The Origin of Stars

Current Star Formation
Molecular Clouds

- **Composition**
  - H₂ (93%), He (6%)
  - Dust and other molecules (~1%)
    - CO next most common after H₂, He

- **Temperature** about 10 K

- **Density** (particles per cubic cm)
  - ~100 cm⁻³ to 10⁶ cm⁻³
  - Air has about 10¹⁹ cm⁻³
  - Water about 3 x 10²² cm⁻³

- **Size** 1-300 ly

- **Mass** 1 to 10⁶ Mₜₜ
A Small Molecular Cloud
Ices on Dust Grains
Current Star Formation

- Occurs in gas with heavy elements
  - Molecules and dust keep gas cool
  - Radiate energy released by collapse
  - Stars of lower mass can form
  - Mass needed for collapse increases with T

- Star formation is ongoing in our Galaxy
  - Massive stars are short-lived
  - Star formation observed in infrared
Spitzer Space Telescope  Launched Aug. 2003, expect a 5 yr life.
Visible to Infrared Views
RCW 49
JHK
(2MASS)
A Dark Molecular Cloud

L1014 distance ~ 600 ly, but somewhat uncertain.

Red light image; dust blocks stars behind and our view of what goes on inside.
Forming Star Seen in Infrared

Three Color Composite:
Blue = 3.6 microns
Green = 8.0 microns
Red = 24 microns

R-band image from DSS at Lower left.

We see many stars through the cloud not seen in R.
The central source is NOT a background star.

L1014 is forming a star

C. Young et al. ApJS, 154, 396
Artist’s Conception

Features:
Dusty envelope
Rotation
Disk
Bipolar outflow

R. Hurt, SSC
The Protostar

- Evolution of the collapsing gas cloud
  - At first, collapsing gas stays cool
  - Dust, gas emit photons, remove energy
  - At $n \sim 10^{11} \text{ cm}^{-3}$, photons trapped
  - Gas heats up, dust destroyed, pressure rises
  - Core stops collapsing
  - The outer parts still falling in, adding mass
  - Core shrinks slowly, heats up
  - Fusion begins at $T \sim 10^7 \text{ K}$
  - Protostar becomes a main-sequence star
The Star (AU Mic) is blocked in a coronograph. Allows you to see disk. Dust in disk is heated by star and emits in infrared.
Angular Momentum

- Measure of tendency to rotate
  - $J = mvr$

- Angular momentum is conserved
  - $J = \text{constant}$
  - As gas contracts ($r$ smaller), $v$ increases
  - Faster rotation resists collapse
  - Gas settles into rotating disk
  - Protostar adds mass through the disk
The Wind

- Accretion from disk will spin up the star
  - Star would break apart if spins too fast
- Angular momentum must be carried off
- The star-disk interaction creates a wind
- The wind carries mass to large distances
  - $J = mvr$, small amount of $m$ at very large $r$
  - Allows star to avoid rotating too fast
- Wind turns into bipolar jet
  - Sweeps out cavity
The Bipolar Jet
Studying the Disk

Starlight Misses Disc

Starlight Grazes Disc

Disc Blocks Starlight

Robert Hurt, SSC
Ices in a Protoplanetary Disc

Spitzer Space Telescope • IRS

ESO • VLT-ISAAC

NASA / JPL-Caltech / K. Pontoppidan (Leiden Observatory)
SMM image of Vega shows dust peaks off center from star (*). Fits a model with a Neptune like planet clearing a gap. Can test by looking for motion of clumps in debris disk.

Disks versus Age of Star
Evidence for Collisions
Binary Stars

- About 2/3 of all stars are in binaries
  - Most common separation is 10-100 AU
- Can binary stars have disks?
  - Yes, but binary tends to clear a gap
  - Disks well inside binary orbit
  - Or well outside binary orbit
Brown Dwarfs

- Stars range from 0.07 to ~100 \( M_{\text{sun}} \)
- Jupiter is about 0.001 \( M_{\text{sun}} \)
- Brown dwarfs between stars and planets
  - Dividing line is somewhat arbitrary
  - Usual choice is 13 \( M_{\text{jupiter}} \)
  - Brown dwarfs rarely seen as companions to stars
  - But “free-floaters” as common as stars
  - Many young BDs have disks
    - Planets around BDs?