Accretion onto Young Disks: Implications for Disks and Planets

Henry Throop
Southwest Research Institute, Boulder, CO
throop@boulder.swri.edu

John Bally
CASA, University of Colorado, Boulder, CO

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Gas Accretion And Young Disks

Young stars orbiting in within their birth clusters may pass through dense molecular gas and experience Bondi-Hoyle accretion from leftover gas reservoirs in these molecular clouds. Such post-formation accretion can occur for several million years, until star formation ceases and the surrounding molecular gas disperses.

This accretion from the ISM is primarily onto the disk, not the star. The mass is accreted after the disk forms but before (or during) the epoch of planetesimal and planet formation. It may therefore have substantial influence on the disk's mass, structure and composition.

This is an poorly studied process and we present here our initial results. We find that the accretion rate is high enough that it may have a substantial and unappreciated effect on the formation of planetary systems.

Formation Environment

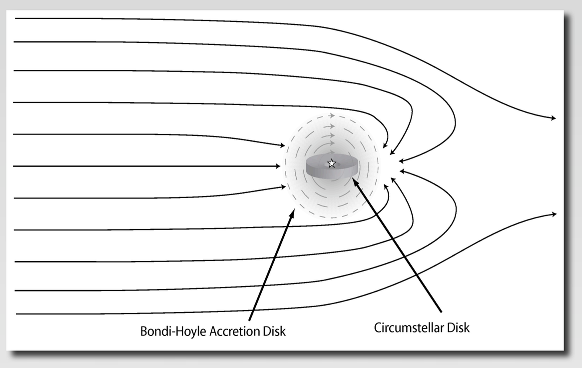
Stars form from the collapse of dense cores in giant molecular clouds (GMCs). While some stars form in relative isolation or is small groups, the majority of stars in the sky appear to be born in transient clusters containing at least hundreds of members.

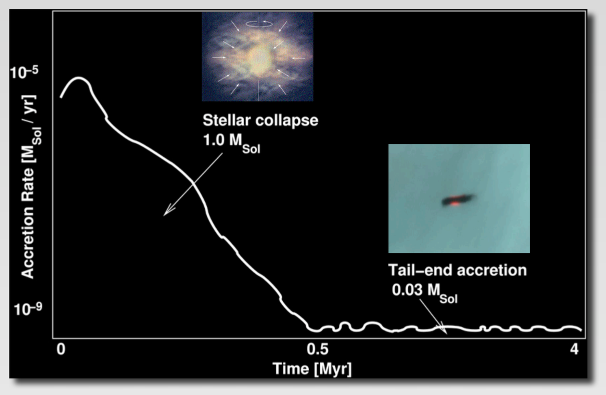
The typical star-formation efficiency (SFE) in a cluster-forming cloud core is ~ 10% - 40%. Thus, the majority of the gas is not consumed by stellar birth, but remains in the cluster.

This gas remains dense, cool, and molecular for up to several Myr, depending on the cluster mass and the onset of massive star formation. During this early time, stars and disks orbiting within the cluster can experience accretion.

Bondi-Hoyle Accretion: Analytic Calculations

Young stars and disks born in clusters can accrete cool molecular gas from their environment after they are born. This molecular gas can be accreted for several Myr before it is ionized and removed by O/B stars and stellar winds. Accretion is highest at low velocity, where the disk's gravitational cross-section is largest.





The accretion rate can be calculated analytically using Bondi-Hoyle accretion:

$$\dot{M} = (4 \pi G^2 M^2 v \, n \, m_h) / (v^2 + c_s^2)^{3/2} \text{ , where}$$

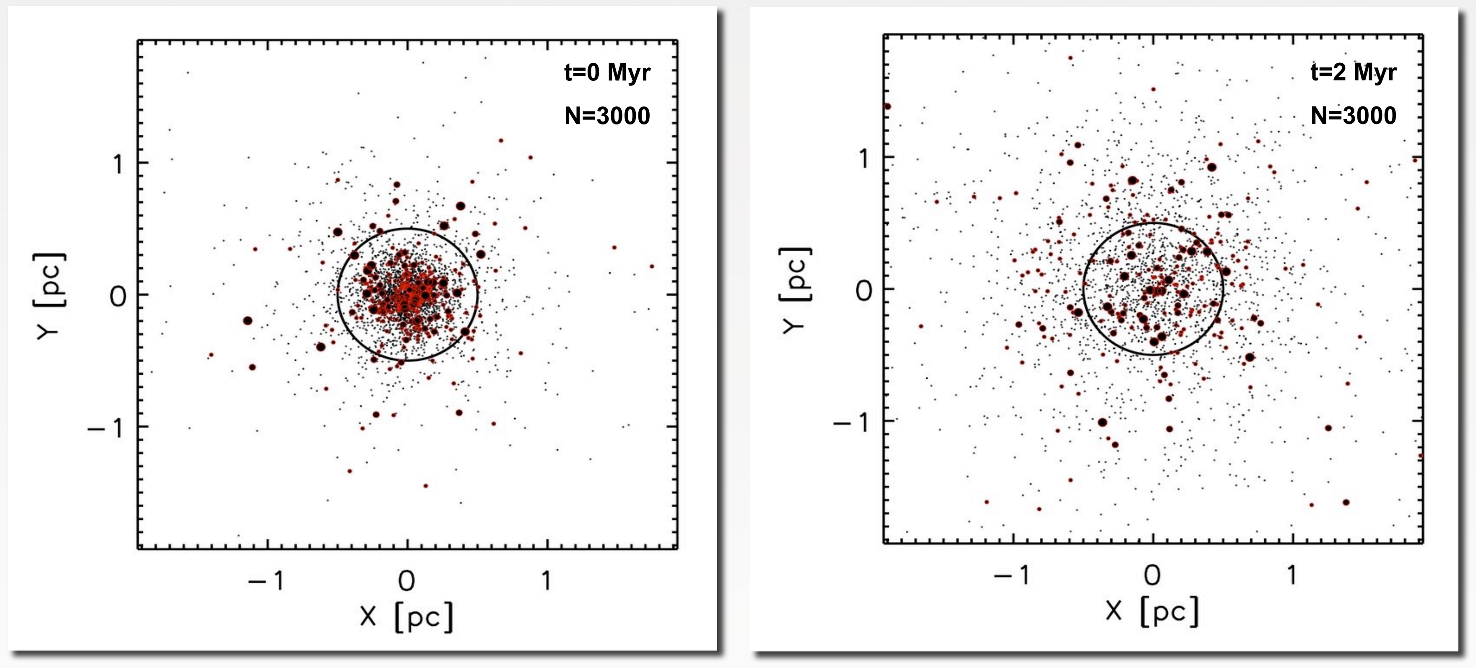
n	= gas number density	~ 10^3 - 10^6 cm^{-3}
v	= stellar-gas velocity	~ 0.1 - 5 km s^{-1}
M	= stellar mass	~ 0.5 - 5 $M_\odot$
c_s	= sound speed	~ 0.1 - 1 km s^{-1}

For typical cluster parameters and a 1 $M_\odot$ star, the calculated accretion rate is ~ 10^{-8} $M_\odot$ yr^{-1}, or ~ 1 MMSN per Myr, where 1 MMSN = 0.01 $M_\odot$. For stars of < 10 $M_\odot$, Bondi-Hoyle accretion is robust against stellar winds, radiation pressure, and outflows.

Bondi-Hoyle Accretion: N-Body Simulations

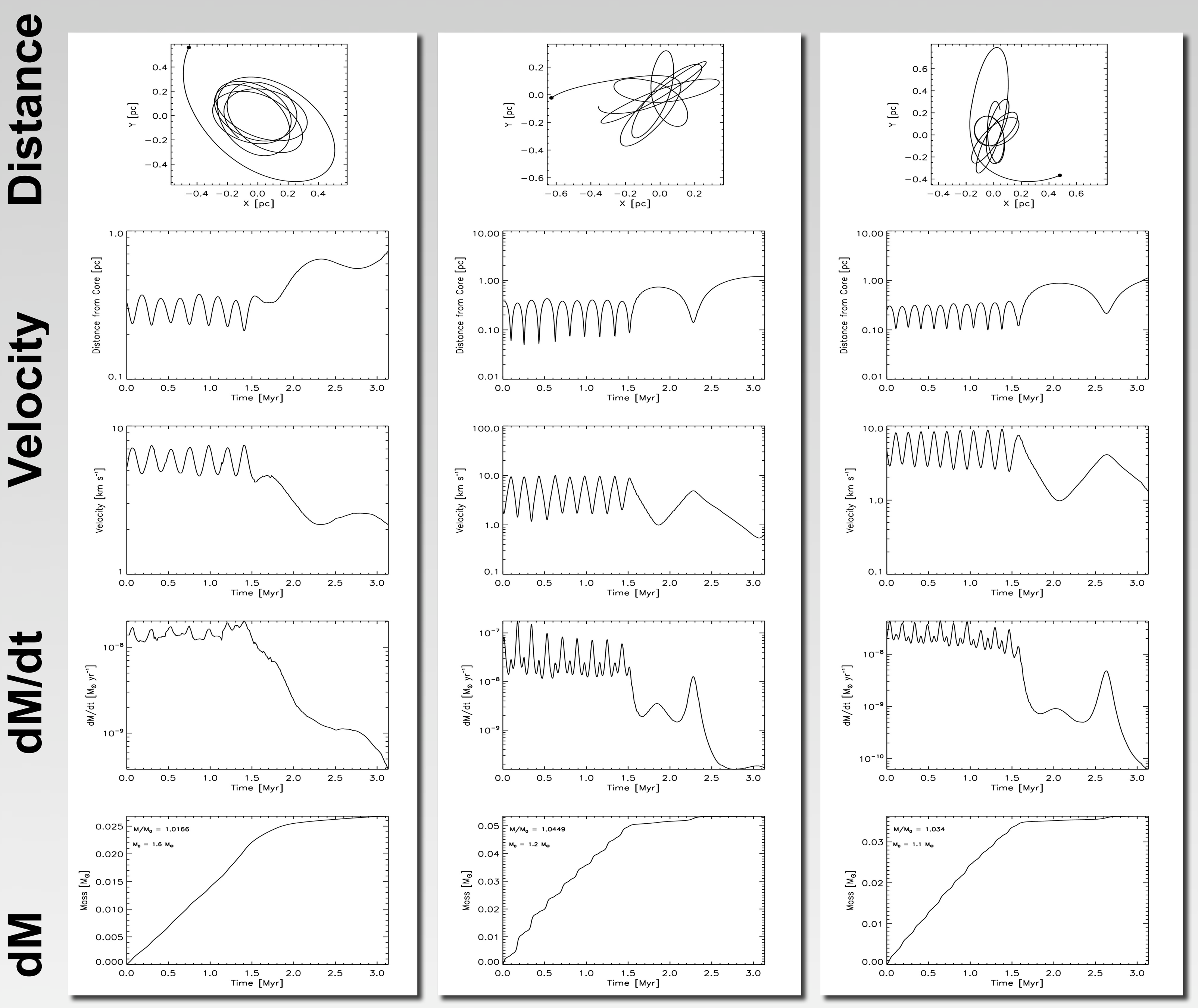
The Bondi-Hoyle equation gives $\dot{M}$ for a single location within the cluster. Because the disks are in orbit through the cluster, we use an N-body code to sample their orbital positions as they orbit. This allows us to obtain time-dependent values for the local gas density and velocity for each star. We then use these and the Bondi-Hoyle equation to calculate accretion onto each disk.

We use the NBODY6 code (S. Aarseth) to simulate clusters of N=30, N=300, and N=3000 stars. Our simulations include gas loss and cluster expansion. Initial star formation efficiency (SFE): $M_* / (M_{gas} + M_*) = 0.3$.



Two snapshots from Orion-like cluster simulation. Disks accrete mass as they orbit through the cluster. By 2 Myr the cluster has spread due to gas loss, and high-mass stars have settled toward the cluster core. The large circle indicate the position inward of which 90% of the mass starts (1 Plummer radius).

ISM → Disk Accretion by Sample Stars in N-Body Simulations



Orbits for three typical stars in N=3000 cluster simulation. We use NBODY6 to compute the stars' **Position** and velocity at each timestep. Each stars' orbit expands as cluster gas is lost. The **Distance** from the core determines the local gas density of the molecular cloud. The density and the **Velocity** are used to compute the Bondi-Hoyle accretion, **dM/dt.** Finally, the total mass gain, **dM**, is computed by summing dM/dt. Most of the mass accretion occurs during brief, episodic passes near the cluster core, where the density is highest. Accretion also peaks at apoapse, where the velocity is lowest. These stars (or their disks) gain 2%, 4%, and 3% of their original mass; in all cases the accreted mass exceeds the MMSN disk of 0.01 $M_\odot$.

N-Body Simulation Results

Our N-body simulations allow us to compute the effective accretion onto disks for stars orbiting in realistic young clusters. Performing a fit to our entire computational dataset, we find the accretion rate is approximately

$$\dot{M} = 10^{-8} (M/M_\odot)^2 \, M_\odot \, yr^{-1} = 1 \text{ MMSN Myr}^{-1}$$

Somewhat surprisingly, this result is only weakly depending on the cluster size: large clusters have far higher gas density, but this is canceled by their higher stellar velocities. The accretion rate is highly time-variable (see plots), and individual stars in a cluster can be as much as 50× higher or lower depending on their individual orbits.

Implication: Disk Masses and Evolution

The mass accreted onto young disks is ~ 1 MMSN per Myr, or up to *several initial disk masses* within 5 Myr. This late accretion of mass can have substantial influence on the disk.

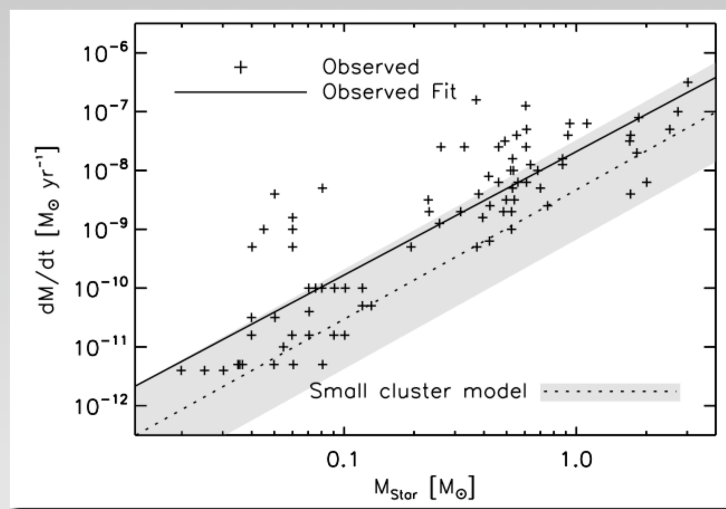
Accretion may cause the total disk mass to *increase*. In this case, the measured disk mass at any instant may be substantially higher than the disk's initial mass.

However, if the angular momentum vectors of the disk and accreting material are not aligned (or even anti-aligned), the disk mass could be *decreased* as a result.

In both cases, mass within the disk may be re-distributed by the mass and angular momentum of the accreted material from the ISM. And, in both cases the total amount of mass processed by the disk may be very different than its initial or current masses.

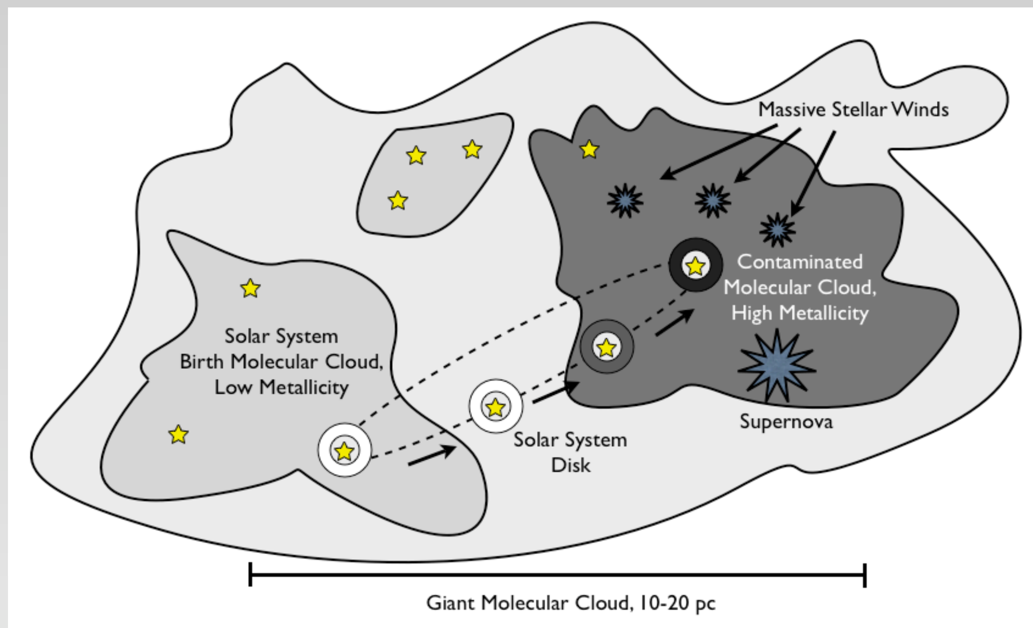
We are currently undertaking AMR simulations to understand better the local dynamics of the ISM-disk interaction and its effects on disk structure.

Implication: An explanation for the $\dot{M} \propto M^2$ relationship in young stars?



Many observations have detected accretion onto young stars, with the accretion rate varying with stellar mass as $\dot{M} \sim M^2$ (e.g. Muzerolle et al 2005). The source of this accretion has been unexplained. Following Padoan et al (2006), we propose that Bondi-Hoyle accretion may be an explanation. Accretion from ISM ➔ disk (which we calculate here) can trigger accretion disk ➔ star (which is observed). The slope and magnitude of the observed accretion matches our results very well.

Implication: Polluted Accretion in Star Clusters



Accretion may cause the disk's *composition* to change, if the local ISM has a different composition than the ISM where the star originally formed. Thus, the disk's composition can reflect spatial and/or temporal heterogeneitieis in the disk. This may explain the variation in metallicities observed in stars of similar mass and age in Orion (e.g., Cunha et al 1998)

Such heterogeneities may be caused by high-mass stellar 'pollution' such as red supergiant winds or supernova ejecta. Such pollution enriches the ISM, allowing for the possibilitiy of disks with with substantially higher metallicity than their central stars. This may explain the present-day Solar System, where Jupiter is enriched in metals by ~3x over the Sun (Throop & Bally 2008b).