Synthetic Observations of Galactic Clumps

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Motivation:

– SN-driven 3D simulation: real star formation
– Synthetic observations of Herschel bands
– To compare the infall rates derived from observation and actual infall rates to understand (interpret) massive star formation (observations):

1. The Larson velocity-size relation in Traficante et al. 2018
2. The infall rate in Traficante et al. 2017

In this work, we study the physical properties of the clumps and compare them with the catalog of Hi-GAL compact sources extracted in the inner Galaxy, to make sure we have a clump catalog that compares well with the observations.

Outline

1. SN-driven simulation

2. Synthetic observations

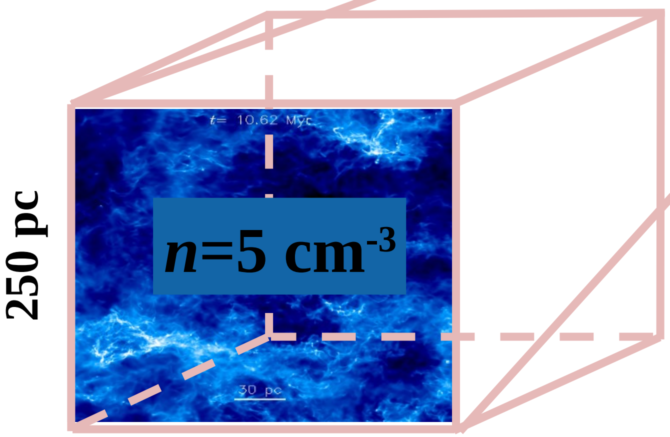
3. Detection of the clumps (CuTEx)

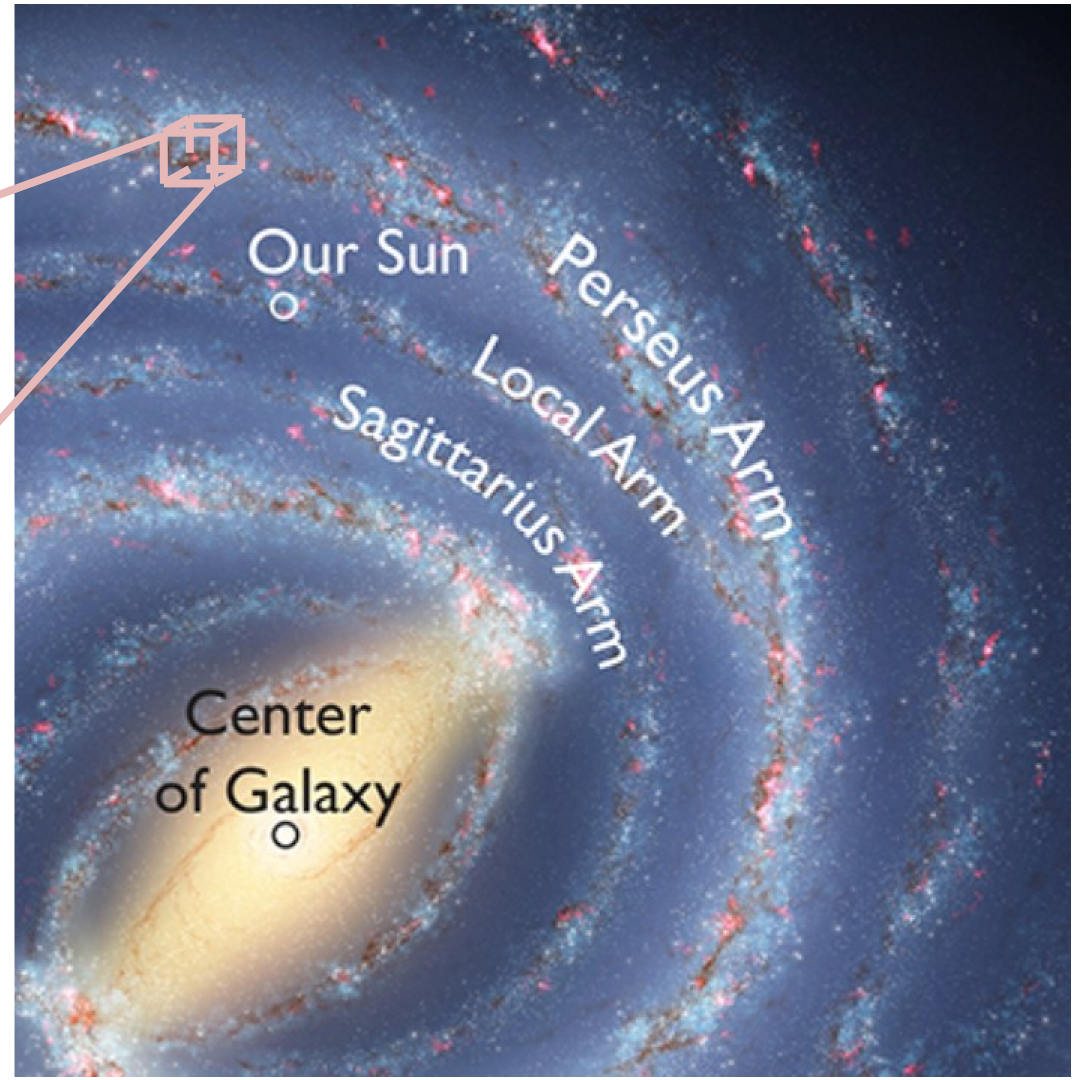
4. Properties of the clumps

5. Summary

We simulate a 250 pc (*periodic*) 2.E6 $M_\odot$ chunk of a spiral arm (*Ramses*)

With SN driving the outer scale is $\lesssim$ 100 pc.





First random SNe, ~6 SNe/Myr

Then ***real SNe*** from resolved stars for the first time.

Model Setup (*Ramses*):

Physics: 3D MHD equations, parametrized cooling and heating, individual SNe (thermal energy with exponential profile)

Resolution: dx=0.0076 pc (512^3 root grid + 6 AMR levels), $\boldsymbol{r_{SN}}$**=3dx=0.02 pc**, 2.5e8 tracers

AMR criteria: pressure and density *gradients*, density levels (dx / λ_J = const)

Initial conditions: Uniform n=5 cm^{-3}, uniform B=4.6 muG

Total time: 45 Myr with random SNe + 45 Myr with self-gravity, SF and **real SNe**

A huge sample of stars and clouds formed ab initio:

hundreds of SNe and MCs and ~13,000 stars to date

Synthetic observation

Method: Juvela's code: SOC radiative transfer program (Juvela 2019)

SOC is a Monte Carlo RT program for the calculation of dust emission and scattering.

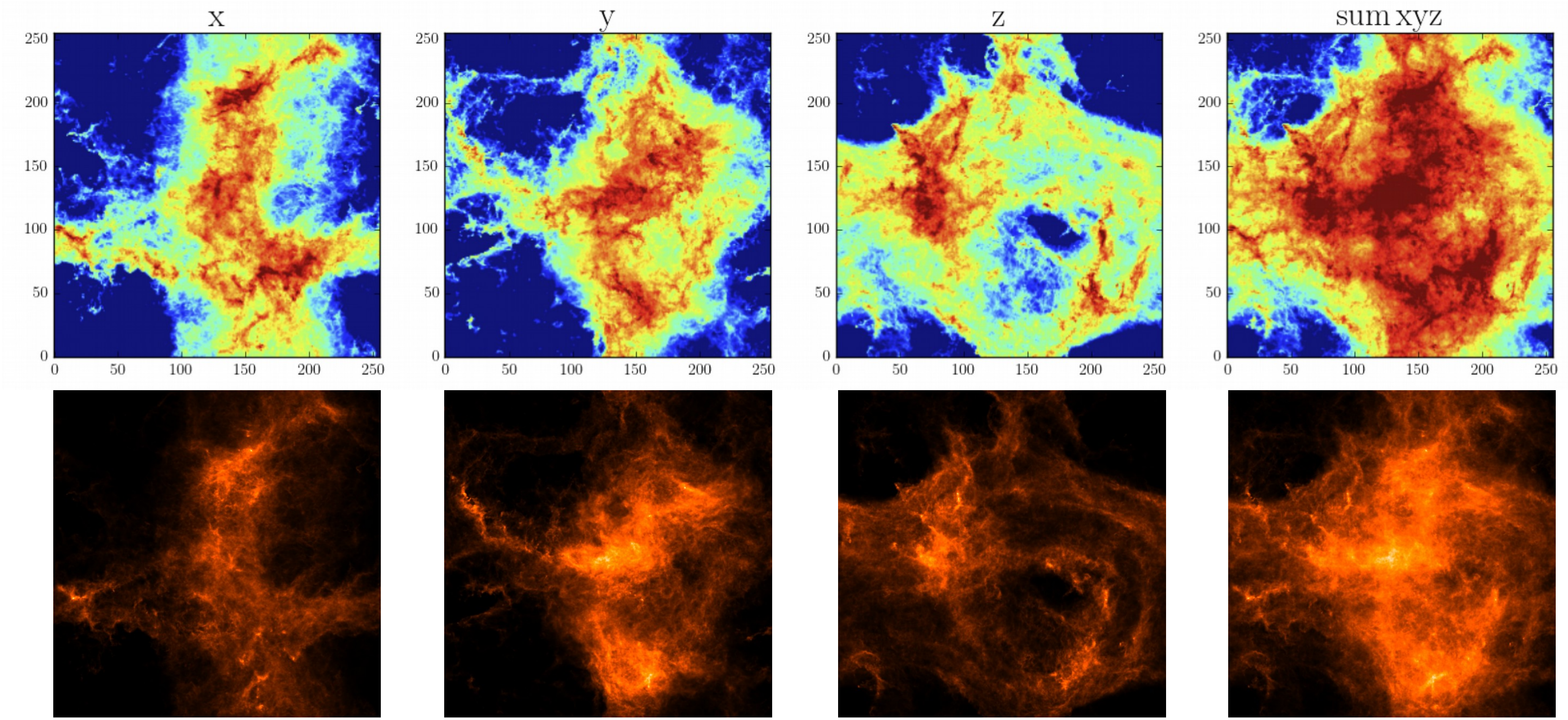
Physical resolution of synthetic observation simulation: 0.0305 pc

All stars with masses >2 Msun, number of stars: 8050

Maps: at Herschel bands: 70, 160, 250, 350, 500 microns
4 different distance: 2, 4, 8, (12) kpc
(Maps are resampled, so that Herschel beam is 3 pixels in each map.)
3 directions: x, y, z

Total maps: 60 maps

Density and synthetic observation maps



Simulation time: ~ 89.63 Myr, 250 micron map.

Detection and flux extraction by CuTEx

- Synthetic observations of Herschel bands
- Clumps detection with the CuTEx code developed by Molinari et al. 2011

- **CuTEx** – Curvature Thresholding Extractor

CuTEx was designed to find and extract point sources from star forming regions, 1 beam to 3 beams in size.

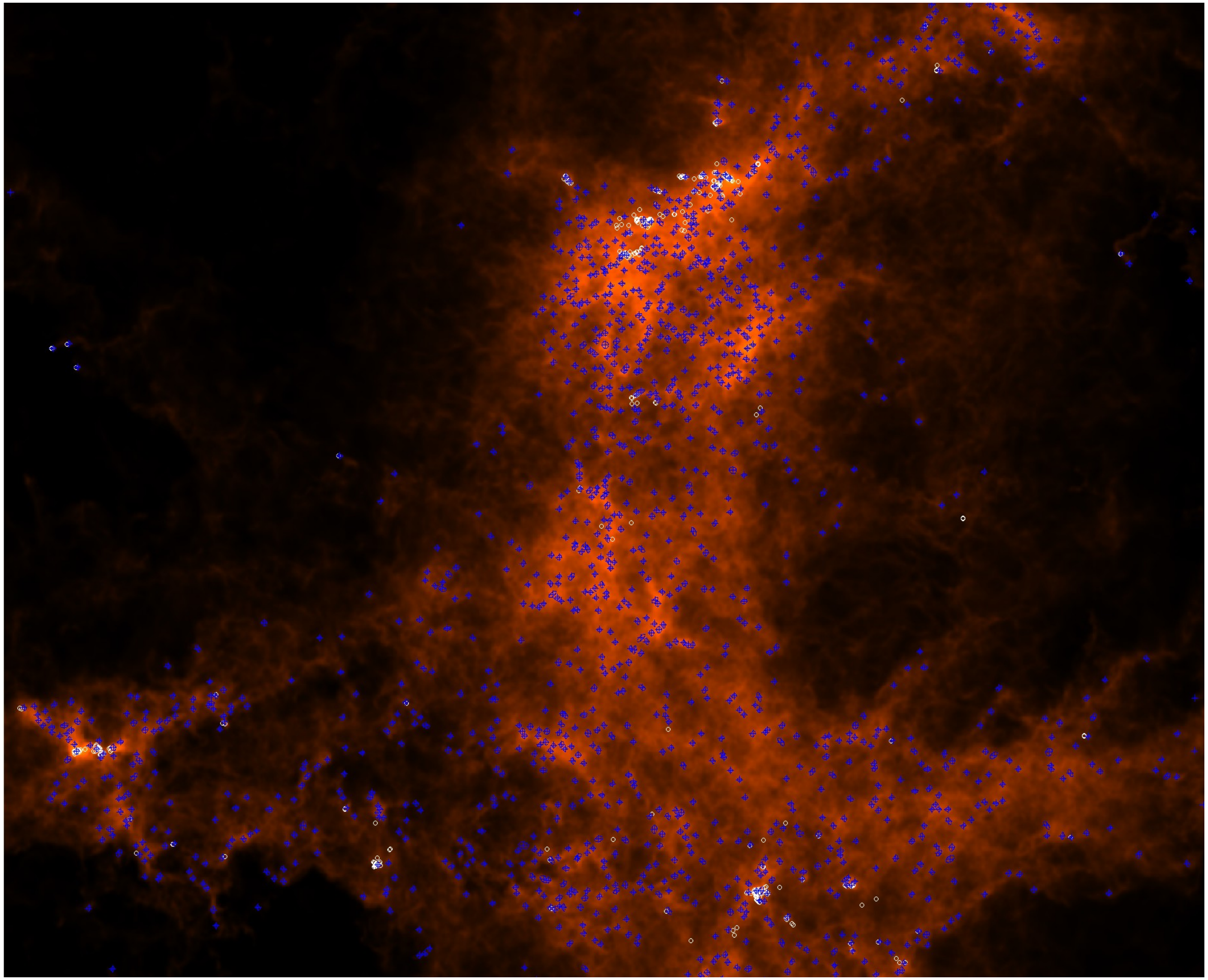
Two main algorithms: source detection and flux extraction.

Detection: the technique at the base of the CuTEx detection is the use of the second derivatives.

Flux Extraction: the source list produced by the detection software is used as input for the photometry routine. The peak positions are fitted with a 2D Gaussian profile plus a plateau model.

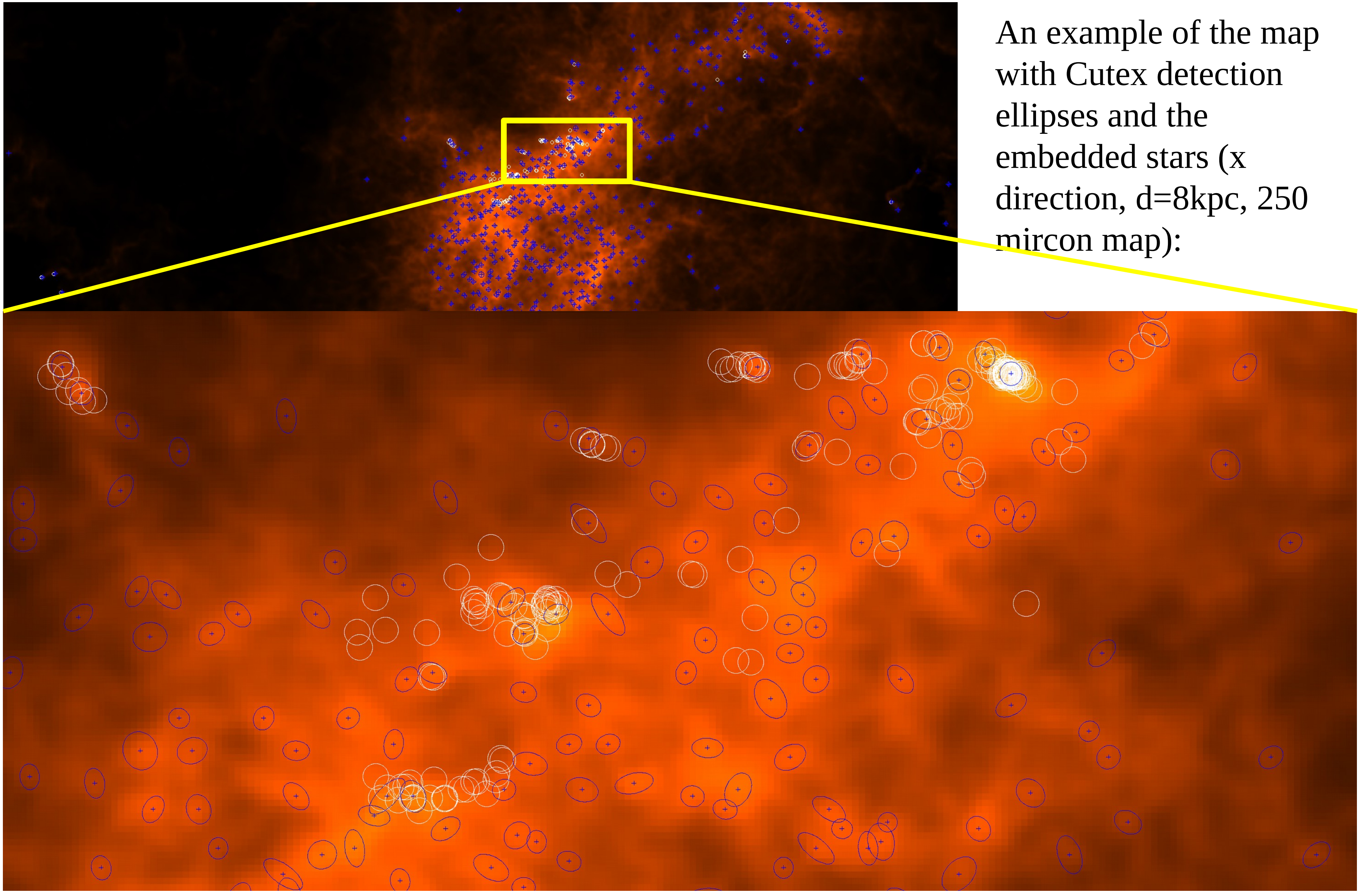
Molinari, et al. 2011

Detection by CuTEx



An example of the map with Cutex detection ellipses and the embedded stars (x direction, d=8kpc, 250 mircon map):

Detection by CuTEx



An example of the map with Cutex detection ellipses and the embedded stars (x direction, d=8kpc, 250 mircon map):

Band merging

Method:

1. Starting from the 500 micron sources, we seek detections at shorter wavelengths that are a positional match.

2. Taking the center of 350 micron sources, and check which ones fall inside a circle around the 500 micron source (radius = $0.5*(FWHM_1^2+FWHM_2^2)^{1/2}$).

500+350 associations, together with the 350-only (no 500 micron counterpart)

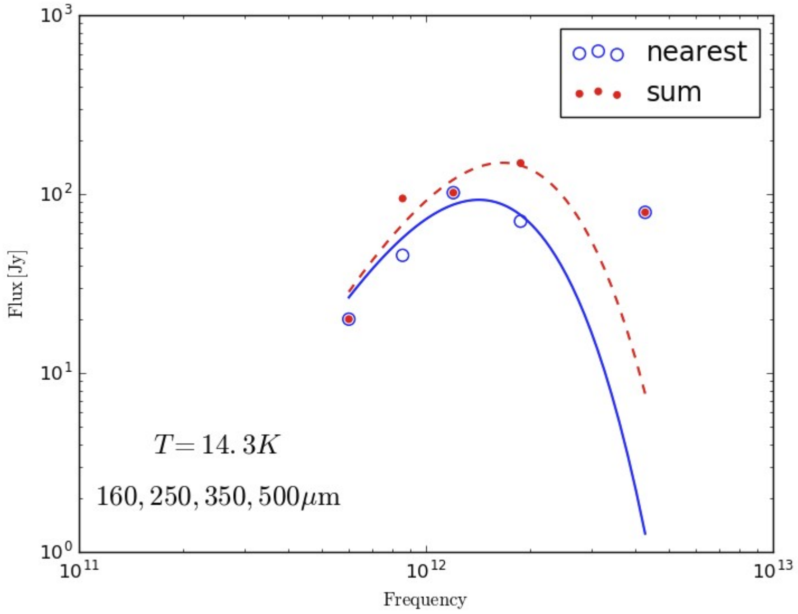
3. Starting searching for next association with the 250 and 160 microns.

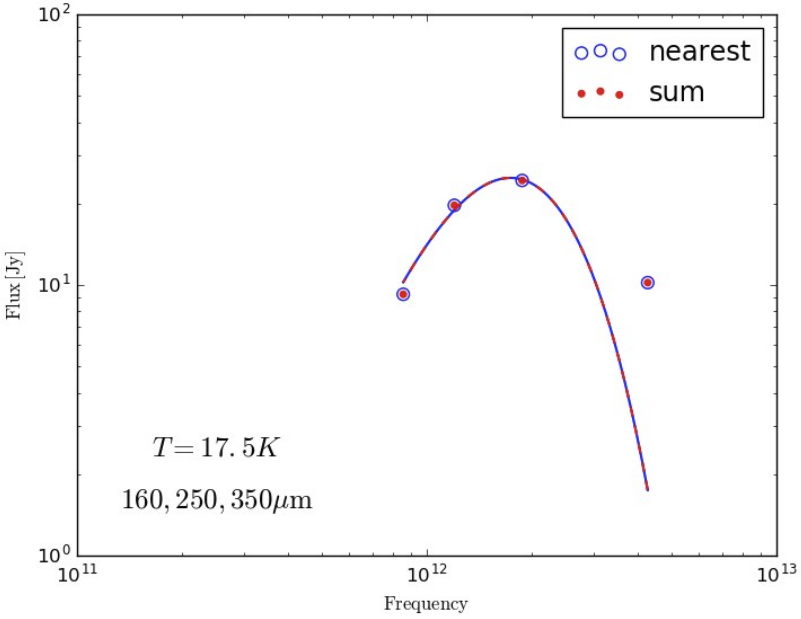
– **nearest**: just take the flux of the closest source in distance whose center falls inside the source of the longer wavelength.
– sum: the sum of the fluxes of all sources within the circle.

Detected at least in three consecutive Herschel bands:
the combinations of 160–250–350 or 250–350–500, or 160–250–350–500 microns.

SED fitting

1. With detection in at least three adjacent bands between 160 and 500 micron, to contain the peak of the emission of the cold dust;
2. Without a dip in the SED between three adjacent wavelengths.
3. Flux at 350 micron > Flux at 500 micron





– SED fitting with grey body function (least-square fitting).
– The highest frequency point is 70 micron, but it is not part of the SED fitting.

How to calculate clump mass ?

The grey body function:

$$F_\nu = (1 - e^{-\tau_\nu})B_\nu(T_d)\Omega$$

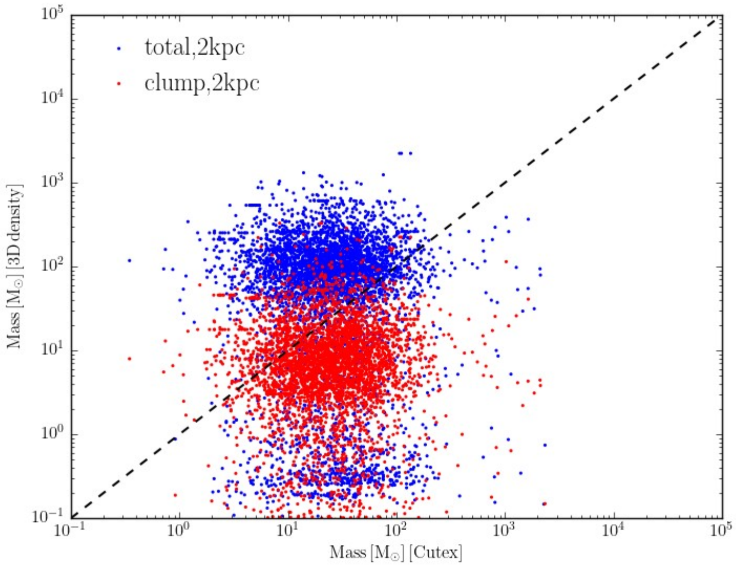
The optical depth:

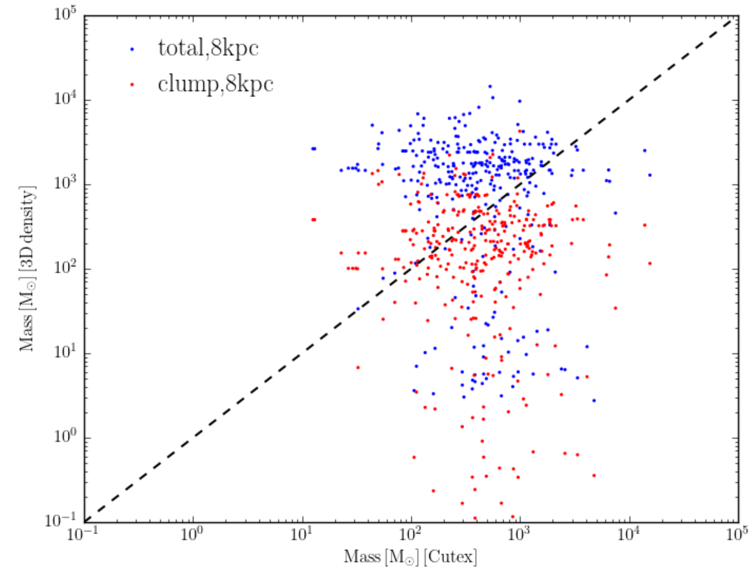
$$\tau_\nu = (\nu/\nu_0)^\beta$$

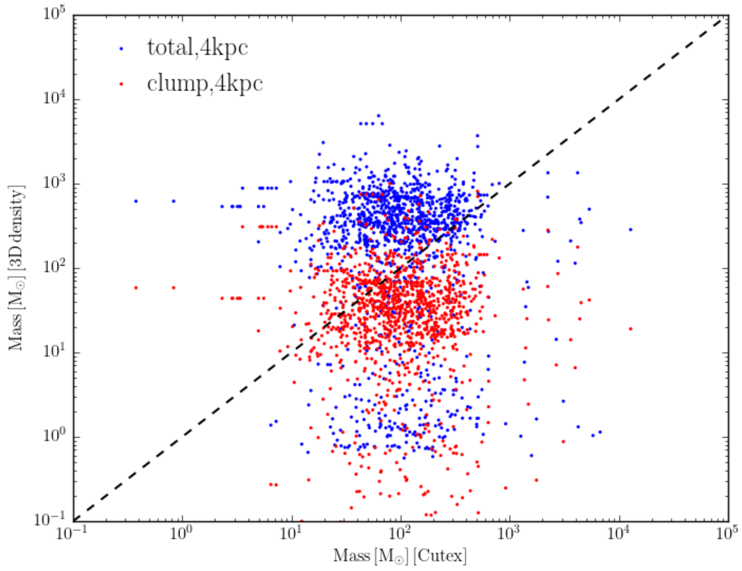
$$M = (d^2\,\Omega / \kappa_{ref})\,\tau_{ref}$$

$$M = [\,F_\nu\, d^2 / \kappa_{ref} / B_\nu(T_d)\,]\;(\nu_{ref}/\nu)^\beta$$

Clump masses calculated from 3D density





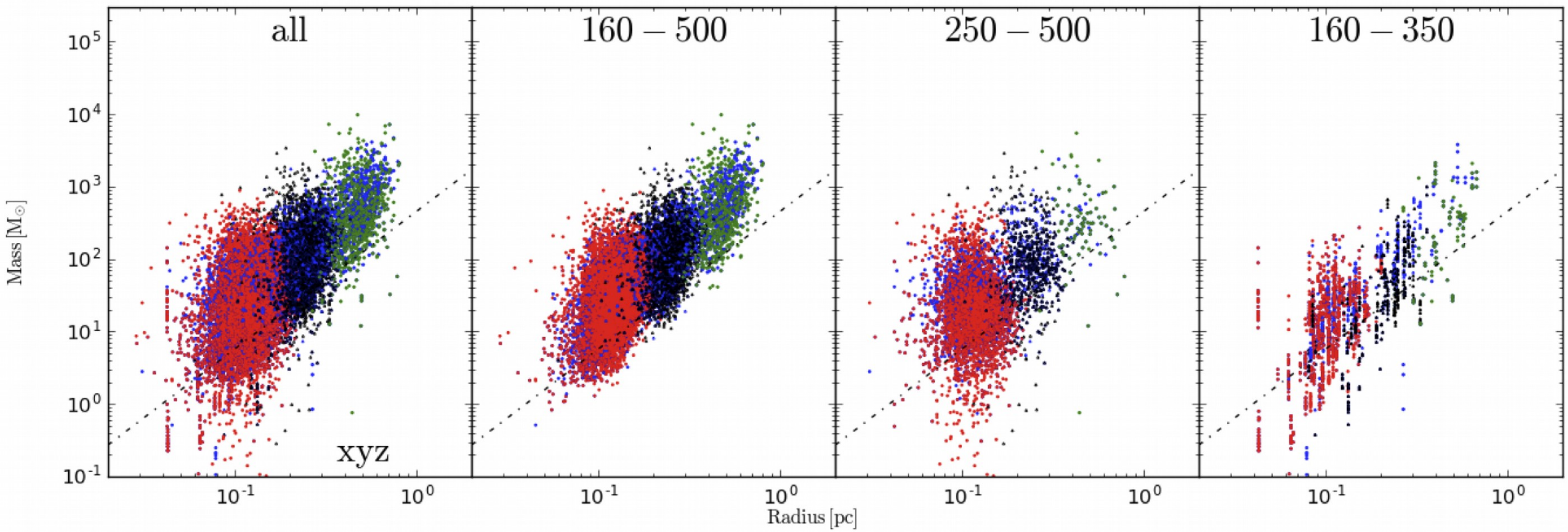


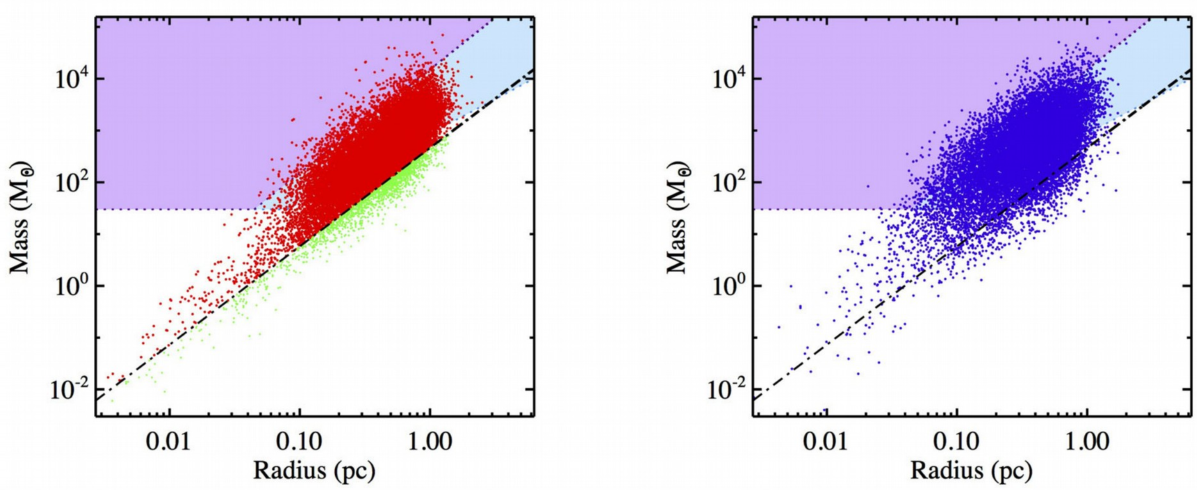
– Comparing the clump mass derived from CuTEx with those calculated from 3D density mass.

– Clump: the most dense region in the line of sight (mass within radius of the clump)

– Total: total mass in the line of sight on footprint of the clump.

Clump mass vs radius



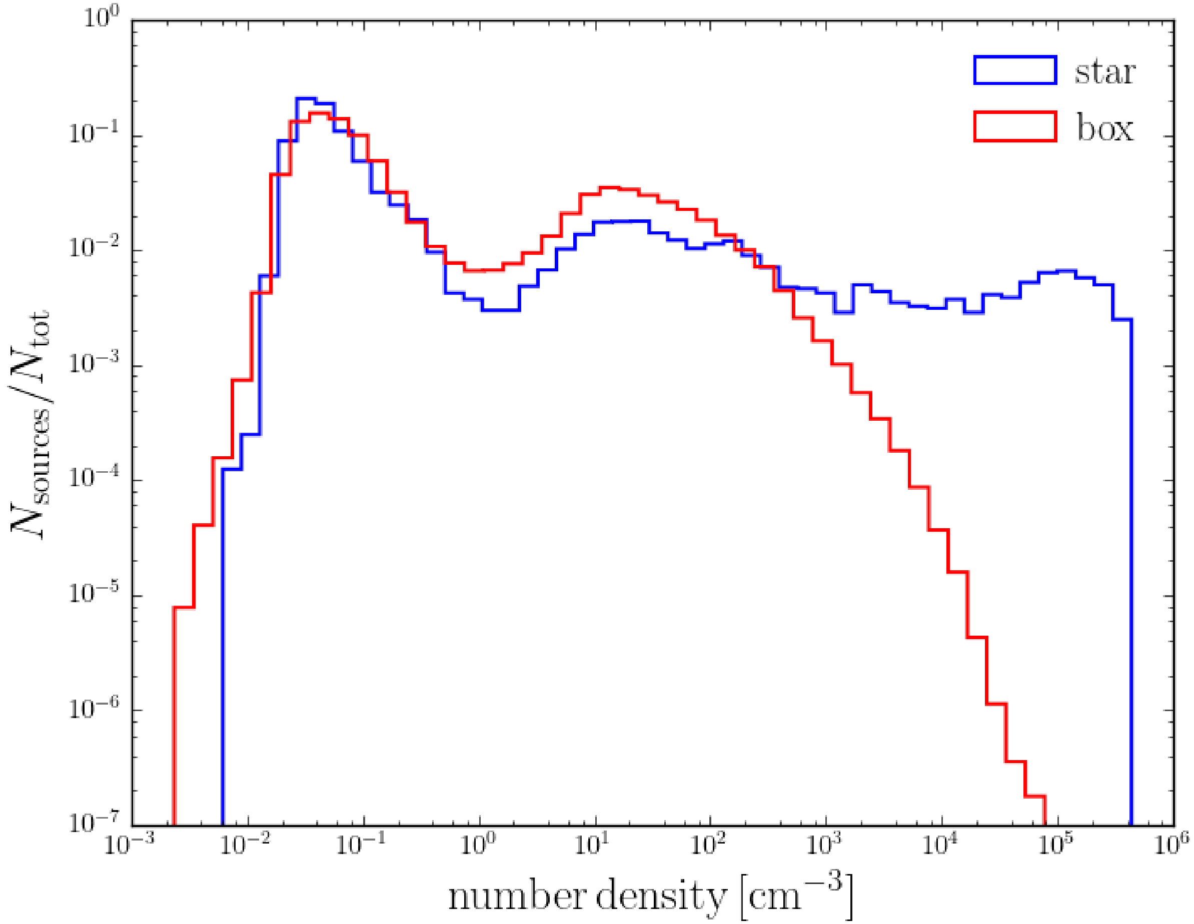


Elia et al. 2017

The beam-deconvolved diameter are as estimated by CuTEx:

$$\theta_\lambda = \sqrt{\mathrm{FWHM}_{\mathrm{maj},\lambda} \times \mathrm{FWHM}_{\mathrm{min},\lambda} - \mathrm{HPBM}_\lambda^2}$$

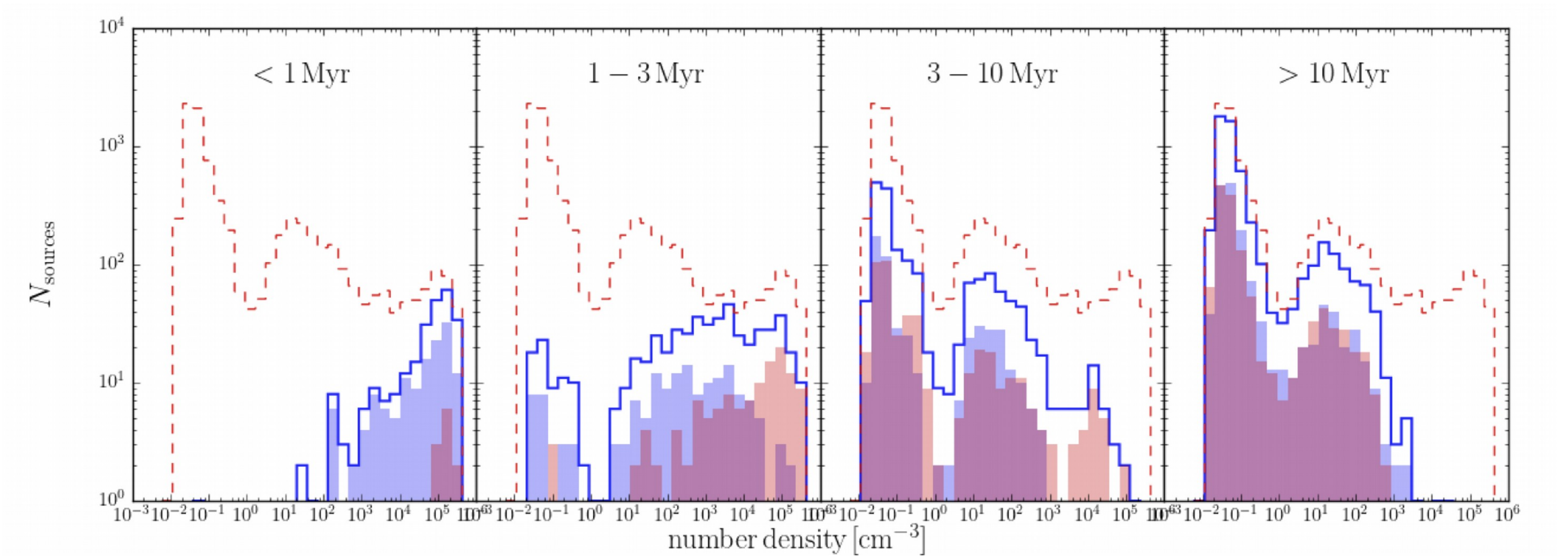
Distribution of number density of star environment



Box resolution: 1024
(physical resolution=0.25 pc)

Density of star environment:
mean number density within
R ~ 0.37 pc
(resolution=4096)

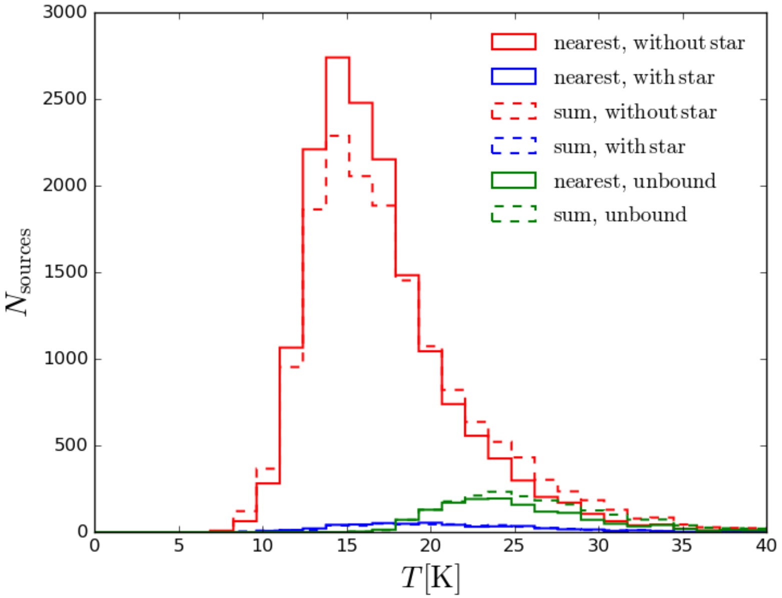
Distribution of number density of star environment

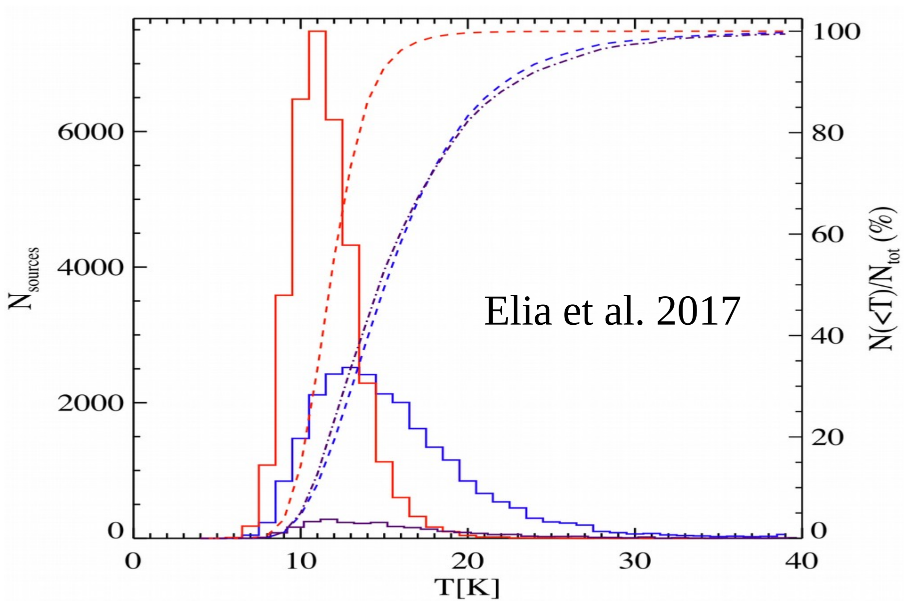


– Blue bar histogram: star mass < 5 Msun, pink bar histrogram: >20 Msun

– Younger and massive stars dominate the most dense peak.

T distribution of prestellar and protostellar





– Elia et al. 2017:

The sources have a 70 micron counterpart and are thus considered as protostellar. While the remainder are considered as starless (unbound) or prestellar.

– Our clumps:

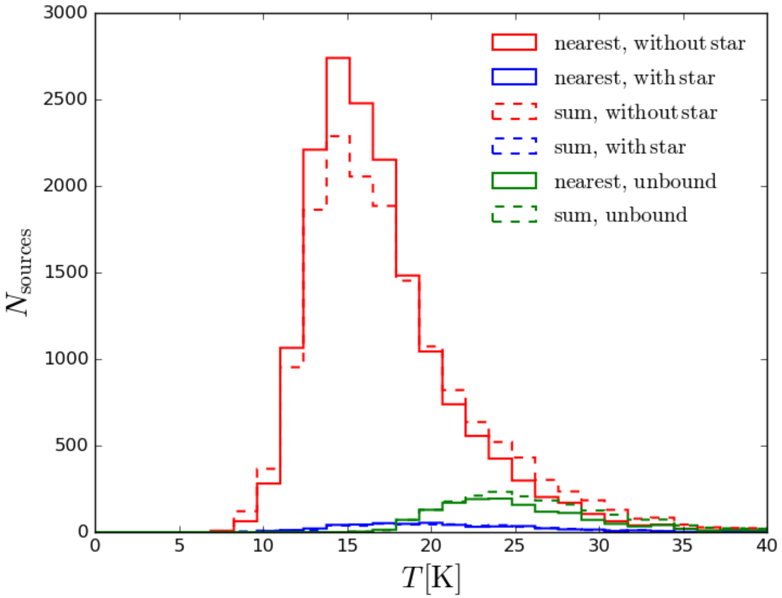
The sources which have a star in the line of sight footprint of geometry size are consider as protostellar.

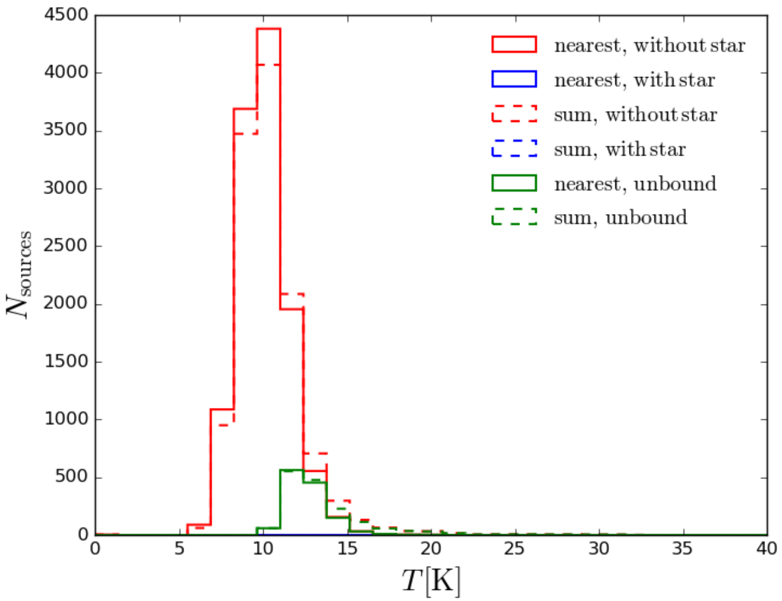
We just did the star matching of the embedded stars (number density >1e3 cm^{-3}).

Unbound starless:

$M(r) < 460$ Msun $(r/pc)^{1.9}$

T distribution without star sources





– Just background radiation.

– We have selected two earlier snapshots that have less stars.

–> We will have more environment cases.

Summary

1. We present a catalog of clumps of compact sources extracted in SN-driven simulation.

2. This work is still in progress.

3. We will do the molecular line calculations to measure gas velocities after we have a clump catalog that compares well with the observations.