Formation and Lifetimes of Molecular Cloud Cores

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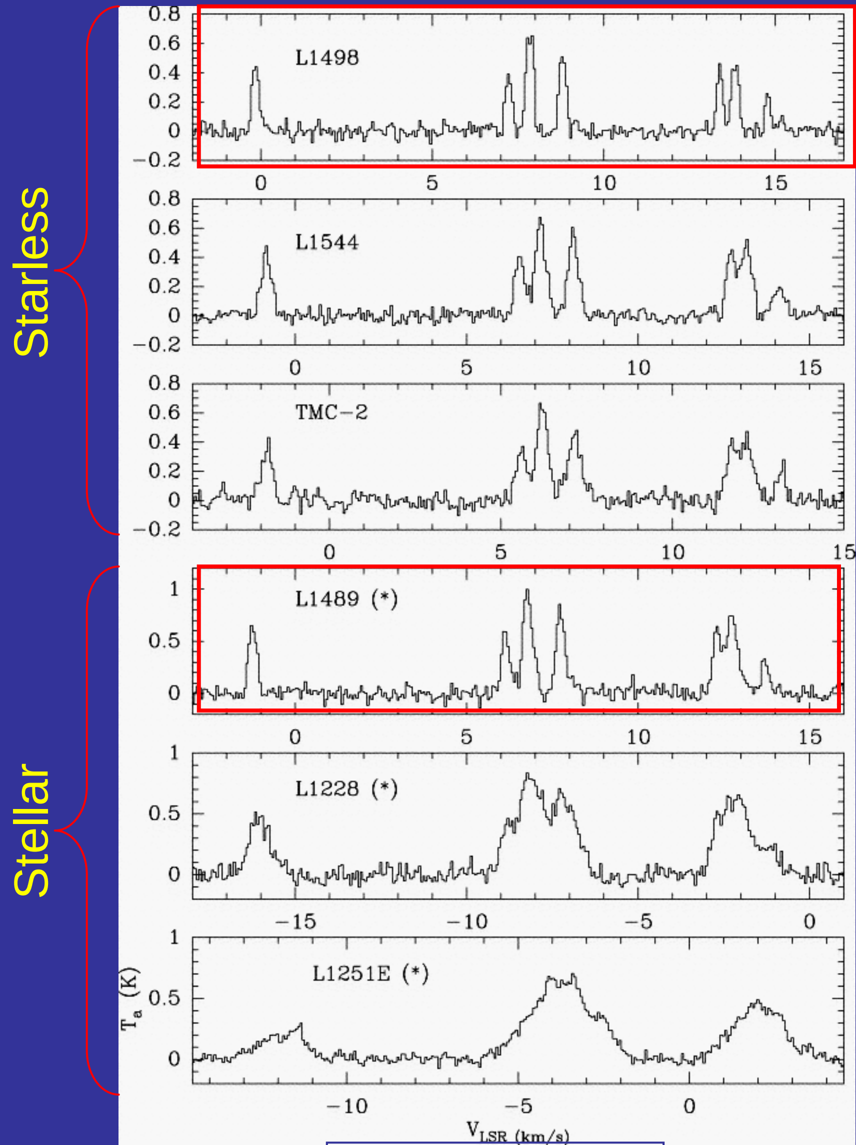
Introduction

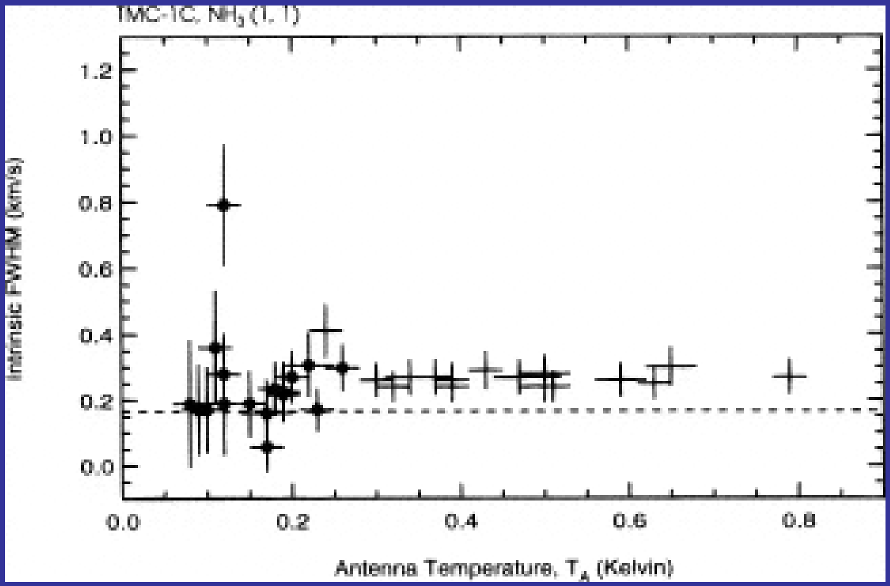
- Molecular cloud (MC) cores are believed to be turbulent density fluctuations formed by the supersonic turbulence in the clouds (e.g., Sasao 1973; Elmegreen 1993; Vázquez-Semadeni 1994; Padoan 1995; Passot & Vázquez-Semadeni 1998; Ballesteros-Paredes et al. 1999).

- On the other hand, MC cores are known to often be
  - Quiescent: with subsonic internal velocity dispersions,
  - Coherent: with radius-independent velocity dispersions,
  - Bonnor-Ebert-like,
  - Relatively long-lived, with lifetimes of several times the free-fall time.

Quiescence and coherence

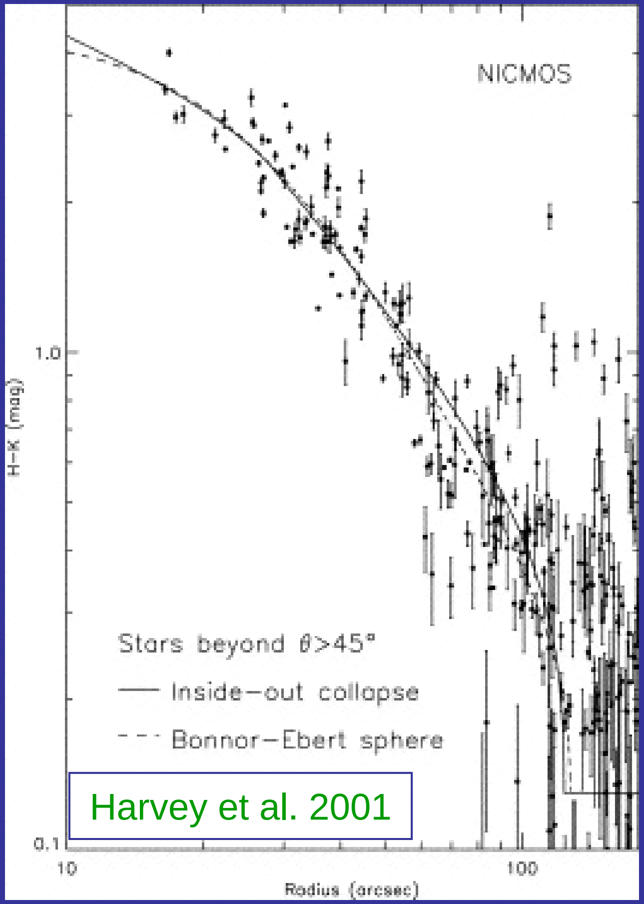


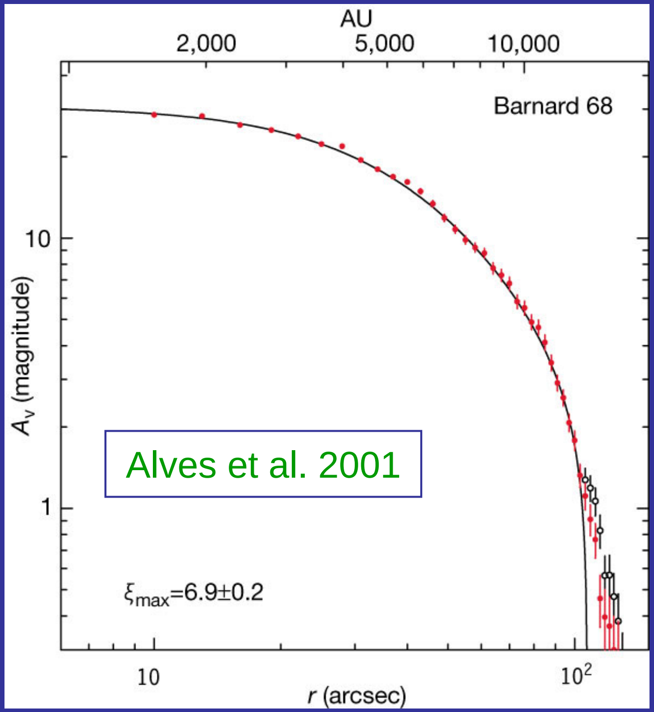
Caselli et al. 2002



Barranco & Goodman 1998

Bonnor-Ebert profiles:

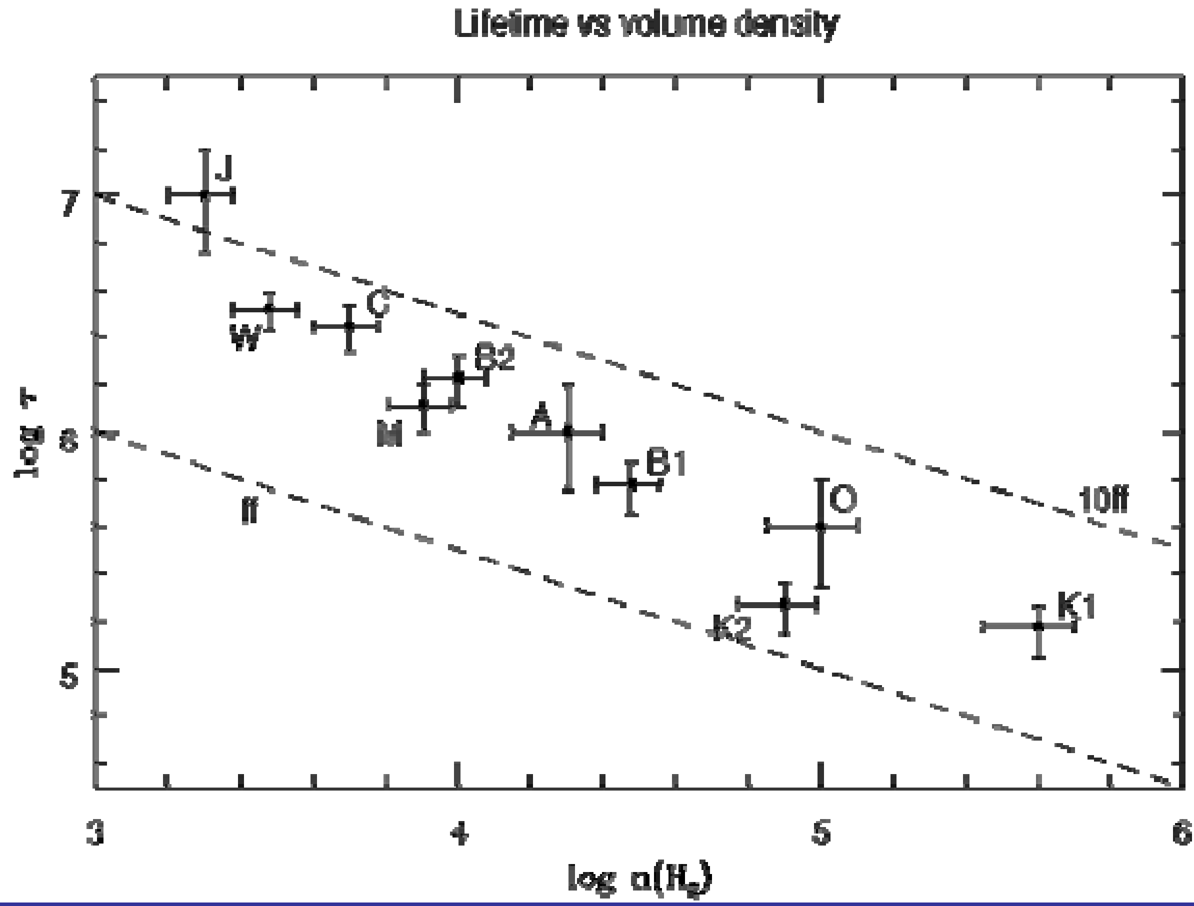




Lifetimes

Typically several times the free-fall time.

Ward-Thompson et al. 2007 (Protostars & Planets V)



- It is often thought that cores formed by turbulent density fluctuations in driven, magnetically supercritical turbulent environments have
  - Arbitrary density profiles (inconsistent with high observed fraction of BE-like profiles),
  - Too short lifetimes (~ 1 τ_{ff}),
  - Too large velocity dispersions (too high a fraction of transonic or supersonic cores).

- Actually,
  - Ballesteros-Paredes et al. (2003) and Hartmann (2004) suggested angular- and LOS-averaging can cause apparent BE-like column density profiles.
  - Klessen et al. (2005) found ~25% of quiescent cores in numerical simulations of HD, driven, self-gravitating turbulence.
  - Vázquez-Semadeni et al. (2005) observed core lifetimes 1.5-6 τ_{ff} in MHD simulations.
  - Whitworth et al (2007) suggested core formation naturally involves a delay before collapse and BE structures.

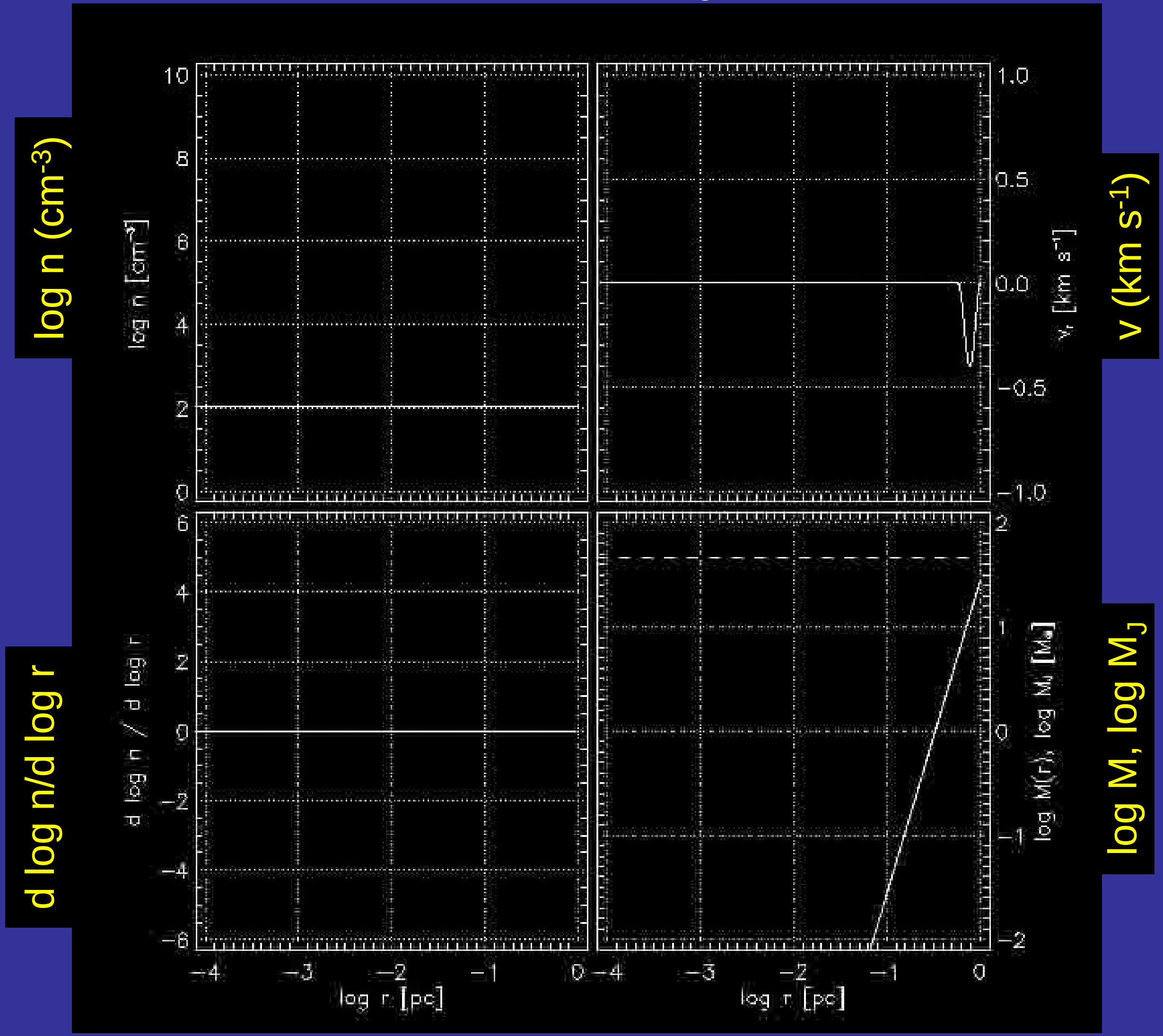
- This work:
  - Detailed investigation of idealized 1D spherical model of core formation.
    - Do BE-profiles arise naturally?
    - Does a quiescent structure arise naturally?
  - Systematic measurement of core lifetimes and number ratios in 3D MHD simulations of magnetically supercritical isothermal clouds.

I. Numerical simulations of compression-induced core formation in non-magnetic, spherically symmetric clouds

(Gómez, VS, Shadmehri, & Ballesteros-P. 2007, ApJ in press, arXiv/0705.0559; see also Hennebelle et al. 2003 and Whitworth et al. 2007).

- Spherical compression justified because focusing is necessary to induce collapse in isothermal media (McKee et al. 1993; VS et al 1996; Whitworth et al 2007)
- Features:
  - R = 1 pc
    $n = 110\ cm^{-3} \sim 0.7\ n_J$
    T = 11.4 K
    $c_s = 0.2\ km\ s^{-1}$
    → Jeans *stable.* (Unconfined)
  - Compressive velocity pulse:
    - centered at $r_0 = 1/3\ R$, $2/3\ R$,
    - width ~ 0.1 pc (finite duration),
    - amplitude $2c_s$.
  - Look at core *formation* process, before collapse.

- A collapsing case. $r_0 = 2/3$ pc



Core starts out with negligible self-gravity, at uniform (high) density.

Core mass eventually overtakes M_J, and core collapses.

—— M(r)

- - - - M_J(r)

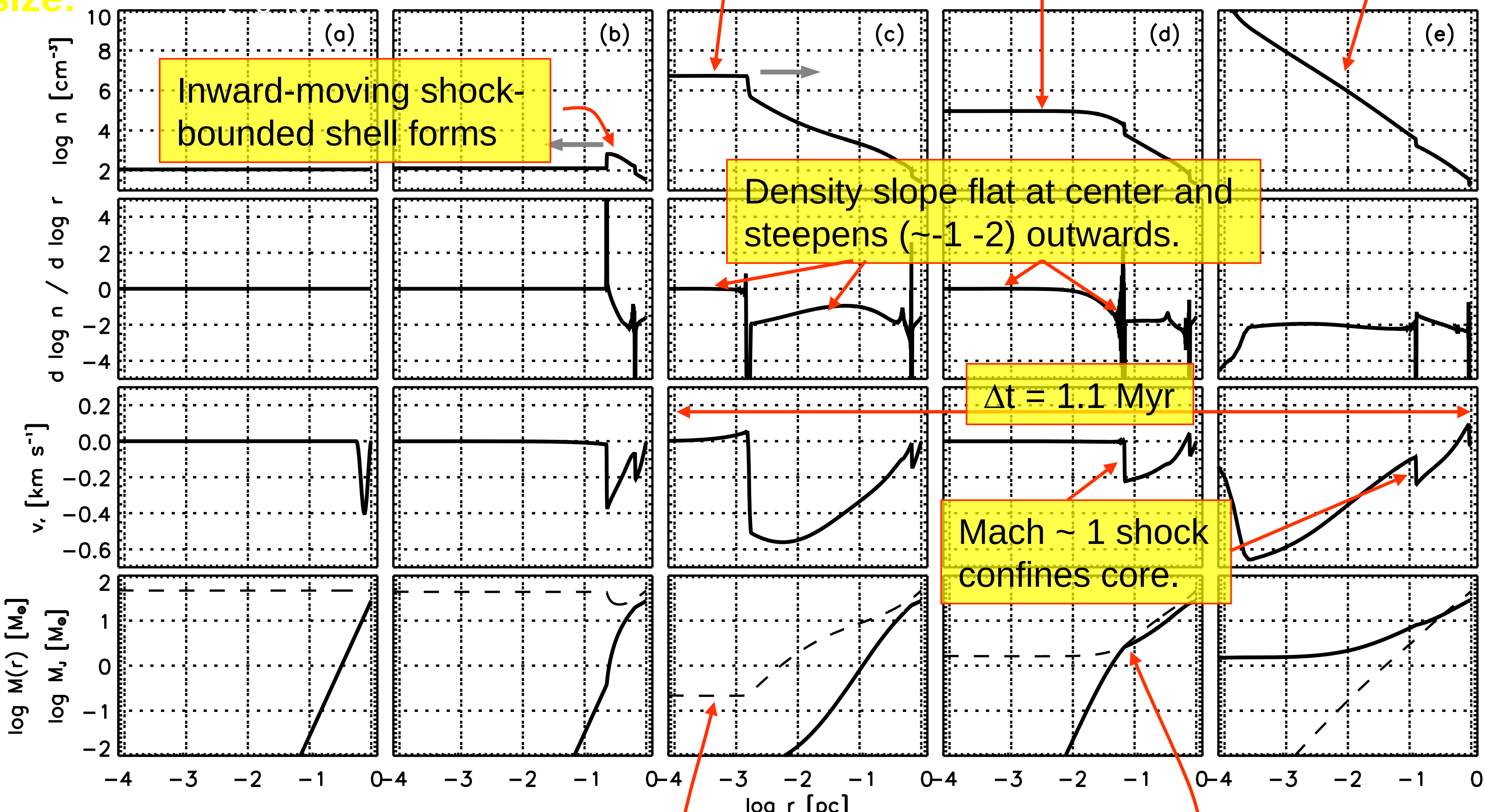
Gómez et al. 2007, ApJ submitted, astro-ph/0705.0559

Compression forms central core that grows in mass and size:

Non-self-gravitating central core with high uniform density.

Self-gravitating central core with BE-like density profile.

Collapsed core, with SIS profile.



t=0 Myr t=1.125 Myr t=1.525 Myr t=2.0 Myr t=2.625 Myr

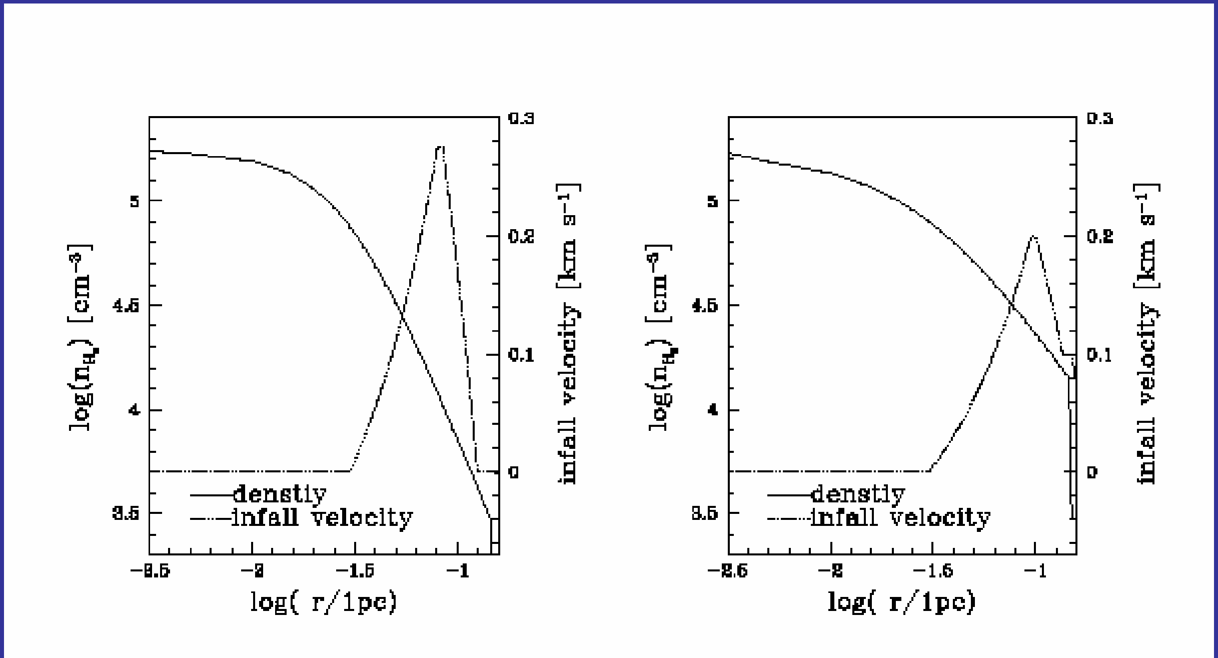
Jeans mass decreases in central dense core.

Core's mass catches up with Jeans mass.

Gómez et al. 2007, ApJ in press, arXiv/0705.0559

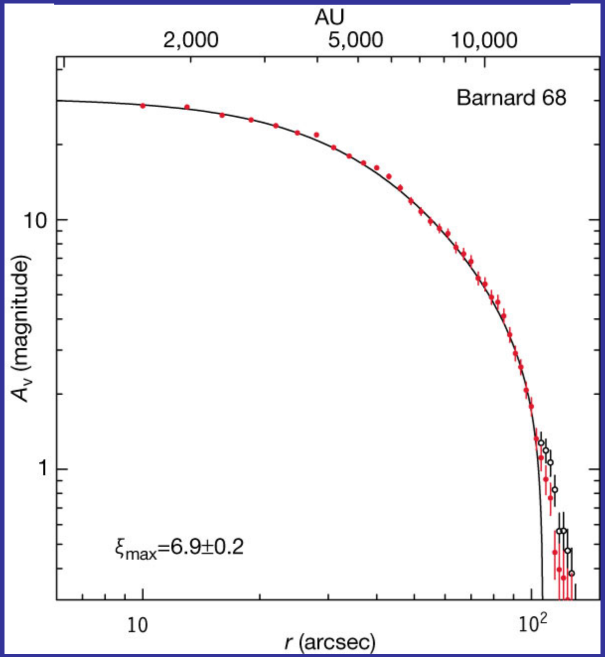
- Summary of evolution:
  - Start with Jeans-stable, uniform region, with compressive pulse.
  - Compressive wave forms a shock-bounded shell of infalling material.
  - Inner shock reaches center and rebounds, leaving a high-density, zero-velocity spherical region inside (a ***quiescent core***).
  - Quiescent core accretes mass from the shell, mediated by a shock.
  - Core's evolution:
    - Initially its self-gravity is negligible, so has uniform density, and is confined by ram pressure.
    - As it grows in mass and size, self-gravity becomes increasingly dominant, developing curved density profile – a ram-pressure-confined, growing, stable BE sphere.
    - Eventually, the core may become Jeans-unstable and collapse (an unstable BE sphere).
    - Lifetime ~ 1 Myr: 0.5 Myr to grow, and 0.5 Myr to collapse.

- Preliminary comparison with observations:
  - Central core is quiescent.
  - Envelope infalling at transonic speeds.
  - Compares well to, e.g.,
    - Lee et al. 1999; Caselli et al. 2002; Tafalla et al. 2004: subsonic inflow line profiles. Detailed radiative transfer study coming soon (Ballesteros-Paredes, Vázquez-Semadeni & Gómez 2007).
    - Lee et al. 2007 (ApJ accepted, astro-ph/0702330): velocity profile inferred from radiative transfer model for cores L694-2 and L1197: transonic peak at r ~ 0.1 pc).

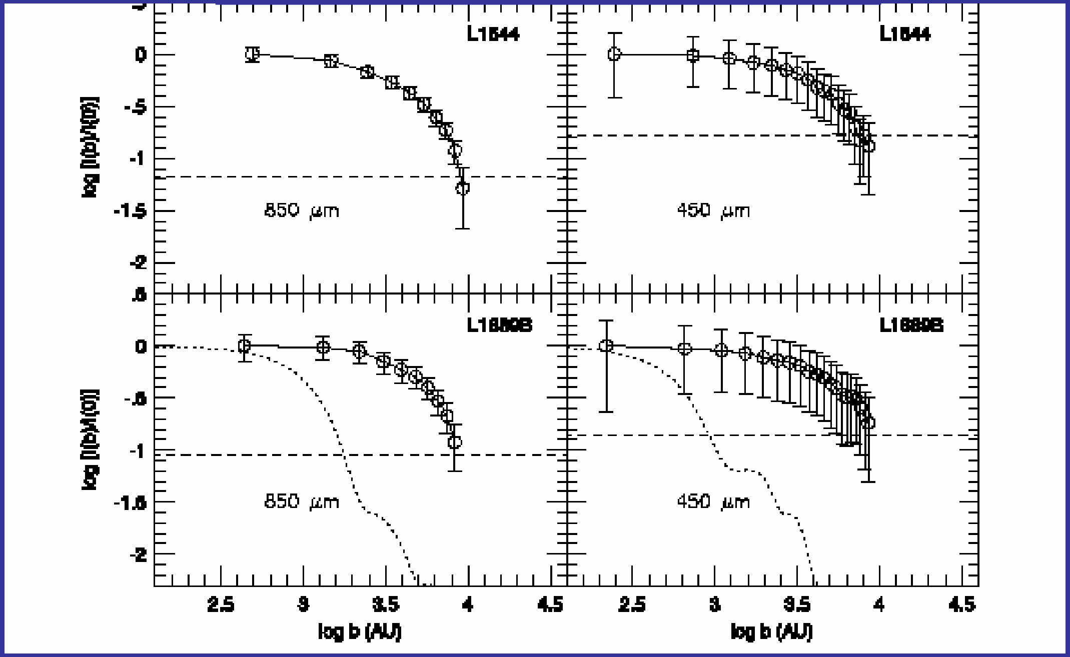


- Preliminary comparison with observations (cont'd):
  - Core+envelope structure has profile with flat center and $r^{-1.5}$—r^{-2} outskirts. Compares well to profiles of prestellar cores obtained from extinction and submm continuum maps.

Alves et al. 2001, extinction

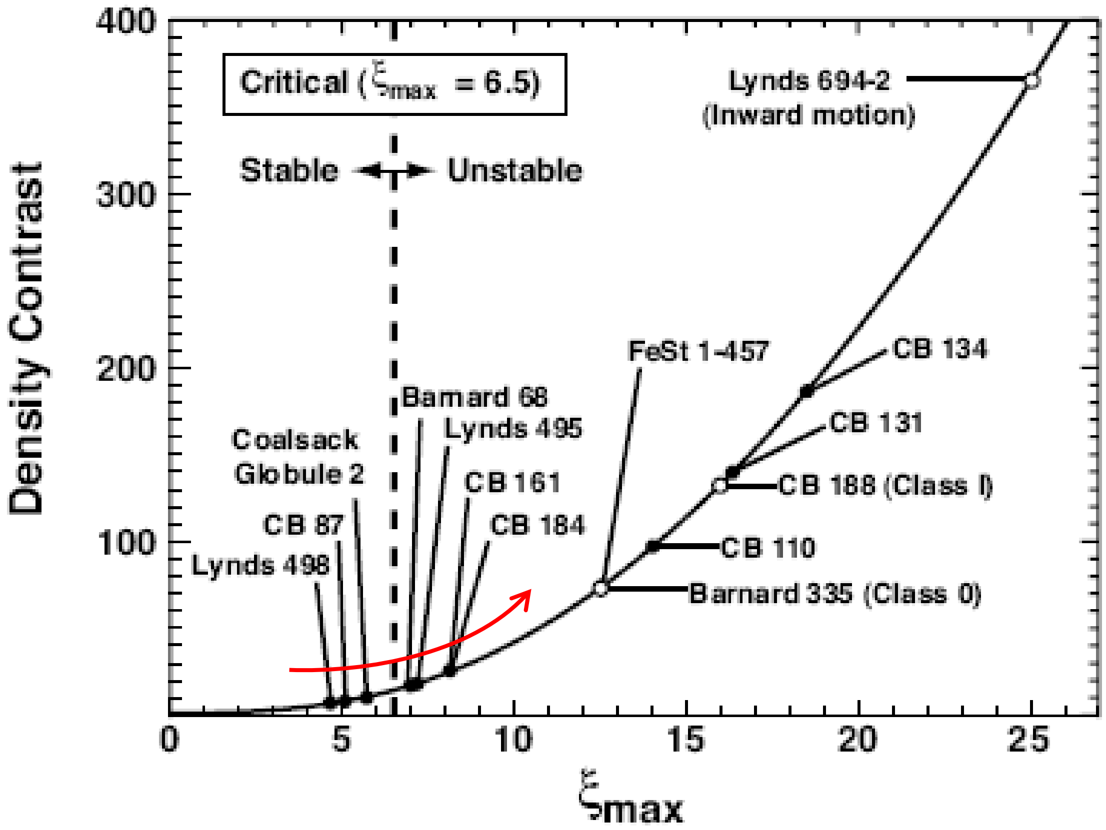


Shirley et al. 2000, submm continuum



– ... and evolves along the stability sequence:

Lada et al. 2007 (Protostars & Planets V)



- Conclusions:
  - “Focused” turbulent compressions in spherically-symmetric isothermal clouds produce cores that (see also Whitworth et al. 2007)
    - Are ram-pressure confined, growing BE spheres.
    - Evolve from stable to unstable configurations.
    - Are quiescent inside.
    - Have a build-up stage that lasts as long as the collapse stage.
      - The collapse stage itself lasts ~2 τ_{ff}.

The End