High-mass protostars and pre-stellar cores at the dawn of *Herschel* and ALMA

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Seeking the precursors of high-mass stars

Criteria previously used to search for the progenitors of UCH IIs:

- high-luminosity sources — $> 10^3 \, L_\odot$
- embedded in massive envelopes — red FIR colors, dense gas
- associated with hot dust & gas — hot core and masers
- <u>without a developed H II region</u> — no or weak cm free-free

⇒ High-luminosity IR protostar candidates (HMPOs)

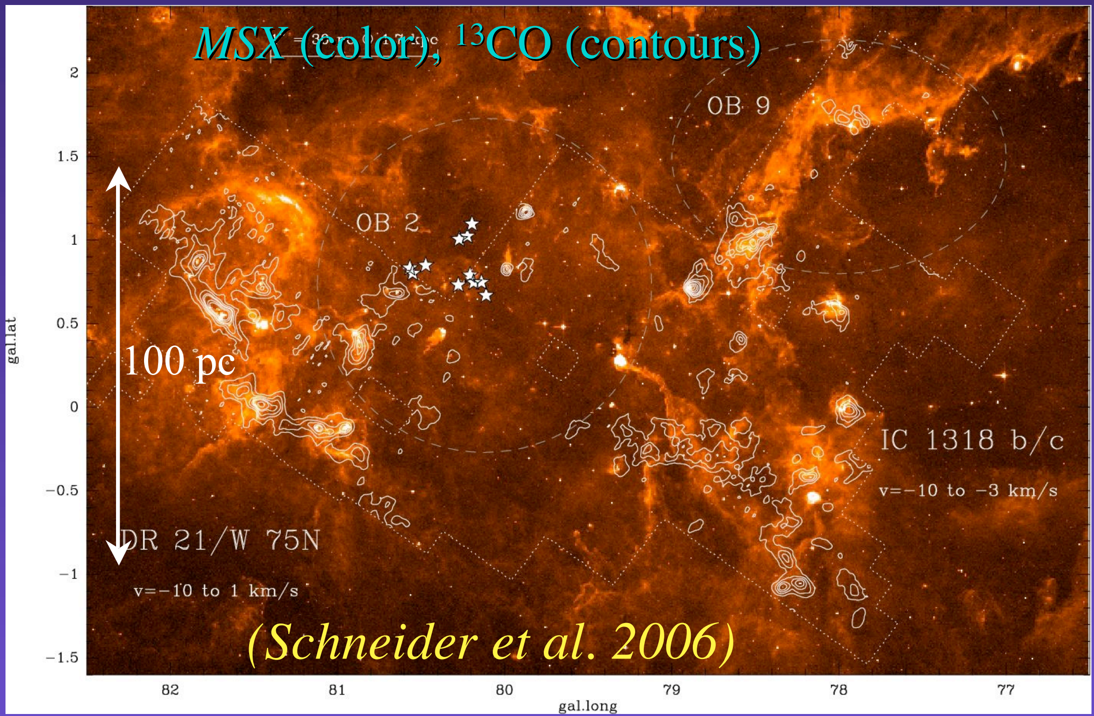
Criteria to use to search for the even earlier phases:

- small-scale cloud fragments — diameter = 0.01-0.1 pc
- which are dense — $\langle n_{H2} \rangle > 10^5 \text{-} 10^7 \text{ cm}^{-3}$
- weak @ mid-IR λ — $< 10^3 \, L_\odot$

⇒ High-mass class 0 protostars and massive pre-stellar cores

(Sub-)millimeter dense cores (present talk and poster by Schuller et al.) or cores within IR dark clouds.

Study of entire, nearby (<3 kpc), molecular complexes forming OB stars



+ enough statistics to survey high-mass YSOs
+ better spatial resolution than most existing surveys

Cygnus X complex:
massive (4 x 10^6 $M_\odot$)
@ 1.7 kpc
several OB associations

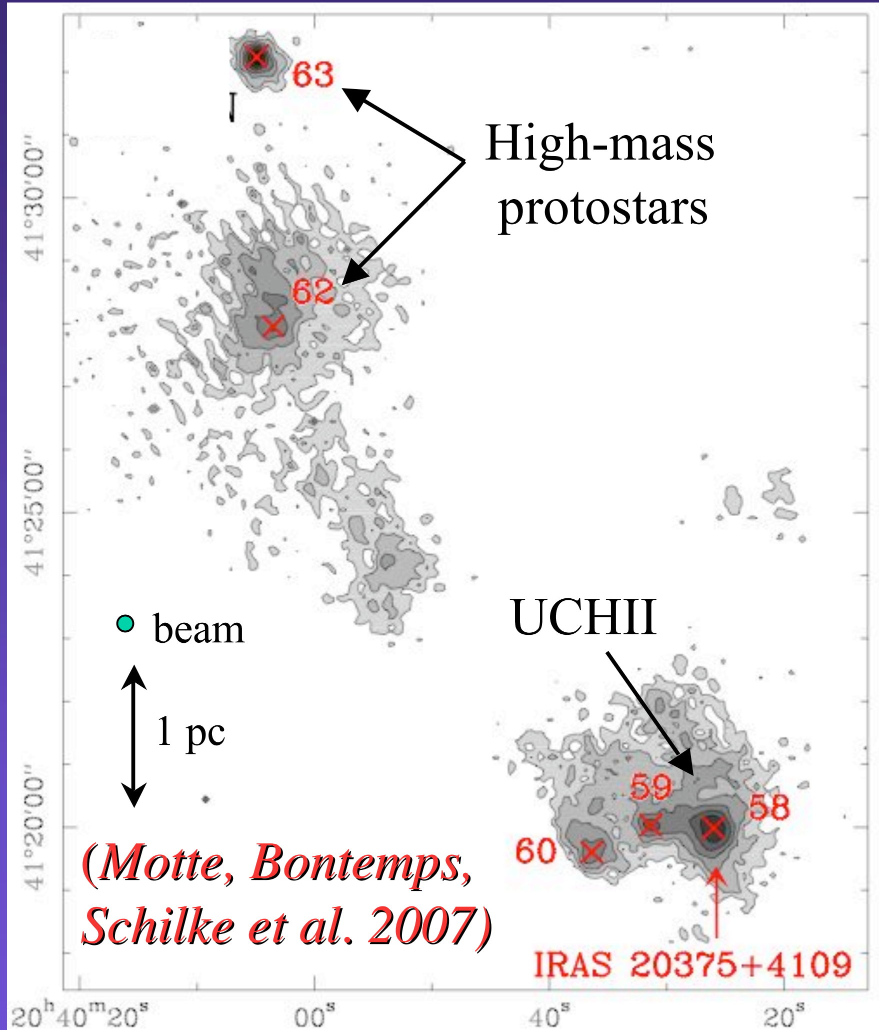
The submm imaging of such regions provides samples which are:

+ complete: they contain massive pre-stellar and protostellar objects
+ homogeneous: all sources are at the same distance
- statistically limited to the precursors of 10-40 $M_\odot$ stars

A 1.2 mm continuum survey of Cygnus X

MAMBO-2 / IRAM 30m
~ 3 deg^2, 11" beam
Tracing spatial scales: 0.09 - 5 pc

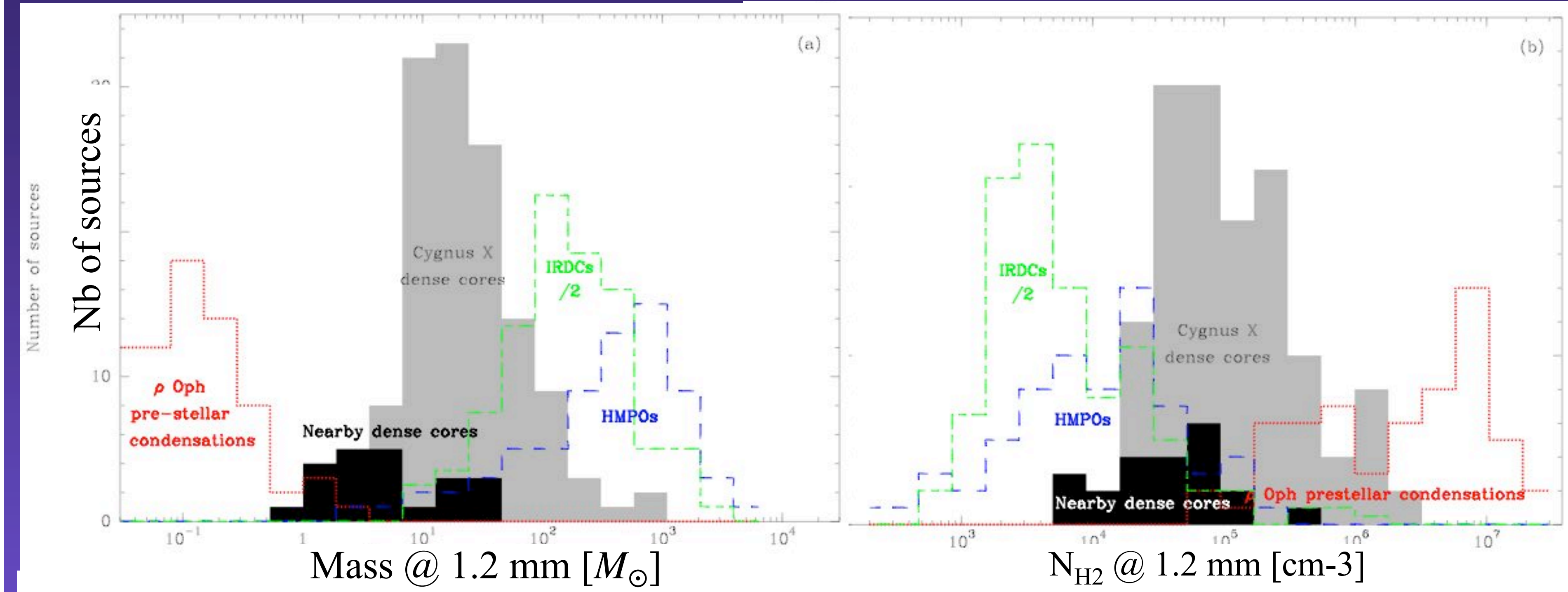
Dense cores (~ 0.1 pc) extracted from clumps (~ 1 pc) with a multi-resolution analysis of the cloud structure (cf. *Motte et al. 2003, 2007*)



Unbiased census in Cygnus X:

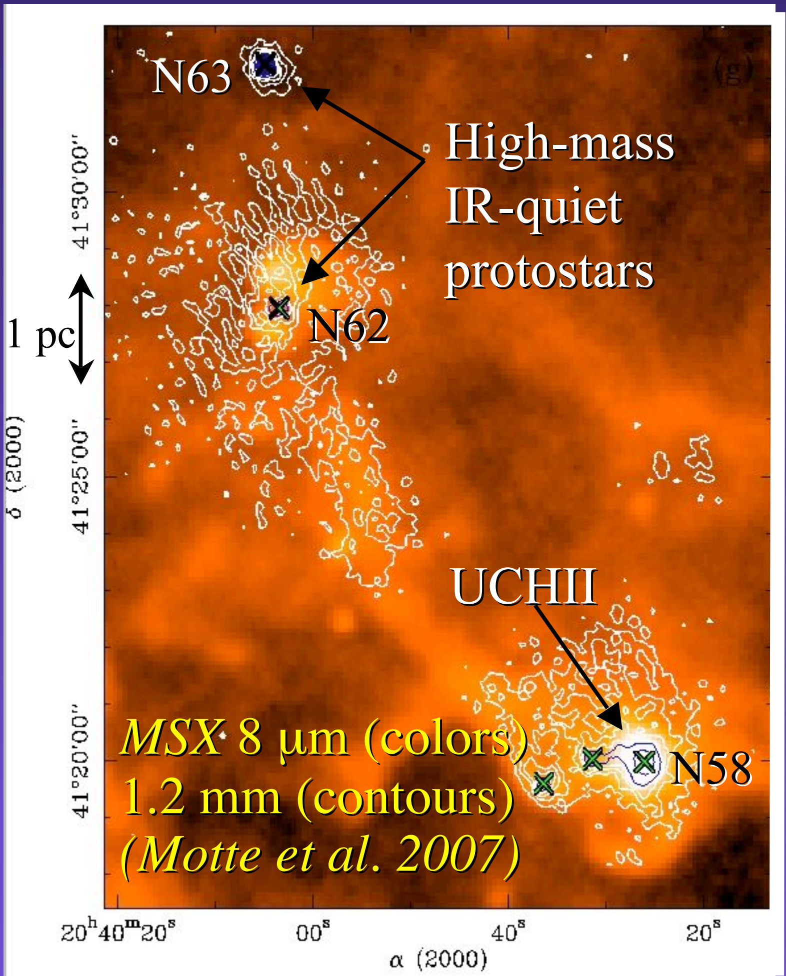
➡ 42 dense cores (compact cloud fragments, ~ 0.1 pc) which are probable precursors of high-mass stars (> 40 $M_\odot$)

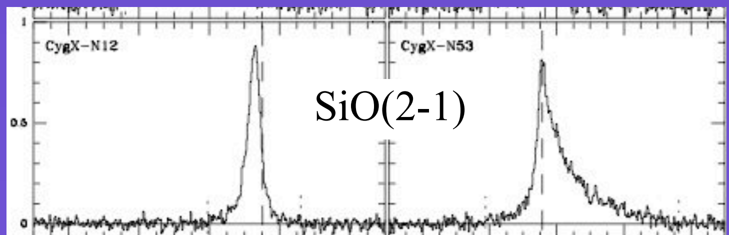
A sample of very high-density cores



	HMPOs clumps	IRDCs clumps	Cygnus X dense cores	Nearby low-mass dense cores	ρ Ophiuchi condensations
FWHM sizes	0.5 pc	0.5 pc	0.13 pc	0.1 pc	0.01 pc
Mass	290 $M_\odot$	150 $M_\odot$	91 $M_\odot$	5 $M_\odot$	0.15 $M_\odot$
Mean density	7 10^4 cm^{-3}	5 10^4 cm^{-3}	1.5 10^6 cm^{-3}	3 10^5 cm^{-3}	1.5 10^7 cm^{-3}
	(Beuther et al. 2002)	*(Rathborne et al. 2006)*	*(Motte et al. 2007)*	*(Ward-Thompson et al. 1999)*	*(Motte et al. 1998)*

Pre-stellar or protostellar dense cores?





- IR-quiet or High-luminosity?

"IR-quiet" = less luminous than a B3 star ($< 10^3\ L_\odot$)
$\Rightarrow S_{21\ \mu m} < 10$ Jy @ 1.7 kpc

Cygnus X high-mass dense cores are:
- UCH IIs for ~40%
- High-luminosity protostars for ~20%
- IR-quiet sources for ~40%

- High-mass IR-quiet dense cores: protostellar or pre-stellar?

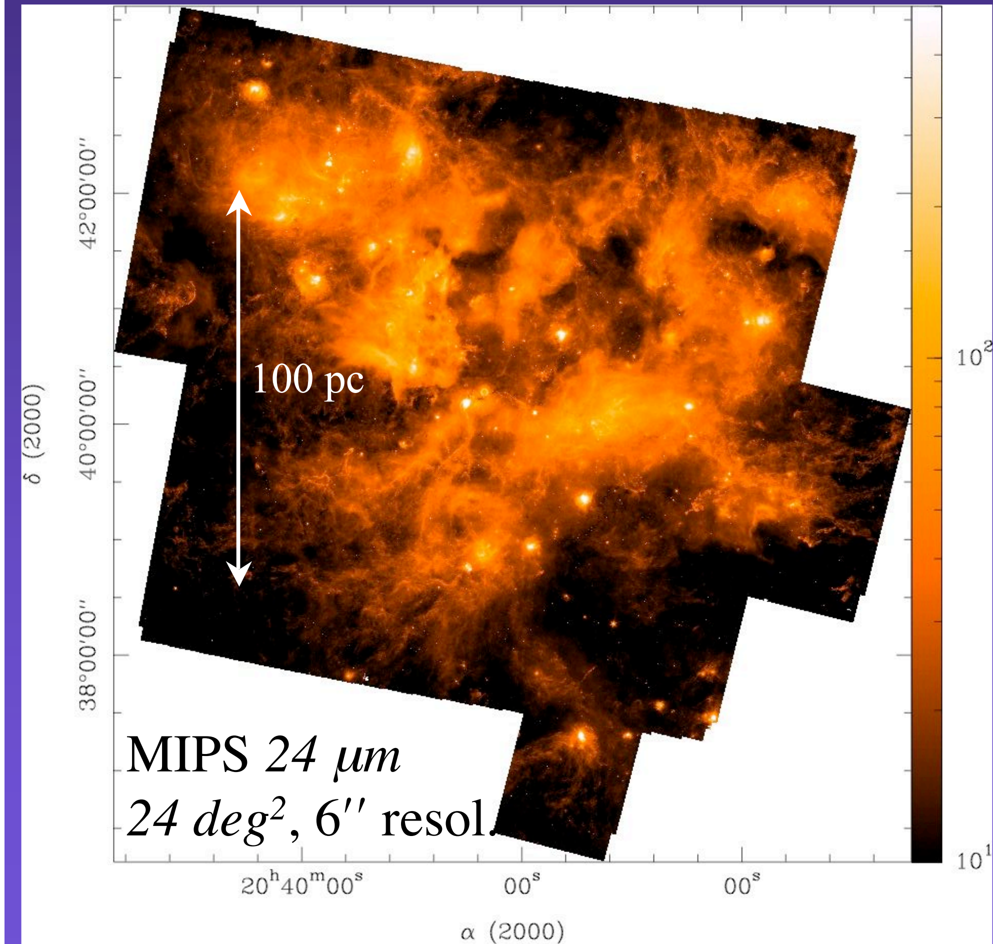
SiO outflows are very powerful

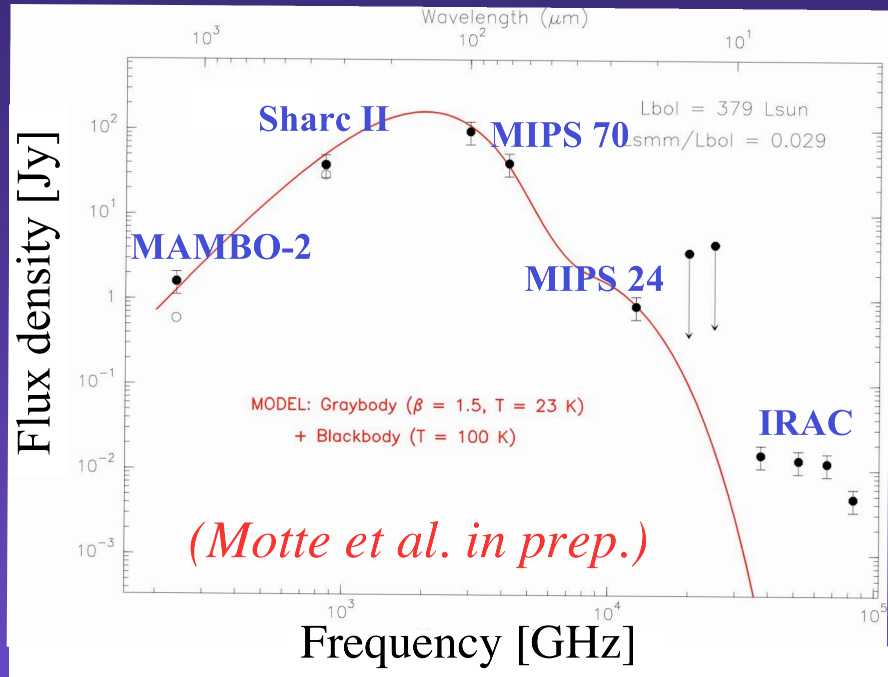
➡ They all may harbor one high-mass class 0 protostar

Luminosity of IR-quiet high-mass dense cores

Spitzer legagcy survey of Cygnus X:

(Hora, Bontemps, Megeath et al.)



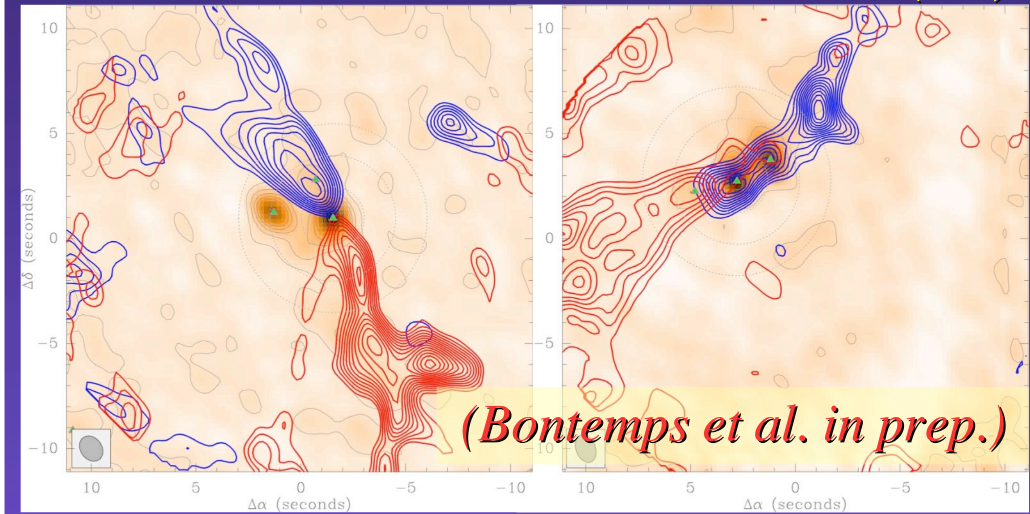


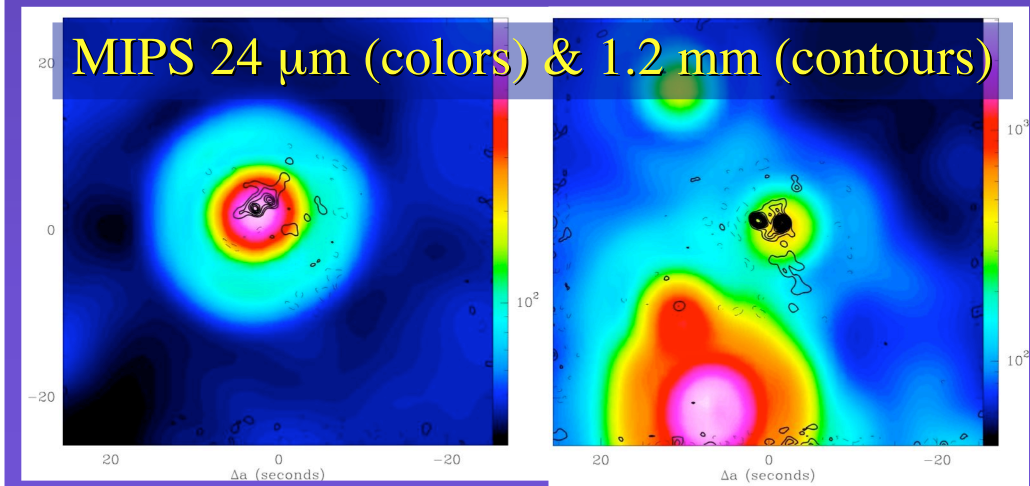
- L_{bol} = 150 - 3500 $L_\odot$
- L_{smm}/L_{bol} ratio like class 0s
- Strong $S_{24\,\mu m}$ flux relatively to low-mass Class 0s

➡ Young protostellar embryo that will probably be massive

From massive IR-quiet dense cores to high-mass class 0 protostars

IRAM PdBI 1.2 mm continuum & SiO(2-1)





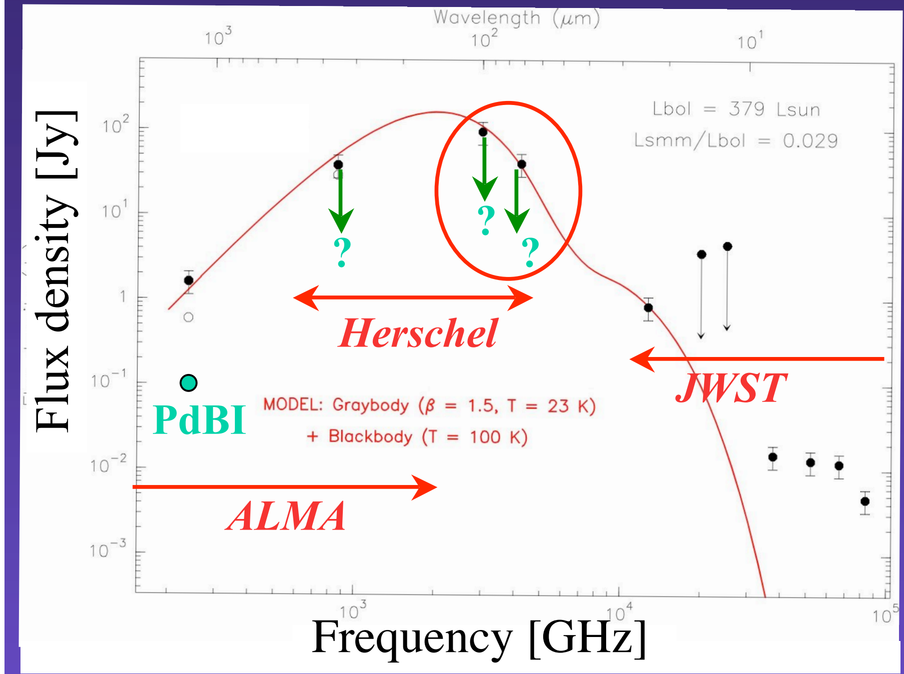
IRAM Plateau de Bure maps identify individual protostars (1″ ~ 0.01 pc resolution)

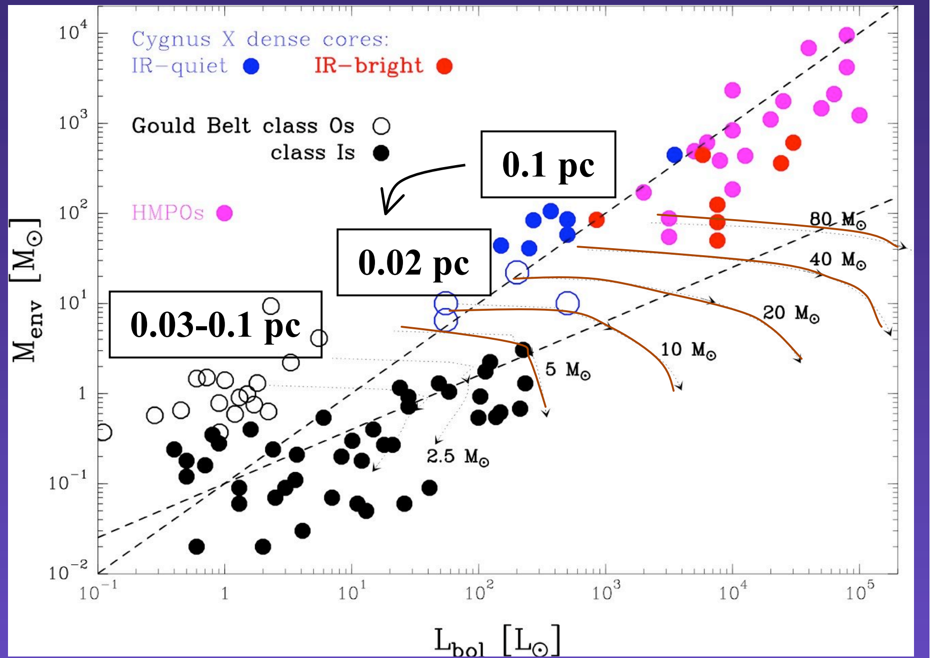
6/17 IR-quiet protostars already observed

First results:

- 1-3 massive (~ 5-20 $M_\odot$) components
- one is coinciding with the *Spitzer*/MIPS (0.05 pc) source
- integrated SiO is dominated by a single outflow

High-mass class-0 protostars





We need *Herschel* and ALMA/JWST to measure accurate bolometric luminosity for individual protostars.

Rough scaling gives: 50-500 $L_\odot$

Evolutionary M_{env}/L_{bol} diagram of high-mass protostars: 5-20 $M_\odot$

L_{smm}/L_{bol} ~ 1-3% ⇒ very young

$\langle n_{H2} \rangle$ ~ 10^7 cm^{-3} ⇒ SFE> 50% ?

Lifetime of high-mass protostars and pre-stellar condensations

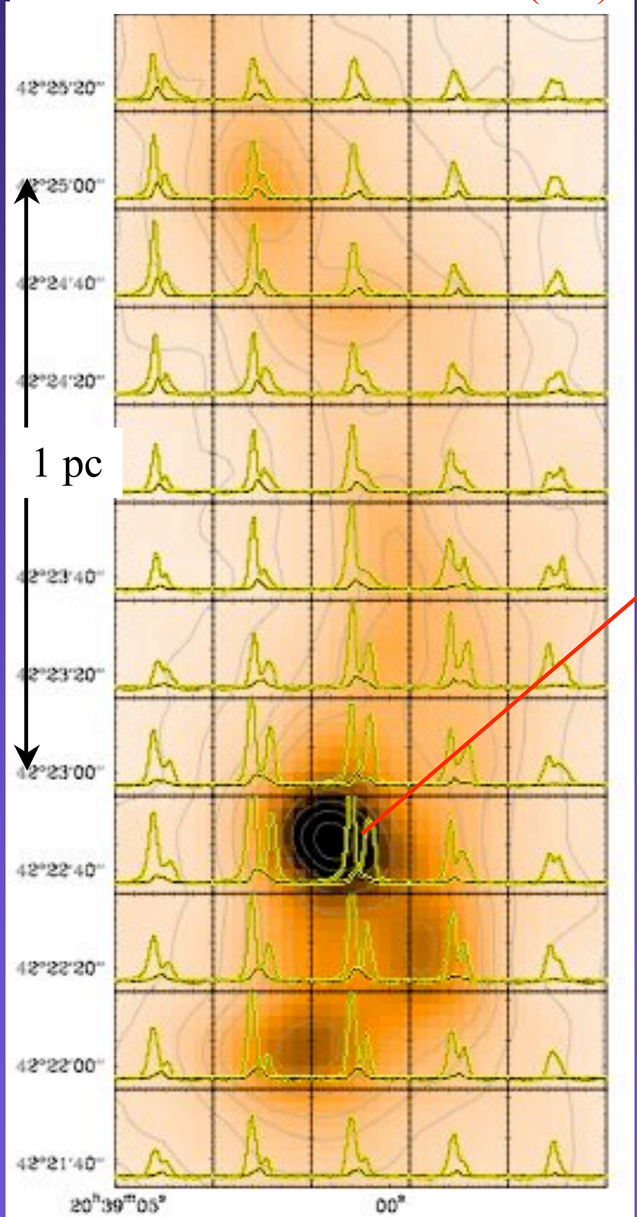
Estimates in Cygnus X from 0.1 pc studies *(Motte et al. 2007)* and 0.02 pc extrapolations *(Bontemps et al. in prep.)*:

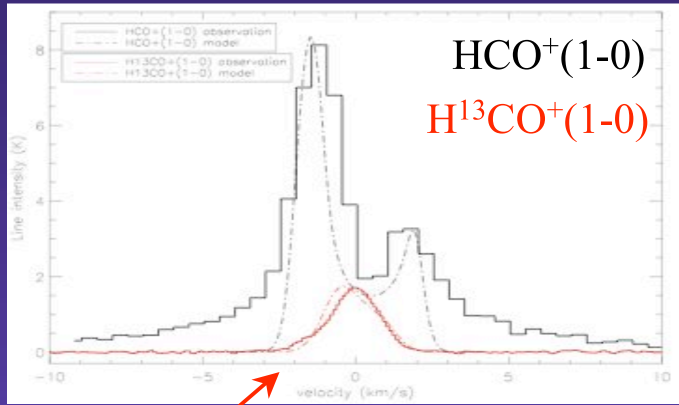
	OB stars	High-mass protostars (high-luminosity IR + IR-quiet)	Pre-stellar condensations
Nb in Cygnus X	2 600	(23 + 14 to 16) x 1 to 2	1 to 16
Statistical lifetimes relative to OB stars	2 10^6 yr	**~ 3 to 6 10^4 yr**	**~ 0.1 to 1 10^4 yr**
Expected lifetime		**one x 2 10^4 yr (free-fall)**	**a few x 2 10^4 yr (free-fall)**
Low-mass analogs		**2 10^5 yr**	**2 10^5 yr**

Unbiased studies shows that the high-mass star formation process is
⇒ rapid compared to low-mass star formation in nearby clouds.
⇒ supersonic during its protostellar <u>and starless phases</u> (convergent flows? global contraction?).

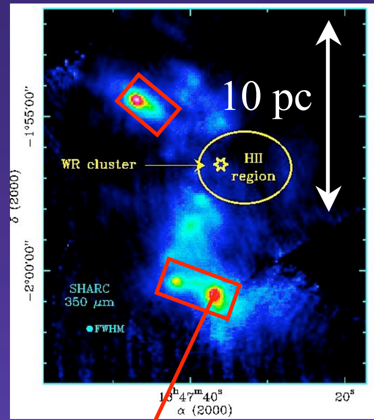
Global collapse observed in dense clouds

DR21 in HCO^+ and $H^{13}CO^+$ (1-0)





(Schneider et al.)

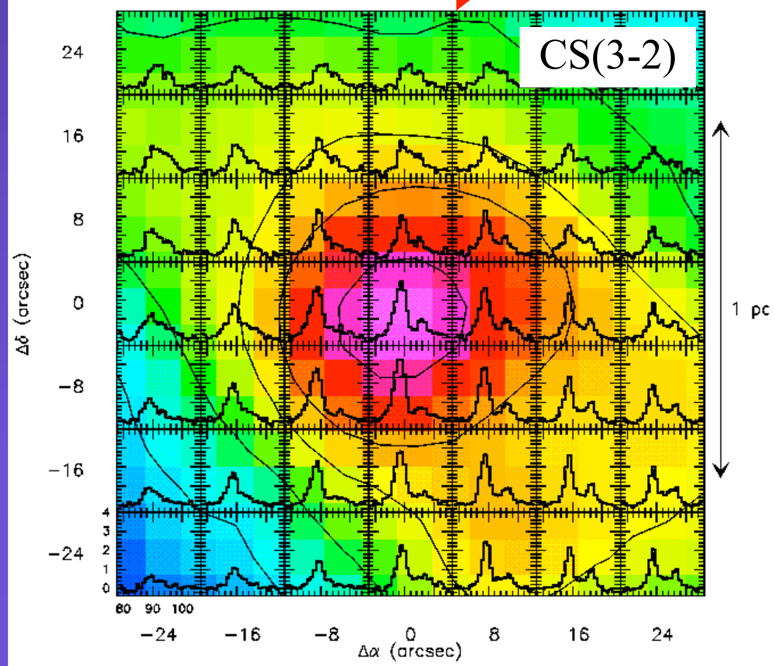


(Motte et al.)

V_{in} = 1-2 km s^{-1}
on several parsec
where
n_{H2}~ 10^6 cm^{-3}

(see also Williams & Garland 2002; Peretto et al. 2005)

W43 in CS, HCO^+ and $H^{13}CO^+$



Summary and near future

We may have identified bona-fide high-mass (20 $M_\odot$?) class 0 protostars in Cygnus X. They are:

- small-scale cloud condensations — diameter = 0.02 pc
- extremely dense — $\langle n_{H2} \rangle \sim 10^7$ cm^{-3}
- low-luminosity — $L_{bol} \sim 10^2$-10^3 $L_\odot$
- globally cold but with a large excess @ mid-IR λ — $S_{24\mu m}/S_{1mm}$ x10 (wrt low-mass class 0s)
- which drive powerful outflows — I_{SiO} x 2 (wrt *the most extreme cases of intermediate-mass* class 0s)

- Studying other complexes is mandatory to have a better statistics (cf. HOBYS on *Herschel*, ATLASGAL at APEX, + follow-ups…)

- ALMA is necessary to:

measure the luminosity of high-mass protostars,

trace their kinematics,

resolve further-away >20 $M_\odot$ protostars, …

Postdoctoral positions

Three postdoctoral positions in France

- dates: for 2 to 3 years, starting in 2009 or 2010
- focus: the earliest phases of high-mass star formation in our Galaxy
- in the framework of the "PROBES" project: "Proto-OB stars: identifying the targets for ALMA in Galactic-wide surveys"

http://www.obs.u-bordeaux1.fr/radio/SBontemps/probes.html

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Related key programs:

on *Herschel*: HOBYS, WISH, Hi-GAL

on APEX: ATLASGAL

…