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The coolest halo subdwarfs - the oldest brown dwarfs?

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History

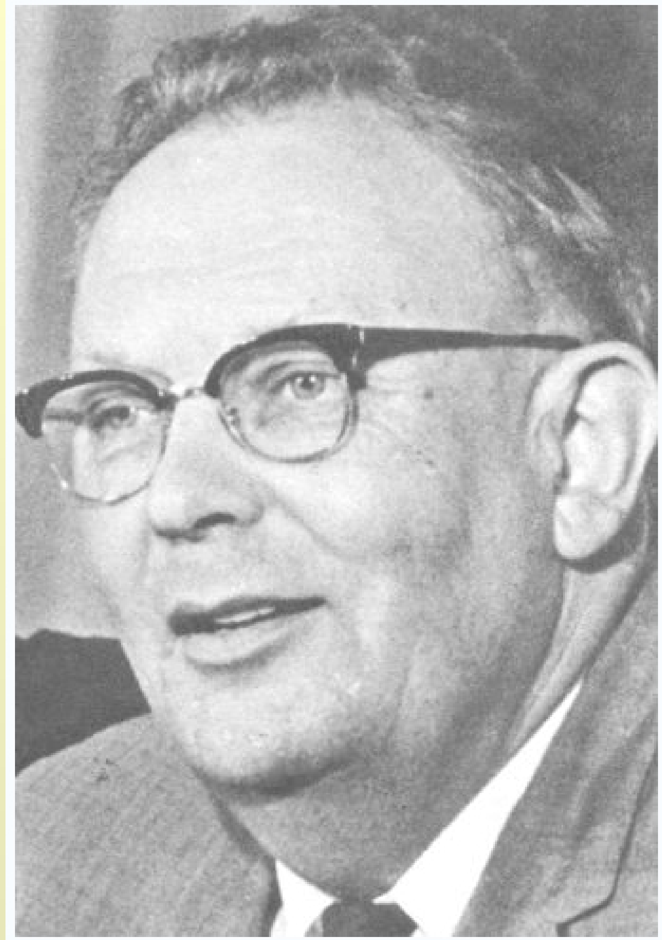
NOTES

TWO NEW WHITE DWARFS; NOTES ON PROPER MOTION STARS

ABSTRACT

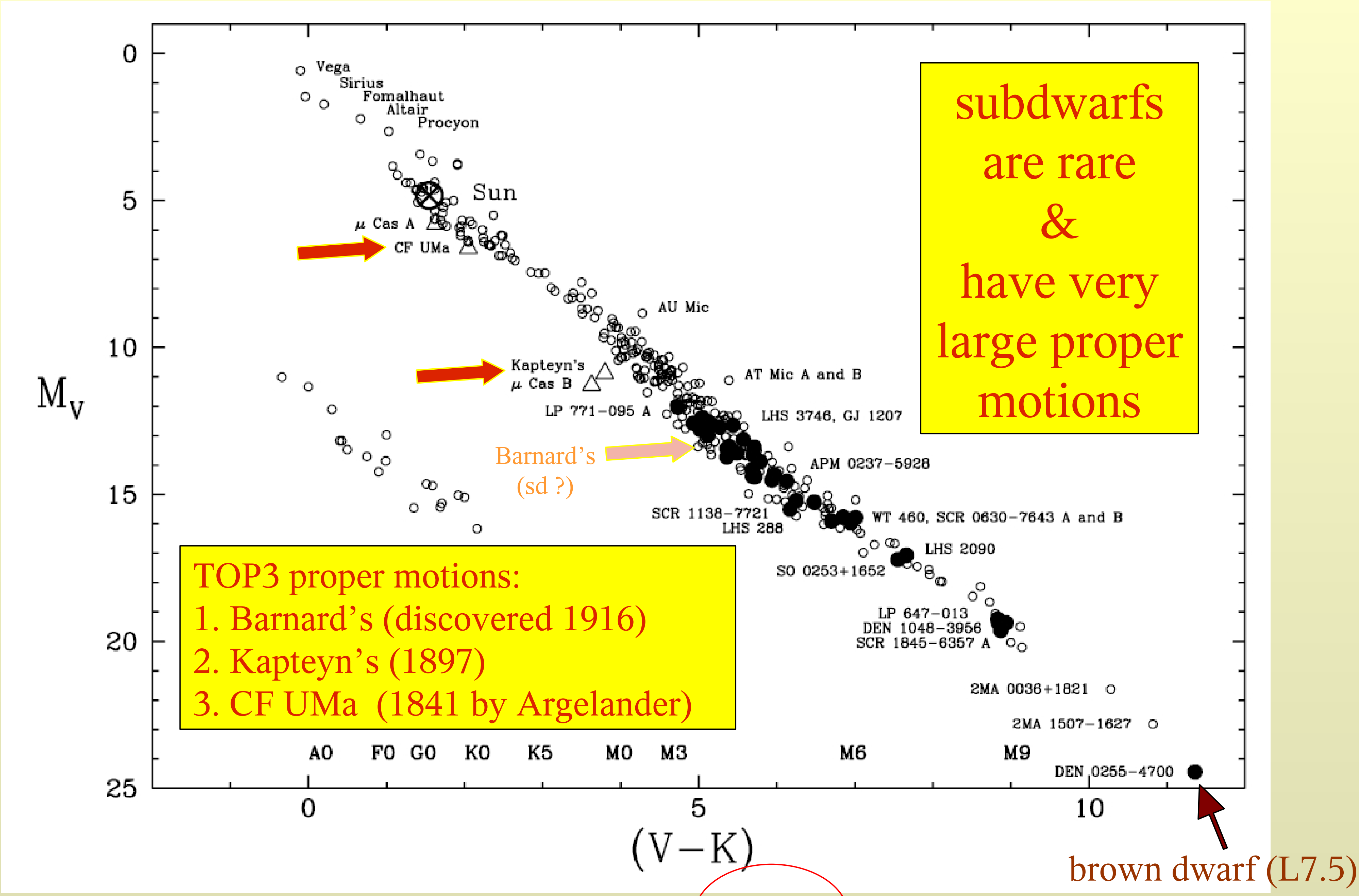
This note is a brief report on some of the observations made with the 82-inch telescope during the first month of its operation.

During the first month of regular operation the 82-inch telescope was used mainly in the determination of accurate spectral types for stars of large proper motion (not less than 0".30 per year). About 400 spectra were obtained for about 250 stars between visual magnitudes 8 and 16. Three classes of objects of special interest are expected to be found in such a survey: (1) white dwarfs; (2) intermediate white dwarfs or, more generally, stars not over 2 or 3 mag. below the main sequence; and (3) stars of large (spectral) parallax. It is found that the second group extends almost along the whole main sequence. Since these stars merge into the main sequence and are much more similar to main-sequence stars than to white dwarfs (probably also in the interior),[1] the name "subdwarfs" is suggested for this class of stars, in analogy with "subgiants." This name will prevent the confusion of these stars with the white dwarfs proper which are very much fainter.



(Kuiper 1939)

Subdwarfs in the 10pc sample



348 objects, incl. 4 sd and 18 wd (Henry et al. 2006)

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 are ultracool, 5 are halo objects including 2 subdwarfs

The effect of low metallicity

Reid & Hawley (2000), Burrows et al. (2001):

Lower opacity in the atmosphere
→ higher effective temperatures and higher luminosities at a given mass

Higher surface temperatures require higher core temperatures
→ minimum mass for hydrogen burning is ~0.02 Solar masses higher at zero metallicity:

Lower opacity and higher transparency
→ more rapid cooling of substellar objects with lower metallicity

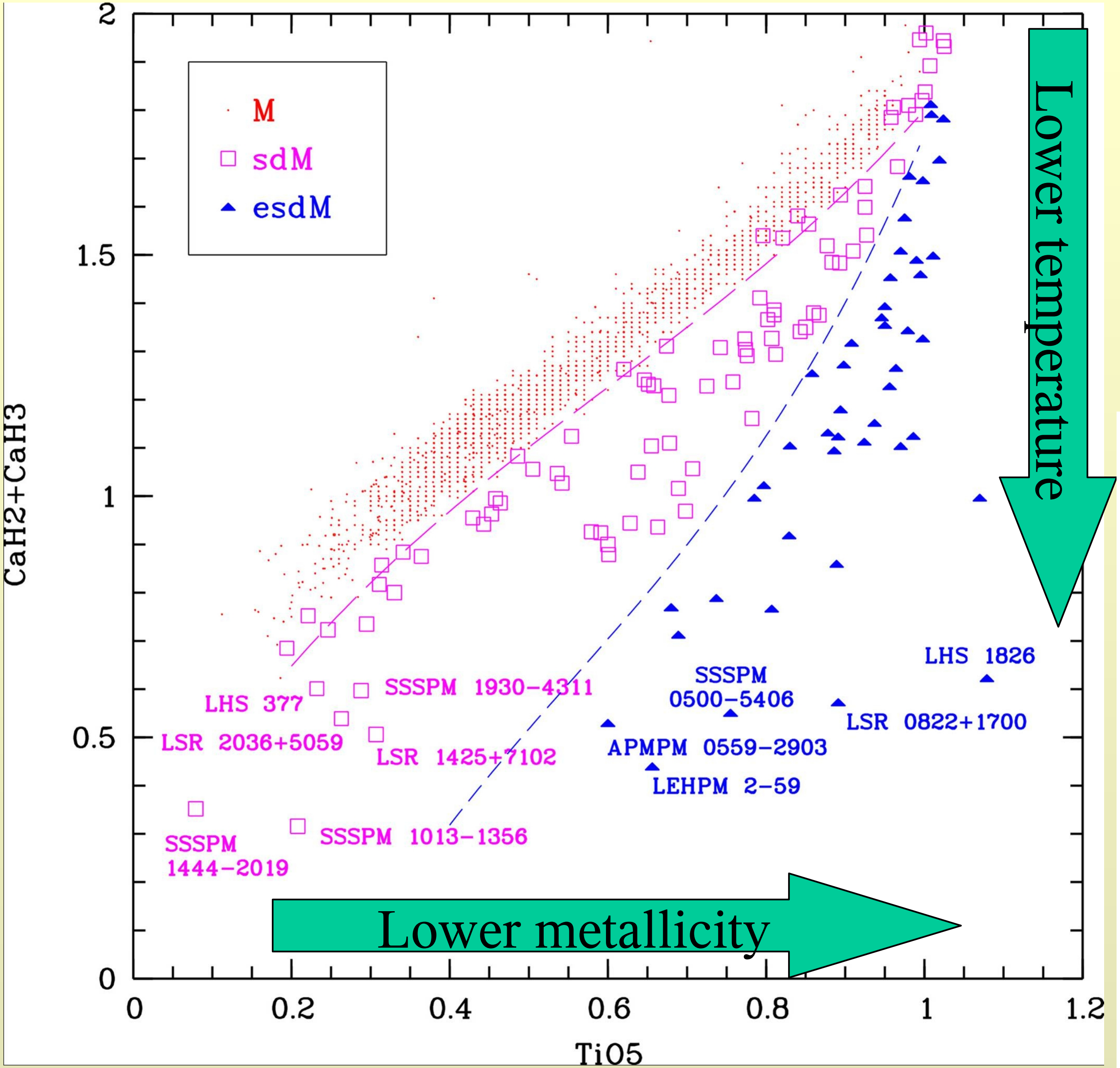
→ the lower the metallicity the brighter the star, but the dimmer the BD

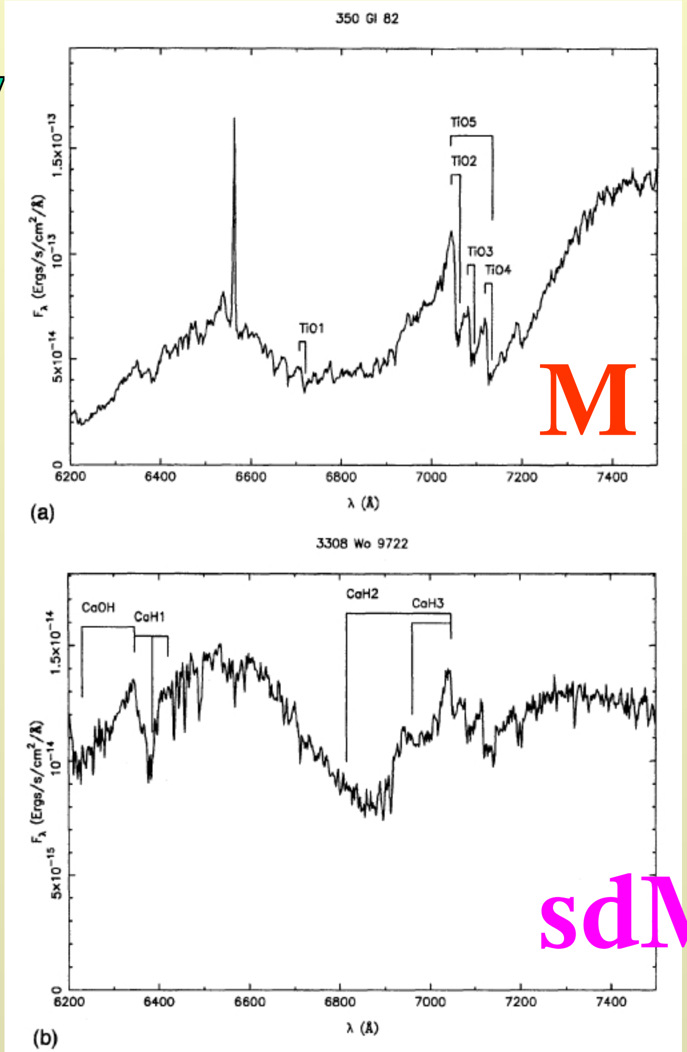
Kirkpatrick (2007):

Fewer metal+metal molecules relative to metal+hydrogen molecules
→ increased absorption by metal hydrides relative to that of metallic oxides
→ reduced condensation in the M/L transition (TiO and VO bands will be still visible)

M Subdwarfs: classification by spectral indices

(Reid et al. 1995, Gizis 1997)



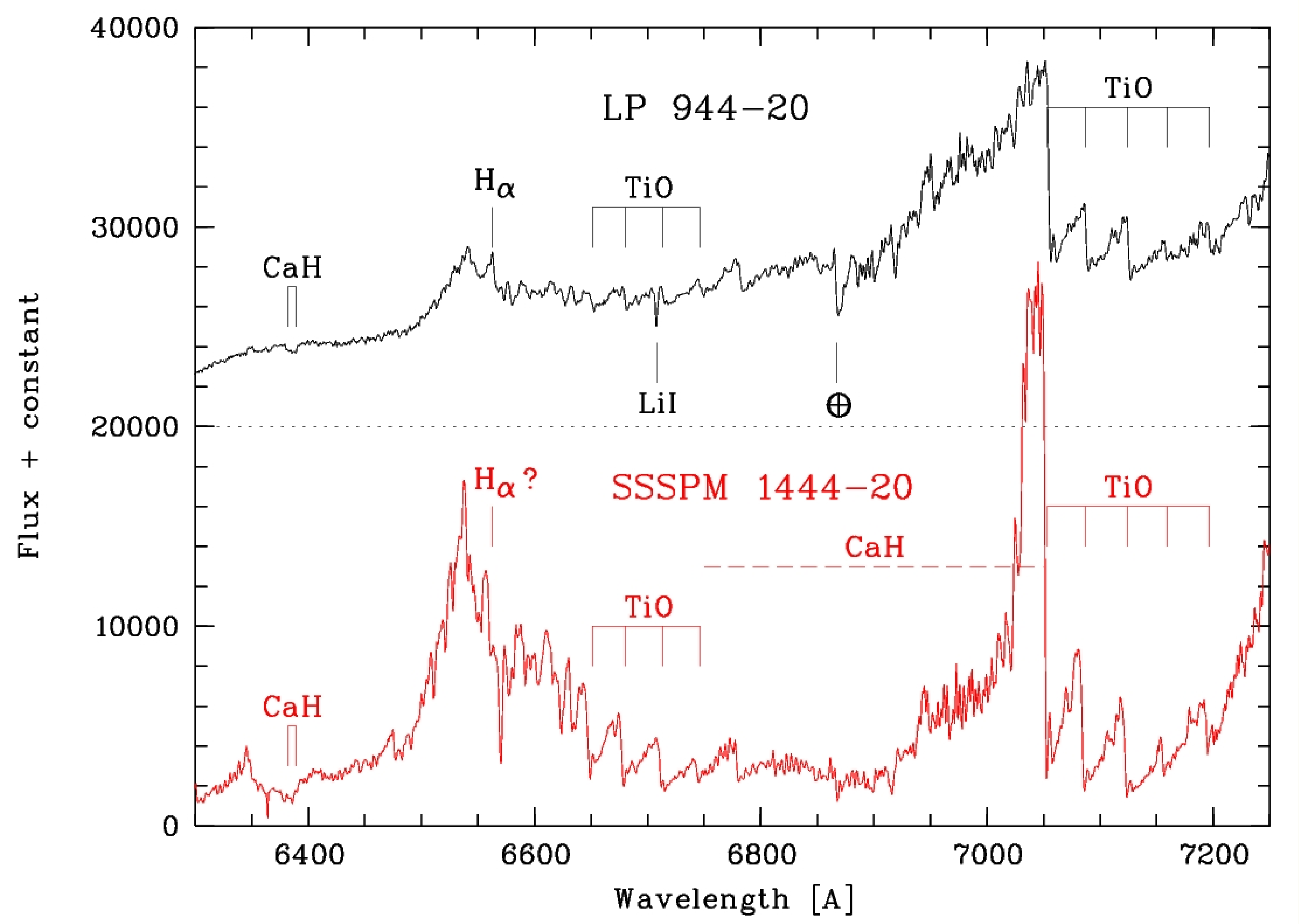


Lepine et al. (2003), Scholz, Lehmann, et al. (2004), Burgasser & Kirkpatrick (2006)

New class: ultracool subdwarfs (> sdM7/esdM7)

(Burgasser et al. 2005)

Is SSSPM 1444 a substellar subdwarf ?



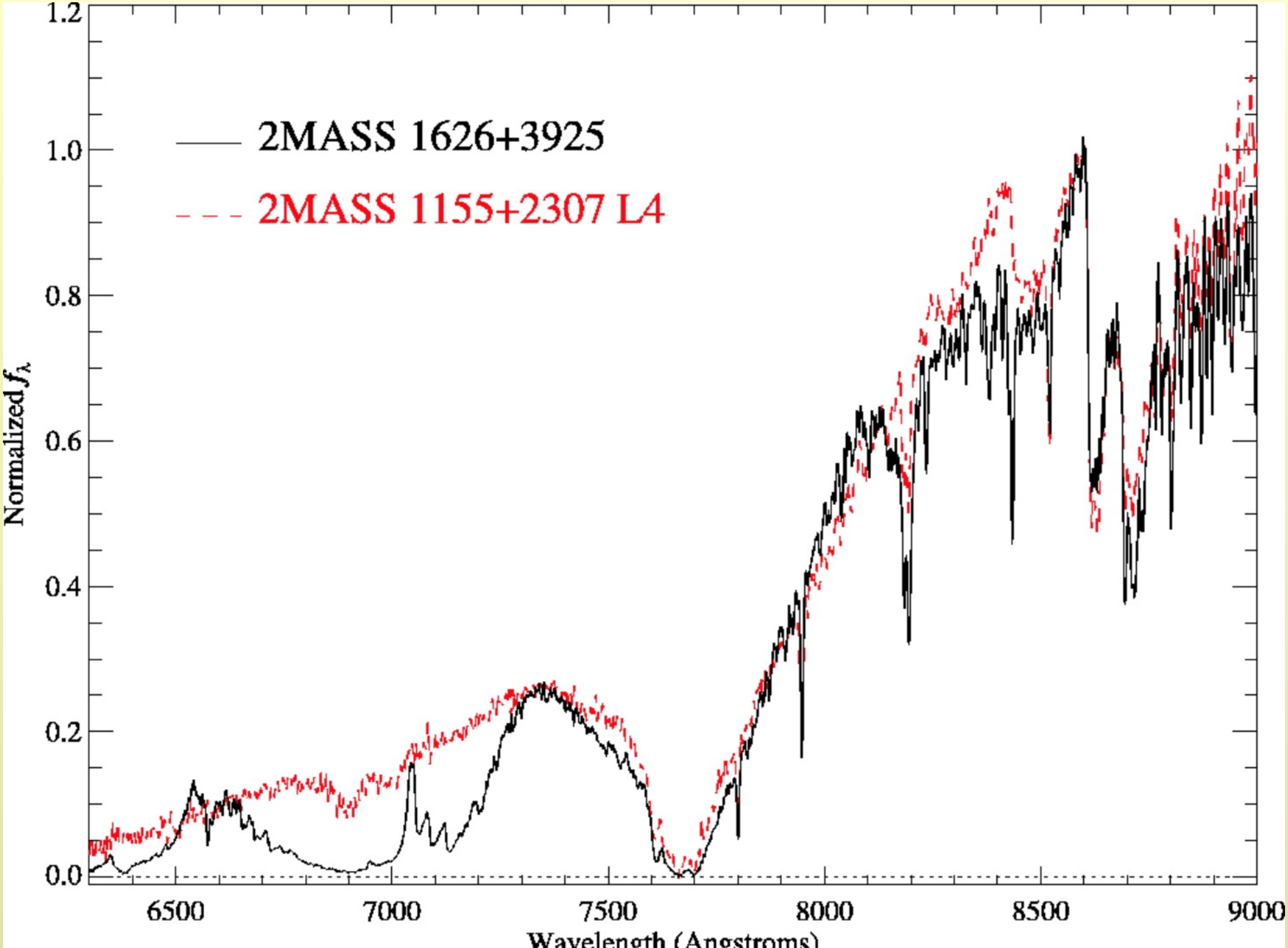
M9.5

sdM9

High-res. spectrum shows no Lithium

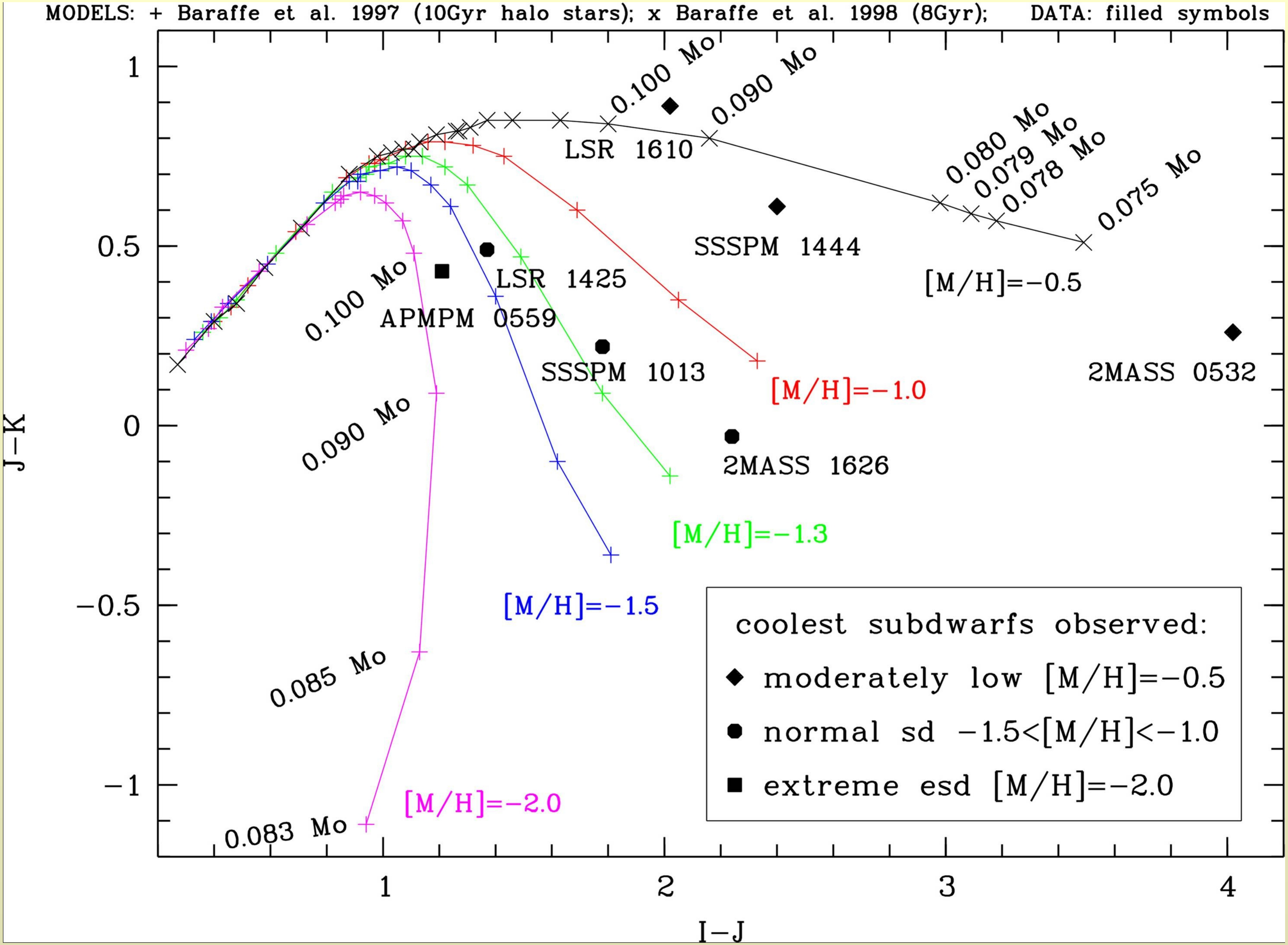
Scholz, Lodieu & McCaughrean (2004)

L dwarf (red) and L subdwarf (black) spectra



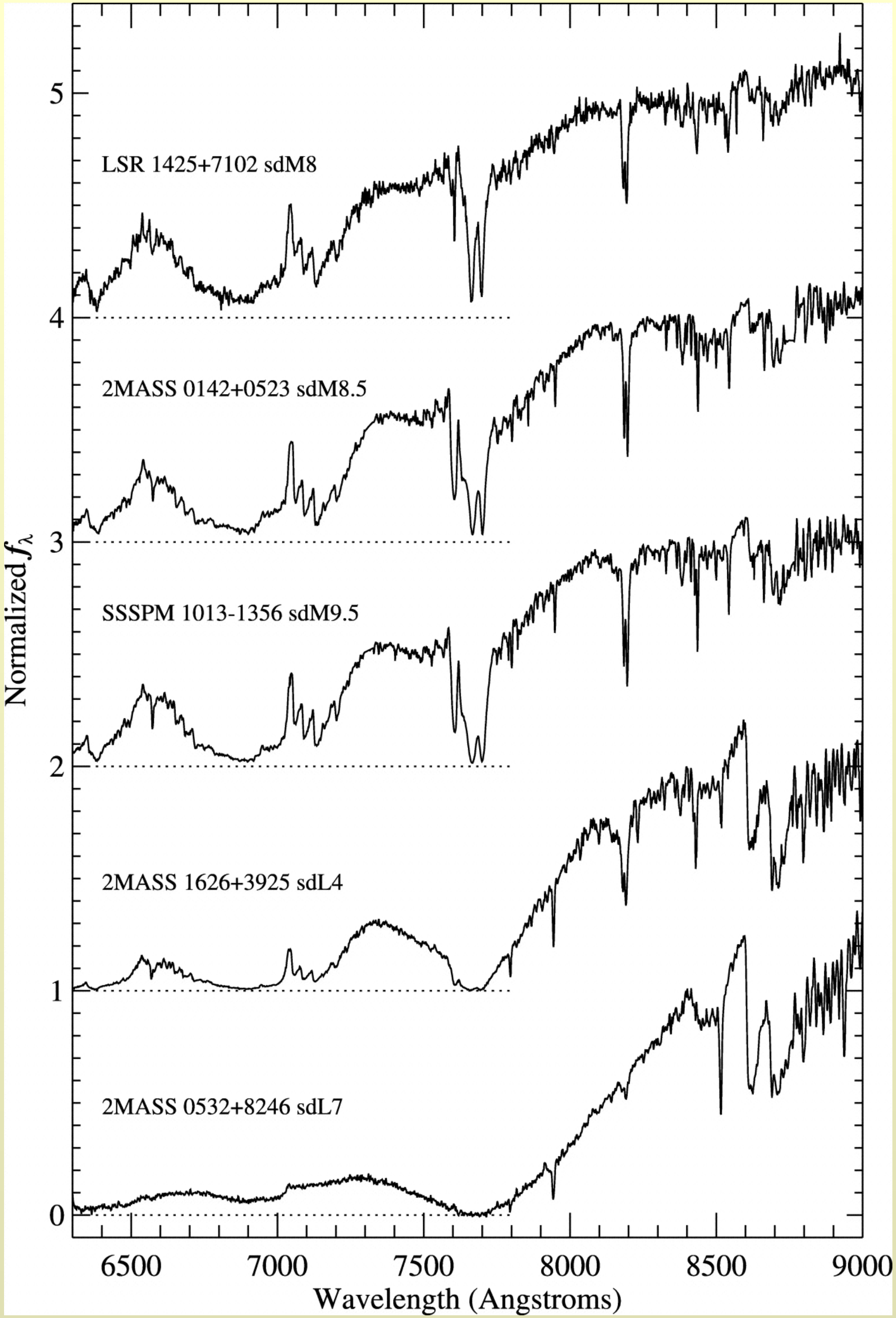
Burgasser, Cruz & Kirkpatrick (2007)

Subdwarf colours – comparison with models



Scholz, Lodieu & McCaughrean (2004)

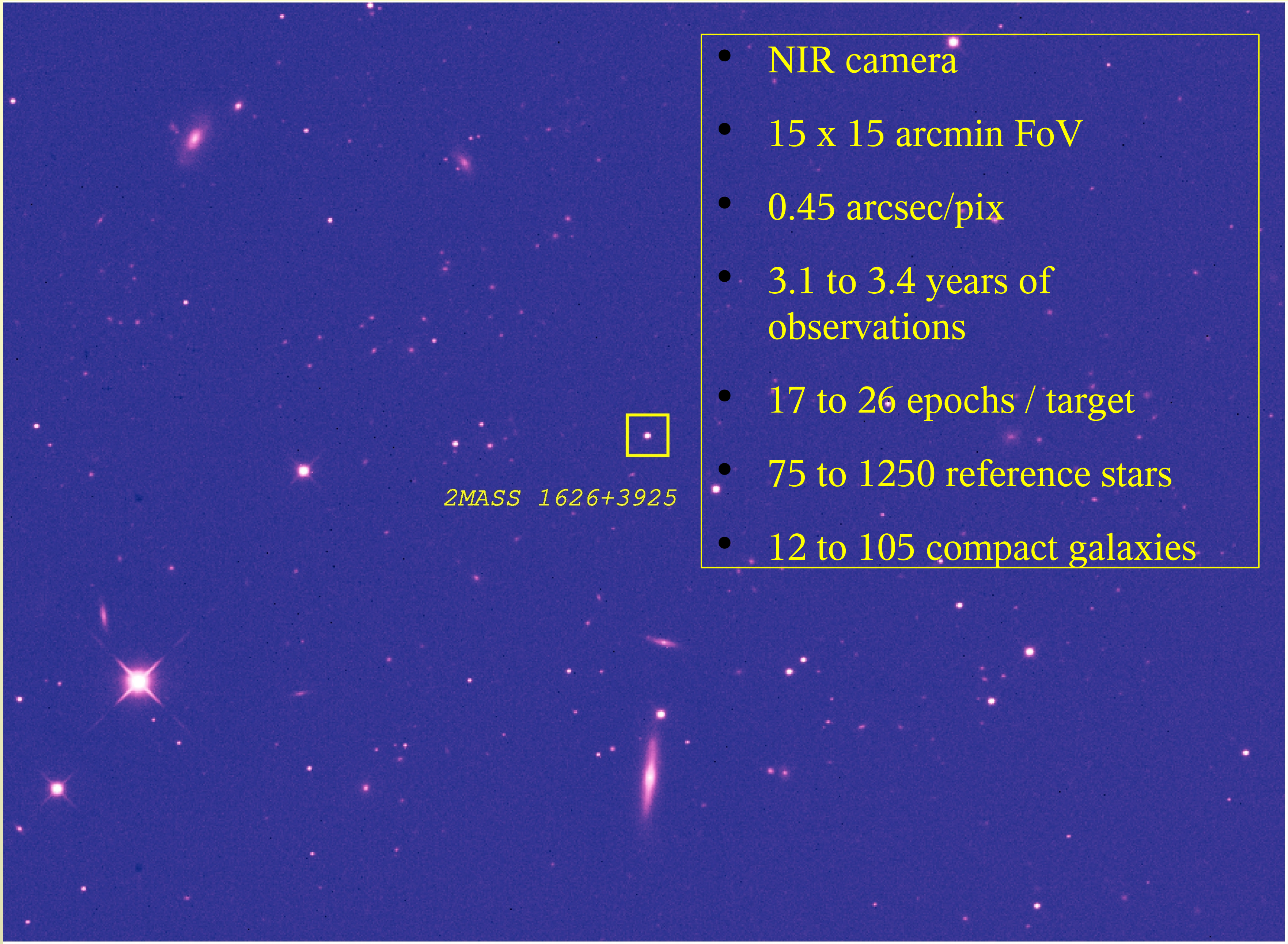
Spectral sequence + list of known ultracool subdwarfs



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

Parallax program @ Calar Alto 3.5m Omega 2000



- NIR camera
- 15 x 15 arcmin FoV
- 0.45 arcsec/pix
- 3.1 to 3.4 years of observations
- 17 to 26 epochs / target
- 75 to 1250 reference stars
- 12 to 105 compact galaxies

Schilbach, Röser & Scholz (2009)

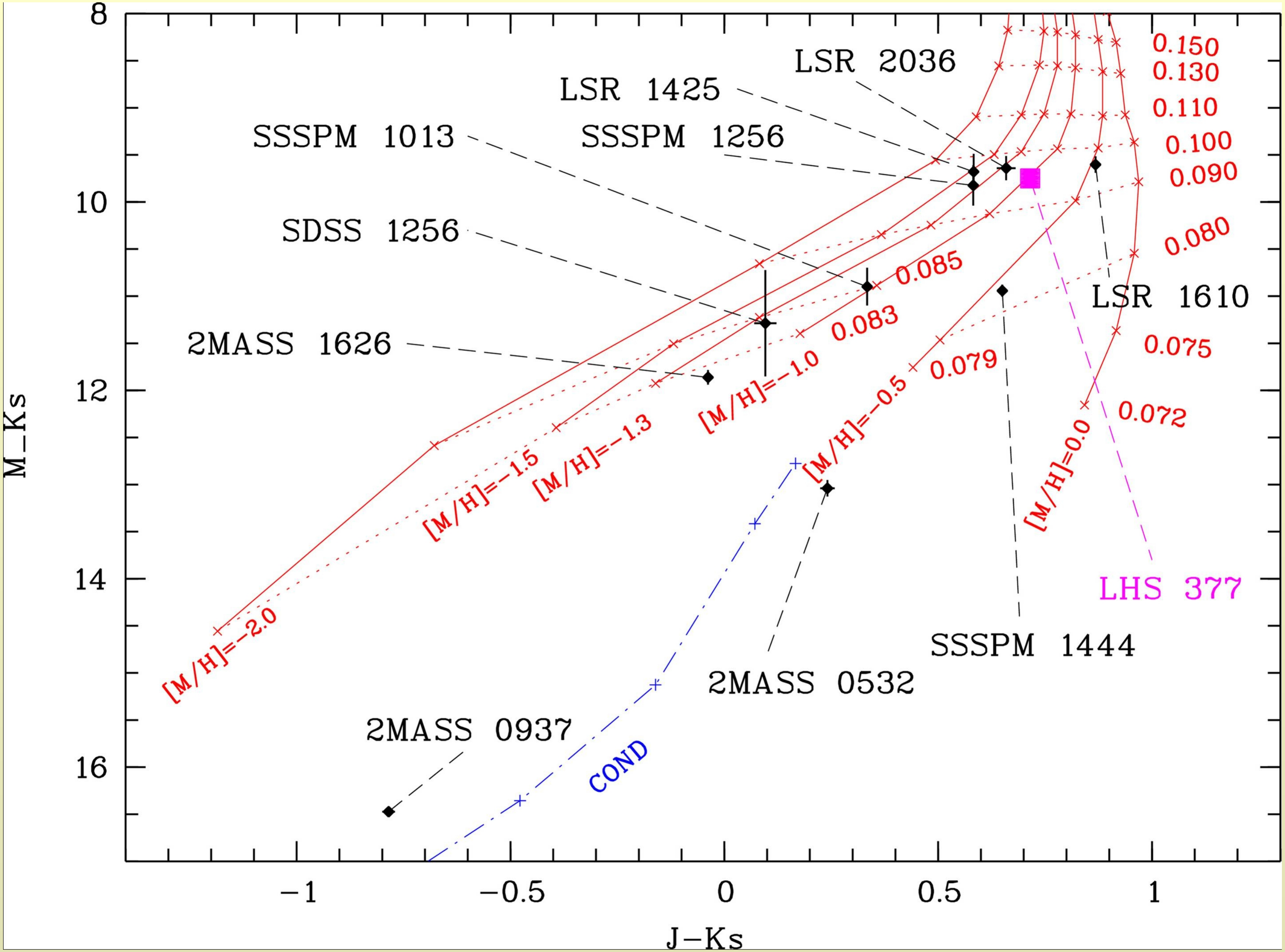
Trig. parallaxes of ten ultracool subdwarfs

(Shaded objects are probably substellar)

	Name	RA J2000.0 [h]	Dec J2000.0 [deg]	π(abs) [mas]	Δ_π [mas]	$\mu_\alpha \cos\delta$ [mas/yr]	μ_δ [mas/yr]
(d/)sdL7	2MASS 0532+82	5.548452	82.779208	42.28 ±1.76	–3.36 ±1.37	2039.46 ±1.52	–1661.79 ±1.64
d/sdT6	2MASS 0937+29	9.626350	29.528189	163.39 ±1.76	–3.39 ±1.18	944.15 ±1.24	–1319.78 ±1.21
sdM9.5	SSSPM 1013–13	10.218708	–13.939245	20.28 ±1.96	–5.11 ±1.24	69.44 ±1.20	–1028.93 ±1.33
?	SSSPM 1256–14	12.937228	–14.144533	18.76 ±1.85	–0.38 ±1.10	–741.11 ±1.40	–1002.13 ±1.38
sdL4:	SDSS 1256-02	12.943648	–2.414587	11.10 ±2.88	–0.43 ±1.11	–512.09 ±1.90	–297.71 ±1.79
sdM8	LSR 1425+7102	14.418059	71.035998	12.19 ±1.07	–0.73 ±0.67	–602.38 ±0.98	–177.71 ±0.99
d/sdM9	SSSPM 1444-20	14.738983	–20.323730	61.67 ±2.12	–2.41 ±1.48	–2906.15 ±2.41	–1963.12 ±2.71
d/sdM7:	LSR 1610–0040	16.174711	–0.681642	33.10 ±1.32	–2.63 ±0.95	–773.84 ±0.91	–1231.58 ±0.88
sdL4	2MASS 1626+39	16.438927	39.422076	29.85 ±1.08	–1.10 ±0.48	–1374.14 ±0.96	238.01 ±0.87
sdM7.5	LSR 2036+5059	20.606002	51.001279	21.60 ±1.26	–1.00 ±1.13	751.93 ±1.10	1252.22 ±1.31

Schilbach, Röser & Scholz (2009)

Ultracool subdwarf absolute magnitudes/colours



Solid lines: Baraffe+ models for 10 Gyr ([M/H]=-1.0..-2.0 and 5 Gyr ([M/H]=0.0..-0.5)

Schilbach, Röser & Scholz (2009)

Conclusions and outlook

- High proper motion surveys continue to play an important role in finding new ultracool subdwarfs (later than ~sdM7/esdM7)
- Our trigonometric parallaxes show that two sequences, normal subdwarfs (sd) with [m/H] = -1.5…-1.0 and moderately low-metallicity objects (d/sd) with [m/H] ~ -0.5, reach into the brown dwarf regime
- Trigonometric parallaxes of extreme ultracool subdwarfs (>esdM7) with [m/H] = -2.0 are still needed
- More M-type ultracool subdwarfs have been detected in SDSS (Lepine & Scholz 2008; Scholz et al. 2009)
- New L-type subdwarfs (e.g. Cushing et al. 2009) are difficult to find due to their blue NIR colours and faint magnitudes
- High-resolution spectra (2MASS 0532 !!) provide accurate RVs and rotational velocities (Reiners & Basri 2006) and will finally lead to elemental abundances