A Discontinuity in the Low-Mass IMF – A Brown Dwarf Mystery

Ingo Thies

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Overview

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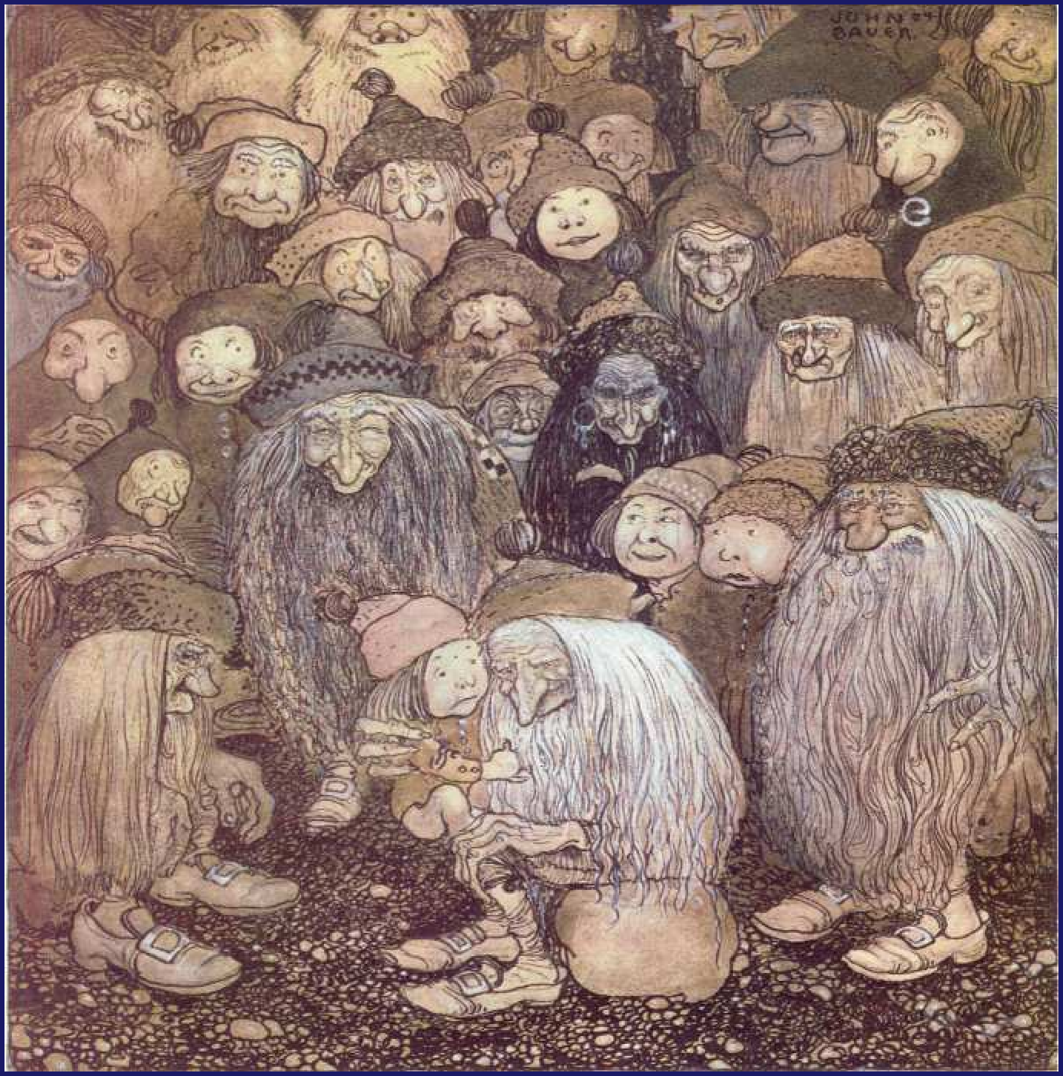


What are Brown Dwarfs?

- Term “Brown Dwarf” (BD) introduced 1975 by Jill C. Tarter for objects below the hydrogen-burning mass (0.075 $M_\odot$)
- BDs are not “brown” but glow red. However, “Red Dwarf” already used for low-mass hydrogen burning stars
- First confirmed discovery of three BDs in 1995, among them Gliese 229B

Image: John Bauer (1909)

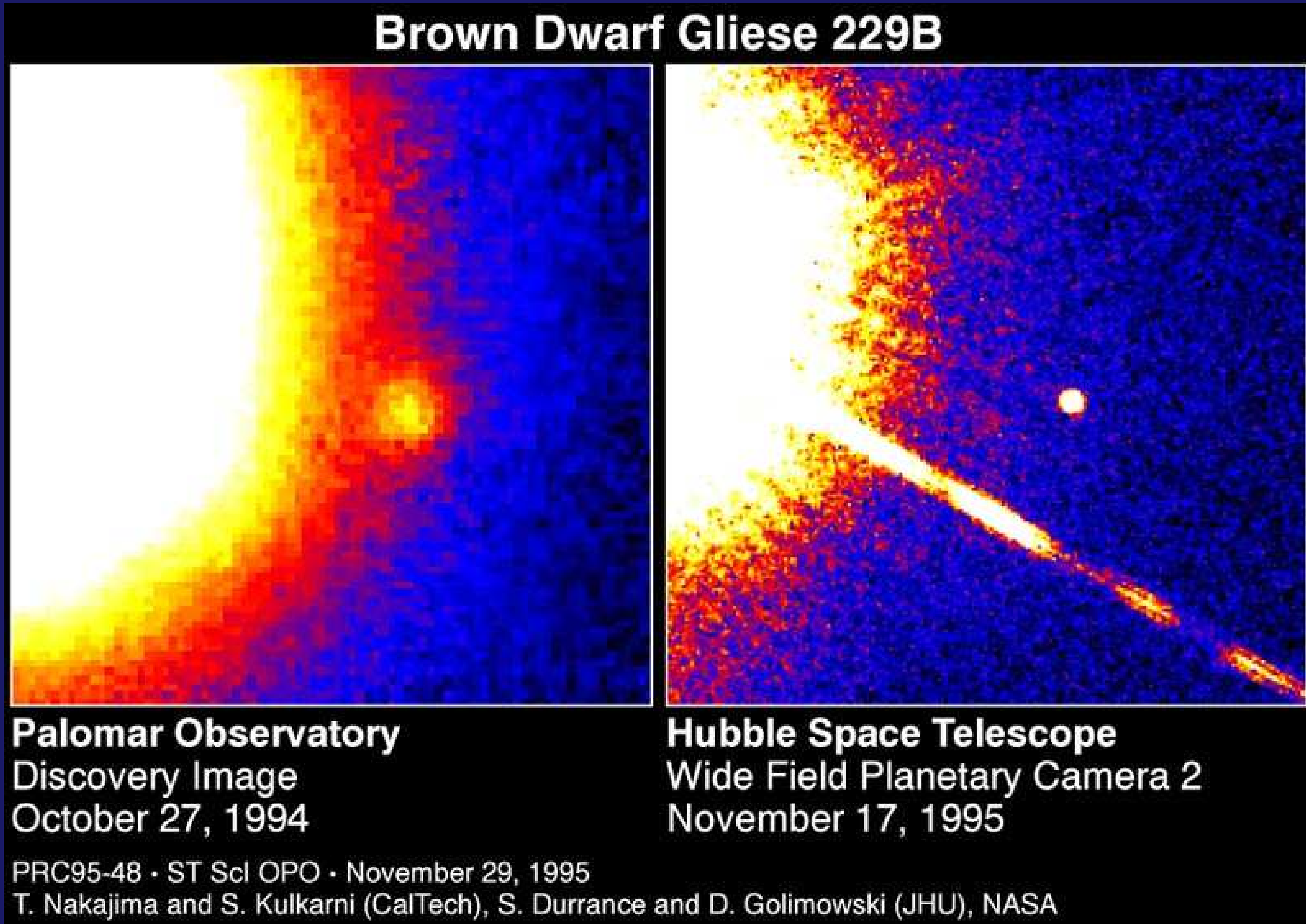

Brown Dwarf Gliese 229B
Palomar Observatory
Discovery Image
October 27, 1994
Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995
PRC95-48 • ST ScI OPO • November 29, 1995
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA

Image: NASA

Binary properties of BDs and stars

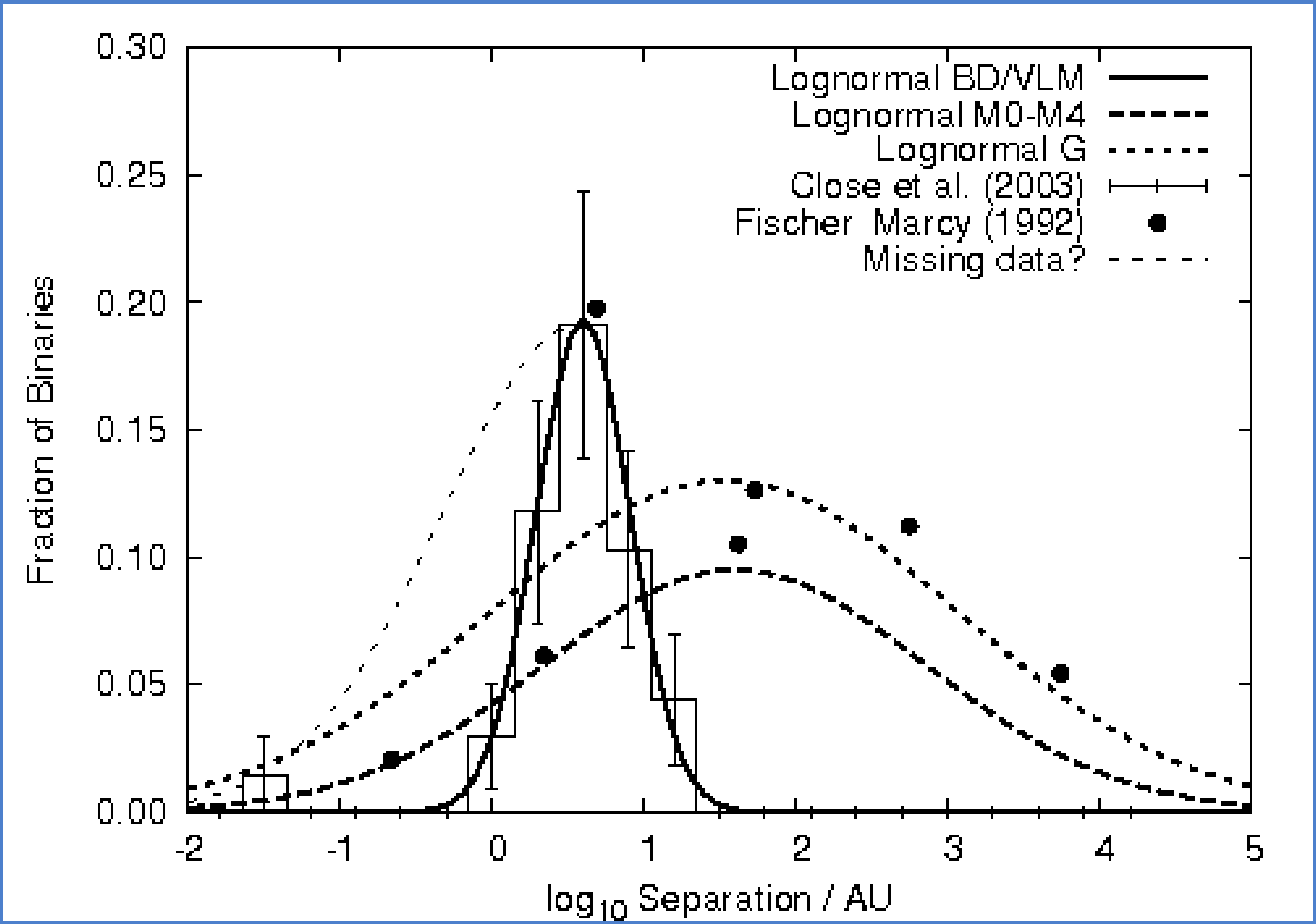
Early theories: Brown Dwarfs (BDs) form like stars but with less mass.

But...

- Almost no BD companions to normal stars found: $\Rightarrow$ BDs and stars don't mix ("Brown Dwarf Desert"!)
- Distribution of semimajor axes of BDs differs from that of stars. BD orbit distribution is truncated above 10 AU.
- BD binaries are less frequent ($\approx 15\,\%$) than stellar binaries ($50 - -100\,\%$)

$\Rightarrow$ BDs and stars belong to different populations!

Orbital distribution of BDs and stars



But…

What happens to the IMF?

Two IMFs for two populations

Initial Mass Function: $\xi(m) = \frac{\mathrm{d}N}{\mathrm{d}m}$

BDs and stars have to be devided into two populations with possibly overlapping mass regimes:

1. star-like, $m/M_\odot = \approx 0.07 \cdots \approx 100$
2. brown-dwarf-like, $m/M_\odot = \approx 0.01 \cdots \approx 0.2?$

Each population has its own IMF. Problems:

- Populations may overlap in mass range.
- Observations: Classify objects by brightness (and thus mass)
- $\Rightarrow$ Very-low-mass star-likes and very-high-mass BD-likes may by indistinguishable!

Fitting the observed IMF

Observational data:

- Surveys often do not resolve binaries $\Rightarrow$ observed IMF $\approx$ system IMF
- Average multiplicity can be determined by resolvable samples (outside overlap region)

How to get the IMFs:

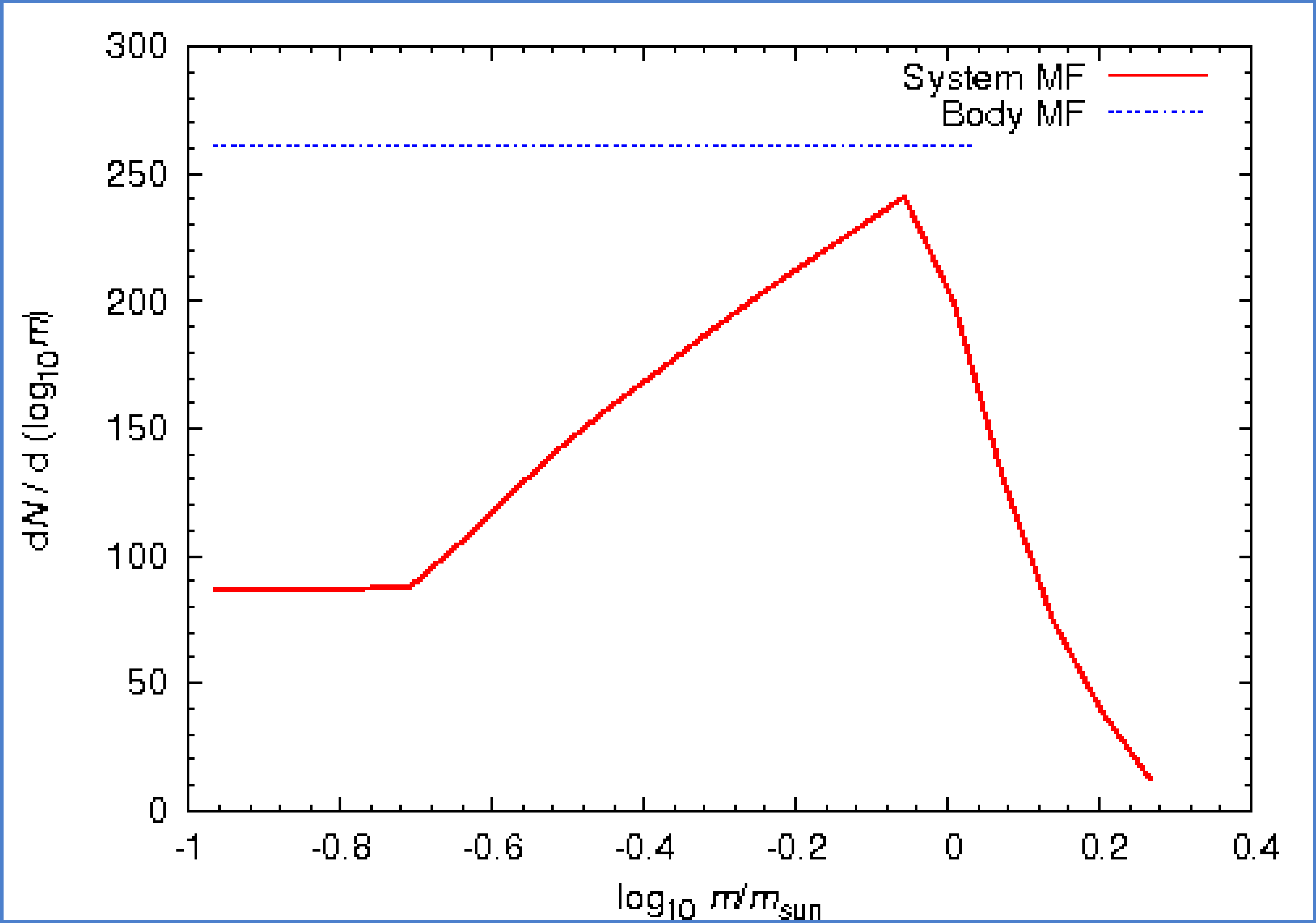
- Use reasonable shapes (e.g. from classical standard IMF) as first trial
- Correct each IMF ξ for multiplicity ($\approx$ binary fraction f)
- Compare the sum of both with observed IMF.
- Repeat this for different IMFs to optimize the fit.

Binary correction formula for random pairing:

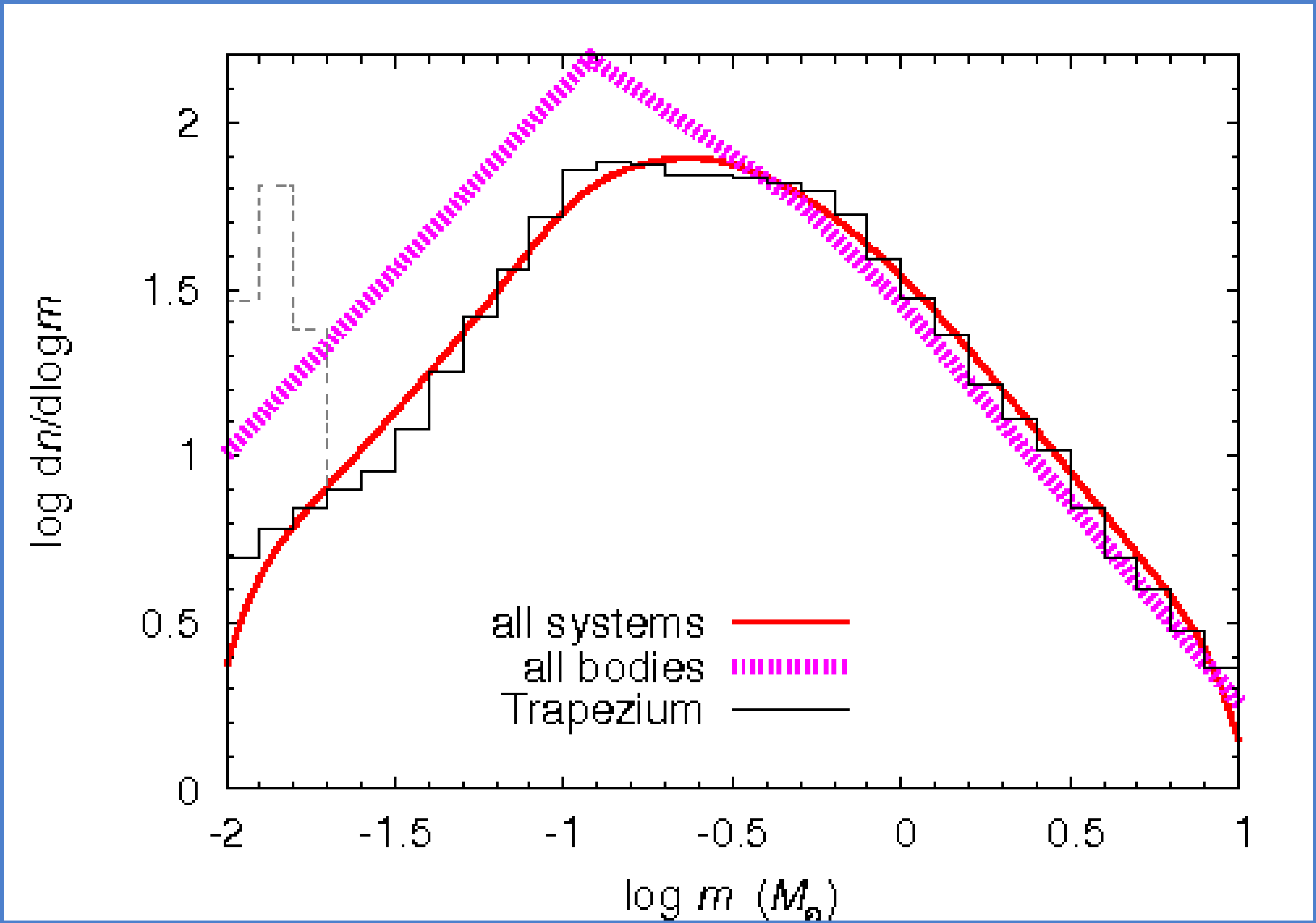
$$\xi_{\mathrm{bin}}(m_{\mathrm{bin}}) = N \int_{m_0}^{m_{\mathrm{bin}}-m_0} \hat{\xi}(m)\hat{\xi}(m_{\mathrm{bin}}-m)\,\mathrm{d}m\,,$$

where $m_0 =$ minimum mass of population, $\hat{\xi} =$ normalized IMF (sum = 1), "bin" indicates "binary".

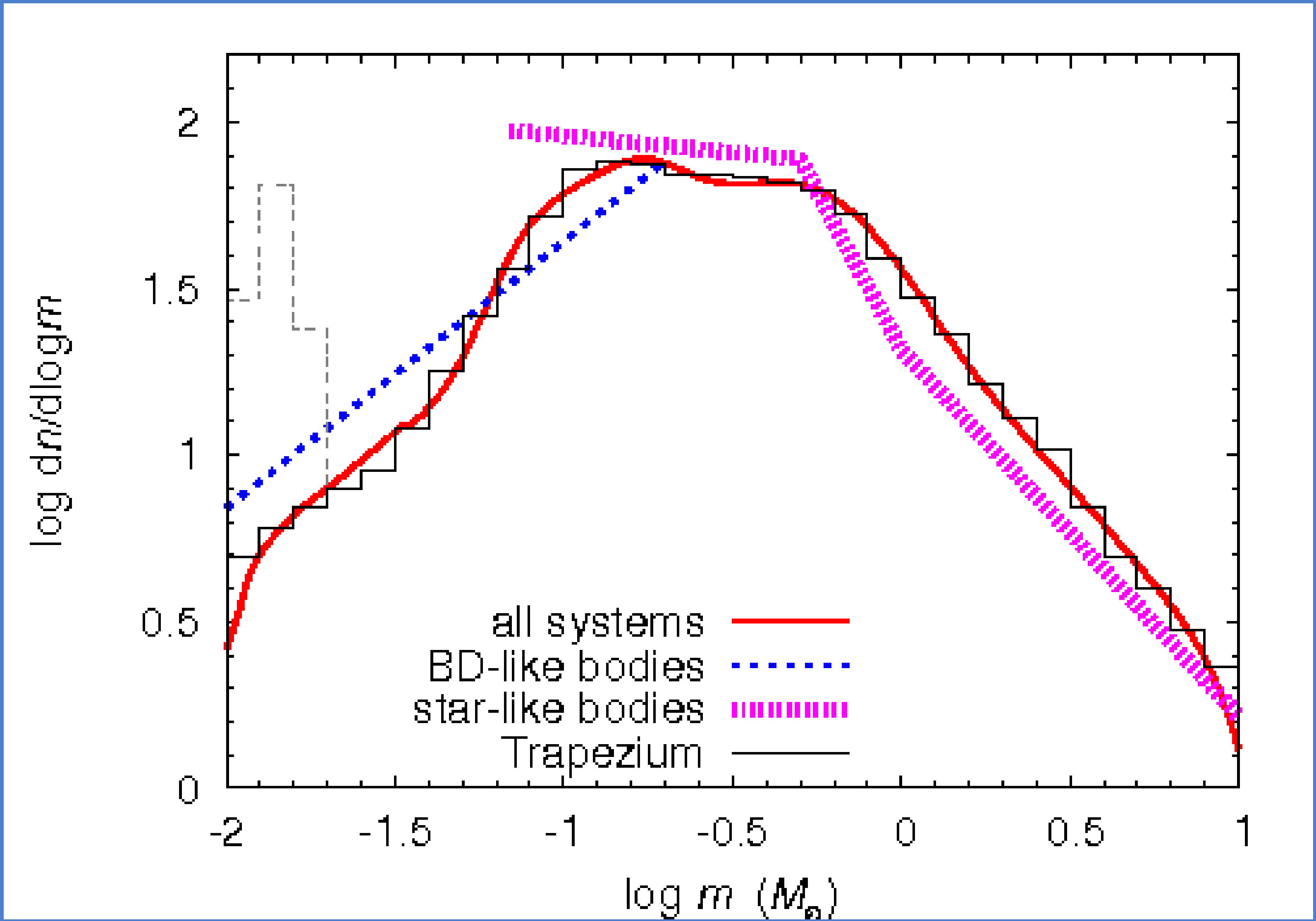
Binary correction of flat IMF with 50% binaries



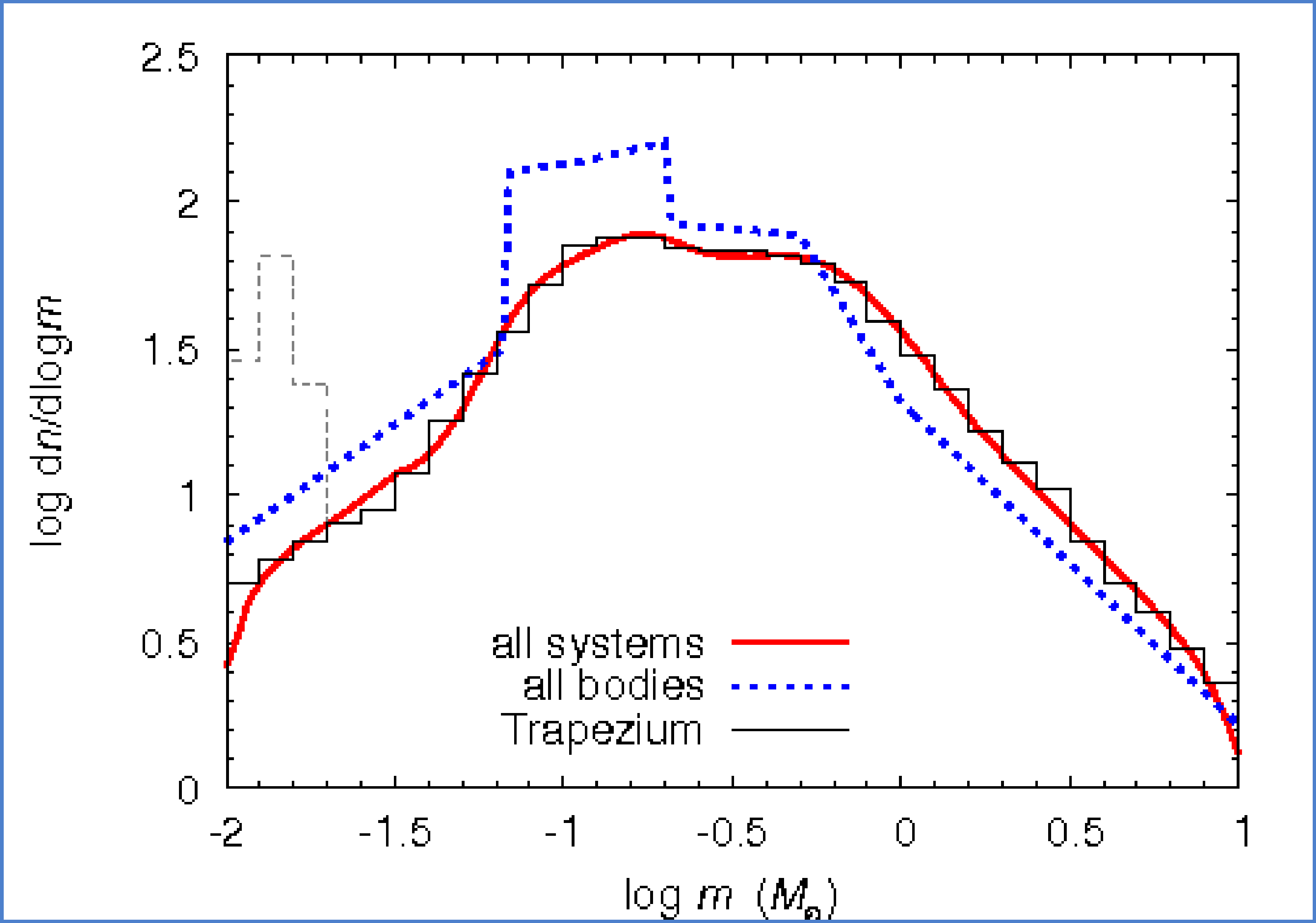
Example: Trapezium Cluster with continuous IMF



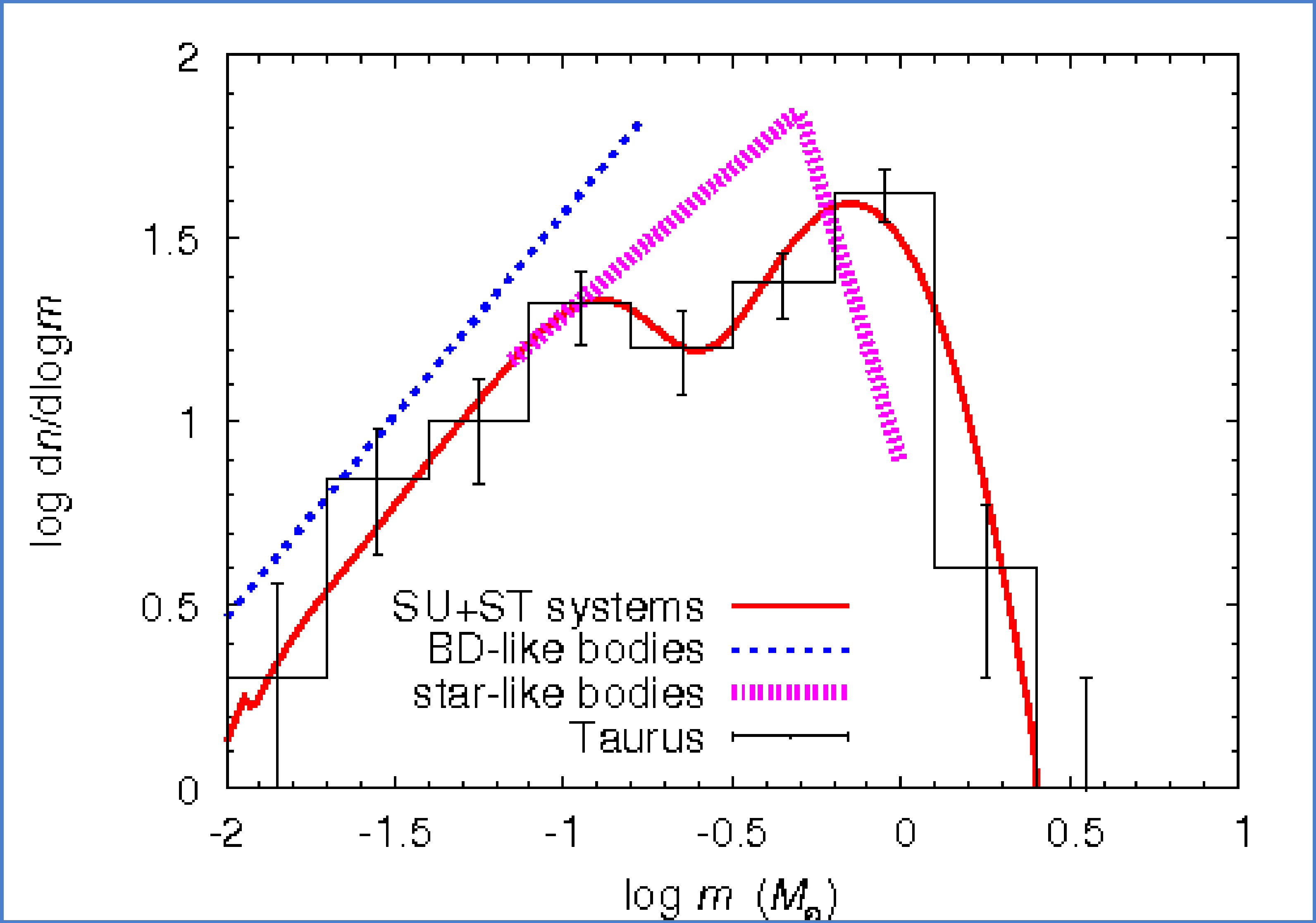
Better: Trapezium Cluster with separate IMFs



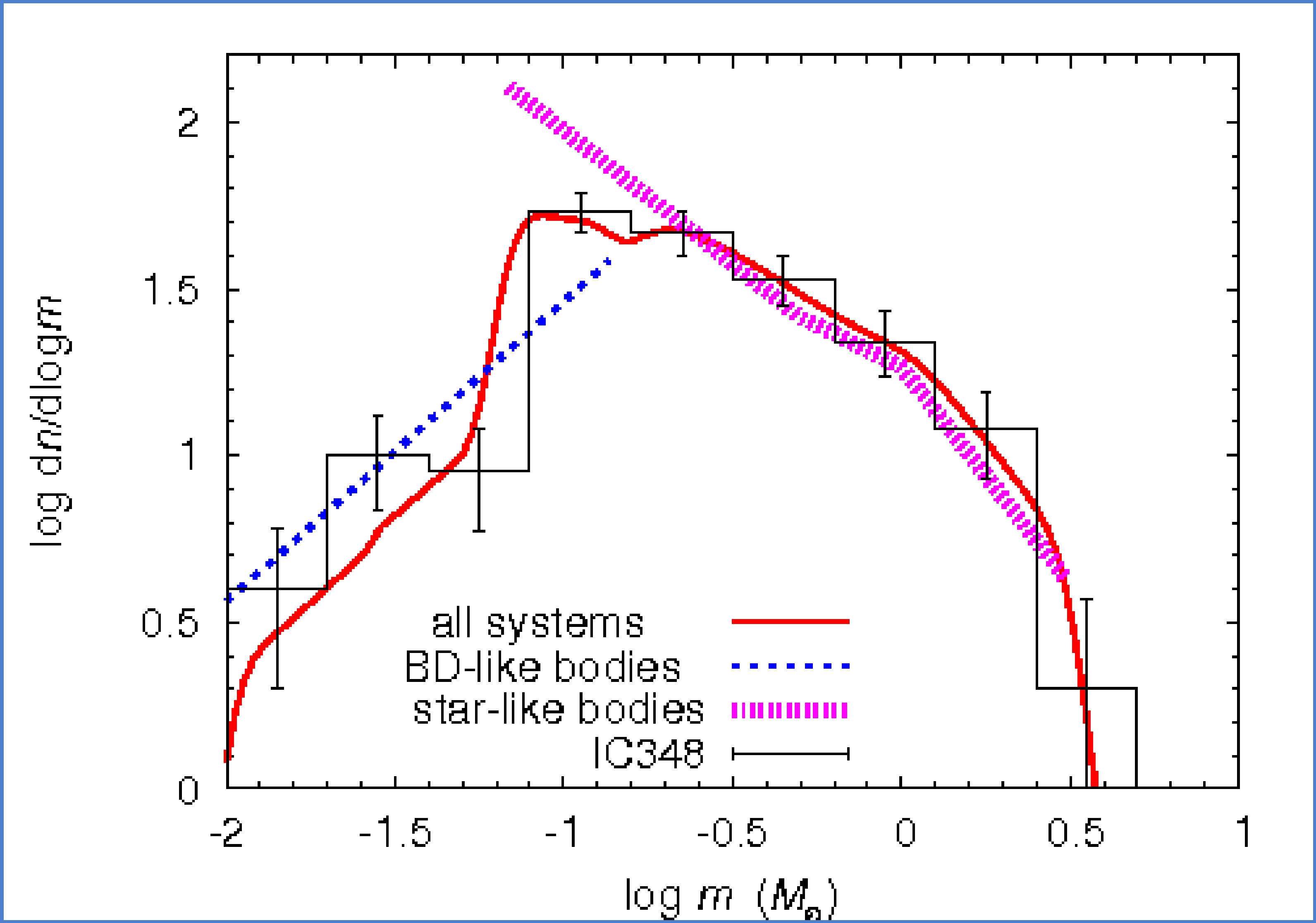
Better: Trapezium Cluster with sum of both IMFs



Taurus-Auriga

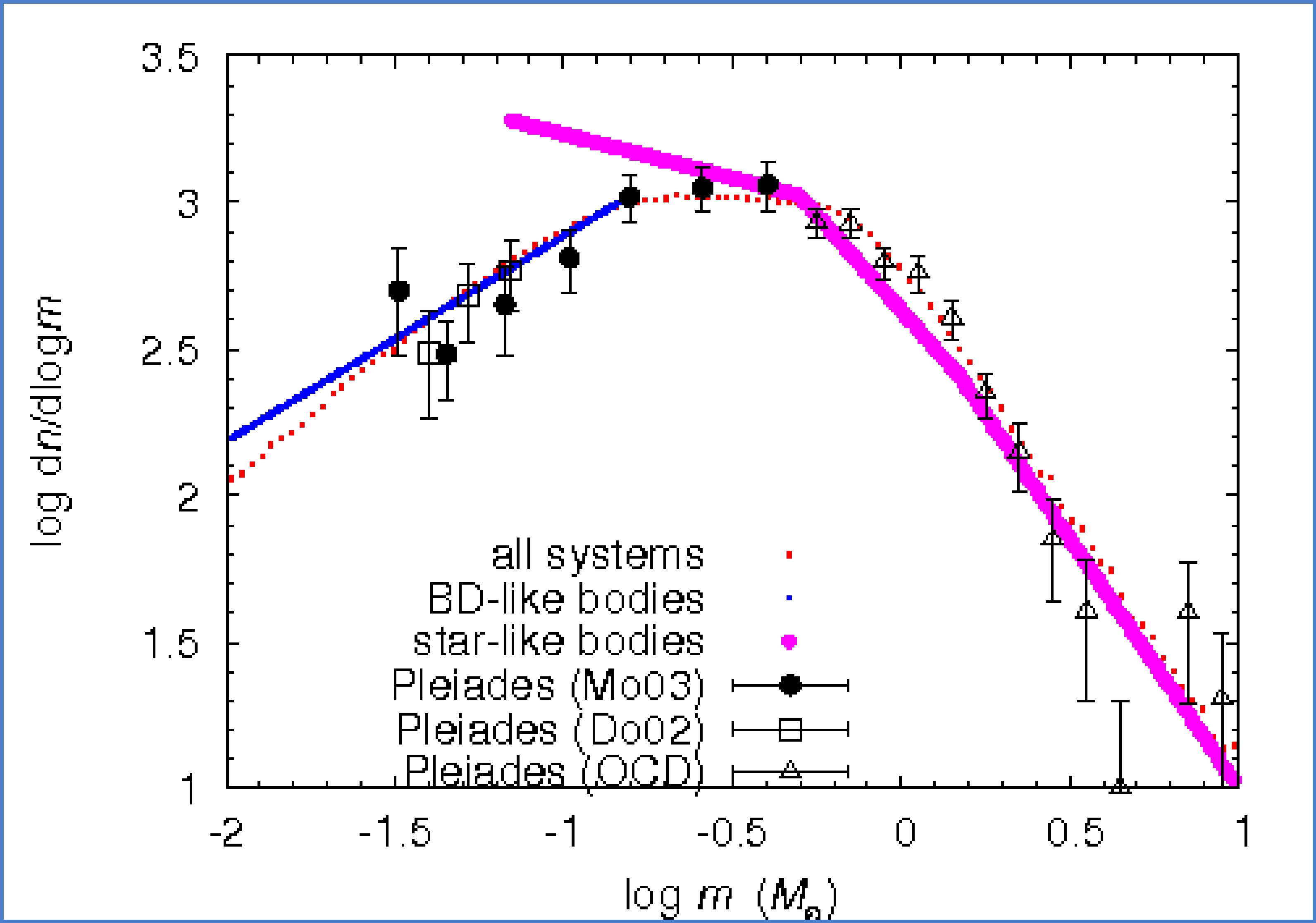


IC 348



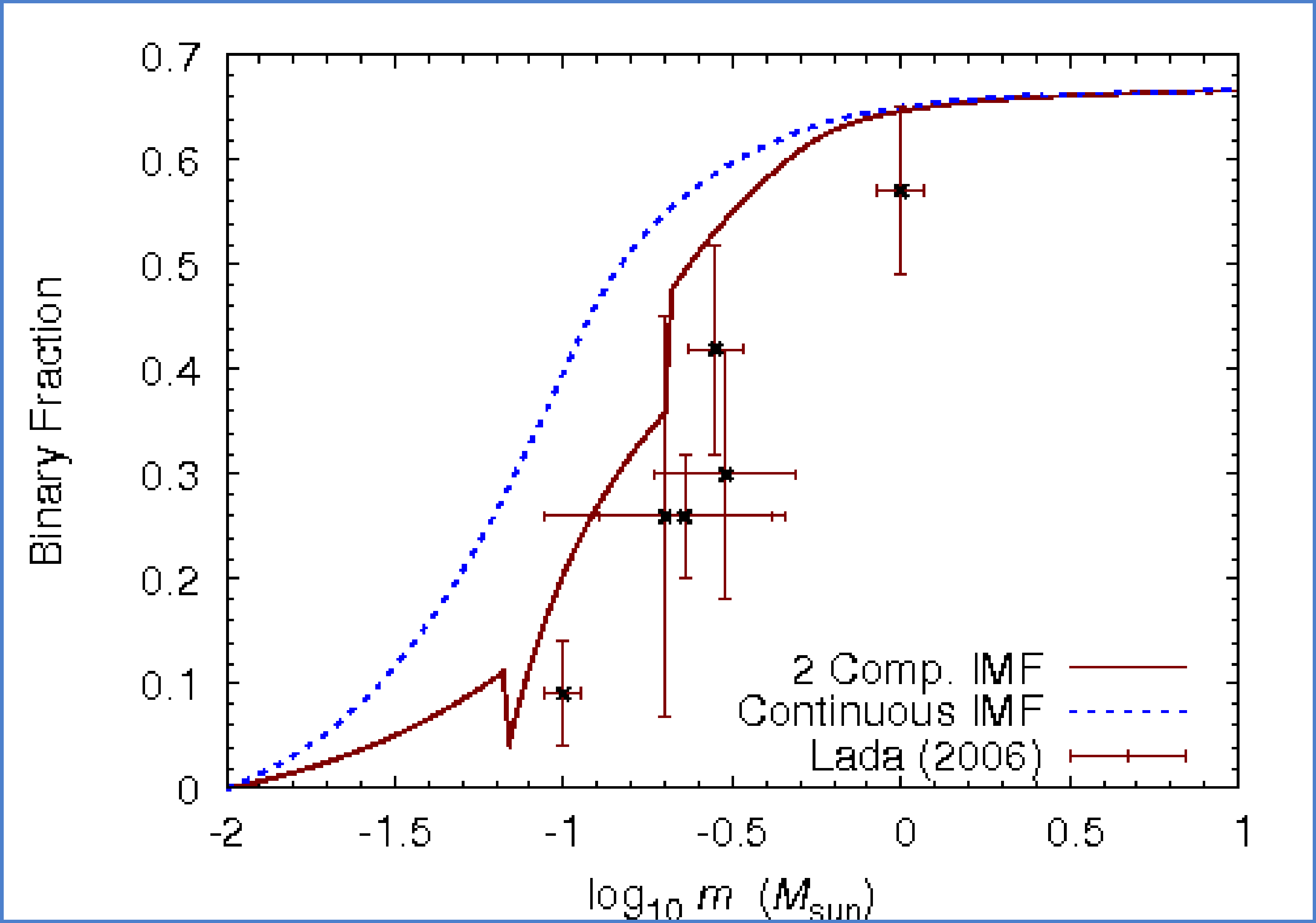
log dn/dlogm
2
1.5
1
0.5
0
-2
-1.5
-1
-0.5
0
0.5
1
log m (M⊙)
all systems
BD-like bodies
star-like bodies
IC348

Pleiades

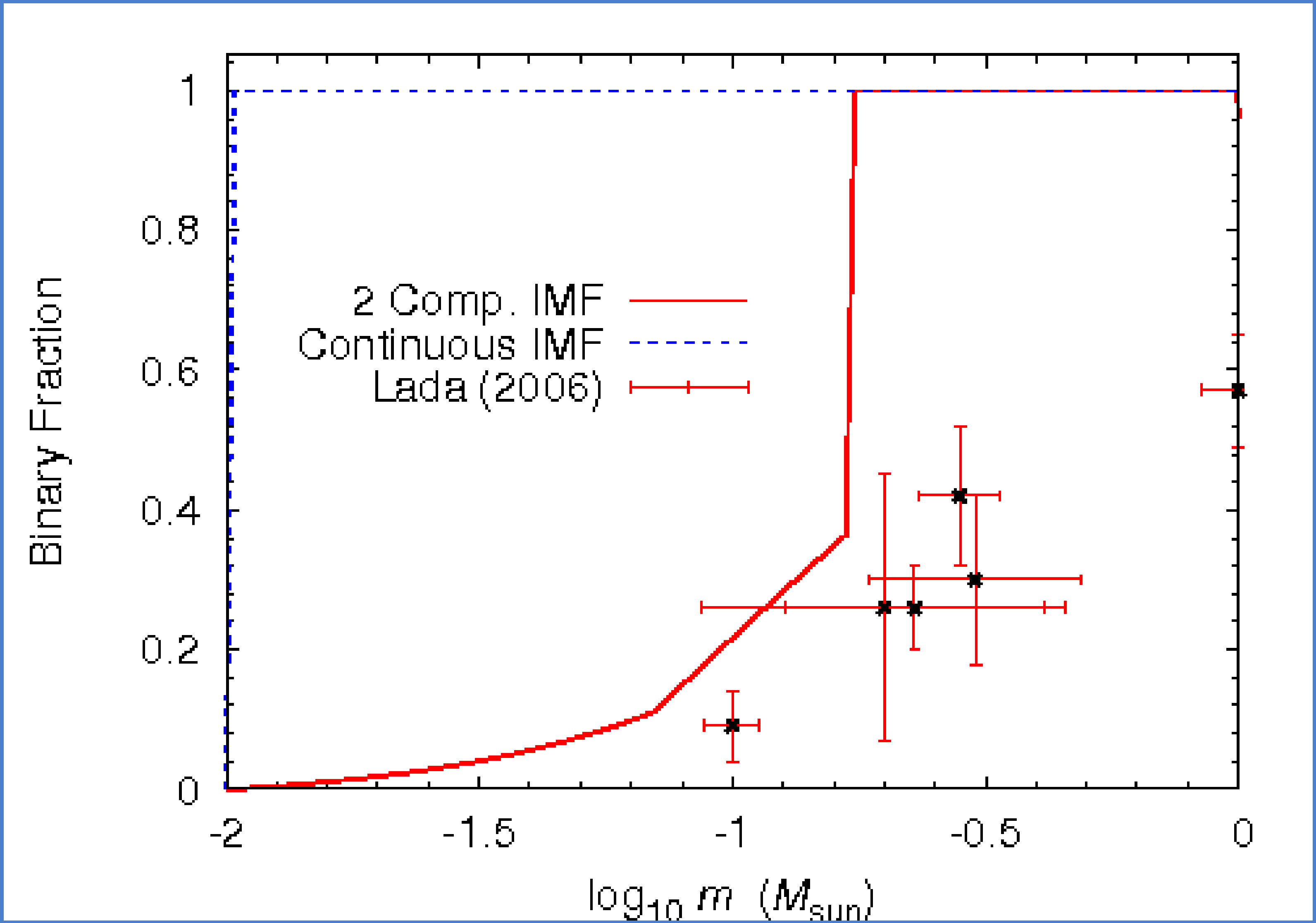


3.5
3
2.5
2
1.5
1
-2
-1.5
-1
-0.5
0
0.5
1
log dn/dlogm
log m ($M_\odot$)
all systems
BD-like bodies
star-like bodies
Pleiades (Mo03)
Pleiades (Do02)
Pleiades (OCD)

Binary fraction: Trapezium



Binary fraction: Taurus



Summary of the studied clusters

Cluster	Age / Myr	N	$f_{\rm star}$	BD-to-star ratio
Taurus-Auriga	~ 1	130	~ 1	0.15
IC 348	2	200	0.5	0.14
Trapezium	2	1000	0.5	0.16
Pleiades	130	500	0.5	0.19

Note that the Pleiades cluster is relatively old

$\Rightarrow$ BDs cool and hard to detect.

$\Rightarrow$ BD data are likely far from completeness.

The Origin of Brown Dwarfs

Four important attempts to solve the BD mystery:

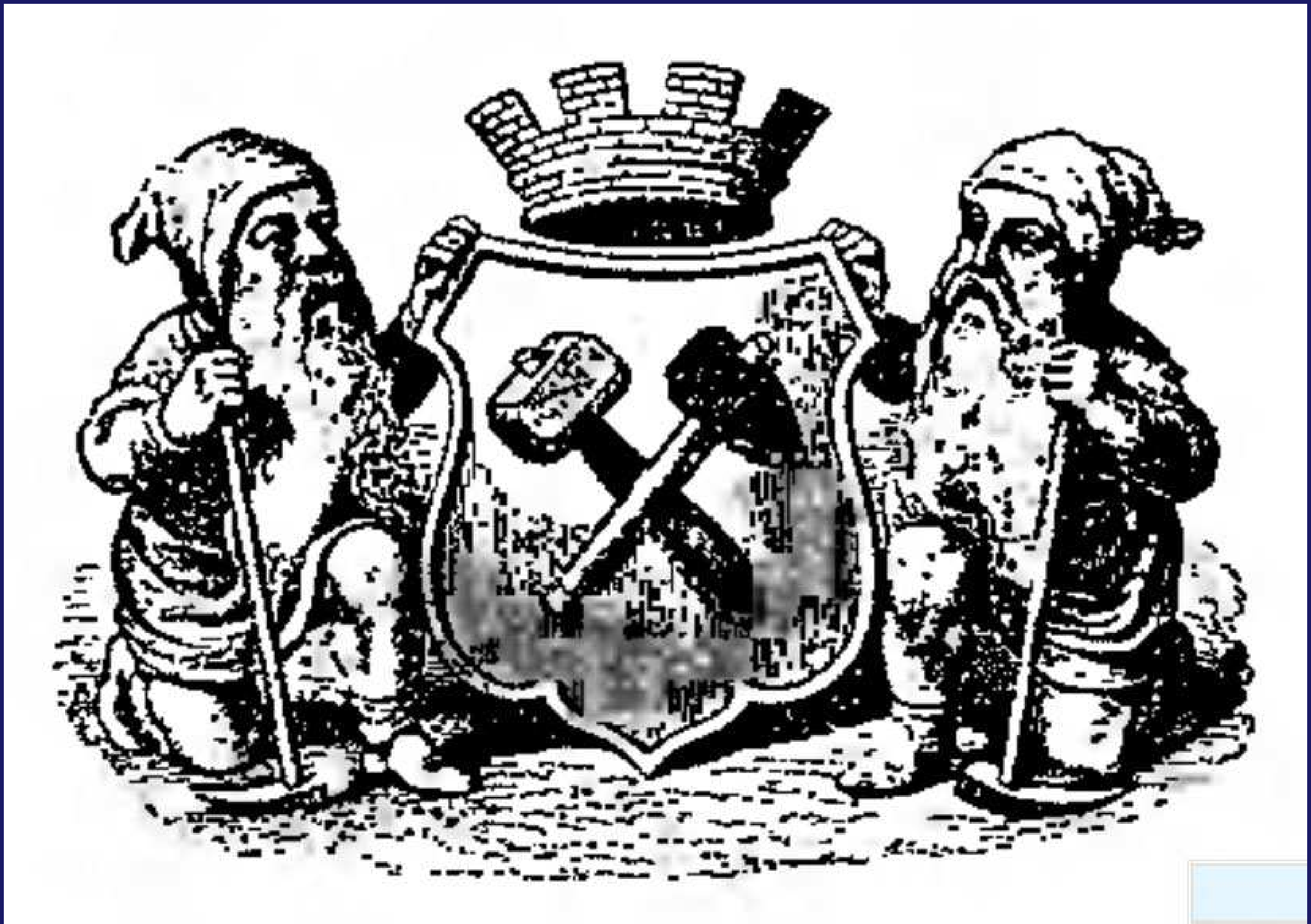
1. BDs form via fragmentation of circumstellar disks
   (viable for singles, but fails to explain binaries);
2. disruption of the proto-substellar accretion envelopes via close stellar encounters before the star is finished
   (improbable, can be ruled out);
3. photo-evaporation of the accretion envelope
   (predicts higher BD/star ratio in massive dense clusters);
4. BDs are unfinished stellar embryos ejected from their birth system (Reipurth & Clarke, 2001)
   (explains BD binary fraction; apparently the favorite scenario)

Summary

- "BD desert" and Binary properties of BDs and stars imply two separate populations ("star-like" and "BD-like")
- Population mass ranges may overlap, allowing "star-like BDs" and "BD-like stars"
- Two separate IMFs better fit the observational mass functions (at least for Trapezium) $\Rightarrow$ supporting the two-populations model
- Binary fraction $f(m)$ for two IMFs in better agreement with observations than continuous IMF
- "Ejected embryo" scenario one of the favorite formation theories today.

Outlook

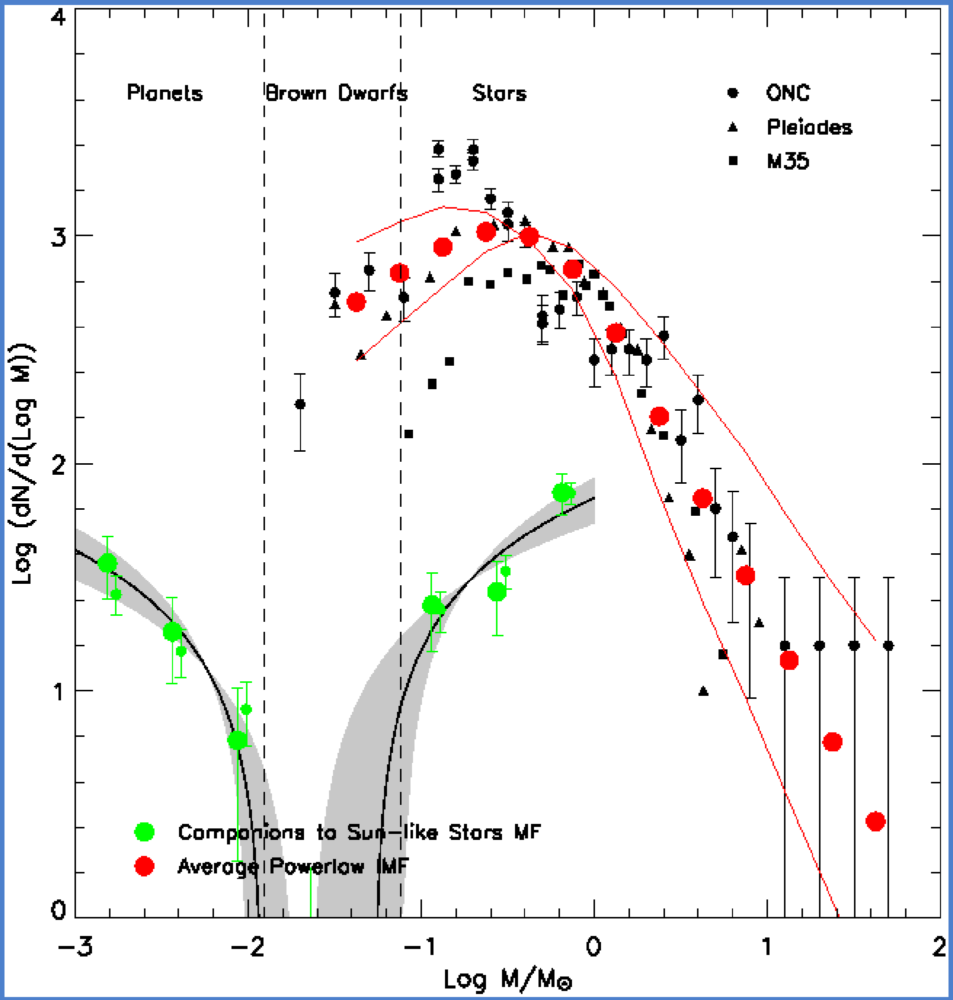
More detailed observations needed for more detailed reseach...



Thank You!

Companion IMF

(Grether & Lineweaver 2006)



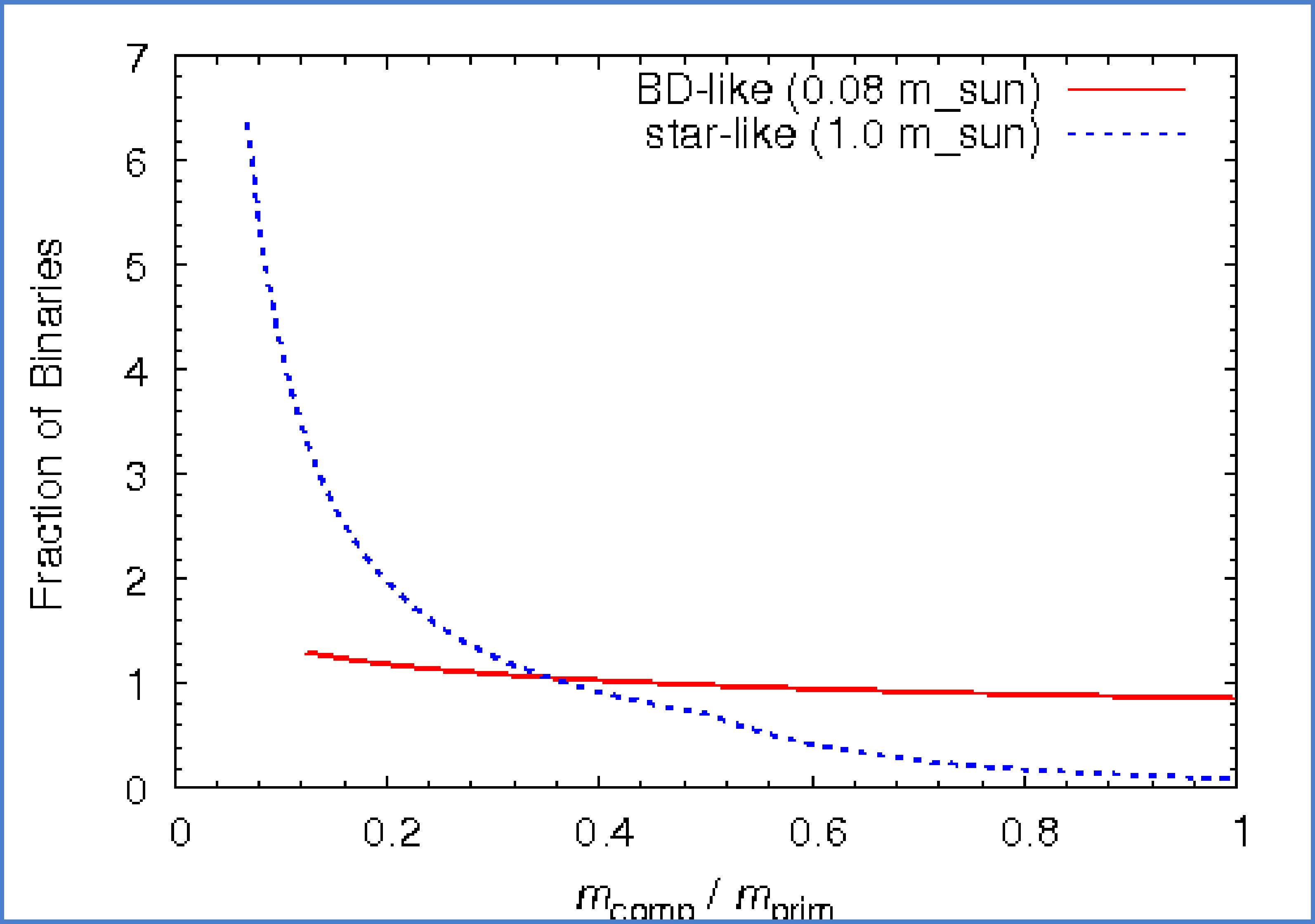
Three mass regimes can be found

1. planetary companions (<0.02 $M_\odot$)
2. BD Desert (0.02–0.08 $M_\odot$)
3. stellar companions (>0.08 $M_\odot$)

But primary sample is limited to sun-like stars ($\sim 1\ M_\odot$).

No information about companions to M-dwarfs.

Mass ratio distribution for Trapezium



Mass ratio distribution for Taurus