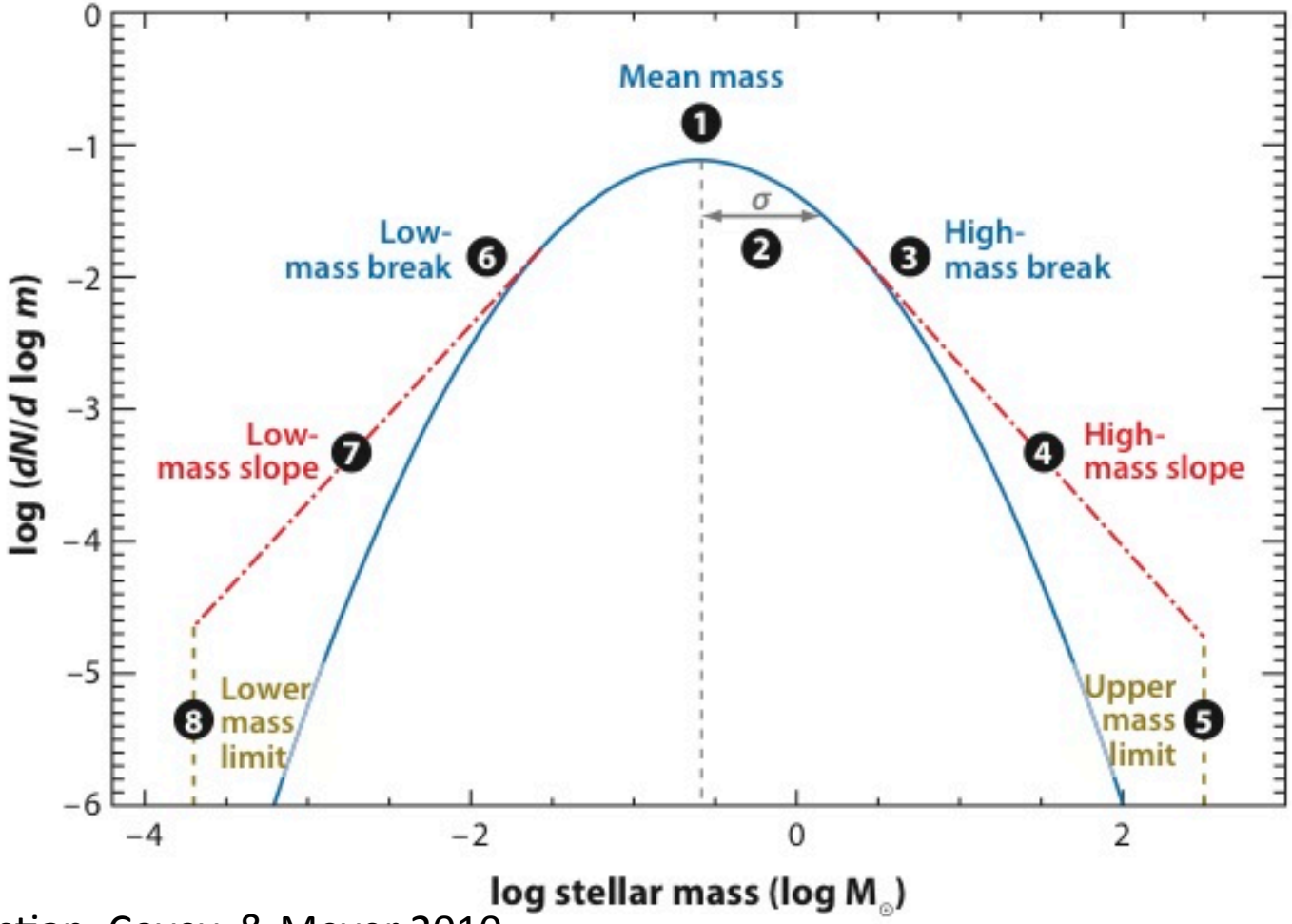
Revealing and Understanding the Low-mass End of the Stellar IMF

K. L. Luhman (Penn State)



Bastian, Covey, & Meyer 2010

Outline

- The field
- Open clusters
- Star-forming regions

See also: Bastian, Covey, & Meyer 2010, ARAA

A Universal Stellar IMF? A Critical Look at Variations

Advantages of Field

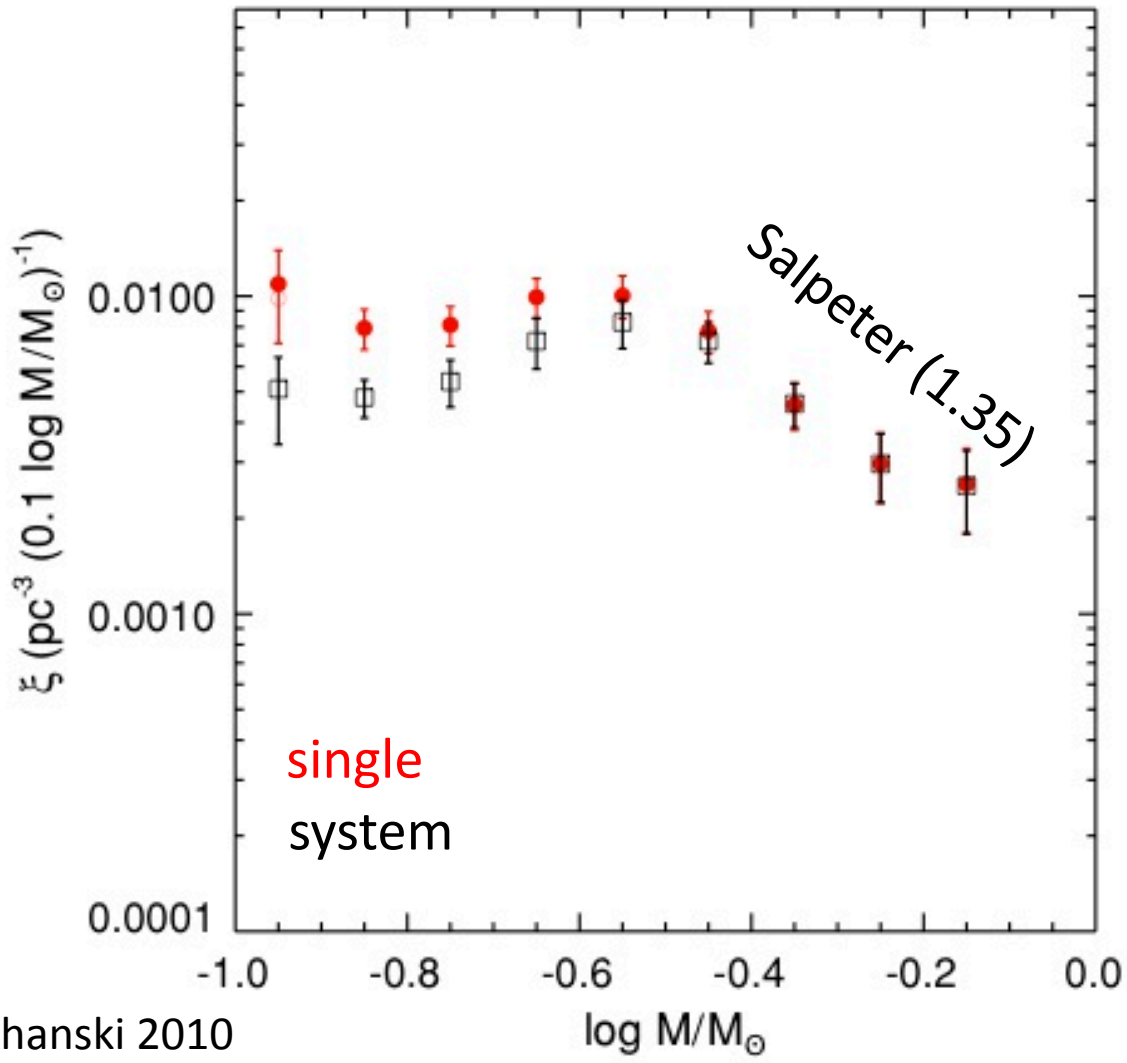
- Avoid uncertainties in models at young ages (initial conditions, accretion history, convection treatment)
- Good statistics from latest surveys

Disadvantages of Field

- Uncertainties in models at cold temperatures
- Because field objects relatively old, cannot reach the masses below ~10 M_{Jup}
- Ages unknown, so individual masses uncertain, and IMF not directly measured
- Must assume functional form for IMF and try to reproduce observed distribution vs. spectral type
- Completeness more difficult to characterize than in clusters since targets have a wide range of distances

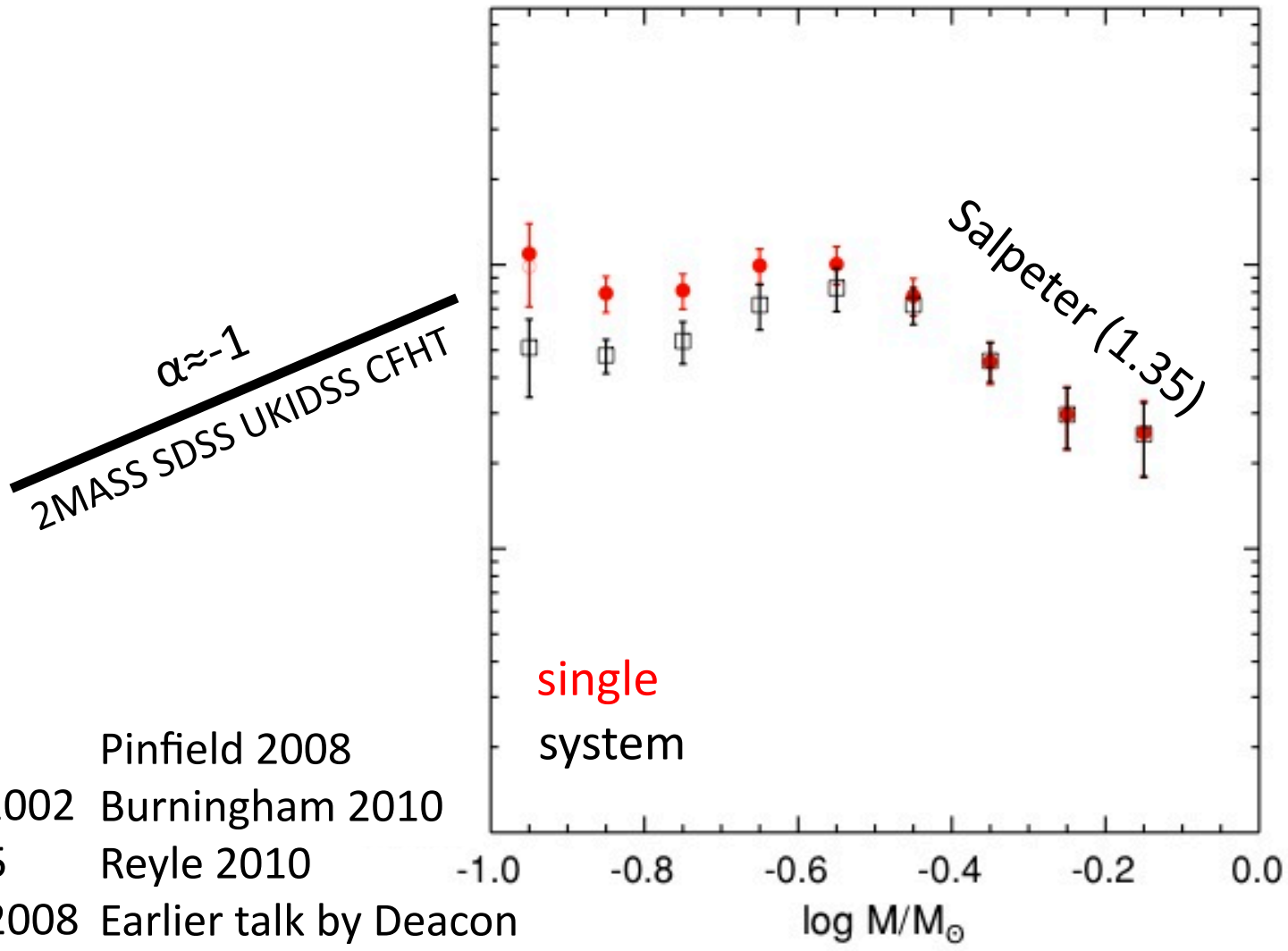
IMF of Low-mass Stars in the Field

See also:
Reid & Gizis 1997
Chabrier 2001
Kroupa 2002
Reid 2002
Covey 2008
Deacon 2008



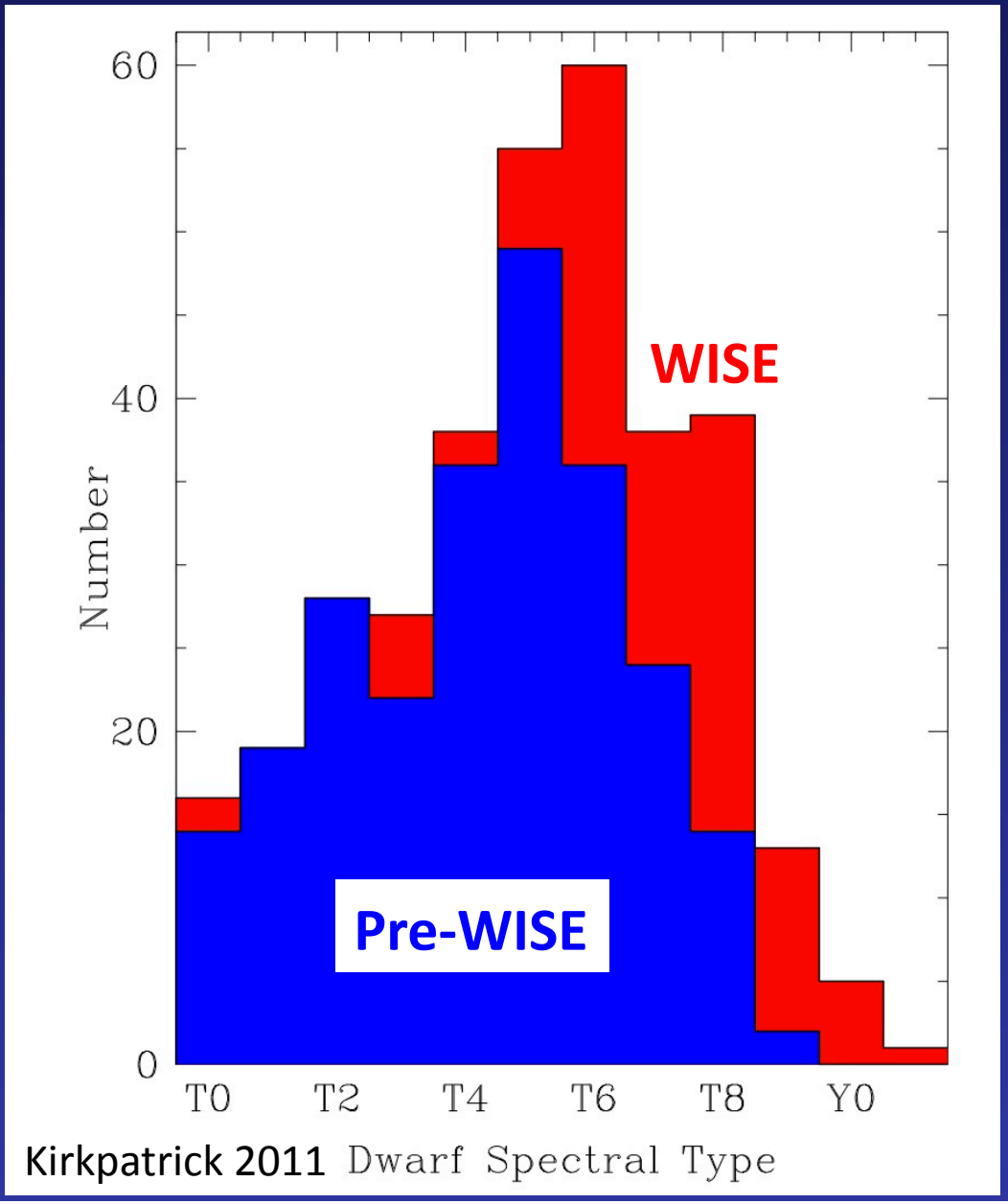
Bochanski 2010

IMF of Brown Dwarfs in the Field

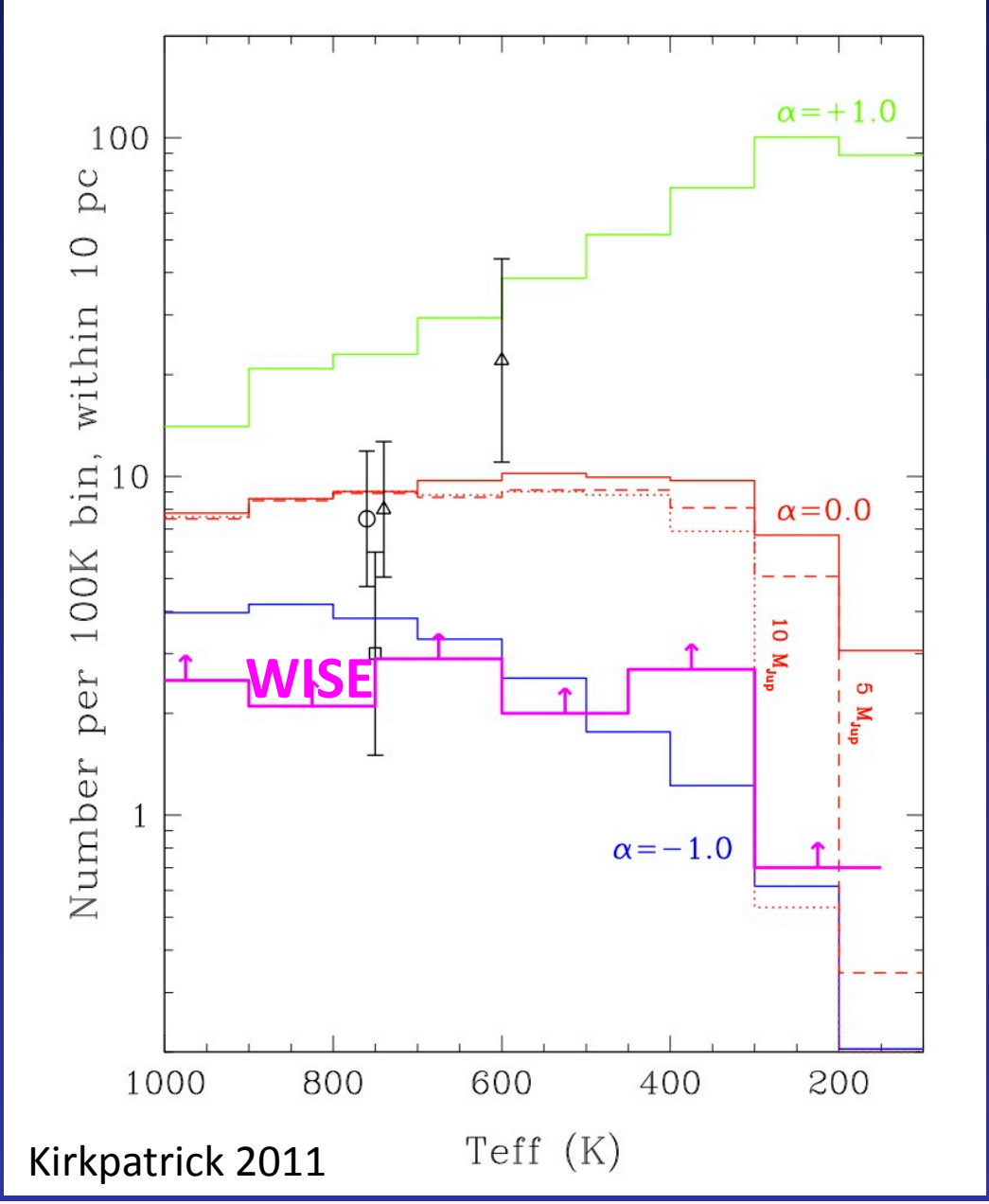


Reid 1999
Chabrier 2002
Allen 2005
Metchev 2008
Pinfield 2008
Burningham 2010
Reyle 2010
Earlier talk by Deacon

New Data from WISE



WISE Constraints on Minimum Mass



Kirkpatrick 2011

Advantages of Open Clusters

- Brown dwarfs are relatively bright because of youth
- But old enough to avoid most of the model uncertainties associated with youth
- All members of a cluster have the same age and distance, so completeness easy to assess
- Good number statistics in nearest clusters
- Minimal extinction

Disadvantages of Open Clusters

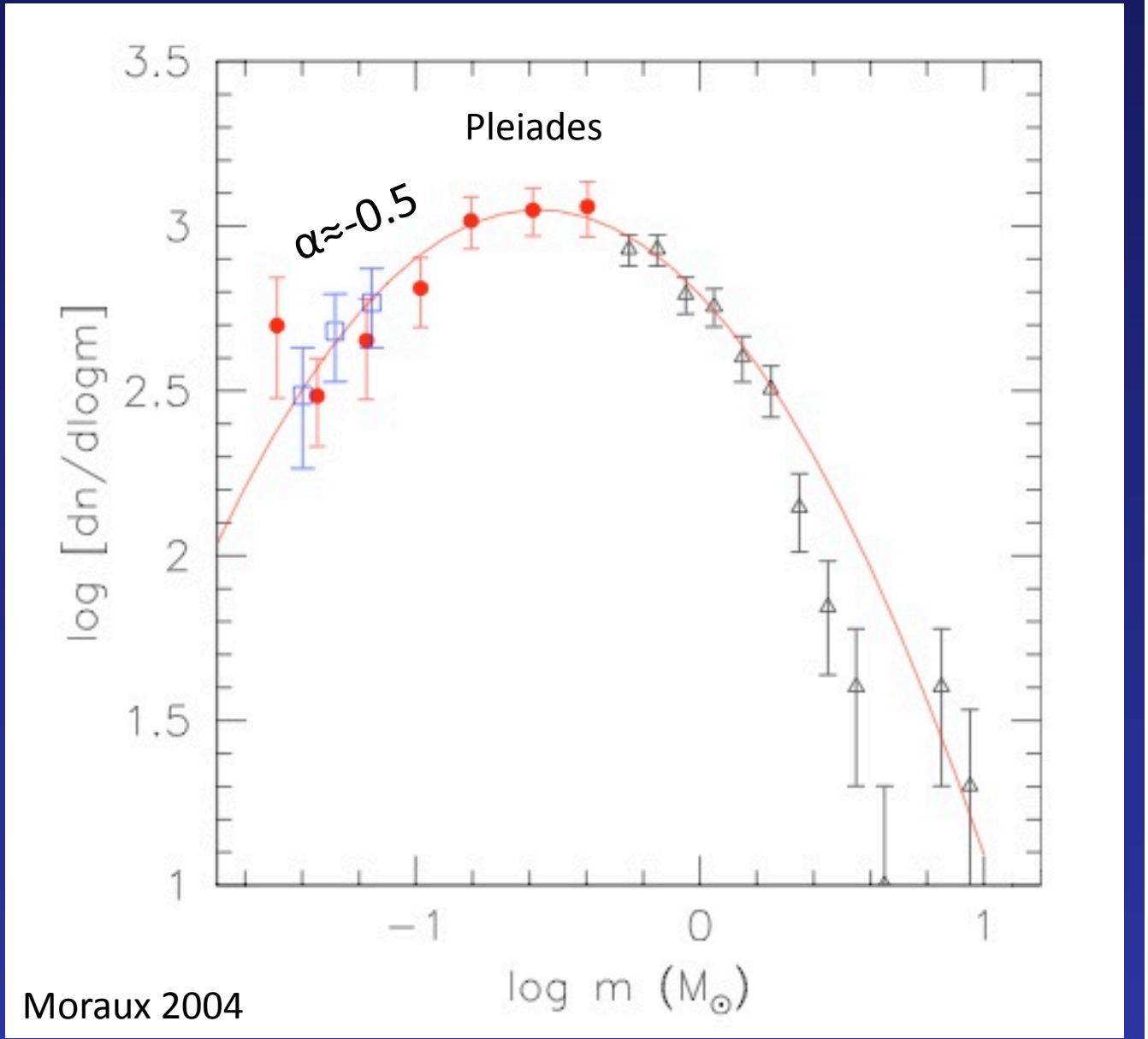
- Brown dwarfs are fainter than in star-forming regions, so mass limits not quite as low
- Little information about dependence on star-forming conditions
- Dynamical mass segregation possible

Low-mass IMF in Open Clusters

See also:
Stauffer, Rebolo, Hambly, Martin, Zapatero Osorio, Bouvier, Barrado, Dobbie, Pinfield, Bihain, Lodieu, Casewell

Confirmed members down to early L (25 M_{Jup}) and candidates down to T (10 M_{Jup}, Casewell)

See poster by Lodieu on new surveys with UKIDSS



Moraux 2004

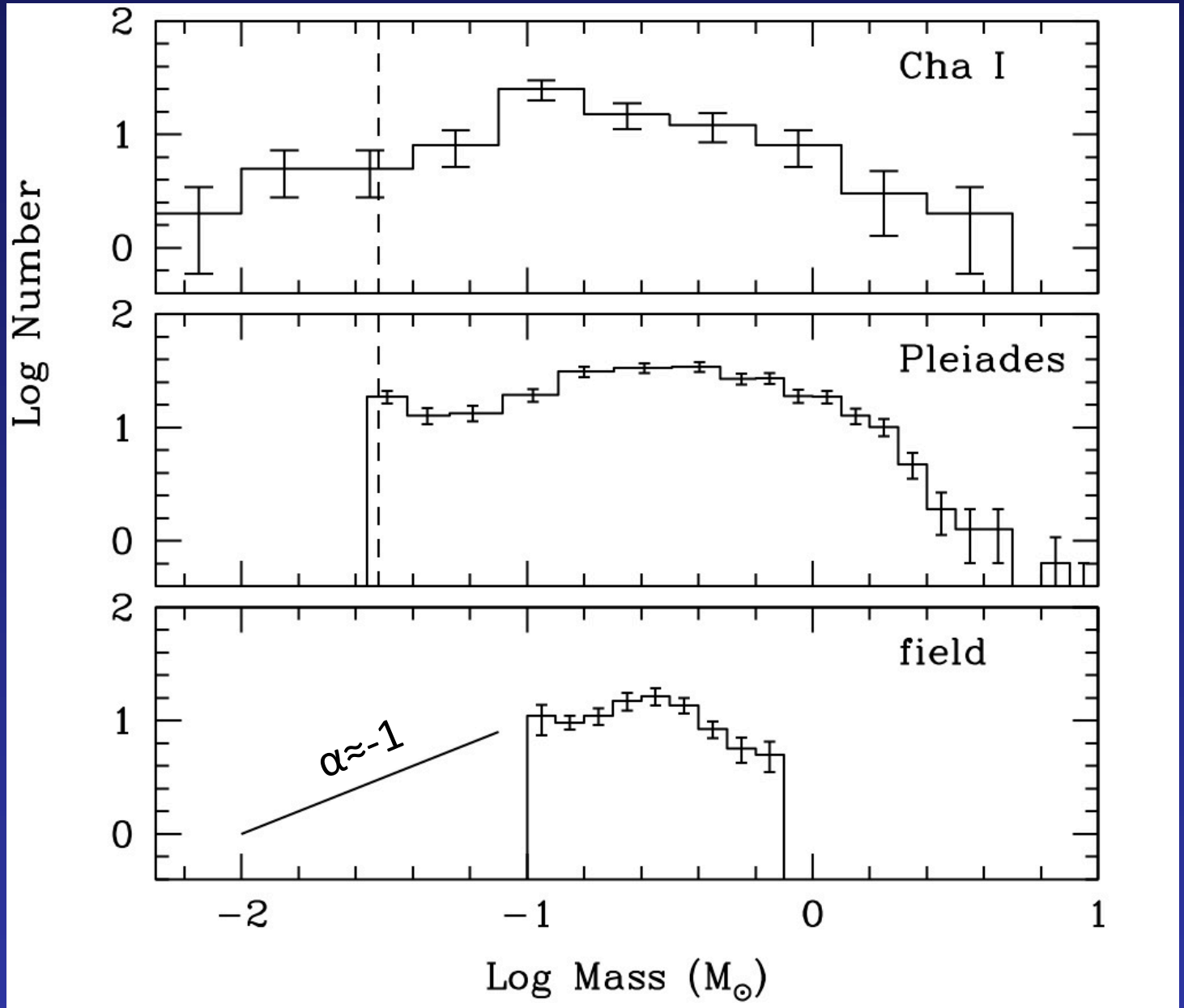
Advantages of Star-Forming Regions

- Brown dwarfs are at their brightest, so lowest masses reached
- All members of a region have the same age and distance
- Dynamical segregation is minimized
- Initial conditions of star formation are observable
- Do not need to assume functional form for IMF

Disadvantages of Star-Forming Regions

- Extinction makes objects fainter, inhibiting detection
- Extinction reddens both members and background sources, inhibiting separation of these populations
- Uncertainties in temperature scale and evolutionary models at young ages, resulting in mass uncertainties
- Magnetic activity may affect spectral types
- Spectra are needed for every object, particularly at low masses

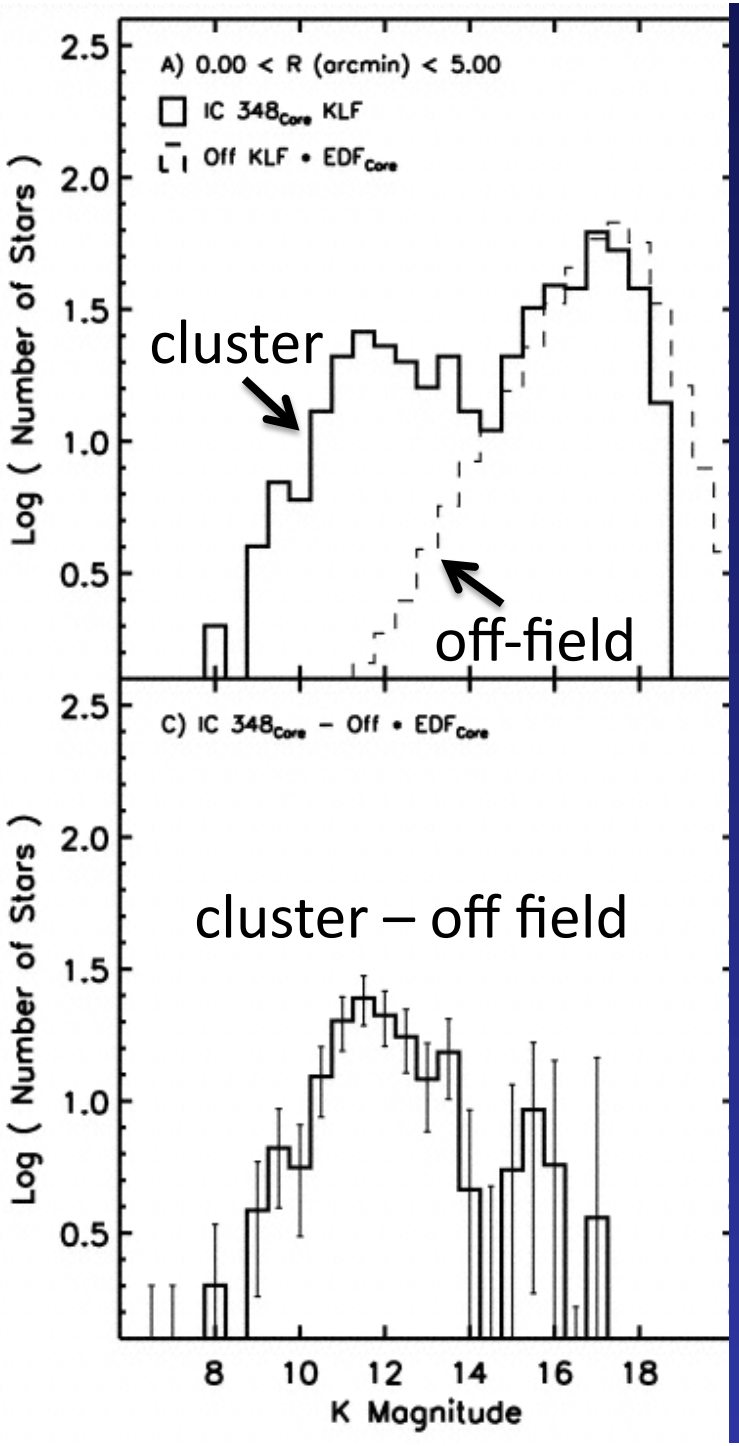
Field ≈ Open Clusters ≈ Star-forming Regions



To reliably detect IMF variations, we need:

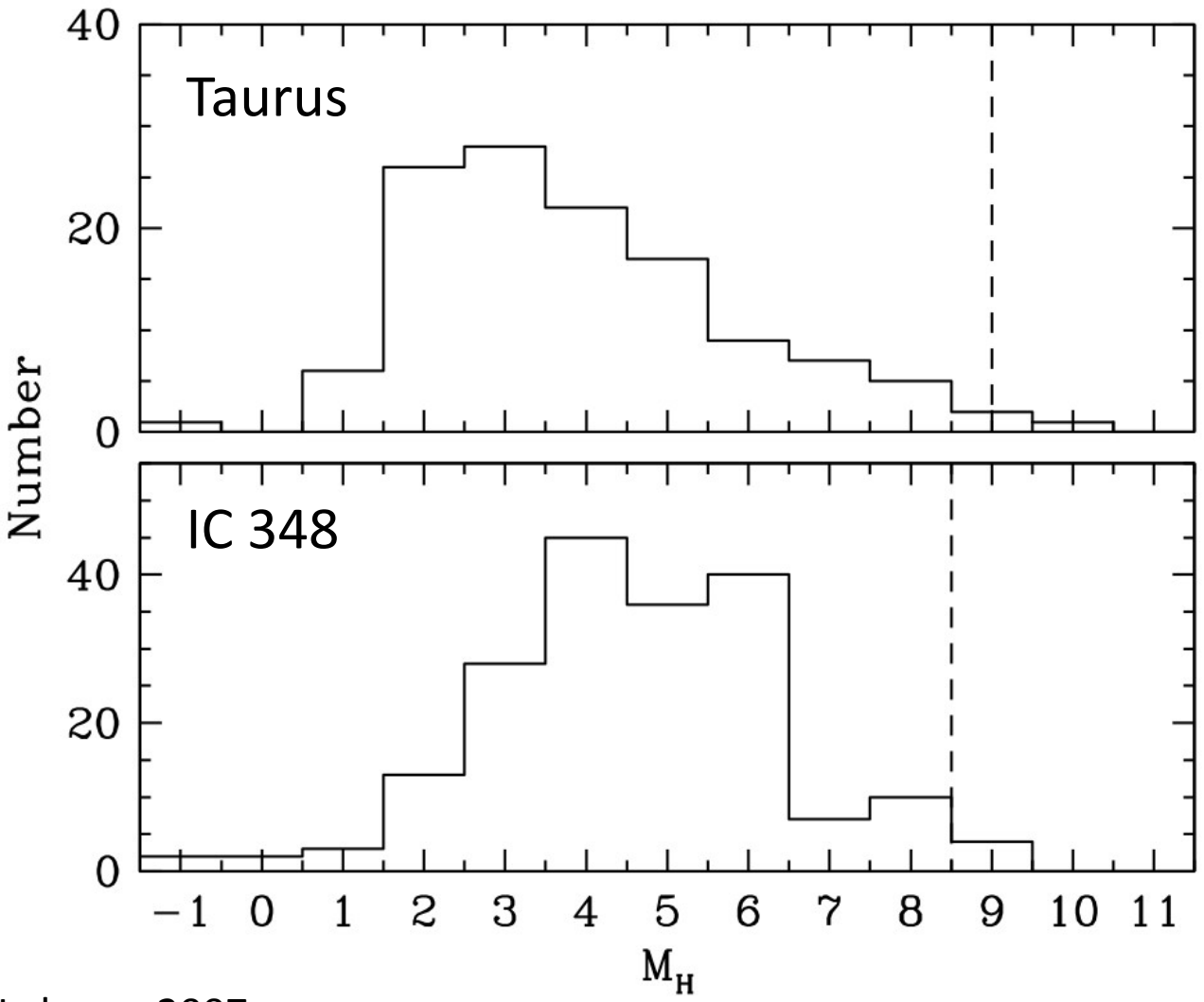
- Spectroscopy of every object to confirm membership and measure spectral types

Luminosity functions are dominated by background stars at fainter levels, making the luminosity functions of brown dwarfs uncertain



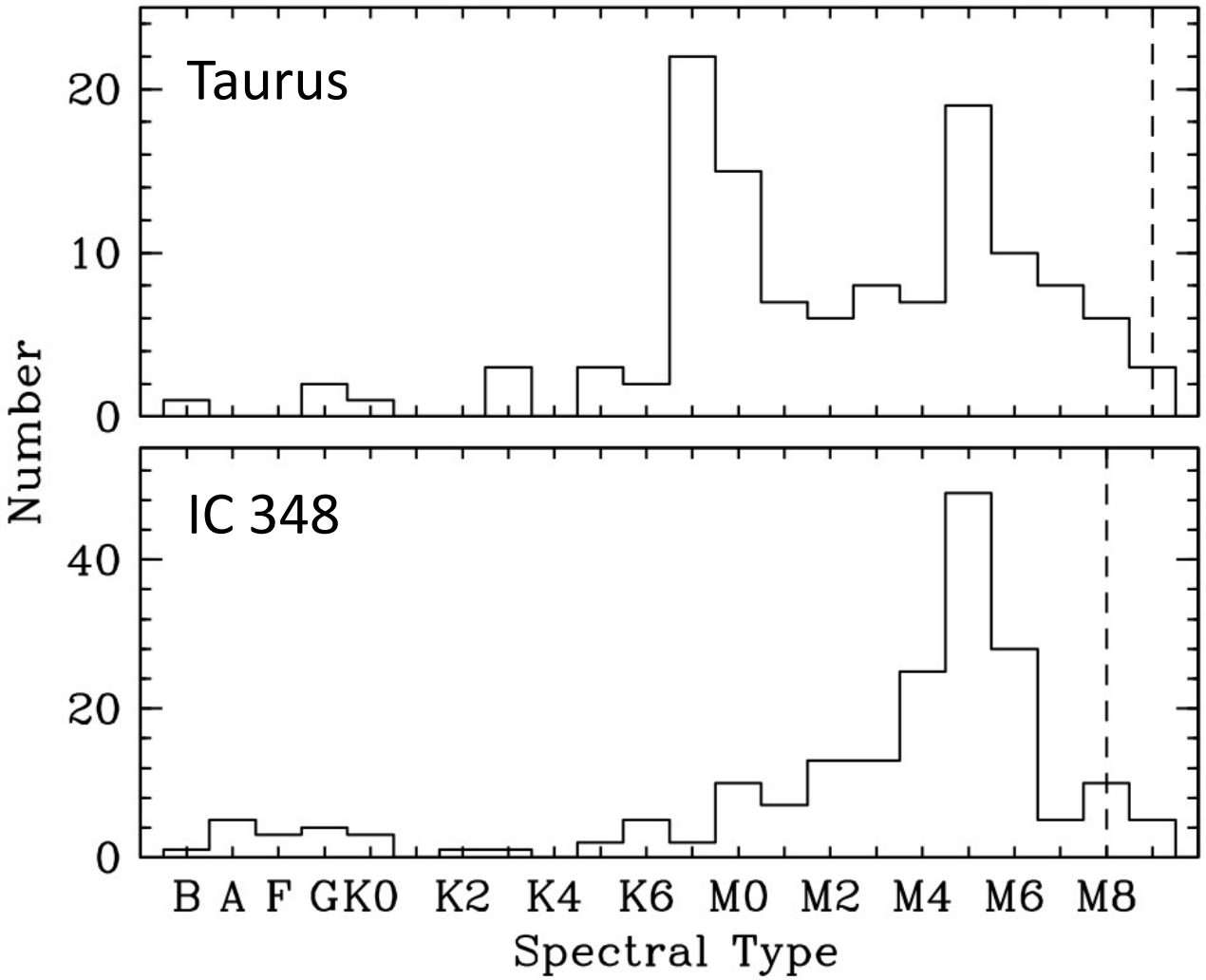
Muench et al. 2003

Luminosity functions have broad peaks



Luhman 2007

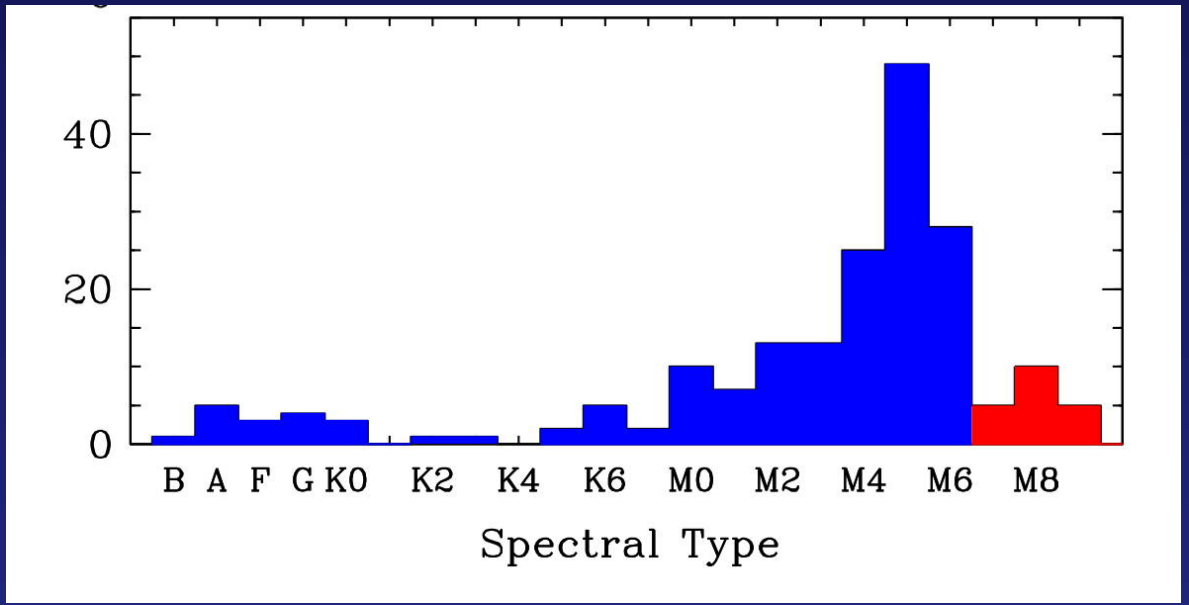
Spectral types have narrow peaks



Luhman 2007

To reliably detect IMF variations, we need:

- Spectroscopy of every object to confirm membership and measure spectral types
- Same spectral classification system applied to all regions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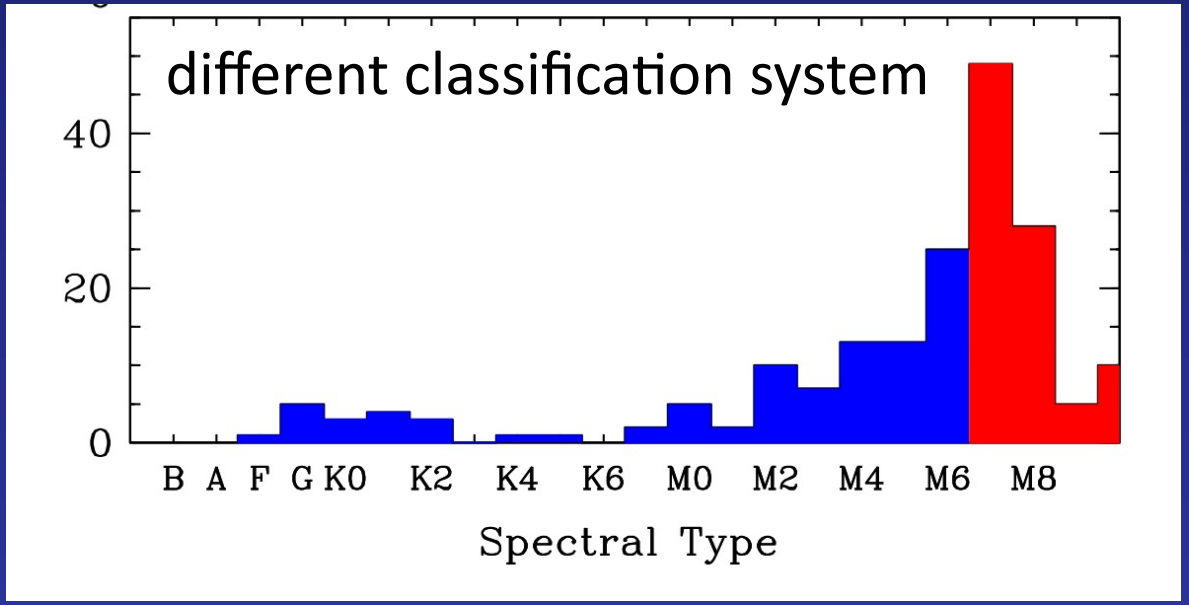
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type


different classification system
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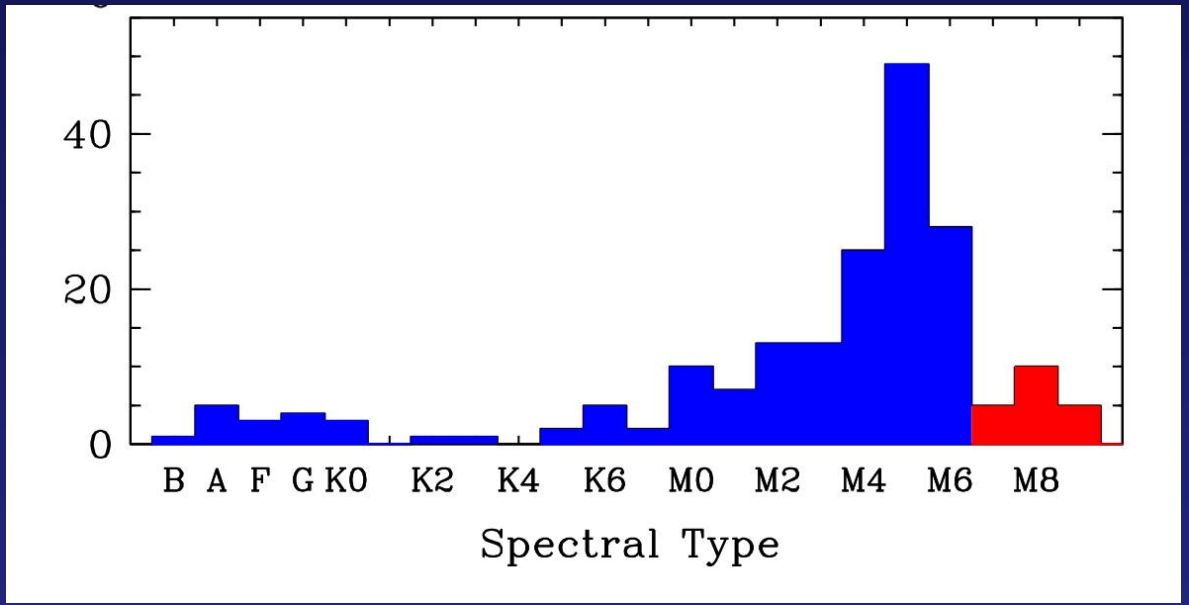
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type

To reliably detect IMF variations, we need:

- Spectroscopy of every object to confirm membership and measure spectral types
- Same spectral classification system applied to all regions
- Adoption of same temperature scale and evolutionary models for all regions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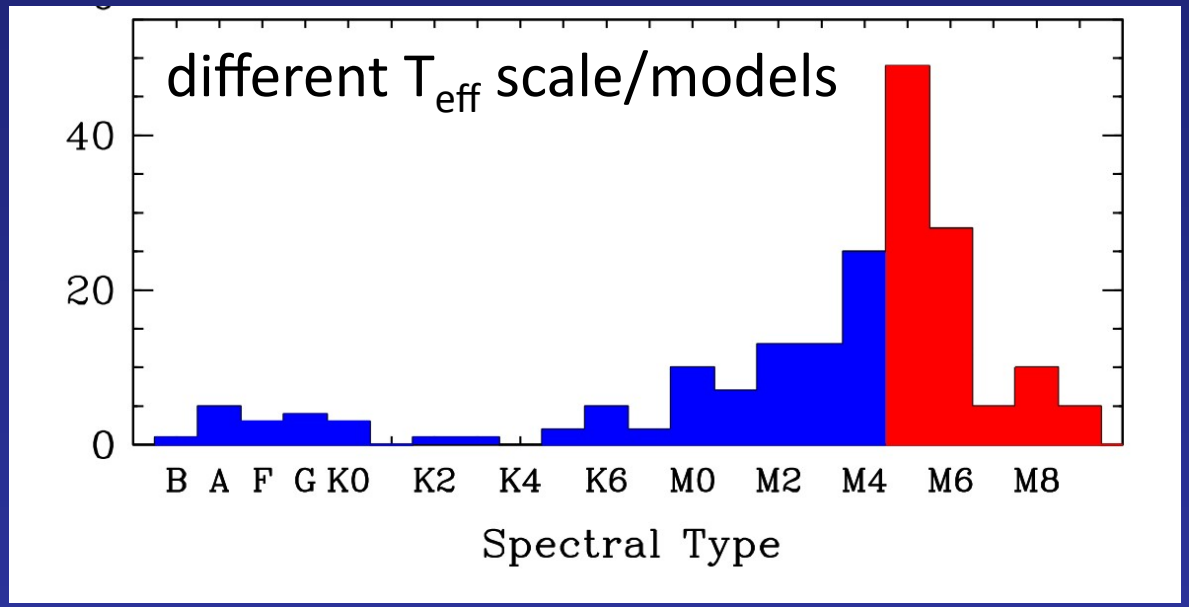
Spectral Type


different T_{eff} scale/models
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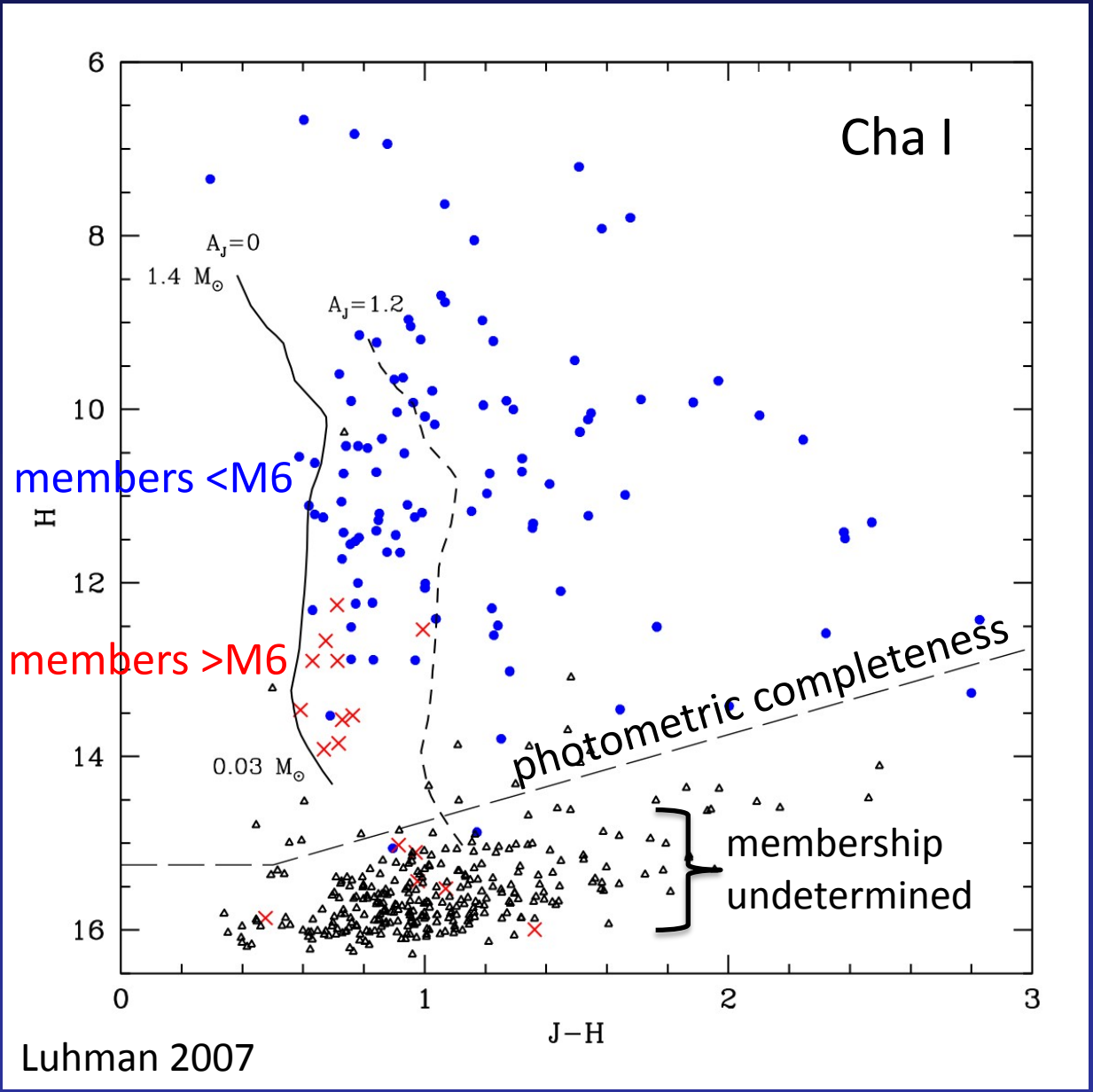
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type

To reliably detect IMF variations, we need:

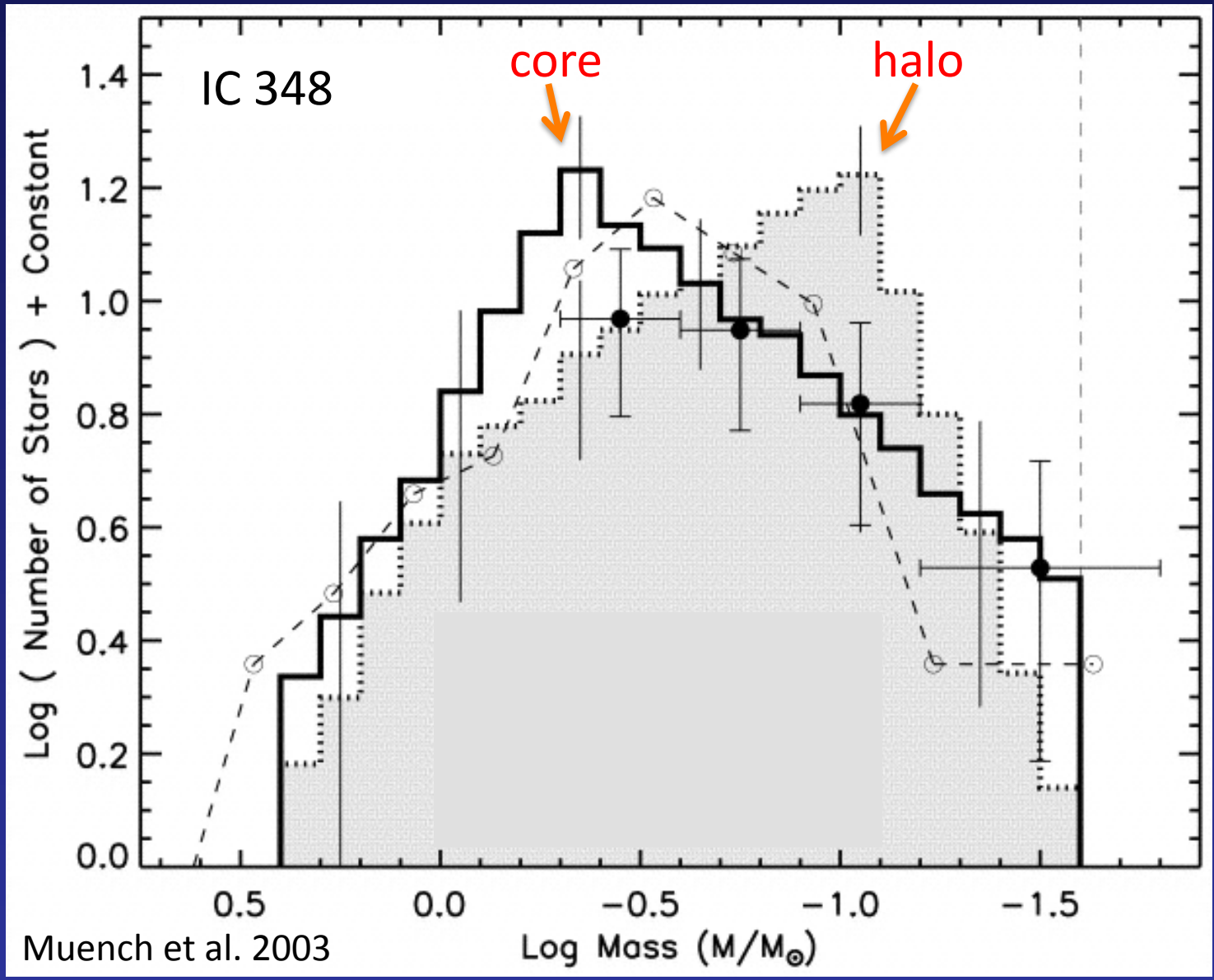
- Spectroscopy of every object to confirm membership and measure spectral types
- Same spectral classification system applied to all regions
- Adoption of same temperature scale and evolutionary models for all regions
- Rigorous assessment of completeness


Cha I
members <M6
members >M6
photometric completeness
membership
undetermined
A_J=0
1.4 $M_\odot$
A_J=1.2
0.03 $M_\odot$
H
J−H
6
8
10
12
14
16
0
1
2
3

Luhman 2007

To reliably detect IMF variations, we need:

- Spectroscopy of every object to confirm membership and measure spectral types
- Same spectral classification system applied to all regions
- Adoption of same temperature scale and evolutionary models for all regions
- Rigorous assessment of completeness
- Large enough fields to avoid effects of mass segregation

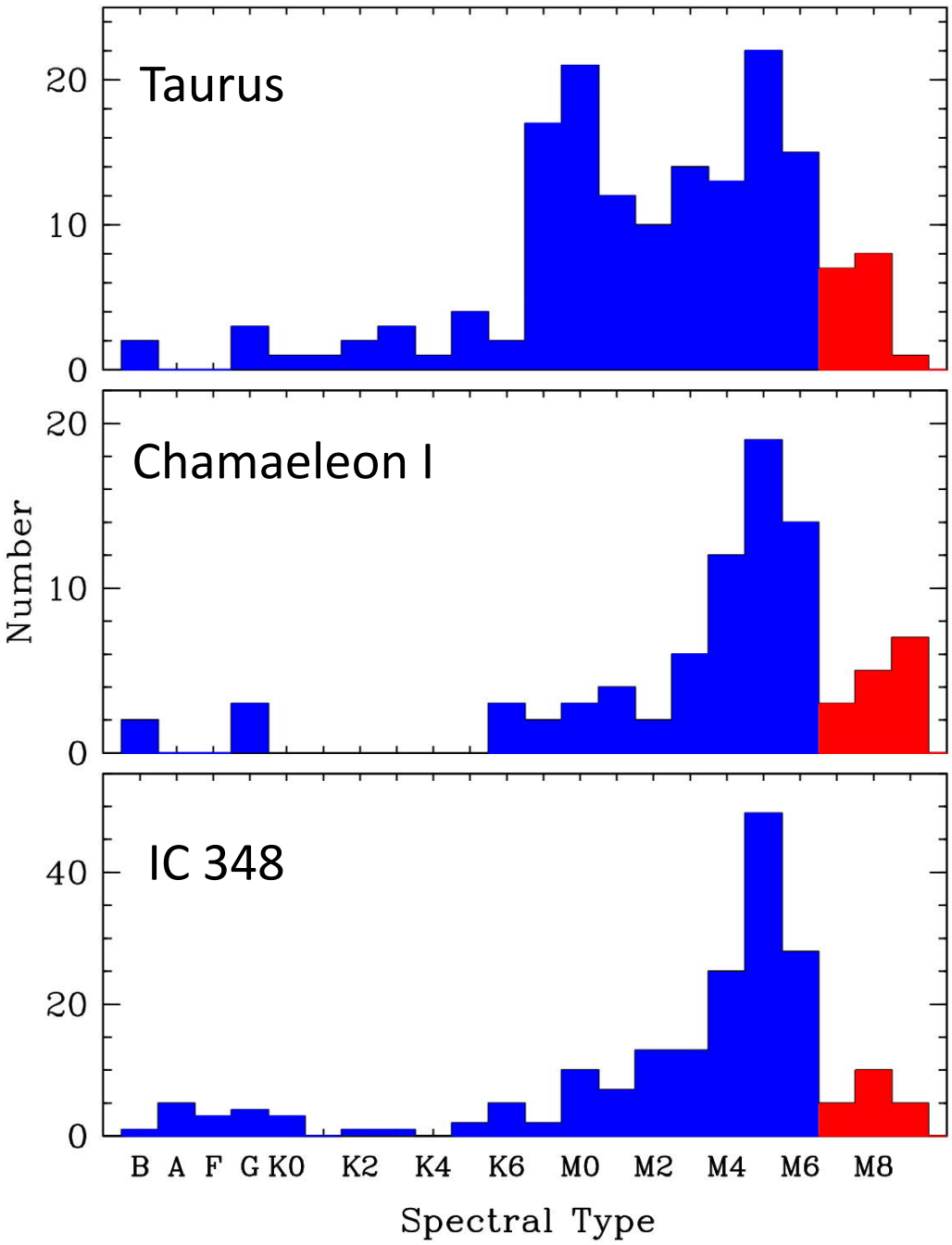


Muench et al. 2003

IMF Variations?

- Most clusters peak at M5 while Taurus has a surplus at K7-M1
- No other significant variations

Briceno 2002, Luhman 2003, 2007, 2009



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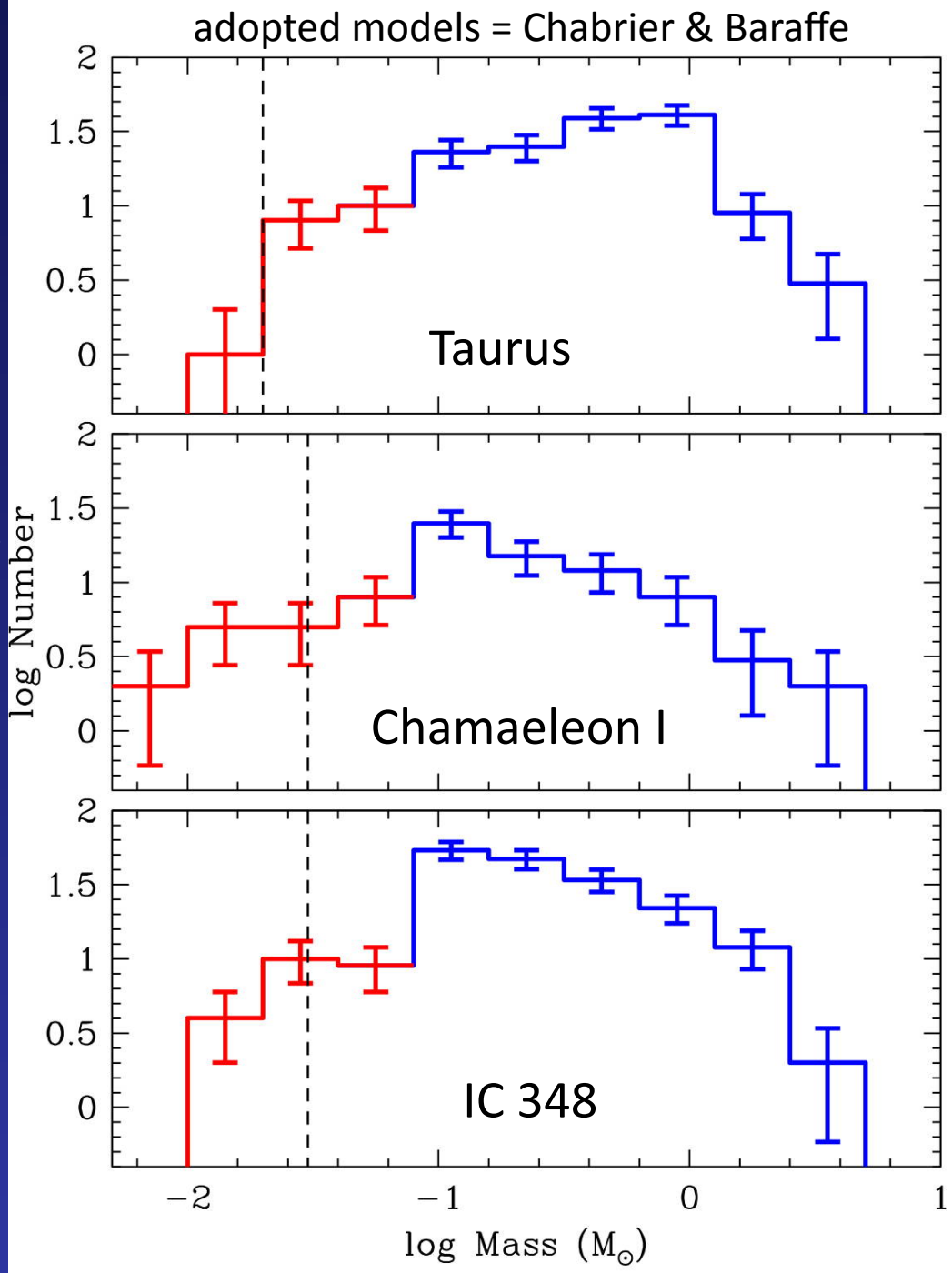
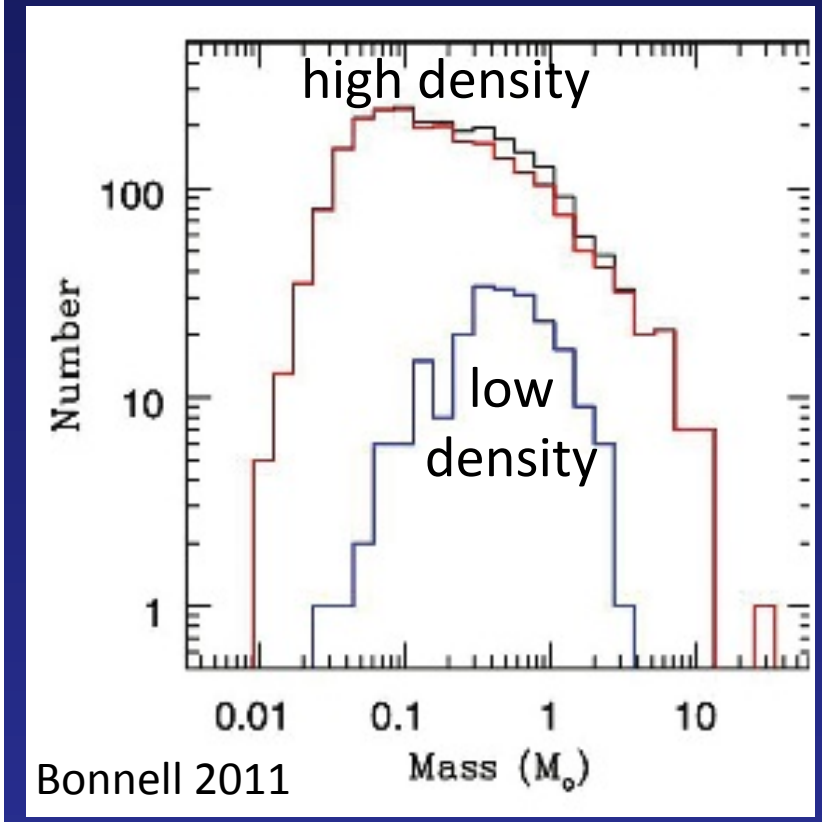
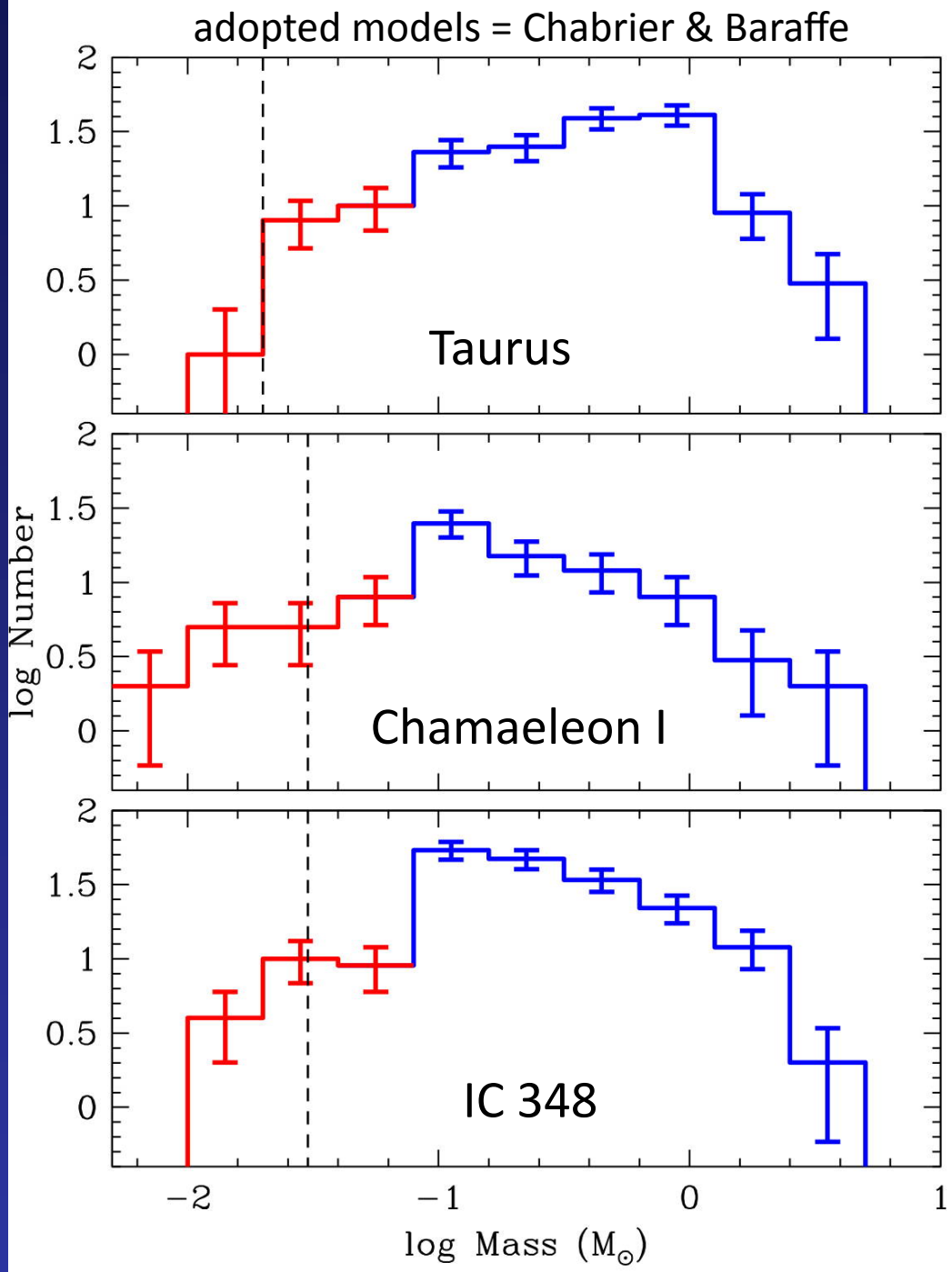


Reproduced by models?

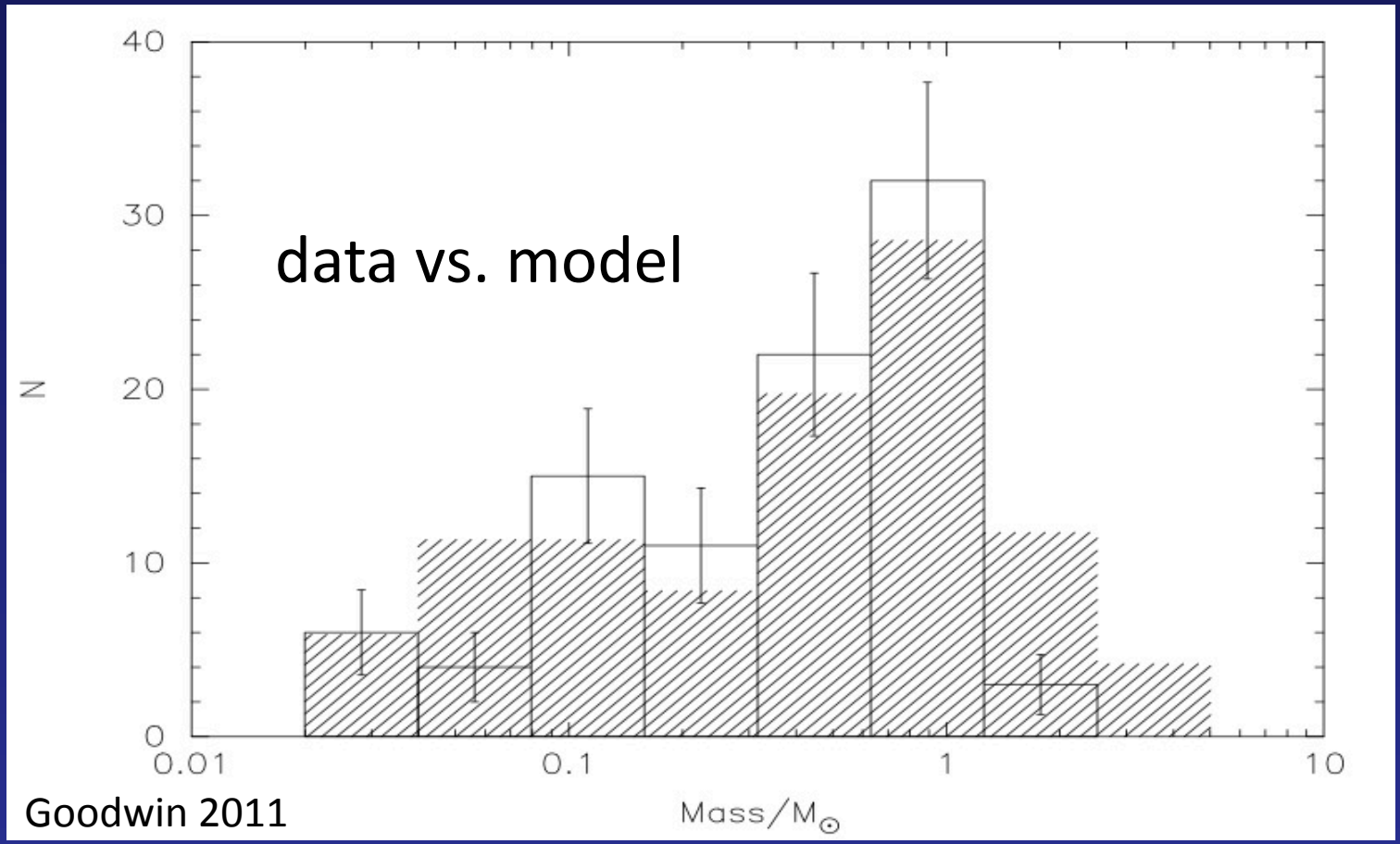


Bonnell 2011

Yes, but Taurus IMF broader than expected



Goodwin et al. 2004 reproduced Taurus IMF

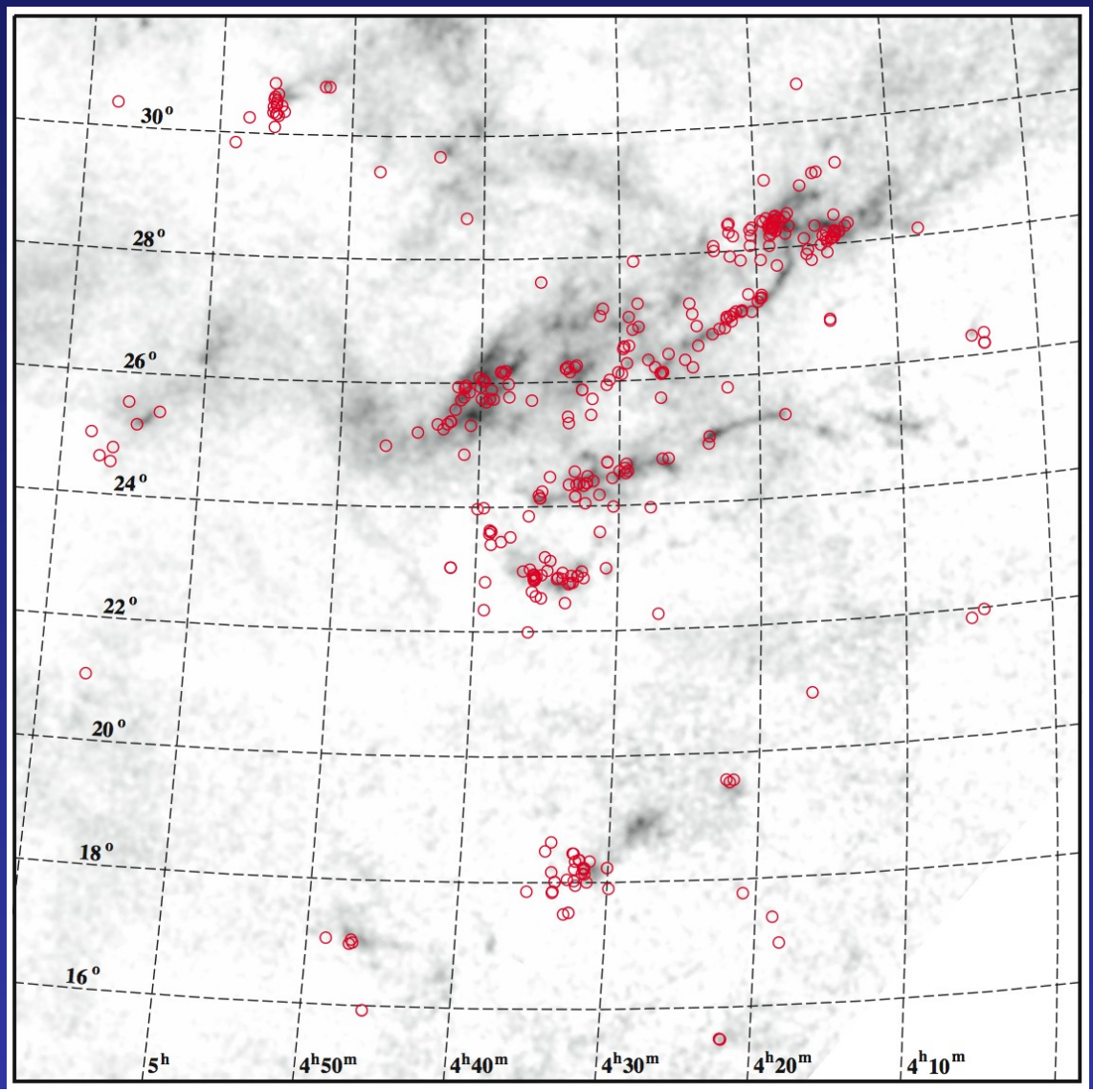


Goodwin 2011

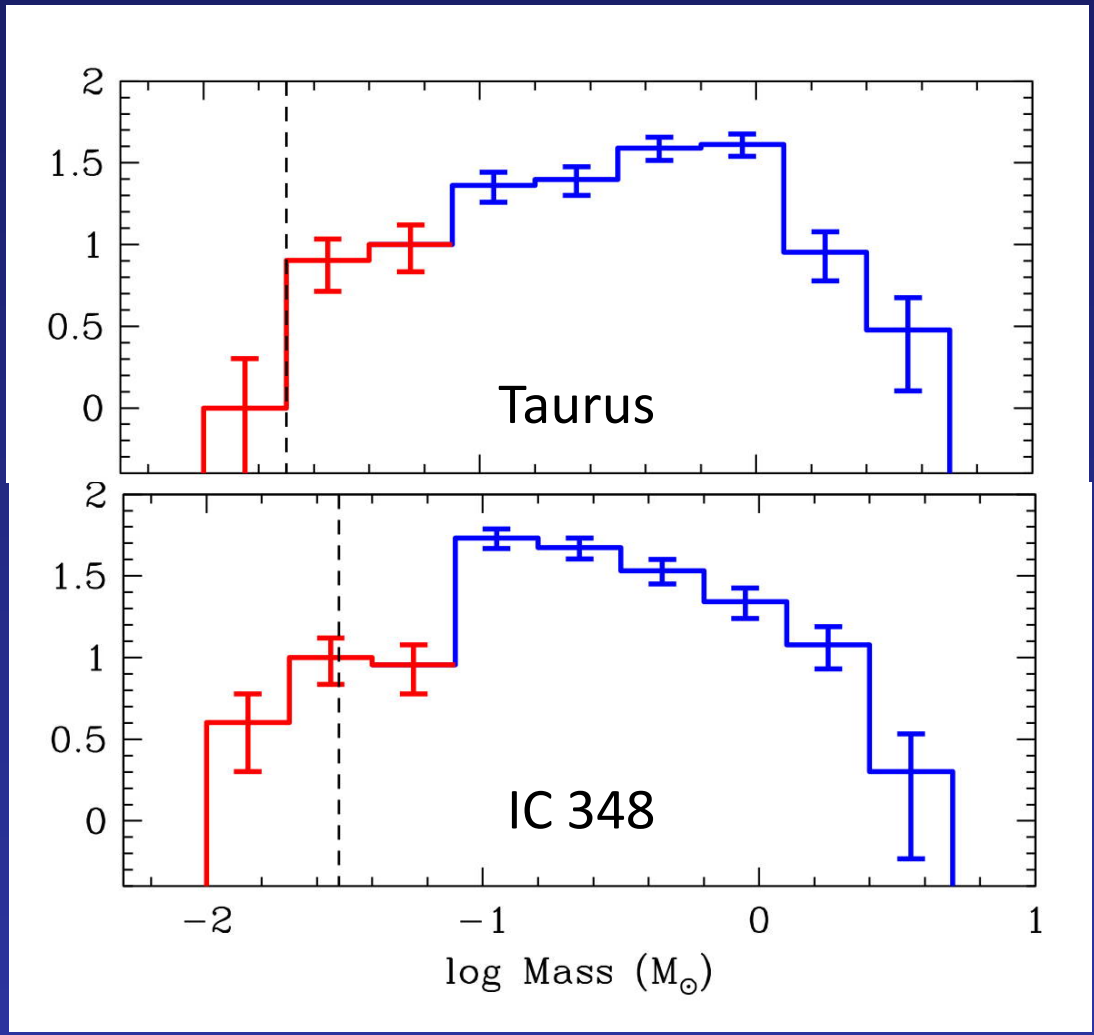
However:

- Assumed core mass function that peaks at higher masses, so isn't surprising that resulting IMF does as well
- Unclear whether Taurus CMF has higher peak mass

Because of its low density and lack of massive stars, the roles of dynamical interactions and photoevaporation are minimized in Taurus

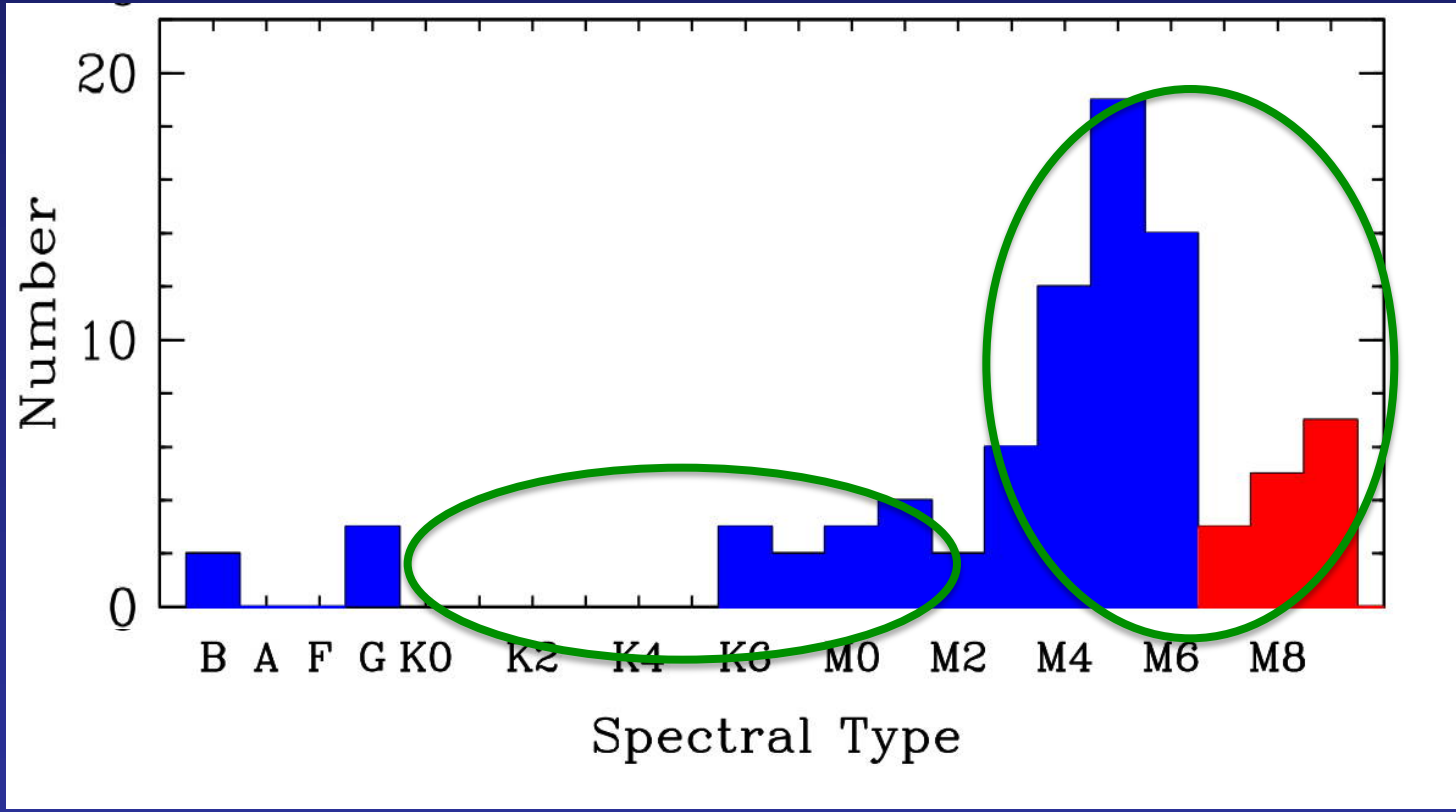


Abundance of BDs similar in Taurus and dense clusters, indicating that dynamical interactions/photoevaporation are not essential for their formation




FU Tau: binary brown dwarf born in isolation
Luhman et al. 2009
Luhman et al. 2009

Solar-type stars are too rare to form the bulk of low-mass stars and brown dwarfs via fragmentation of their disks



Conclusions

- Similar IMFs in field, open clusters, star-forming regions
- IMF extends to ≤5 M_{Jup}
- N(stars)/(BDs) ~ 5; detecting variations difficult
- Surplus of K7-M1 stars in Taurus is only significant evidence of a variation in the low-mass IMF
- Various properties of the IMF indicate that photo-evaporation, dynamical interactions, and disk fragmentation are not essential for BD formation, but they may play a role in some environments