Disks around the Youngest Protostars

Credit: Robert Hurt

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The Youngest Disk: Outstanding Questions

1. When does the circumstellar disk form?
   - Initial conditions for disk and planet evolution

2. What are their early properties and how do they evolve?
   - Size, mass, dust properties

3. What is the initial distribution of binary systems?
   - History of binary formation
When does the circumstellar disk form?

Expect the disk to be a simple consequence of angular momentum conservation... but until recently not strong evidence for young disks

Concluded that not common for Class 0 sources to have disks nor binaries in range of 150 AU < R < 500 AU (cf. Chen et al. 2013)
When does the circumstellar disk form?

Problem for early disks:

- **Magnetic Braking**, e.g. only expect small, young disks (Mellon & Li 2008; Hennebelle & Fromang 2008)
- <10 AU disks until end of Class I stage
Magnetic Field & No Disk

L1157: Chiang et al. 2012
Tobin et al. 2013
Stephens et al. 2013
A New Hope for Class 0 Disks

- L1527-IRS in Taurus, \( D = 140 \) pc
  - Class 0 protostar, large envelope \( \sim 1 \) \( M_{\text{sun}} \)
  - 0.3” (42 AU) mid-IR imaging suggests a \( R \sim 200 \) AU disk

Tobin et al. 2010
"Scattered Light Disks vs. L1527"

Padgett+99, Burrows+96, Stapelfeldt+03
Sub/mm Imaging

- SMA (870 µm) and CARMA (3.4 mm) data
  - Dust emission to probe bulk of disk
  - 0.3” (870 µm) and 0.35” (3.4 mm)
  - A resolved dust disk!
  - But..... What about the kinematics?
**Disk Kinematics**

- CARMA $^{13}$CO observations of structure
- Clear velocity gradient along elongation, very suggestive of disk rotation.

Tobin et al. 2012
- Rotation curve consistent with Keplerian
- $^{13}$CO position-velocity fit gives $M_{ps} = 0.19 \pm 0.04 \, M_{\odot}$
- Youngest directly measured protostellar mass, $\sim 20\%$ of envelope mass
- Can begin to classify protostars with $M_*/M_{env}$
  - True spirit of Class 0 definition $M_*/M_{env} < 1$ (Andre+93)
Disk Properties

Sub/millimeter and Mid-Infrared Modeling Results:

- Disk mass = $0.01 \, M_{\text{sun}}$
- Surface Density $\sim r^{-1.7}$
- Disk radius $\sim 150 \, \text{AU}$
- Scale height $H \sim R^{1.3}$; $H (100 \, \text{AU}) = 39 \, \text{AU}$
- Dust opacity $\beta \sim 0.25$

Blue: L1527 and Red: IRAS 04325+2247

Andrews et al. 2009, 2010
Class 0 System

0.2 solar mass central object

~1 solar mass envelope

0.01 solar mass disk

~25000 AU

Tobin et al. 2012
VLA 1623 system with similarly massed central object

Murillo & Lai 2013

Recently released ALMA data give nice Keplerian motion—best fit of $0.18 \, M_{\odot}$
Just released ALMA data shows the velocity gradient really nicely.
Disks? What about magnetic braking?

In the case of misaligned magnetic fields and rotation axis, we expect larger disks. (Joos et al. 2012, Zhao & Li 2013, and Krumholz et al. 2013)
Disks? What about magnetic braking?

And, TADPOL shows that unaligned magnetic field and rotation axis is typical scenario.

Hull et al. 2013
Disks? What about magnetic braking?

TADPOL results for L1527 and VLA 1623—coupled with no disk detection of L1157—interesting trend

Hull et al. 2013
More Candidates: L1448 IRS2

- Rotation evident in $^{18}$O emission, higher resolution/sensitivity need to determine if Keplerian

Tobin+ in prep.
**L1165 Envelope-Disk Connection**

SMA 1.1 mm Dust emission

$N_2H^+ (1-0)$ CARM + IRAC 8

0.05 pc; 33"; 10000 AU

RA offset (arcsec; J2000)

DEC offset (arcsec; J2000)

6000 AU
CARMA 1.3 mm BC Robust = 1

100 AU (0.33")

RA offset (arcsec; J2000)
L1165 In Depth

CARMA 1.3 mm BC Robust = 1

CARMA 12CO (J=2-1)

100 AU

CARMA 7.3 mm
L1165 Gas Kinematics

SMA HCO+ (J=3-2) with 1.3 mm high-resolution continuum

- ‘High’ velocity red/blue-shifted emission suggestive of rotation in the infalling material
- Disk rotation like L1527?
- Need more observations (tbd)
The Earliest Disks

- ~18 Class 0 protostars observed with resolution to detect disks (<= 80 AU) (e.g. Maury+10, Lee+09, Chiang+12, Murillo+13, ...)
  - L1527, Per-emb14, L1448 IRS2, L1165, HH211, VLA1623A; have evidence of large disks
  - L1527 confirmed rotational support
    - HH211, L1448 IRS2, VLA1623A, L1165 have rotation, Keplerian not yet confirmed
- Large rotationally supported disk fraction could be 6/18 ~33%
- Points to a variety of disk properties, likely linked to initial conditions