



Searching For The Youngest Methane Brown Dwarfs

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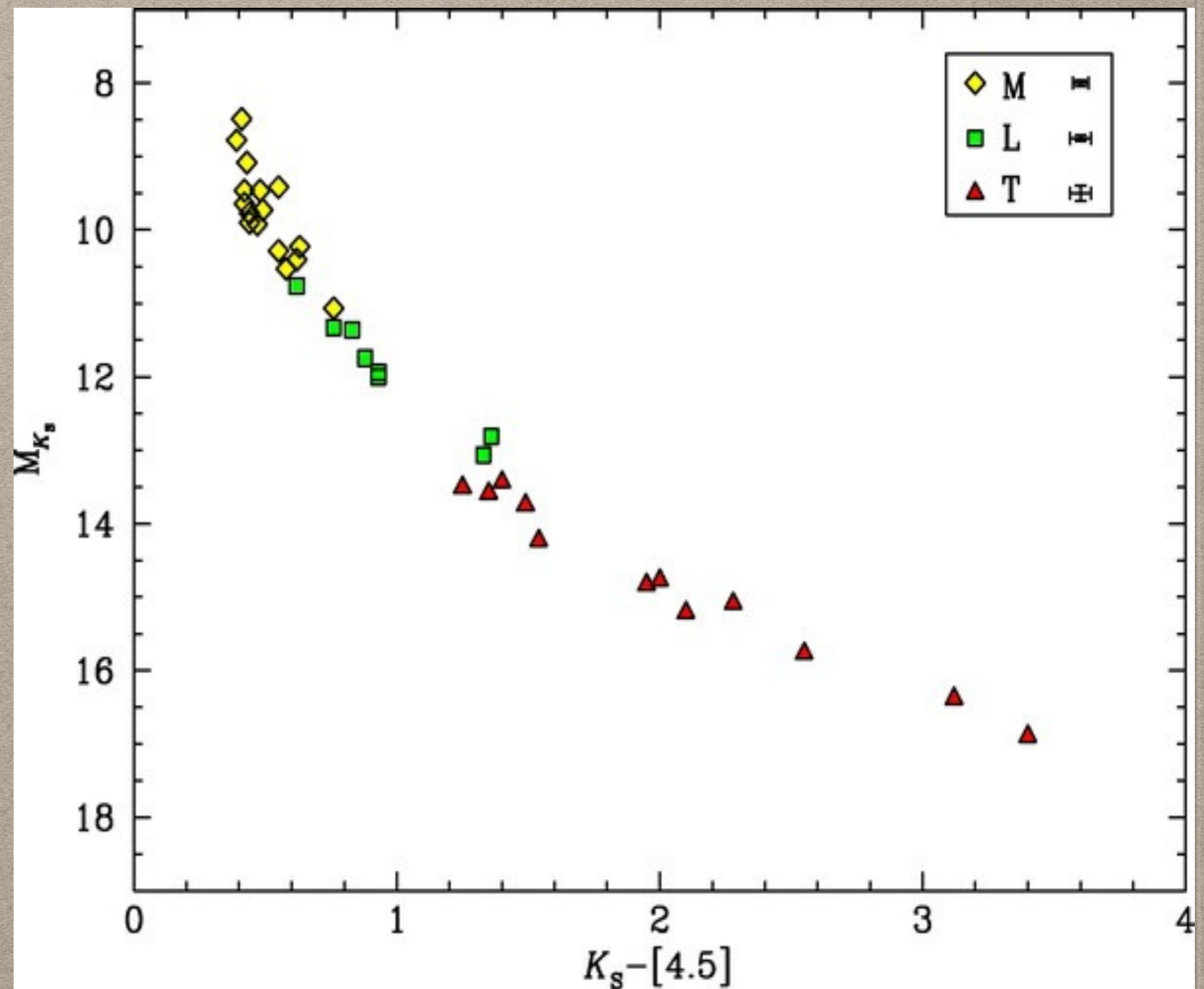
Star Cluster Workshop, ShAO, China 2015.11.20

Brown Dwarfs

- Predicted in 1960s (Kumar)
- No sustainable energy production
- 1st BD was discovered until 1995
- more BDs were found after 2000
- late-M ($> M6$), L, T, Y (~1300 BDs, mostly within 100pc)

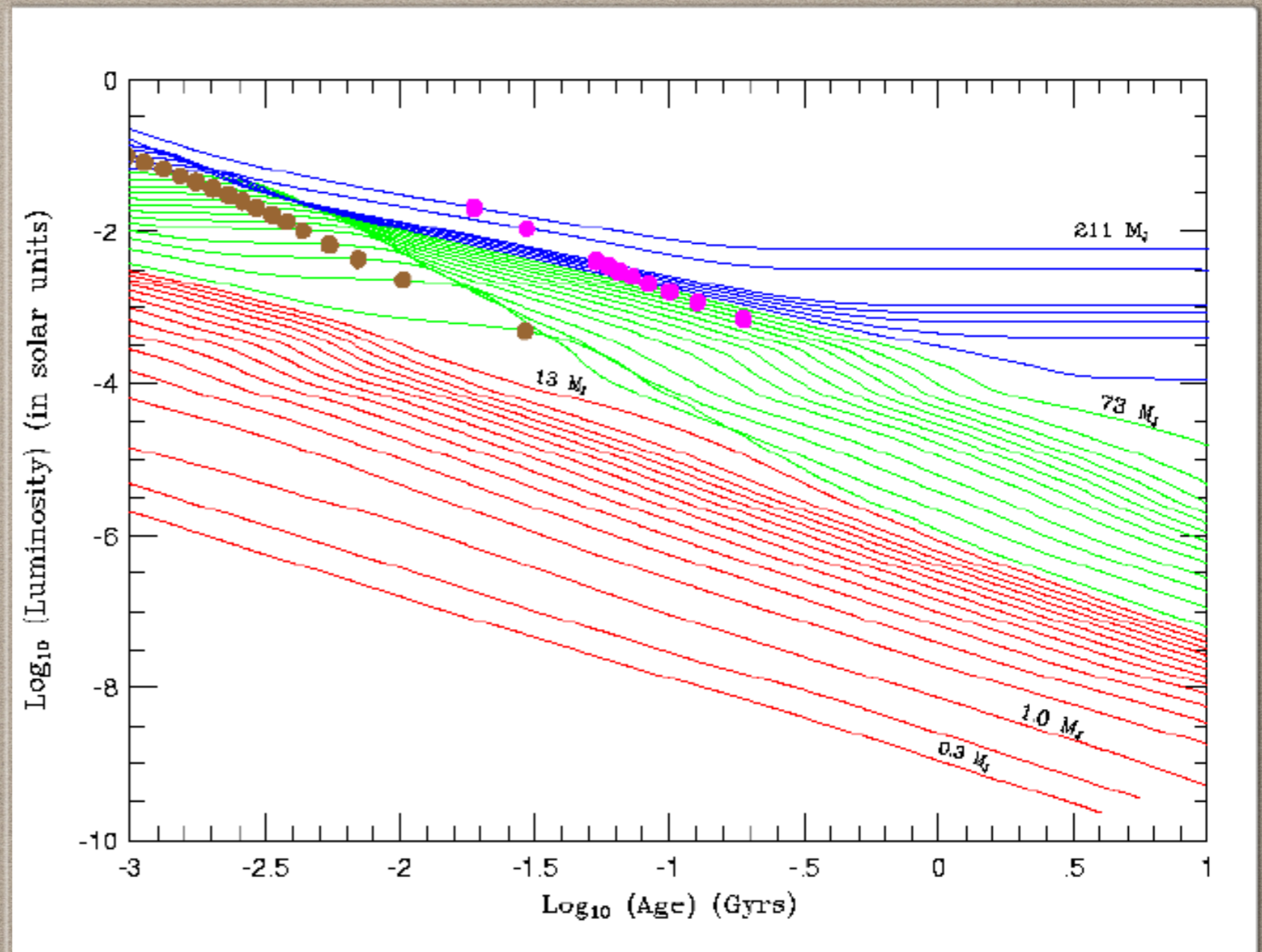
Brown Dwarfs

- Faint
- low mass
- not black-body



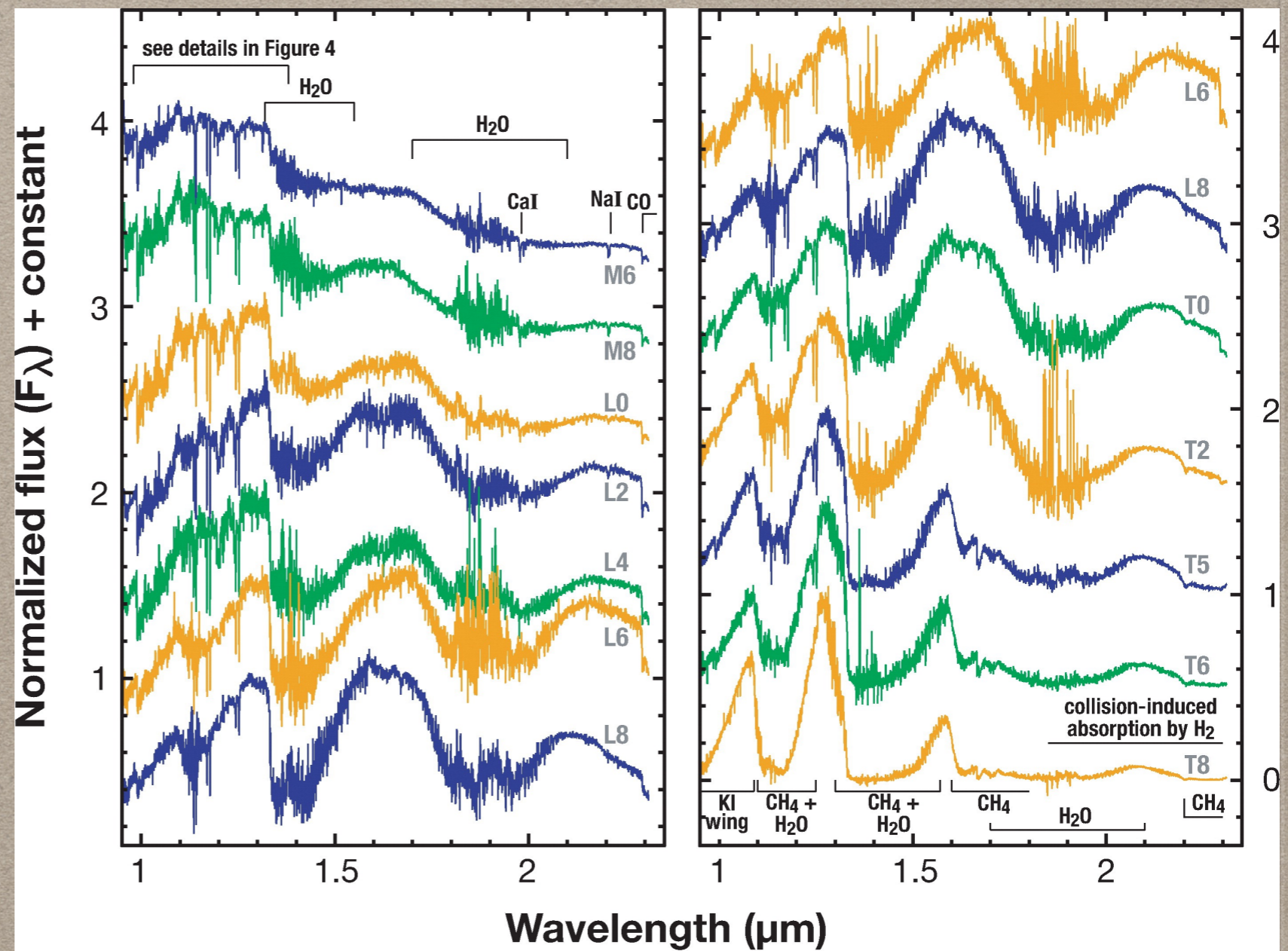
Brown Dwarfs

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Brown Dwarfs

- Faint
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Kirkpatrick, JD. 2005
Annu. Rev. Astron. Astrophys. 43: 195–245

Questions

- Formation beyond the mass of hydrogen burning
 - star-like (hot start)? or planet-like (cold start)?
- (Early) evolution of BDs/PMOs
 - atmospheres, chemical processes
 - exoplanets without host stars
- The initial mass function

ρ Oph Star-Forming Region



image credit – <http://www.eso.org/public/images/eso1248e/>

ρ Oph Star-Forming Region

- Famous SF region
- X-ray to radio
- Age \sim 1 Myr
- $D \sim 130$ pc
- \sim 50 BDs/PMOs (late-M to L type)

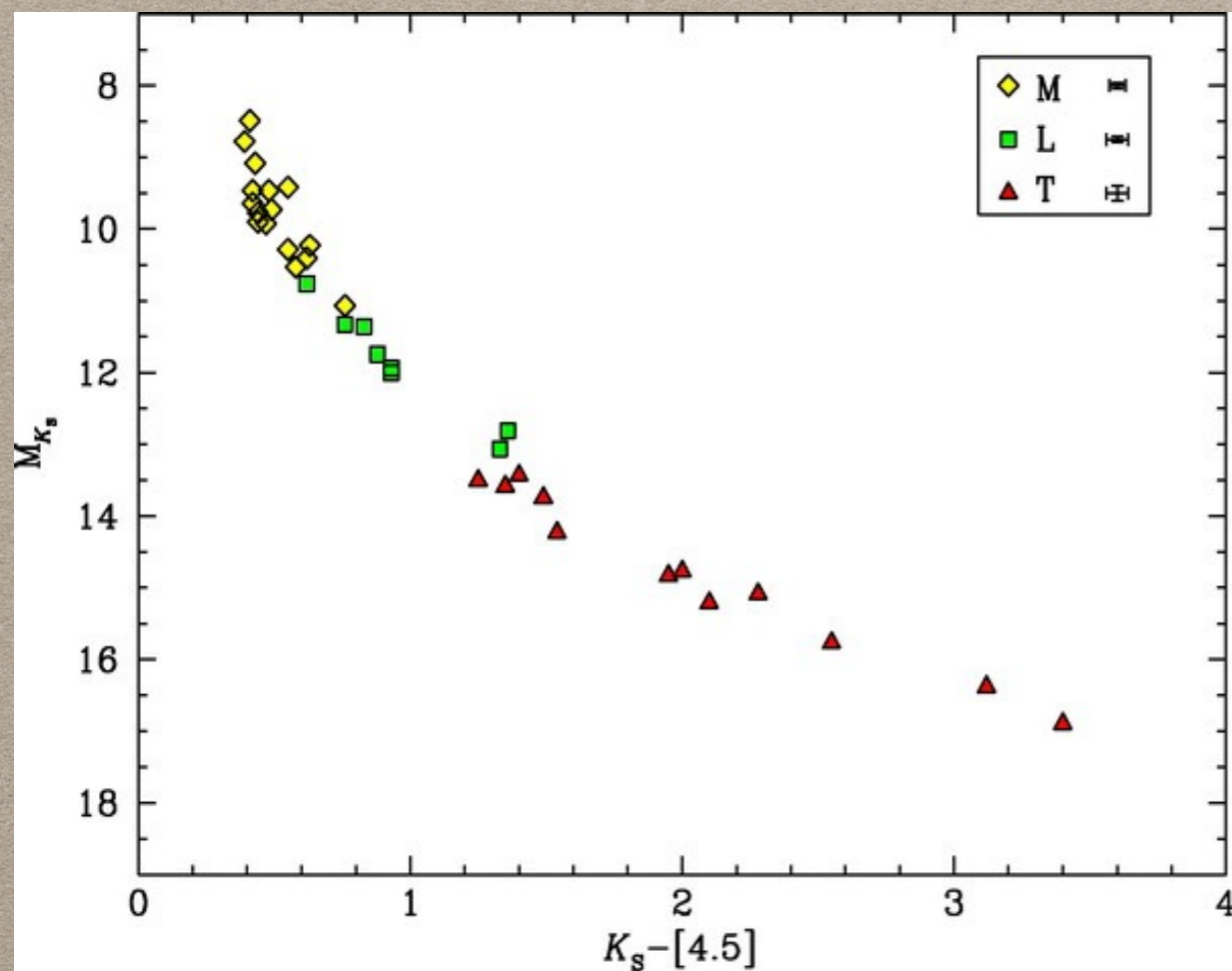


Imaging Observations

- H + CH4ON of CFHT/WIRCam (2010)
- 28 known BDs as our training set
- L1688 dark cloud to search for youngest T dwarf

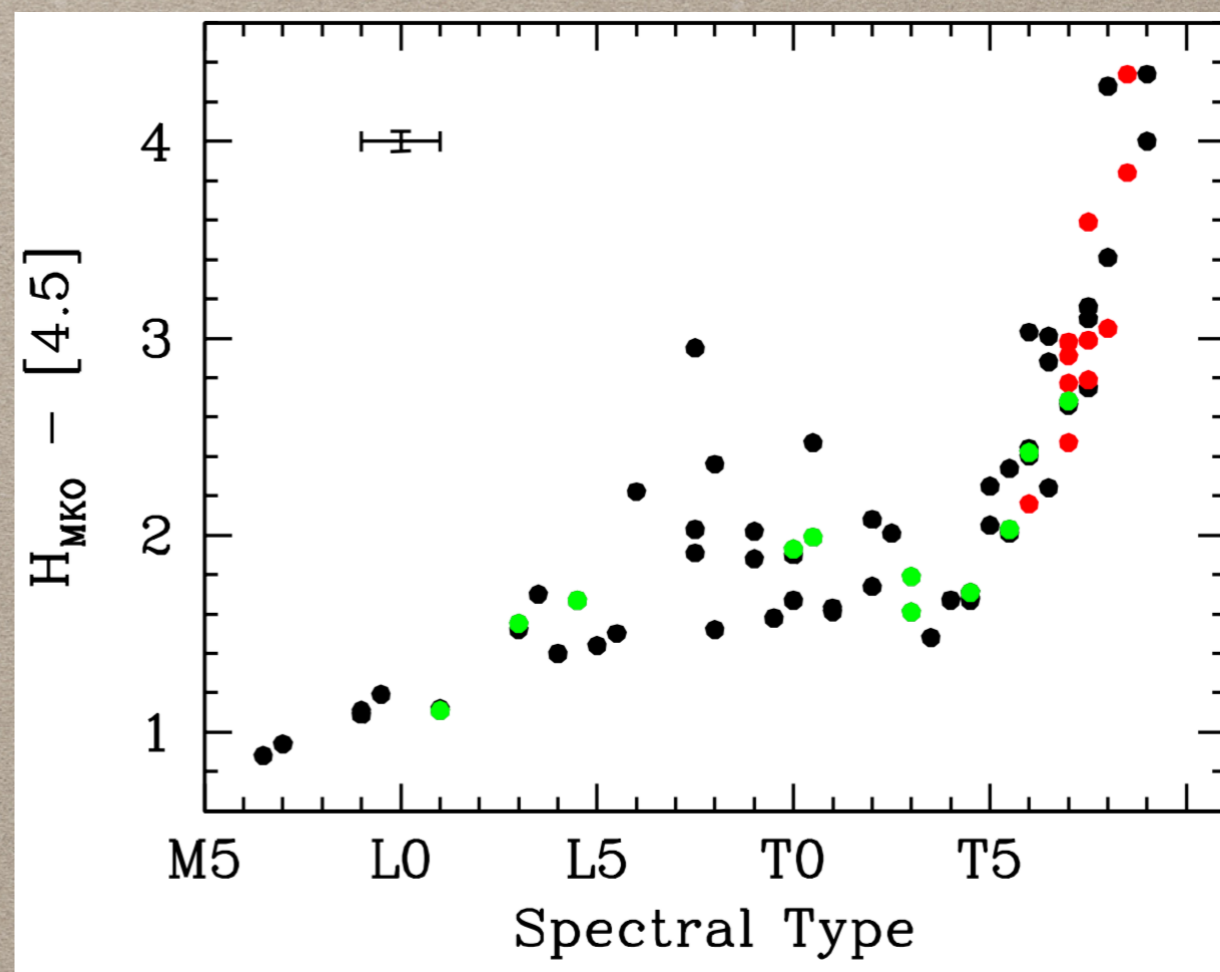
Selection – Cool Temperature

$K - [4.5]$



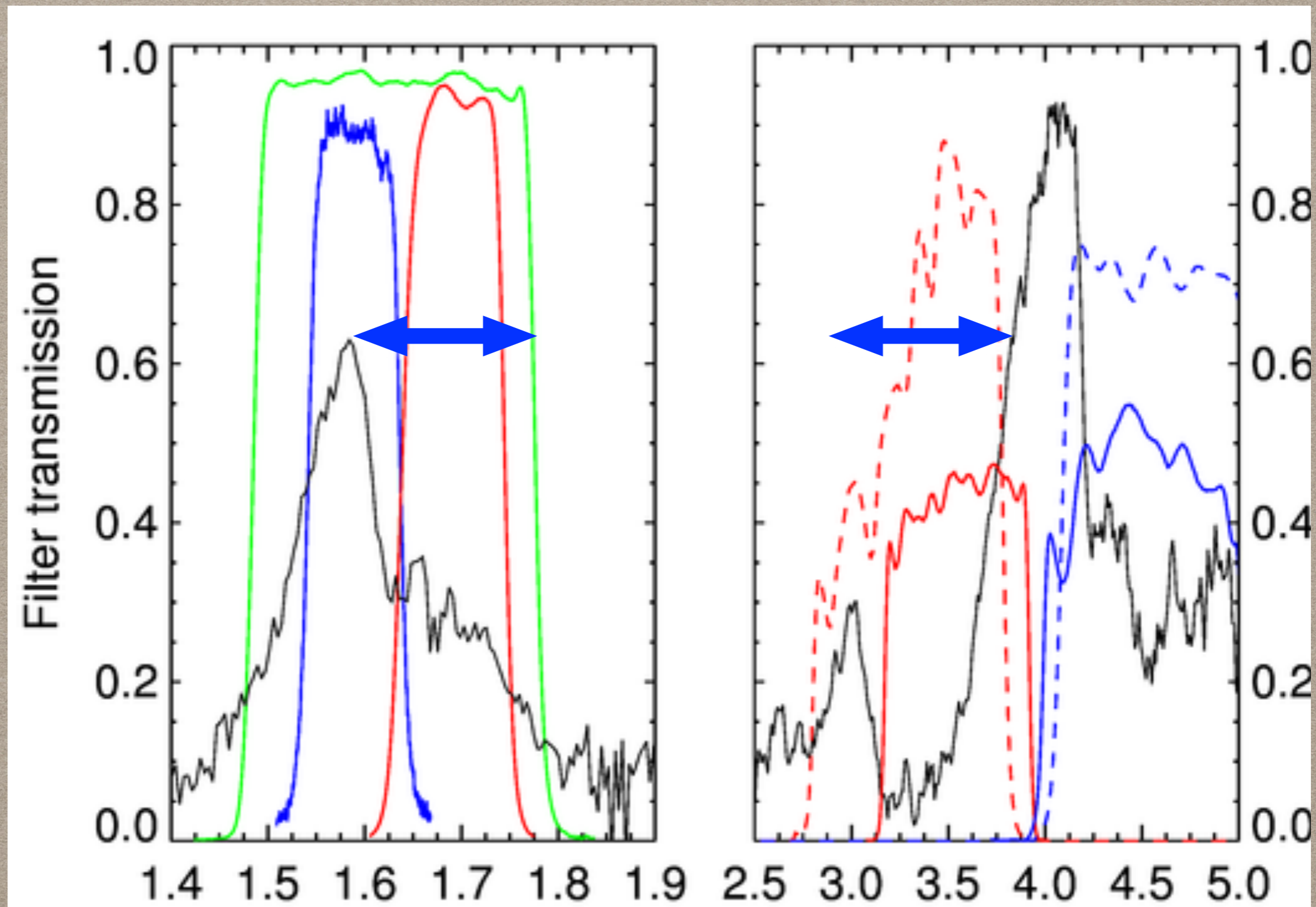
Patten et al. 2006, ApJ

$H - [4.5]$

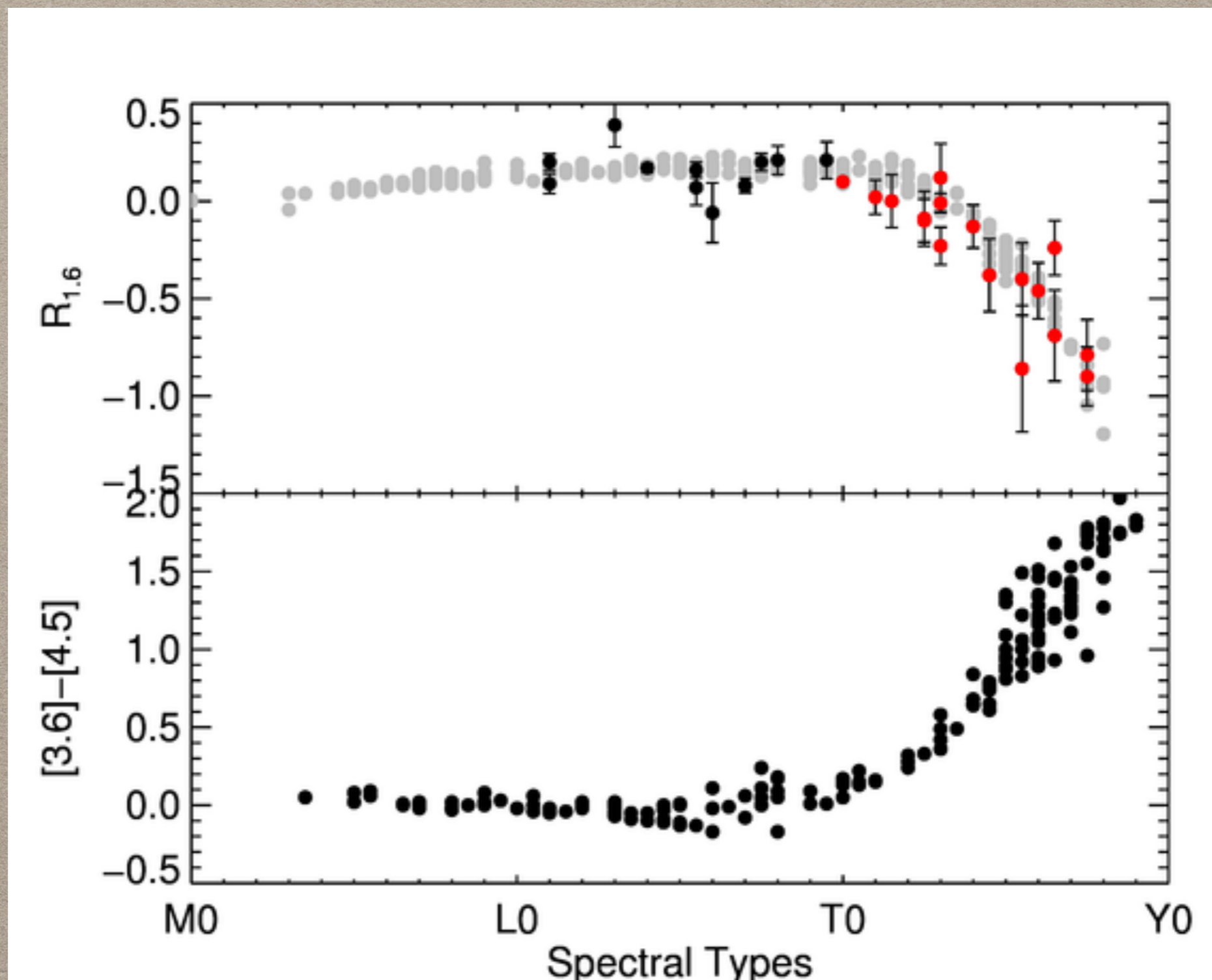


Leggett et al. 2010, ApJ

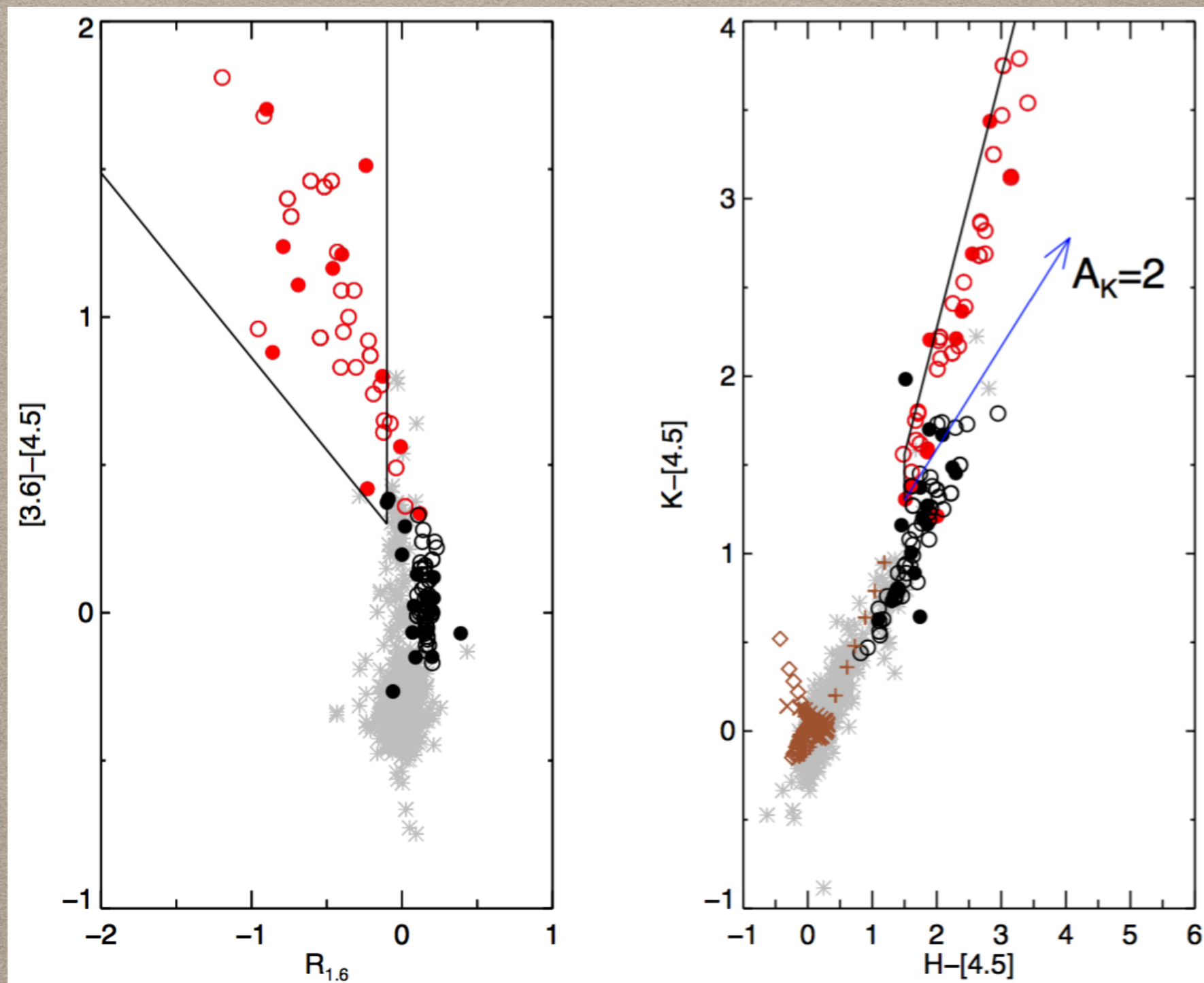
Selection – Methane



Selection – Methane



Field BDs



T-dwarf Candidates in L1688

- in both T zones
- No detection in 24 micron (MIPS 1st channel)

$$R_{1.6} > \sqrt{err_H^2 + err_{CH_4ON}^2}$$

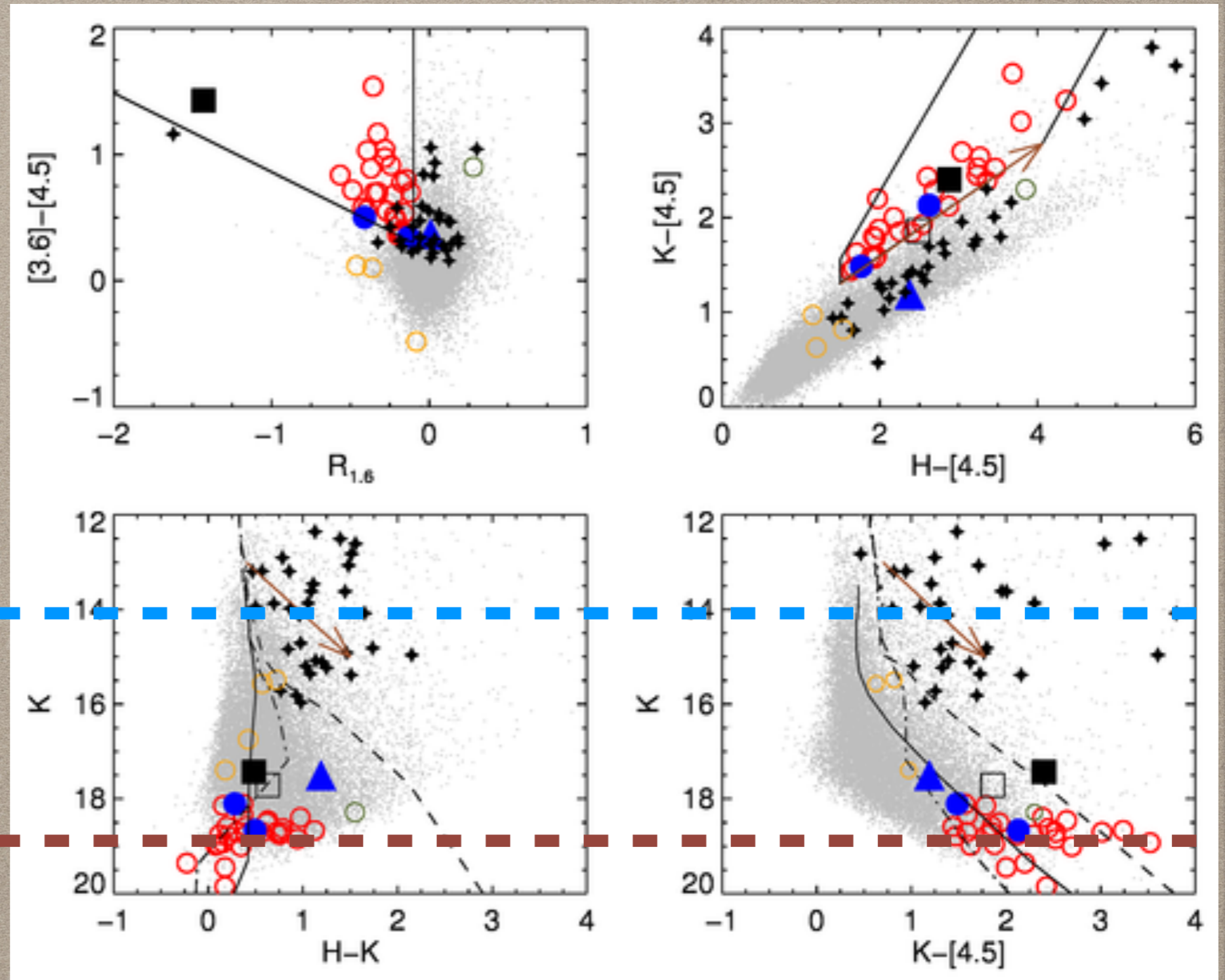
Temperatures and CH4

Reject background galaxies

Significant methane index

T-dwarf Candidates in L1688

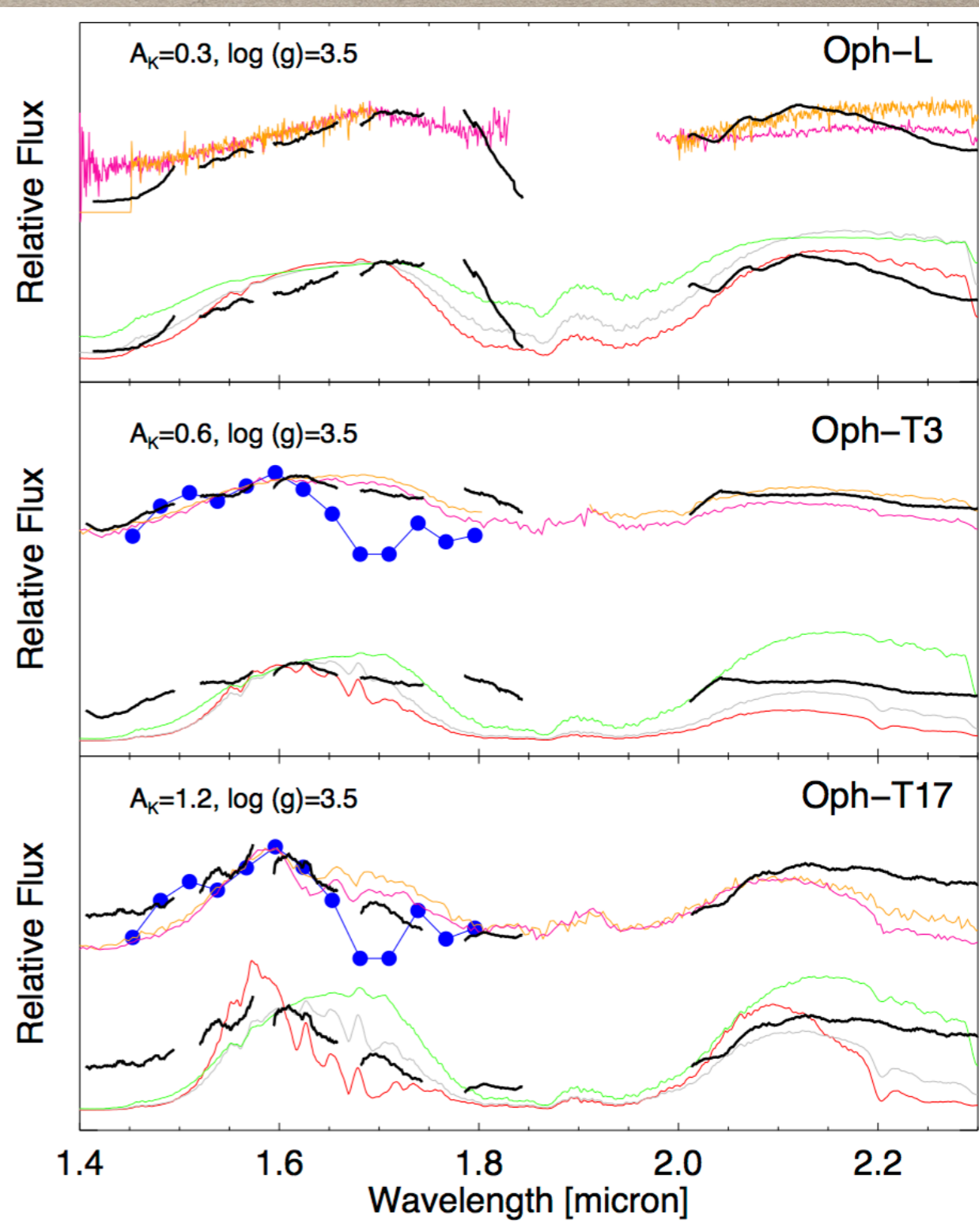
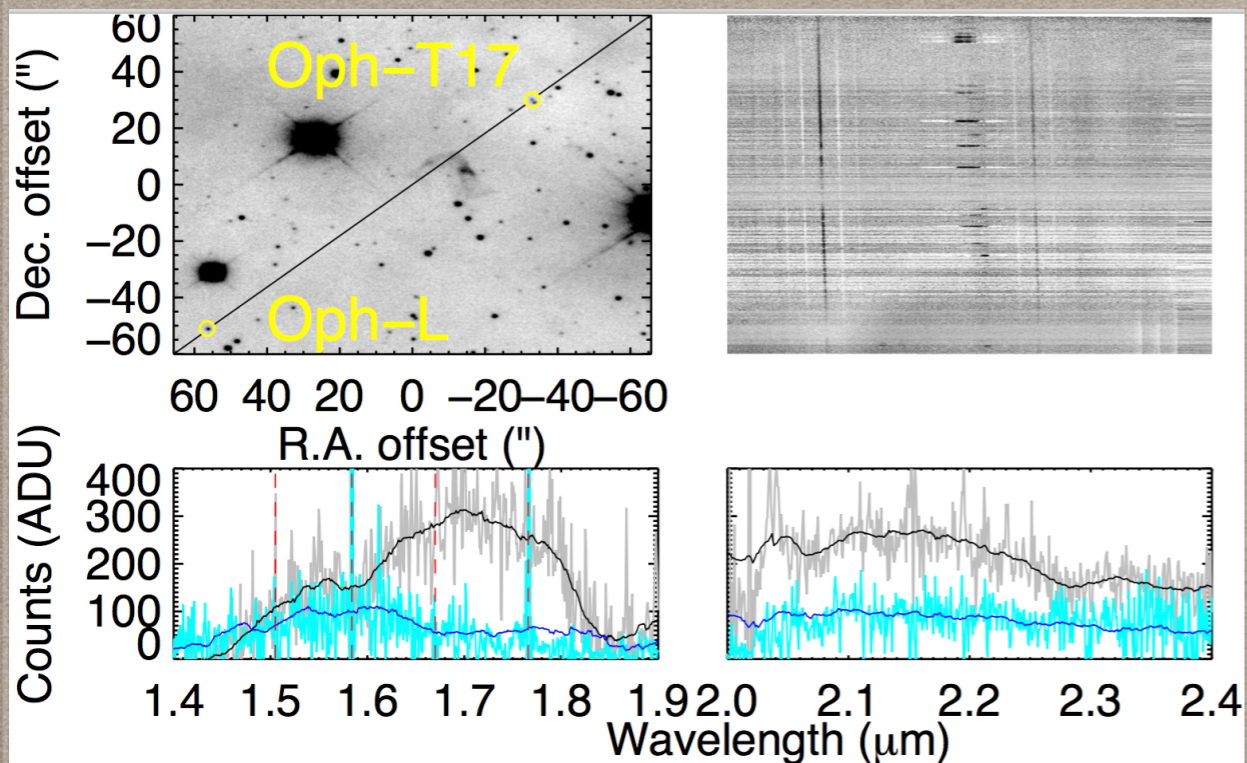
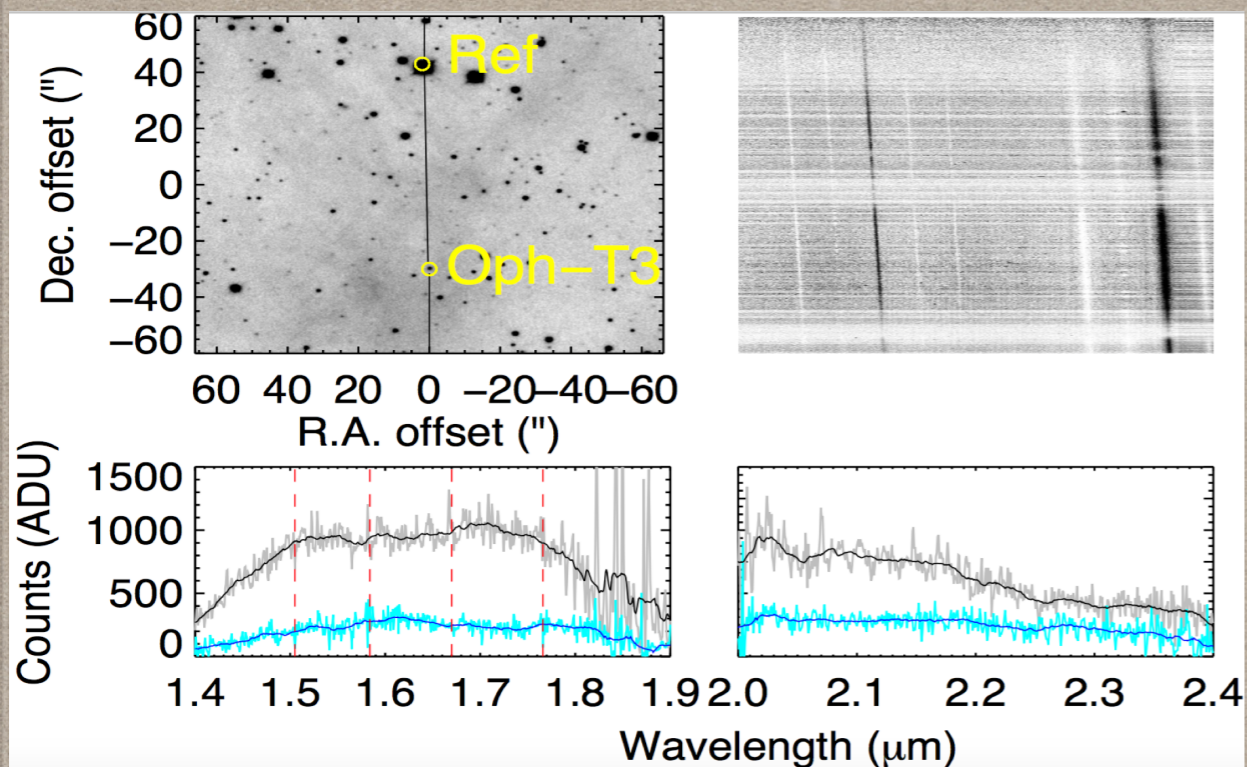
- *T dwarf candidates*
- *Oph-T3 and Oph-T17*
- ▲ *Young L*
- ★ *confirmed BDs*
- *No. 4450*
- *S Ori 70*



Spectroscopic Observations

- Gemini South/FLAMINGOS-2 (2014)
- long-slit, HK prism (1.4~2.4 micron), R~1000
- observed candidates #1, 2, 3, 7, 17, 19
- CH₄ absorptions beyond 1.6 micron

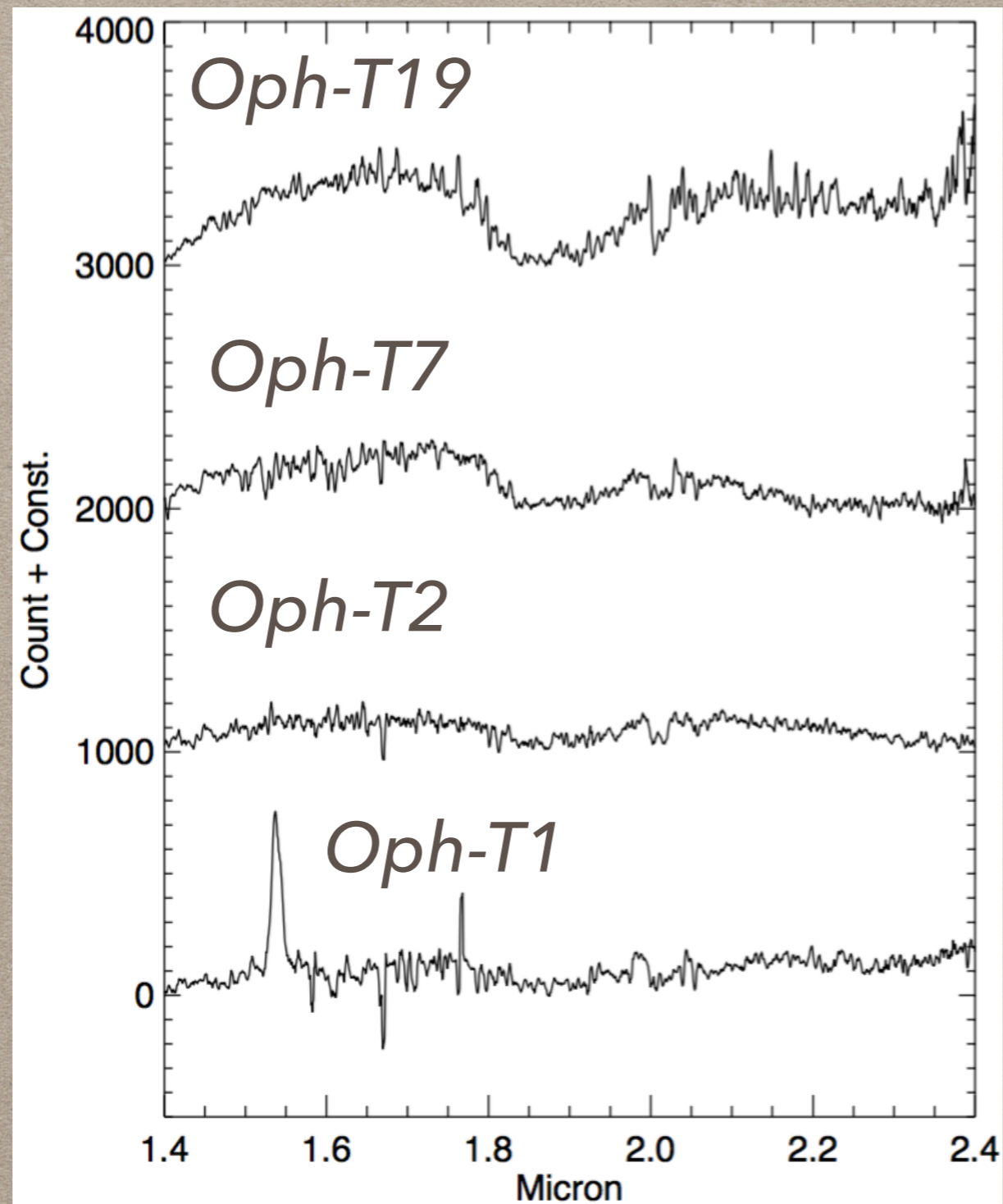
L/T Dwarfs



PMOs in L1688

Measurments	Unit	Oph-T3	Oph-T17	Oph J162651–242110
R.A.	hh:mm:ss.ss (J2000)	16:27:38	16:26:45	16:26:51
Dec.	dd:mm:ss.ss (J2000)	–24:52:40	–24:19:49	–24:21:10
H	mag	18.38	19.16	18.69
CH_4ON	mag	18.51	19.57	18.68
K_s	mag	18.10	18.66	17.50
[3.6]	mag	16.96	17.04	16.68
[4.5]	mag	16.62	16.53	16.31
H ₂ O (B)	$F_{1.456}/F_{1.570}$	0.49 (T0)	0.54 (T0)	0.23
CH ₄ (A)	$F_{1.730}/F_{1.595}$	0.86 (T0)	0.36 (T4.5)	1.44
CH ₄ (B)	$F_{2.200}/F_{2.100}$	0.98 (T0)	0.91 (T0)	0.93
(H ₂ O–H)	$F_{1.470}/F_{1.600}$	0.57 (T0)	0.49 (T1)	0.34
(CH ₄ –H)	$F_{1.648}/F_{1.600}$	0.95 (T0)	0.70 (T3.5)	1.28

False Positives



cool object

bkg stars

bkg galaxy

Future Works

- To find more young PMOs
 - W-band filter survey in nearby SFRs and young clusters
- Planet-planet pairs

