Gas Accretion from the ISM onto Circumstellar Disks

Henry Throop (*)
Department of Space Studies
Southwest Research Institute (SwRI)
Boulder, Colorado
(* on leave at UNAM-CU IA, 2008-2009)

John Bally
Nickolas Moeckel
University of Colorado

TFE08  22 agosto 2008
Orion Constellation (visible light)
Orion constellation
H-alpha

Orion Molecular Clouds
$>10^5 \, M_{\odot}$
100 pc long
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!

Accretion radius $\sim 1000$ AU

Accretion rate $\sim 1$ MMSN / Myr

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

\[
\dot{M}_B = \frac{4\pi G^2 M^2}{(v^2 + c_s^2)^{3/2}} \ n m_n
\]
Timescale of Star Formation

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

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

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

Time [Myr]

$10^{-5}$

$10^{-9}$
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

Throop & Bally 2008
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

Throop & Bally 2008
Gas Accretion + N-Body Cluster Simulations

NBODY6 code (Aarseth 2003)

Stars:
- N=1000
- $M_{\text{star}} = 500 \ M_{\text{sun}}$
- Kroupa IMF
- $R_0 = 0.5 \ \text{pc}$

Gas:
- $M_{\text{gas}} = 500 \ M_{\text{sun}}$
- $R_0 = 0.5 \ \text{pc}$
- Disperses with timescale 2 Myr

Stellar mass = 500 $M_{\text{sun}}$
Gas mass = 500 $M_{\text{Sun}}$

Throop & Bally 2008
BH Accretion: History of individual star

Following trajectory of one star of 3000 from N-body simulation...
Star+disk accretes 5% of own mass in 5 Myr.
Accretion is episodic
- Highest at core: High velocity but high density
• 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.
Accretion onto young stars may be a consequence and confirmation of ISM accretion onto their disks.
Molecular clouds
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region
Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds

Ionized HII region

Molecular clouds
Molecular clouds
Orion constellation
H-alpha

Orion Molecular Clouds
$>10^5 \, M_{\text{sol}}$ 100 pc long
Molecular clouds
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)

Throop & Bally 2008
AJ 135
Astro-ph 8404.0438
Consequences of Tail-End Accretion

- Total disk mass accreted: \( \sim 1 \text{ MMSN per Myr for } 1 \text{ M}_{\text{sol}} \)
- 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)

Throop & Bally 2008
AJ 135
Astro-ph 8404.0438
The End