

Lessons Learned From BLAST



marco viero / university of toronto

BLAST TEAM



UBC
Ed Chapin
Mark Halpern
Gaelen Marsden
Douglas Scott
Don Wiebe

CDF (France)
Guillaume Patanchon

U of T
Peter Martin
Barth
Netterfield
Marco Viero

JPL
Jamie Bock

UPenn
Mark Devlin
Jeff Klein
Marie Rex
Chris Semisch
Matt Truch

Brown University
Greg Tucker

U of Miami
Josh Gundersen
Nick Thomas

INAOE (Mexico)
David Hughes
Itziar Aretxaga

U Puerto Rico
Luca Olmi

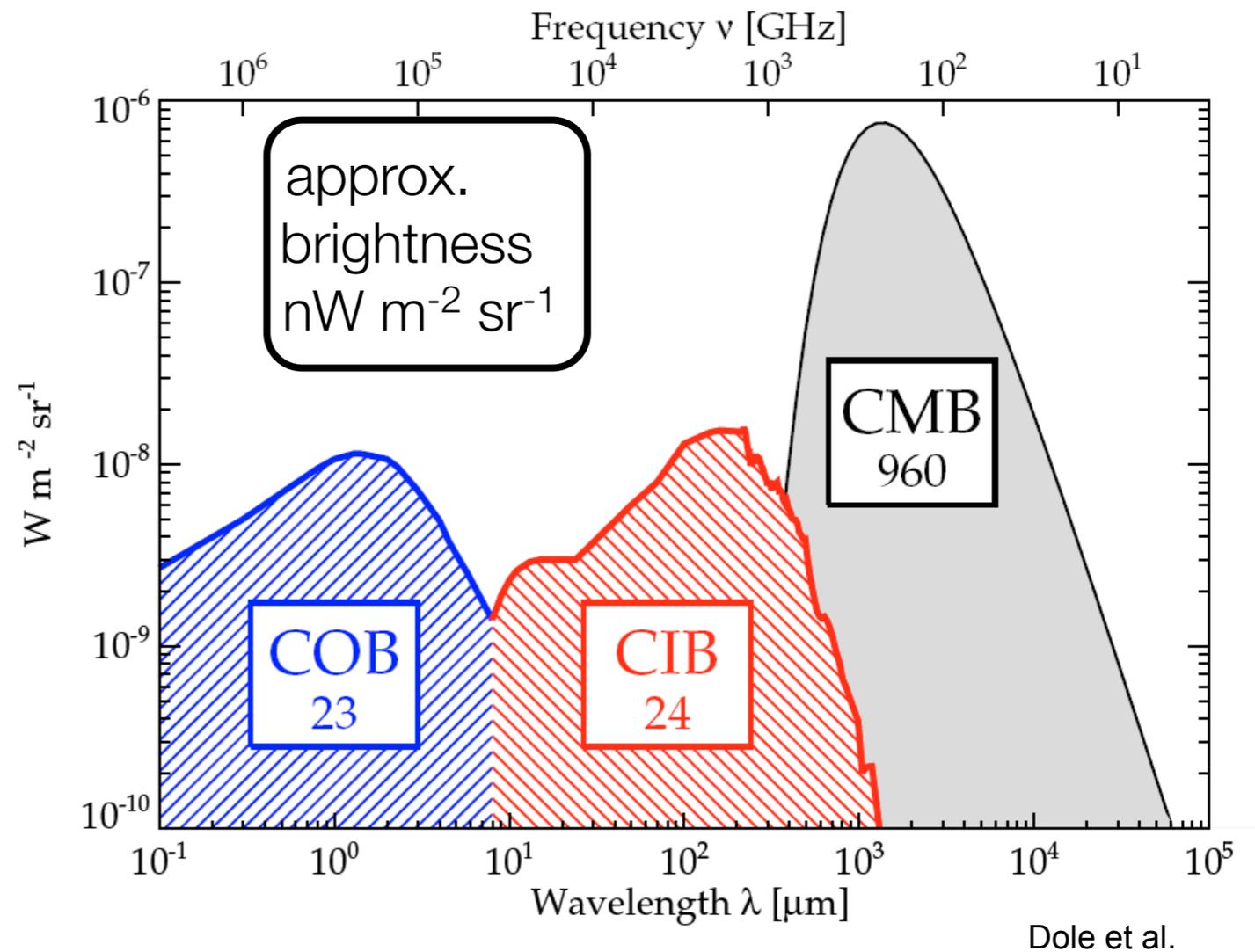
Cardiff University
Peter Ade
Matt Griffin
Peter Hargrave
Phil Mauskopf
Carole Tucker
Enzo Pascale
Lorenzo Moncelisi

Open University
Mattia Negrello

Why IR?

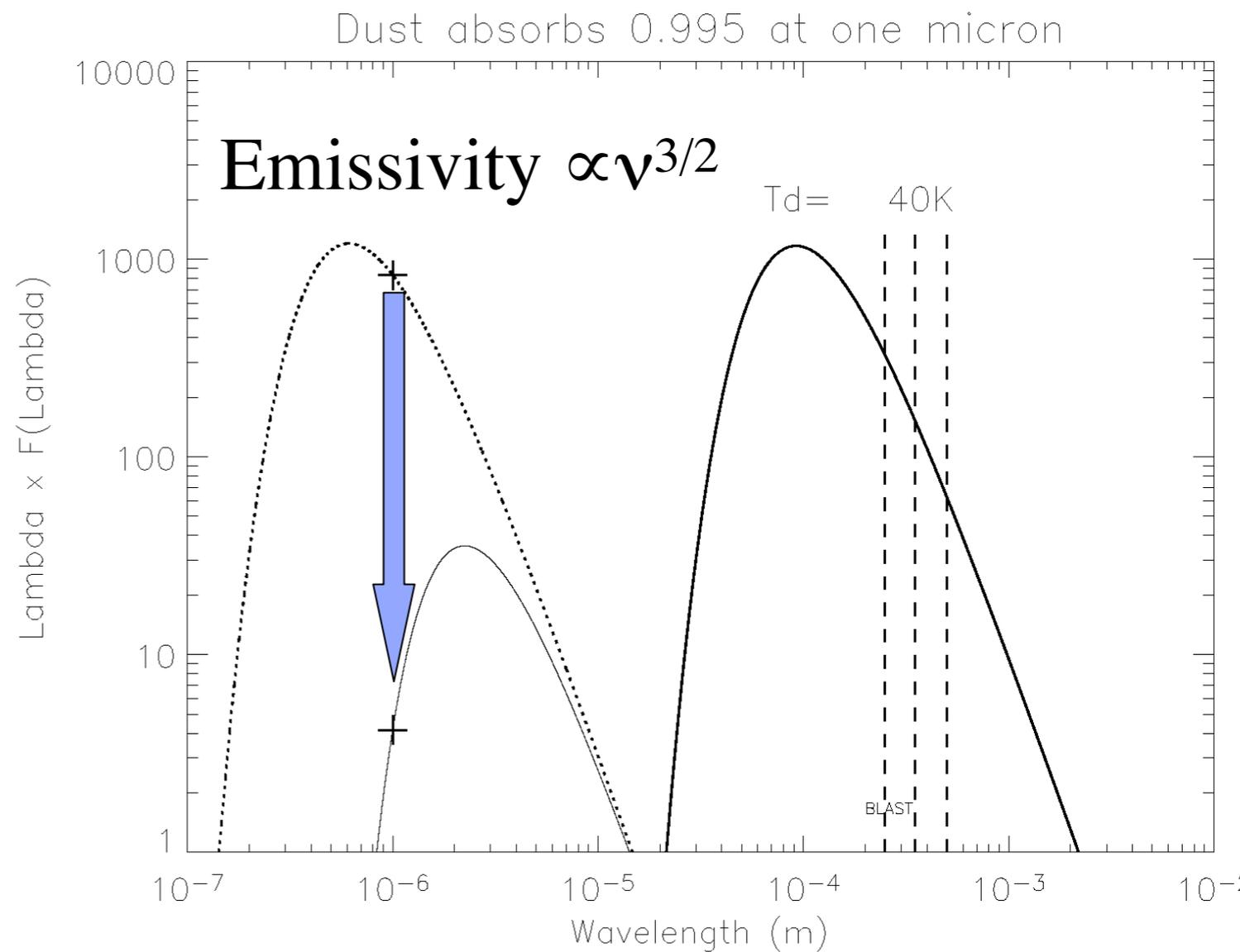
Why IR?

- Half of all light emitted by stars is absorbed and reradiated in the IR



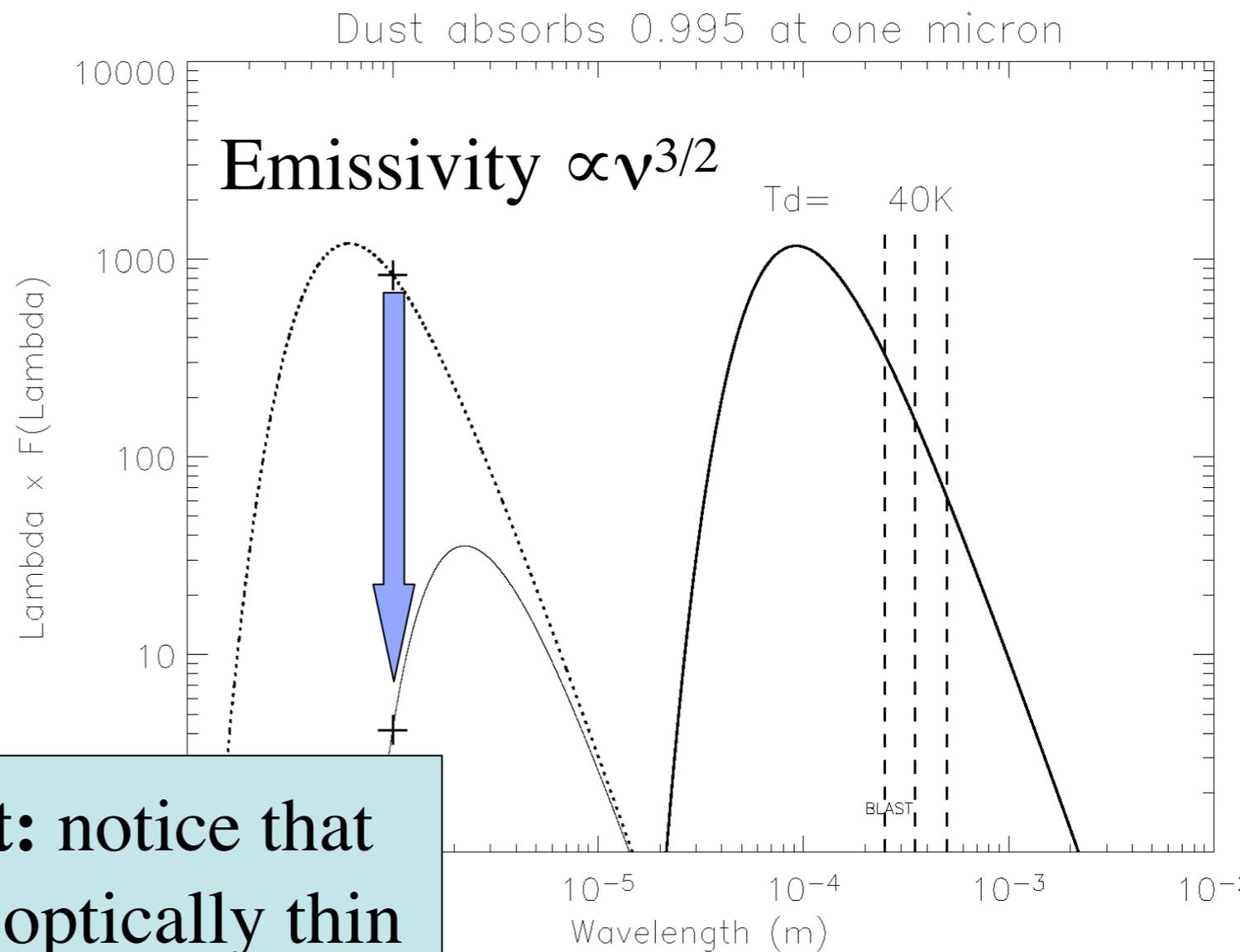
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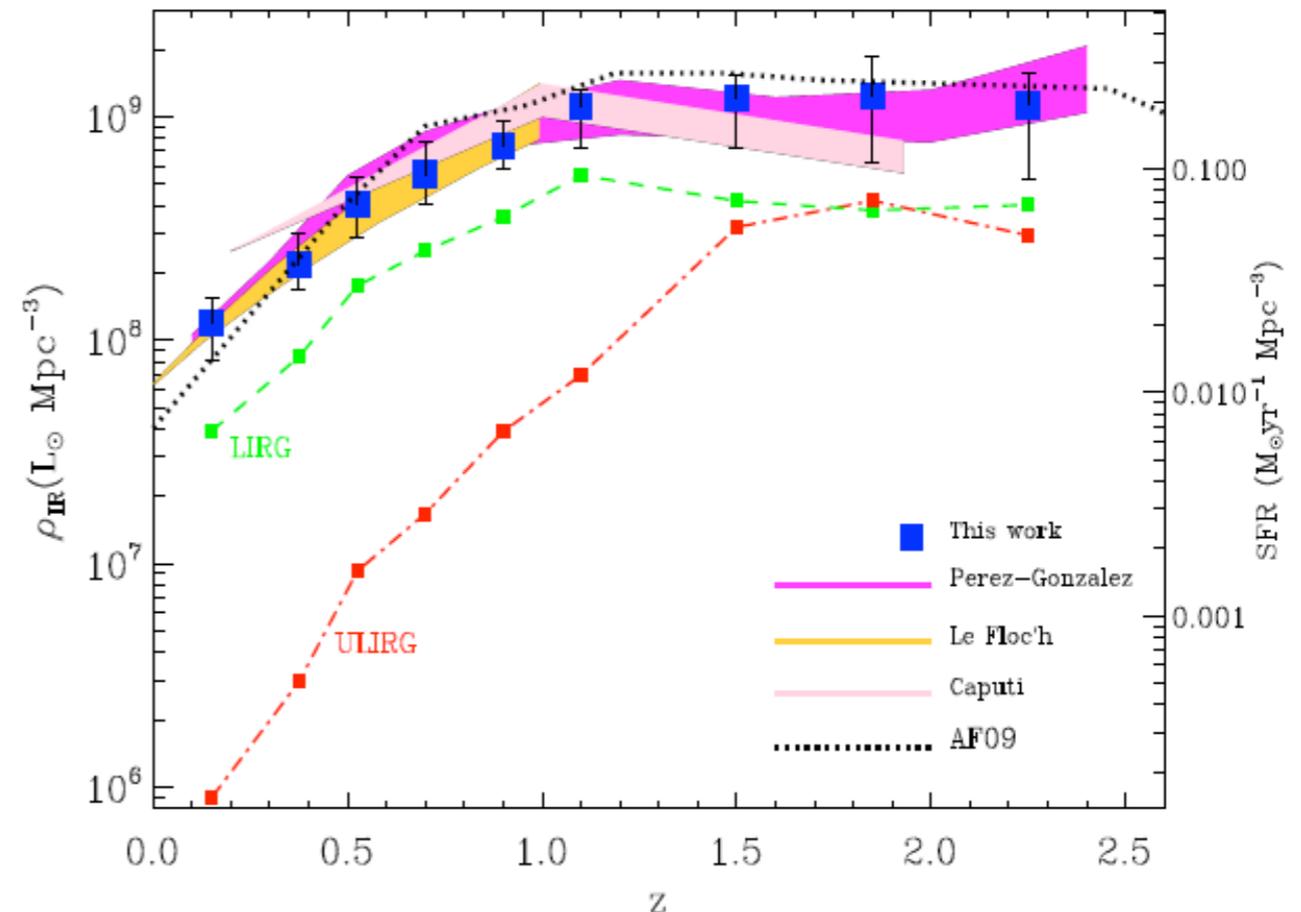
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- Dust emission is an unbiased measure of star-formation because it is optically thin at IR wavelengths



Important: notice that the dust is optically thin by 10 microns. The mm emission is proportional to the total dust mass.

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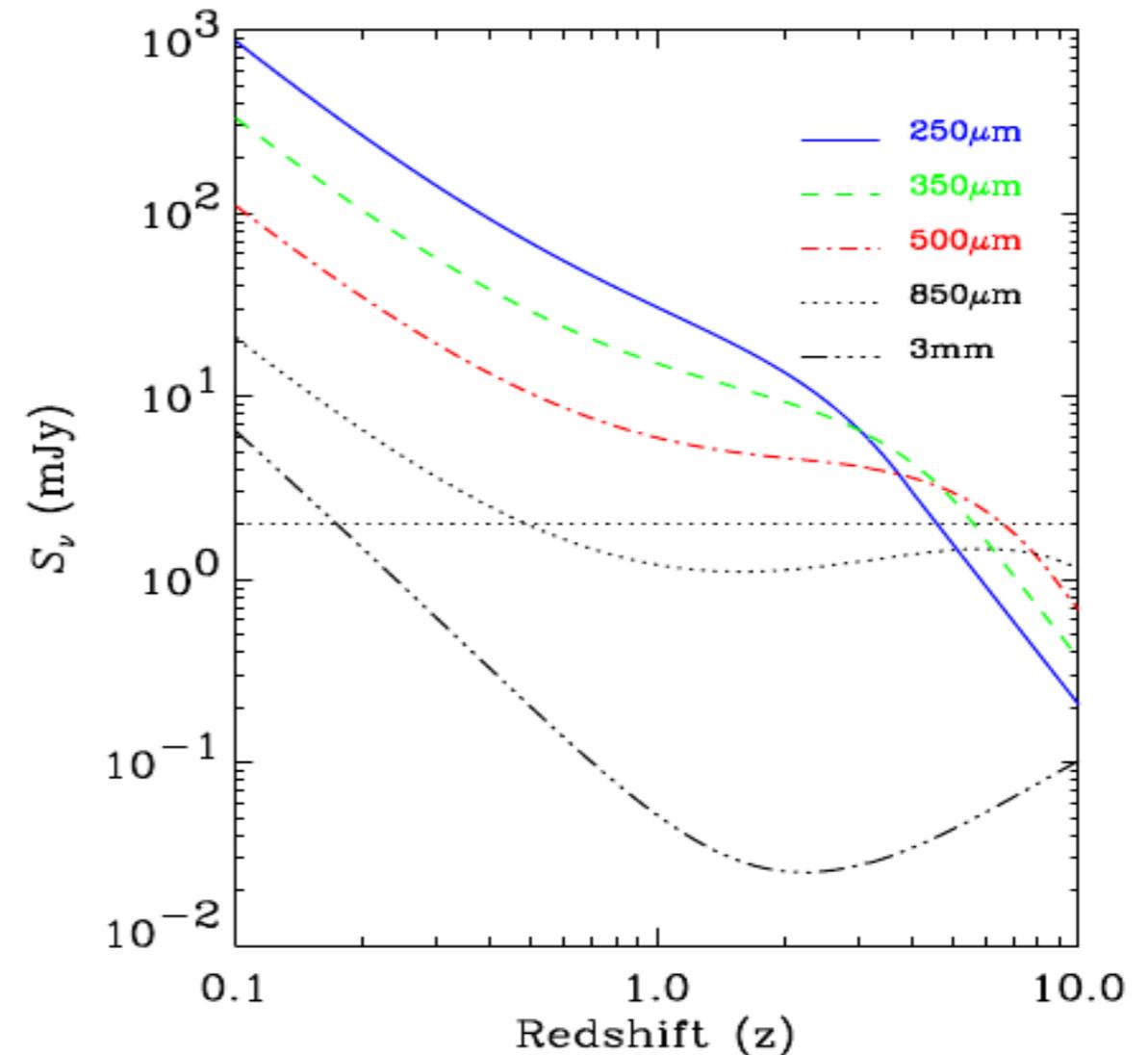
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- Dust emission is an unbiased measure of star-formation because it is optically thin at IR wavelengths
- The bulk of the present day stellar mass formed at $z = 1-3$, and the total IR Luminosity budget due to LIRGS + ULIRGS is
 - ➔ 51% by $z \sim 1$
 - ➔ 93% by $z \sim 2$



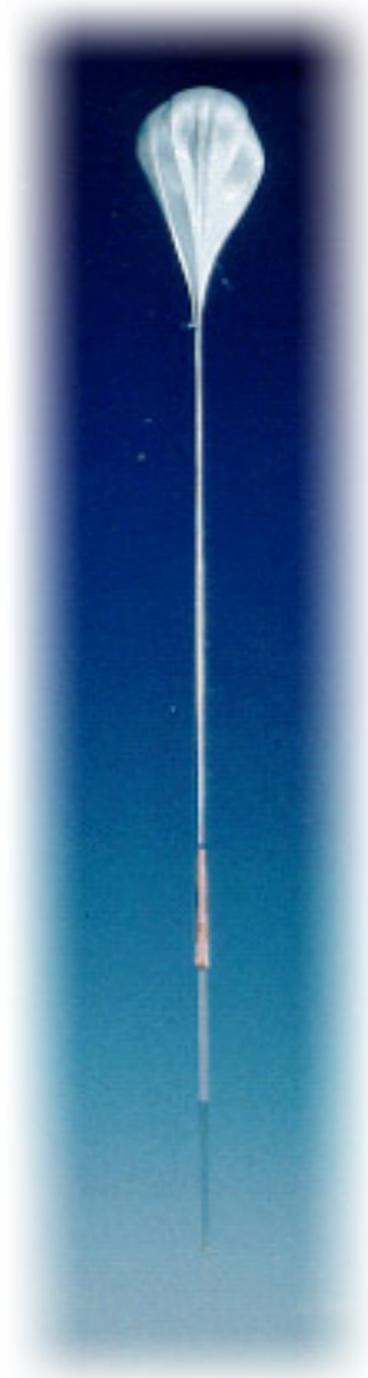
Rodighiero et al. 2009

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- Longer wavelengths more sensitive to higher redshift due to negative k-correction

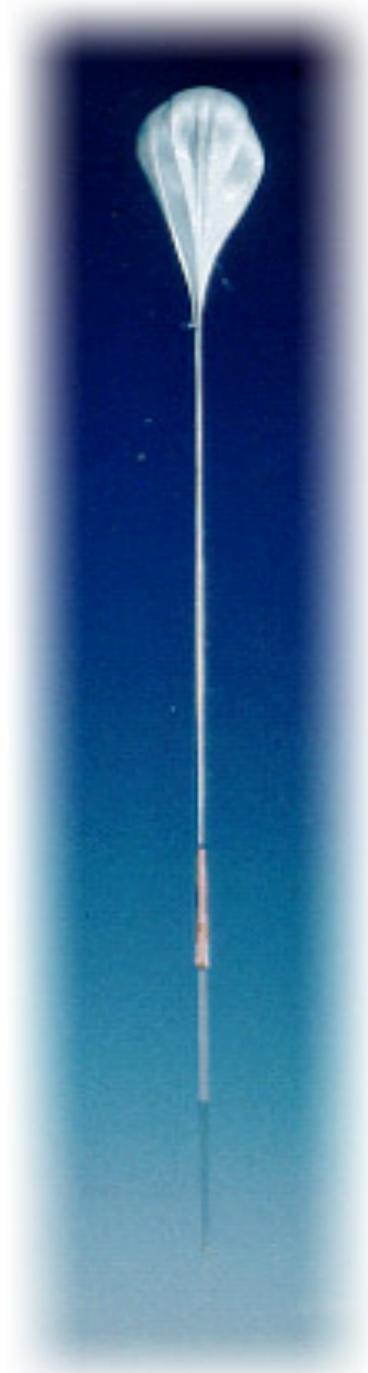


BLAST



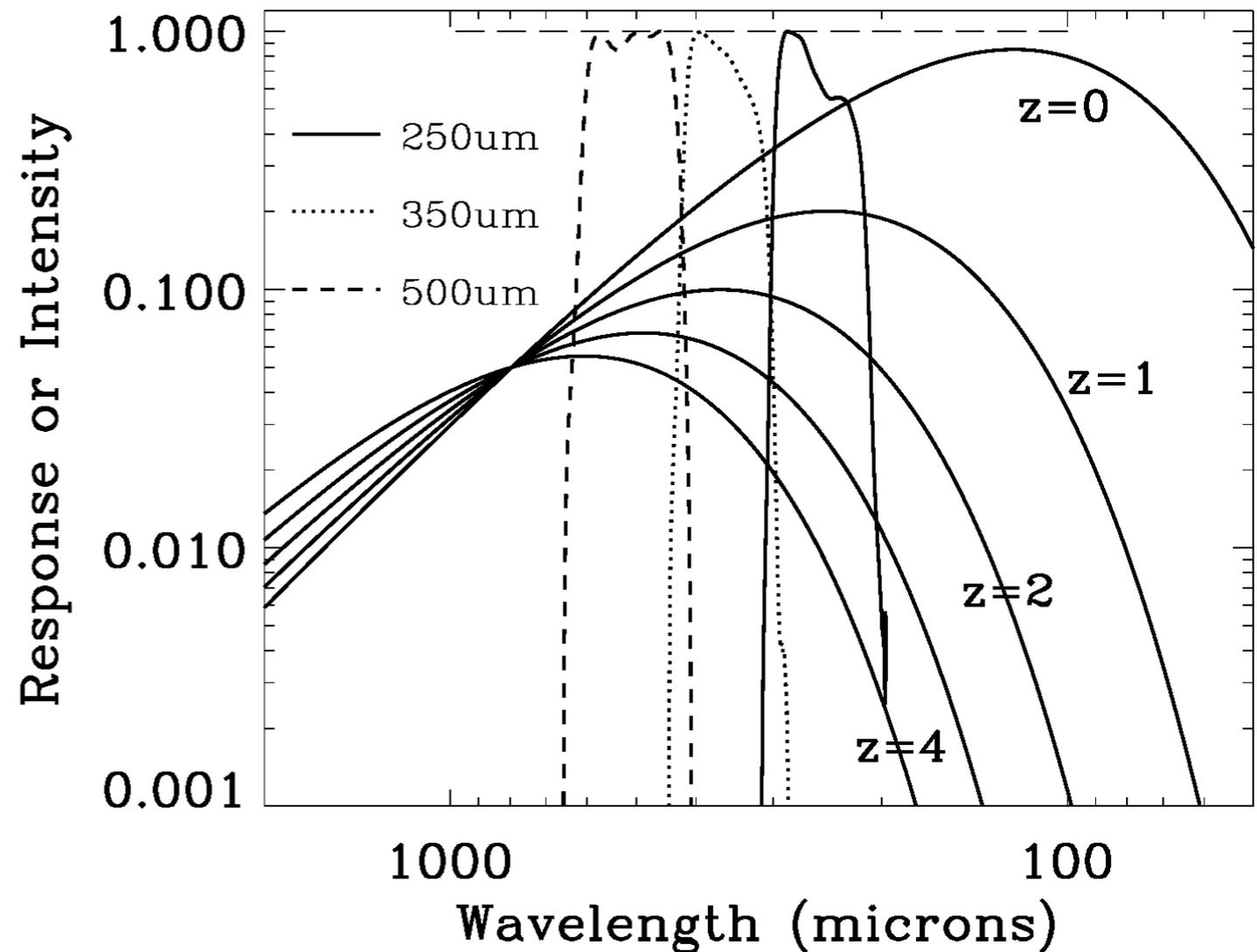
BLAST

- Balloon-borne (~40 km altitude) pathfinder for SPIRE instrument on Herschel Space Observatory



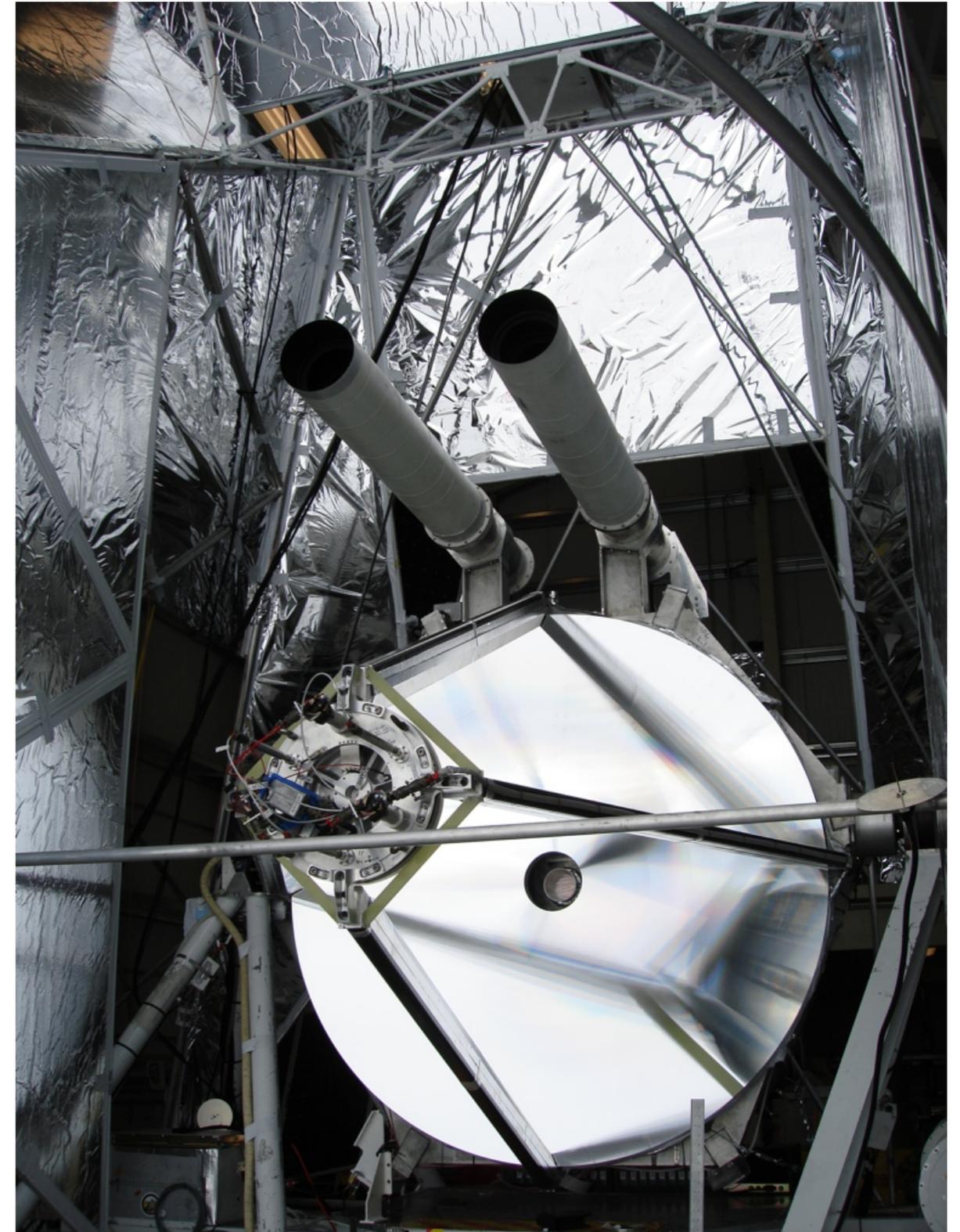
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- 1.8 m under-illuminated primary with nearly diffraction limited beams:
 - ◉ 36, 45 and 60 arcsec FWHM at 250, 350 and 500 μm

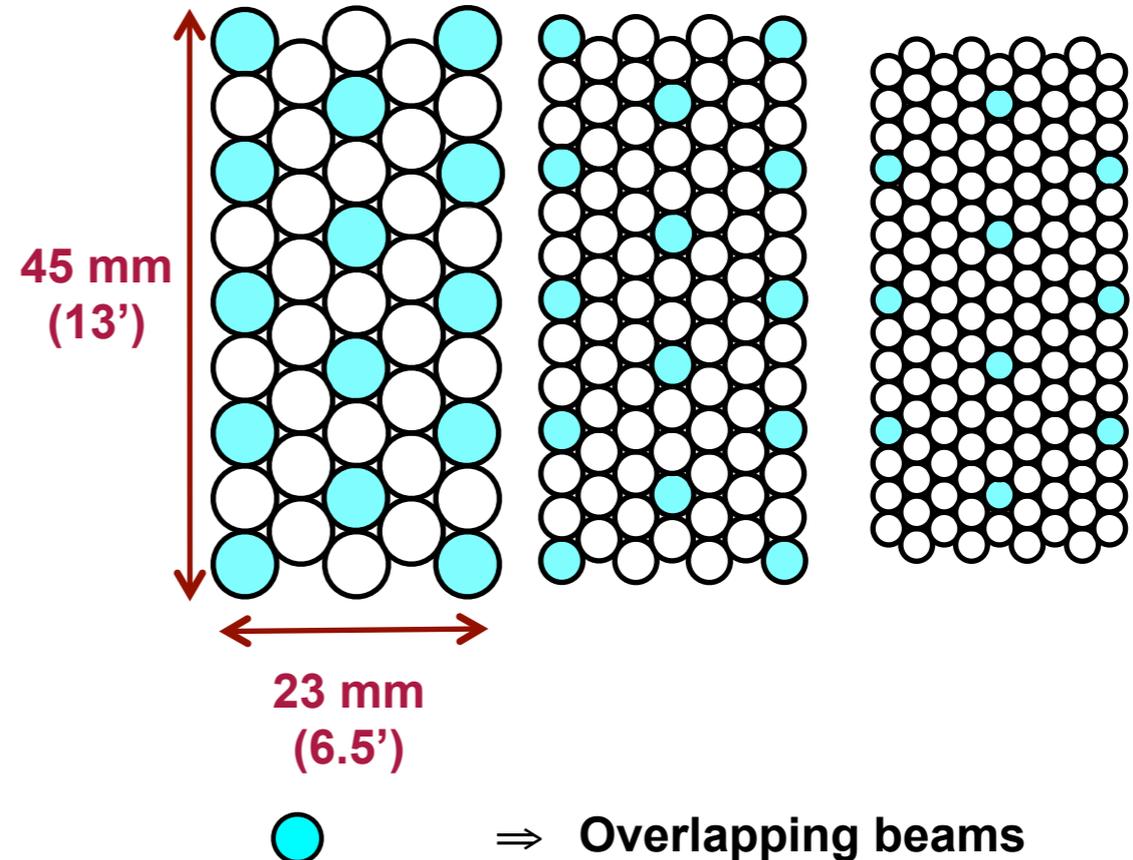


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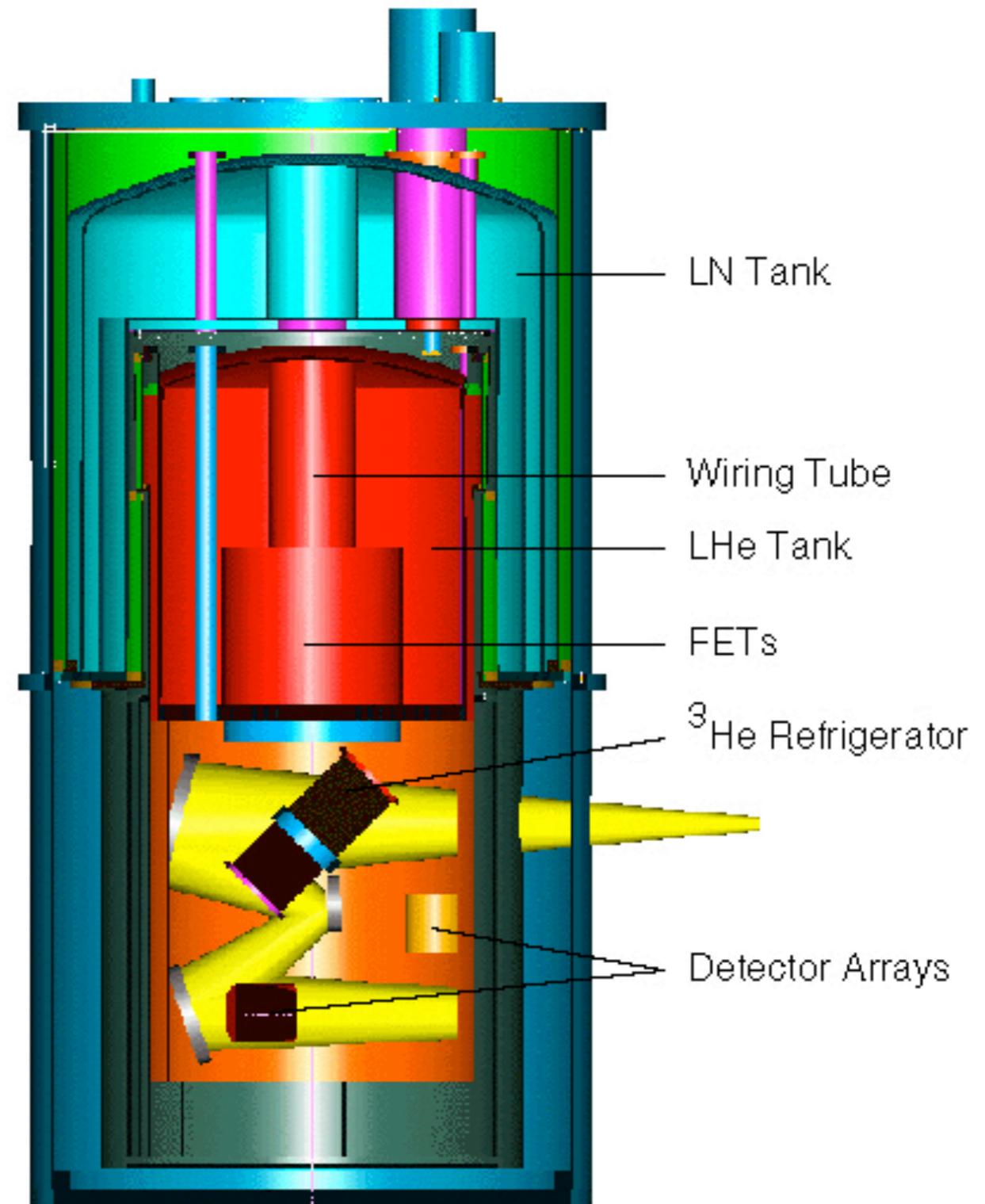


500 μm 43 detectors
350 μm 88 detectors
250 μm 139 detectors

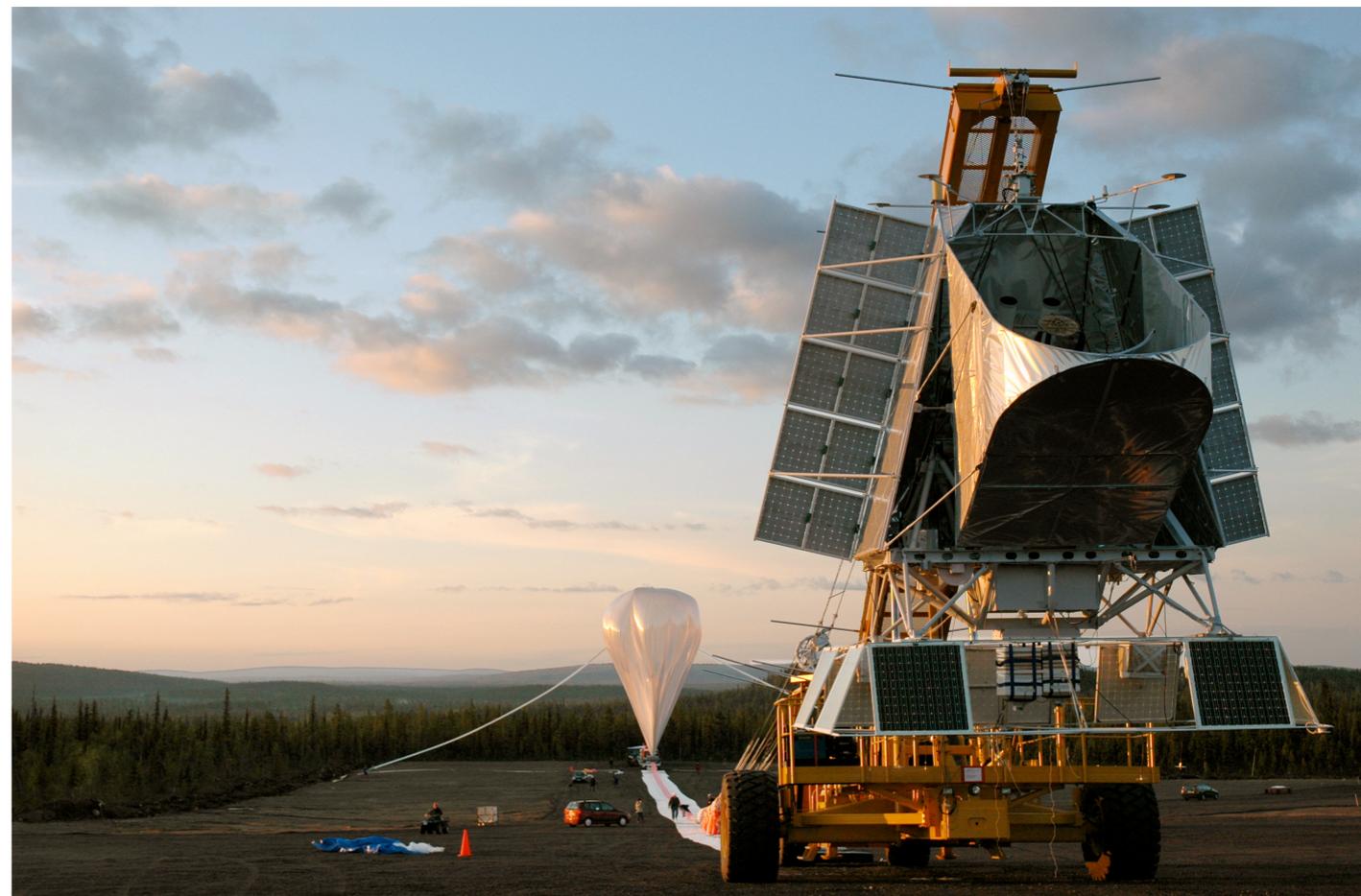
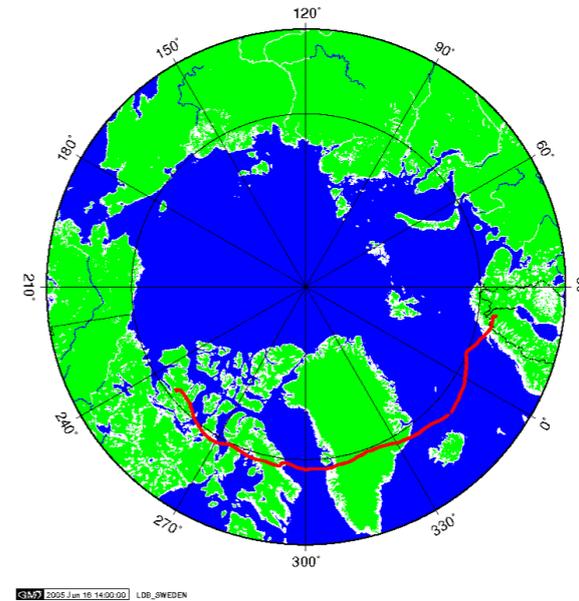


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- Focal Plane Feed-Horns + ~270 bolometer detectors
- Detectors and re-imaging optics housed in a multi-stage cryostat with ~ 11 day hold time

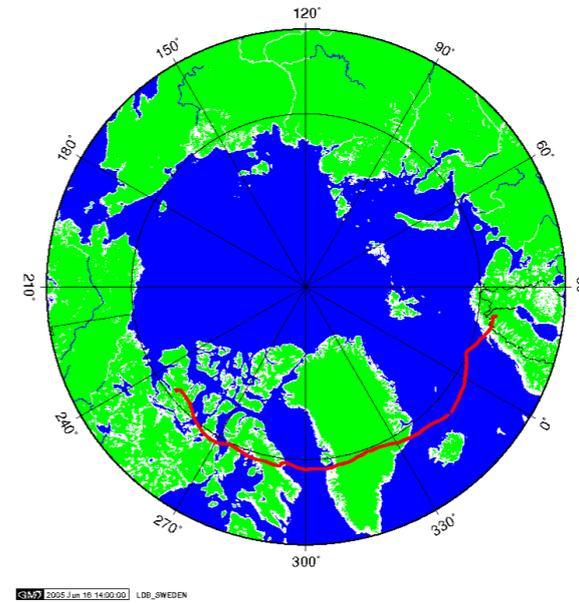


Science Flight (1) - June 2005, Kiruna, Sweden



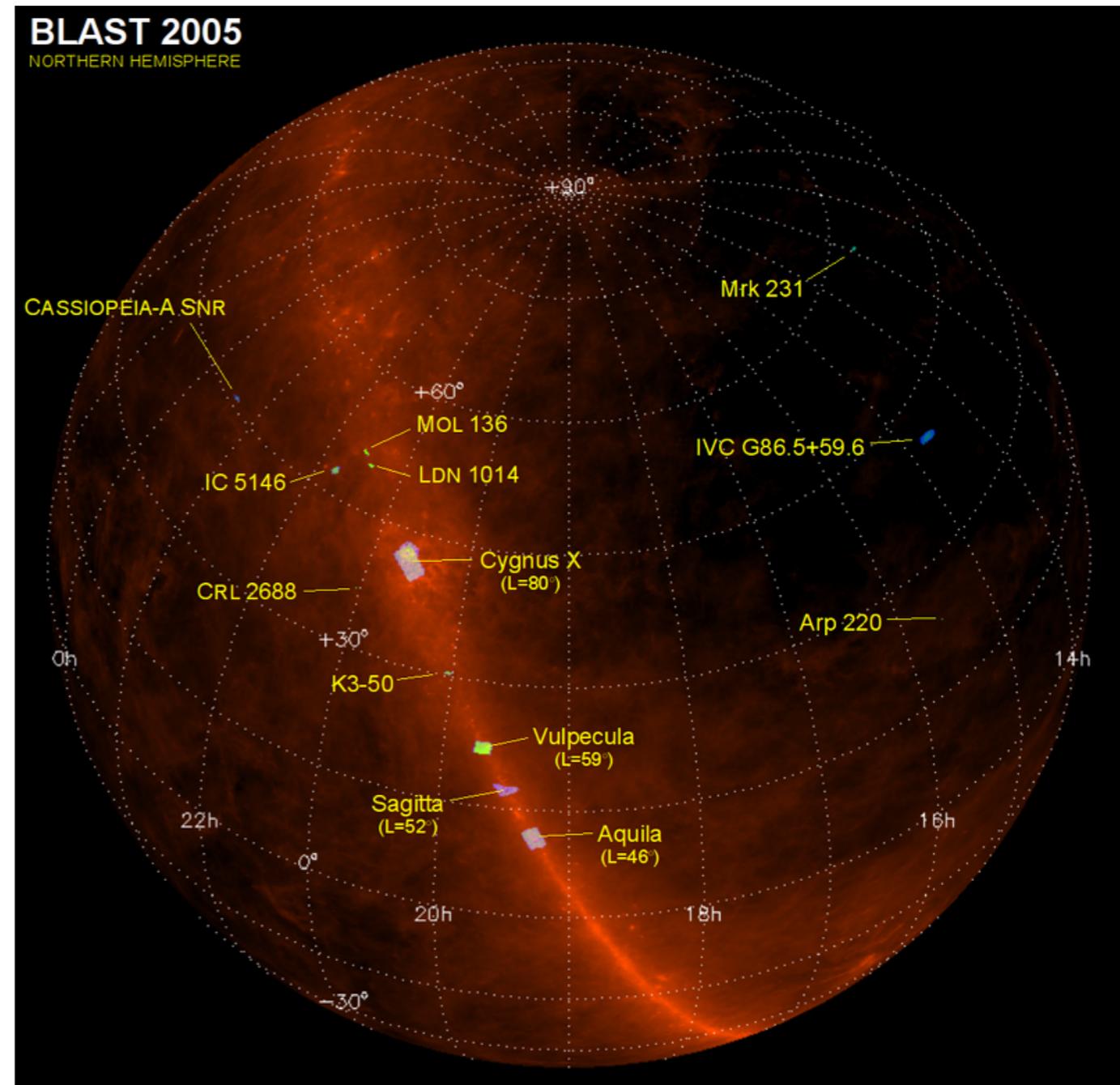
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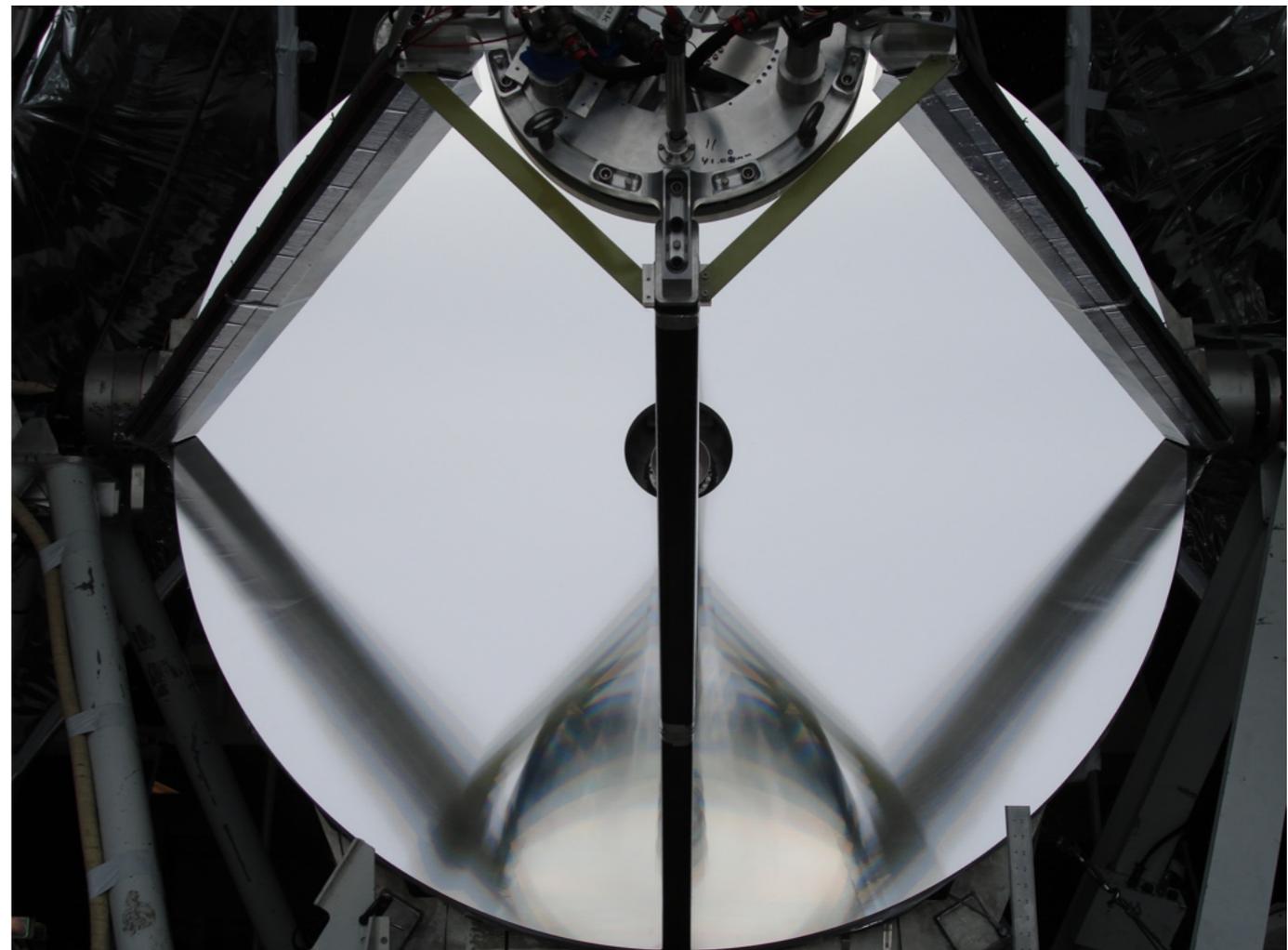
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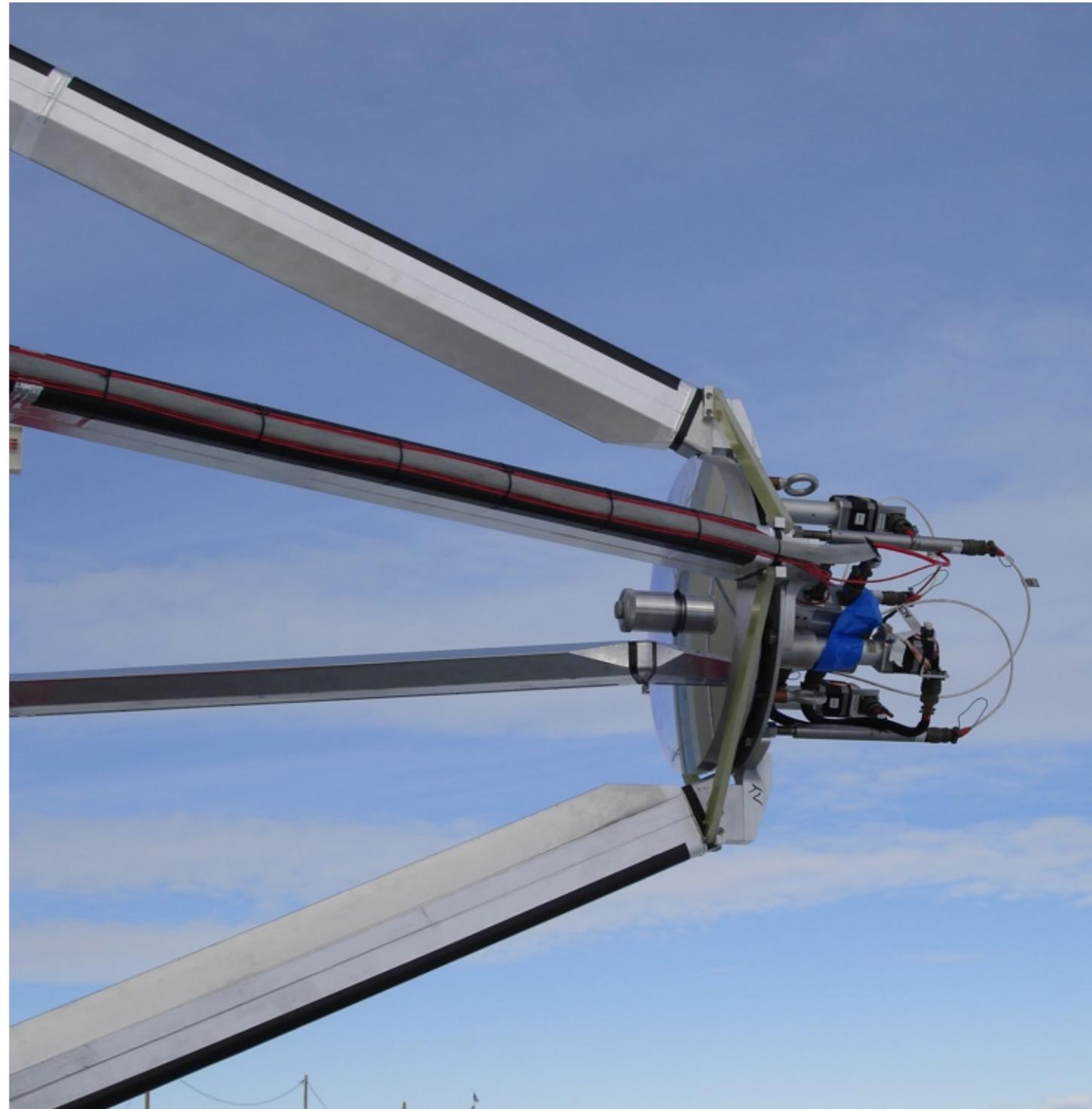
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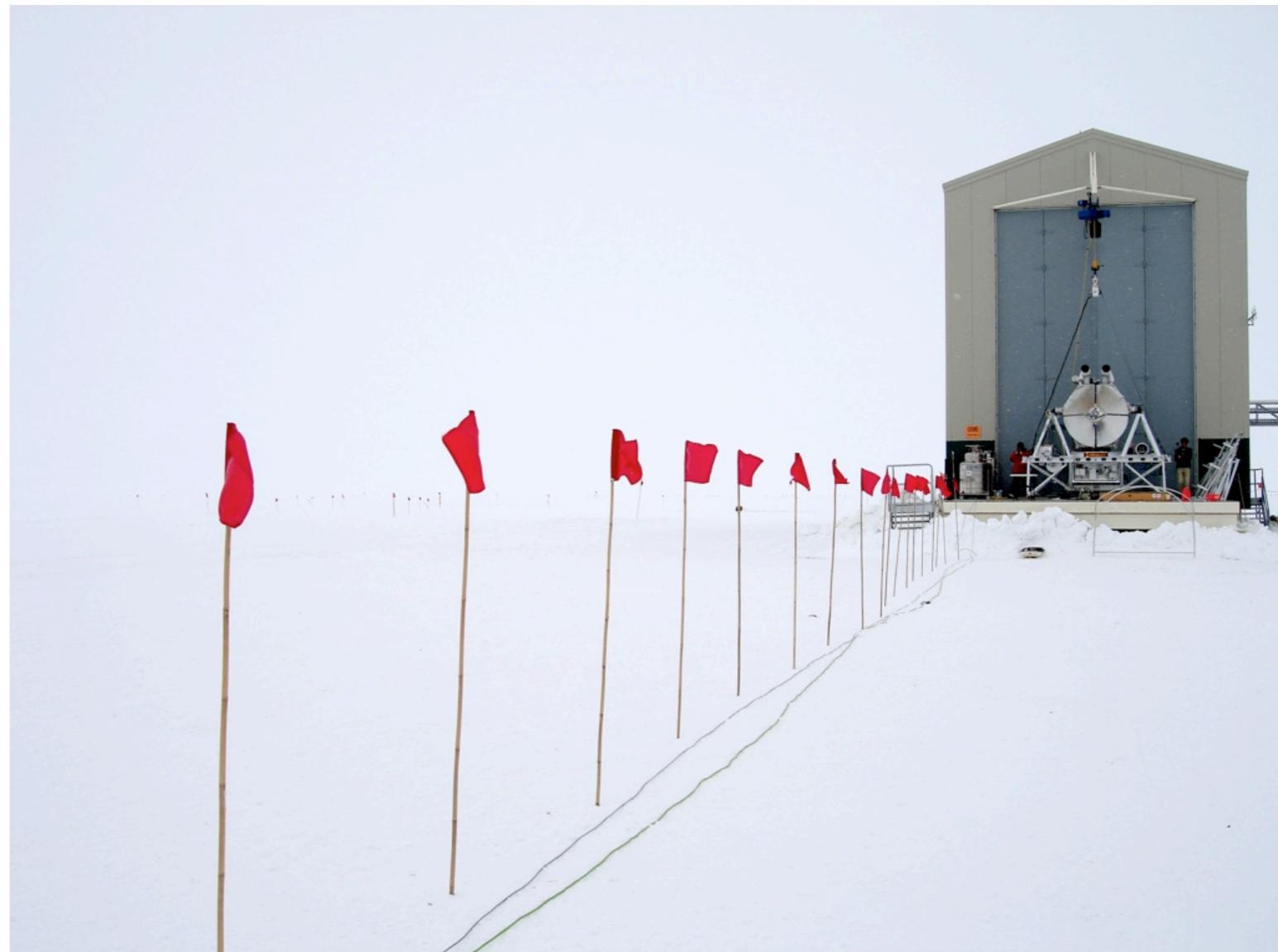
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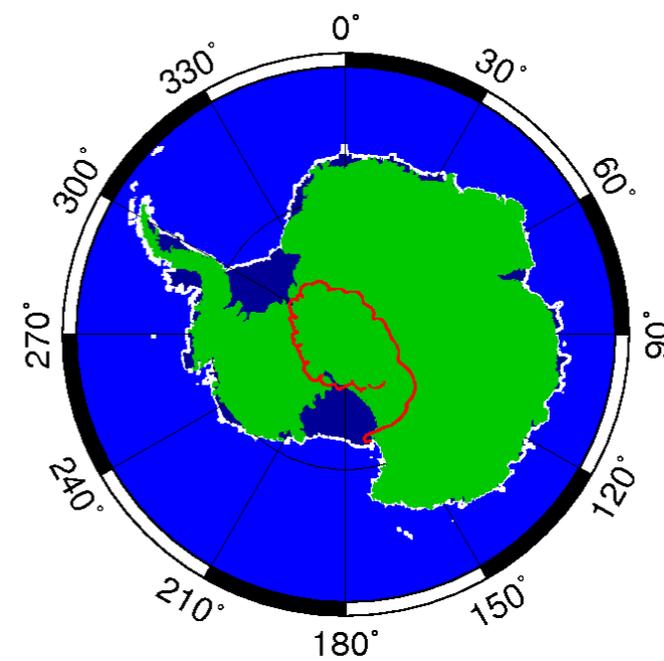


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 - ◉ Pre-flight look-up table to find focus as function of Temperature



Science Flight (2) - December 2006, Antarctica

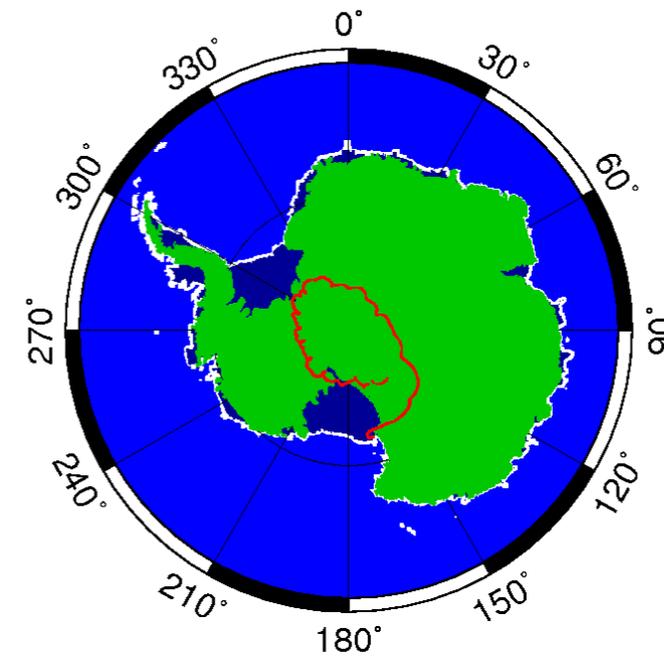


GM 2007 Jan 19 15:45:05 LDB_Antarctica_2006-2007_BLAST



Science Flight (2) - December 2006, Antarctica

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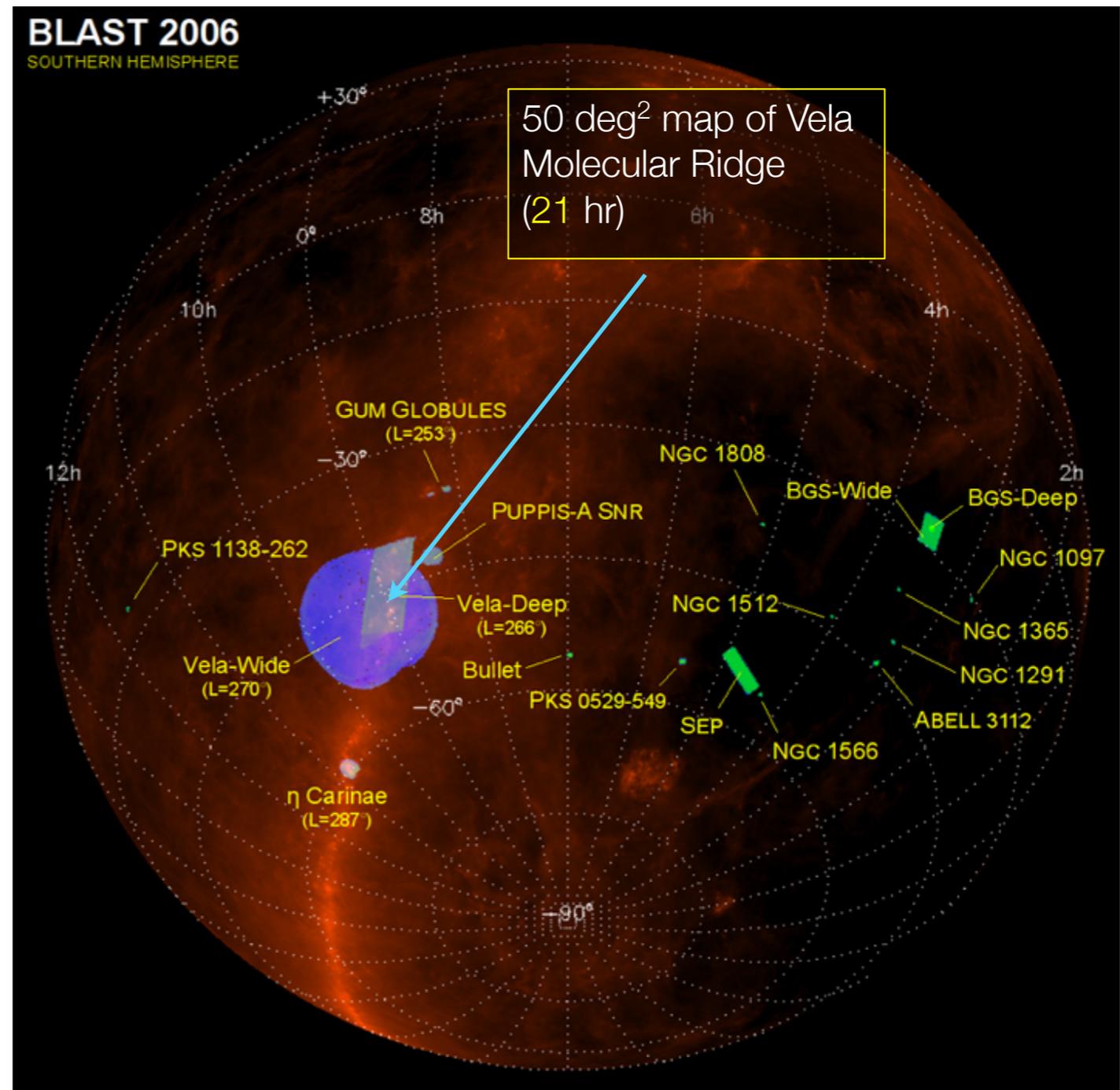


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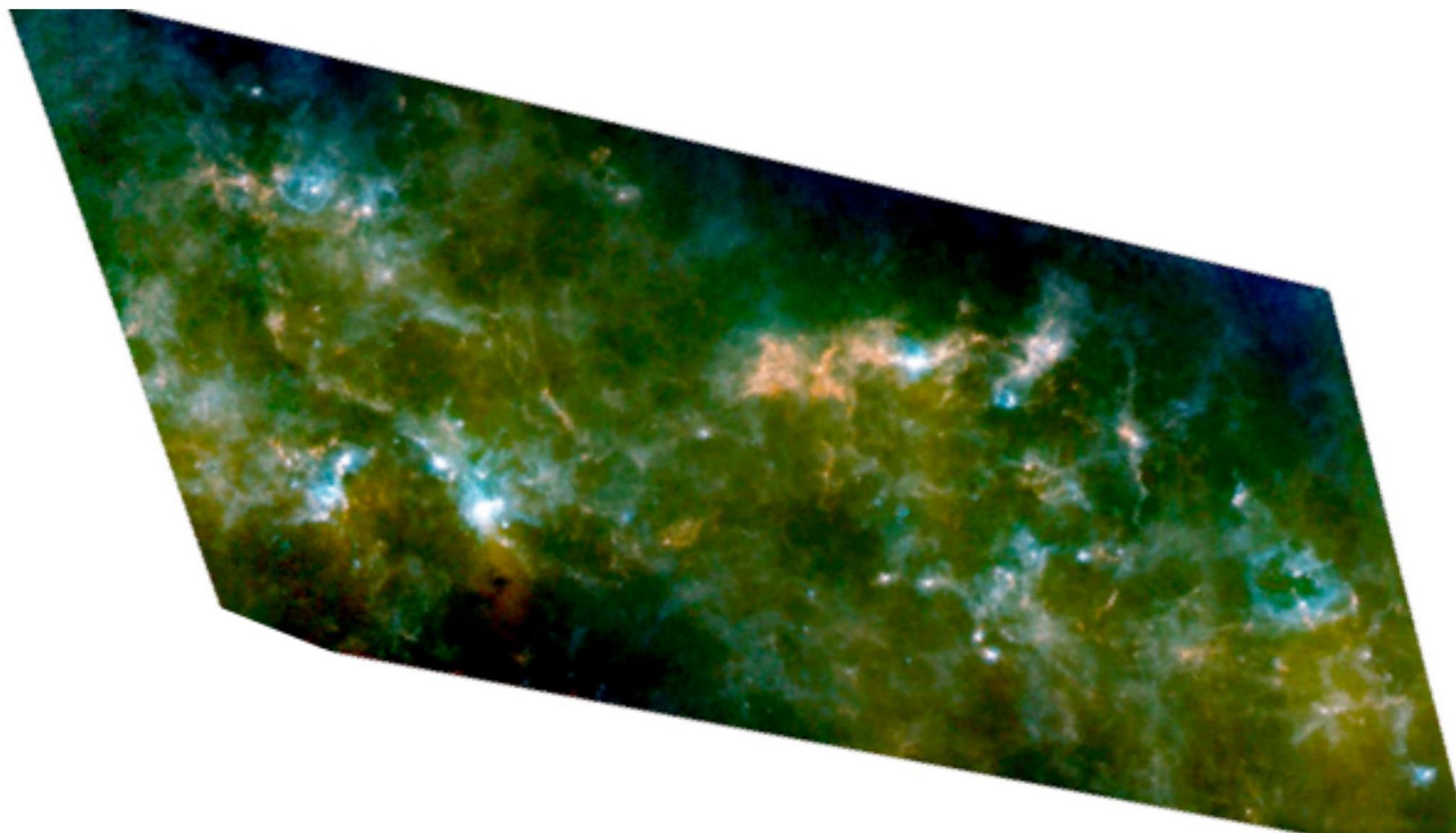
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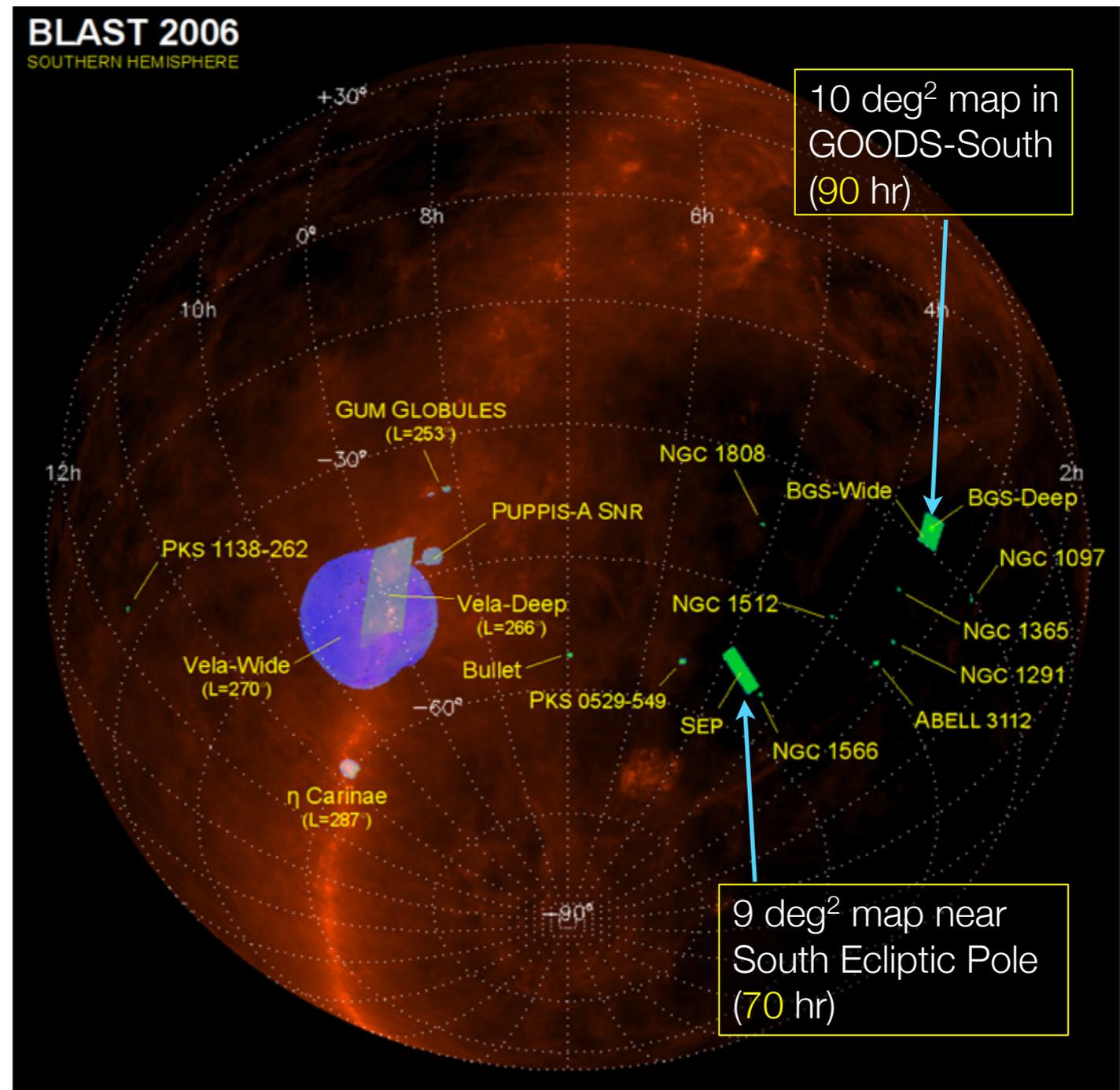
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Netterfield et al. 2009: 50 sq-deg survey in Vela

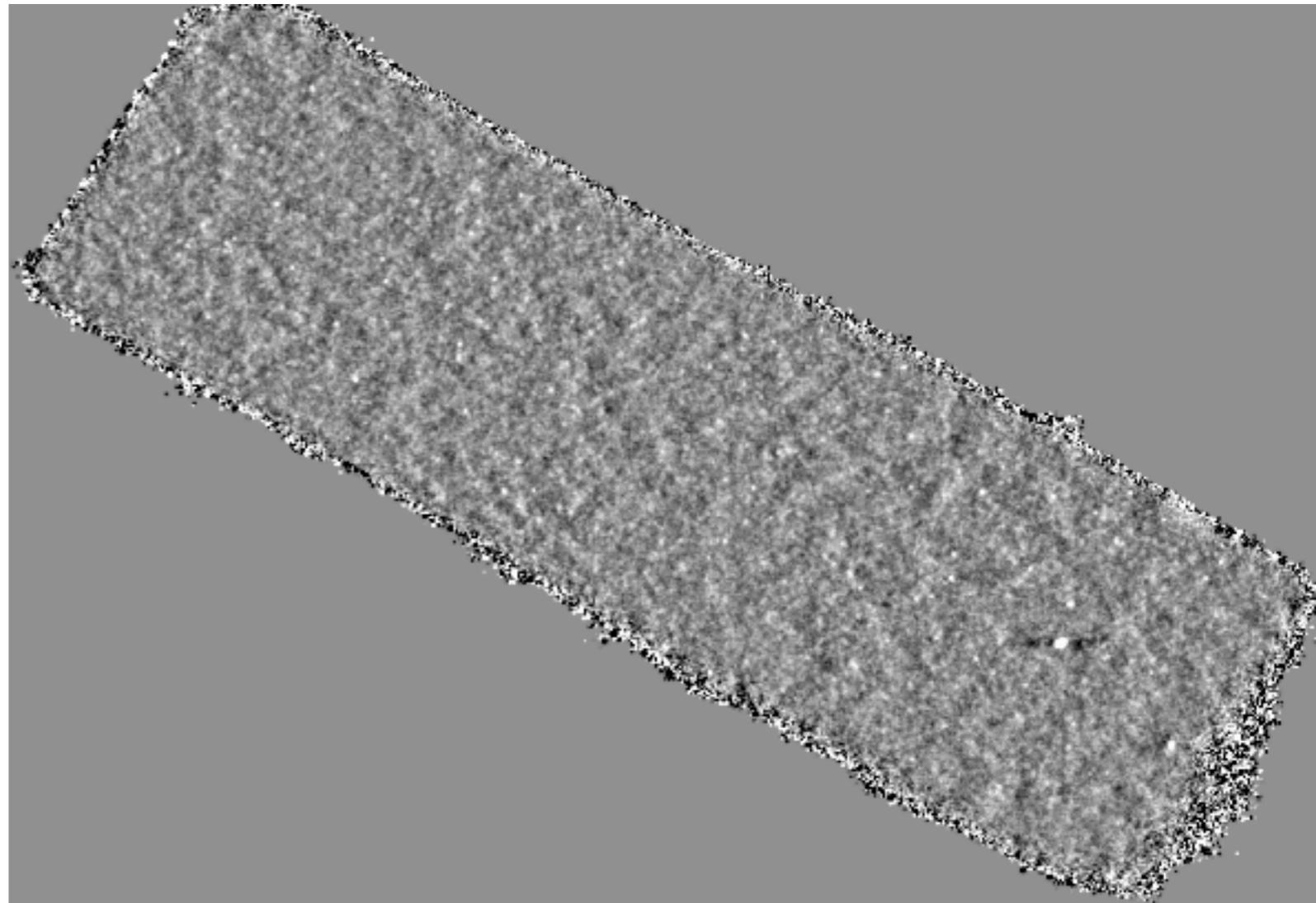
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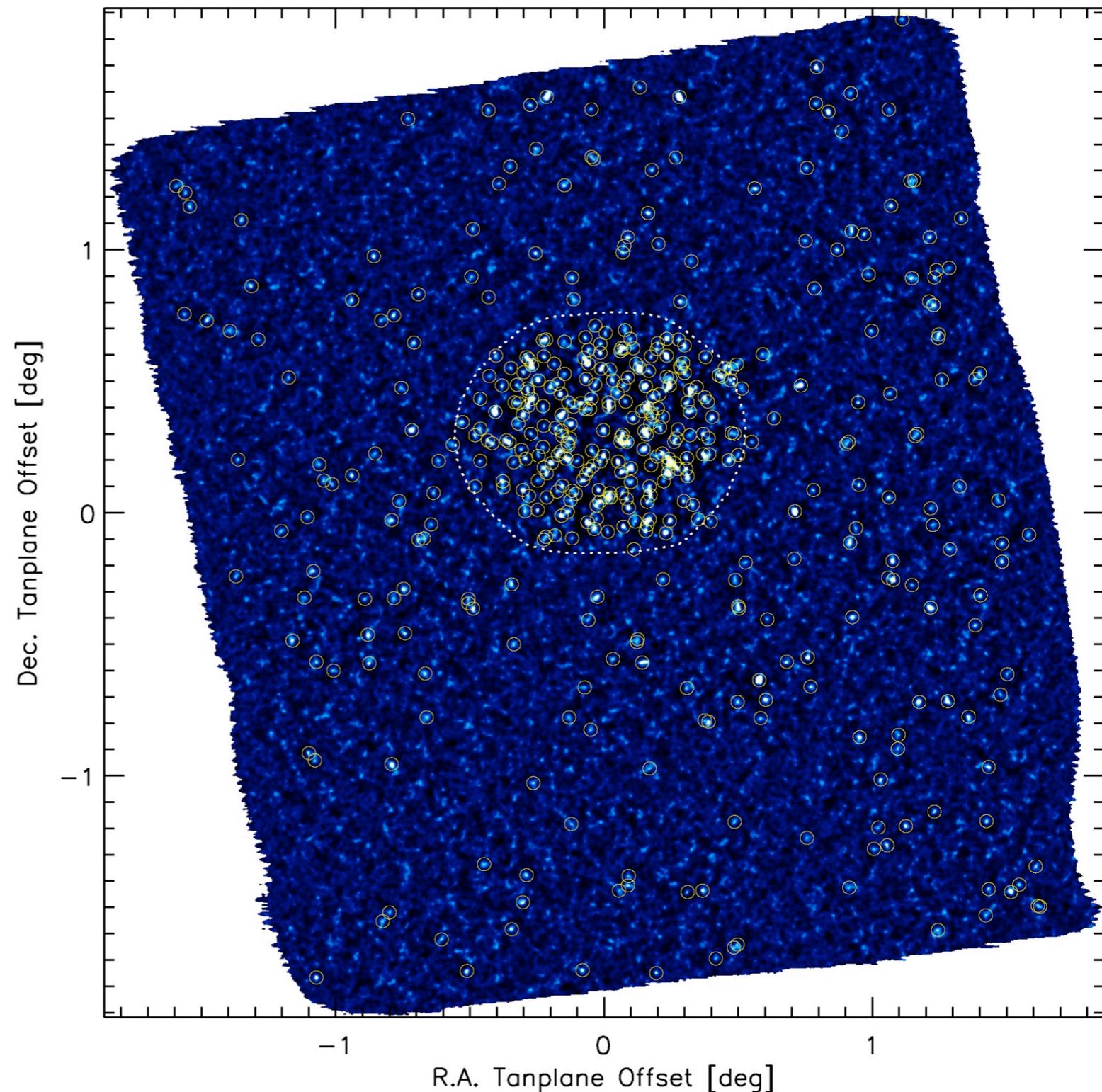
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 - ◉ SEP
 - ~ 230 sources $> 5 \sigma$



Valiante et al. (in Prep.)

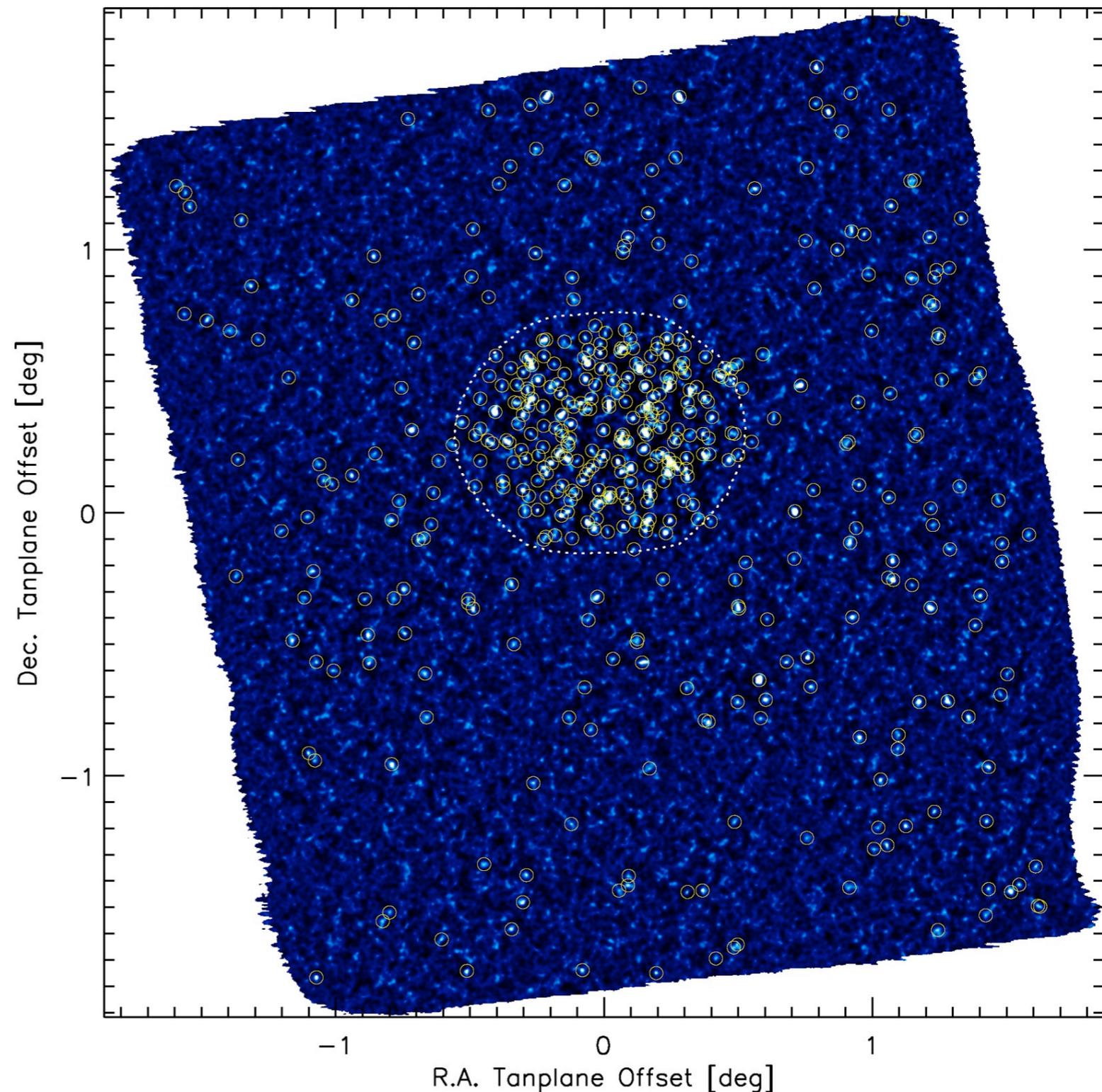
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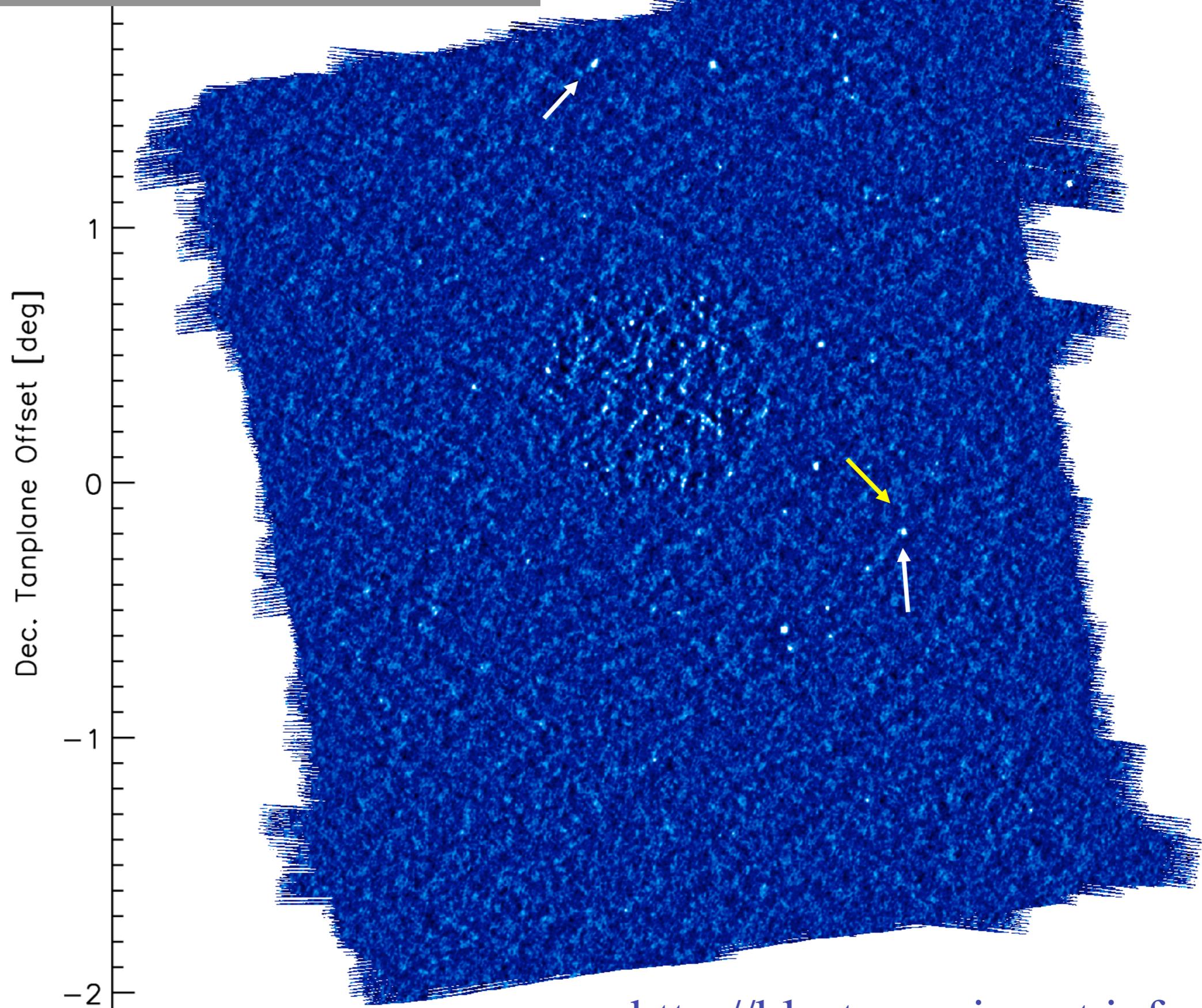
- Long-duration flight (11 days and ~ 250 hours data)
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 - ◉ GOODS-South
 - Deep: ~ 250 sources $> 5 \sigma$
 - Wide: ~ 250 sources $> 5 \sigma$

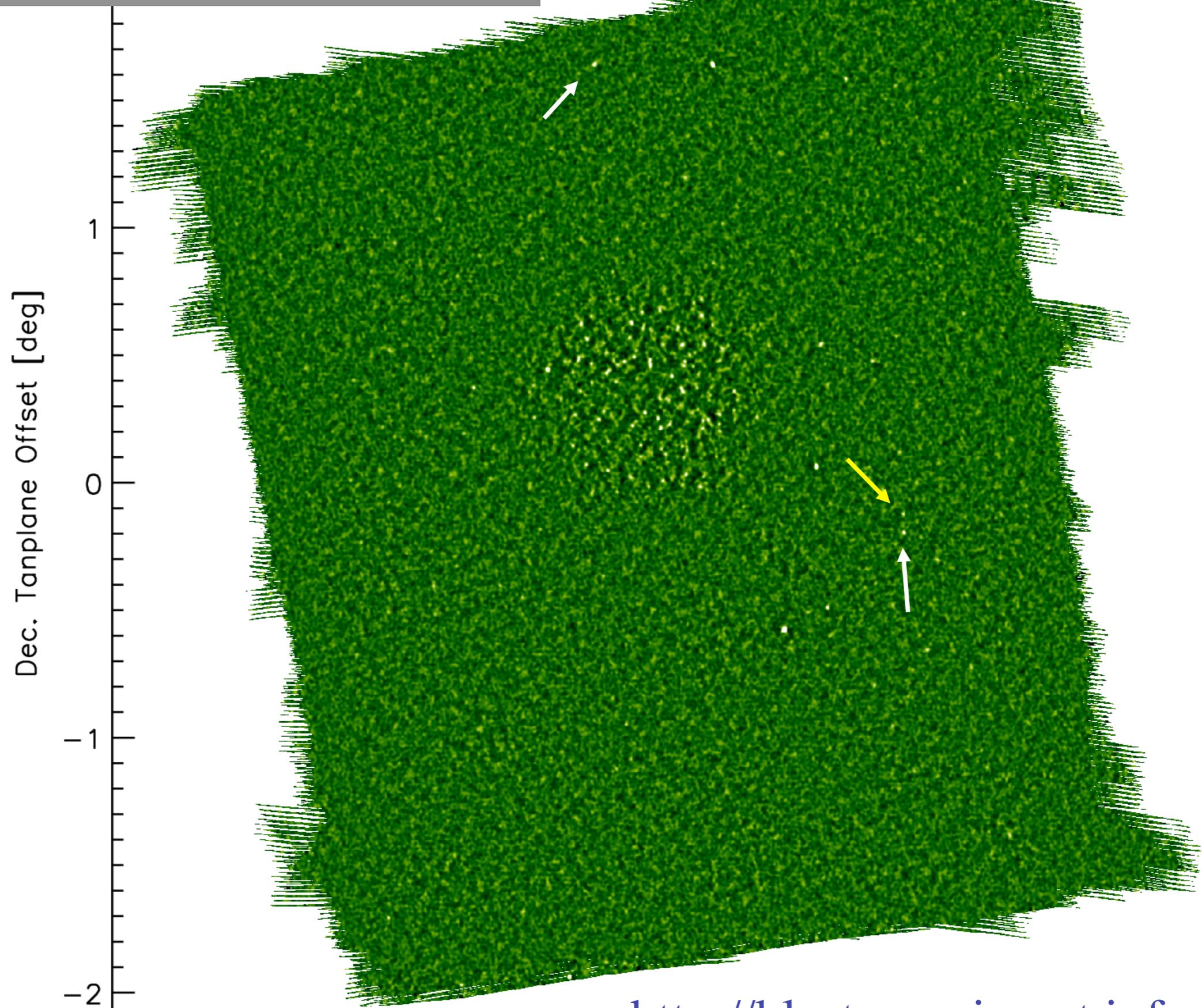


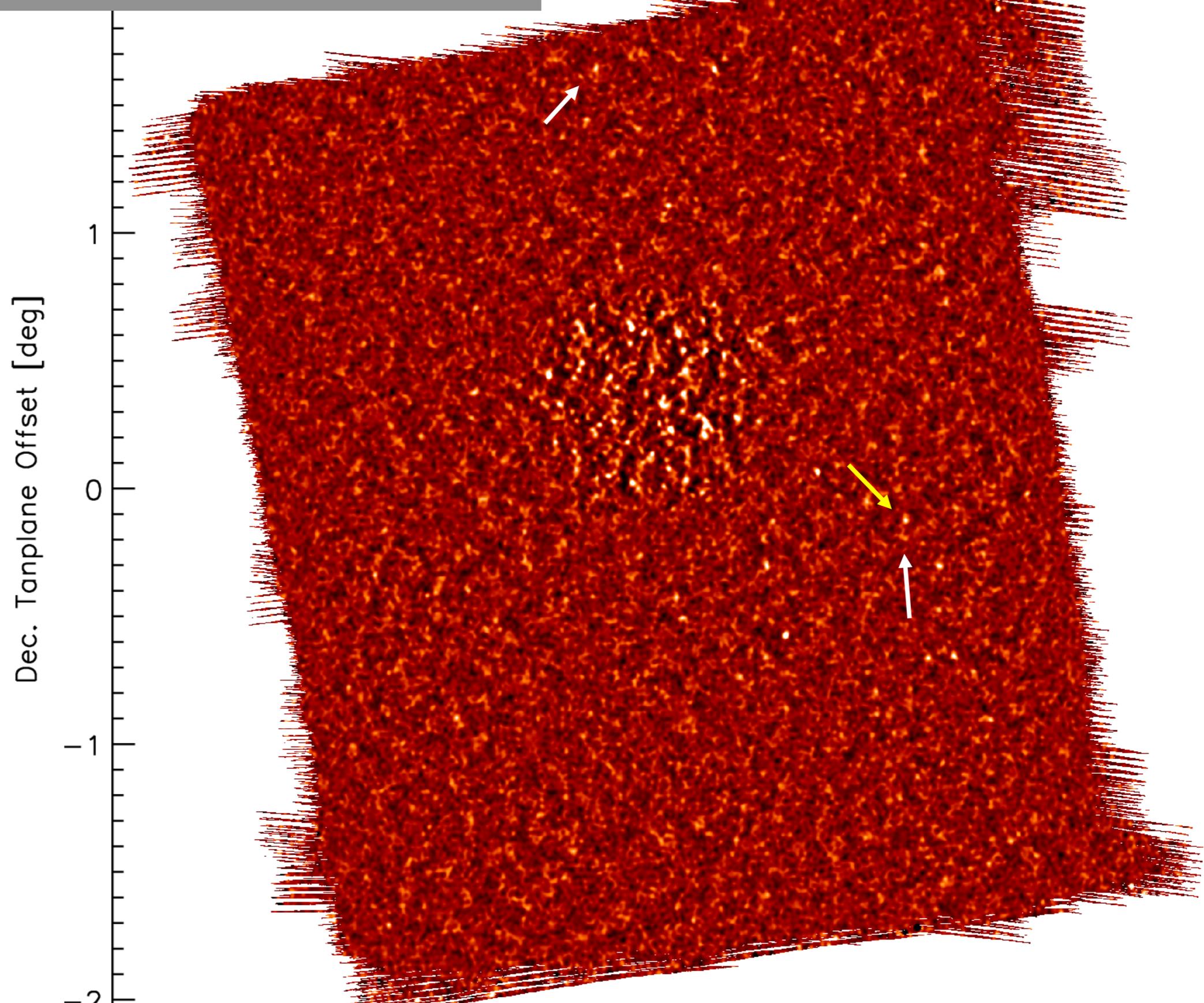
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 - Deep: ~ 250 sources $> 5 \sigma$
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- Confusion Noise ~ 30 mJy









1. "Over half of the far-infrared background light comes from galaxies at $z > 1.2$ ", M. J. Devlin, et al. 2009, Nature, 458
2. "BLAST: Resolving the Cosmic Submillimeter Background", G. Marsden et al. 2009, Astrophysical Journal, 707, 1766
3. "BLAST: A Far-Infrared Measurement of the History of Star Formation", E. Pascale et al. 2009, Astrophysical Journal, 707, 1740
4. "BLAST: Correlations in the Cosmic Far-Infrared Background at 250, 350, and 500 μm Reveal Clustering of Star-Forming Galaxies", M. P. Viero et al. 2009, Astrophysical Journal, 707, 1766
5. "Submillimeter Number Counts From Statistical Analysis of BLAST Maps", G. Patanchon et al. 2009, Astrophysical Journal, 707, 1750
6. "Radio and Mid-Infrared Identification of BLAST Source Counterparts in the Chandra Deep Field South", S. Dye et al. 2009, Astrophysical Journal, 703, 285
7. "A Bright Submillimeter Source in the Bullet Cluster (1E0657-56) Field Detected with BLAST", M. Rex et al. 2009, Astrophysical Journal, 703, 348
8. "BLAST: the Redshift Surveys", S. Eales et al, Astrophysical Journal, 707, 1779
9. "The BLAST 250-micron selected galaxy population in GOODS-South", J. S. Dunlop et al., 2009, Monthly Notices of the Royal Astronomical Society, submitted, arXiv:0910.3642
10. "BLAST: the far-infrared/radio correlation in distant galaxies", R. J. Ivison et al., 2009, Monthly Notices of the Royal Astronomical Society, accepted, arXiv:0910.1091
11. "The Balloon-borne Large Aperture Submillimeter Telescope (BLAST) 2006: Calibration and Flight Performance", M. D. P. Truch et al. 2009, Astrophysical Journal, 707, 1824
12. "Temperature Profiles and the Effect of AGN on Submillimeter Emission from BLAST Observations of Resolved Galaxies", D. V. Wiebe et al. 2009, 707, 1809
13. "The Mass Function, Lifetimes, and Properties of Intermediate Mass Cores from a 50 Square Degree Submillimeter Survey in Vela ($\ell = 265^\circ$) From the 2006 Flight by BLAST", C. B. Netterfield et al. 2009, Astrophysical Journal, 707, 1824
14. "The BLAST Survey of the Vela Molecular Cloud: Physical Properties of the Dense Cores in Vela-D", L. Olmi et al. 2009, Astrophysical Journal, 707, 1836
15. "AKARI and BLAST Observations of the Cassiopeia A Supernova Remnant and Surrounding Interstellar Medium", B. Sibthorpe et al., 2009, Astrophysical Journal, submitted, arXiv:0910.1094

The BLAST Extragalactic Results: Outline

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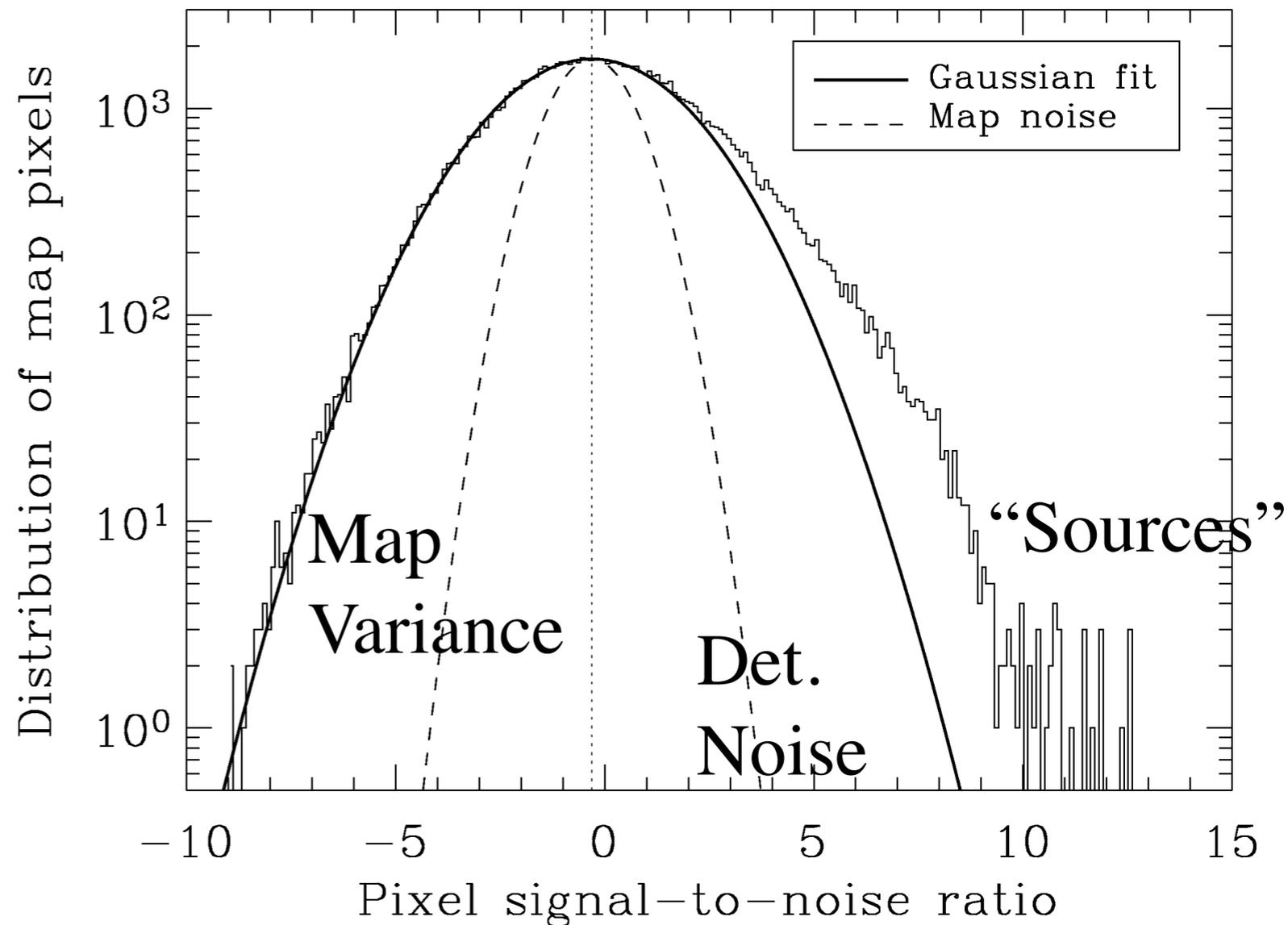
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Goal:

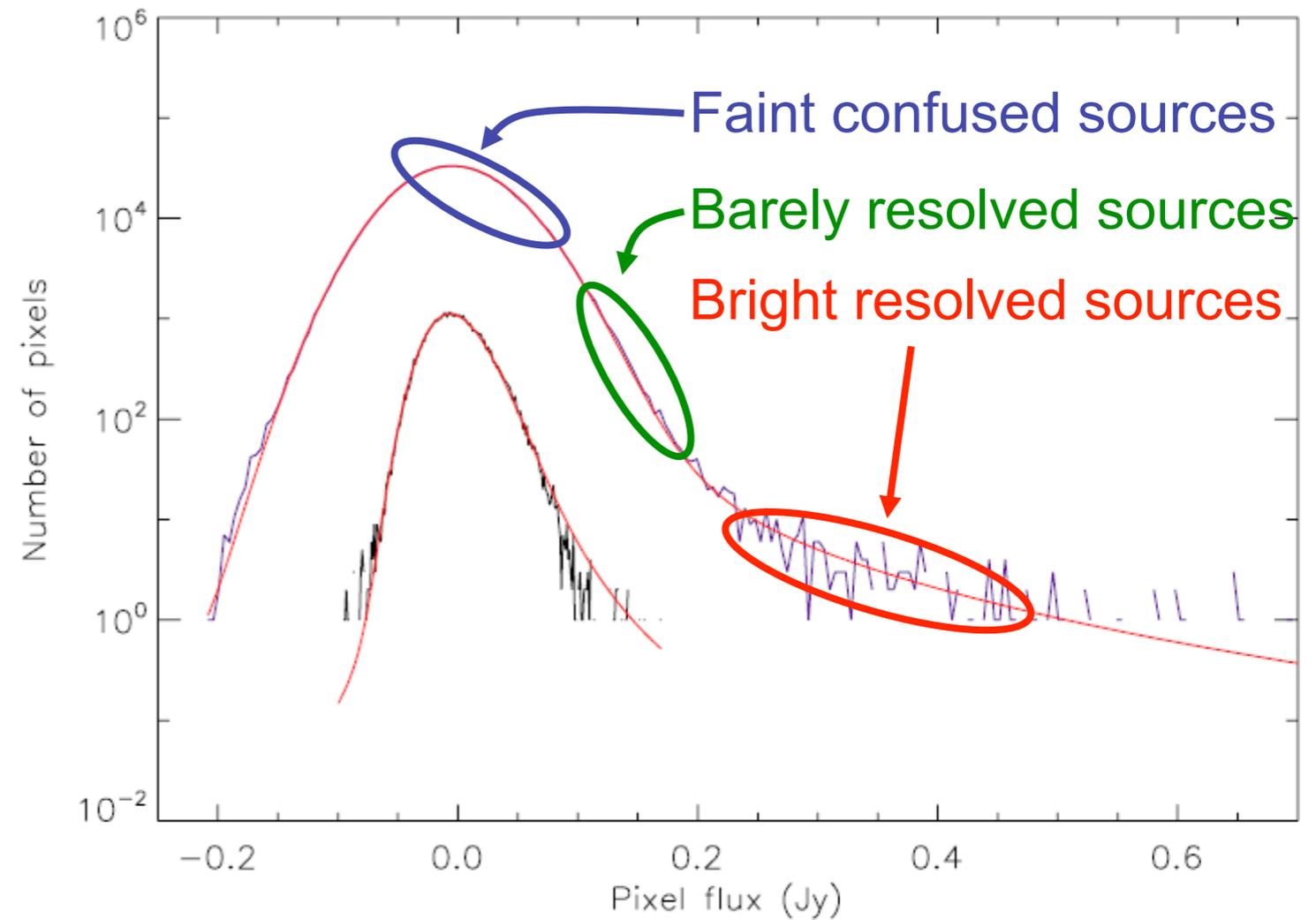
- To convince you that maps are more important than catalogs when working at the confusion limit!



Marsden et al. 0904.1205

Number Counts

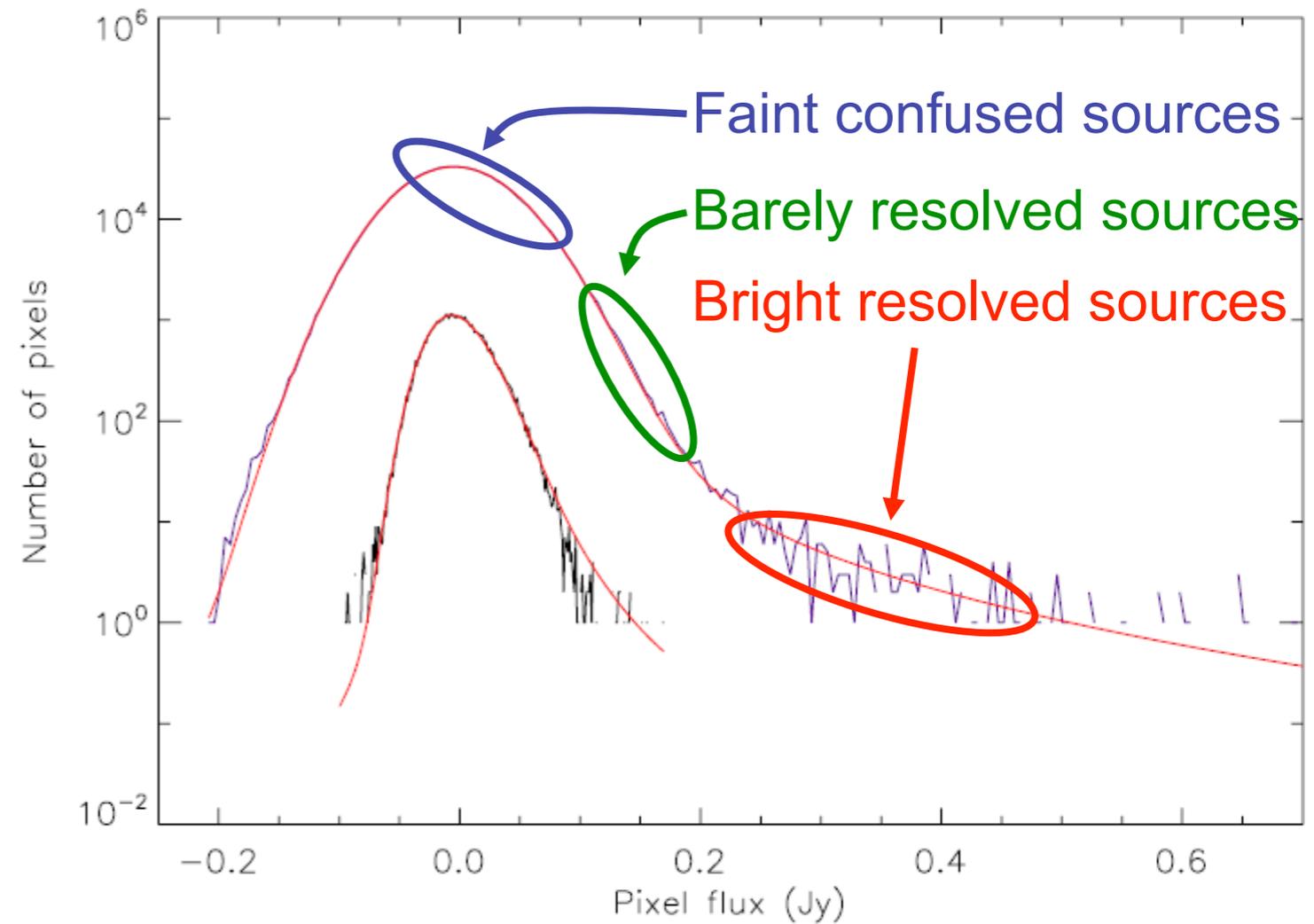
Counts from $P(d)$ analysis



Patanchon et al., 2009

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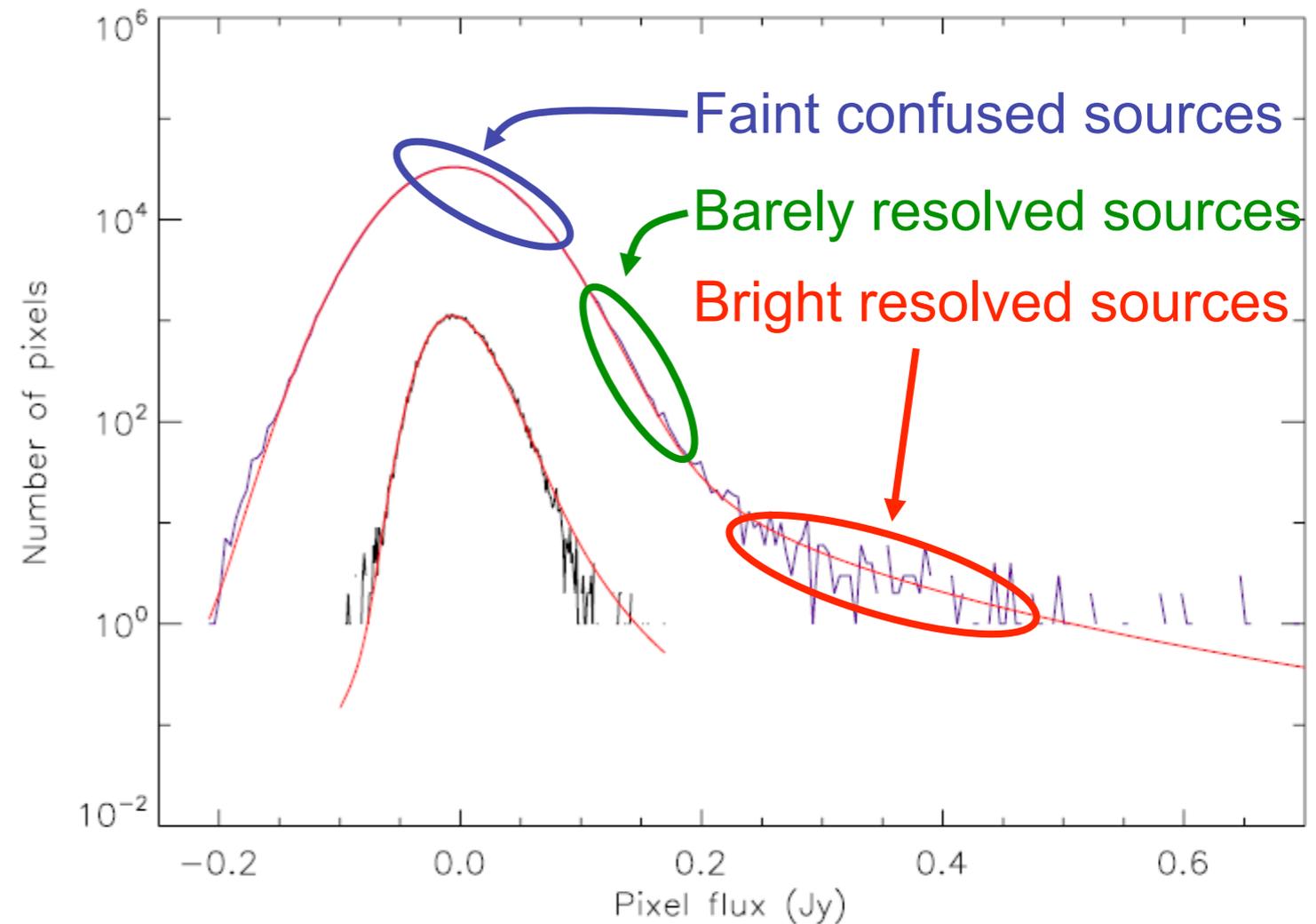
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Patanchon et al., 2009

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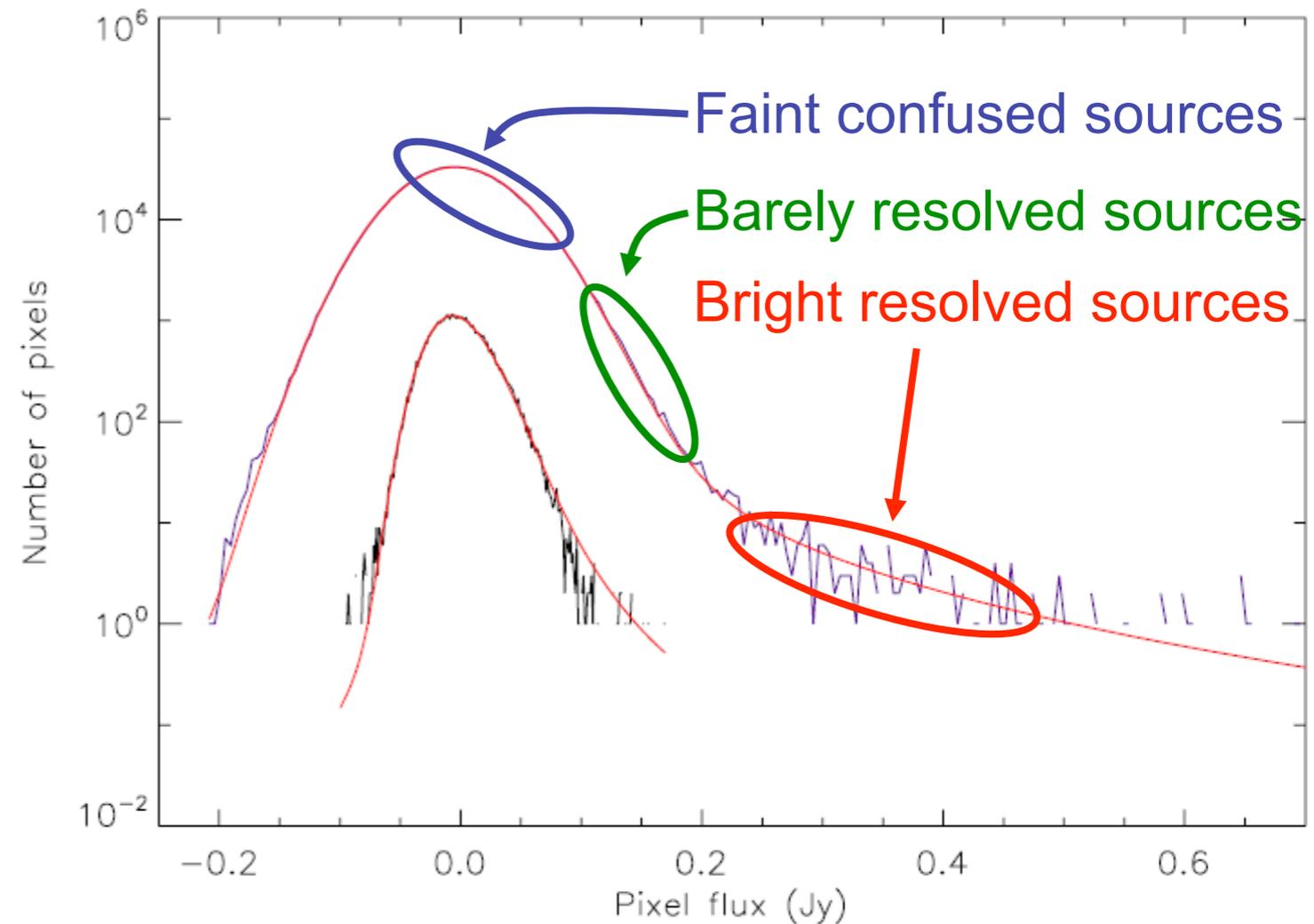
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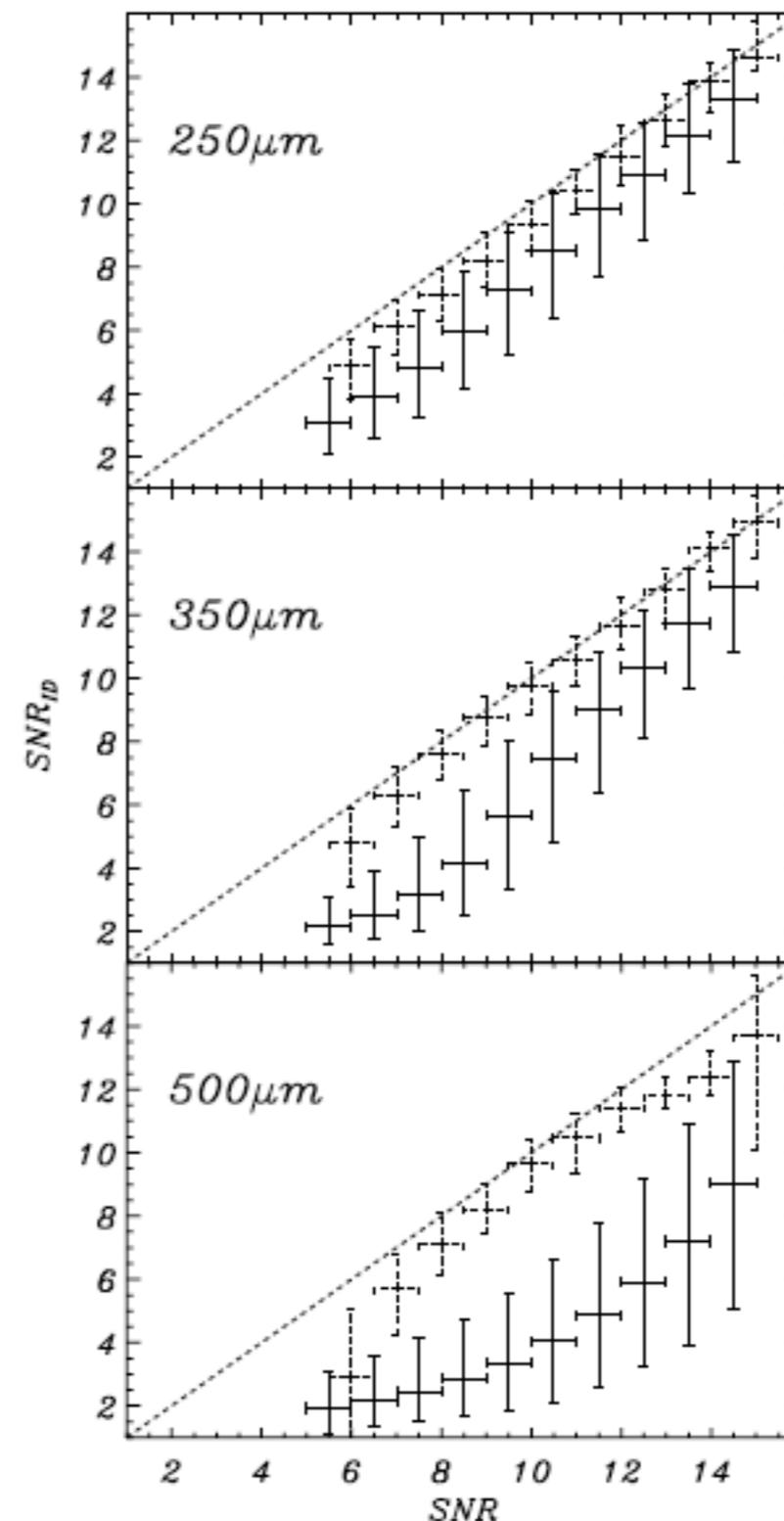
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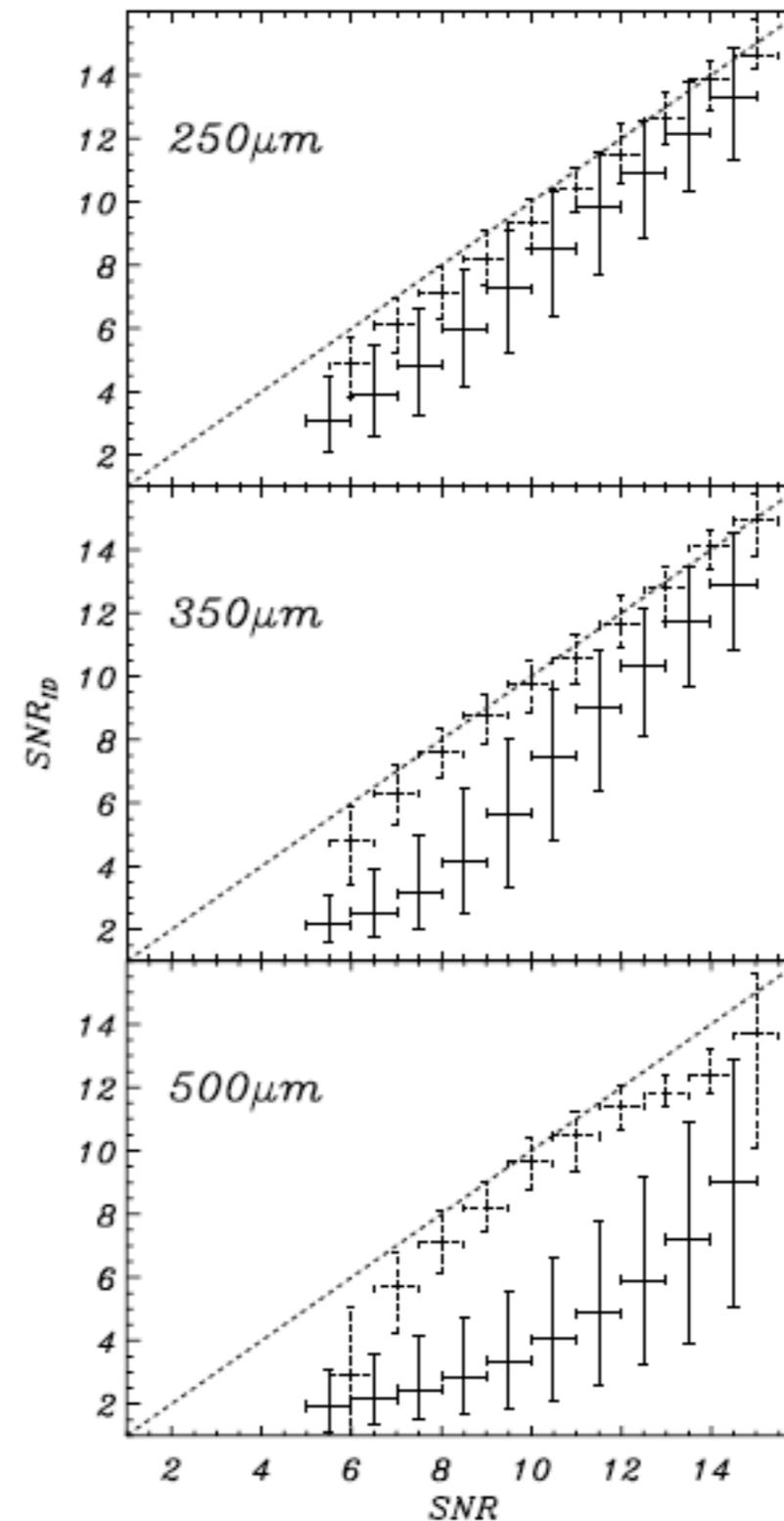
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Moncelsi et al. (in preparation)

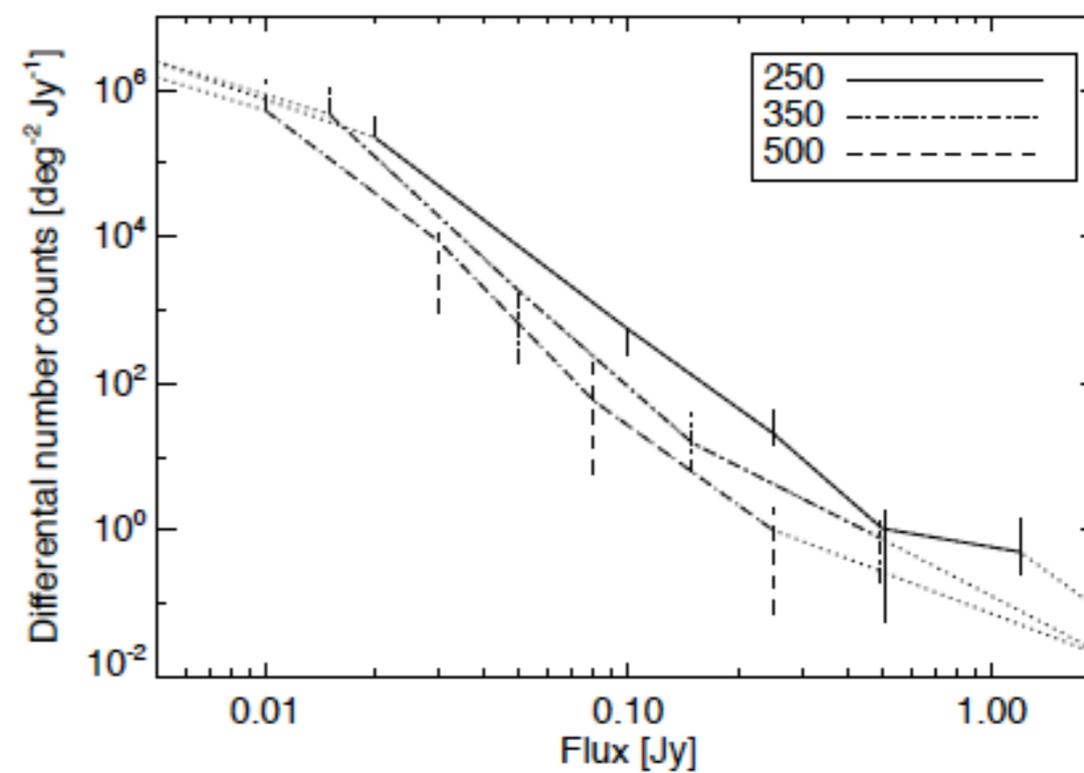
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- In other words: To measure source counts, please don't count sources!



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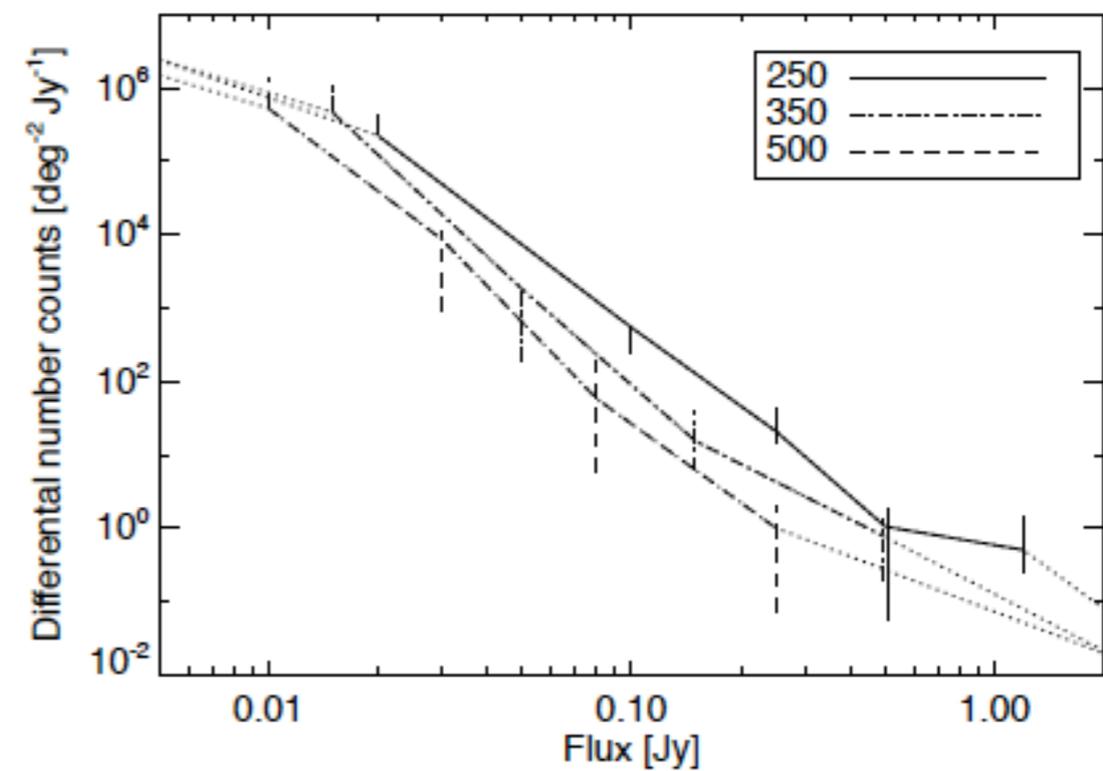
The algorithm



Patanchon et al. 0906.0891

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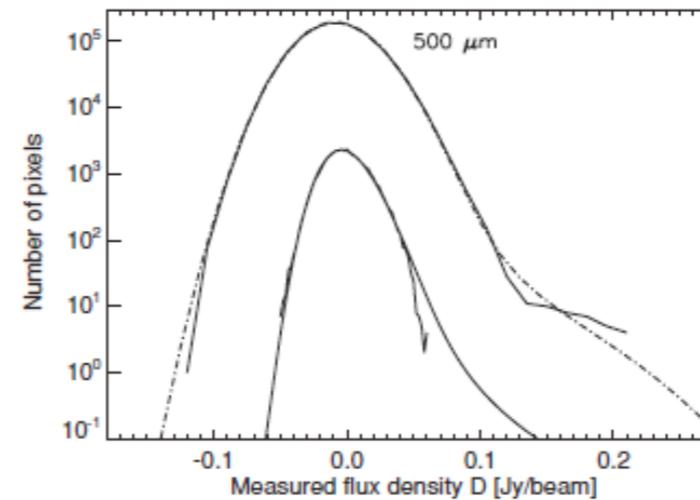
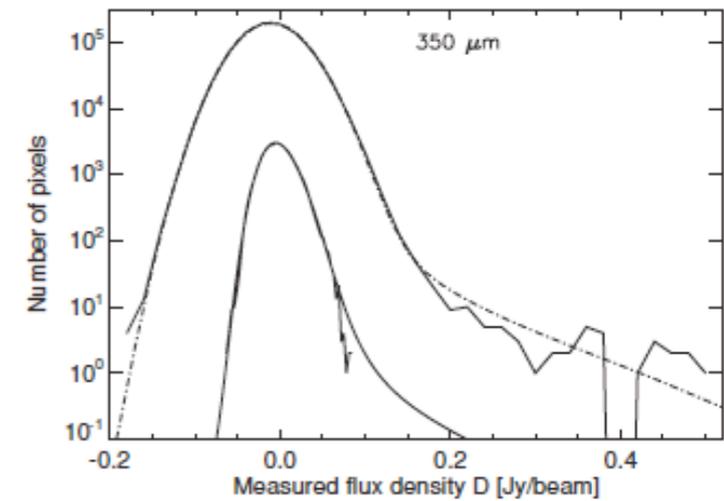
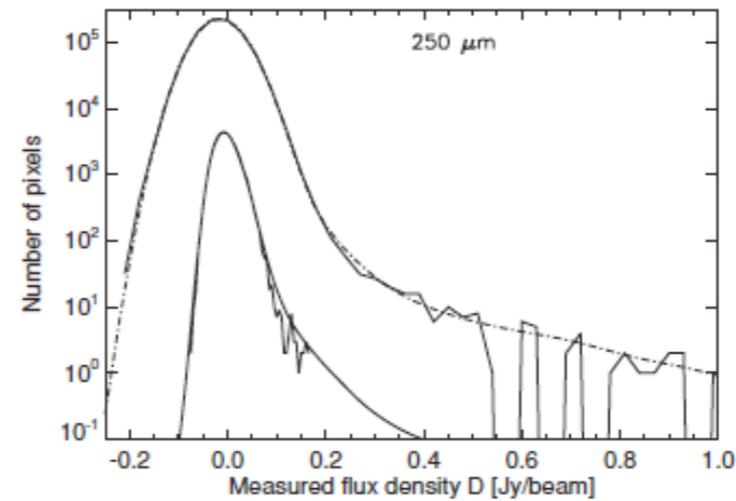
- Make mock map from counts estimate



Patanchon et al. 0906.0891

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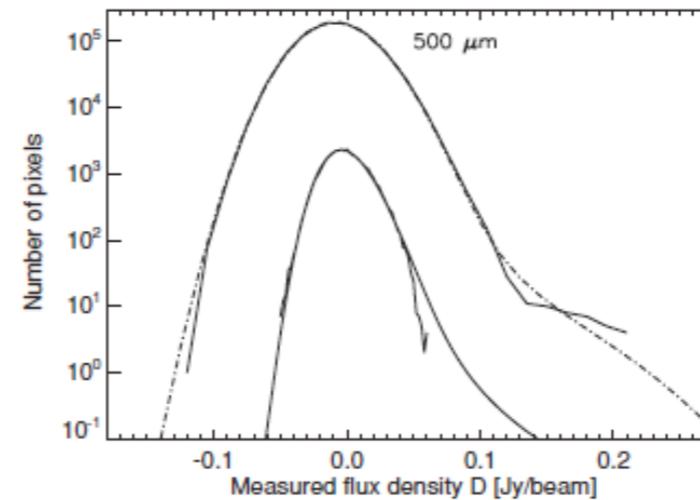
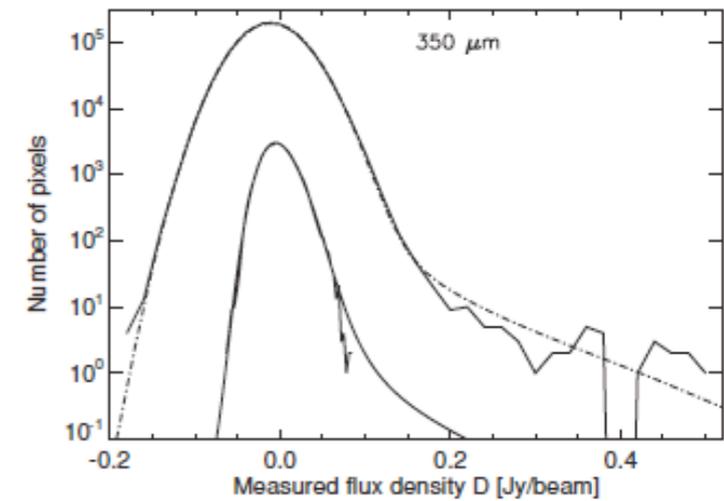
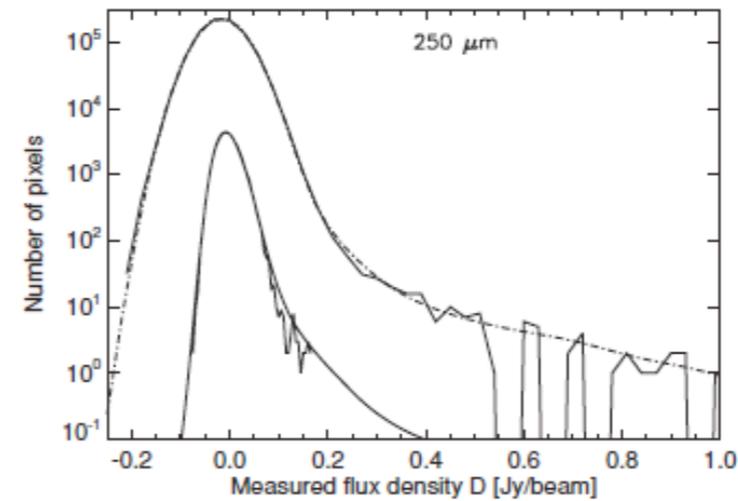
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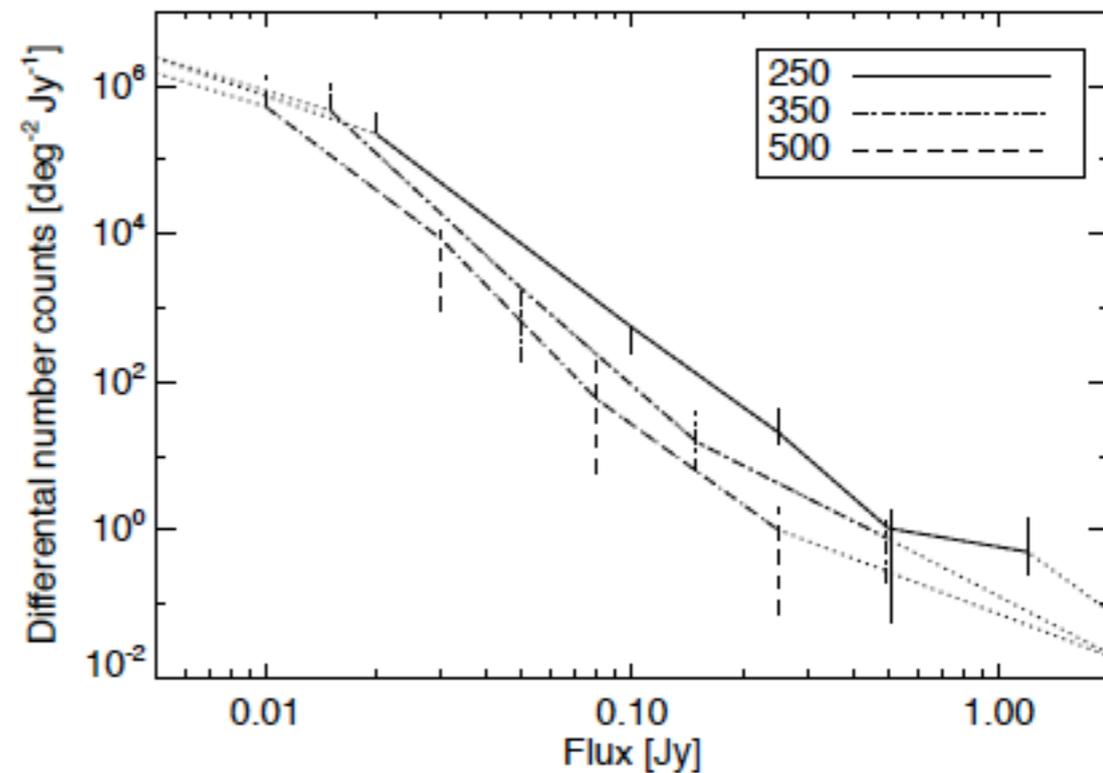
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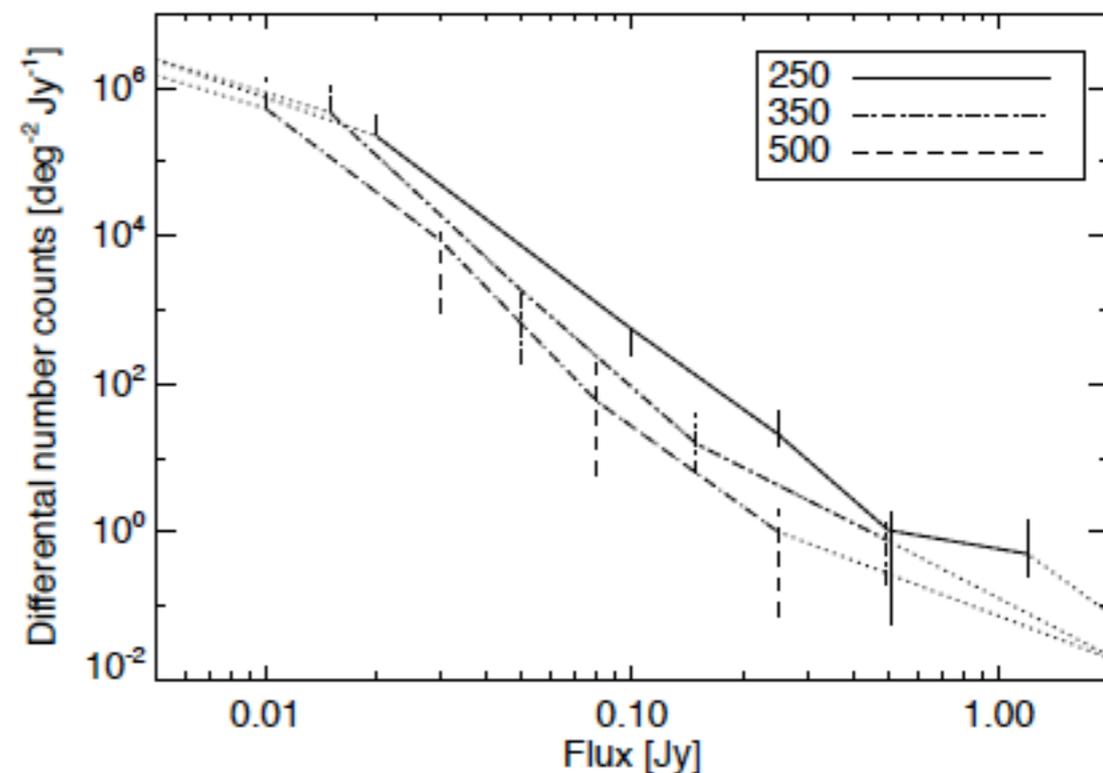
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- Number of nodes used is a compromise between too small/large errors, and such that the fit is not significantly improved with more nodes



Patanchon et al. 0906.0891

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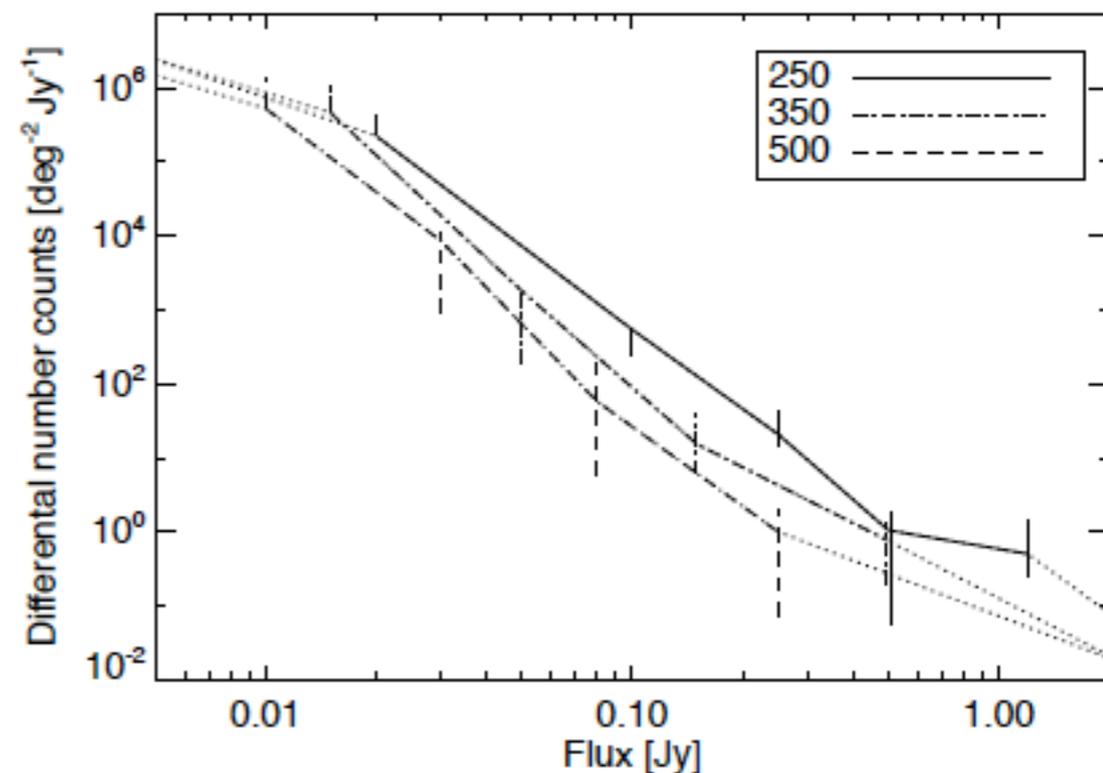
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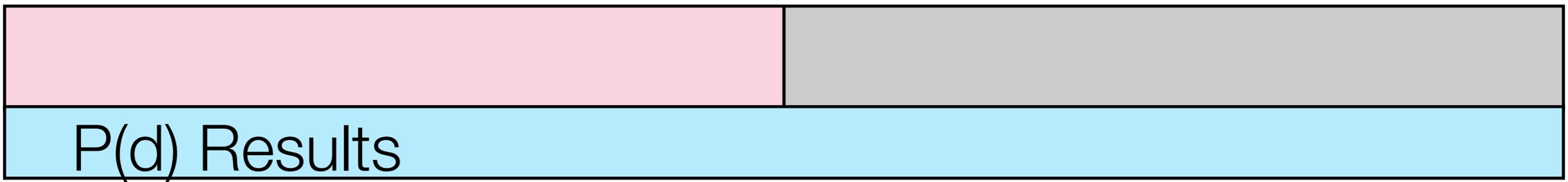
Patanchon et al. 0906.0891

The algorithm

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 - ◉ Assumes Clustering not relevant on scale of the beam. (Analysis more complicated otherwise, as detailed in Patanchon et al. 2009 appendix)



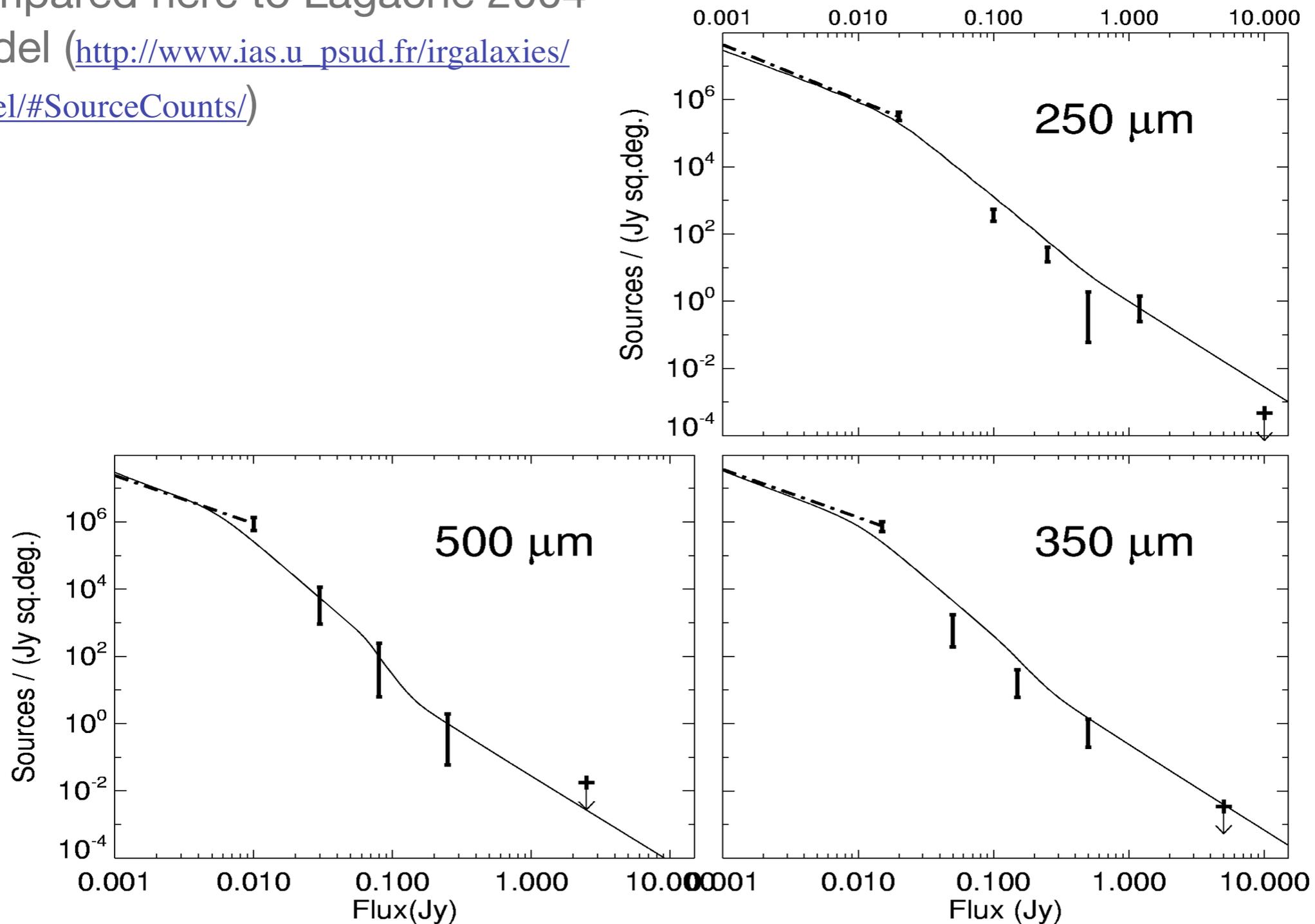
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P(d) Results

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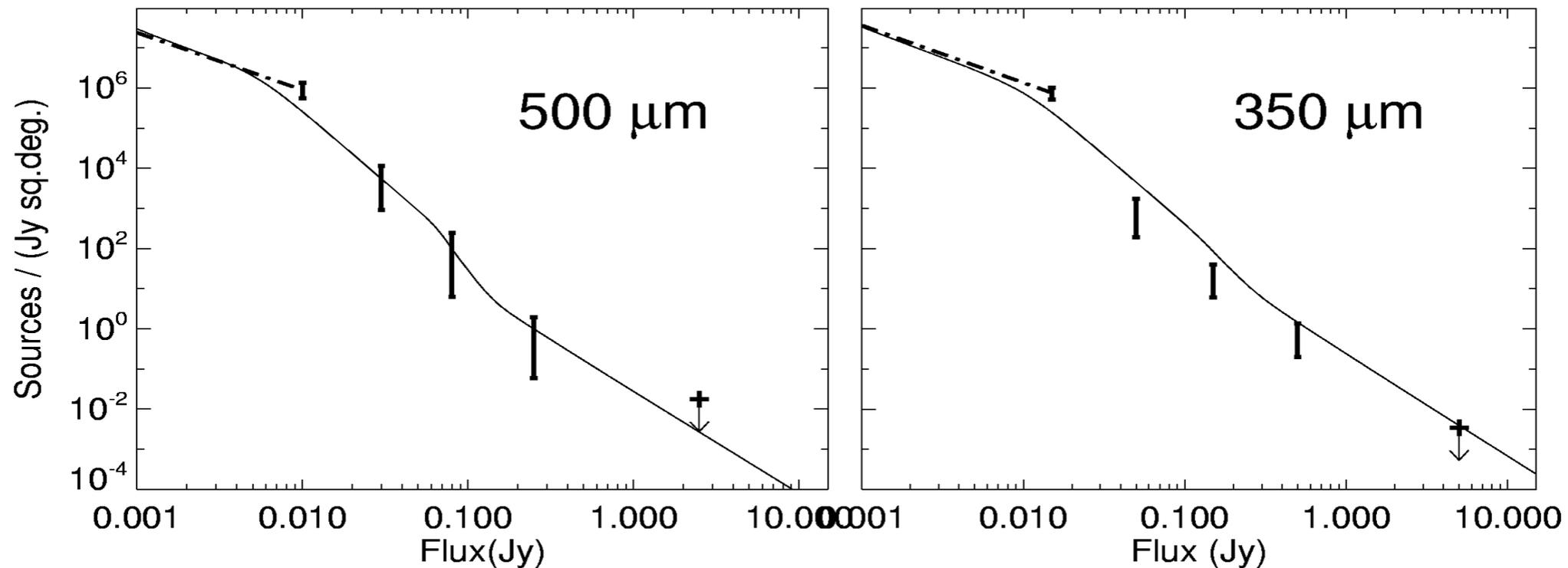
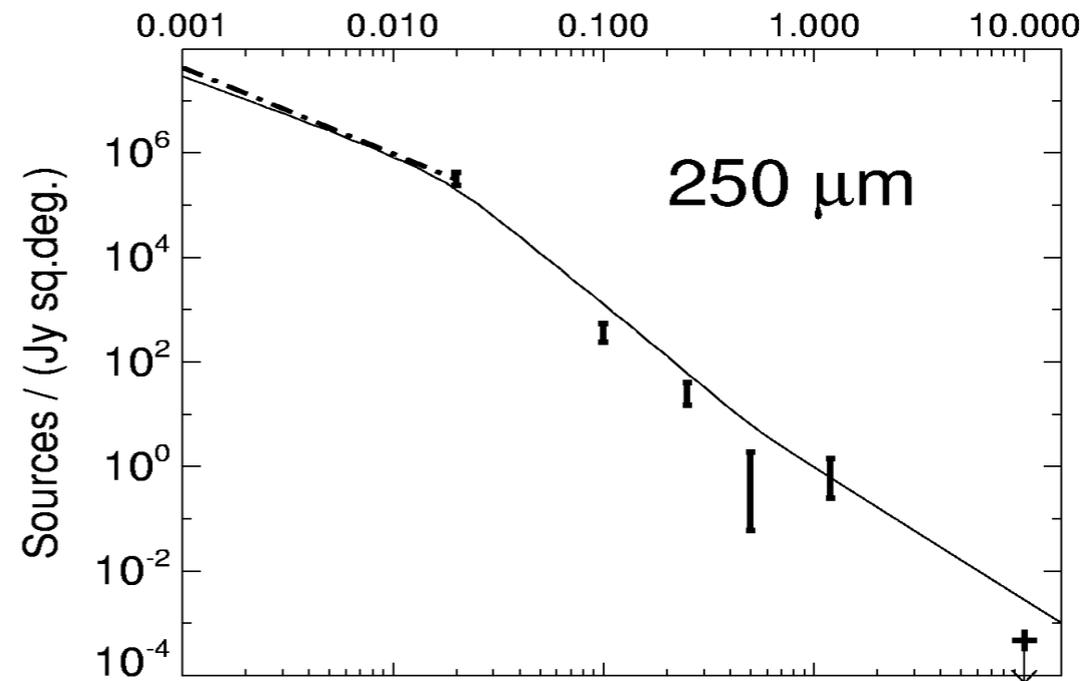
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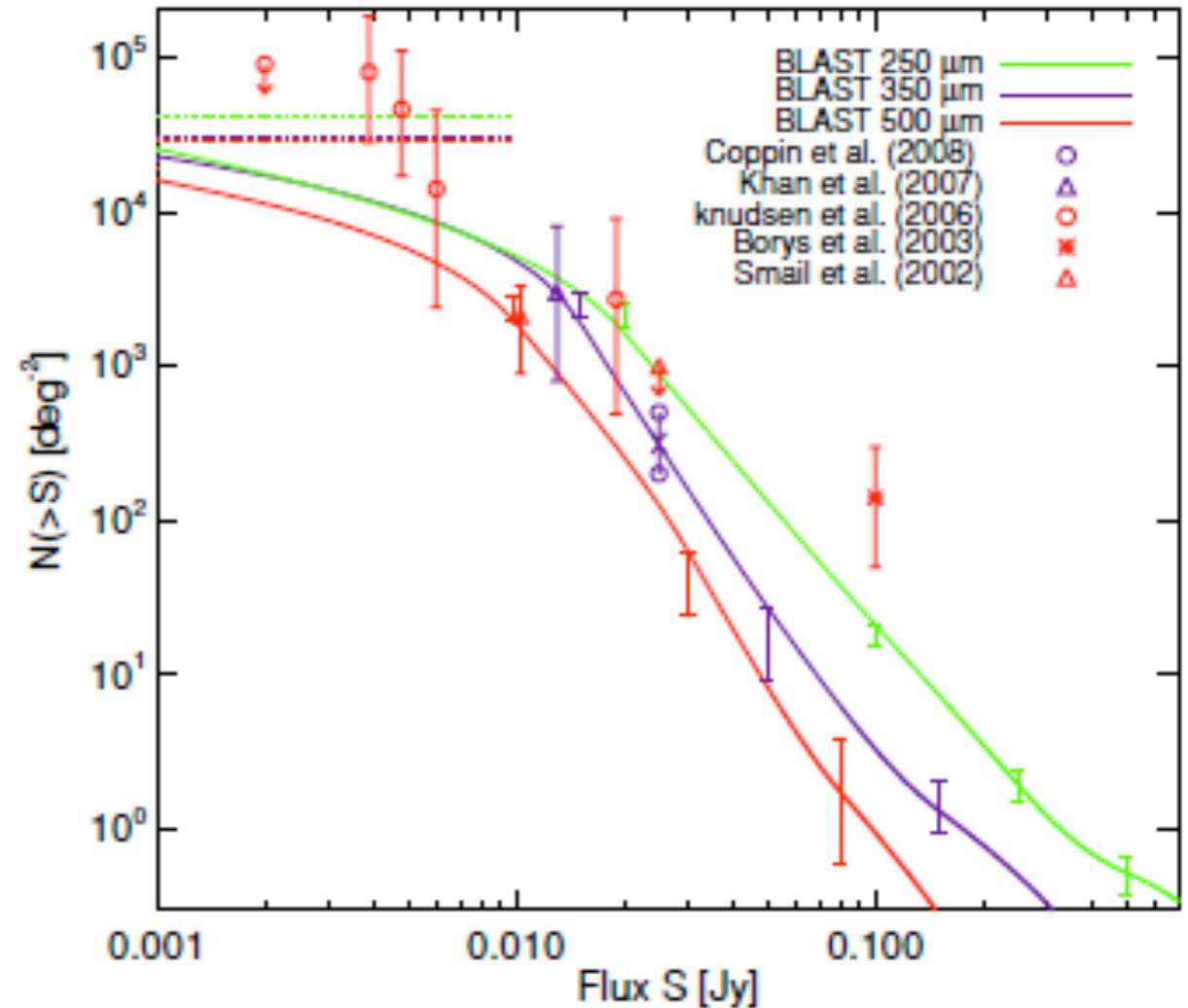
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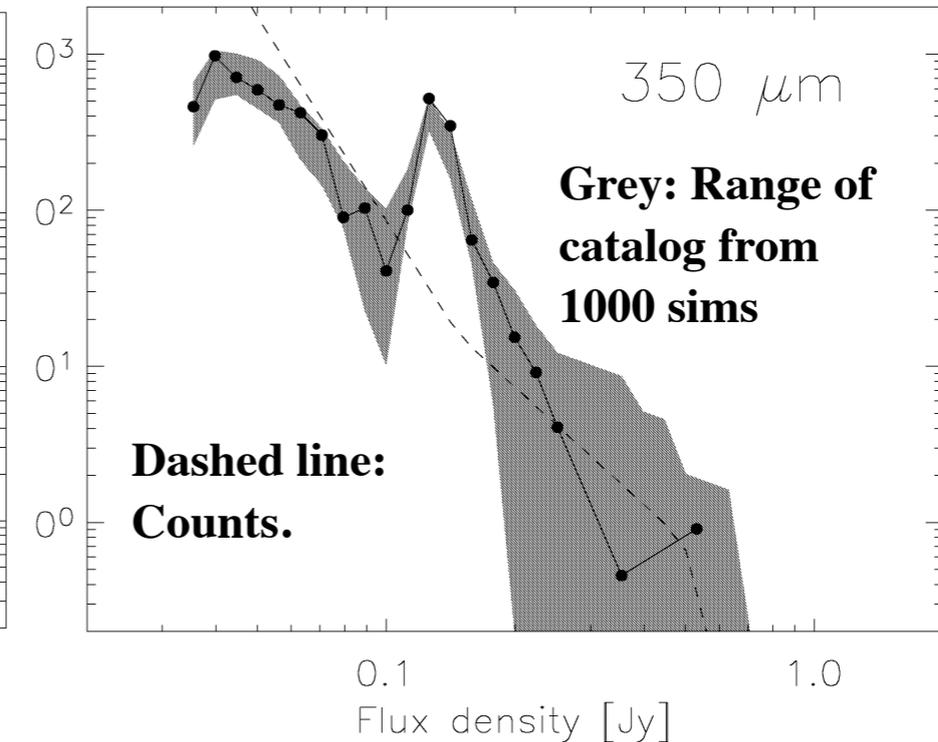
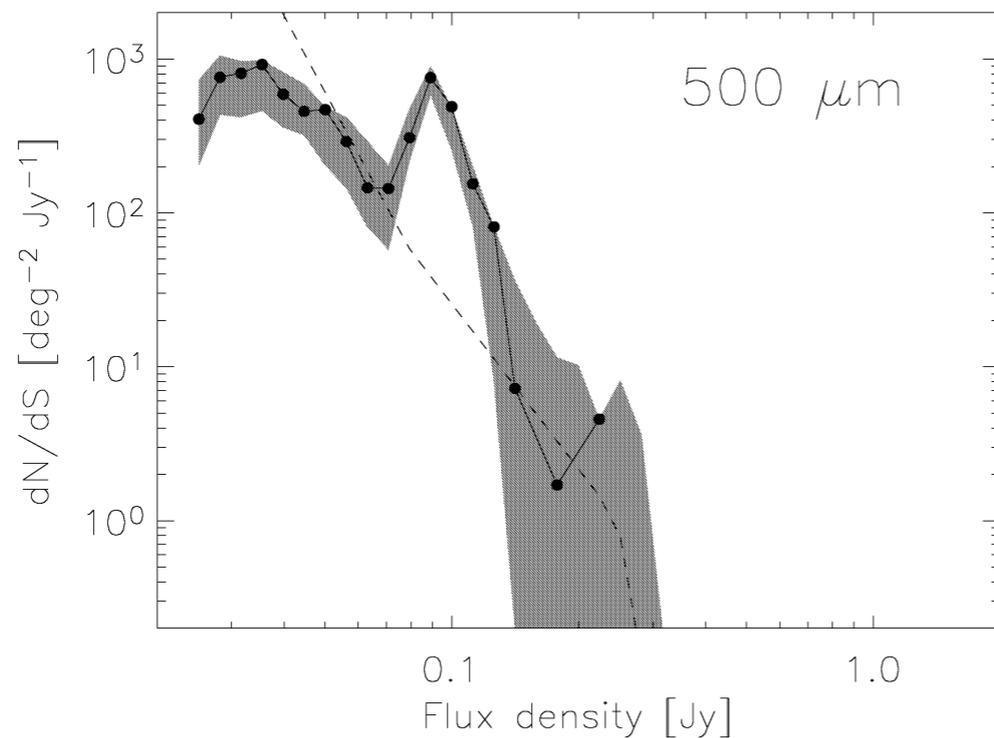
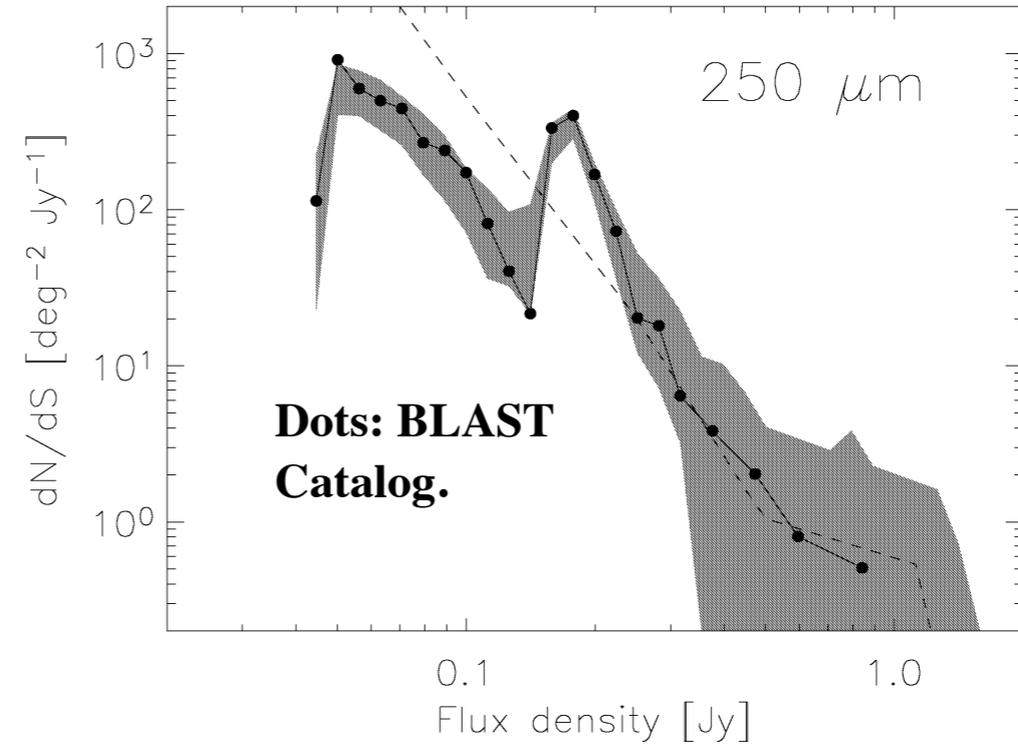
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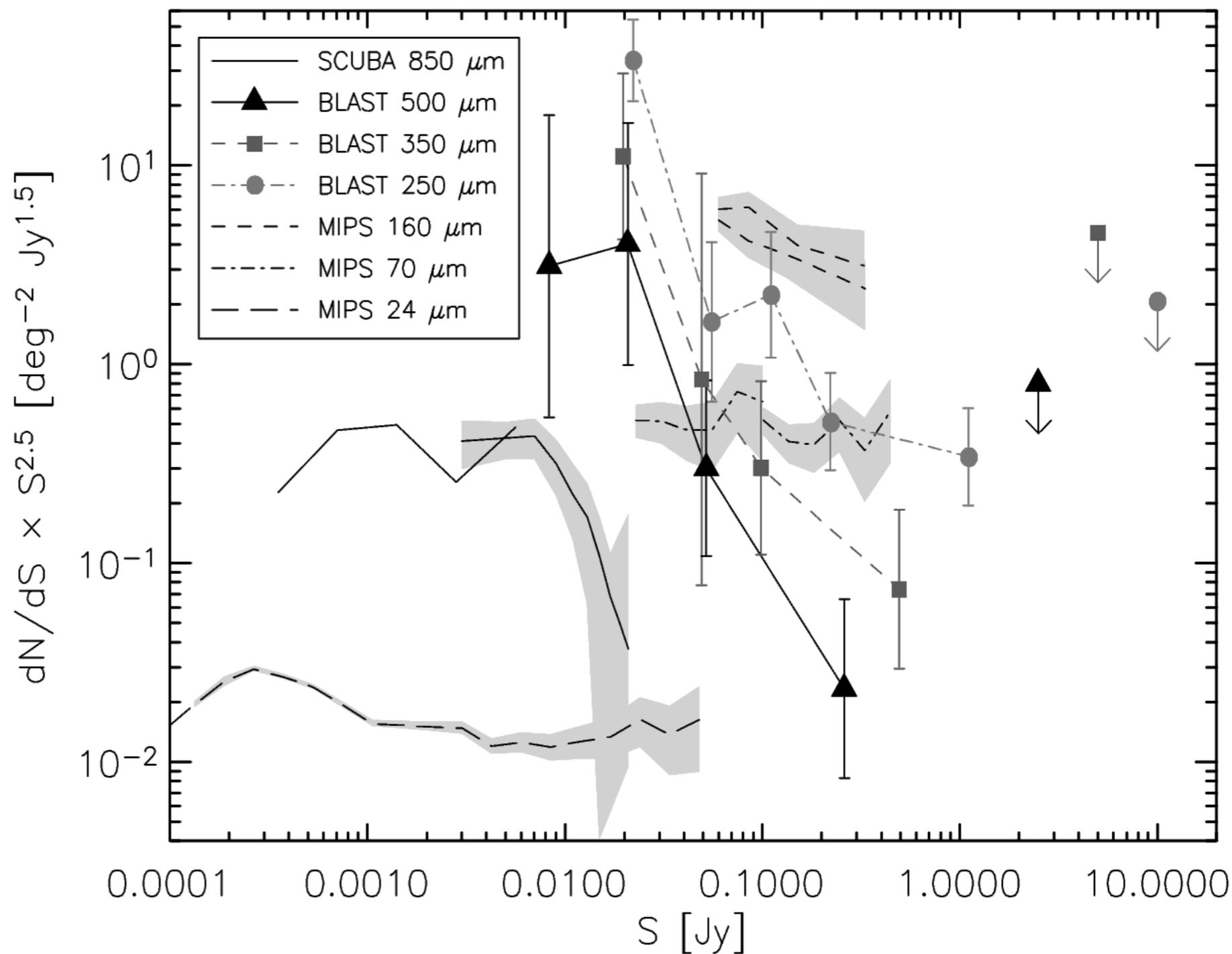
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- What counting sources looks like



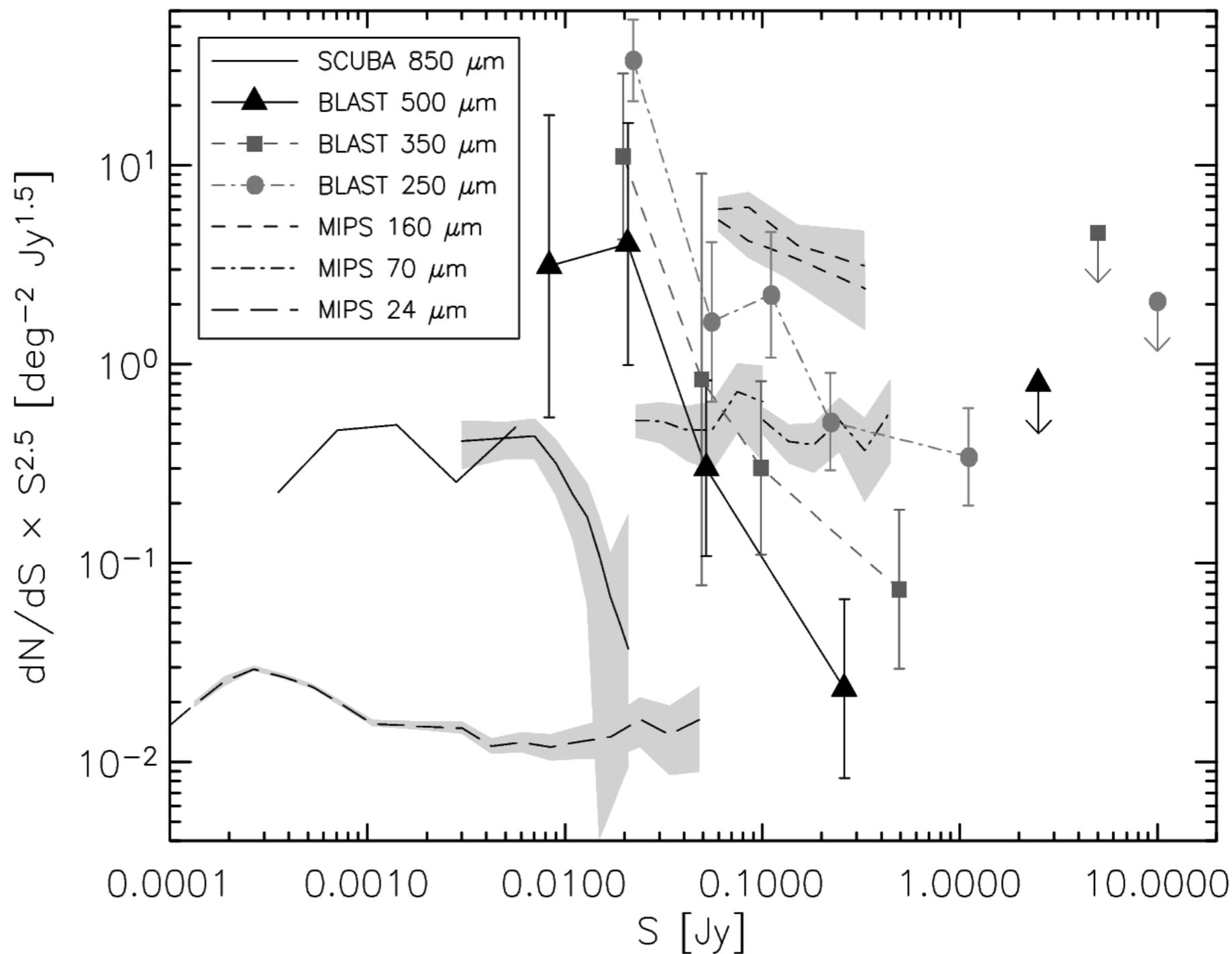
“Euclideanized” counts at FIR/submm wavelengths



Devlin et al. 0904.1201

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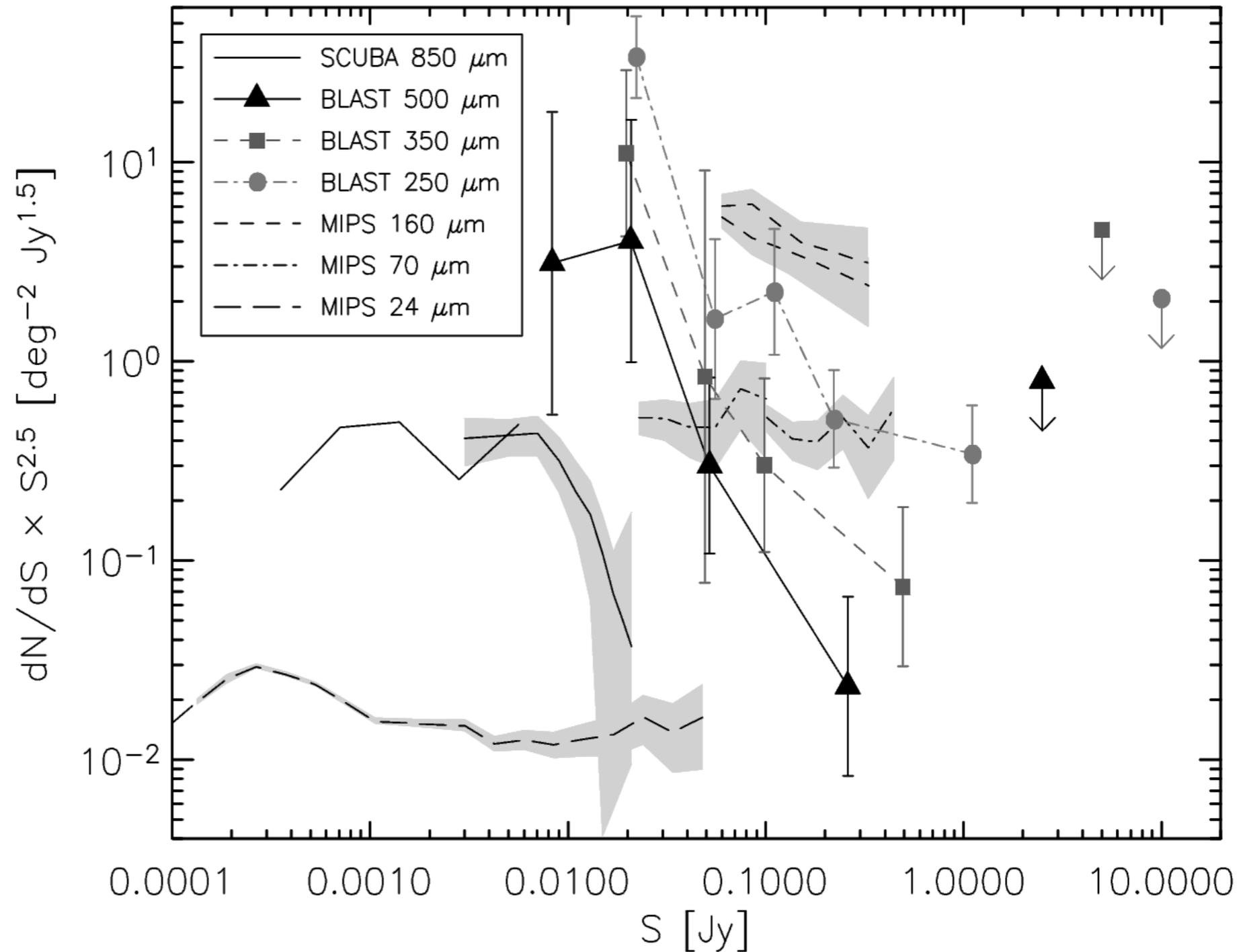
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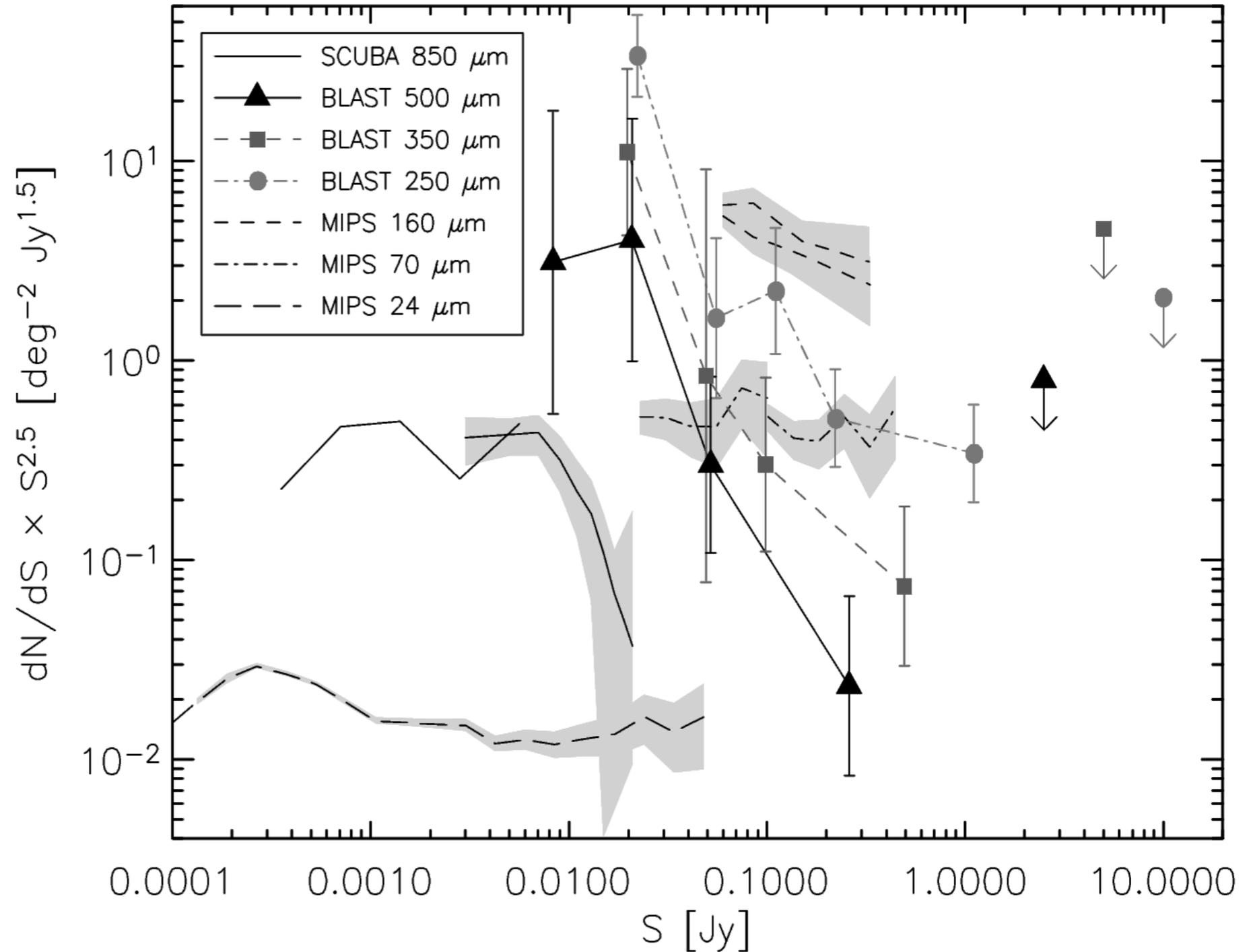
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Devlin et al. 0904.1201

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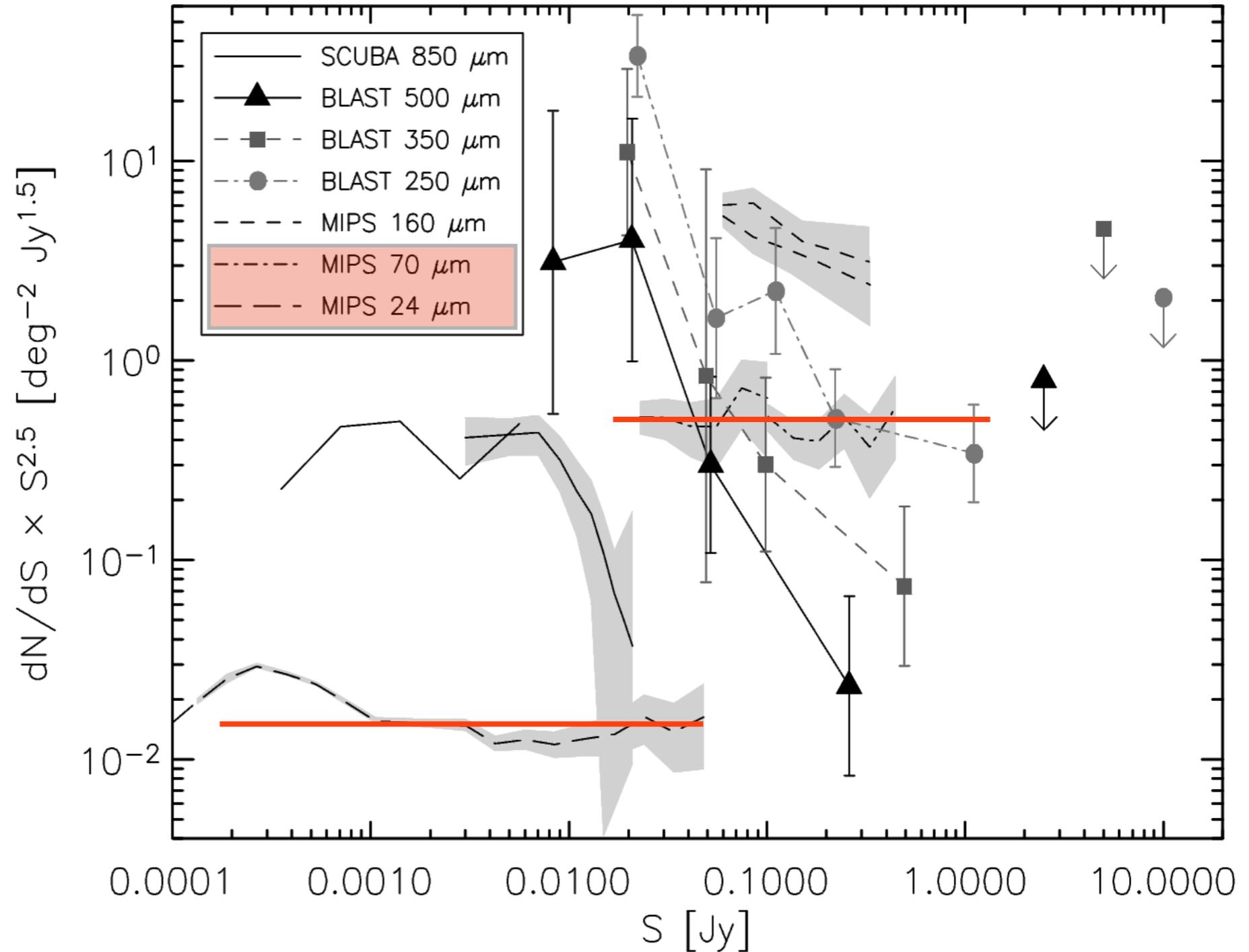
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Devlin et al. 0904.1201

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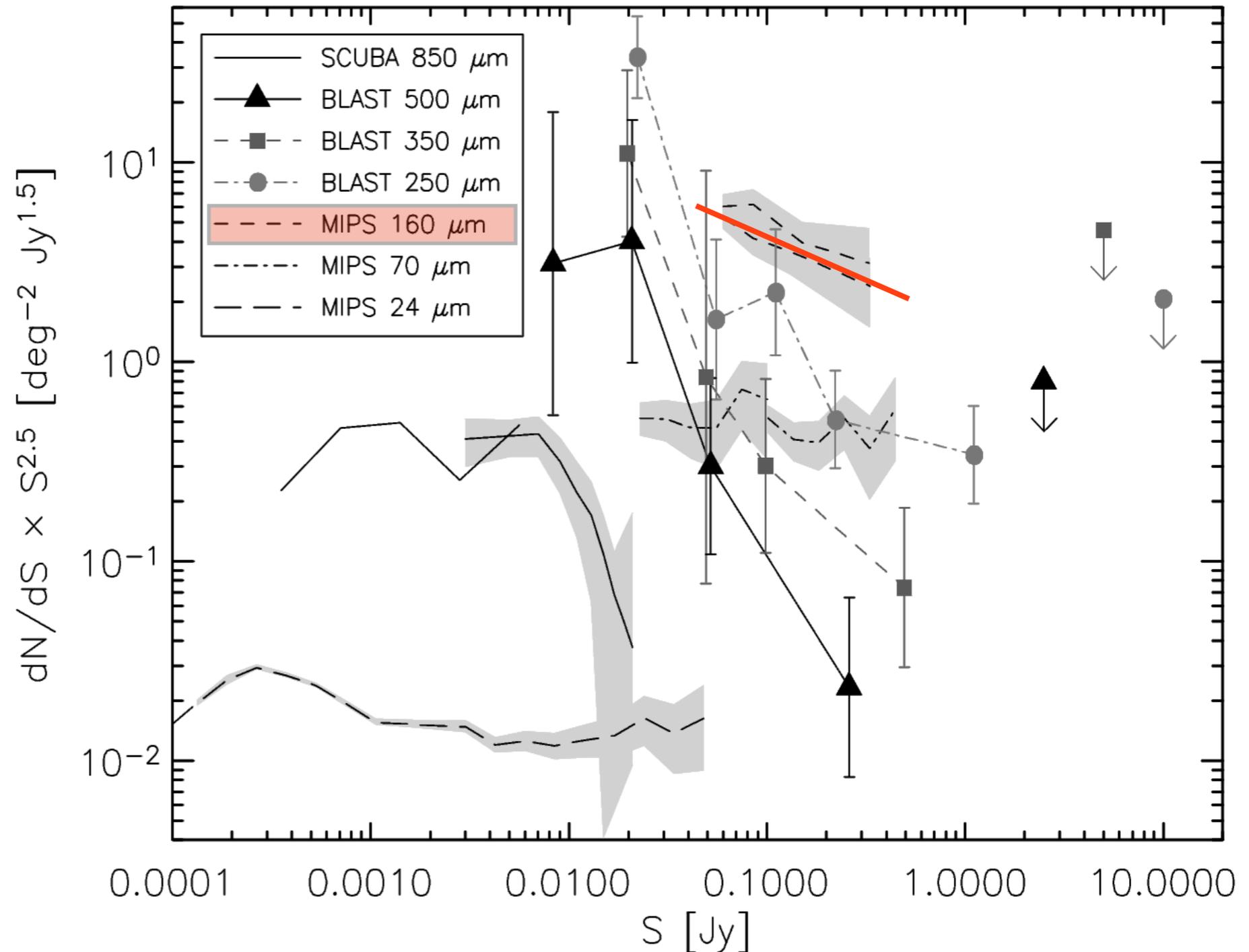
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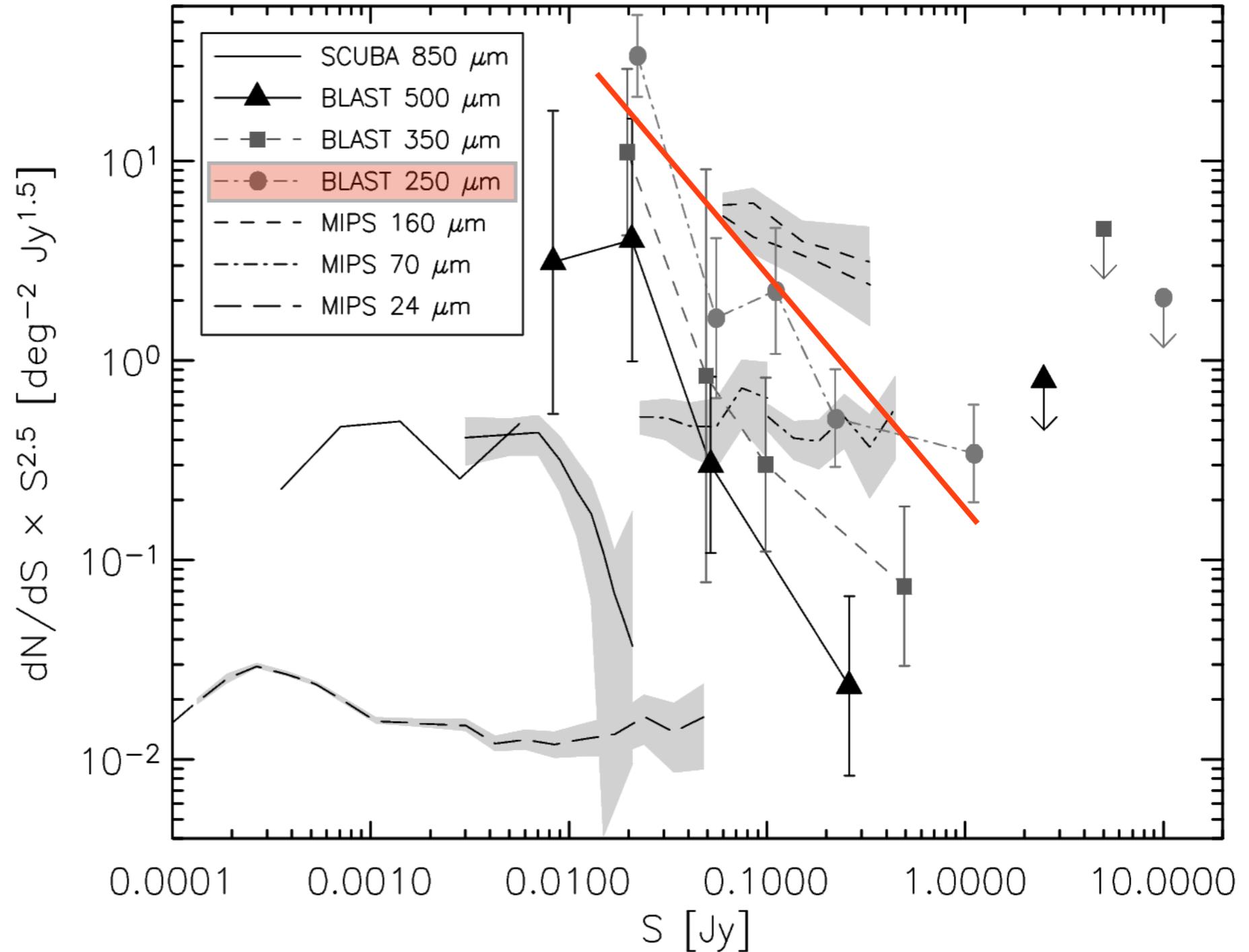
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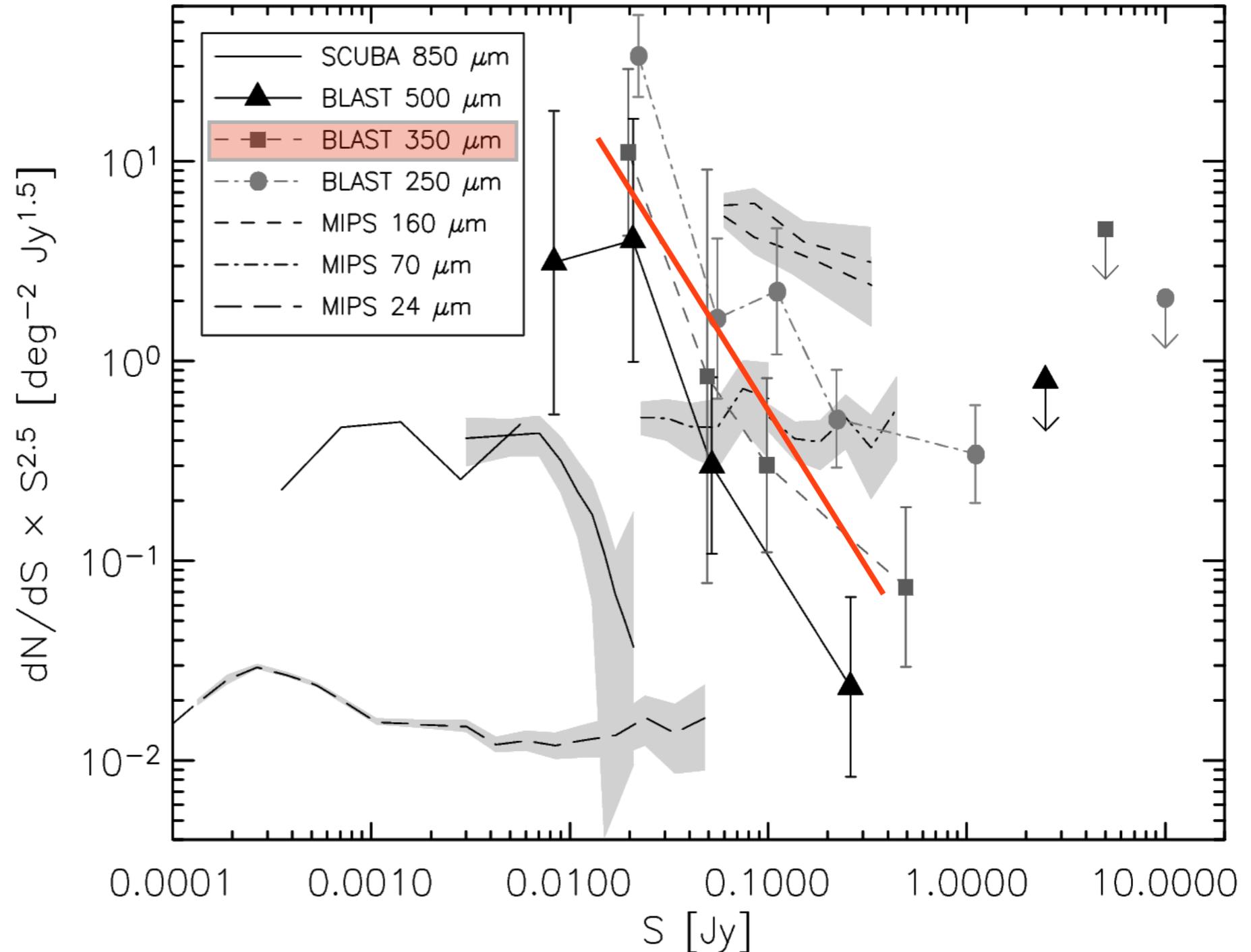
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Devlin et al. 0904.1201

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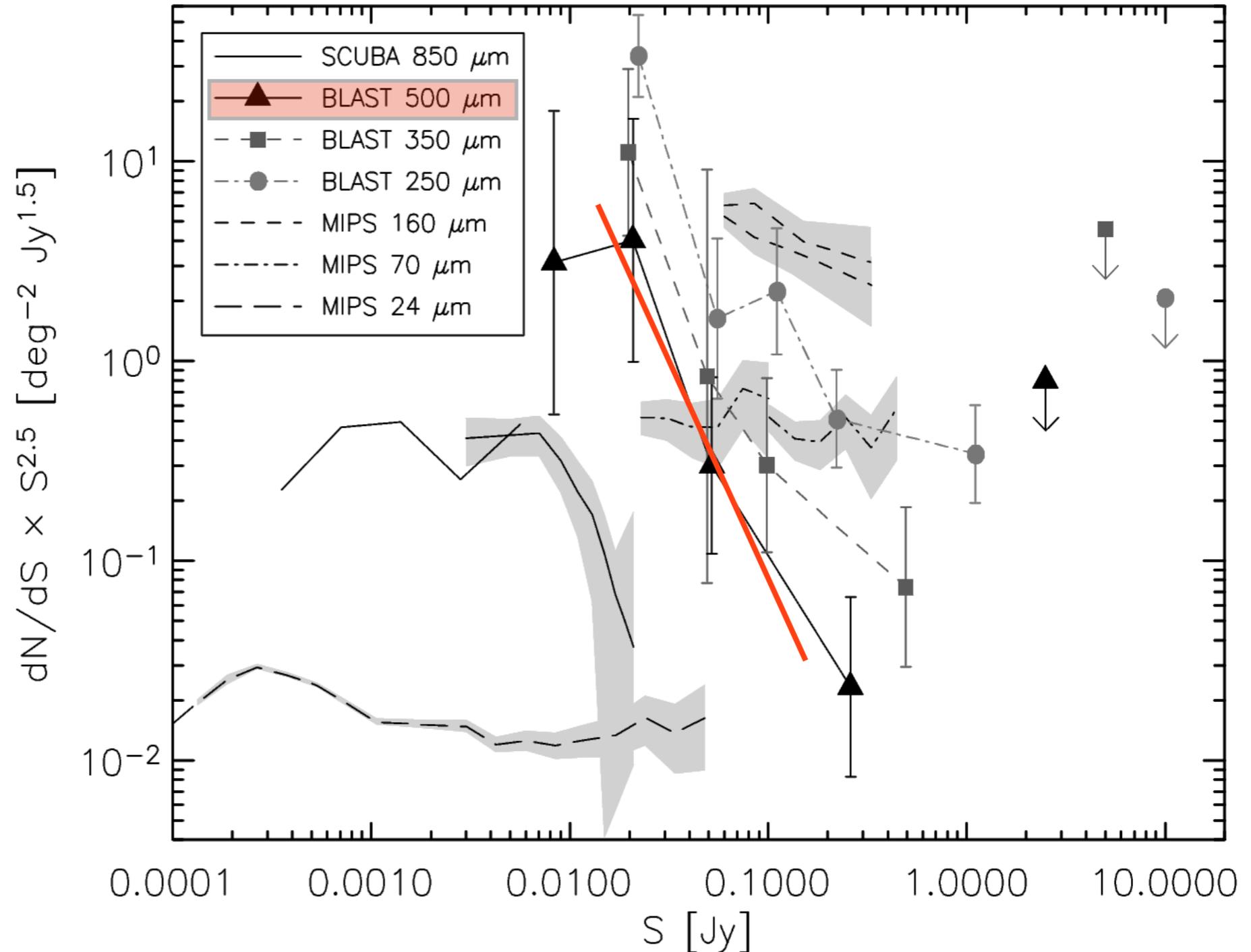
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Devlin et al. 0904.1201

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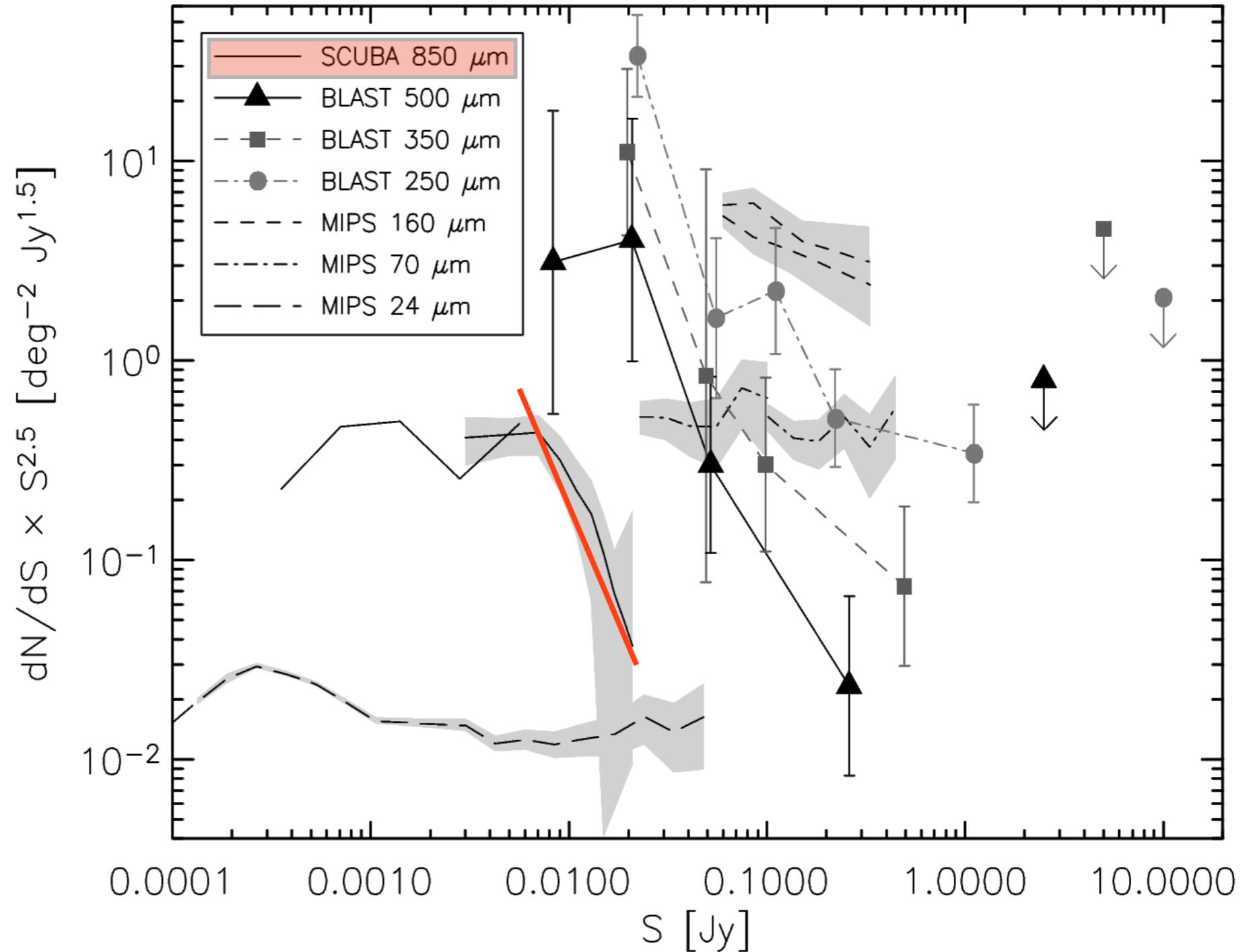
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Devlin et al. 0904.1201

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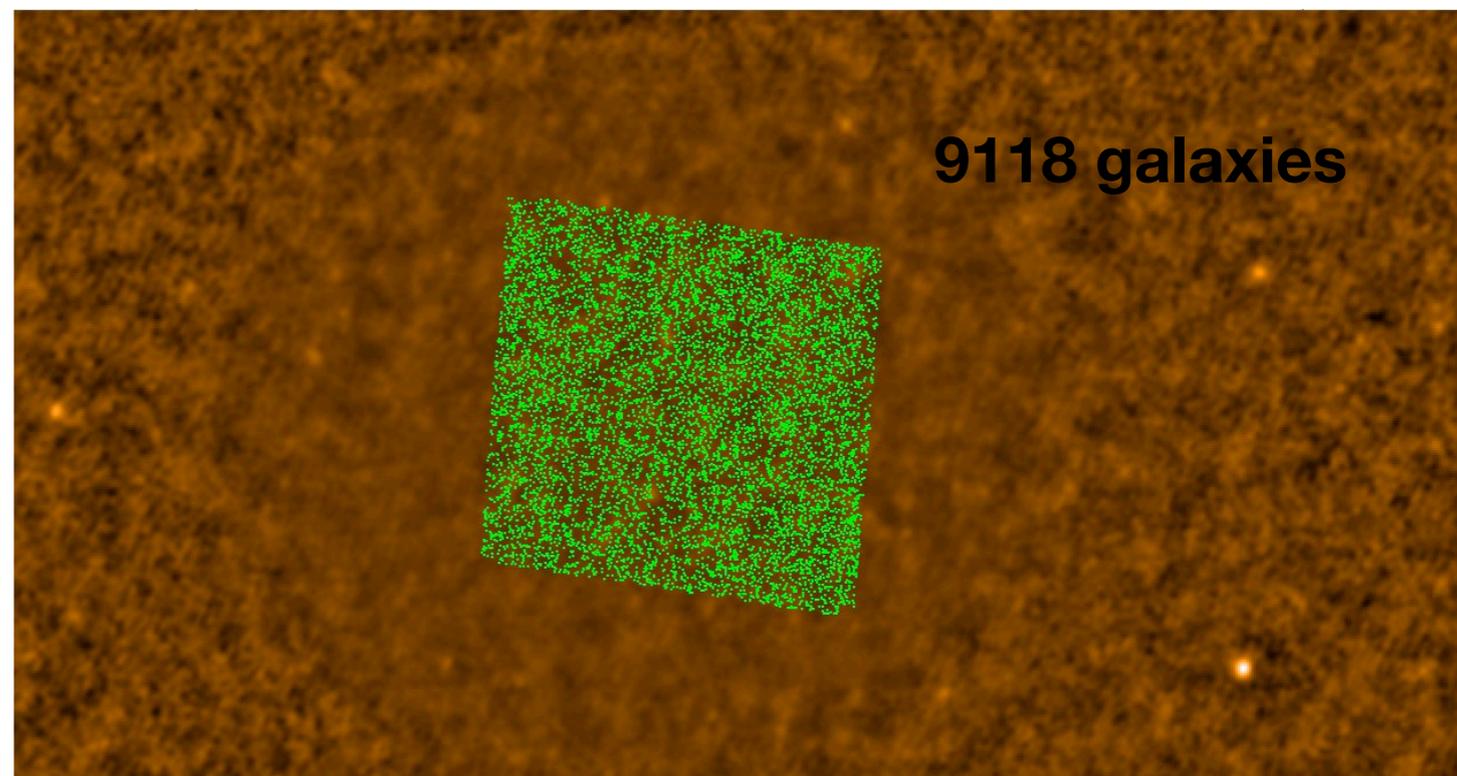
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- 500 as steep as SCUBA
- SCUBA surveys too small to see nearby (Euclidean) galaxies



Devlin et al. 0904.1201

Stacking

Using Great Ancillary Data

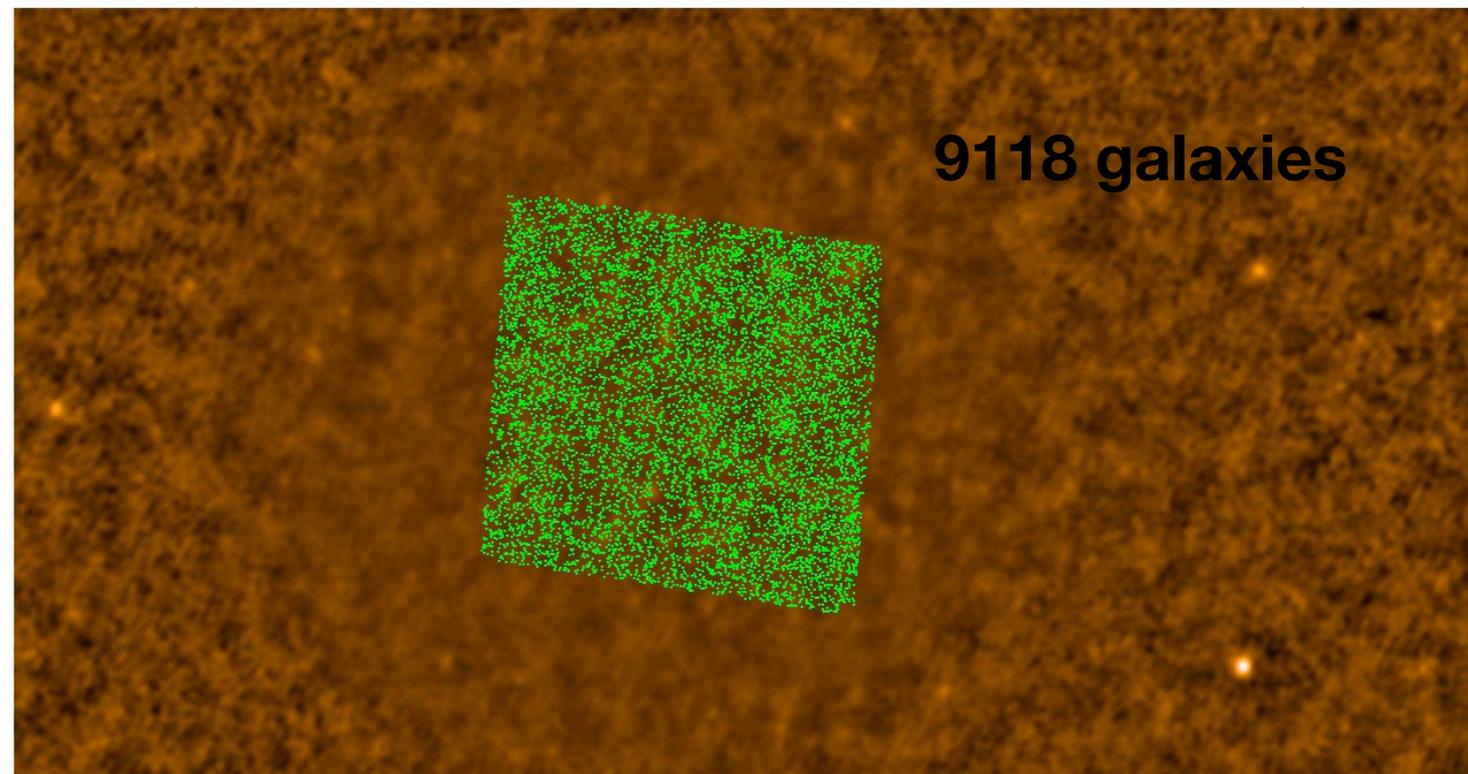


FIDEL 24 micron Catalog

Magnelli et al 2009

Using Great Ancillary Data

- Stack to find mean flux of catalog

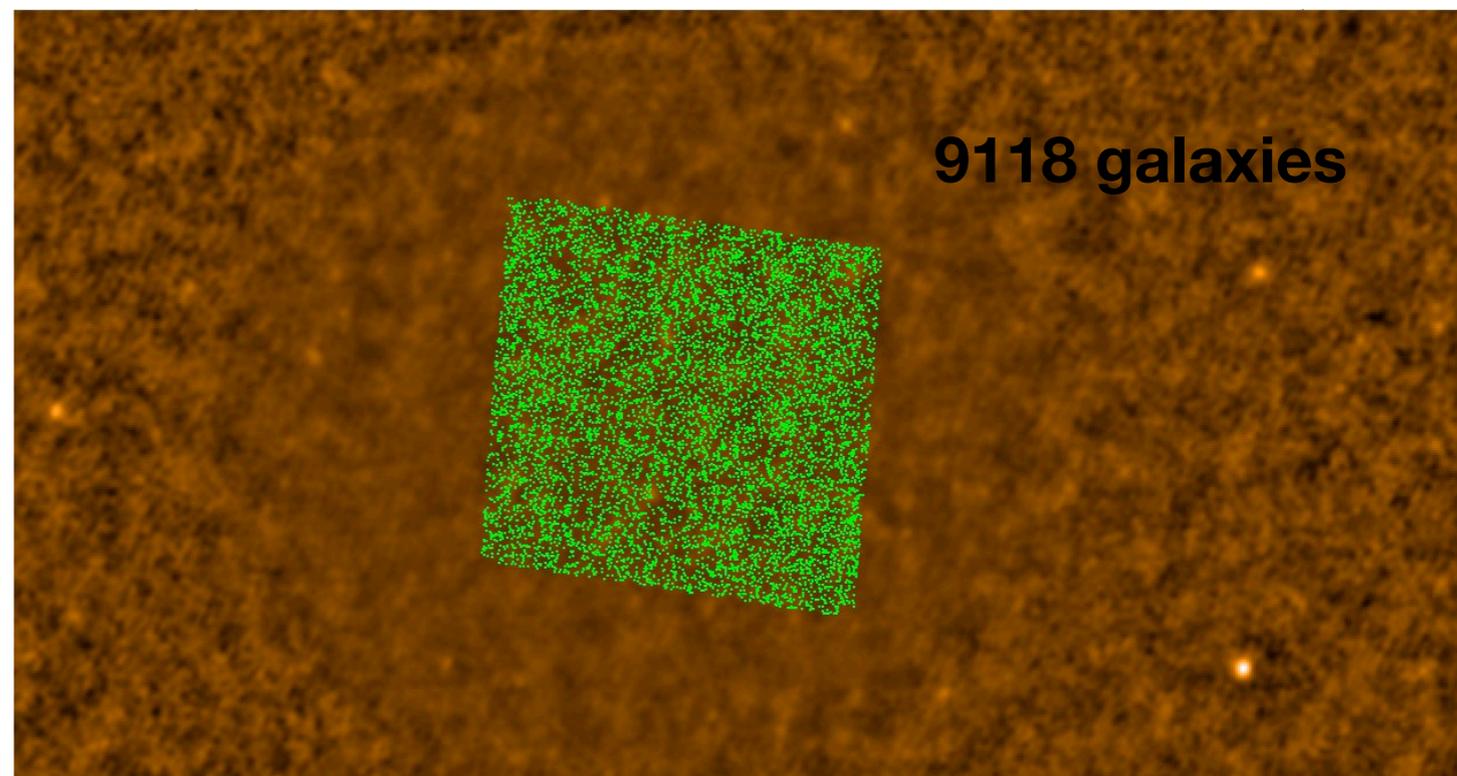


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- From our counts, predict 3×10^4 sources / deg^2 with $S > 1$ mJy, so naively expect the mean flux of sources in catalog > 1 mJy.



FIDEL 24 micron Catalog

Magnelli et al 2009

Obtaining the mean flux of a catalog.

Imagine that we have a map of the sky, described by M_j and separately a catalog of sources found at some other wavelength which has N_j sources in pixel j . If all sources in the catalog have flux \bar{S} in the map, we can think of their flux as a shape on the map, $\bar{S}N_j$, and we can fit for \bar{S} by least squares.

$$\delta^2 = \sum_{pixels} (M_j - \bar{S}N_j)^2. \quad (1)$$

The most likely value of the mean flux comes from

$$\frac{\partial \delta^2}{\partial \bar{S}} = 0 = \sum -2M_jN_j + 2\bar{S}N_j^2 \quad (2)$$

and thus

$$\bar{S} = \frac{\sum N_j M_j}{\sum N_j^2} = \frac{\text{Covariance}}{\text{Number of catalog entries}} \quad (3)$$

because $\sum_j N_j^2 = \sum_j \mu$ if the catalog is poisson.

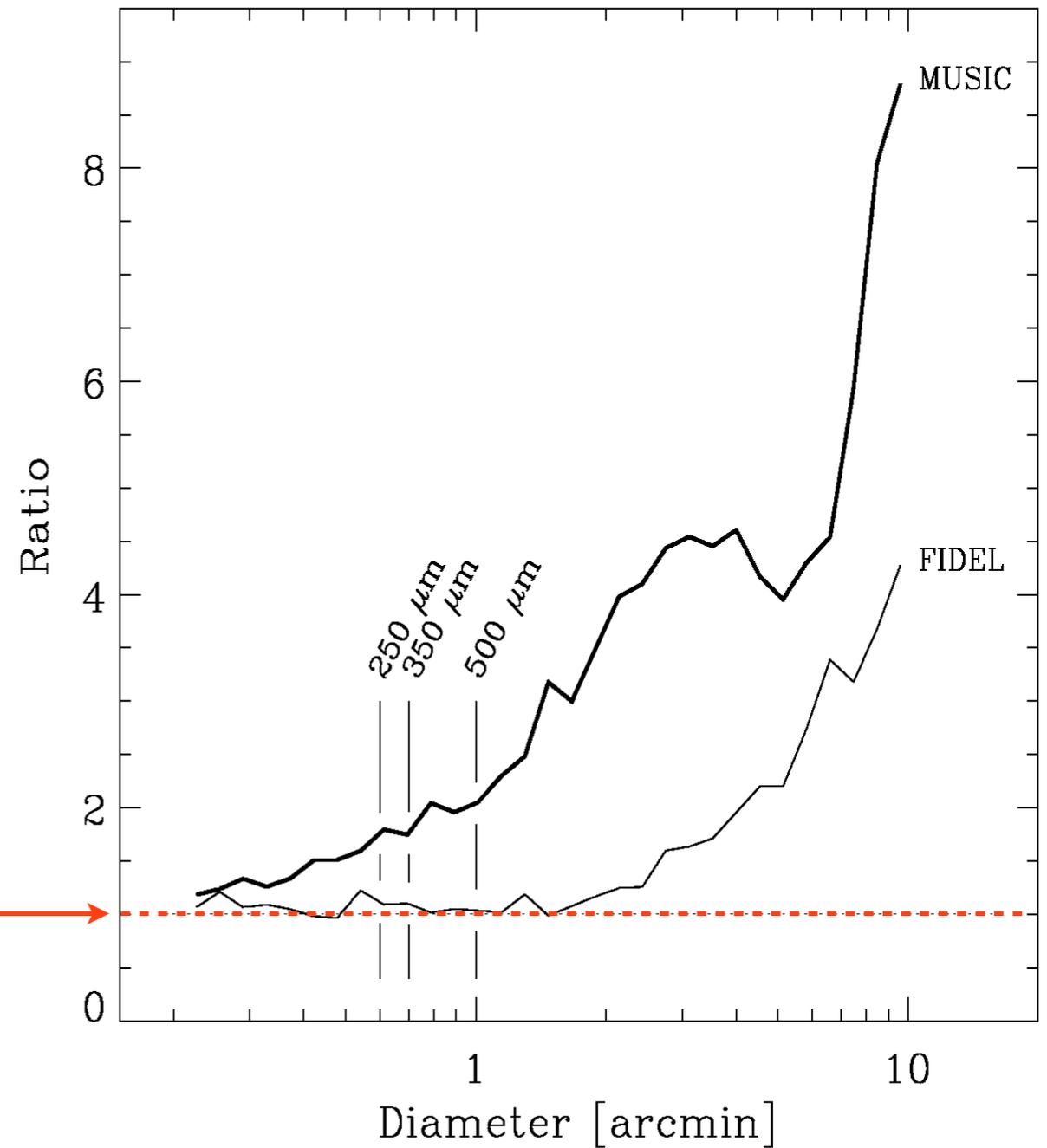
Notice that the covariance can be found from a sum over the catalog.

$$\sum_{pixels} N_j M_j = \sum_{catalog} M_k. \quad (4)$$

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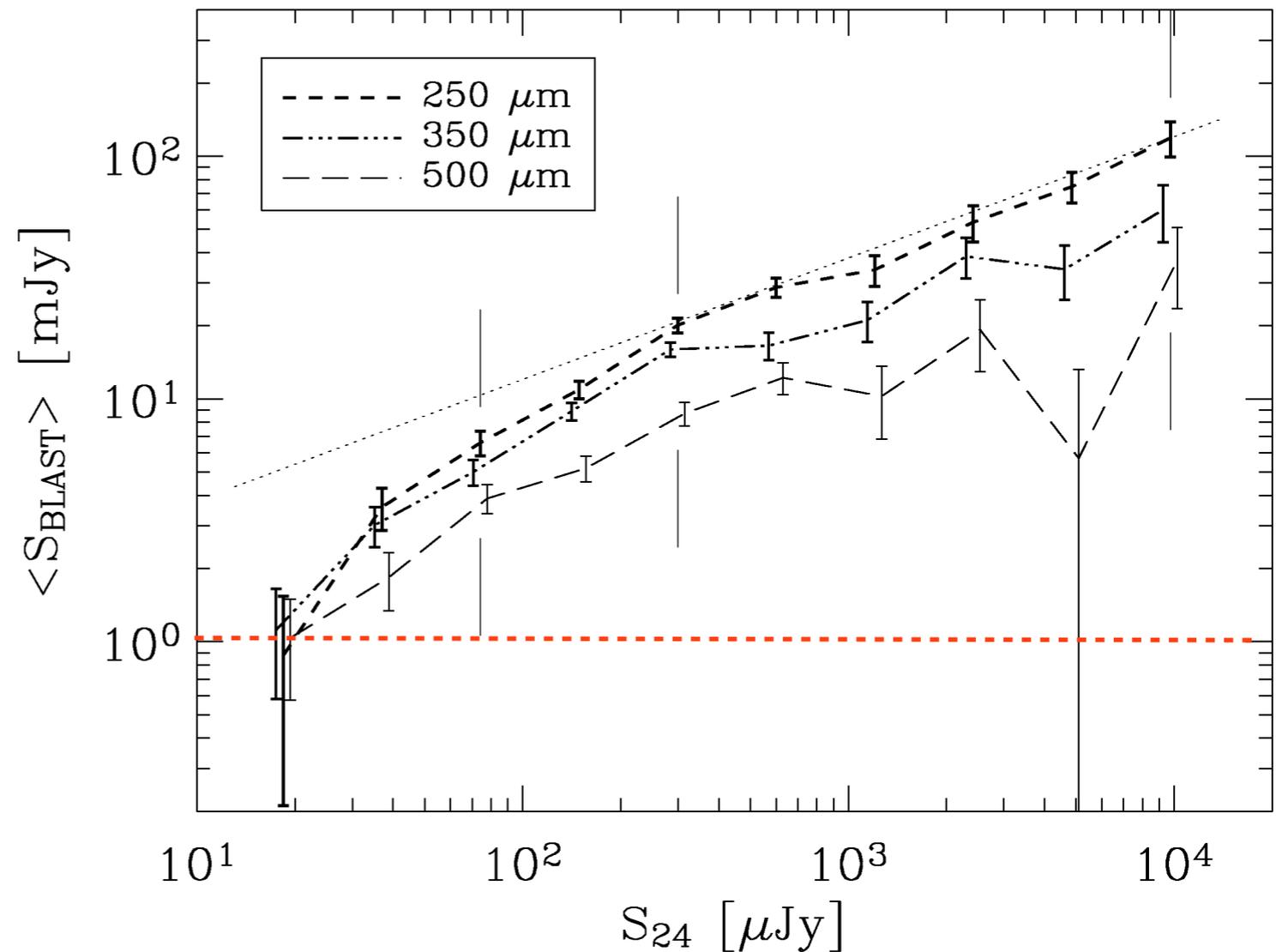
Poisson, i.e., mean = variance →



Marsden et al. 0904.1205

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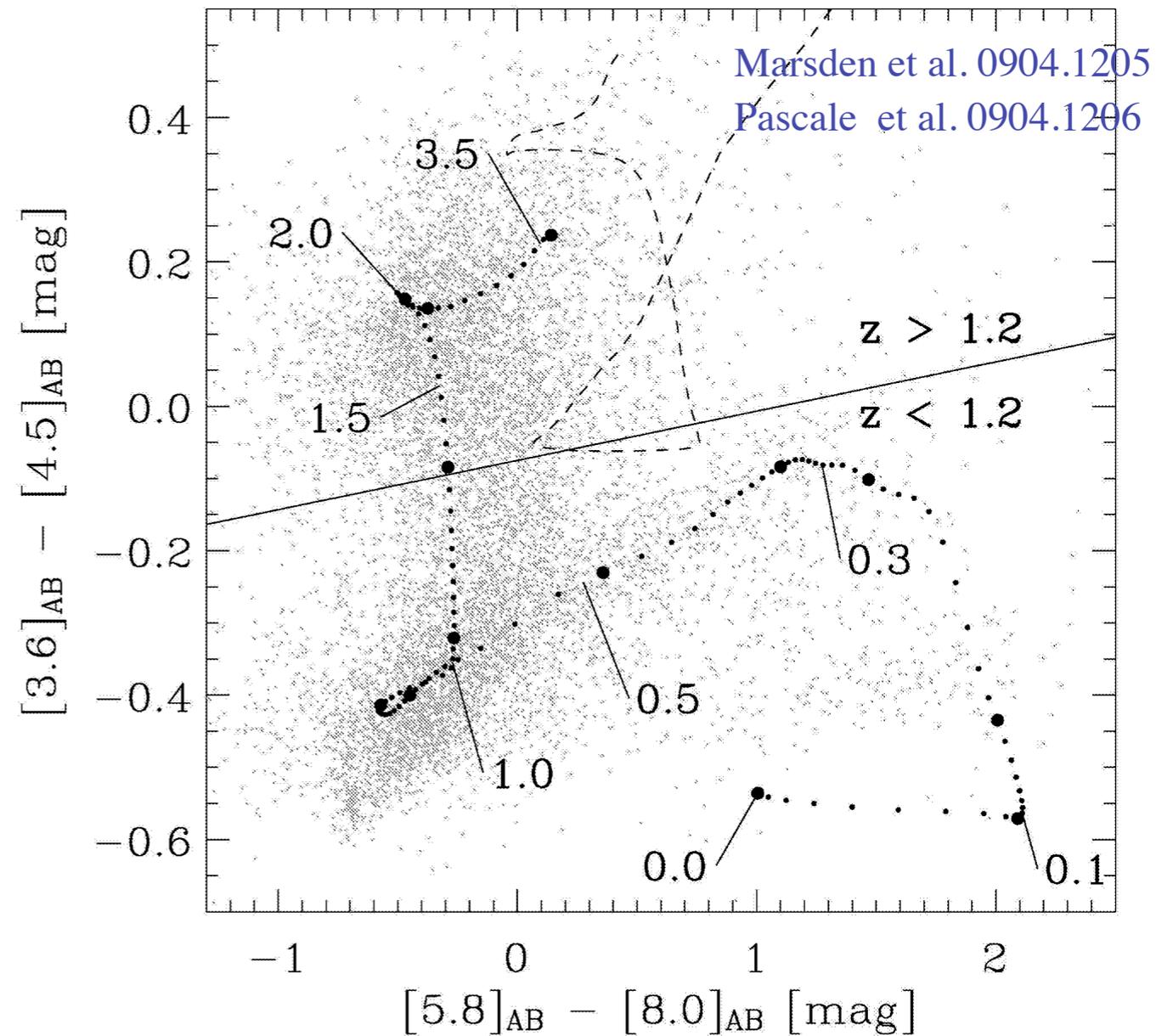
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Marsden et al. 0904.1205

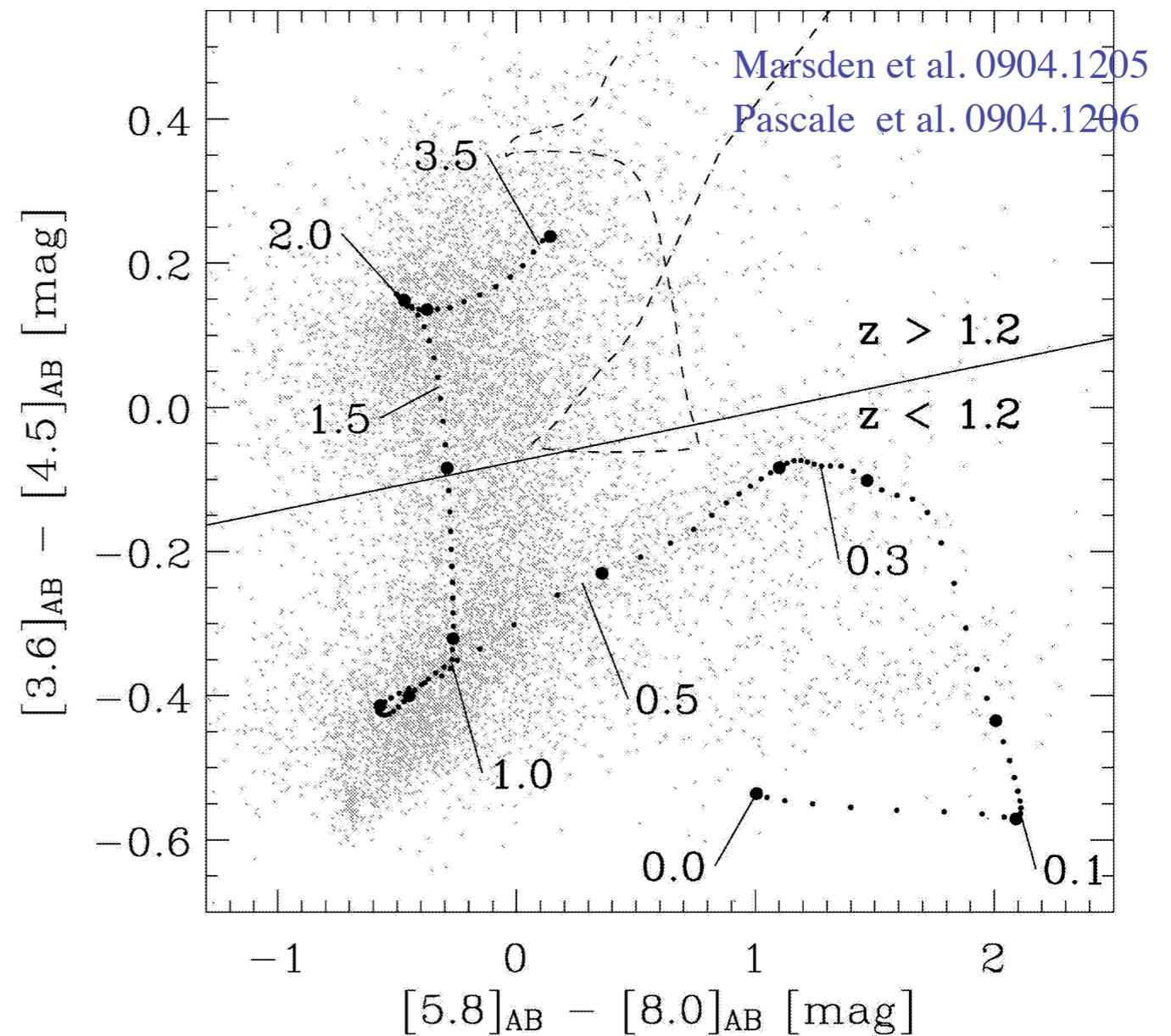
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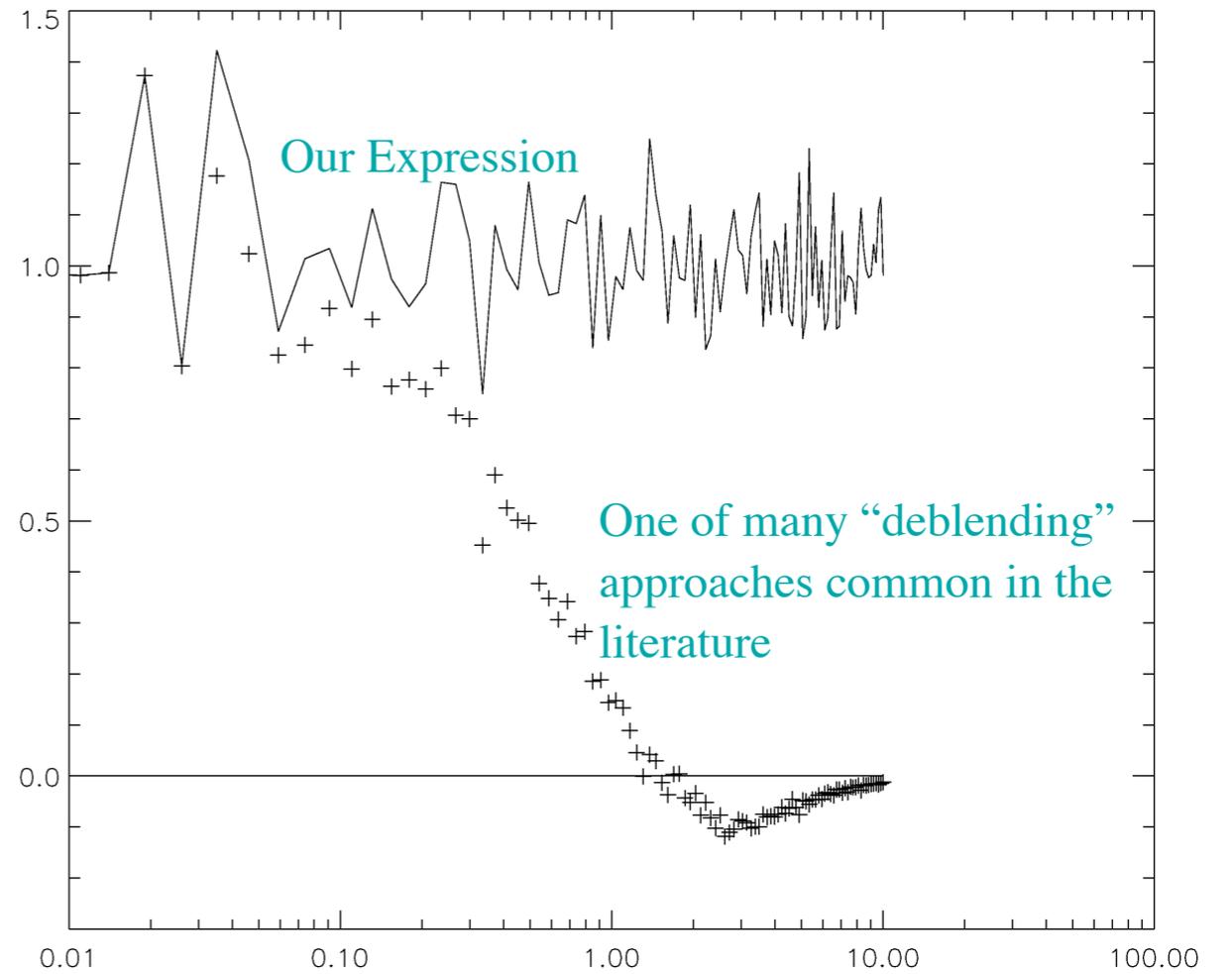
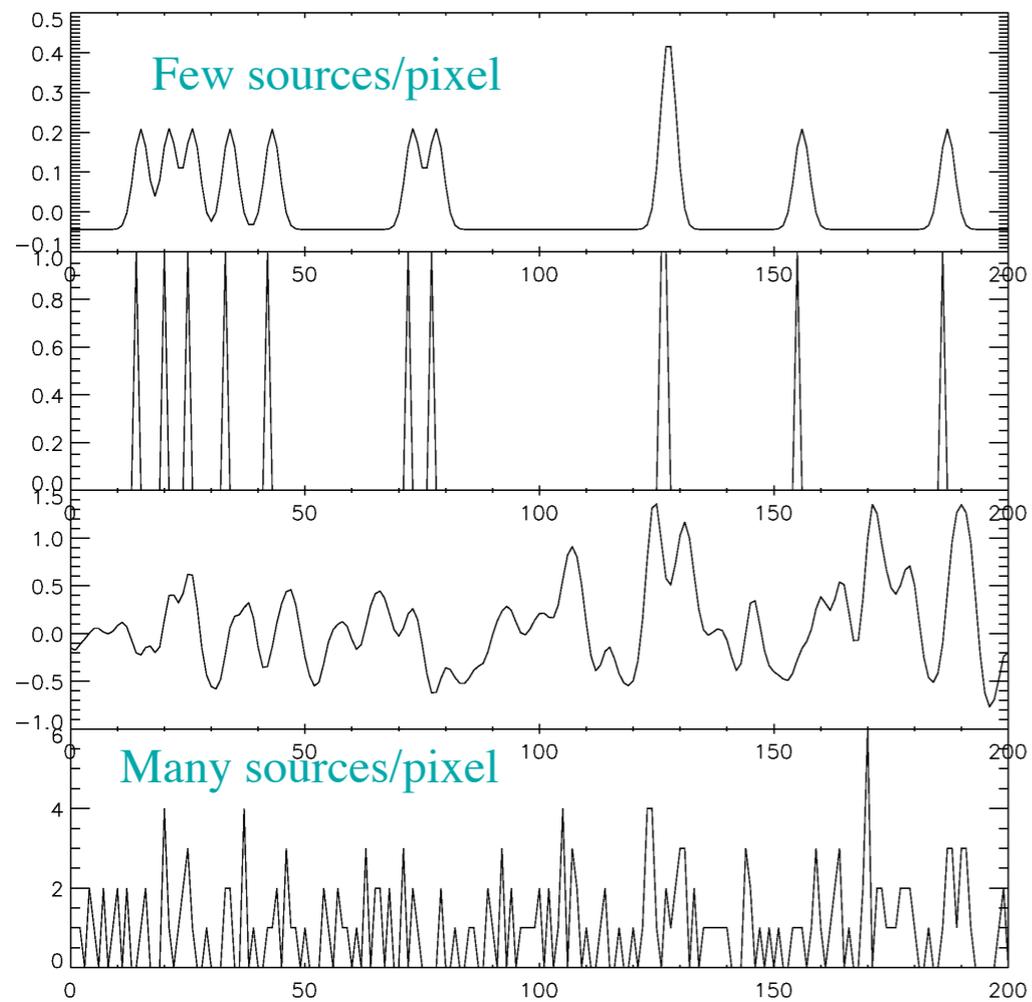


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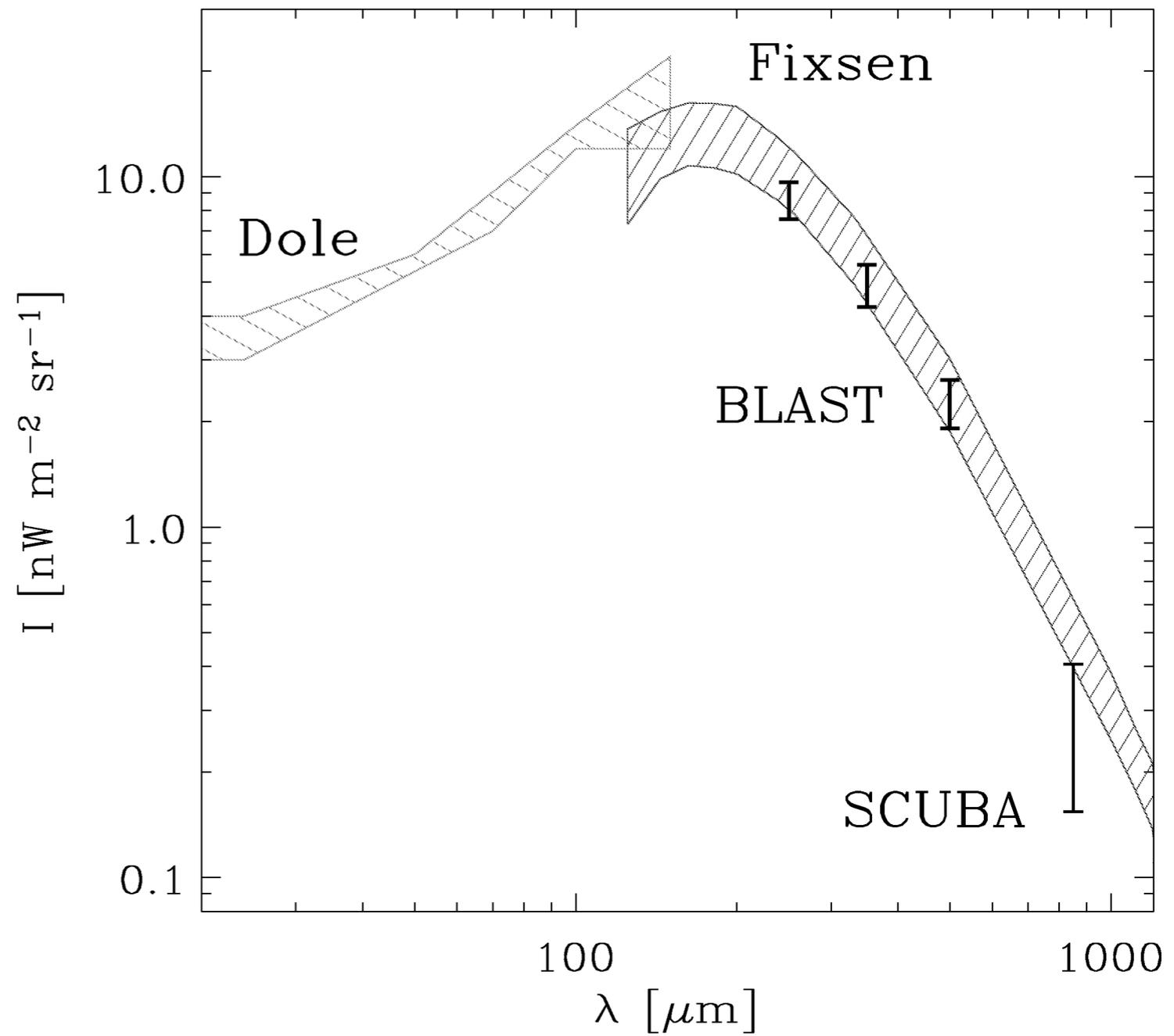


Monte-Carlo for sceptics



courtesy of Mark Halpern

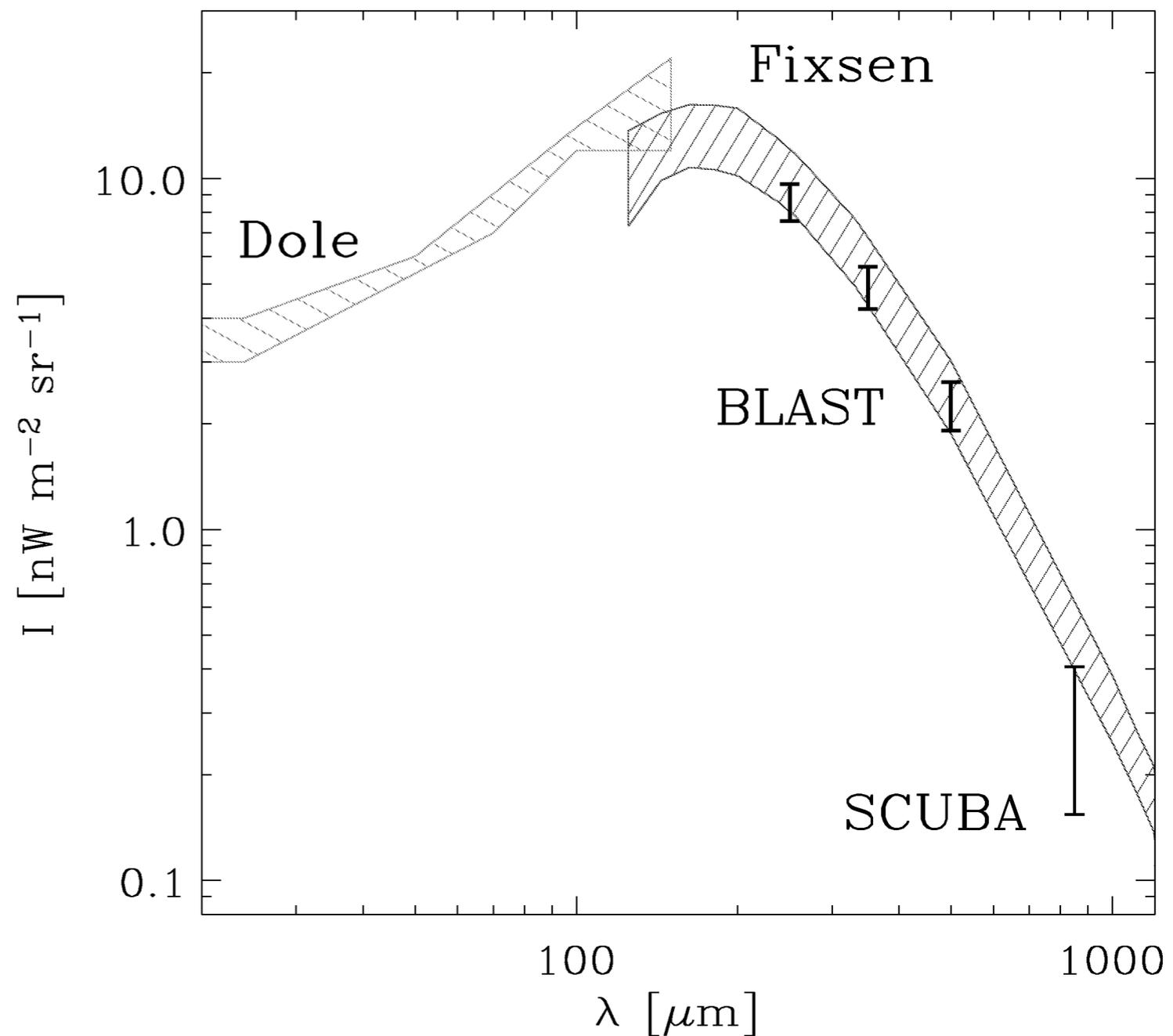
Stacking Result 1 - CIB resolved



Marsden et al. 0904.1205

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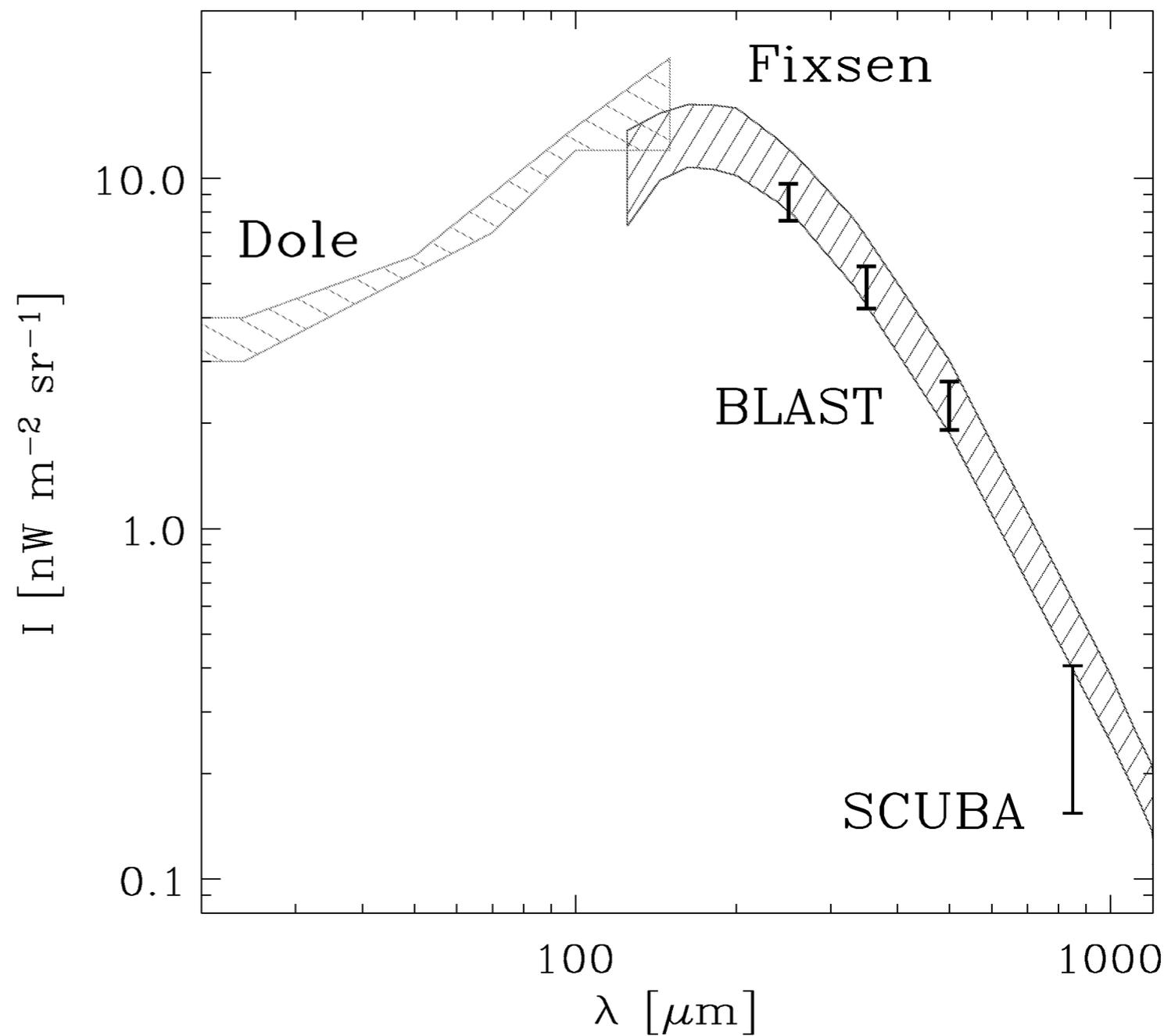
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Marsden et al. 0904.1205

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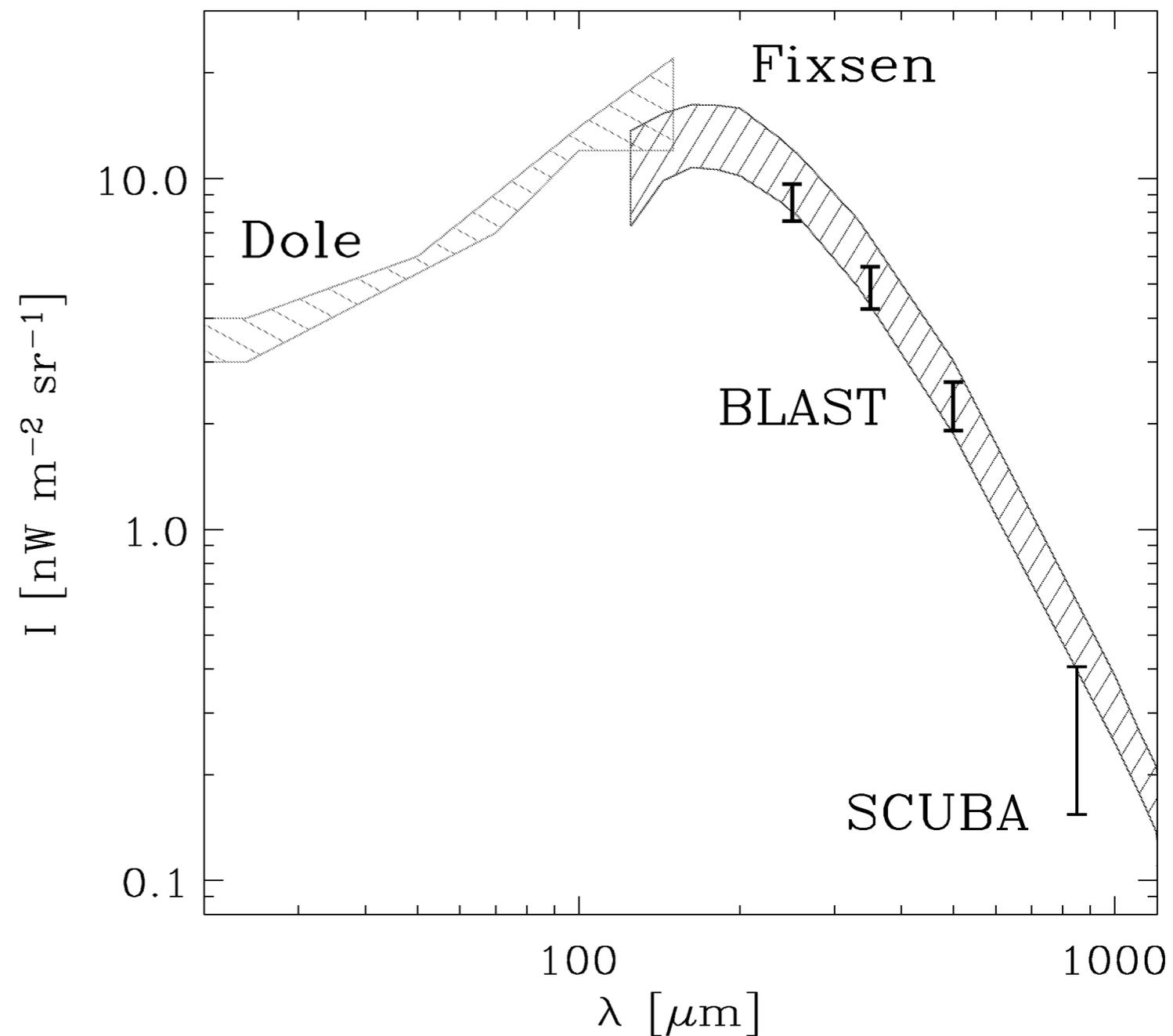
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Marsden et al. 0904.1205

Stacking Result 1 - CIB resolved

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 - ⊙ BLAST 3σ catalog makes up only 15% of the total intensity!



Marsden et al. 0904.1205

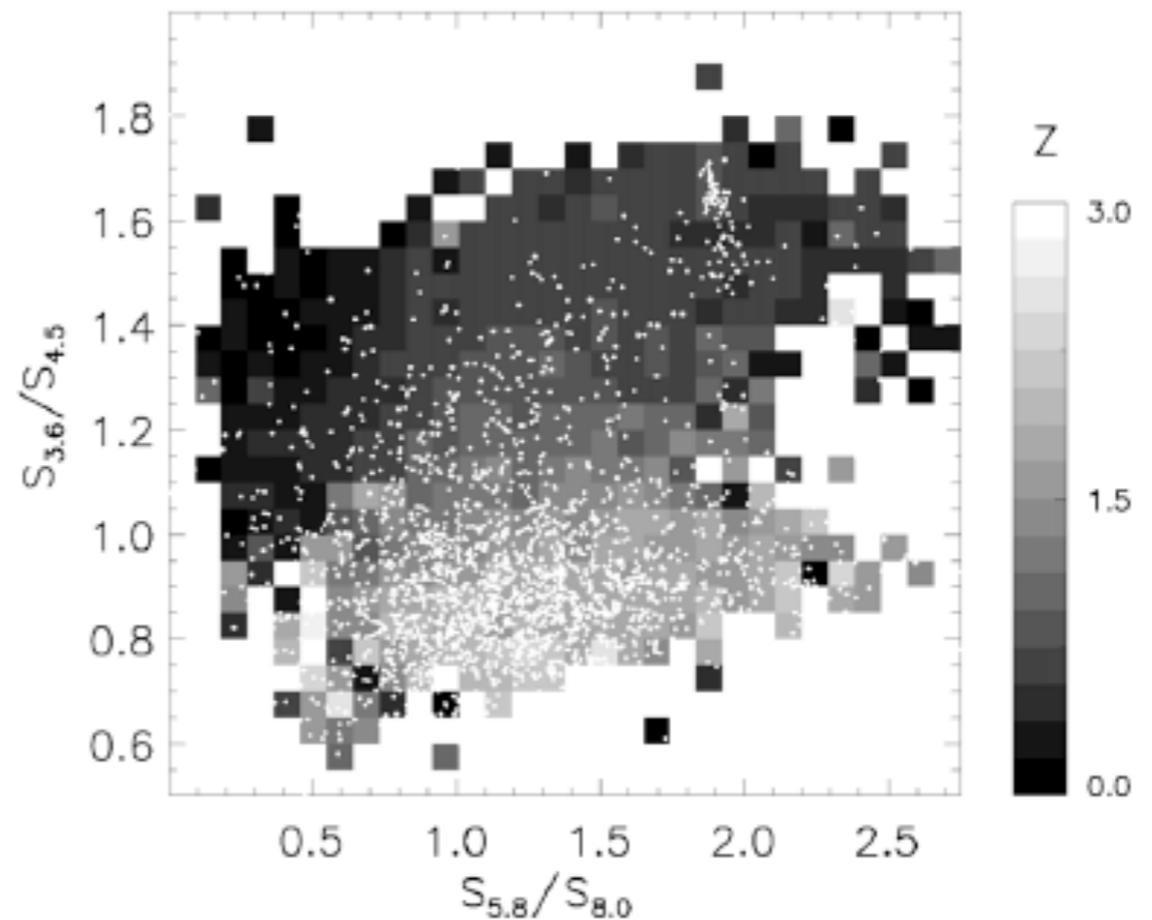
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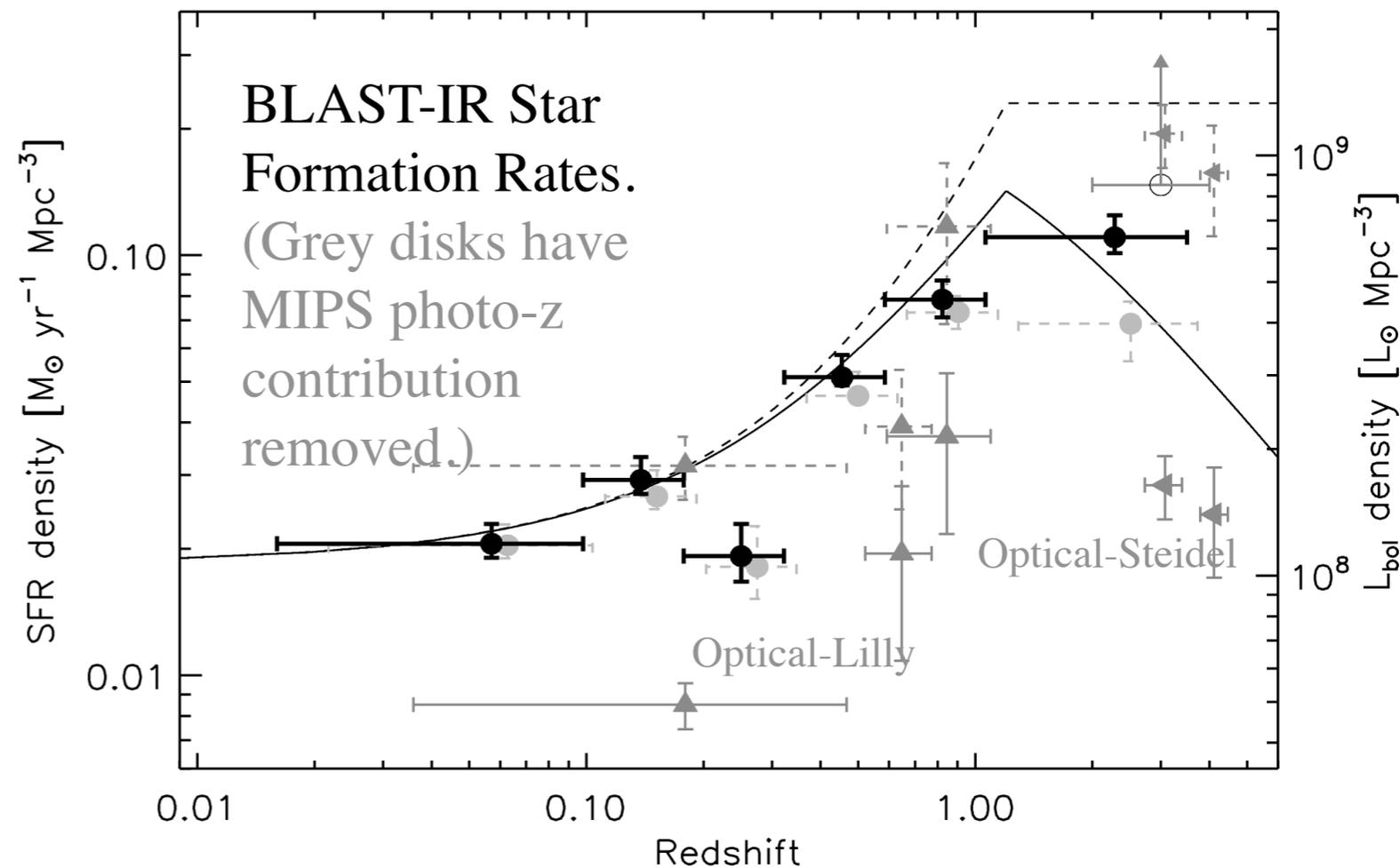
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Pascale et al. 0904.1206

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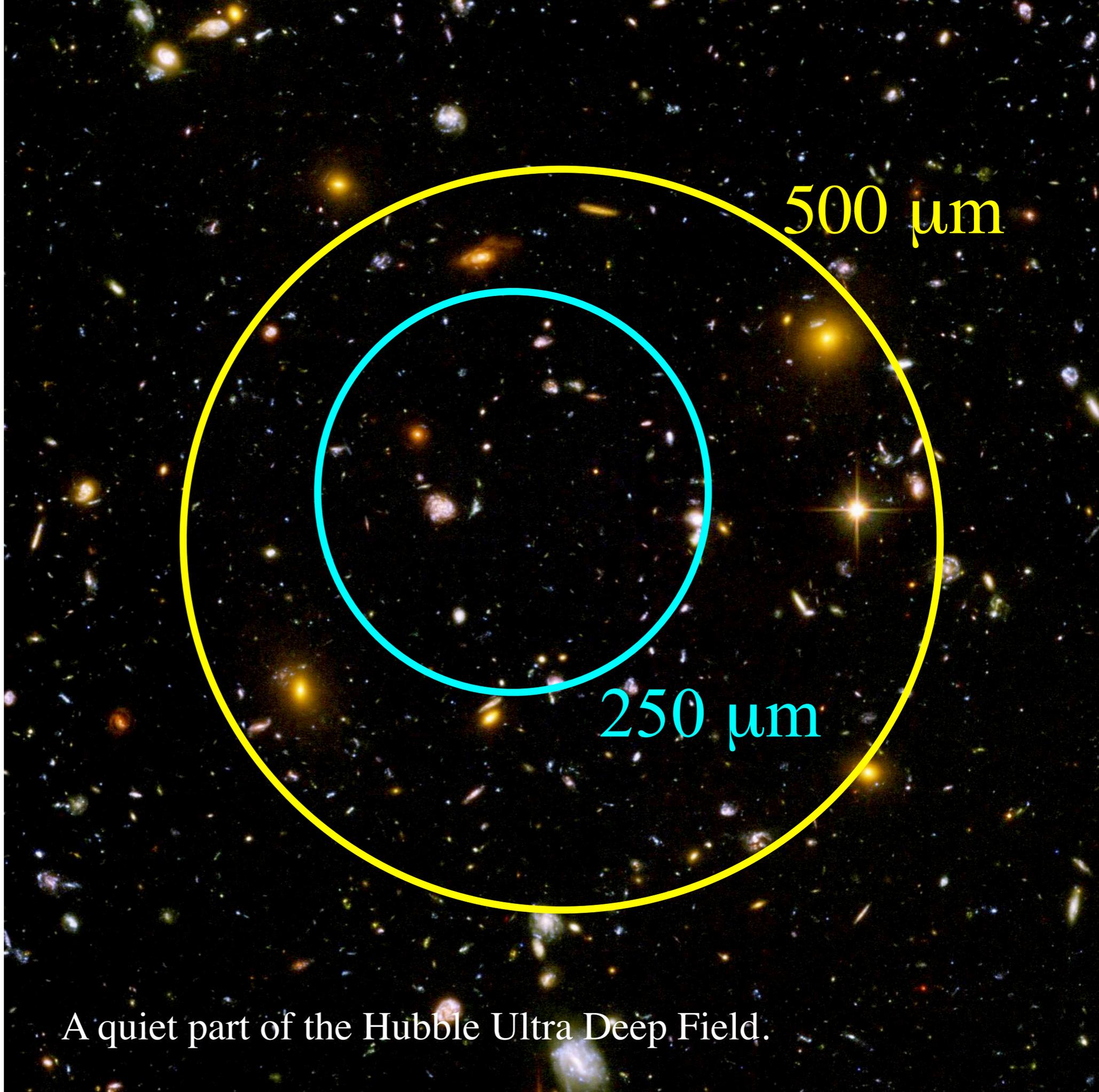
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- Calculate bolometric luminosity, L_{IR} , (by fitting modified blackbody) and use that to infer Star Formation Rate Density



Pascale et al. 0904.1206

Clustering

The BLAST beams are huge compared to galaxies, and even compared to the mean distance between galaxies.

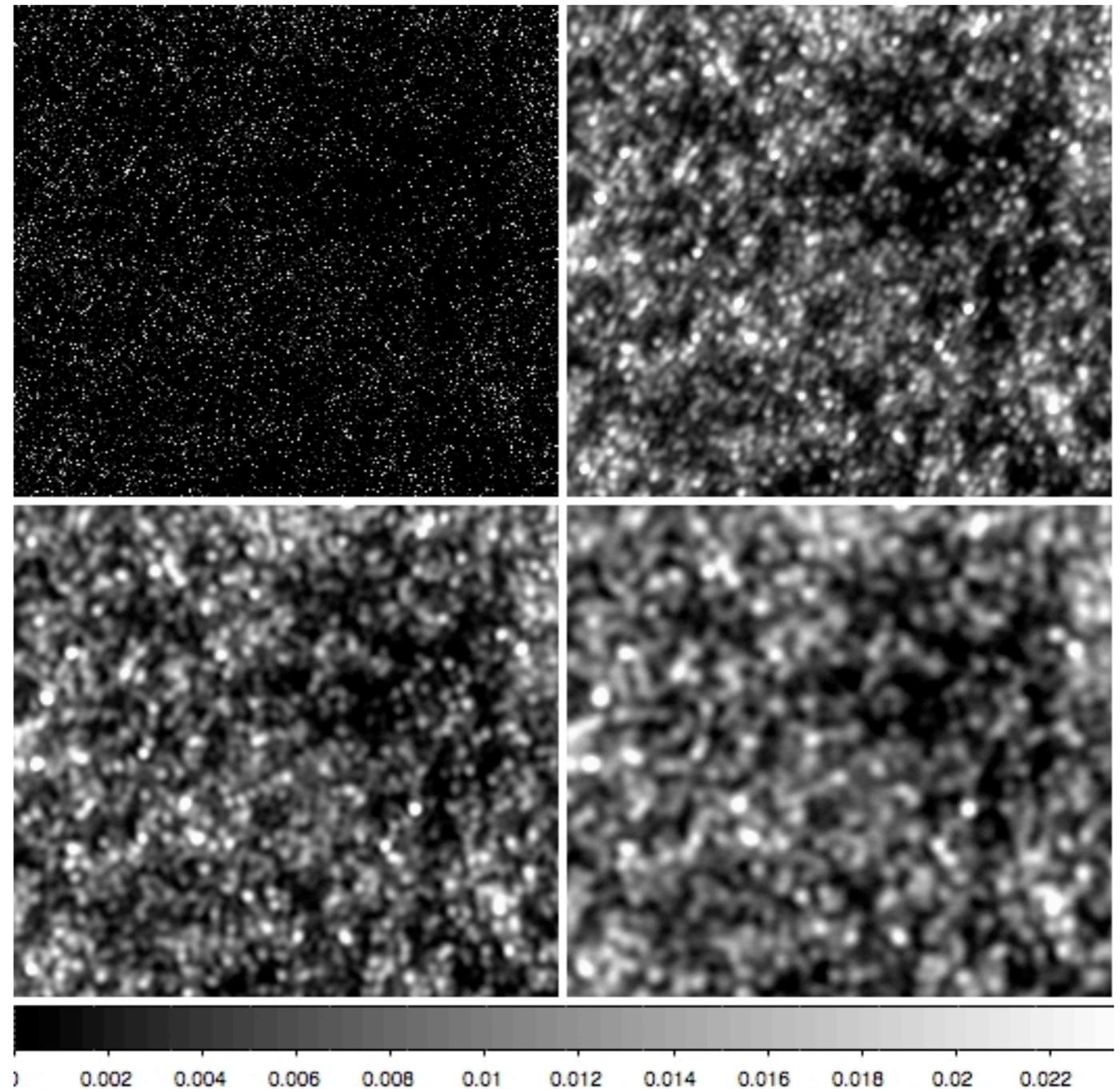


A quiet part of the Hubble Ultra Deep Field.

Complications

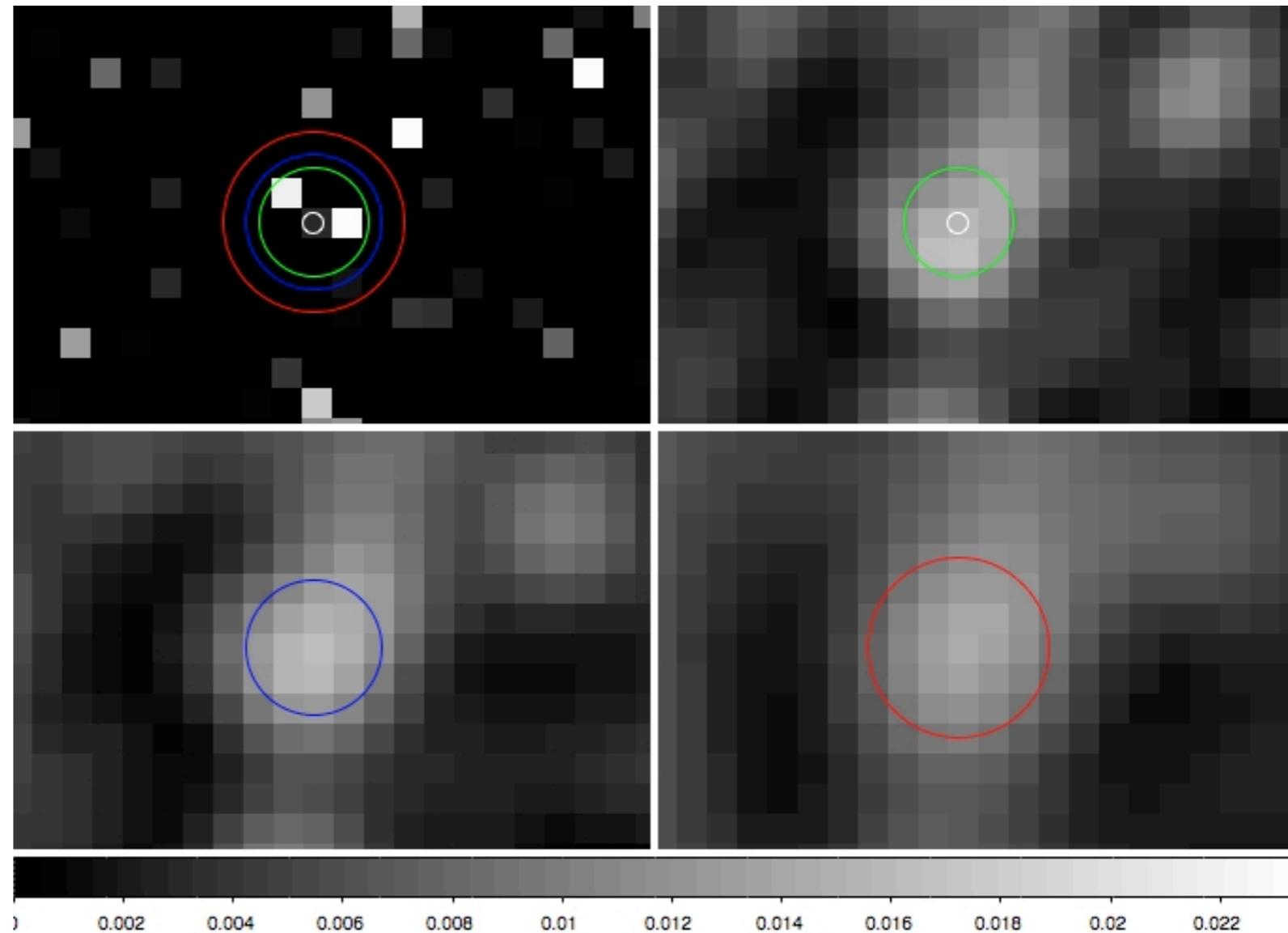
Complications

- While *large scales* well traced



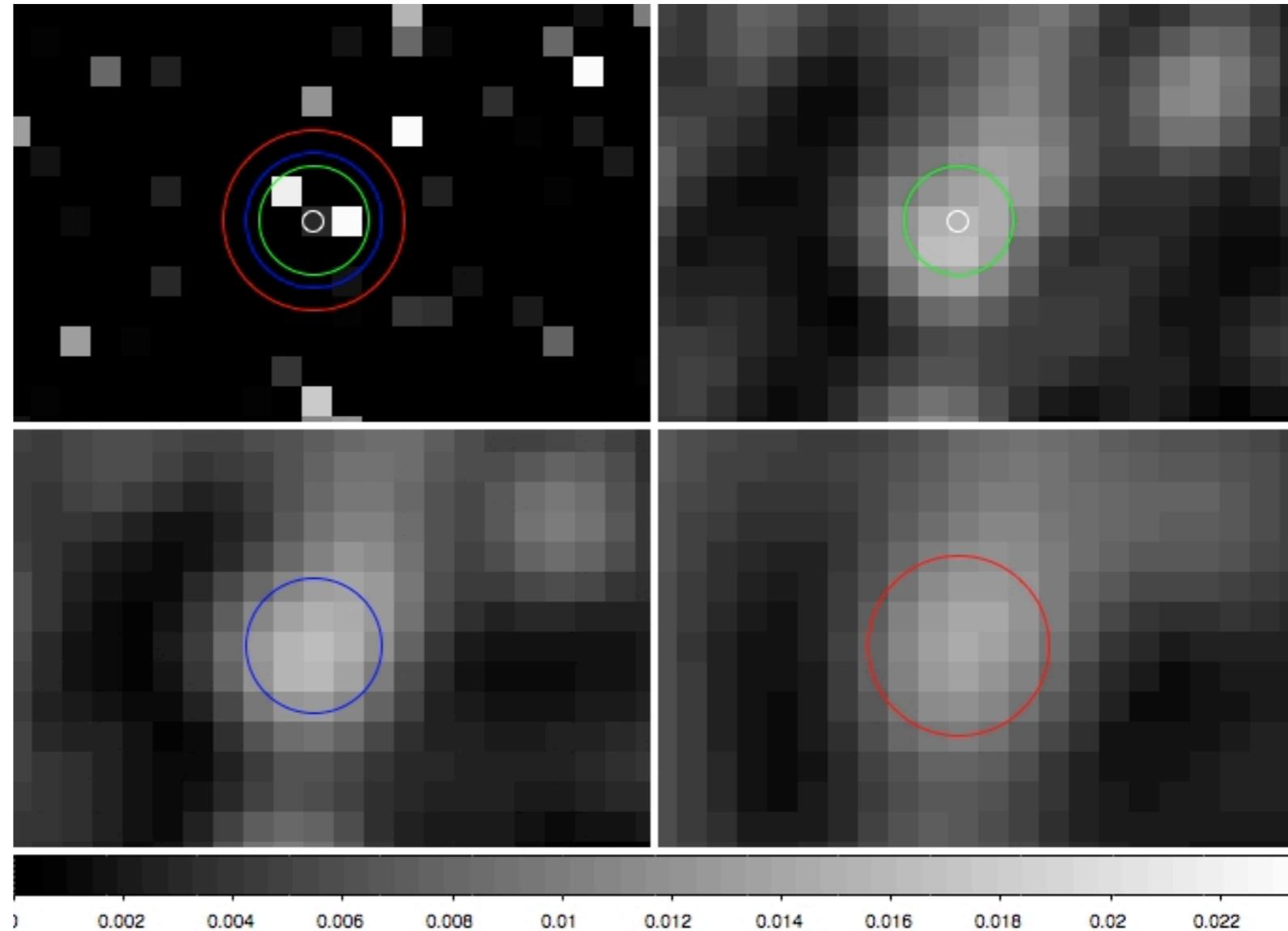
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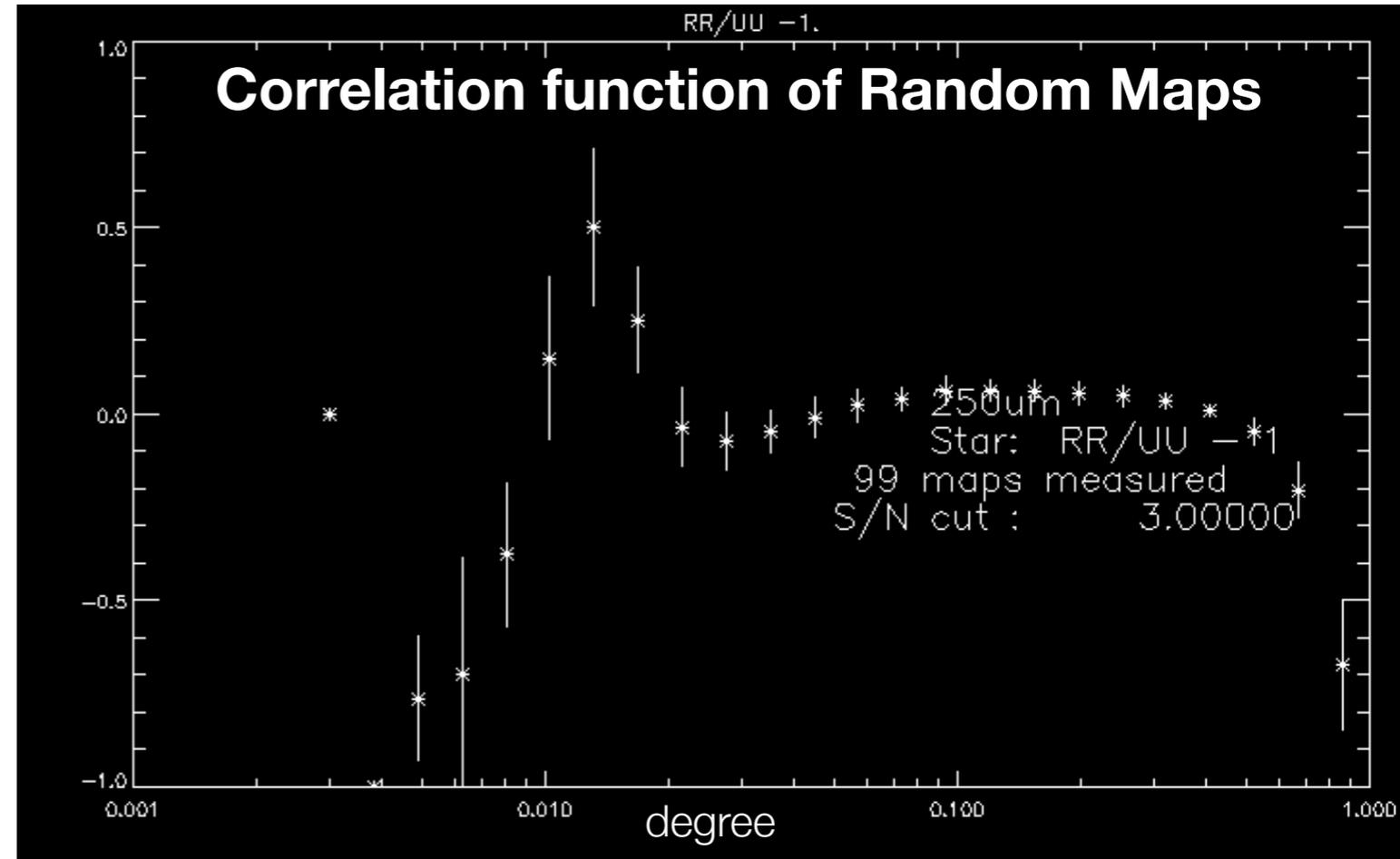
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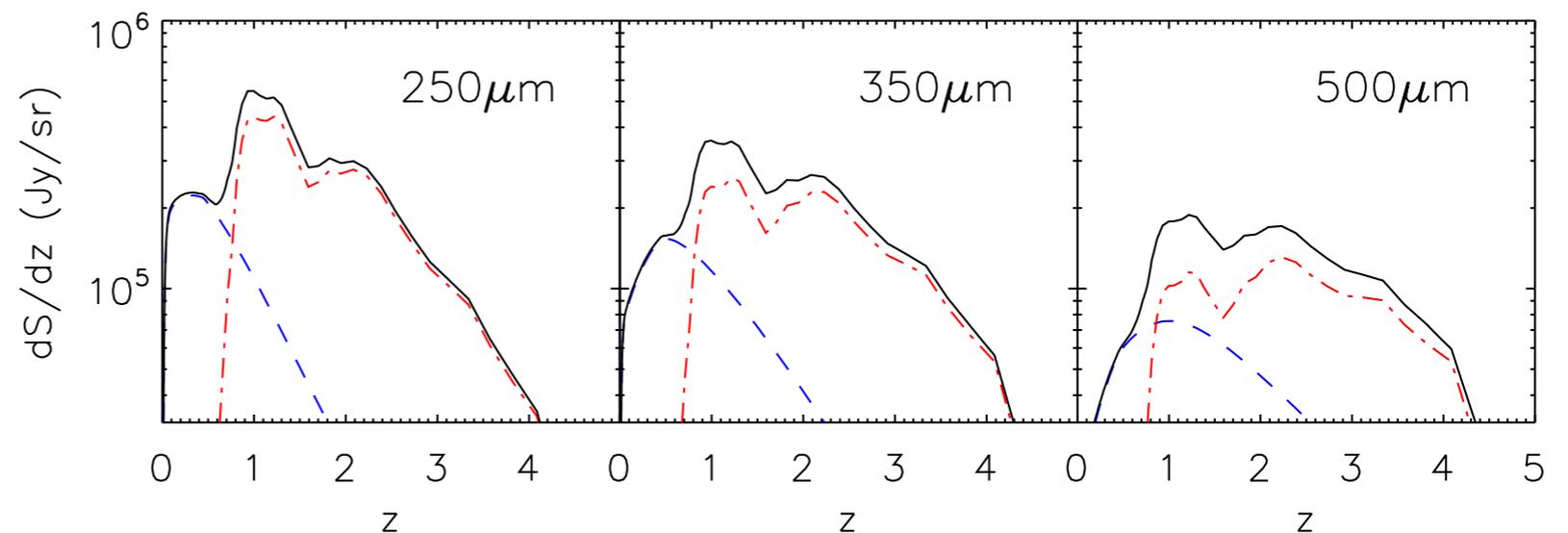
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Complications

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- Wide redshift distribution dilutes angular correlation signal
- Confusion limits number of sources / area, i.e.,
more sources = more area



Clustering from Power Spectrum

Clustering from Power Spectrum

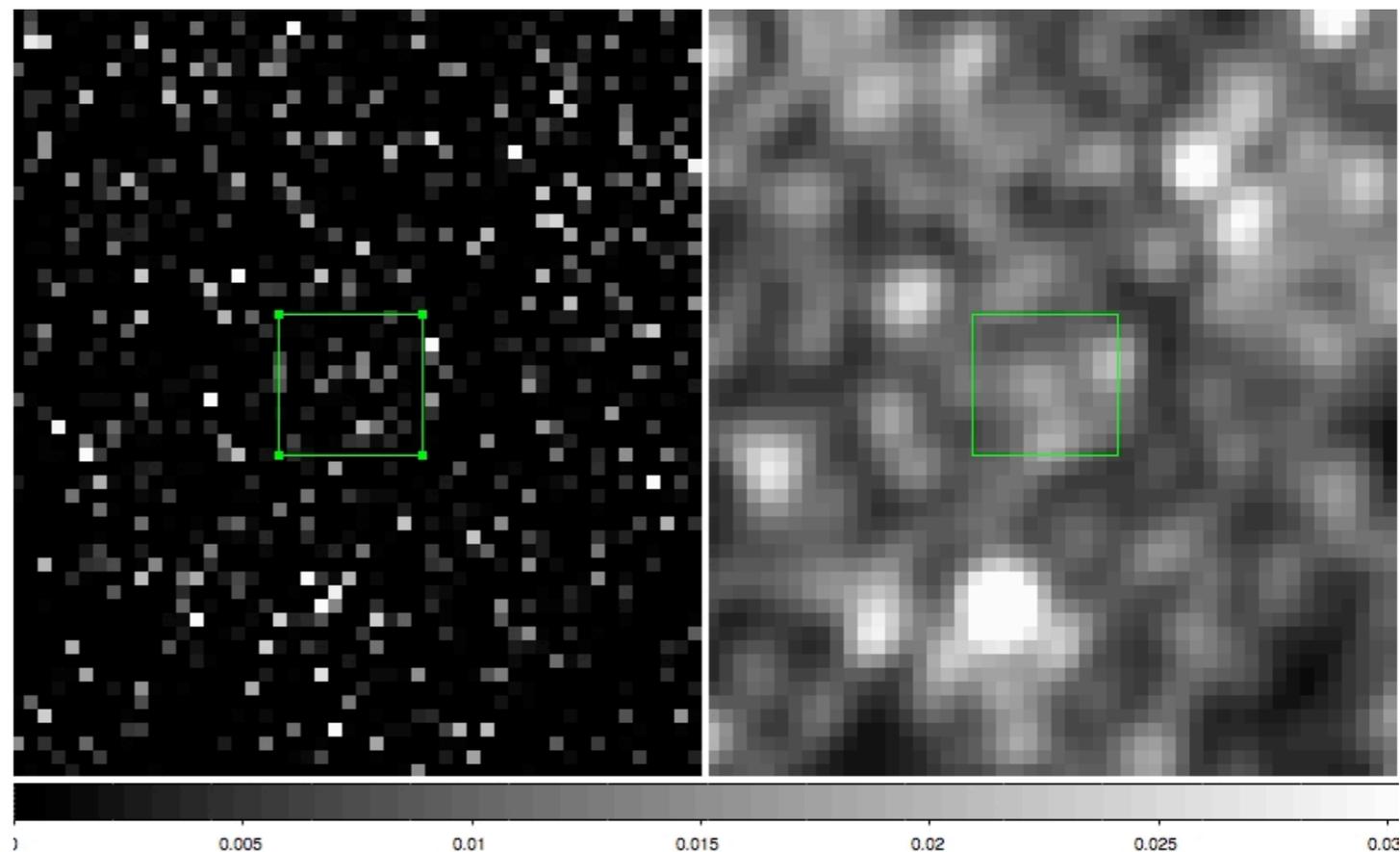
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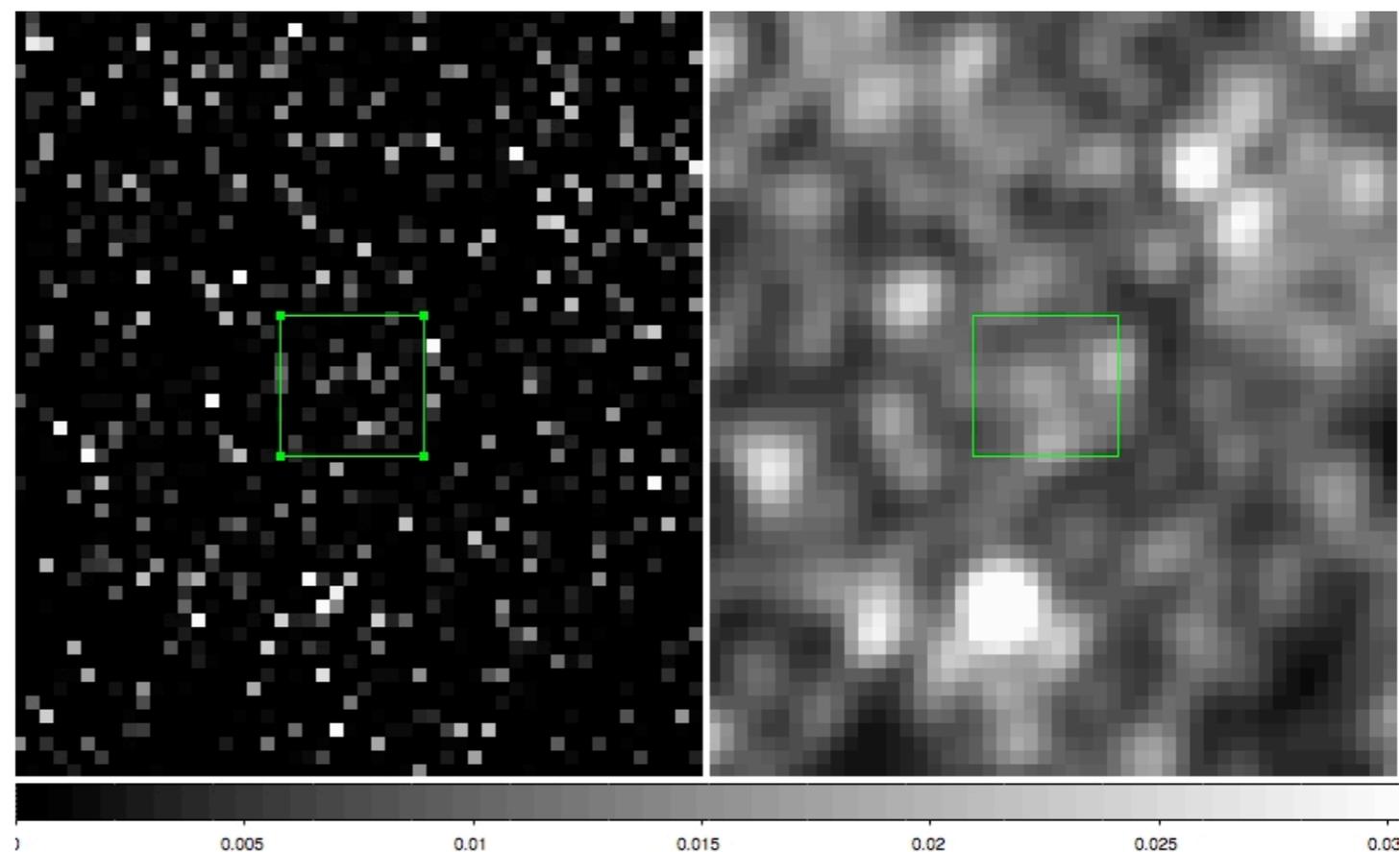
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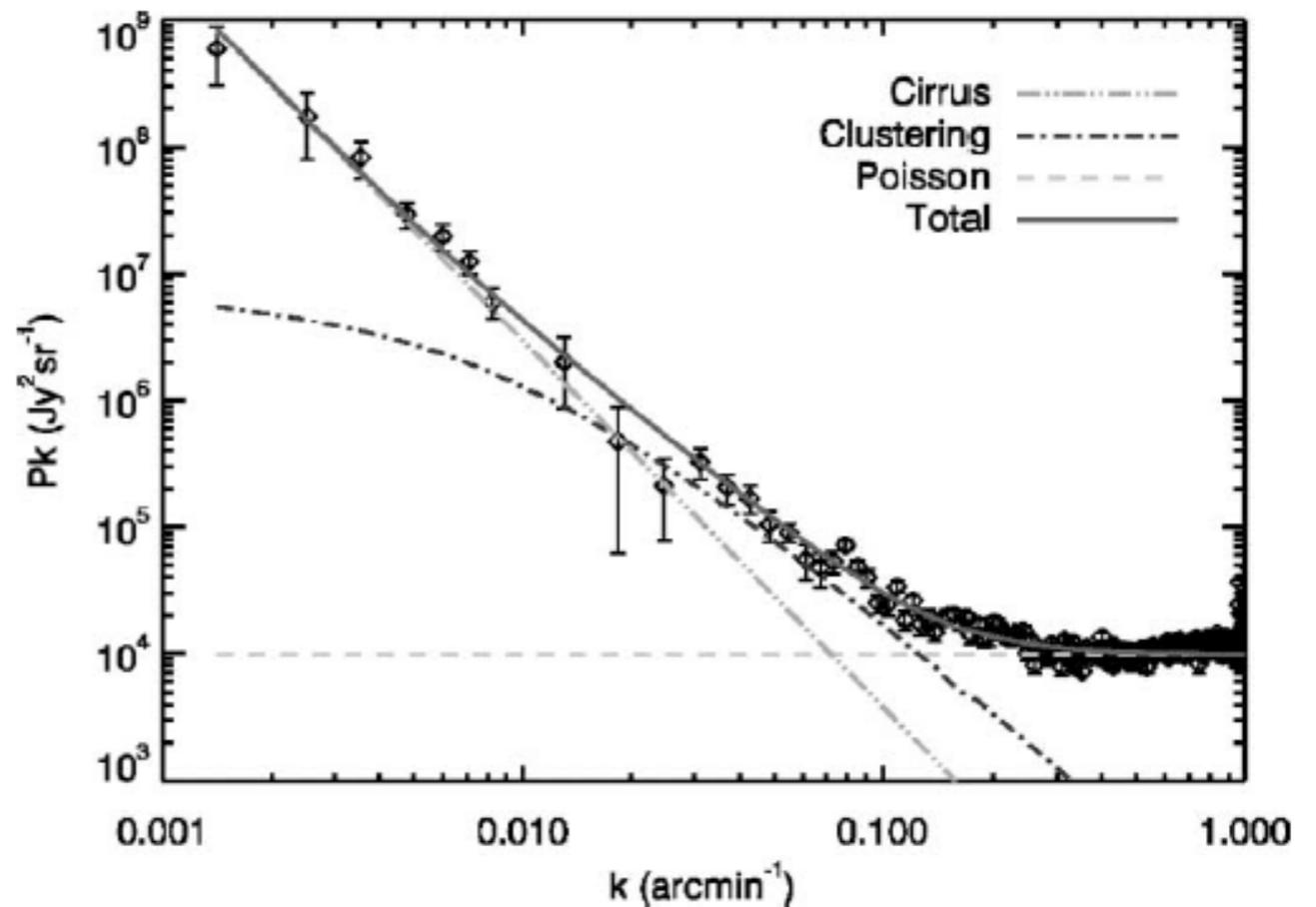
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 - ◉ Grossan & Smoot 2007 (Spitzer 160 μ m)



Lagache+ 2007

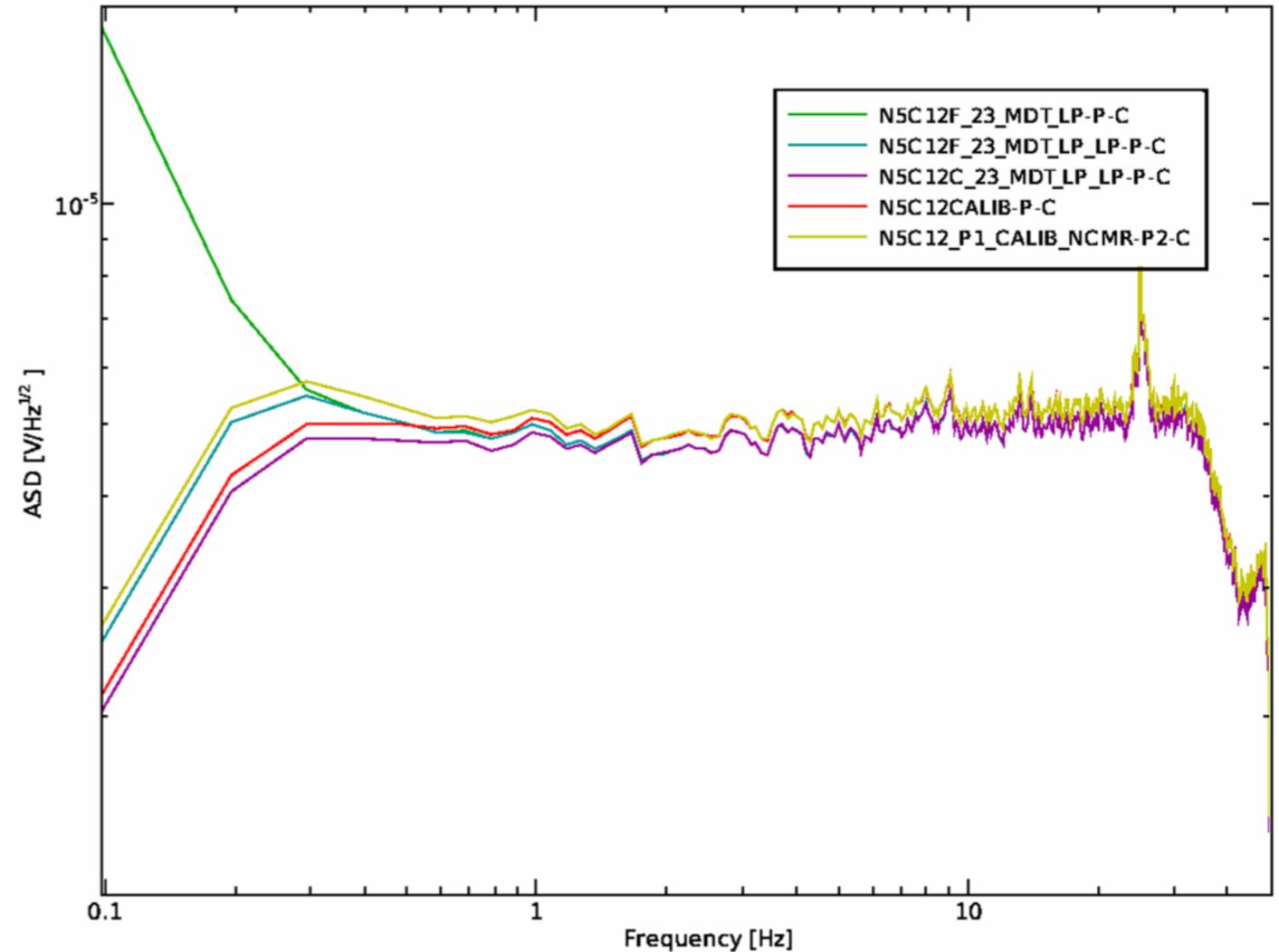
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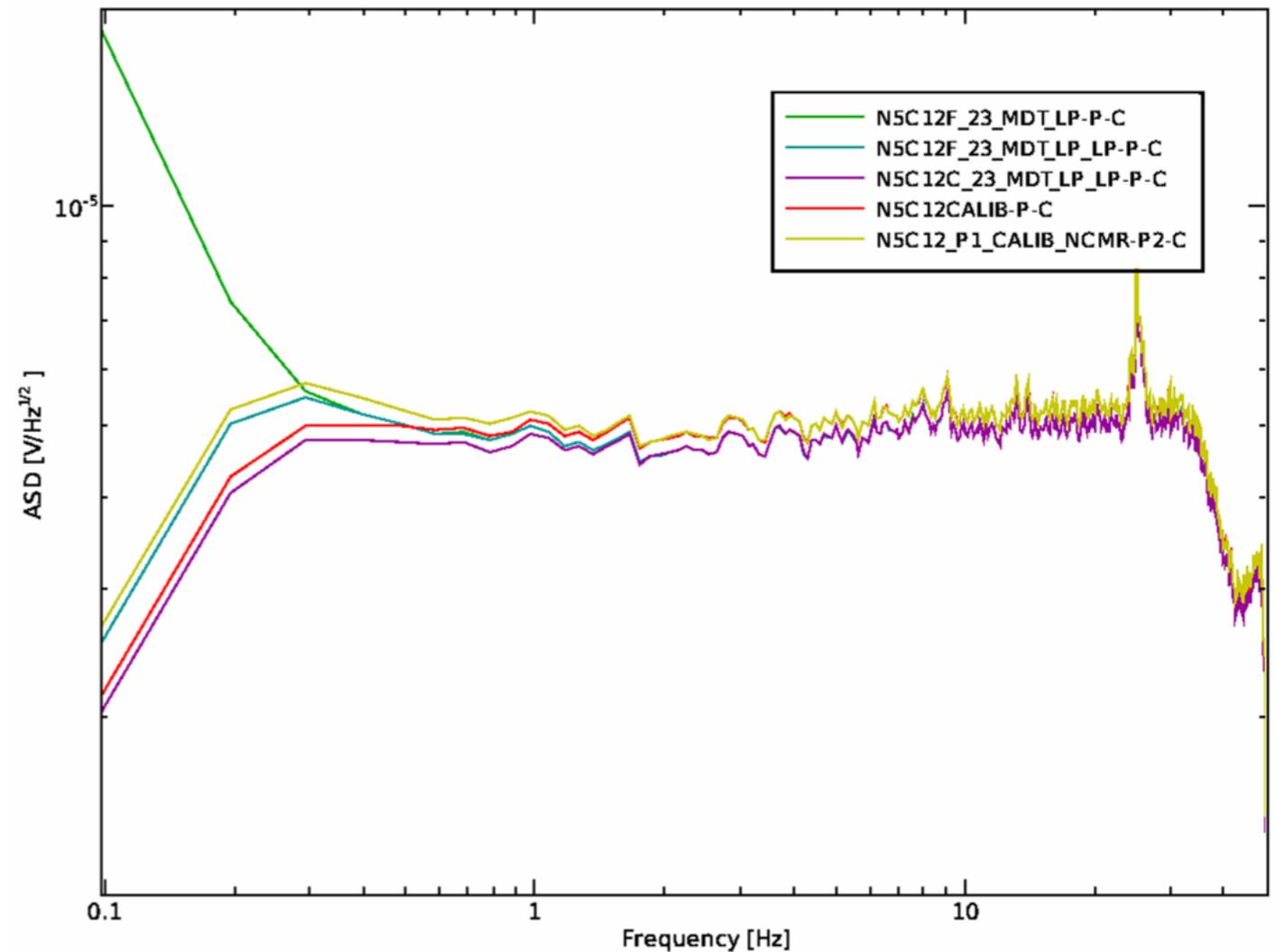
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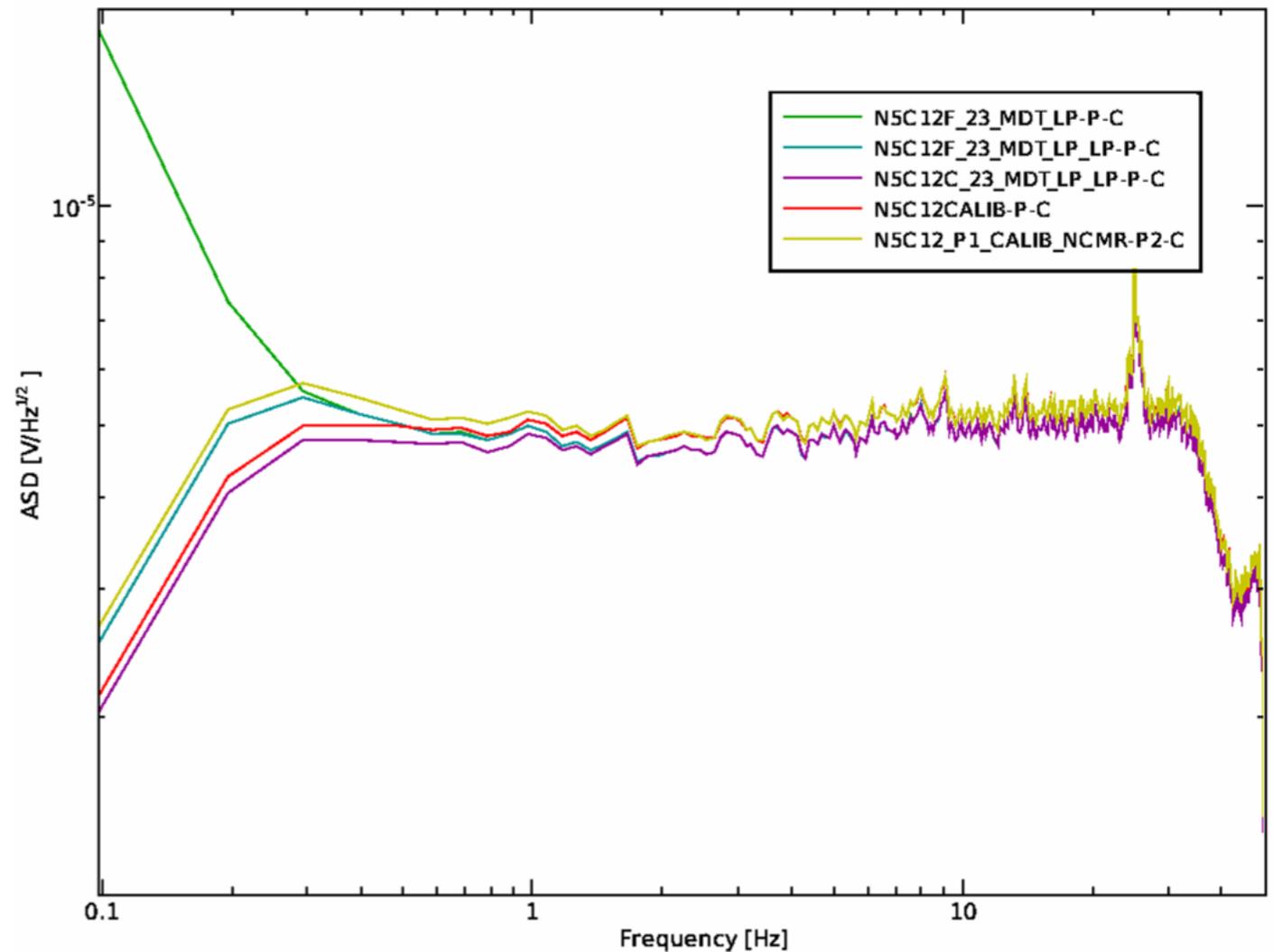
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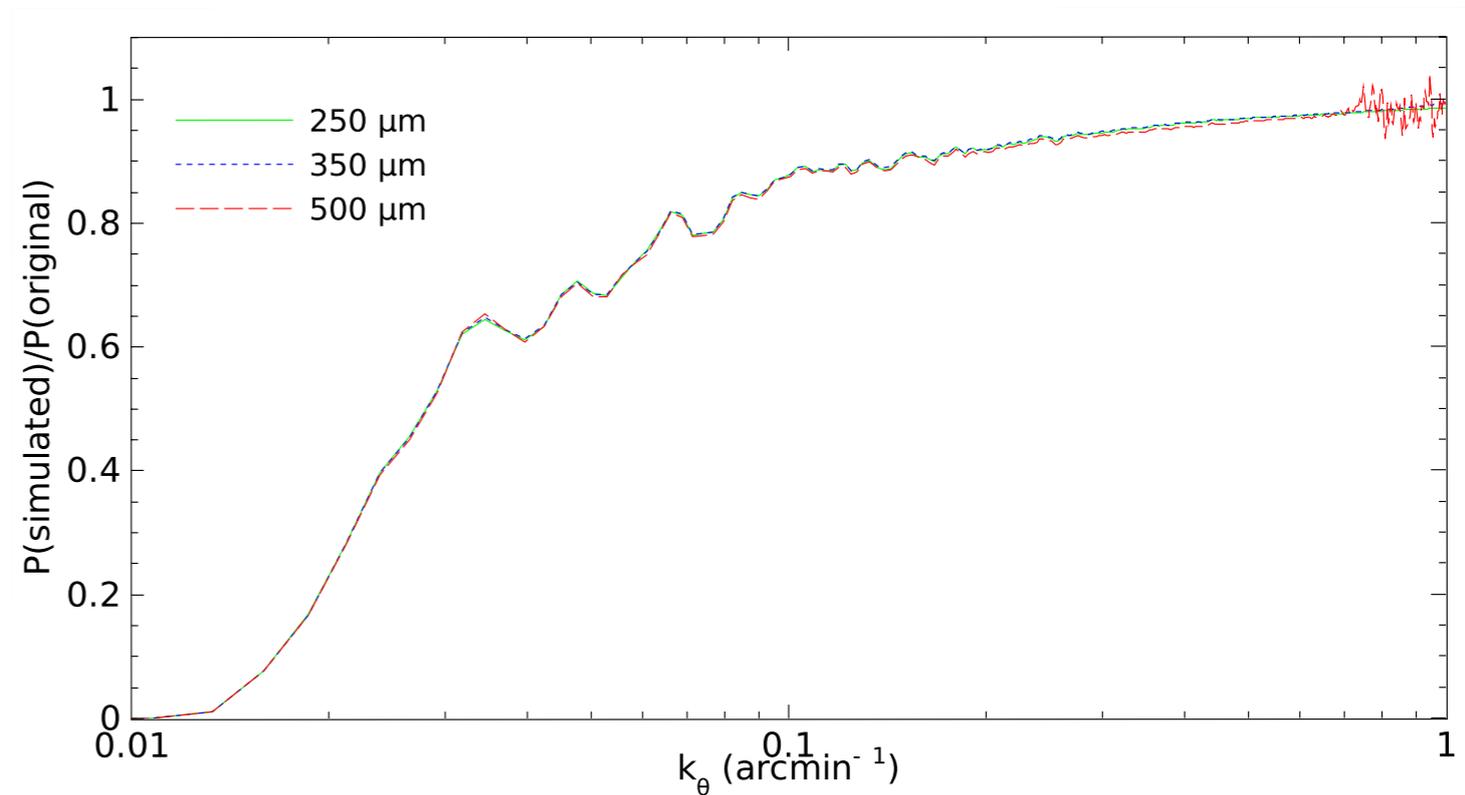
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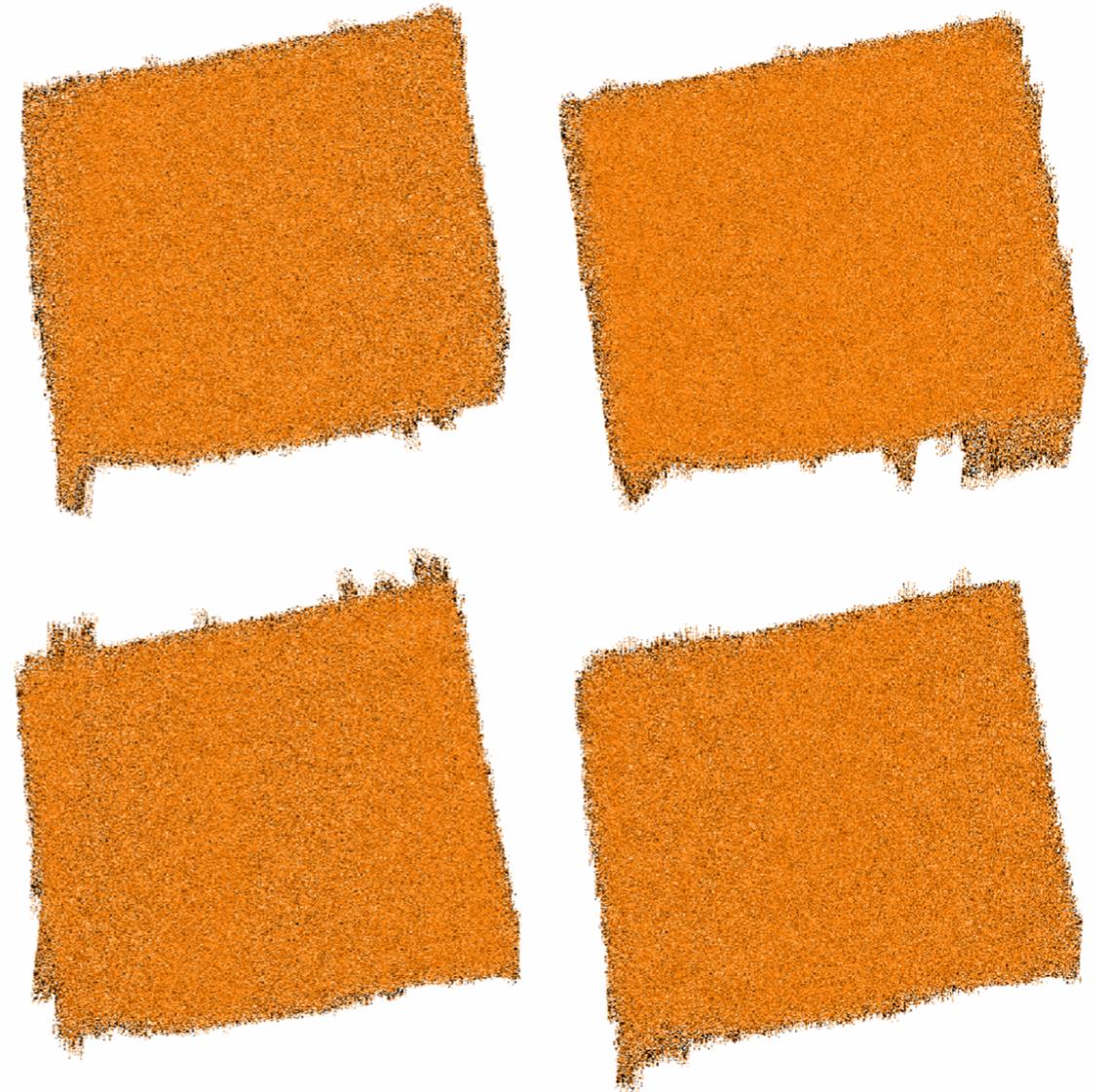
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 - ⦿ Use wide-only maps, with fast scan rate (0.1 deg/sec)
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 - ⦿ recover the large scales with MC-measured transfer function



Viero et al. 0904.1200

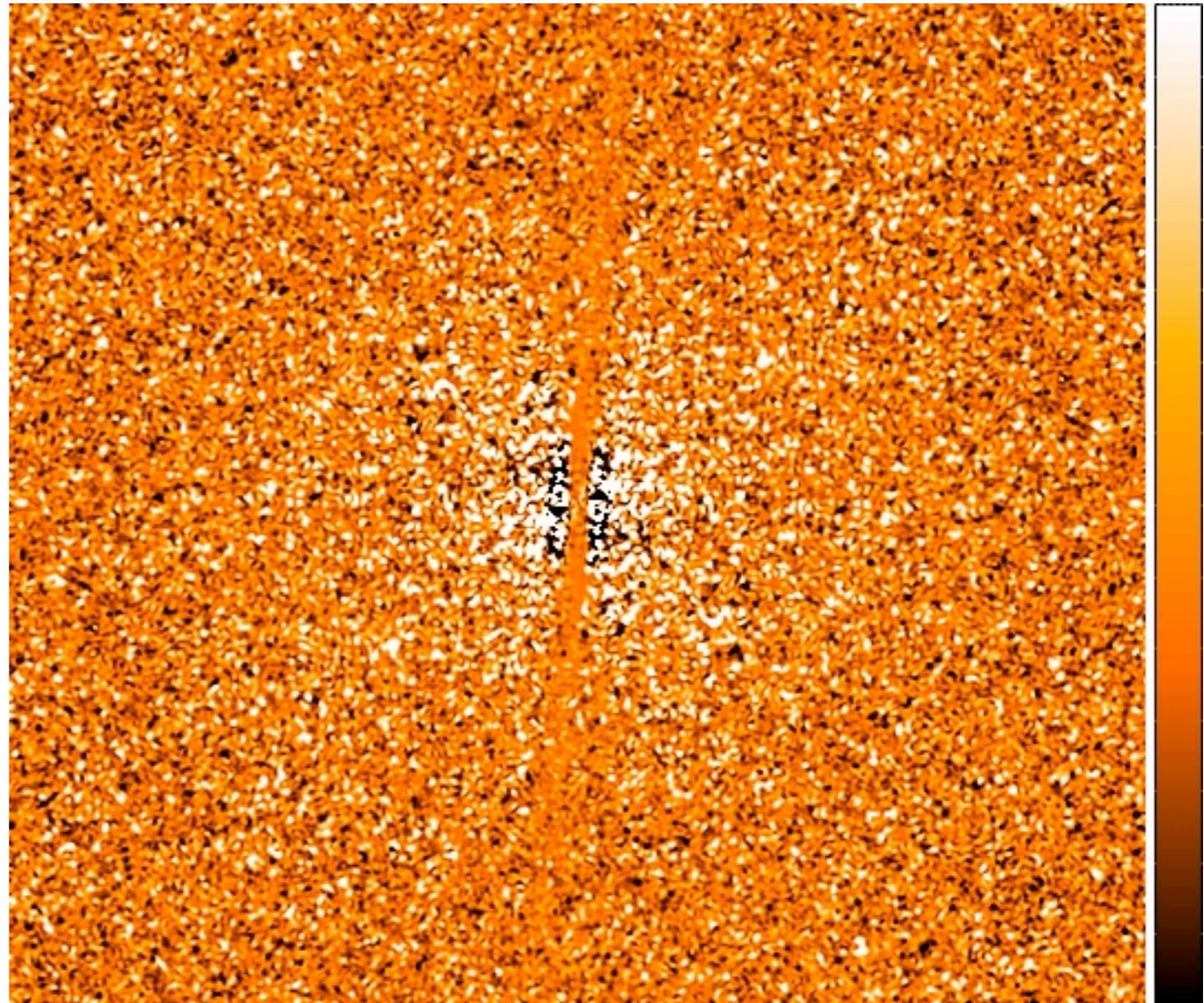
BLAST: Making the Measurement

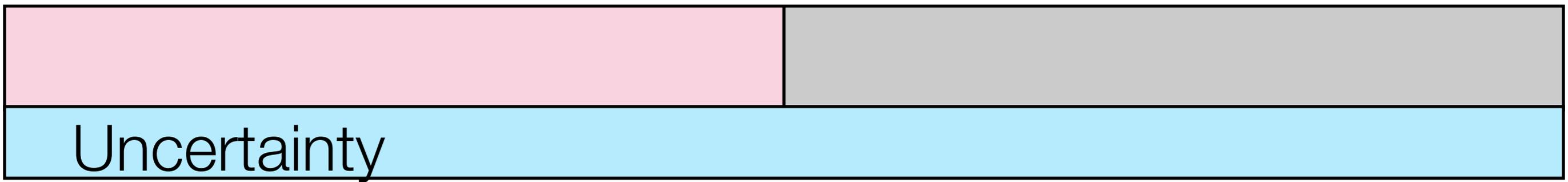
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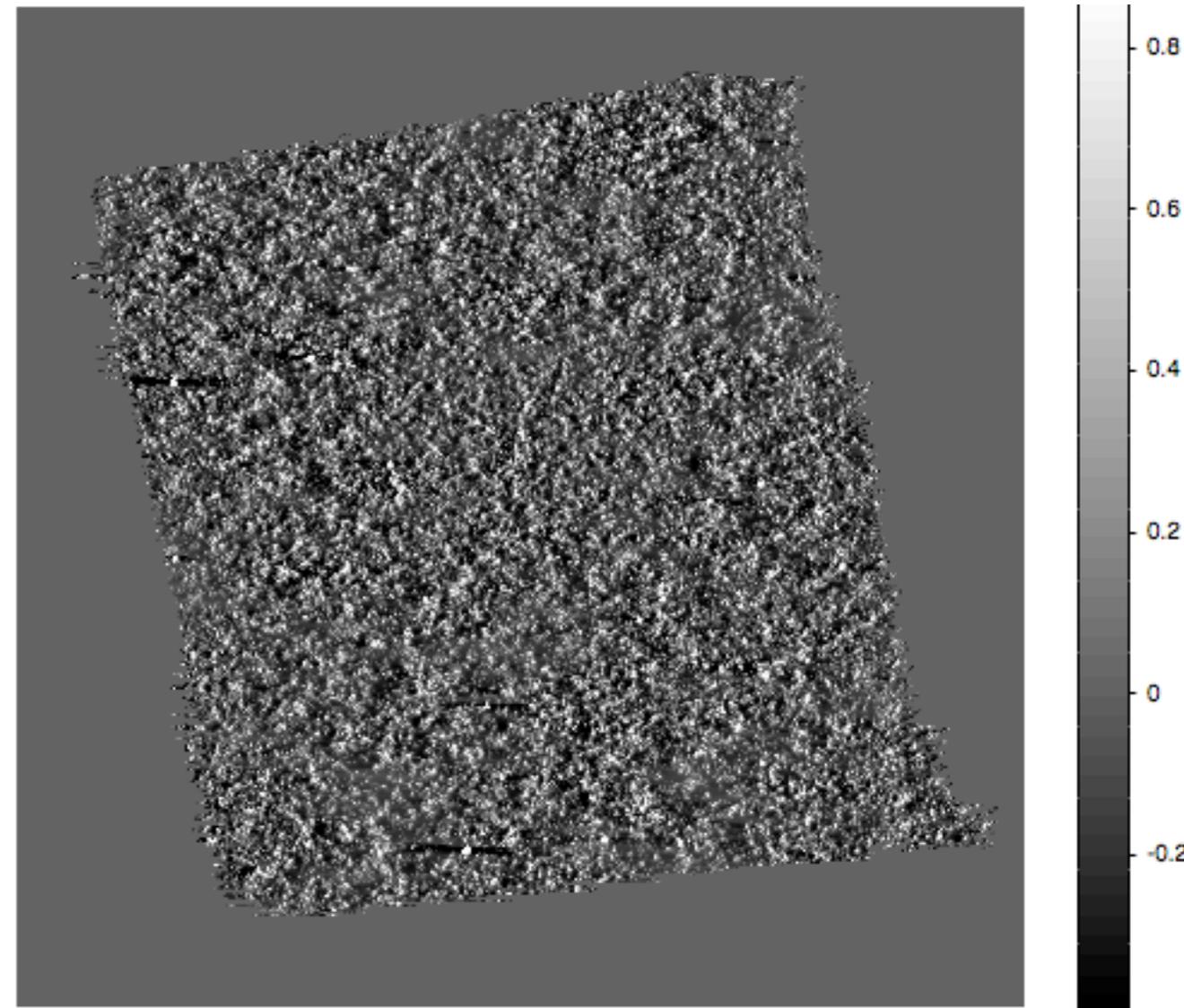
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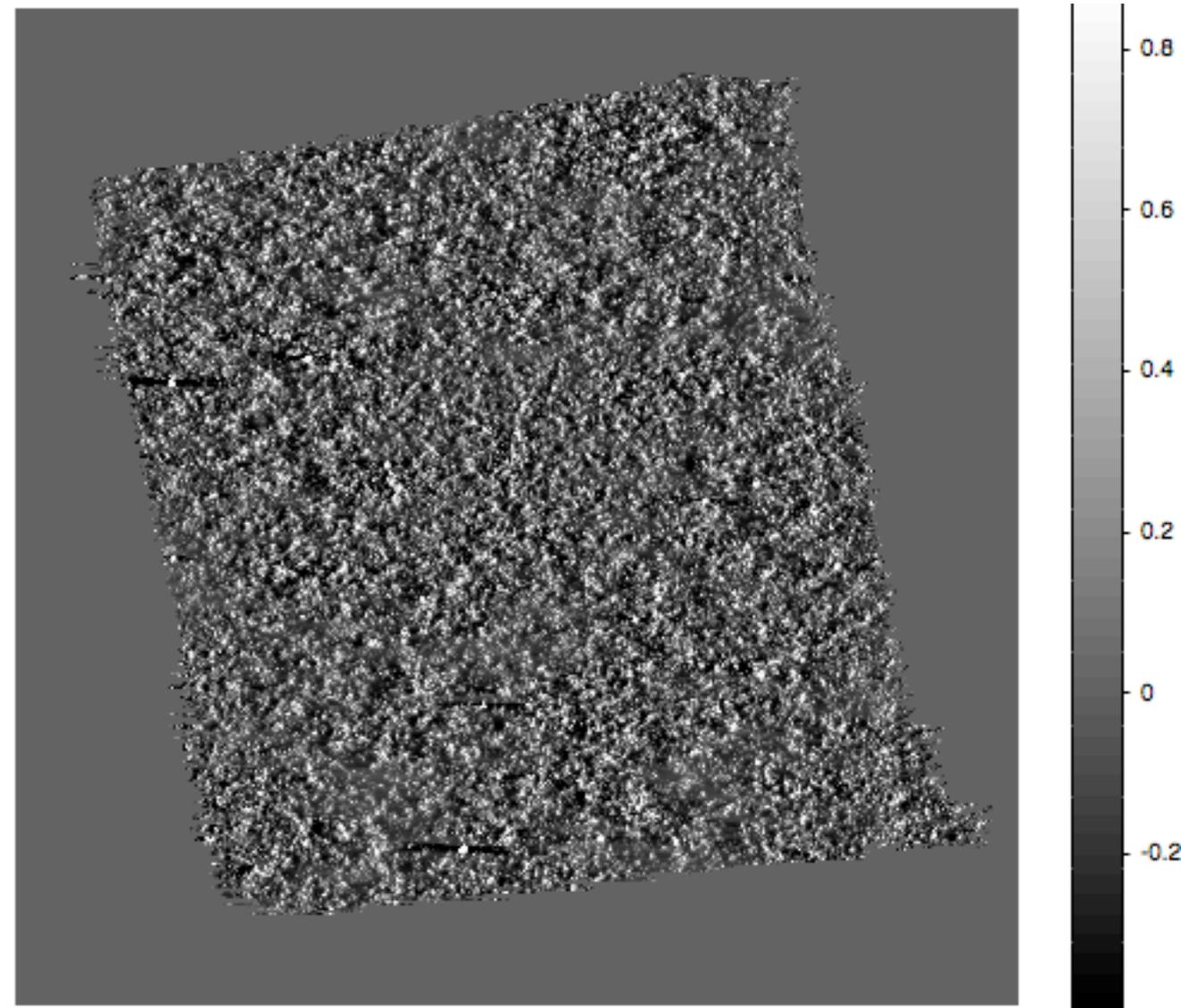
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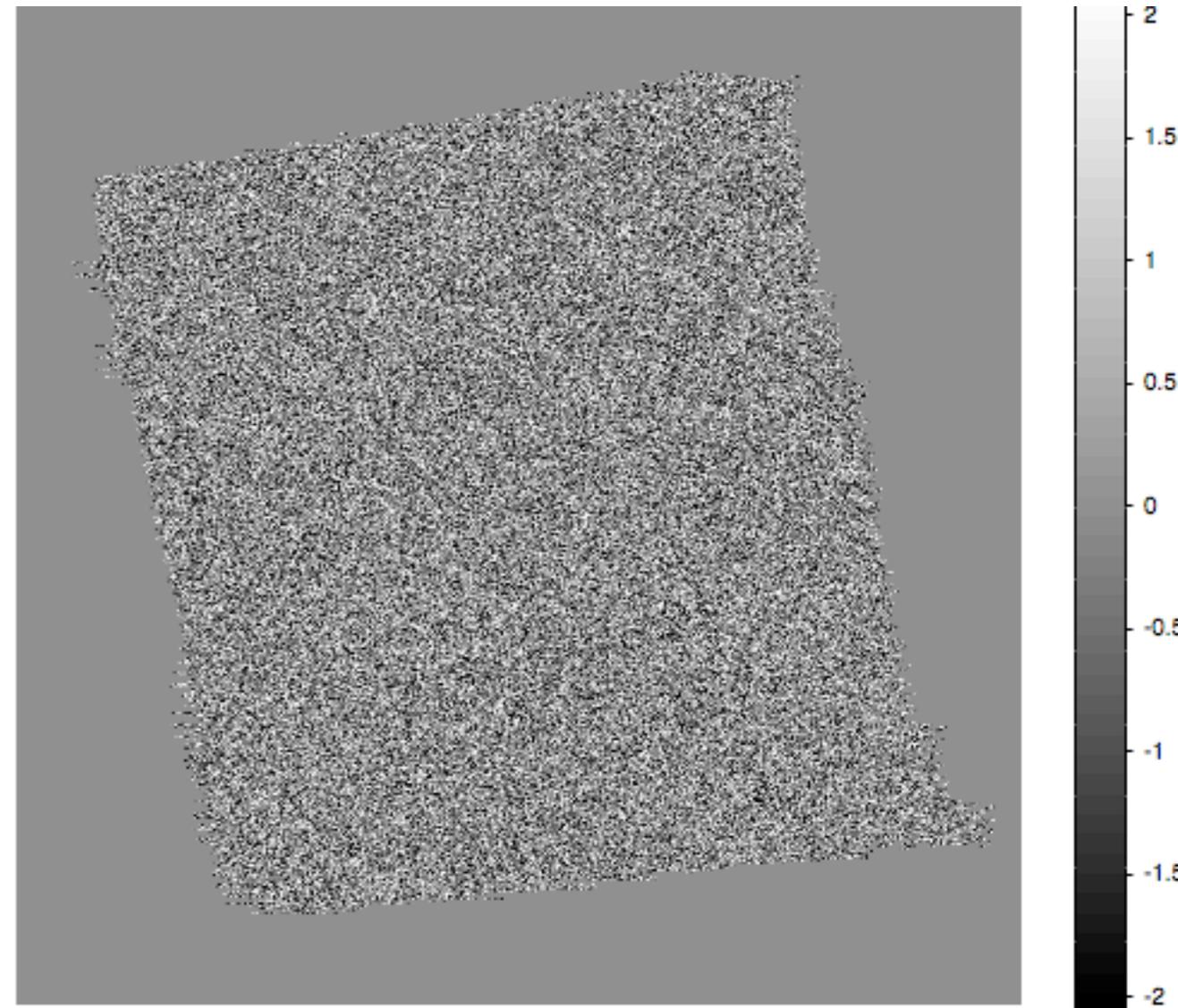
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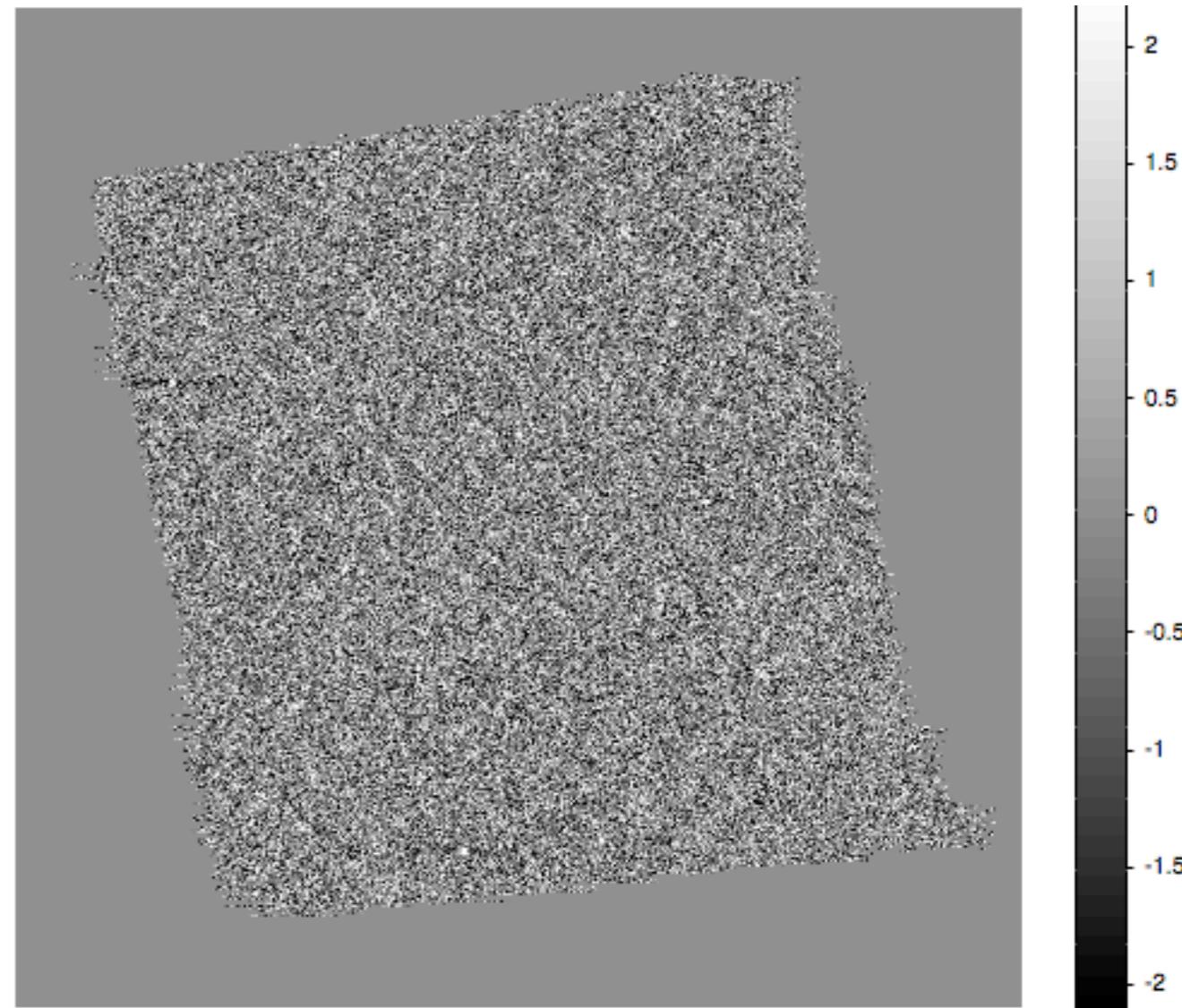
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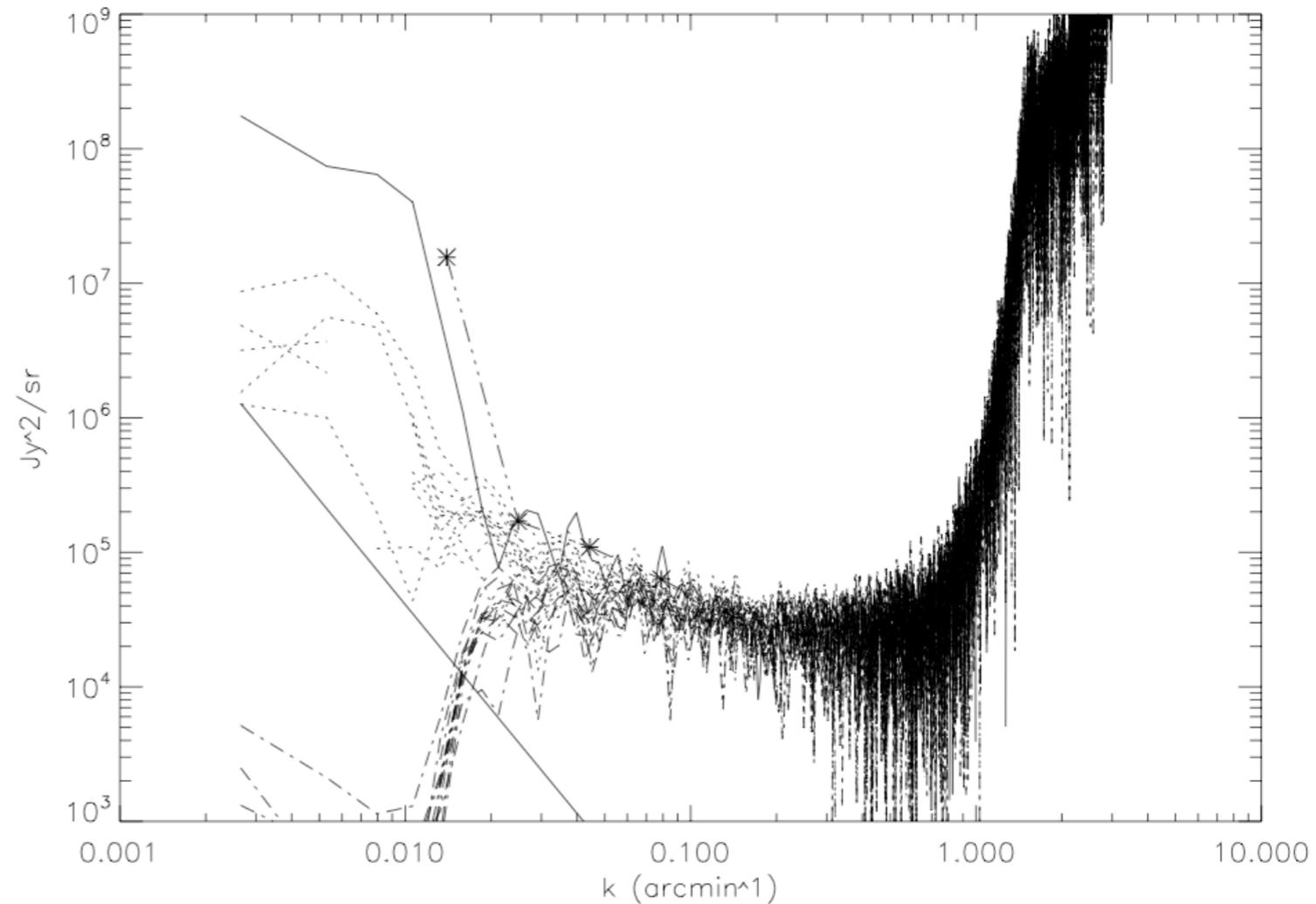
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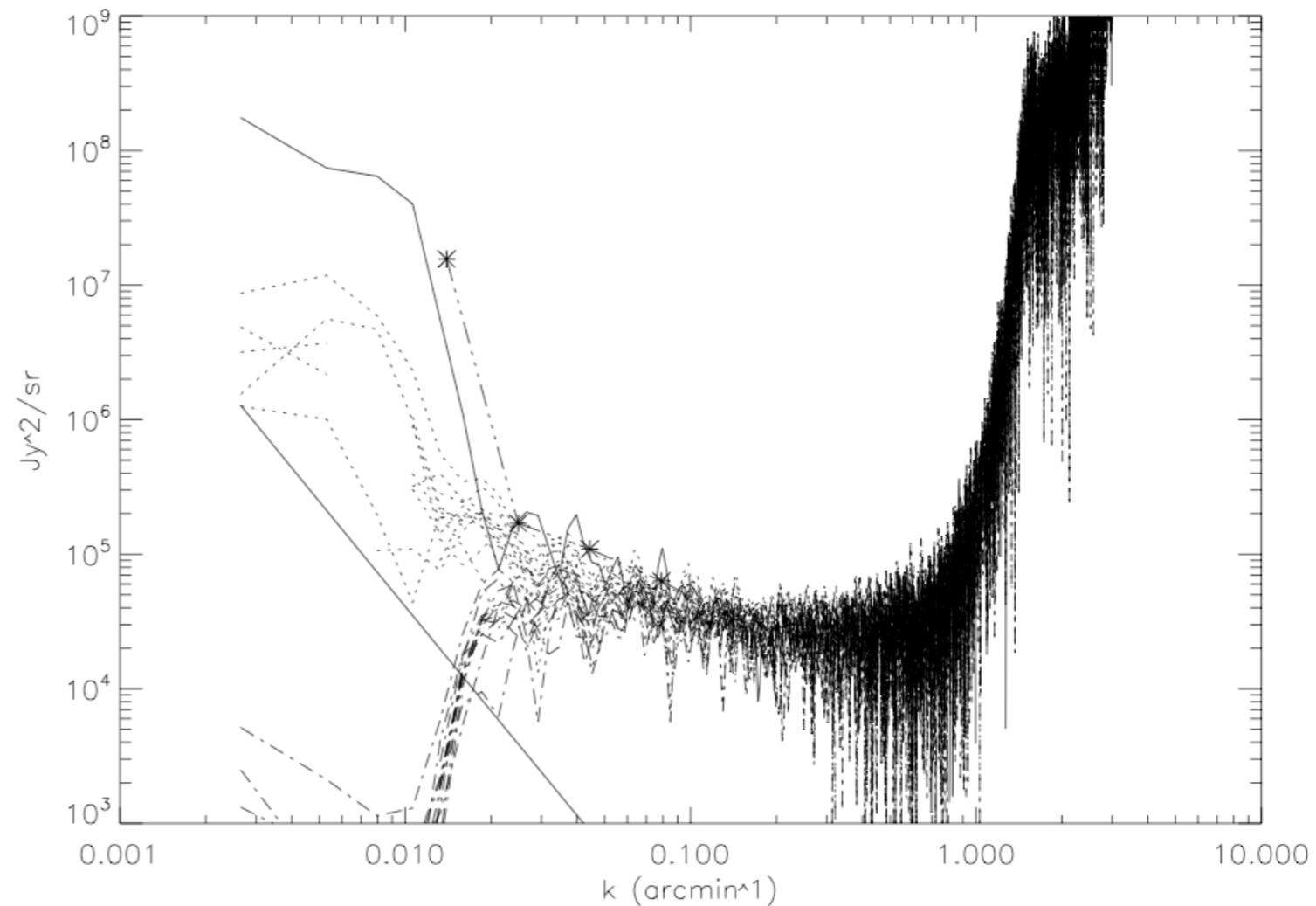
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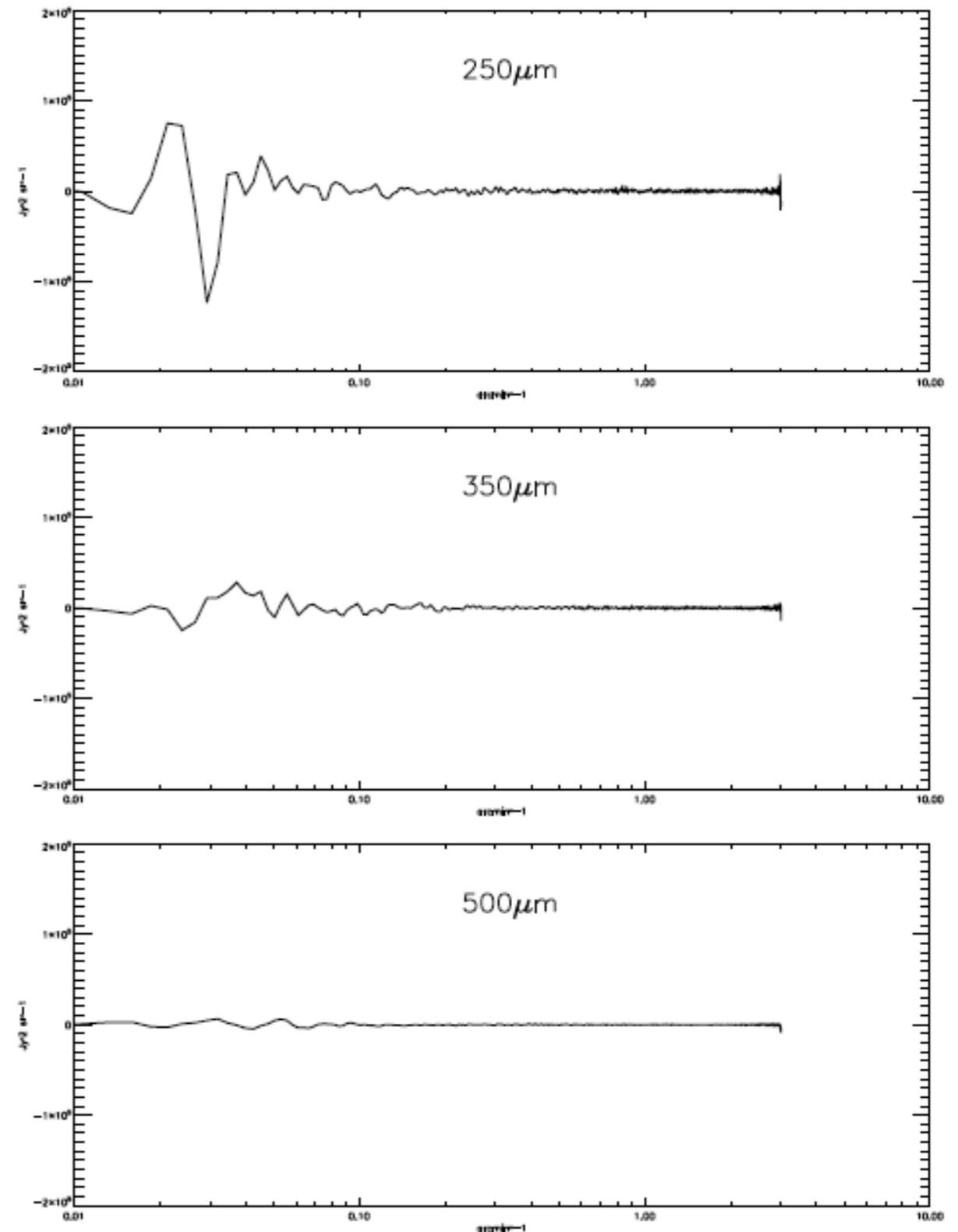
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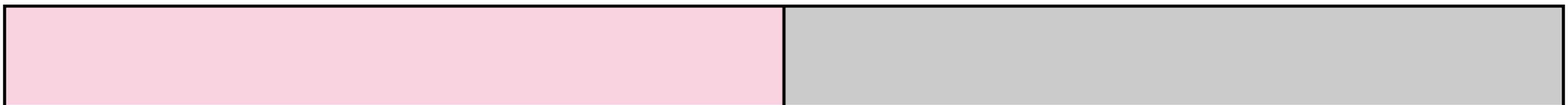
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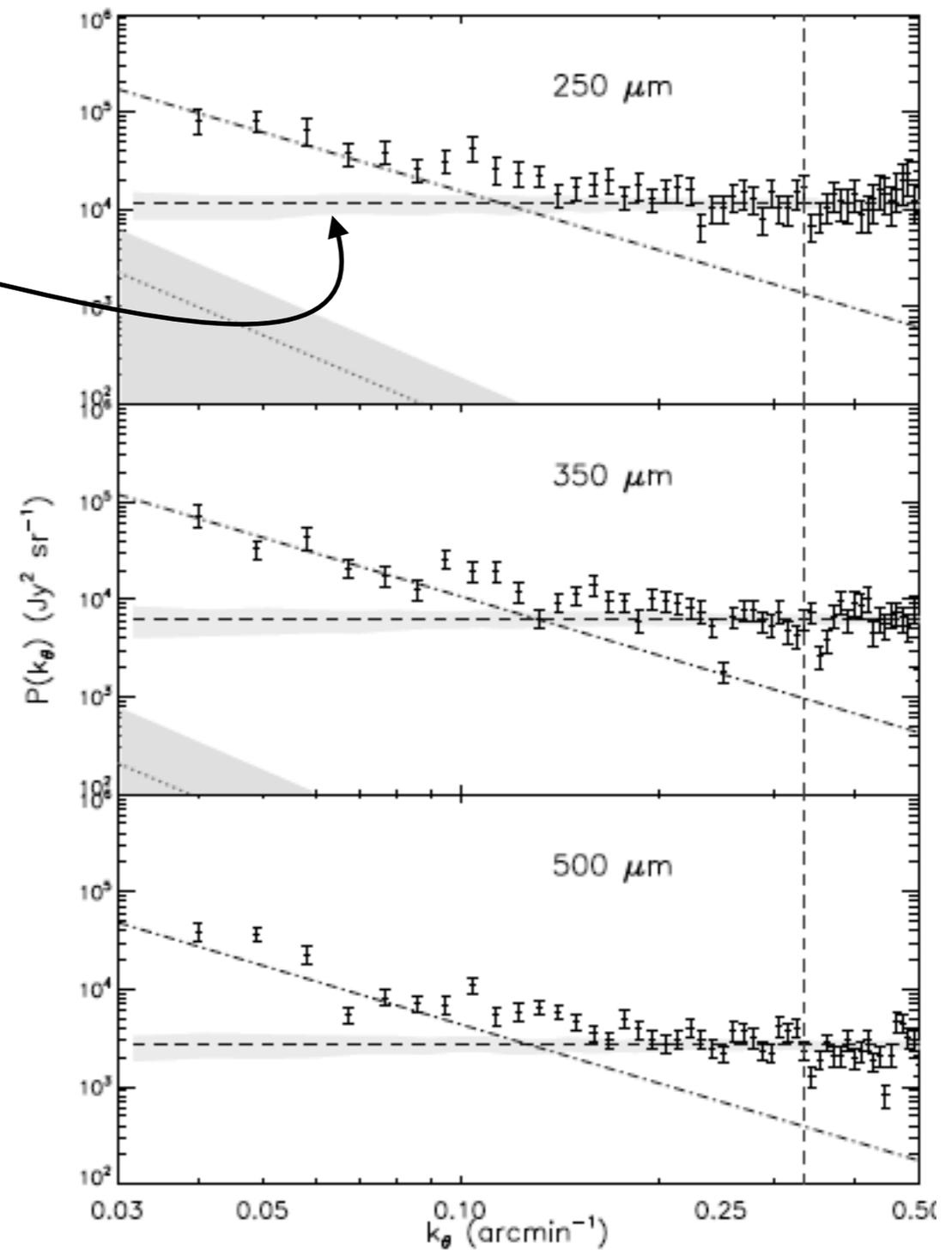




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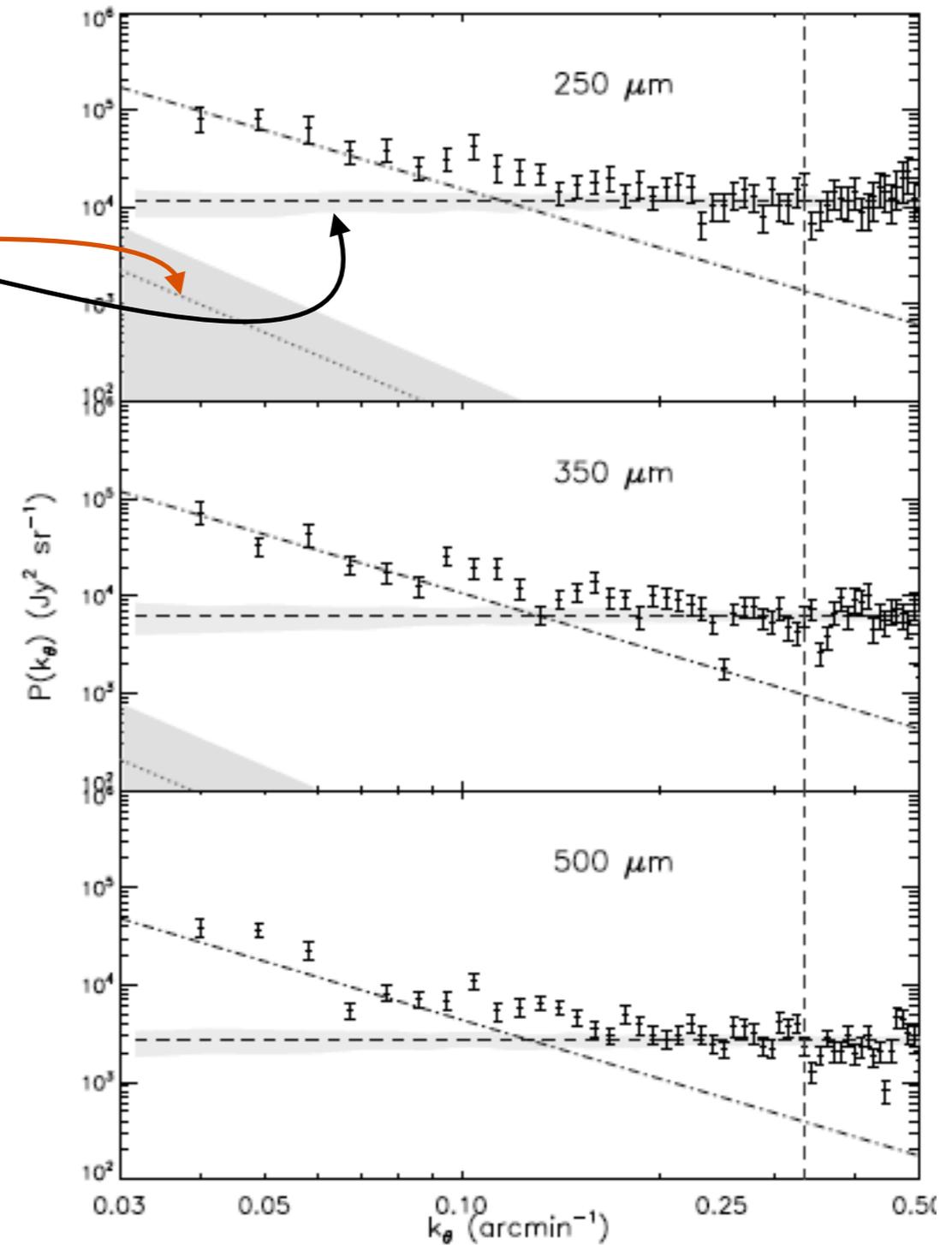
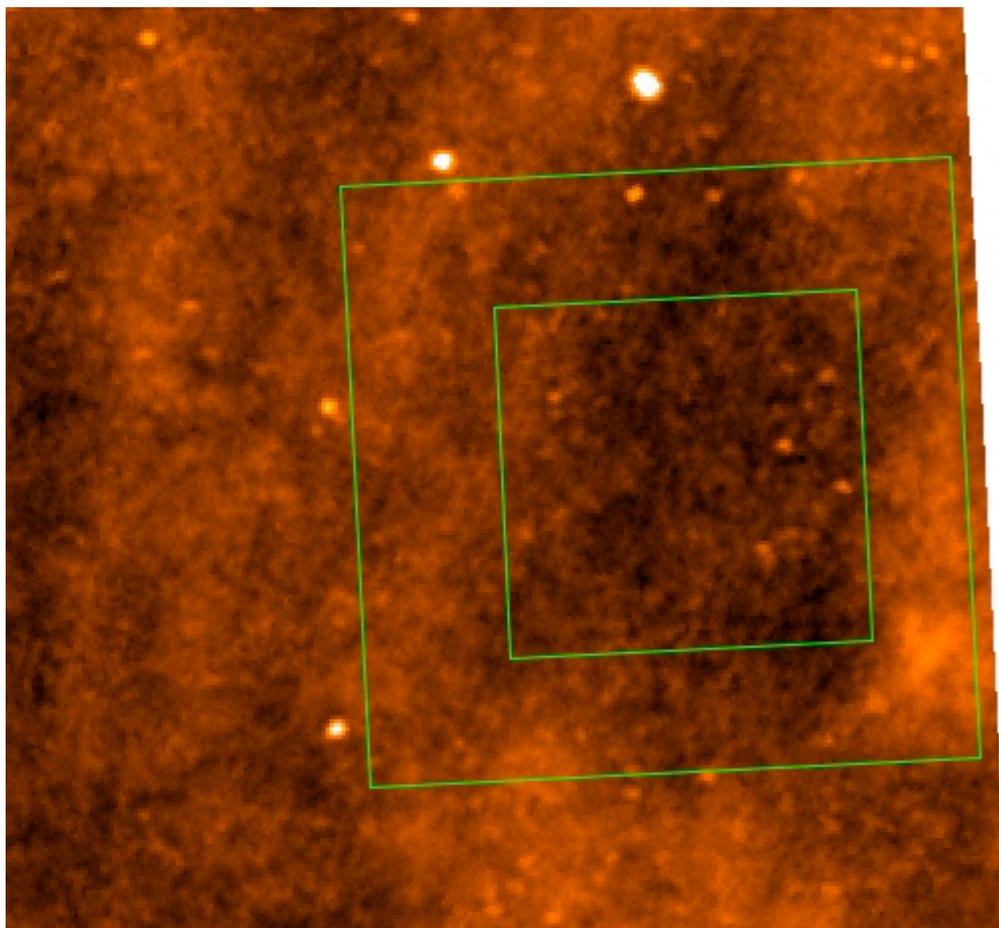
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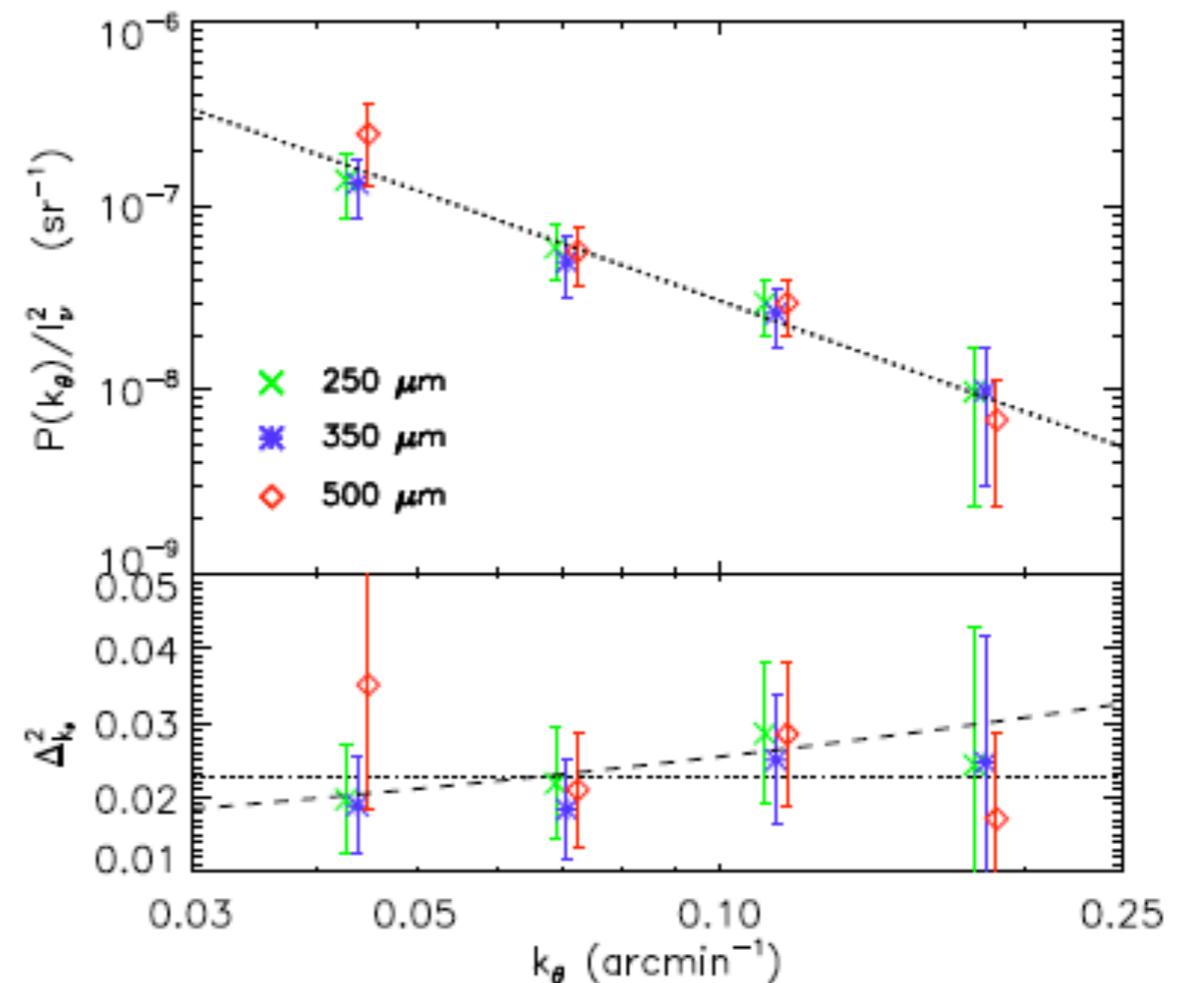
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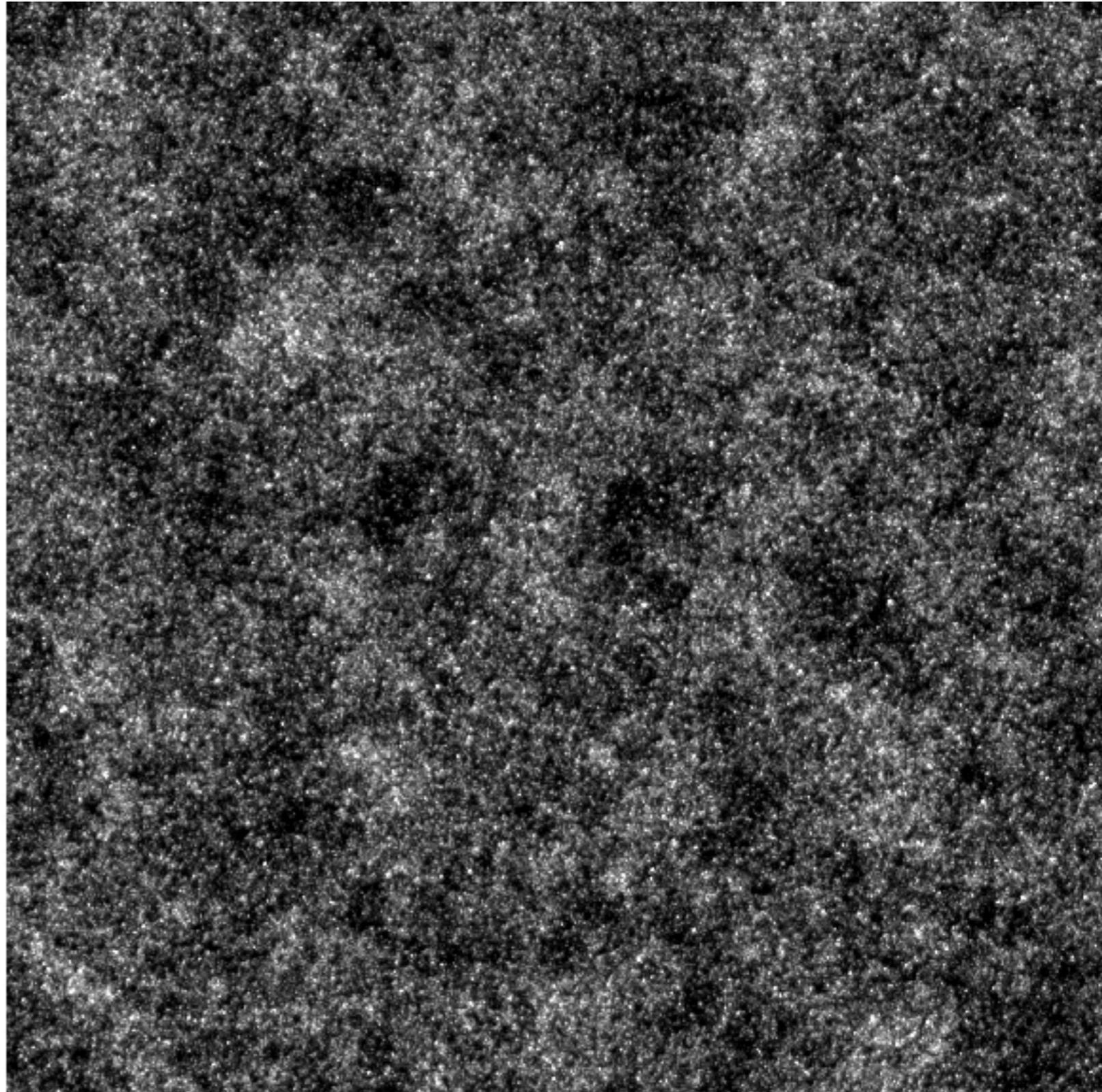
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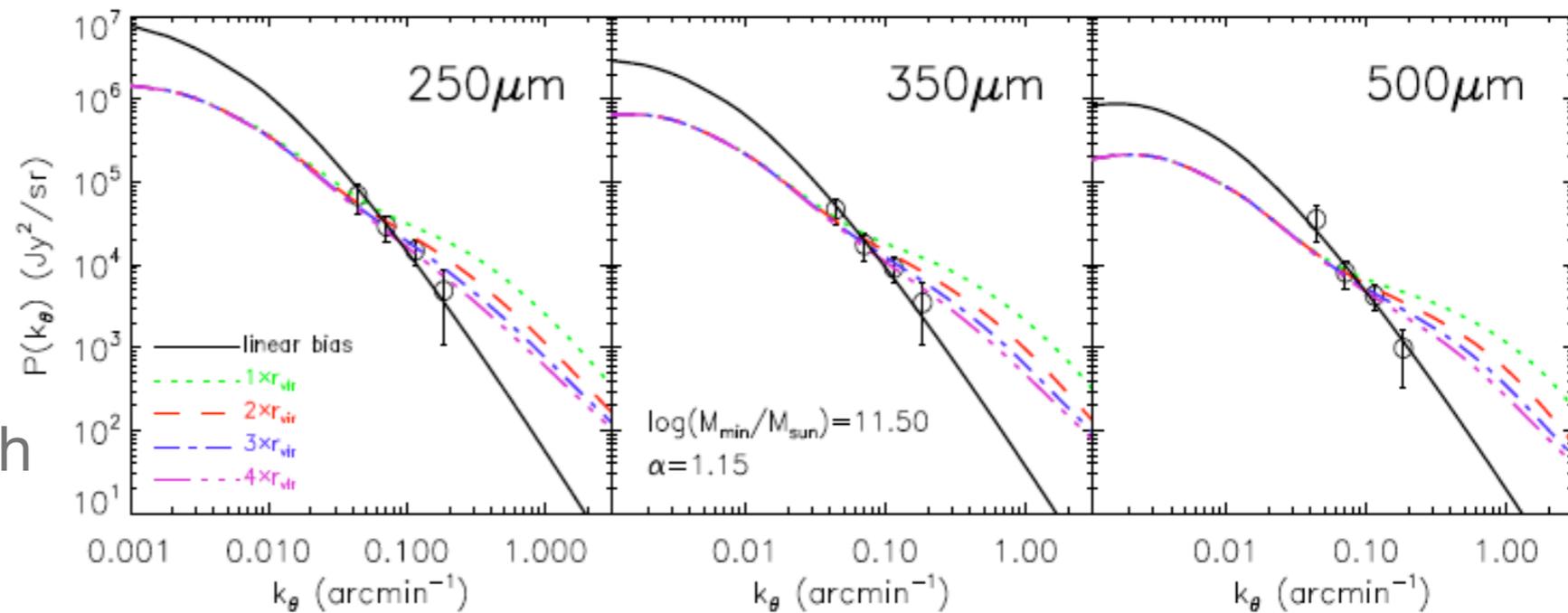
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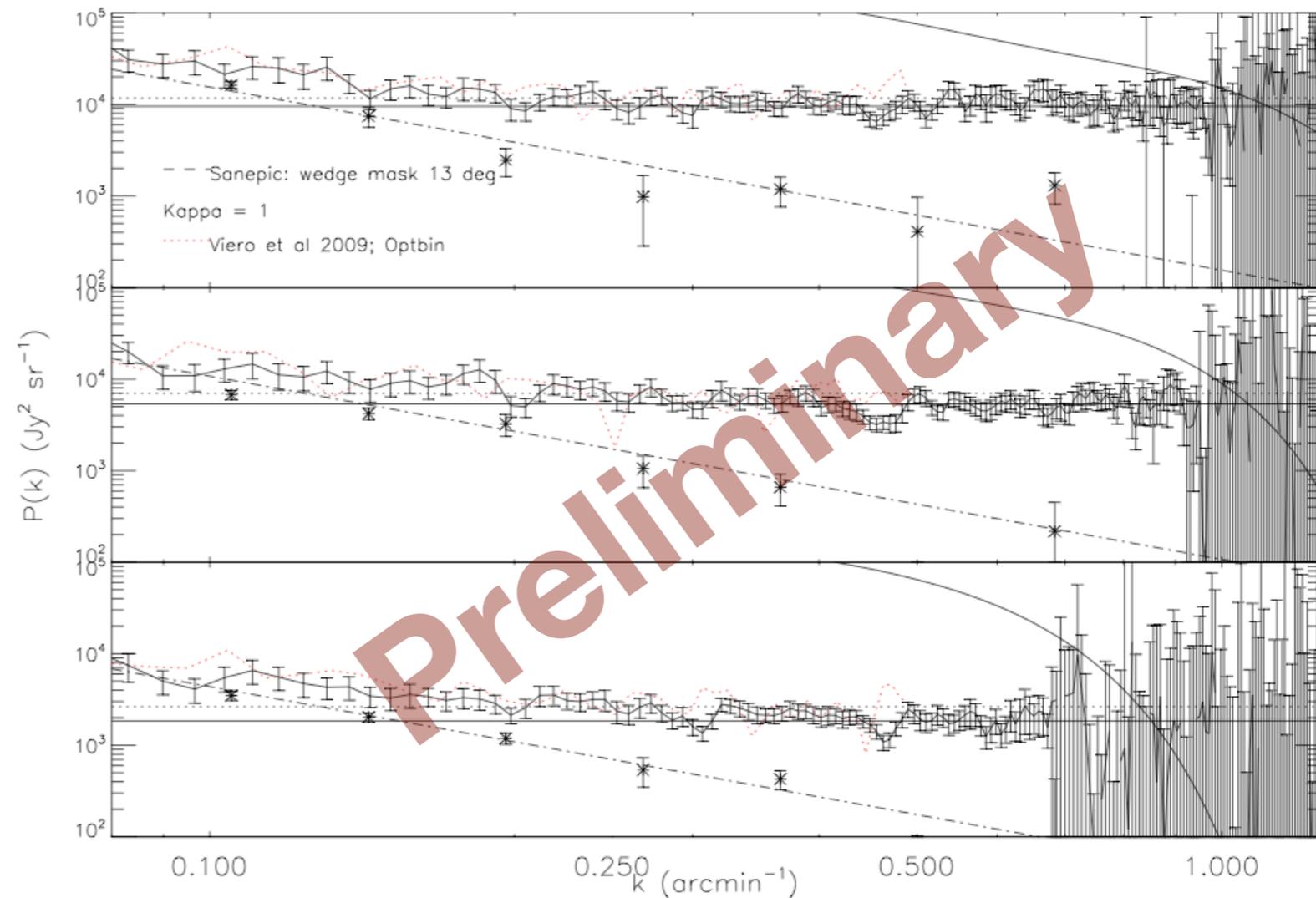
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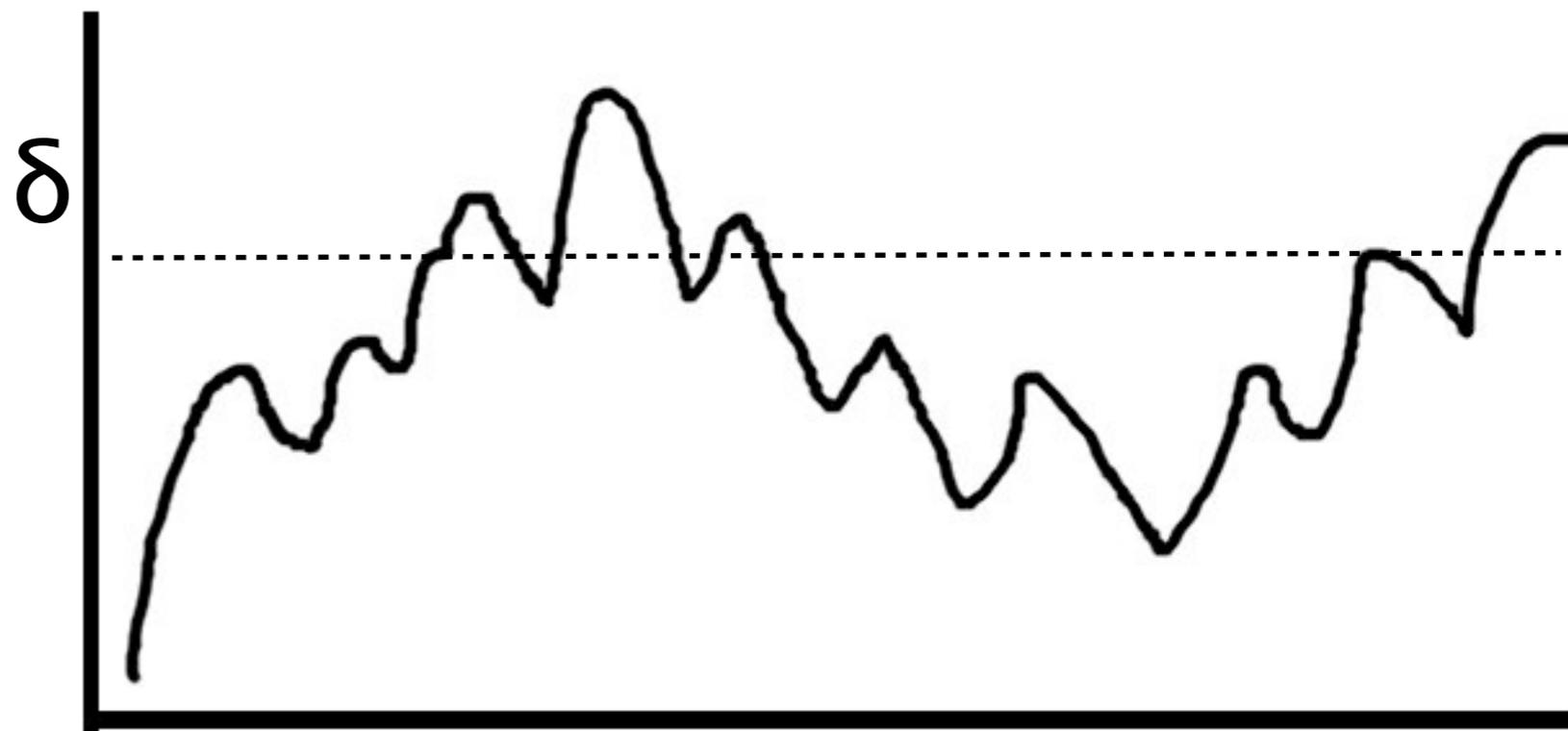
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- Further (ongoing) analysis with twice the data confirm this behaviour on small scales



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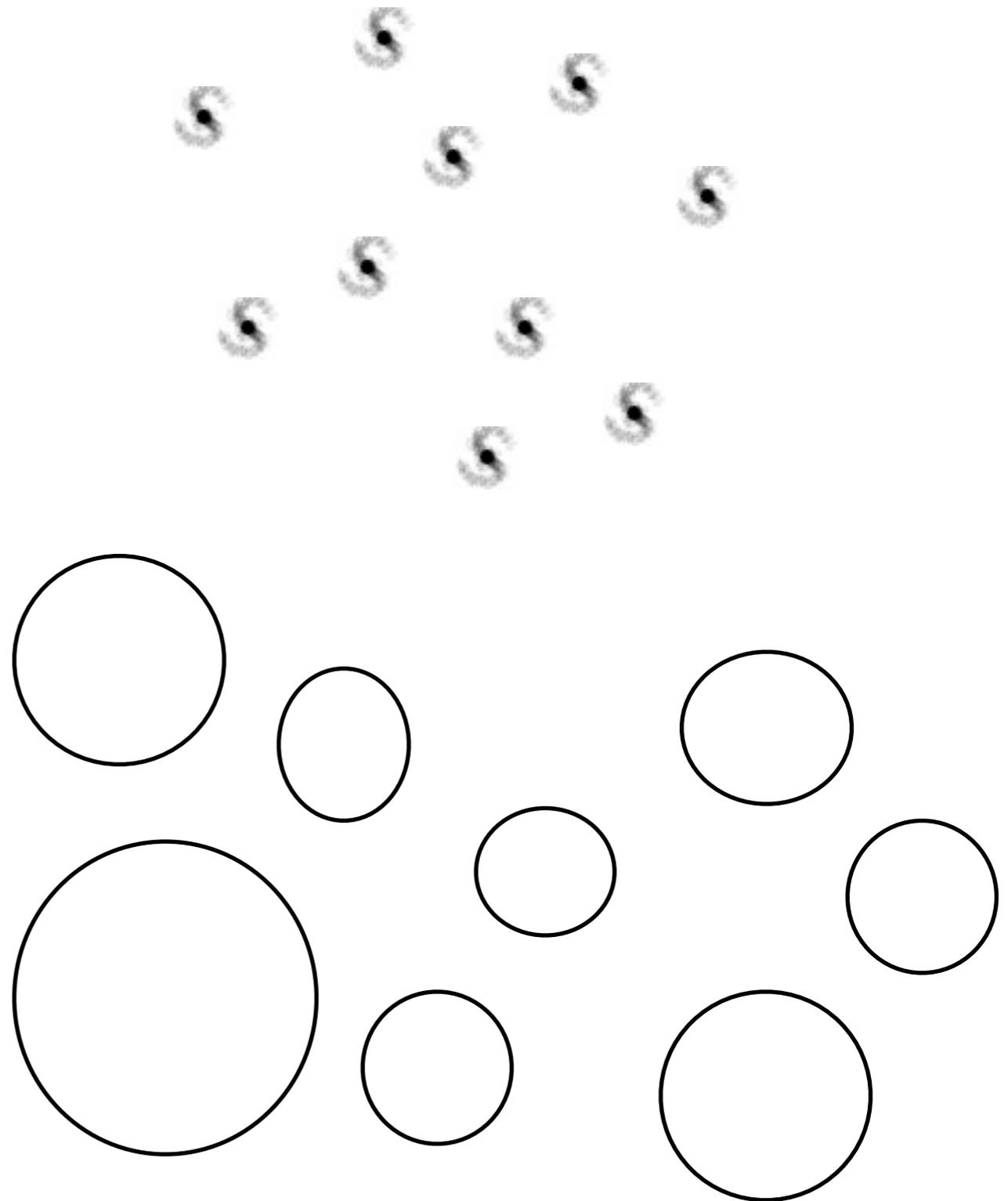
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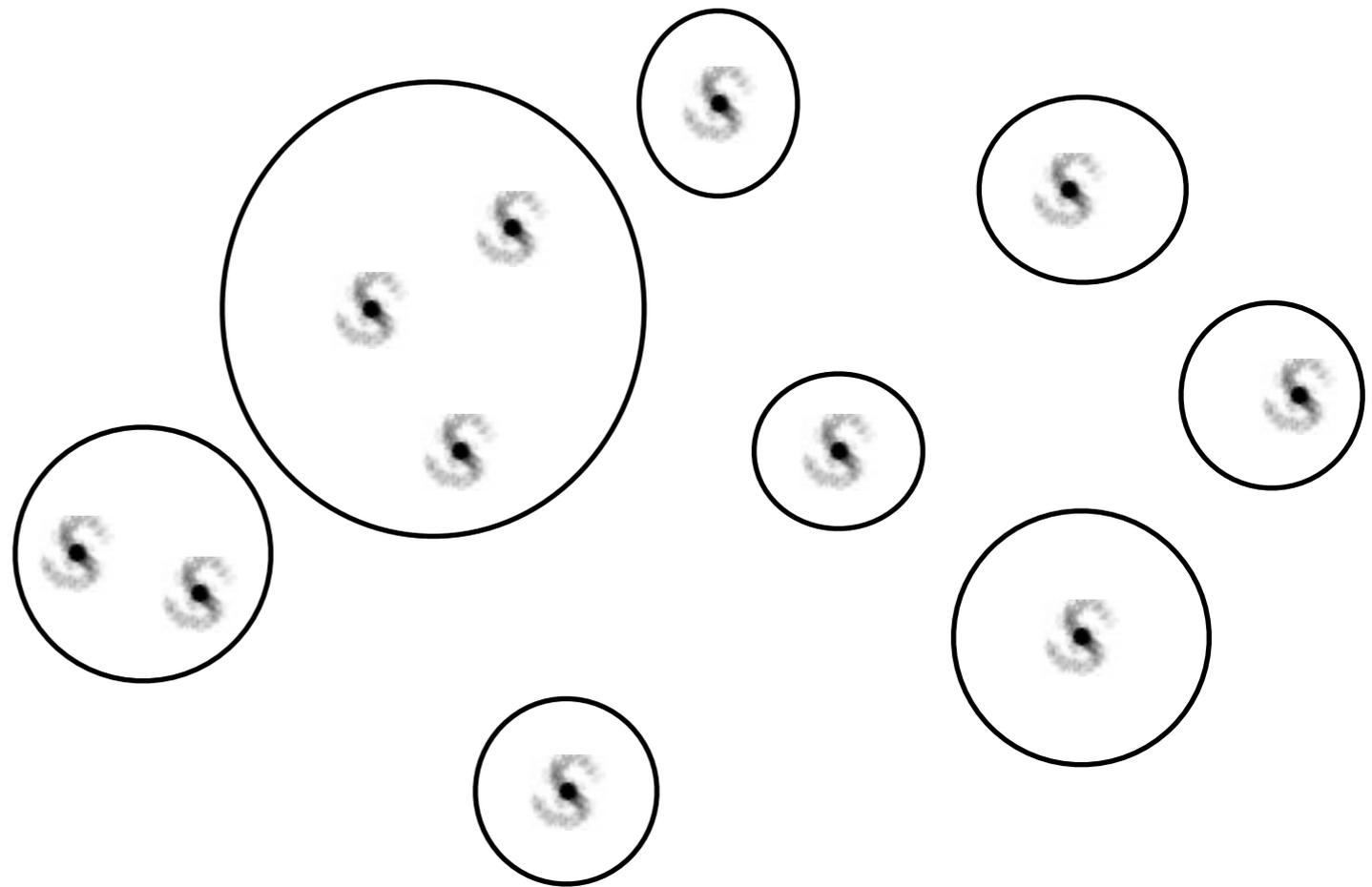
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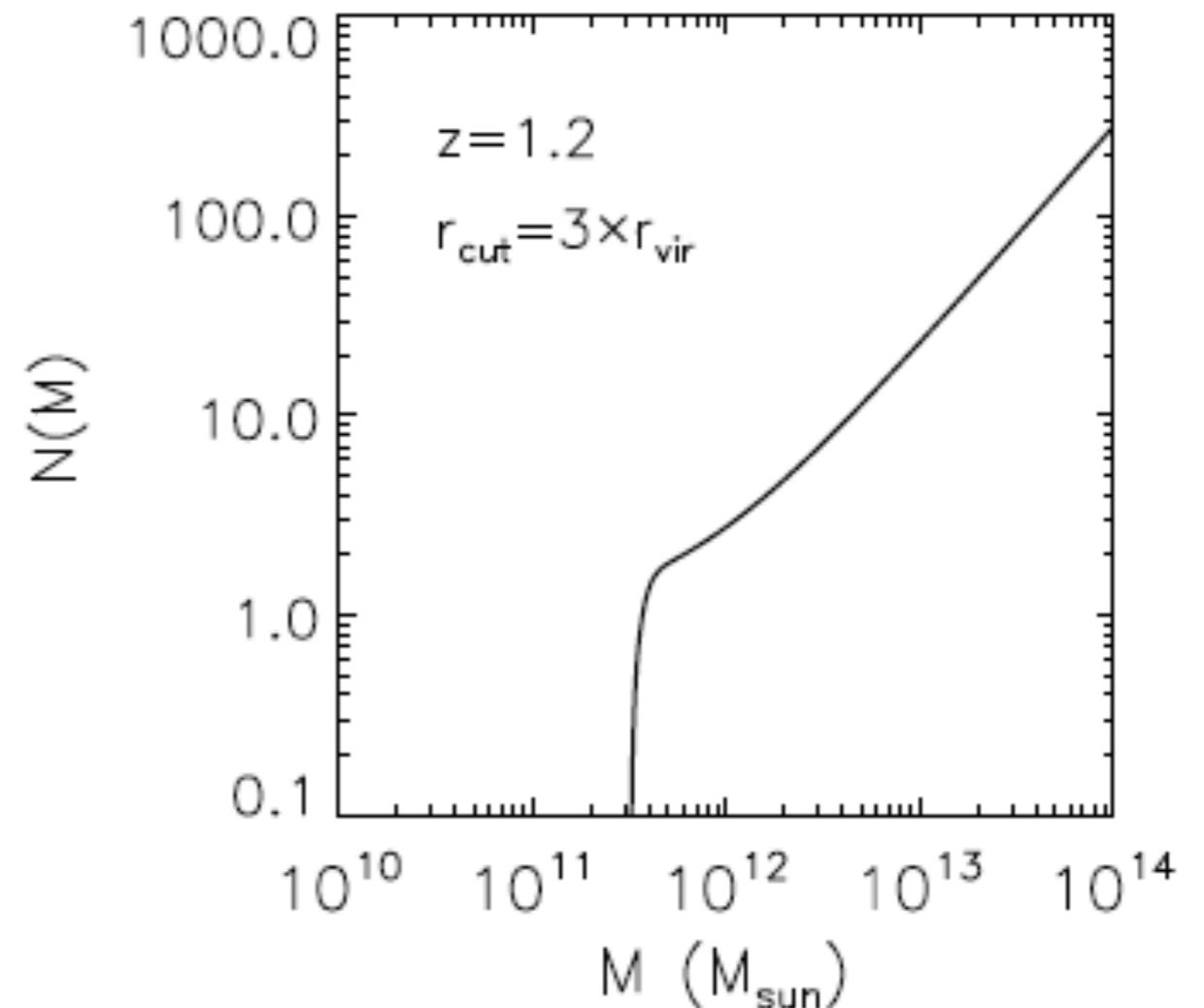
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- Prescription for assigning Galaxies to Halos as Function of Mass (aka HON):
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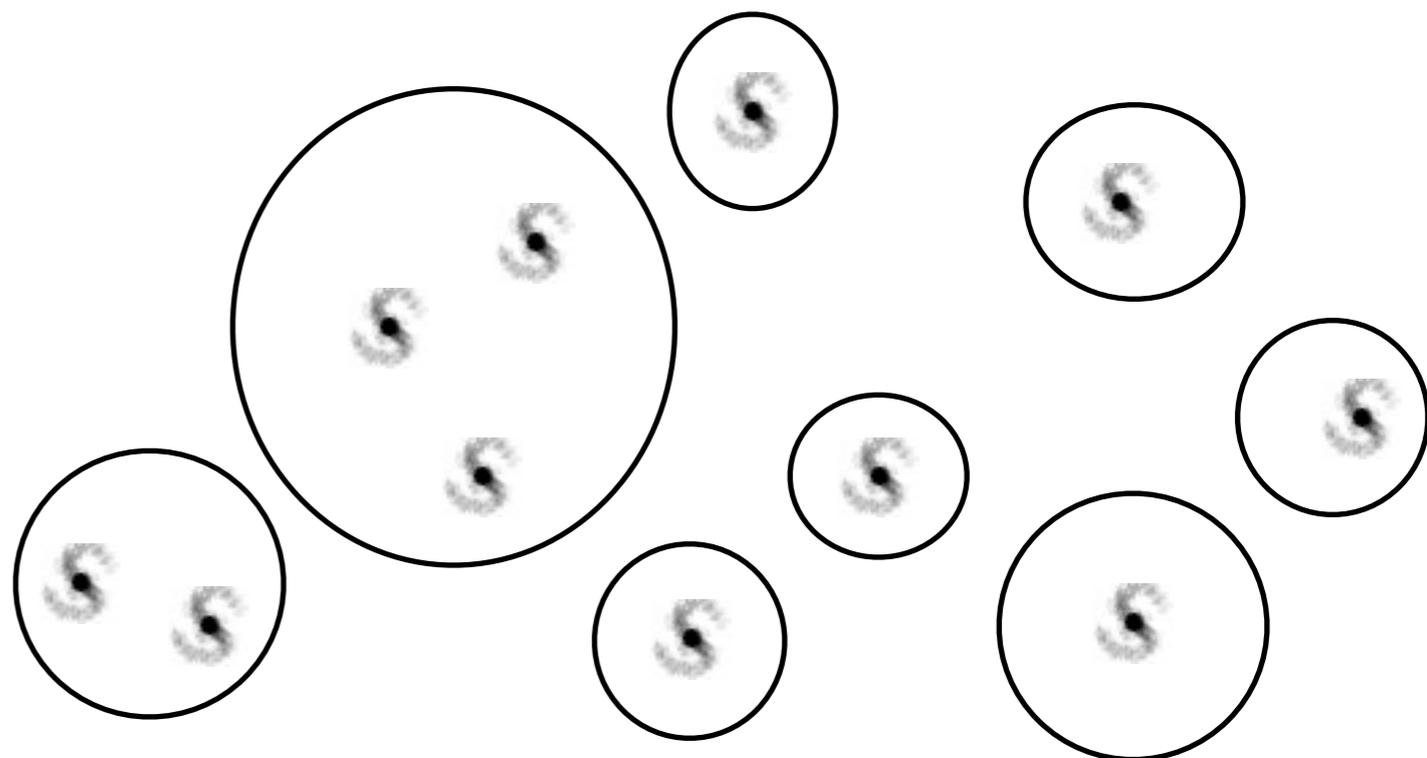


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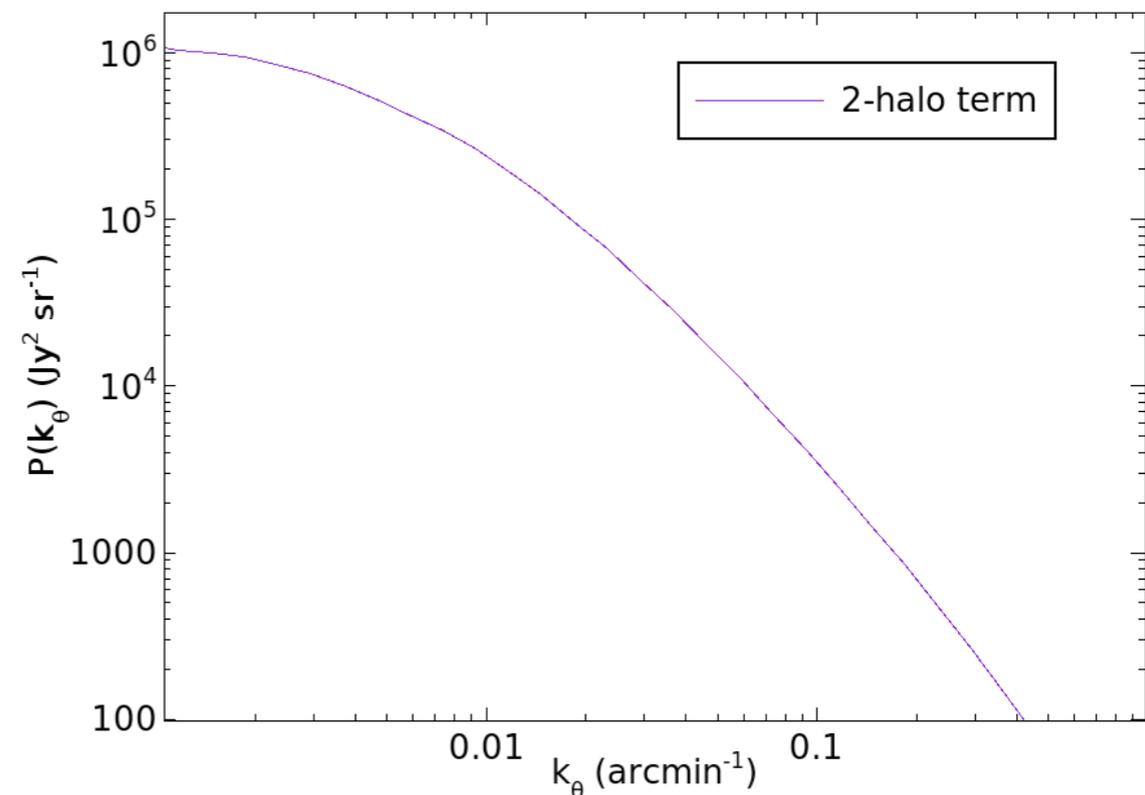
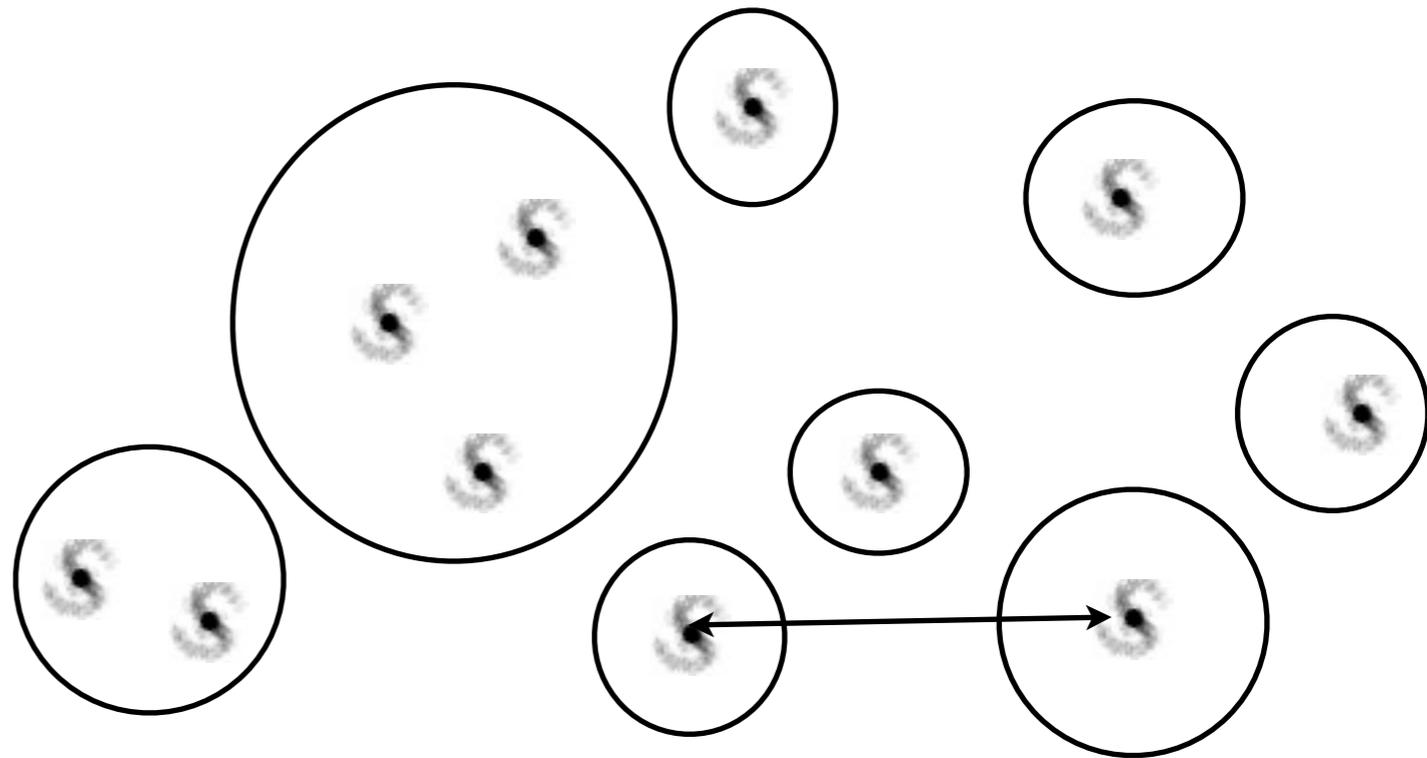
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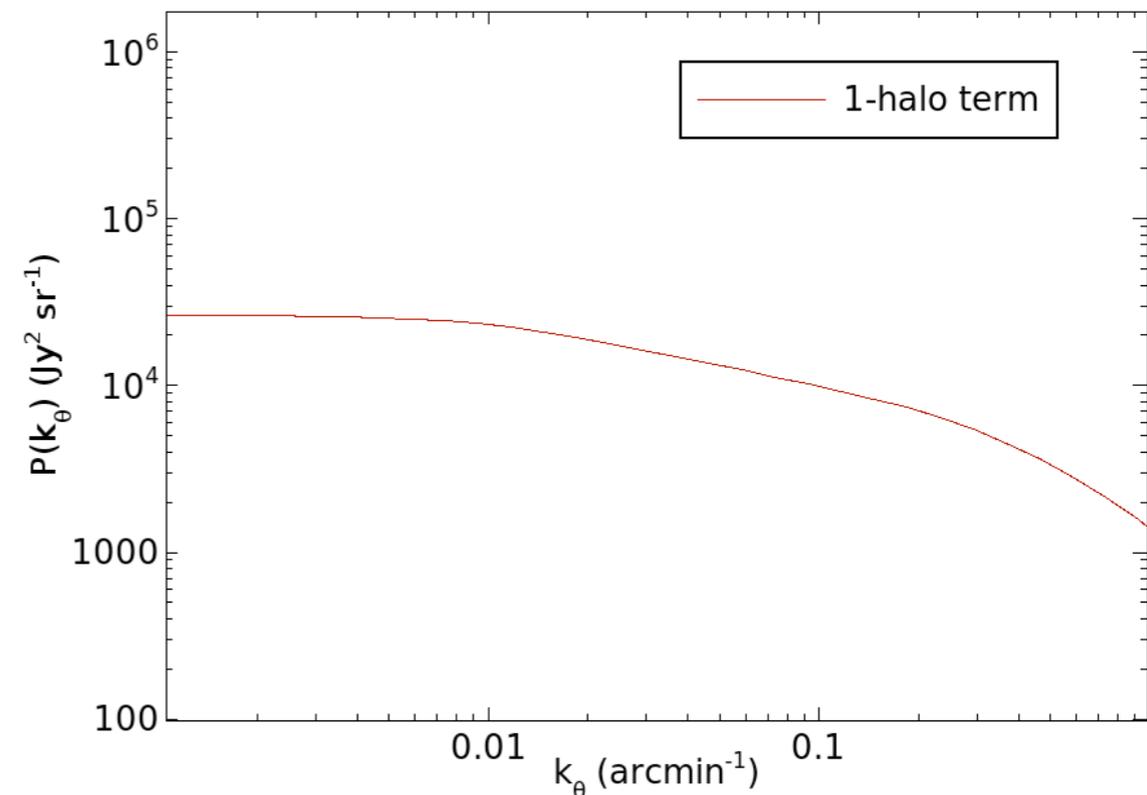
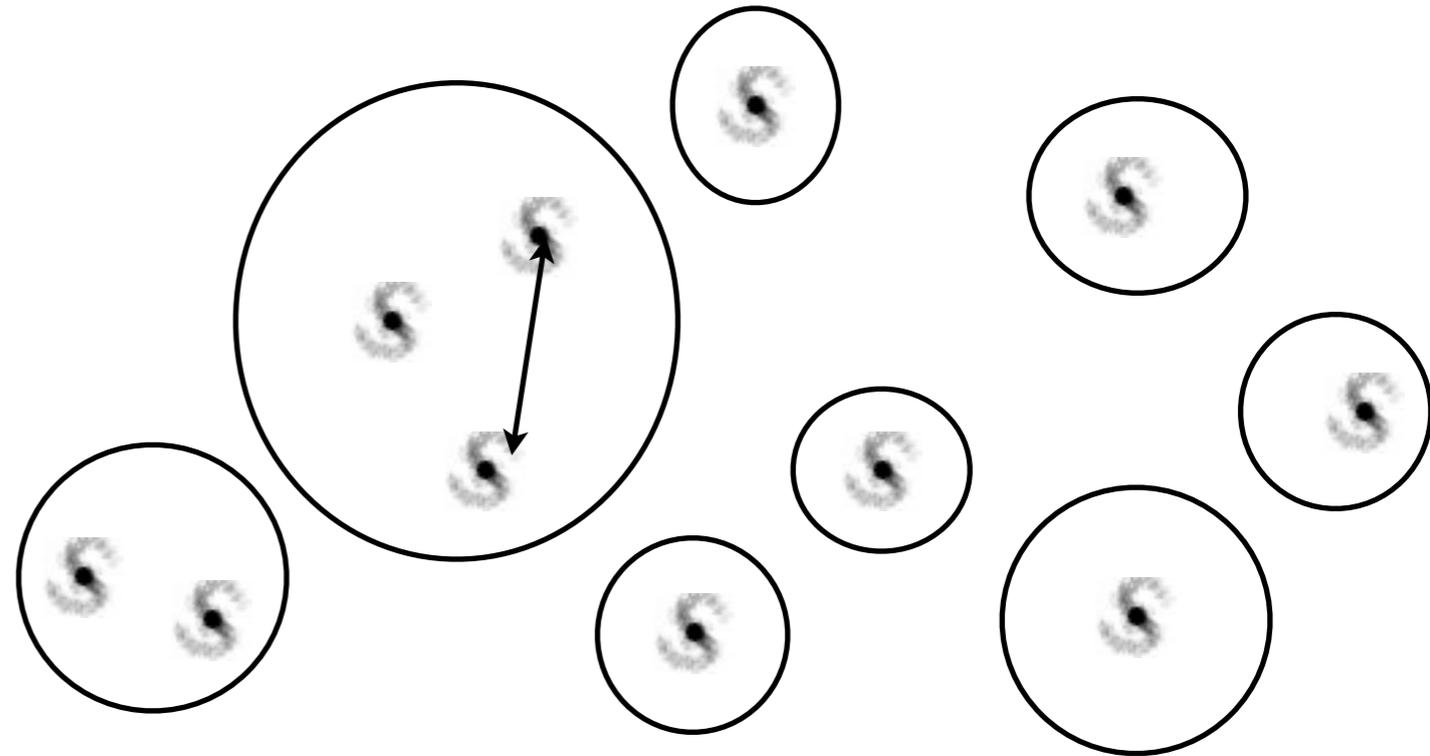
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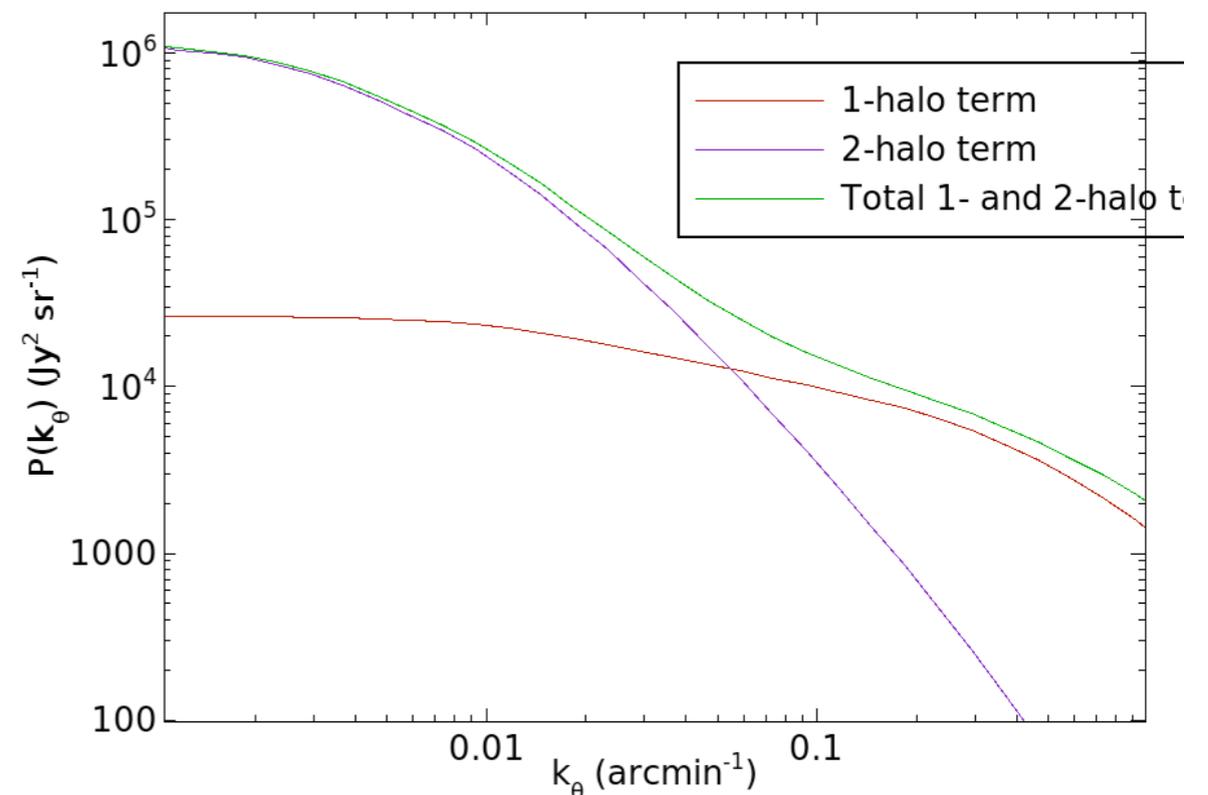
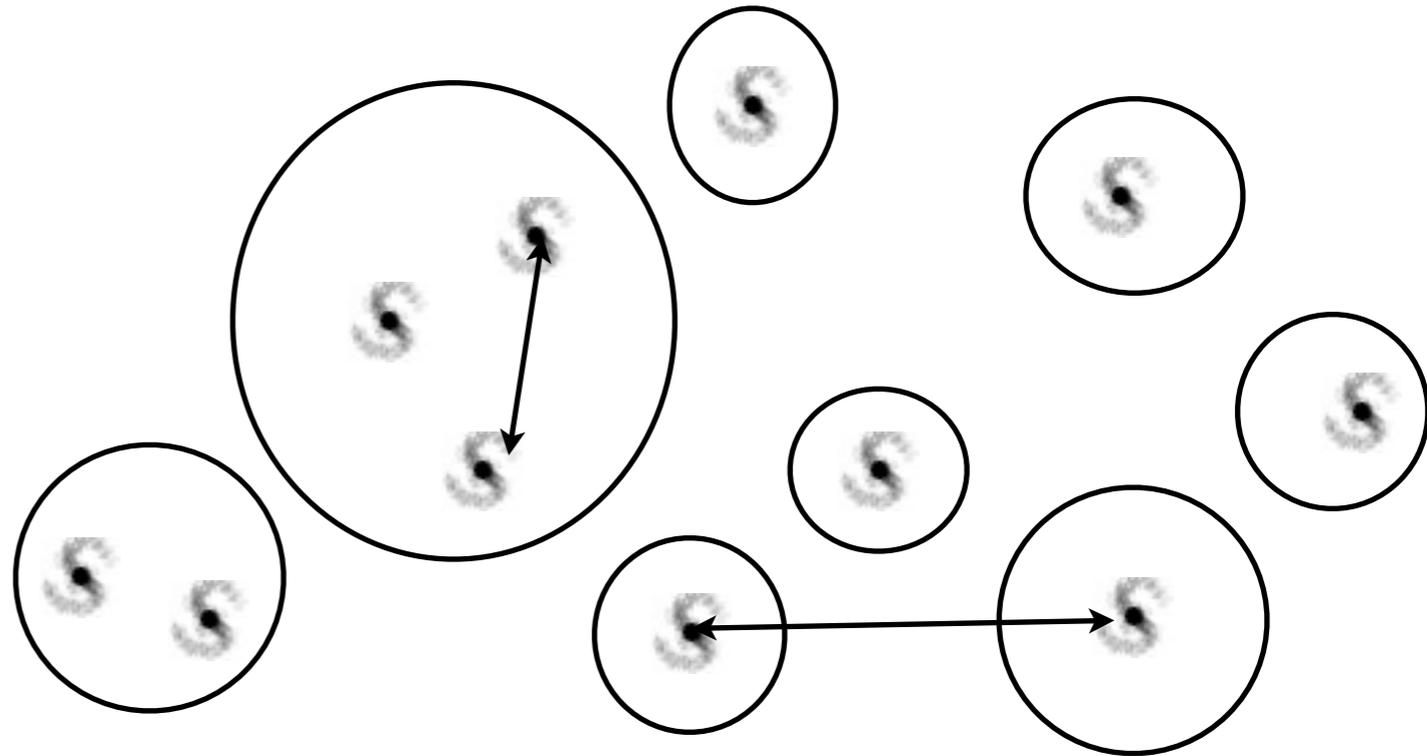
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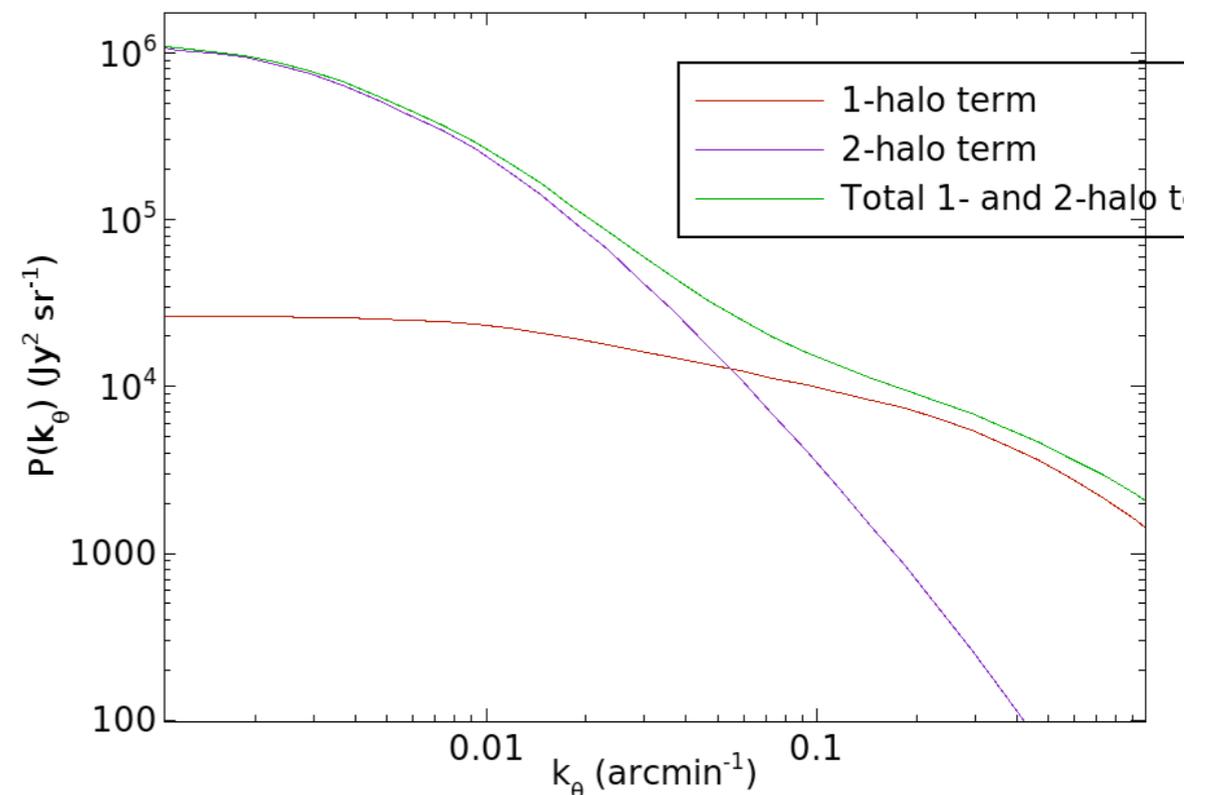
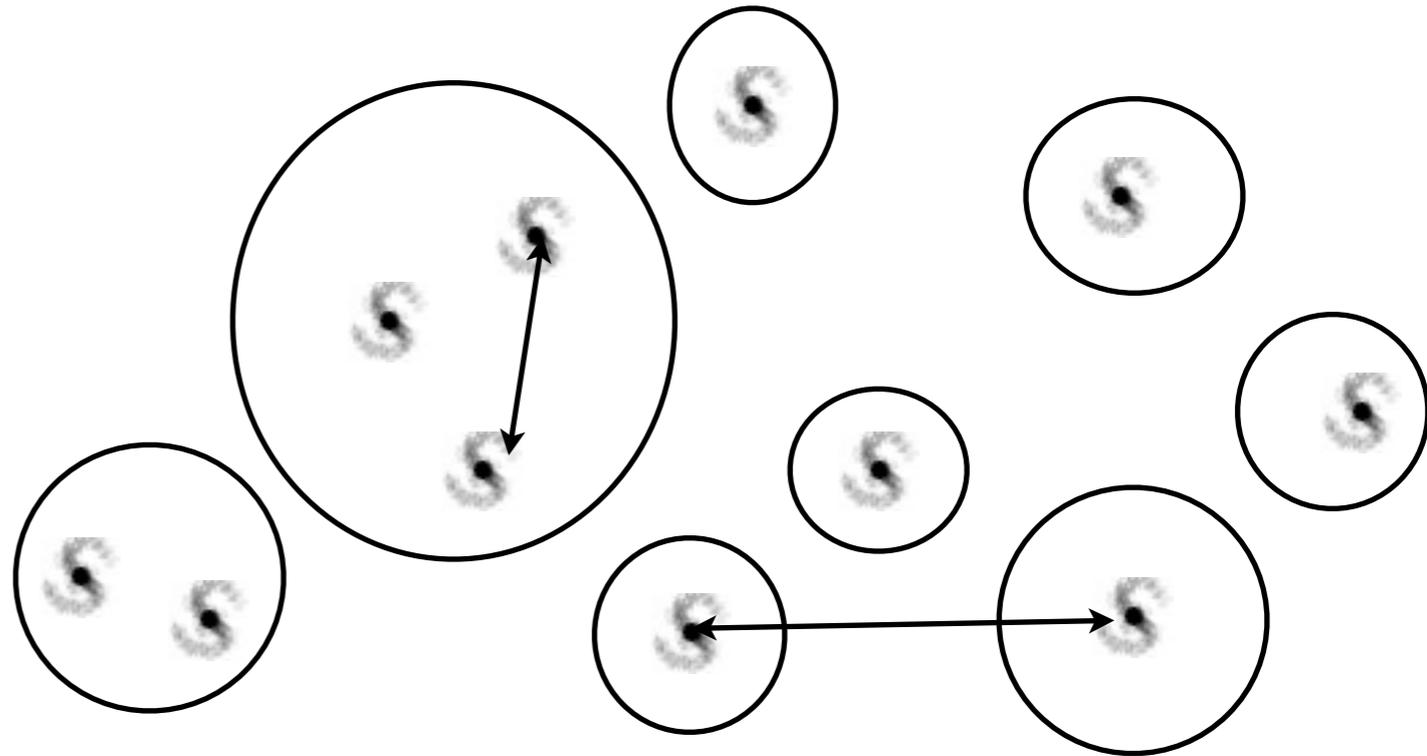
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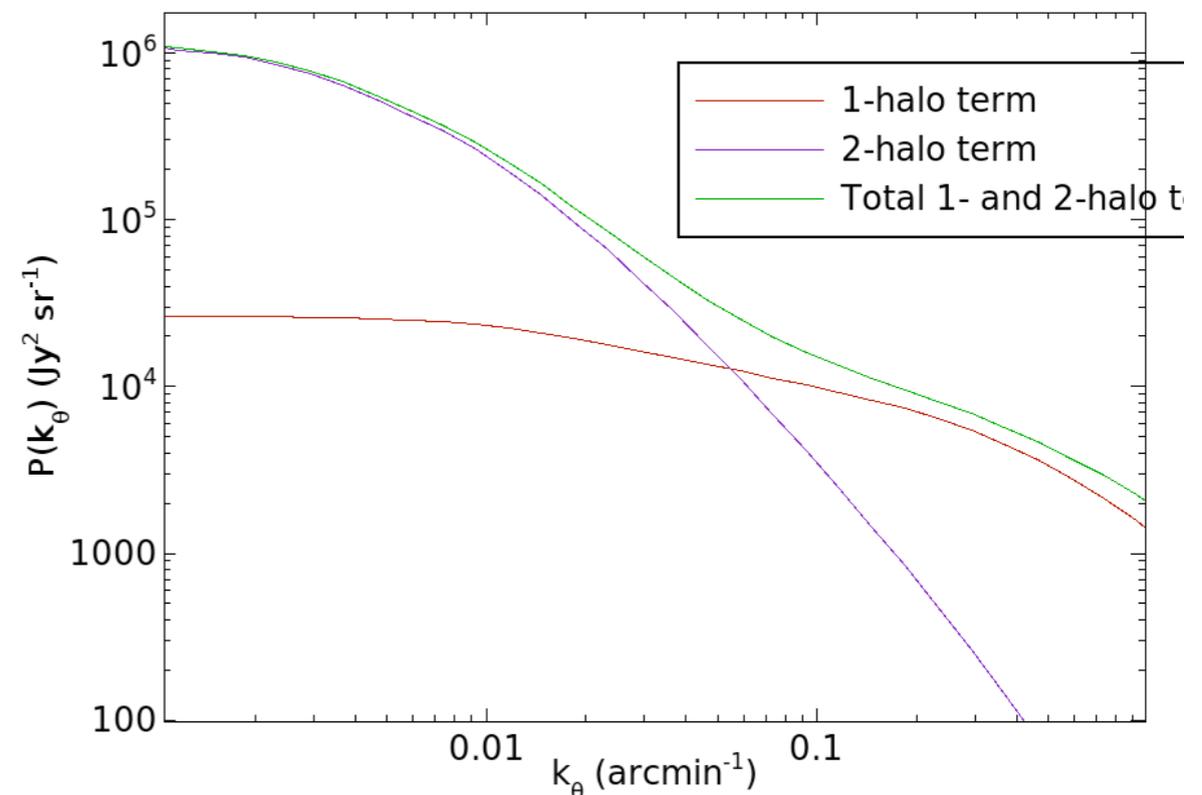
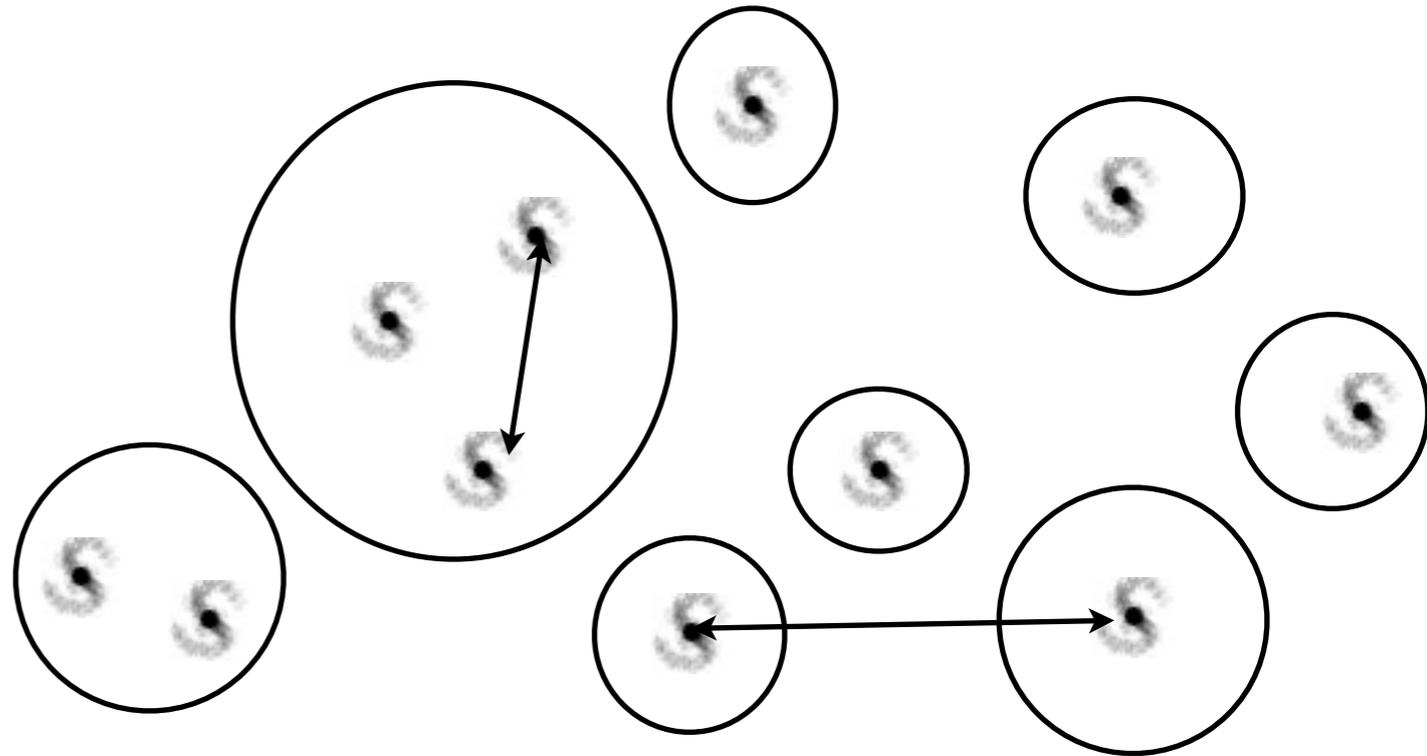
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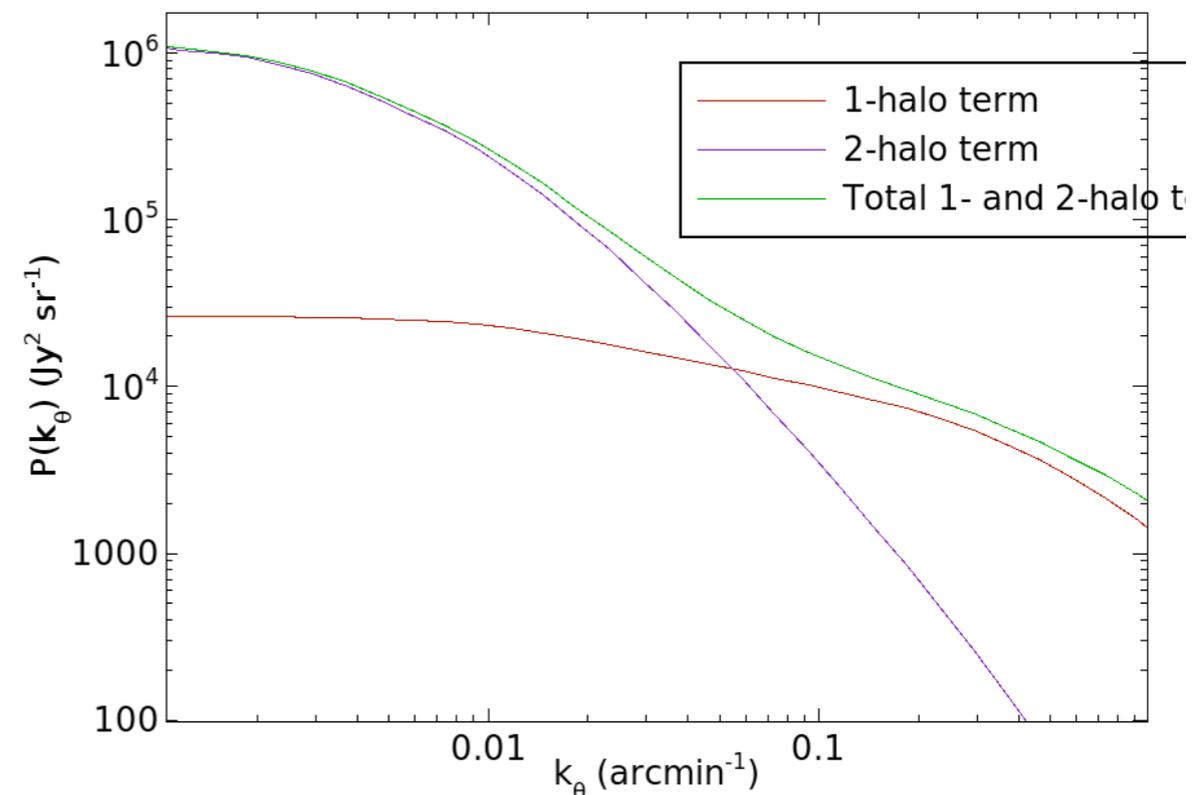
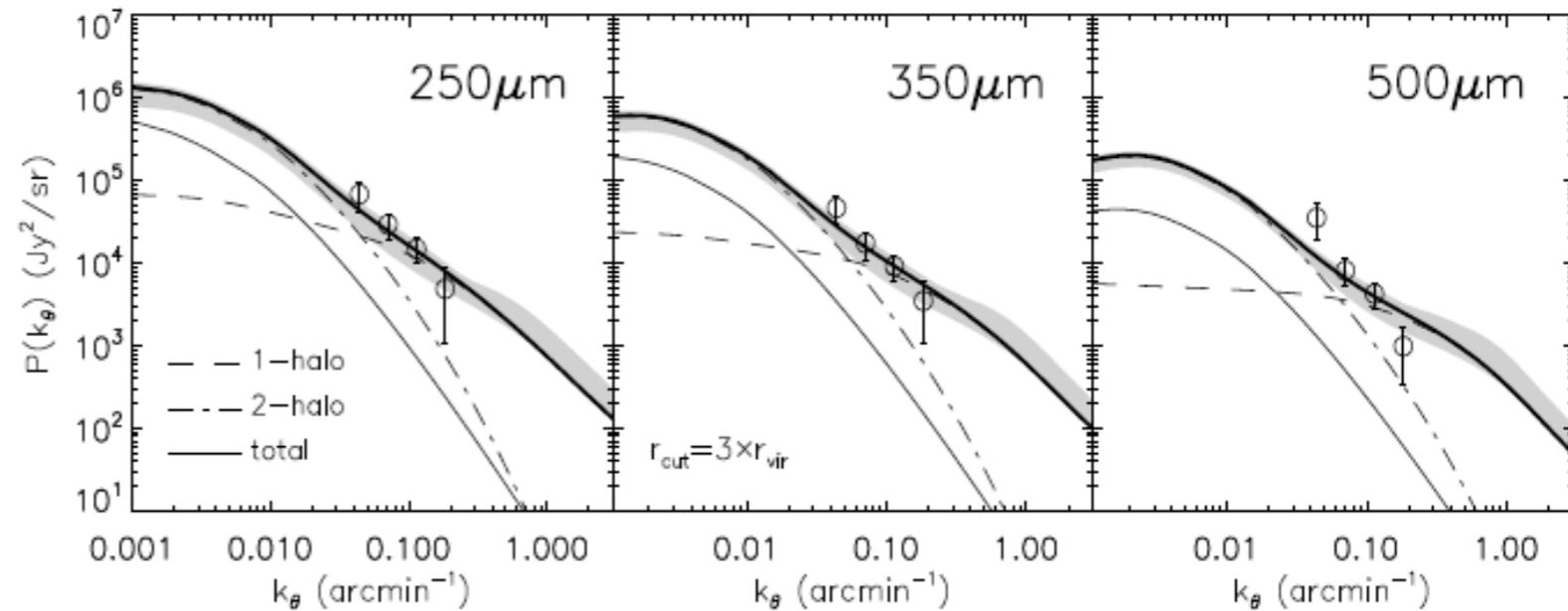
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 - ◉ Model *Must* have a Bump!



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Change the Halos



How to Change Model to Fit Data?

Change the Halos

Change How Galaxies Trace Halos

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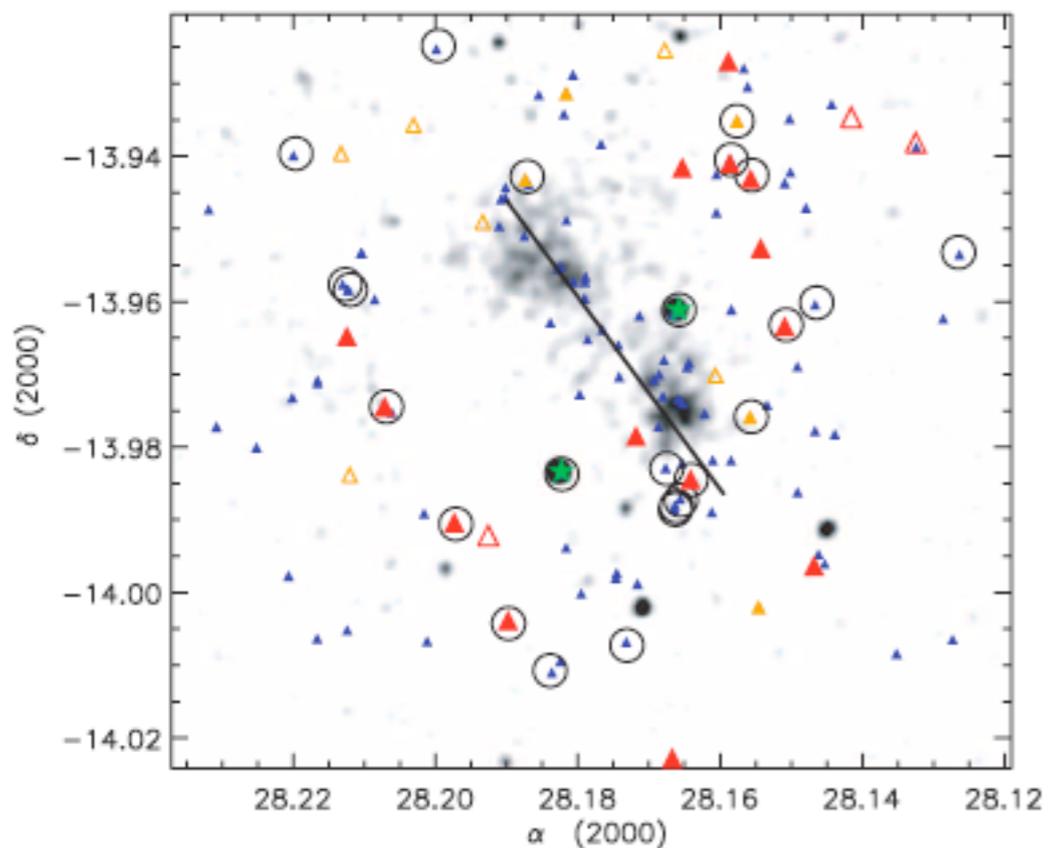
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Marcillac et al. 2007

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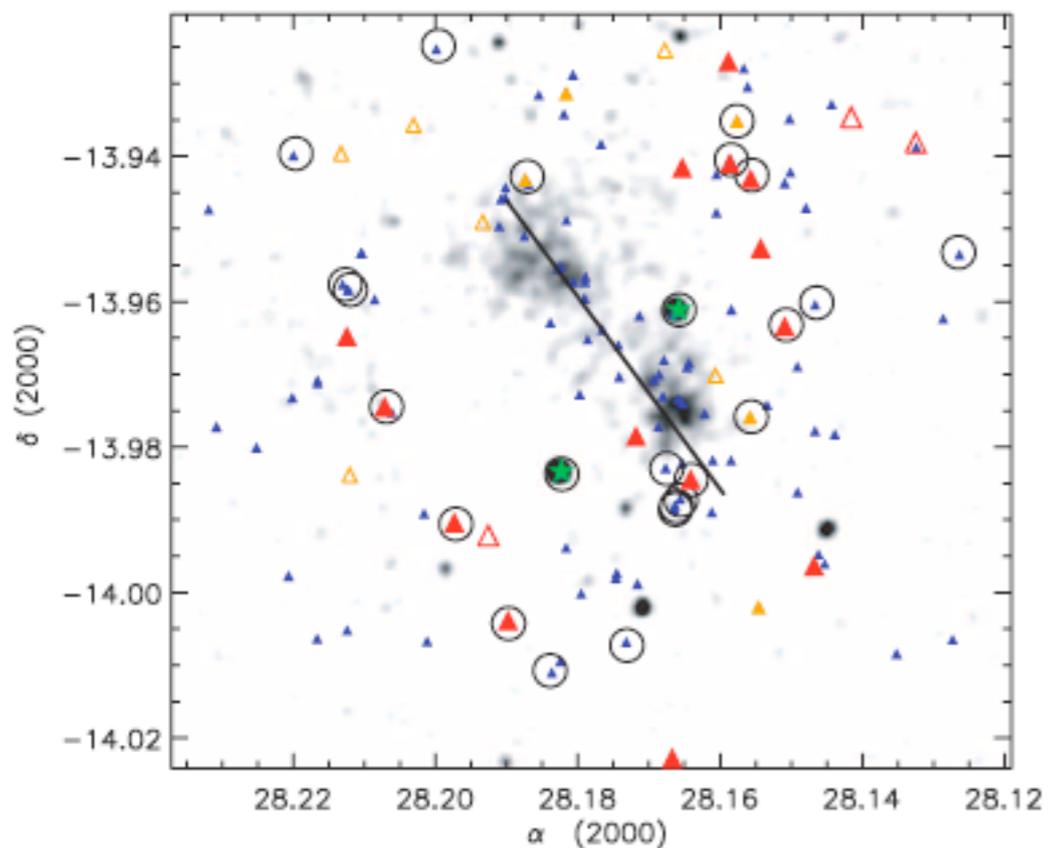
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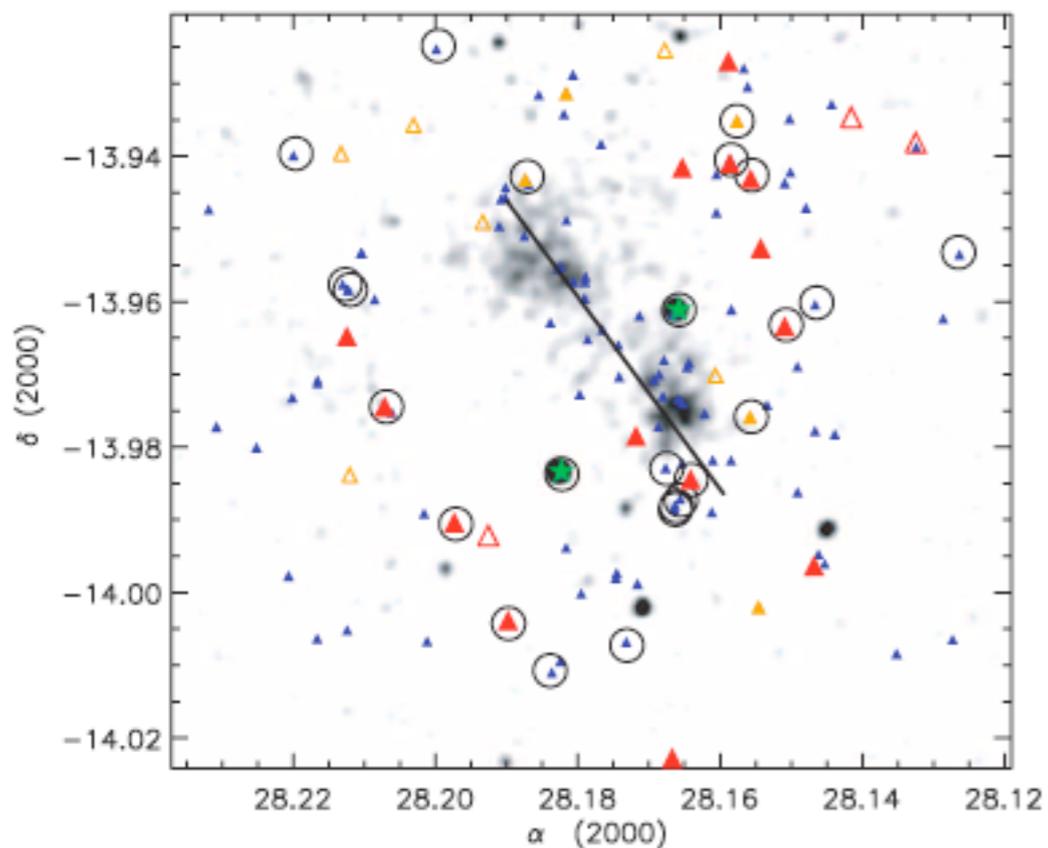
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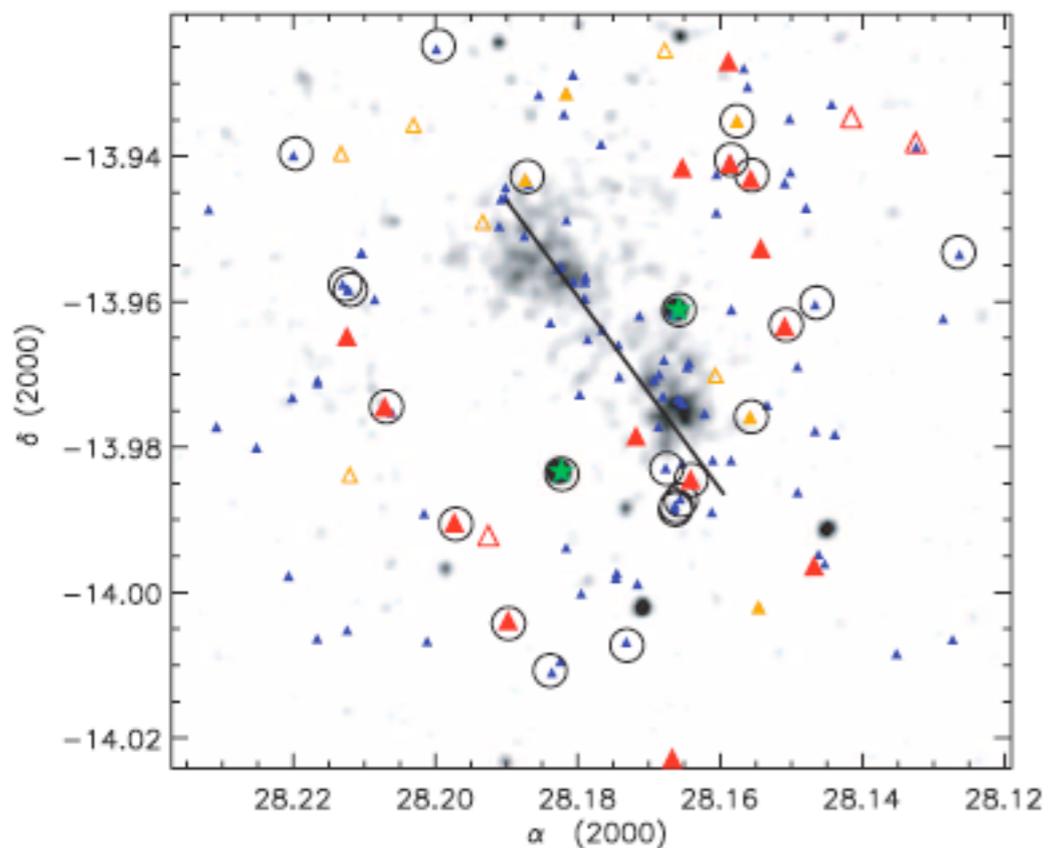
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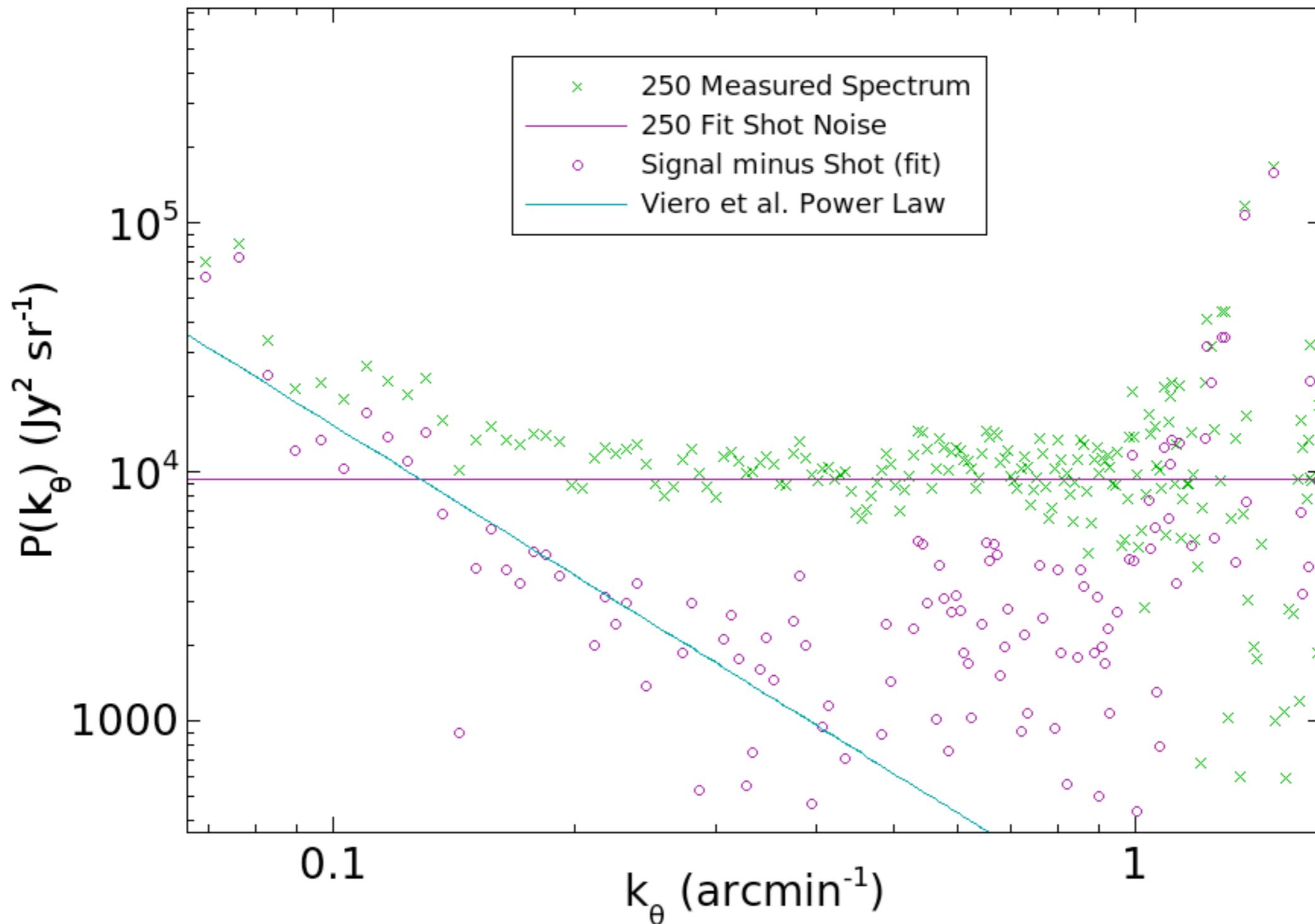
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- It may be that the *environment* influences **where** Star Formation takes place!



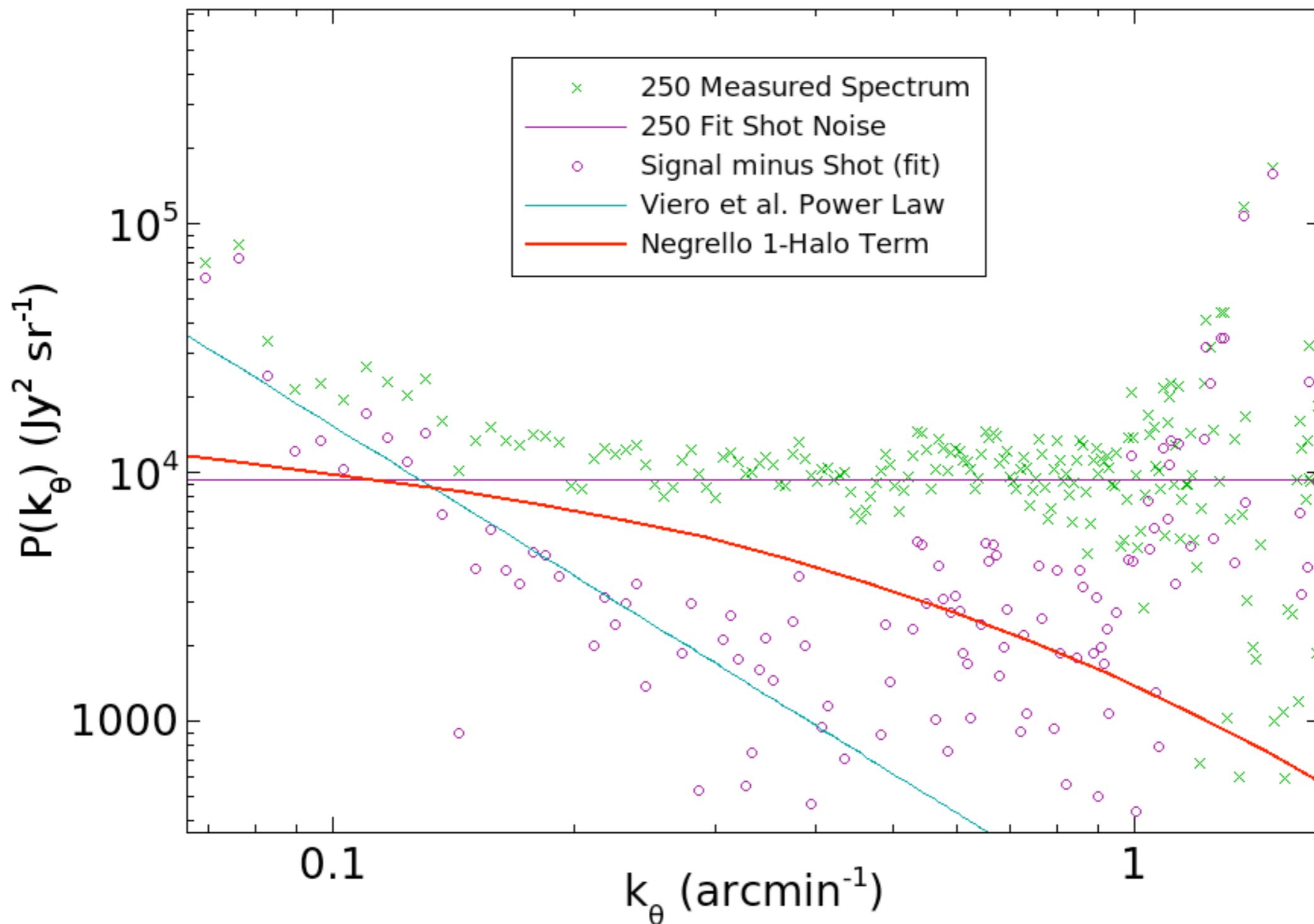
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Shot Noise/1-halo Degeneracy

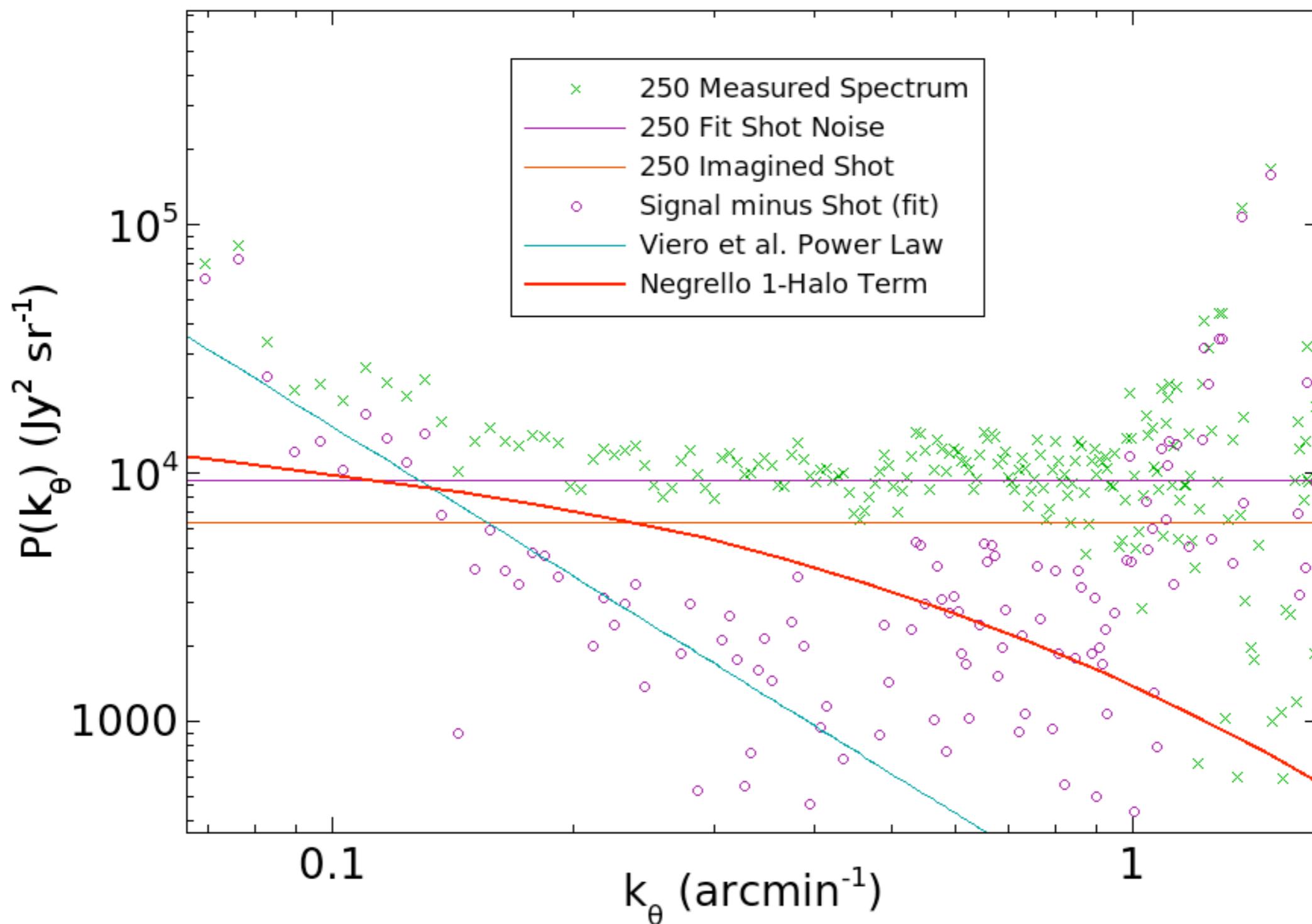
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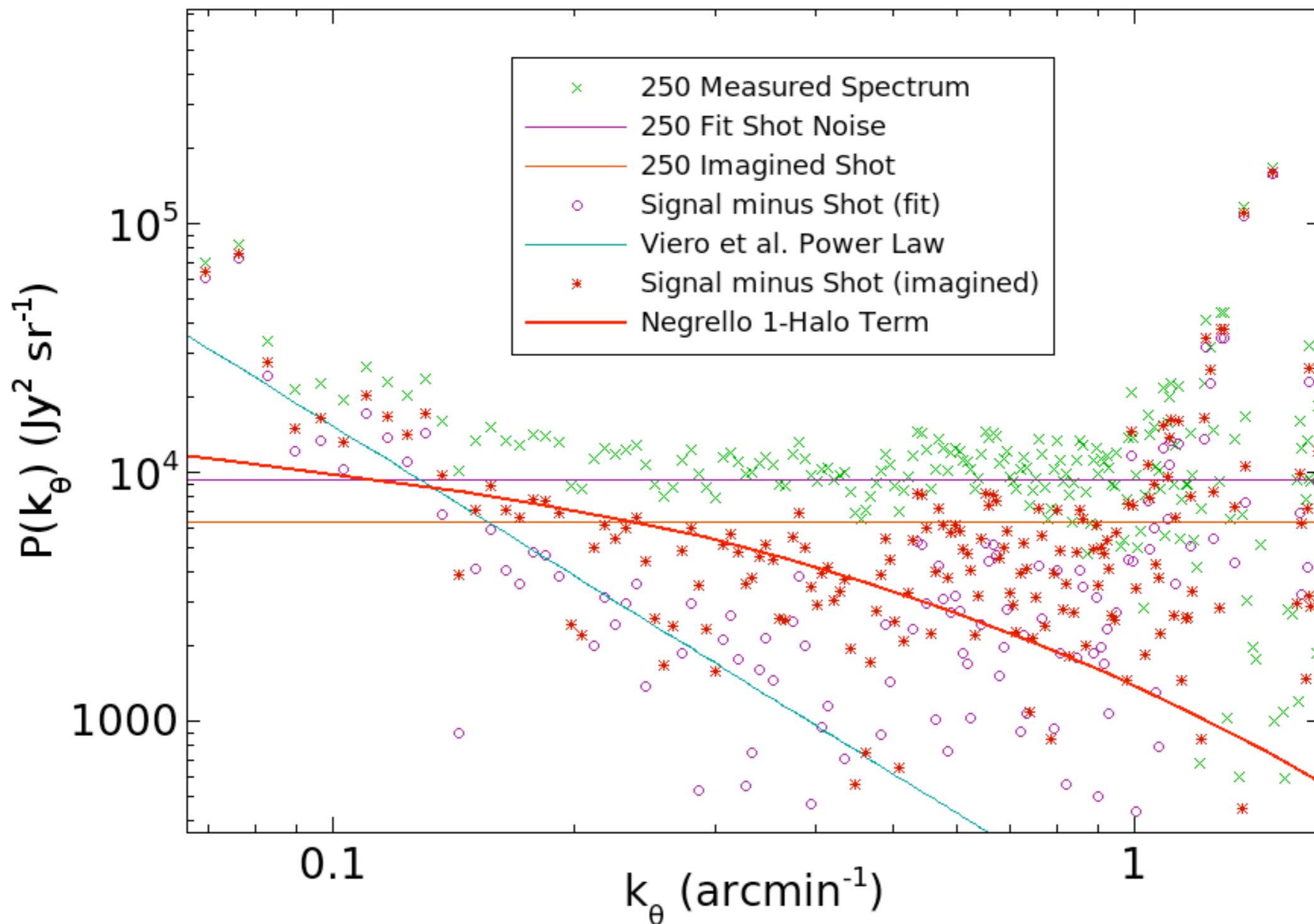
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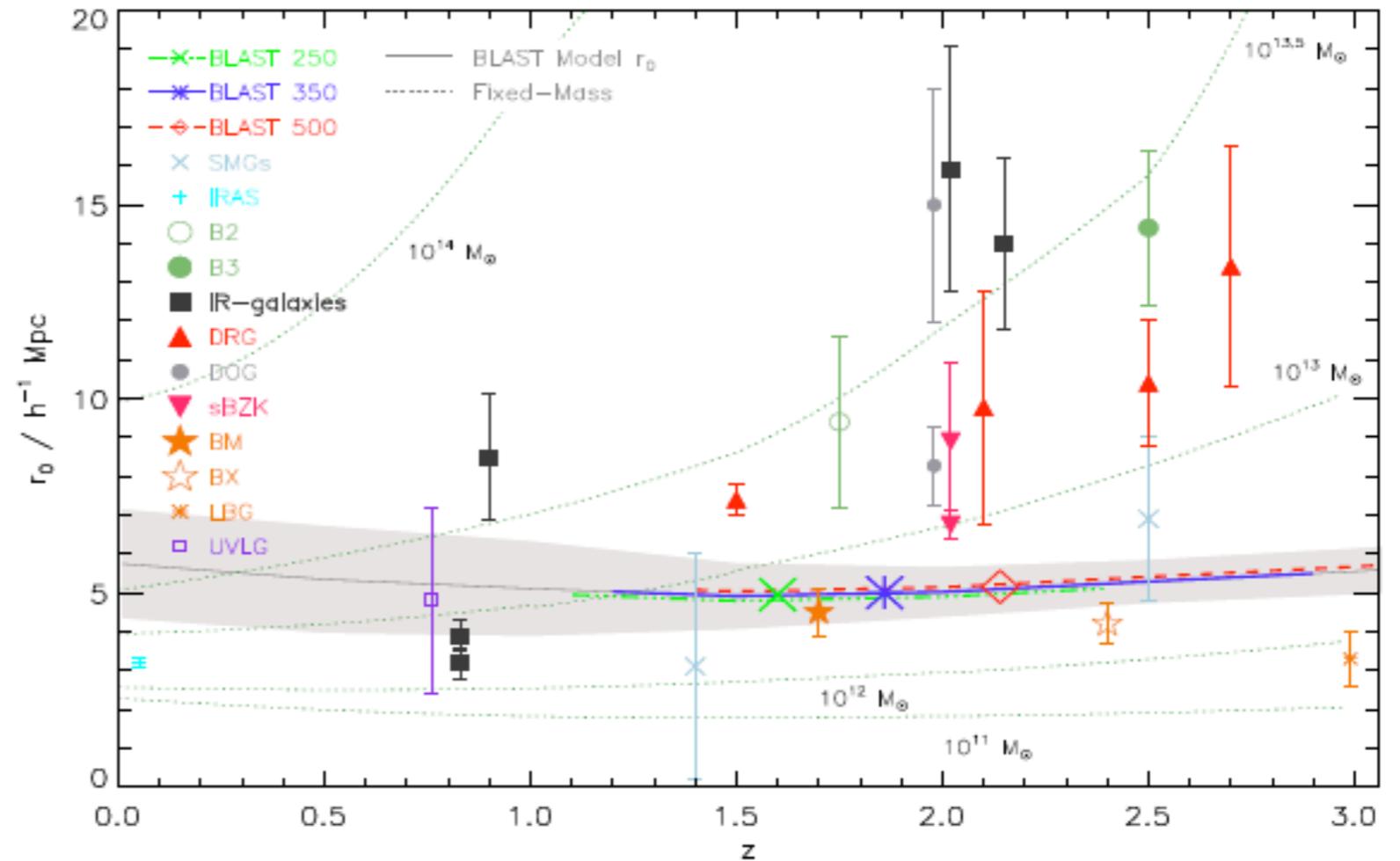
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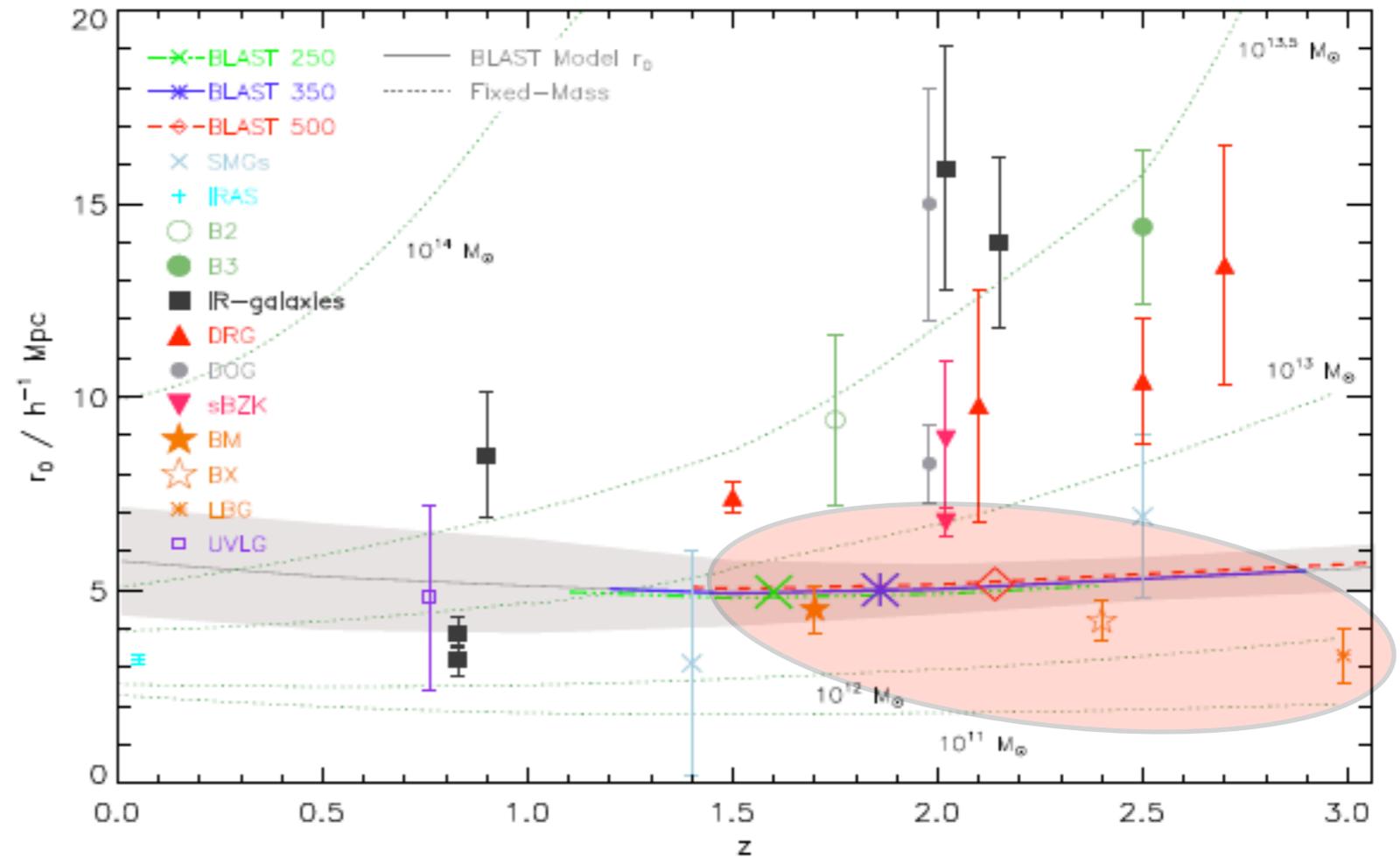
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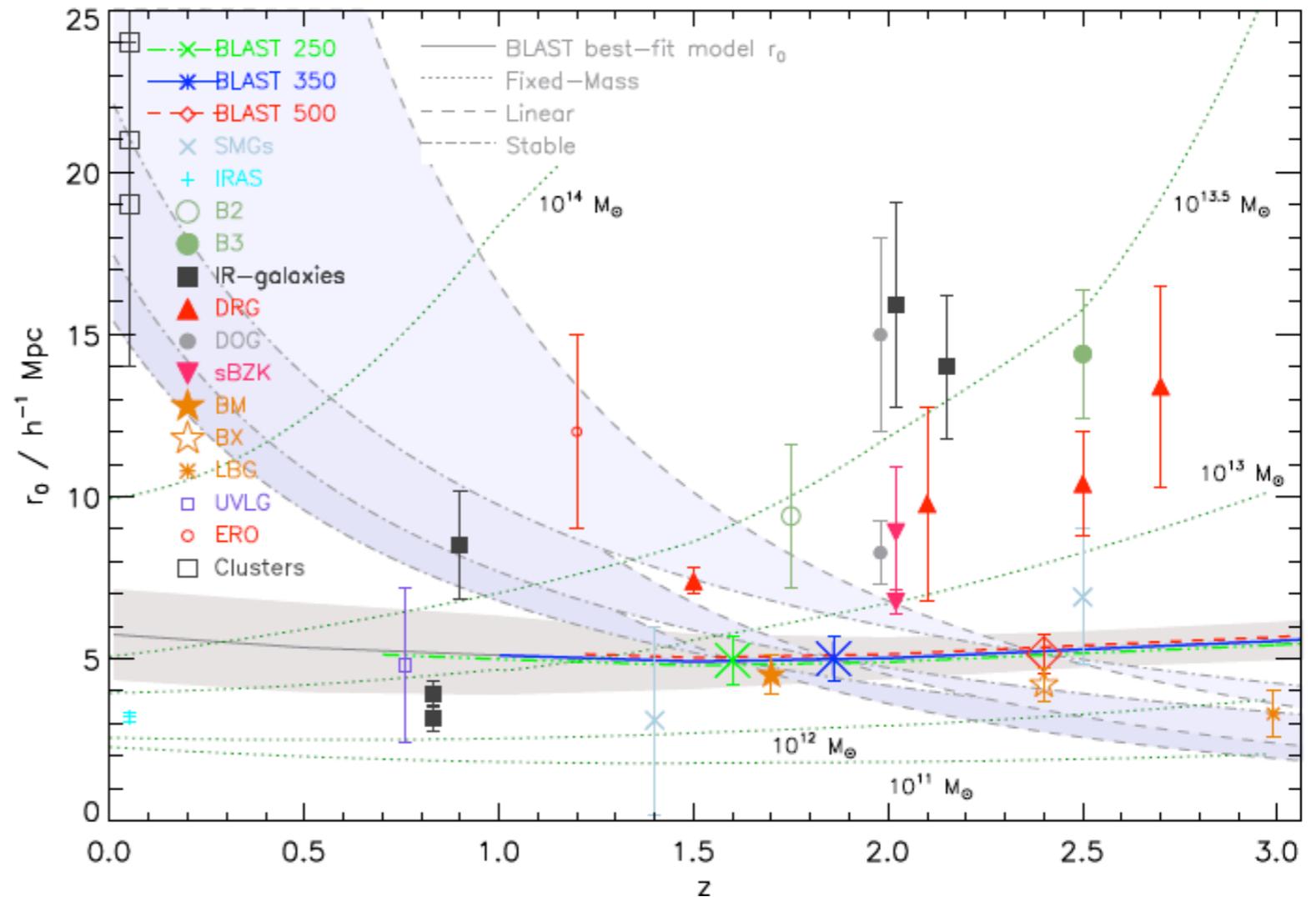
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 - ◉ BLAST, BX/BM and LBGs all seem to have similar clustering properties
- Clustering Evolution
 - ◉ $\xi(r,z) = (r/r_0)^{-\gamma}(1+z)^{\gamma-(3+\epsilon)}$
 - Stable Clustering $\epsilon = 0$,
 - Linear Clustering $\epsilon = 1$



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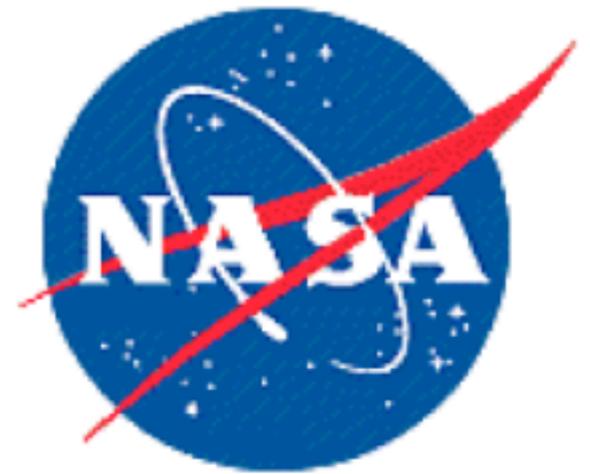
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 - Unbiased way to measure the SFR of a given population
 - ◉ Power Spectrum a natural way to measure galaxy clustering in confused maps
 - BLAST clustering on small scales may indicate dusty star-forming galaxies do not trace halos in a simple way, which may be due to environmental effects in large halos



Science & Technology
Facilities Council



BLAST

Balloon-borne Large-Aperture Sub-millimeter Telescope



NSERC
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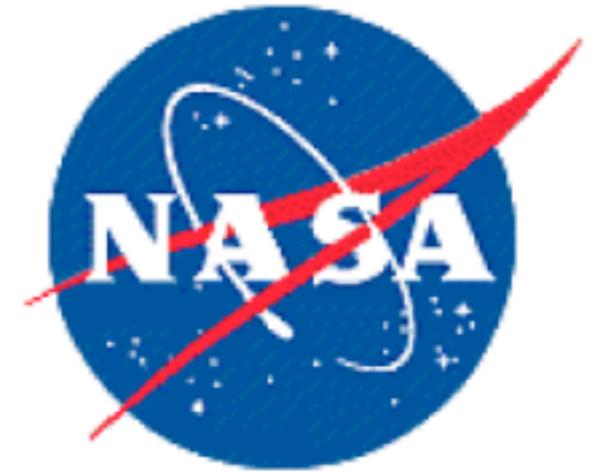
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