A PANORAMIC VIEW OF STAR FORMATION IN MILKY WAY: RECENT RESULTS FROM GALACTIC PLANE FIR/SUB-MM SURVEYS

VIALACTEA

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Large surveys forever

Importance of large panoramic surveys not only to obtain statistically significant samples of sources and structures, but also to investigate large-scale phenomena

Molinari+ 2014, PP VI

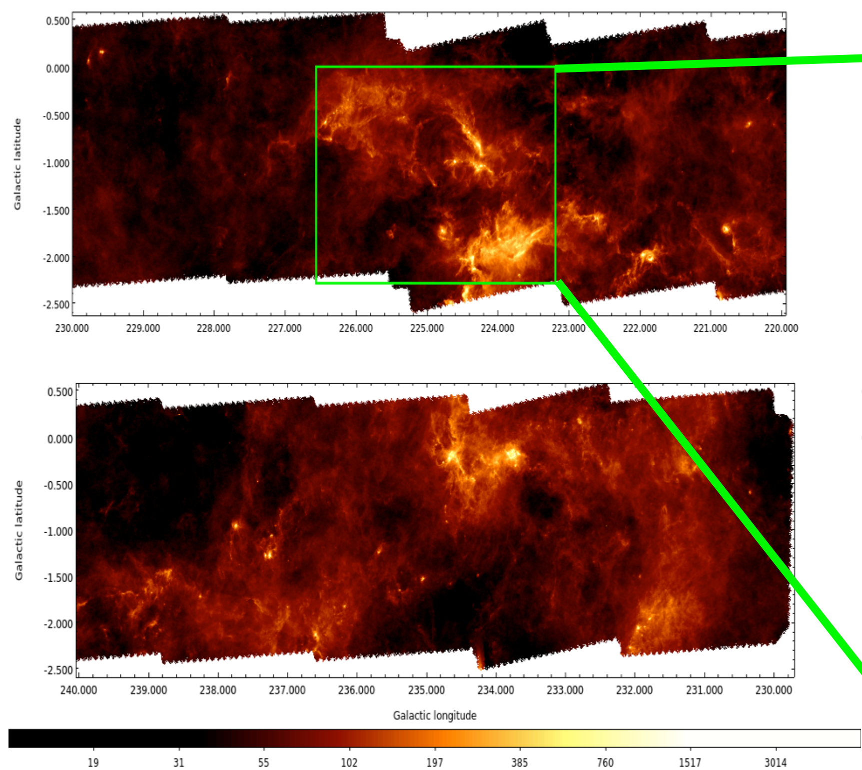
Table 1: List of most representative surveys covering the Galactic Plane

Surveys facilities	λ or lines	Surveys notes
		Ground-based
Columbia/CfA	CO, ^{13}CO	9 - 25′ resolution (*Dame et al.*, 2001)
DRAO/ATCA/VLA	HI-21 cm OH/Hα-RRL/1-2GHz cont. 5GHz cont.	IGPS: unbiased HI-21cm 255°$\leq l \leq$ 357° and 18°$\leq l \leq$ 147° (*McClure-Griffiths et al.*, 2001; *Gibson et al.*, 2000; *Stil et al.*, 2006) + THOR: unbiased HI-21cm/OH/Hα-RRLs/1-2GHz cont. 15°$\leq l \leq$ 67° (Beuther et al. in prep.)+ CORNISH: 5GHz continuum 10°$\leq l \leq$ 65° (*Hoare et al.*, 2012)
FCRAO 14 m	CO, ^{13}CO	55″ resolution. Galactic Ring Survey (*Jackson et al.*, 2006) + Outer Galaxy Survey (*Heyer et al.*, 1998)
Mopra 22 m	CO, ^{13}CO, N_2H^+, (NH_3 + H_2O) maser, $HCO^+/H^{13}CO^+$ + others	HOPS: (*Walsh et al.*, 2011; *Purcell et al.*, 2012), MALT90: ~ 2000 clumps 20° $\geq l \geq -60$° (*Foster et al.*, 2013), Southern GPS CO: unbiased 305°$\leq l \leq$ 345° (*Burton et al.*, 2013), ThrUMMS: unbiased 300°$\leq l \leq$ 358° (*Barnes et al.*, 2013), CMZ: (*Jones et al.*, 2012, 2013)
Parkes	CH_3OH maser	Methanol MultiBeam Survey (*Green et al.*, 2009)
NANTEN/ NANTEN2	CO, ^{13}CO, $C^{18}O$	NGPS: unbiased, 200° $\leq l \leq$ 60° (*Mizuno and Fukui*, 2004) + NASCO: unbiased in progress, 160° $\leq l \leq$ 80°
CSO 10 m	1.3 mm continuum	Bolocam Galactic Plane Survey (BGPS), 33″ (*Aguirre et al.*, 2011)
APEX 12 m	870 μm continuum	ATLASGAL, 60°$\geq l \geq -80$° (*Schuller et al.*, 2009)
		Space-borne
IRAS	12, 25, 60 and 100 μm cont.	3-5′, 96% of the sky
MSX	8.3, 12.1, 14.7, 21.3 μm cont.	Full Galactic Plane (*Price et al.*, 2001)
WISE	3.4, 4.6, 11, 22 μm continuum	All-sky (*Wright et al.*, 2010)
Akari	65, 90, 140, 160 μm continuum	All-sky (*Ishihara et al.*, 2010)
Spitzer	3.6, 4.5, 6, 8, 24 μm continuum	GLIMPSE+GLIMPSE360: Full Galactic Plane (*Benjamin et al.*, 2003), (*Benjamin and GLIMPSE360 Team*, 2013) + MIPSGAL, 63°$\geq l \geq -62$° (*Carey et al.*, 2009)
Planck	350, 550, 850, 1382, 2098, 3000, 4285, 6820, 10^4 μm cont.	All-sky, resolution $\geq$5′ (*Planck Collaboration et al.*, 2013a)
Herschel	70, 160, 250, 350, 500 μm cont.	Hi-GAL: Full Galactic Plane (*Molinari et al.*, 2010a)

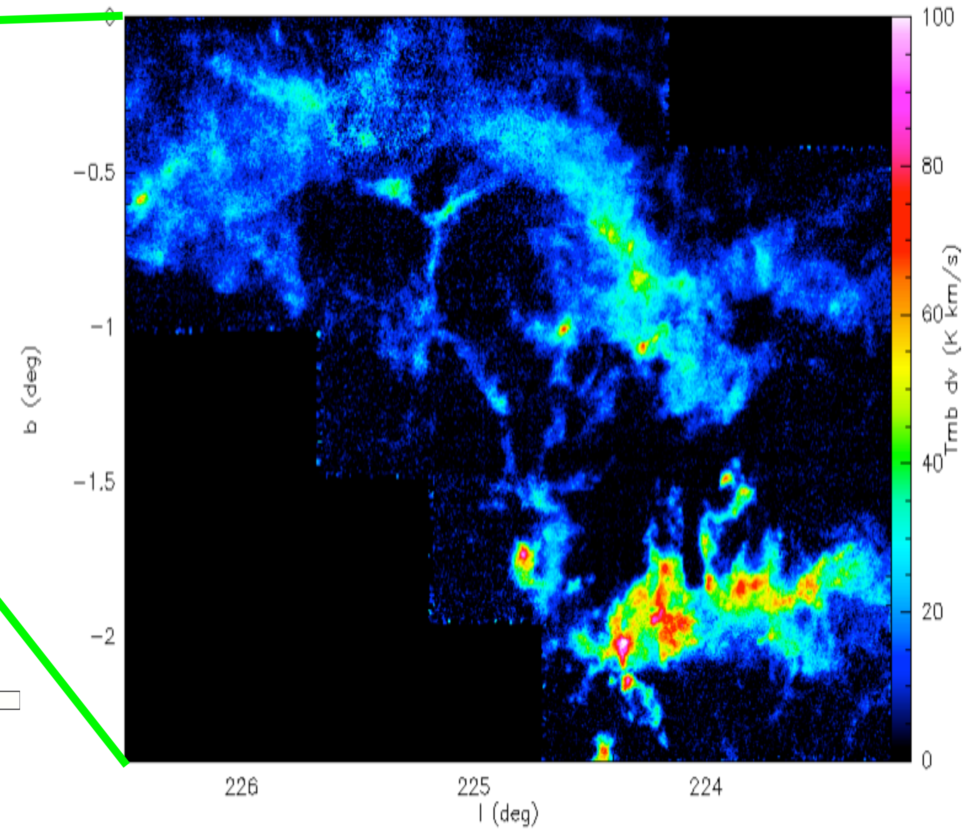
The Forgotten Quadrant Survey

600 hr ESO project at ARO 12-m (IAPS-OAA-IRA)

A ^{12}CO and ^{13}CO (1-0) survey of a strip (220° < *l* < 240° and 0° < *b* < -2°) of the Galactic plane in the third quadrant



Herschel-SPIRE 250 micron maps of the portion of the Galactic Plane observed in the FQS project.



^{12}CO (1-0) map integrated over the velocity range 8 -24 km s^{-1}.

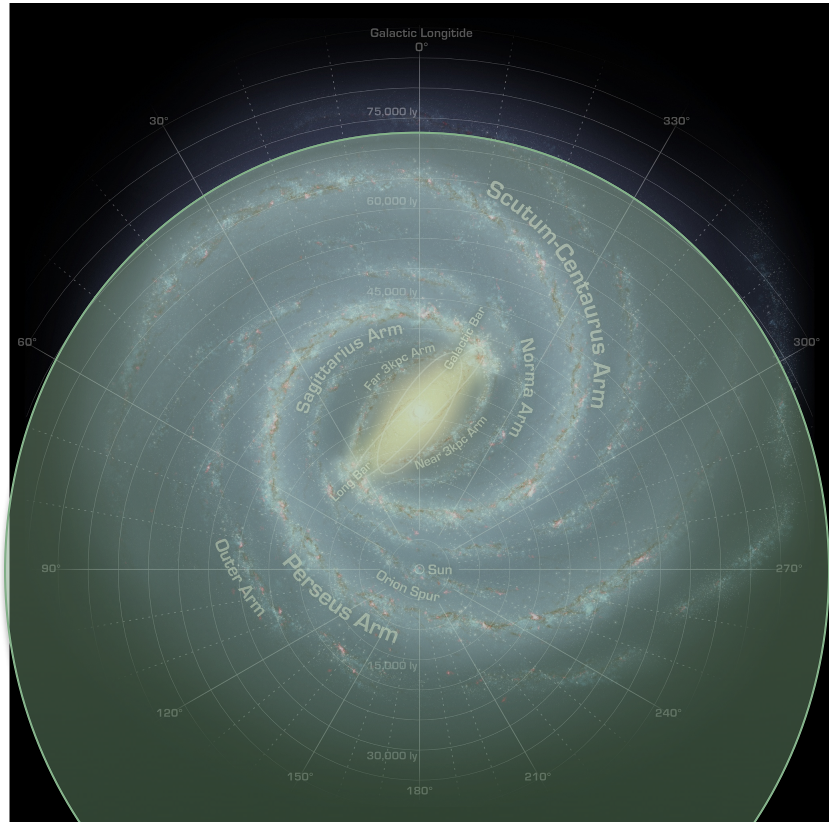
Hi-GAL The Herschel infrared Galactic Plane Survey

The entire Plane has been observed. Images access (with registered astrometry and absolute flux calibration) and compact source catalogues for longitudes between 65° and 290° have been recently released

Simultaneous 5-bands (*70-160-250-350-500μm*) continuum mapping of 720 sq. deg. of the Galactic Plane (|*b*|≤1°)

With almost 900 hours observing time is the largest OPEN TIME Herschel KP

Galaxy-wide Census, Luminosity, Mass and SED of dust structures at all scales from massive YSOs to Spiral Arms



STRUCTURE OF THE *VIALACTEA* PROJECT

Four scientific work packages (WP1-4):

- **WP1 – diffuse structure (filaments, bubbles) analysis**
- **WP2 – compact structure (clump) analysis**
- **WP3 – distance estimation**
- **WP4 – combination of WP1-3 into a global scenario of the Galaxy as a star formation engine**

one technical work packages

- **WP5 – Tools and Infrastructures:**
  - **Database and Virtual Observatory Infrastructure**
  - **Data Mining Systems**
  - **3D Visual Analytics systems**
  - **Science Gateway**

…other packages dedicated to dissemination, management and coordination activities.

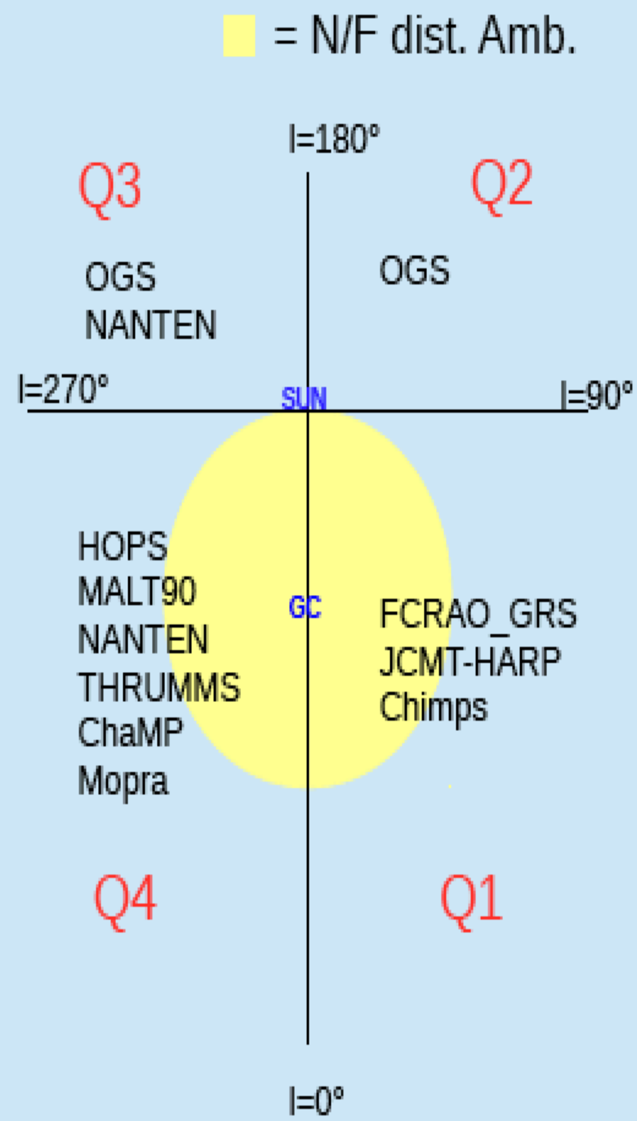
WP3: Kinematical analysis of radio spectroscopic surveys

The VIALACTEA knowlegde database :

- CHaMP (HCO+ 1-0)
- HOPS (H2O 6-1-6_5-2-3 , NH3 1-1_1-1, NH3 2-2_2-2)
- FCRAO_GRS (13CO 1-0)
- MALT90 (HCO+ 1-0, HCN 1-0, N2H+ 1-0, HNC 1-0)
- THRUMMS (12CO 1-0, 13CO 1-0, C18O 1-0)
- NANTEN (12CO 1-0)
- OGS (12CO 1-0, 13CO 1-0)
- JCMT-HARP (12CO 3-2)
- Mopra CO survey (12CO 1-0, 13CO 1-0)
- CHIMPS (13CO 3-2, C18O 3-2)
- VGPS (HI 21cm)
- CGPS (HI 21cm)

The general automatic process :

- Sub-cube extraction => around a source
- Profile fitting => velocities
- Morphological analysis => adopted velocity
- Distance hierarchical analysis



The Hi-GAL Compact Source "Physical Catalog"

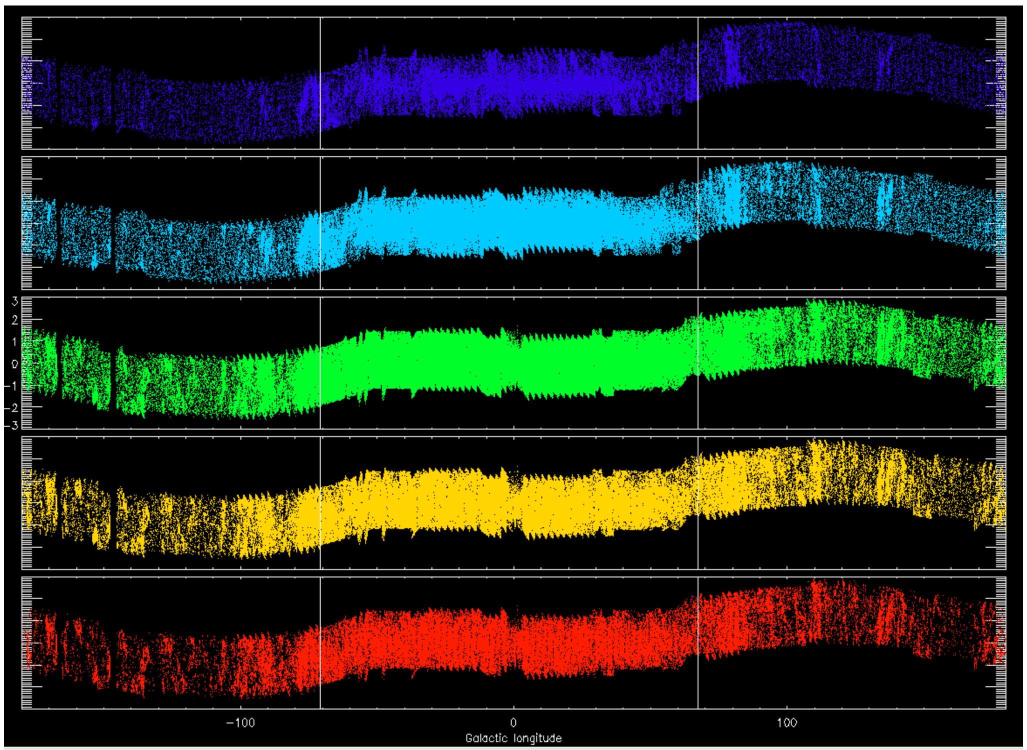
The underlying idea behind this catalog is to extract physical information from the SEDs of the sources, collected from 21 to 1100 μm.

Cross-correlation with other tracers represents a further development of this work.

SED selection is performed in the 160-500 μm range: only SED eligible for greybody fit are taken into account.

Hi-GAL is statistics

First-generation Hi-GAL Photometric Catalogues created using CuTEx package (Molinari+11).

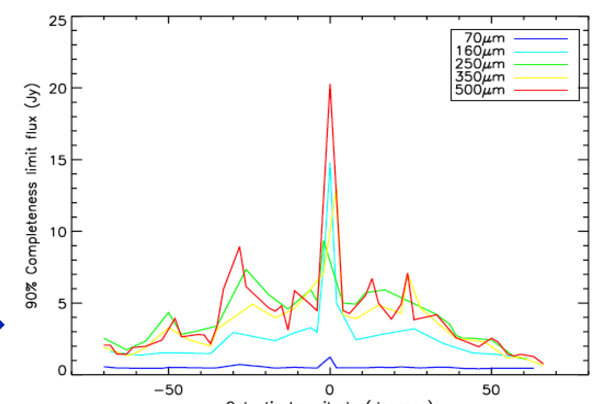


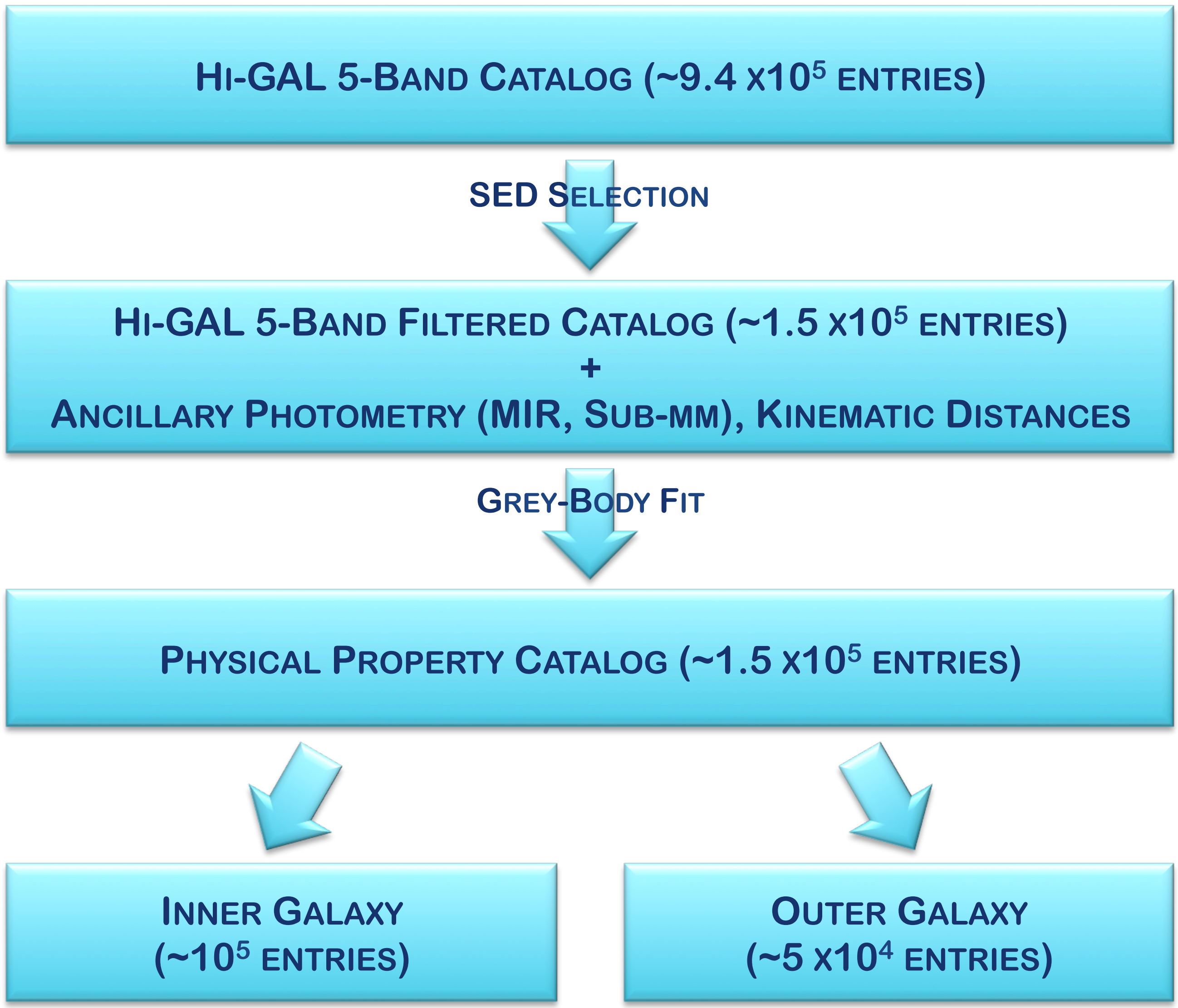
Molinari+2016, Merello+2017

Source statistics

	-71° < *l* < 68°	0° < *l* < 360°
70 μm	**122971**	**141994**
160 μm	**292051**	**322827**
250 μm	**280258**	**355924**
350 μm	**161855**	**215134**
500 μm	**85880**	**110991**

Completeness estimation →



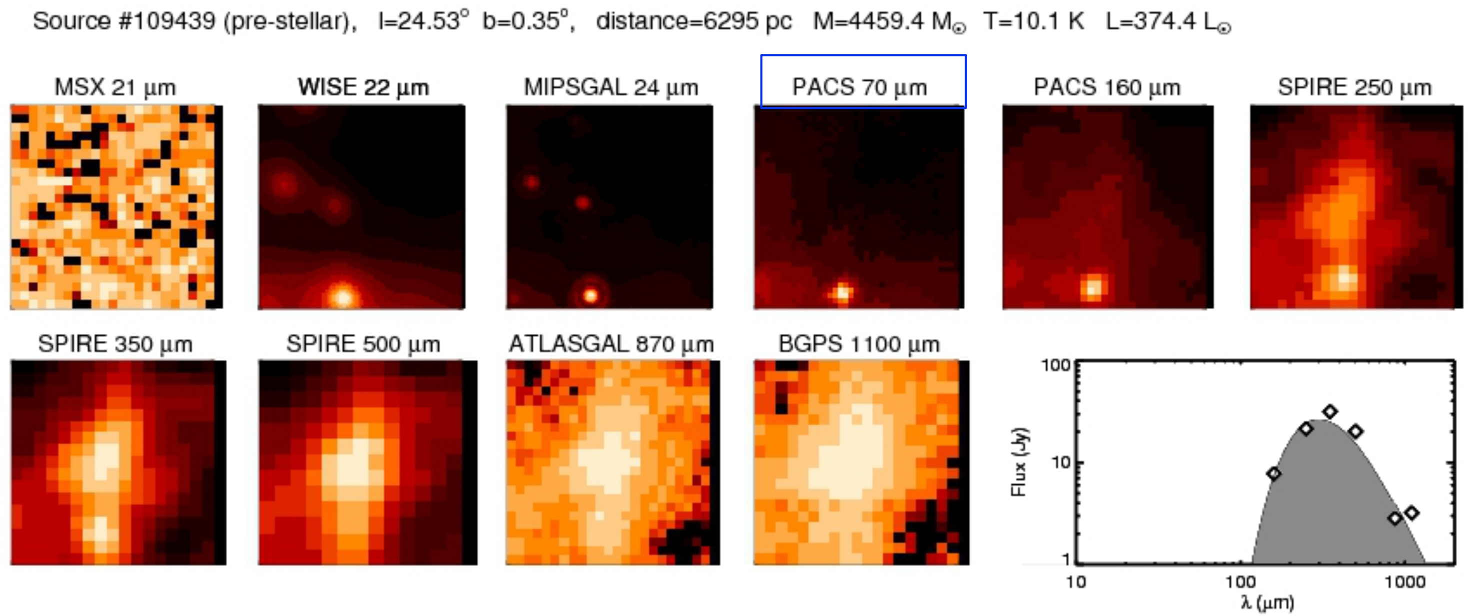


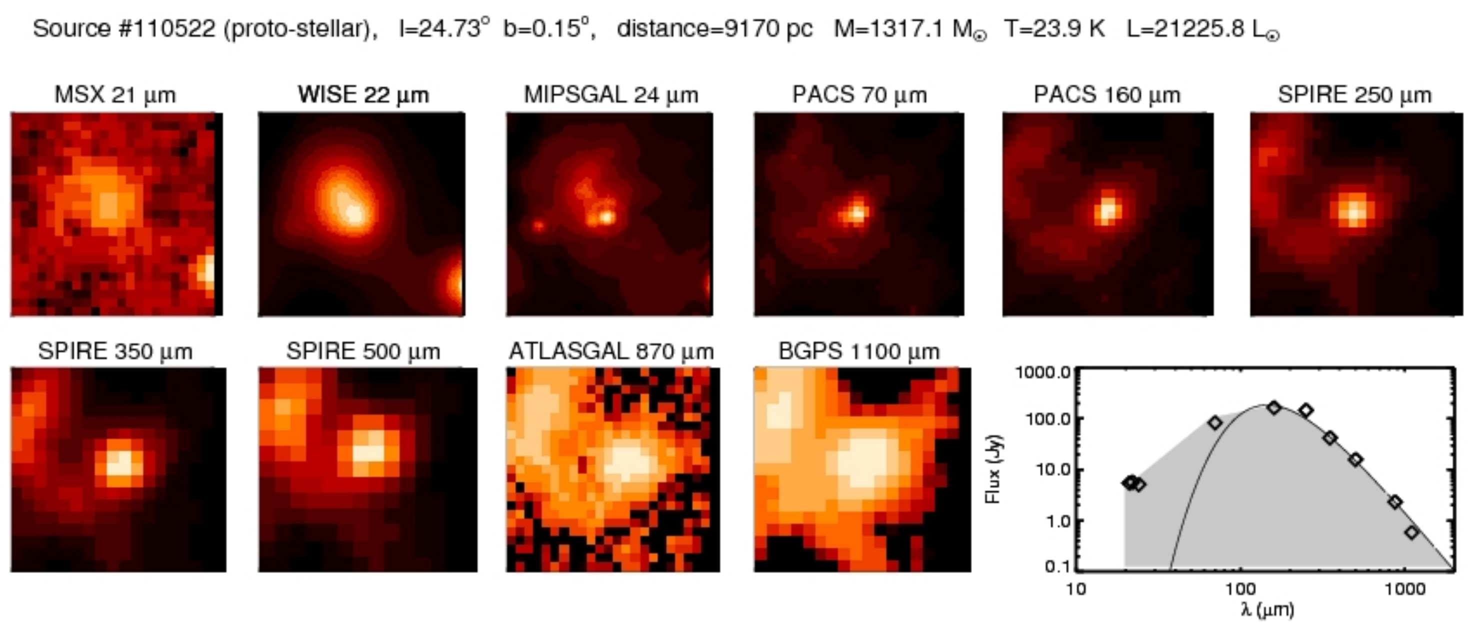
Elia+ 2017, MNRAS

Merello+ 2017, in prep.

SEDs are further split in a "Low-" and a "High-reliability" list

Starless sources vs Proto-stellar



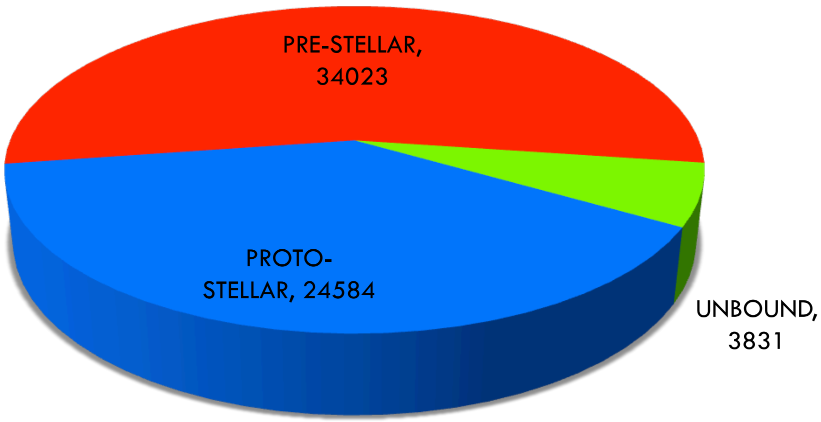


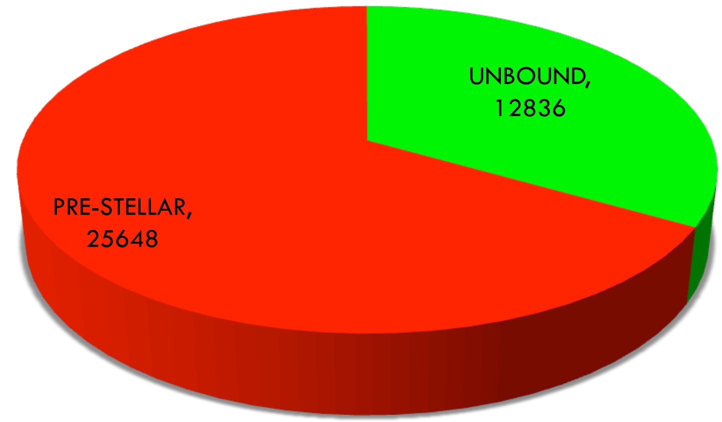
Clump demographics

"High-reliability" catalog

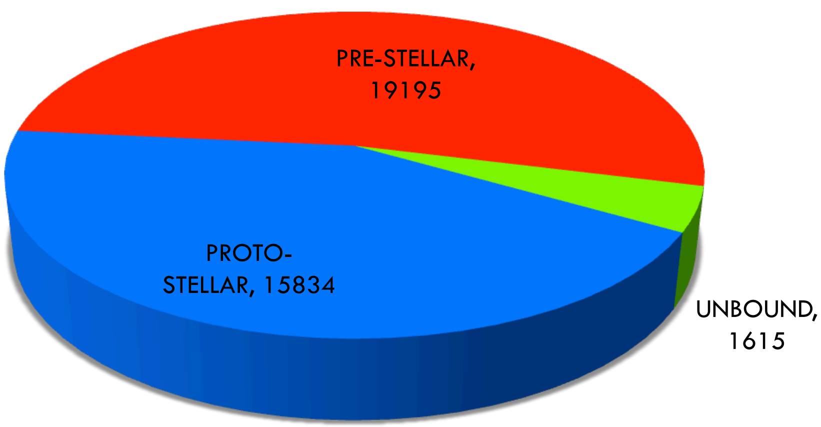
"Low-reliability" catalog

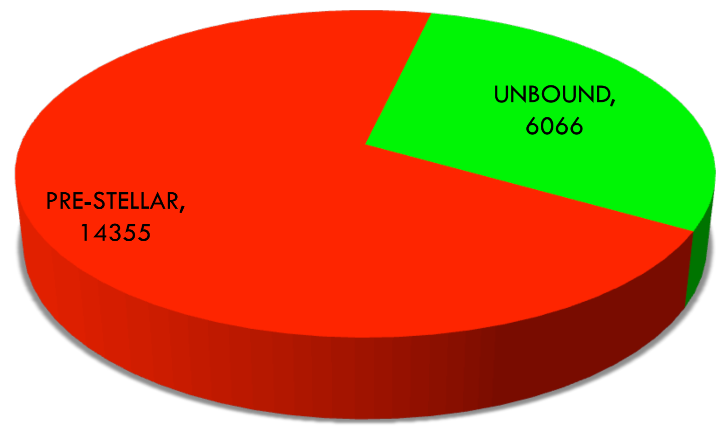
whole catalog



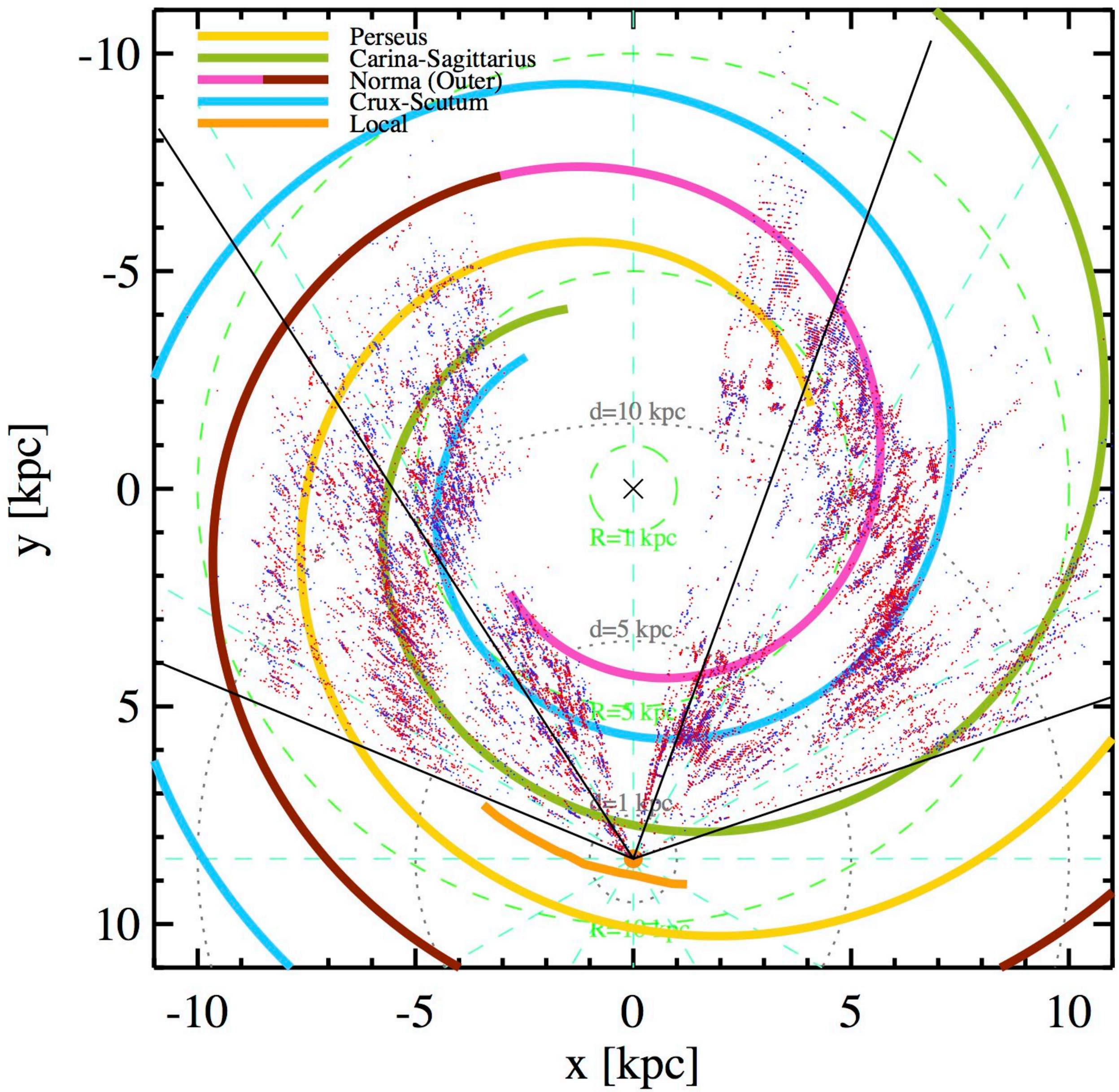


with distance





Source disposition in the inner Galaxy



◆ **Proto-stellar**

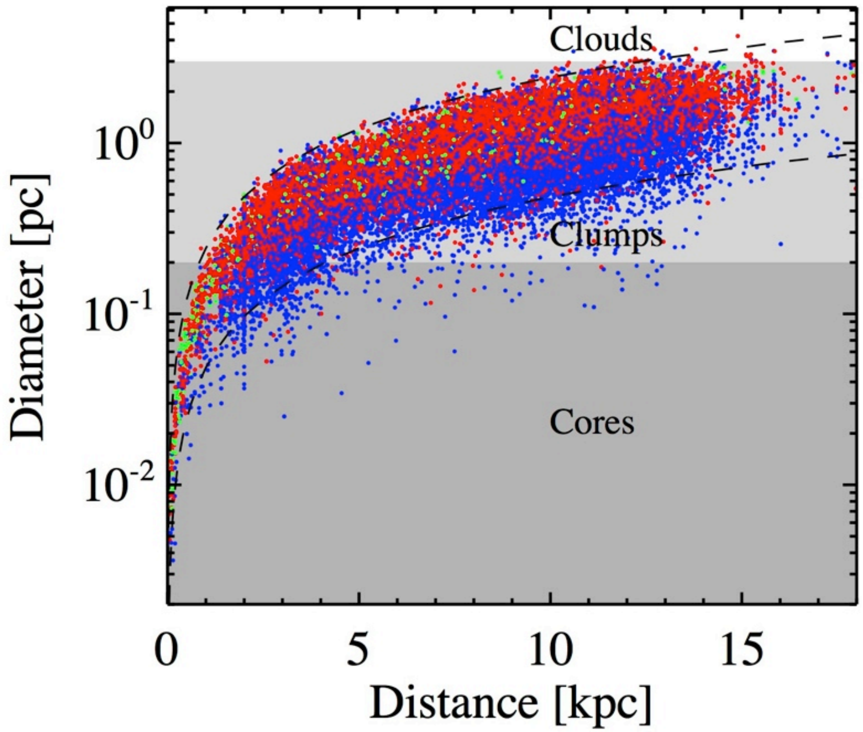
◆ **Pre-stellar**

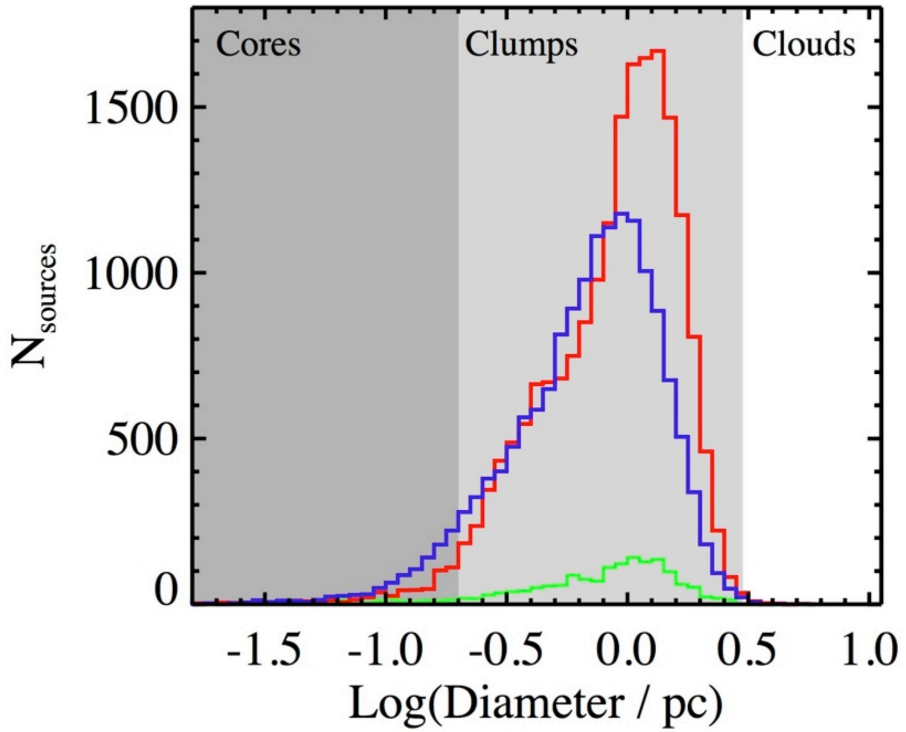
(let's use this color convention throughout this presentation!)

Arm prescription by Hou, Han & Shi (2009)

Ranges corresponding to the tips of the Galactic bar (-30° < *l* < -20°, 19° < *l* < 33°) also studied in Veneziani+2017

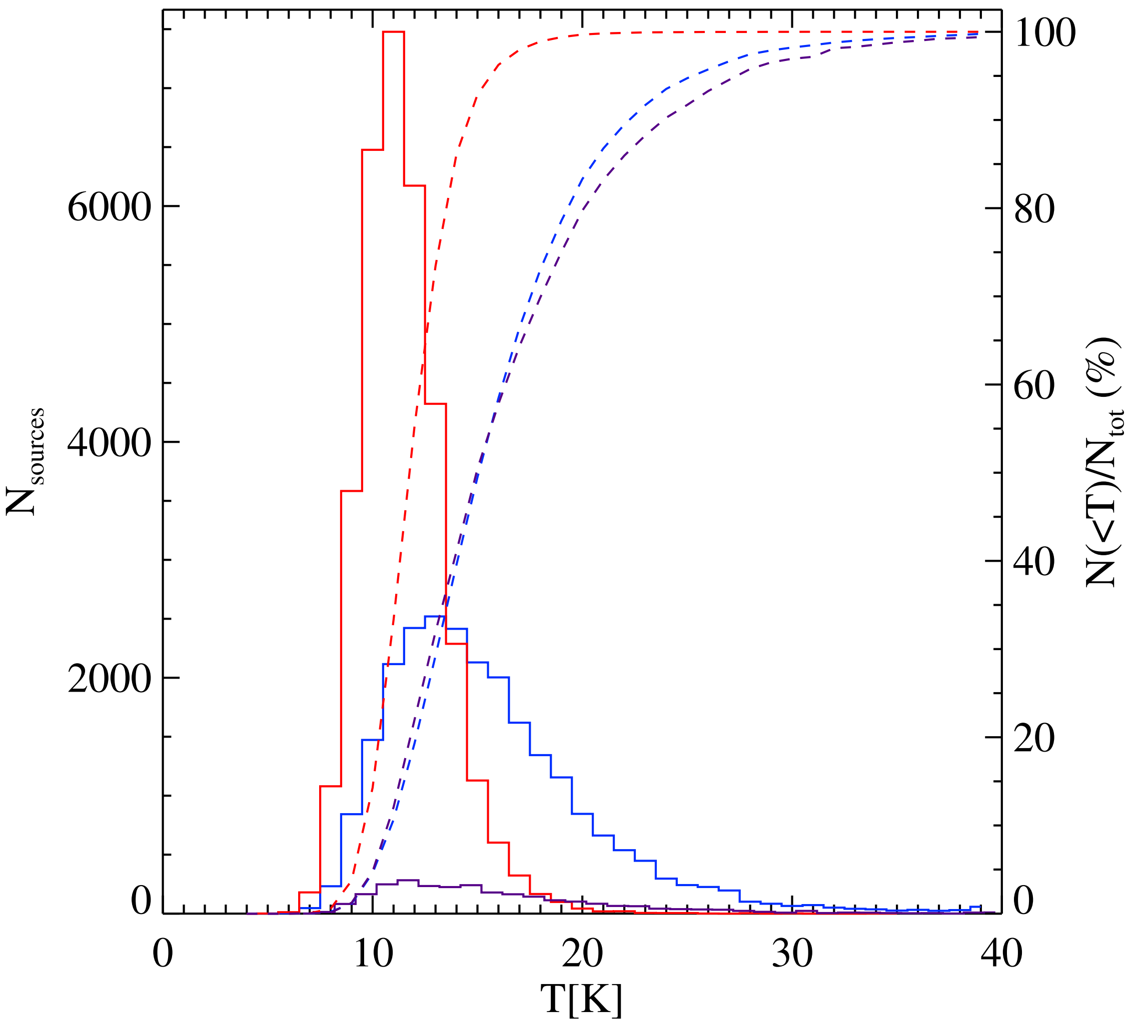
Size distributions





- The angular size is calculated starting from the one estimated by CuTEx at 250 μm.
- Most sources fulfill the definition of "clump" (e.g., Bergin & Tafalla, 2007).
- Given a distance, proto-stellar ones are, on average, more compact than pre-stellar ones.

Temperature distributions



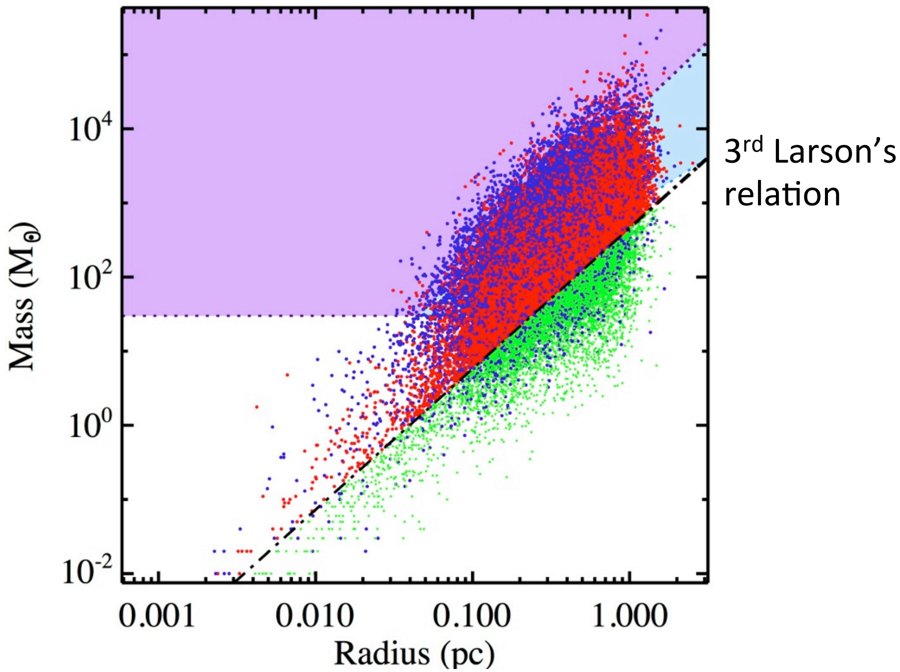
$\langle T_{pre} \rangle$ = 12.0 K

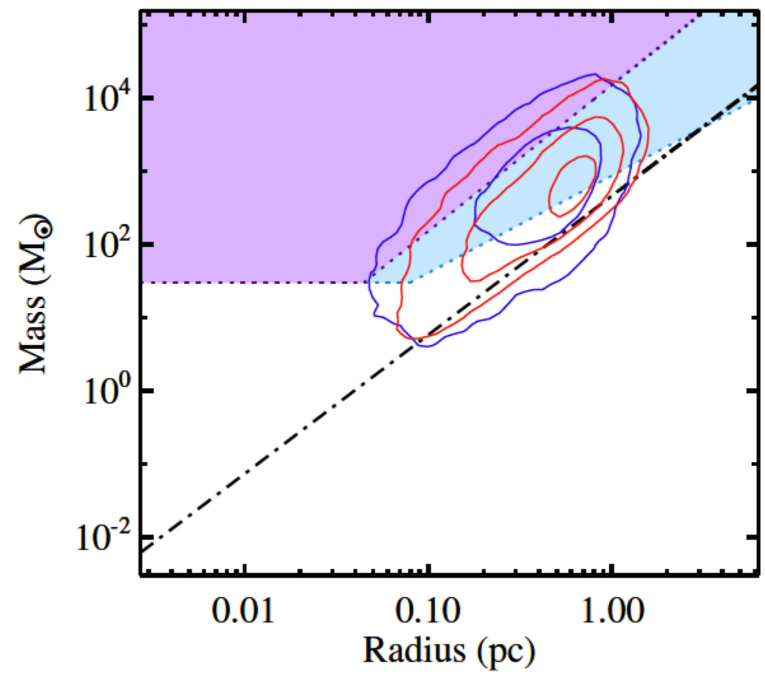
$\langle T_{proto} \rangle$ = 16.0 K

Mass-Radius relation

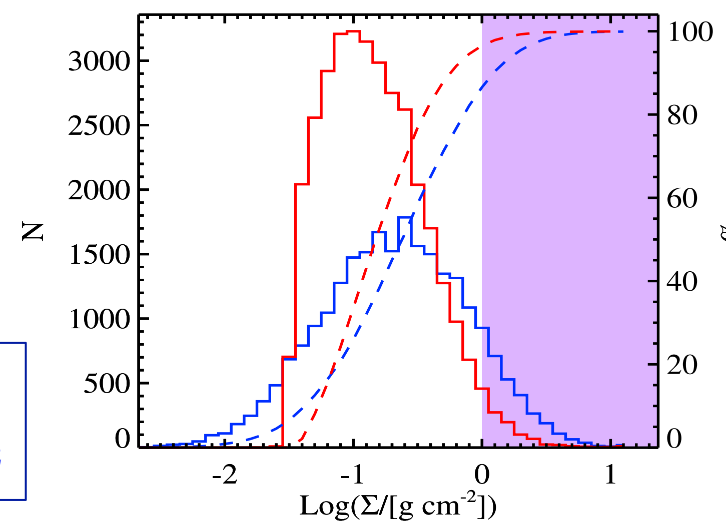
Kauffmann & Pillai (2010)

Krumholz & McKee (2008)





	$\Sigma > \Sigma_{KP}$		$\Sigma > \Sigma_{KM}$	
	counts	%	counts	%
Proto-stellar	11210	71.3	2062	13.1
Pre-stellar	12431	64.8	546	2.8

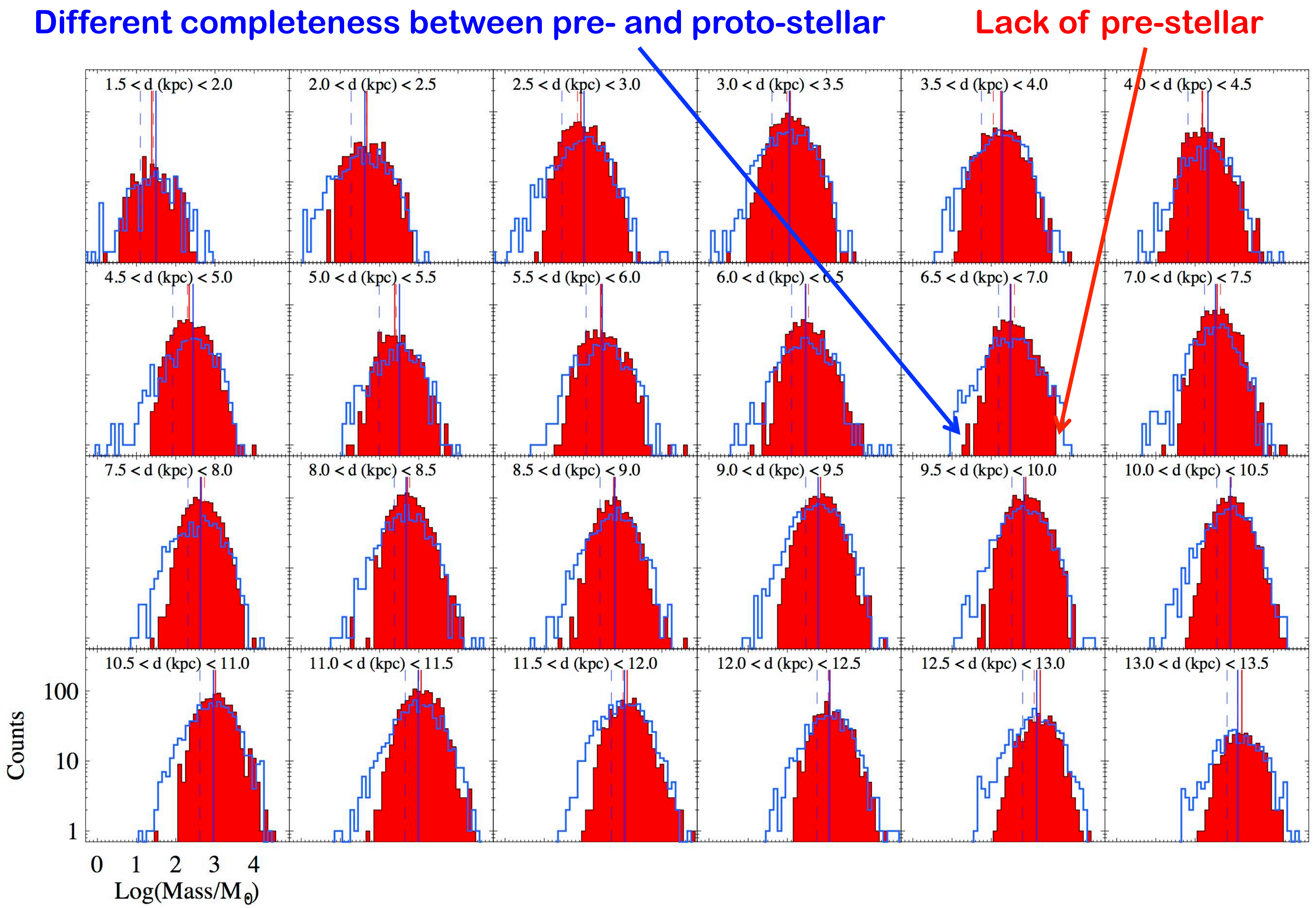


On average, proto-stellar sources are denser than pre-stellar ones.

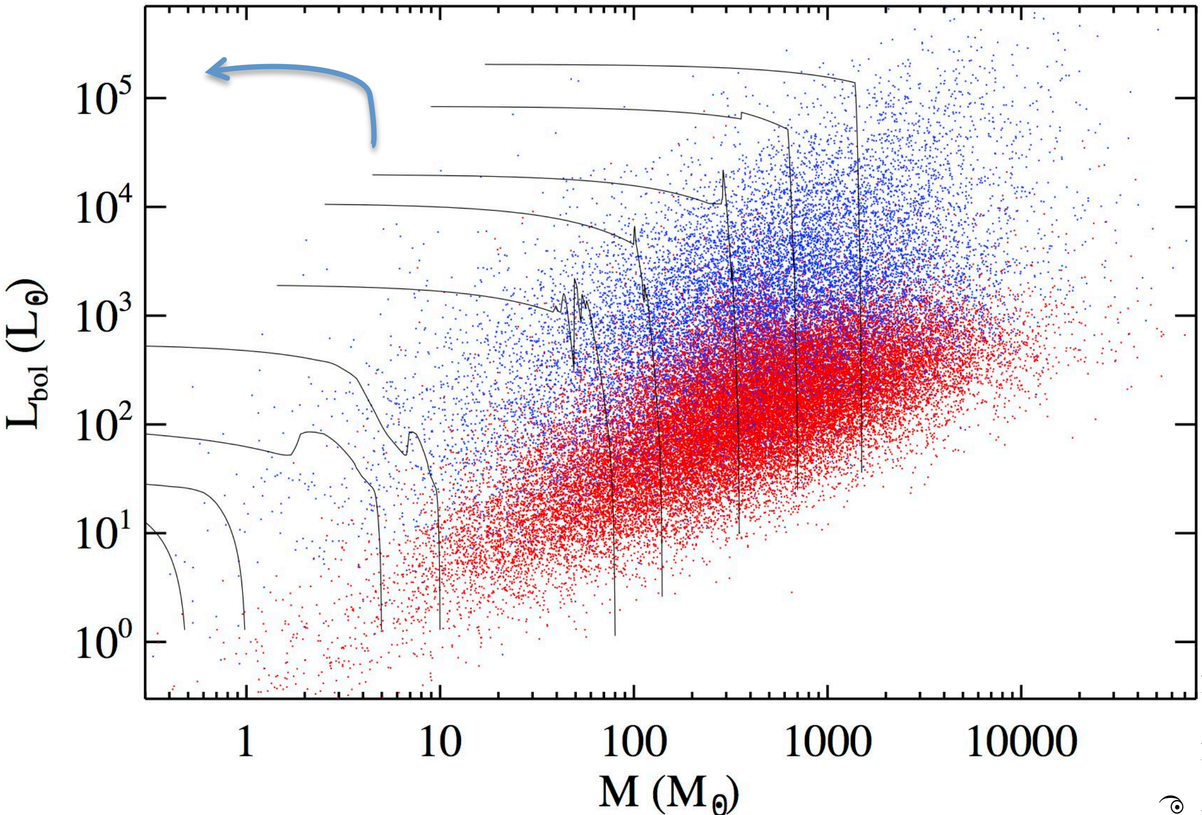
$<\Sigma_{pre}> = 0.26$ g cm^{-2}

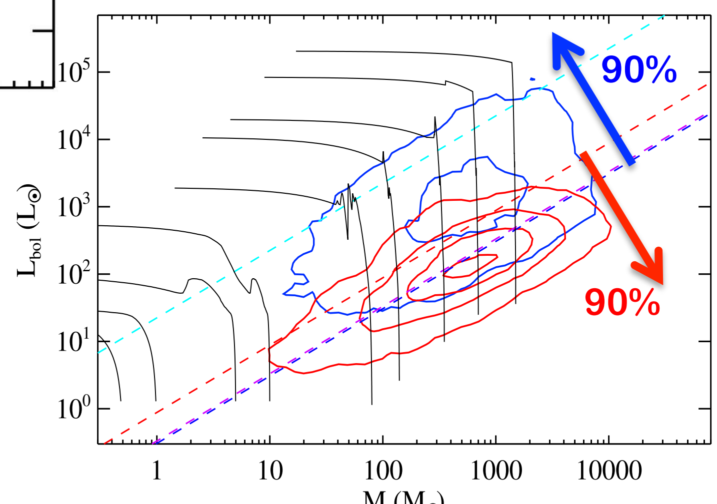
$<\Sigma_{proto}> = 0.51$ g cm^{-2}

Clump Mass Function Slope

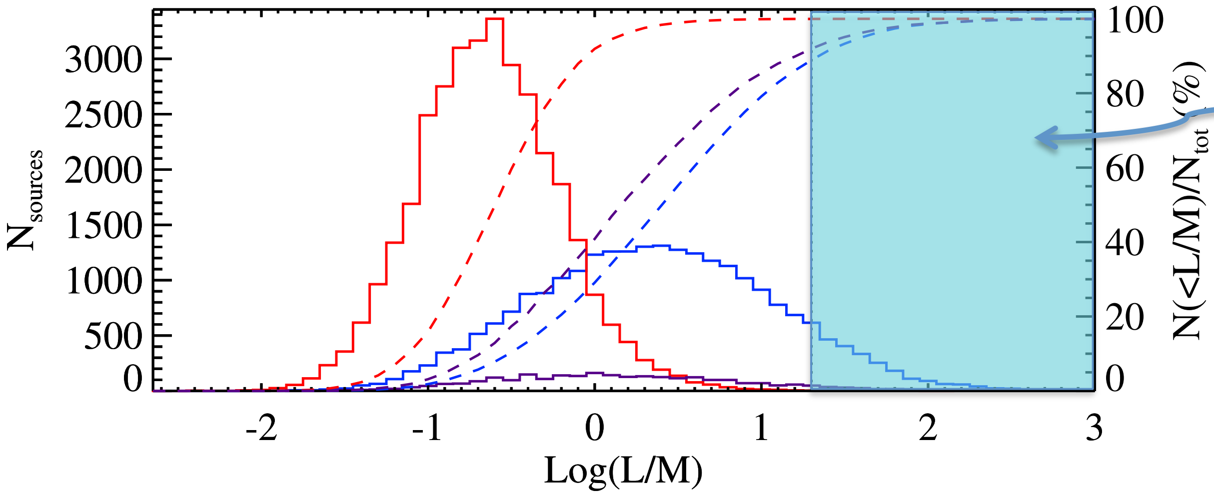


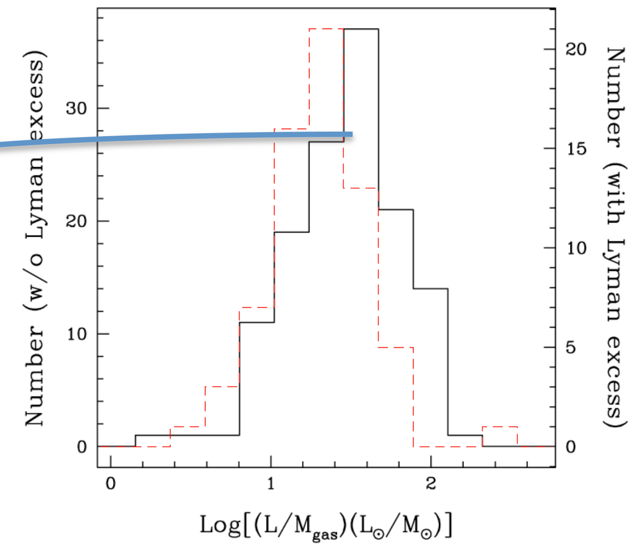
L_{bol} vs M_{env} diagram

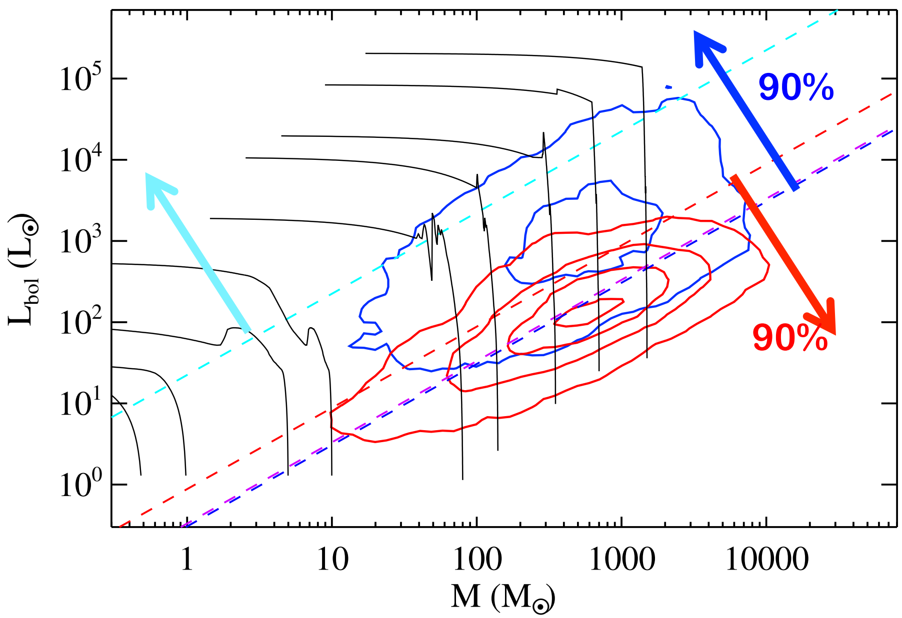




L_{bol}/M_{env} ratio







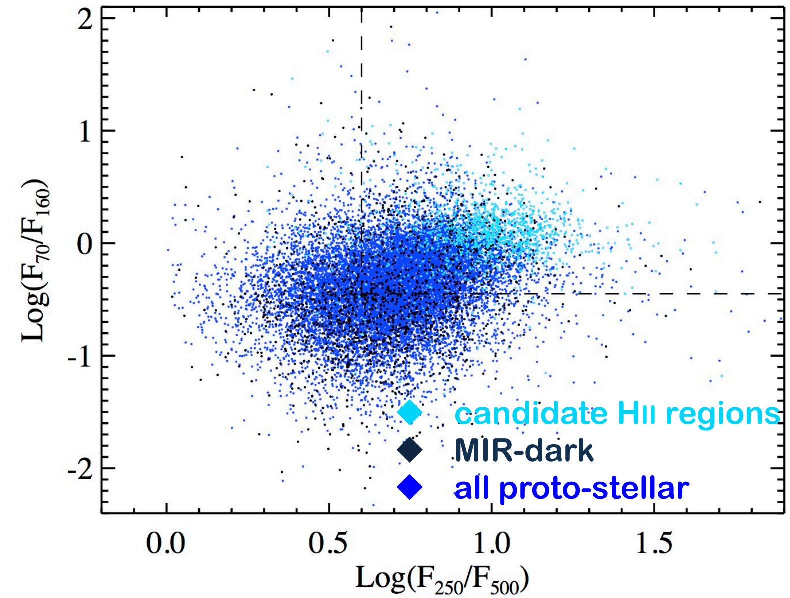
Cesaroni+(2015), Hi-GAL sources detected in CORNISH

> **Reliable HII region candidates can be searched among sources above the *L*/*M* > 22.4 $L_\odot/M_\odot$ threshold.**

Two possible sub-classes of proto-stellar sources

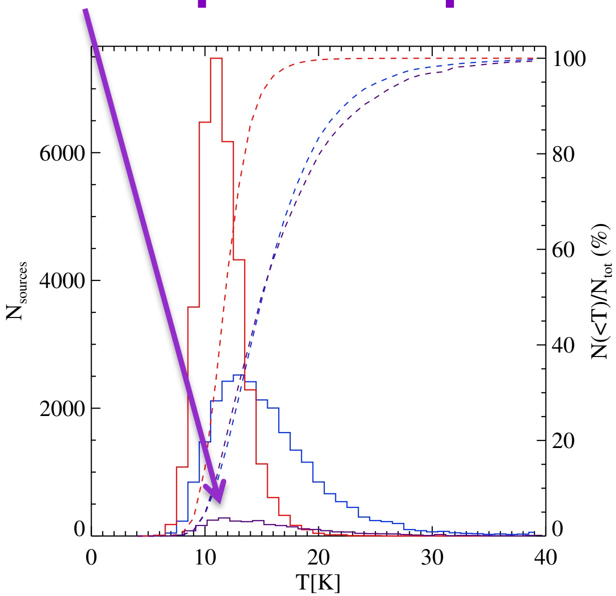
High-*L*/*M* sources

Compatible with typical *L*/*M* of HII regions

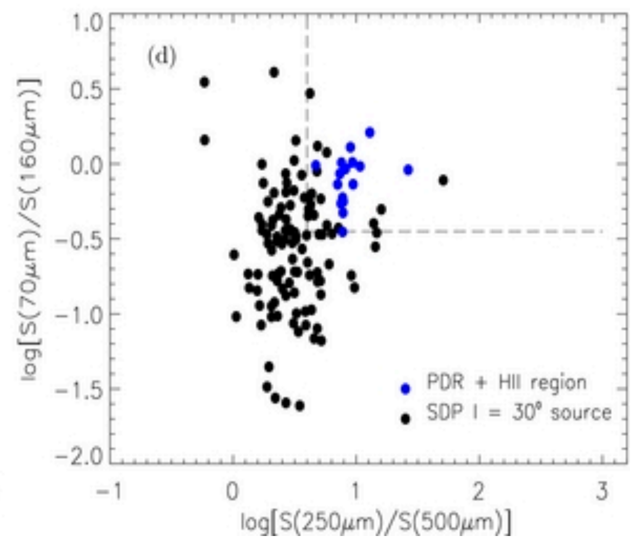


MIR-dark sources

Average temperature in the middle between pre- and proto-stellar



Paladini+2012



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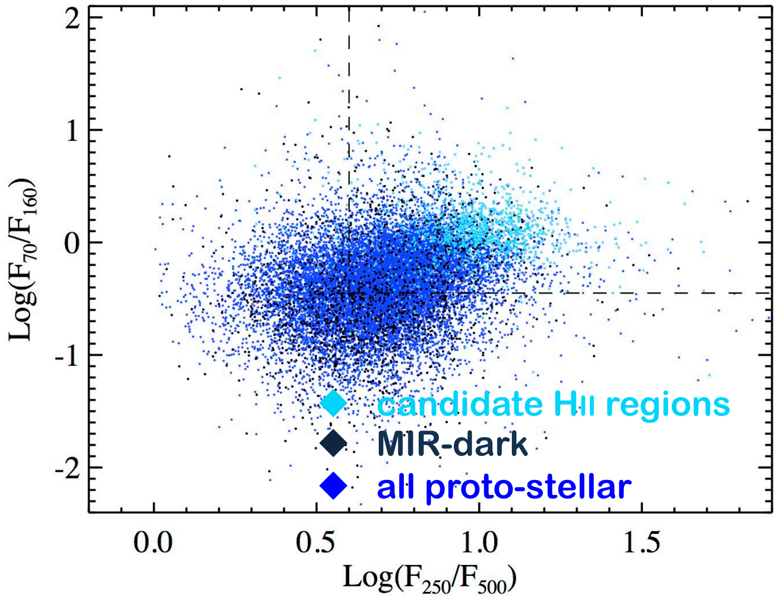
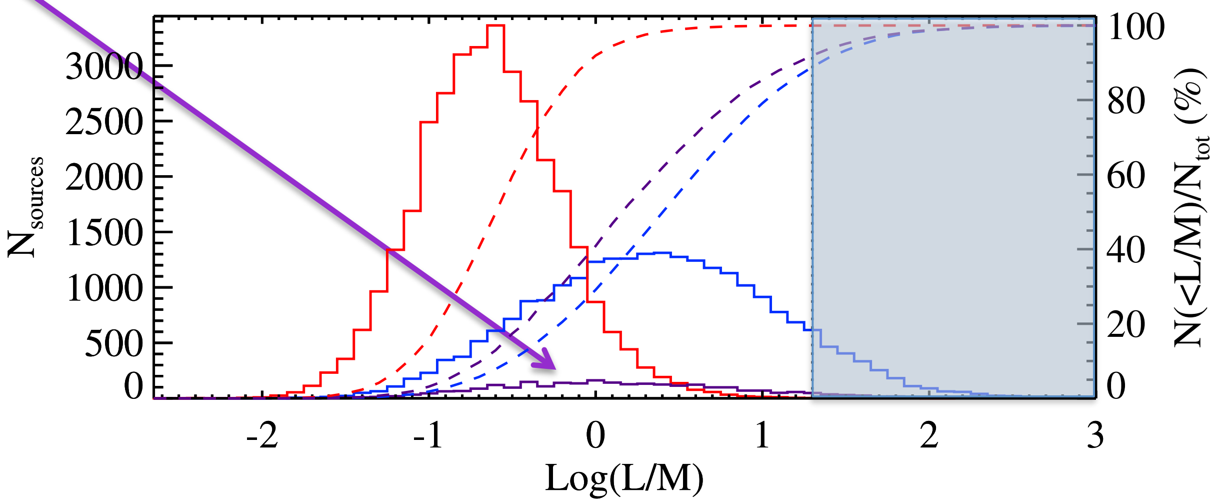


MIR-dark sources

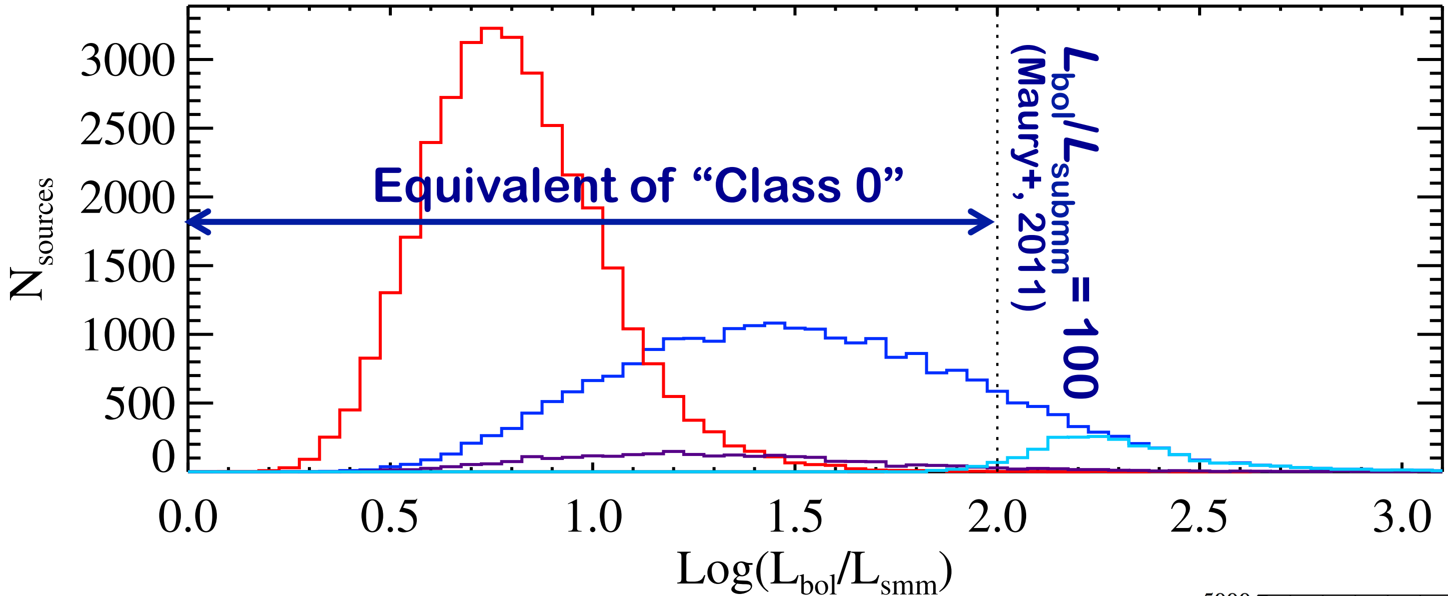
Average temperature in the middle between pre- and proto-stellar…

…but these sources do not constitute the left tail of the L/M distribution, and are highly scattered in the col-col diagram.



L_{bol}/L_{submm} ratio

L_{submm} calculated for λ > 350 μm

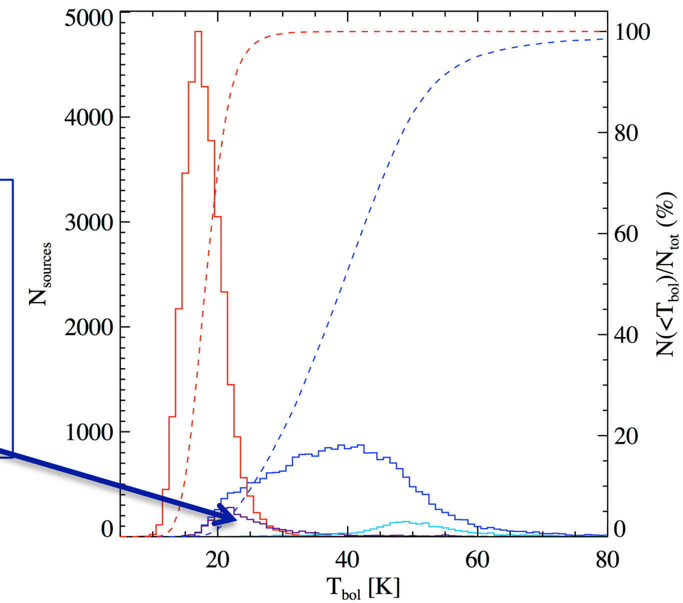


Bolometric Temperature

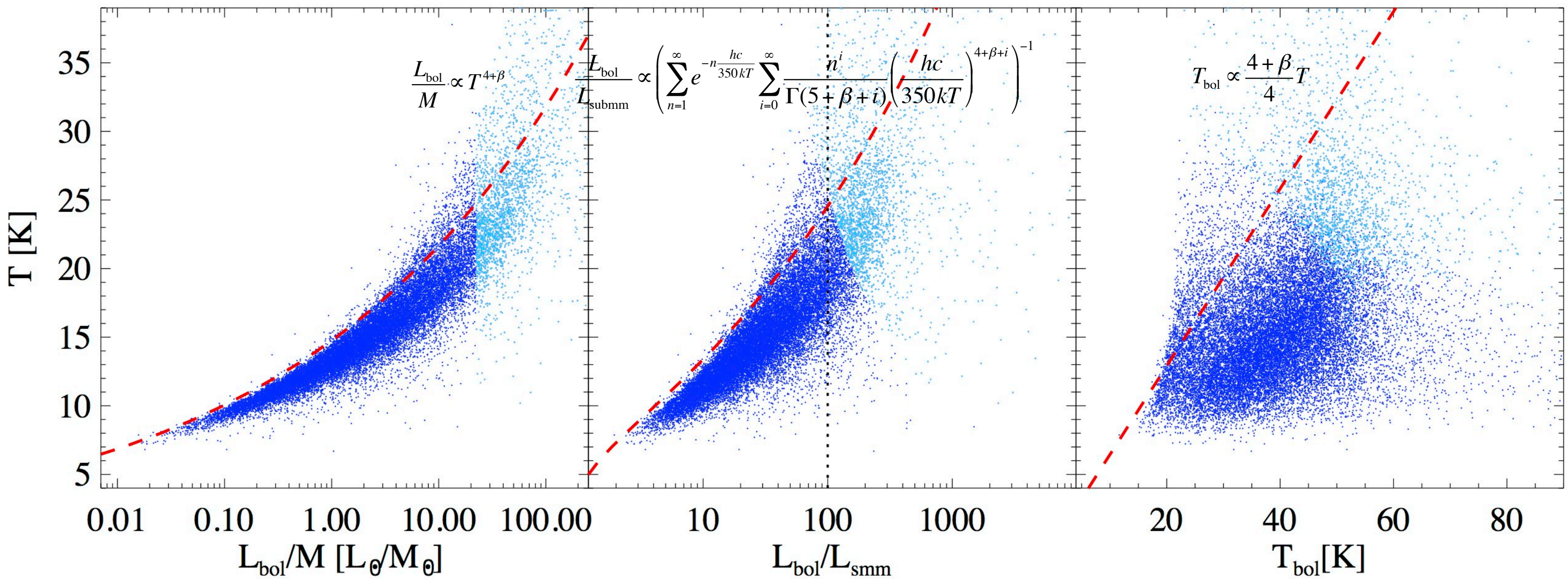
$$T_{bol} = 1.25 \times 10^{-11} \frac{\int_{-\infty}^{\infty} \nu F_{\nu}\, d\nu}{\int_{-\infty}^{\infty} F_{\nu}\, d\nu}$$

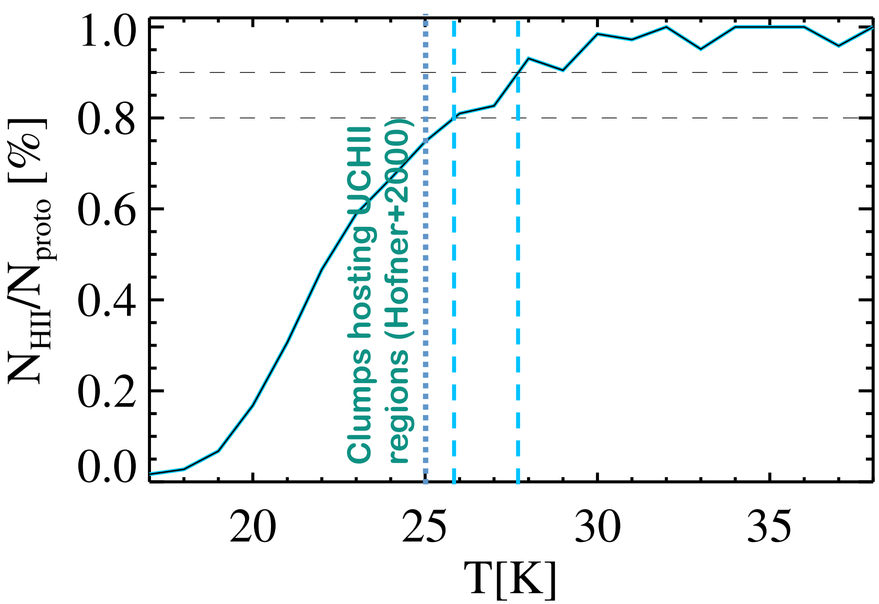
The sub-sample of MIR-dark proto-stellar sources constitutes the left tail of the proto-stellar distribution.

Segregation between pre- and proto-stellar sources appears more evident.



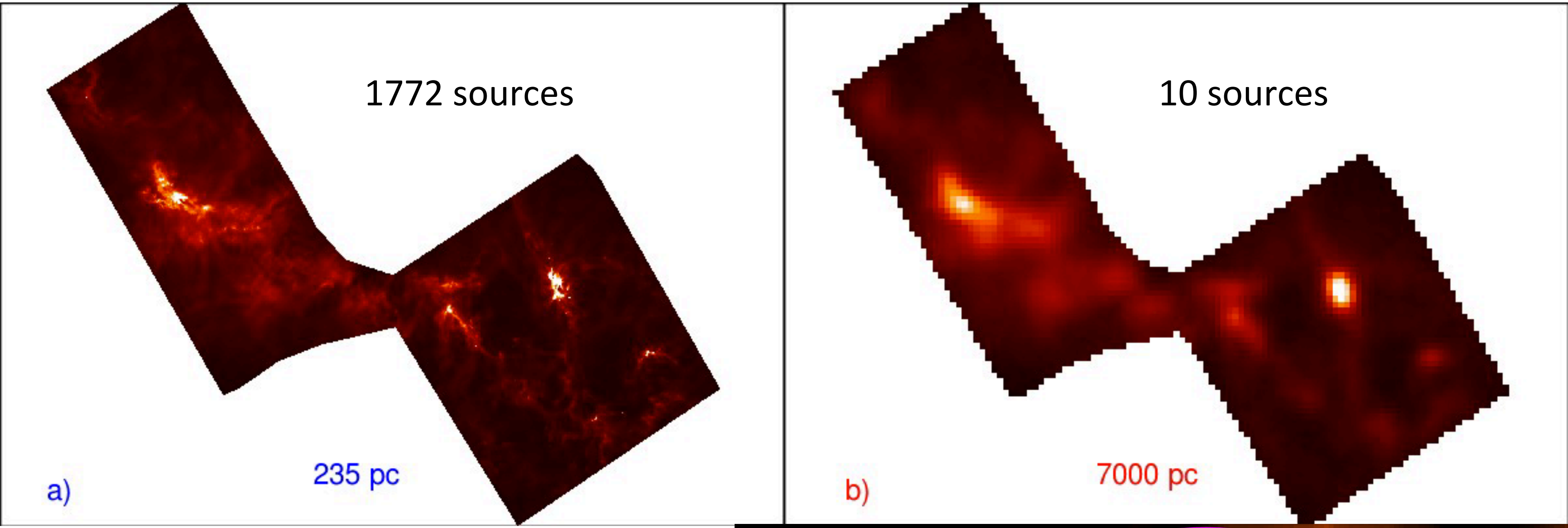
Dust temperature vs evolutionary descriptors

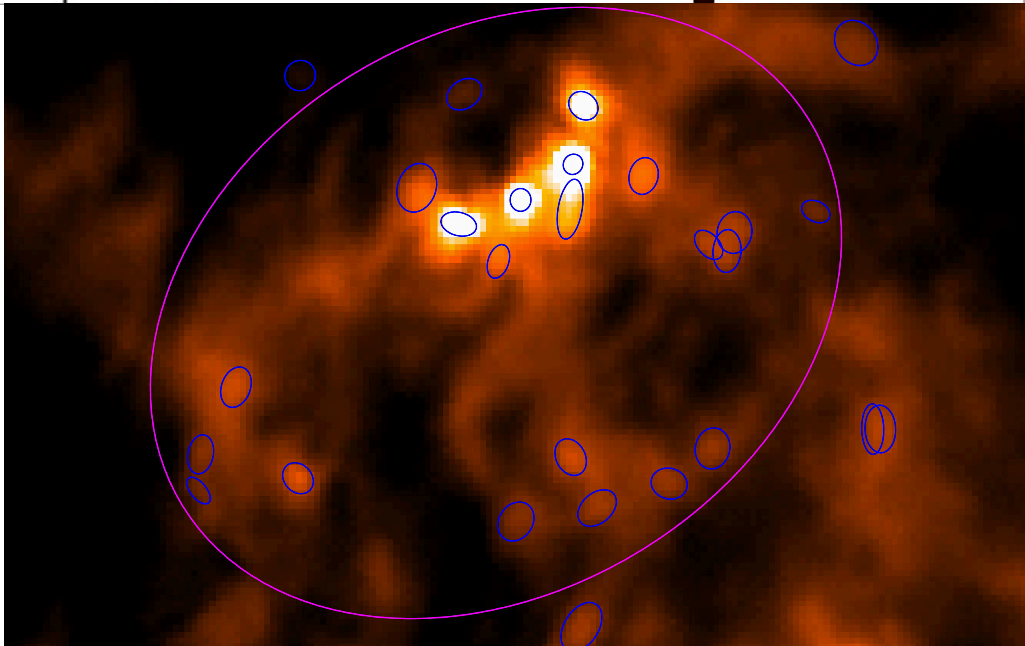




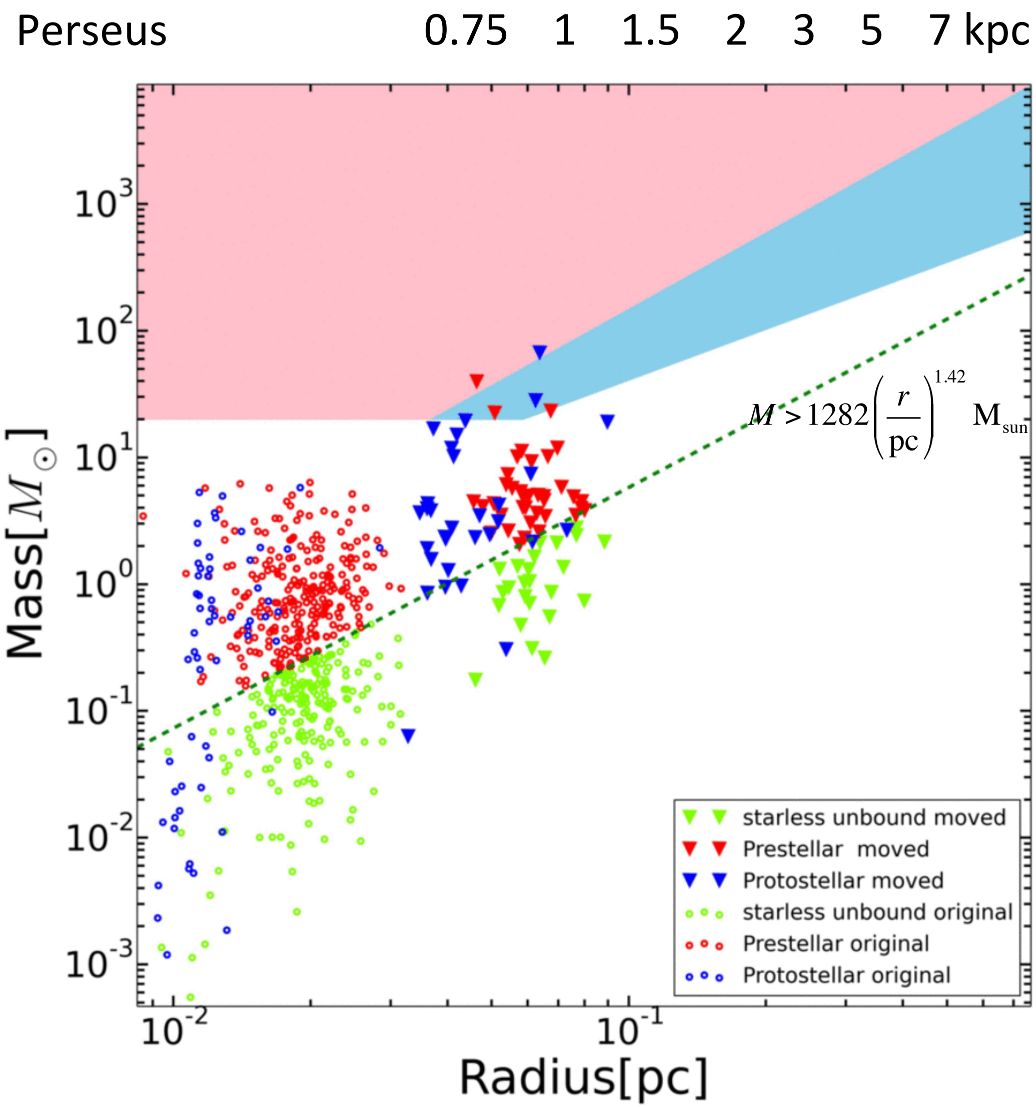
- **Temperature itself is a valid evolutionary indicator.**
- **Pre-stellar sources follow relations expected for the greybody (Elia & Pezzuto 2016), while for the same temperature proto-stellar sources generally appear more evolved.**

“Moving away” SF regions (Baldeschi et al. 2017, I)





Distance bias on *M* - *r* relation



$$M > 1282\left(\frac{r}{\mathrm{pc}}\right)^{1.42} \mathrm{M_{sun}}$$