Externally induced protoplanetary disc dispersal

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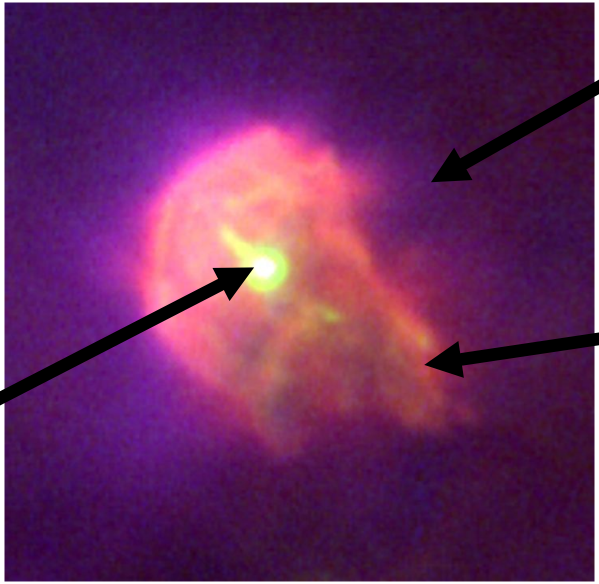
External dispersal mechanisms

- PPDs can be depleted by external photoevaporation (typically not dynamical encounters – multiples only!)

- Extreme and far ultraviolet photons drive thermal winds

PDR region optically thick to EUV

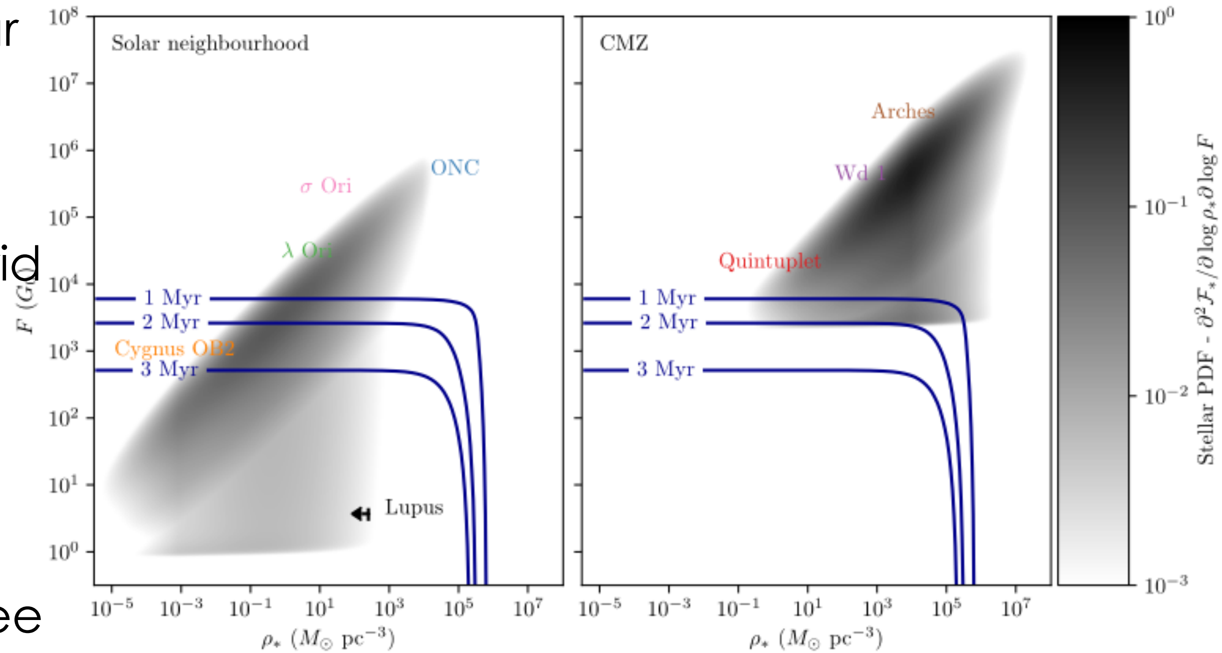


'Cometary tail' pointing away from ionizing source

Proplyd - HST

Solar neighbourhood vs. CMZ

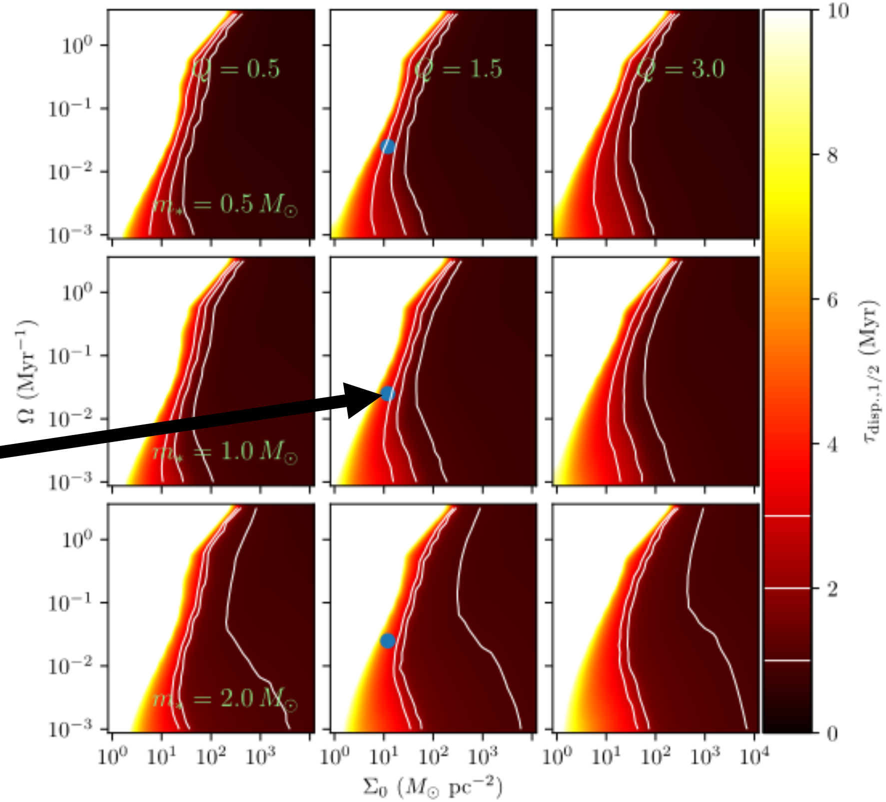
- Theoretical PDF of stellar birth environment
- Dispersal rate contours: viscous disc + 'FRIED' grid (Haworth+ 2018)
- Large fraction (~90%) PPDs dispersed within 1 Myr of primordial gas expulsion in the CMZ (see e.g. Stolte 2010)



Winter+ 2019b
(obs. from Winter+ 2018b)

Is the solar neighbourhood special?

- Parameter space exploration in Σ-Ω-Q space (galactic scale primordial gas)
- **Solar neighbourhood sits at approximately maximum surface density where PPDs aren't quickly externally dispersed!**



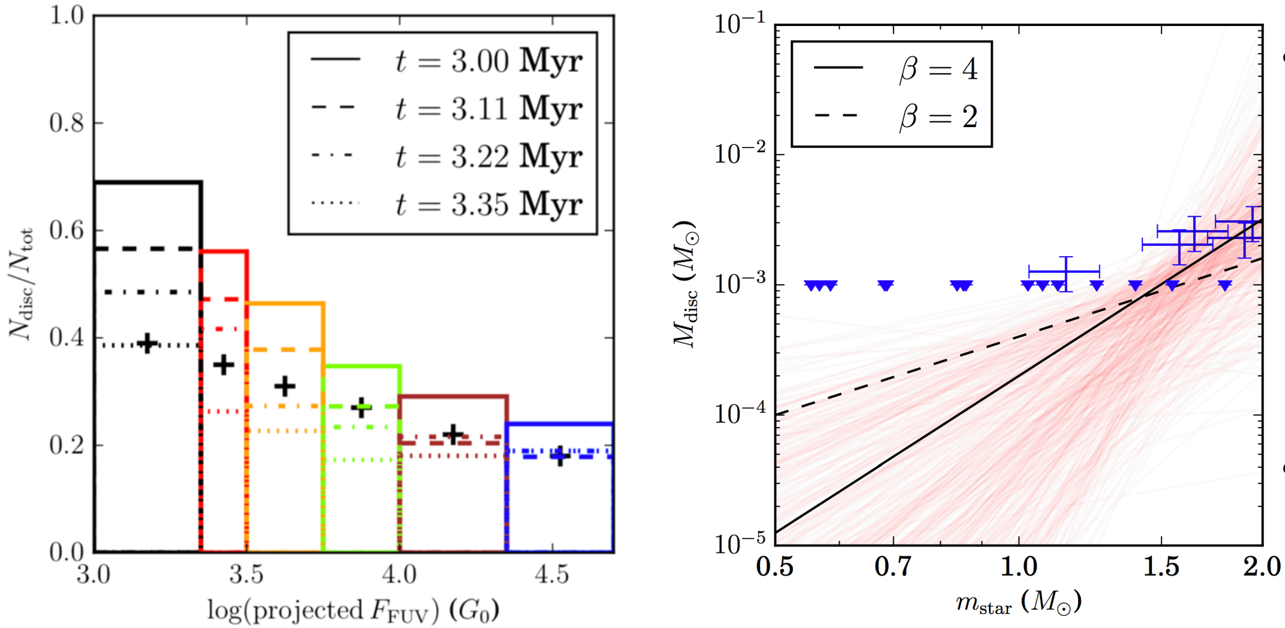
Winter+ 2019b

Is the solar neighbourhood special?

Are we studying PPDs which are not representative of the progenitors of the exoplanet population we are trying to understand?

Winter+ 2019b

Observational evidence: Cygnus OB2



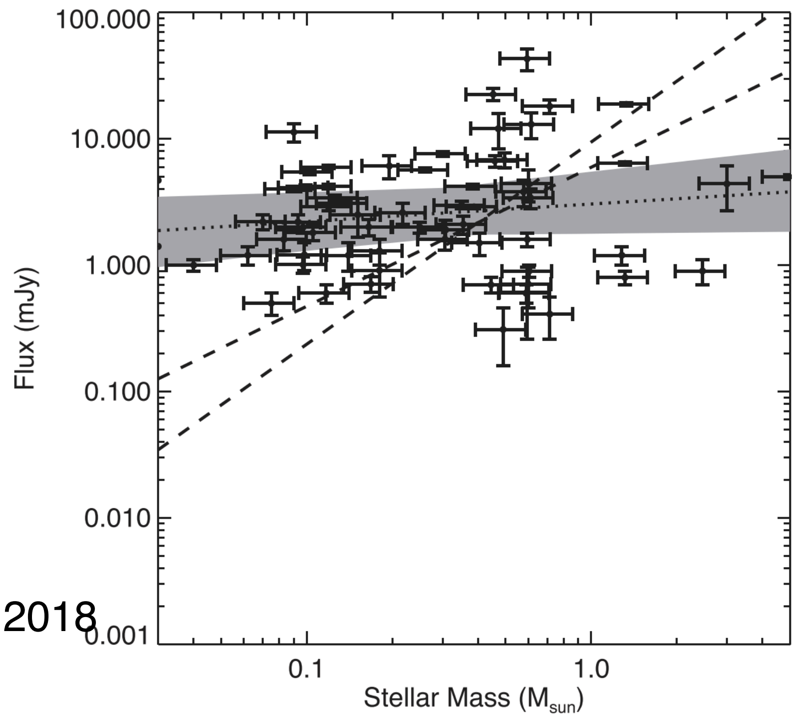
Winter+ 2019a

- Can reproduce disc fractions in CygOB2 using same model (obs. by Guarcello+ 2016)
- Steep disc mass-host mass relationship?

"Proplyd lifetime problem"

- Orion Nebula cluster (ONC) often used as the archetype for external photoevaporation investigations
- Problem: `proplyds' (ionized PPDs) in the ONC exhibit mass loss rates $\sim 10^{-7}$-10^{-6} $M_\odot$ yr^{-1} → destroyed in < 1 Myr, but 80% of discs remain despite ~3 Myr average age of the stars
- Störzer & Hollenbach 1999 – radial orbits? Scally & Clarke 2001 – no. Discs are always dispersed on ~1 Myr time-scales.
- How can we reconcile this with theory and e.g. Cygnus OB2?

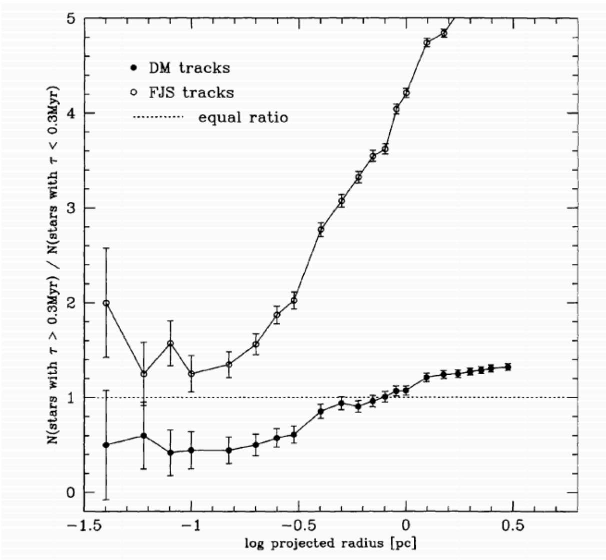
ONC: Flat disc mass-host mass relationship



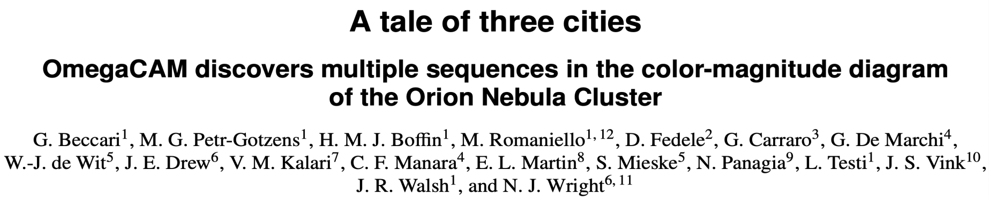
Eisner+ 2018

- Not the only strange thing about PPDs in the ONC…
- Disc mass apparently not correlated with host mass
- In contrast to other regions of similar age and contradicts Cygnus OB2 results?

ONC: Stellar age gradient



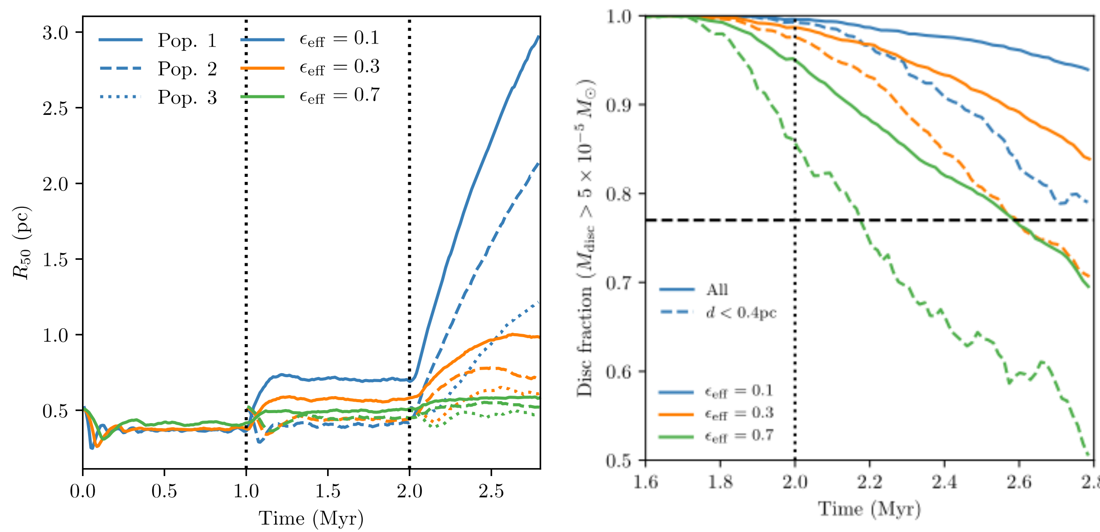
Hillenbrand 1997



Beccari+ 2017, Jerabkova+ 2019

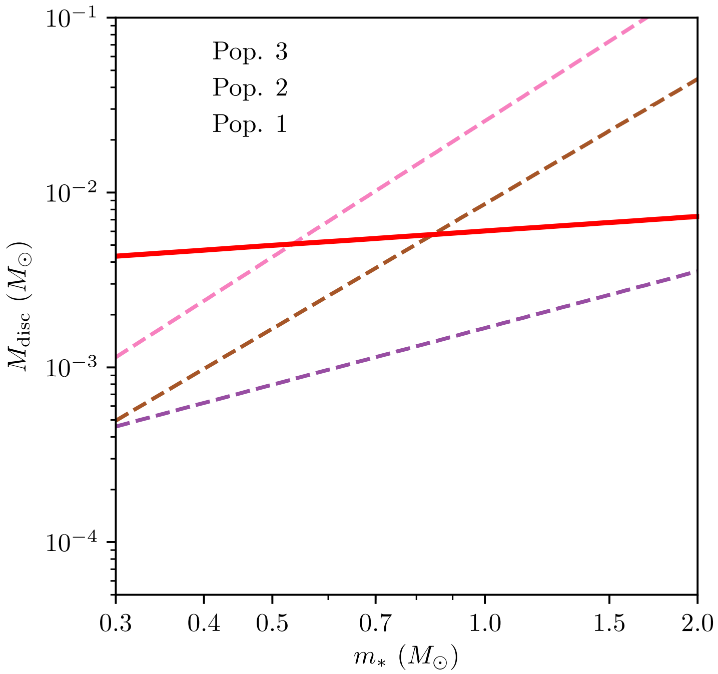
Modelling multiple stellar populations

- Stars form over an extended period, subvirial with respect to stars + gas mass
- Collapse and subsequent expansion → stellar age gradient, youngest stars preferentially close to Θ^1C
- Plus interstellar extinction



Winter+ to be submitted

Disc mass-host mass relationship



- Reproduce the observed flat disc mass-host mass relationship – contamination from different age discs!

Solution to "Proplyd lifetime problem"

1. Population of young stars wrt average age of ONC
2. Radial orbits due to gas expulsion (like Störzer & Hollenbach 1999)
3. Interstellar extinction
4. Disc outer radius depletion (less efficient mass loss)
5. Observational biases (preferentially proplyds are bright & extended – highest mass loss rates!)

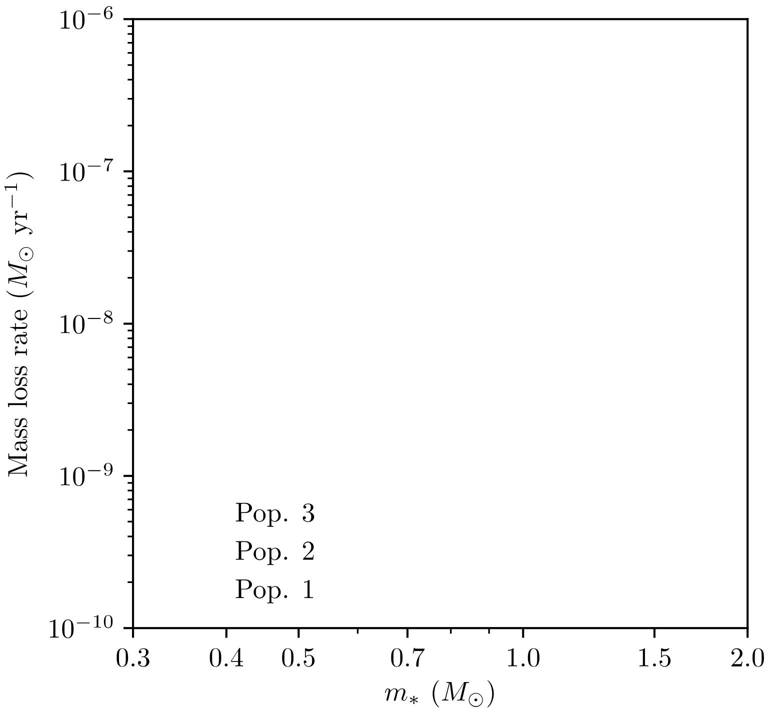
Summary

1. **Secularly evolving discs ARE NOT the progenitors of the exoplanets we observe. Environment cannot be ignored for planet formation!**
2. Many star forming regions in the solar neighbourhood experience FUV flux sufficient to shorten PPD lifetimes
3. Higher (galactic-scale) gas surface densities are linked to shorter dispersal time-scales – is the solar neighbourhood special?
4. Complicated star formation history and young stars can confuse signatures (e.g. ONC)

Observational bias in proplyds

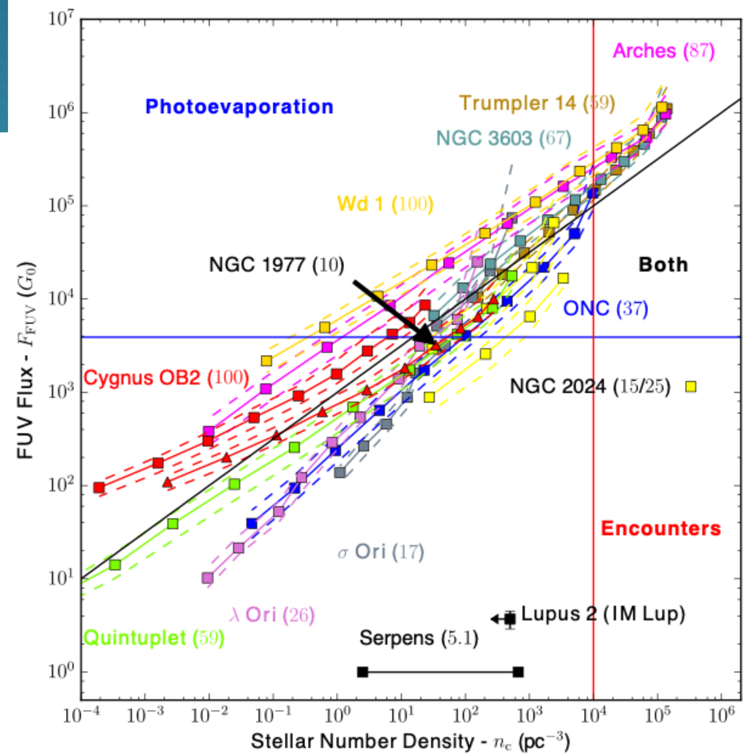
- Preferentially measure mass loss rates in extended and bright proplyds

- Typical mass loss rates closer to ~5 $\cdot 10^{-8} M_\odot \, yr^{-1}$ – factor few lower than extreme cases, which are comparatively rare



Dominant mechanism?

- Which mechanism influences PPDs in observed star forming regions?
- Fitting formula for angle averaged tidal encounters + 1D viscous evolution model & FRIED mass loss rates (Haworth+ 2018)
- **External photoevaporation dominates**
- Relationship between local density and FUV flux



Winter+ 2018b

Demographics of star forming regions

- To generalise, we consider initial cluster mass function (Reina-Campos & Kruijssen 2017, Trujillo-Gomez+ 2019), and PDF of stellar density

- Mean FUV flux in a galactic environment using empirical relationship between flux and density:

Fraction of stars

Normalised mean flux

Normalised luminosity

Normalised mass of star forming region

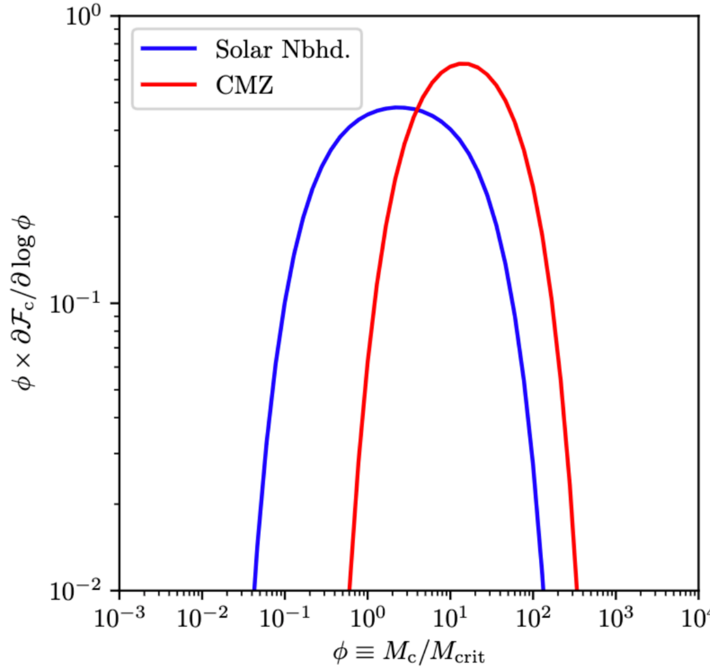
$$\left.\frac{\partial \mathcal{F}_*}{\partial \psi_0}\right|^{\psi_0>\psi_0^{\mathrm{f}}} = \frac{\partial \mathcal{F}_*}{\partial \phi}\left|\frac{\partial \phi}{\partial \psi_0}\right| = \frac{\partial \mathcal{F}_*}{\partial \phi}\left|\frac{\partial \Lambda}{\partial \psi_0}\frac{\partial \phi}{\partial \Lambda}\right| = \frac{\partial \mathcal{F}_*}{\partial \phi}\left|\frac{\partial \Lambda}{\partial \phi}\right|^{-1}$$

- Dispersion from mean:

$$\frac{\partial \mathcal{F}_*}{\partial \psi} = \int \mathrm{d}\psi_0 \, \frac{\partial \mathcal{F}_*}{\partial \psi_0}\frac{\partial \mathcal{F}_*}{\partial \delta\psi}\frac{1}{\psi_0}.$$

Initial cluster mass function

- Upper mass limit given by the Toomre mass (length scale above which ISM stable to perturbations) and feedback timescale (Reina-Campos & Kruijssen 2017)
- Low mass limit given by single object mergers (limit of high SFE, slow feedback – Trujillo Gomez+2019)
- Between – power law index β=2, hierarchical collapse

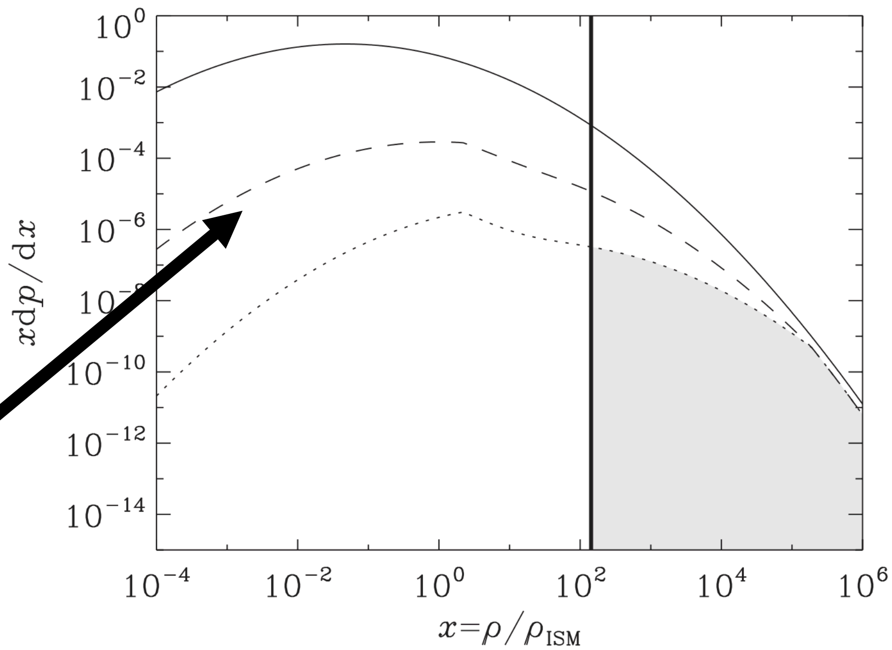


Stellar density PDF

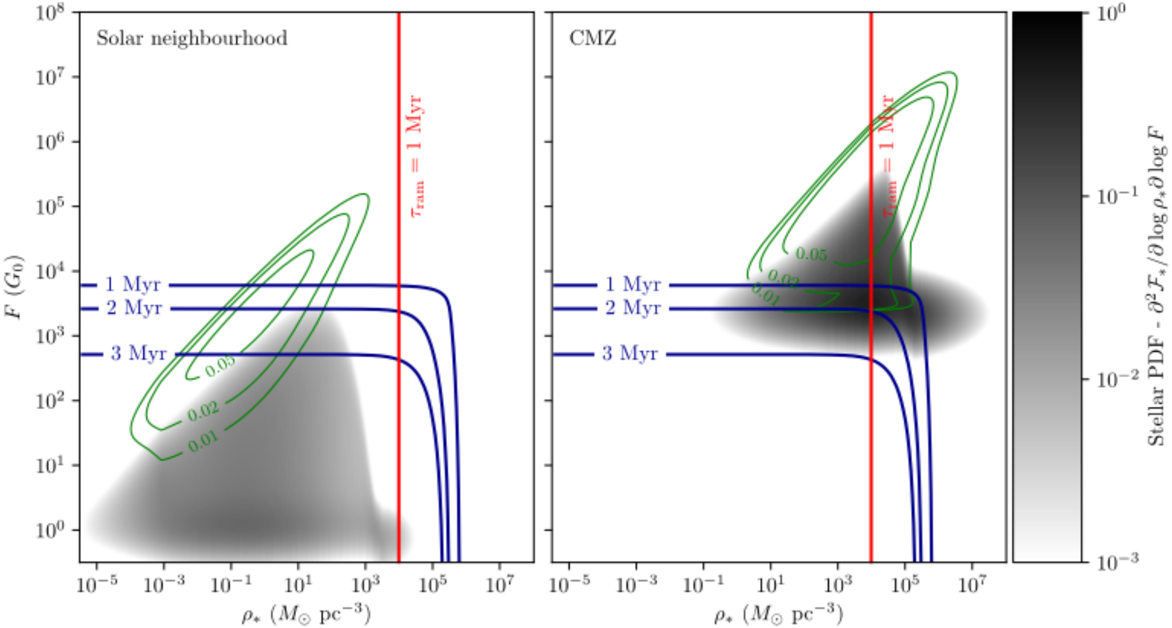
- Lognormal gas density distribution:

$$\frac{\partial p}{\partial x} = \frac{1}{\sqrt{2\pi\sigma_\rho^2}x} \exp\left\{-\frac{(\ln x - \overline{\ln x})^2}{2\sigma_\rho^2}\right\}$$

- Weight by theoretical SFE to give stellar density PDF



Interstellar extinction

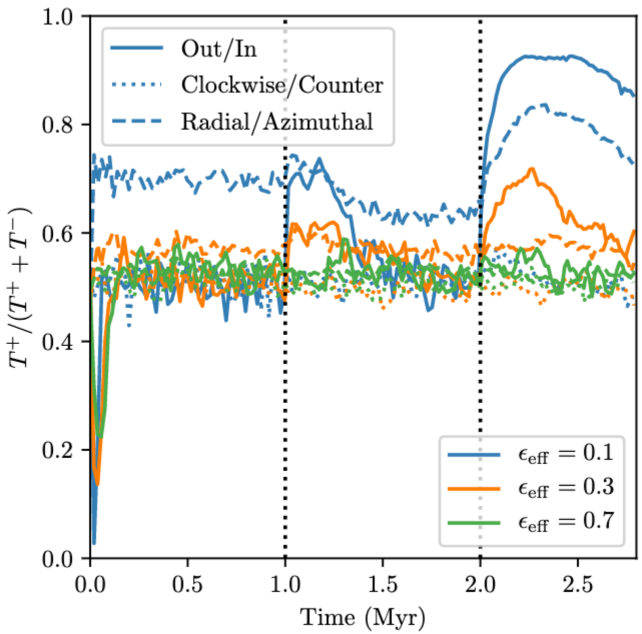


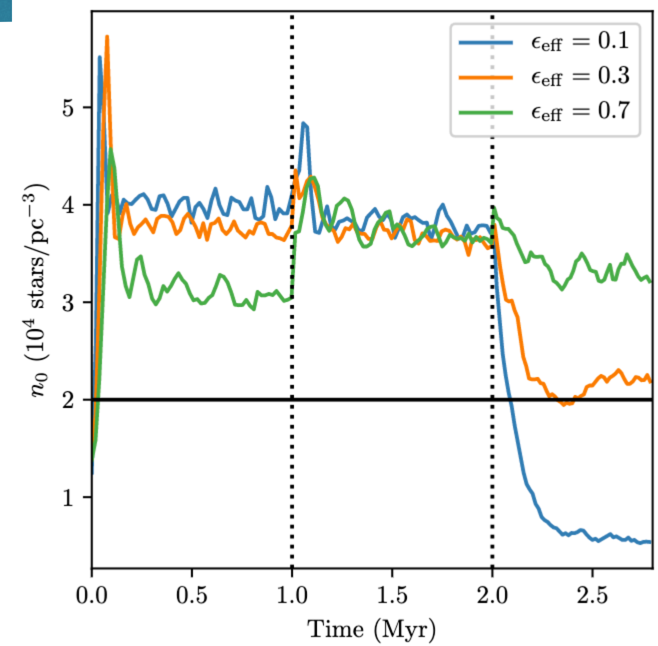
$$\psi_0^{\rm ext} = e^{-C_{\rm ext}\chi} \Lambda + \psi_0^{\rm f}.$$

$$\chi_1 \approx \frac{(1-\epsilon)}{3\epsilon^{1/3}} \left(\frac{3M_{\rm crit}\rho_0^2}{4\pi\Sigma_0^3} \right)^{1/3} x^{2/3} \phi^{1/3} (1+\gamma)^{5/3} \times \left\{ \frac{\gamma(2\gamma^2+3)}{(1+\gamma^2)^{3/2}} - \frac{\gamma_{\rm S}(2\gamma_{\rm S}^2+3)}{(1+\gamma_{\rm S}^2)^{3/2}} \right\}$$

$$\frac{\partial \mathcal{F}_*}{\partial \psi_0^{\rm ext}} \approx \int_{\delta\chi}^{\infty} {\rm d}\chi_1 \, \frac{\partial \mathcal{F}_*}{\partial \chi_1} \frac{\partial \mathcal{F}_*}{\partial \phi} \left| \frac{\partial \psi_0^{\rm ext}}{\partial \phi} \right|^{-1}$$

ONC: stellar kinematics and central density





ONC: proplyd properties