Physical Properties of Star Forming Regions

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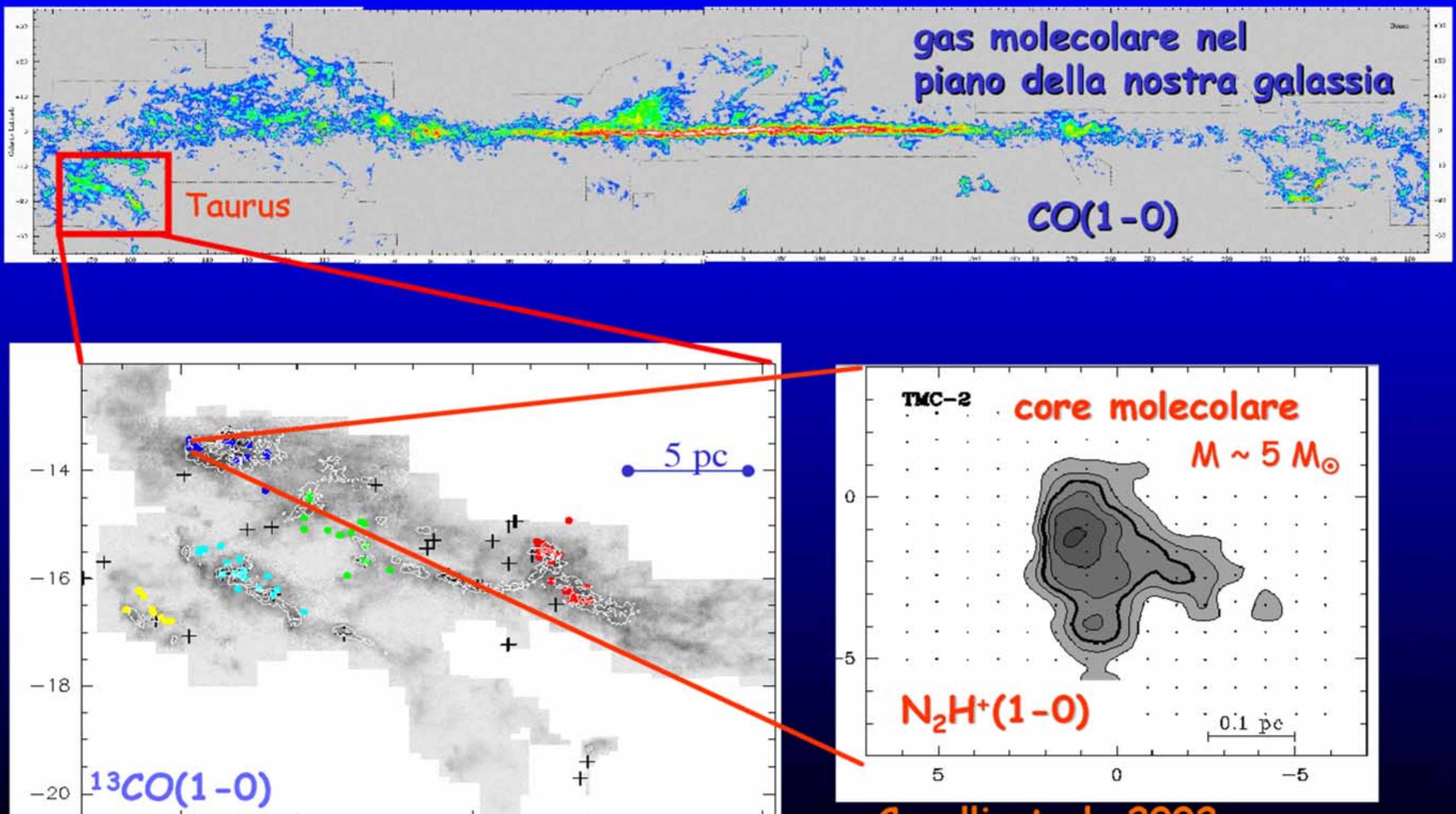
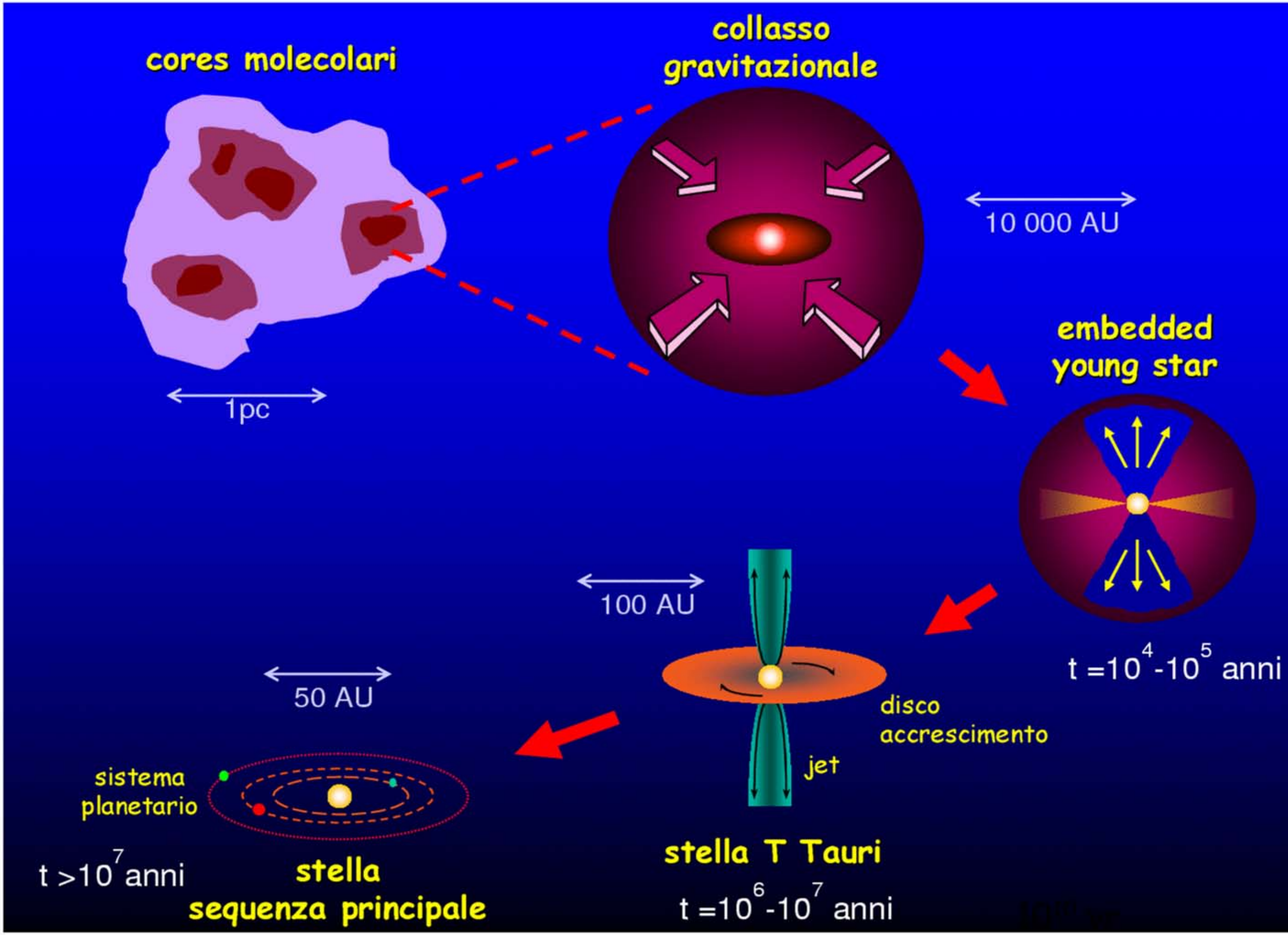
La Formazione Stellare Avviene nelle Condensazioni di Gas Molecolare



Caselli et al. 2002


cores molecolari
1pc
collasso gravitazionale
10 000 AU
embedded young star
t =10^4-10^5 anni
100 AU
disco accrescimento
jet
stella T Tauri
t =10^6-10^7 anni
50 AU
sistema planetario
t >10^7 anni
stella sequenza principale

Generalised Jeans criteria

- **Gravitation against the rest**

WHAT ARE THE CONDITIONS FOR A CORE TO COLLAPSE AND FORM A STAR?

$$E_{gr} > E_{th} + E_{turb} + E_{mag}$$

An external pressure may trigger the collapse

BALANCE E_{gr}, E_{th} $\Rightarrow$ Jeans criterium

$$M > \left(\frac{5}{2}\frac{kT}{G\mu m_H}\right)\left(\frac{4}{3}\pi\rho\right)^{-1/2}$$
$$\sim 8M_\odot \; T^{3/2} n^{-1/2} = M_{cr,th}$$

where we express the Jeans mass as a function of T, n, which are the most commonly observed quantities.

BALANCE E_{gr}, E_{th}, E_{rot}:

$$M > \frac{M_{cr,th}}{1 - \frac{\Omega^2}{4\pi G\rho}} = M_{cr,rot}$$

BALANCE E_{gr}, E_{mag}:

$$M > \frac{1}{3\pi}\sqrt{\frac{5}{2G}}\,\Phi \sim 3M_\odot \left(\frac{B}{30\mu G}\right)\left(\frac{R}{0.1pc}\right)$$
$$= M_{cr,mag}$$

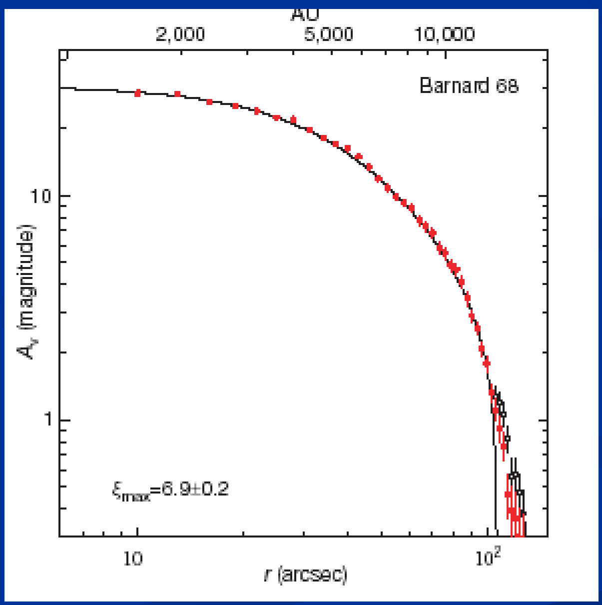
where Φ is the magnetic flux, $\Phi = \pi R^2 B$.

Determining physical conditions in a core

- Estimating the importance of gravitational relative to kinetic, thermal, magnetic energies requires measuring the thermal and density structure

- This is done by :
  - Molecular Line measurements in the mm, cm wavelength ranges (e.g. NH_3(1,1) and (2,2) allows T estimates)
  - Dust Emission in mm and dust absorption in IR (rel. independent of depletion).

A hydrostatic equilibrium structure fits very well the NIR extinction measurements



Alves et al. 2001

Structure of nearby Cores

The true physical structure is best defined by the dust (either absorption in the NIR mid IR or mm emission). This shows:

- Rough agreement with Bonnor-Ebert distribution with flat nucleus
- Highly non-spherical structures
- Polarisation of mm emission from dust

➡ ***presence of magnetic field***

Importance of magnetic fields

- Difficult to establish because:
  - Zeeman measurements in dense gas difficult
  - Chandrashekar-Fermi not very credible
  - Grain alignment not understood
- Difficult to neglect because:
  - Non-spherical appearance of quiescent objects
  - Polarisation properties of cores
  - The available measurements show that magnetic and gravitational energy are often comparable

Ambipolar Diffusion

- In an essentially neutral plasma (e.g. with ionization degree 10^{-8}), the magnetic field together with the ions can move relative to the neutrals
- This is known as ambipolar diffusion and allows a local change in the flux-to-mass ratio
- Thus an initially magnetically sub-critical core becomes supercritical ($M>M_{cr}$)

Two main theories

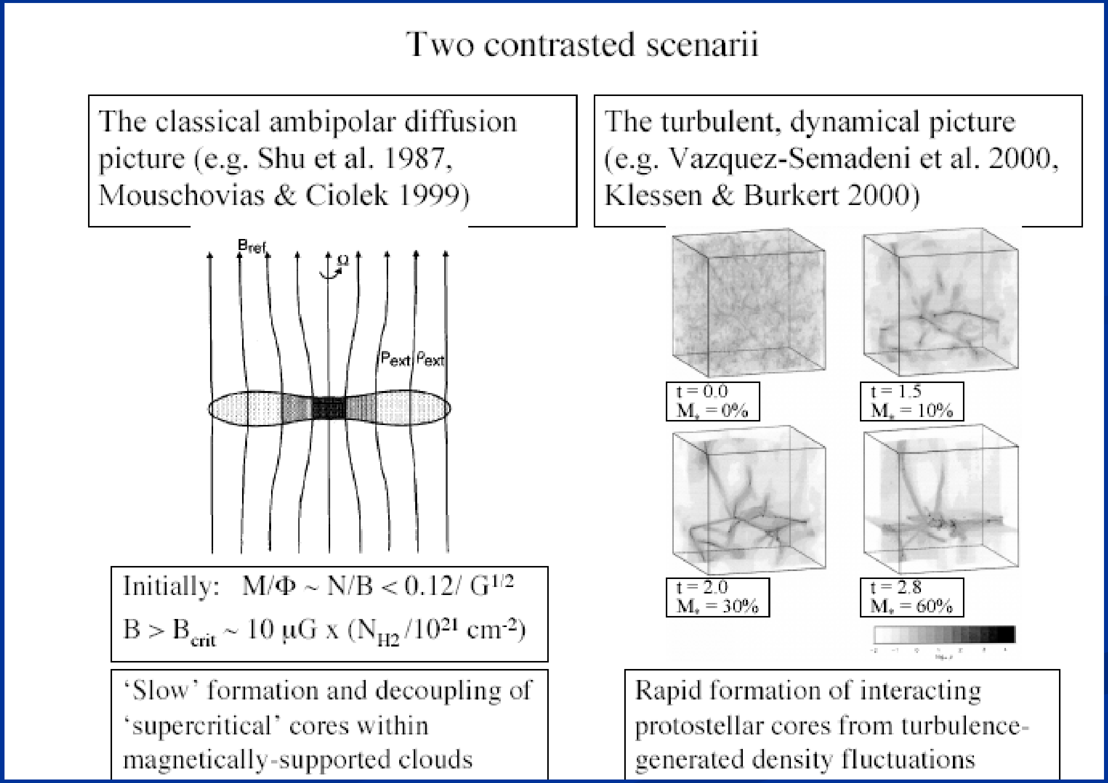
- **Magnetically Controlled Star Formation as in the review of Shu et al. where time scale is essentially that for ambipolar diffusion**

- **Turbulent model where cumulative shocks build up a gravitationally unstable core.**

It is hotly debated which of these is correct and I do not know.
In the following, I will concentrate on the magnetically controlled option

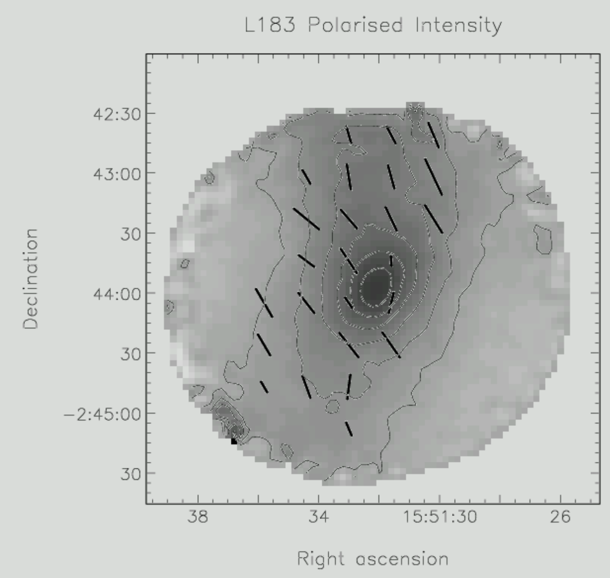
Formation and Evolution of a core

- **Magnetic field or no magnetic field; that is the question**

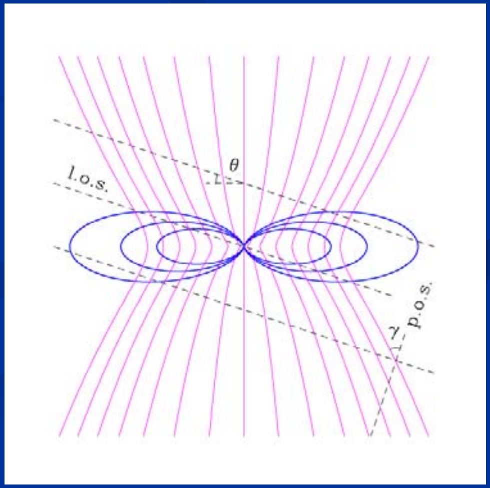


Polarisation maps

Polarisation maps show relatively uniform percentage pol. with a decrease towards the high density nucleus.

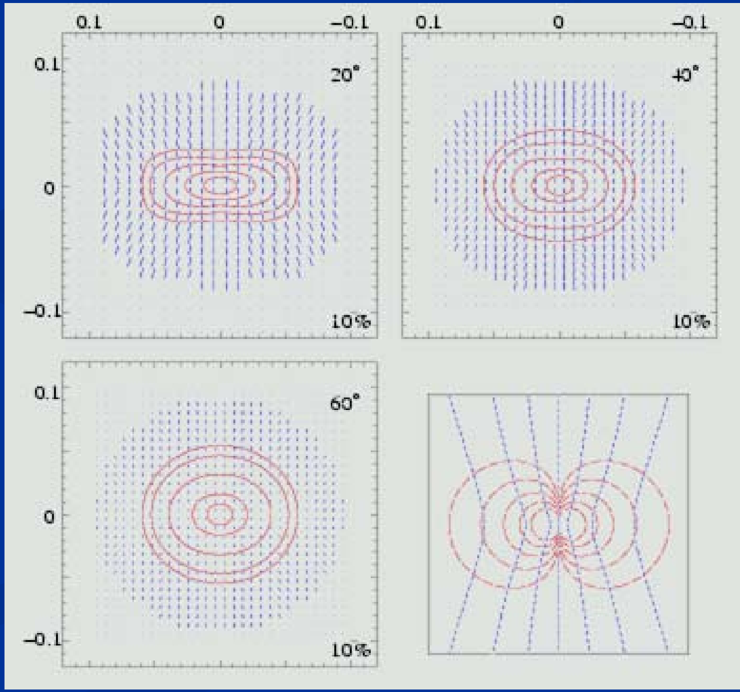


Goncalves and Galli interpret that in terms of a hydromagnetic equilibrium configuration with twisted B-field in the nucleus.



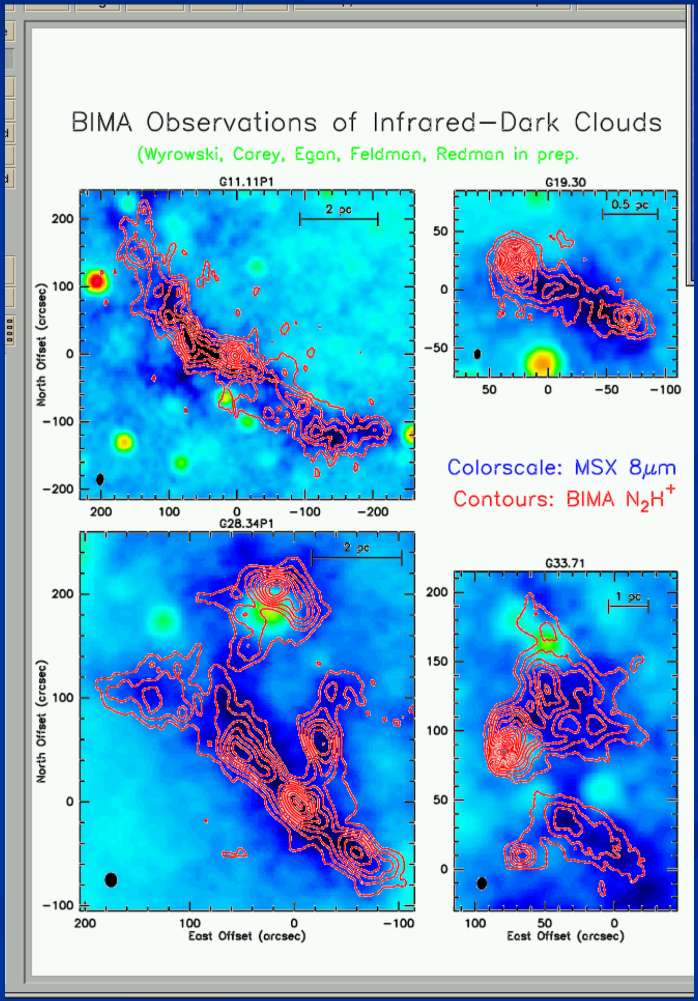
Polarisation as function of elongation

- **In this type of model, elongated cores should show high polarisation**
- **Not clear that this is true !**



How do you find pre-stellar cores?

- **Strong mm emission**
- **NIR/MIR absorption**
- **Low dust and gas T**

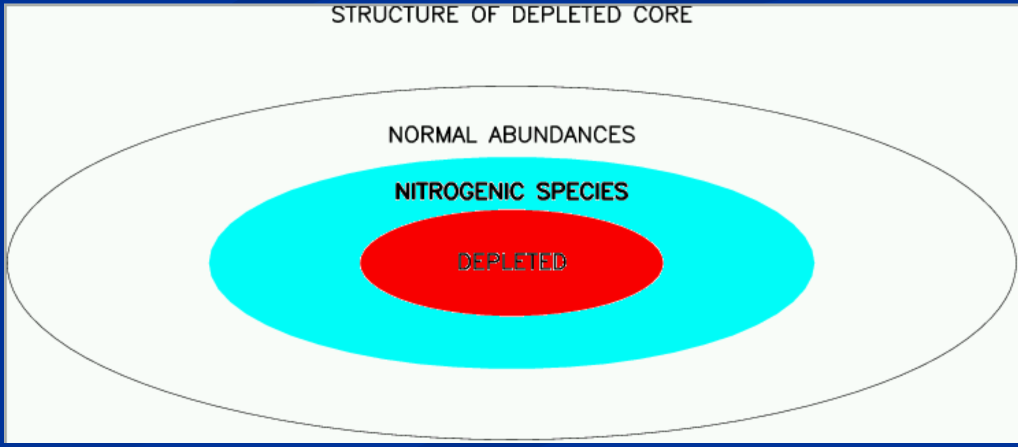


Characteristics of Pre-stellar Cores

- High Column Density corresp. 100 mag. of visual absorption
- High density (10^5 cm^{-3})
- Low Temperature (below 20 K)
- No evidence of protostars inside
- Depletion of CO and emission in NH_3, N_2H^+

Depleted cores may have shell-like structure

- Highest density core completely depleted of heavy elements
- Exterior has CO,CS etc in normal abundance
- Intermediate shell has N-containing species such as NH3,N2H+



Contracting Core Model

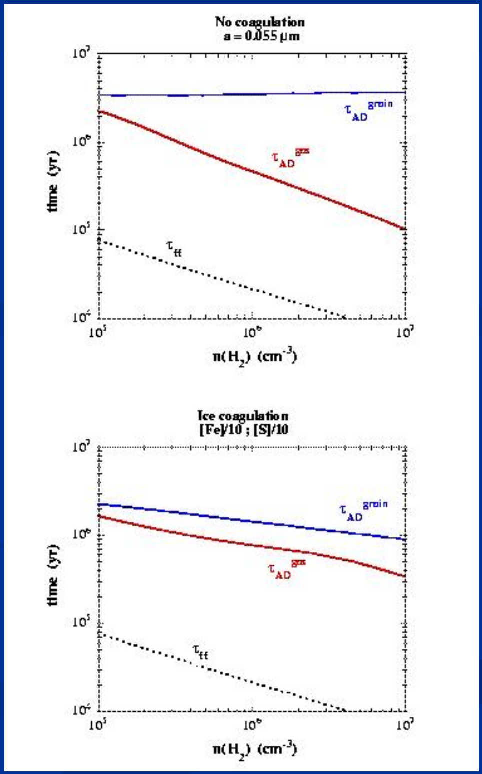
- We (David Flower, Guillaume Pineau des Forets, CMW) have been investigating the variation of ambipolar time duing the evolution of a core contracting on roughly 1 free-fall time
- We allow grain coagulation and depletion onto grain surfaces to occur simultaneously and follow the gas phase chemistry as density increases
- We finish with a "completely depleted core" in which the main ions may be H+, H3+, D3+ etc.

Results from evolutionary model

- At max. coagulation rates, freeze-out is not affected even though grains grow beyond 0.1 micron
- Ambipolar time is affected but never drops below 10 times free-fall time
- One finishes with "completely depleted conditions" in high density ($>10^6$ cm^{-3})

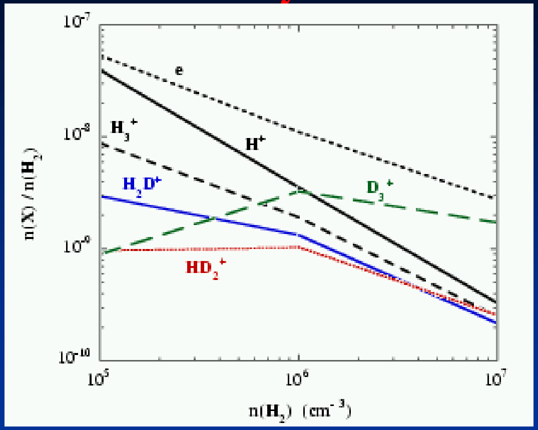
Ambipolar timescale during core evolution

- As core evolves, density increases and heavy species like CO deplete out
- Ionization degree goes down via dissociative recombination of ions and reactions with charged grains
- Grain Coagulation does not change much.
- Relative to free-free time, little changes !

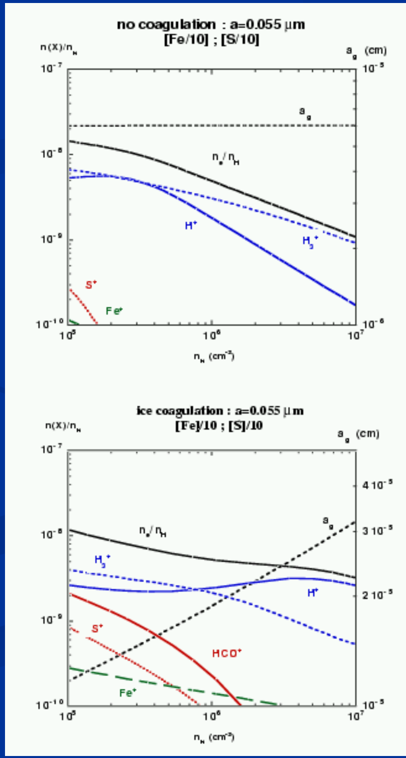


Effect on Ions

Steady-state



Time-dependent

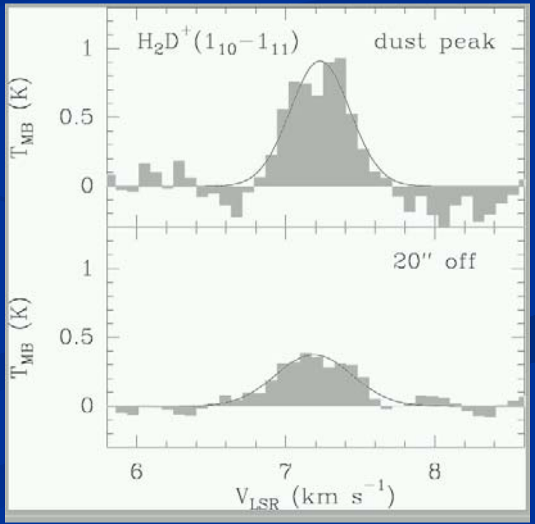


- The question of what is the major ion in various parts of the core depends sensitively on the depletion.
- In the completely depleted region, either H^+ or D_3^+ can become major ion depending on density and grain size
- The most observable species in the completely depleted region may be H_2D^+,D_2H^+

Why does this matter ??

- Mainly because understanding what is happening just prior to collapse requires a tracer of the kinematics

- Recent detections of H2D+ and D2H+ suggest that this may be possible (see Caselli et al in L1544)



Future in this area

- The future is certainly high angular resolution both in IR and mm-submm.
  - ALMA
  - VLT(VLTI)
  - NGST

Galactic Star Formation must be very inefficient !

- **What is the present galactic star formation rate ??**
  - **About 3 Solar Masses per year**

- **BUT if all the galactic molecular clouds were collapsing at the free fall rate, there would be 300 $M_{\odot}$ per year**