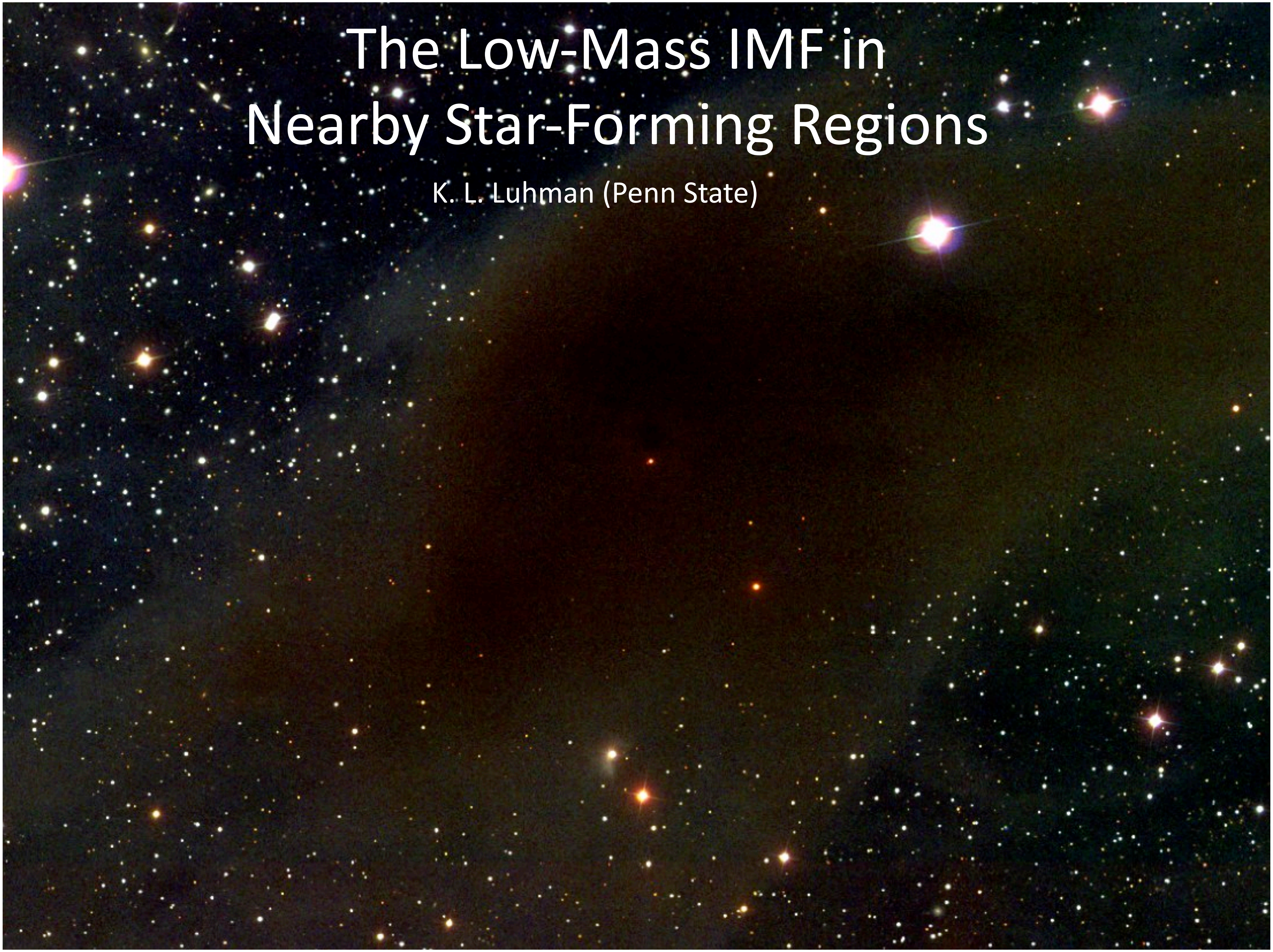


The Low-Mass IMF in Nearby Star-Forming Regions

K. L. Luhman (Penn State)

Outline

- Advantages/disadvantages of star-forming regions
- Requirements for detecting IMF variations
- Summary of IMF measurements for nearby clusters

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

A Universal Stellar IMF? A Critical Look at Variations

Advantages of Star-Forming Regions

- Brown dwarfs are brightest when they are young
- All members of a region have the same age and distance
- Dynamical segregation is minimized
- Initial conditions of star formation are observable

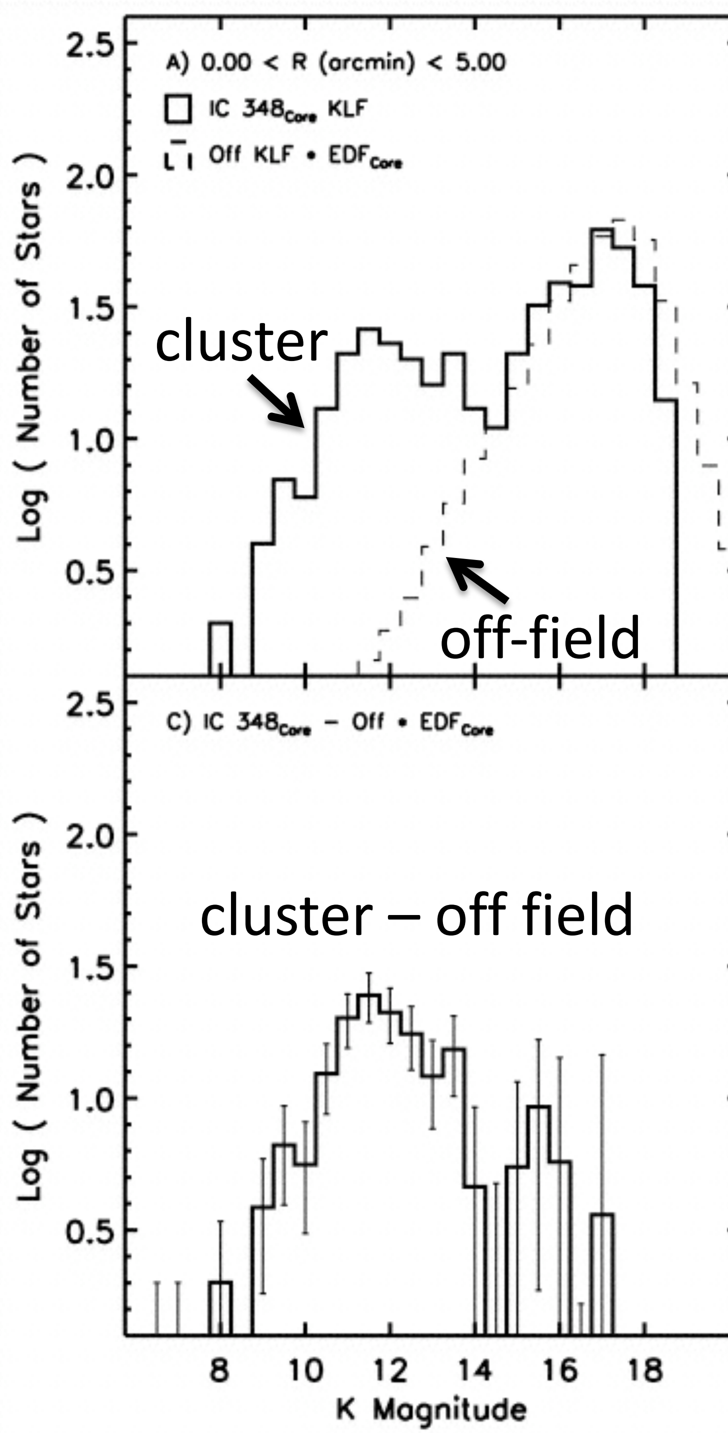
Disadvantages of Star-Forming Regions

- 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
- Blue and red excesses from accretion and disks complicate measurements of spectral types and luminosities
- Spectra are needed for every object, particularly at low masses

To reliably detect IMF variations, we need:

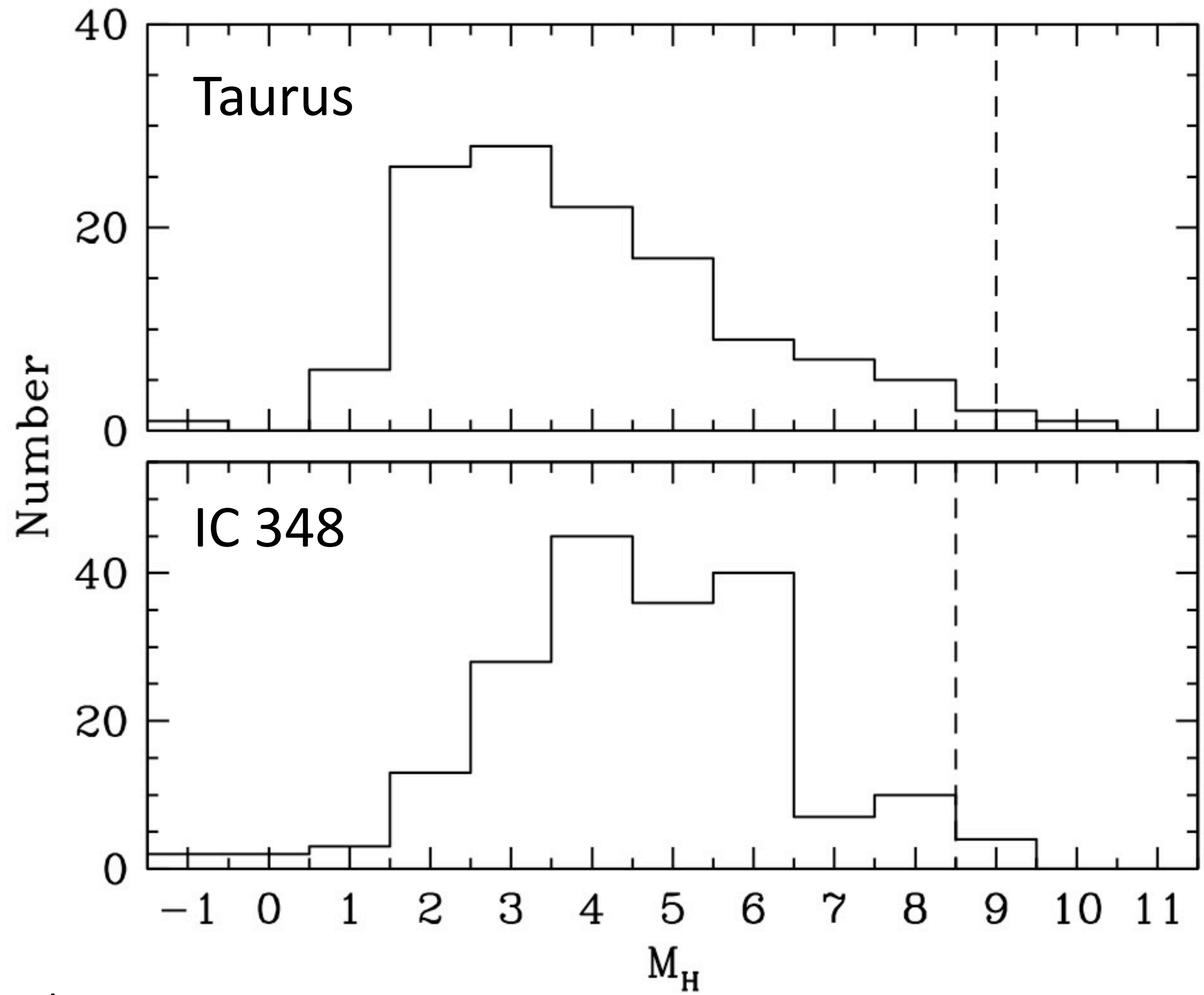
- Spectroscopy of every object to confirm membership and measure spectral types, particularly at low masses

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



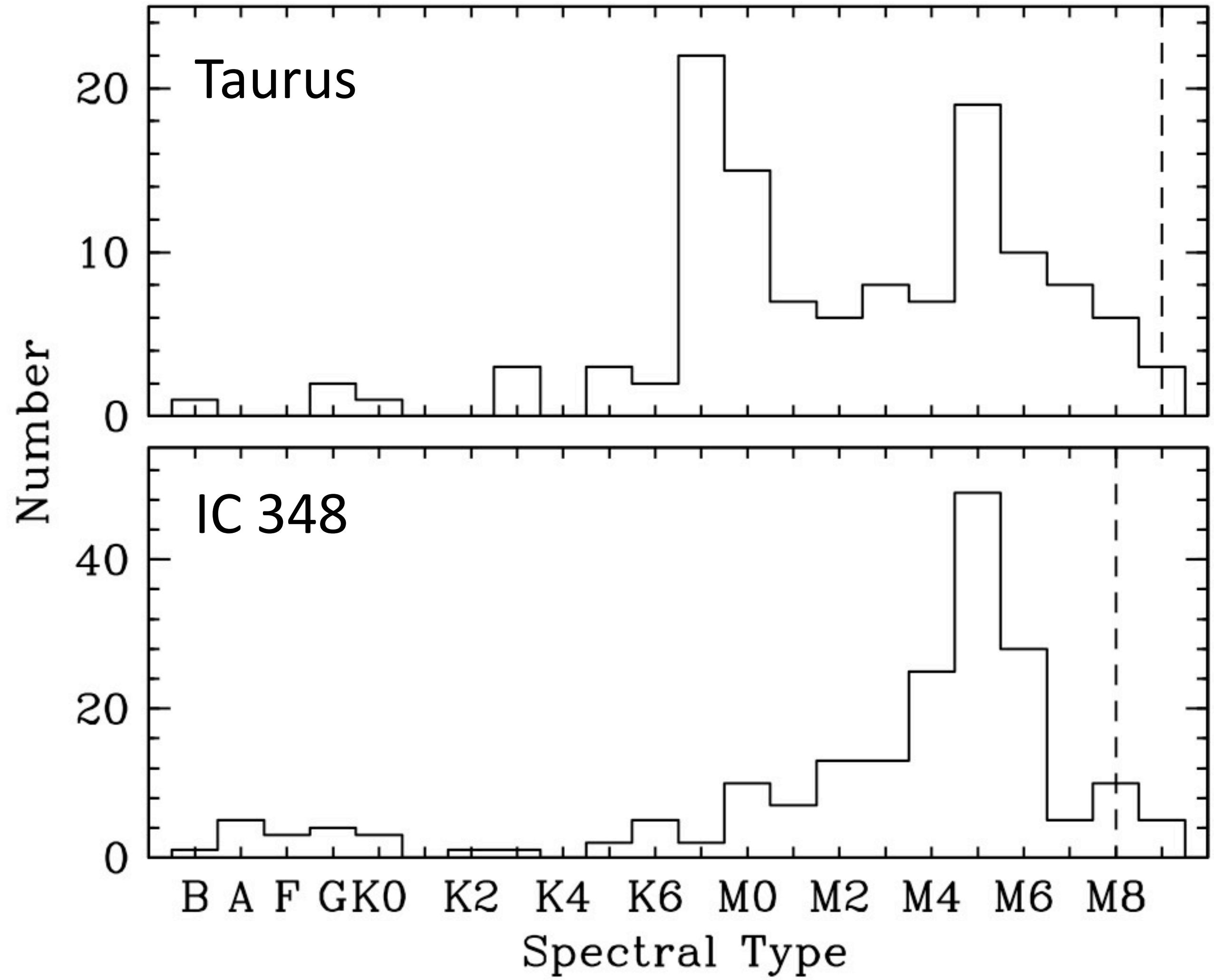
Muench et al. 2003

Luminosity functions have broad peaks



Luhman 2007

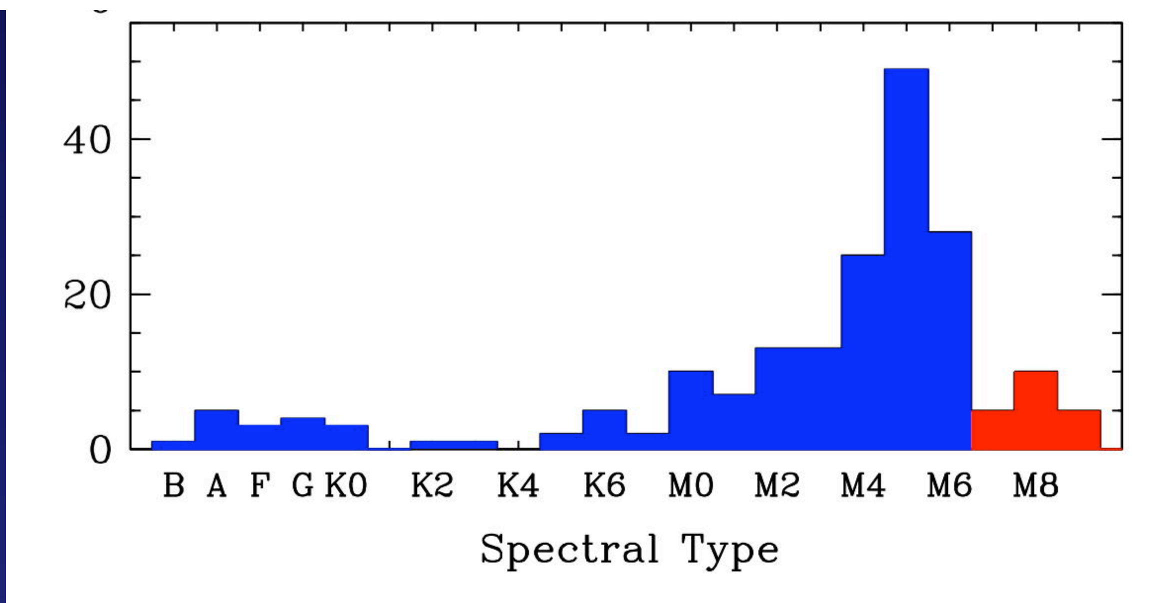
Spectral types have narrow peaks

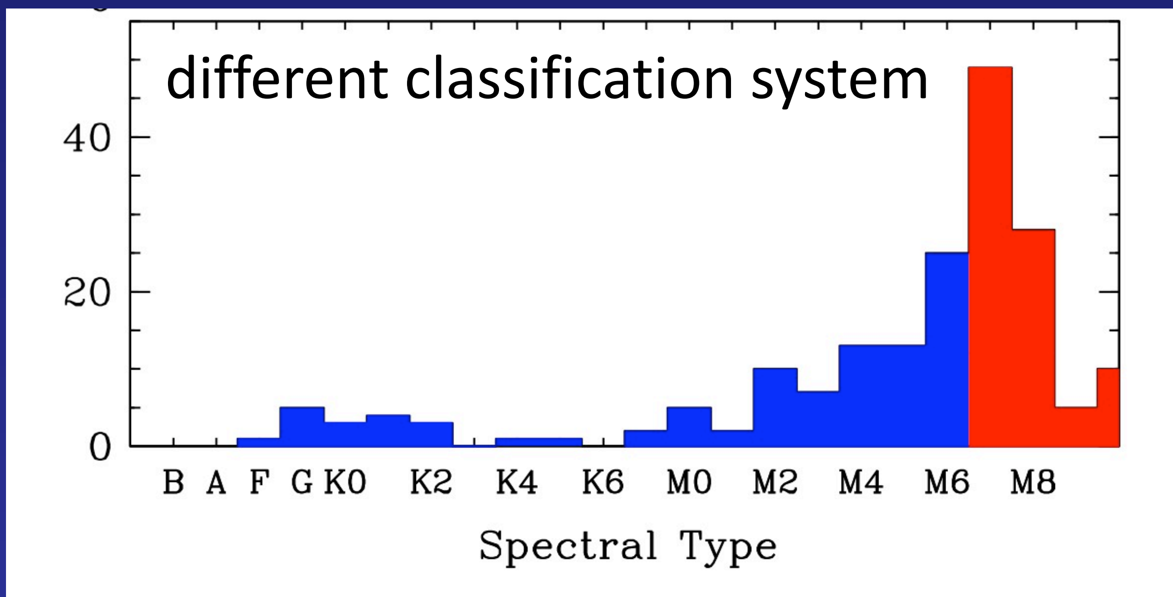


Luhman 2007

To reliably detect IMF variations, we need:

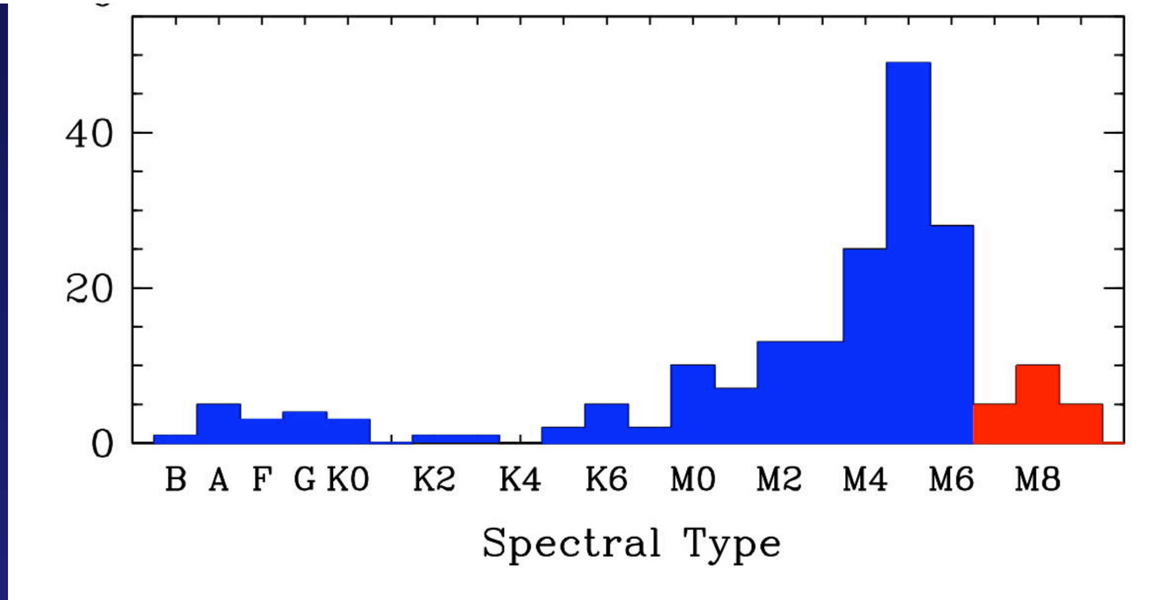
- Spectroscopy of every object to confirm membership and measure spectral types, particularly at low masses
- Same spectral classification system applied to all regions

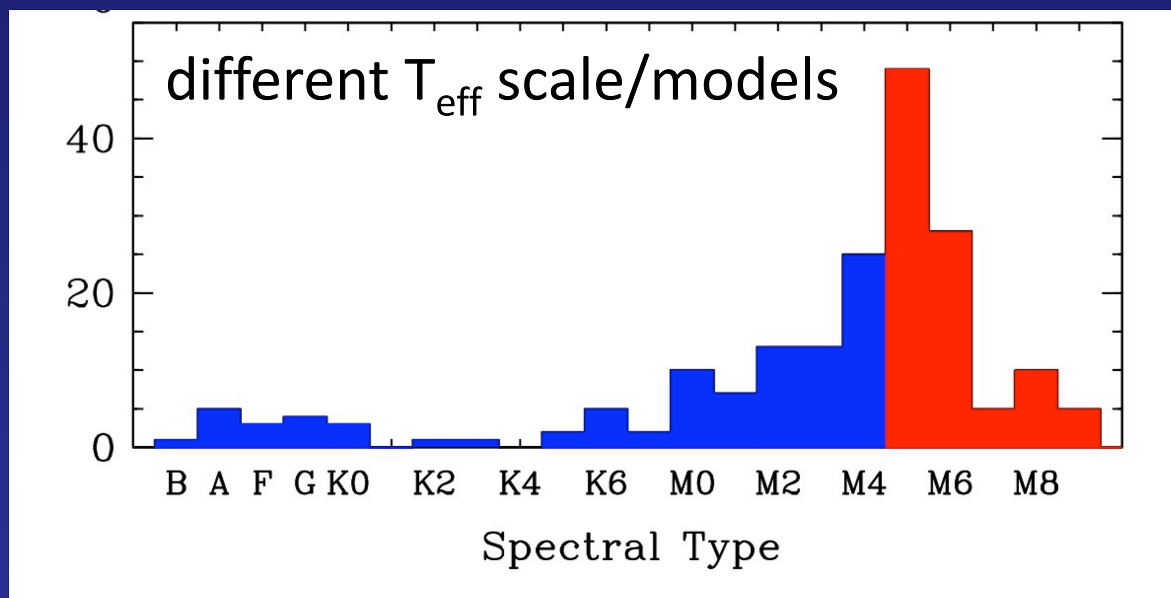

40
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type


different classification system
40
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type

To reliably detect IMF variations, we need:

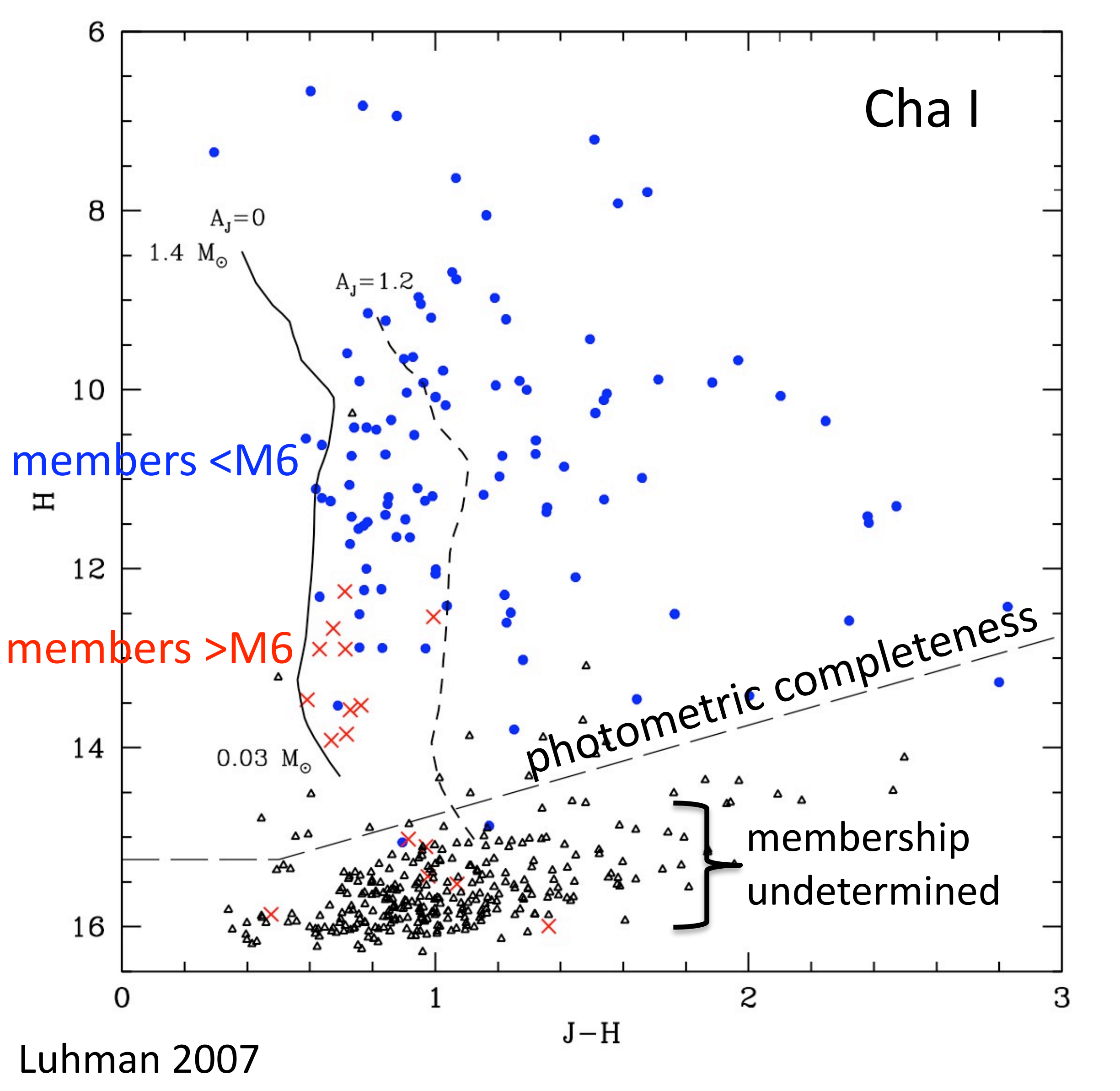
- Spectroscopy of every object to confirm membership and measure spectral types, particularly at low masses
- Same spectral classification system applied to all regions
- Adoption of same temperature scale and evolutionary models for all regions


40
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type


different T_{eff} scale/models
40
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type

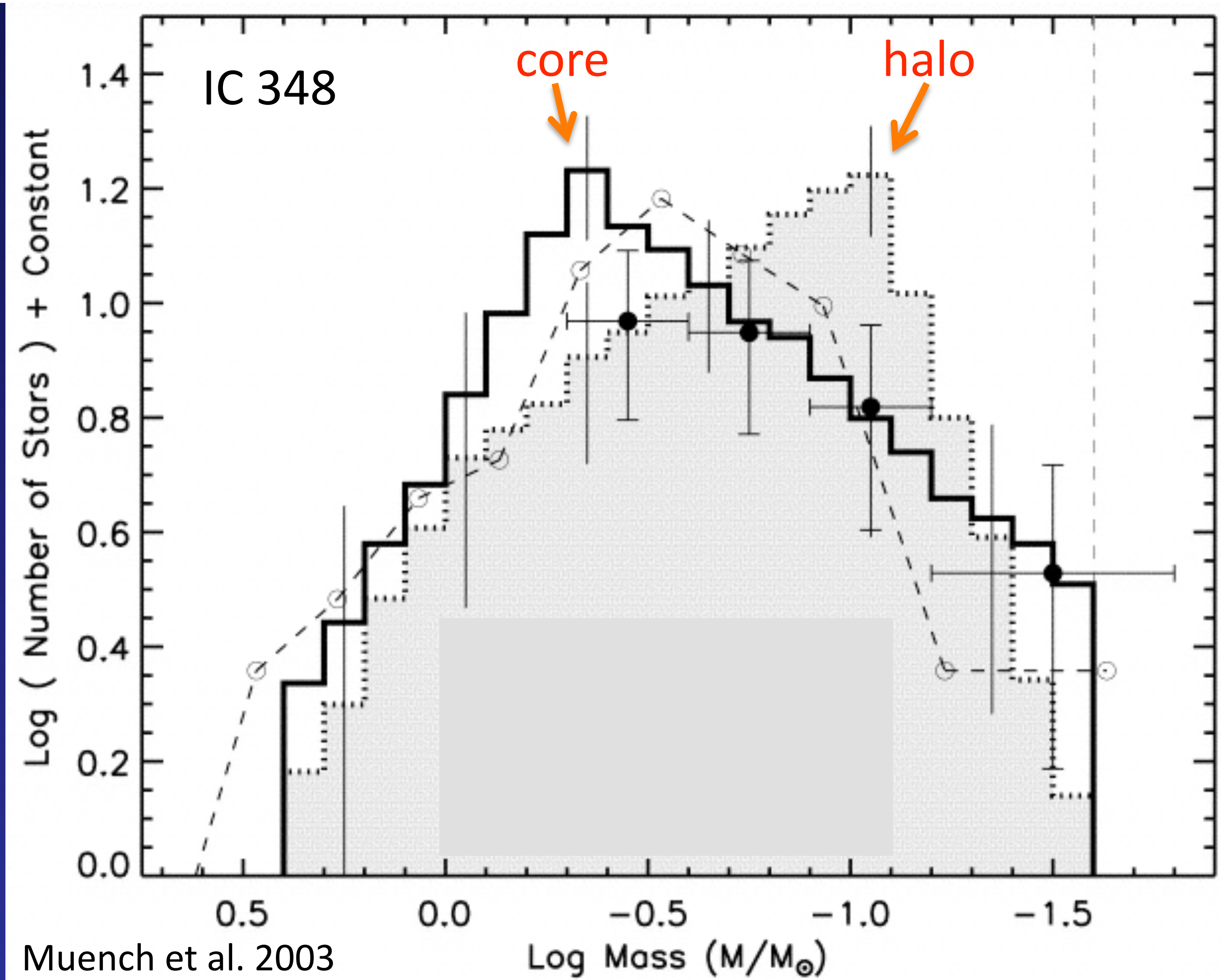
To reliably detect IMF variations, we need:

- Spectroscopy of every object to confirm membership and measure spectral types, particularly at low masses
- 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⊙
A_J=1.2
0.03 M⊙
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, particularly at low masses
- 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

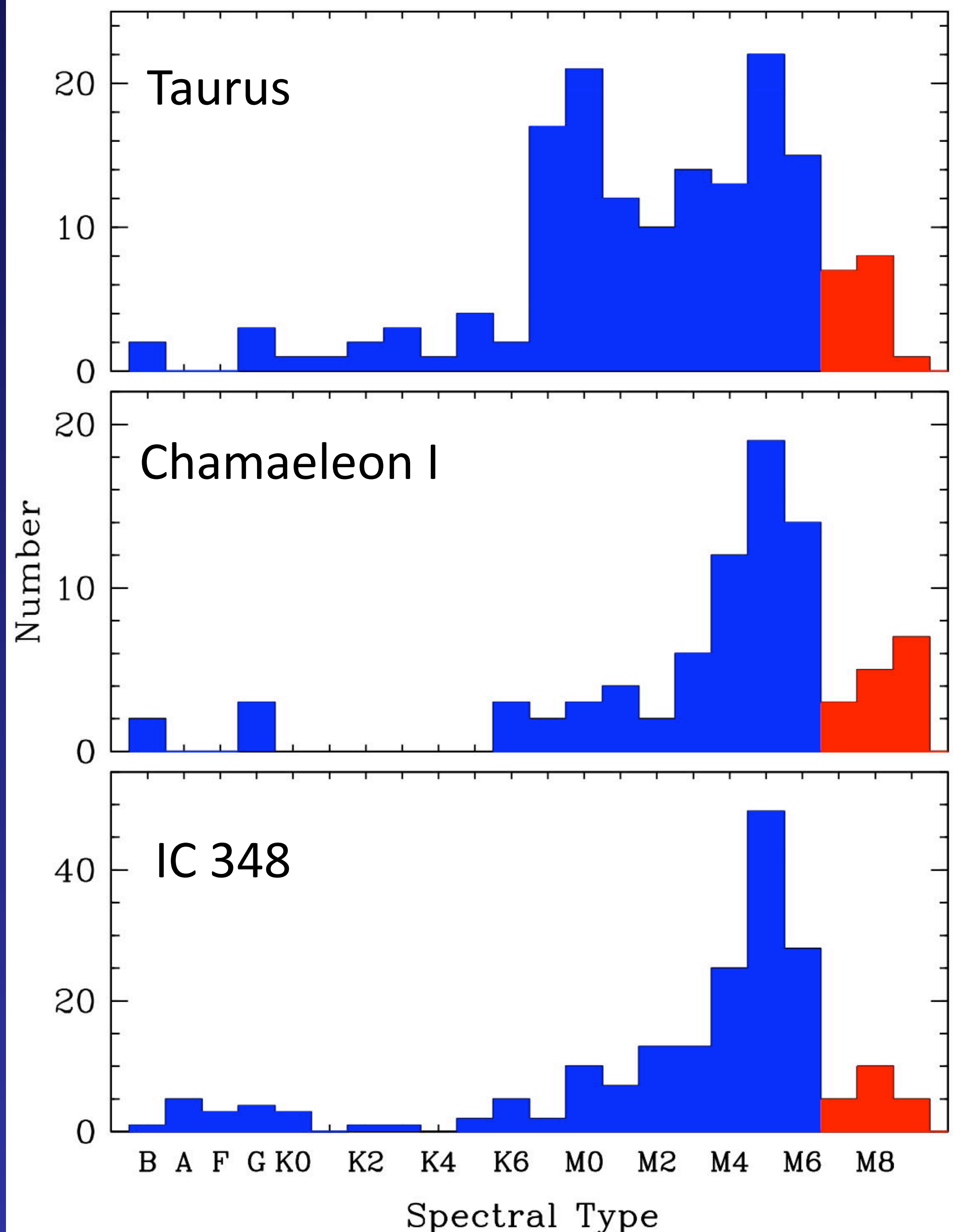

IC 348
core
halo
Log (Number of Stars) + Constant
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.5
0.0
−0.5
−1.0
−1.5
Log Mass ($M/M_\odot$)
Muench et al. 2003

Nearby Young Populations (<10 Myr)

- IC 348 (Perseus)
- Chamaeleon I
- Taurus
- NGC 1333 (Perseus)
- Ophiuchus
- Orion Nebula Cluster
- σ Ori
- Upper Sco
- η Cha

- IC 348 and Cha I peak at M5
- Taurus has a surplus at K7-M1
- Ratios of stars/BDs are 5-10, agreeing within a factor of 2
- BDs found down to ~5 M_{jup}
- Candidates in IC348 <5 M_{jup} (Burgess 2009)

Briceno 2002, Luhman 2003, 2007, 2009



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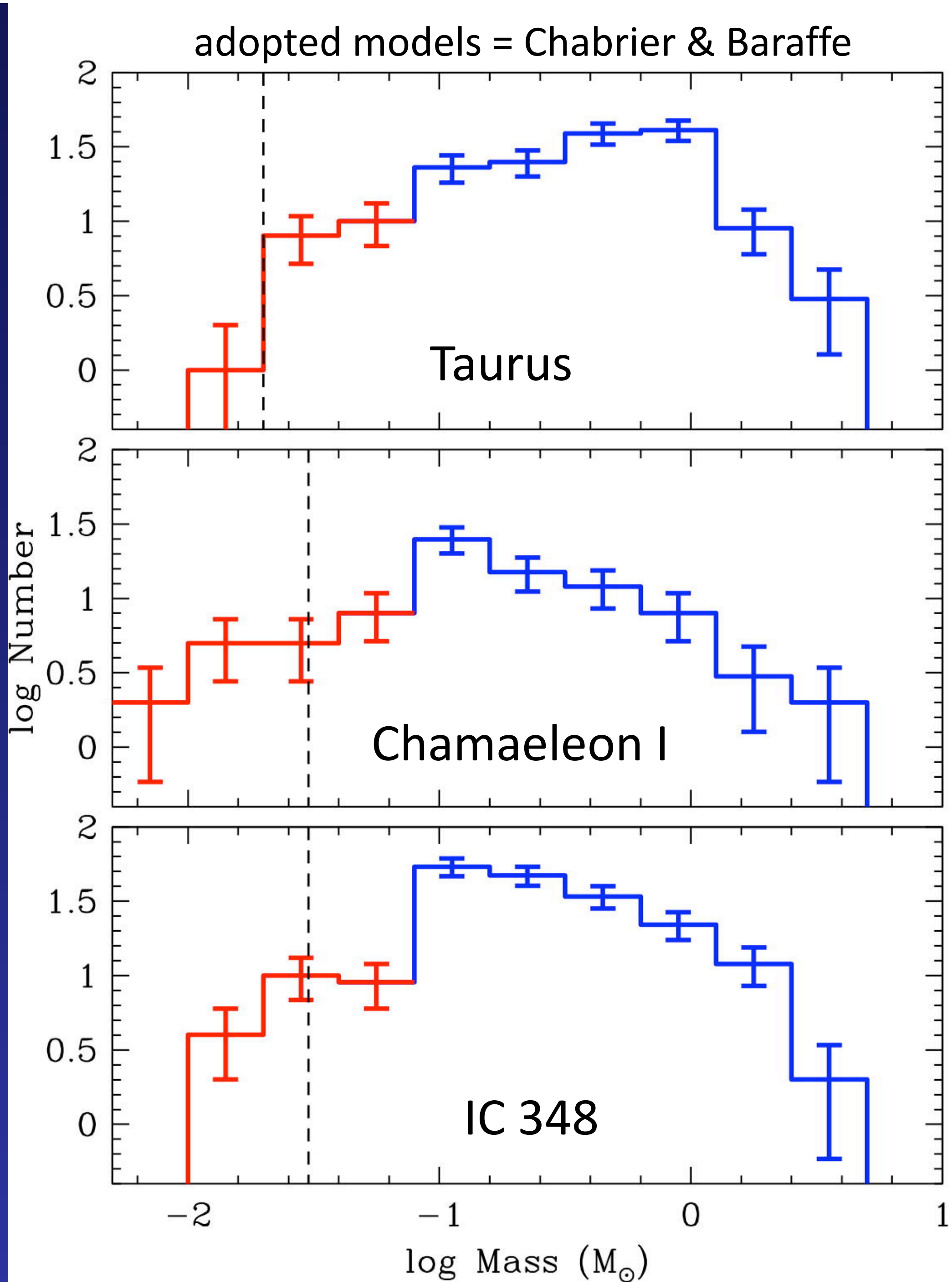
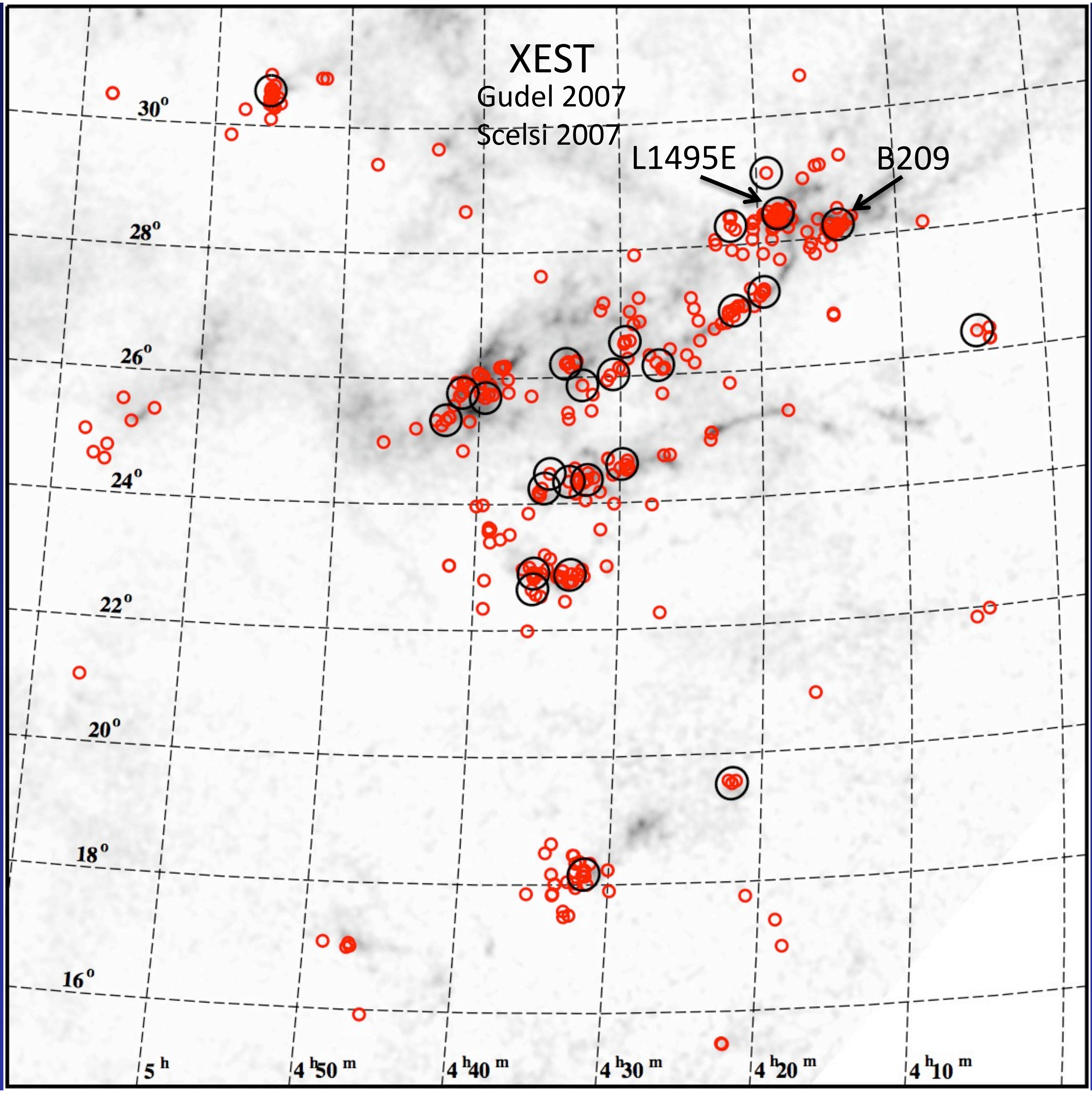
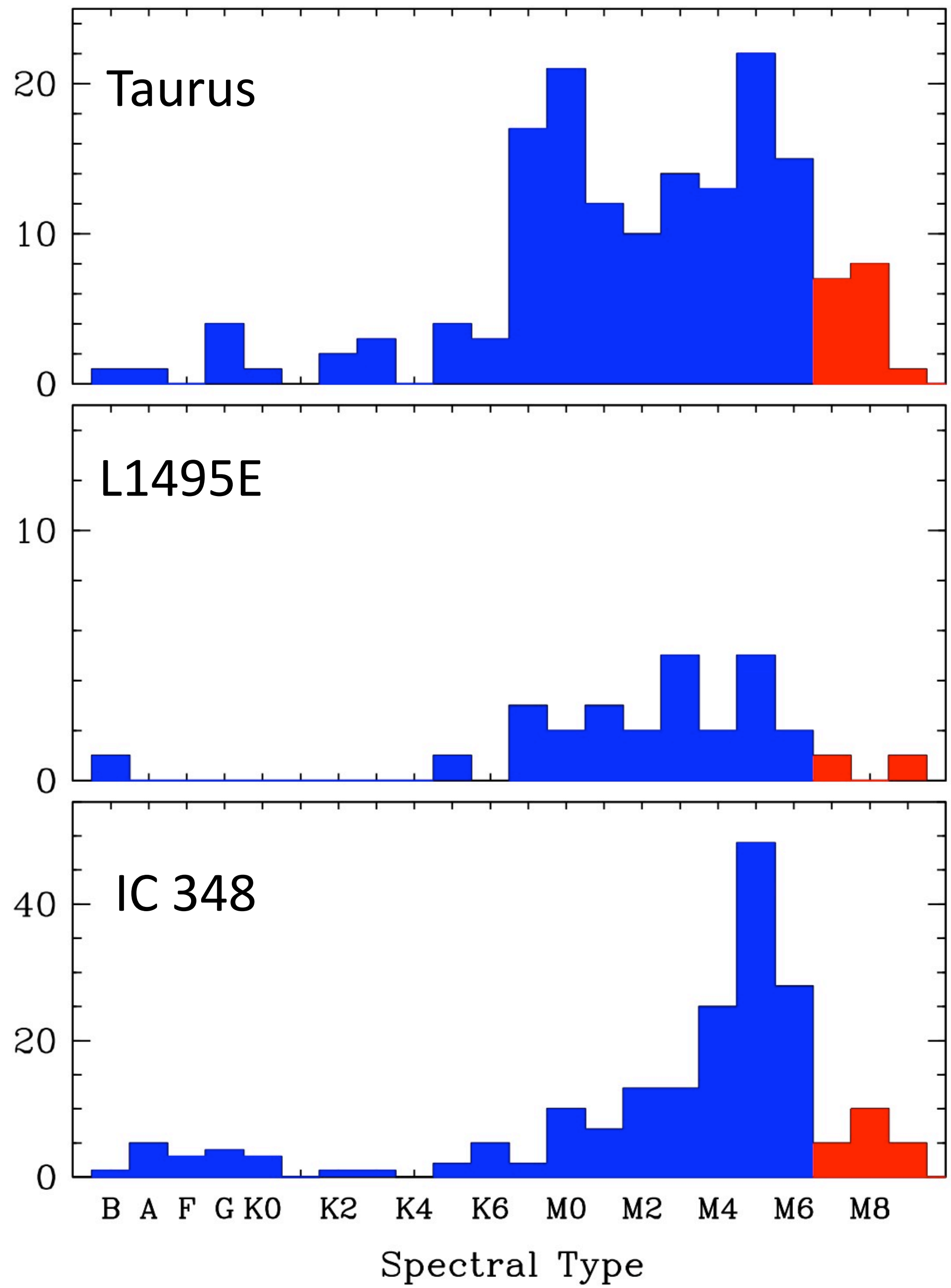
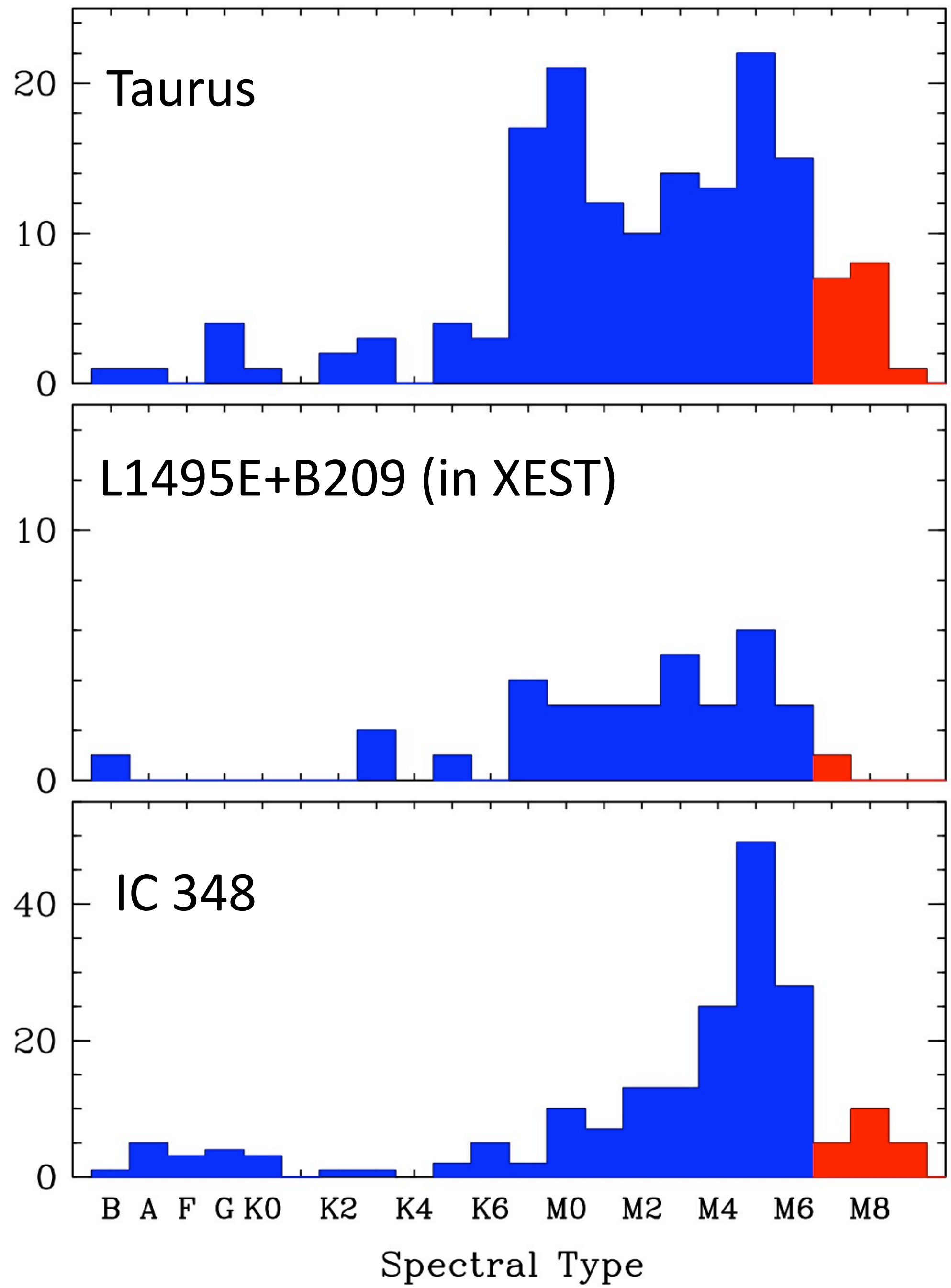
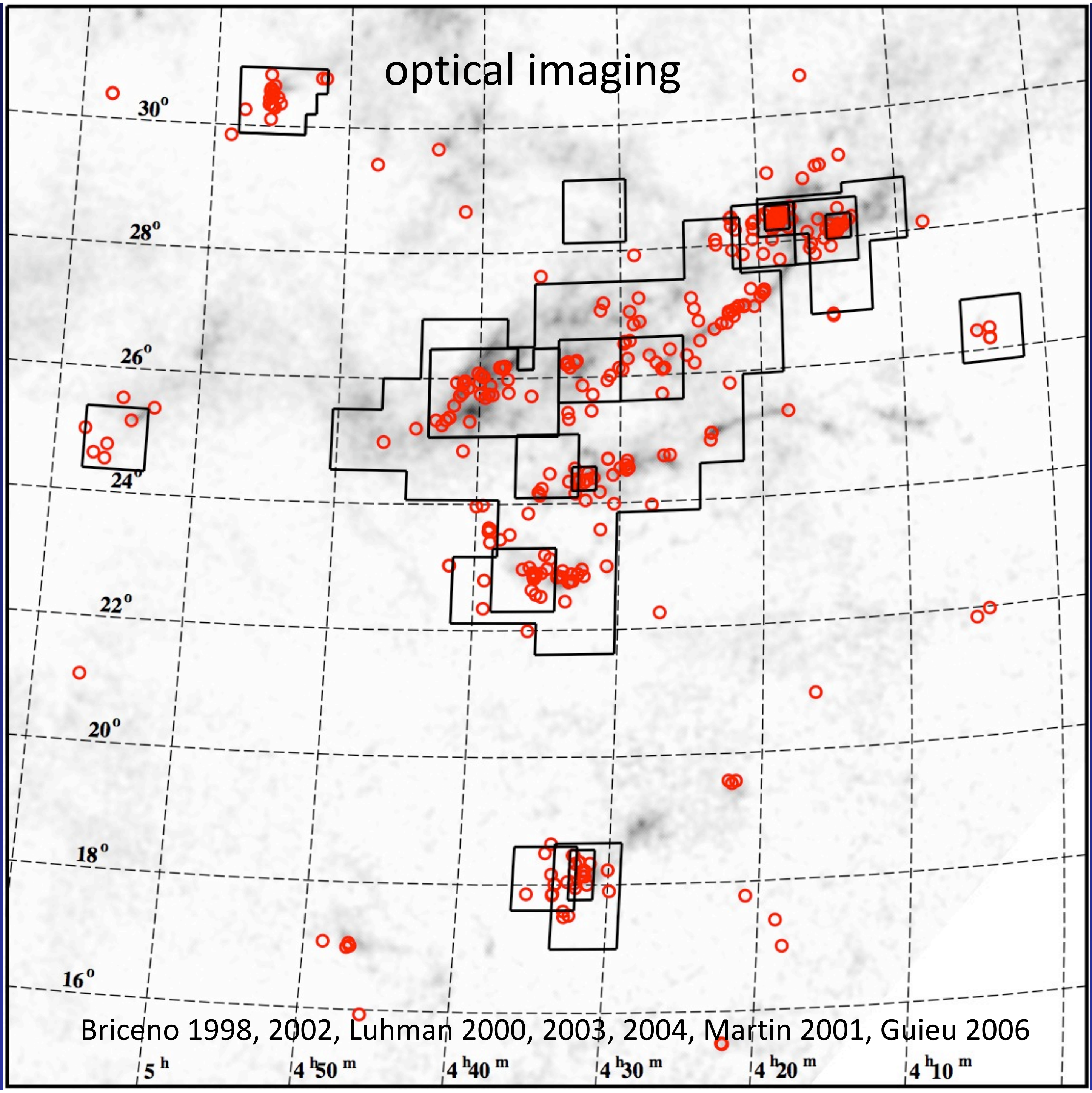


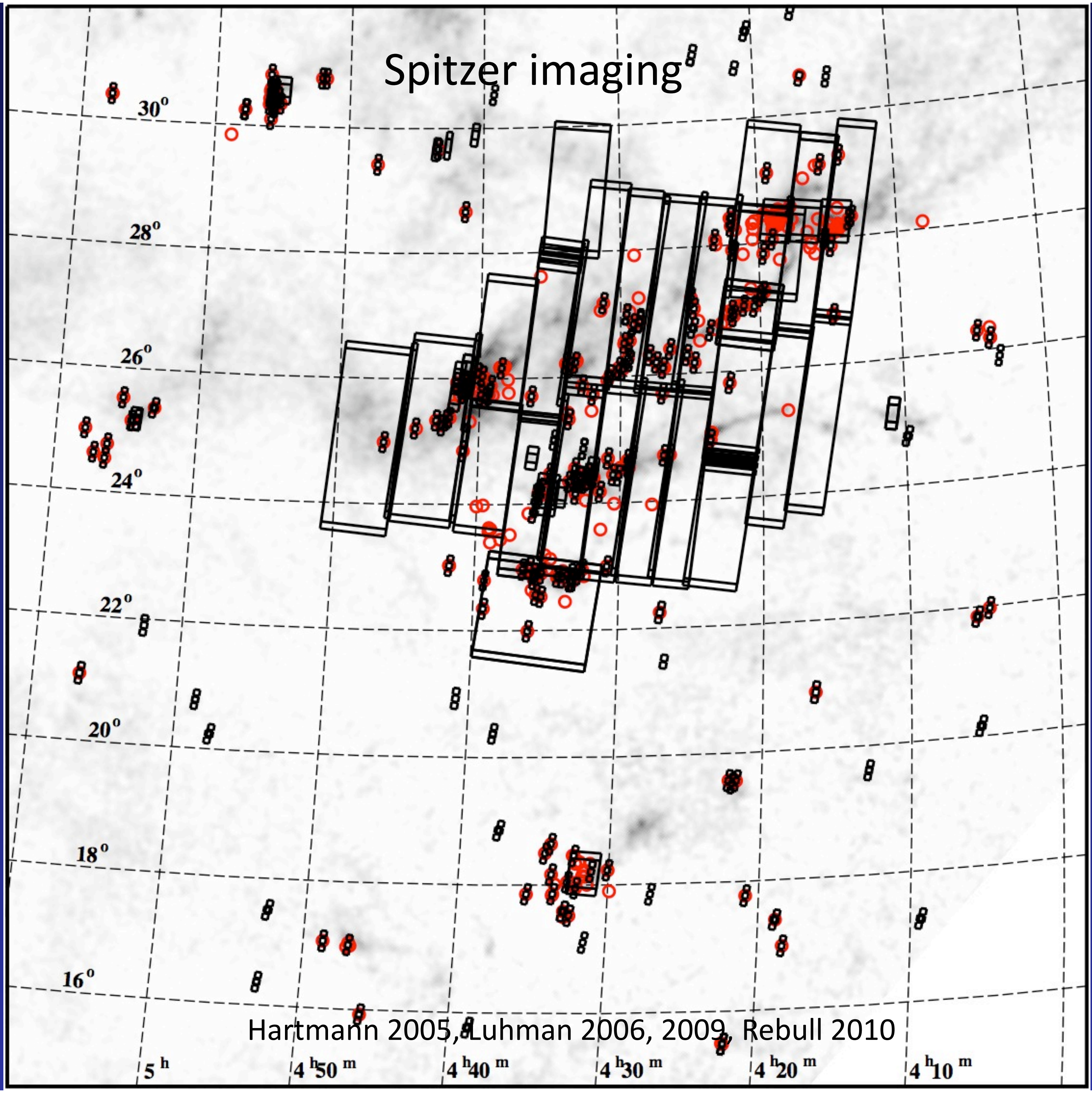

XEST
Gudel 2007
Scelsi 2007
L1495E
B209
30°
28°
26°
24°
22°
20°
18°
16°
5 h
4 h 50 m
4 h 40 m
4 h 30 m
4 h 20 m
4 h 10 m

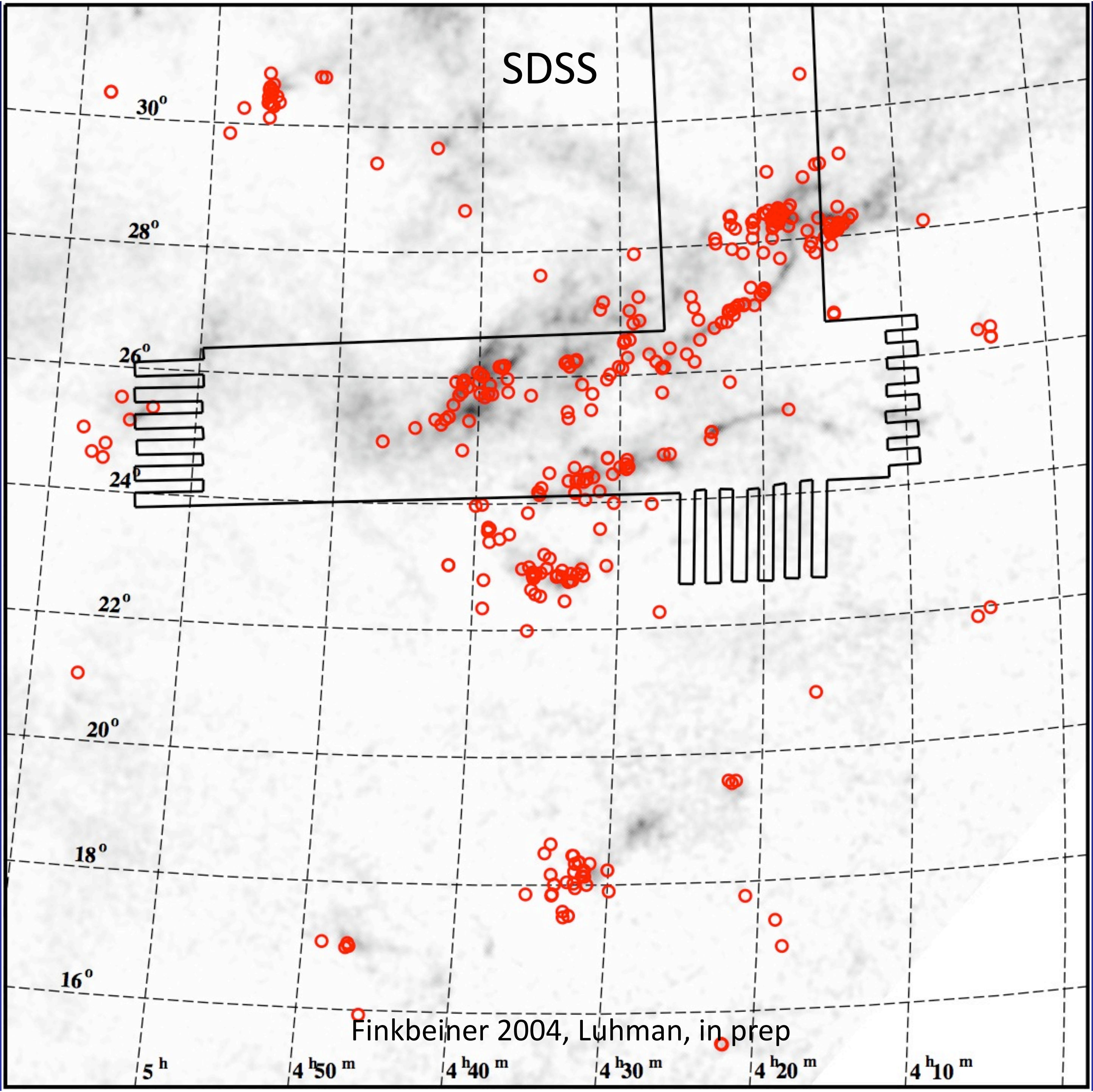

Taurus
L1495E
IC 348
20
10
0
10
0
40
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type



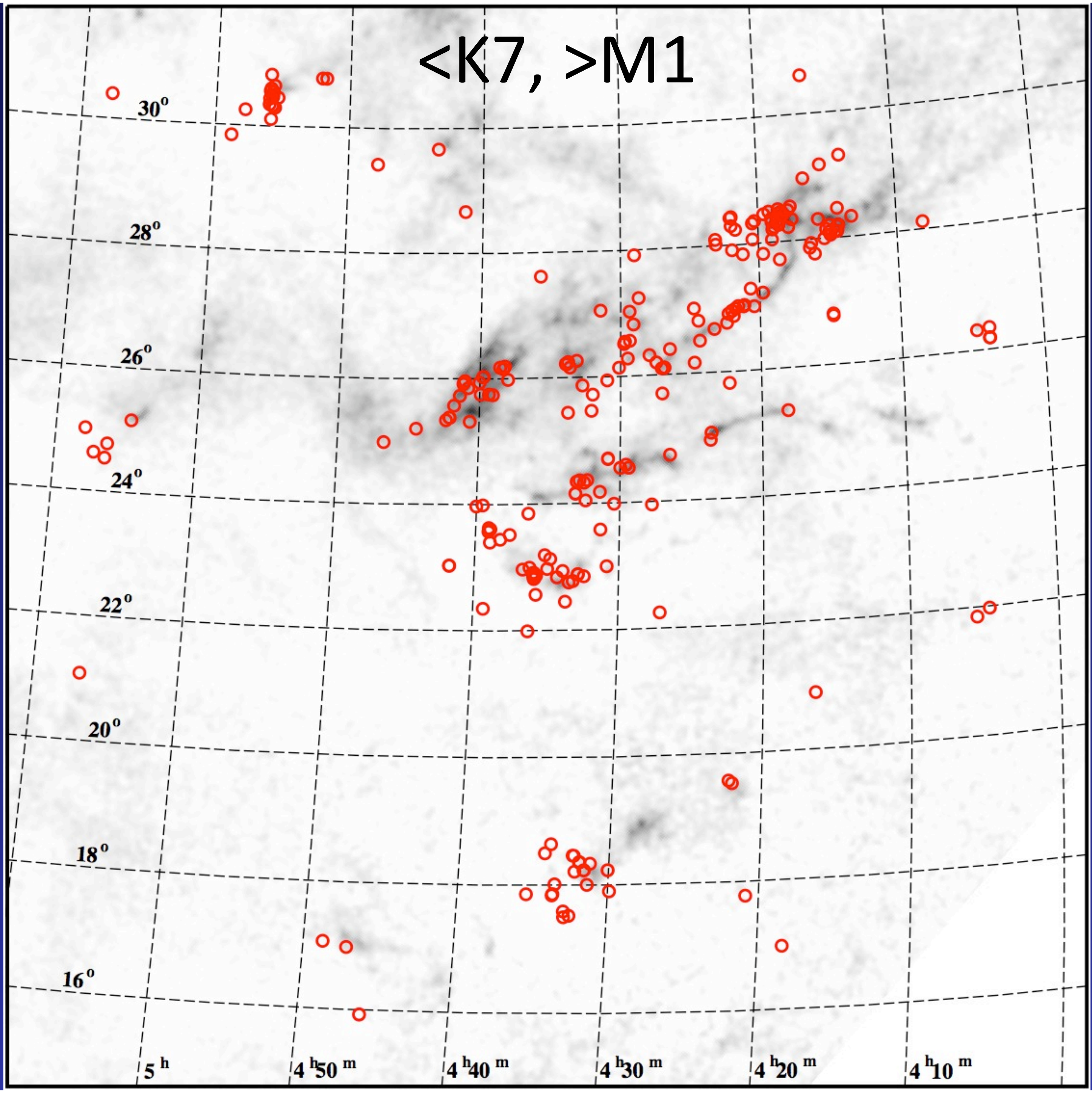
Taurus
L1495E+B209 (in XEST)
IC 348
20
10
0
10
0
40
20
0
B A F G K0 K2 K4 K6 M0 M2 M4 M6 M8
Spectral Type

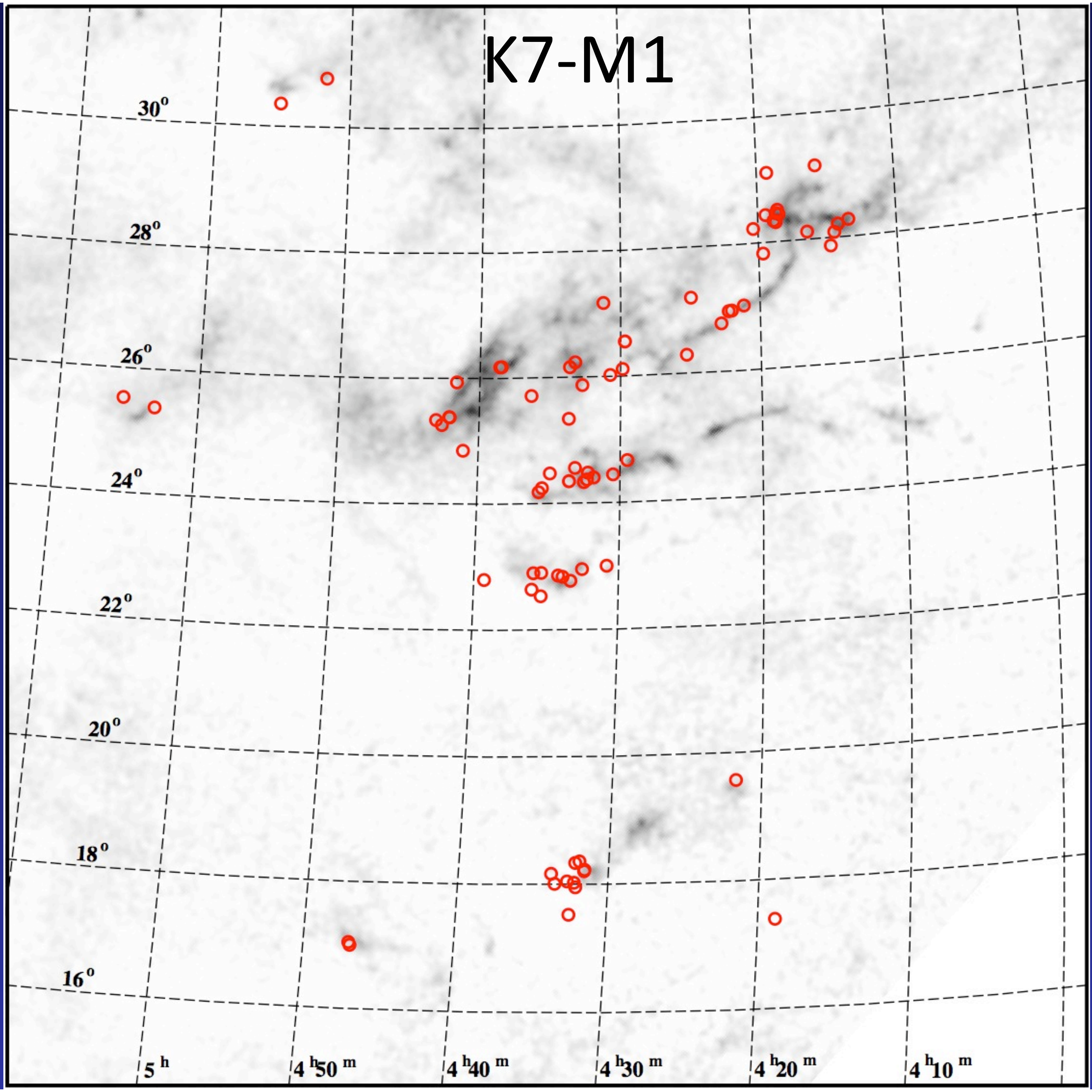

optical imaging
30°
28°
26°
24°
22°
20°
18°
16°
5 h
4 h 50 m
4 h 40 m
4 h 30 m
4 h 20 m
4 h 10 m
Briceno 1998, 2002, Luhman 2000, 2003, 2004, Martin 2001, Guieu 2006


Spitzer imaging
30°
28°
26°
24°
22°
20°
18°
16°
5h
4h50m
4h40m
4h30m
4h20m
4h10m
Hartmann 2005, Luhman 2006, 2009, Rebull 2010



SDSS
30°
28°
26°
24°
22°
20°
18°
16°
5 h
4 h 50 m
4 h 40 m
4 h 30 m
4 h 20 m
4 h 10 m
Finkbeiner 2004, Luhman, in prep


<K7, >M1
30°
28°
26°
24°
22°
20°
18°
16°
5 h
4 h 50 m
4 h 40 m
4 h 30 m
4 h 20 m
4 h 10 m

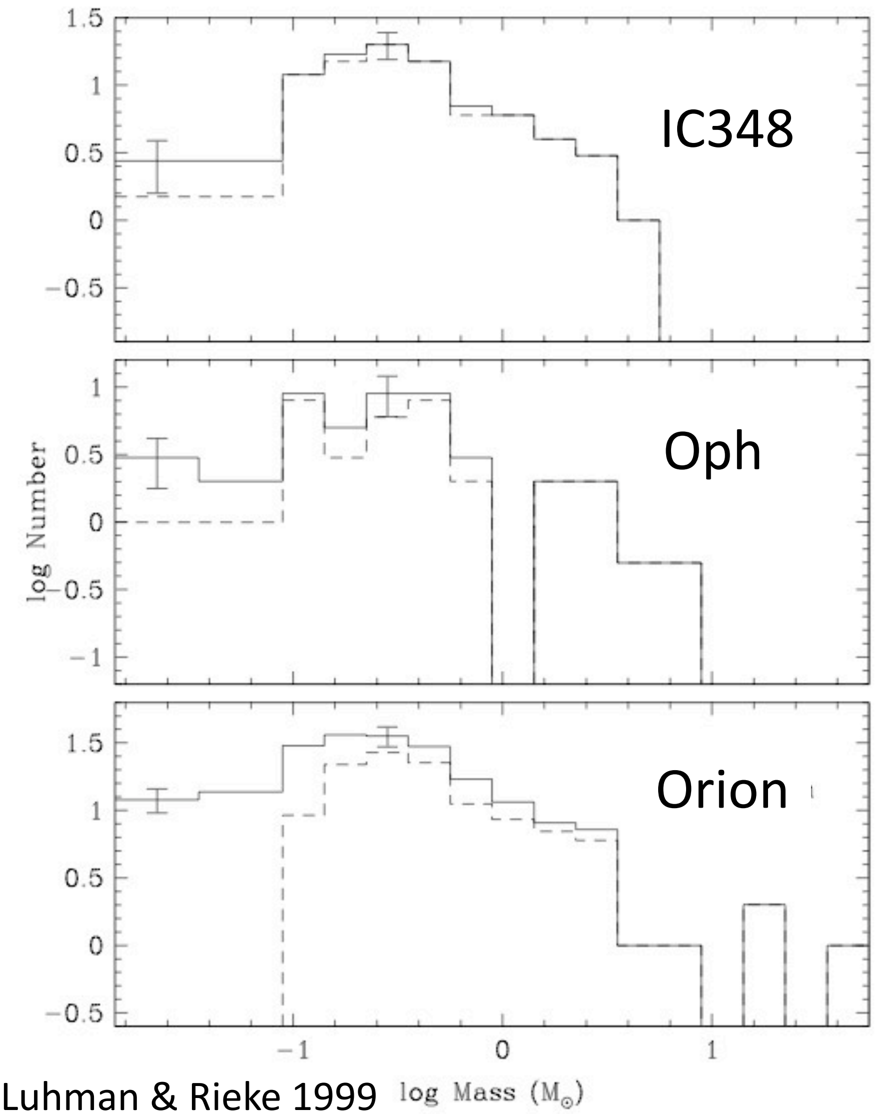

K7-M1
30°
28°
26°
24°
22°
20°
18°
16°
5 h
4 h 50 m
4 h 40 m
4 h 30 m
4 h 20 m
4 h 10 m

NGC 1333

- Some spectroscopy (Wilking 2004, Greissl 2007, Winston 2009, Scholz 2009), but a complete sample is unavailable
- Greissl 2007: large surplus of brown dwarfs? caveats:
  - small sample
  - affected by mass segregation?
  - same spectral type system as other regions?
- Scholz 2009: 2-5x more BDs at 0.02-0.08 $M_{\odot}$ but higher low-mass cutoff (0.015 $M_{\odot}$) than other clusters
  - T_{eff} from comparison of observed model/spectra
  - since spectral types not measured, meaningful comparison to other clusters is not possible

Ophiuchus

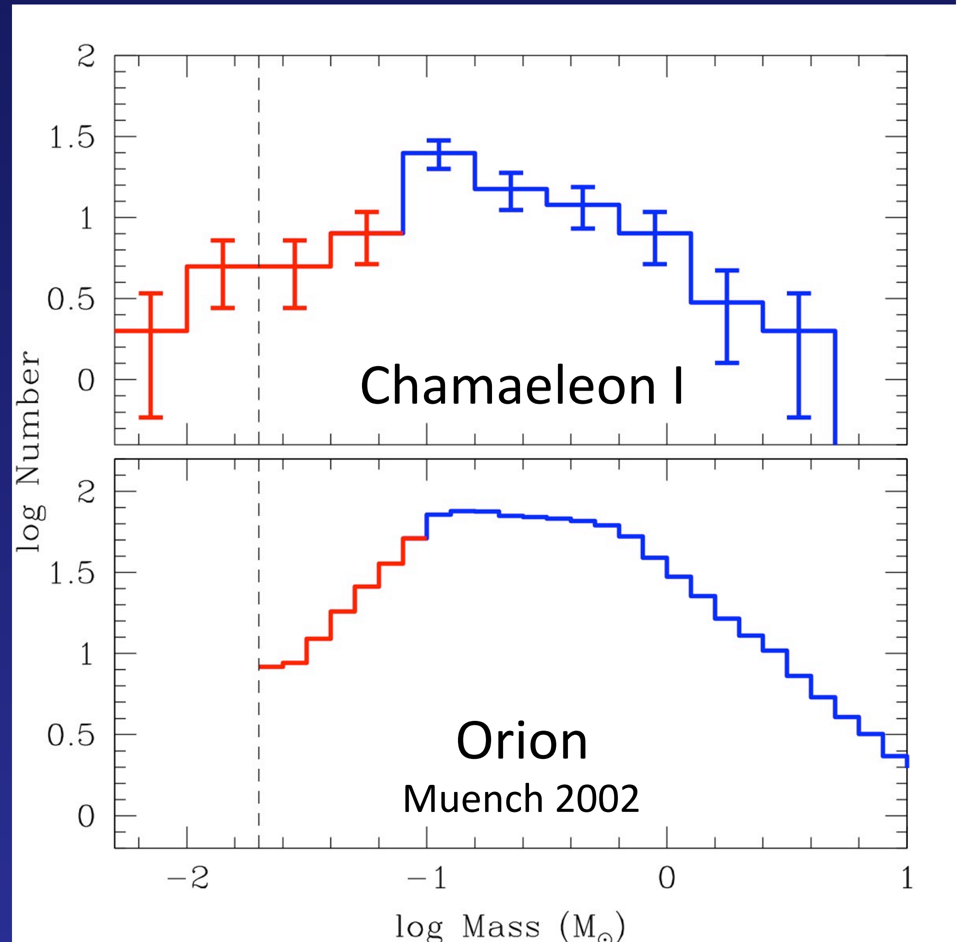
- IMF roughly similar to other clusters (Luhman & Rieke 1999), although small sample
- T –type member at ~2-3 M_{jup}? (Marsh 2010a)
- Oph has more BDs than other clusters, but based on only photometric candidates (Marsh 2010b)
- See talk by Alves de Oliveira and poster by Haisch for BD surveys



Luhman & Rieke 1999

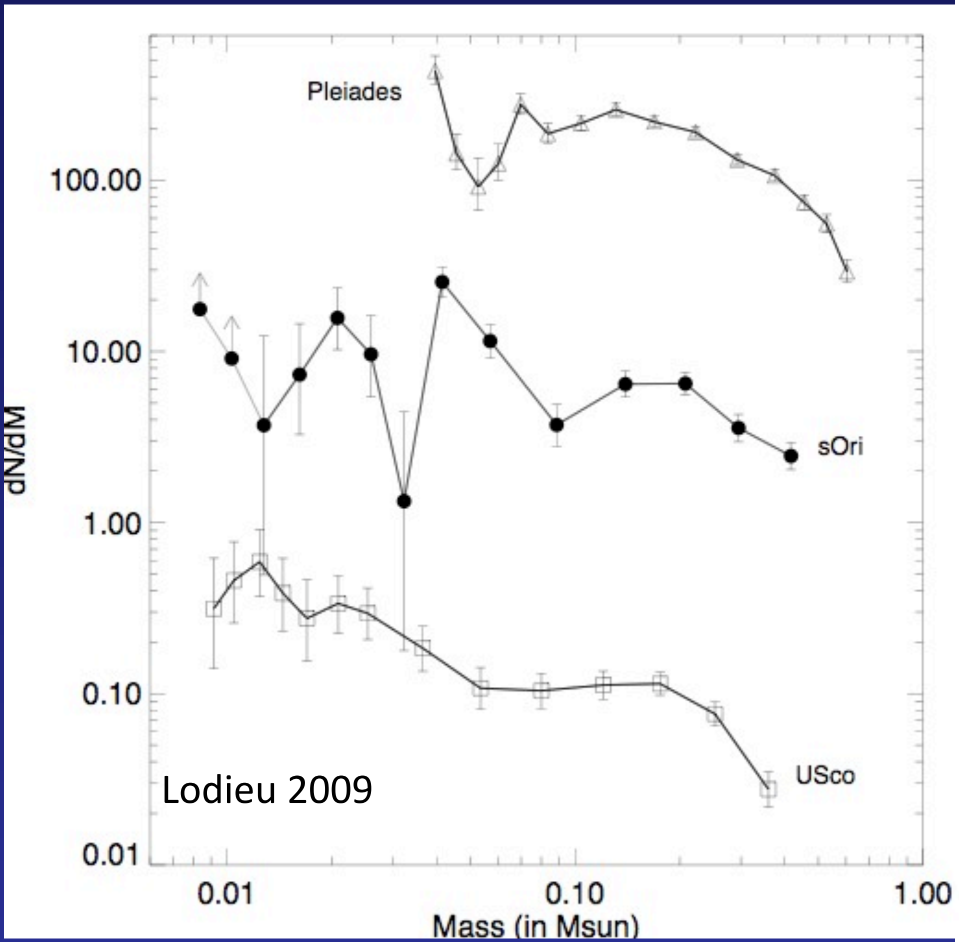
Orion Nebula Cluster

- Extensive spectroscopy (e.g., Hillenbrand 1997), although spectroscopic sample incomplete at later types
- IMF from spectra and luminosity function is similar to those in IC348 and Cha I
- BDs detected down to ~5 M_{jup} (Lucas 2005, Weights 2009)



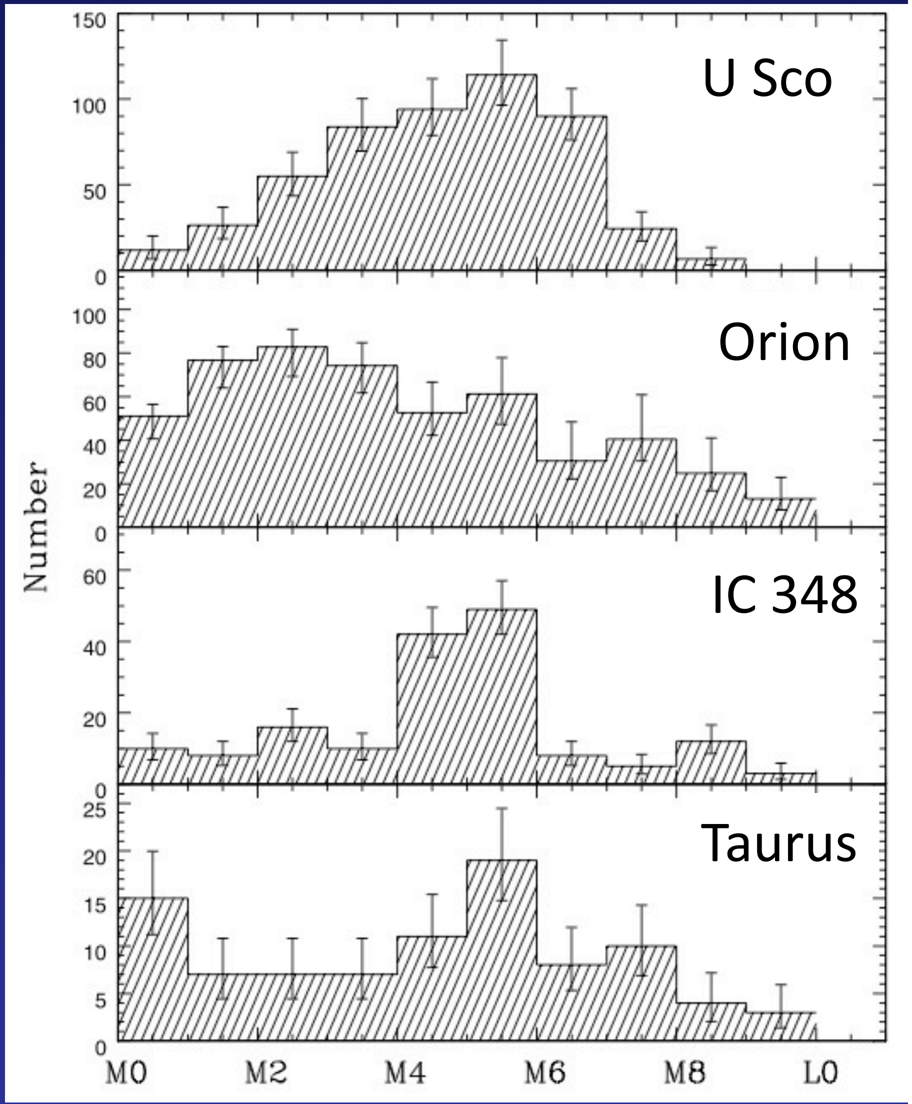
σ Ori

- Extensive spectroscopy (Martín, Zapatero Osorio, Béjar, Barrado), although focused on late types
- Slope of substellar IMF similar to that of other clusters (Caballero 2007; Lodieu 2009)
- Possible BDs detected down to ~3 M_{jup} (Zapatero Osorio 2002, Bihain 2009)
- See posters by Petr-Gotzens and Ramirez



Upper Sco

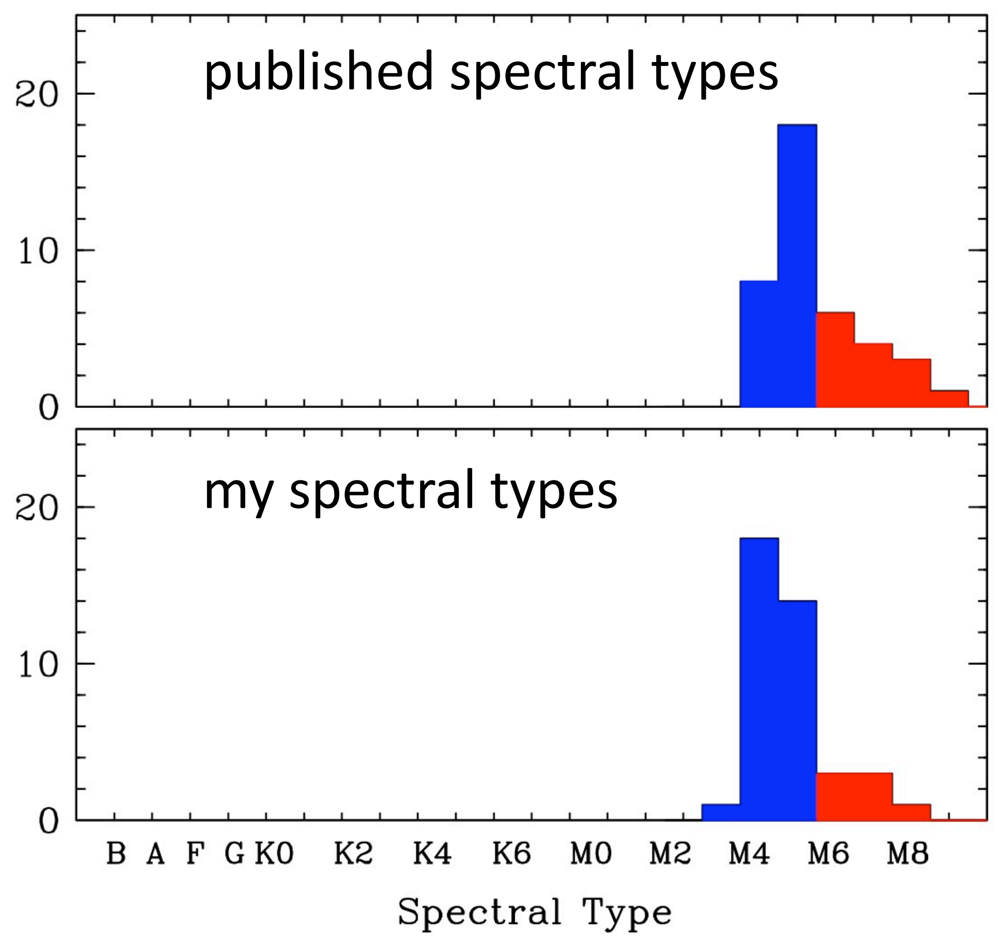
- Extensive spectroscopy (Preibisch, Ardila, Martín, Slesnick, Lodieu), although heterogeneous in mass and location
- U Sco peaks at M5, but broader distribution than IC348 & Cha I; differences in classification systems?
- Slope of substellar IMF similar to that of other clusters (Lodieu 2007)



Slesnick 2008

Upper Sco

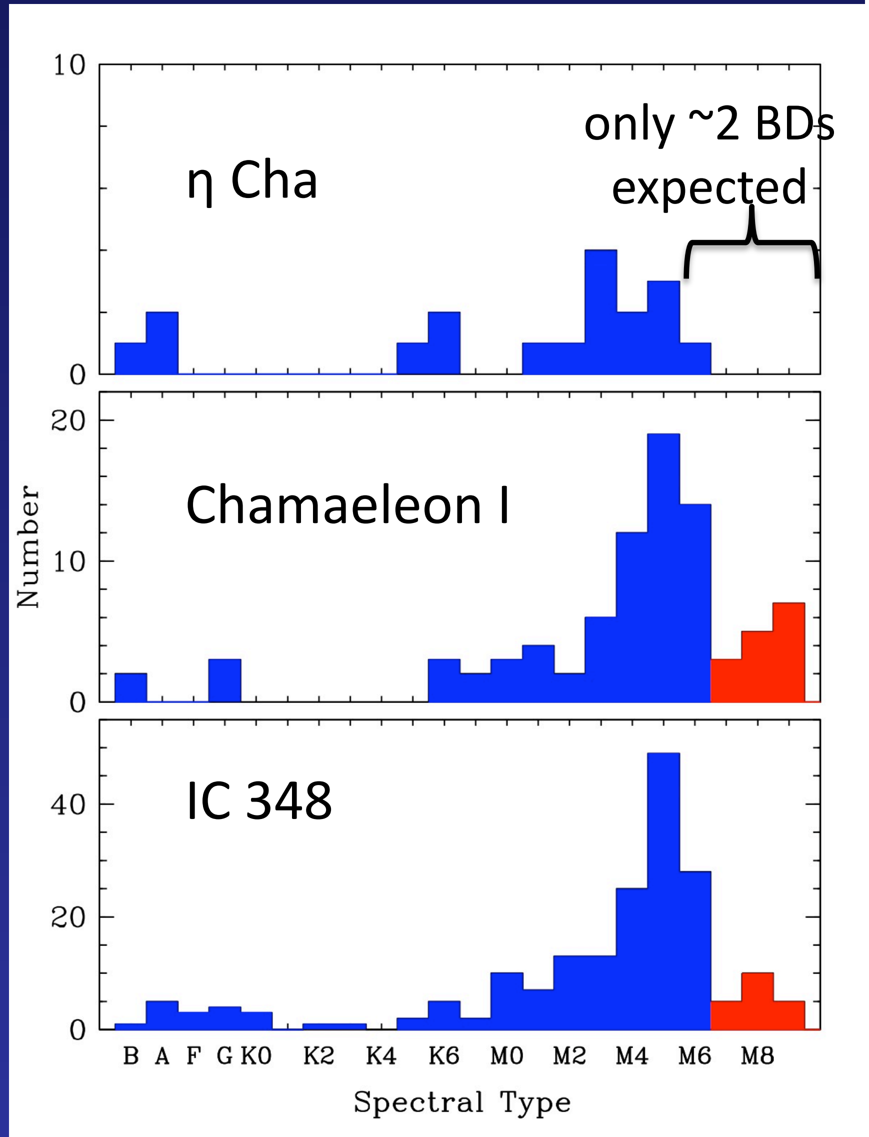
sample of U Sco members for which I have spectra:



→ BD/star ratio differs by more than a factor of 2

η Cha

- Lyo 2004 suggested that η Cha has a deficit of 20-29 low-mass stars and BDs relative to the field and other clusters
- However, IMF is consistent with other clusters, except for the proportion of B/A stars (Luhman 2004, 2009)



Conclusions

- The surplus of K7-M1 stars in Taurus is the only significant evidence of a variation in the IMF in nearby star-forming regions
- Detecting variations in the ratio of stars/BDs is very difficult because of the close proximity of the IMF peak to the hydrogen burning limit
- Low-mass cutoff reported in only 1 cluster (and probably not real); deeper observations needed before it can be detected and compared among clusters.