L1014-IRS
A proto-brown-dwarf in a starless core?

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Molecular Cloud Cores

- "starless cores" contain no embedded source $L > 0.1L_{sun}(d/140pc)$ (IRAS)

  (Myers et al. 1987; Beichman et al. 1986)

- "prestellar cores" – mm/submm dust continuum emission peaks $n \sim 10^5$ cm^{-3}

  (Ward-Thompson et al. 1994)

- protostellar cores – a known protostar

"typical core" – 0.1 pc, a few M_{sun}, 10^4-10^5 cm^{-3}, 10 K

Molecular Cloud Cores

- "Evolved prestellar cores" (prestellar+)

  – evolved chemistry, eg CO depletion, centrally concentrated N_2H^+/NH_3, deuterated species

  – infall asymmetry in multiple lines

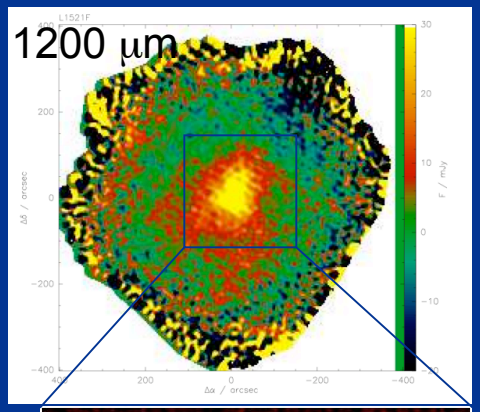
  – larger $N(H_2)$, line width, central density

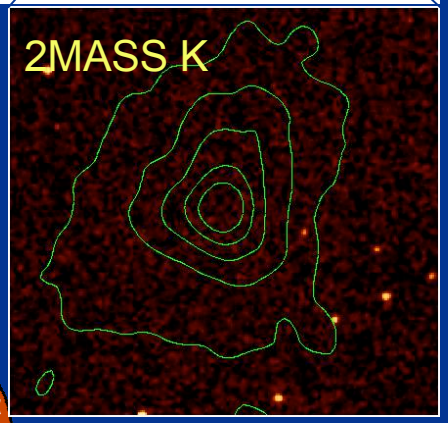
(Lee et al. 2001; Tafalla et al. 2002; Caselli et al. 2002; Crapsi et al. 2004b; Bourke et al. 2005)

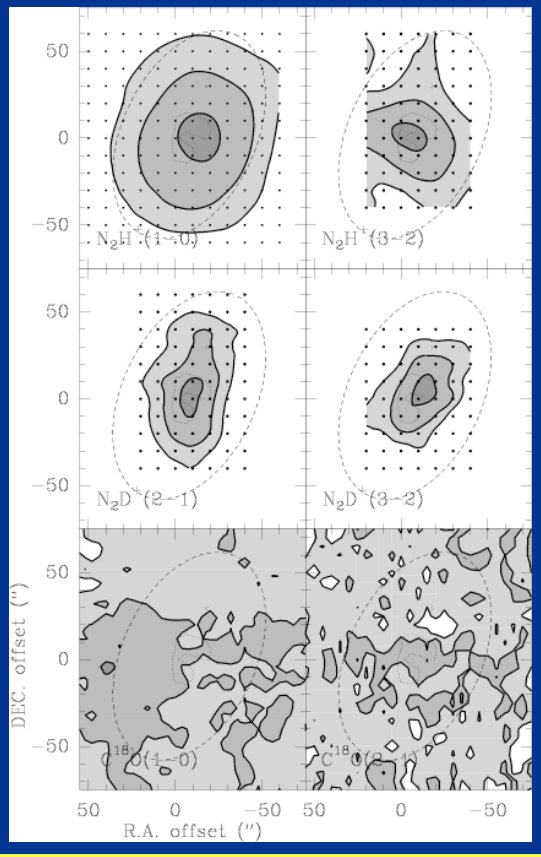
L1521F, an evolved prestellar core

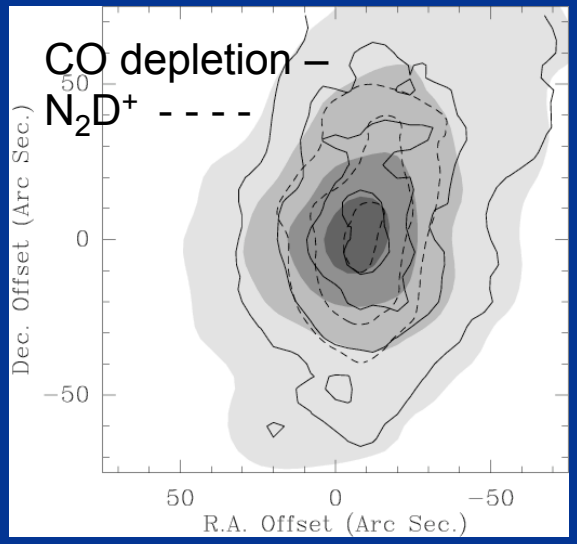
– No IRAS, no 2MASS, no known outflow

– Has all the properties of an evolved prestellar core, best example after L1544 (Crapsi et al. 2004a, b)









Expectations with Spitzer

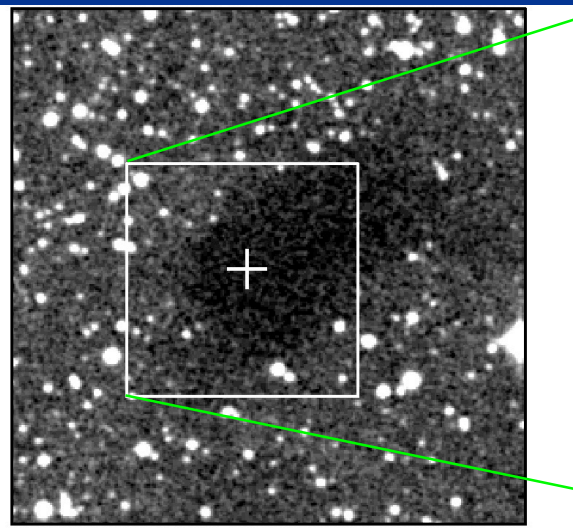
- new low luminosity sources near known protostars
- new low luminosity sources in "starless cores", most likely in prestellar and evolved prestellar cores

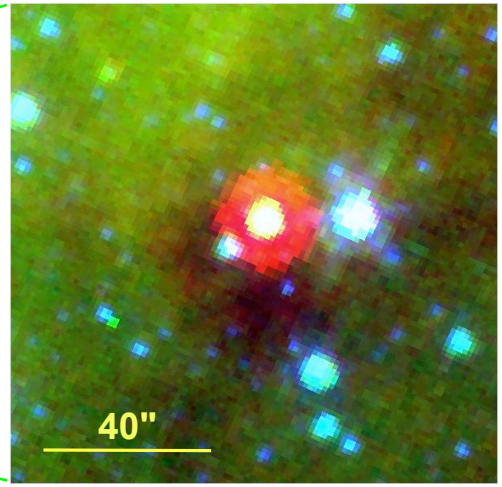
– proto Brown-dwarfs?
– very low mass protostars

L1014 – a "starless" core

- ordinary starless core, not "evolved"
- Mass ~2 M_{sun} from (sub)mm observations
- no obvious signs of star-formation in (sub)mm spectral line observations (infall, outflow)

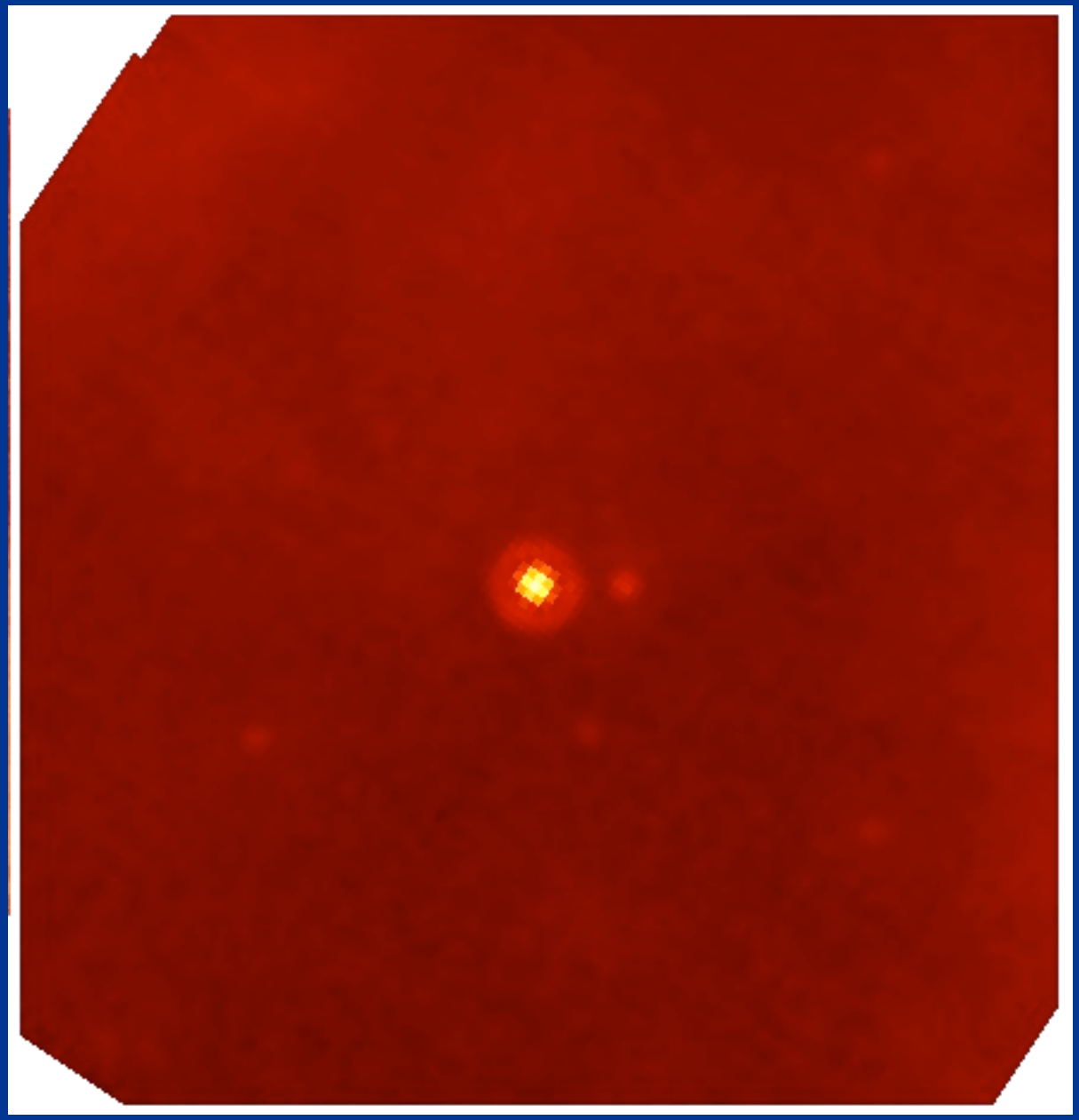
Spitzer reveals a low luminosity source





4.5 μm 8.0 μm 24 μm

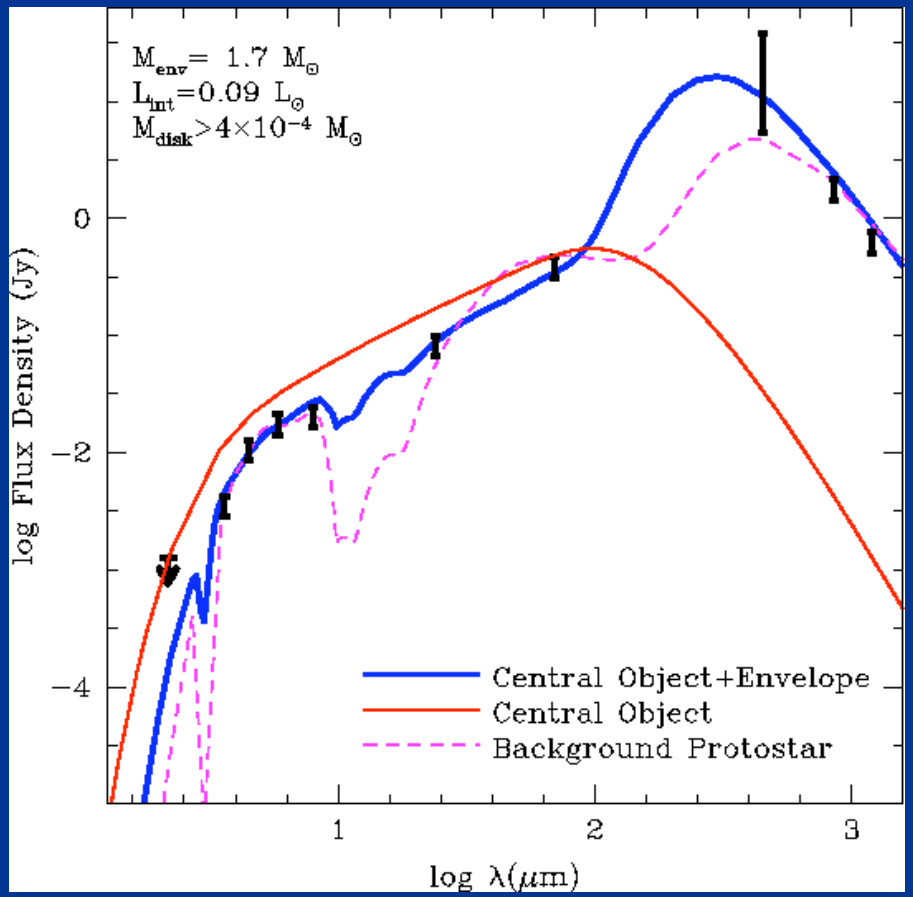
D = 200 pc



- Model bb+disk+envelope
- L1014-IRS L_{bol} ~ 0.09 L_{sun}
  M << 0.1 M_{sun}

- Disk-like component (MIPS)
  $M = 4x10^{-4}(R/50AU)^{0.5}$
  $T(r) \sim r^{-0.5}$

- Bonnor-Ebert like envelope
  $n \sim 1.5 \times 10^5$ cm^{-3}
  L_{bol} ~ 0.3 L_{sun} ISRF sufficient
  M ~ 1.7 M_{sun}



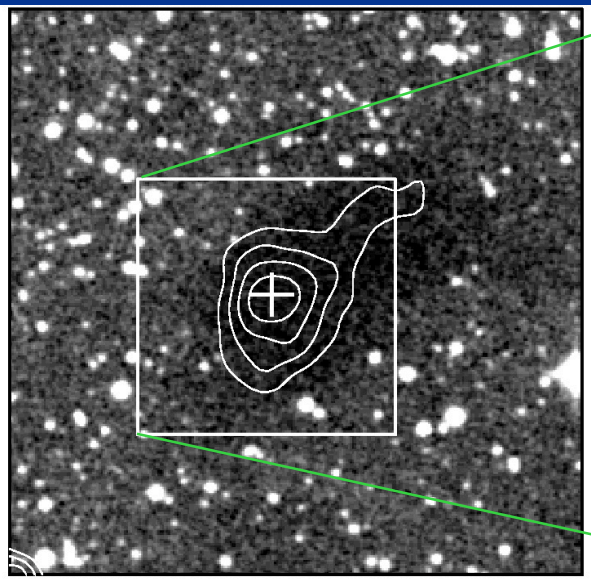
If background then L ~ 16 L_{sun}(d/2.6kpc)

Near or Far?

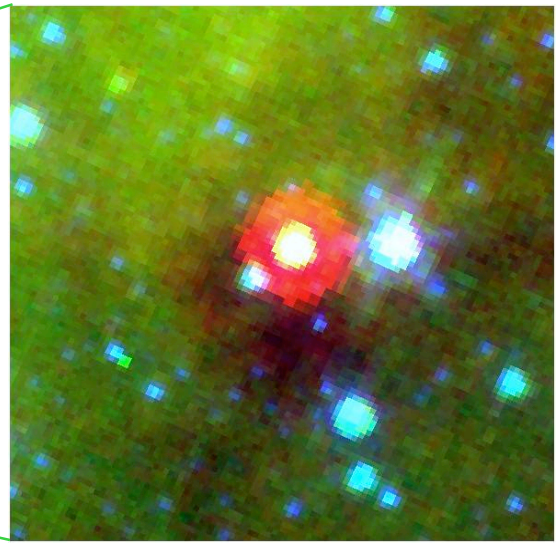
- two velocities, +4 (200 pc) and –40 km/s (2.6 kpc)

Evidence supports association with near cloud:

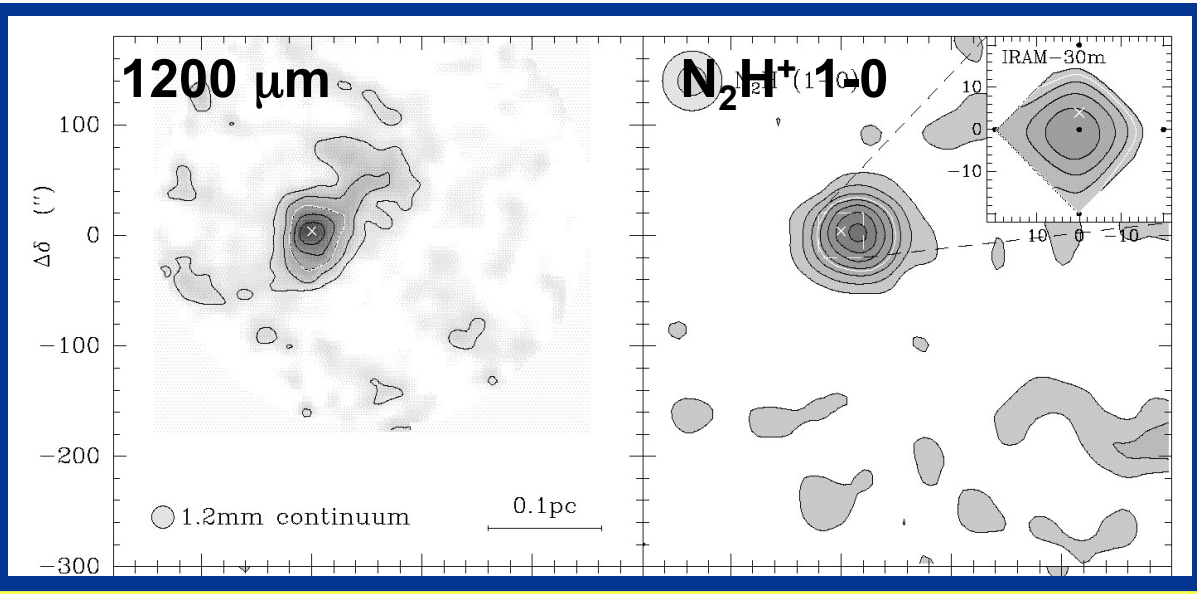
- No dense gas at –40 km/s, e.g., N_2H^+ (Crapsi et al. 2005)
- Near infrared bipolar nebula (Huard et al. 2005)
- Compact CO outflow at –4 km/s (Bourke et al. 2005)
- Chance alignment unlikely

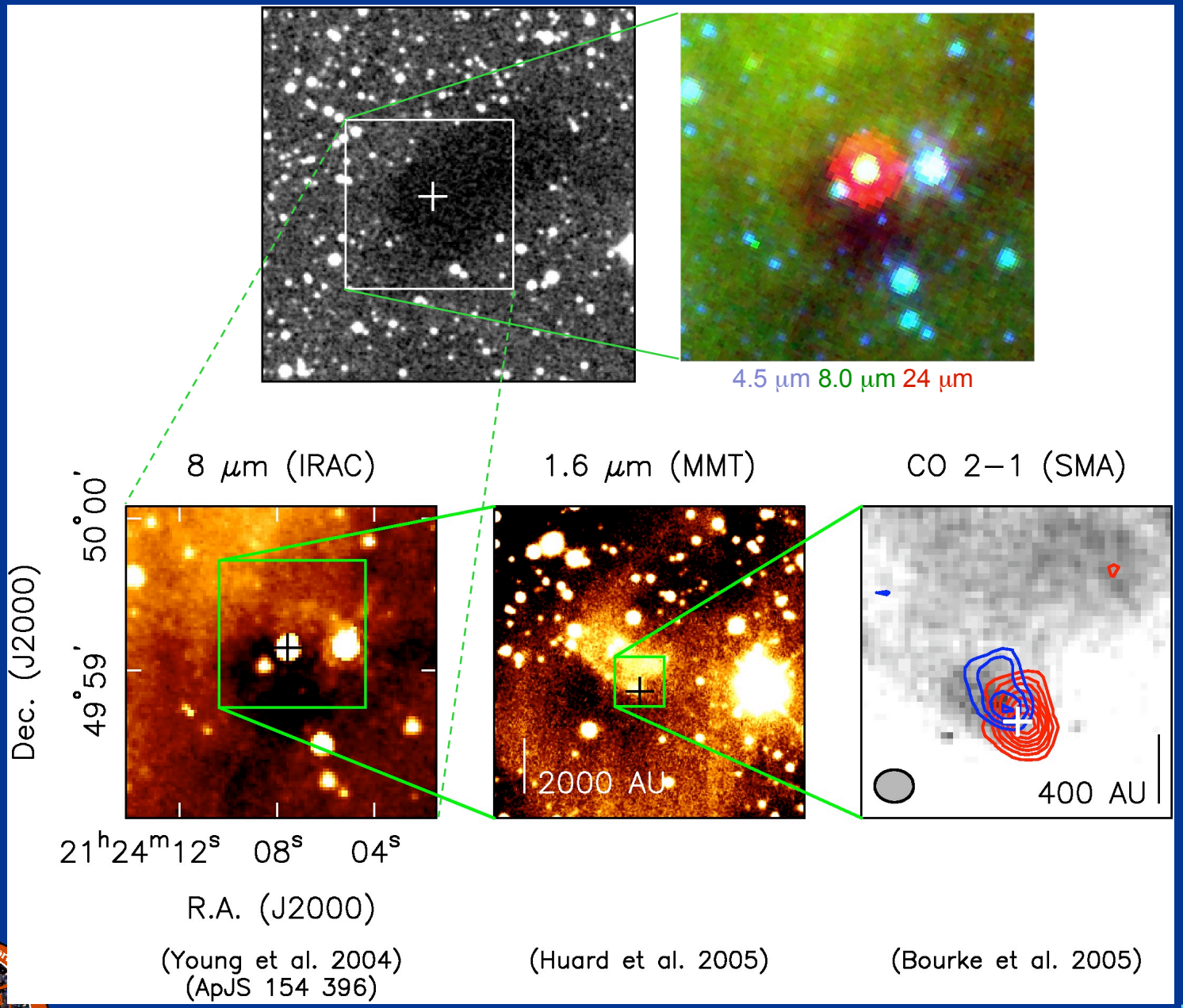


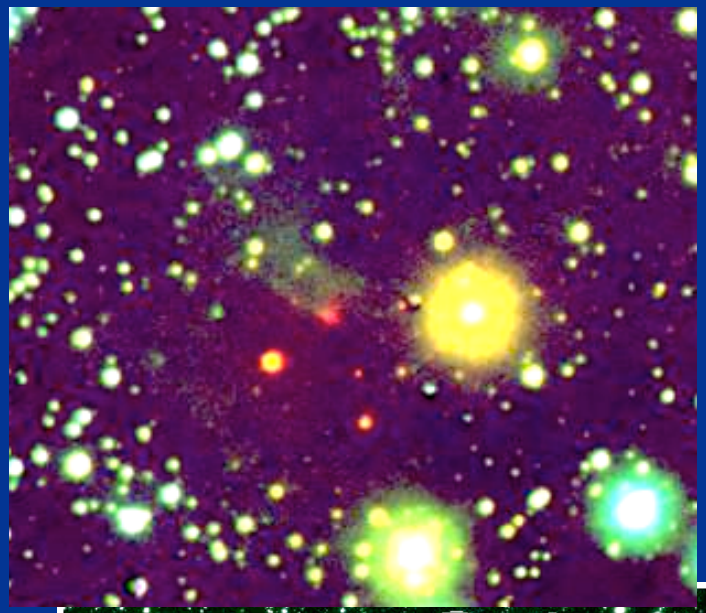
1200 μm contours over optical R



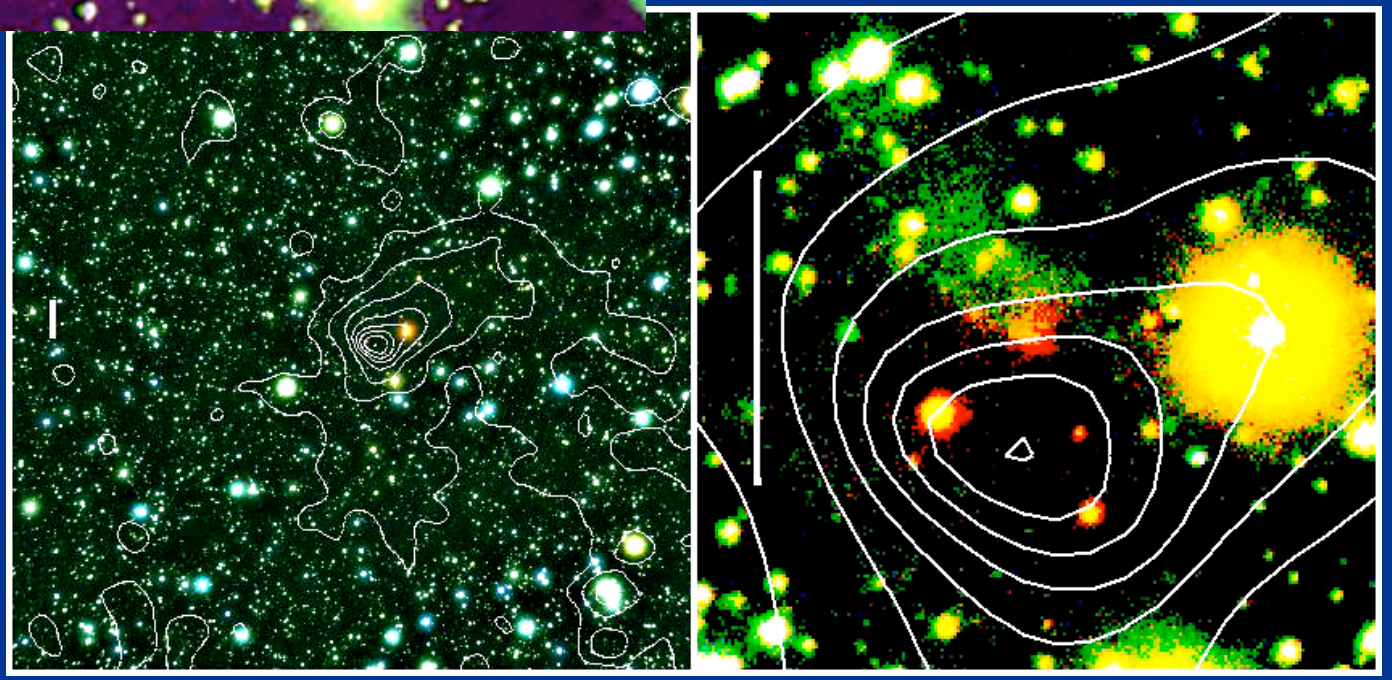
4.5 μm 8.0 μm 24 μm




4.5 μm 8.0 μm 24 μm
8 μm (IRAC)
1.6 μm (MMT)
CO 2−1 (SMA)
Dec. (J2000)
50°00'
49°59'
2000 AU
400 AU
21h24m12s
08s
04s
R.A. (J2000)
(Young et al. 2004)
(ApJS 154 396)
(Huard et al. 2005)
(Bourke et al. 2005)



Scattered light nebula
(Huard et al. 2005)



Outflow Parameters & Consequences

- Mass 1.4 x 10^{-5} M_{sun}
- Size 0.0026 pc, Age 700-7000 yrs (t_d – $10t_d$)
- Force 3-70 x 10^{-9} M_{sun} km/s yr^{-1}
- Assuming momentum conservation:

$(dM/dt)_{acc} = F / (f \times V_w)$ with [f=0.1, V_w=200 km/s]

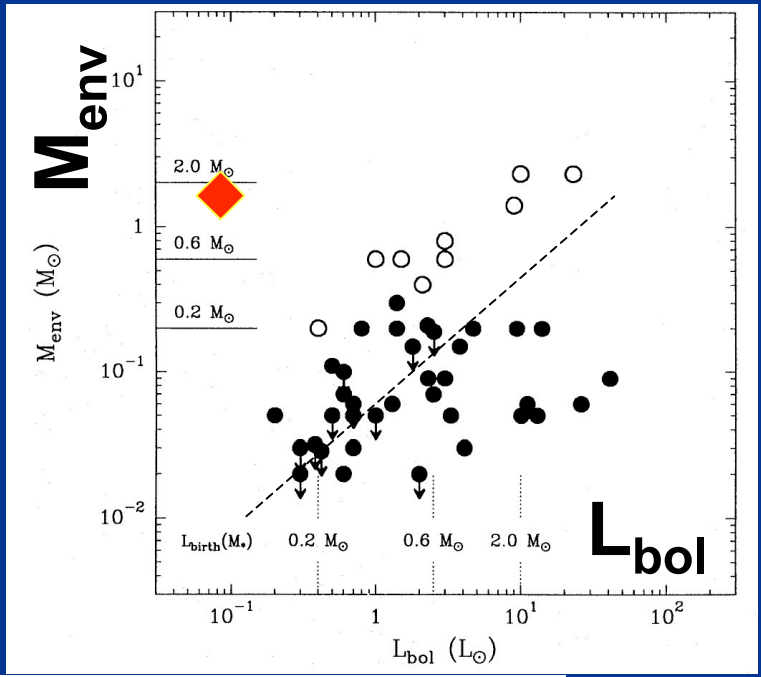
$\Rightarrow$ $(dM/dt)_{acc}$ ~ 2-35 x 10^{-9} M_{sun}/yr

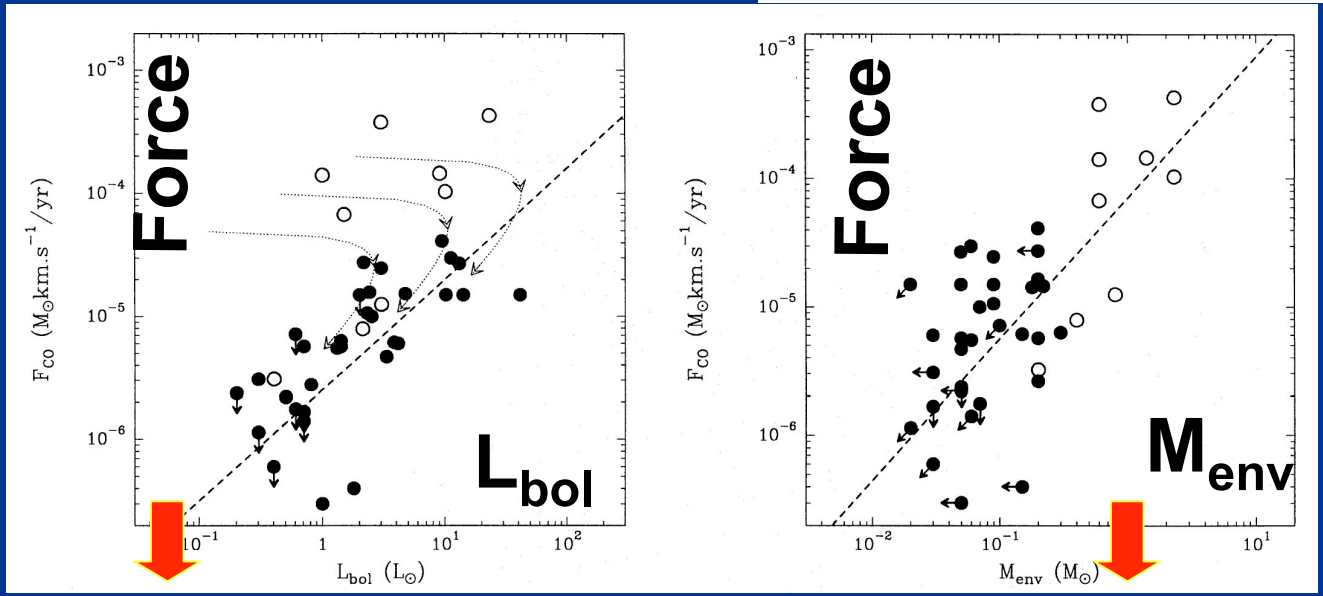
Accretion rate very low, but larger than young BDs (10^{-10} – 10^{-12} M_{sun}/yr; Muzerolle et al 2005)

Like other protostars ...except for M_{env}

Force 3-70 x 10^{-9} M_{sun} km/s yr^{-1}

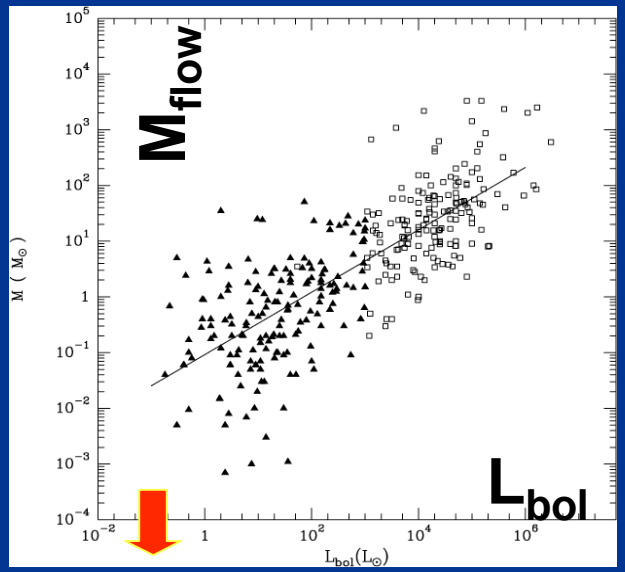
Bontemps et al 1996

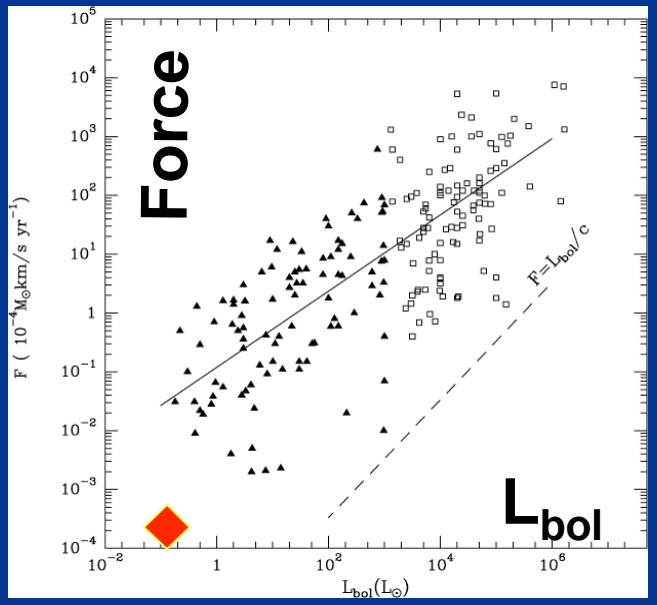


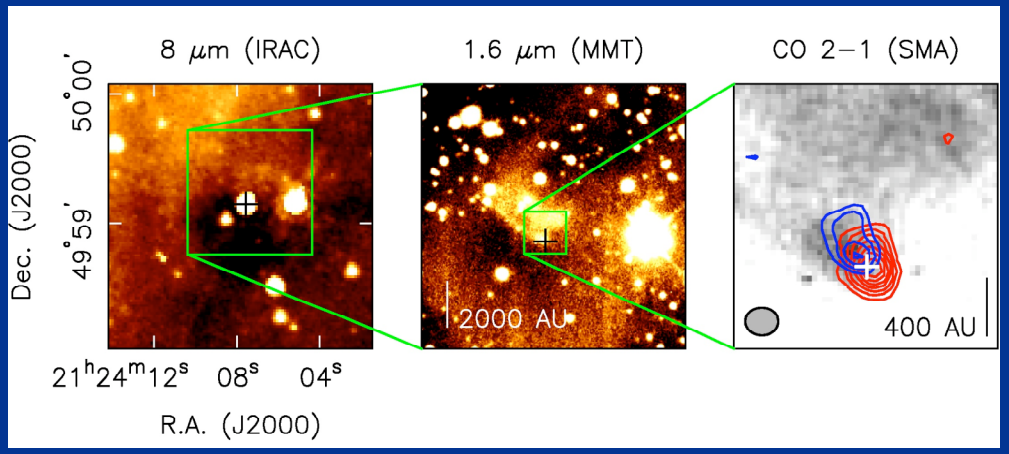


Compilation of 391 outflows
(Wu et al 2004 A&A 426 503)

L1014 is a weaker version of a typical outflow







Outflow not detected with 30-m (11" beam)

Is it substellar? – Mass estimates

$(dM/dt)_{acc} \sim 10^{-8}\ M_{sun}/yr$

Low L_{bol}, Low $(dM/dt)_{acc}$ → Low mass

Age ~ 10^5 yr (~Class 0/I transition) → ~0.001 M_{sun}

if $(dM/dt)_{acc}$ constant…likely larger in the past

cf. 0.09 L_{bol} @ 10^5 yr → ~0.03 M_{sun} (Lyon98/00 tracks)

(Chabrier et al 2000; Baraffe et al 1998)

Proto-Brown Dwarf Candidate

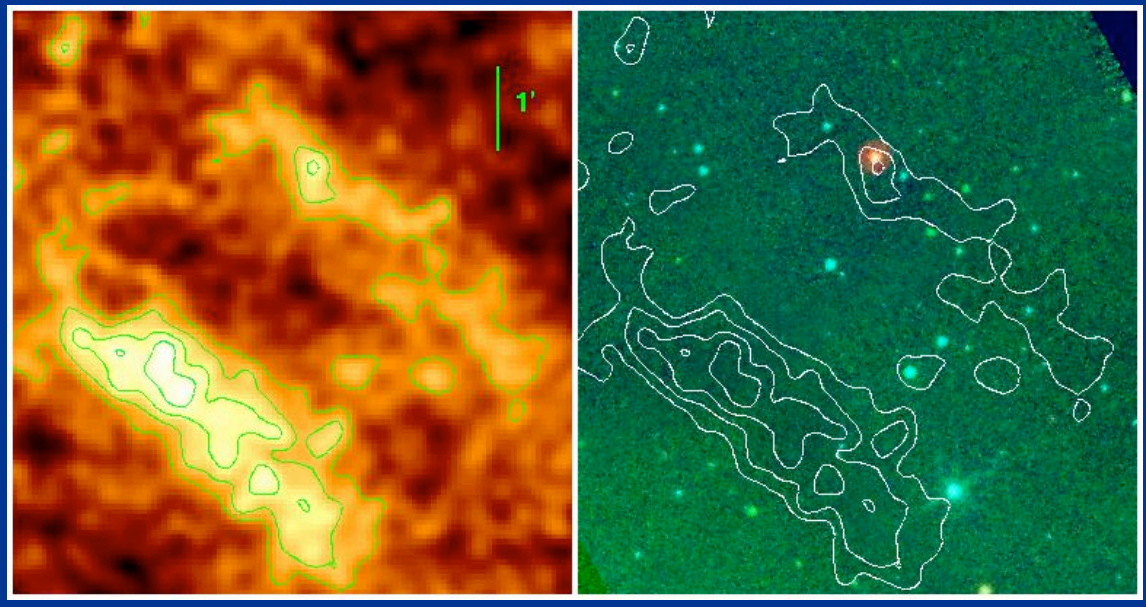
L1148B - Another Spitzer Surprise

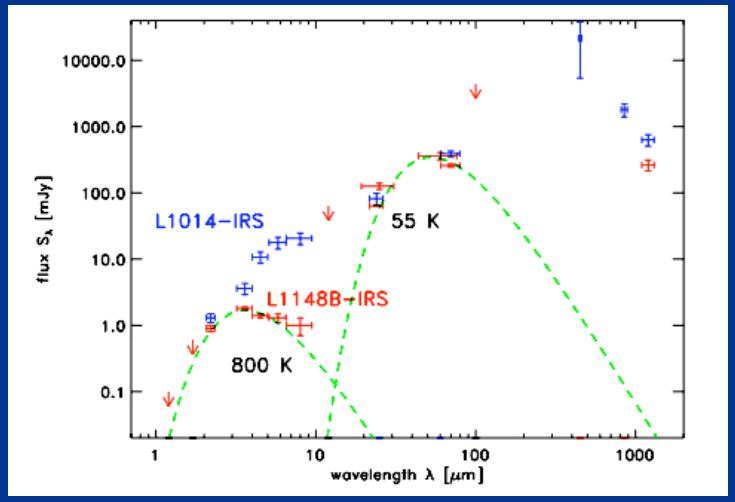
SED similar to that of L1014, but with less emission in mid-IR

L1014 and L1148B protostars did not form in prestellar cores like L1544

Not all differences among cores are due to evolution

(Kauffmann et al. in prep)





Summary

- L1014-IRS is a low L_{bol}, low M protostar (weak outflow)

  But is it substellar? (10-m class NIR spectrum)

- did not form from an evolved core (cf. L1544/L1521F)
- other low L_{bol} examples are emerging from c2d:

  ⇒ L1148B similar to L1014 (fainter, no outflow yet)

  ⇒ L1521F has a protostar, and scattered light neb.

- more examples in "ordinary" cores, not "evolved" cores

  ⇒ need to fit these results into the low mass sf paradigm, or we need a paradigm shift; lowest mass sources form in different cores?

Spitzer probing brown dwarf formation