Time Variable Photo-Evaporation of Protoplanetary Disks

DDA Meeting
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Orion Constellation (visible light)
Orion constellation
H-alpha
Orion constellation
H-alpha

Orion Molecular Clouds

$>10^5 \, M_{\text{sol}} \quad 100 \, \text{pc long}$
Orion core (visible light)
Orion Star Forming Region

- Closest bright star-forming region to Earth
- Distance ~ 1500 ly
- Age ~ 10 Myr
- Radius ~ few ly
- Mean separation ~ $10^4$ AU
Orion Trapezium cluster

O/B stars

Low mass stars;
Disks with tails
• 100+ disks directly observed, diameters 100-1200 AU
• 80%+ of stars in Orion show evidence for having disks

These stars are too distant and young to directly search for planets... but we want to study the environment and processes to understand the planets which would be produced in these dense clusters -- and therefore throughout the galaxy.
## Regions of Star Formation

<table>
<thead>
<tr>
<th></th>
<th>Large Dense Clusters: Orion</th>
<th>Small Sparse Clusters: Taurus</th>
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</thead>
<tbody>
<tr>
<td><strong># of stars</strong></td>
<td>$10^3 - 10^4$</td>
<td>$10 - 100$</td>
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<tr>
<td></td>
<td>$10^4$ stars in last 10 Myr (Orion)</td>
<td></td>
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<tr>
<td><strong>OB stars</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Distance</strong></td>
<td>450 pc (Orion)</td>
<td>140 pc (Taurus)</td>
</tr>
<tr>
<td><strong>Distance between stars</strong></td>
<td>5000 AU</td>
<td>20,000 AU</td>
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<tr>
<td><strong>Dispersal lifetime</strong></td>
<td></td>
<td>Few Myr</td>
</tr>
<tr>
<td><strong>% of stars with disks</strong></td>
<td></td>
<td>$&gt; 80%$</td>
</tr>
<tr>
<td><strong>% of stars that form here</strong></td>
<td>$70-90%$</td>
<td>10-30%</td>
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**Orion:** Hot, Dense, Massive

Most stars form in large clusters.

**Taurus:** Dark, Small, Cold

Most planet formation models study small clusters.
How does Cluster Environment affect Disk Evolution?

Work we have done involves ...

– UV photo-evaporation from massive stars

– Interaction with cluster gas

– Close stellar encounters

– Organics and UV photolysis from massive stars

Photo-evaporation controls disk structure in large clusters, where nearly all stars form.
Photo-Evaporation in Orion

- Disks surrounding solar-type stars are heated by UV-bright stars.
- Gas is heated and removed from disk on 1-10 Myr timescales.
- If disk is removed quickly, we can’t form planets!
Photo-evaporation from external O stars removes disks in $10^5$-$10^6$ years.
Triggered Planet Formation?

Photo-evaporation removes gas and allows gravitational instability to form planetesimals.
Disk Photo-Evaporation

Mass loss rate from disk: \[
\frac{dM}{dt} = 4\pi r_d^2 v_0 n_0 m_H
\]

Disk surface gas density \( n_0 \)
Gas velocity \( v_0 \sim T^{1/2} \sim (F_{UV})^{1/2} \sim R^{-1} \)
Gas mass \( m_H \)
Disk radius \( r_d \)
Distance from O star \( R \)

Virtually all previous PE models assume static stellar positions: \( R \sim 0.1 \text{ pc} \sim 20,000 \text{ AU} \).

But we know that stars move quickly, with many cluster crossings in first several Myr.
We performed N-body simulations to look at how distance between disks and external O star changes over few Myr.
N-body sims track individual history of solar-mass stars in large Orion-like clusters.
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We couple N-body sims, PE, and a viscous disk evolution model:

\[ M_d = 0.05 \, M_\odot \]
\[ r_d = 100 \, \text{AU} \]
\[ \Sigma = -3/2 \]
\[ \alpha = 0.01 \]
Photo-evaporation is highly episodic.
90% of the UV flux is deposited during 10% of the time.
Real clusters will have more variability than our models: more O stars, stellar evolution, ISM structure, disk structure, etc.
Variability causes a diversity of disk structures and masses, even for disks of the same age and composition formed in the same cluster.