Important Questions

- What don’t we known about a star’s lifetime?
- What are molecular outflows?
- How have we studied them?
- What do we know about molecular outflows?
- What can be done to learn more?
We do know:

- The life of a star after it has started fusion (mostly)
- We’re really close to a star we can study... the Sun
- Are we missing something?
- Now, we have to work backwards

What we don’t know:

- How a star is born
- Well, ok... we have an idea...
- But, it’s really not that simple
- Stellar birth depends on:
  - Available Material/Mass
  - Surrounding Environment
- Outflows are different depending on type of star forming
- There is believed to be an overall trend
Molecular Outflows

- Bipolar (we believe) ejections of material from a forming star
- Occurs in all forming stars. (Bachiller et al. 2009)
- Detected by Doppler shift.
- Can be tricky determining if what we see is legitimate or not.

Snell et al. 1980
Outflow Signatures

- **Spatial-Velocity Diagrams:**
  - We look for gas “trailed” away from the main cloud.

- **Integrated Intensity Spectra:**
  - We look for velocity wings.

- **Nearby associated objects:**
  - Forming stars – sources of outflows
  - Herbig-Haro objects – “holes” in outflows
  - Molecular Hydrogen Emission-Line Objects – tracers of shock-excited features
  - H13CO cores – high density tracers
Outflow Signatures

Morphology and Composition

- Morphologies:
  - 2 lobes (red-shifted and blue-shifted)
  - Jets, shells
  - Wide-angle winds
  - Knots or bullets
  - Precession

- Chemistry:
  - SiO, CH$_3$OH, and H$_2$CO, and more!

- Evolution from jets to winds
- Theory must connect these morphologies
**Morphology**

Garcia et al. 2009

**Outflow Models**

- Four classes of models:
  - Wind-driven shells
  - Jet-driven bow shocks
  - Jet-driven turbulent flows
  - Circulation flows
- First 3 models suggest matter is "carried" away
- Last model suggest infalling matter is deflected
Outflow Models

- Wind-driven shells:  
  - Wide-angle wind blows into the surrounding material, sweeping up a thin shell

- Jet driven bow-shock:  
  - Highly collimated jet moves into the surrounding material while producing a thin outflow shell surrounding the jet

- Jet-driven turbulent flows:  
  - Instabilities along jet form turbulent layer along which material is entrained

- Circulation flows:  
  - Outflow is formed by infalling matter that is deflected away from the protostar

Outflow Causes

- Theory suggests caused by magnetic stresses in the circumstellar disk-protostar system
- We can’t understand until we know how they behave
- So, we should do more studies!

HH30  
Watson et al. 1995
What do we do next?

- Study molecular clouds!
- More data = better statistics.
- Do simulations.
- Collect diverse data, i.e. cover the wide range of stellar environments and masses.