Brown dwarf formation across environments

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centra

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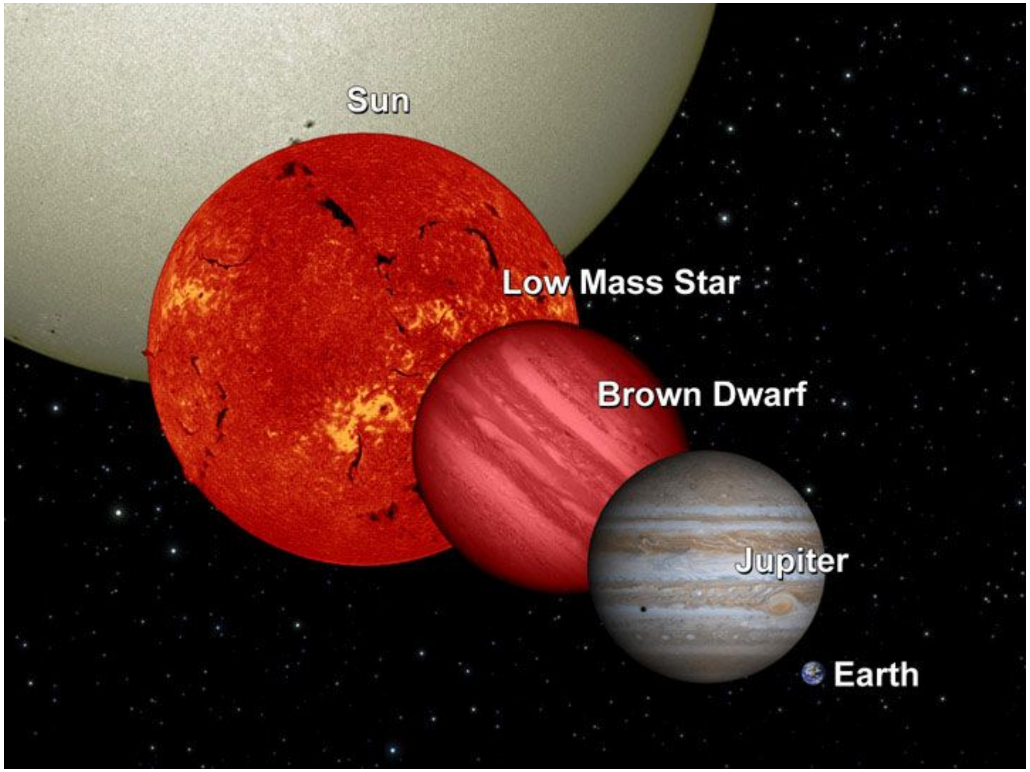
Brown dwarfs

Objects below Hydrogen-burning limit (mass < 0.075 $M_\odot$)

They cool down as they age

Possible formation channels:

- Turbulent fragmentation
- Disk fragmentation
- Ejection from multiple systems
- Photoevaporation



Brown dwarfs

Young BDs share many properties with low-mass stars
(disks, outflows, multiplicity properties...)

Most brown dwarfs probably form like stars*

*at least down to 5-10 Jupiter masses

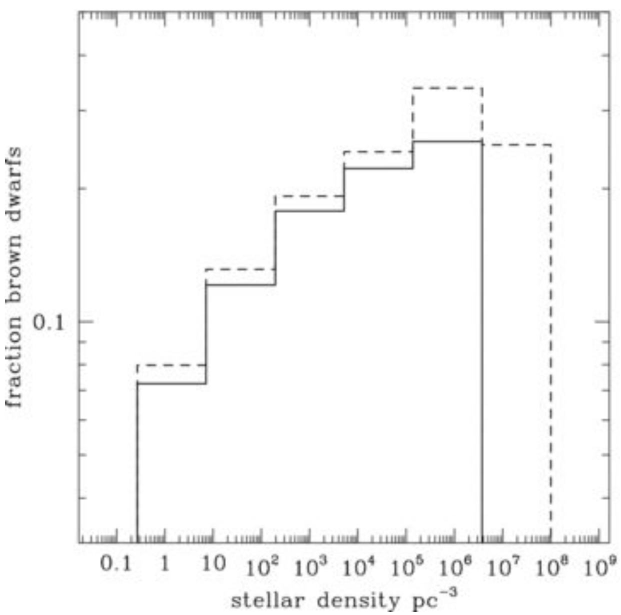
Multiple unsolved questions:

How far in mass does the stellar IMF extend?
Do the lowest-mass objects form “like stars” or “like planets”?
Is BD formation environment dependent?

Does the brown dwarf formation efficiency depend on star forming environment?

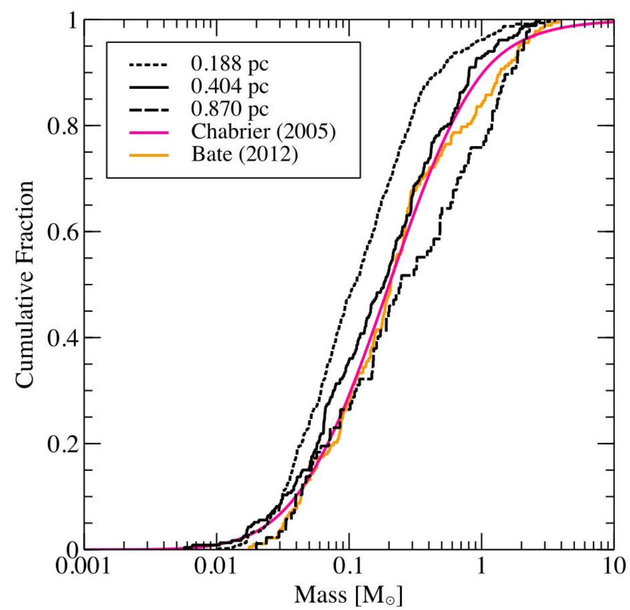
Brown dwarf formation theories: Yes, it should matter

Stellar Density



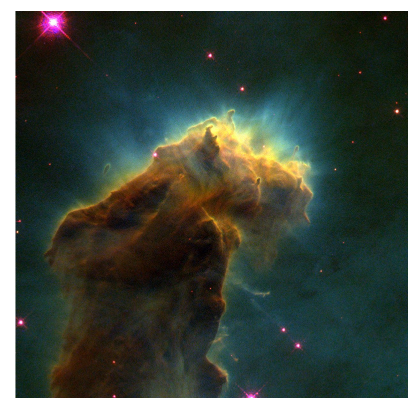
Bonnell et al. (2008)

Gas Density



Jones & Bate (2018)

Massive stars



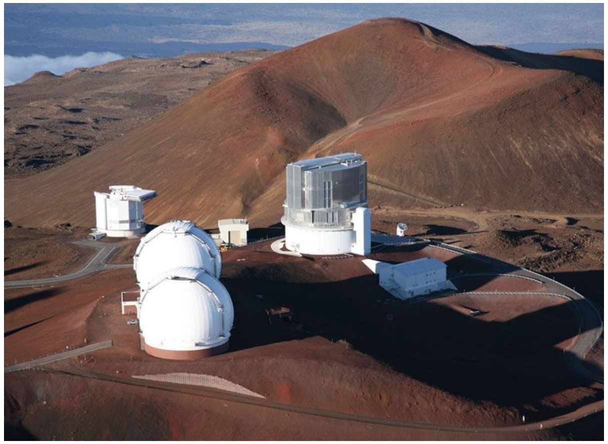
SONYC - Substellar Objects in Nearby Young Clusters

browndwarfs.org/sonyc

Goal: find all the young brown dwarfs in diverse regions and examine their properties

Strategy: deep optical and NIR photometry + spectroscopic follow-up

How deep can we go? 5-10 Jupiter masses (nearest SFRs, extinction dependent)

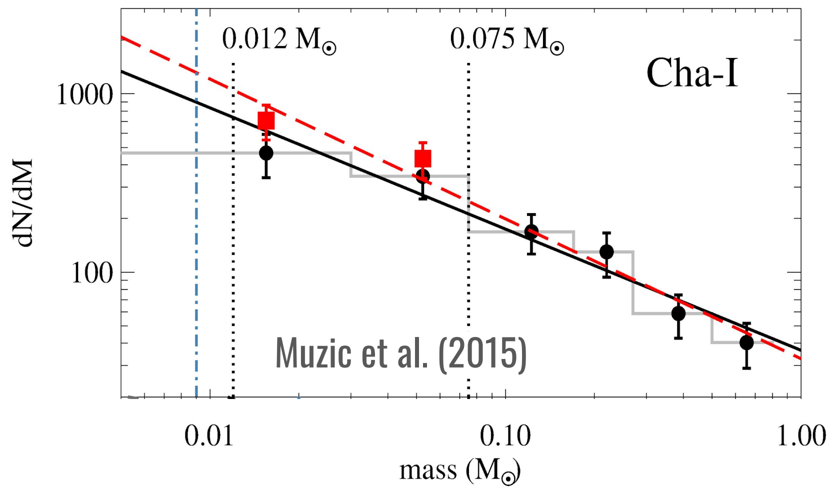


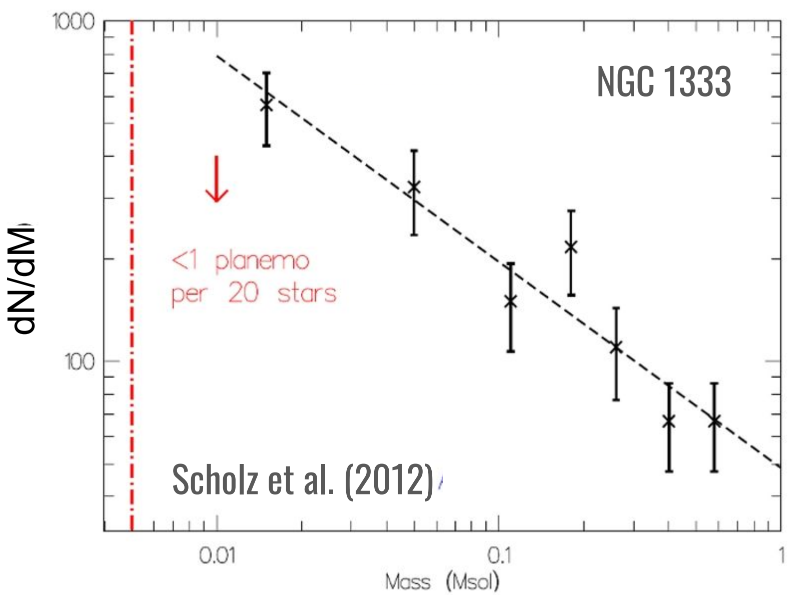
5 regions (<5 Myr)

> 700 spectra

~ 100 confirmed brown dwarfs and very-low mass stars

SONYC - Substellar Objects in Nearby Young Clusters





Power-law IMF $dN/dM \propto M^{-\alpha}$

α = 0.6 - 1

N(*)/N(BD) = 2 - 5

Other similar works

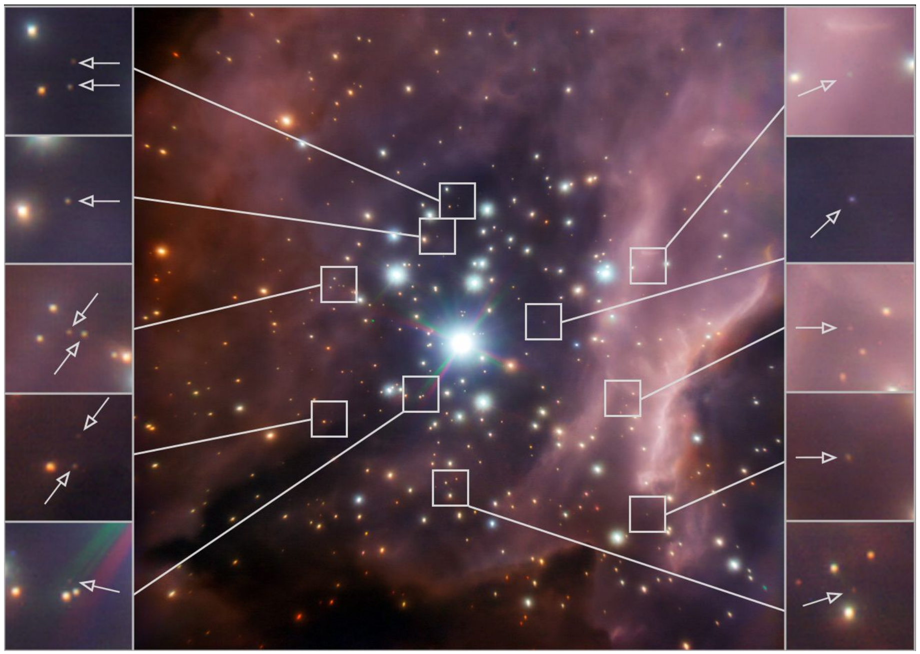
	α	Mass range	Reference
σ Ori	0.6 ± 0.2	0.006 - 0.35	Peña Ramírez+2012
Collinder 69	0.2 - 0.4	0.01 - 0.65	Bayo+2011
Upper Sco	0.45 ± 0.11	0.009 - 0.2	Lodieu+2013
IC 348	0.7 ± 0.4	0.012 - 0.075	Alves de Oliveira+2013
ρ Oph	0.7 ± 0.3	0.004 - 0.075	Alves de Oliveira+2013

New massive cluster program

RCW 38

1-2 Myr

NGC 2244



Densest stellar system within 4 kpc

> 10 x denser than NGC 1333

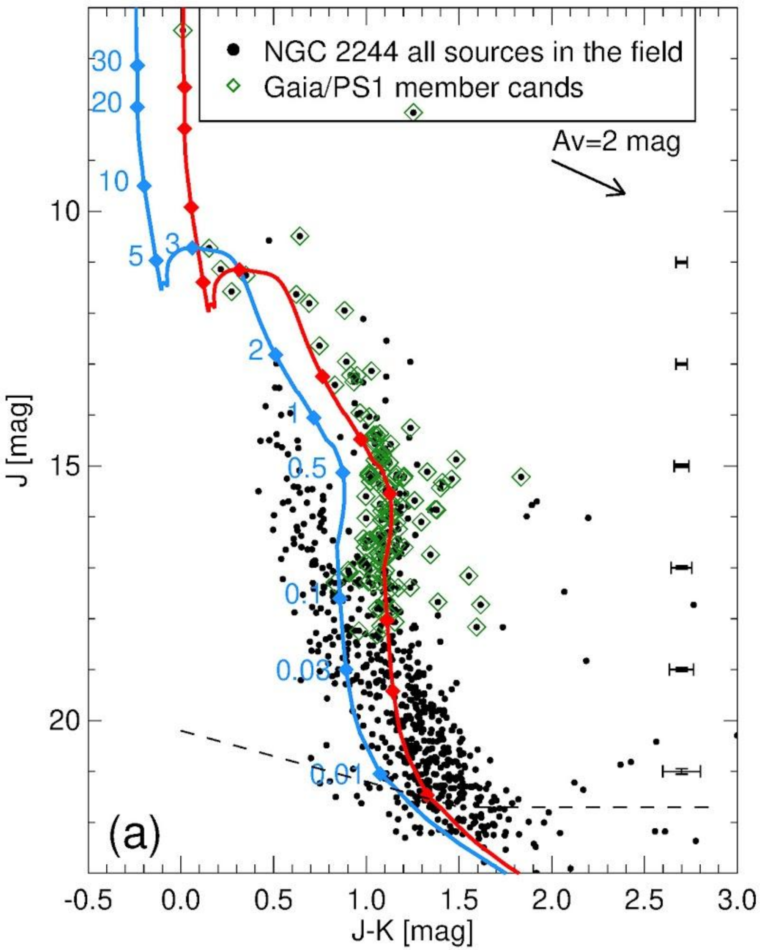
~100 x denser than Cha-I

Rich in massive stars

Density similar to Cha-I

Rich in massive stars

NGC 2244



FLAMINGOS/Gemini-S JHK imaging

Complete down to ~0.02 $M_\odot$

Stellar part well characterized by Gaia DR2

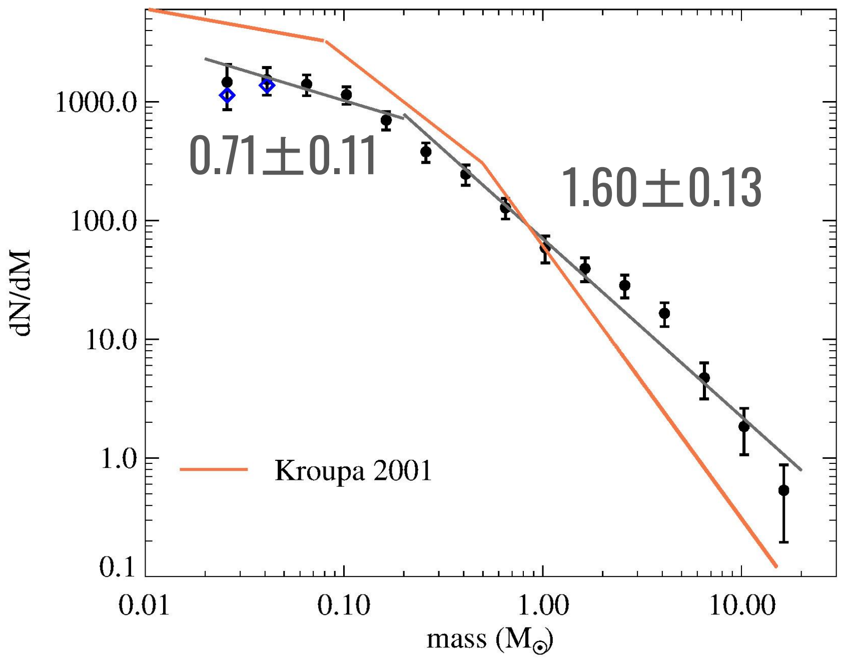
Below ~0.1 $M_\odot$ statistical determination of membership (comparison to a control field)

Spectroscopic follow-up in progress - see poster by Víctor Almendros-Abad

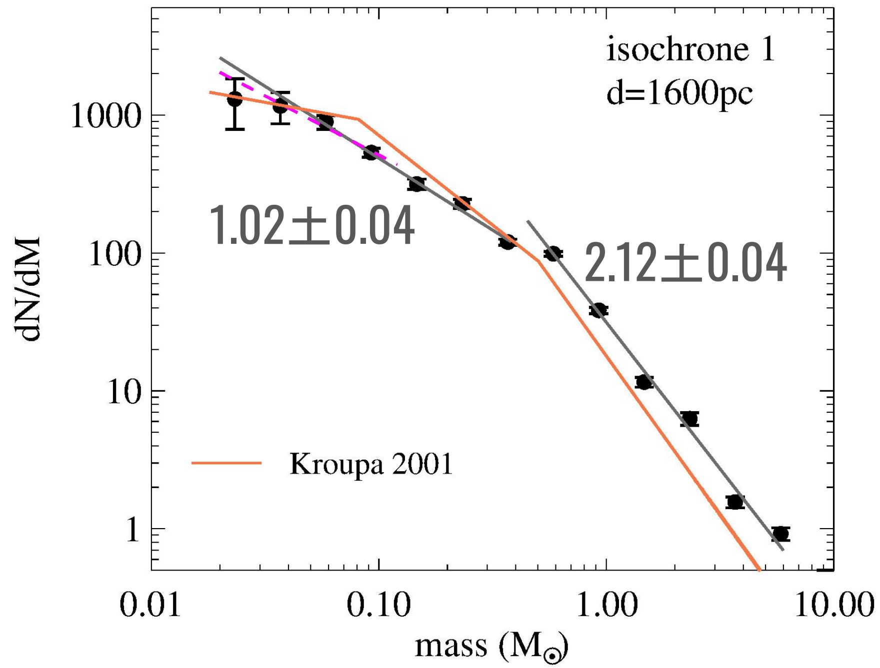
Muzic et al. (2019, subm.)

Initial Mass Function

RCW 38



NGC 2244

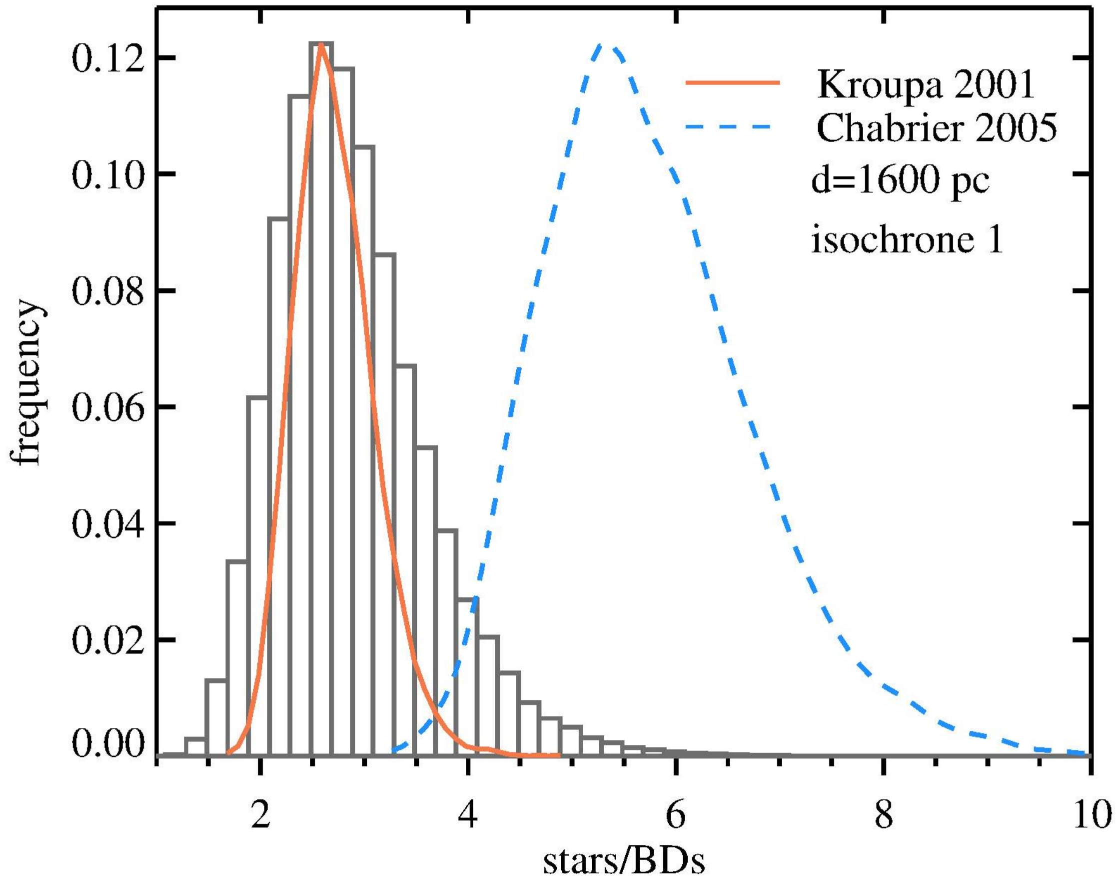


Muzic et al. (2017, 2019 subm.)

Star-to-BD number ratio

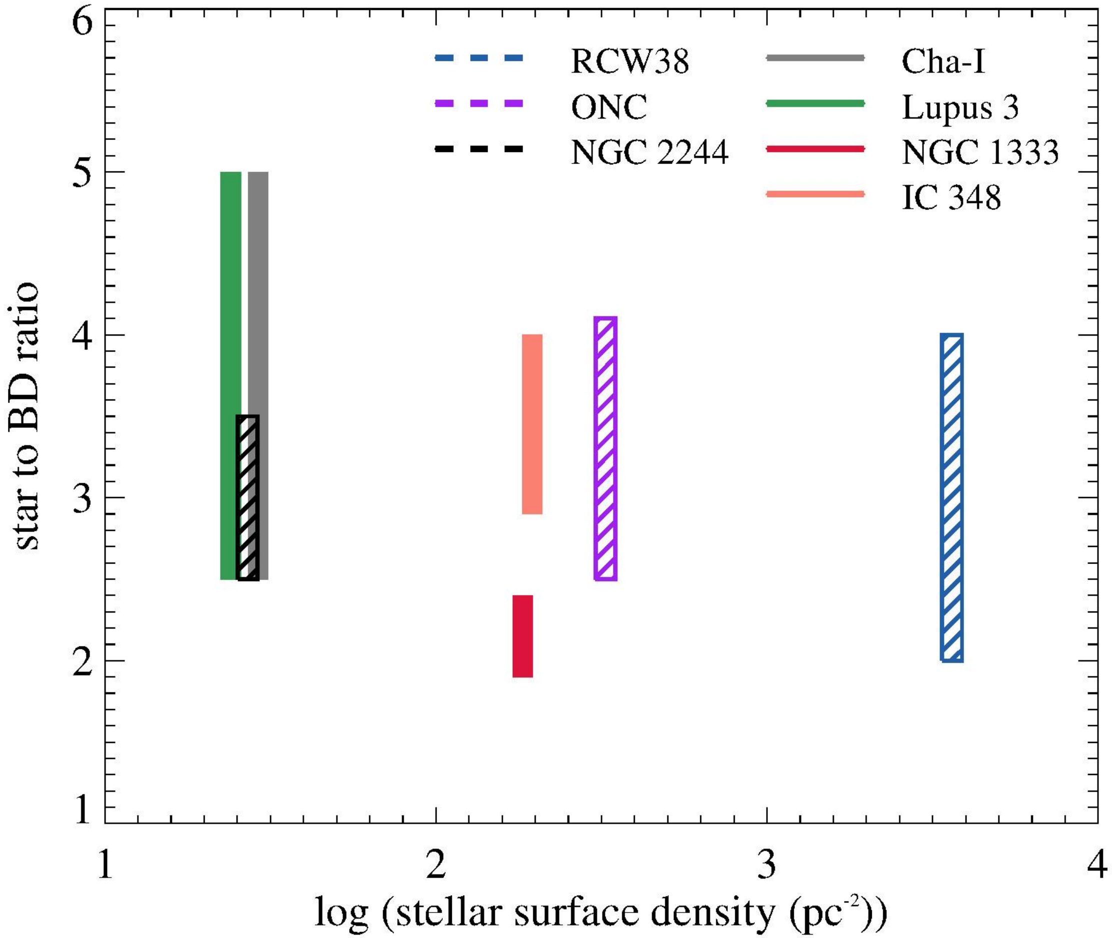
$$\frac{N(0.075 - 1\,M_{\odot})}{N(0.03 - 0.075\,M_{\odot})}$$

NGC 2244



Muzic et al. (2019 subm.)

Star-to-BD ratio versus stellar surface density



NGC 1333, IC348, Lupus 3, Cha-I: SONYC series

ONC: Andersen et al (2008)

Muzic et al. (2019, subm.)

Star-to-BD number ratio

N(*)/N(BD) = 2 - 5

The span does NOT reflect differences between the region, rather the uncertainties!

Sources of uncertainties:

- Ages, distances, isochrones, extinction law (see Scholz et al. 2013)
- Spectroscopic follow-up
  - SONYC: completeness
  - massive clusters: lack of
- Treatment of incompleteness (RCW 38)
- Unresolved binaries
  - our simulation show that the system IMF α is flatter than the resolved one, but within uncertainties for RCW 38 (Muzic et al. 2017)

Conclusions

For every 10 star, star forming regions produce 2 - 5 brown dwarfs

Brown dwarf formation in the Milky Way seems to be universal

There is no clear evidence for variations in the formation efficiency of BDs and VLM stars due to the lack or presence of OB stars, or a change in stellar densities

If environment has an influence on BD formation, this must be on a much more subtle level than the observational uncertainties currently permit us to measure