Confusion limit of future Far-InfraRed observatory in spectroscopy

Negligible or unavoidable ?

Internship's Stakes

Why this mission ?

NASA PRIMA Mission selection : Far InfraRed or X-ray

→ Is a Far InfraRed mission a priority ?

Field unexplored after Herschel because of instrumental limitations (atmosphere & thermal emission)

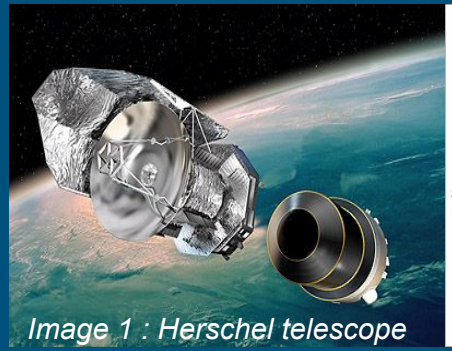


Image 1 : Herschel telescope

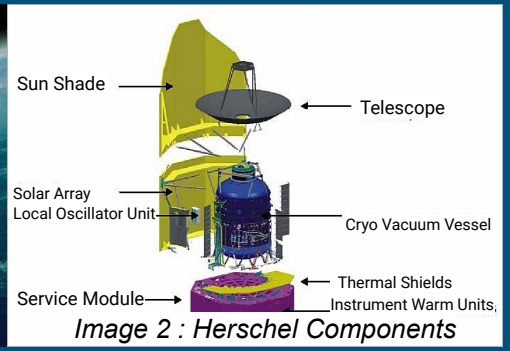


Image 2 : Herschel Components

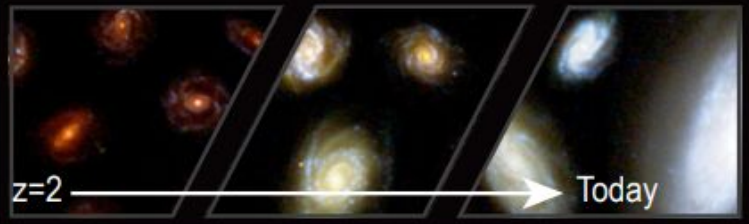
Image 3 : PRIMA telescope

Proposed project :

➢ Cryogenic mirror (~5K) : good sensitivity but limited size or poor resolution ⇒ confusion

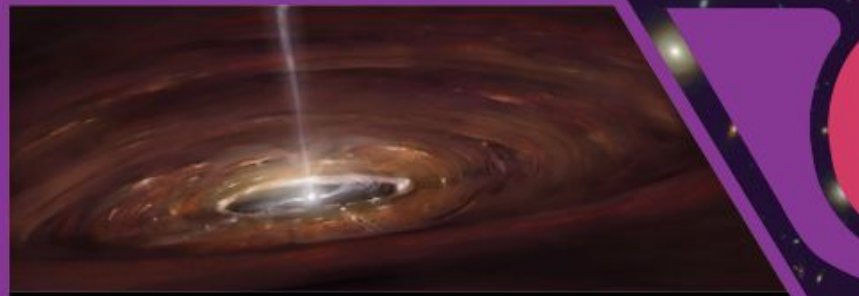
Effect studied in photometry but not in spectroscopy

Decadal Goal: Probe the co-evolution of galaxies and their supermassive black holes across cosmic time.



EVOLUTION OF GALACTIC ECOSYSTEMS

PRIMA Objective: Provide a simultaneous measurement of black hole and galaxy growth from the peak of their development at z=2 (cosmic noon) up to the present day, and determine if winds in luminous galaxies quench star formation.



Decadal Goal: Trace the astrochemical signatures of planet formation.

ORIGINS OF PLANETARY ATMOSPHERES

PRIMA Objective: Determine abundances in protoplanetary disks for comparison with exoplanet atmospheres and reveal whether water is essential to planet assembly.

Decadal Goal: Measure the buildup of heavy elements and interstellar dust from early galaxies to today.

BUILDUP OF DUST AND METALS

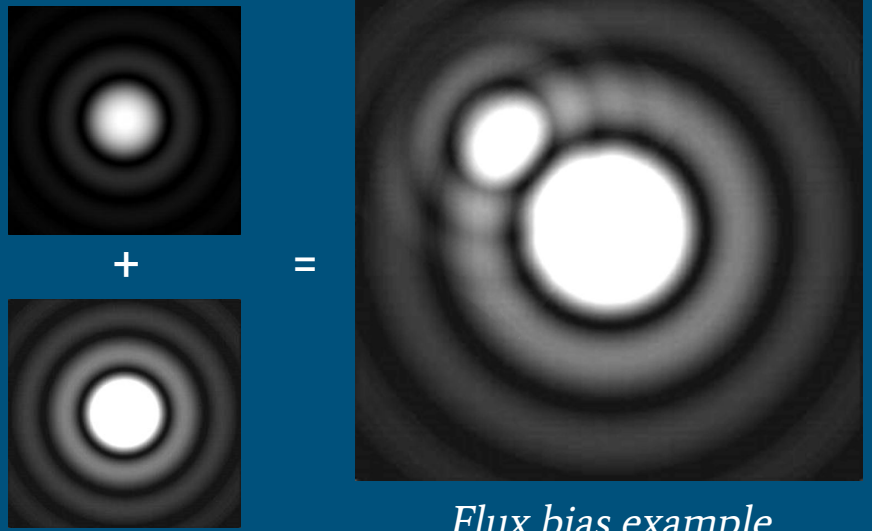
PRIMA Objective: Compare the dust properties and metal content of dusty galaxies from cosmic noon to the present day and quantify the diversity of dust environments in the local universe.

From PRIMA Website

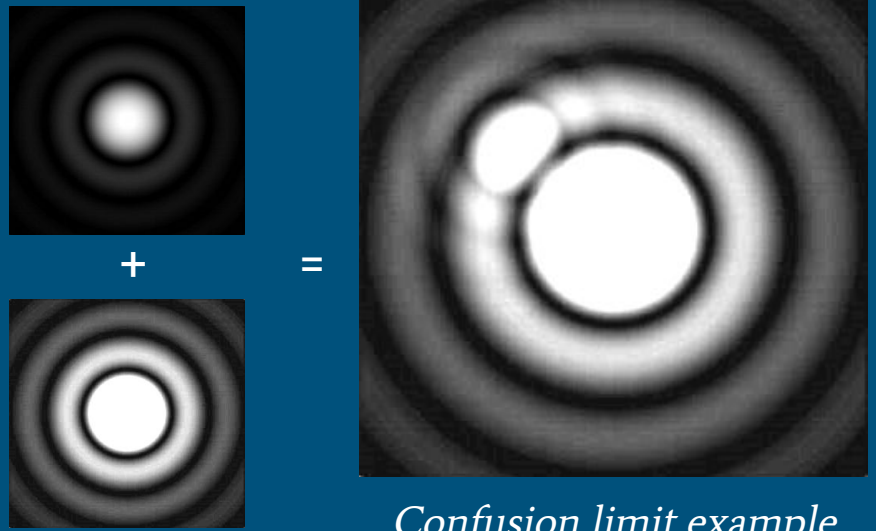
Confusion Limit & Flux Bias: Definitions

Confusion limit: faintest flux density at which we can extract sources reliably (in the limit of zero instrumental noise).

Flux bias : Ratio of brightest real flux / measured flux



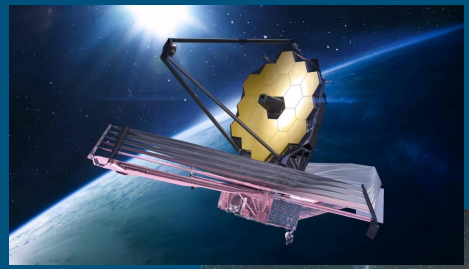
Flux bias example



Confusion limit example

Complete UV Observations

Space-Based Telescope



FIR Rays

Star/AGN

UV Rays

Ground-Based Telescope

Molecular Cloud + Dust

(lines ↔ 1% of the emission) (continuum)

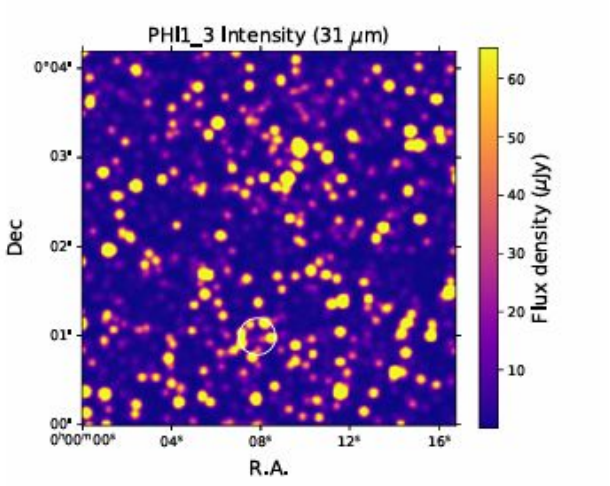
Study confusion limit - Continuum (PRIMA)

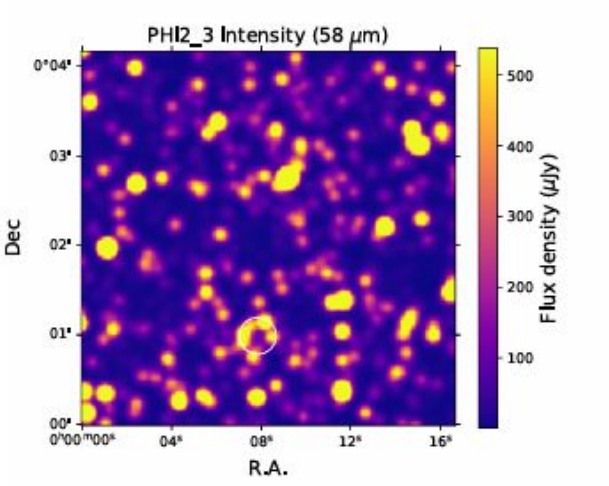
The Simulated Infrared Dusty Extragalactic Sky (SIDES) : *Semi-empirical Galaxy evolution simulation model*

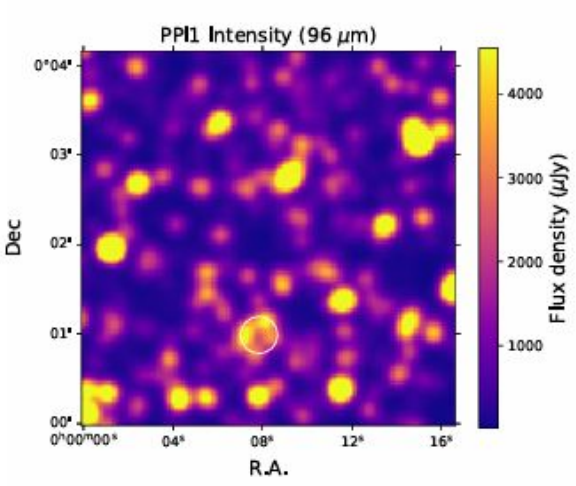
Simulated PRIMAger maps

affected only by the confusion noise

(and not the instrumental one)

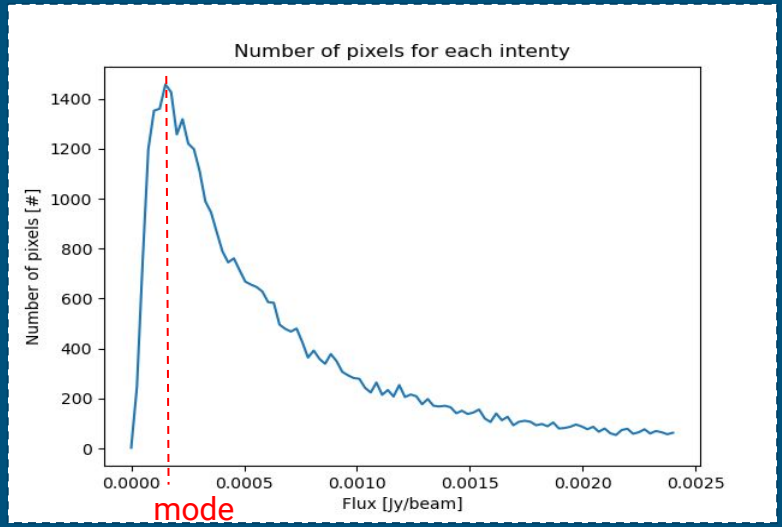




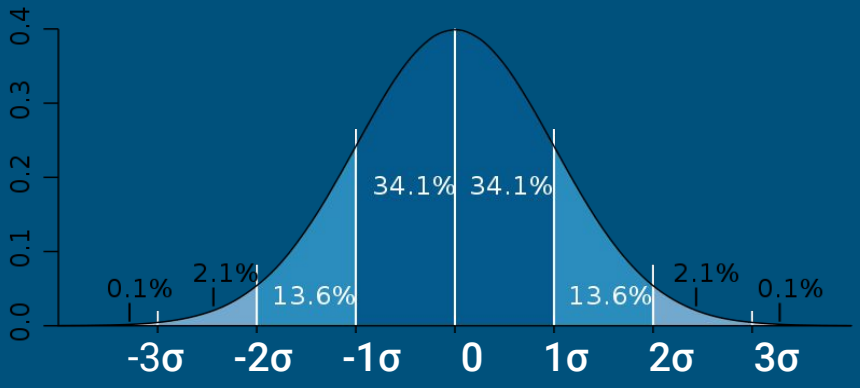


Background :

difficult to determine due to confusion
→ mode = artificial one



Standard deviation σ :



5σ commonly used in
Astrophysics & Particles Physics

→ analogy with Gaussian

↪ Probability of 0.00006% that the data are fluctuations and not a signal

Confusion Limit = mode + 5σ

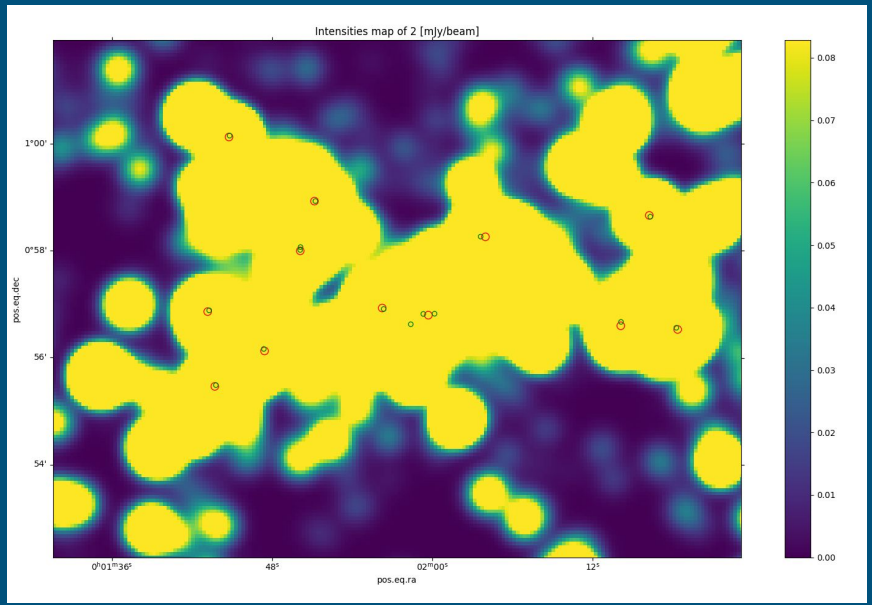
How reproduce confusion in a simulation

Reproduce the instruments behavior: convolution filter to blur each source

- realistic Airy function
- modulated by the distance

⇒ Creating confusion

We seek to return to the original source emitting with the right intensity as much as possible.



Peaks-Sources extraction

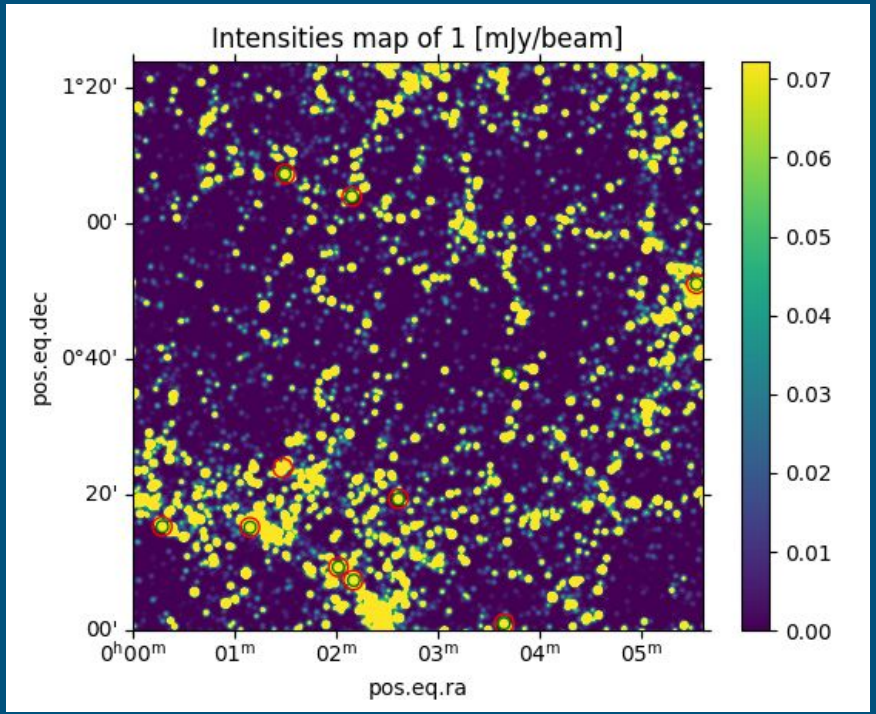
Objective :

Create our own extractor to detect sources above a given threshold.

(the mode previously calculated)

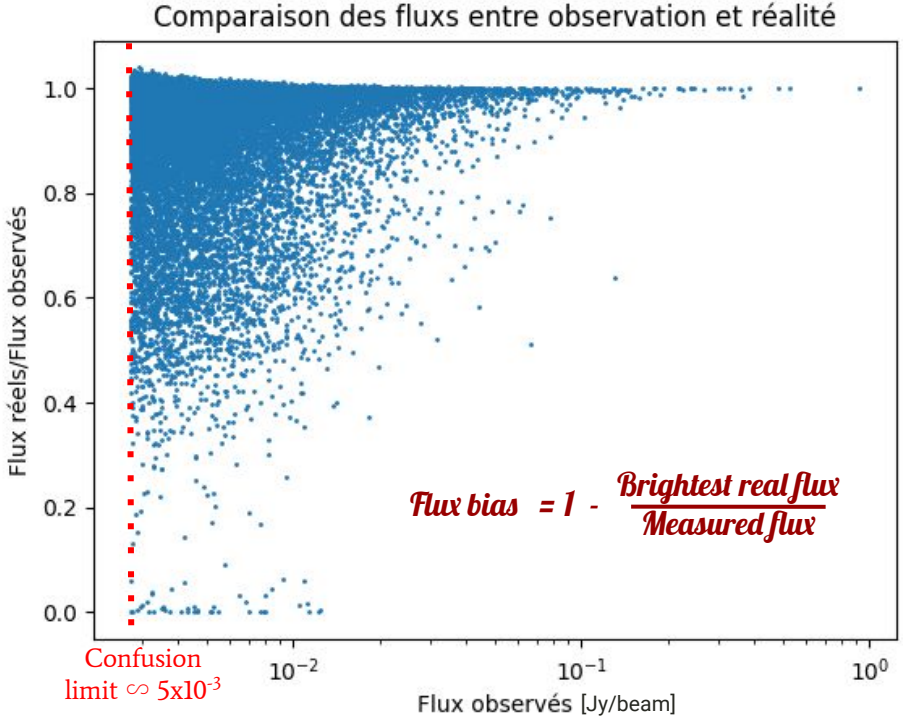
Then, comparison with an already existing source extractor.

Finally, match to the simulation input galaxy catalog.



Comparison of the 10 most intense sources

Confusion limit & flux bias (Continuum)



↪ Flux bias of 0

⇒ All the signal comes from the brightest galaxy

⇒ Non polluted source

↪ Flux bias close to 0.5

⇒ Half of the measured signal comes from neighbours

⇒ Polluted source

Retrieve Paper results :

Confusion Limit ∽ 4.6 mJy/beam

Spectroscopy

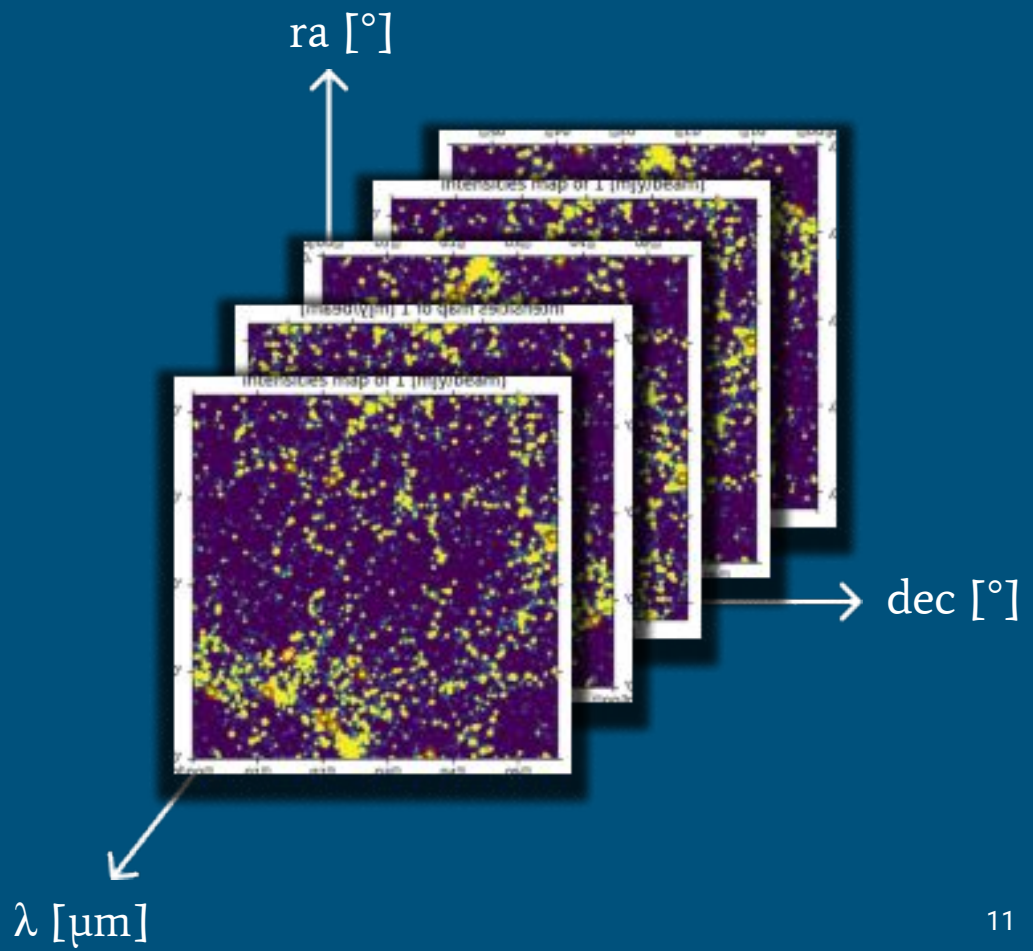
Generation of a 3D cube

(3rd dimension: frequency)

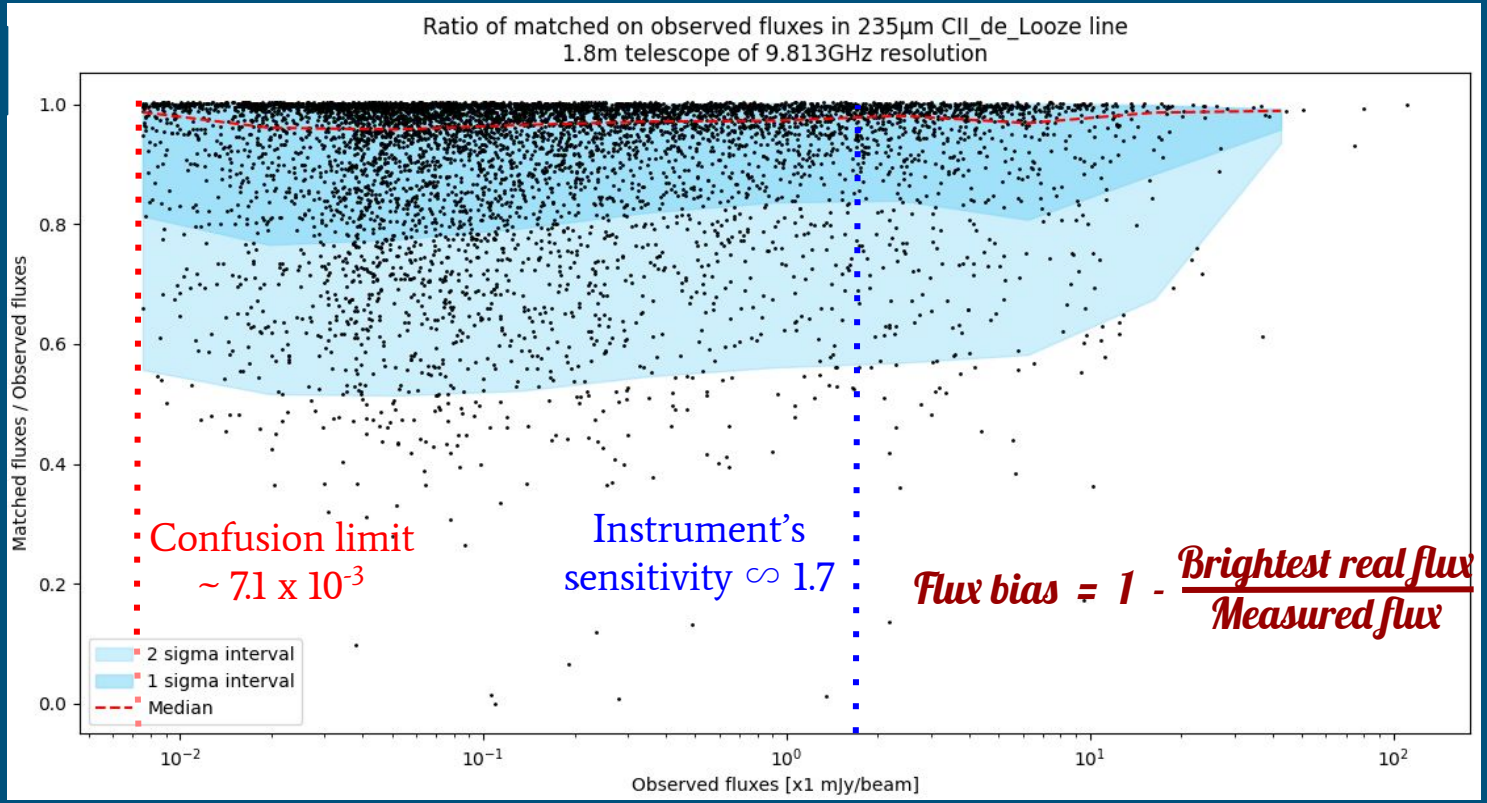
$$z = \frac{\upsilon_{emitted}}{\upsilon_{observed}} - 1$$

(redshift)

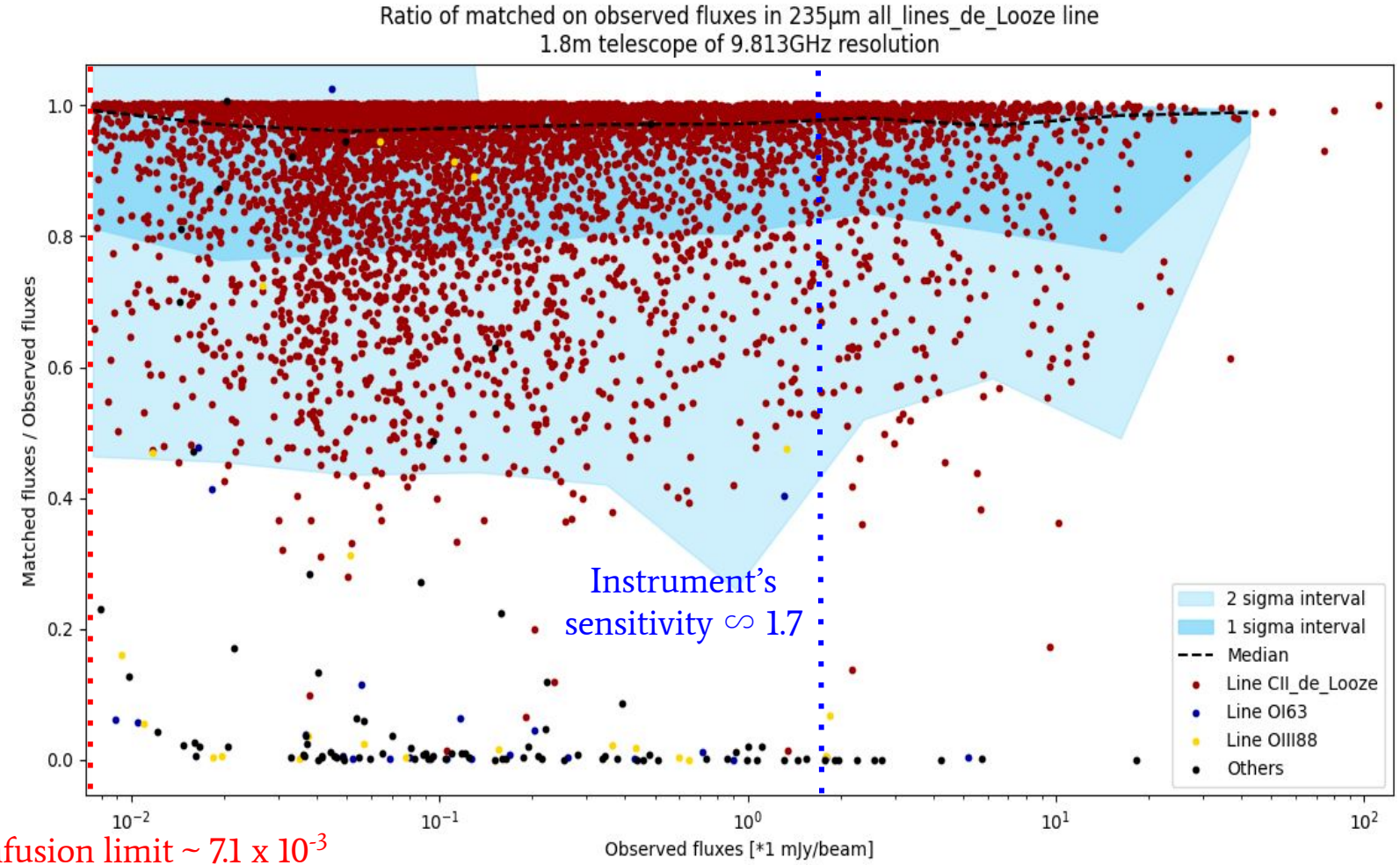
Is confusion negligible in spectroscopy ?



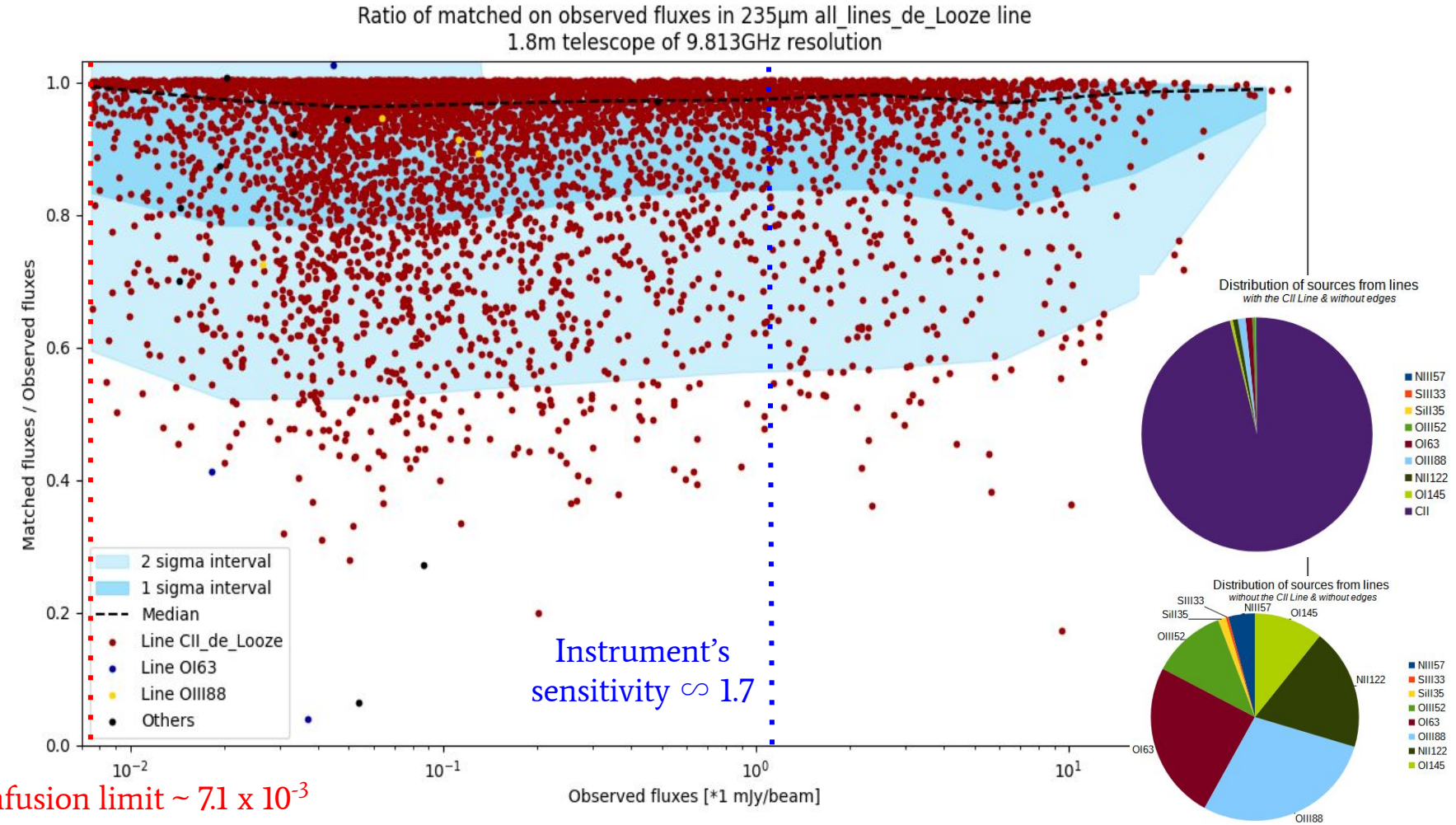
Determining the confusion limit



→ slight bias but 20 % come from overestimated sources



Confusion limit ~ 7.1 x 10^{-3}



Confusion limit ~ 7.1 x 10^{-3}

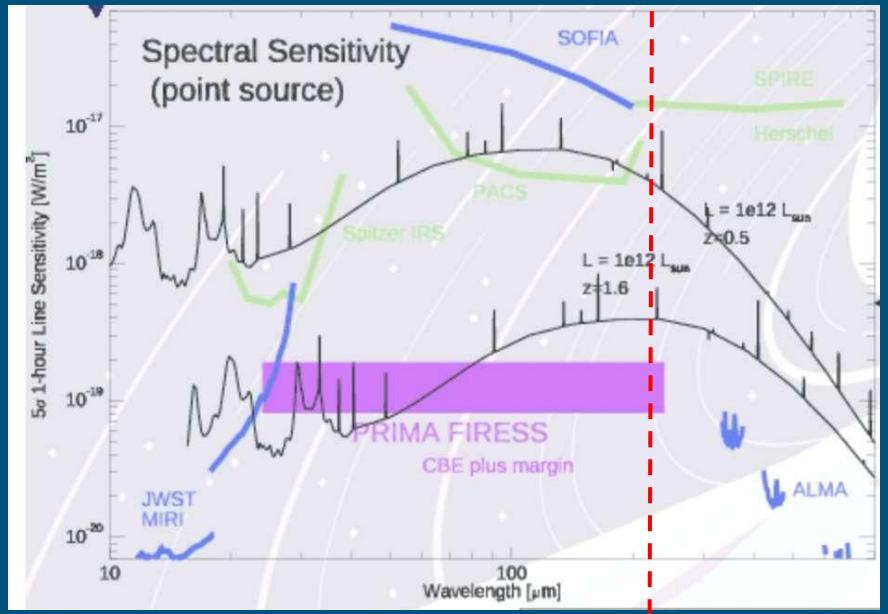
Instrumental limit

Sensitivity: 4 Jy km/s ⇔ 1.7341 mJy/beam

- Value ∽ 10^2 higher than the confusion limit
- Worst Case Scenario
- 1 hour observation value
- Sensitivity ∝ 1 / √time

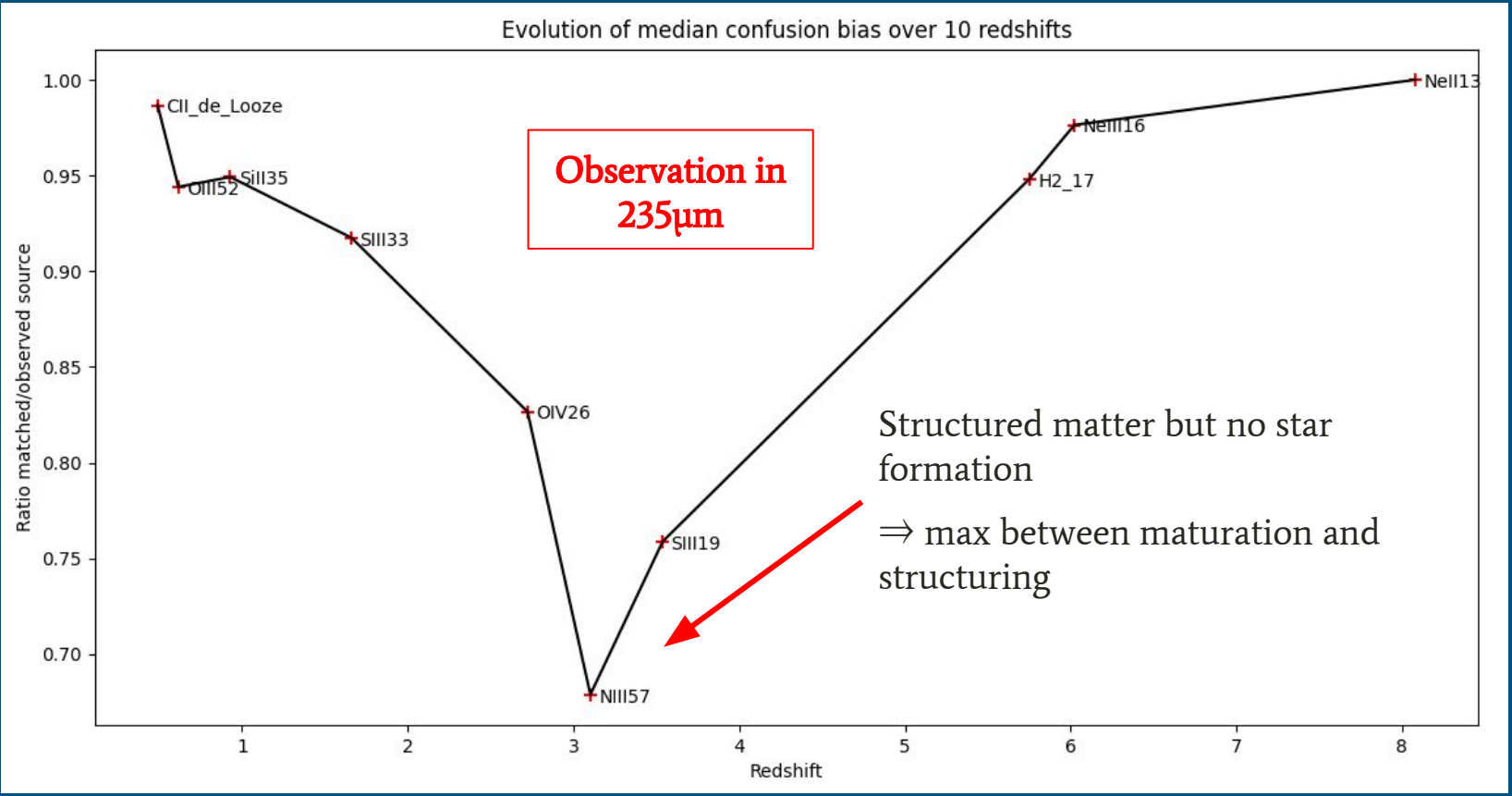
⇒ ∽ *10^4 hours (∽ 42 days) would be necessary to reach the confusion limit !*

Not physically reasonable, so the confusion limit is not a problem.

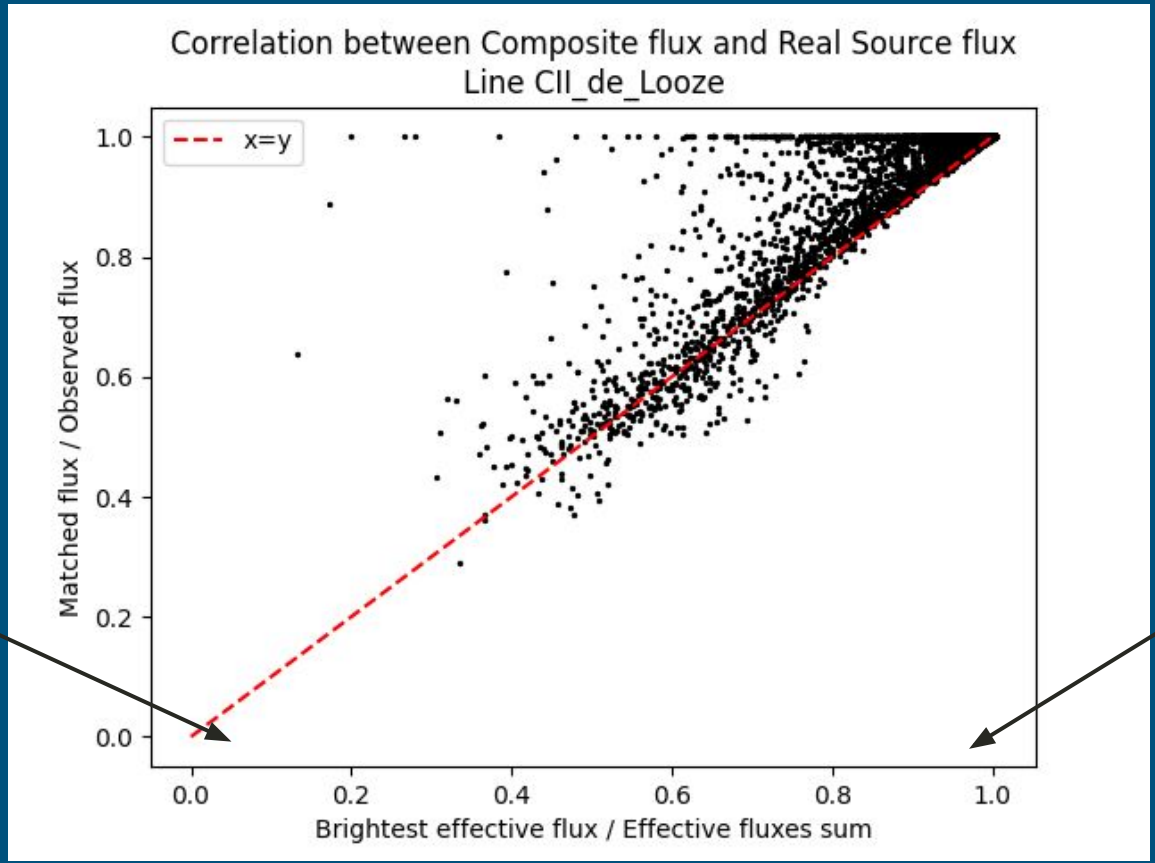


Problem solved ? Not completely...

Median flux bias for various lines

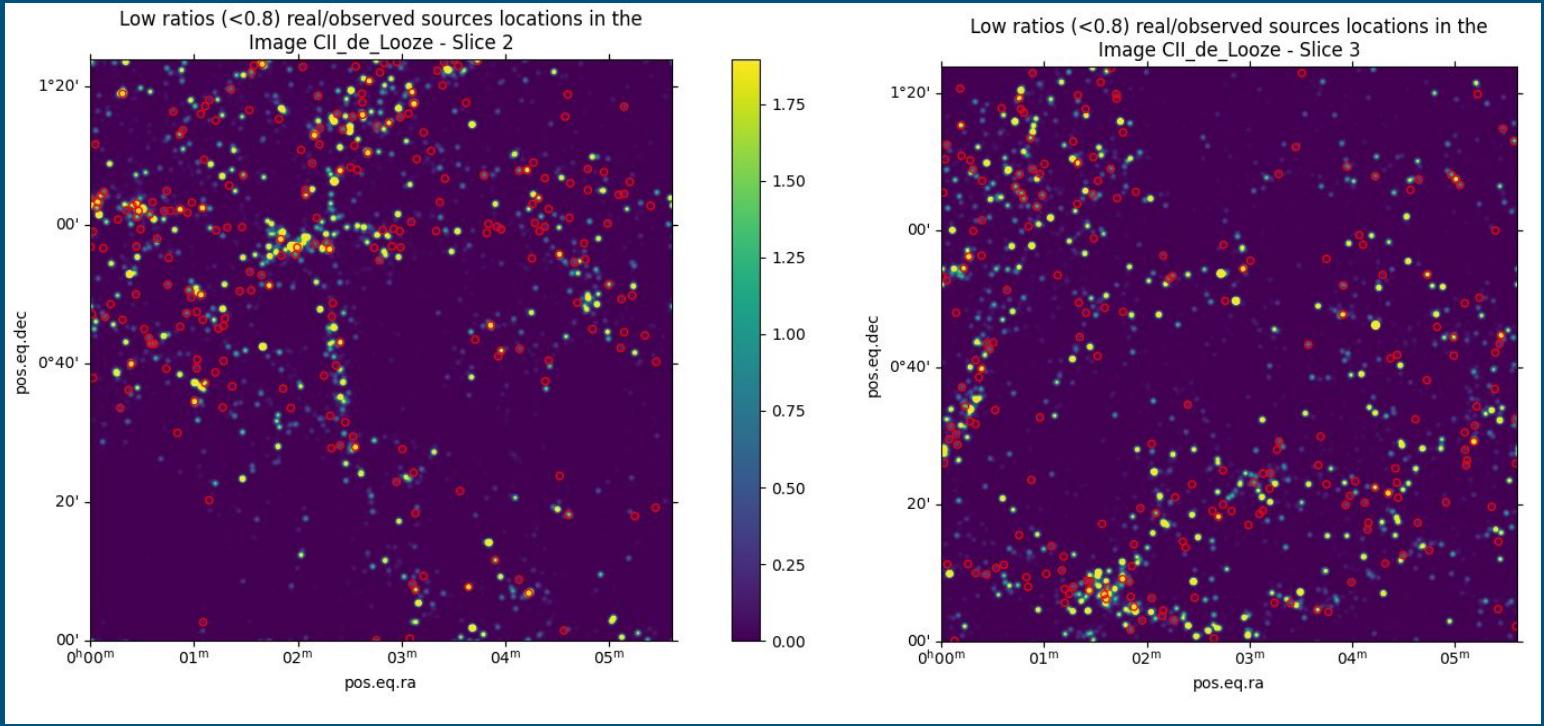


Clustering


Correlation between Composite flux and Real Source flux
Line CII_de_Looze
x=y
Matched flux / Observed flux
Brightest effective flux / Effective fluxes sum
0.0
0.2
0.4
0.6
0.8
1.0

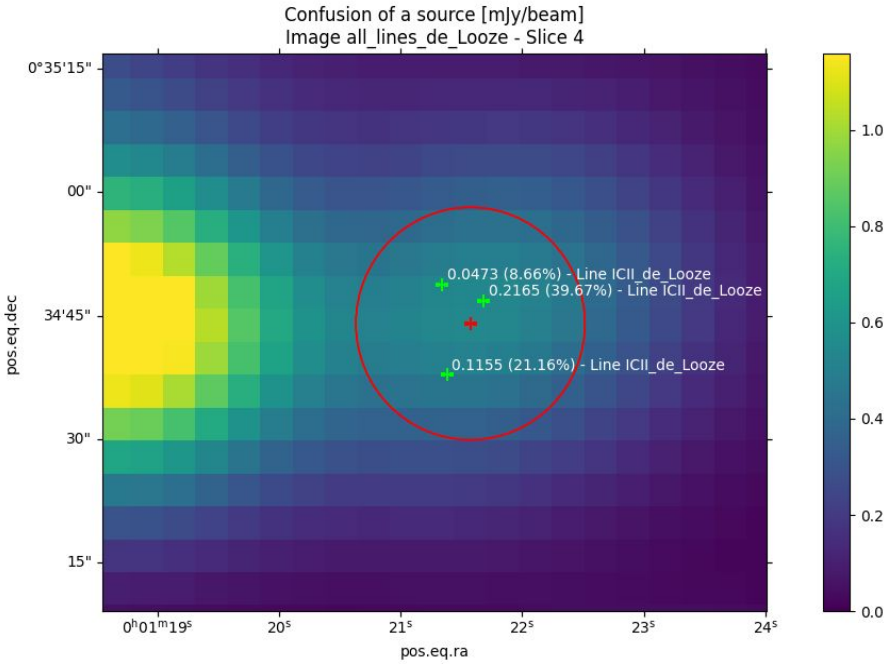
Spatial distribution of confused sources

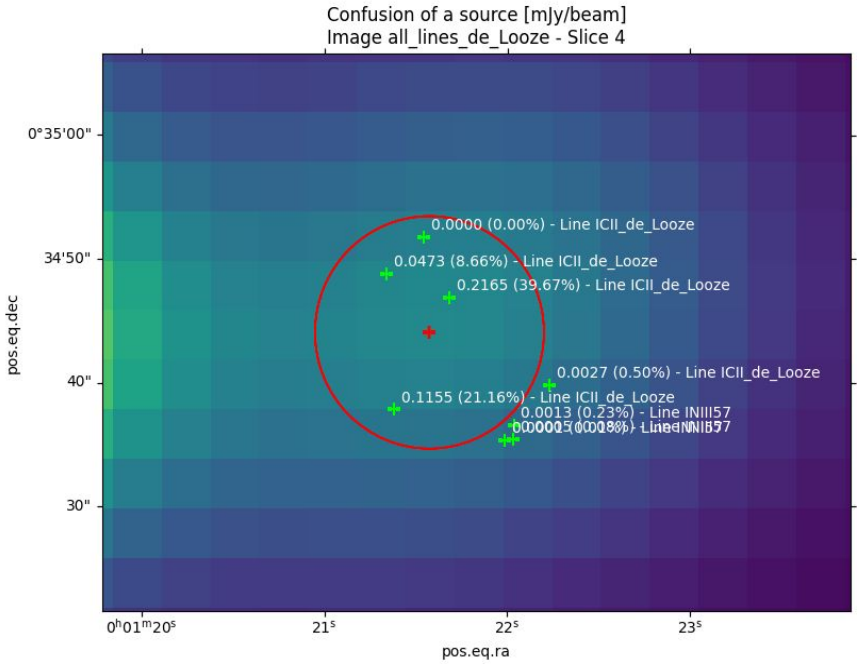
Confused sources are mainly within the structures



Composite fluxes composition

Which lines are contributing to a given confused source ?





Conclusion

- ★ Different lines lead to different bias
- ★ Low confusion limit ~ 10^{-2} mJy/beam
  - Negligible & not reached
- ★ But 15-20% of the sources are more than 20% contaminated
  - *bias expected for faint sources but not bright ones...*

Perspectives: Study at long wavelength in spectroscopy → Negligible at shorter wavelengths and comment on treating and correcting this effect ?

References

1. **[ART] -** CONCERTO: High-fidelity simulation of millimeter line emissions of galaxies and [CII] intensity mapping; *M. Bethermin et al.* https://ui.adsabs.harvard.edu/abs/2022A%26A...667A.156B/abstract
2. **[ART] -** The impact of clustering and angular resolution on far-infrared and millimeter continuum observations; *M. Bethermin et al.* *https://ui.adsabs.harvard.edu/abs/2017A%26A...607A..89B/abstract*
3. **[ART] -** Confusion of extragalactic sources in the far infrared: a baseline assessment of the performance of PRIMAger in intensity and polarization; *M. Bethermin et al.* https://ui.adsabs.harvard.edu/abs/2024arXiv240404320B/abstract
4. **[ART] -** Predictions for Cosmological Infrared Surveys from Space with the Multiband Imaging Photometer for SIRTF (MIPS); *H. Dole* https://arxiv.org/pdf/astro-ph/0211312
5. **[URL] -** PRIMA's Website https://prima.ipac.caltech.edu