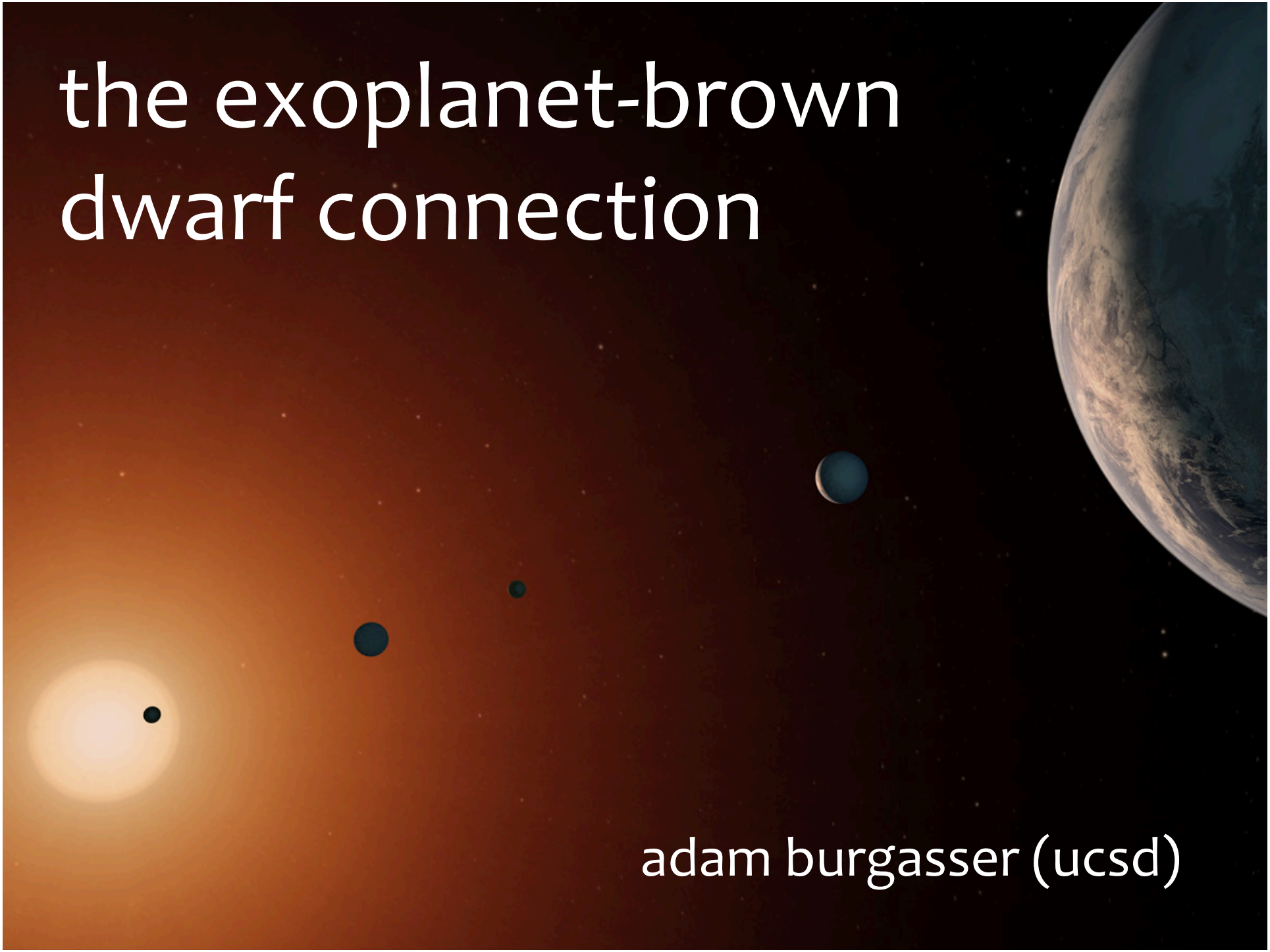
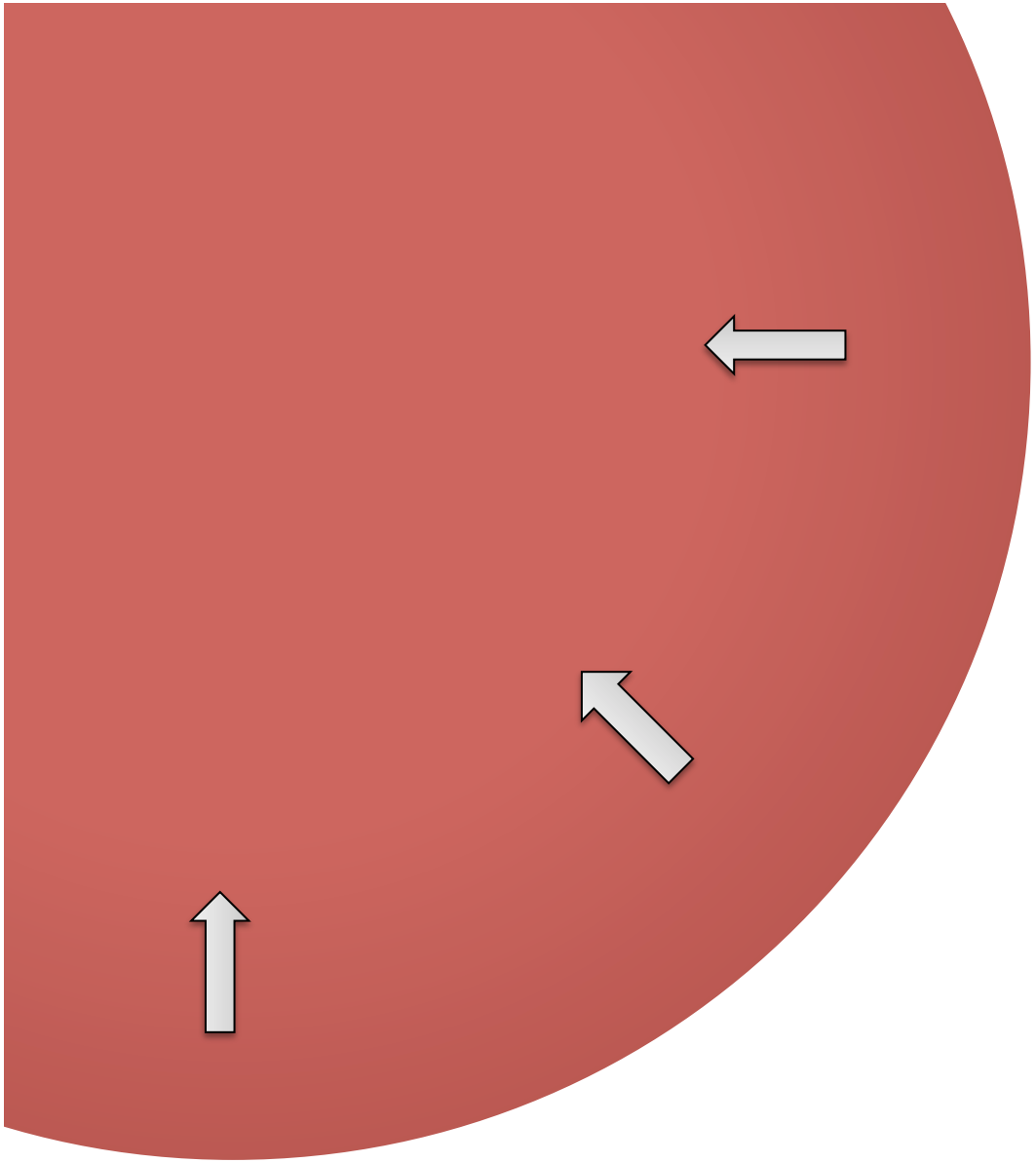
the exoplanet-brown dwarf connection



adam burgasser (ucsd)

this talk is not about stars (see title)
it's about brown dwarfs and why its worth paying attention them

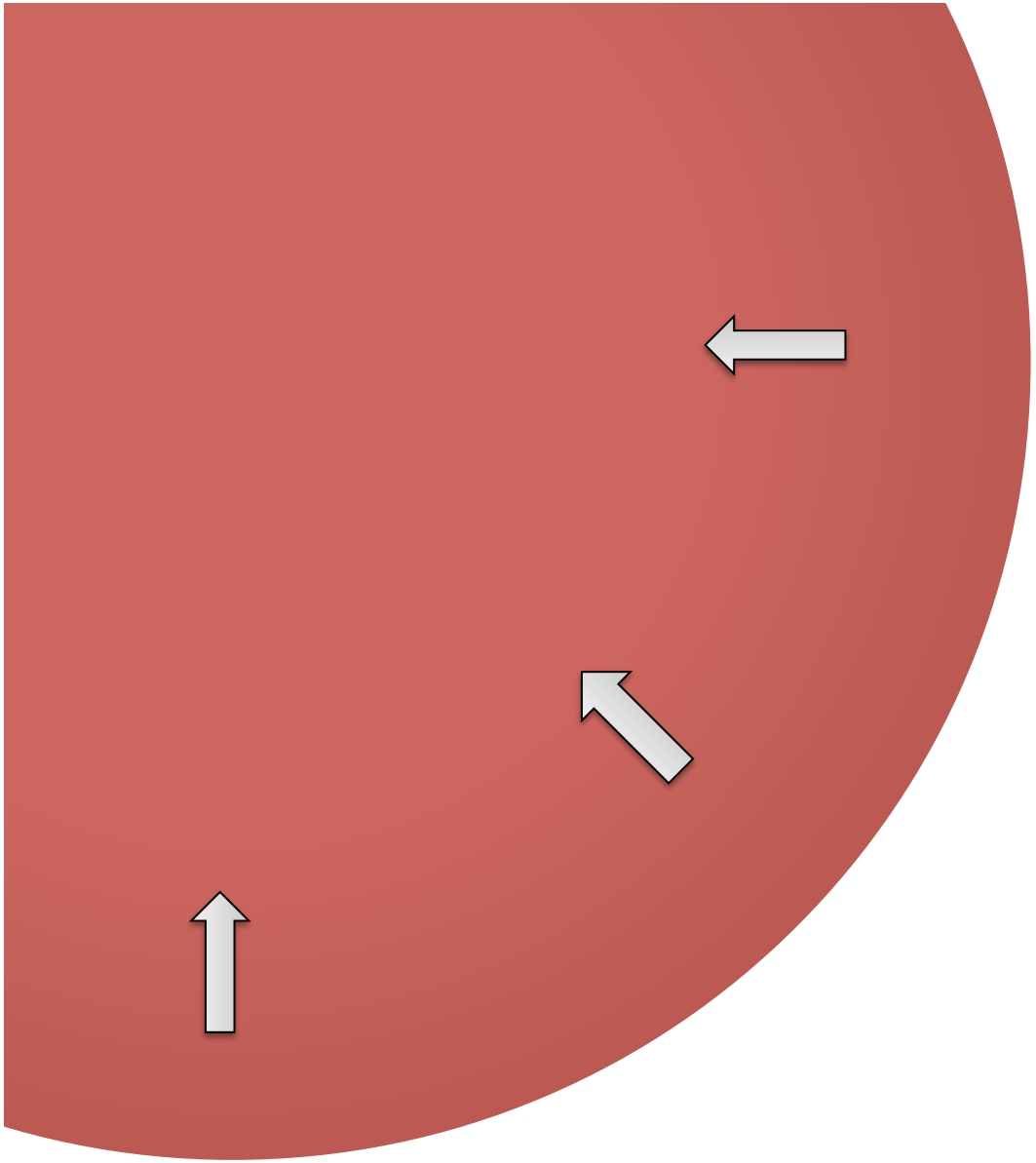

OLD MAN YELLS AT CLOUD



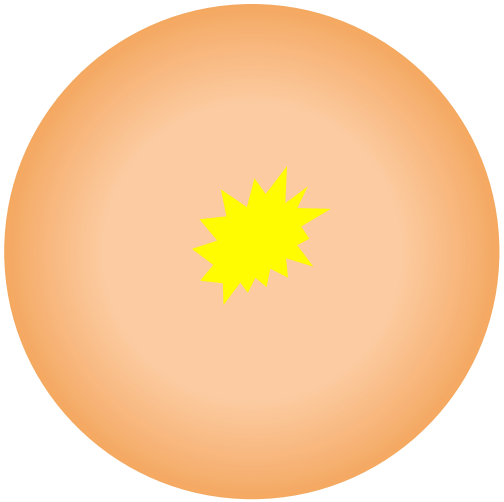
stars = transducers

pre-main-sequence:
gravitational->thermal->radiation

stars = transducers

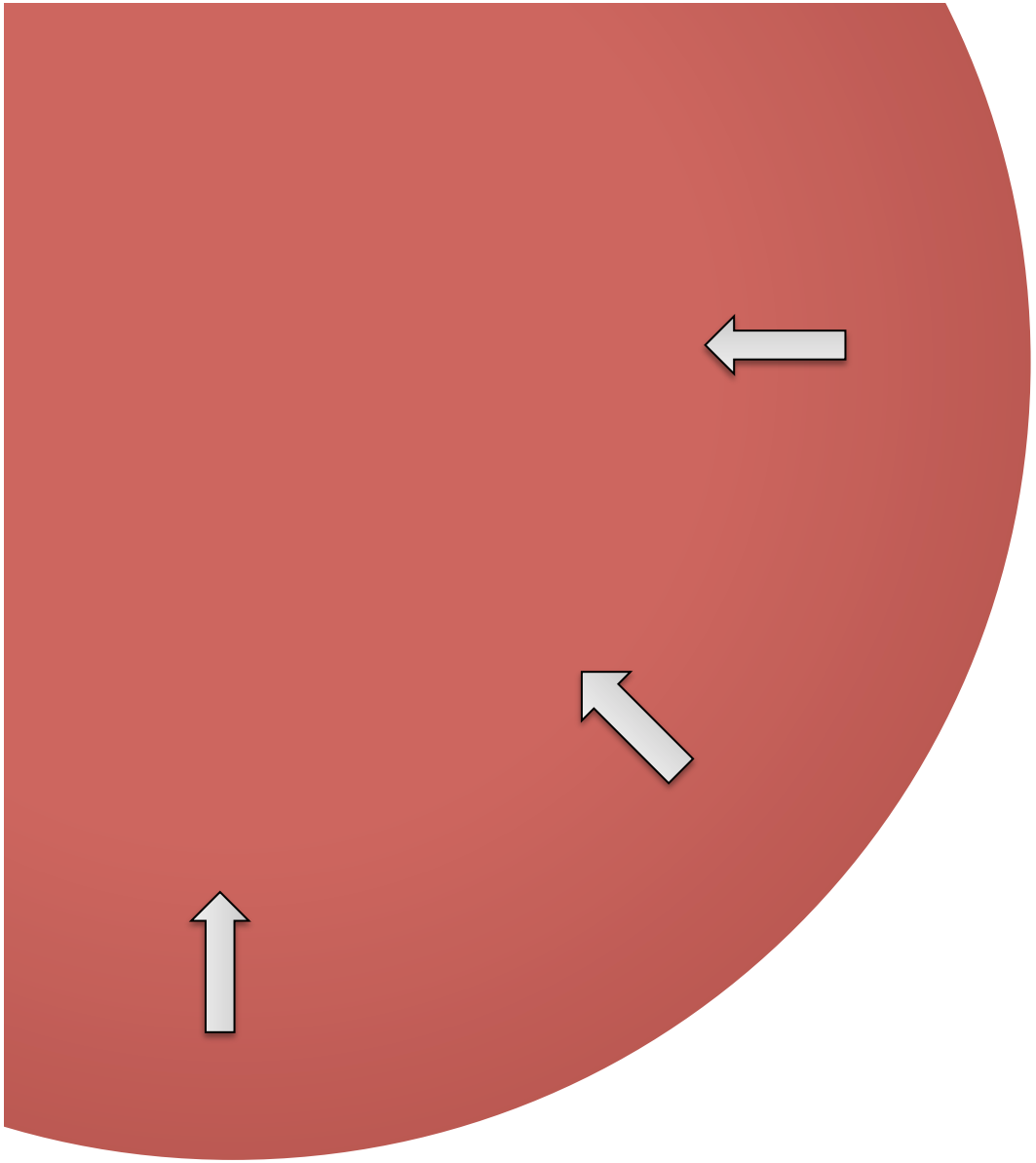


pre-main-sequence:
gravitational->thermal->radiation

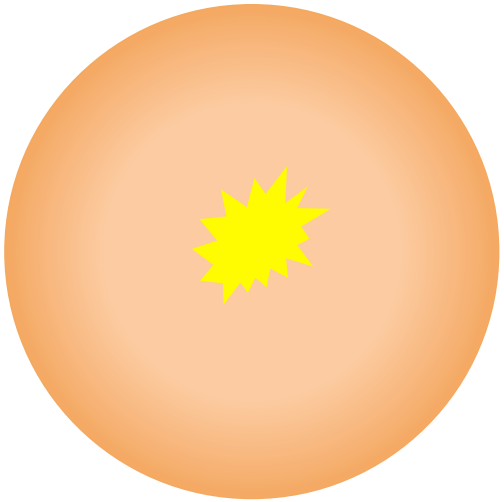


main sequence:
nuclear->thermal->radiation

stars = transducers

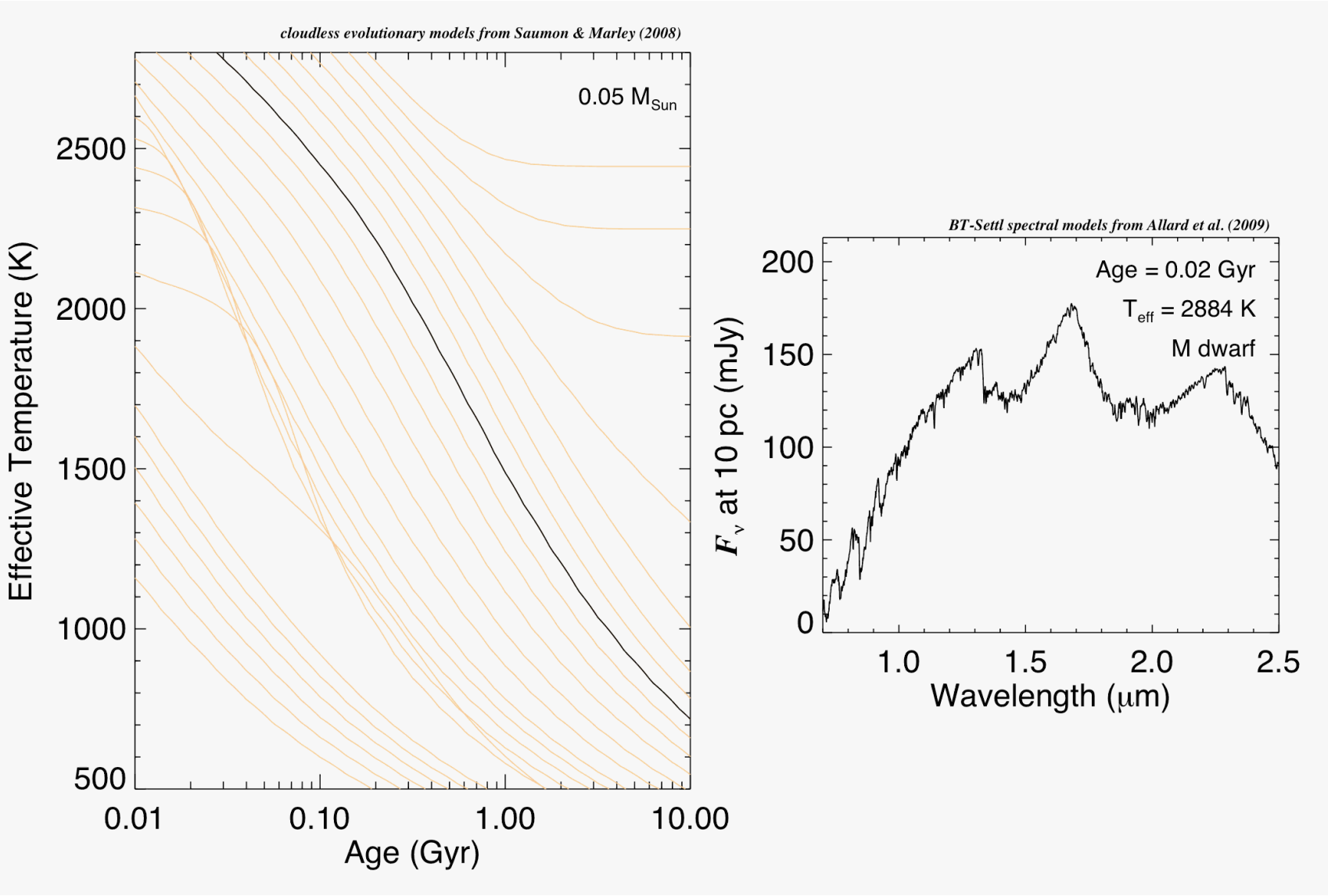


pre-main-sequence:
gravitational->thermal->radiation

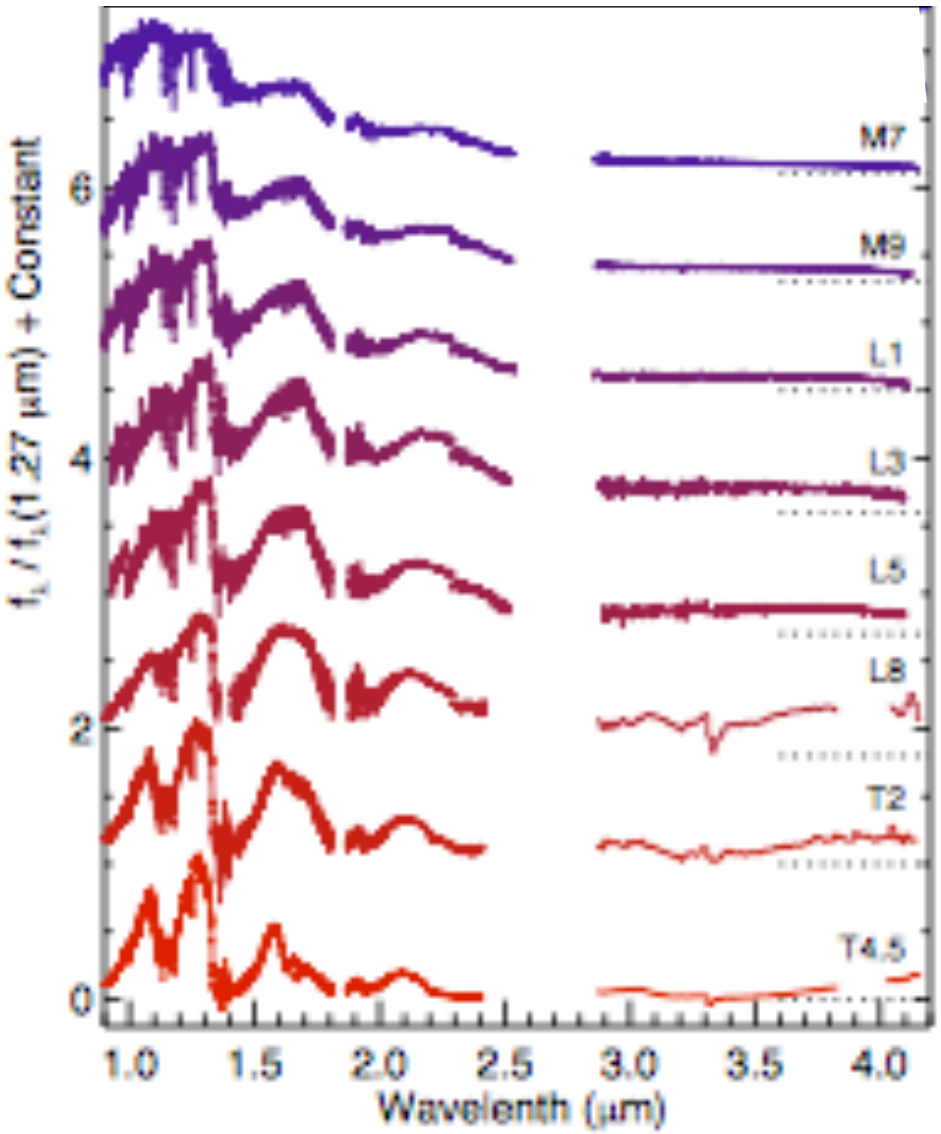


main sequence:
nuclear->thermal->radiation

degenerate sequence:
thermal->radiation
(mass < 0.07 $M_{\odot}$)



(lack of) fusion has consequences



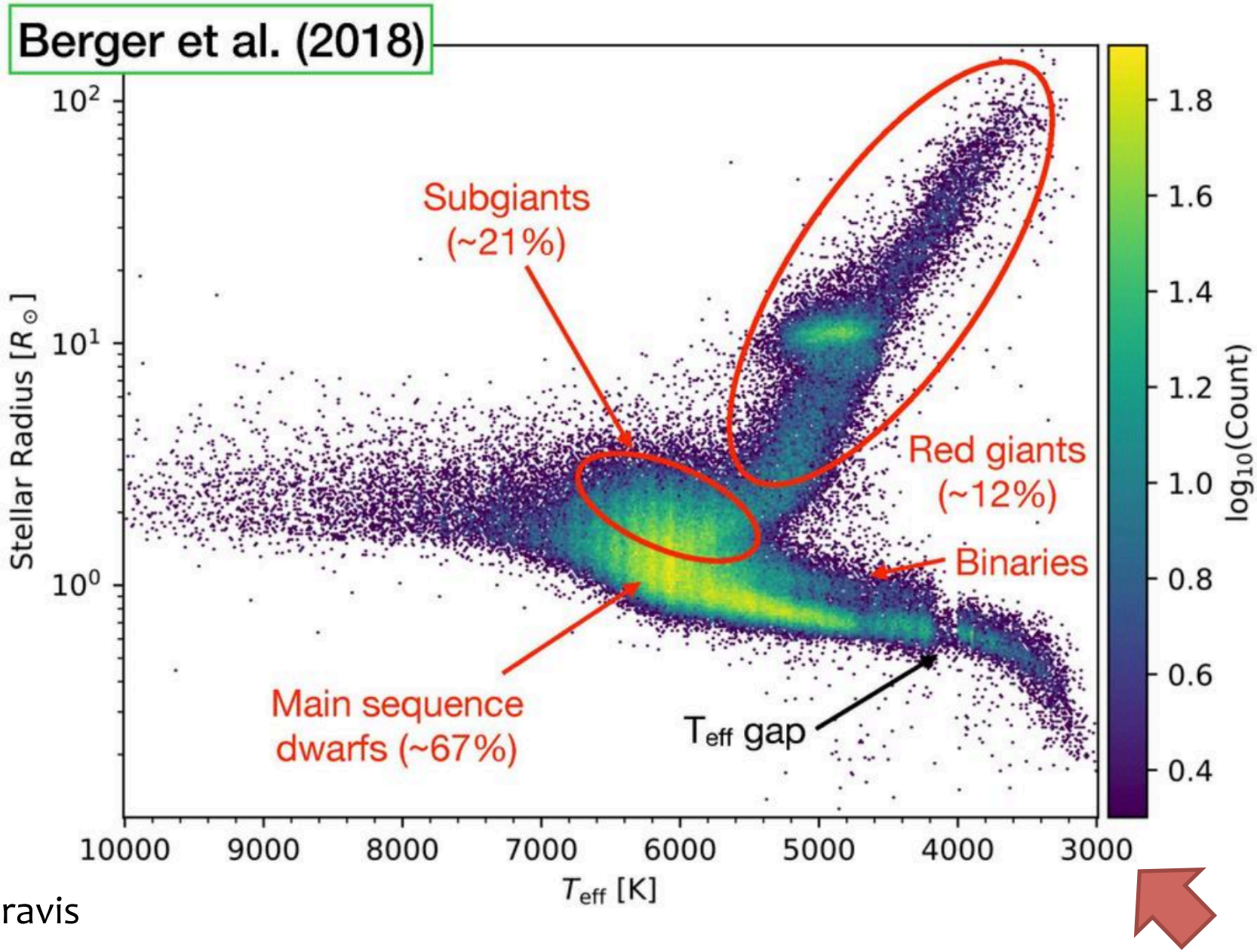
cushing et al. (2005)

"ultracool dwarfs" are unevolved stars with t_{eff} < 3000 K, including late-m, l, t & y dwarfs

"brown dwarfs" are objects that don't sustain h fusion (m < 0.07 $M_\odot$)

"planets" are objects that don't undergo any fusion (m < 0.01 $M_\odot$), and/or formed in a protoplanetary disk and/or the subject of a nasa funding proposal

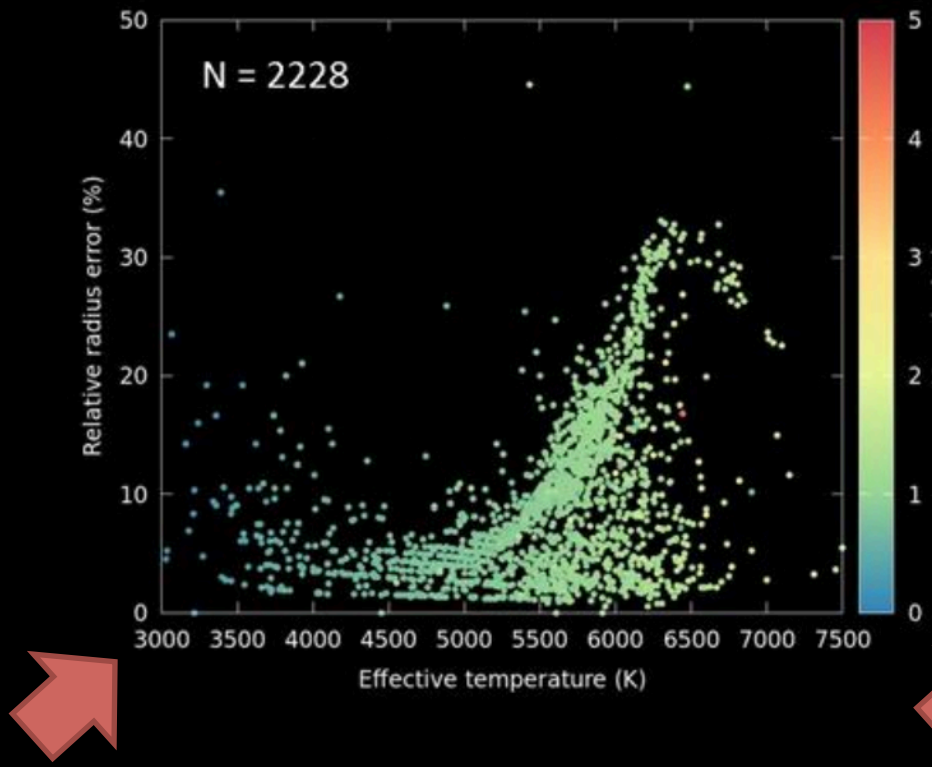
how many plots this week stopped at t_{eff} = 3000 K or m = 0.1 $M_{\odot}$?

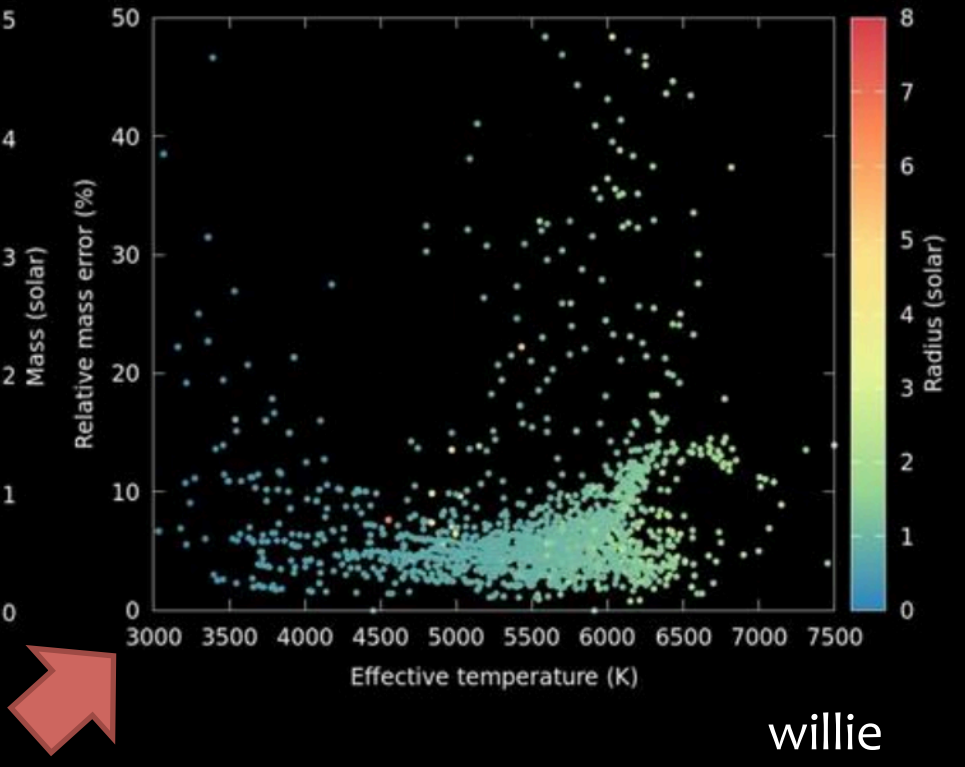

Berger et al. (2018)
Subgiants
(~21%)
Red giants
(~12%)
Binaries
Main sequence
dwarfs (~67%)
Teff gap
Stellar Radius [R⊙]
Teff [K]
log10(Count)
10000
9000
8000
7000
6000
5000
4000
3000
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

travis

How well are M_* and R_* determined in the literature?

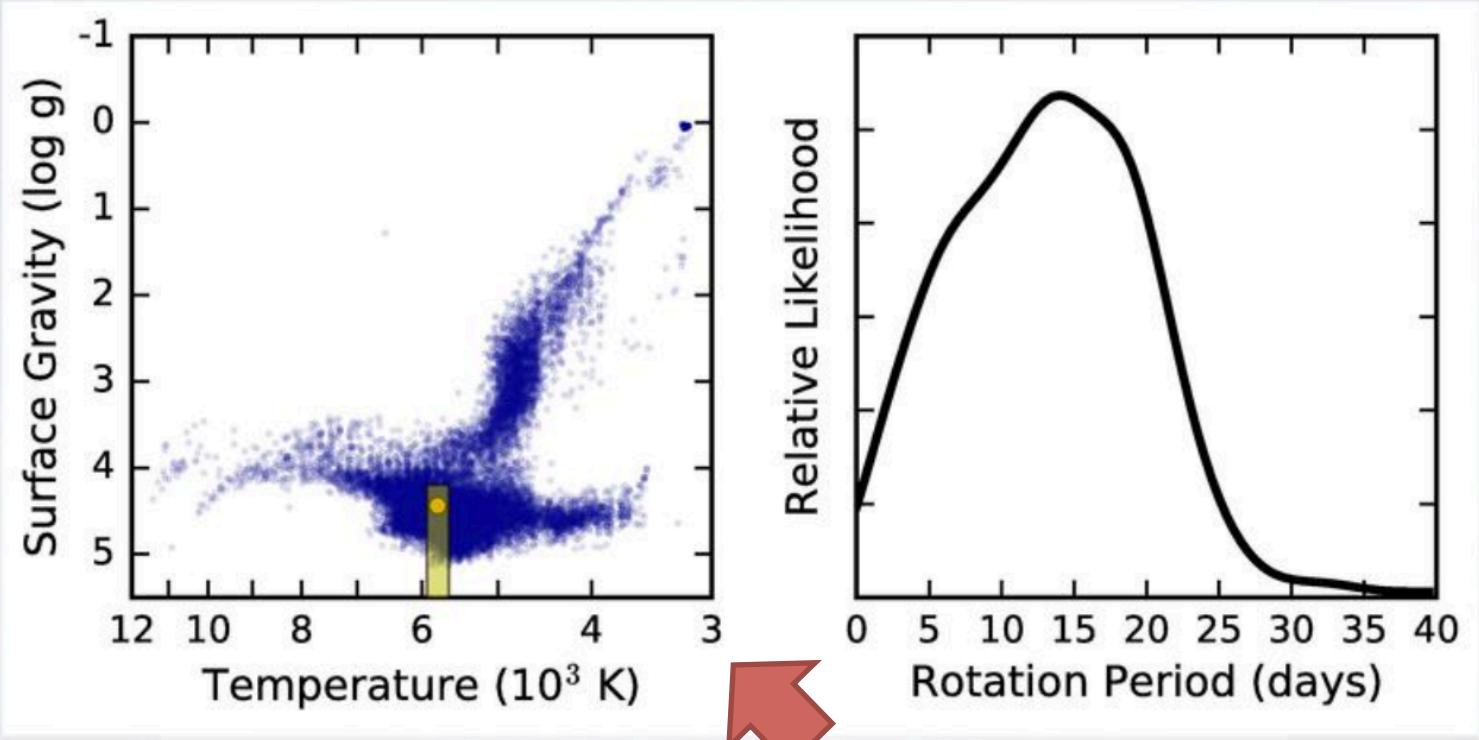
- NASA Exoplanet Archive
  - Many different methods, many different authors





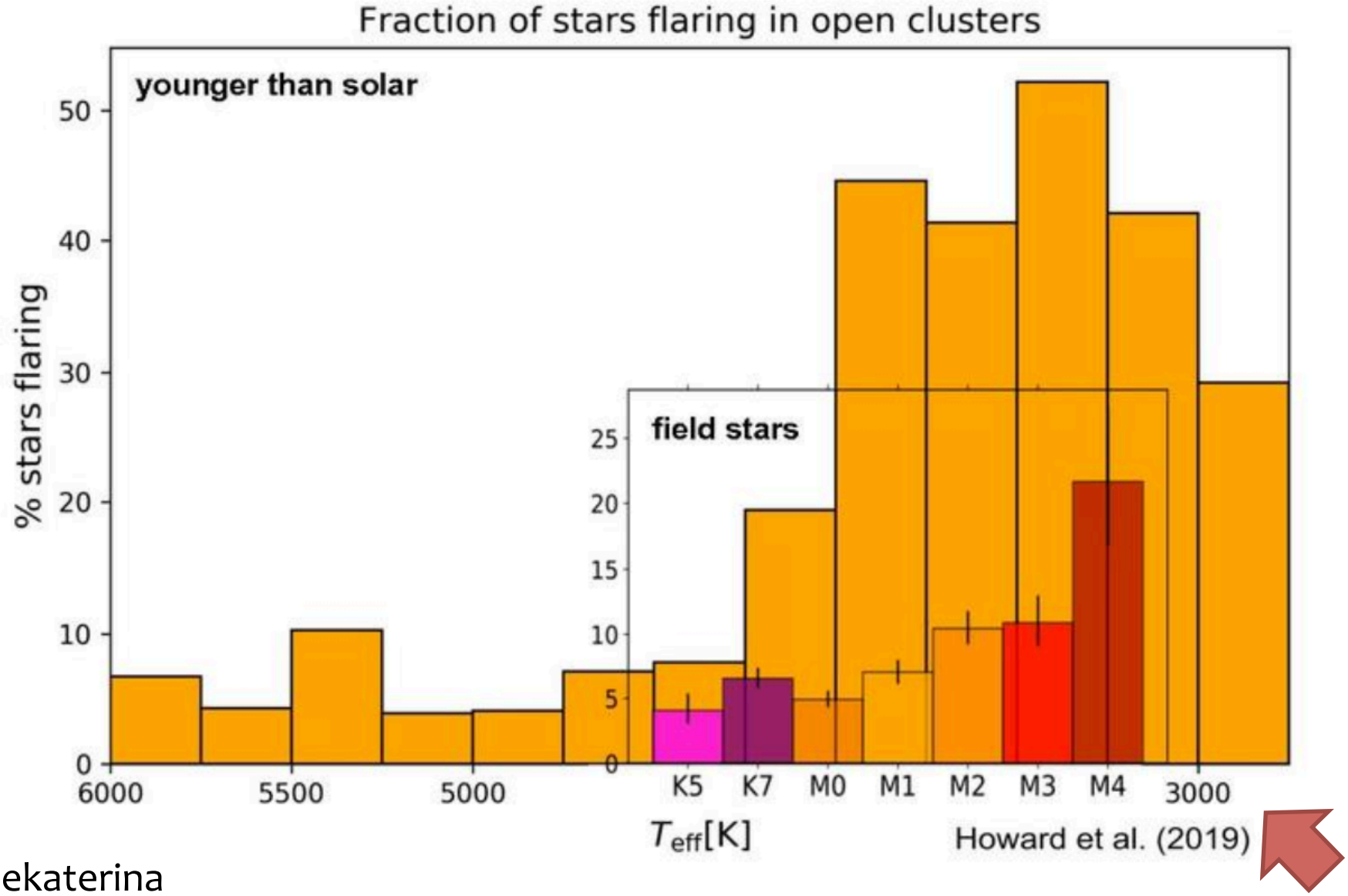
willie

Kepler observed thousands of Sun-like stars



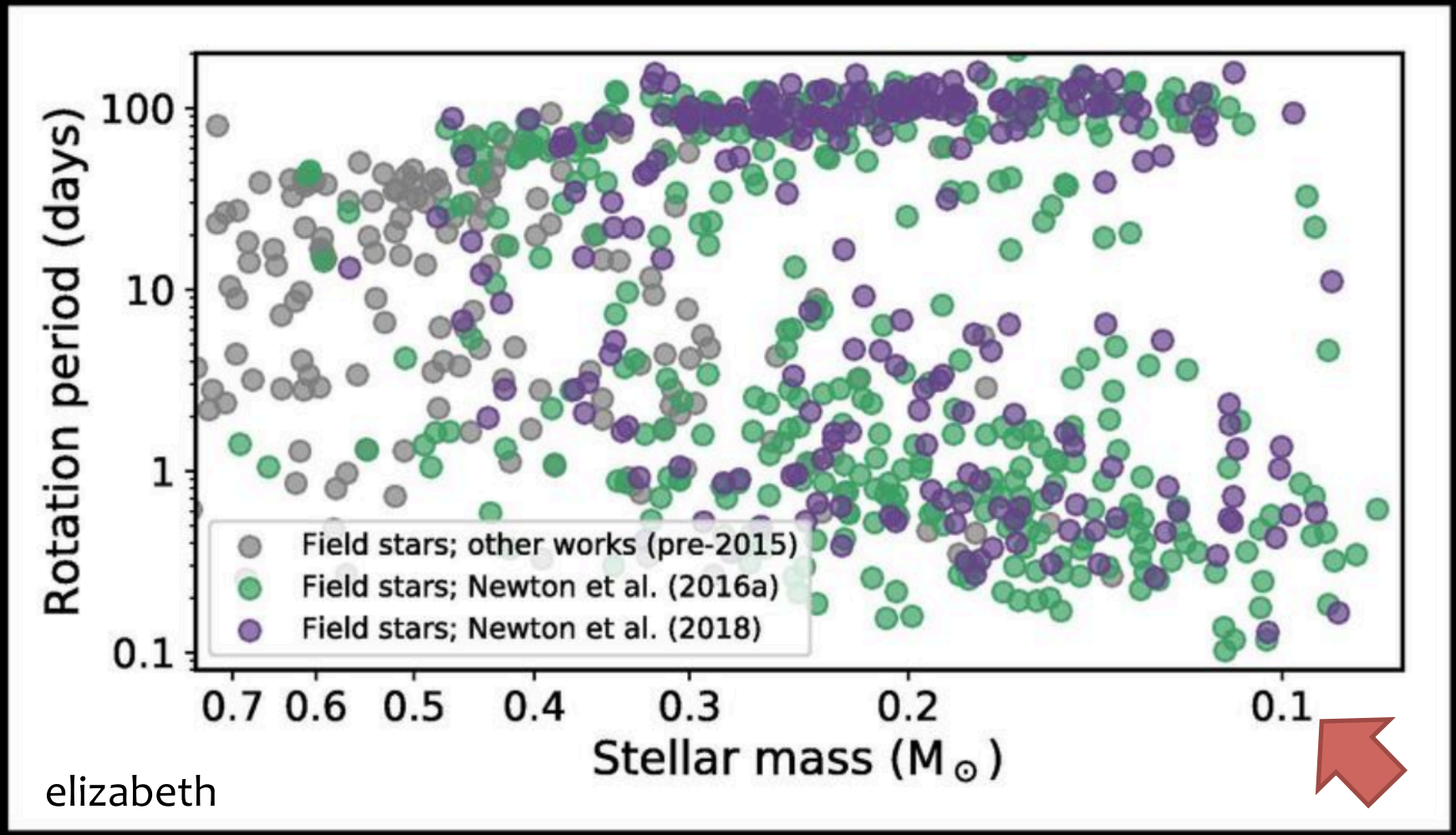
Montet, Tovar, and Foreman-Mackey (2017)

ben


Fraction of stars flaring in open clusters
younger than solar
field stars
% stars flaring
0
10
20
30
40
50
0
5
10
15
20
25
6000
5500
5000
K5
K7
M0
M1
M2
M3
M4
3000
T_{eff}[K]
Howard et al. (2019)

ekaterina

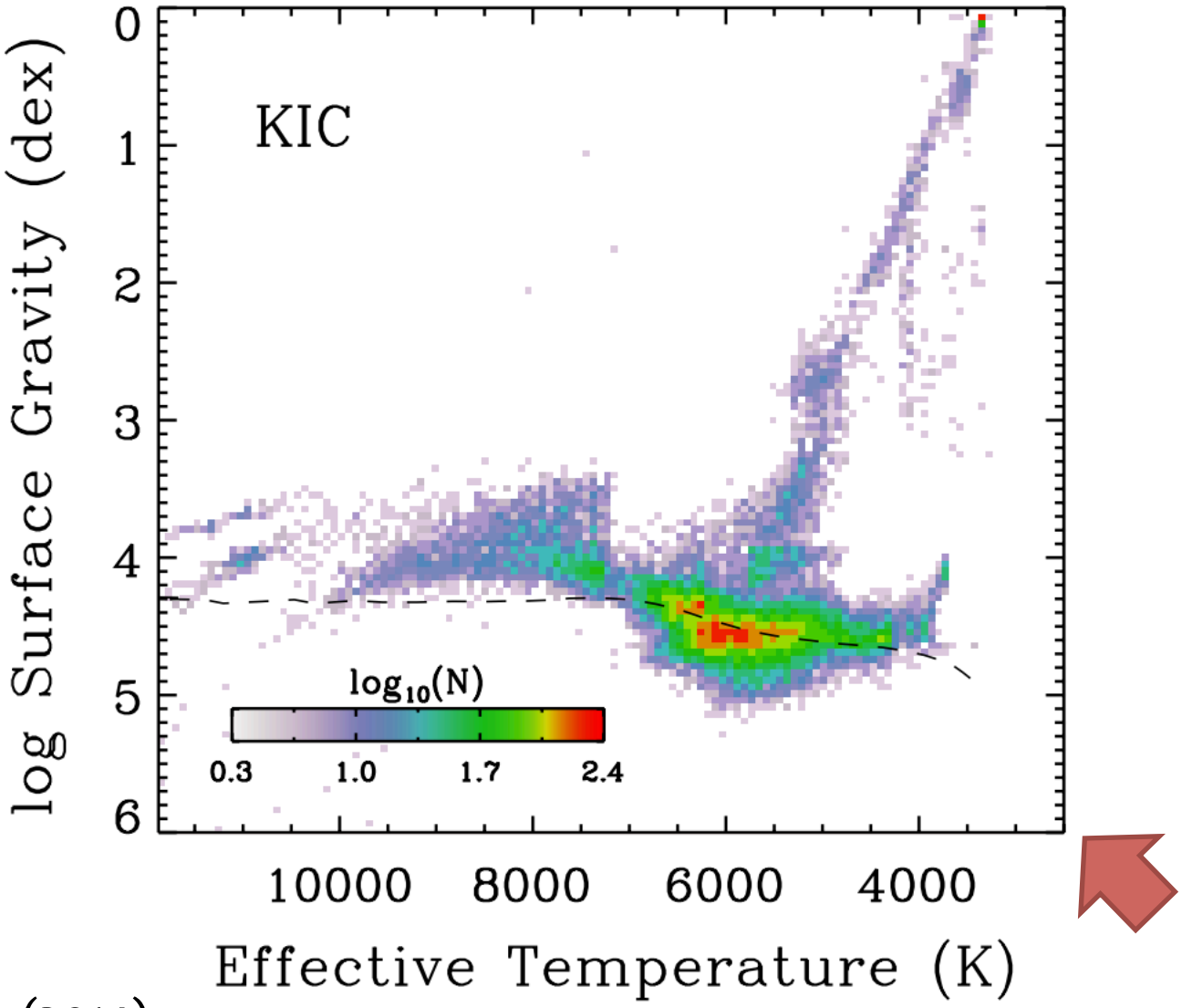
Rotation periods of field stars



elizabeth

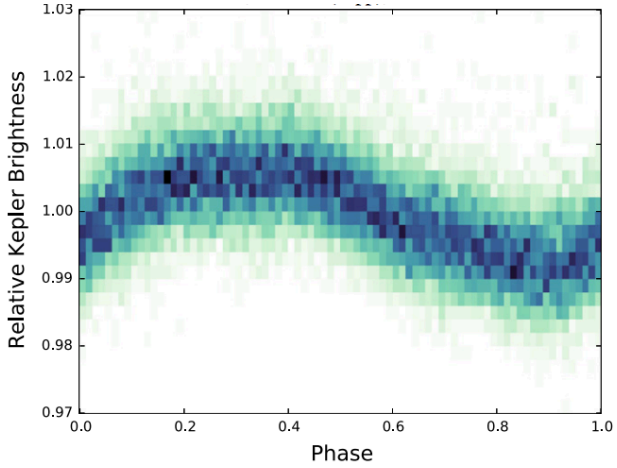
Let's go brown….

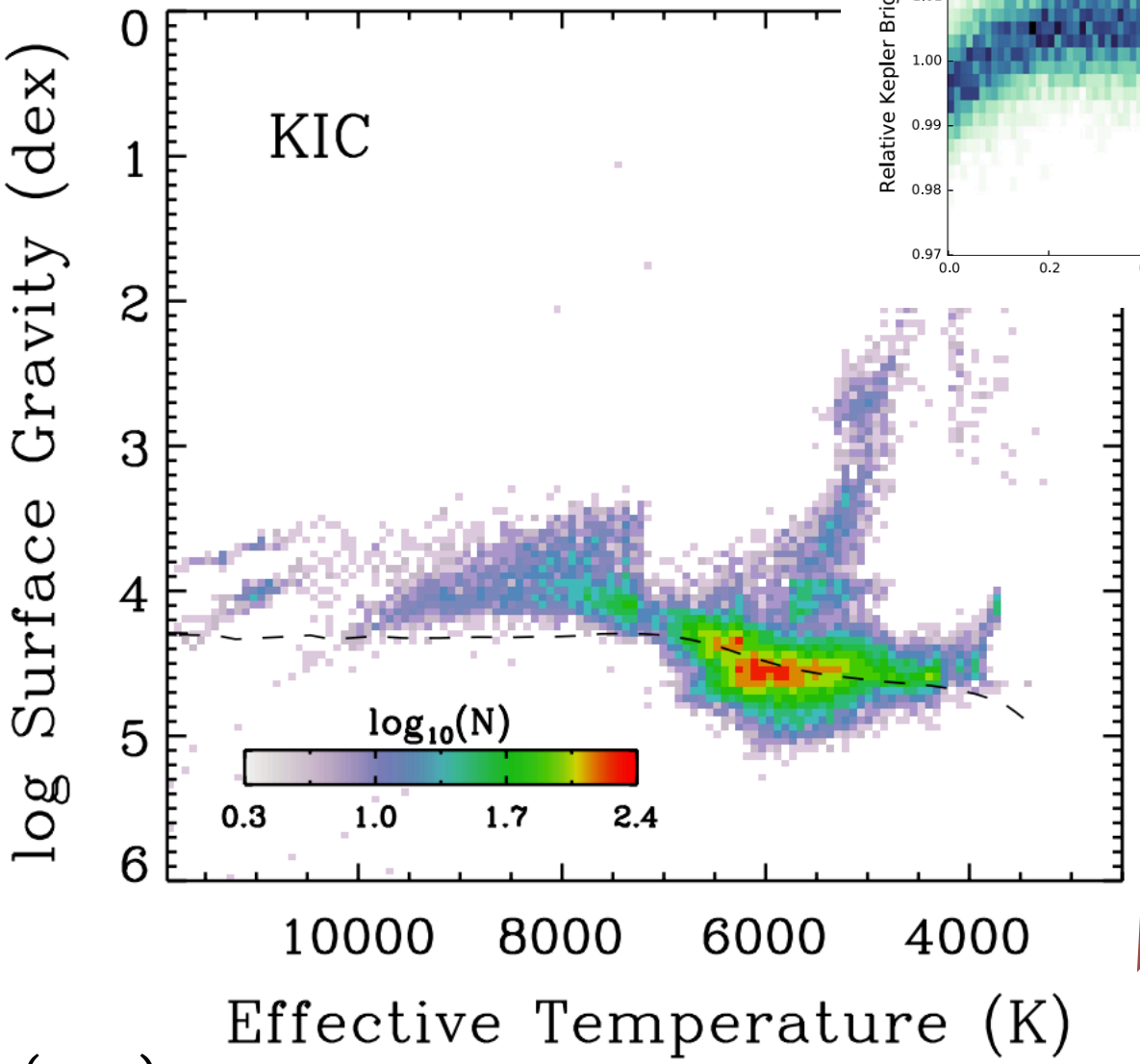
kepler input catalog



huber et al. (2014)

kepler input catalog

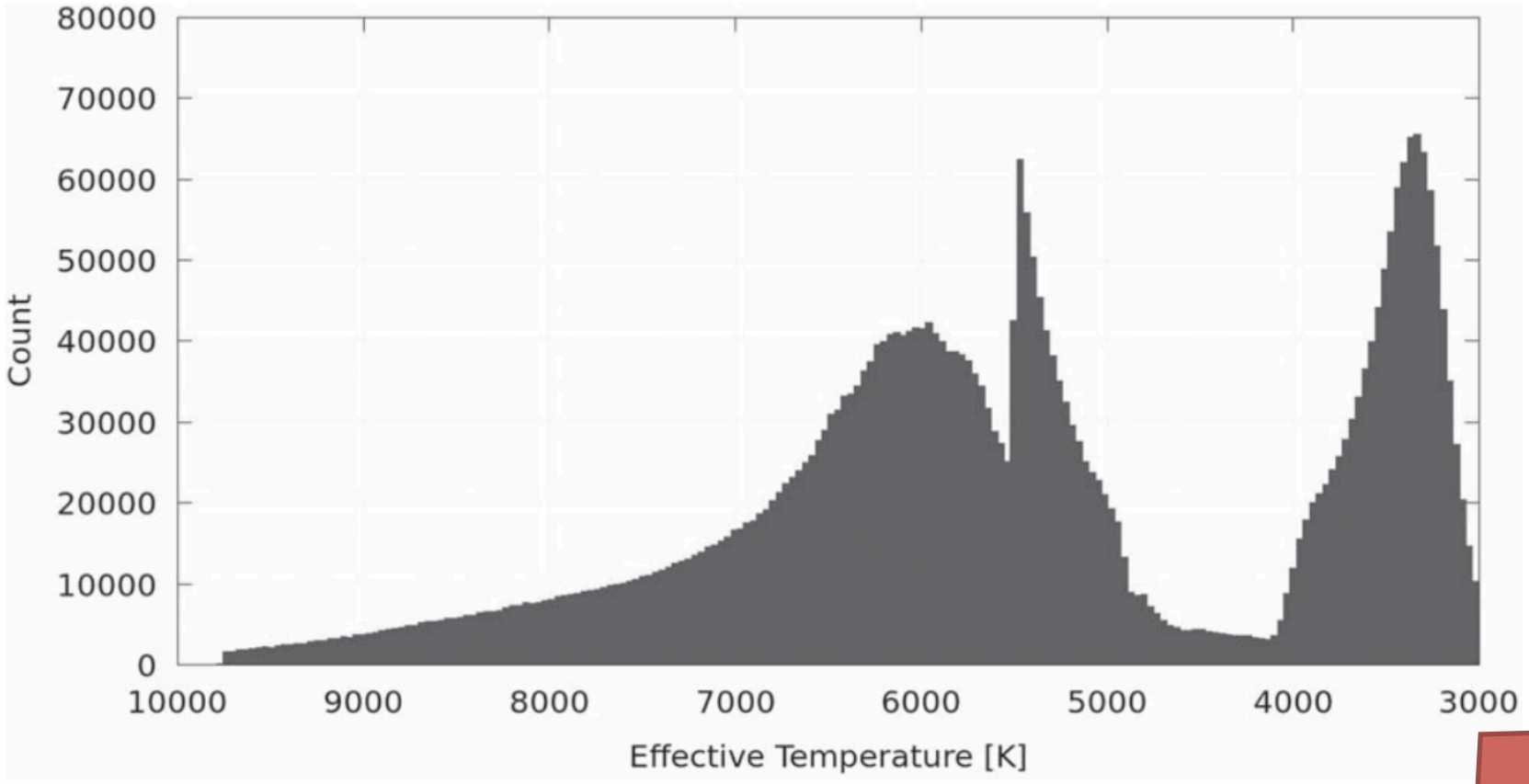




kepler l1 dwarf
gizis et al.
(2013, 2015)

huber et al. (2014)

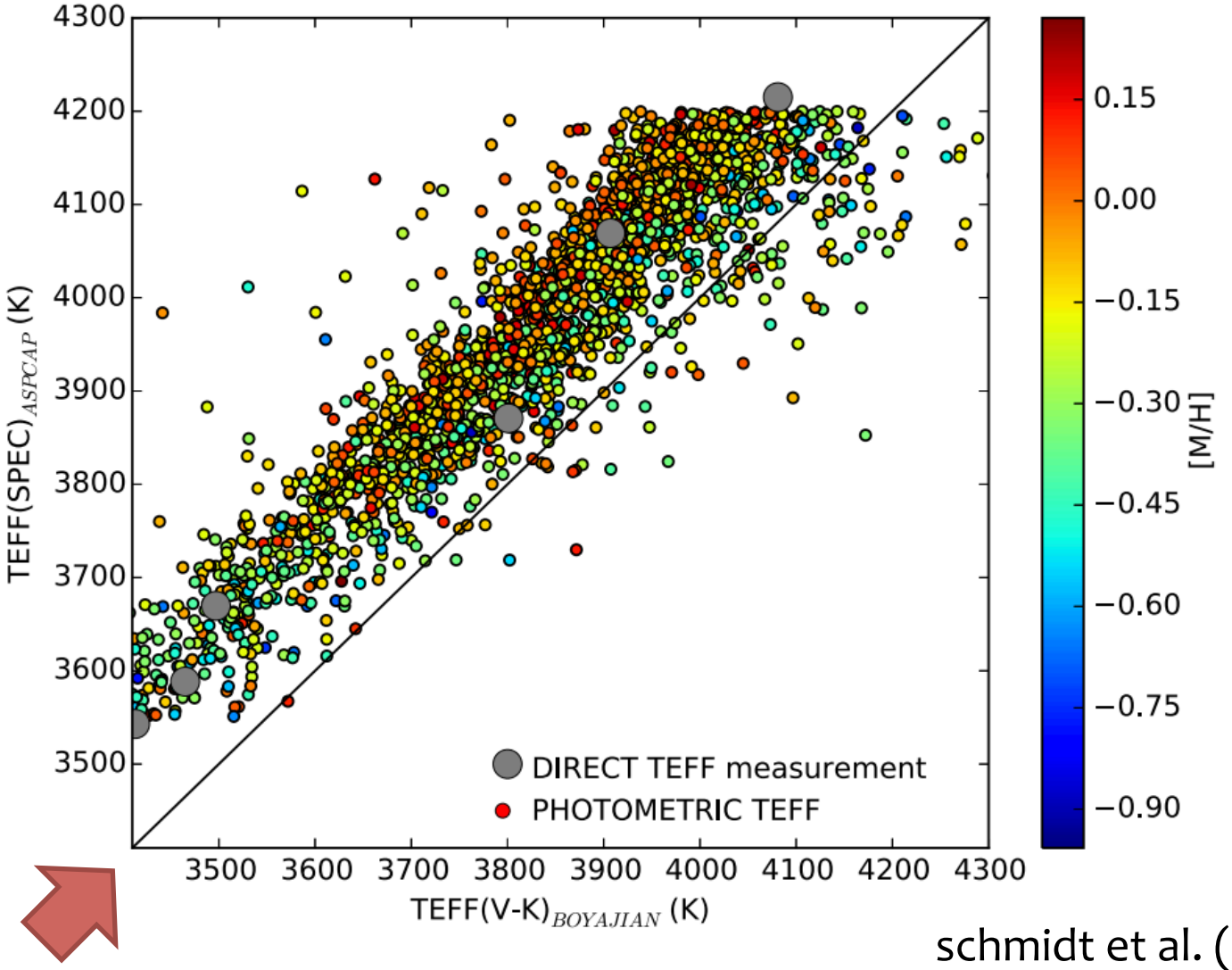
tess input catalog



stassun et al. (2018)

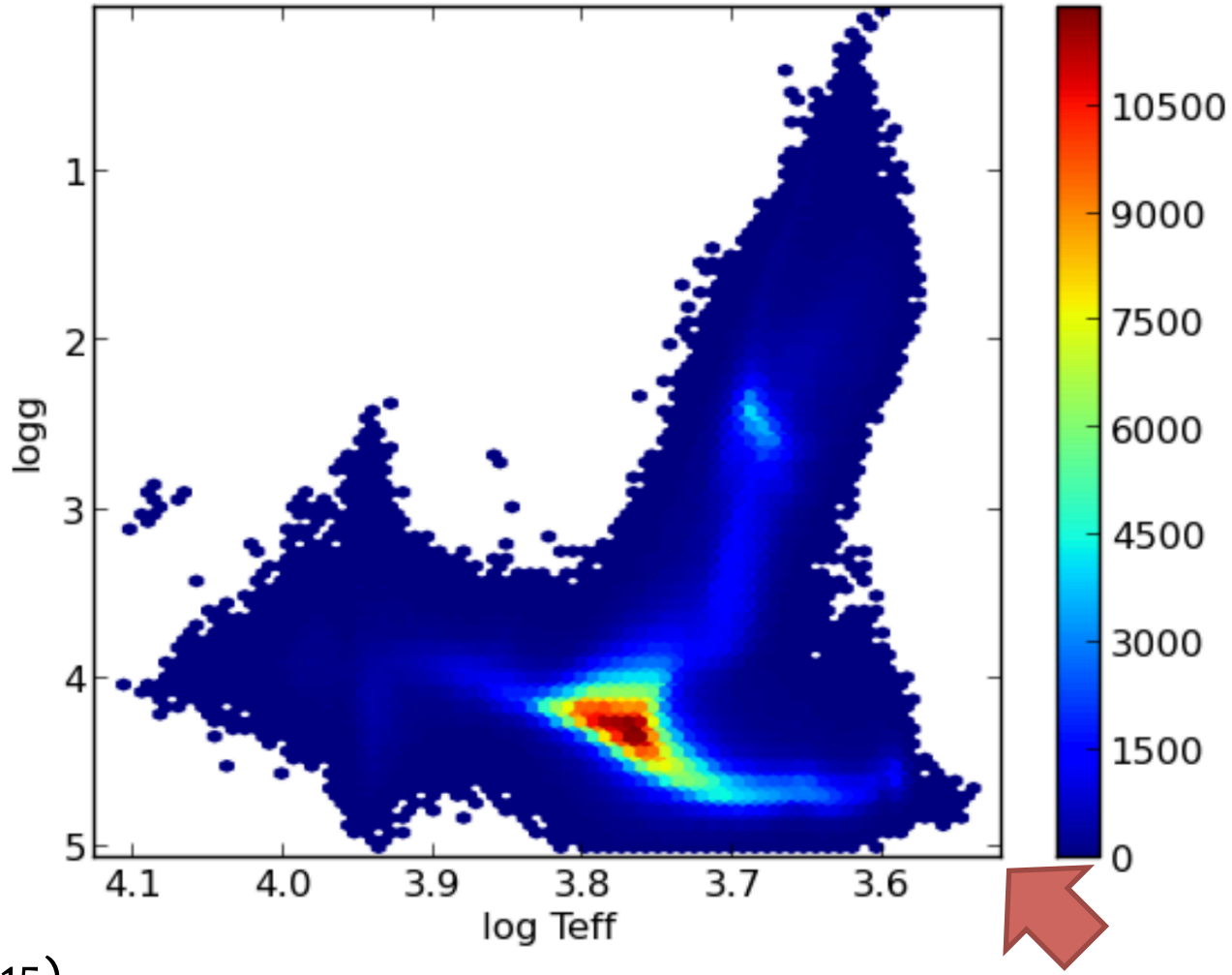
sebastian pineda is leading
a program to look over here

apogee (aspcap)



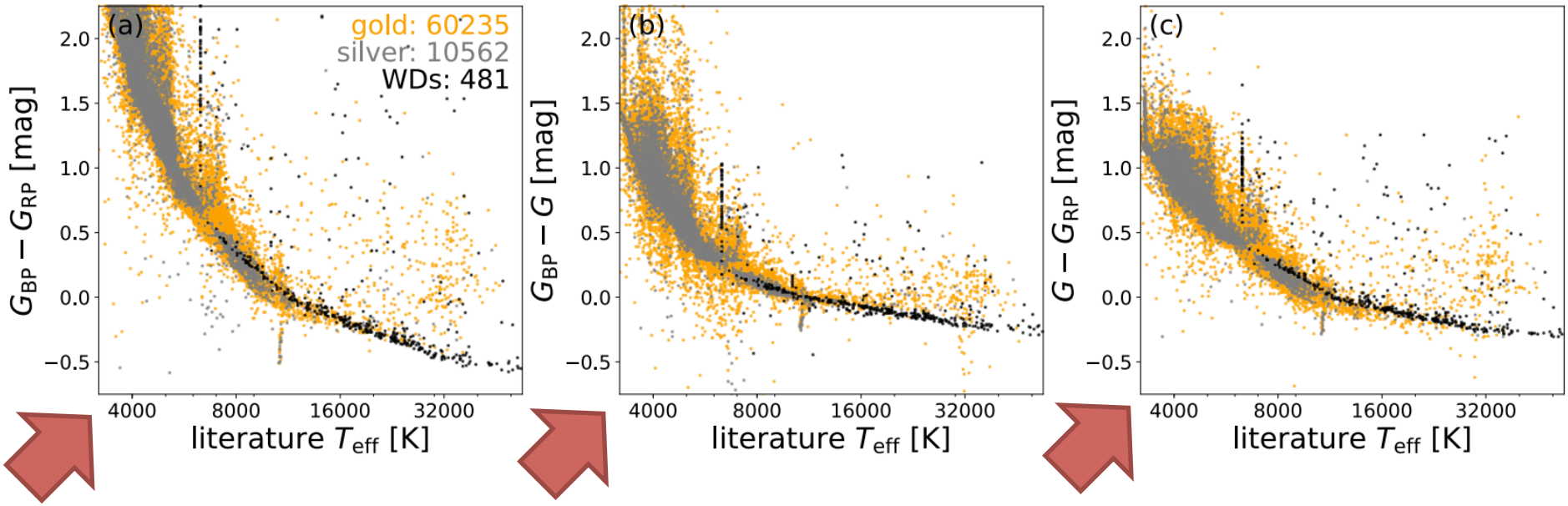
schmidt et al. (2016)

lamost



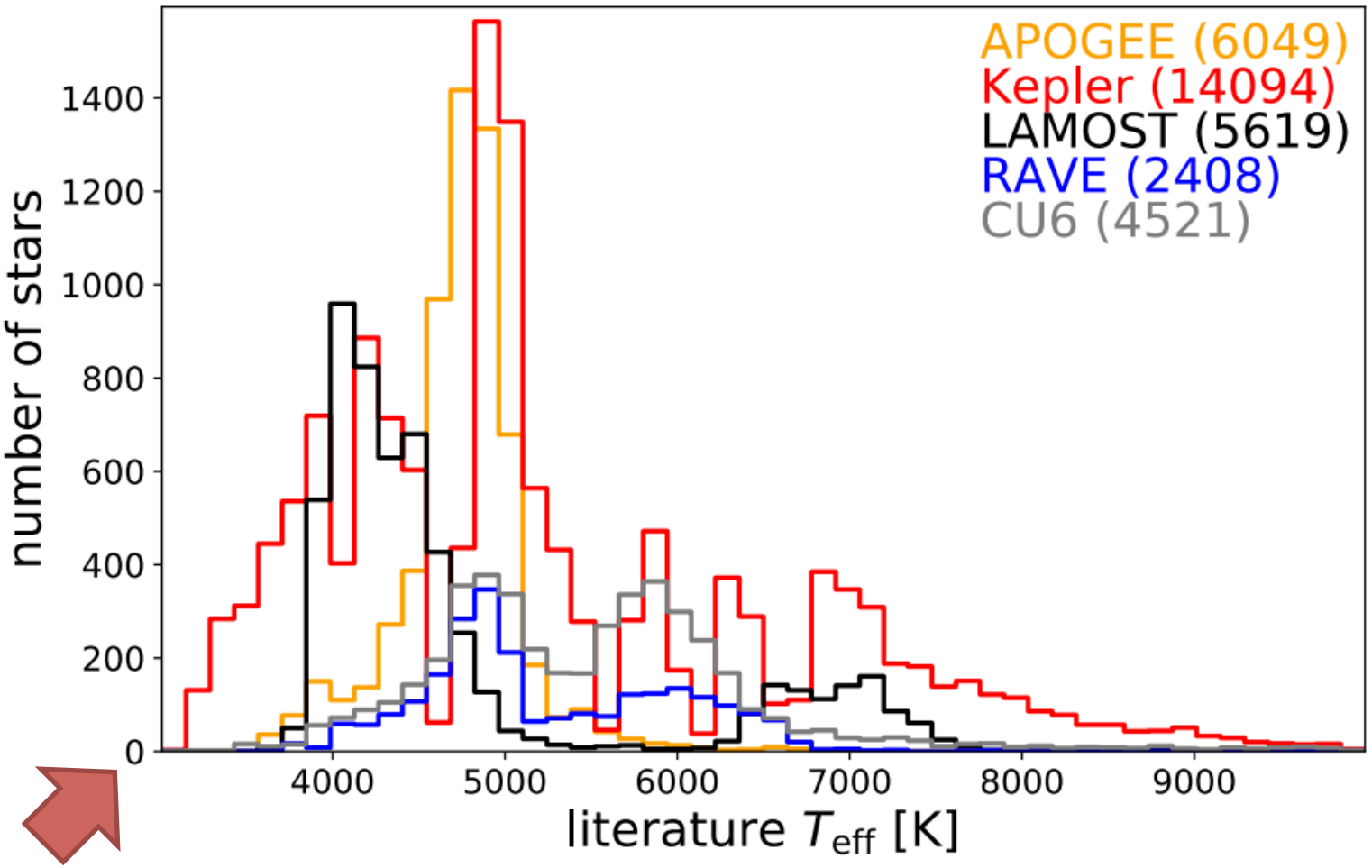
luo et al. (2015)

gaia dr2 (apsis)



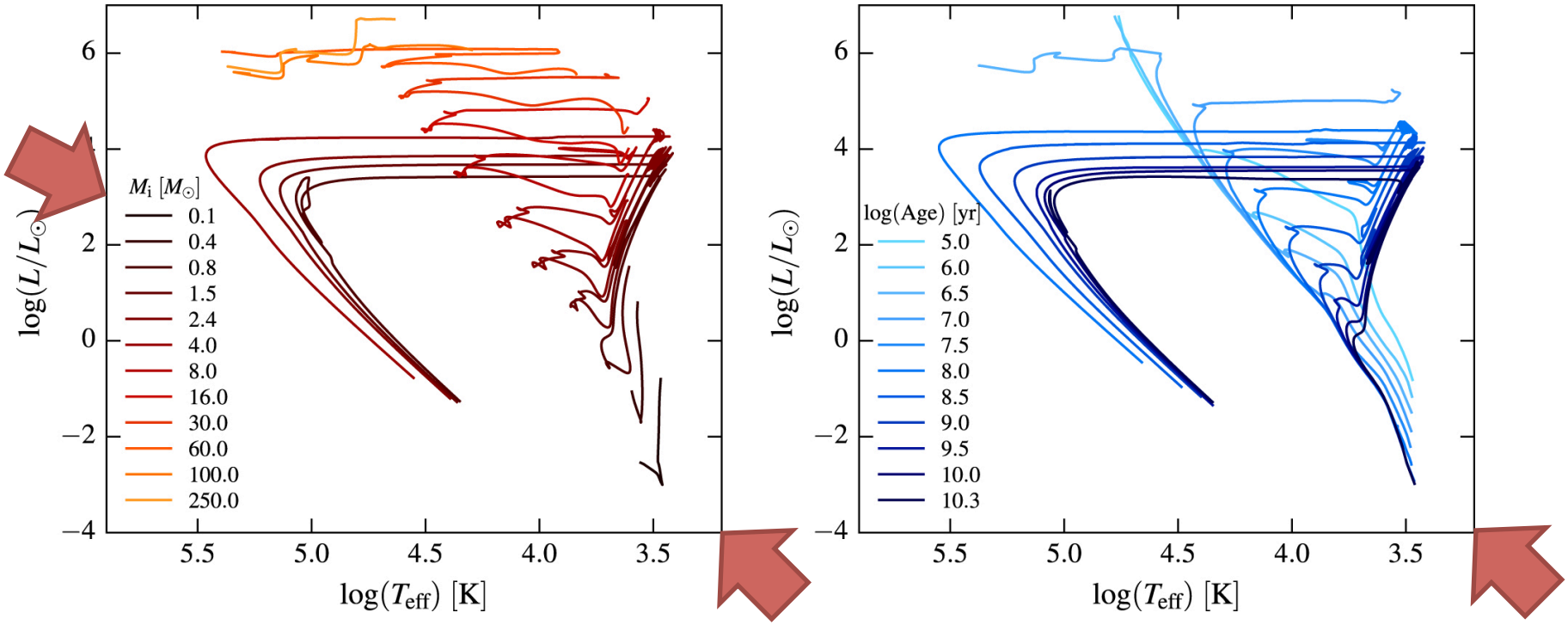
andrae et al. (2018)

all y'all



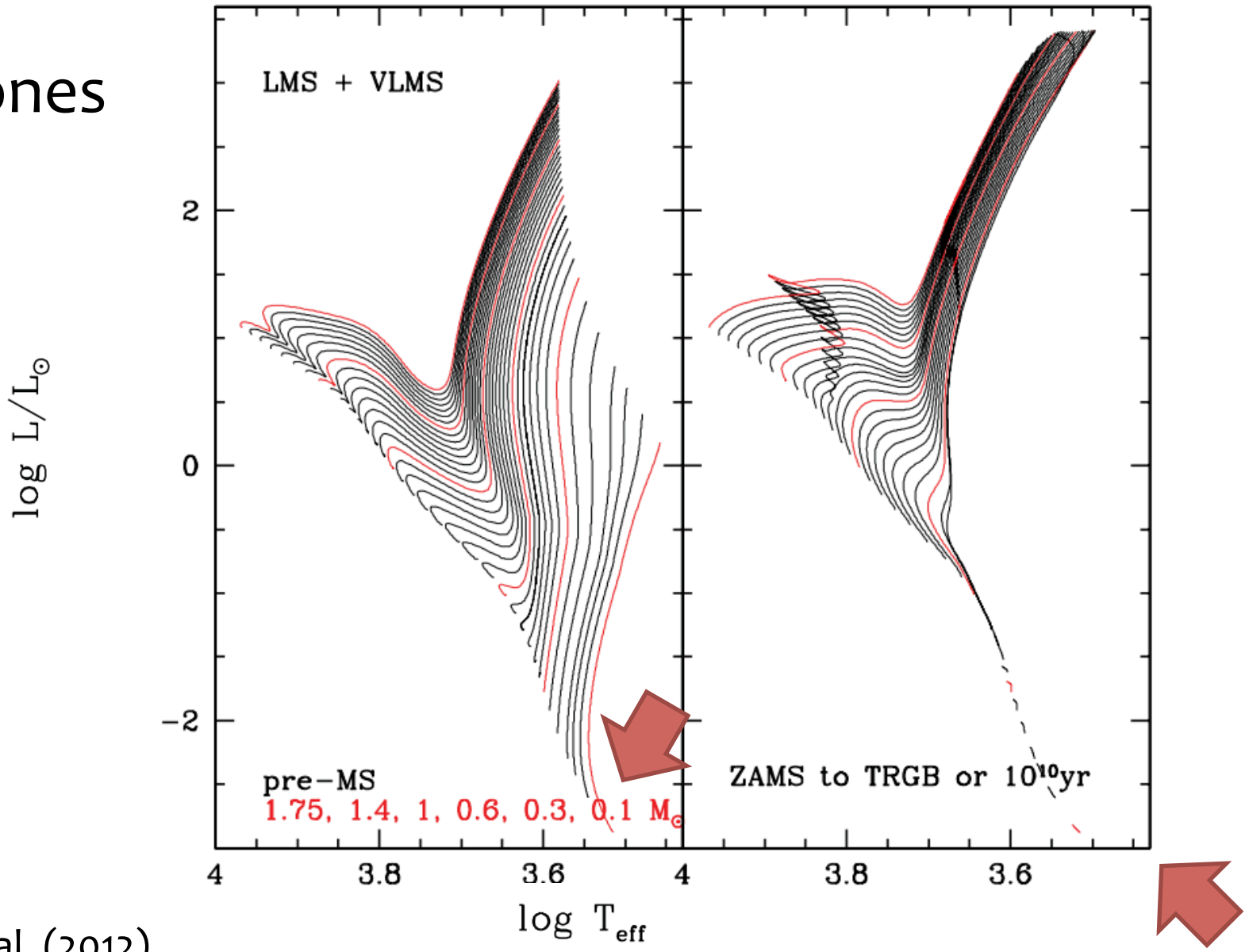
andrae et al. (2018)

mist isochrones



dotter (2016)
choi et al. (2016)

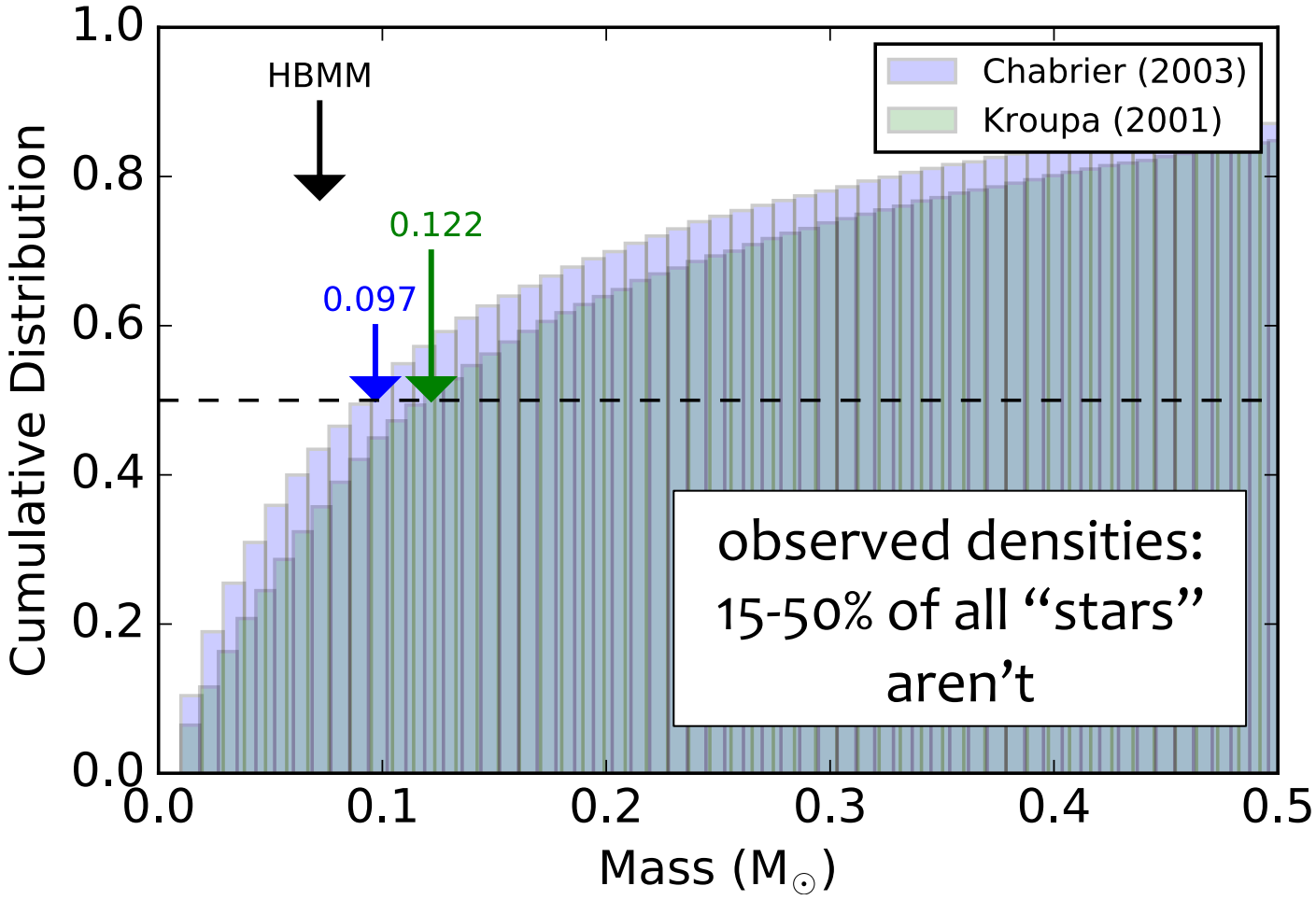
parsec isochrones



bressen et al. (2012)

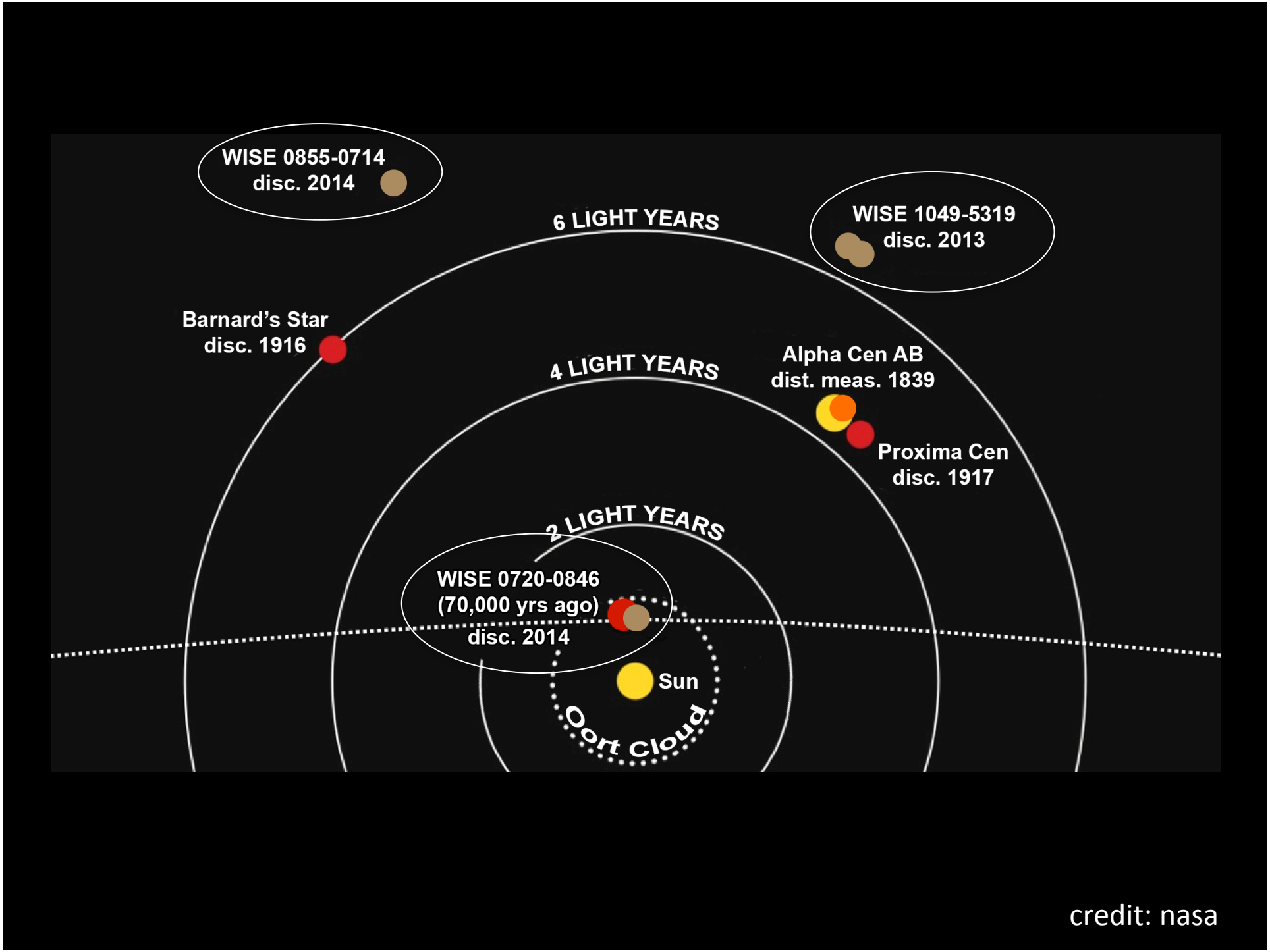
this is unfortunate, because brown dwarfs could be exceptionally productive for exoplanetary science

there are a lot of brown dwarfs in the galaxy…

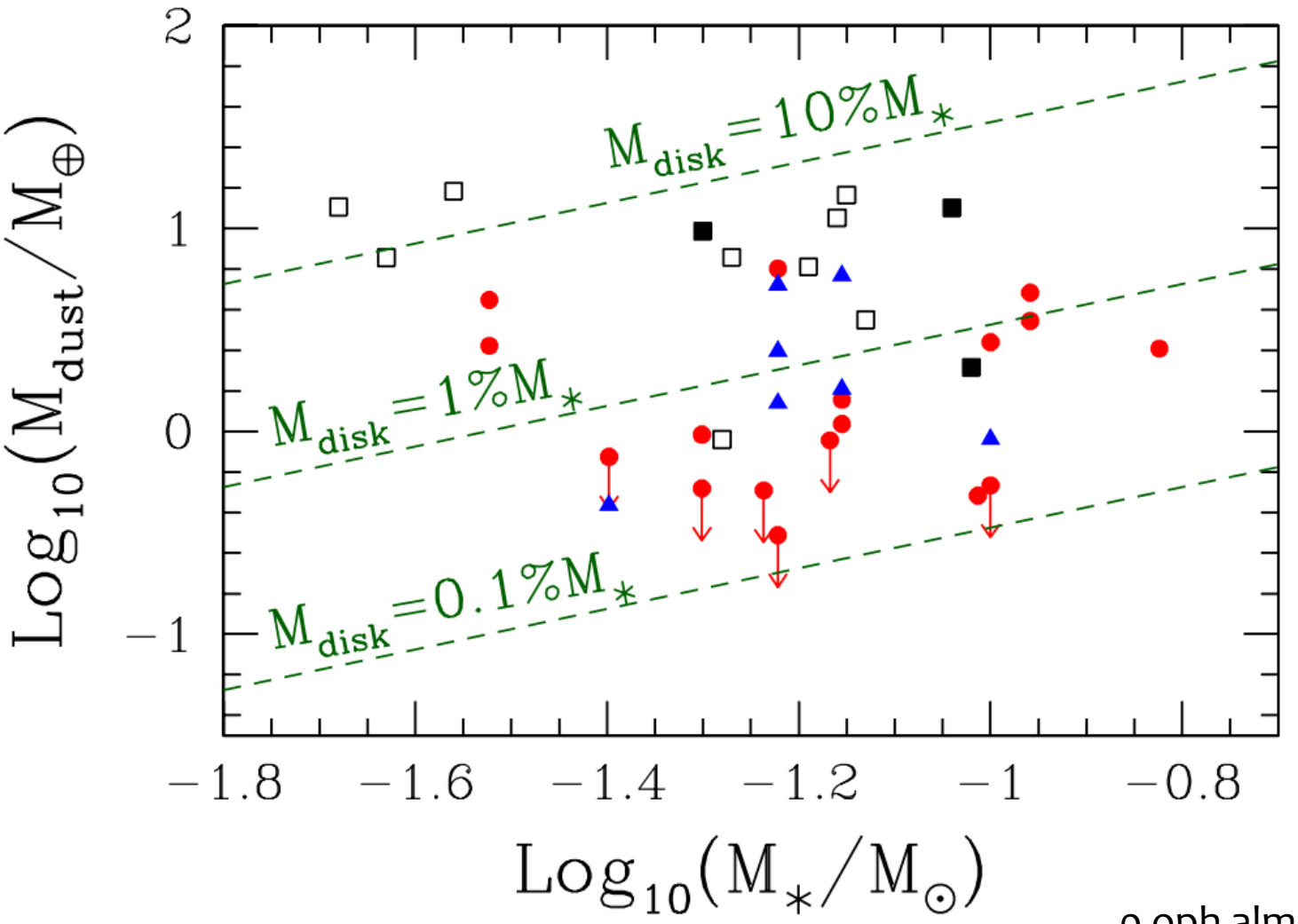


*assuming a mass range 0.01-10 $M_\odot$

mf: kroupa (2001); chabrier (2003)
lf: mužic+ (2017); kirkpatrick+ (2019)

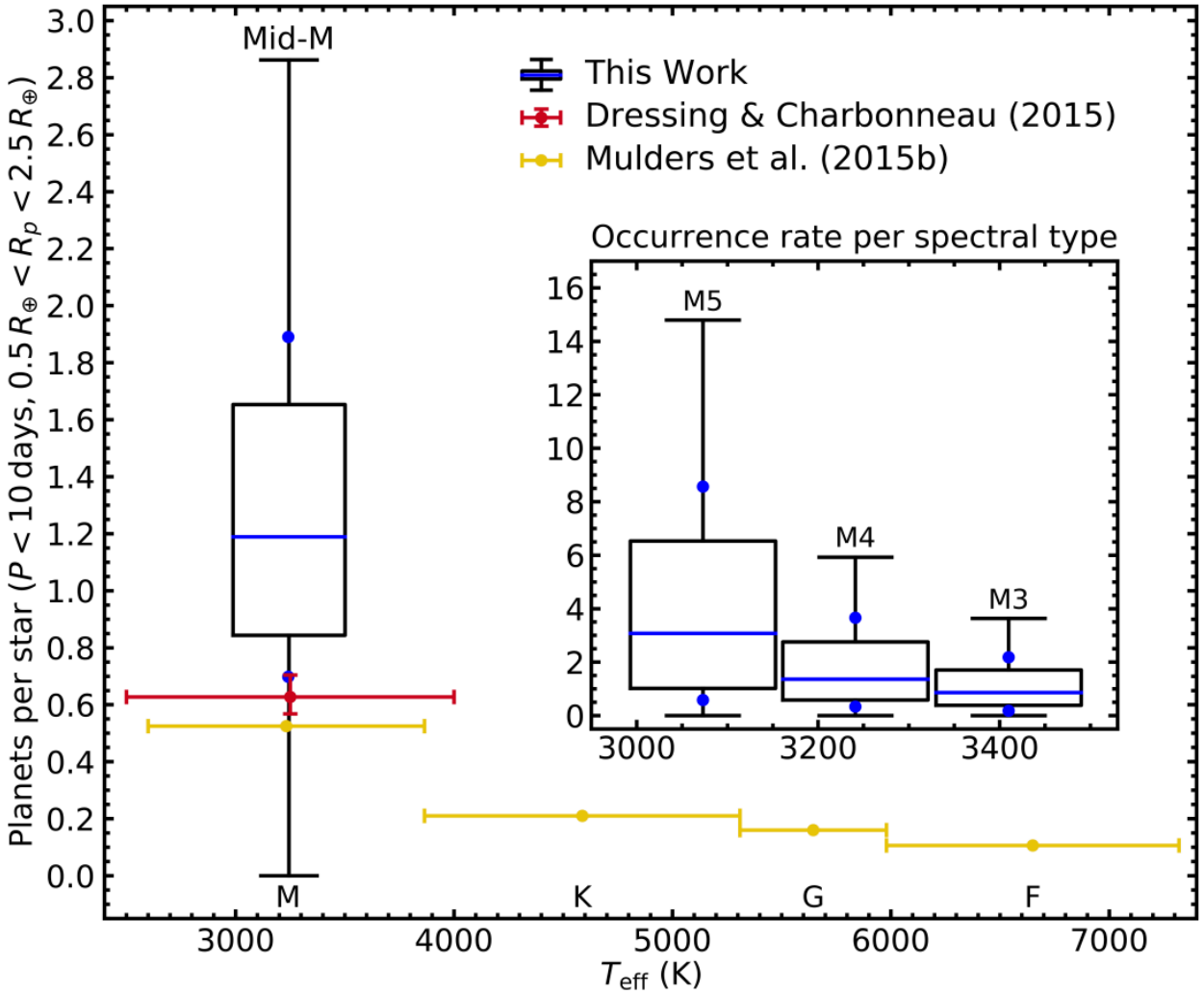

WISE 0855-0714
disc. 2014
6 LIGHT YEARS
WISE 1049-5319
disc. 2013
Barnard's Star
disc. 1916
4 LIGHT YEARS
Alpha Cen AB
dist. meas. 1839
Proxima Cen
disc. 1917
2 LIGHT YEARS
WISE 0720-0846
(70,000 yrs ago)
disc. 2014
Sun
Oort Cloud
credit: nasa

…we're pretty sure they can make planets…



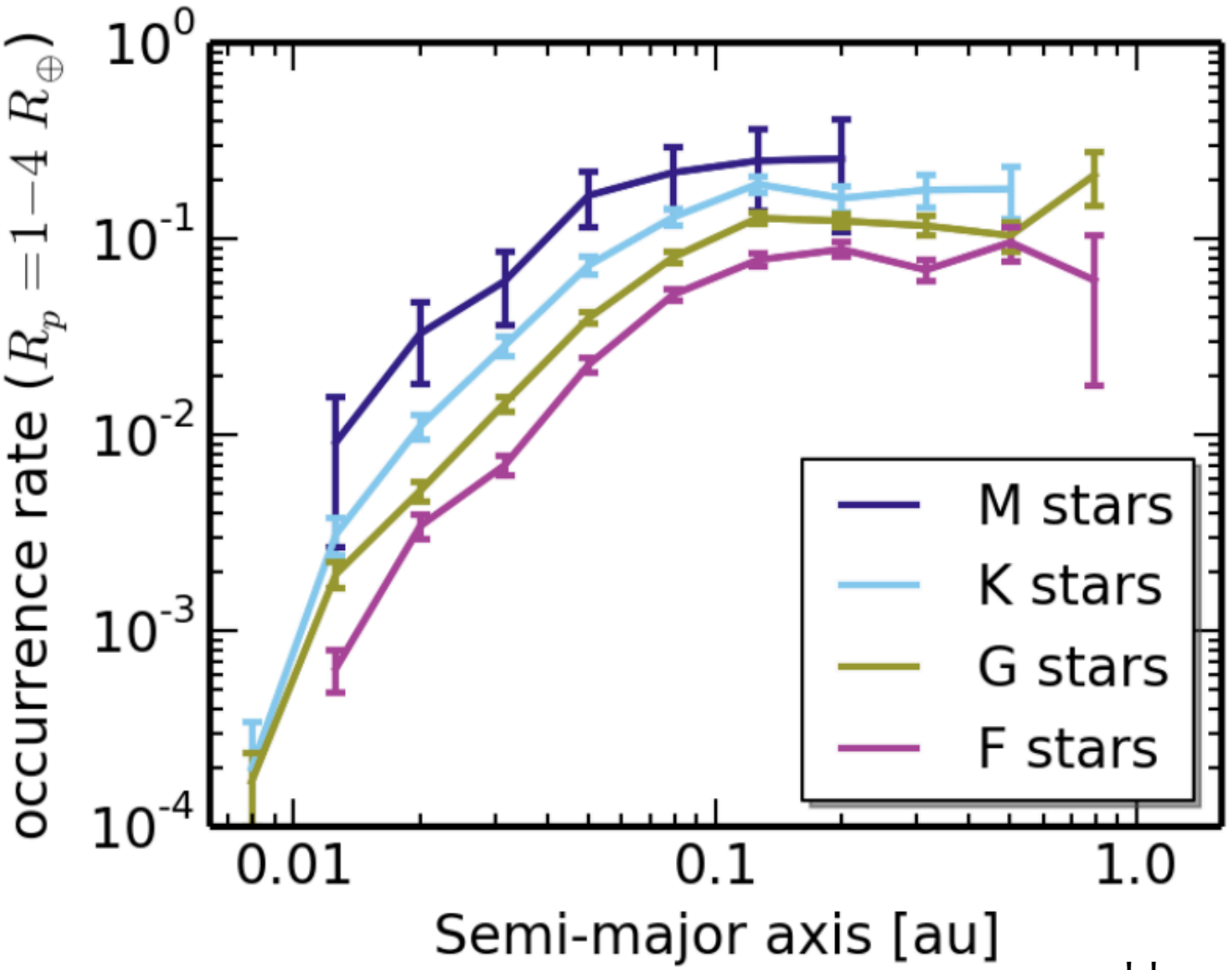
ρ oph alma disks
testi et al. (2016)

…maybe a lot of planets…



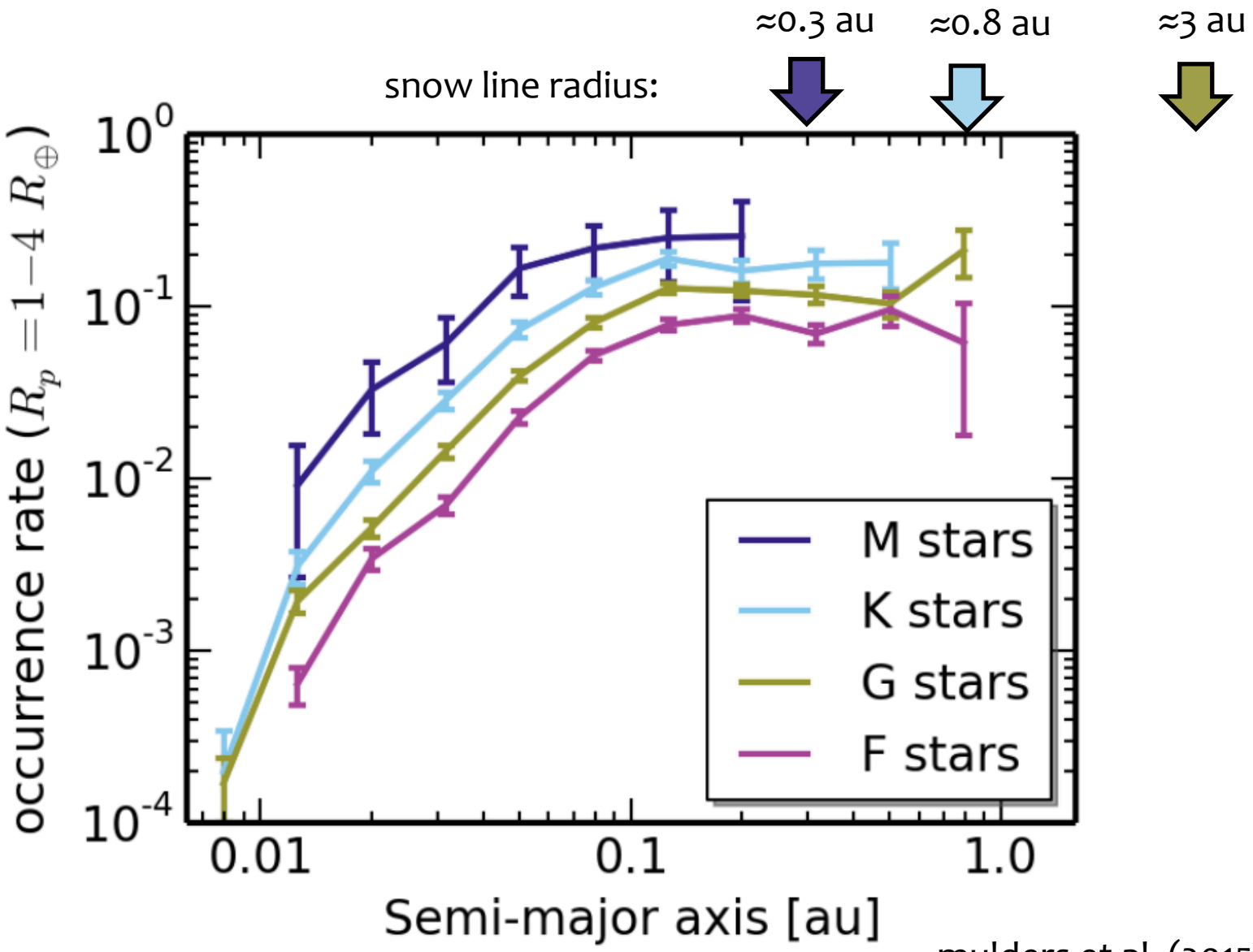
hardegree-ullman et al. (2019)

…maybe a lot of volatile-rich planets…



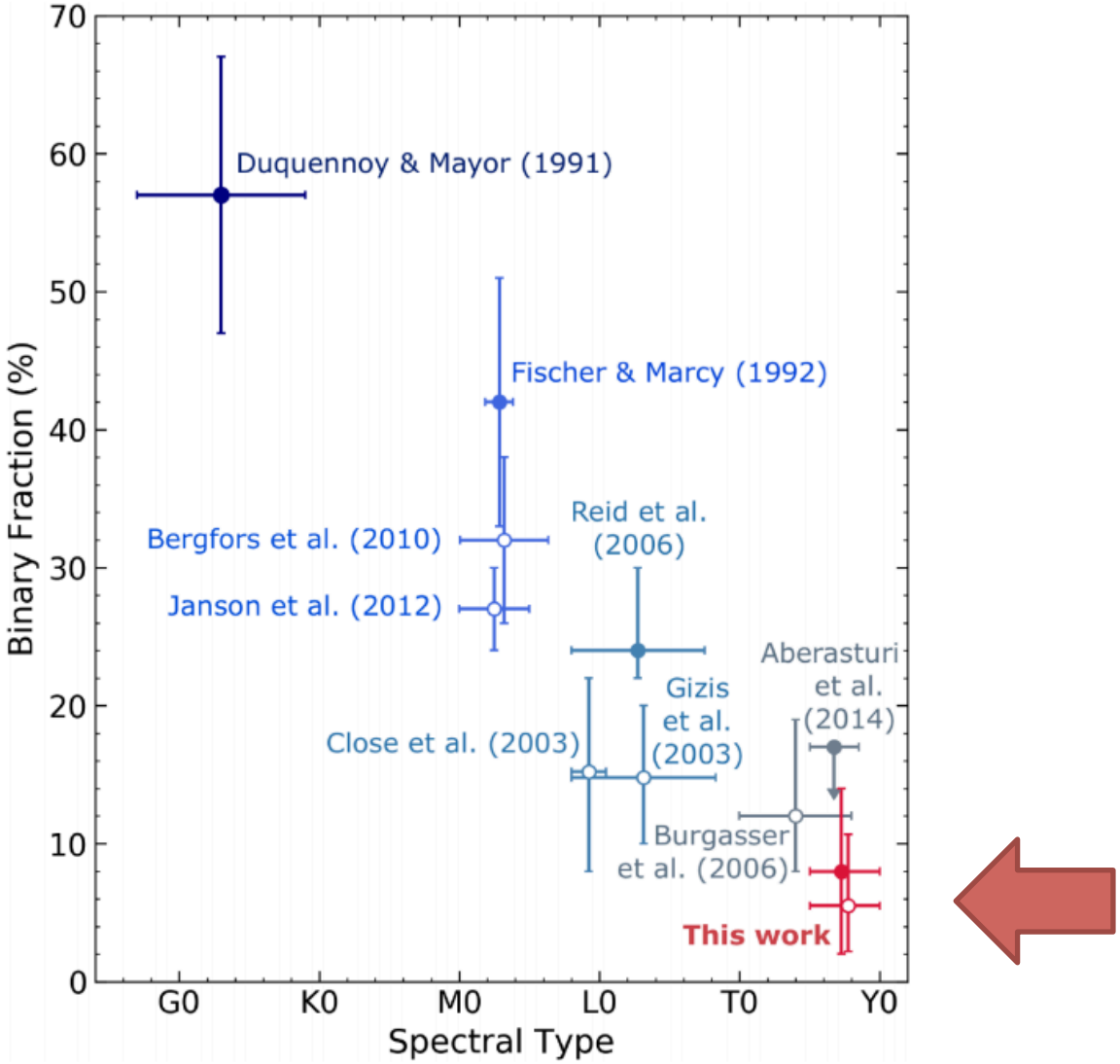
mulders et al. (2015)

…maybe a lot of volatile-rich planets…



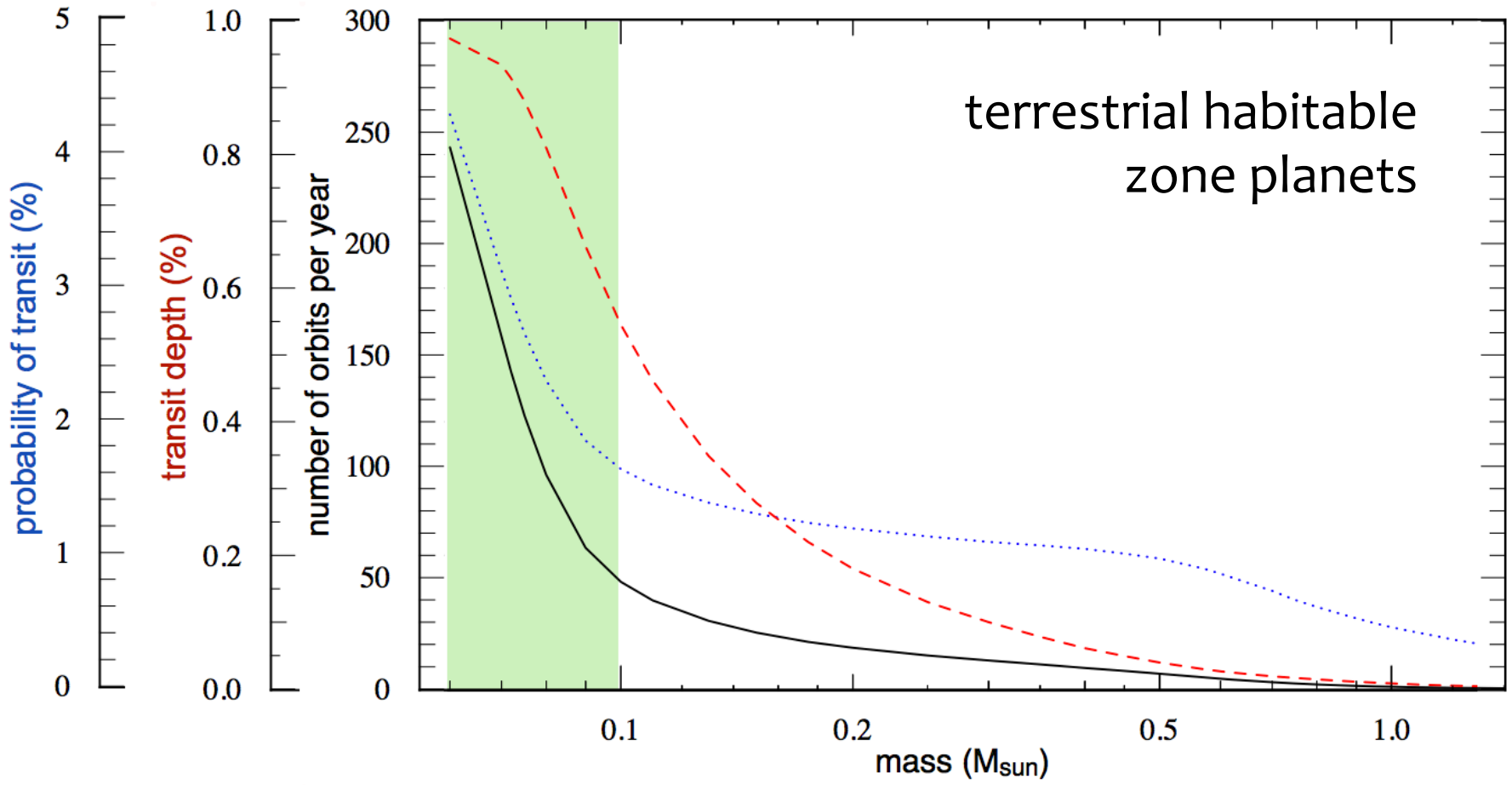
mulders et al. (2015)

…less likely to be disturbed by binaries…



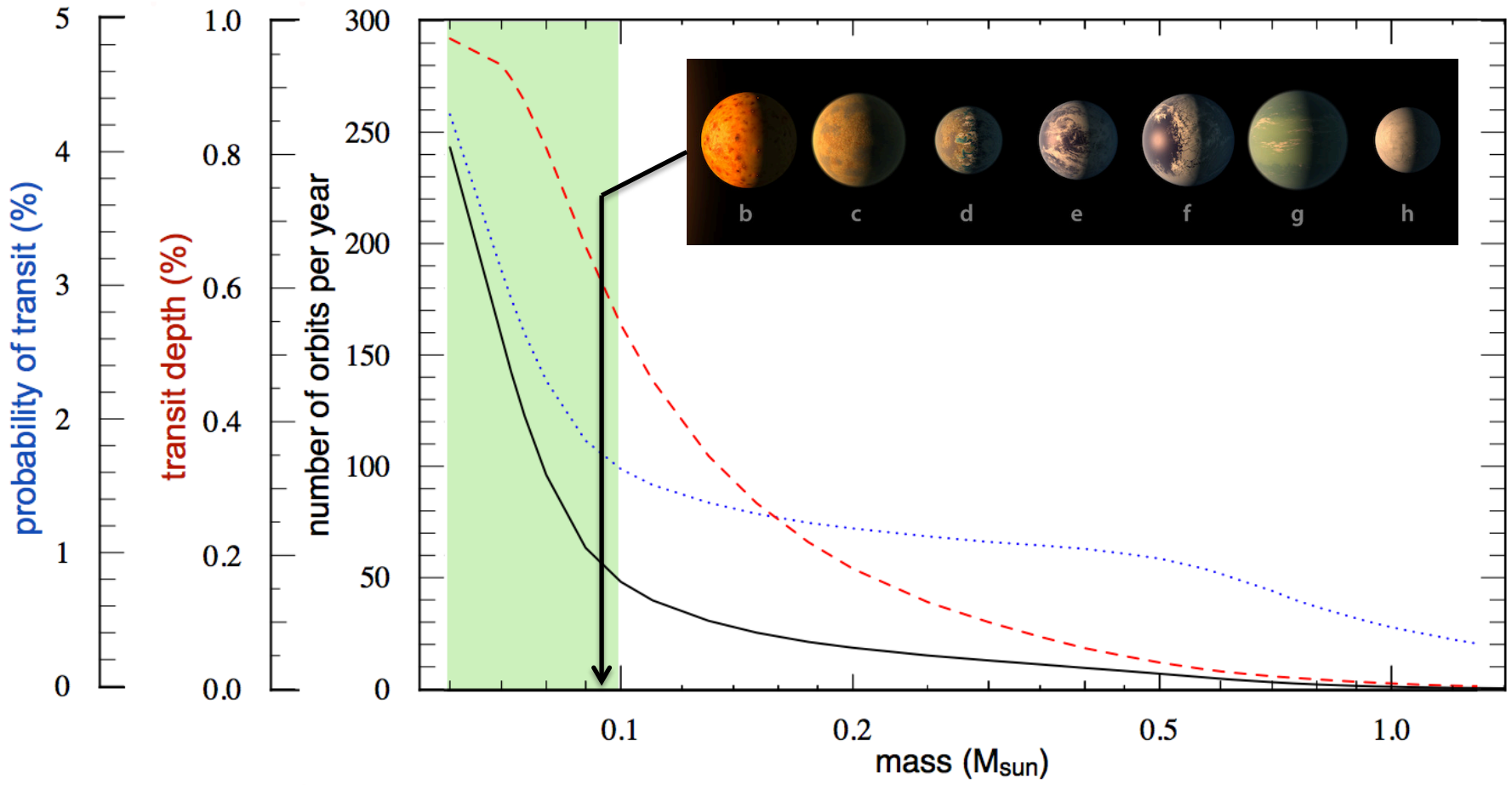
fontanive et al. (2018)

…and those planets are *relatively* easy to find



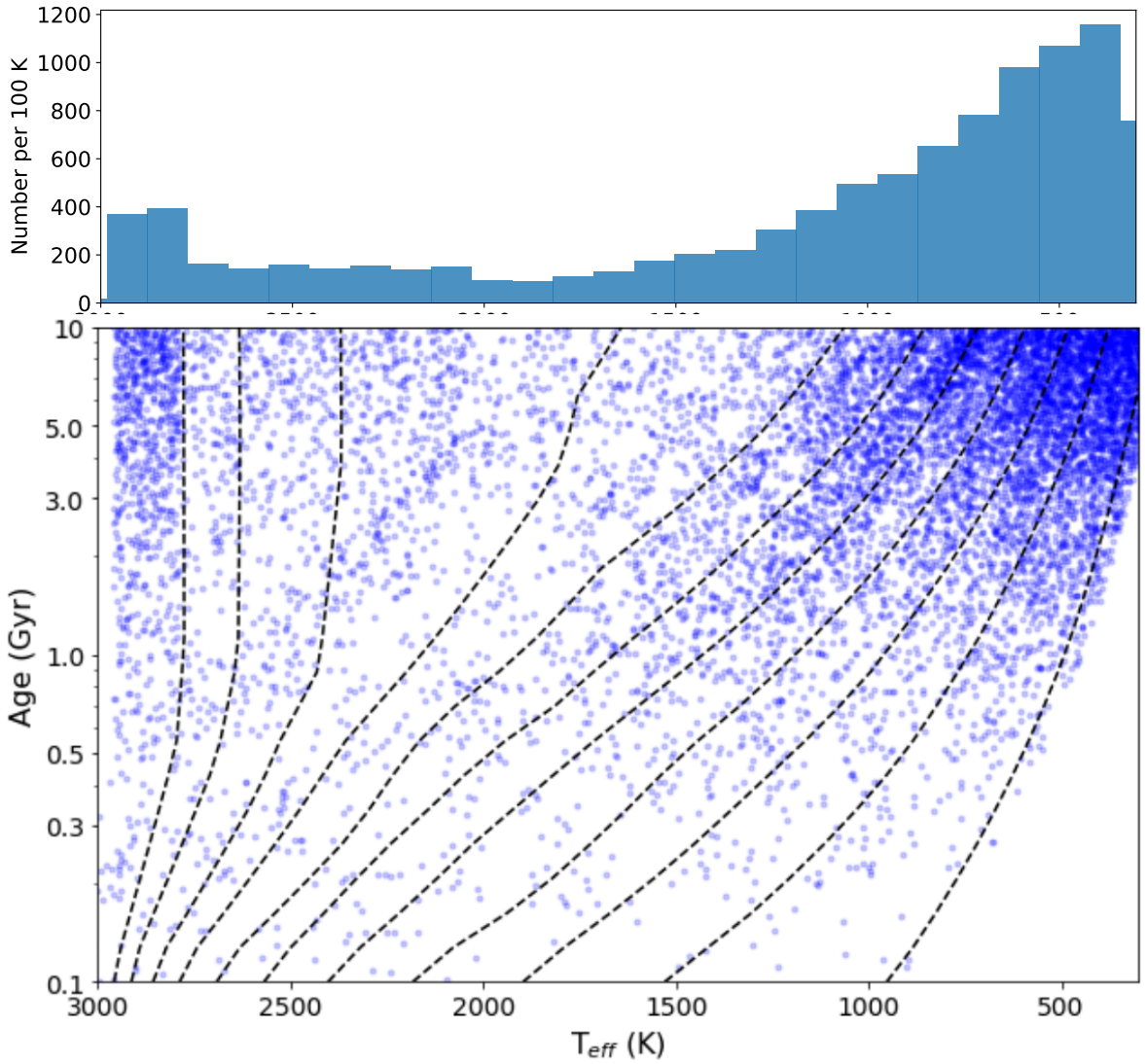
triaud+ (2013); he+ (2017)

…and those planets are *relatively* easy to find



triaud+ (2013); he+ (2017)

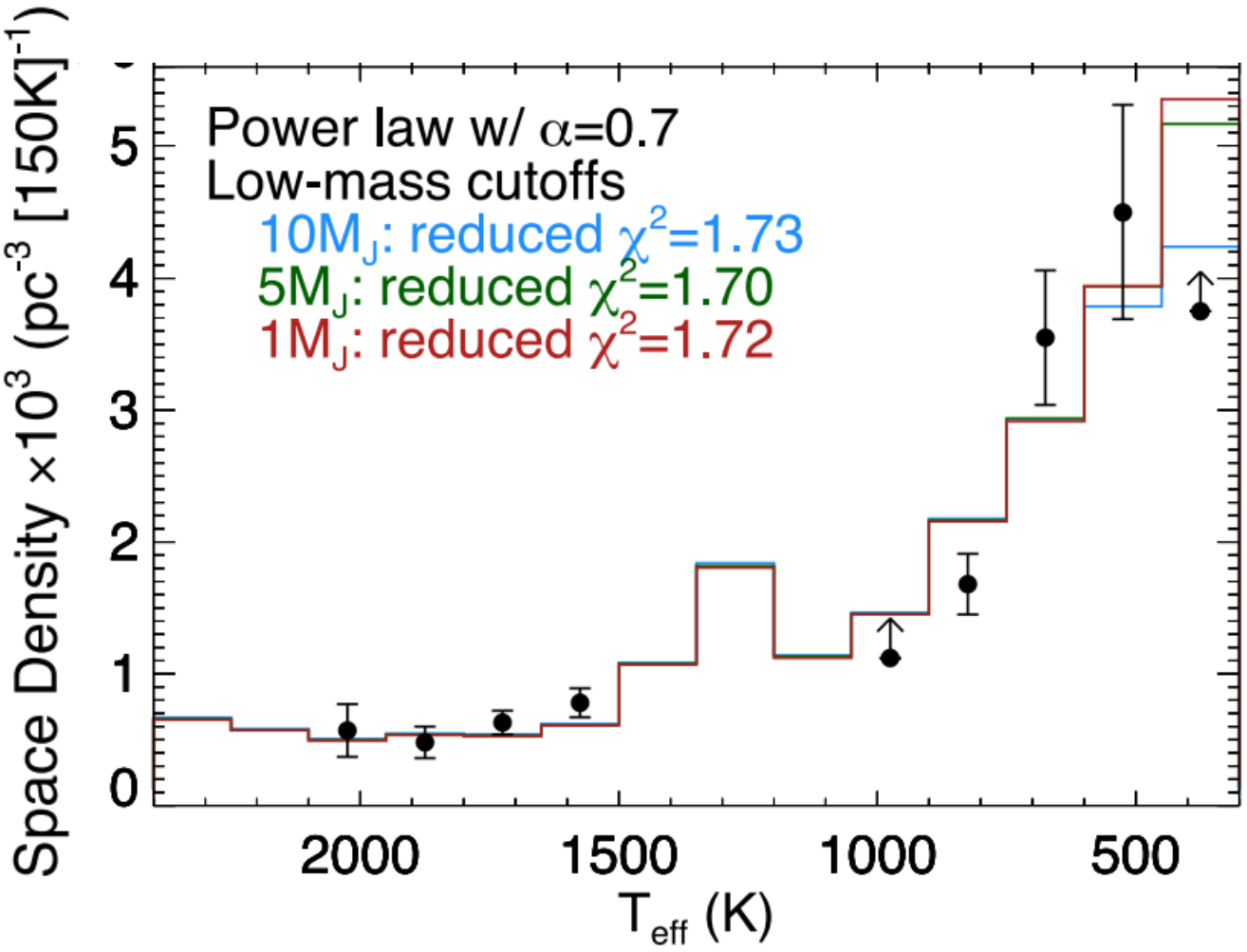
…but most of them are *really* cold & faint…



these are mostly (74%) t & y dwarfs

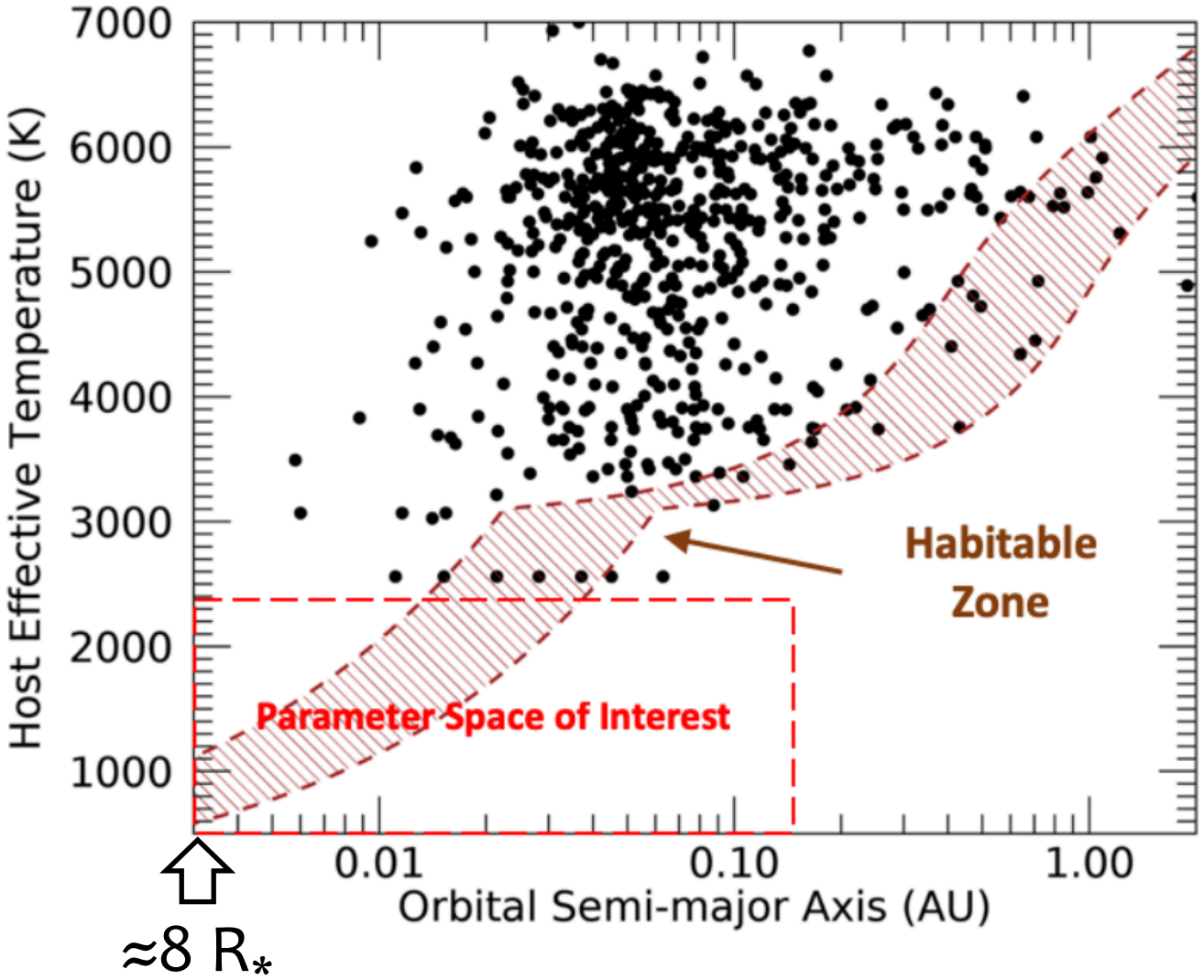
evolutionary models: baraffe et al. (2003)

…but most of them are *really* cold & faint…



kirkpatrick et al. (2019)

…maybe too cold & close for habitability

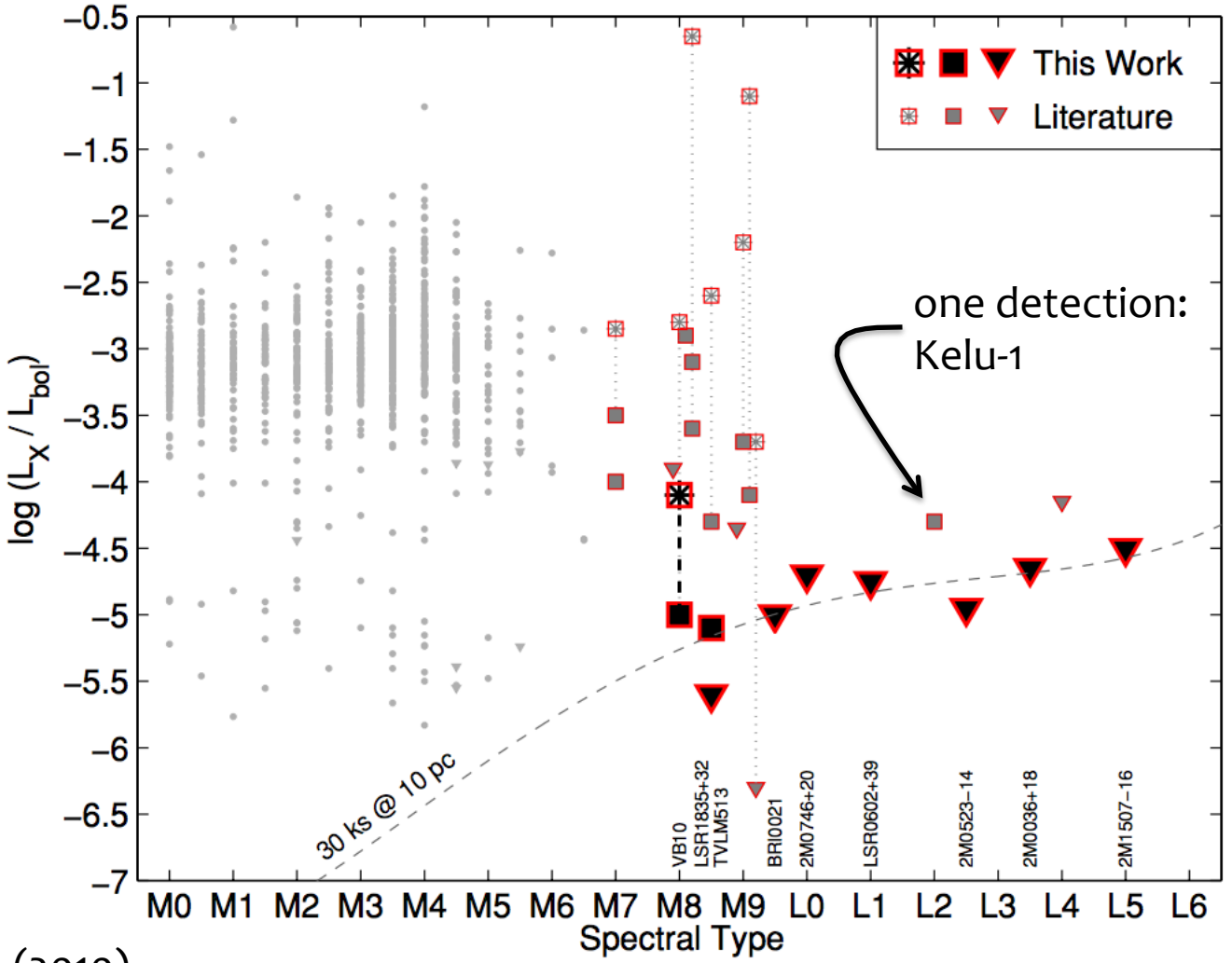


muirhead et al. (astro2020 wp)

about those hell worlds…

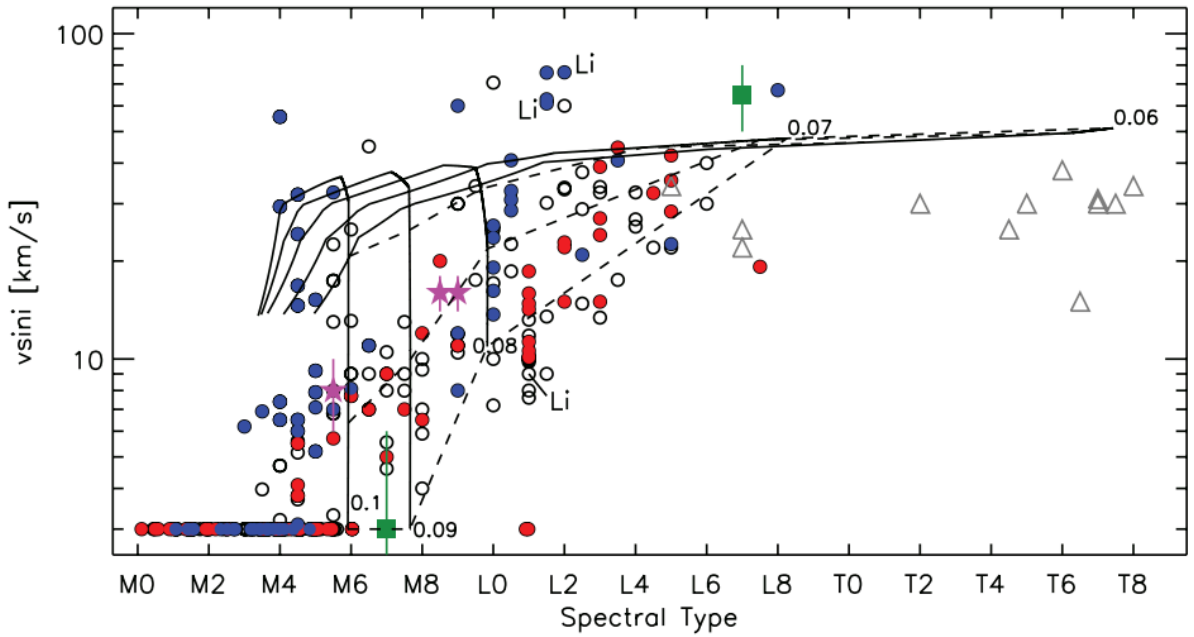
artwork by skwaggeragnerok88

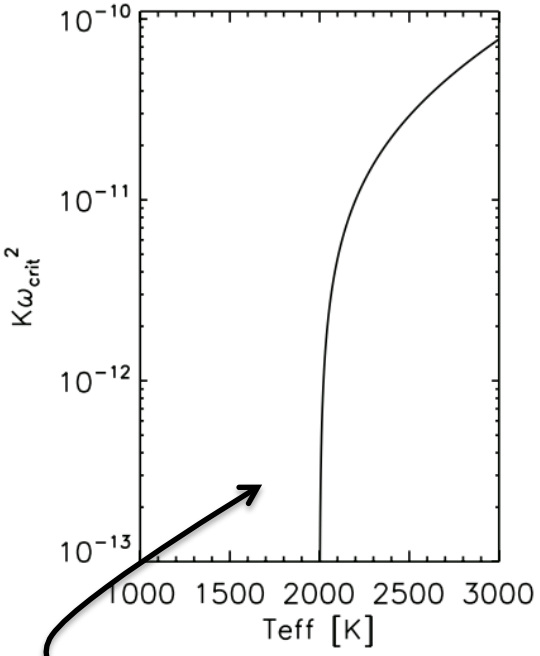
…high energy magnetic emission largely disappears at the end of the M dwarf sequence…



berger et al. (2010)

…and the winds seem to disappear…

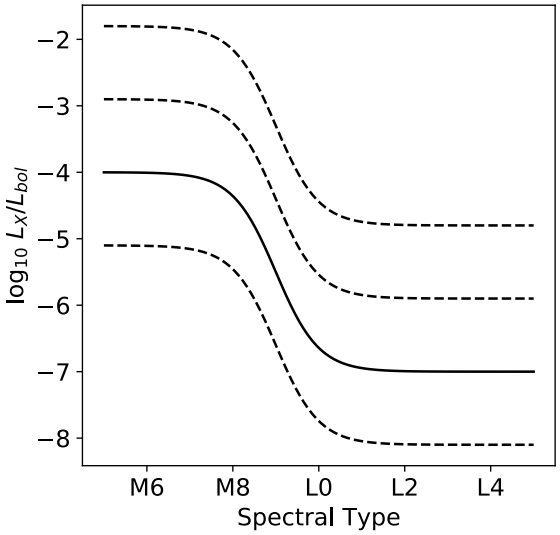




reiners & basri (2008)

t_{eff}-dependent dampening of braking efficiency

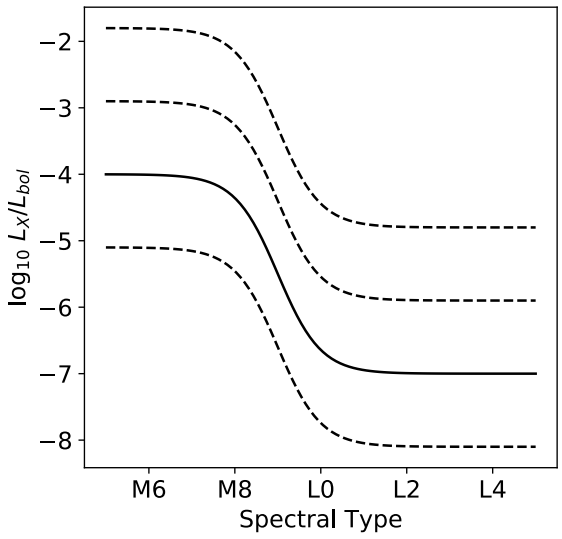
a toy model



+

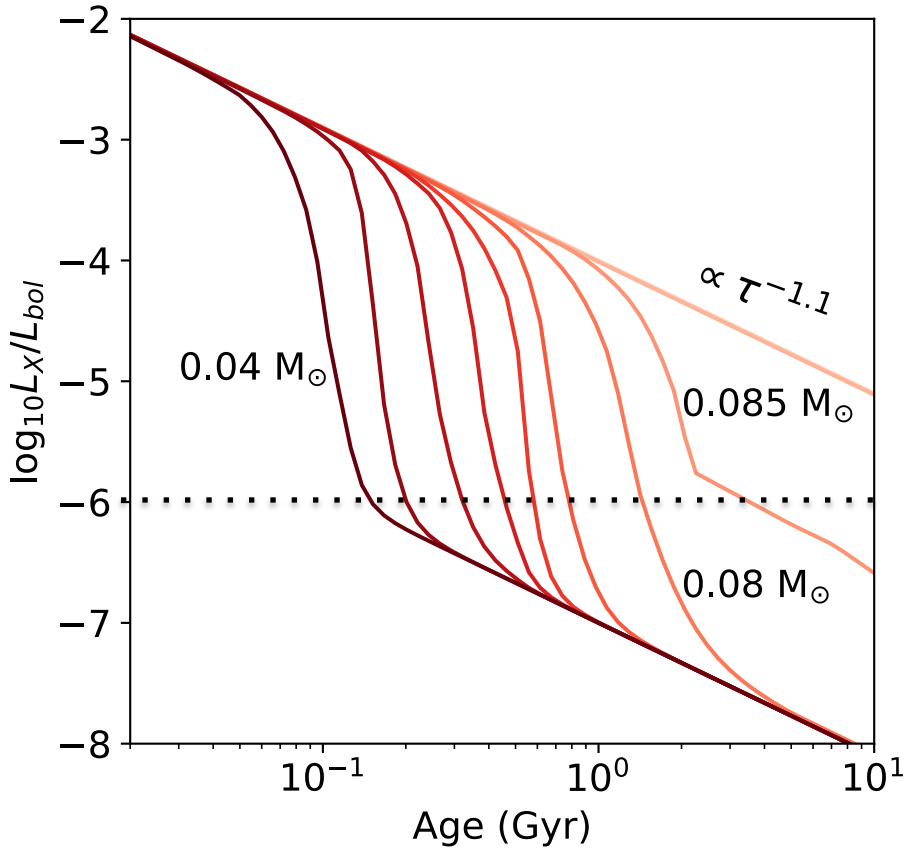
thermal evolution

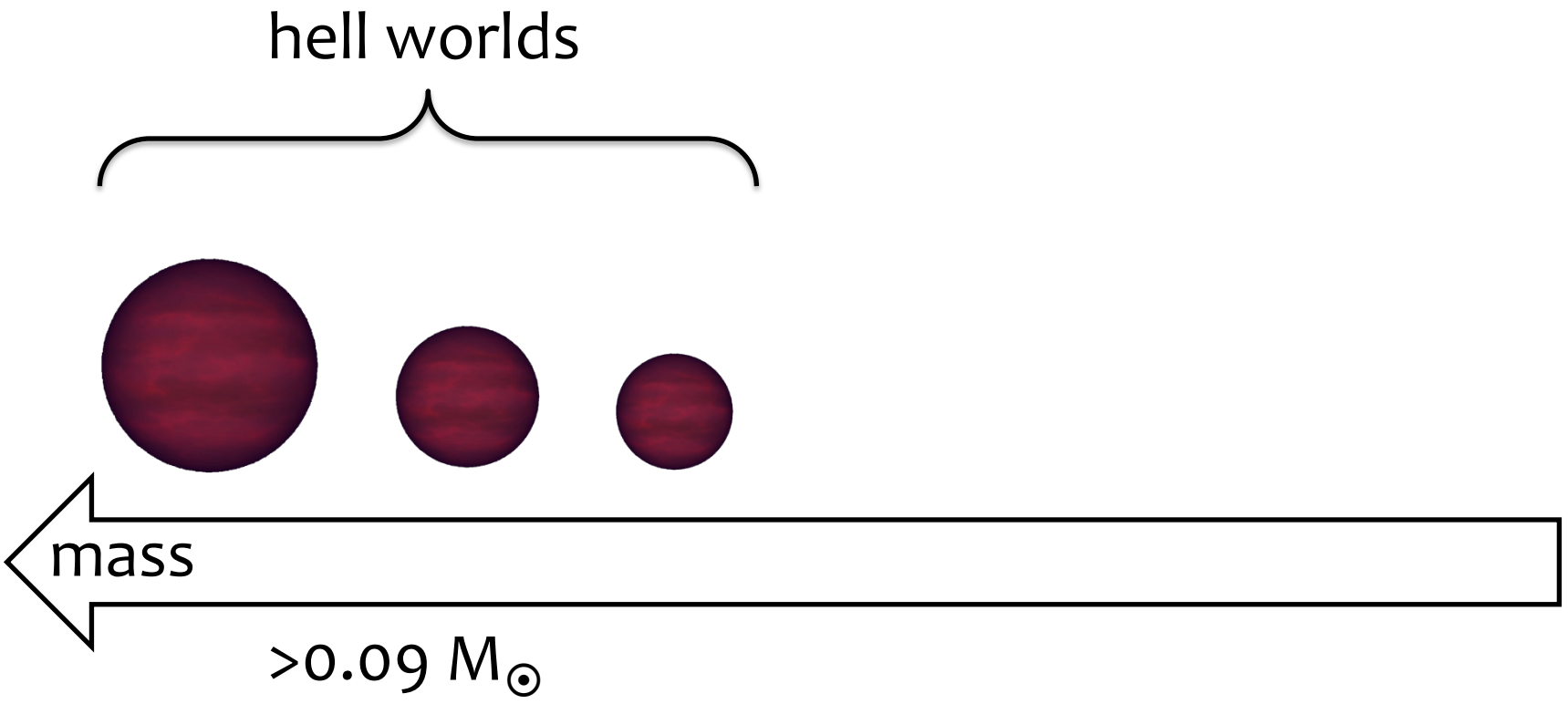
a toy model

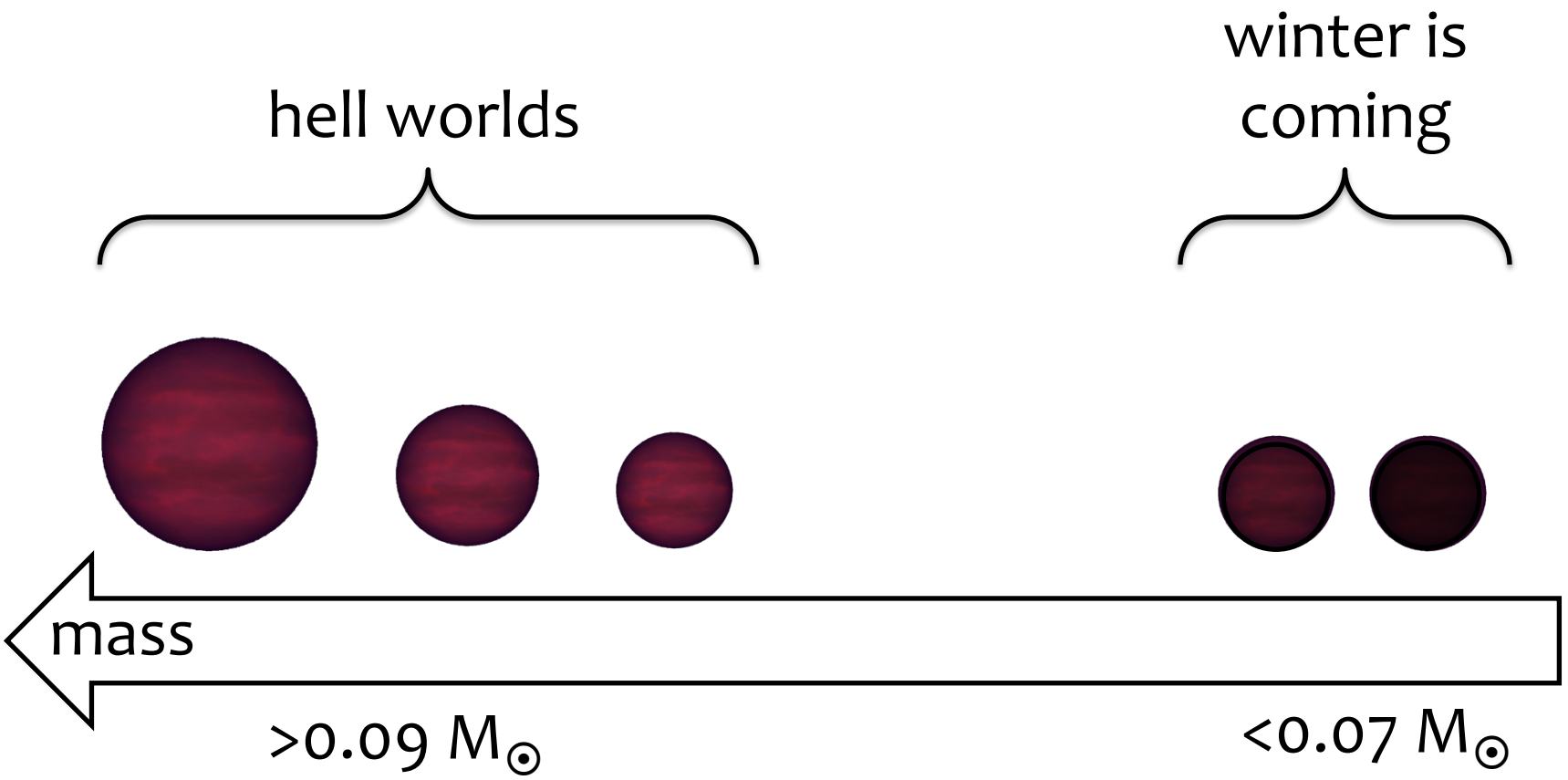


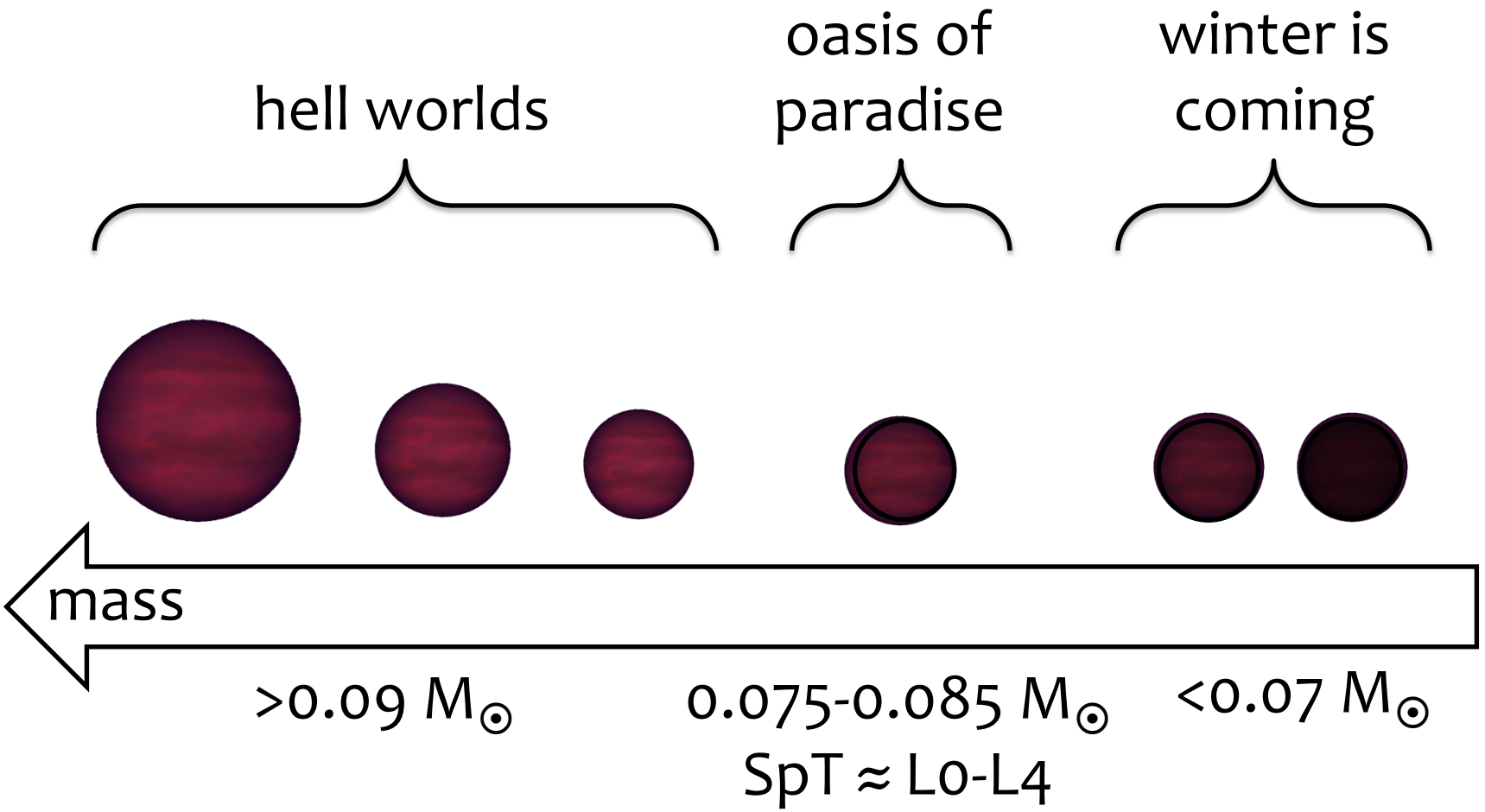
+

thermal evolution

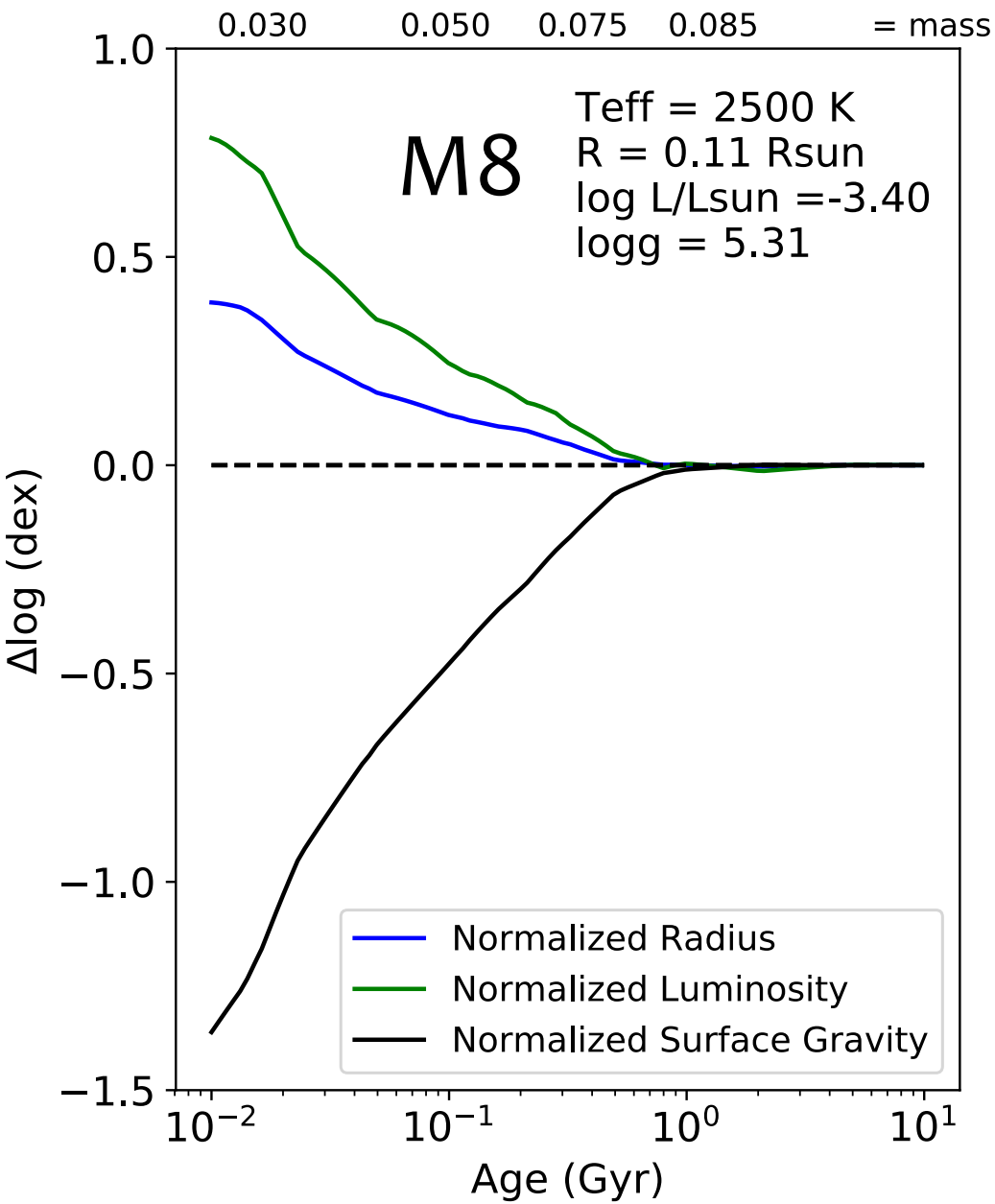



hell worlds
mass
>0.09 $M_\odot$

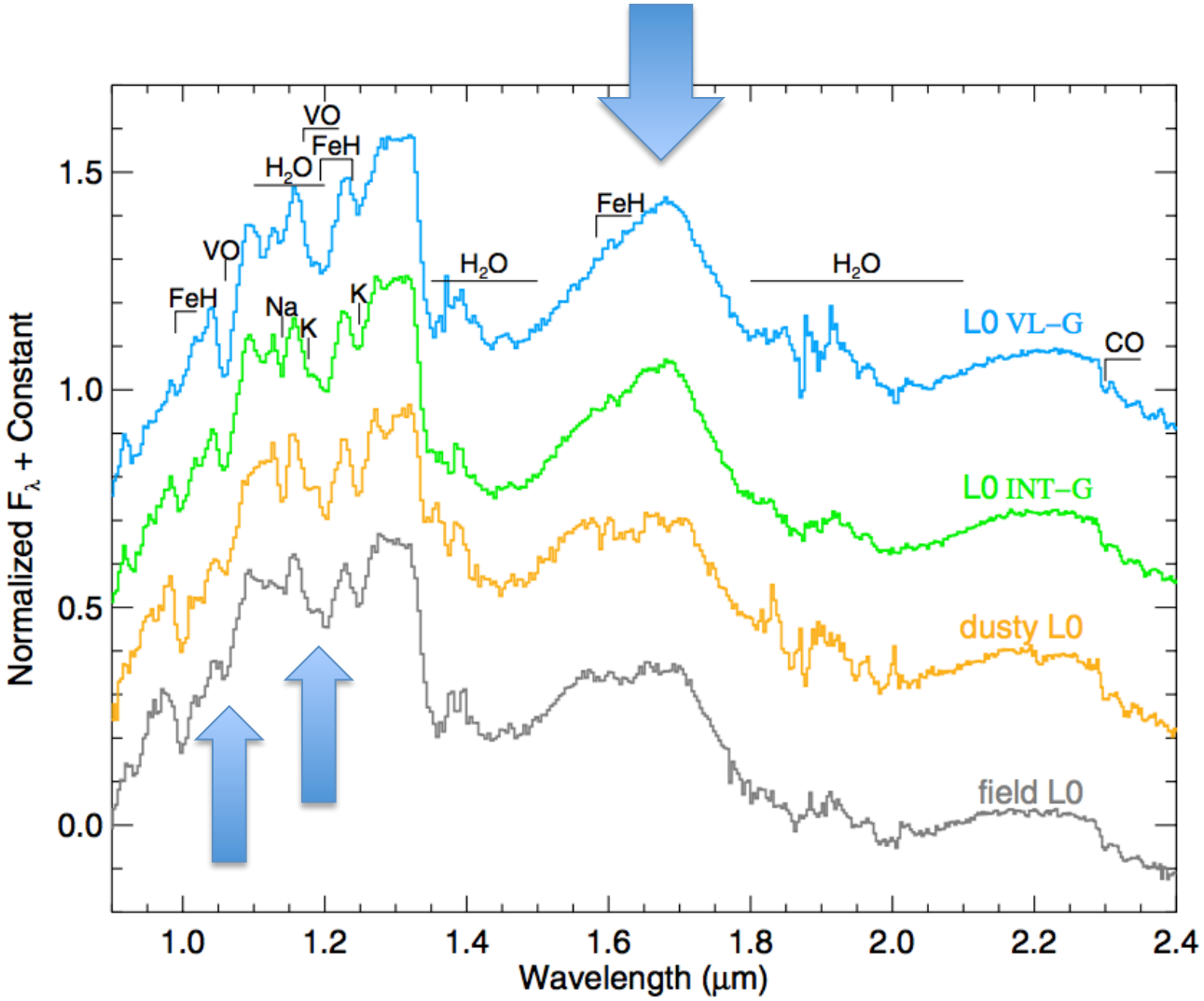

hell worlds
winter is coming
mass
>0.09 $M_\odot$
<0.07 $M_\odot$


hell worlds
oasis of paradise
winter is coming
mass
>0.09 M⊙
0.075-0.085 M⊙
SpT ≈ L0-L4
<0.07 M⊙

an issue of age

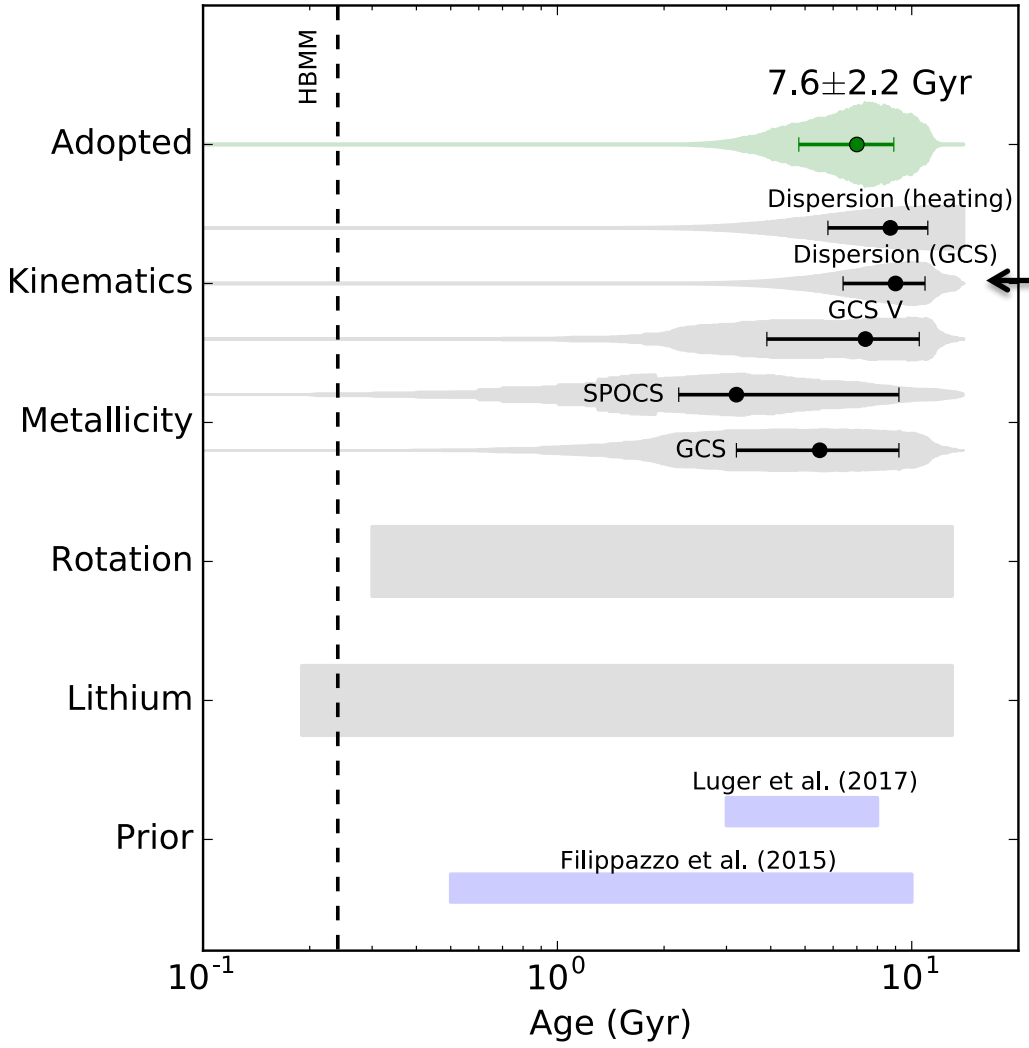


getting ages for young ultracool dwarfs is doable…



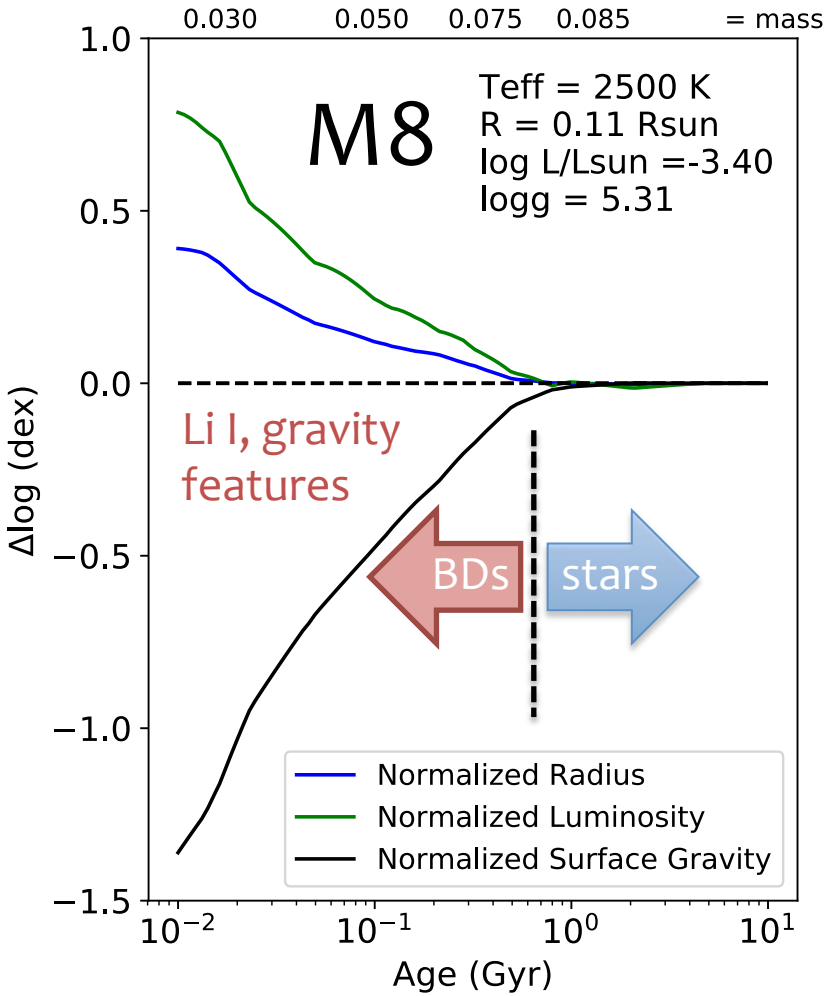
allers & liu (2013)

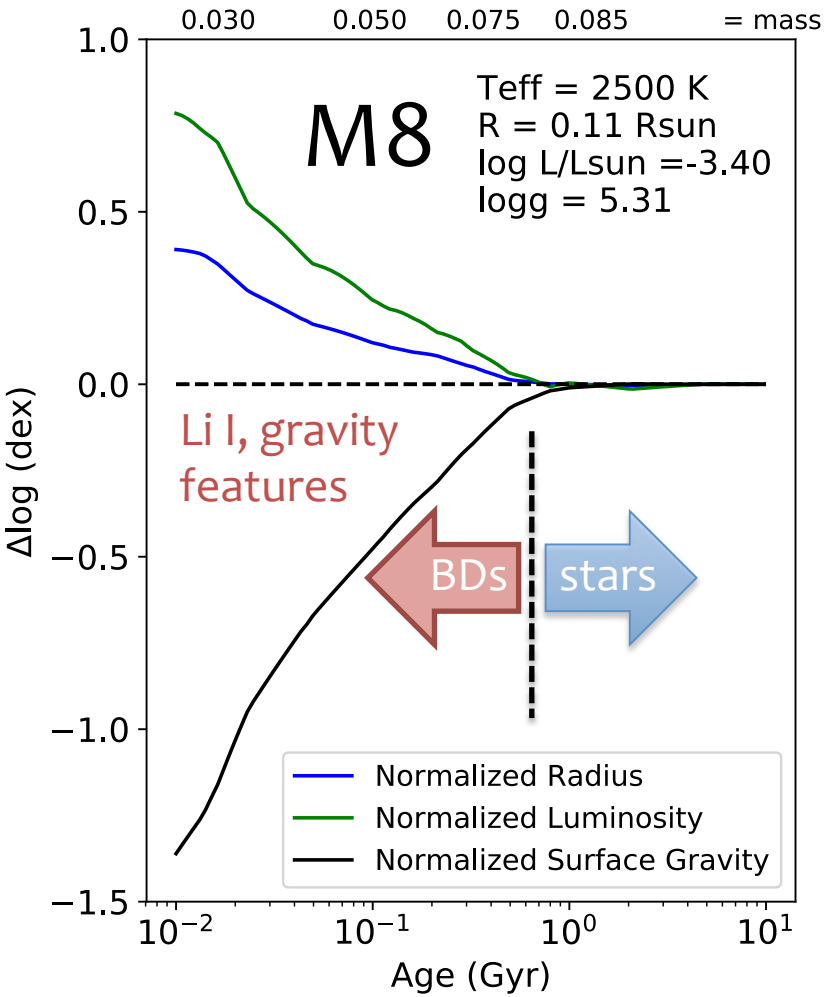
… but getting ages for old ultracool dwarfs is hard

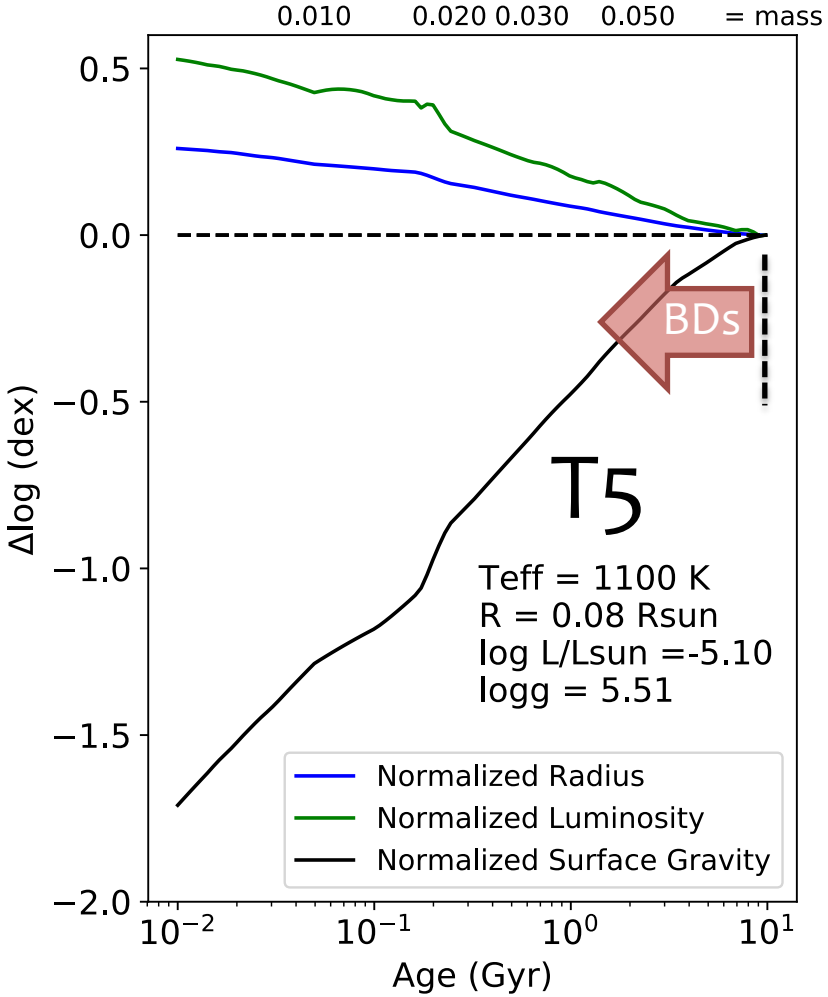


kinematics provided the most predictive power for trappist-1

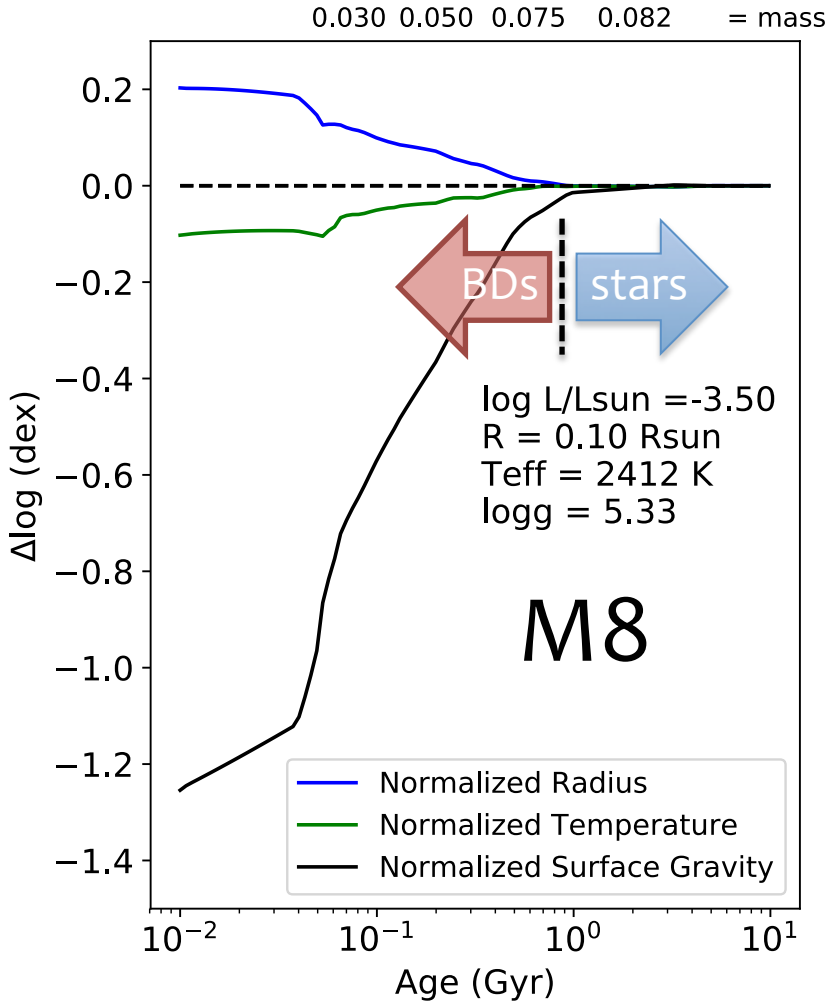
burgasser & mamajek (2017)

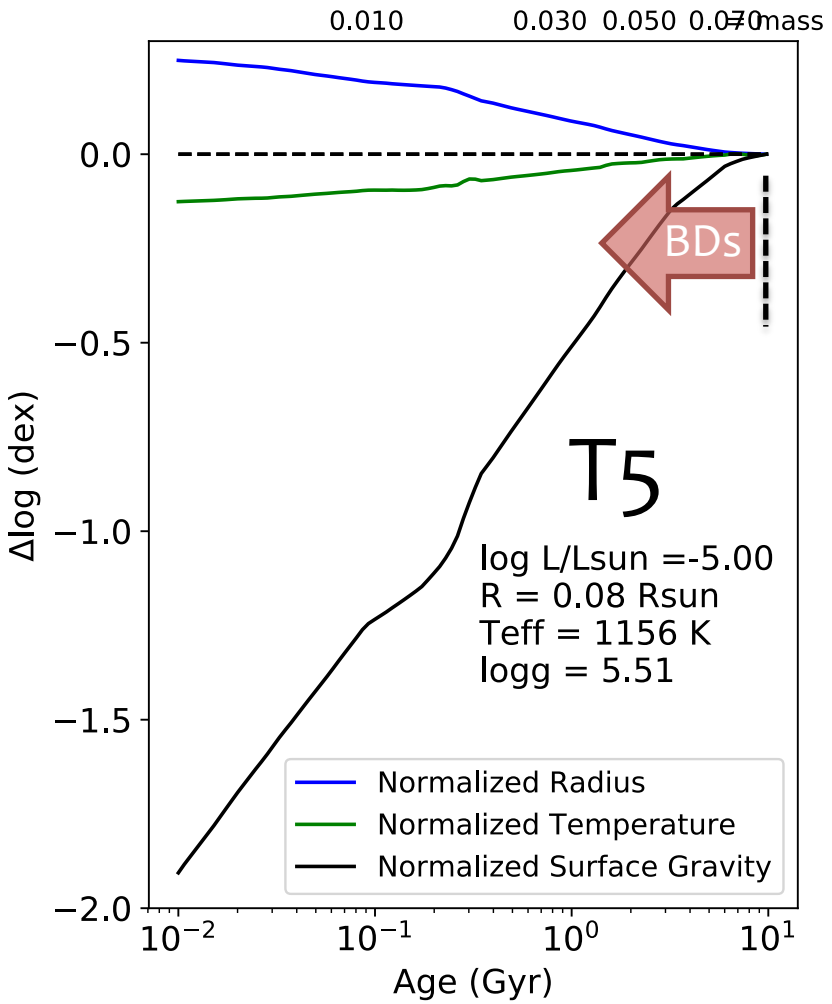

0.030
0.050
0.075
0.085
= mass
M8
Teff = 2500 K
R = 0.11 Rsun
log L/Lsun =-3.40
logg = 5.31
Li I, gravity features
BDs
stars
Normalized Radius
Normalized Luminosity
Normalized Surface Gravity
Δlog (dex)
Age (Gyr)
1.0
0.5
0.0
−0.5
−1.0
−1.5
10^{-2}
10^{-1}
10^{0}
10^{1}



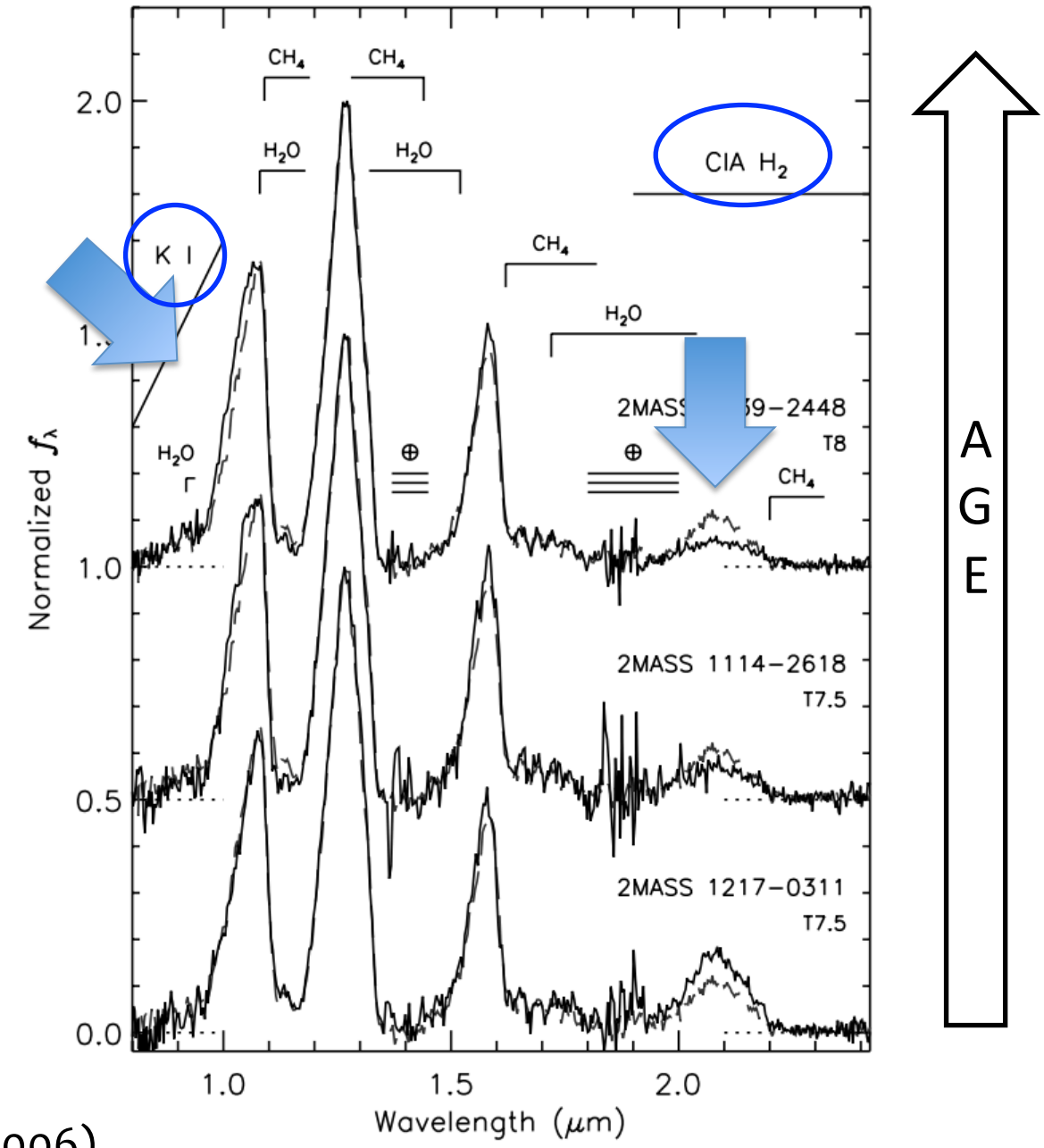


cold brown dwarfs are natural clocks



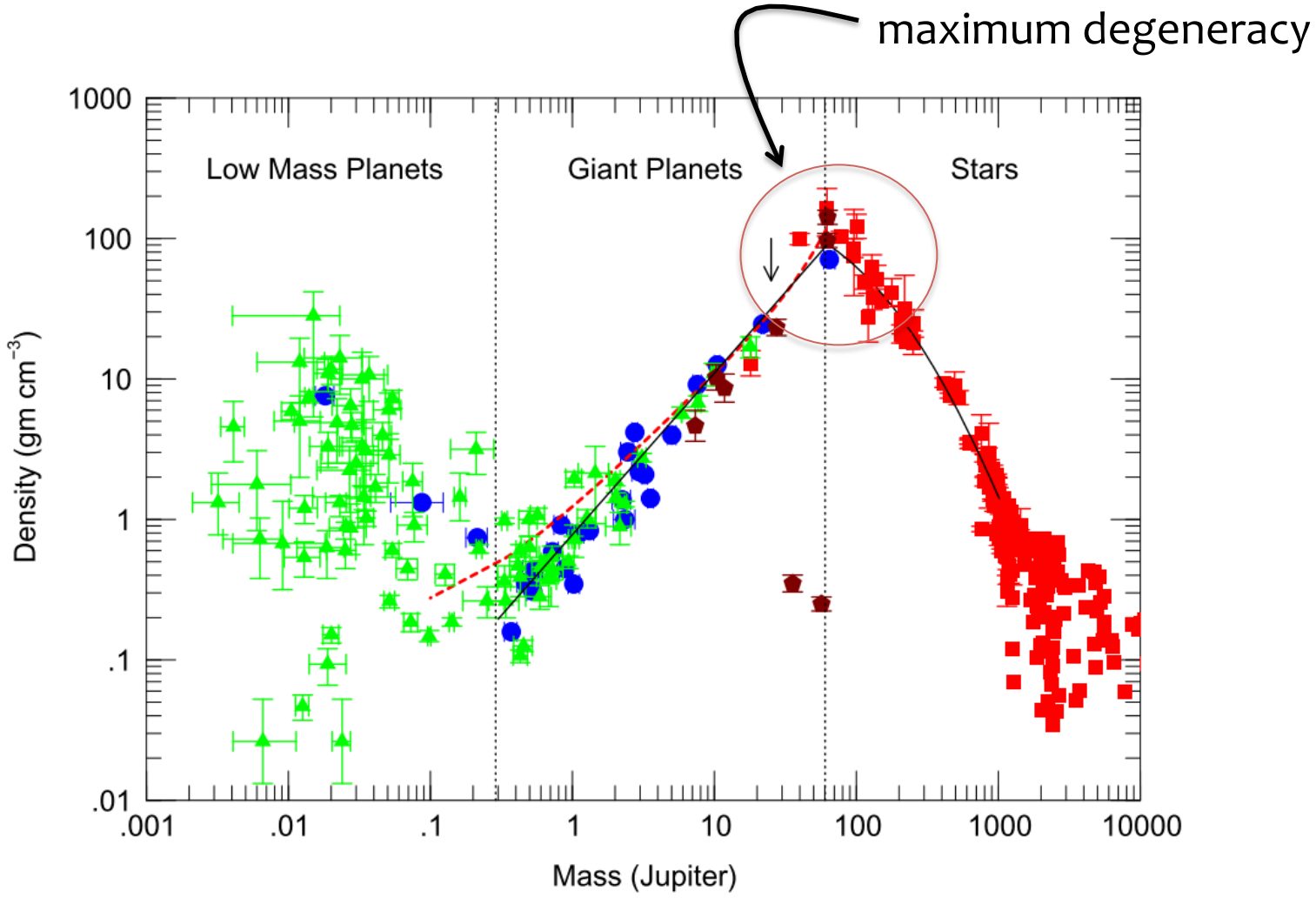


cold brown dwarfs are natural clocks



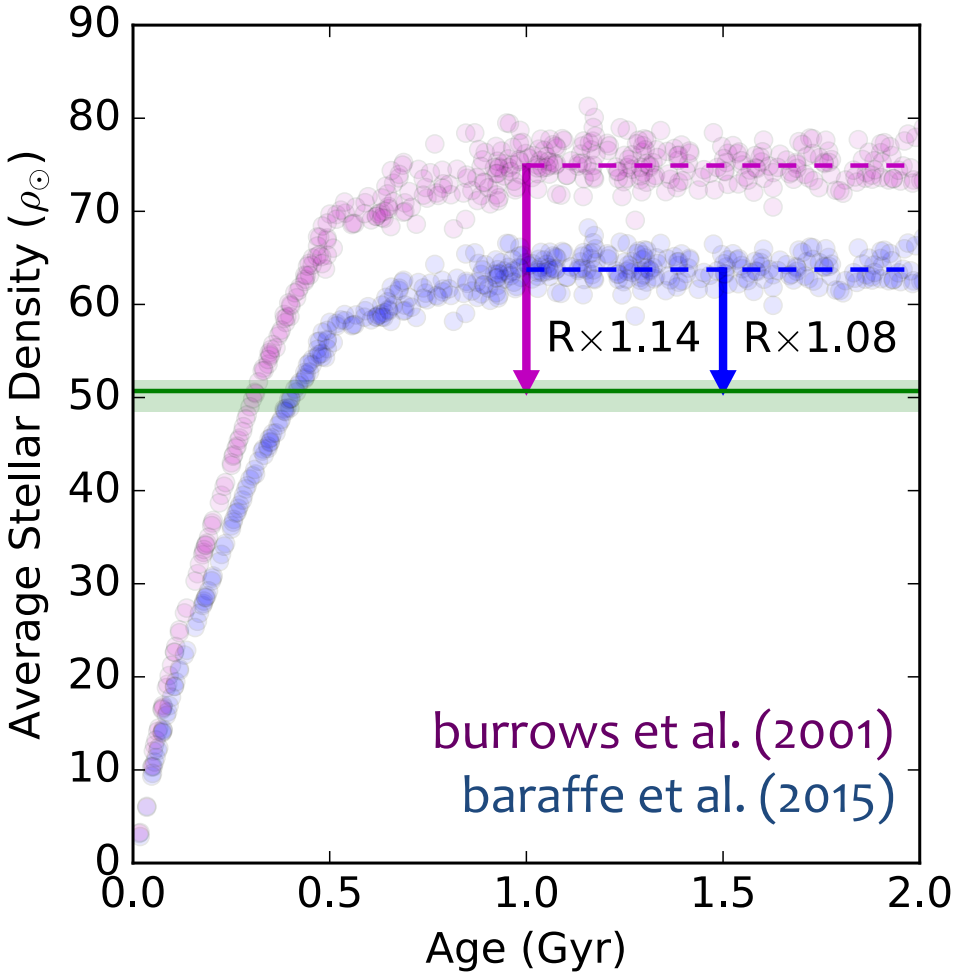
burgasser et al. (2006)

exoplanet searches also helps BD physics



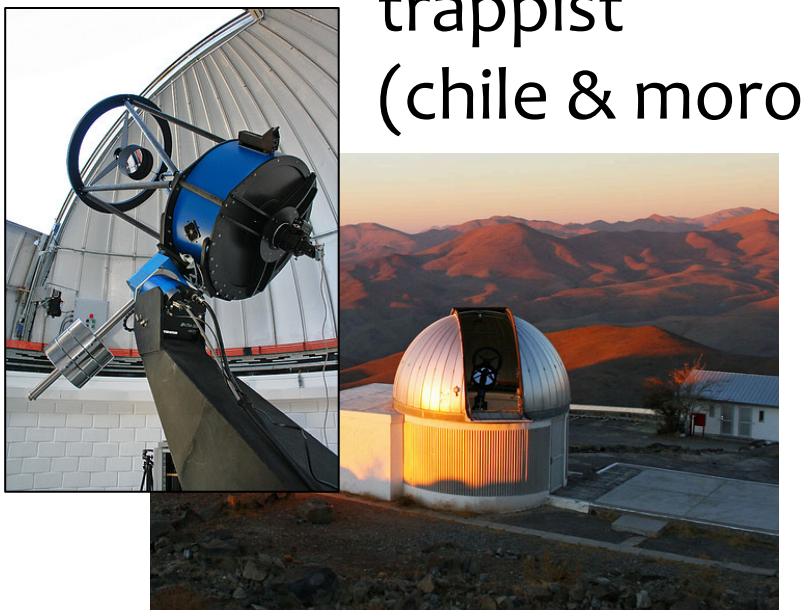
hatzes & rauer (2015)

exoplanet searches also helps BD physics



burgasser & mamajek (2017)

we won't know if we don't look...



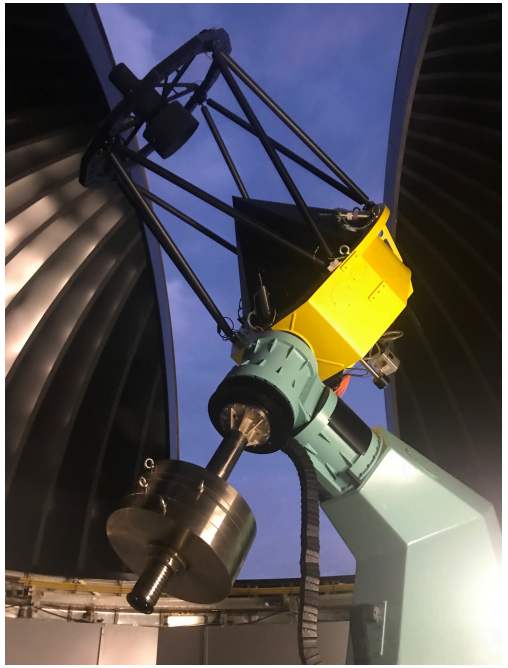
trappist
(chile & morocco)

"TBD"
phil muirhead
(us/az)

SPECULOOS
Search for habitable Planets EClipsing ULtra-cOOl Stars

(chile)

saint-ex
(san pedro
martir,
mx)



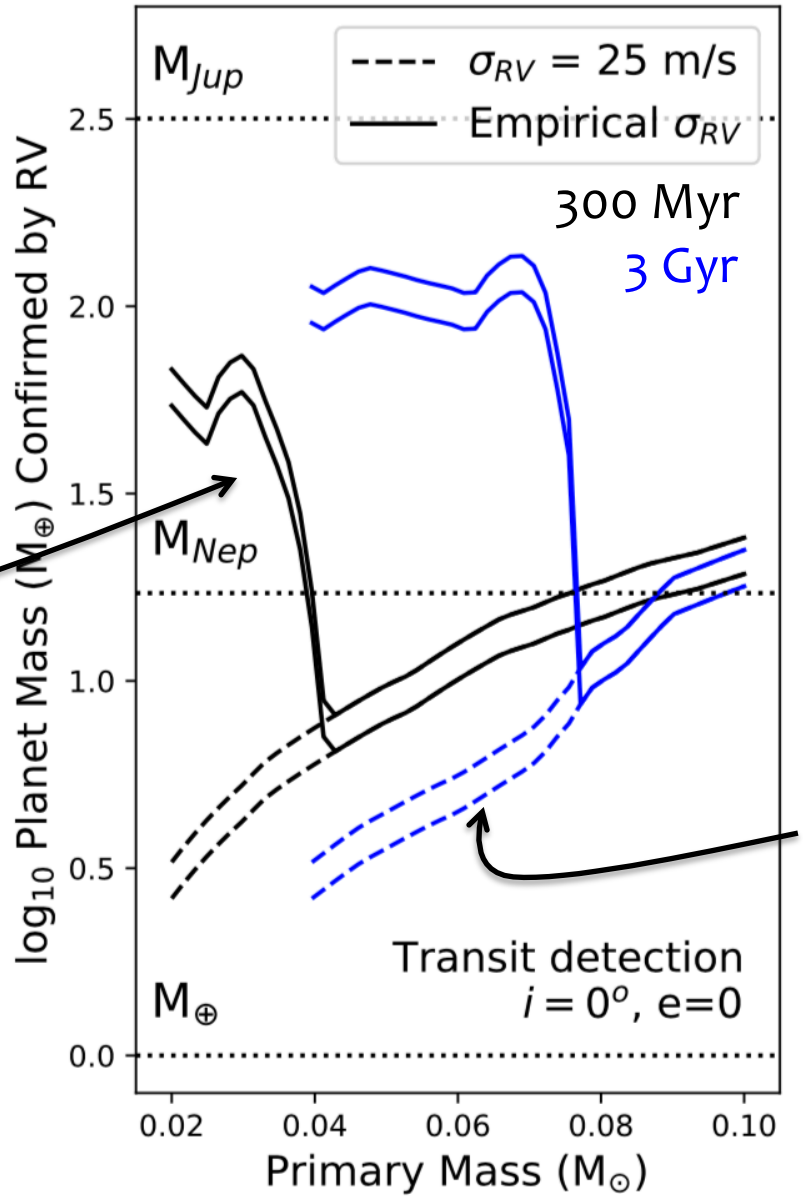
take aways:

1. **don't ignore the brown dwarfs!** they are plentiful, potentially planet-rich, and have strong detection signals
2. habitable zones will either be fried or frozen, but there is a narrow range of masses (0.075-0.085 $M_{\odot}$) that may be just right
3. habitability aside, brown dwarf evolution can be used to infer system ages and study exoplanet evolution and formation history over the entire age of the galaxy
4. searches have begun, but we need help!

additional slides

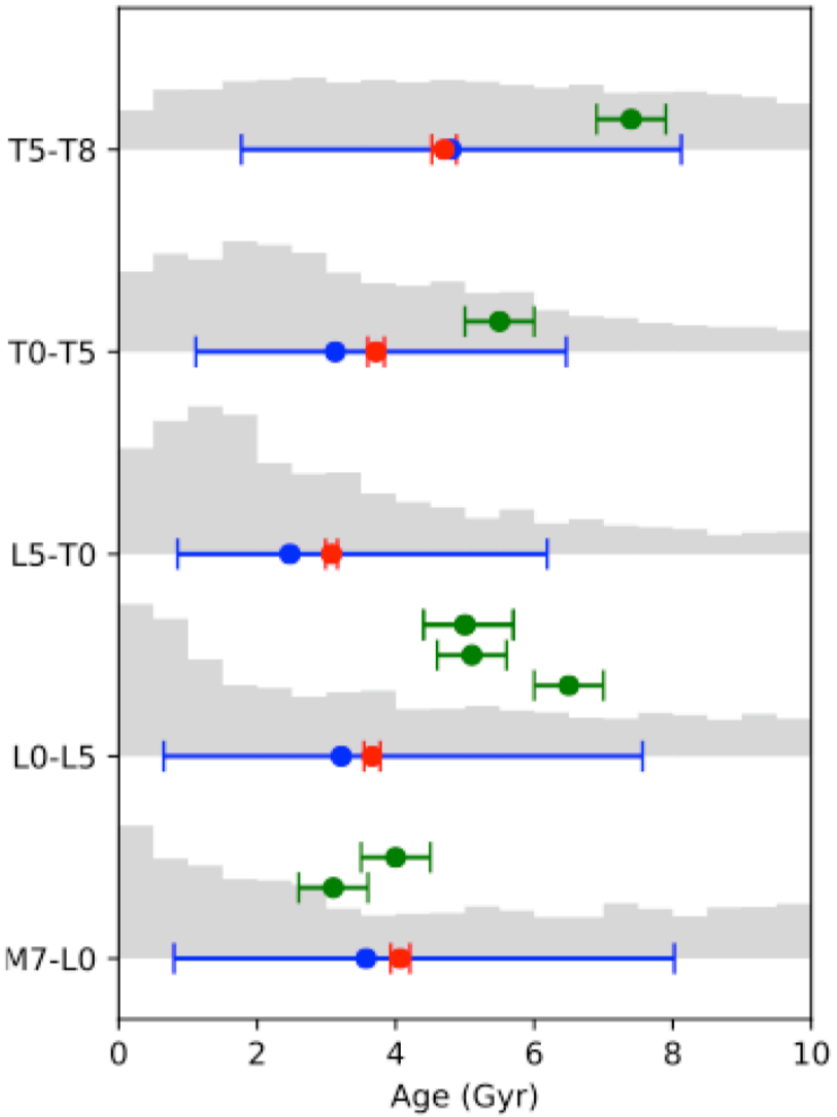
…but we need to improve nir-rv precisions

actual performance



s/n > 50

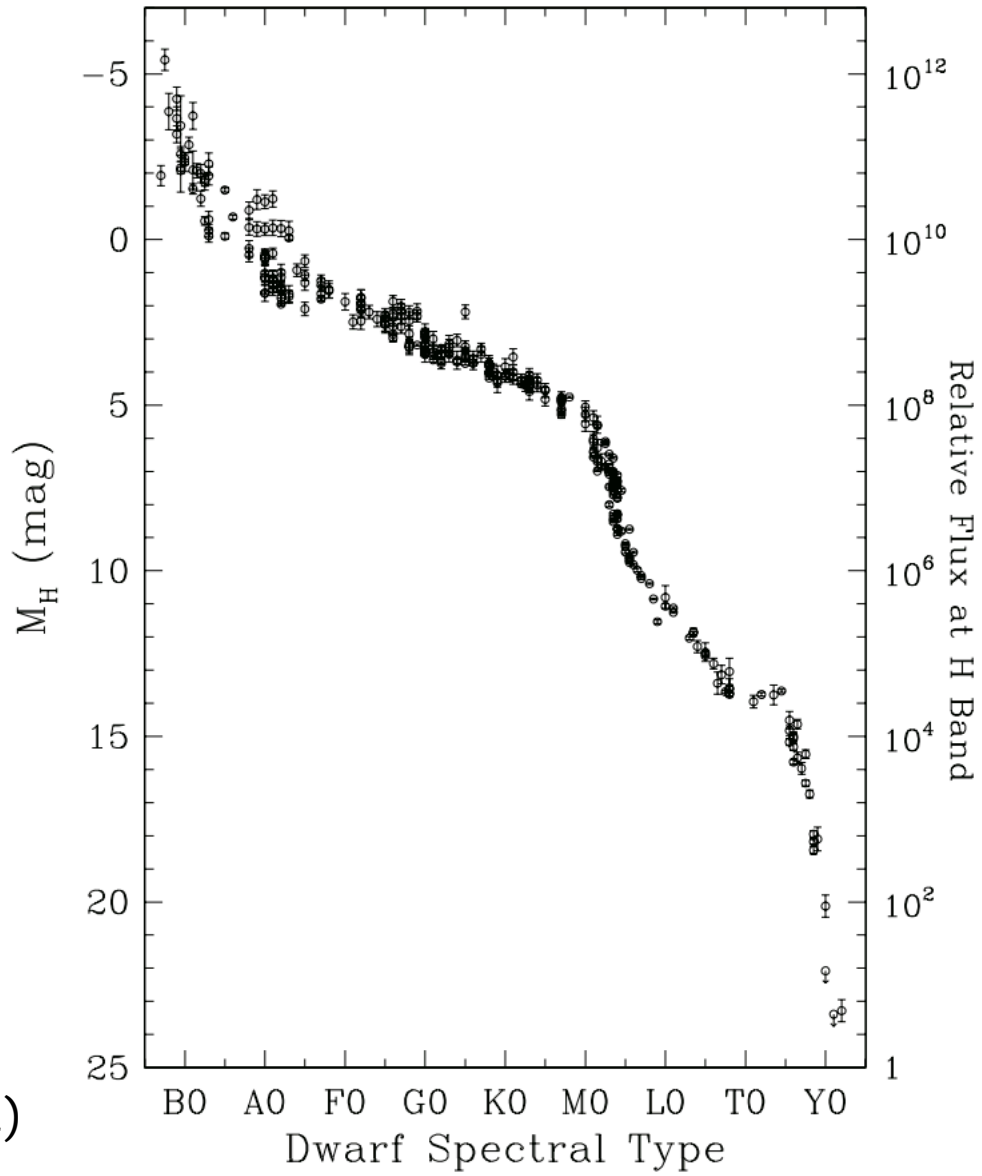
what are the ages of the local bd population?



simulation
- range of ages
- kinematic ages

measurements
- kinematic ages

… but most of them are *really* cold & faint…



kirkpatrick et al. (2012)