Centro de Astrobiología

Searching for bona-fide proto brown dwarfs (BDs)

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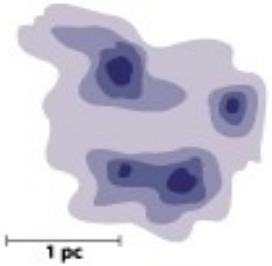
Outline

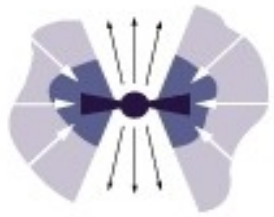
1. The problem
2. Strategy to search for proto-BDs
   - Spitzer
   - IRAM30m, CSO
3. A proto-BD candidate
   - Observations: CAHA, VLA, Kitt Peak
   - Results: SED, radial intensity profile

starless

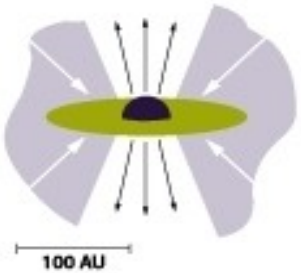


Class 0

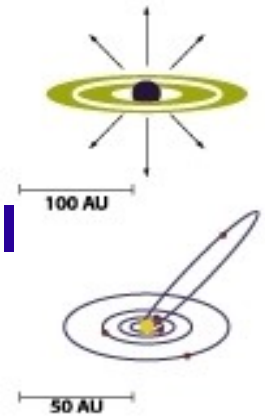
Class I



Class II



Class III



Question: can we find BDs with the properties of the youngest low-mass stars?

- If yes: favor scaled-down formation
- If yes: BDs should be associated with envelopes, disks, outflows/jets...
- Encouraging: VeLLOs have similar properties to low-mass YSOs

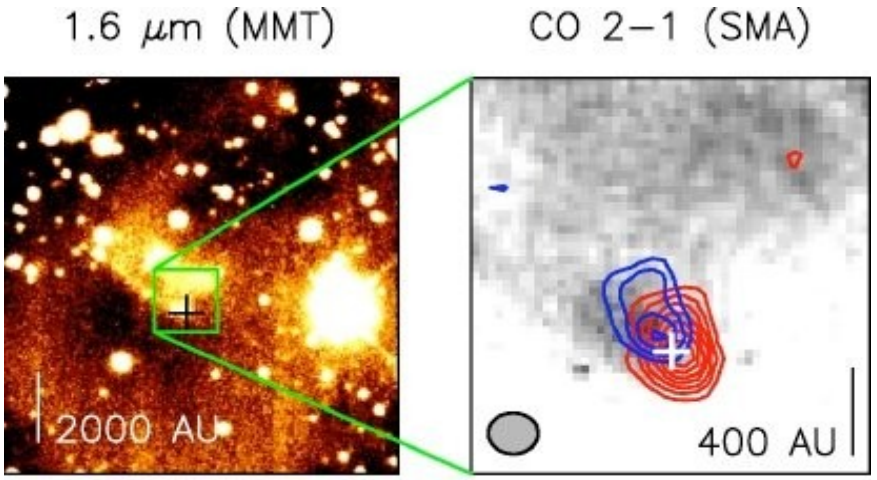
L1014-IRS

Young et al. (2004)

Bourke et al. (2005)

Huard et al. (2006)

Shirley et al. (2007)



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- Strategy to search for proto-BDs (I):
  - search around 8 Class 0/I sources from Froebrich 2005 (ApJSS, 156, 169 sample) at dist < 300pc:

TABLE 1

OBTAINED OBJECT PARAMETERS, SORTED BY SED QUALITY

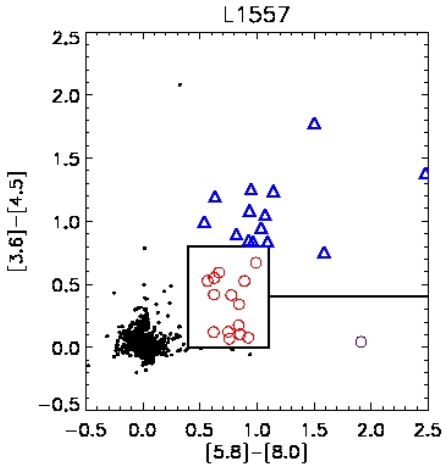
Object[a]	β	T_{bol} (K)	L_{bol} ($L_\odot$)	L_{smm}/L_{bol}	M_{env} ($M_\odot$)	Class[b]
L1448 I2	1.0	43	6.0	0.030	1.0	0/1 (yyn6)
L1448 NW	2.1	<30	<2.8	>0.16	1.2	0 (yyy6)
L1448 N	0.6	70	10	0.028	2.2	0/1 (yyn4)
L1448 C	1.4	<60	8.3	0.029	1.1	0 (yyy6)
RNO 15 FIR	1.5	63	9.7	0.016	0.45	0/1 (yyn5)
RNO 15	1.5	<73	15	0.013	0.43	0 (yyy6)
NGC 1333 I1	1.9	<85	18	0.010	0.39	0/1 (?yy6)
IRAS 03256+3055	0.3	<61	1.0	0.043	0.34	0[c] (yyy5)
NGC 1333 I2	1.4	<51	43	0.010	1.5	0 (yyy7)
NGC 1333 I4 A	0.3	<42	18	0.037	5.8	0 (yyy6)
NGC 1333 I4 B	1.2	<43	17	0.036	3.1	0 (yyy6)
IRAS 03282+3035	0.5	<63	1.3	0.062	0.73	0 (yyy5)
HH 211 MM	1.3	<33	3.6	0.046	0.80	0 (yyy6)
B213	0.7	72	<0.39	<0.028	0.19	0/1 (yyn5)
IRAM 04191	0.6	<36	0.12	0.208	0.48	0 (yyy5)
L1551 IRS 5	1.2	92	22	0.008	1.6	1 (nyn4)
L1551 NE	0.5	91	4.2	0.009	0.57	1 (nyn5)
IRAS 04325+2402	1.4	73	0.97	0.057	0.52	0/1 (yyn4)
L1527	1.6	56	1.9	0.056	0.80	0/1 (yyn4)

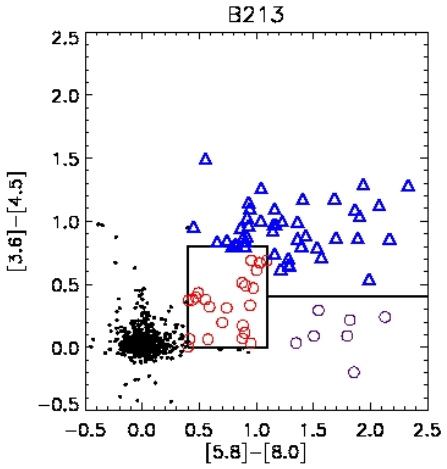
2. Strategy: region with high ratio of Class I vs Class II

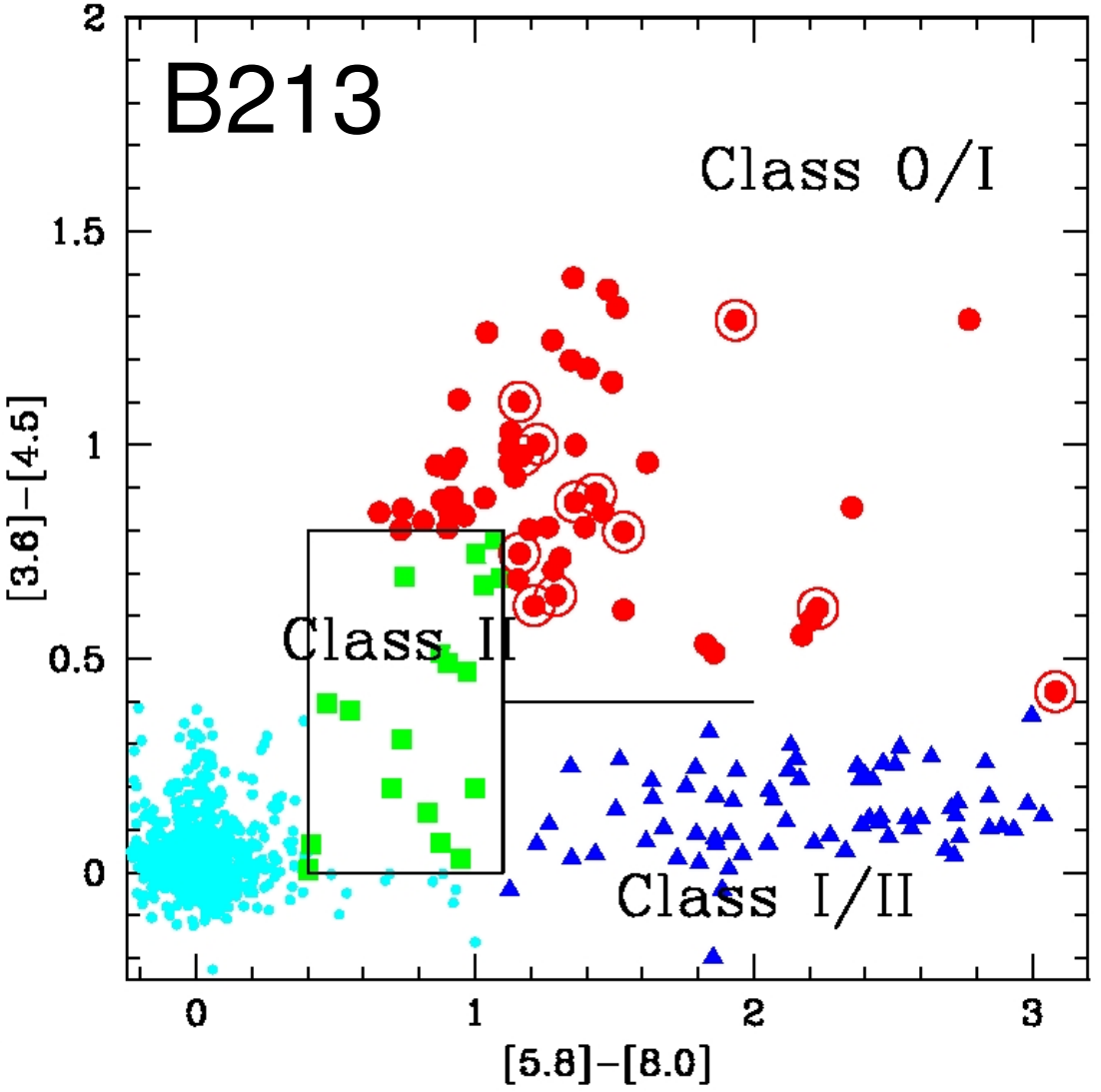
- Strategy to search for proto-BDs (II): for each Froebrich region...
  - Spitzer archive, point sources, select sources detected in 4 IRAC bands
  - build IRAC color-color diagram (Allen et al. 2004)
  - compute ratio Class0/I vs ClassII

We selected the Froebrich region with highest Class 0/I vs Class II ratio:

B213



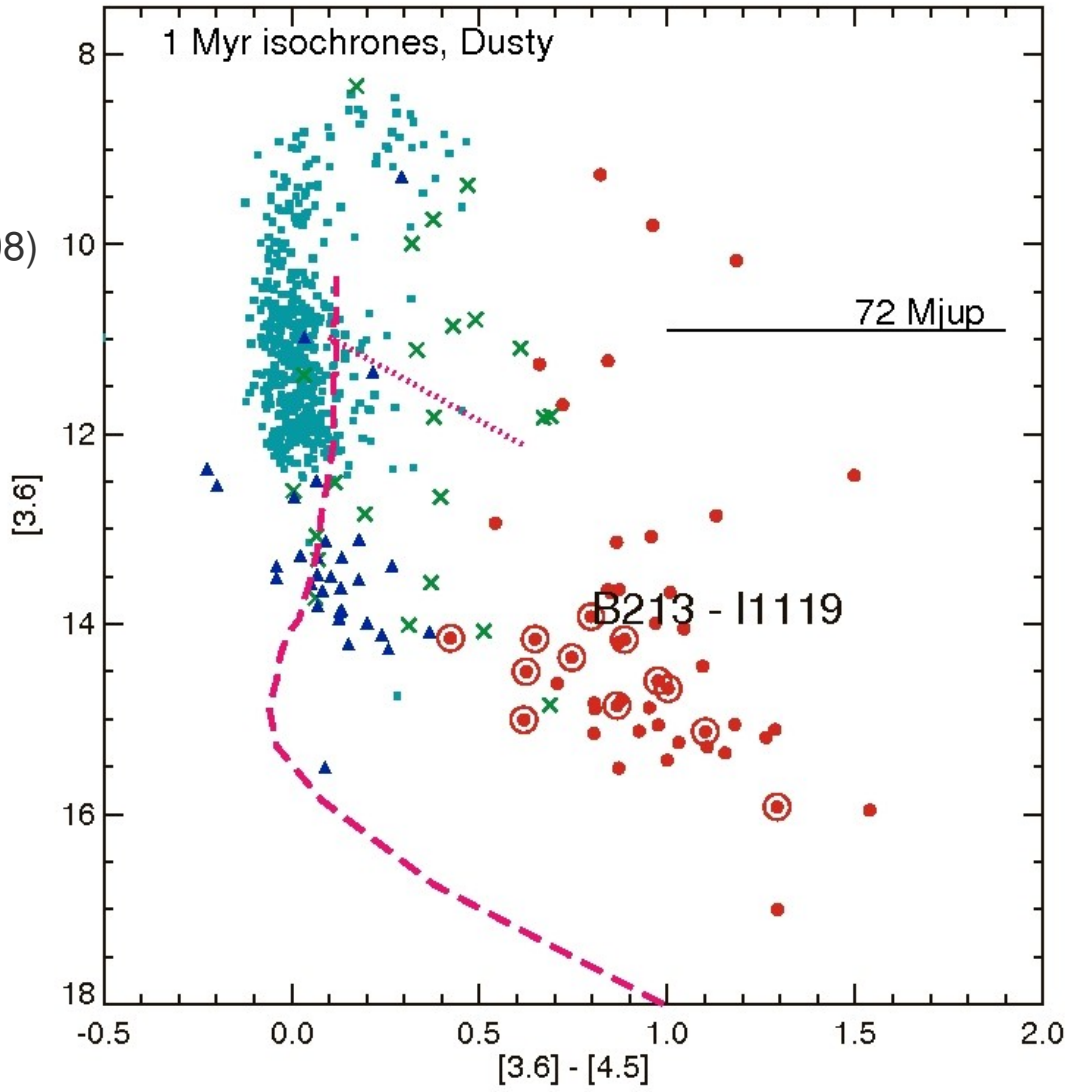




- Strategy (III): the best Spitzer sources in B213
  - B213: build mag-color --> substellar nature (Baraffe et al. 2003)
  - B213: cross Spitzer with 2MASS: SEDs from 1 to 24 µm:
    - steep SED
    - no 2MASS
  - B213: rejection of clear extragalactic contaminants from mag-color (Gutermuth et al. 2008)

12 Spitzer substellar sources most embedded and being no clear background objects

We observed these 12 targets with the IRAM30m telescope



2. Strategy: IRAM30m observations

- We observed the 12 targets from B213 with the IRAM30m Telescope:

ON-OFF 1.2 mm observations: May, Oct, Dec 2007

Nov 2008 Director's Time

Table 2. 1.2 mm observations with the IRAM 30 m

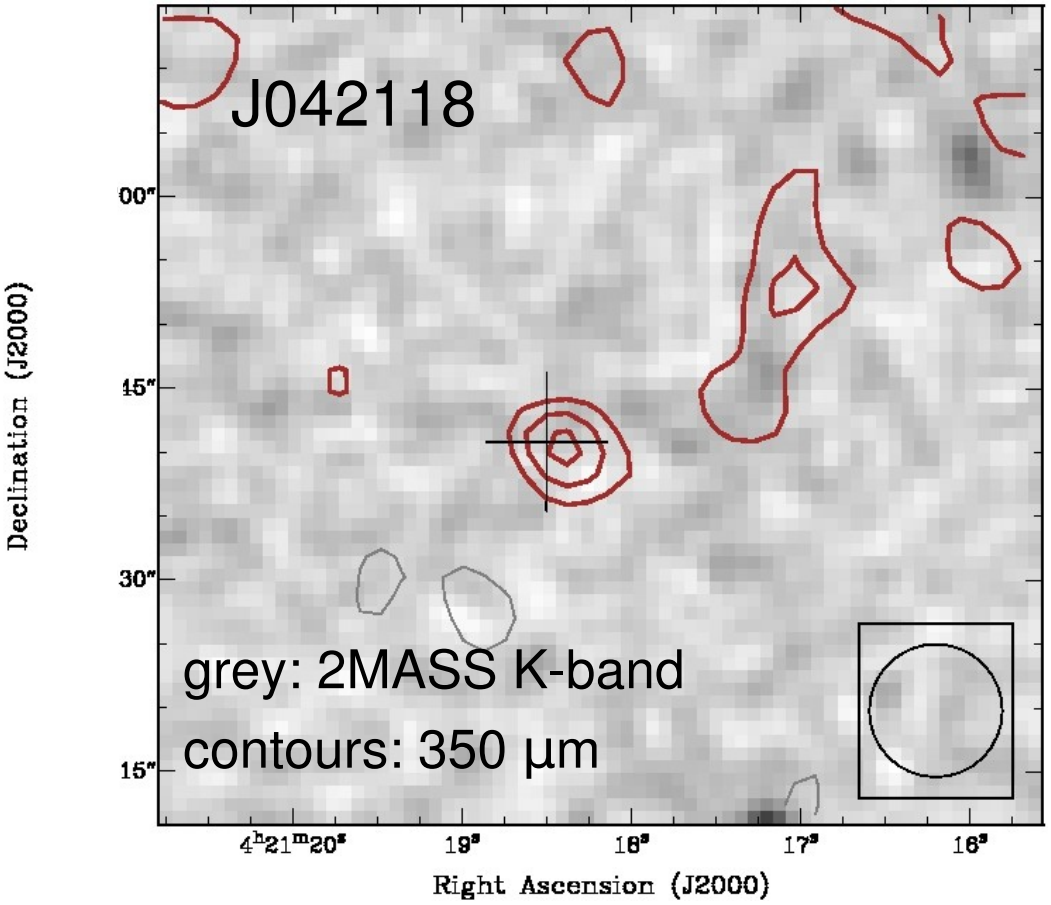
Source	Date	$\tau_{250\ GHz}$	Skynoise (K)	Flux (mJy)	S/N
J041757	28/05/07	0.303	110	1.40 ± 1.33	
	06/10/07	0.330	79	3.54 ± 1.80	
	06/10/07	0.379	42	2.84 ± 1.80	
	14/11/08	0.290		0.93 ± 1.89	
	14/11/08	0.290		1.62 ± 1.03	
	weighted mean			1.891 ± 0.72	**2.63**
J042118	28 11	0.403	40	2.92 ± 1.41	
	29 11	0.305	39	1.41 ± 1.39	
	weighted mean			2.15 ± 1.00	**2.15**
J041726	28 05	0.375	104	−0.60 ± 1.09	< 1
	06 10	0.330	65	−1.05 ± 1.23	< 1
J041913	07 10	0.379	44	0.48 ± 1.22	< 1
J041740	28 05	0.303	144	0.22 ± 1.22	< 1
	07 10	0.379	46	0.04 ± 1.19	< 1
J042019	28 05	0.303	126	−0.13 ± 1.07	< 1
J042123	28 11	0.403	37	−0.28 ± 1.10	< 1
J041938	28 05	0.303	93	−0.57 ± 1.13	< 1
J042016	28 11	0.403	37	−1.28 ± 1.12	< 1
J041828	07 10	0.379	53	−1.47 ± 1.16	< 1
J041836	28 05	0.303	145	−1.82 ± 1.43	< 1
J041847	07 10	0.379	66	−2.11 ± 1.17	< 1

- Combining the good data of all these periods we end up with:

S_nu(1.2mm) = 1.9 +/- 0.7 mJy S/N ~ 2.6 for J041757

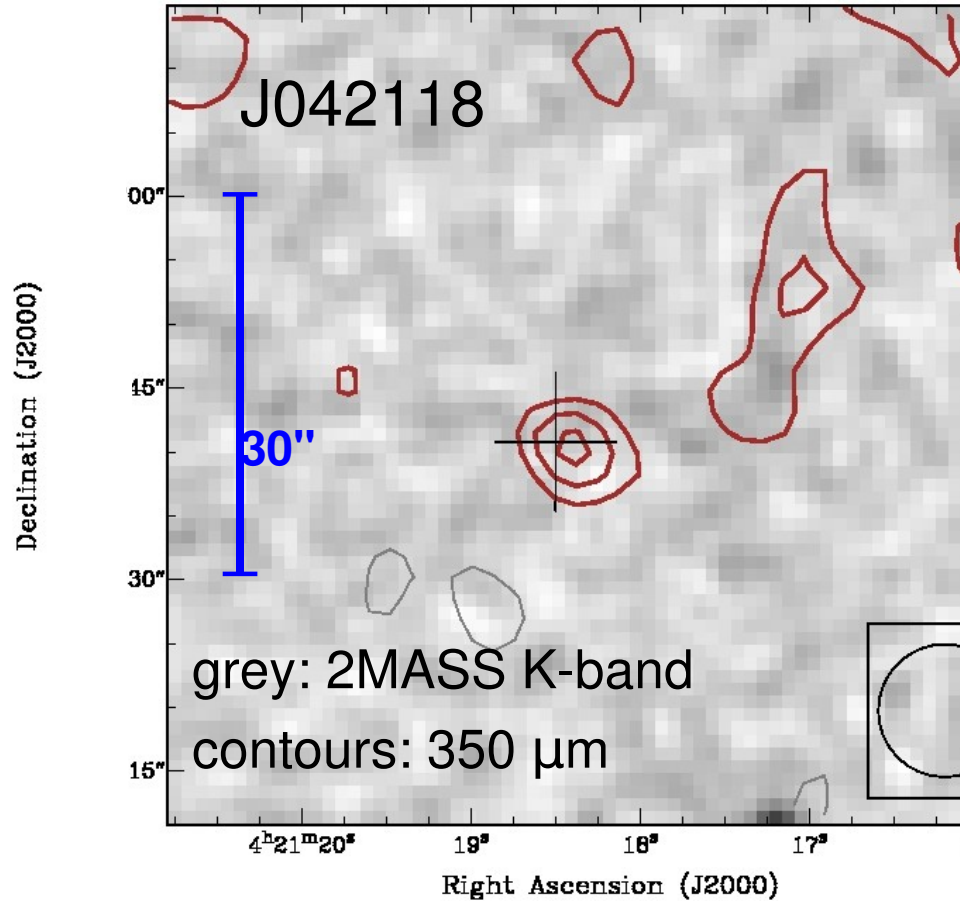
S_nu(1.2mm) = 2.1 +/- 1.0 mJy S/N ~ 2.1 for J042118

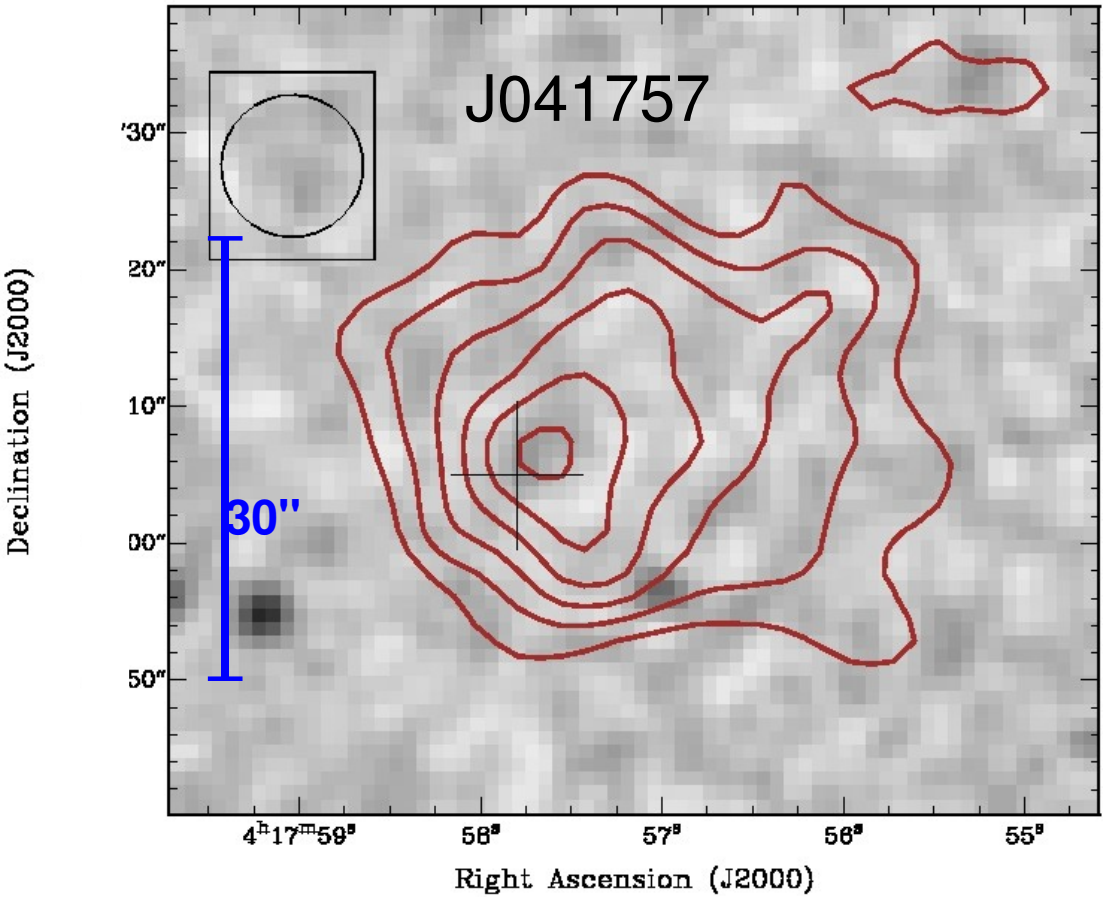
- CSO observations: imaging at 350 μm



- J042118: compact sub-mm source:
  - Menv = 0.2—1.3 Mjup
  - (for Td 12—25 K)
  - Size ~ 1500 AU

- CSO observations, Jan 2008: Imaging at 350 μm





- J041821: compact sub-mm source:
  - Menv = 0.2—1.3 Mjup
  - Size ~ 1500 AU
- J041757: partially extended submm source:
  - Menv = 5—30 Mjup
  - Size ~ 4500 AU

Search for the most embedded: follow up of J041757

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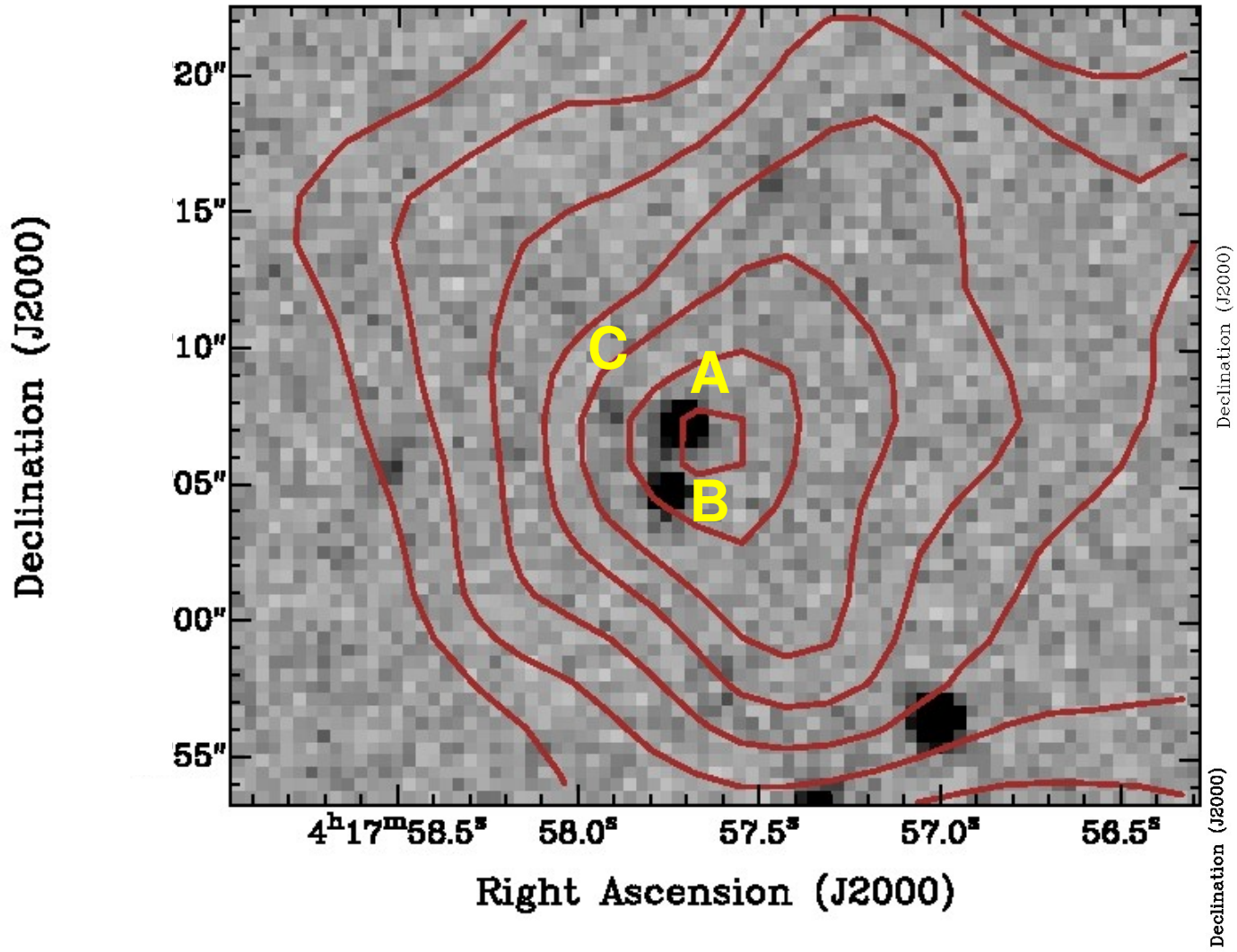
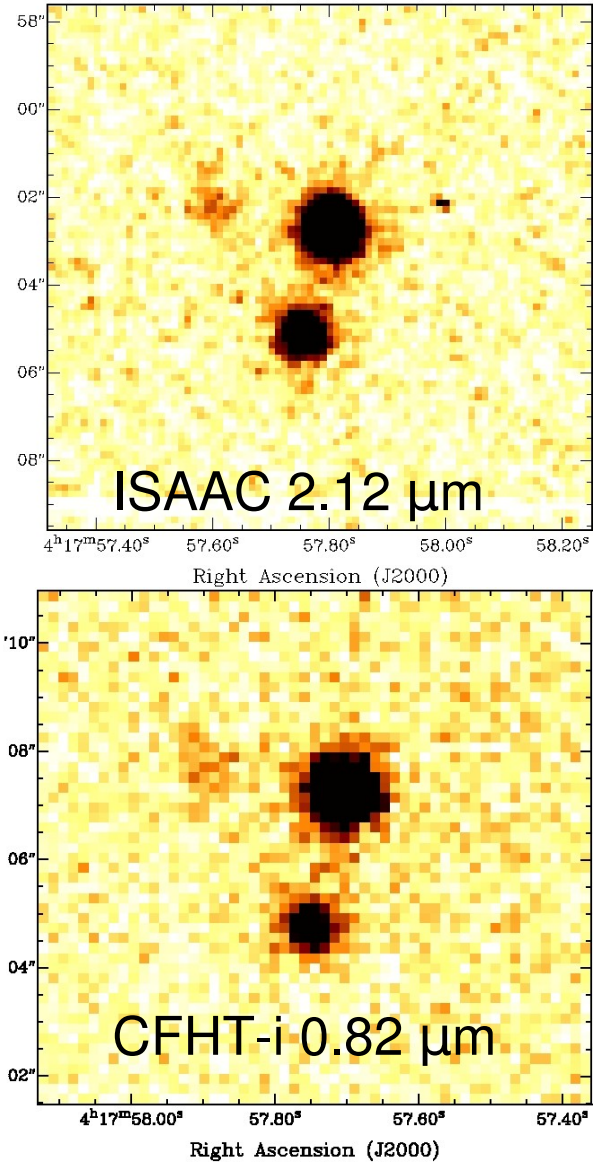
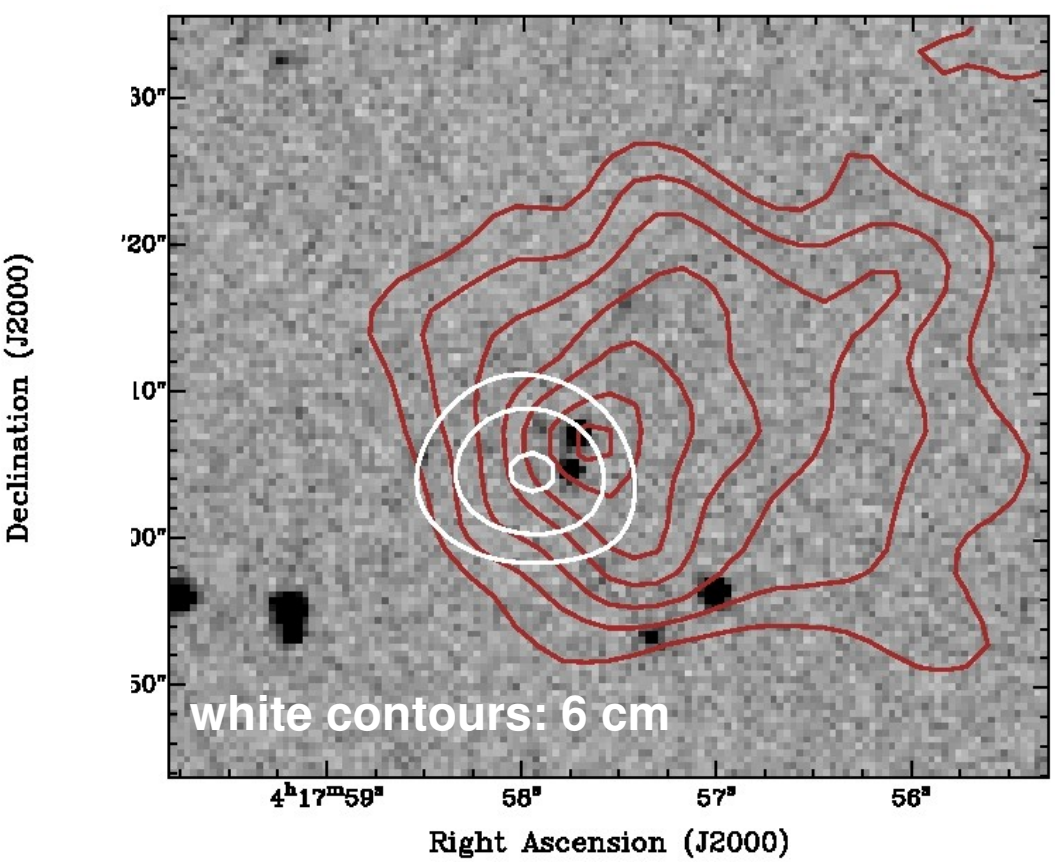




- CAHA-Omega2000 observations:
  Deep imaging at J, H, K bands
- J041757 splits up into **3 NIR sources**: A, B, C
  - A, B are point sources
  - C faint and extended in the opt and NIR
    - ISAAC also 2.19 μm (cont): is C an H2 knot? must be confirmed spectroscopically (time allocated)

3. A proto-BD candidate

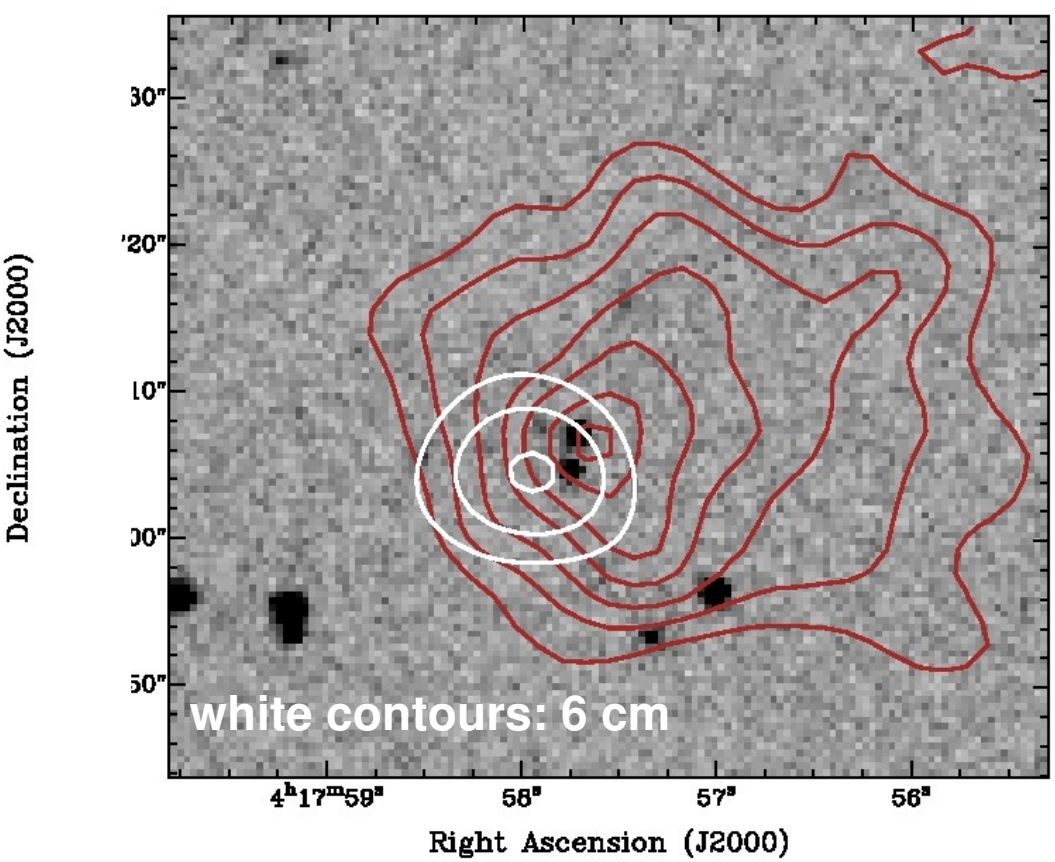


VLA D-config observations

Imaging at 6 cm, beam ~ 16":

Compact cm source...

3. A proto-BD candidate



VLA D-config observations:

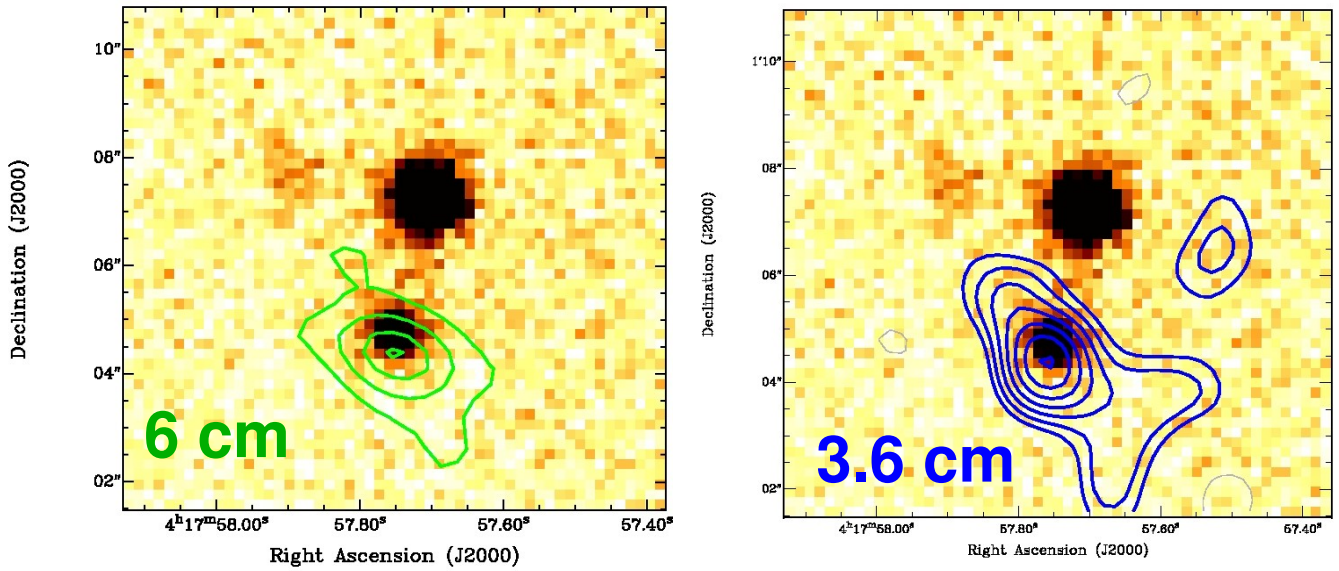
Imaging at 6 cm, beam ~ 16":

Compact cm source...

VLA B-config observations:

Imaging at 6 and 3.6 cm, beams ~ 2"

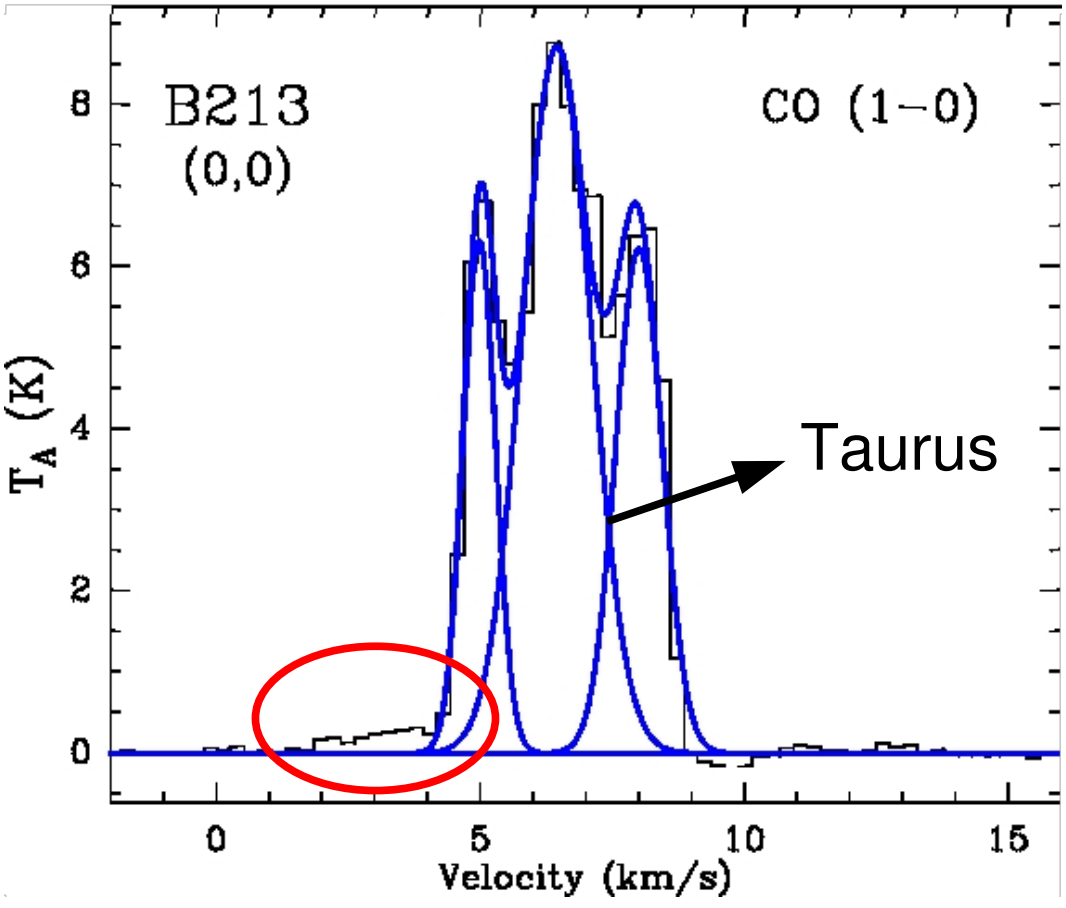
Compact cm sources assoc with B!



spectral index: -0.7 +/- 0.8 --> does not discriminate btw thermal/non-thermal

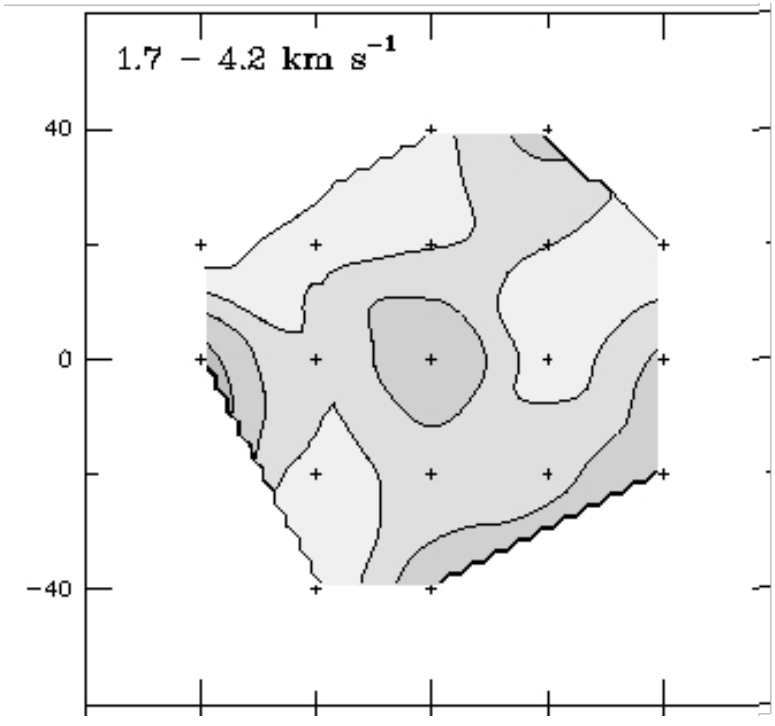
cm also in L1014-IRS VeLLO (Shirley et al. 2007)

3. A proto-BD candidate

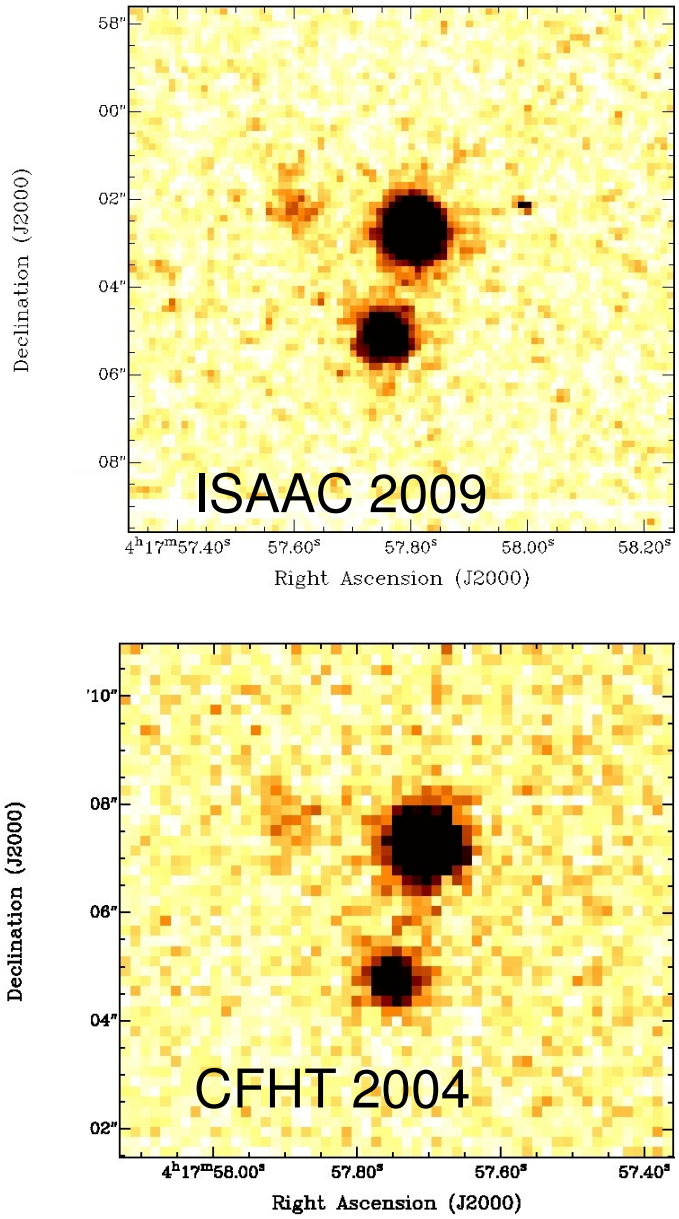


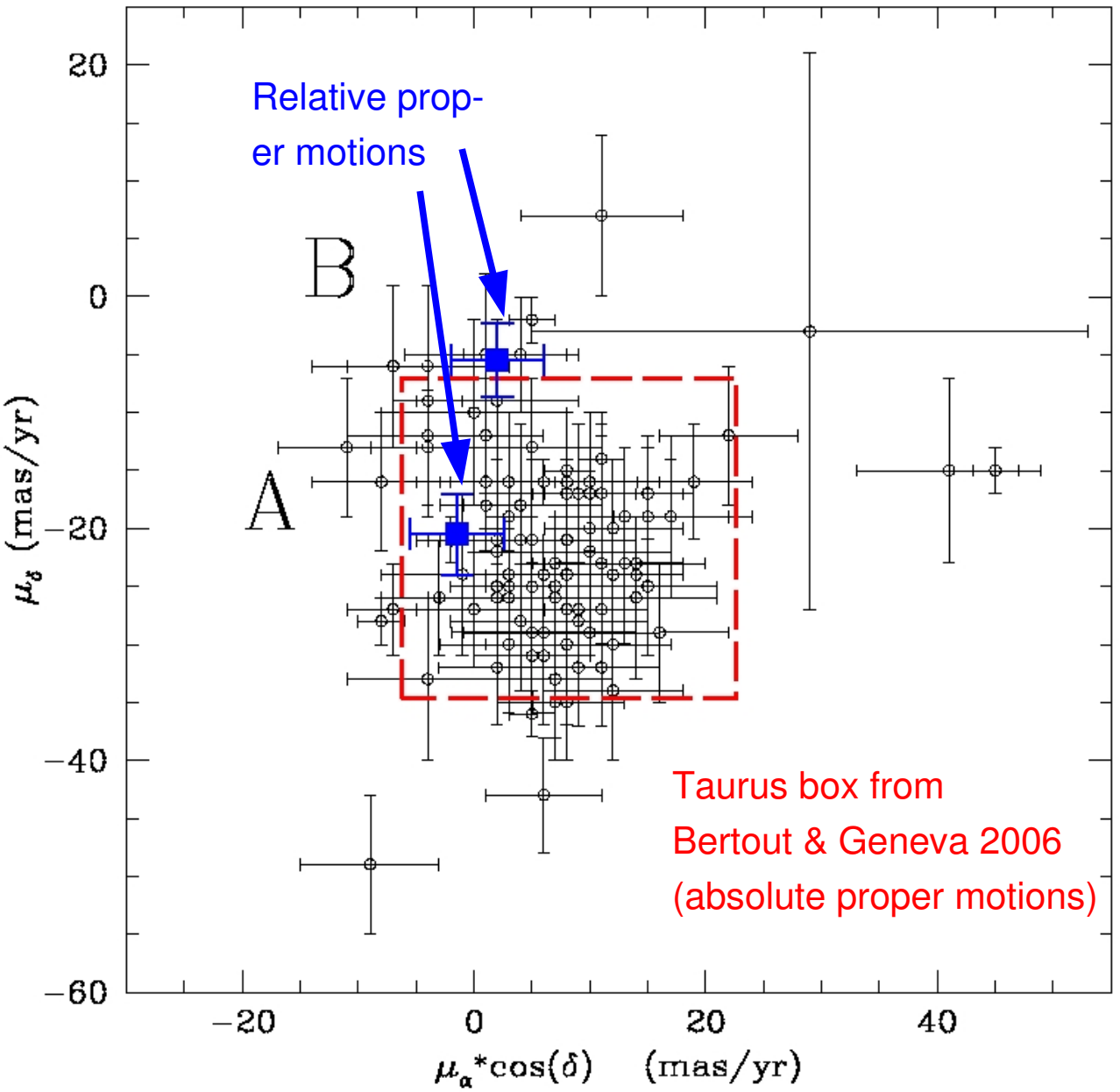
- Kitt Peak obs: Dec 2008, beam ~ 1': CO(1—0)
  - Emission in the 1.7—4.2 km/s range: blue wing, seems to be associated with the object
  - No significant emission within a 600 km/s wide band, above 0.36 K
- Dust emission at 350 μm most likely associated with these gas component in Taurus

Scheduled obs. with IRAM30m to do CO(2—1) map



3. A proto-BD or a background source?





- Component A seems to belong to Taurus, and component B could be

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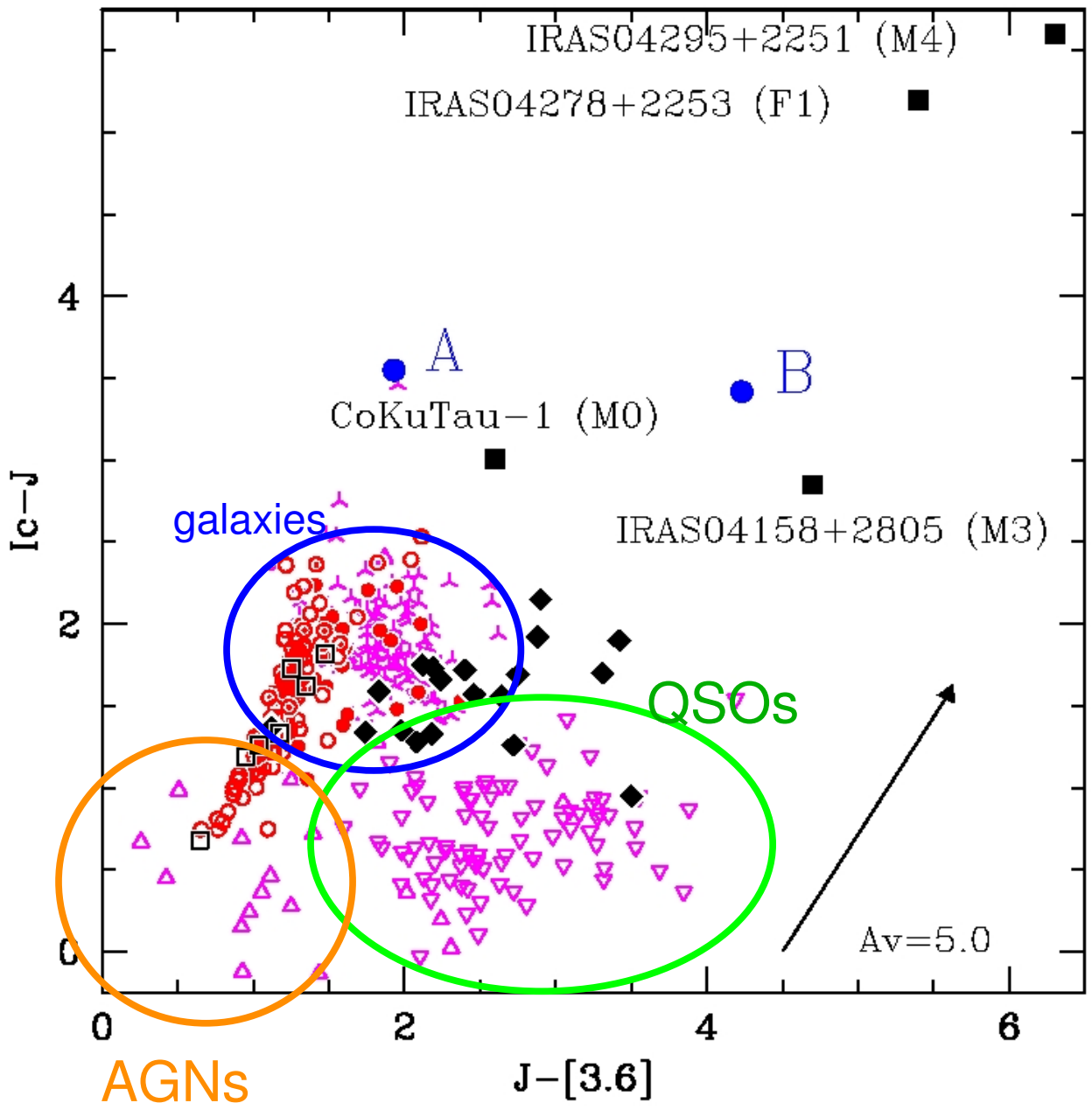
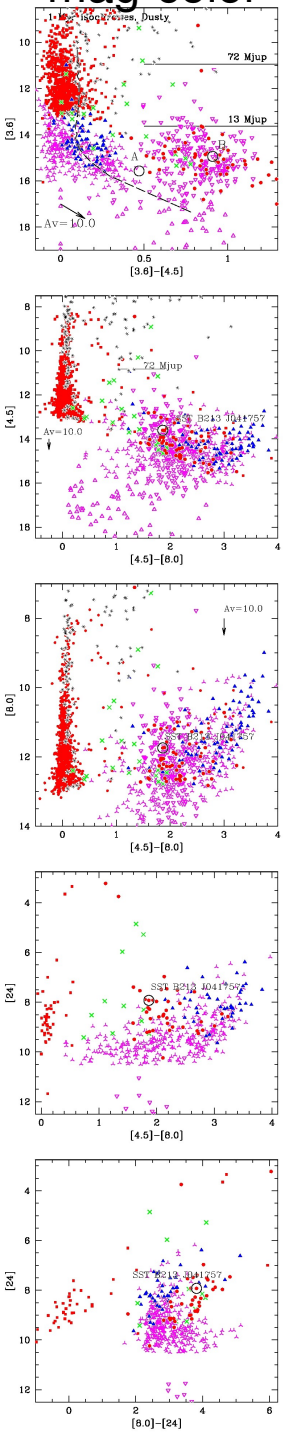
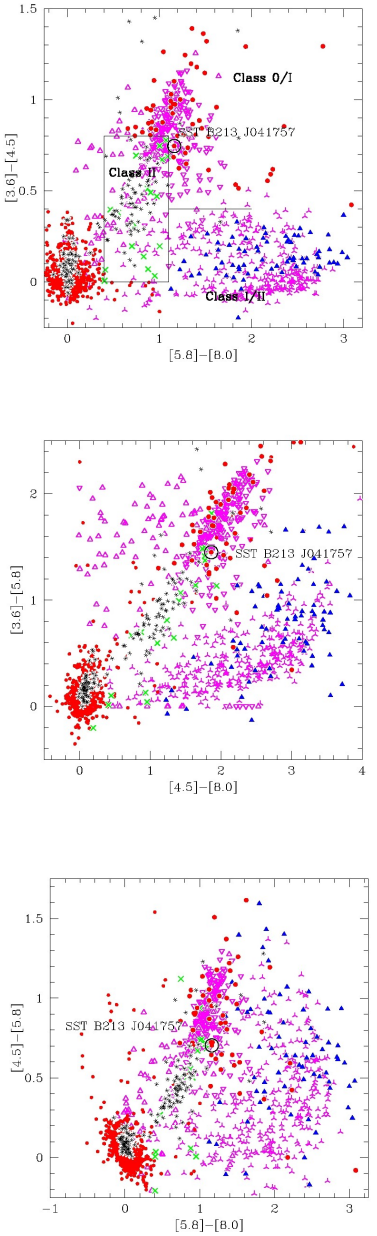


mag-color



color-color

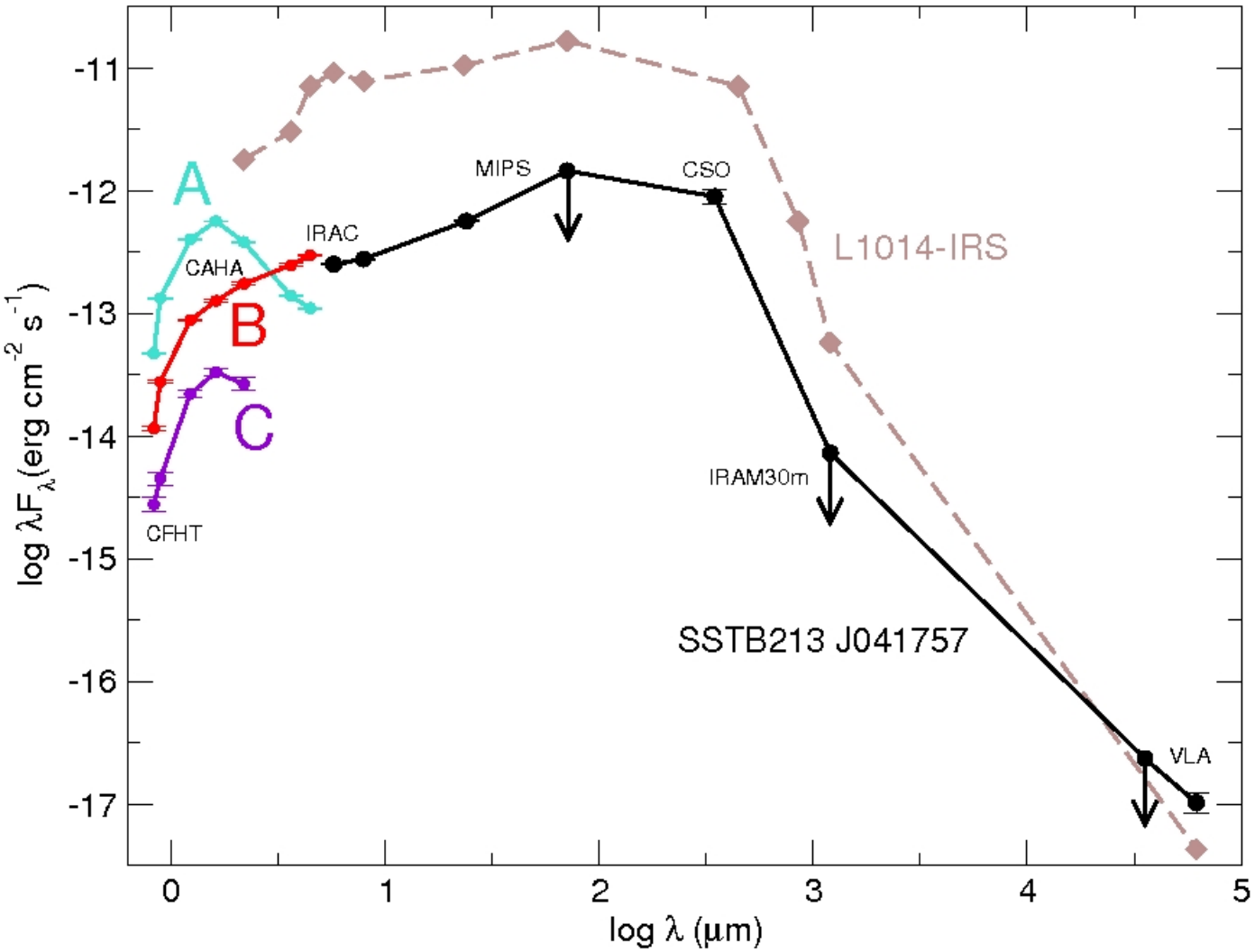


- If component B was an extragalactic object, it would be a very strange object

IRAC+MIPS diagrams

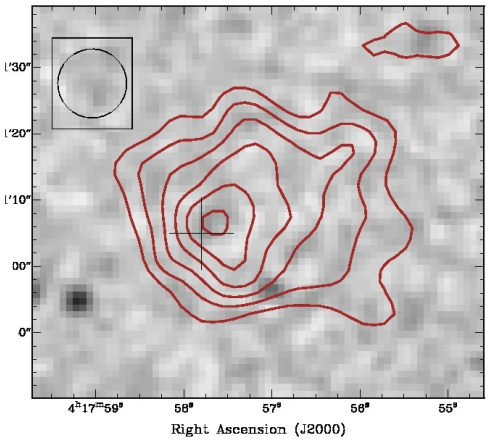
3. A proto-BD candidate?

- Spectral Energy Distribution:



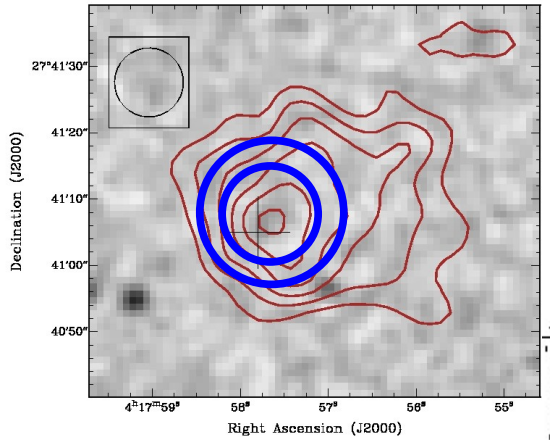
- SED properties (B comp):
  - positive spectral index btw 2 and 25 μm (Class I)
  - Tbol matching Class I
  - peak longward of 100 μm (Class 0)
  - Lsmm/Lbol matching Class 0

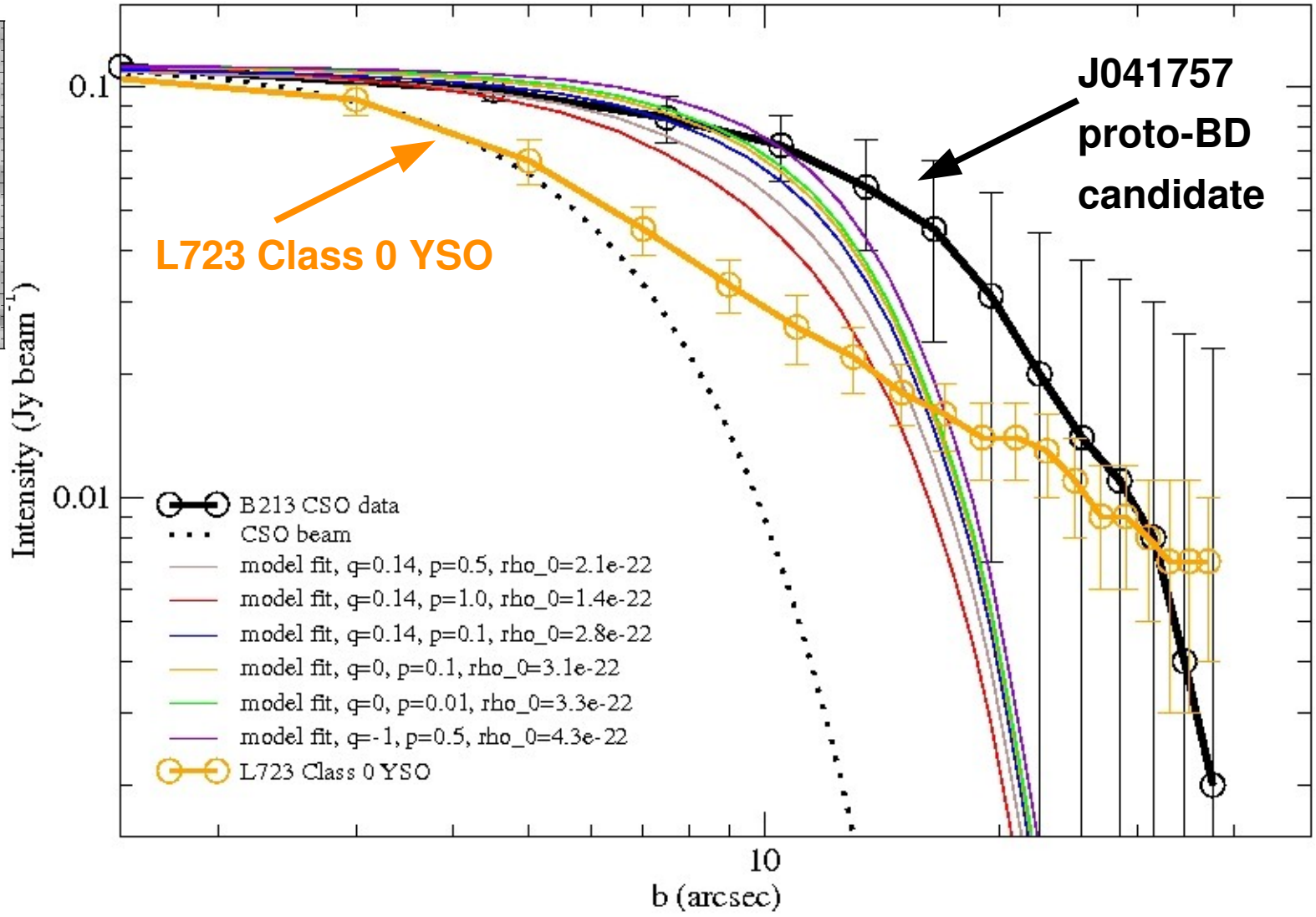
Class I of 0.003 Lsun: among the least luminous young objects



Using the criteria to classify low-mass YSOs, J041757 is a Class 0/I BUT envelopes of proto-BDs are not well known and may be different from those of Class 0 YSOs...

- Radial intensity profile for J041757:





- Preliminary results:
  - comparison with radial profiles of well-known Class 0 YSOs, proto-BD profile seems shallower BUT NEEDS TREATMENT OF T(R), ISRF

CONCLUSIONS

- Selection strategy from Spitzer data yields candidates to proto-BDs
- If J041757 is confirmed as a proto-BD in Taurus:
  - Extremely low luminosity
  - proto-BD embedded within an envelope, as Class 0/I YSO
  - BUT envelope seems to have
    - radial intensity profile different from that of Class 0/I YSOs
- Future work:
  - Model of the envelope as:
    - $T = T_0 (R/R_0)^{-q}$
    - $\rho = \rho_0 (R/R_0)^{-p}$
    - To simultaneously fit the SED and the radial intensity profile
  - Confirm outflow
  - Search for dense gas, study kinematics: infall?

Thank you so much!