Insights into Early Phases of High Mass Star Formation from 6.7 GHz Methanol Masers

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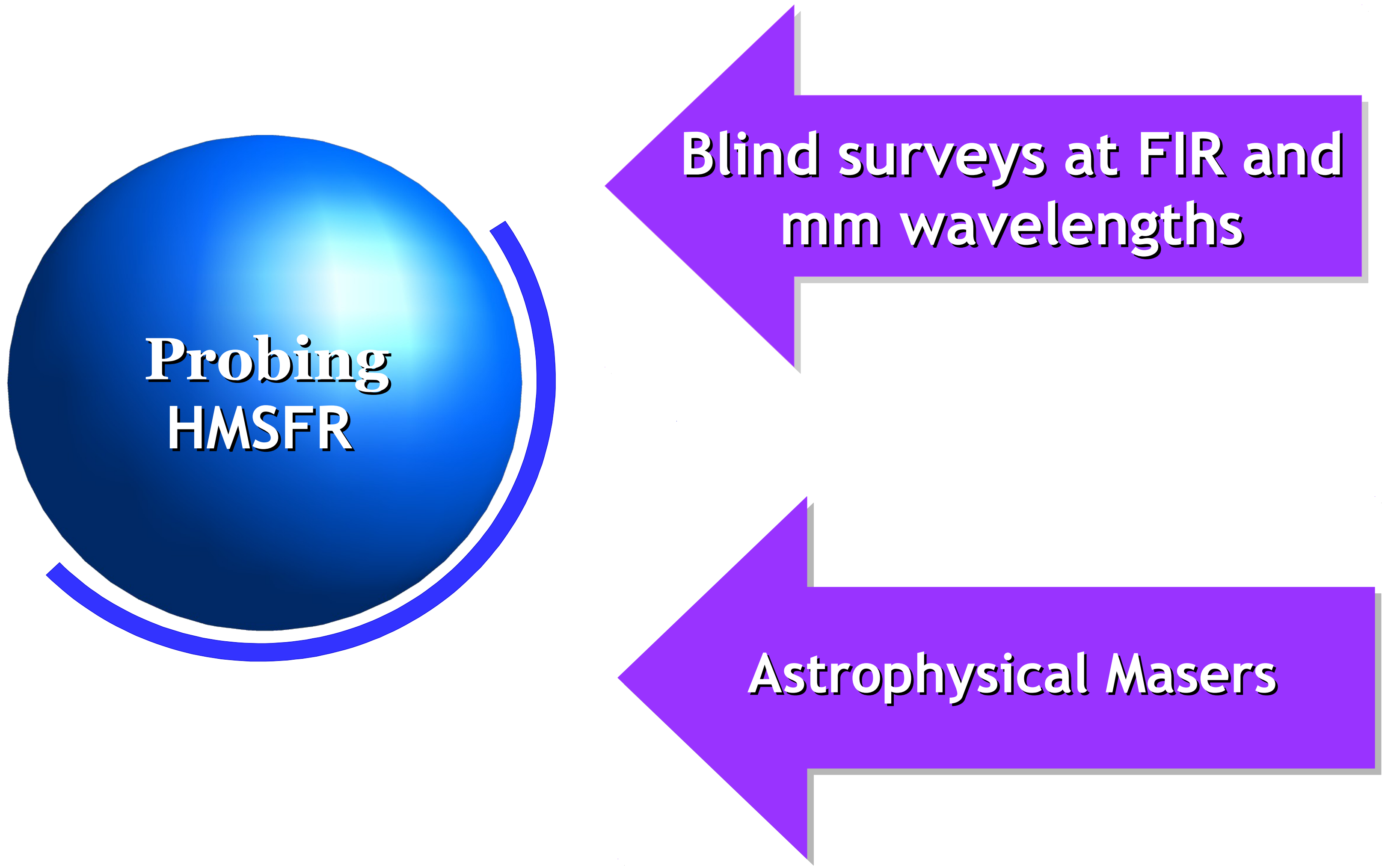

Probing
HMSFR
Blind surveys at FIR and mm wavelengths
Astrophysical Masers

Probing the early stages

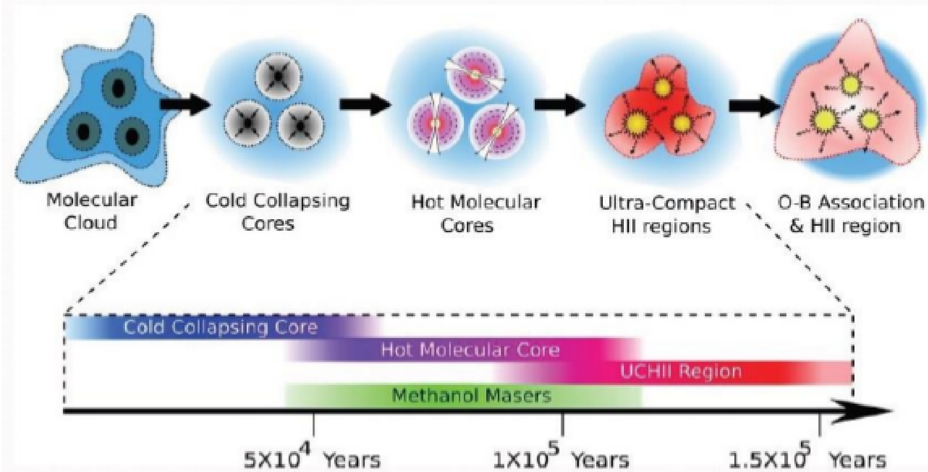
METHANOL MASER... AN EXCELLENT TRACER !!

Best signposts of young, high mass star forming regions.

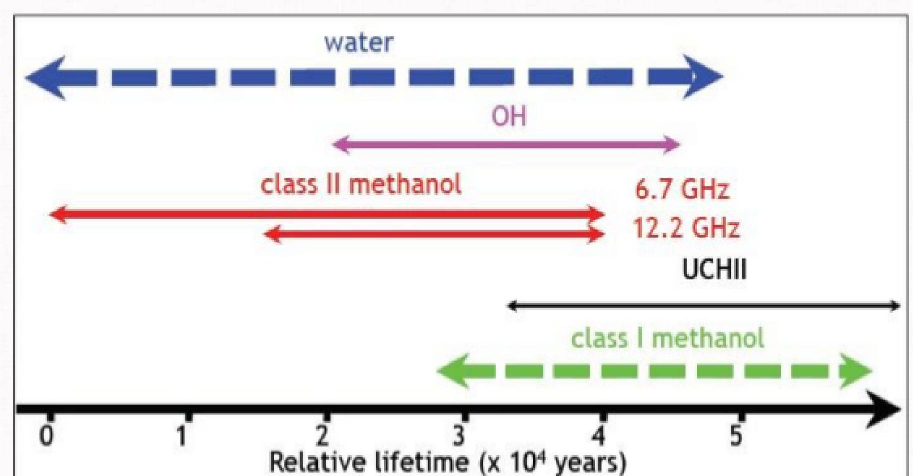
6.7GHz Masers Brightest methanol maser(Class II)

Traces the very early phase of massive star formation

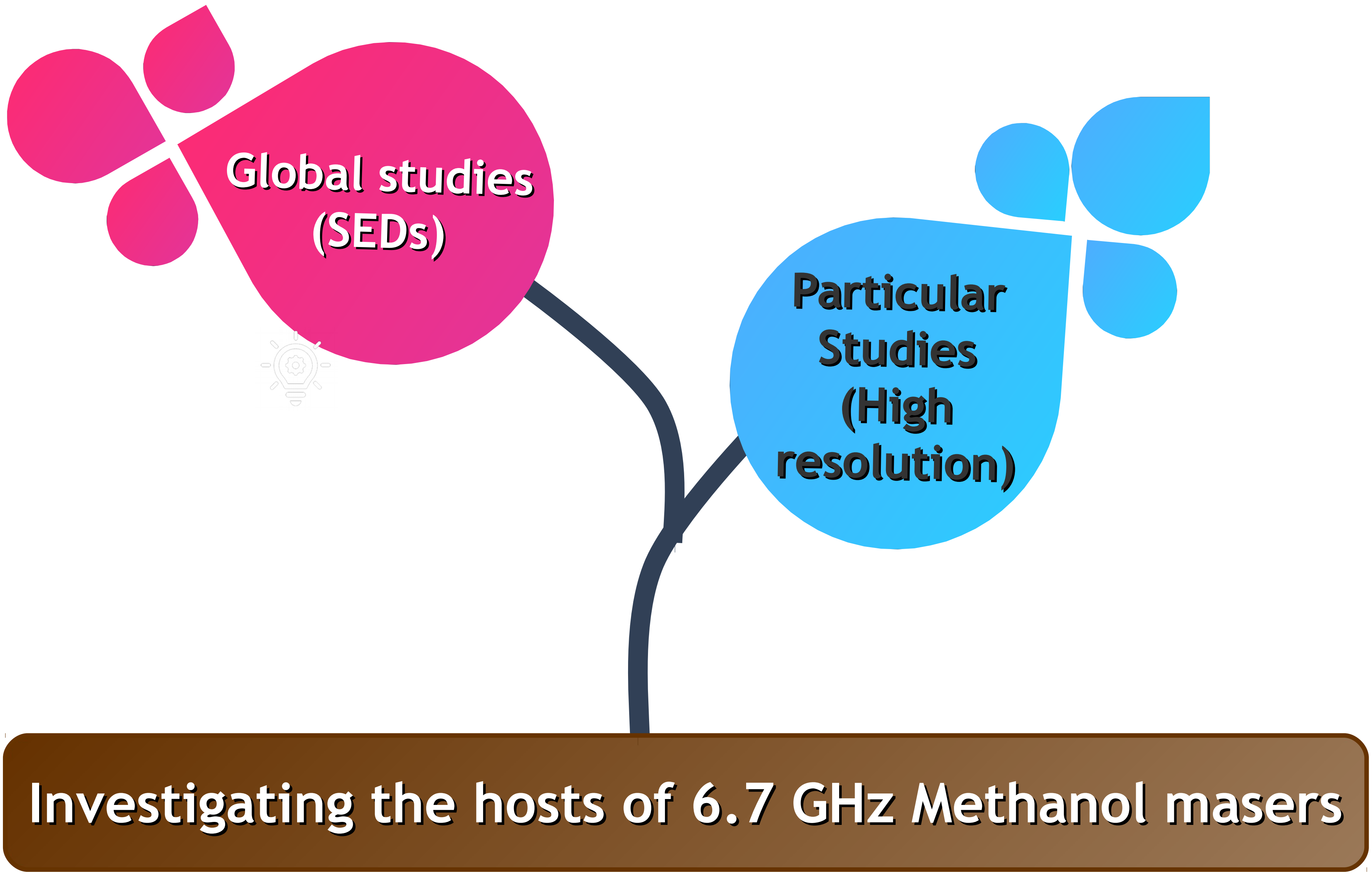
Pandian et al., 2010



Breen et al., 2010



Ellingsen 2006

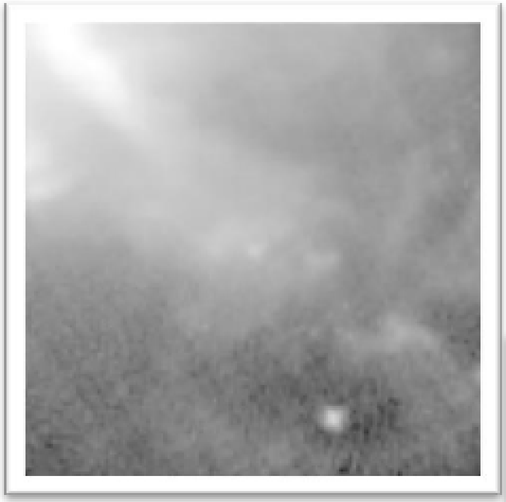

Global studies (SEDs)
Particular Studies (High resolution)
Investigating the hosts of 6.7 GHz Methanol masers

Challenges in Photometry : Herschel

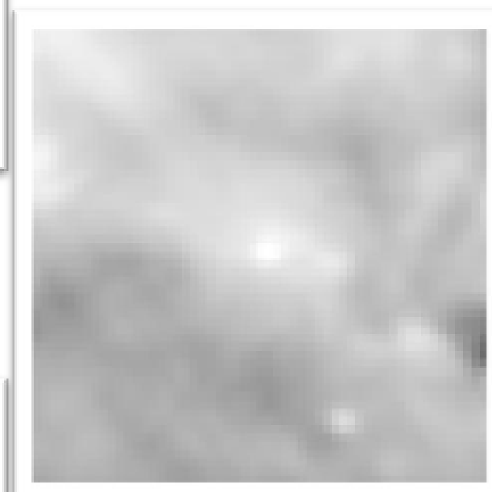
Sources are often observed on top of a complex, highly variable background

Often blended in to multiple, closely spaced objects

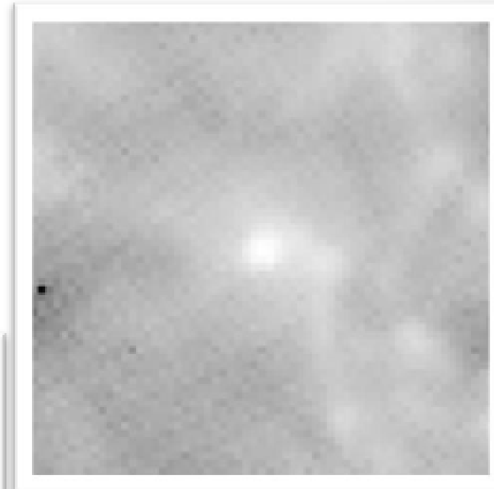
Spatial resolution and sensitivity of the observations are wavelength dependent



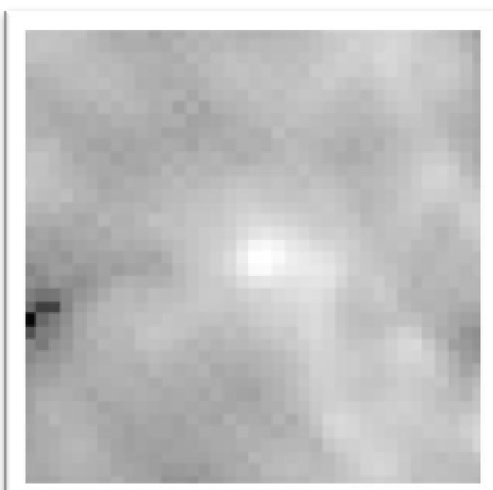
70 µm



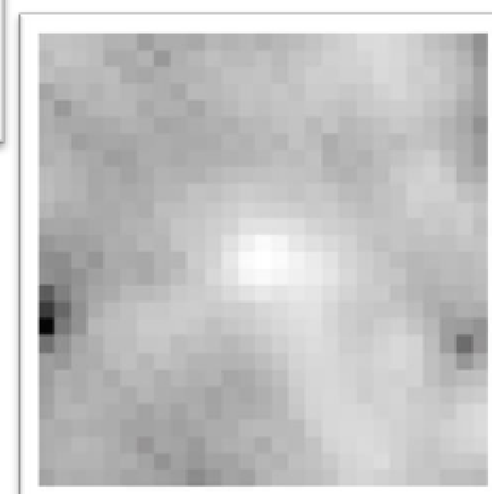
160 µm



250 µm



350 µm



500 µm

Hyper

Hybrid Photometry and Extraction Routine

- Uses elliptical apertures for photometry

    Minimised flux contamination from the background

- The background is estimated locally

    Modelling the background with different polynomial orders (upto 4^{th} order)

- The 2d gaussian fit defines the aperture used to integrate the flux arising from the same volume of dust and gas at all wavelengths
- Fast and light in its memory usage
- Freely available to scientific community

Surveys Used

- Methanol Multi Beam Survey (MMB)

  Across the Galactic longitude region 186°, through the Galactic Centre, to 60°, $|b| \leq 2^{\circ}$

- Herschel Infrared Galactic survey (Hi-Gal)

  Range : $|l| \leq 60^{\circ}$, $|b| \leq 1^{\circ}$

- APEX Telescope Large Area Survey of the Galaxy (ATLASGAL)

  Across the Galactic longitude region 186°, through the Galactic Centre, To 60°, $|b| \leq 2^{\circ}$

Methodology

SOURCE SELECTION

- **972** maser sources from MMB survey.
- Only **630** falls in the Hi-GAL range
- The distances are taken from (Urquhart et al. 2013b; Reid et al. 2014; Pandian et al. 2009; Green et al. 2017).
- Discarded sources that are either saturated in the Hi-GAL data or are in very crowded fields
- Sources that have ATLASGAL counterparts. Final methanol maser sample of **320** sources

Methodology

SOURCE SELECTION

- The masers are studied using the ATLASGAL and Hi-GAL data ; λ ~ 160 - 870 micrometers.
- Source extraction and photometry using Hyper
- Determined SEDs at 160-870 μm wavelength ranges.
- The best fit parameters of the SED fits are then used to obtain to obtain the clump properties.

Fitting of the SED

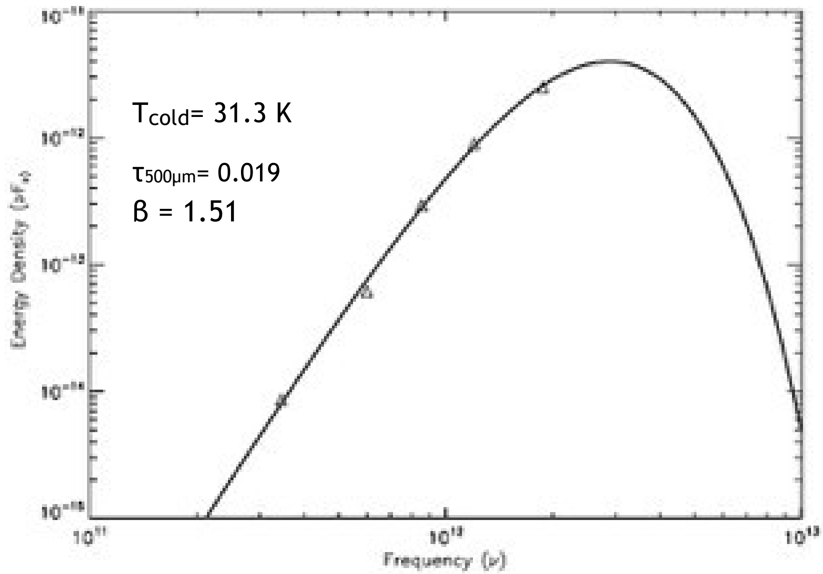
- A single grey body component fit was used to model the cold dust emission.

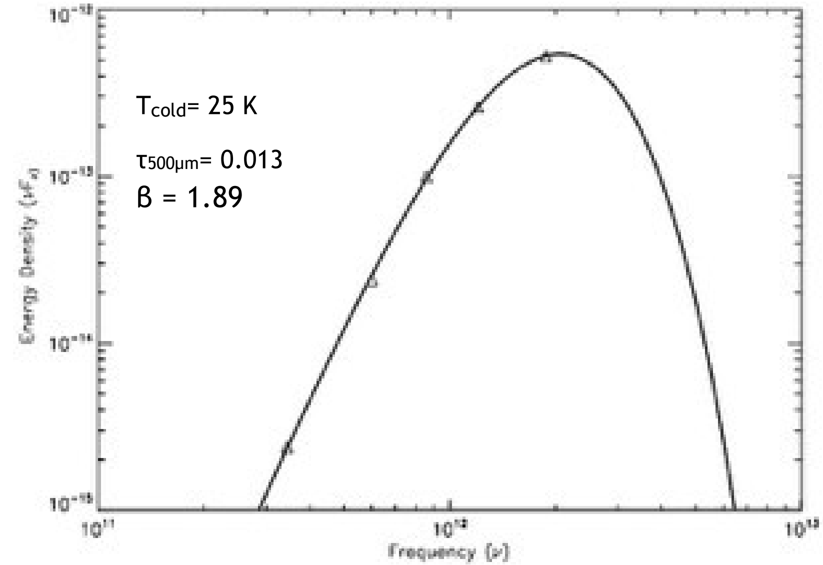
$$F_\nu = \Omega B_\nu(T_c)(1-\exp(-\tau_\nu))$$

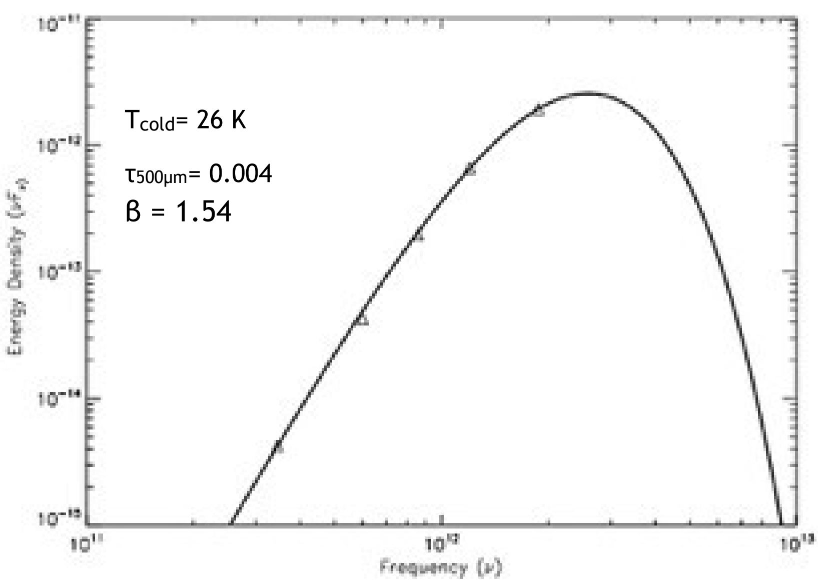
$$\tau_\nu = \tau_0 (\nu/\nu_0)^\beta$$

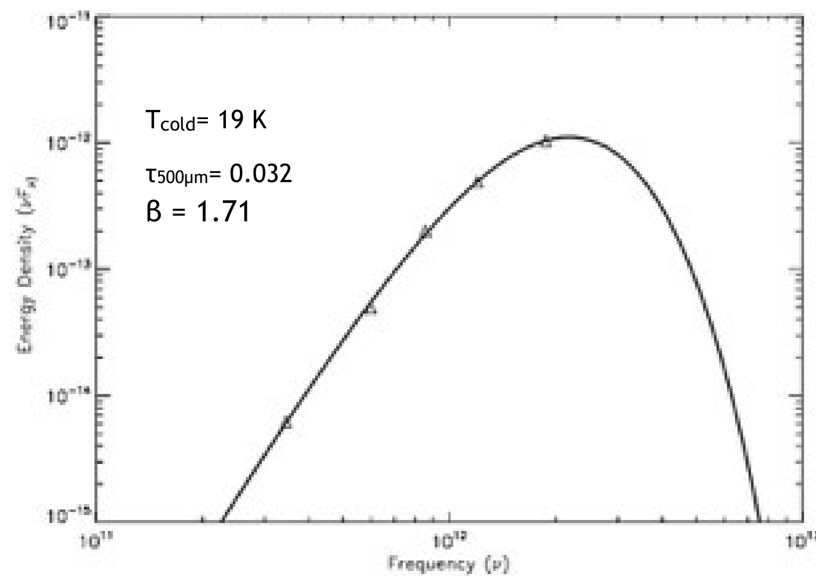
- We have modelled the emission from cold dust excluding the 70 μm flux values.

Sample SED Fits

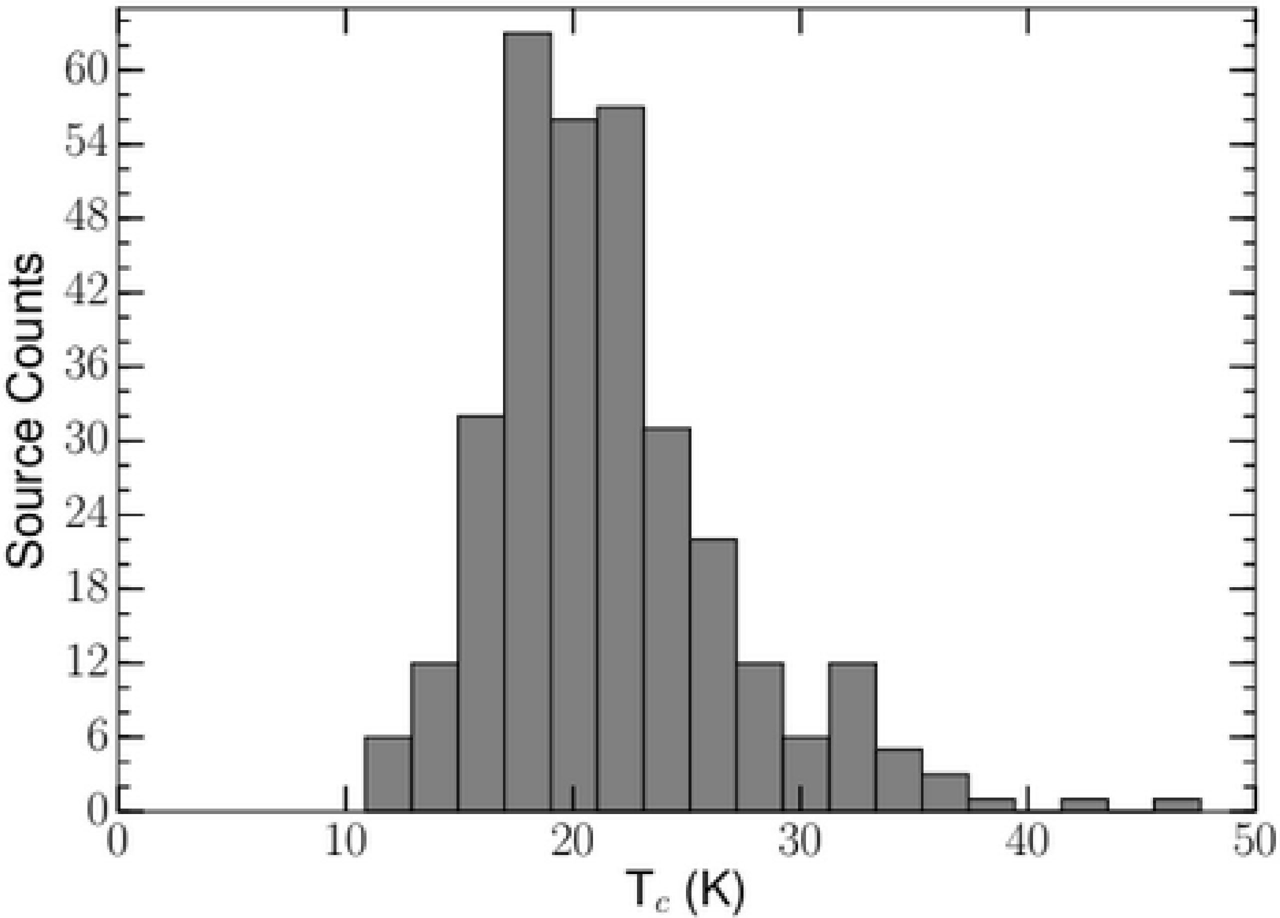




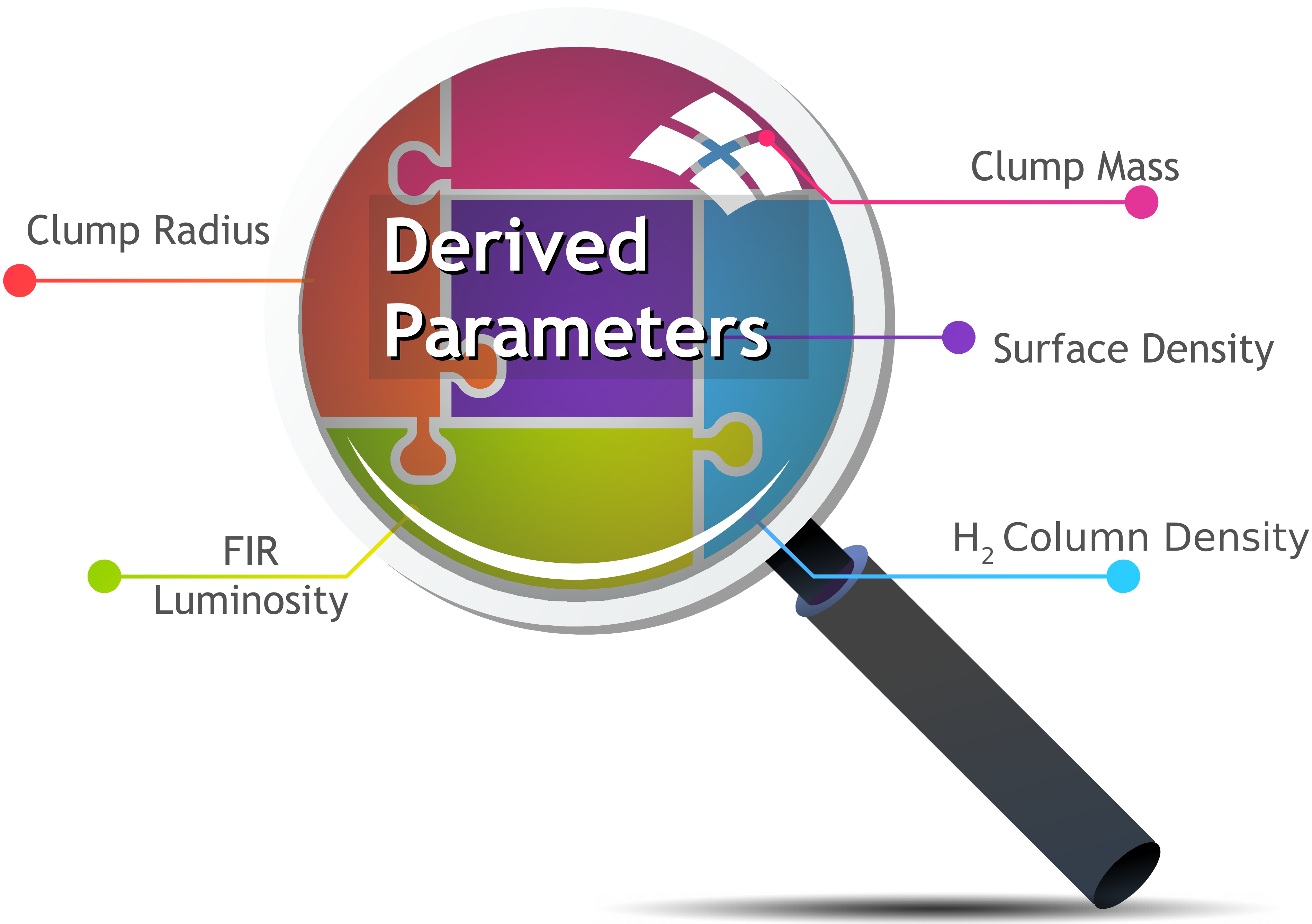




Best Fit Parameters



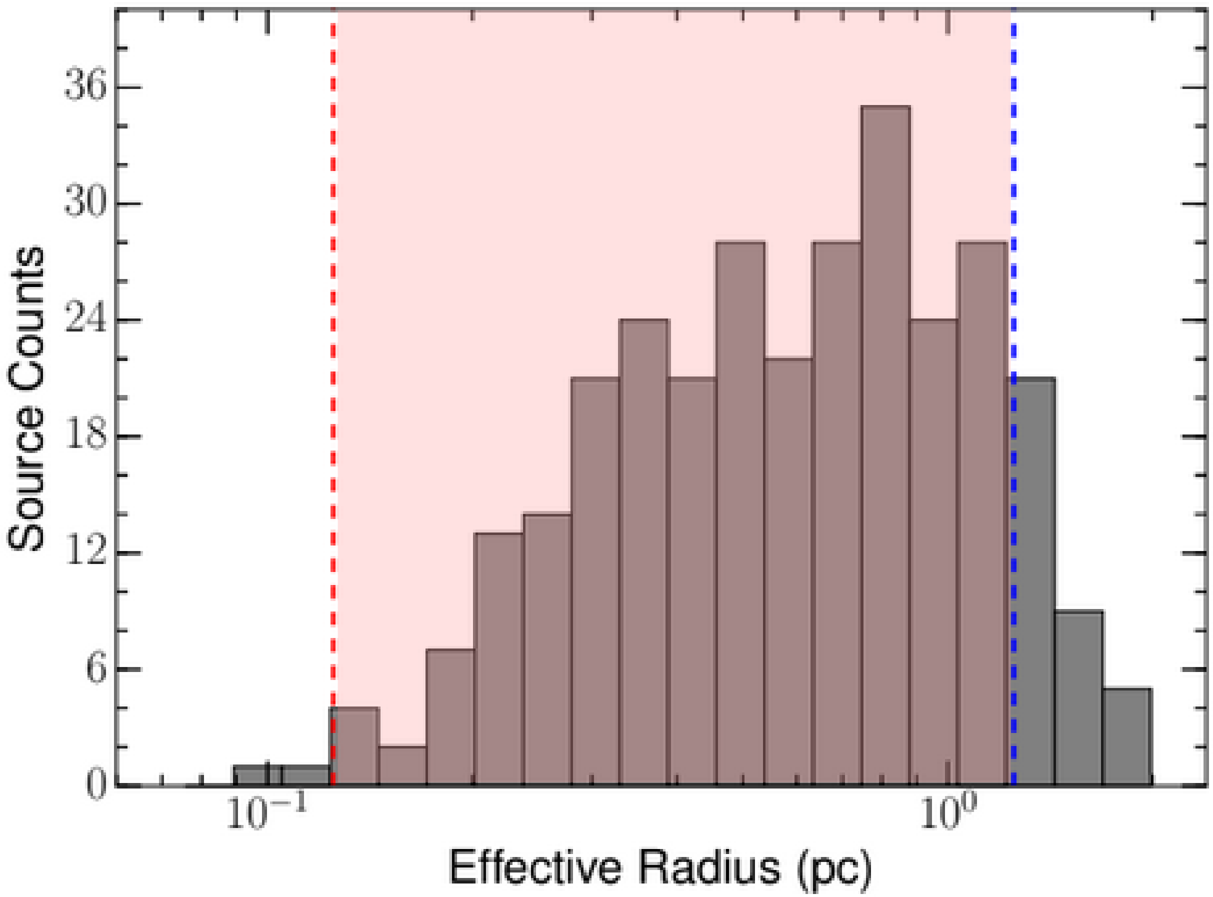
The values of β ranges from 1 to 2.56



Derived Parameters
Clump Mass
Clump Radius
Surface Density
H_2 Column Density
FIR Luminosity

Clump Radius

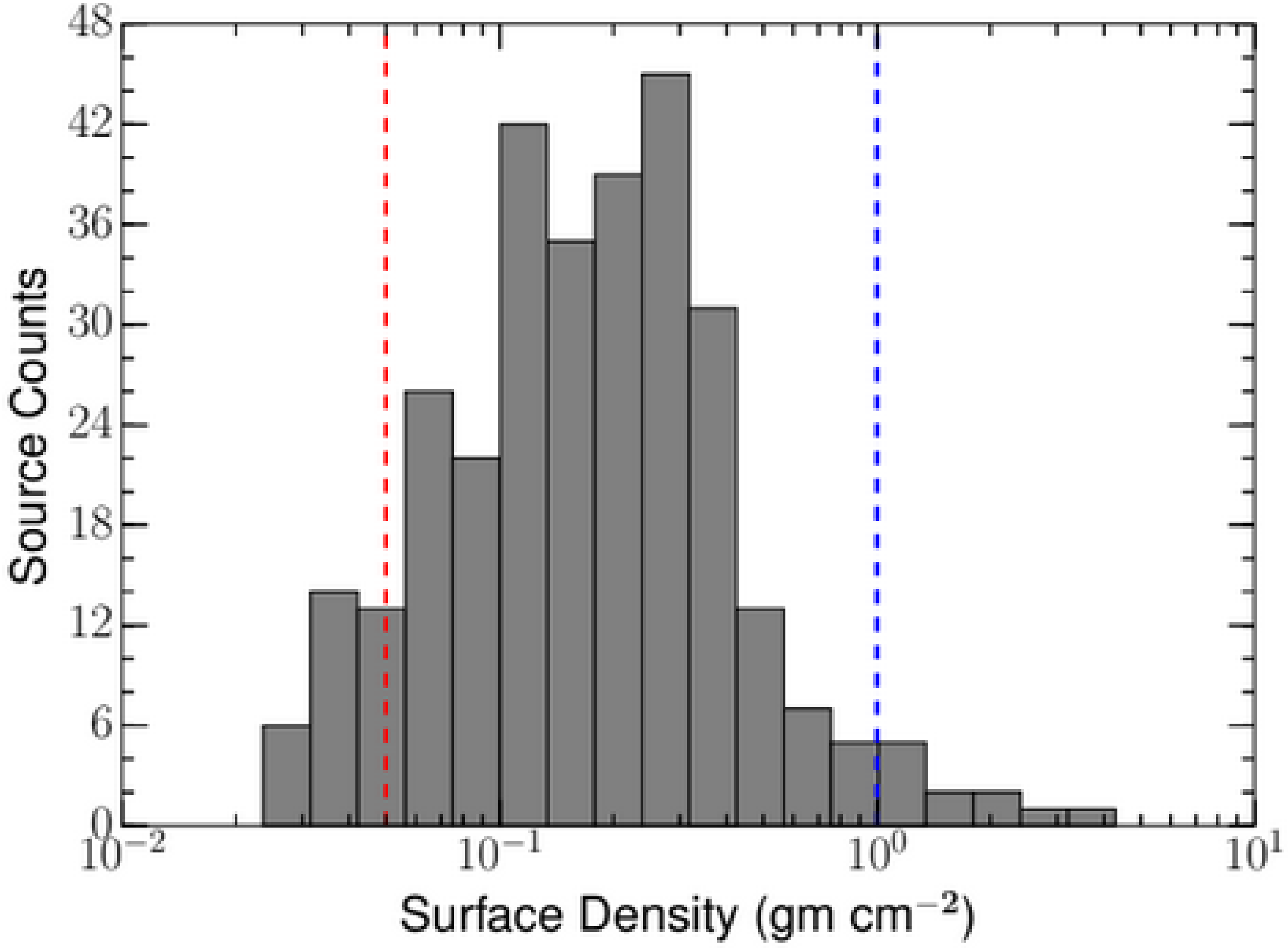
$$\theta_R = \eta\left[\left(\sigma_{maj}^2 - \sigma_{beam}^2\right)\left(\sigma_{min}^2 - \sigma_{beam}^2\right)\right]^{1/4}$$



θ_{beam} = 18”

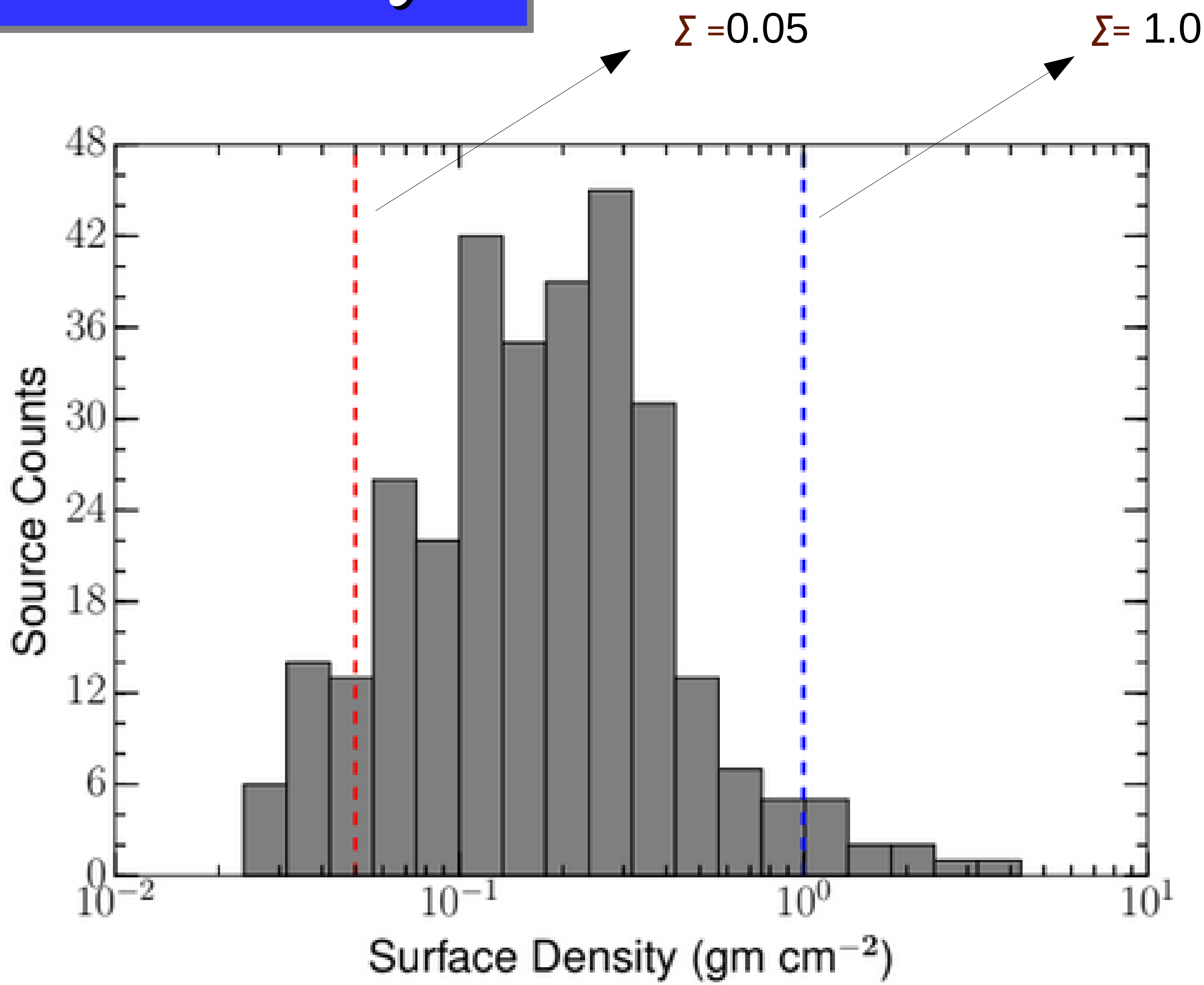
Rosolowsky et al. (2010)

Surface Density



*** very high Σ values from poorly resolved sources*

Surface Density



*** very high Σ values from poorly resolved sources*

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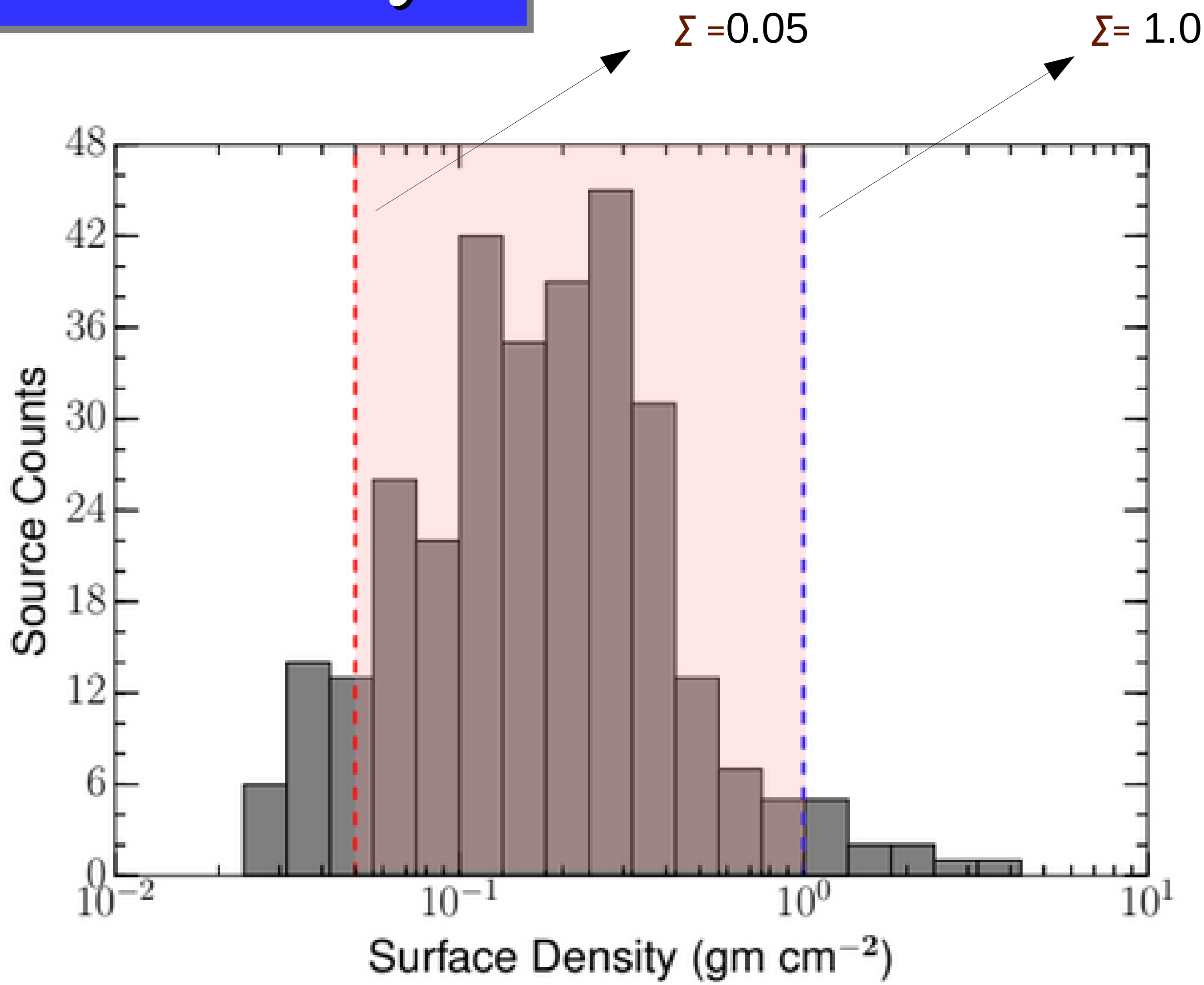
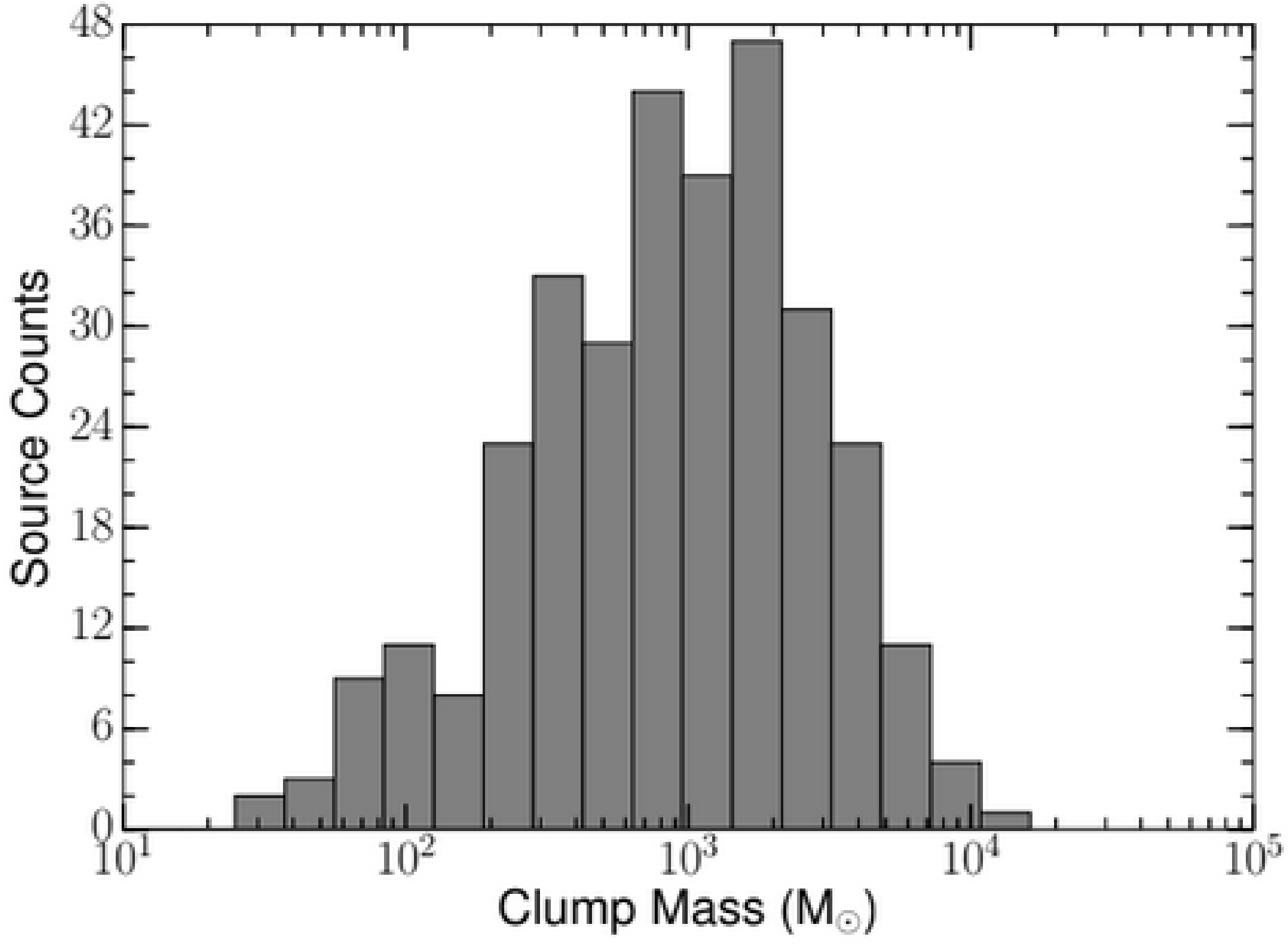


*** very high Σ values from poorly resolved sources*

Clump Mass

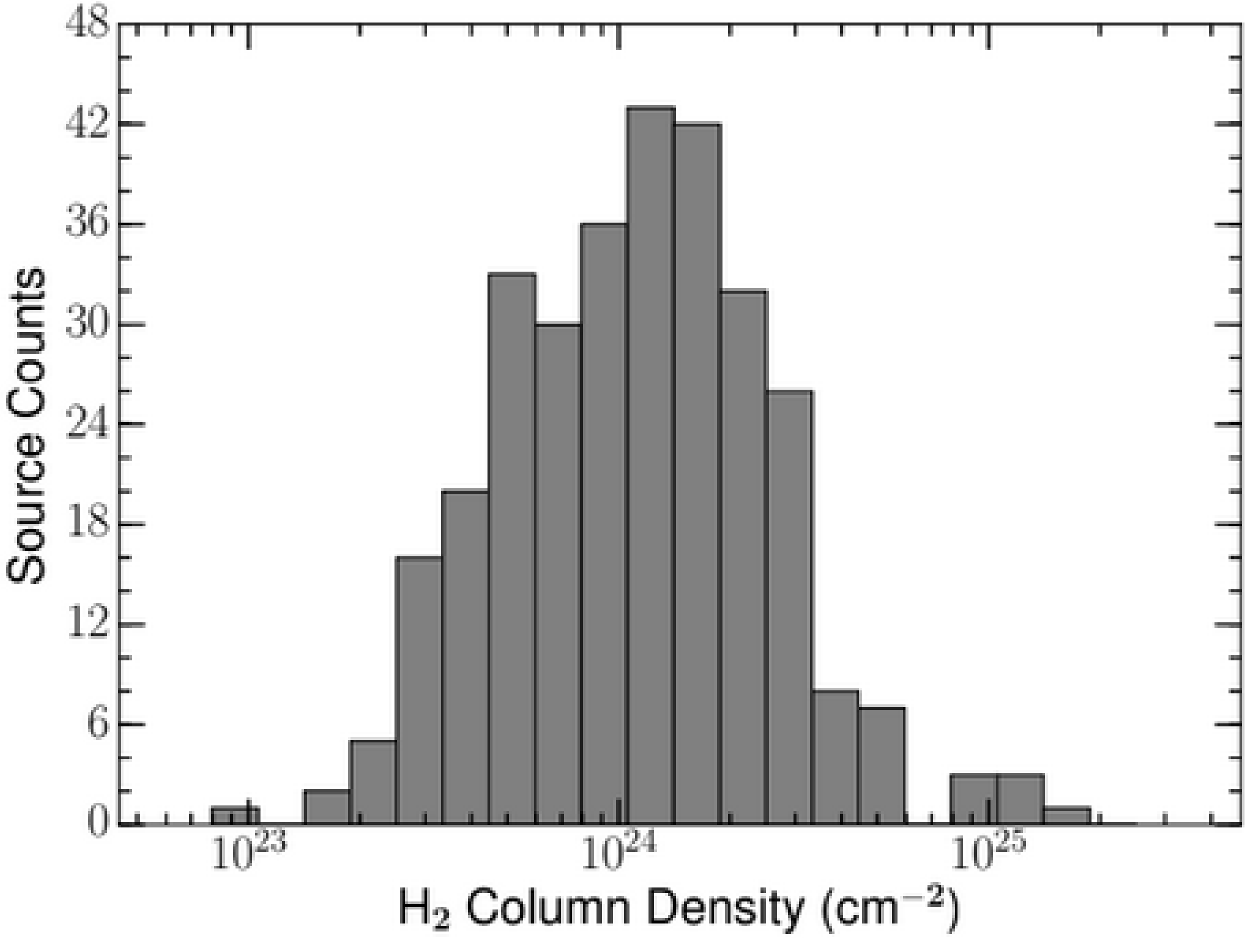
$$M = \frac{D^2 S_\nu R}{B_\nu(T_D)\kappa_\nu}$$



Hydrogen Column Density

$$N_{H_2} = \frac{S_\nu R}{B_\nu(T_D)\Omega\kappa_\nu \mu m_H}$$

Schuller et al. (2009)



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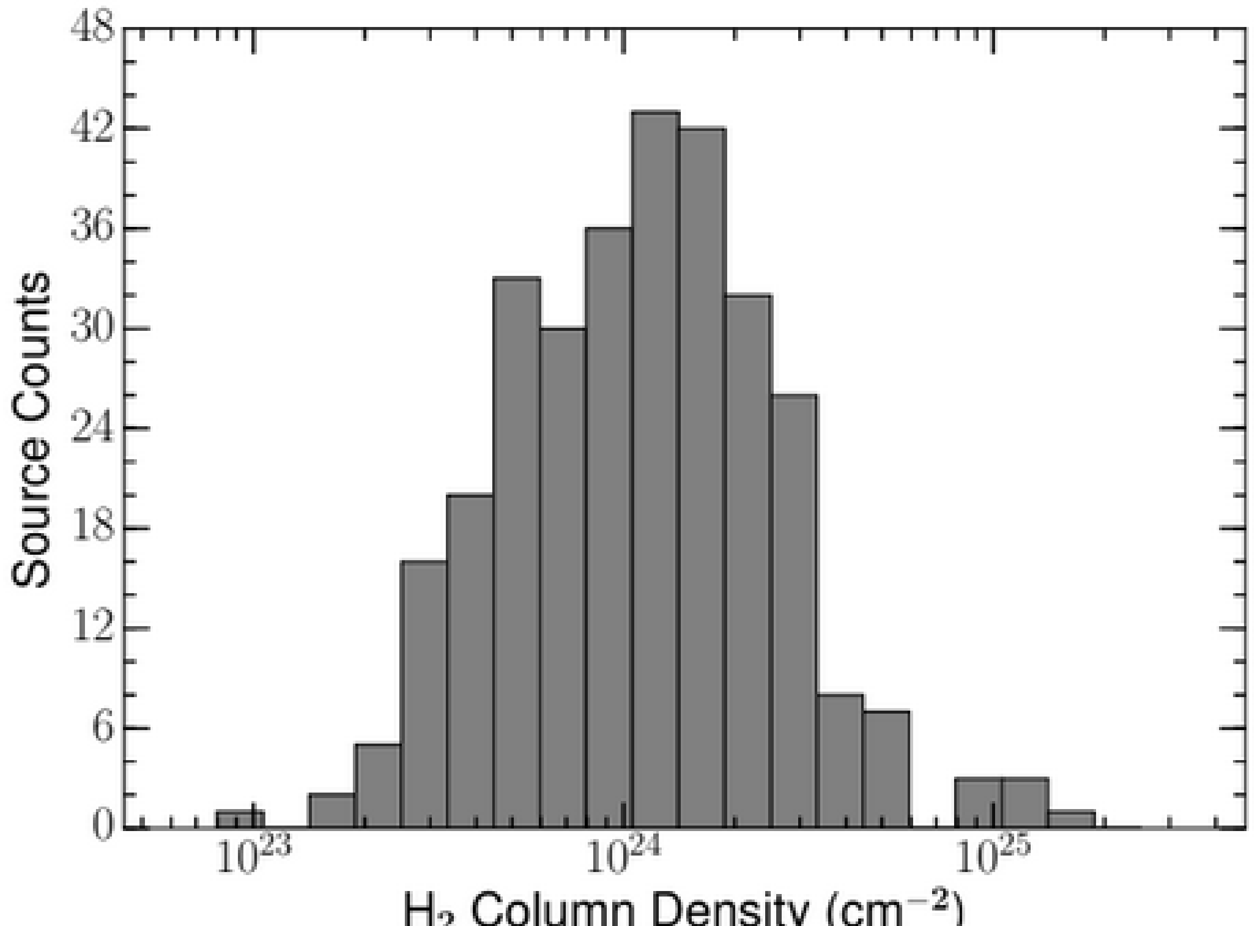
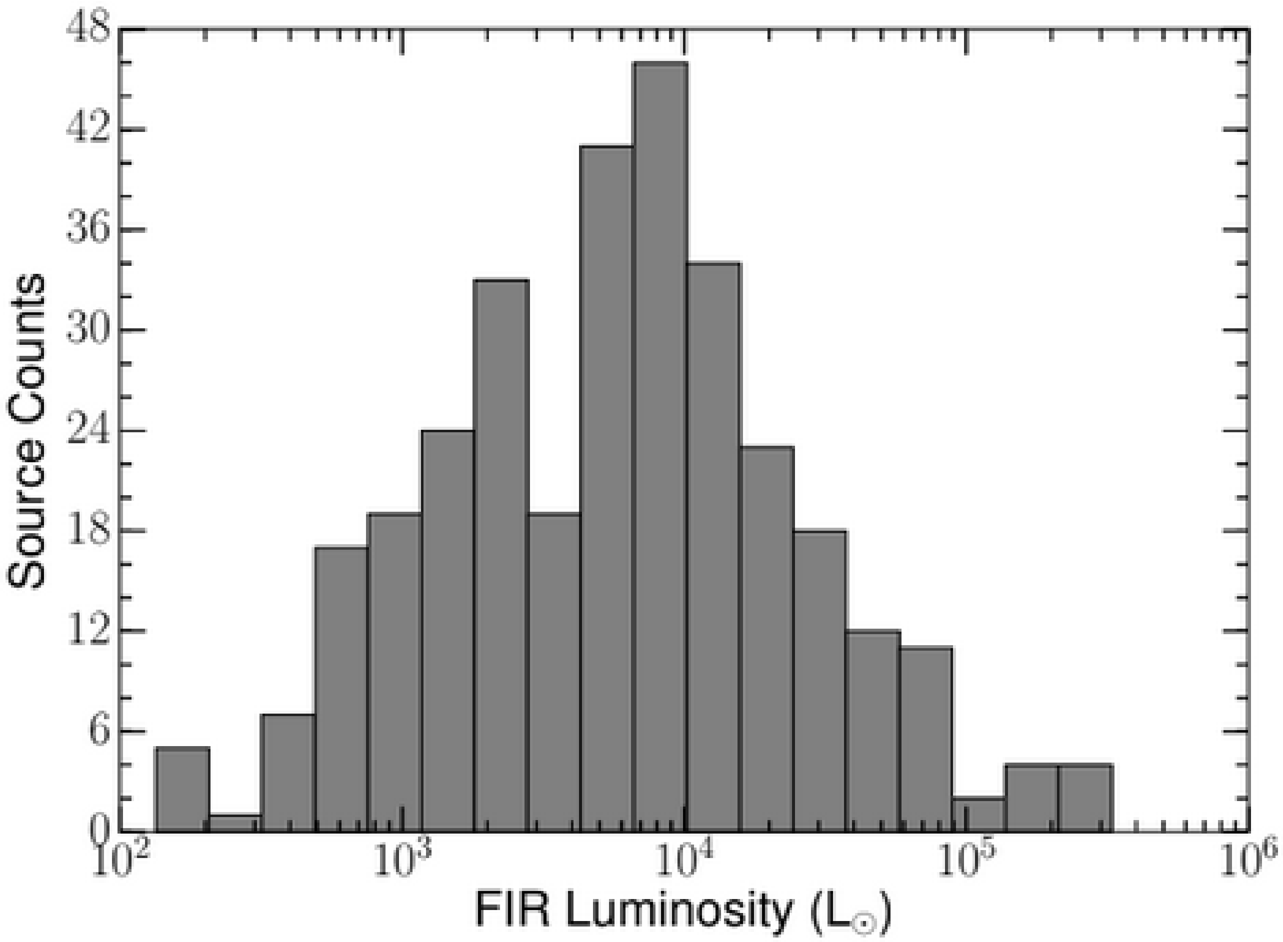


10^{22} - 10^{25}

FIR Luminosity

$$L = 4\pi D^2 \int f_\nu d\nu$$



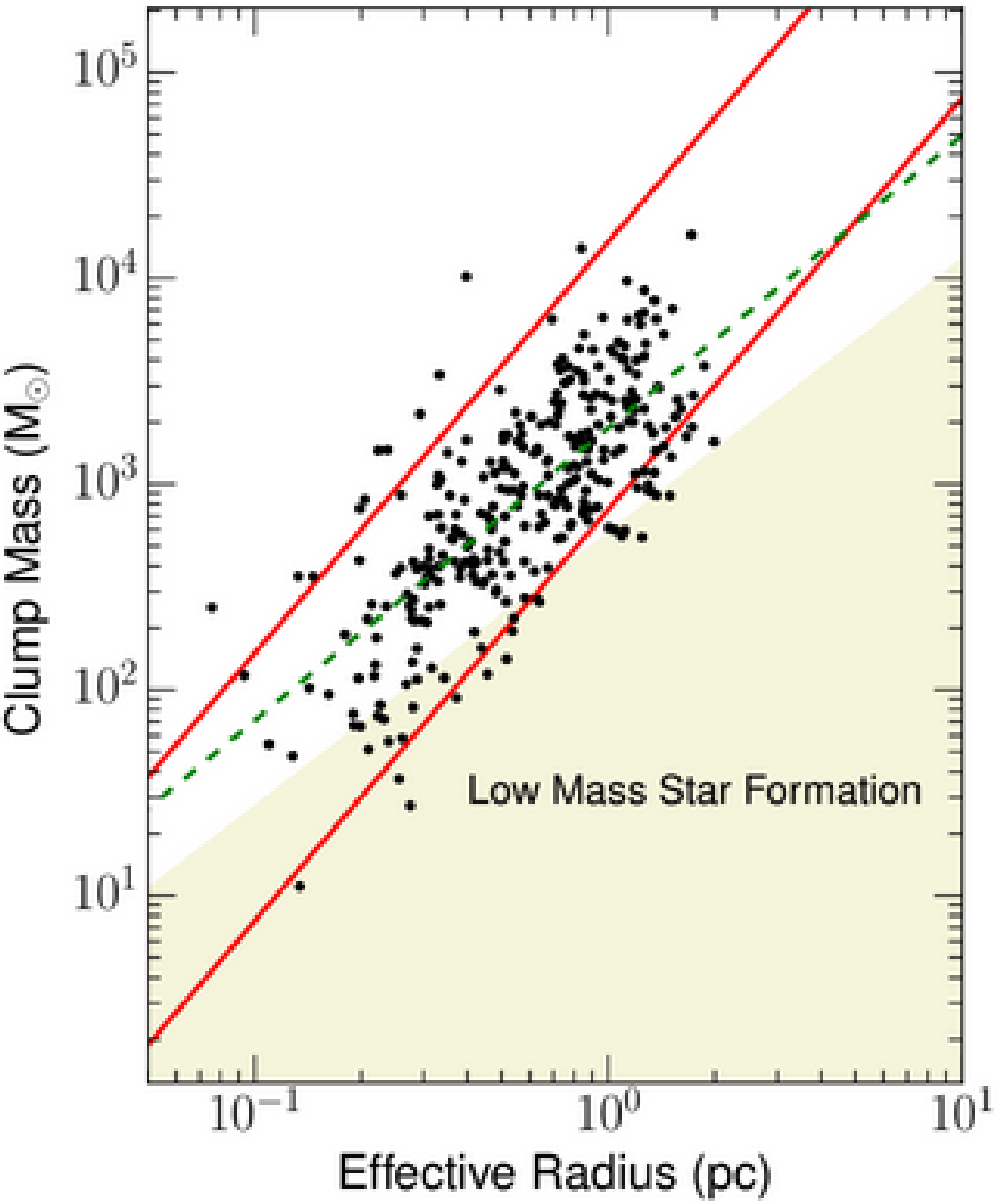
Summary

Parameter	Mean	Standard deviation	Median	Min	Max
Effective radius (pc)	0.67	0.41	0.62	0.03	2.01
Surface Density (gm cm^{-2})	0.31	0.47	0.17	0.01	3.77
Clump Mass ($M_\odot$)	1.86×10^{3}	2.46×10^{3}	1.01×10^{3}	26.32	1.63×10^{4}
Column Density (cm^{-2})	1.76×10^{24}	2.41×10^{24}	1.16×10^{24}	7.95×10^{22}	8.12×10^{25}
FIR luminosity ($L_\odot$)	1.98×10^{4}	3.91×10^{4}	6.22×10^{3}	78.93	3.11×10^{5}

M-R Diagram

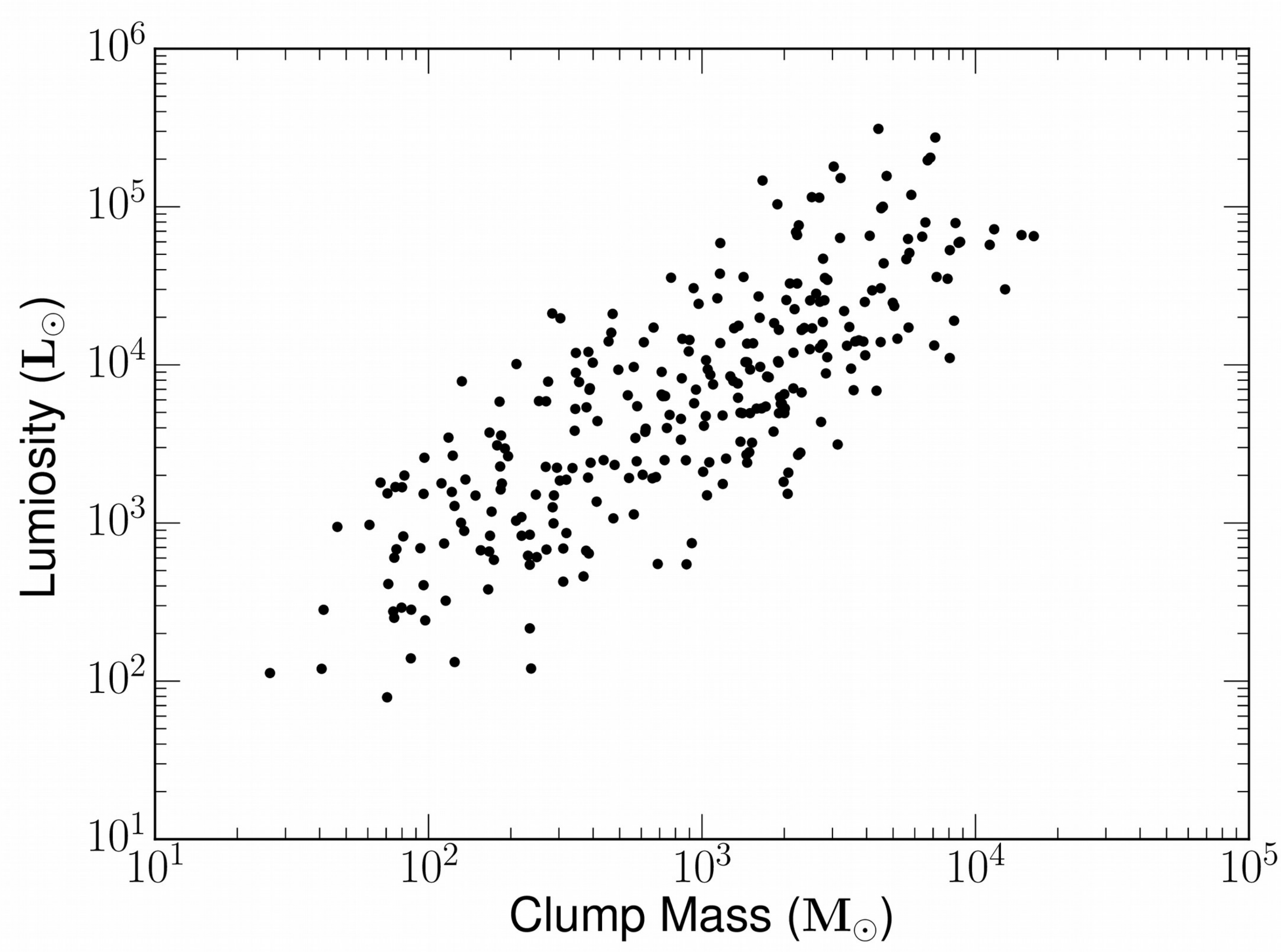
Lower limit for high mass star formation is given by $M(r) \geq 580\ M_{\odot}\ (r_{eff}/pc)^{1.33}$

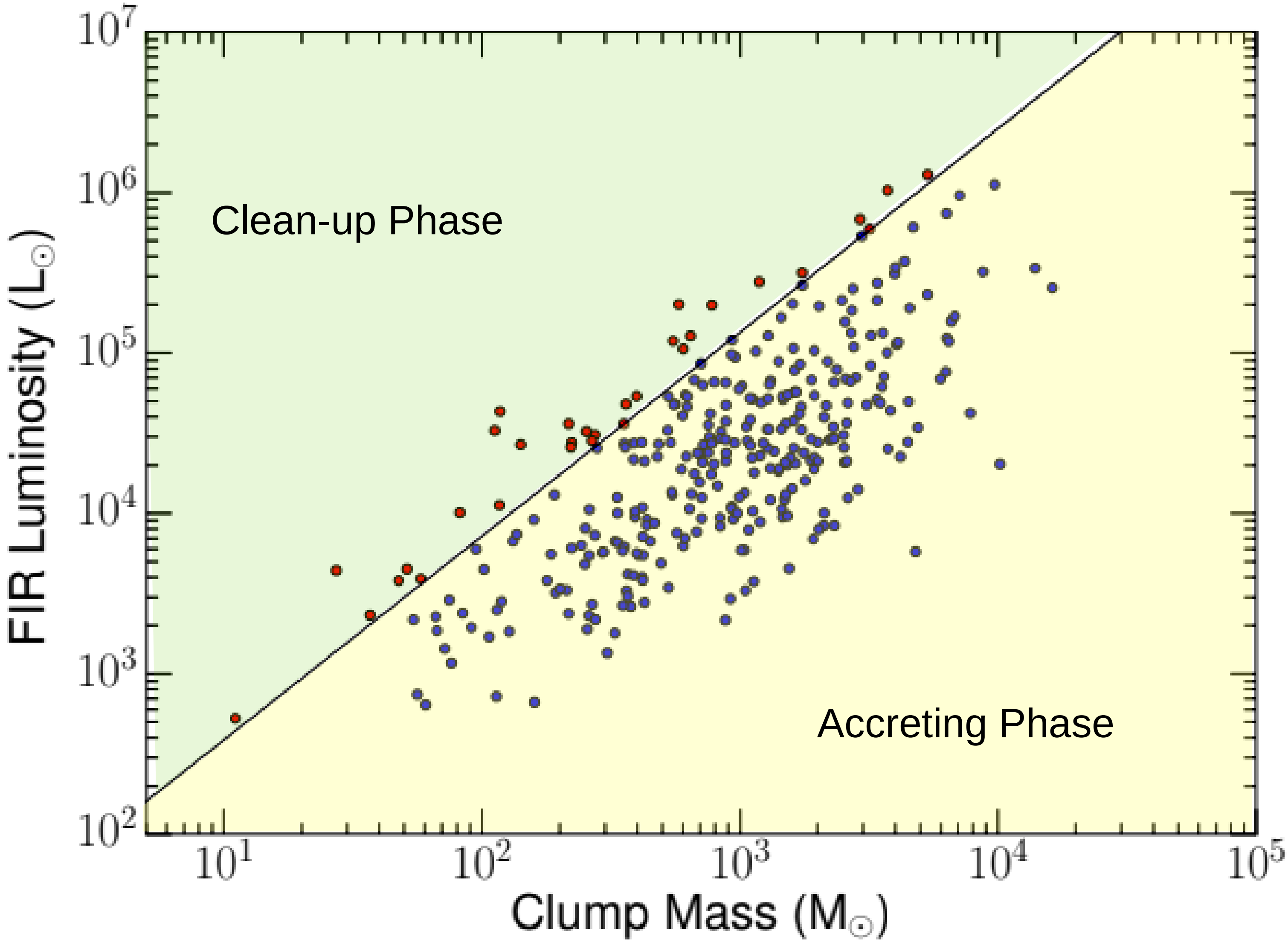
Kauffman et al. (2010)



Our Studies	Urquhart et al (2013)
Hyper (Gaussian aperture) (Traficante et al. 2015)	ATLASGAL Fluxes from SExtractor (Contreras et al. 2013)
Measures the flux of the compact source	Flux of the entire clump including the diffuse emission around the compact source
Dust temperature derived by fitting the SED	Assumption of a uniform dust temperature of 20 K

Luminosity-Mass Diagram





Molinari et al. 2008

91 % AP

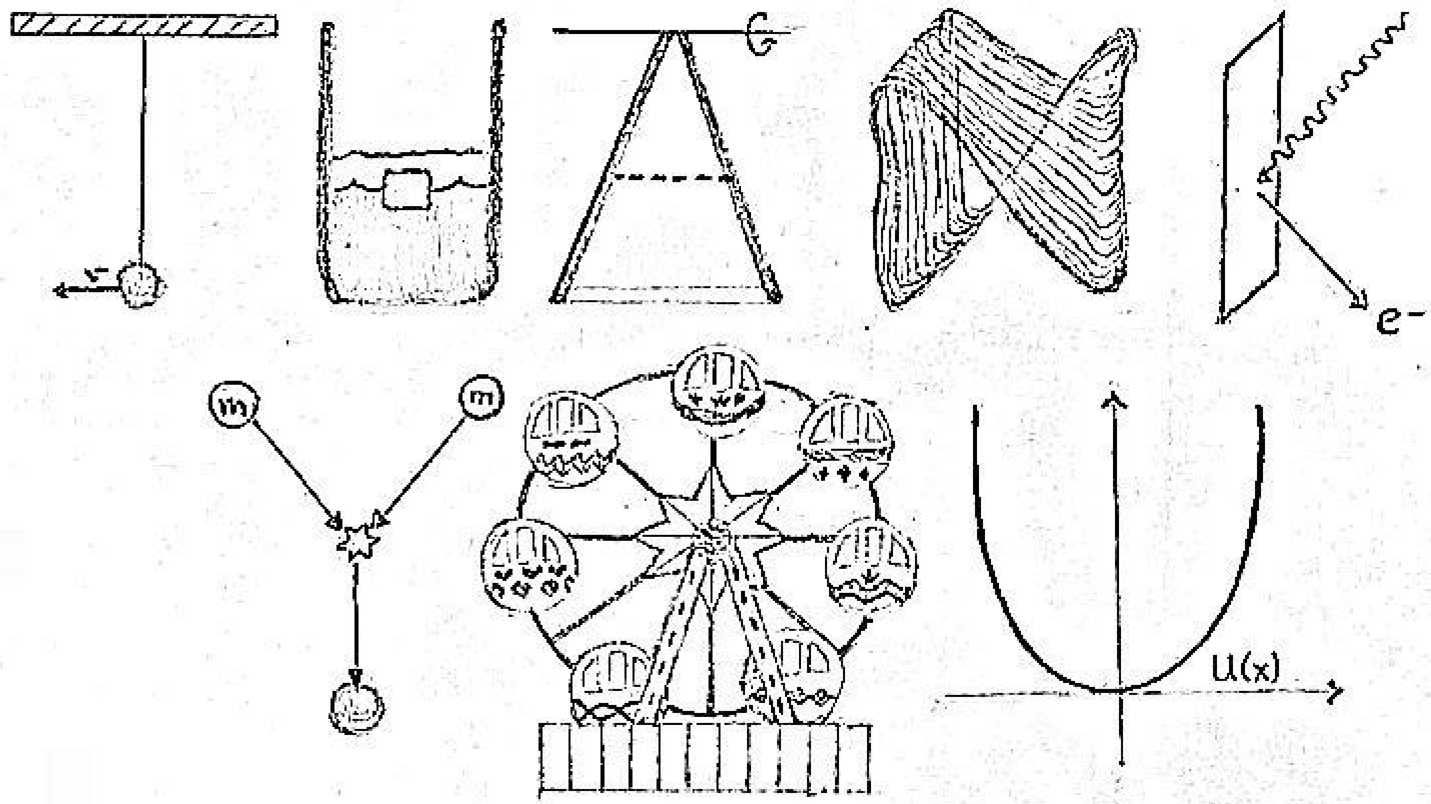
Are 6.7 GHz methanol masers exclusively associated with massive star formation?

- A small population of 6.7 GHz methanol masers which may be associated with intermediate or low-mass stars.
- 11 M⊙ --> likely to form a star < 8 $M_{\odot}$
- A similar conclusion was inferred by Urquhart et al. (2013a)
- The mechanism by which 6.7 GHz methanol masers are excited by low-mass protostars is not clear.
- 6.7 GHz maser action in low-mass protostars may be restricted to select geometries wherein the physical conditions for maser pumping are satisfied.
- This might be the reason why the vast majority (> 95%) of the methanol masers are associated with high-mass star formation.

Conclusions

- All sources are fitted with grey body models with T ranging from 11- 48 K
- The clump masses ranging from 11 – 10^5 $M_{\odot}$ --> most of them have the potential to form at least one massive star.
- The bolometric luminosities for the whole sample ranging from 10^2-10^5 $L_{\odot}$
- The L-M diagram indicates that the methanol maser sources are at their early evolutionary stage with majority of them being in the accretion phase.
- There also appears to be a small population of sources that are likely to be associated with intermediate mass stars

  Suggests association between high-mass star formation and methanol maser emission is not exclusive.


e⁻
m
m
U(x)