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Astrometric detection and characterisation of brown dwarfs

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AIP

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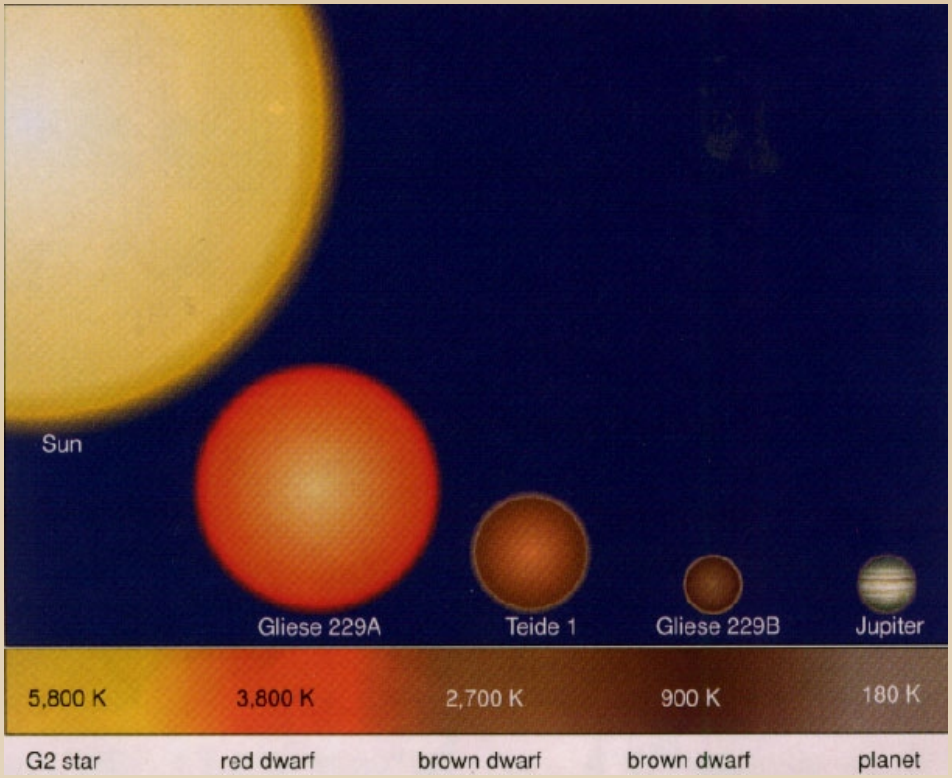
Low-mass Stars … Brown Dwarfs (BDs) … Planets

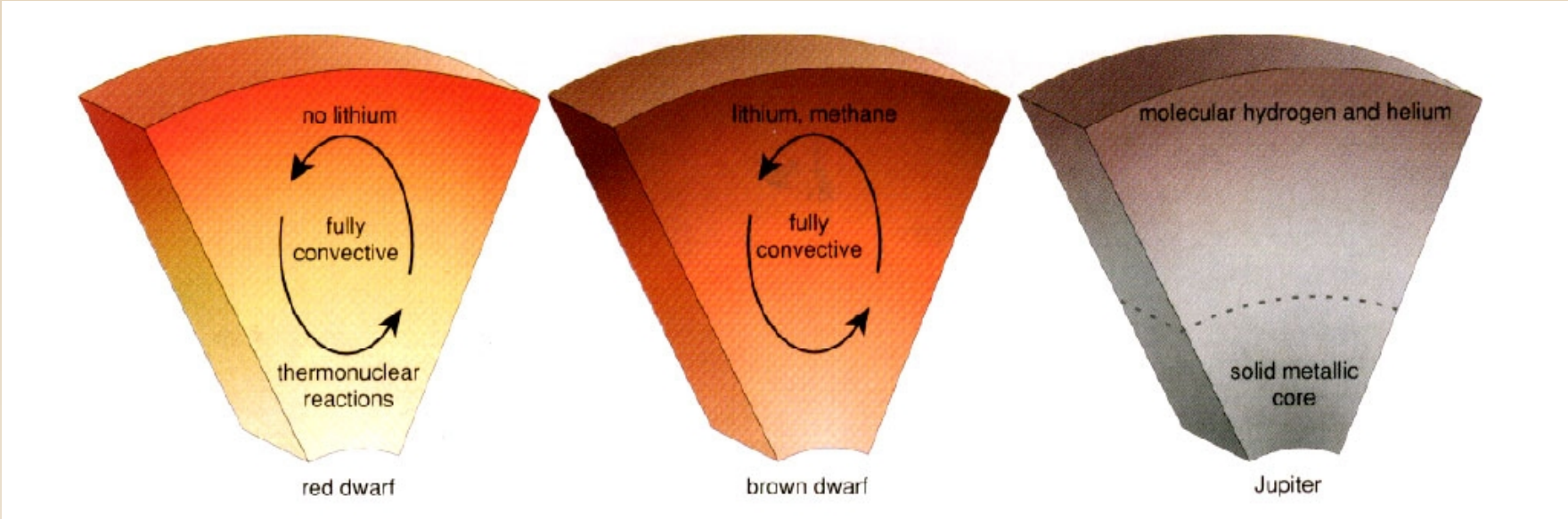
BDs form like stars but do not reach critical mass of stars (~0.08 Msolar) → no long-lasting thermonuclear burning in their cores → become fainter and cooler with time

Theory: similar radii of relatively old (>100 Myr) low-mass stars, BDs, and giant planets (hard to observe)

Observations: spectra (temperature, chemical composition), astrometry (→ luminosity, kinematics, masses in binary systems)

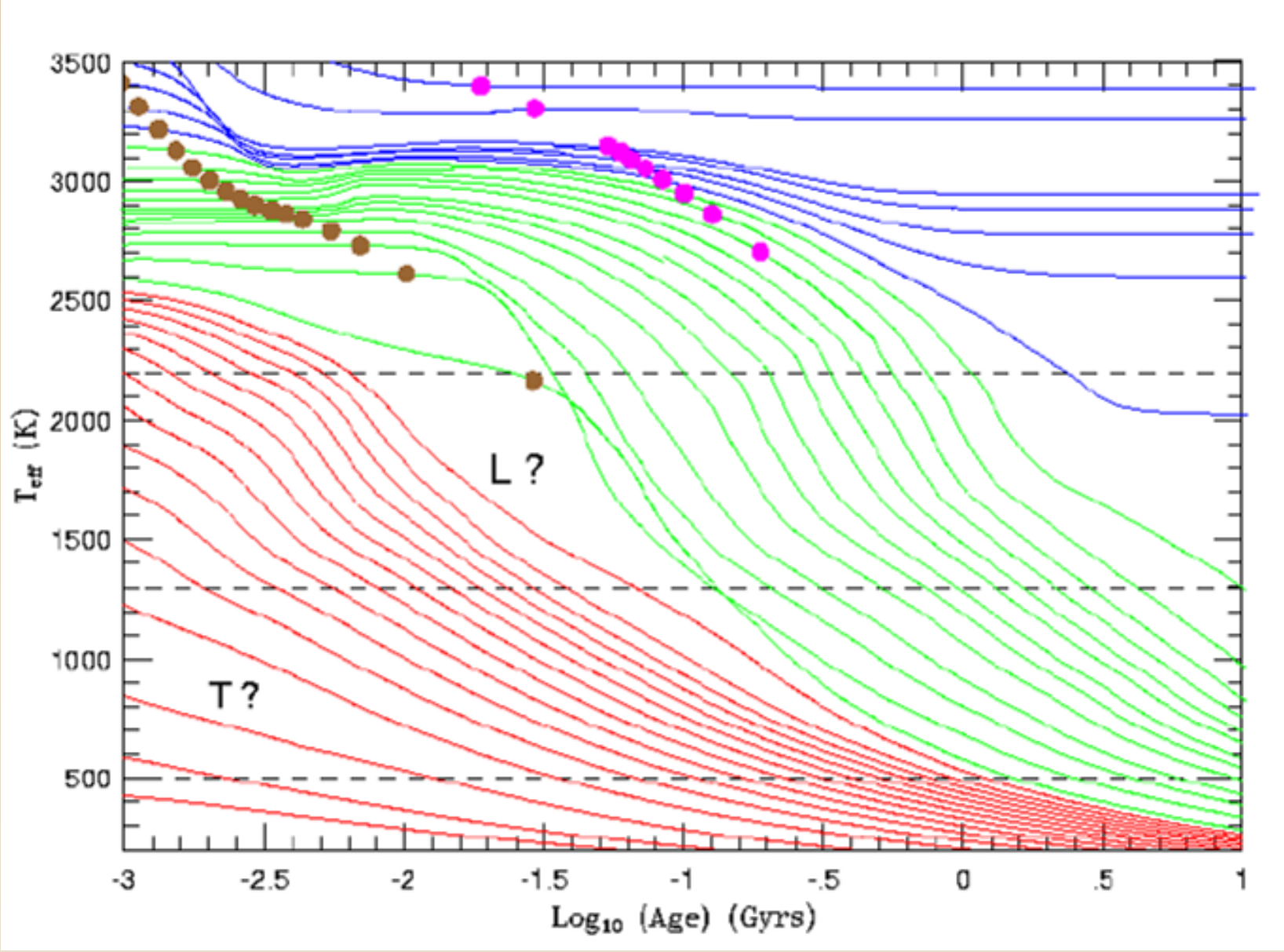


Mass in Solar units: 1 0.6...0.08 0.08...0.013 0.001



(www.astron.berkeley.edu/~stars/bdwarfs/)

Theory: evolution of low-mass stars, BDs, planets



[M_{solar}]

0.2

Low-mass Stars
M dwarfs
+ early L dwarfs

0.08

0.075

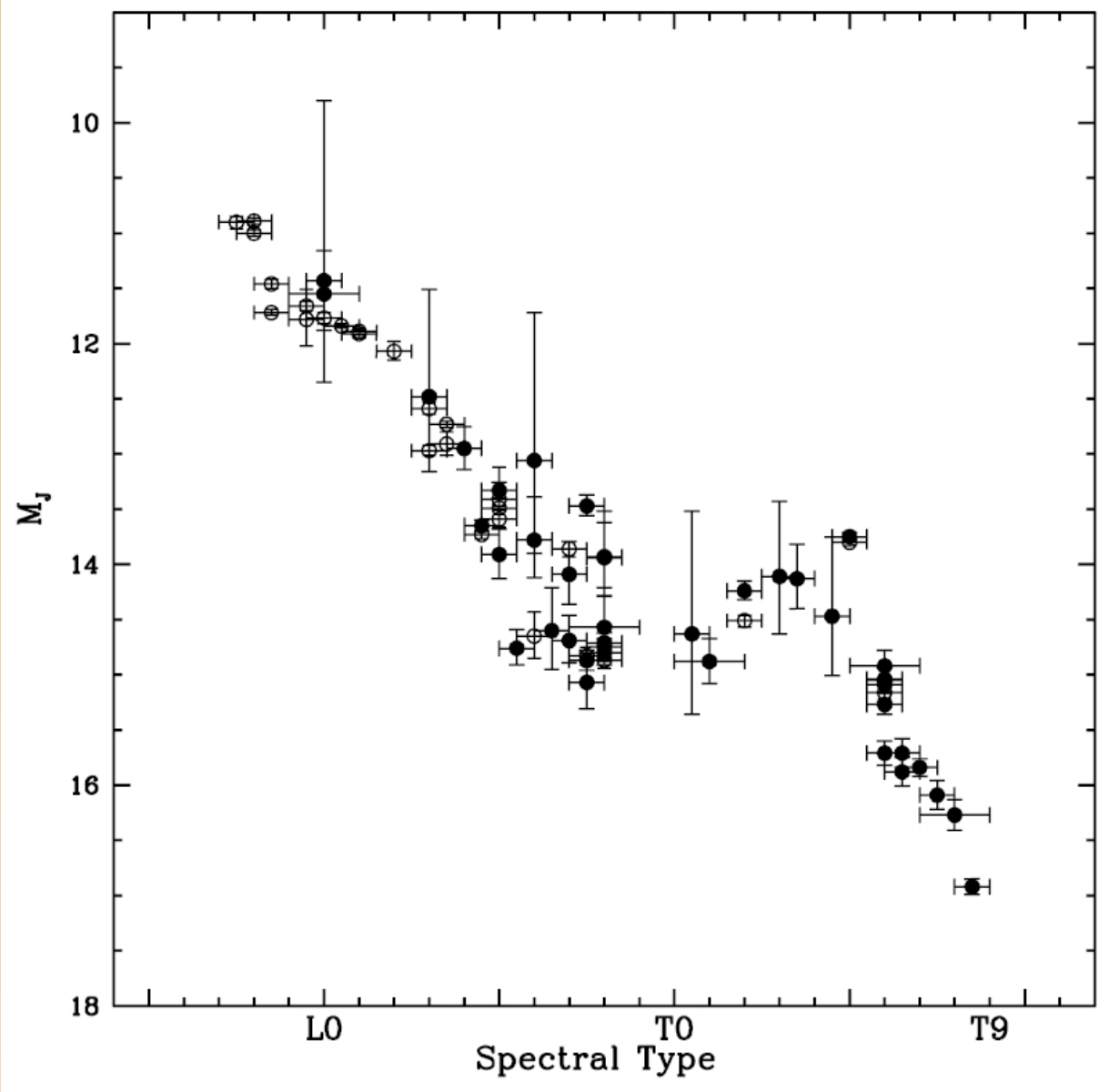
BDs
M, L, T dwarfs

0.013

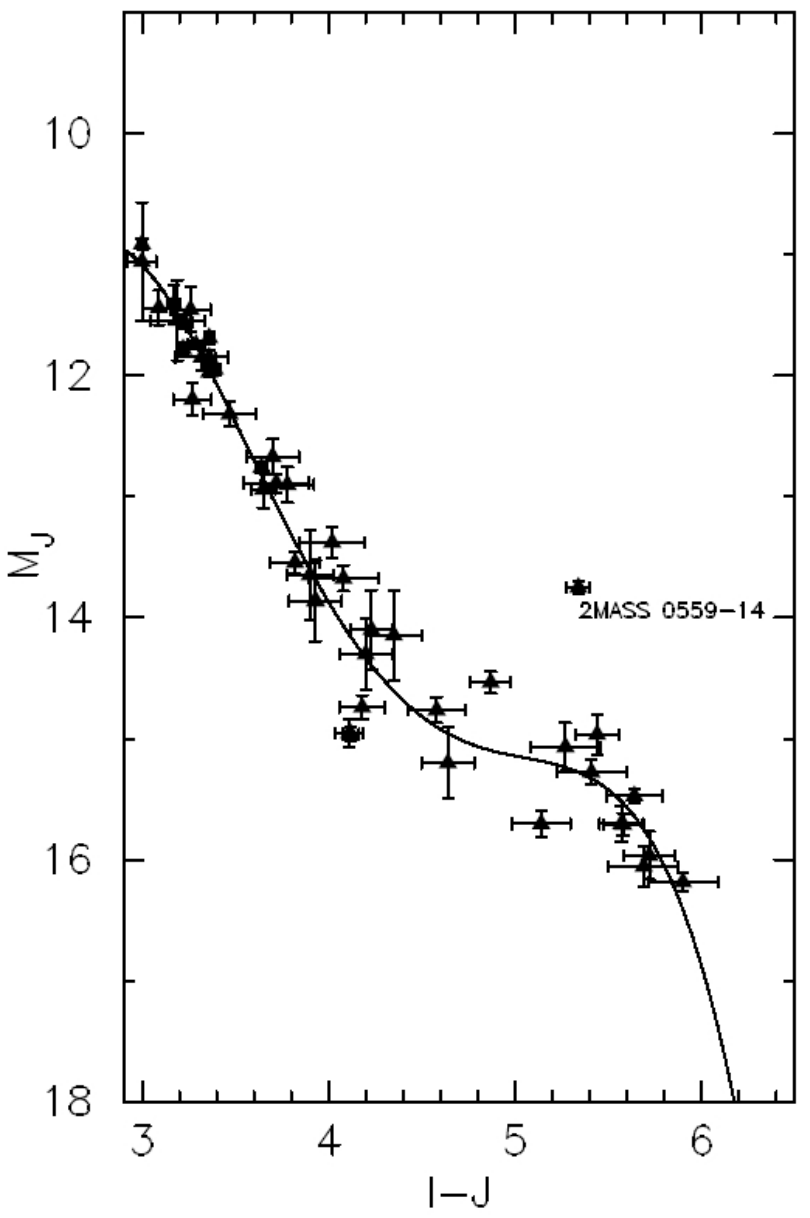
Planets
M, L, T, … Y?

(Burrows et al. 2001)

Observed absolute magnitudes/colours of BDs

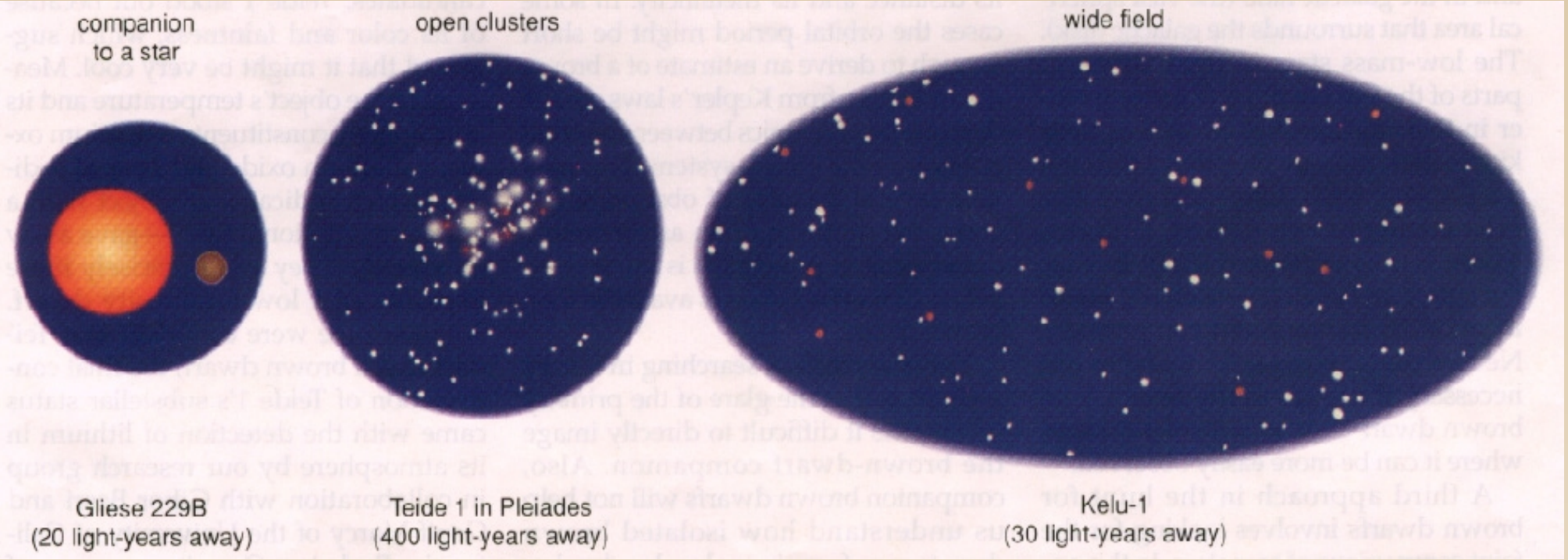


Vrba et al. (2004): prelim. parallaxes of L and T dwarfs



Phan-Bao et al. (2007, arXiv:0708.4169v1)

The search for brown dwarfs



(www.astron.berkeley.edu/~stars/bdwarfs/)

Astrometric Detection:

Wobble / CPM	Common	High Proper Motion (HPM)
~1 mas/yr /	Proper Motion (CPM)	0.1 – 10 arcsec/yr
~100 mas/yr	~10 mas/yr	

Single Epoch Positional Accuracy

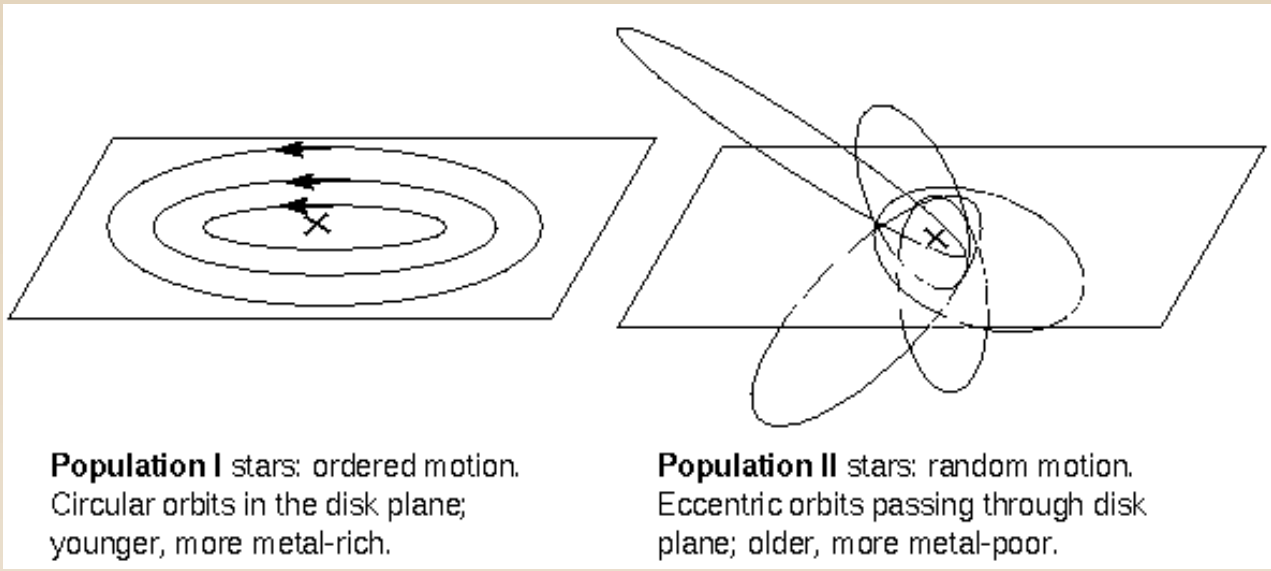
~0.1 – 10 mas ~100 mas

First discoveries of brown dwarfs

Name (spectral type)	Discovery	Astrometry
GD 165B (L4)	WD companion (Becklin & Zuckerman 1988)	CPM measured later by Zuckerman & Becklin (1992)
Gl 229B (T7)	Companion of M2 dwarf (Nakajima et al. 1995)	crude measurement of CPM included in discovery paper
Teide 1 (M8)	Pleiades member (Rebolo et al. 1995)	Astrometric membership established (CPM with cluster)
Kelu 1 (L2)	Free-floating (Ruiz et al. 1997)	detected in HPM survey
Denis 0205 (L7), **1058** (L3), **1228** (L5)	Free-floating (Delfosse et al.1997)	HPM initially not measured
LP 944-20 (M9.5)	Free-floating (Tinney 1998)	previously known HPM object (NLTT catalogue, Luyten 1979)
GJ 802b (?)	Companion of M5.5 dwarf (Pravdo, Shaklan & Lloyd 2005)	Astrometric wobble detected

High proper motion as rough distance measure

- Proper motion μ = apparent motion (large values: ~0.1 to ~10 arcsec/yr)
- Real velocity [in km/s] scales with distance d [in pc] $v_{tan} = 4.76 \cdot \mu \cdot d$
- Typical relative velocity of local Galactic disk stars ~ 40 km/s
- Disk star with μ = 1 arcsec/yr has typically d ~ 10 pc
- Halo stars do not take part in Galactic rotation (~220 km/s at the location of the Sun) → same μ indicates 5 times larger distance



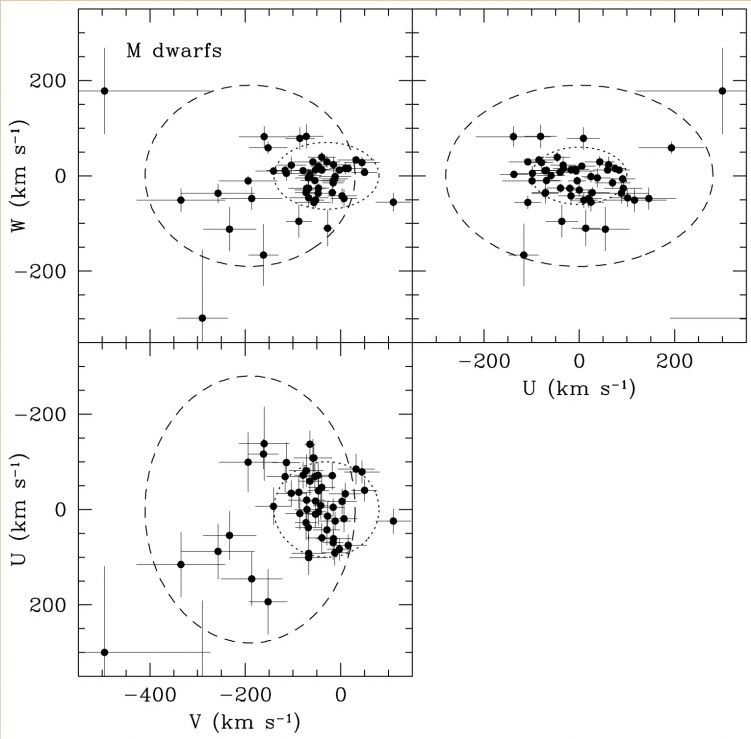
Population I stars: ordered motion. Circular orbits in the disk plane; younger, more metal-rich.

Population II stars: random motion. Eccentric orbits passing through disk plane; older, more metal-poor.

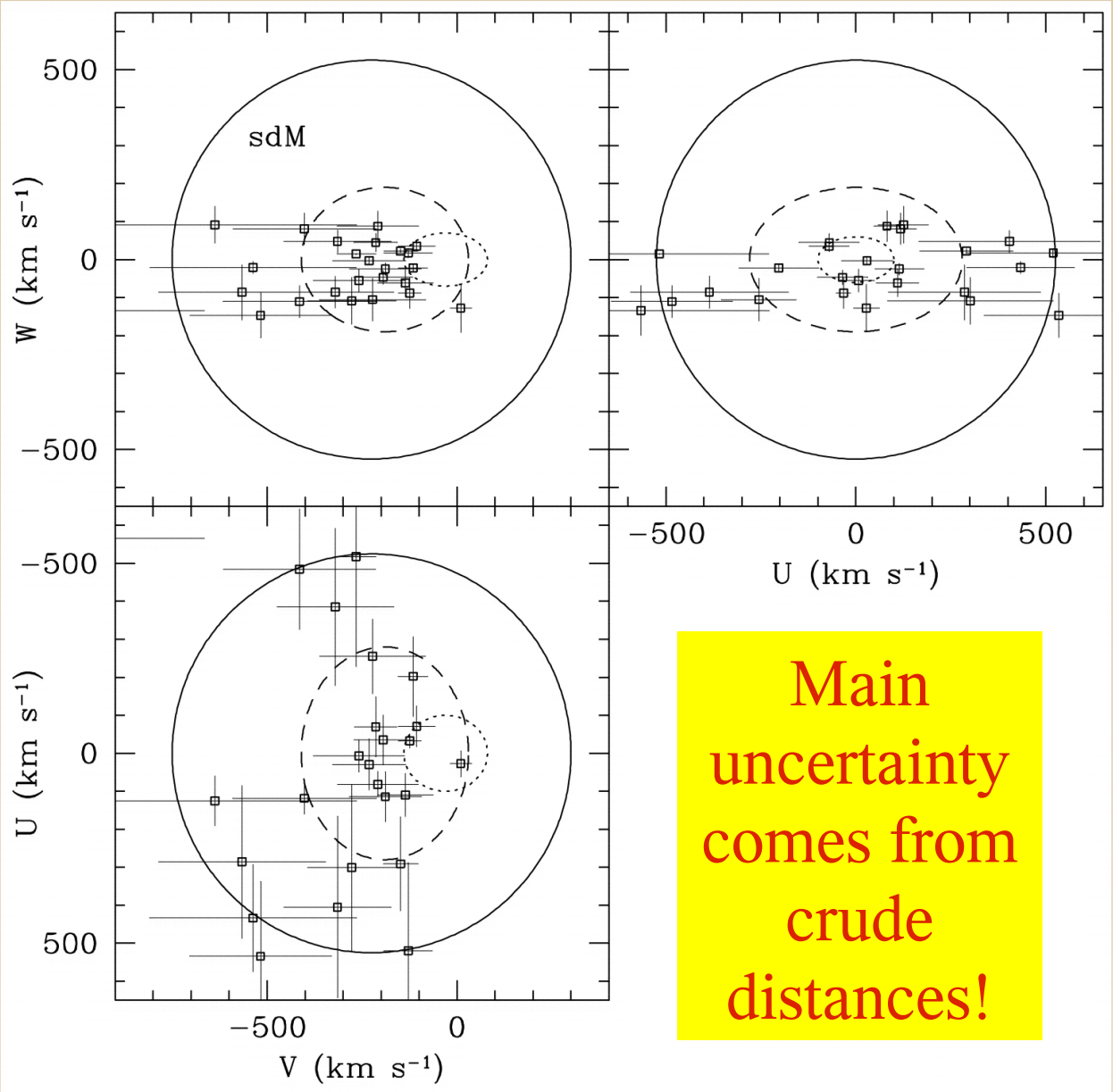
Proper motion samples are halo biased

Galactic space velocities UVW for proper motion stars from Lepine, Shara & Rich (2003):

Normal red dwarfs



red subdwarfs



Dotted and dashed ellipses - 2σ velocity dispersions of local disk and halo stars, respectively (Chiba & Beers 2000)

Solid circles - limit for stars gravitationally bound to the Galaxy (model of Dauphole & Colins 1999)

Main uncertainty comes from crude distances!

Recent discoveries with μ > 2 arcsec/yr

Name	proper motion [arcsec/yr]	Discovery paper	Distance (plx. ref.) [pc]	object type
SO 0253+1652	5.11	Teegarden+03	3.84 (1)	disk M6.5
ε Indi Ba,Bb	4.70	Scholz+03, McCaughrean+04	3.625 (2)	disk T1+T6
SSSPM 1444−2019	3.51	Scholz+04b	∼20	halo sdM9
2MASS 1114−2618	3.05	Tinney+05	∼7	disk T7.5
SCR 1845−6357 AB	2.66	Pokorny+03, Hambly+04, Biller+06	3.854 (1)	disk M8.5+T6
2MASS 0532+8246	2.60	Burgasser+03	26.7 (5)	halo sdL7
PM 13420−3415	2.55	Lépine, Rich & Shara 05	∼18	halo WD
LEHPM 3396	2.45	Pokorny+03, Phan Bao+06	∼8	disk M9.0
LSR 1826+3014	2.38	Lépine+02	∼14	halo M8.5
F351-50	2.33	Ibata+00	35 (4)	halo cool WD
2MASS 0415−0935	2.26	Burgasser+02	5.74 (3)	disk T8.5
2MASS 0251−0352	2.17	Cruz+03, Schmidt+07	∼12	disk(?) L3.0
SCR 1138−7721	2.15	Hambly+04, Scholz+04a	8.18 (1)	disk M5.5

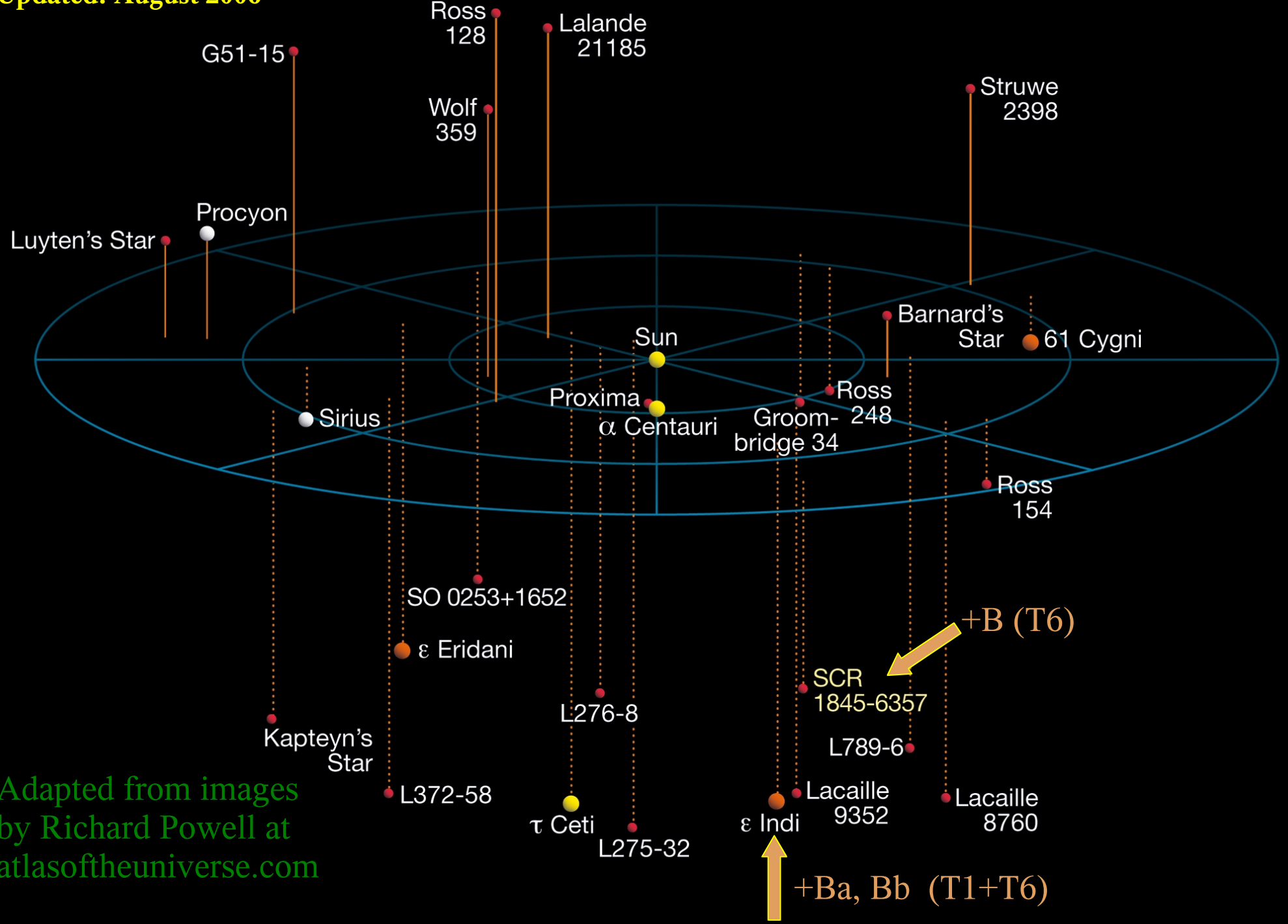
Trig. parallaxes: 1 - Henry+06, 2 - ESA97, 3 - Vrba+04, 4 - Ducourant+07, 5 - Burgasser+07

13 new discoveries since 2000 - compared to 73 known LHS stars!
Most new objects are at or below the substellar mass limit

The Solar neighbourhood

10 Lightyears

Updated: August 2006



Adapted from images by Richard Powell at atlasoftheuniverse.com

New high proper motion survey using SSS

Compared to previous efforts needed to conduct a high proper motion survey (e.g. Luyten Half Second = LHS) …

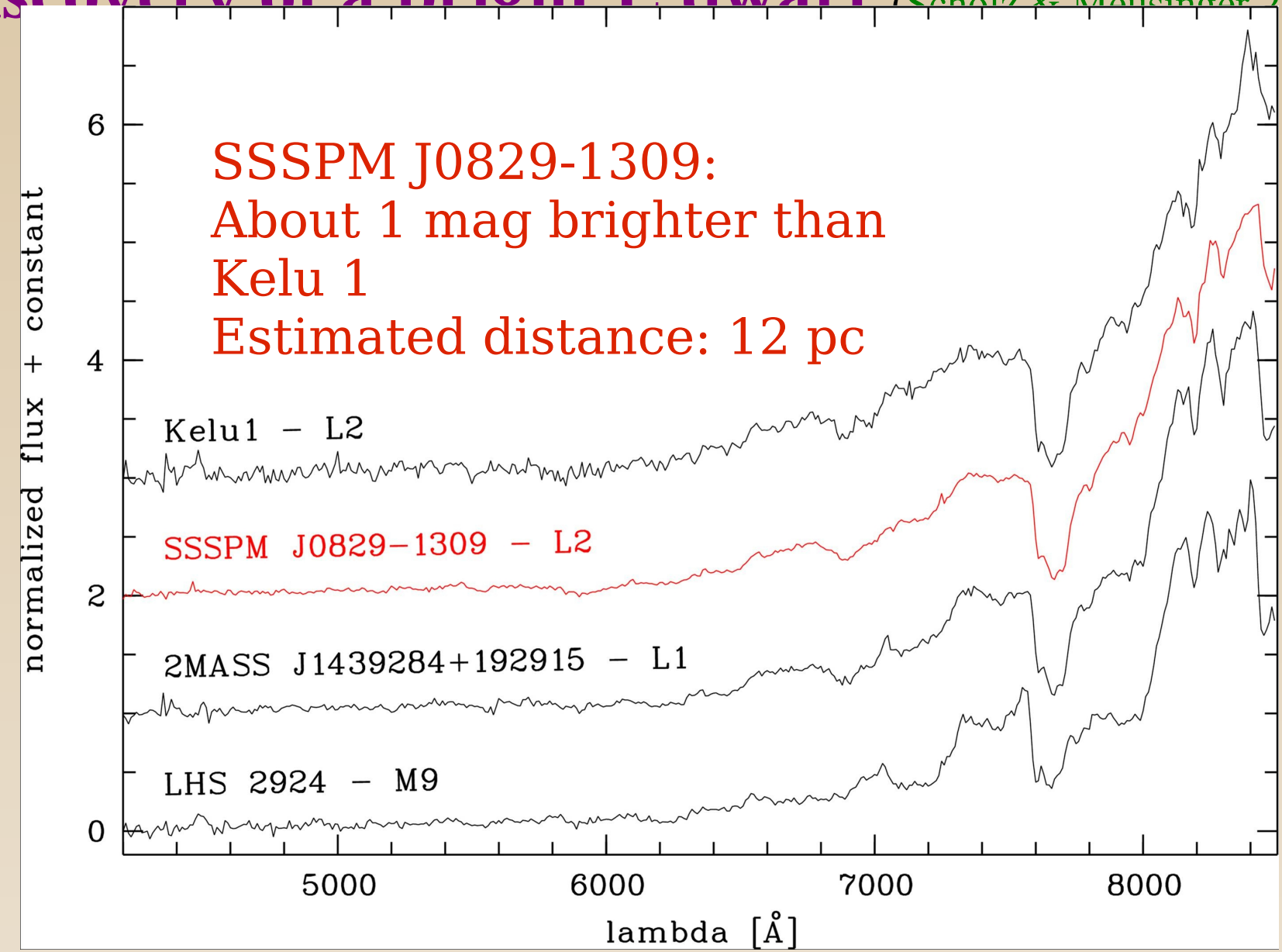
Willem Jacob Luyten (1899-1994)

… it is now much easier thanks to digitised observations & convenient access to public data bases, e.g. the SuperCOSMOS Sky Surveys (SSS)

goal

- Fill the gaps in Southern sky
- Extend the magnitude limit
- Find cooler nearby objects (bd)
- Find cool halo objects (wd, sd)

Discovery of a bright L dwarf (Scholz & Meusinger 2002)



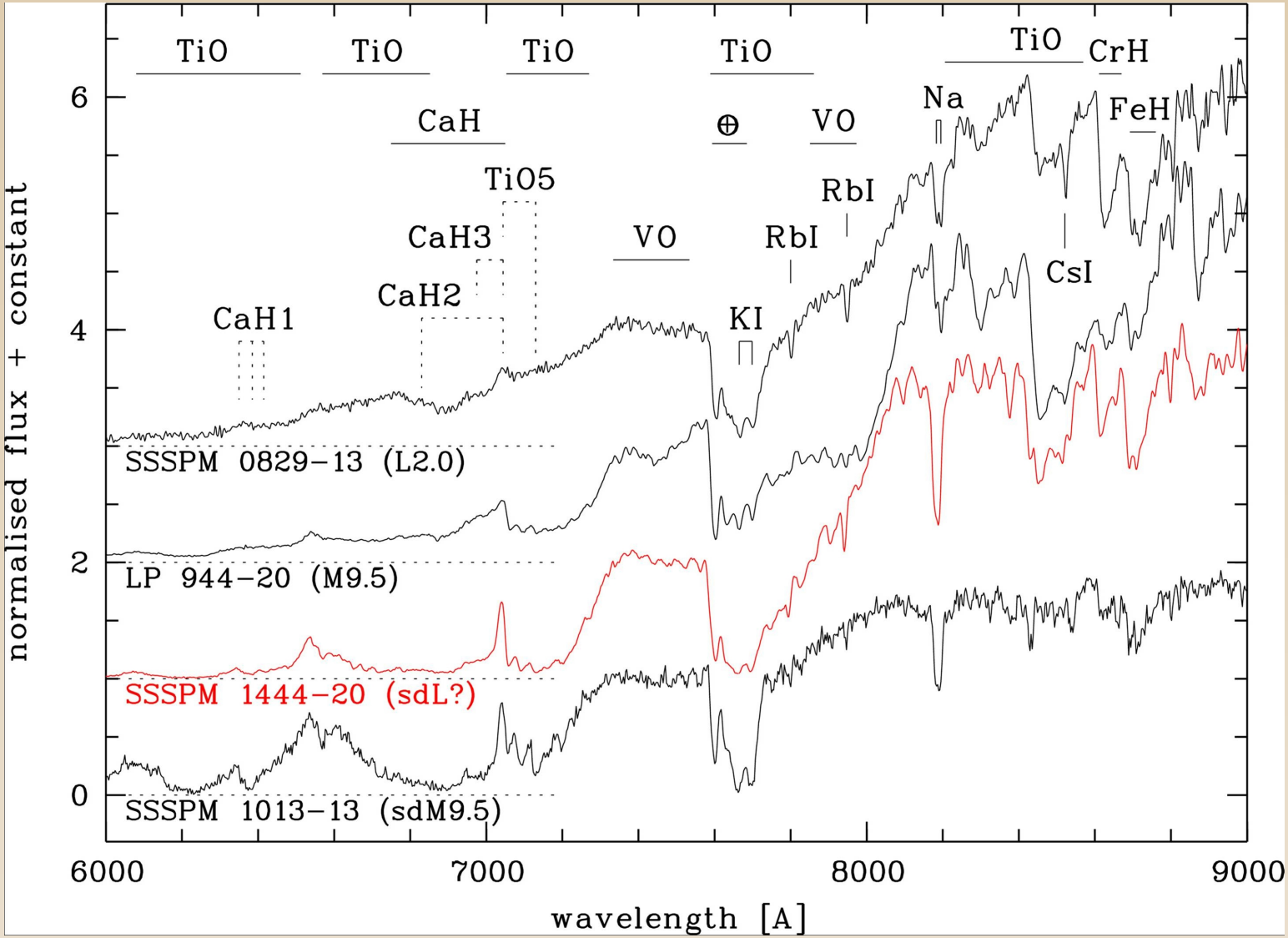
Detected in SSS high pm survey; spectroscopic classification with 2.2m@Calar Alto;
More high pm L dwarfs classified with ESO 3.6m and NTT (Lodieu et al. 2002, 2005)

A visitor from the Galactic halo:

SSSPM J1444−2019

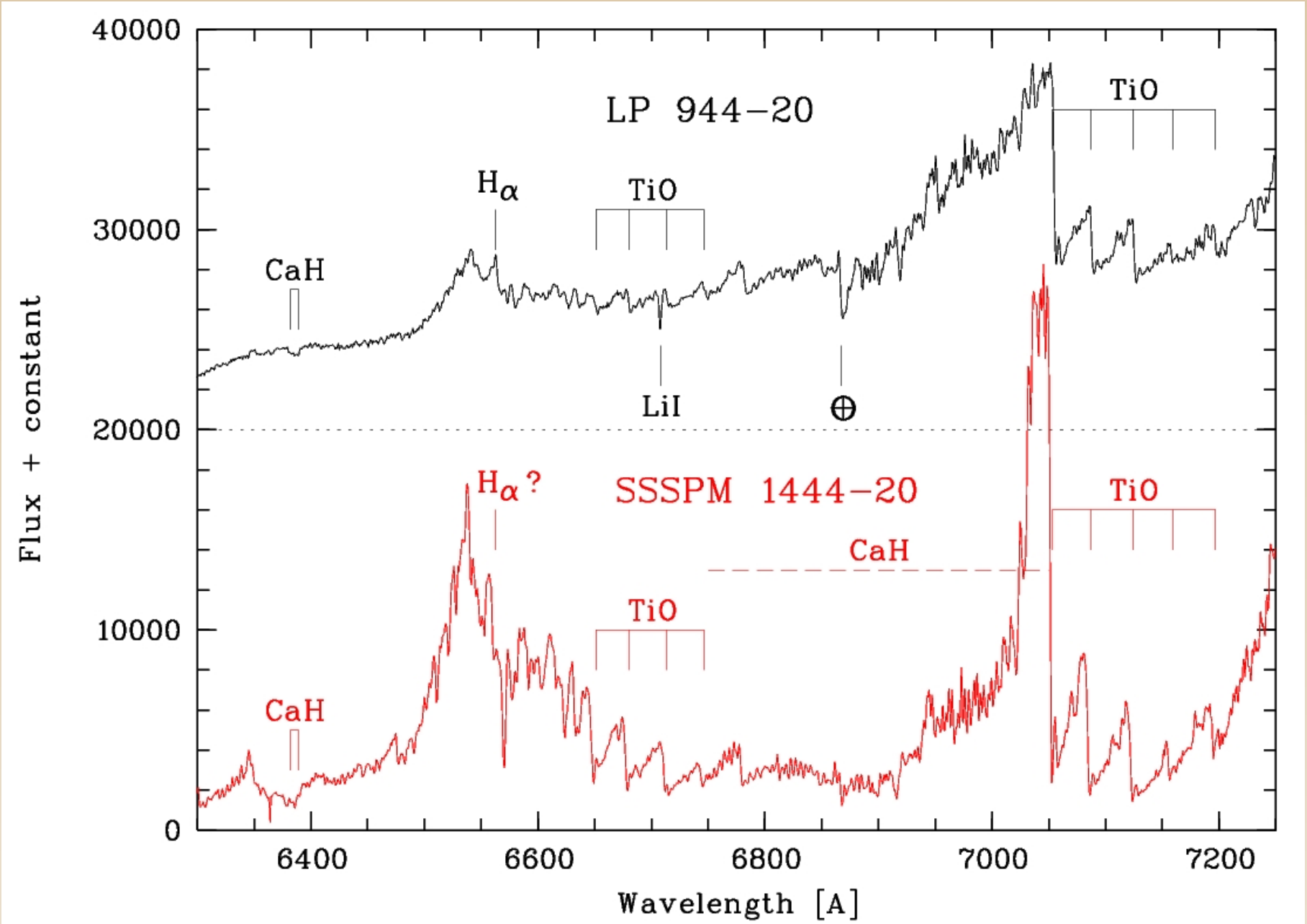
Extremely large proper motion: 3.5 arcsec/yr

sdM9, but L-type spectral features (RbI, FeH, CrH, no VO!)



Scholz, Lodieu & McCaughrean (2004)

Is SSSPM 1444 a substellar subdwarf ?



High-res. spectrum shows no Lithium Scholz, Lodieu & McCaughrean (2004)

Near-infrared trigonometric parallax program

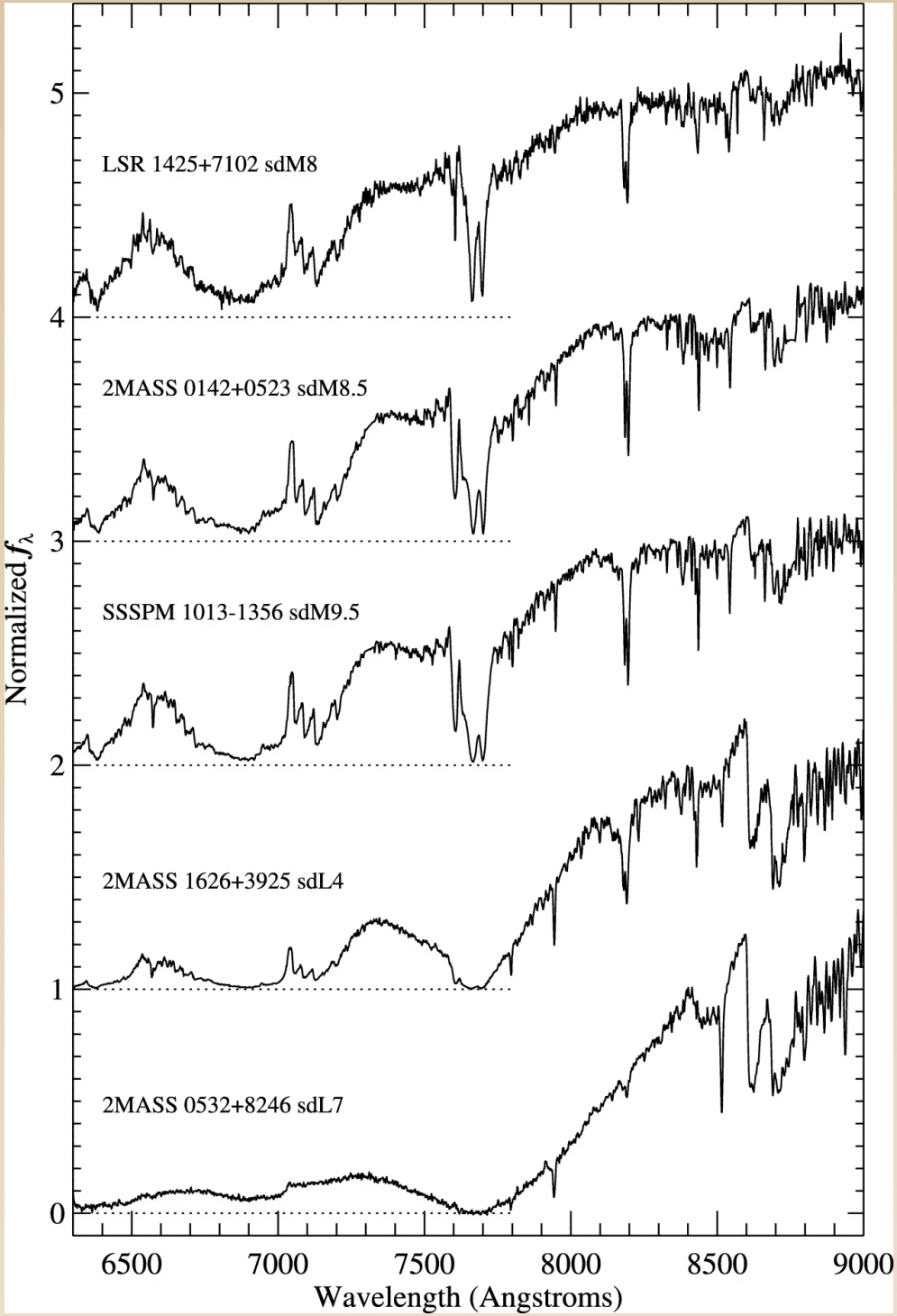
@ Calar Alto 3.5m Omega 2000 targetting 10 ultracool subdwarfs (Röser, Schilbach & Scholz)

Table 2. Preliminary parallaxes of ultracool subdwarfs

Name	Spectral Type	Ref.	$\mu_\alpha \cos\delta$ [mas/yr]	μ_δ [mas/yr]	π [mas]	Ref.
SSSPM 1444−2019	sdM9 (sdL:)	(1)	-2901.5 ± 2.5	-1977.9 ± 2.2	55.1 ± 2.8	(4*)
2MASS 0532+8246	sdL7	(2)	$+2047.7 \pm 1.8$	-1658.6 ± 1.5	40.8 ± 1.7	(4*)
			$+2041.9 \pm 1.8$	-1648.2 ± 1.8	37.5 ± 1.7	(6)
2MASS 0937+2931	sdT6	(3)	$+952.2 \pm 1.6$	-1308.3 ± 1.7	161.6 ± 1.8	(4*)
			$+973.0 \pm 7.1$	-1297.8 ± 7.1	161.5 ± 3.9	(5)

References: 1 - Scholz *et al.* (2004b), 2 - Burgasser *et al.* (2003), 3 - Burgasser *et al.* (2002), 4* - Röser *et al.* (prelim. relative parallaxes), 5 - Vrba *et al.* (2004), 6 - Burgasser *et al.* (2007b)

Spectral sequence + list of all ultracool subdwarfs

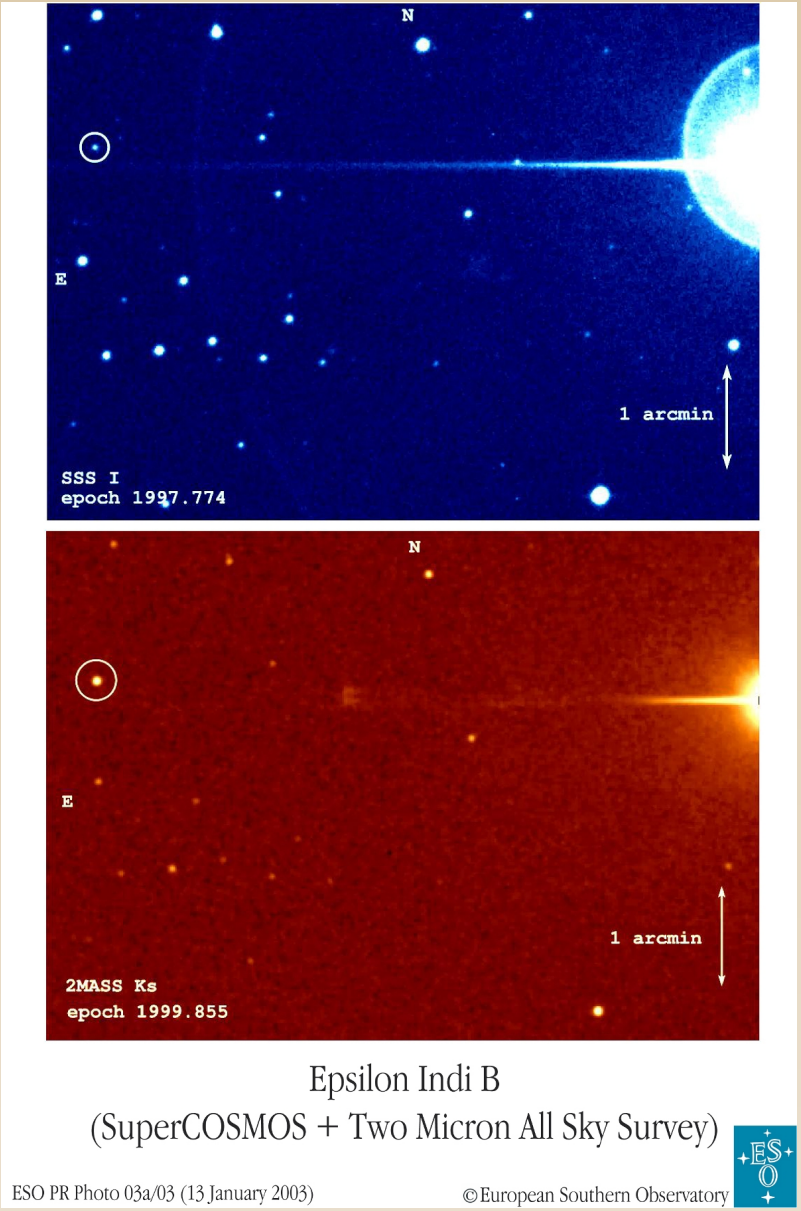


Source	Spectral Type
LSR 1610−0040	d/sdM7:
SSSPM 1444−2019	d/sdM9
2MASS 1640+1231	d/sdM9
2MASS 0937+2931	d/sdT6
LHS 377	sdM7
SSSPM 1930−4311	sdM7
LSR 2036+5059	sdM7.5
LSR 1425+7102	sdM8
2MASS 0142+0523	sdM8.5
SSSPM 1013−1356	sdM9.5
SDSS 1256−0224	sdL4:
2MASS 1626+3925	sdL4
2MASS 0532+8246	sdL7
APMPM 0559−2907	esdM7
2MASS 1227−0447	esdM7.5
LEHPM 2−59	esdM8

Burgasser, Cruz & Kirkpatrick (2007) and references therein

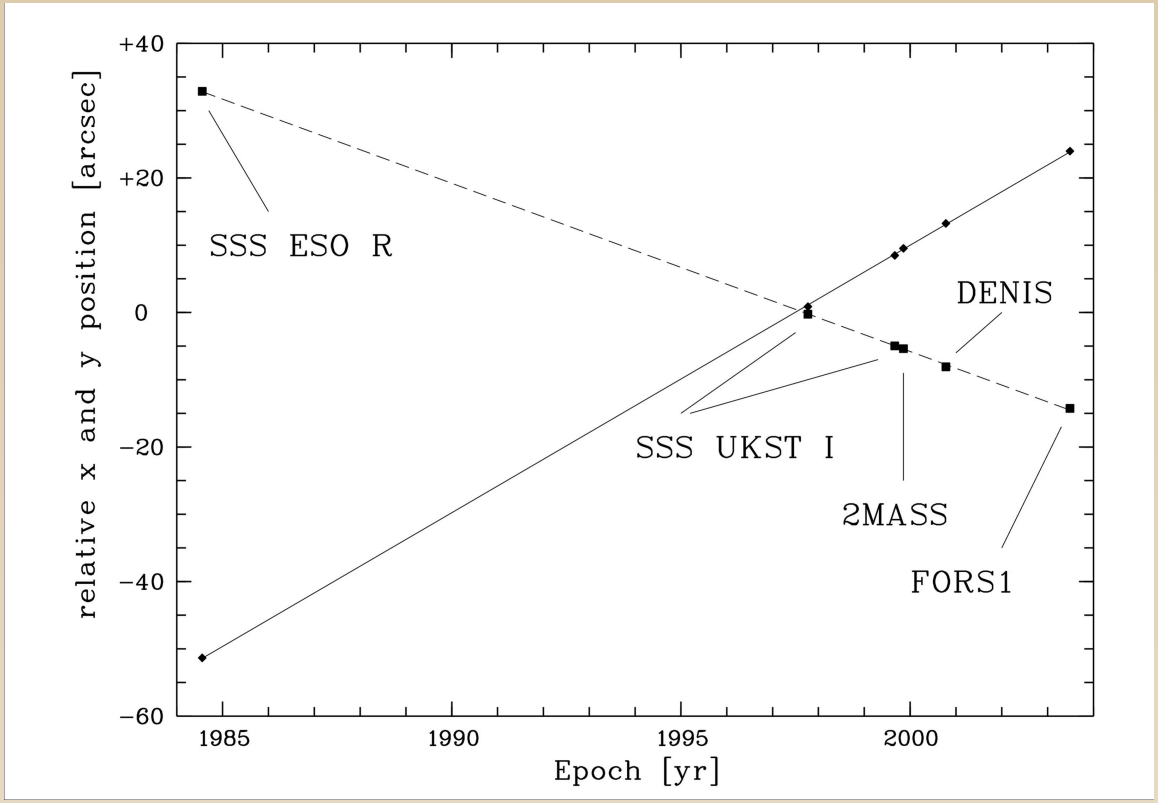
Discovery of the nearest brown dwarf: ε Indi B

resulting from SSS high proper motion survey



Scholz et al. (2003)

initially discovered on two overlapping I plates in SSS (+2MASS), improved proper motion solution with all available data

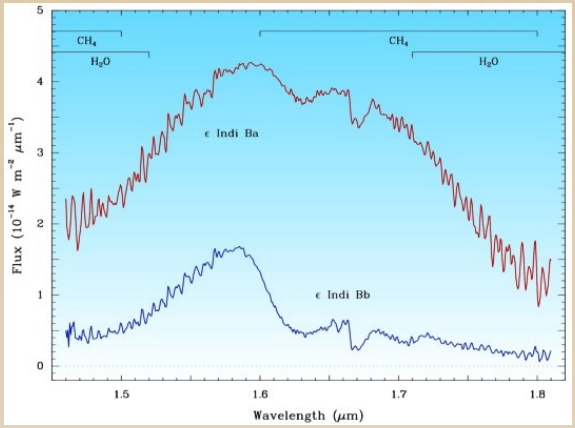


	pm_x	pm_y	[mas/yr]	
ε Indi B	+4131 ± 71	-2489 ± 25		(Scholz et al. 2003)
ε Indi B	+3976 ± 13	-2500 ± 14		(McCaughrean et al. 2004)
ε Indi A	+3961.4 ± 0.6	-2538.3 ± 0.4		(ESA 1997)

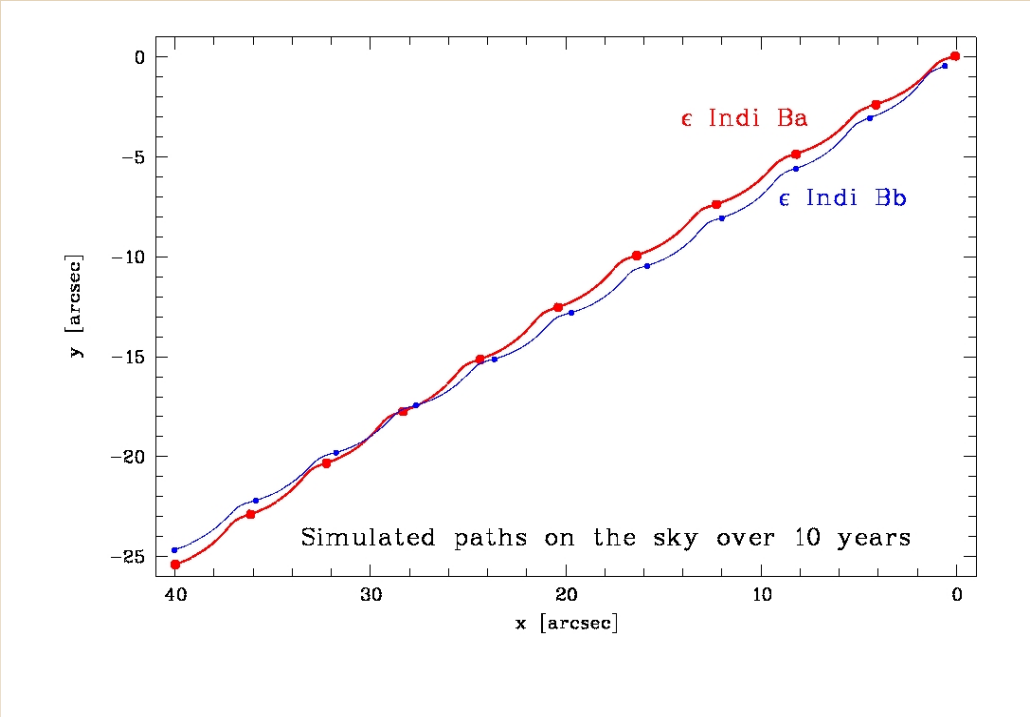
Residual difference ~40 mas/yr is consistent with orbital motion

... resolved as a T1+T6 binary

using adaptive optics at VLT+NACO

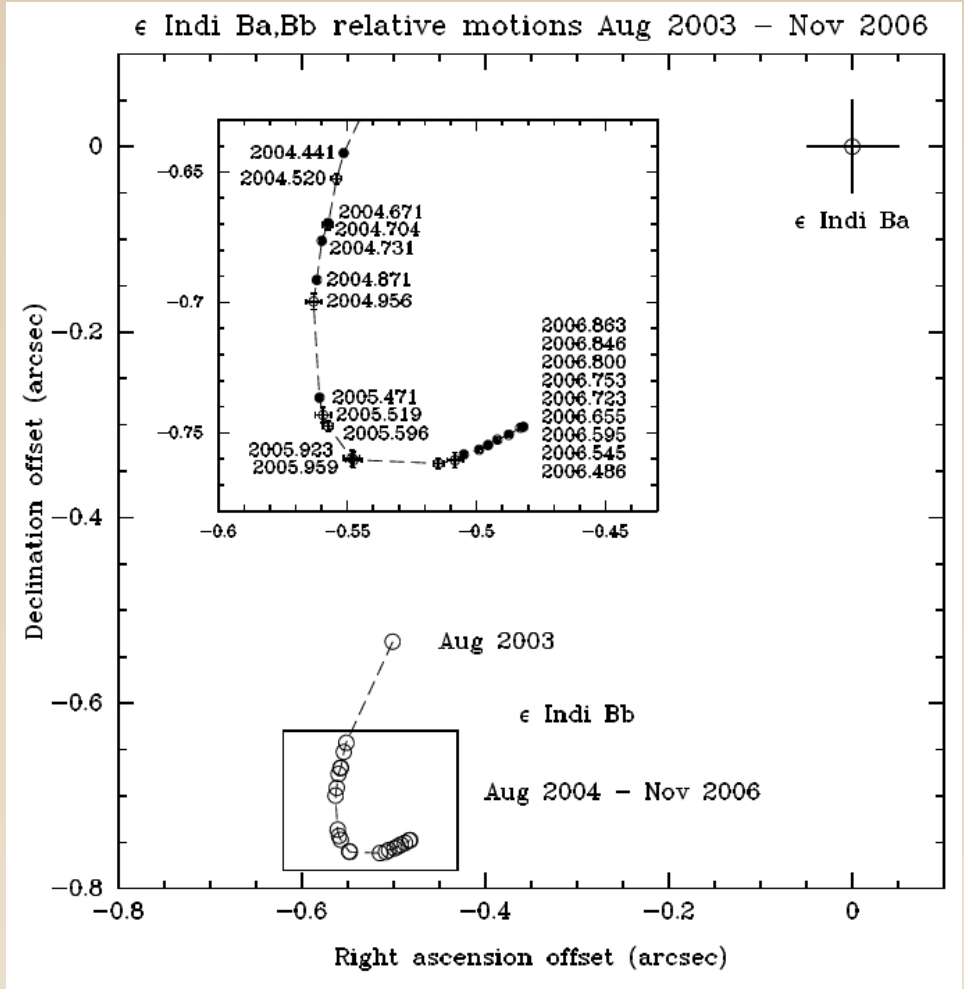


McCaughrean et al. (2004)

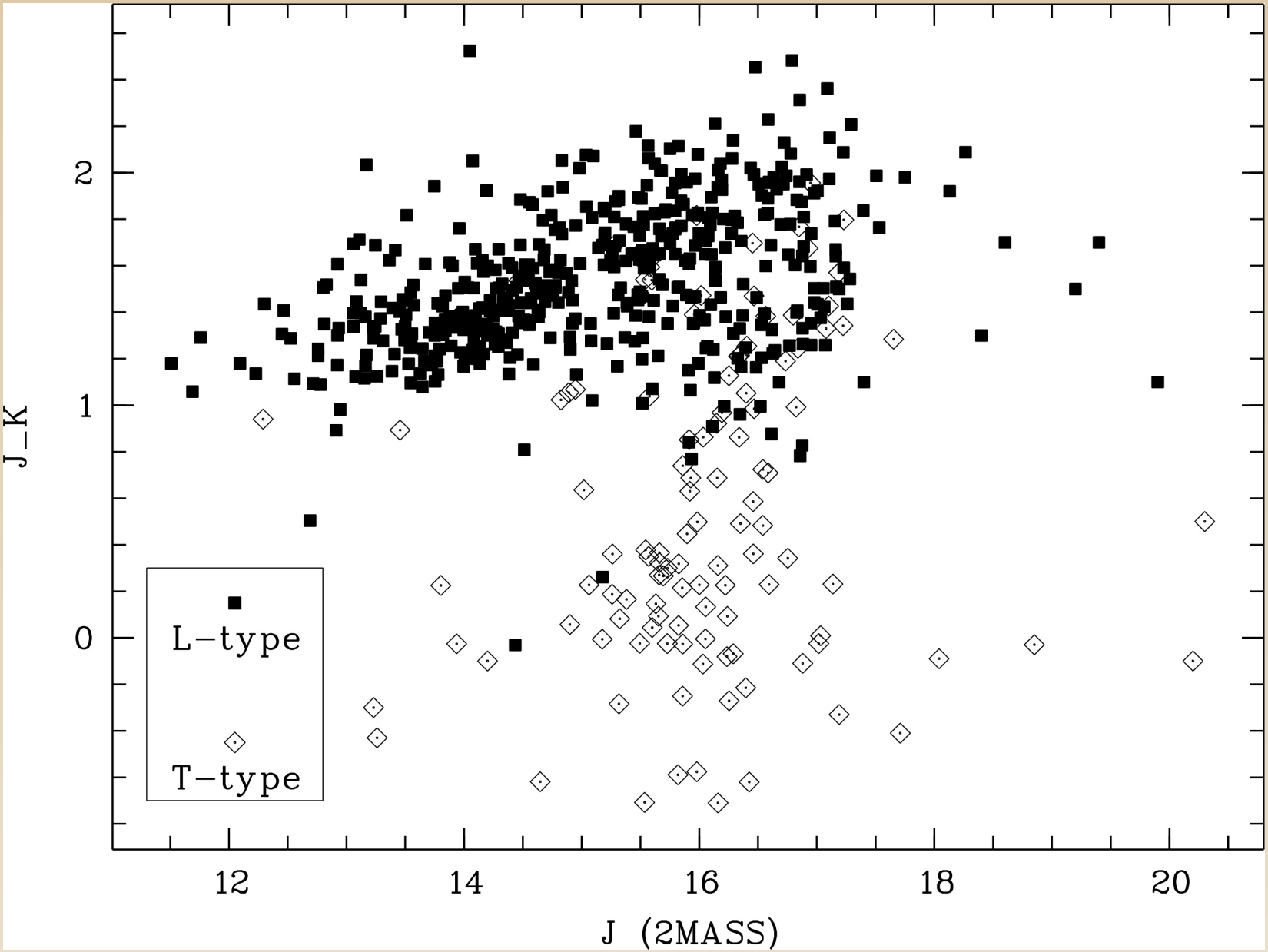


pm + parallax + orbital motion (simulation)

Ongoing orbital monitoring program with VLT NACO+FORS (P.I.: McCaughrean) aiming to determine individual dynamical masses:

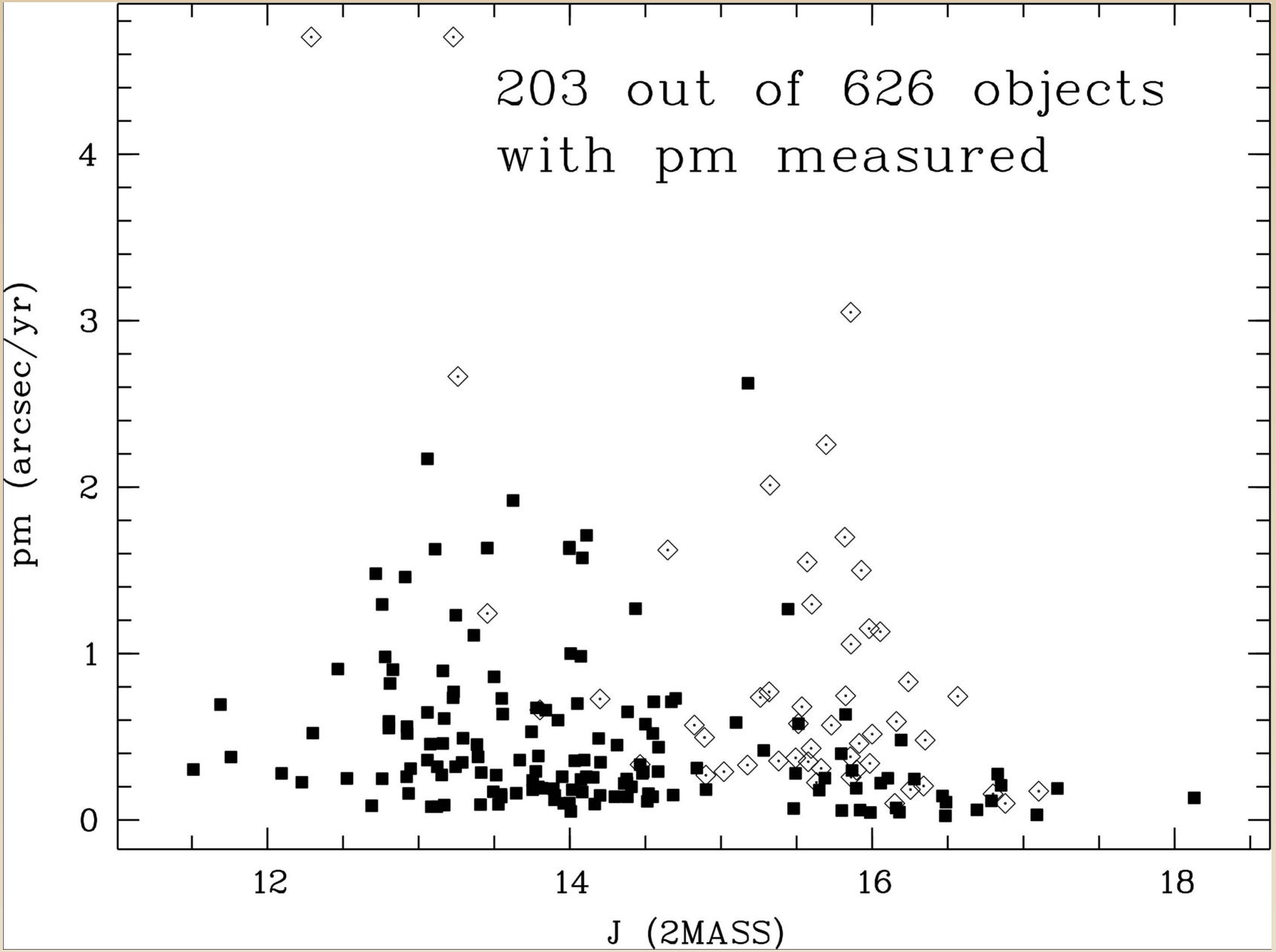


L & T dwarfs: near-infrared colours, magnitudes



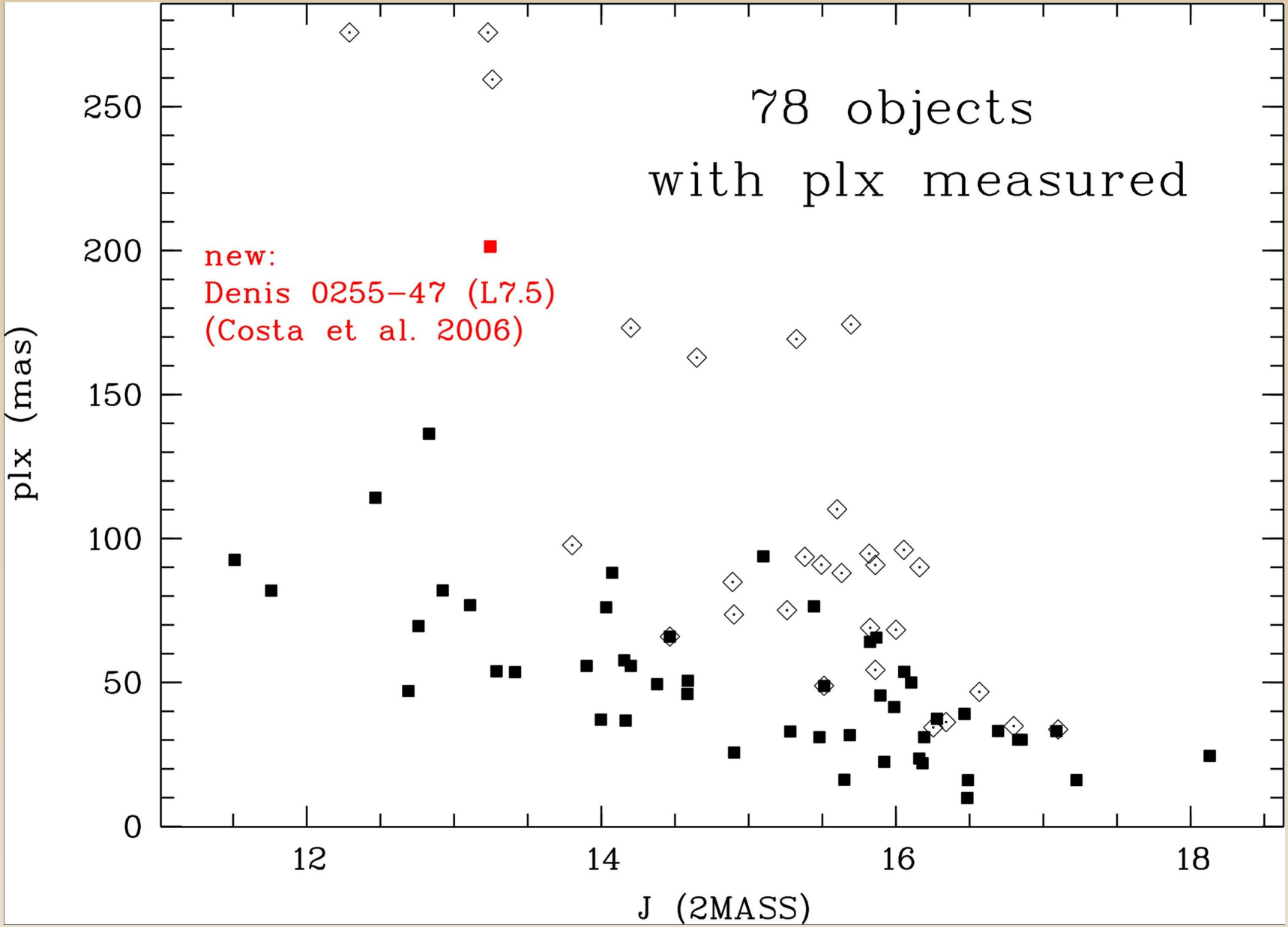
Kirkpatrick, Gelino & Burgasser – DwarfArchives.org – as of 1 October 2007

L & T dwarfs: proper motion measurements



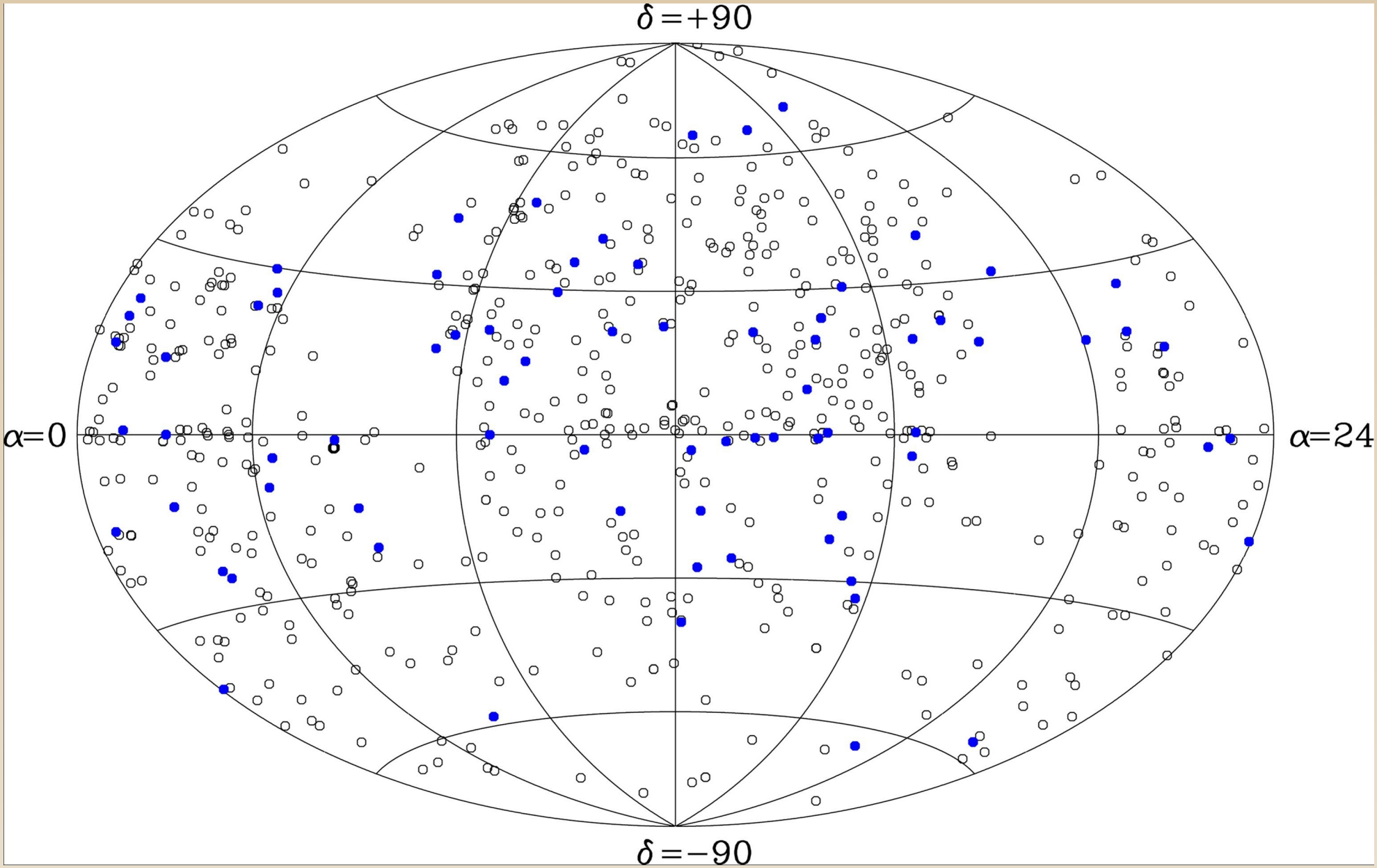
Kirkpatrick, Gelino & Burgasser – DwarfArchives.org – as of 1 October 2007

L & T dwarfs: parallax measurements



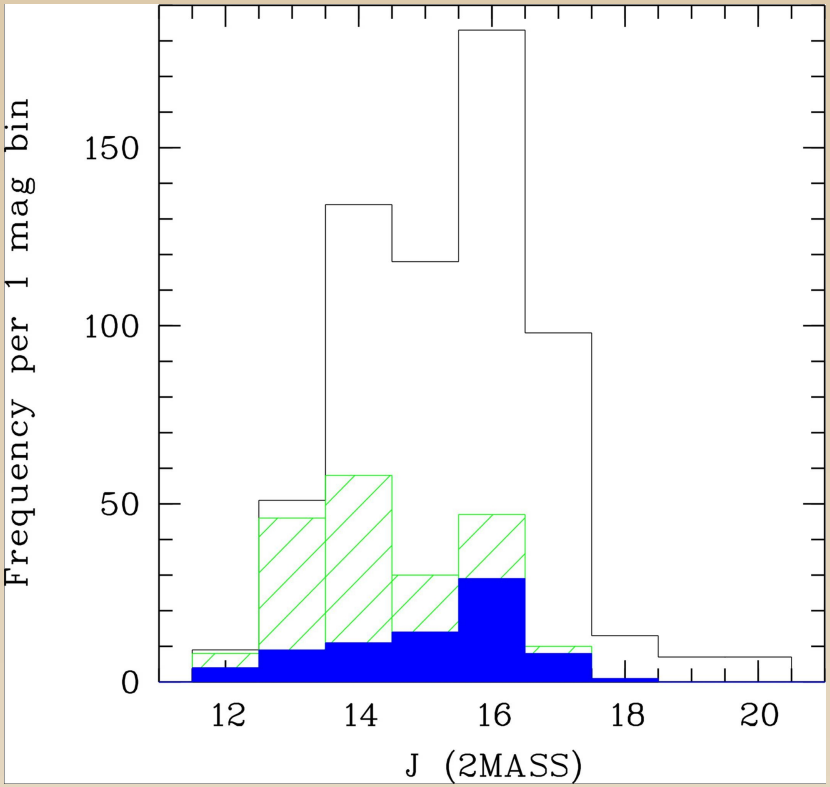
Kirkpatrick, Gelino & Burgasser – DwarfArchives.org – as of 1 October 2007

626 known L & T dwarfs on the sky



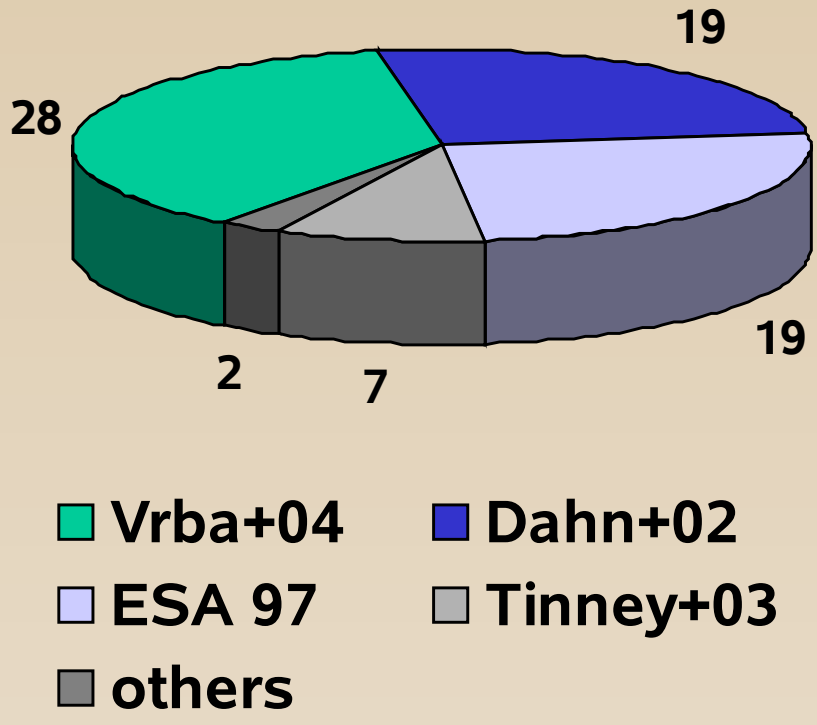
Kirkpatrick, Gelino & Burgasser – DwarfArchives.org – as of 1 October 2007

L & T dwarfs: more astrometry needed !



Completeness of astrometric parameter determination as a function of magnitude:
Hashed – available proper motions
Shaded – available parallaxes

Number of determined parallaxes



Kirkpatrick, Gelino & Burgasser – DwarfArchives.org – as of 1 October 2007

Concluding remarks

- Archival (photographic) data are not yet fully exploited in high proper motion surveys detecting brown dwarfs
- Large area multi-epoch near-infrared surveys will uncover most of the hidden brown dwarfs
- Considerable efforts are needed for astrometric characterisation of brown dwarfs and ultracool subdwarfs (see also Poster 2.2.4 by Faherty et al.)
- Ground-based high-accuracy astrometry will play a major role since mosts brown dwarfs are too faint to be seen by GAIA (see also talk 7.1.4 by Smart et al.)