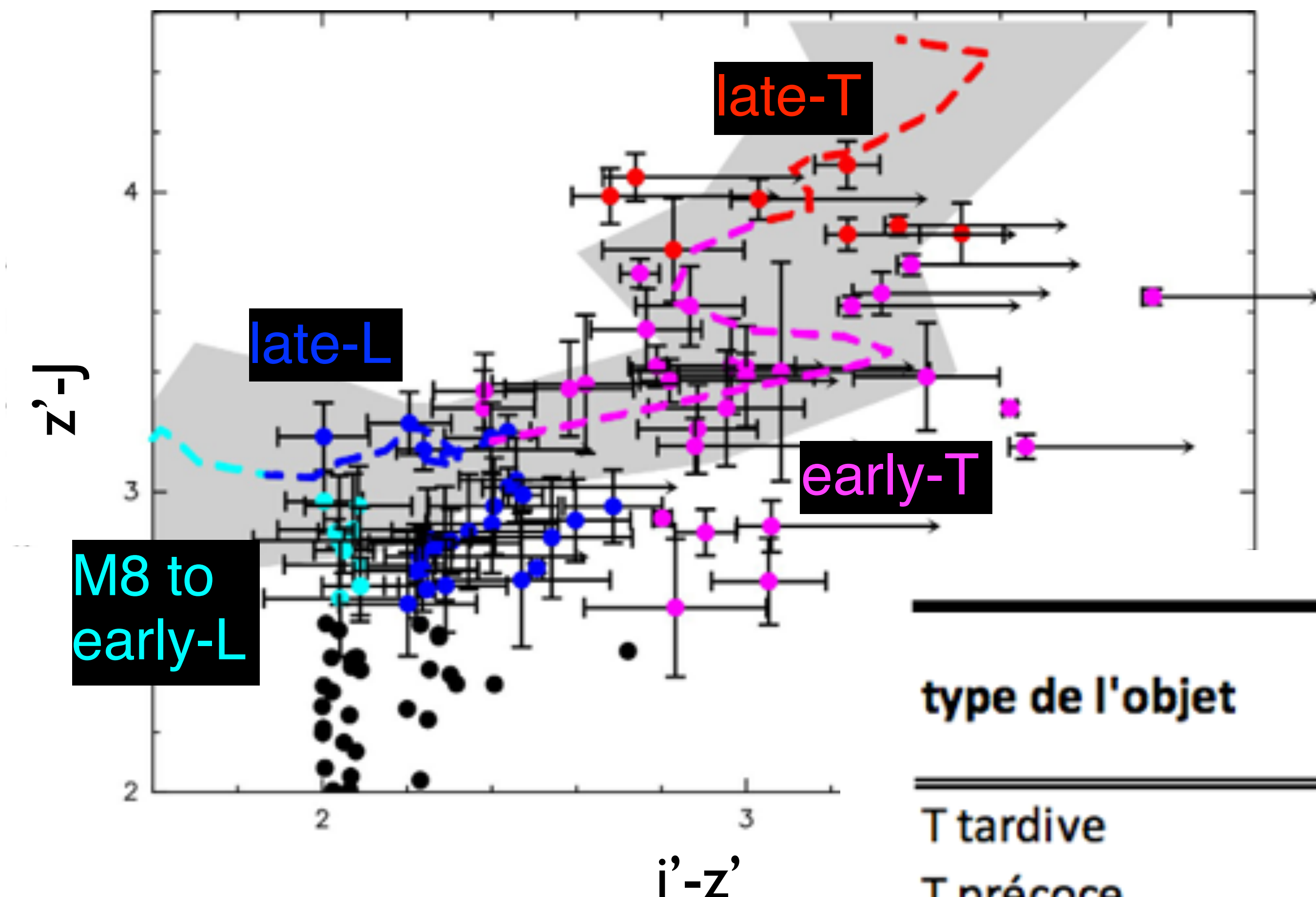
We identify candidates in i' and z' images, with typical ultracool dwarfs i'-z' colours

1400 candidates found over 50×10^6 sources in 780 deg^2, up to z'=22.5



Follow up with pointed near infrared J imaging on several telescopes

The Canada France BD Survey



Spectroscopic follow-up for the T dwarfs (Albert et al 2011)

type de l'objet	nombre	pourcentage	distance maximale de détection (pc)
T tardive	25	2.5%	60
T précoce	48	4.7%	100
L tardive	131	12.9%	200
L pécoce & >M8	147	14.4%	300
<M8	632	62.0%	500
artecfacts ou quasars	36	3.5%	
total	1019		

The Canada France BD Survey

Halfway through the survey we draw a complete and well defined sample of 102 ultracool dwarfs to investigate the luminosity function and space density of field dwarfs

Need to correct carefully the **contamination** and **uncompleteness**

Need to compute the maximum volume probed by the magnitude-limited survey at a given colour or spectral type (that is at a given absolute magnitude) and to estimate a distance for each object

Assume absolute magnitude vs colour or spectral type relations

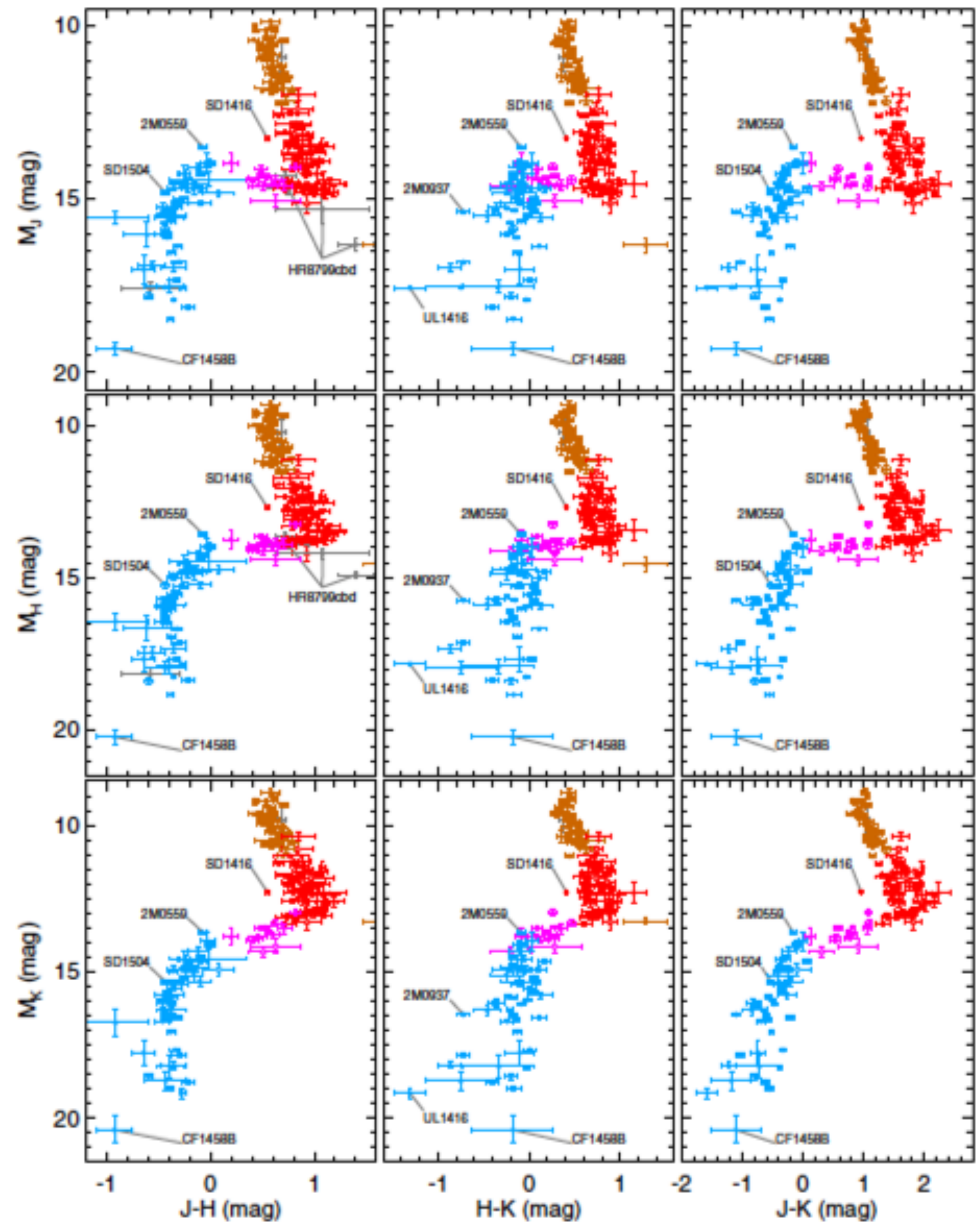
➤ Parallaxes

Dupuy & Liu 2012:

parallaxes for 83 ultracool dwarfs using WIRCam (CFHT)

M6-L2
L2.5-L9
L9.5-T4
≥T4.5

significant scatter



→ Parallaxes

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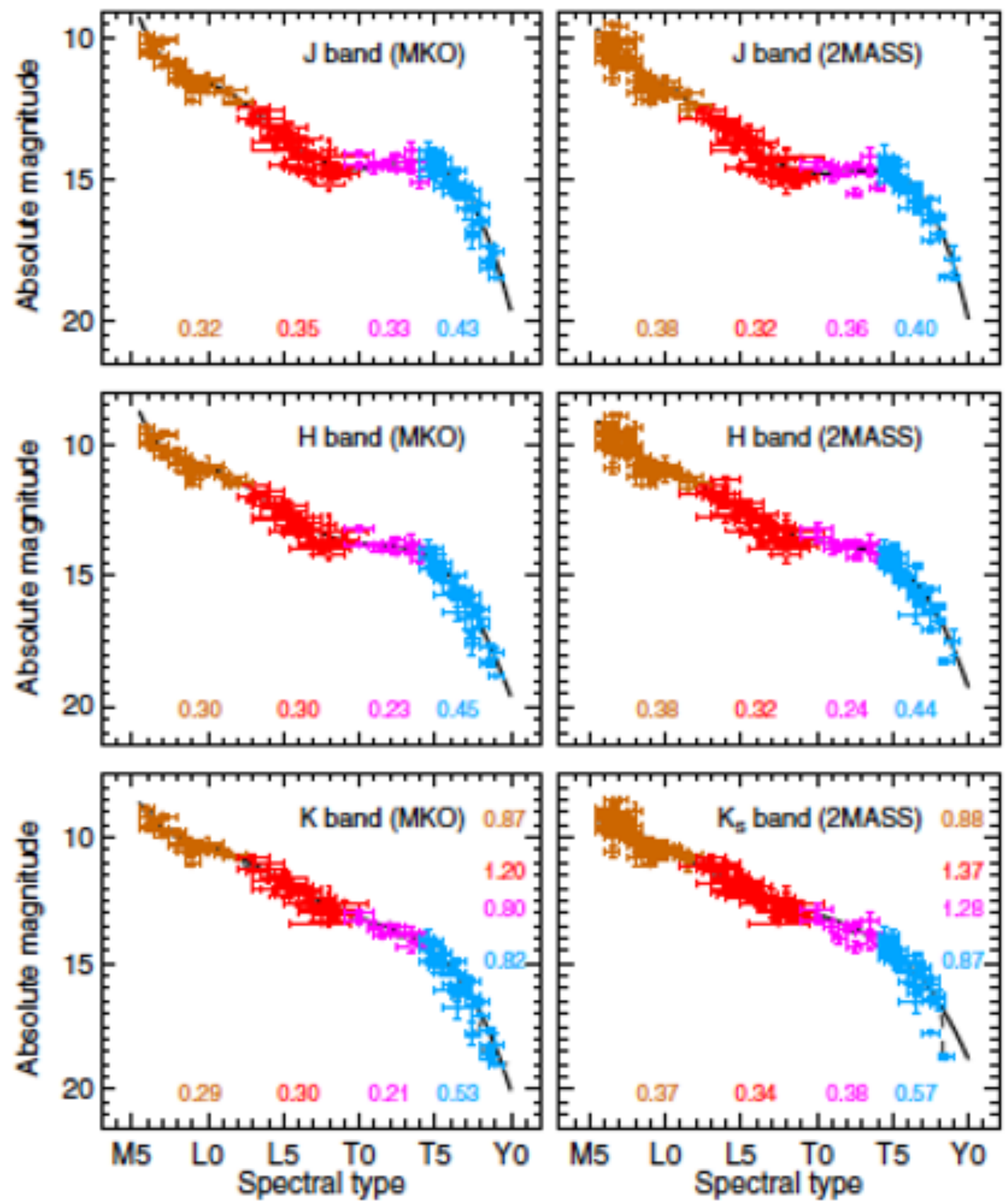
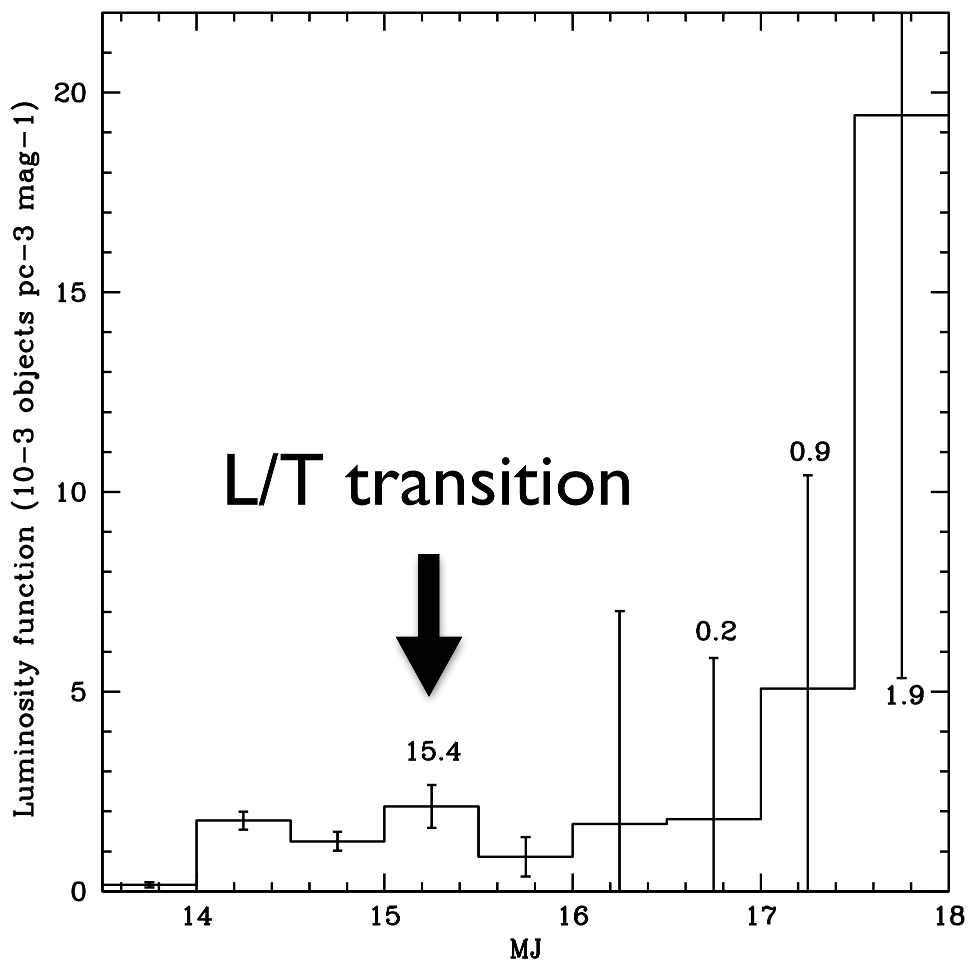


cf J. Bochanski talk for other parallaxe programs

see also posters by C. Ducourant, Y. Wang

The Canada France BD Survey



Reylé et al 2010

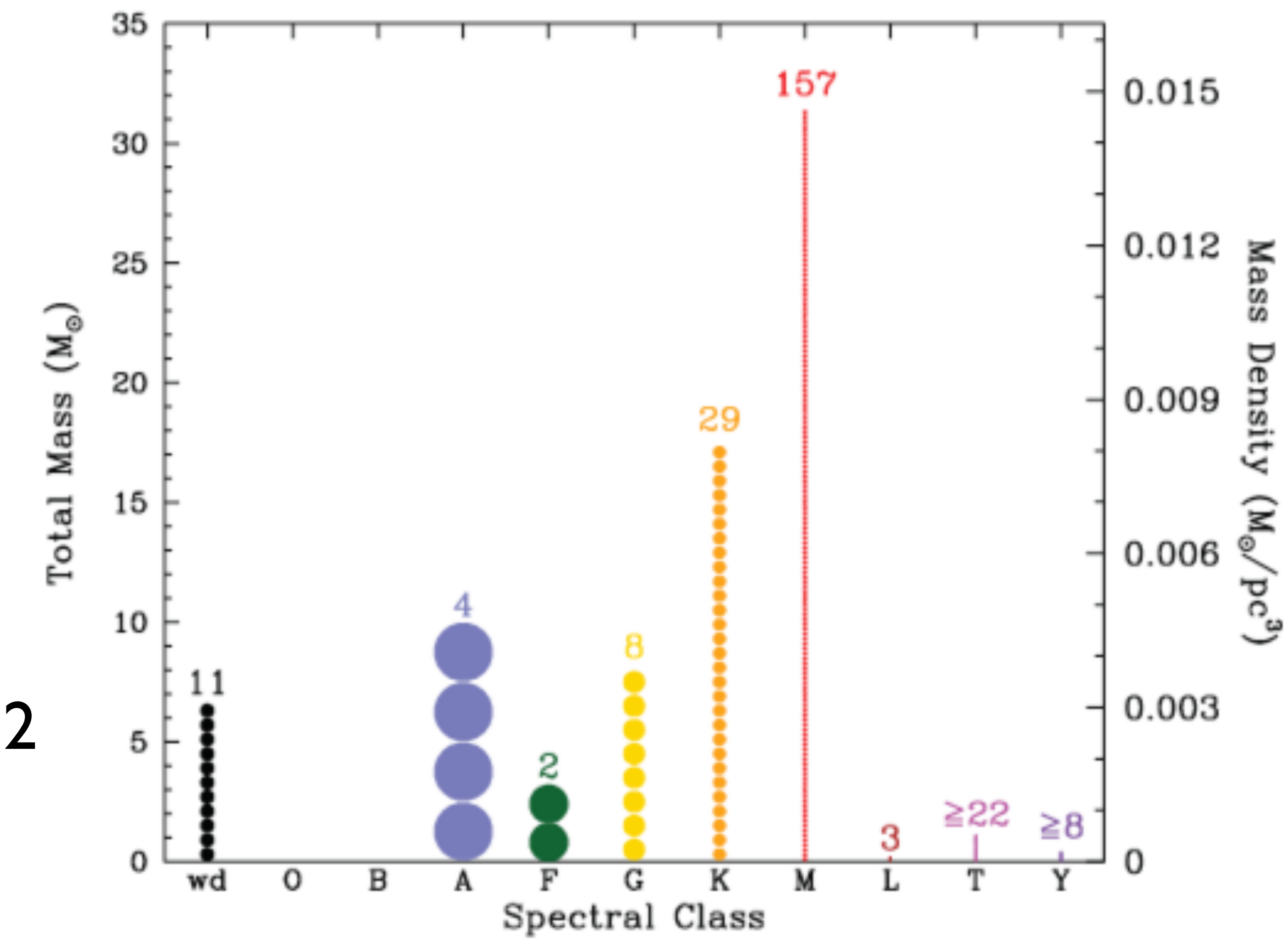
Table 8. Comparison of the brown dwarf space densities ρ (10^{-3} objects pc^{-3}) obtained from CFBDS given separately for L and T-dw
Allen et al. (2005); Cruz et al. (2007); Metchev et al. (2008).

M_J $\rho_{\rm tot}$(CFBDS)	ρ(Cruz)	ρ(Allen)	ρ(Metchev)	ρ_L(CFBDS)	ρ_T(CFBDS)
13.75	0.5 ± 0.2	1.0 ± 0.3	–	–	$0.78^{+0.30}_{-0.24}$
14.25	$>0.7 \pm 0.2^a$	$>1.7 \pm 1.4^a$	–	$1.09^{+0.30}_{-0.26}$	$1.86^{+0.60}_{-0.49}$
14.75	$>0.3 \pm 0.2^a$	$>2.3 \pm 1.4^a$	–	$2.18^{+0.78}_{-0.63}$	$0.62^{+0.76}_{-0.41}$
15.25	–	$>1.9 \pm 0.9^a$	–	$0.79^{+0.49}_{-0.34}$	$1.14^{+1.12}_{-0.67}$
15.75	–	2.0 ± 1.5	–	$0.57^{+1.63}_{-0.52}$	$2.52^{+3.67}_{-1.82}$
16.25	–	4.7 ± 0.3	–	–	$3.75^{+7.23}_{-3.04}$
T0-T5.5	–	–	$2.3^{+0.9}_{-0.9}$	–	$1.4^{+0.3}_{-0.2}$
T6-T8	–	–	$4.7^{+3.1}_{-2.8}$	–	$5.3^{+3.1}_{-2.2}$
T8.5-T/Y	–	–	–	–	$8.3^{+9.0}_{-5.1}$

Expected number within 10 pc:
T0-T5.5 5 to 7
T6-T8 13 to 35
T8.5-Y 14 to 73
Low-mass BD and old BD accumulate in this SpT range

The census within 8 pc

BDs cool down to the latest and coldest end of the spectral range after a few Gyr and should accumulate there because the cooling rate significantly slows down at these low temperatures. This speculation would agree interestingly with the hints from Gould et al. (2009) that old-population brown dwarfs could be much more numerous than young ones.



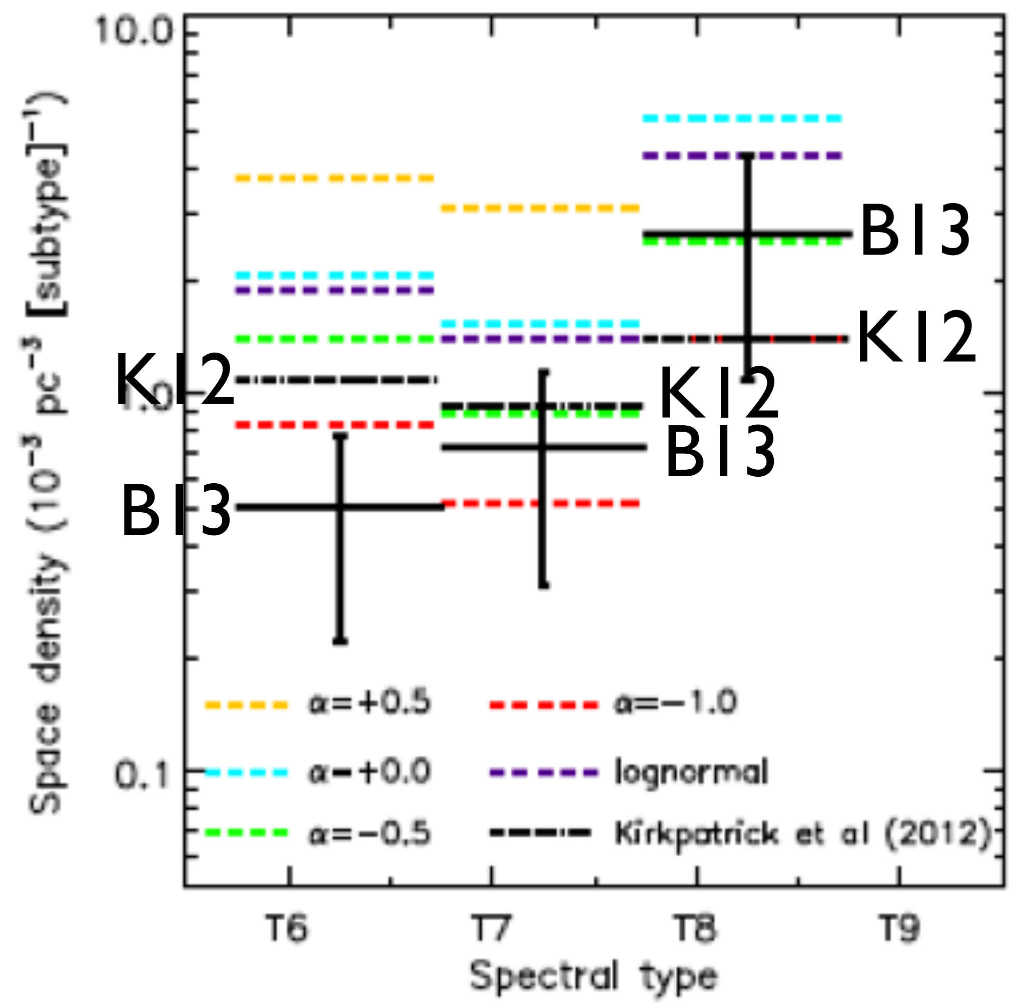
Kirkpatrick et al 2012

Recent studies

Kirkpatrick et al 2012:
WISE 148 T6-≥Y1

Day-Jones et al 2013:
UKIDSS Large Area Survey DR7
63 L4-T1.5 over 495 deg^2

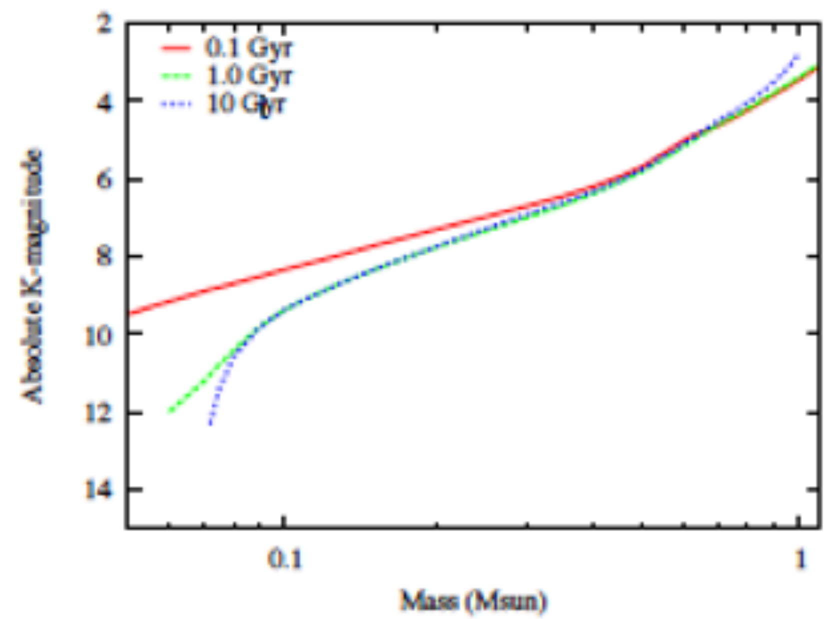
Burningham et al 2013:
UKIDSS Large Area Survey DR8
78 T6-T8.5 over 2270 deg^2



Burningham et al 2013

On the way to the mass function

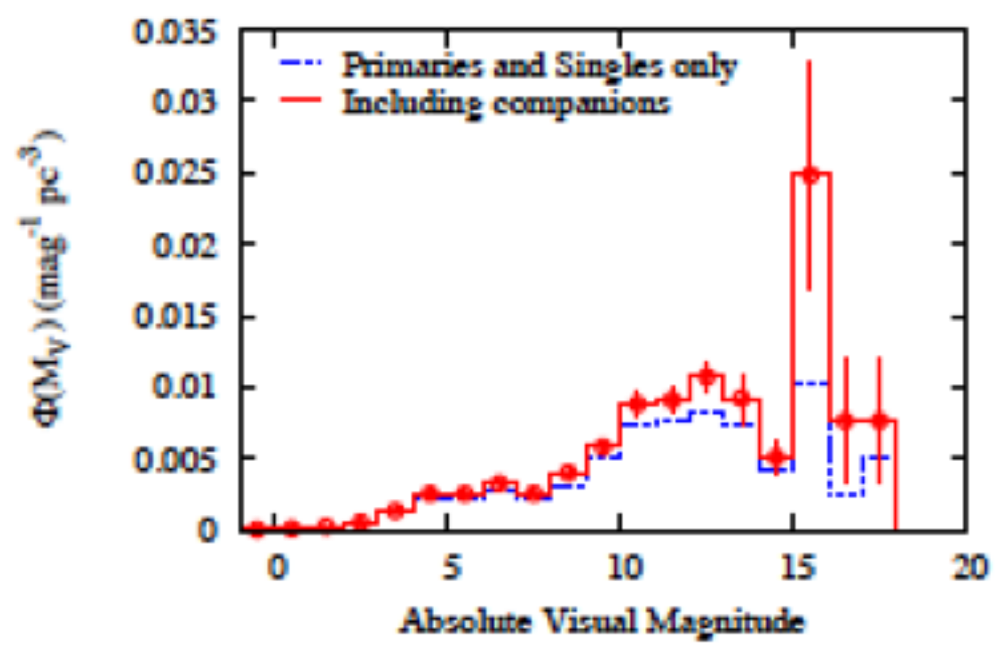
Need to assume a mass-luminosity relation. Degeneracy with age.



M_K vs mass using Baraffe et al 1998 evolutionary models (Jeffries et al 2012)

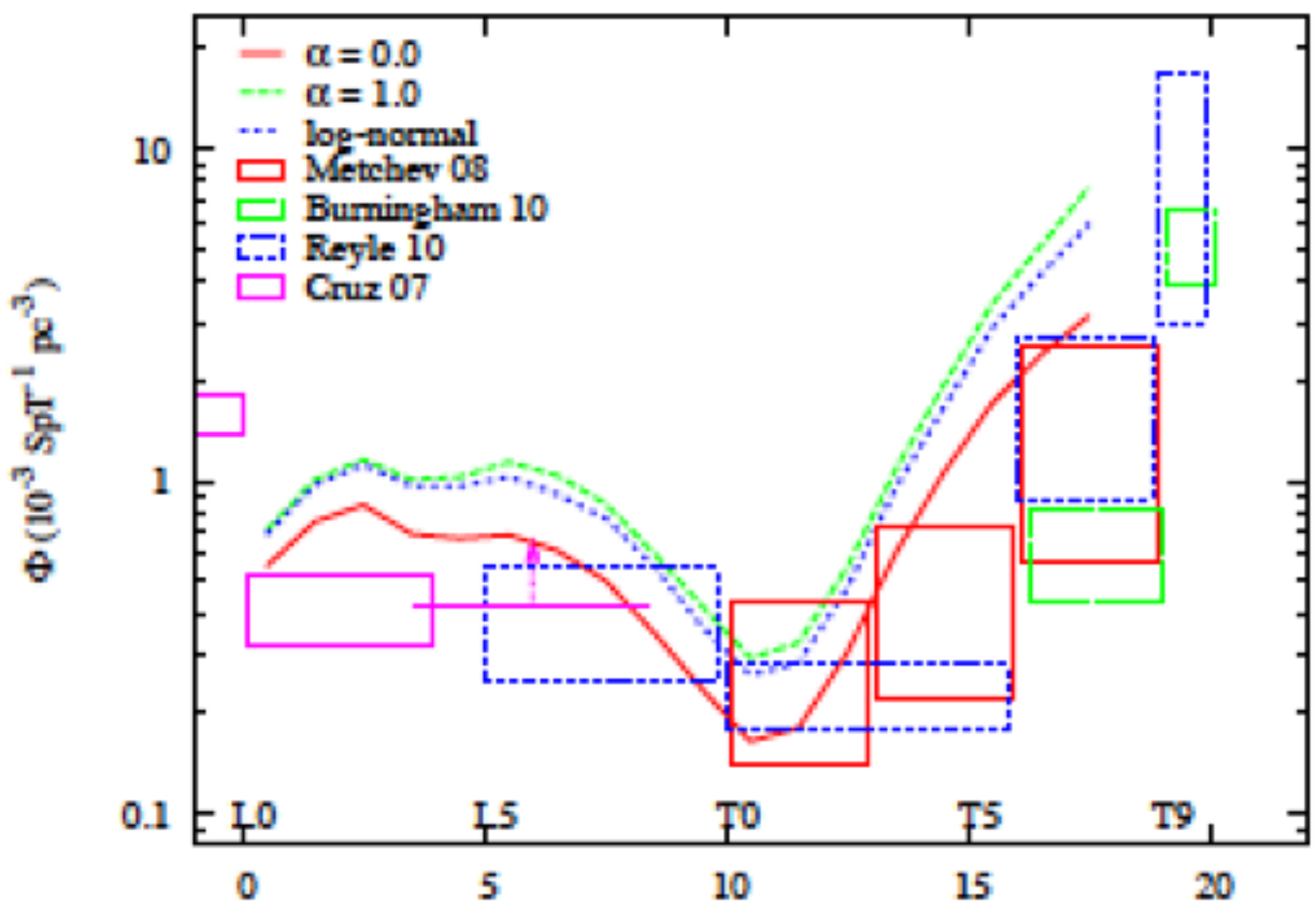
On the way to the mass function

Need to assume a binarity rate



The LF of nearby stars from Reid et al 2002
(from Jeffries et al 2012)

On the way to the mass function



Study	Survey	Method	Sample	α
Allen *et al.* 2005	2MASS 14800 deg^2 $J < 16.5$	vol-lim(ML) mag-lim(T) JHK + spec.	180 ML 18 T5-T8	$+0.3 \pm 0.6$
Cruz *et al.* 2007	2MASS 14800 deg^2 $J < 16.5$	vol-lim JHK+spec.	45 L	≤ 1.5
Metchev *et al.* 2008	SDSS/2MASS 2099 deg^2 $z < 21$	mag-lim $izJHK$+spec.	15 T0-T8	≤ 0
Reylé *et al.* 2010	CFBDS 444 deg^2 $z < 22.5$	mag-lim izJ+spec.	102 L5-T9	≤ 0
Burningham *et al.* 2010	UKIDSS 980 deg^2 $J < 18.8$	mag-lim $zYJH$+spec.	47 T6-T9	-0.5 ± 0.5

The field BD luminosity function compared to model loci taken from Burgasser et al 1997. They predict the observed LF based on evolutionary models with an assumed value for the IMF $dN/dm=m^{-\alpha}$ (Jeffries 2012)

On the way to the mass function

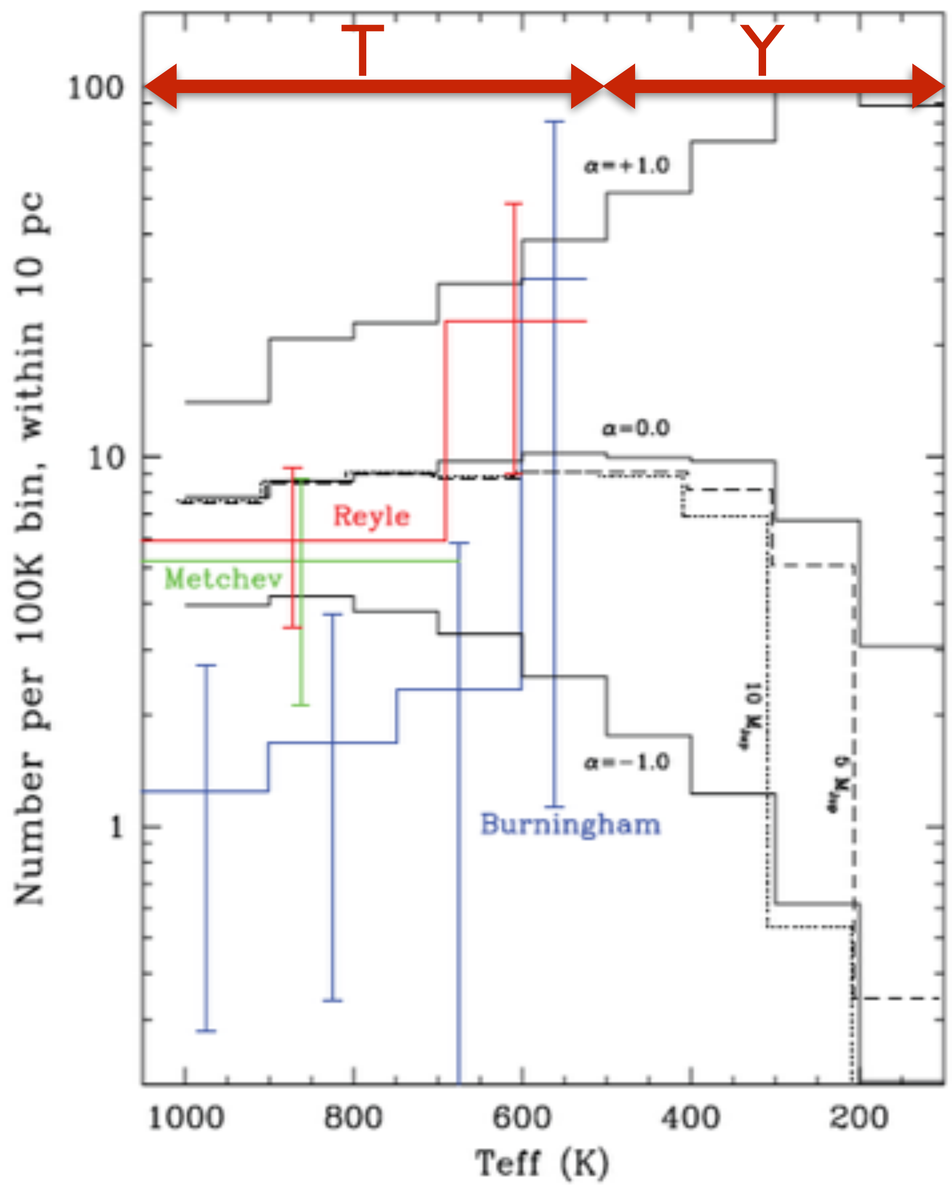


Figure 15. Previous measurements of the space density of mid- to late-T dwarfs from Metchev et al. (2008) (green), Reylé et al. (2010) (red), and Burningham et al. (2010) (blue) overplotted on the same simulations from Figure 14.

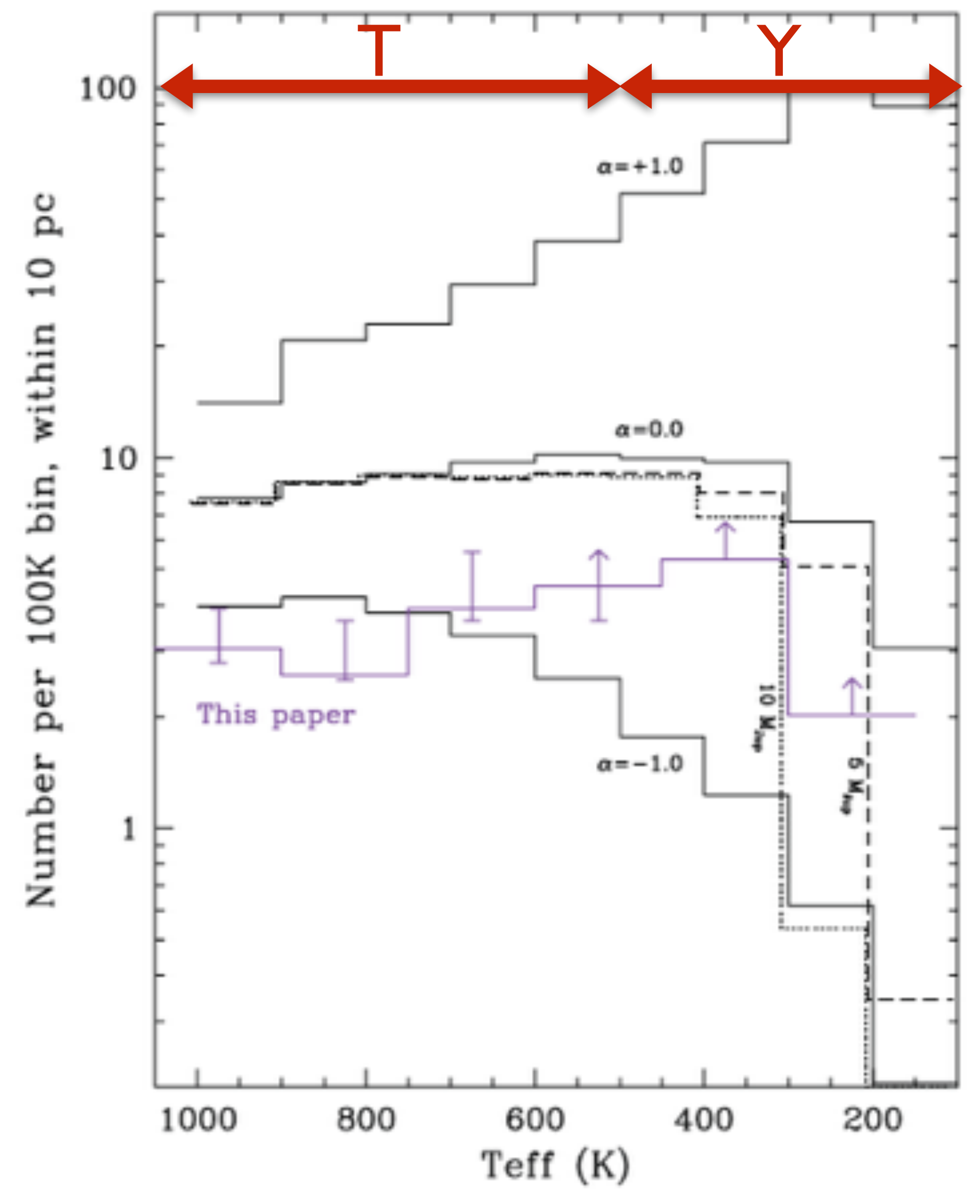


Figure 14. Predicted number of brown dwarfs within 10 pc for three different power-law mass functions ($dN/dM \propto M^{-\alpha}$) with $\alpha = -1$, 0, and +1 (solid black) having a minimum formation mass of 1 $M_{\rm Jup}$. Also shown for the $\alpha = 0$ model is the predicted number of brown dwarfs if a minimum formation mass of 5 $M_{\rm Jup}$ (dashed black) or 10 $M_{\rm Jup}$ (dotted black) is assumed. These simulations are from Burgasser et al. (2004, 2007). Space densities using our full accounting of objects in the immediate solar neighborhood (Tables 8 and 9) are shown by the heavy purple line.

Kirkpatrick et al 2012

On the way to the mass function

Survey	Sample	Limit	α	Ref[a]
UKIDSS	Late T	Mag. limited	$-1<\alpha<-0.5$	1
	mid-L to mid-T	Mag. limited	$-1<\alpha<0$	2
WISE	Late T to early Y	Vol. limited	$-0.5<\alpha<0$	3
CFHTBD	L and T	Mag. limited	$\alpha<0$	4
2MASS/SDSS	T	Mag. limited	~ 0	5
2MASS	L	Vol. limited	~ 1.5	6
2MASS	MLT	Vol./Mag. limited	$\sim 0.3\pm0.6$	7

[a] References. (1) Burningham et al. (2013); (2) Day-Jones et al. (2013); (3) Kirkpatrick et al. (2012); (4) Reylé et al. (2010); (5) Metchev et al. (2008); (6) Cruz et al. (2007); (7) Allen et al. (2005).

results converge to a field substellar mass function with $\alpha<0$

Cluster	Age (Myr)	α	Ref.[a]
Pleiades	125	0.6 ± 0.11	1, 2, 3
IC 4665	30	~0.6	4, 5
Blanco 1	100	0.69 ± 0.15	6
Alpha Per	80	0.59 ± 0.05	7, 8, 9
IC 2391	50	Consistent with Pleiades	10, 11, 12
Praesepe	600	Consistent with Pleiades	13
Hyades	600	Brown dwarfs depleted	14

[a] References. (1) Moraux et al. (2003); (2) Casewell et al. (2007); (3) Luhman (2007); (4) de Wit et al. (2006); (5) Lodieu et al. (2011); (6) Moraux et al. (2007); (7) Barrado y Navascués et al. (2002); (8) Lodieu et al. (2005); (9) Lodieu et al. (2012b); (10) Barrado y Navascués et al. (2004); (11) Boudreault & Bailer-Jones (2009); (12) Spezzi et al. (2009); (13) Boudreault et al. (2010); (14) Bouvier et al. (2008).

results converge to a field substellar mass function with $\alpha\simeq0.6$

Alves de Oliveira 2013

Limitations and how Gaia can (or not) help

BD census: found in large photometric surveys and extensive spectroscopic follow-ups to determine spectral types and remove contaminants.

P**arallaxes** are needed to determine luminosities and the space density
Difficult to obtain for large samples
Empirical **relations between magnitude and spectral type** are used to estimate distances.

Completeness, contamination, and correction for observational bias.

The field brown dwarfs are of different ages (from 0 to 10 Gyr): individual masses cannot be estimated with the **age-dependent mass-luminosity relation** to construct the mass function.

Statistical simulations of the expected LF are needed. They assume various mass functions, birthrate, evolutionary models, and binarity.
Heavily **model-dependent**!

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The substellar mass function of field objects is uncertain. The difference with clusters should be taken with caution, results not mature enough.

On the observational side the T-dwarf (and now Y-dwarf) census is vastly improving thanks to WISE. Significant efforts are still needed to measure precise trigonometric parallaxes for very faint objects and to understand their physics.

Masses are probably not well-predicted by the luminosities given by the current evolutionary models. Strong need to obtain masses for **benchmark BDs in binaries** with known age.

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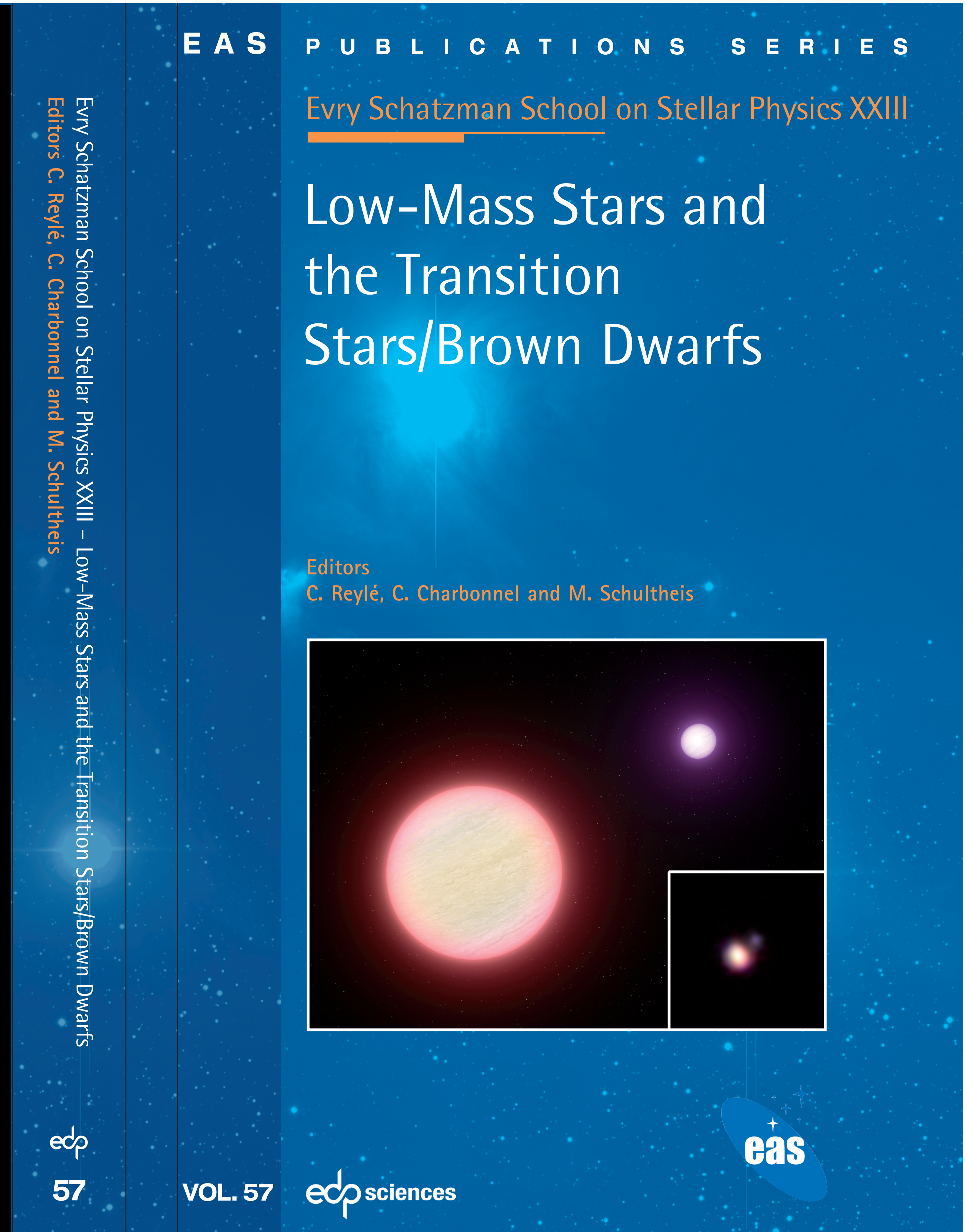
Merci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