Characterization of Substellar objects in Star Clusters

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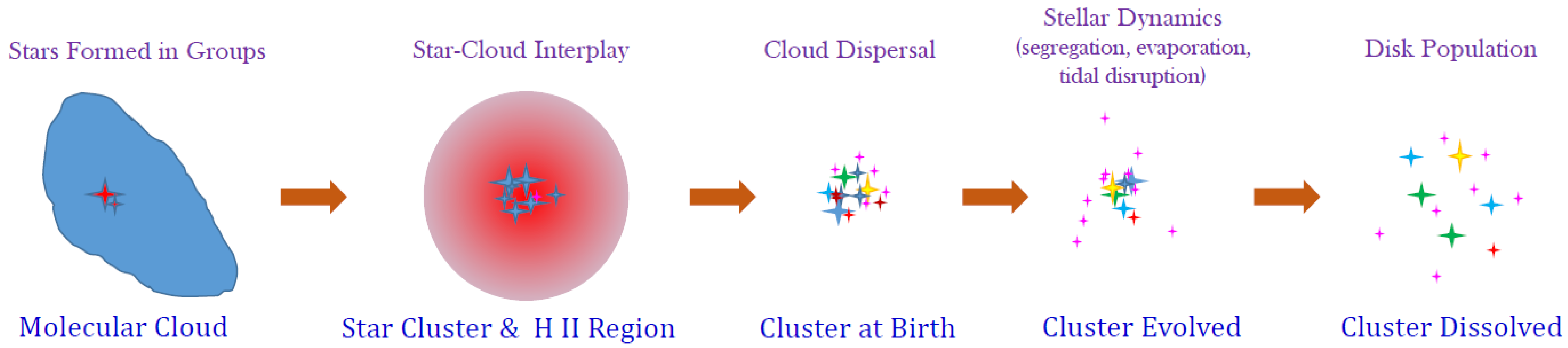
Stars are formed in groups out of dense molecular cores; planets, maybe are formed in young circumstellar disks.

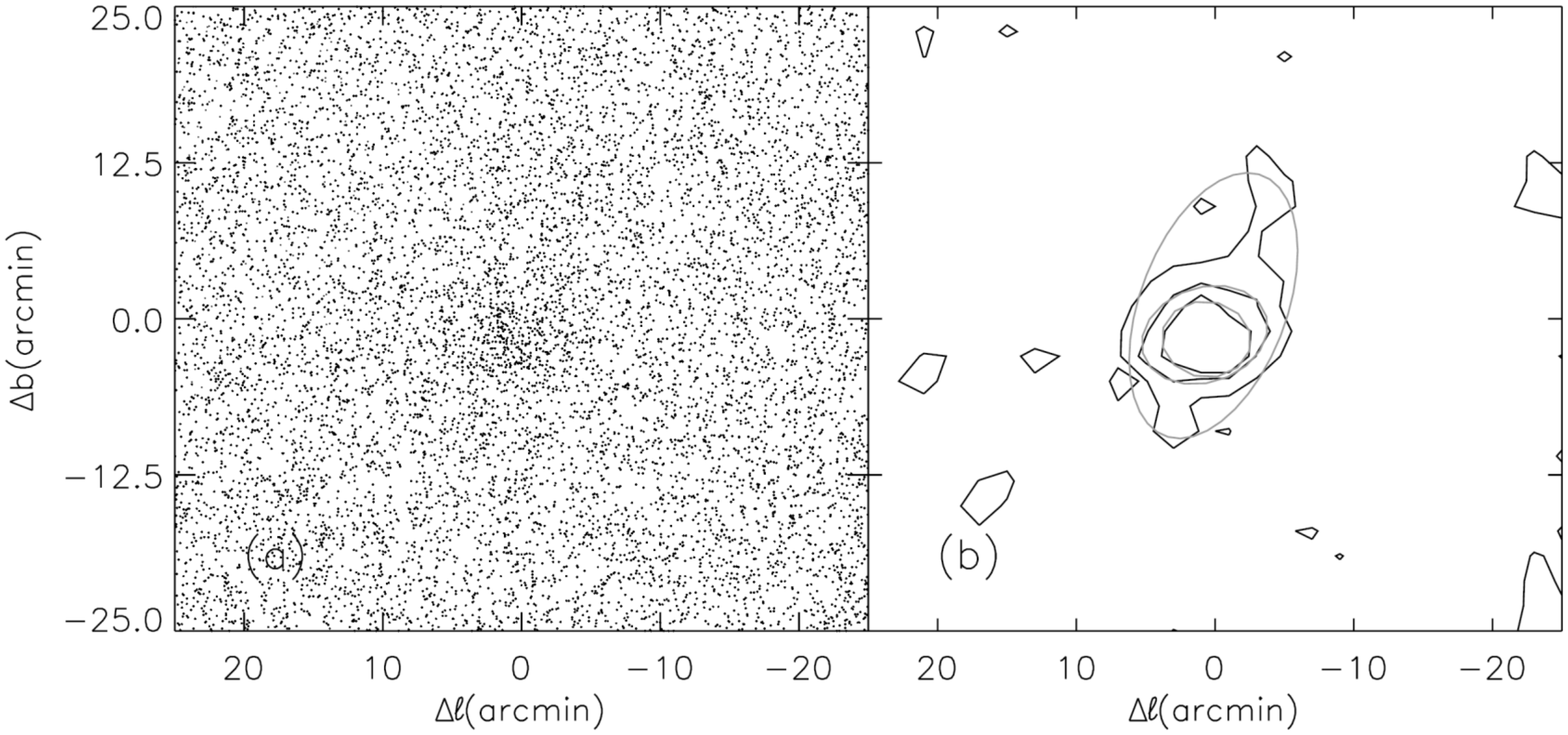


Evolution of Star Clusters

- (Initial) Molecular clouds are clumpy and filamentary; so are the youngest star clusters.
- (Internal) Mutual gravitational interaction among members virializes the cluster into a spherical shape, with more massive stars more concentrating toward the center (mass segregation). Lowest-mass members are vulnerable to ejection out from the system (stellar evaporation).
- (External) Eventually Galactic perturbations (tidal forces, differential rotation) distort and rip apart the star clusters

    → Disk population

Chen, Chen & Shu, 2004, Chen & Chen, 2010



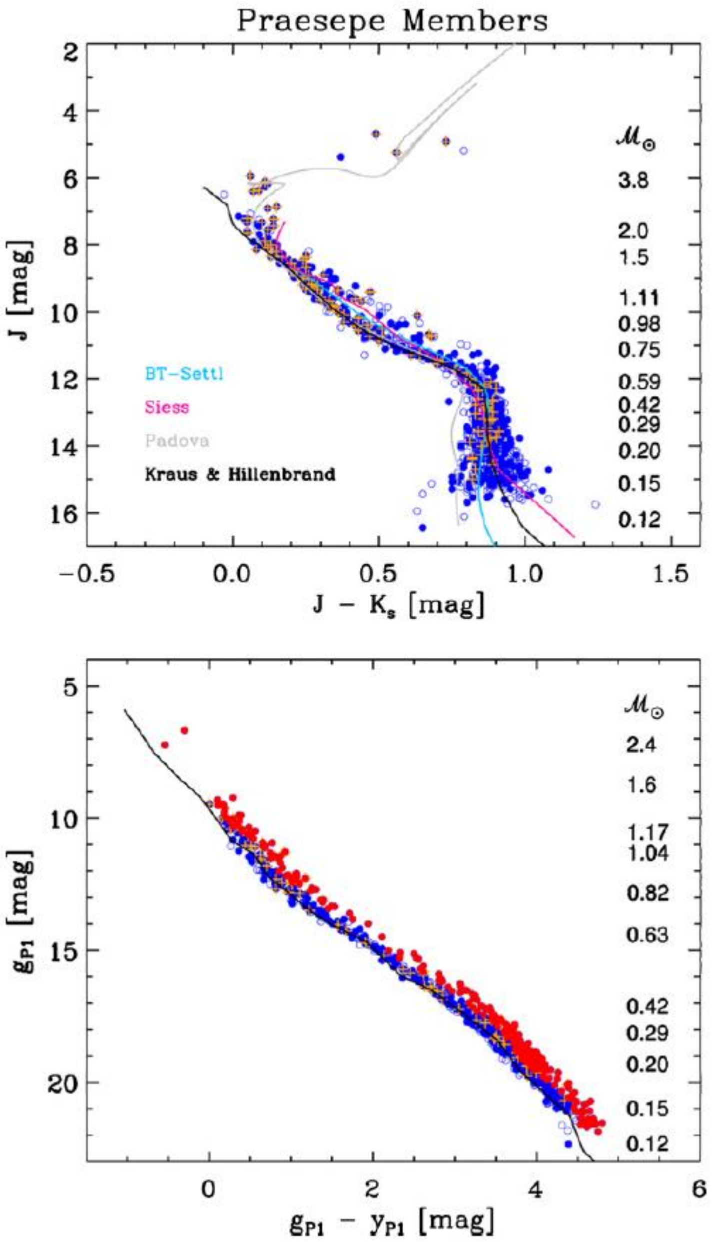
The oldest (10 Gyrs) open cluster Berkeley 17

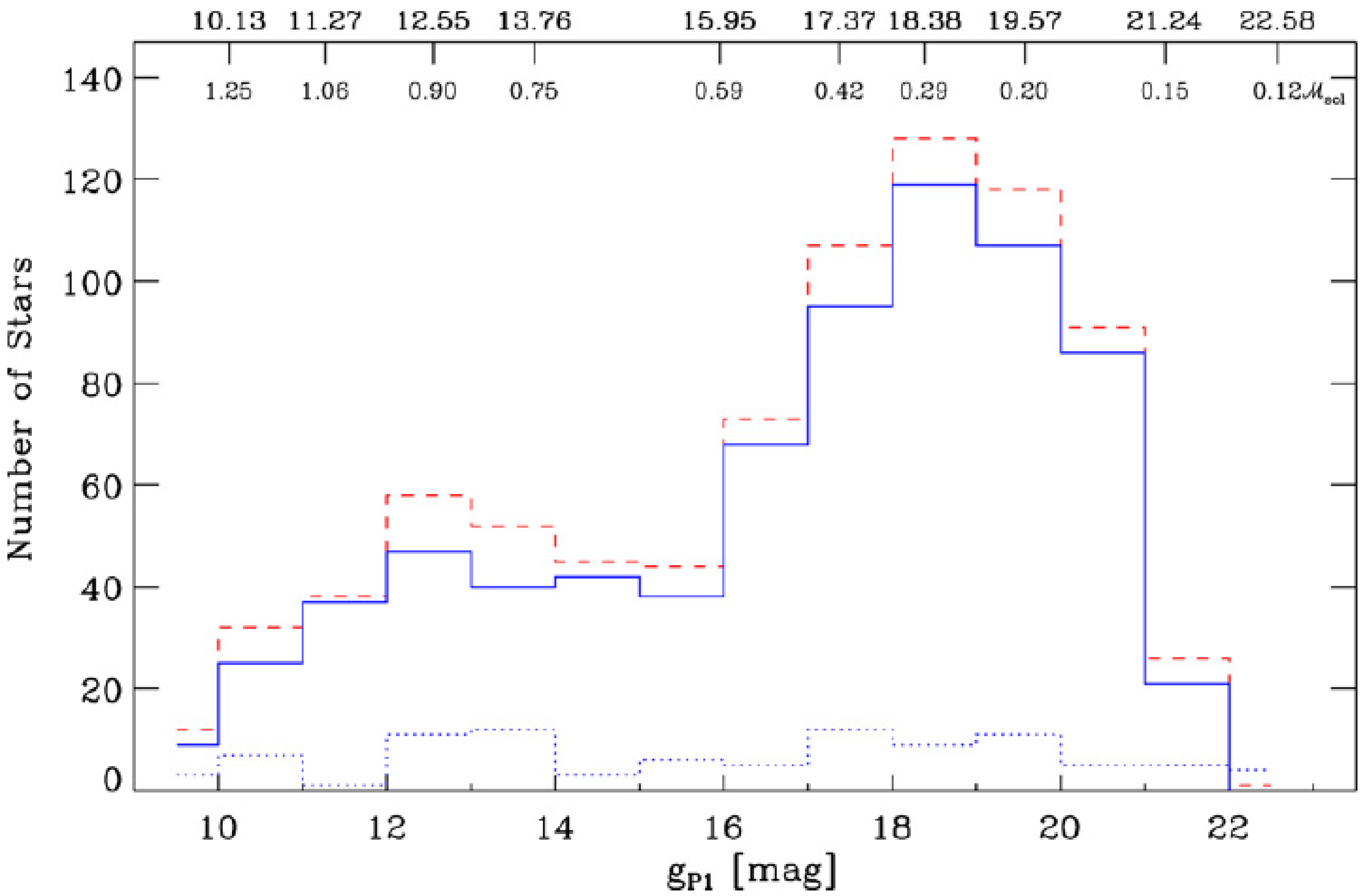
(Chen+04)

Most OCs are elongated, even among the youngest ones with ages ~a few Myr → shaped in the cluster formation process

As an OC evolves, its core becomes circularized by stellar dynamics, whereas the overall size expands and stellar density becomes sparse.

Stars in the tails are of lower masses than those in the core.

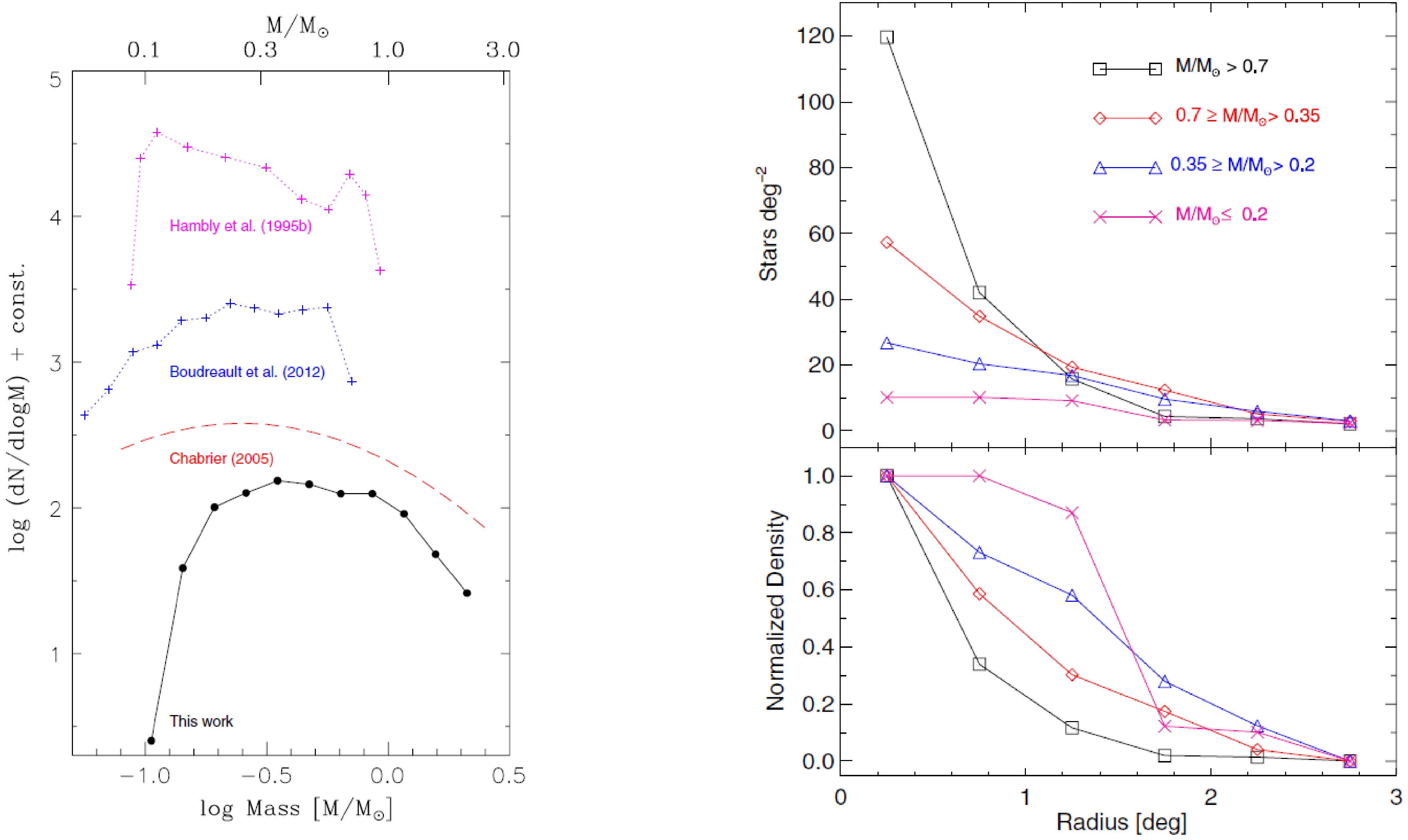




2MASS, PS1, PPMXL → 1040 member candidates

Wang+14

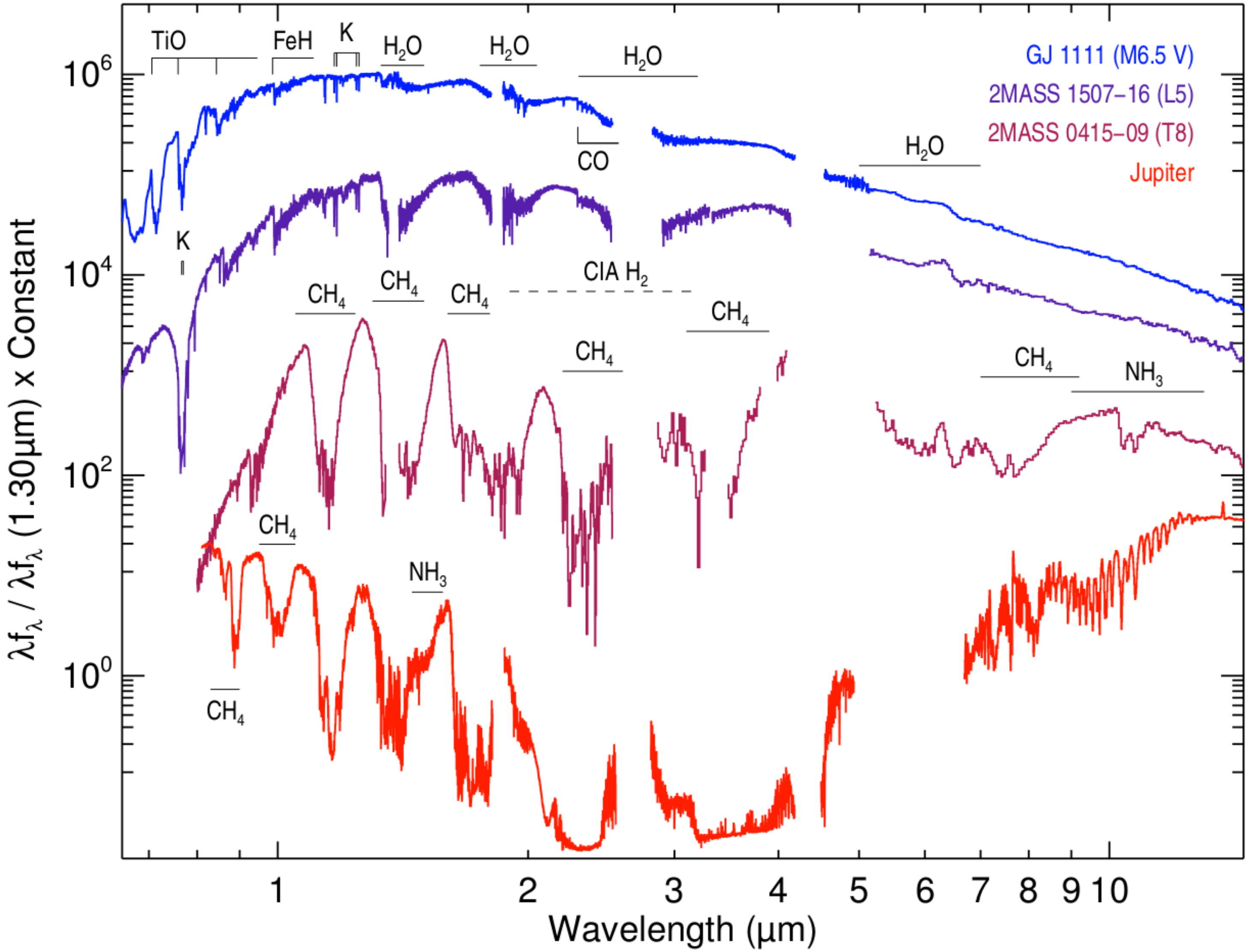
Praesepe (M44; 757 Myr, 180 pc)



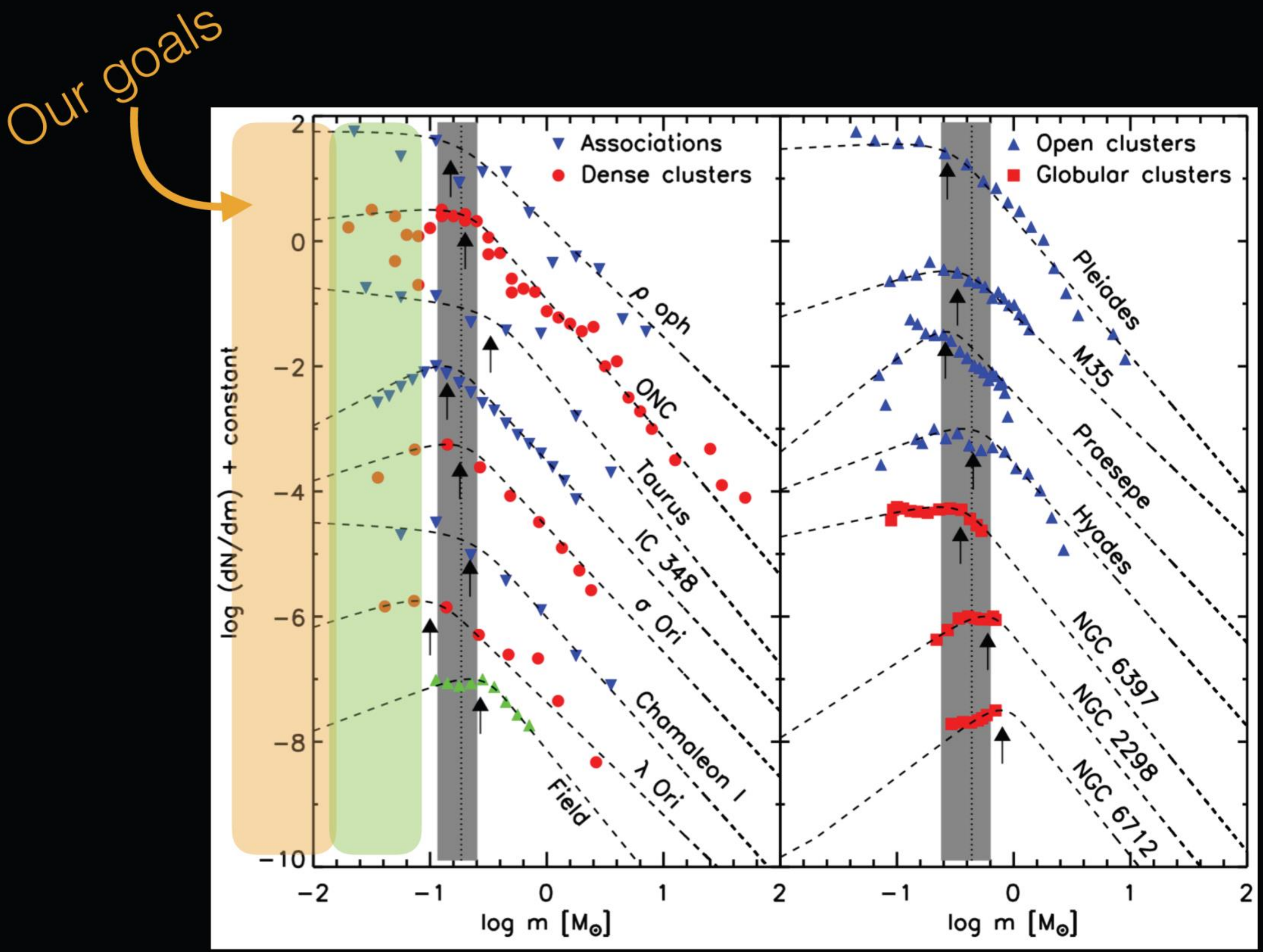
MF peak ~0.3 $M_{\odot}$; lowest-mass members being "evaporated"

Wang+14

What about brown dwarfs and Planetary-mass objects?



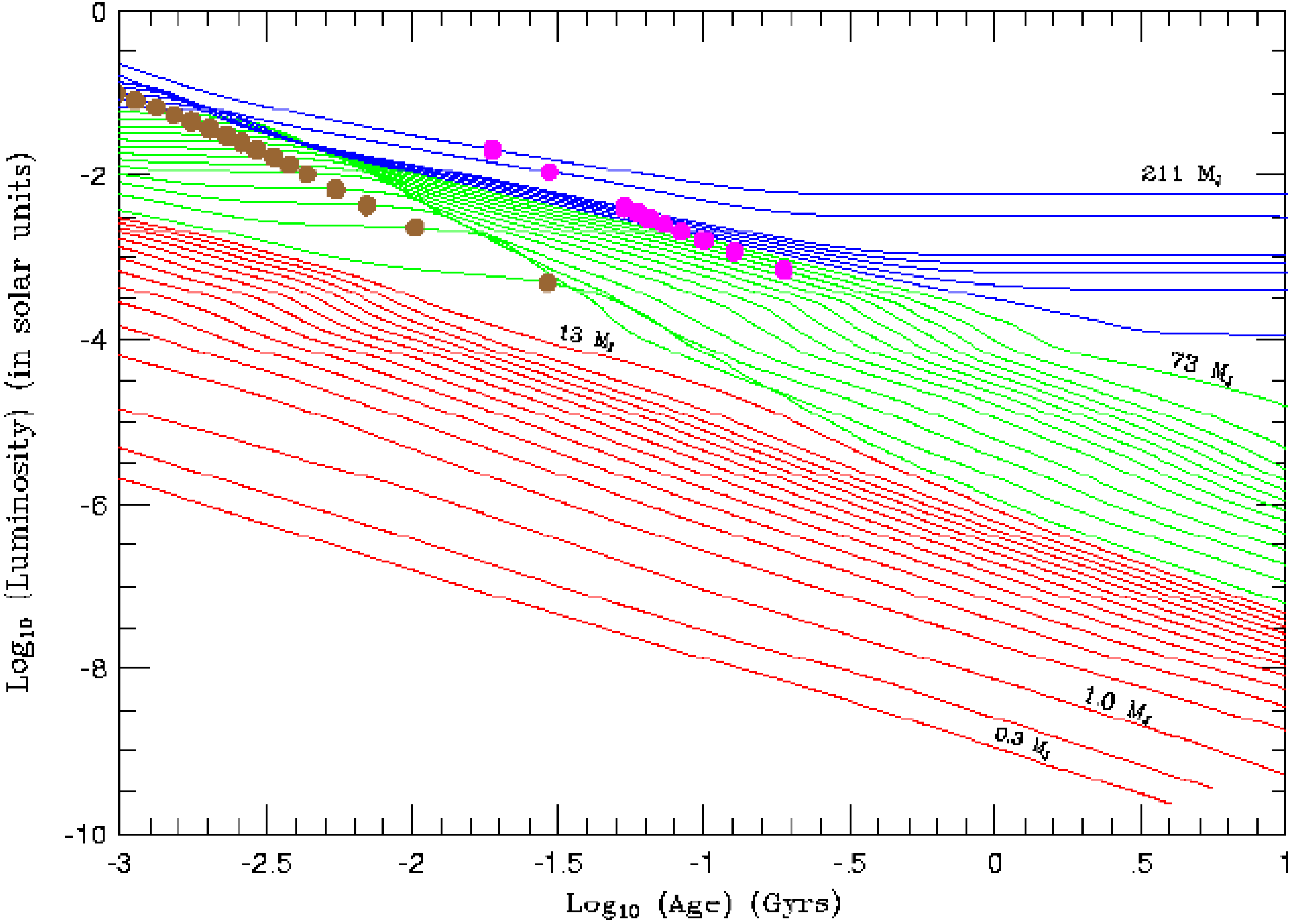
http://www.exoclimes.com/paper-outlines/exoplanets-and-brown-dwarfs-ii/



Bastian et al. 2010, ARA&A

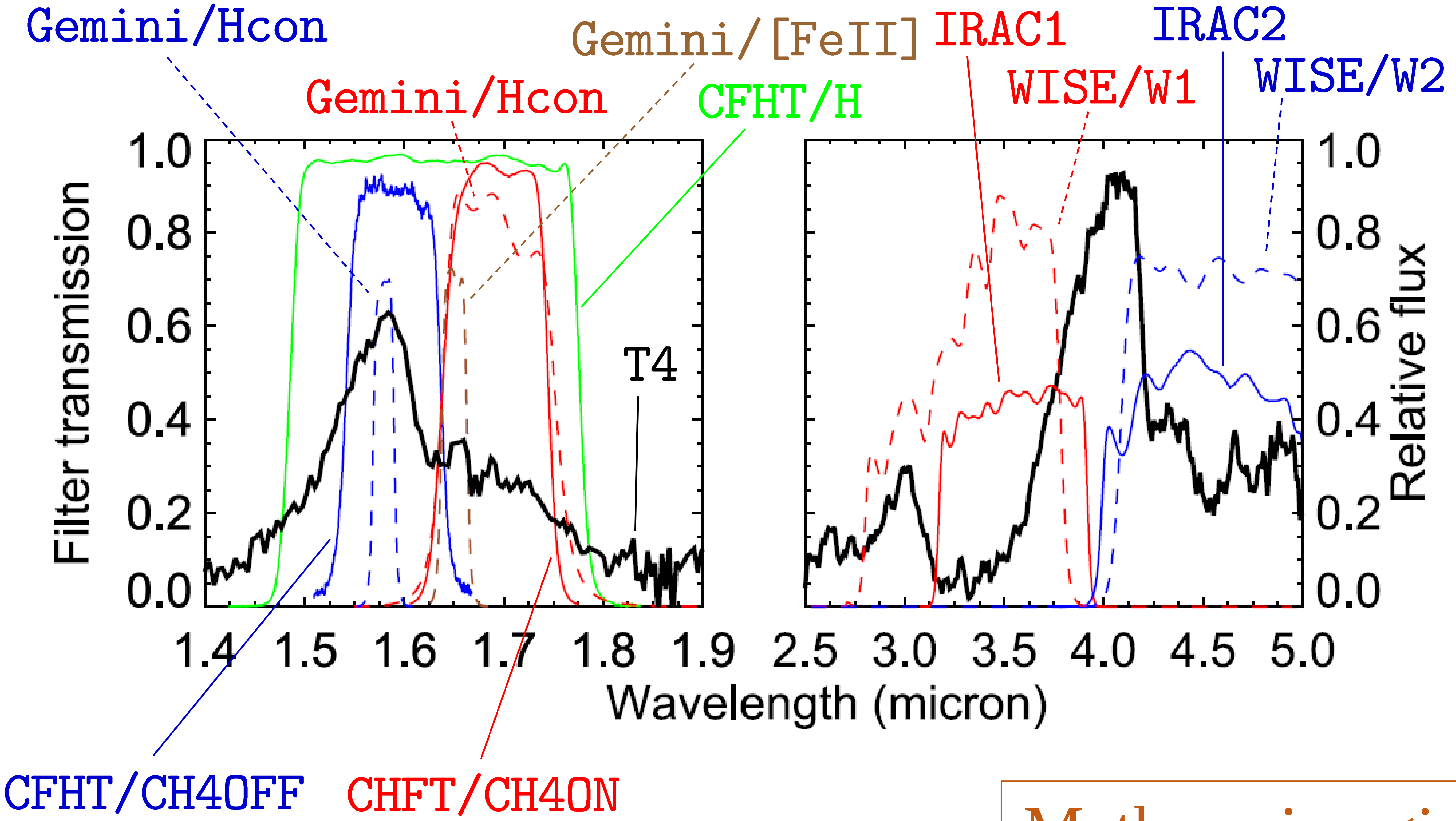
See the poster
by Oasa-san

- Most known brown dwarfs and planet-mass objects are in the field, so have aged.
- To study their formation and early evolution → need a young sample
- They are brighter when younger. But even the nearest SFRs are a far cry.
- Strategy:
    - ◆CFHT imaging (methane or water on-off), cool atmospheres in CMDs to identify candidates
    - ◆Gemini/VLT/Subaru spectroscopic confirmation



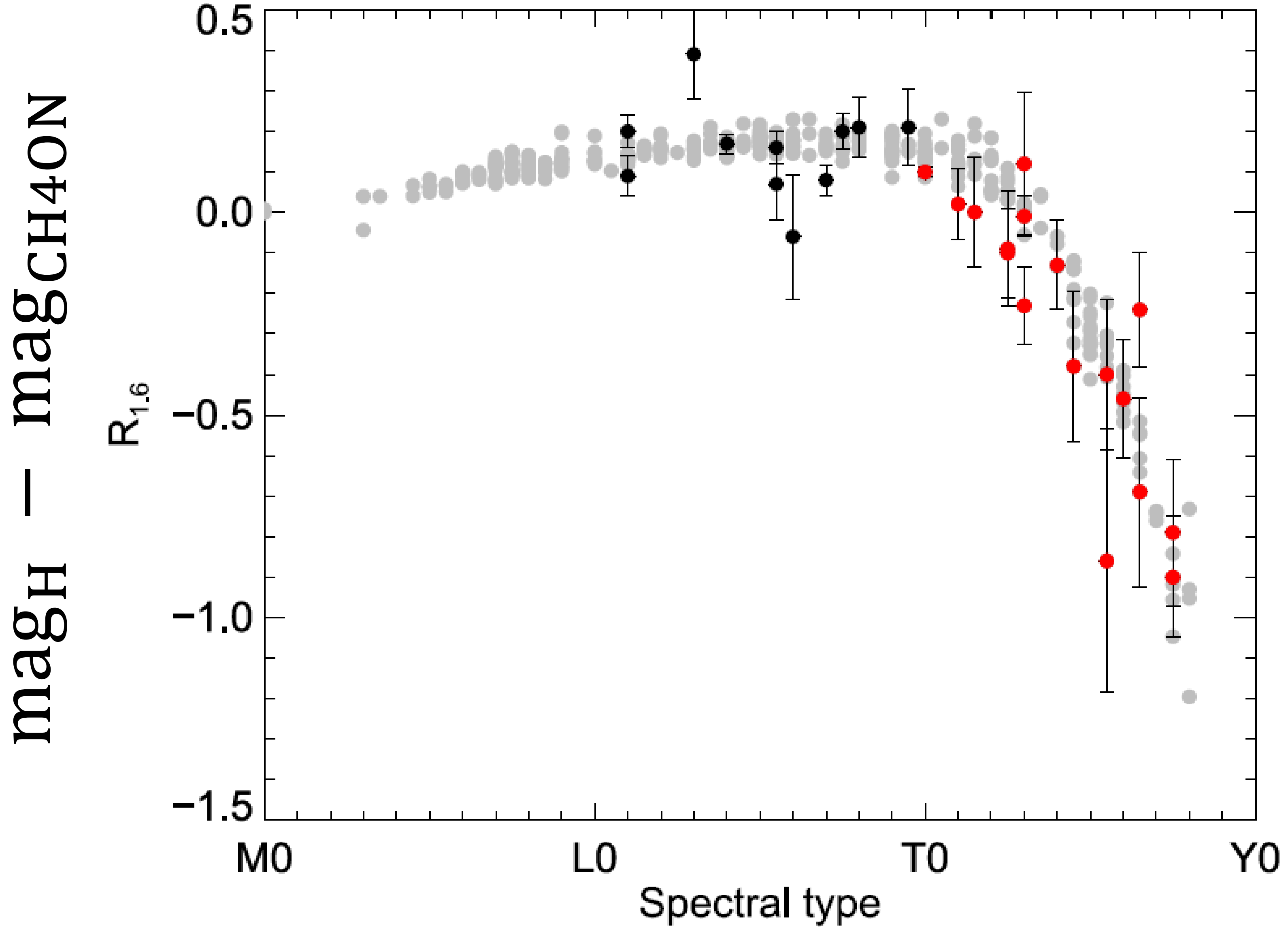
0
-2
-4
-6
-8
-10
-3
-2.5
-2
-1.5
-1
-.5
0
.5
1
Log10 (Luminosity) (in solar units)
Log10 (Age) (Gyrs)
211 MJ
73 MJ
13 MJ
1.0 MJ
0.3 MJ

Burrows+01



Methane imaging

Calibration with known field population

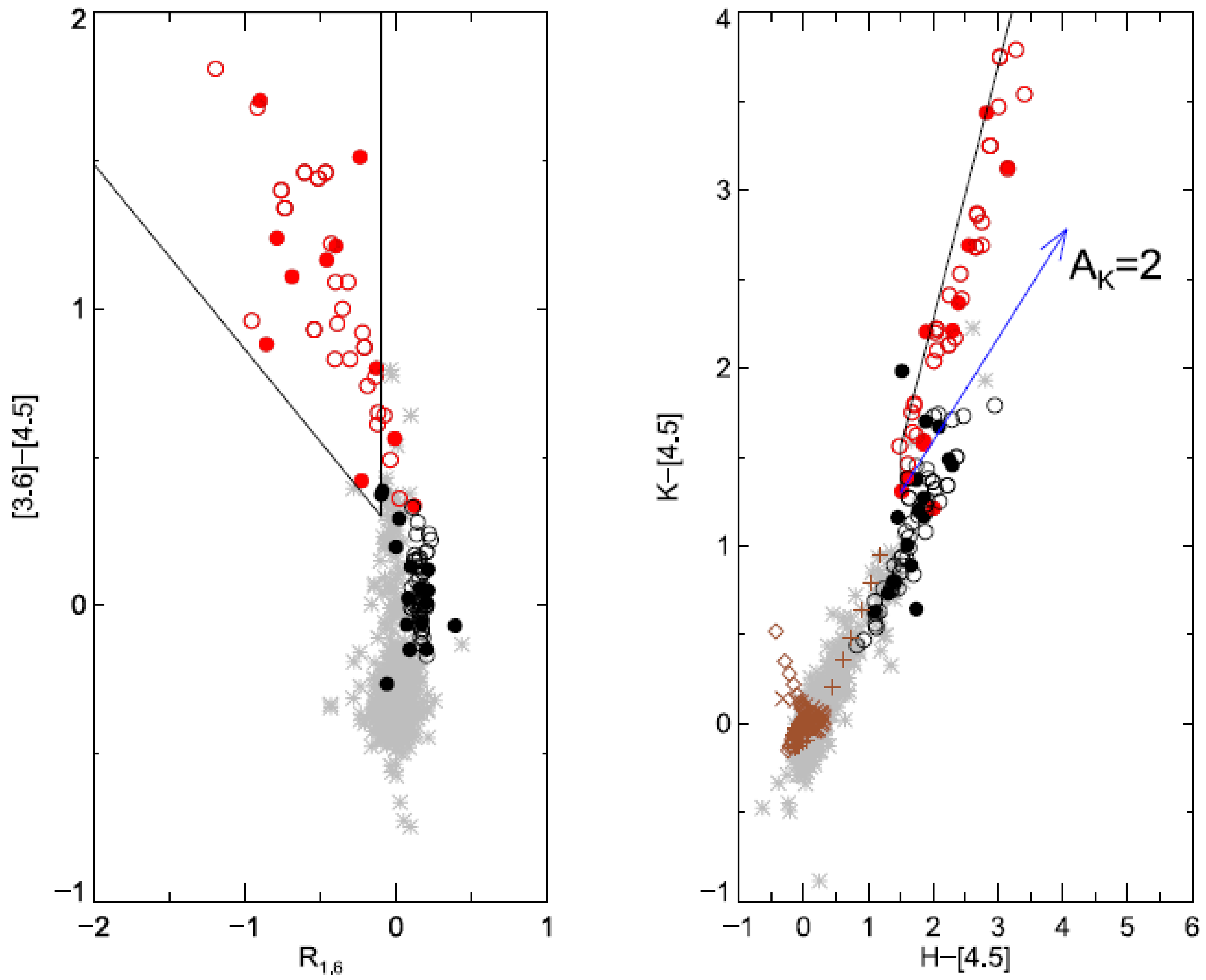


Known **L** and **T** dwarfs observed with CH4 imaging

Gray: computed from the SpeX library

Chiang+15

Calibration with known field population



Known field **L** and **T** dwarfs observed with CH4 imaging (filled)

Known field **M/L** and **T** dwarfs computed R1.6 from the Spex (open)

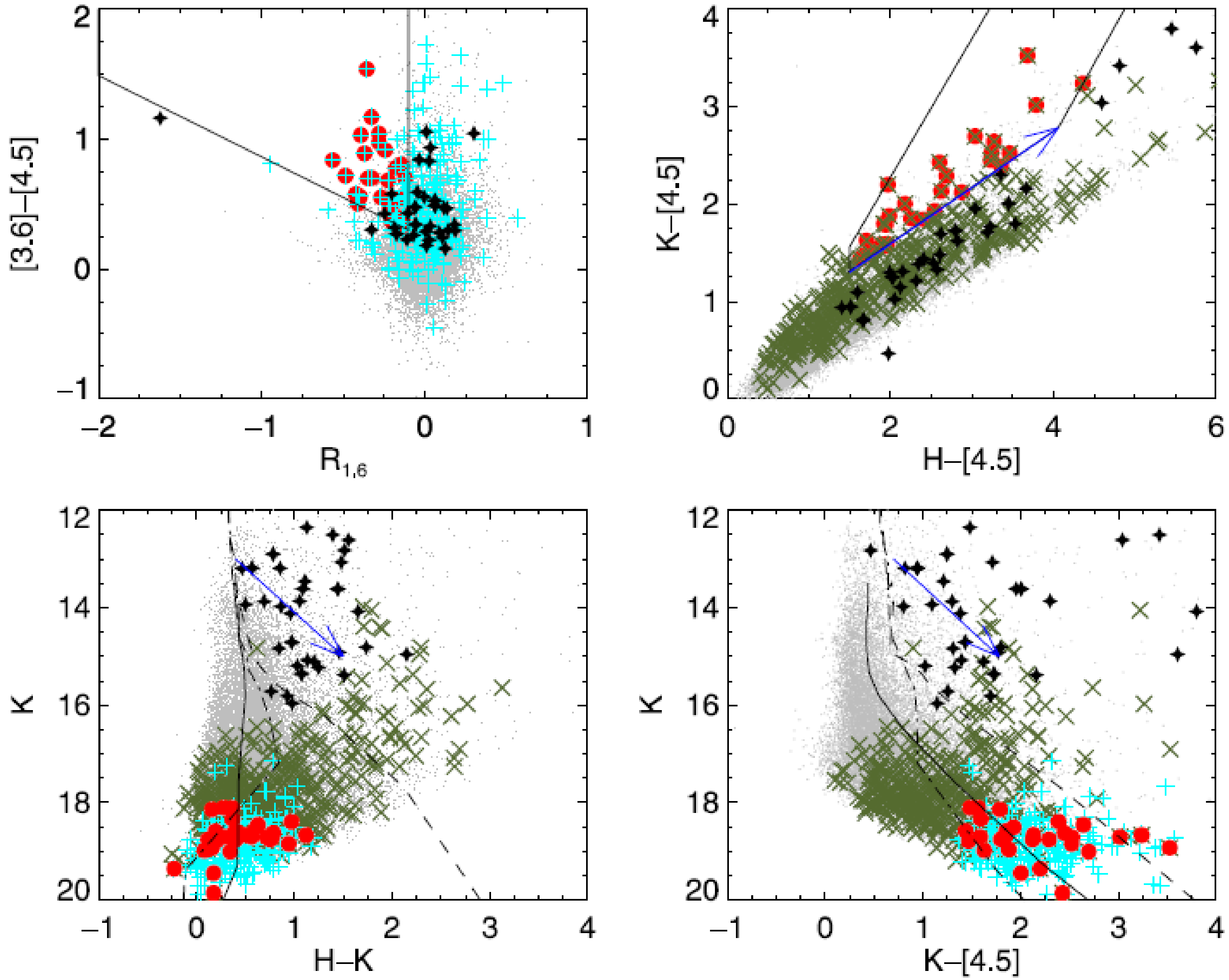
Field stars

dwarfs (pluses), giants (crosses), supergiants (diamonds)

Chiang+15

Finding L dwarfs in Rho Oph/L1688

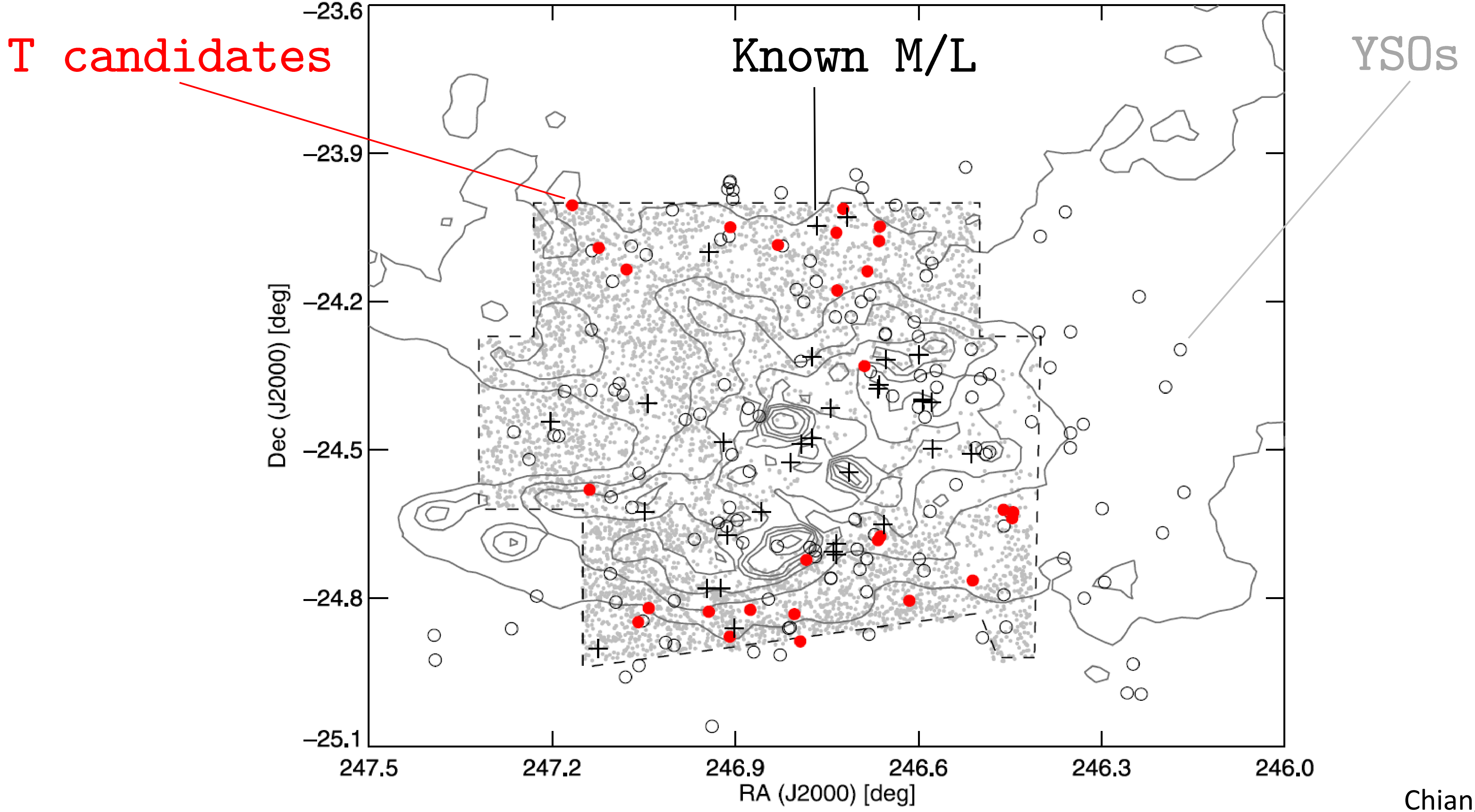
Chiang+15



All WIRCam/c2d (N=23,974)
Methane selected (441)
Temp selected (268)
+ known M/L in Rho Oph

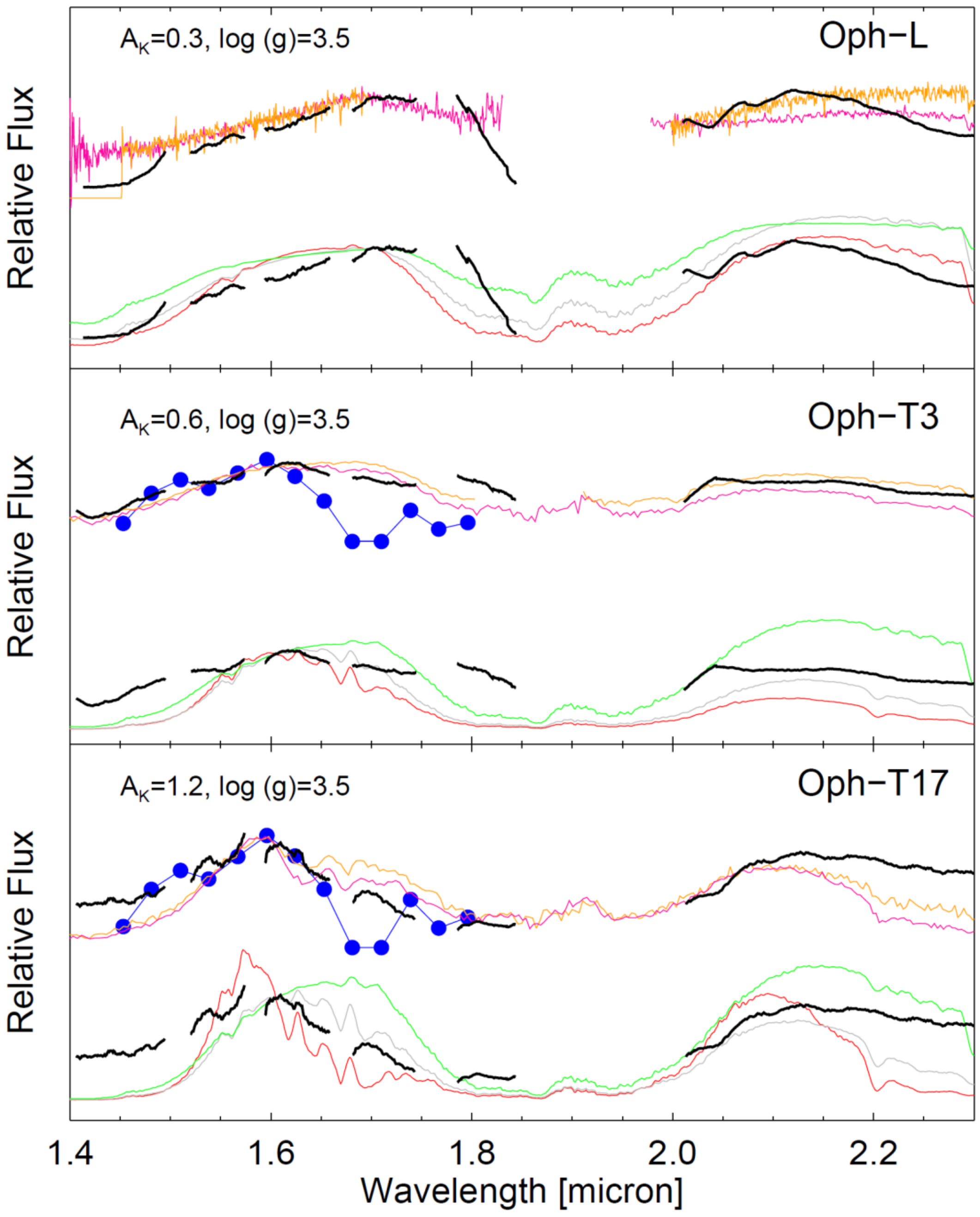
A total of 28 **T dwarf candidates** found (1) with methane features, (2) with cool atmospheres, (3) not detected by *Spitzer* MIPS, (4) with consistent PMs.
Half may be false positives.

1 Myr isochrones:
COND (solid); DUSTY (dashed), BT-Settl (dot-dashed)


T candidates
Known M/L
YSOs
−23.6
−23.9
−24.2
−24.5
−24.8
−25.1
Dec (J2000) [deg]
247.5
247.2
246.9
246.6
246.3
246.0
RA (J2000) [deg]

Chiang+15

2 T dwarfs and 1 L dwarf confirmed



2M0437 (L0); 2M1207b (low-*g* exoplanet)

1100, 1200, 1300 K

L9, T1, HR8799e

H=18.38

900, 1000, 1100 K

T3, T4

H=19.16, 18.80

800, 900, 1050 K

Gemini-S/Flamingo2

1800-2000 s

6 candidates observed in 2014, 1 emGalaxy, 1 bg star, 2 cool stars but no methane

Chiang & Chen (2015)

The W Team …… CFHT/WIRCam (newly commissioned W filter)

Beth Biller … ROE (UK)

Deacon Niall … Hertfordshire U (UK)

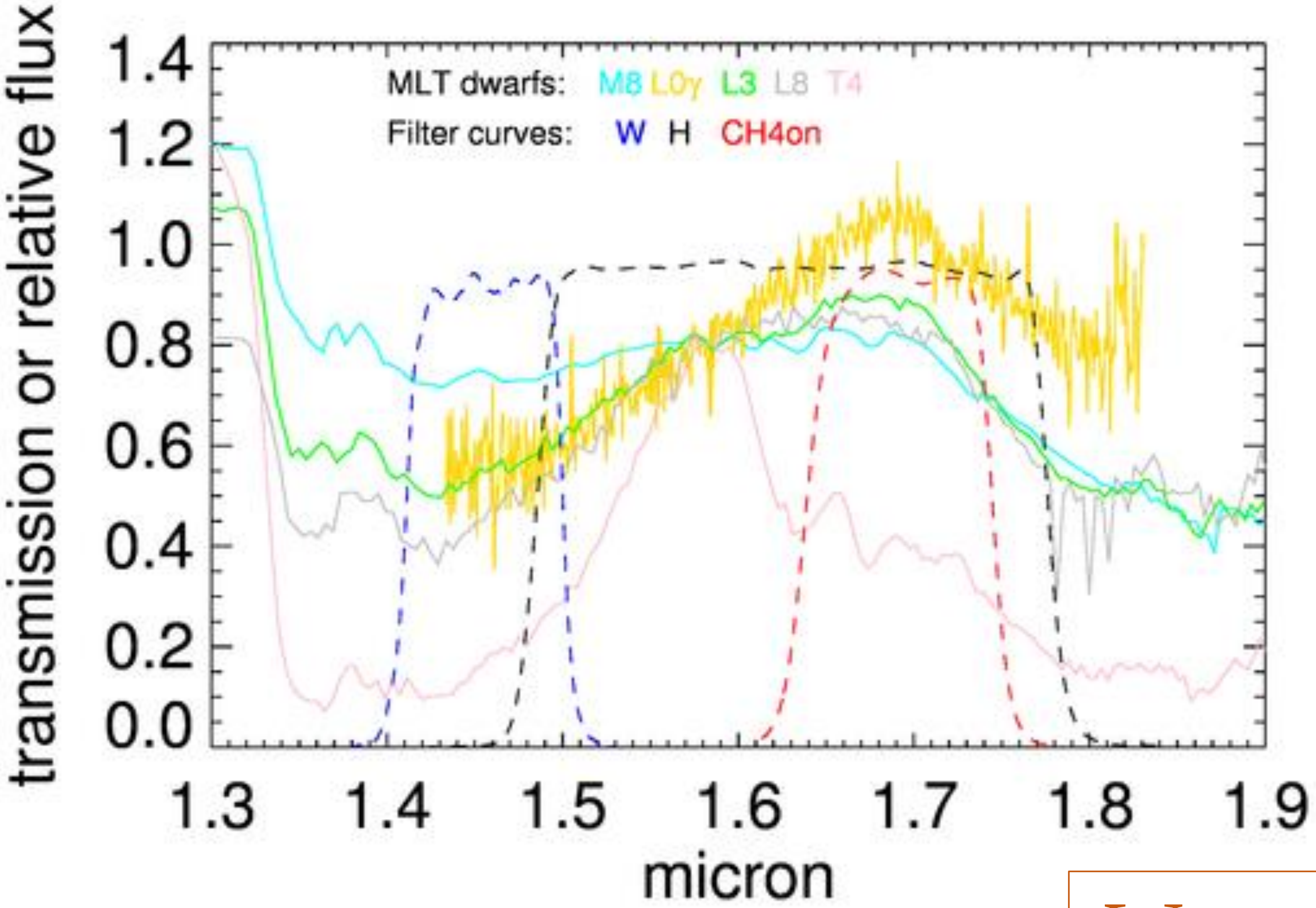
Loic Albert, Etienne Artigau, Rene Doyon … U Montreal (Canada)

Gregory Herczeg, Jessy Jose … NAOC (China)

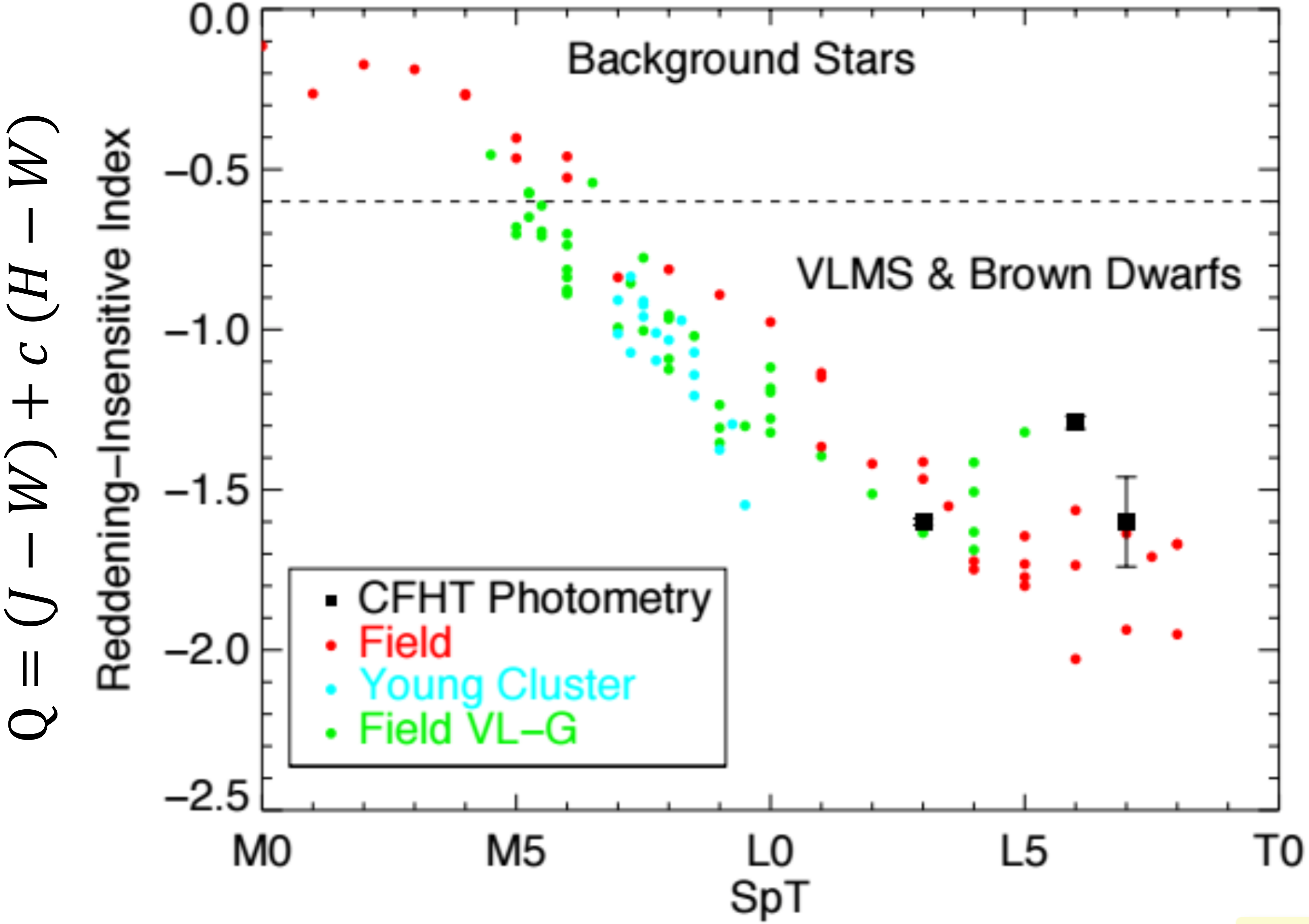
Mickael Bonnefoy, Philippe Delorme … UJF (France)

Mike Liu … IfA (UH, USA)

Poshih Chiang, Wen-Ping Chen … NCU (Taiwan)



Water imaging



■ known low-gravity L observed by WIRCam/W

A W-band survey of nearby SRFs; started with Taurus

L1495

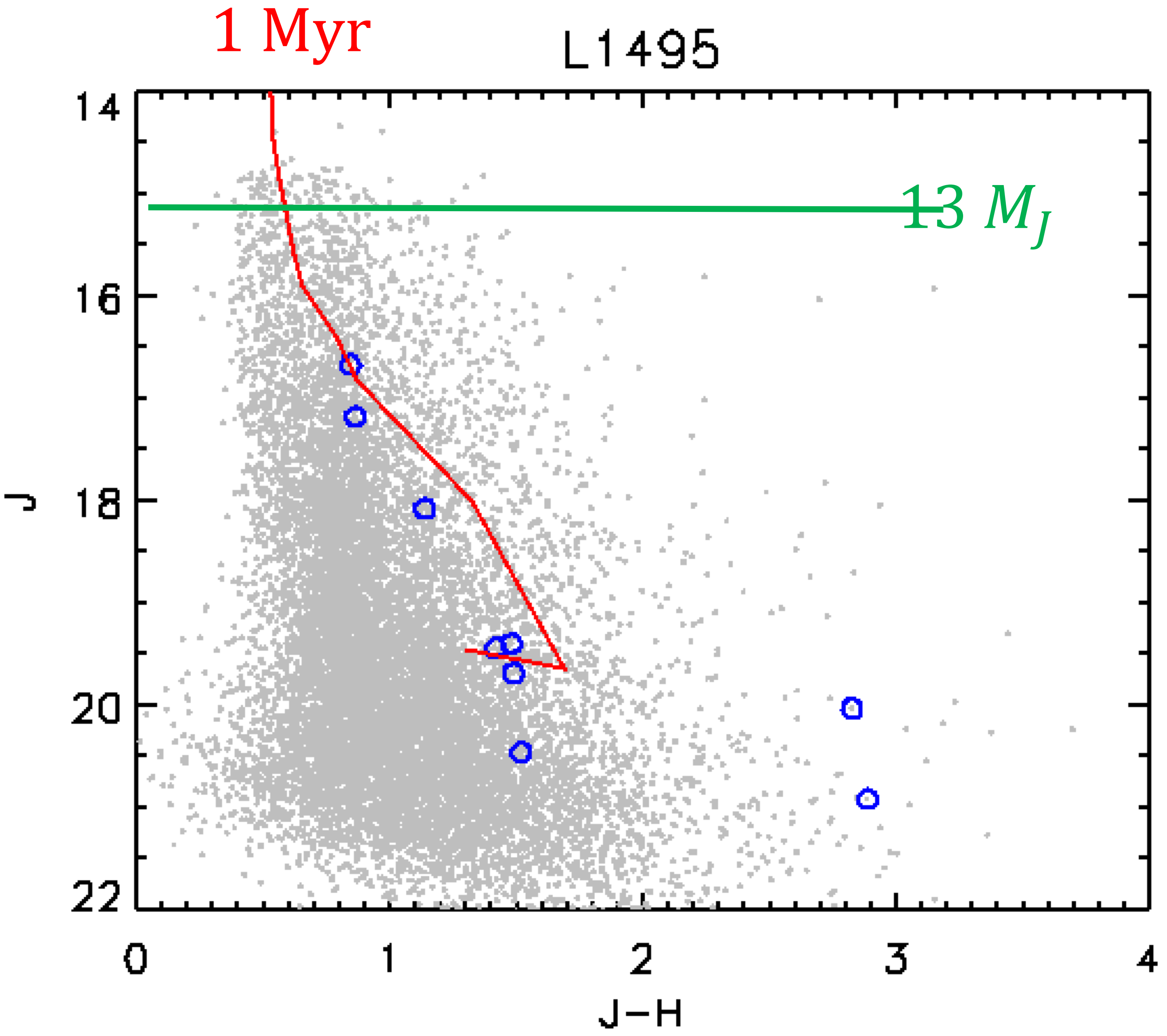
2012 (JHK) + 2015 (W)

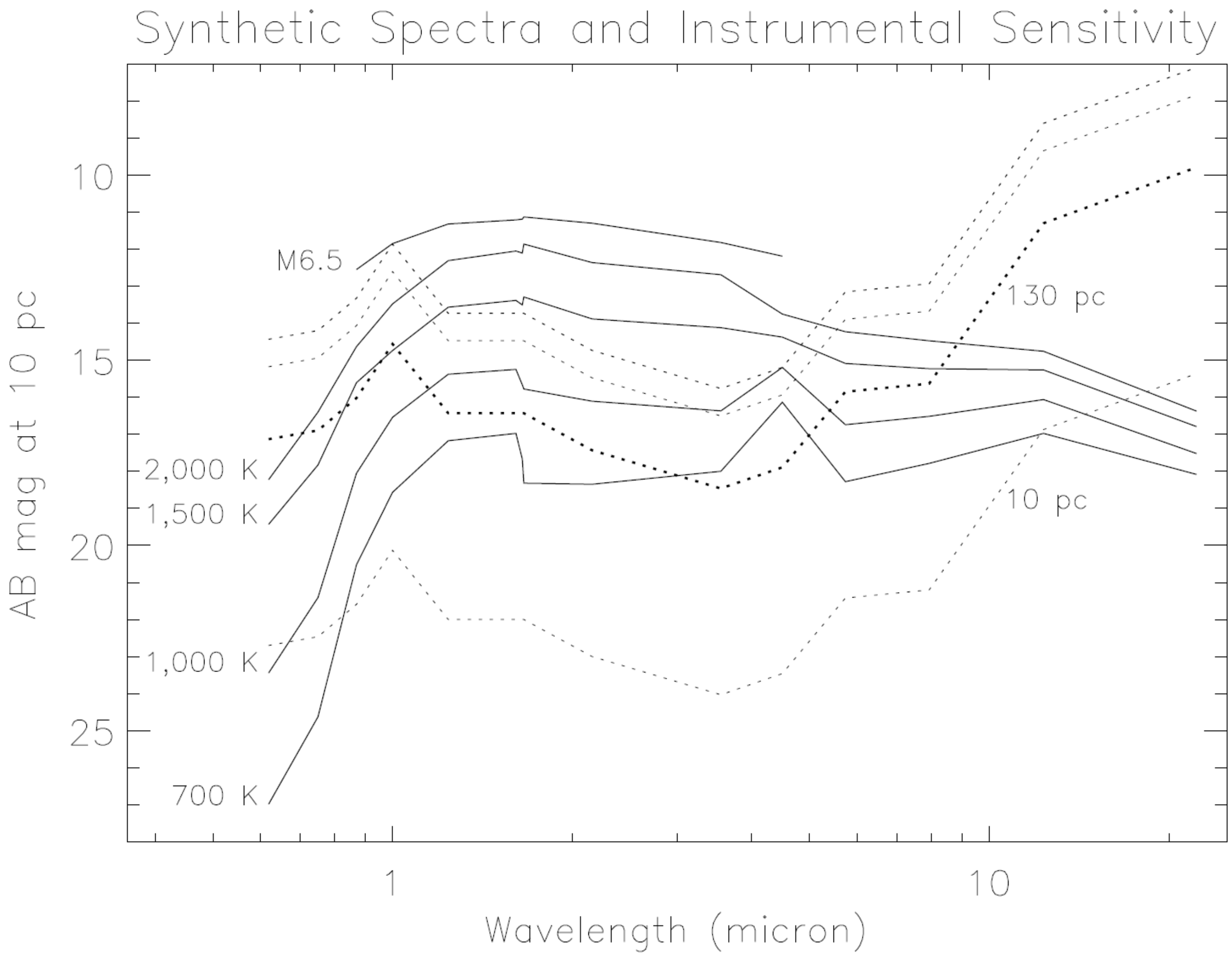
J (21), H/W (19.5), K (18.5)

Candidates:

- ABS(Q) > 3 Qerr
- Q < −0.6
- K > 15 mag

→ 9 candidates





from bottom up, for a target at 10, 130 (Taurus/Oph), 320 (IC348), and 450 (Orion) pc.

SEDs (solid lines) of cool atmospheres, computed from models by Burrows et al. (2001). Dashed lines show the sensitivity of PanSTARRS (r’, i’, z’, y’), CFHT (magAB~ 21 in J, H, and K), Spitzer/IRCA 3.6, 4.5, 5.8, and 8.0, and WISE 12 and 22 microns,

Conclusions

- Now … 4 m class to select (reliable) candidates;
  Rho Oph, Taurus (130 pc); IC 348 (320 pc)
  8-10 m to secure the discovery
  Rho Oph, Taurus OK; no Ts beyond

- Next … 8-10 m for candidacy
  TMT spectroscopic confirmation AND <u>characterization</u>

→ Cool atmosphere physics and chemistry (cloud formation, isotopes …)

→ Census of young BDs and PLAMOs vs YSOs
spatial distribution, velocity dispersion, binary/disk/mass …