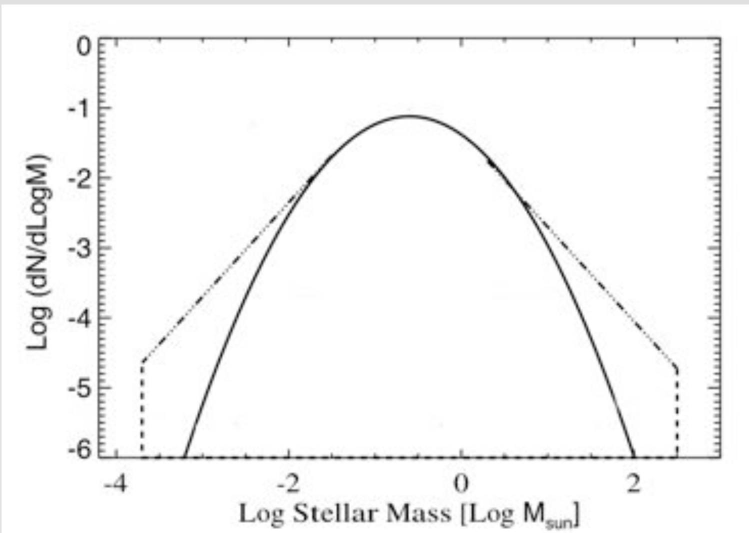
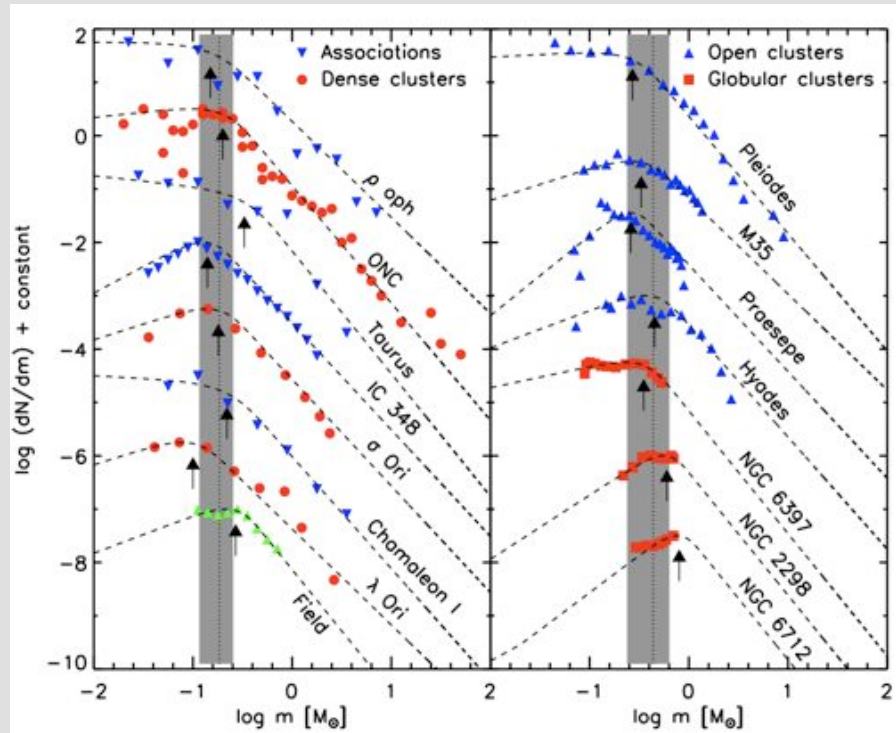
Star formation in nearby young clusters

Catarina Alves de Oliveira

European Space Agency

What determines the mass of a star?





Credits: Adapted from Bastian et al. 2010 & de Marchi et al. 2010.

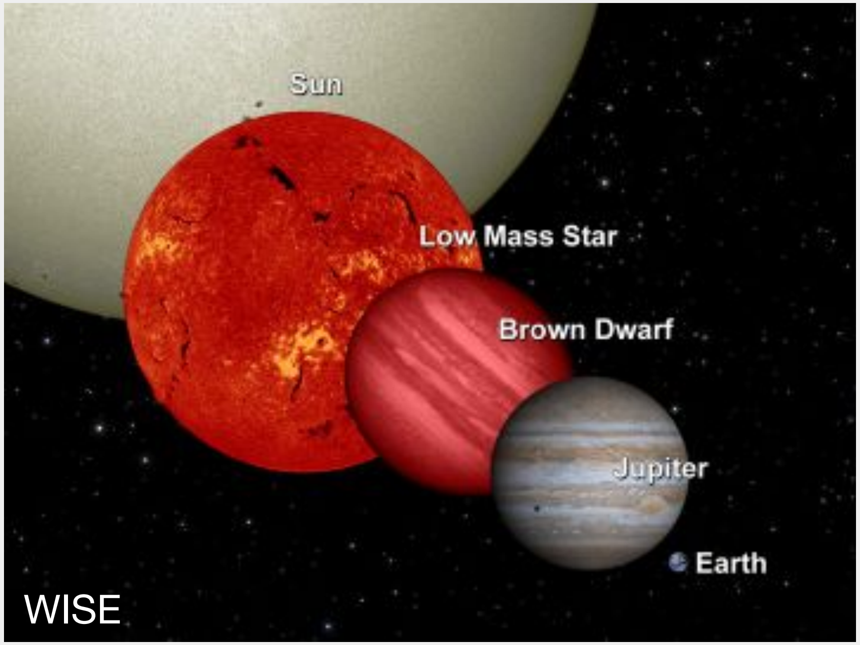
Introduction

Bridging the gap between stars and planets: Brown dwarfs

Objects not massive enough to sustain stable hydrogen fusion (M < 0.075 $M_{\odot} \approx 75\ M_{Jup}$)

Theoretical prediction 50 years ago by Shiv S. Kumar:

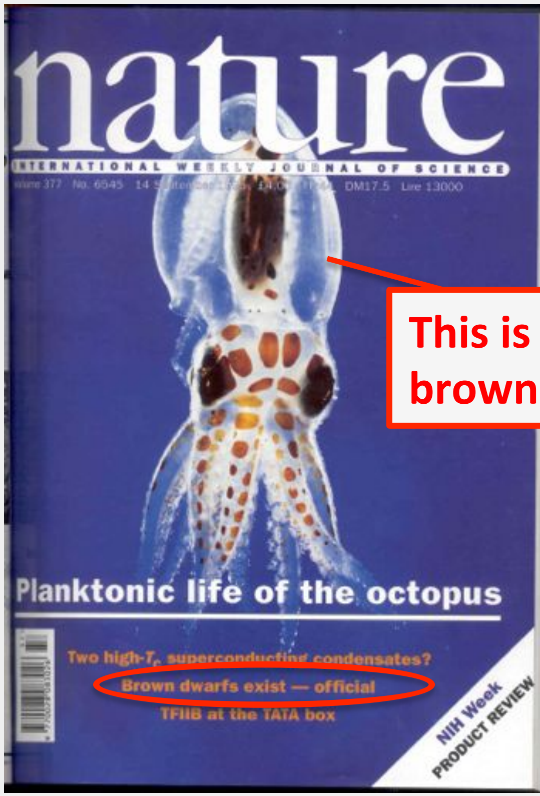
"There exists a limiting mass below which a contracting star cannot reach the main-sequence stage." Kumar 1963



Introduction

Bridging the gap between stars and planets: Brown dwarfs

First discoveries in 1995:

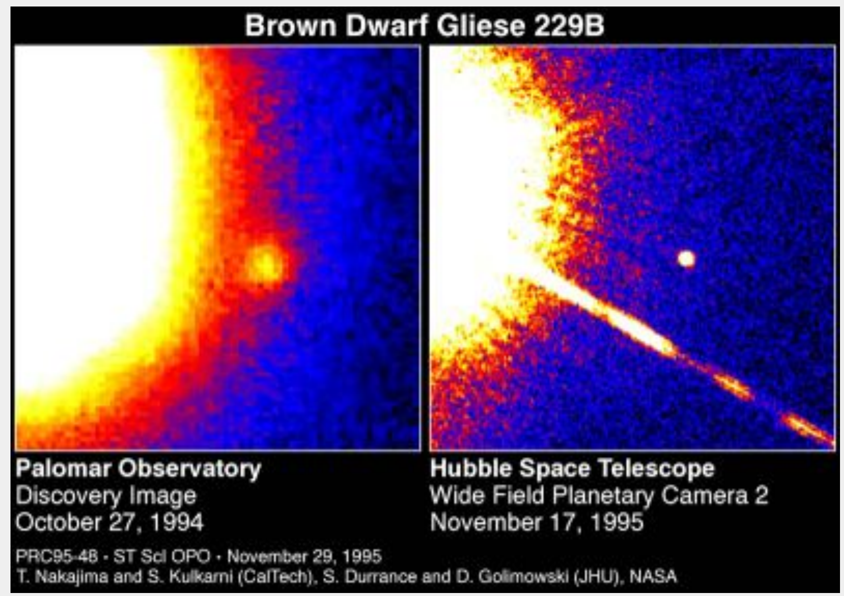


This is not a brown dwarf!

Rebolo, Zapatero-Osorio & Martin 1995

Nakajima et al. 1995

Oppenheimer et al. 1995



Introduction

Bridging the gap between stars and planets: Brown dwarfs

Fast growing field in the last years:

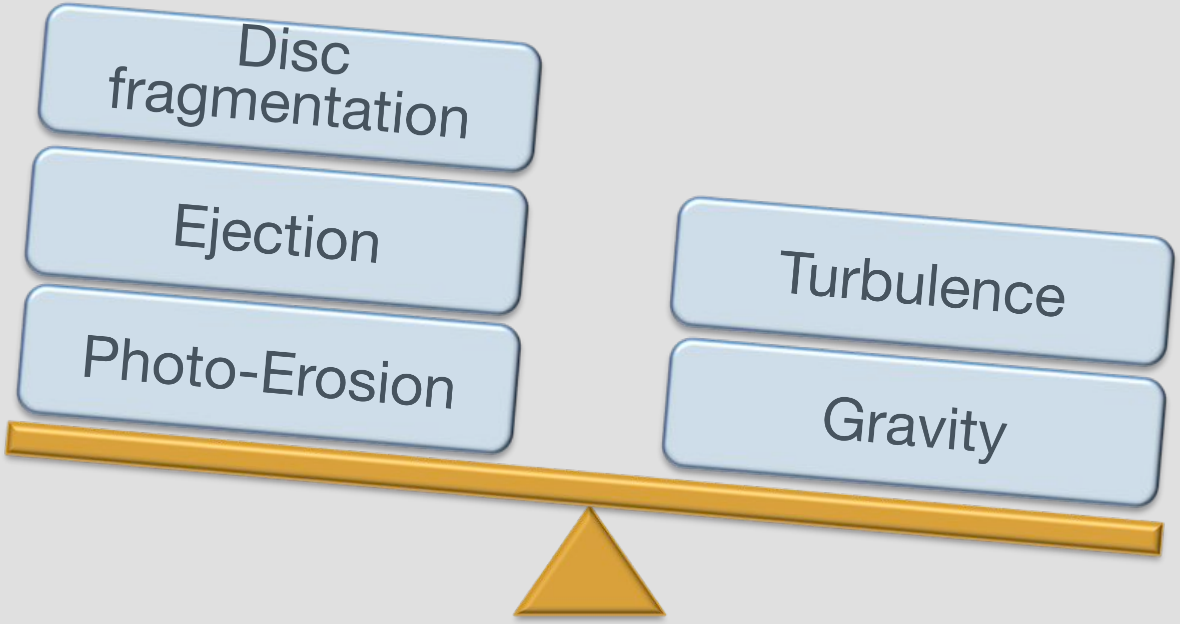
- M, L, T, and Y spectral classes
- coolest brown dwarf known to date: ~300 K (~25 ^{o}C !)
- ratio of brown dwarfs to stars in the Galaxy ~ 1/5

Introduction

Brown dwarfs – how do they form?

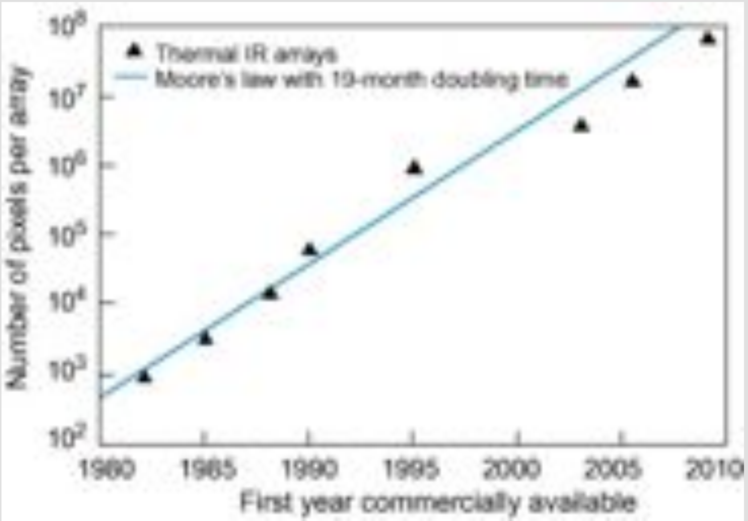
Different from solar-type stars

Like solar-type stars

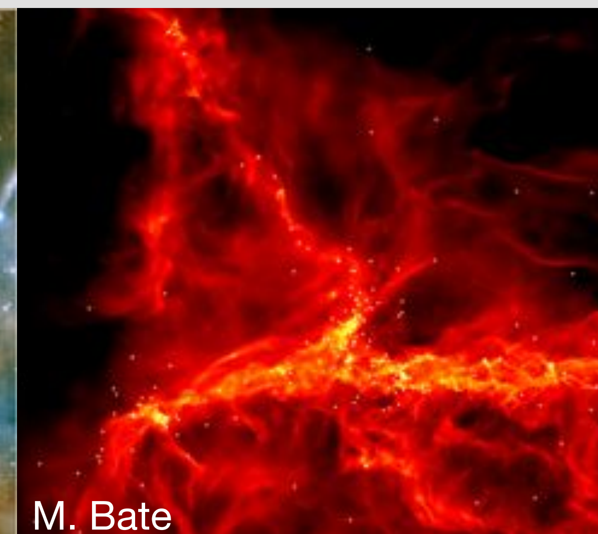


Introduction

Introduction



Advances in IR detectors impelled the development of wide-field instruments shaping our view of the cold Universe.

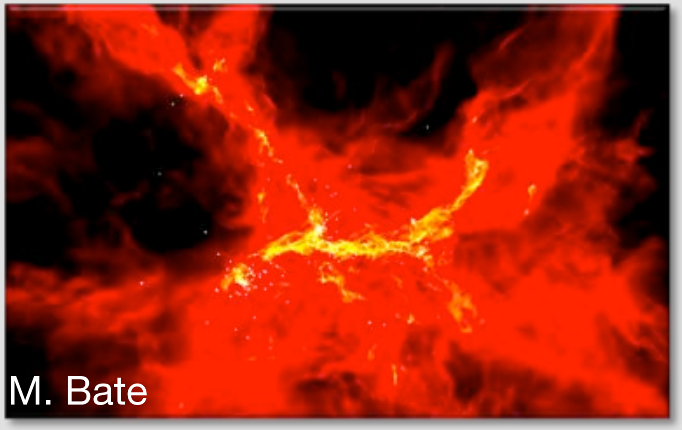


Brown dwarfs in star-forming regions

ADVANTAGES
_ DETECTABILITY
_ MIN. DYNAMICAL EVOLUTION

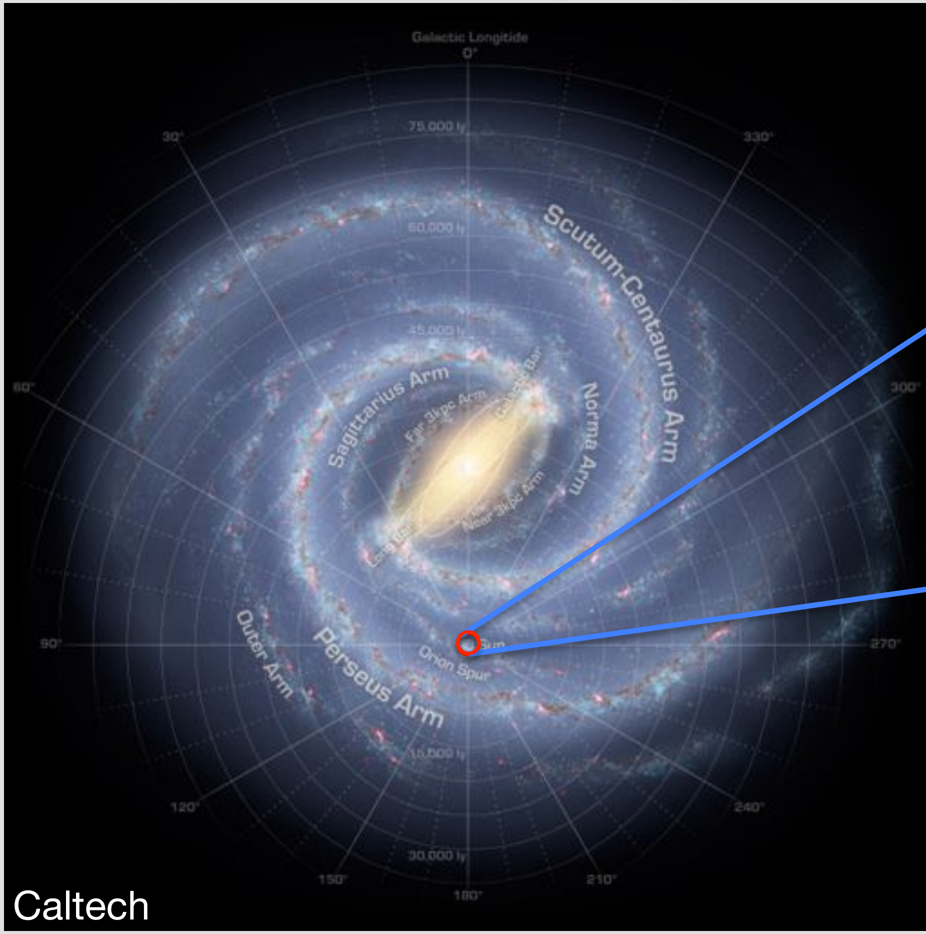
DISADVANTAGES
_ CONTAMINATION
_ MODELS

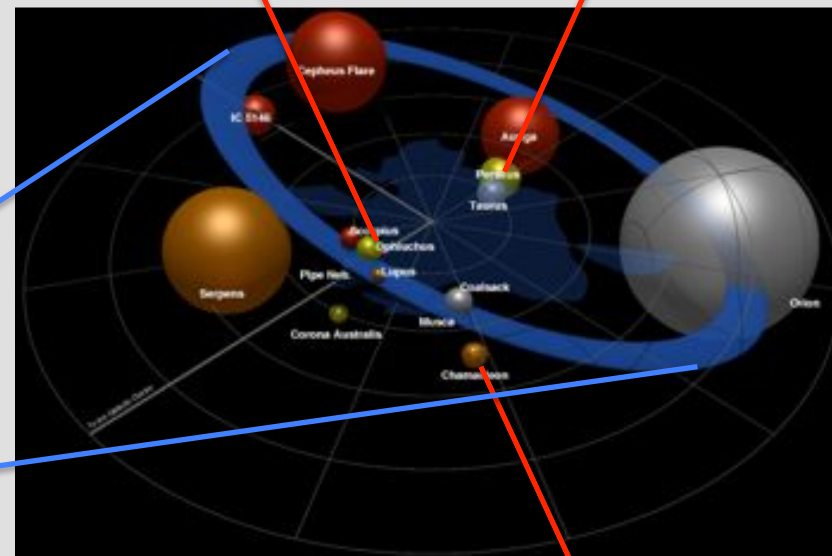

Alves de Oliveira & Casali


M. Bate

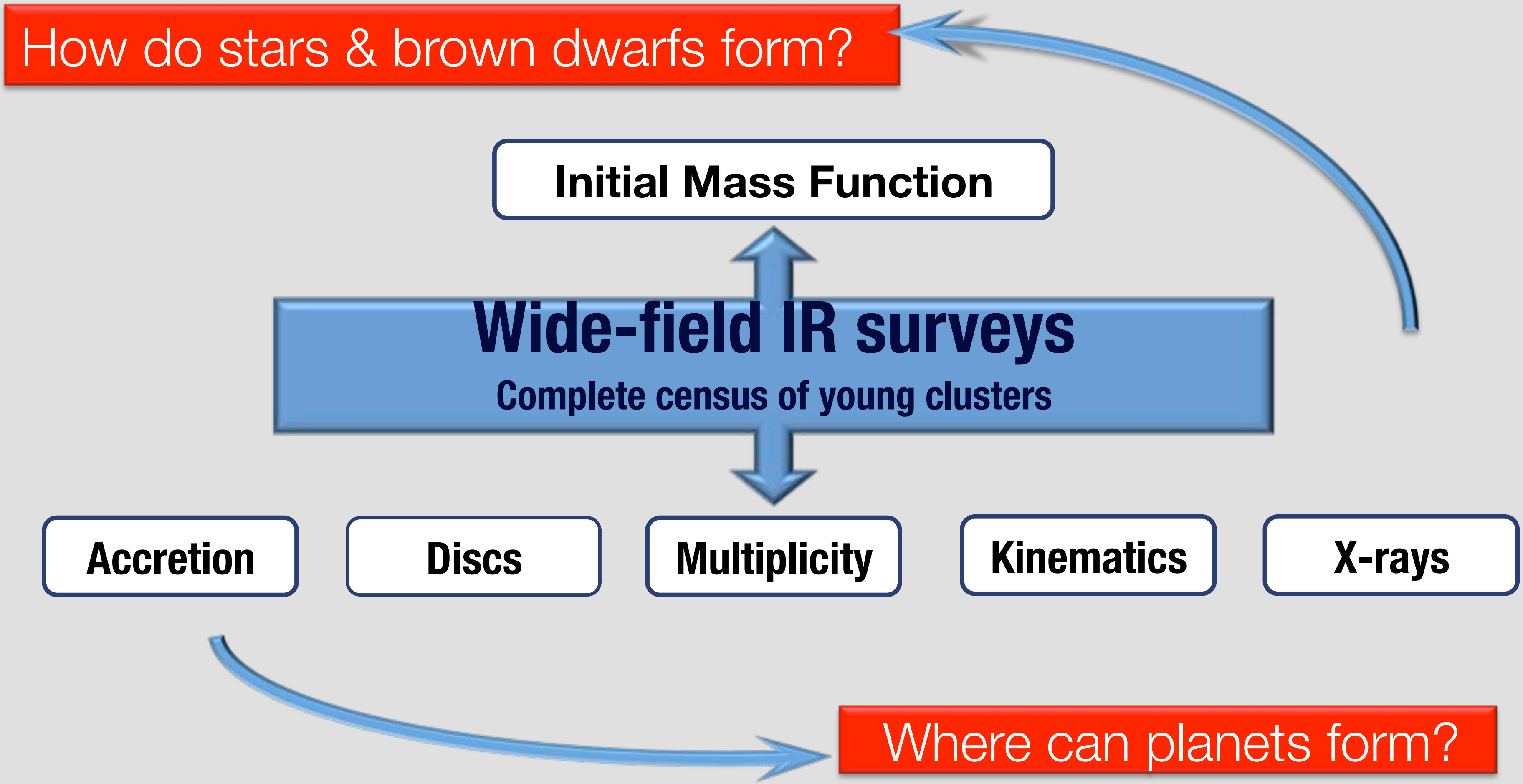
Introduction

Nearby star-forming regions



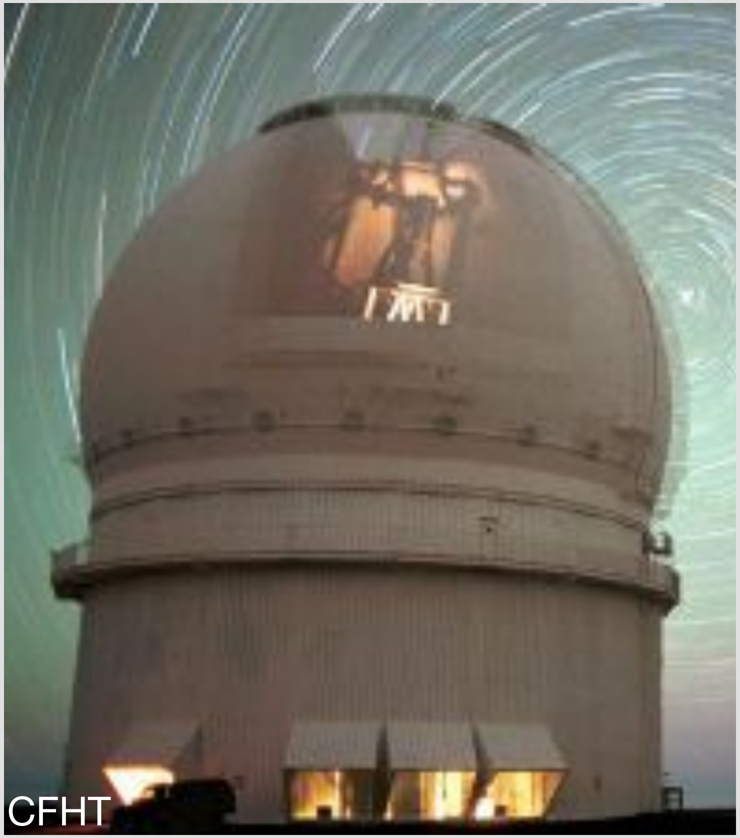


Introduction



CFHT survey

Science case



CFHT, 3.6m telescope, Mauna Kea

WIRCam, near-IR camera (YJHKs)
MegaCam, optical camera (z)

Survey of nearby clusters with deep exposures over large fields:

- IC 348
- Rho Oph

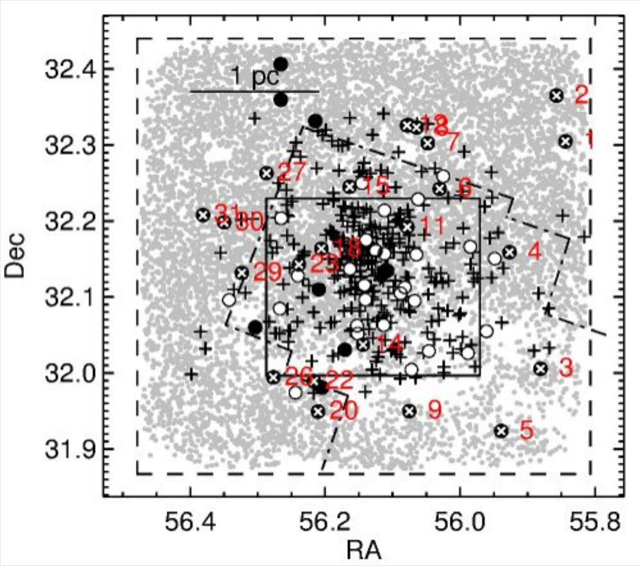
CFHT survey

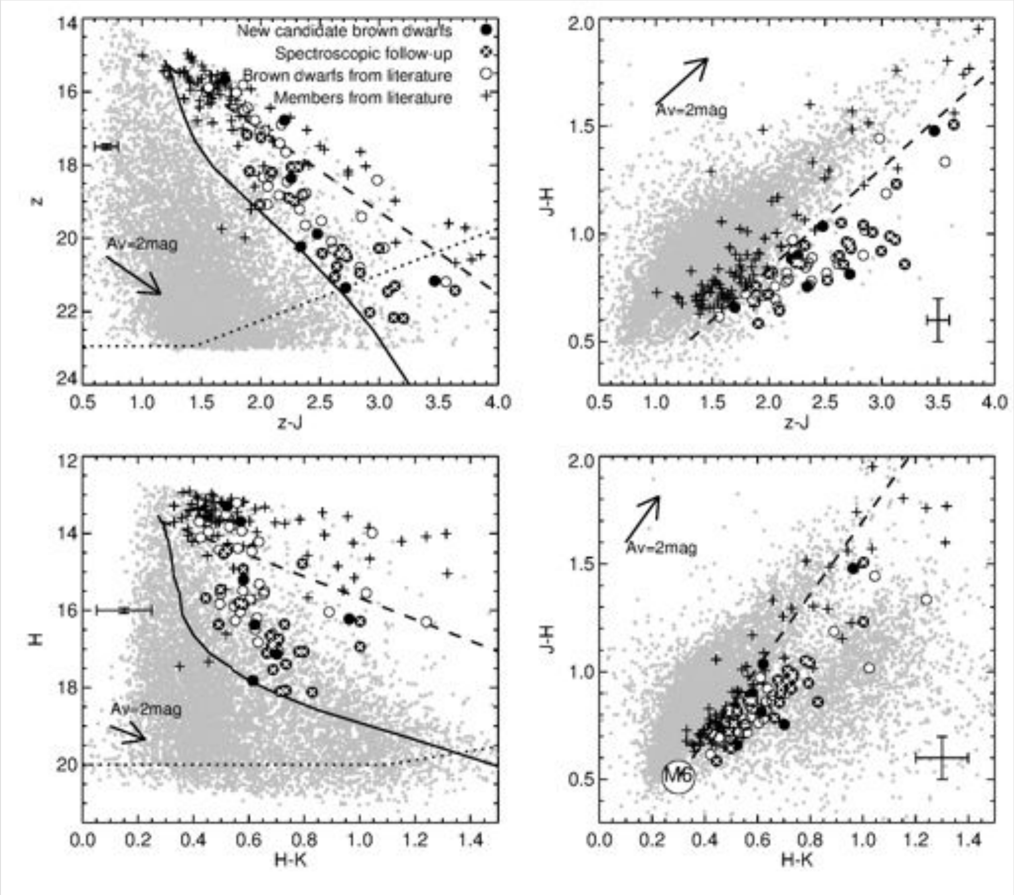
IC 348

2 Myr
316 pc
345 members (30 brown dwarfs)

Photometry

CFHT-photometric survey:
31 substellar candidates





IC 348

Photometry

Photometry is not enough…

Need spectroscopy:

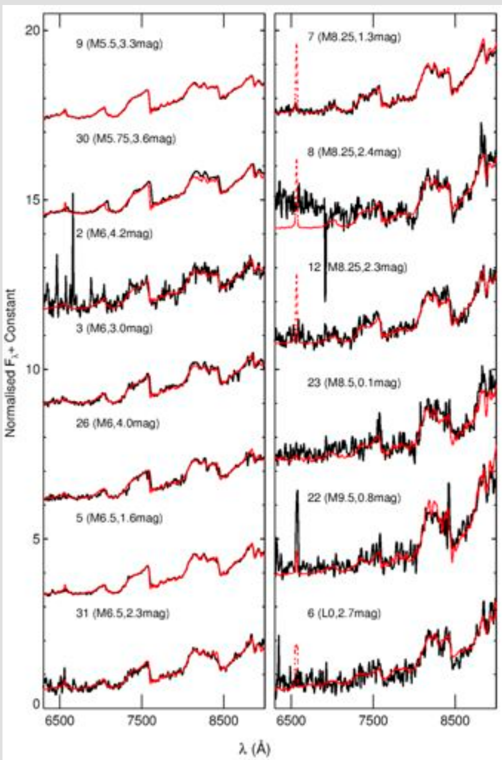
- to confirm their membership via signature of youth

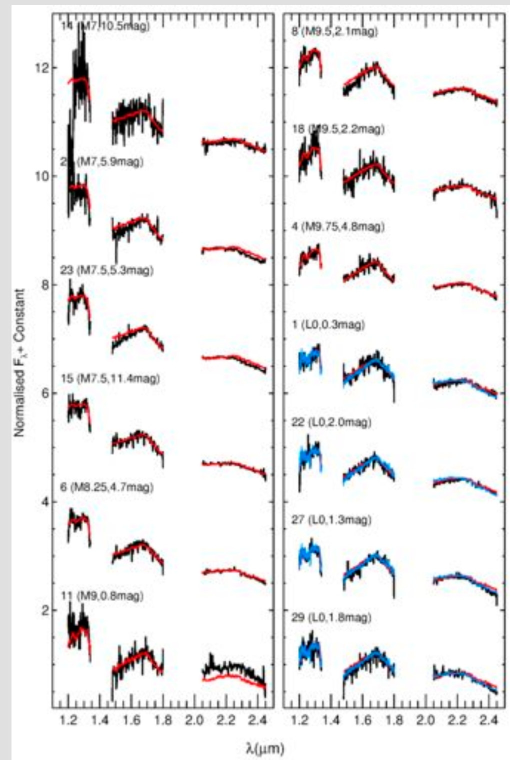
- to derive spectral types, which constrain temperature and mass

Spectroscopic follow-up of 24 candidates (84% within completeness limit and Av<4)

Osiris/GTC
10.4 m, La Palma
10 hours
z ~ 20 mag

GNIRS/GEMINI
8.1 m, Hawaii
25 hours
J ~17 mag



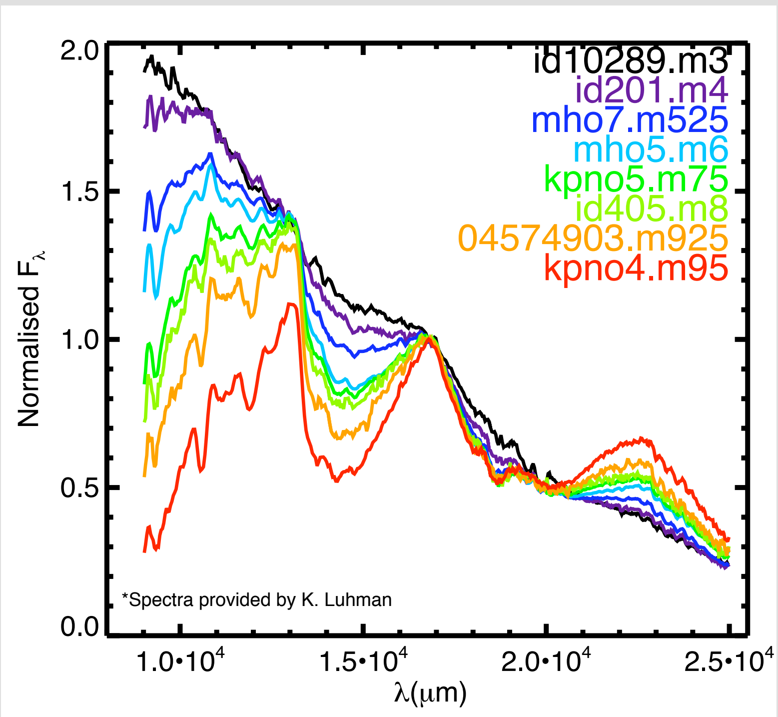


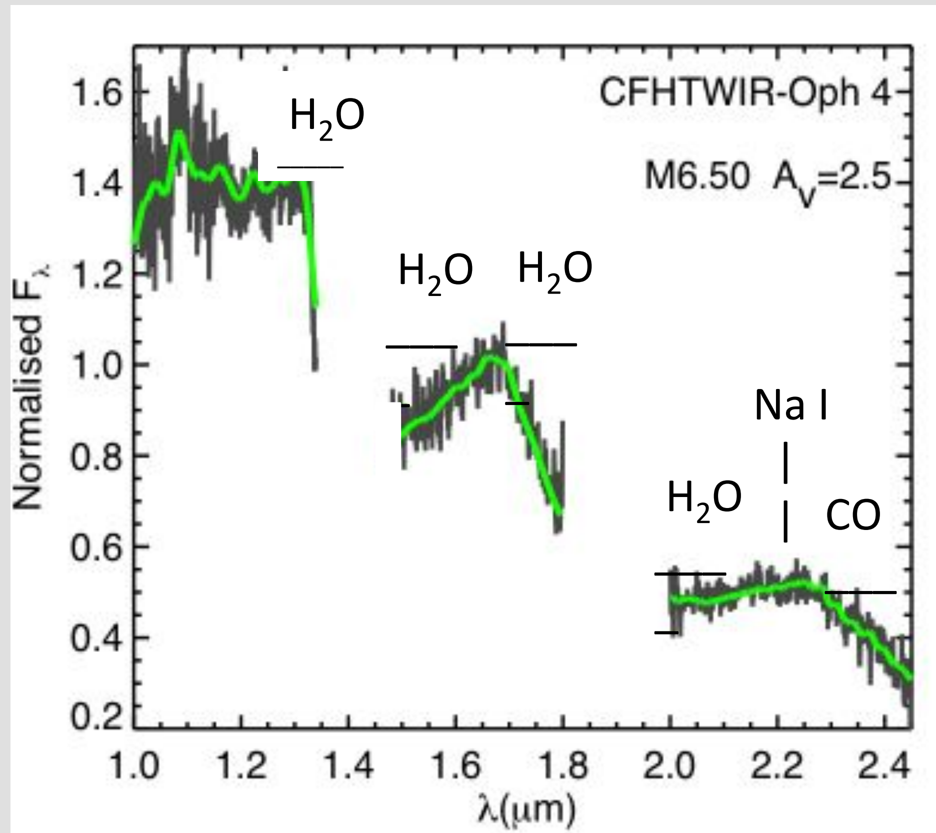
IC 348

Spectroscopy

Grid of young templates:
M3-M9 (<2Myr): IC 348 / Taurus / Cha I (Briceno et al. 2002, Luhman et al. 2003a,b, Luhman 2004a,b)
optical and near-IR spectra (K. Luhman)

Numerical spectral fitting to simultaneously derive spectral type and extinction



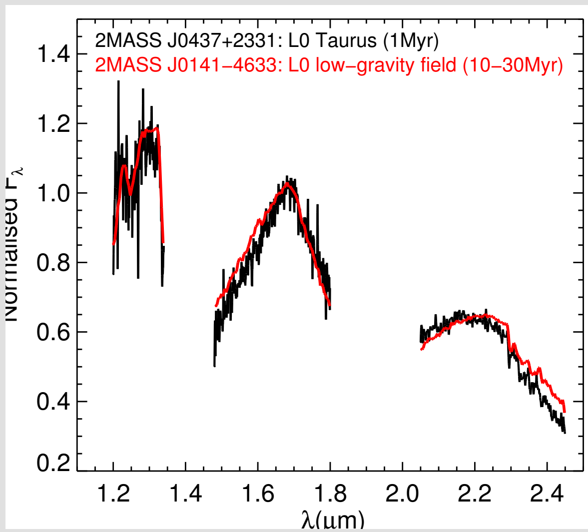


Spectral typing

Spectroscopy

Grid of L-SpT templates:

L0-L5 (10-30Myr): low-gravity field brown dwarfs (moving groups?, Cruz et al. 2009)
optical (publicly available) and near-IR (K. Luhman)



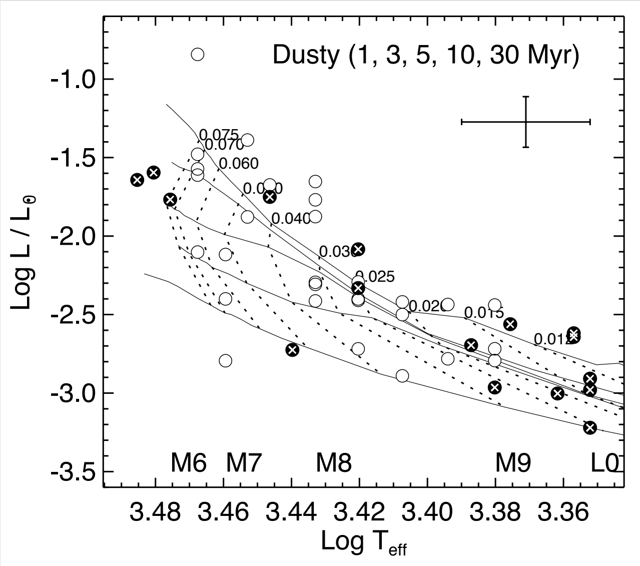
L0 Taurus: our GEMINI/GNIRS data

L0 low-g field: courtesy K. Luhman

Spectral typing

Spectroscopic follow-up of 24 candidates (84% within completeness limit and Av<4)

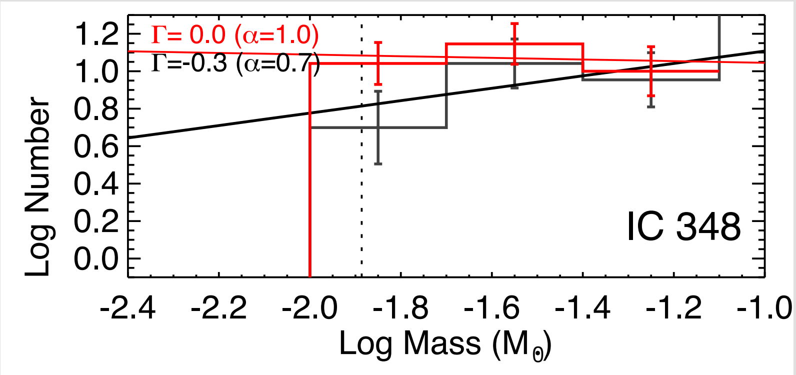
- Confirmed spectroscopically 16 new members, including **13 brown dwarfs**
- 5 new members with L0 spectral type (according to models ~ 13M_{Jup})
- Evidence for disks around two L0 brown dwarfs



IC 348

Spectroscopy

Alves de Oliveira et al. 2012b



Substellar mass function

IC348: 43 spectroscopic BDs (13 new)

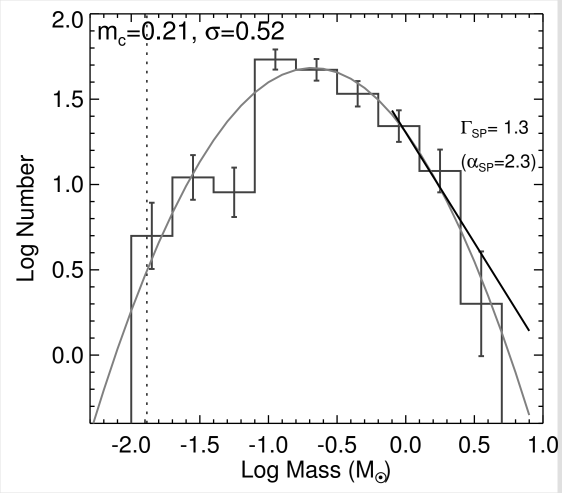
Av<4: 35 spectroscopic BDs (9 new)

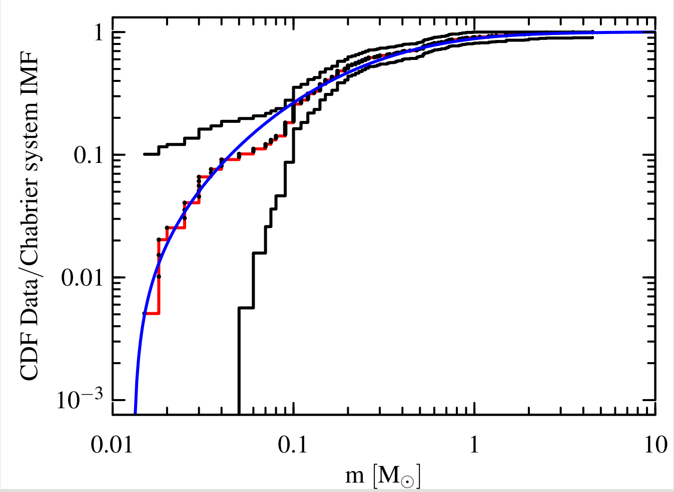
$\alpha = 1.0 \pm 0.3$

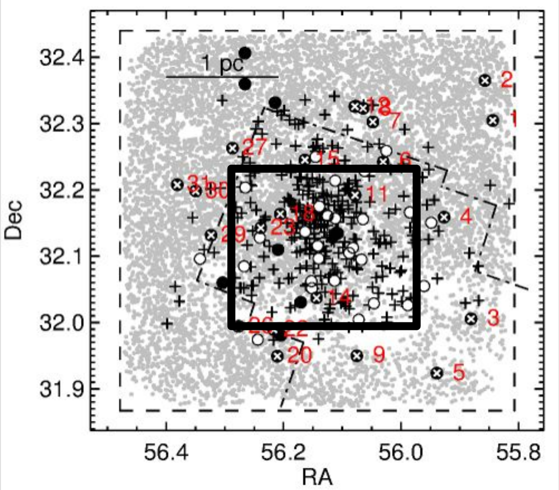
Av<4 + sub-field: 25 spectroscopic BDs (3 new)

$\alpha = 0.7 \pm 0.4$

No indication for IMF variations (Av<4 + sub-field: Luhman et al. 2003 + our work, 197 spec.)





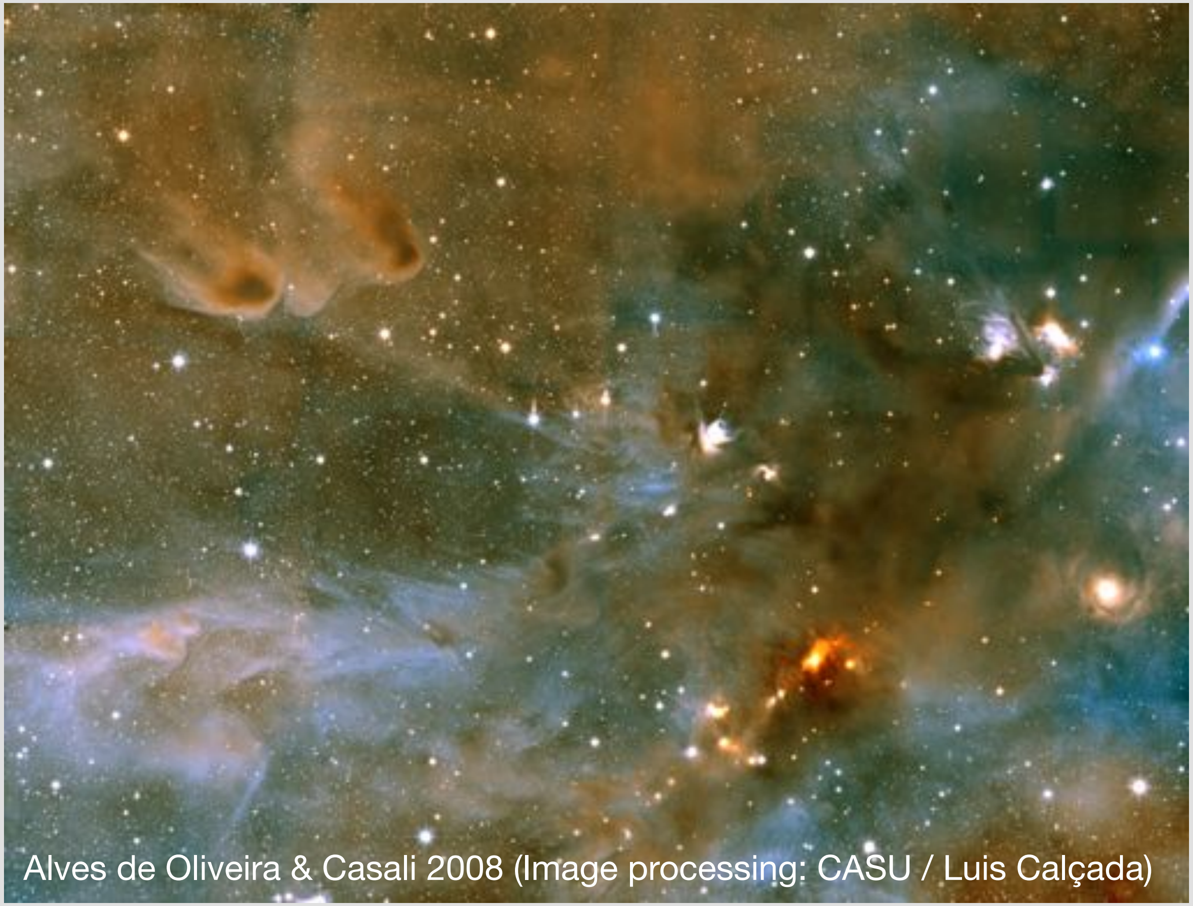


IC 348

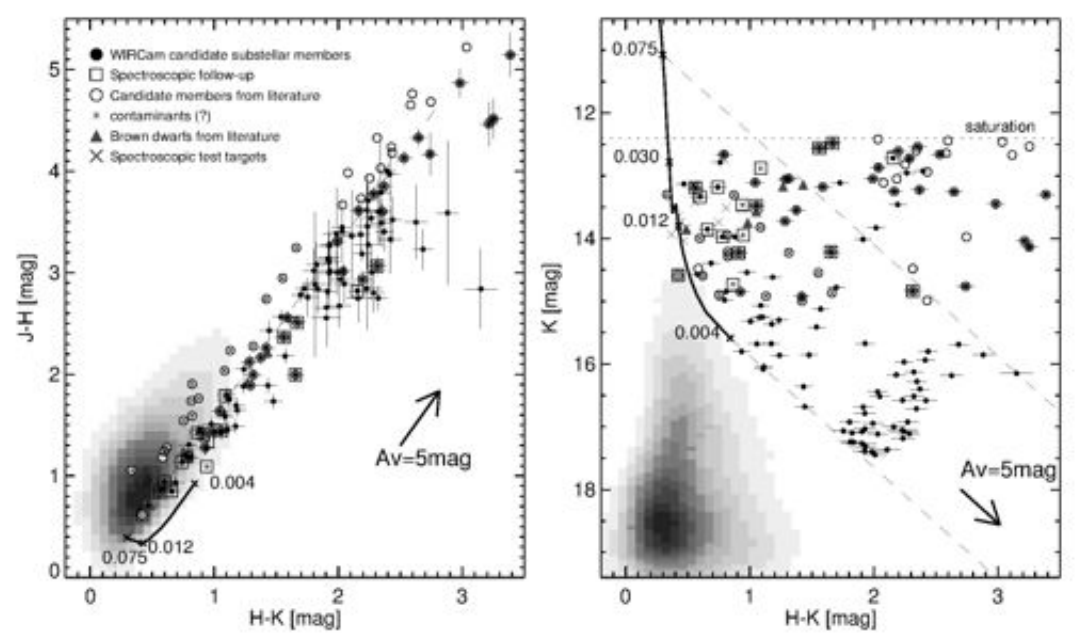
IMF

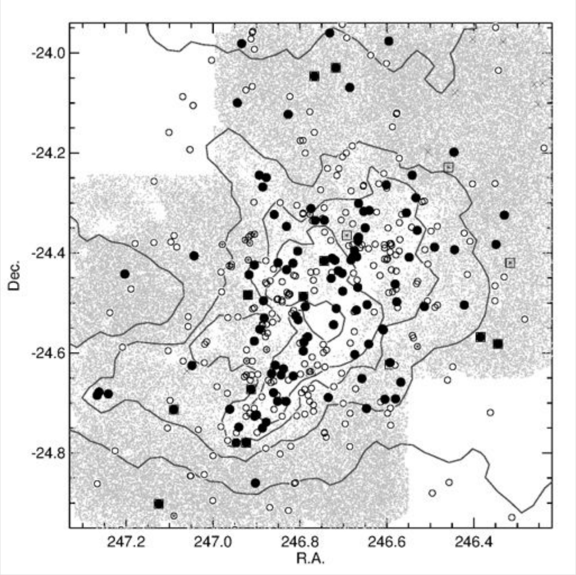
Rho Oph

1 Myr
120 pc
~300 members
(11 brown dwarfs)



CFHT-photometric survey:
110 substellar candidates





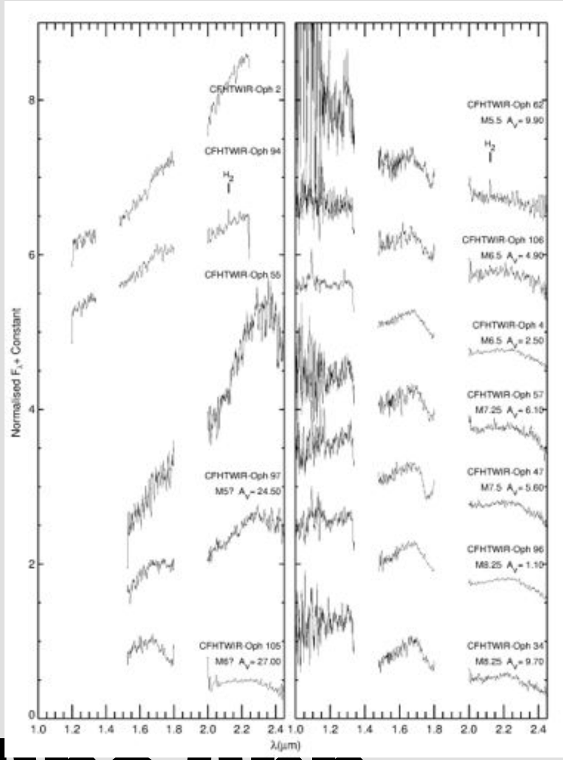
Rho Oph

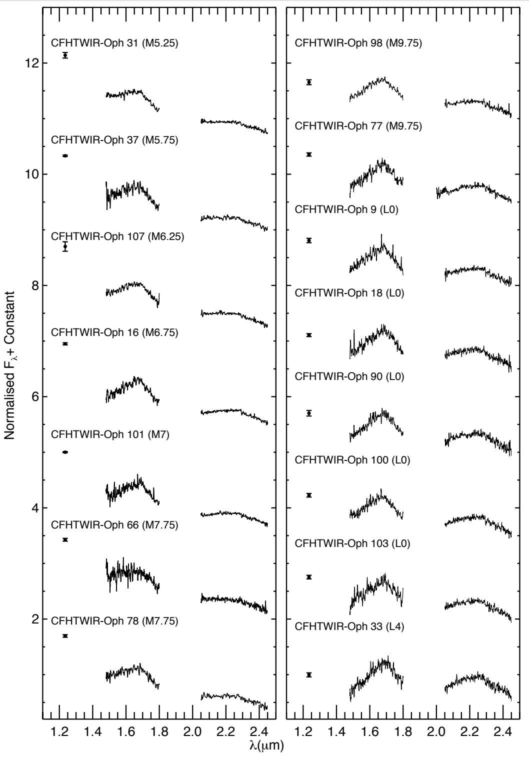
Photometry

Spectroscopic follow-up of 45 candidates (~93% within completeness limit and Av<20)

SofI/NTT
3.6 m, La Silla,Chile
6 nights
J ~15 mag

ISAAC/VLT
8 m, Paranal, Chile
3 nights
H ~ 17 mag





Rho Oph

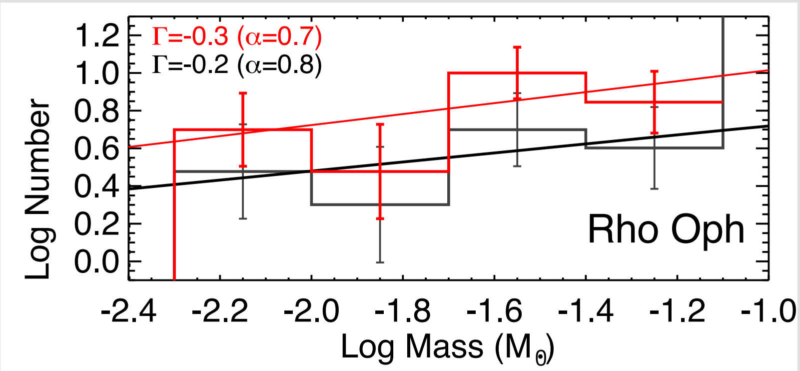
Spectroscopy

Spectroscopic follow-up of 45 candidates (~93% within completeness limit and Av<20)

- Confirmed spectroscopically 27 new members, including **20 brown dwarfs**
- 4 new L0 members and 1 L4 (according to models ~ 5-9M_{Jup})

Rho Oph

Alves de Oliveira et al. 2010 + Alves de Oliveira et al. 2012a (A&A)



Substellar mass function

Rho Oph: 43 spectroscopic BDs (20 new)

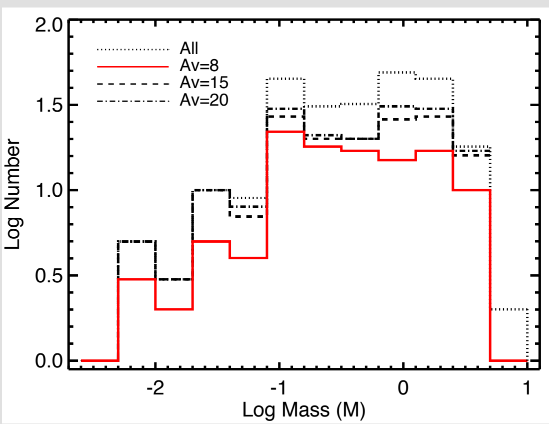
Av<15: 33 spectroscopic BDs (18 new)

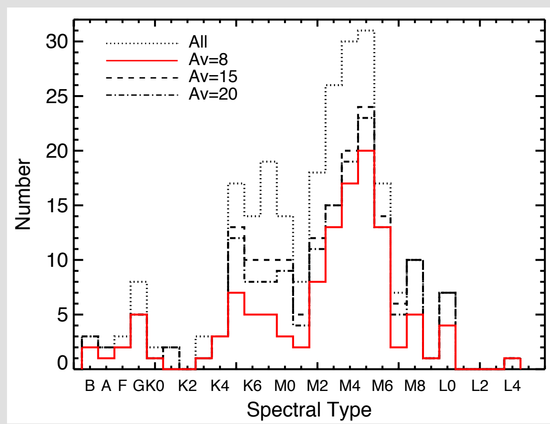
$\alpha = 0.7 \pm 0.3$

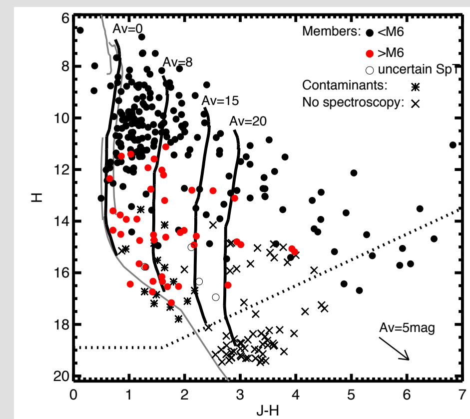
Av<8: 19 spectroscopic BDs (9 new)

$\alpha = 0.8 \pm 0.4$

Peak of IMF and ratio BD/stars are consistent with other clusters: **no IMF variation** (251 spec.)







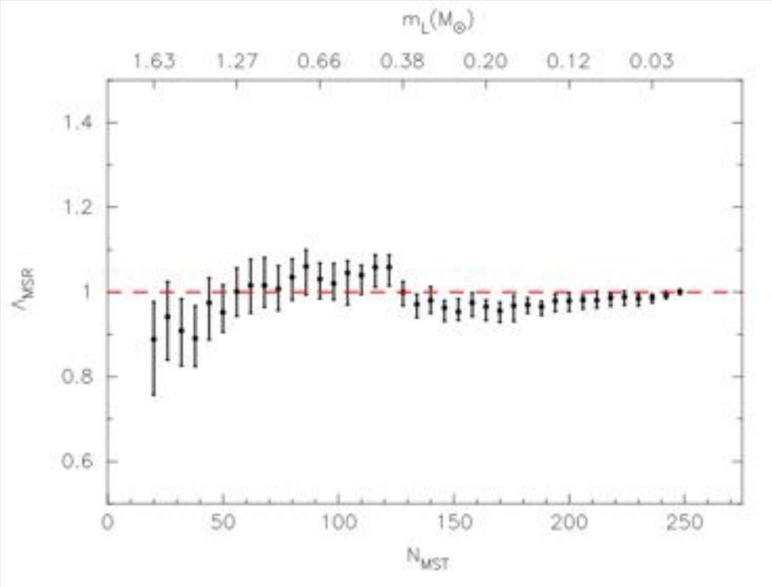
Rho Oph

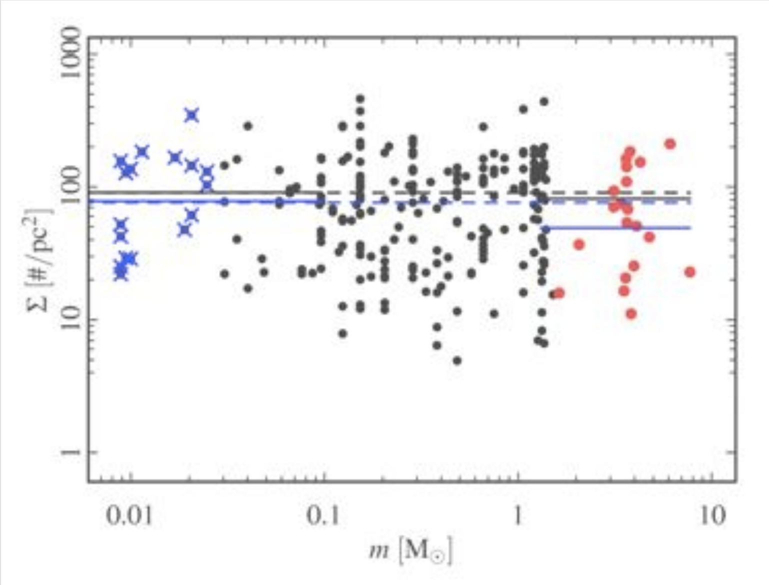
IMF

Parker, Maschberger & Alves de Oliveira 2012 (MNRAS)

No signature of mass segregation in Rho Oph:
- λ_{MSR} (based on minimum spanning tree, Allison et al. 2009a)
- m-Σ method (based on stellar surface density, Maschberger & Clarke 2011)

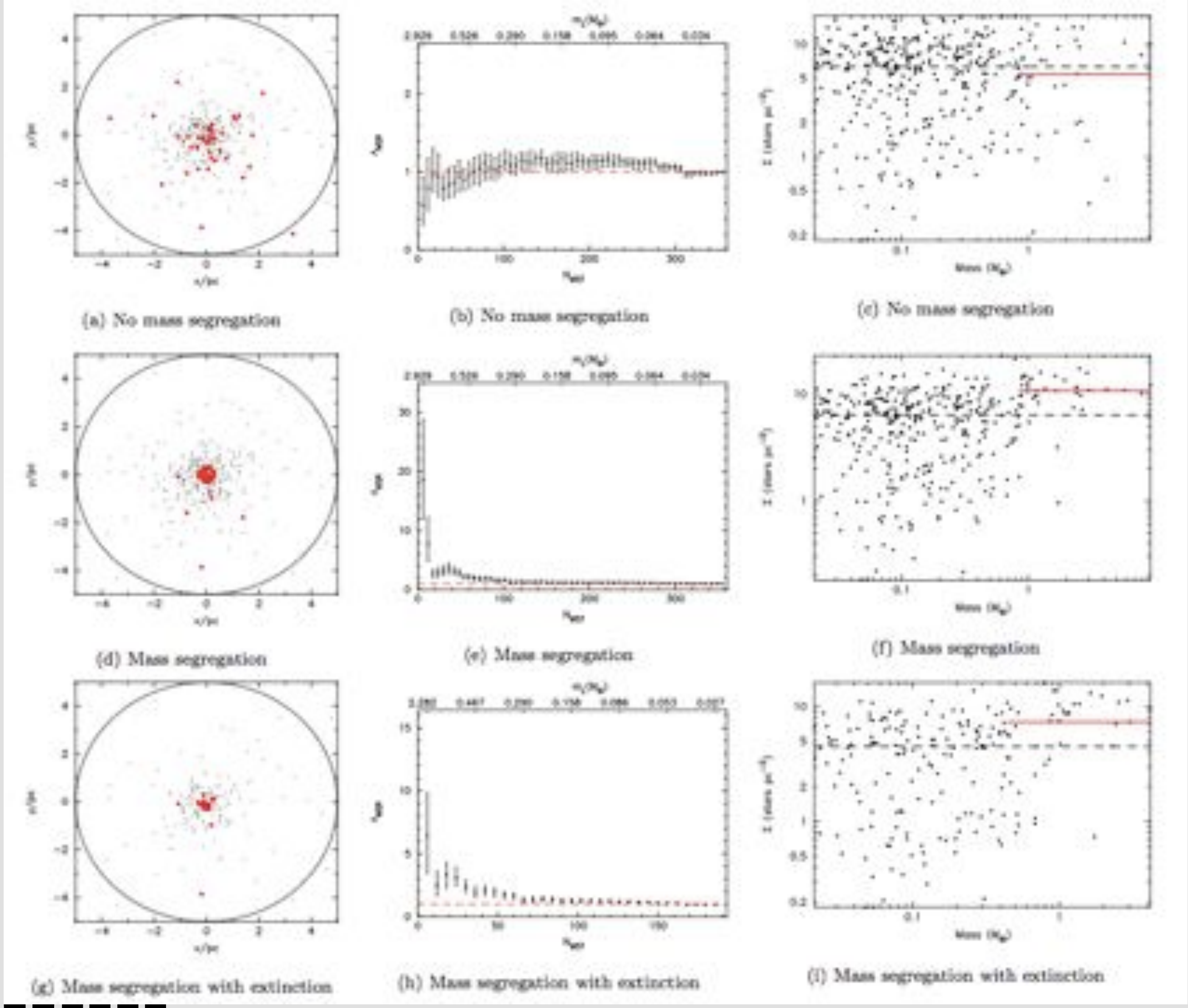
Indication that mass segregation is not primordial (but dynamical)





Rho Oph

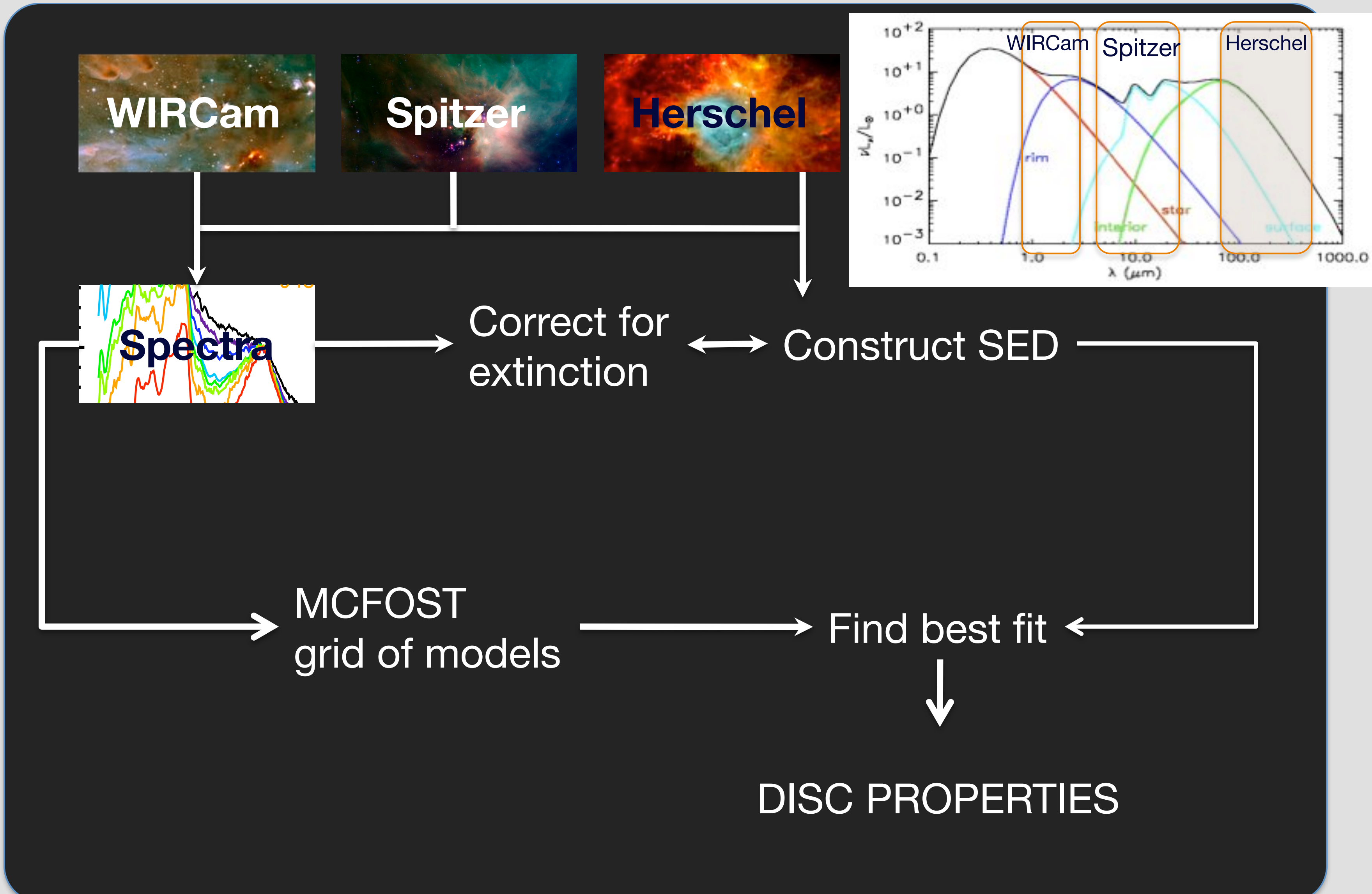
Parker, Maschberger & Alves de Oliveira 2012 (MNRAS)



Rho Oph

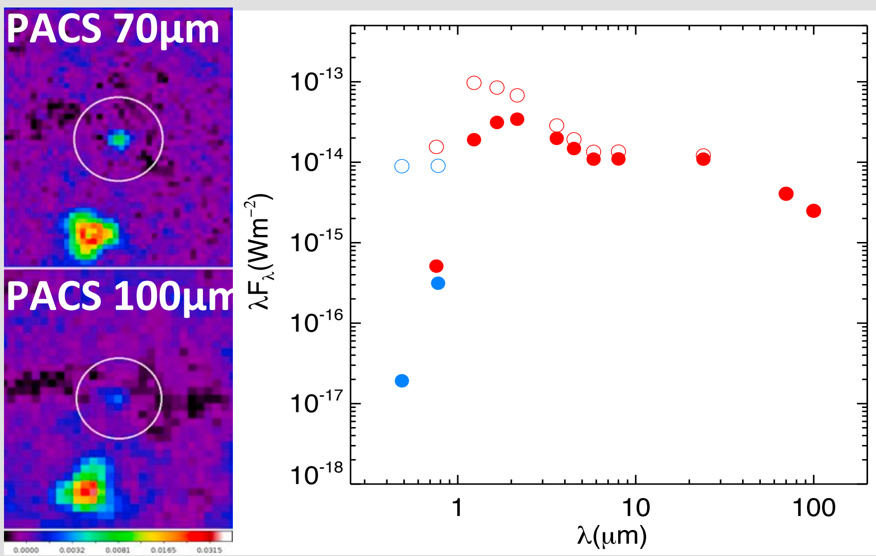
Mass segregation

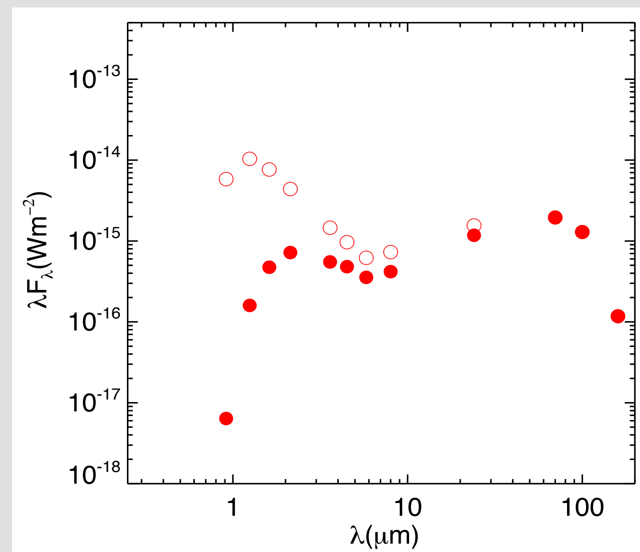
Alves de Oliveira et al., *in prep:* ***Herschel*** **survey of brown dwarf disks in Rho Oph**



Alves de Oliveira et al., *in prep:* ***Herschel* survey of brown dwarf disks in Rho Oph**

- Detect 12 brown dwarf disks (M6 < SpT < M8.5) at 70μm and 100μm (5 at 160μm)



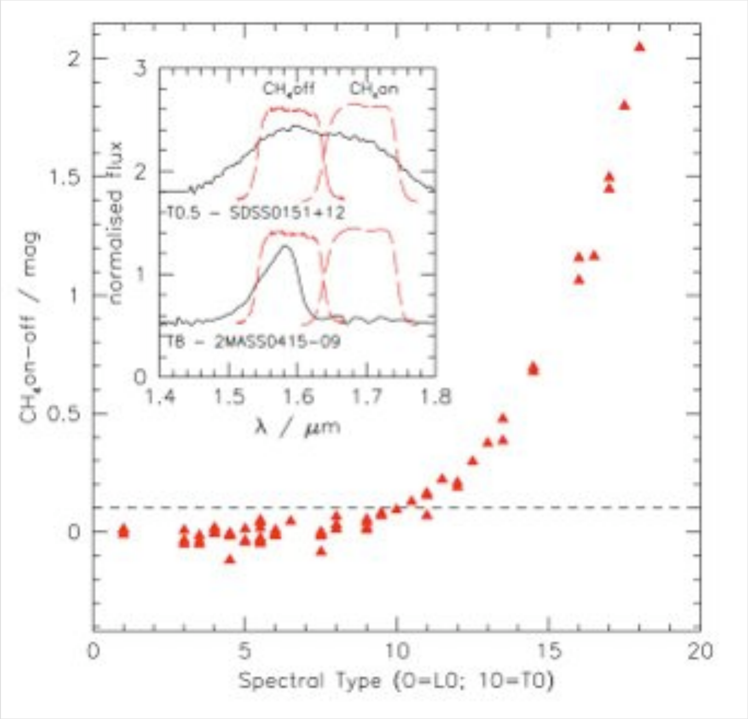


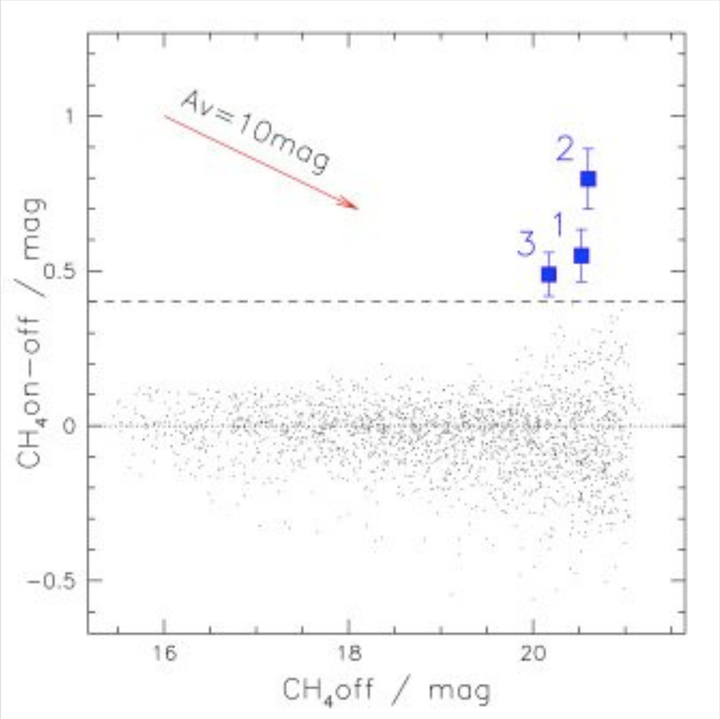
Rho Oph

Disks with *Herschel*

CFHT survey for young T dwarfs:

Serpens: 2 photometric candidates (Spezzi, Alves de Oliveira et al. 2012, A&A)
IC 348: 1 photometric candidate (Burgess et al. 2009, A&A)



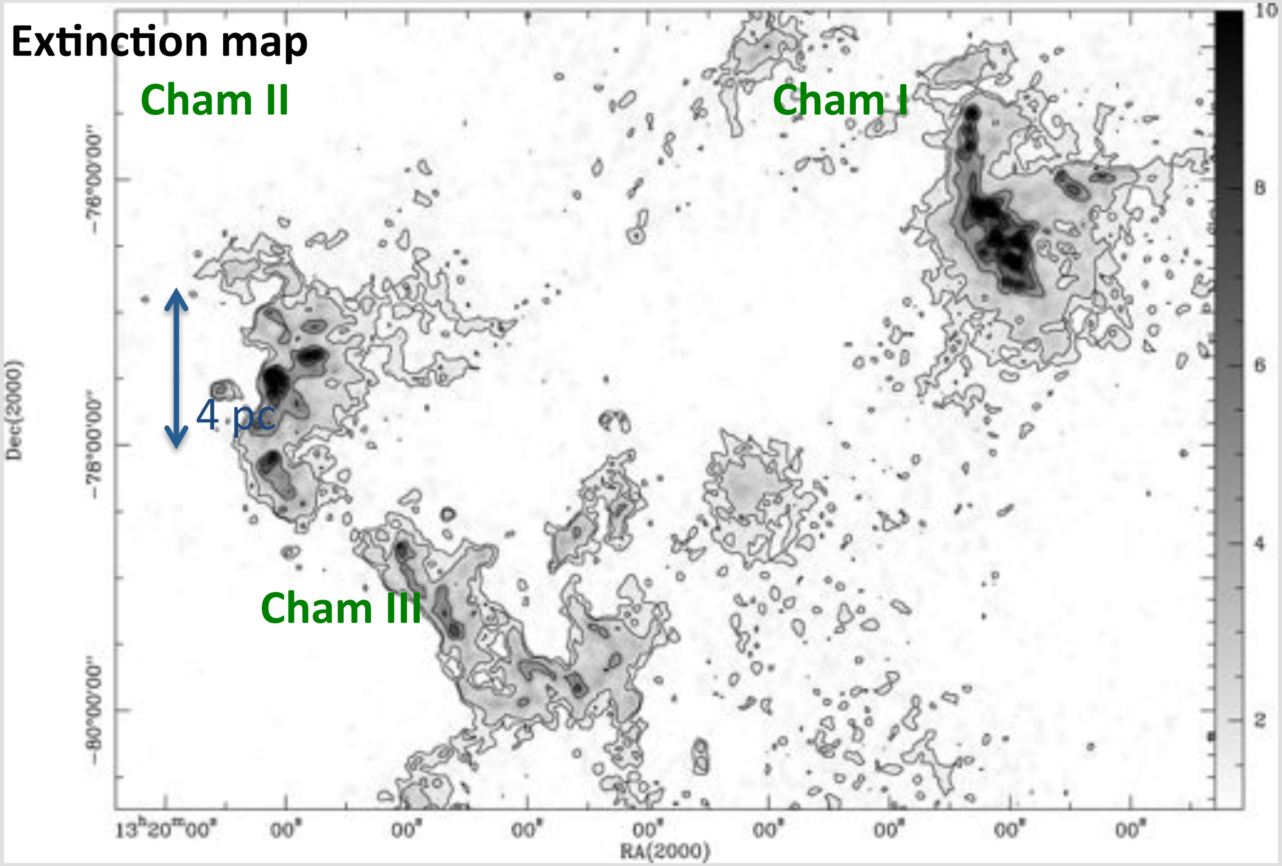


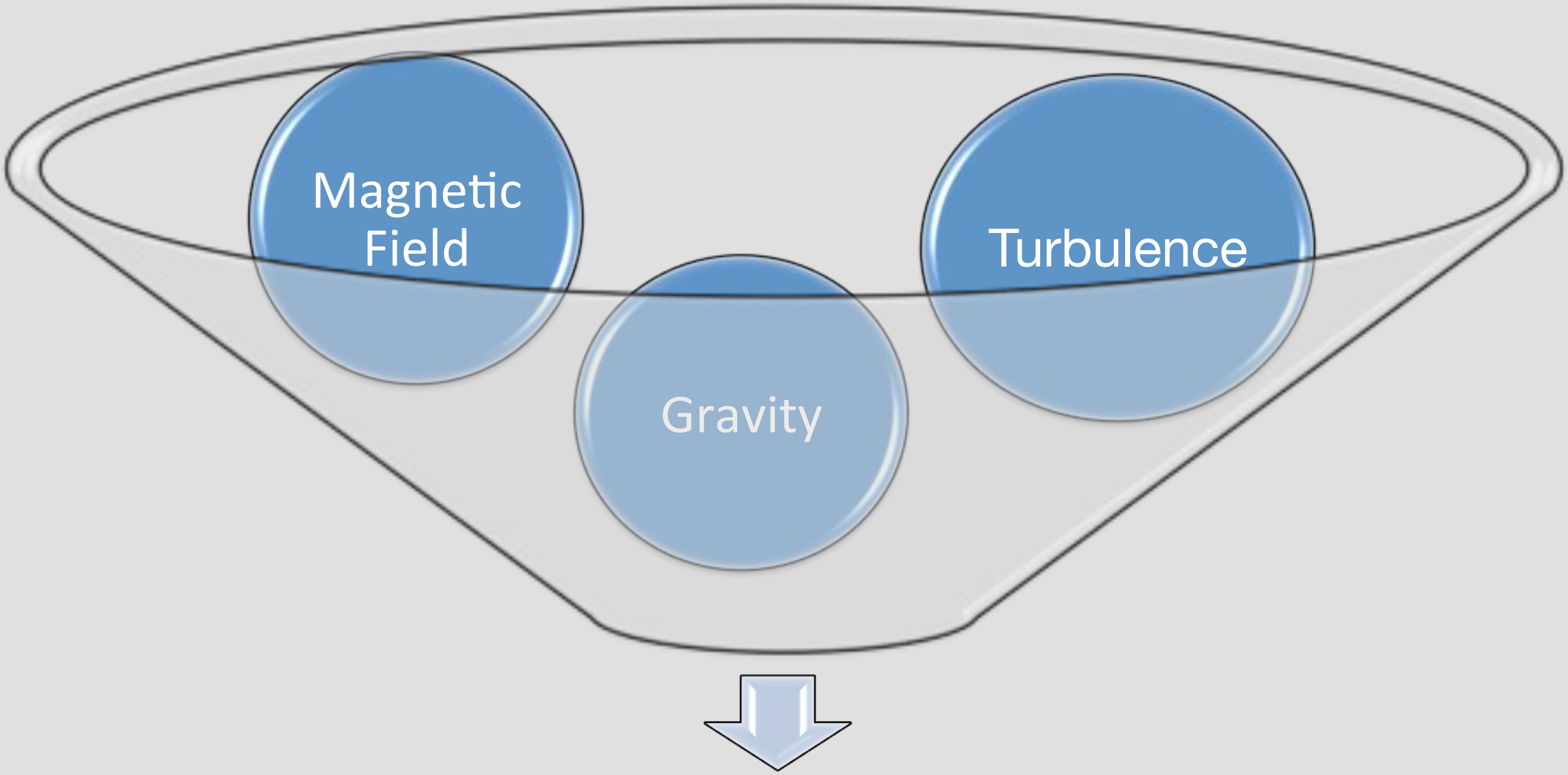
Young T dwarfs

IC348 and Serpens

Chamaeleon

2 Myr
160-180 pc
Cha I: ~300 members
Cha II: ~60 members
Cha III: no YSOs

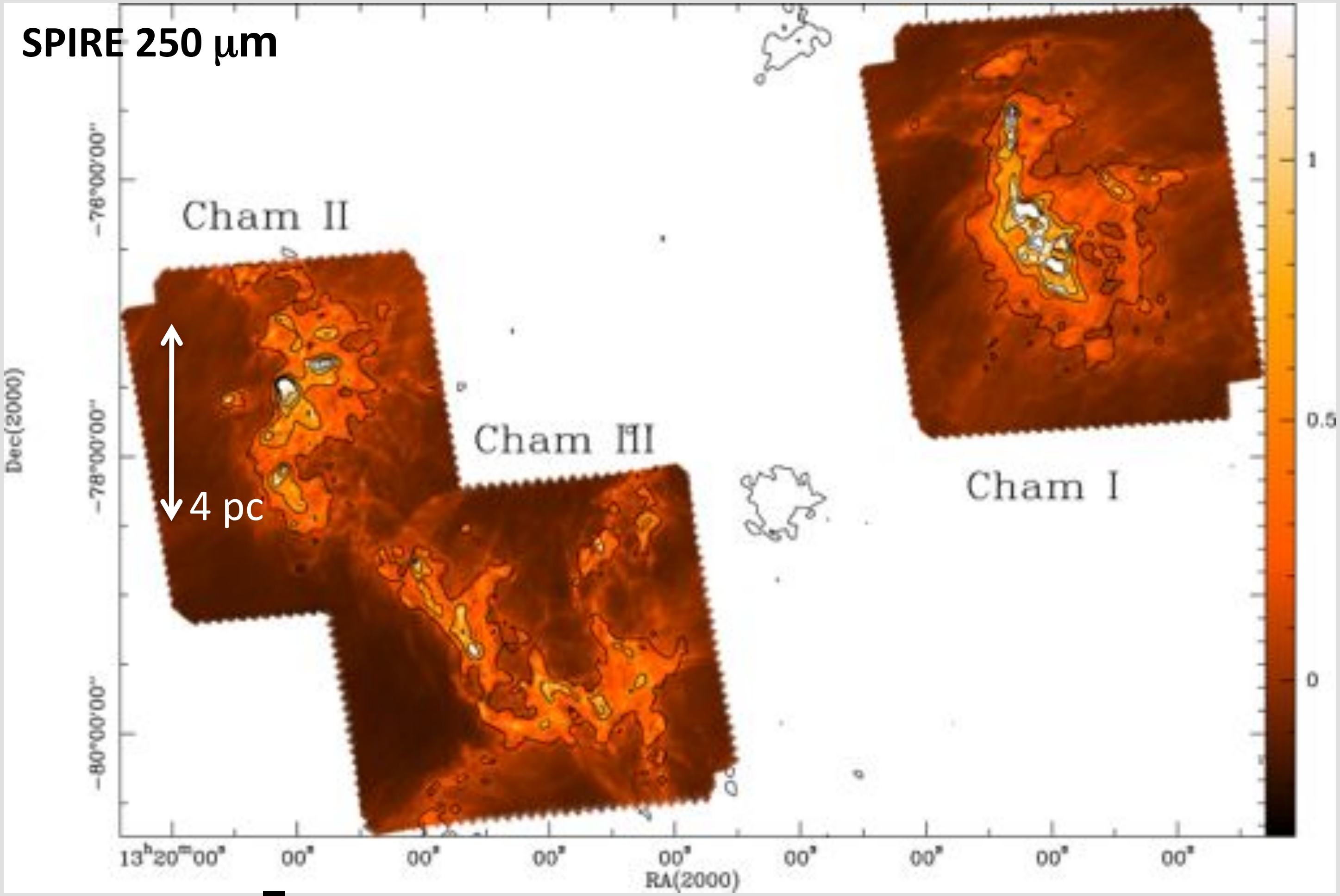




What determines if a star will form?

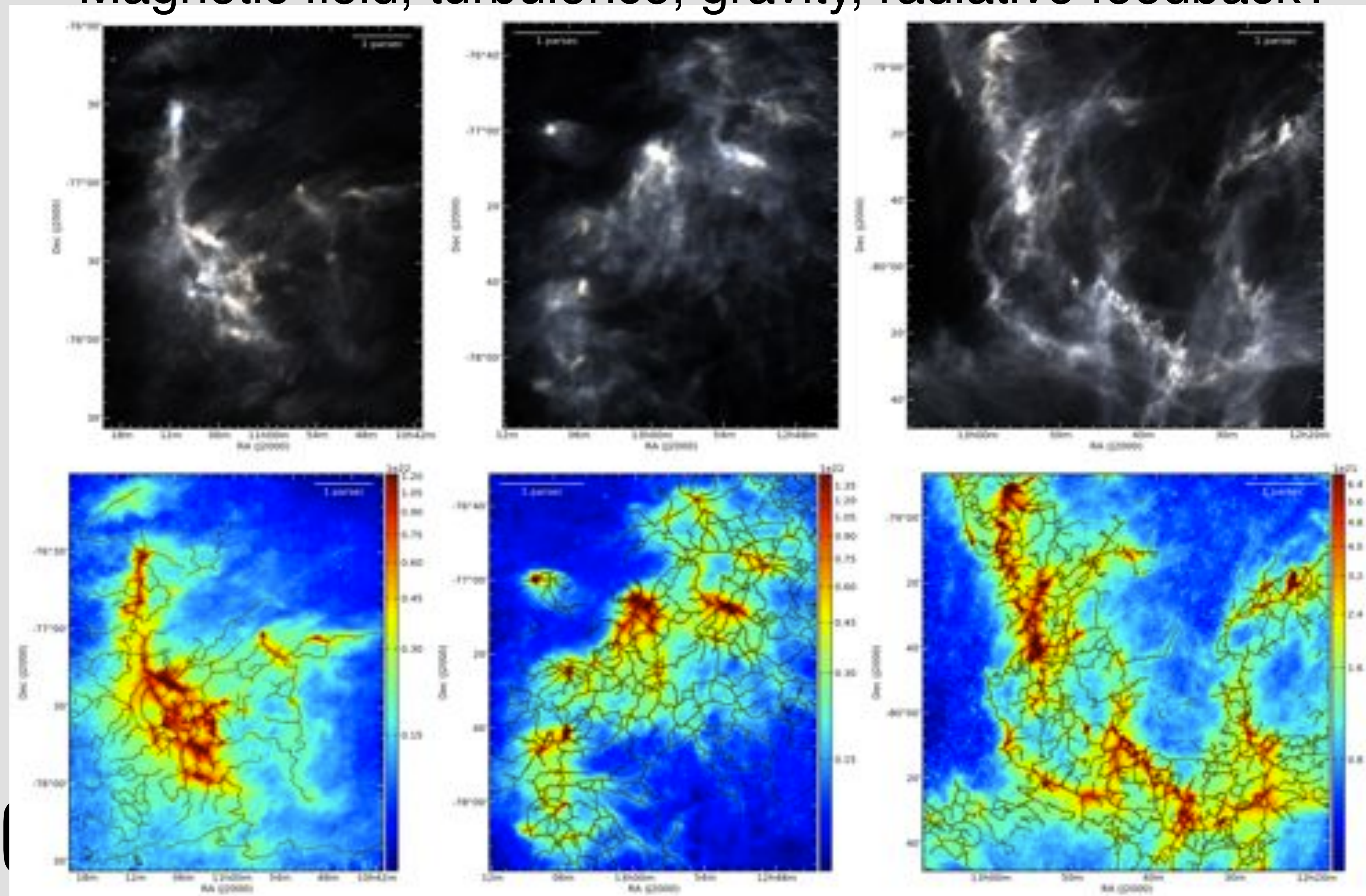
Chamaeleon

Herschel's view of the large-scale structure in the Chamaeleon dark clouds

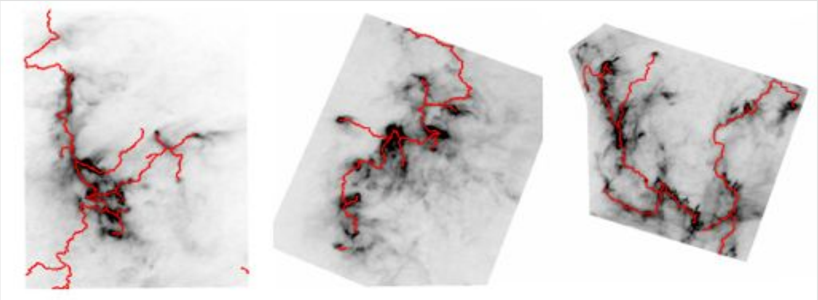


Chamaeleon

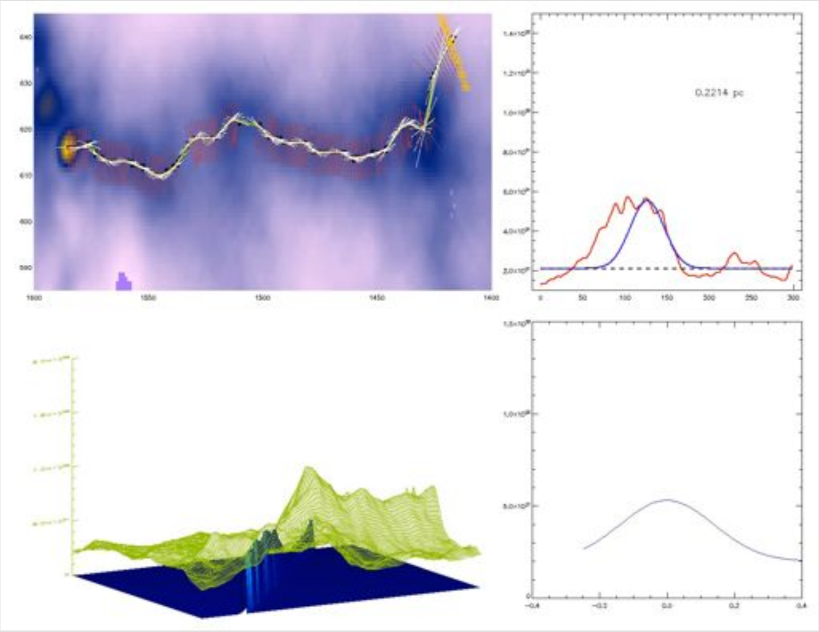
Which are the main players in Cha I, II, and III: Magnetic field, turbulence, gravity, radiative feedback?



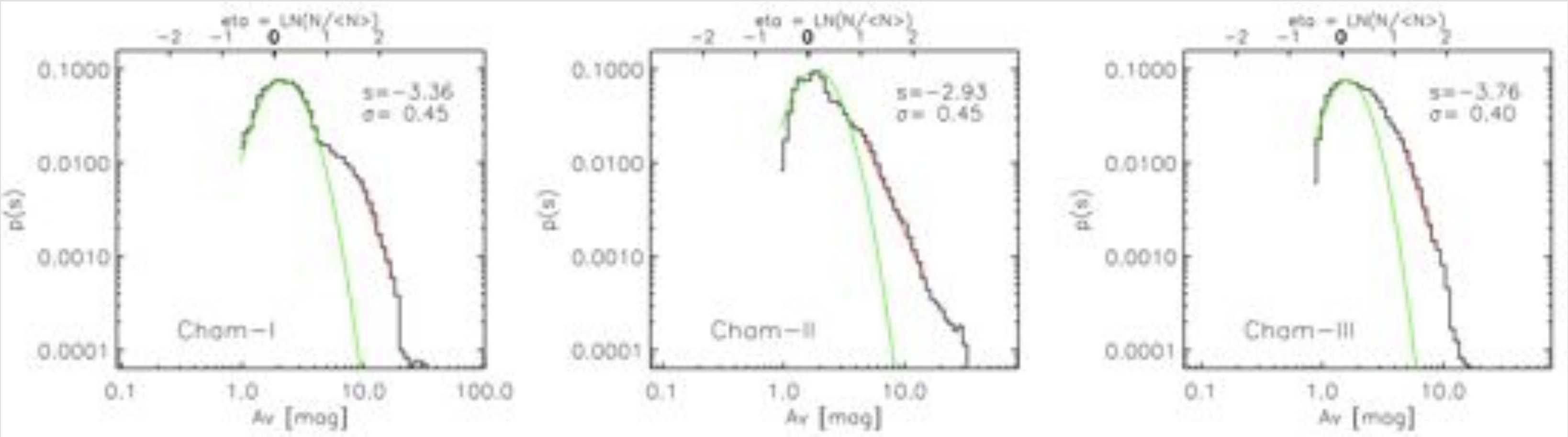
DisPerSe (Sousbie 2011) to trace structure

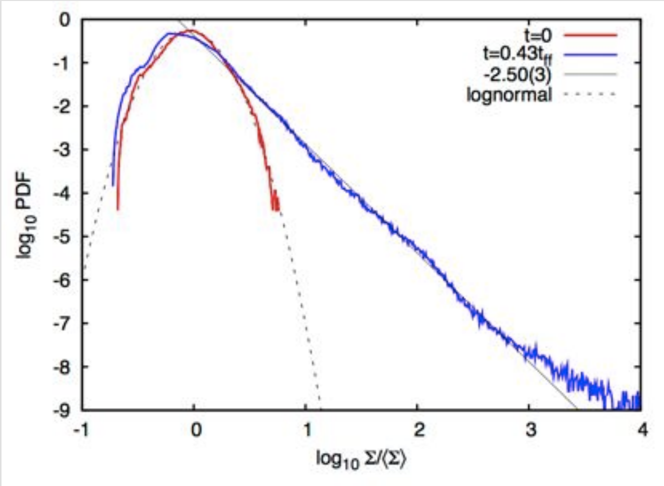


Tool to characterize filaments



Chamaeleon

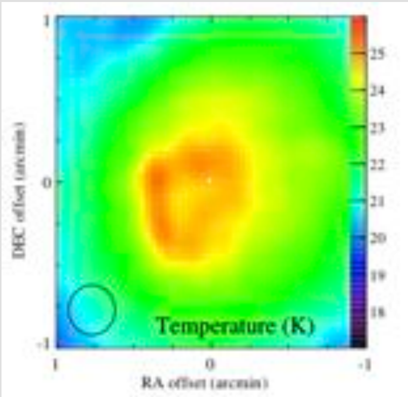




Column density PDF within the simulation by Kritsuk et al. (2011). At t = 0 the distribution is log-normal. At later times, a high density power-law tail develops.

From Hennebelle & Falgarone 2012

Chamaeleon



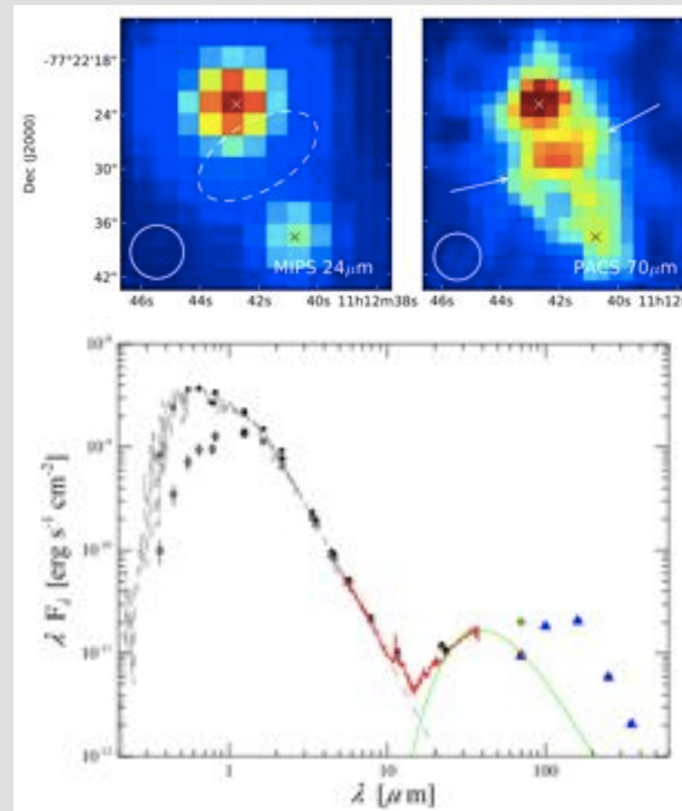
Interstellar matter with *Herschel*

Bubble blown into the surrounding interstellar mater and heated by the star HD97300

Kóspál et al (incl. Alves de Oliveira) 2012, A&A

A new *Herschel* view of the young star T54: not a transitional disk?

Matrà et al (incl. Alves de Oliveira) 2012, *A&A*



Herschel **survey of discs in Chamaeleon**

Winston et al (incl. Alves de Oliveira) 2012, A&A

Spezzi et al (incl. Alves de Oliveira) 2012, *in prep.*

Ribas et al (incl. Alves de Oliveira) 2012, *in prep.*

Chamaeleon

- CFHT photometric survey of IC348 and Rho Oph uncovered several candidate brown dwarfs, and spectroscopic follow-up confirmed 13 new brown dwarfs in IC 348, and 20 in Rho Oph

- Discovery of first L0 dwarfs in IC 348 (~13M_{Jup}) and Rho Oph (4 L0, 1 L4, 4-9M_{Jup})

- No evidence for variation of the mass function in both clusters (down to ~13M_{Jup} in IC348, and ~4M_{Jup} in Rho Oph)

- New census represents fundamental step for further studying properties of young brown dwarfs, e.g. in Rho Oph:
  - no indication for mass segregation
  - on-going *Herschel* survey detects brown dwarf disks down to 160μm

- On-going work: understand star-formation history of the Chamaeleon complex

Conclusions

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Elena Puga, ESA
Göran Pilbratt, ESA
Alvaro Ribas, CAB

Nicola Schneider, LAB
Philippe André, CEA
Vera Könyves, CEA
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