New Evidence for a Substellar Over-Luminosity Problem

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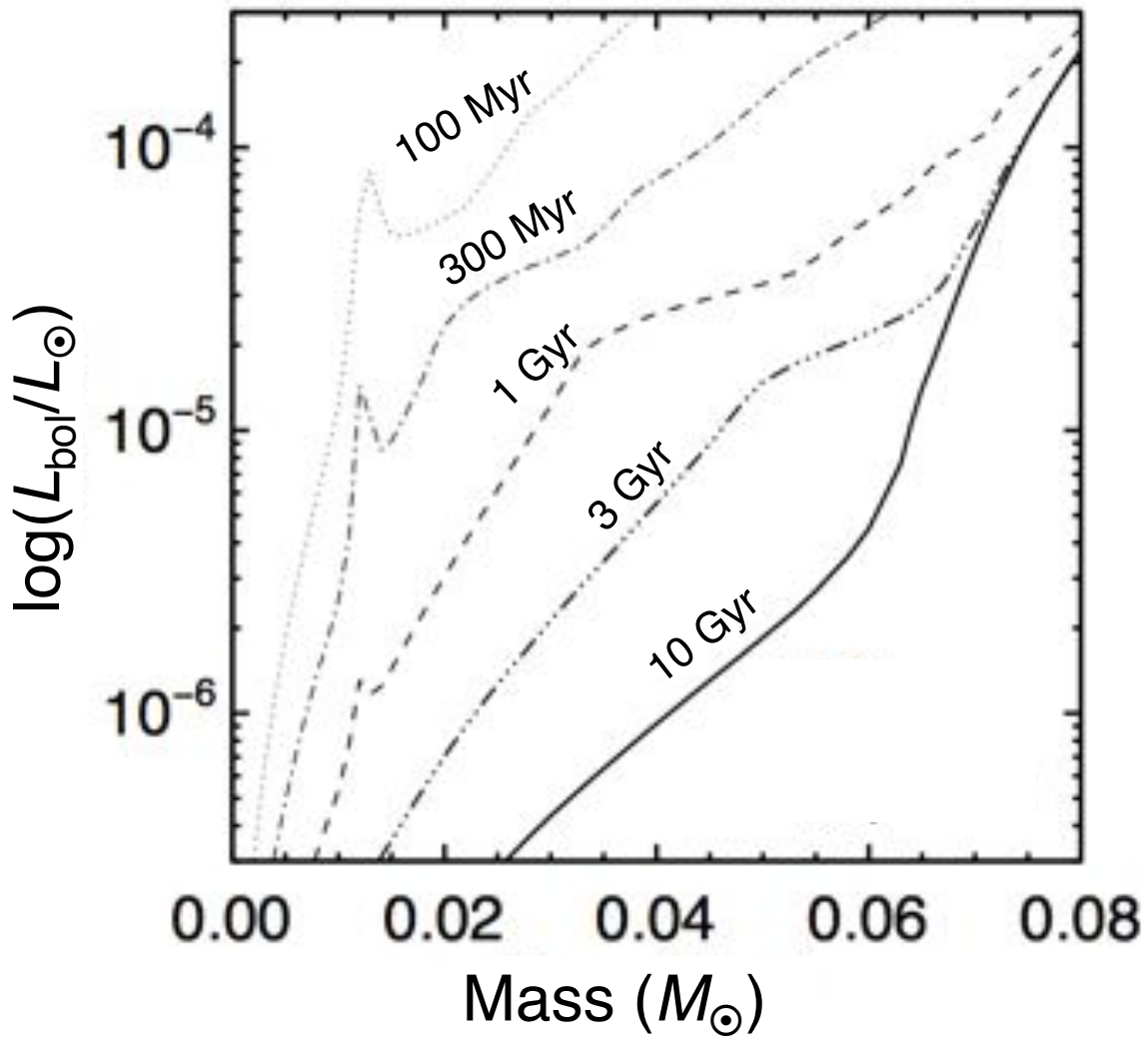
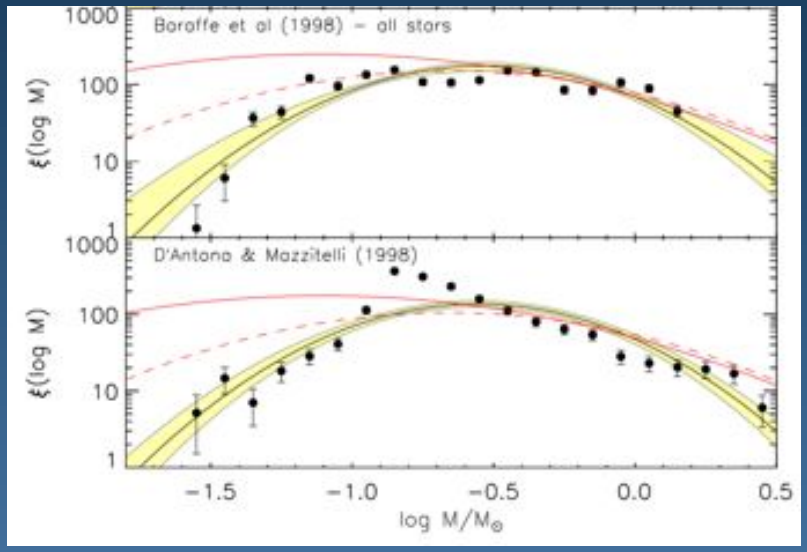
Michael Liu, Michael Ireland



Saumon & Marley (2008) “hybrid” tracks

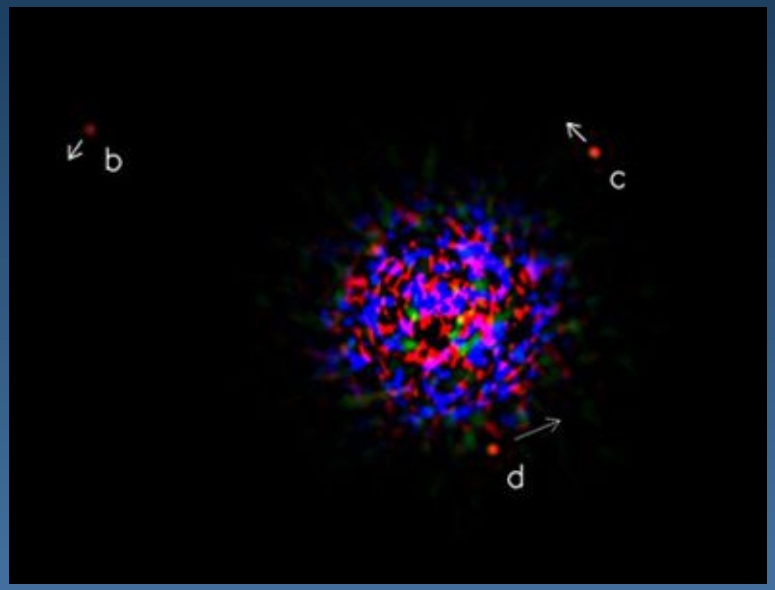
Trent Dupuy (CfA/SAO)

Initial mass function

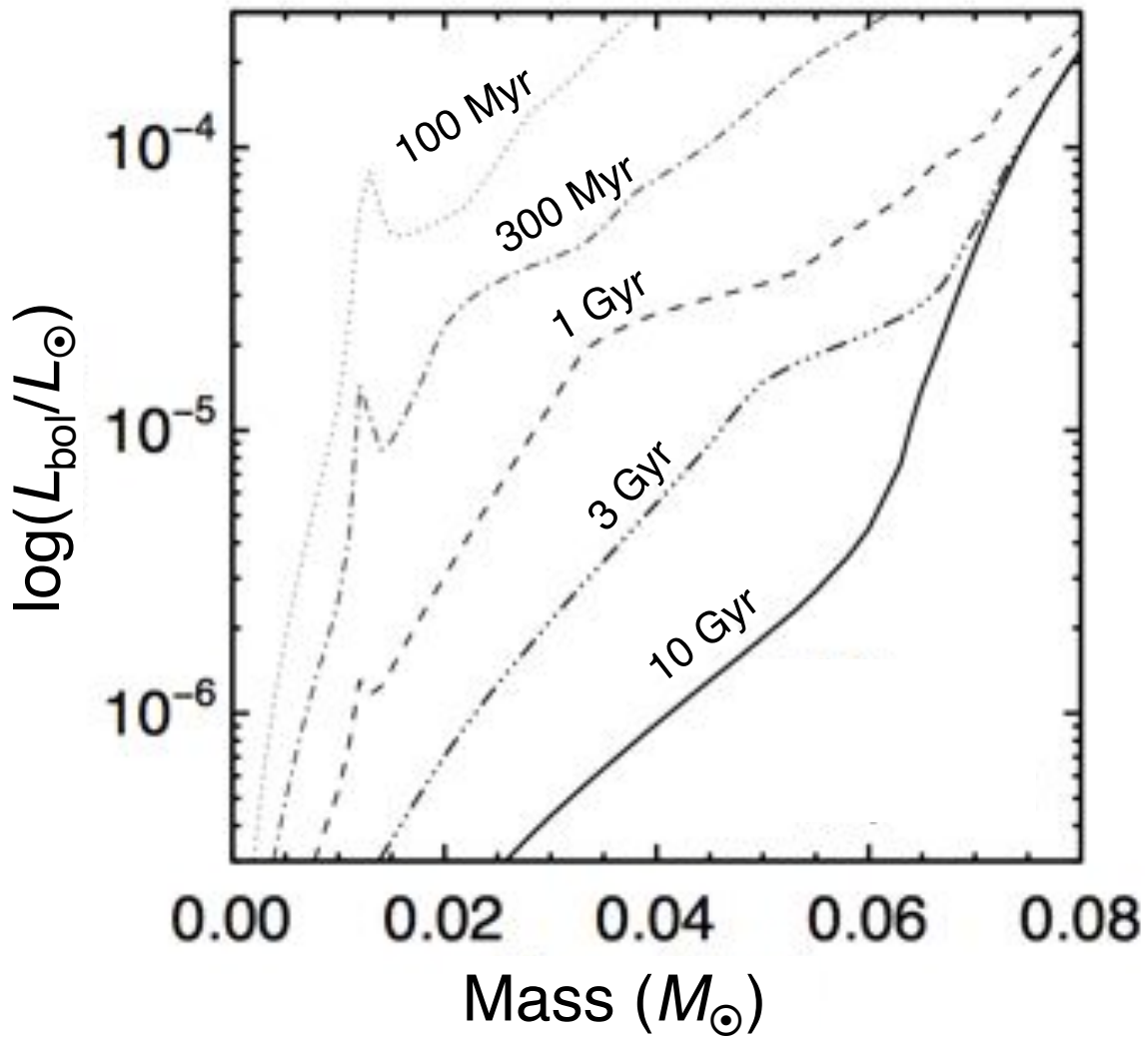


Da Rio et al. (2012)

Directly imaged planets



HR 8799 (Marois et al. 2008, 2010)



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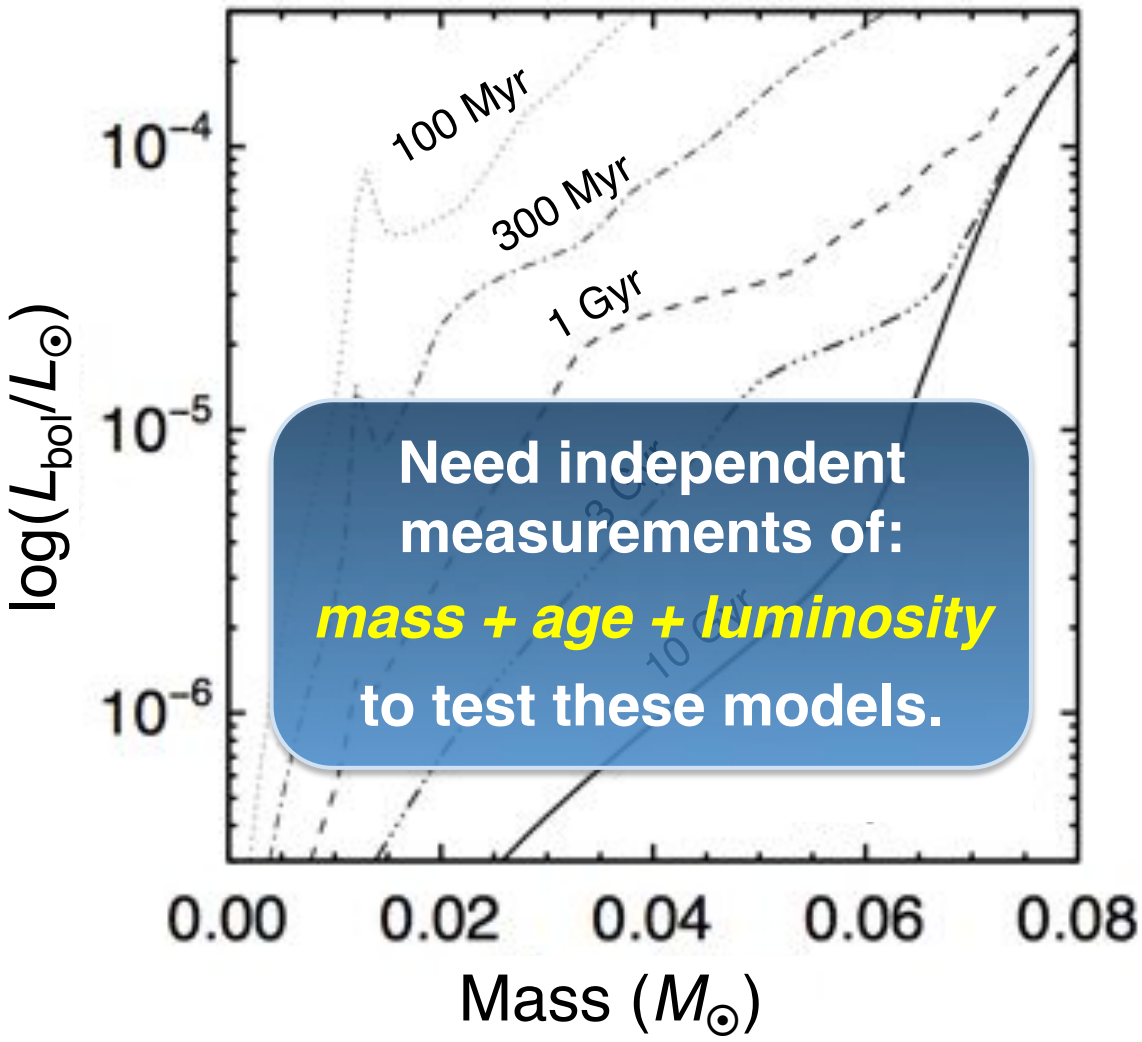

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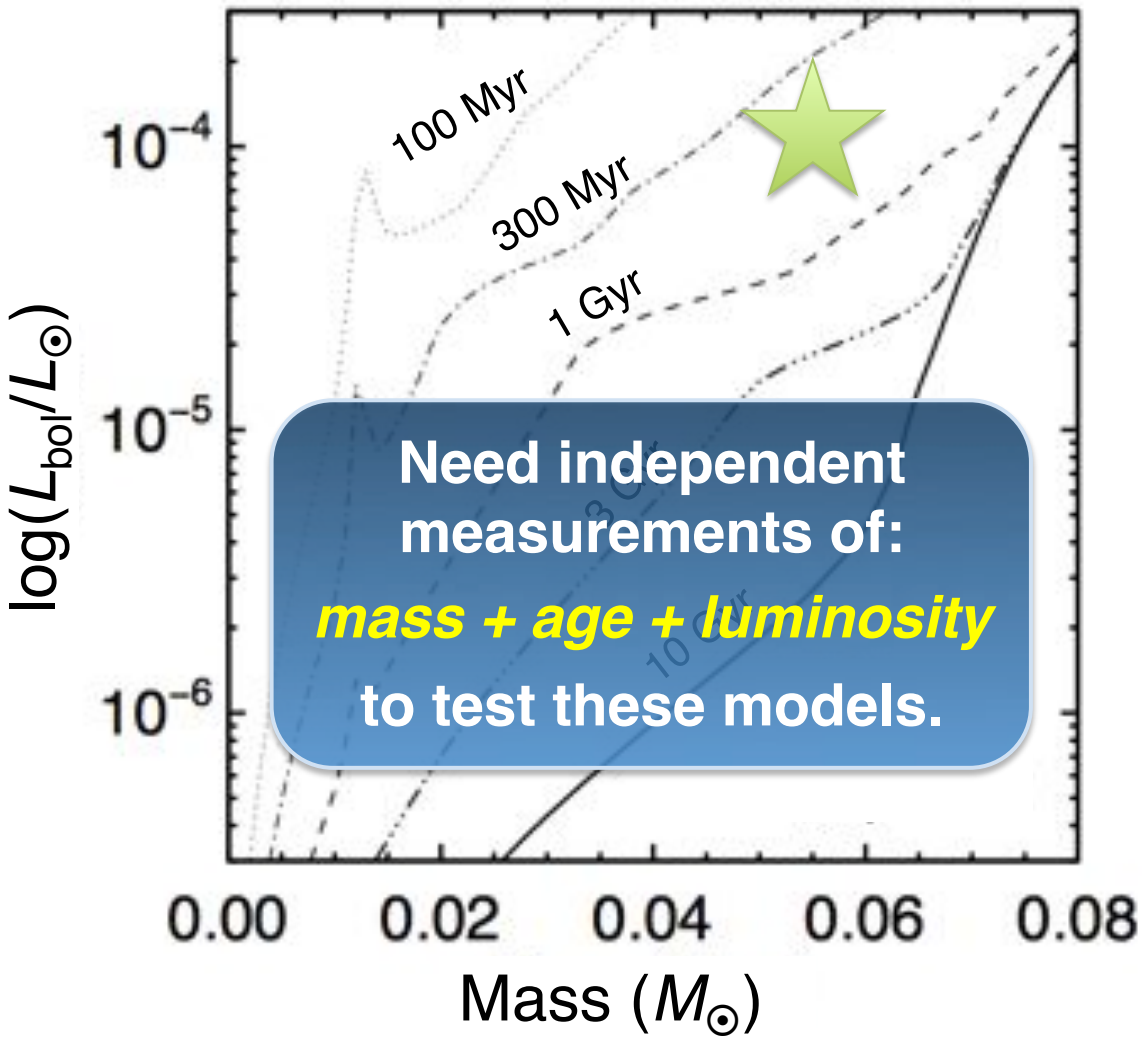

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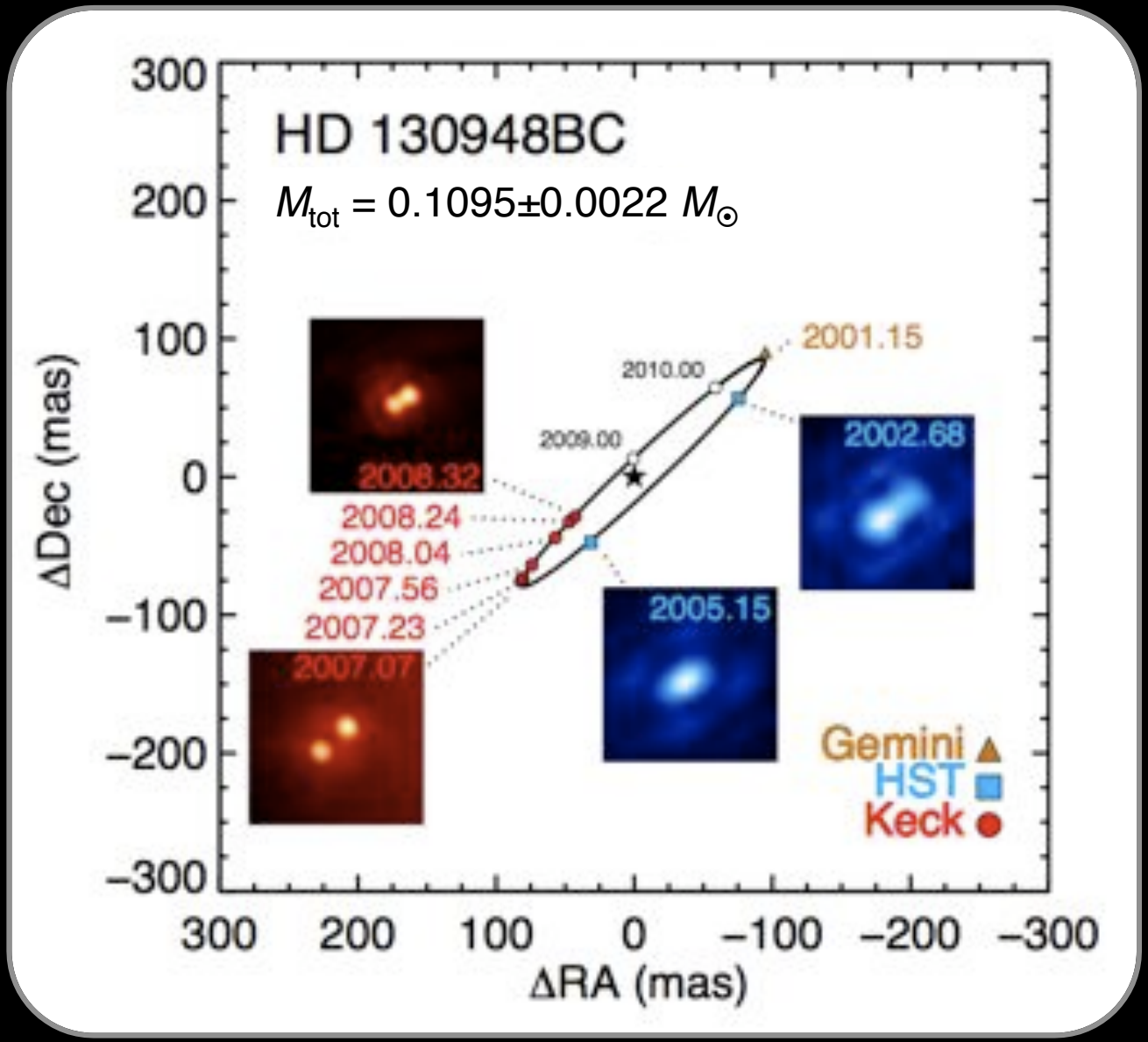

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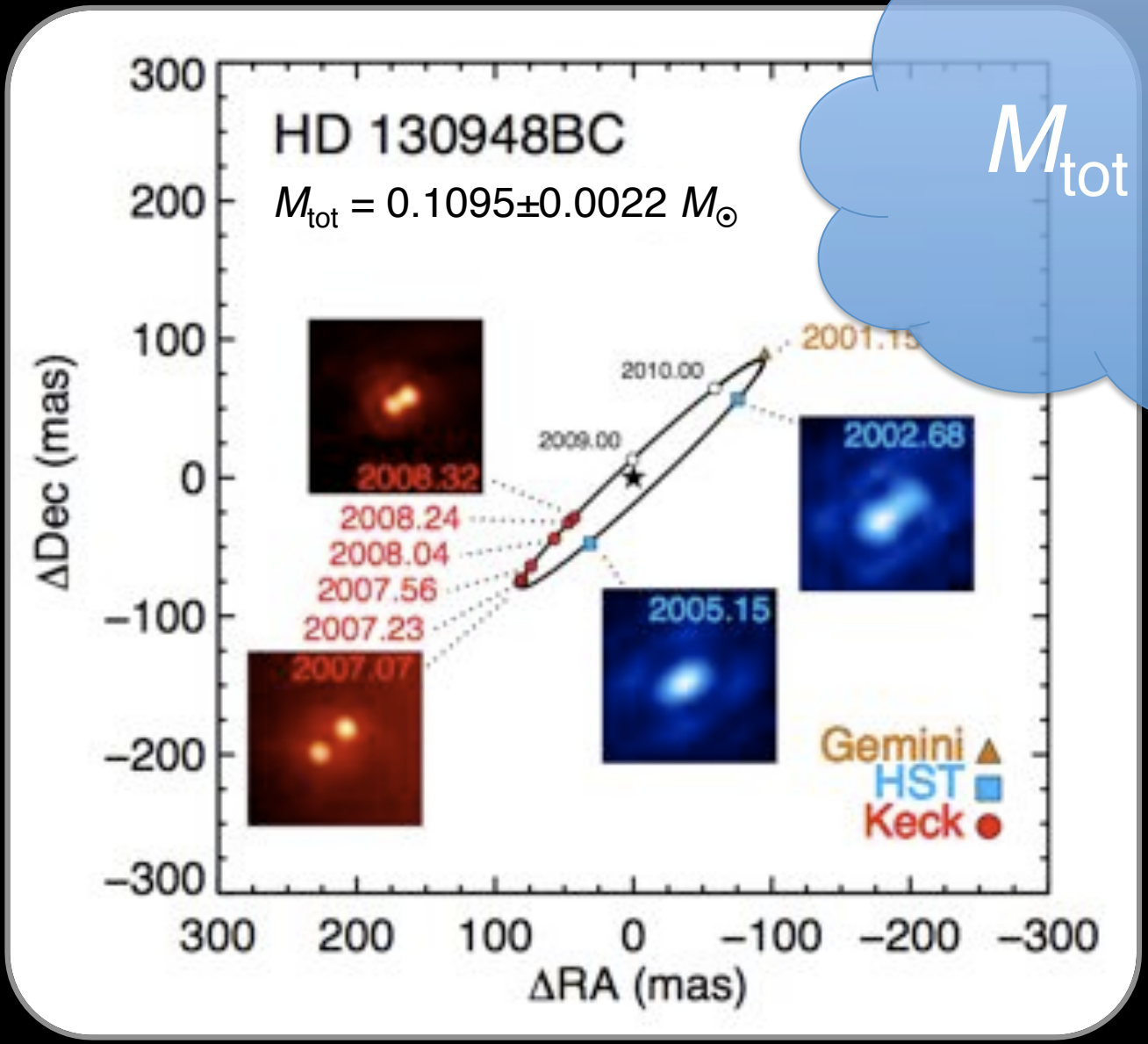


$$M_{tot} = \frac{a^3}{P^2}$$

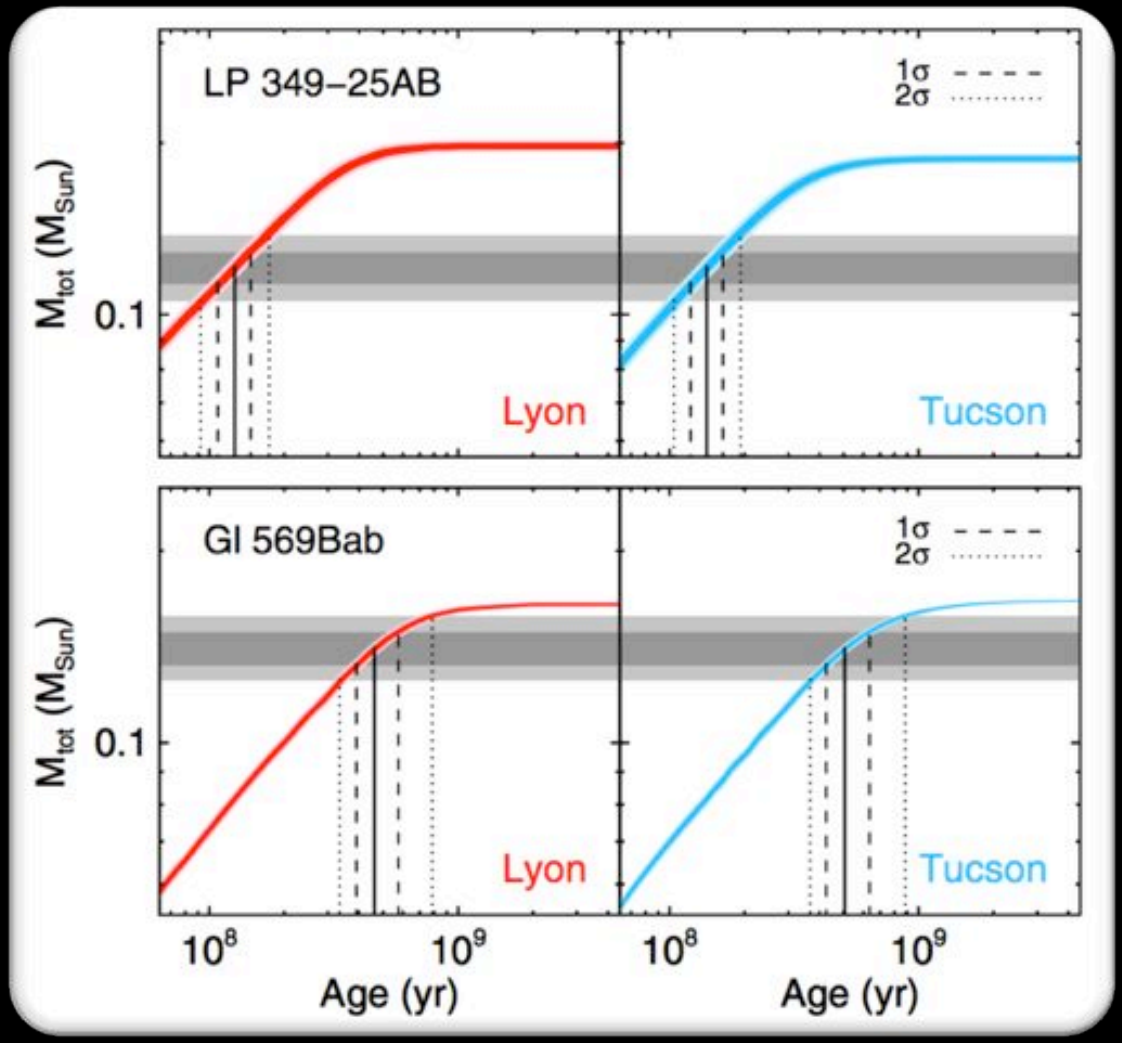
How do we test the models?

- measure: $L_{bol,1}$ $L_{bol,2}$ and M_{tot}
- at each age compute M_1 and M_2 from L_{bol} values using model
- apply M_{tot} constraint to the computed M_1+M_2 values to get age

Pros:

- retains high precision of the input mass, L_{bol}

- readily derive any physical property



Dupuy et al. (2010)

First Test of Substellar Luminosity Evolution

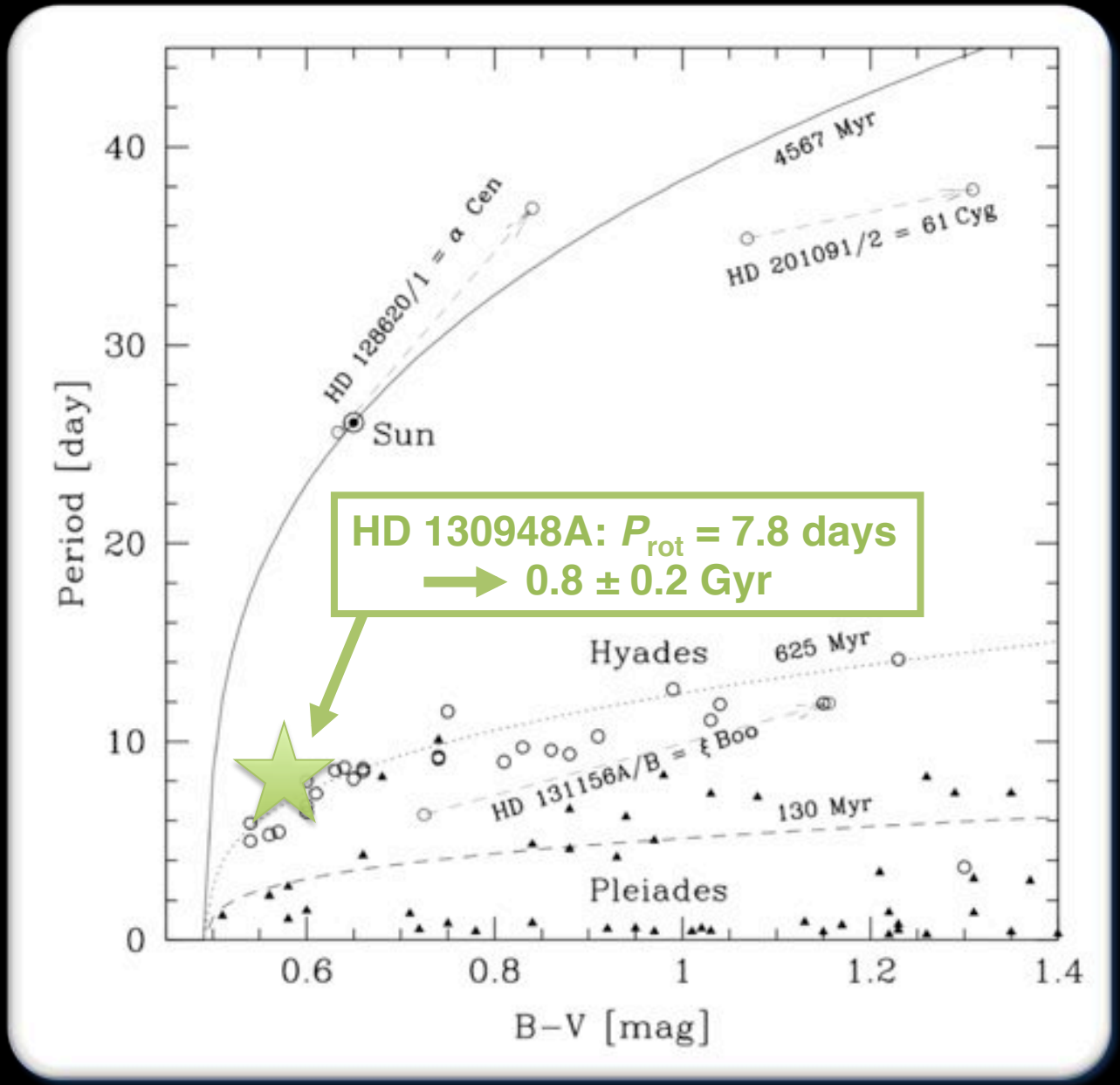
$M_{tot} = 0.1095 \pm 0.0022\ M_{\odot}$

↓

model-derived age: 450±30 Myr

HD 130948

Dupuy et al. (2009)



Mamajek & Hillenbrand (2008)

First Test of Substellar Luminosity Evolution

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↓

model-derived age: 450±30 Myr

Age Indicator	Age (Myr)	Error
Gyrochronology	**790±190**	**25%**
Chrom. activity	500±300	60%
Isochrones	300–2500	≈2×
X-ray activity	≈Hyades	…
Lithium	≈Hyades	…

References — Mamajek & Hillenbrand (2008); Barnes (2007); Takeda et al. (2007); Stern et al. (1995); Gaidos (1998); Gaidos (2000); Hünsch et al. (1999); Stelzer & Neuhäuser (2001); Soderblom et al. (1993a,b,c)

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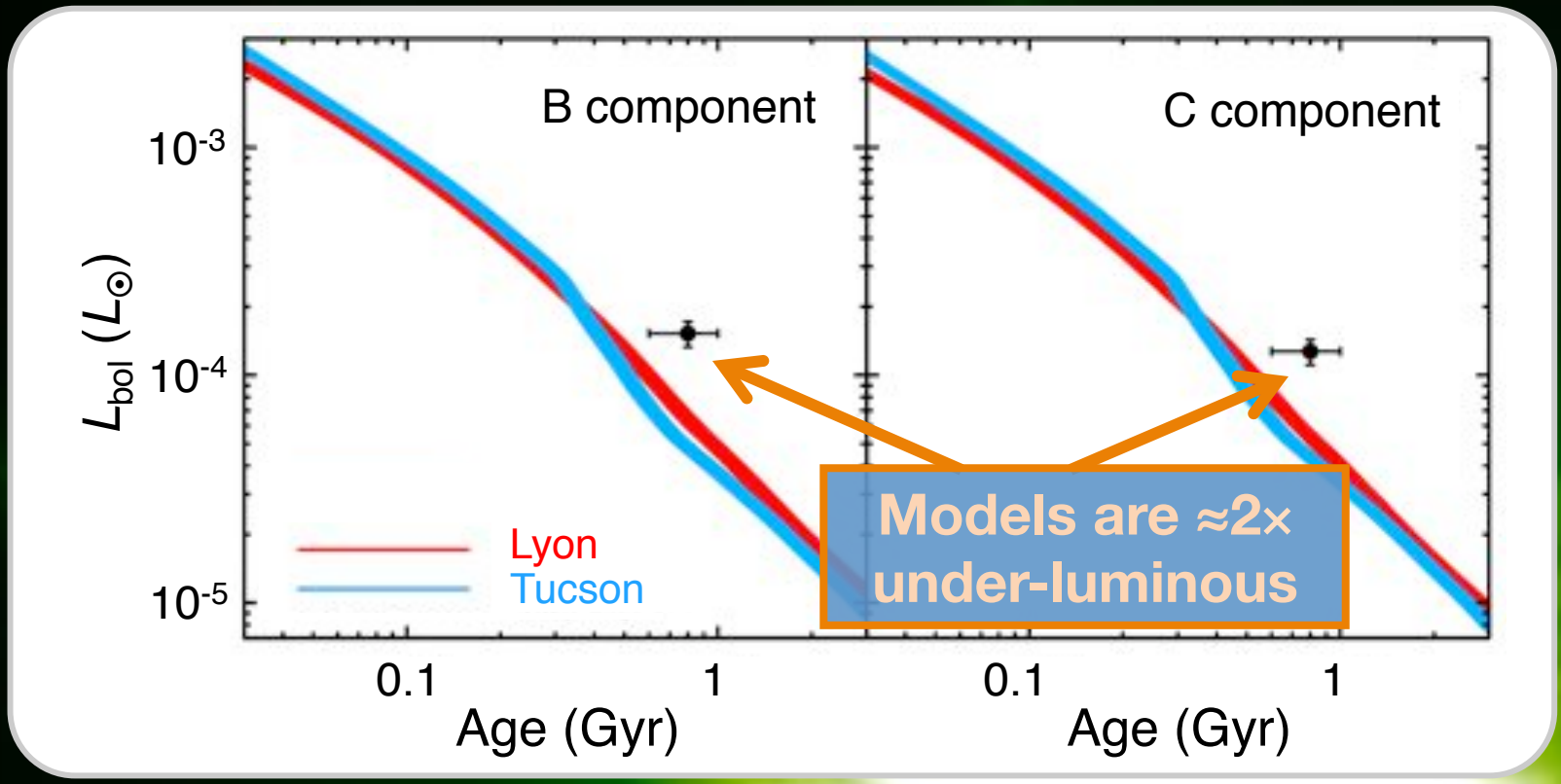


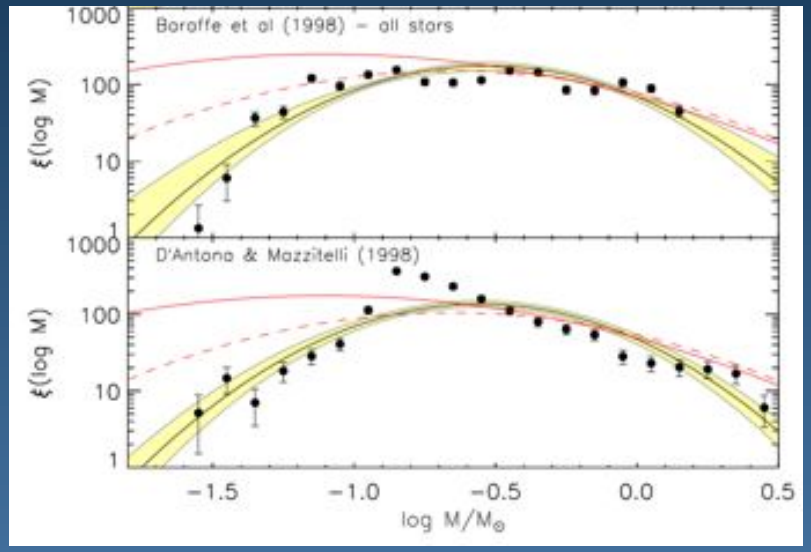
HD 130948

Dupuy et al. (2009)

"Luminosity problem": evolutionary models under-luminous

- HD 130948BC model age inconsistent with primary star

Initial mass function



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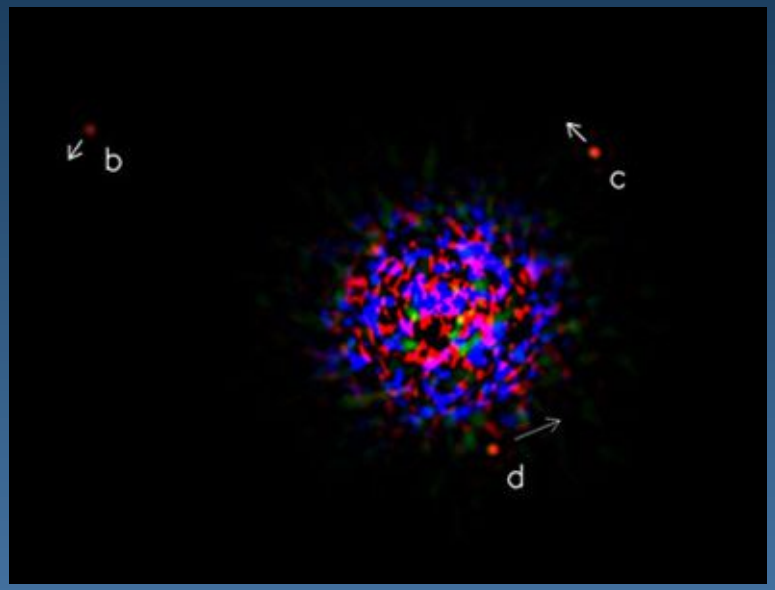
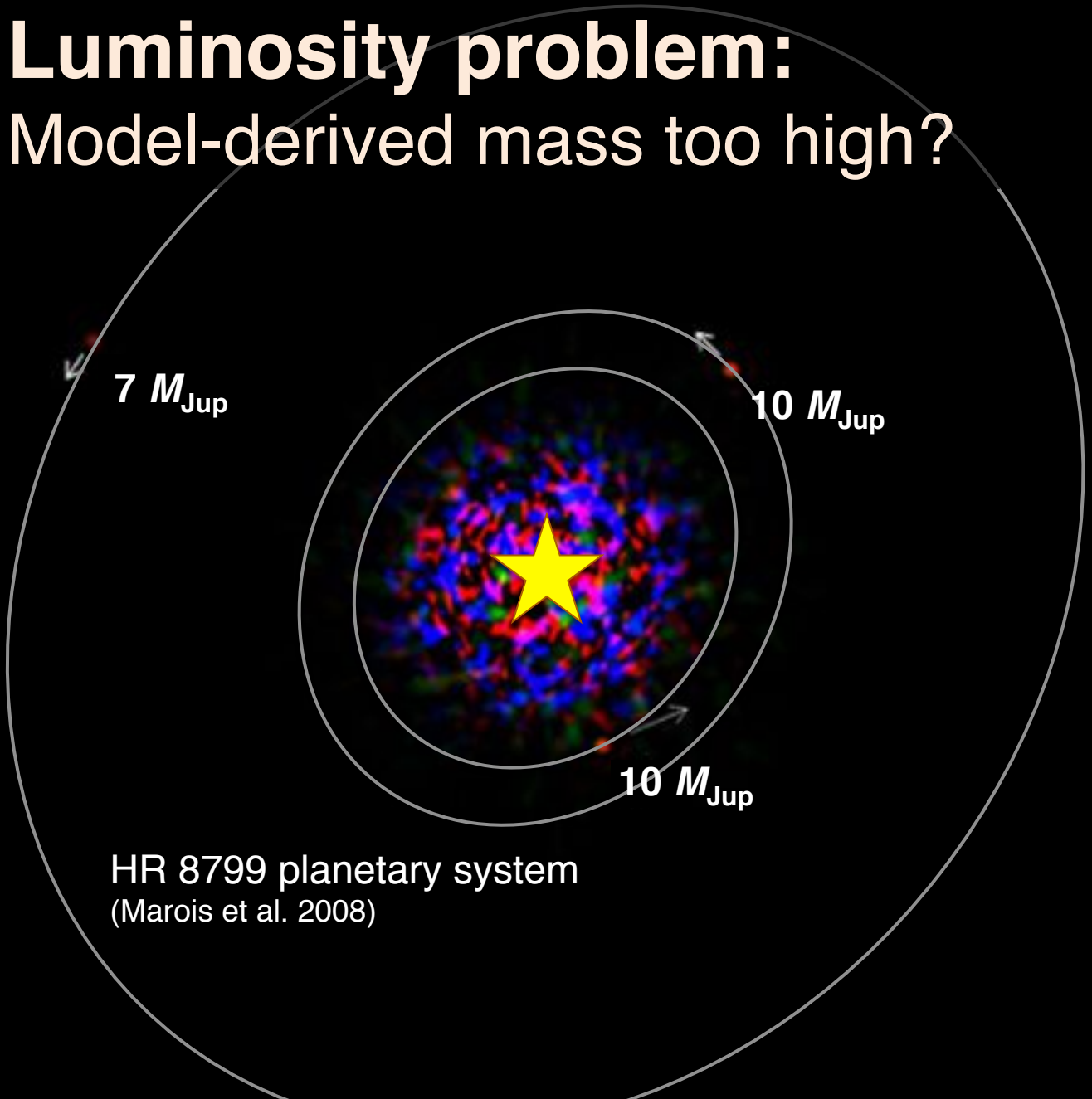


HR 8799 (Marois et al. 2008, 2010)

Luminosity problem:
Model-derived mass too high?



HR 8799 planetary system
(Marois et al. 2008)

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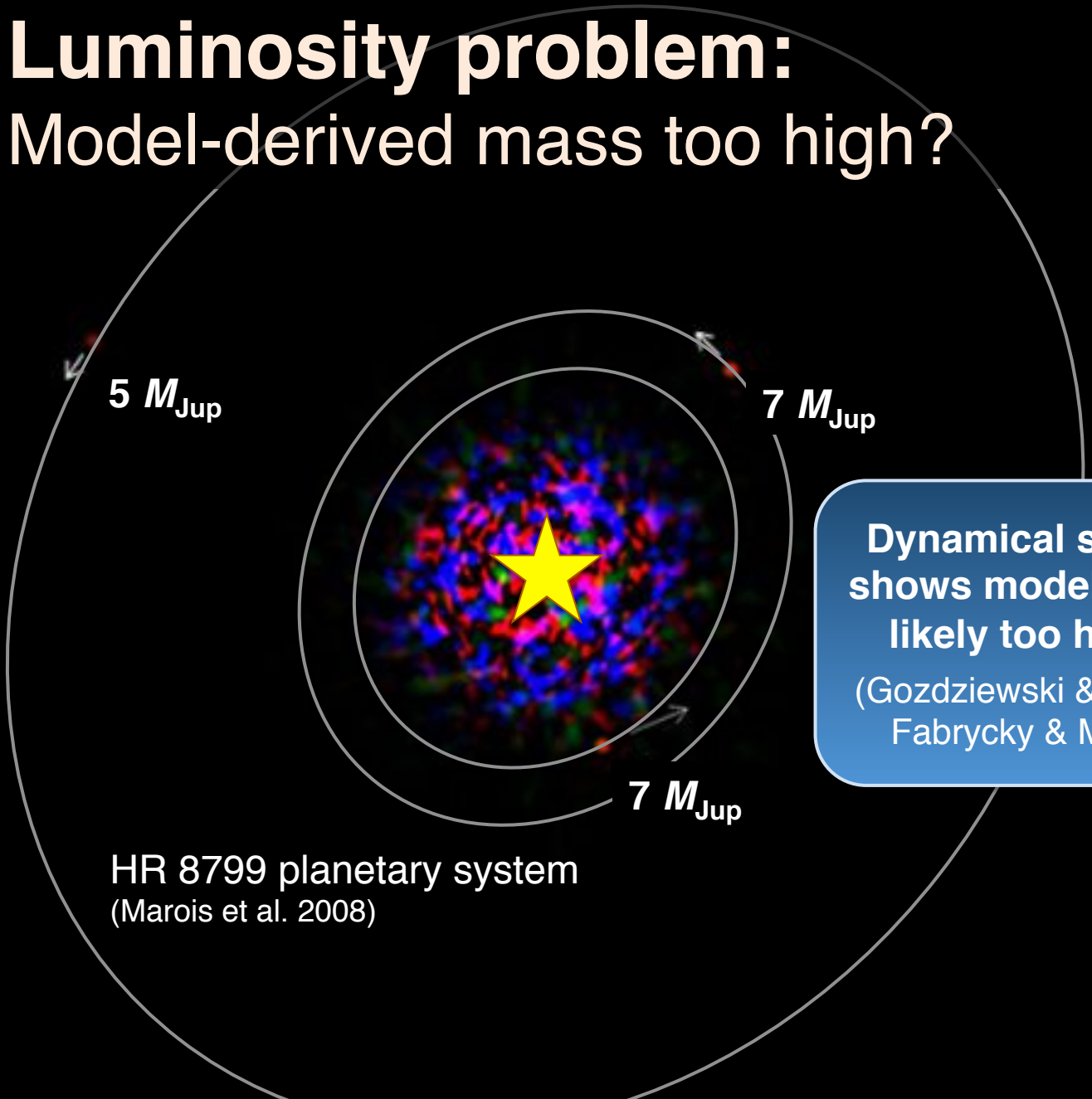

HR 8799 planetary system
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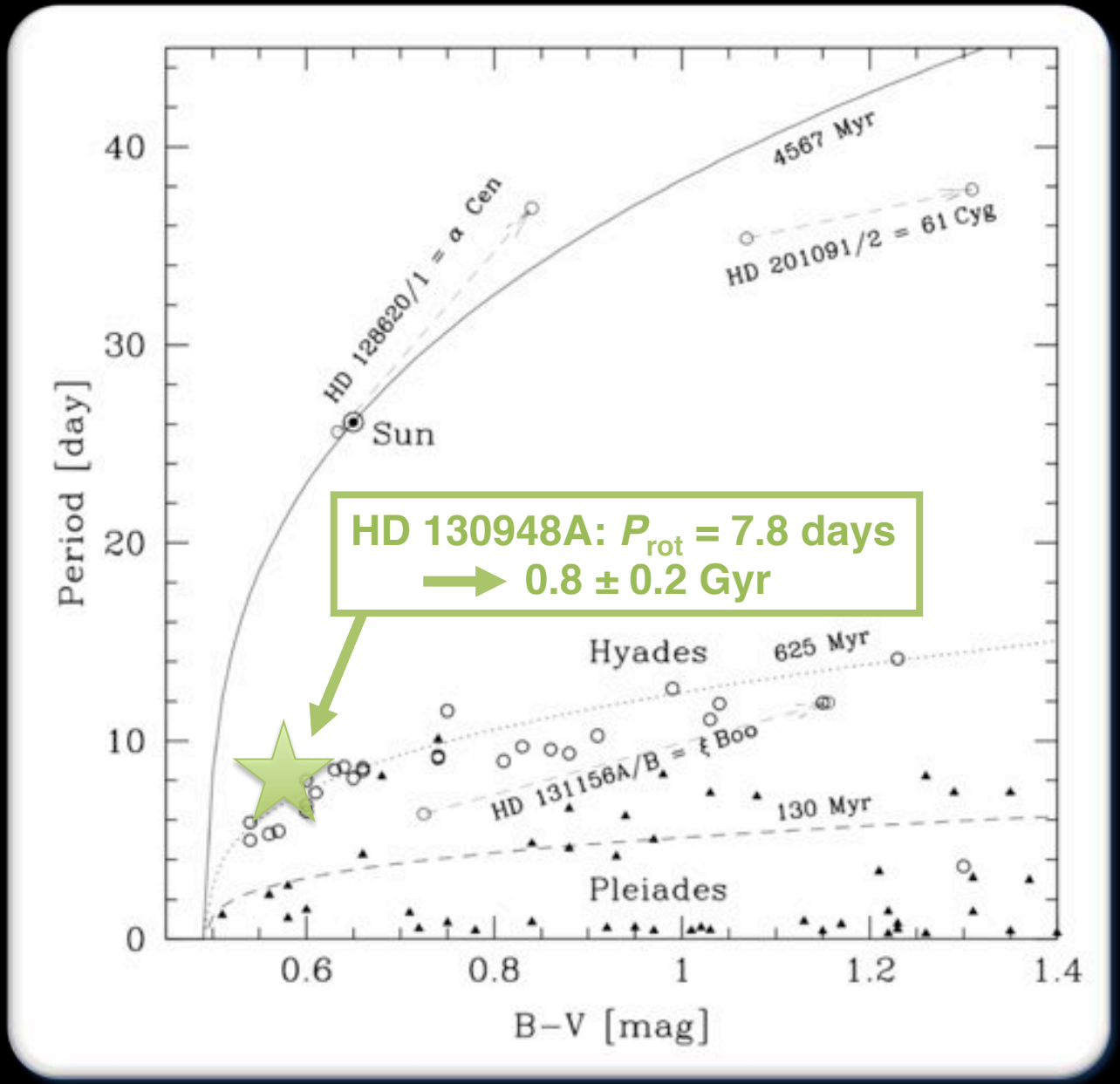
Dynamical stability analysis shows model-derived masses likely too high by 20–30%

(Gozdziewski & Migaszewski 2009; Fabrycky & Murray-Clay 2010)

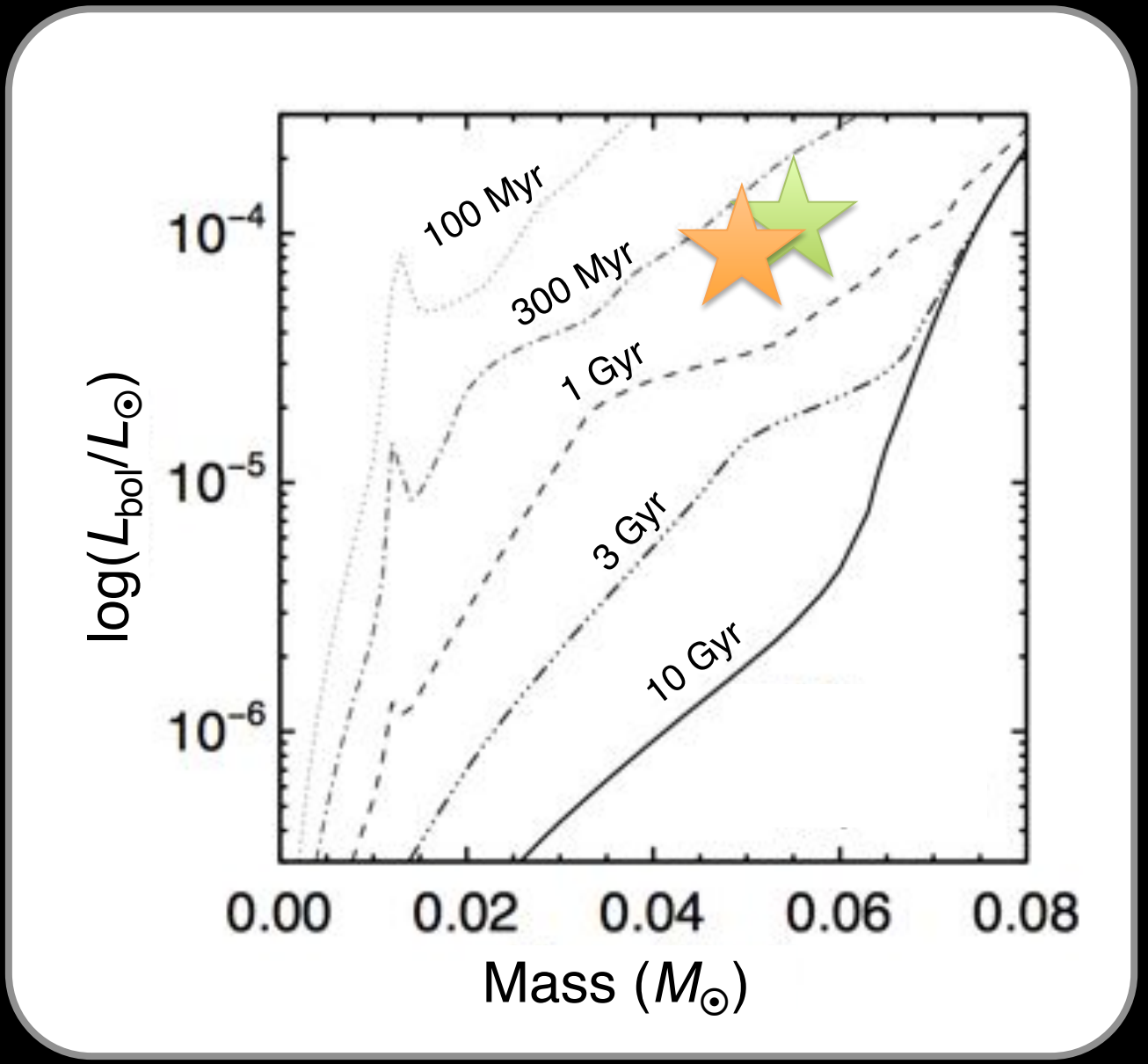


Mamajek & Hillenbrand (2008)

Luminosity Problem

Caveats

- What if the star's rotation period was affected by the presence of these companions?
- Are the errors on the gyro age really Gaussian?
- Can you really trust the age for a single star?



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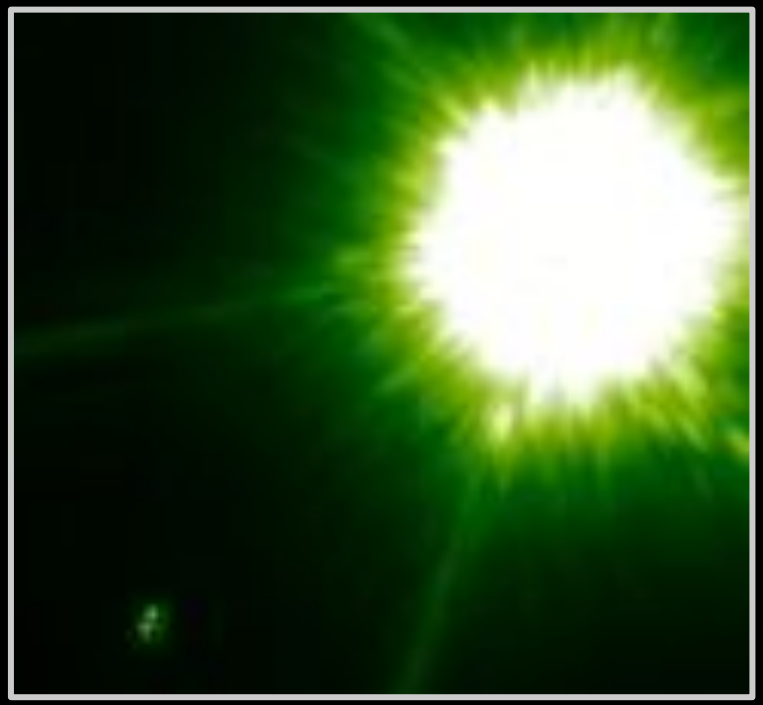


Credit: M. Liu, T. Dupuy

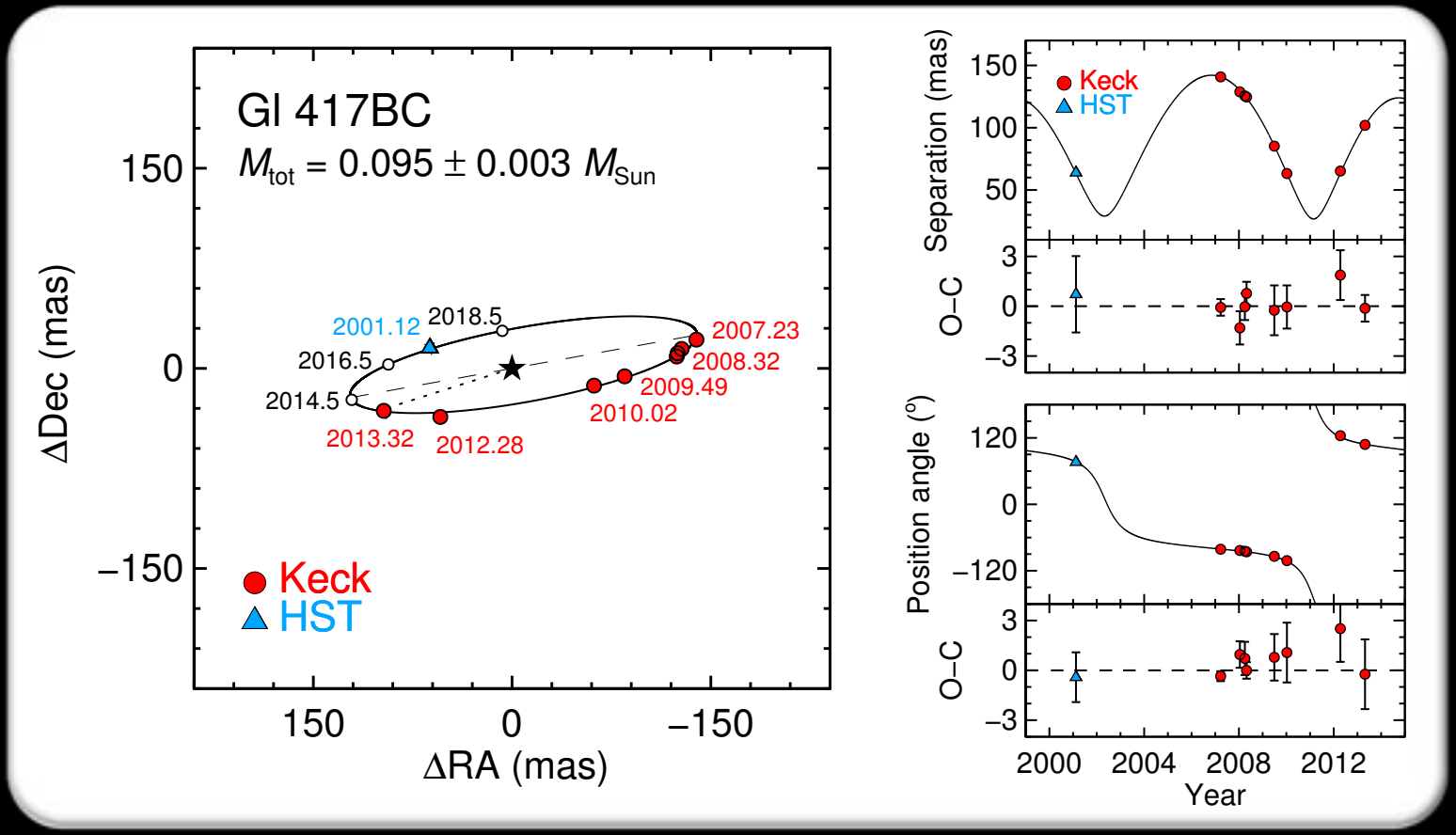
Credit: 2MASS / IRSA

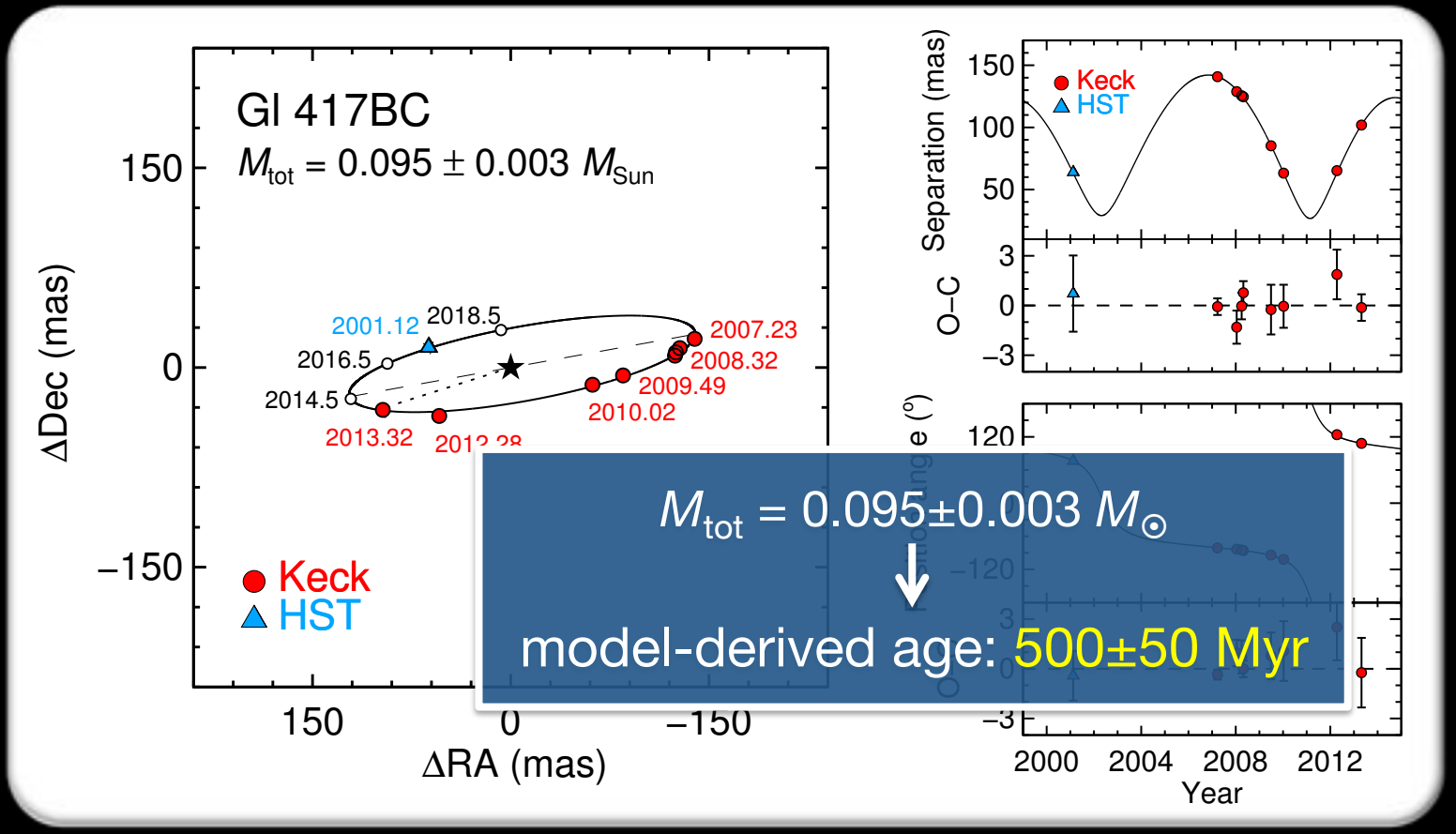
HD 130948BC

- 47 AU projected separation from G1-type host star
- 790 Myr (±0.08 dex) gyro age
- [Fe/H] = 0.05
- L4+L4 spectral types

Gliese 417BC

- 1970 AU projected separation from G6-type host star
- 750 Myr (±0.08 dex) gyro age
- [Fe/H] = 0.09
- L4.5+L6 spectral types


Gl 417BC
M_{tot} = 0.095 ± 0.003 M_{Sun}
2001.12
2018.5
2016.5
2014.5
2007.23
2008.32
2009.49
2010.02
2013.32
2012.28
Keck
HST
ΔDec (mas)
ΔRA (mas)
150
0
−150
Separation (mas)
Position angle (°)
O–C
Year
2000
2004
2008
2012
120
100
50
−120
3
−3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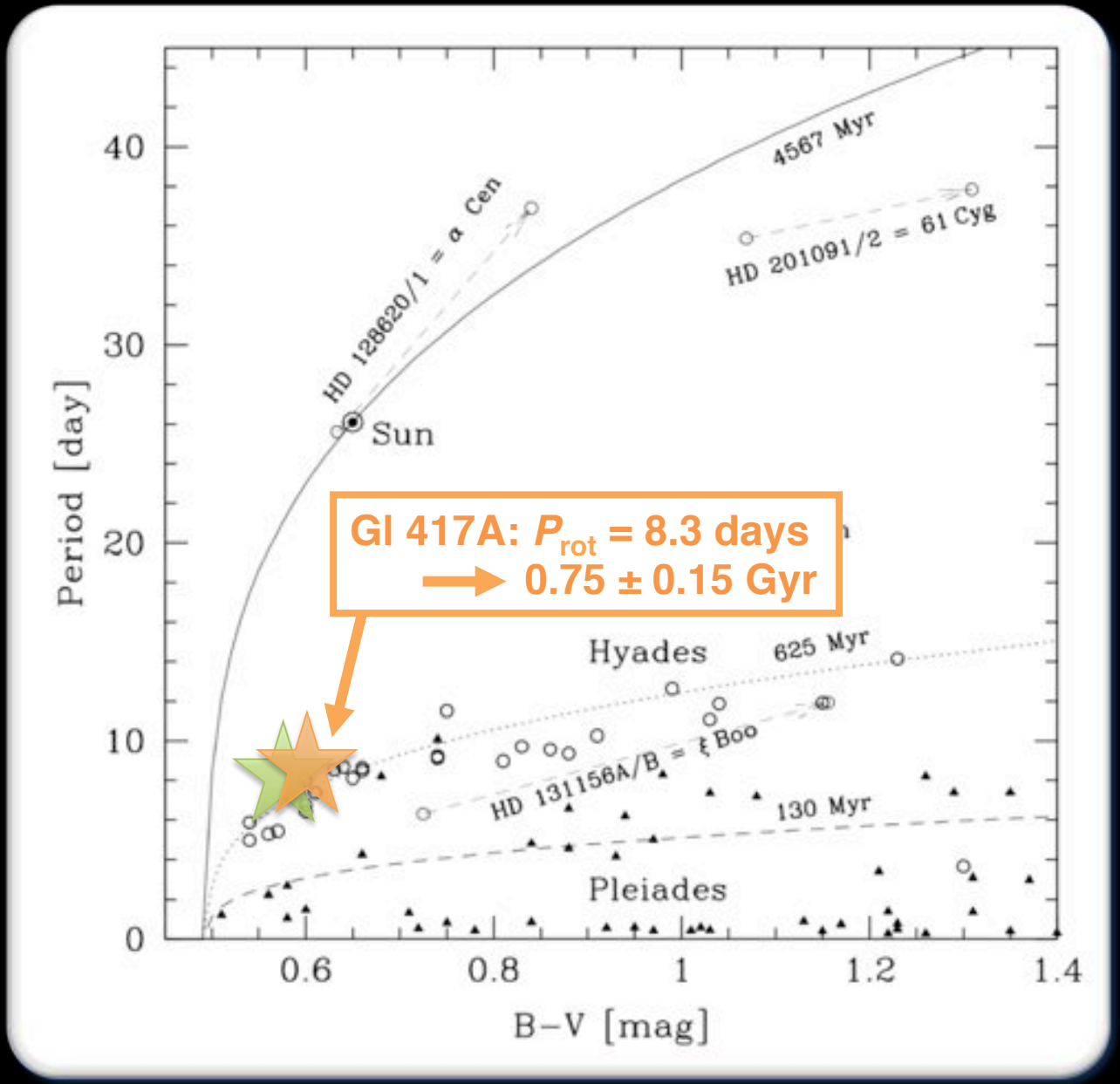
HST
ΔDec (mas)
ΔRA (mas)
150
0
−150
Separation (mas)
O−C
Year
2000
2004
2008
2012
M_{tot} = 0.095±0.003 $M_\odot$
model-derived age: 500±50 Myr



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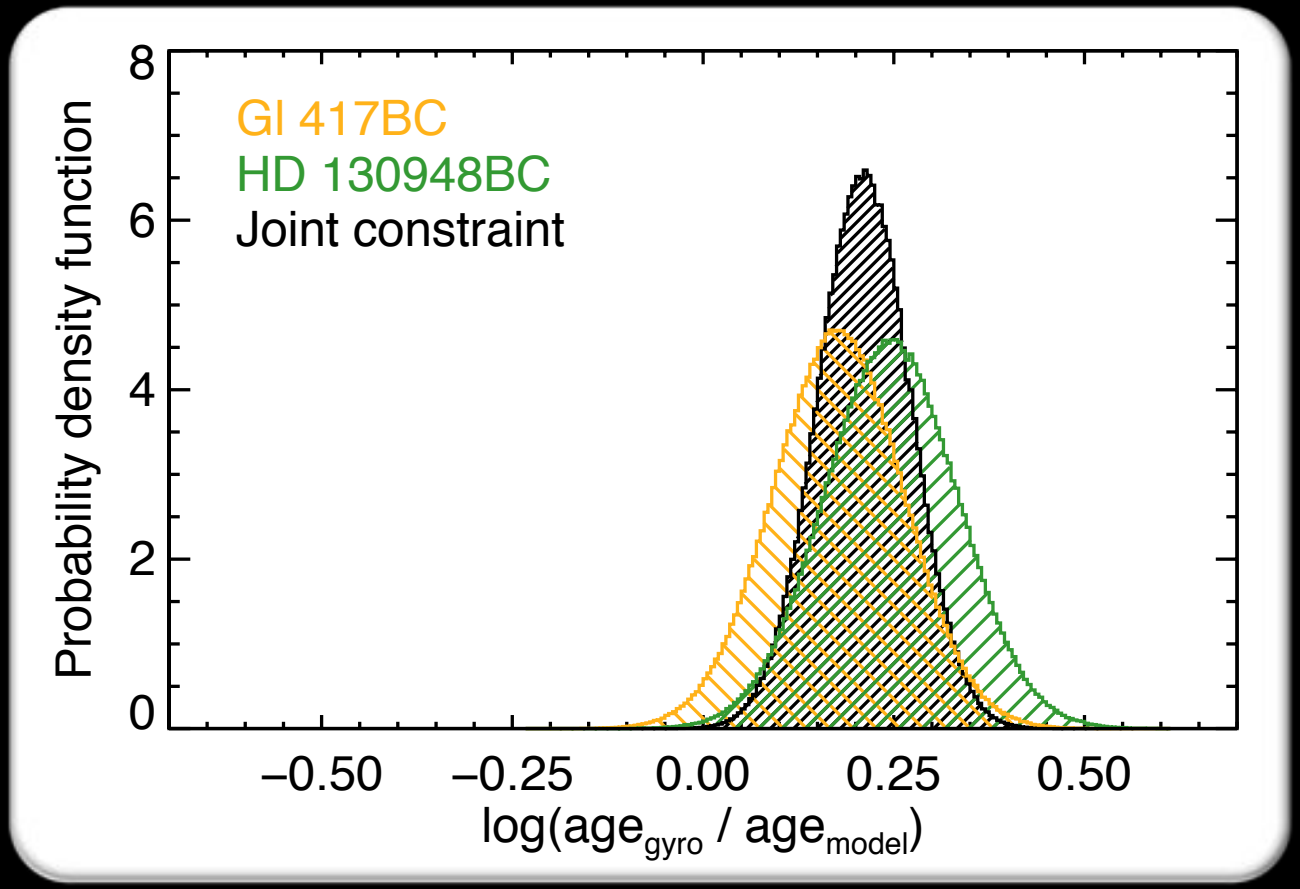
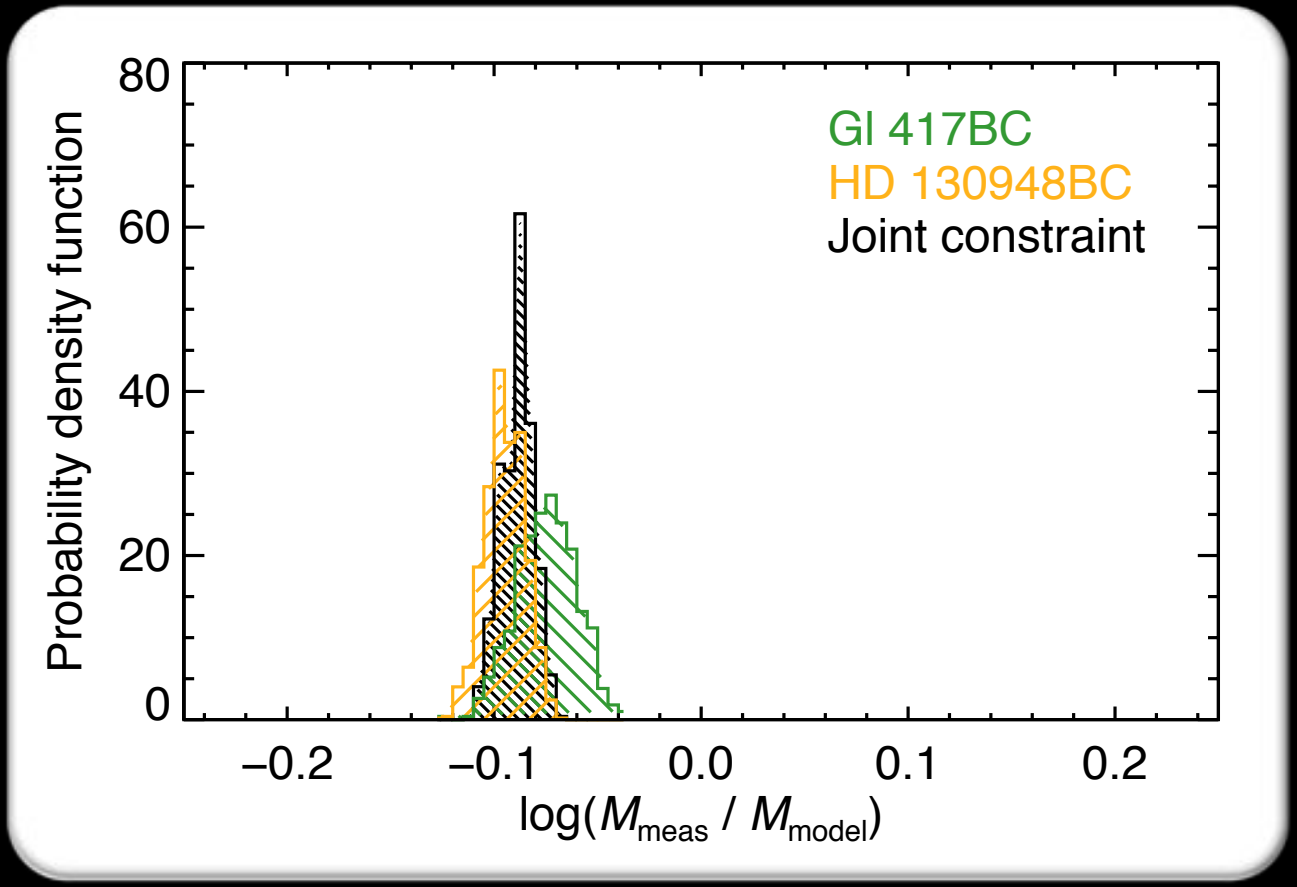


Dusty

Δage = 0.25±0.09 dex
Δage = 0.17±0.08 dex

Δage = 0.21±0.06 dex

Masses derived from L_{bol} + age



Dusty

Mass derived from models too high by ≈0.1 dex

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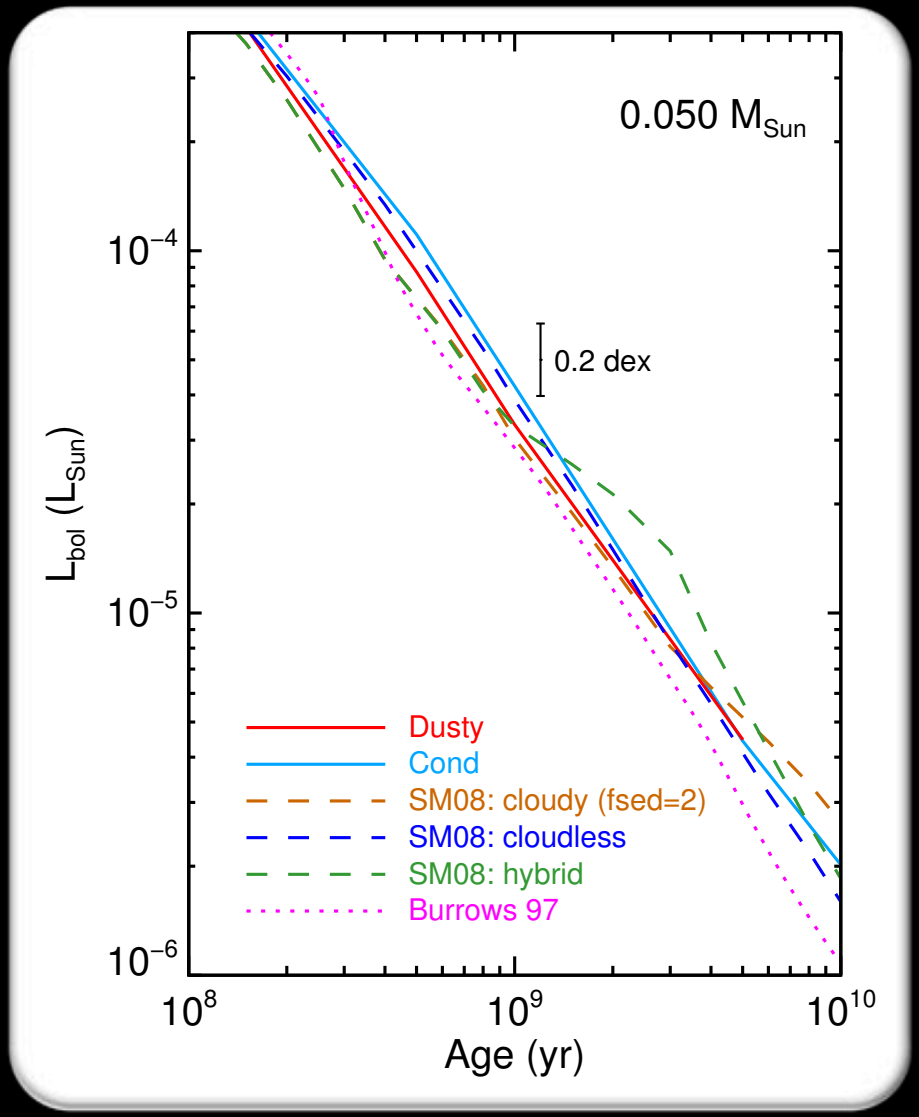
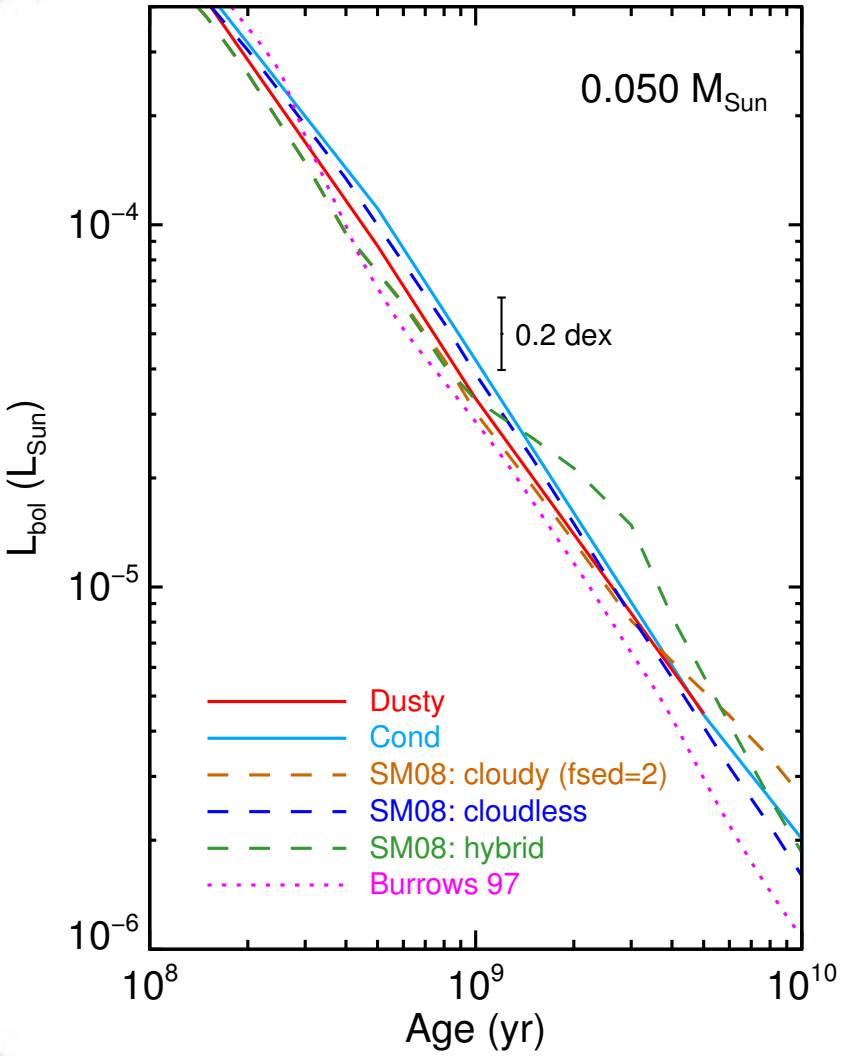
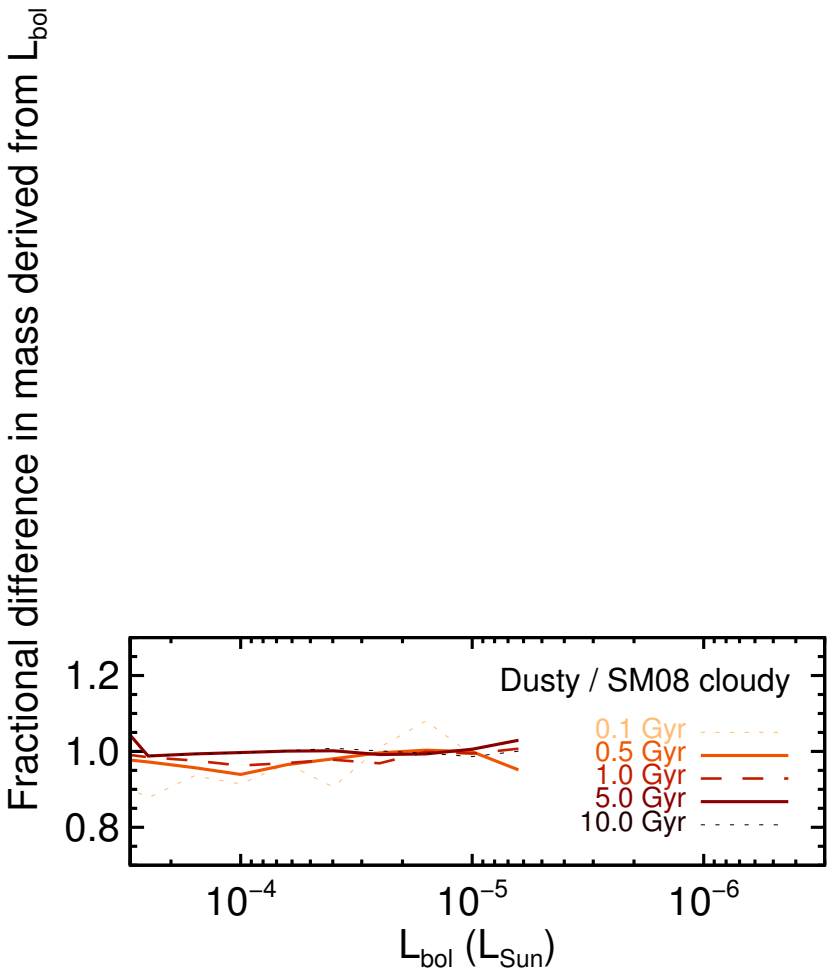
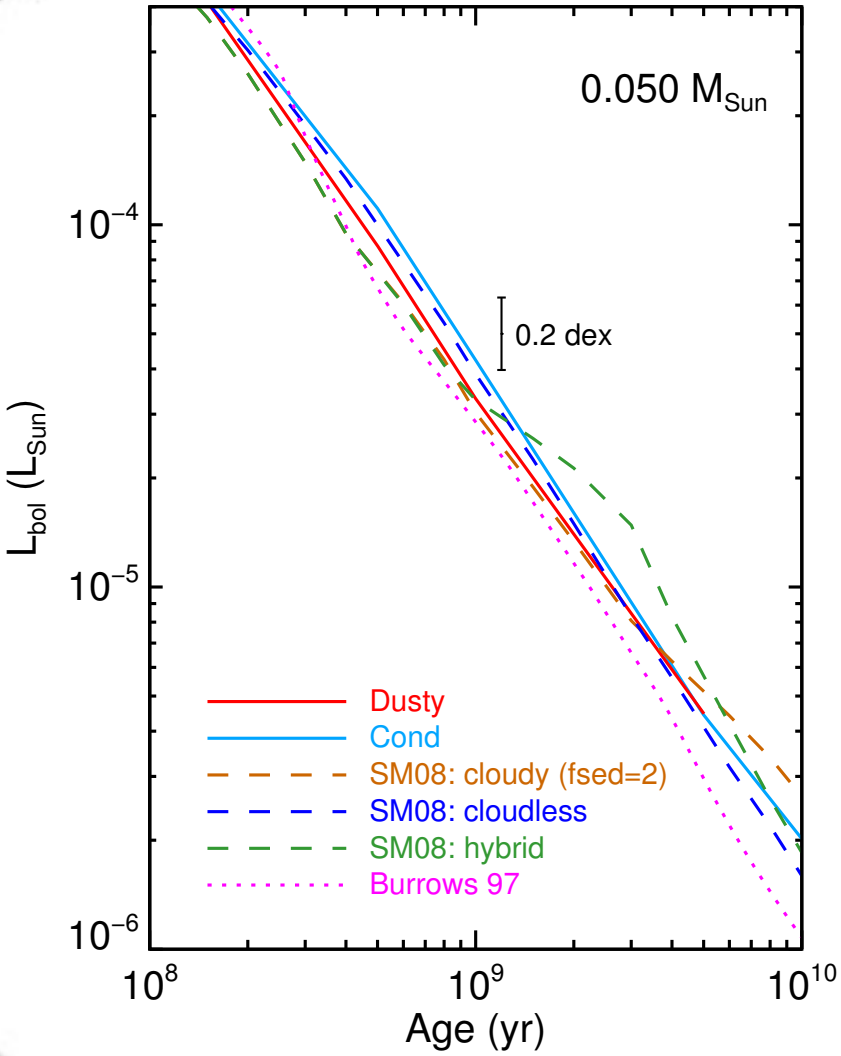



0.050 M_Sun
0.2 dex
Dusty
Cond
SM08: cloudy (fsed=2)
SM08: cloudless
SM08: hybrid
Burrows 97
L_bol (L_Sun)
Age (yr)


Fractional difference in mass derived from L_bol
Dusty / SM08 cloudy
0.1 Gyr
0.5 Gyr
1.0 Gyr
5.0 Gyr
10.0 Gyr
L_bol (L_Sun)


0.050 M_Sun
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SM08: cloudy (fsed=2)
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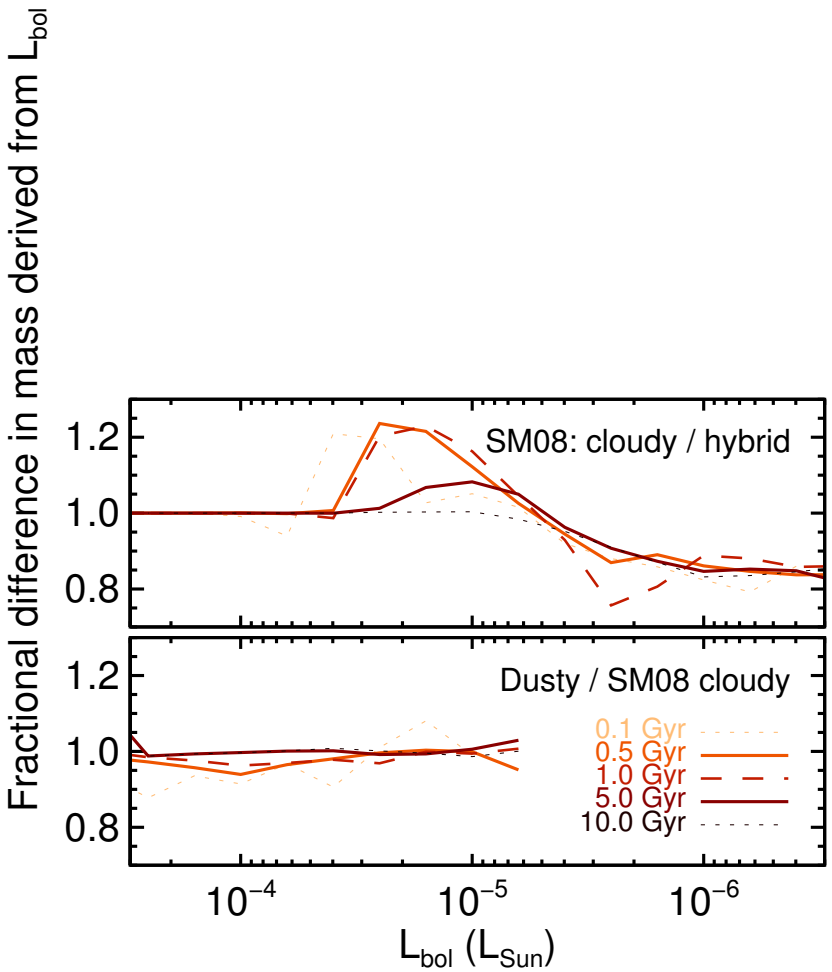
Age (yr)


Fractional difference in mass derived from L_bol
SM08: cloudy / hybrid
Dusty / SM08 cloudy
0.1 Gyr
0.5 Gyr
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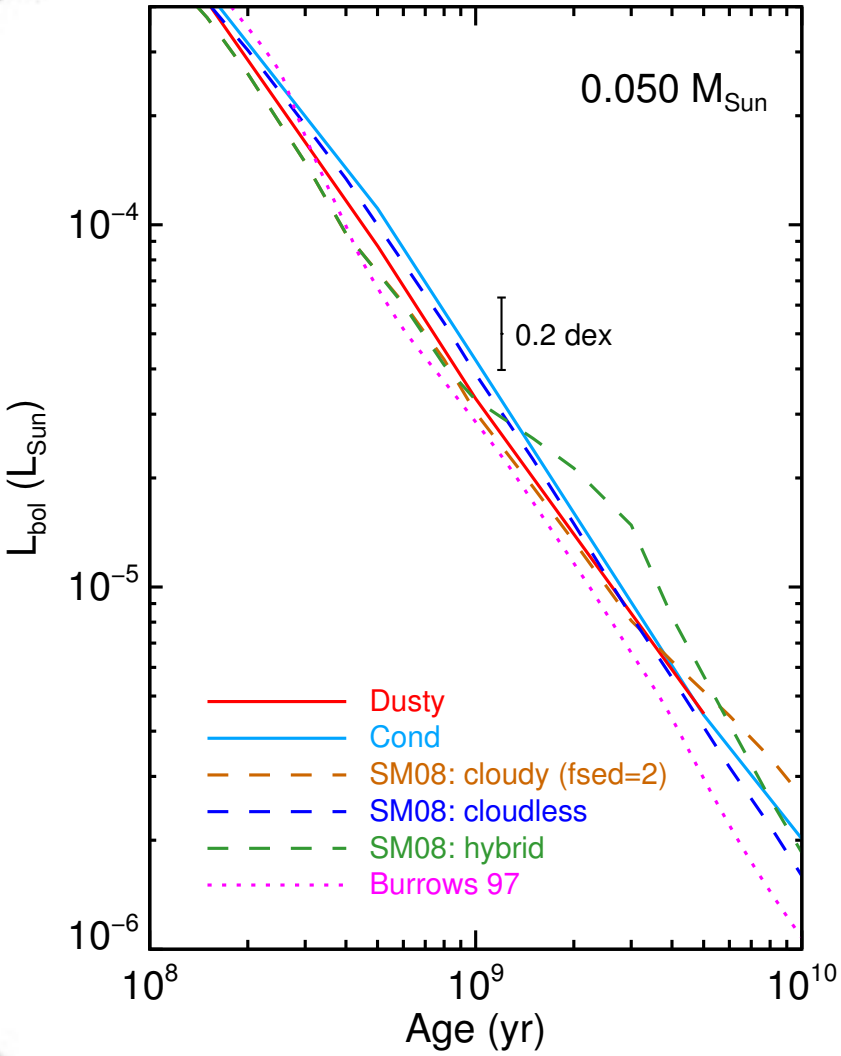
10.0 Gyr
L_bol (L_Sun)


0.050 M_Sun
0.2 dex
Dusty
Cond
SM08: cloudy (fsed=2)
SM08: cloudless
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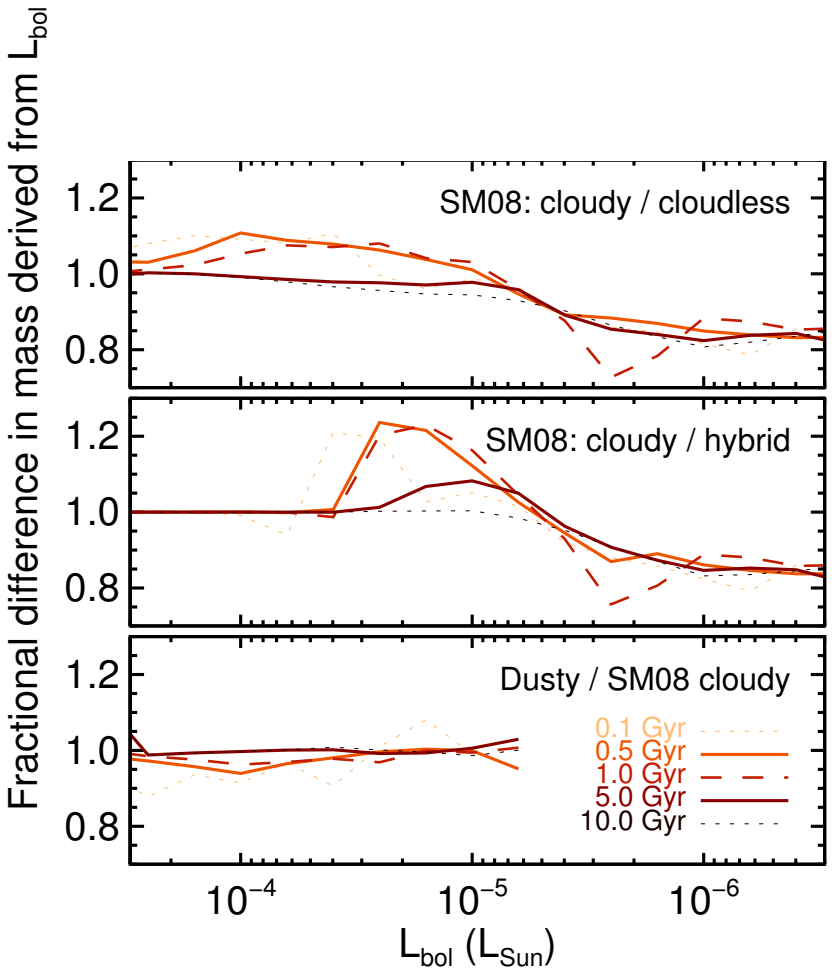
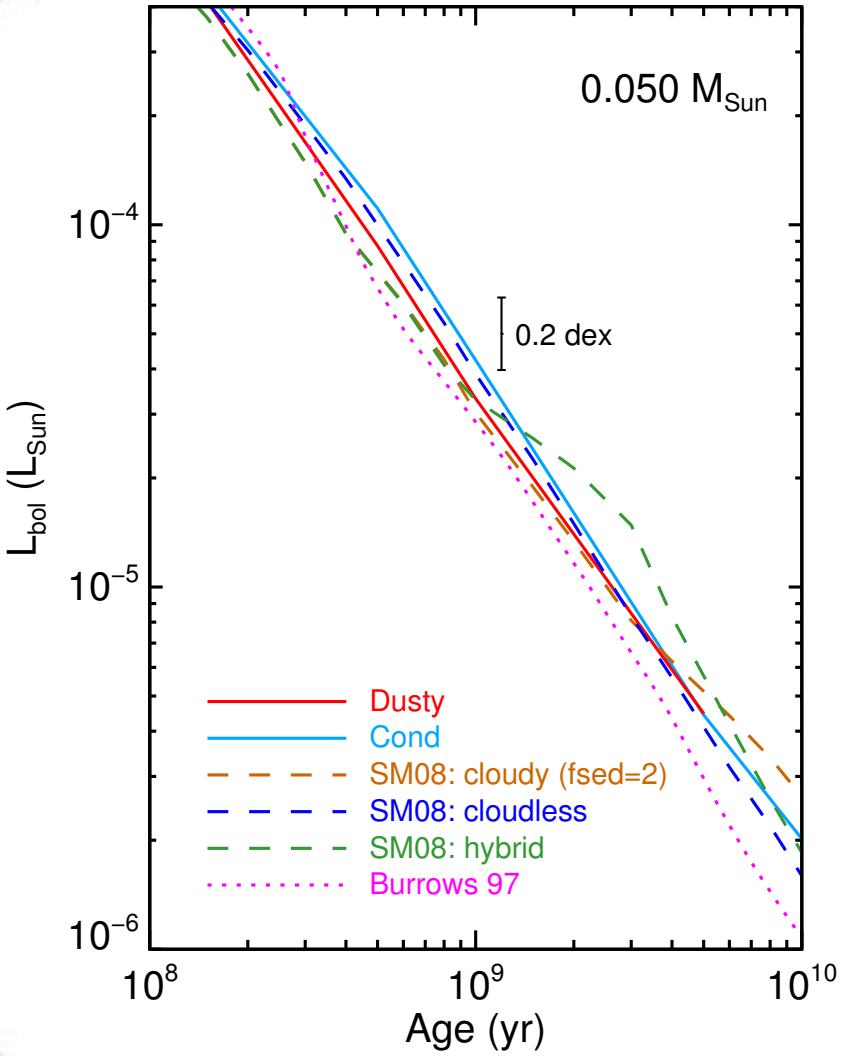
L_bol (L_Sun)
Age (yr)


SM08: cloudy / cloudless
SM08: cloudy / hybrid
Dusty / SM08 cloudy
0.1 Gyr
0.5 Gyr
1.0 Gyr
5.0 Gyr
10.0 Gyr
Fractional difference in mass derived from L_bol
L_bol (L_Sun)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Dusty
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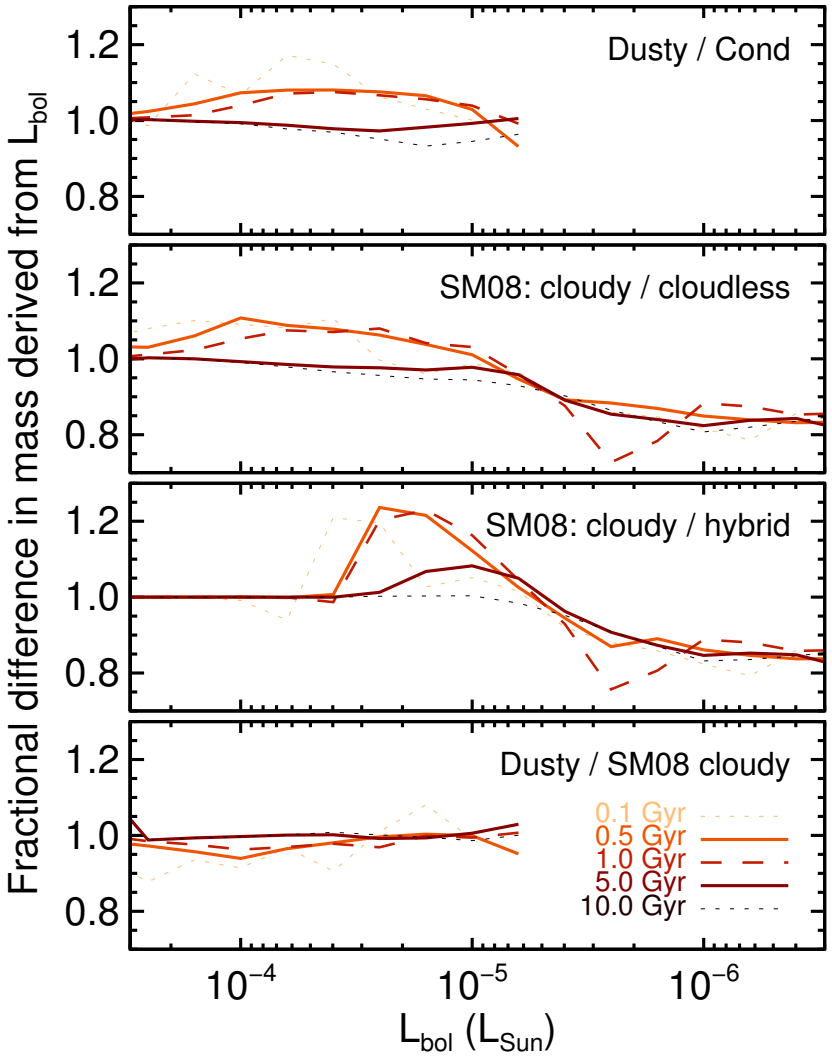
Age (yr)


Dusty / Cond
SM08: cloudy / cloudless
SM08: cloudy / hybrid
Dusty / SM08 cloudy
0.1 Gyr
0.5 Gyr
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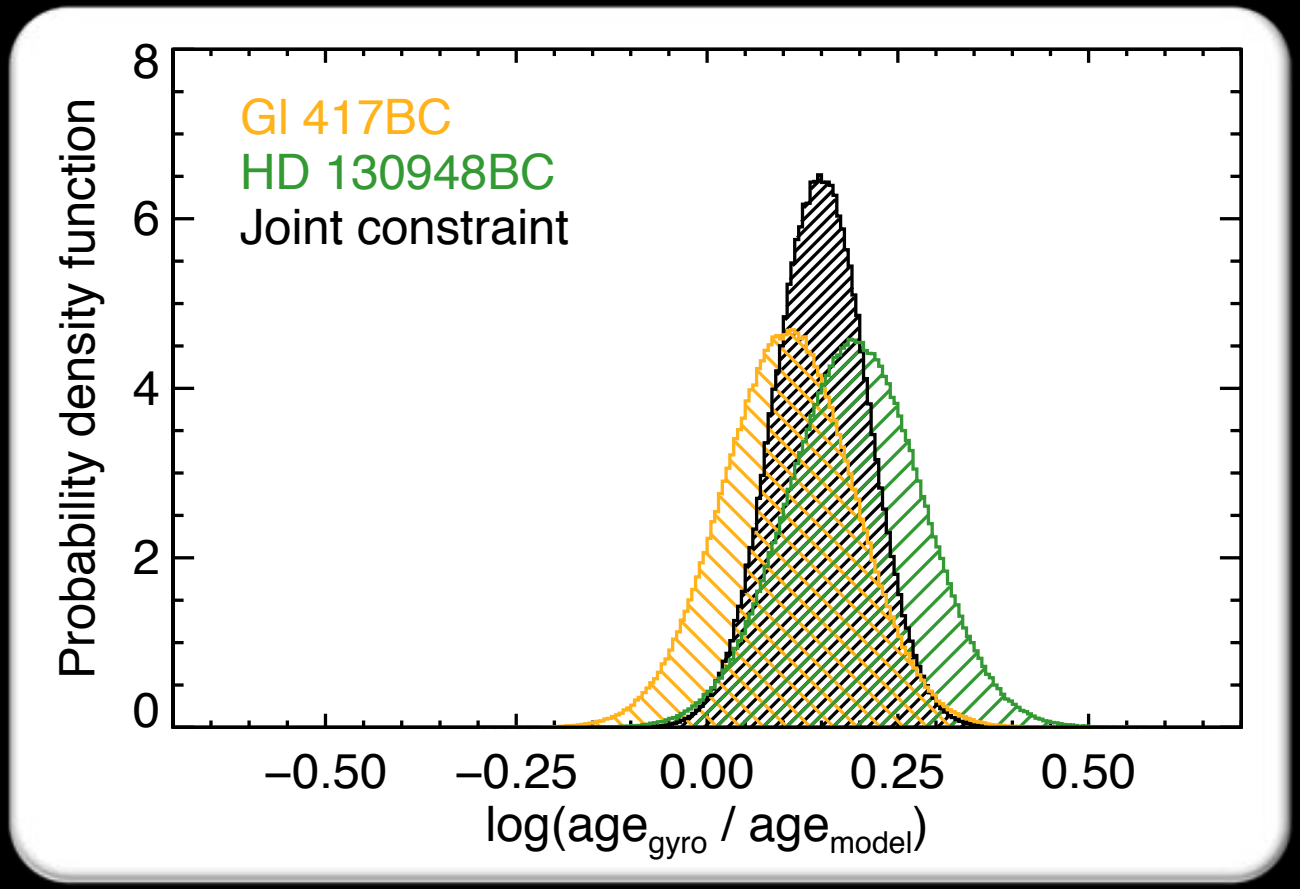
5.0 Gyr
10.0 Gyr
Fractional difference in mass derived from L_bol
L_bol (L_Sun)



Cond

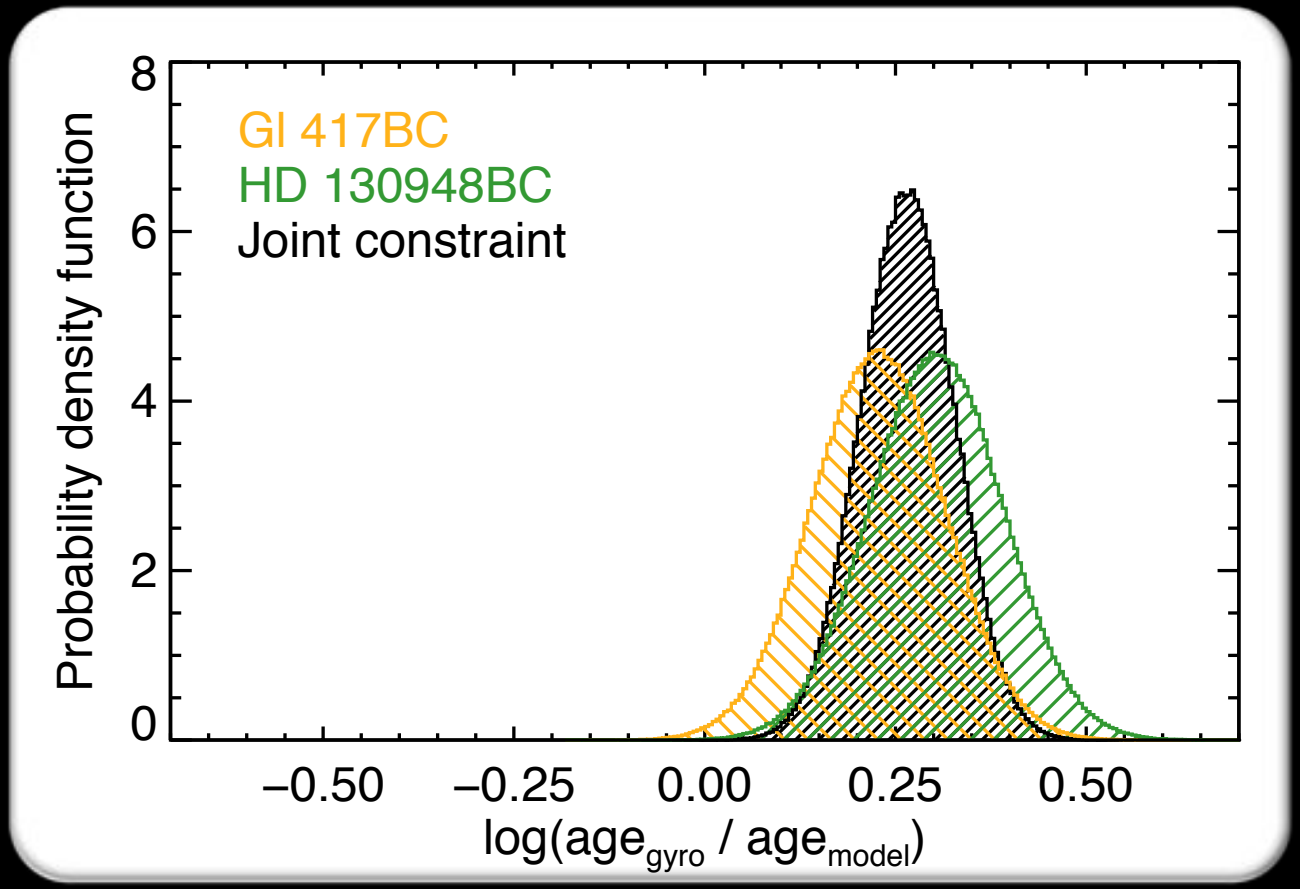
Δage = 0.19±0.09 dex

Δage = 0.11±0.08 dex

Δage = 0.15±0.06 dex

vs. Dusty

Δage = 0.21±0.06 dex



SM08 hybrid

Δage = 0.31±0.10 dex
Δage = 0.22±0.09 dex

Δage = 0.26±0.06 dex

vs. Dusty

Δage = 0.21±0.06 dex

New Evidence for a Luminosity Problem

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- Beware that the various models make quite different predictions for the L_{bol} evolution of substellar objects.