Molecular Cloud Fragmentation and the IMF

SHANTANU BASU

COLLABORATORS: S. AUDDY, G. CIOLEK, W. DAPP, T. KUDOH, J. WURSTER

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Set up turbulent initial conditions – shocks, instability. Also initial mass-to-flux ratio.

Fragmentation of cloud into large scale structures (filaments/ribbons, etc.).

Formation of dense cores within larger structures.

Core collapse to form hydrostatic protostar.

Disk formation, outflows, multiplicity, BDs, planets.
The Turbulent ICs of Molecular Clouds

Federrath 2014; also Wang et al. 2011, Li & Nakamura 2007, plus Padoan talk to follow.

Some combination of magnetic fields and protostellar outflows can keep cloud stirred up and lower SFR.
Molecular Cloud Progenitors are subcritical H I Clouds

Heiles & Troland (2008)

Flux freezing in HI gas ➔ Significant regions of molecular clouds may be subcritical.

Heiles & Troland (2005)
Molecular Cloud Accumulation Constraints

\[
L \approx \frac{B}{2\pi G^{1/2} \rho} \approx 150 \left( \frac{\mu}{1} \right) \left( \frac{B}{3 \times 10^{-6} \ G} \right) \left( \frac{n}{1 \ cm^{-3}} \right) \text{pc},
\]

\[
\nu \equiv \frac{L}{t} \approx 150 \left( \frac{\mu}{1} \right) \left( \frac{B}{3 \times 10^{-6} \ G} \right) \left( \frac{n}{1 \ cm^{-3}} \right) \left( \frac{t}{10^6 \ yr} \right)^{-1} \text{km/s}.
\]

Mestel (1999), Stellar Magnetism, and earlier papers quotes \(10^3\) above, not 150.

Bottom line: Highly supercritical MC and rapid formation time \(t\) is unlikely.
Molecular Cloud Scenario

Supercritical high-density regions assembled by large scale flows/turbulence

Subcritical common envelope; can enforce low SFR/SFE

Magnetic Ribbon Model

\[ B_0 = B_Z \]

\[ L = L_0 \left[ 2 \left( \frac{v_{t0}}{v_{A0}} \right)^2 + 1 \right]^{-1} \]

Magnetic vs. turbulent pressure

Observed width depends on turbulent compression scale, Alfvénic Mach number, and viewing angle.

Auddy, Basu, & Kudoh (2016)
Magnetic Ribbon Model

Observe from a set of random viewing angles: blue dots.

- \( L \)
- Average over random viewing angles
- \( 2H \approx \lambda_f \)

Assuming trans-Alfvénic turbulence and turbulent scale \( L_0 \sim 1 \text{ pc} \).

Auddy, Basu, & Kudoh (2016)
Probability Functions in Star Formation – Universal or Varying?

- Core Mass Function
- Column Density PDF
- Stellar (and substellar) Initial Mass Function
Magnetic Field affects the CMF

**\( \mu_0 = 0.5 \)**

\[ x' = x / (2\pi Z_0) \text{, etc.} \]

Periodic isothermal thin-sheet model. Initial small amplitude perturbations. \( B \) is initially normal to sheet.

**\( \mu_0 = 1.1 \)**

Column density and velocity vectors (unit 0.5 \( c_s \))

Note variation in sizes, shapes, velocity fields.

**\( \mu_0 = 2.0 \)**

Basu, Ciolek & Wurster (2009, NewA, 14, 221)
Jeans scale is a sensitive function of mass-to-flux ratio and peaks at transcritical values.

\[
\frac{\lambda_{gm}}{L_0} \quad \mu_0
\]

\[
\tau_{ni,0} / t_0 = 0.0
\]

\[
\times_i = 10^{-7} \left( \frac{n}{10^4 \text{ cm}^{-3}} \right)^{-1/2}
\]

\[
\lambda_{g,m} = 2\pi Z_0
\]

Ciolek & Basu (2006)
Column Density PDF ($\Sigma$PDF/NPDF) from 3D non-ideal MHD simulations

- **Supercritical** → shallow power-law $N_{pdf}$ consistent with B-E spheres
- **Subcritical** → steeper power-law from ambipolar diffusion regulated evolution
- **Subcritical+turbulence** → lognormal plus shallow power law at high column density

Auddy, Basu, & Kudoh (2017)
IMF in clusters

- Significant substellar population generally detected
- Stars/BD ratio ~ 2-5
- New paper by Drass et al. (2016) finds 1:1 ratio in ONC. Not spectroscopically confirmed

Bastian et al. (2010)
Substellar population: direct collapse, ejection, other processes?

\[ M_J = 5.5 M_{\text{sun}} \left( \frac{n}{10^4 \text{ cm}^{-3}} \right)^{-1/2} \left( \frac{T}{10 \text{ K}} \right)^{3/2} \]

- Star Formation as an accretion process or a fragmentation process?

- Do disks play a role in determining stellar/substellar masses?
Variations in IMF

Bayesian analysis shows that posterior probability density functions for IMF parameters show a significant variation and do not overlap significantly in many cases.

Intermediate to high mass power-law index
Magnetic fields can play a role in large scale regulation of star formation rate through 1. subcritical mass-to-flux ratio envelopes 2. efficient transport of turbulent energy from outflows

Big data era leading to calculation of various PDFs in star formation

Simulations show evidence that CMF and NPDFs will be strongly influenced by ambient magnetic field strength

IMF: possible significant underlying substellar population

IMF: Big data era can test and challenge ideas of universality