What causes the low Multiplicity in the Orion Nebula Cluster?

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The Problem

The binary frequency in the Orion Nebula Cluster is
\[ \sim 2 - 3 \text{ times lower than in Taurus-Auriga} \]
\[ \sim 1.5 \text{ times lower than among solar-type main-sequence stars} \]
Theories

Bonnell & Kroupa (1998):
Binaries are destroyed in close encounters with other stars

Durisen & Sterzik (1994):
The formation rate of binaries depends on the precollapse cloud conditions (e.g. temperature)
Interaction time as function of radius

Time between interactions: \( \tau \propto (n\sigma S)^{-1} \)

Stellar density: \( n \propto r^{-2} \)

Velocity dispersion: \( \sigma \approx \text{constant} \)

Binary cross section: \( S = \text{constant} \)

\[ \implies \tau \propto r^2 \]

With typical numbers, for a 0.5 arcsec binary in Orion:

\( \tau \approx 1 \text{ Myr} \) in the center

\( \tau \gtrsim 250 \text{ Myr} \) at \( r = 1 \text{ pc} \)
Observations in the Periphery of the ONC

- Adaptive Optics observations in K with ADONIS at the 3.6 m Telescope on La Silla and NIRC2 at the Keck Telescope on Mauna Kea
- Select stars from Jones & Walker (1988)
  - brighter than $I = 12.5 \text{ mag}$
  - at radii 5 – 15 arcmin (0.7 – 2 pc) from center

⇒ 52 Fields

(11 observed with Keck, the rest with ADONIS)
Example: Field around JW0971

- 2MASS image
- ADONIS image

70 arcsec
12.8 arcsec
The Sample

- 52 fields containing some 230 stars
- + 134 stars in the core region (Petr 1998)

Binaries with
- separation $> 0''13 = 60 \text{ AU}$ (diffraction limit)
- separation $< 1''12 = 500 \text{ AU}$ (chance alignment)
Corrections

- subtract chance alignments
  \[ (= \text{area} \times \text{surface density}) \]
- (in)completeness
Masses

- 166 stars in Hillenbrand (1997) (masses from spectroscopy and photometry)
- 145 mass estimates from IR-photometry
## Results

<table>
<thead>
<tr>
<th>Mass range</th>
<th>Systems</th>
<th>Binaries</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 M⊙</td>
<td>33</td>
<td>0</td>
<td>0 ± 0%</td>
</tr>
<tr>
<td>0.1 – 2 M⊙</td>
<td>227</td>
<td>11</td>
<td>4 ± 2%</td>
</tr>
<tr>
<td>&gt; 2 M⊙</td>
<td>48</td>
<td>9</td>
<td>17 ± 6%</td>
</tr>
</tbody>
</table>
Binary Stars in the Orion Nebula Cluster

Stars with $M < 2M_\odot$

Fraction of binaries

Distance from cluster center [pc]
Conclusion so far:

This is not the effect we are looking for!

*Köhler et al., A&A 458, 461 (2006)*
(from Sterzik & Durisen 2003, A&A 400, 1031)
Low-Mass Stars (0.1 – 2 M⊙)

- Orion: 3.4 ± 1.5 %
- Taurus-Auriga: 14 ± 3 % (Köhler & Leinert 98)
- Main-sequence stars:
  - solar-type: 9 ± 2 % (Duqennoy & Mayor 91)
  - M-dwarfs: 3 ± 2 % (Reid & Gizis 97)

Companion star frequency corrected for chance alignments and completeness
Mass Distribution of the Orion Sample
Mass Distribution of the Orion Sample
Low- and Lower-Mass Stars

Orion

\[ 0.45 < M \leq 2 \quad 8 \pm 3\% \ (79 \text{ systems, 6 bin.}) \]

\[ 0.1 < M \leq 0.45 \quad 5 \pm 2\% \ (147 \text{ systems, 7 bin.}) \]

Main-sequence stars

solar-type \quad 9 \pm 2\% \ (Duqennoy & Mayor 91)

M-dwarfs \quad 3 \pm 2\% \ (Reid & Gizis 97)

No corrections!
Conclusions so far

- Multiplicity in Orion is not exceptionally low
  ≈ main-sequence stars of comparable mass
  (⇒ make sure you know what you observe!)

- much lower than in Taurus-Auriga

- not (strongly) dependent on radius

Observations with NACO/VLT

- Adaptive Optics observations in J, H, K
- include cluster center
- 3 nights in December 2004
- 27 fields,
  - ∼ 415 stars detected,
  - ∼ 131 in 2MASS – 21 binaries (16%)
Low- and Lower-Mass Stars

(NACO + Periphery)

Orion

0.45 < M ≤ 2 \quad 11 \pm 3\% \quad (100\ systems,\ 11\ bin.)

0.1 < M ≤ 0.45 \quad 4 \pm 2\% \quad (131\ systems,\ 5\ bin.)

Main-sequence stars

solar-type \quad 9 \pm 2\% \quad (Duqennoy\ &\ Mayor\ 91)

M-dwarfs \quad 3 \pm 2\% \quad (Reid\ &\ Gizis\ 97)

No corrections!
ONC compared to Main Sequence

![Graph showing ONC compared to Main Sequence](image)
To Do

- Photometric calibration
- Measure binary separations
- Corrections for completeness & chance alignments
- Study separation distribution
- Dependence on position in cluster?
Conclusions

- Multiplicity in Orion is **not** exceptionally low
  \[ \approx \text{main-sequence stars of comparable mass} \]
- much lower than in Taurus-Auriga
- not (strongly) dependent on radius