Star clusters:
Nature or nurture?

Simon Goodwin

The University Of Sheffield.

Environments of young stars

We observe stars in *very* different environments with factors of >10^5 in density (Taurus to the core of R136).

Is there any sense in which their formation could be the ‘same’?

(Planet formation must be environment dependent as environment will matter on Myr timescales.)

Star cluster formation

When we observe a star cluster

a) did the stars form in a cluster at the density we see it now - or a higher density?
b) did the stars form at lower density and assemble into a cluster?

What is a cluster?

I will assume a star cluster:

Is a bound pc-scale system.

Has a fully-sampled IMF.

Has a mass >10^3 $M_\odot$ (density >10^2 $M_\odot$ pc^{-3}).

Clusters: ONC, NGC3603, R136, Wd1, Arches…
Not clusters: Taurus, Cham I, Serpens…

(ρ Oph an intermediate case.)

Incompatible statements?

‘Most stars form in clusters.’

‘Star formation is universal.’

Both of these statements cannot be true…

Universal star formation

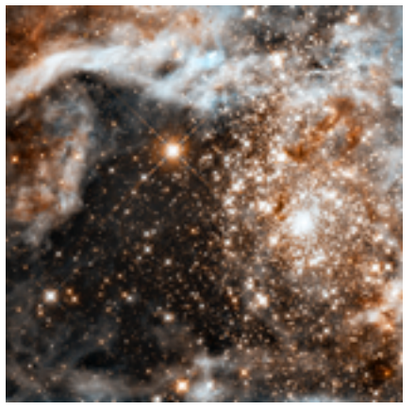
To be ‘universal’ the outcome of SF must always be statistically the same.

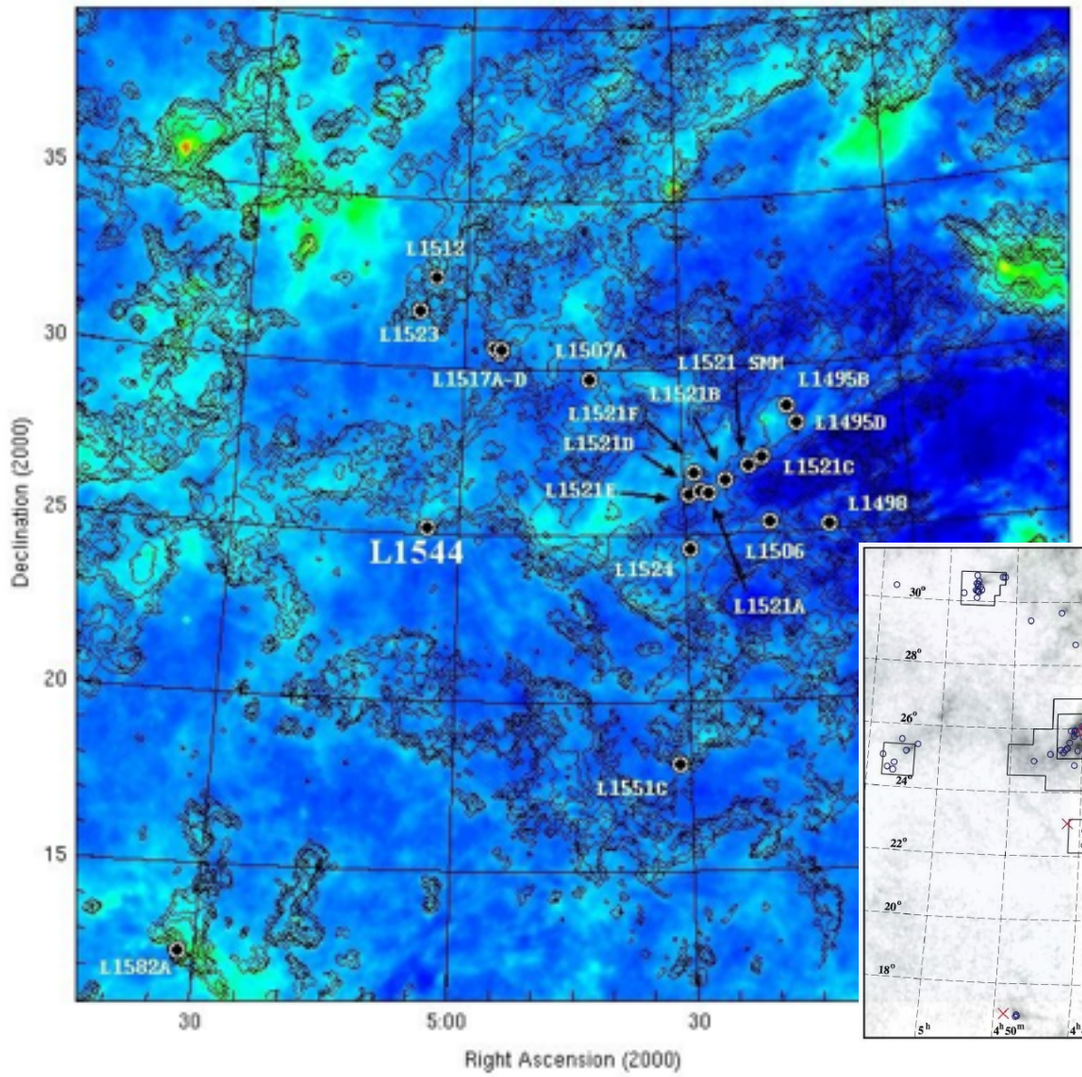
‘Mass assembly phase’ is universal: this sets (initial) system masses, multiplicity, mass ratios, disc properties.

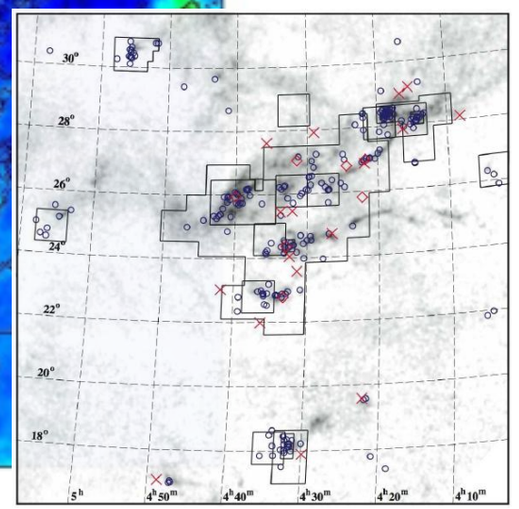
Embedded class 0/I phase of protostars (lasting 0.2-0.5 Myr?).

Local SF

~0.1 pc cores O($M_\odot$) collapse and fragment into multiple systems.
The mass assembly phase occurs in ‘isolation’ (systems do not know about each-other).







Star formation

Maximum density for systems to be ‘isolated’ is about 10^2 systems pc^{-3}.
Put typical ‘cores’ into clusters and the filling factor is ~1 and collisions/interactions inevitable.
Therefore the mass assembly phase would be very different - not universal SF…

Star formation

In ‘associations’ which we observe nearby and base much of our understanding of star formation have systems (cores) that go through mass assembly in isolation.

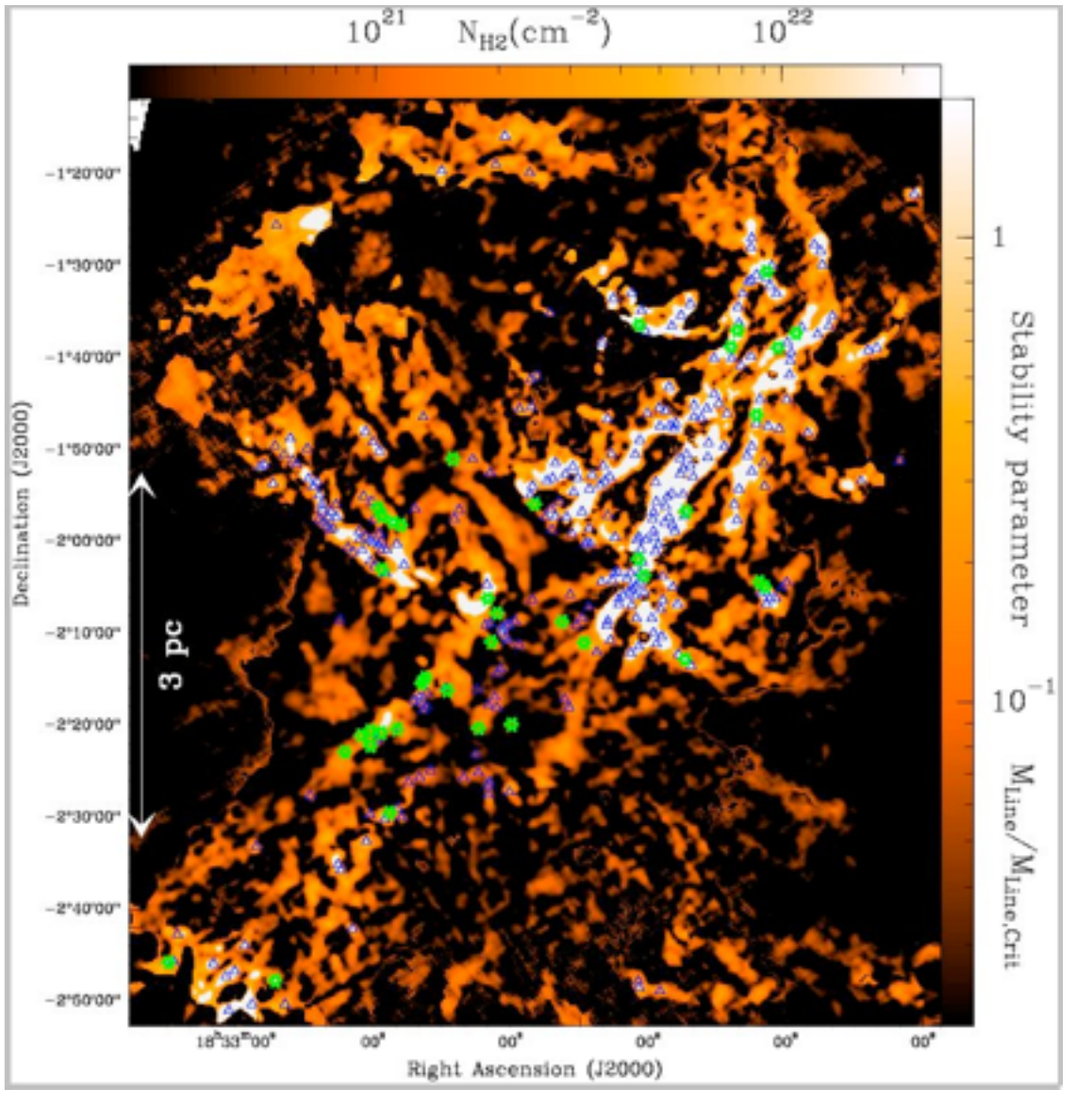
In ‘clusters’ star formation is dynamic and systems/stars assemble mass while being strongly influenced by the local environment.

<u>If star formation is universal it must be ‘isolated’ because we observe this locally.</u>

Or ‘universal’ has a different definition…

Hierarchical vs. clustered

Aquila has a cluster (W40, >10^3 $M_\odot$) and surrounding low-density star formation.
Two different modes in the same region? Or did W40 grow by accreting stars formed at lower density?



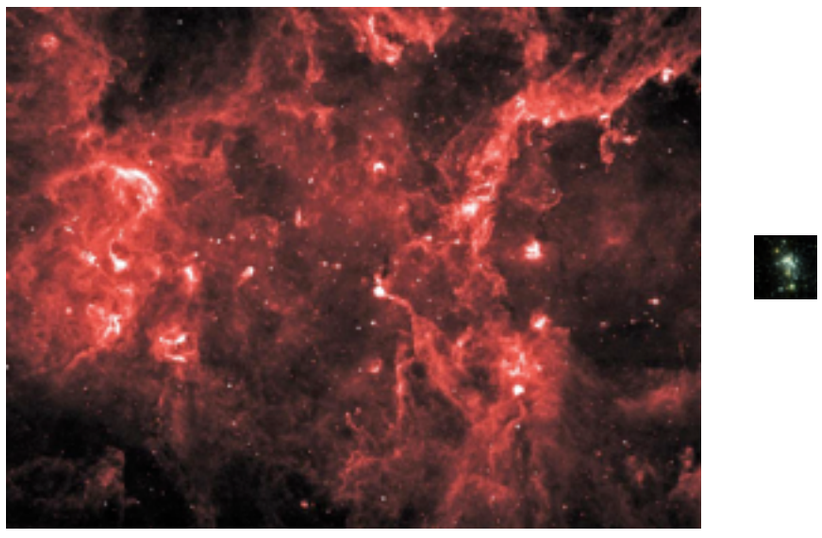
Konyves+

Cyg OB2 vs. Wd 1

Same mass (~10^5 M_{sun}) and same IMFs.
Cyg OB2 formed at ~100 stars pc^{-3} (Wright+).

So both knew they were going to be big? Did they form at the same low density and Wd1 collapse?

Different modes, but same IMF?



Implications for SF

We observe some (many?) stars forming in an ‘isolated’ mode.

- if some stars form in clusters SF is not universal.

If some (most?) stars form in clusters then they form in a dynamic environment very different to local SF.

- we don’t understand low-mass SF.

Implications for SF

Are star clusters nature or nurture?

If nature: big problem is getting so much gas together and then forming a full IMF (highly compressive flows?). SF is not universal - so how does it change, what is the importance of different modes?

If nurture: big problem is timescale, have to increase stellar density and build clusters in <2Myr.

Whichever is true I doubt young clusters are virialised star-gas Plummer spheres…

Implications for SF

Do we have different modes?

Is clustered SF a single mode or is SF in the ONC different to NGC3603 different to R136 (factor of 100 in density)?

What is the relative importance of different modes?