Gas Accretion from the ISM onto Circumstellar Disks

Henry Throop
Department of Space Studies
Southwest Research Institute (SwRI)
Boulder, Colorado

John Bally
Nickolas Moeckel
University of Colorado

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Orion constellation
H-alpha

Orion Molecular Clouds
$>10^5 \ M_\text{sol}$  100 pc long
Orion core (visible light)
**Bondi-Hoyle Accretion**

- Gravitational accretion onto a moving body
- Cool molecular $\text{H}_2$ from cluster ISM accretes onto disks
- Accretion flow is **onto disk**, not star.
- Accretion is robust against stellar winds, radiation pressure, turbulence.
- This accretion is not considered by existing Solar System formation models!

\[ R_B = \frac{2GM}{(v^2 + c_s^2)} \]

\[ \dot{M}_B = \frac{4\pi G^2 M^2}{(v^2 + c_s^2)^{3/2}} \] \( n m_h \)

Accretion radius $\sim 1000$ AU

Accretion rate $\sim 1$ MMSN / Myr
Timescale of Star Formation

Stellar collapse
1.0 $M_{\text{Sol}}$

Tail-end accretion
0.03 $M_{\text{Sol}}$

Accretion Rate [$M_{\text{Sol}} / \text{yr}$]

Time [Myr]
**Gas Accretion + N-Body Cluster Simulations**

NBODY6 code (Aarseth 2003)

**Stars:**
- \( N = 1000 \)
- \( M_{\text{star}} = 500 \, M_{\odot} \)
- Kroupa IMF
- \( R_0 = 0.5 \, \text{pc} \)

**Gas:**
- \( M_{\text{gas}} = 500 \, M_{\odot} \)
- \( R_0 = 0.5 \, \text{pc} \)
- Disperses with timescale 2 Myr

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BH Accretion: History of individual star

Following trajectory of one star of 3000 from N-body simulation...
BH Accretion: History of Individual Star

Star+disk accretes 5% of own mass in 5 Myr.

Accretion is episodic
- Highest at core: High velocity but high density
Results of N-Body sims

- Typical mass accreted by disks surrounding Solar-mass stars is 1 MMSN per Myr
- Accretion occurs for several Myr, until cluster disperses or cloud is ionized
Observations of accretion in young stars

- Accretion observed onto hundreds young stars in molecular clouds varies with stellar mass: \( \frac{dM}{dt} \sim M^2 \)
  - Natta et al 2006, Muzerolle et al 2005, etc
- Accretion is \( \sim 0.01 \, M_\odot \, \text{Myr}^{-1} \)
- There is no accepted physical explanation for this relationship.
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Accretion onto young stars may be a consequence and confirmation of ISM accretion onto their disks.
Molecular clouds
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Ionized HII region
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Accretion of ‘polluted’ ISM

• Stars of same age/position/type in Orion show metallicities that vary by up to 4x in Fe, O, Si, C (Cunha et al 1998)

• Could stars have accreted metallic ‘veneers’ by passing through nearby molecular clouds?

• Molecular clouds contaminated in metals by SN ejecta.
A Crazy idea for forming Jupiters?

1. Star and disk forms in a young cluster
2. Jupiter’s rocky core forms slowly
3. Disk gas is photo-evaporated before Jupiter can form
4. Disk gas is rejuvenated by passage through molecular cloud
5. Jupiter forms its atmosphere from new disk
A solution to the $^{60}$Fe problem?

- $^{60}$Fe is created in supernovae -> Solar System formed in large cluster
- But, in order to directly implant $^{60}$Fe into disk we need:
  - Solar System formed in an OB association
  - Solar System was close to an O star, $d < 0.2$ pc
  - But not too close!
  - And this happened at just the right time, as SN explodes
- Odds of this happening: < 1% (Gounelle + Meibom 2008)

We propose instead:

1. Sun forms in molecular cloud
2. O star forms ~ 10 pc away and explodes
3. SN ejecta mixes with ISM, distributes $^{60}$Fe
4. Solar System disk accretes $^{60}$Fe from ISM
Consequences of Tail-End Accretion

- Total disk mass accreted: $\sim 1$ MMSN per Myr for $1\,M_{\text{sol}}$
- Disk may still be accreting mass at $>5$ Myr, after planetesimals form
- Disk may be ‘rejuvenated’ after being partially lost
- Final composition of disk may be different than star
- Process is robust, and occurs in molecular clouds of all sizes (e.g., Taurus to Orion)

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The End