Disks: The Early Years

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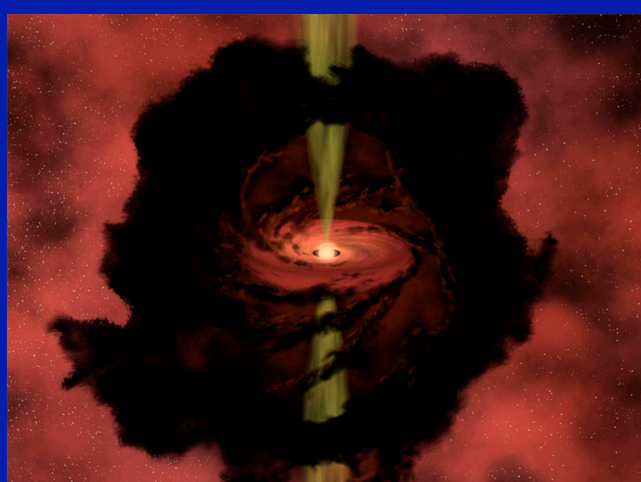
Rotating Collapse forms Disks



Features:
Dusty envelope
Rotation
Disk
Bipolar outflow

R. Hurt, SSC

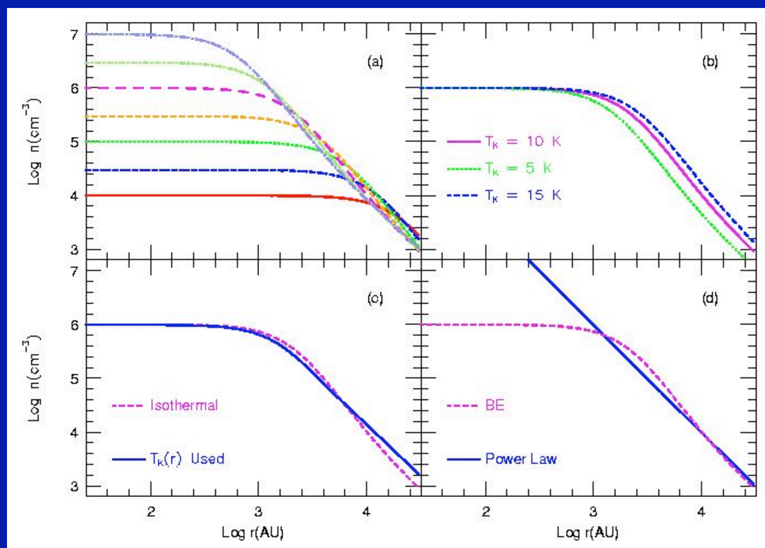
Disk Origins

- How do disk properties depend on:
  - – Properties of collapsing envelope
  - – Nature of the forming star or substar
  - – Nature of building blocks (dust, ice, gas)
- How early can we observe them?
- What do processes in early disks affect?

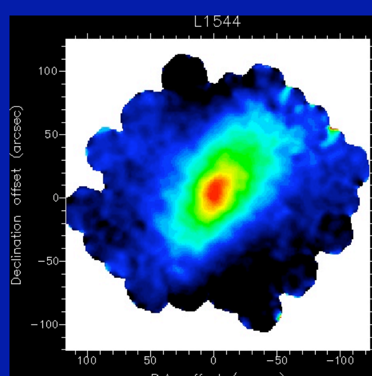
Envelope properties

- Studies of individual, isolated cores
  - – Masses around 2 M_{sun}
  - – Very low turbulence
  - – Centrally peaked
    - Look like Bonnor-Ebert spheres
    - Sequence of increasing central density
    - Approach singular isothermal sphere
    - But do they ever reach it?

Bonnor-Ebert Spheres



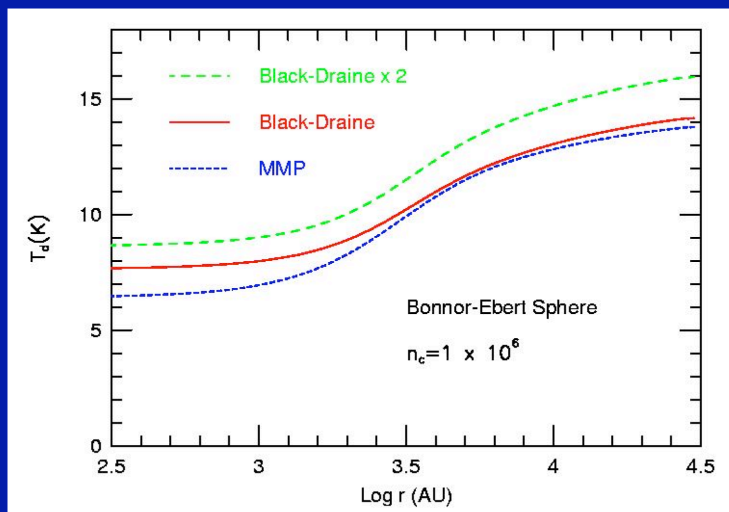
Isolated Cores



Dust continuum emission at 850 microns
Mapped with SCUBA on JCMT

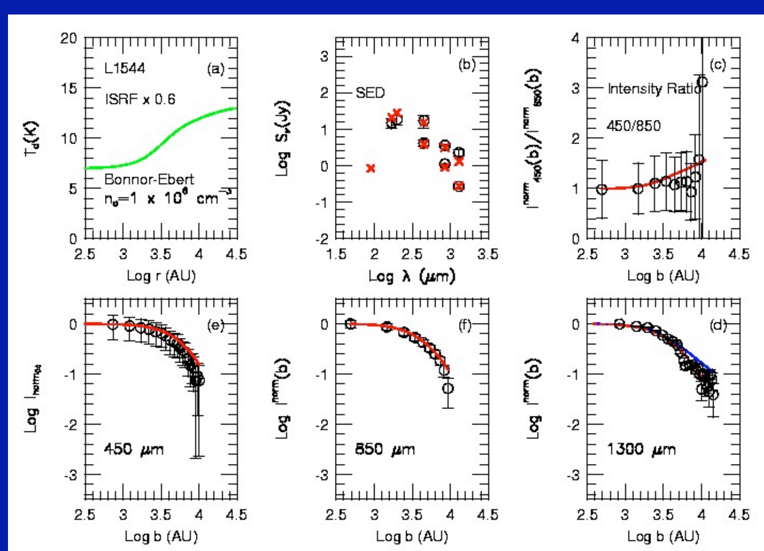
Shirley et al. 2000

Dust Temperature

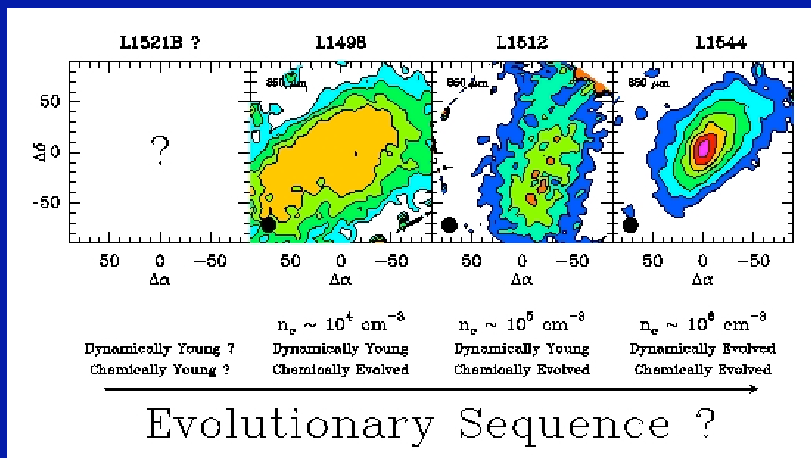


Evans et al. 2001

Bonnor-Ebert Fits Well



Evolutionary Sequence?



Shirley et al. 2005

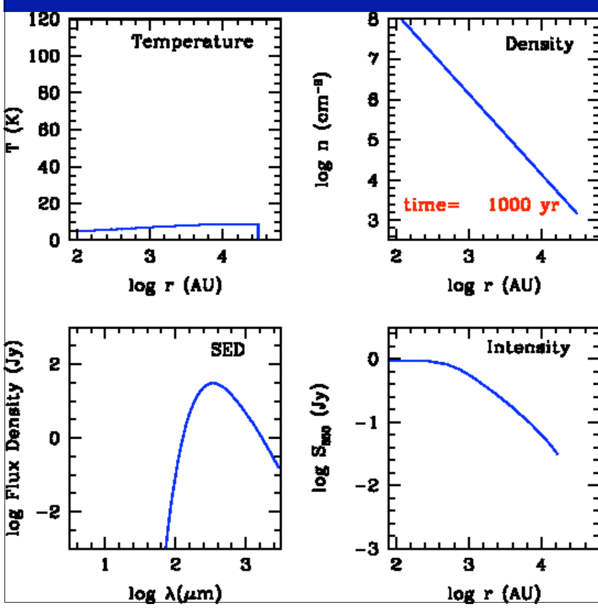
Initial Conditions: Summary

- Isolated cores
  - Centrally condensed
  - Very cold in center
  - Molecular tracers depleted
  - Can be modeled as BE spheres: ~ 2 M_{sun}
  - Sequence of increasing central density
  - Most condensed (e.g., L1544) can be power-law
  - 3D modeling confirms basic results of 1D
    - Doty et al. (2005)

Collapse

- If initial conditions approach power-law,
  - Collapse from singular isothermal sphere (SIS)
  - Or do earlier inward motions modify?
- Simple models
  - BE spheres with increasing central density
  - Transition to collapse of SIS
  - Model dust, gas energetics, chemistry, radiative transfer, observing process

Dust Temperature and Observables

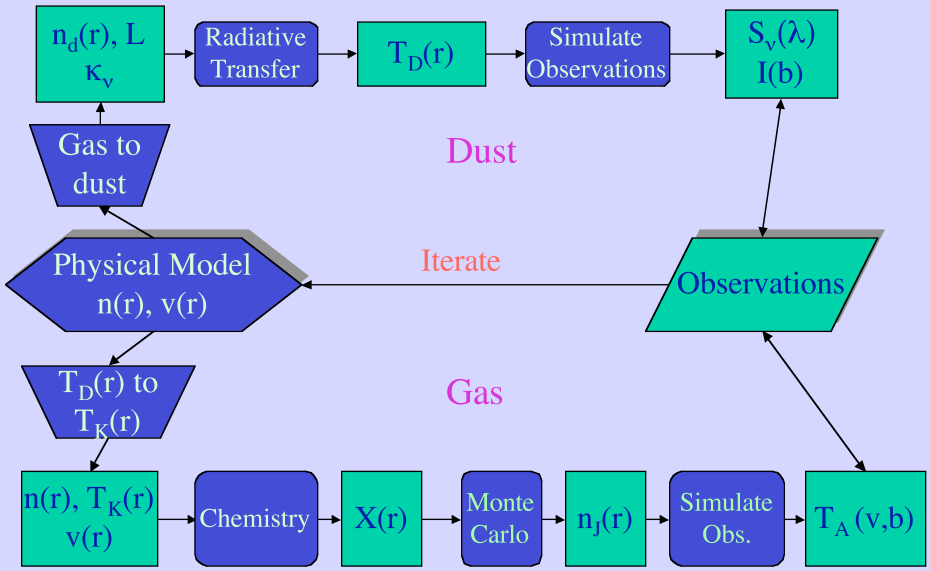


Use DUSTY to compute T_d(r, t). Include interstellar radiation and central heating from L(t).

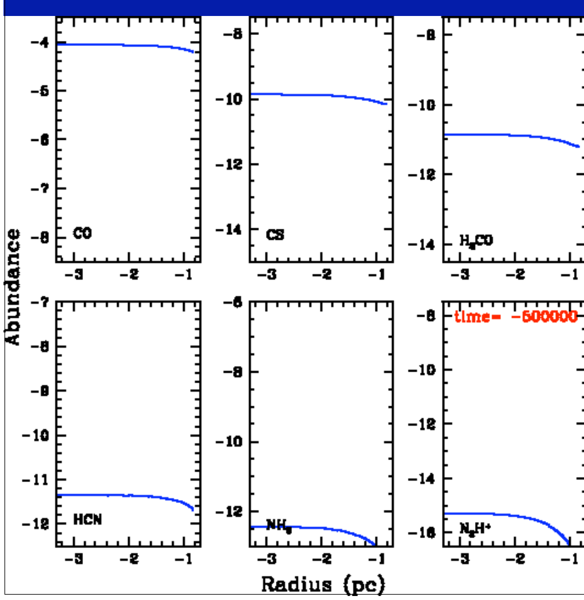
Compute SED and radial profile from DUSTY and obssphere.

C. Young and Evans, submitted

Combined Modeling of Dust and Gas



Calculate Abundances



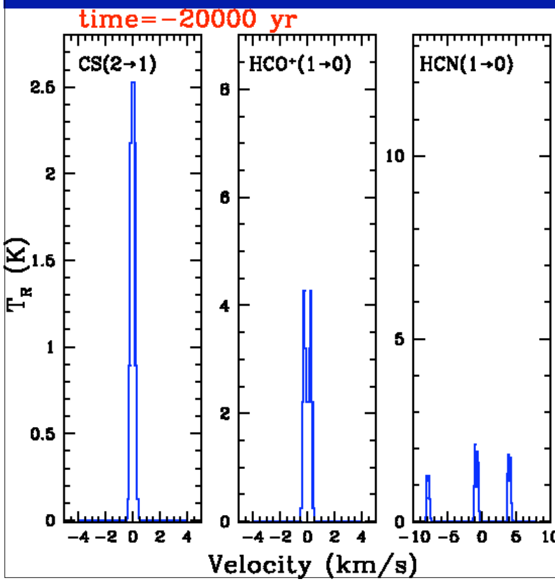
Chemical code by E. Bergin
198 time steps of varying length, depending on need.
Medium sized network with 80 species, 800 reactions.
Follows 512 gas parcels.

Includes freeze-out onto grains and desorption due to thermal, CR, photo effects. No reactions on grains. Assume binding energy on silicates for this case.

Movies available at:
http://peggysue.as.utexas.edu/sf/CHEM/

J. Lee et al. 2004

Calculate Observables



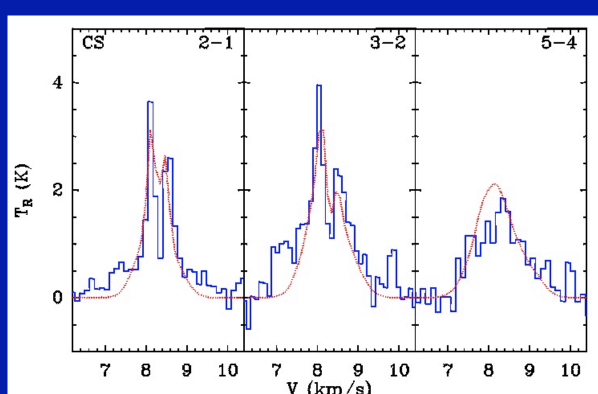
Line profiles calculated from Monte Carlo plus virtual telescope codes. Includes collisional excitation, trapping. Variations in density, temperature, abundance, velocity are included.

Assumes distance of 140 pc and typical telescope properties.

Movies available at:
http://peggysue.as.utexas.edu/sf/CHEM/

J. Lee et al. 2004

Comparison to Observations



Observations of B335
Three CS transitions

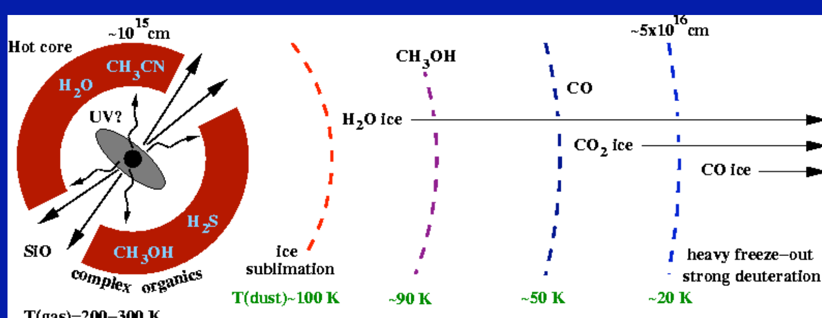
Red line is from chemical model.

Evans et al. 2005, submitted

Outstanding Questions

- Do dust and gas tracers tell the same story?
  - Not exactly
    - Dust tracers prefer much smaller infall radius
    - Or more abrupt change in power law at r_{inf}
  - Dust models need to incorporate more facts
    - Inner envelope and disk
    - Changes in dust properties from icy mantles
      - Freeze-out more in dense, cold regions
      - Evaporate in inner “hot” core

Dust/ice/gas interactions in inner envelope



- Hot core structure for luminous central source; zones of different ices.
-For low luminosity sources, icy dust may reach the disk.

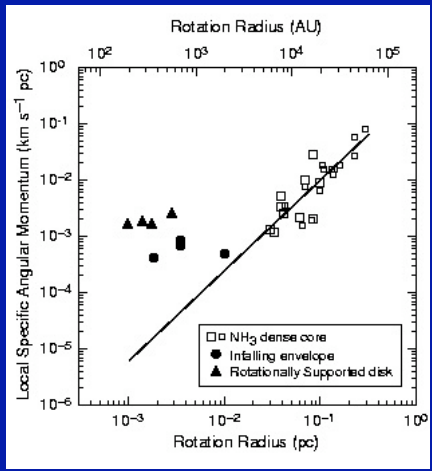
Summary: Collapse

- Collapse models predict observables
  - Characteristic “blue” line profiles
  - These are seen in many, but not all cores
- Self-consistent models reproduce observations
- Needs work:
  - Chemical rates
  - Alternative dynamics
  - Environmental effects
  - Dust properties as function of radius, time, …
  - 2D, 3D models, effects of rotation, outflows

Rotation

- Rotation rates
  - Most are slowly rotating
    - 1×10^{-14} to 1.3×10^{-13} s^{-1} (Goodman et al. 1993)
    - Many upper limits
  - Centrifugal Radius (R_C) depends on $Omega^2$
  - Large range of R_C may be possible
    - Factor of 170
  - Consequences ?
    - Disk radius
    - Disk mass?
    - Rate of disk evolution?

Trends with Radius

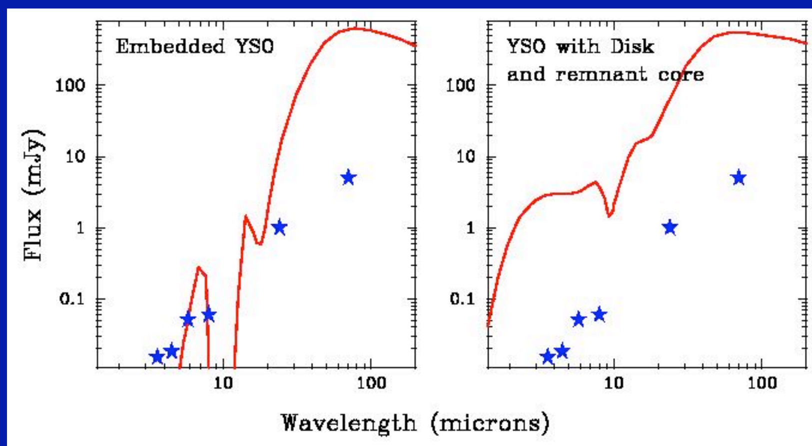


- Goodman et al. (1993)
- Ohashi et al. (1997)
- Specific Ang. Mom.
  - $j = V_{rot}R$
  - Decreases with R
  - Then constant
  - Large variations

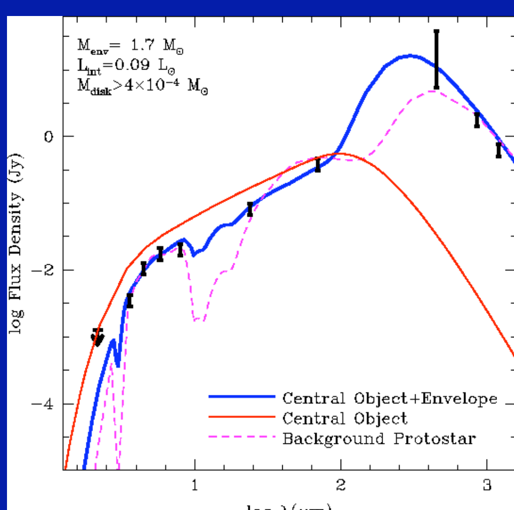
Early Disks

- What is expected?
- Disk radius strong function of time (t^3)
  - Early disks should be small
  - Disks should show strong evolution

Spitzer can detect them…



… and it has



Model of SED for d = 200 pc. Central object has very low luminosity: 0.09 L_{sun}.

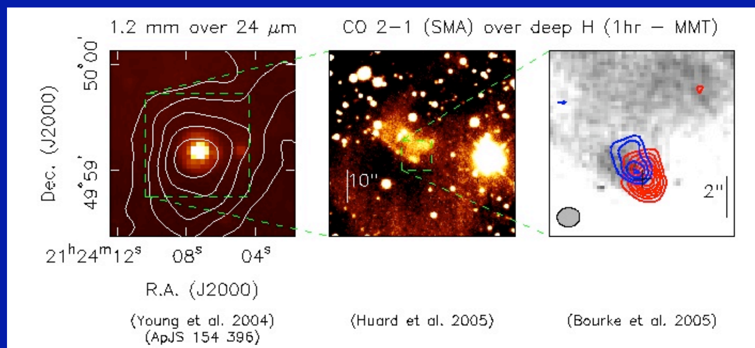
Requires BB plus disk (red line) in an envelope. M(envelope) about 2 M_{sun}.

Cannot be a stellar-mass object with significant accretion. Probably sub-stellar at this point.

Alternative model: more distant (2.6 kpc) object lined up by chance with peak of a foreground core (dashed line)

C. Young et al. ApJS, 154, 396

Small scattering cone and outflow



At the velocity of the nearby core, L1014

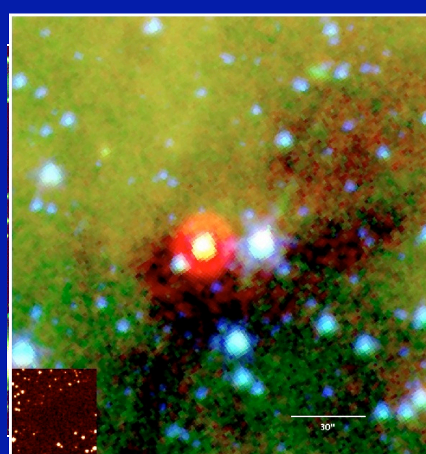
JHK Image

J, H, K Image of L1014
KPNO 4-m + Flamingos
J (19.7) H(20.9) K(19.4)
Huard et al. in prep.
Preliminary reduction

Faint conical nebula to north with apex on IRAC source.

BIMA peak to south likely obscures southern lobe.

Not a background source.



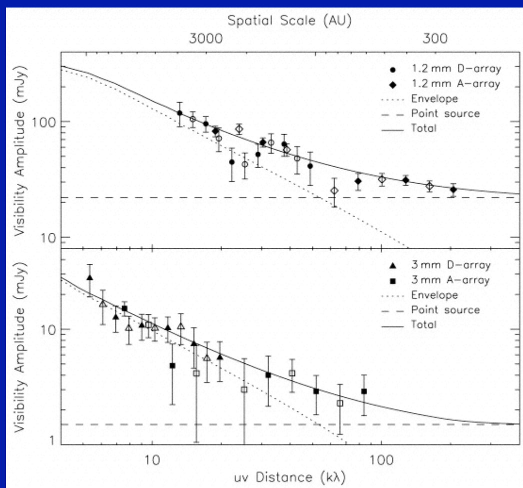
Summary

- Disks can be detected very early
  - Disks of very low mass
  - $M_d \sim 4 \times 10^{-4}\ M_{sun}\ (R_d/50AU)^{0.5}$ for L1014 disk
  - Easily detected (S/N about 50 to 100)
- Disks surround objects of very low L
  - Luminosity of L1014 is about 0.1 L_{sun}
  - Relevant to formation of substars?
  - New regimes for disks, planets

Remaining Issues

- Can detect in MIR, but disk is optically thick
- Need mm/smm to be sure of masses
  - Hard to separate disk from inner envelope
    - Looney et al. (ApJ 529, 477)
    - Need interferometer/camera at same wavelength
      - SMA, CARMA, ALMA
  - Need to measure rotation, early planet formation?
    - Dynamics, gaps, …
    - Need sensitive, high resolution (spatial and spectral)
    - ALMA, MIR ($R \sim 10^5$)

Separating disk from envelope



B335 with PdBI
Both 1.2 and 3 mm
Multi-config.
Resolution of ~0.5”

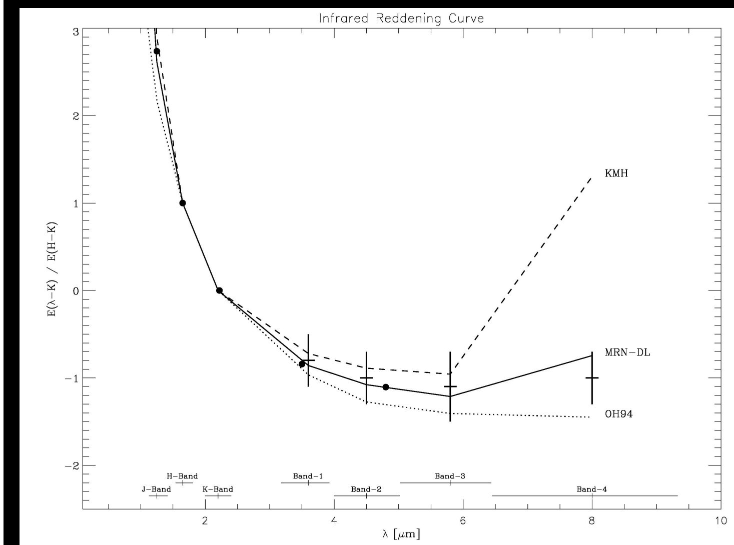
Envelope + disk fits better
Easier to see at 1 mm

D. Harvey et al. 2003, ApJ 596, 383

How do the building blocks evolve?

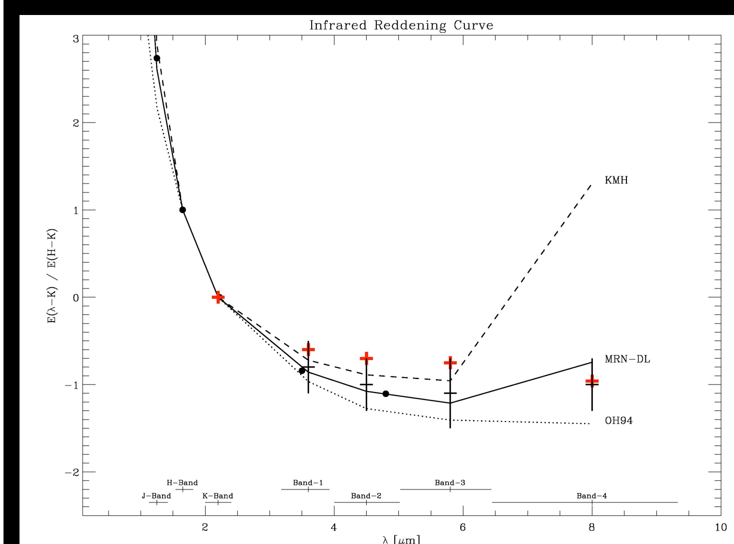
- Do dust and ice in the cloud evolve?
  - Extinction law (T. Huard)
  - Ice features
- How do they evolve in collapsing cores?
  - Further freeze-out
  - Evaporation as luminosity rises
- How do they evolve in disks?

Flattening of the Extinction Law



Indebetouw et al. 2004

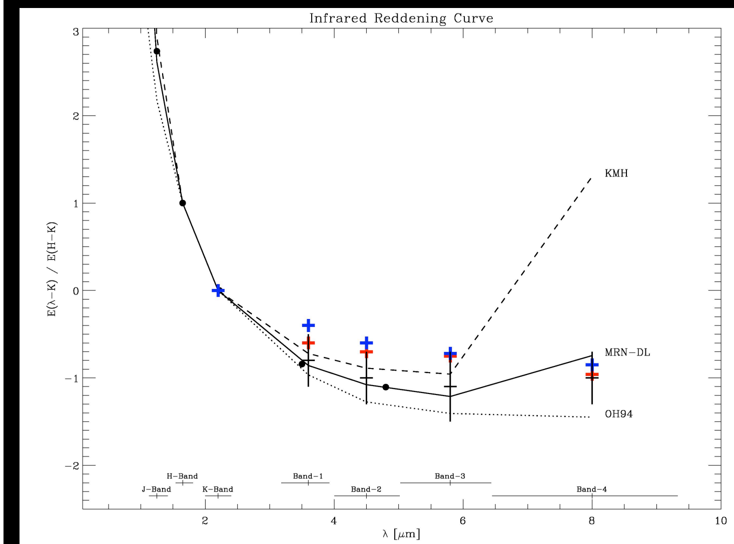
Flattening of the Extinction Law



L1014 (2MASS)

Indebetouw et al. 2004

Flattening of the Extinction Law

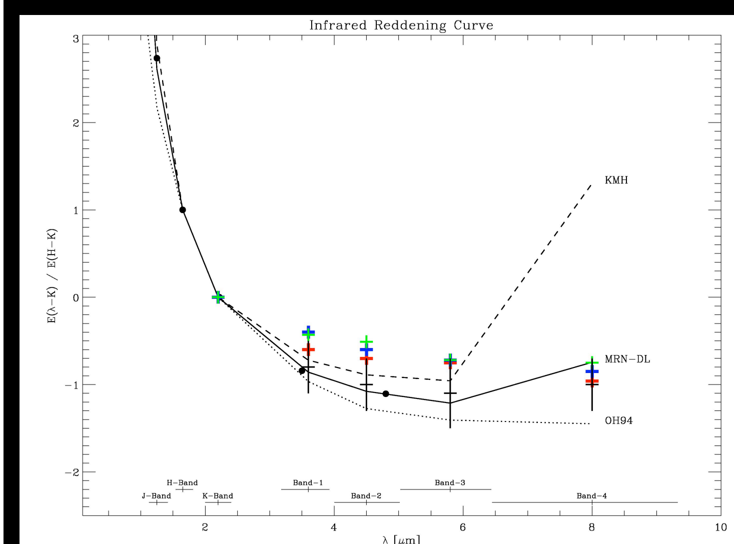


L1014 (deep NIR)

L1014 (2MASS)

Indebetouw et al. 2004

Flattening of the Extinction Law



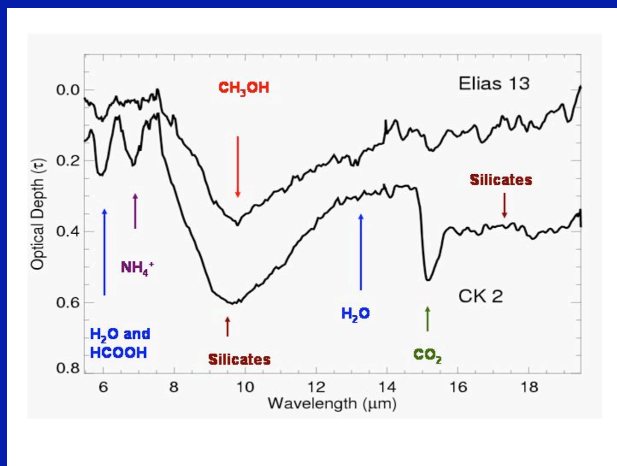
L723 (deep NIR)

L1014 (deep NIR)

L1014 (2MASS)

Indebetouw et al. 2004

Background sources: quiescent clouds



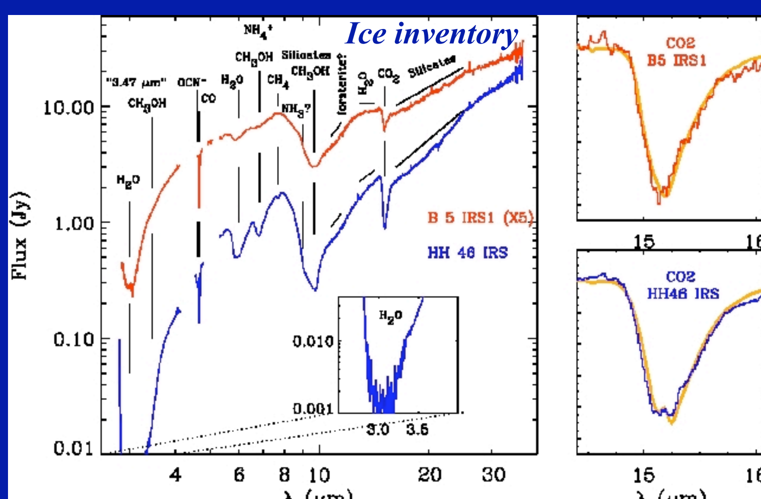
Elias 13: behind A_V = 12 mag in Taurus

CK 2: behind A_V~35 to 50 mag and dense region in Serpens

- Probe ice composition prior to star formation

Knez et al. in prep.

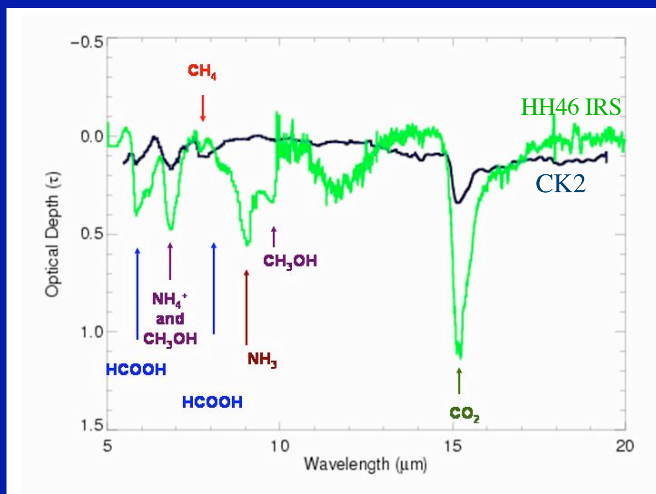
Embedded protostars



- Abundances comparable to those found in high-mass YSO's, but significant variations from source to source for some species (e.g., CH_3OH, NH_3)
- First detection CH_4 ice toward low-mass YSO's

Boogert et al. 2004

Protostellar vs Dense, Starless



HH46 IRS Compared to CK2 (starless)

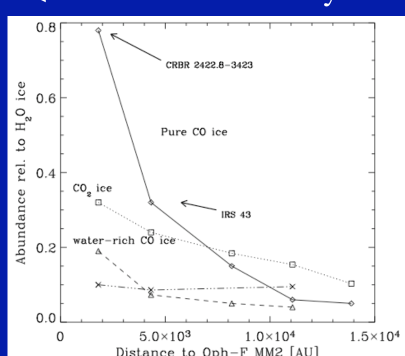
Silicate and water ice removed

Caution in region of silicates…

C. Knez et al. in prep.

Mapping the Ice Distribution

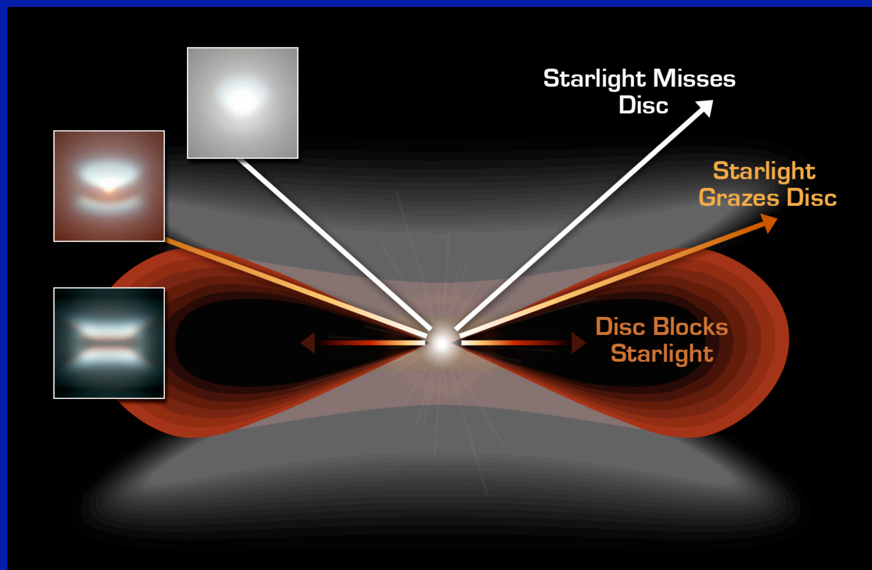
Density



- Abundance of ice varies
- Increases as n increases
- Nature of ice changes

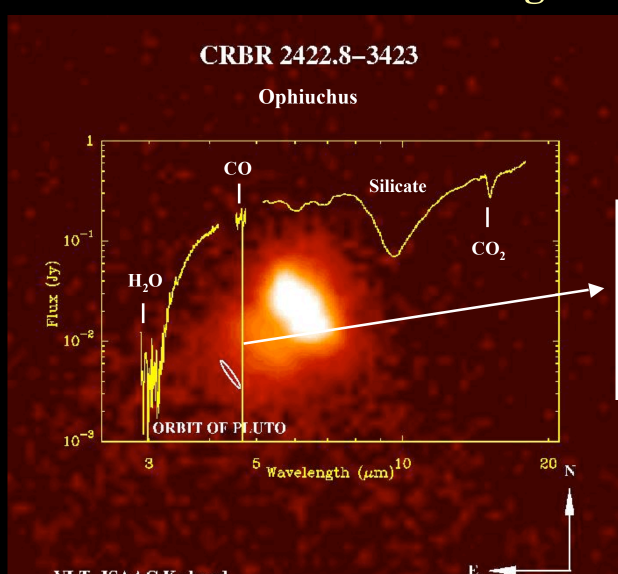
Pontoppidan et al.

Chemistry in Disks

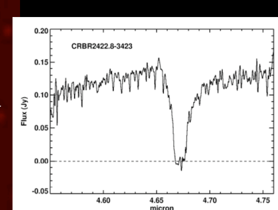


Robert Hurt, SSC

Heated ices in an edge-on disk



Very strong solid CO absorption



CO_{solid}/CO_{gas}~1
$T_{ex}(CO)$~50 K

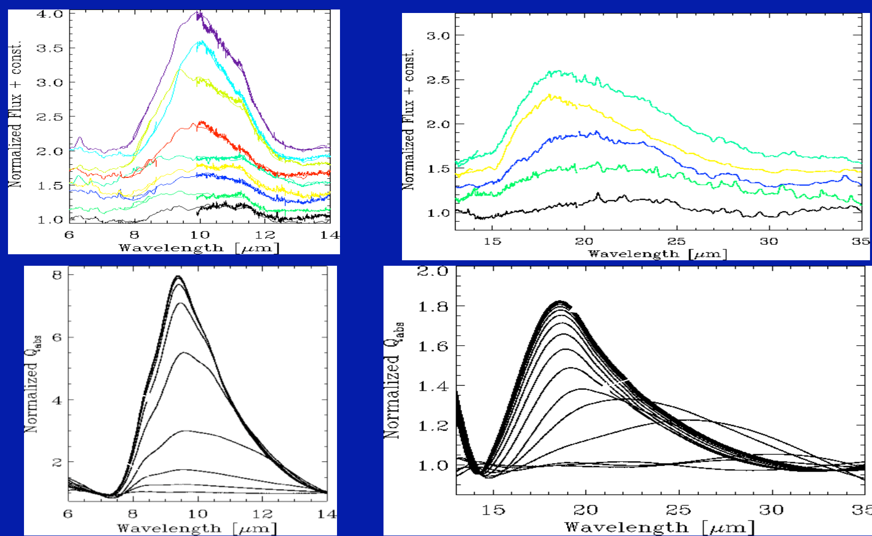
Thi et al. 2002
Pontoppidan et al. 2004

- Detailed modeling of disk + surroundings indicates that up to 50% of ice absorptions arise in disk
- Ices in disk heated to >40 K

Pasadena

Evidence for grain growth in disks

10 μm band | 20 μm band



Kessler-Silacci et al., in prep

Outstanding Questions

- How much grain growth/ice mantle growth
  - In cloud before collapse?
  - During collapse?
- Effects of ice evaporation?
  - Reversible, or are refractory ices left?
- What gets delivered to disks?
  - Function of L_{star}, radius in disk, environment

Summary

- We can begin to study early disks
  - Spitzer can detect them
  - Need CARMA/ALMA/SMA to study
  - Need to understand transition from
    - Envelope to disk
- Dust evolves continuously
  - In cores before collapse (growth/freeze-out)
  - During collapse (heating/evaporation)
  - In disk (further heating, transport, coagulation)