Local-density-driven clustered star formation

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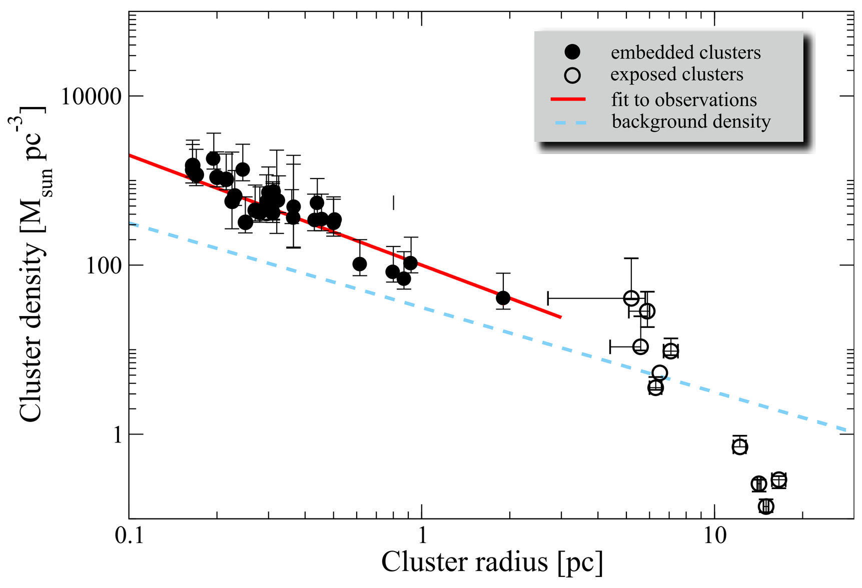
Analytical model for massive star formation based on density dependent SFE

The mass-radius relation

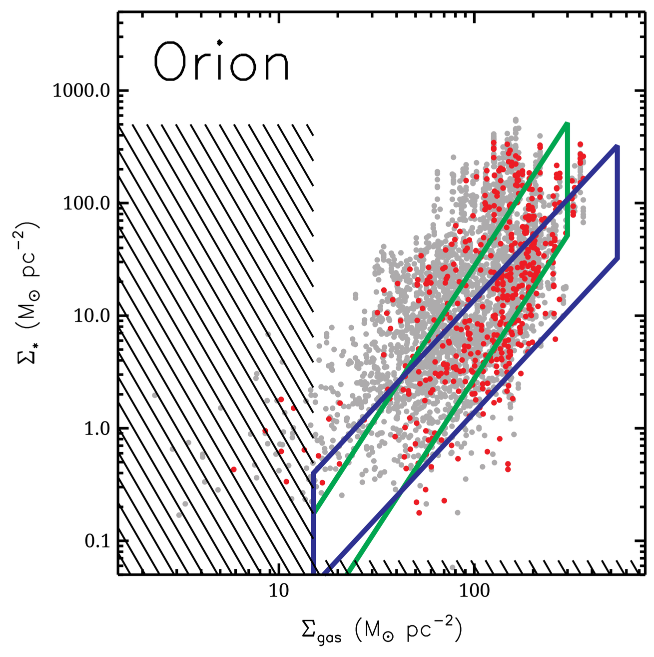


- Relation between observed mass, $M_{cluster}$, and radius, $r_{cluster}$, of clusters during gas-embedded phase ([1],[2]):

$$m_{cluster}[M_\odot] \simeq 360 \cdot r_{cluster}^{1.7}[pc]$$

- Interpretation: **time sequence**; as the cluster stellar content builds up, its (apparent) radius increases.

Density-dependent SFE



- Observational finding ([3]): $\Sigma_{stars} \propto \Sigma_{gas}^2$
- Green/blue zones: relations observed for MonR2/Oph molecular clouds
- Interpretation: Star Formation Efficiency (SFE) is local-density dependent and must be measured locally.

Analytical model

- Molecular clump with volume density profile $\rho_0(r)$
- Constant SFE per free-fall time, ϵ_{ff}

Stellar density profile at time t:

$$\rho_s(t,r) = \rho_0(r)\left[1 - \left(1 + \frac{\epsilon_{ff}}{2}\frac{t}{\tau_{ff,0}(r)}\right)^{-2}\right]$$

$\tau_{ff,0}(r)$: free-fall time of initial gas profile:

$$\tau_{ff,0}(r) = \sqrt{\frac{3\pi}{32G\rho_0(r)}}$$

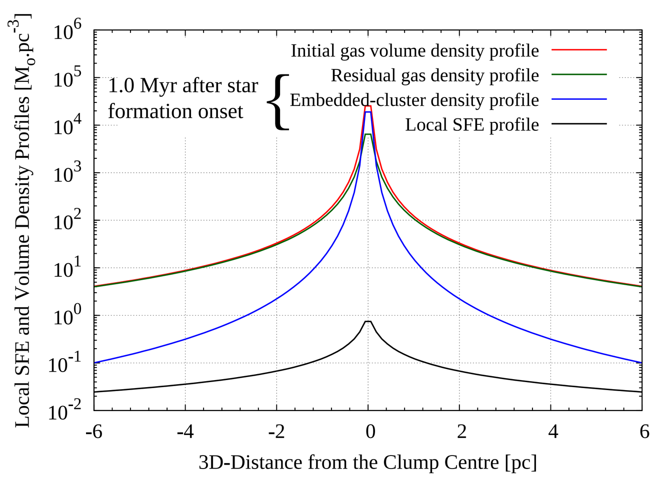
Easy description of stellar-density evolution

Radial dependent SFE

- Cluster-forming clump: radially-varying gas density

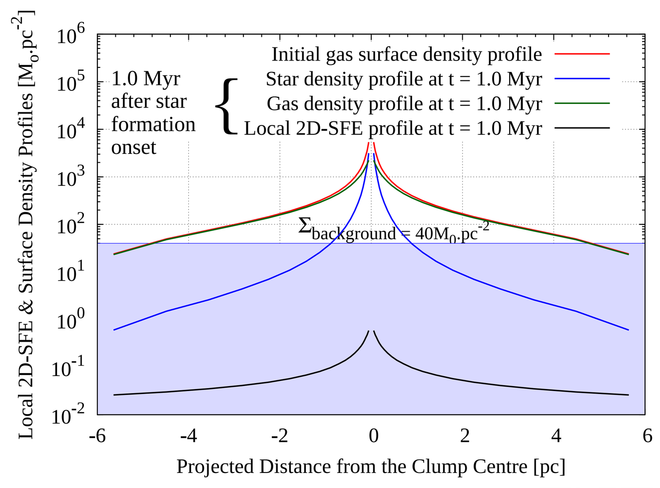
⇒ Shorter free-fall time at centre

⇒ Faster stellar mass growth at centre



Radially-varying SFE and improved likelihood of cluster survival after residual gas expulsion

Stellar Background



Have a look at the time development at http://tiny.cc/gas_to_stars

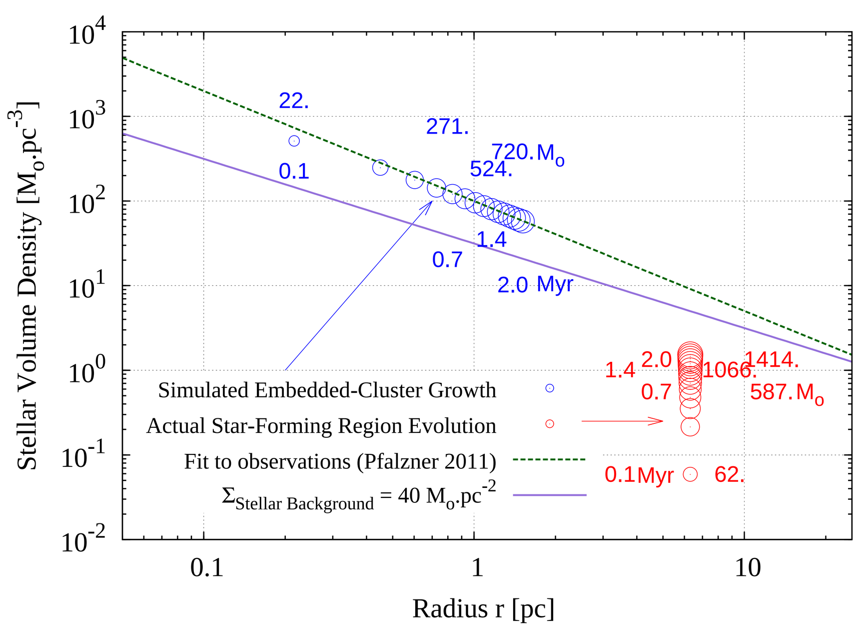
- Account for stellar background onto which the cluster is seen projected

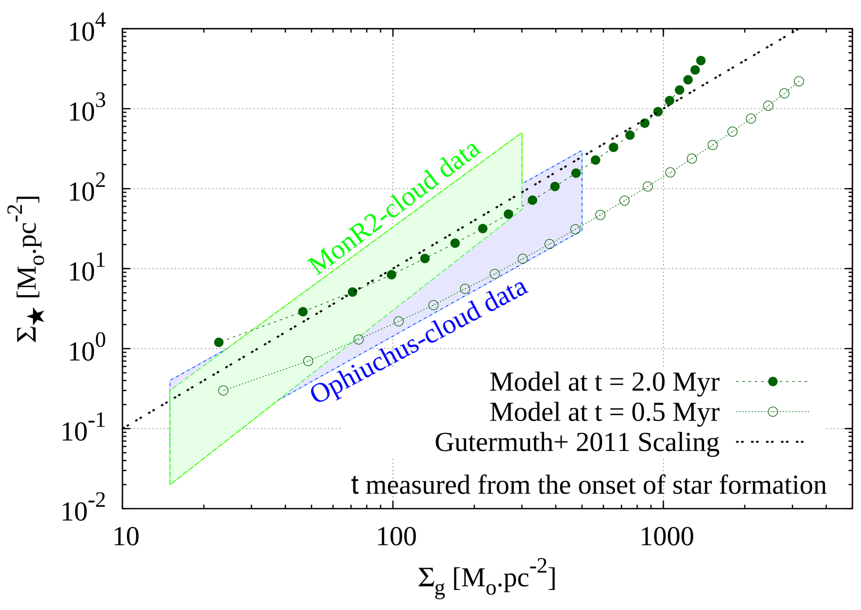
⇒ Cluster outskirts concealed by stellar background

⇒ Only tip of cluster makes it above stellar background

⇒ Observed masses and radii underestimate actual ones

Simulations versus Observations





○ Stellar-density increase of entire star-forming region

○ Stellar-density evolution observed above background level (Parmentier & Pfalzner 2013 [4])

Model (○) follows data (green line) when surface density threshold (violet line) is applied ⇒ Mass-radius relation appears as cluster-growth sequence

- Slope of predicted star formation law matches observed one
- Normalisation of predicted star formation law to match the observed one

⇒ Star formation efficiency per free-fall time estimate: $\epsilon_{ff} \simeq 0.1$

⇒ Measured SFE is time AND location dependent

Conclusion

- Mass-radius relation of embedded clusters is "iceberg tip" of local star formation law
- Initial conditions of physically-motivated N-body models of clusters after gas removal now in hands
- Ultimate goal: to model the evolution of environments in which planets form

References

[1] Pfalzner, S., 2011, A&A, 536, 90

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[3] Gutermuth, R.A., Pipher, J.L., Megeath, S.T., Myers, P.C., Allen, L.E., Allen, T.S. 2011, ApJ, 739, 84

[4] Parmentier, G., Pfalzner, S. 2013, A&A, 549, 132

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