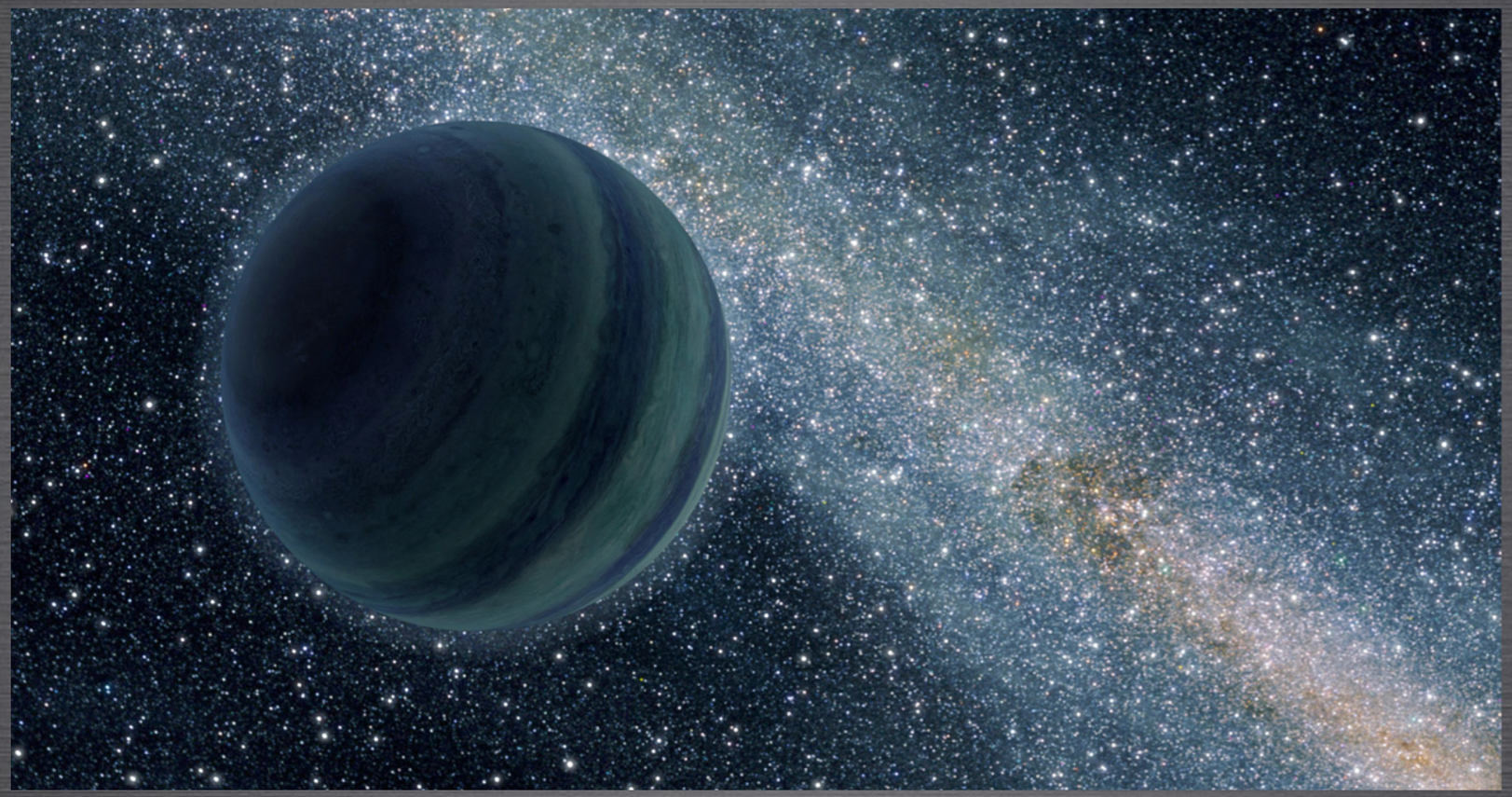


NASA/JPL-Caltech

The Brown Dwarf to Exoplanet Connection through Young Moving Groups

Sagan Fellows Symposium, 2015

Jonathan Gagné, David Lafrenière, René Doyon, Jackie Faherty, Lison Malo,
Étienne Artigau, Kelle Cruz, Adam Burgasser, Marie-Ève Naud, Loïc Albert

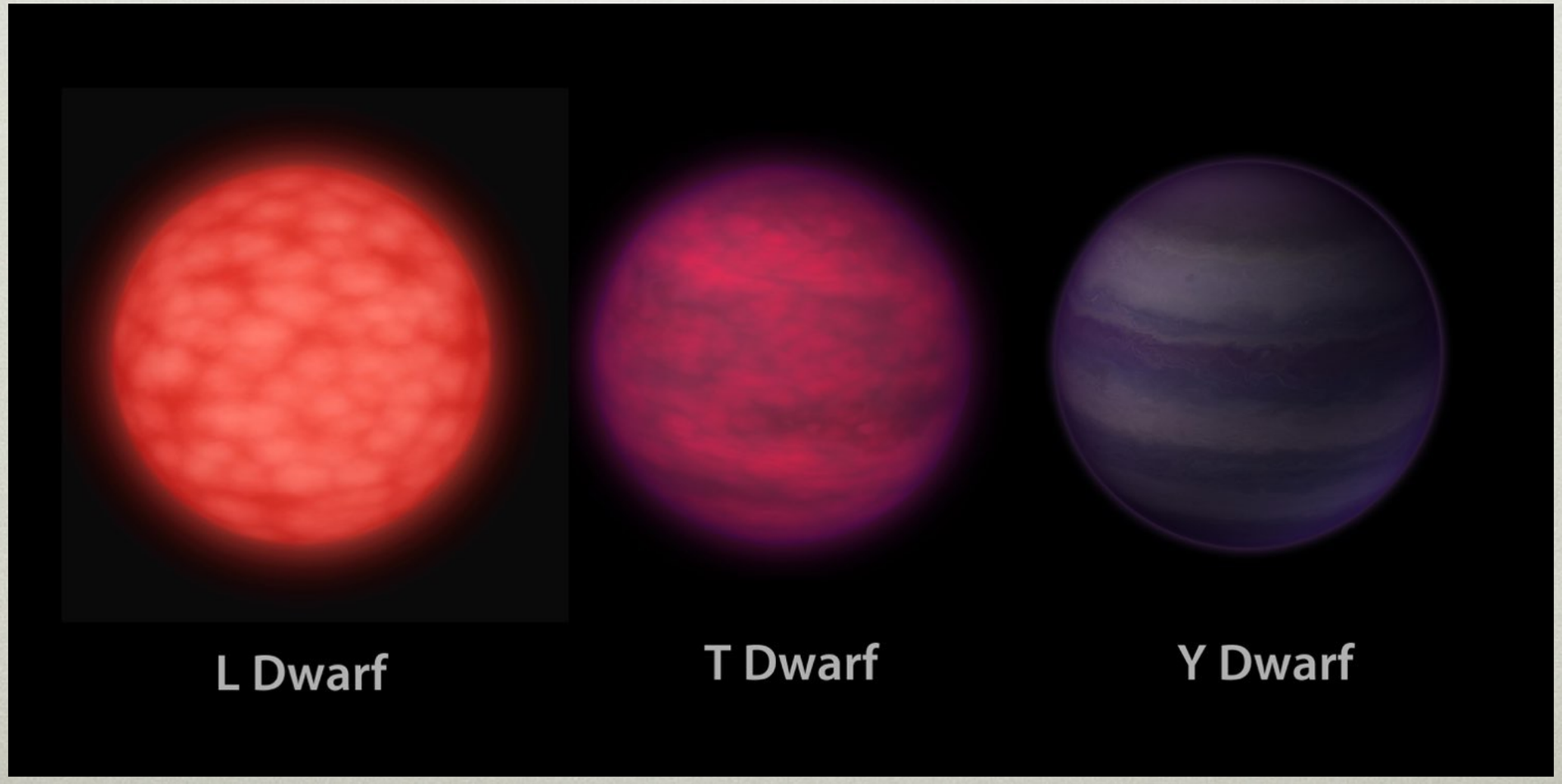
Brown Dwarfs (BDs)

Super-Jupiters / Failed stars

Similar to Jupiter but much more massive

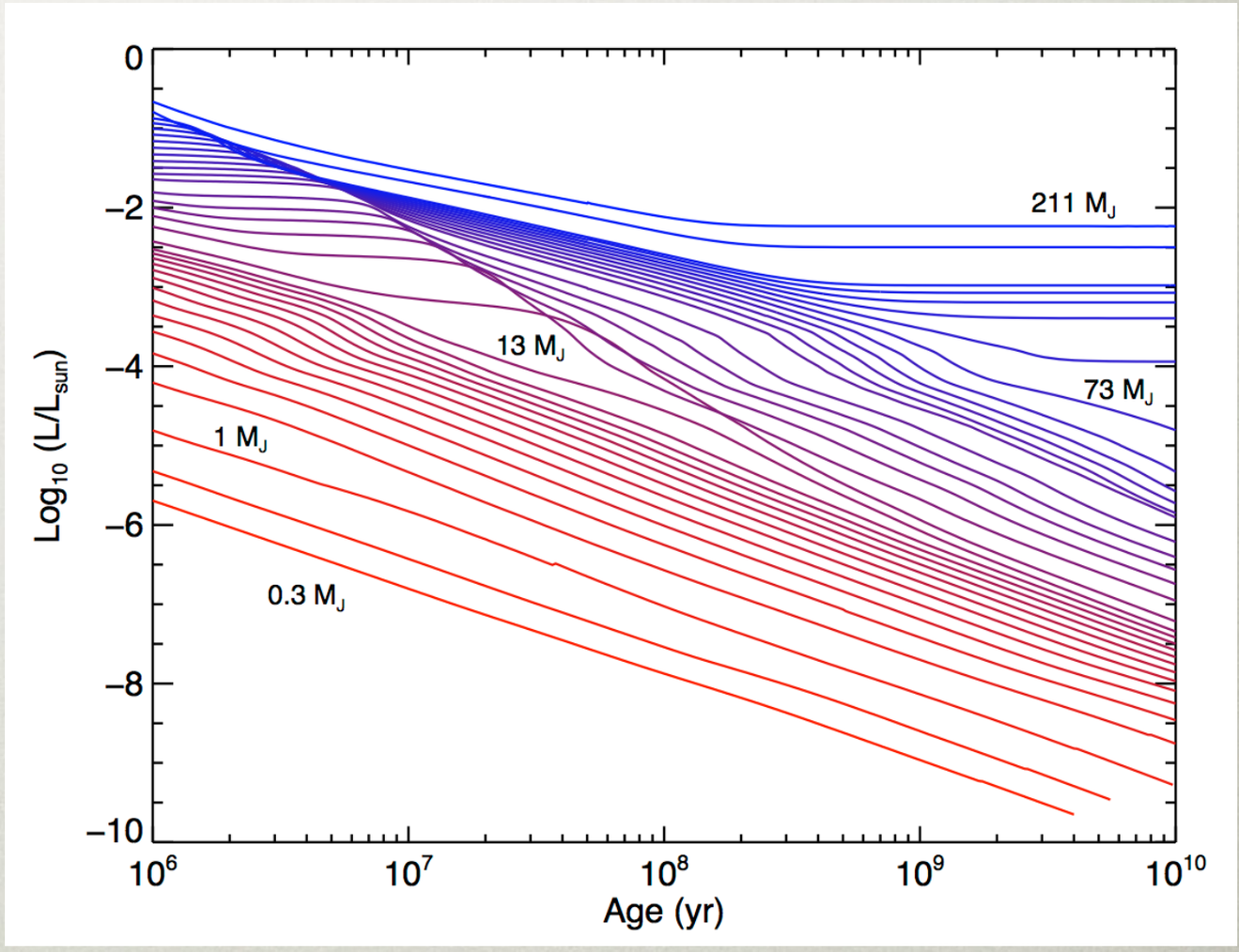
Often isolated in space

Water / Methane / Ammonia + dust clouds



Why Young BDs ?

- **Least massive BDs are really faint**
- **Younger = Hotter, brighter**
- We find young BDs with < 13 M_{Jup}
- Properties very similar to giant exoplanets



Burrows et al. (2001)

Why Young BDs ?

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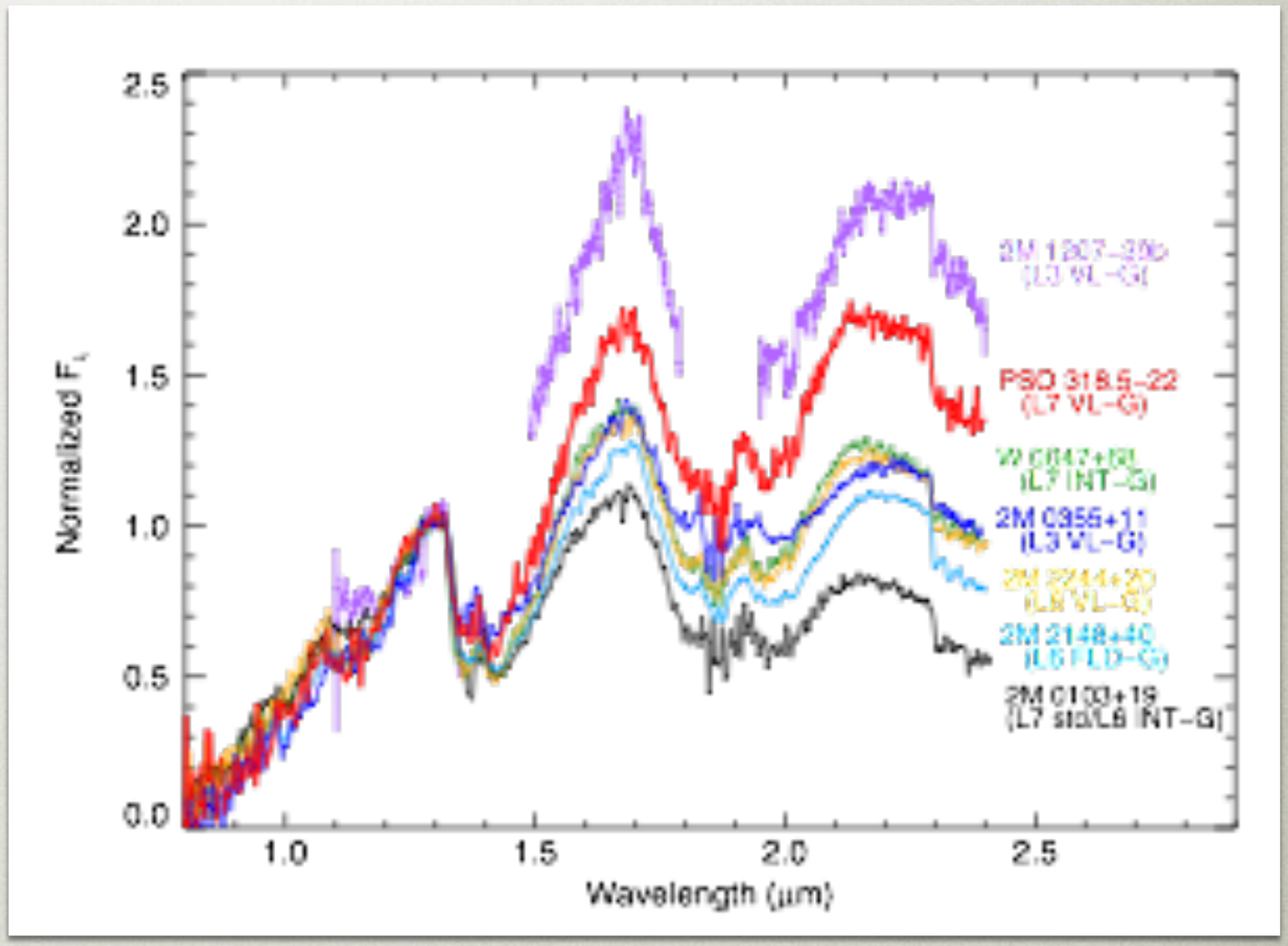
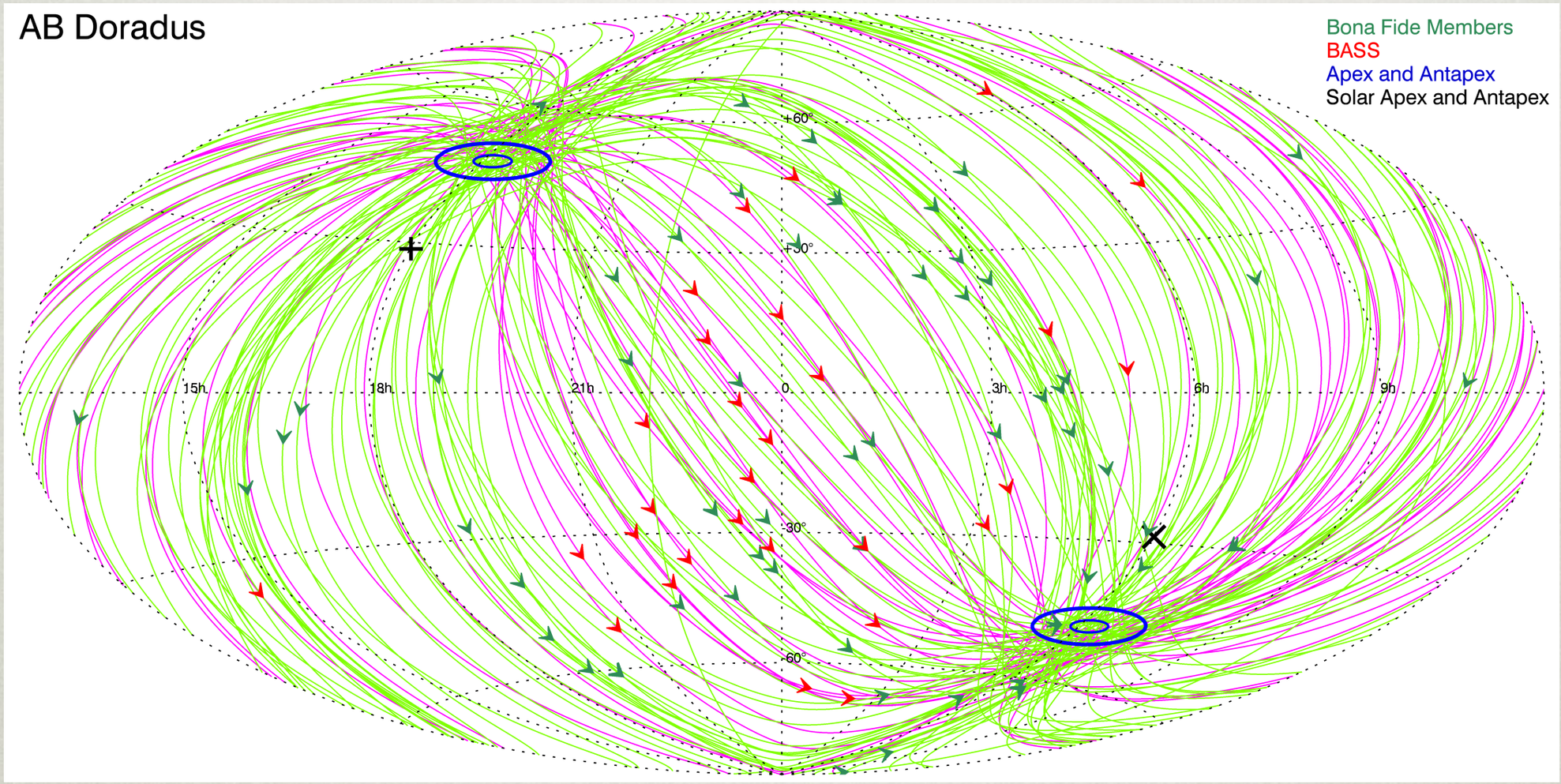


Liu et al. (2013)

Moving Groups 4/34

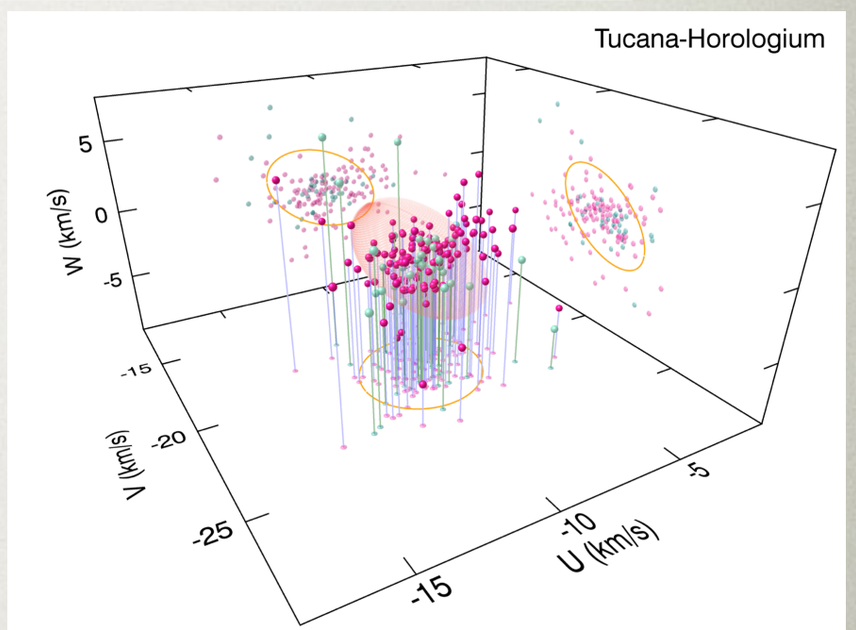
Gagné et al. 2015 ApJ, 798, 73



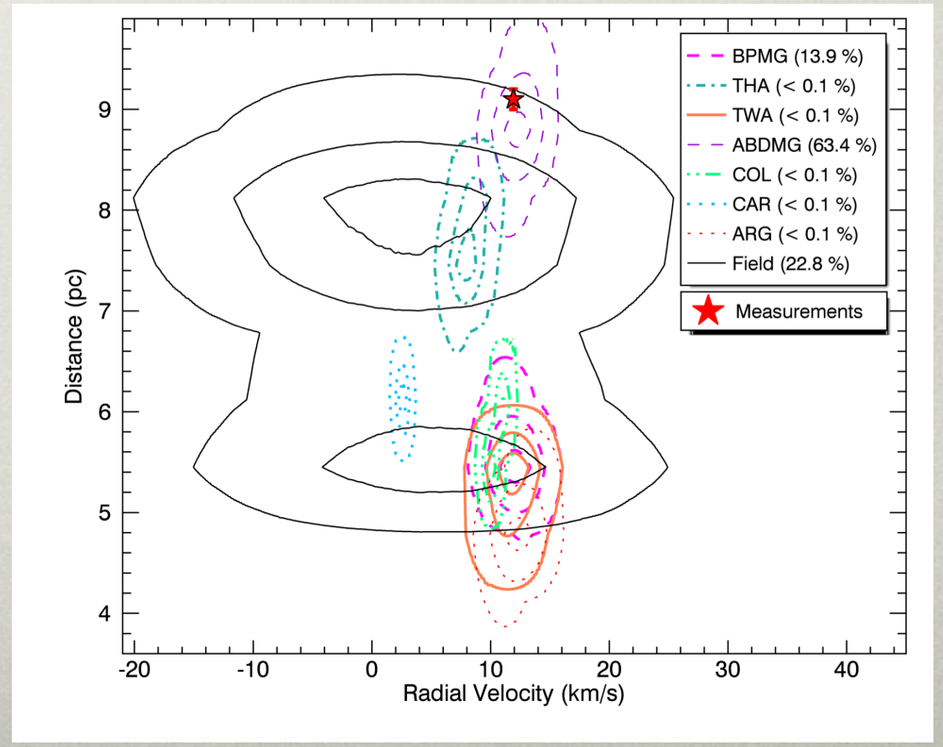
- Group of young coeval stars (typically < 200 Myr)
- Born in same molecular cloud
- Similar galactic velocities
- Nearby = Spread-out on the sky
- Brown dwarf population largely missing !

BANYAN II

- Position + PM + J/H/K/W1/W2
- Compare to kinematic model with Bayes' theorem
- Yields a 2D probability density function
- RV and distance are generally unknown
- We marginalize (integrate over) them
- Final output is membership probability



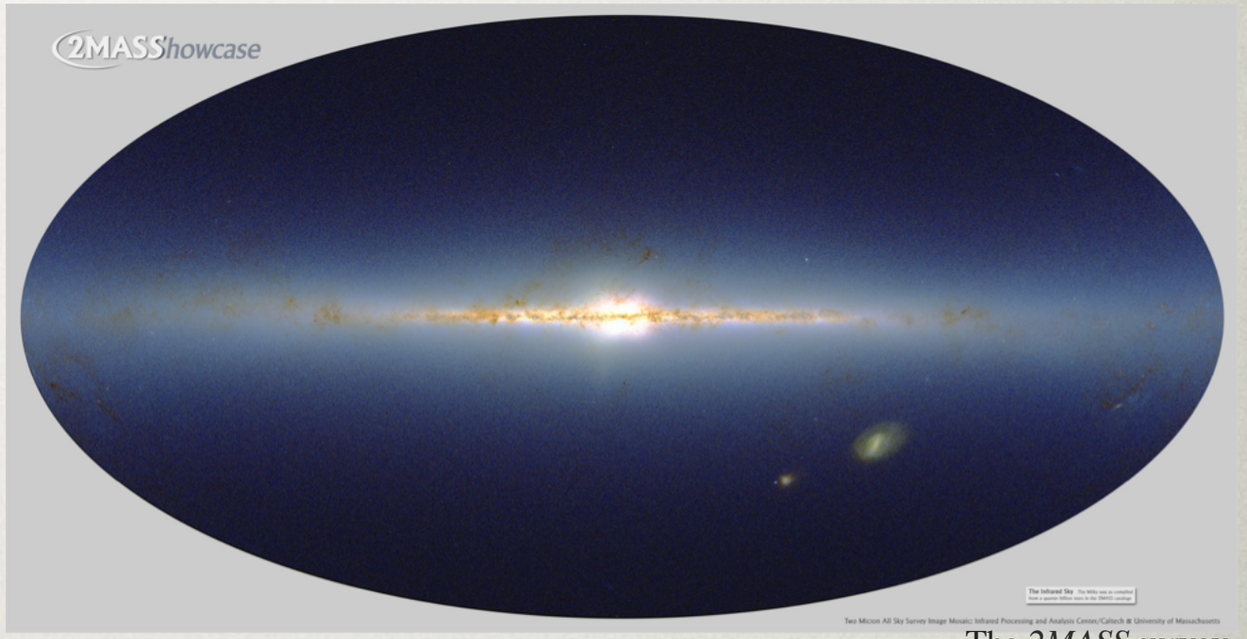
Gagné et al. 2015 ApJ, 798, 73



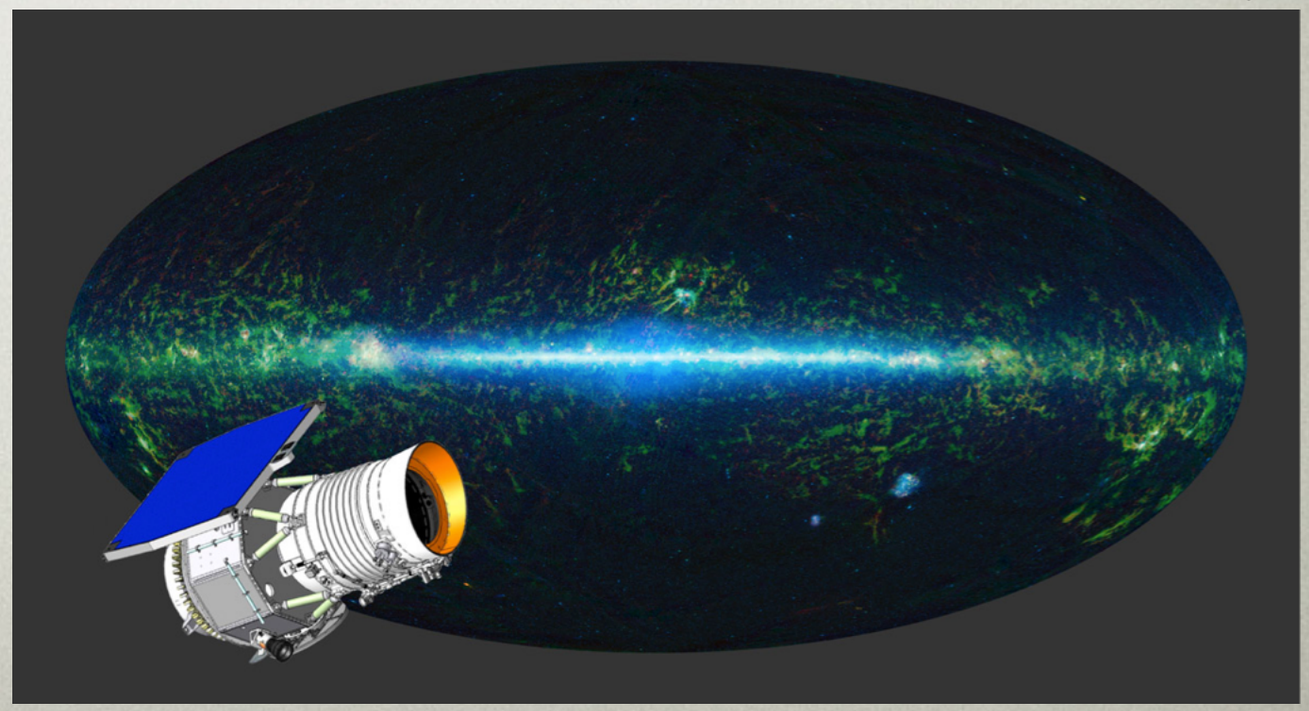
Gagné et al. 2014 ApJ, 783, 121

The BASS survey

- BASS = Banyan All-Sky Survey
- Cross-Match of the full *2MASS* + *AllWISE* catalogs
- 100,000 potential > M5 dwarfs with PMs
- BANYAN II tool to identify candidate members of MGs
- 230 new high priority candidates
- 250 new low priority candidates

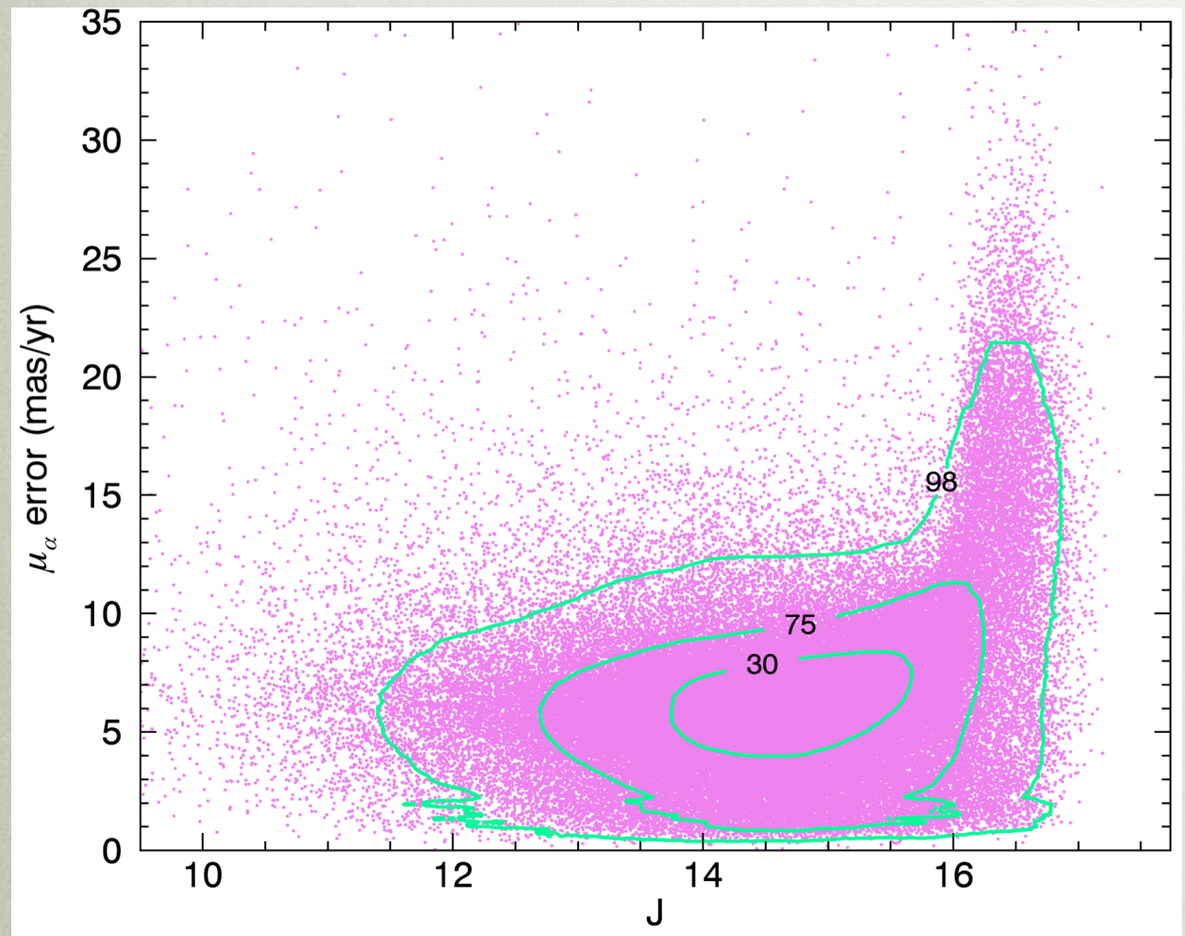


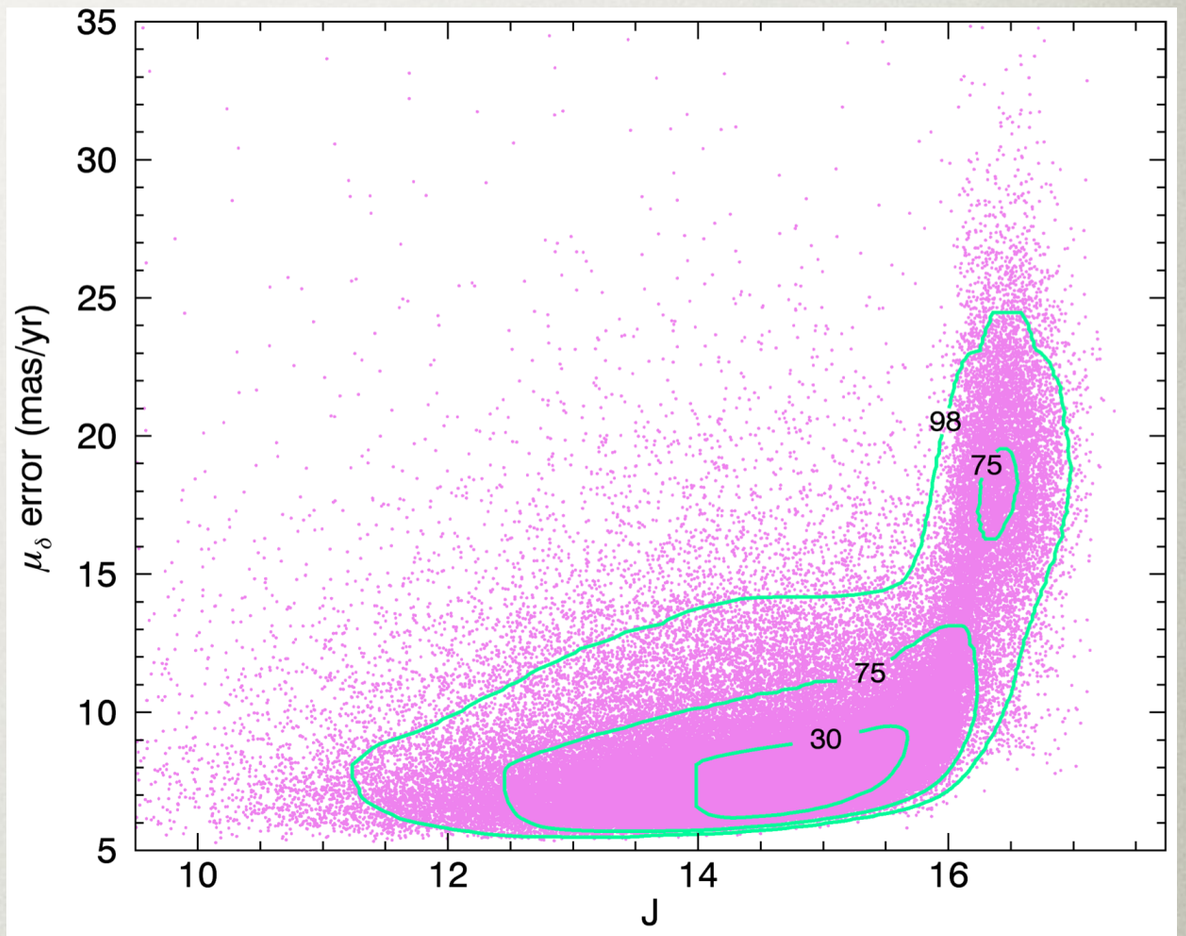
The *2MASS* survey



The *WISE* survey

The BASS survey



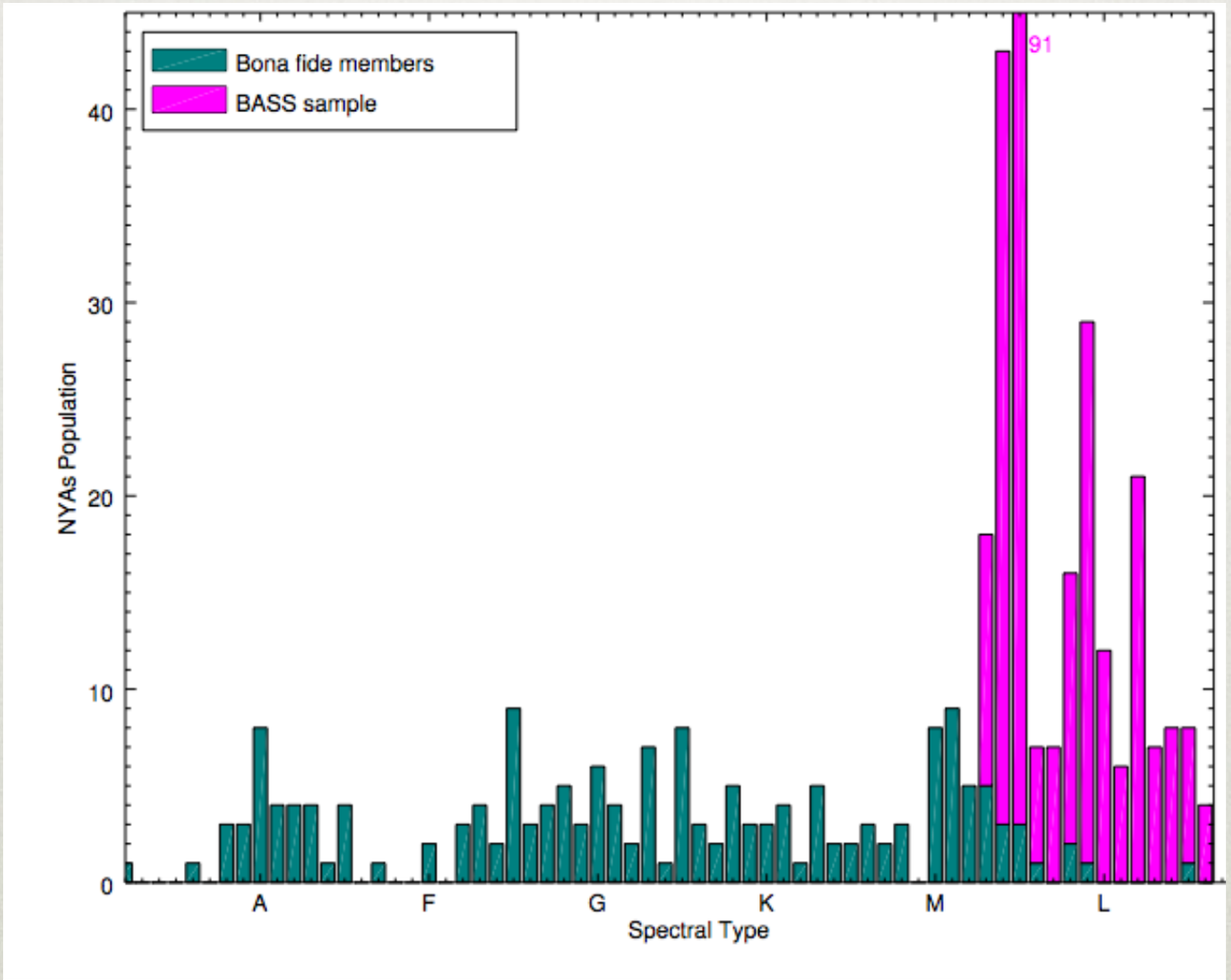


Gagné et al. 2015 ApJ, 798, 73

The 2MASS / AllWISE cross-match yields pretty good PM measurements !

Typical precision is ± 10 - 20 mas/yr

The BASS survey



Gagné et al. 2015 ApJ, 798, 73

Estimated Spectral Types span M5 — L6,
A largely unexplored space for MG members

Spectrocopic Follow-up

Now What ?

Several measurements are still needed to confirm membership

- Radial velocity : needs hi-resolution spectroscopy
  => big telescopes, lots of time
- Parallax : need a large temporal coverage
  => small telescopes, **lots** of time
- Signs of youth : needs low-resolution spectroscopy
  => easier !

IRTF Telescope

We thus started with low-resolution NIR spectroscopy

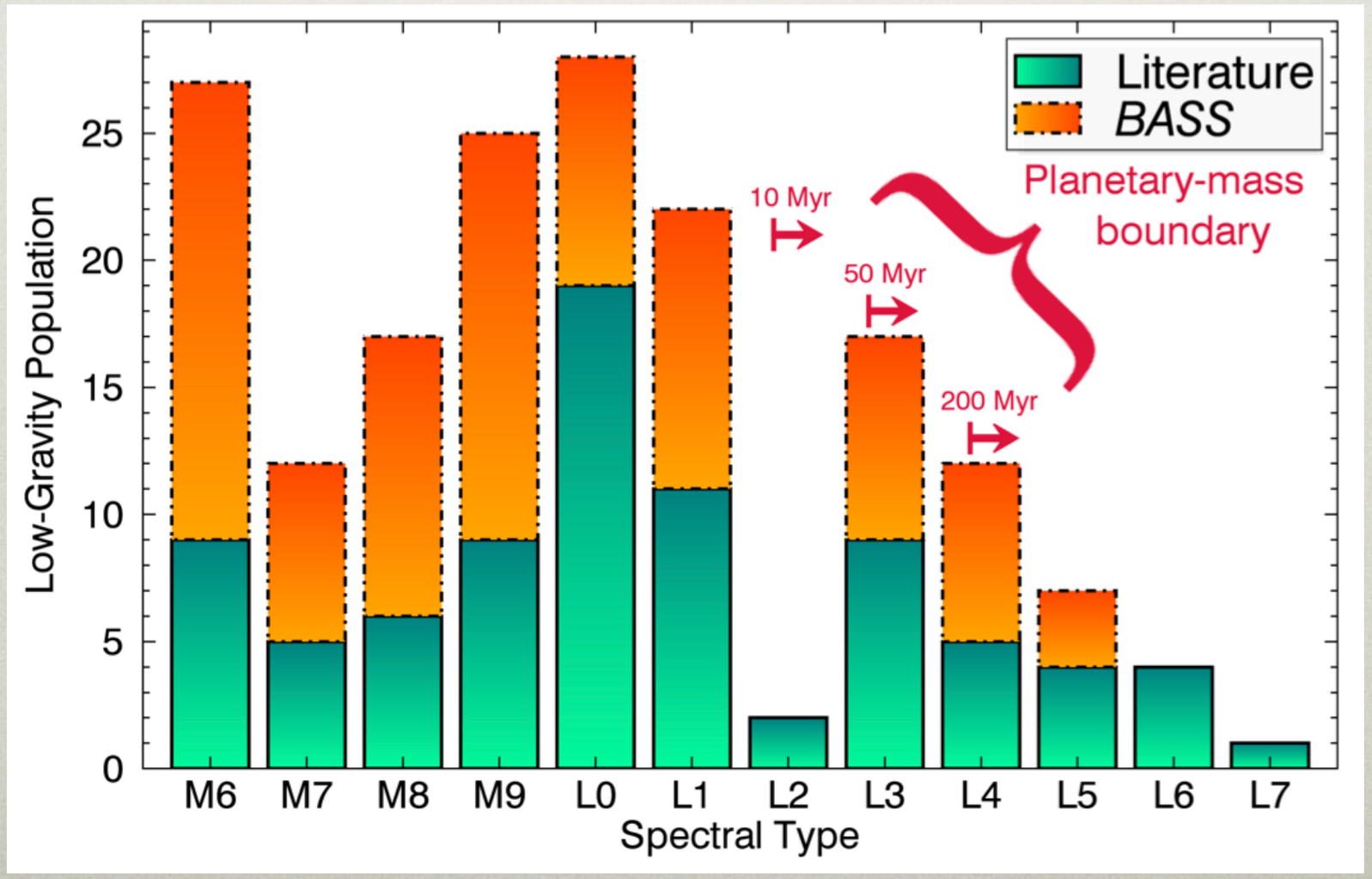
=> Identify young brown dwarfs, reject contaminants

Spectrocopic Follow-up

=> We followed more than 240, from which 100 are high-priority candidates

=> Discovered > 100 new M6 - L5 low-gravity dwarfs

=> Identified new signs of Low-g in ~ 30 known objects



Gagné et al., submitted to ApJ

Spectrocopic Follow-up

The properties of young brown dwarfs ;

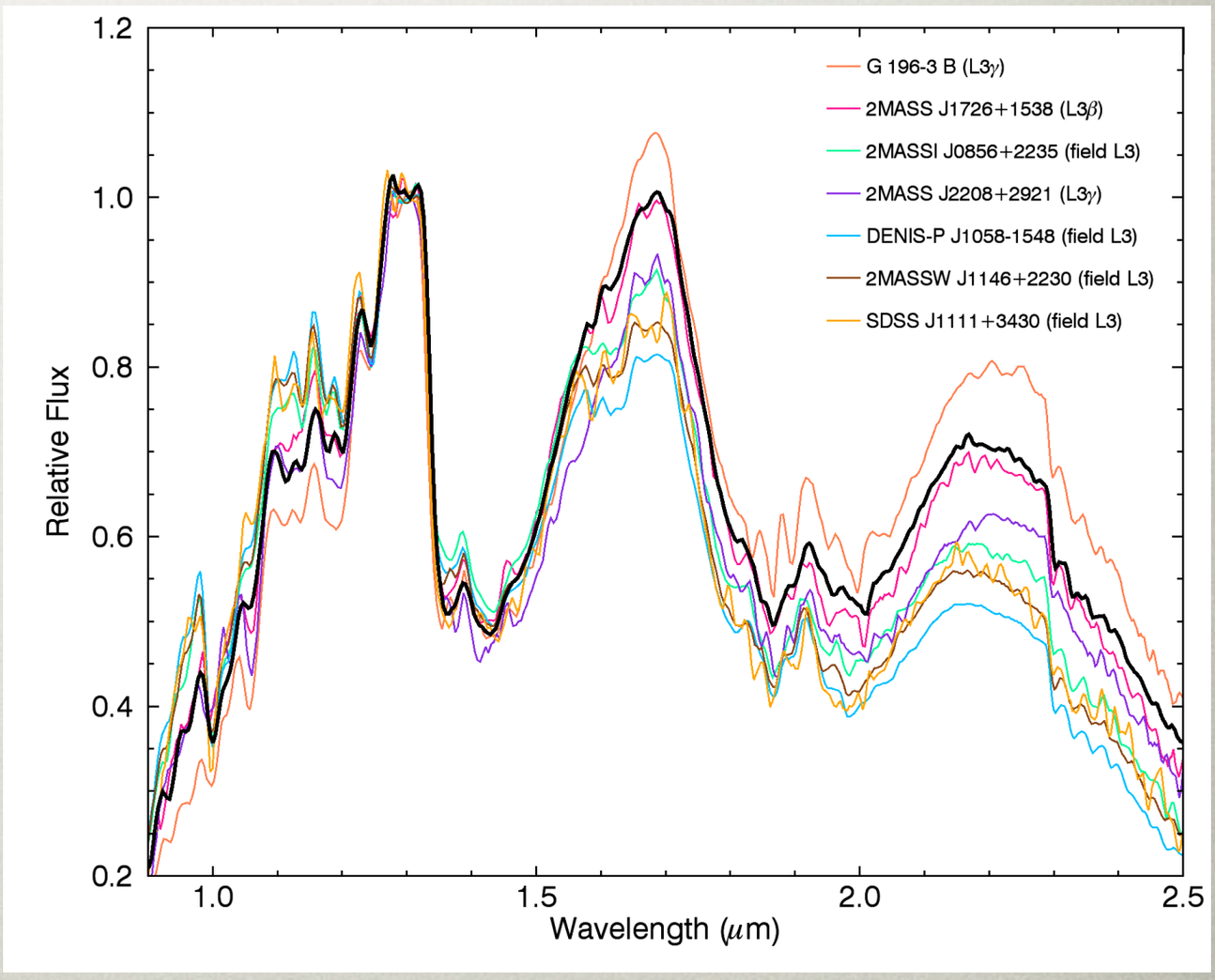
=> Triangular H-band

=> Red Slope

=> weak atomic lines
(Na I, K I)

=> Deeper VO absorption

=> Different shape in K band



Gagné et al., submitted to ApJ

Spectrocopic Follow-up

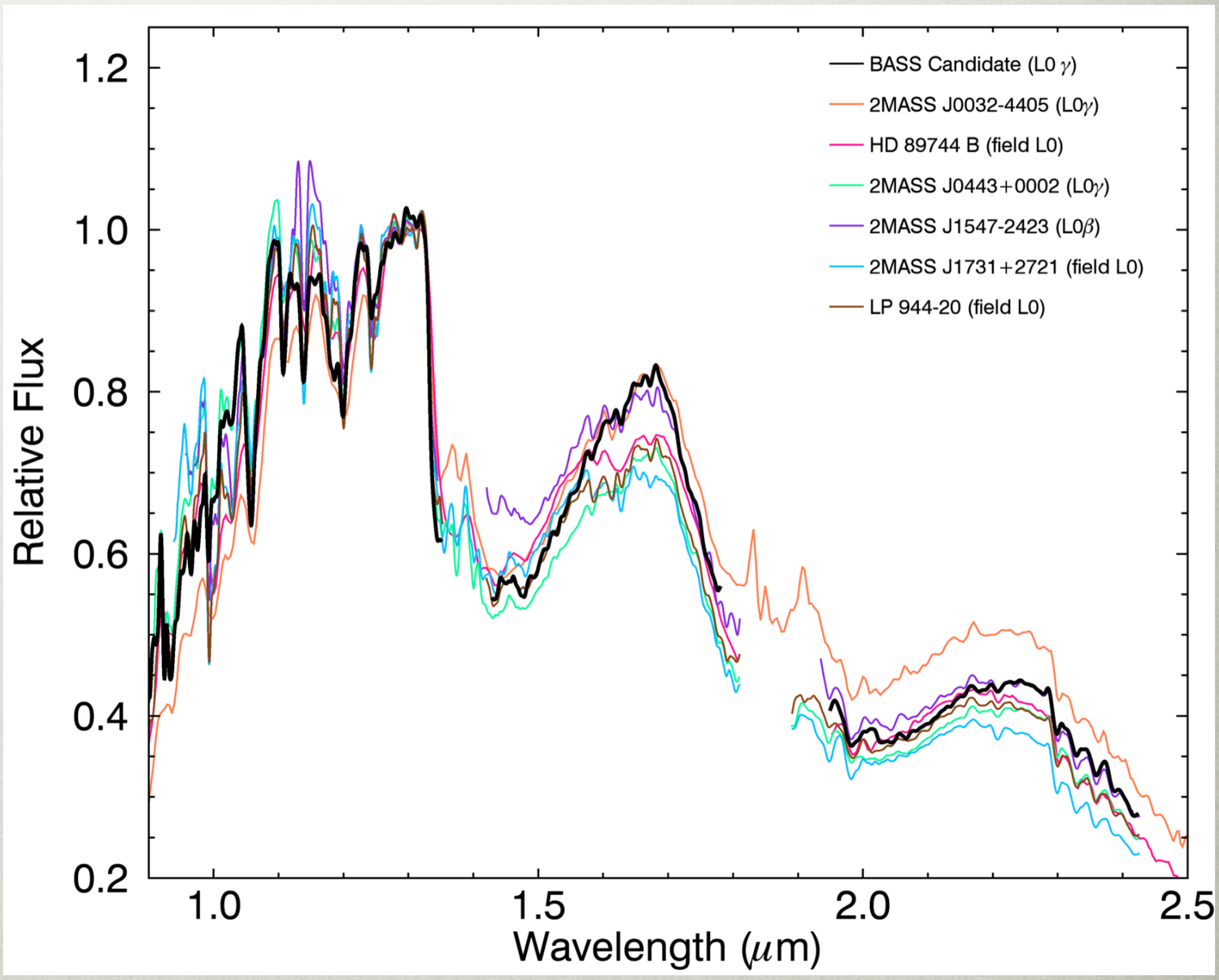
Why ?

INFLATED RADIUS + SMALLER MASS = LOWER G, LOWER P

=> Less pressure broadening

=> Thicker clouds

=> Less CIA of H2



Gagné et al., submitted to ApJ

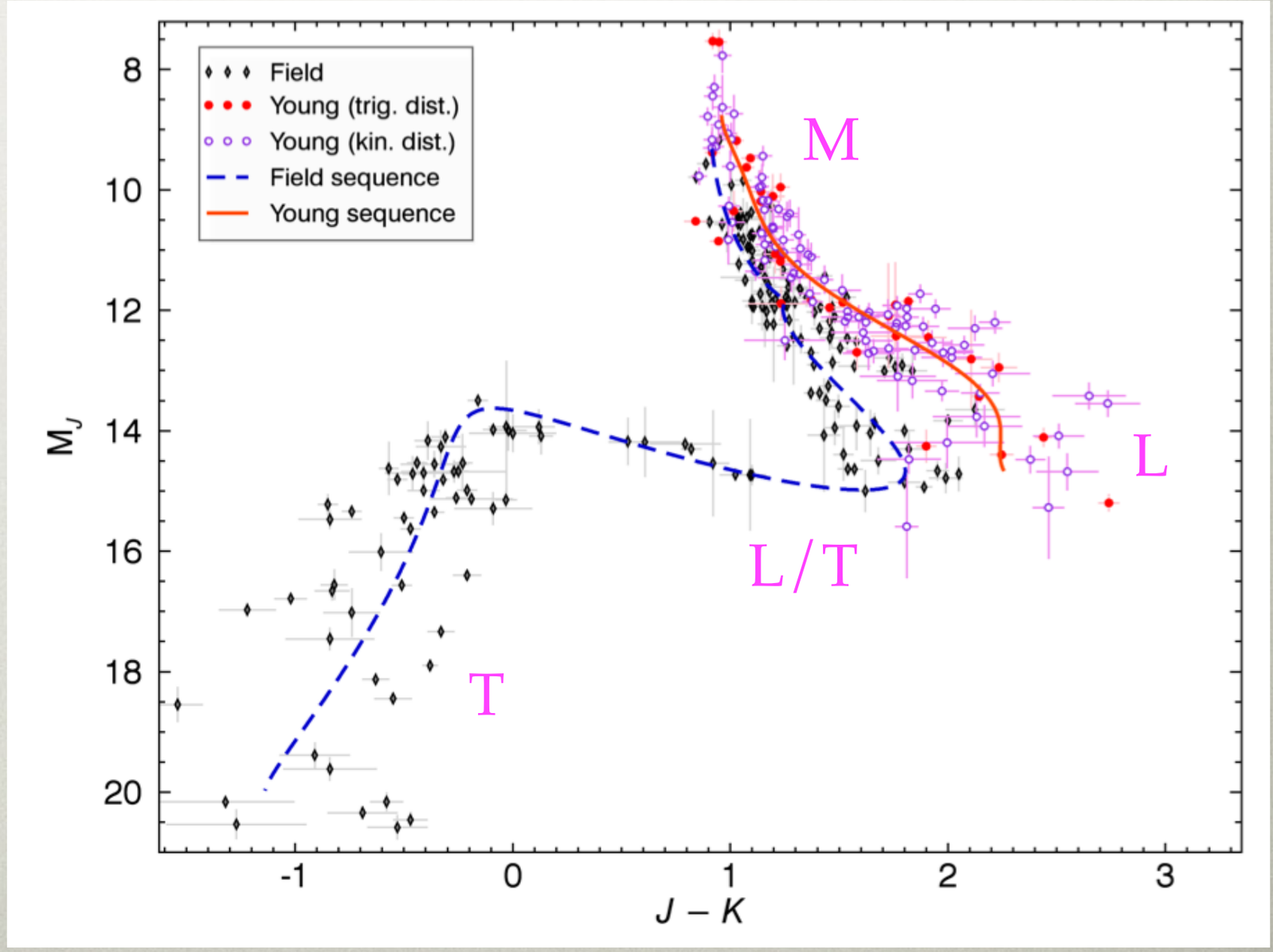
Photometric Sequences

Kinematic Distances Allow us to create CMD diagrams :

=> Filled Red = Low-Gravity + PLX

=> Open Purple = Low-Gravity + Kinematic Distance

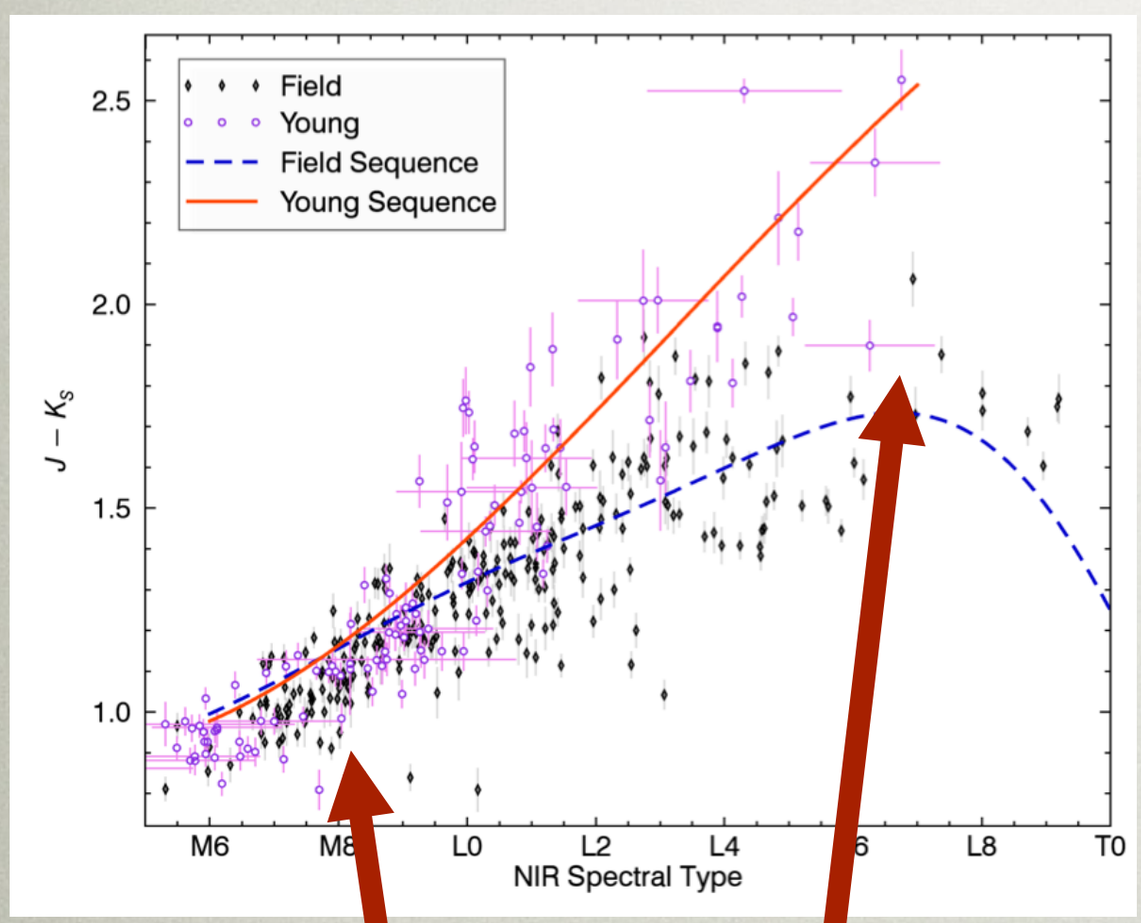
=> Black = Field



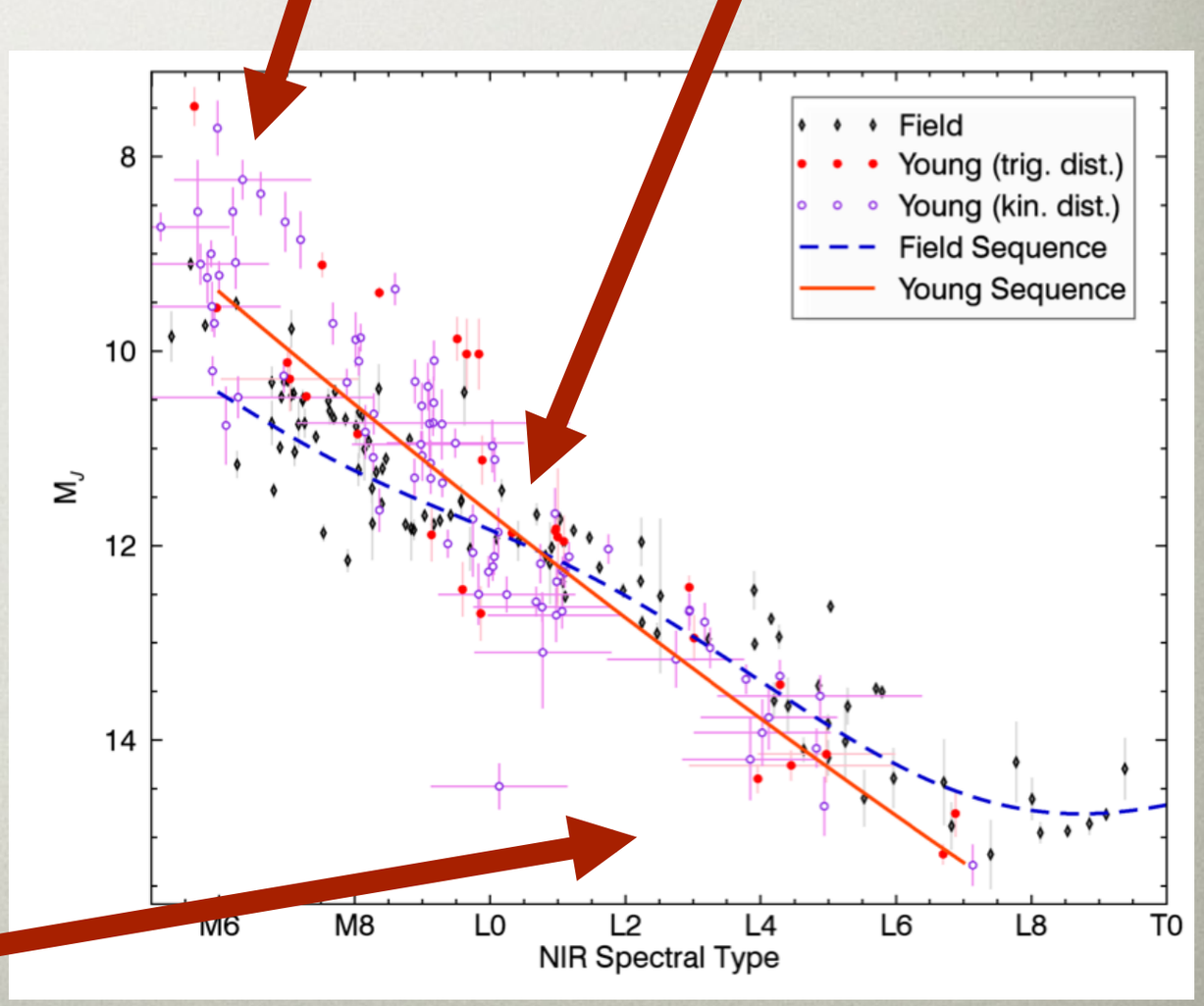
Gagné et al., submitted to ApJ

Photometric Sequences

We define new M6 - L7 empirical sequences :



Gagné et al., submitted to ApJ



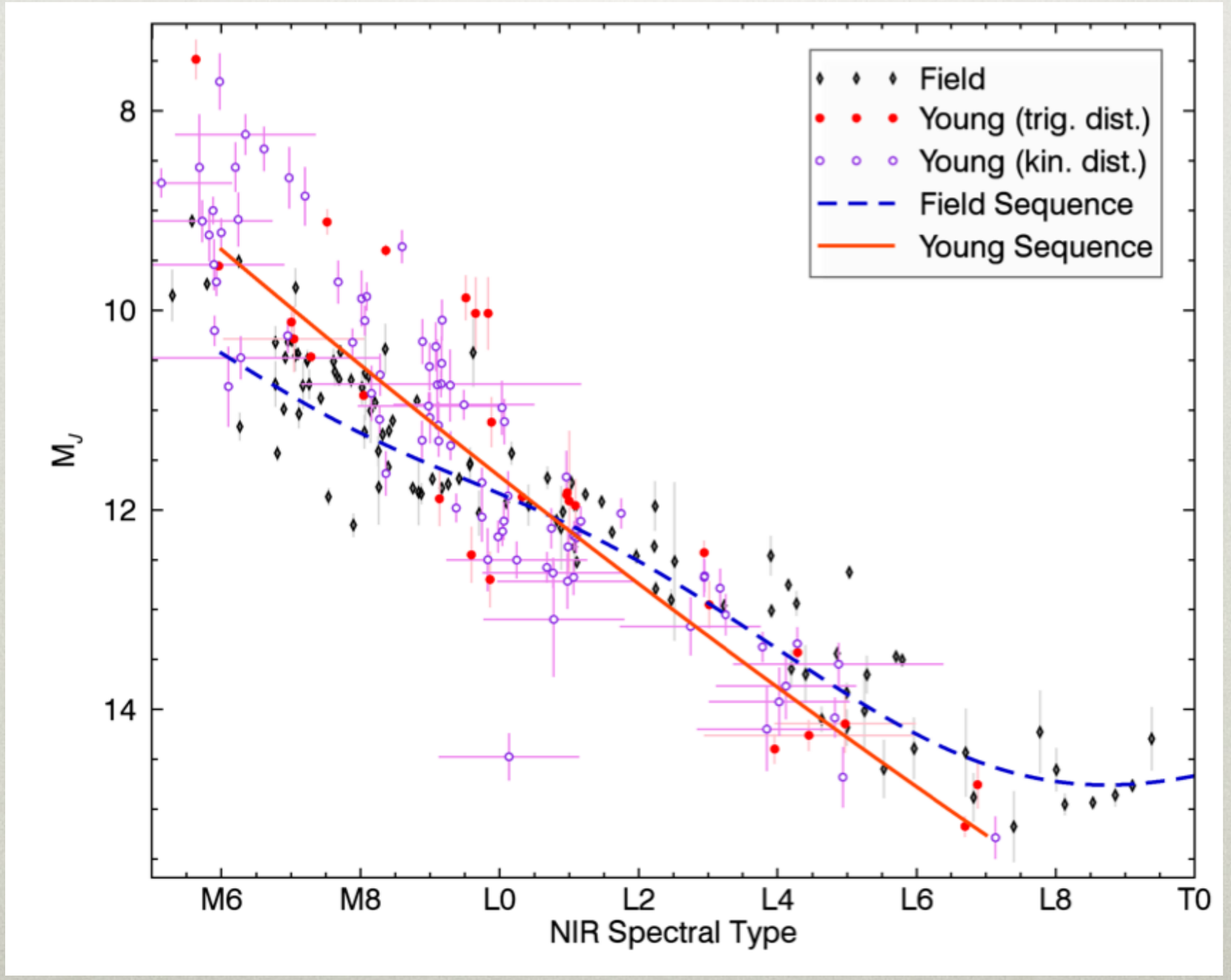
Inflated radii = brighter

Clouds block the light !

No clouds

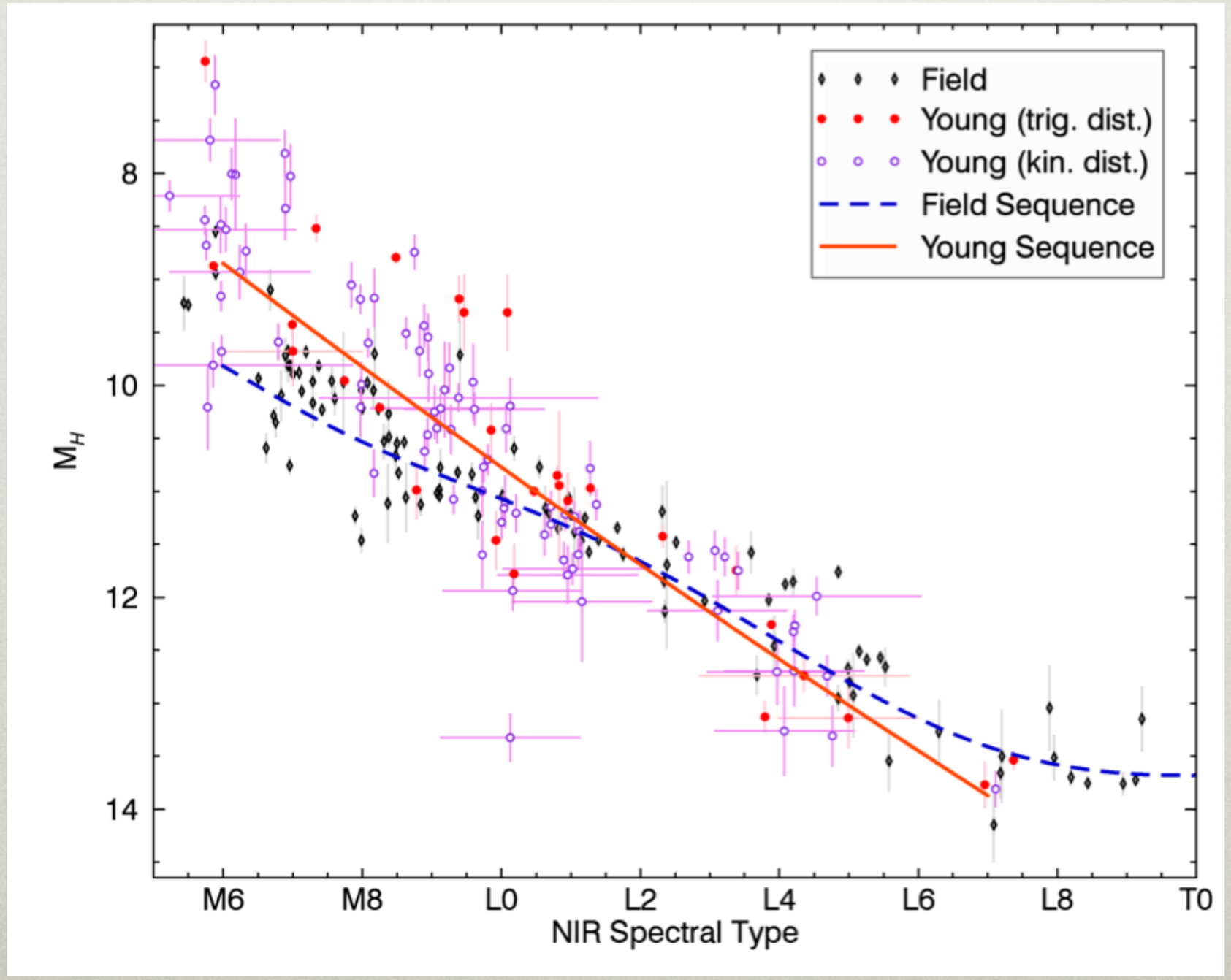
Thick clouds

Photometric Sequences



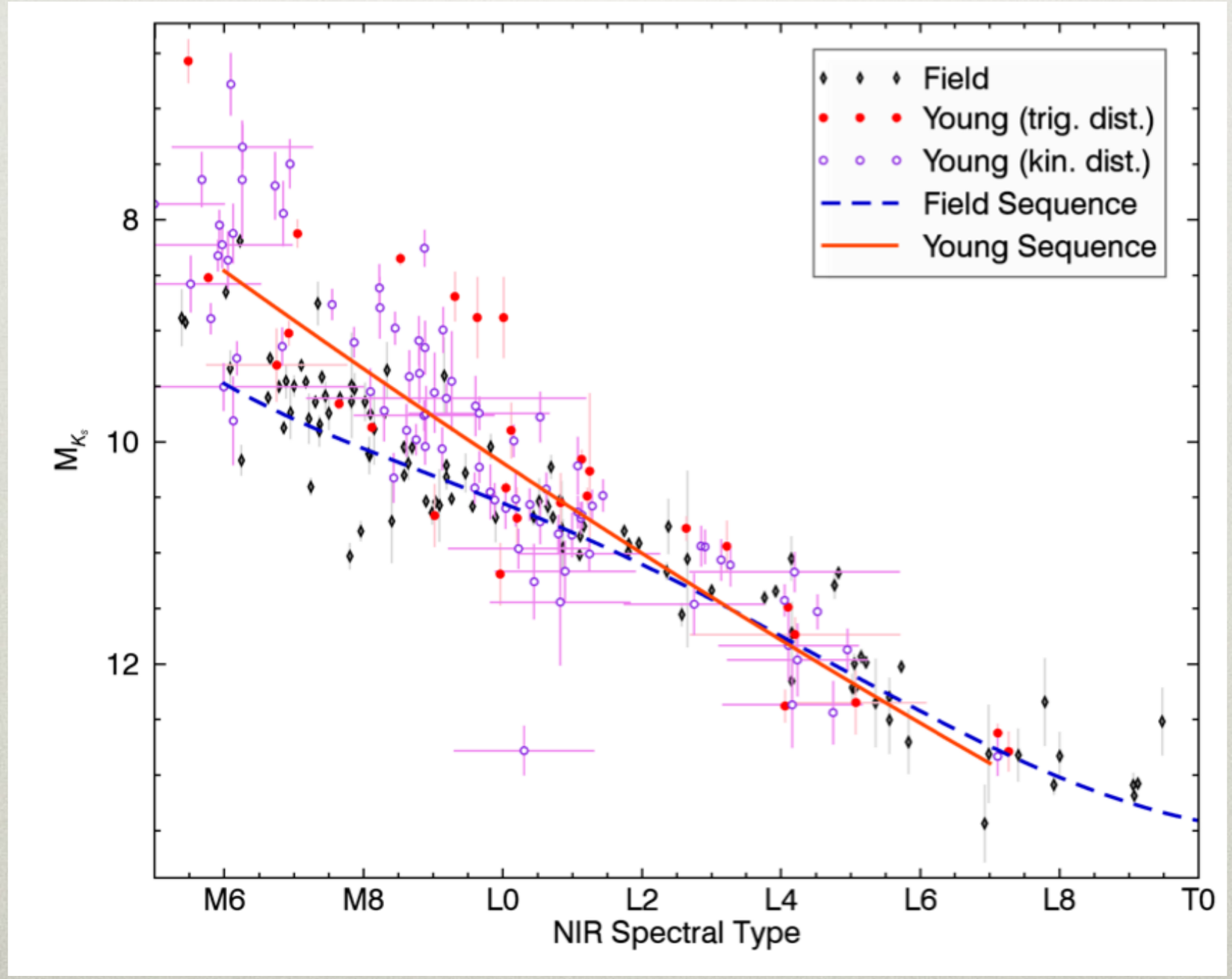
Gagné et al., submitted to ApJ

Photometric Sequences



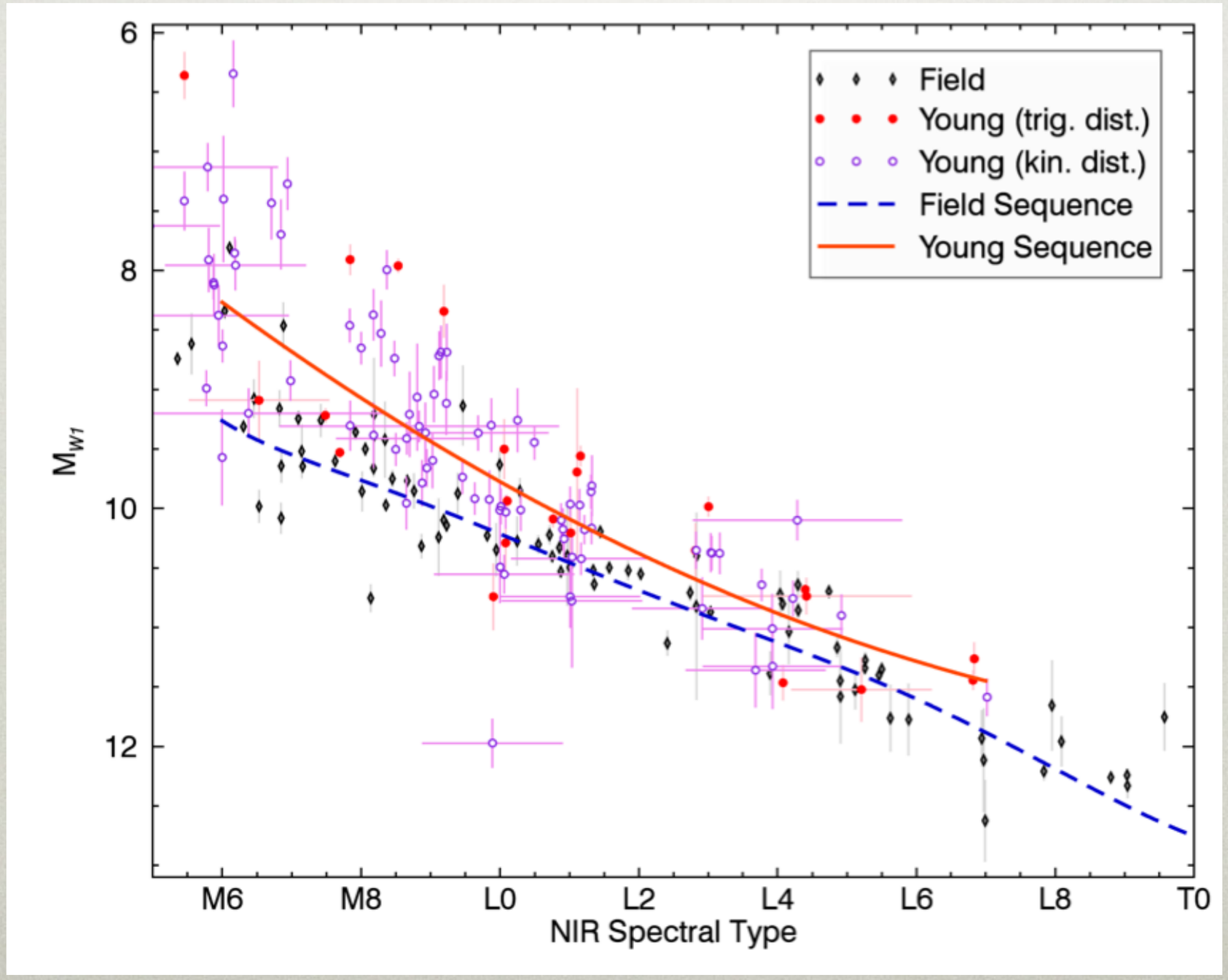
Gagné et al., submitted to ApJ

Photometric Sequences



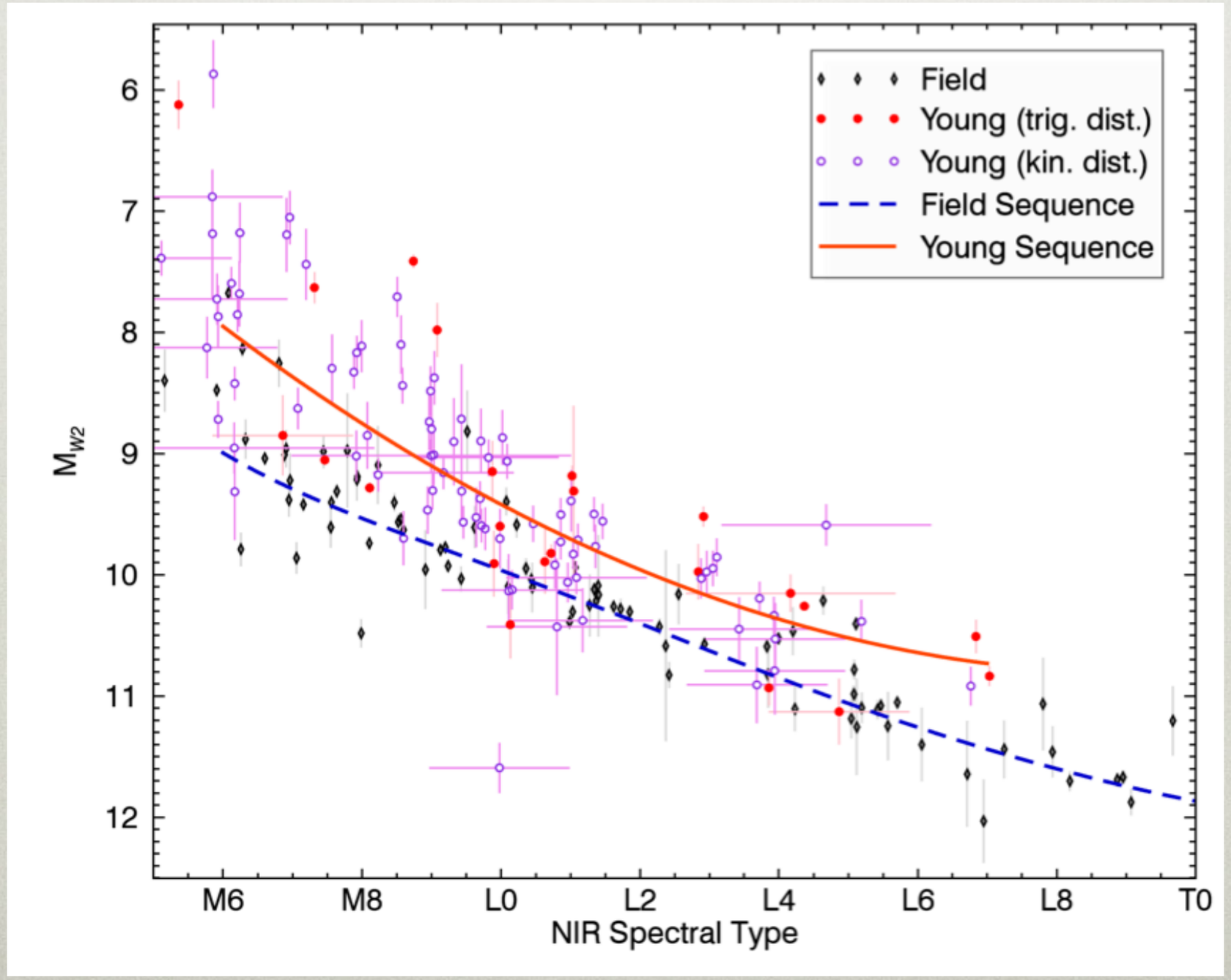
Gagné et al., submitted to ApJ

Photometric Sequences



Gagné et al., submitted to ApJ

Photometric Sequences

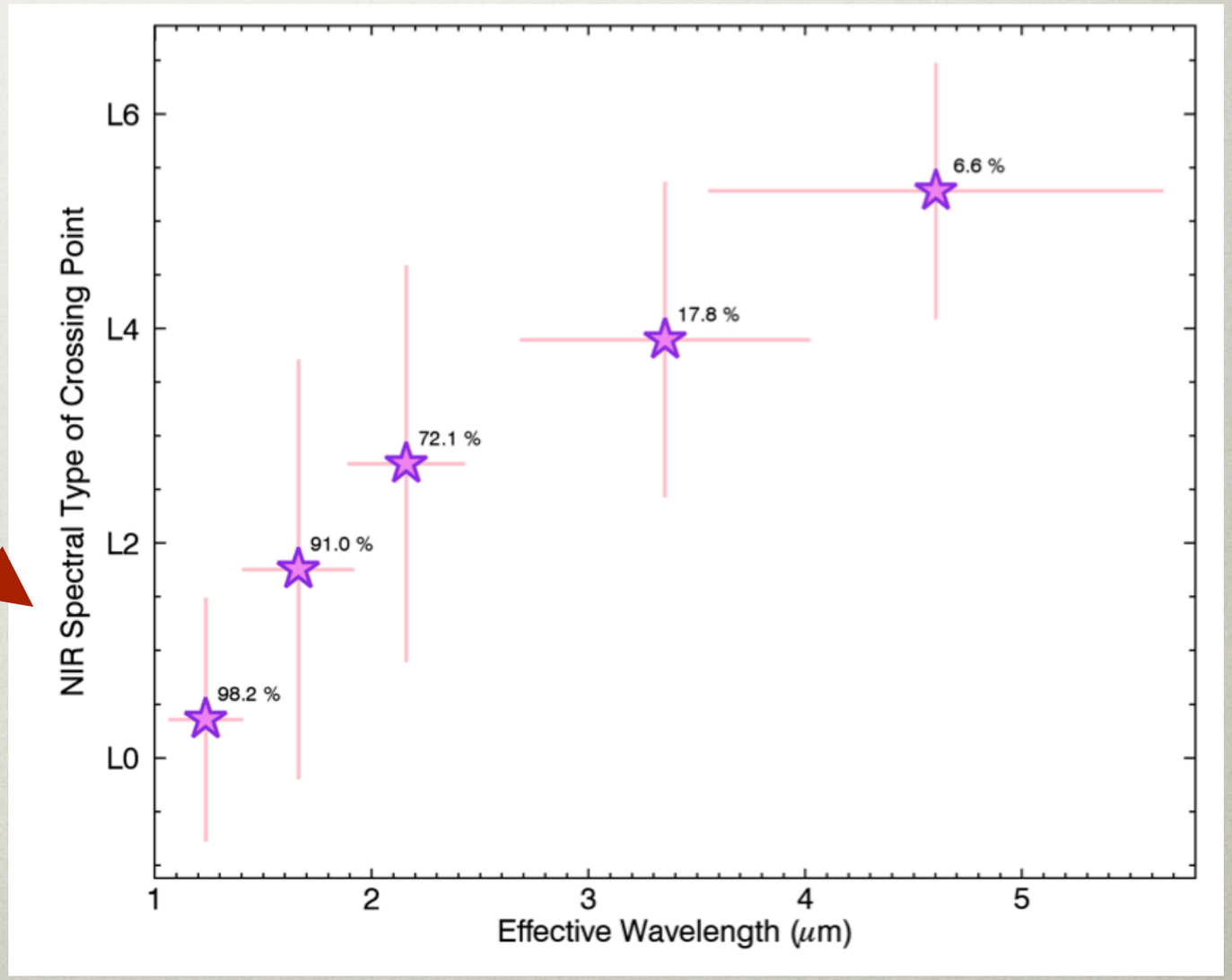


Gagné et al., submitted to ApJ

Photometric Sequences

Absolute Magnitude - Spectral Type Sequences cross At different Spectral types in different filters !

Clouds redirect flux from ~ 1 μm to longer wavelengths



Gagné et al., submitted to ApJ

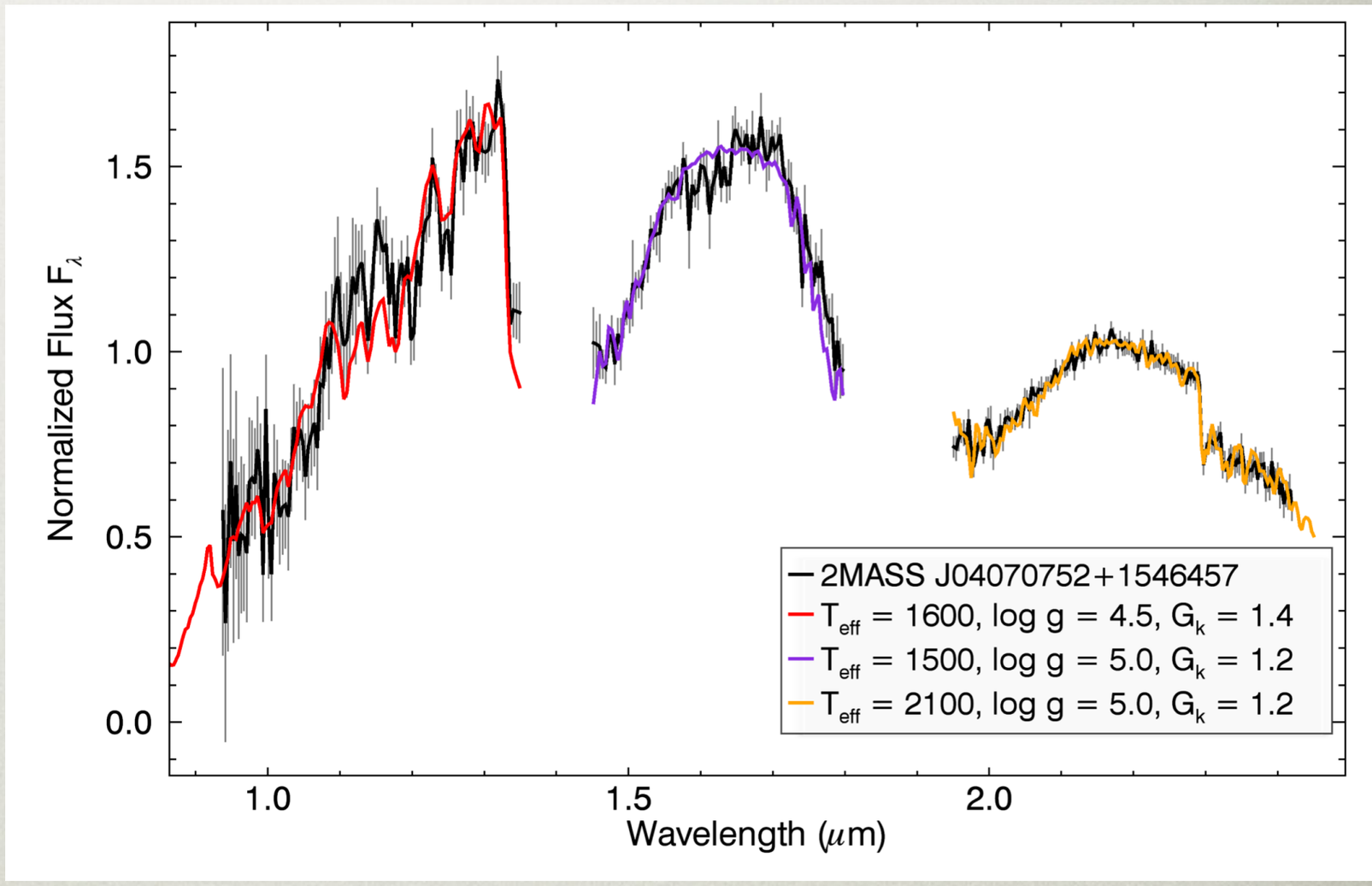
Physical Parameters

We use

CIFIST2011/BT-SETTL models

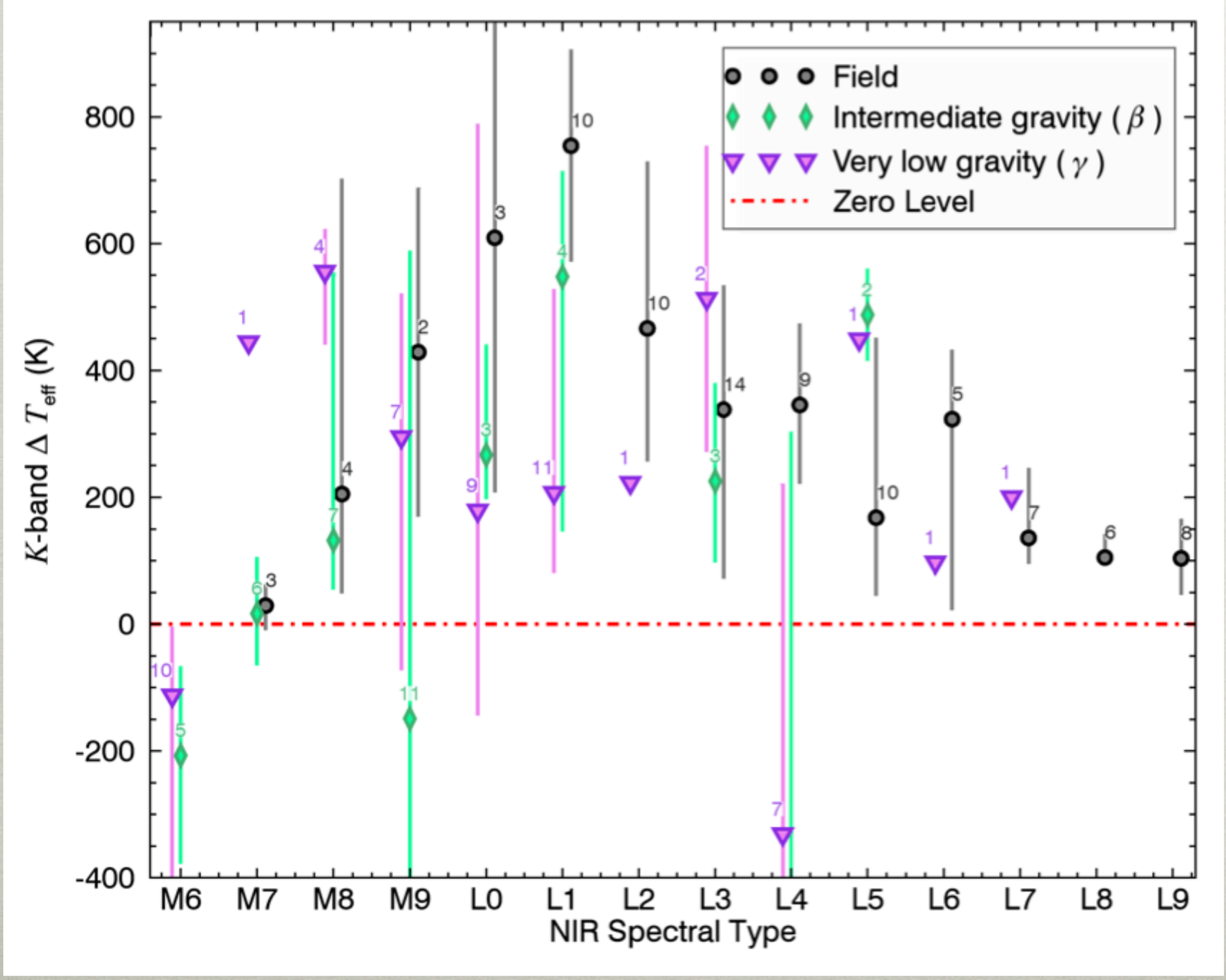
To investigate :

- Mass
- Temperature
- Log g



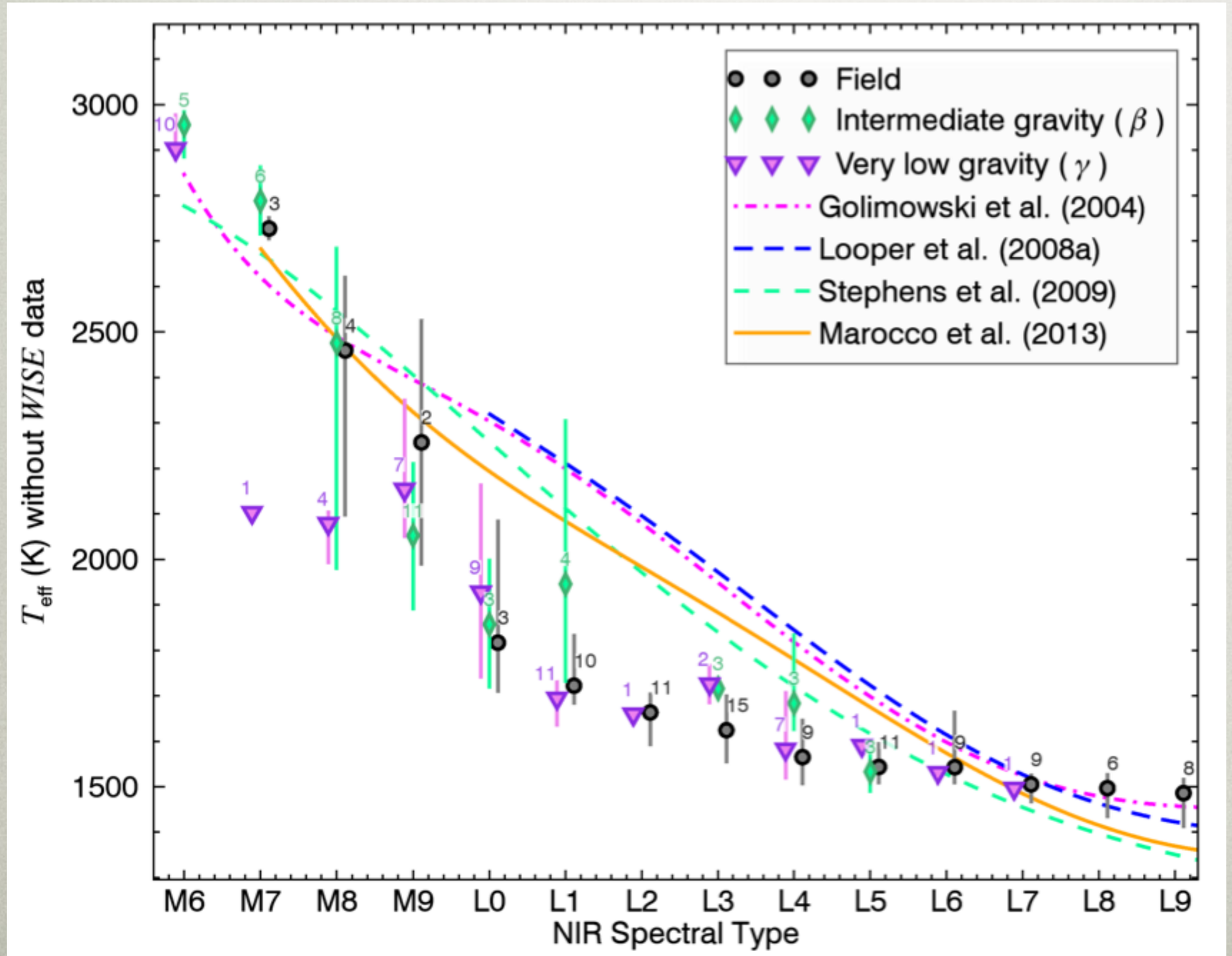
Gagné et al., submitted to ApJ

Physical Parameters



Gagné et al., submitted to ApJ

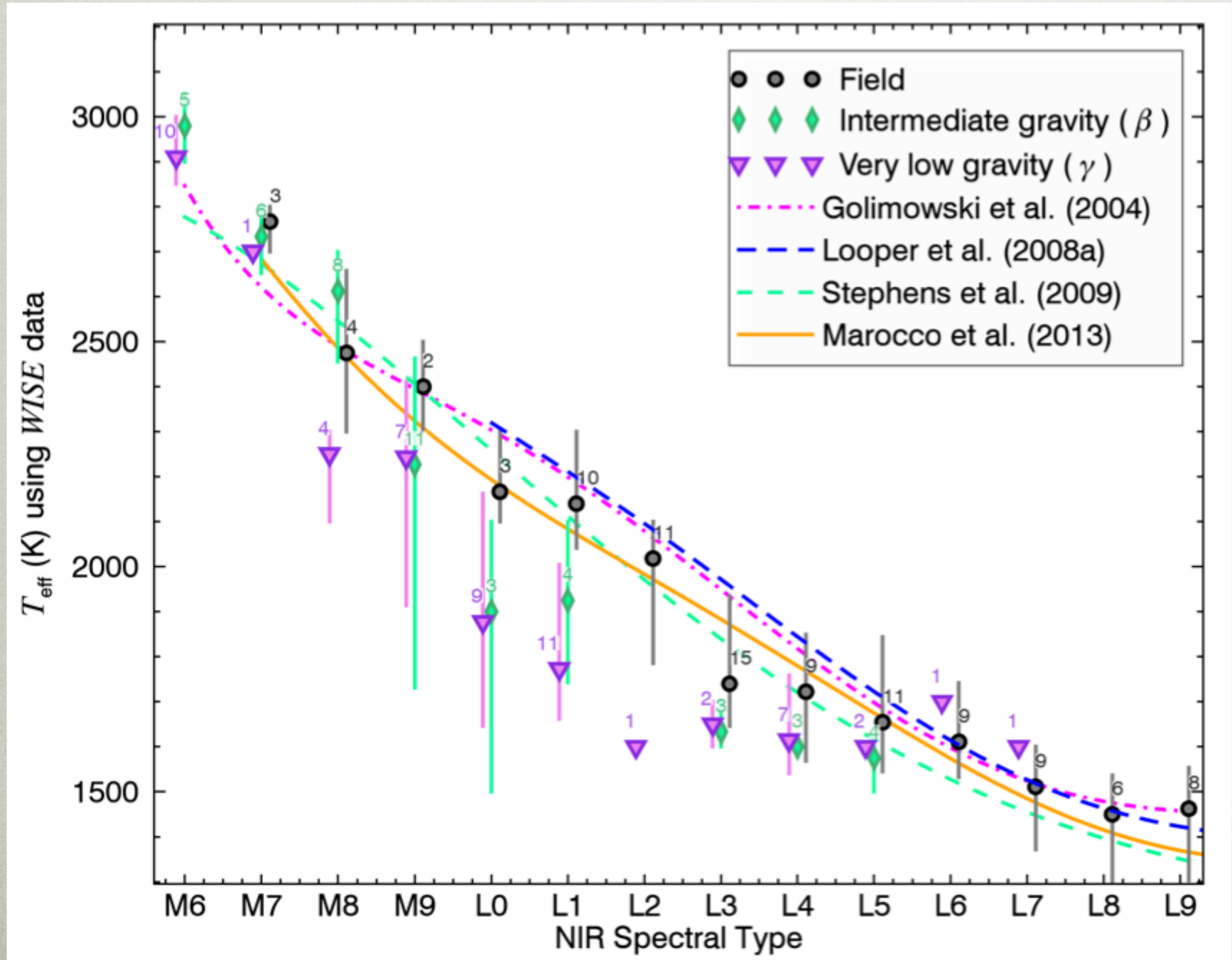
Physical Parameters



Gagné et al., submitted to ApJ

Physical Parameters

+ WISE Data :



Gagné et al., submitted to ApJ

Physical Parameters

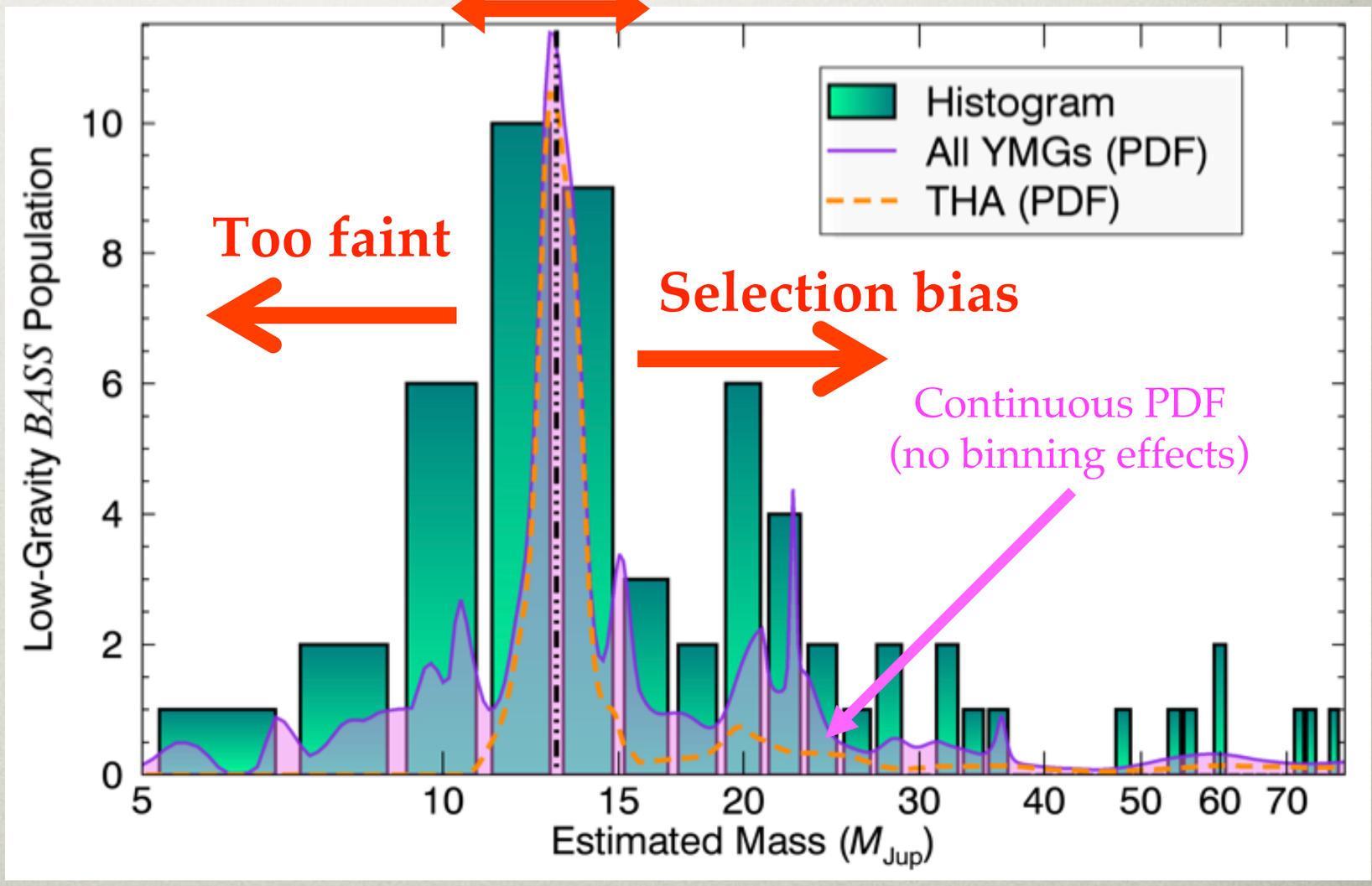
Estimated Mass of Low-G BDs in BASS :

We find 36x too many
~ 13 M_{Jup} in Tucana

=> Young field contaminants ?
Unlikely

=> isochrones folding on themselves (Bowler 2013) ?
Cannot reproduce this

=> Missing massive members in Tucana ?
Unlikely



Gagné et al., submitted to ApJ

Physical Parameters 26/34

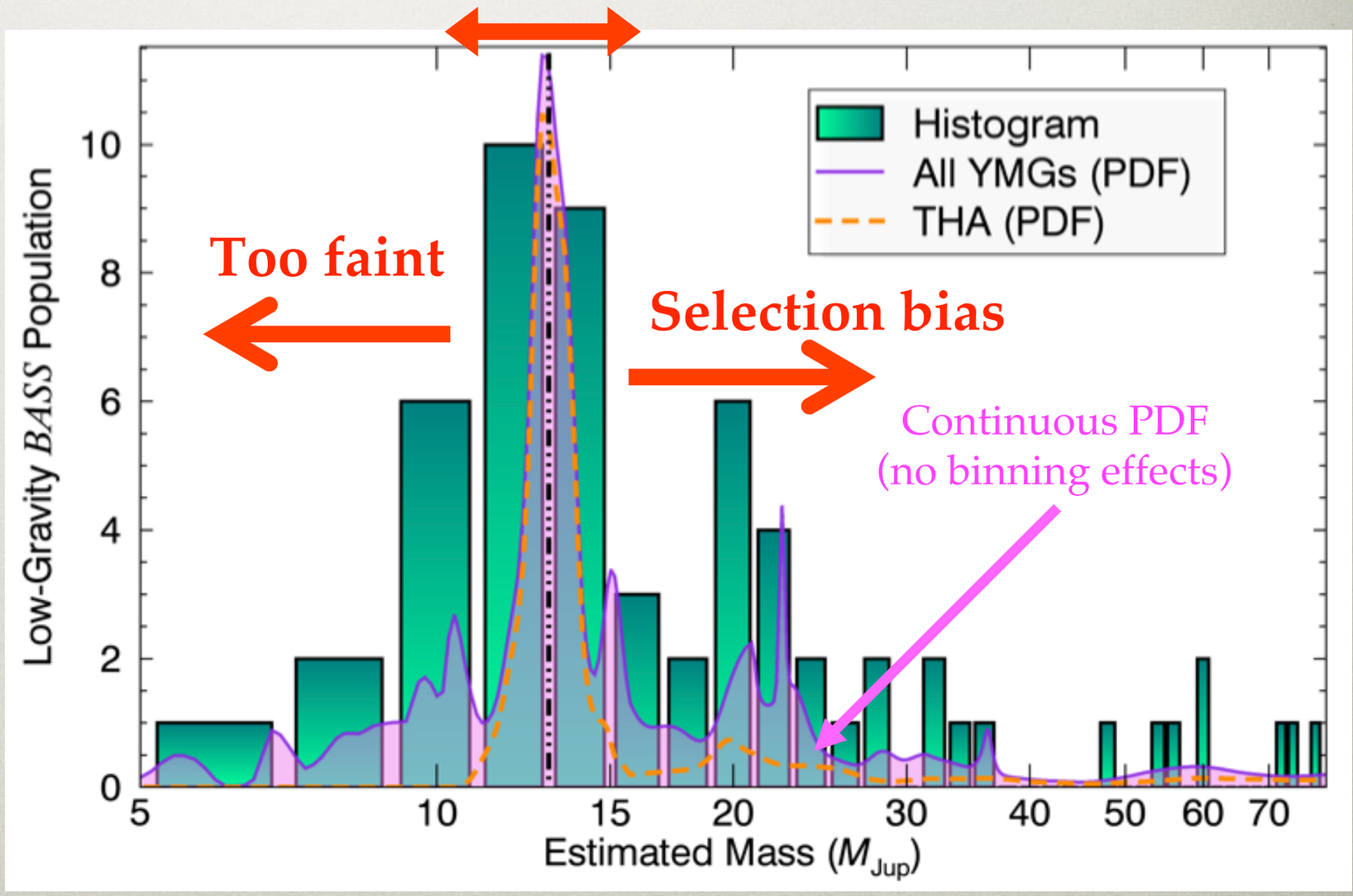
Estimated Mass of Low-G BDs in BASS :

Our best Hypotheses :

1 => Systematic effects in models

2 => Tucana-Hor has a weird IMF

3 => Ejected planets



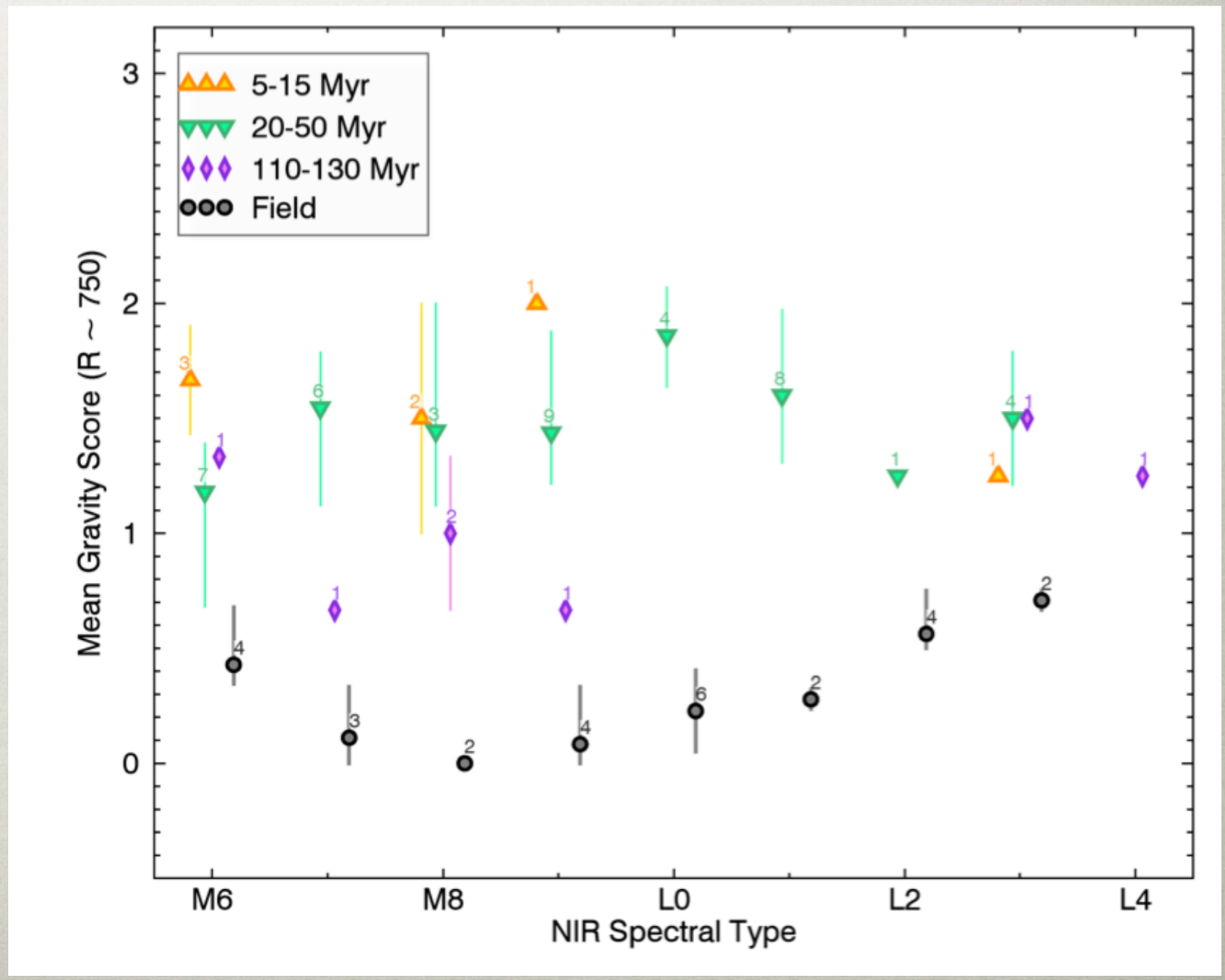
Gagné et al., submitted to ApJ

Age Calibration ? 27/34

Can we calibrate the age of BDs with their NIR spectra ?

=> Mean gravity score from Allers & Liu (2013) correlate with age

=> However, overlaps

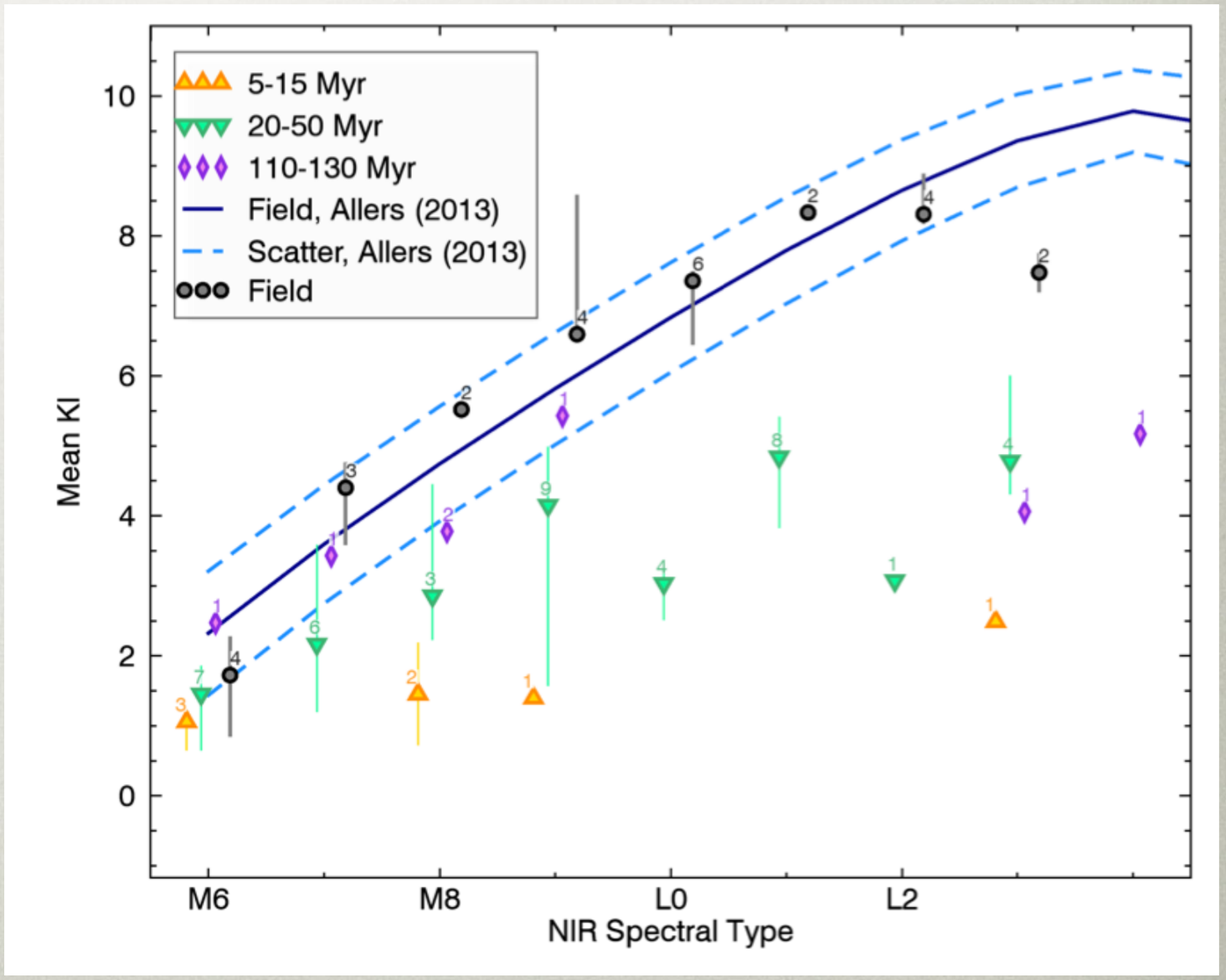


Gagné et al., submitted to ApJ

Age Calibration ?

Can we calibrate the age of BDs with their NIR spectra ?

=> Same for the mean K I equivalent width

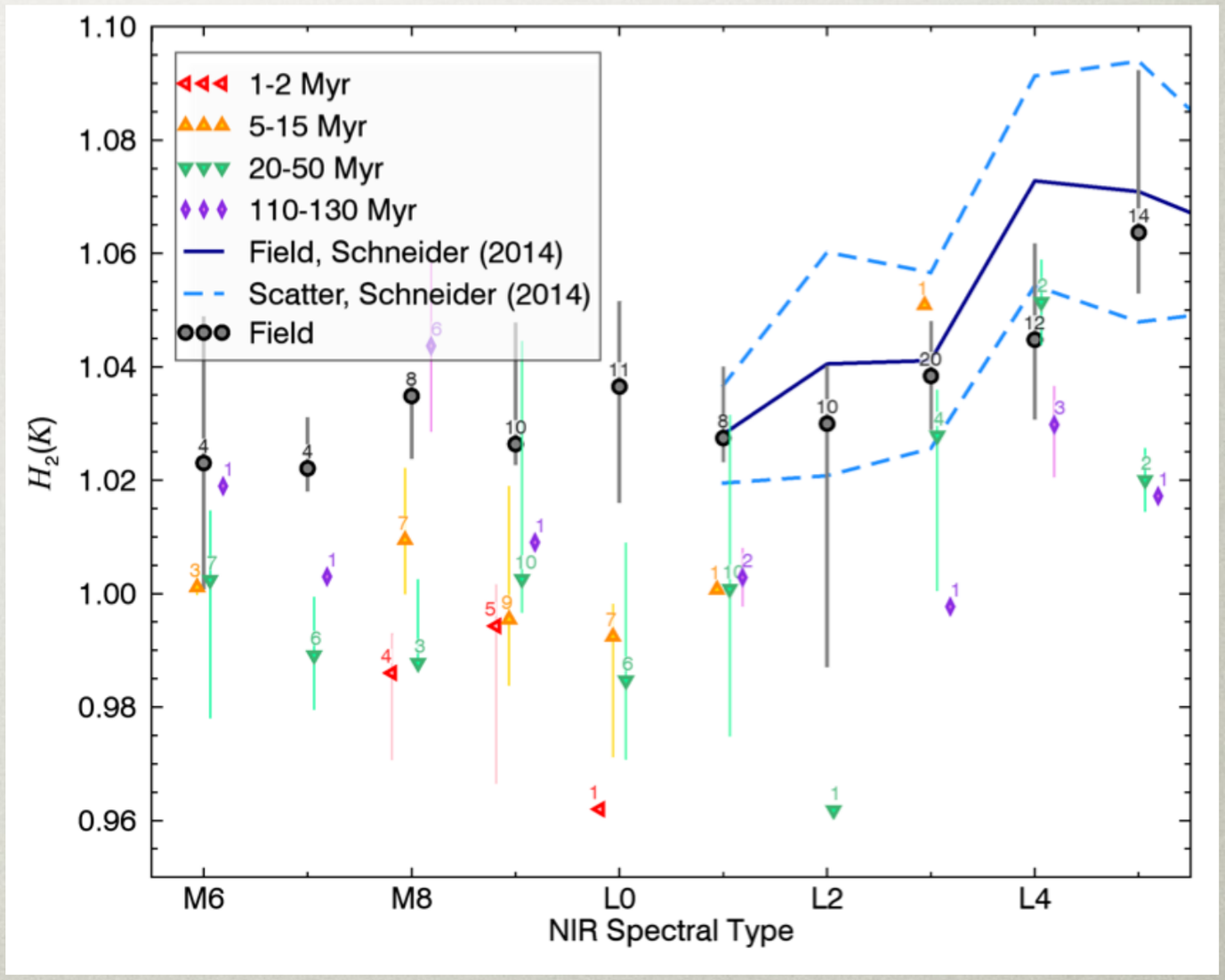


Gagné et al., submitted to ApJ

Age Calibration ?

Can we calibrate the age of BDs with their NIR spectra ?

=> And with Canty (2013)'s H_2K

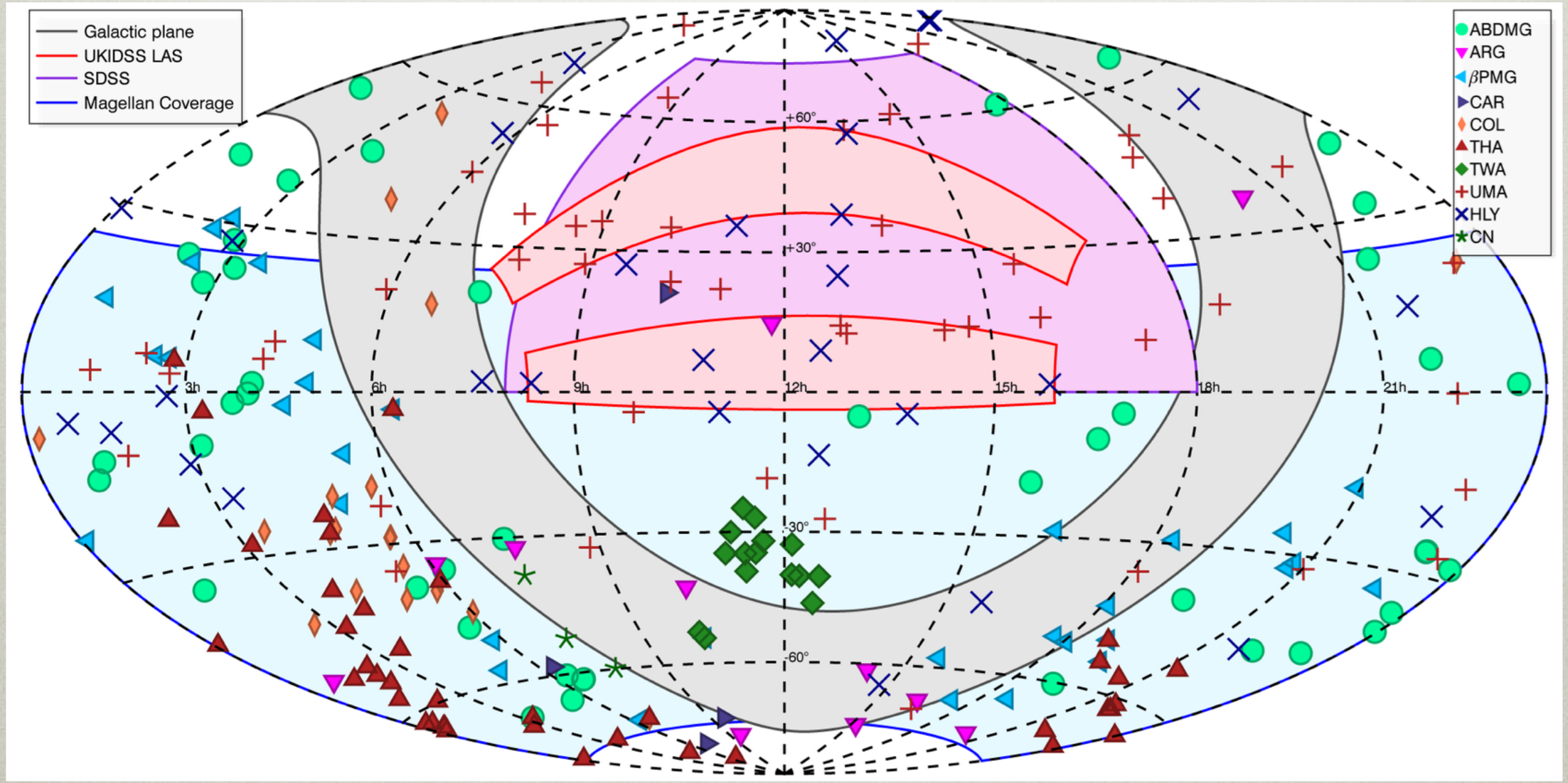


Gagné et al., submitted to ApJ

Future Project

More moving groups, More input catalogs

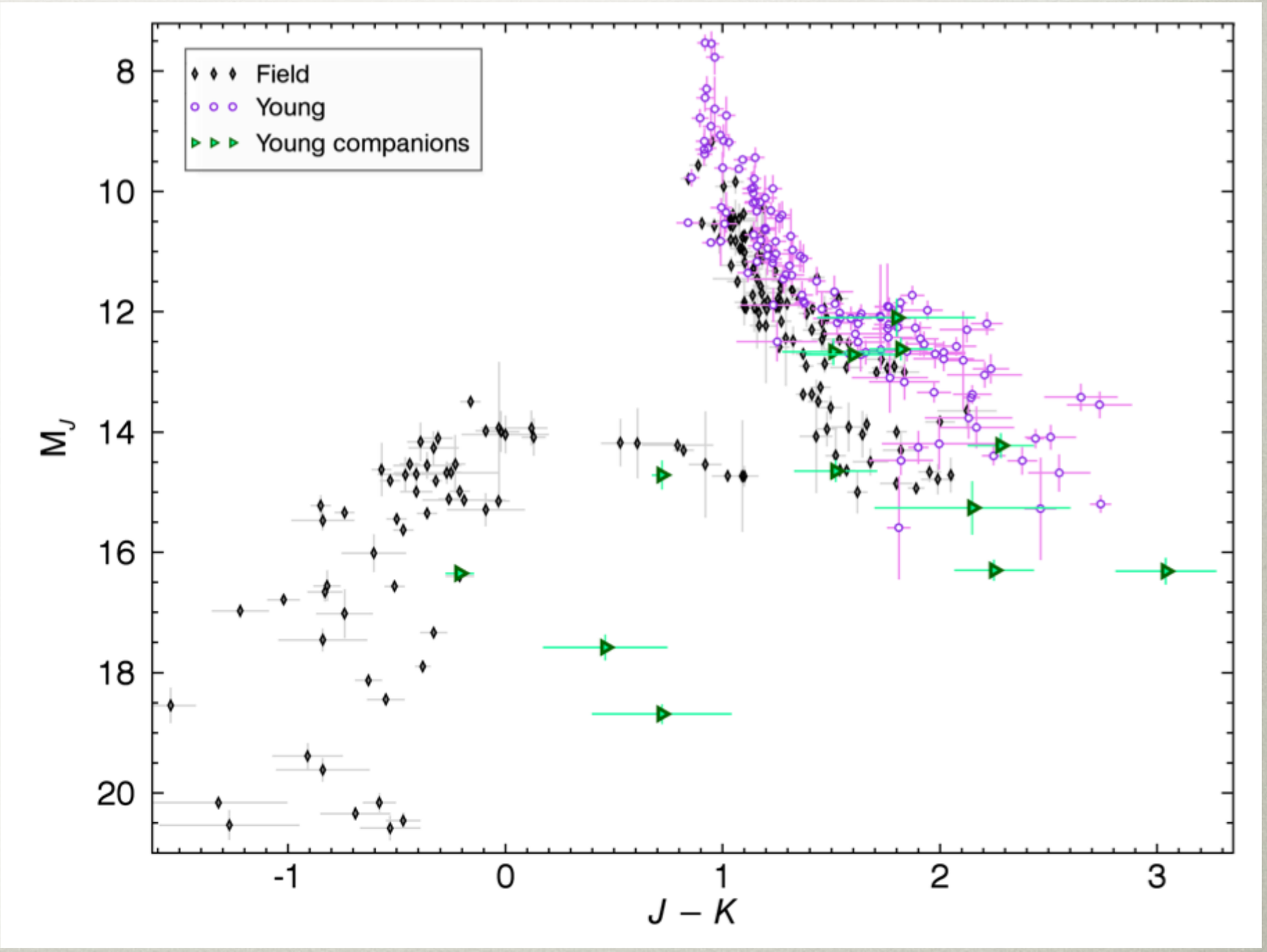
Updated filters (cooler members)



Gagné et al., in preparation

Future Project

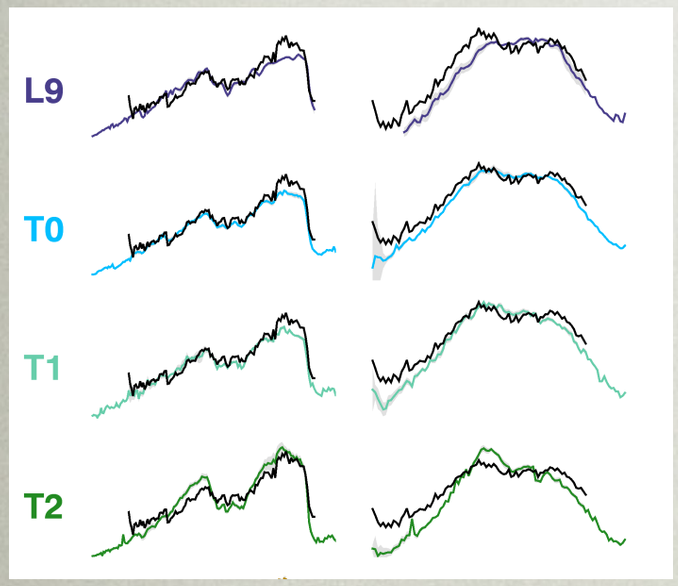
=> This is what we have now :

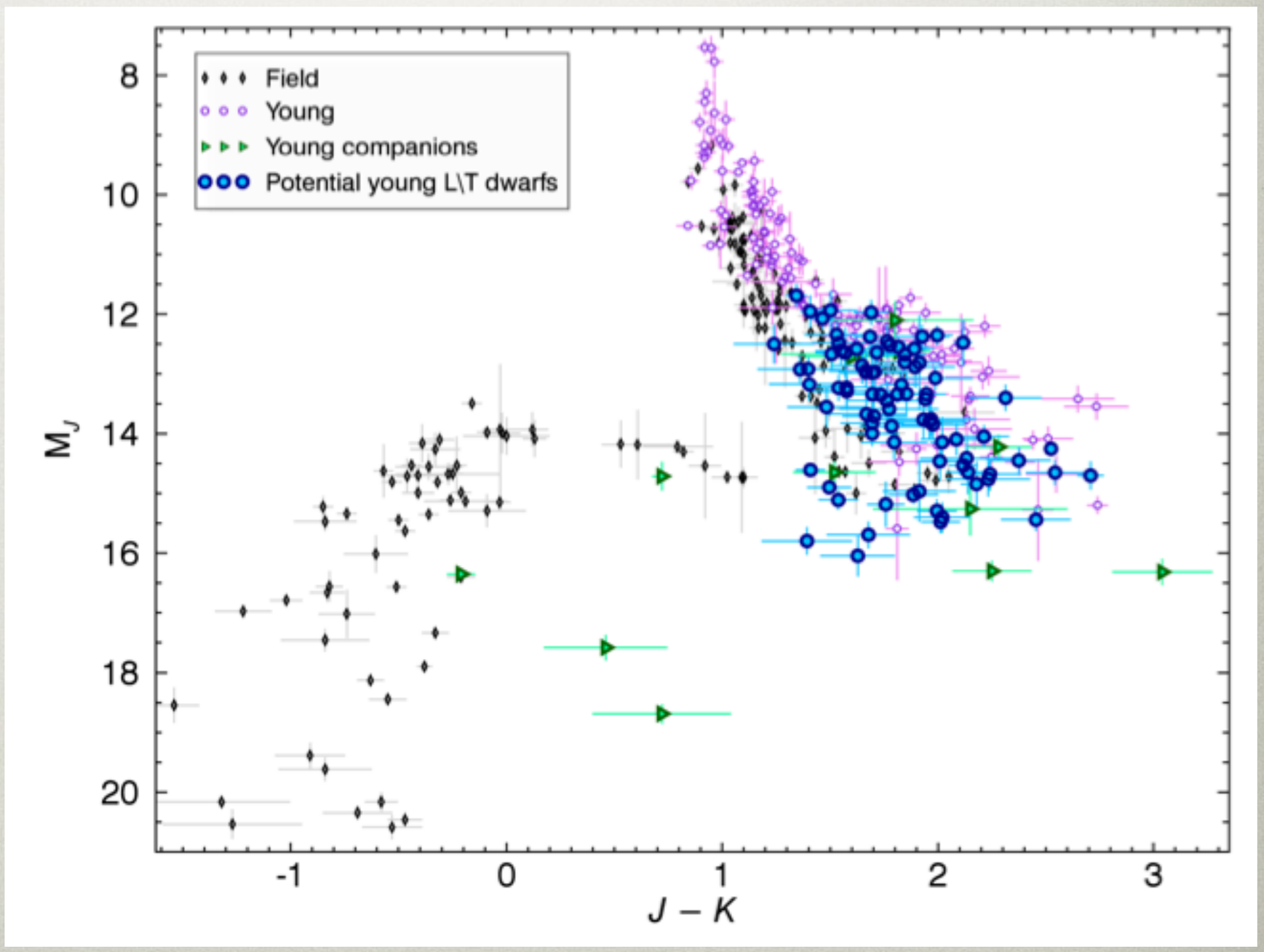


Gagné et al., in preparation

Future Project

=> New Candidate Young L/T :

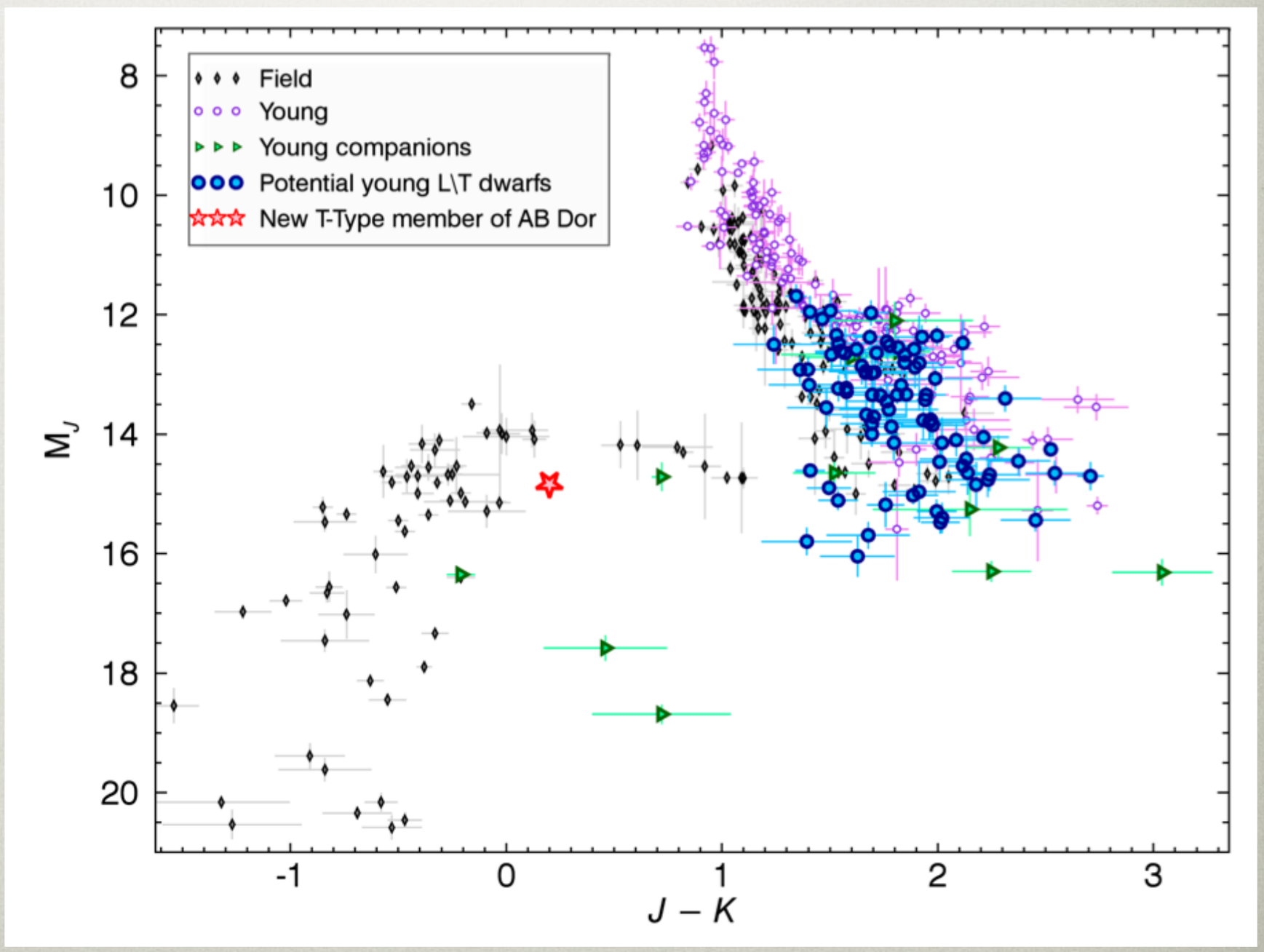




Gagné et al., in preparation

Future Project

=> New T-type
AB Dor member



Gagné et al., in preparation

Future Project 34/34

=> Magellan twin
6.5-m telescopes

=> High-R NIR/
Optical spectro.

=> Sensitive to much
lower masses !

Magellan / Chile

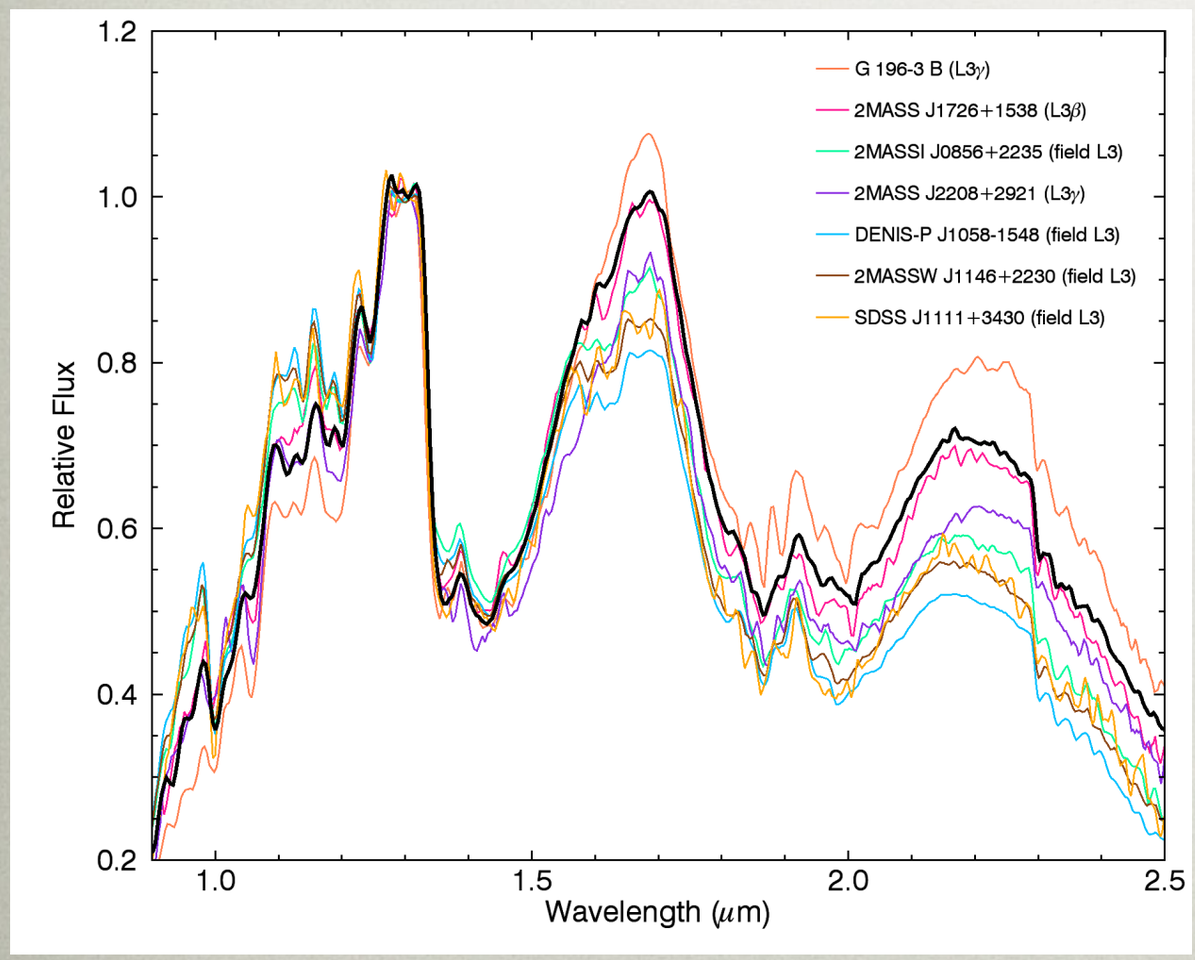
Thank You !

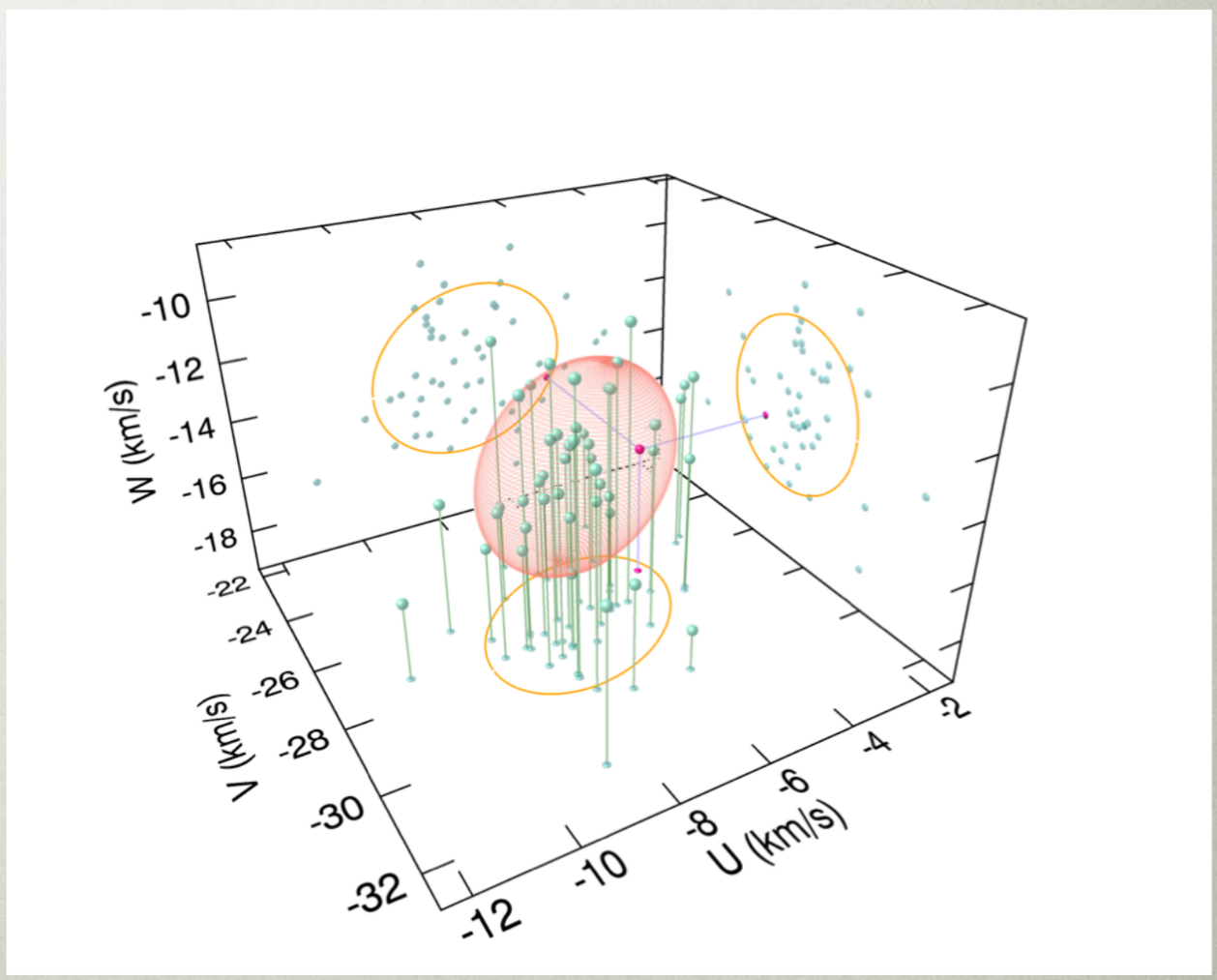
Sagan Fellows Symposium, 2015

BASS Discoveries Extra 1

(1) A new low-gravity L3 bona fide member in AB Doradus !

Estimated mass : 22 $M_{\rm Jup}$

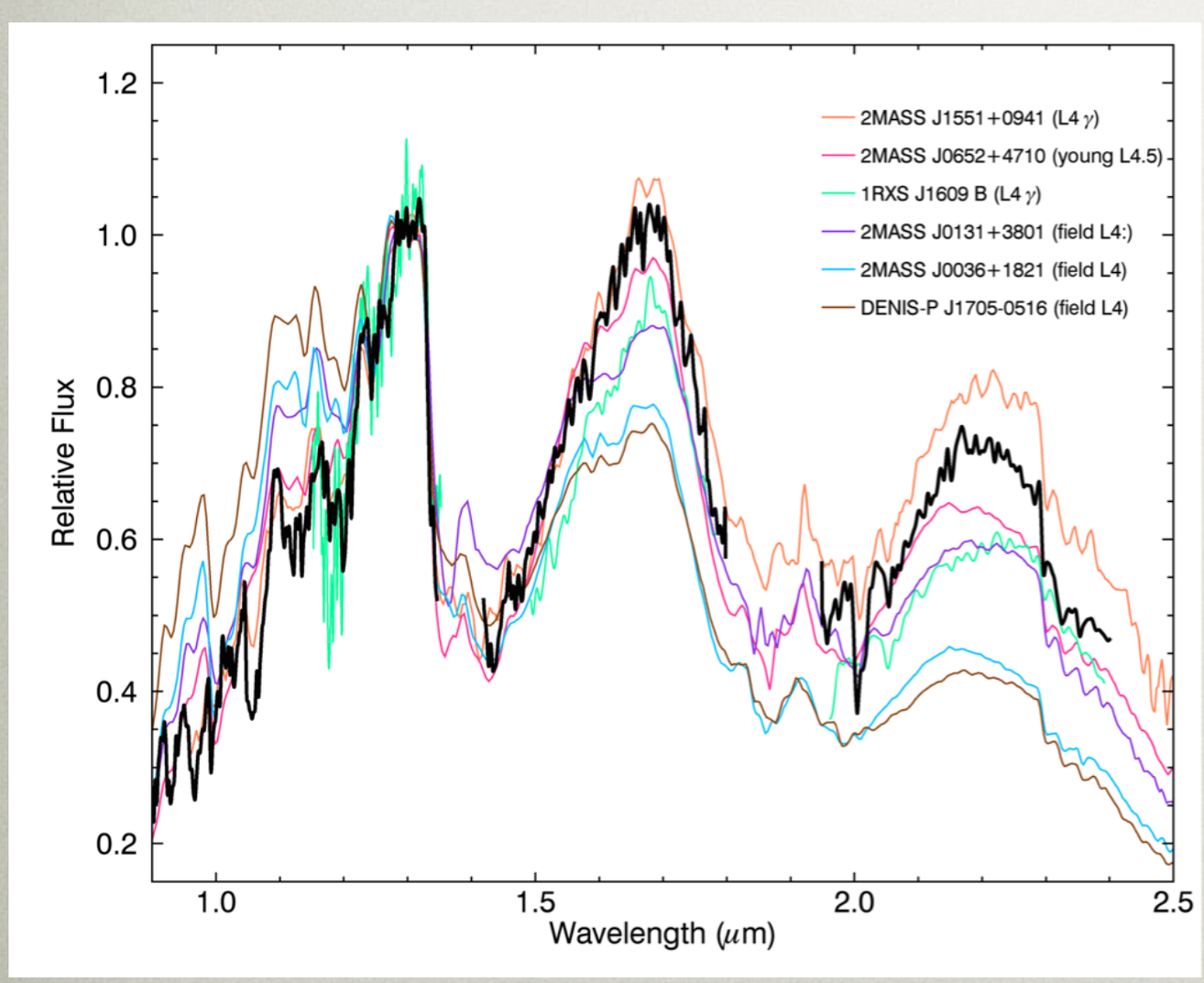




Gagné et al., submitted to ApJ

BASS Discoveries Extra 2

(2) A new low-gravity L4 planetary-mass companion to a low-gravity M6 candidate member of Tucana-Horologium



R ~ 6 000 resolved spectrum of the companion !

Estimated mass : 13 M_{Jup}

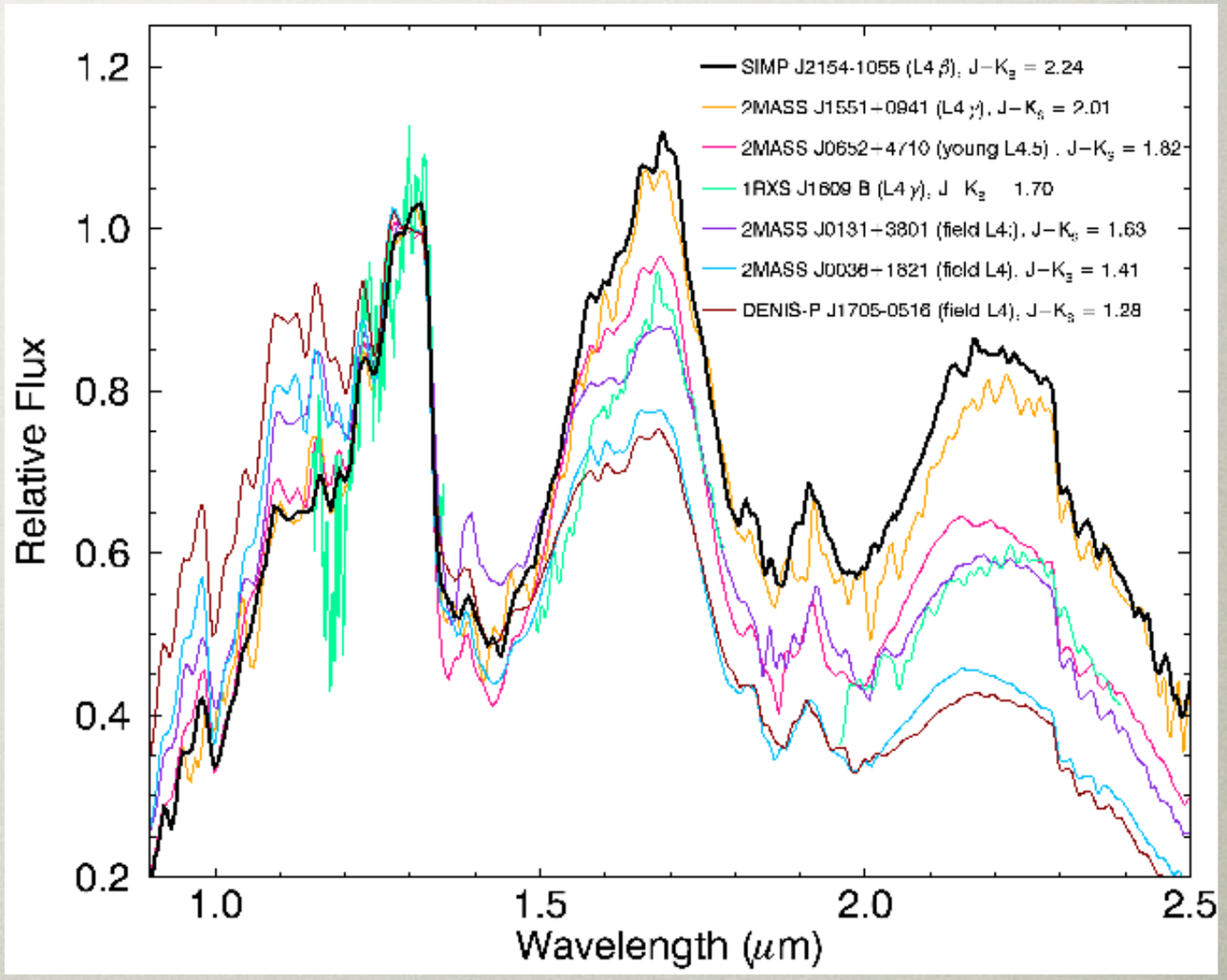
Artigau et al., submitted to ApJ

BASS Discoveries Extra 3

(3) A new low-gravity L4 candidate member of Argus

... that was accidentally discovered in the SIMP survey !

Estimated mass : 10 $M_{\rm Jup}$

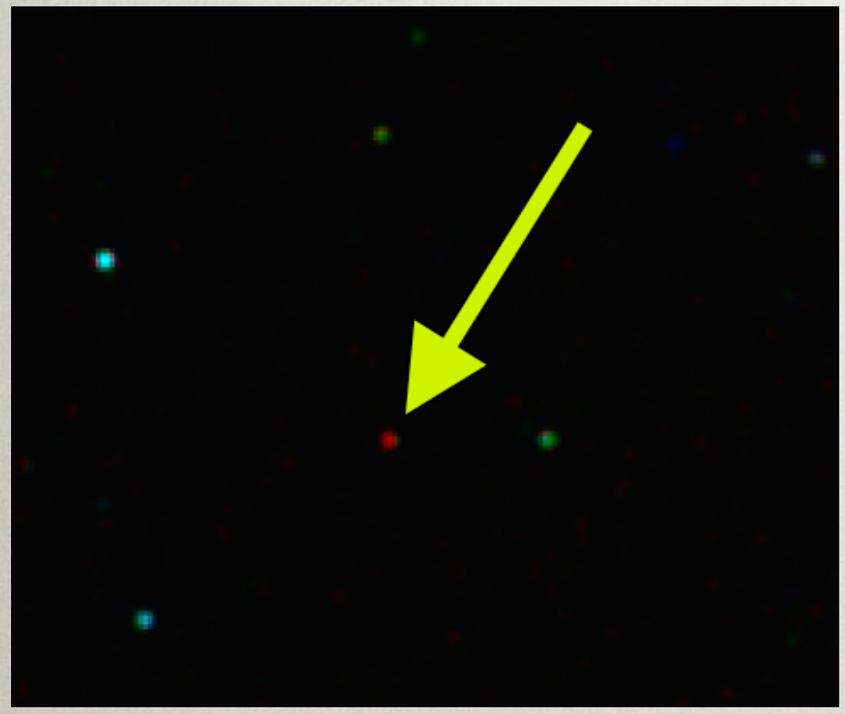


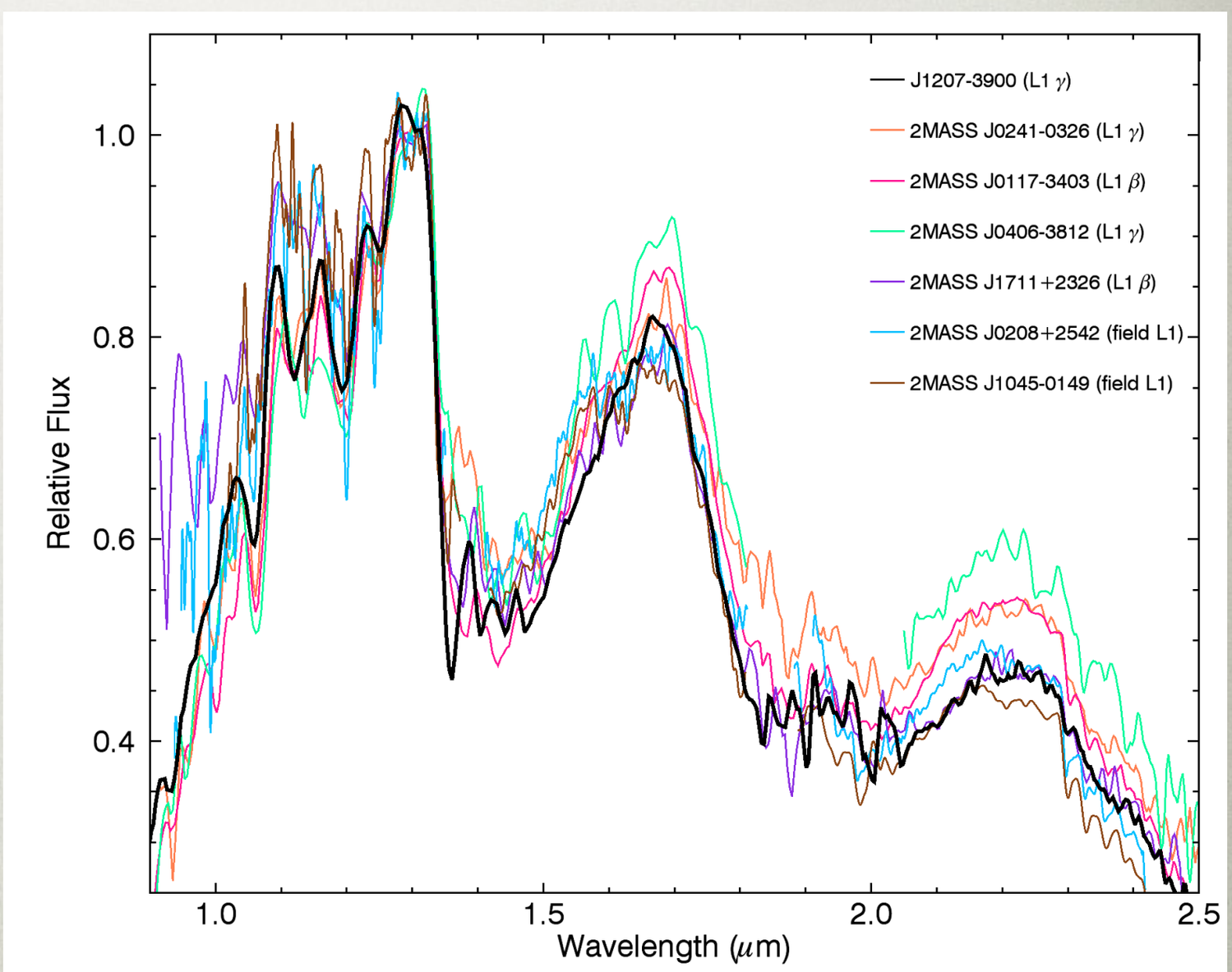
Gagné et al., 2014c
ApJ, 792L, 17

BASS Discoveries Extra 4

(4) The first L dwarf candidate member of TW Hydrae

Estimated mass : 12 $M_{\rm Jup}$

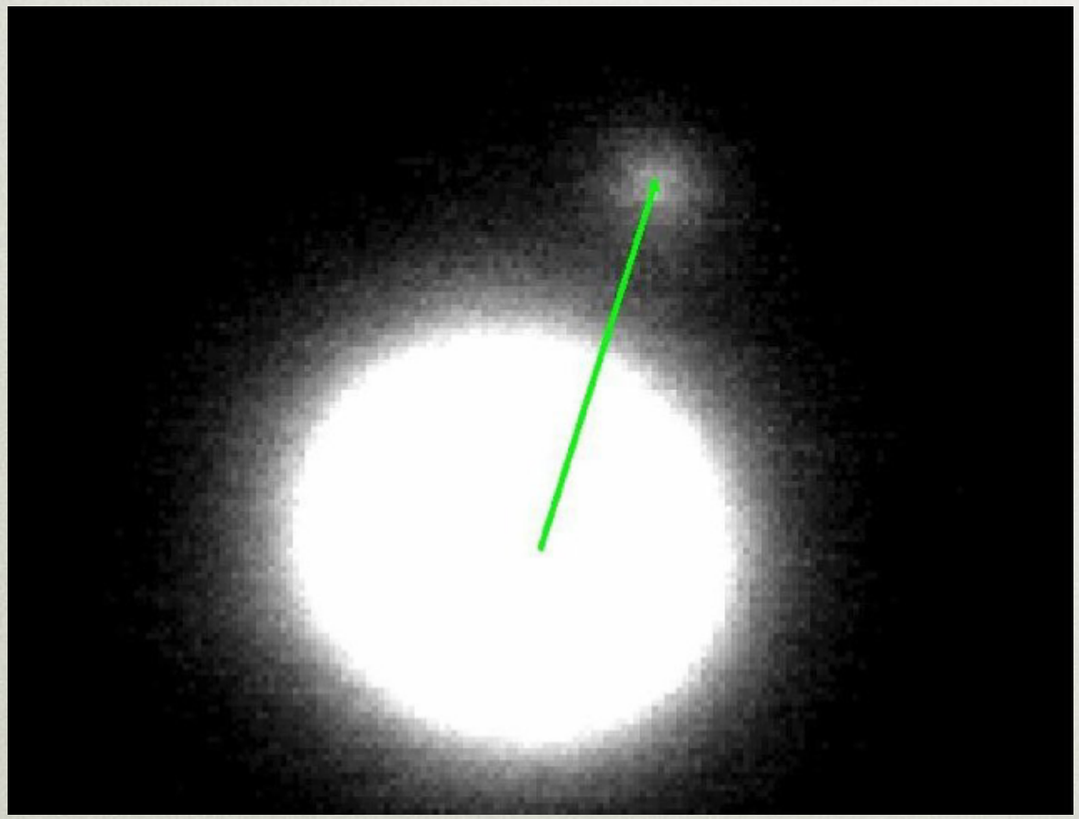




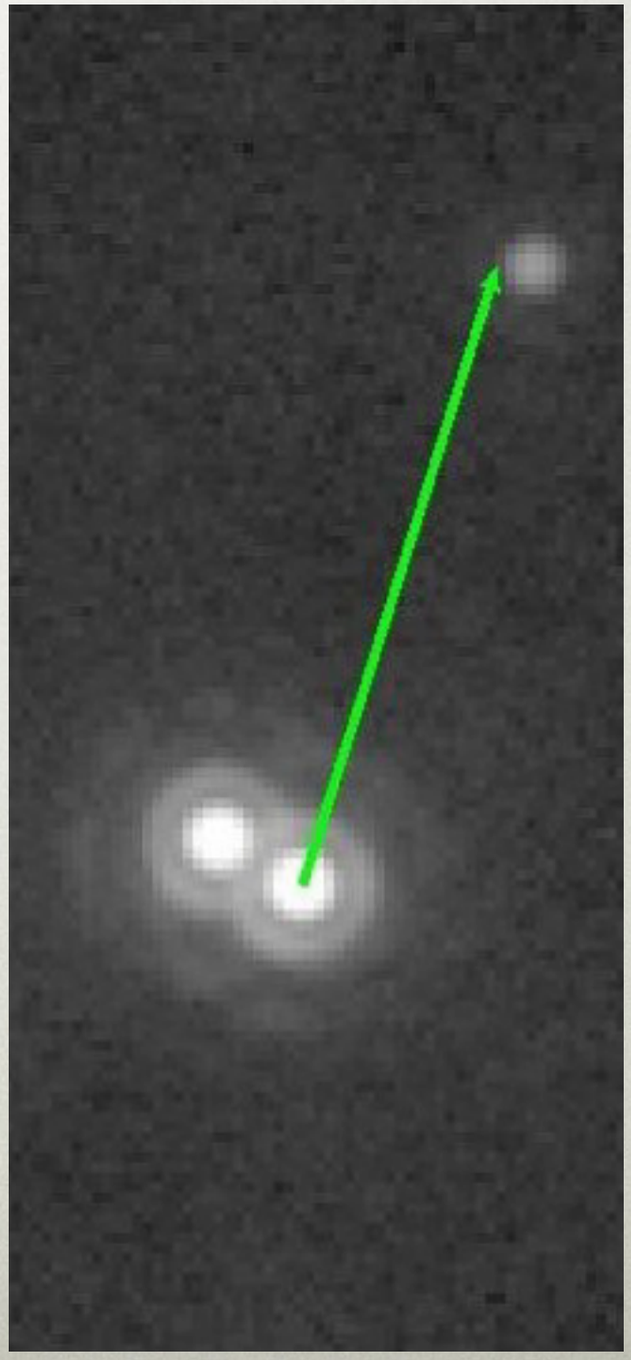
Gagné et al., 2014b
ApJ, 785L, 14

BASS Discoveries Extra 5

(5) J0103-5515, the M5 + M5 + 12-14 $M_{\rm Jup}$ companion in Tucana-Horologium



Naco *H*-band



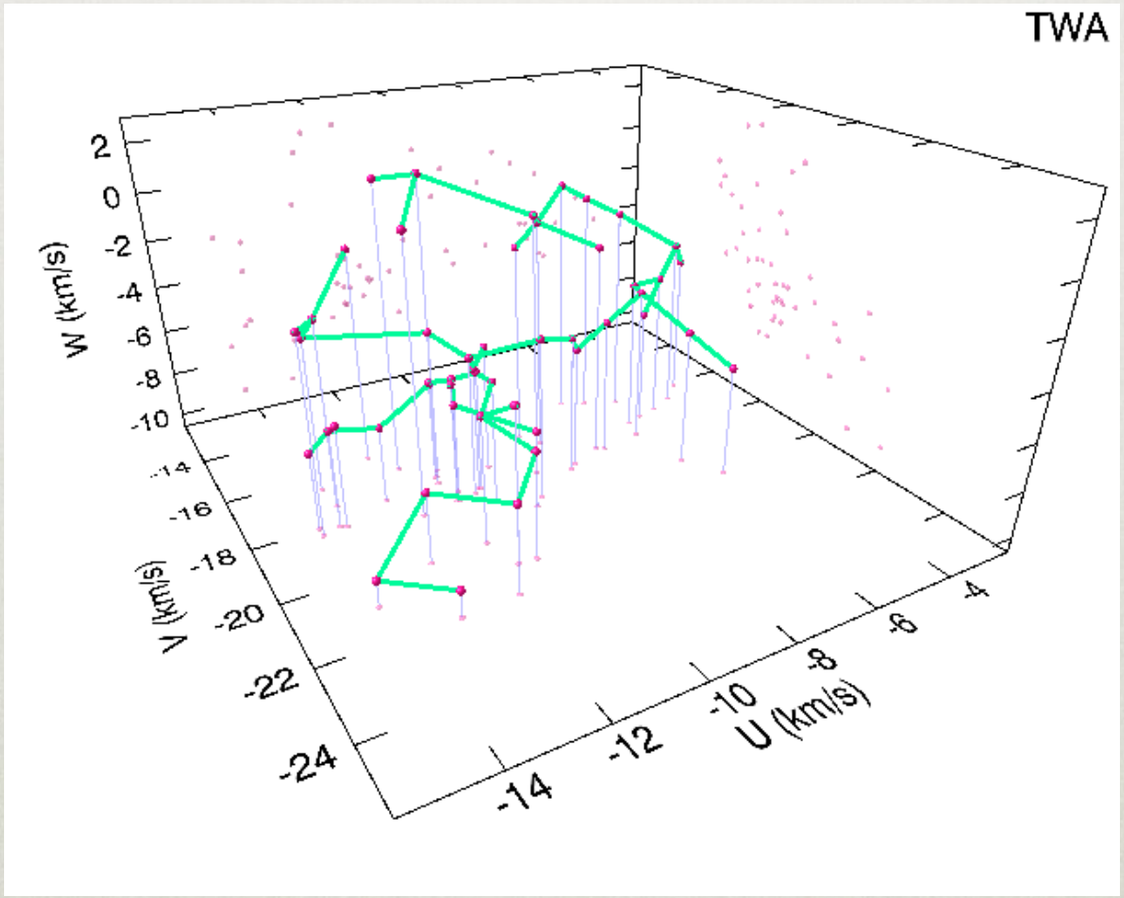
Naco *L'*-band

Delorme et al., 2013
A&A, 553L, 5

Mass Segregation ? Extra 6

With the Method of Minimal Spanning Trees,

=> We do not need to know the center of mass <=



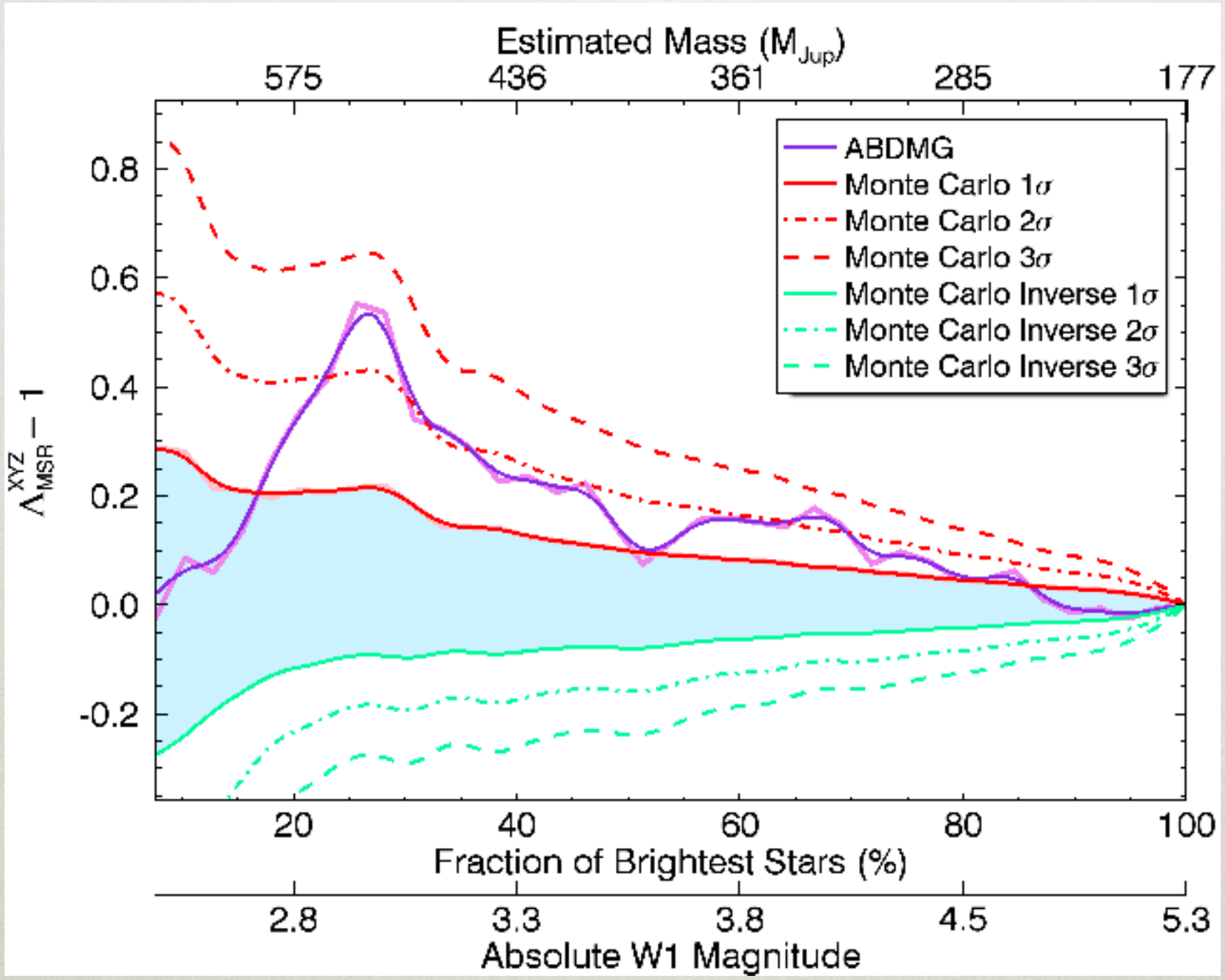
Gagné et al. 2015 ApJ, 798, 73

(1)Build the shortest network that connects all UVW point

(2)No Loops are Allowed

(3)Measure the total length of the Network

Mass Segregation ? Extra 7



Gagné et al. 2015 ApJ, 798, 73

(4) Build MST for N brightest members

(5) Repeat for N random members

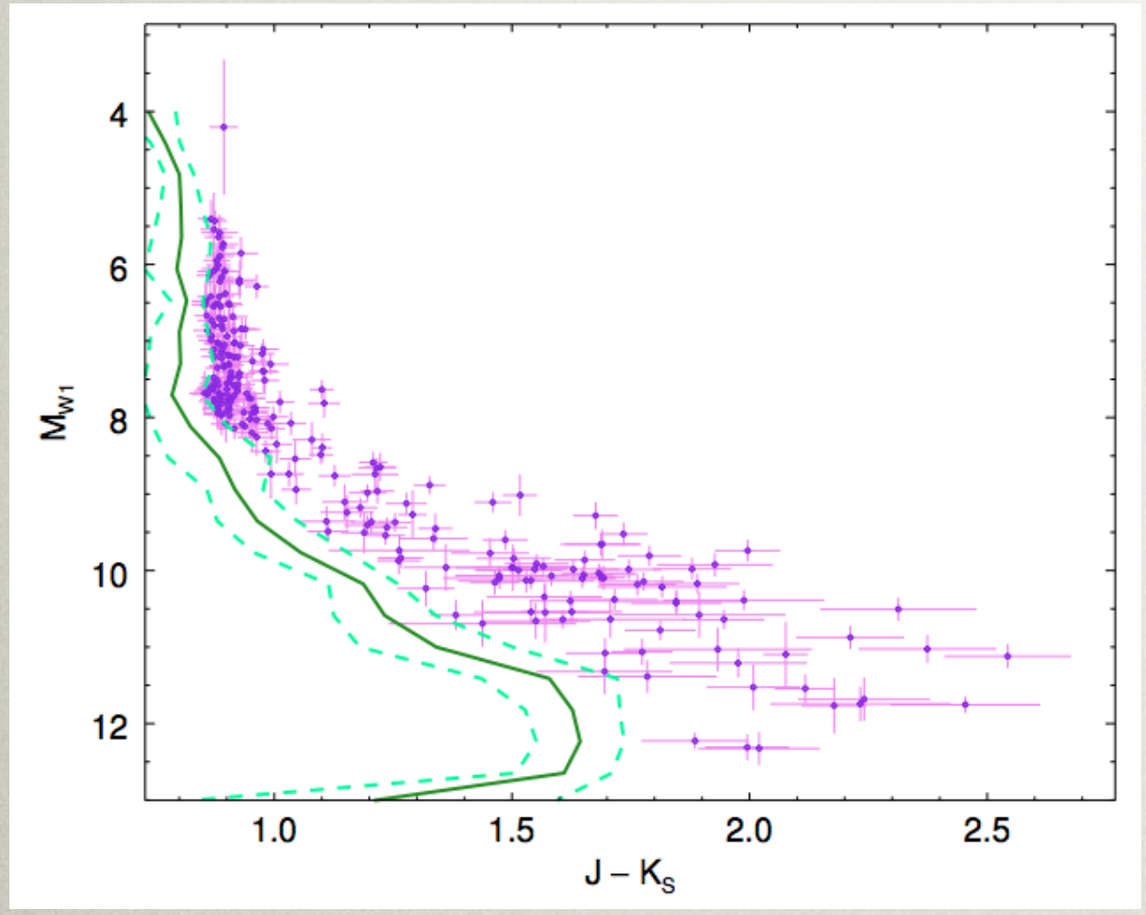
Mass Segregation ? Extra 8

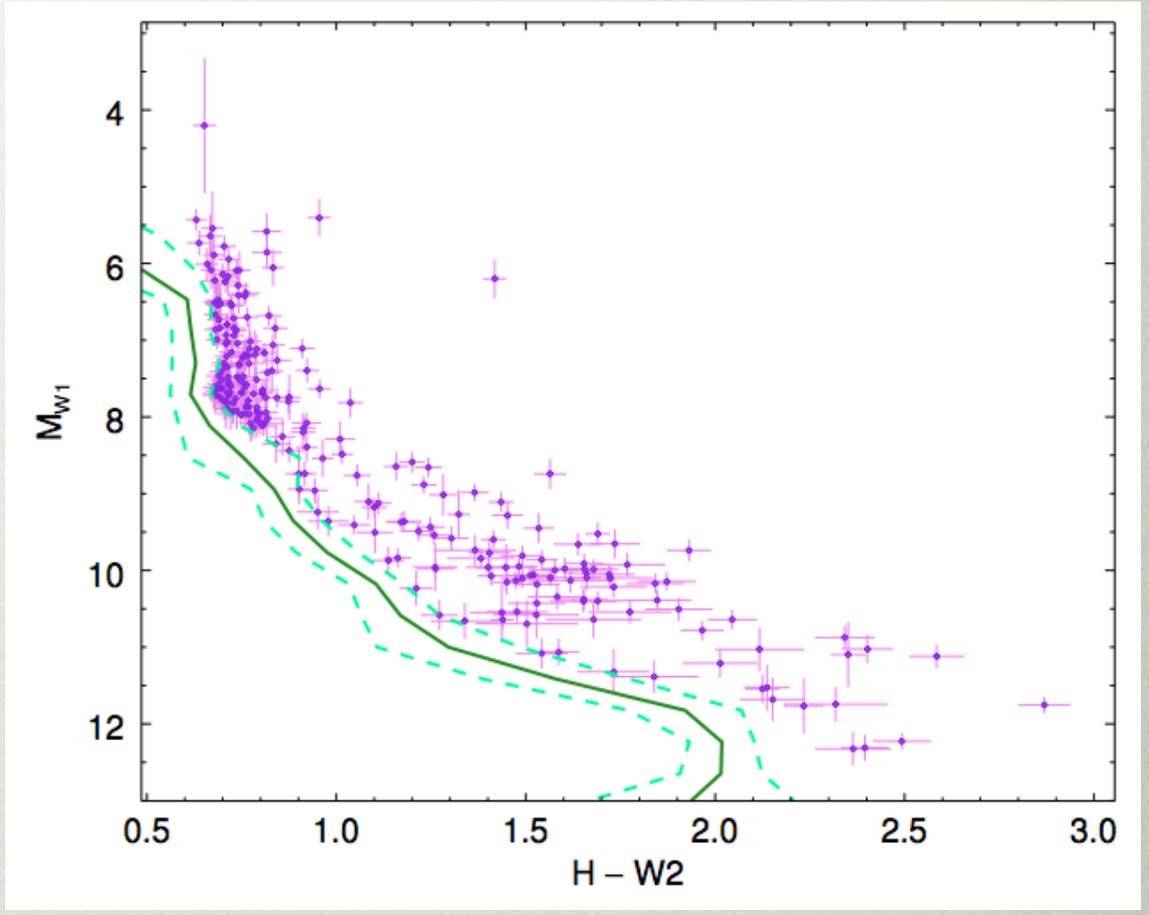
Mass Segregation is detected at ~ 2-3 sigma for :

- AB Doradus (both spatial and dynamical)
- β Pictoris (spatial only)
- Columba (dynamical only)
- Including BASS candidates increases these detections to 2 - 4 sigma + Tucana starts showing spatial + dynamical mass segregation !

=> we must measure parallax, RV and confirm youth for more substellar members to verify this

The BASS survey Extra 9



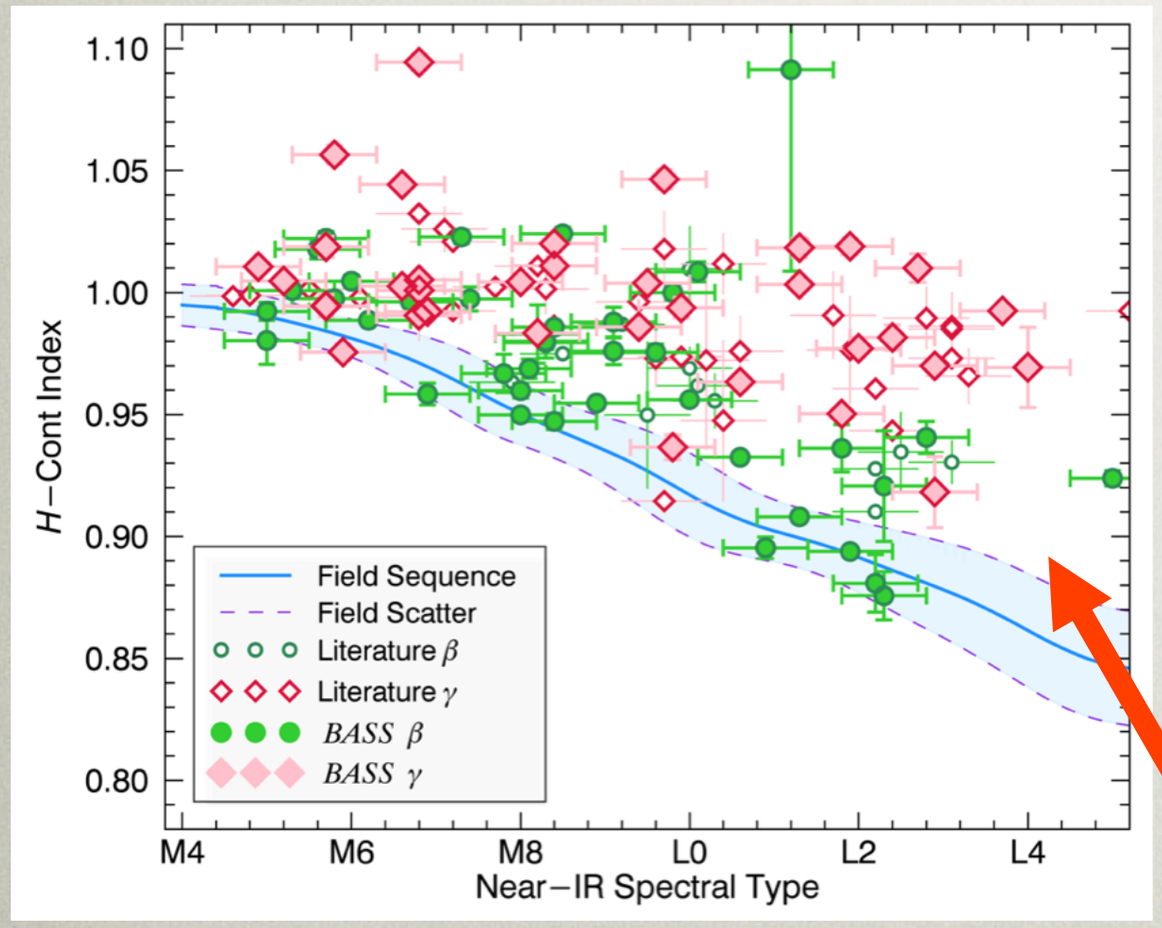


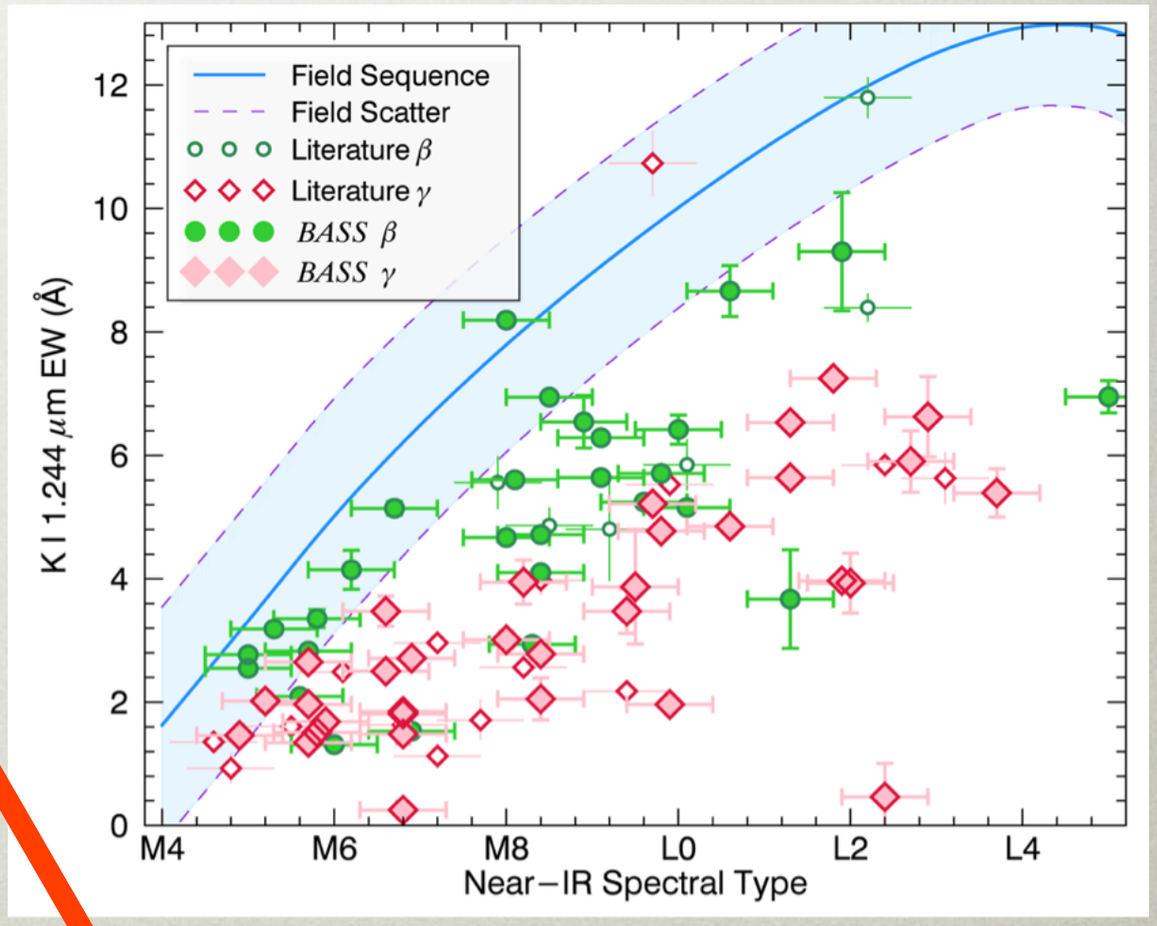
Gagné et al. 2015 ApJ, 798, 73

The Kinematic distances of BASS candidates
is consistent with redder colors / larger luminosity
than field dwarfs

Spectrocopic Follow-up Extra 10

We used the Allers & Liu (2013) + Visual comparison To assign spt + gravity class





Gagné et al., submitted to ApJ

Lots of new low-G brown dwarfs !