The Effect of Ionizing Feedback on Turbulent Molecular Clouds

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Star Formation in the Pillars in M16

• OMP-parallel tree/SPH-Code: iVINE: Ionization + VINE
• Following the radiation along a grid of line-of-sights (ray shooting)
• The size Δy of the rays is determined by the smoothing length close to the area of infall
• As soon as the ray size gets twice as large as the local smoothing length, the ray is refined.
Ionization of a Turbulent Cloud

- the radiation sweeps up hydrogen and triggers it into collapse

Turbulent box (Mach 5):

<table>
<thead>
<tr>
<th>Particles</th>
<th>T</th>
<th>( n_{\text{mean}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2 Mio</td>
<td>10 K</td>
<td>300 cm(^{-3})</td>
</tr>
</tbody>
</table>

Source of ionization:

\( F_0 = 5 \times 10^9 \) photons cm\(^{-2}\)

\( \rightarrow \) spatial resolution as high as 0.03 pc
\( \rightarrow \) with self-gravity (open boundaries)

\( \rightarrow \) \( M_{\text{part}} \sim 10^{-4} \) M\(_{\odot}\)
\( \rightarrow \) hydrodynamics: periodic boundaries
Driving Turbulence

\[ v' = \rho^{1/2} v \]

\[ 10^2 \text{cm}^{-3} < \rho < 10^4 \text{cm}^{-3} \]

Conversion efficiency:

\[ \sigma = \frac{e_{\text{turb}}}{e_{\text{Ly}}} \approx 2 \cdot 10^{-5} \]

Previous estimates:

\[ \sigma \approx 2 \cdot 10^{-6} \]

(e.g. MacLow & Klessen, 2004)

See also Poster EP6 by Mohaddesseh Azimlu
Pillar and Core Formation

$M_{core} \sim 0.7 M_{\odot}$

$M_{pillarI} \sim 12 M_{\odot}$

$M_{pillarII} \sim 8 M_{\odot}$

$t = 550$ kyr
The Dancing Queen Trunk

Gahm et al. 2006, A&A, 454, 201:

[Diagram of data analysis]
A very likely formation mechanism
Parameter Study

- fiducial (M5, k=1..4)
- lower resolution
- boundary conditions
- warm gas
- low flux
- high flux
- low density
- k=4..8
- Mach 4
- Mach 7
- 2pc
- 8pc
The Formation of Pillars

10K vs 100K

\[ \Rightarrow \rho_{\text{high}} T_{\text{cold}} \leq \rho_{\text{low}} 2T_{\text{hot}} \]
Mach Number

\[ \log_{10} \Sigma \ [g/cm^2] \]

-5.6  -4.9  -4.2  -3.5  -2.8

0 kyr  0 kyr  0 kyr  0 kyr

T = 250 kyr  T = 250 kyr  T = 250 kyr  T = 250 kyr

T = 500 kyr  T = 500 kyr  T = 500 kyr  T = 500 kyr

Mach 2  Mach 5  Mach 7  Mach 12.5
### Pillars and Globules

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Mach 5</th>
<th>Mach 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tip 1</td>
<td>Tip 2</td>
</tr>
<tr>
<td>$M [M_\odot]$</td>
<td>0.62</td>
<td>1.87</td>
</tr>
<tr>
<td>$v_0^T [\text{km/s}]$</td>
<td>0.60</td>
<td>1.08</td>
</tr>
<tr>
<td>$v_{500}^T [\text{km/s}]$</td>
<td>0.10</td>
<td>0.47</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Mach 7</th>
<th>Mach 12.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Globule 1</td>
<td>Globule 2</td>
</tr>
<tr>
<td>$M [M_\odot]$</td>
<td>0.32</td>
<td>0.15</td>
</tr>
<tr>
<td>$v_0^T [\text{km/s}]$</td>
<td>2.44</td>
<td>2.31</td>
</tr>
<tr>
<td>$v_{500}^T [\text{km/s}]$</td>
<td>3.00</td>
<td>2.85</td>
</tr>
</tbody>
</table>
Conclusions

• With standard MC parameters the formation of pillar-like substructures around HII regions is very likely

• Secondary star formation within these structures is frequently triggered

• The size, density and number of structures depends directly on the turbulent initial conditions