Brown Dwarf Candidates in the Serpens Core

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Outline

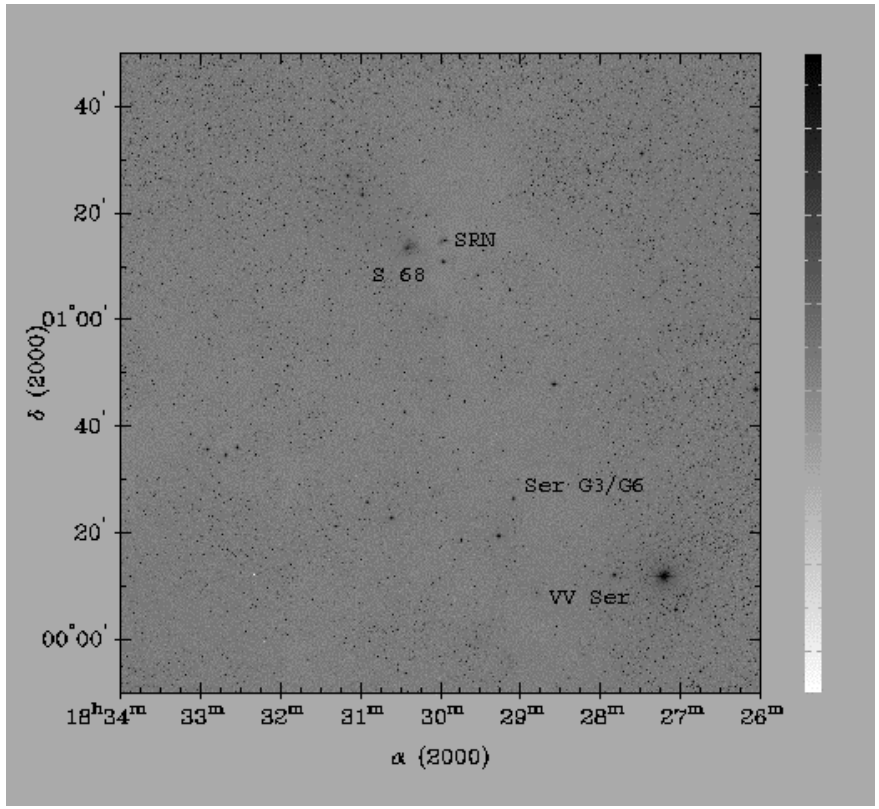
- Short description of the Serpens cloud & core
- Embedded population + spatial distribution
- Near-IR cluster

  -- Near-IR diagrams
- BD candidates

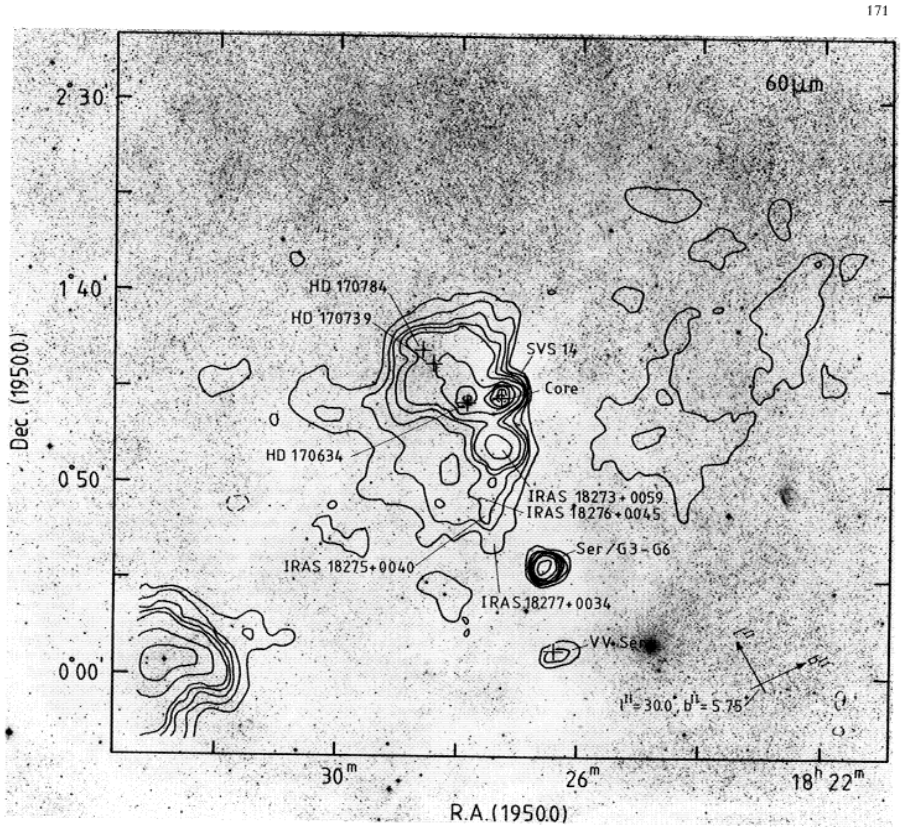
Serpens Cloud

Nearby dark cloud of several degrees in size; part of the Aquila rift

-- $l^{II} = 32^o$, $b^{II} = 5^o$; d ≈ 250 pc



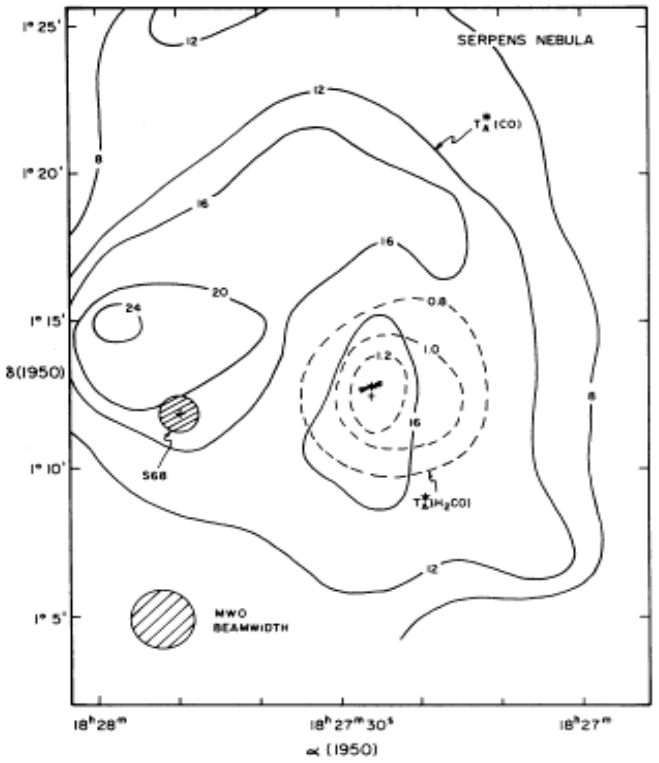
DSS – R plate



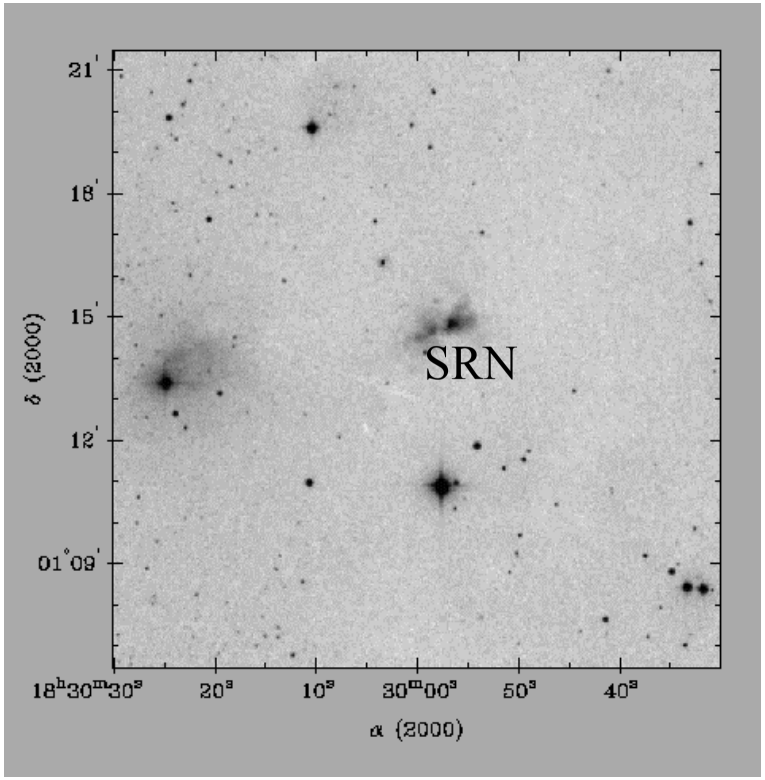
IRAS 60 μm (Zhang et al. 1988)

Serpens Core

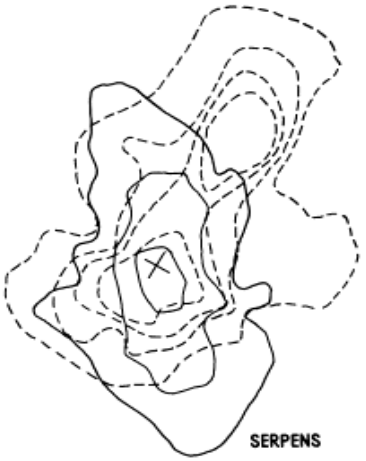
H_2CO core: ~ 6 arcmin in diameter ⇔ ~ 0.5 pc
Large scale CO molecular outflow



Loren et al. (1979)



DSS - R plate

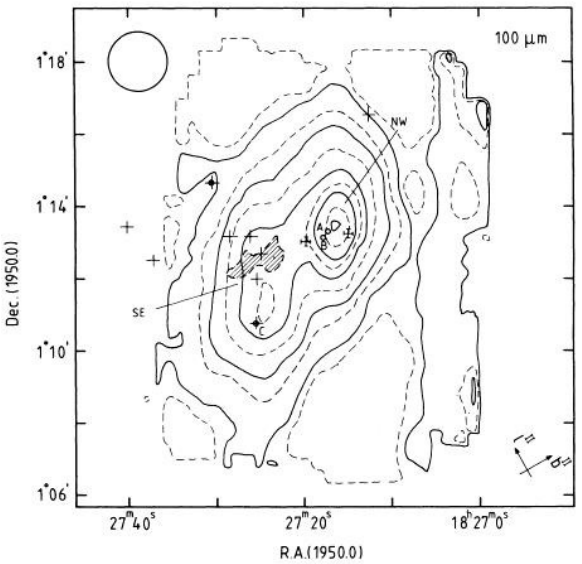


Bally & Lada, 1983

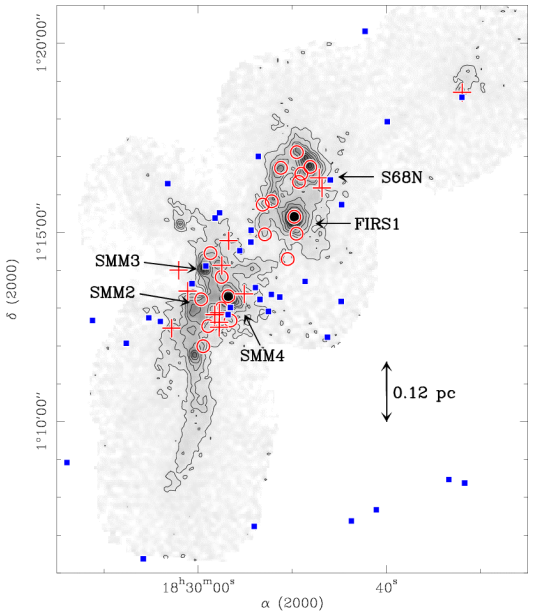
Serpens core: 100 μm,1.3 mm & CO

Core structured into two sub-clumps

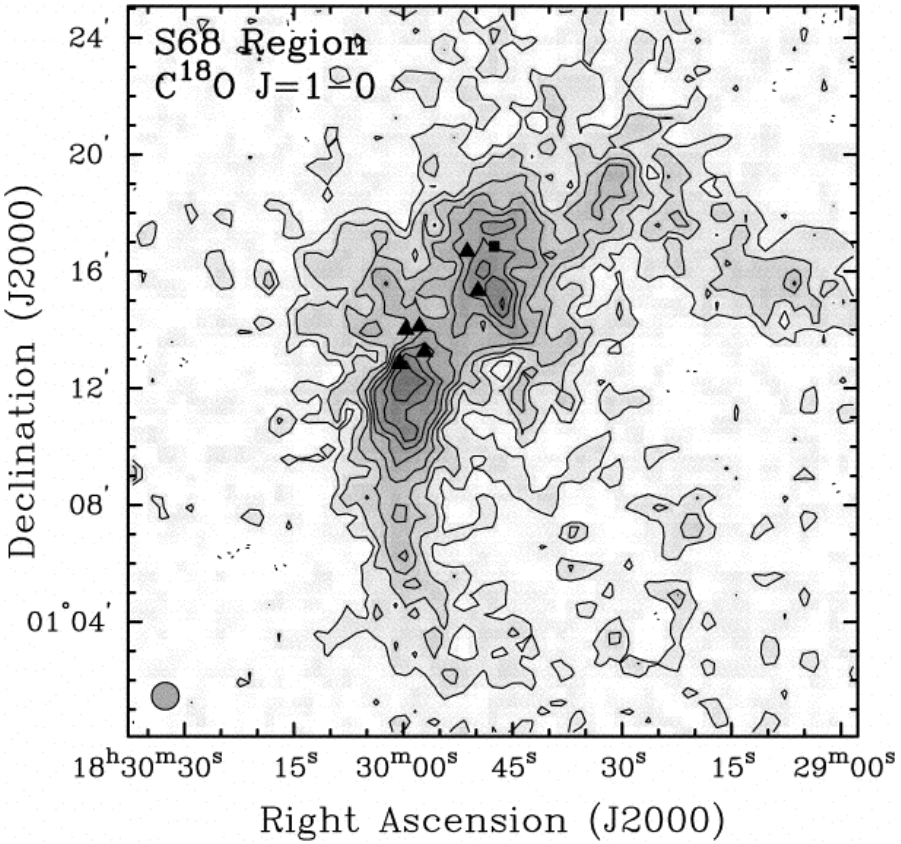
Embedded stellar population shows different evolutionary properties



Zhang et al. 1988



Kaas et al. 2004

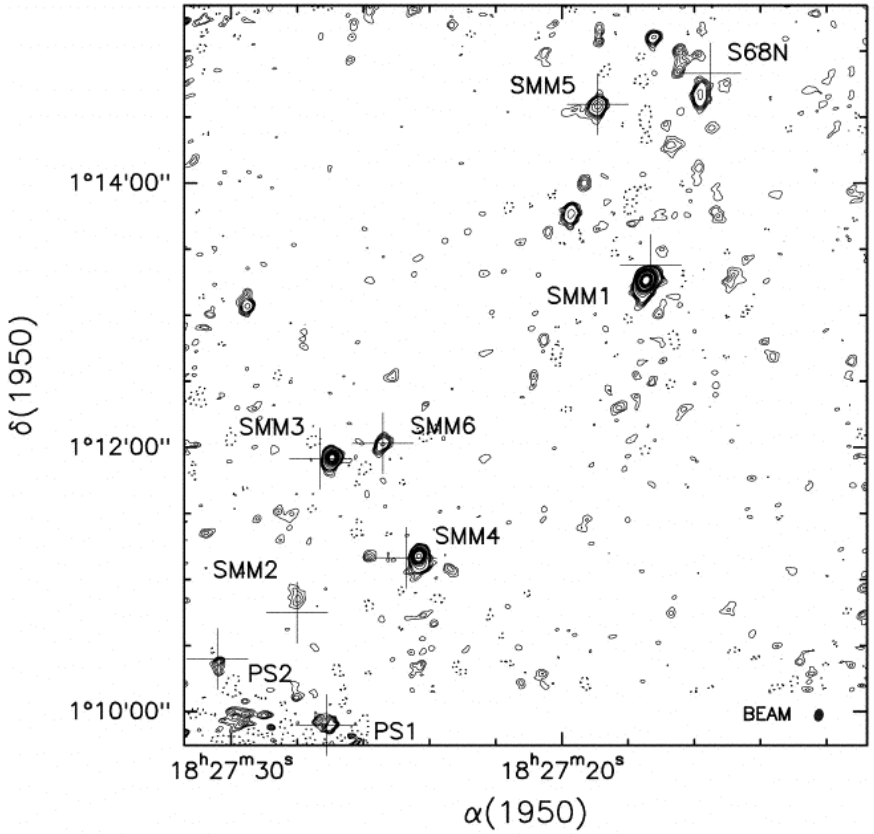


McMullin et al. 2000

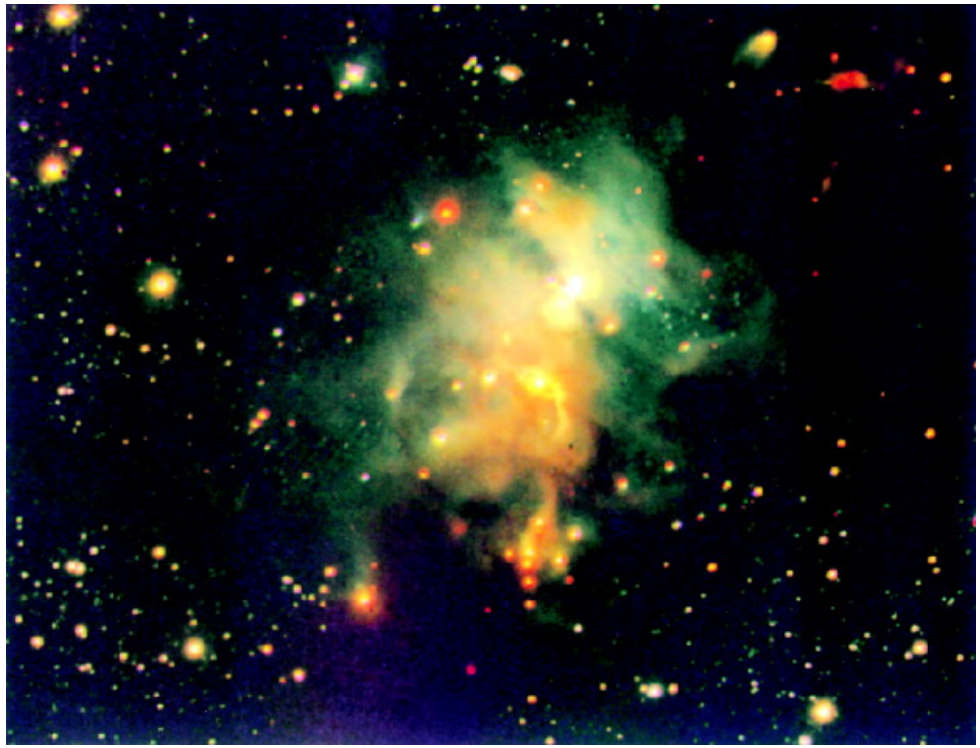
Embedded Population

Optical, near-IR, mid-IR, submm, mm, cm + X-Ray studies provide different views of the embedded population

Very rich star formation activity



3mm: Testi & Sargent (1998)



J+H+K: Kaas (1999)

Embedded Population

26 3 mm cores (Testi & Sargent, 98)
11 submm sources (Casali et al. 93, White et al 95, Davis et al. 99)
76 ISO sources (6.7 + 14.3 μm) (Kaas et al. 2004)
188 near-IR sources (Eiroa & Casali 89, 92, Horrobin et al 97, Sogawa et al 97, Giovannetti et al. 98, Kaas 99, Klotz et al. 04, Eiroa et al. 05)
18 0.9 μm sources (Gómez de Castro et al. 87, Giovannetti et al. 98)
16 VLA sources (Smith et al. 99, Eiroa et al. 05)
14 XMM X-Ray sources (Preibisch 98, 03)

➢ Very Young Population (ISOCAM comparison)

	Class I	Class II	Class III	
Serpens	20	56 (13+43)	5 !!	Kaas et al. 2004
Ophiuchus	16	123	77	Bontemps et al. 2001
Chamaeleon		46	19	Persi et al. 2000

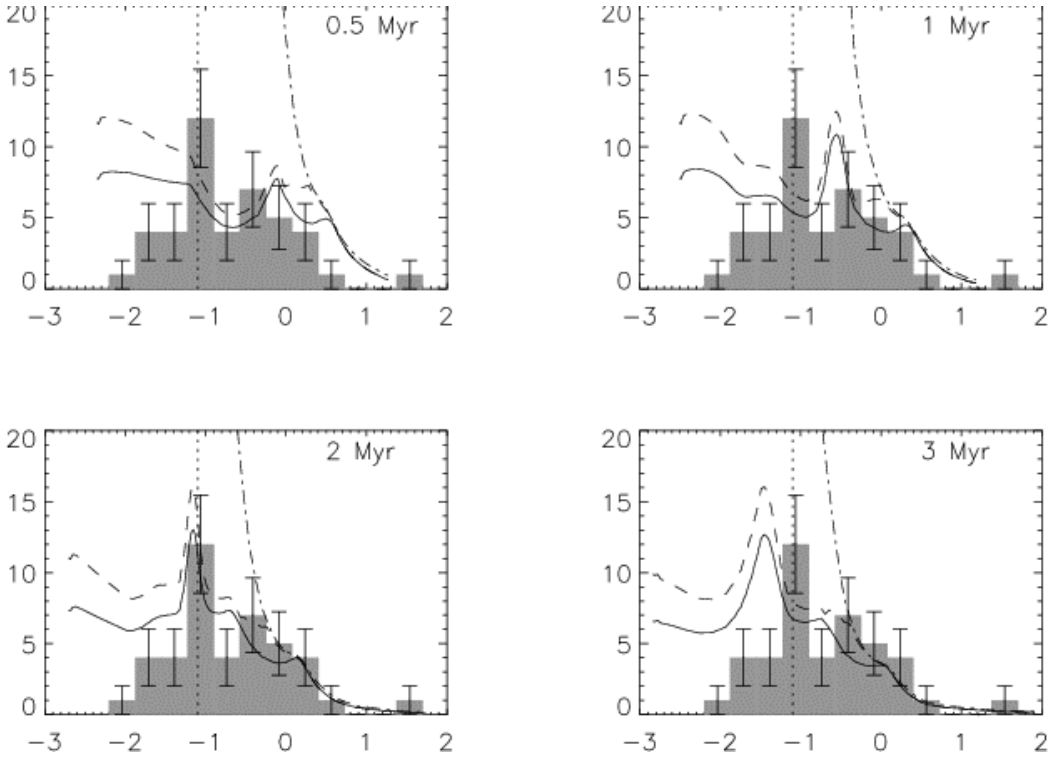
Class II ISO sources: Age

Kaas et al. 04: Luminosity function of the 43 ISO Class II sources on the basis of the ISO 6.7 μm flux and A_V from near-IR magnitudes

-- Comparison with different IMFs (Kroupa et al. 93, Scalo 98) plus evolutionary tracks (D'Antona & Mazzitelli 98, Baraffe et al. 98)

➔Best fit: 2 Myr

Lodieu et al. 02 estimate ~ 3.5 Myr for BD-Ser1 (EC 61)

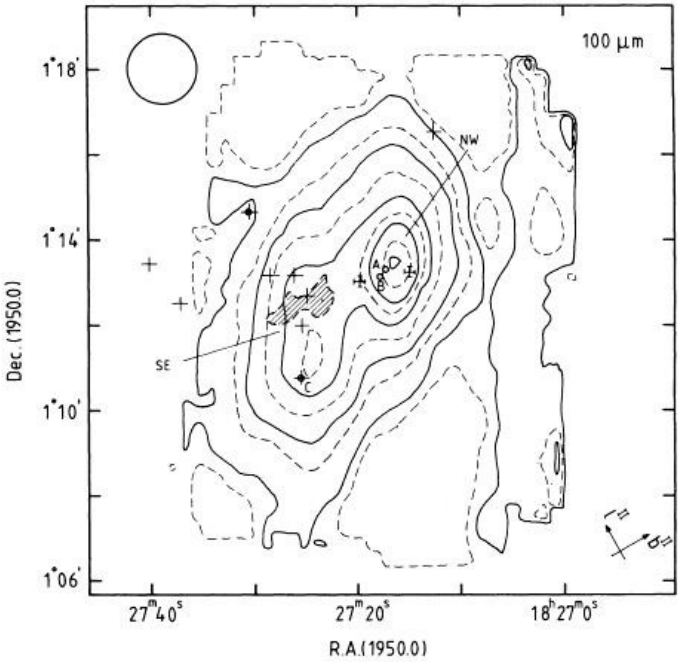


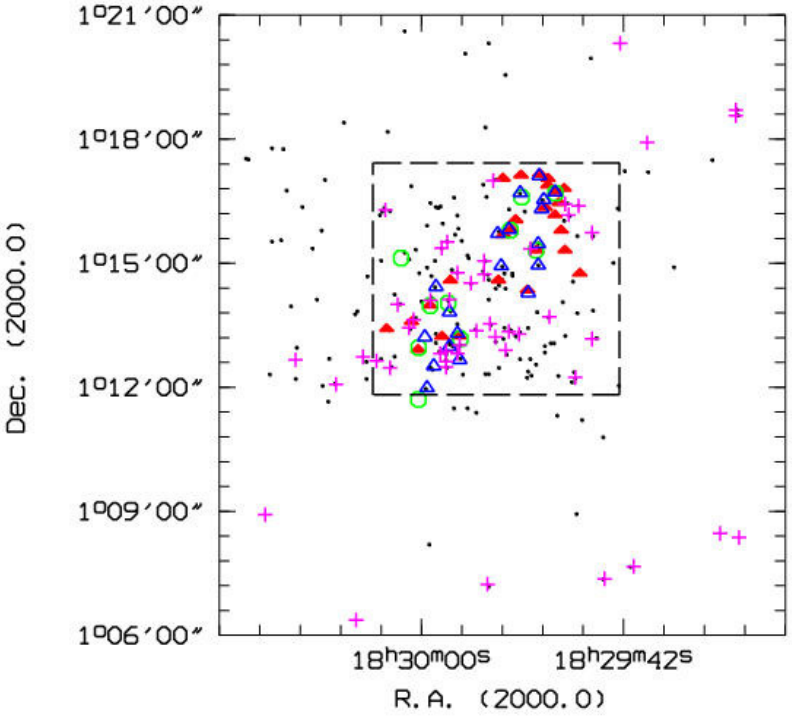
Kaas et al (2004)

Distribution of Serpens YSOs

Most sources located in the 6' x 6' central (mm) core

-- but clear differences between the NW and SE clumps

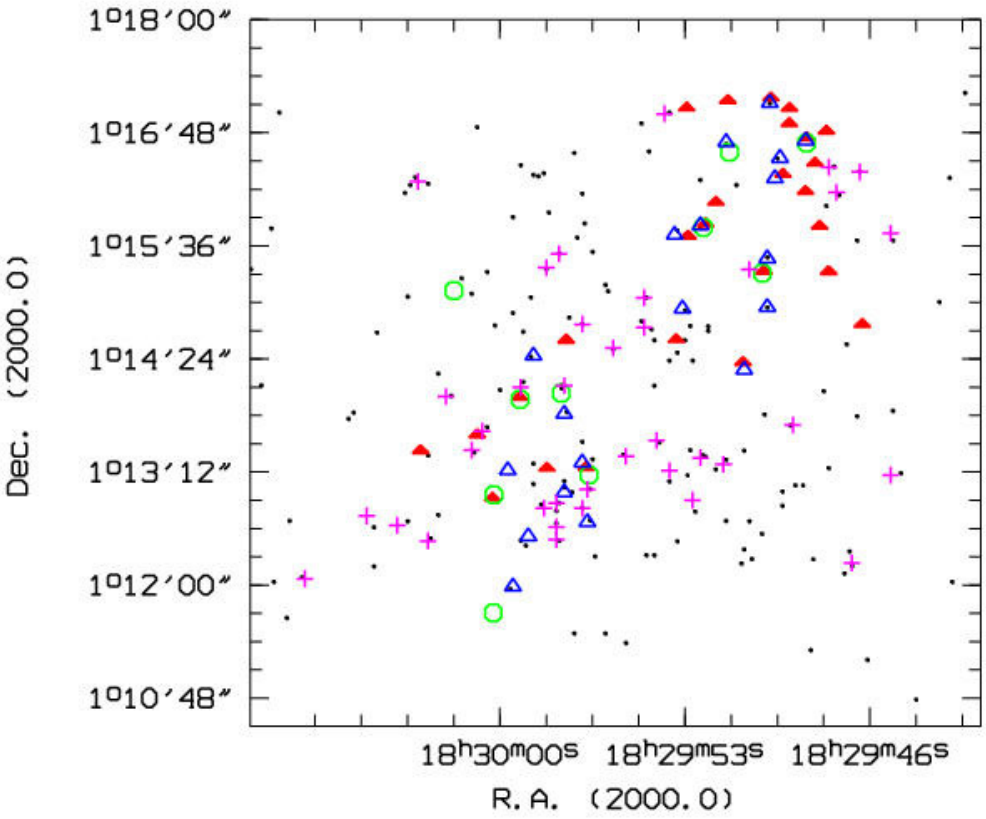




Dots: near-IR cources
Crosses: ISO Class II
Triangles: ISO Class I
Hexagons: smm sources
Filled triangles: mm cores

Detailed Distribution

- Near-IR sources found across the whole core, but more concentrated towards the SE clump
- Class II approx. follows same trend
- Class I, Class O: approx. same number in both SE and NW clumps
- mm cores more common in the NW clump



Dots: near-IR cources
Crosses: ISO Class II
Triangles: ISO Class I
Hexagons: smm sources
Filled triangles: mm cores

- ✓ Star formation is currently taking place in both clumps; but more active in the NW one
- ✓ Star formation was more efficient or began earlier in the SE clump
- ✓ Several star formation phases have taken place

Near-IR population in the Core

- ~ 1000 near-IR sources detected in the central (~ 8' x 8') core

Total number of identified Serpens near-IR sources: 188

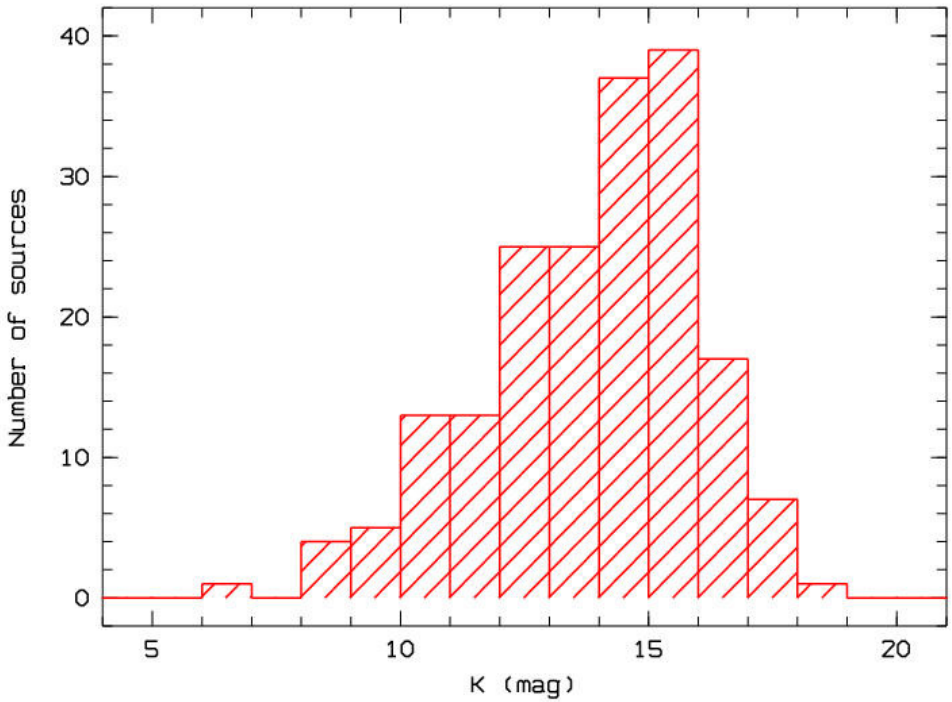
Main identification criteria for Serpens membership:

-- near-IR excesses

-- variability

-- association with nebulosity

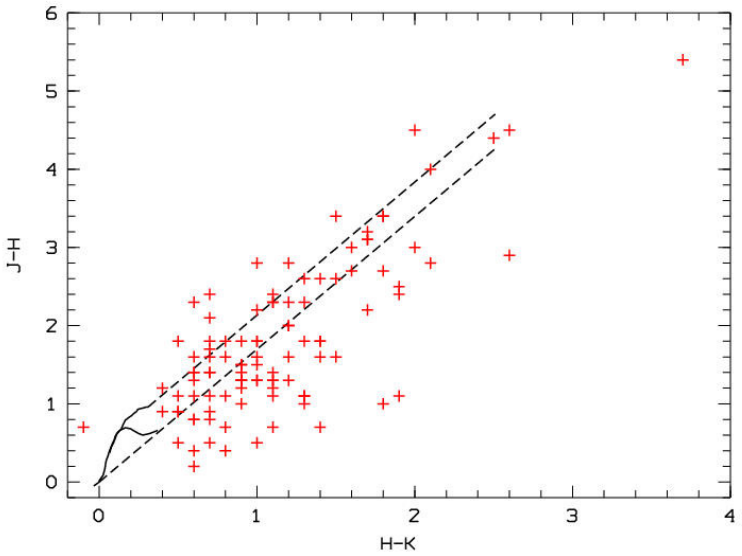
-- Eiroa & Casali, 92: 51 sources
-- Sogawa et al., 97: 38 sources
-- Giovannetti et al, 98 : 55 sources
-- Kaas, 99: 55 sources
-- Kaas et al. 2004: 8 sources
-- Klotz et al. 04(*): 14 sources
-- Eiroa et al. 05: 13 sources

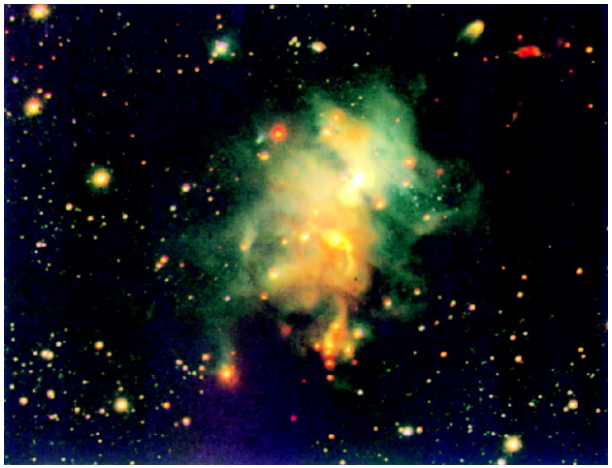


(*) The deep survey (K ~ 19 mag) by Klotz et al. 04 mainly extends to an area 5'x10' towards the SW of the core where extinction is substantially lower. Several thousands of sources are detected

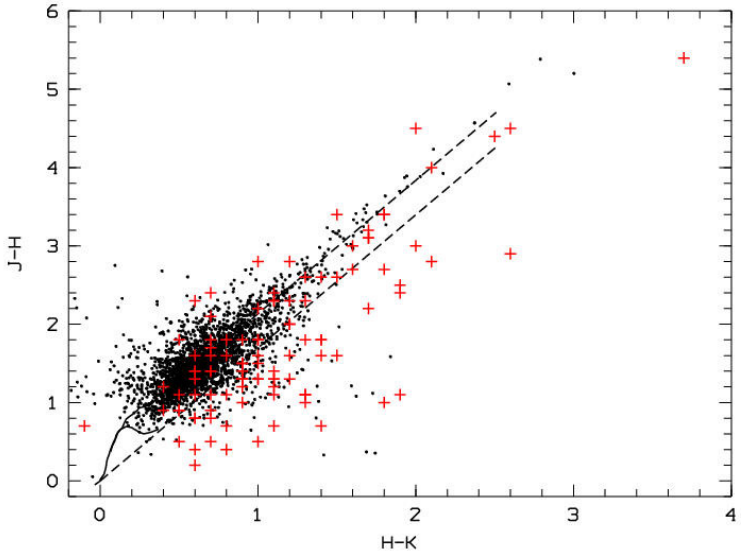
(H-K,J-H) diagram

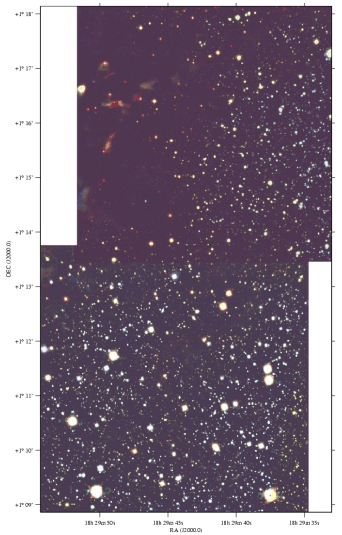
IR sources embedded in the core



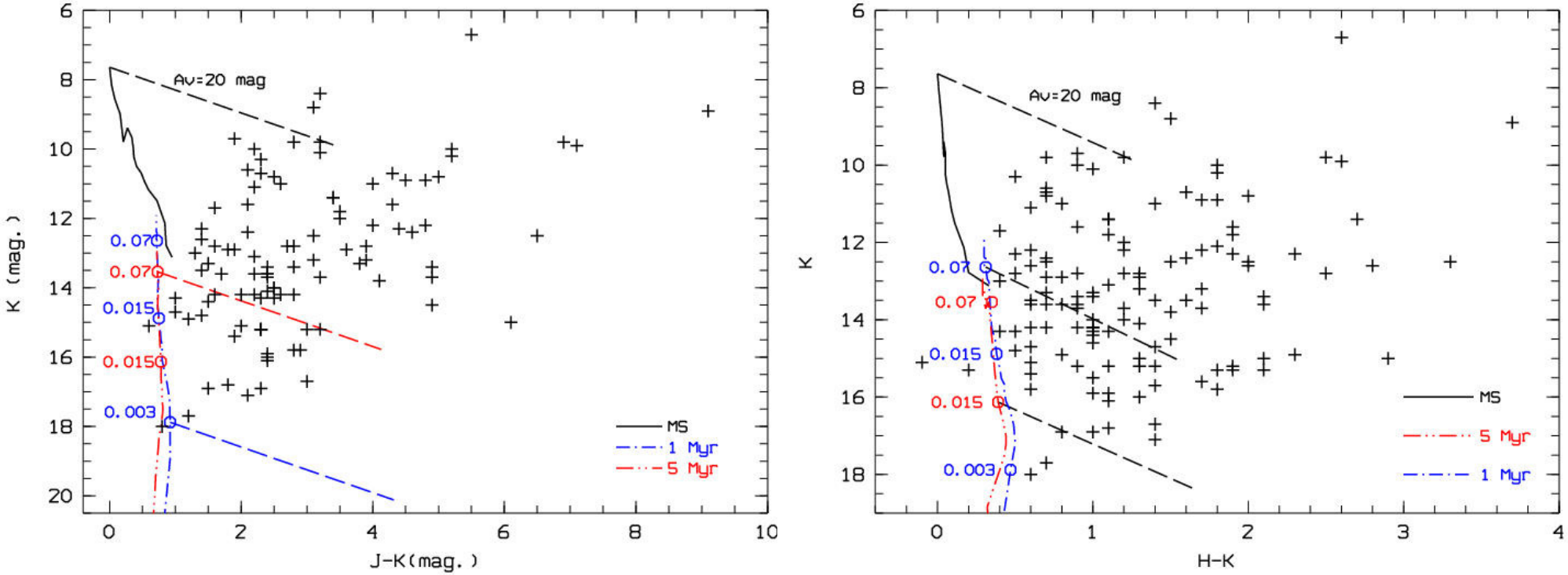


Core + Klotz et al. 04 sources





Near-IR diagrams



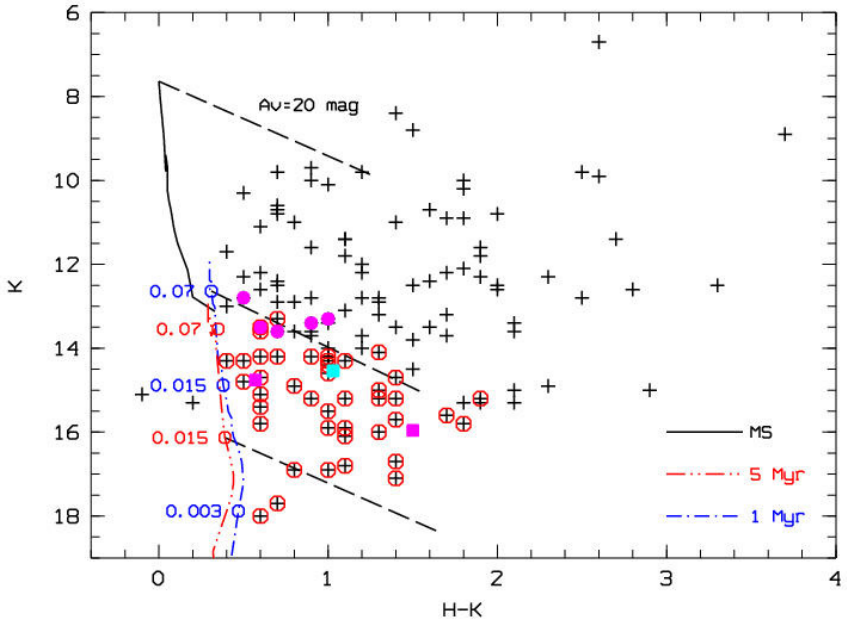
Color-magnitude diagrams of embedded sources in the Serpens core.

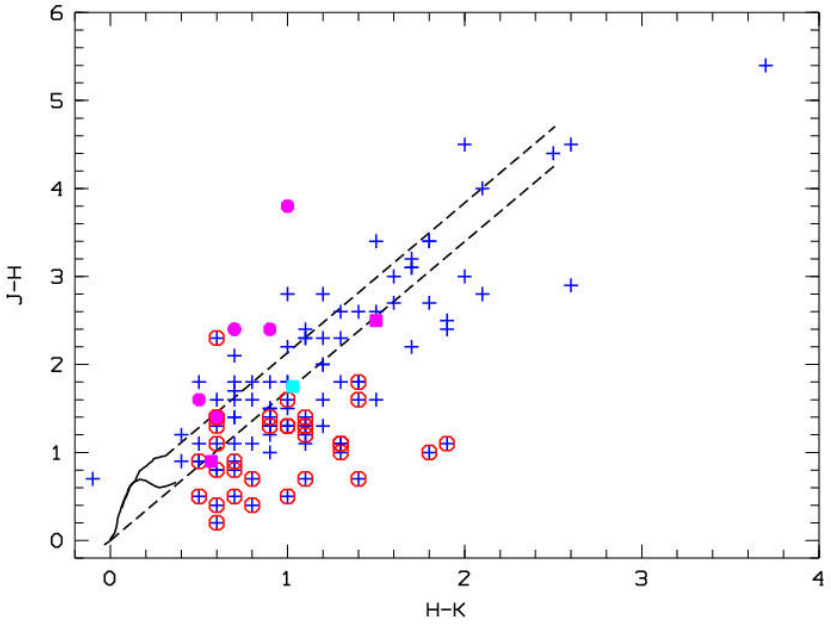
-- ~ 40 sources below 0.07 M_{sun}, down to planetary masses

⇔ 20% of the Serpens near-IR objects

Isochrones from Baraffe et al. 03

BD Candidates: Near-IR Diagrams





Color-magnitude and color-color diagrams of BD candidates

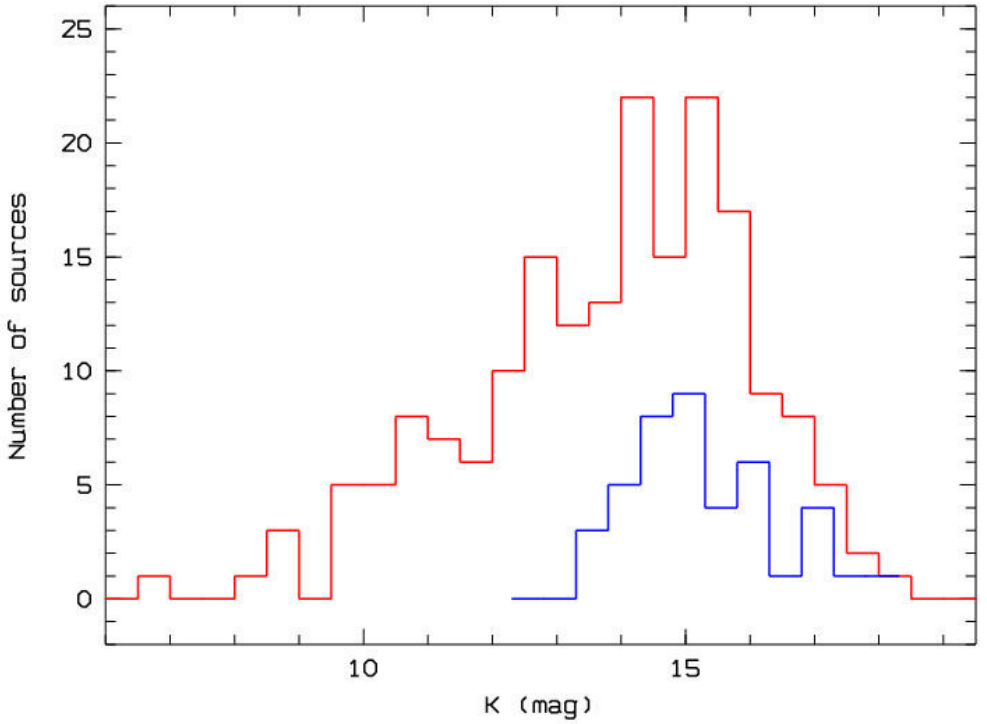
Square: BD-Ser1 (EC61)
Suggested BDs:
-- Kaas et al. 04 (ISO, dots)
-- Klotz et al. 04 (near-IR, squares)
Hexagons: BD candidates (this work)

- 28 sources show near-IR excesses
- 16 sources are variable (typically $\Delta K \sim 0.5$ mag, much larger than typical 3σ errors)

BD candidates: K-band histogram

Since the BD candidates are faint, important to check that they are "real":

- most BD candidates well above the completeness limit of the near-IR studies
- 22 sources common in different works
- 12 sources detected in several epochs by Kaas (1999)
- 8 sources only detected in one work



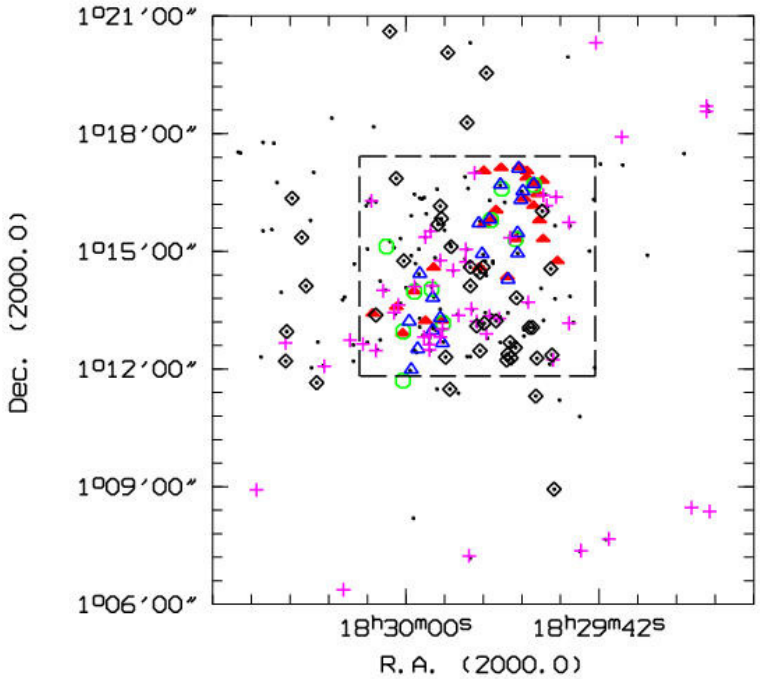
Difficult to estimate the intrinsic K-band distribution because of:

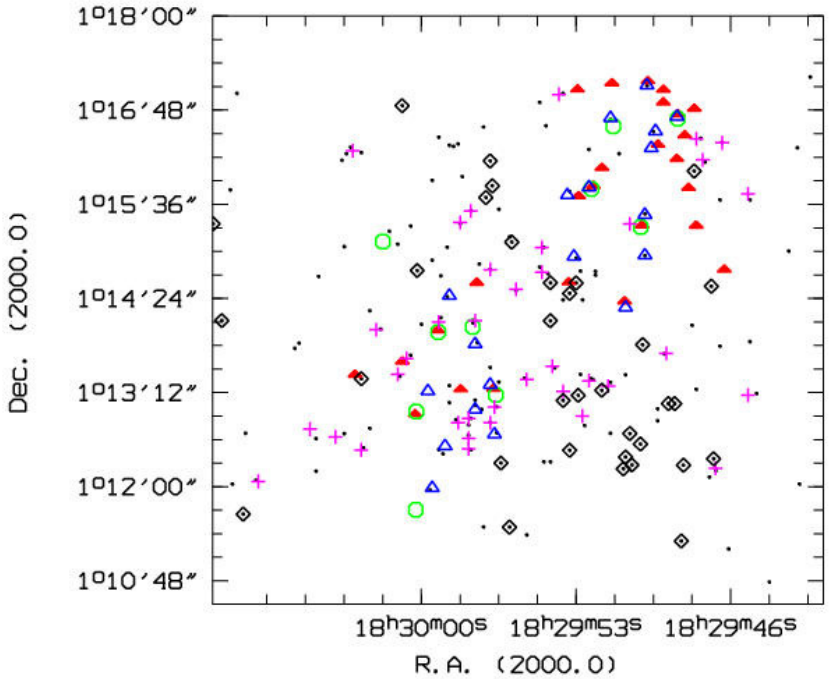
i) Color excess

ii) Variability

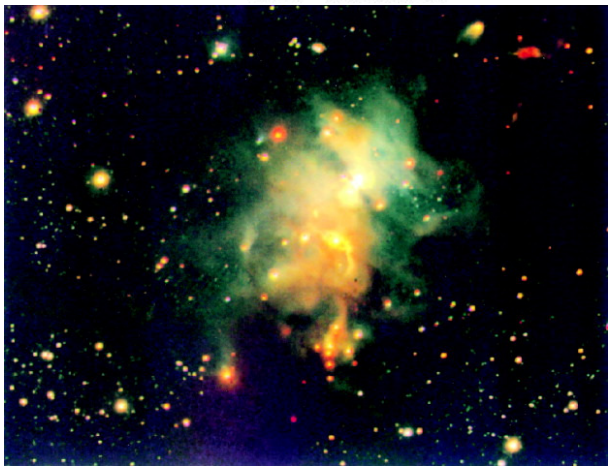
$\Rightarrow$ Both i) and ii) make it difficult to estimate extinction

BD Candidates: Spatial distribution

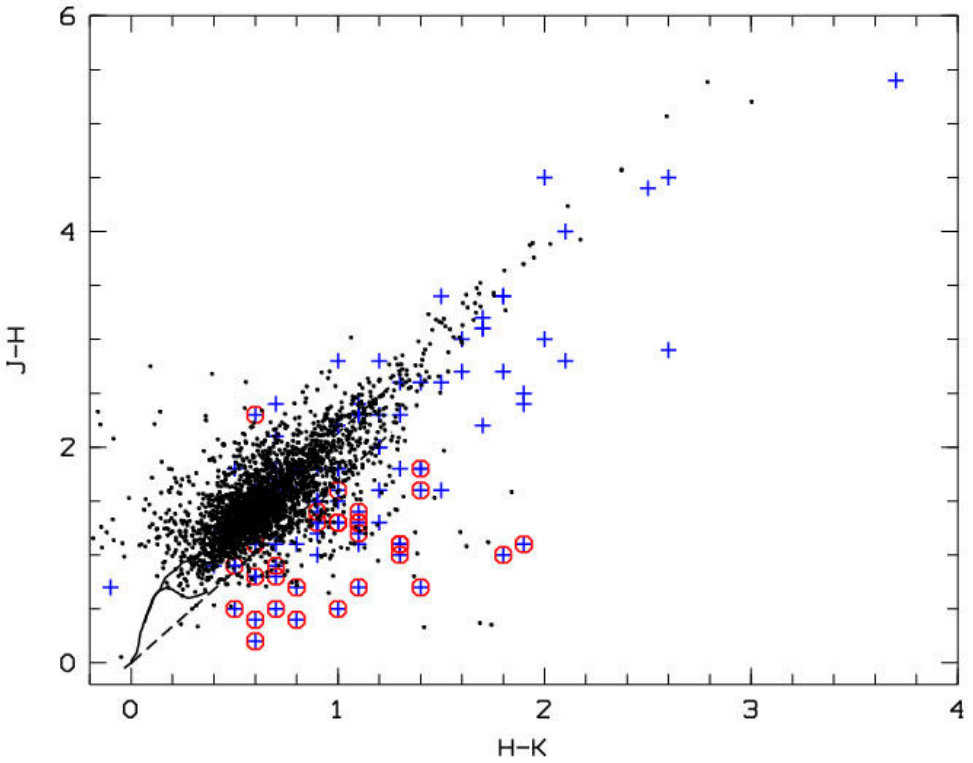


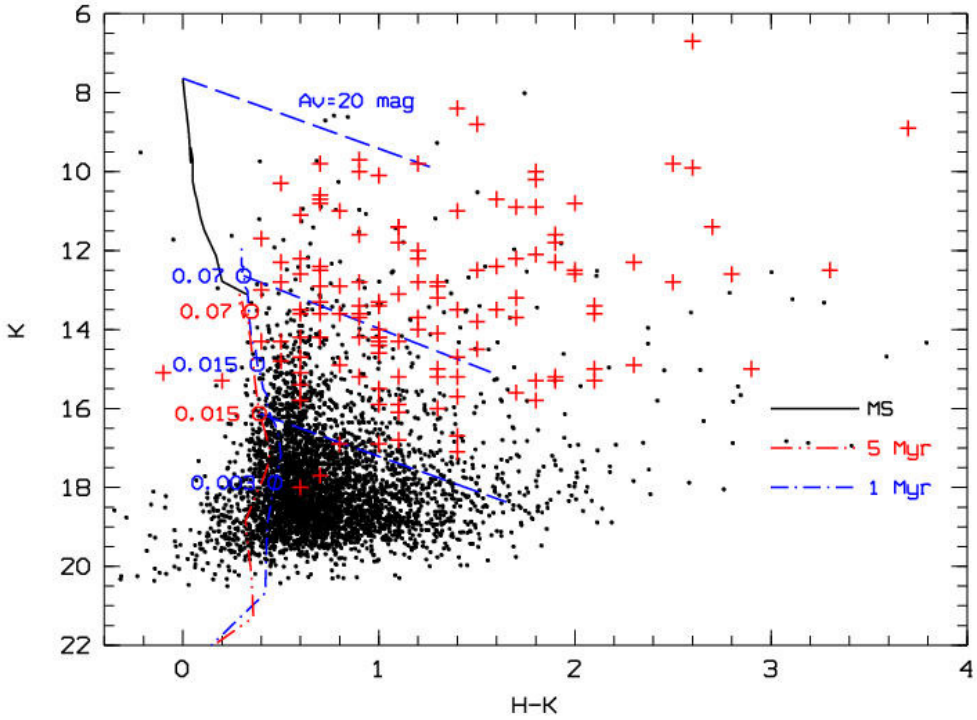


BD candidates located towards the less obscured part of the core, avoiding the very dense NW clump and the densest part of the SE clump.

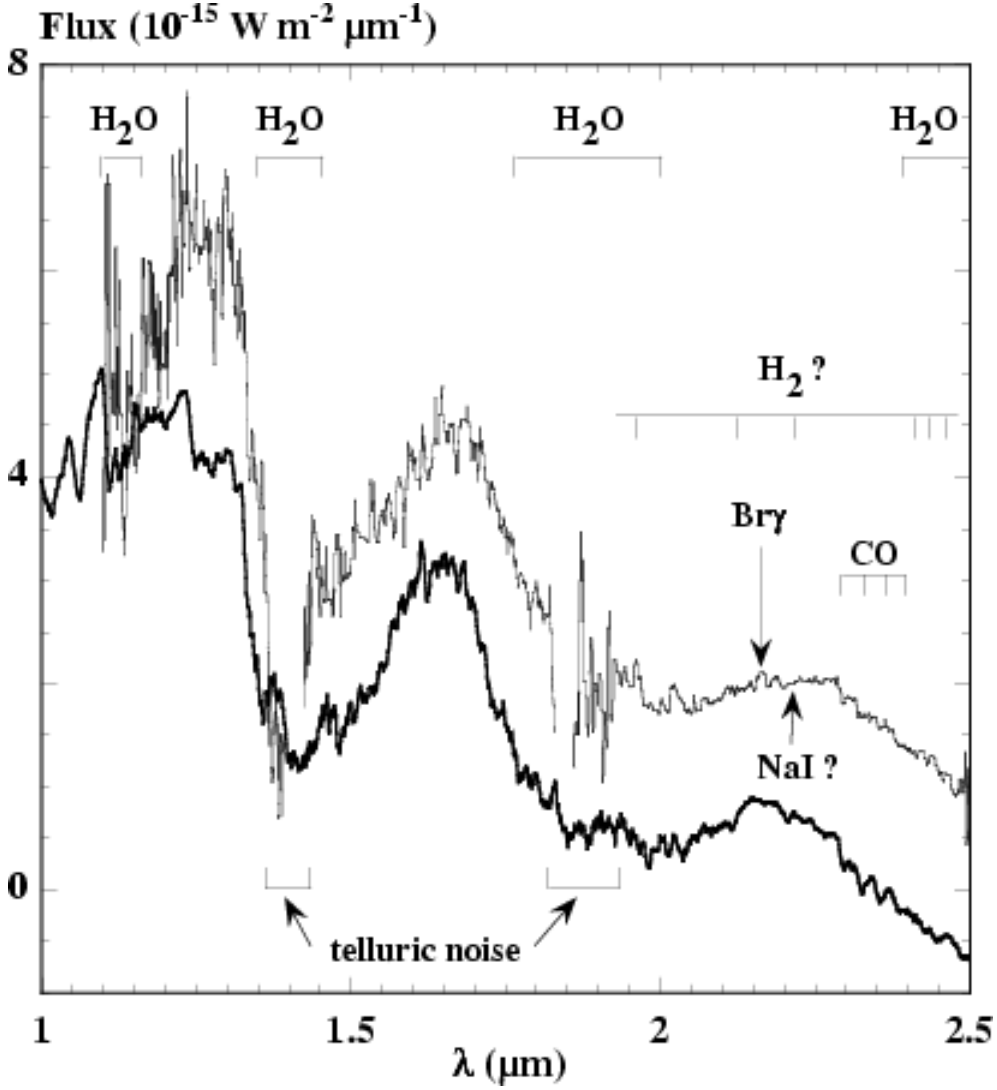


Near-IR: diagrams of Klotz's sources and Serpens embedded objects





Lodieu's BD-SEr1 Spectrum



Summary

- ~ 20% of the near-IR YSOs detected (so far) in the Serpens core could be brown dwarfs
- Age: 2 – 4 x 10^6 years
- Candidates need spectroscopic confirmation
- They could represent the lower mass (substellar) end of a very young YSO cluster