Brown dwarfs vs. Exoplanets: two different mass functions

Hans Zinnecker

Eric Becklin

SOFIA Science Center

(DSI and USRA)

Pathways towards HZ II,
Univ. Bern, 13 July 2015

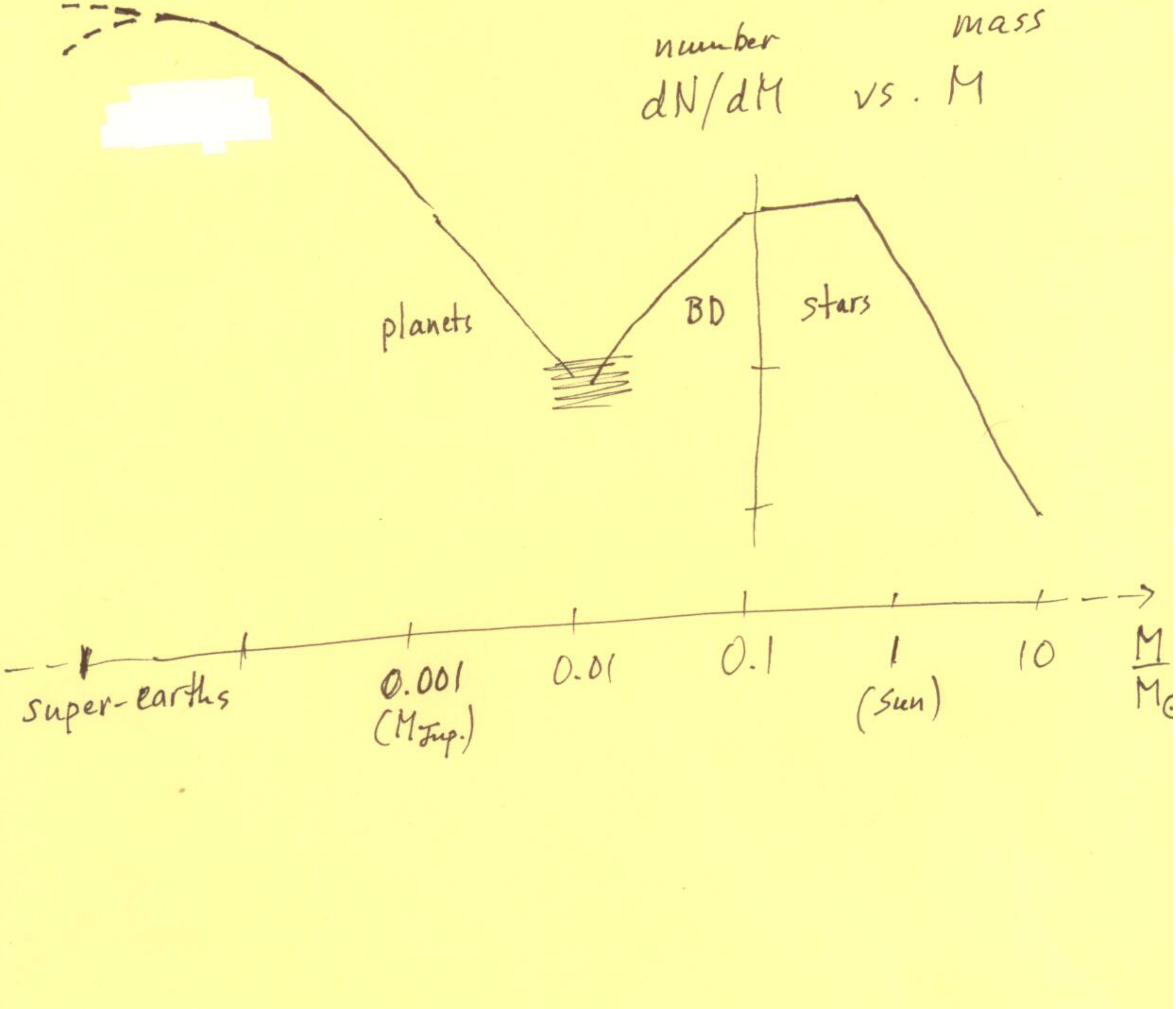
take home message:
two different mass functions

brown dwarfs:
dN/dm ~ const
or dN/dlogm ~ m

exoplanets:
dN/dm ~ m^(-1)
dN/dlogm ~ const

→ two different formation processes

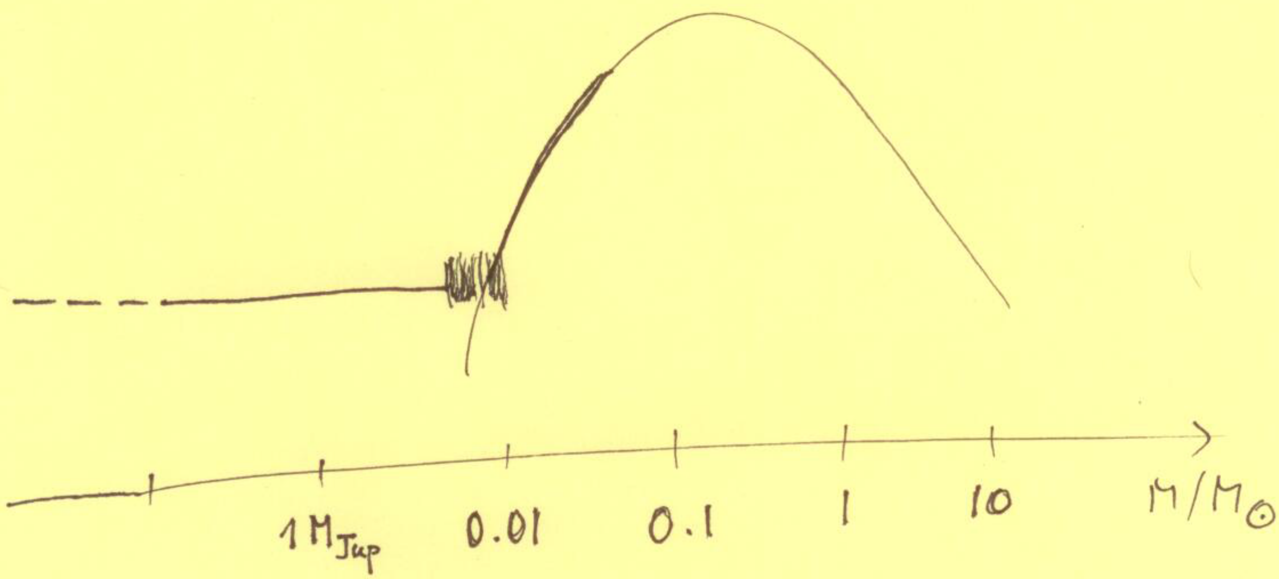
mass function of stars, brown dwarfs, and planets



Pathways II, 11 July 2015
(Hans Zinnecker)

IMF of stars, brown dwarfs, and planets

sketch dN/dlogM vs. M



Zinnecker & Becklin
Pathways II (Bern)
11 July, 2015

Two different formation processes:

brown dwarfs:
cloud collapse/fragmentation
(like stars)

exoplanets:
planetesimal collisional growth
in circumstellar disks
(core accretion)

top down vs. bottom up

obs. evidence

two different mass functions

brown dwarfs:

McCaughrean et al. 2002

Luhman 2012

Brown Dwarf Desert

(Lineweaver & Grether 2005)

exoplanets:

Mayor et al. 2011 (RV)

A. Howard 2013 (Kepler)

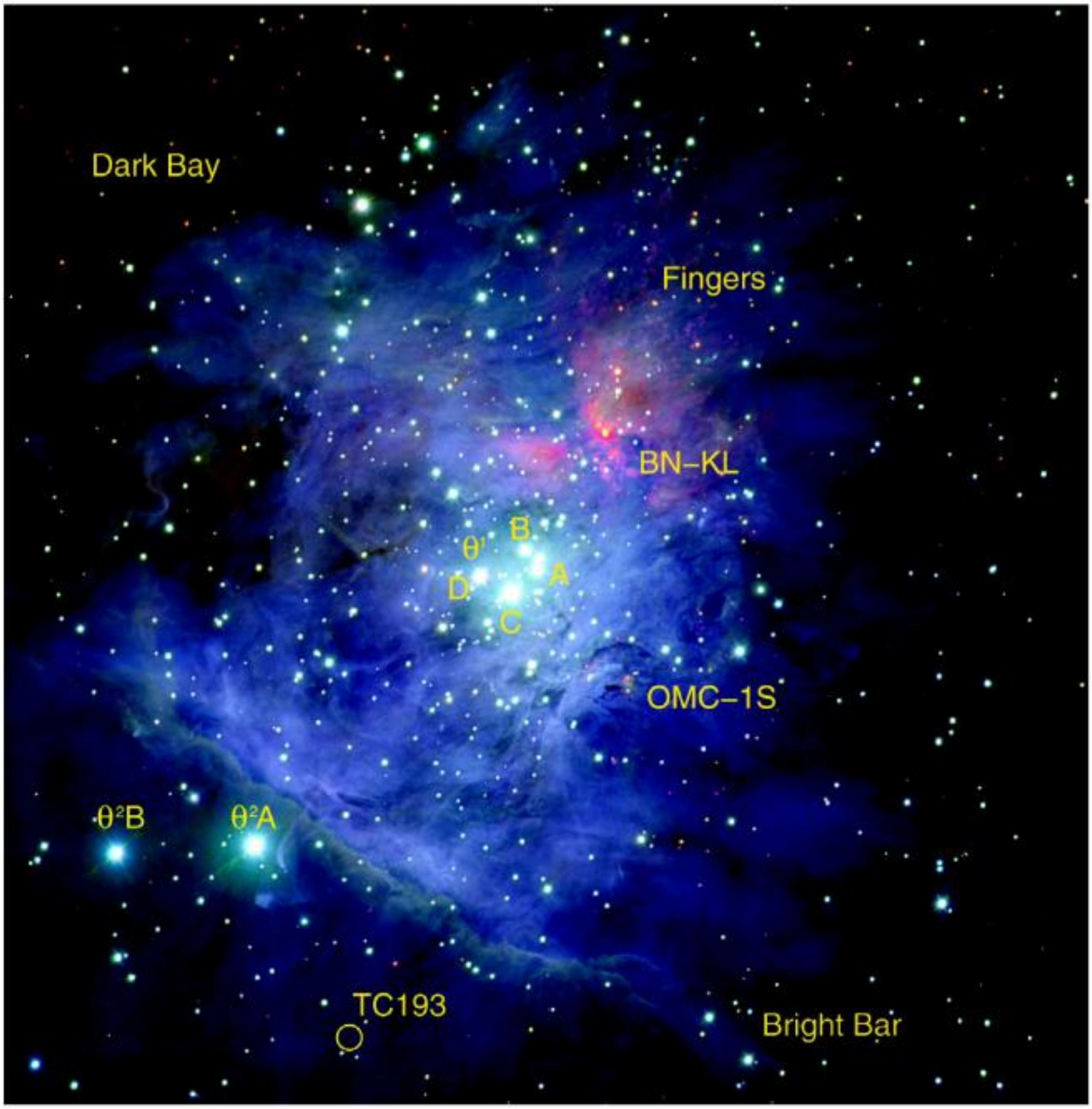


Figure 2: A true-colour near-infrared (1–2.5 μm) image of the Orion Nebula and Trapezium Cluster made using ISAAC on Antu in December 1999. The J_s data are shown as blue, H as green, and K_s as red. In this representation, cube root intensities and unsharp masking were used to compress the dynamic range and emphasise point sources, at a cost of some enhancement in the noise. The original version can be seen in McCaughrean et al. (2001). The image covers 7 × 7 arcmin, or 0.9 × 0.9 pc at the 450 pc distance to the nebula. North is up, east left. Total integration time in this subset of our data is 270 seconds per filter, and the seeing is 0.5 arcsec FWHM. For orientation, we have labelled the eponymous Trapezium OB stars at the centre of the image (θ^1 Ori A, B, C, & D); the two other well-known OB stars (θ^2 Ori A & B) just the south-east of the Bright Bar ionisation front; active star-formation centres embedded in the background molecular cloud, OMC-1S and BN-KL, the latter also being the origin of a massive outflow and the associated broad fan of shocked emission-line fingers to the north-west; and the Dark Bay, a region of high extinction in visible images that is penetrated here at infrared wavelengths. Also marked with a circle is TC193, a member of the Trapezium Cluster. With J_s, H, K_s magnitudes of $18^{m}.4$, $17^{m}.7$, and $17^{m}.2$, respectively, this source is roughly 13 magnitudes fainter than θ^1 Ori C, illustrating the huge dynamic range that must be faced in such studies. TC193 is part of a sample for which we already have ISAAC spectroscopy: a preliminary estimate of its spectral type is L2, which would yield a mass of roughly 6 M_{Jup} assuming an age of 1 Myr, according to the models of Chabrier et al. (2000). Dereddening the near-infrared magnitudes back to the same isochrone would suggest a mass nearer 10 M_{Jup}. Keep in mind also that it lies 2–3 magnitudes above our detection limits, and there are a significant number of potentially lower-mass sources to be studied in detail.

(McCaughrean et al. 2002, ESO Messenger)

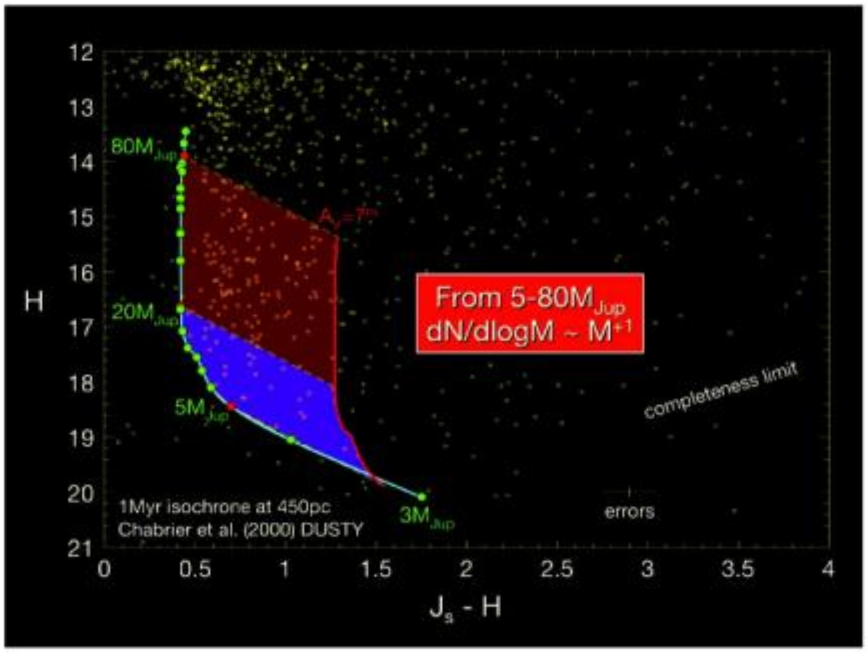
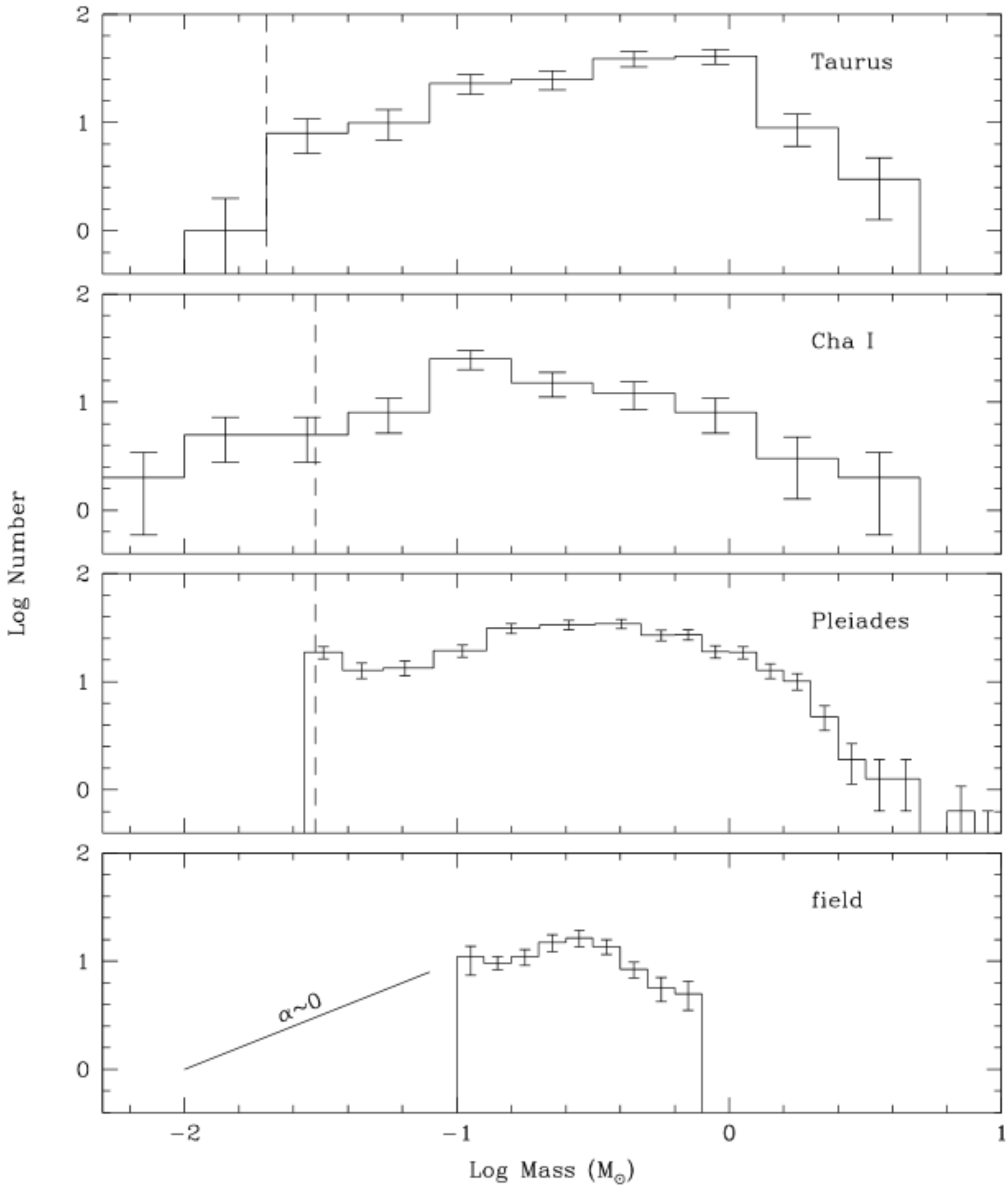


Figure 3: The (J_s–H) vs. H colour-magnitude diagram derived from our ISAAC imaging survey of the Trapezium Cluster (see Fig. 2). The completeness limit and typical photometric errors for sources just above this limit are shown. The 1 Myr isochrone from the pre-main sequence (DUSTY) models of Chabrier et al. (2000) is plotted assuming a distance of 450 pc. The great majority of the sources lie redwards of the isochrone due to intracluster dust extinction of up to ~ 20^m and greater. There is a pile-up of sources at $H = 12^m$–13^m due to the effects of deuterium burning, although sources brighter than this saturated within the 10 second on-chip integration time used for the survey. The number of potential brown dwarfs is large, but not dominant. As described in the text, we have also plotted the 0.005–0.08 $M_\odot$ (5–80 M_{Jup}) segment of the isochrone reddened by $A_V \sim 7^m$: by counting sources in the 5–20 and 20–80 M_{Jup} bins, we can see that the brown dwarf end of the IMF is clearly falling, as crudely characterised by the form $dN/d \log M \propto M^{+1}$.

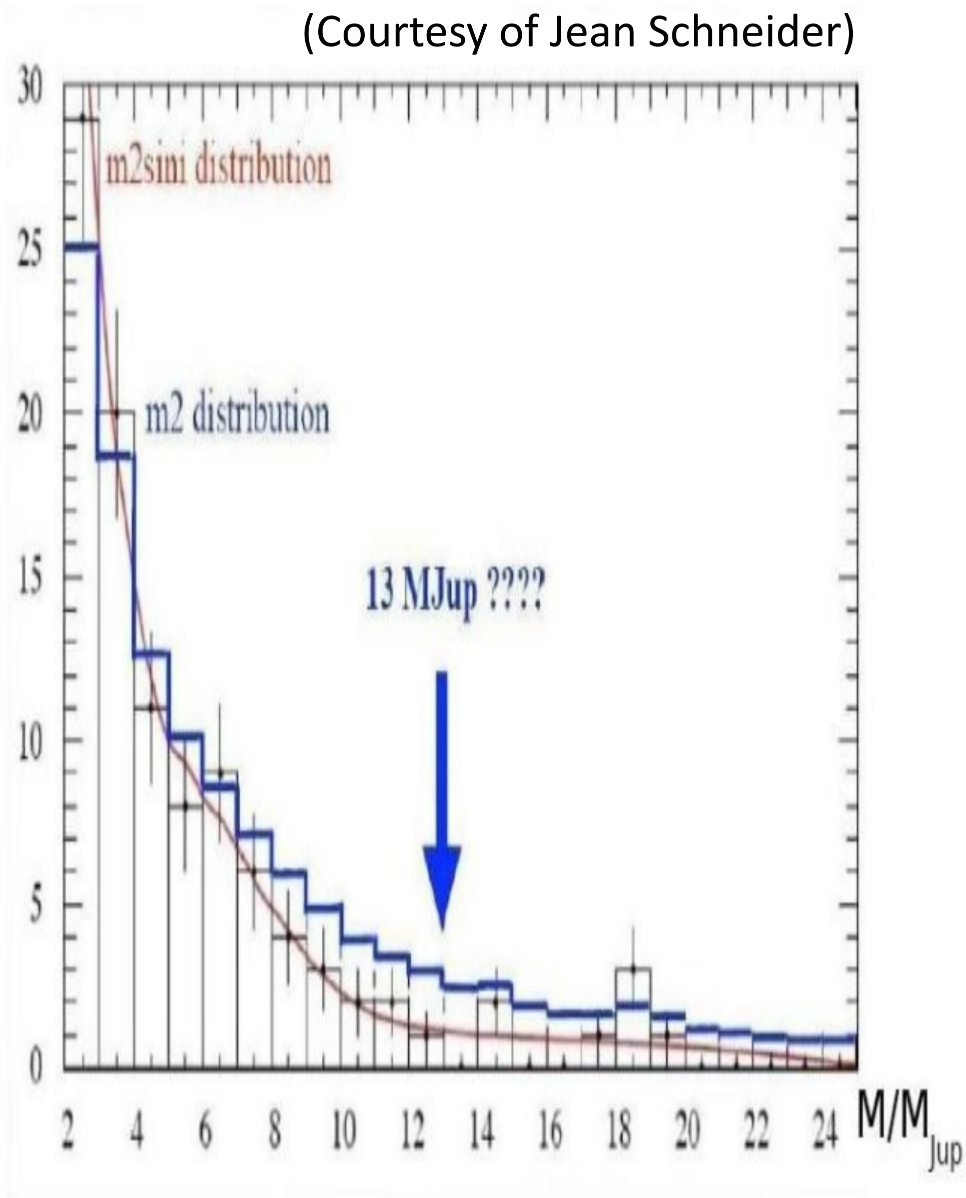
McCaughrean, Zinnecker et al. 2002:
(dN/dlogm ~ m^(+1) in the Orion TC
for masses in the range 5-80 M_Jup)

Mass functions of stars and brown dwarfs (M<0.08 Mo) in young stellar groups, field

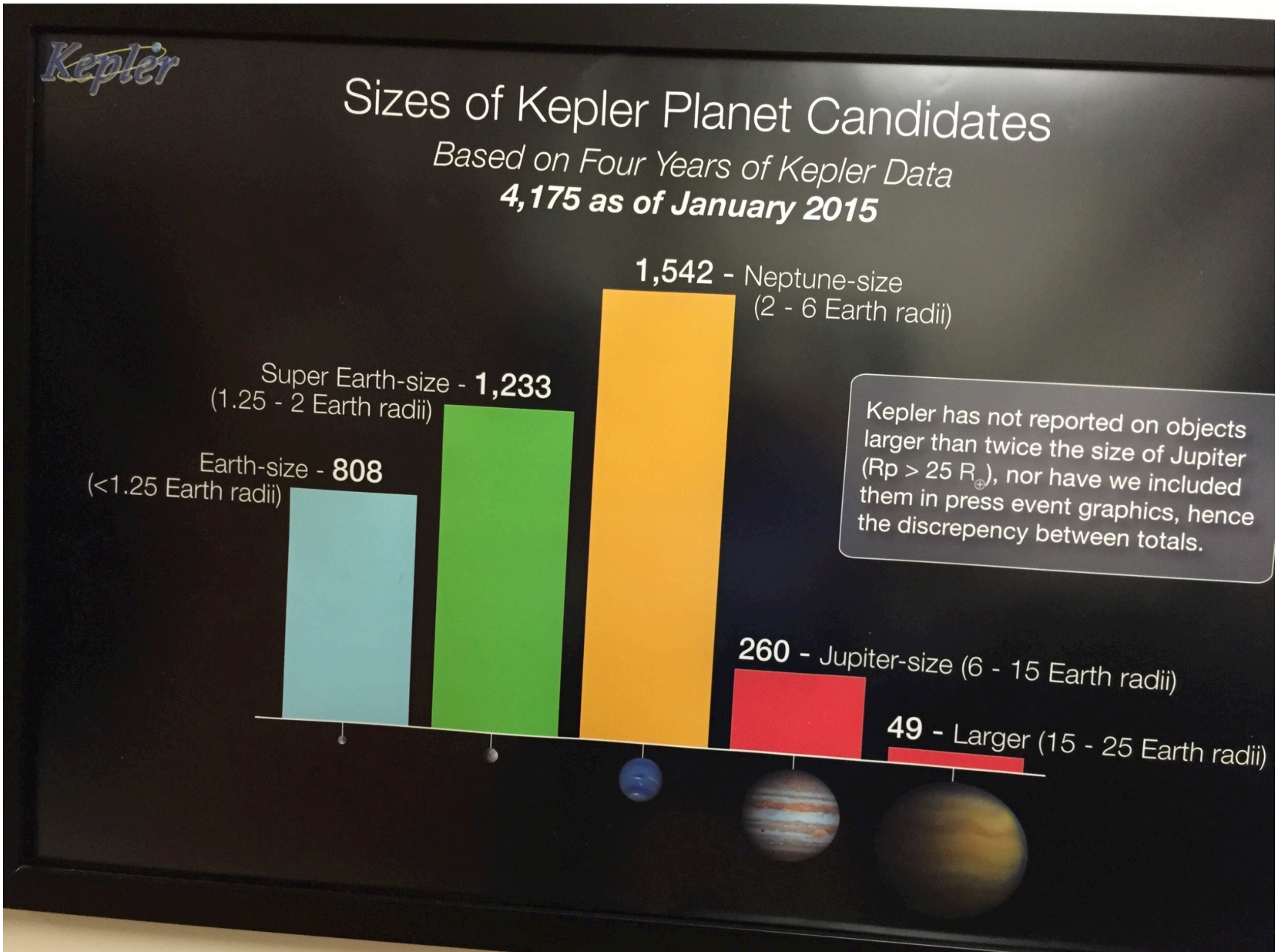
ARAA (2012)



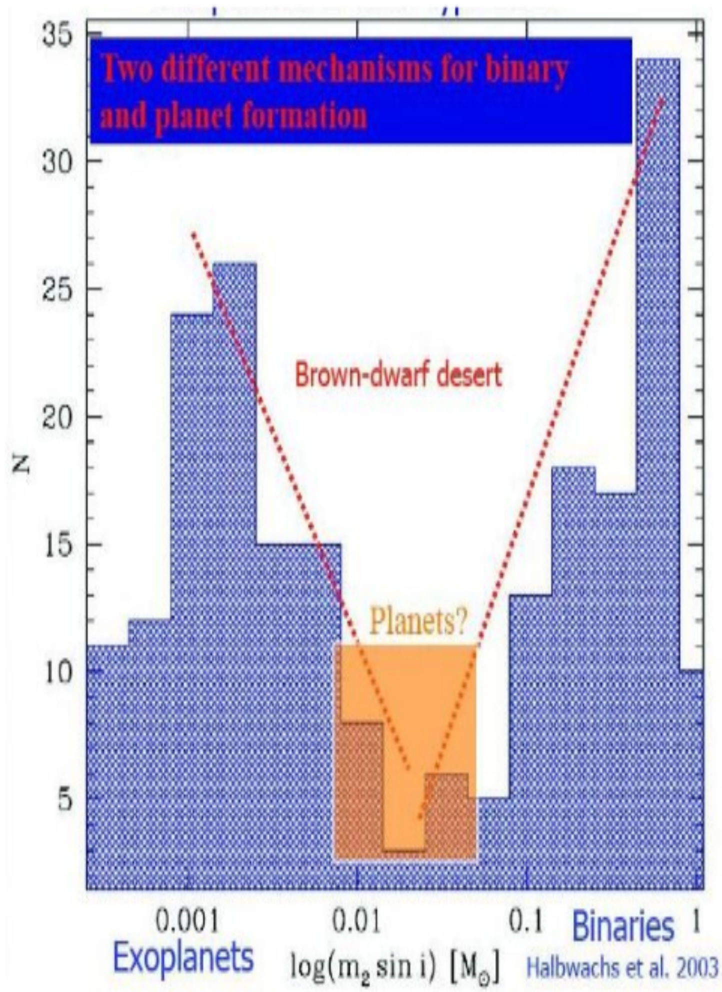
Mayor et al. 2011
(Courtesy of Jean Schneider)



PS. Most massive transiting planets include:
KOI 423b (19 M_Jup), CoRoT 3b (22 M_Jup)



Recent (2015) Poster from the Kepler Science Center, NASA-Ames



Jean Schneider, priv. commun.

==> 25 M_{jup}
better limit

than 13 M_jup
(deuterium burning limit)

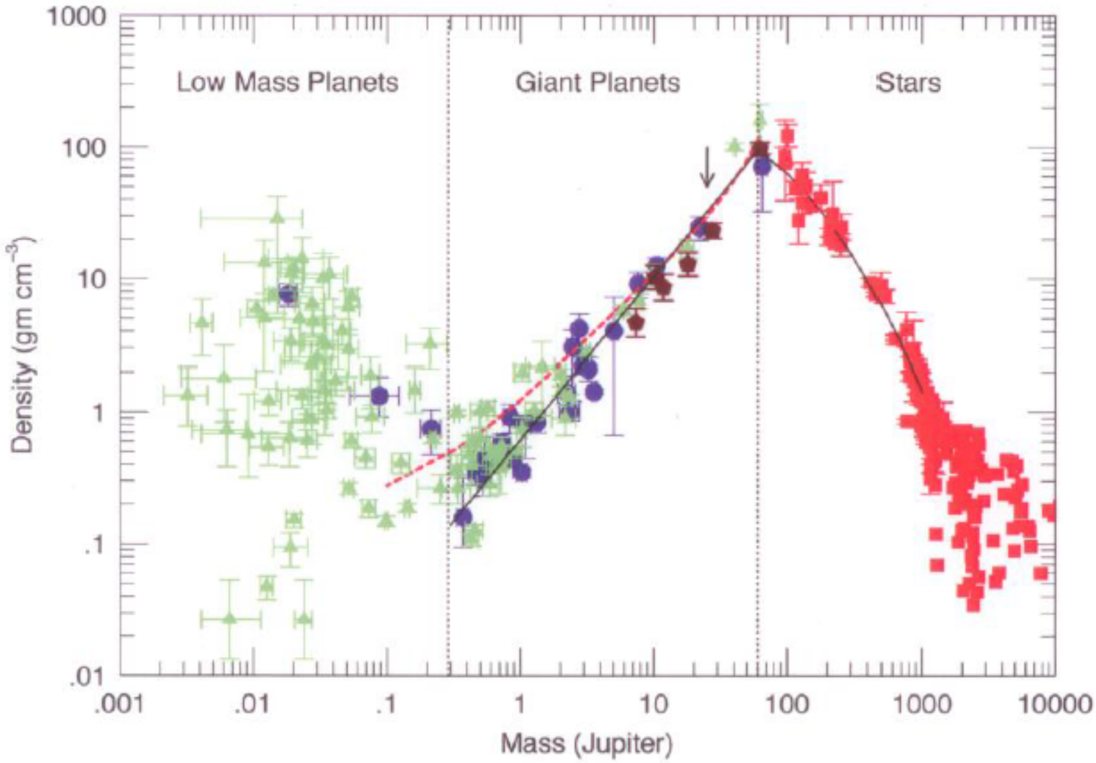


Fig. 1.— The density and mass of stars (red squares), giant planets and brown dwarfs, and low mass planets. Triangles represent Kepler discoveries and dots are CoRoT exoplanets. Ground-based discoveries for high mass giant planets are shown by pentagons. The line represents a linear fit to the giant planets and brown dwarfs in the mass range M = 0.35 - 60 M_{Jup}. A second order polynomial fit (curved line) was made to the lower end of the stellar main sequence. The boundary between the low mass planets and giant planet occurs at $M = 0.3\ M_{Jup}$. The boundary between the giant planets and stars is at $M = 60\ M_{Jup}$ ($0.060\ M_{\odot}$). The dashed red line shows the mass-density relationship for H/He dominated giant planets taken from Fortney et al. (2007).

Rauer and Hatzes 2015, astroph 1506.05097

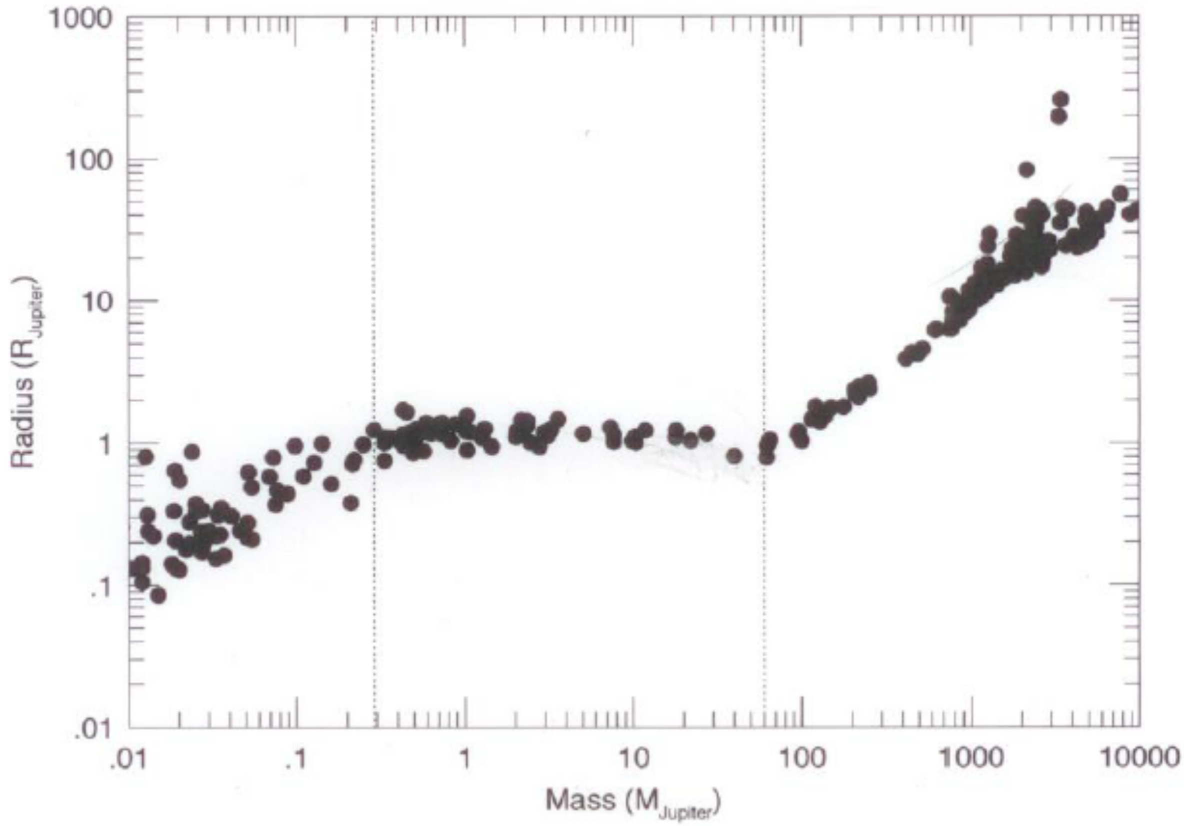


Fig. 2.— The points from Figure 1 shown in the mass-radius plane.

Hatzes and Rauer 2015, astroph 1506.05097

DISCUSSION
planet population synthesis
(Benz et al. 2015, PPVI)

which stars can host planets?
We suggest 0.3-3.0 M_solar
(disk mass, disk lifetime, UV)

Does each stellar mass have a charact. planet family?
Or is the outcome chaotic?
(diversity of planetary systems, Kornet etal. 2001)

Metallicity dep ! (speculation)
HZ 2002 (Bio-Astronomy Conf.)
Kokubo & Ida 2000, Buchhave et al. 2012:
implications of reduced dust mass in lower metallicity systems (eg. LMC/SMC, Halo)

thanks to:

Fred Adams
Jeff van Cleve
Jason Rowe
Jean Schneider

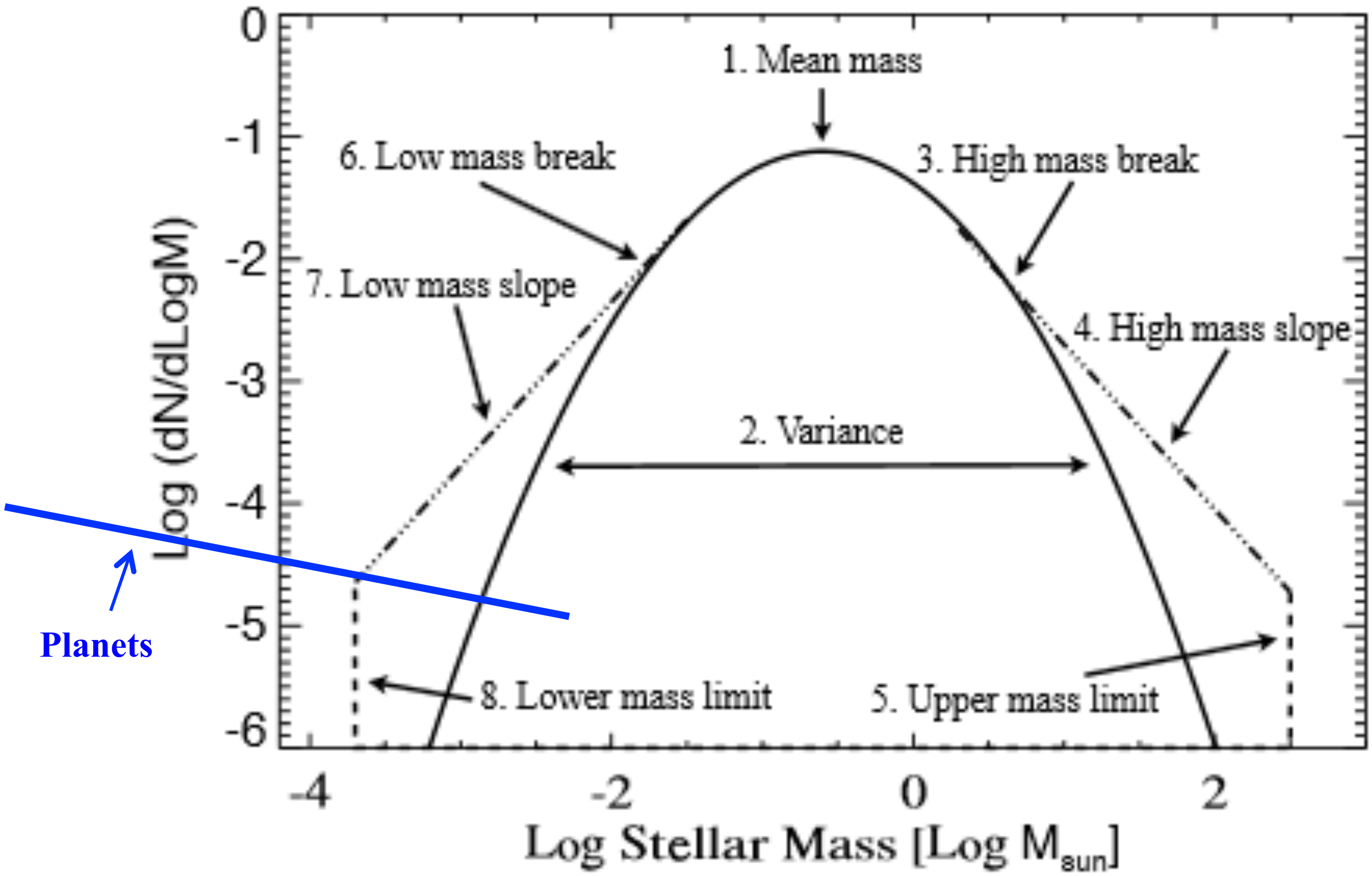
Mike Meyer
A. Quirrenbach
(after the talk)

Discussion (cont'd)

alternative origin for giant planets:
gravitational instability
in circumstellar disk

brown dwarfs origin like stars:
BD-BD binaries, BD disks

Microlensing:
Free-floating brown dwarfs
free floating planets
(planets can be ejected from disks)
masses can overlap
(blur near 10-20 M_jup)



Note: overlap of brown dwarfs and planets near 10 M_jup

Bastian, Covey, Meyer 2010, ARAA)