Simulating Scatter in Populations of Accreting Substellar Objects

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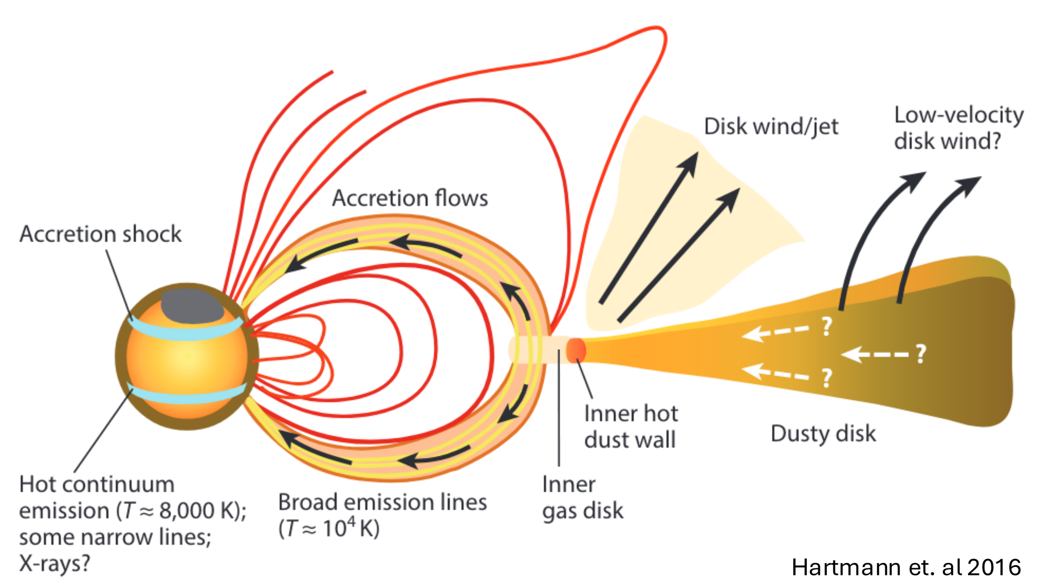
Motivation

Observing accreting substellar objects allows us to better understand formation physics which, in turn, allows us to answer questions like: Did these substellar objects form via core collapse or disk fragmentation?

This work begins with the idea that mass and mass accretion rate are related by a power law. In theory a distribution of solar masses should follow this relation but there is are uncertainties introduced into any set of observations. Whether that be observational uncertainty like distance, spectral type, and age or intrinsic dispersion like age scatter and variability. We anticipate that different mass regimes do not follow the same prescription for accretion physics, but this is discussed in future work.

This tool was created by Amherst College thesis student Joseph Palmo (2021) and improved upon by thesis student Khalid Mohamed (2022). It was constructed to help understand uncertainty scatter in accreting substellar populations. Doing this allows us to better understand previous observations and improve future observing proposals. This is all in an effort to put tighter constraints on planet and star formation physics.

What BD Accretion Tells Us



Hartmann et. al 2016

- Accretion: Mass flows from debris disks around brown dwarf onto object
- Accretion rate can be a formation tracer
    - Different rates of accretion at low masses can indicate different formation mechanisms
- Hard to differentiate groups of objects in the mass - mass accretion rate regime
    - Uncertainty
- Our tool intends to mitigate this issue

References –

J. Palmo. "Simulated Scatter: Computational Modeling of (Sub)Stellar Accretion Rates." (2021)

K. Mohamed. "Simulating the Observed and Unobserved: Computational Modeling and Detection Estimates for (Sub)Stellar Accreting Objects." (2022)

S. K. Betti, , K. B. Follette, K. Ward-Duong, A. E. Peck, Y. Aoyama, J. Bary, B. Dacus, S. Edwards, G. -D. Marleau, K. Mohamed, J. Palmo, C. Plunkett, C. Robinson, H. Wang. "The Comprehensive Archive of Substellar and Planetary Accretion Rates." (2023).

Stamatellos, Dimitris, Gregory J., Herczeg. "The properties of discs around planets and brown dwarfs as evidence for disc fragmentation". Monthly Notices of the Royal Astronomical Society 449. 4(2015): 3432-3440.

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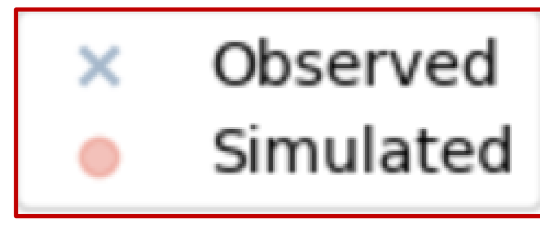
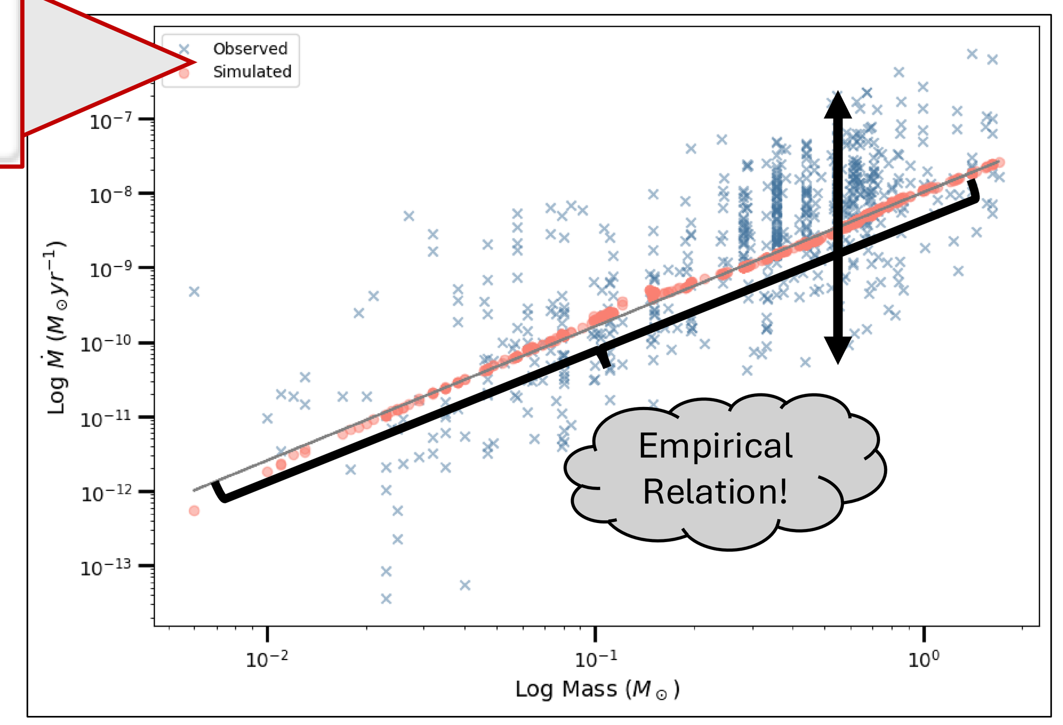
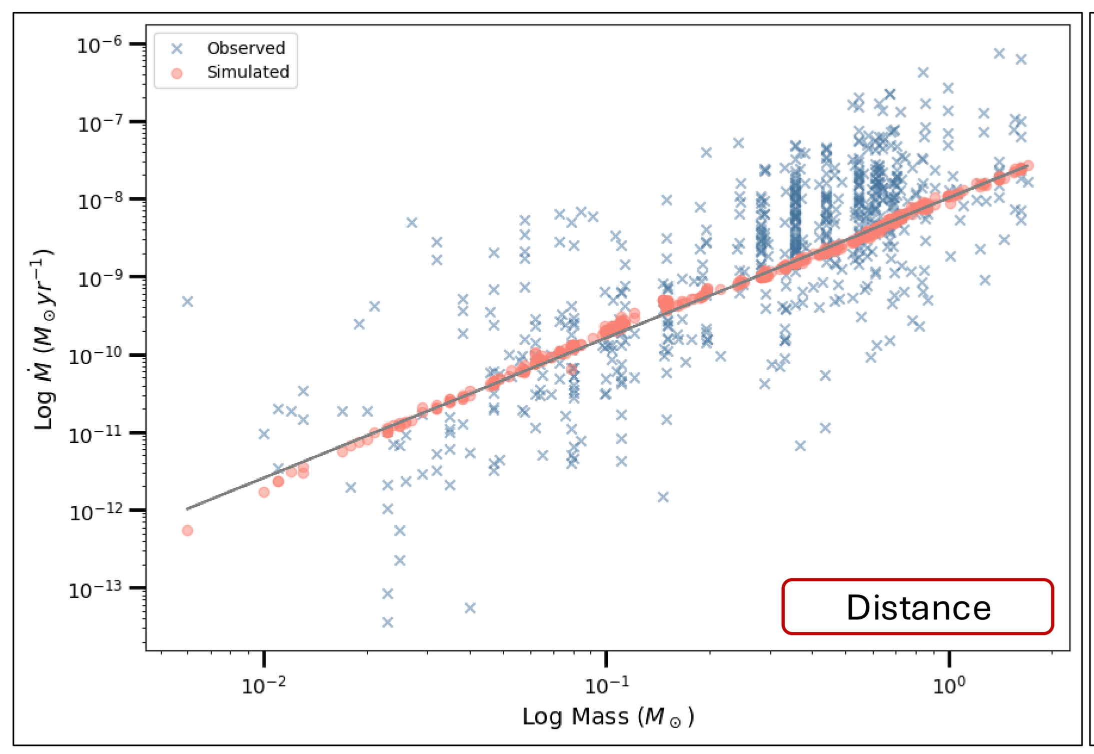
STARSPOP: An MC Simulation of Accretion Rates

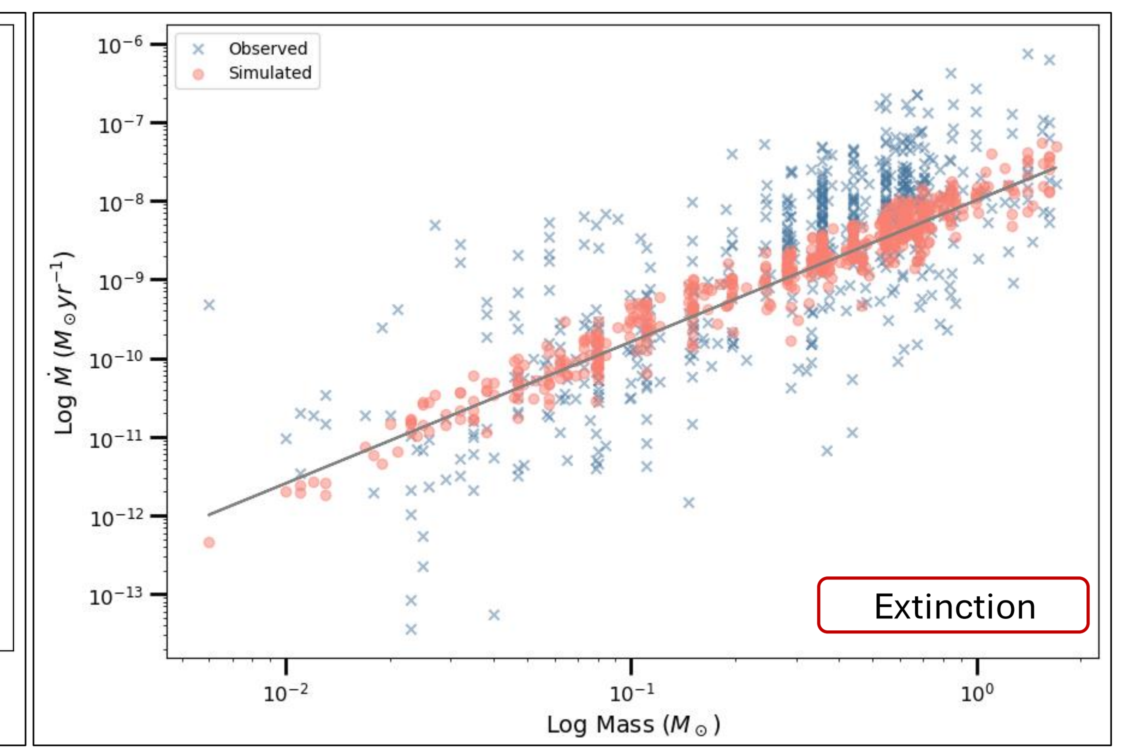


1. The original code takes the mass and uses an empirical relationship, $\log(\dot{M}) = 1.87 * \log(mass) - 7.73$, to find ideal mass accretion rate. The plot shows the simulated population following this relation across all mass regimes.

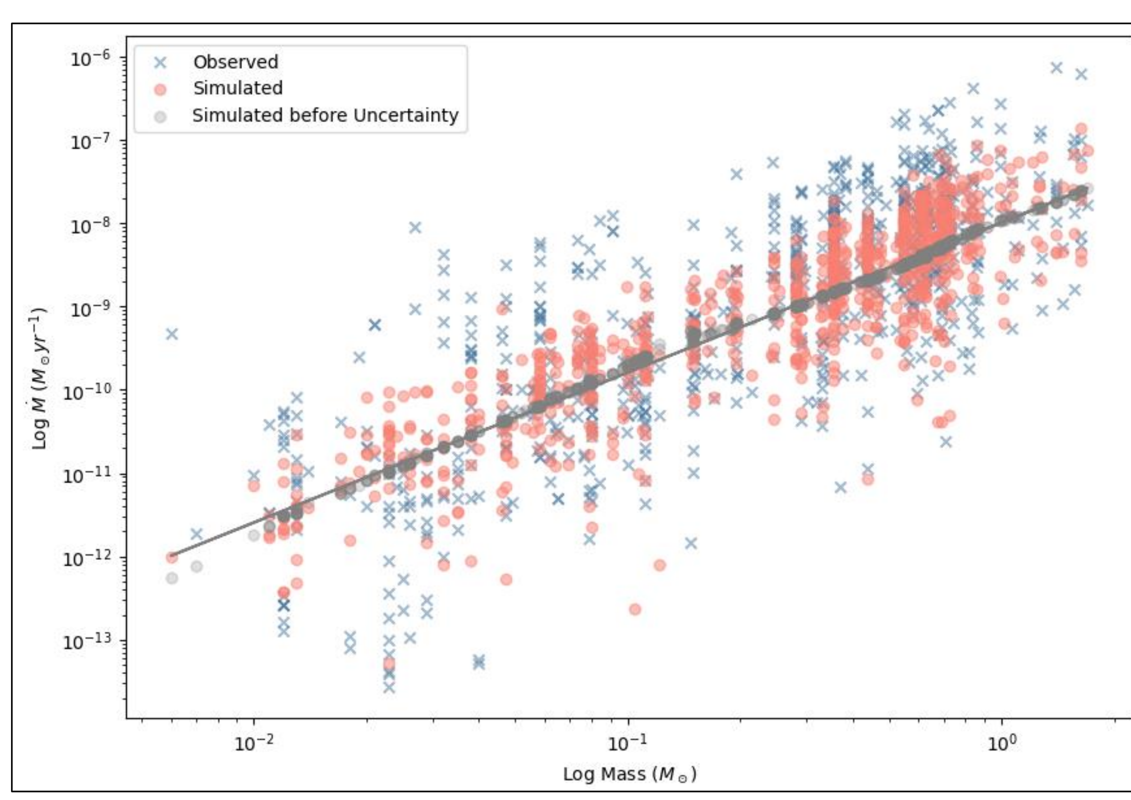


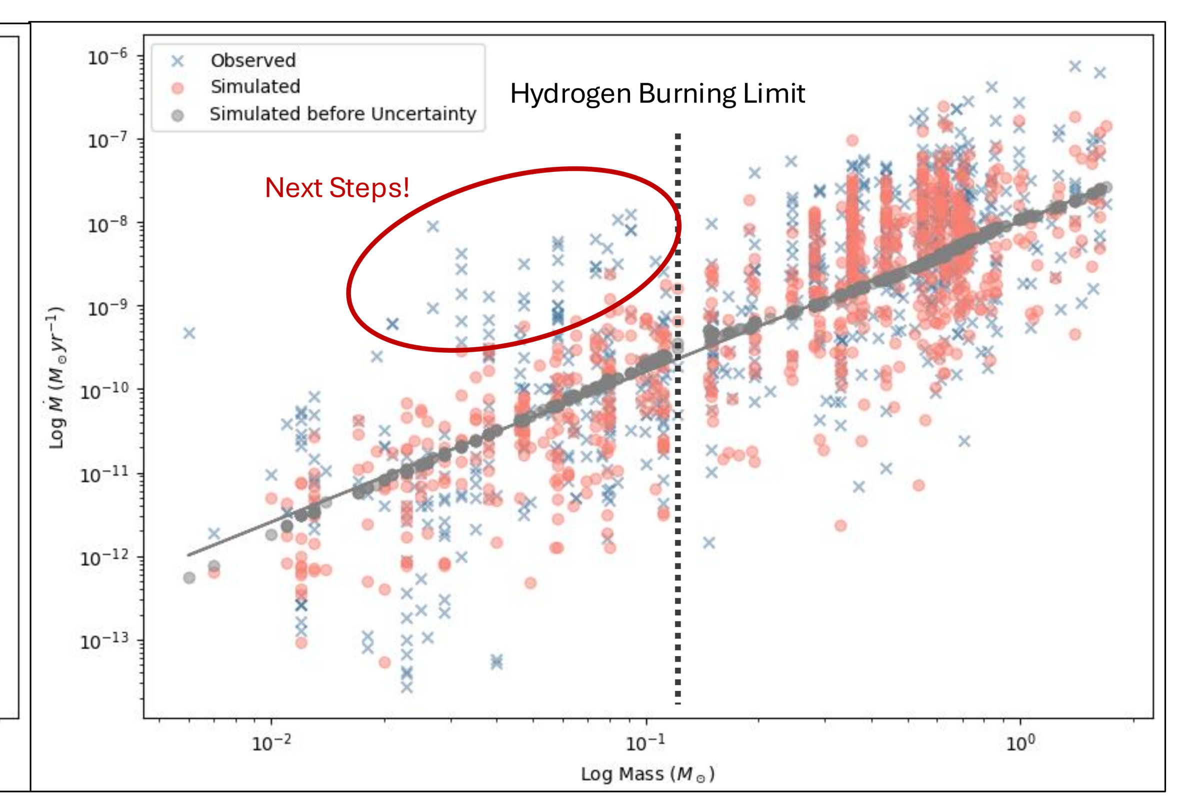
- Tool was created to help us understand how each uncertainty parameter affects a population
- Simulates a population then compares it to an observed population to determine model accuracy
- With a comprehensive understanding of how these uncertainties affect these distributions, we can put constraints on mass accretion rate which will hopefully decrease the scatter, revealing distinct populations





2. Code takes all the uncertainty values that were drawn and uses them to calculate the mass accretion rate. These plots are just a few of the uncertainties when they are propagated into the initial collapsed mass – mass accretion rate distribution.



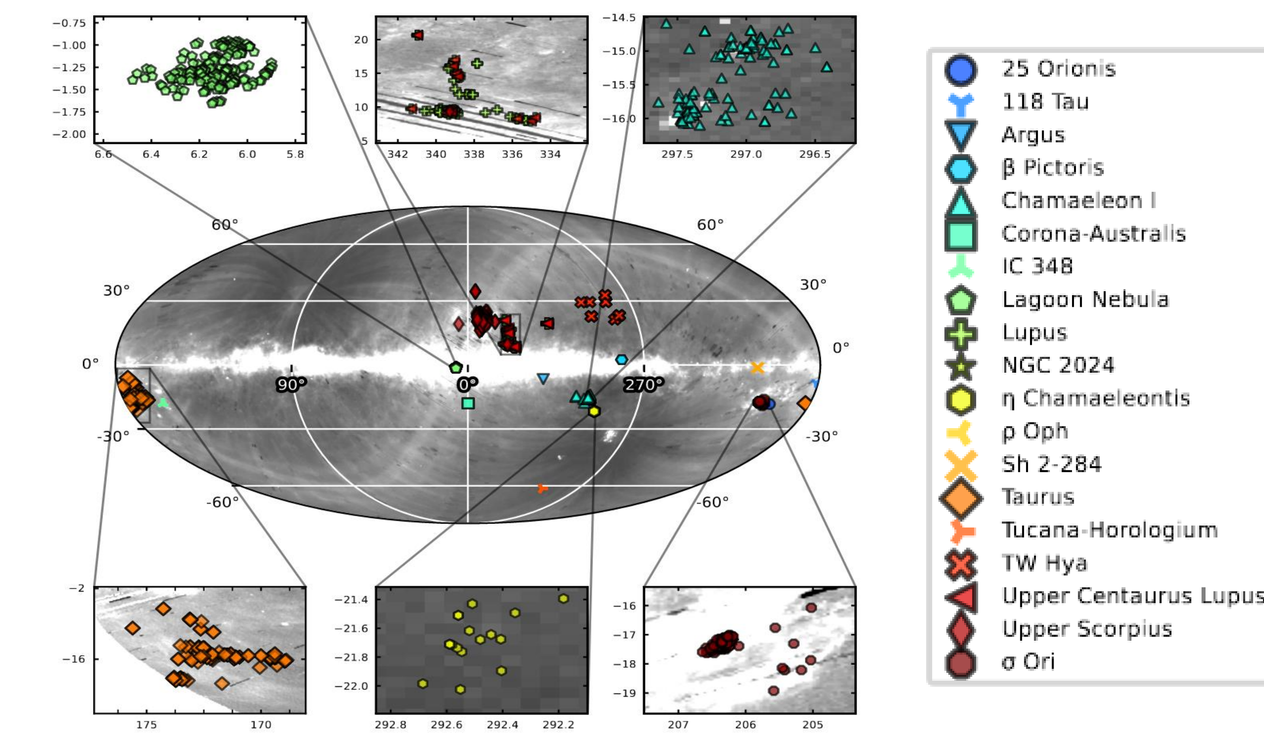


3. This is the final plot with only the observational uncertainties propagated throughout the distribution.

4. Here is the final plot with both the observational and intrinsic dispersion propagated throughout the distribution.

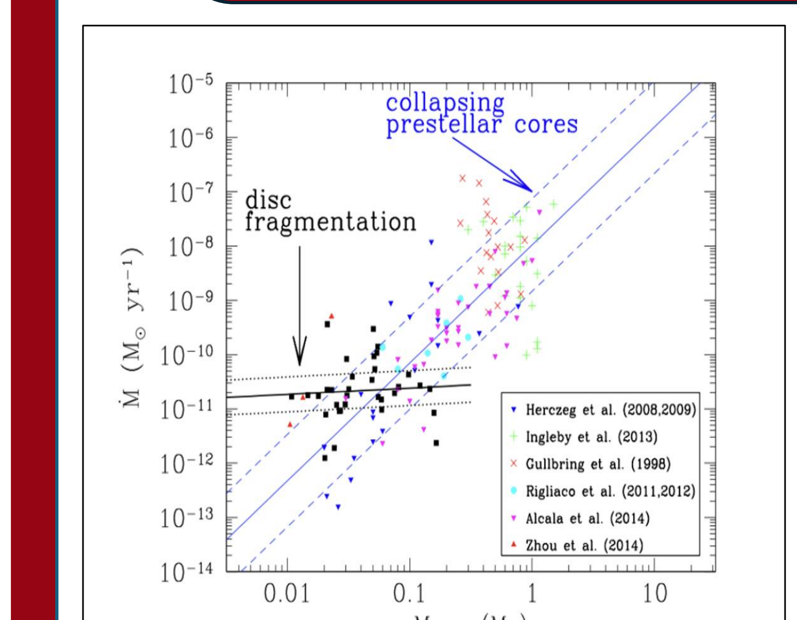
What is CASPAR?

CASPAR – It is the Comprehensive Archive of Substellar and Planetary Accretion Rates created by Dr. Sarah Betti. With 658 stars, 130 brown dwarfs, and 10 bound planetary mass companions, it is the largest catalog of accretion diagnostics. It provides unified re-derivations of distance, age, spectral type, effective temperature, mass, luminosity, radius, continuum excess, and line luminosities. It, currently, consists of 798 objects across measurements from 1998 – 2022.

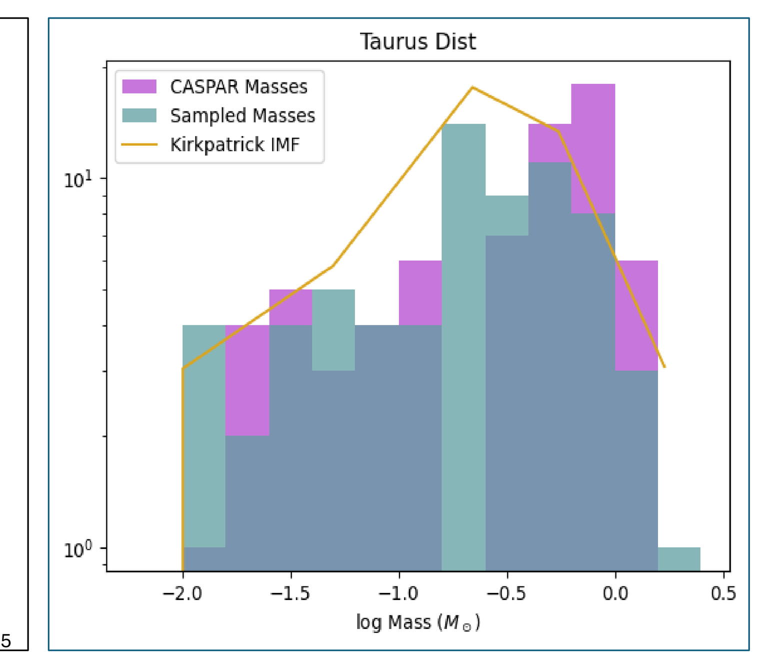


Star forming regions – CASPAR contains data from 19 different star forming regions. This plot shows the different star forming regions in the sky as well highlighting a few of the regions.

Next Steps



Stamatellos et. al 2015



Different Formation Mechanisms/ M-$\dot{M}$ relations

- Population of objects that the simulation cannot accurately represent
    - Between 0.03-0.1 solar masses
- Stars should follow an empirical relationship that relates their mass and mass accretion rate
    - Relationship begins to break down once you enter the brown dwarf mass regime at around 10^(−1)solar masses
- Stamatellos suggests that objects that could have formed like planets follow a flatter empirical mass - mass accretion rate relation

Implementing an IMF

- Gaps in simulated mass distribution
- Encoded the Kirkpatrick et. al 2024 IMF
    - More sensitive to the lower mass regime compared to Chabrier