Simulation of binaries properties in a fragmented cluster

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PhD work with
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Introduction

**Aim of my PhD:** try to simulate the complexity of star forming region (SFR):

- Multiphysical process
- Deal with large to small spatial scales

**First work:** made with the AMUSE platform on binaries

**Question:** Are stars of the field born in observed SFR?

- Difference between the binaries in the field and in SFR:
Same architecture and interface to use lots of different codes

Allow to compute multiphysics with the code you want

Code developed in Leiden
By Portegies Zwart et al
https://github.com/amusecode/amuse
The AMUSE multiple module

- Pure Nbody code usually numerically complex
- AMUSE Multiple module:
  uses different code to model different scale:
  (2+1 pure Nbody solver)
  - one for the whole cluster (top level)
  - two for the multiple systems (smallN)
Initial conditions:
- Cluster of 100 stars in a virialized king model
- With canonical IMF
- ~30% of binaries randomly positionned following observational parameters (review of Duchêne and Kraus 2013)

<table>
<thead>
<tr>
<th>Mass range</th>
<th>Multiplicity fraction</th>
<th>Mass fraction</th>
<th>Semimajor axis [AU]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLM type</td>
<td>0.22 ± 0.05</td>
<td>$q^{4.2}$</td>
<td>logNormal ($\mu=4.5$, $\log\sigma = 0.5$)</td>
</tr>
<tr>
<td>[0.01M$\odot$; 0.1M$\odot$]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M type</td>
<td>0.26 ± 0.03</td>
<td>$q^{0.4}$</td>
<td>logNormal ($\mu=5.3$, $\log\sigma = 1.3$)</td>
</tr>
<tr>
<td>[0.1M$\odot$; 0.7M$\odot$]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar type</td>
<td>0.44 ± 0.02</td>
<td>$q^{0.3}$</td>
<td>logNormal ($\mu=45$, $\log\sigma = 2.3$)</td>
</tr>
<tr>
<td>[0.7M$\odot$; 1.5M$\odot$]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A type</td>
<td>[0.5; 0.7]</td>
<td>$q^{-0.5}$</td>
<td>logNormal ($\mu=350$, $\log\sigma = 3$)</td>
</tr>
<tr>
<td>[1.5M$\odot$; 5M$\odot$]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B type</td>
<td>[0.6; 0.7]</td>
<td>$q^{-0.5}$</td>
<td>Uniform(0.15, 15)</td>
</tr>
<tr>
<td>[5M$\odot$; 16M$\odot$]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O type &gt; 16M$\odot$</td>
<td>[0.8, 1]</td>
<td>$q^{-0.5}$</td>
<td>Uniform(0.15, 15)</td>
</tr>
</tbody>
</table>
Evolution during 20 Myr:

- Unstable system
- Lots of collisions in the first Myr: leads to mass segregation
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First basic simulation

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Evolution during 20 Myr:
- Unstable system
- Lots of collisions in the first Myr:
  - leads to mass segregation
  - Modifies the binaries properties
Binaries properties

Initial conditions

Primary mass evolution

Number of binaries

Mprim [MSun]

10^{-1} 10^{0} 10^{1}
Binaries properties

After 10 Myr

Primary mass evolution

Number of binaries

Mprim [MSun]
Binaries properties

Initial conditions

Semimajor axis distribution

Number of binaries

\[ \text{Number of binaries} \]

\[ a \text{ [AU]} \]

\[ 10^{-1} \text{ to } 10^{3} \]
Binaries properties

After 10 Myr

Semimajor axis distribution

Number of binaries

10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}

a [AU]
Binaries properties

Initial conditions

Eccentricities distribution

Number of binaries

$\text{e}$
Binaries properties

After 10 Myr

Eccentricities distribution

Number of binaries

e

0.0 0.2 0.4 0.6 0.8
Julien Dorval PhD work:
- Adiabatic expansion of a 100k stars cluster (no hydro)
- leads to fragmentation

Extract cubes of 3-5k stars and select subgroups with MST method of ~100 stars.
Fragmented cluster

- Auto-coherent method to generate initial conditions
- Mass segregated
- Multiplicity rate ~30%
Fragmented cluster

Initial conditions

Primary mass evolution

Number of binaries

$M_{\text{prim}}$ [MSun]

$10^{-1}$ $10^0$ $10^1$
Fragmented cluster

After 10 Myr

Primary mass evolution

Number of binaries

$M_{prim}$ [MSun]
Fragmented cluster

Initial conditions

Semimajor axis distribution

Number of binaries

$10^0$    $10^1$    $10^2$    $10^3$    $10^4$

$a$ [AU]
Fragmented cluster

After 10 Myr

Semimajor axis distribution

Number of binaries

$\frac{r}{\text{[AU]}}$

$10^0$ $10^1$ $10^2$ $10^3$ $10^4$
Fragmented cluster

Initial conditions

Semimajor axis distribution

Number of binaries

$10^0$  $10^1$  $10^2$  $10^3$  $10^4$

$a$ [AU]
After 10 Myr

**Fragmented cluster**

![Semimajor axis distribution](image)

Number of binaries

$\text{a [AU]}$
Fragmented cluster

Initial conditions

Eccentricities distribution

Number of binaries

0.0 0.2 0.4 0.6 0.8

e
Fragmented cluster

After 10 Myr

Eccentricities distribution

Number of binaries

0 1 2 3 4 5 6 7 8
0.0 0.2 0.4 0.6 0.8 e
Summary:
- Binary evolution very sensitive in star formation environment
- How precise the observed binary properties distribution are?

Perspective:
- Add stellar evolution to compute the stars luminosity and extract luminosity maps
- Add gas