

Lessons Learned From BLAST



marco viero / university of toronto

BLAST TEAM



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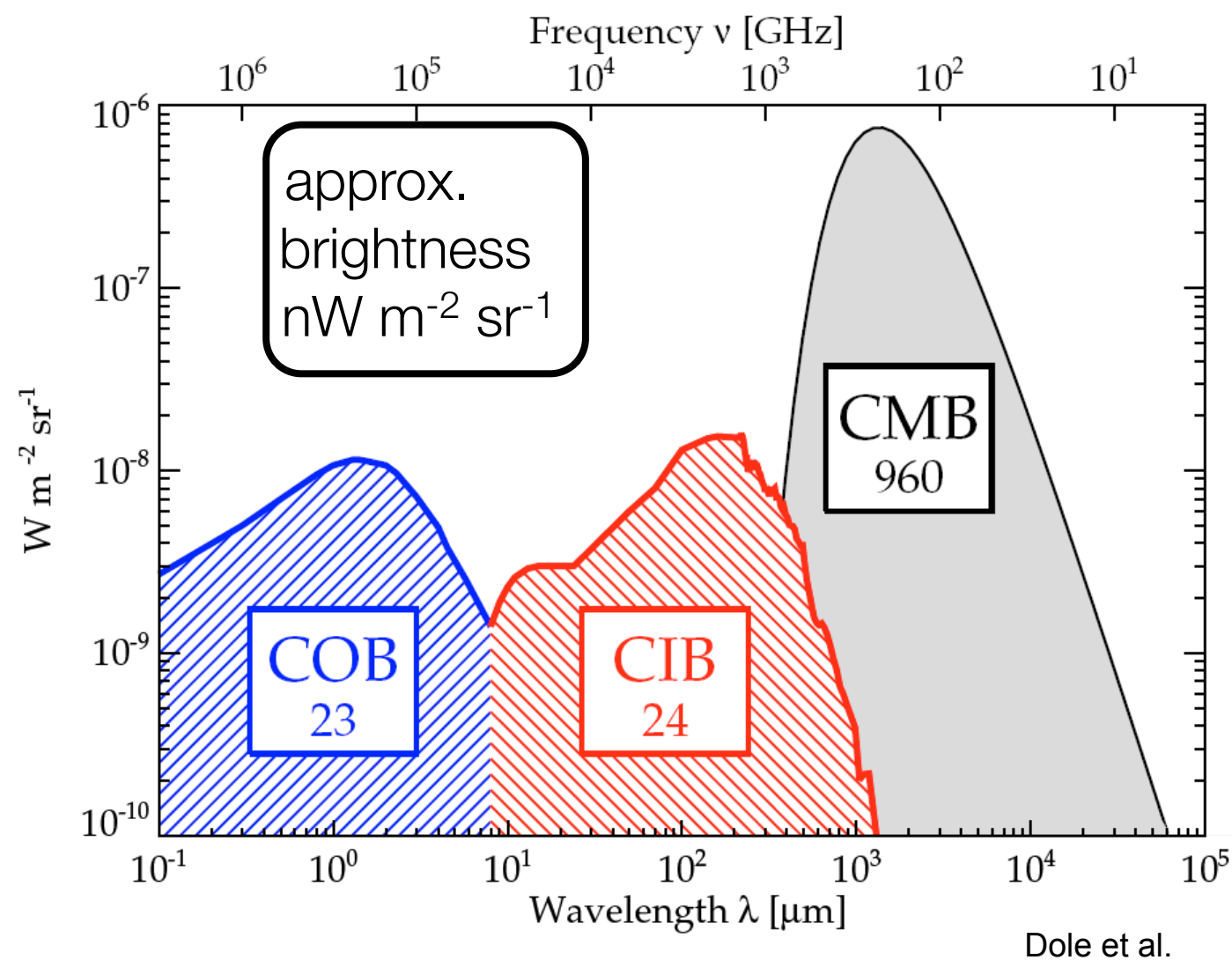
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Luca Olmi

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

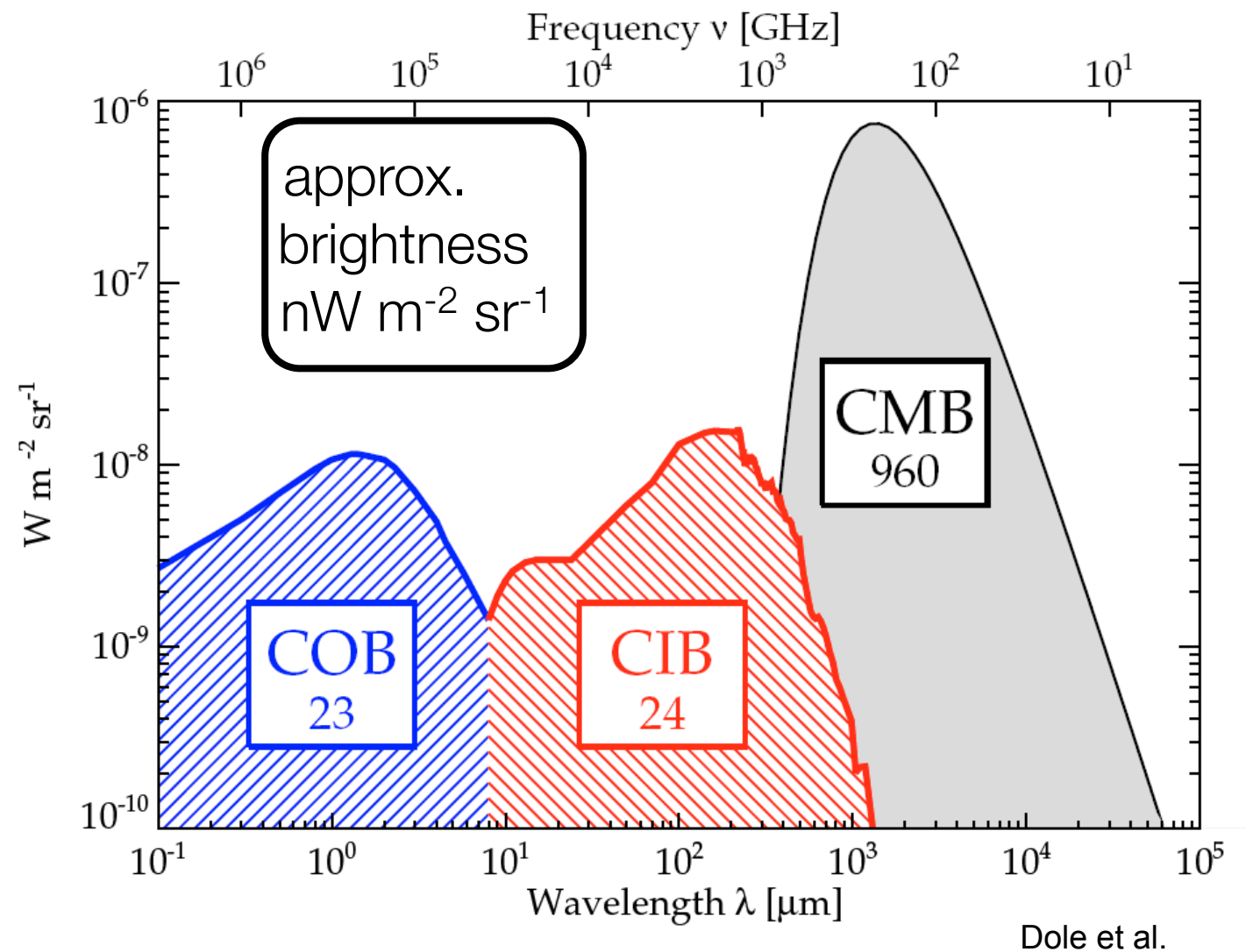
Open
University
Mattia Negrello

Why IR?



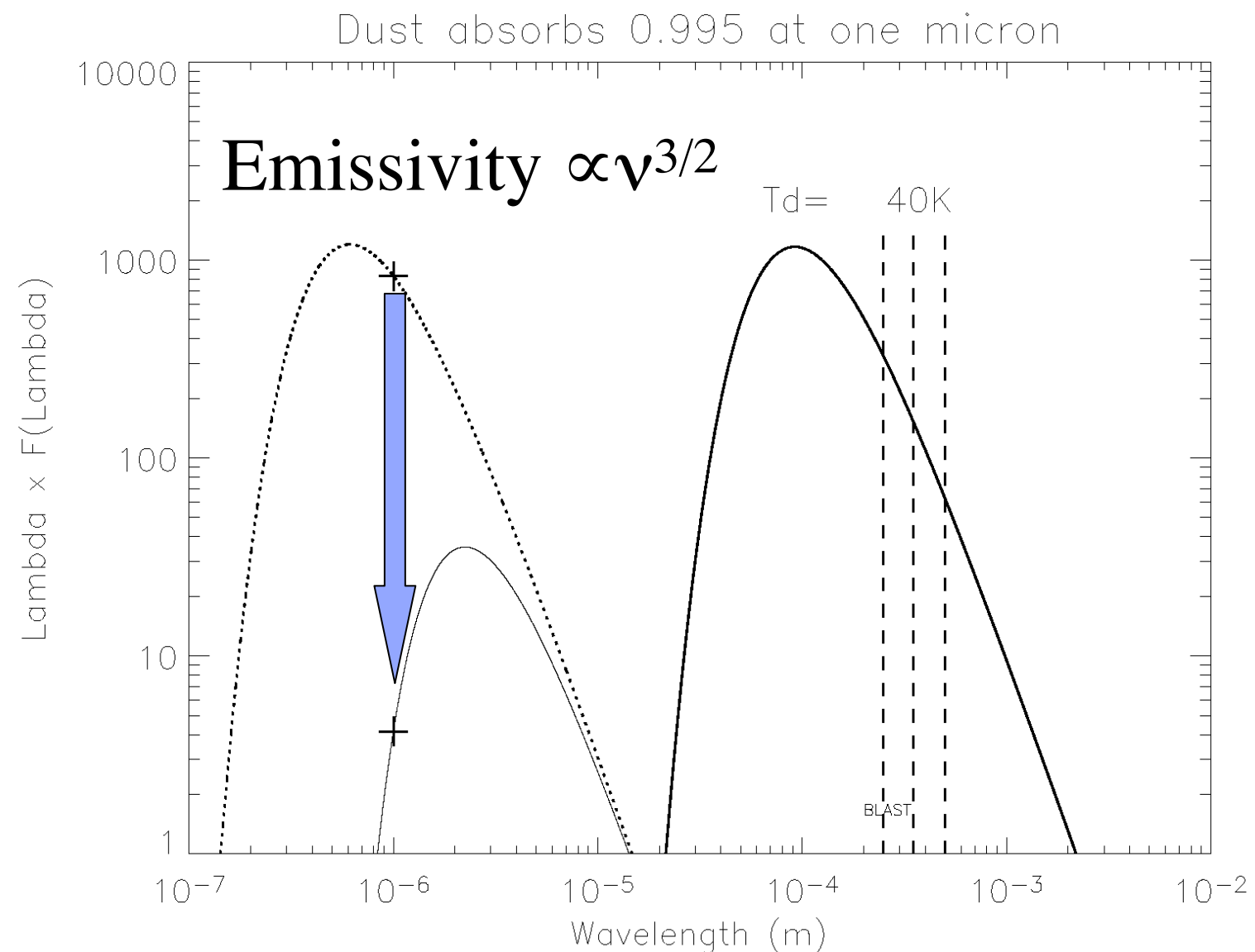
Why IR?

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



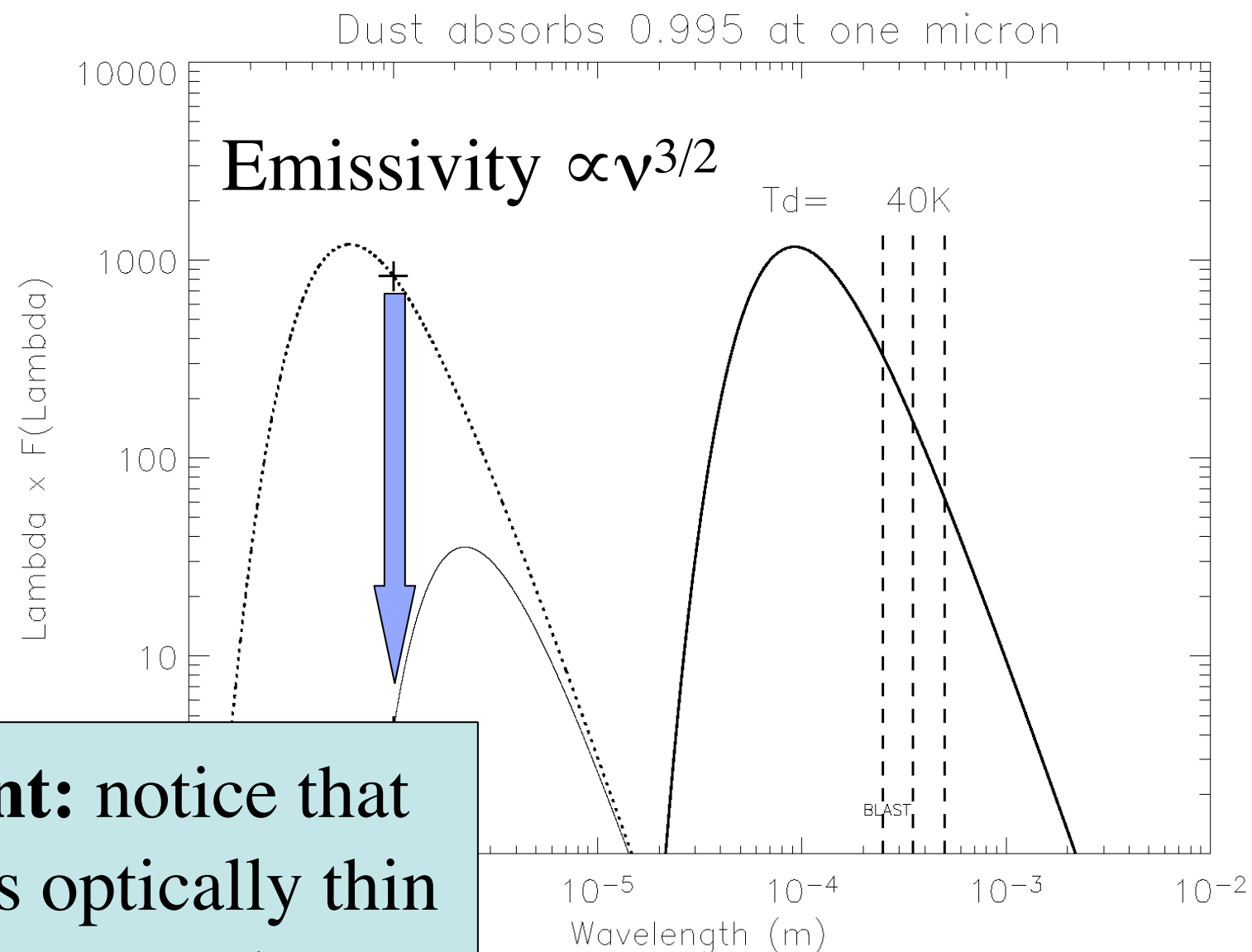
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- Dust is particularly efficient at absorbing UV light, originating largely from young, hot, short-lived stars, thus is sensitive to star-formation



Why IR?

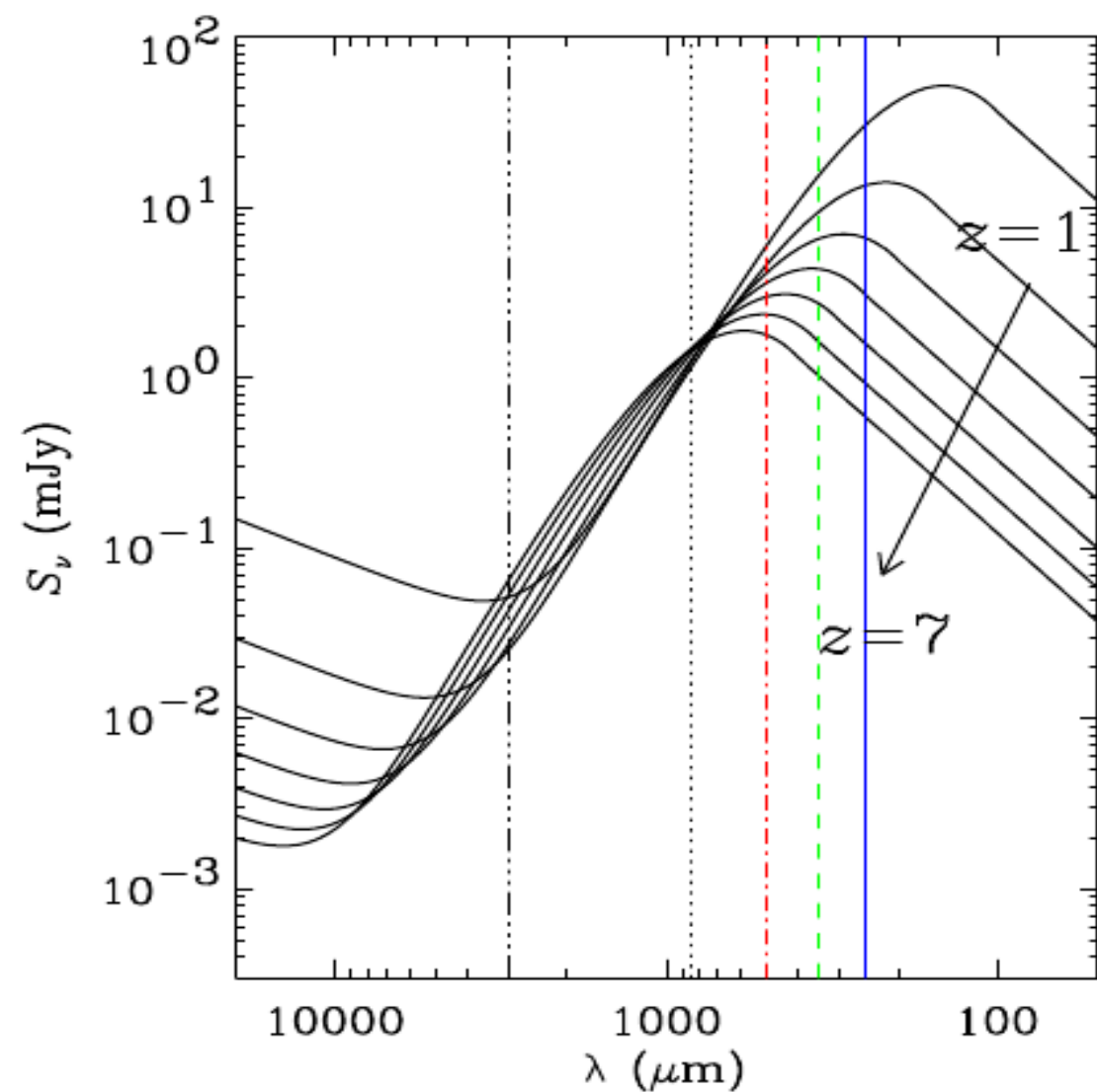
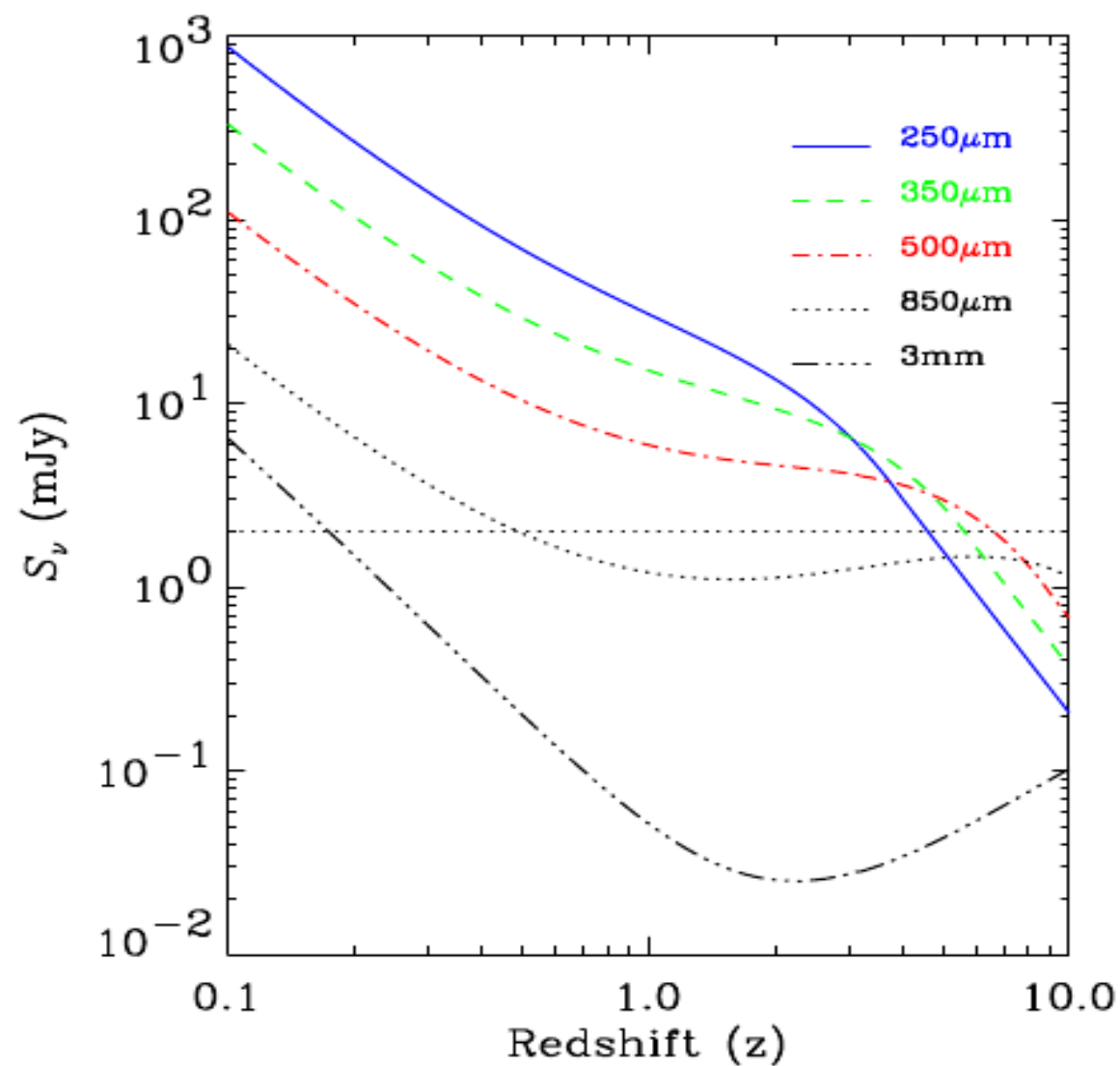
- Half of all light emitted by stars is absorbed and reradiated in the IR
- Dust is particularly efficient at absorbing UV light, originating largely from young, hot, short-lived stars, thus is sensitive to star-formation
- Dust emission is an unbiased measure of star-formation because it is optically thin at IR wavelengths



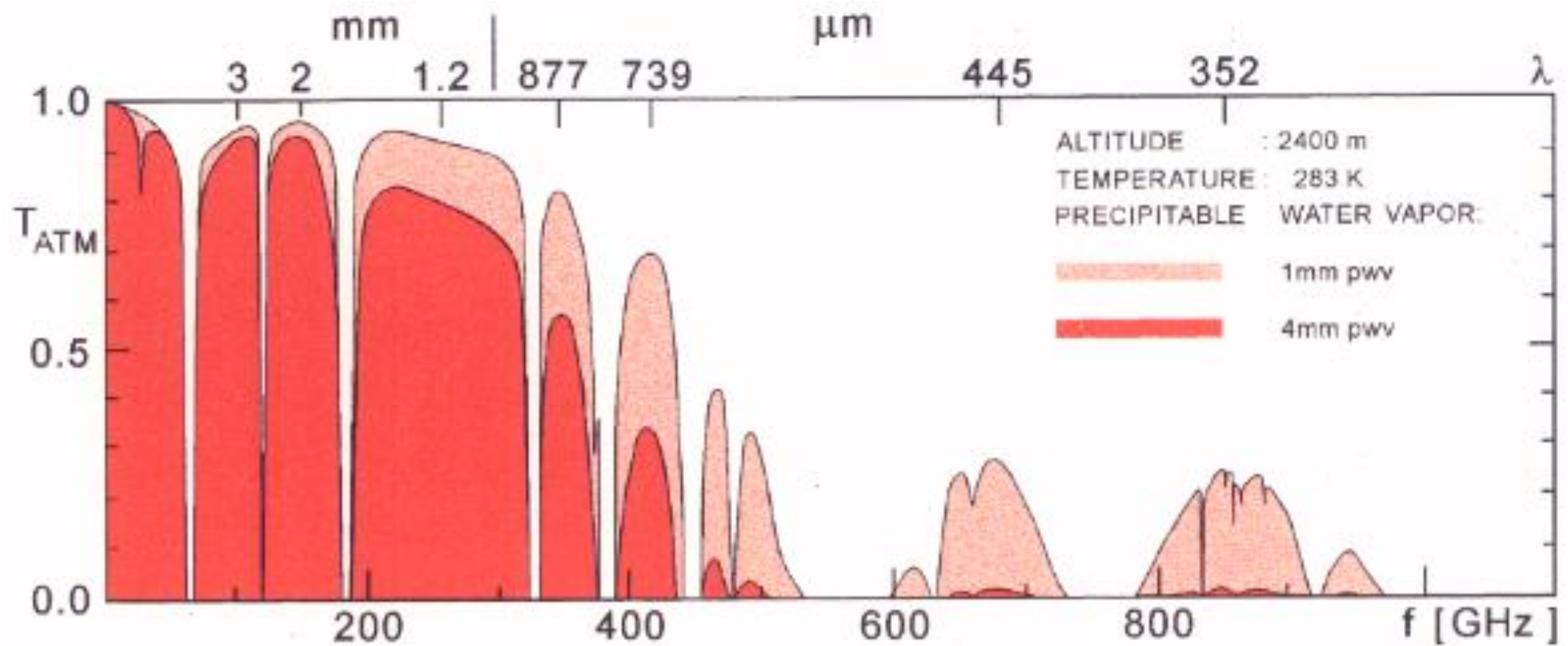
Important: notice that the dust is optically thin by 10 microns. The mm emission is proportional to the total dust mass.

Why IR?

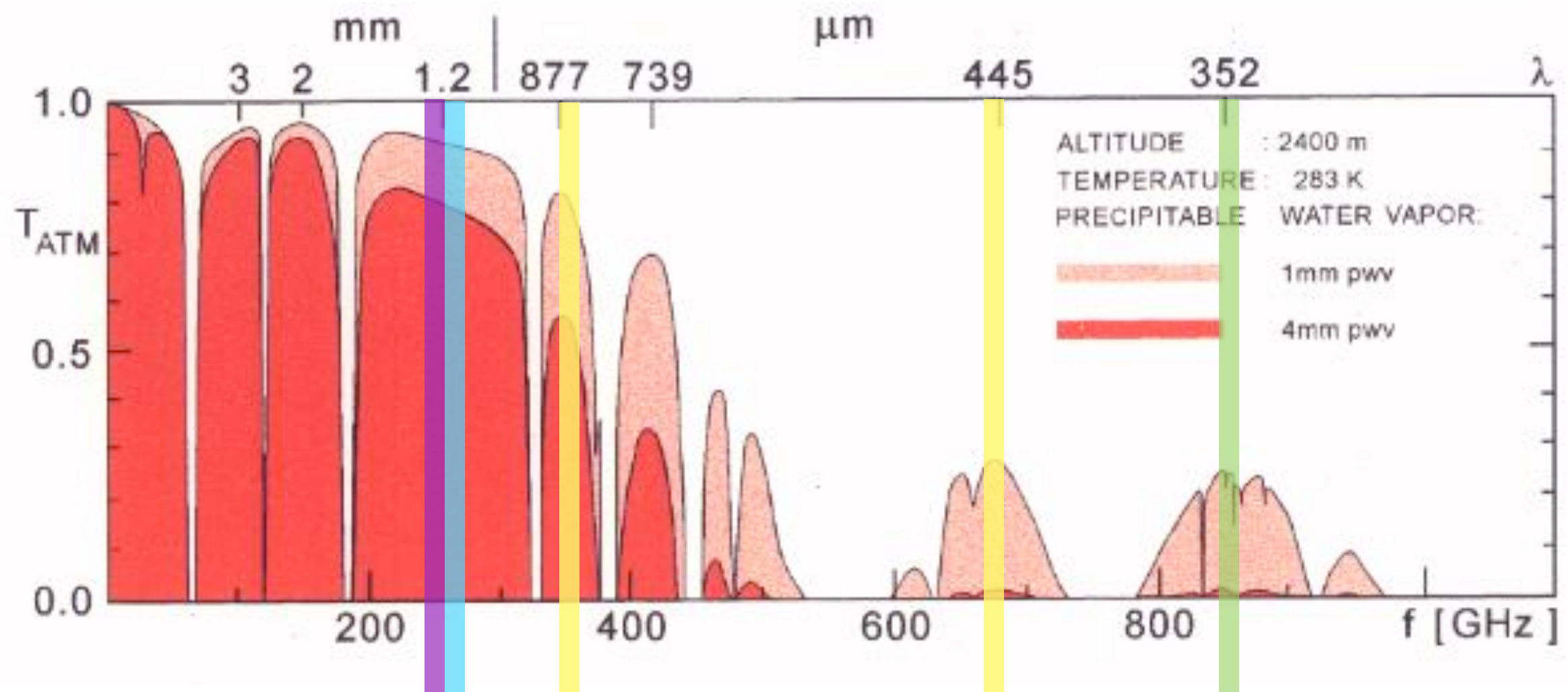
- Longer wavelengths more sensitive to higher redshift due to negative K-correction



But....



But....

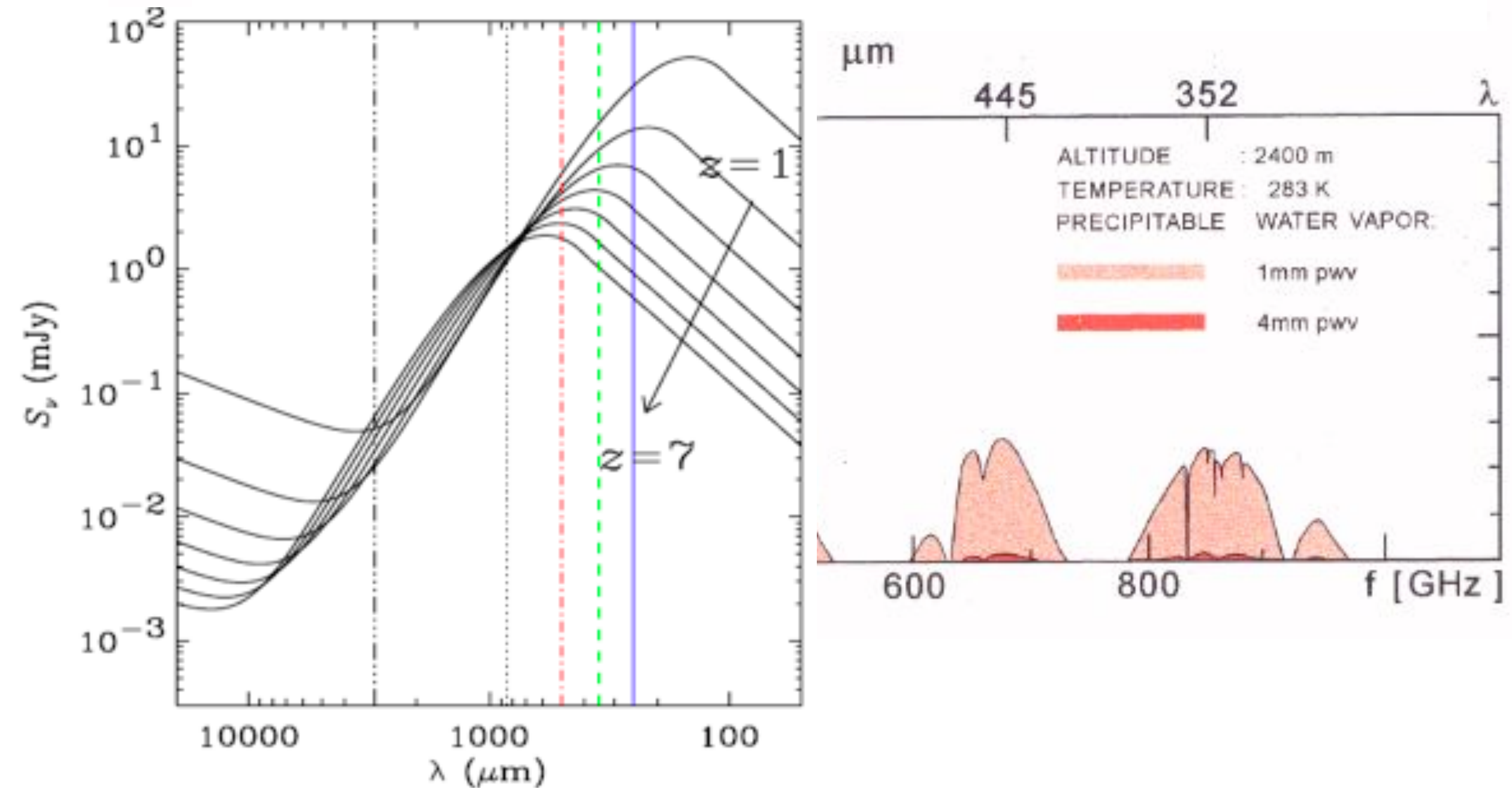


MAMBO
AzTEC

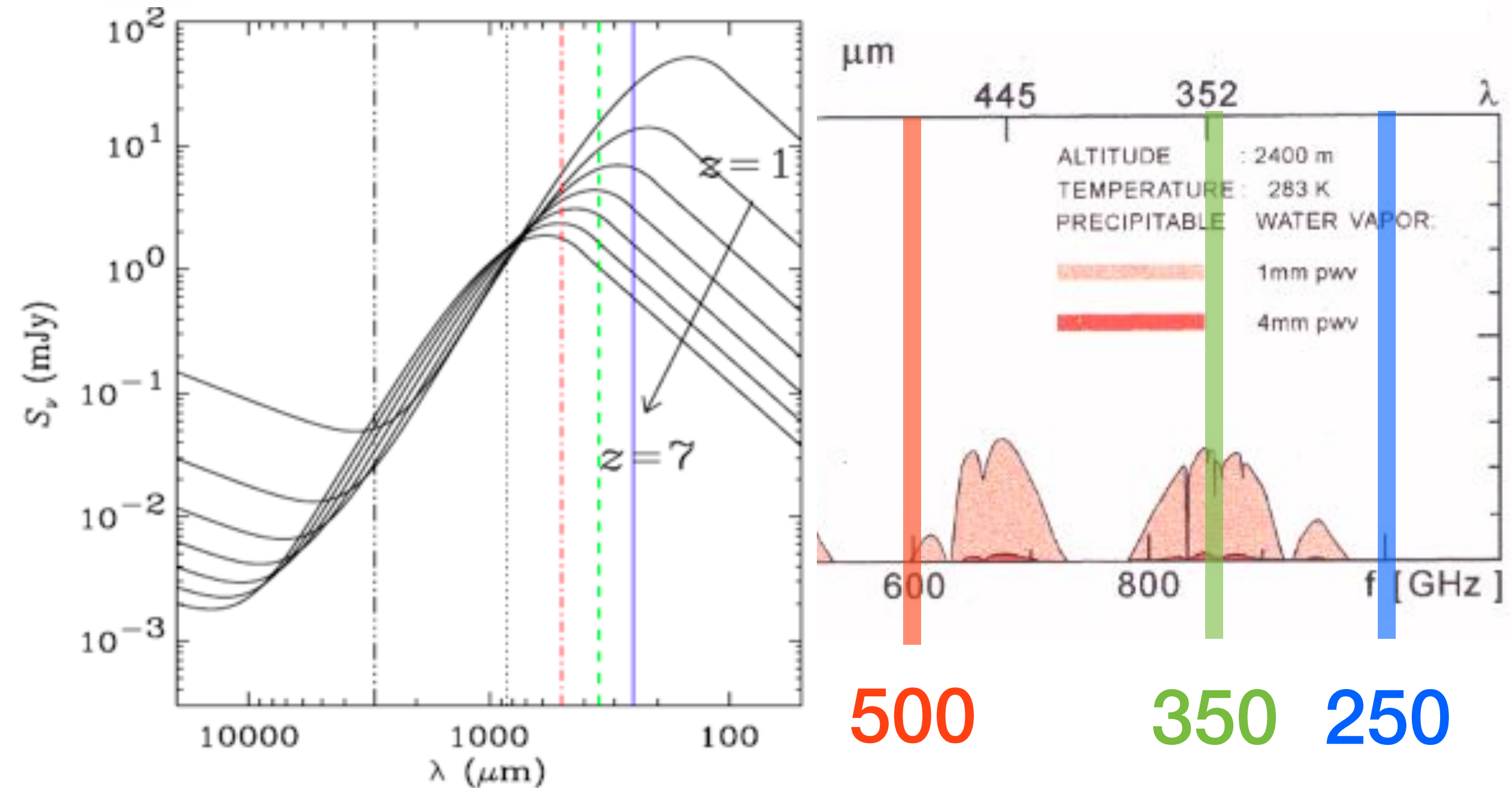
SCUBA

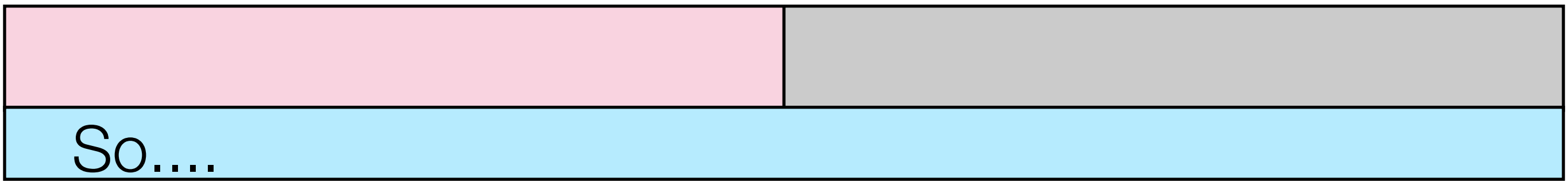
SHARC

But....

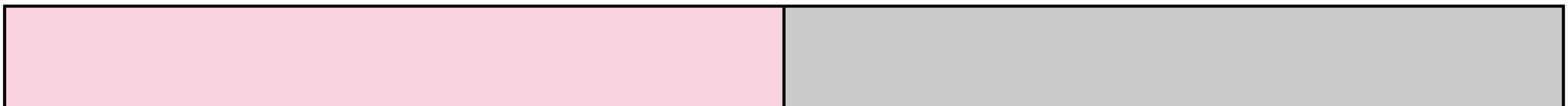


But....





So....



So....

- To get above the atmosphere you can:

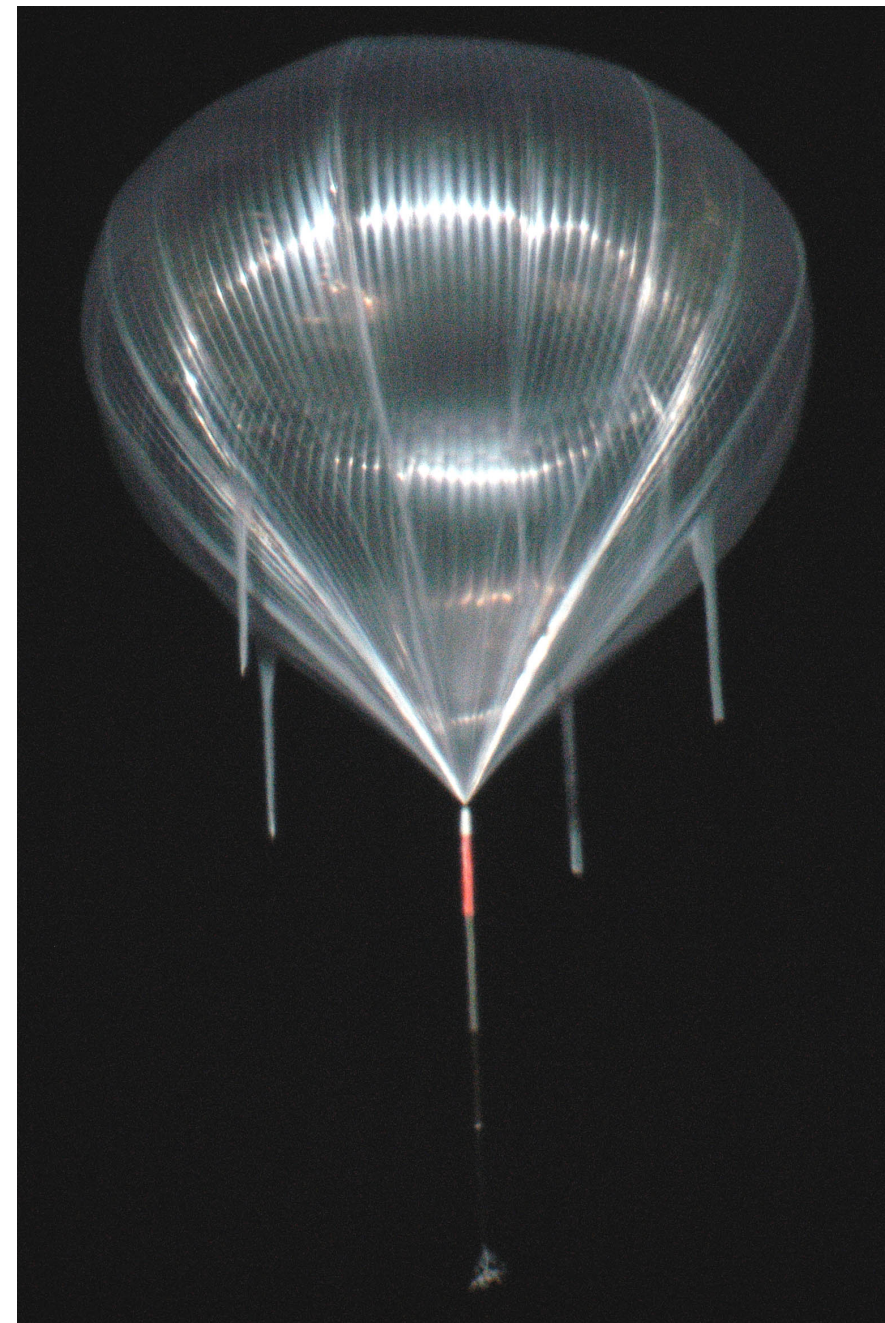
So....

- To get above the atmosphere you can:
 - ◉ Build and launch a satellite
 - Cost ~ billions
 - Timescale ~ 10+ years

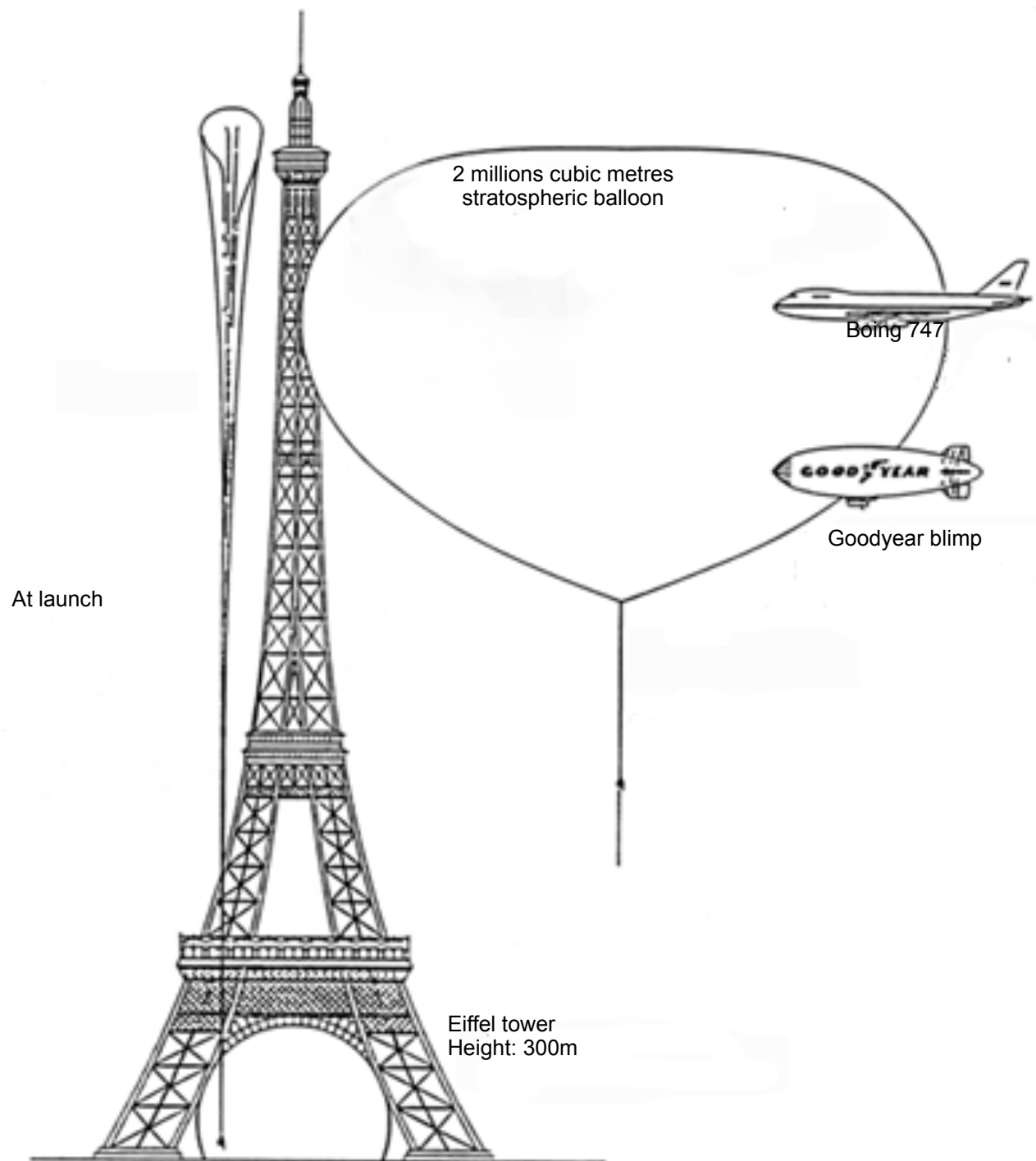


So....

- To get above the atmosphere you can:
 - ◎ Build and launch a satellite
 - Cost ~ billions
 - Timescale ~ 10+ years
 - ◎ Build and fly a balloon-born telescope
 - Cost ~ millions
 - Timescale ~ 5'ish years
 - Train Students to boot!

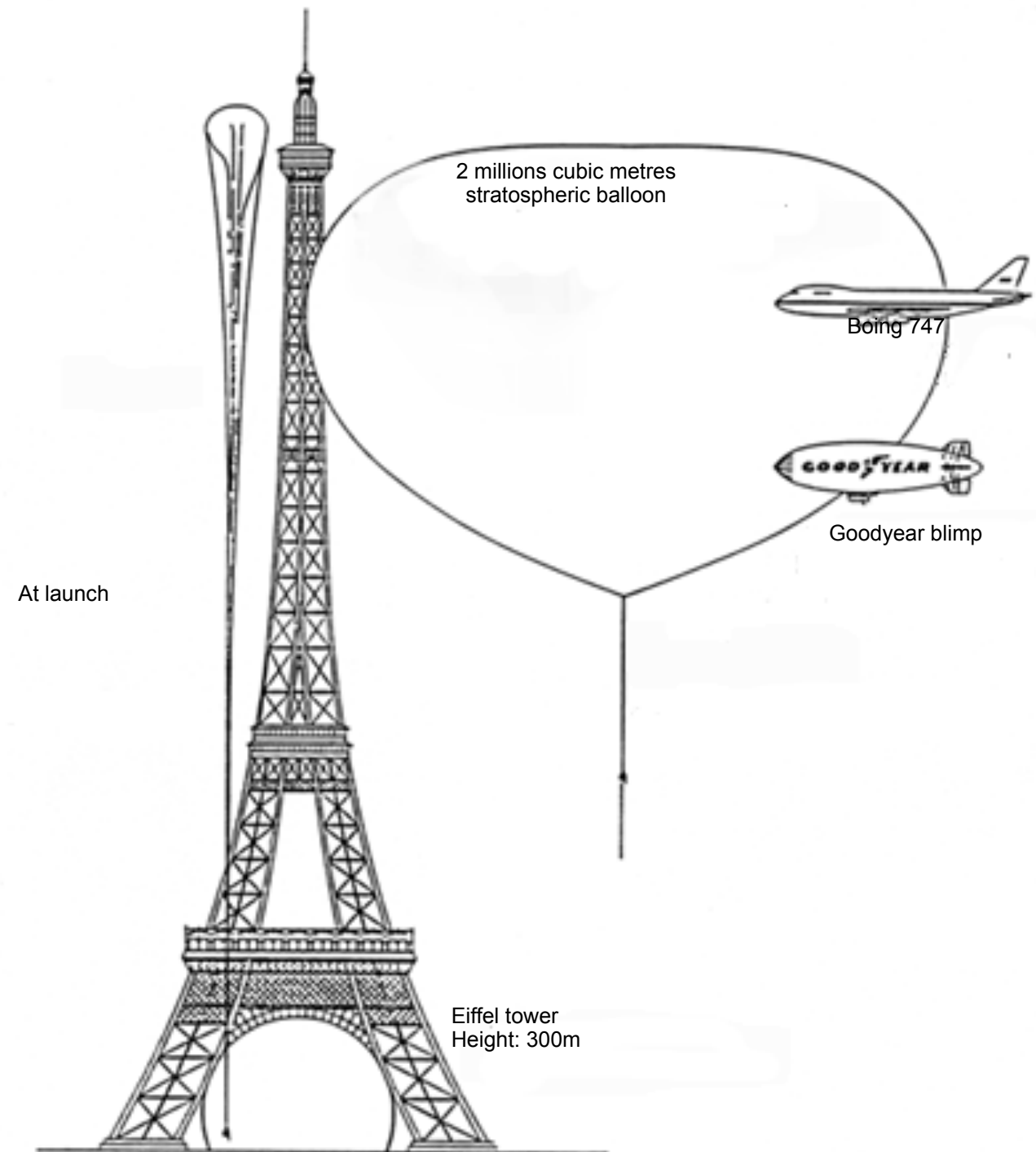


The Balloon-born Platform



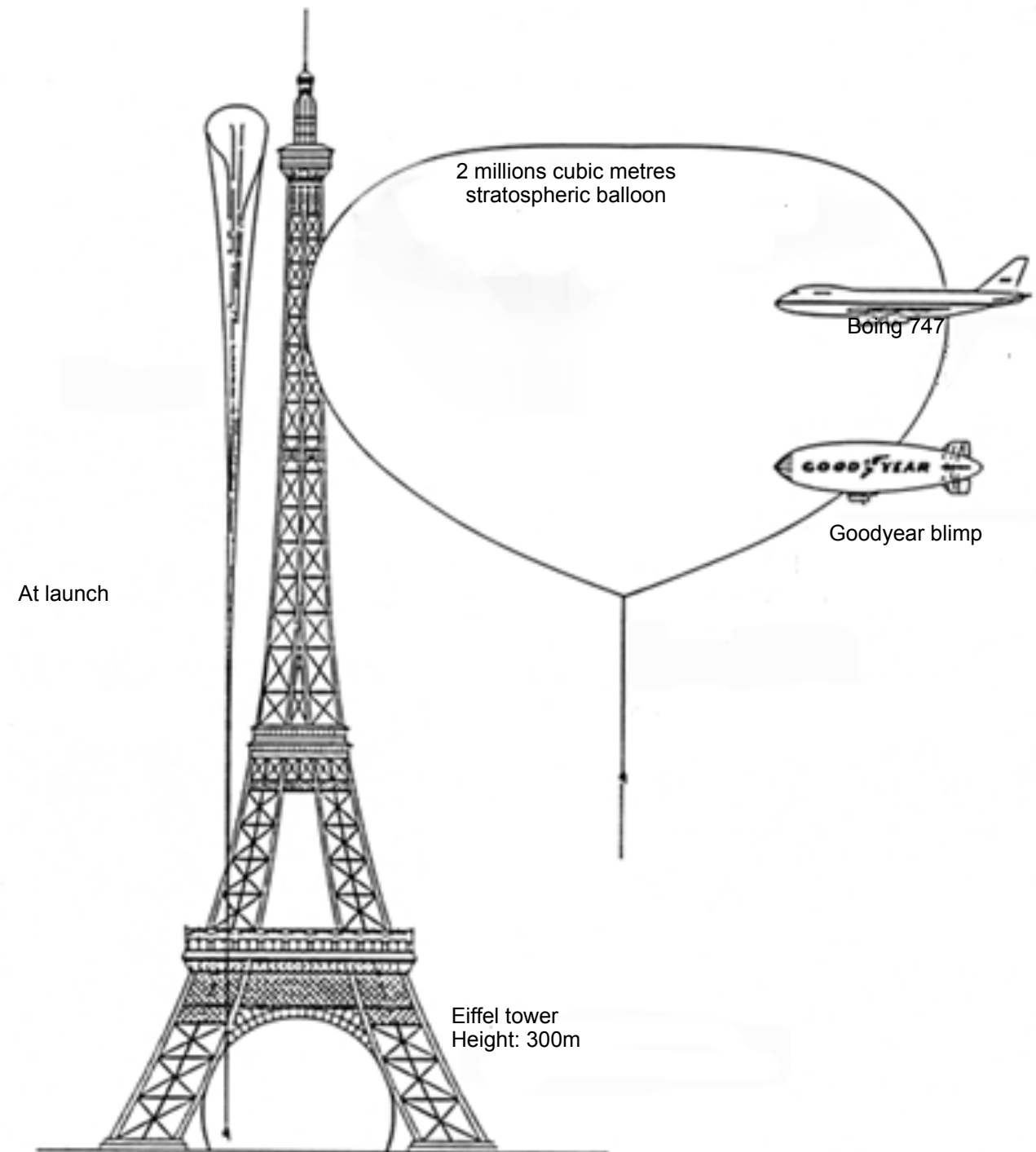
The Balloon-born Platform

- Weights about the same as a pickup truck (~ a few thousand kg)
 - ◉ Need a BIG balloon!



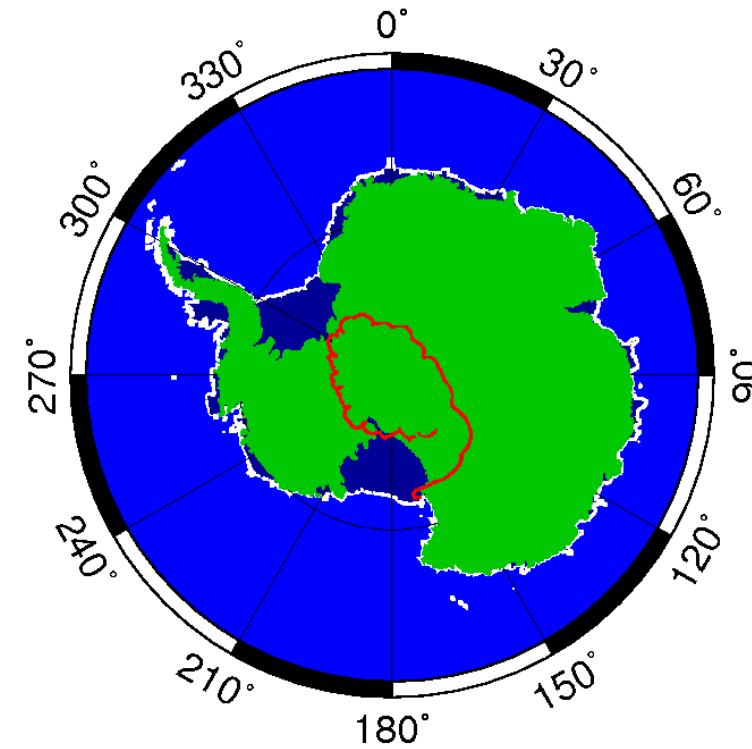
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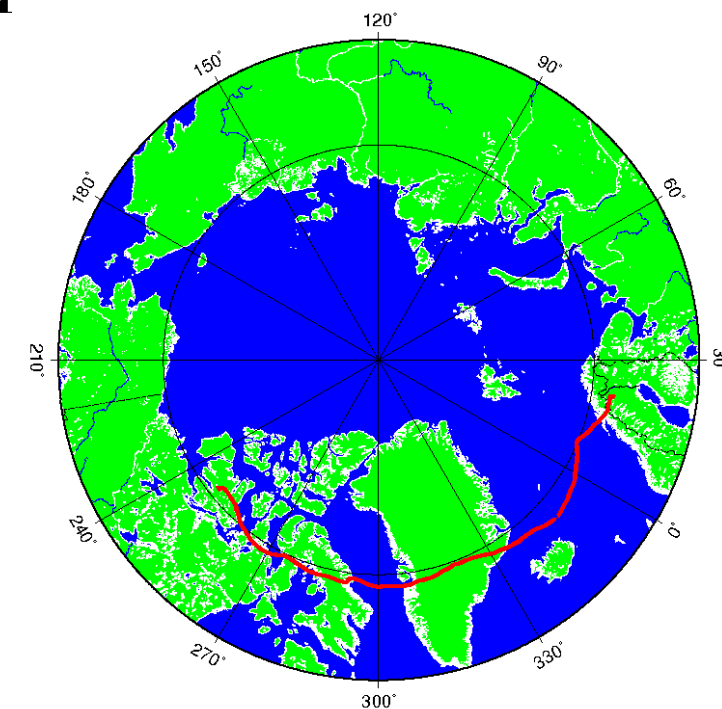


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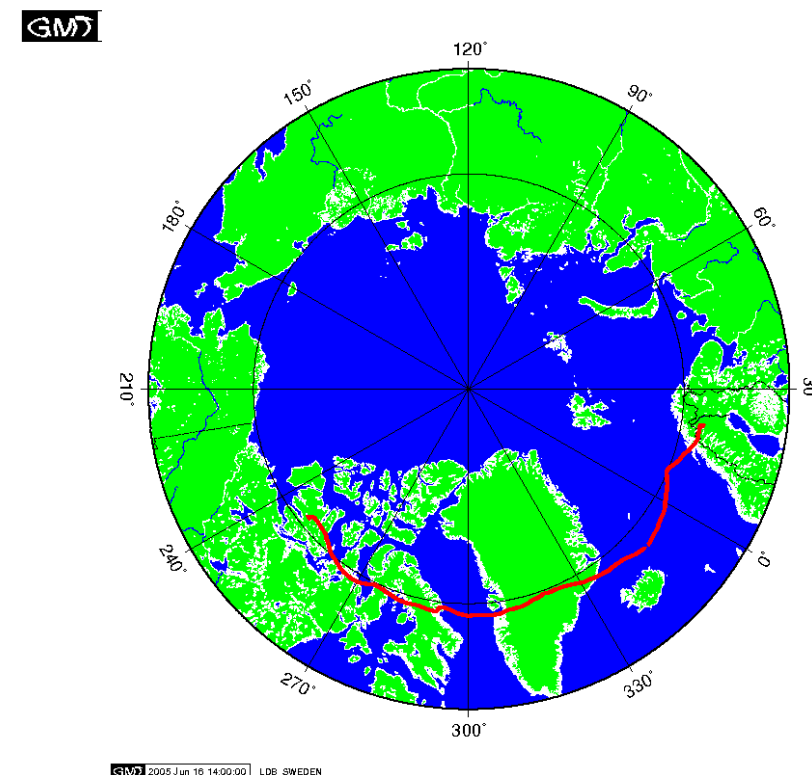
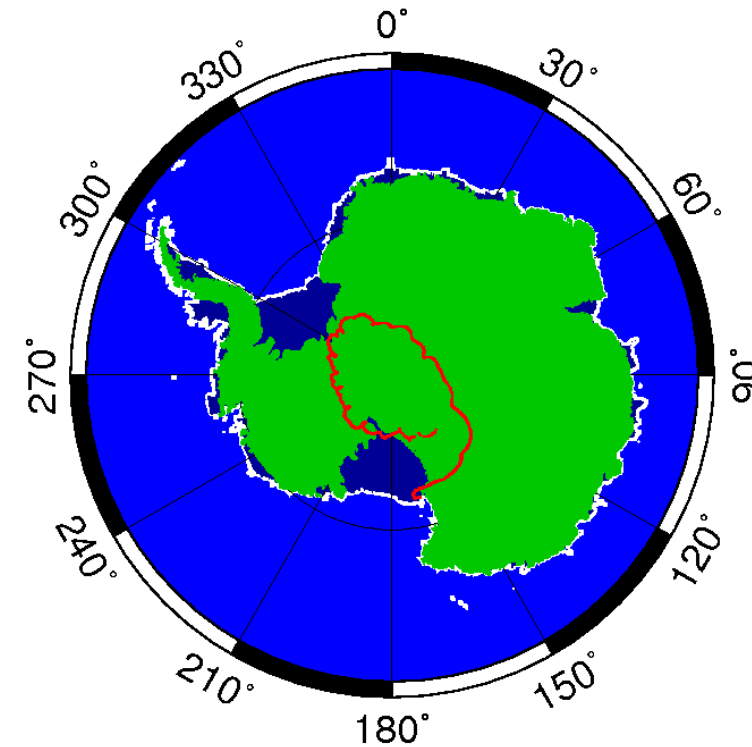
GM7



GM7 2005 Jun 10 14:00:00 LDB_SWEDEN

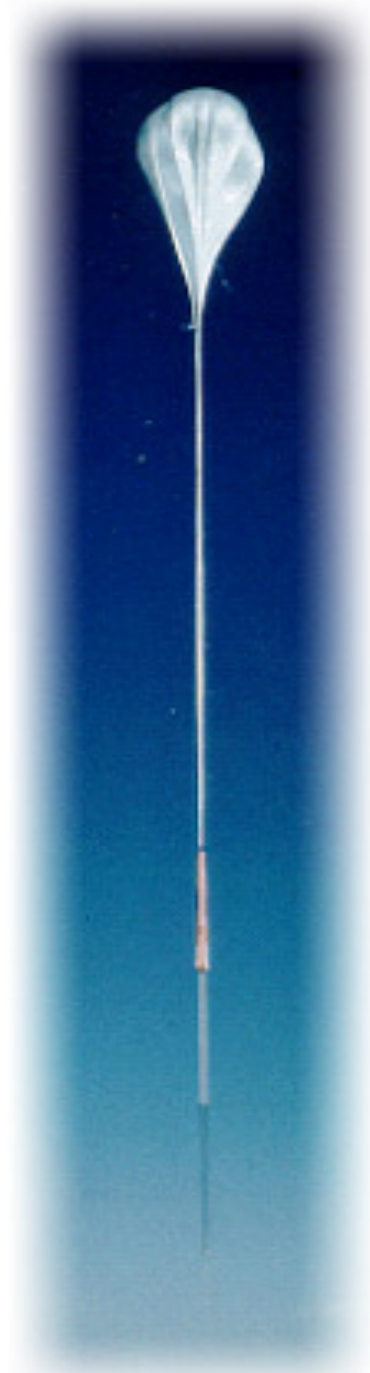
The Balloon-born Platform

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 - ◉ Need a BIG balloon!
- Flies at ~40 km altitude
- No control of where it goes so fly at place and time of year where the winds are predictable
- Flights from poles also have 24 hours daylight. Advantages:
 - ◉ Solar power
 - ◉ Maintain constant altitude



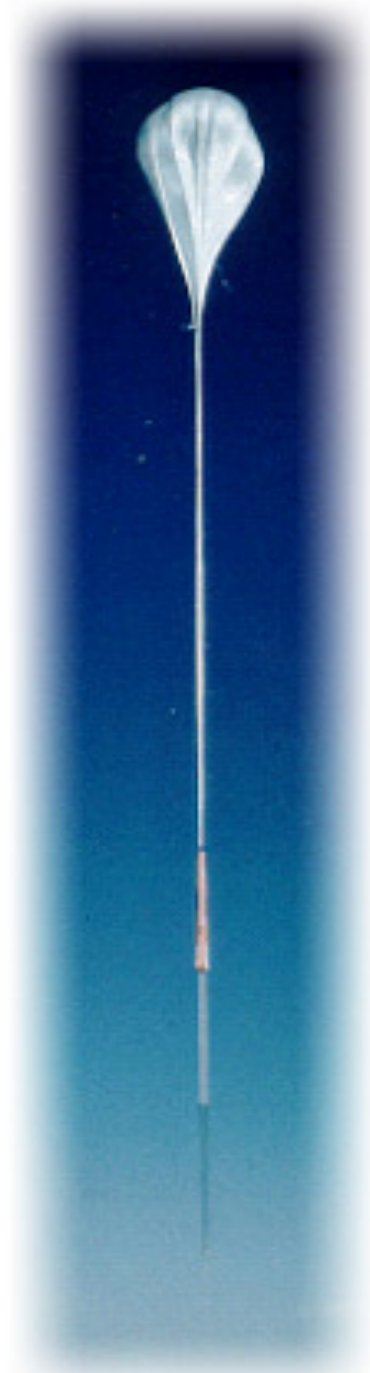
GMV 2005 Jun 10 14:00:00 LDB_SWEDEN

BLAST



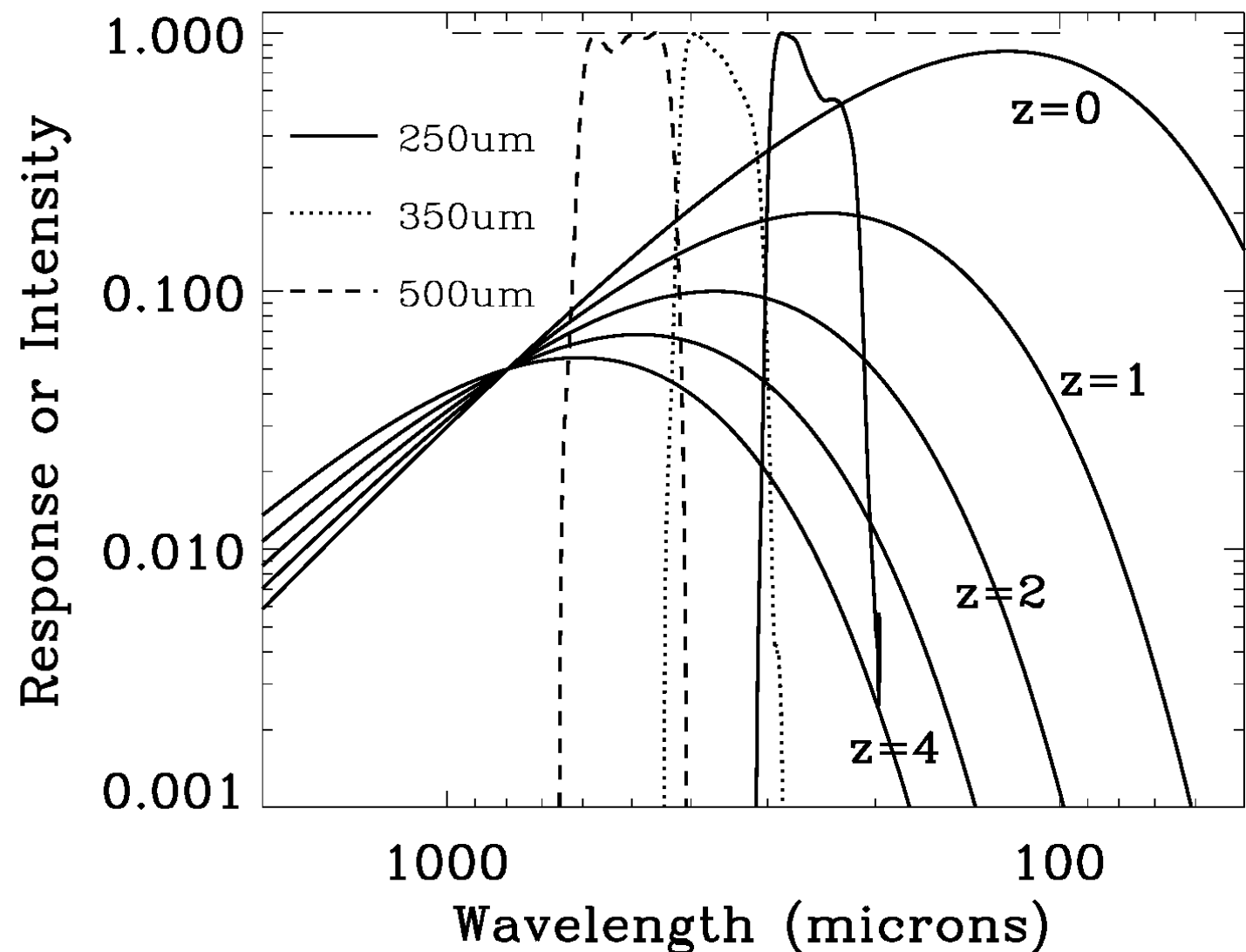
BLAST

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



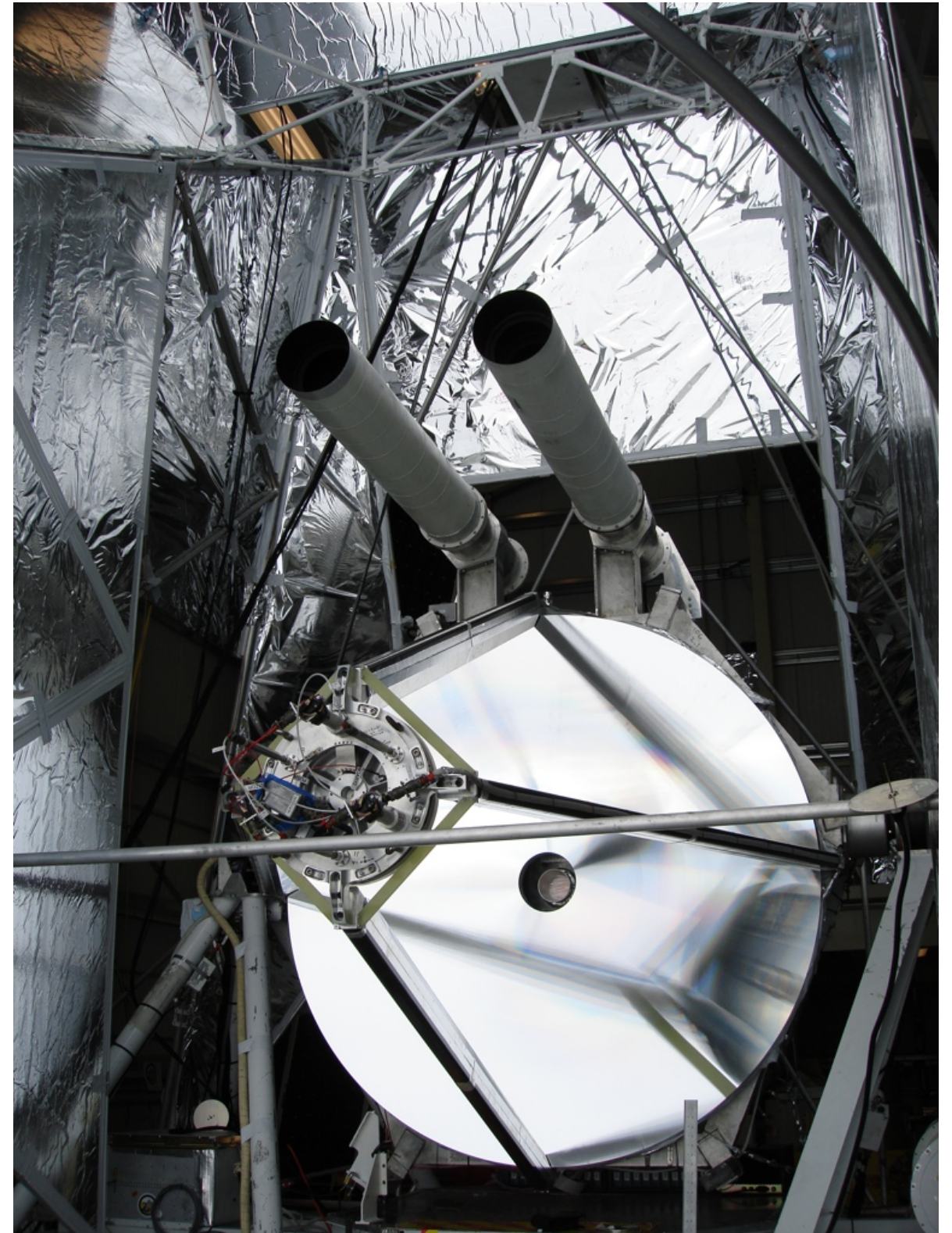
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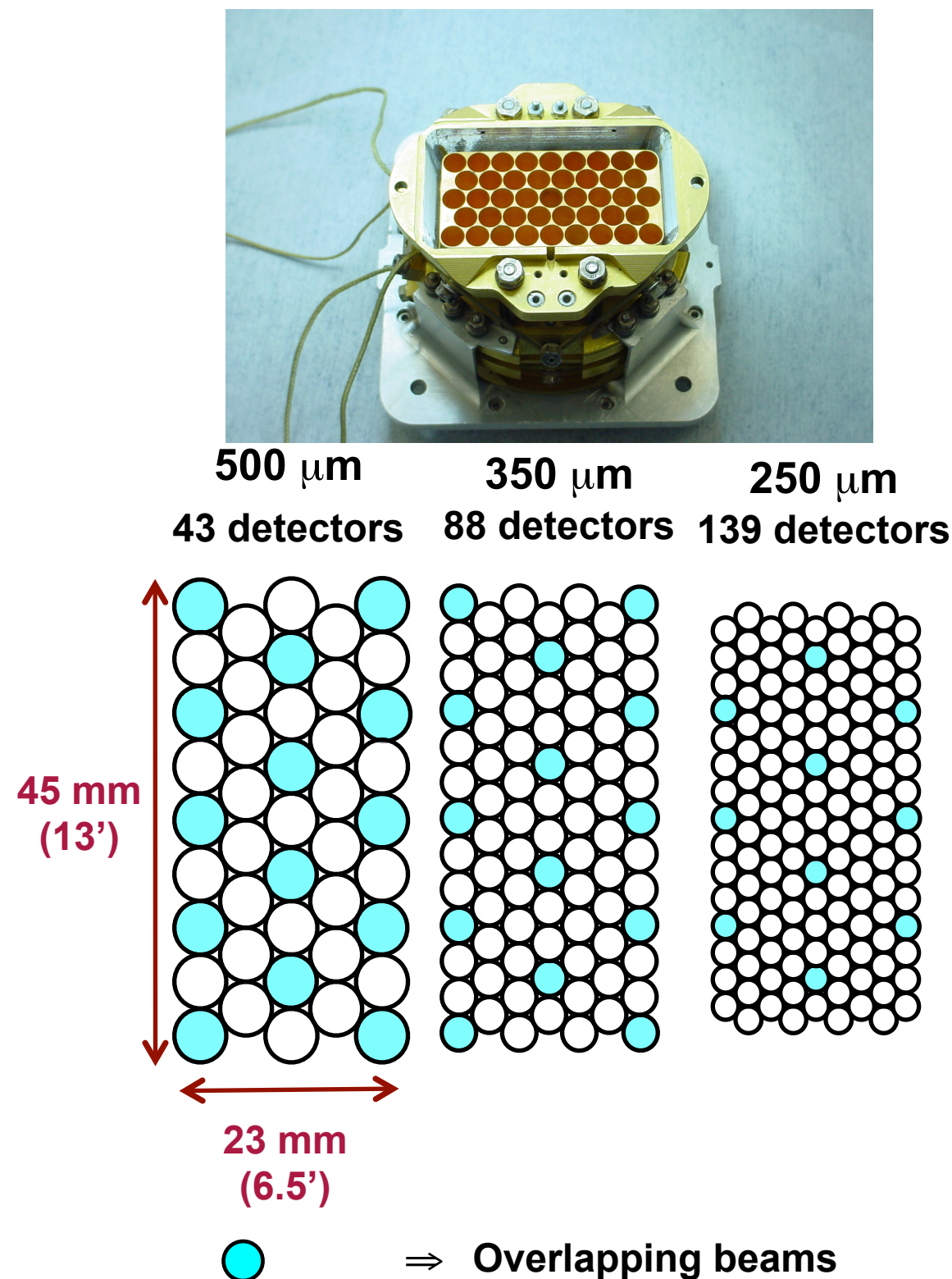
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- Designed to bracket redshifted peak of the warm (~35 K) dust SED (star-forming galaxies/AGN)
- 1.8 m under-illuminated primary with nearly diffraction limited beams:
 - ◉ 36, 45 and 60 arcsec FWHM at 250, 350 and 500 μm



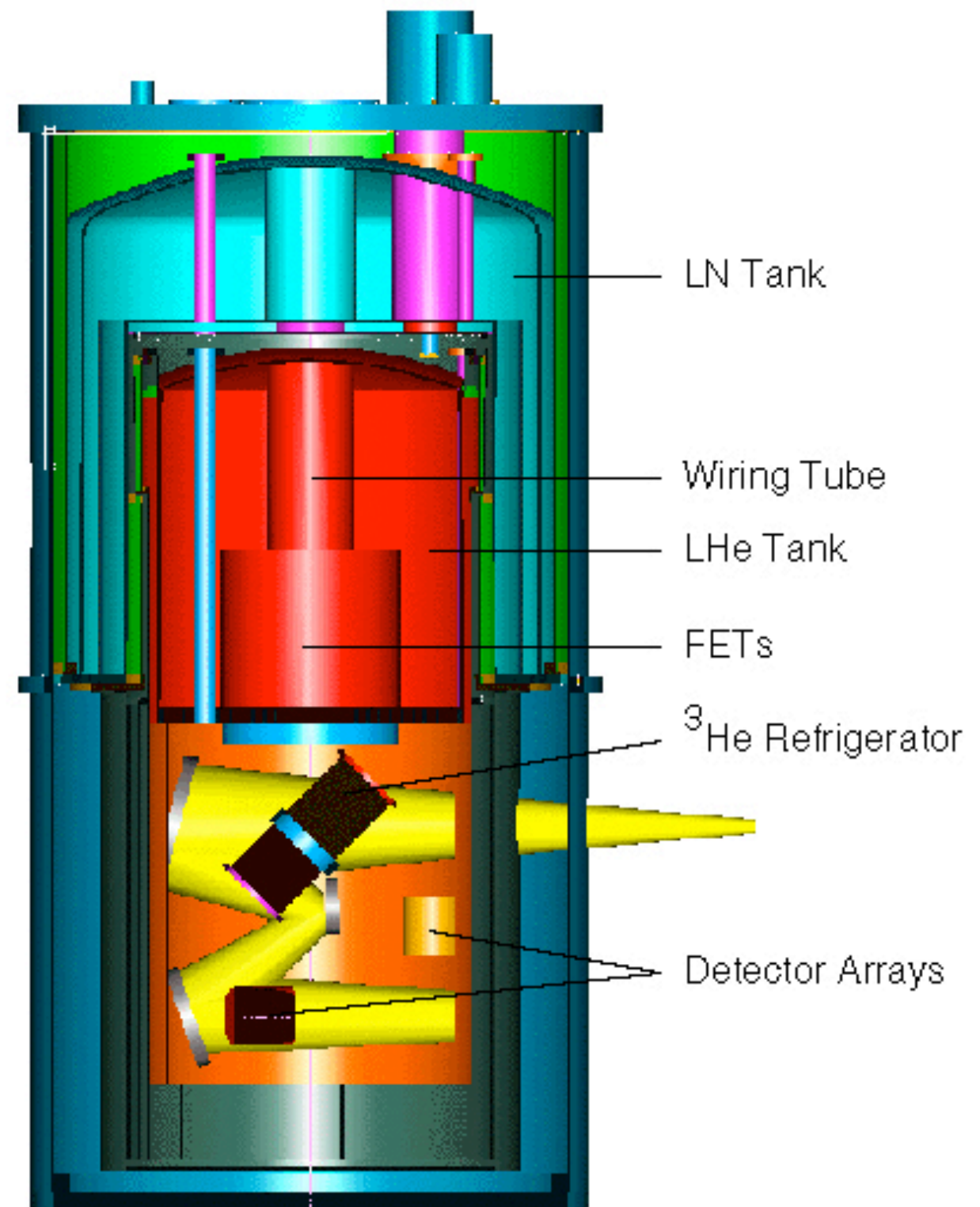
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- Focal Plane Feed-Horns + ~270 bolometer detectors

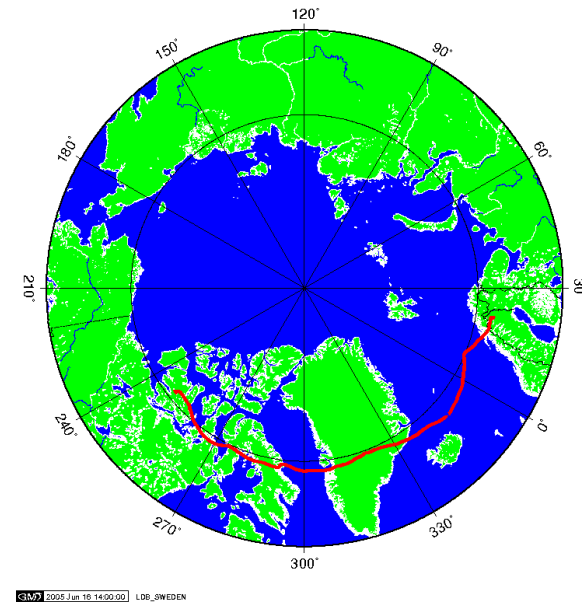


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 - ◉ 36, 45 and 60 arcsec FWHM at 250, 350 and 500 μm
- Focal Plane Feed-Horns + ~270 bolometer detectors
- Detectors and re-imaging optics housed in a multi-stage cryostat with ~ 11 day hold time

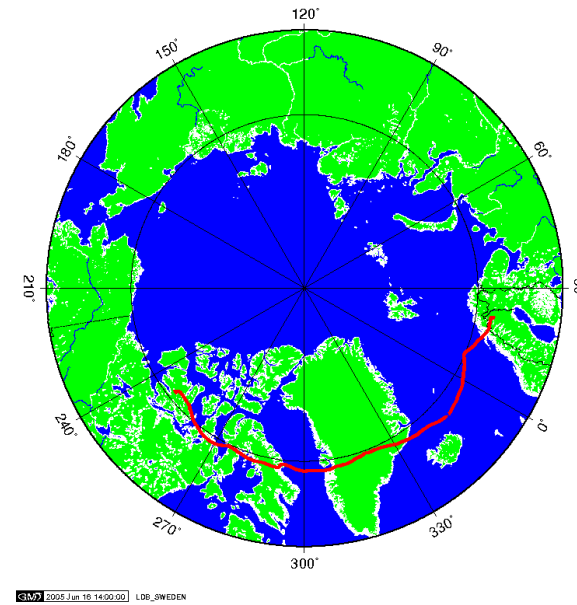


Science Flight (1) - June 2005, Kiruna, Sweden



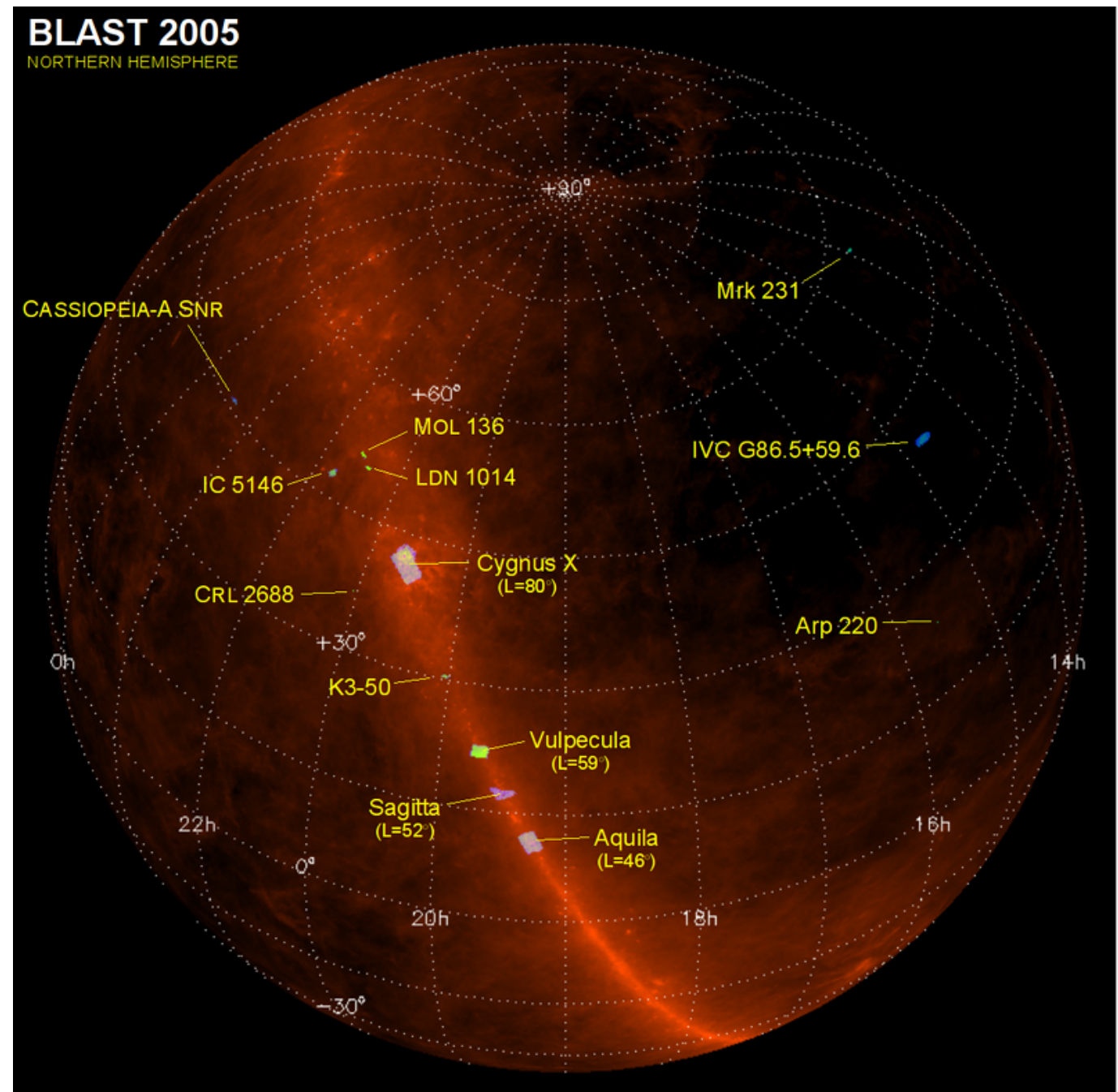
Science Flight (1) - June 2005, Kiruna, Sweden

- Long-duration flight (5 days and ~ 100 hours data)



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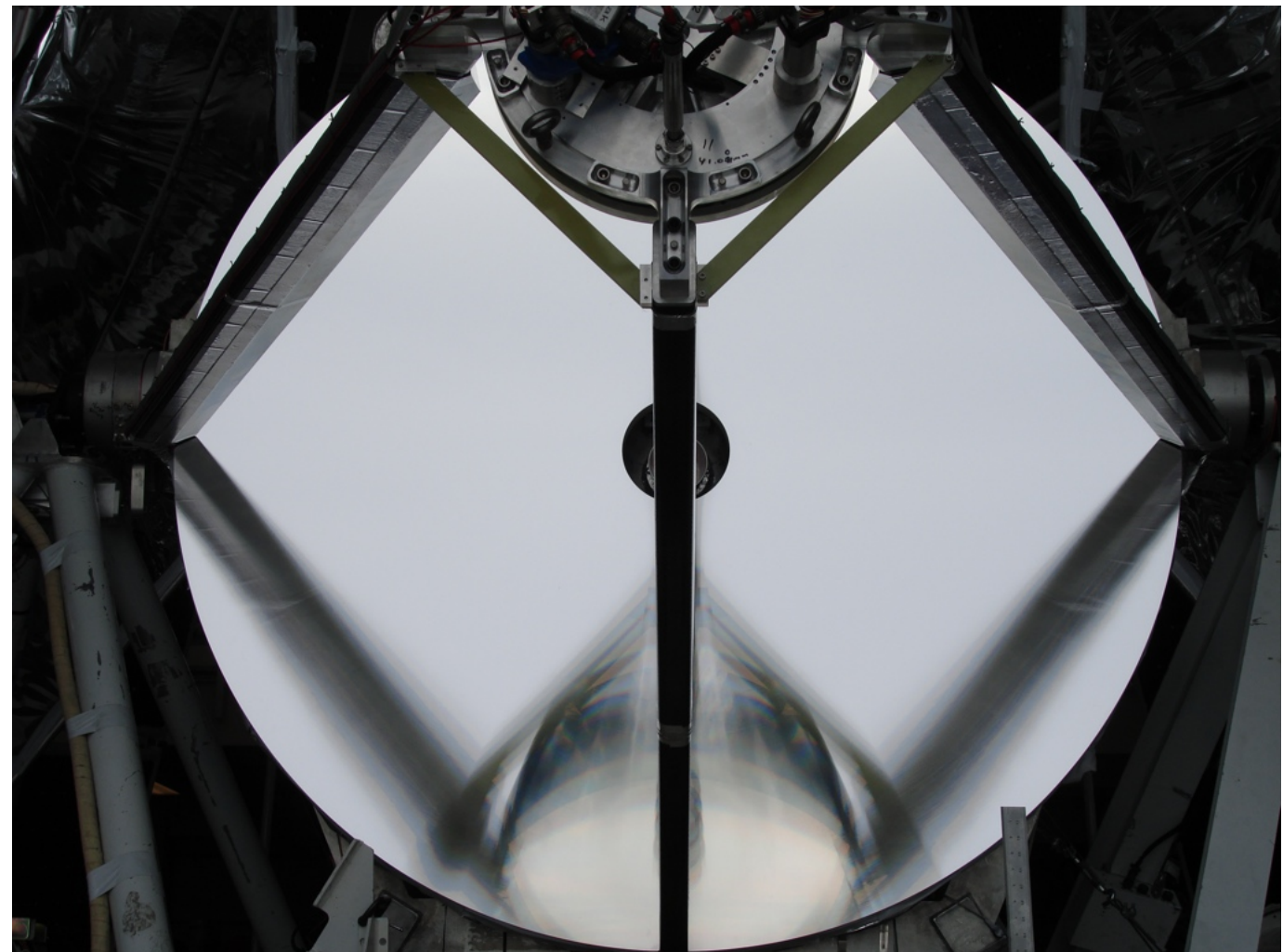
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 - ◉ Focus by moving the secondary mirror with motorized actuators

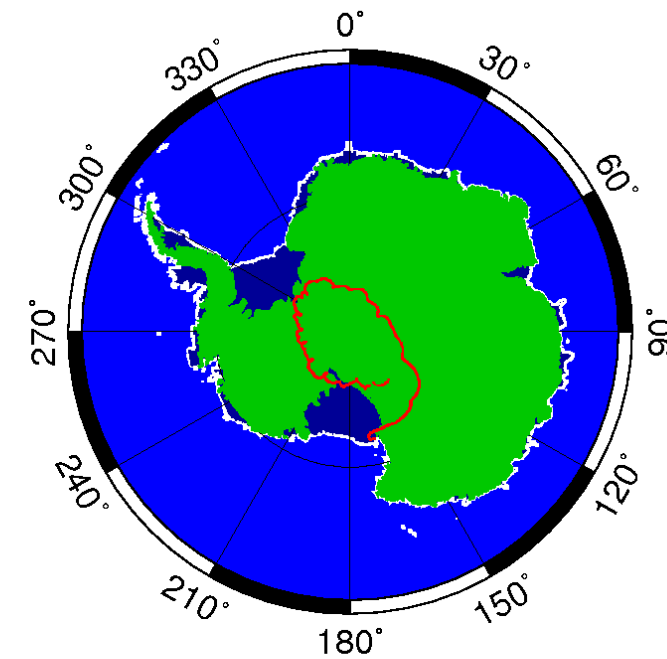


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 - ◉ Focus by moving the secondary mirror with motorized actuators
 - ◉ Pre-flight look-up table to find focus as function of Temperature



Science Flight (2) - December 2006, Antarctica

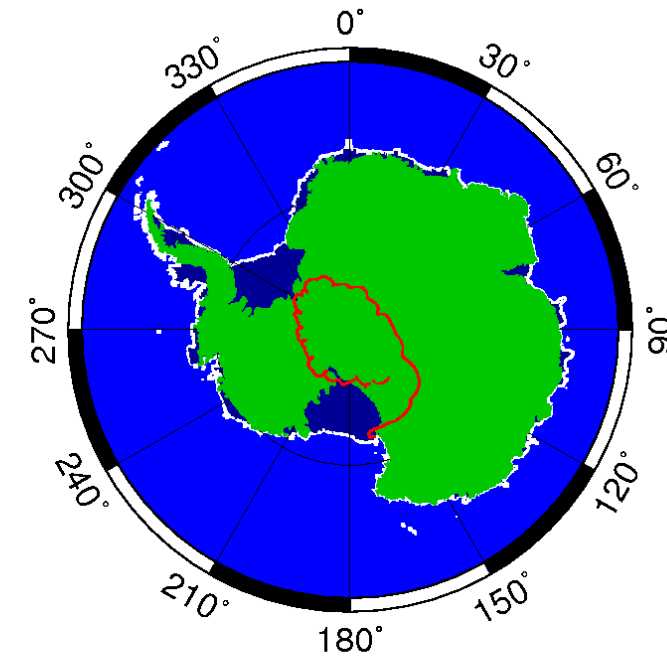


GM 2007 Jan 19 15:45:05 LDB_Antarctica_2006-2007_BLAST



Science Flight (2) - December 2006, Antarctica

- Long-duration flight (11 days and ~ 250 hours data)



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



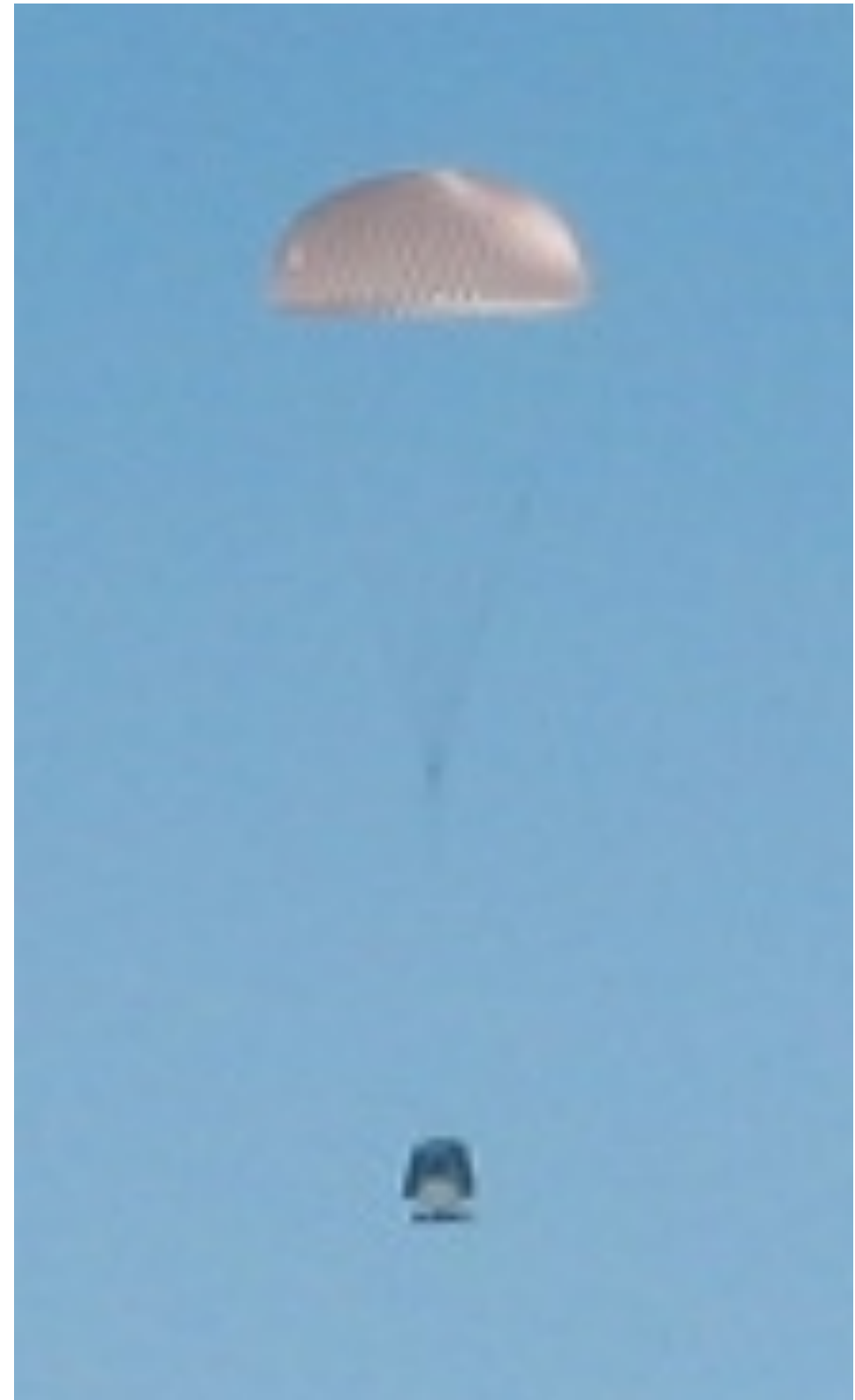
Science Flight (2) - December 2006, Antarctica

- Long-duration flight (11 days and ~ 250 hours data)
- In focus, perfect flight!



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- Or not....



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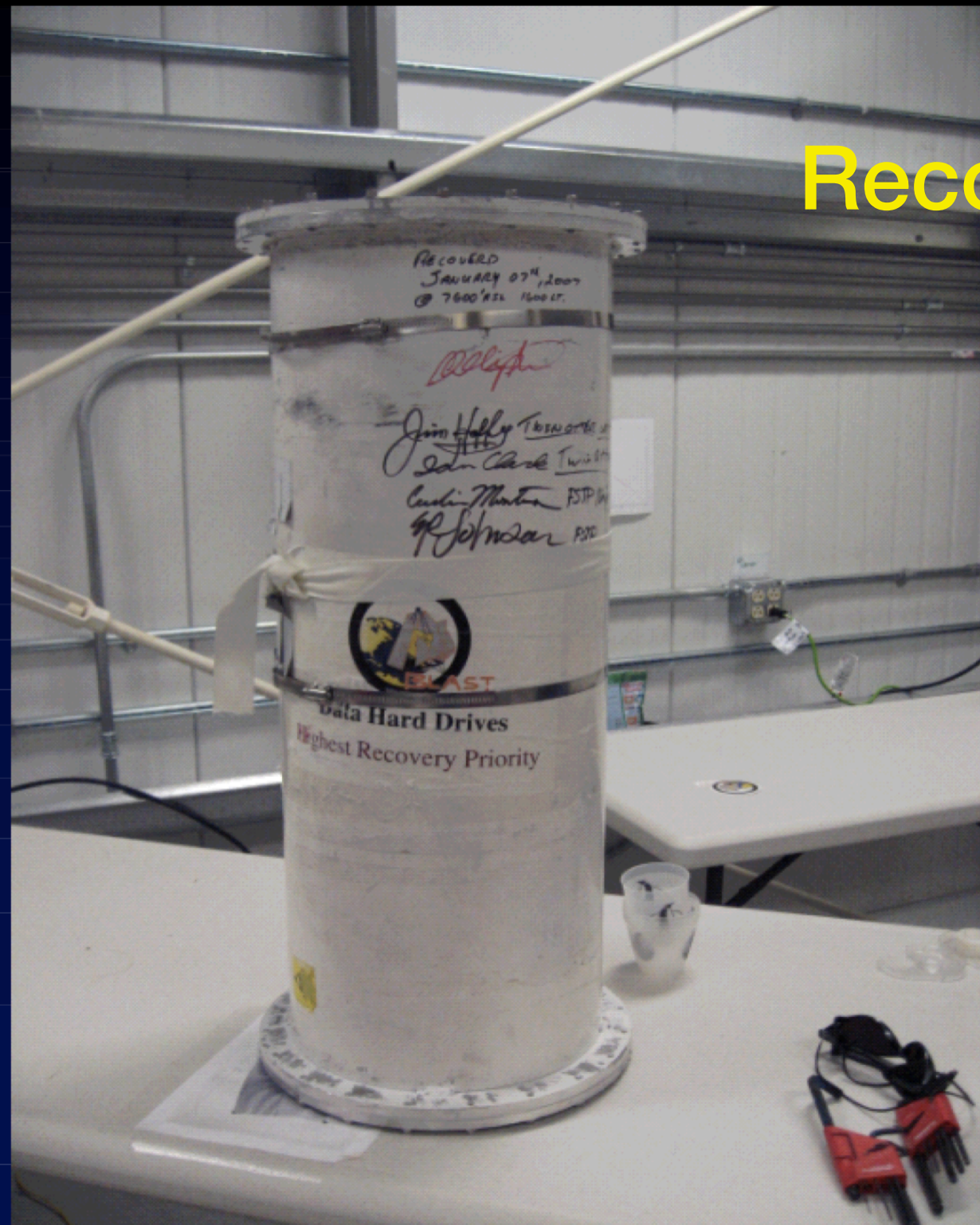


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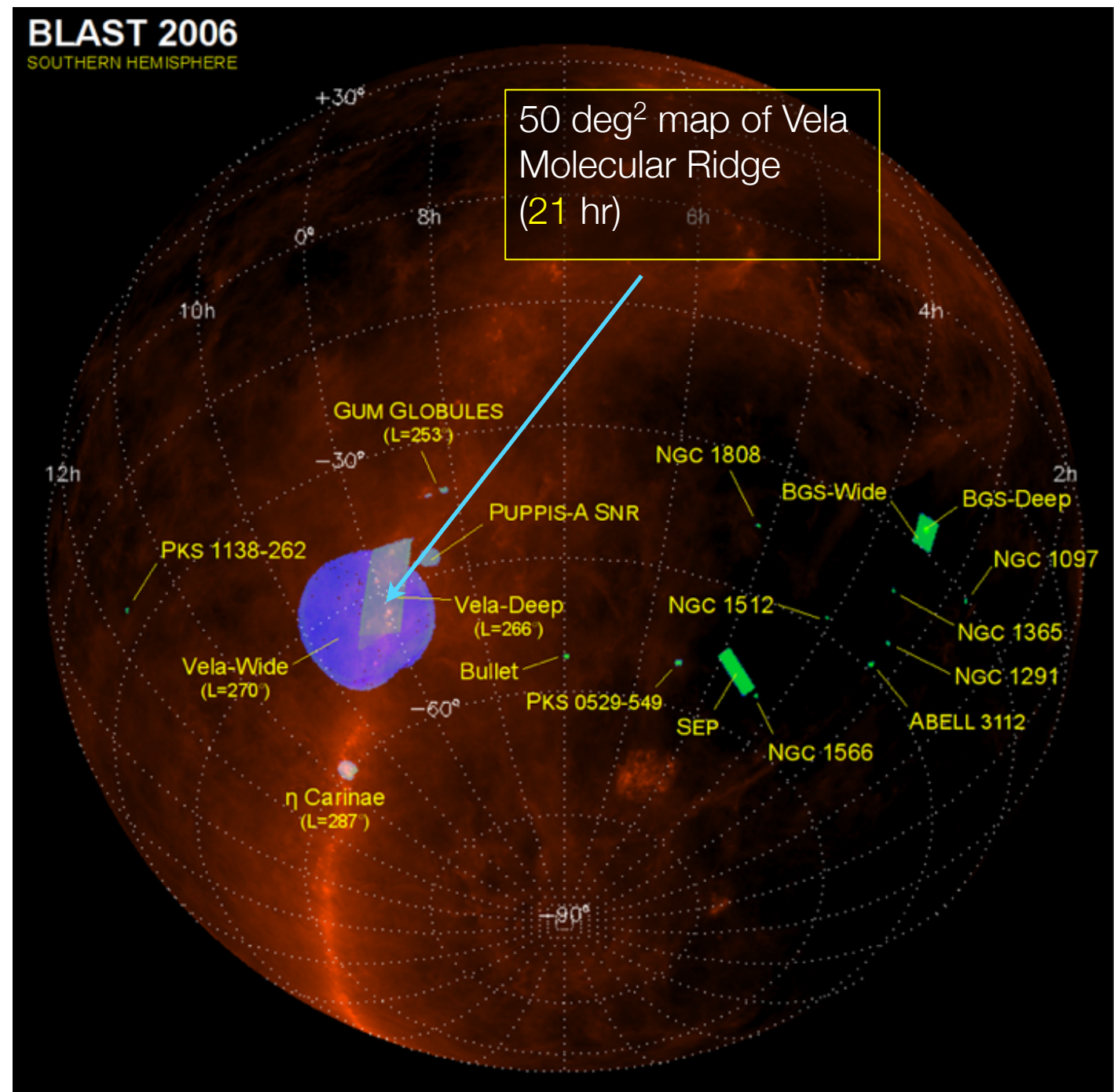


Recovered!!

Science Flight (2) - December 2006, Antarctica

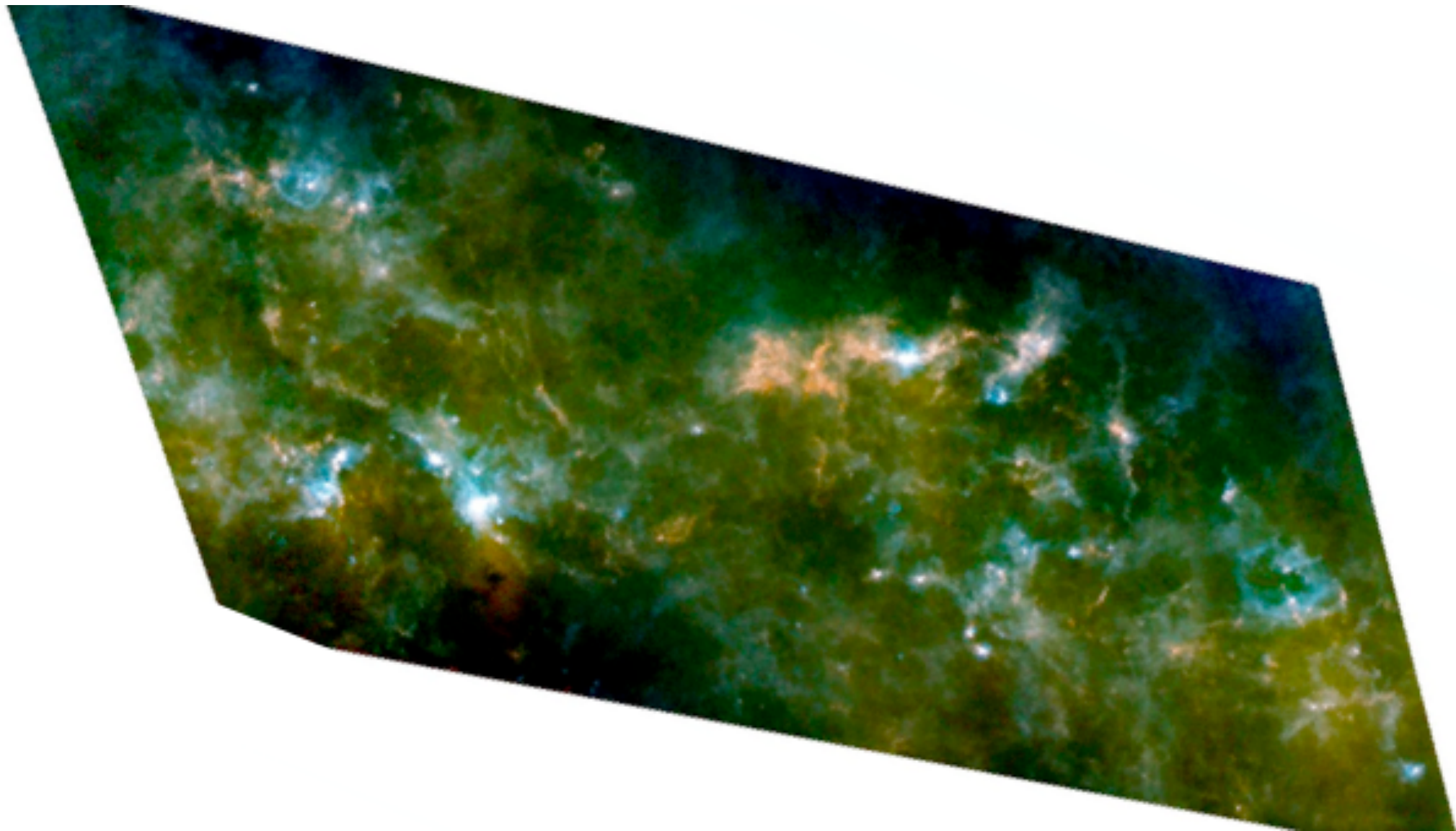
Science Flight (2) - December 2006, Antarctica

- A very wide Galactic-plane field



Science Flight (2) - December 2006, Antarctica

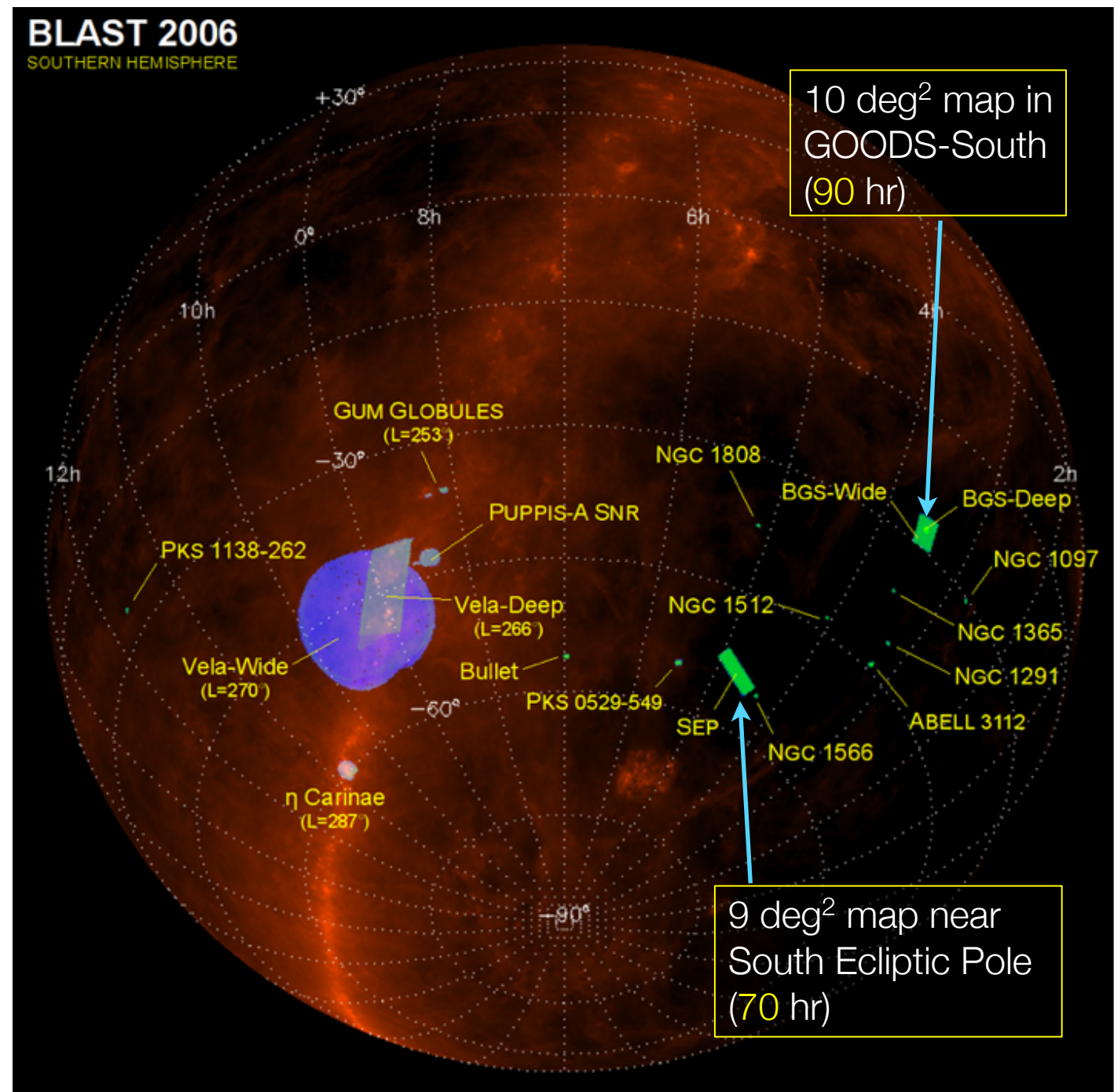
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Netterfield et al. 2009: 50 sq-deg survey in Vela

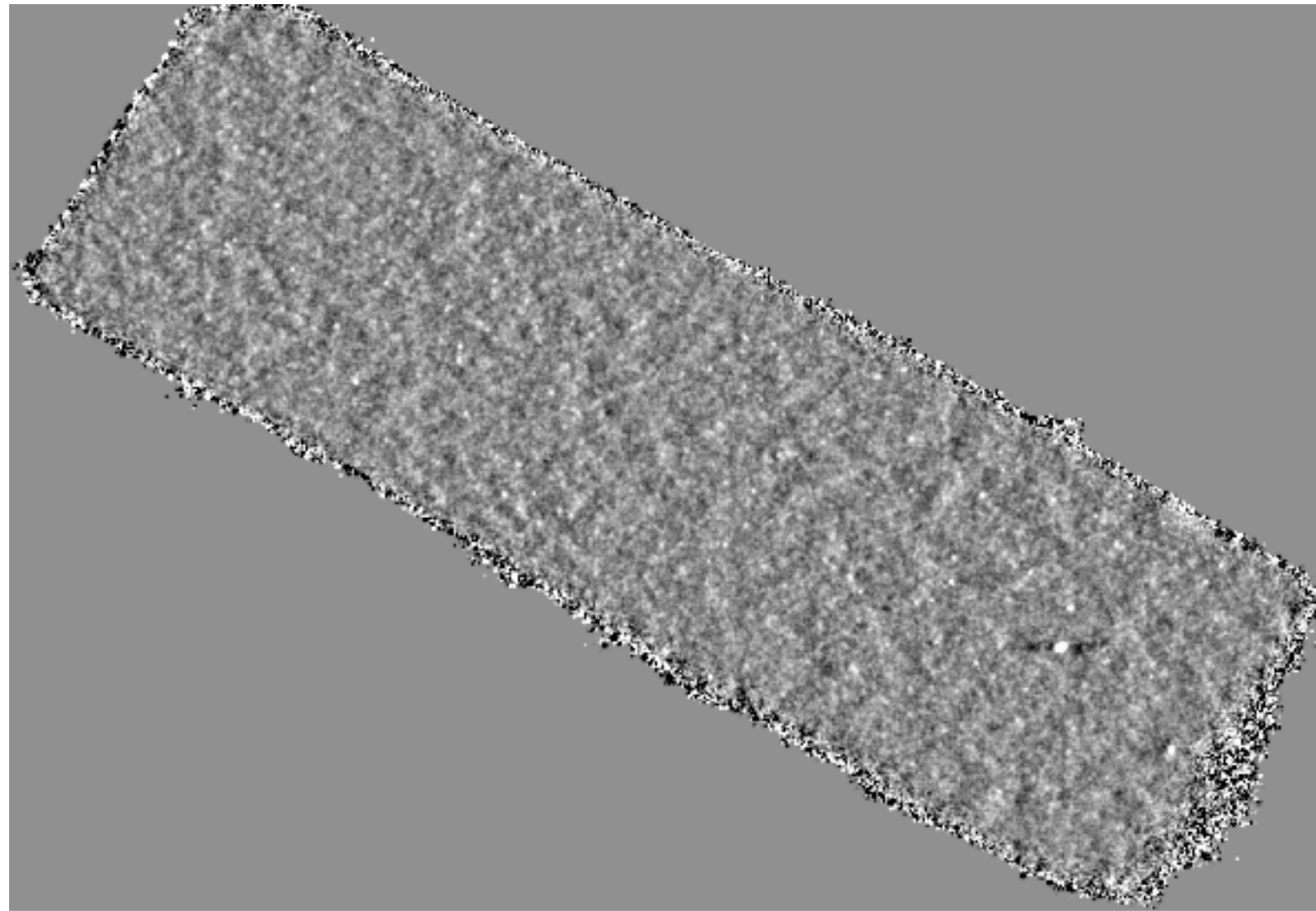
Science Flight (2) - December 2006, Antarctica

- A very wide Galactic-plane field
- 2 major extragalactic fields



Science Flight (2) - December 2006, Antarctica

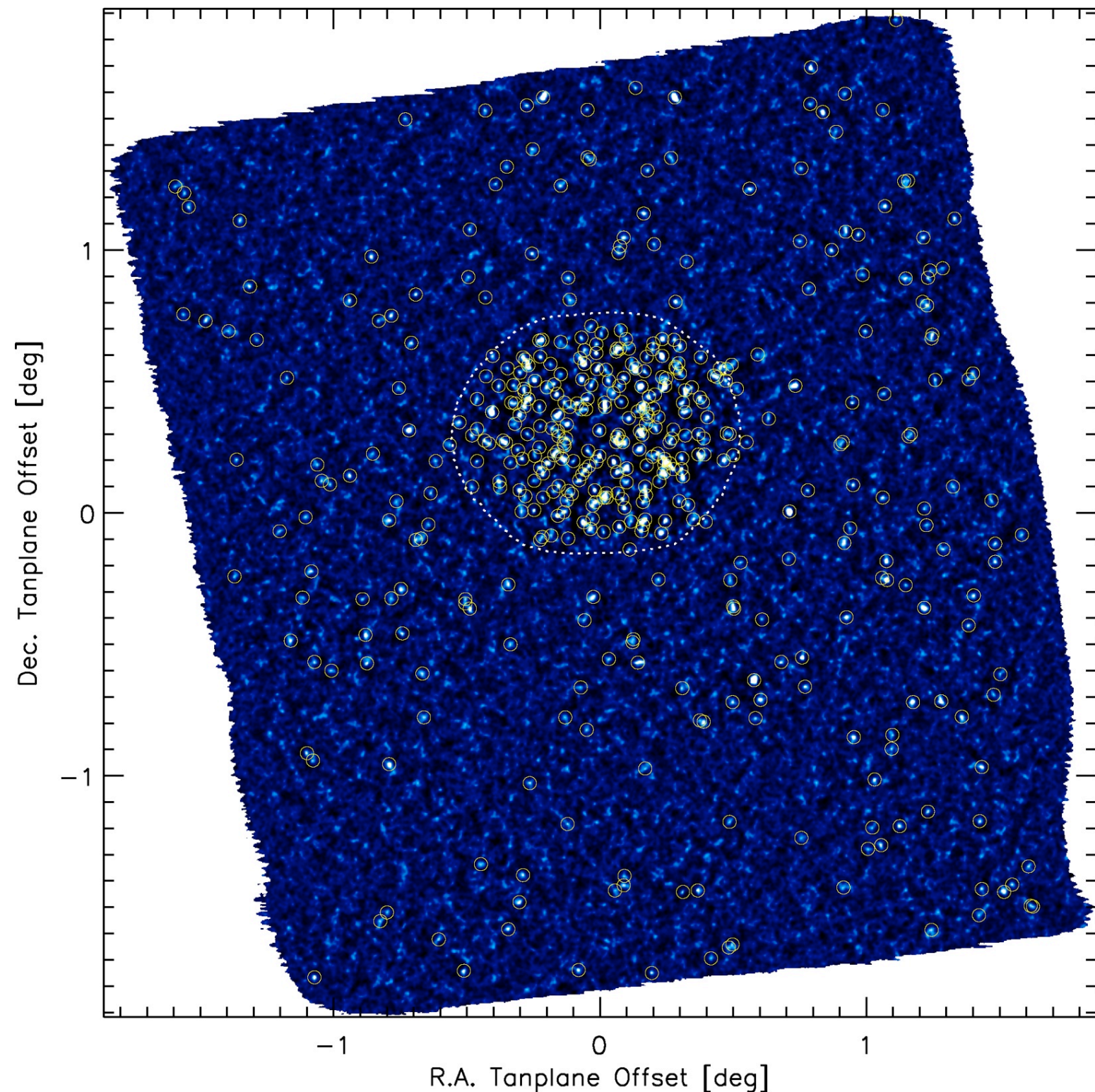
- A very wide Galactic-plane field
- 2 major extragalactic fields
 - ◉ SEP



Valiante et al. (in Prep.)

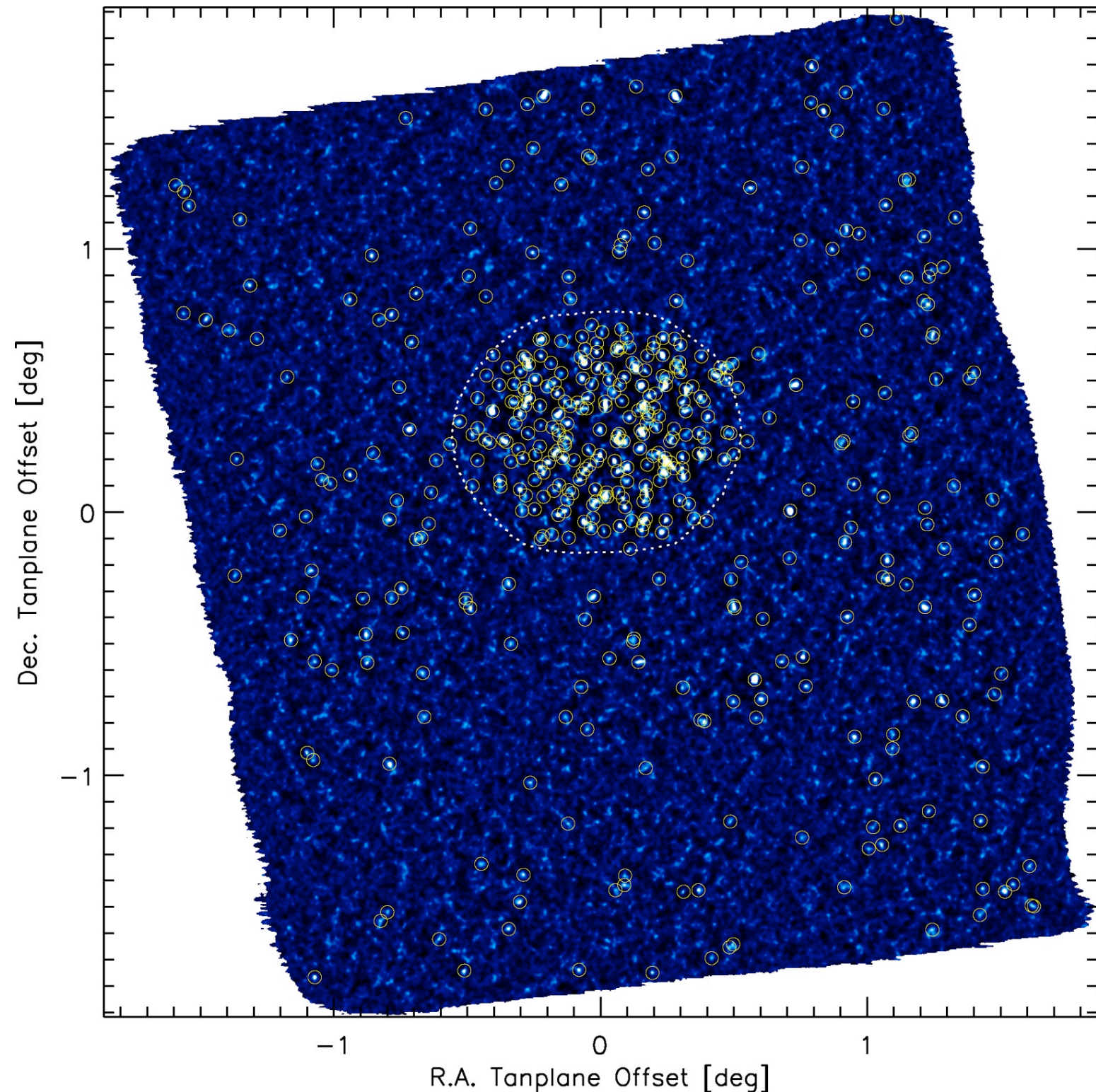
Science Flight (2) - December 2006, Antarctica

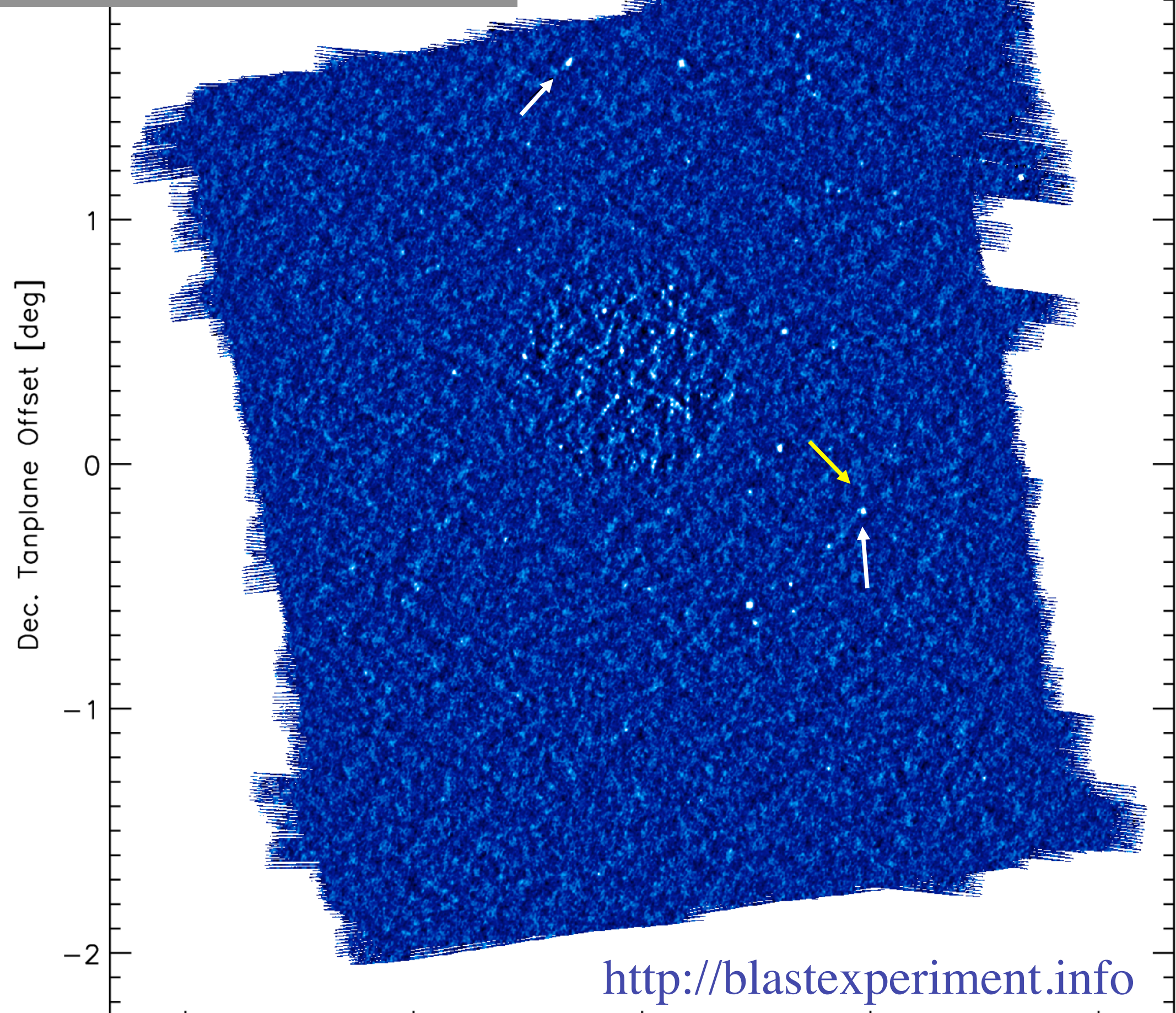
- A very wide Galactic-plane field
- 2 major extragalactic fields
 - ◉ SEP
 - ~ 230 sources $> 5\sigma$
 - ◉ GOODS-South



Science Flight (2) - December 2006, Antarctica

- A very wide Galactic-plane field
- 2 major extragalactic fields
 - ◉ SEP
 - ~ 230 sources $> 5\sigma$
 - ◉ GOODS-South
 - Deep: ~ 250 sources $> 5\sigma$
 - Wide: ~ 250 sources $> 5\sigma$
- Confusion Noise ~ 30 mJy





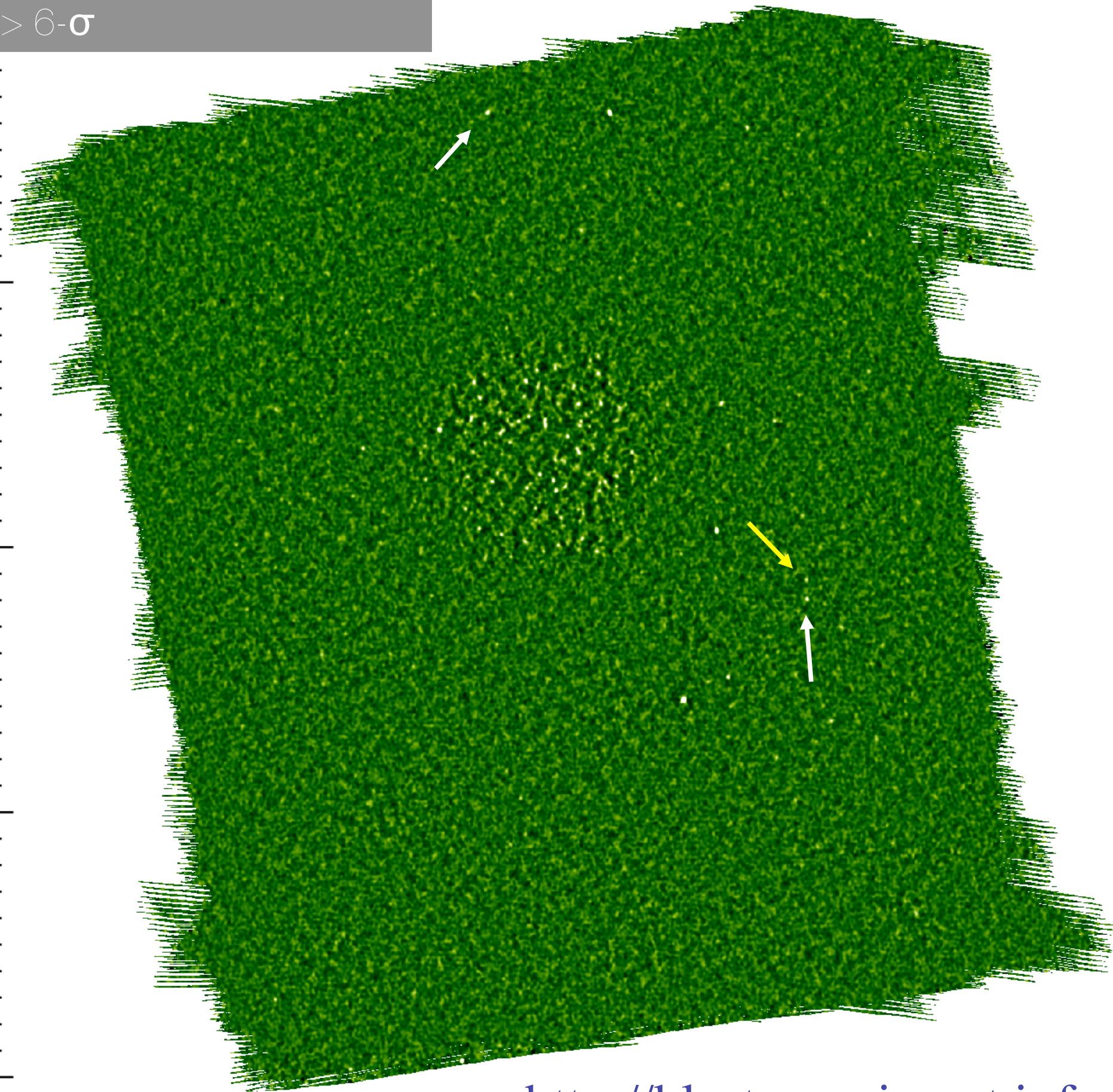
Dec. Tanplane Offset [deg]

1

0

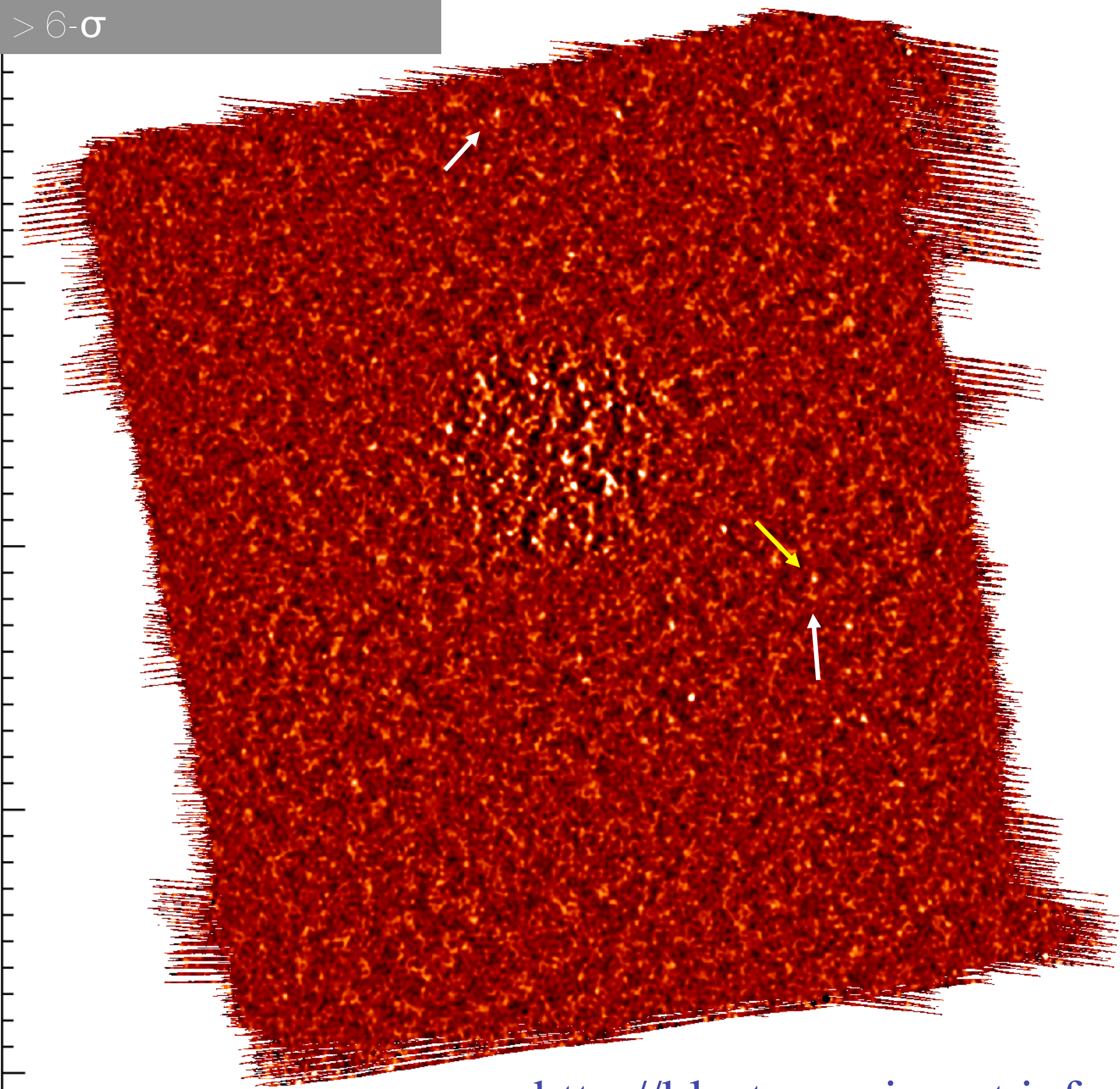
-1

-2



Dec. Tanplane Offset [deg]

1
0
-1
-2



1. “Over half of the far-infrared background light comes from galaxies at $z \sim 1.2$ ”, 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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- Counts
 - ◉ Devlin et al. 2009,
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The BLAST Extragalactic Results: Outline

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 - ◉ Marsden et al. 2009,
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The BLAST Extragalactic Results: Outline

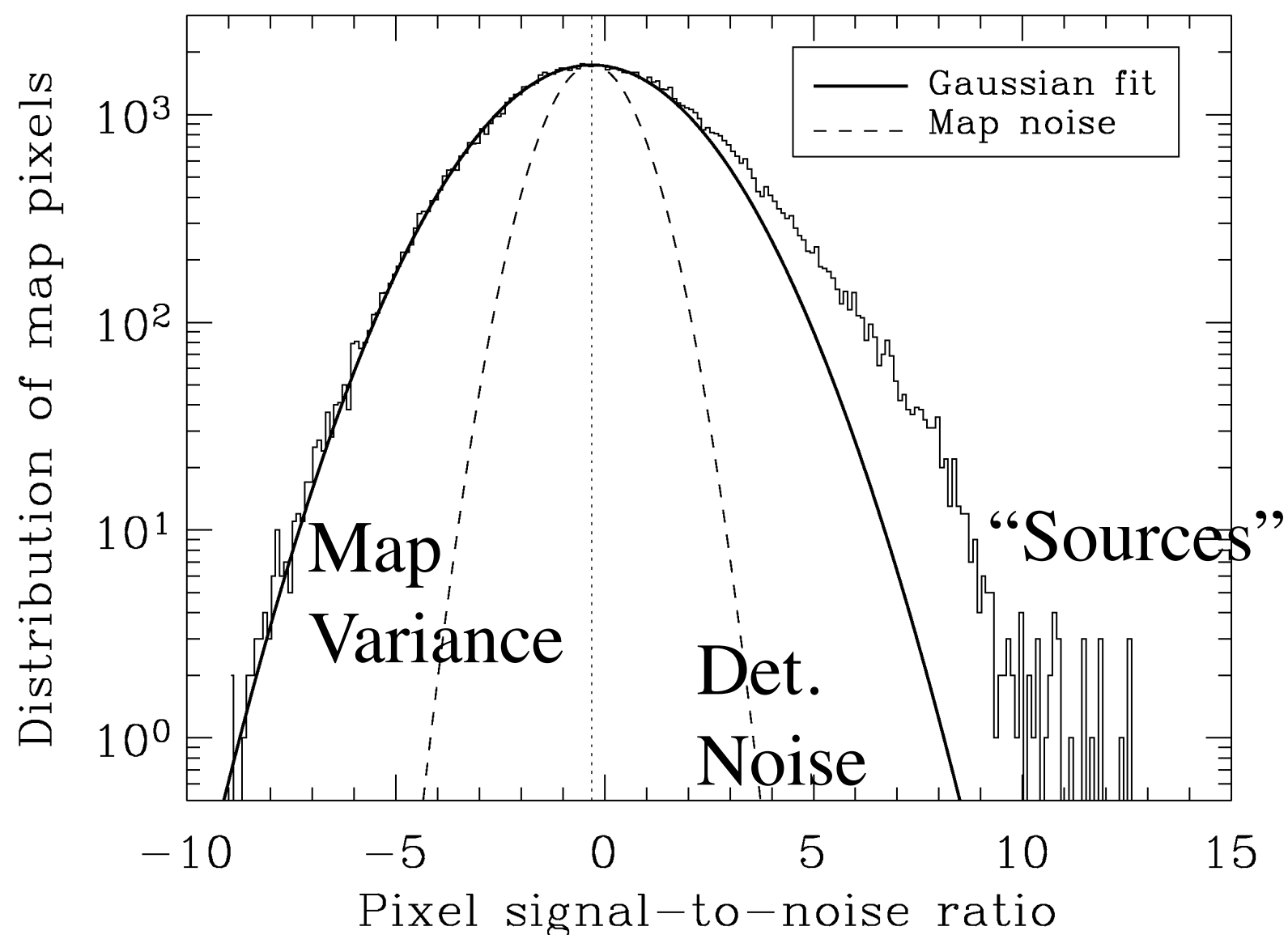
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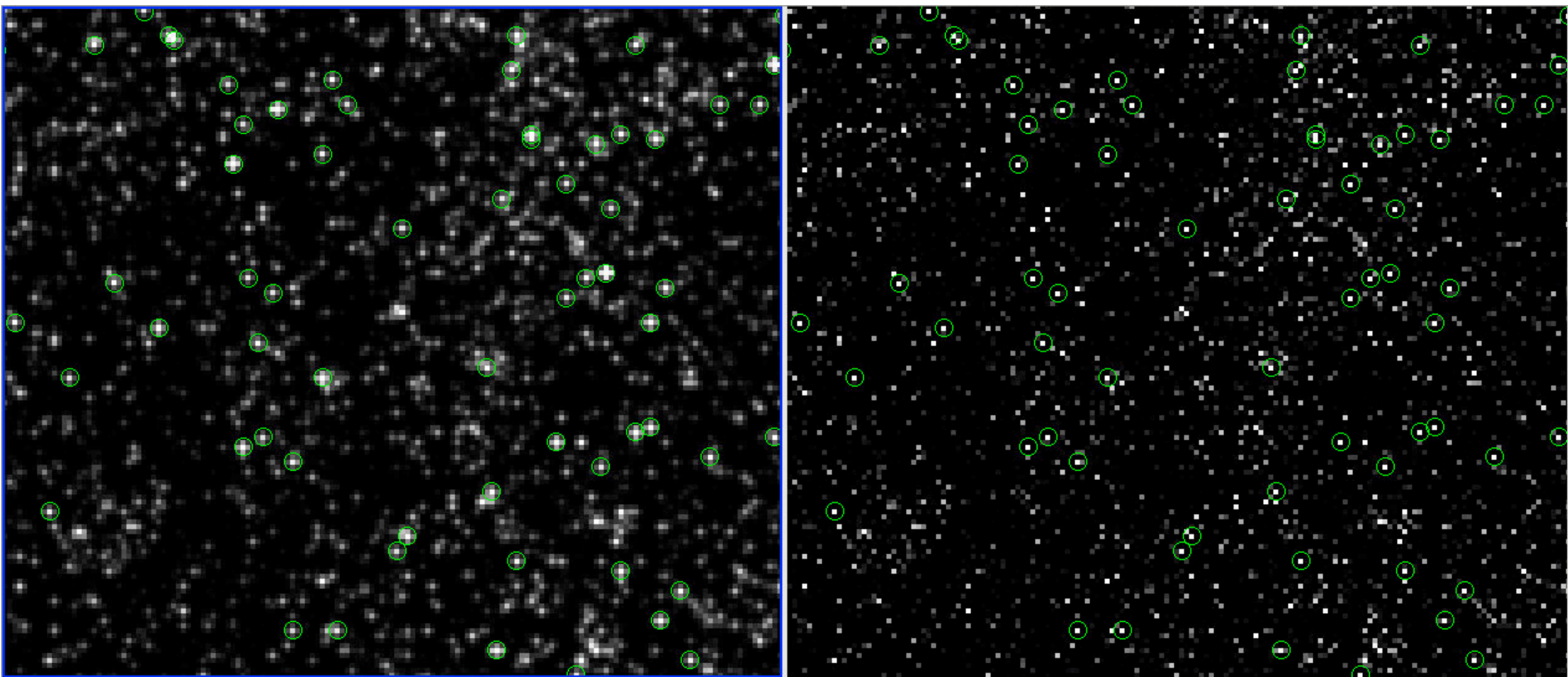
Goal:

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



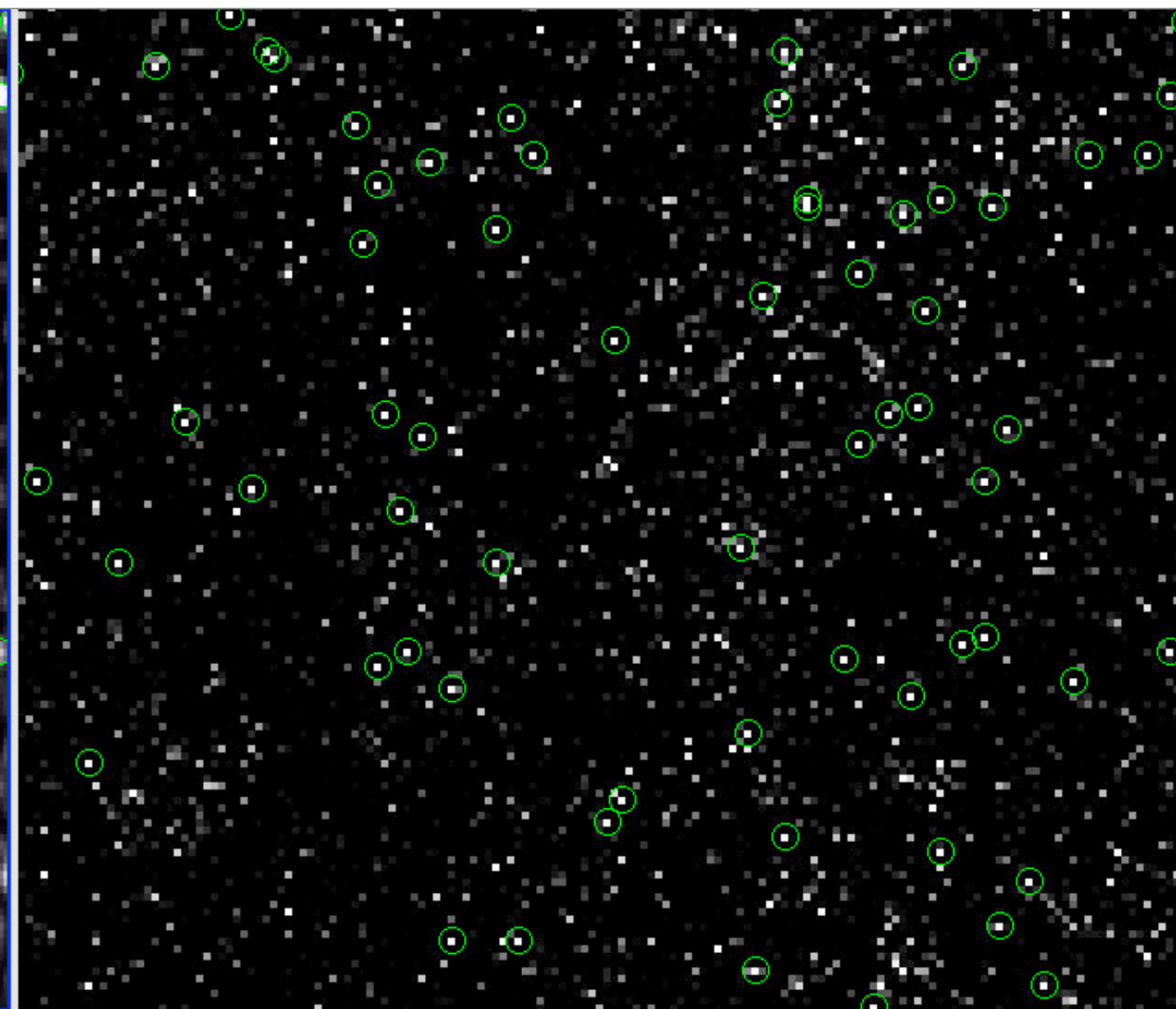
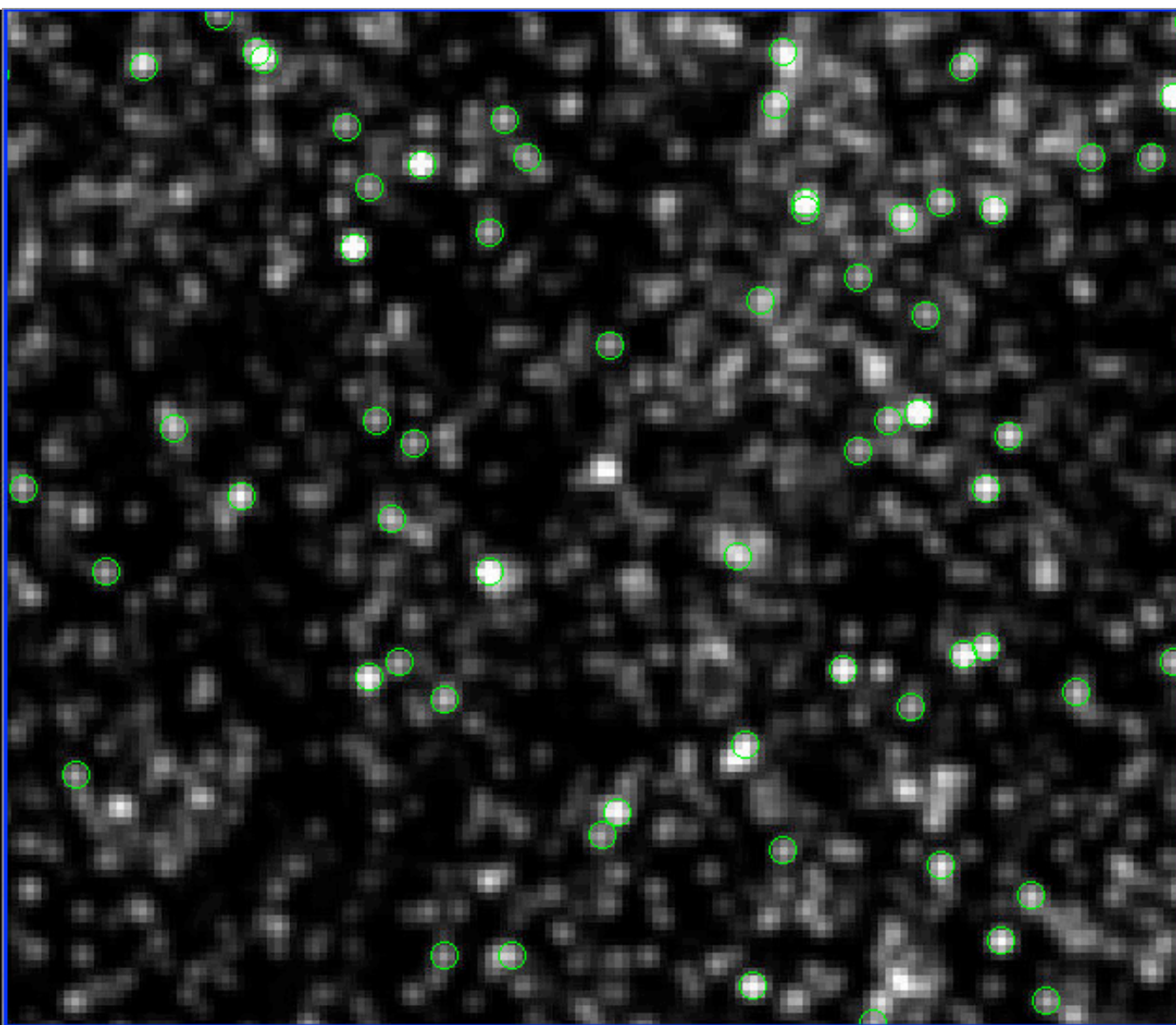
Marsden et al. 0904.1205

Identifying “Sources”



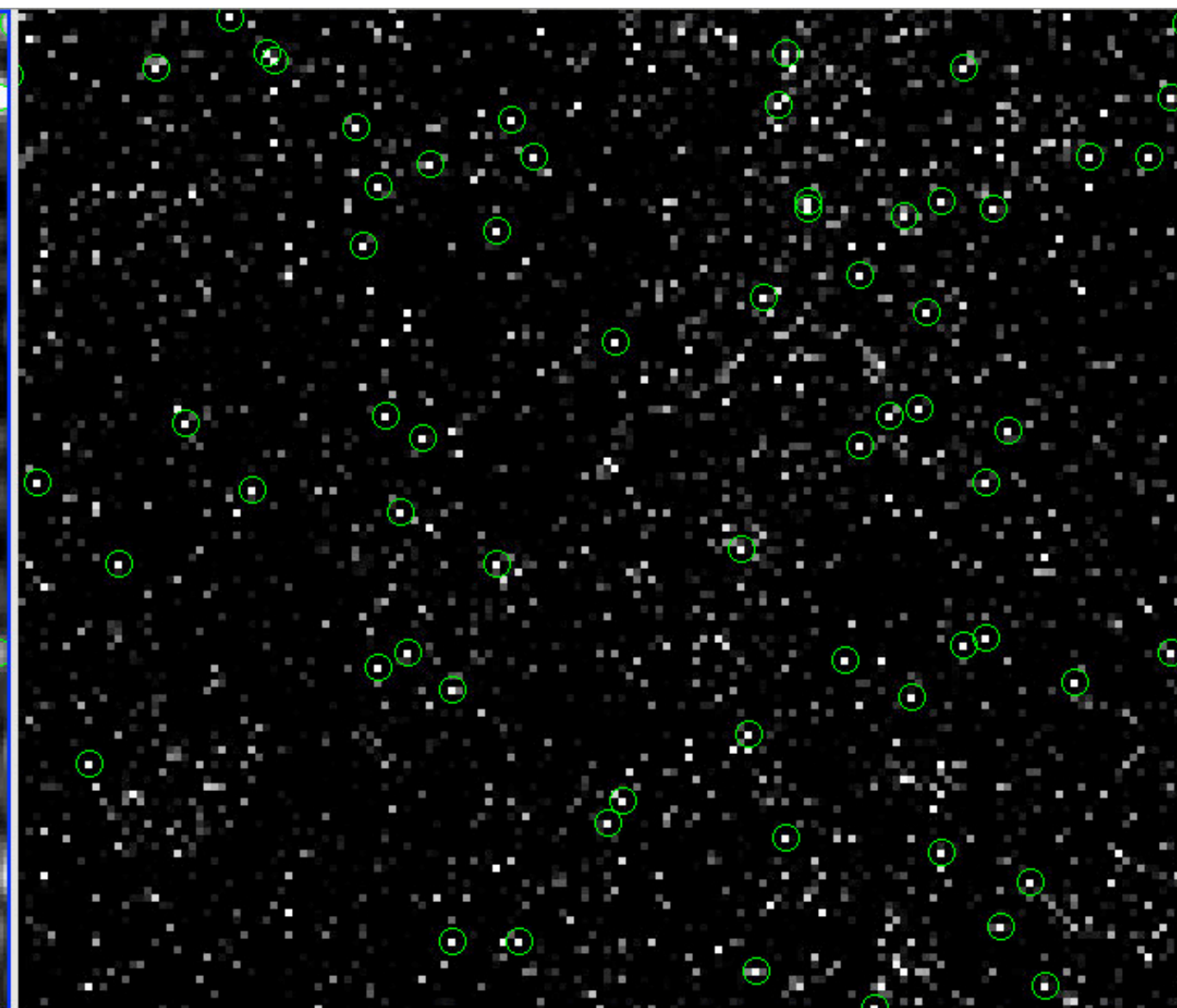
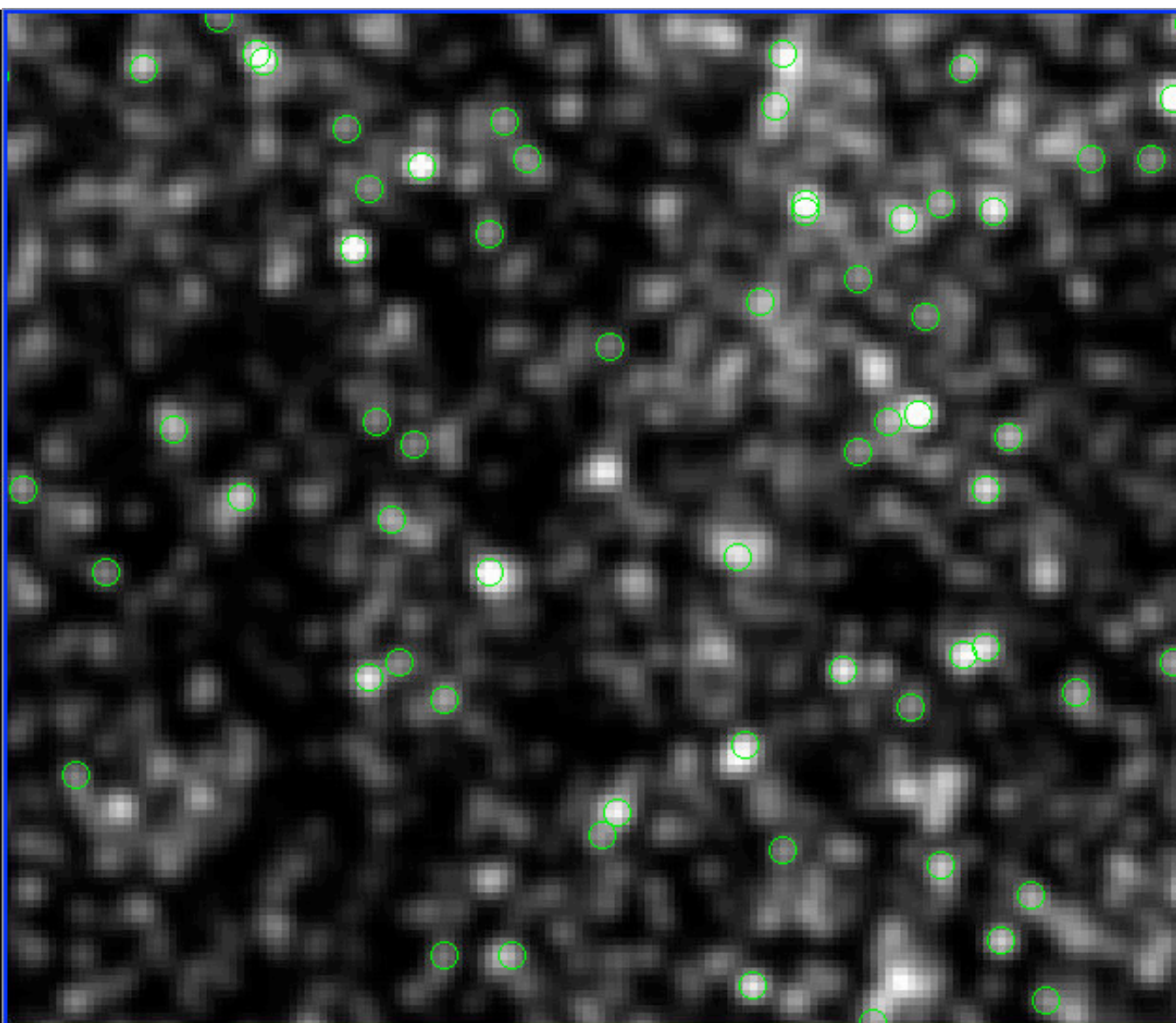
15 arcsec

Identifying “Sources”



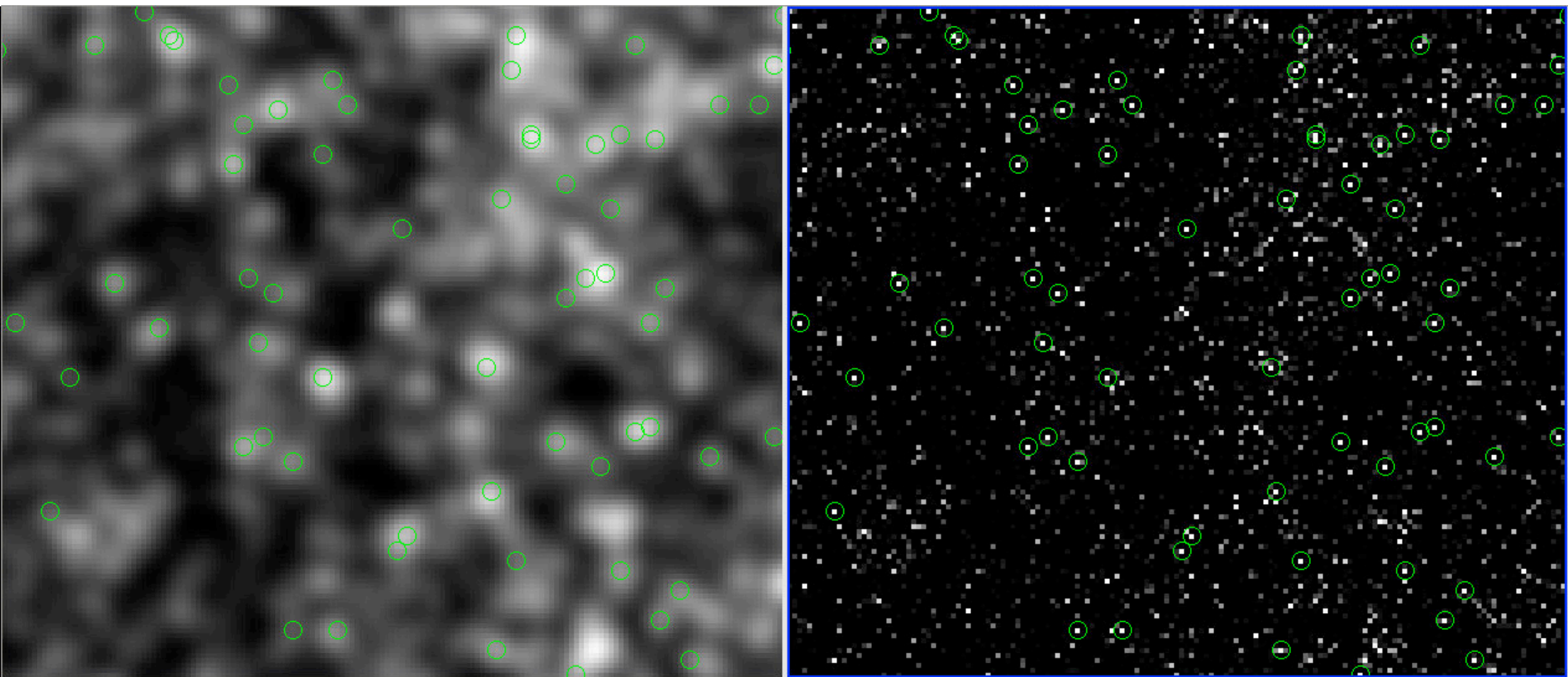
25 arcsec

Identifying “Sources”



35 arcsec

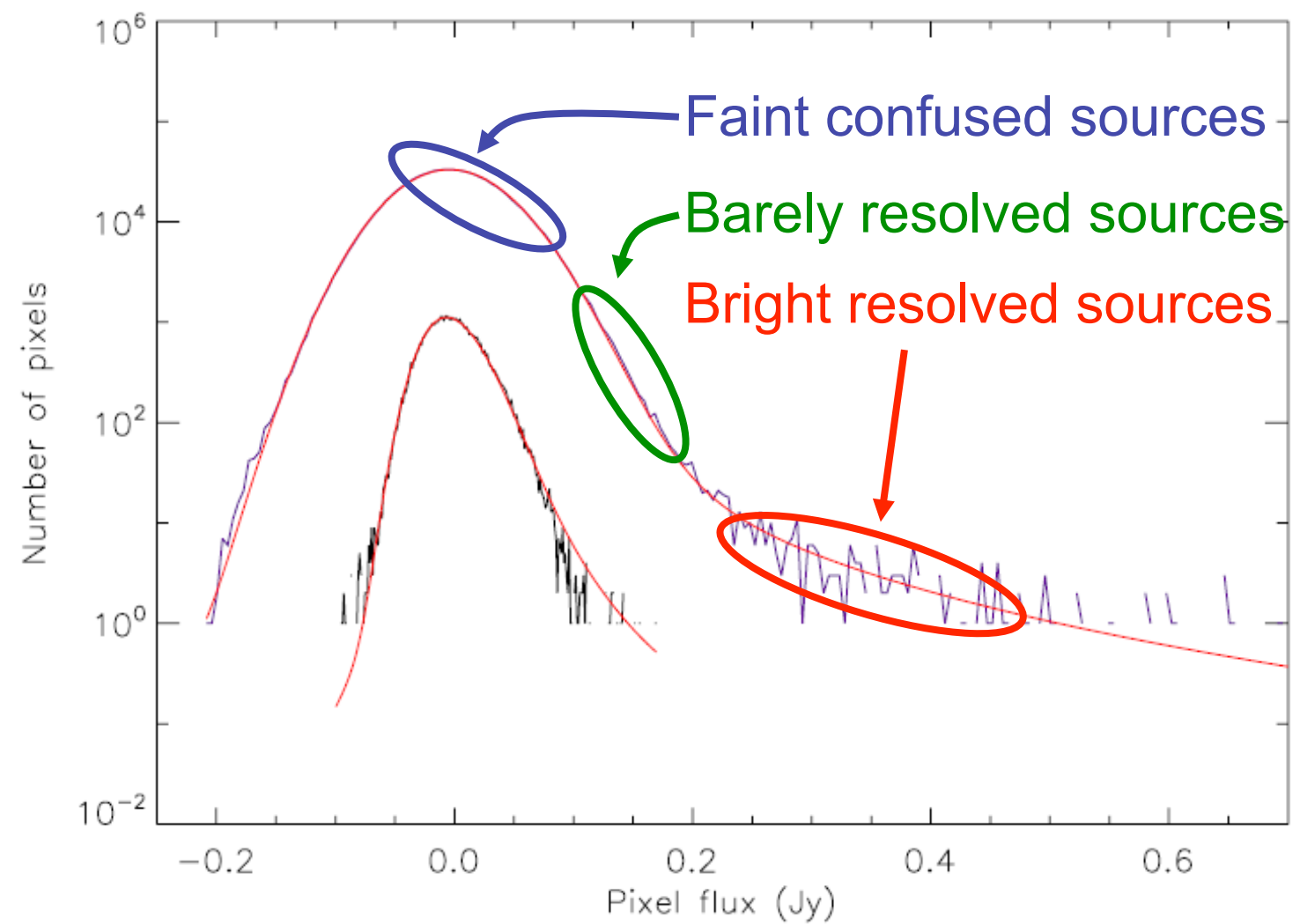
Identifying “Sources”



65 arcsec

Number Counts

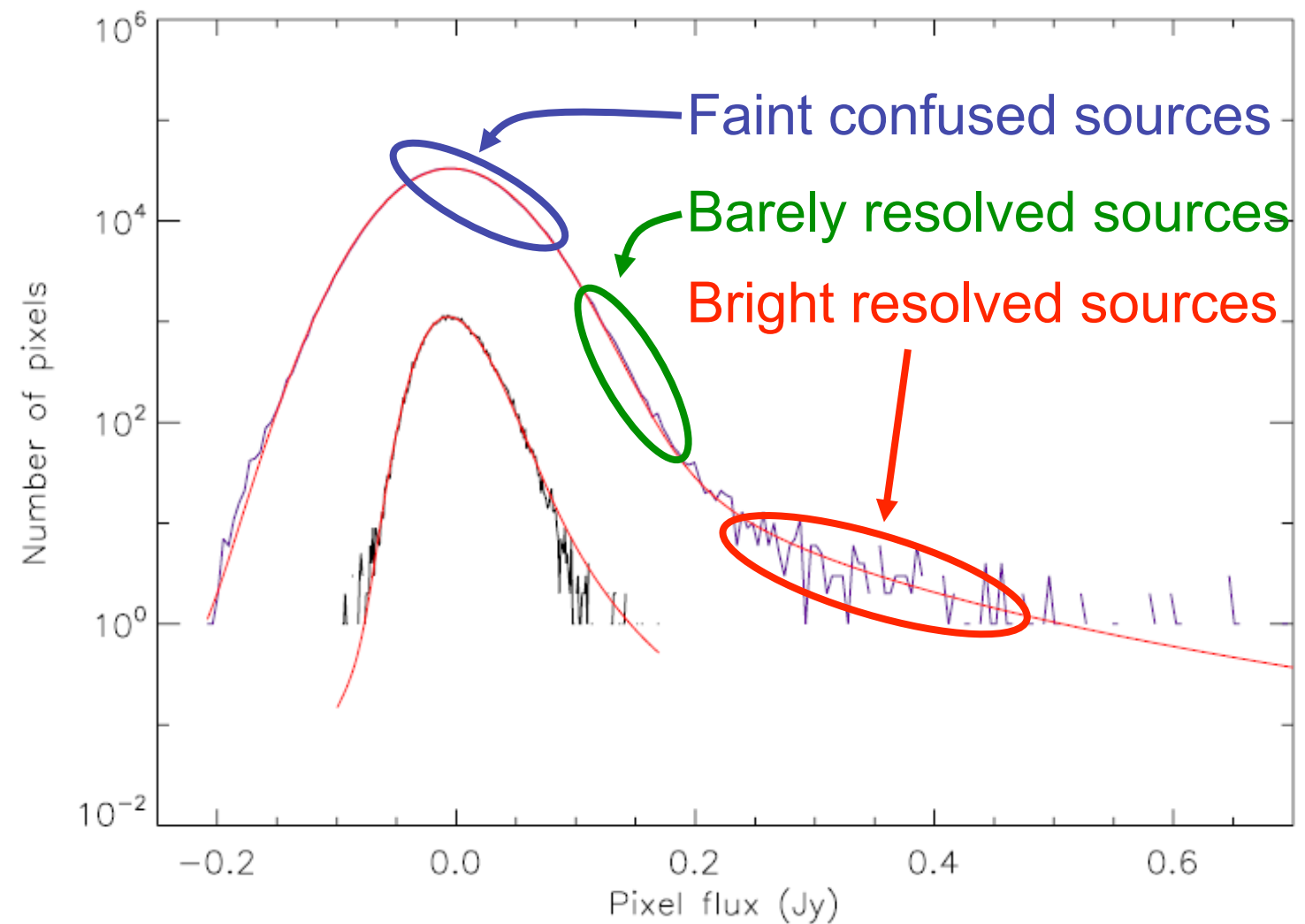
Counts from P(d) analysis



Patanchon et al., 2009

Counts from $P(d)$ analysis

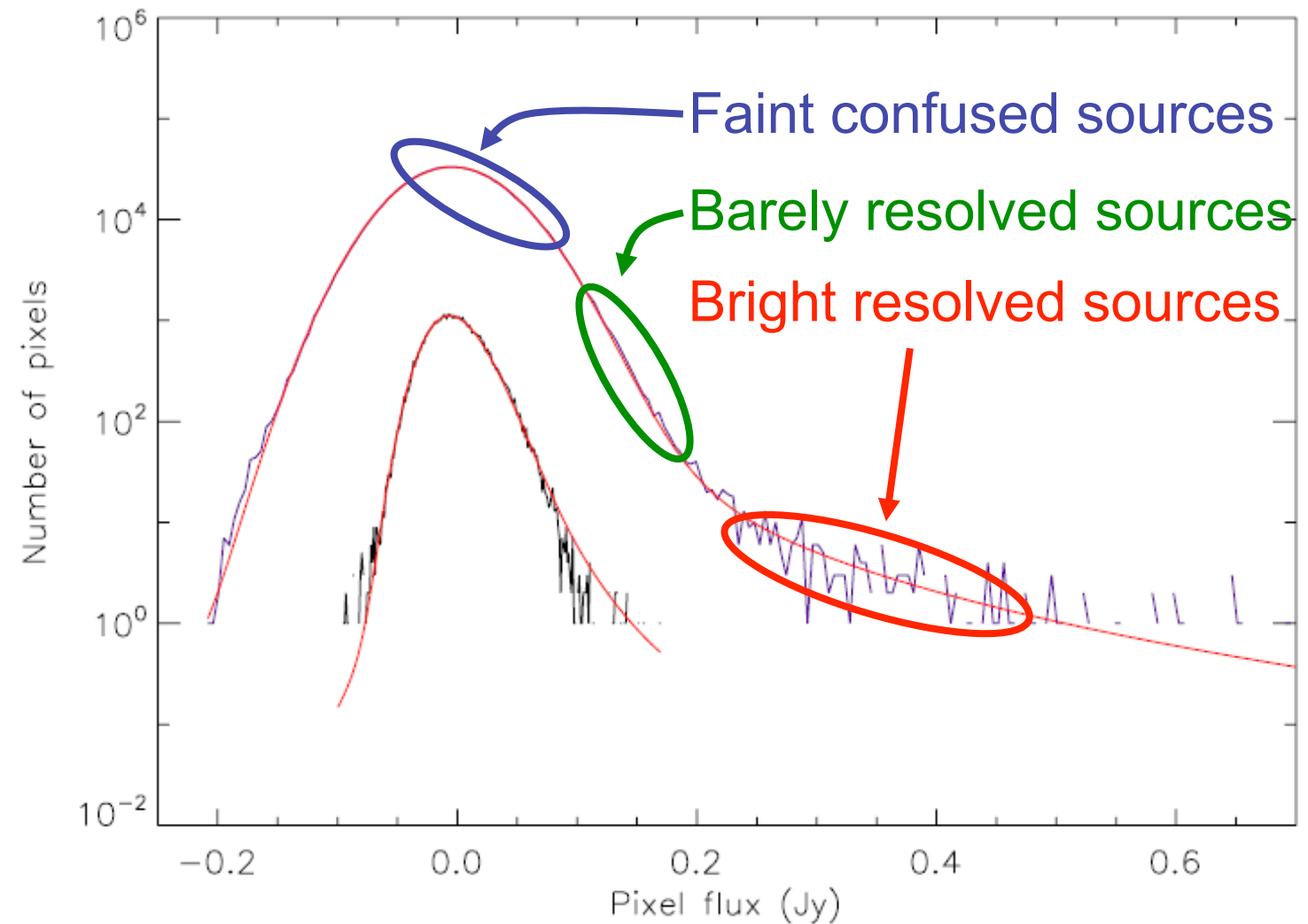
- Pioneered by Radio Astronomers in the 1950's



Patanchon et al., 2009

Counts from $P(d)$ analysis

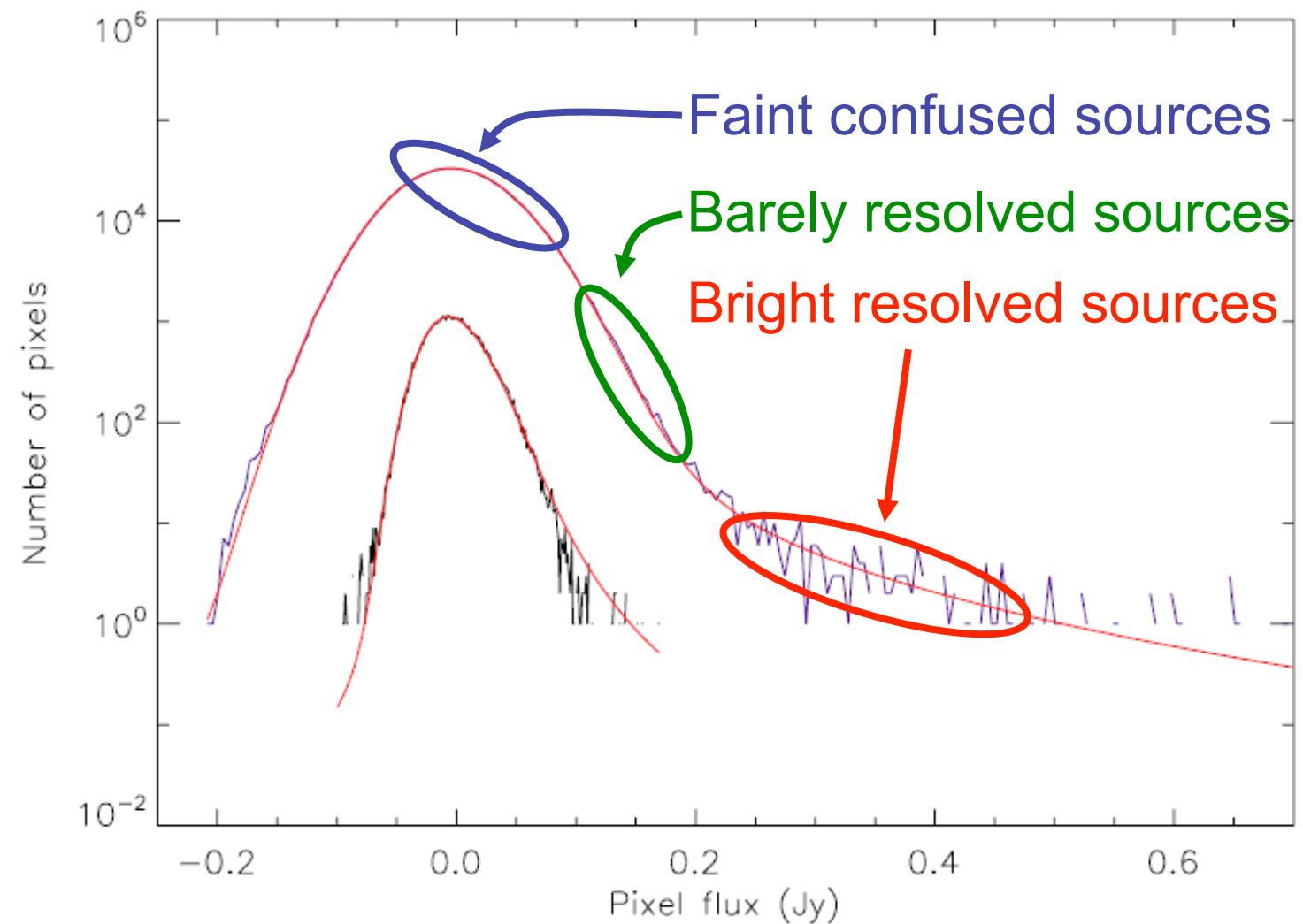
- Pioneered by Radio Astronomers in the 1950's
- Essentially a histogram of pixel values in a map



Patanchon et al., 2009

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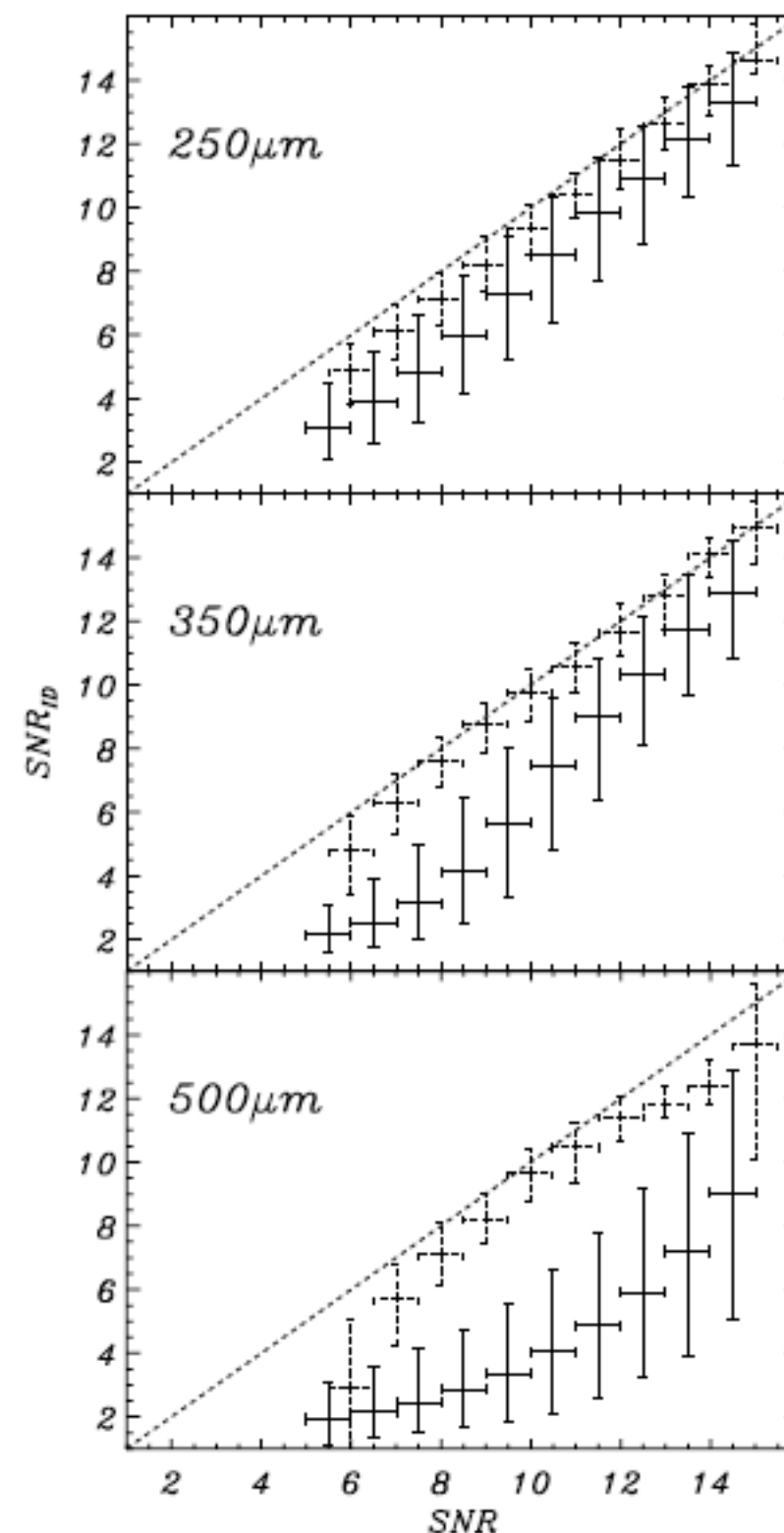
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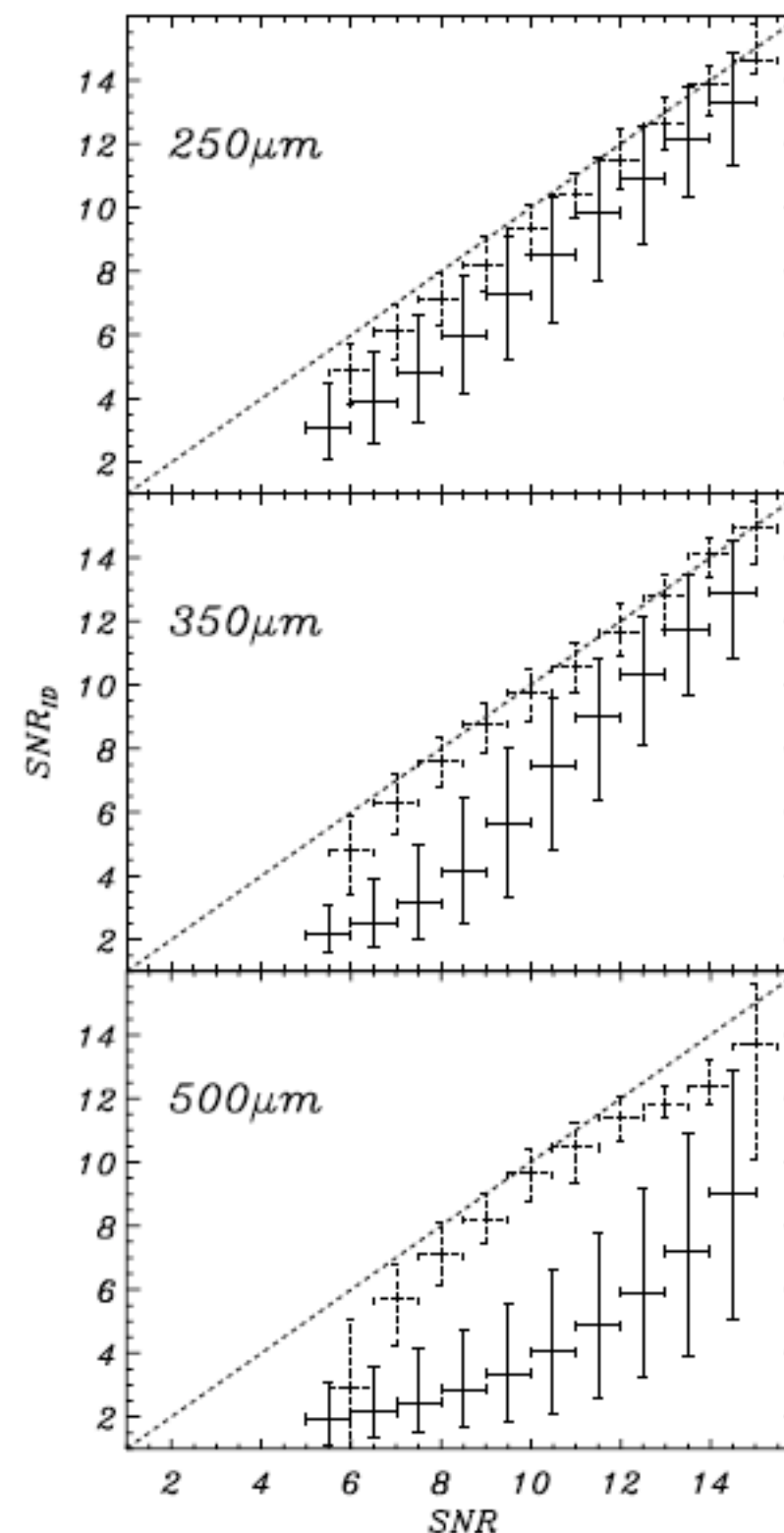
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Monceli et al. (in preparation)

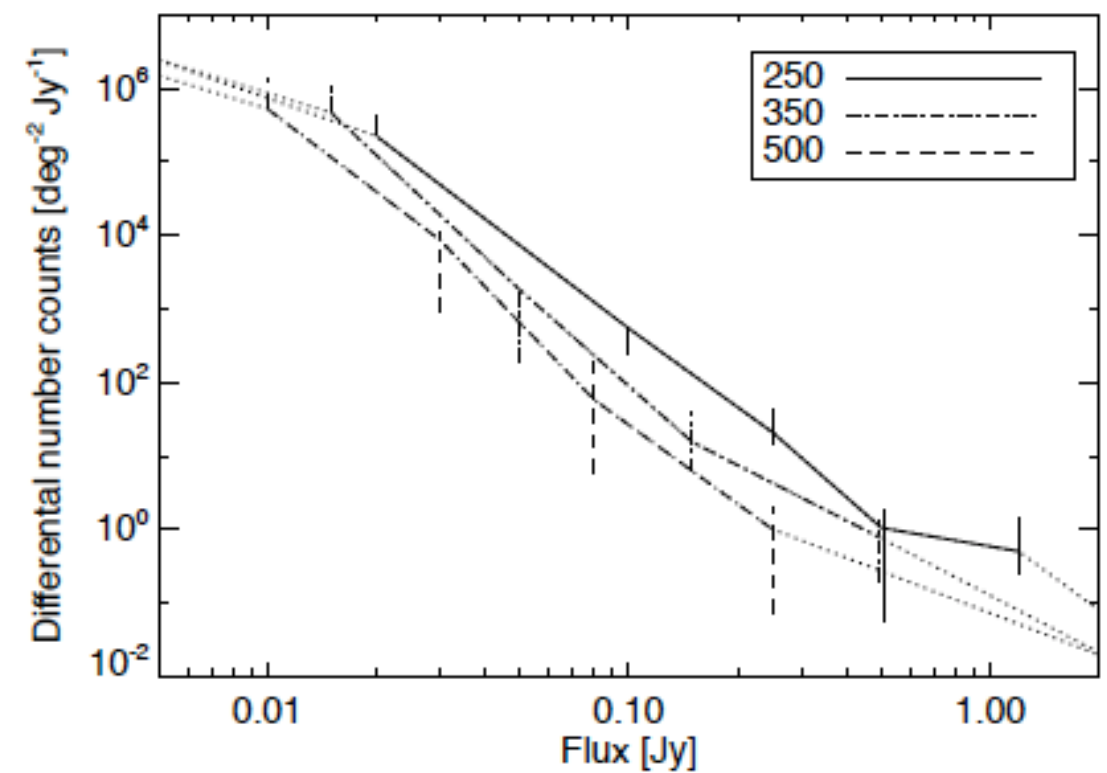
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- Conventional approach is to count bright objects and use $P(d)$ for the faint end
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- In other words: To measure source counts, please don't count sources!



Monceli et al. (in preparation)

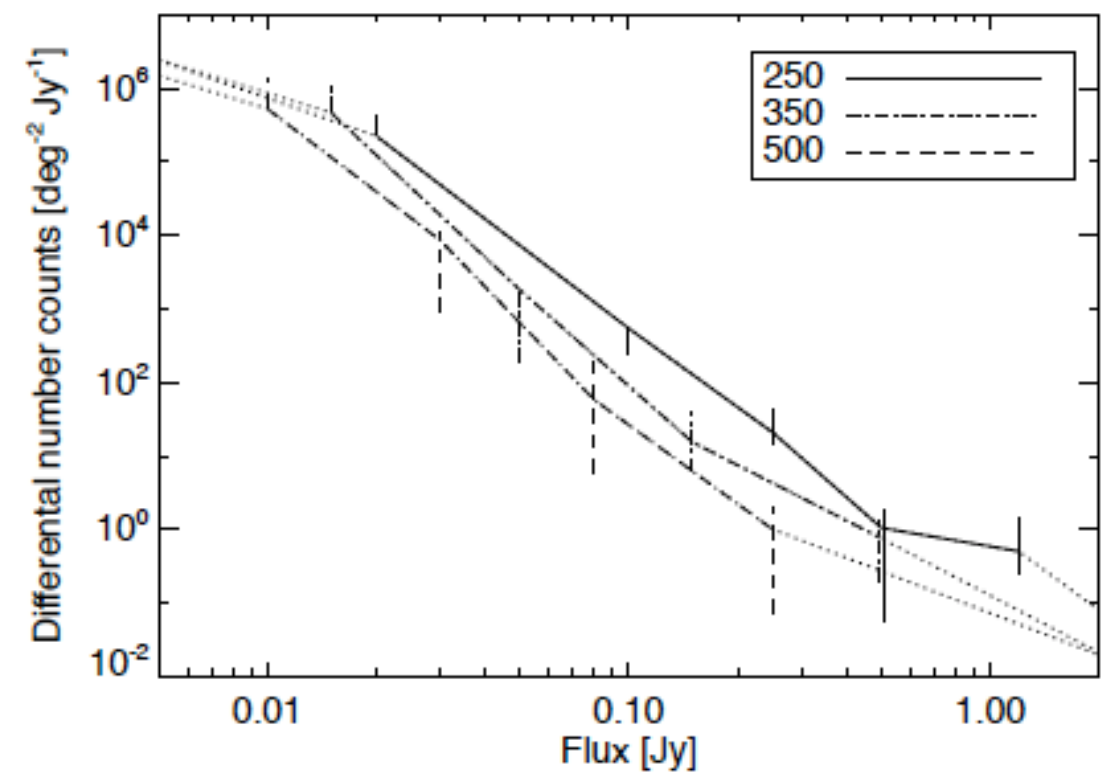
The algorithm



Patanchon et al. 0906.0891

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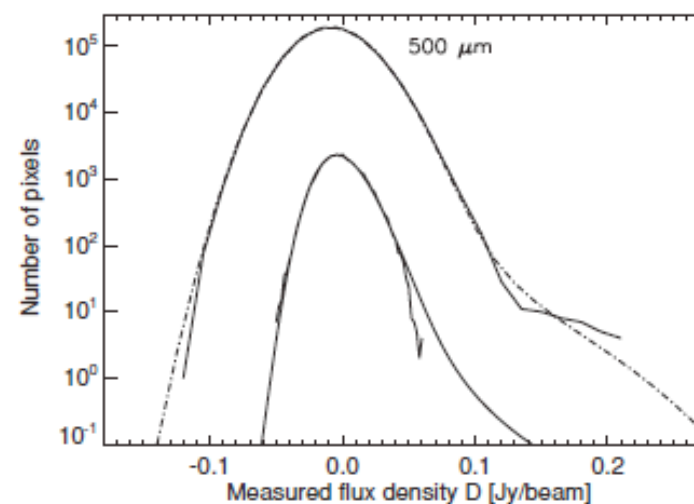
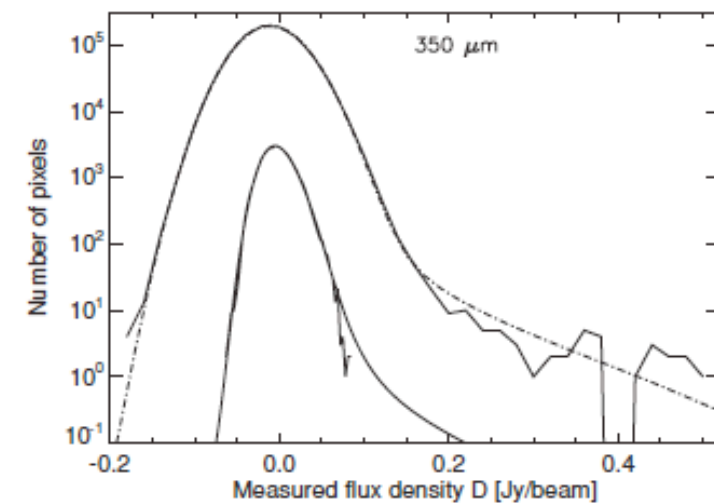
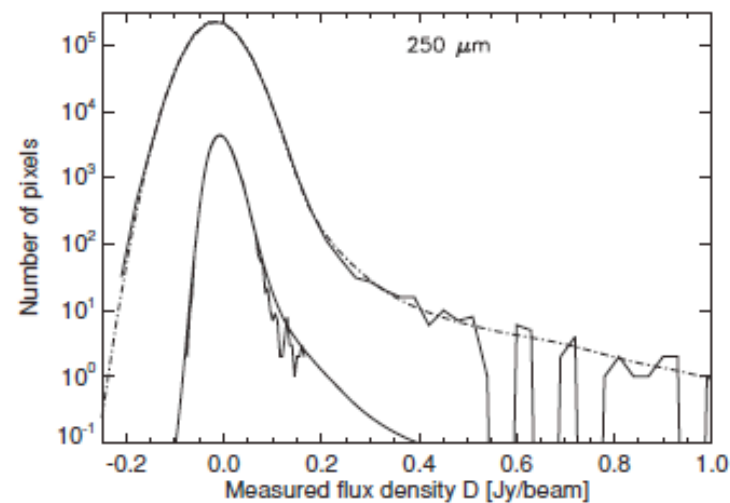
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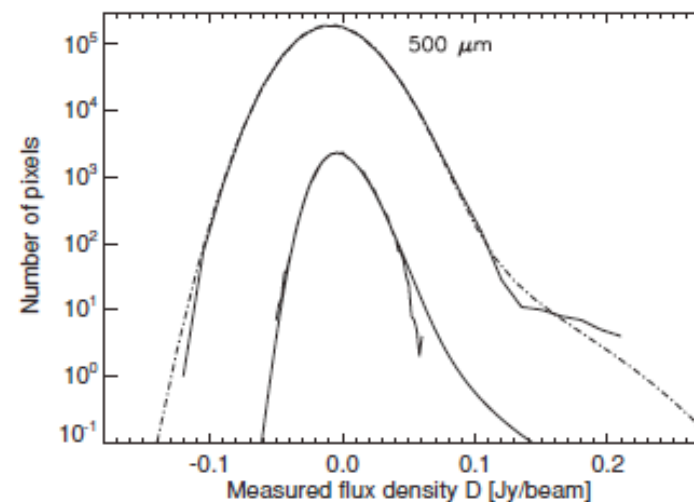
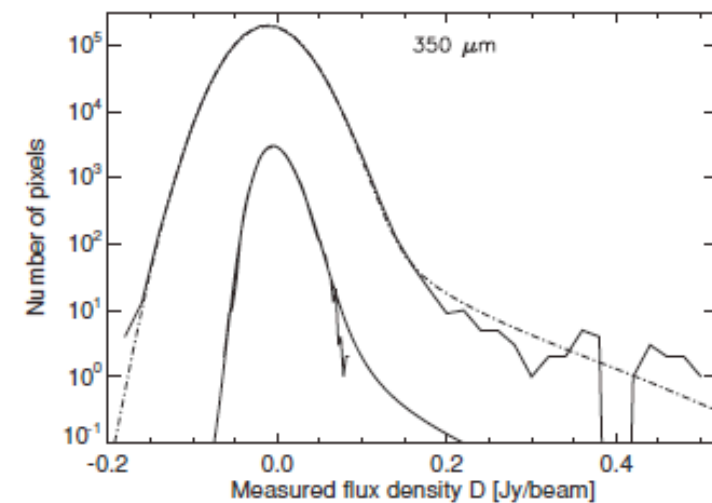
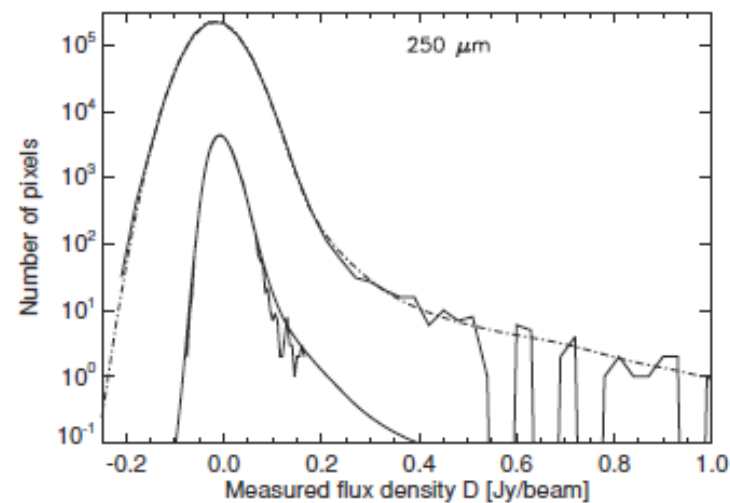
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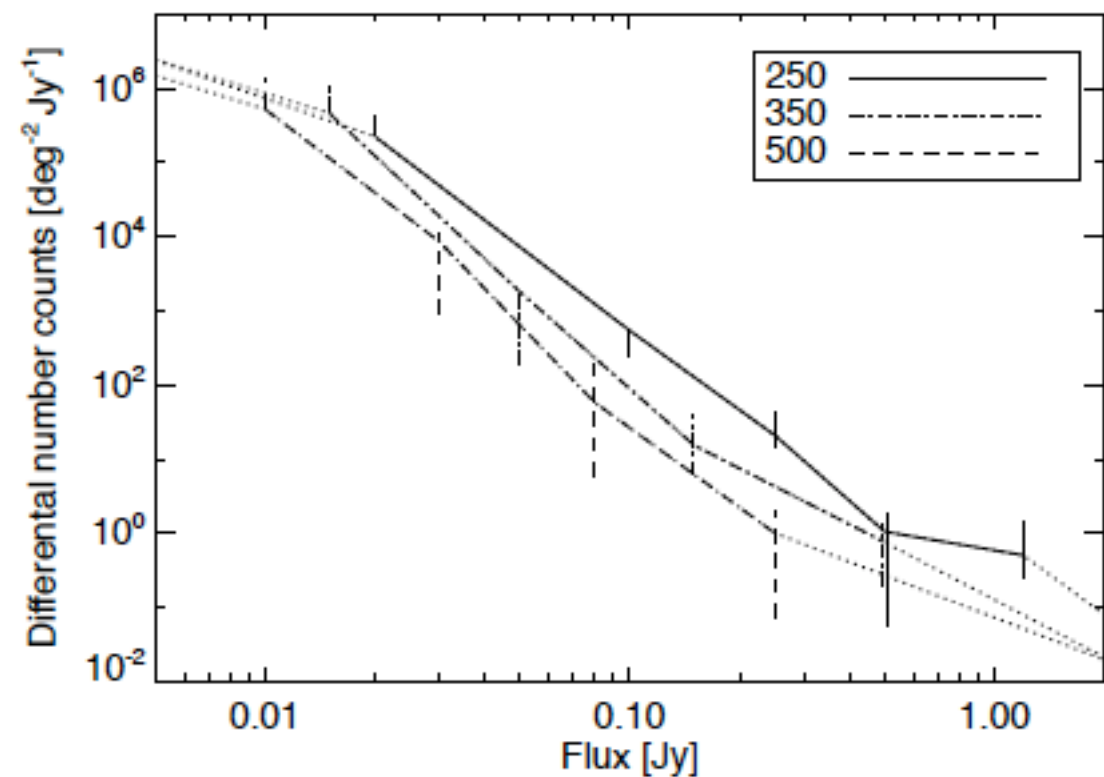
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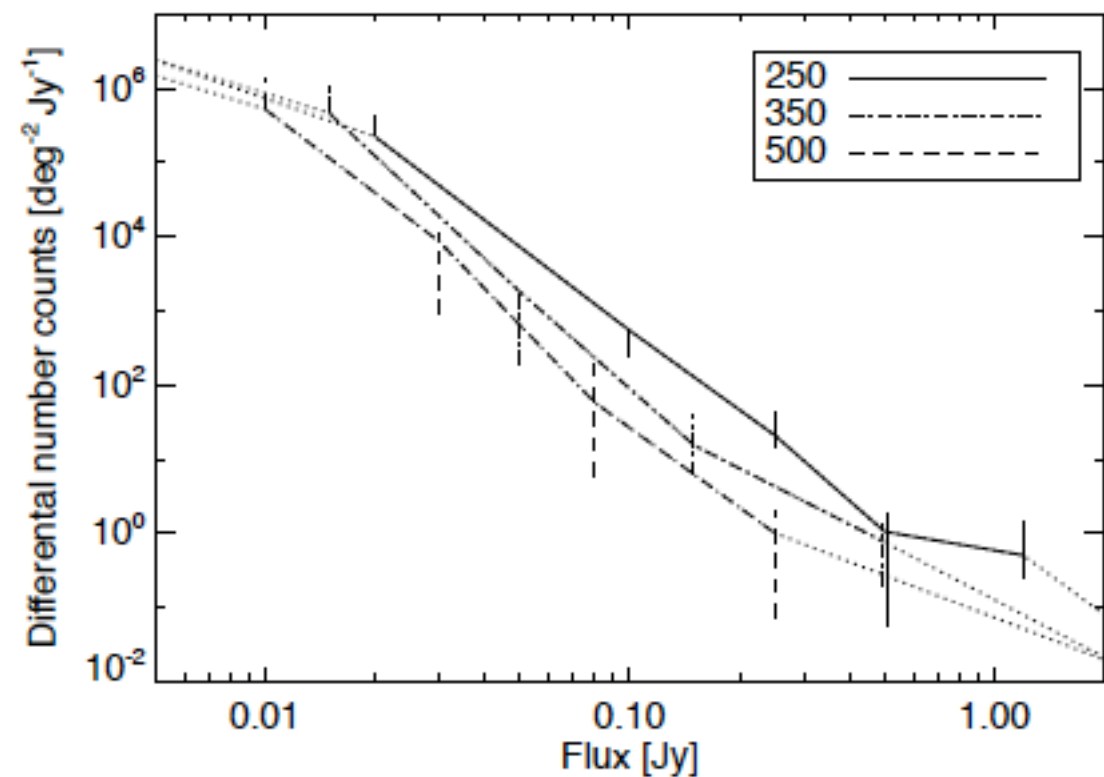
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Patanchon et al. 0906.0891

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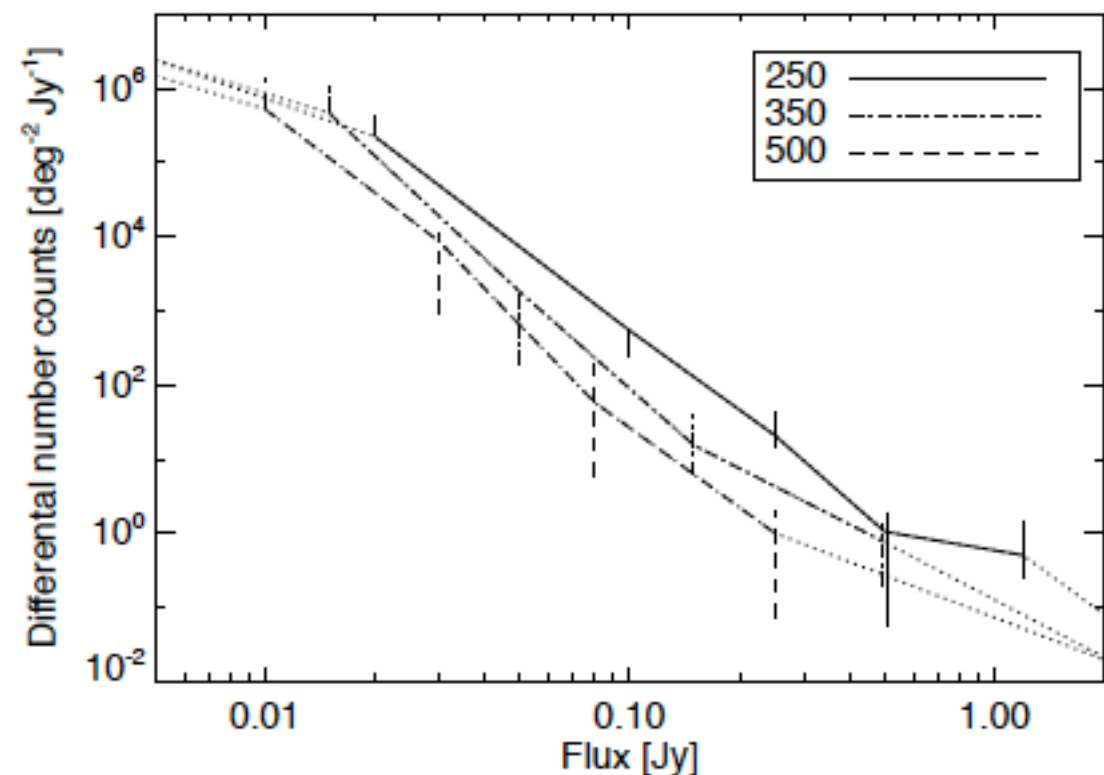
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- Use FIRAS to constrain the faint end
- Note:
 - ◉ Errors Highly Correlated
 - ◉ Assumes Clustering not relevant on scale of the beam. (Analysis more complicated otherwise, as detailed in Patanchon et al. 2009 appendix)

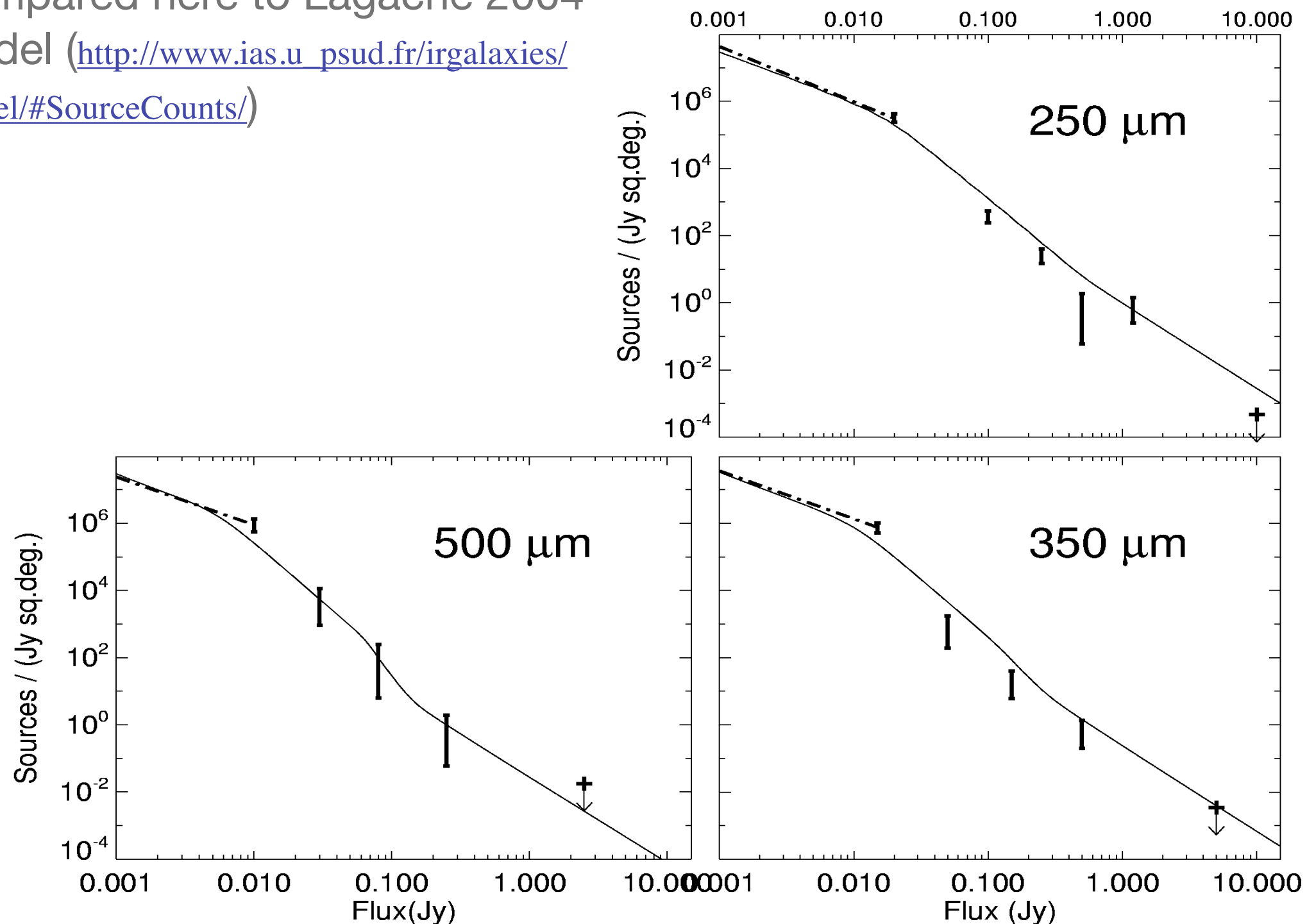


Patanchon et al. 0906.0891

P(d) Results

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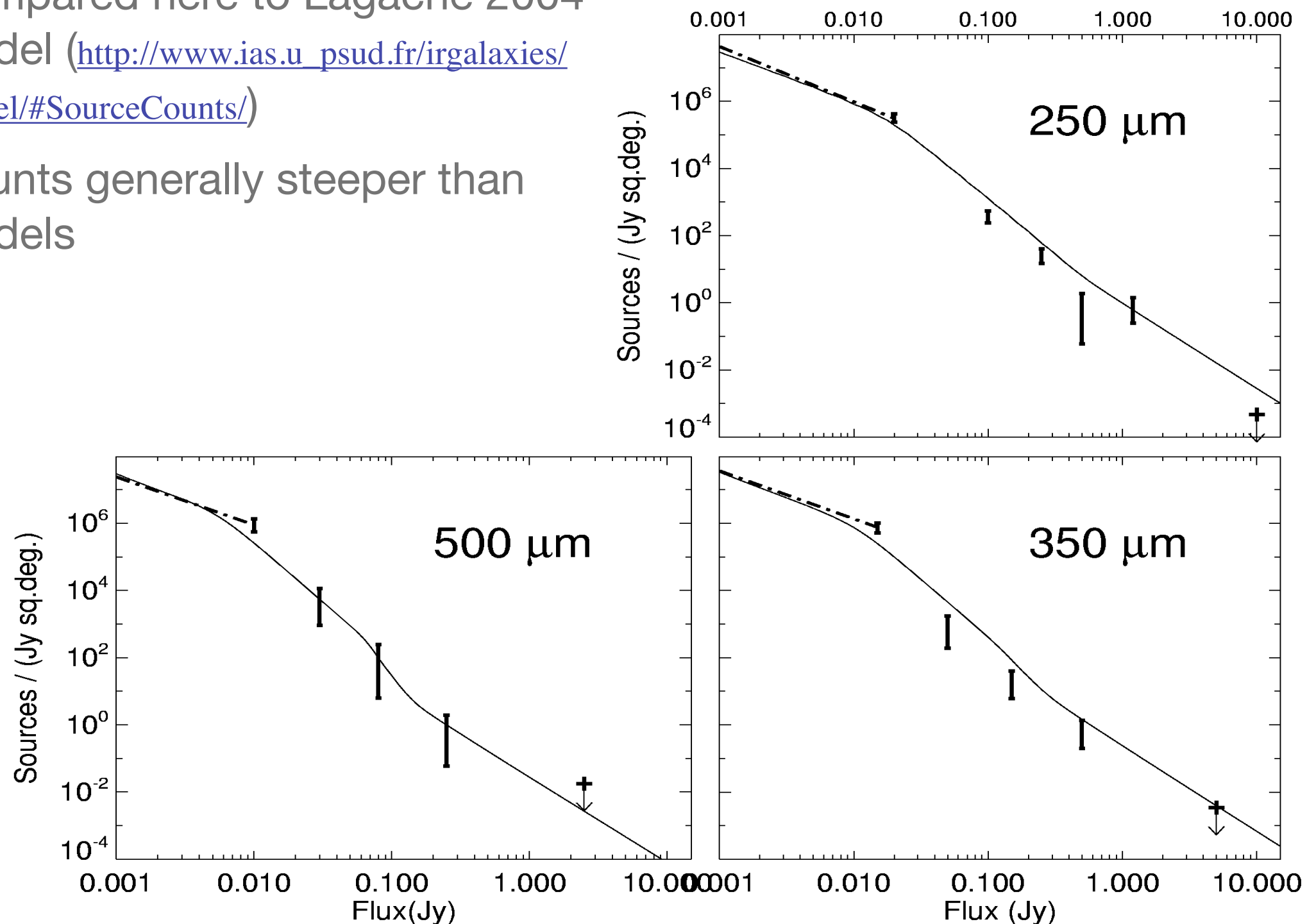
- Compared here to Lagache 2004 model (<http://www.ias.u-psud.fr/irgalaxies/Model/#SourceCounts/>)



Patanchon et al. 0906.0891

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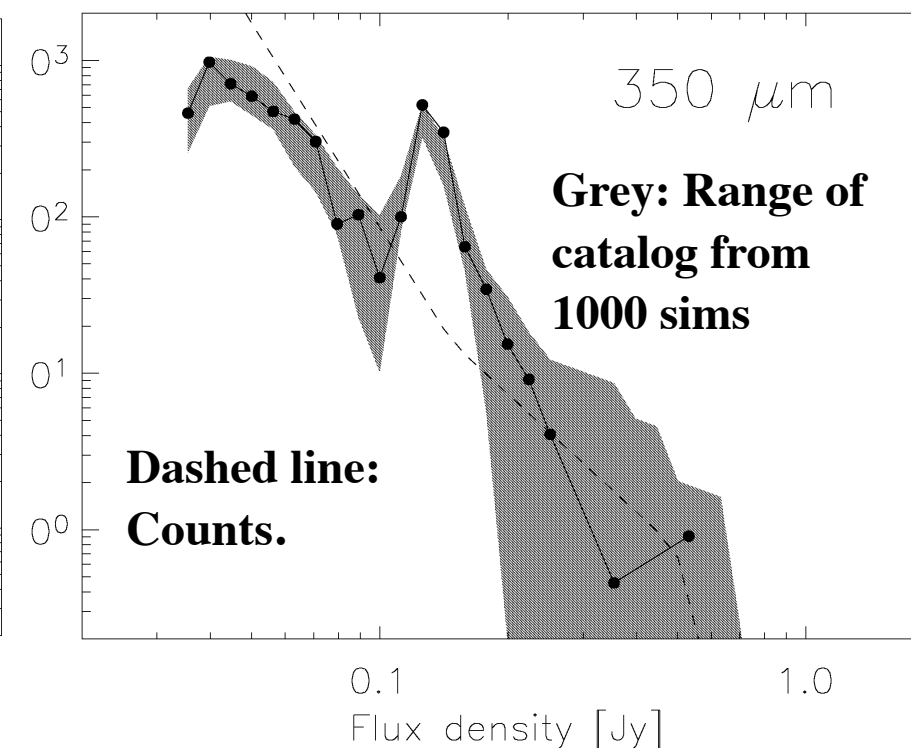
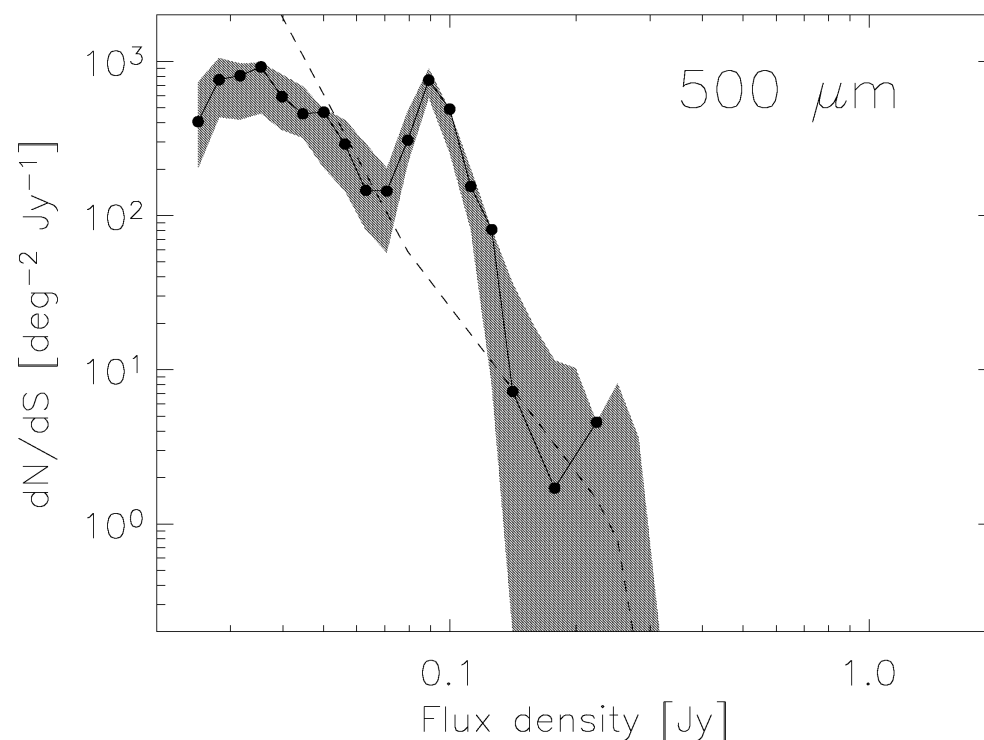
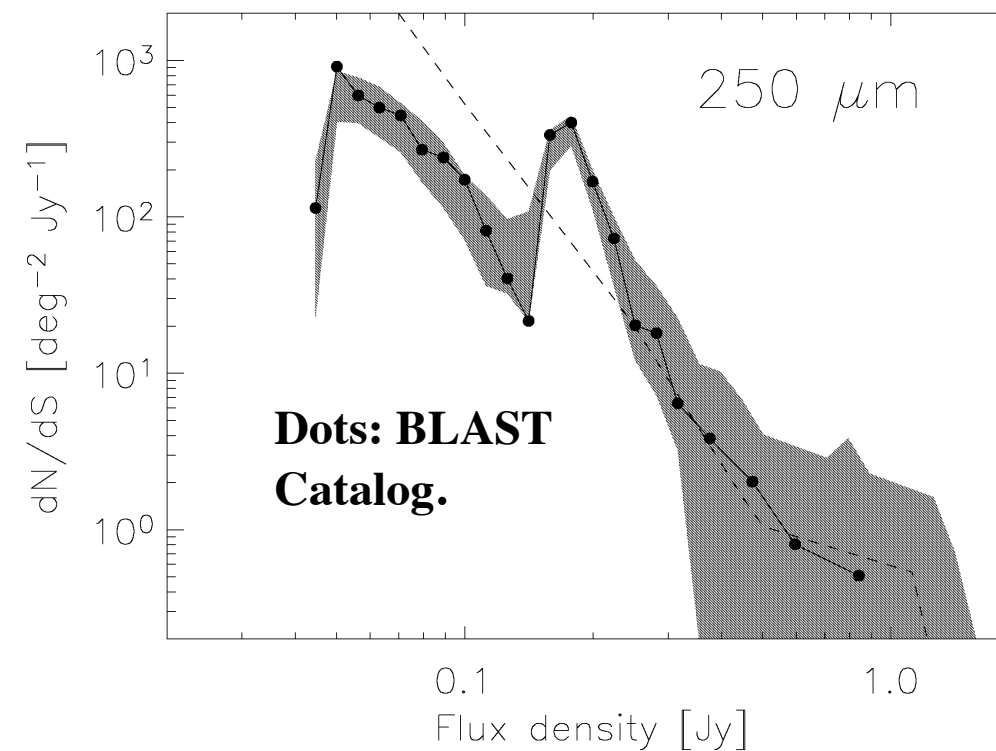
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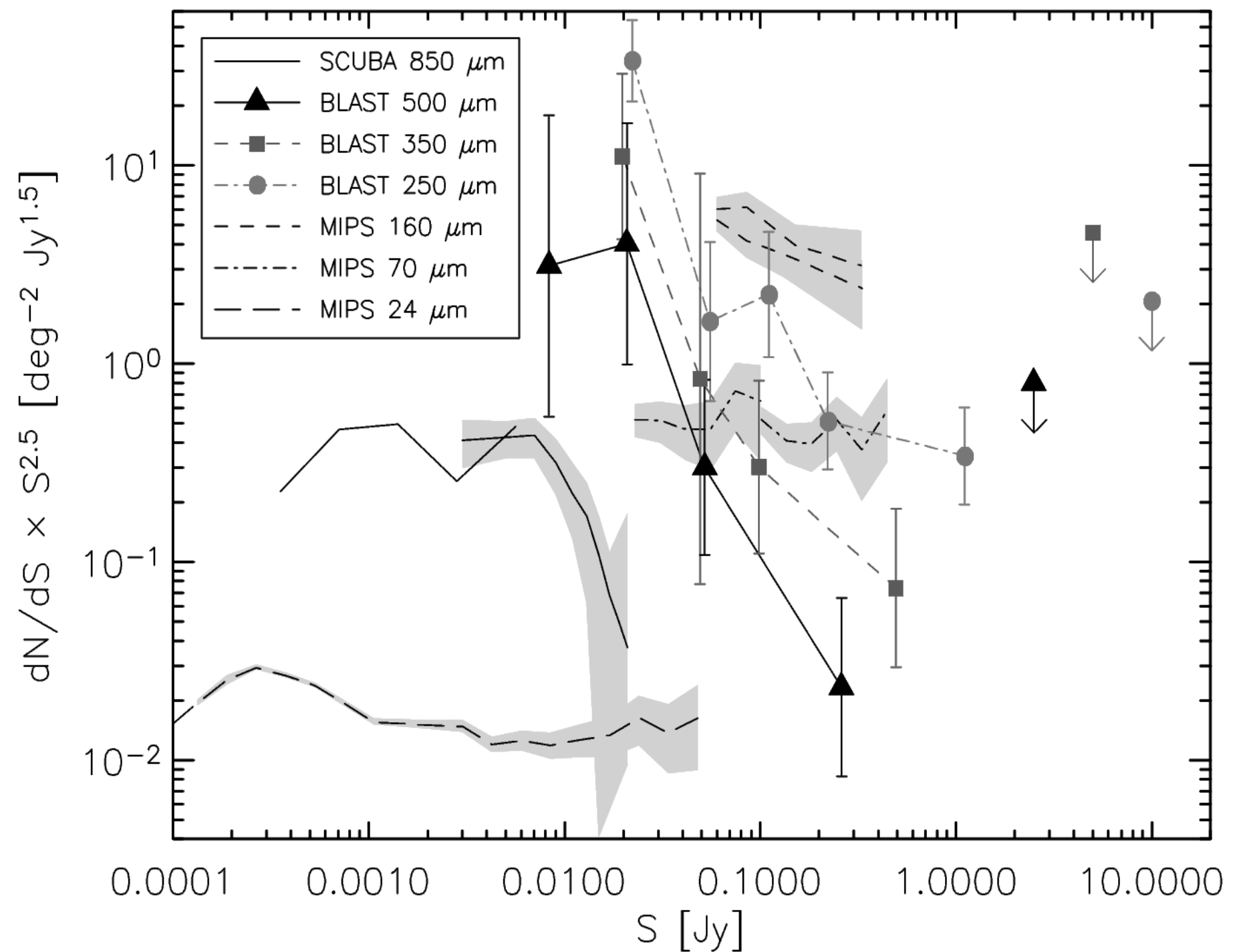
Patanchon et al. 0906.0891

P(d) Results

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- What counting sources looks like



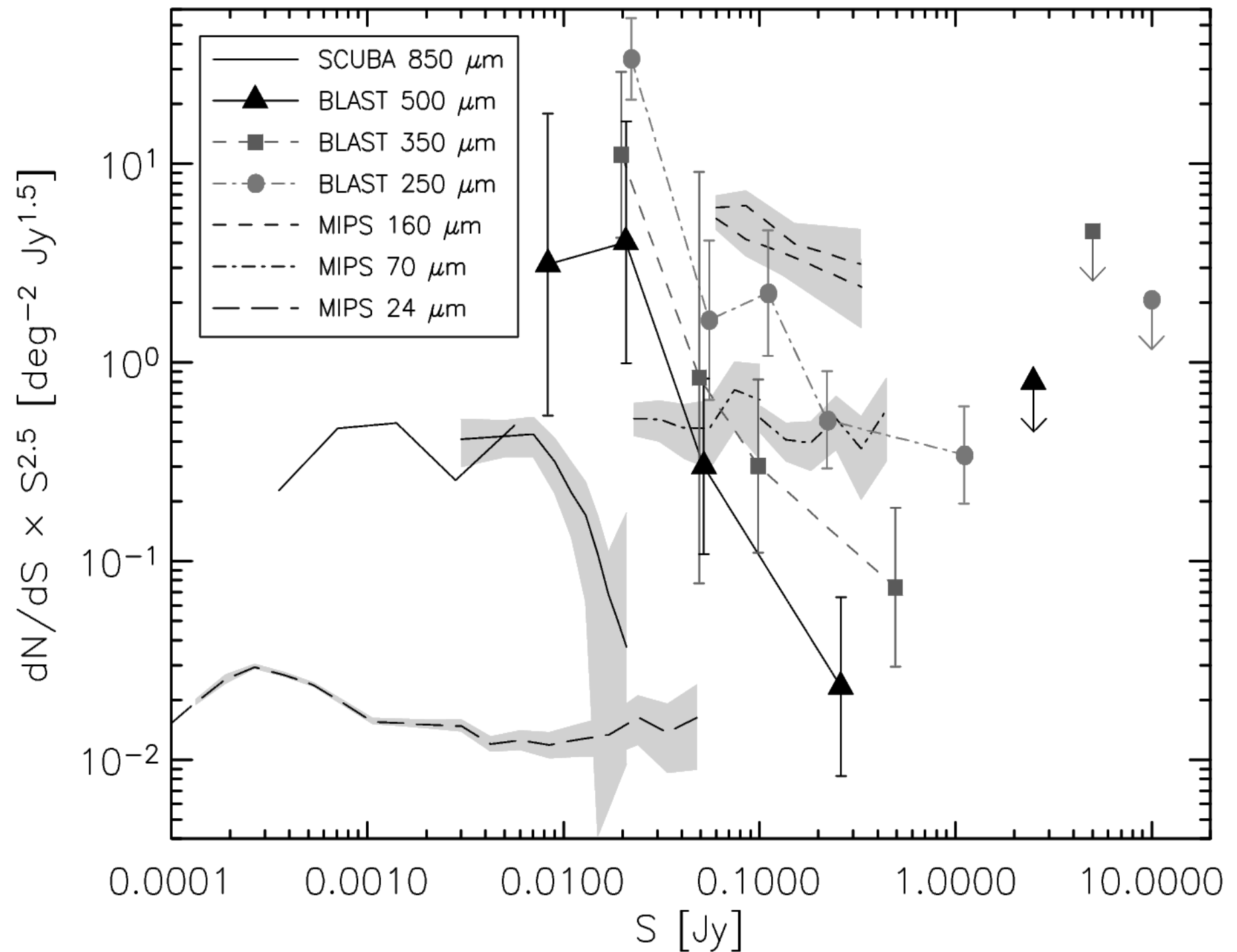
“Euclideanized” counts at FIR/submm wavelengths



Devlin et al. 0904.1201

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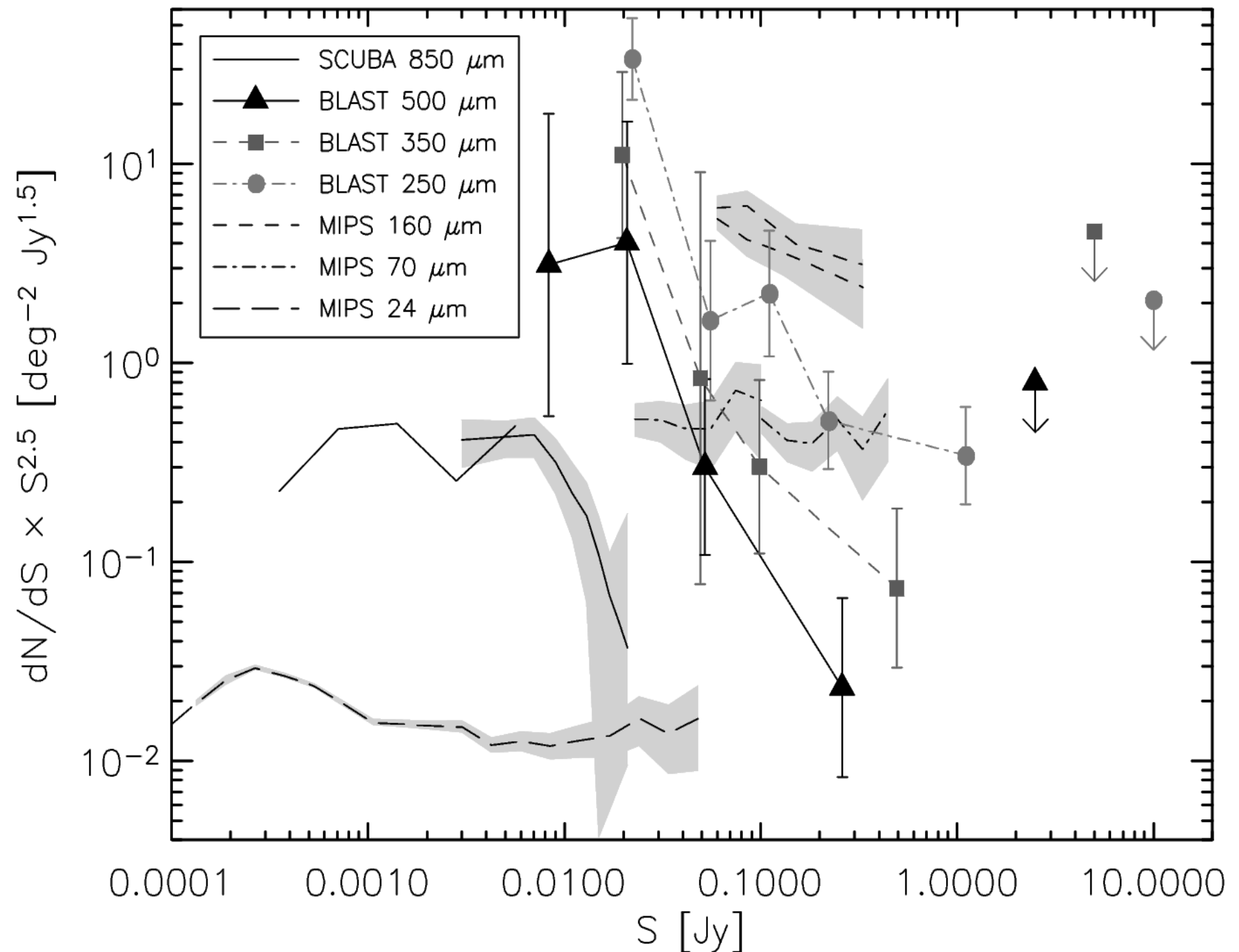
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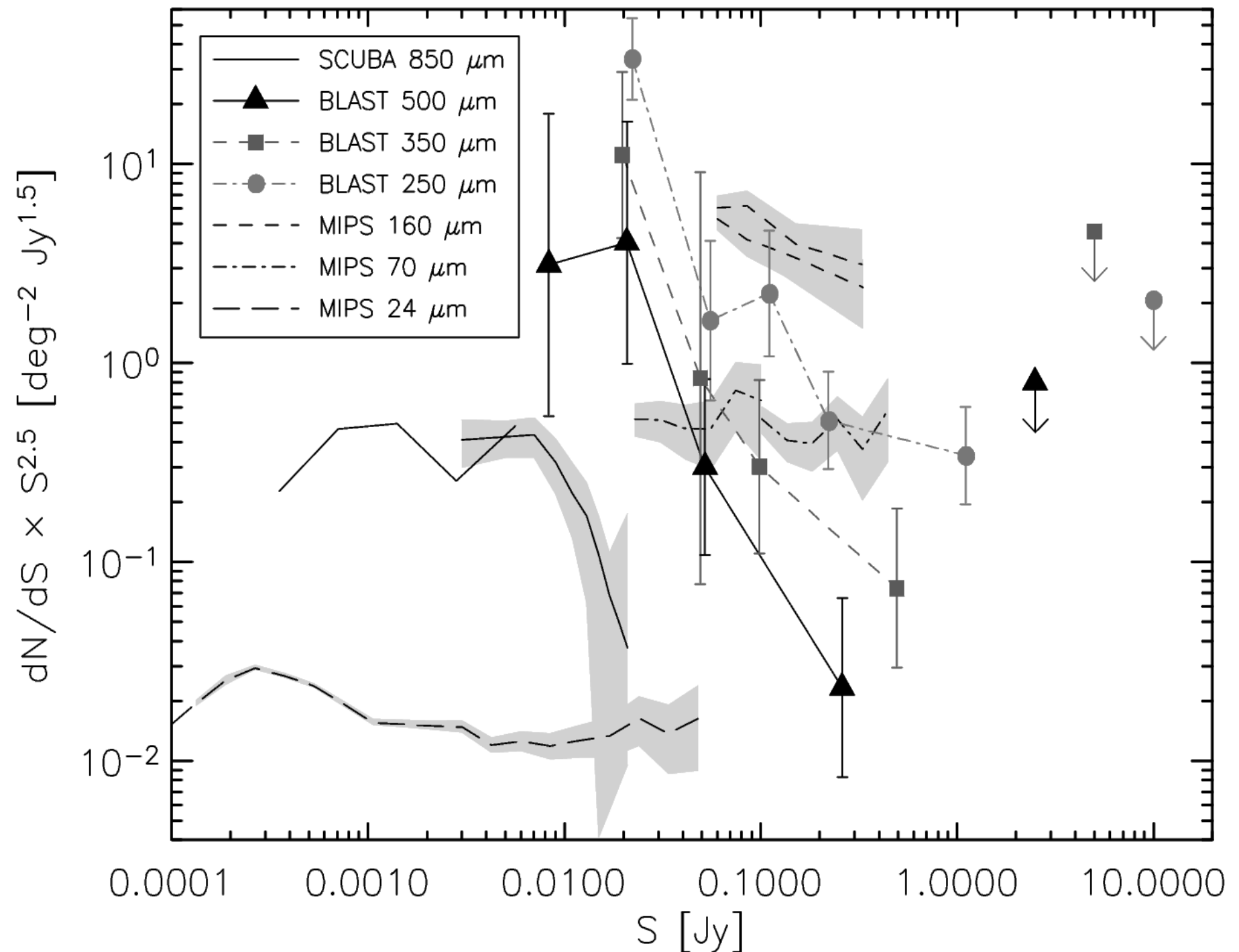
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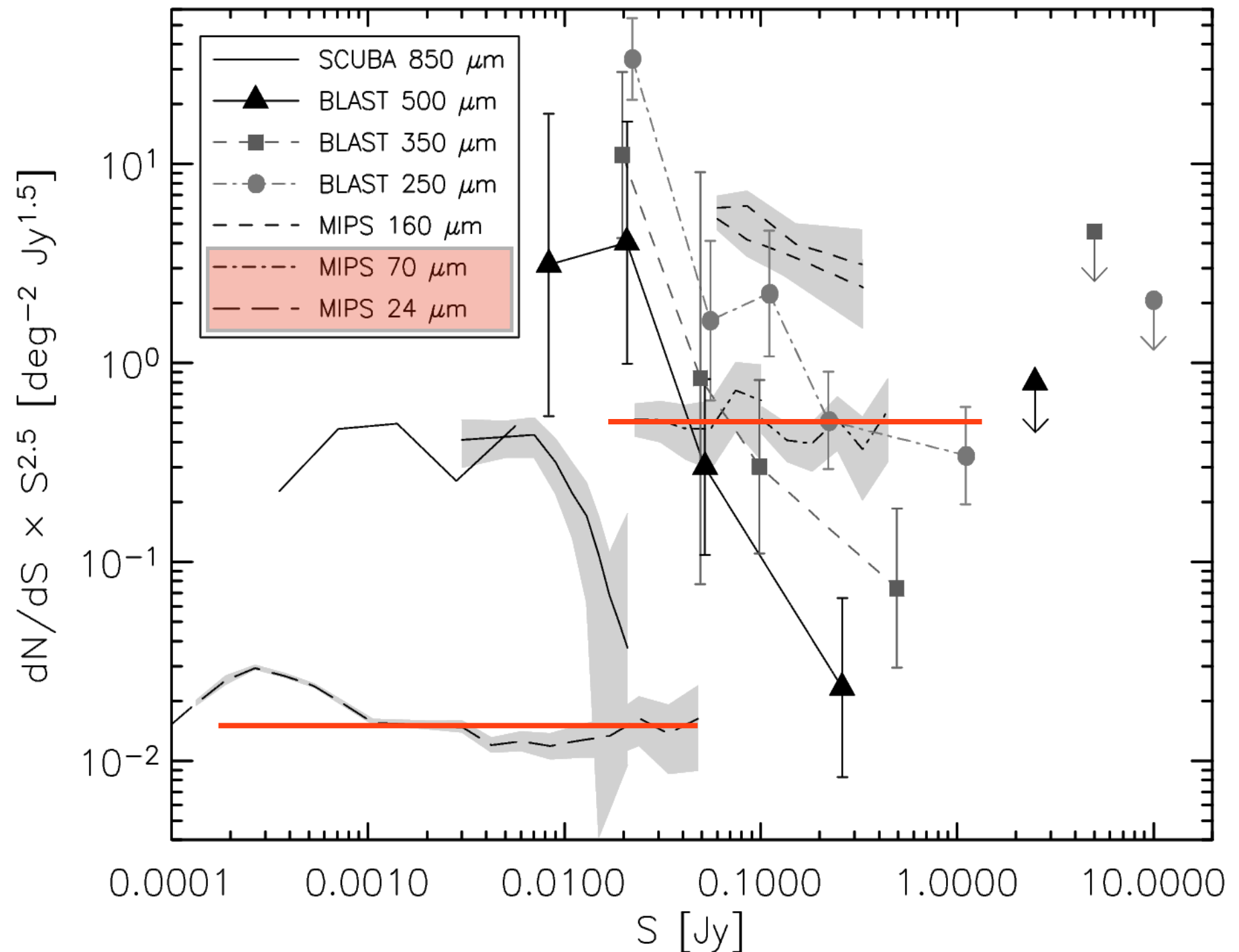
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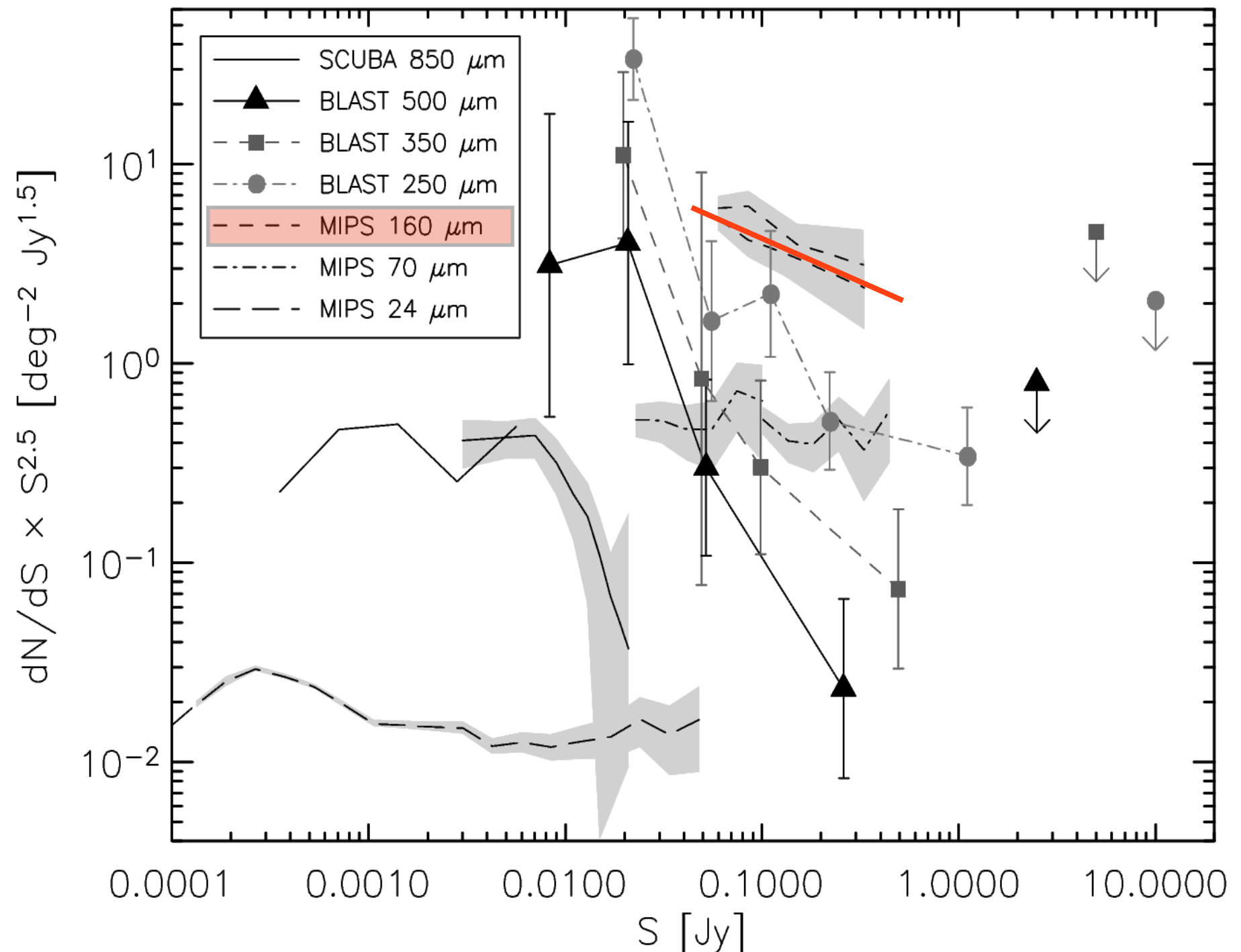
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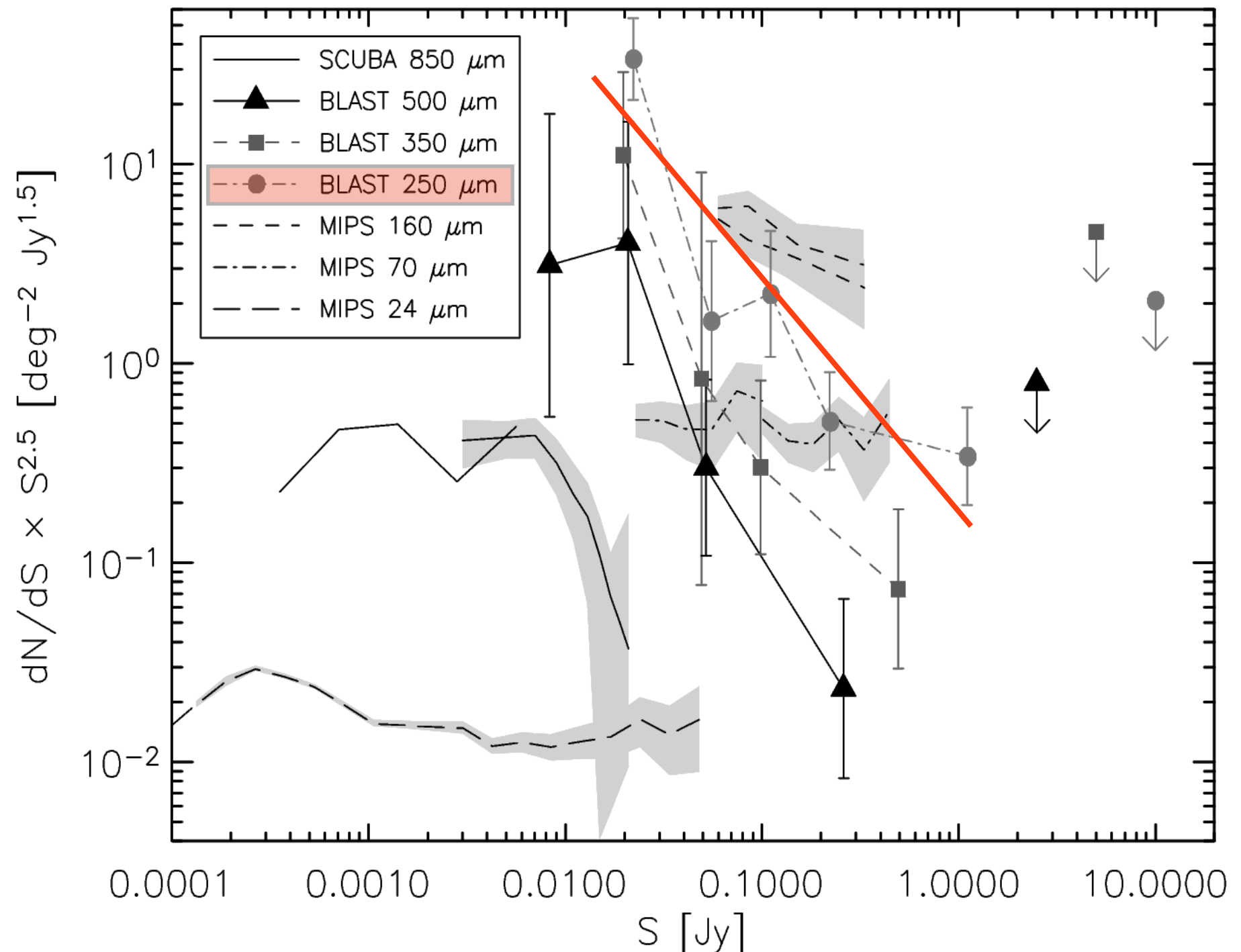
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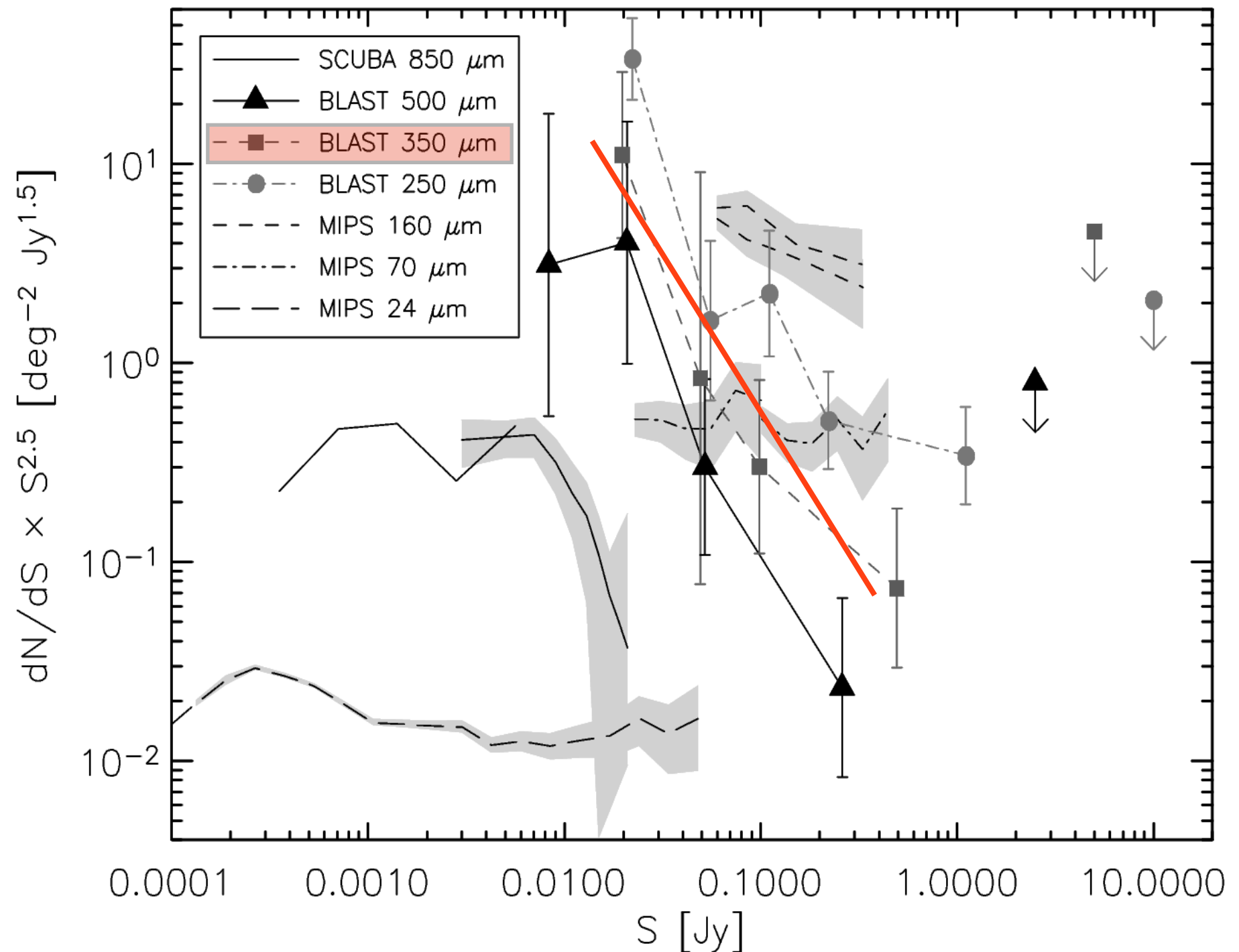
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Devlin et al. 0904.1201

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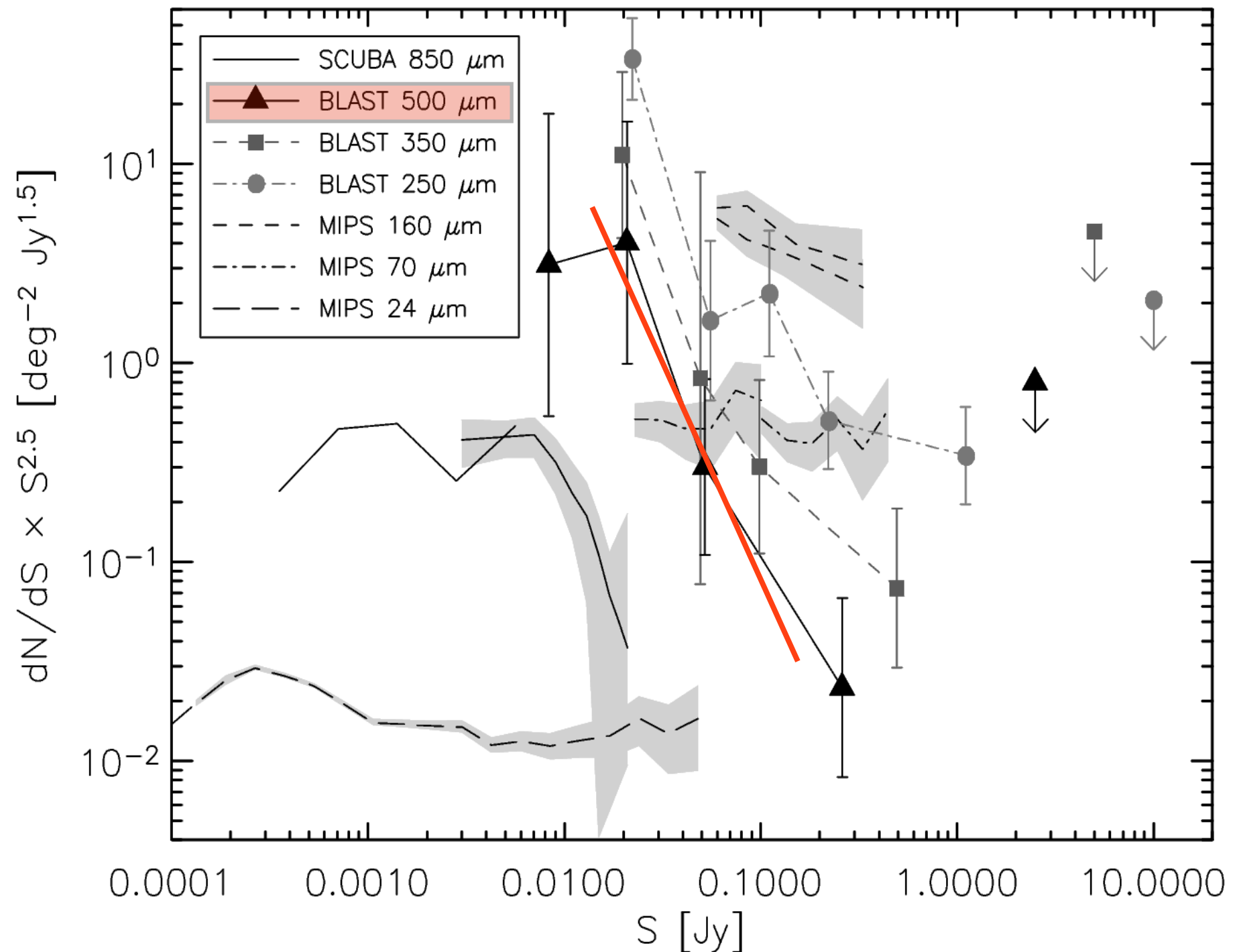
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Devlin et al. 0904.1201

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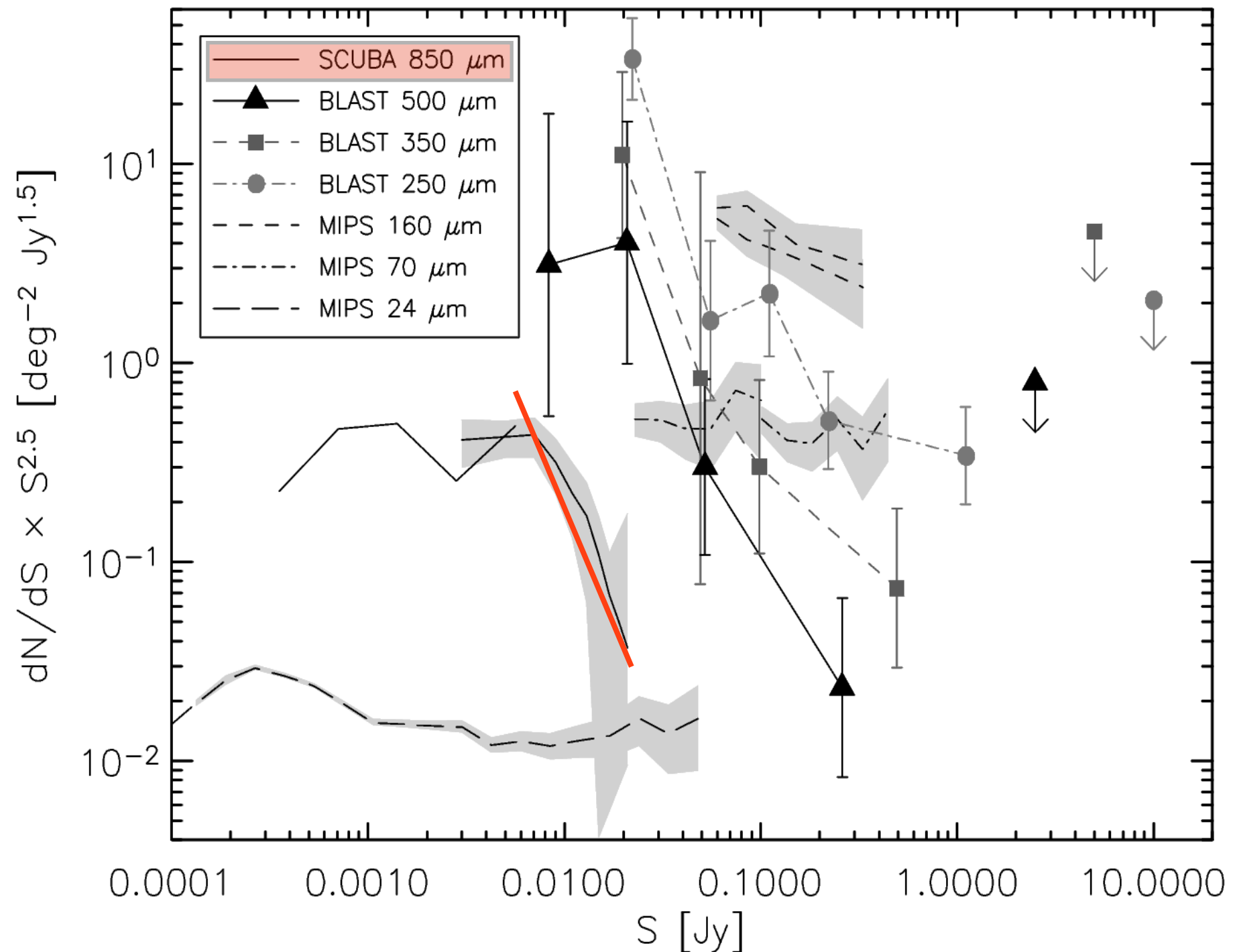
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Devlin et al. 0904.1201

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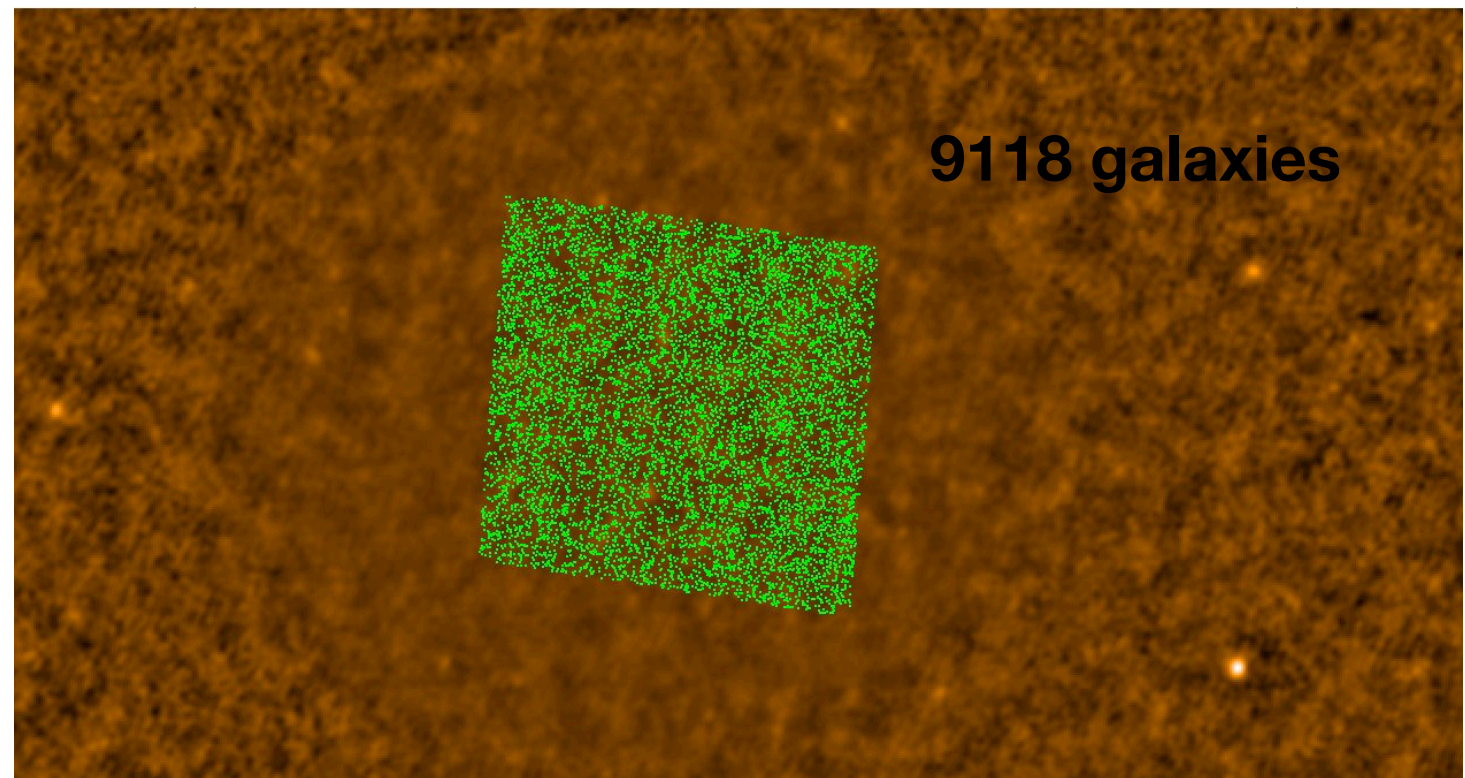
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- 350 steeper still
- 500 as steep as SCUBA
- SCUBA surveys too small to see nearby (Euclidean) galaxies



Devlin et al. 0904.1201

Stacking

Using Great Ancillary Data

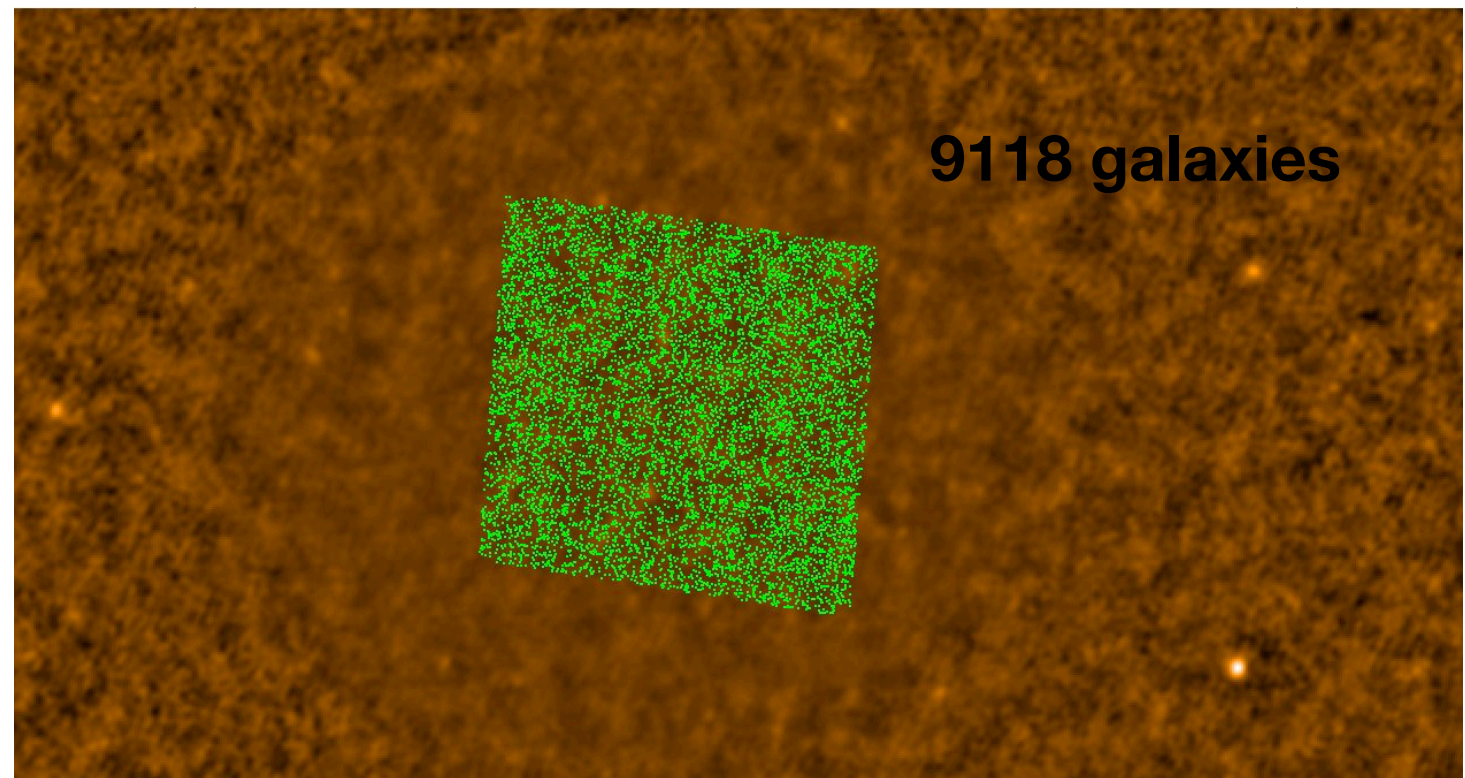


FIDEL 24 micron Catalog

Magnelli et al 2009

Using Great Ancillary Data

- Stack to find mean flux of catalog

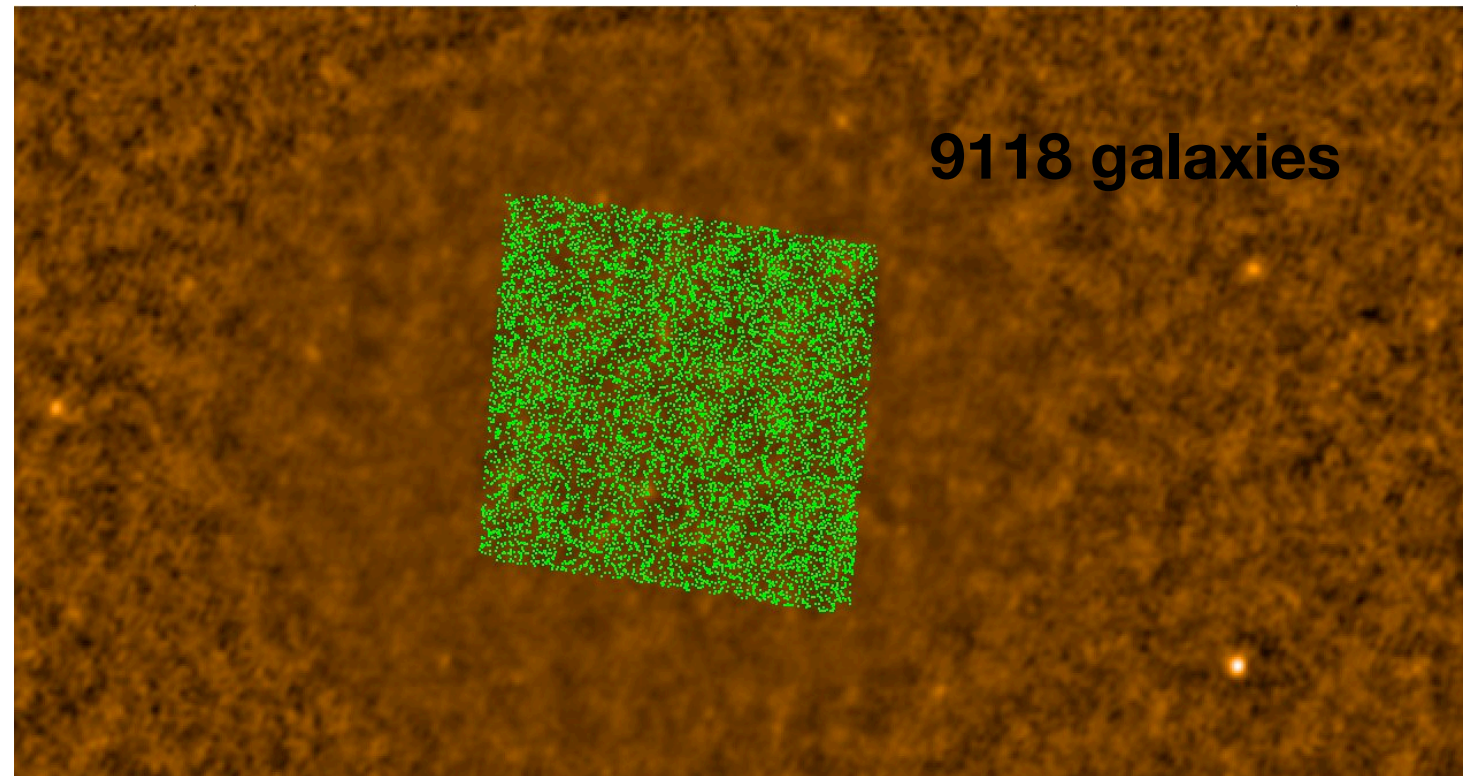


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- From our counts, predict 3×10^4 sources / deg^2 with $S > 1$ mJy, so naively expect the mean flux of sources in catalog > 1 mJy.



FIDEL 24 micron Catalog

Magnelli et al 2009

Obtaining the mean flux of a catalog.

Imagine that 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

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

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

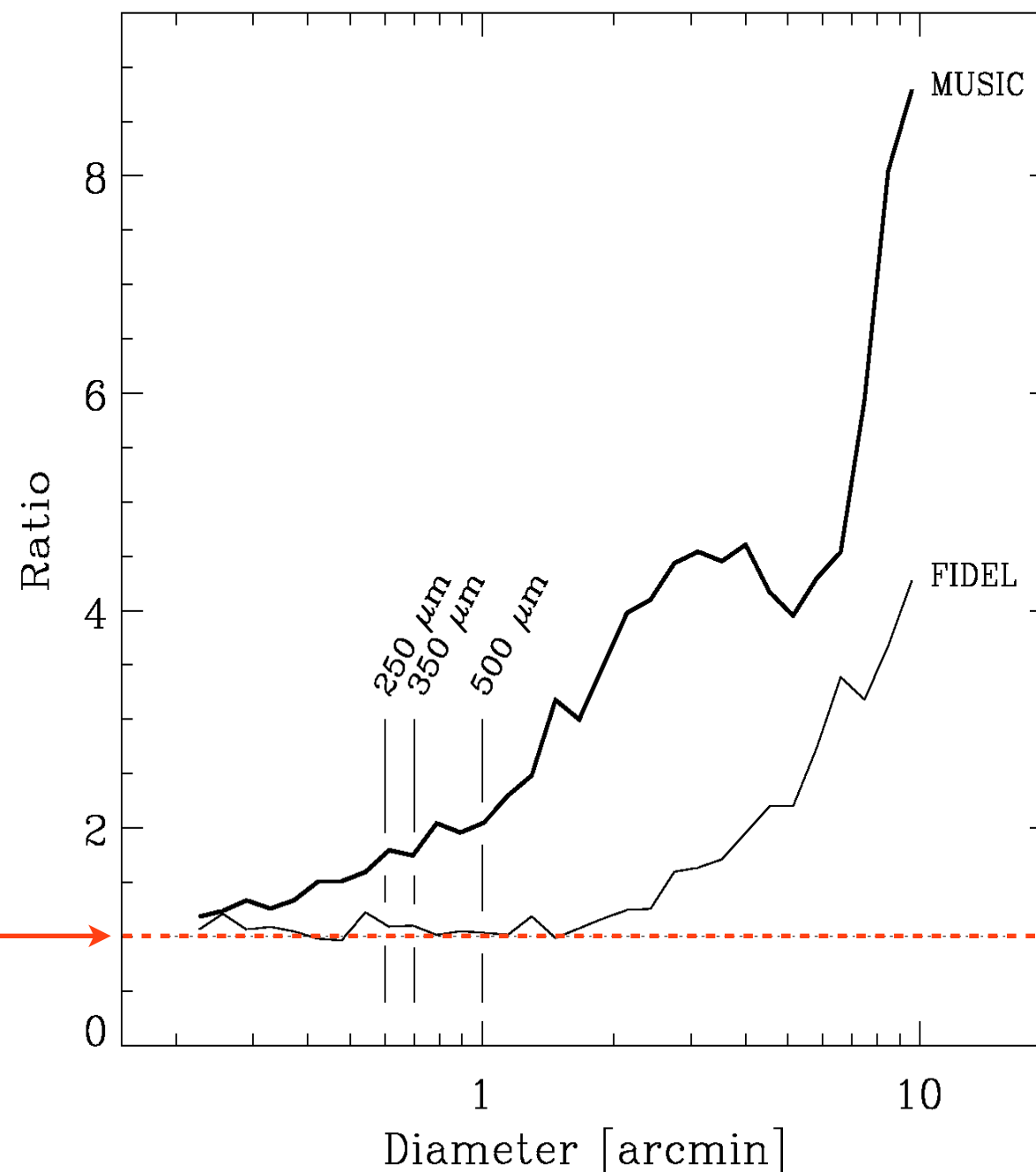
Notice that the covariance can be found from a sum over the catalog.

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

Using Great Ancillary Data

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- Stacking algorithm requires catalog sources uncorrelated on the scale of the beam
 - ◉ counts in cells shows this to be the case (for FIDEL!)

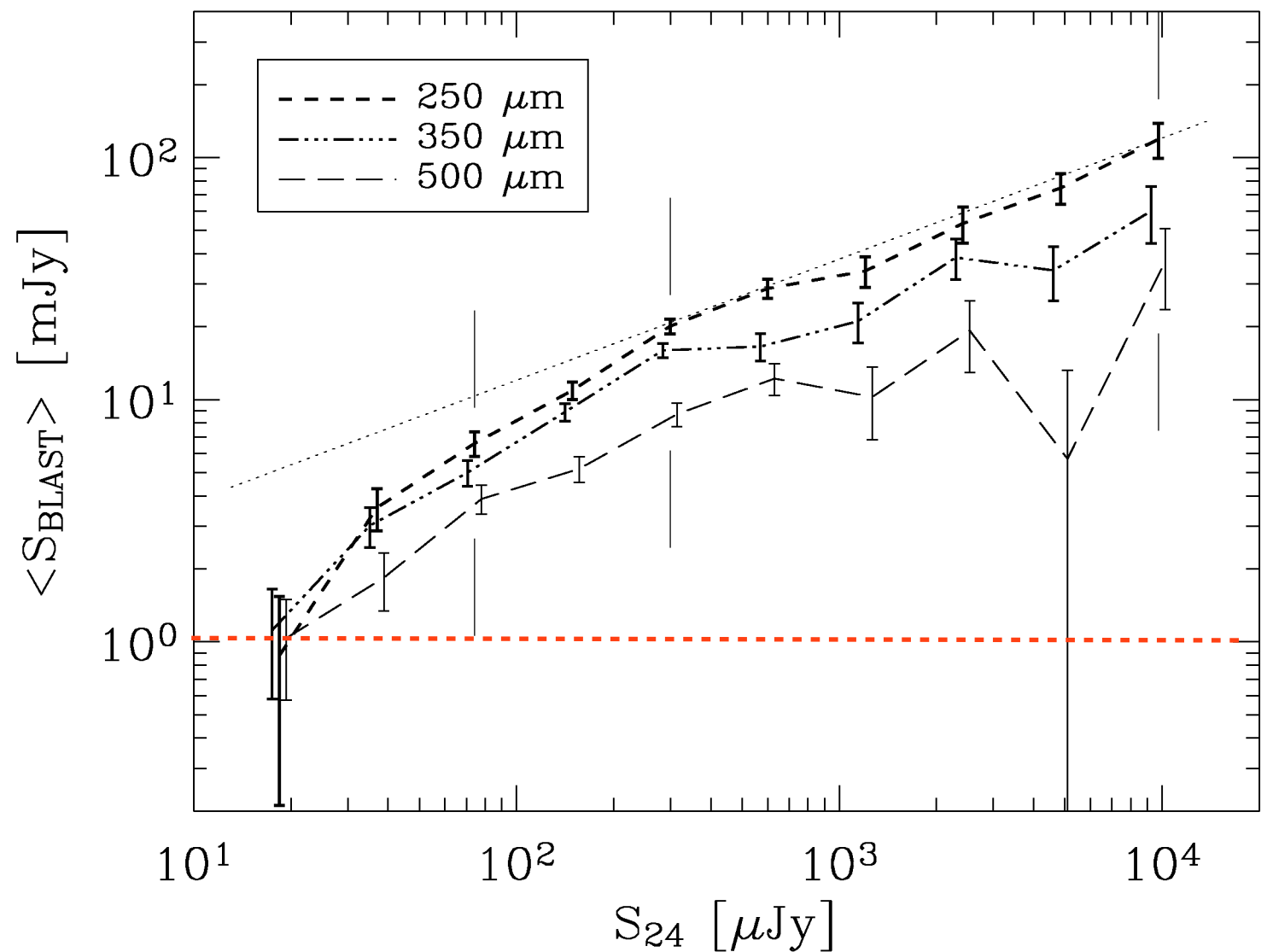
Poisson, i.e., mean = variance →



Marsden et al. 0904.1205

Using Great Ancillary Data

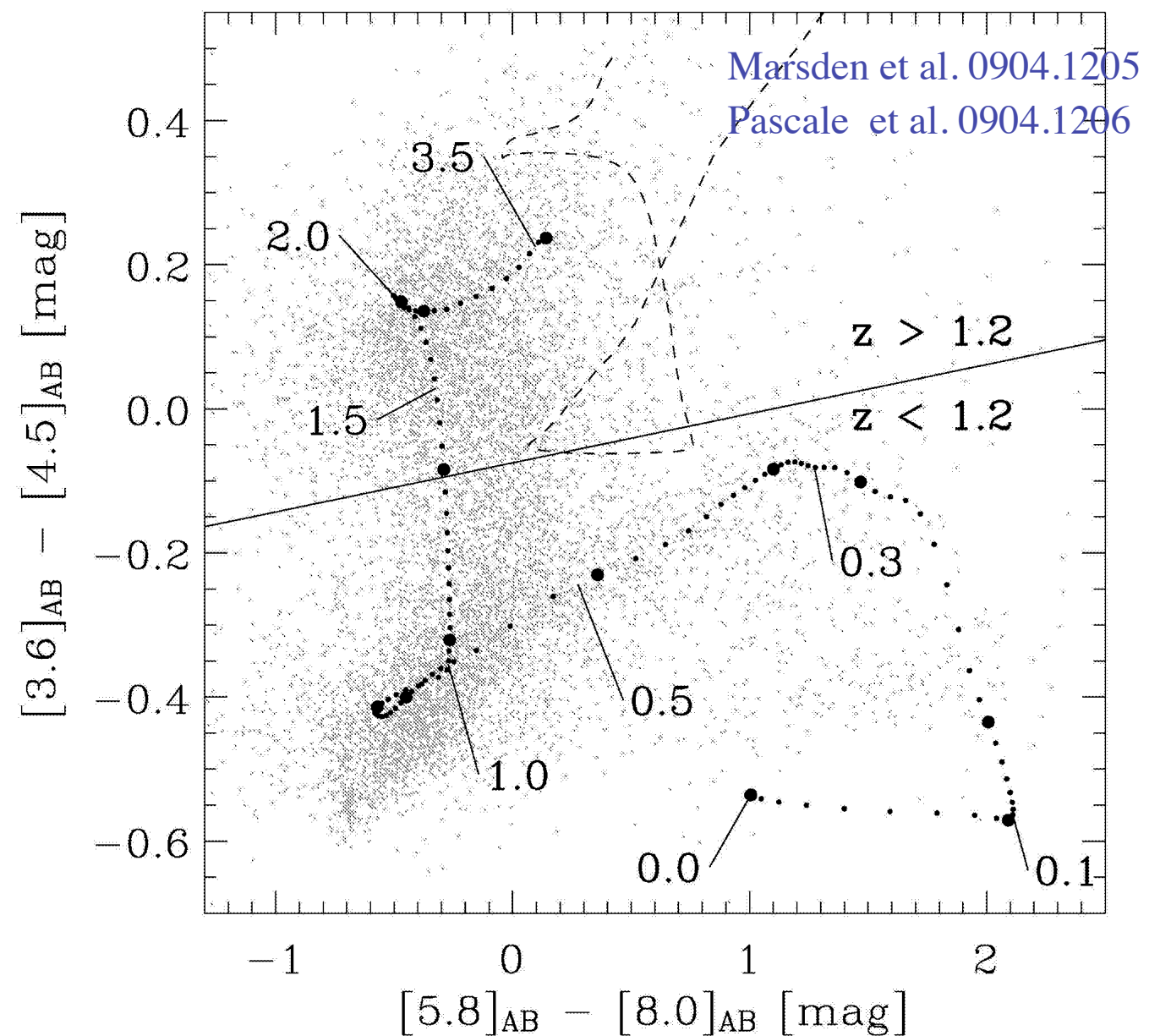
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- Find indeed **$S > 1$ mJy**, confirming counts



Marsden et al. 0904.1205

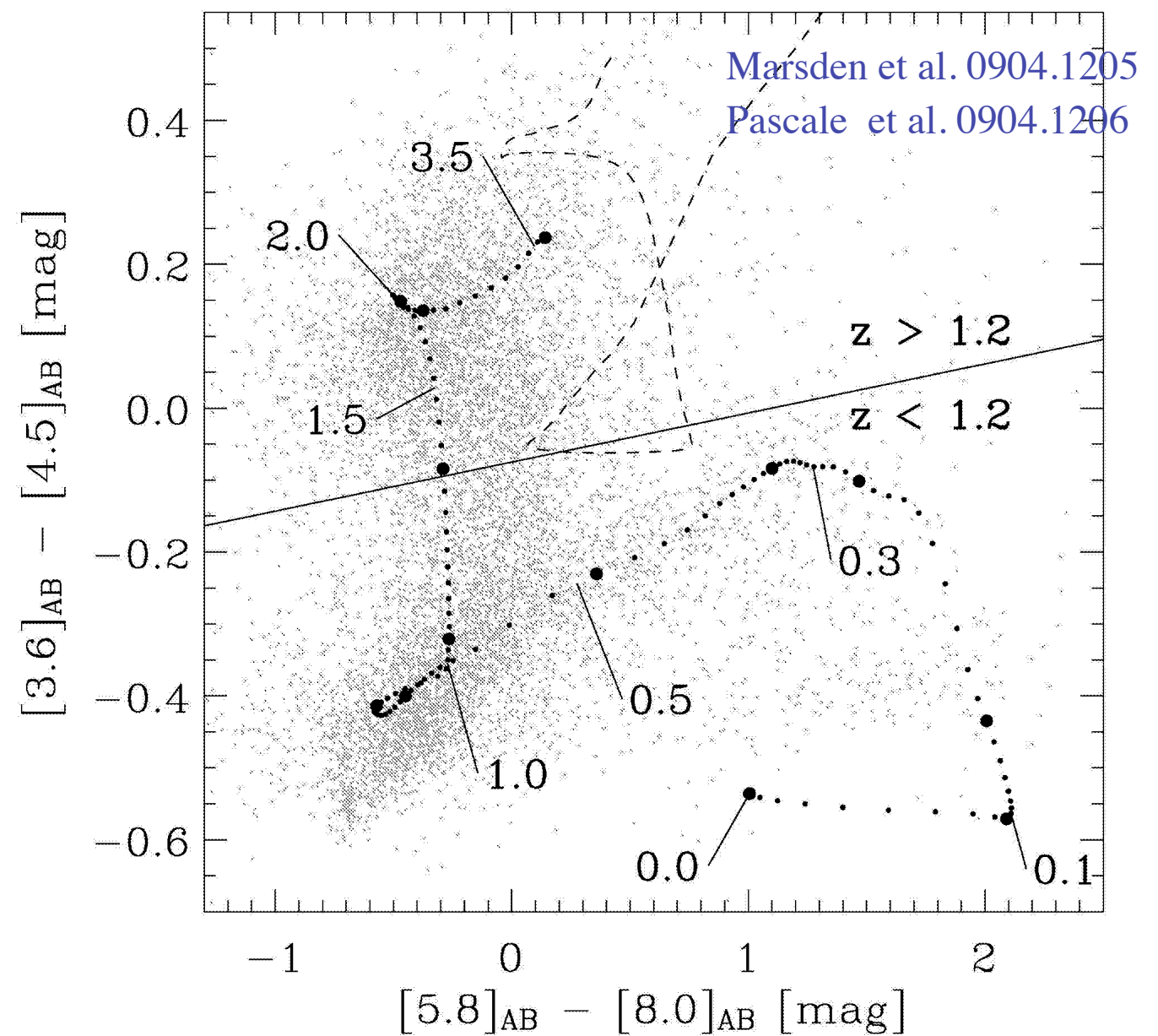
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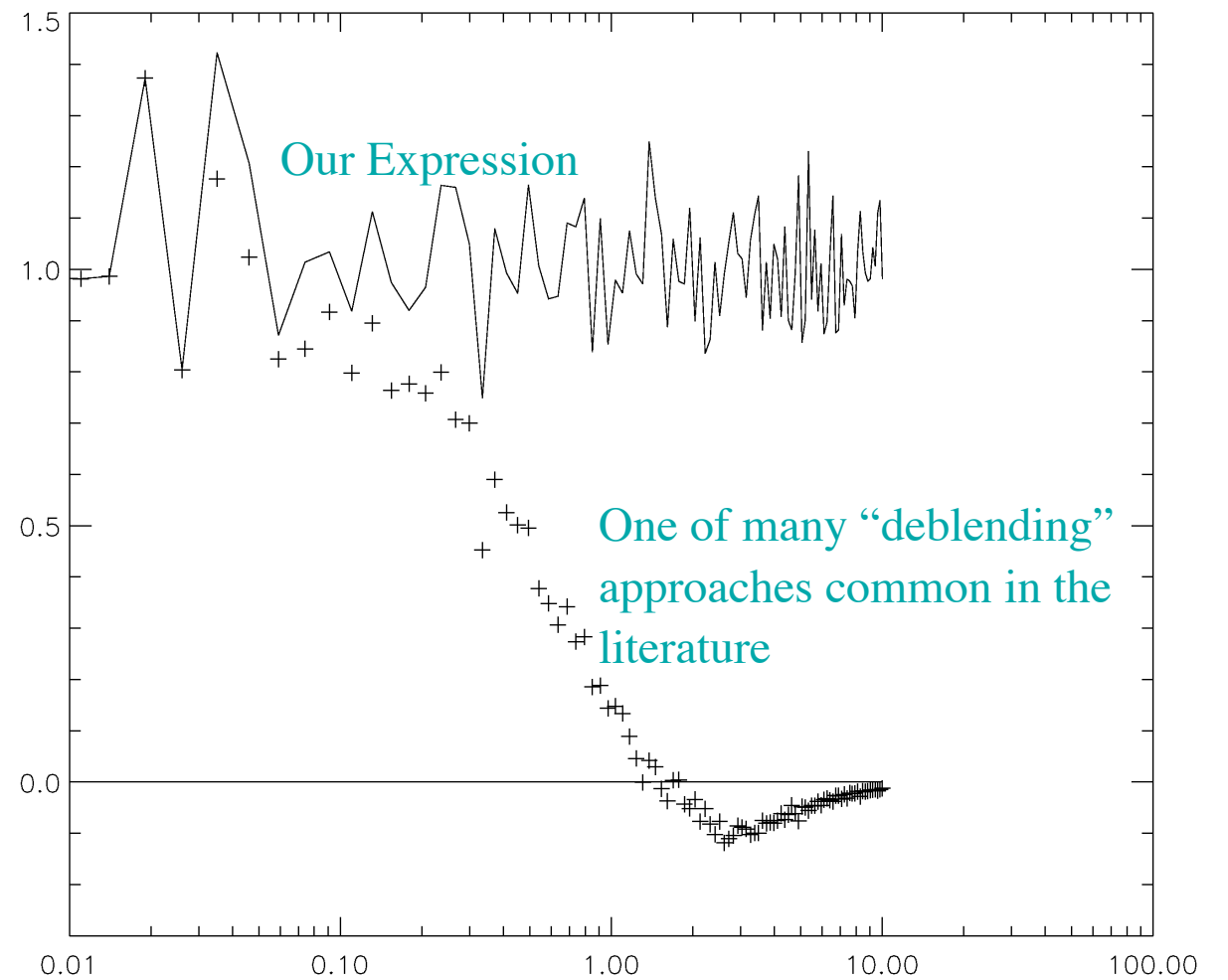
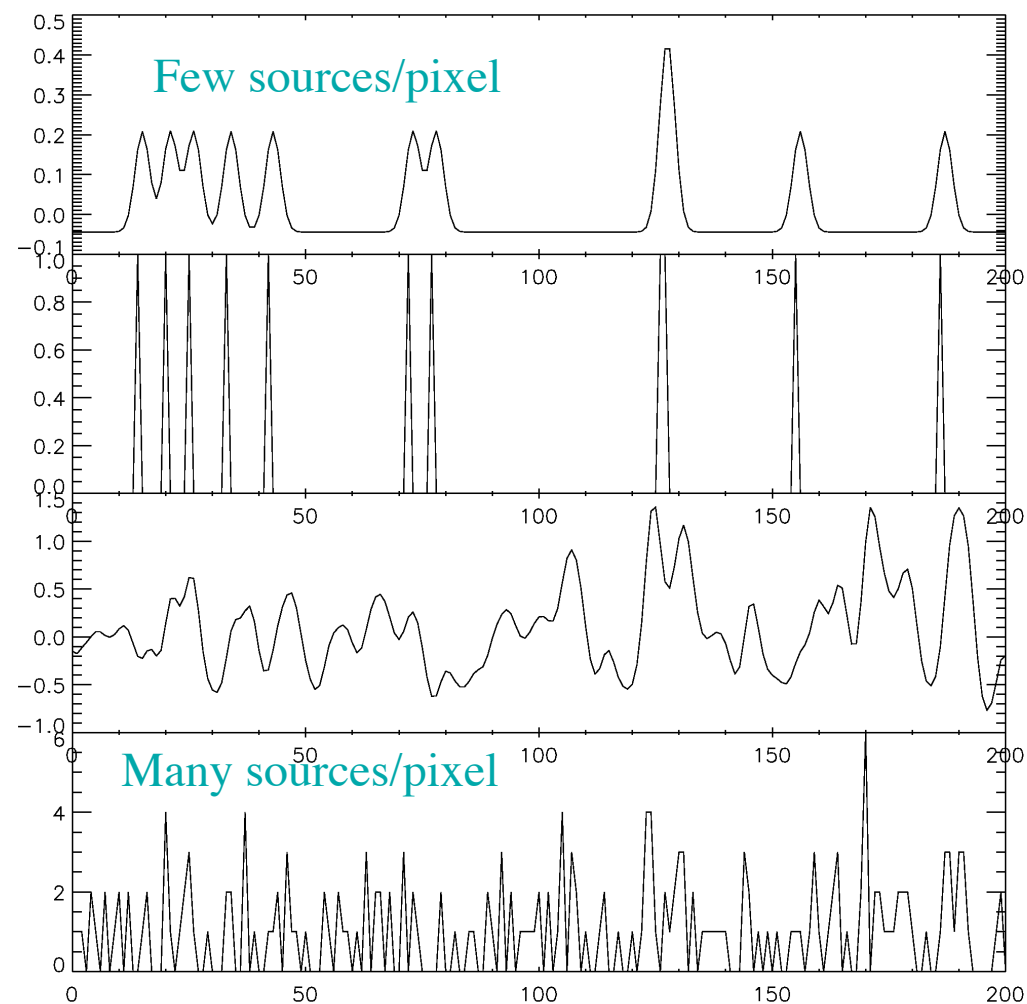


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 - ◉ $S \sim 1$ mJy Corresponds to Luminosity $>$ LIRGS at $z > 1$

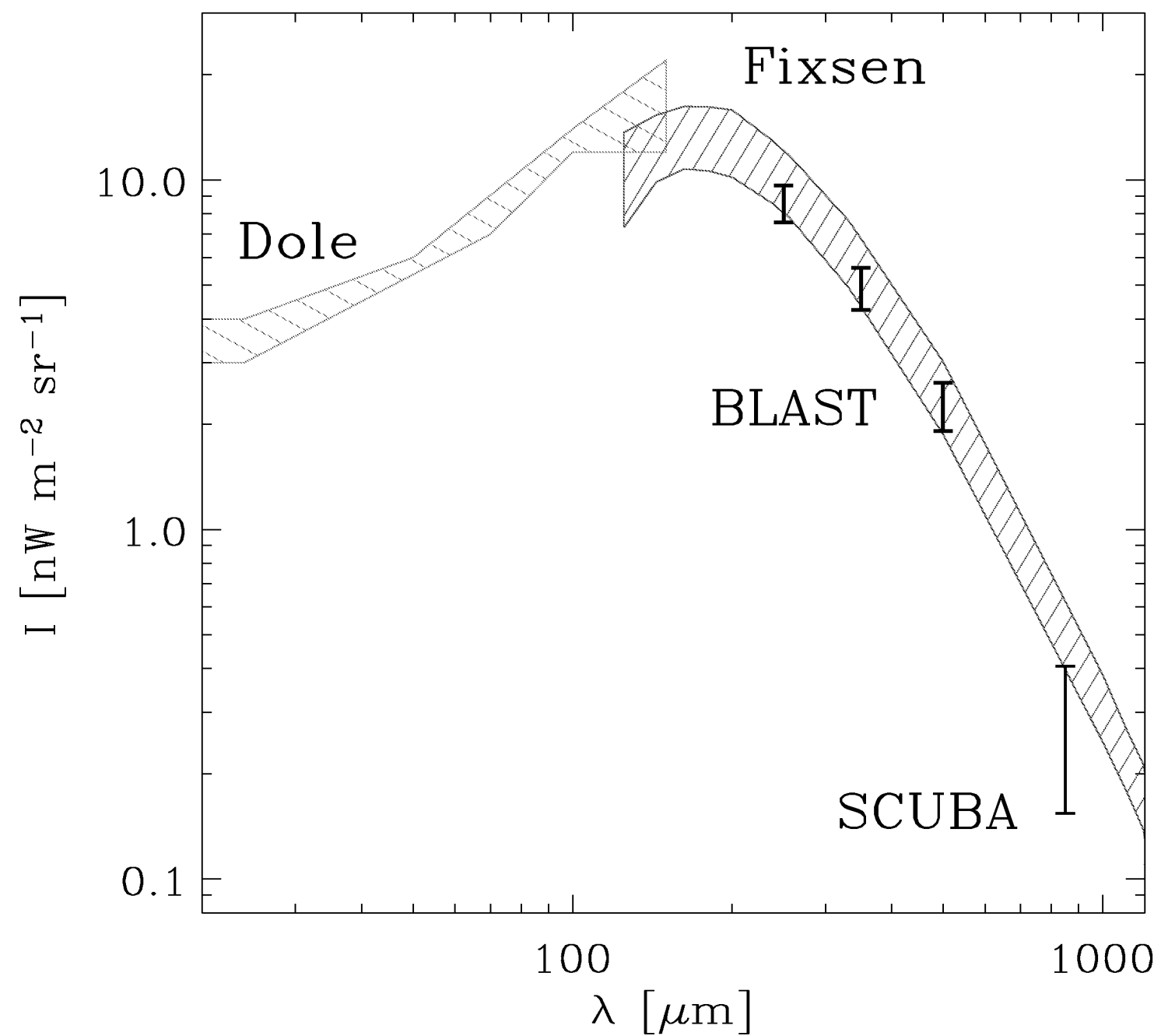


Monte-Carlo for sceptics



courtesy of Mark Halpern

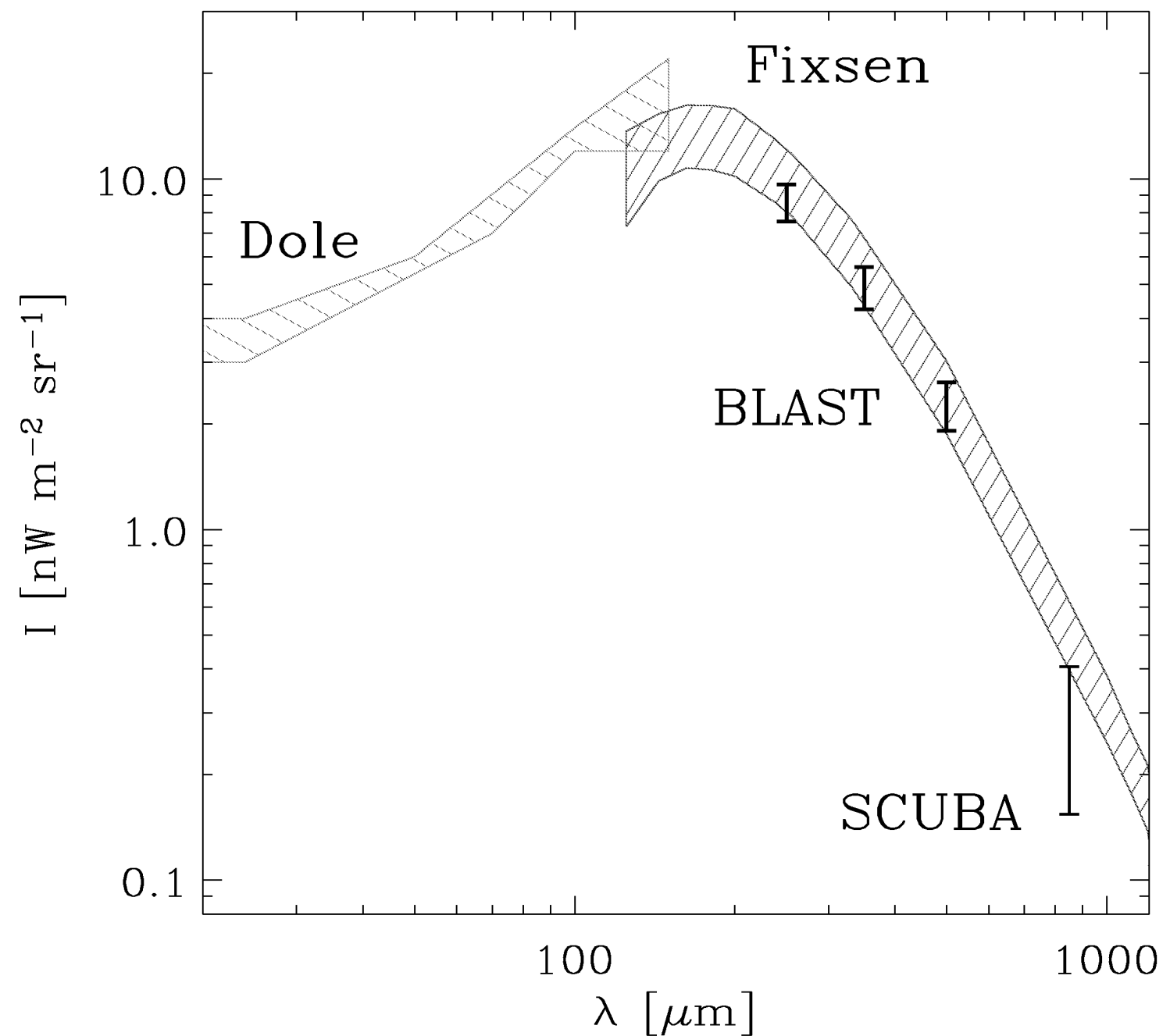
Stacking Result 1 - CIB resolved



Marsden et al. 0904.1205

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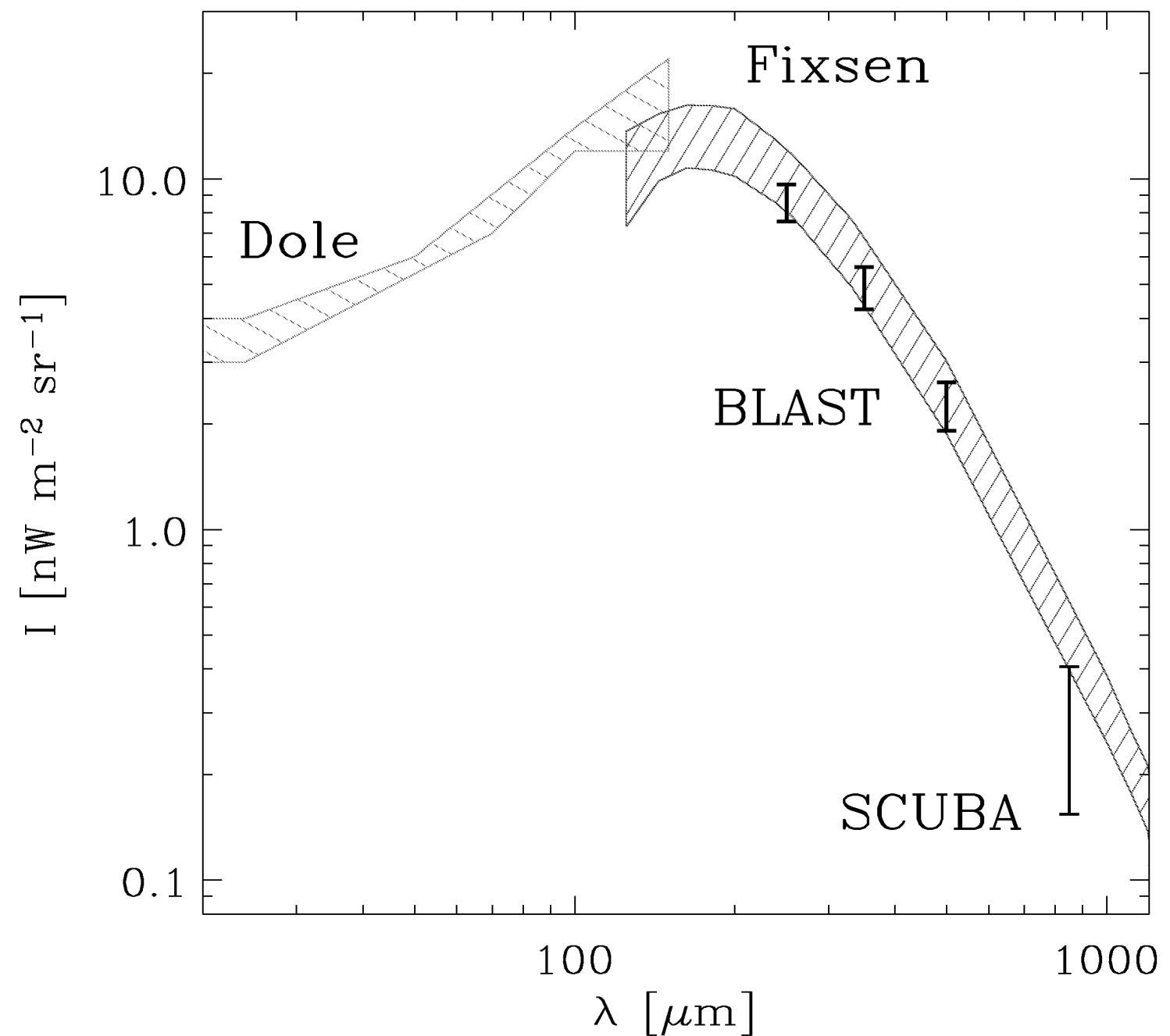
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Marsden et al. 0904.1205

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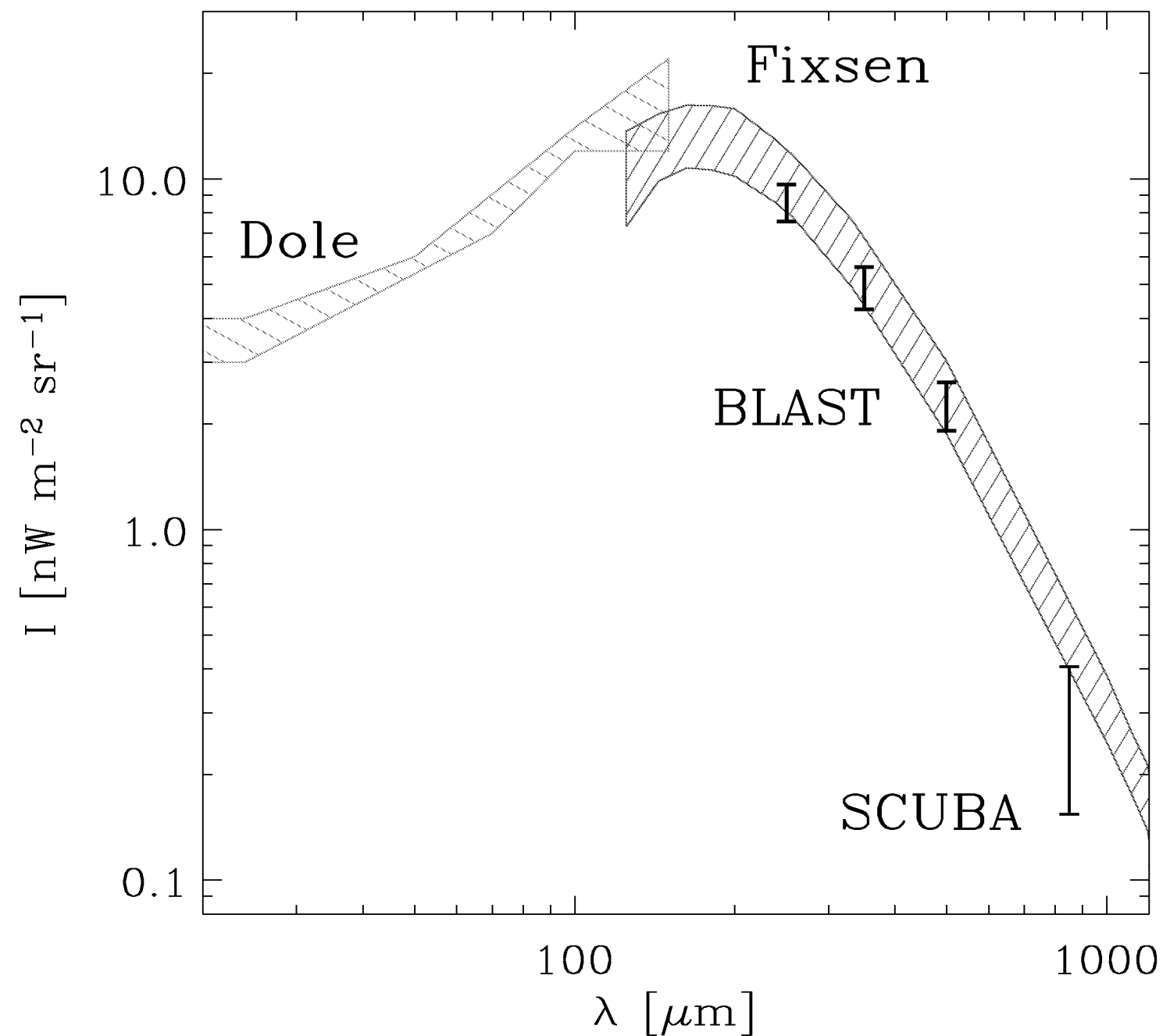
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Marsden et al. 0904.1205

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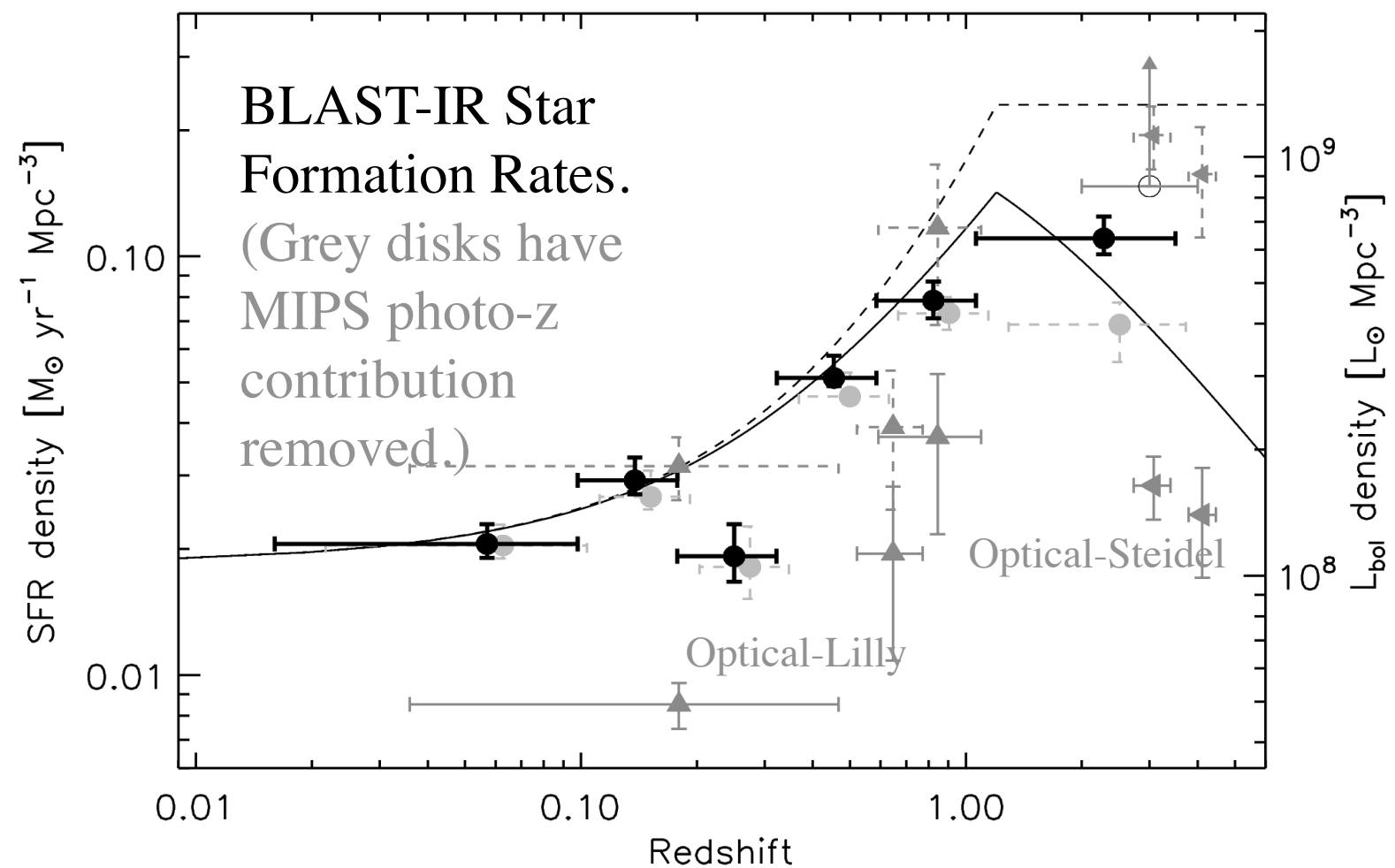
- CIB is composed of emission from identified galaxies
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 - ◉ BLAST 3σ catalog makes up only 15% of the total intensity!



Marsden et al. 0904.1205

Stacking Result 2 - Star Formation History

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



Pascale et al. 0904.1206

Clustering

Clustering

Clustering

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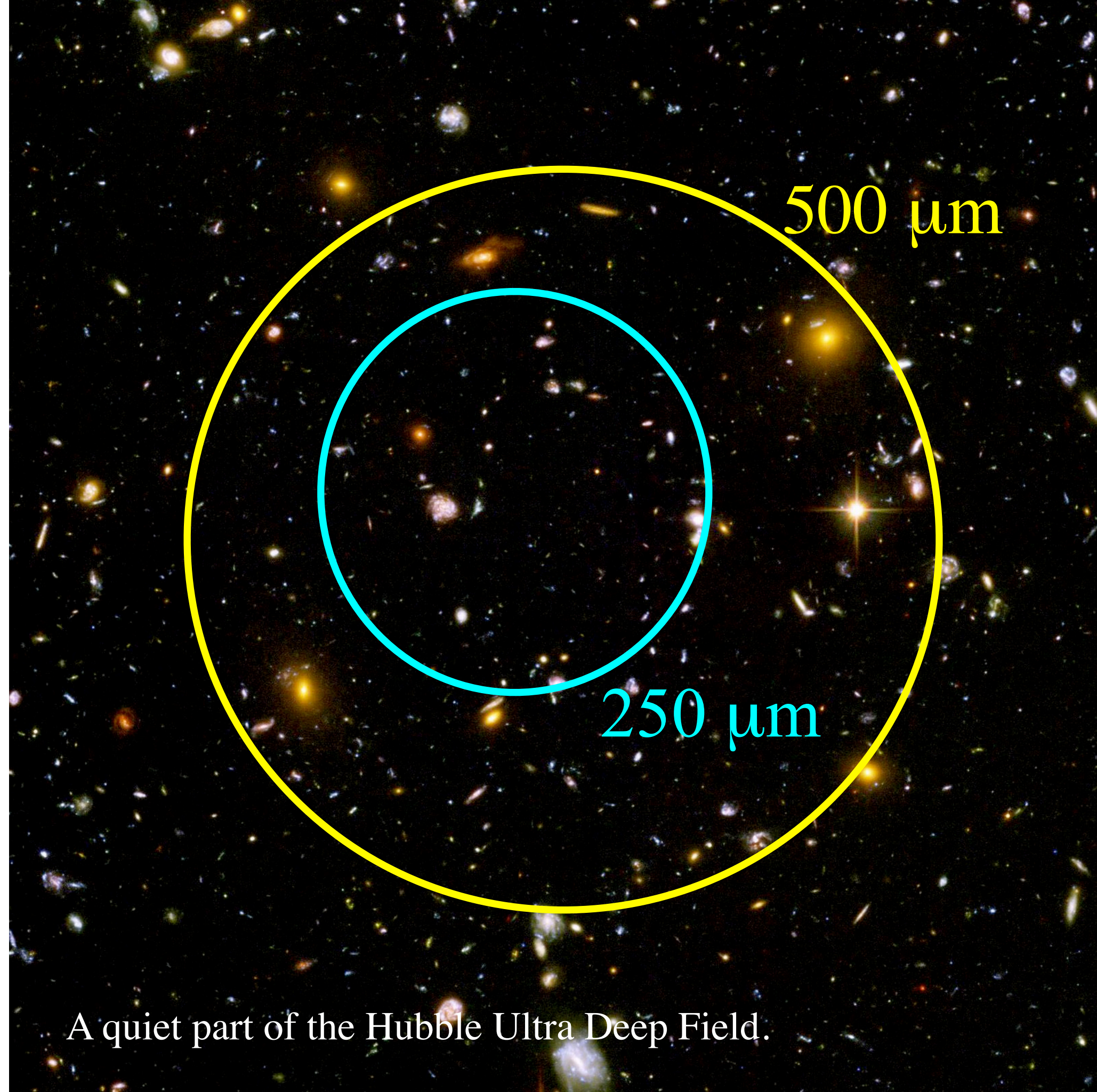
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 - ◉ Link populations

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

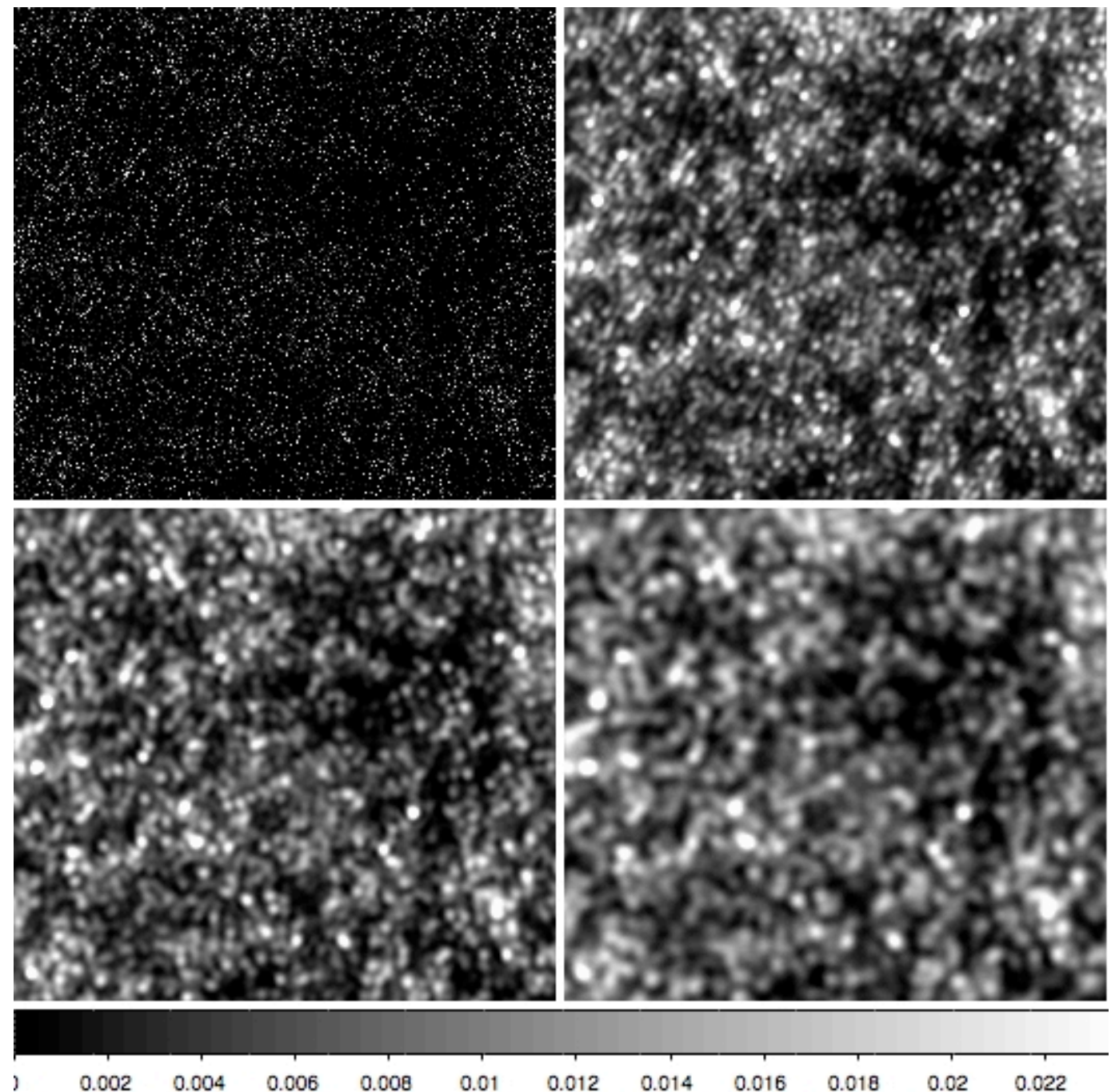


A quiet part of the Hubble Ultra Deep Field.

Complications

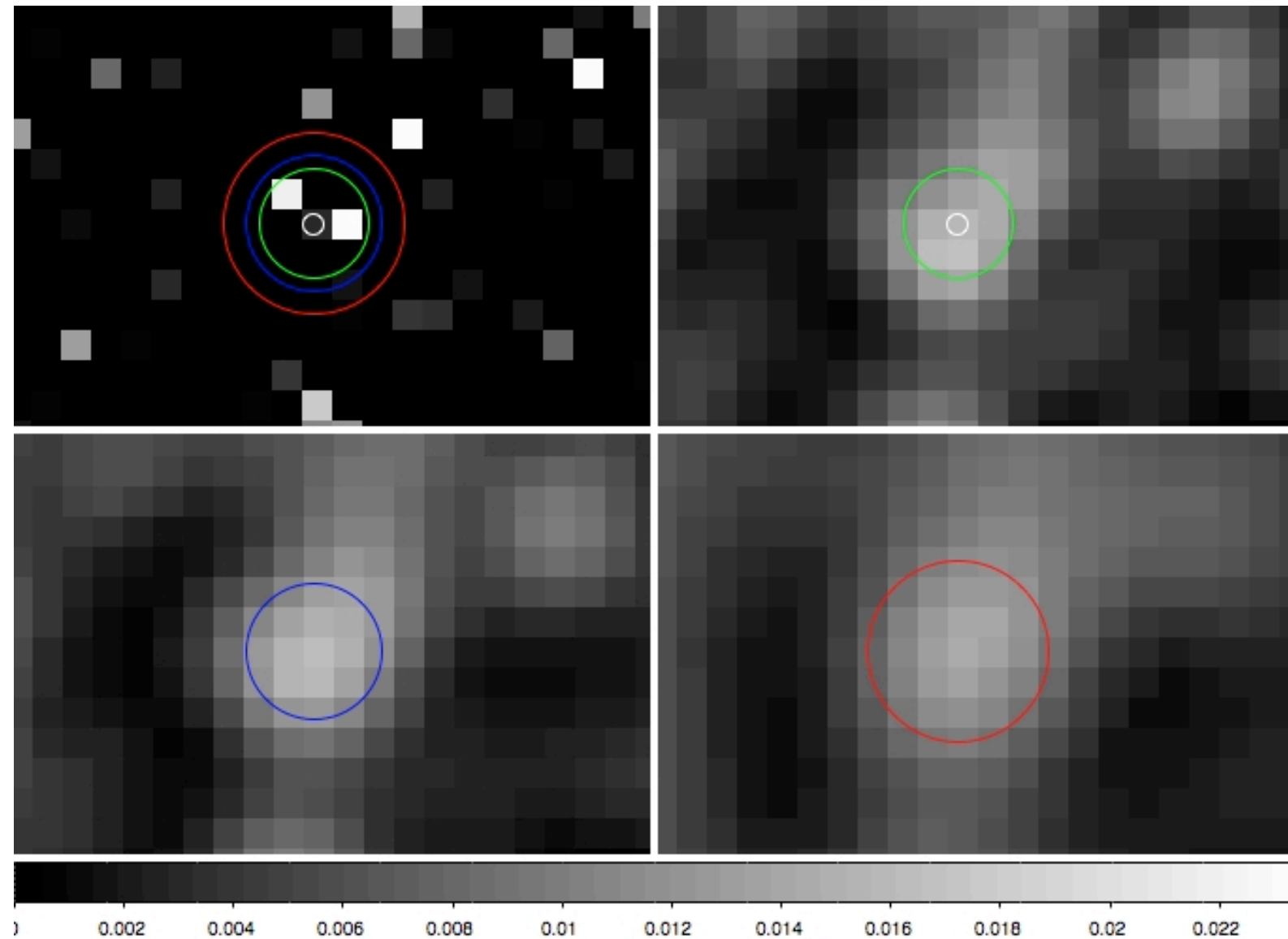
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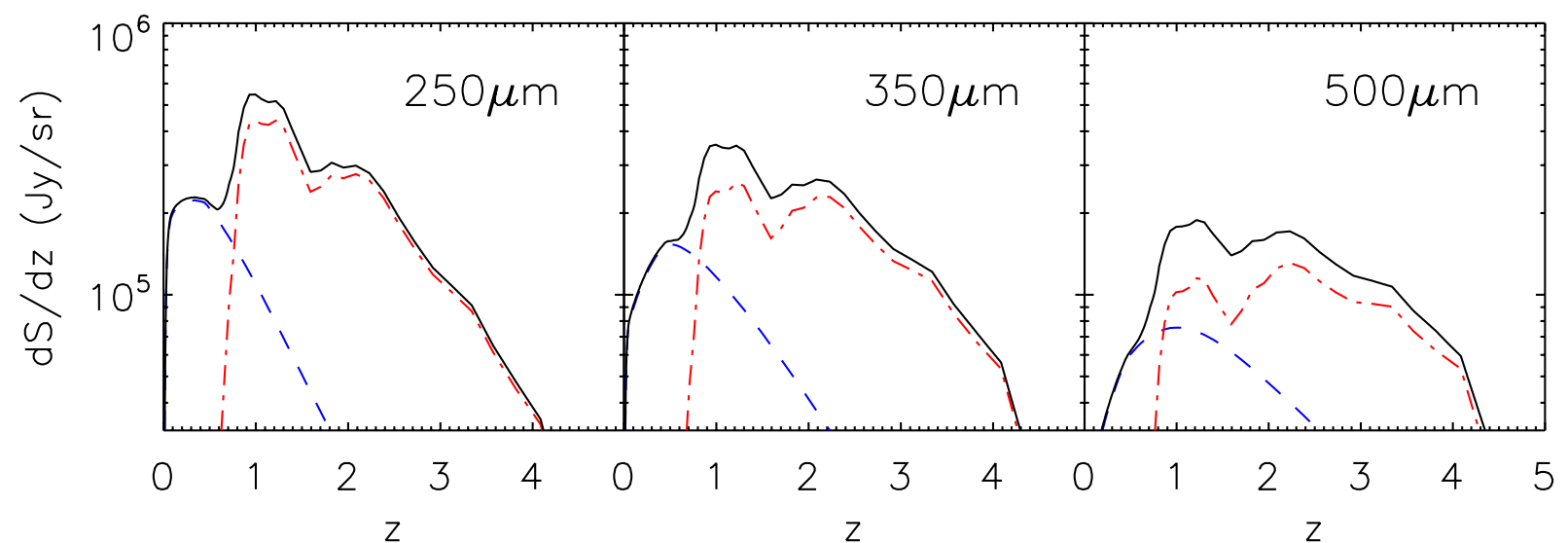
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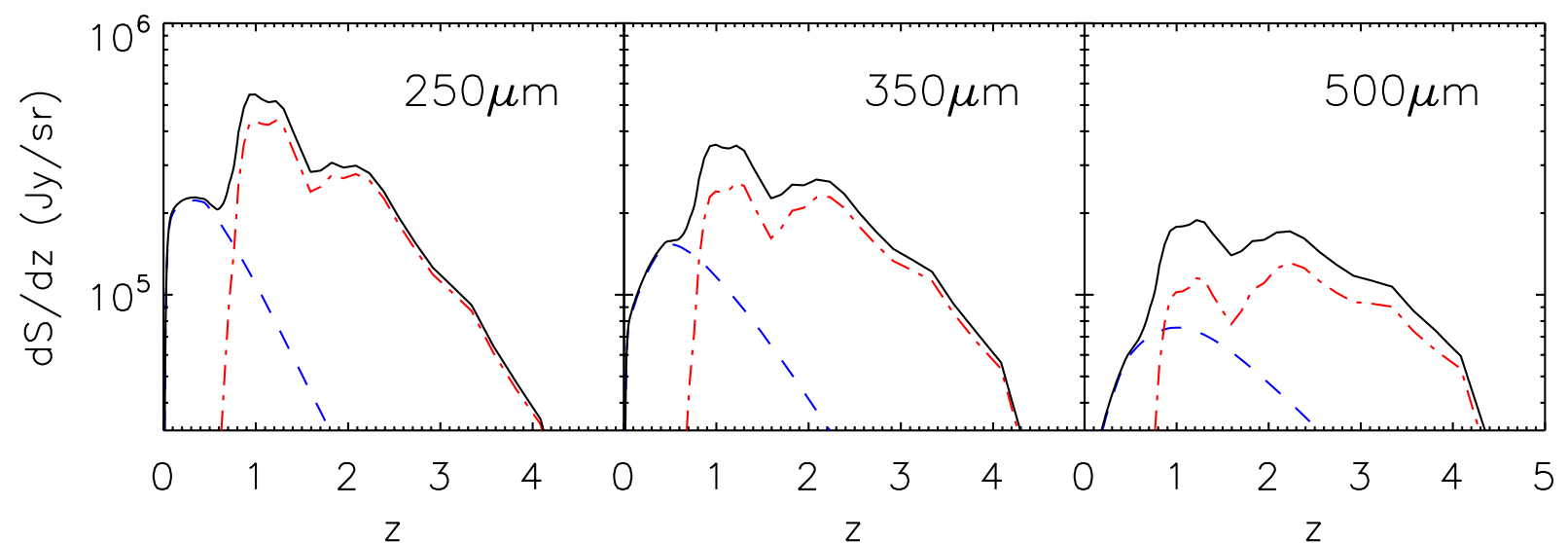
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Complications

- While *large scales* well traced
- *Small scales* more difficult
 - ◉ What is a submm source?
- 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

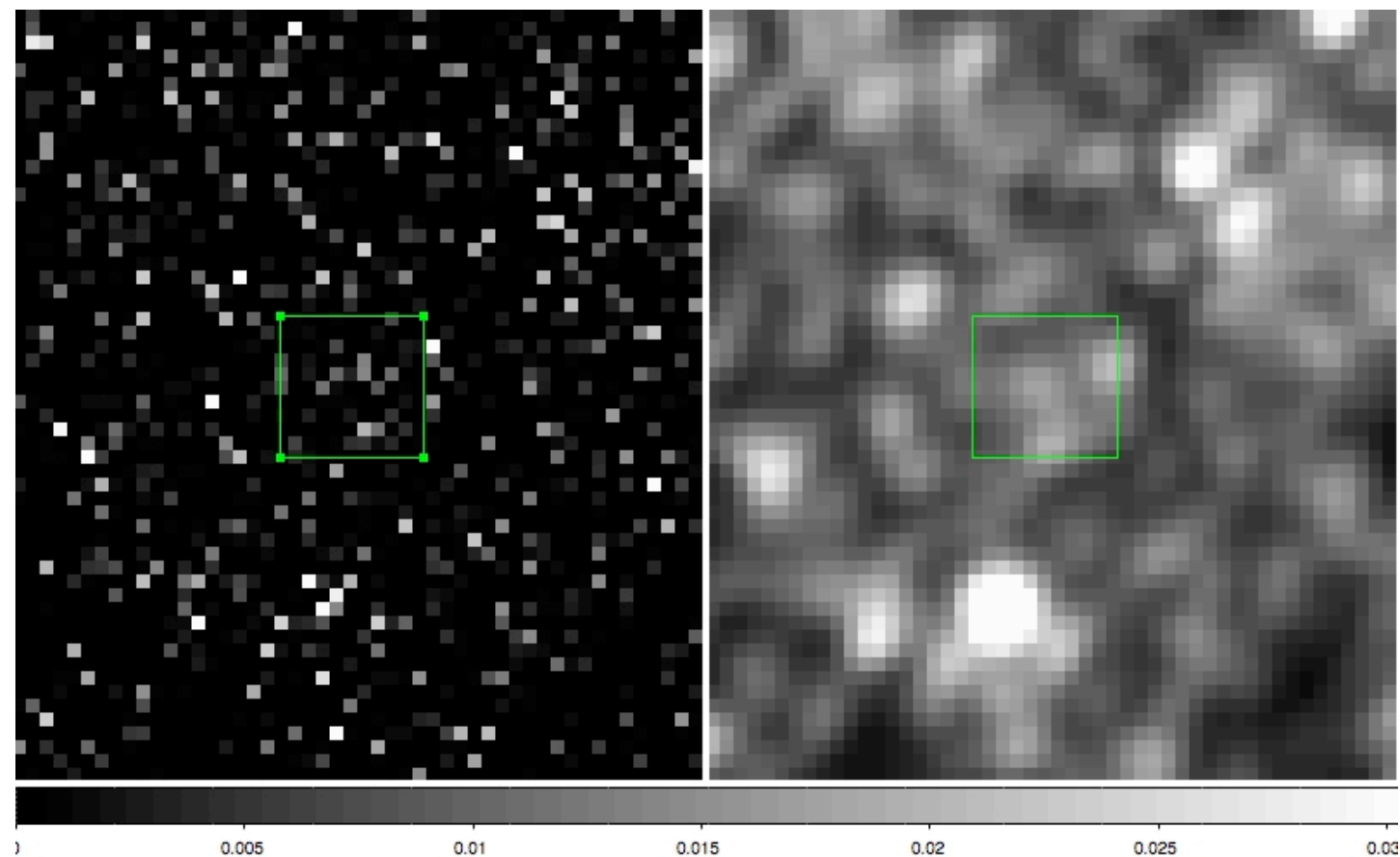
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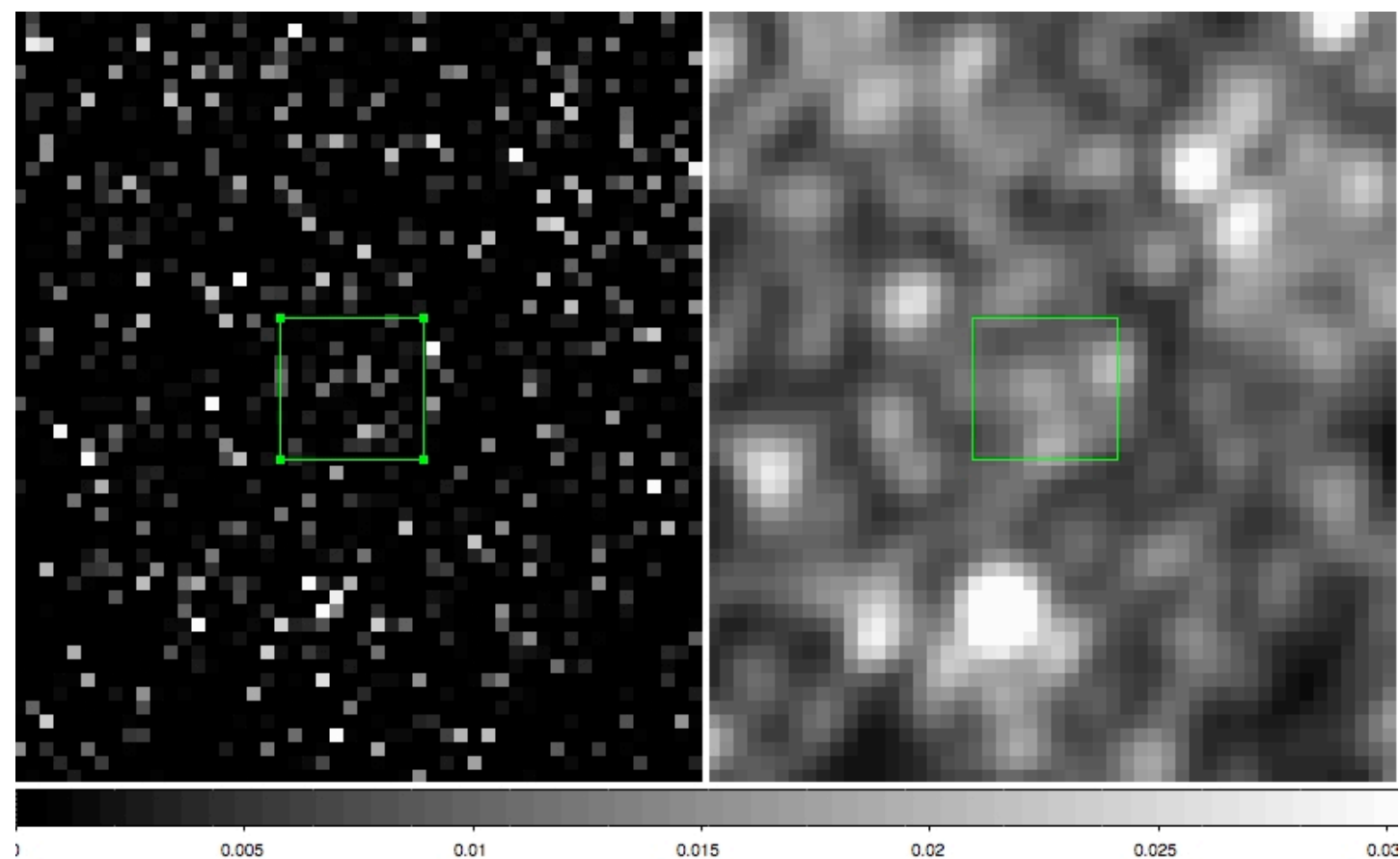
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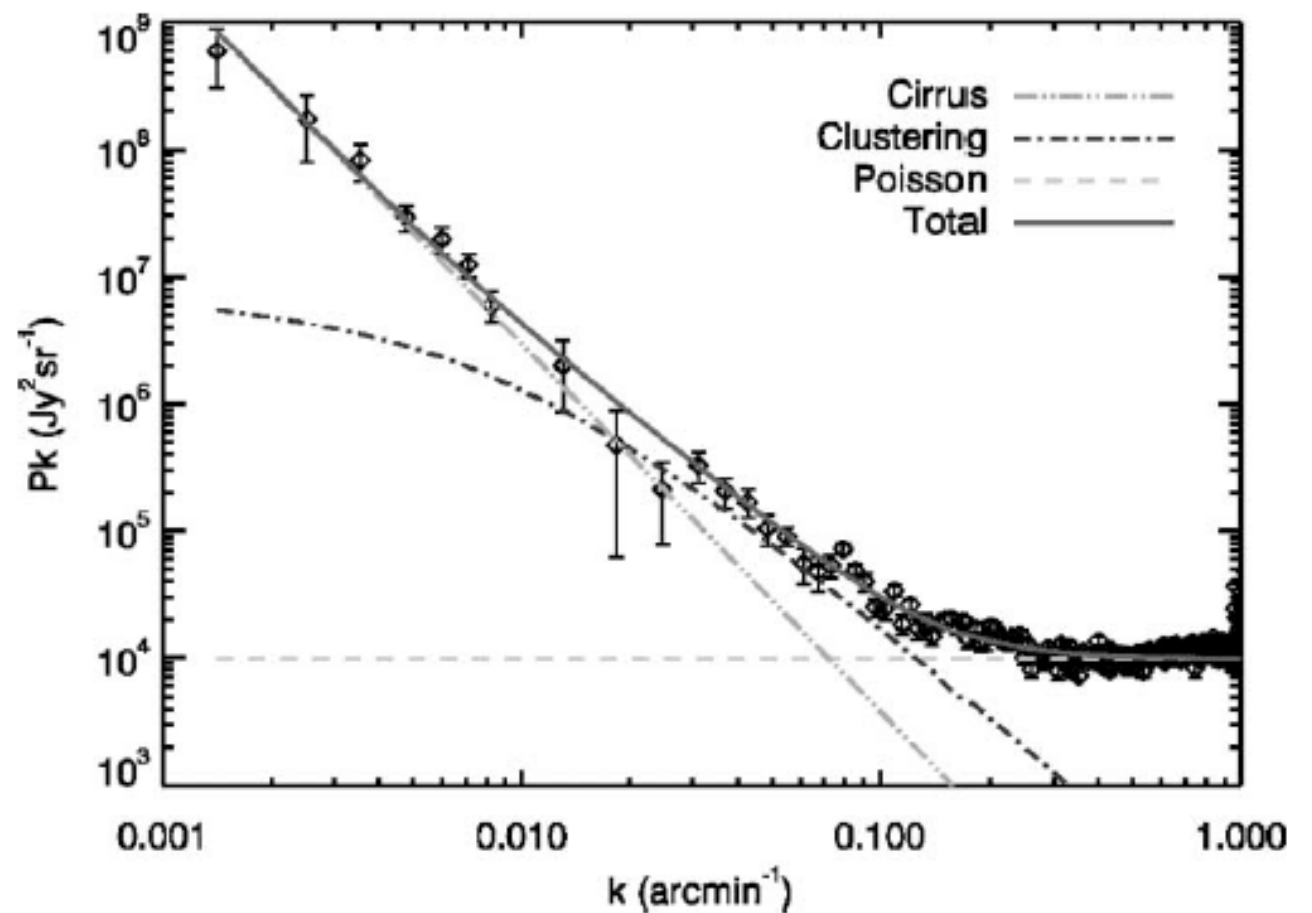
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- First measurements of the power spectrum from clustered galaxies from
 - ◉ Lagache+ 2007 (Spitzer 160 μ m)
 - ◉ Grossan & Smoot 2007 (Spitzer 160 μ m)



Lagache+ 2007

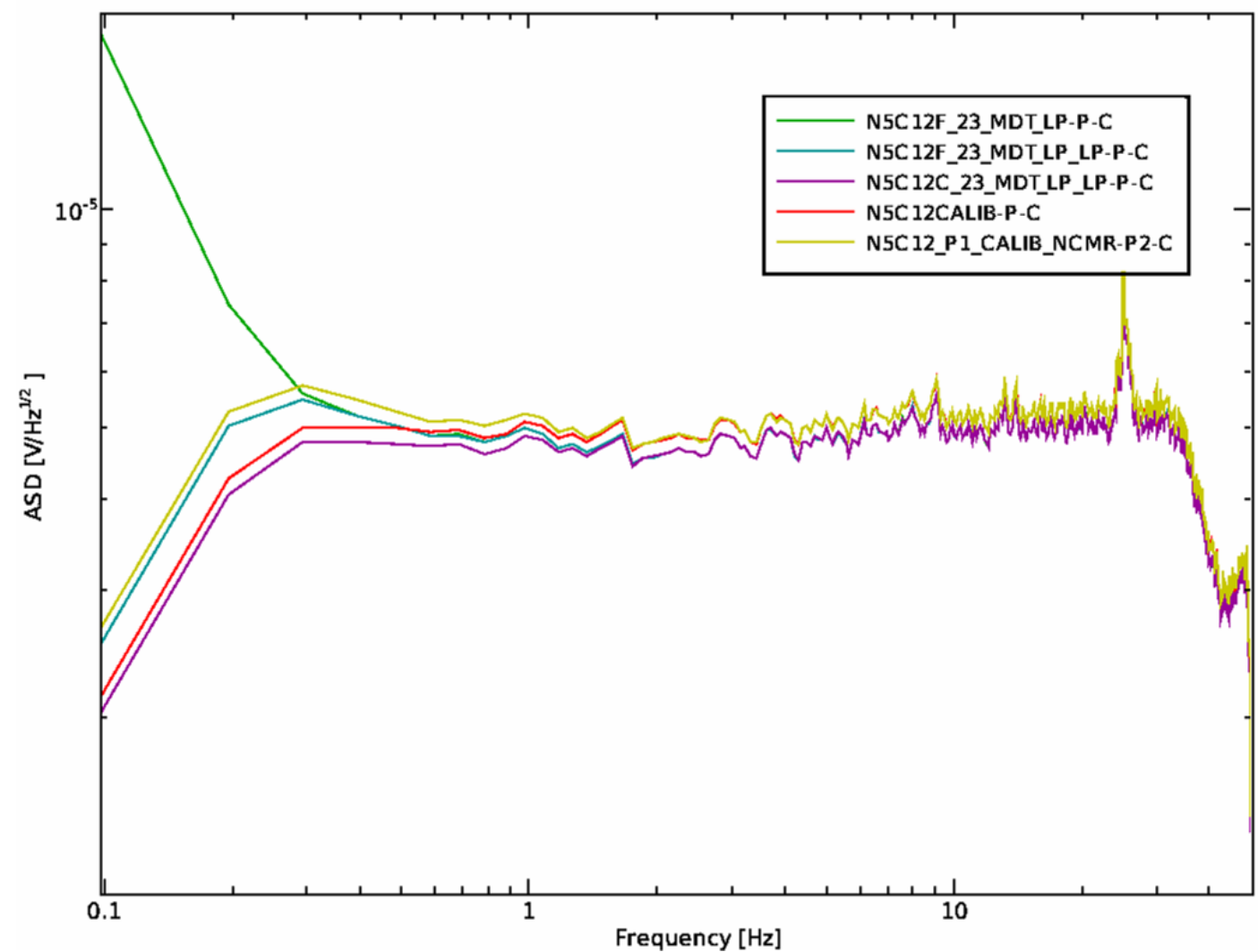
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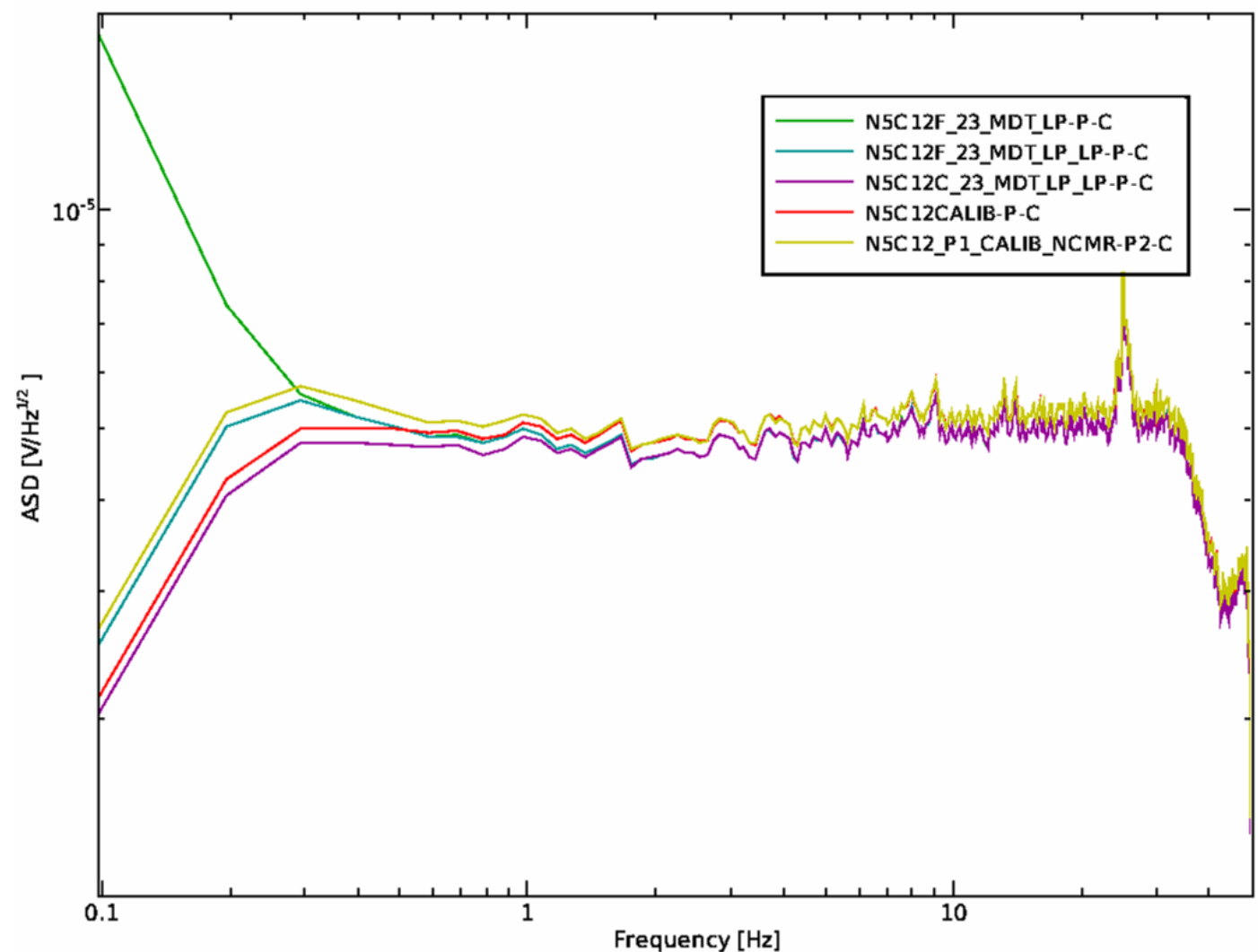
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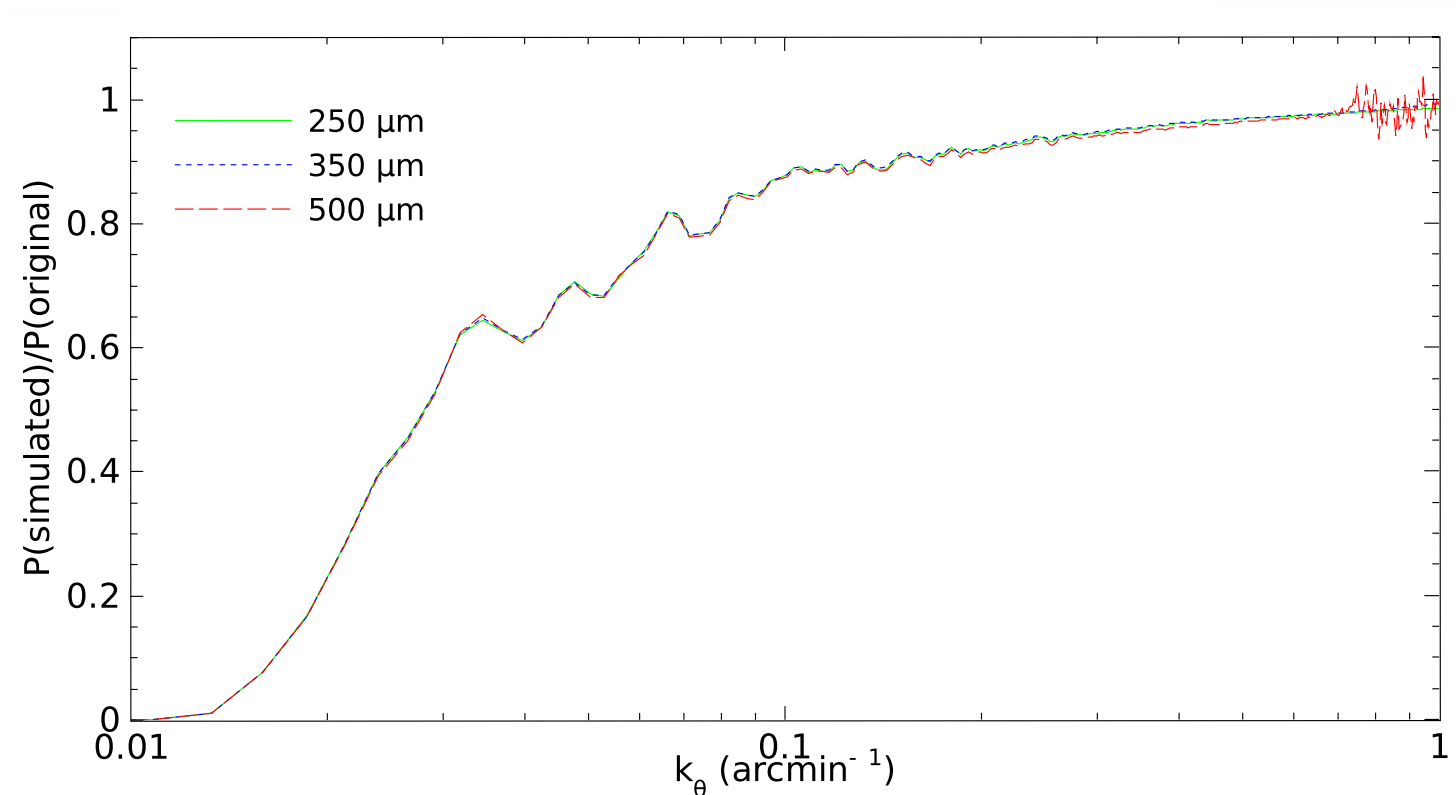
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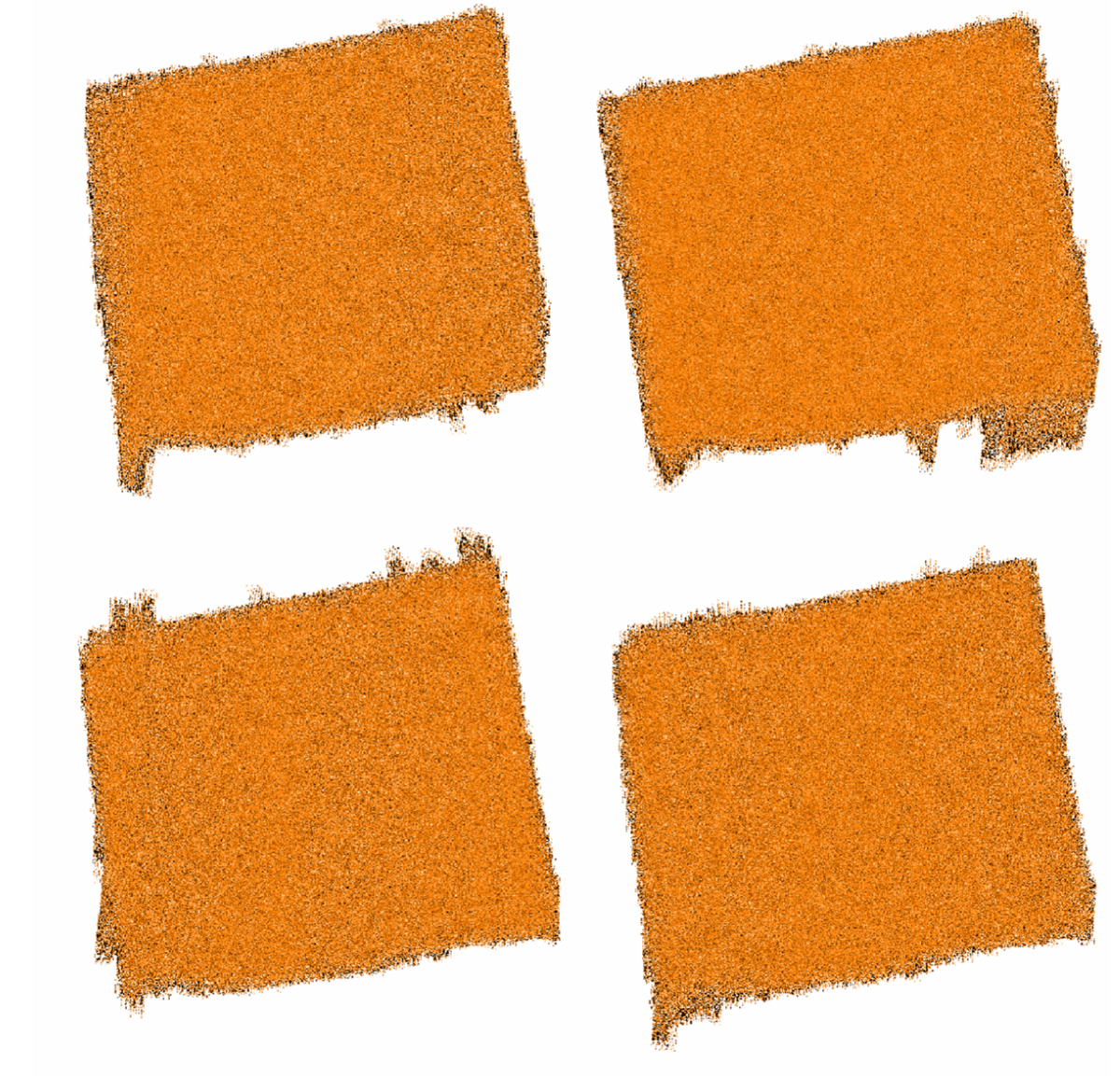
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Viero et al. 0904.1200

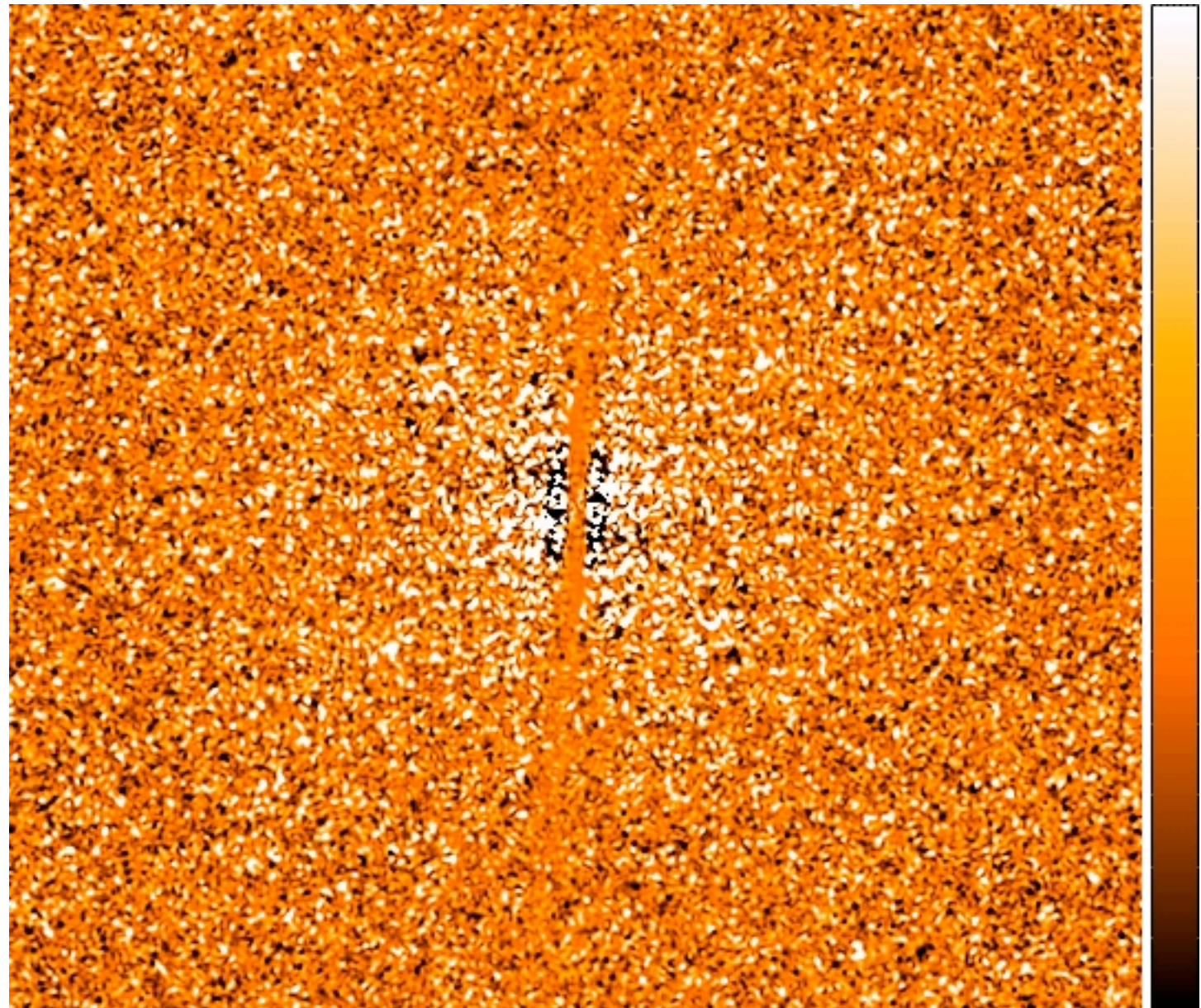
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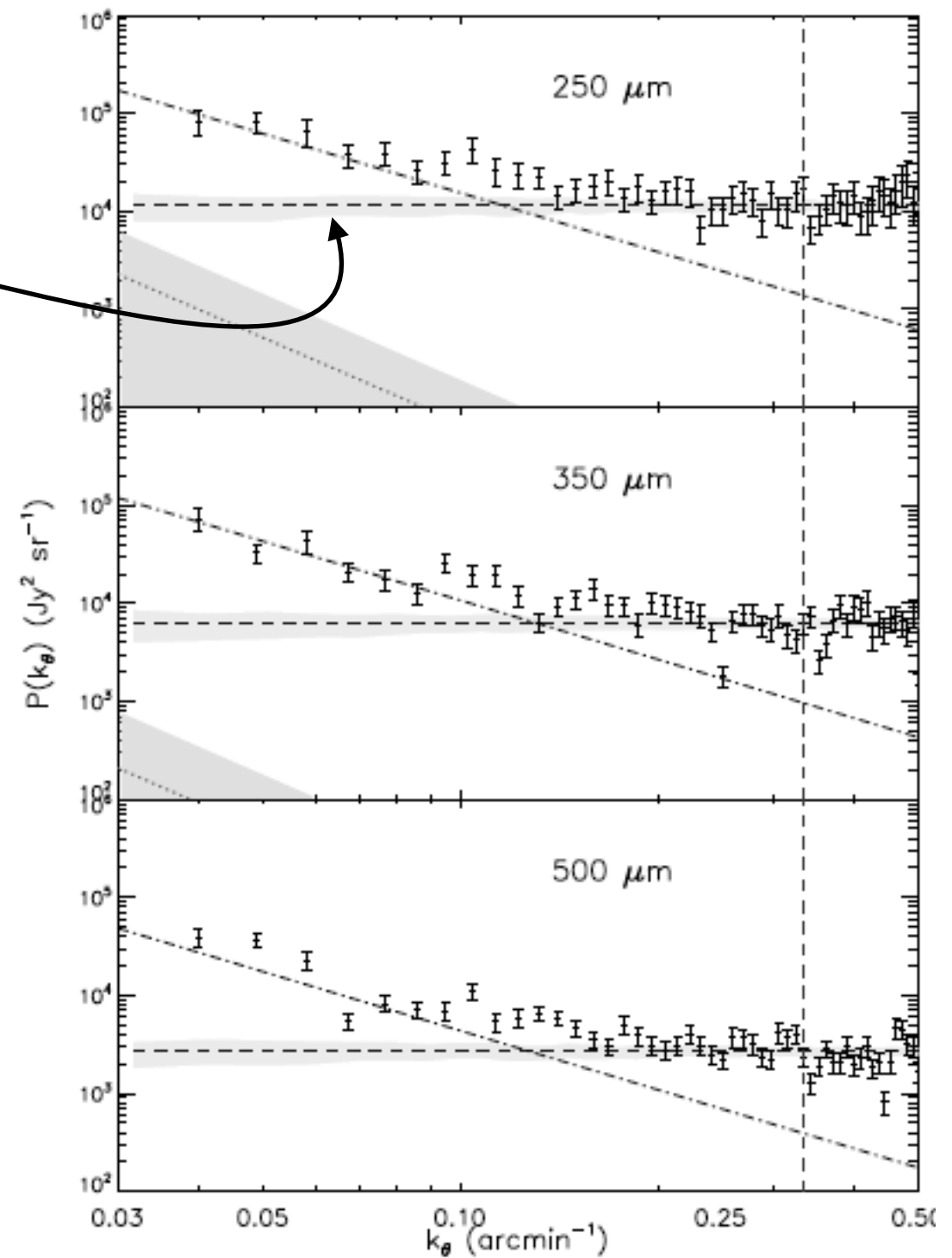
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 - ◉ power spectrum is the radial average of cross-correlation of sub-maps, corrected with TF



BLAST Clustering Power Spectrum

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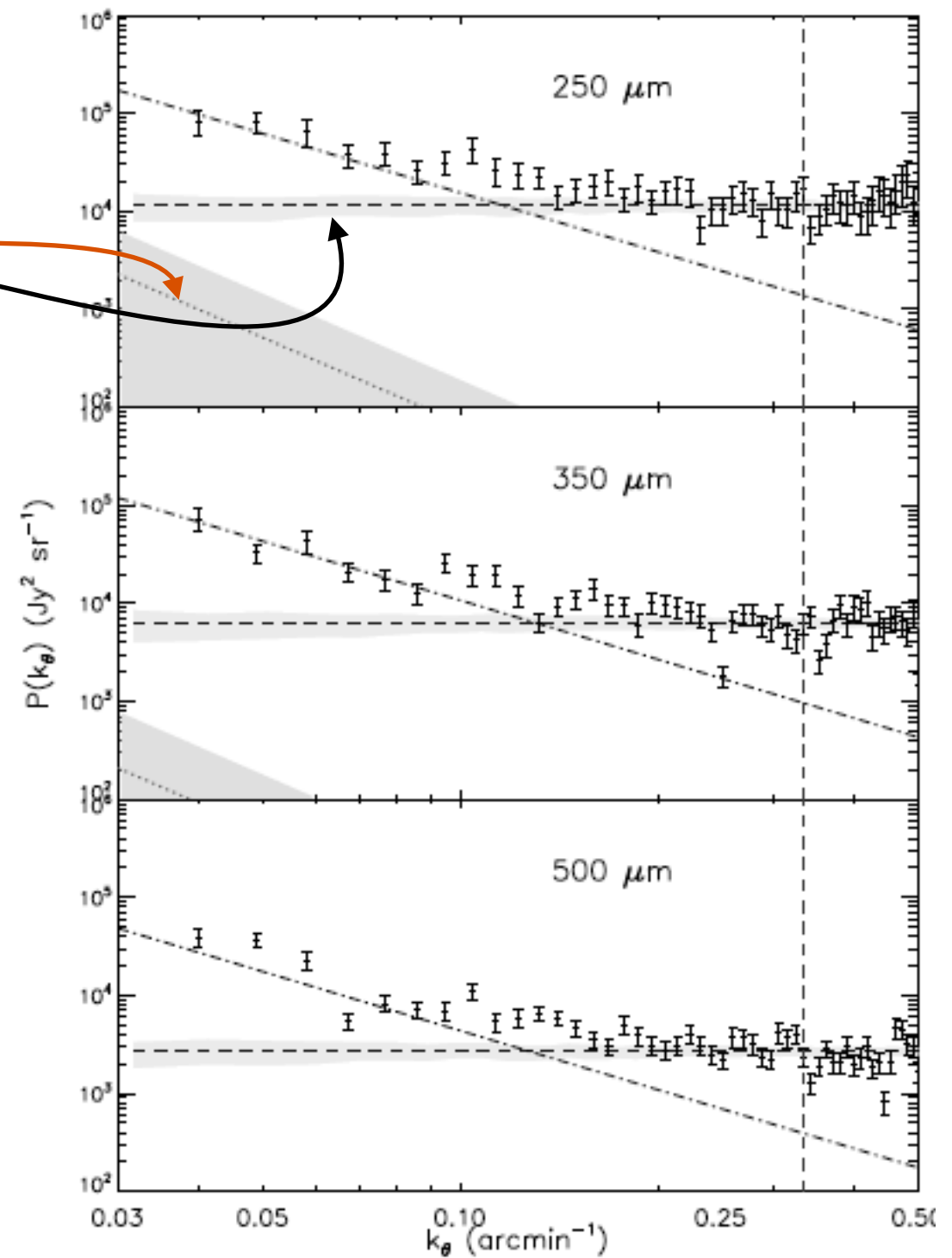
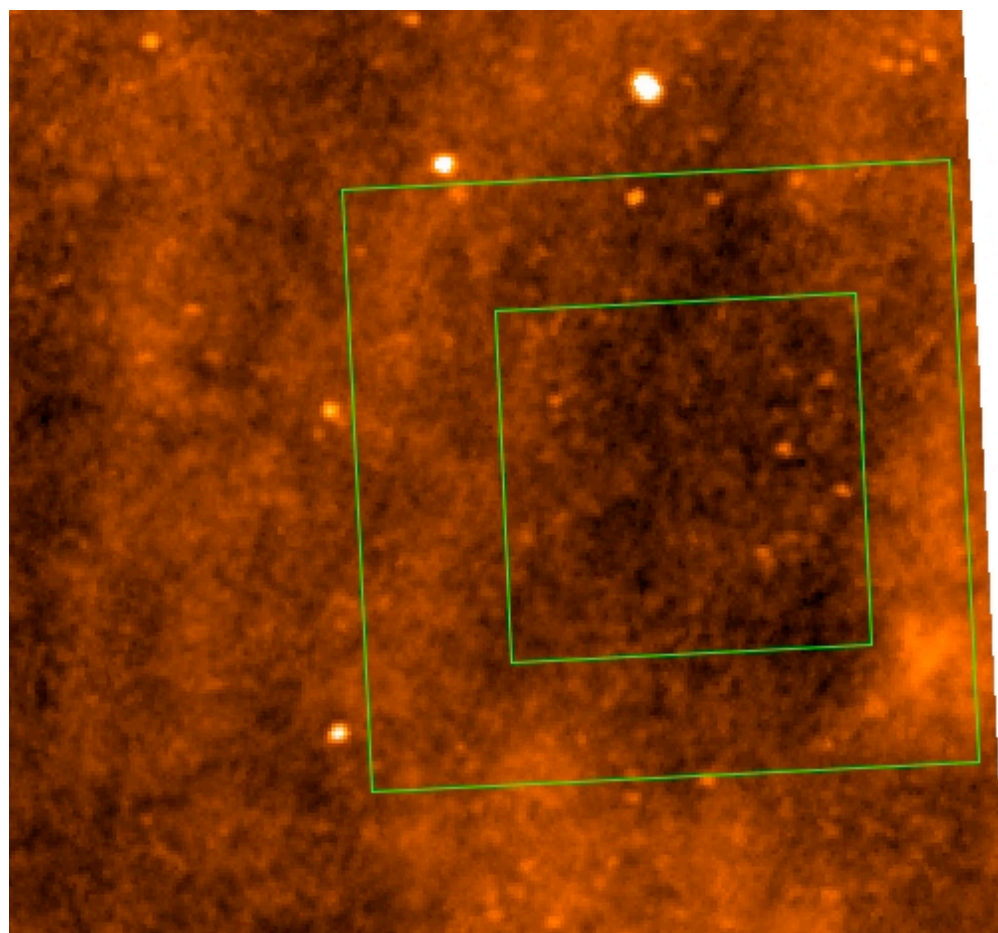
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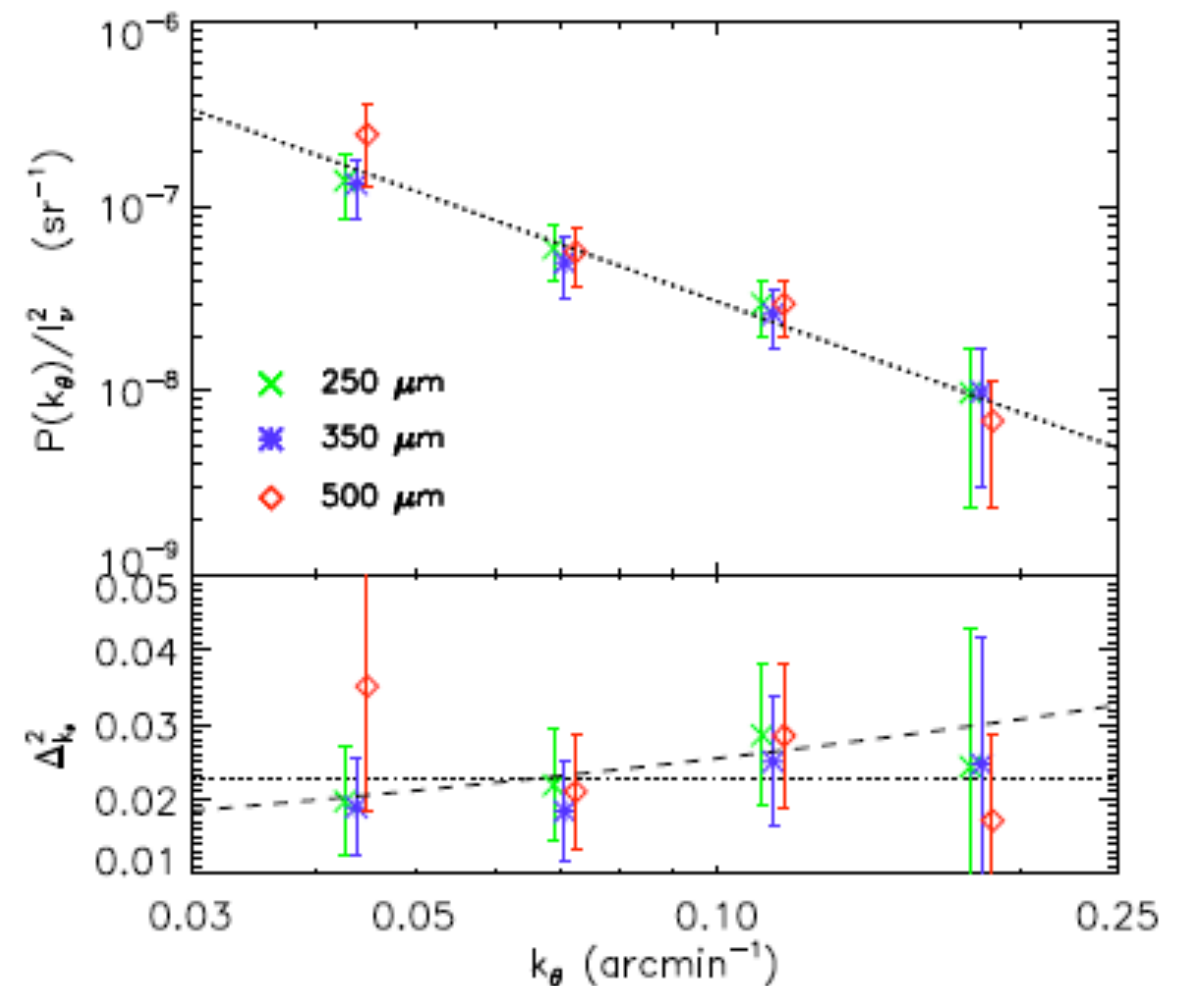
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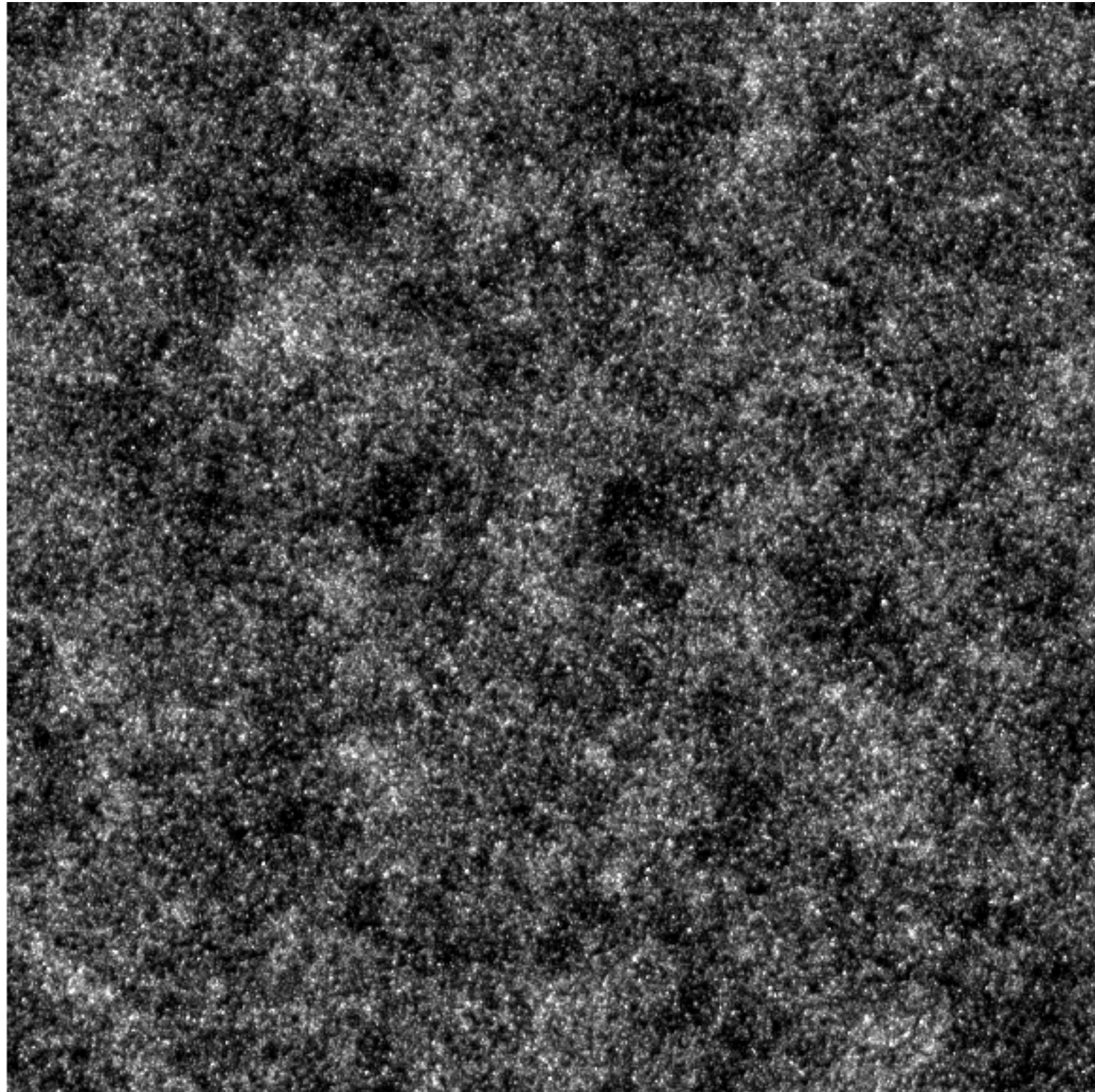
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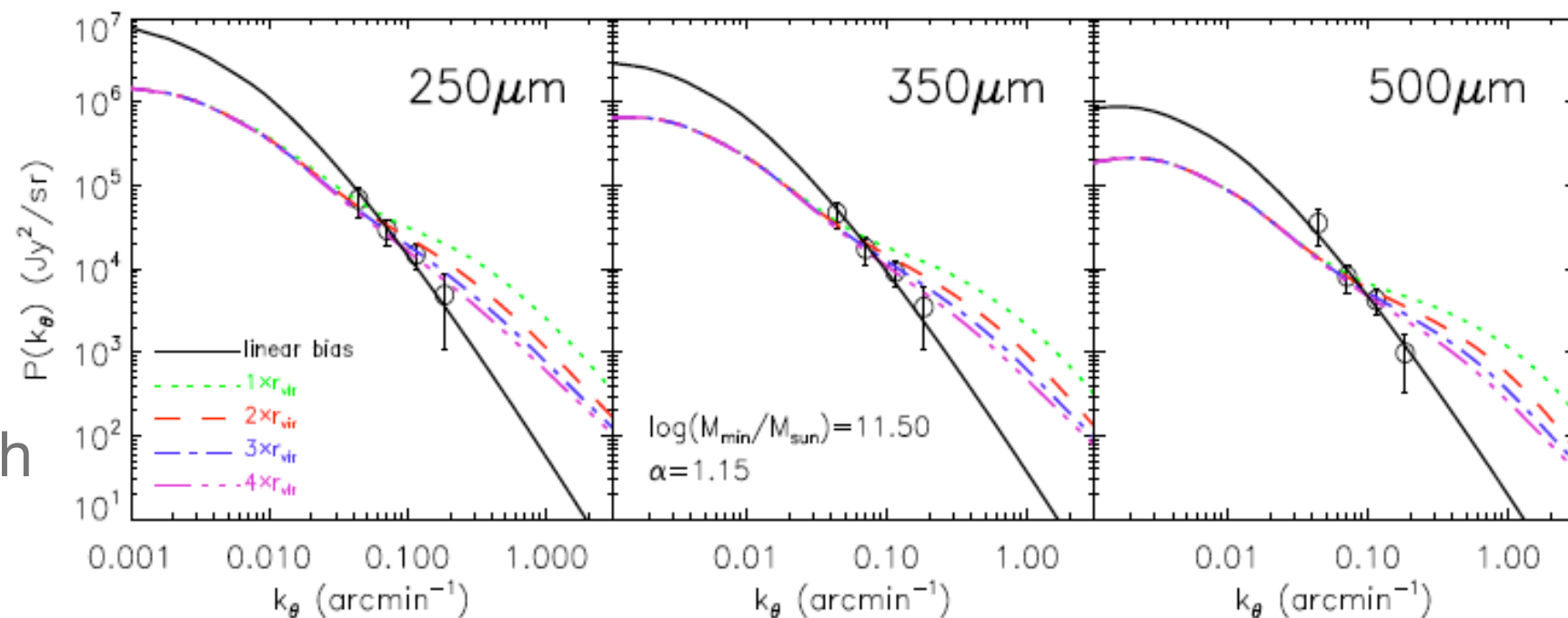
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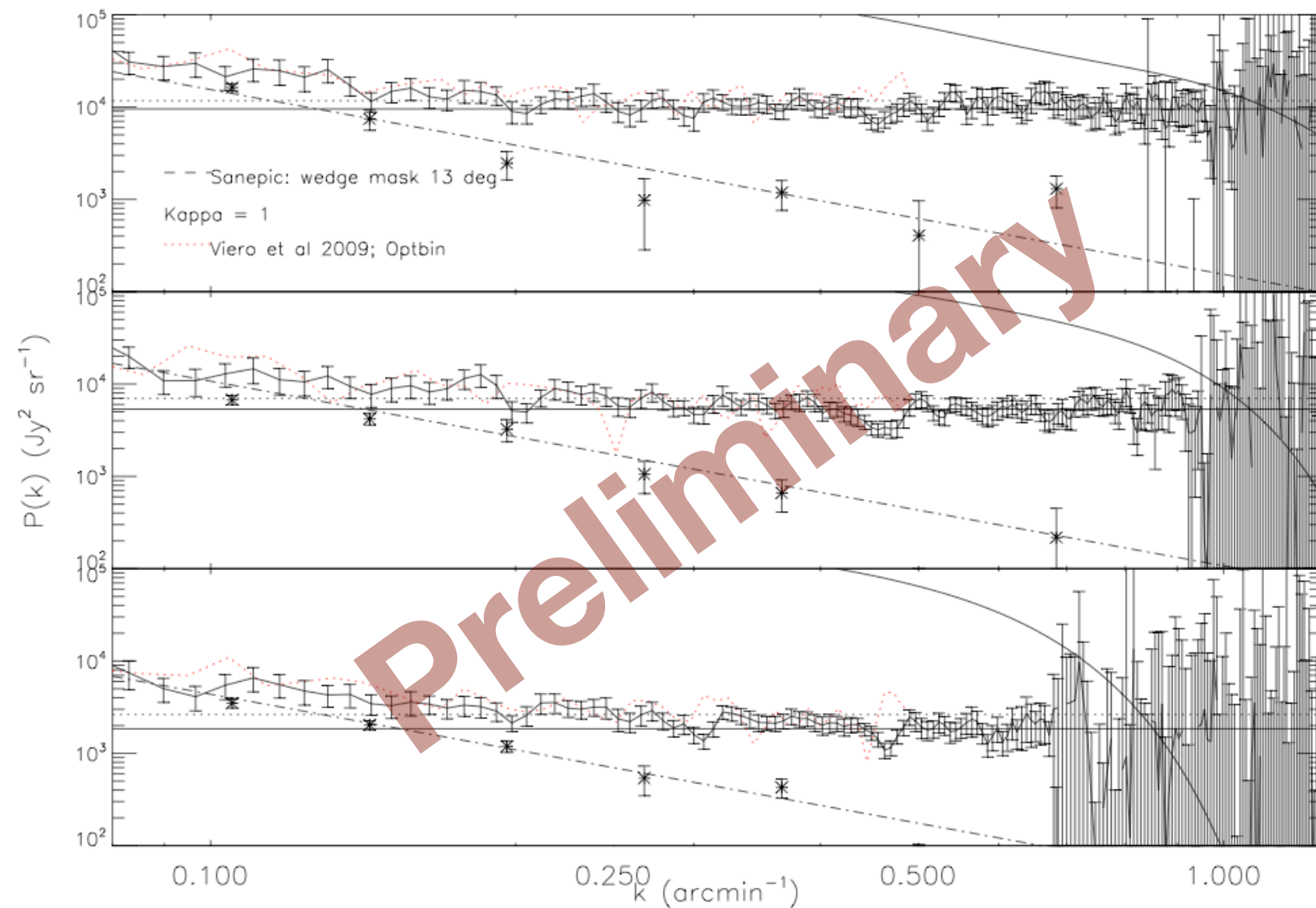
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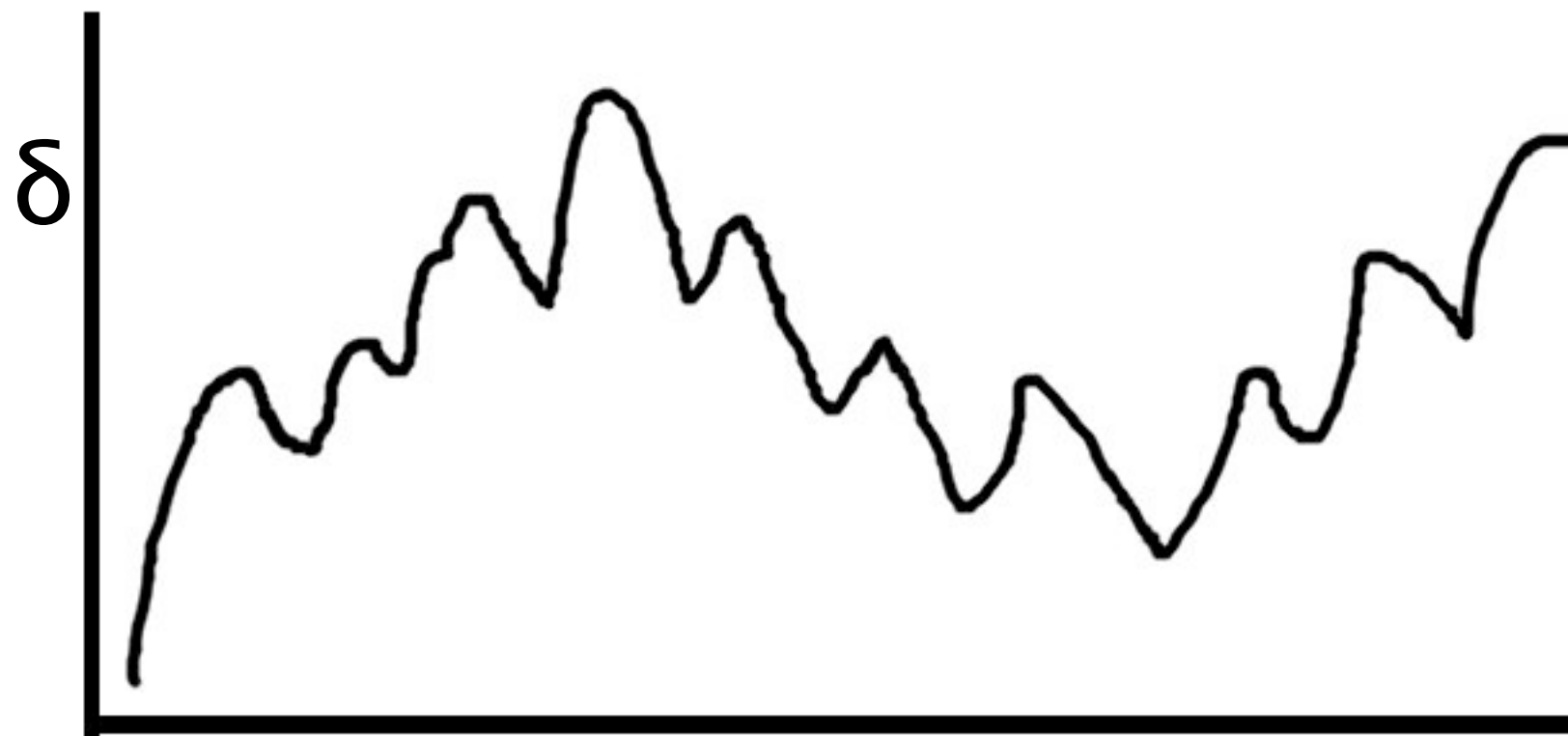
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- Further (ongoing) analysis with twice the data confirm this behaviour on small scales



Briefly: Halo-Model

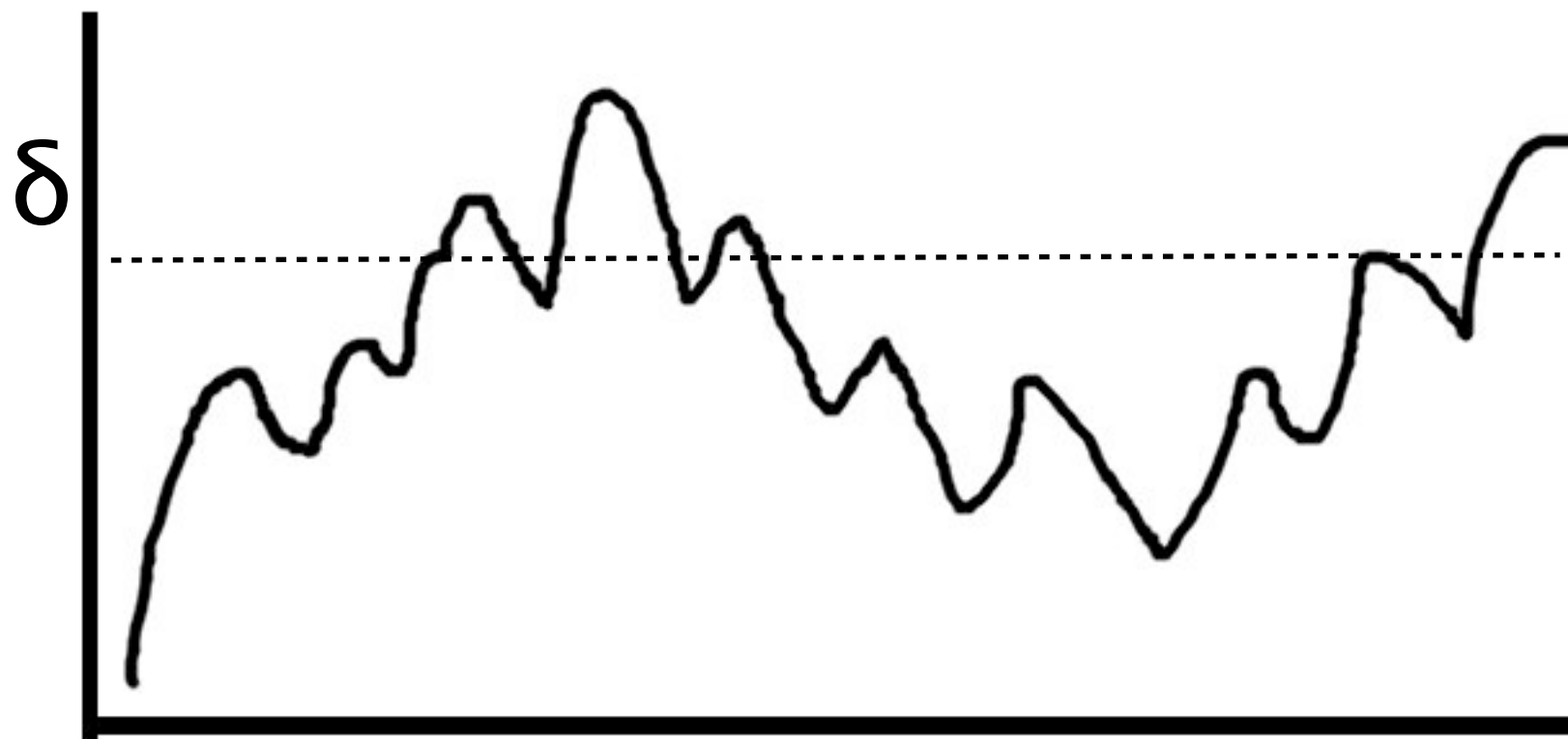
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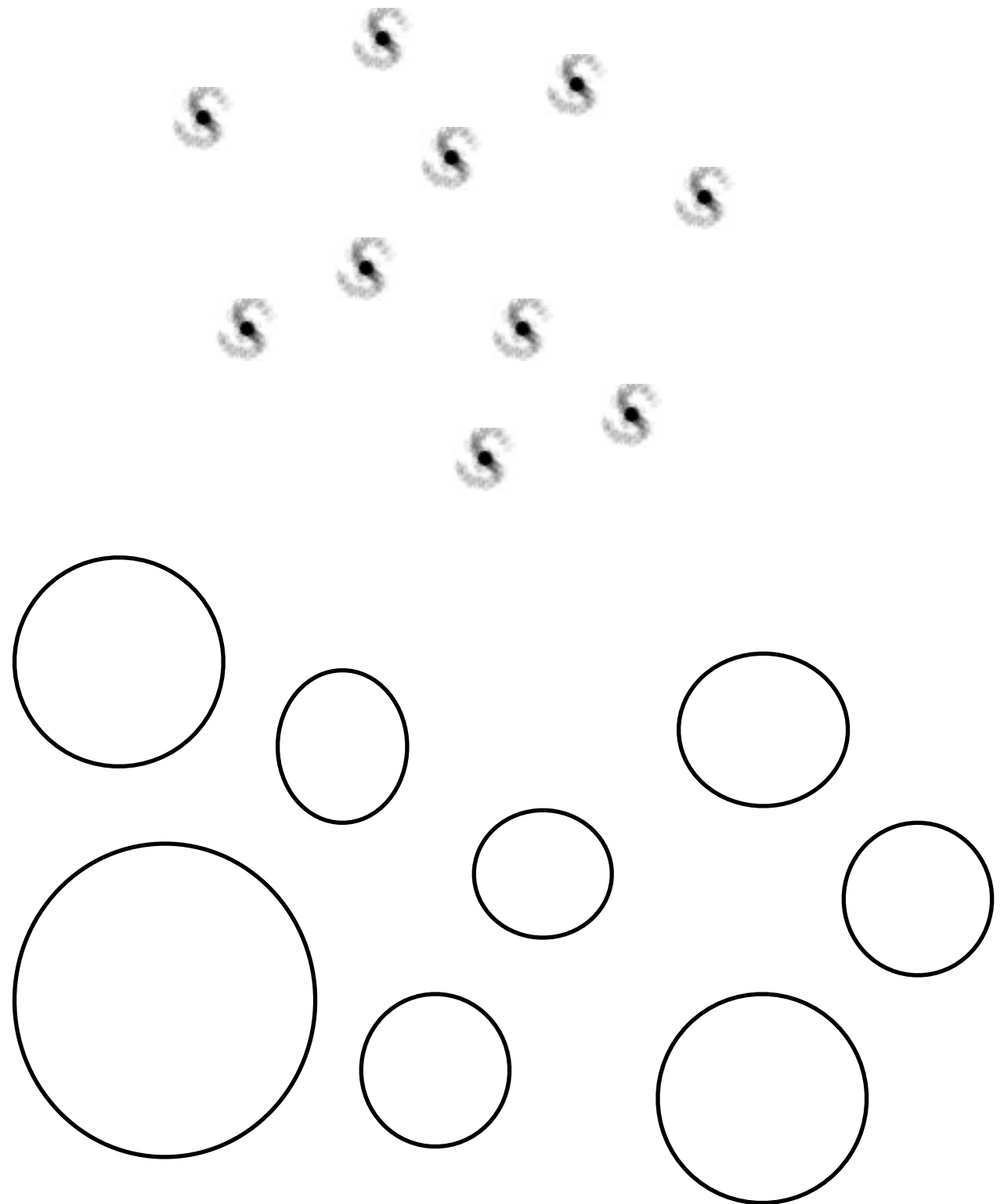
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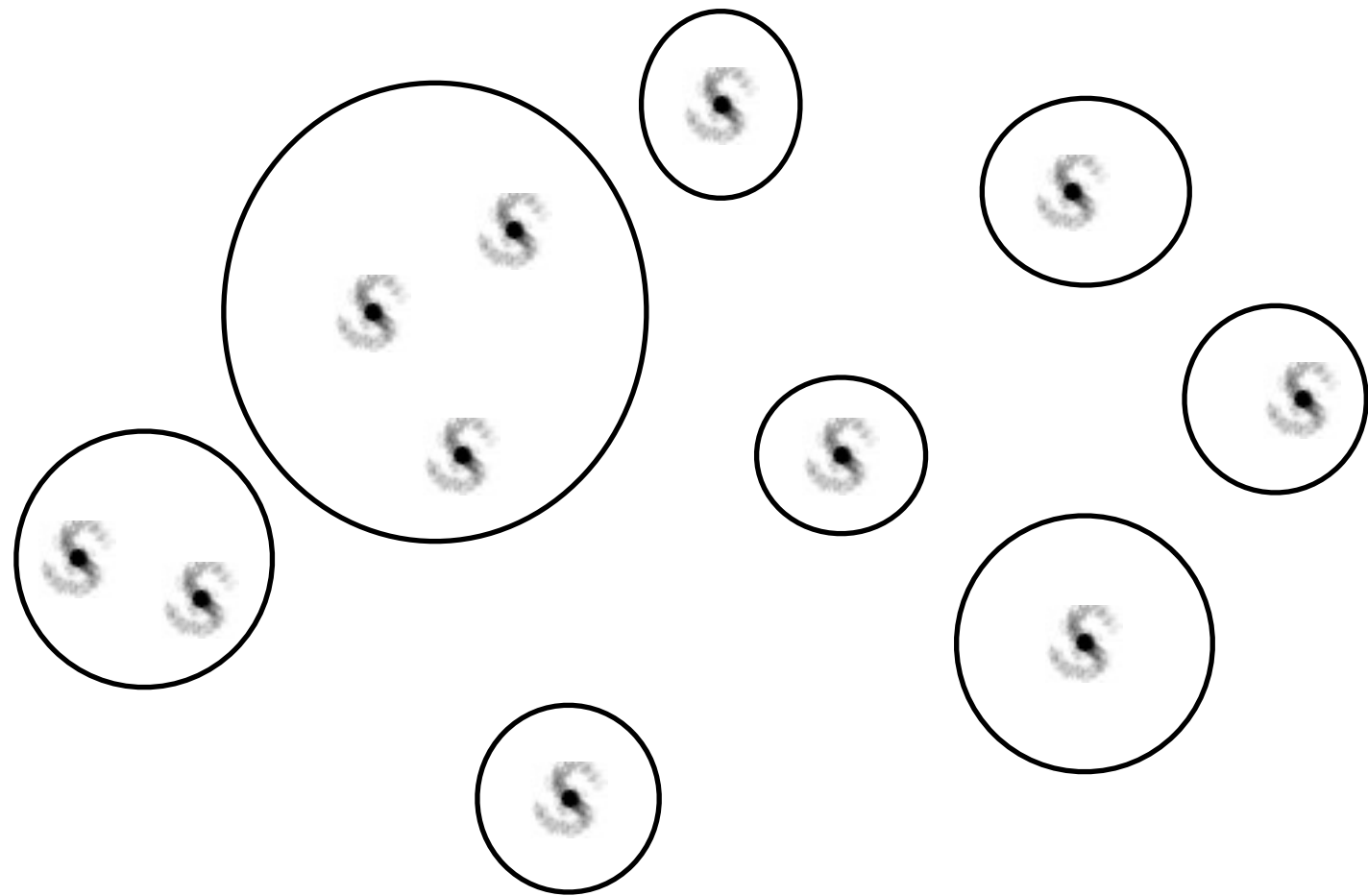
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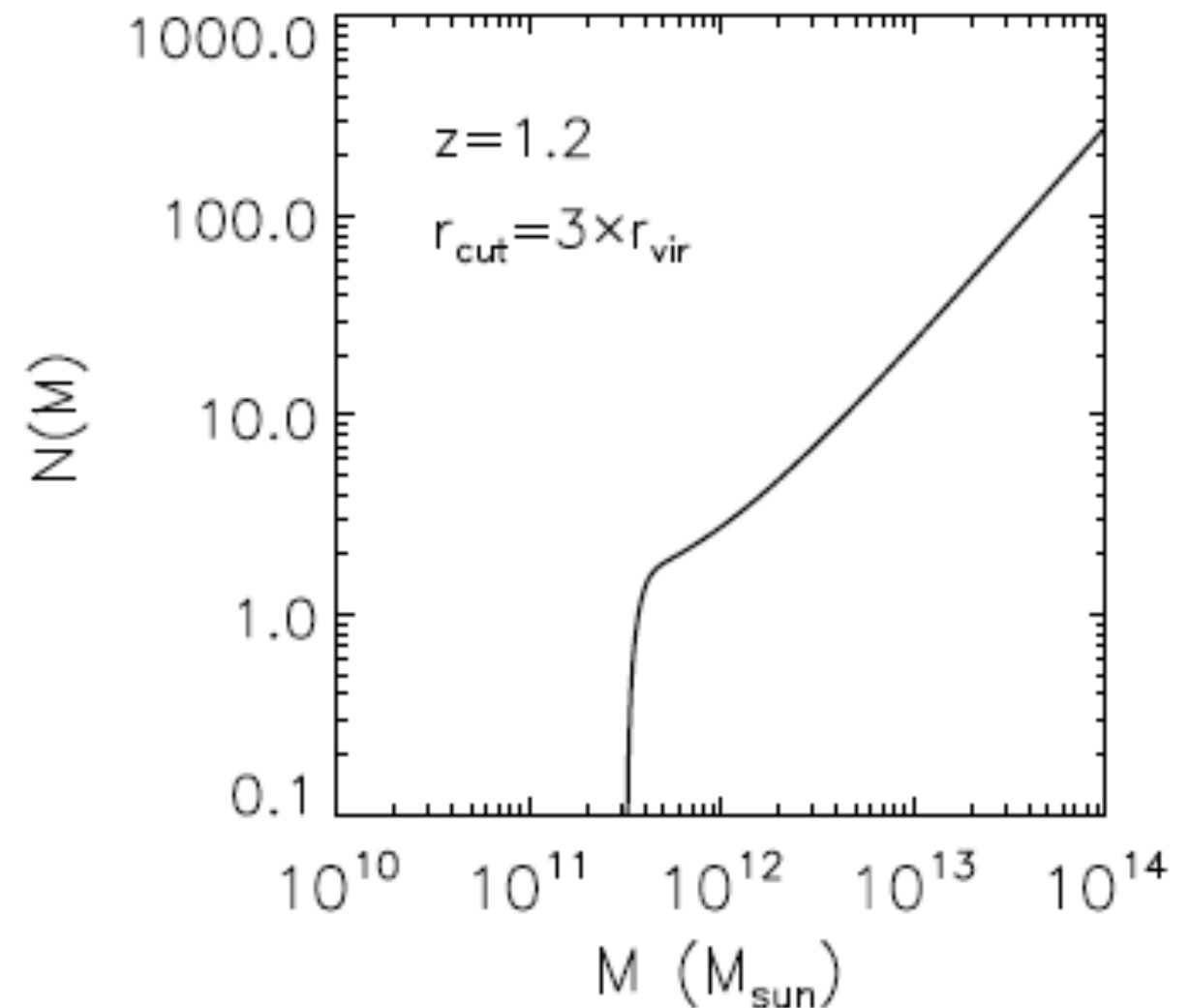
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- Prescription for assigning Galaxies to Halos as Function of Mass (aka HON):
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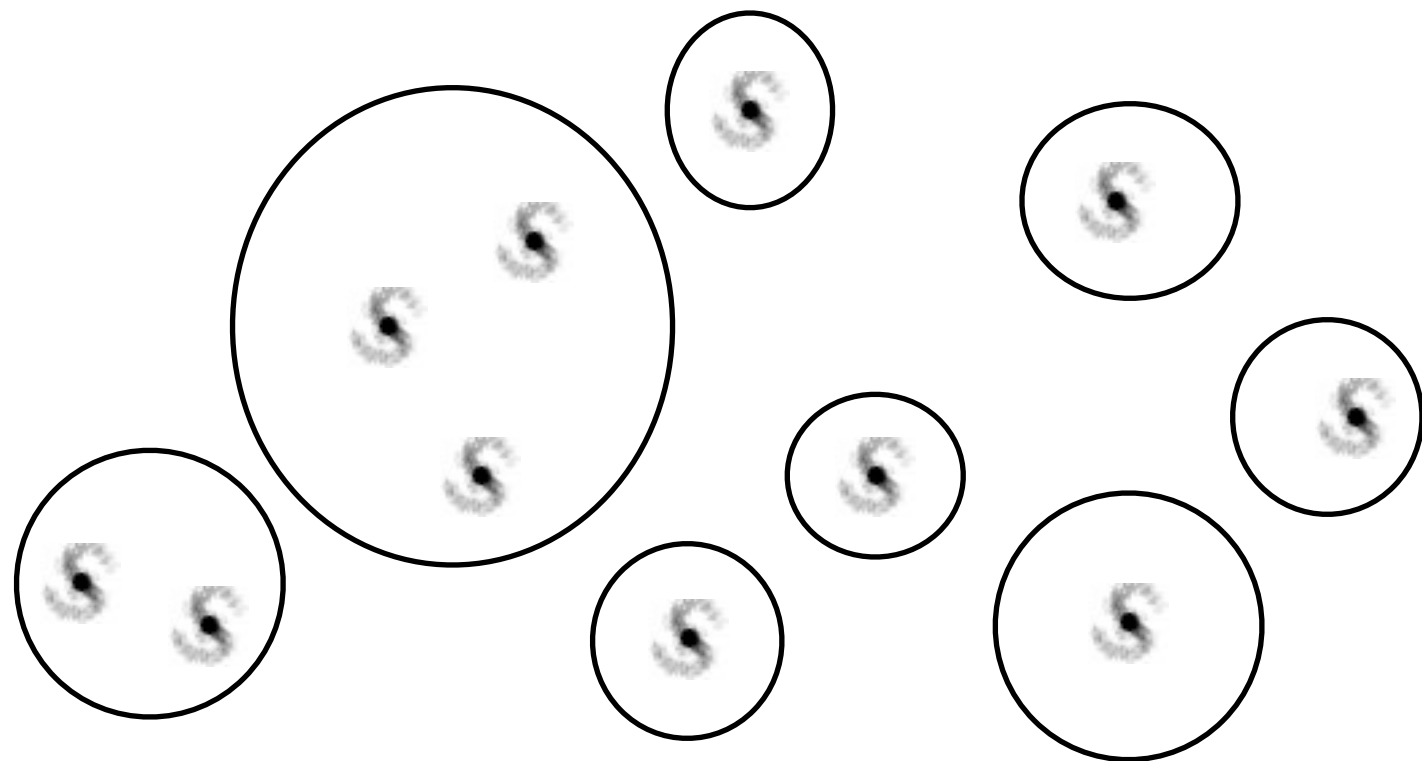


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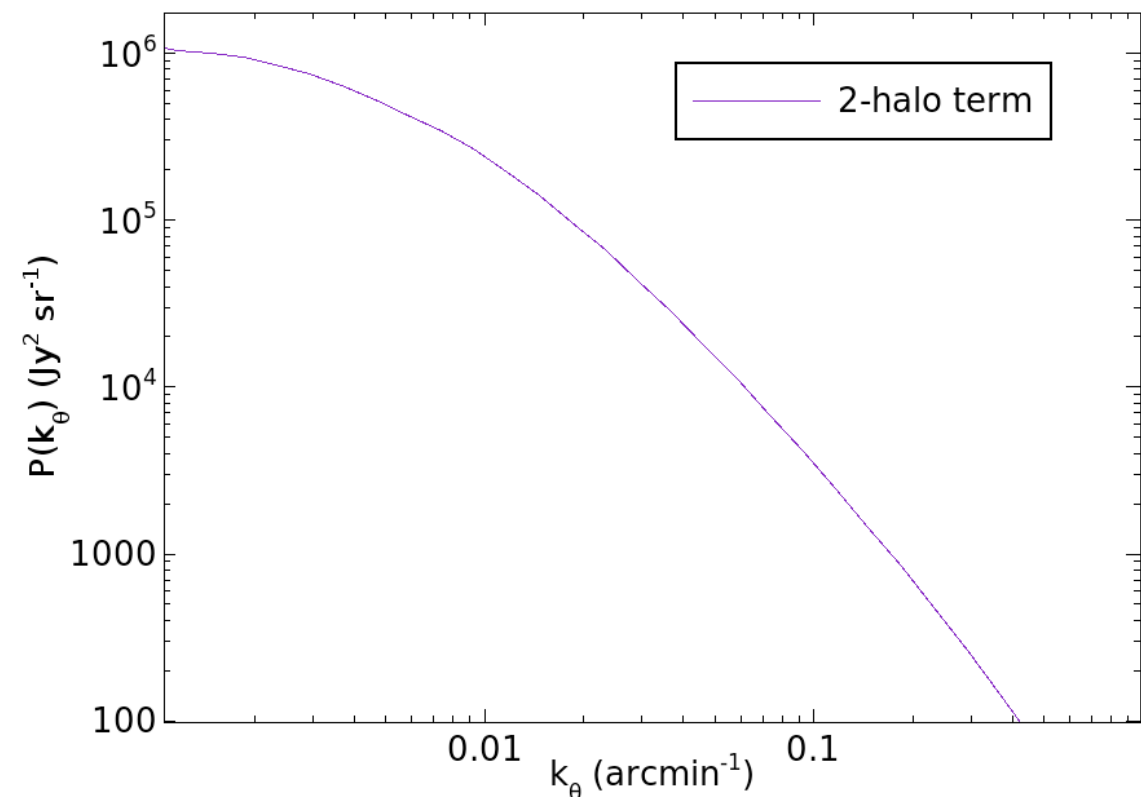
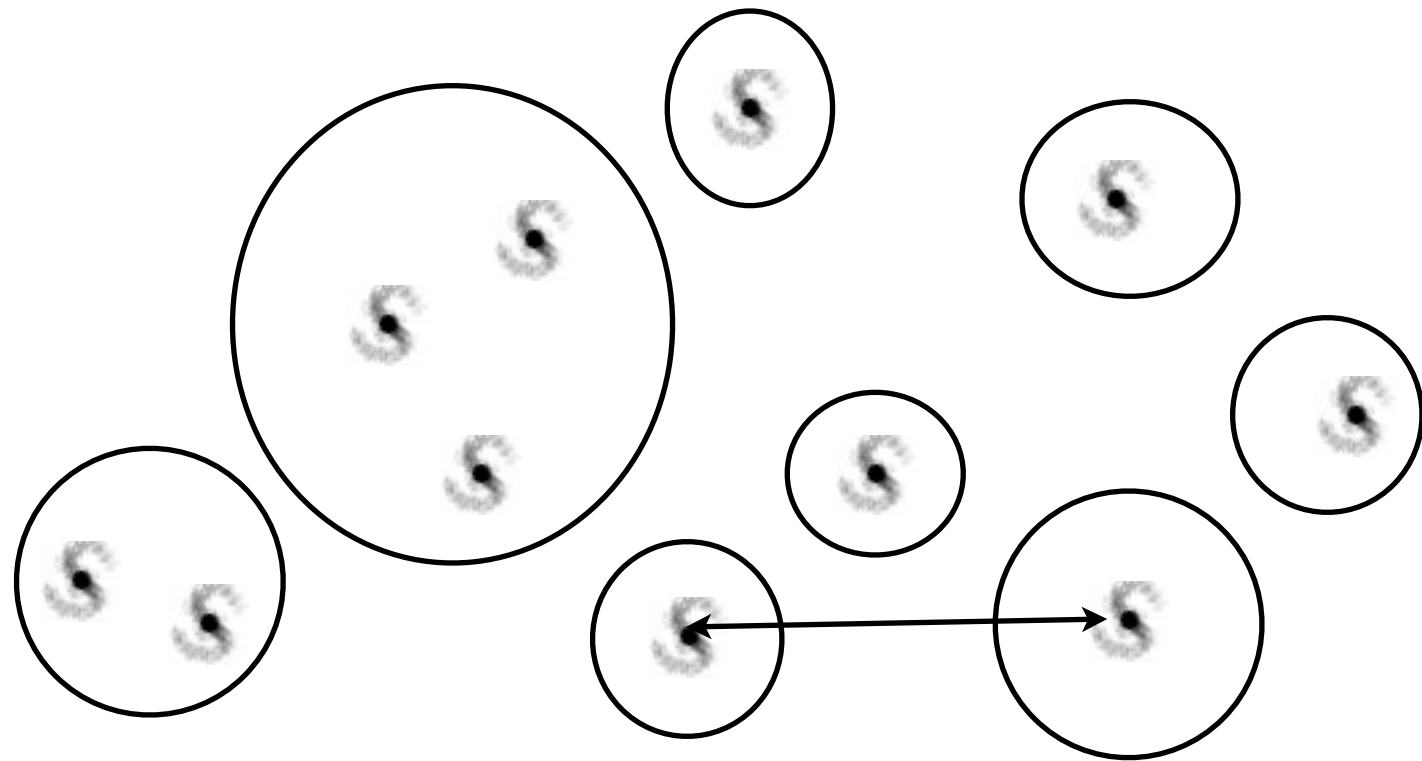
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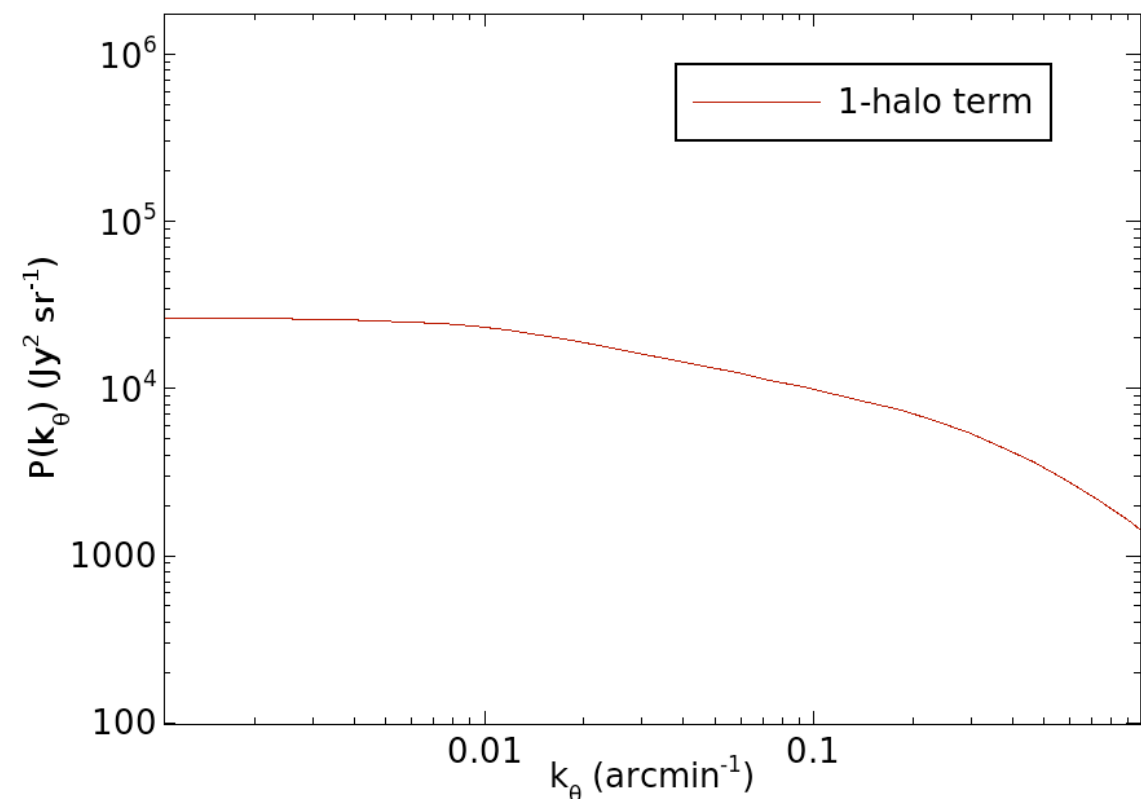
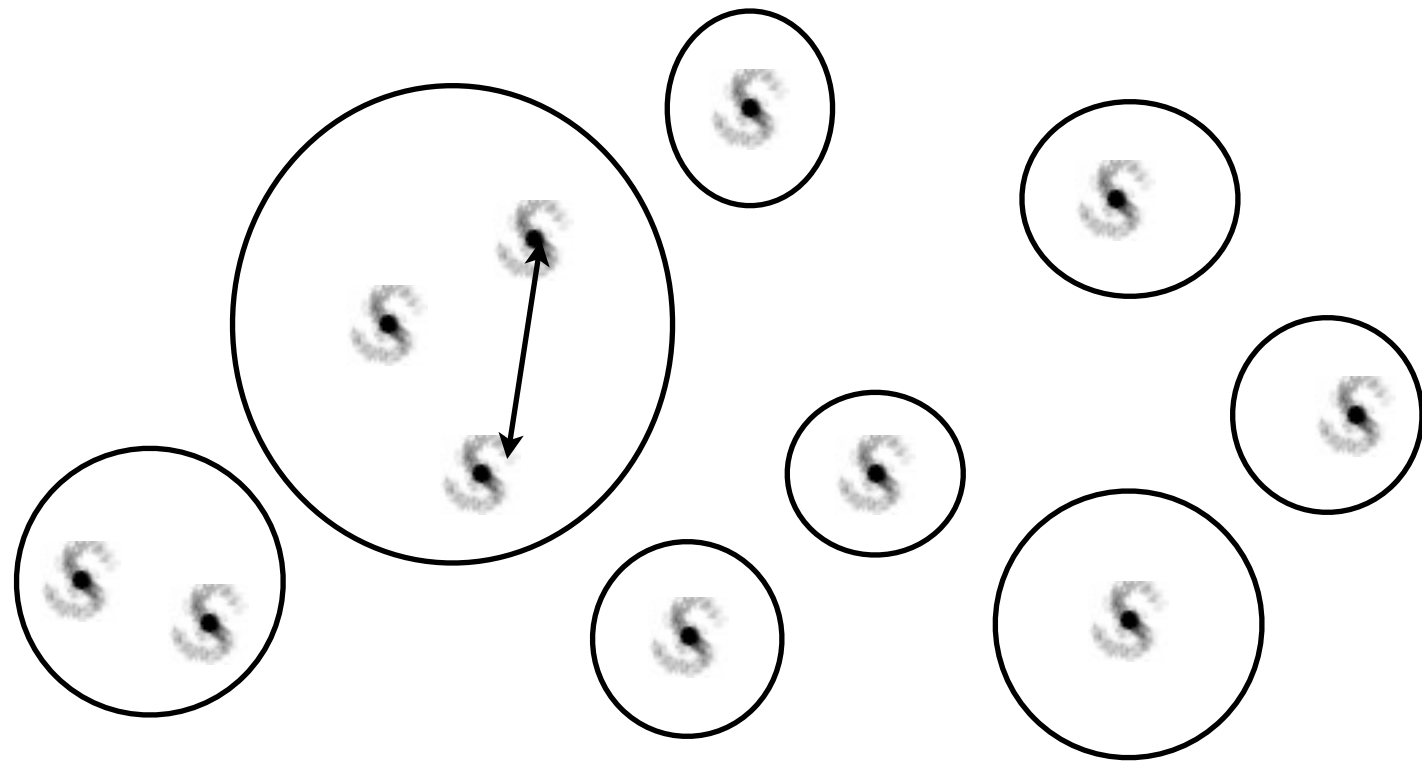
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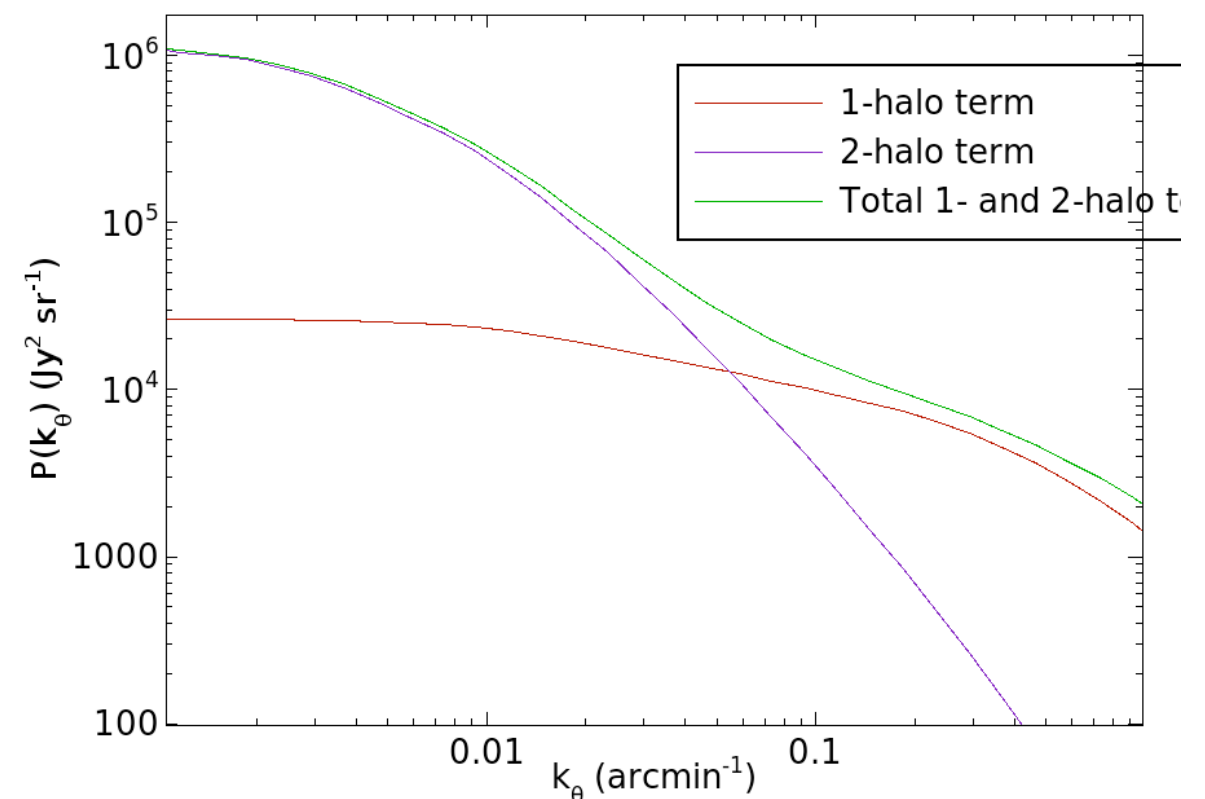
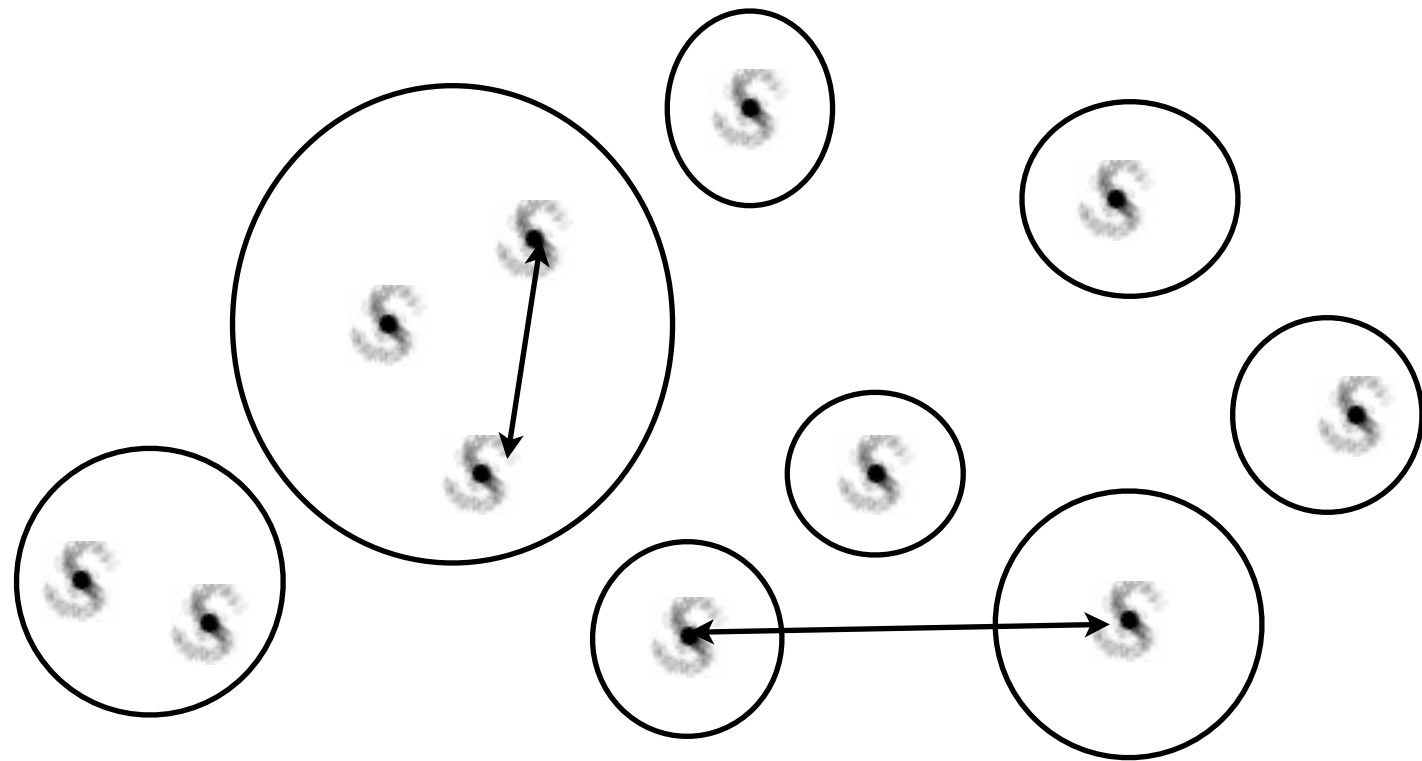
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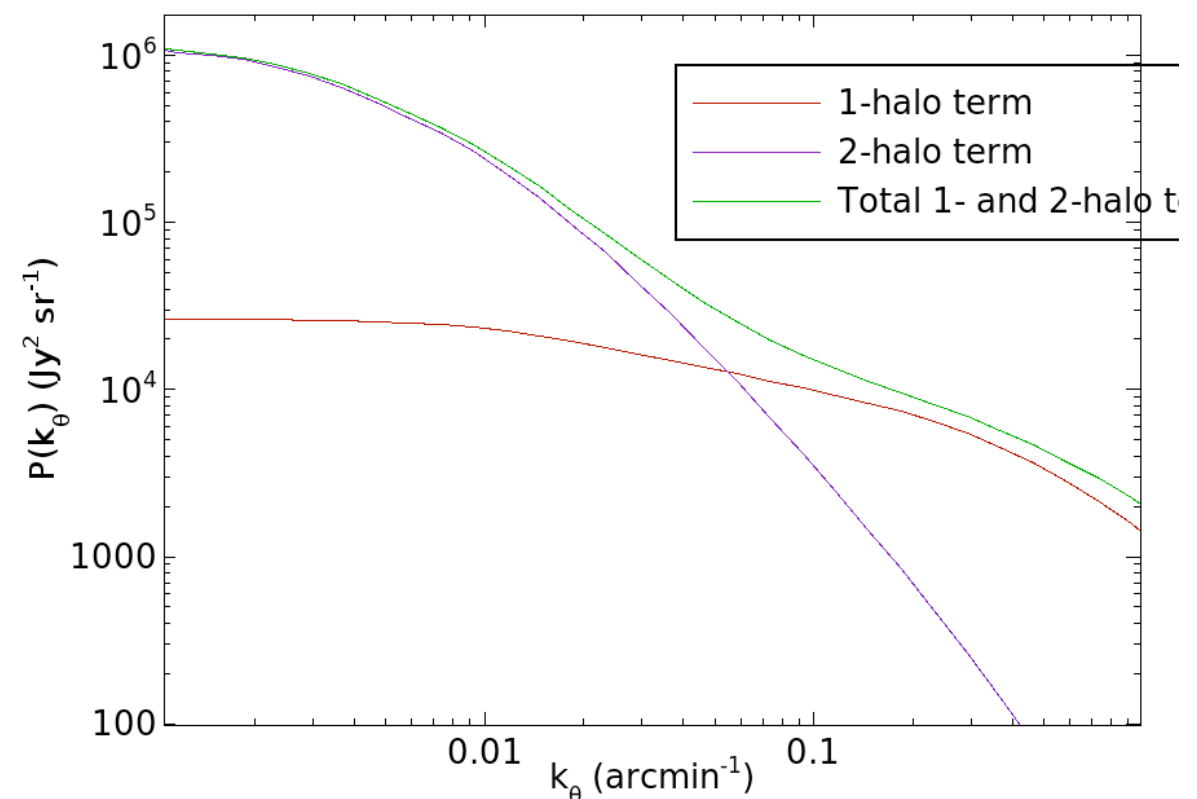
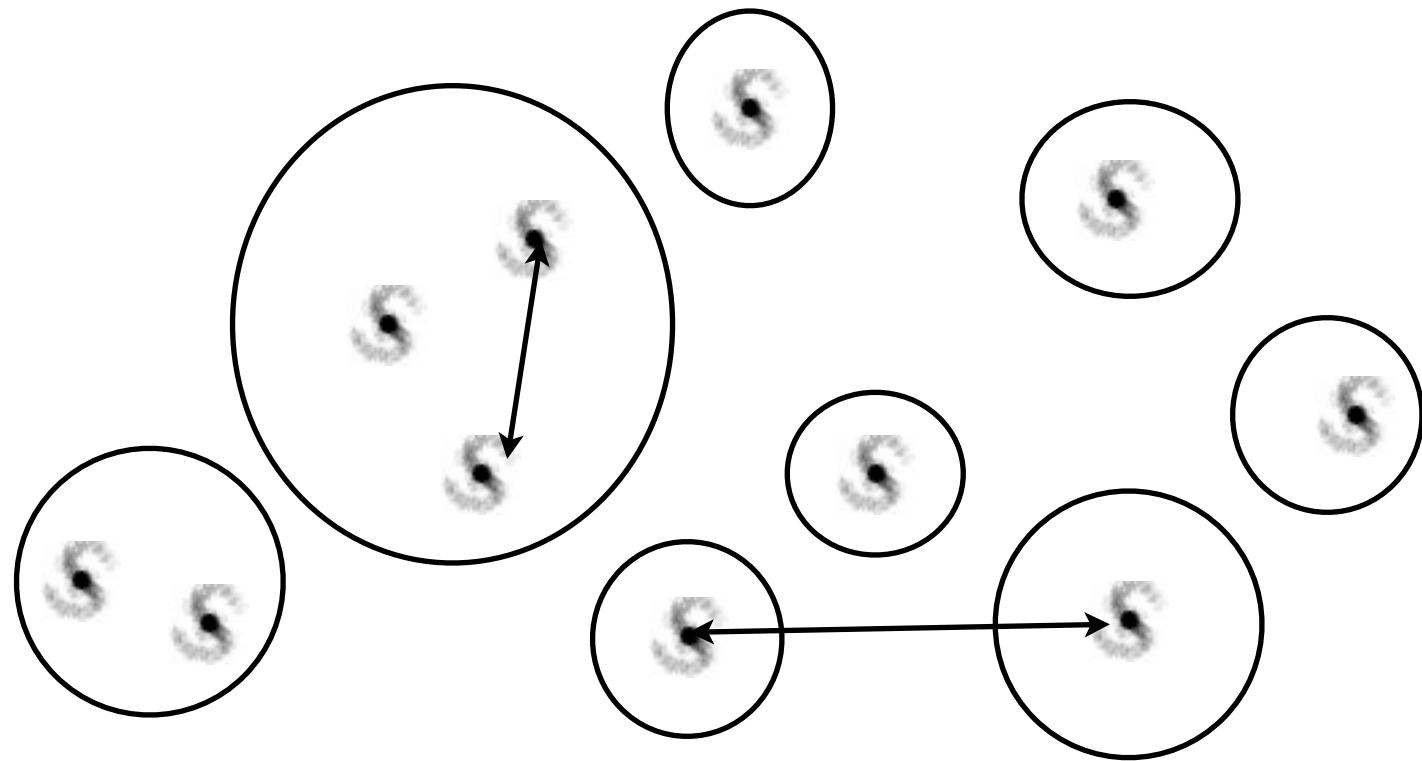
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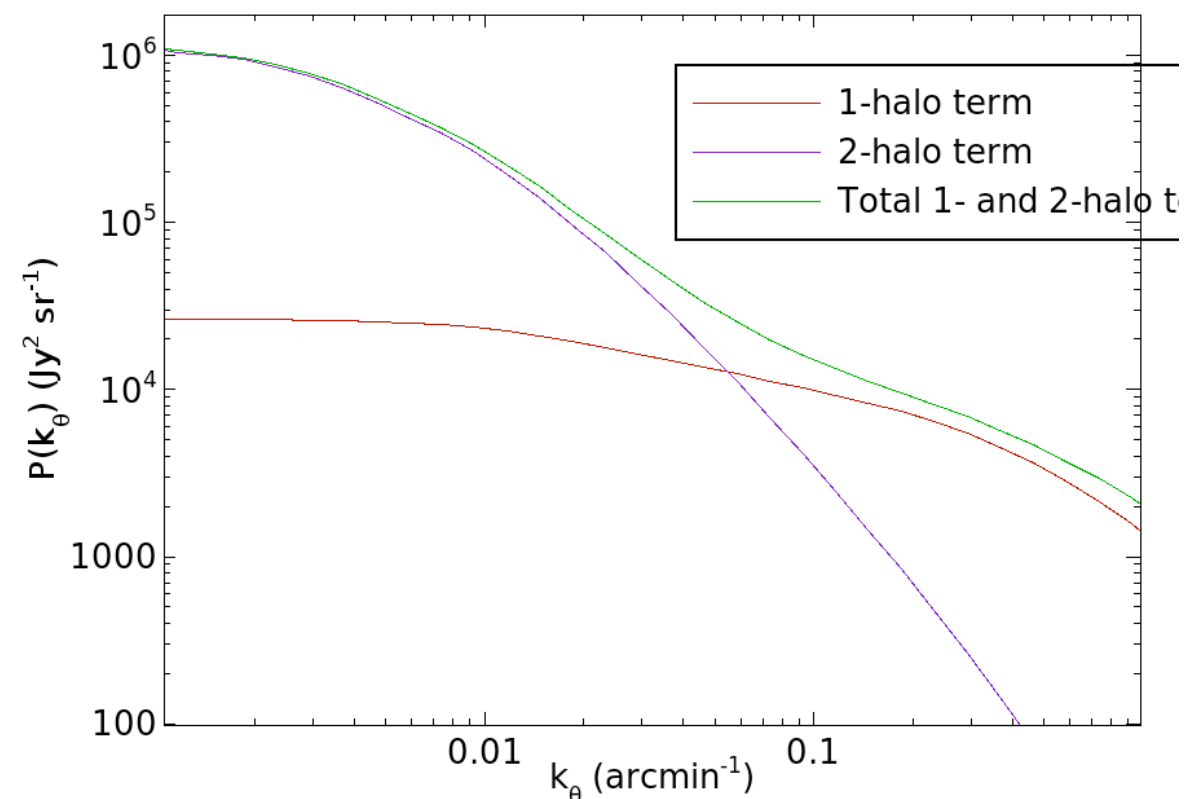
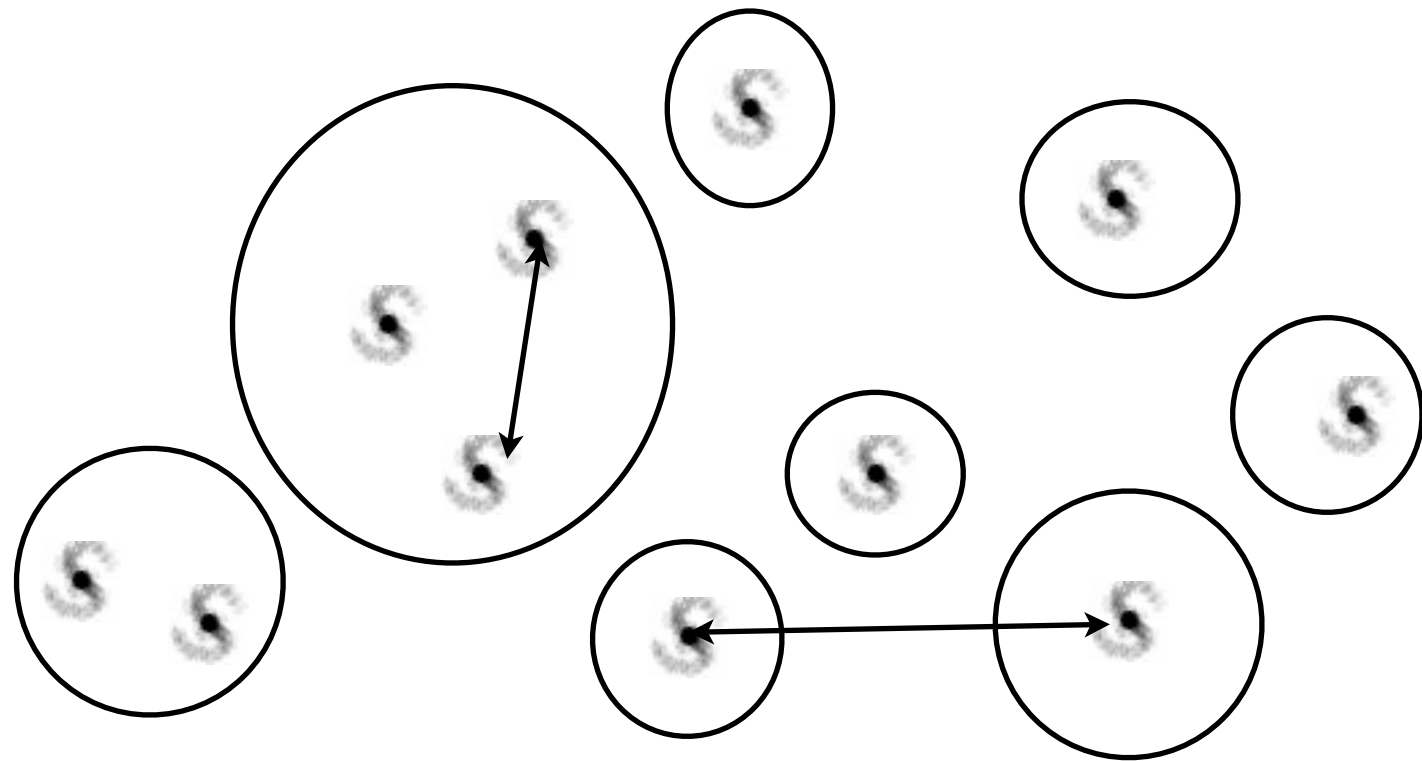
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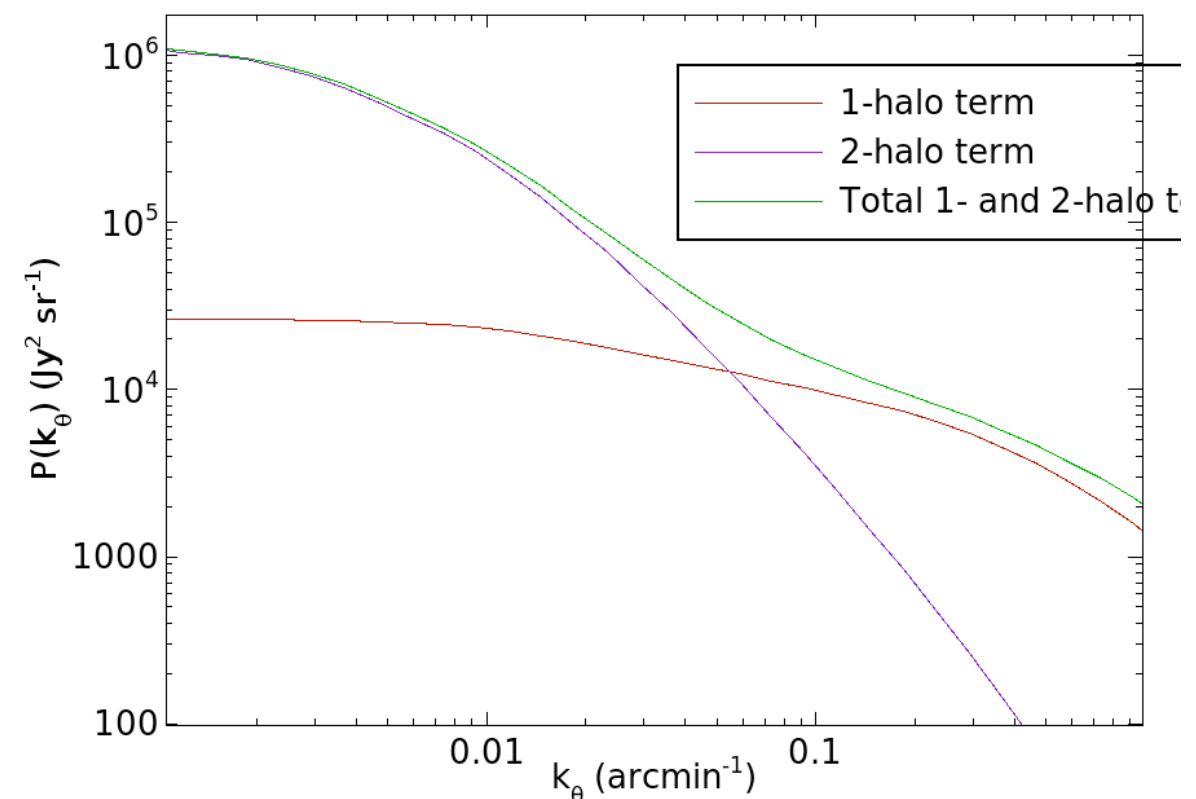
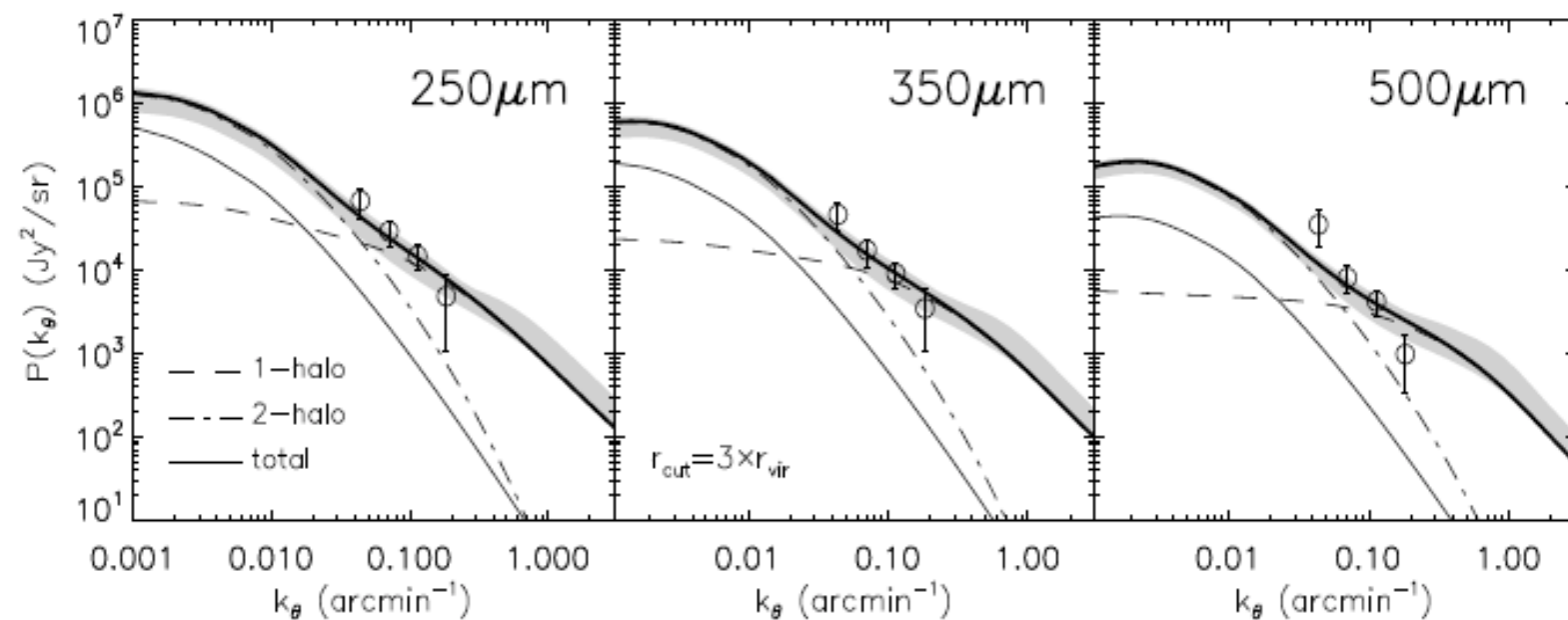
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- ◉ Model *Must* have a Bump!



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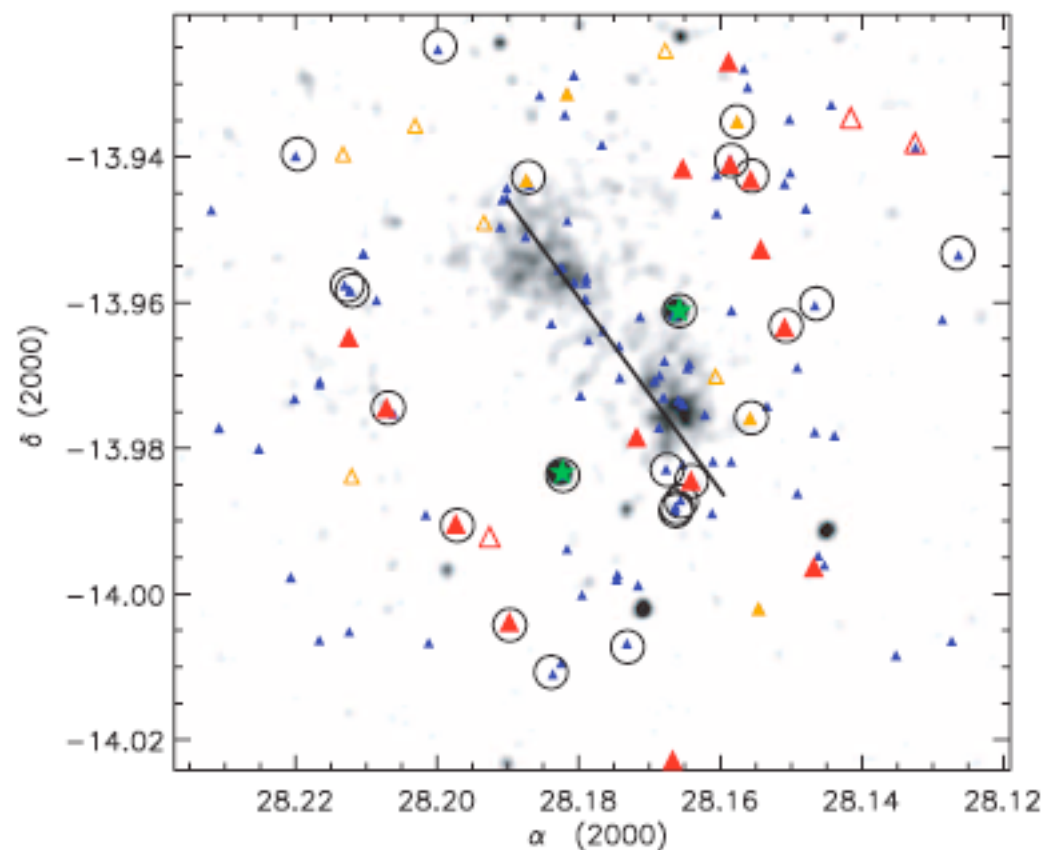
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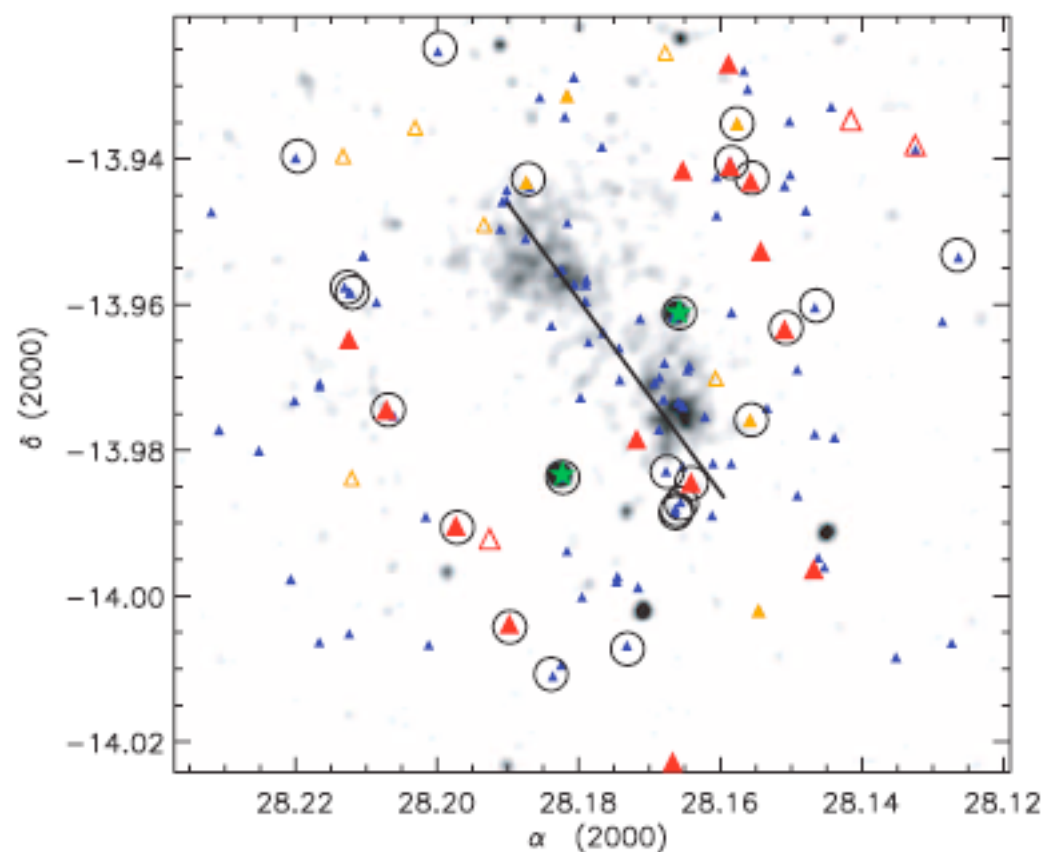


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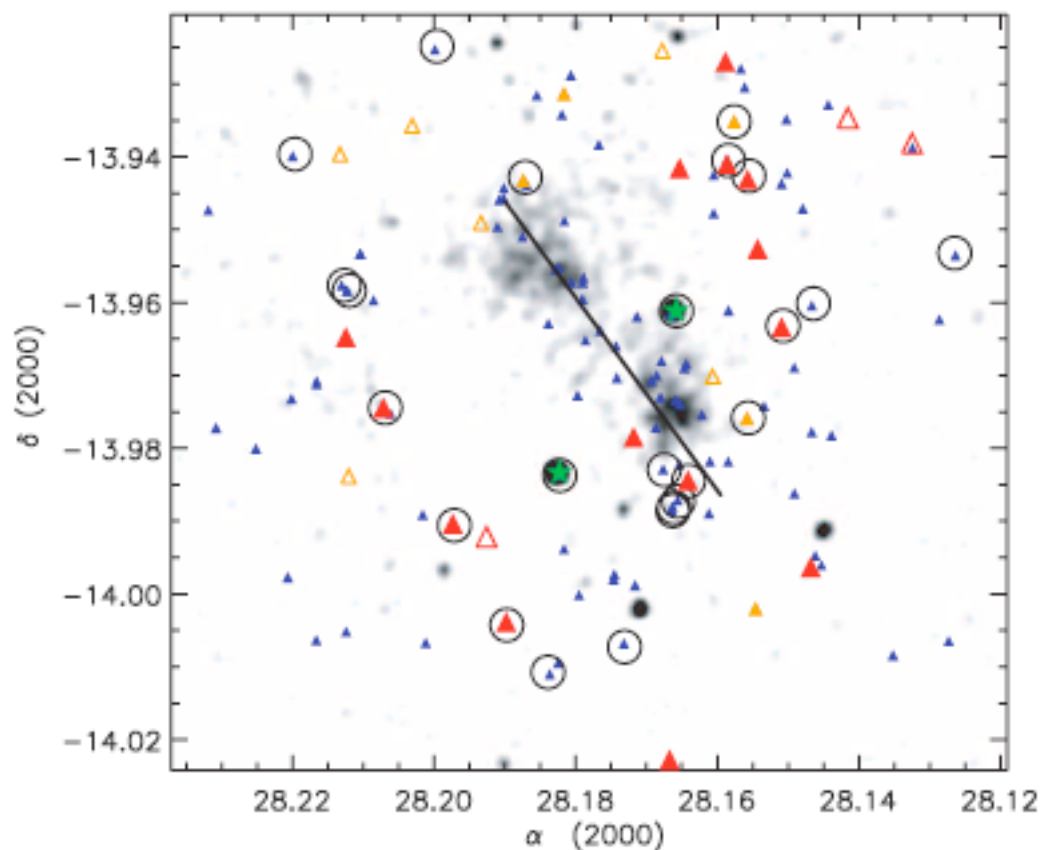


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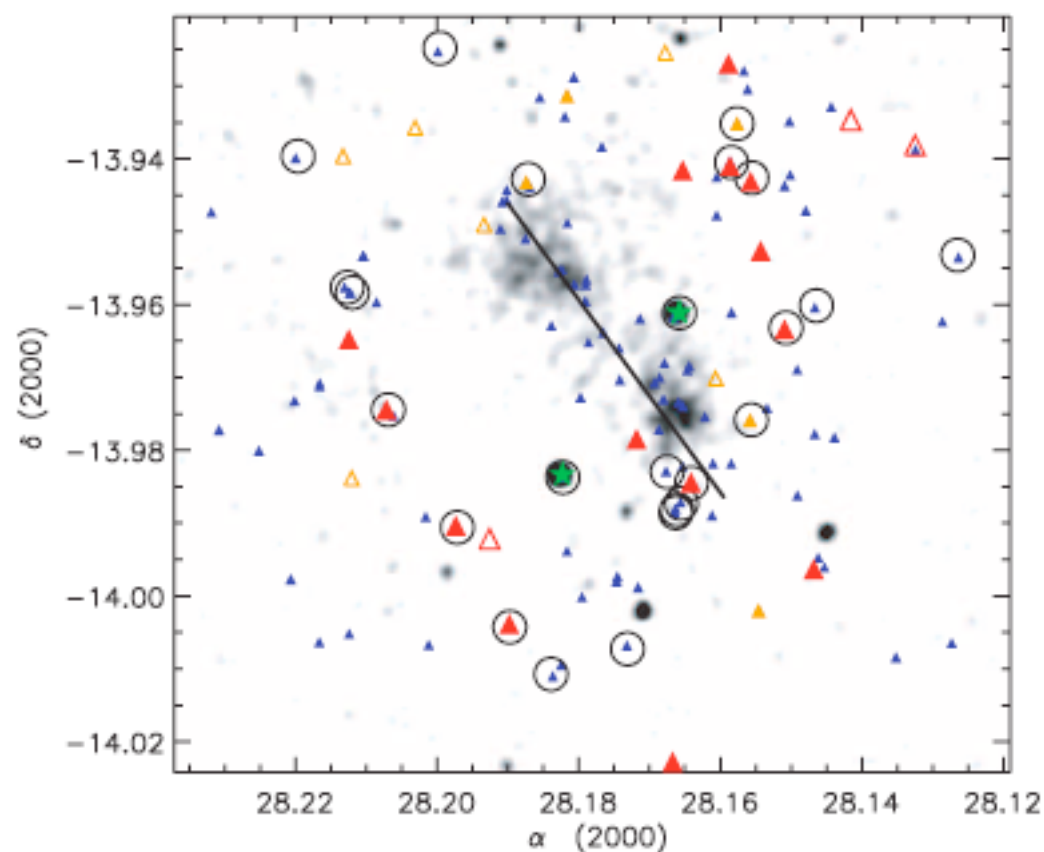
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 - It may be that the *environment* influences **where** Star Formation takes place!

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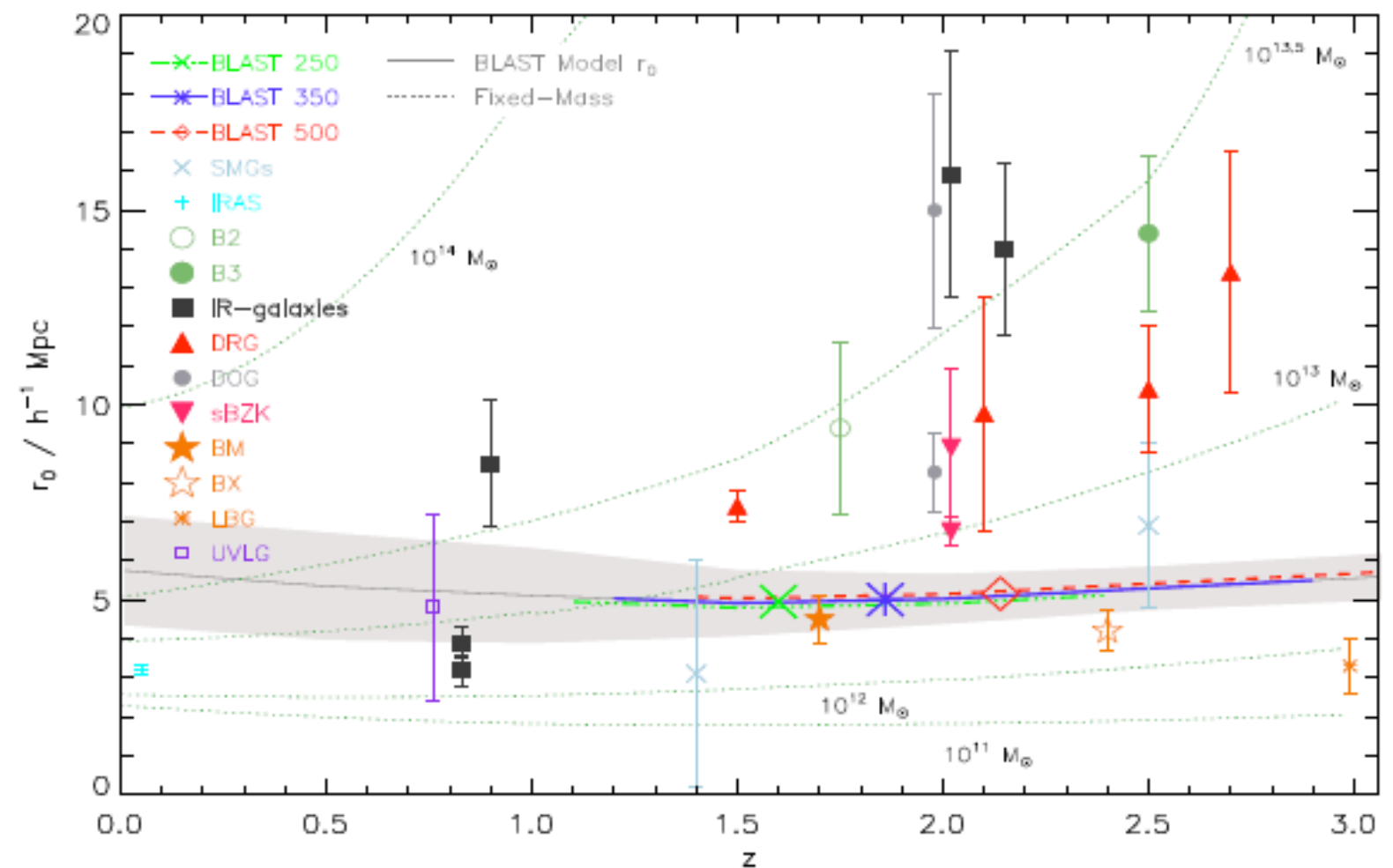
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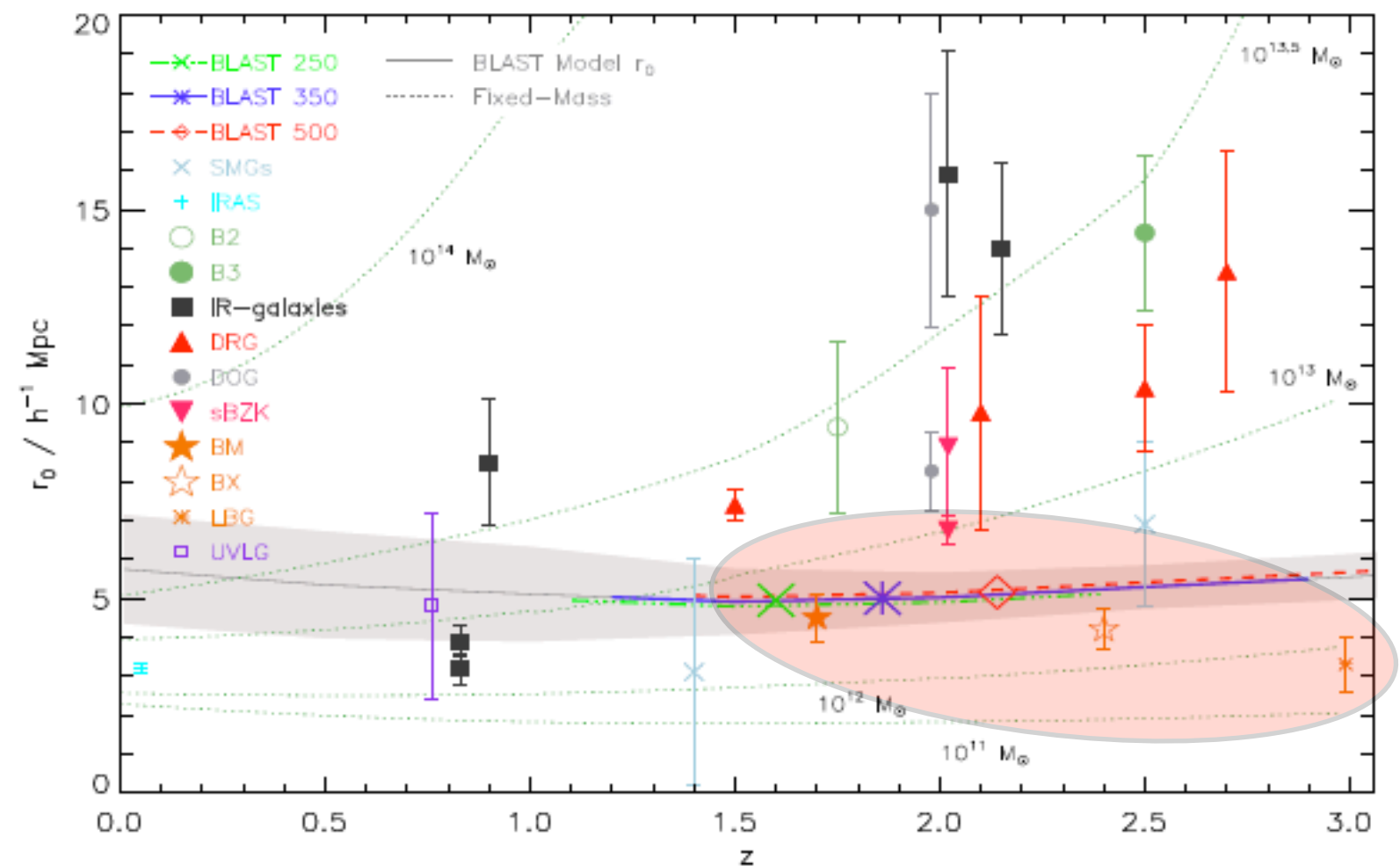
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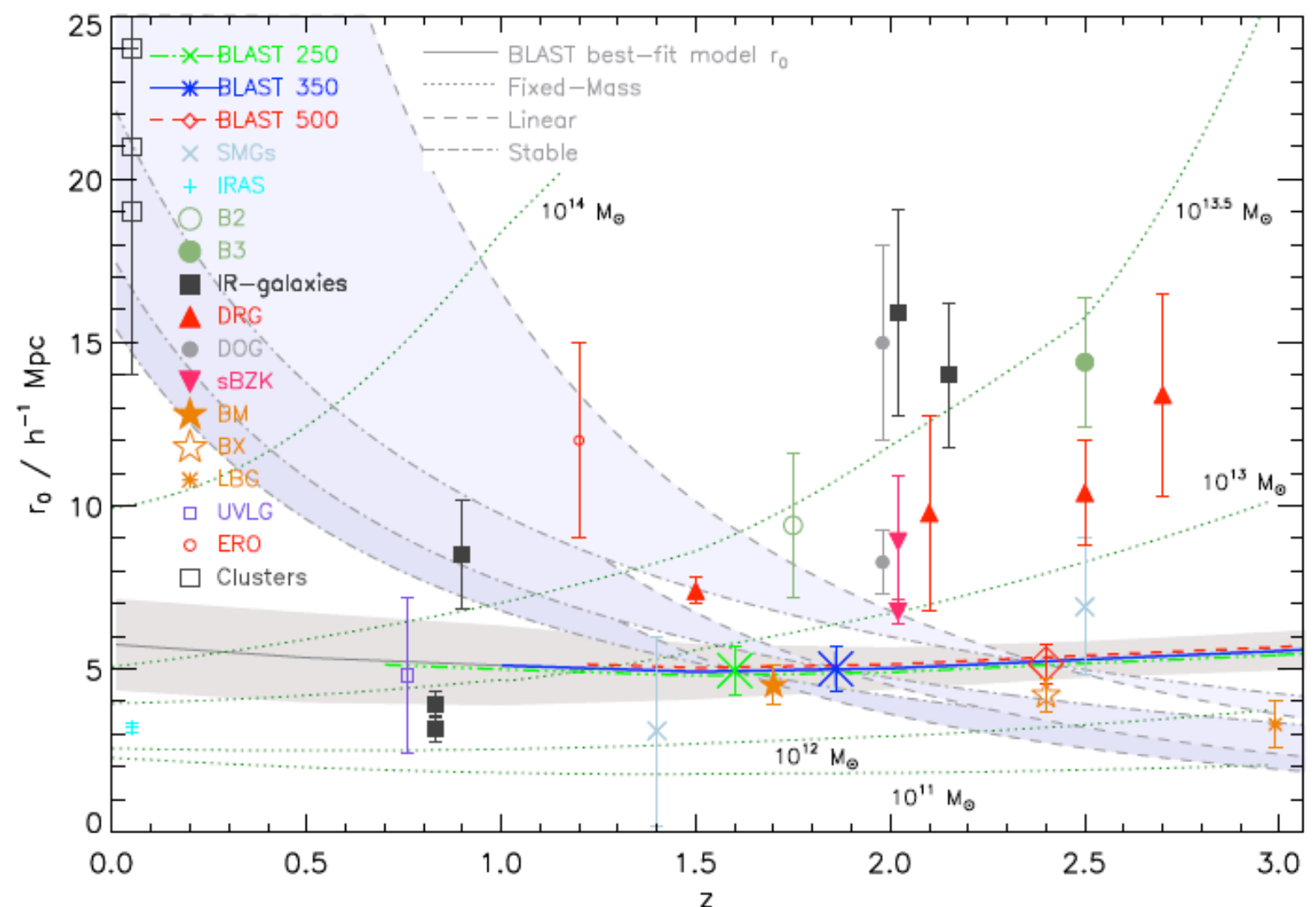
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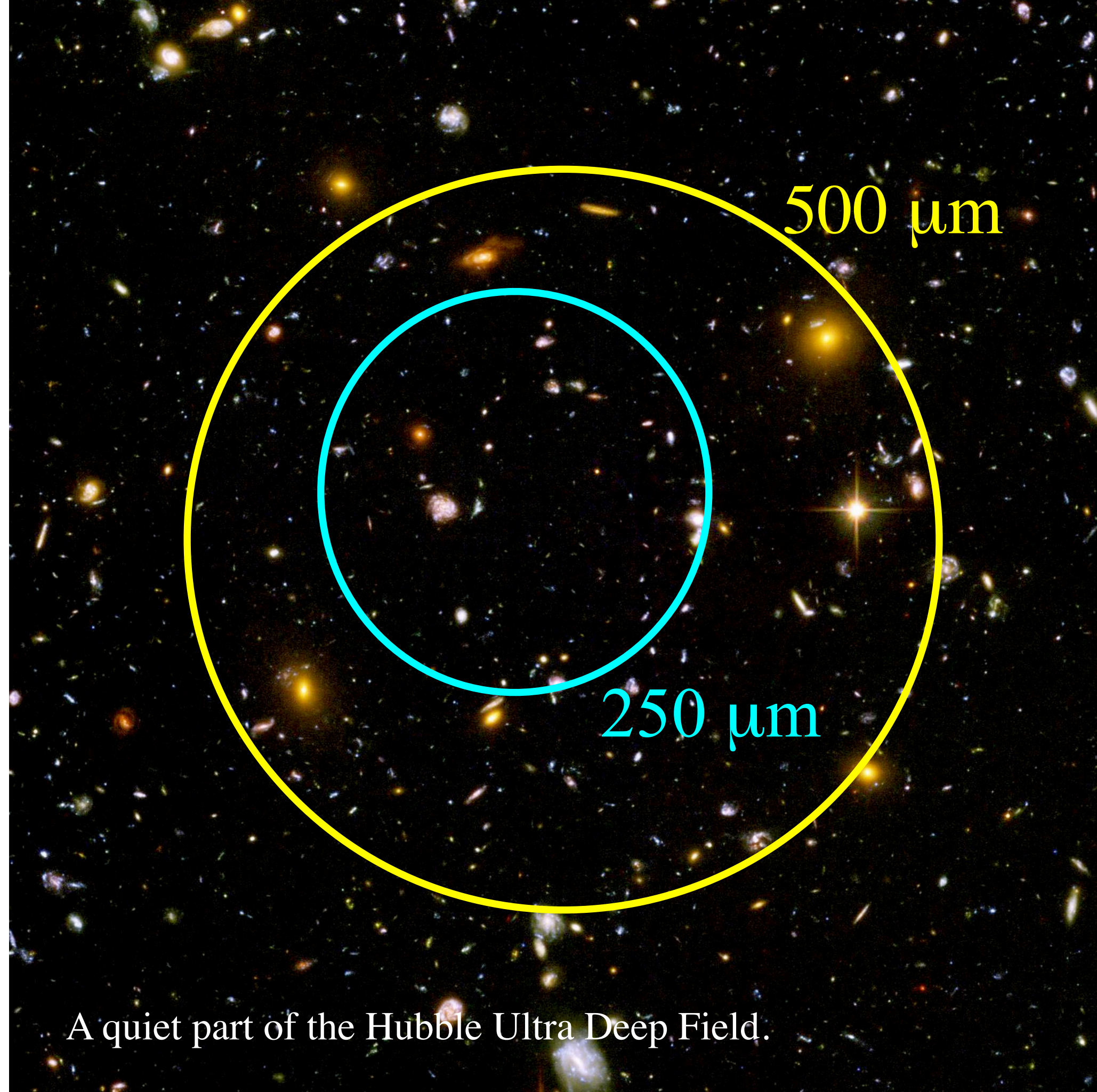
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- Clustering Evolution
 - ◉ $\xi(r,z) = (r/r_0)^{-\gamma}(1+z)^{\gamma-(3+\epsilon)}$
 - Stable Clustering $\epsilon = 0$,
 - Linear Clustering $\epsilon = 1$



TAKE HOME

- The BLAST/Herschel/Planck beams are huge compared to galaxies, and even compared to the mean distance between galaxies.
- Using all the information available to you (i.e., maps rather than catalogs) is of vital importance in confusion limited maps



A quiet part of the Hubble Ultra Deep Field.



Science & Technology
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BLAST

Balloon-borne Large-Aperture Sub-millimeter Telescope



NSERC
CRSNG



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