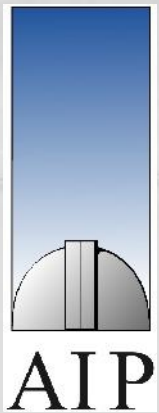
Conference "The Milky Way Halo" at AIfA, Bonn, 29 May – 2 June 2007

Galactic halo ultracool subdwarfs crossing the Solar neighbourhood

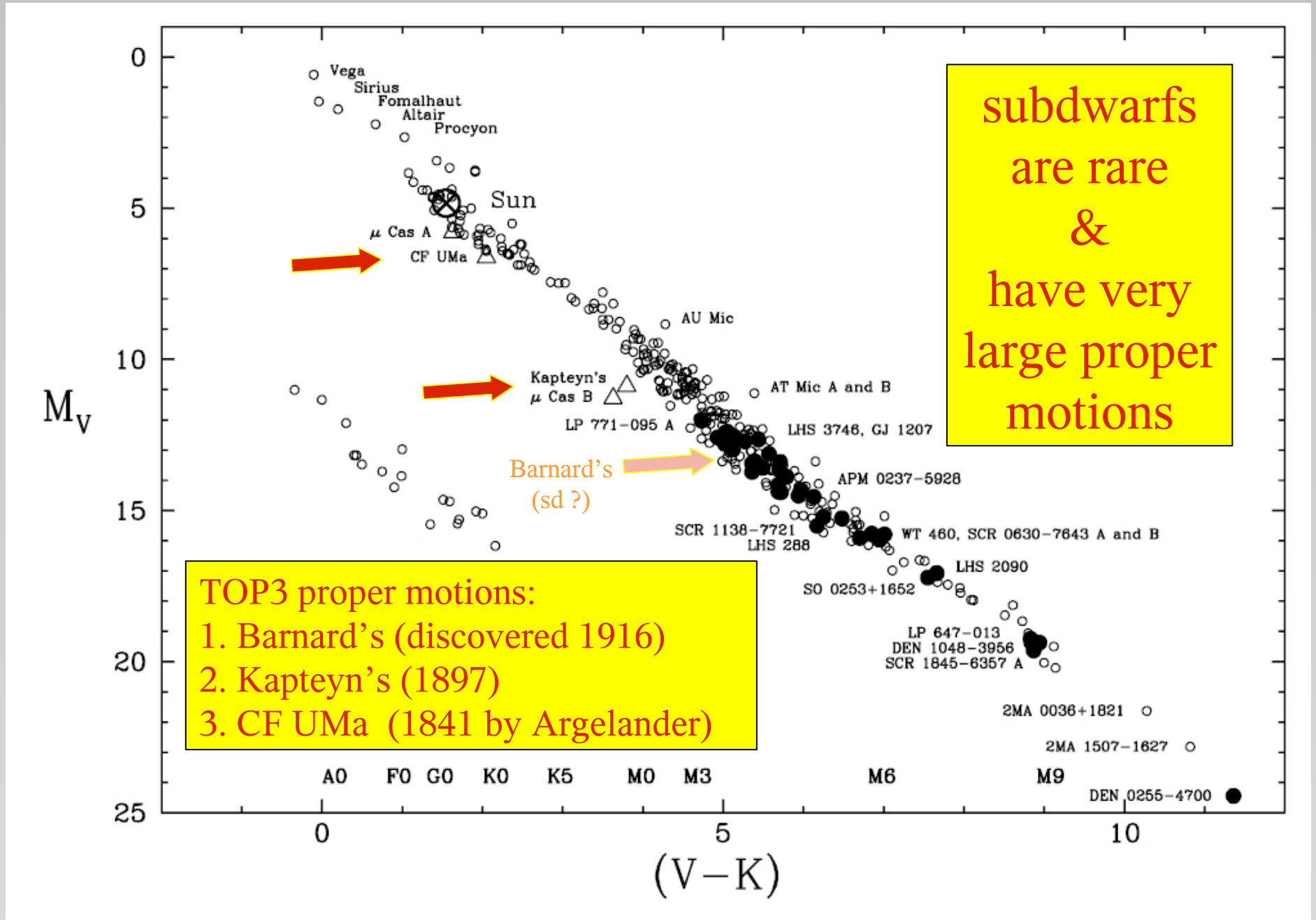
Ralf-Dieter Scholz
Astrophysikalisches Institut Potsdam



in collaboration with:

- Hartmut Jahreiß @ Heidelberg
- Ingo Lehmann @ (Potsdam – Garching –) Potsdam
- Nicolas Lodieu @ (Potsdam – Leicester –) Tenerife
- Mark McCaughrean @ (Potsdam –) Exeter
- Helmut Meusinger @ Tautenburg
- Siegfried Röser @ Heidelberg
- Elena Schilbach @ Heidelberg
- Hans Zinnecker @ Potsdam

Subdwarfs in the 10pc sample



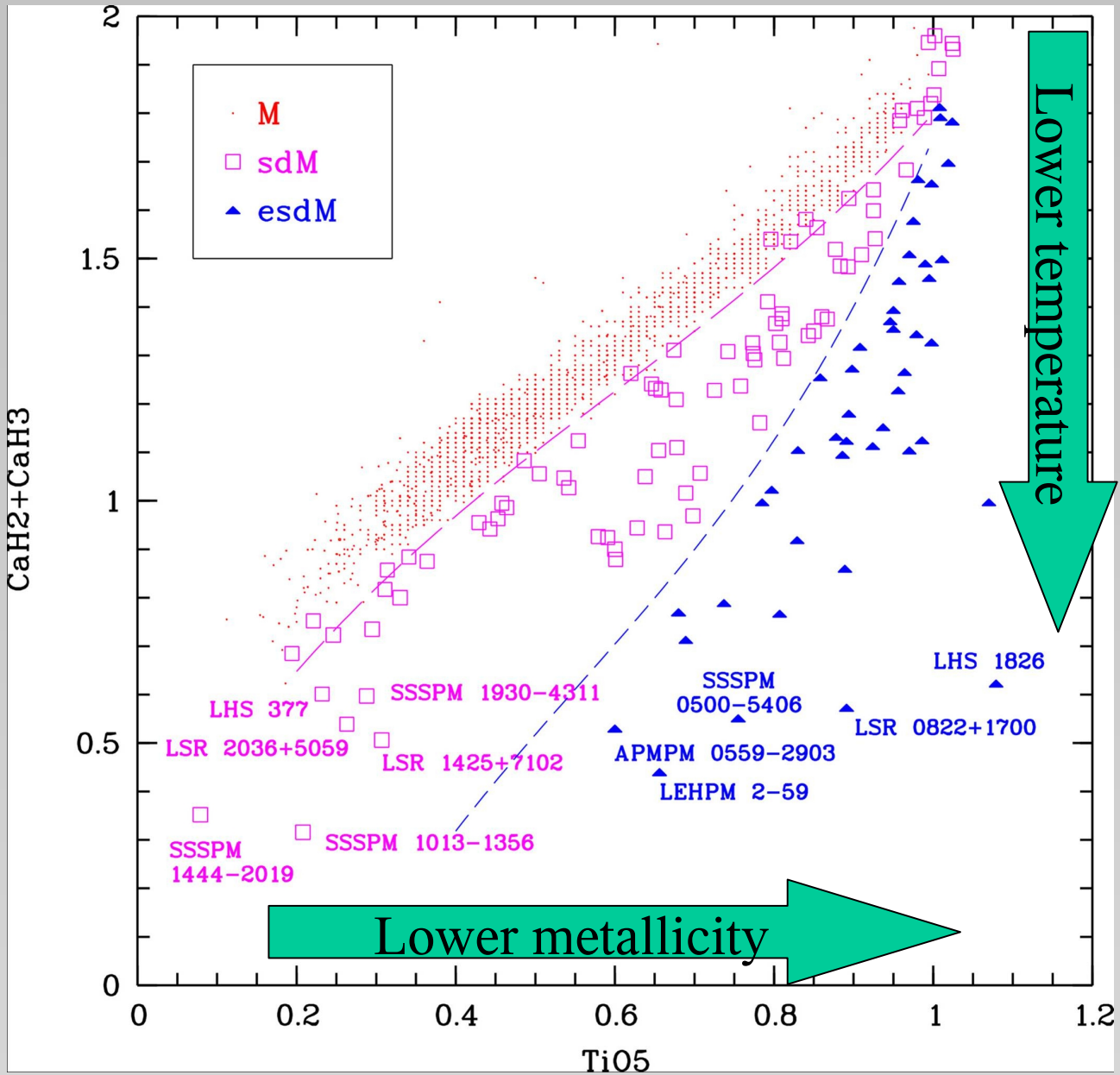
348 objects, incl. 4 sd and 18 wd (Henry et al. 2006)

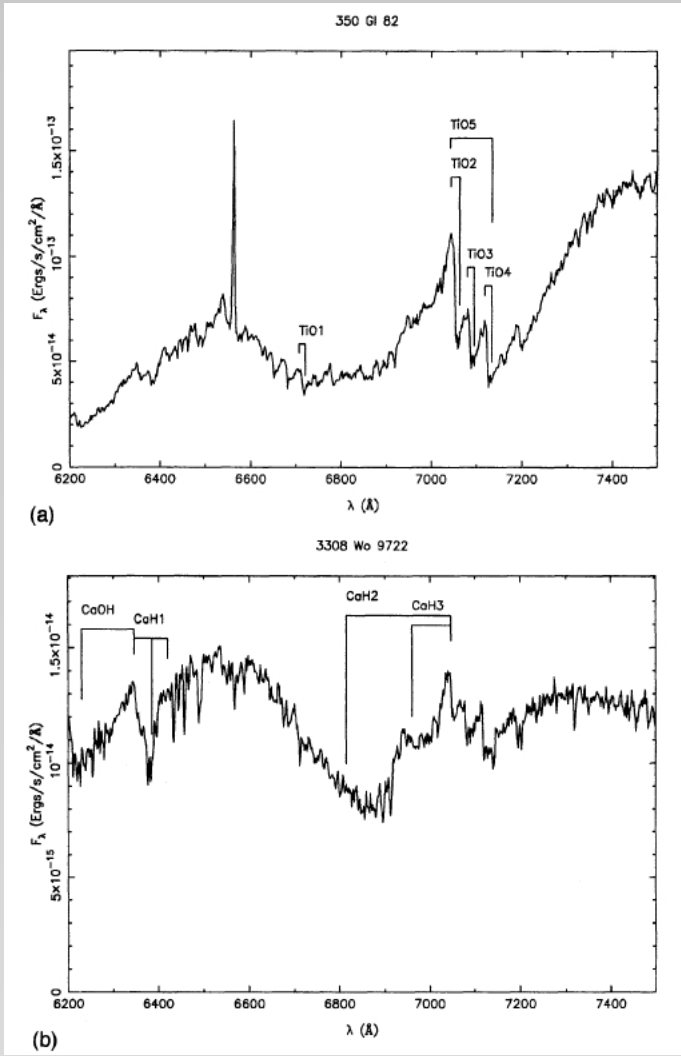
The class(es) of subdwarfs

- Kuiper (1939): stars up to 2-3 mag below the main sequence selected “mainly on the basis of abnormally high transverse motion under the assumption of the star being a normal dwarf” (spectral types A, F, G, K)
- Subdwarfs are metal-deficient stars
- Hot subdwarfs (sdO, sdB)
- Later types (sdF, sdG) are already called “cool”
- Really cool subdwarfs (sdK, sdM) and the new class of ultracool subdwarfs (>sdM7, sdL, sdT – substellar subdwarfs)
  - typically thick disk or halo kinematics
  - lifetimes larger than age of the Galaxy – representatives of 1st generations of stars

M Subdwarfs: classification by spectral indices

(Reid et al. 1995, Gizis 1997)

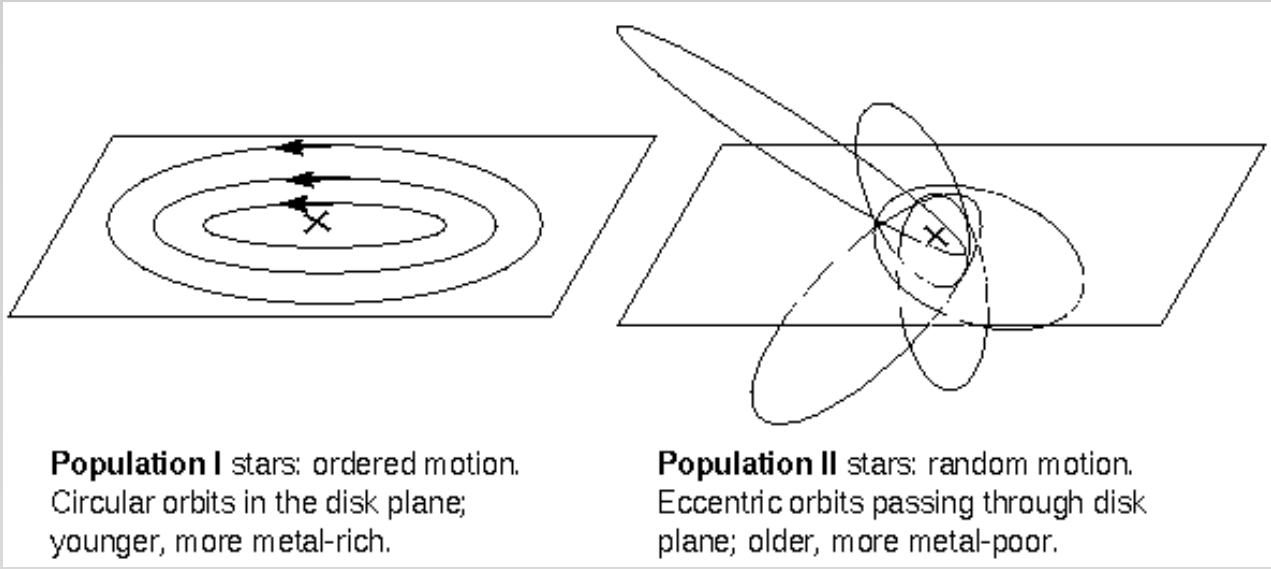




Lepine et al. (2003), Scholz, Lehmann, et al. (2004), Burgasser & Kirkpatrick (2006) [new data from Burgasser, Cruz & Kirkpatrick (2007) not yet included]

Proper motion as a rough distance measure

- Proper motion μ = apparent motion on the sky (large values range from ~0.1 to ~10 arcsec/yr)
- Real velocity [in km/s] can only be estimated if the distance from the Sun d [in pc] is known: $v_{tan} = 4.76 \cdot \mu \cdot d$
- 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



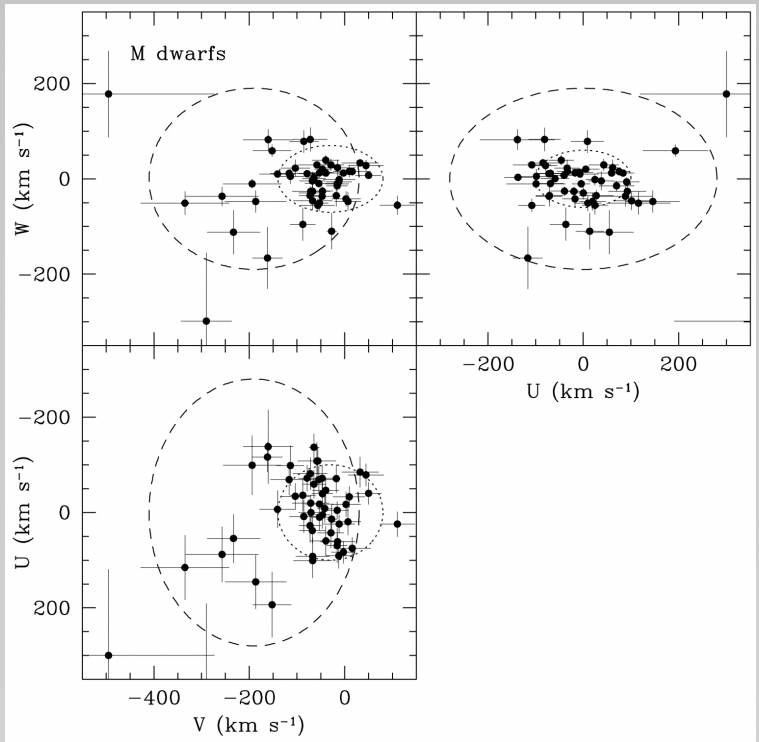
Population I stars: ordered motion. Circular orbits in the disk plane; younger, more metal-rich.

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

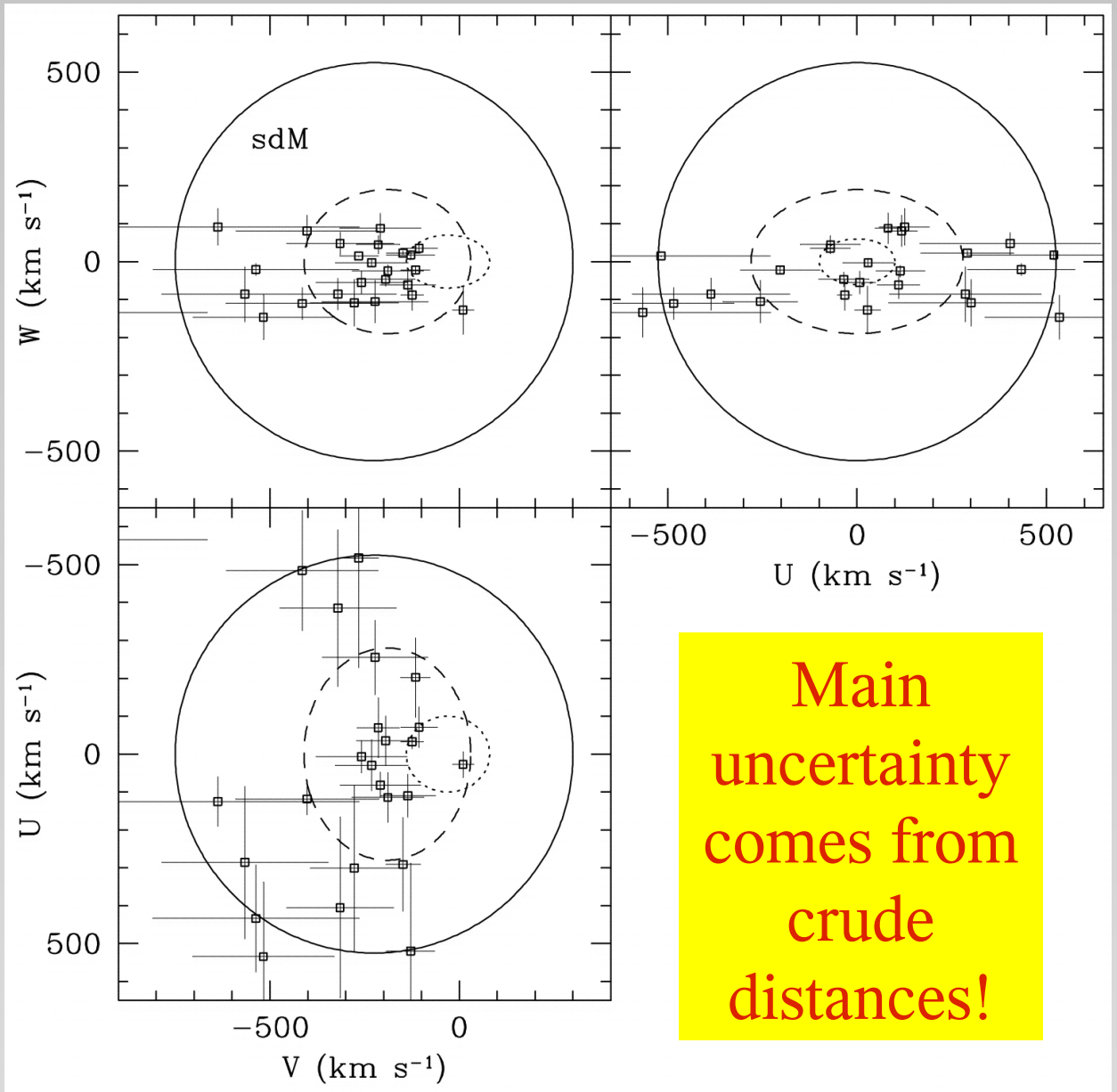
Proper motion samples are halo biased

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 (reference) [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	2.66	Pokorny+03, Hambly+04	3.854 (1)	disk M8.5
2MASS 0532+8246	2.60	Burgasser+03	∼20	**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

Trigonometric parallax references: 1 - Henry+06, 2 - ESA 97, 3 - Vrba+04, 4 - Ducourant+07

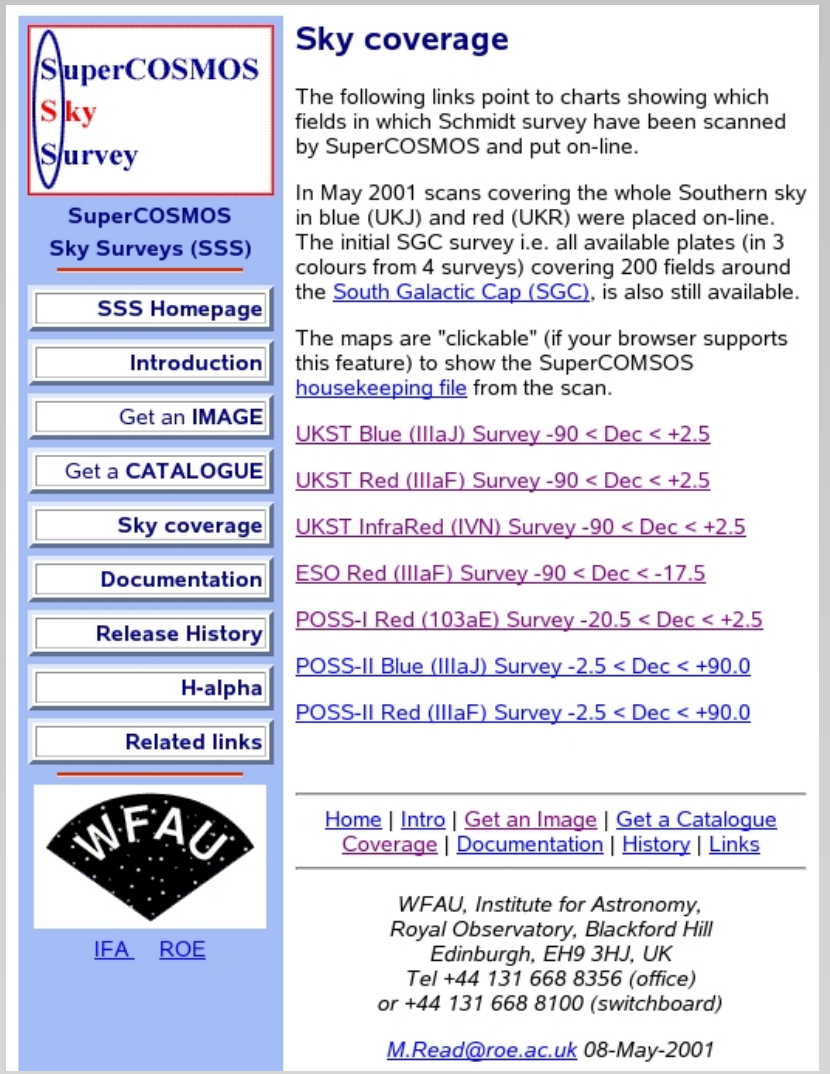
13 new discoveries since 2000 - compared to 73 known LHS stars!

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

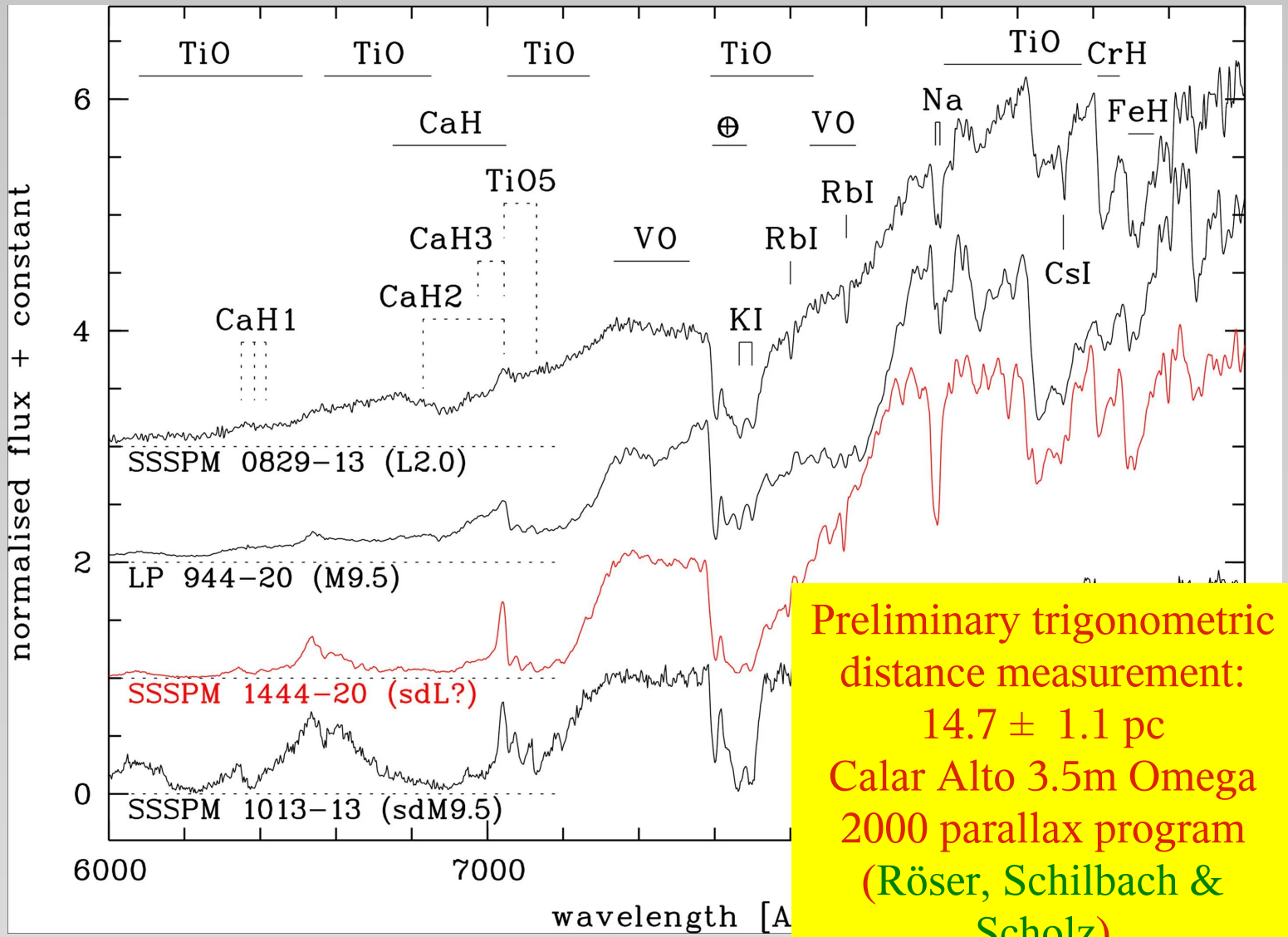
- Fill the gaps in Southern sky
- Extend the magnitude limit
- Find cooler nearby objects (bd)
- Find cool halo objects (wd, sd)

A visitor from the Galactic halo:

SSSPM J1444−2019

Extremely large proper motion: 3.5 arcsec/yr

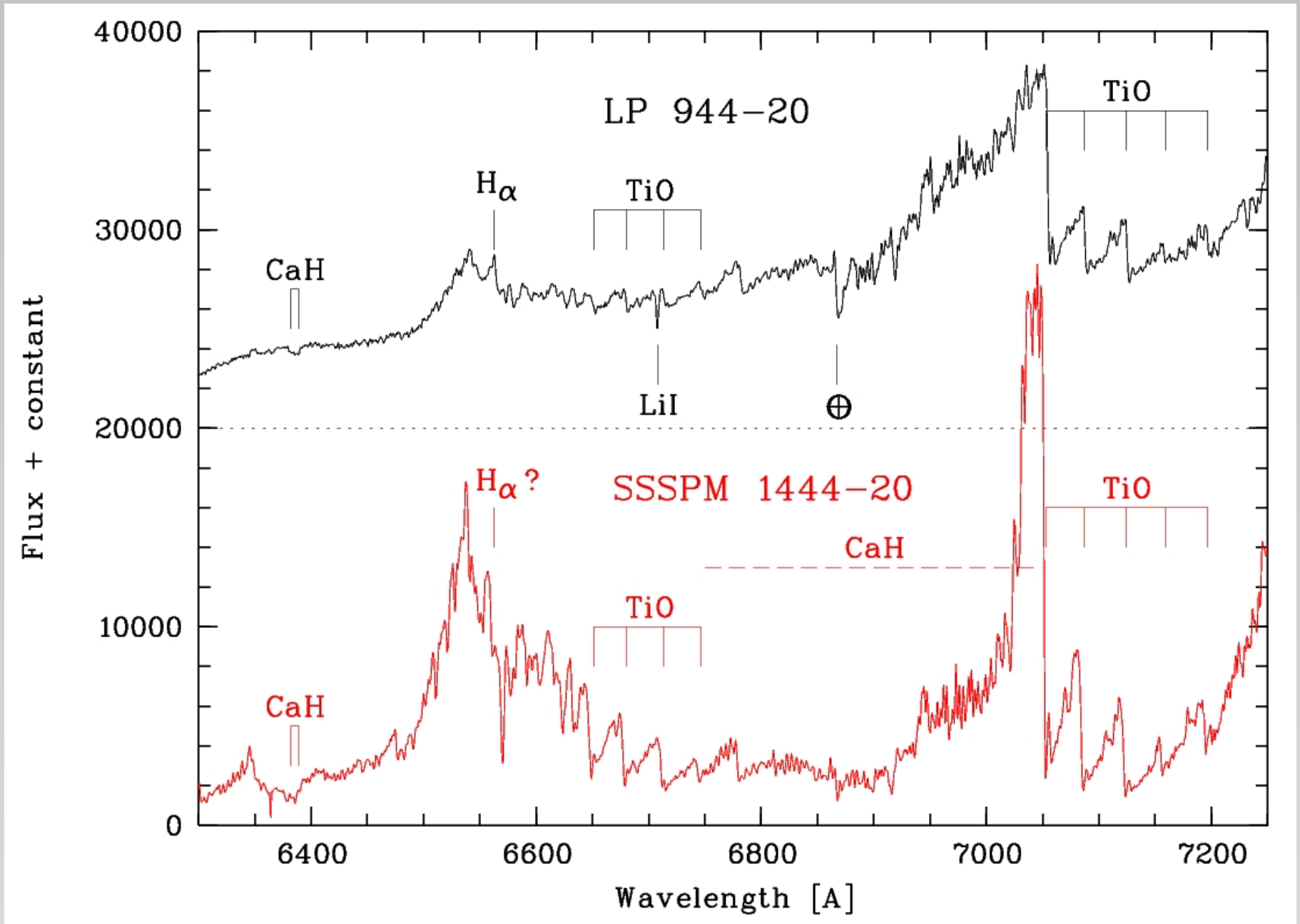
sdM9, but L-type spectral features (RbI, FeH, CrH, no VO!)



Scholz, Lodieu & McCaughrean (2004)

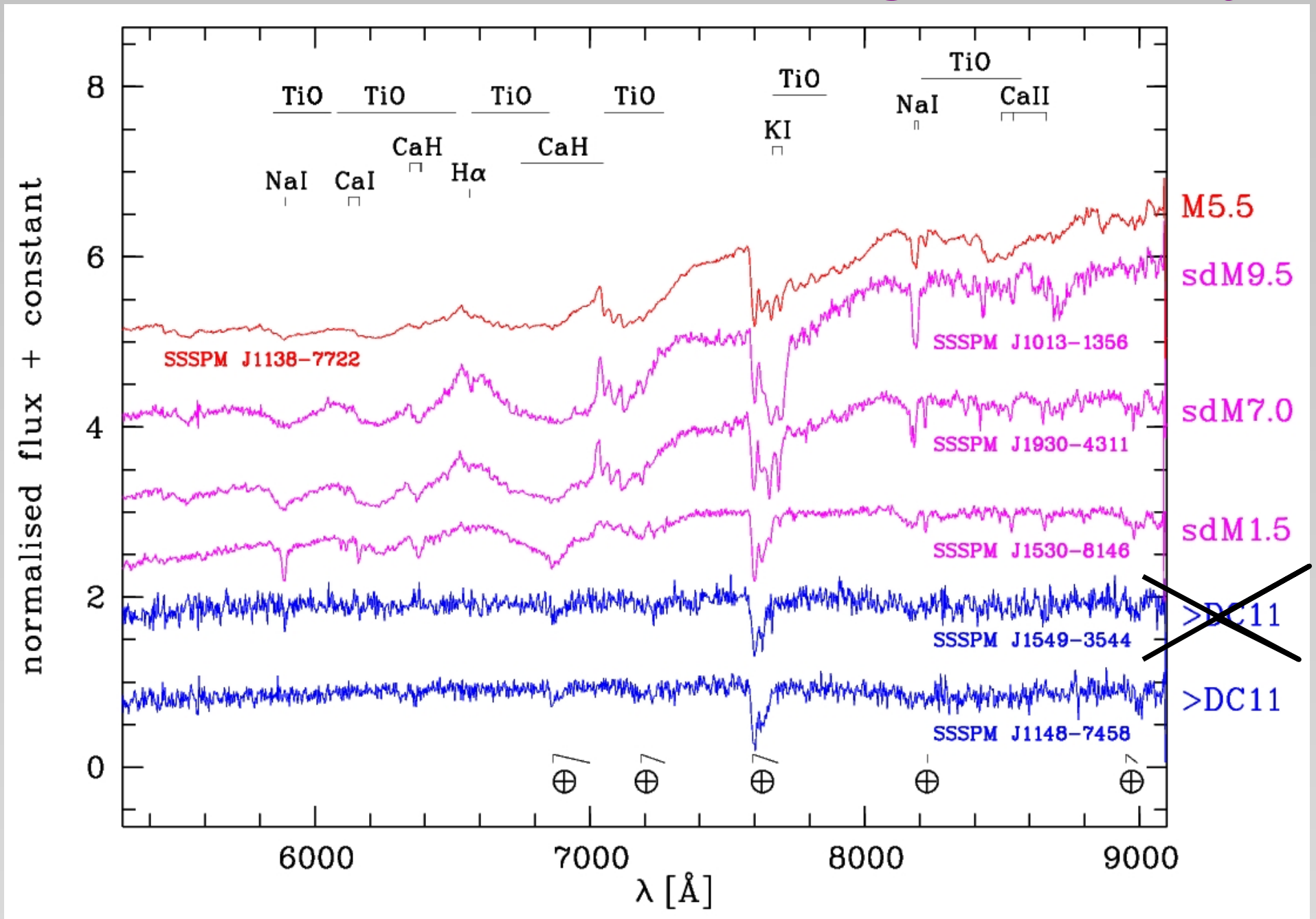
Preliminary trigonometric distance measurement:
14.7 ± 1.1 pc
Calar Alto 3.5m Omega 2000 parallax program
(Röser, Schilbach & Scholz)

Is SSSPM 1444 a substellar subdwarf ?



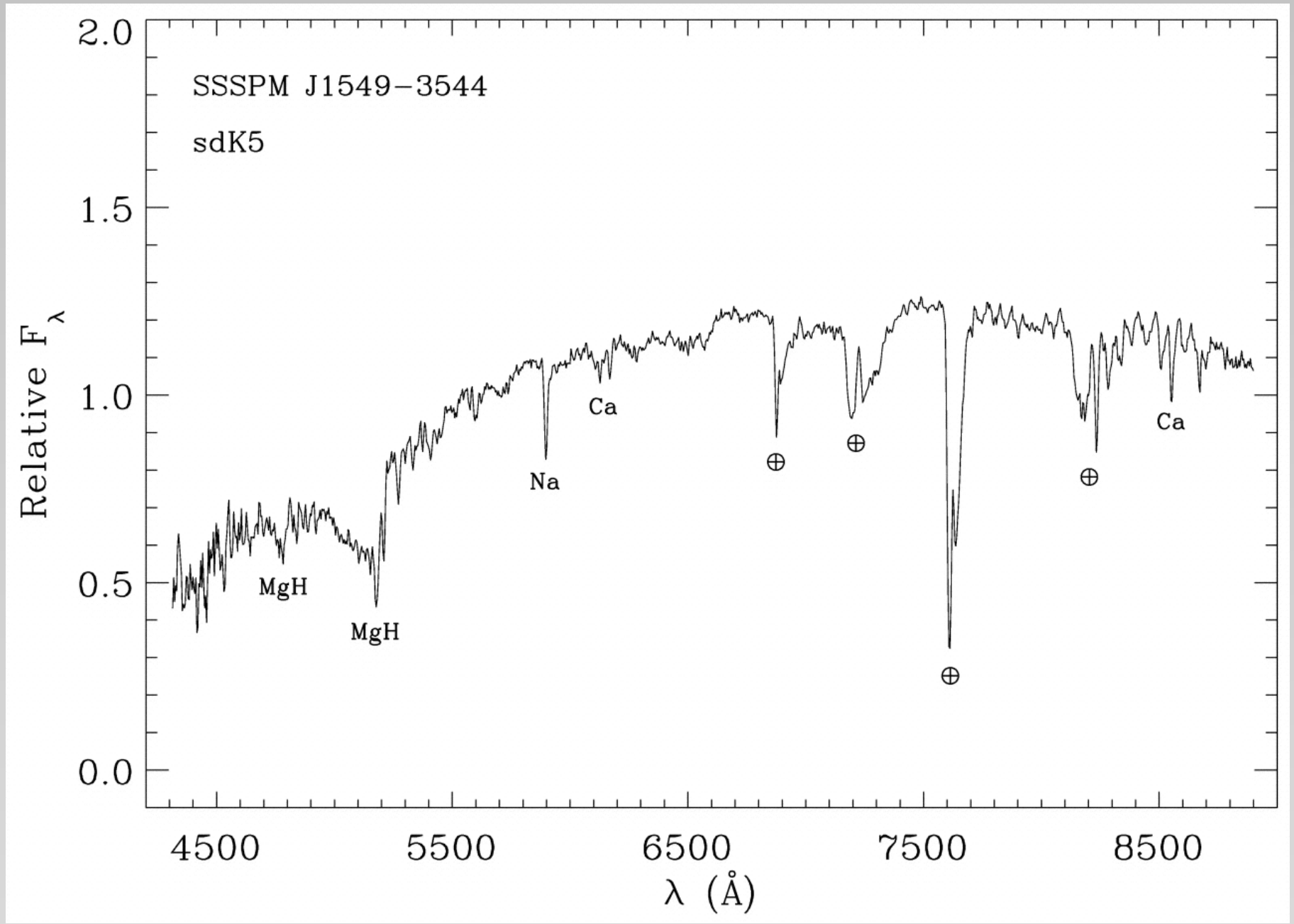
High-res. spectrum shows no Lithium Scholz, Lodieu & McCaughrean (2004)

More ultracool subdwarfs among SSSPM objects



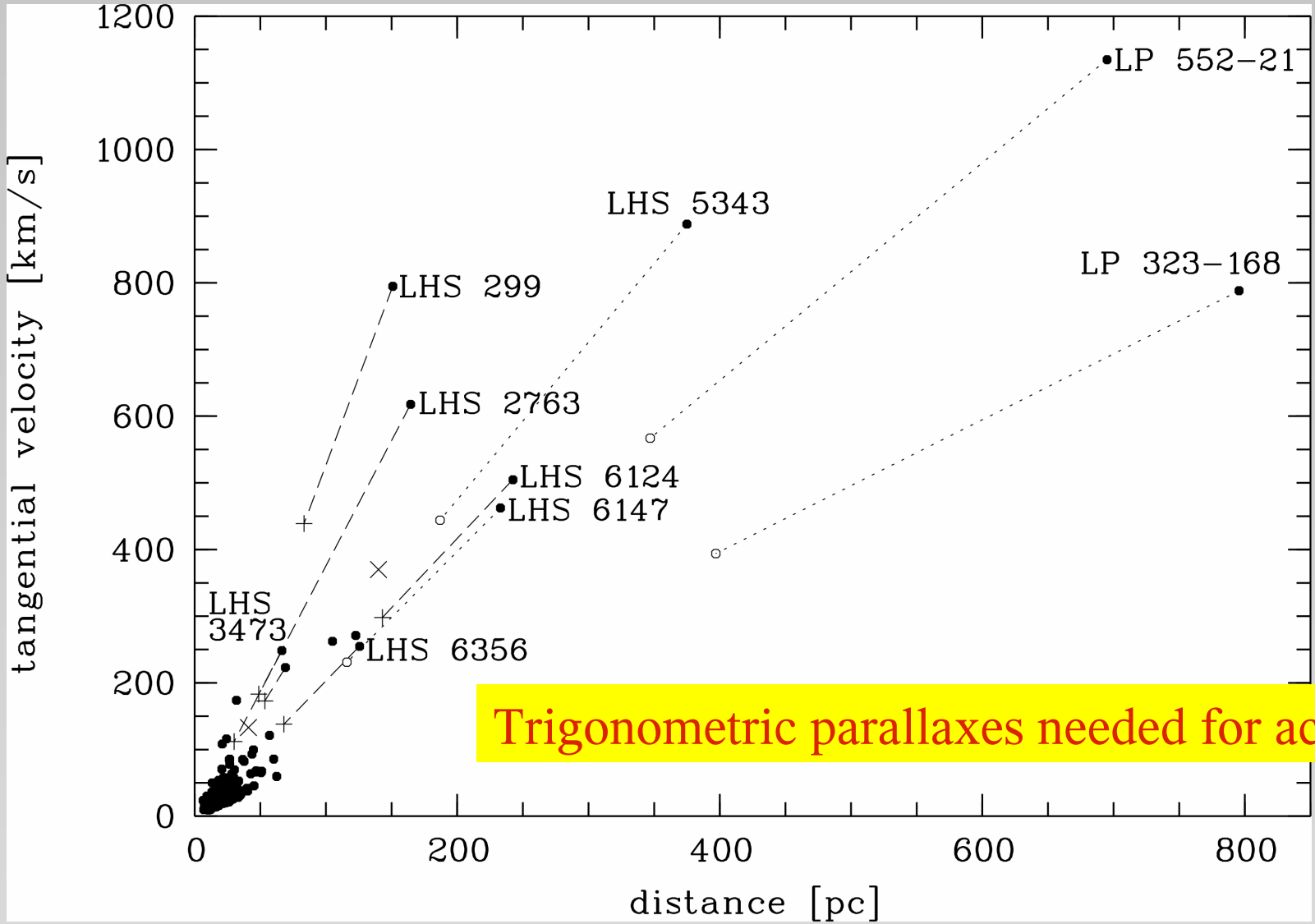
Scholz, Lehmann, et al. (2004)

Not a nearby WD but a distant halo subdwarf !



Farihi, Wood & Stalder (2005)

Hyper-velocity subdwarf (candidates) from NLTT
(to be confirmed by higher-resolution spectroscopy)



- our spectroscopic distance estimates (if normal K/M dwarfs)

\+ trigonometric parallaxes (obviously these are subdwarfs)

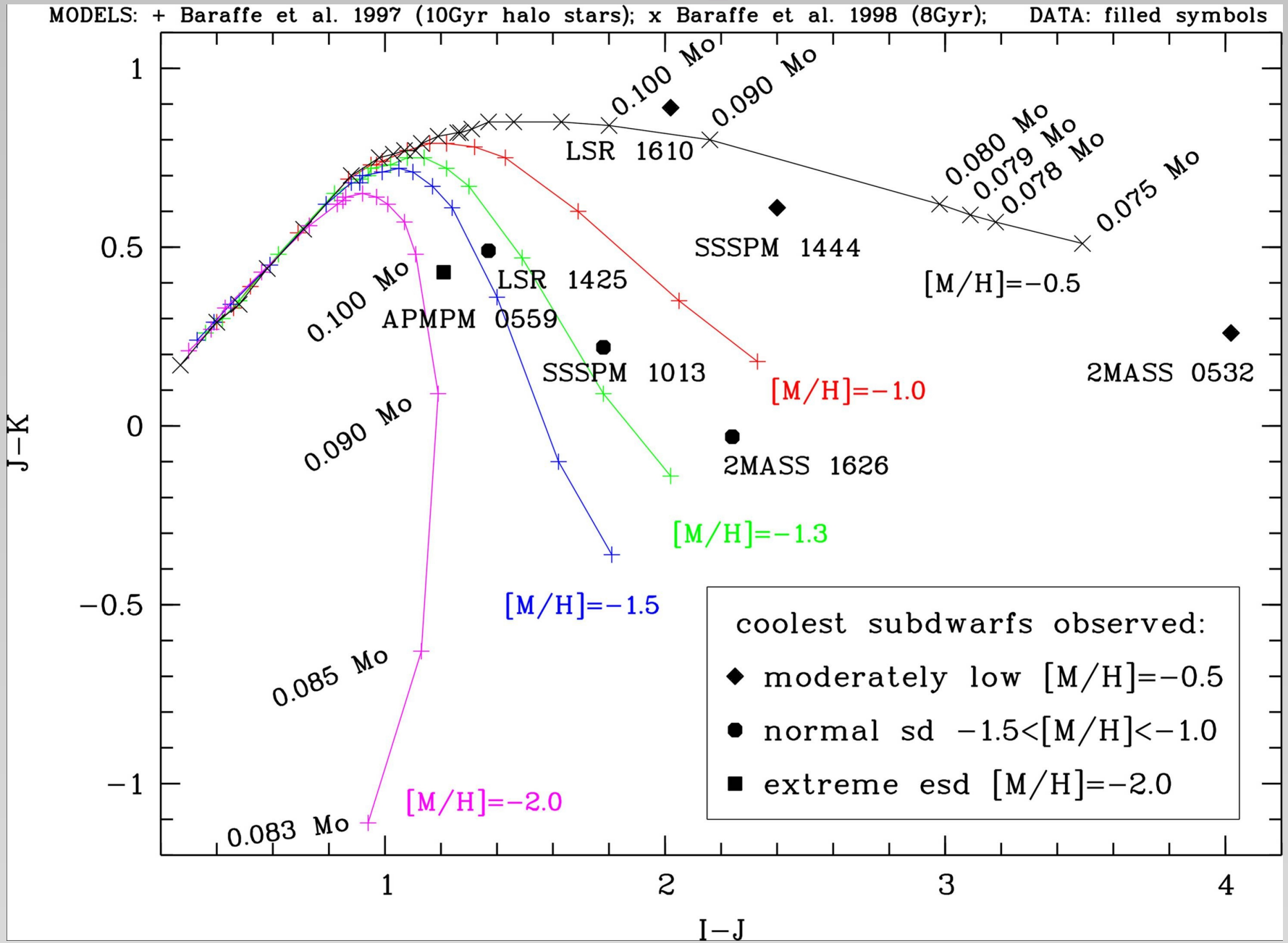
x white dwarfs

o assumed subdwarfs (~50% smaller values)

Trigonometric parallaxes needed for accurate velocities

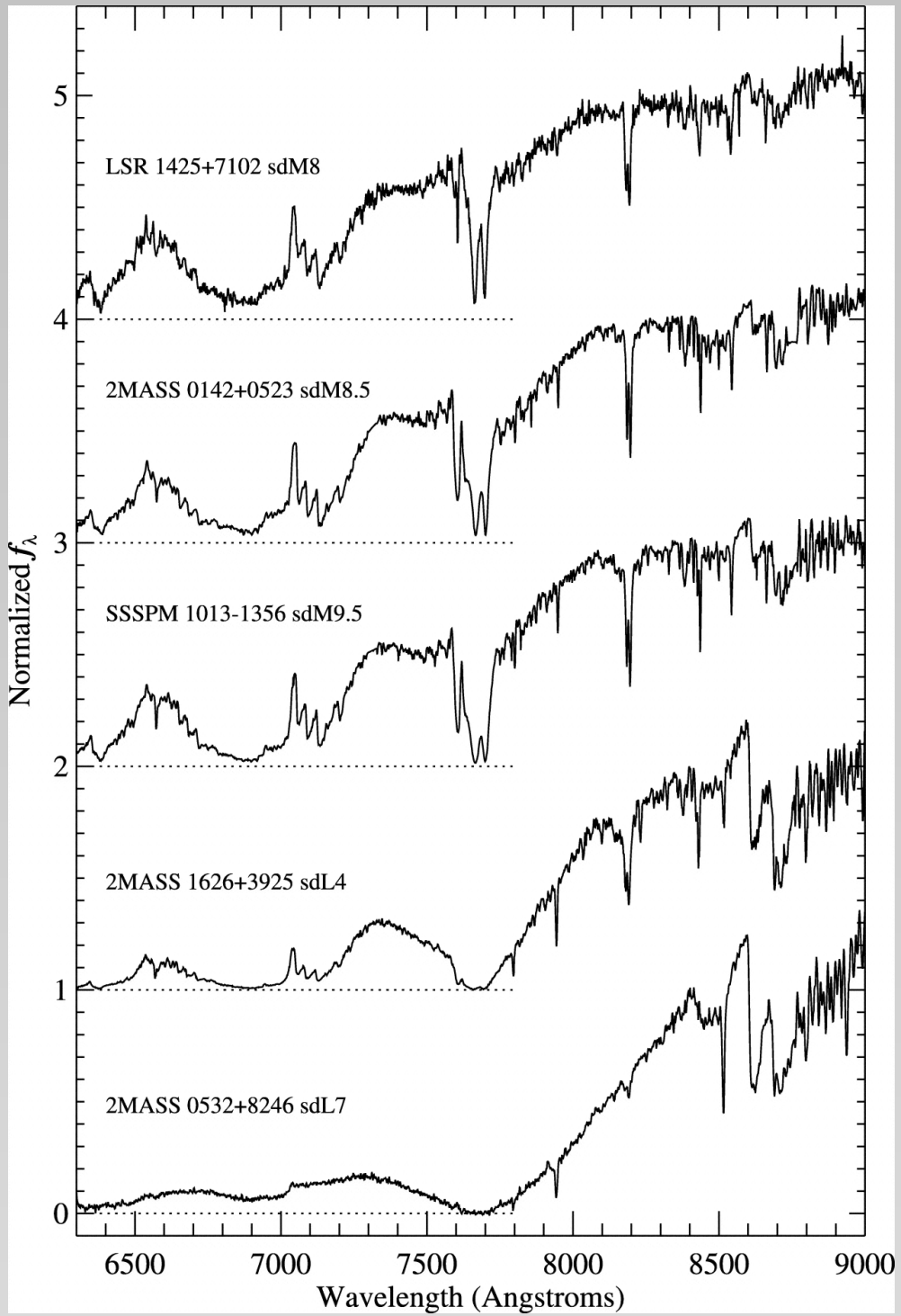
(Scholz, Meusinger & Jahreiß 2005)

Subdwarf colours – comparison with models



Scholz, Lodieu & McCaughrean (2004)

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

Conclusions and outlook

- High proper motion surveys continue to play an important role in finding new ultracool subdwarfs
- Classification spectroscopy with sufficient signal-to-noise and including blue optical wavelengths helps to distinguish nearby cool white dwarfs and more distant cool subdwarfs
- Trigonometric parallaxes are necessary for accurate UVW
- Existing classification scheme needs extension for >sdM7
- In addition to extreme subdwarfs (esd) with [m/H]~ -2.0 and normal subdwarfs (sd) with [m/H] = -1.5…-1.0 there are ultra-cool halo objects with moderately low-metallicity [m/H] ~ -0.5
- First high-resolution spectra (2MASS 0532 !!) have provided accurate RVs and rotational velocities (Reiners & Basri 2006)