# The early evolution of star clusters


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constellation

# The origin of stars

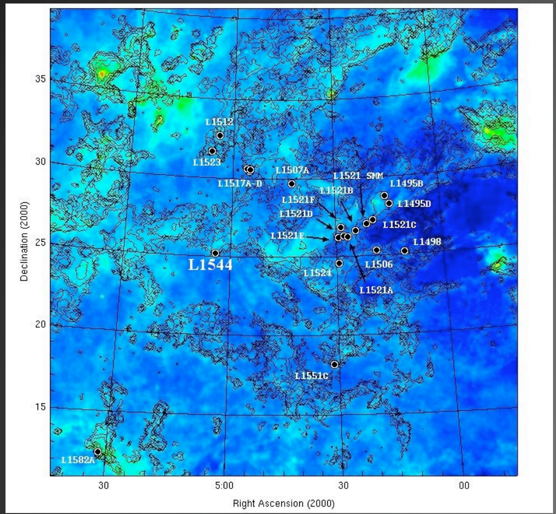
Most stars (70-90%?) form in clusters (of 10-$10^6$ $M_\odot$).

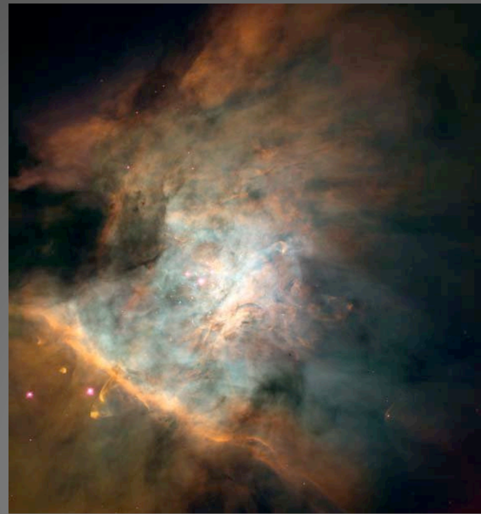
How important is environment? Is SF in Taurus and USco A, and Orion, and NGC3603, and R136, and Wd 1 the same? Is star formation* universal?

The IMFs always look similar. Might binary properties (separation and mass ratios in particular) be a more sensitive probe of star formation?

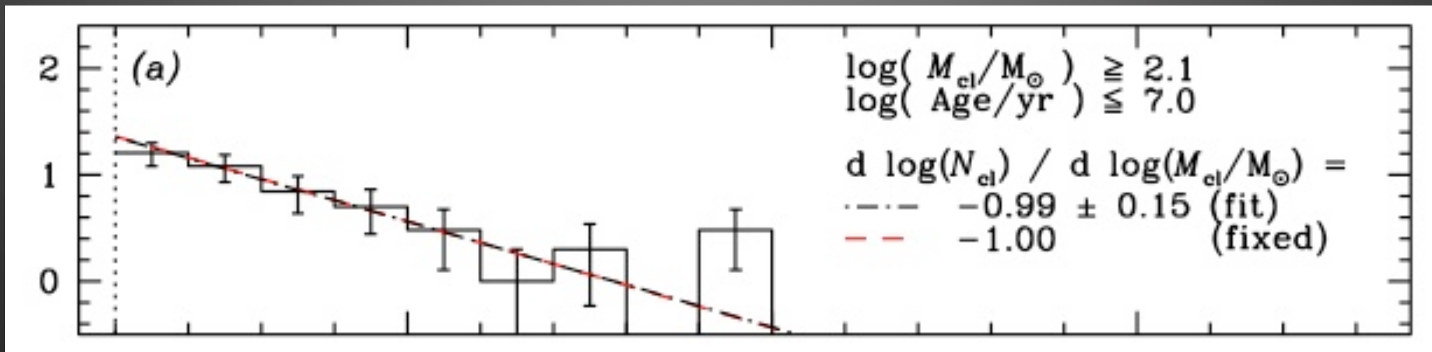
*the outcome at the end of the class I phase

# All clusters are equally important



Cluster MF: N(M) α $M^{-2}$




(Lada & Lada 2003; Lada 2009; de Grijs & Goodwin 2007 for SMC)

# All clusters are equally important

$N(M) \propto M^{-2}$

'Isolated' SF: about 25% of stars
Clusters $10^2$ - $10^3$ $M_\odot$ : about 25% of stars
Clusters $10^3$ - $10^4$ $M_\odot$ : about 25% of stars
Clusters $10^4$ - $10^5$ $M_\odot$ : about 25% of stars

Each mass is equally important and there is no such thing as a 'typical' cluster.

(is isolated SF just N=a few end of the cluster MF?)

# Is star formation universal?

We observe very different binary populations in different regions: Taurus has lots, Orion looks a bit like the field even though their IMFs are similar(ish).

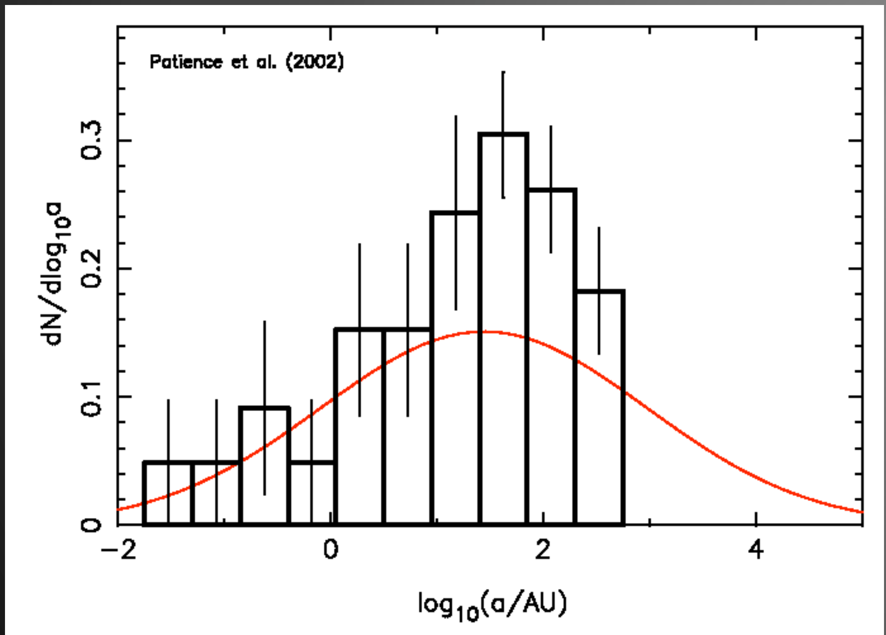
Is this primordial – (binary) star formation is fundamentally different in different regions?

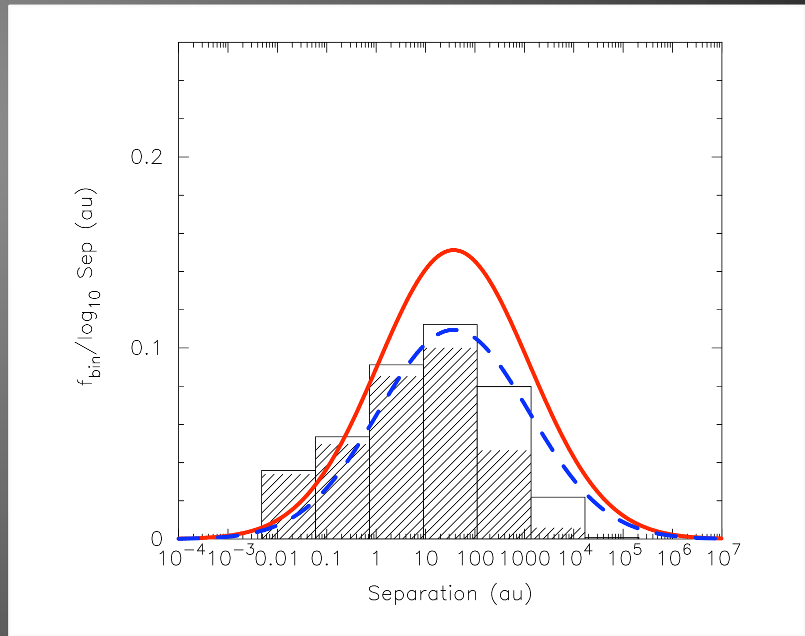
Is this due to dynamical processing – (binary) star formation is universal and then altered?

(Parker et al. 2009; Goodwin & Kouwenhoven 2009; Goodwin 2009)

# Dynamical processing

The primordial binary population is modified by dynamical interactions: the extent of which is mainly set by the densest phase of the cluster's evolution.




(lots of papers by Kroupa; Parker et al. 2009a,b)

# Early dense phases

What is important for binary processing is

a) The maximum density the cluster reached (not the current density). This sets the hard-soft boundary.

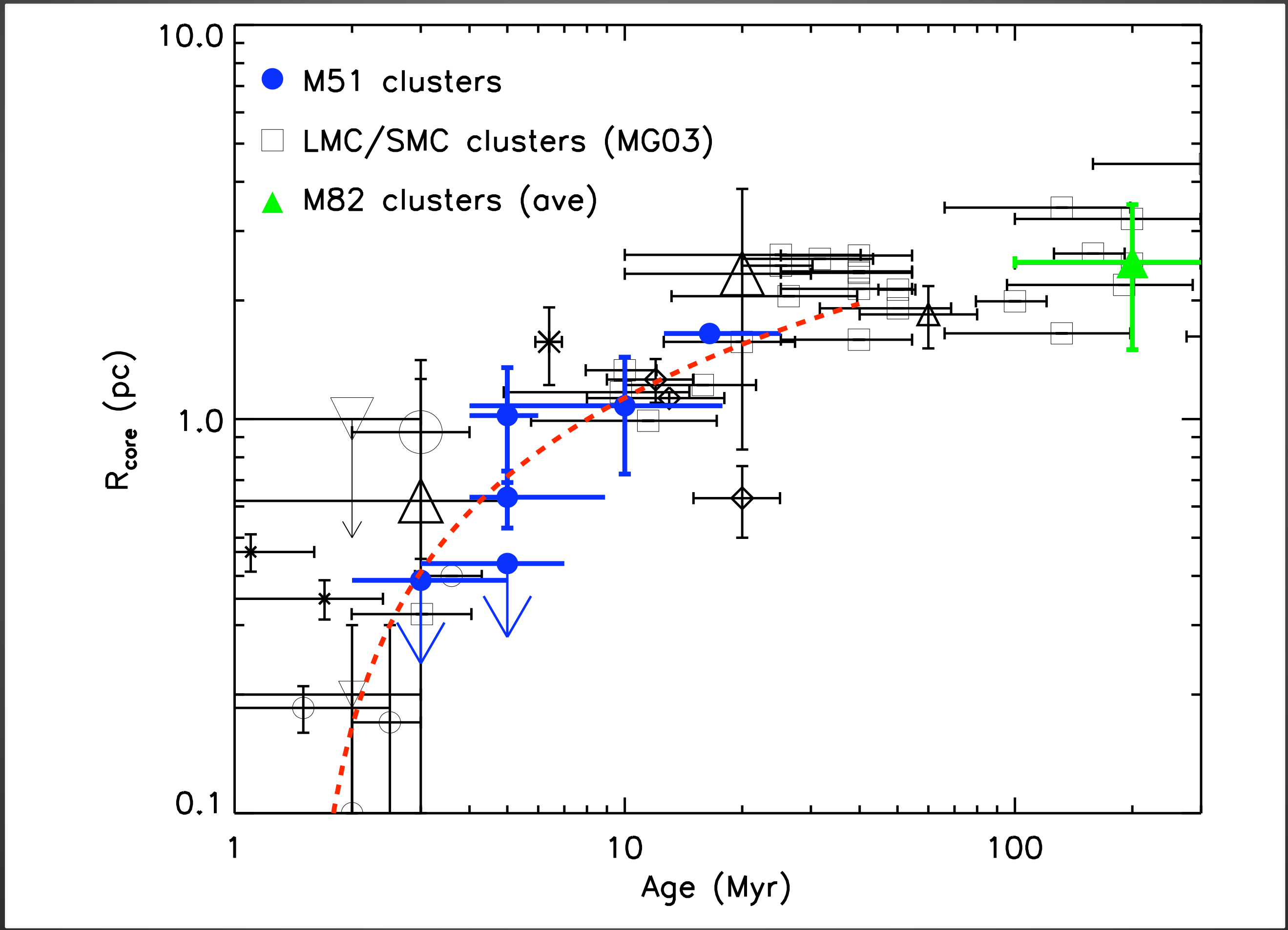
b) The dynamical age of the cluster – if it was denser in the past it might be dynamically very old, irrespective of current crossing time.

Note than many characteristics of a cluster might be instantaneous and varying very rapidly.

(Goodwin & Bastian 2006; Bastian et al. 2008; Parker et al. 2009)

# Early dense phases

Cold and clumpy = collapse and bounce.




(Bastian et al. 2008; Allison et al. 2009)

# Dynamical processing

So if you see a wide binary it must never have been in a dense environment…

| Object | Separation (mas) | PA (°) | Δflux (magnitudes) |
|---|---|---|---|
| **Known binaries detected:** | | | |
| VX Cas | 5340[1] | 165.3[1] | K:4.8[1] |
| V380 Ori | 125 ± 25[2] | 224.0 ± 2.0[2] | K:1.42[2] |
| HK Ori | 347.7 ± 2.5[2] | 41.8 ± 0.7[2] | V: 0.87[2] |
| T Ori | spectroscopic[4] + 7700 ± 200[3] | 72.6[3] | K:> 4.5[3] |
| V586 Ori | 990[1] | 30.3[1] | K:2.8[1] |
| HD 37357 | 186[5] | 49[5] | K:1.7[1] |
| V1788 Ori | 520[1] | 352.9[1] | K:3.5[1] |
| HD 245960 | 130[1] | 77.1[1] | K:1.5[1] |
| V350 Ori | 290[1] | 206.8[1] | K:3.2[1] |
| HD 45677 | | 150 ± 17[6] | |
| MWC 147 | 150[1] | 55.6[1] | K:3.8[1] |
| LKHα 215 | 8500[1] | 226.6[1] | K:4.8[1] |
| R Mon | 670[7] | 290.7[7] | K:4.9[1] |
| GU CMa | 654[8] | 194.5[8] | V:0.95 ± 0.02[8] |
| MWC 166 | 654[8] | 297.8[8] | V:1.41[8] |
| BD +40 4124 | 720[1] | 175.1[1] | K:5.4[1] |
| MWC 361 | 2250 ± 240[9] | 164 ± 1[9] | K:4.9[9] |
| SV Ceph | 1090[2] | 311.6[2] | K:5.5[2] |
| Il Ceph | 6960[9] | 147[9] | K:0.0[9] |
| MWC 1080 | 760 ± 2[4] | 267 ± 1[4] | K:3.25 ± 0.08[4] |
| **Known binaries not/possibly detected:** | | | |
| UX Ori | 22(min)[10] | 257.42 ± 18.42[10] | |
| MWC 758 | 2280[1] | 311.3[1] | K:8.3[1] |
| MWC 297 | 3930 ± 200[11] | 313 ± 2[11] | H:8.5 ± 0.25[11] |
| HD 179218 | 2540[1] | 140.5[1] | K:6.6[1] |
| BHJ 71 | 6170[1] | 29.2[1] | K8.3[1] |
| V1271 Ori | 8380[1] | 294.7[1] | K6.7[1] |
| V590 Mon | 5007[1] | 97.1[1] | K6.6[1] |
| **New detections of binary systems:** | | | |
| V1366 Ori, HD 35929, RR τ, MWC 120, V742 Mon, OY Gem, HD 76868 and HD 81357 | | | |
| **Possible new detections:** | | | |
| V594 Cas, IP Per, MWC 480, V1012 Ori, V346 Ori, MWC 790, MWC 137, and HD 190073 | | | |

>60% of ‘isolated’ Herbig Ae/Be stars are in fairly wide binaries (>100 au, probably a few hundred au).

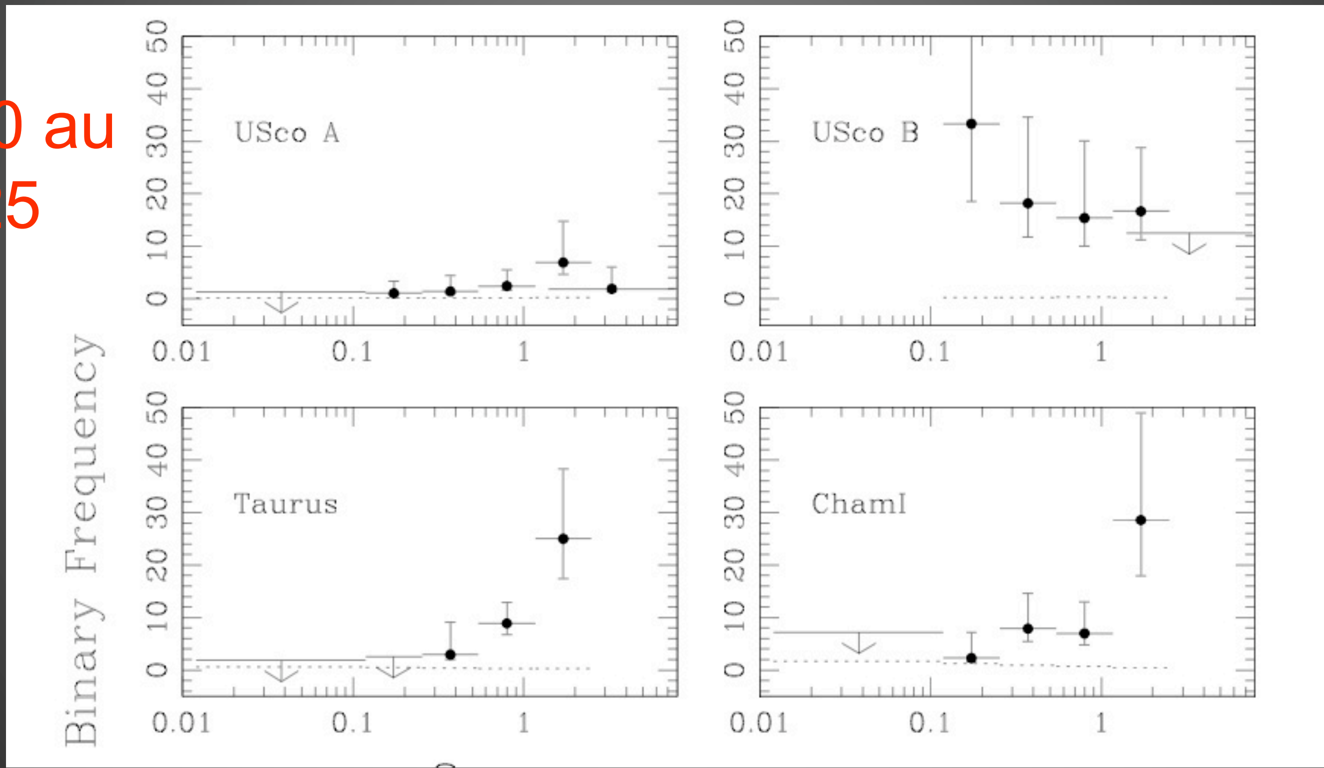
Did these form in isolation? Or are they the remnants of destroyed clusters?

(Wheelwright et al. 2009)

# Different star formation?

So different properties in different regions might reflect different initial populations or different processing.

330-1650 au
q > 0.25




(Köhler et al. 2000; Bouy et al. 2006; Kraus & Hillenbrand 2007+)

# Massive binaries

2 of 3 very massive systems in NGC 3603 are few day binaries. (Including a 116-89 $M_{\odot}$ system).

But R136 has maybe only 1 of 6.

Is this significant? Is it different formation (how *do* you form them?), or the result of dynamical evolution (core collapse hardening?).

(Schnurr et al. 2008, 2009)

# Is SF universal?

Different regions have different binary properties.

- In some regions this can be explained by dynamical processing: Taurus to Orion works perfectly well (on the other hand, different initial populations can also work).

- In some regions it might not: USco A and USco B, and Taurus/ChamI are dynamically young, and have different wide binary populations. What about massive close binaries in NGC 3603 and R136?

# A rant about M-dwarfs

The most common mode (90%!) of star formation is M-dwarfs: star formation *is* M-dwarf formation.

M-dwarf binary properties contain most of the information about star formation. And there are so many of them the statistics are as good as we can get.

Massive stars, brown dwarfs, and G-dwarfs contain far less information so why are we so obsessed by them but not M-dwarfs?

# A rant about the field

The field is the sum of star formation in *all clusters* (and isolated SF). All of this star formation will have been dynamically processed to some degree depending on density, mass, initial binary properties etc.

Comparing cluster simulations to the field is pointless.

If it looks like the field it might not be right, if it doesn't look like the field it might be right.

What must be right is that if star formation is universal, it is NOT like the field.

# Summary

- All masses of clusters are equal contributors to SF, there isn't a 'typical' cluster.
- Young clusters can be very out-of-equilibrium so their properties are instantaneous.
- Binary properties are probably the key to star formation but they get processed in clusters.
- Do binary properties vary with environment? Is it a signature of fundamentally different SF? Or nothing important?
- M-dwarfs contain most of the information about star formation.