Properties of metal-poor transitional and degenerate brown dwarfs

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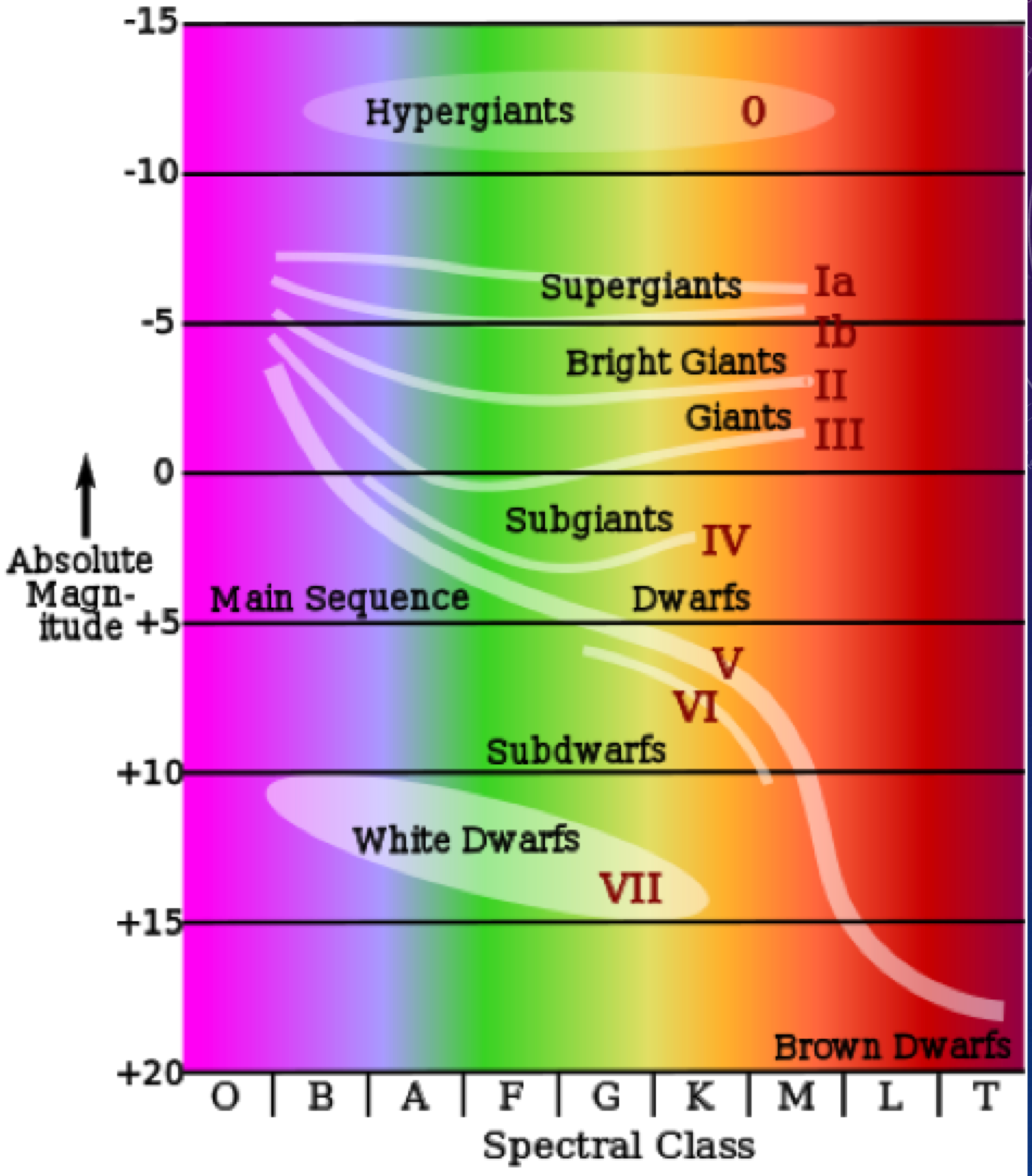
Outline

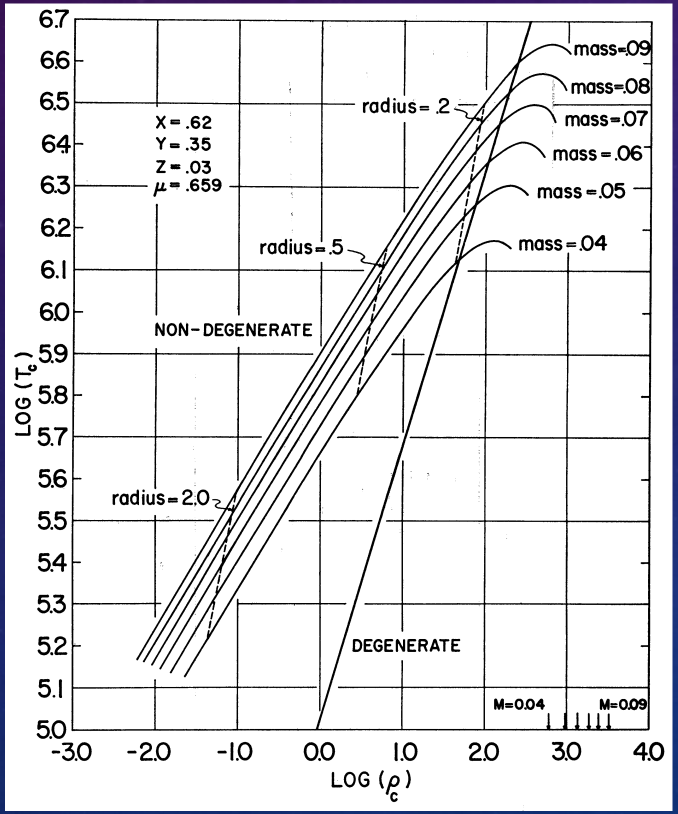
- Theories of brown dwarfs (BD) and early discoveries
- The identification and classification of L subdwarfs
- Physical properties of ultracool subdwarfs
- Transition zones related to nuclear burnings (H, Li, D).
- Properties of transitional BDs (T-BD) and degenerate BDs (D-BD)

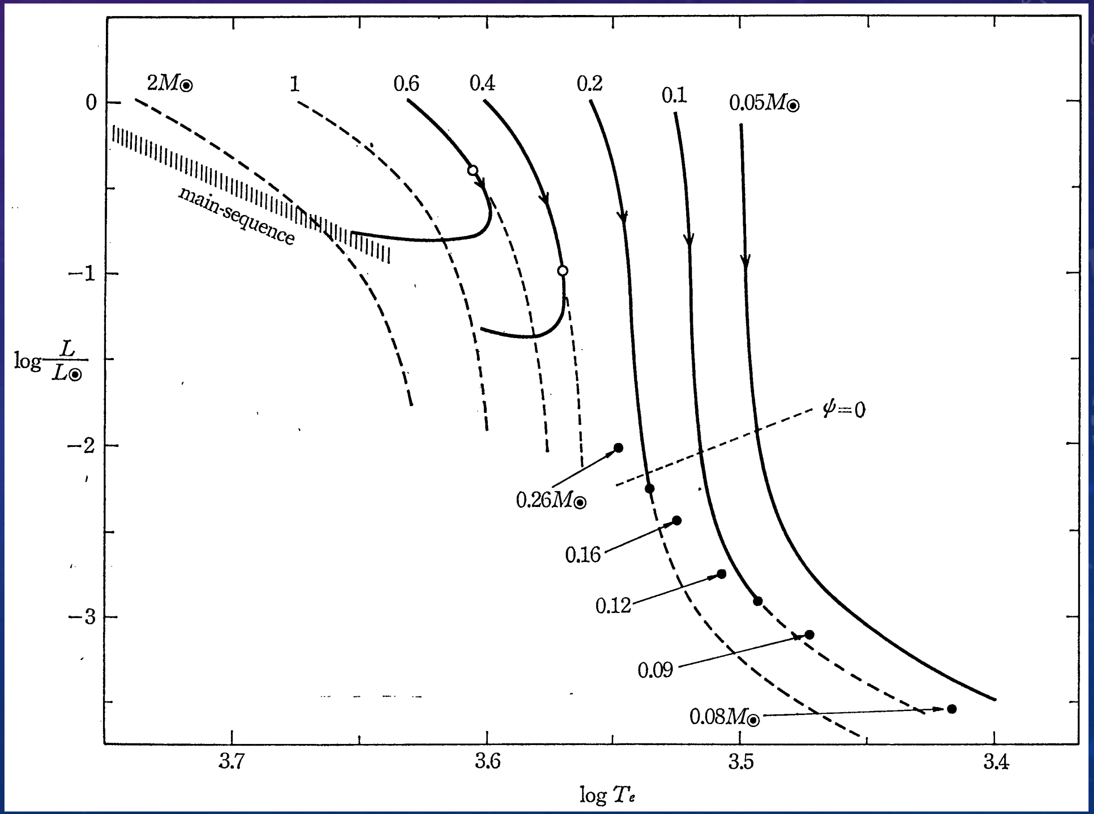
The HR diagram



Theoretical predictions

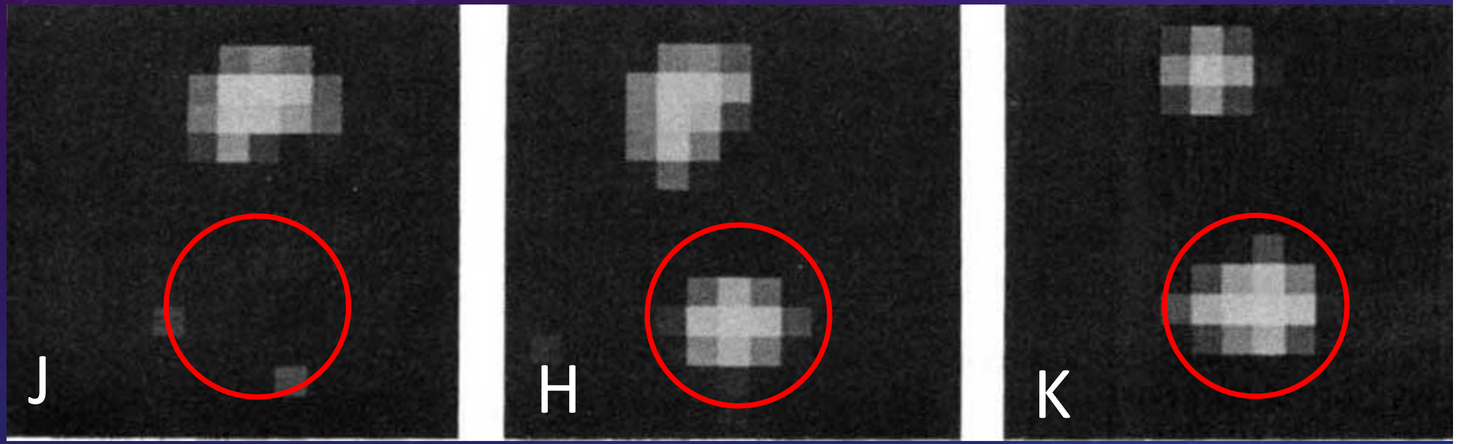
- Without convection, the time-scale for stars <0.1 Msun to reach radiative equilibrium is >100 Gyr.
- Hayashi (1962), low-mass pre MS stars are fully convective during contraction.
- Kumar 1963ab, HBMM is between 0.07 $M_\odot$ for Pop I (0.09 $M_\odot$ Pop II).
- Hayashi & Nakano (1963), HBMM ~ 0.08 $M_\odot$ for Pop I.

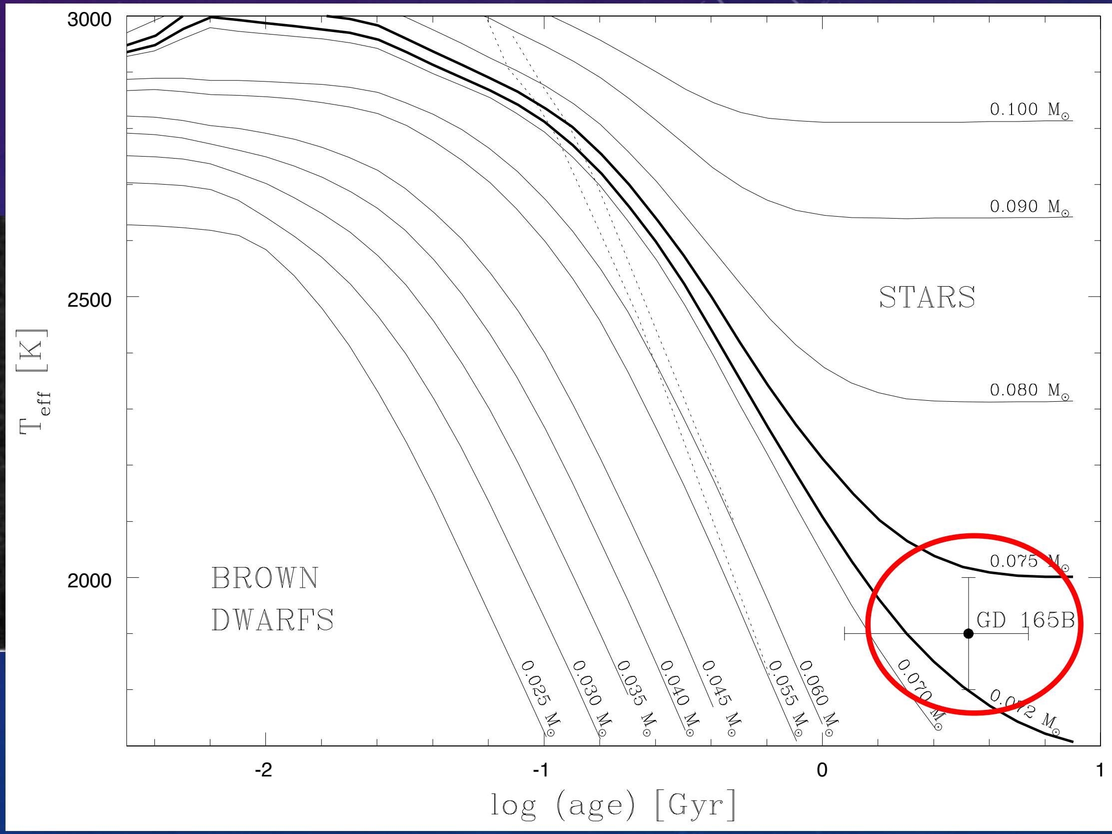




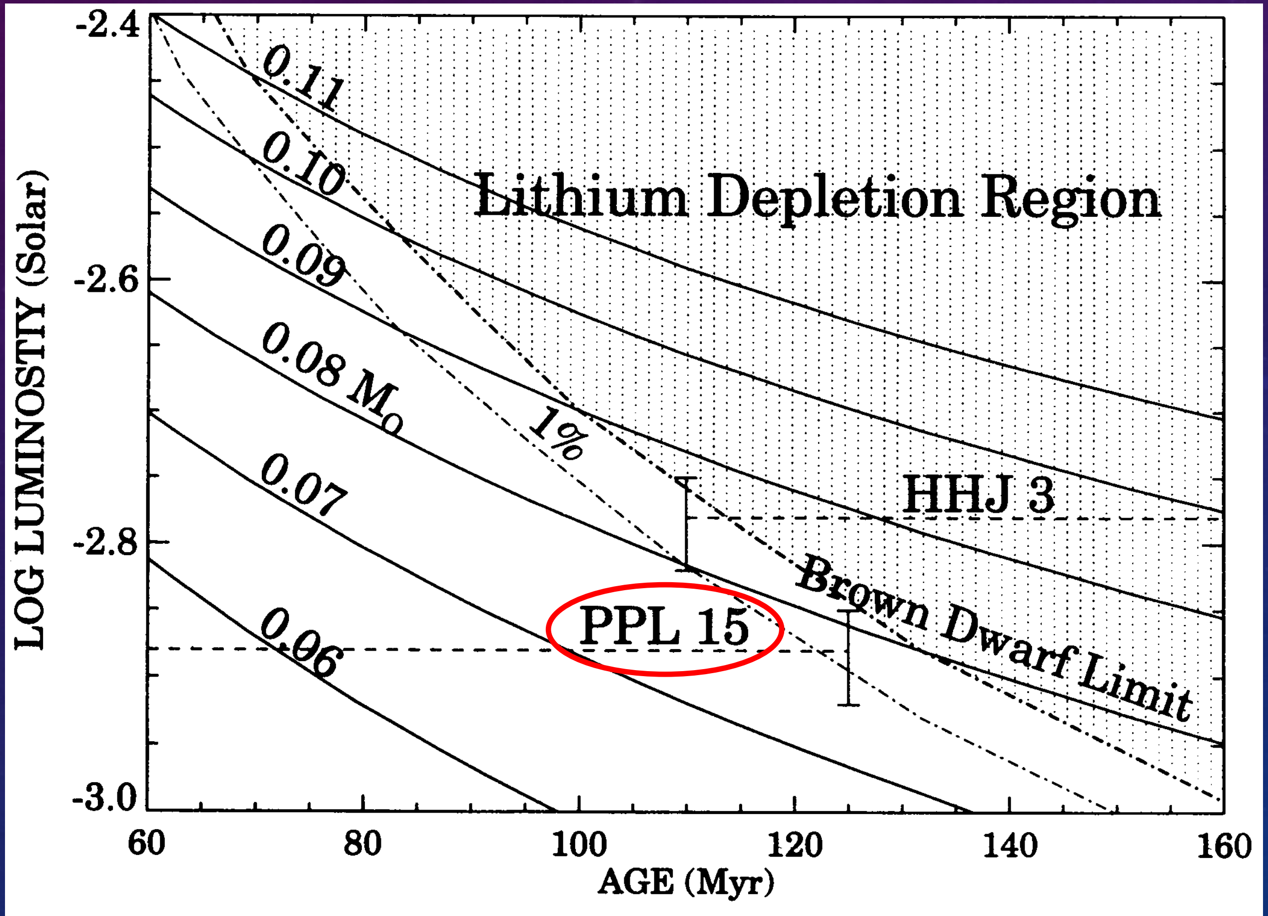
GD 165B: an L4 companion to a DA4 WD

Becklin & Zuckerman 1988; Kirkpatrick et al. 1993, 1999



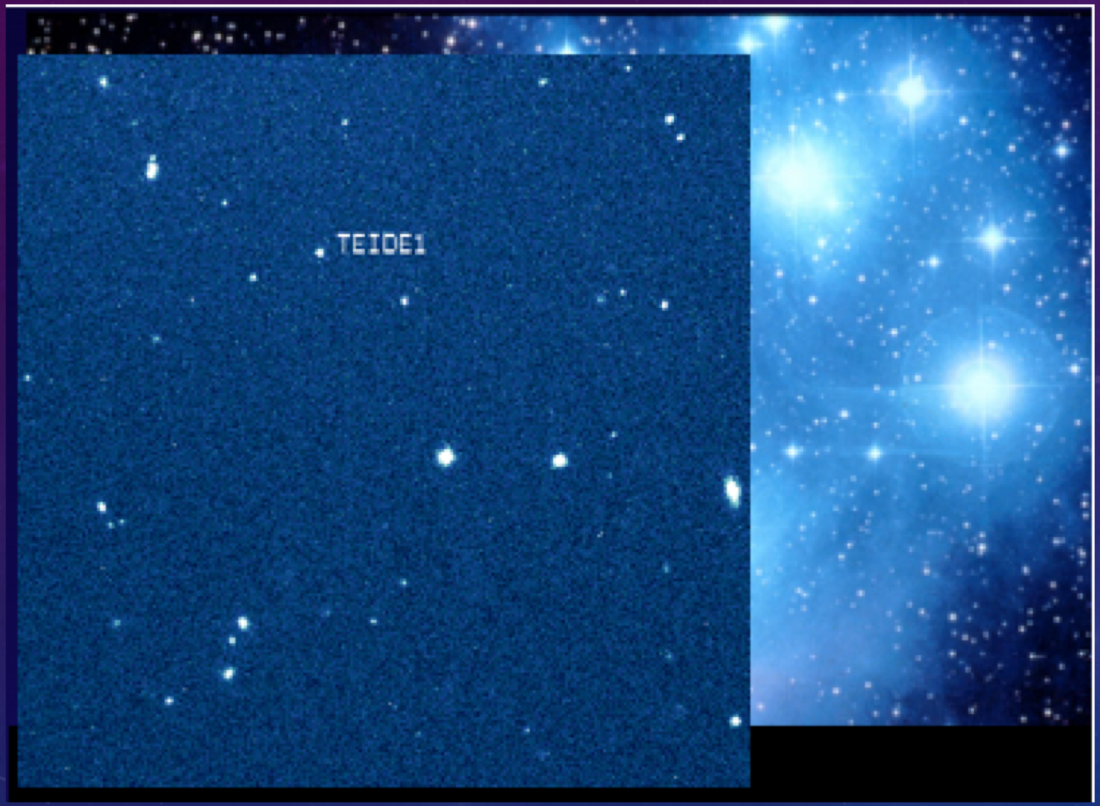


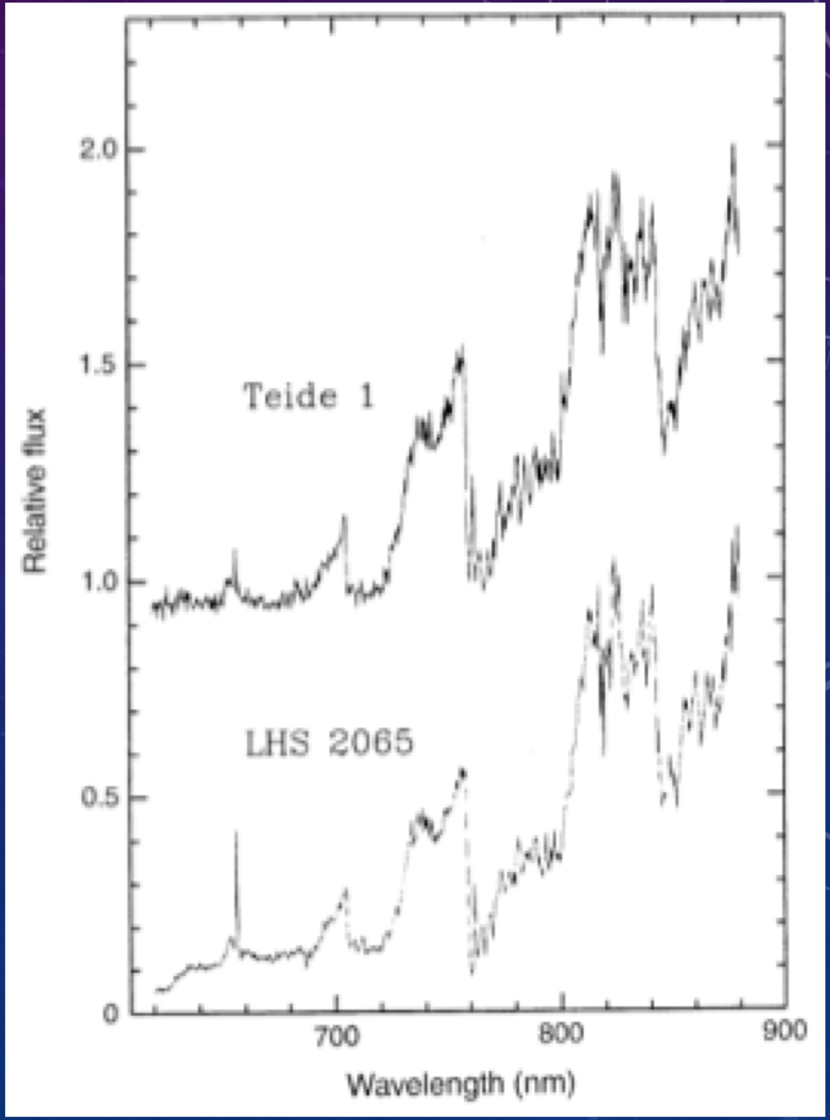
PPL 15 AB: a M6.5 lithium BD binary



Basri+1996, 1999

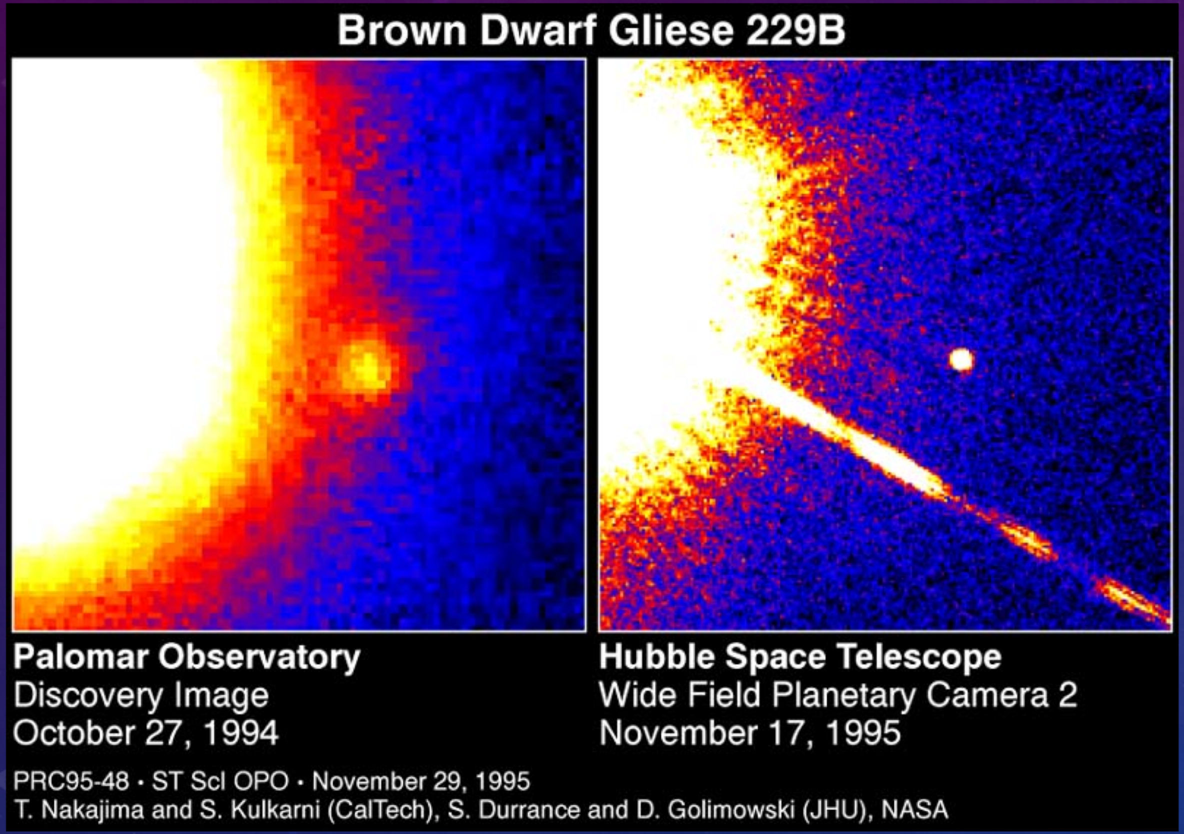
Teide 1: a M8 dwarf in the pleiades

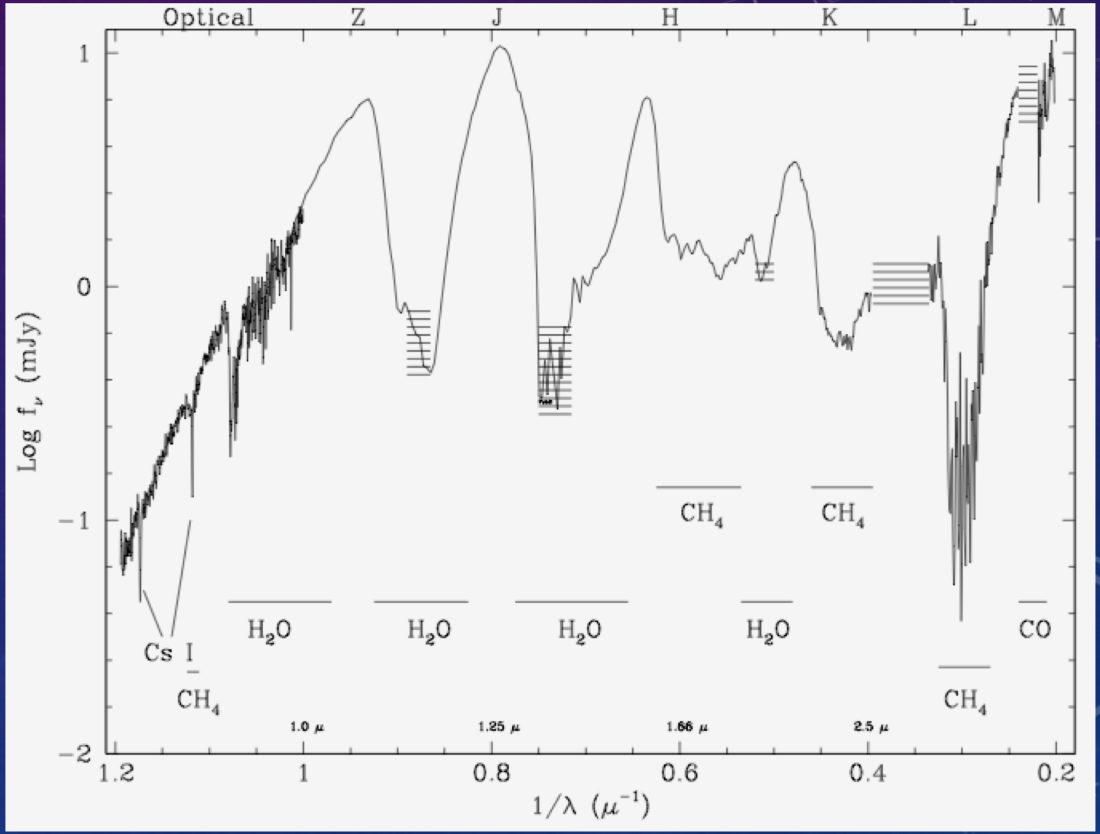




Rebolo, Zapatero Osorio & Martin 1995
Rebolo+96, Li line.

GL229 B: a T7 companion to a M1 dwarf





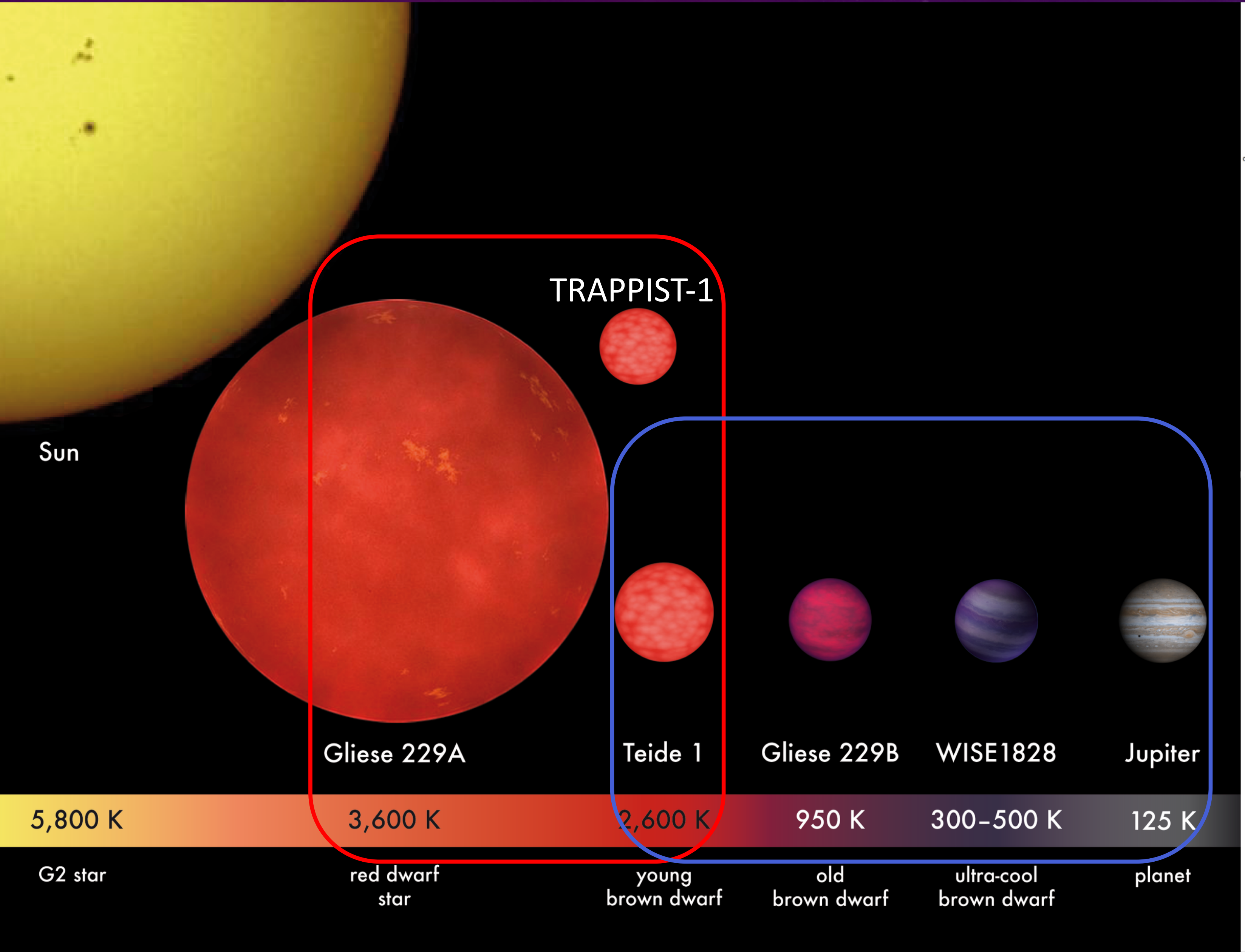
Nakajima+1995; Oppenheimer+1995

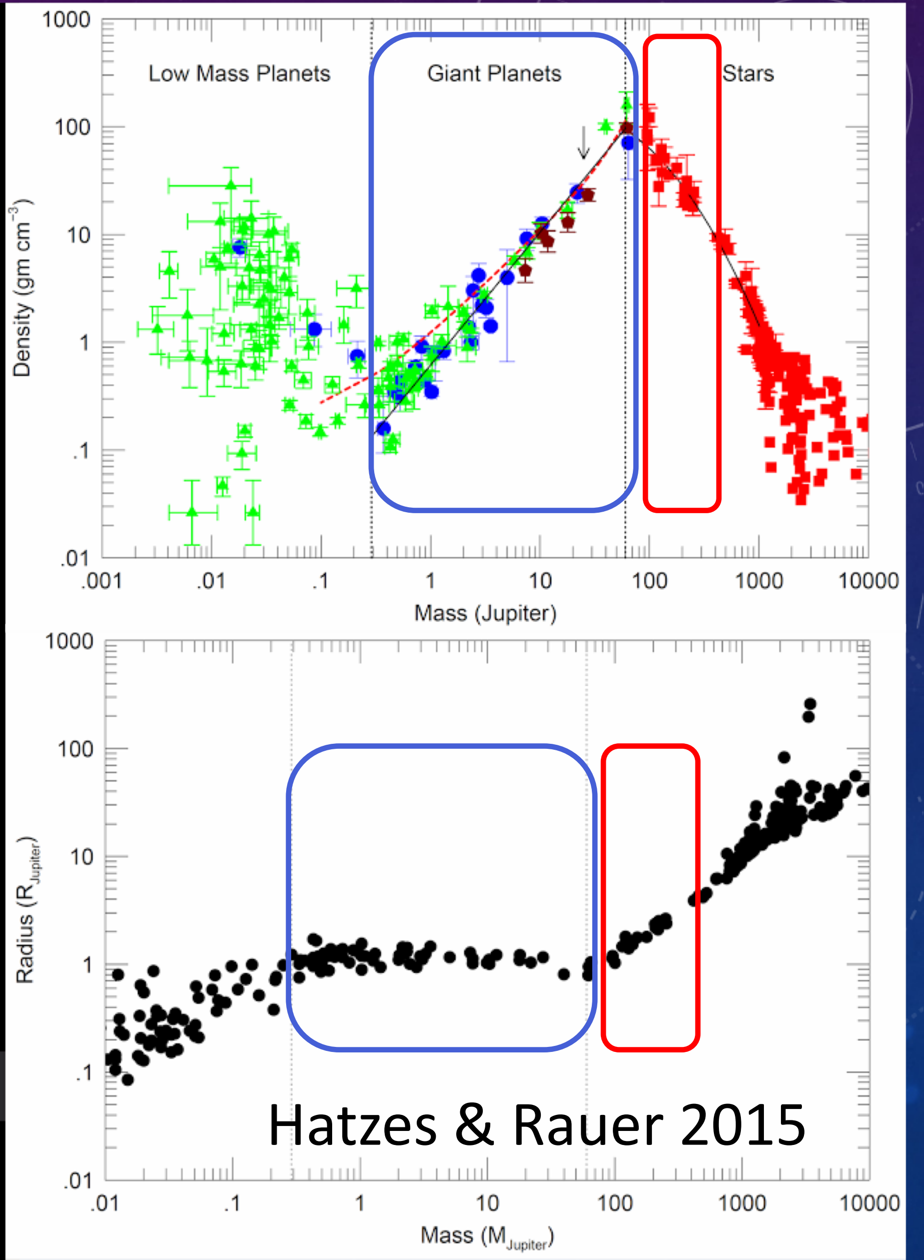
Spectral classification

- O B A F G K
- M: CaH, TiO. (Bessell 1991; Kirkpatrick, Henry, & McCarthy 1991)
- L: alkali lines, oxide, hydride (FeH). (Kirkpatrick et al. 1999; Martin et al. 1999)
- T: Methane (CH4), Water, broad potassium (KI). (Burgasser et al. 2002,2003)
- Y: Ammonia (NH3). (Cushing et al. 2011; Kirkpatrick et al. 2012)

- Oh, Be A Fine Girl/Guy Kiss My Lips Tonight, Yahoo!

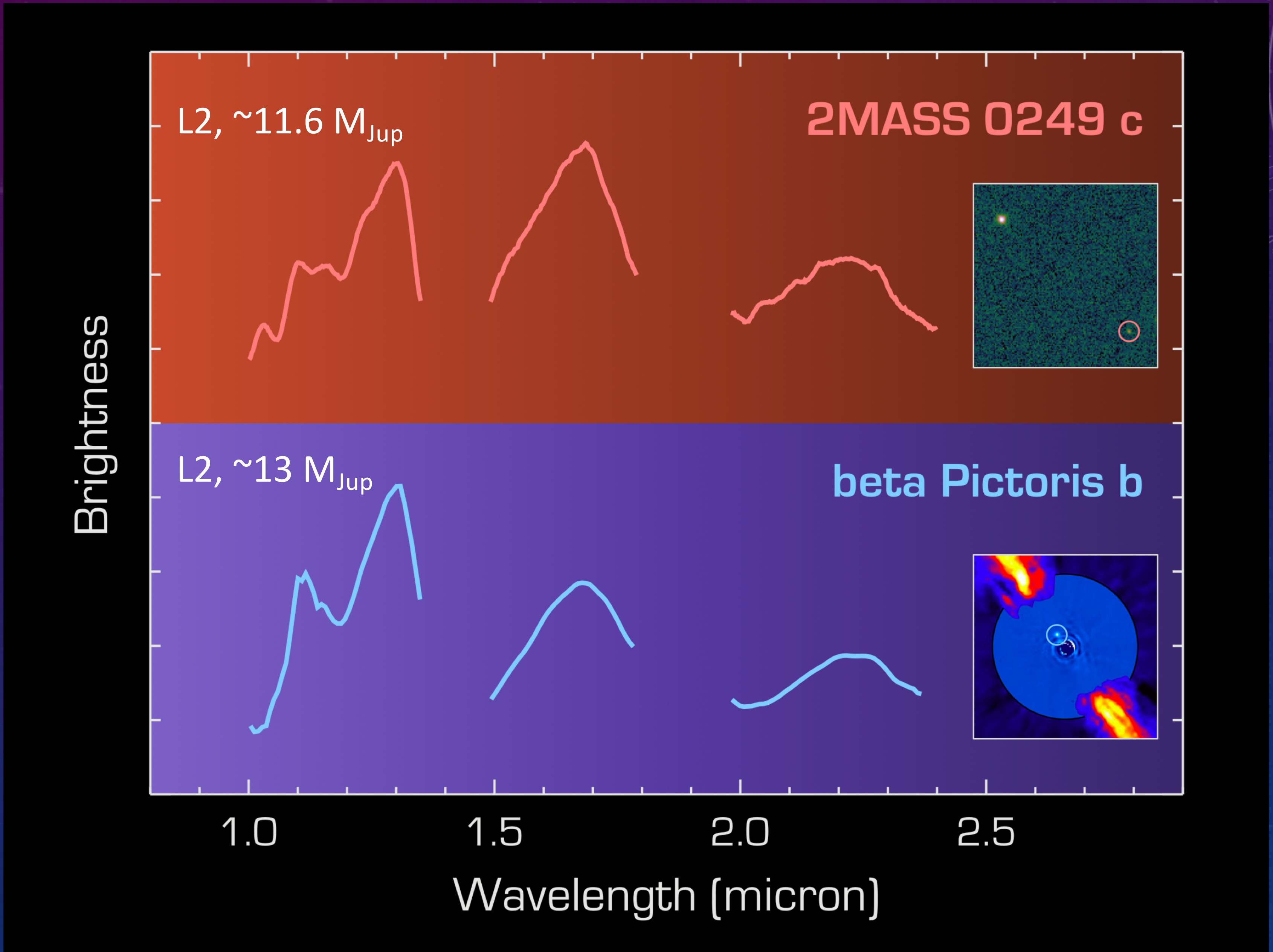
The low-mass populations





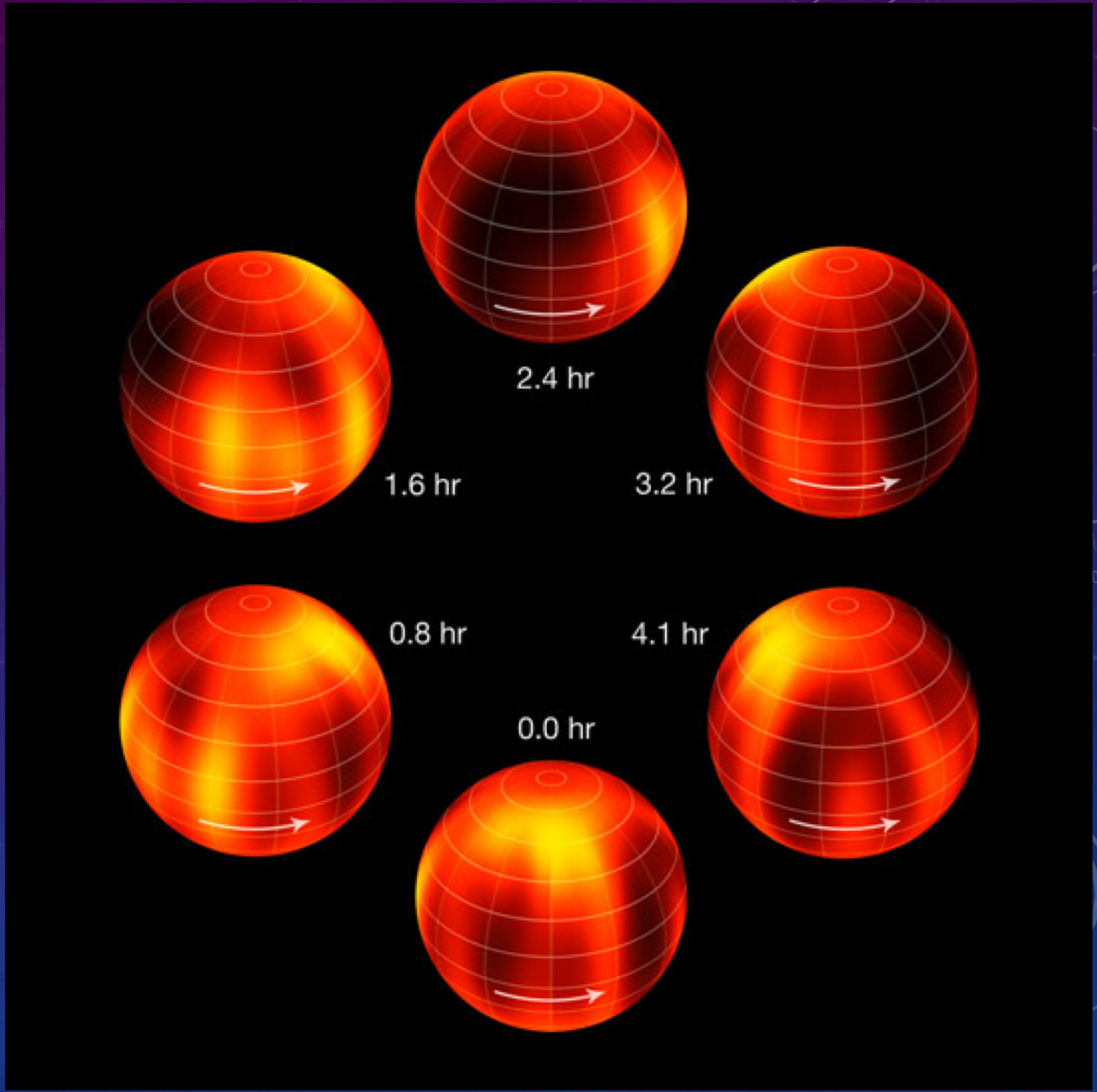
Hatzes & Rauer 2015

2MASS 0249 c (Dupuy+18) & Beta Pictoris b (Chilcote+17)



Hour-day variable periods

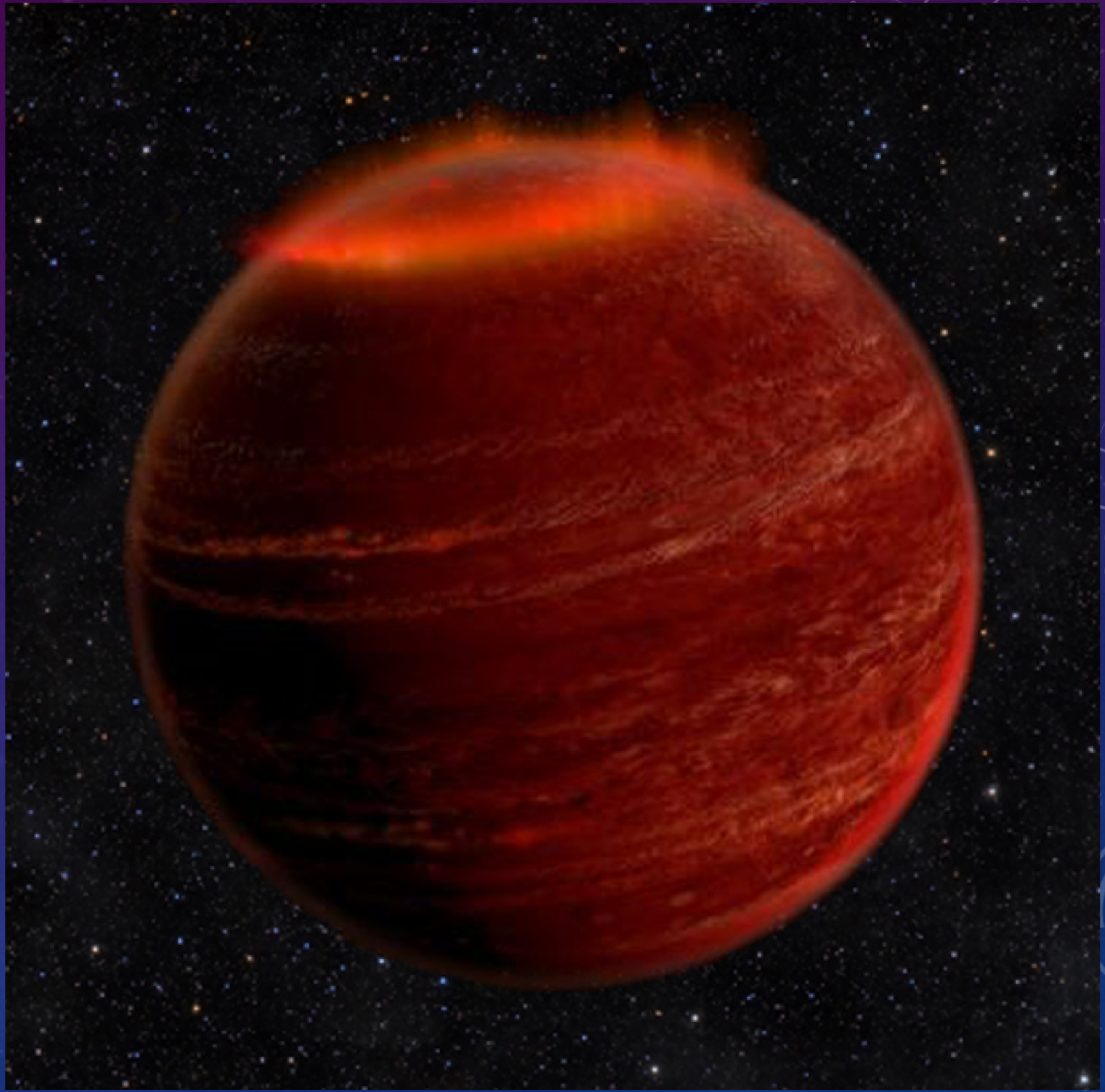
- Stanimir et al. 2015,
- Biller 2017



Luhman 16B; Crossfield et al. 2014

Radio emissions

- Berger et al. 2001;
- Hallinan et al. 2008

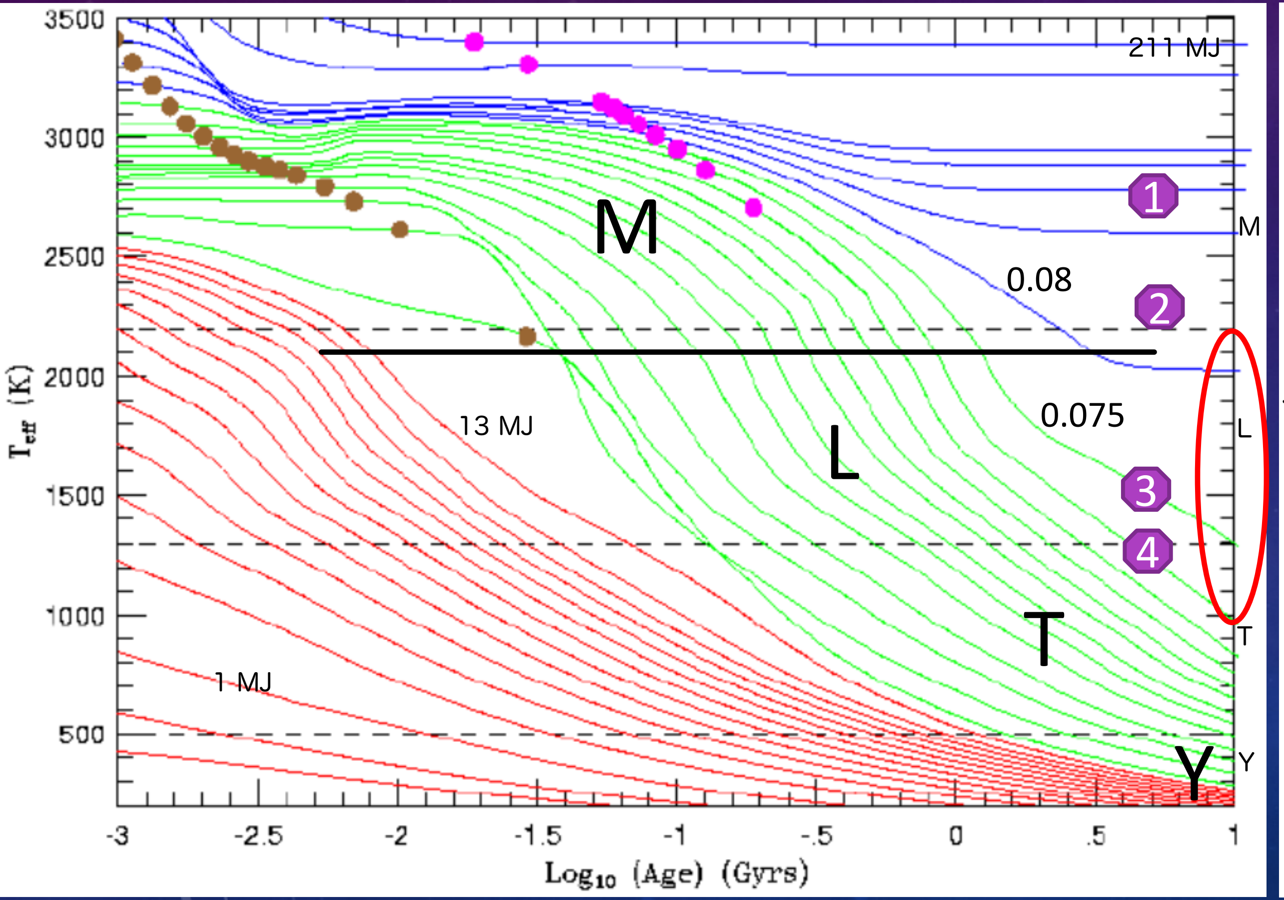


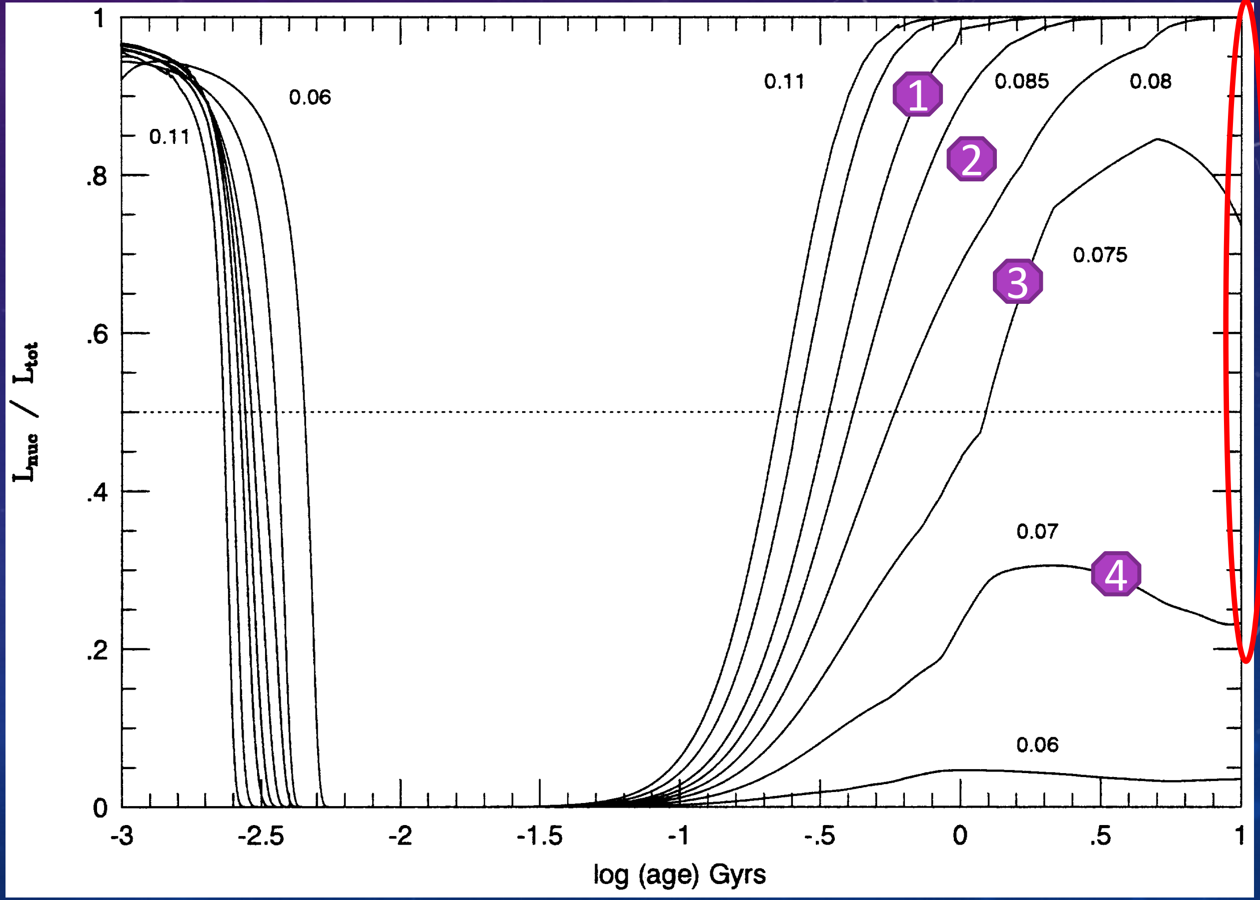
LSR J1835+3259; Hallinan et al. 2015

Impacts in other fields

- Sensitive to initial mass function.
- Test stellar/substellar formation theories.
- Help to characterize exoplanets.
- As exoplanet hosts.

Evolutionary tracks and energy supply (Burrows+93, 97)



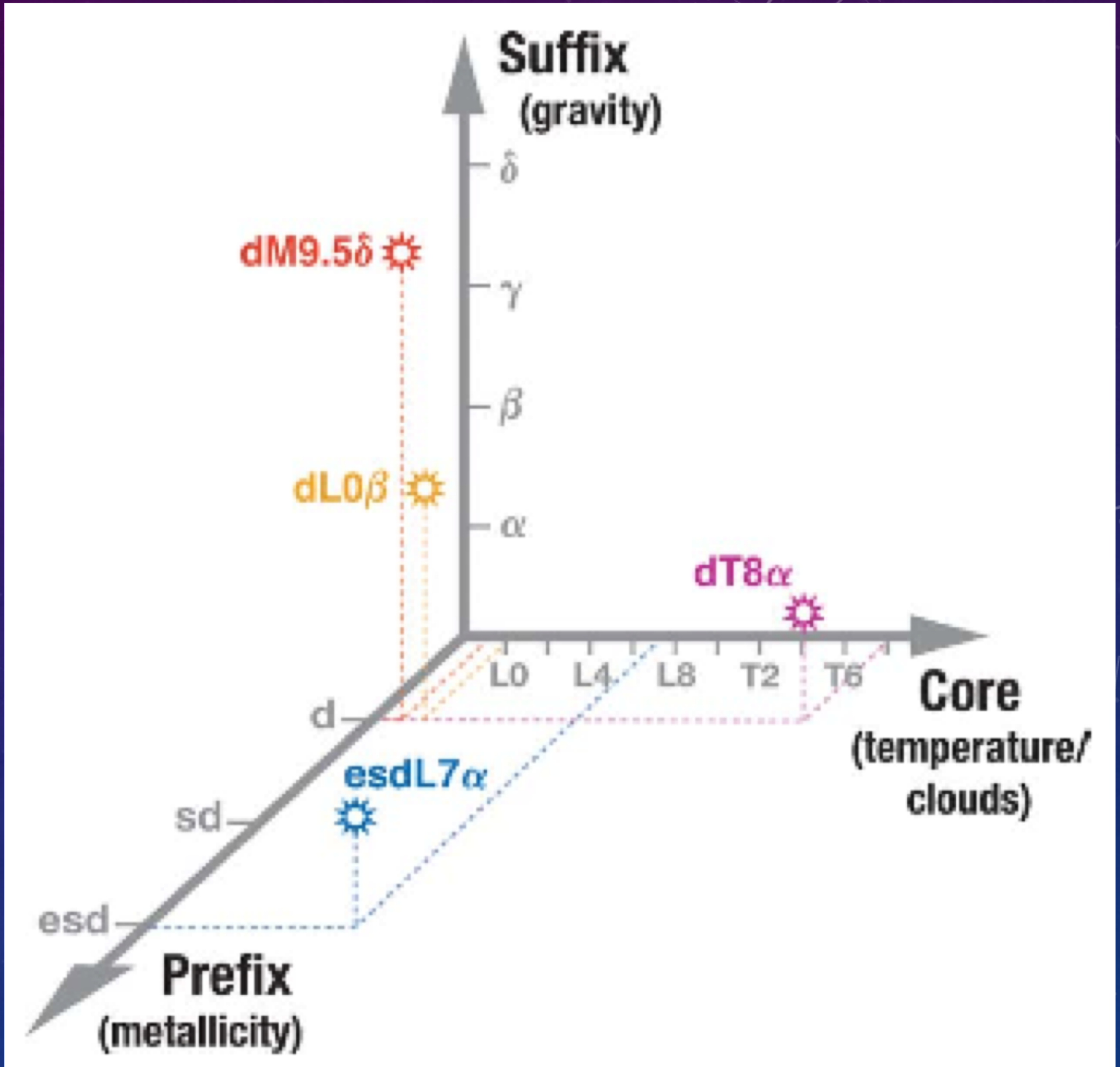


Metal-poor brown dwarfs

- Halo or thick disk populations, high velocities and proper motions
- Low opacity, higher maximum mass.
- Stronger metal hydride (FeH), weaker metal oxide (CO, VO, TiO), and suppressed NIR flux.

Spectral classification

- Prefix + Core + Suffix for Metallicity + Temperature and clouds + Gravity. (Kirkpatrick 2005)
- Burgasser et la. 2007
- Kirkpatrick et al. 2010

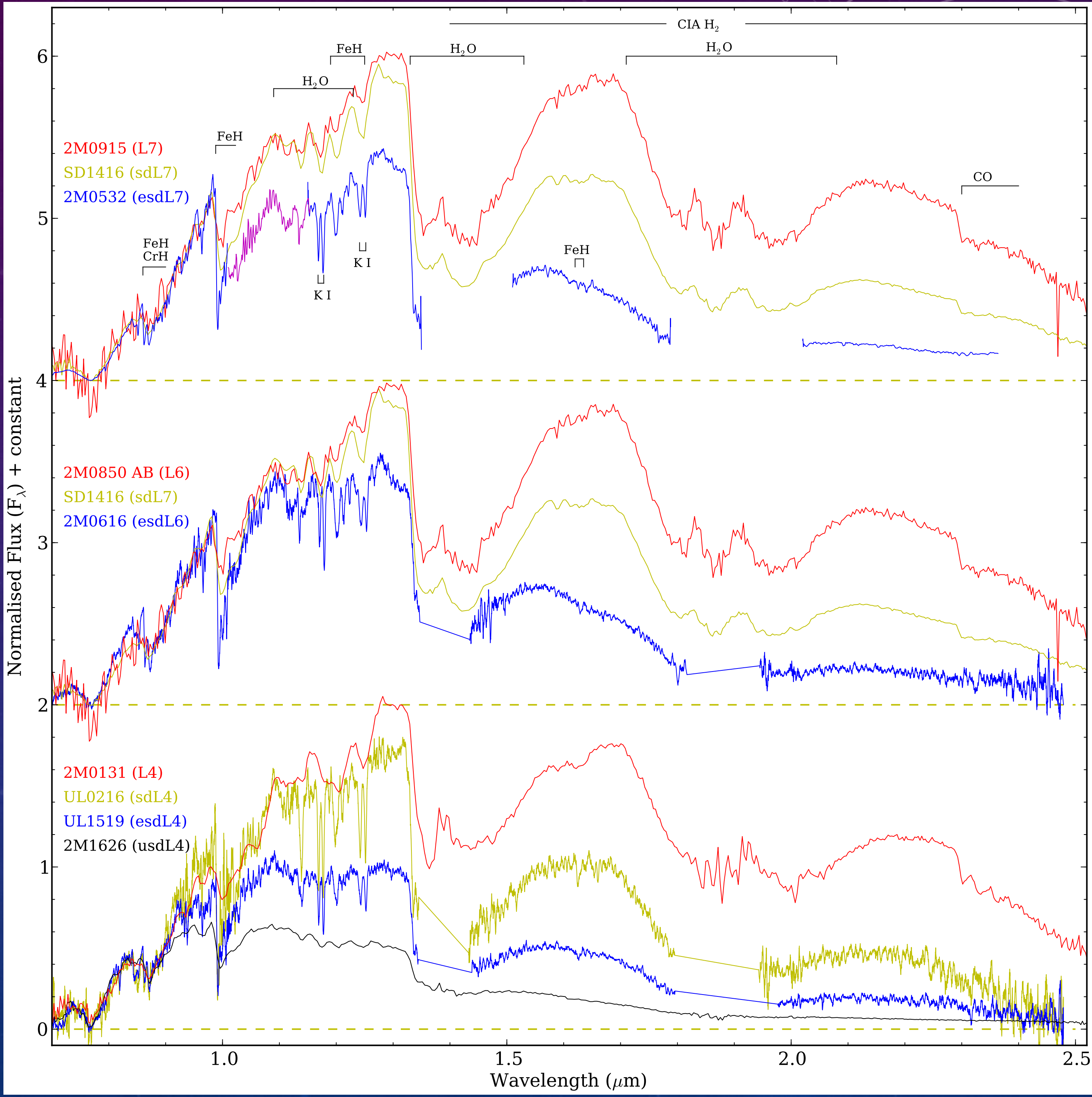


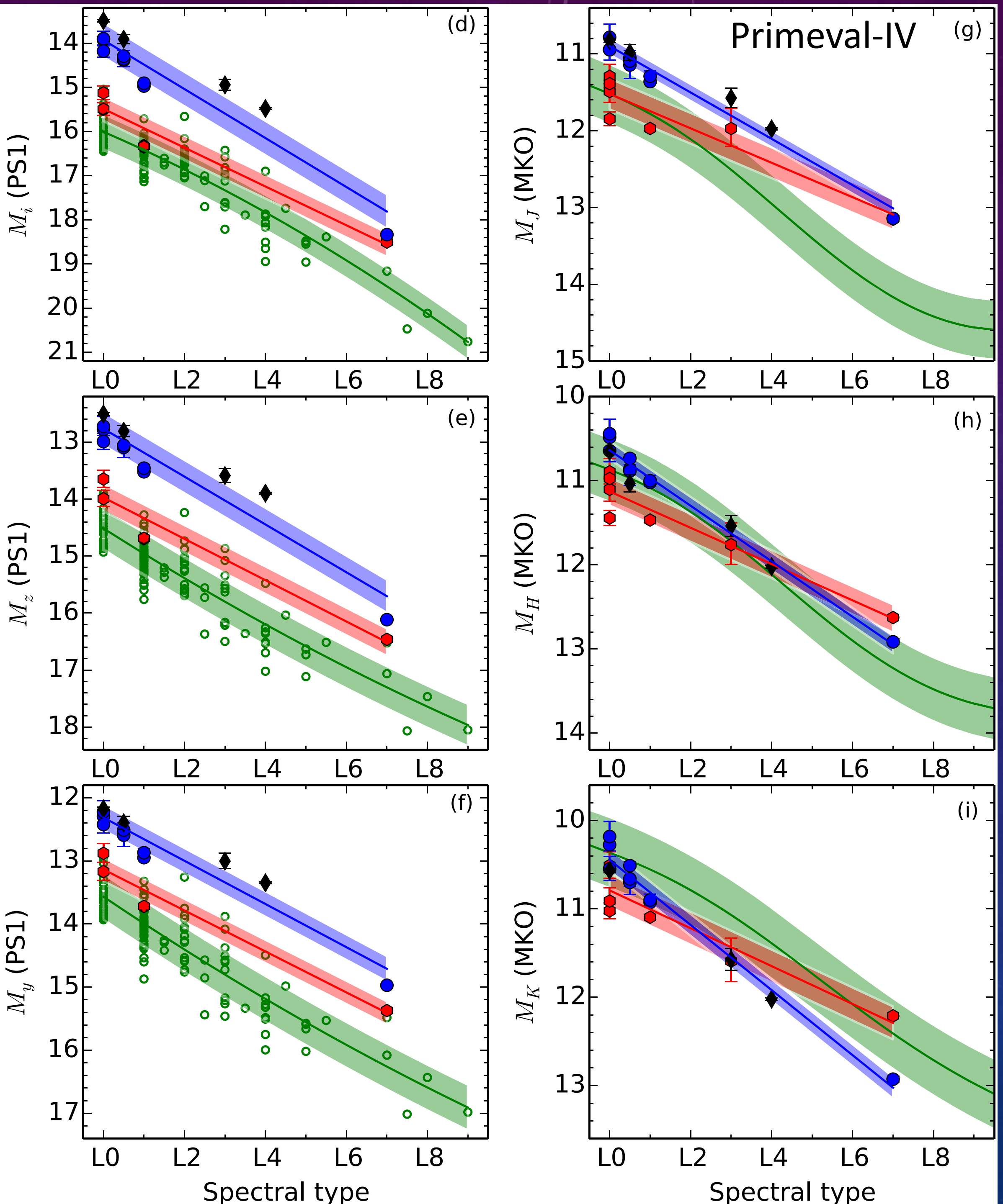
Kirkpatrick 2005

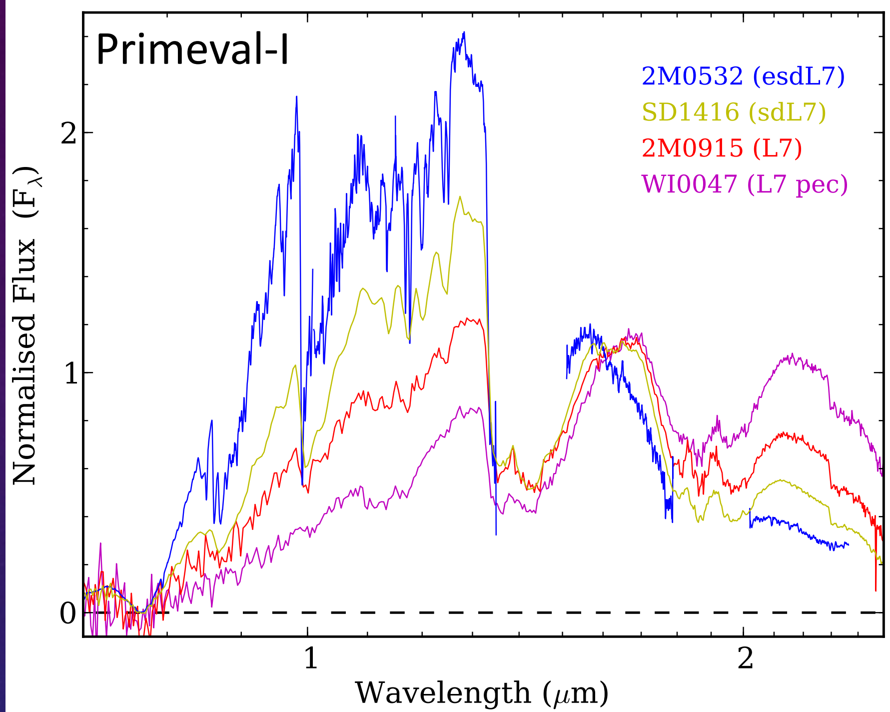
Spectral classification of L subdwarfs (Primeval-I)

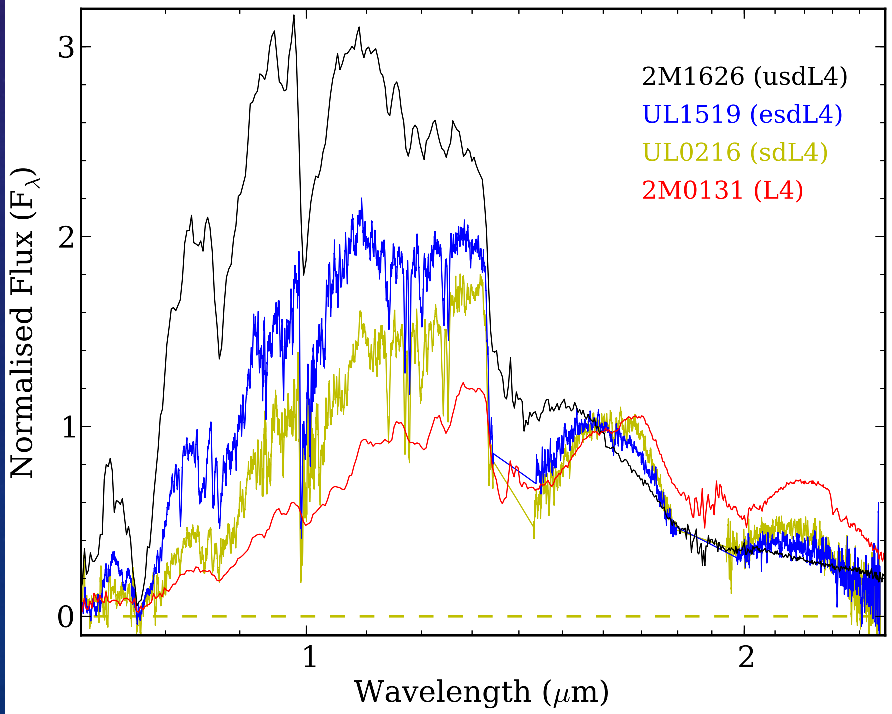
- dL, [Fe/H] > -0.3 Thin
- sdL, -1.0 < [Fe/H] < -0.3 Thick
- esdL, -1.7 < [Fe/H] < -1.0 Halo
- usdL, [Fe/H] < -1.7 Halo

Stars	BDs
O B A F G K M -	L T Y

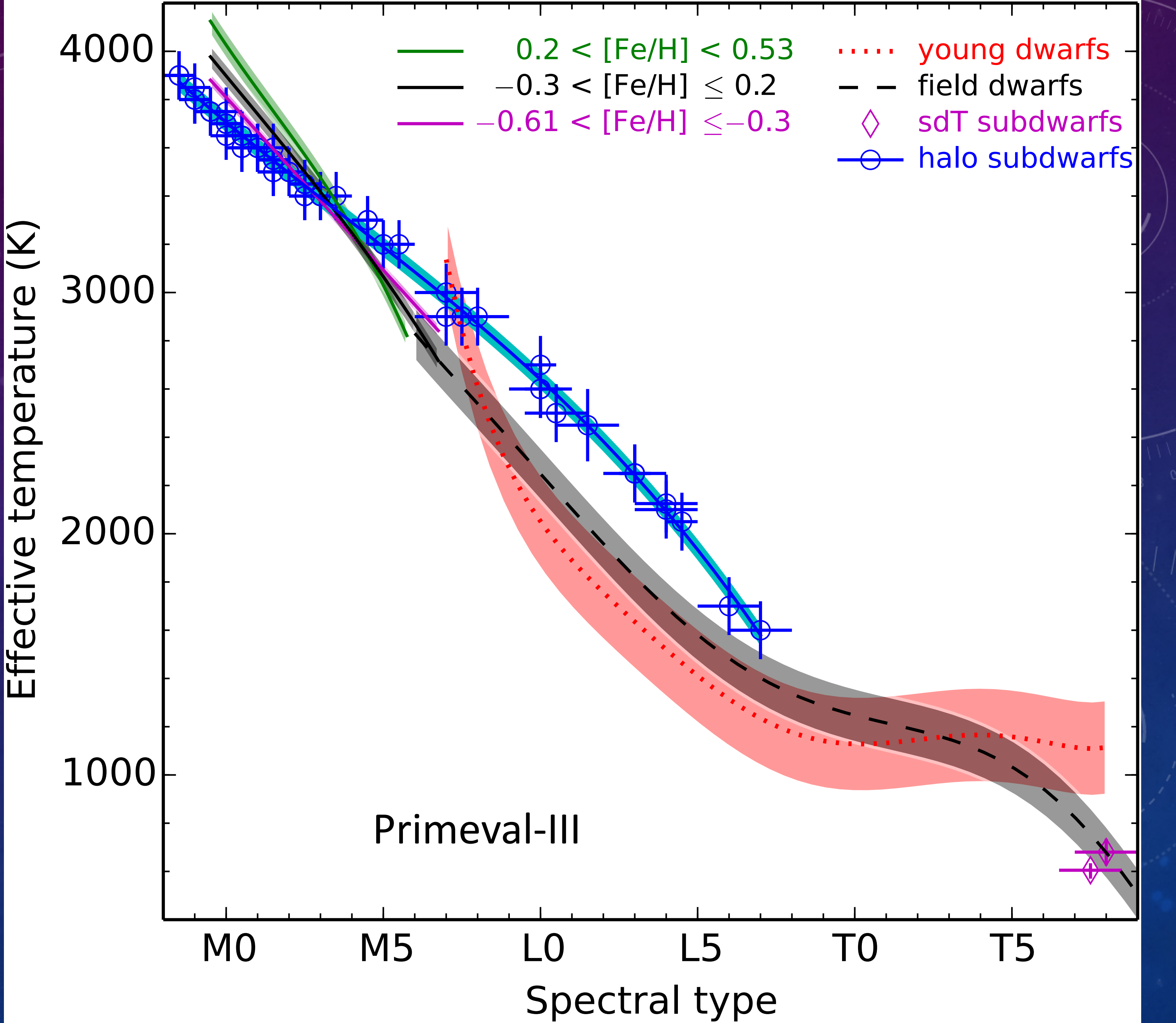



Primeval-IV
(d)
(e)
(f)
(g)
(h)
(i)
M_i (PS1)
M_z (PS1)
M_y (PS1)
M_J (MKO)
M_H (MKO)
M_K (MKO)
L0 L2 L4 L6 L8
Spectral type
Spectral type

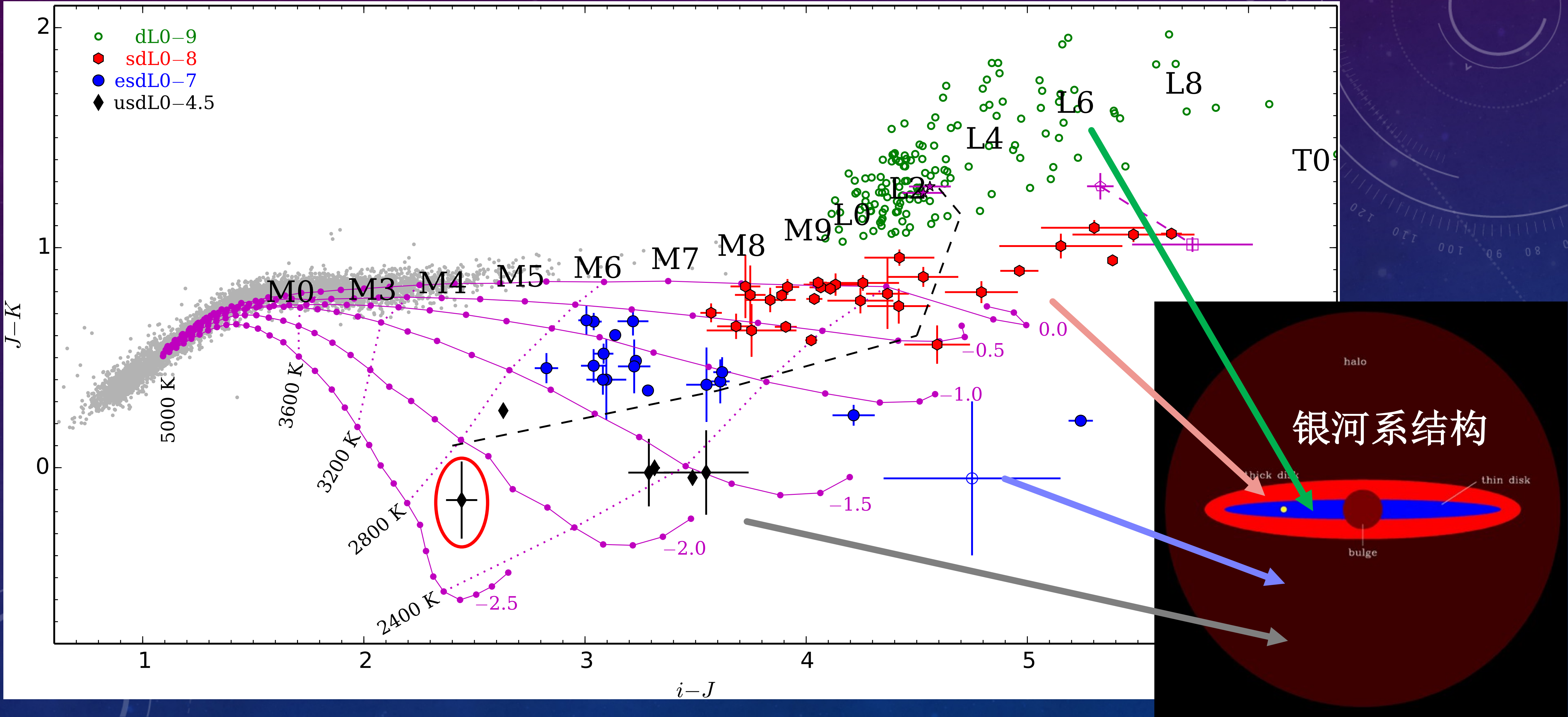

Primeval-I
2M0532 (esdL7)
SD1416 (sdL7)
2M0915 (L7)
WI0047 (L7 pec)
Normalised Flux (F_λ)
Wavelength (μm)


2M1626 (usdL4)
UL1519 (esdL4)
UL0216 (sdL4)
2M0131 (L4)
Normalised Flux (F_λ)
Wavelength (μm)

T_{eff} of subdwarfs



Colours of L subdwarfs (Primeval-I, III, IV)



The most metal-poor substellar object (Primeval-II)

- SDSS J0104+15
- usdL1.5
- 2450 K
- **[Fe/H] = -2.4**
- 0.086 $M_{\odot}$

NEWS & PRESS

Astronomers identify purest, most massive brown dwarf

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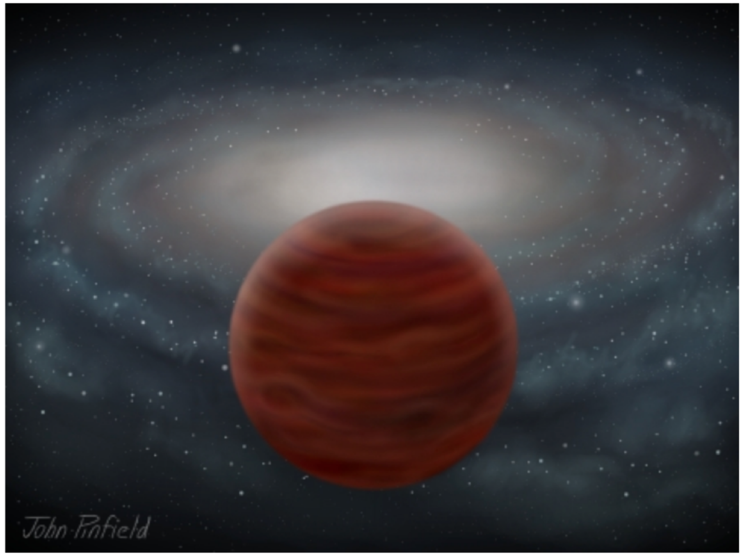
Published on Friday, 24 March 2017 06:00

An international team of astronomers has identified a record breaking brown dwarf (a star too small for nuclear fusion) with the 'purest' composition and the highest mass yet known. The object, known as SDSS J0104+1535, is a member of the so-called halo – the outermost reaches - of our Galaxy, made up of the most ancient stars. The scientists report the discovery in *Monthly Notices of the Royal Astronomical Society*.



An artist's impression of the new pure and massive brown dwarf. Credit: John Pinfield. Click for a full size image

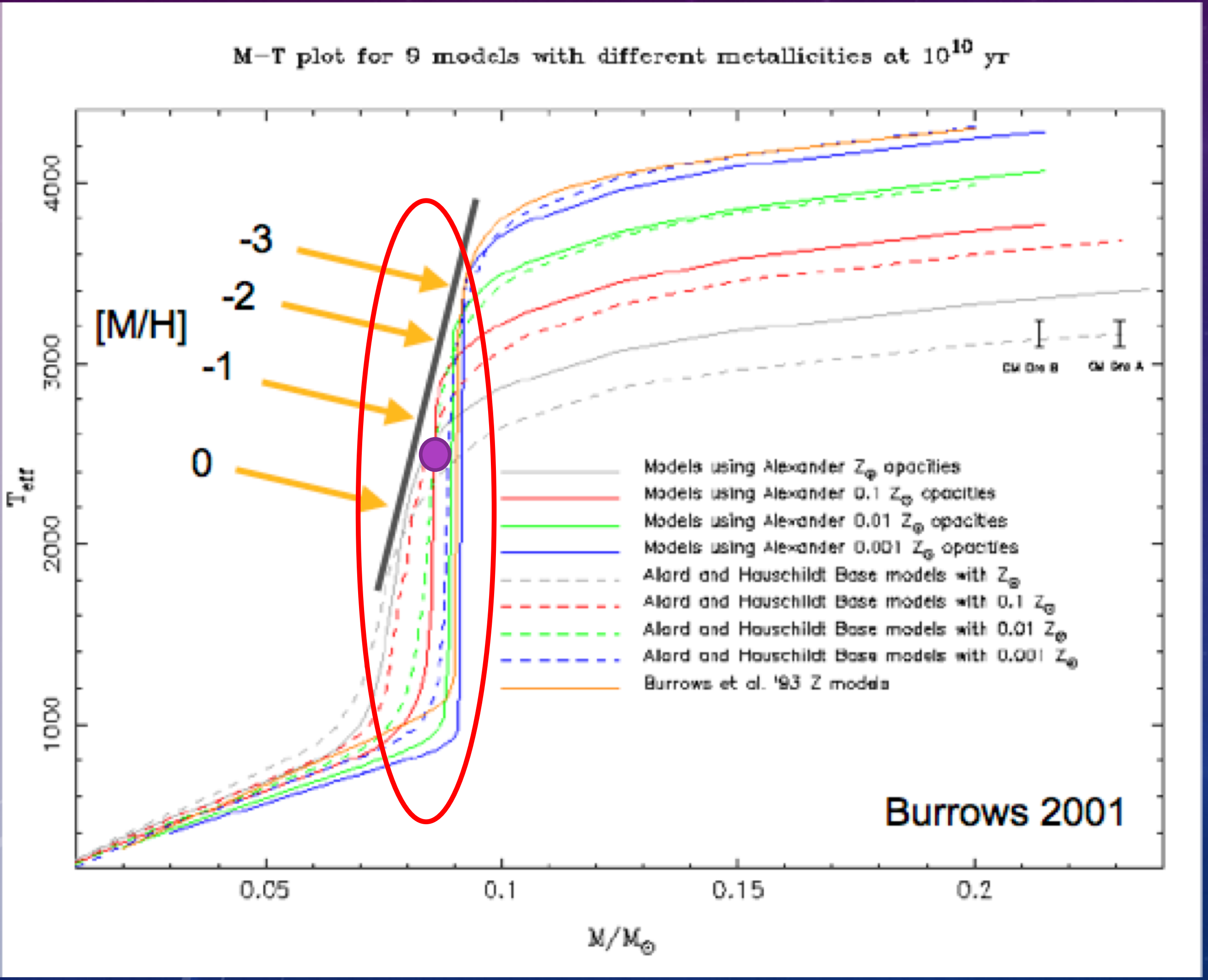
Brown dwarfs are intermediate between planets and fully-fledged stars. Their mass is too small for full nuclear fusion of hydrogen to helium (with a consequent release of energy) to take place, but they are usually significantly more massive than planets.

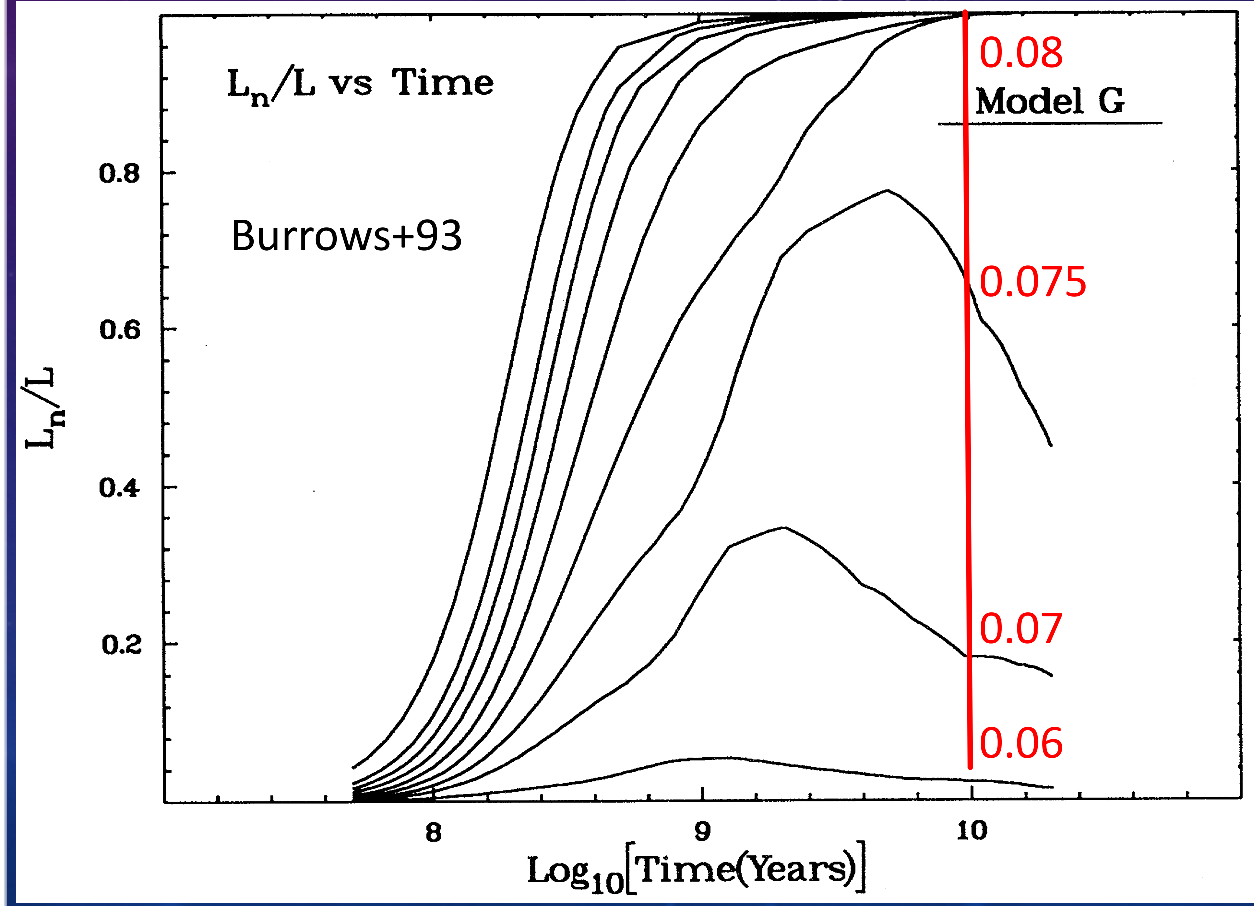
Located 750 light years away in the constellation of Pisces, SDSS J0104+1535 is made of gas that is around 250 times purer than the Sun, so consists of more than 99.99% hydrogen and helium. Estimated to have formed about 10 billion years ago, measurements also suggest it has a mass equivalent to 90 times that of Jupiter, making it the most massive brown dwarf found to date.

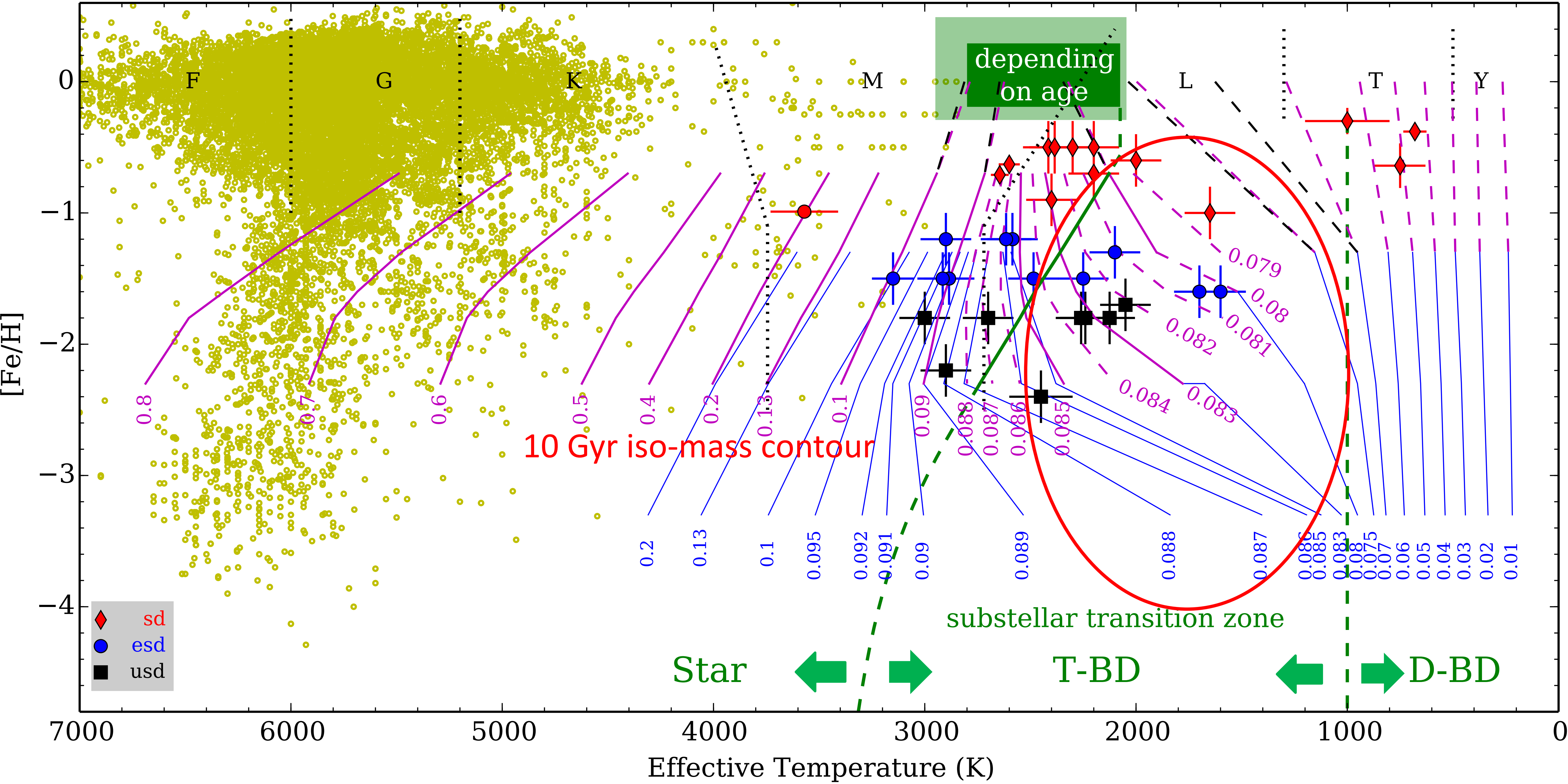
It was previously not known if brown dwarfs could form from such primordial gas, and the discovery points the way to a larger undiscovered population of extremely pure brown dwarfs from our Galaxy's ancient past.

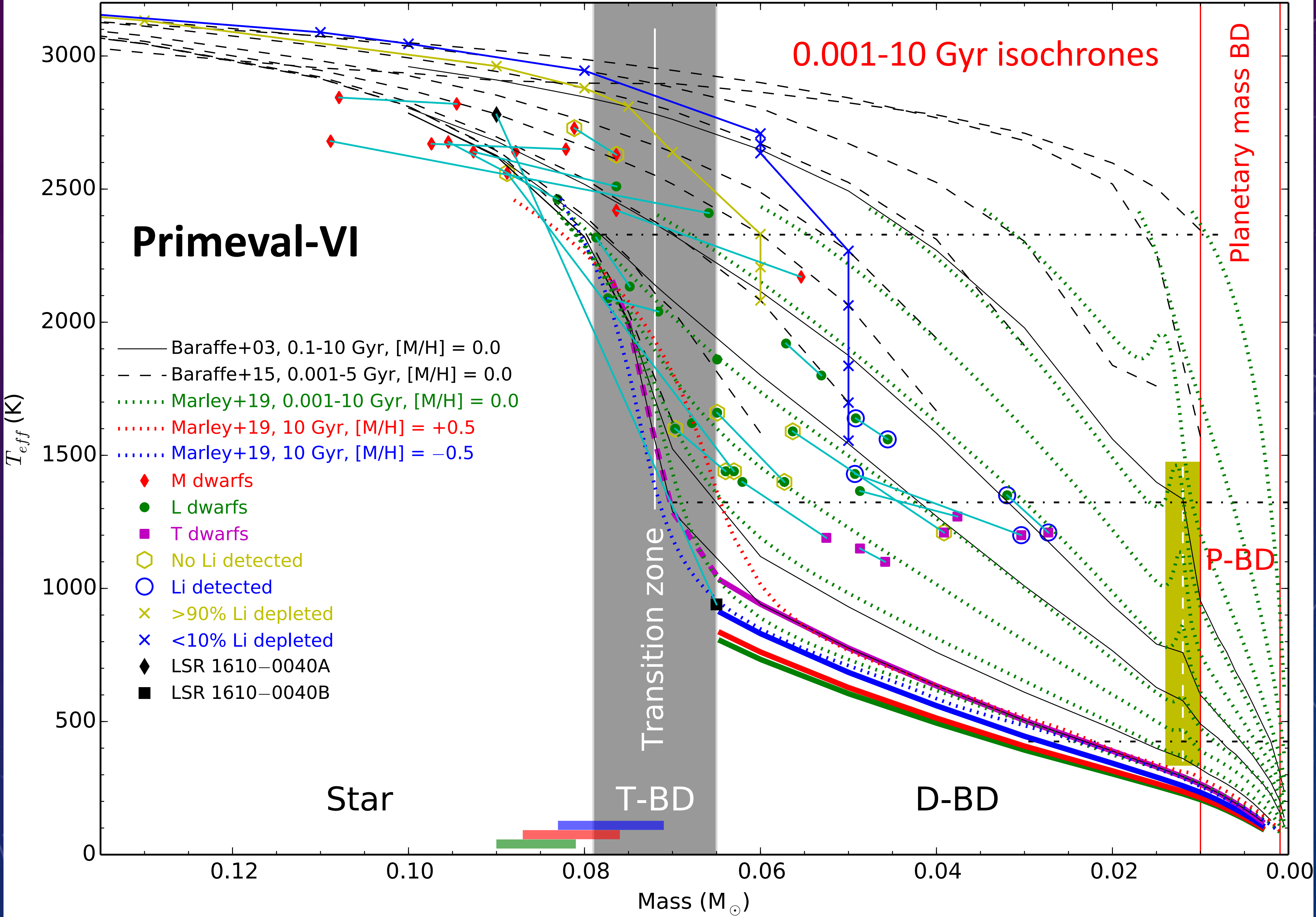
The research team was led by Dr ZengHua Zhang of the Institute of Astrophysics in the Canary Islands. He said: "We really didn't expect to see brown dwarfs that are this pure. Having found one though often suggests a much larger hitherto undiscovered population - I'd be very surprised if there aren't many more similar objects out there waiting to be found."

10 Gyr Teff isochrones with different metallicity





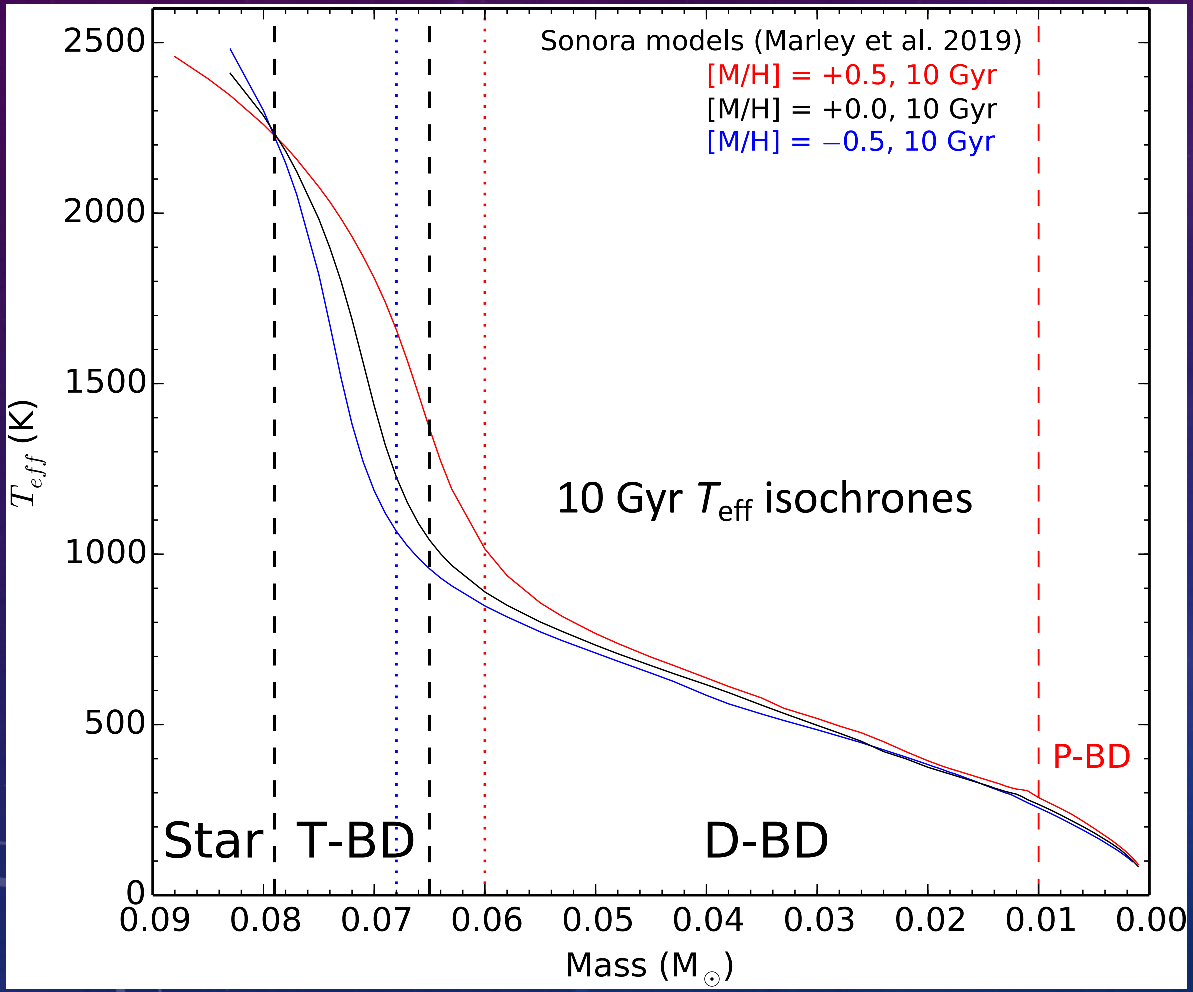

depending
on age
F
G
K
M
L
T
Y
[Fe/H]
Effective Temperature (K)
0.8
0.7
0.6
0.5
0.4
0.2
0.13
0.1
0.09
0.088
0.087
0.086
0.085
0.079
0.08
0.081
0.082
0.083
0.084
10 Gyr iso-mass contour
0.2
0.13
0.1
0.095
0.092
0.091
0.09
0.089
0.088
0.087
0.086
0.085
0.083
0.08
0.075
0.07
0.06
0.05
0.04
0.03
0.02
0.01
substellar transition zone
Star
T-BD
D-BD
sd
esd
usd
7000
6000
5000
4000
3000
2000
1000
0
0
−1
−2
−3
−4

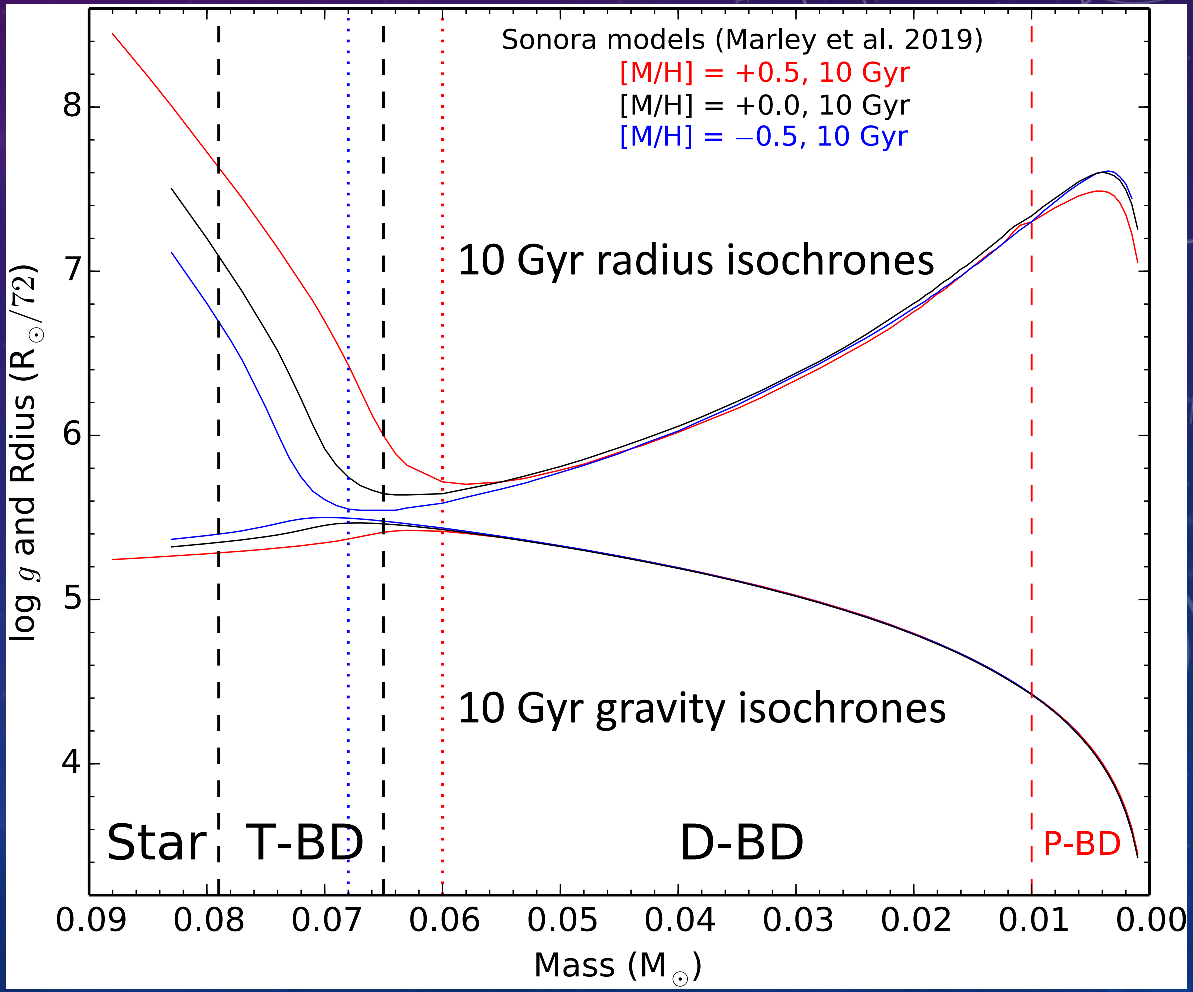


Primeval-VI
0.001-10 Gyr isochrones
Planetary mass BD
Baraffe+03, 0.1-10 Gyr, [M/H] = 0.0
Baraffe+15, 0.001-5 Gyr, [M/H] = 0.0
Marley+19, 0.001-10 Gyr, [M/H] = 0.0
Marley+19, 10 Gyr, [M/H] = +0.5
Marley+19, 10 Gyr, [M/H] = −0.5
M dwarfs
L dwarfs
T dwarfs
No Li detected
Li detected
>90% Li depleted
<10% Li depleted
LSR 1610−0040A
LSR 1610−0040B
Transition zone
Star
T-BD
D-BD
P-BD
T_{eff} (K)
Mass ($M_\odot$)
3000
2500
2000
1500
1000
500
0
0.12
0.10
0.08
0.06
0.04
0.02
0.00

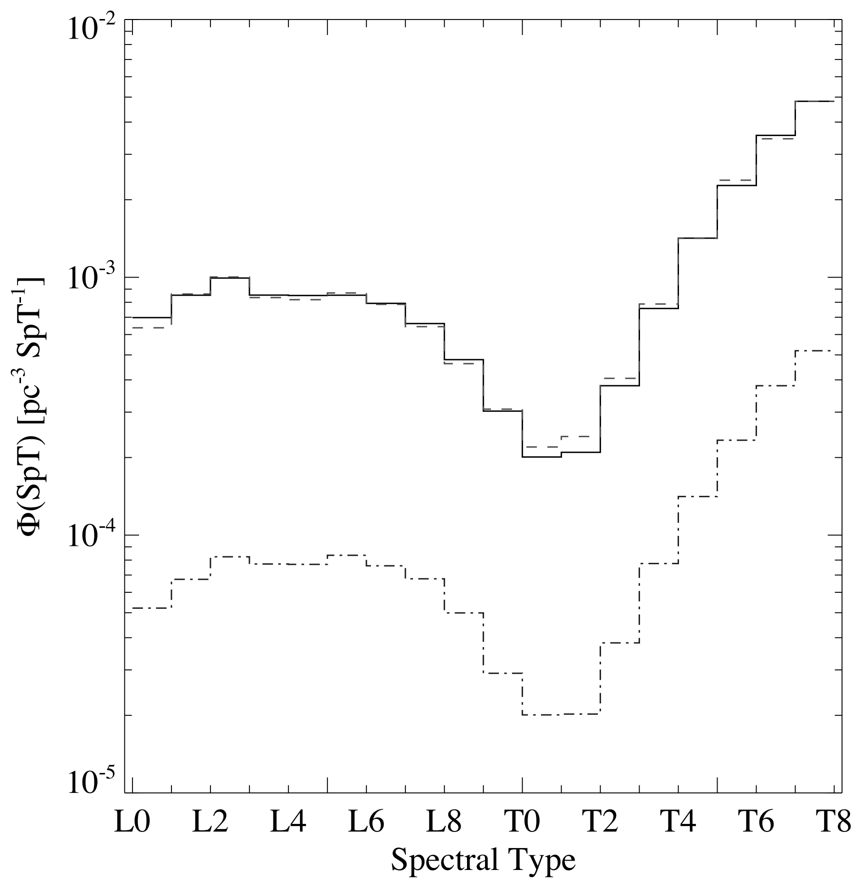
M
L0
T0
Y0

The boundaries between Stars, T-BDs, and D-BDs are around 7.9% and 6.5% $M_\odot$ at $Z_\odot$ (Primeval-IV, Zhang+18)

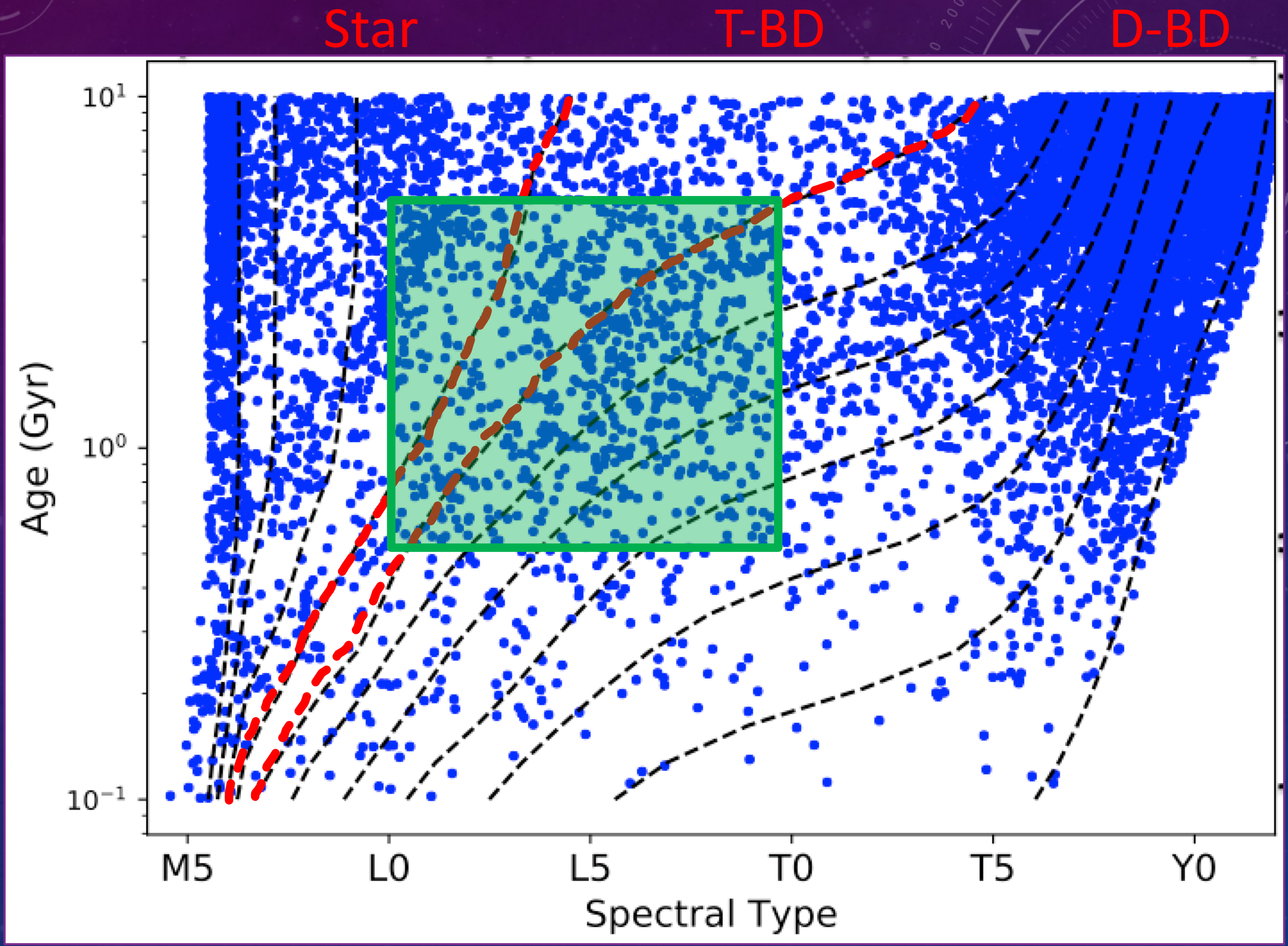




L/T transition number densitiy

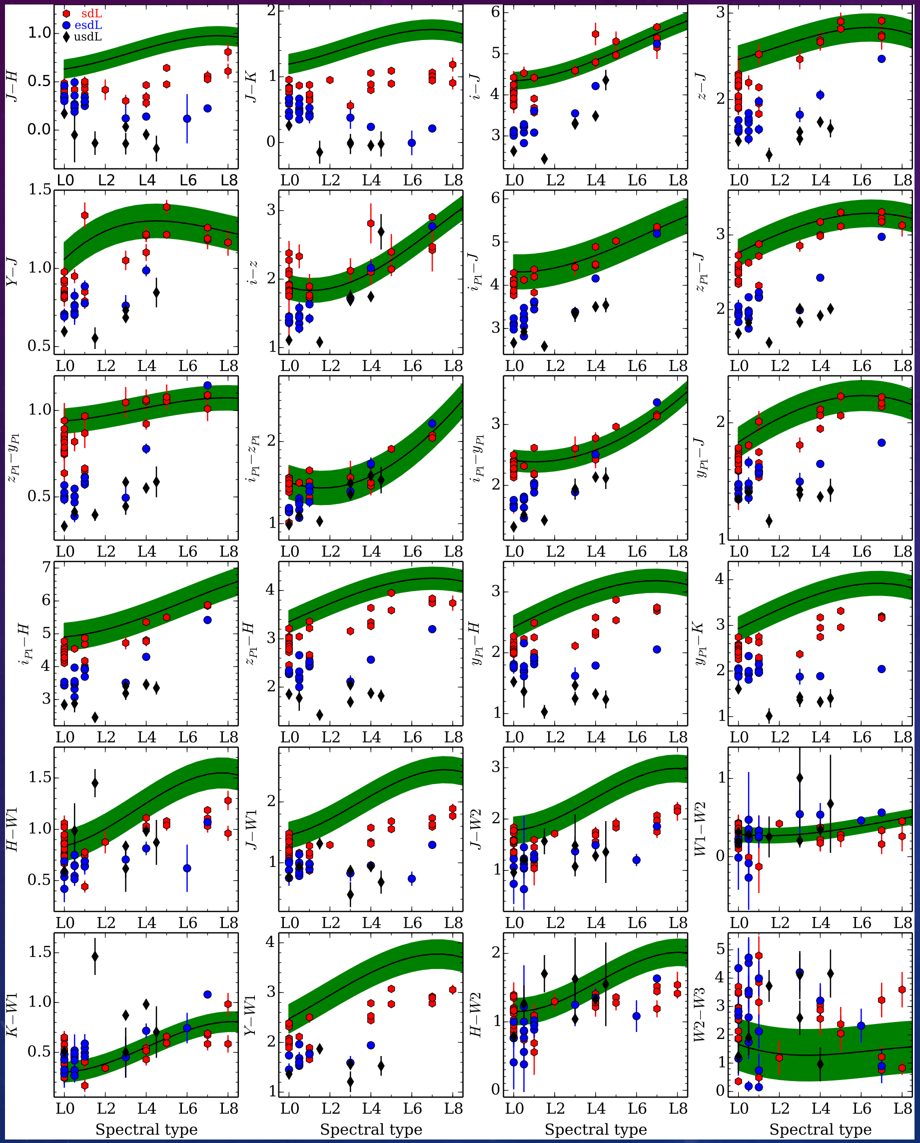


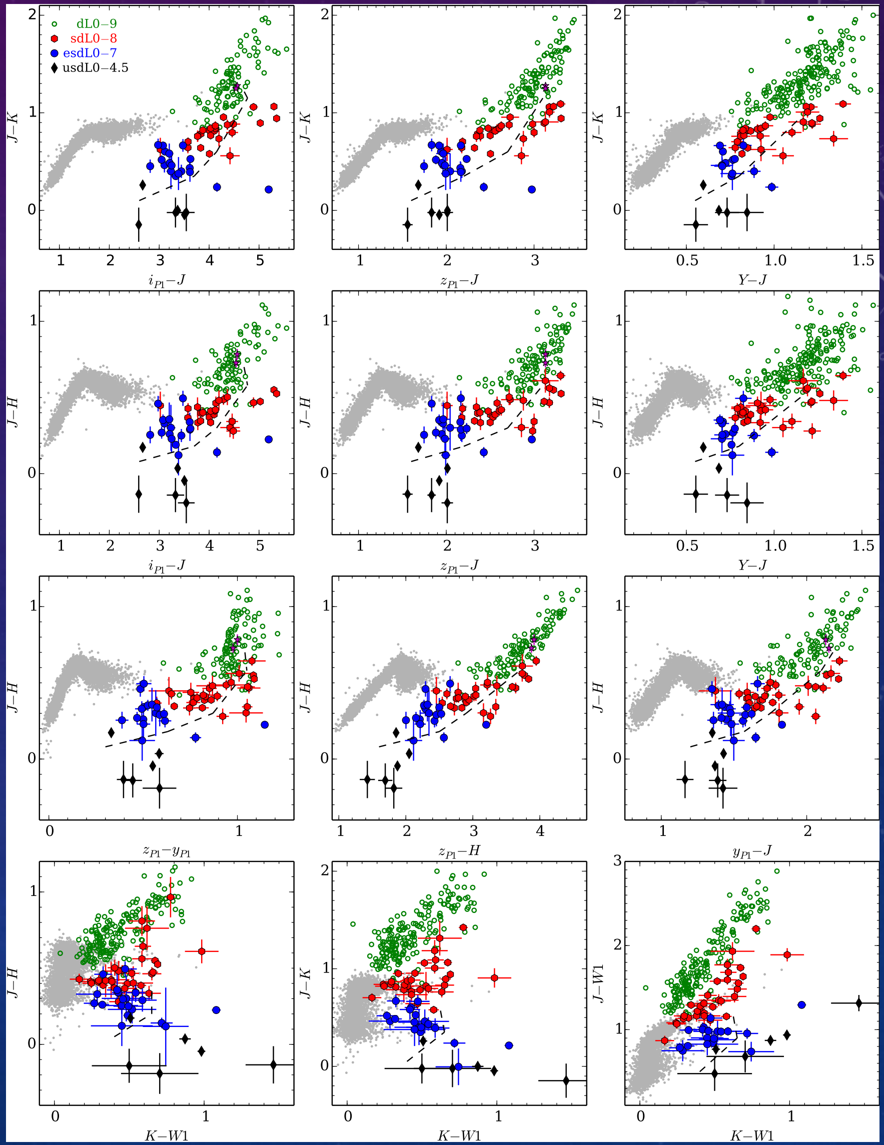
L/T transition, Burgasser+07

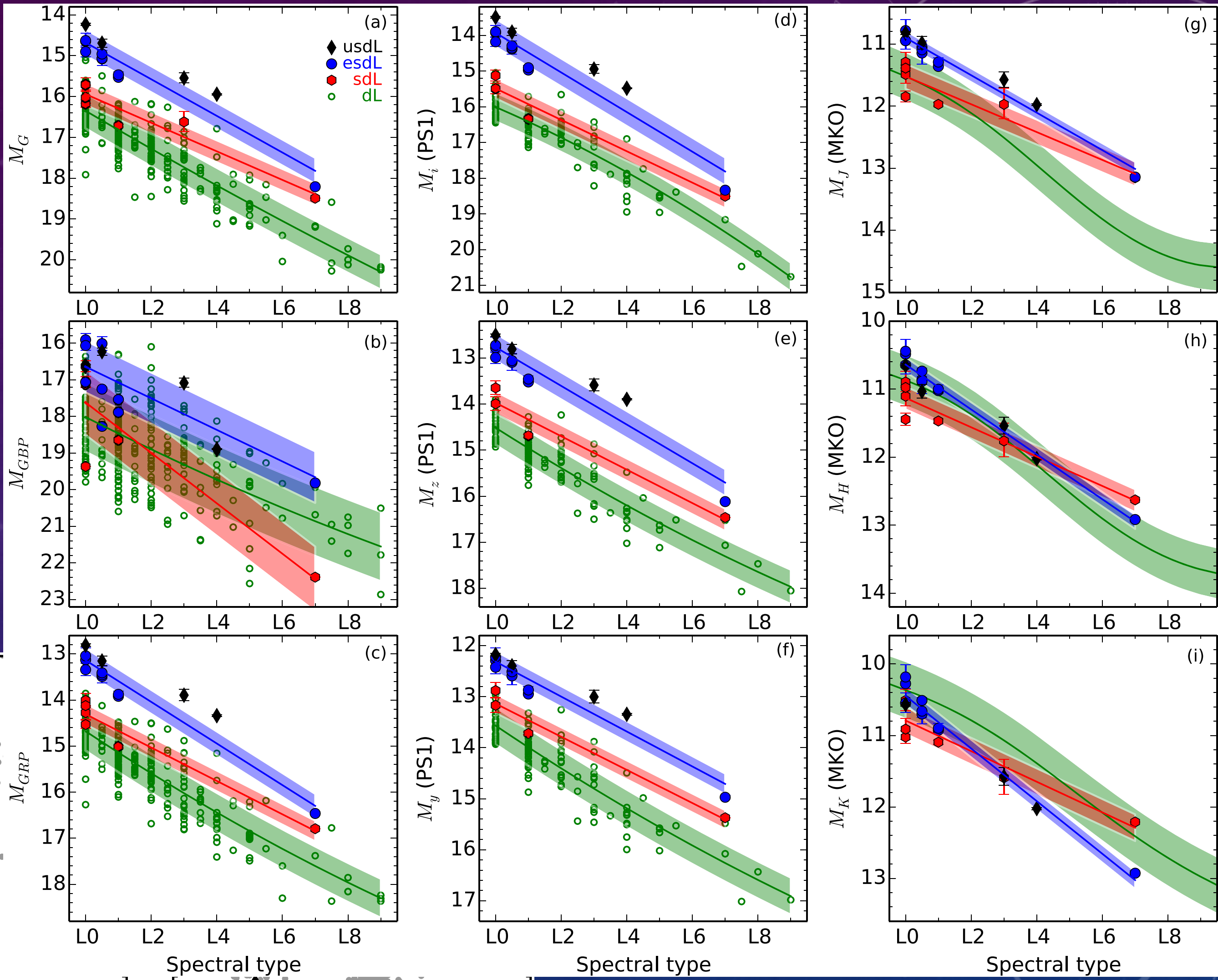


0.01-0.15 M_{Sun}, simulation by Adam Burgasser

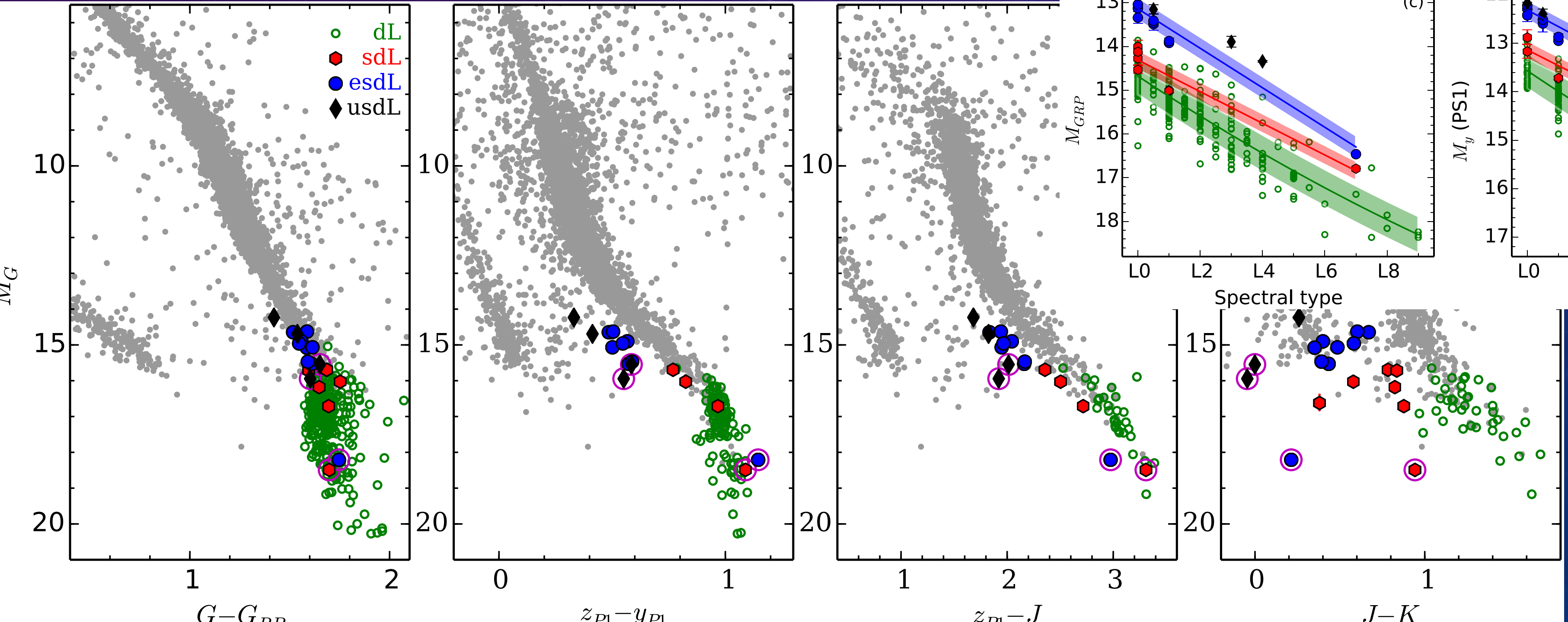
Properties of L subdwarfs (Primeval-IV)







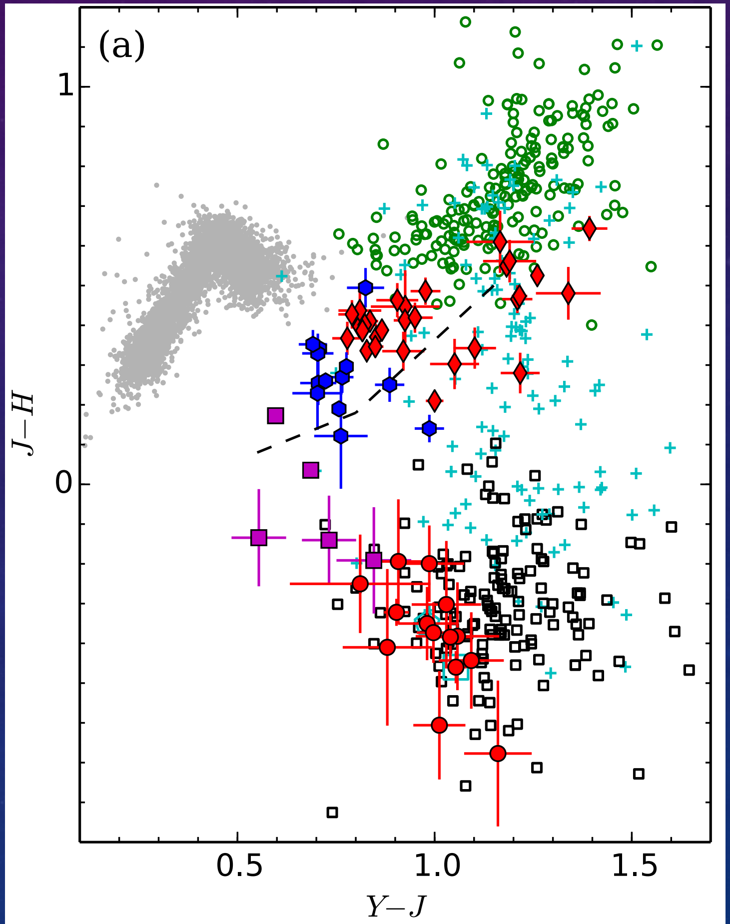
usdL
esdL
sdL
dL
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
M_G
M_{GBP}
M_{GRP}
M_i (PS1)
M_z (PS1)
M_y (PS1)
M_J (MKO)
M_H (MKO)
M_K (MKO)
L0 L2 L4 L6 L8
Spectral type

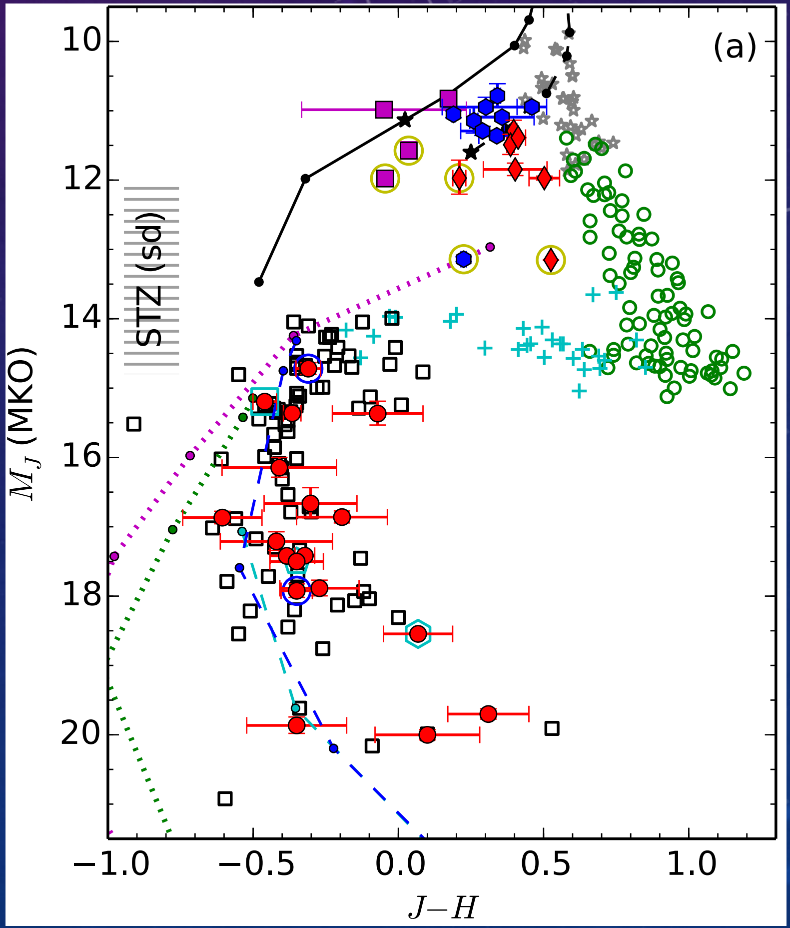


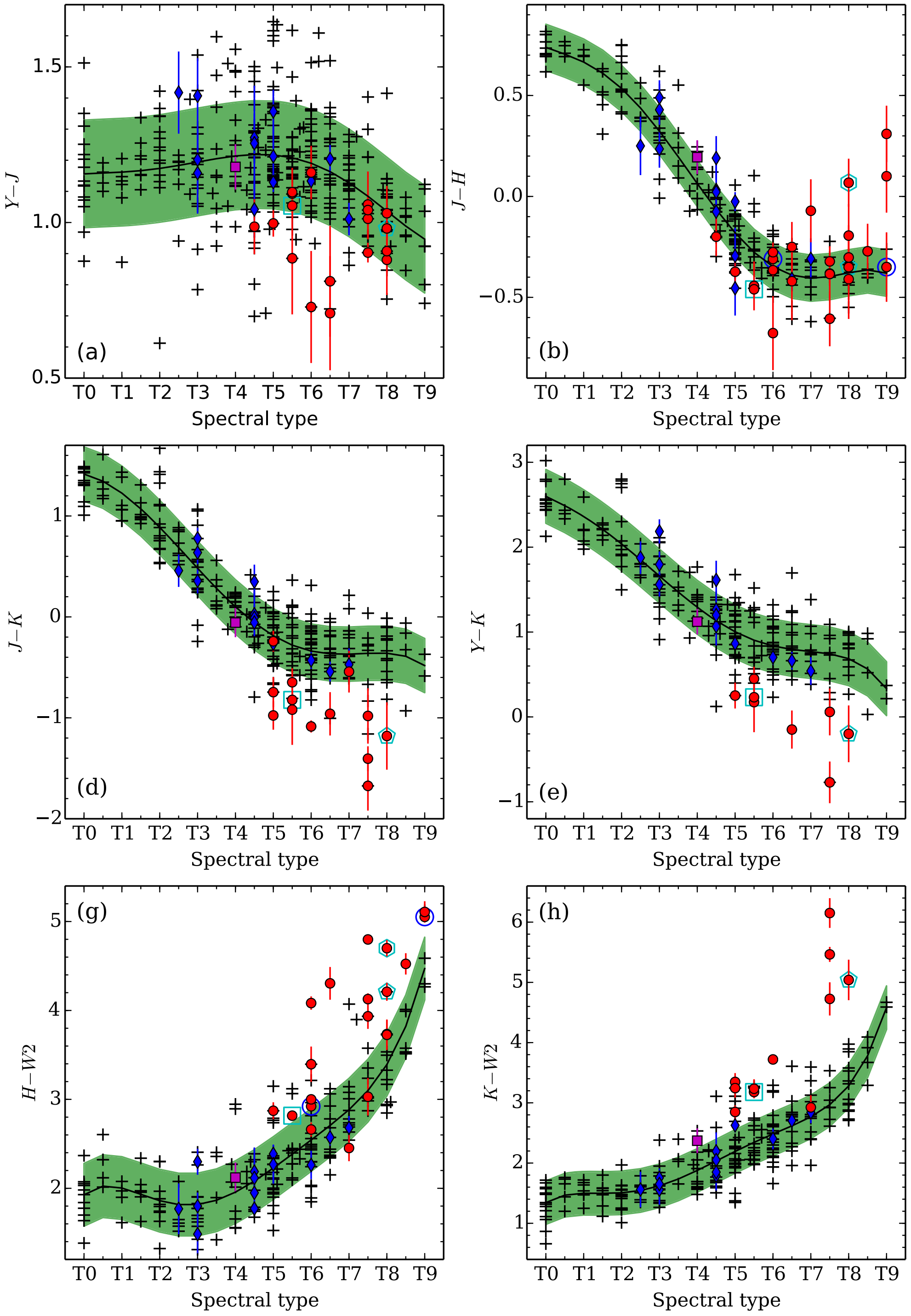
dL
sdL
esdL
usdL
M_G
$J-K$

Properties of T subdwarfs (Primeval-VI)

- Spectral type – Colour
- Colour – colour
- Spectral type – absolute magnitude
- Colour – absolute magnitude






Y−J
J−H
J−K
Y−K
H−W2
K−W2
(a)
(b)
(d)
(e)
(g)
(h)
T0 T1 T2 T3 T4 T5 T6 T7 T8 T9
Spectral type

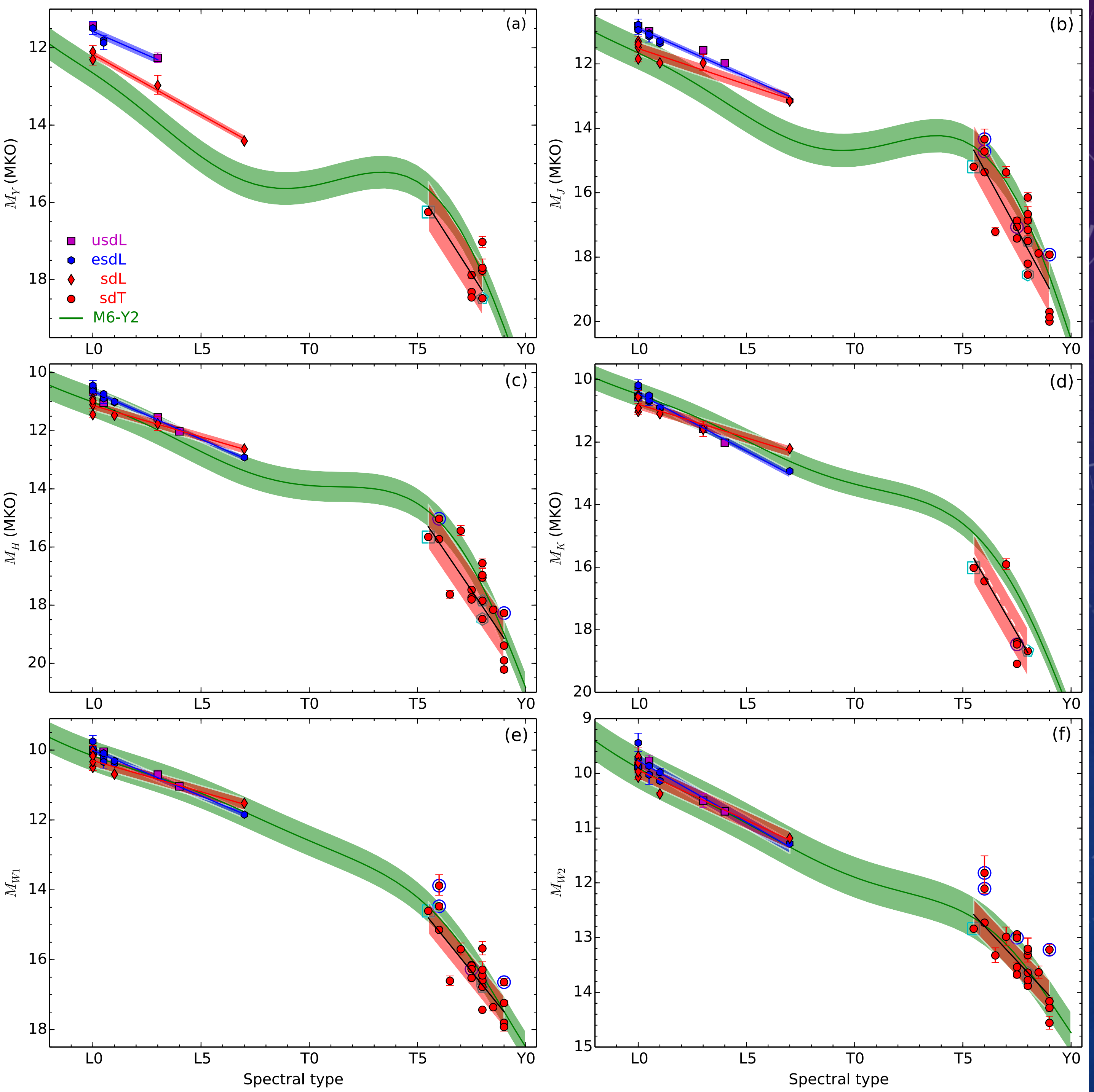
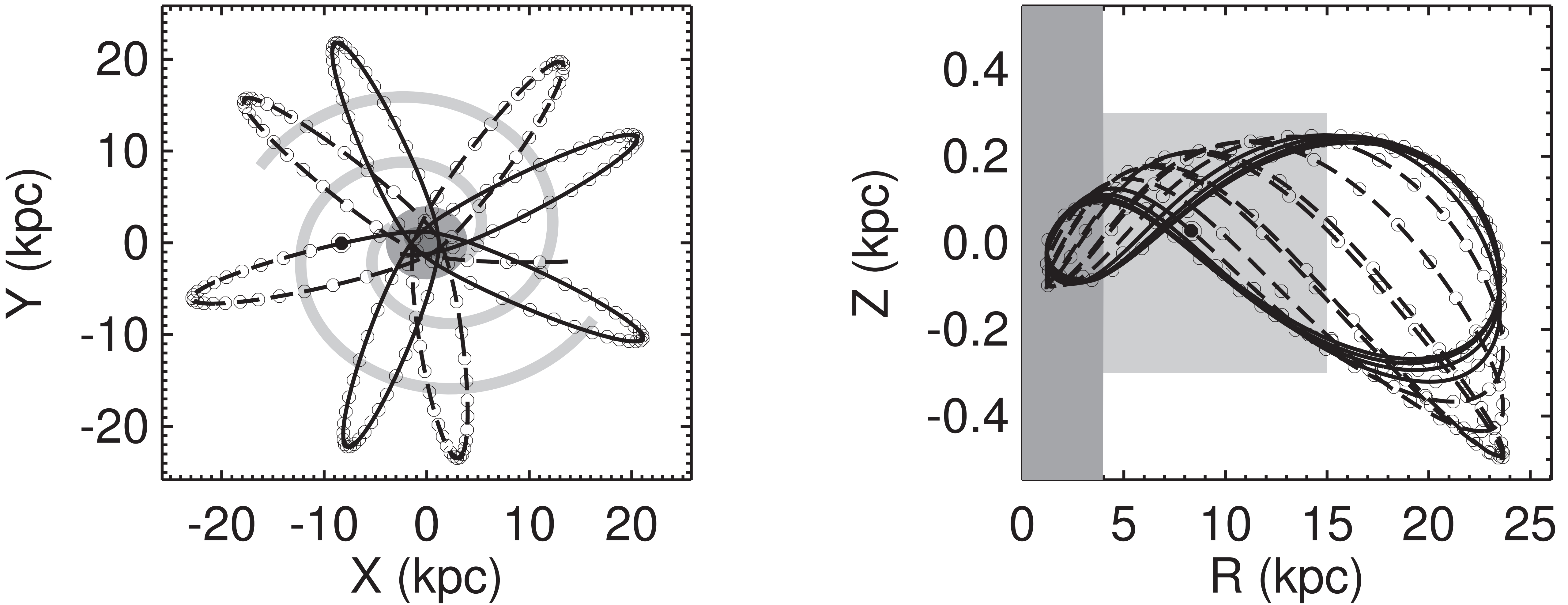

(a)
(b)
(c)
(d)
(e)
(f)
M_Y (MKO)
M_J (MKO)
M_H (MKO)
M_K (MKO)
M_W1
M_W2
usdL
esdL
sdL
sdT
M6-Y2
L0 L5 T0 T5 Y0
Spectral type

Table 6. T5–9 subdwarf discovery capability of *Euclid* and *WFIRST*, *WISE*, LSST, and *CSS-OS* surveys. Limiting magnitudes ($m_{\rm limit}$) in AB system are converted to Vega system according to table 7 of Hewett et al. (2006). Note the actual discovery number of halo T subdwarfs could be lower (see the last paragraph of Section 6).

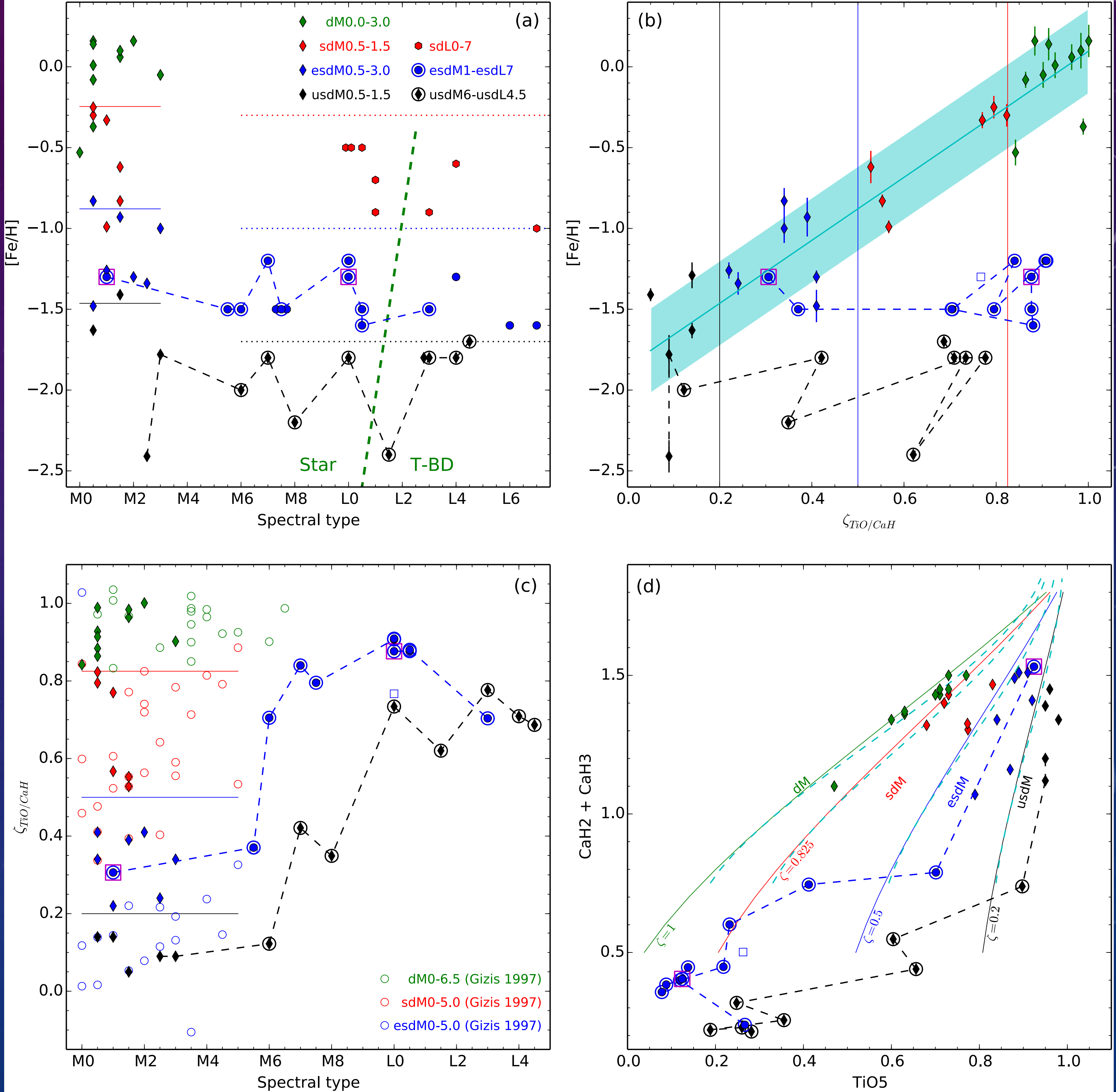
Name	Survey	Filter	Coverage (deg^2)	$m_{\rm limit}$ (AB)	$m_{\rm limit}$ (Vega)	$M_{\rm sdT7.5}$ (AB)	$M_{\rm sdT7}$ (Vega)	$d_{\rm sdT7}$ (pc)	Thick disc	Halo
Euclid	Wide	slitless	15000	$H = 19.5$	18.121	–	16.95	17	4	0
Euclid	Wide	Y	15000	24.0	23.366	–	17.41	155	3174	272
Euclid	Wide	J	15000	24.0	23.062	–	16.52	203	7151	613
Euclid	Wide	H	15000	24.0	22.621	–	16.95	136	2147	184
WFIRST	HLS	slitless	2000	$H = 21.5$	20.121	–	16.95	43	9	1
WFIRST	HLS	Y	2000	26.7	26.066	–	17.41	538	17640	1512
WFIRST	HLS	J	2000	26.9	25.962	–	16.52	773	52395	4491
WFIRST	HLS	H	2000	26.7	25.321	–	16.95	472	11931	1023
WFIRST	HLS	(K_s)	2000	25.5	23.600	–	17.38	175	611	52
WISE	*AllWISE*	$W1$	all sky	–	17.9	–	15.90	25	37	3
WISE	*AllWISE*	$W2$	all sky	–	16.4	–	13.17	44	203	17
WISE	*CatWISE*	$W1$	all sky	–	18.55	–	15.90	34	91	8
WISE	*CatWISE*	$W2$	all sky	–	17.05	–	13.17	60	499	43
LSST	Single-visit	z	18000	23.3	–	21.78	–	20	8	1
LSST	Single-visit	y	18000	22.1	–	19.94	–	27	20	2
LSST	Coadded	z	18000	26.1	–	21.78	–	73	398	34
LSST	Coadded	y	18000	24.9	–	19.94	–	98	965	83
CSS-OS	Wide	z	17500	25.3	–	21.78	–	51	128	11
CSS-OS	Wide	y	17500	24.7	–	19.94	–	90	711	61

A halo L3 subdwarf with prograde eccentric orbit in the Galactic plane (Primeval-V)



Metallicity of M and L subdwarfs (Zhang submitted, Primeval VII)

- Zeta index is good for M0-M5 subdwarfs
- Zeta index is not valid for ultracool subdwarfs (<0.1 M $_{\odot}$) due to their dusty atmospheres and favouring H_2O and metal hydride (CaH, FeH) under higher pressure (gravity).



Primeval very low-mass stars and brown dwarfs series on the MNRAS

- I. Six new L subdwarfs, classification and atmospheric properties
- II. The most metal-poor substellar object
- III. The halo transitional brown dwarfs
- IV. New L subdwarfs, *Gaia* astrometry, population properties, and a blue brown dwarf binary
- V. A halo L3 subdwarf with prograde eccentric orbit in the Galactic plane
- VI. Population properties of metal-poor degenerate brown dwarfs

- The Substellar Transition Zone: A Stretched Temperature Canyon in Brown Dwarf Population due to Unsteady Hydrogen Fusion

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A Chinese poetry (ci) for Chile

《鹊桥仙·智利》

智利路远，国土狭长，大地富含宝藏。
铜硝钼锂铼金银，葡萄酒、柠檬佳酿。
智利山高，气候晴朗，这里星空最亮。
天文学者来相聚，望远镜、宇宙天窗。

Immortal at the Magpie Bridge (tune) · Chile

Chile is far, the land is long, and full of treasures.
Copper/nitre/molybdenum/lithium/rhenium/gold/silver, excellent wine, and pisco sour.
Chile has high montains, fine climate, and the best starry night.
Astronomers are gathered here, for the telescopes, windows to the Universe.

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Gracias!