Gas Accretion And Young Disks

Young stars orbiting 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 hundreds of members.

The typical star-formation efficiency (SFE) in a cluster-forming cloud core is 10% - 40% (Elmegreen et al 2000, and references therein). 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 OB 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:

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

where

- $n$ = gas number density
- $v$ = stellar-gas velocity
- $M$ = stellar mass
- $c_s$ = sound speed

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.

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. Thus, this is a potentially extremely important source of material.

Accretion may cause the 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 redistributed by the additional 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 compute) 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 heterogeneities 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 possibility of disks 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).