The Early Evolution of Stellar (Sub)Clusters

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Modeling the Evolution of Star Clusters

- Traditionally:
  - Spherical
  - Virial equilibrium
  - Stars appear on ZAMS (not pre-main sequence)
  - All stars formed instantaneously
  - Gas-free
  - No mass segregation
  - All single stars, or a simple binary population that is evenly distributed throughout the cluster

Because that's what young clusters look like!

Or not.

NGC 6334, Cat's Paw Nebula

Image credit: ESO

MYStIX

Massive Young stellar complex Study in Infrared and X-ray

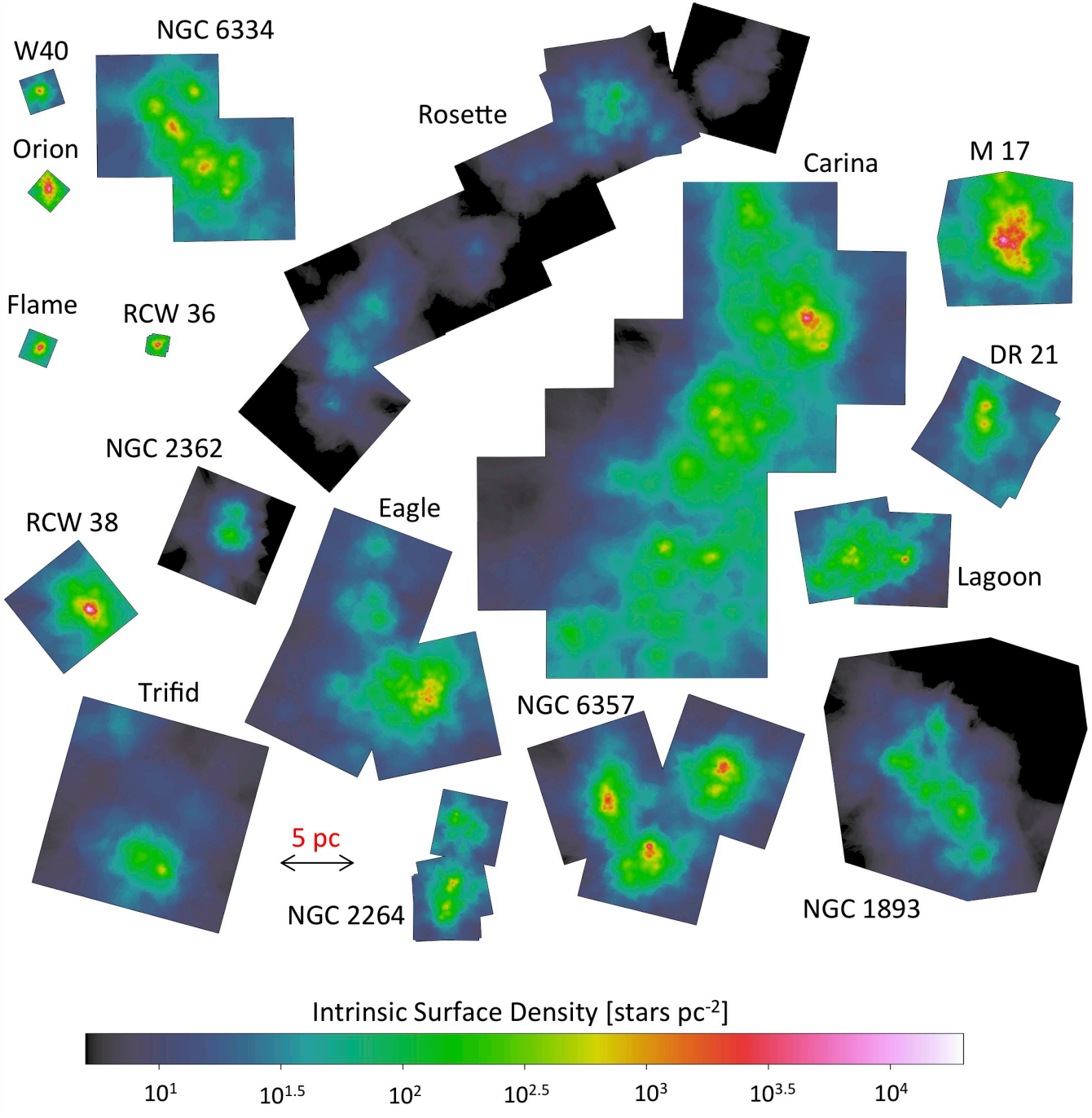
Multiwavelength surveys of 20 massive SFRs

Data analysis: 2009-12; papers: 2013-15

http://astro.psu.edu/mystix

Led at Penn State by Eric Feigelson & Leisa Townsley

Michael Kuhn, Kostantin Getman, Patrick Broos, Matthew Povich, Kevin Luhman, Heather Busk, Alexander Richert, Tim Naylor, Robert King, Matthew Bate, Mark McCaughrean, Ralph Pudritz, Alison Sills, James Wadsley, Julian Pittard, Remy Indebetouw, Adrian Baddeley, Yong Song



Intrinsic star surface density maps

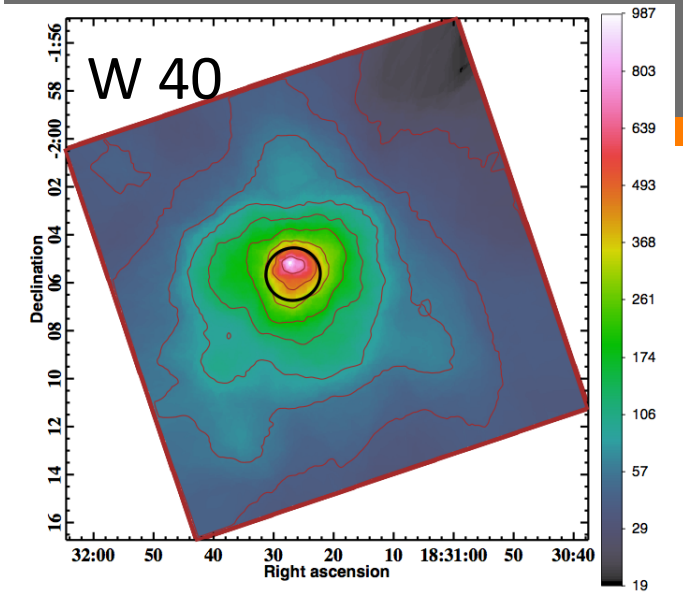
(corrected for X-ray flux sensitivity limits)

Kuhn et al. 2014b

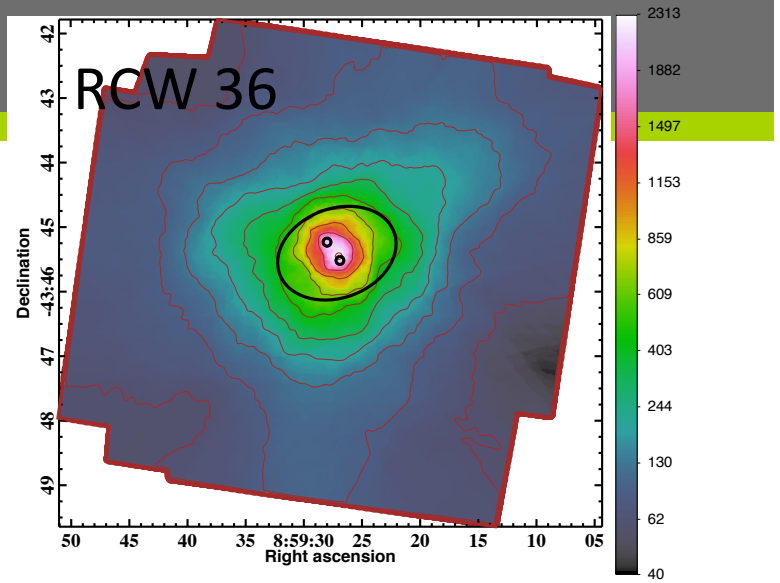
Morphology of star clusters in massive star forming regions

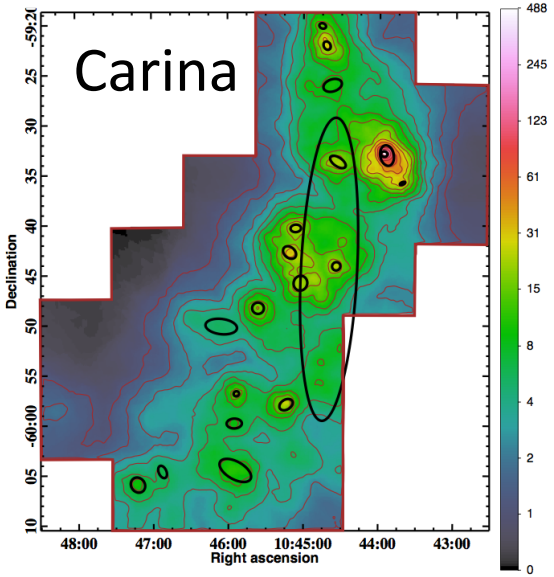
Kuhn et al. 2014a

Simple



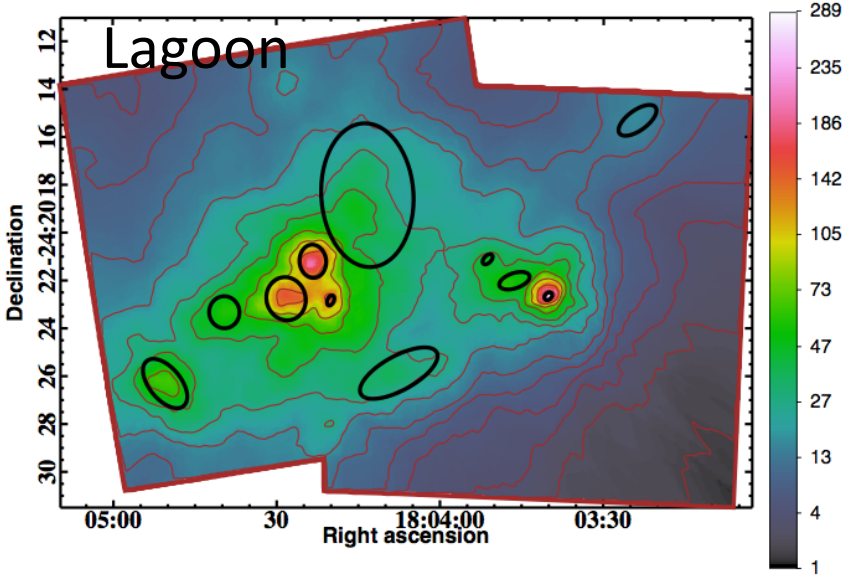
Core-halo



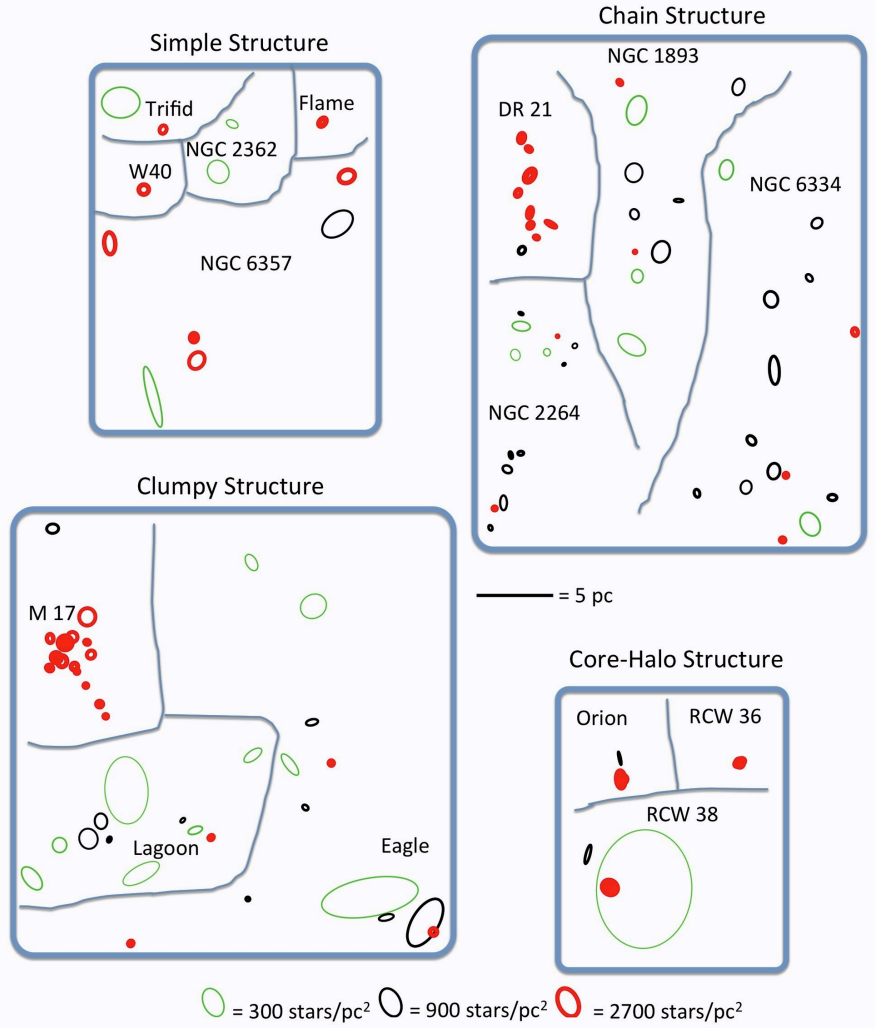


Multiple clusters

Complex clusters

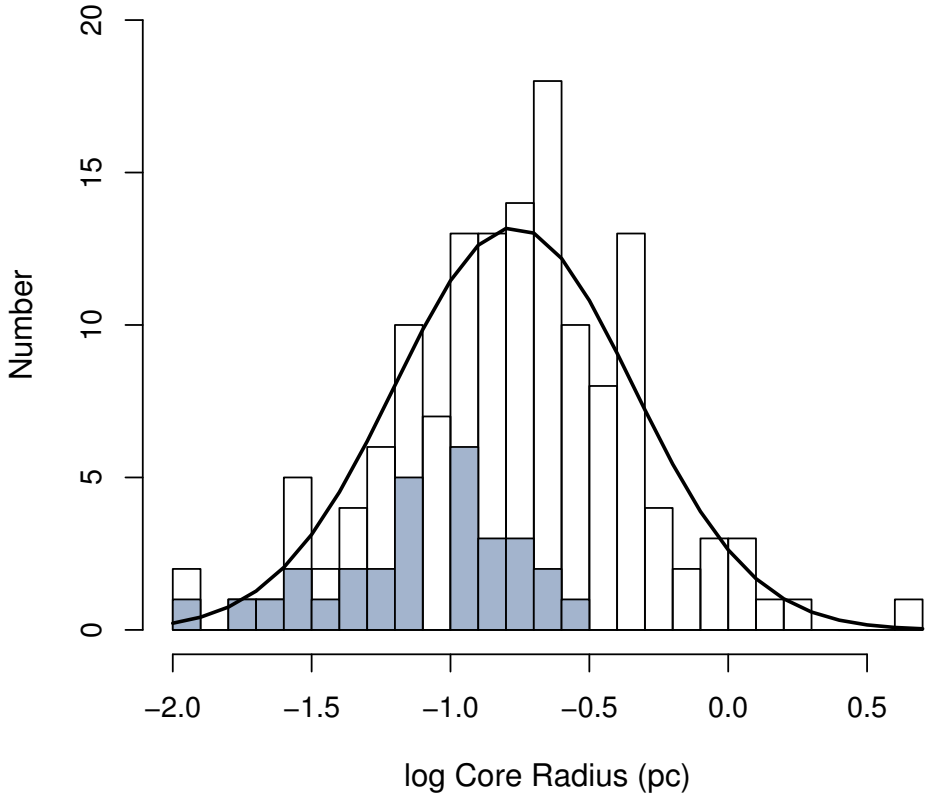


Variety of Substructure



Kuhn et al. 2014a

Core Radius distribution



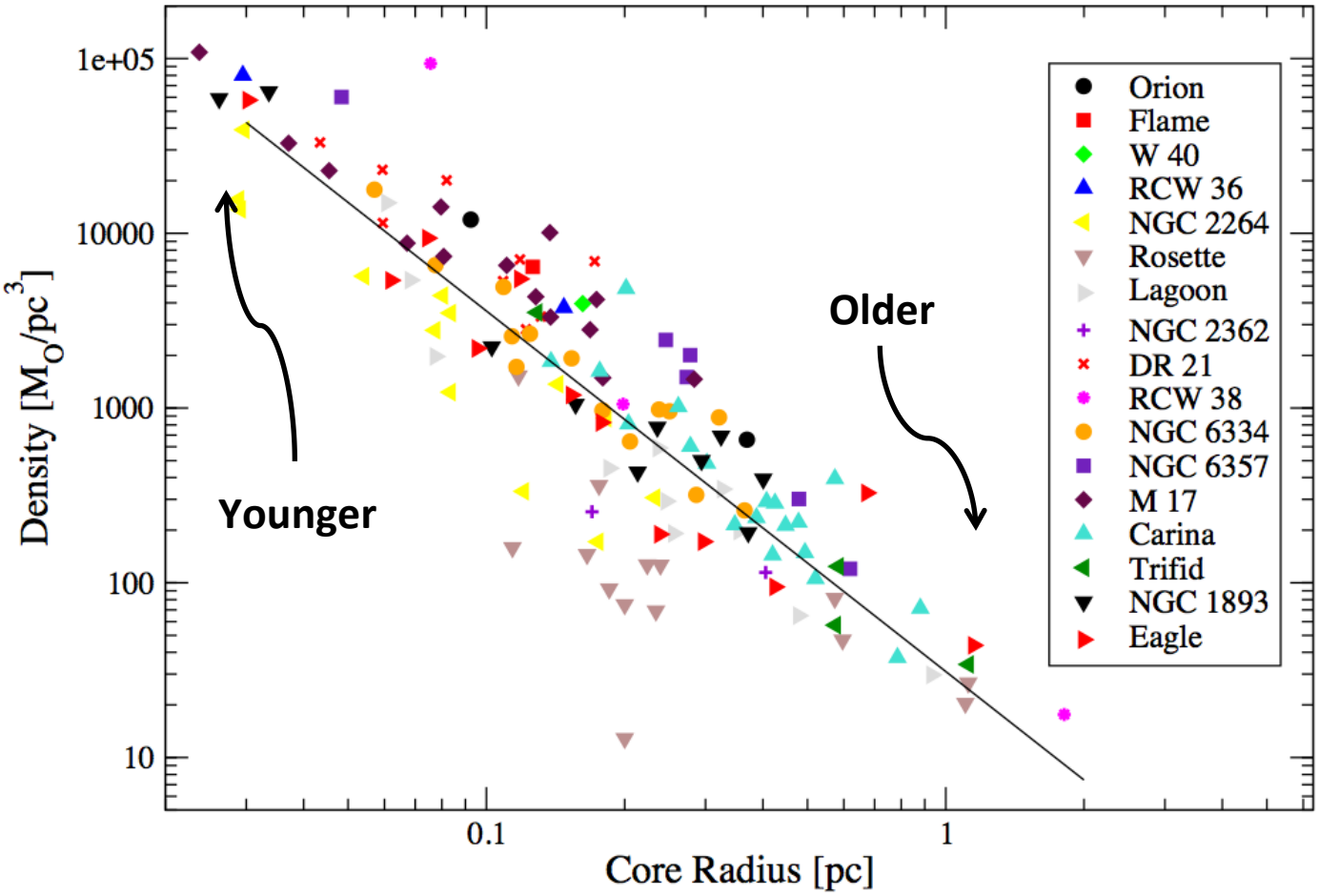
Histogram of subcluster core radii. Embedded clusters are shown in grey.

Kuhn et al. 2014a

Central Core Density vs. Core Radius

This relationship clearly supports the model that clusters are born at a uniform high density and expand to lower density

Expansion is plausibly due to loss of molecular gas gravitational potential, violent relaxation of subcluster merger, …



Kuhn et al. 2014b
see Pfalzner 2009, 2012

Can Simple Models Tell Us Anything?

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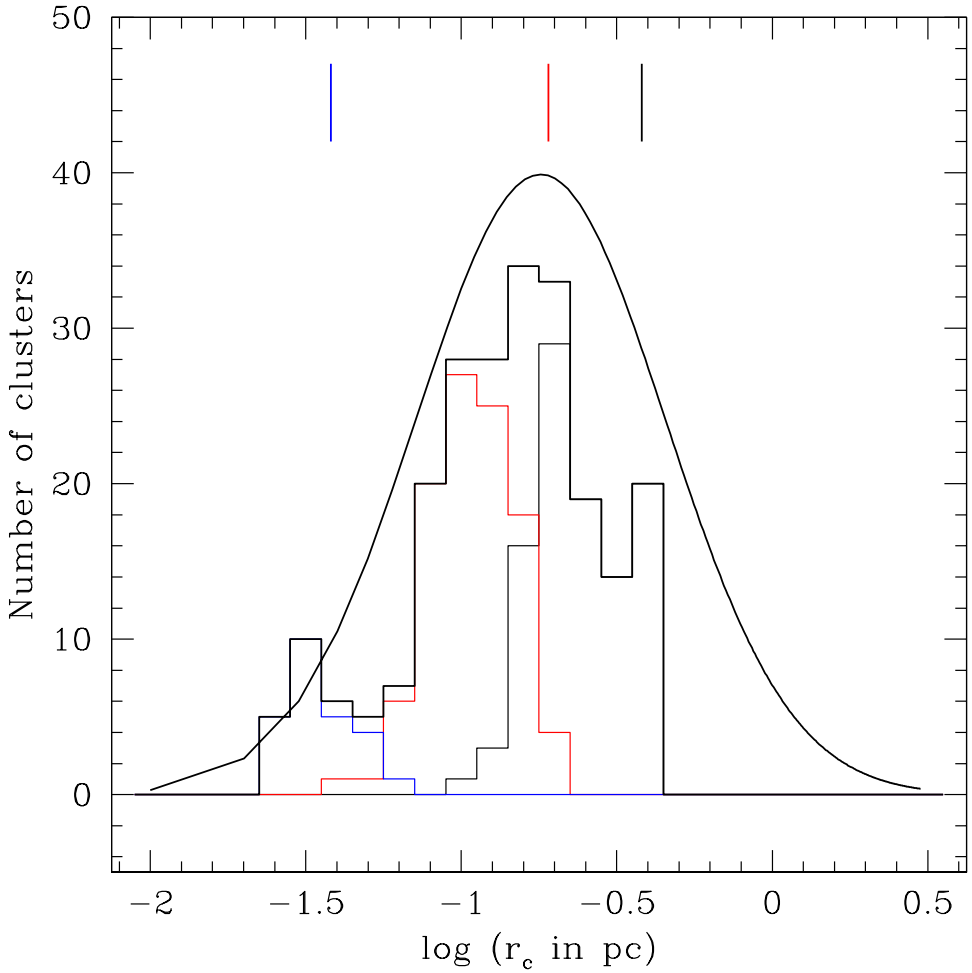
Can Simple Models Tell Us Anything?

- Traditionally:
  - Spherical ✔ Plummer
  - Virial equilibrium ✔
  - Stars appear on ZAMS (not pre-main sequence) ✔
  - All stars formed instantaneously ✔
  - Gas-free same Plummer, different gas fractions
  - No mass segregation ✔
  - All single stars ✔

Using AMUSE to simultaneously follow evolution of gas and stars (Pelupessy & Portegies Zwart 2012)

Histogram of Core Radii



150 stars (~50 $M_\odot$) + 10^5 gas particles

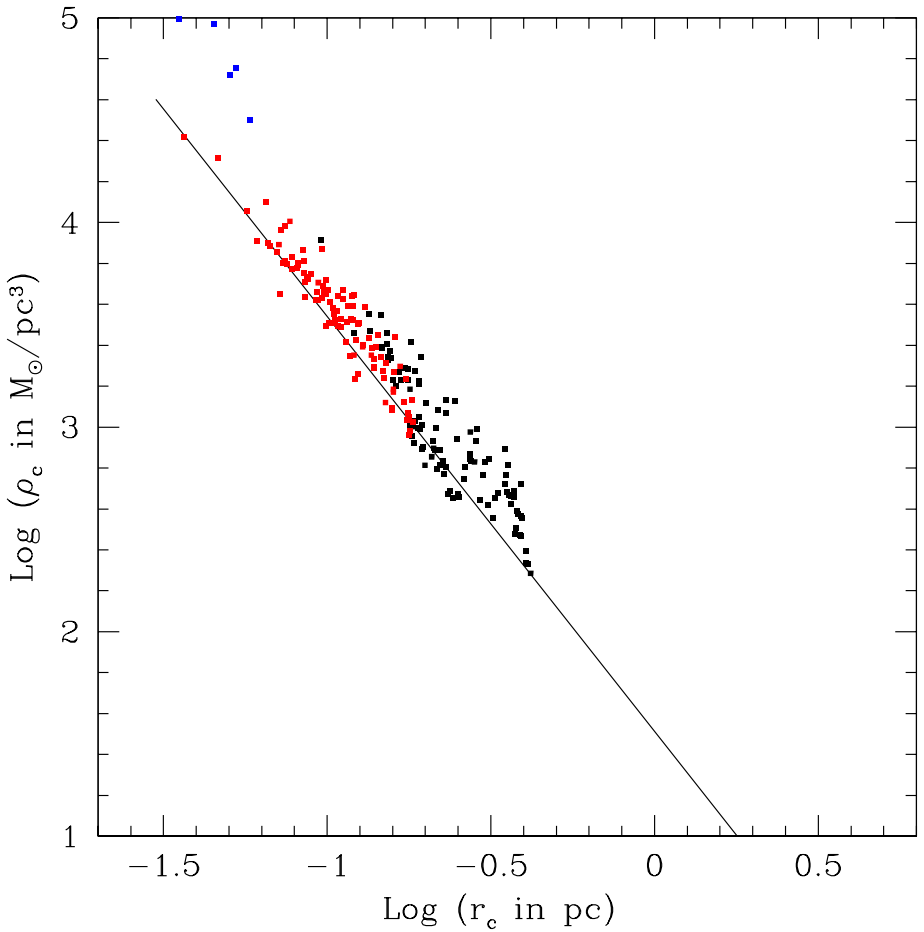
Gas mass = 100% of stellar mass

Initial r_c = 0.04, 0.2, 0.4 pc

0-10 Myr, snapshot every 10^5 years.

Gaussian – fit to MYStIX data

Central Density vs Core Radius



Black – initial r_c = 0.4 pc
Red – initial r_c = 0.2 pc
Blue – initial r_c = 0.04 pc

Line shows fit to the MYStIX data

Smallest clusters can reach higher densities than observed clusters

Gas is static in these models – impact of expulsion not seen

Results so far

- Simple models with some gas can reproduce distribution of core radii, and the central density-core radius trend in very young clusters
  - Especially if we take the embedded MYStIX clusters as an indication of initial core radii
- Gas seems to play a small role (if any) at these levels
  - What happens if we start with gas masses that are larger than the stellar mass?
- Are subclusters different than isolated clusters?

Future Work

- Continue to explore the simple models
- Add more realistic physics
  - Gas expulsion at various rates
  - More realistic feedback (e.g. Pelupessy & Portegies Zwart 2012)
  - Non-virialized & non-spherical initial conditions
- Use youngest MYStIX clusters as initial conditions for dynamical simulations: DR21
- Eventually: explore the stellar properties of these subclusters (mass segration etc)