Extremely short dynamical lifetimes of young massive stellar groups

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Massive star formation is thought to occur in groups.

We have modelled the dynamical evolution of several young groups:

- The minicluster Theta 1 Ori B
- The Orion Trapezium itself
- 10 additional massive (O-B3) trapezia

We perform N-body integrations, using as initial conditions best available data for planar positions, transverse velocities, radial velocities, masses, and distances. Unavailable data are modelled randomly, within realistic intervals.
LBT AO Brγ (2.16 μm) images of the θ1 Ori B group. Resolution 006. Logarithmic color scale. North is up and east is to the left. Strehl is ~75% (Close et al. 2013).

Note that the object "B1" is really an eclipsing spectroscopic binary (B1-B5), where the unseen companion B5 orbits B1 every 6.47 days (Abt et al. 1991).
The system θ¹ Ori B (now)

Image in H band. Companion B6 at 13 mas (5.3AU) separation. Martina et al. 2018
GRAVITY Collaboration
The system Theta$^1$ Ori B

Allen et al. (2015) tried to answer the questions:

Is the group Theta$^1$ Ori B long-term stable?
Is orbit B2- B3 long-term stable?

-Precise positions and relative (transverse) velocities were available.
-Since z-positions and radial velocities were unknown we used N-body Monte Carlo simulations to provide insight.
The system Theta¹ Ori B

Are our results still valid with new data?

- System B1+B5 was assumed to act like a point mass
  New system B1+B5+B6 also acts like a point mass

- Mass of B1+B5 was taken as 14 Mo
  New mass of B1+B5+B6 is \((7+2+5) = 14\) Mo

- Orbit of B6 around B1+B5 is now in process (Costero et al. 2019). Detailed interaction of B1+B5+B6 with other components will be modelled in the future
Results

Three sets were computed, 100 realizations each. 

\( Tc = 5, 10, 100 \) (1500-30 000 years)

<table>
<thead>
<tr>
<th></th>
<th>5</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable</td>
<td>29, 39, 35</td>
<td>18, 26, 22</td>
<td>1,1, 4</td>
</tr>
<tr>
<td>Triple</td>
<td>43, 40, 49</td>
<td>42, 46, 55</td>
<td>19, 28, 31</td>
</tr>
<tr>
<td>Dissolved*</td>
<td>28, 21, 16</td>
<td>40, 28, 23</td>
<td>80, 71, 45</td>
</tr>
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*Double^2 | 6, 1, 0 | 6, 4, 4 | 7, 5, 9 |
Theta¹ Ori B: Summary

- The sextuple system Theta¹ Ori B is a bound group, but extremely unstable dynamically.

- It will probably disintegrate in less than 30,000 yr, producing binaries ($<a>=80$ au, but some as close as 6 au), triples, and many escapers.

- Most escapers are low velocity, but some runaway stars were produced (7% with $v>21$ km/s).

- The orbit B2-B3 is rapidly disrupted
Modeling now the Orion Trapezium

Transverse velocities (with respect to to C):

<table>
<thead>
<tr>
<th>Separation Velocities</th>
<th>Projection Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: $-2.3 \pm 0.7$ km/s</td>
<td>221.9 degrees</td>
</tr>
<tr>
<td>B: $-1.4 \pm 0.9$</td>
<td>72.9</td>
</tr>
<tr>
<td>C: 0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>D: $-0.9 \pm 0.6$</td>
<td>151.8</td>
</tr>
<tr>
<td>E: $+5.7 \pm 0.8$</td>
<td>51.5</td>
</tr>
</tbody>
</table>
Modelling now the Orion Trapezium

Systemic radial velocities (with respect to to C):

A: 0.7 ± 1.0
B: -1.3 ± 1.0
C: 0.0
D: 5.1 ± 3.0
E: 7.0 ± 1

NB. In order for none of the bright components to have radial velocities exceeding the escape velocity we took the average of the two best observational values for C
Aggregate masses of the components:

A: 27 (+-1.35) Mo
B: 15 (+-0.75) Mo
C: 45 (+-10) Mo, or 65(+3.25) Mo
D: 25 (+-1.25) Mo
E: 7 (+-0.35) Mo

All components will be considered as point masses for the N-body integrations
Main difficulty: Multiplicity in the Orion Trapezium

C: astrometric and spectroscopic binary, possibly with a third companion. It is also an oblique magnetic rotator

A: eclipsing and spectroscopic binary with a probable interferometric companion (now confirmed)

B: eclipsing binary, with a third star, and with three additional interferometric companions, i.e. it is a sextuple mini-cluster

D: spectroscopic binary (now with 3\textsuperscript{rd} close companion)

E: escaping spectroscopic binary

Hence, systemic velocities and masses are VERY difficult to obtain, and have large observational uncertainties
Monte Carlo models of the Orion Trapezium

- As initial conditions we take the planar positions and velocities of Olivares et al (2013)
- $z$-positions are randomly assigned, with a dispersion of 1500 AU
- Radial velocities and masses are taken from the literature - with caution!
- Random perturbations compatible with observational uncertainties are applied to all quantities
- For the integrations we use the Mikkola & Aarseth code, which includes chain regularization.
Results: lifetimes

![Graph showing lifetimes of different masses.](graph.png)
Results: lifetimes

\[ M_C = 65M_\odot \]
Orion Trapezium results:

- Lifetimes (<10,000 yr) are extremely short with M(C) = 45 Mo

- Lifetimes more reasonable (about 30,000 yr) with M(C) = 65 Mo

- The dynamical lifetime of the Orion Trapezium agrees with the age (<30,000 years) we found for one of its components, the mini-cluster Theta¹ Ori B, provided we assume M(C) = 65 Mo.

- Star E always escapes right at the beginning (within 2-3 thousand years)

- Reversing the runs, Star E is recaptured in 26% of the cases
Orion Trapezium results-cont.

- The end result of integrations is a wide binary ($a_0 = 2000$ au) or a hierarchical triple. No closer binaries ($a < 250$ au) were formed.

- The ejected stars have low velocities. No runaways were formed.

- No very close encounters occurred.

- The properties of the resulting binaries (distribution of major semiaxes, of eccentricities, the period-semiaxis relation) are similar to those observed.
Other massive trapezia

- From the literature we collected data for 10 additional trapezia of types B3 and earlier, so as to minimize contamination by optical or pseudo-trapezia.

- We obtained Monte Carlo realizations of 100 systems for each trapezium and performed N-body integrations.

- Most systems turned out to be unbound. Since the masses are quite uncertain (due to undetected companions, etc.) we doubled their value. A few additional systems became bound.
Other trapezia-results

- Lifetimes for bound systems (ADS 719) are around 15 000 years.

- Many non-hierarchical triples survive for as long as 300 000 yr.

- Unbound systems disperse in less than 10 000 years.

- Doubling the values of the (uncertain) masses a few more systems become bound, with similar lifetimes.

- Frequency distributions of major semiaxes and eccentricities of binaries formed were obtained. Those of bound systems resemble observed distributions of wide binaries.
Conclusions

- The (future) dynamical lifetimes we find by Monte Carlo N-body simulations of the Orion Trapezium and other massive trapezia are all very short.
- With a larger mass for the system Theta¹ Ori C (65 Mo), lifetimes become comparable to the ages of other young structures in the Orion region (from about 500 to 15,000 - 30,000 years).
- N-body simulations of 10 O-B3 trapezia result in many unbound systems, and very short lifetimes (15 000 yr for bound systems).
- Doubling the masses results in slightly longer lifetimes and a larger number of bound systems.
- Many binaries are formed, with properties similar to observations. This is relevant to problem of observed massive star multiplicity (with separations from a few to thousands au).
Discussion

A possible problem: are the disintegration times too short?

- In the Orion region there are other extremely young structures. Examples: the BN-I-n object (500 years, Rodriguez et al. 2005, Gomez et al. 2008), the Orion Nebula itself (illumination age: 15,000 yr, O´Dell et al. 2009)

- The dynamical age of Theta¹ Ori agrees with that of one of its components (B: the mini-cluster): about 30,000 years

- We should remember that masses and radial velocities are very uncertain (problem of multiplicity)
- If O-stars are formed in trapezium-like groups, then the extremely short dynamical lifetimes and the large number of unbound systems imply that trapezia should be rare in the field.

- Indeed, there are about 800 O-stars (B<12, Maiz-Apellaniz et al. 2013), but we found only 3 true O-trapezia.

- The mean age of an O-star is about 500,000 yr, large compared to the dynamical lifetimes (<50,000 yr). If O stars are formed in trapezium groups, there should be about 80 observed O-trapezia.

- The scarcity of field trapezia is compatible with their extremely short lifetimes (<10,000 yr). Only a few survivors are found!
Thank you