CFHT Infrared Parallax Program

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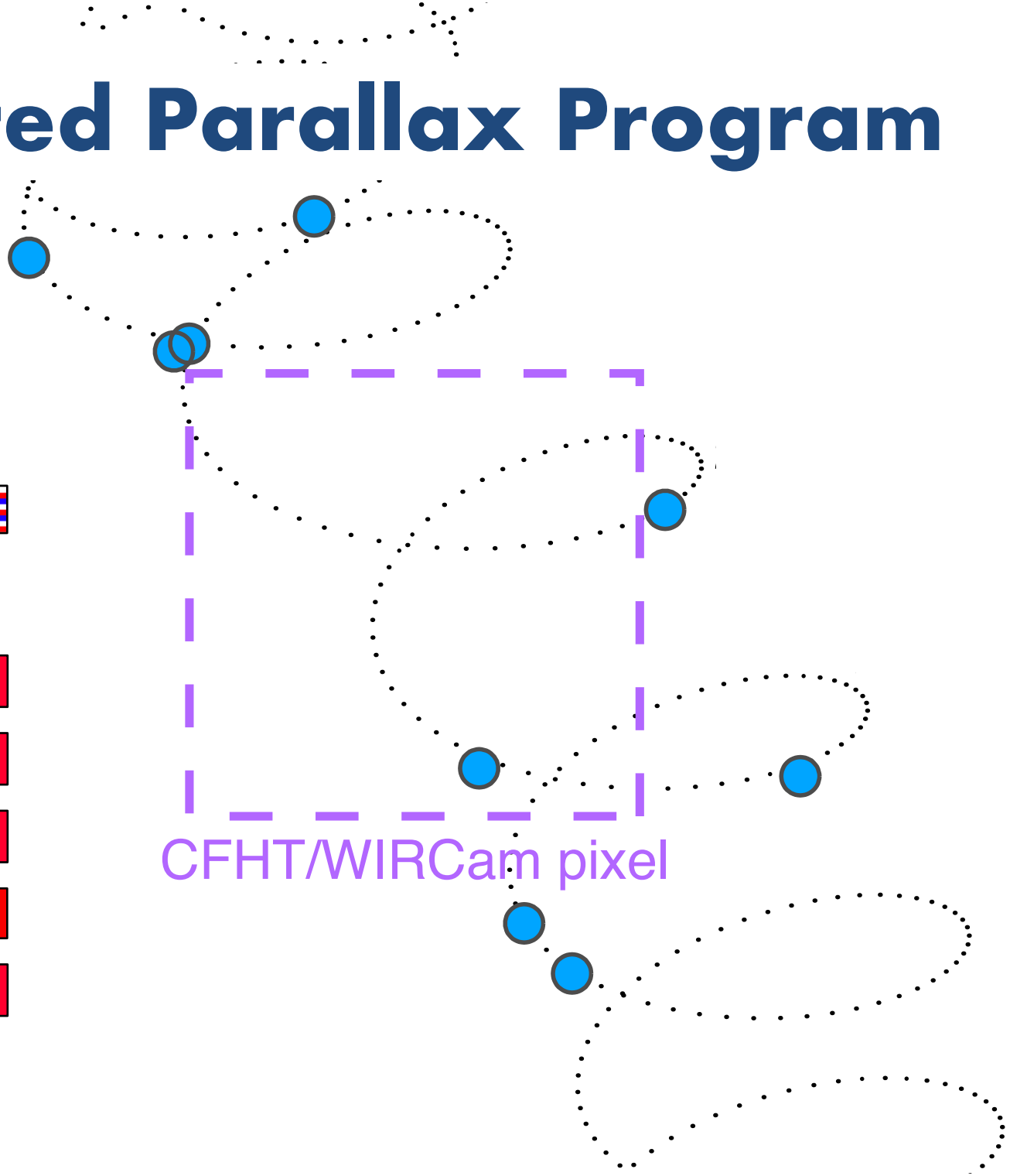
P. Tremblin



Observables

photometry
spectra

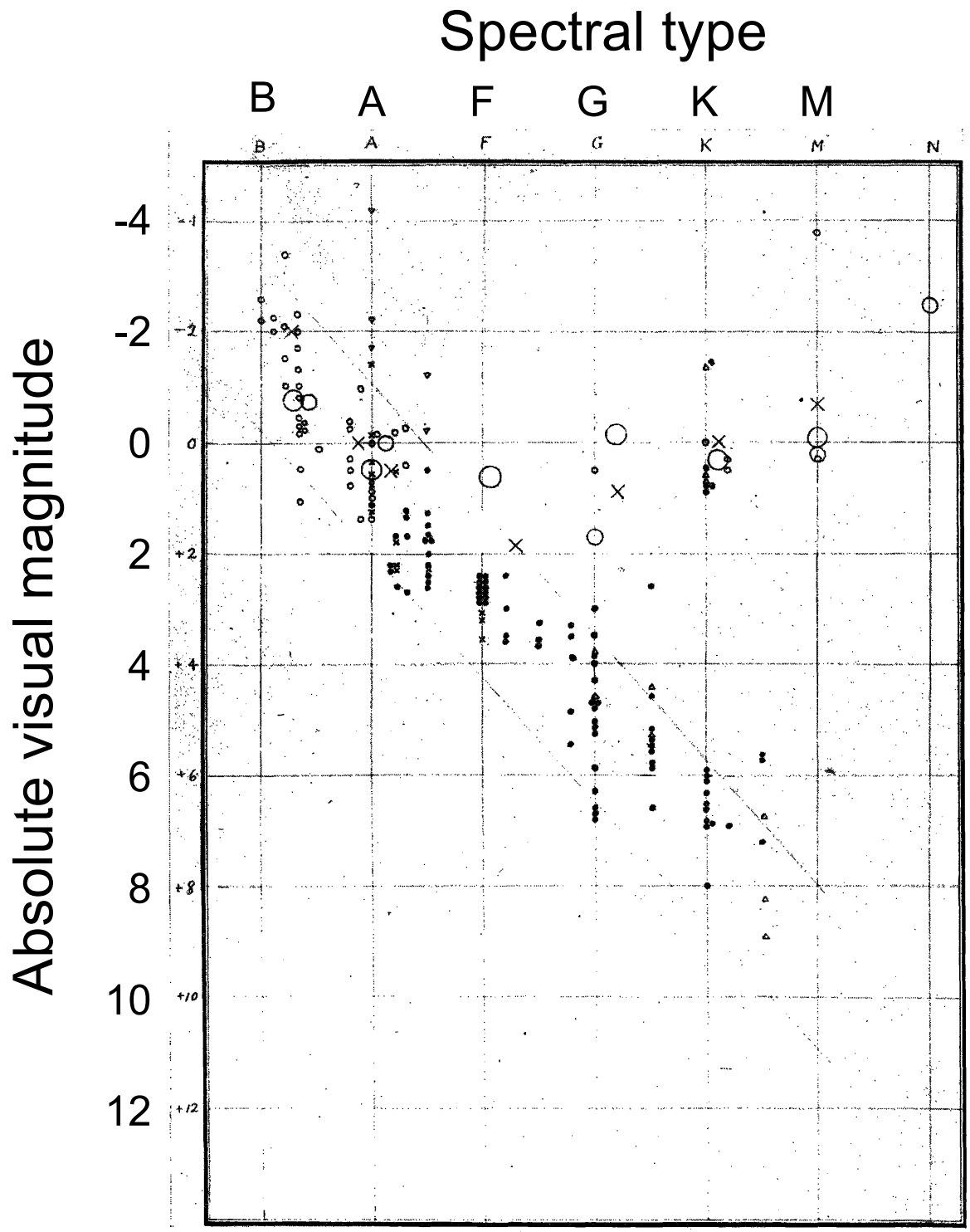
proper motions

parallax

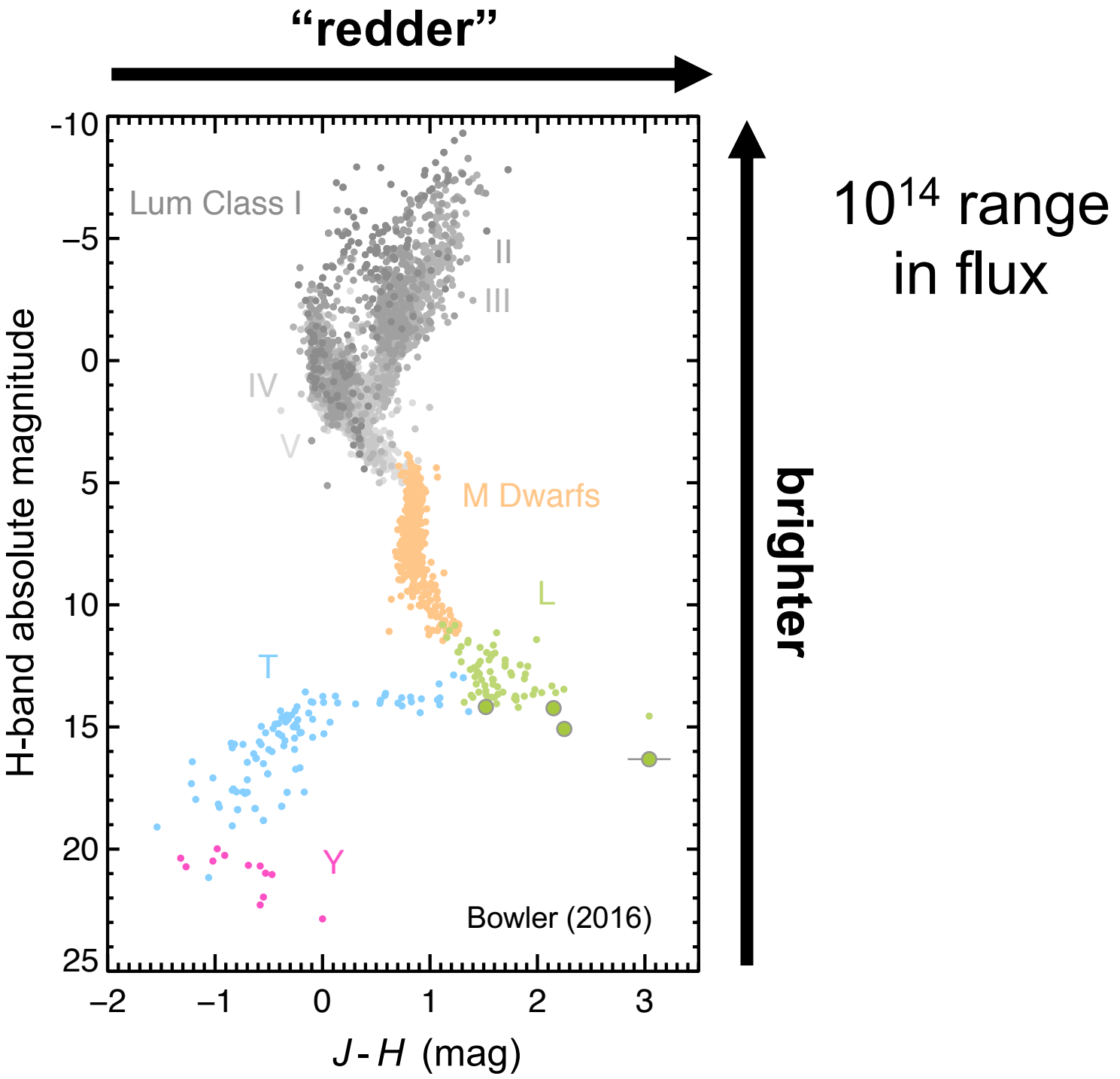
Physical Properties

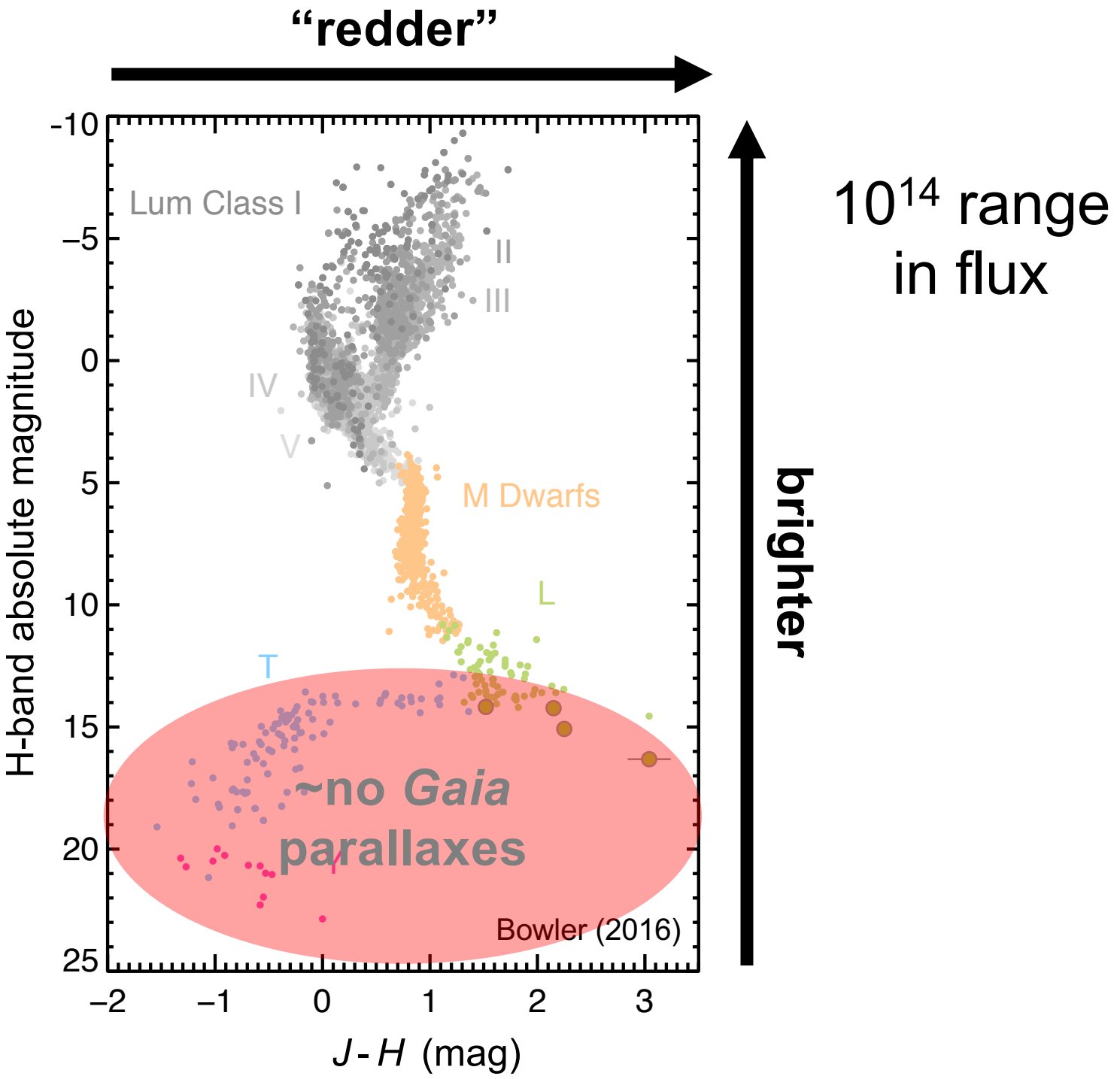
absolute flux,
luminosity, mass

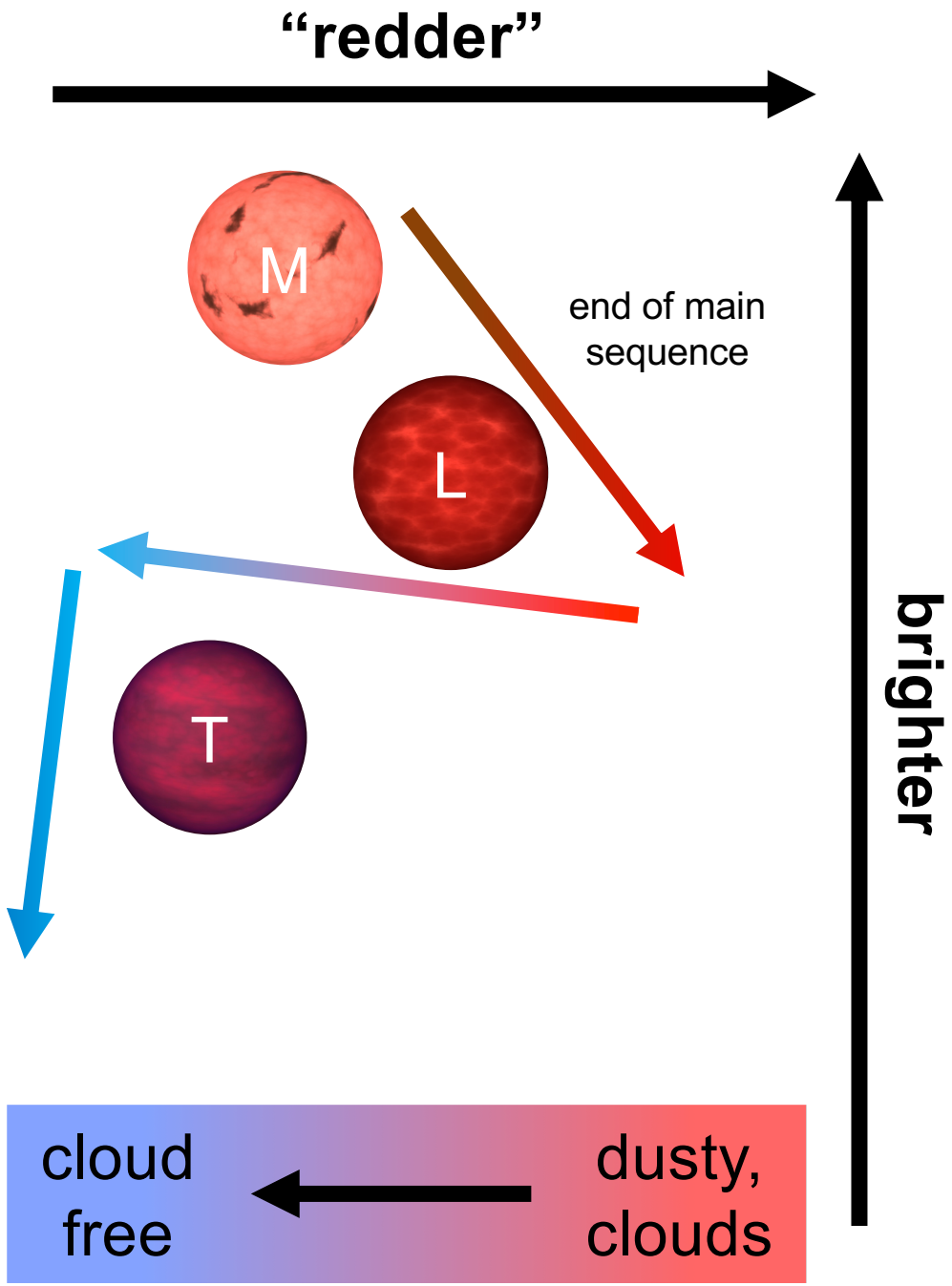
kinematics

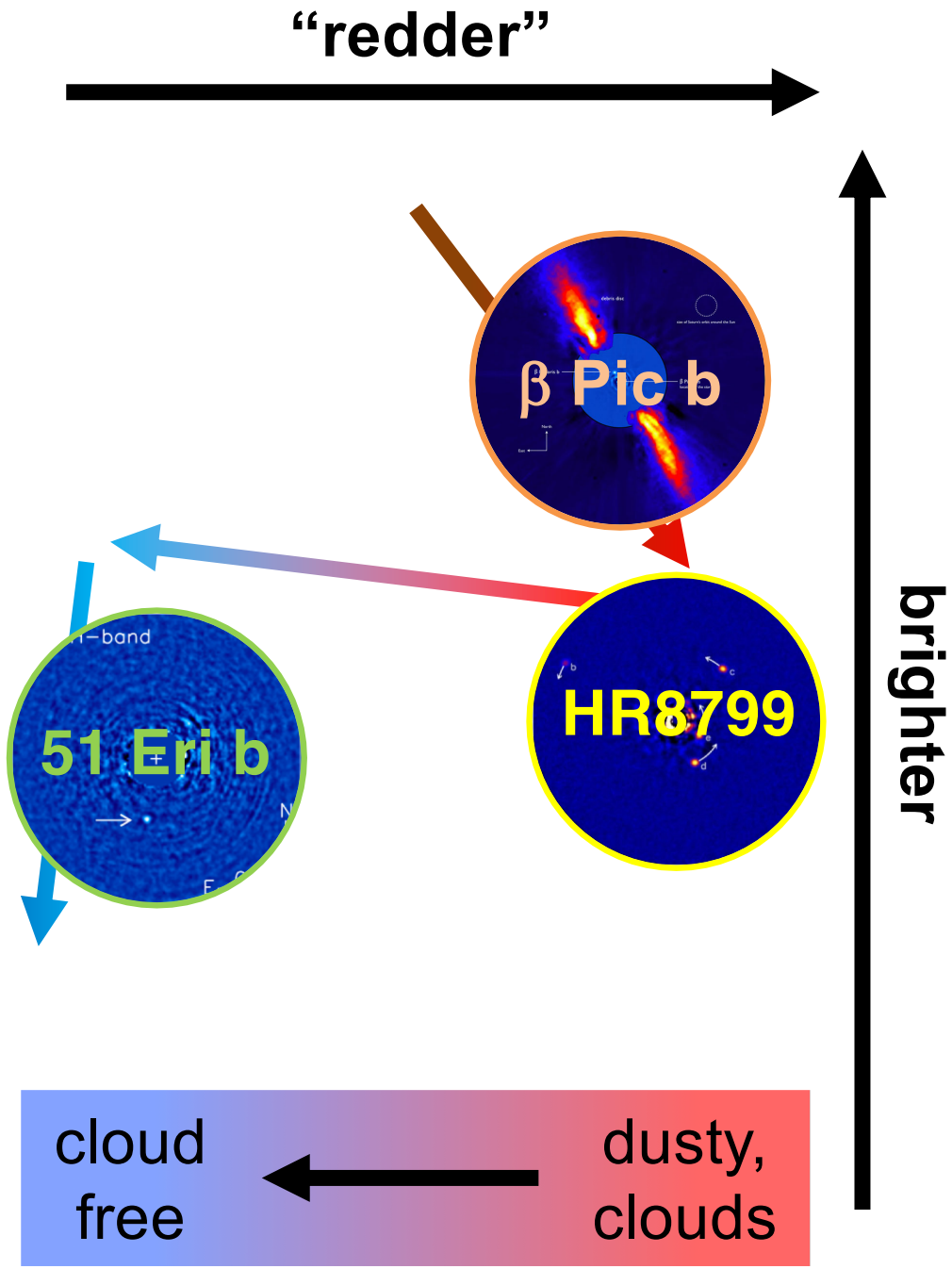


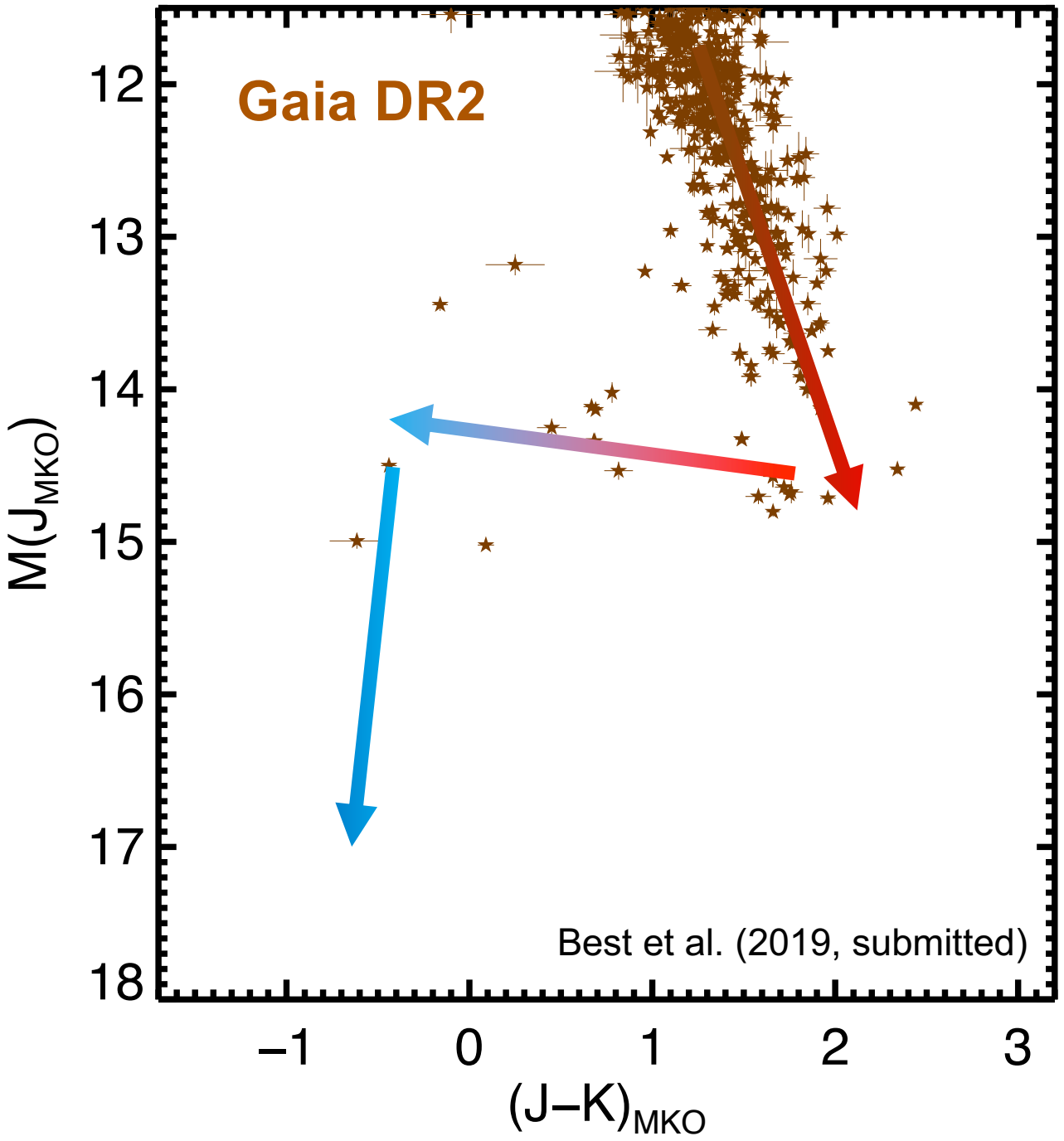
H-R Diagram
(Russell 1914)


"redder"
brighter
10^{14} range in flux
H-band absolute magnitude
J - H (mag)
Lum Class I
II
III
IV
V
M Dwarfs
L
T
Y
Bowler (2016)
-10
-5
0
5
10
15
20
25
-2
-1
0
1
2
3


"redder"
Lum Class I
II
III
IV
V
M Dwarfs
L
T
~no Gaia parallaxes
Bowler (2016)
H-band absolute magnitude
J - H (mag)
-10
-5
0
5
10
15
20
25
-2
-1
0
1
2
3
brighter
10^14 range in flux


“redder”
M
end of main sequence
L
T
brighter
cloud free
dusty, clouds


“redder”
β Pic b
51 Eri b
HR8799
brighter
cloud free
dusty, clouds

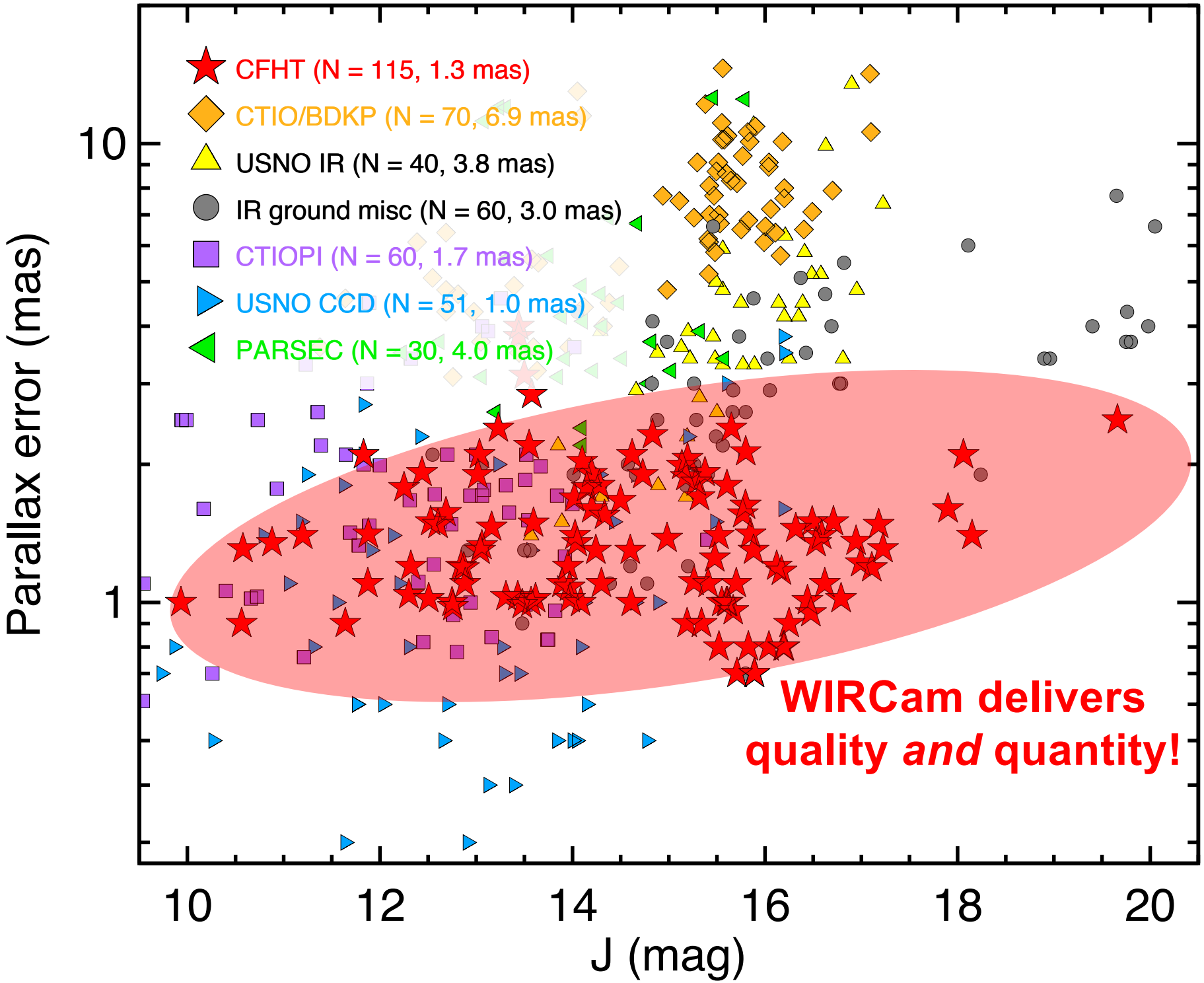

Gaia DR2
Best et al. (2019, submitted)
M(J_MKO)
(J–K)_MKO
12
13
14
15
16
17
18
–1
0
1
2
3

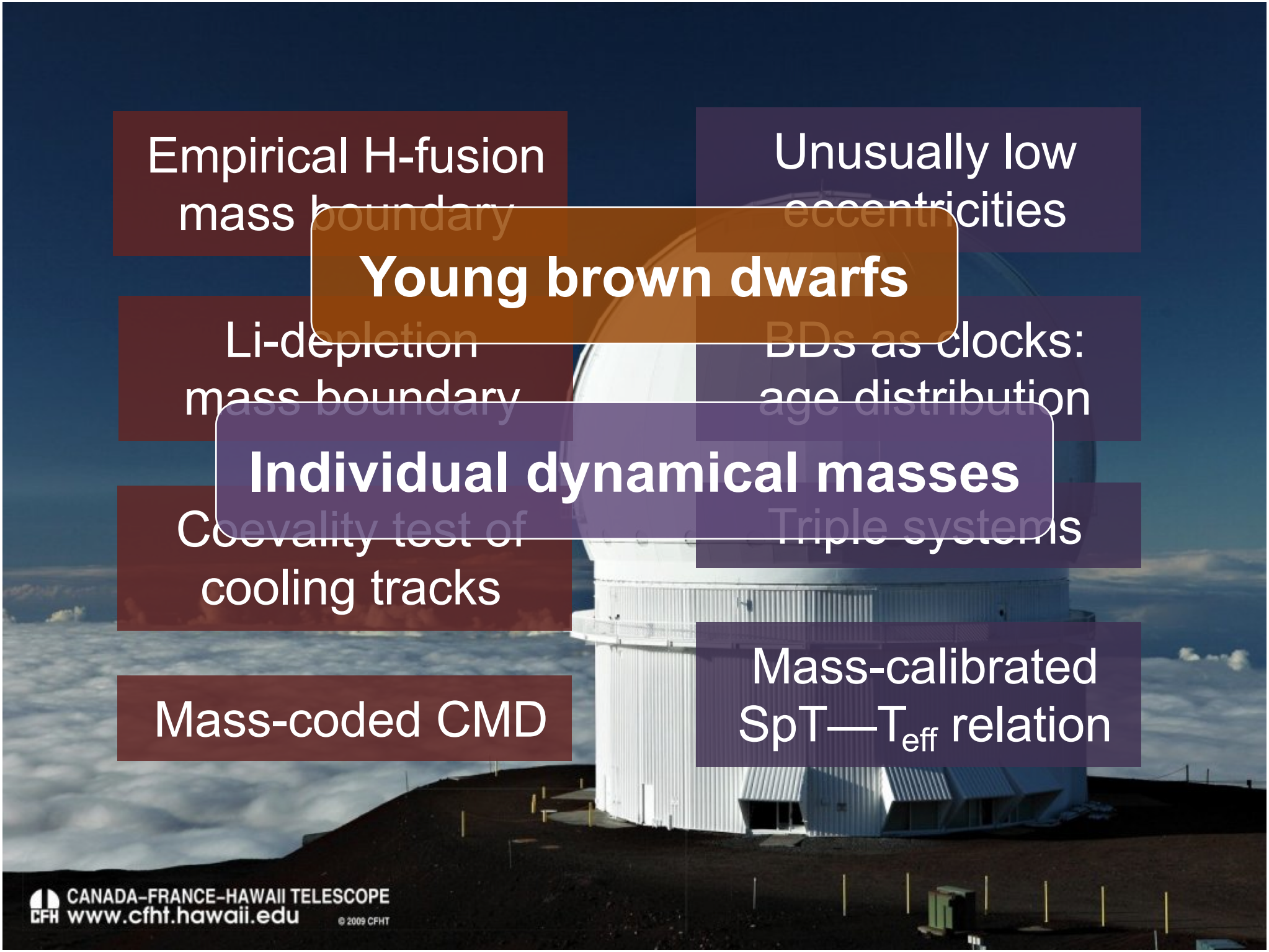
began in 2007 as my PhD thesis at IfA

WIRCam's image quality & CFHT queue scheduling are ideal for astrometric monitoring

longest running IR parallax program

>500 objects monitored


CFHT (N = 115, 1.3 mas)
CTIO/BDKP (N = 70, 6.9 mas)
USNO IR (N = 40, 3.8 mas)
IR ground misc (N = 60, 3.0 mas)
CTIOPI (N = 60, 1.7 mas)
USNO CCD (N = 51, 1.0 mas)
PARSEC (N = 30, 4.0 mas)
WIRCam delivers
quality *and* quantity!
Parallax error (mas)
10
1
10
12
14
16
18
20
J (mag)


Empirical H-fusion mass boundary
Unusually low eccentricities
Young brown dwarfs
Li-depletion mass boundary
BDs as clocks: age distribution
Individual dynamical masses
Coevality test of cooling tracks
Triple systems
Mass-coded CMD
Mass-calibrated SpT—T_{eff} relation
CANADA–FRANCE–HAWAII TELESCOPE
www.cfht.hawaii.edu
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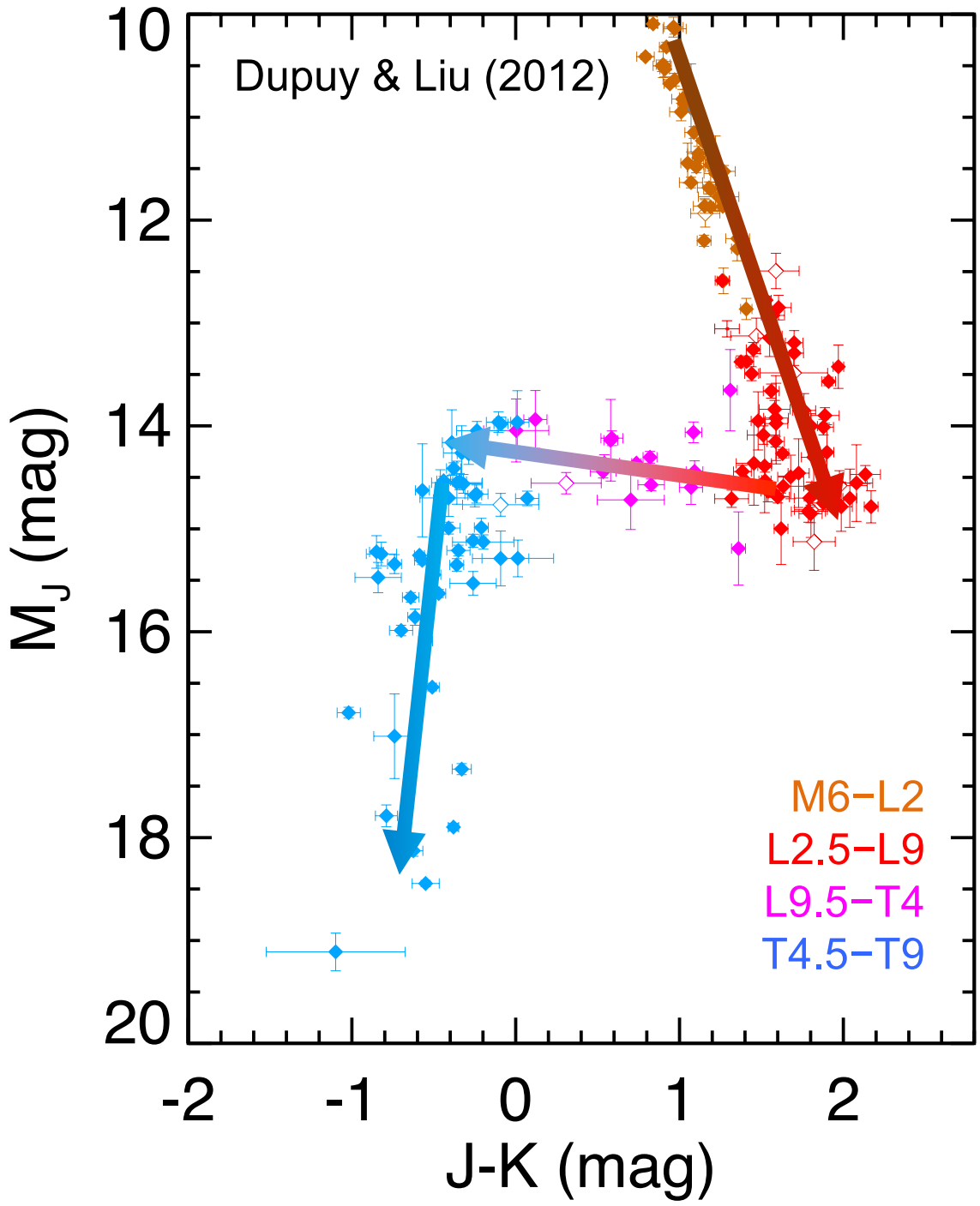
Ultracool Dwarf Parallaxes c. 2012

N ~ 300, but almost all ***old objects***



Others: Dahn+02; Tinney+03; Vrba+04; Costa+06; Lepine+09; Schilbach+09; Marocco+10; Andrei+11; Faherty+12

65 CFHT parallaxes

+

26 young companions

+

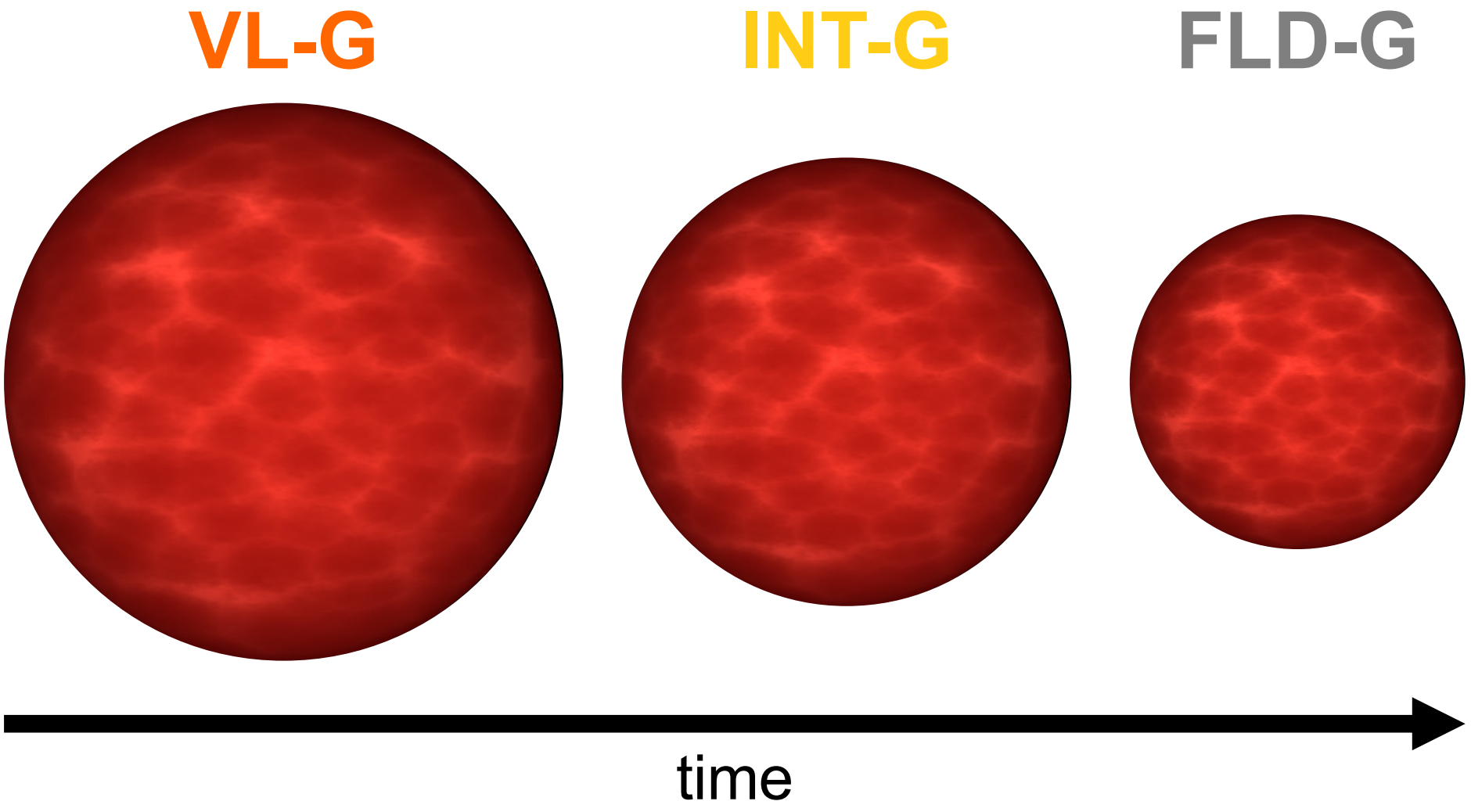
11 other parallaxes

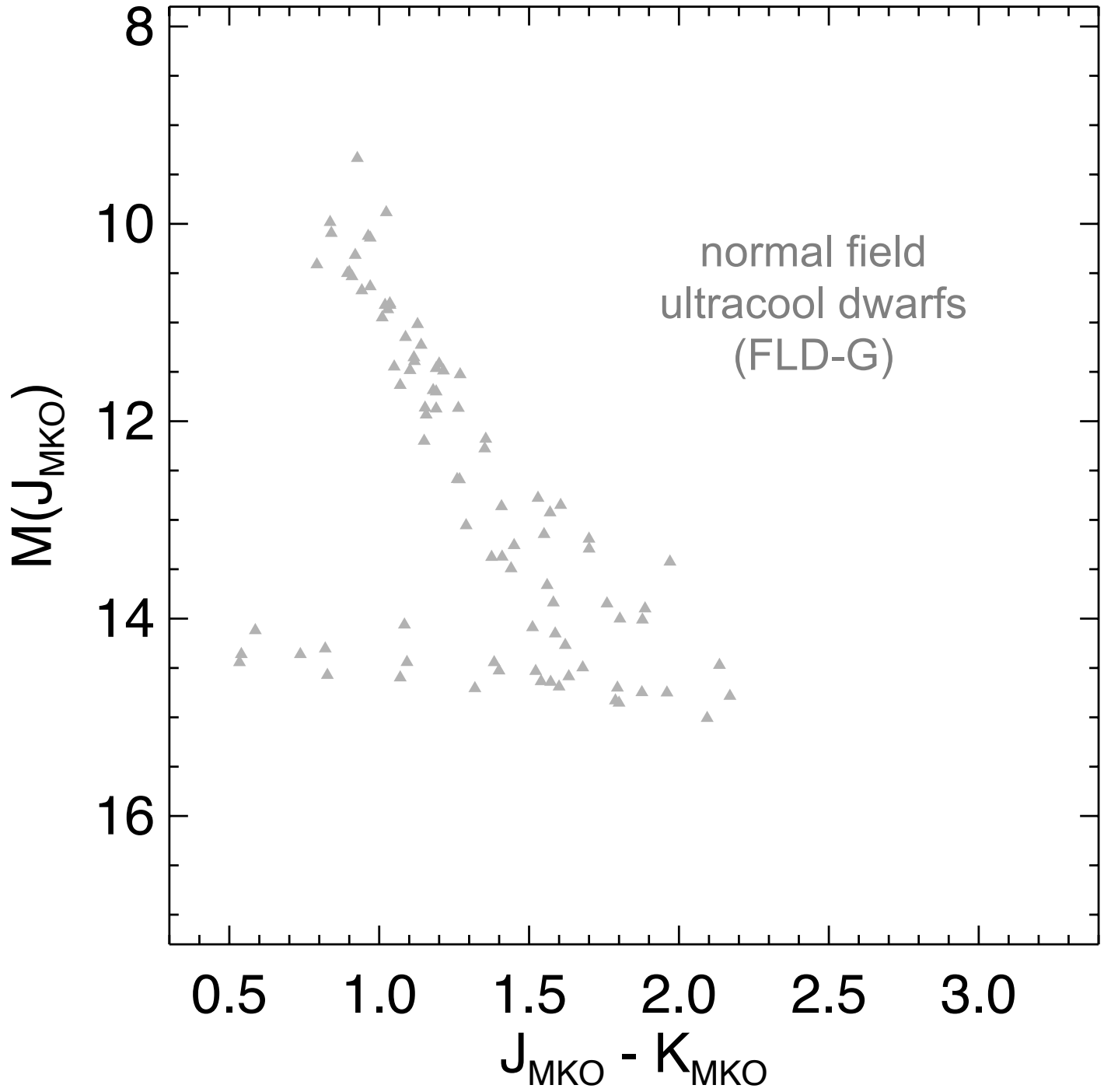
102 young objects

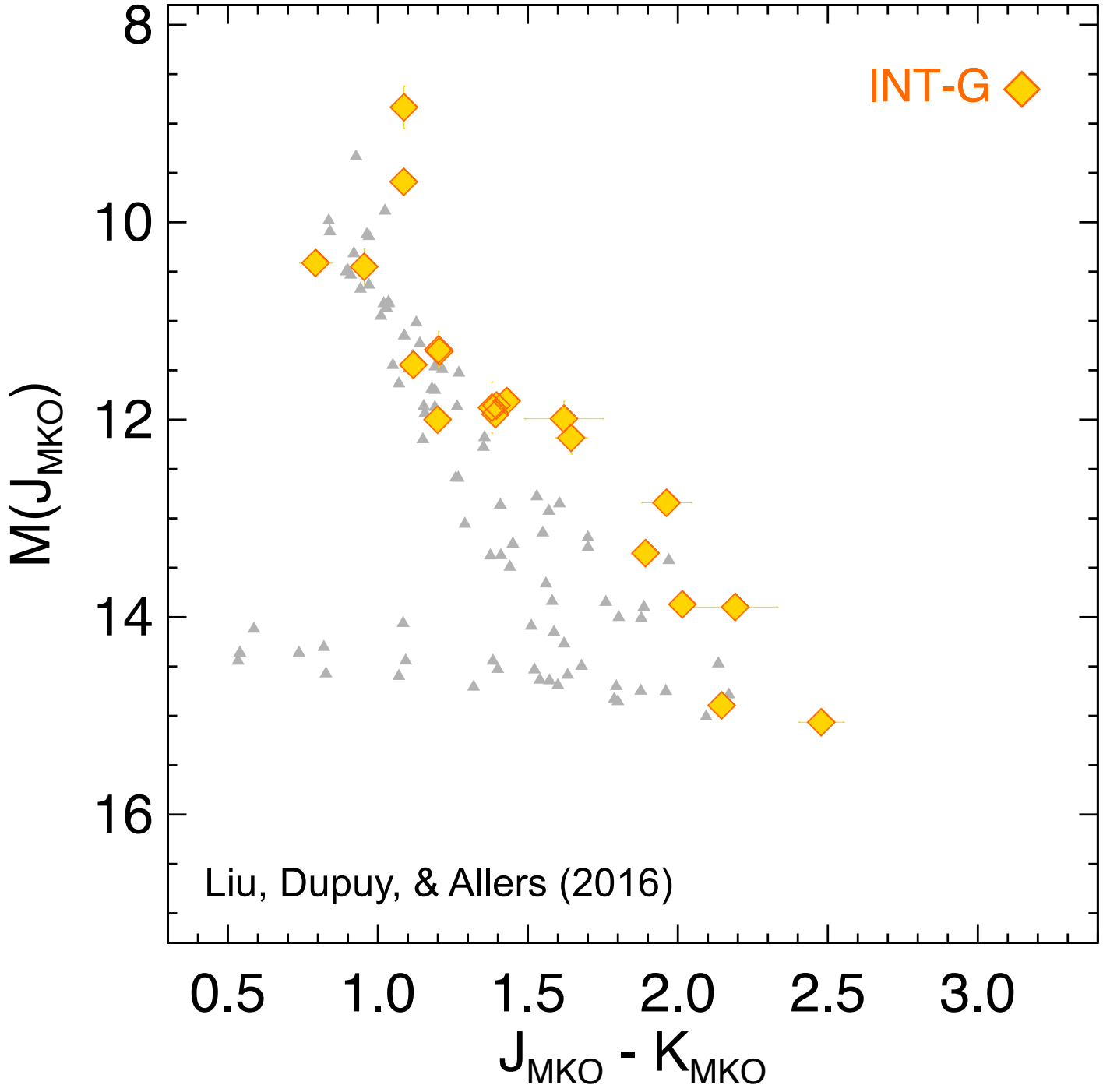
with parallaxes & uniform NIR classification

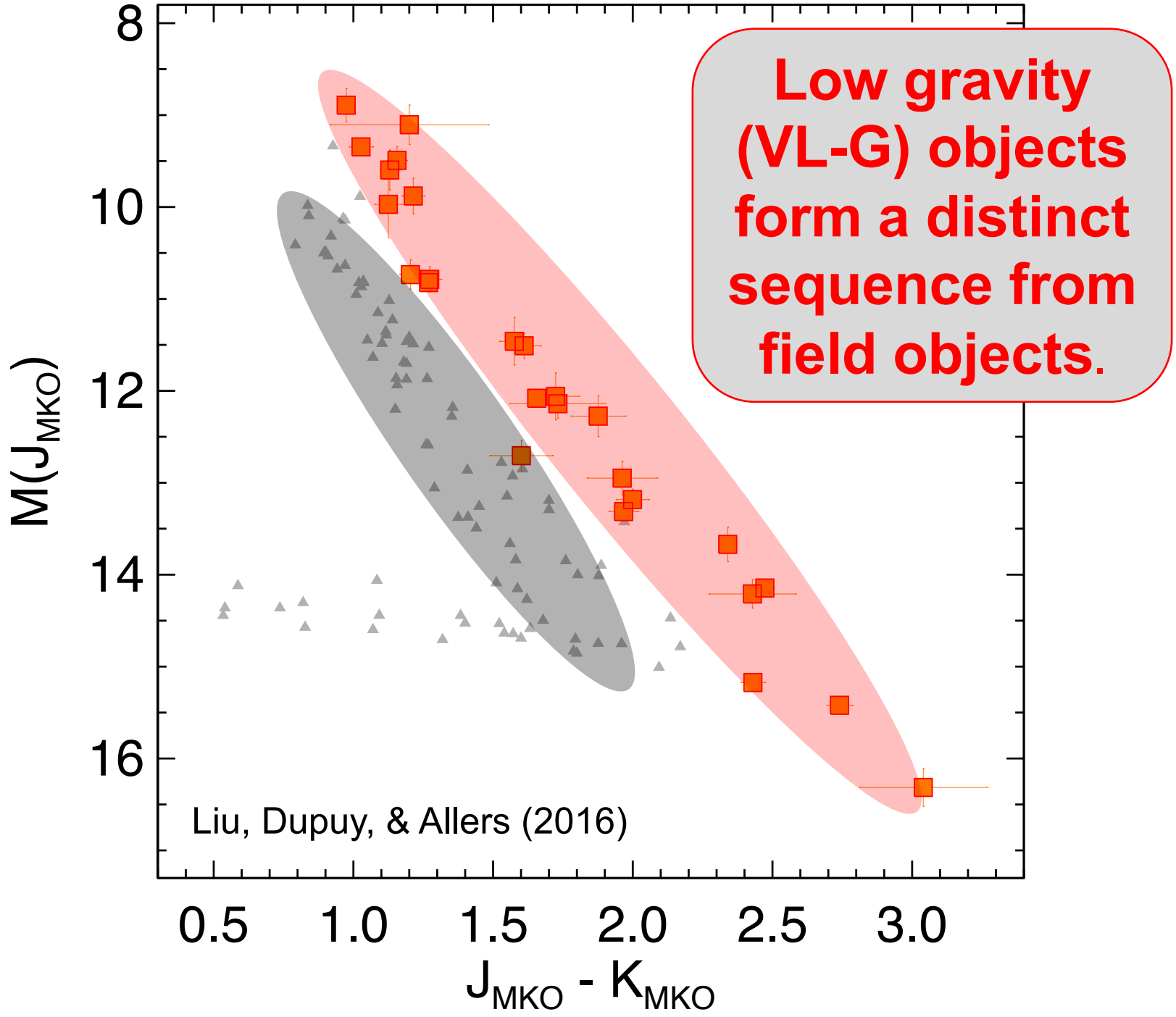
Other parallaxes: Dieterich+2014, Dittman+2014, Ducourant+2008, Ducourant+2014, Faherty+2012, Gatewood & Coban 2009, Marocco+2013, Riedel+2014, Vrba+2004, Wahhaj+2011, Weinberger+2013

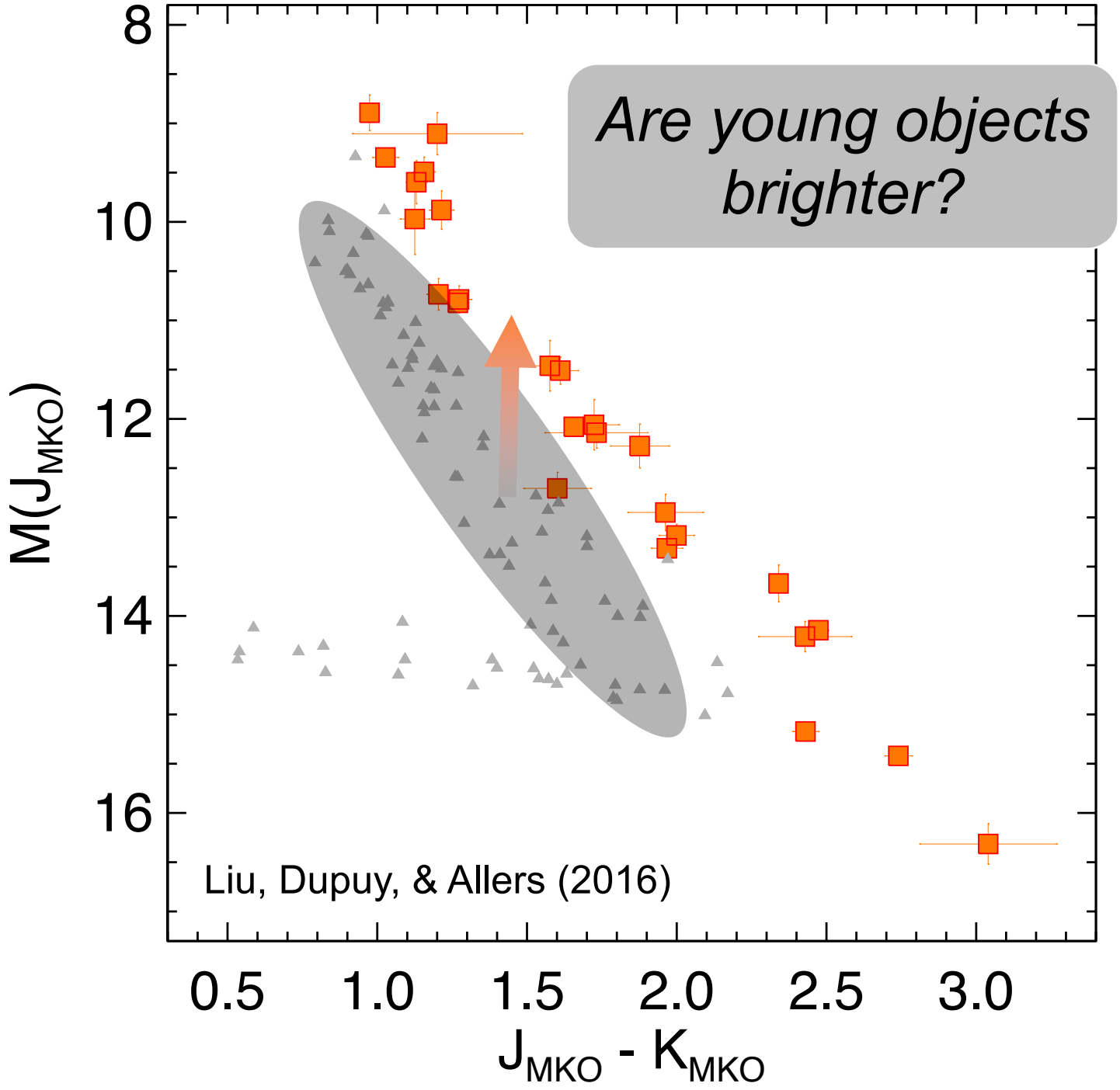
Spectroscopic gravity signatures evolve with age.

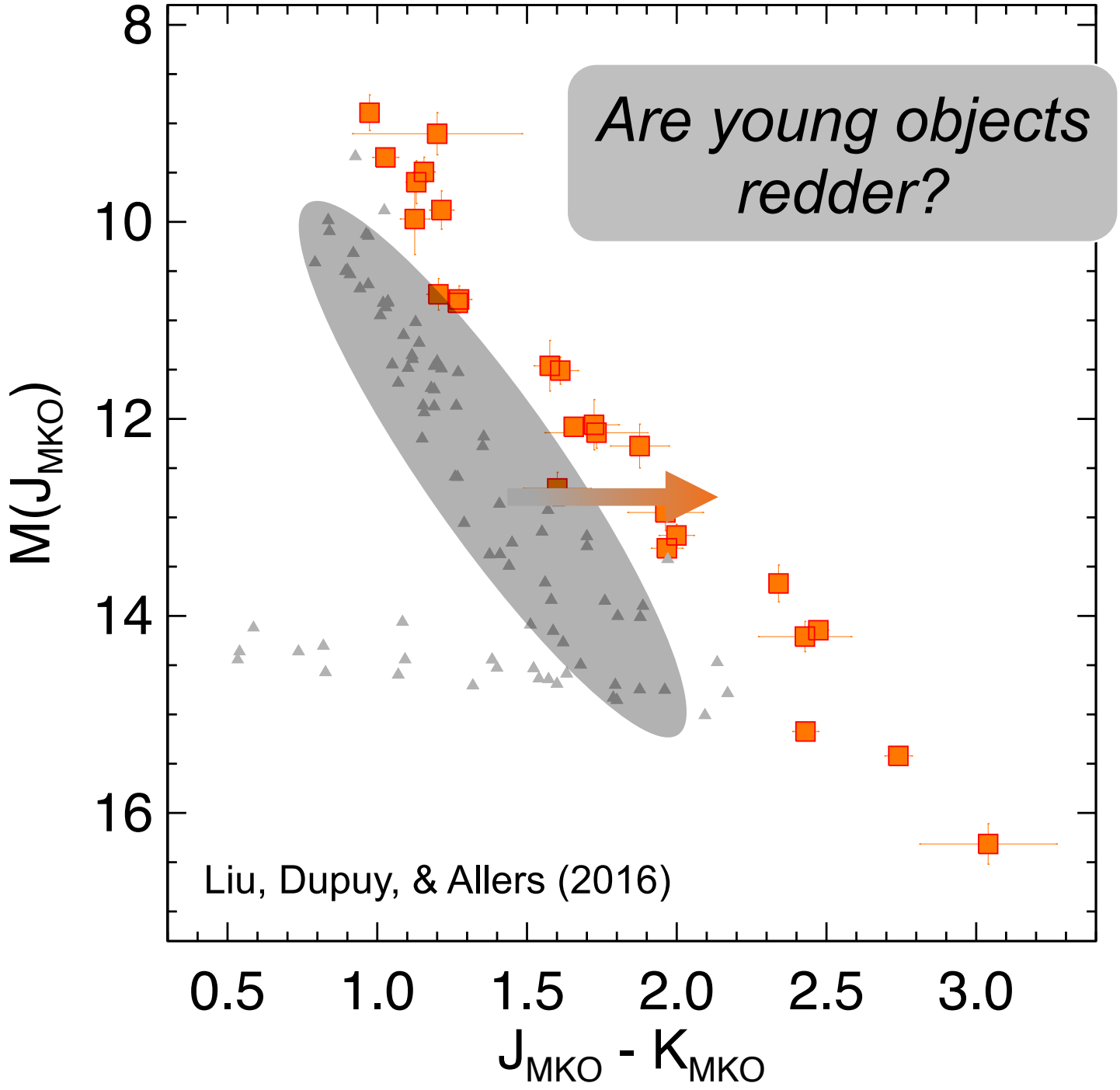


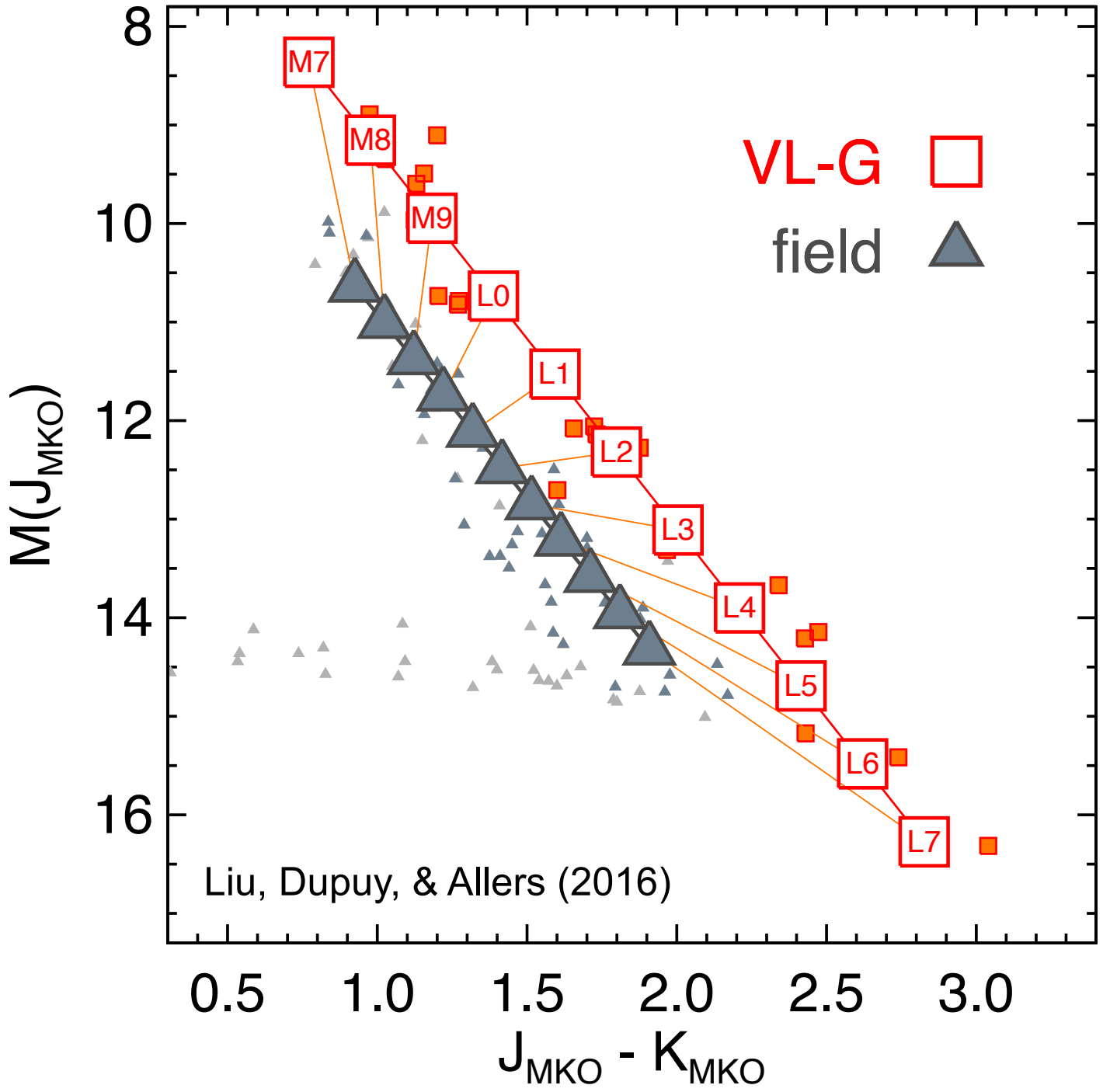

8
10
12
14
16
M(J_MKO)
0.5
1.0
1.5
2.0
2.5
3.0
J_MKO - K_MKO
normal field
ultracool dwarfs
(FLD-G)

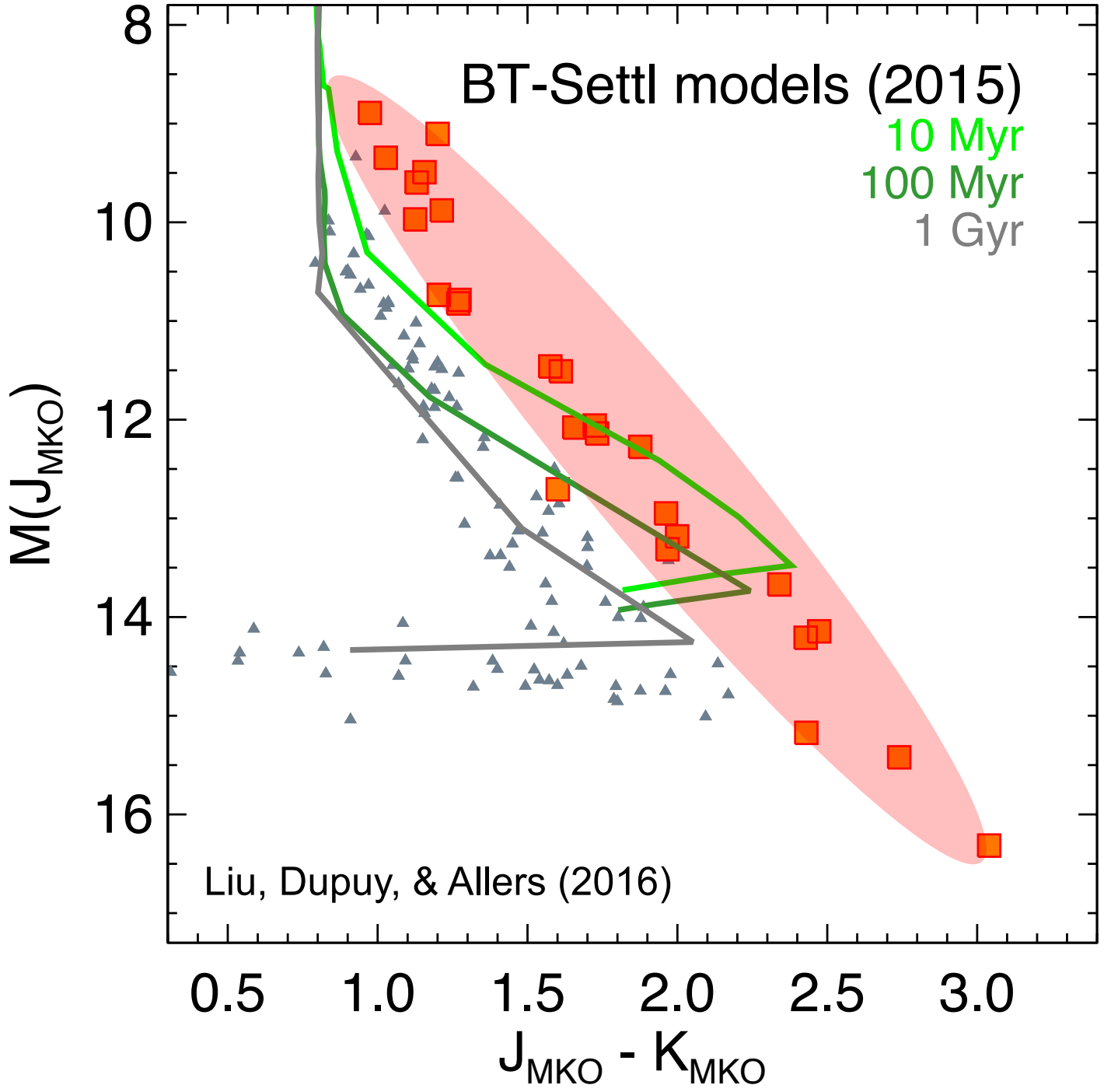

INT-G
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0

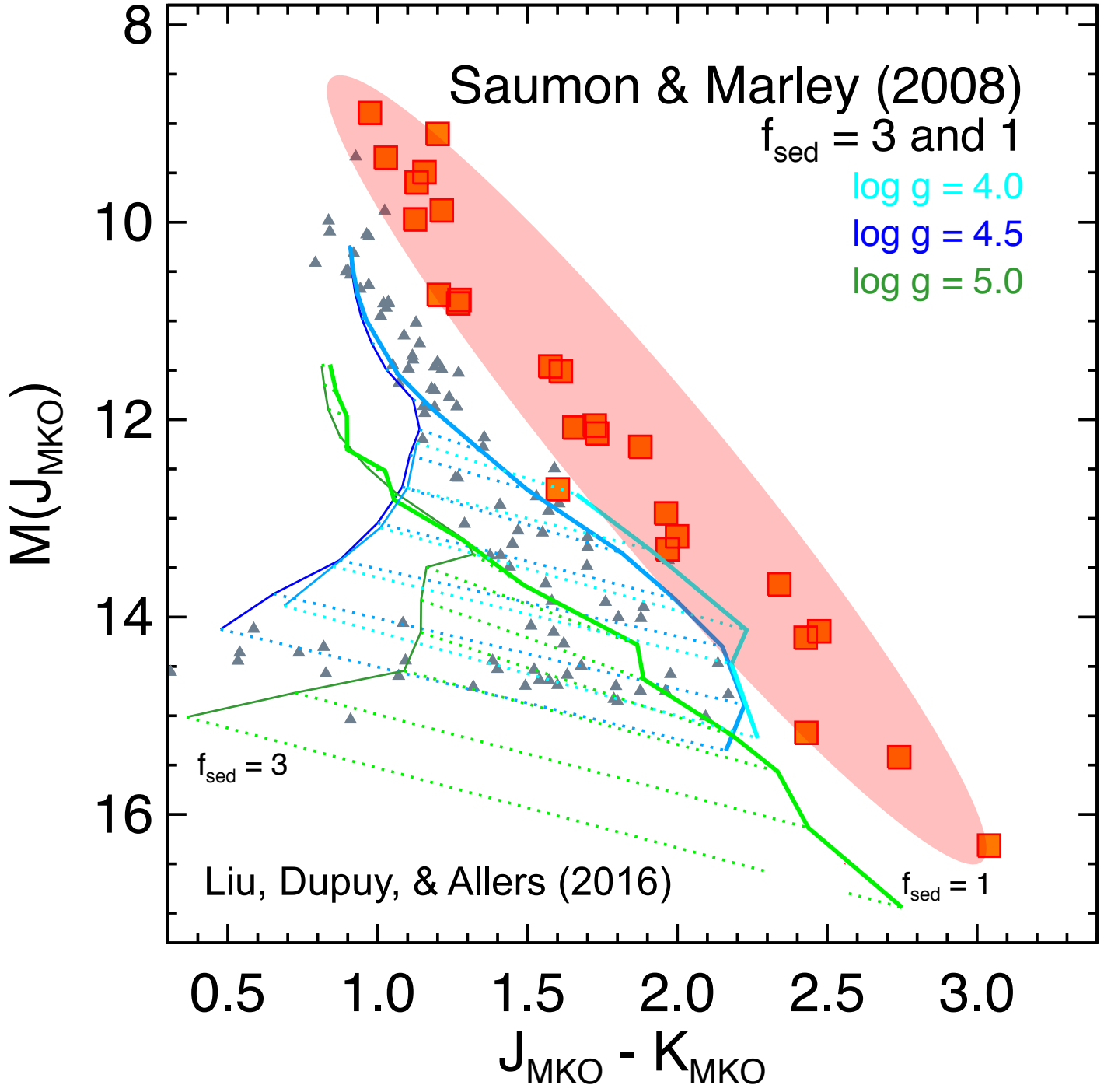

Low gravity (VL-G) objects form a distinct sequence from field objects.
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0

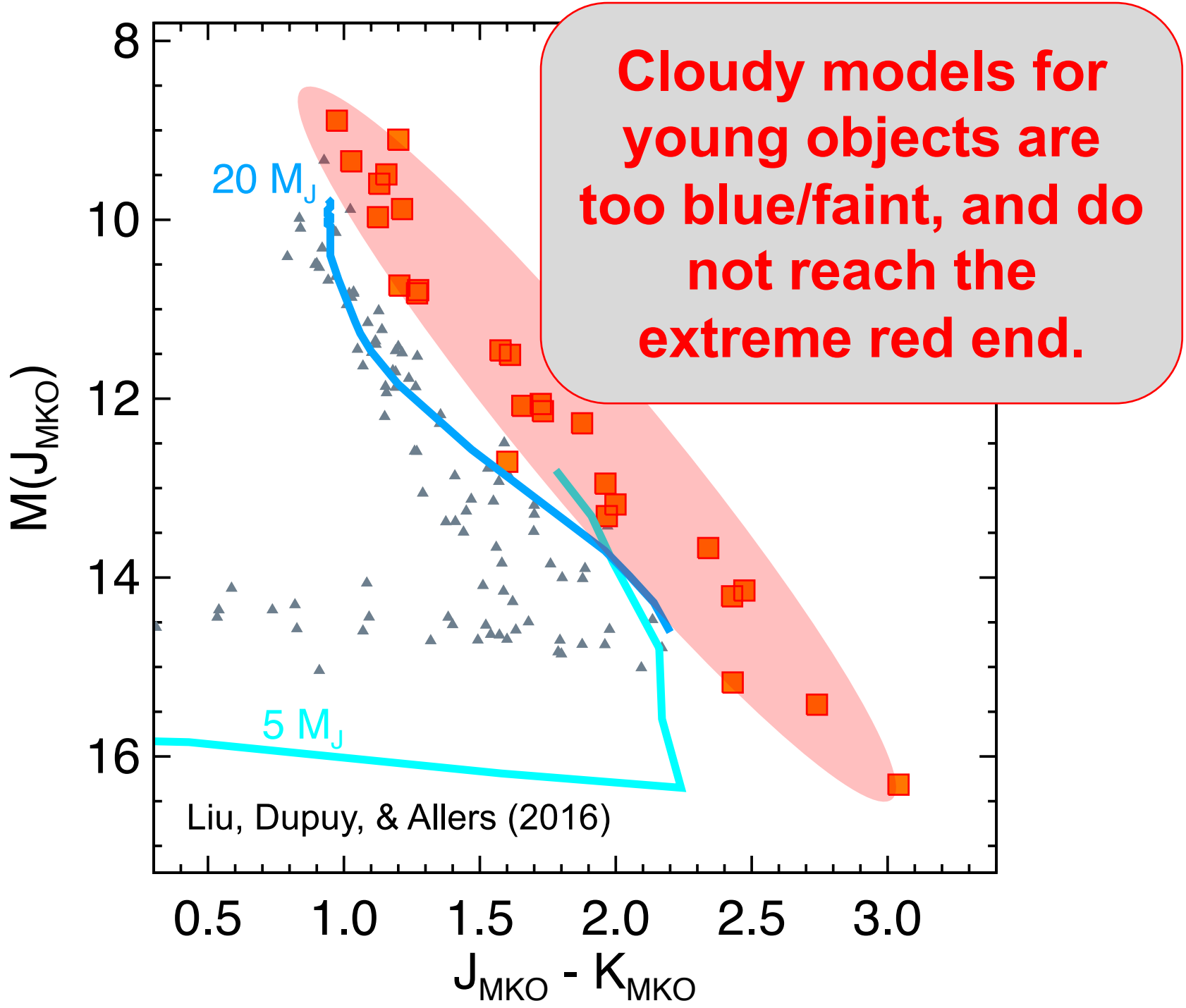

Are young objects brighter?
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0

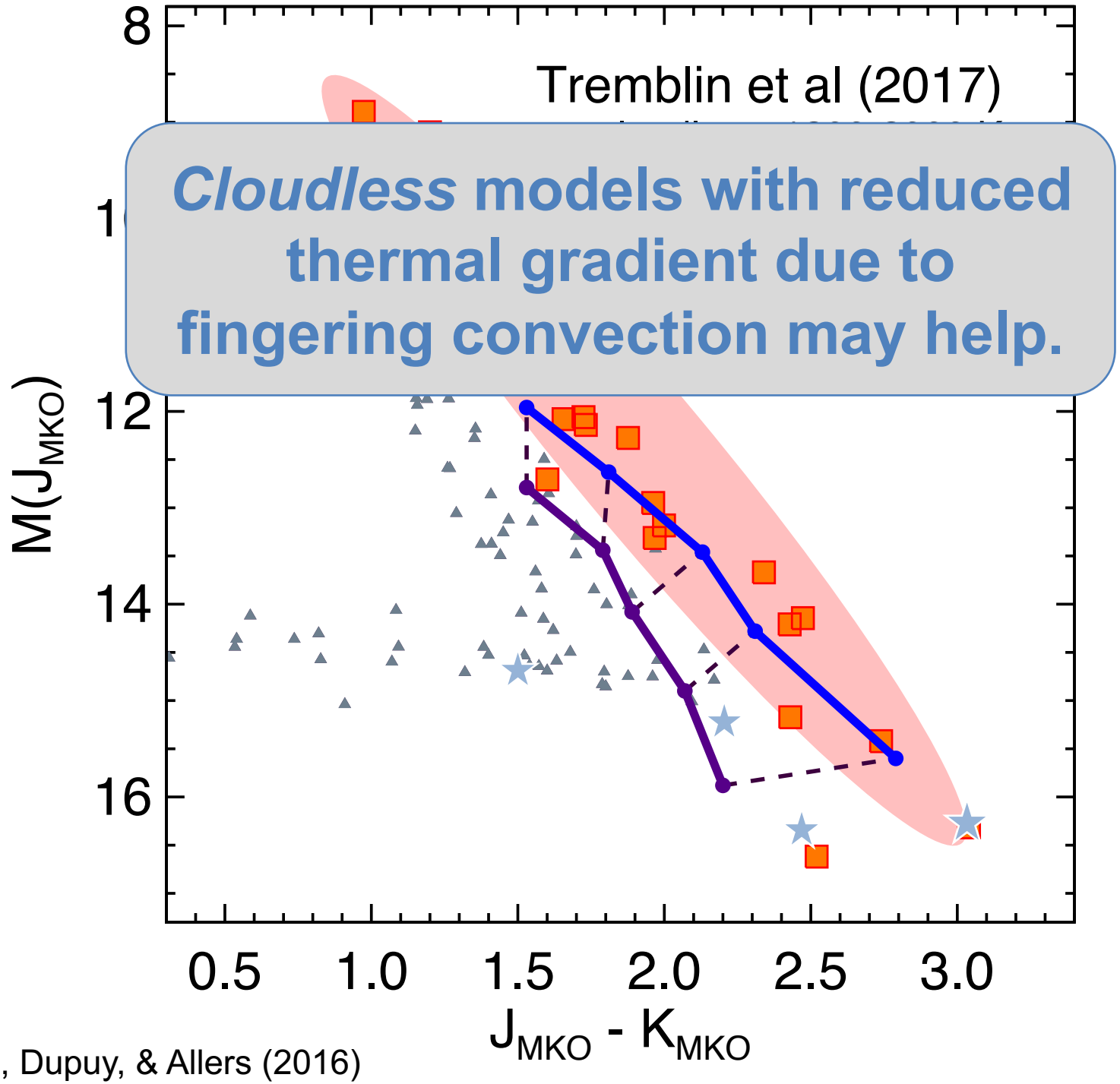

Are young objects redder?
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0


VL-G
field
M7
M8
M9
L0
L1
L2
L3
L4
L5
L6
L7
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0


BT-Settl models (2015)
10 Myr
100 Myr
1 Gyr
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0

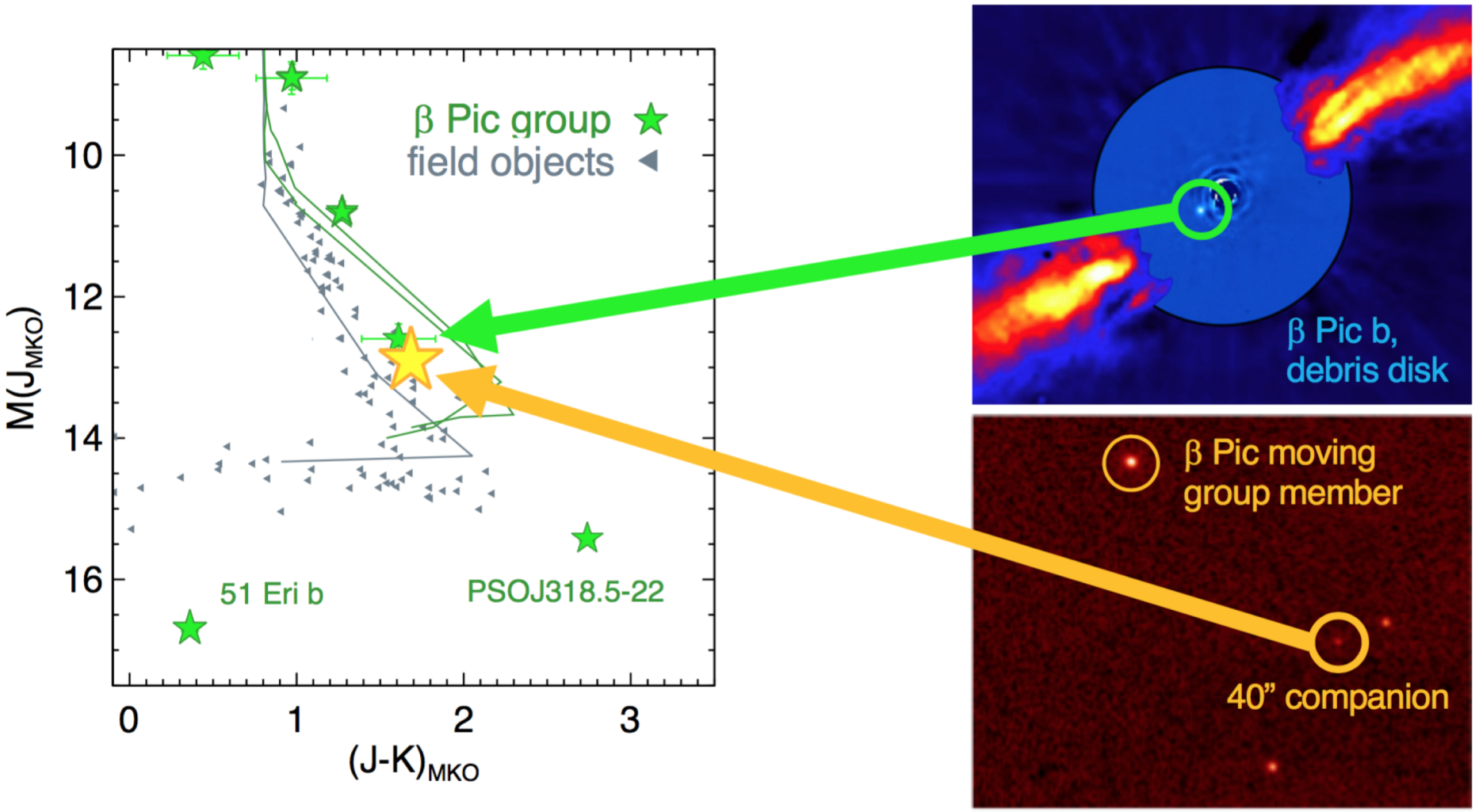

Saumon & Marley (2008)
f_sed = 3 and 1
log g = 4.0
log g = 4.5
log g = 5.0
f_sed = 3
f_sed = 1
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0

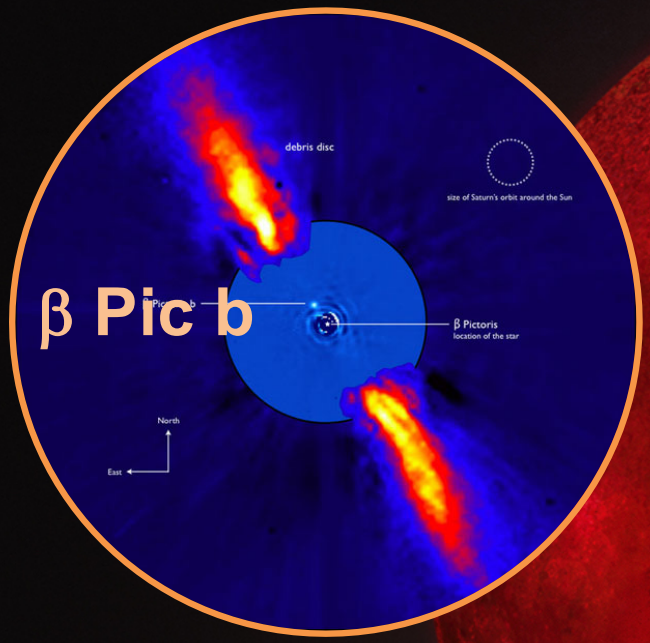

Cloudy models for young objects are too blue/faint, and do not reach the extreme red end.
20 M_J
5 M_J
Liu, Dupuy, & Allers (2016)
M(J_MKO)
J_MKO - K_MKO
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0



Data from Liu, Dupuy, & Allers (2016)

CFHT/WIRCam discovery of a wide “planet”





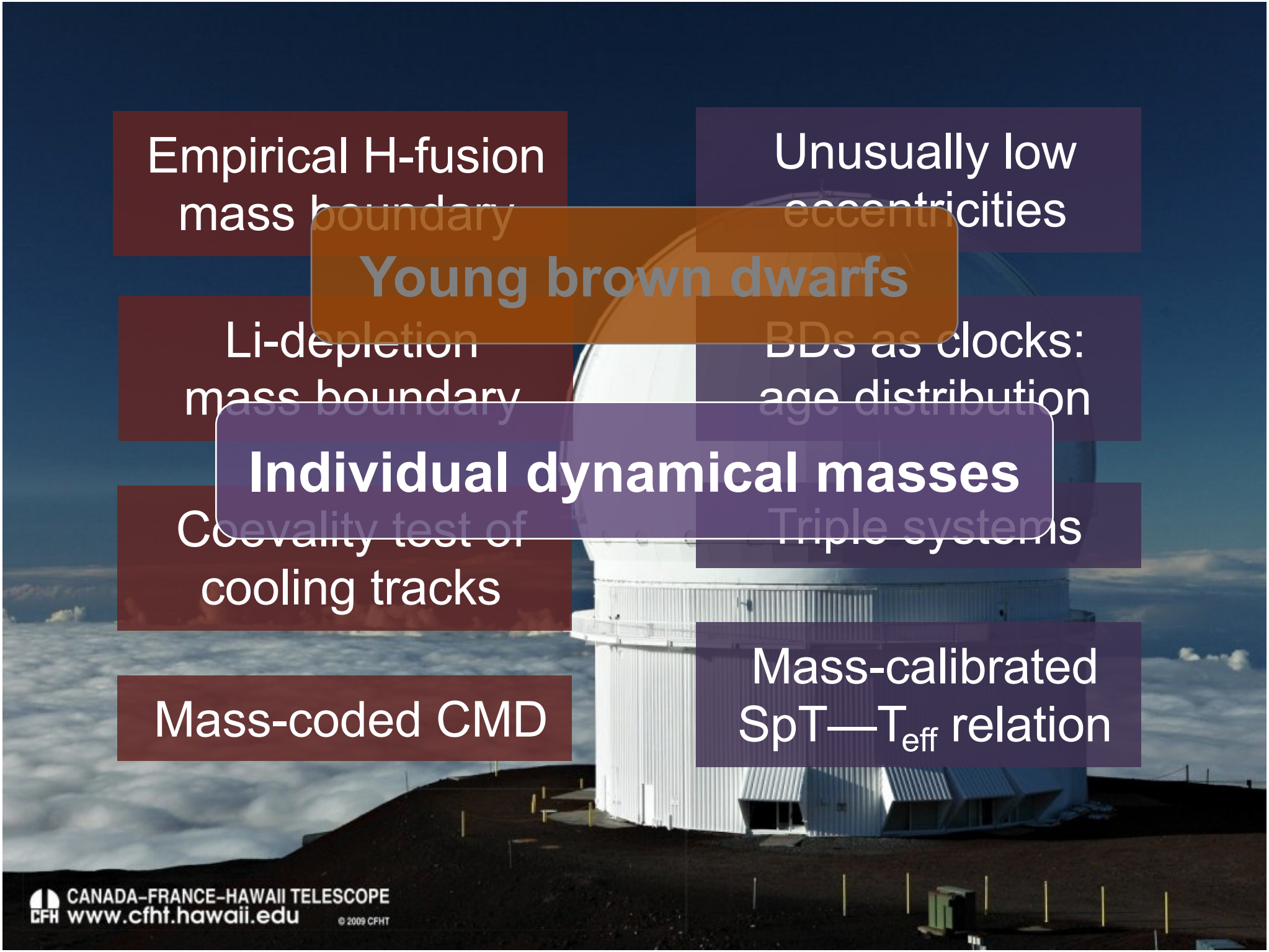
β Pic b

2MASS J0249 c
(Dupuy, Liu et al. 2018)

2MASS J0249AB
BD binary in β Pic

Credit: Keck Imaginarium

https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/


Empirical H-fusion mass boundary
Unusually low eccentricities
Young brown dwarfs
Li-depletion mass boundary
BDs as clocks: age distribution
Individual dynamical masses
Coevality test of cooling tracks
Triple systems
Mass-coded CMD
Mass-calibrated SpT—T_{eff} relation
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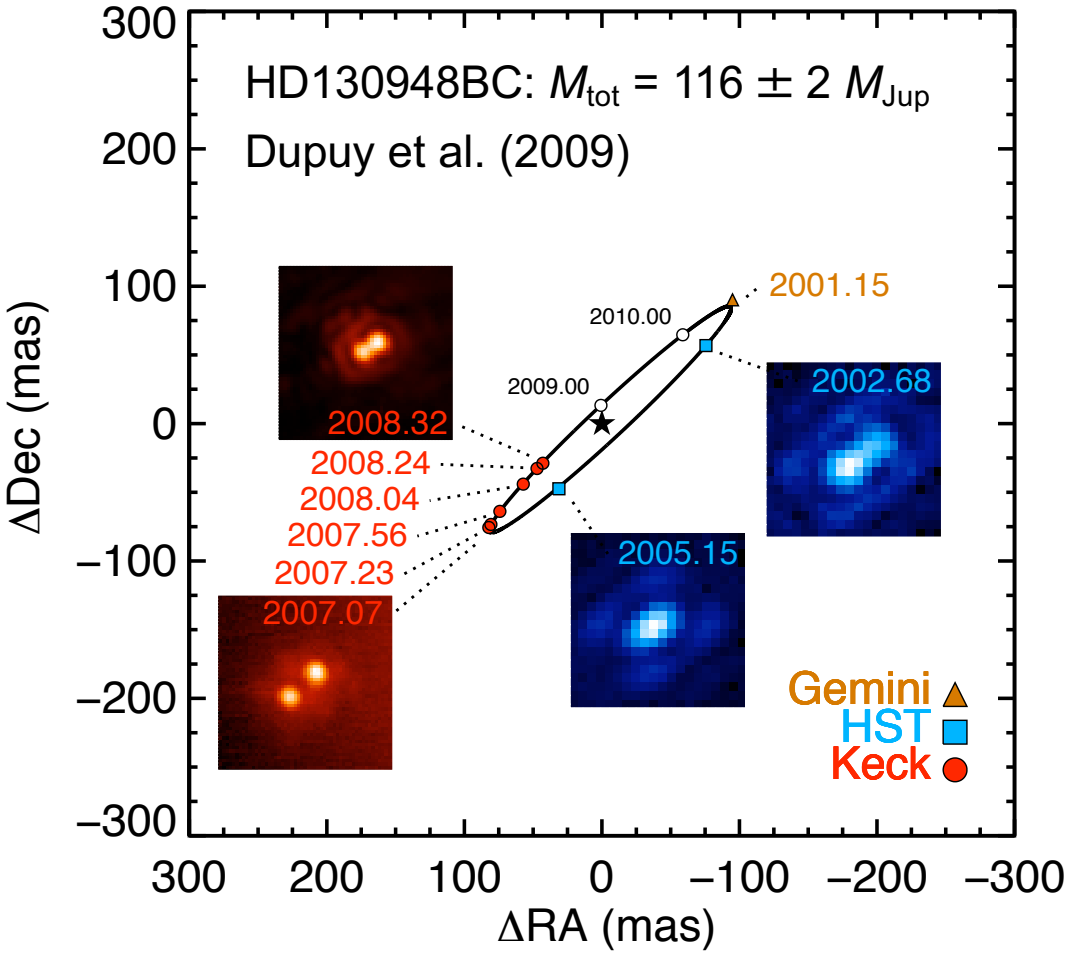
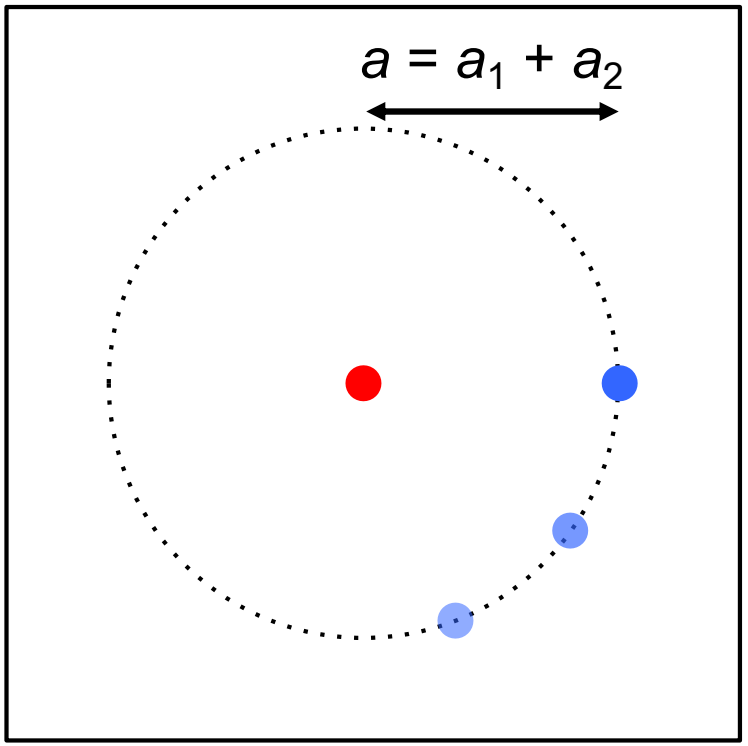
Relative Astrometry Gives Total Mass



$$M_{tot} = \frac{(a / \mathrm{AU})^3}{(P / \mathrm{yr})^2}$$

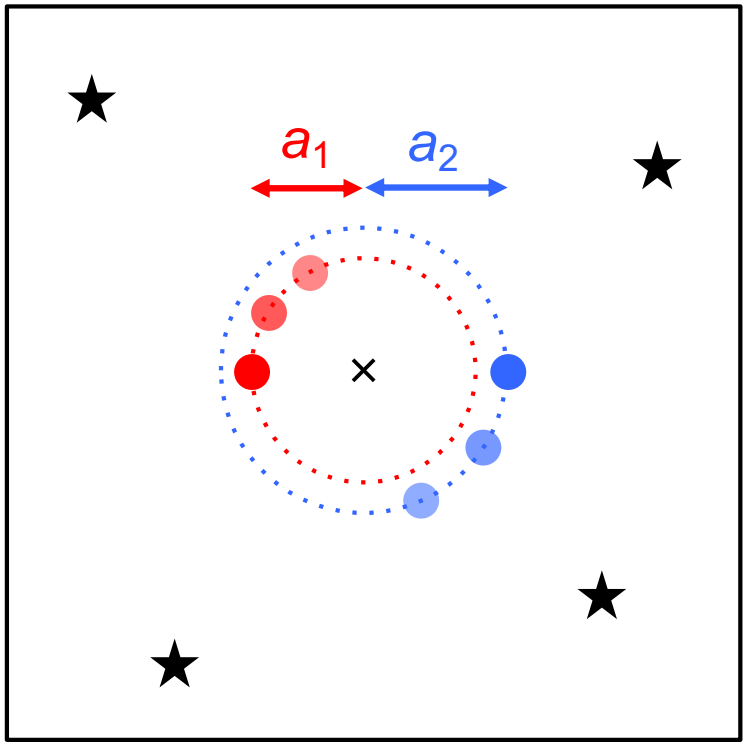
Kepler

relative orbit (AO data)



$$M_{tot} = a^3 / P^2$$

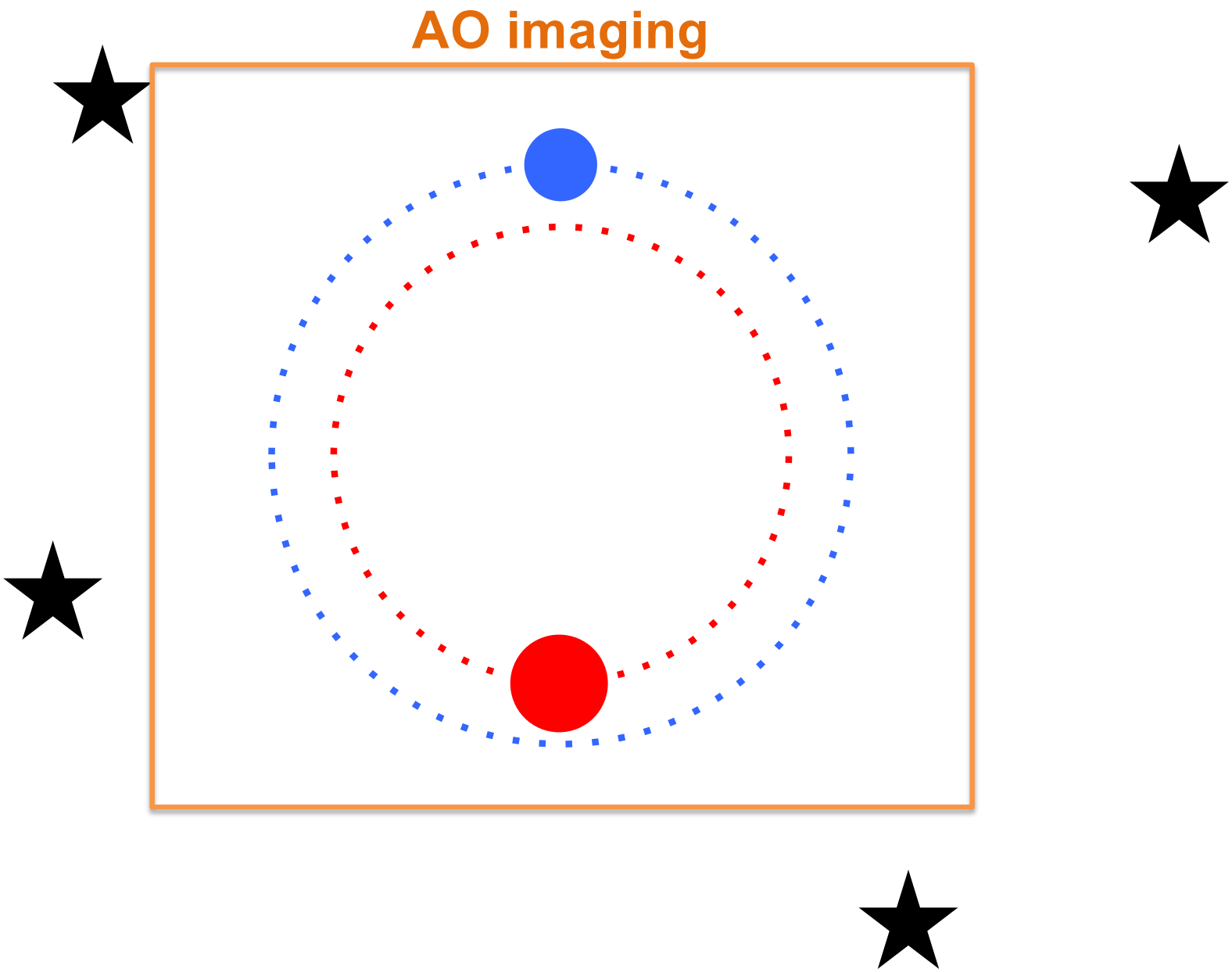
absolute orbit



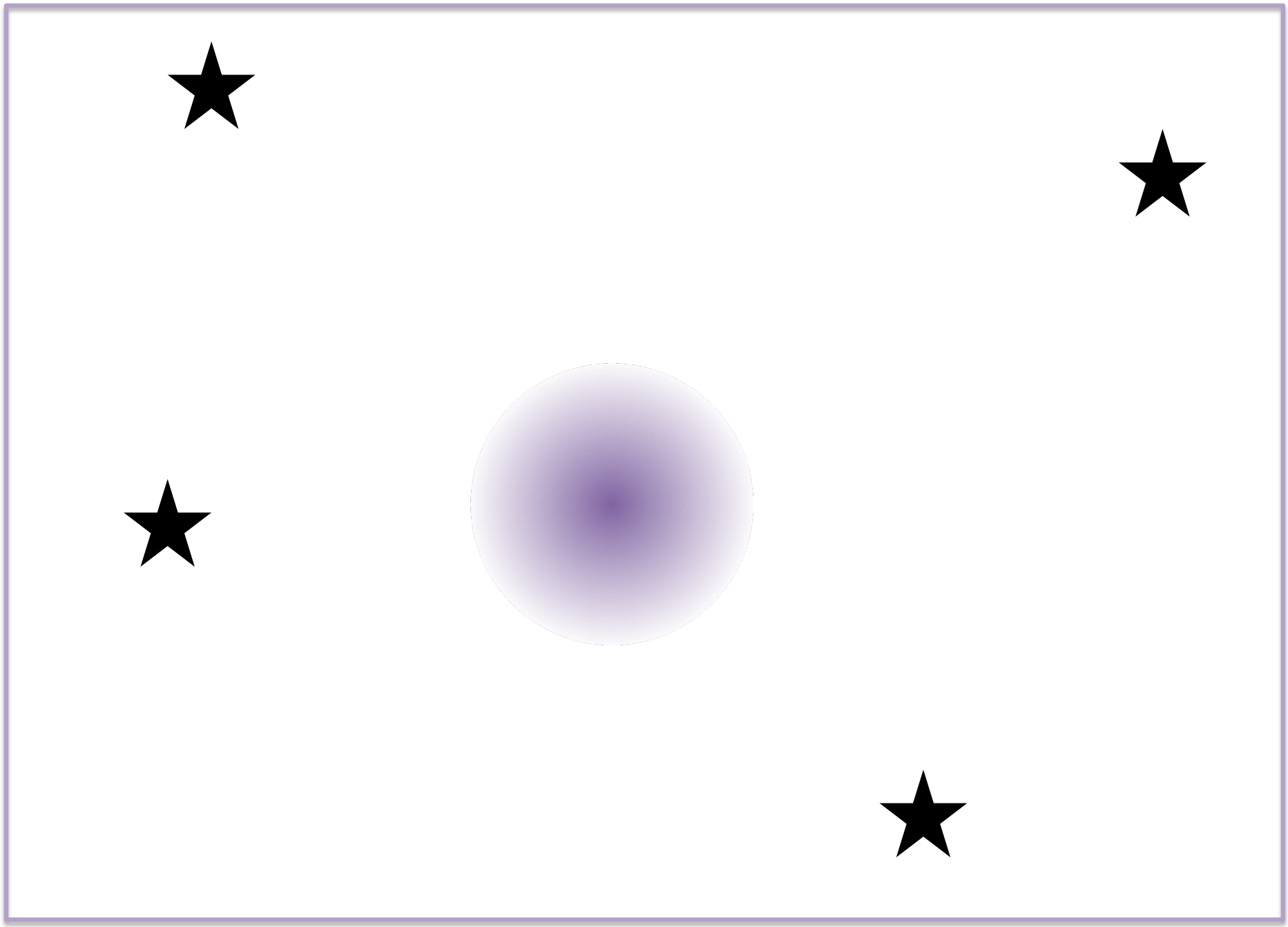
$$M_{tot} = a^3 / P^2$$

$$M_1 = M_{tot} (a_2 / a)$$

$$M_2 = M_{tot} (a_1 / a)$$

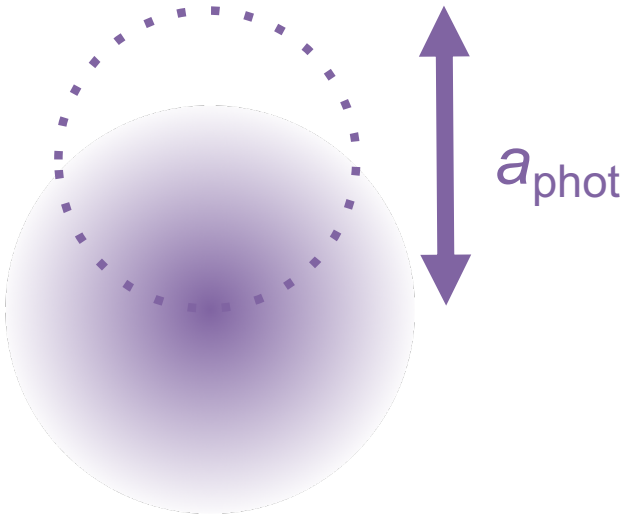

AO imaging

WIRCAM imaging



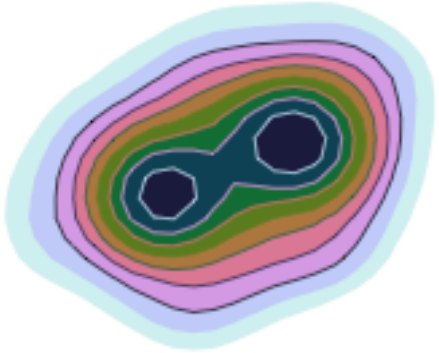
$$\frac{M_2}{M_1+M_2} = \frac{a_{\mathrm{phot}}}{a_1+a_2} + \frac{f_2}{f_1+f_2}$$

from adaptive optics
from seeing-limited



→ First *individual* masses for field L & T dwarfs

SDSS J1052+44AB
(Dupuy et al. 2015)



=

"cloudy"

SpT = L6.5

$log(L_{bol}) = -4.5$

51 +/- 3 M_{Jup}

+

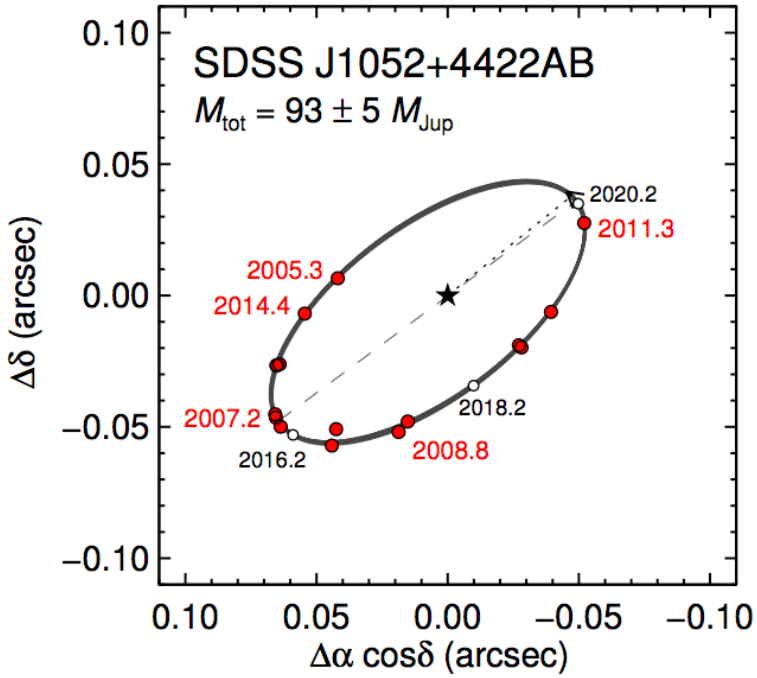
"partly cloudy"

SpT = T1.5

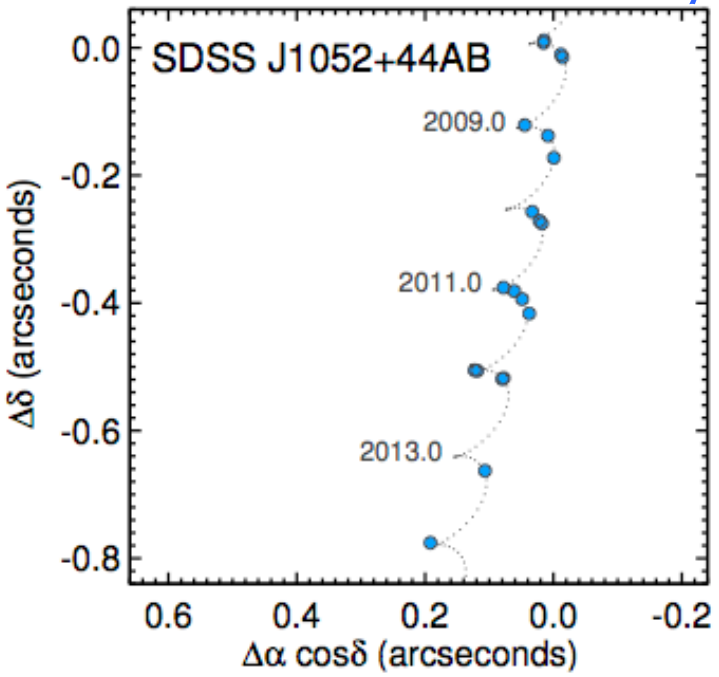
$log(L_{bol}) = -4.6$

42 +/- 3 M_{Jup}

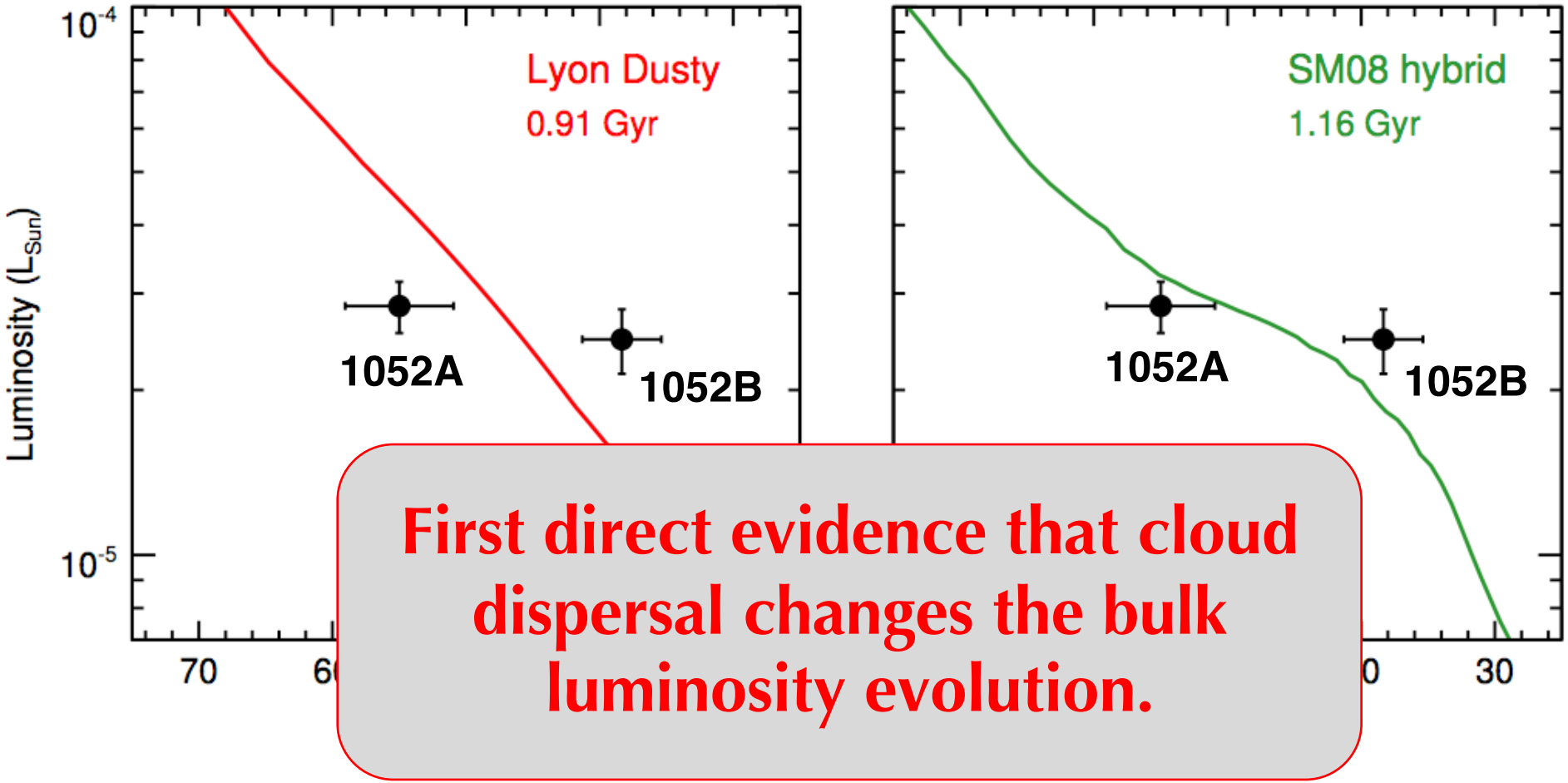
Keck LGS AO



CFHT IR astrometry

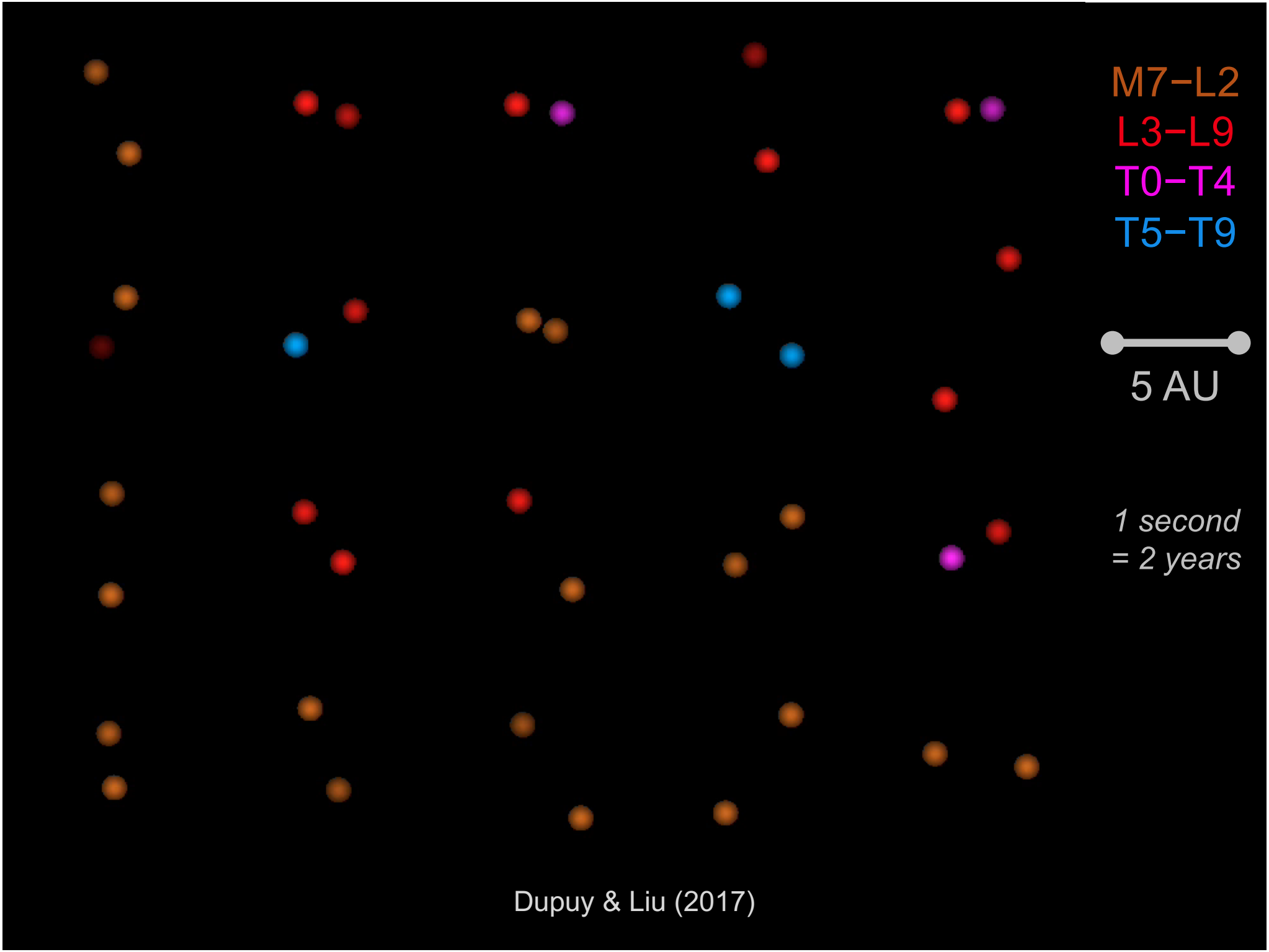


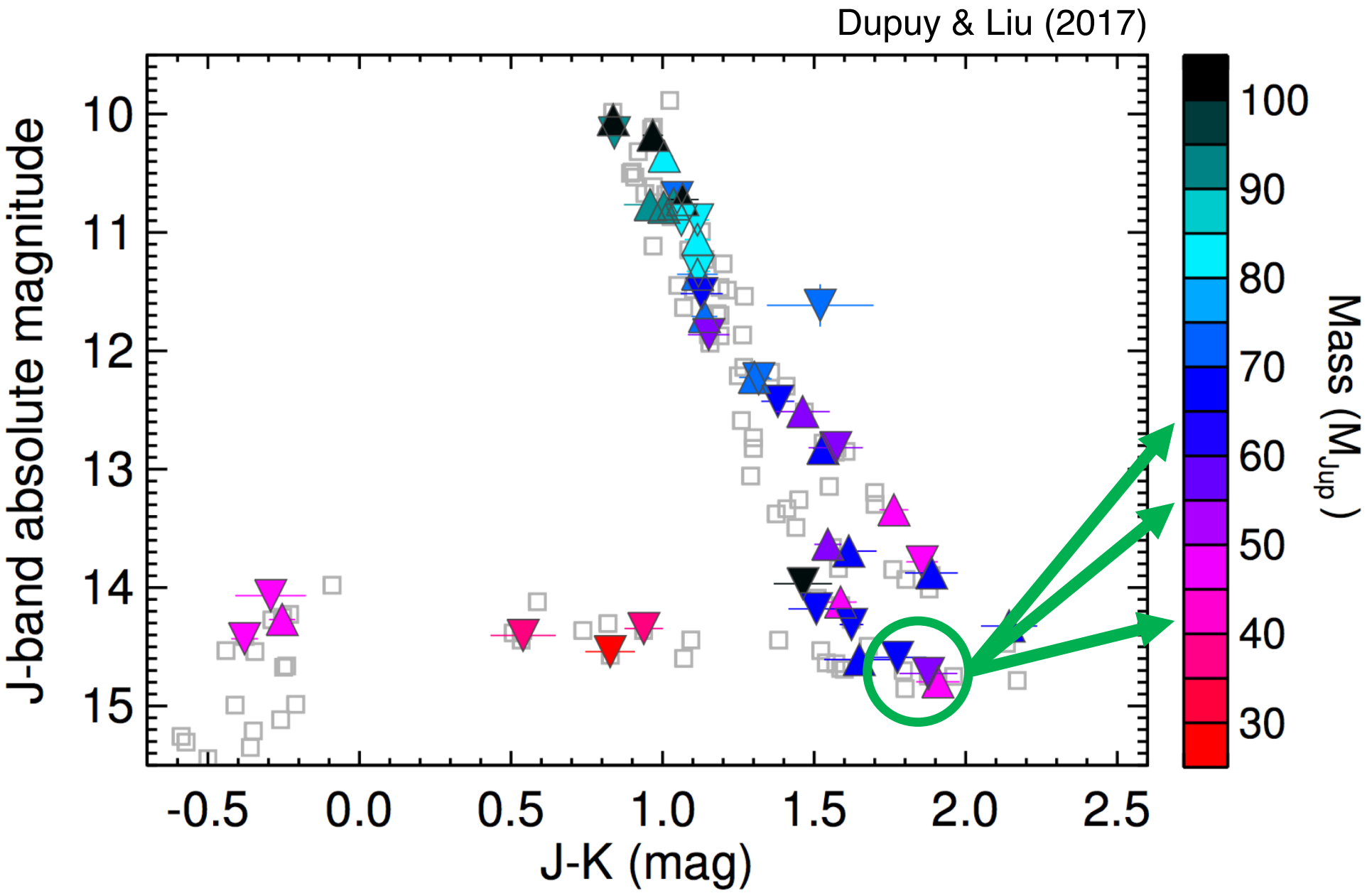
The mass-luminosity relation is shallow at the L/T transition.

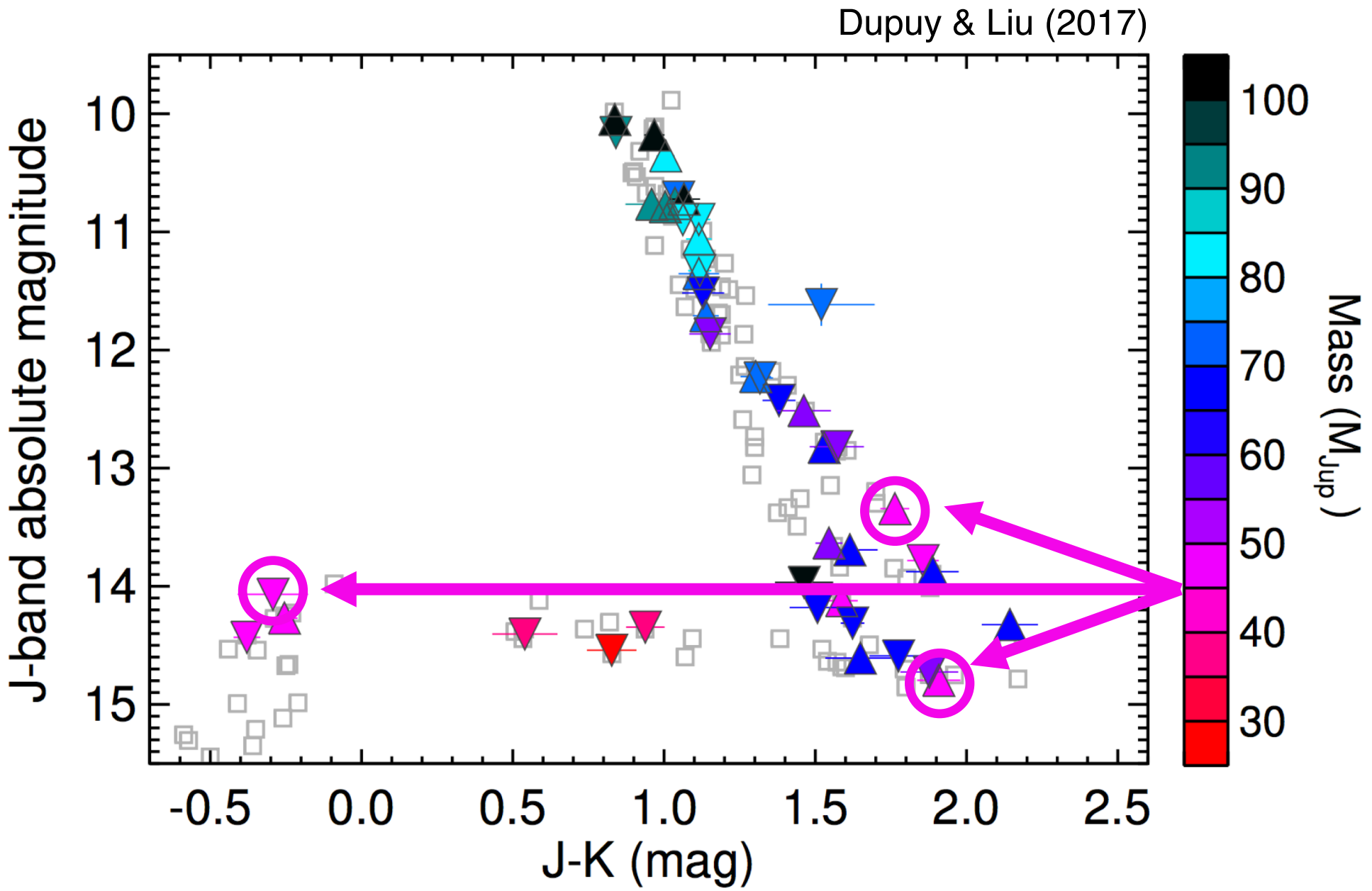


First direct evidence that cloud dispersal changes the bulk luminosity evolution.

Dupuy, Liu & Ireland (2015)
Dupuy & Liu (2017)


M7−L2
L3−L9
T0−T4
T5−T9
5 AU
1 second
= 2 years
Dupuy & Liu (2017)


Dupuy & Liu (2017)
J-band absolute magnitude
10
11
12
13
14
15
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
J-K (mag)
100
90
80
70
60
50
40
30
Mass (M_Jup)


Dupuy & Liu (2017)
J-band absolute magnitude
10
11
12
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14
15
-0.5
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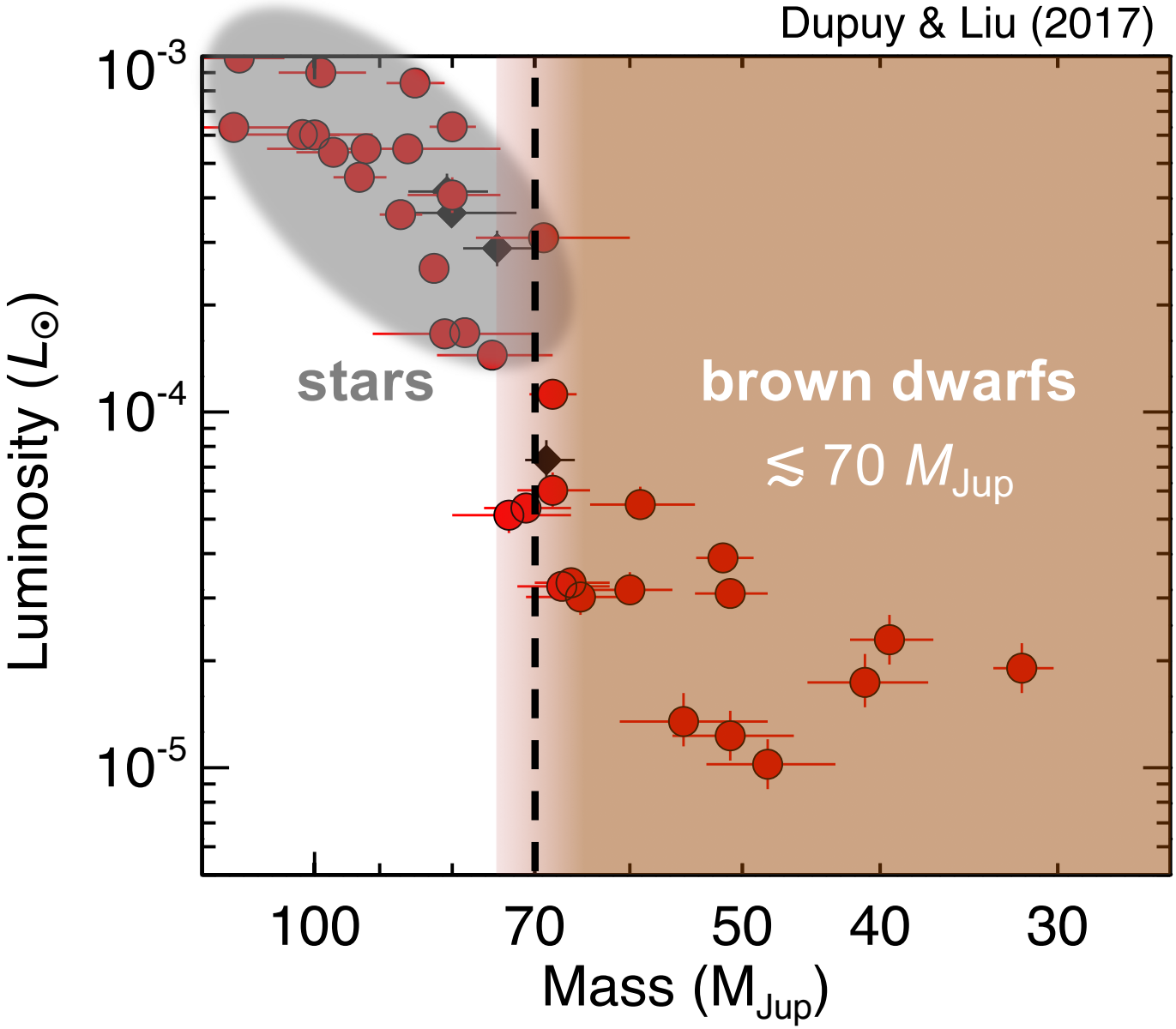
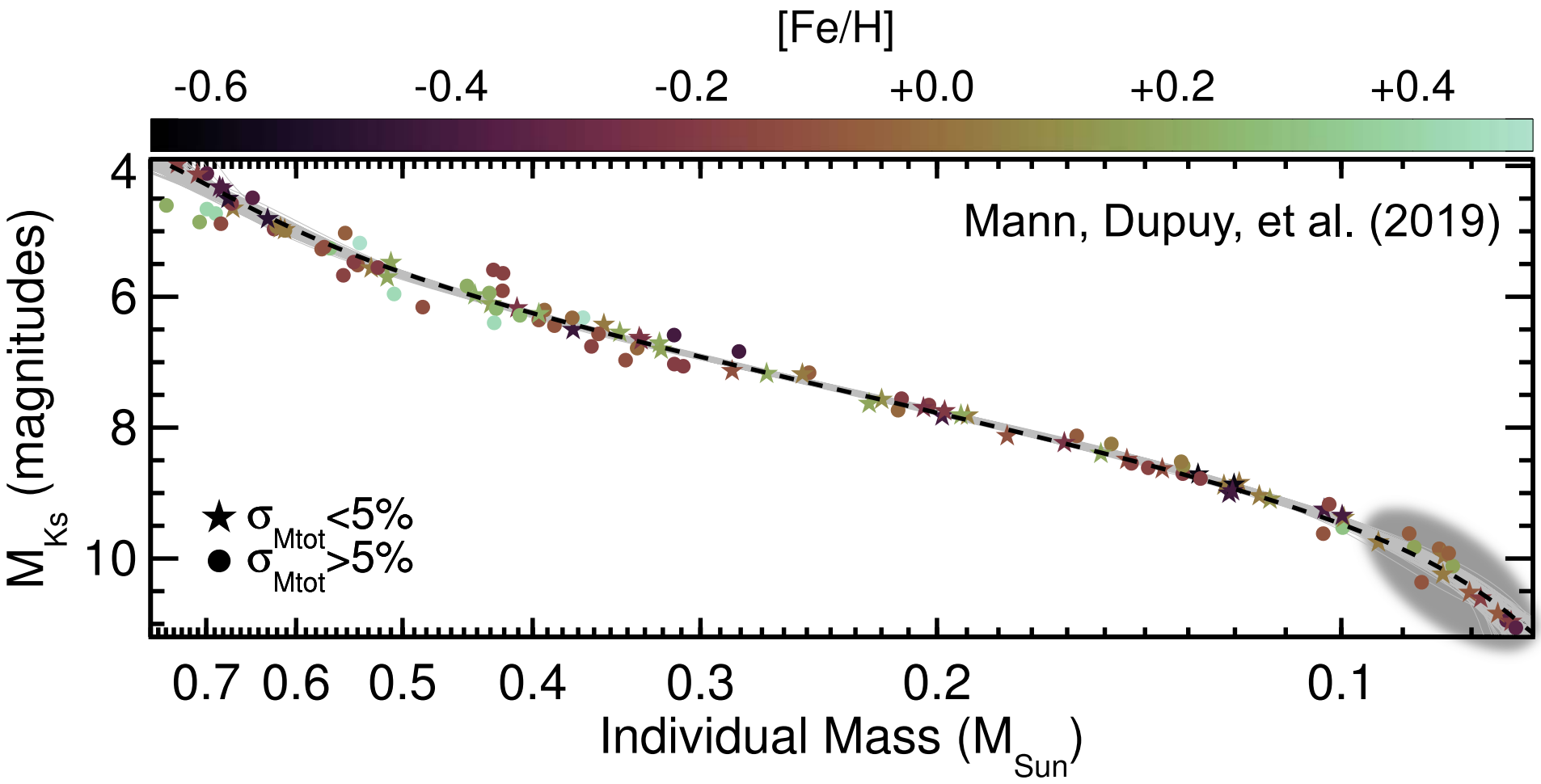
0.5
1.0
1.5
2.0
2.5
J-K (mag)
100
90
80
70
60
50
40
30
Mass (M_Jup)

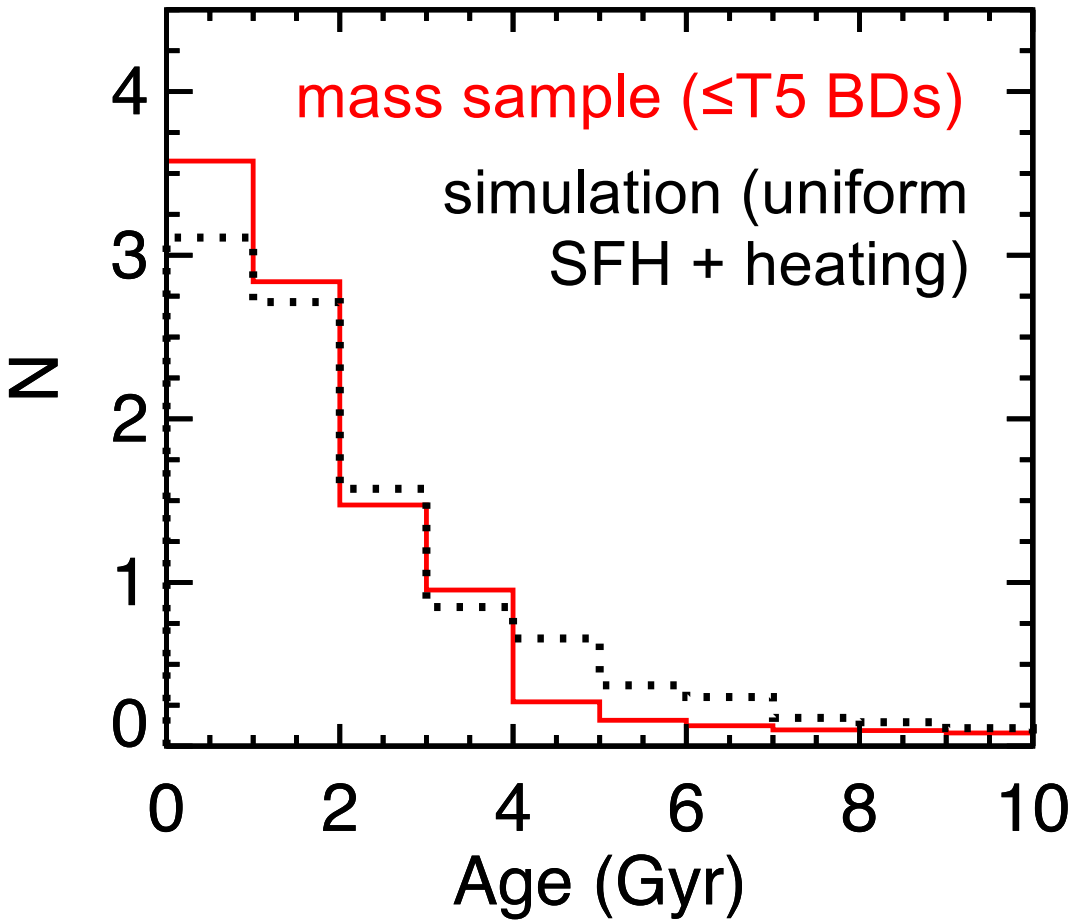
First Empirical Substellar Boundary



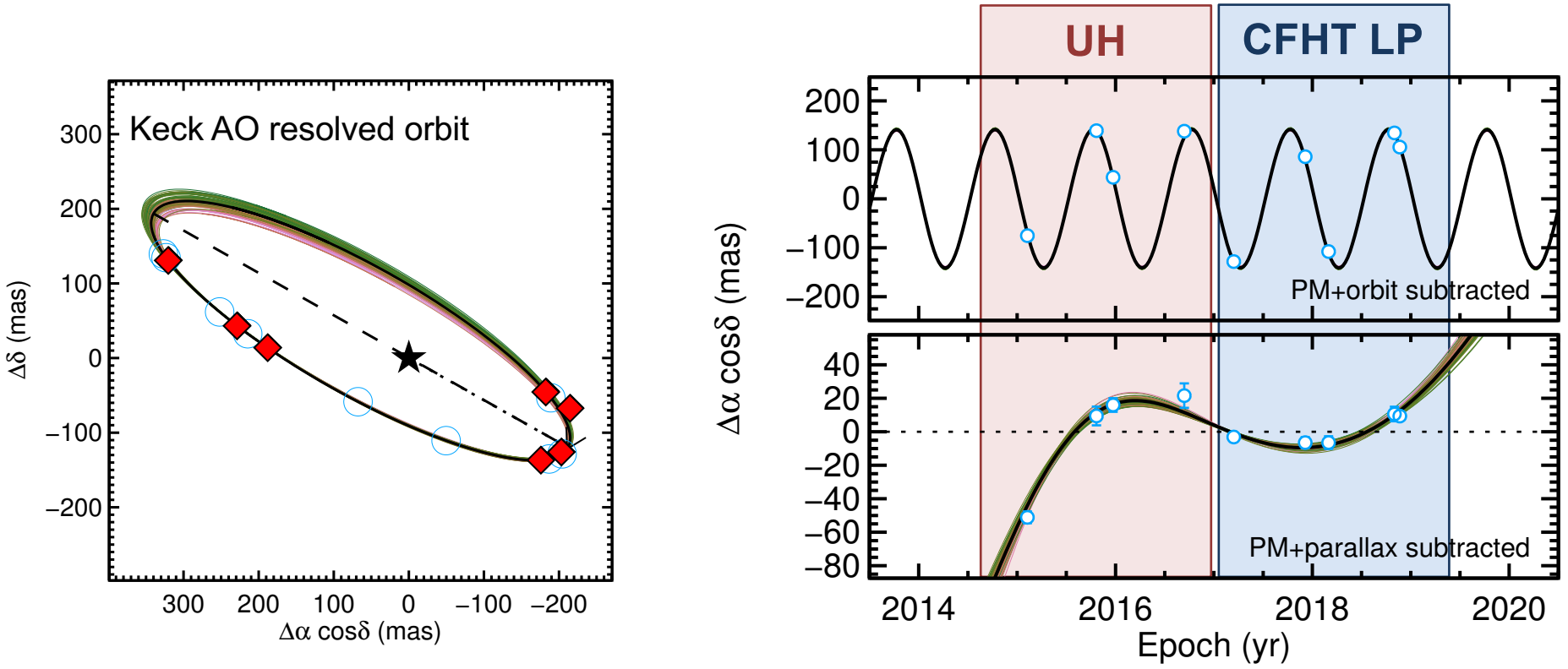
Mass−Magnitude−Metallicity Relation



Brown Dwarfs as Clocks



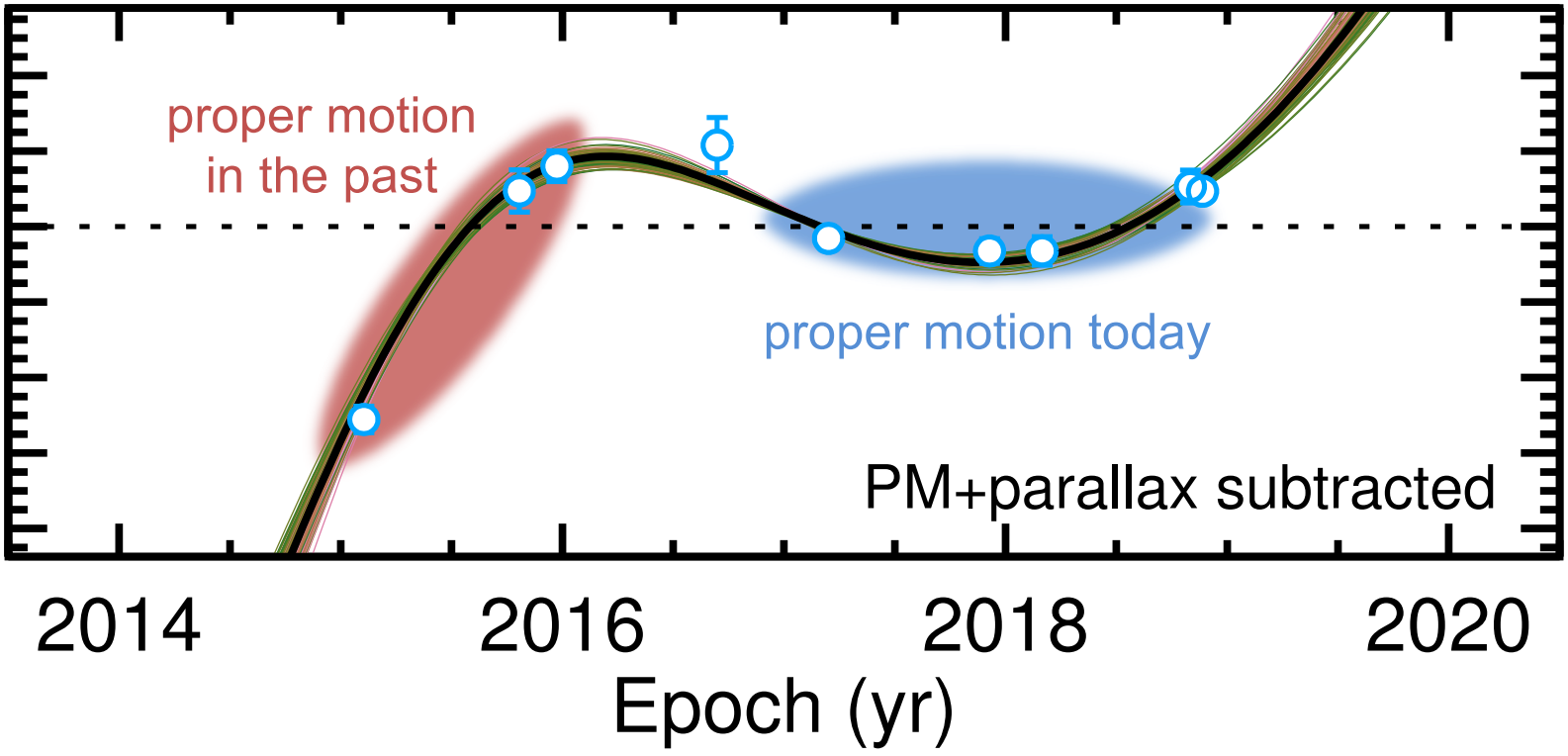
New Science Enabled with Extended Time Baseline



large CFHT/WIRCam wobble relative to Keck AO orbit

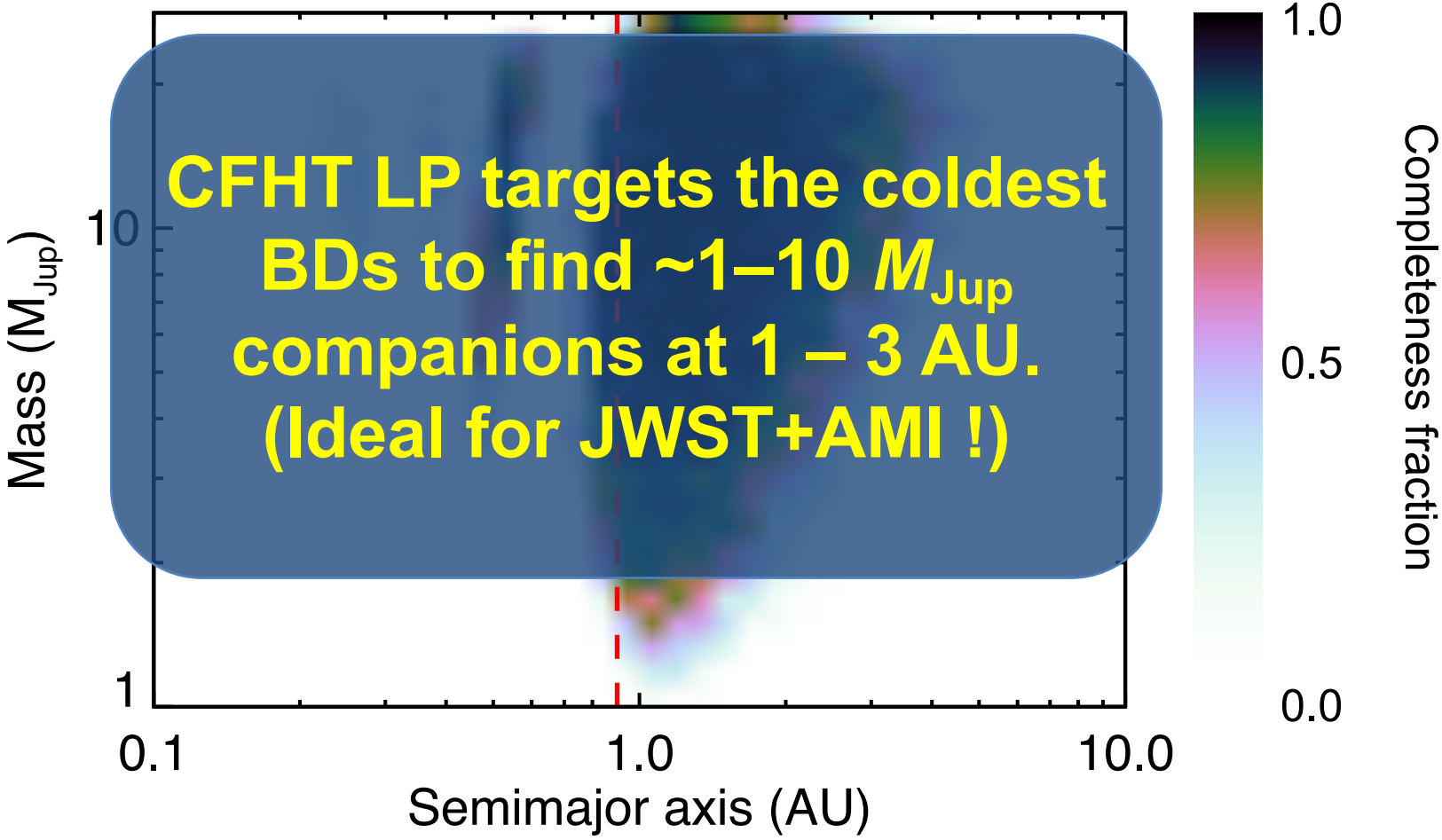
→ *T dwarf companion is massive*

New Science Enabled with Extended Time Baseline



→ **find companions via WIRCam astrometric wobble**

Large Program: New Science with Extended Time Baseline



→ **find companions via WIRCam astrometric wobble**

CFHT Infrared Parallax Program

WIRCam is the leader in IR astrometry thanks to image quality, queue scheduling, stability & baseline.

Continues to play a leading role in the connection between BDs and exoplanets, discovering planetary-mass objects, and measuring dynamical masses.

WIRCam astrometry is a unique resource that offers multiple synergies with *Gaia* and *JWST* science.