



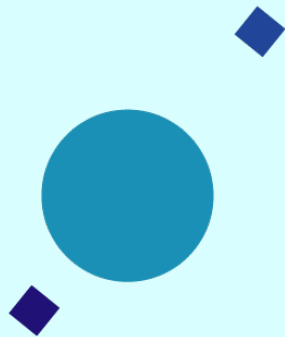
Publication Year	2017
Acceptance in OA	2020-08-26T11:08:05Z
Title	A Panoramic View of Star Formation in Milky Way: Recent Results from Galactic Plane FIR/Sub-mm Surveys
Authors	ELIA, Davide Quintino
Publisher's version (DOI)	10.5281/zenodo.1153787
Handle	http://hdl.handle.net/20.500.12386/26835

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

Davide Elia

ISTITUTO NAZIONALE DI ASTROFISICA
ISTITUTO DI ASTROFISICA E PLANETOLOGIA SPAZIALI DI ROMA

INAF



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

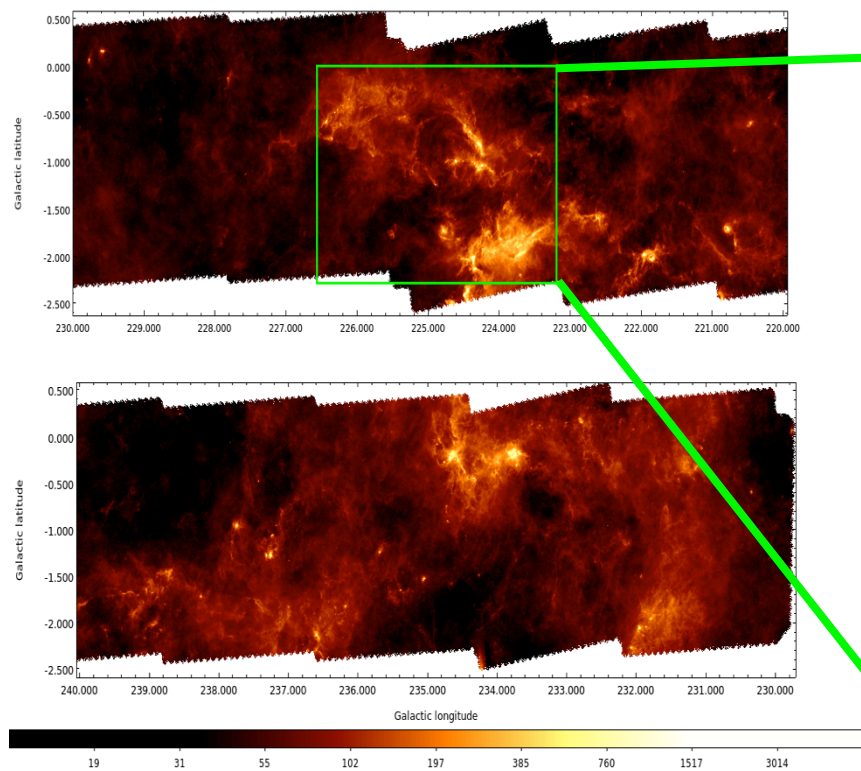
Table 1: List of most representative surveys covering the Galactic Plane

Surveys facilities	λ or lines	Surveys notes
Ground-based		
Columbia/CfA DRAO/ATCA/VLA	CO, ^{13}CO HI-21 cm OH/H α -RRL/1-2GHz cont. 5GHz cont.	9 - 25' resolution (<i>Dame et al.</i> , 2001) IGPS: unbiased HI-21cm $255^\circ \leq l \leq 357^\circ$ and $18^\circ \leq l \leq 147^\circ$ (<i>McClure-Griffiths et al.</i> , 2001; <i>Gibson et al.</i> , 2000; <i>Stil et al.</i> , 2006) + THOR: unbiased HI-21cm/OH/H α -RRLs/1-2GHz cont. $15^\circ \leq l \leq 67^\circ$ (Beuther et al. in prep.)+ COR-NISH: 5GHz continuum $10^\circ \leq l \leq 65^\circ$ (<i>Hoare et al.</i> , 2012)
FCRAO 14 m	CO, ^{13}CO	55'' resolution. Galactic Ring Survey (<i>Jackson et al.</i> , 2006)
Mopra 22 m	CO, ^{13}CO , N $_2\text{H}^+$, (NH $_3$ + H $_2\text{O}$) maser, HCO $^+$ /H $^{13}\text{CO}^+$ + others	+ Outer Galaxy Survey (<i>Heyer et al.</i> , 1998) HOPS: (<i>Walsh et al.</i> , 2011; <i>Purcell et al.</i> , 2012), MALT90: ~ 2000 clumps $20^\circ \geq l \geq -60^\circ$ (<i>Foster et al.</i> , 2013), Southern GPS CO: unbiased $305^\circ \leq l \leq 345^\circ$ (<i>Burton et al.</i> , 2013), ThrUMMS: unbiased $300^\circ \leq l \leq 358^\circ$ (<i>Barnes et al.</i> , 2013), CMZ: (<i>Jones et al.</i> , 2012, 2013)
Parkes NANTEN/ NAN-TEN2 CSO 10 m	CH $_3\text{OH}$ maser CO, ^{13}CO , C ^{18}O 1.3 mm continuum	Methanol MultiBeam Survey (<i>Green et al.</i> , 2009) NGPS: unbiased, $200^\circ \leq l \leq 60^\circ$ (<i>Mizuno and Fukui</i> , 2004) + NASCO: unbiased in progress, $160^\circ \leq l \leq 80^\circ$
APEX 12 m	870 μm continuum	Bolocam Galactic Plane Survey (BGPS), 33'' (<i>Aguirre et al.</i> , 2011) ATLASGAL, $60^\circ \geq l \geq -80^\circ$ (<i>Schuller et al.</i> , 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 (<i>Price et al.</i> , 2001)
WISE	3.4, 4.6, 11, 22 μm continuum	All-sky (<i>Wright et al.</i> , 2010)
Akari	65, 90, 140, 160 μm continuum	All-sky (<i>Ishihara et al.</i> , 2010)
Spitzer	3.6, 4.5, 6, 8, 24 μm continuum	GLIMPSE+GLIMPSE360: Full Galactic Plane (<i>Benjamin et al.</i> , 2003), (<i>Benjamin and GLIMPSE360 Team</i> , 2013) + MIPS GAL, $63^\circ \geq l \geq -62^\circ$ (<i>Carey et al.</i> , 2009)
Planck	350, 550, 850, 1382, 2098, 3000, 4285, 6820, 10 4 μm cont.	All-sky, resolution $\geq 5'$ (<i>Planck Collaboration et al.</i> , 2013a)
Herschel	70, 160, 250, 350, 500 μm cont.	Hi-GAL: Full Galactic Plane (<i>Molinari et al.</i> , 2010a)

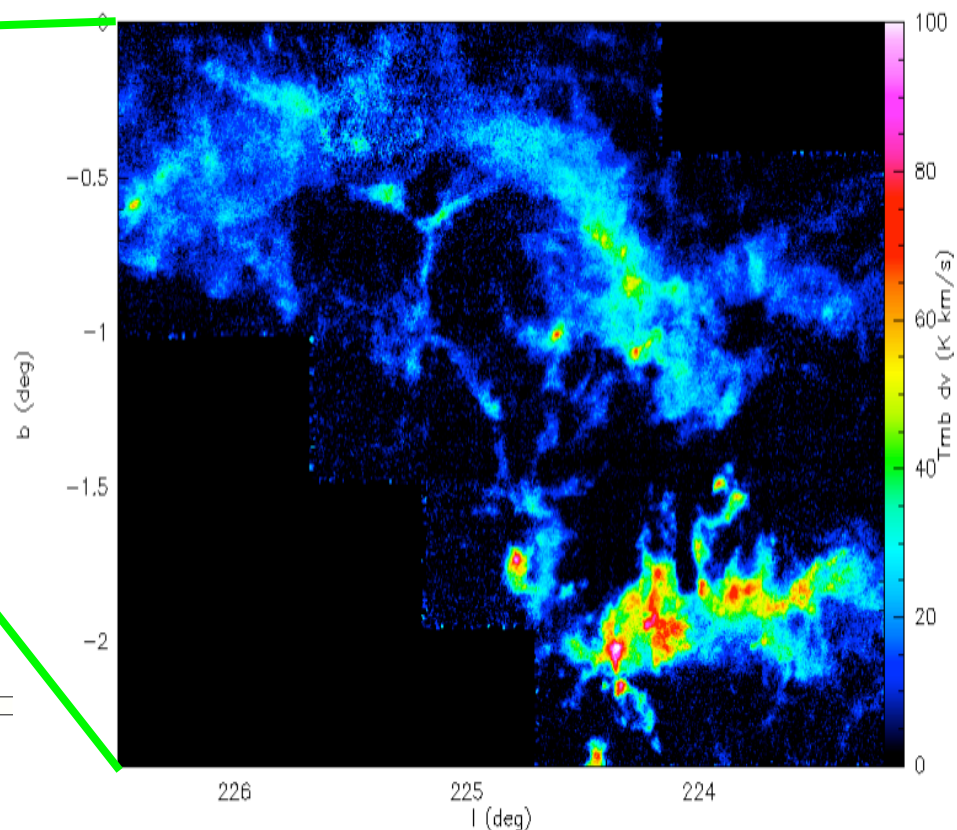
The Forgotten Quadrant Survey

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

A ^{12}CO and ^{13}CO (1-0) survey of a strip ($220^\circ < l < 240^\circ$ and $0^\circ < b < -2^\circ$) 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.



Hi-GAL

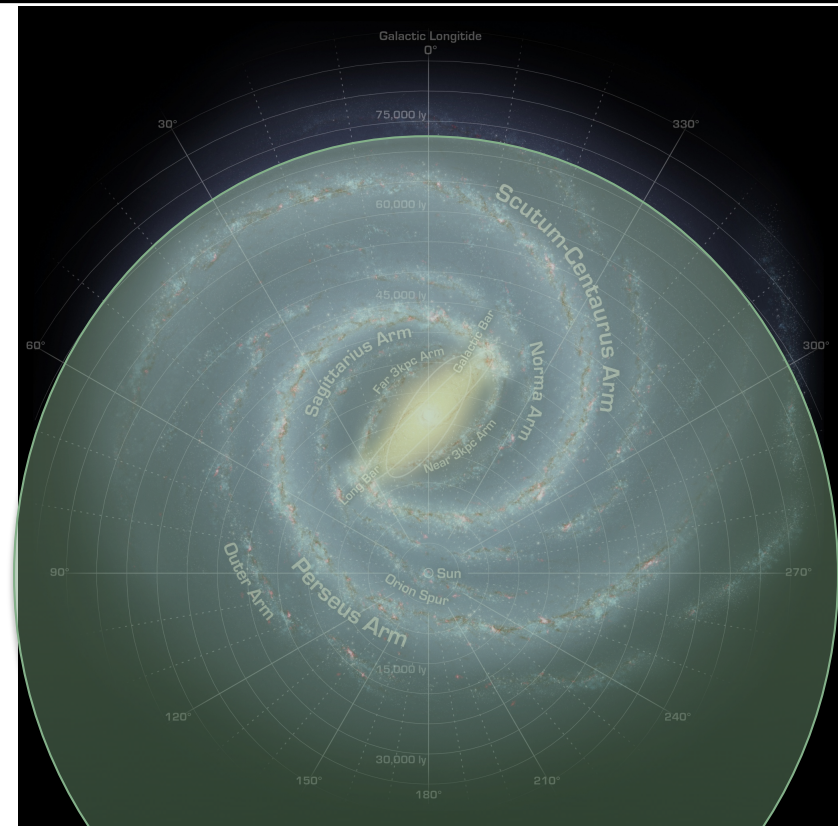
The Herschel infrared Galactic Plane Survey

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
(70-160-250-350-500 μm) continuum
mapping of 720 sq. deg. of the Galactic
Plane ($|b| \leq 1^\circ$)

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

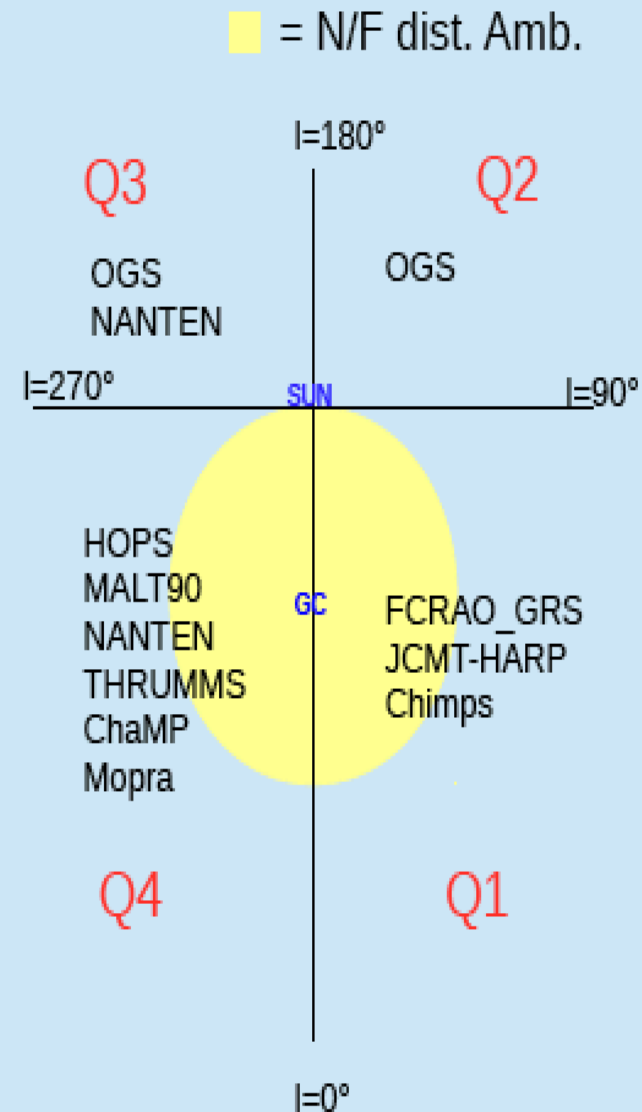


The VIALACTEA knowlegde database :

- 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”

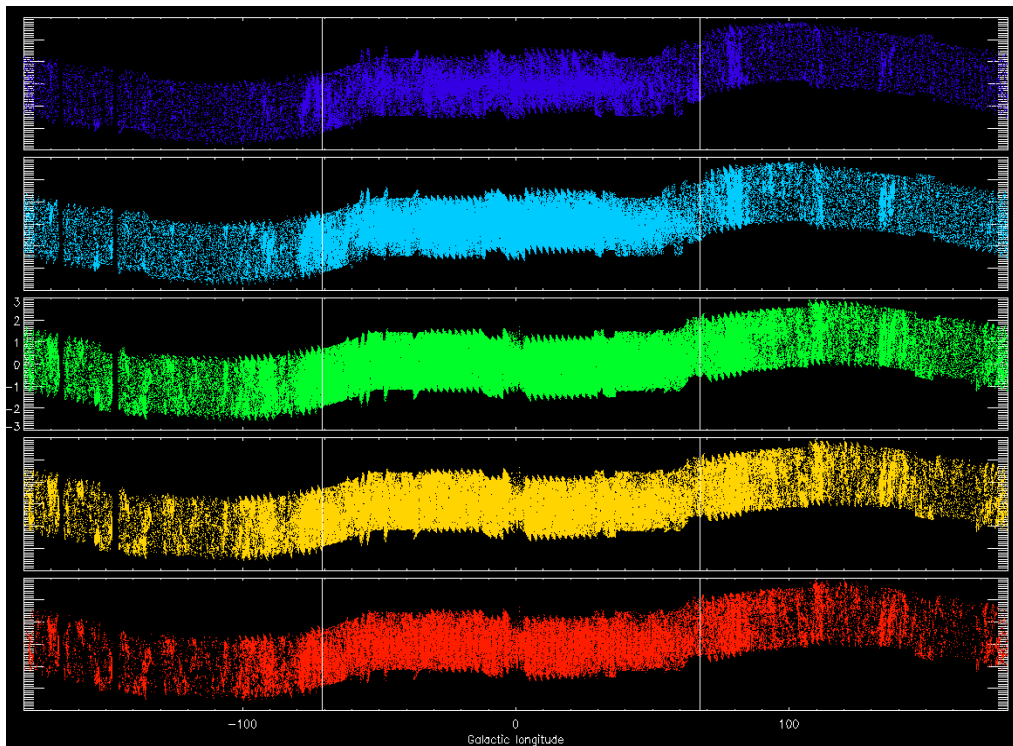
The underlying idea behind this catalog is to extract physical information from the SEDs of the sources, collected from 21 to 1100 μm .

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).

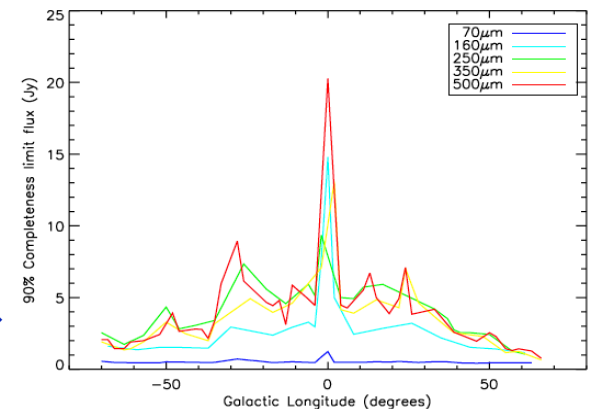


Molinari+2016, Merello+2017

Completeness estimation →

Source statistics

	$-71^\circ < l < 68^\circ$	$0^\circ < l < 360^\circ$
70 μm	122971	141994
160 μm	292051	322827
250 μm	280258	355924
350 μm	161855	215134
500 μm	85880	110991



HI-GAL 5-BAND CATALOG ($\sim 9.4 \times 10^5$ ENTRIES)

SED SELECTION



**HI-GAL 5-BAND FILTERED CATALOG ($\sim 1.5 \times 10^5$ ENTRIES)
+
ANCILLARY PHOTOMETRY (MIR, SUB-MM), KINEMATIC DISTANCES**

GREY-BODY FIT



PHYSICAL PROPERTY CATALOG ($\sim 1.5 \times 10^5$ ENTRIES)



**INNER GALAXY
($\sim 10^5$ ENTRIES)**



**OUTER GALAXY
($\sim 5 \times 10^4$ ENTRIES)**

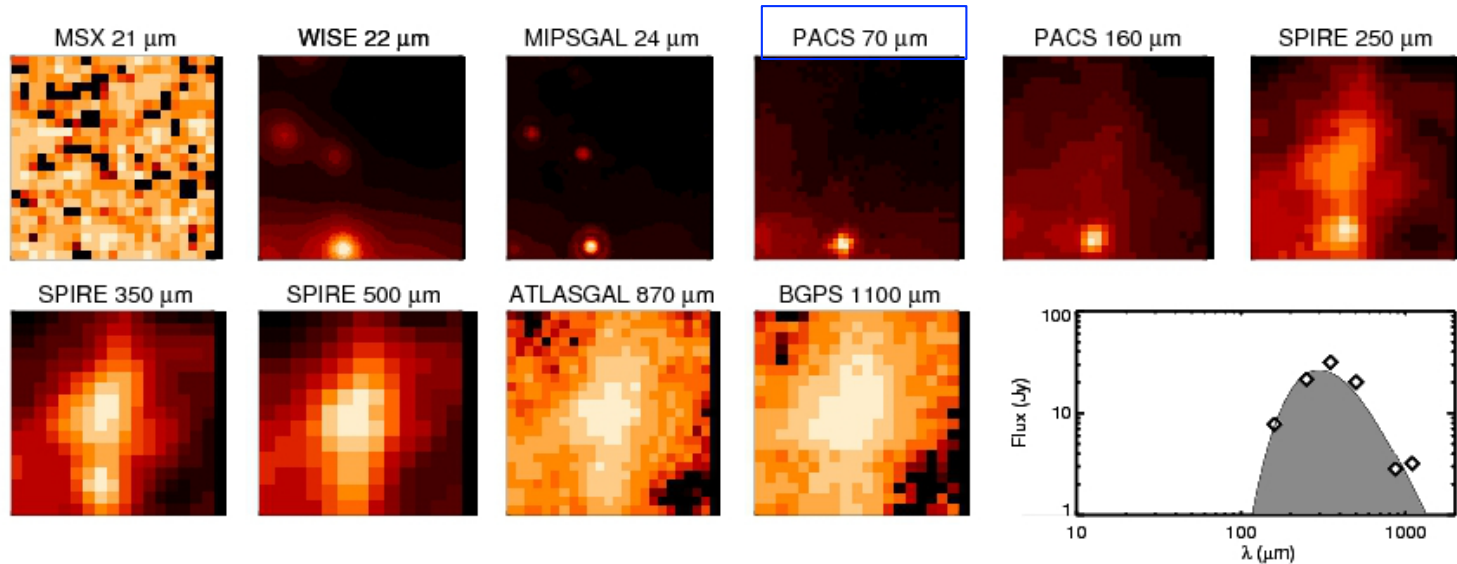
**Elia+ 2017,
MNRAS**

**Merello+ 2017,
in prep.**

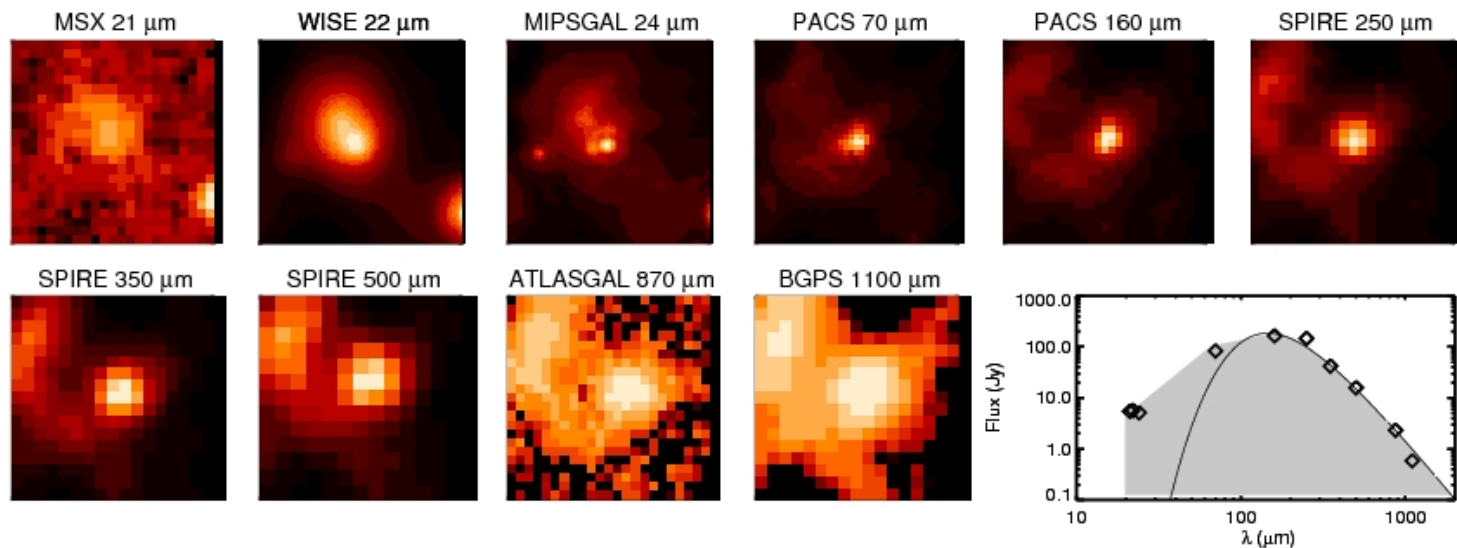
**SEDs ARE FURTHER SPLIT IN A “LOW-”
AND A “HIGH-RELIABILITY” LIST**

Starless sources vs Proto-stellar

Source #109439 (pre-stellar), $l=24.53^\circ$ $b=0.35^\circ$, distance=6295 pc $M=4459.4 M_\odot$ $T=10.1$ K $L=374.4 L_\odot$



Source #110522 (proto-stellar), $l=24.73^\circ$ $b=0.15^\circ$, distance=9170 pc $M=1317.1 M_\odot$ $T=23.9$ K $L=21225.8 L_\odot$

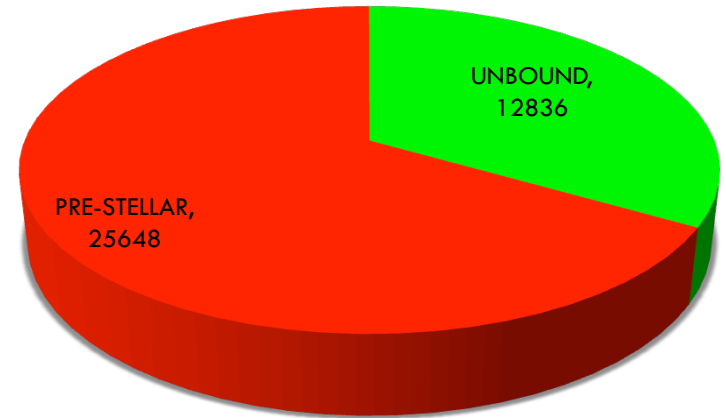
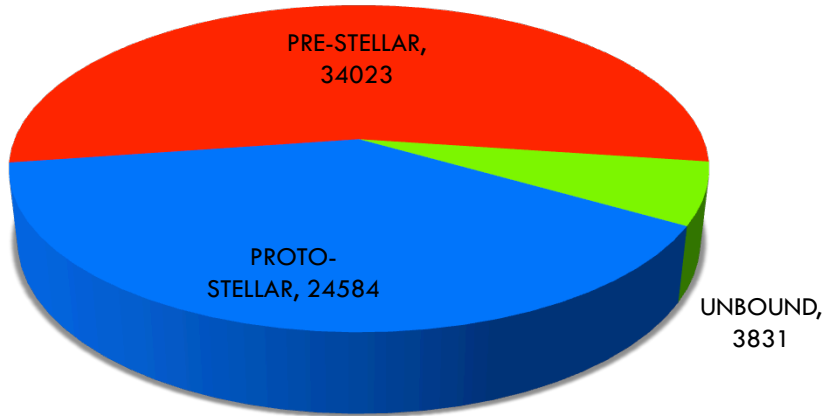


Clump demographics

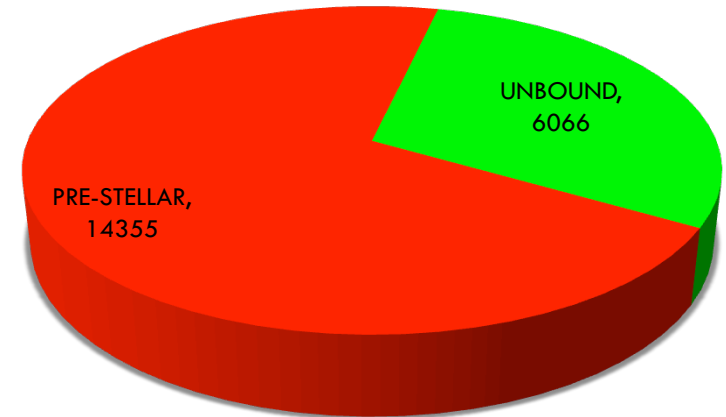
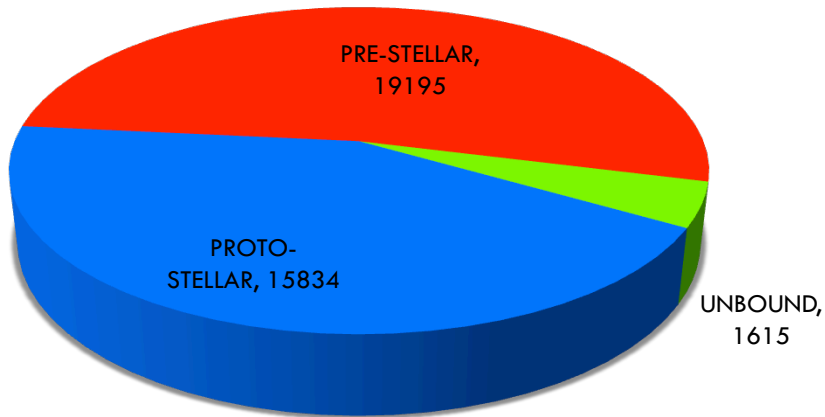
“High-reliability” catalog

“Low-reliability” catalog

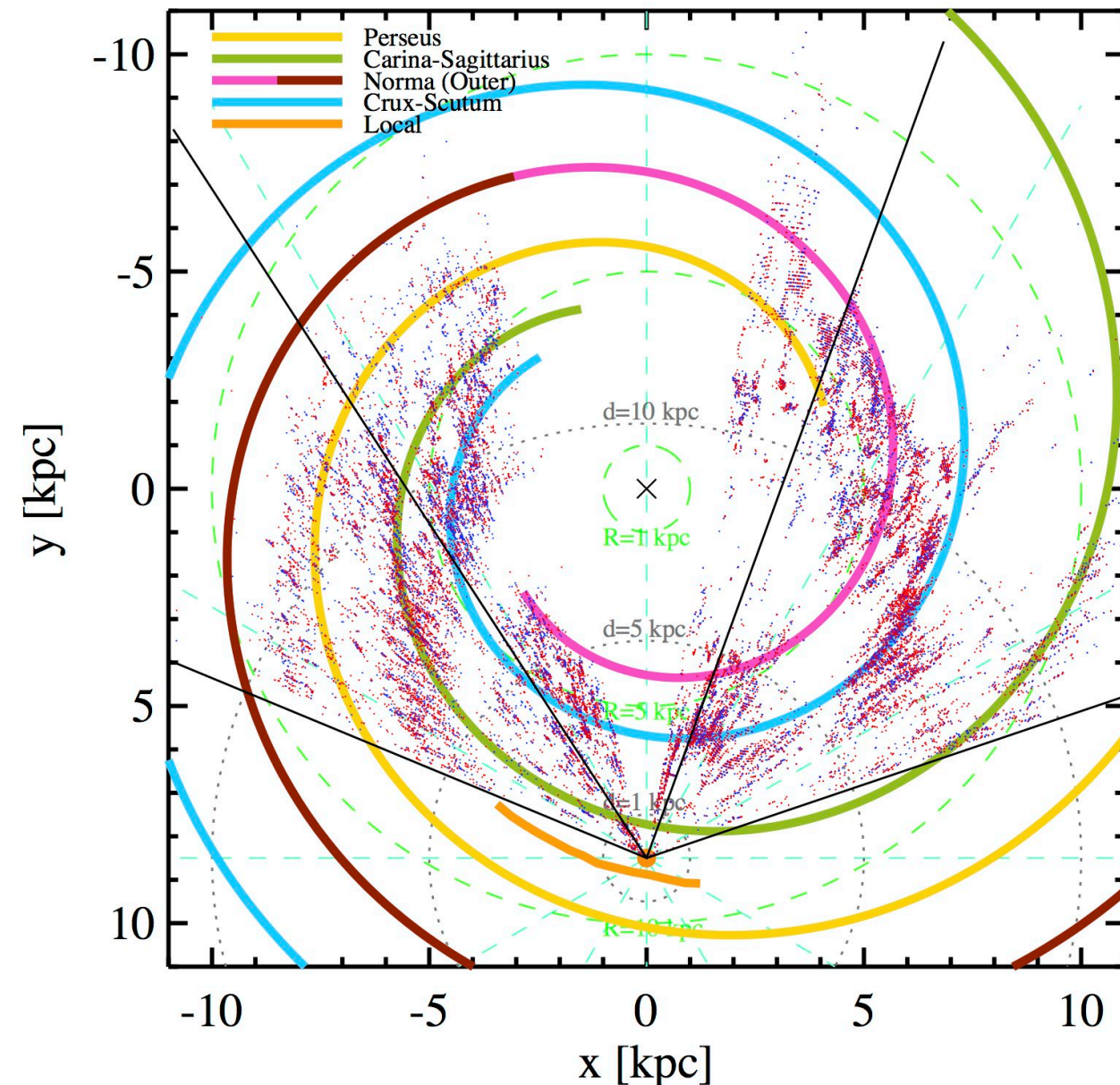
whole
catalog



with
distance



Source disposition in the inner Galaxy



◆ Proto-stellar

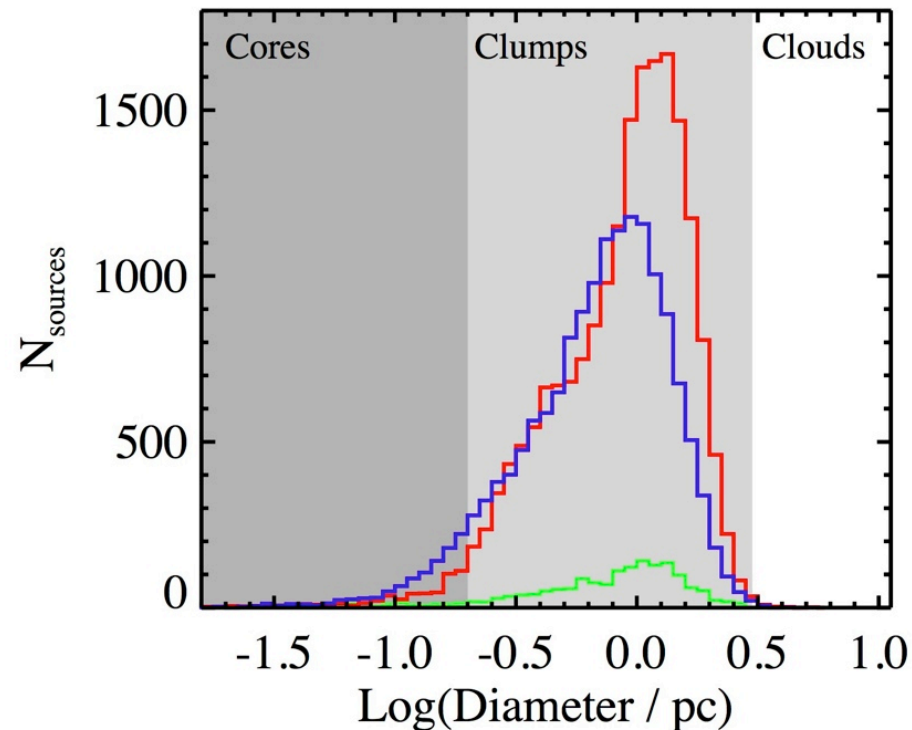
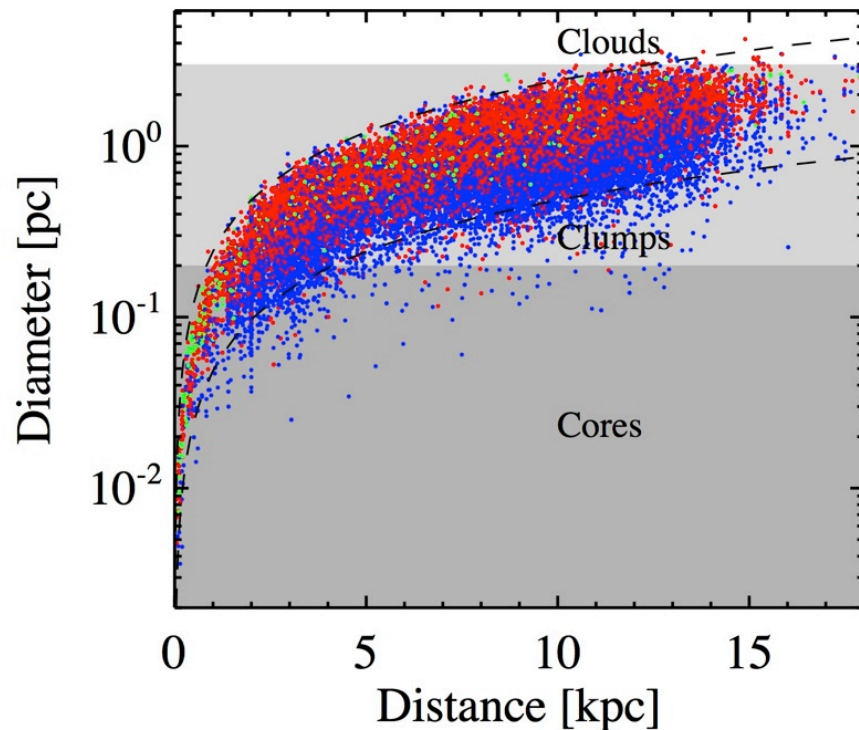
◆ Pre-stellar

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

**Arm prescription
by Hou, Han & Shi (2009)**

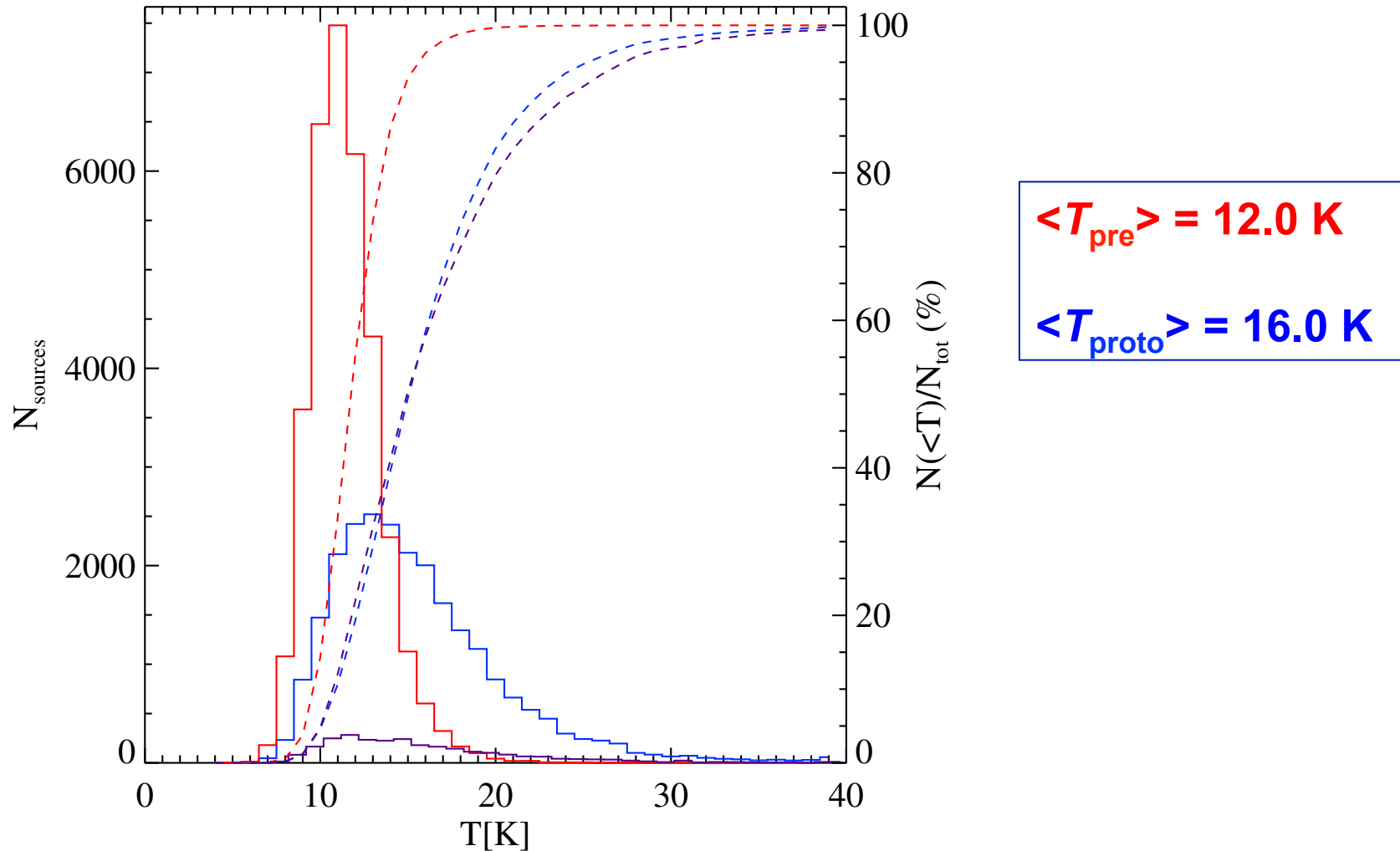
**Ranges corresponding to
the tips of the Galactic
bar ($-30^\circ < l < -20^\circ$,
 $19^\circ < l < 33^\circ$) also studied
in Veneziani+2017**

Size distributions



- The angular size is calculated starting from the one estimated by CuTex at $250 \mu\text{m}$.
- 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.

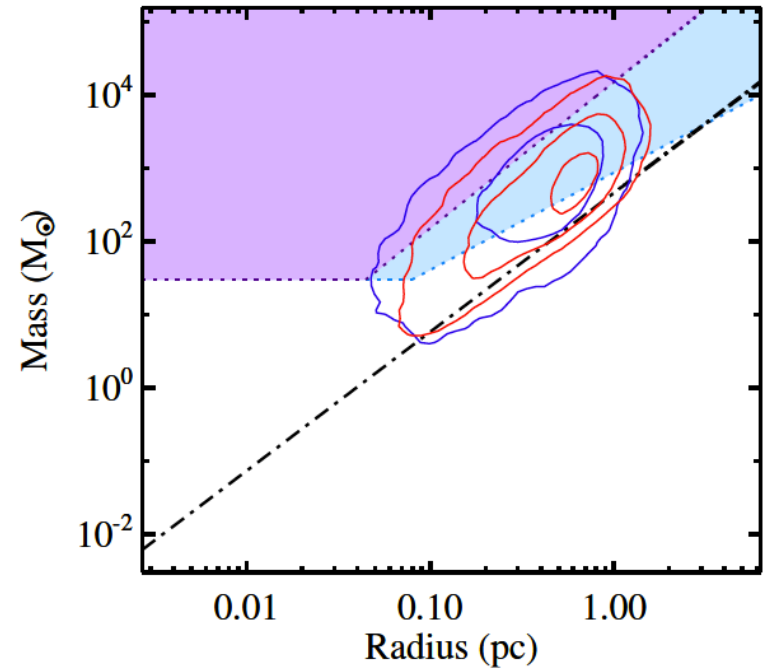
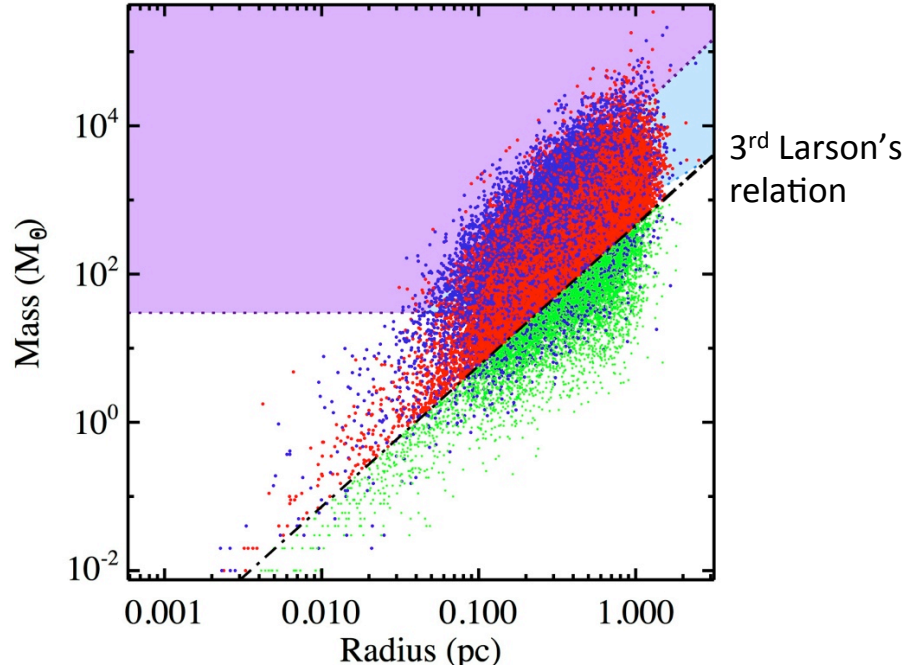
Temperature distributions



Mass-Radius relation

Kauffmann & Pillai (2010)

Krumholz & McKee (2008)

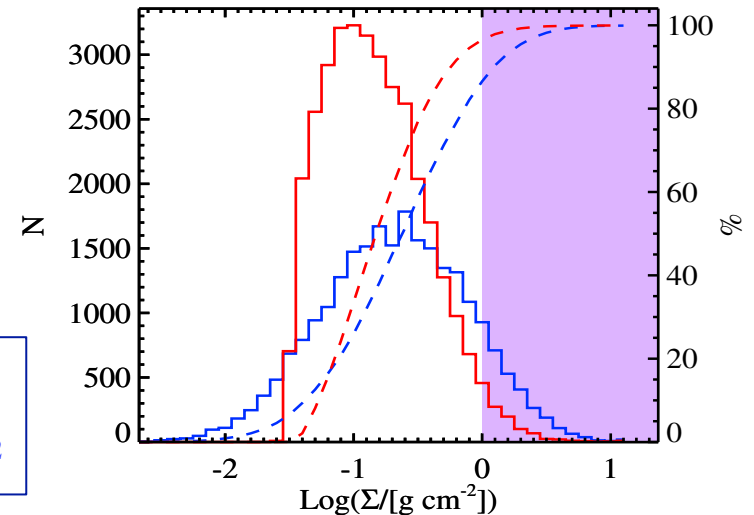


	$\Sigma > \Sigma_{KP}$		$\Sigma > \Sigma_{KM}$	
	counts	%	counts	%
Proto-stellar	11210	71.3	2062	13.1
Pre-stellar	12431	64.8	546	2.8

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

$$\langle \Sigma_{\text{pre}} \rangle = 0.26 \text{ g cm}^{-2}$$

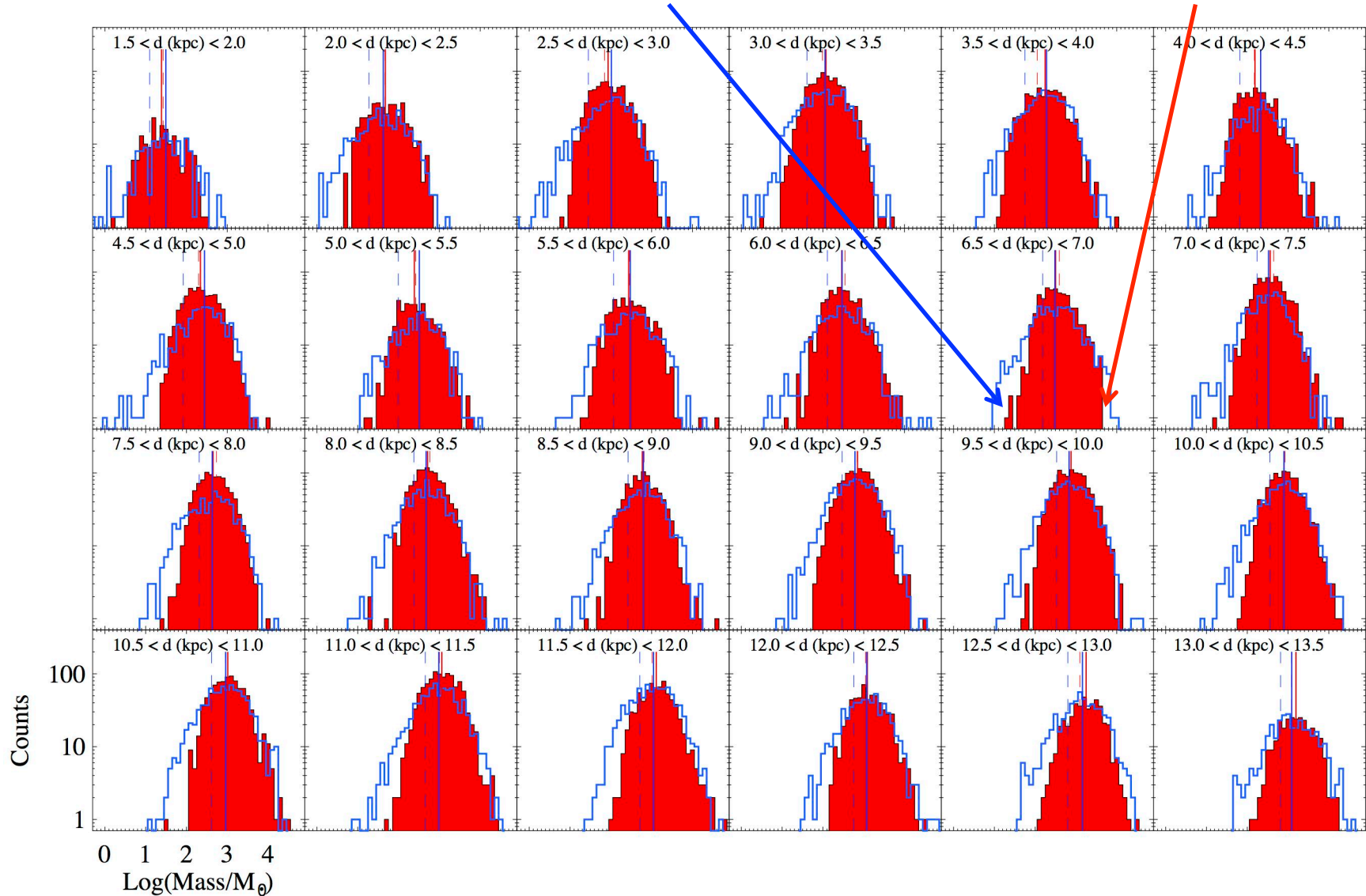
$$\langle \Sigma_{\text{proto}} \rangle = 0.51 \text{ g cm}^{-2}$$



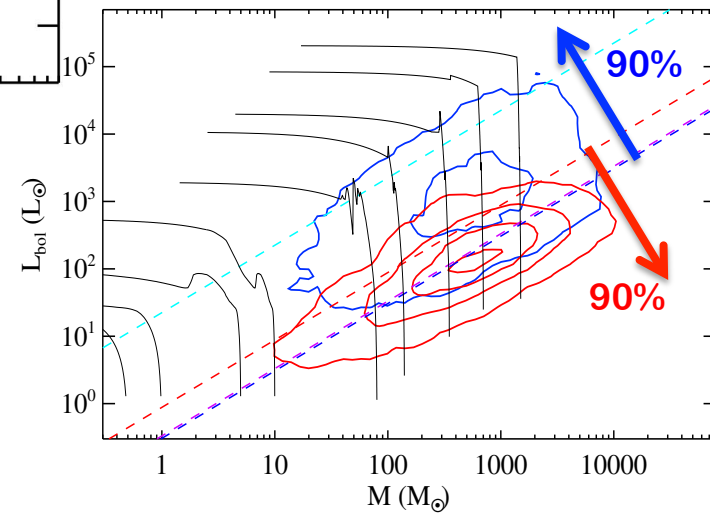
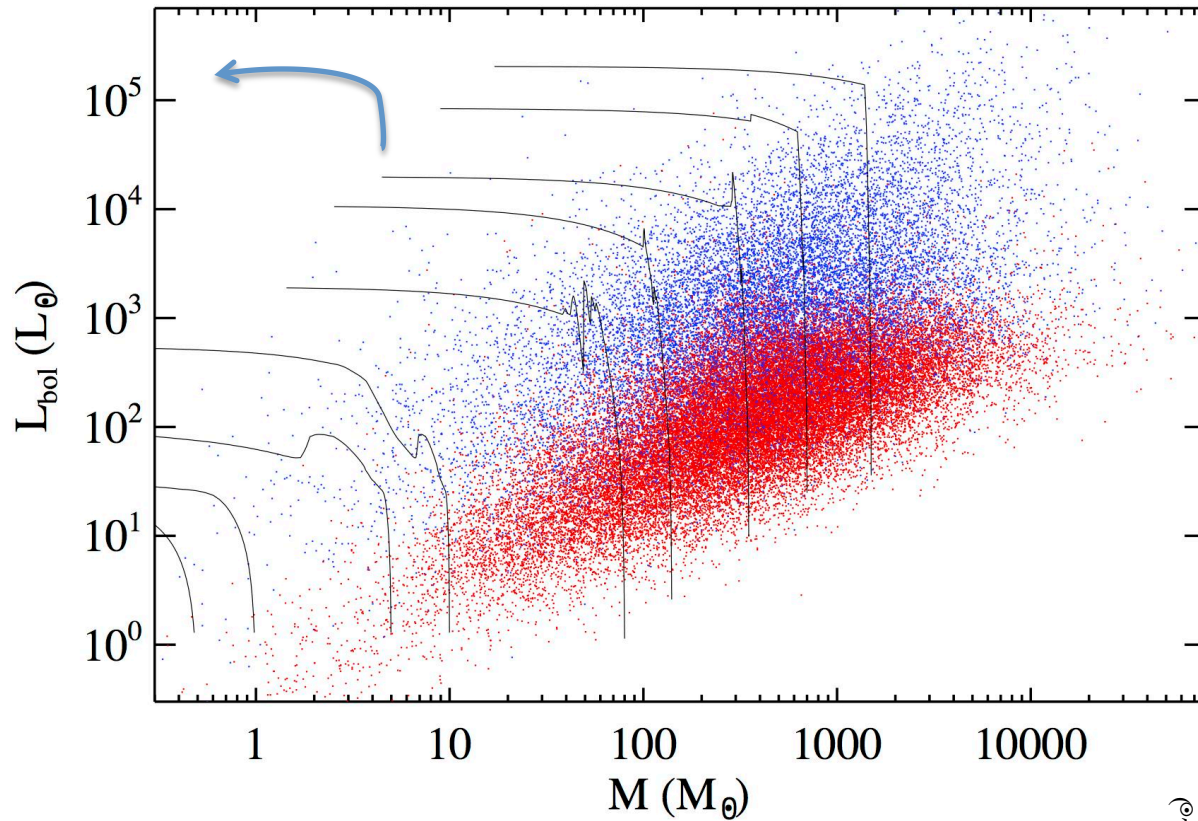
Clump Mass Function Slope

Different completeness between pre- and proto-stellar

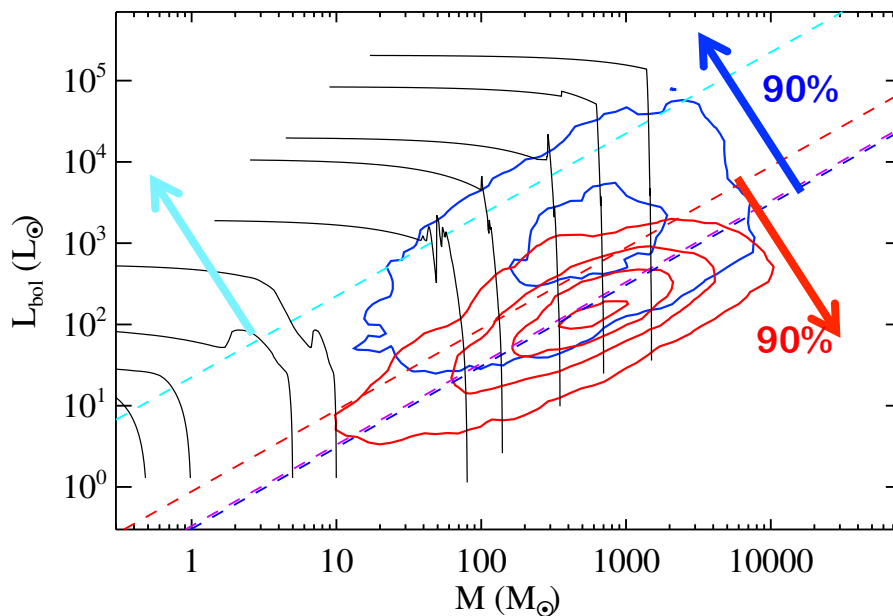
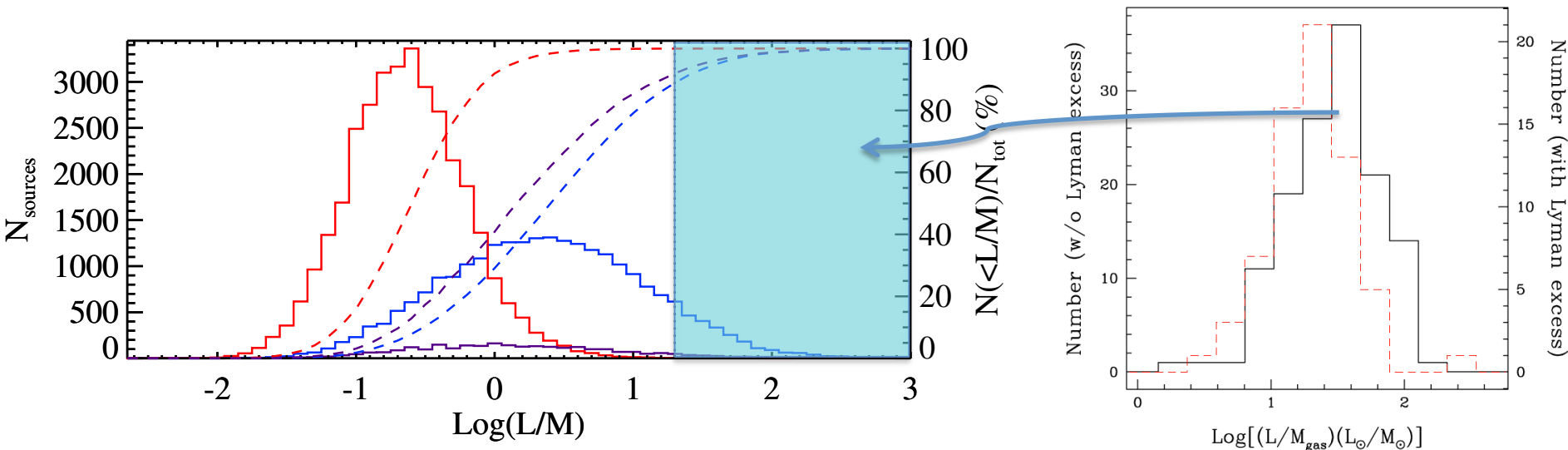
Lack of pre-stellar



L_{bol} vs M_{env} diagram



$L_{\text{bol}}/M_{\text{env}}$ 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.

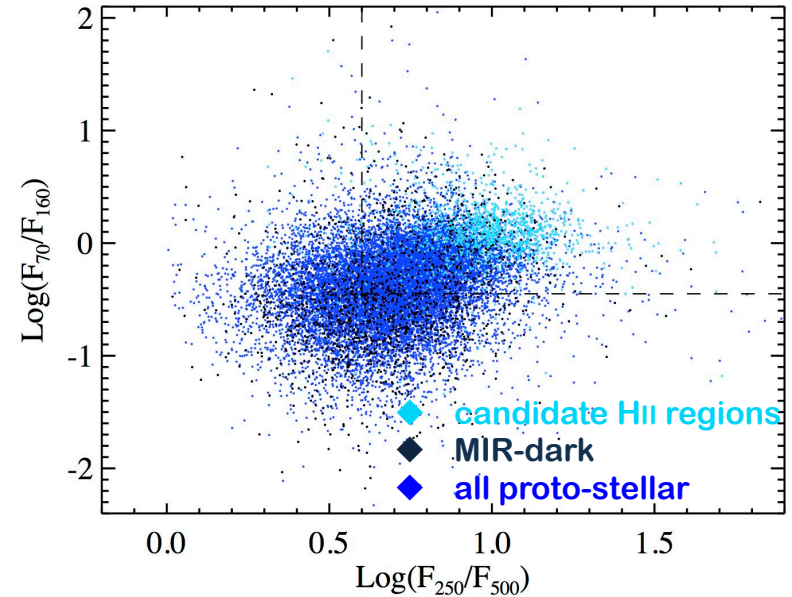
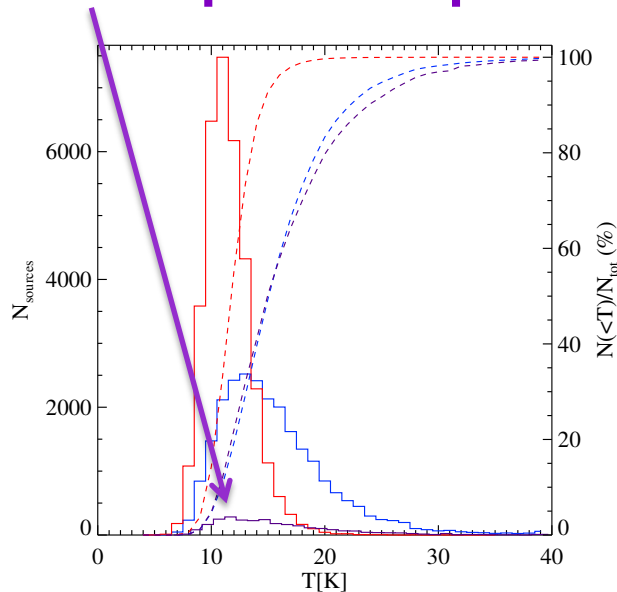
Two possible sub-classes of proto-stellar sources

High- L/M sources

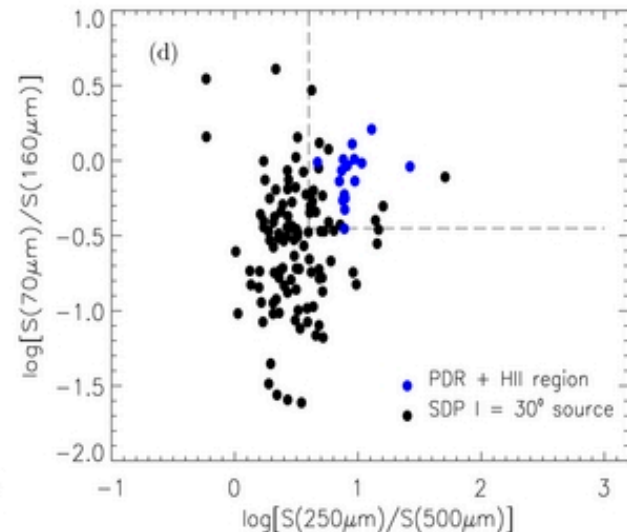
Compatible with typical L/M of HII regions

MIR-dark sources

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



Paladini+2012



Two possible sub-classes of proto-stellar sources

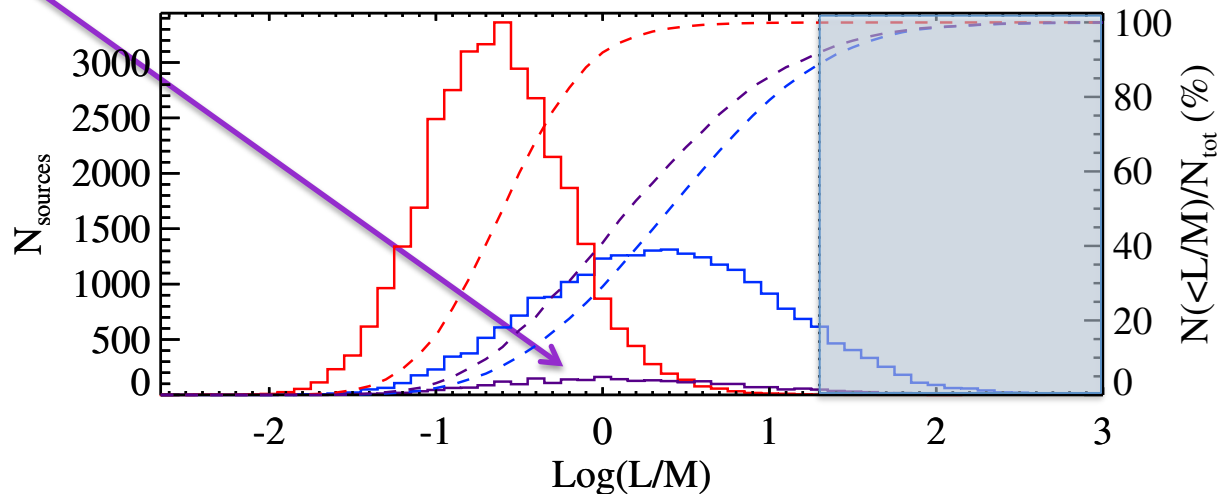
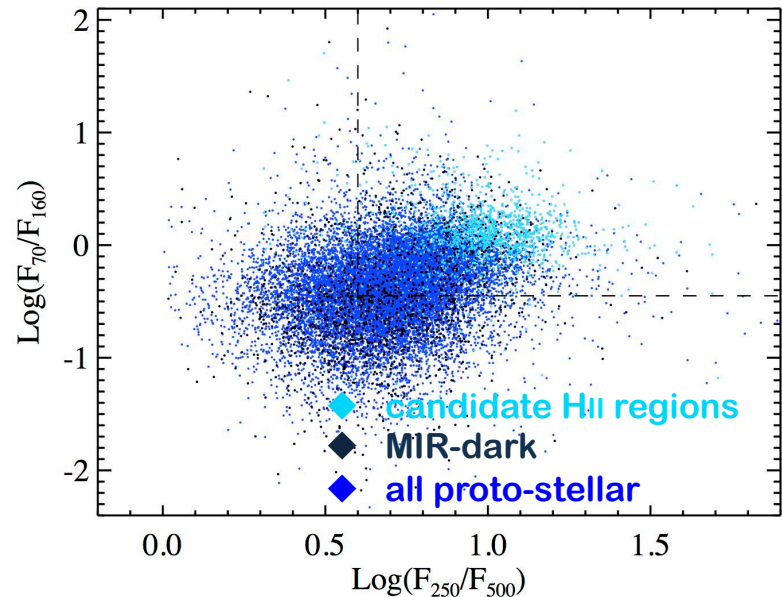
High- L/M sources

Compatible with typical L/M of HII regions

MIR-dark sources

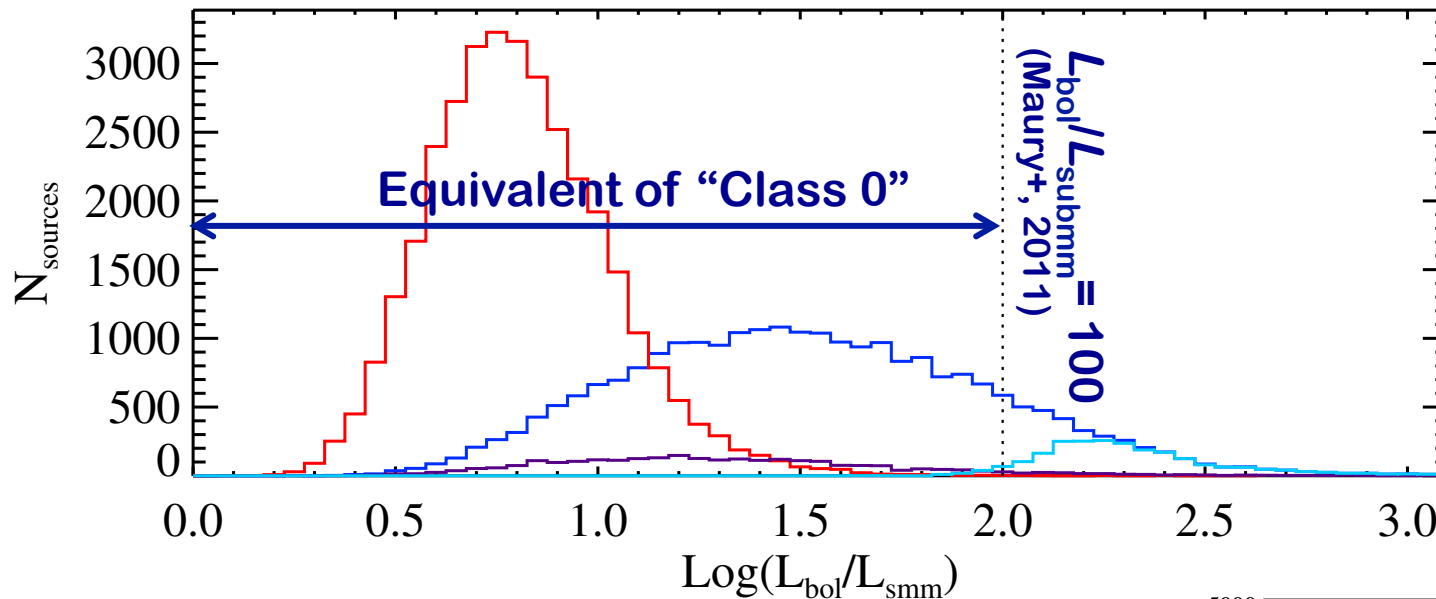
Average temperature in the middle between pre- and proto-stellar...

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



$L_{\text{bol}}/L_{\text{submm}}$ ratio

L_{submm} calculated for $\lambda > 350 \mu\text{m}$

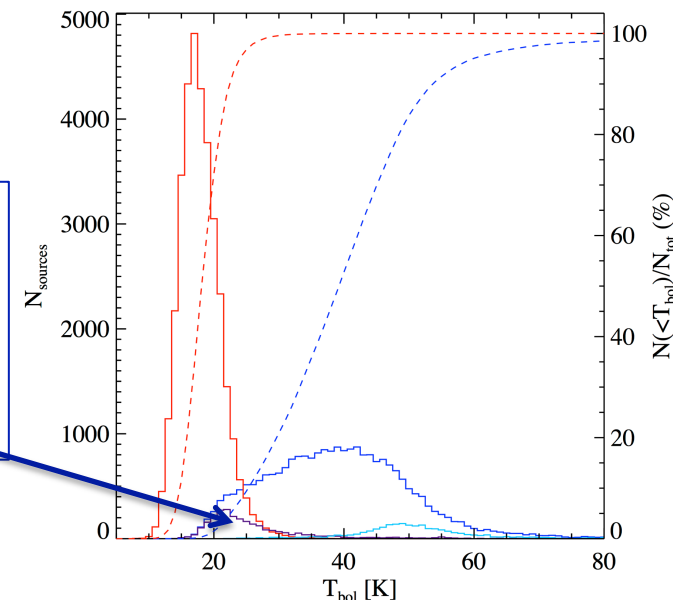


Bolometric Temperature

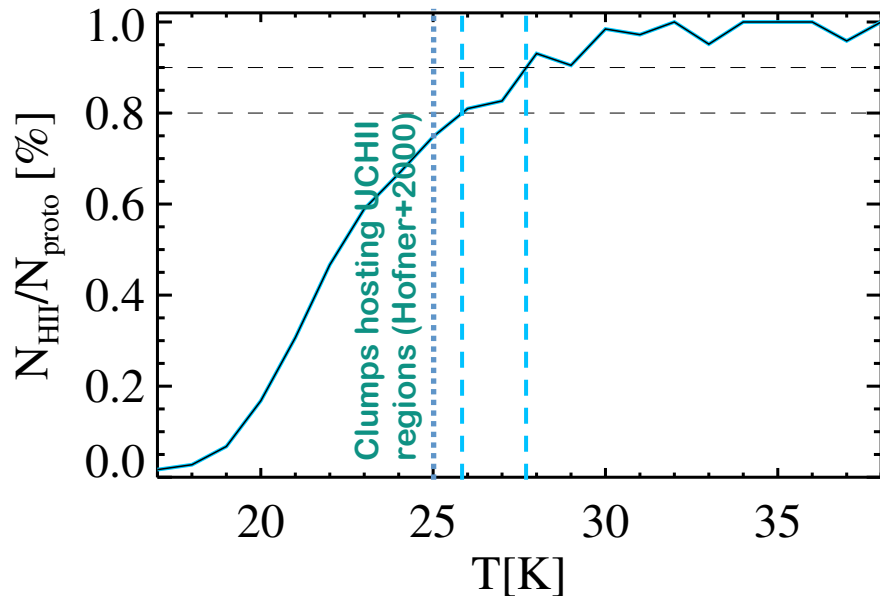
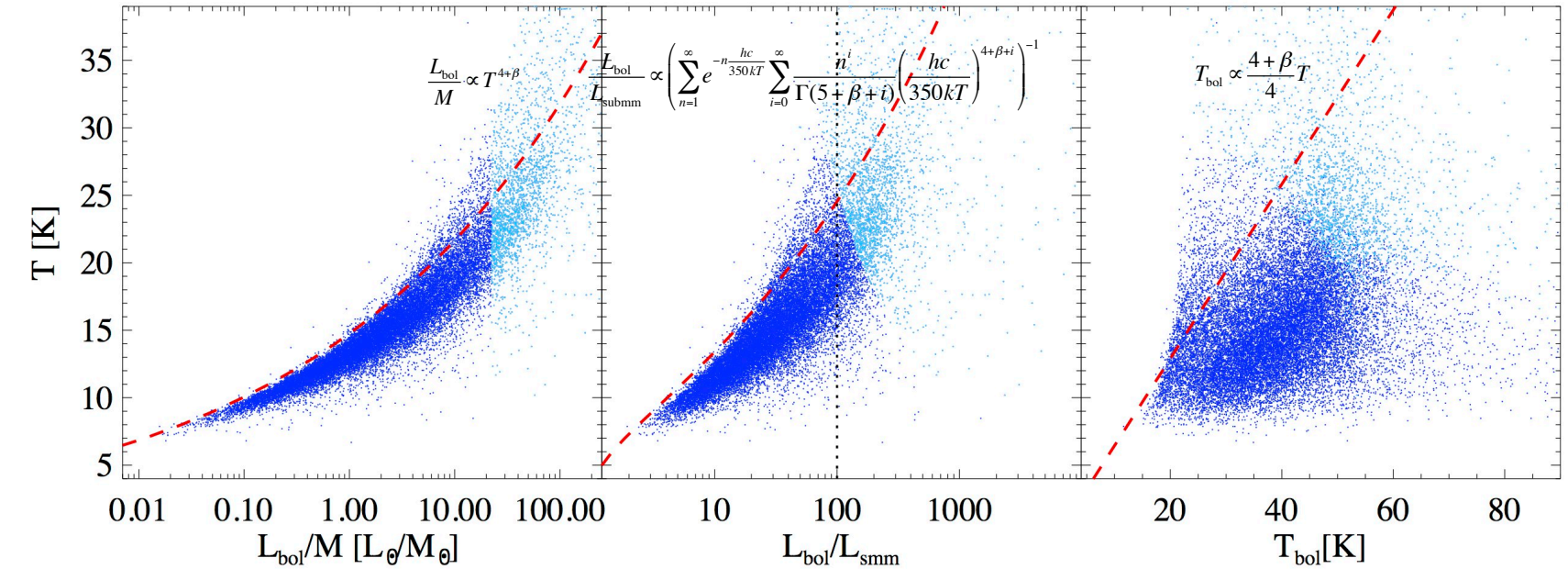
$$T_{\text{bol}} = 1.25 \times 10^{-11} \frac{\int_{-\infty}^{\infty} \nu F_{\nu} d\nu}{\int_{-\infty}^{\infty} F_{\nu} d\nu}$$

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.



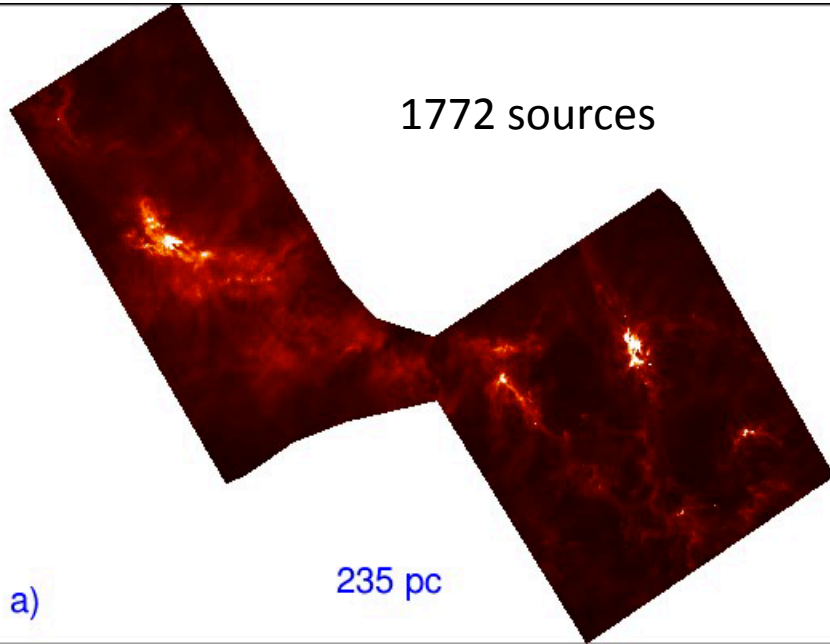
Dust temperature vs evolutionary descriptors



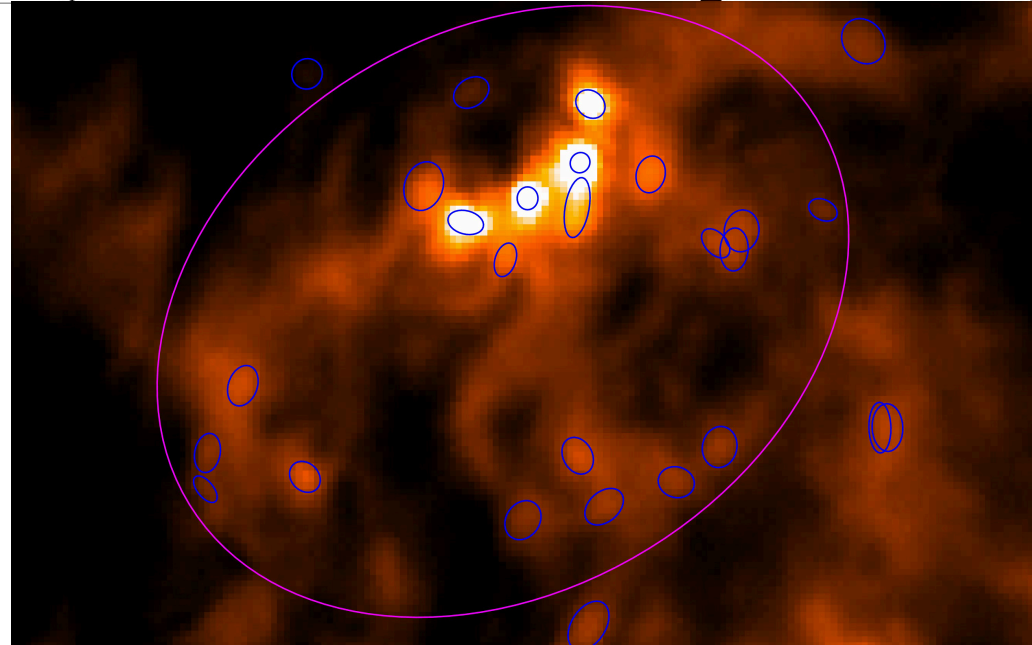
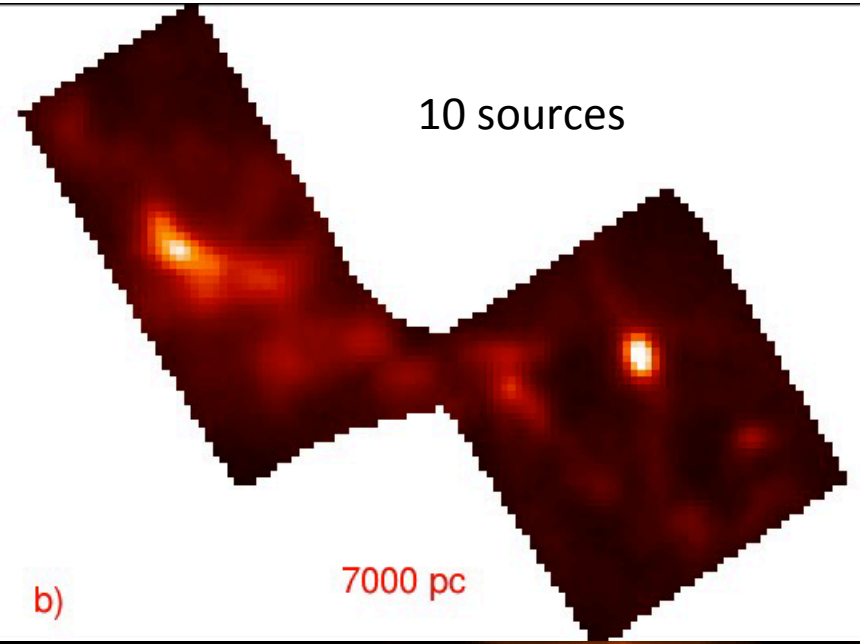
- Temperature itself is a valid evolutionary indicator.
- Pre-stellar sources follow relations expected for the greybody (Elia & Pezzuto 2016), while for the same temperature proto-stellar sources generally appear more evolved.

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

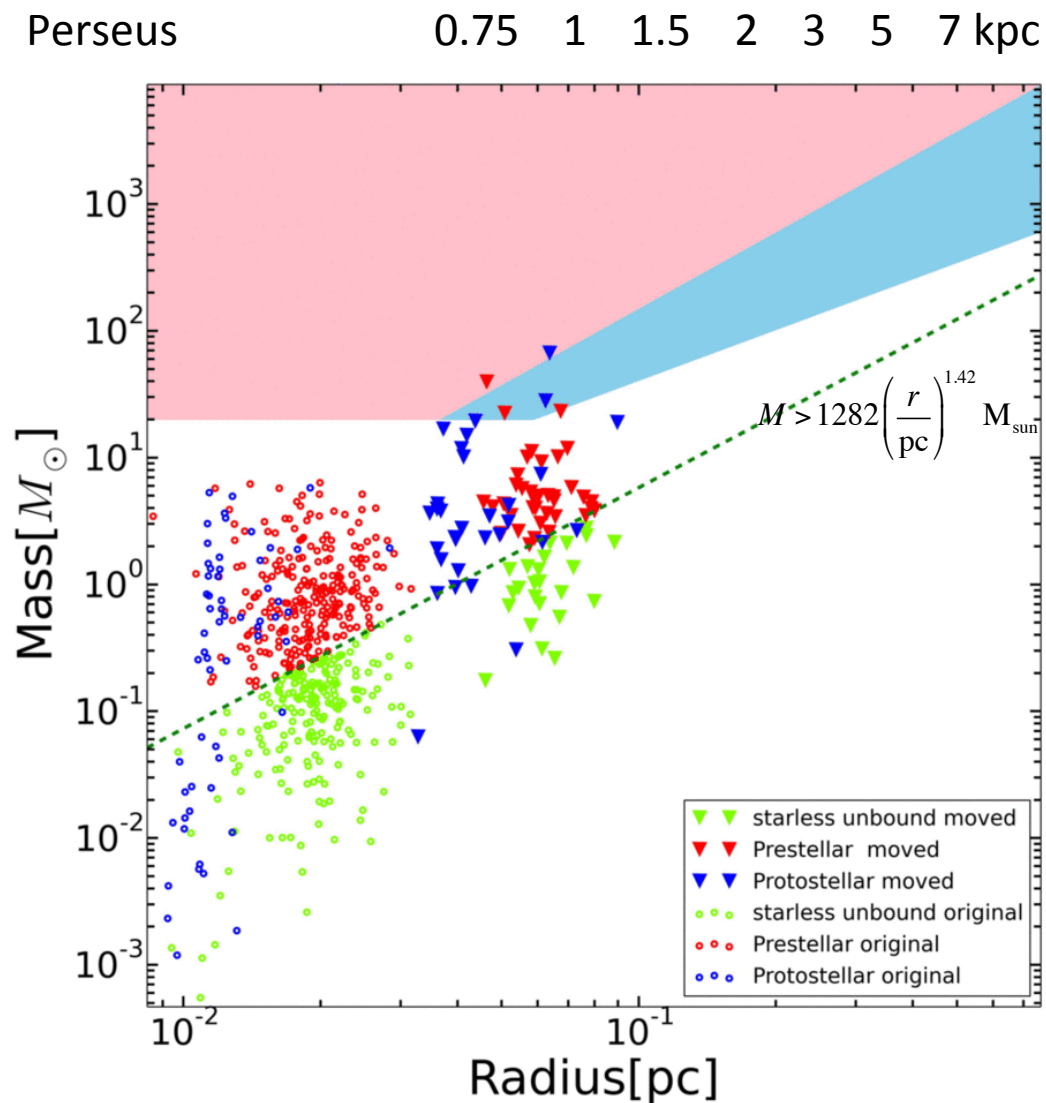
1772 sources



10 sources



Distance bias on $M - r$ relation



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

