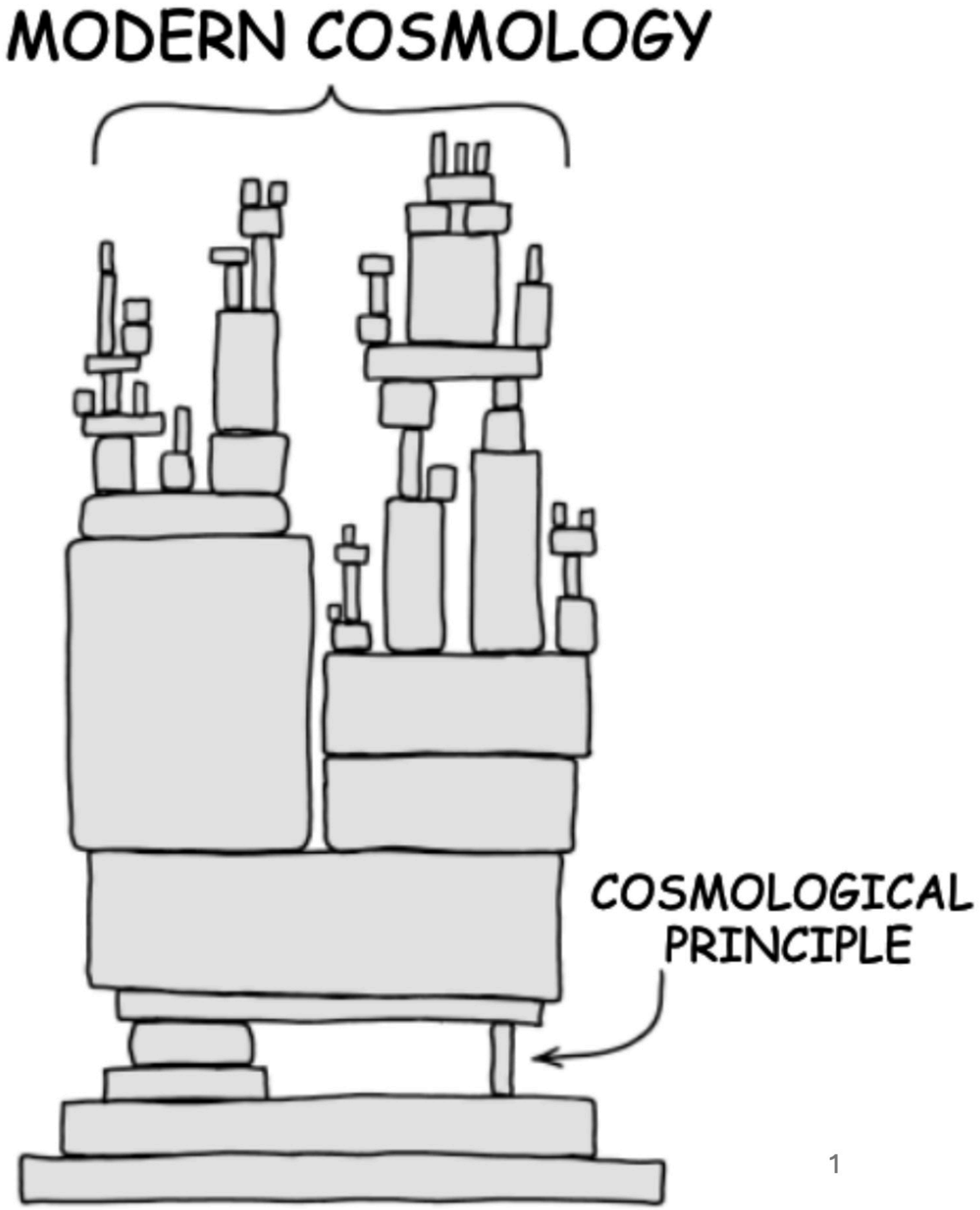
Confronting the Cosmological Principle

Vasudev Mittal
Sydney Institute for Astronomy

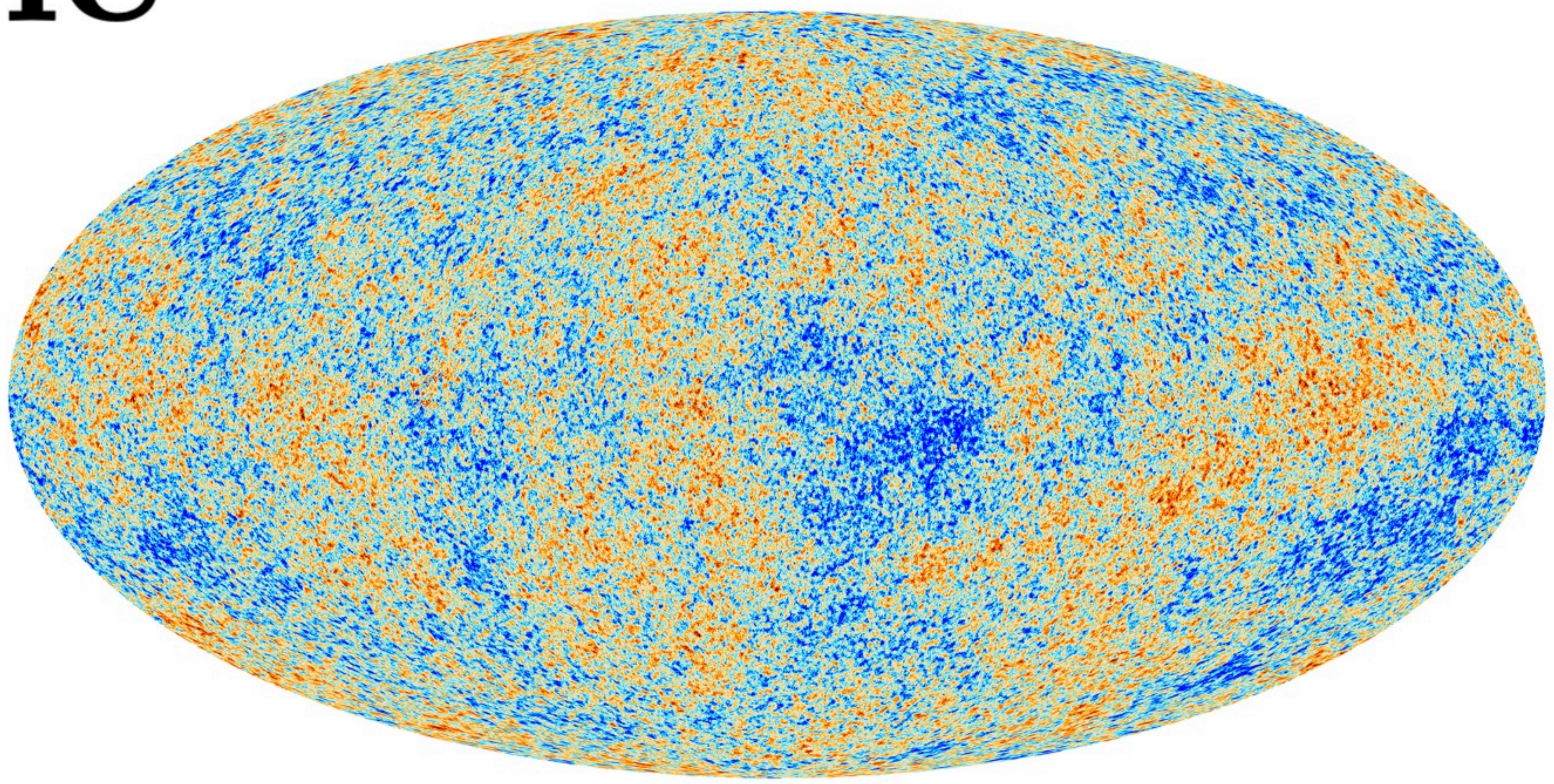
THE UNIVERSITY OF SYDNEY



Structure

- TTT: Theory, Test and Tension
- Methodology
- Results: Quasars
- The future

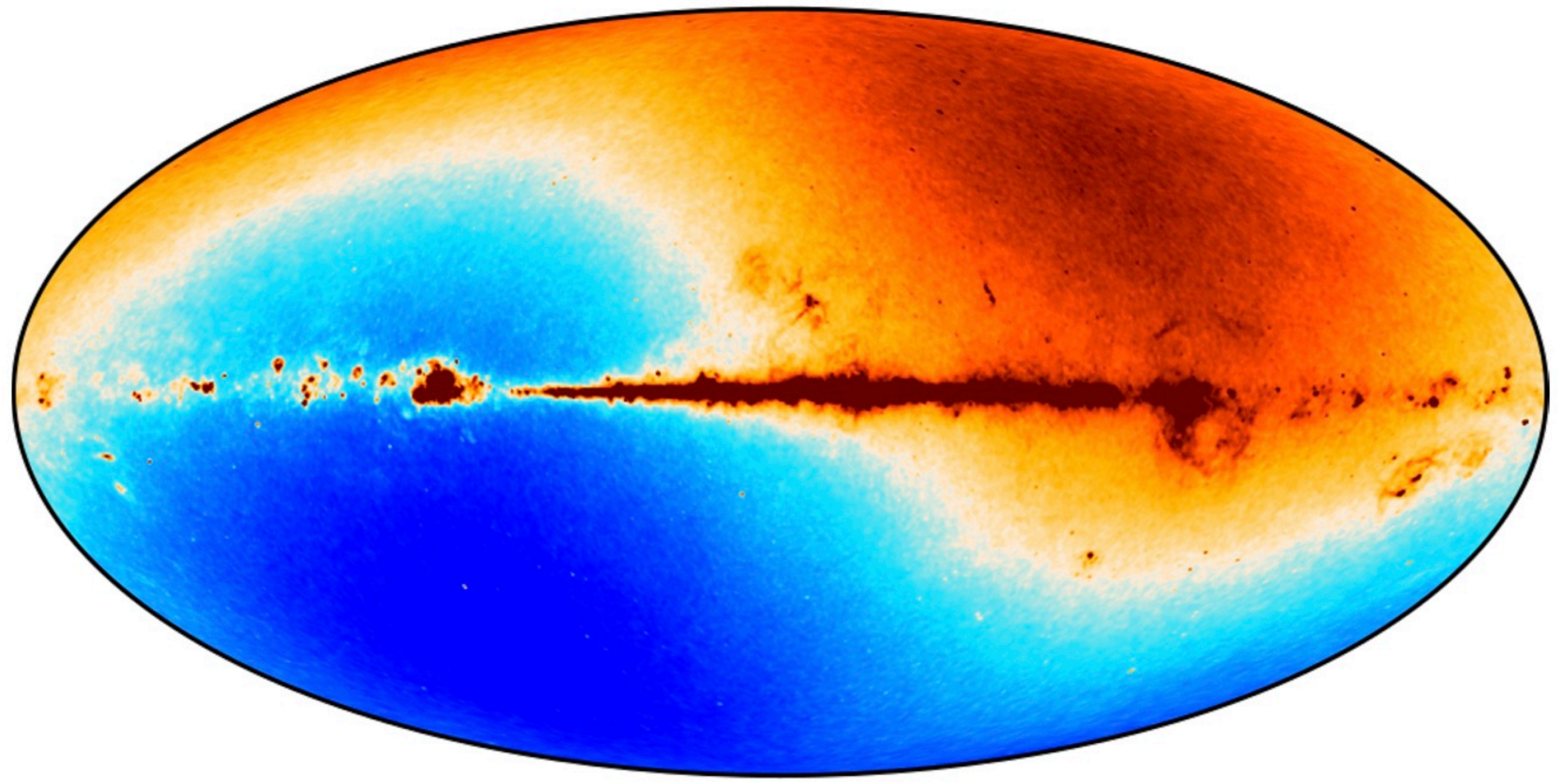
Theory: CMB Dipole



Interpretation: non-Hubble motion

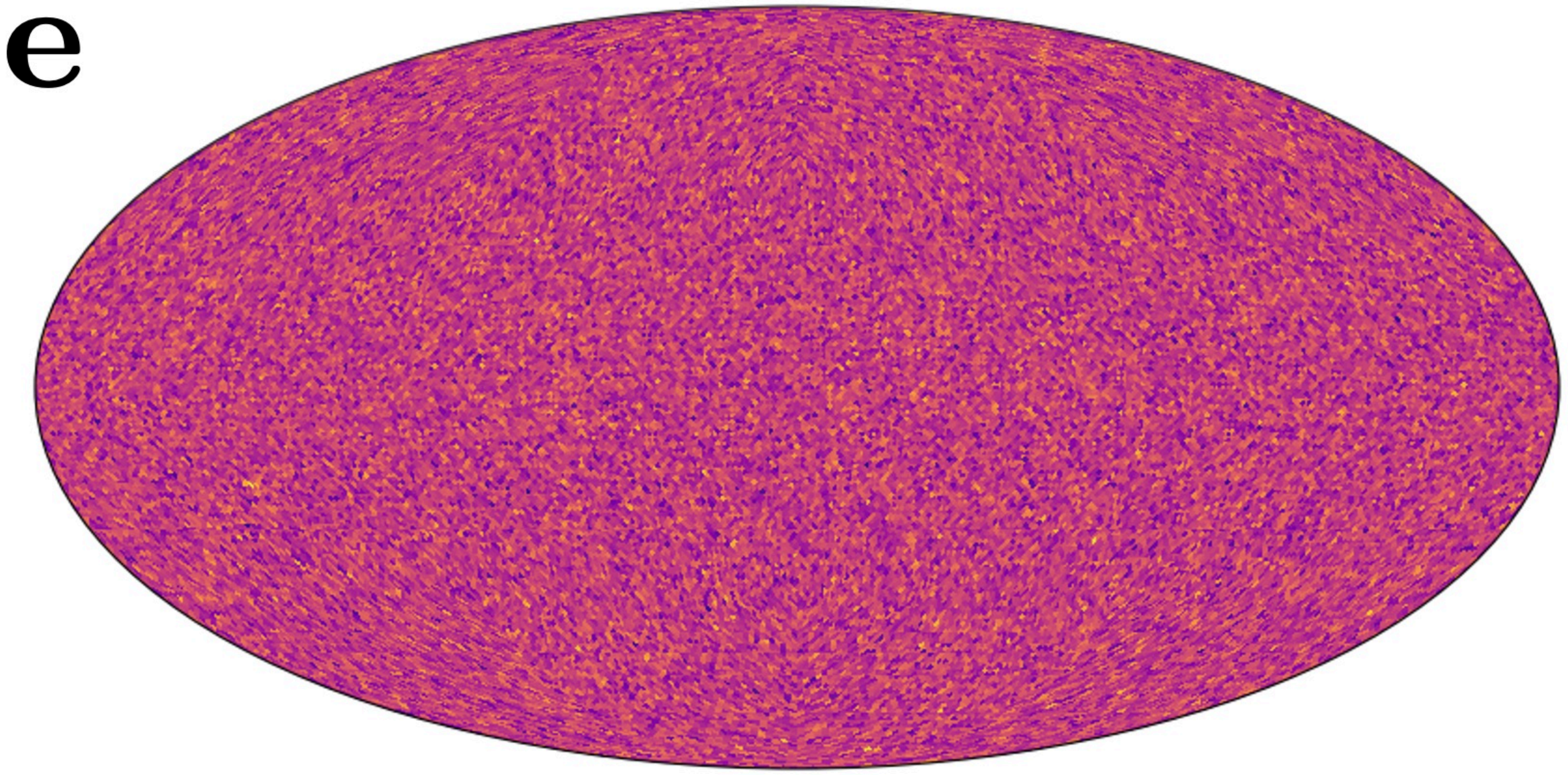
velocity = 369.82 ± 0.11 km/s

(l,b) = (264°.021; 48°.253)



Test: Matter Dipole

$$z \approx 1,\ S \propto f^{-\alpha},\ N(>S_0) \propto S_0^{-x}$$

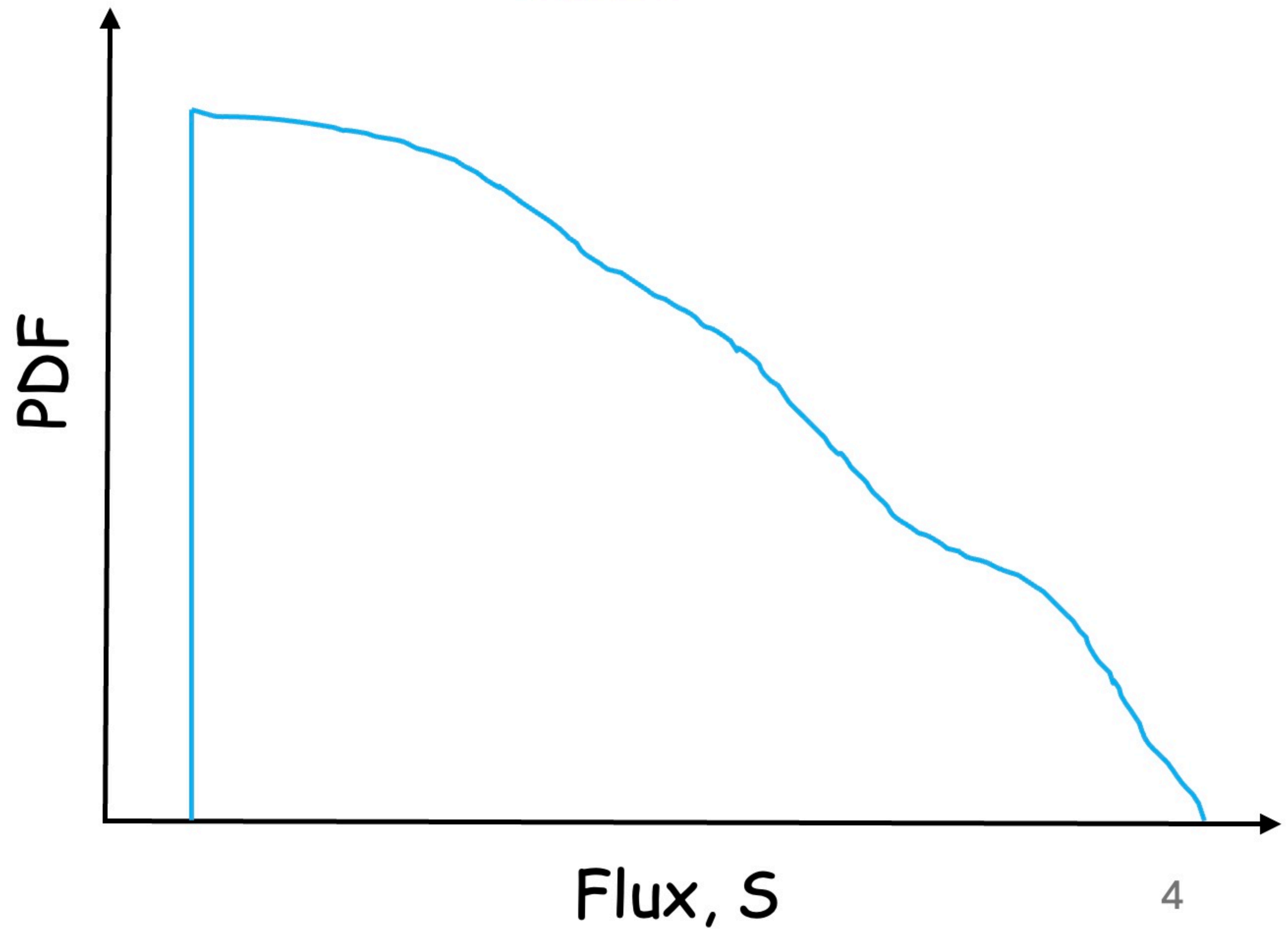


Mon. Not. R. astr. Soc. (1984) **206**, 377–381

On the expected anisotropy of radio source counts

G. F. R. Ellis★ and J. E. Baldwin† *Orthodox Academy of Crete, Kolymbari, Crete*

Received 1983 May 31; in original form 1983 March 31



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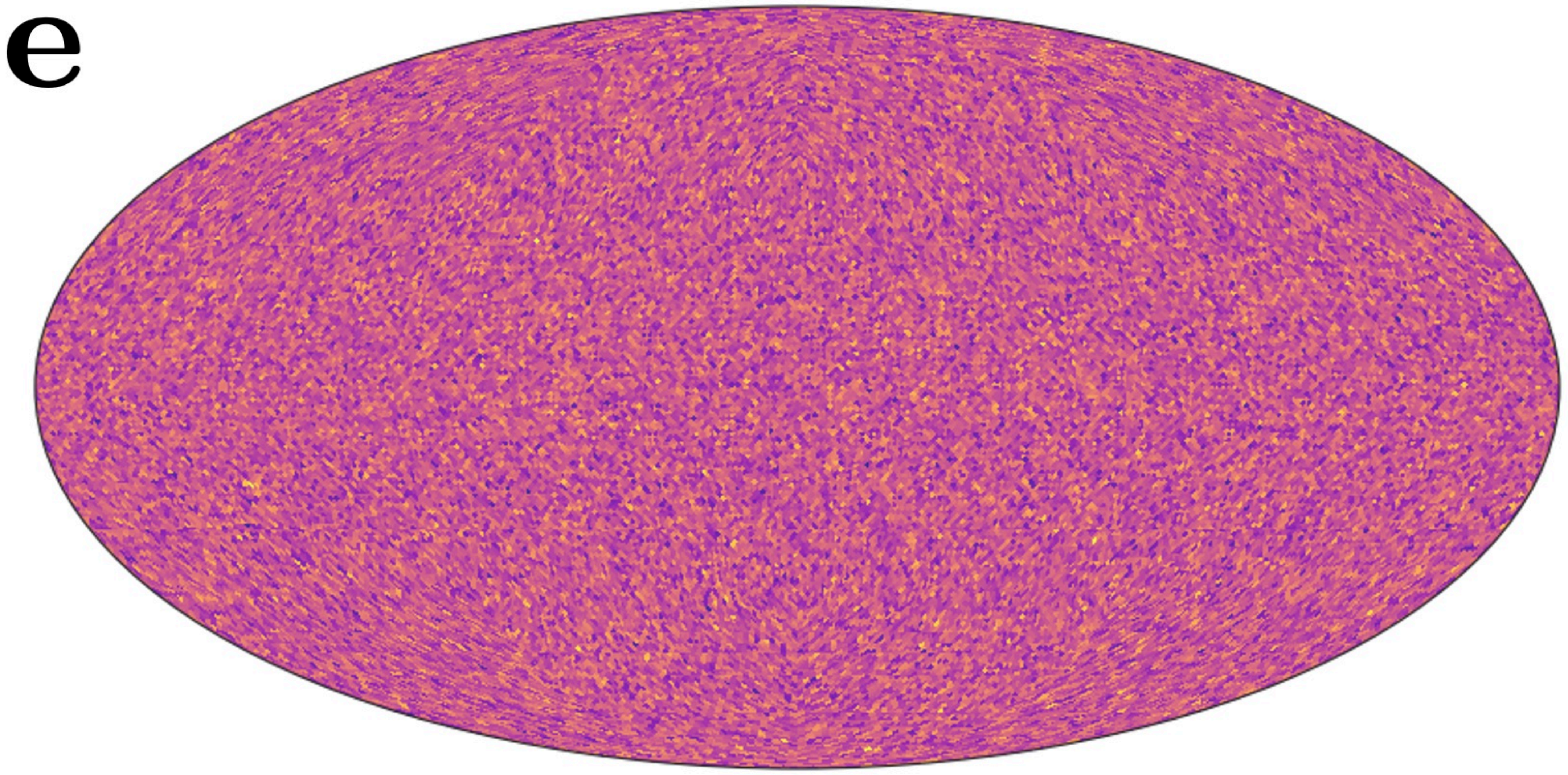

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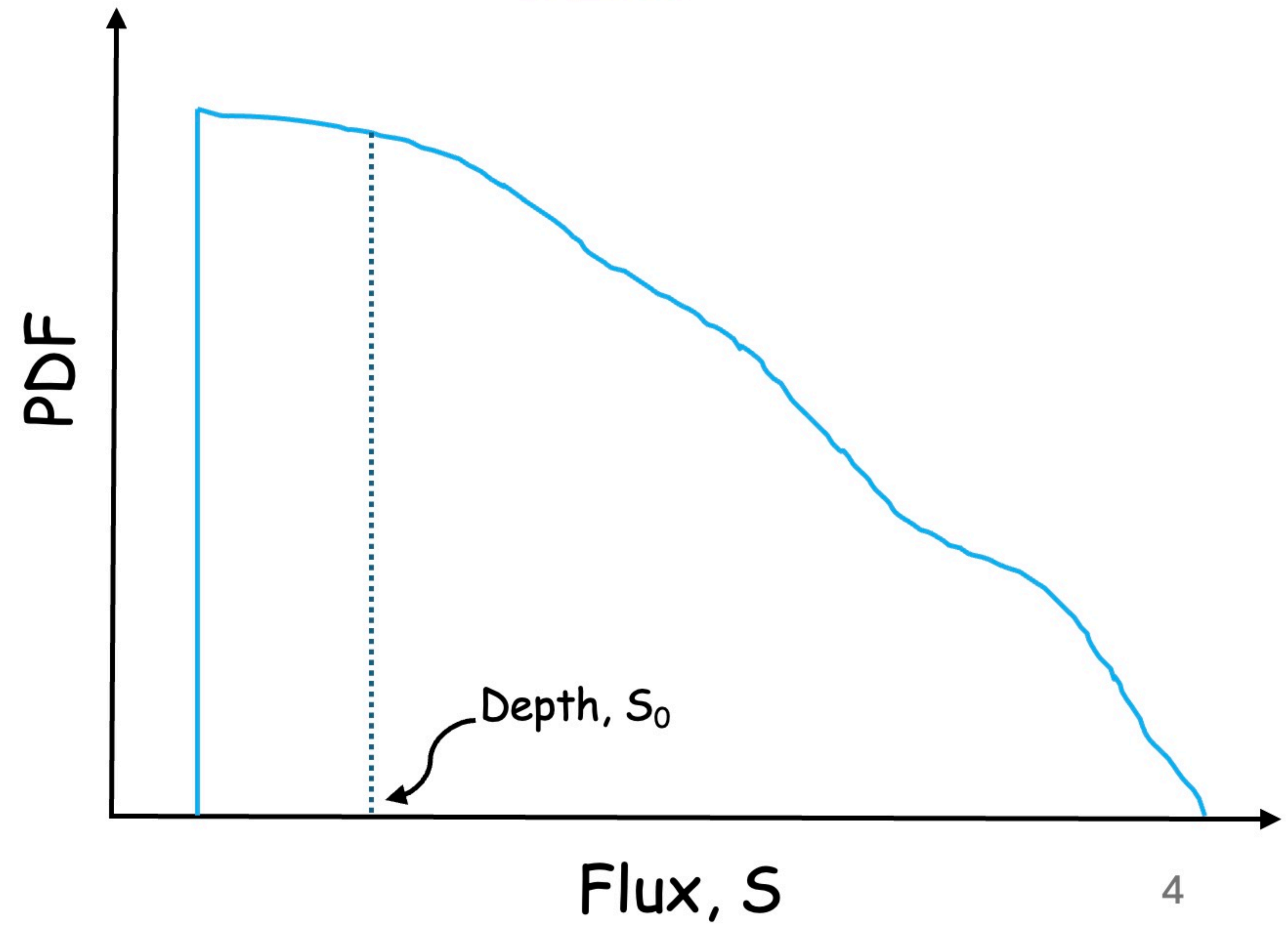

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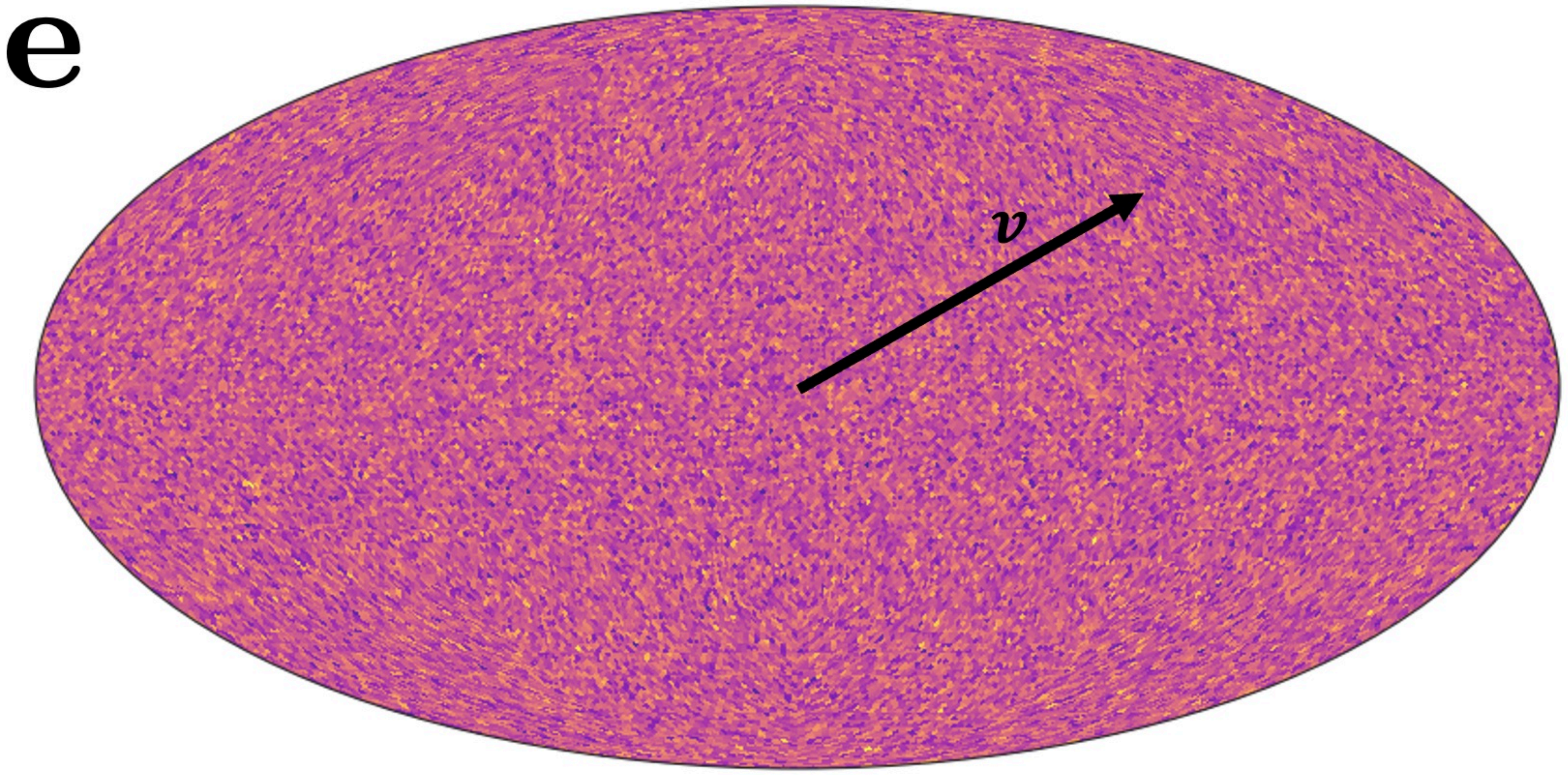

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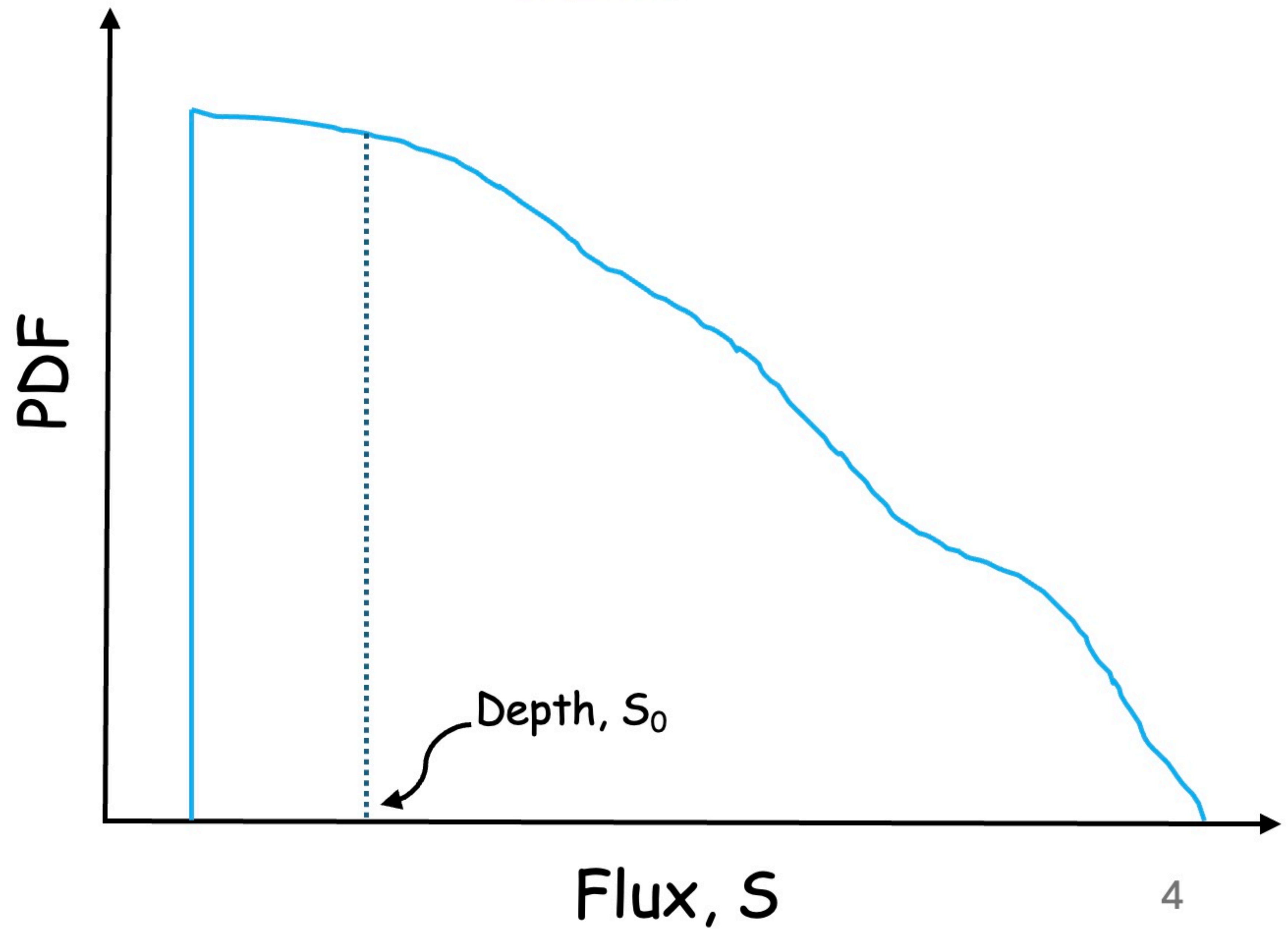
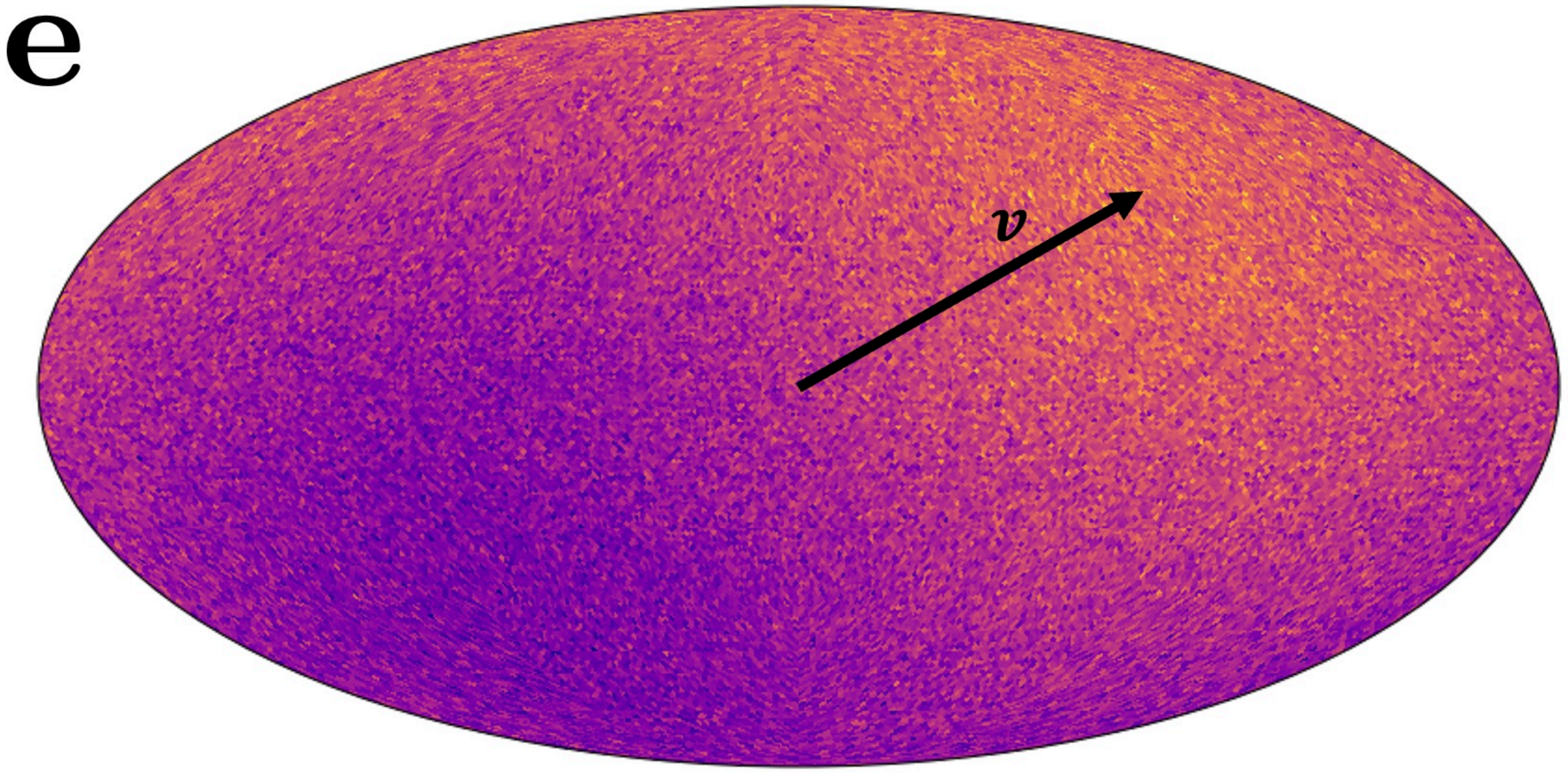


Test: Matter Dipole

Aberration



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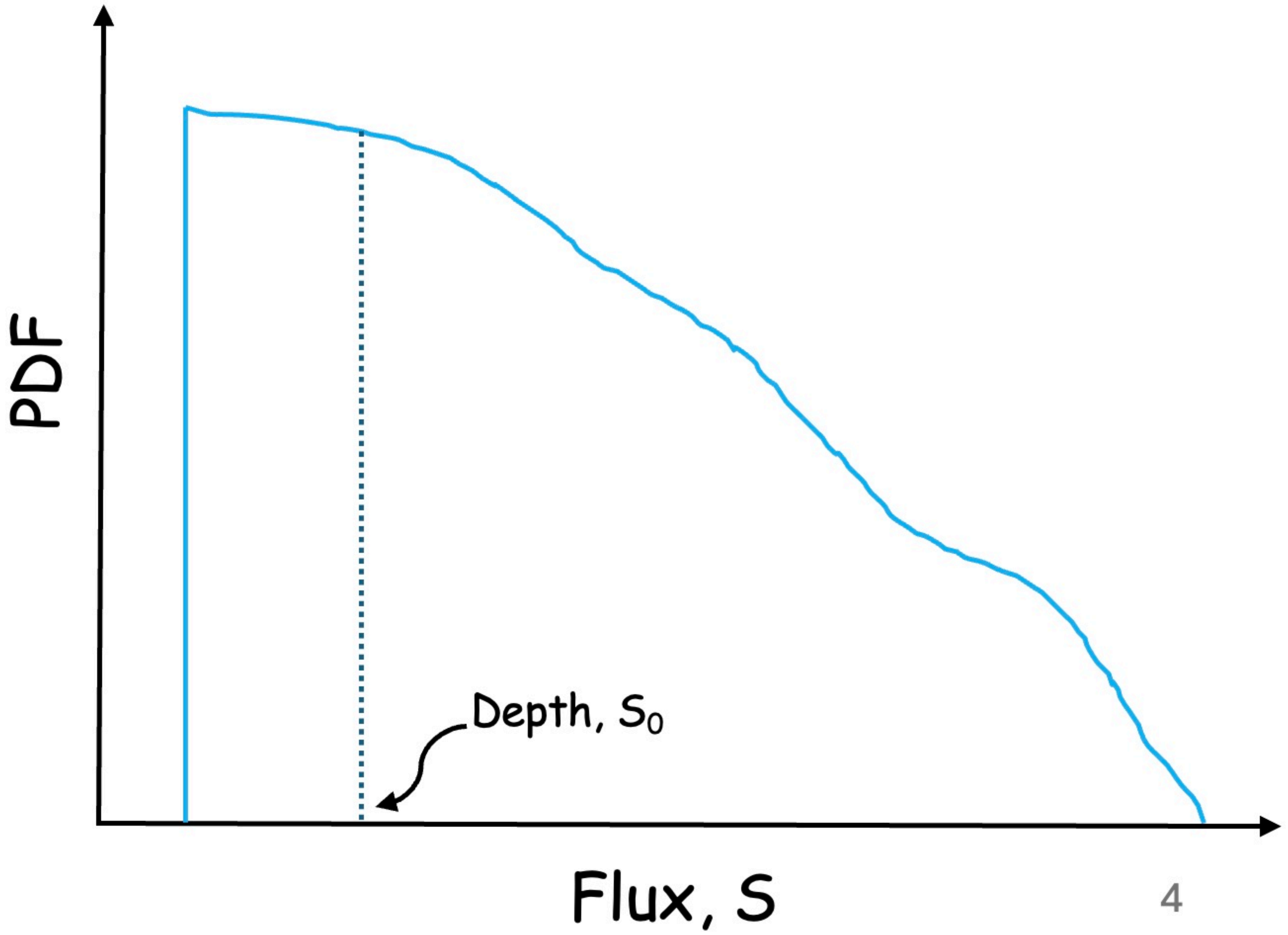
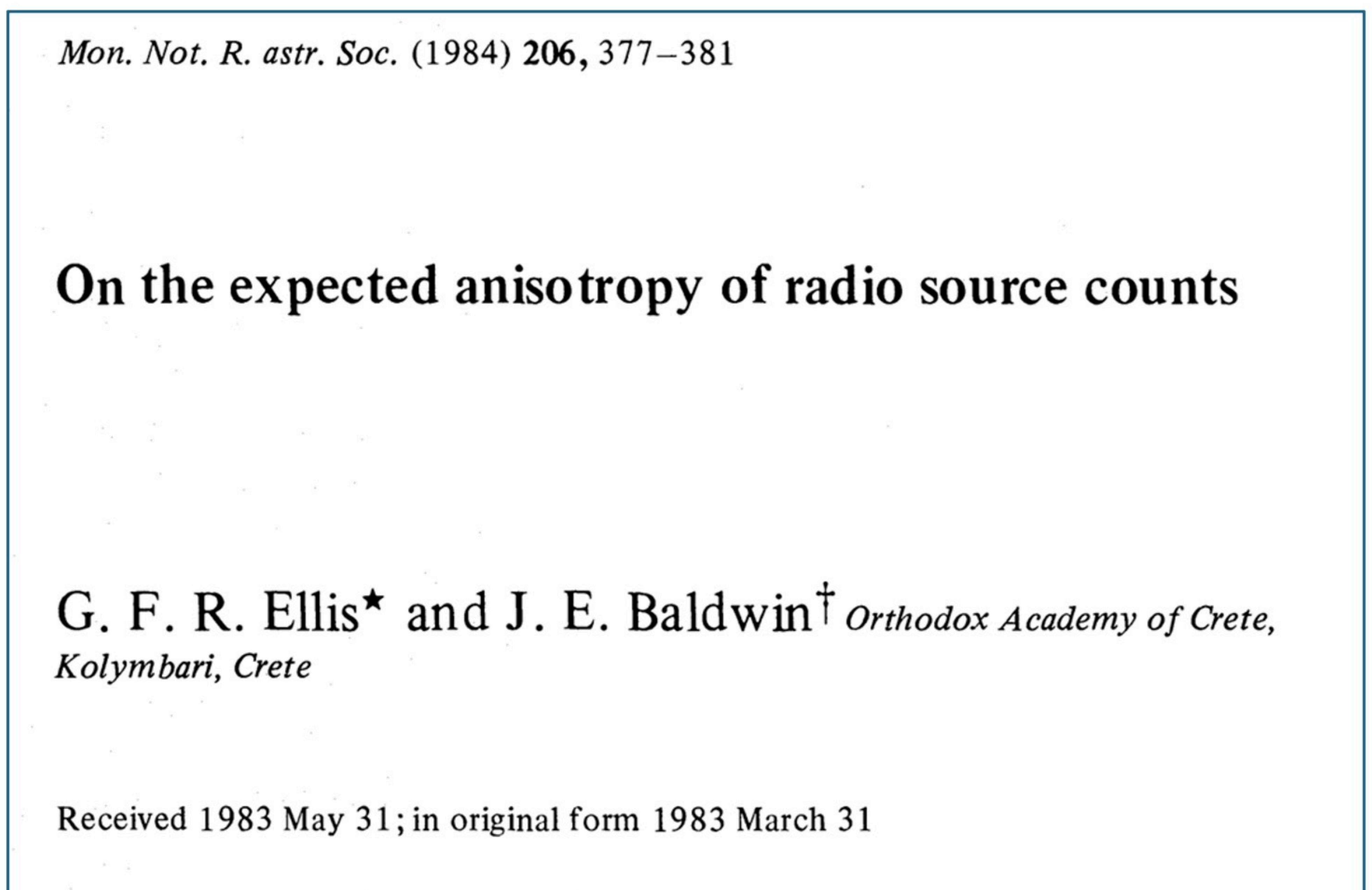


Test: Matter Dipole

Doppler shift

[due to $S \propto f^{-\alpha}$, affects $N(> S_0) \propto S_0^{-x}$]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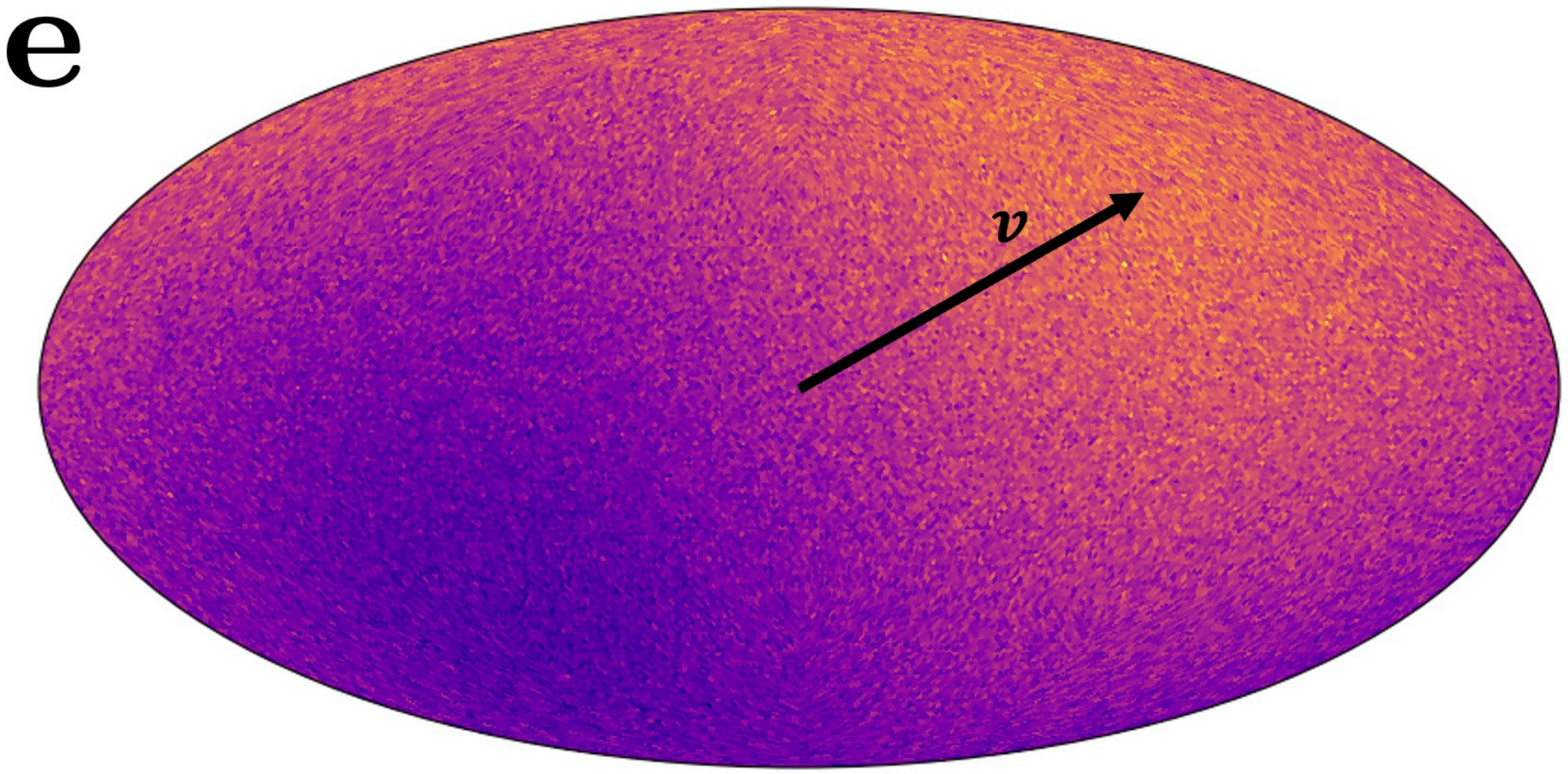
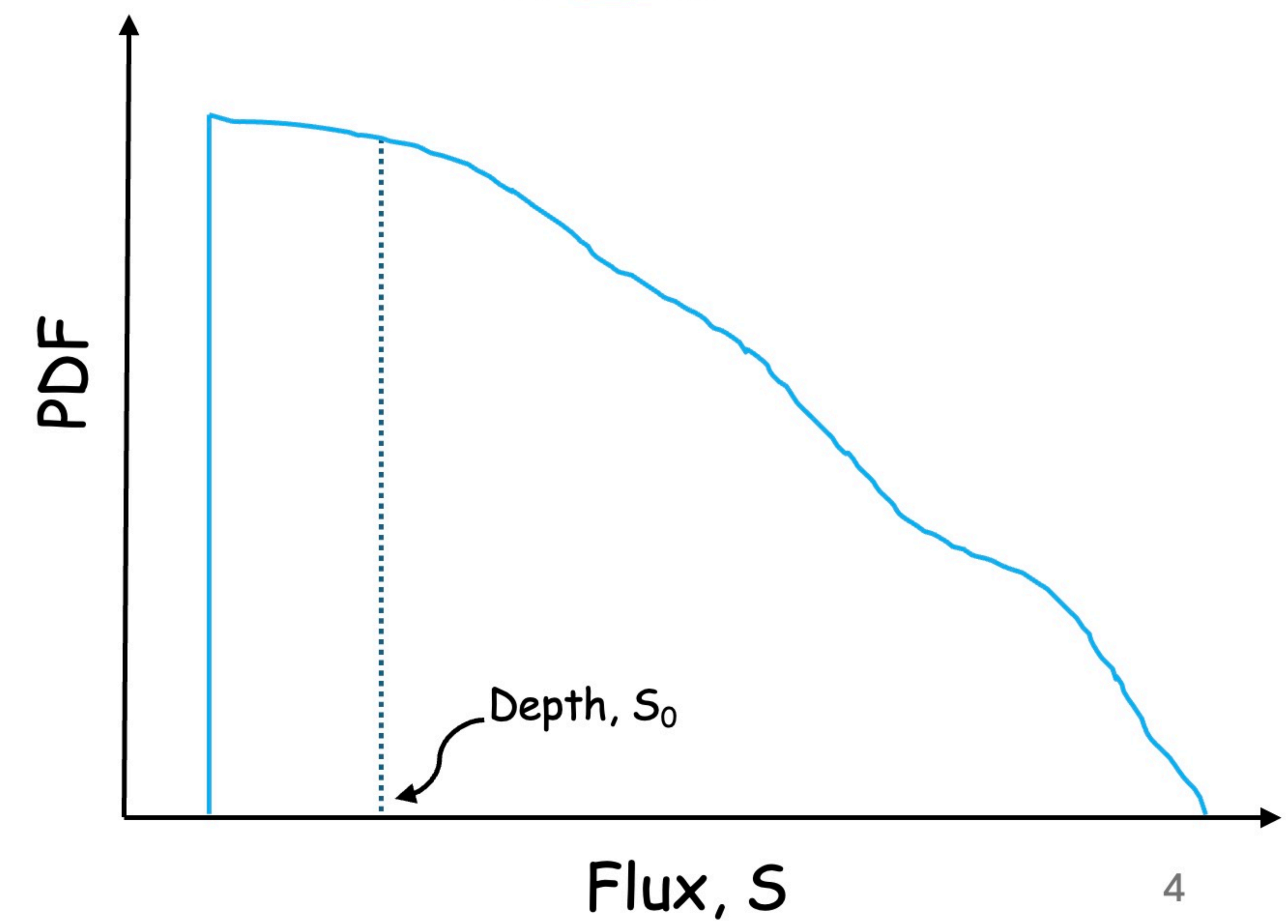
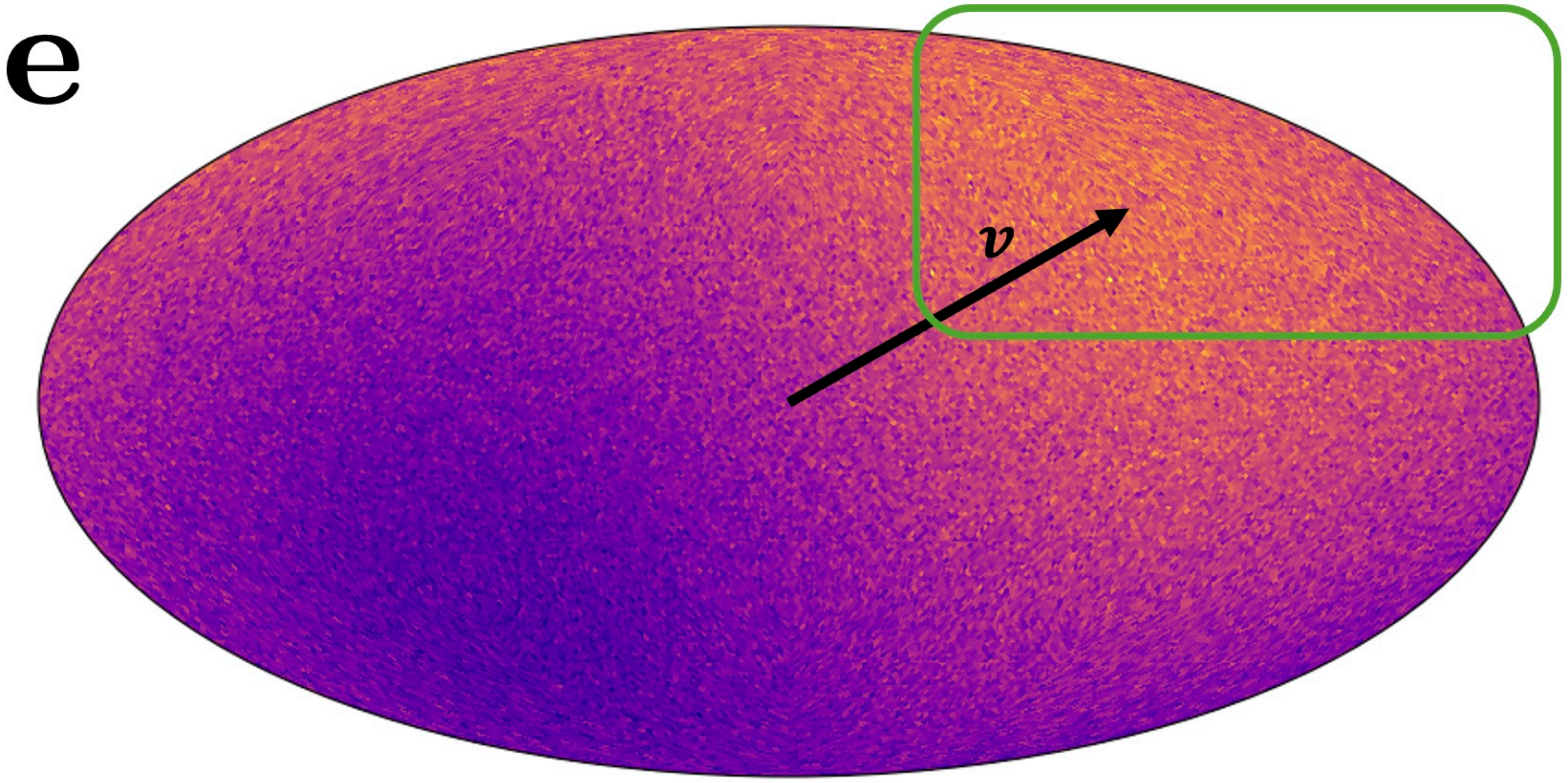




Test: Matter Dipole



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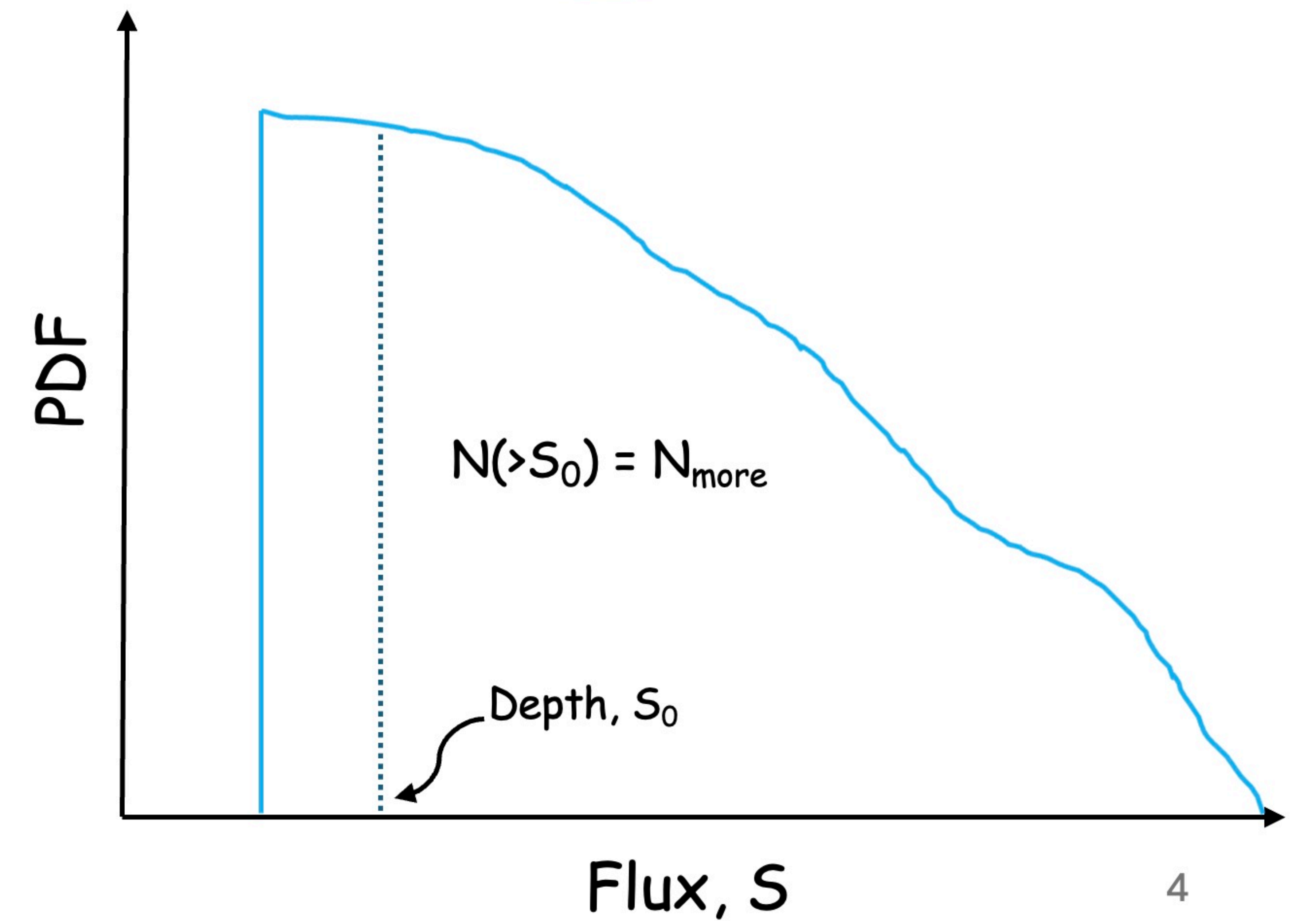
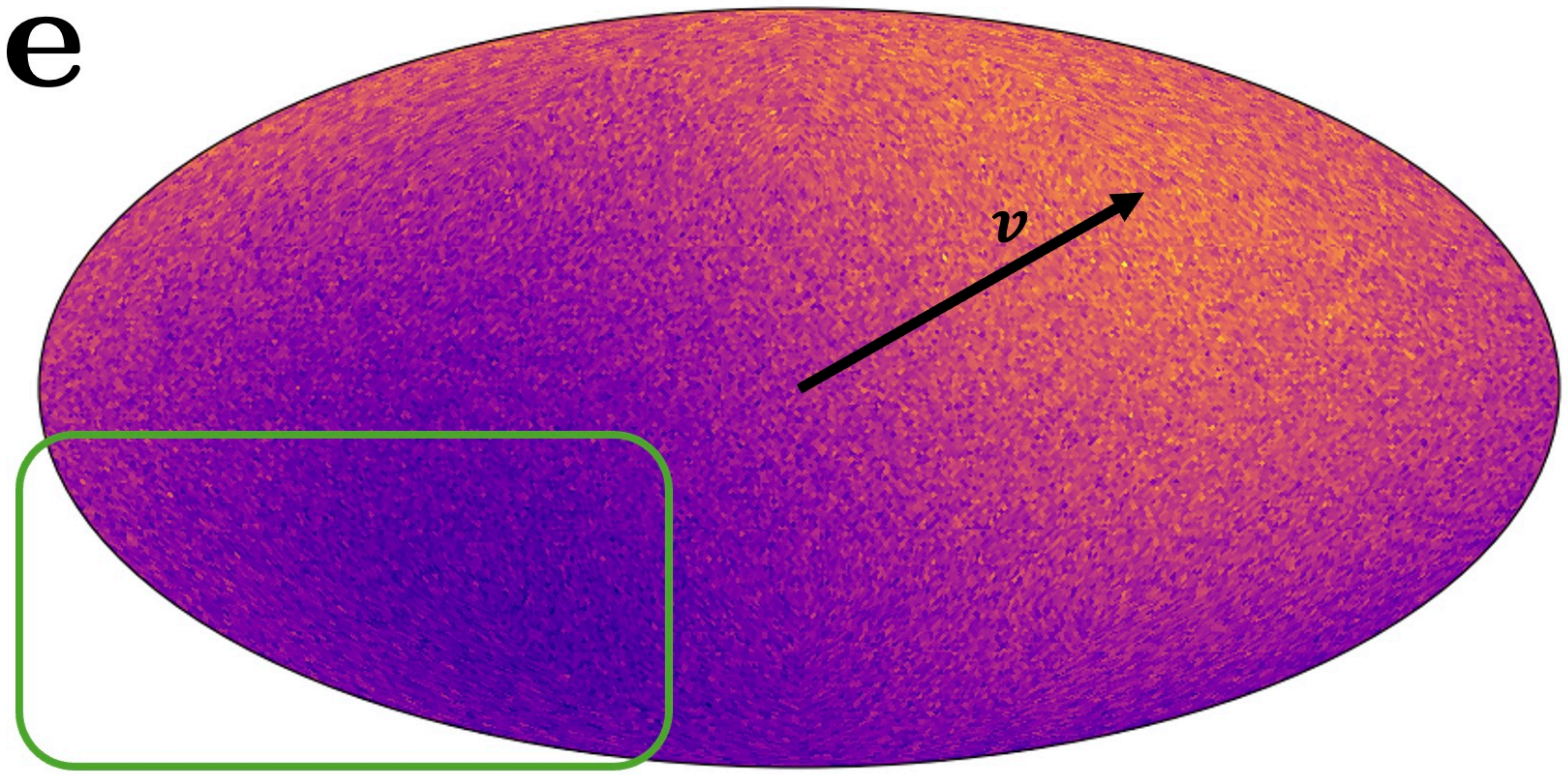


Test: Matter Dipole



Doppler shift

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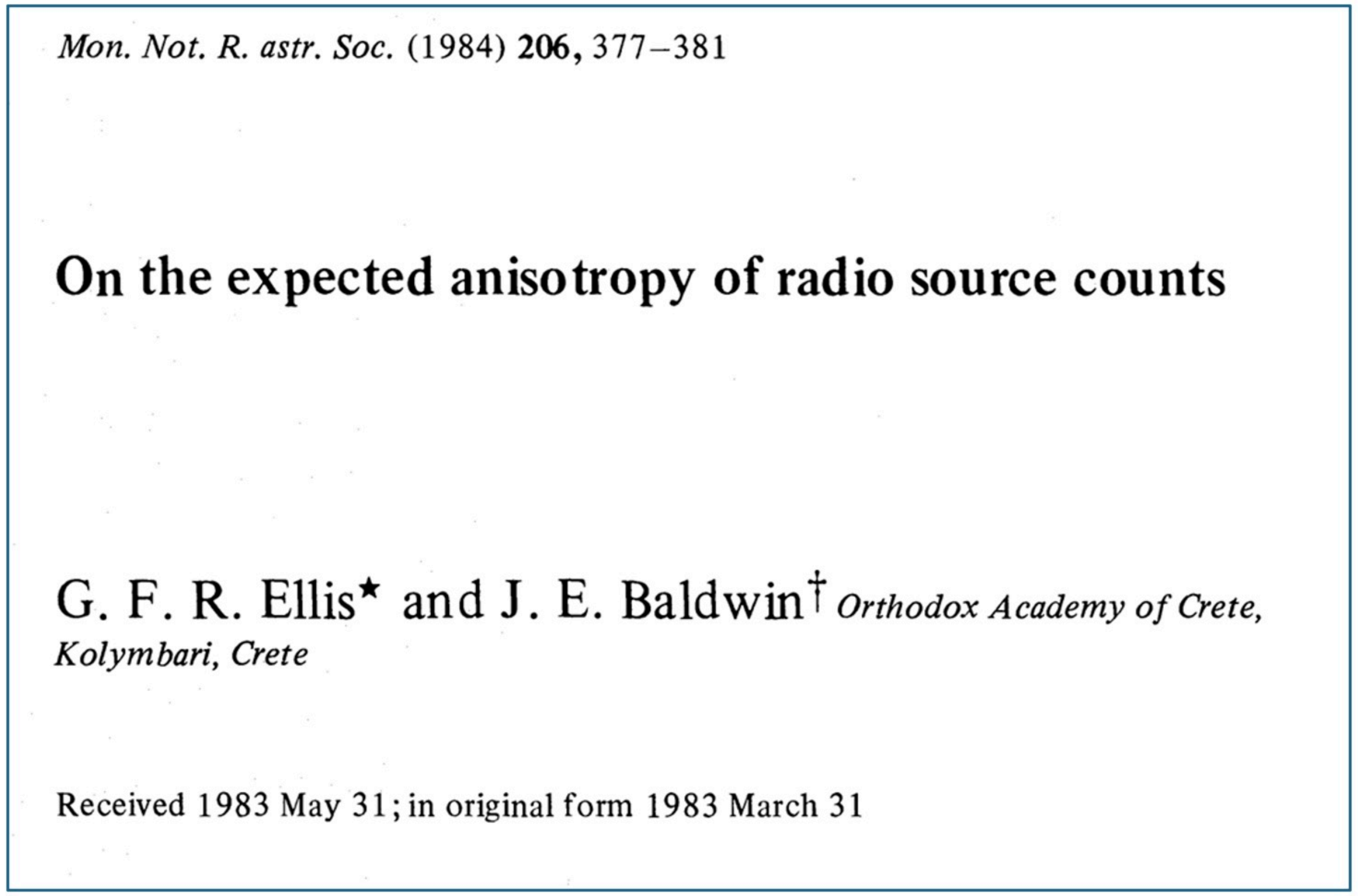
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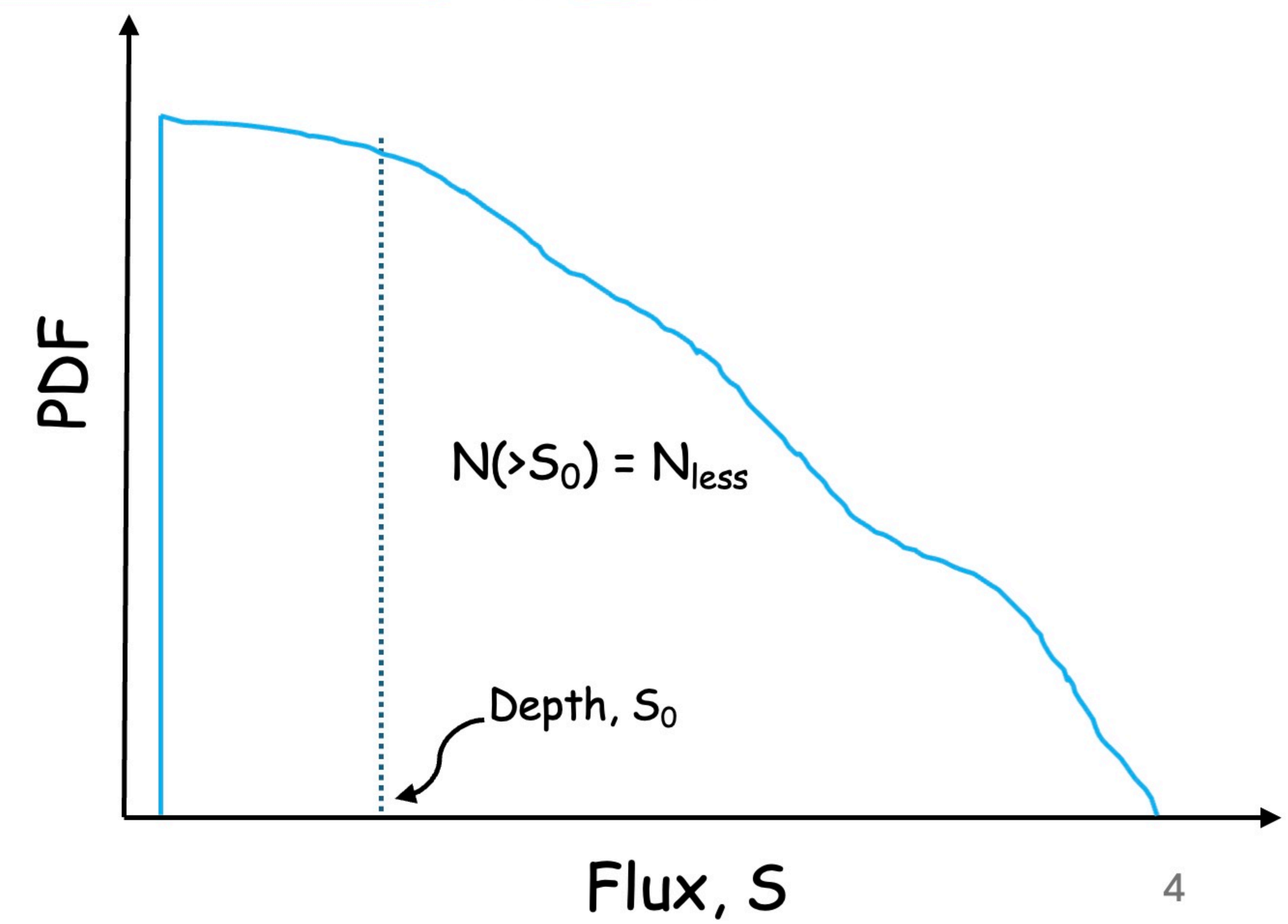
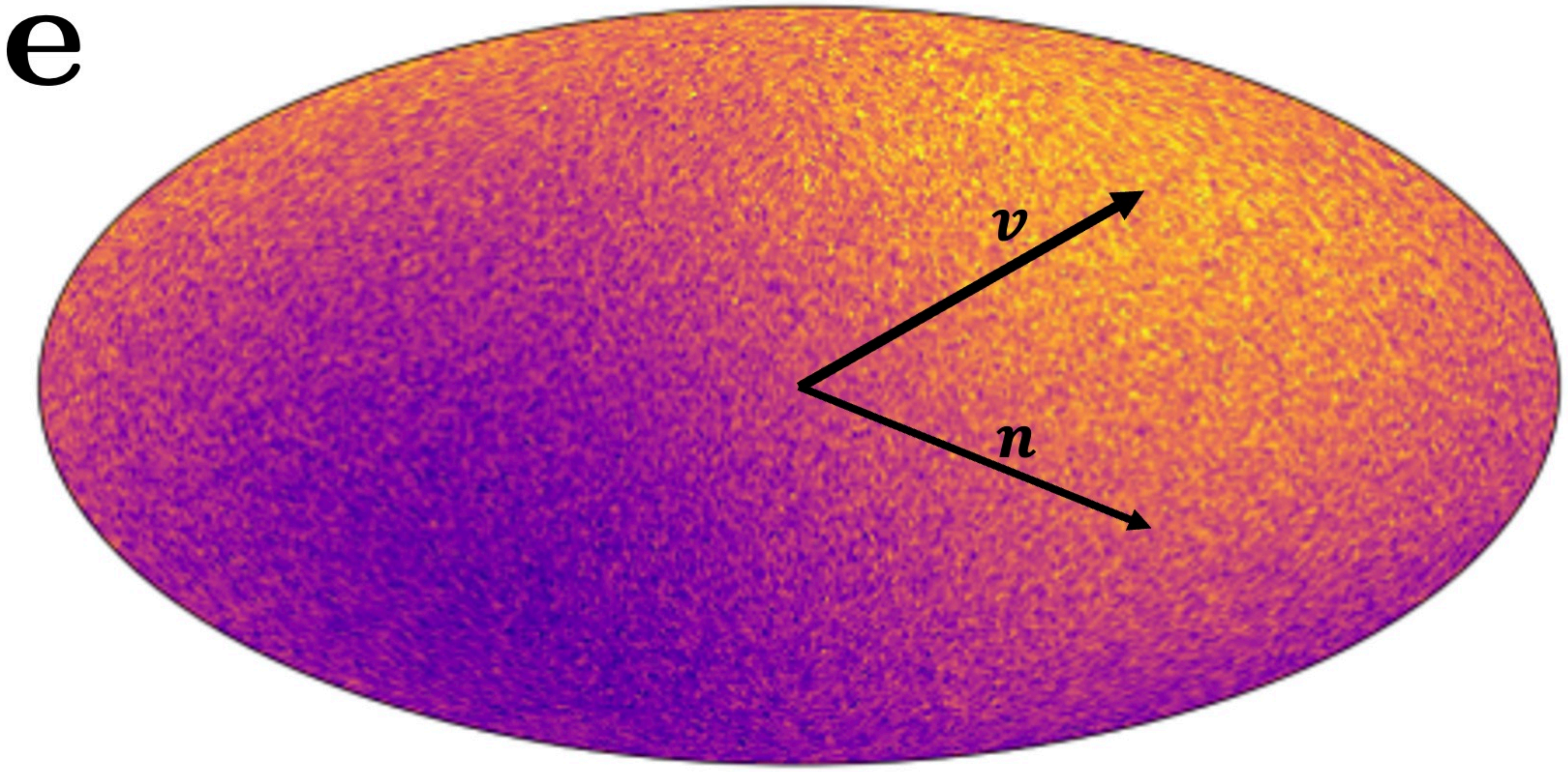


Test: Matter Dipole

$$\frac{\Delta N}{N} = \boldsymbol{D} \cdot \boldsymbol{n} = [2 + x(1+\alpha)]\,\frac{\boldsymbol{v}}{c} \cdot \boldsymbol{n}$$



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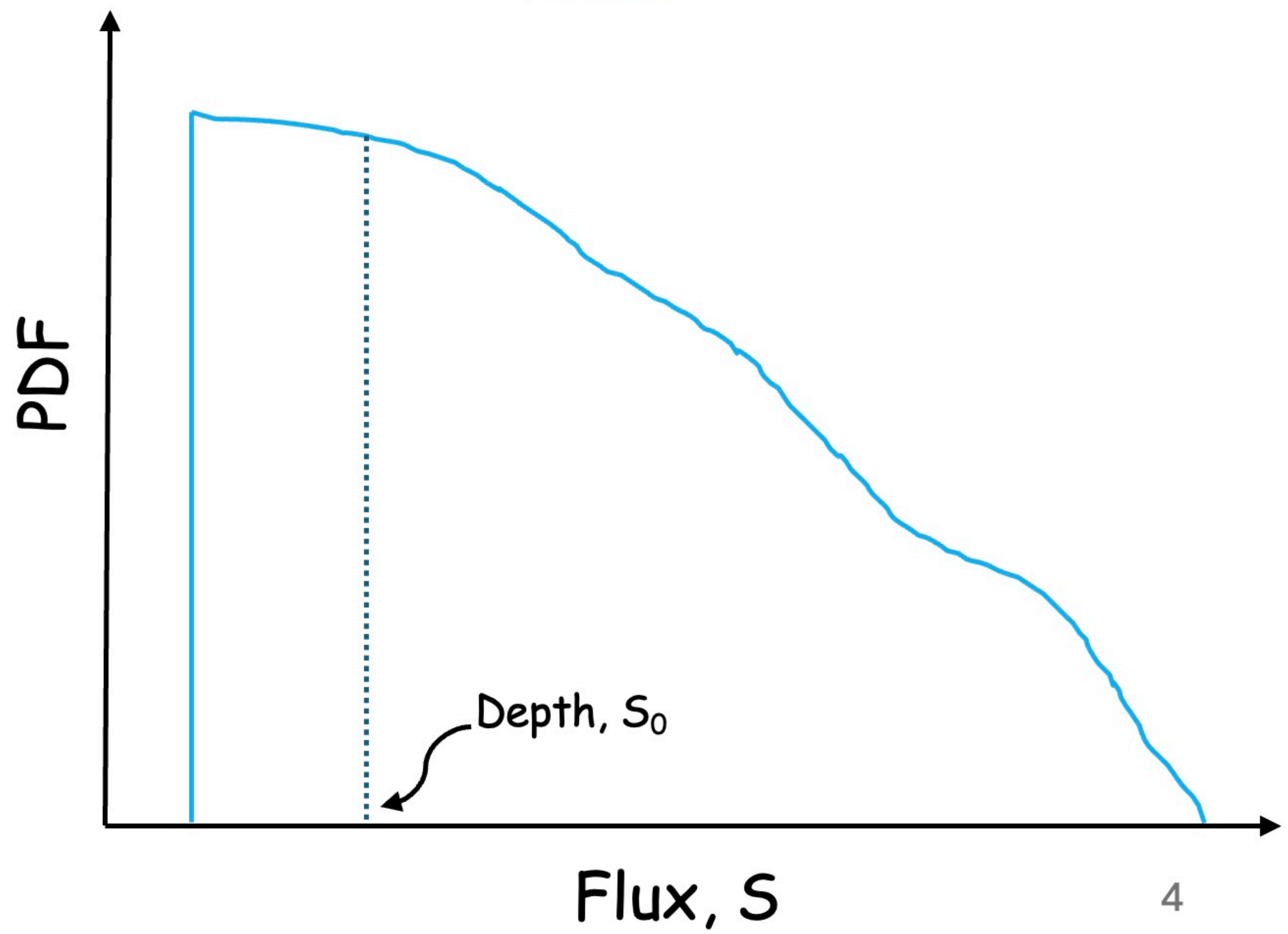
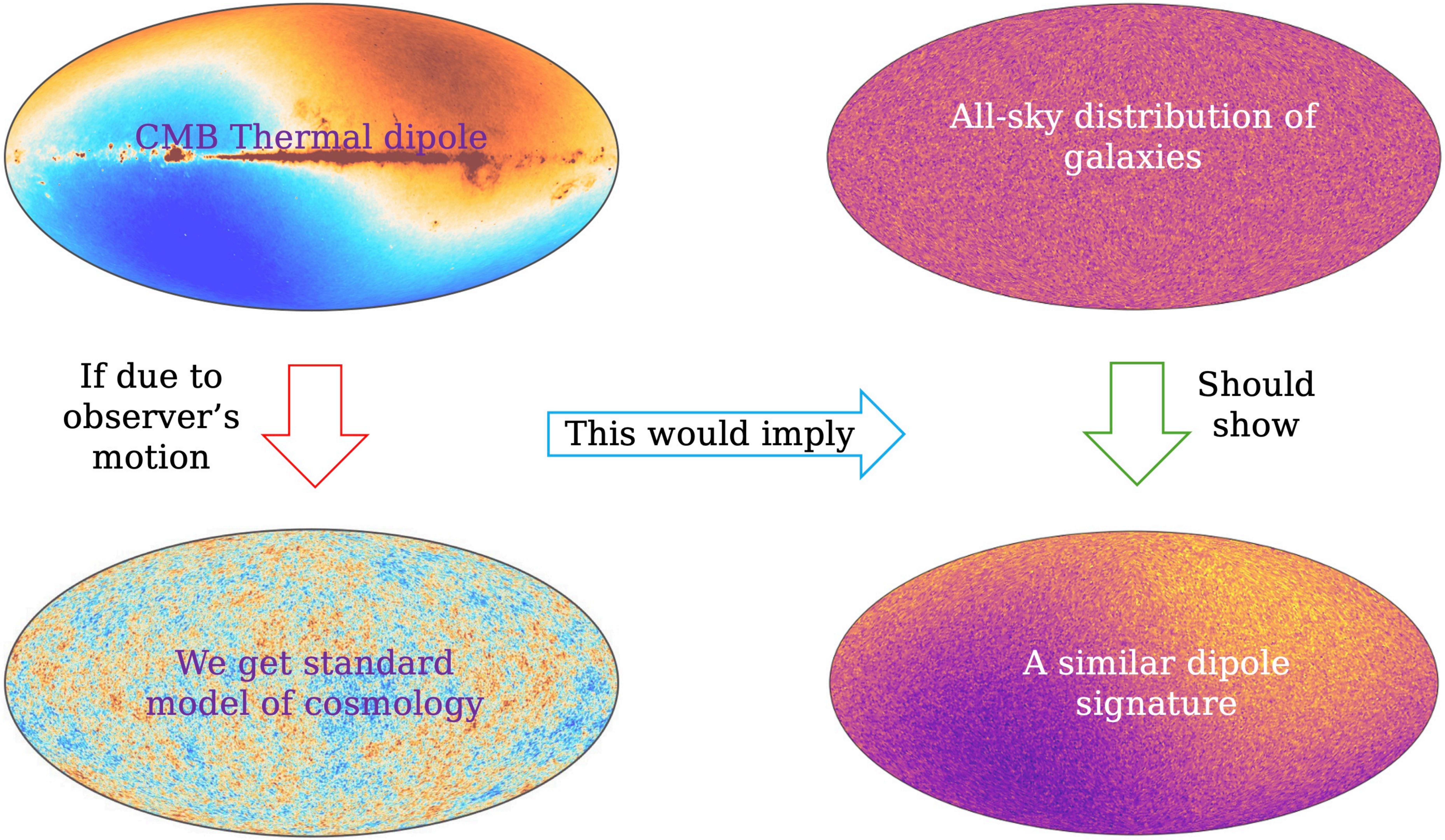
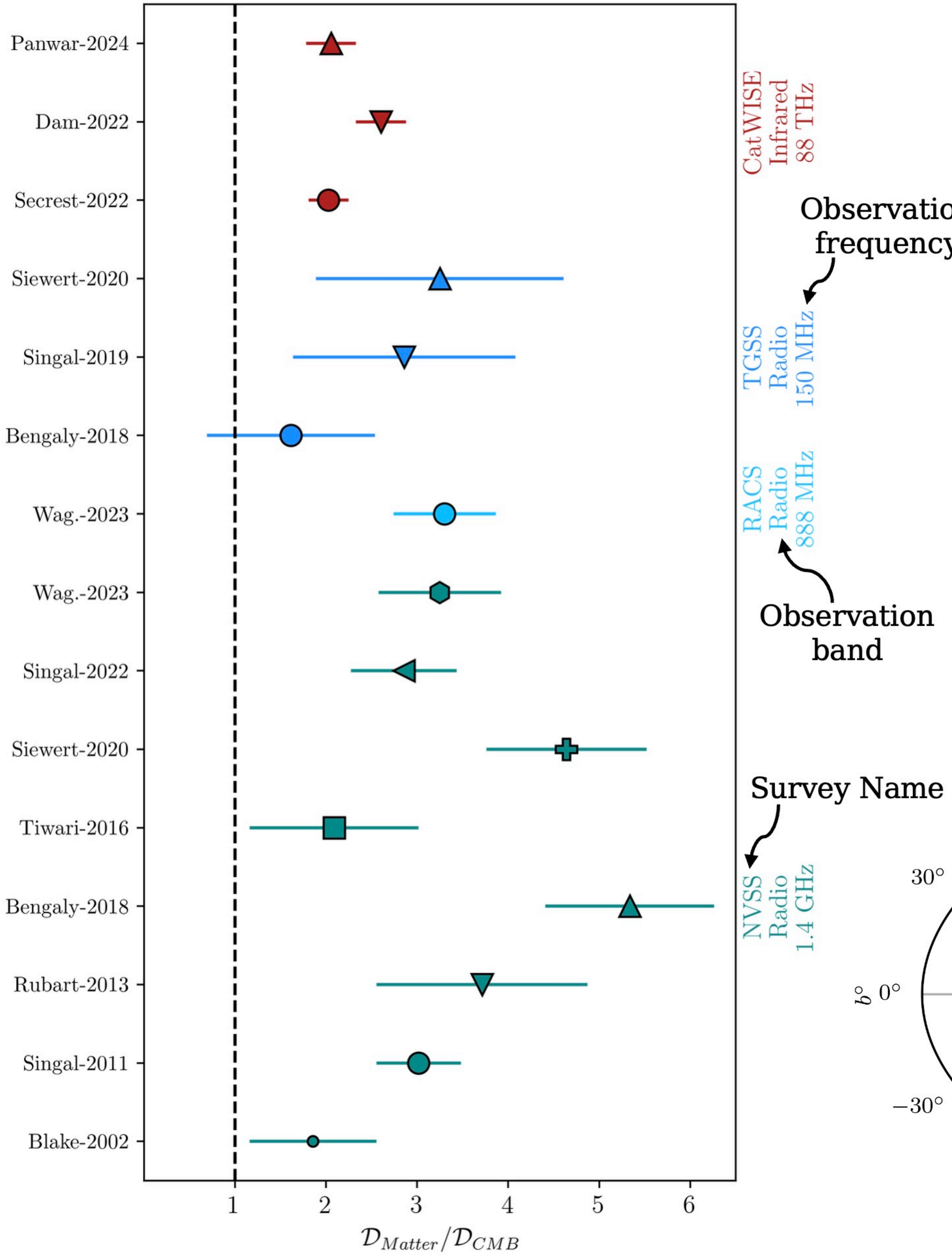
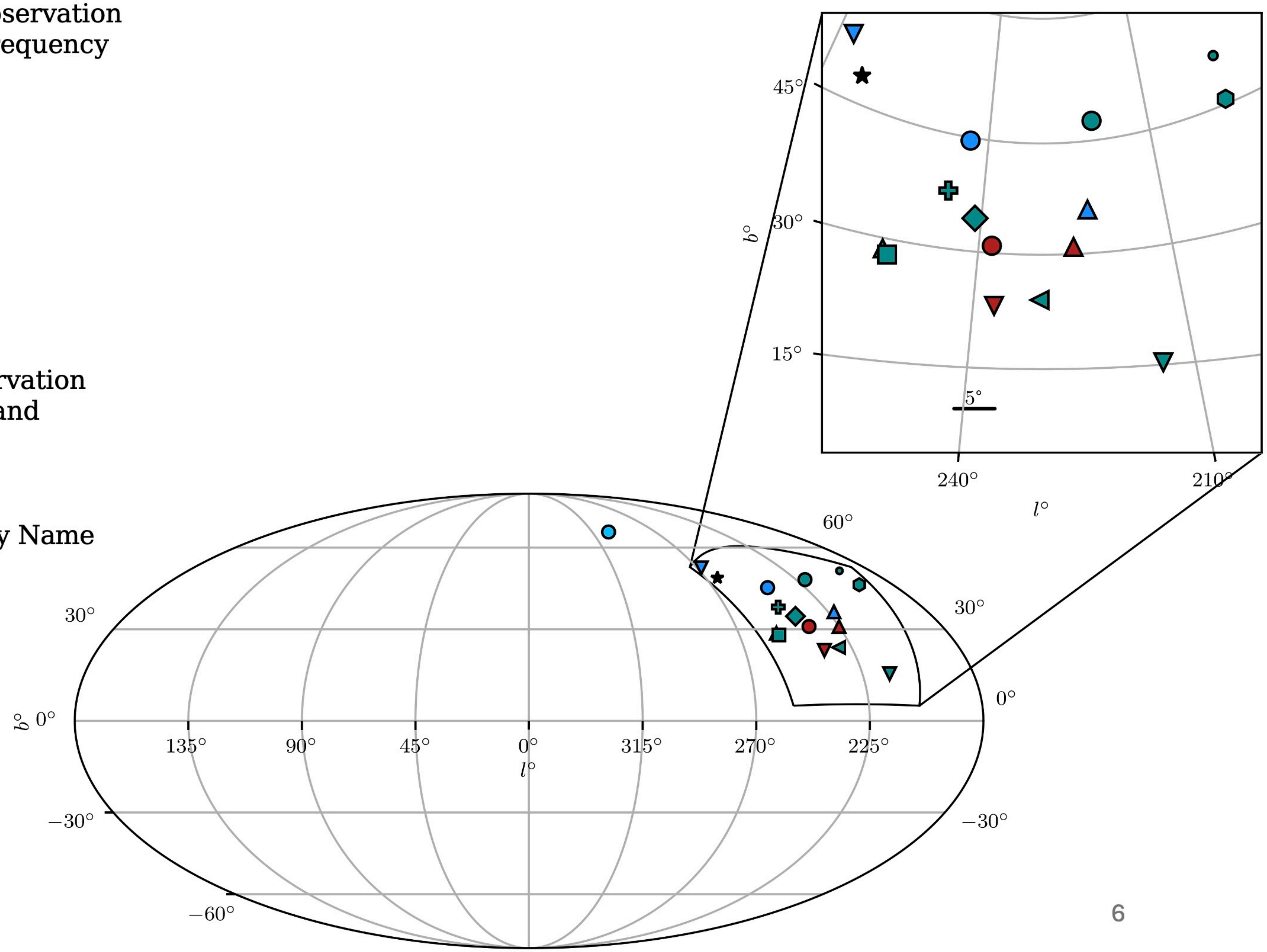



CMB Thermal dipole
All-sky distribution of galaxies
If due to observer's motion
This would imply
Should show
We get standard model of cosmology
A similar dipole signature

Tension



Panwar-2024
Dam-2022
Secrest-2022
Siewert-2020
Singal-2019
Bengaly-2018
Wag.-2023
Wag.-2023
Singal-2022
Siewert-2020
Tiwari-2016
Bengaly-2018
Rubart-2013
Singal-2011
Blake-2002
CatWISE Infrared 88 THz
TGSS Radio 150 MHz
RACS Radio 888 MHz
NVSS Radio 1.4 GHz
Observation frequency
Observation band
Survey Name
$\mathcal{D}_{Matter}/\mathcal{D}_{CMB}$



45°
30°
15°
5°
240°
210°
$l°$
$b°$
60°
30°
0°
−30°
−60°
135°
90°
45°
0°
315°
270°
225°

Methodology: Why?

No correlation between errors.

Estimator properties: coordinate dependent.

Complicated models: difficult to implement.

Published: doi.org/10.33232/001c.144907

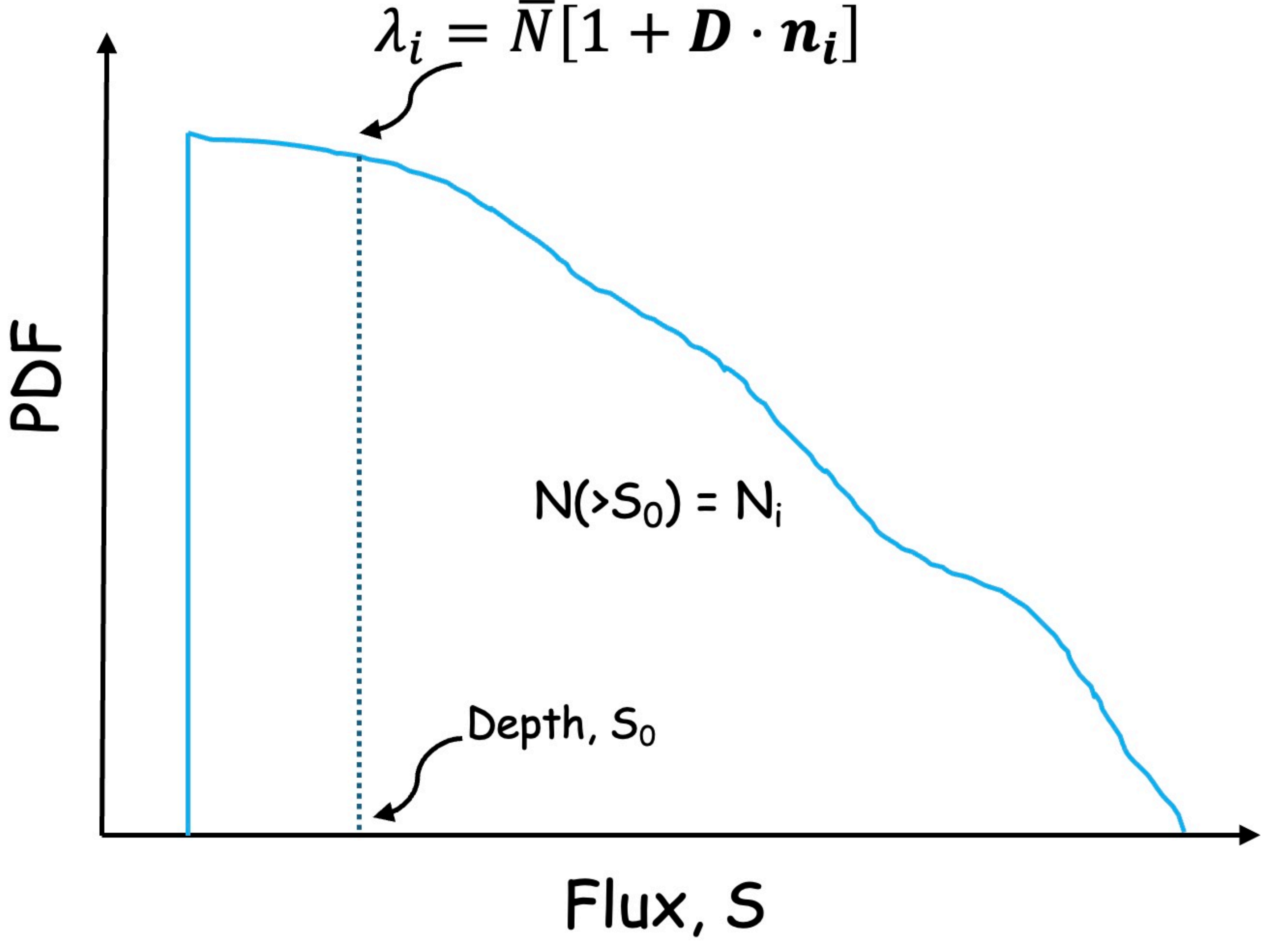
Methodology: Bayesian

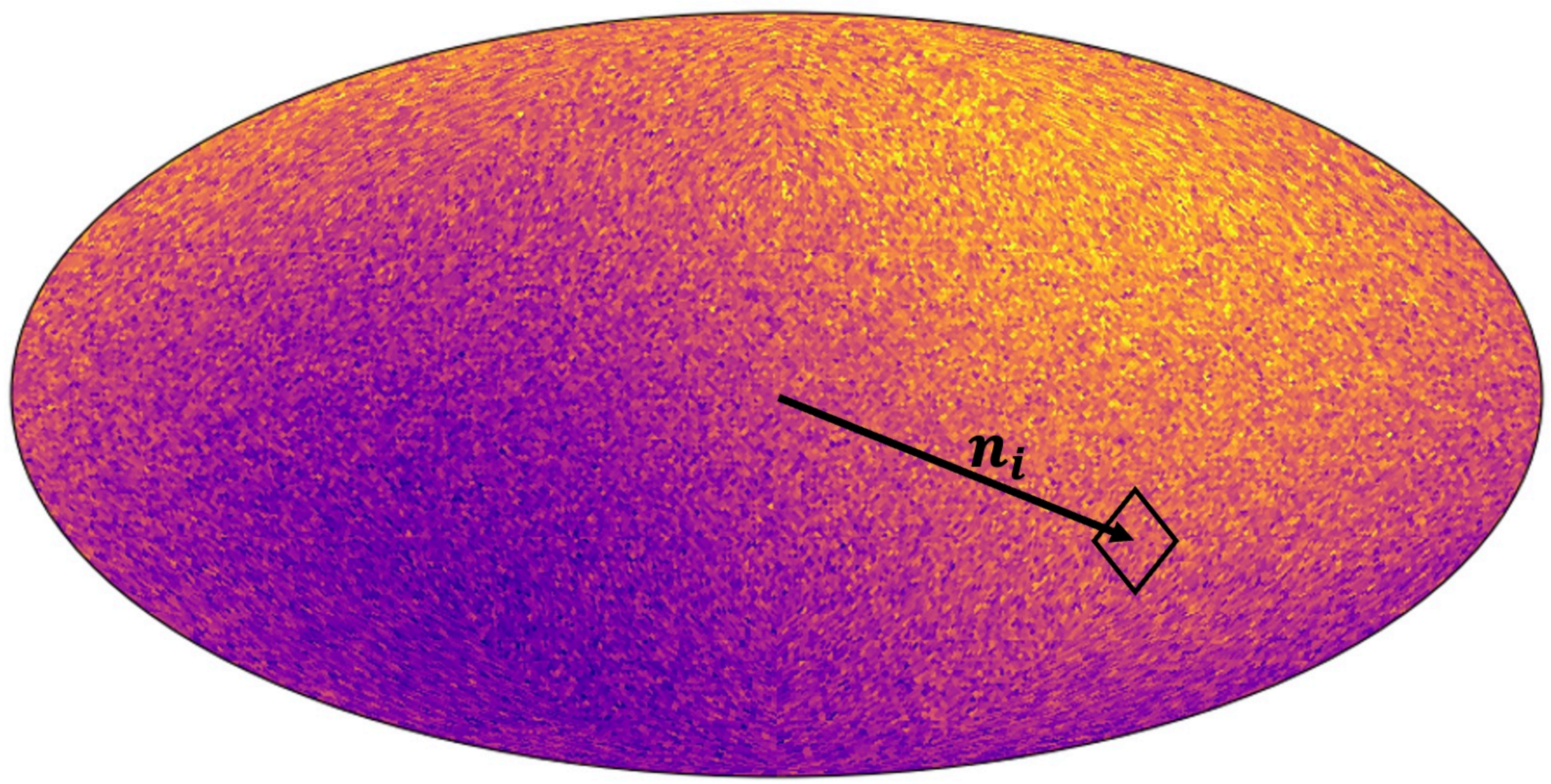
Bayes theorem: $P(\Theta|D, M) = \frac{\mathcal{L}(D|\Theta, M)\pi(\Theta|M)}{\mathcal{Z}(D|M)}$,

Bayes factor: $ln\, B_{12} = ln\, \mathcal{Z}_1 - ln\, \mathcal{Z}_2$.

$\mathcal{L}(D|\theta, M) = \prod_i \frac{\lambda_i^{N_i} e^{-\lambda_i}}{N_i!}$ [can use others as well!]

$\lambda_i = \bar{N}[1 + \boldsymbol{D} \cdot \boldsymbol{n_i}]$





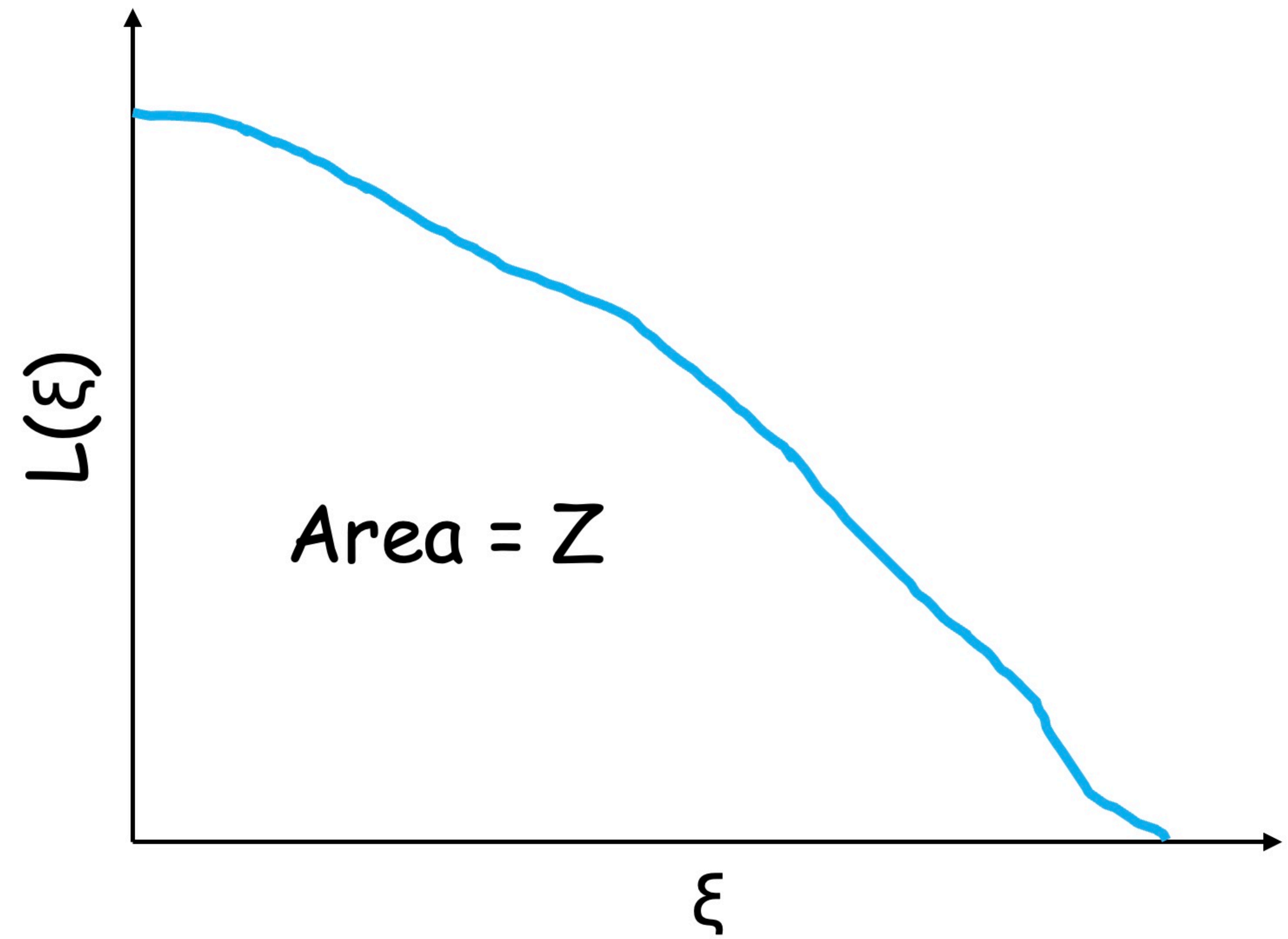
Methodology: Nested Sampling

Introduced by Skilling

$$\xi(\lambda) = \int_{\mathcal{L}(\Theta)>\lambda} \pi(\theta) d\theta,$$

$$d\xi = \pi(\theta) d\theta$$

$$\mathcal{Z} = \int \mathcal{L}(\Theta)\pi(\Theta)\, d\Theta = \int_0^1 \mathcal{L}(\xi)\, d\xi$$



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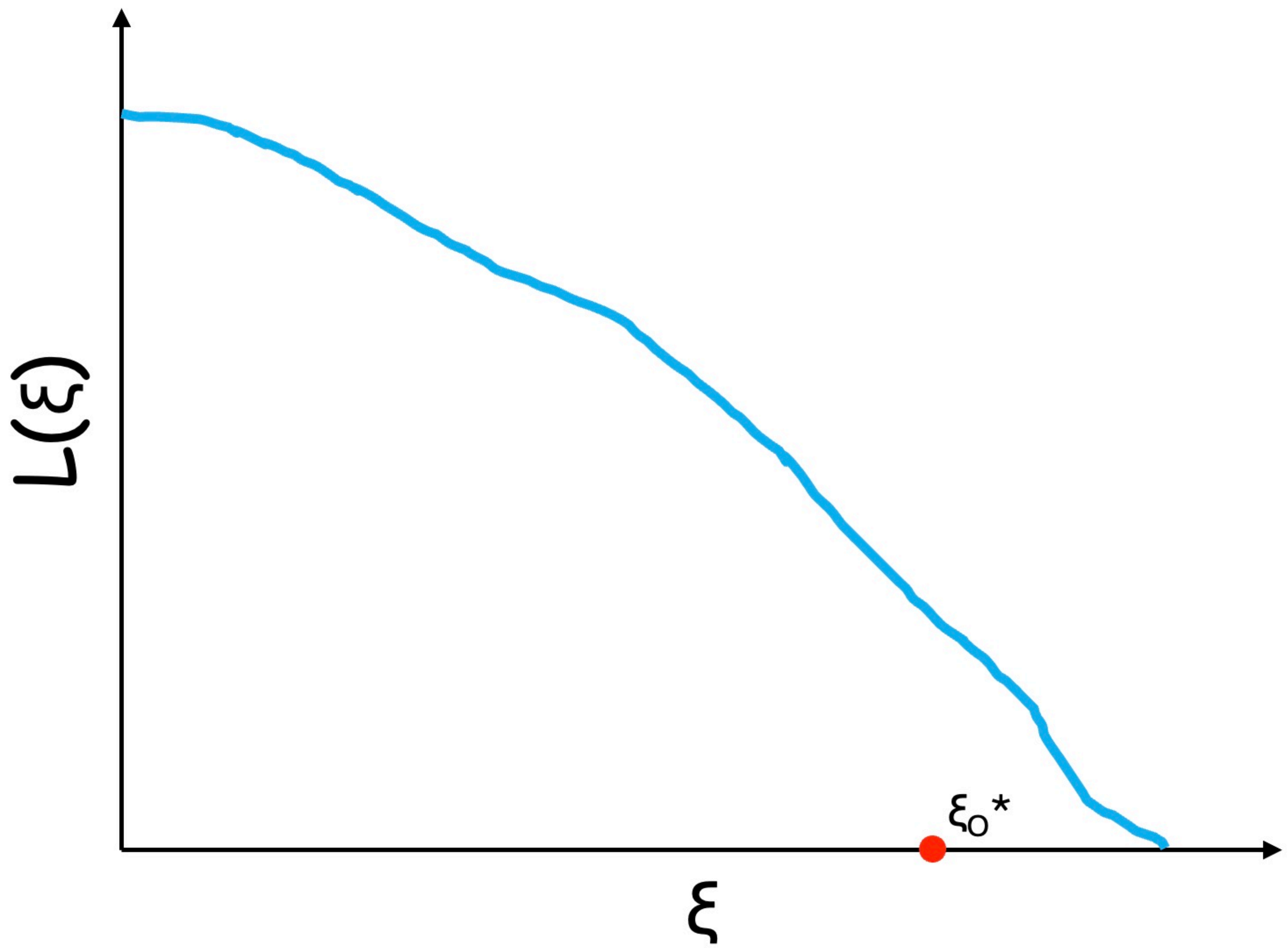

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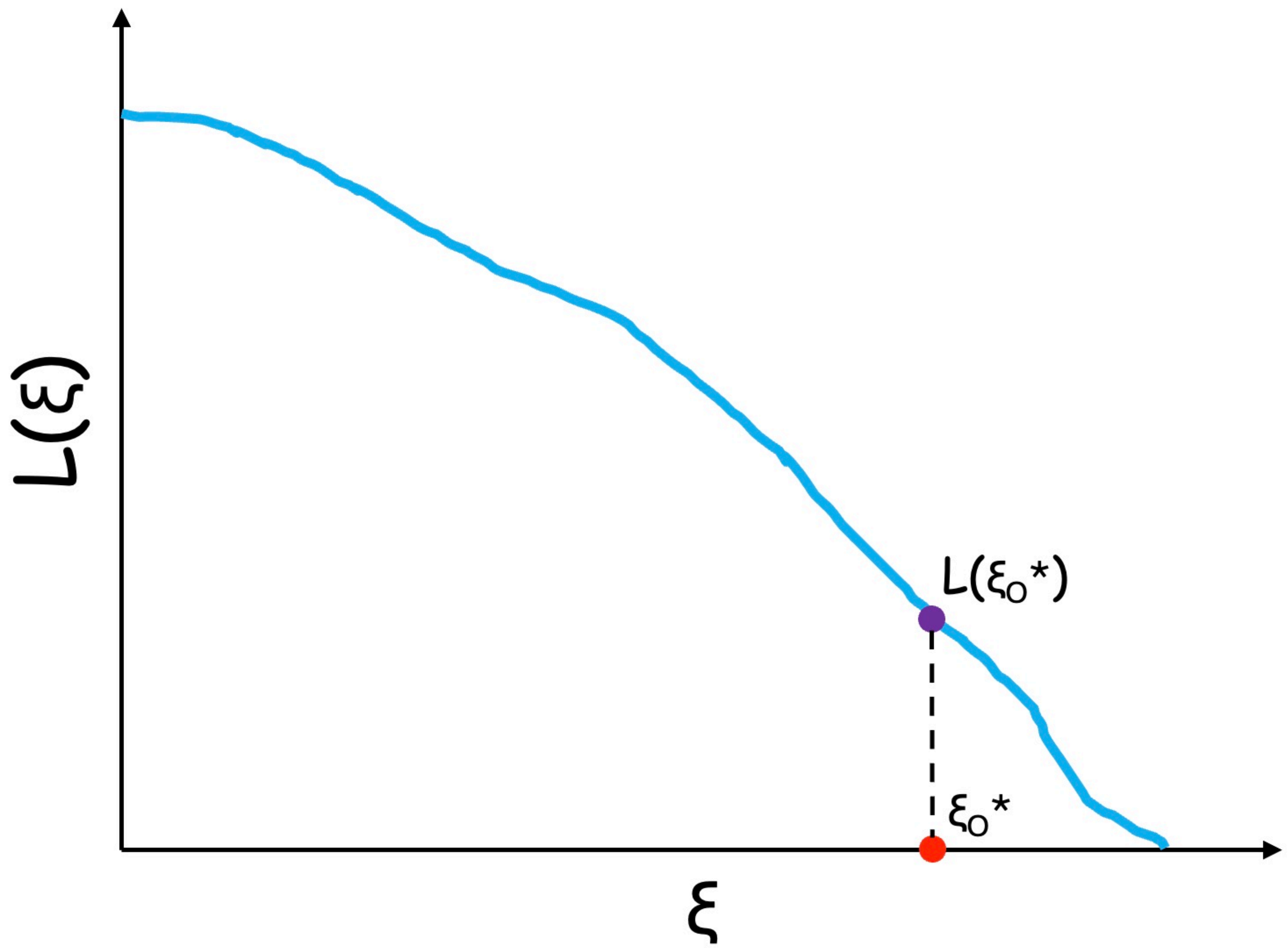

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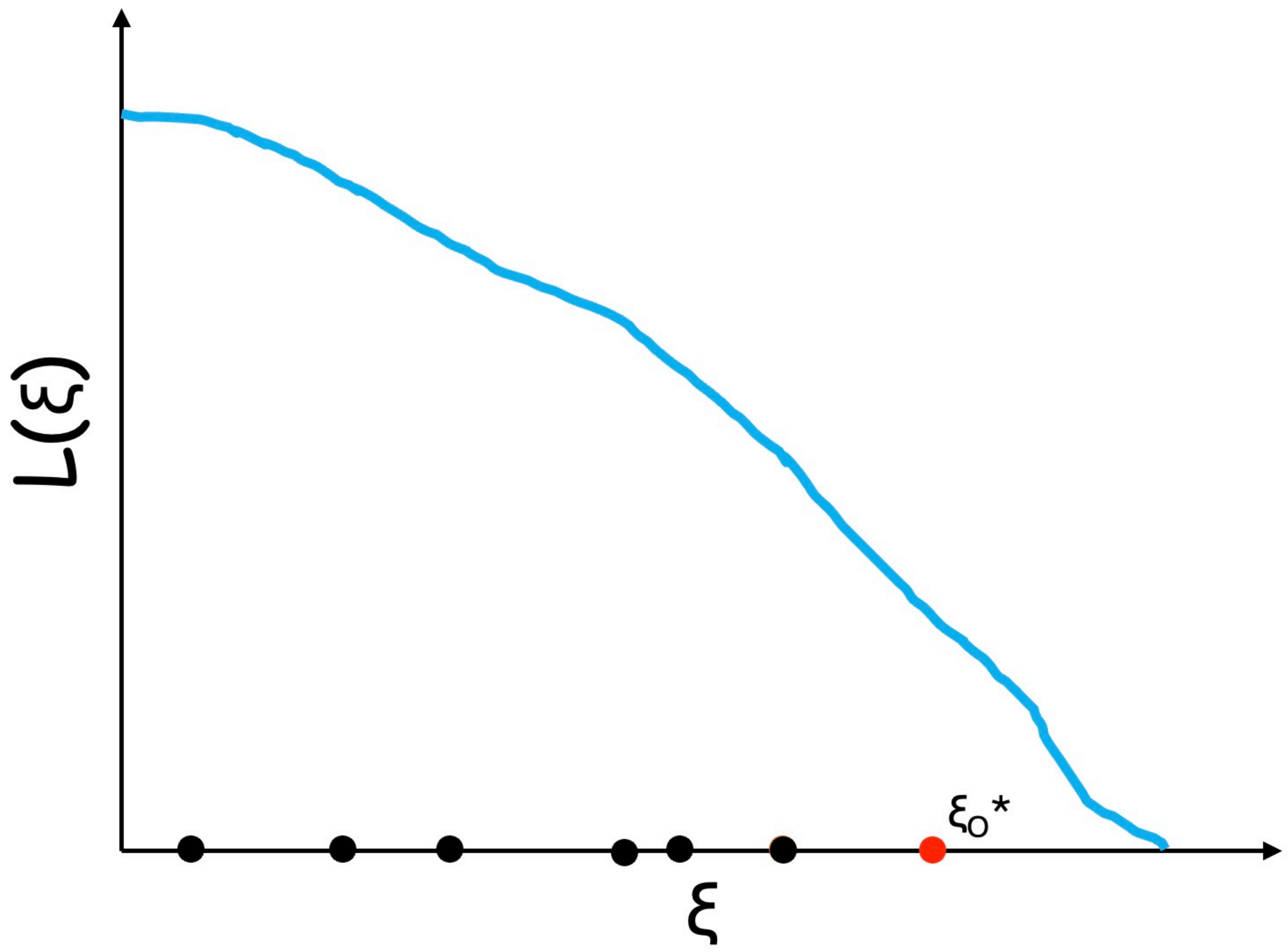

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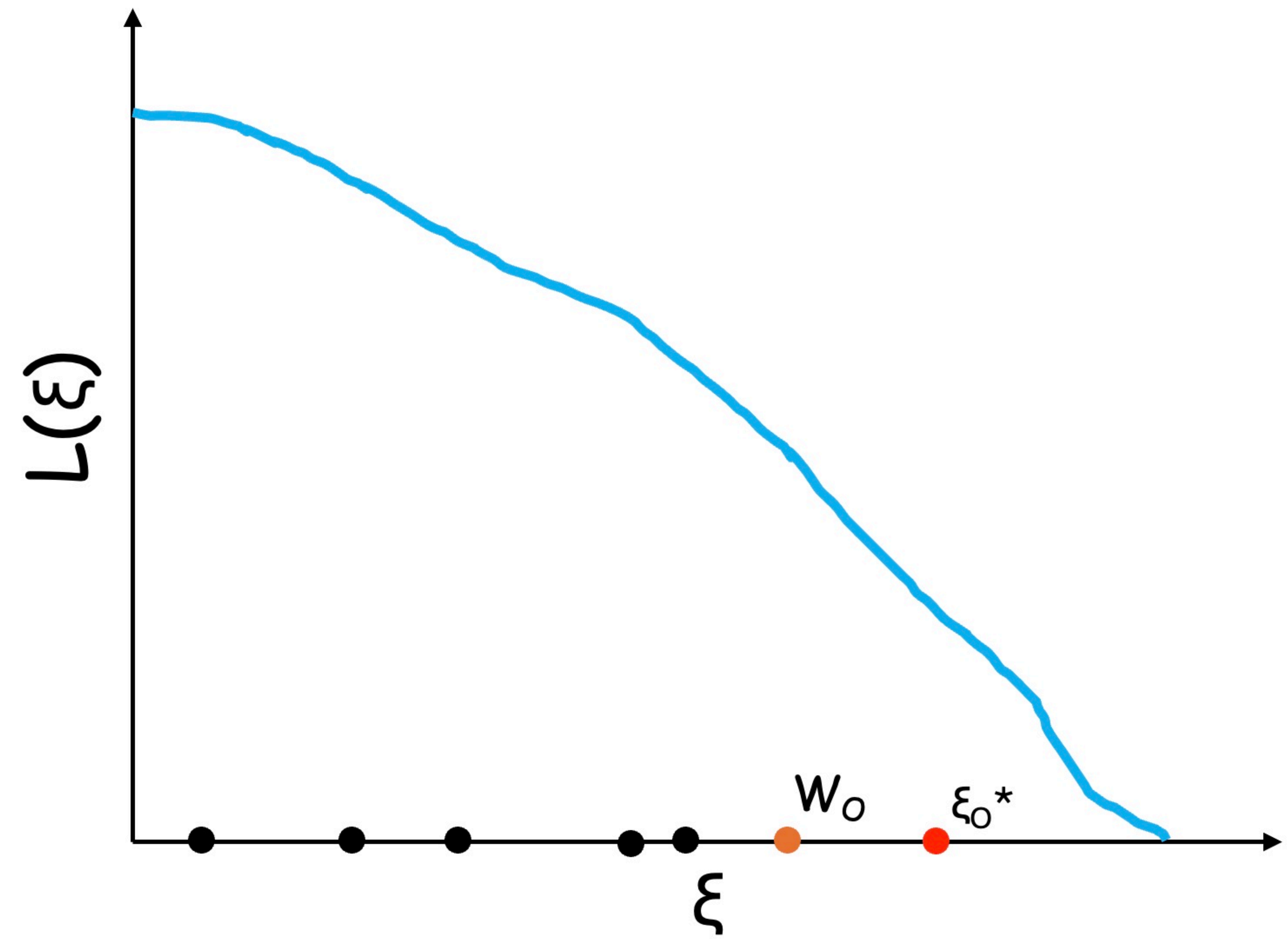

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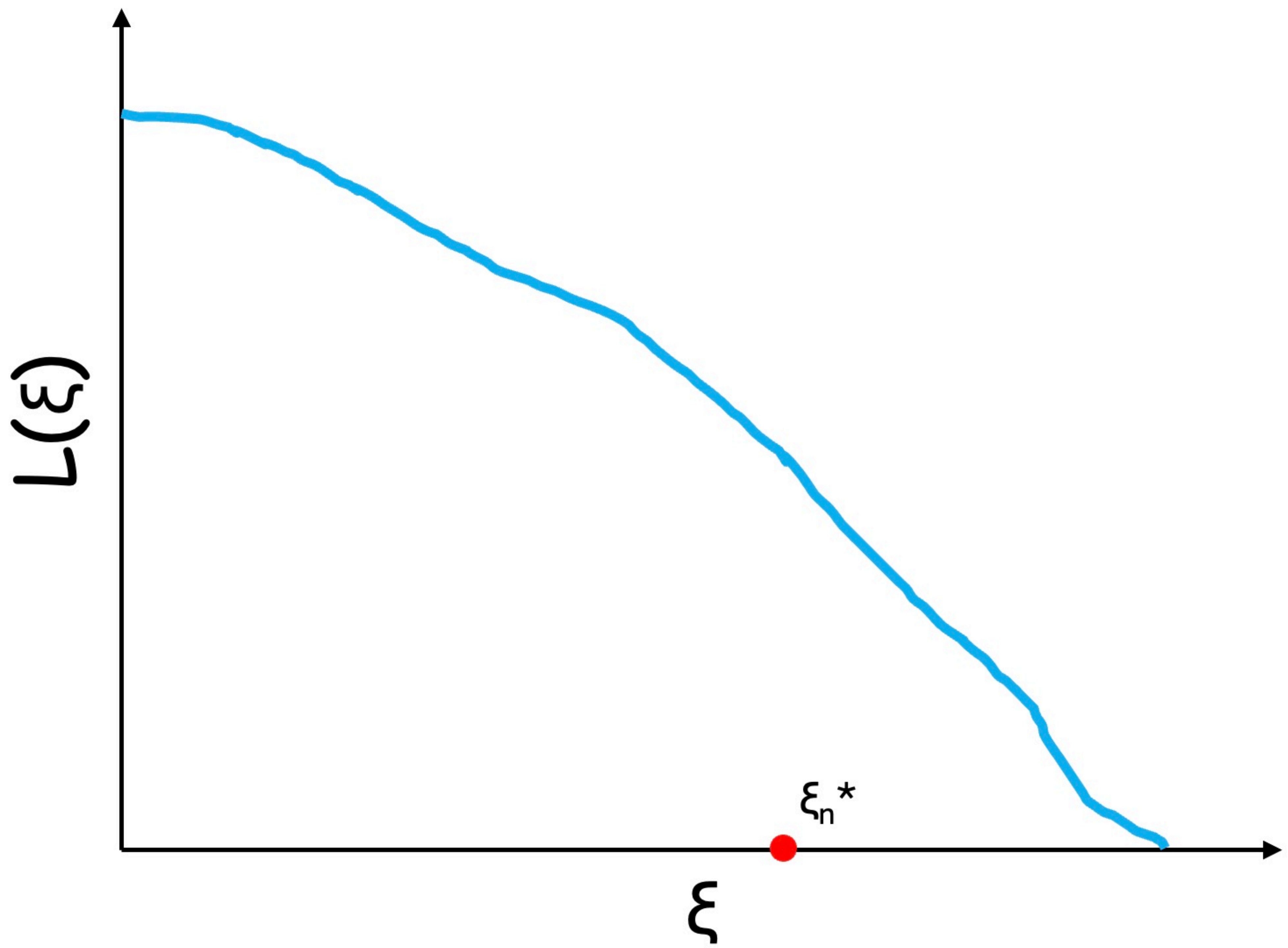

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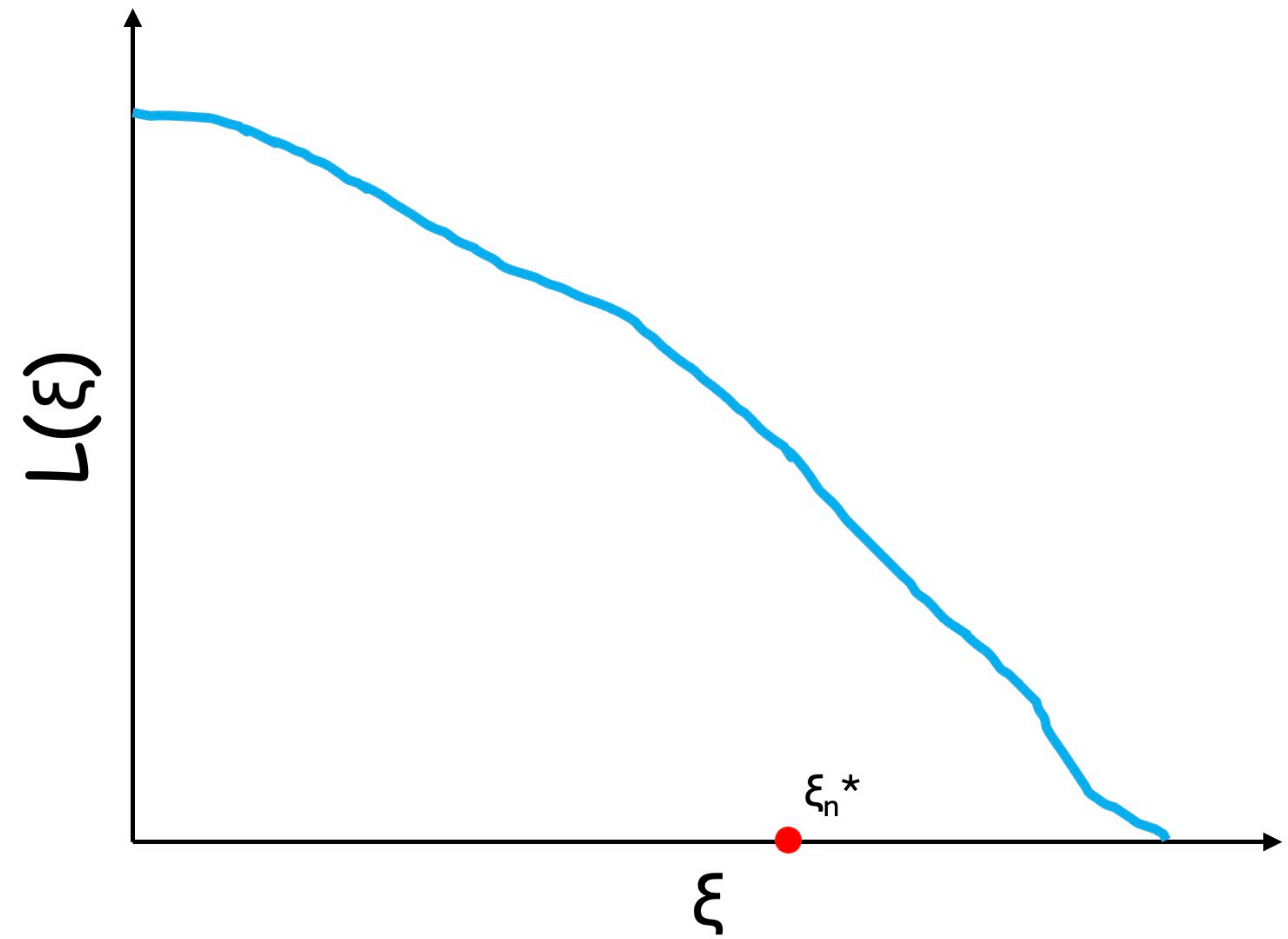
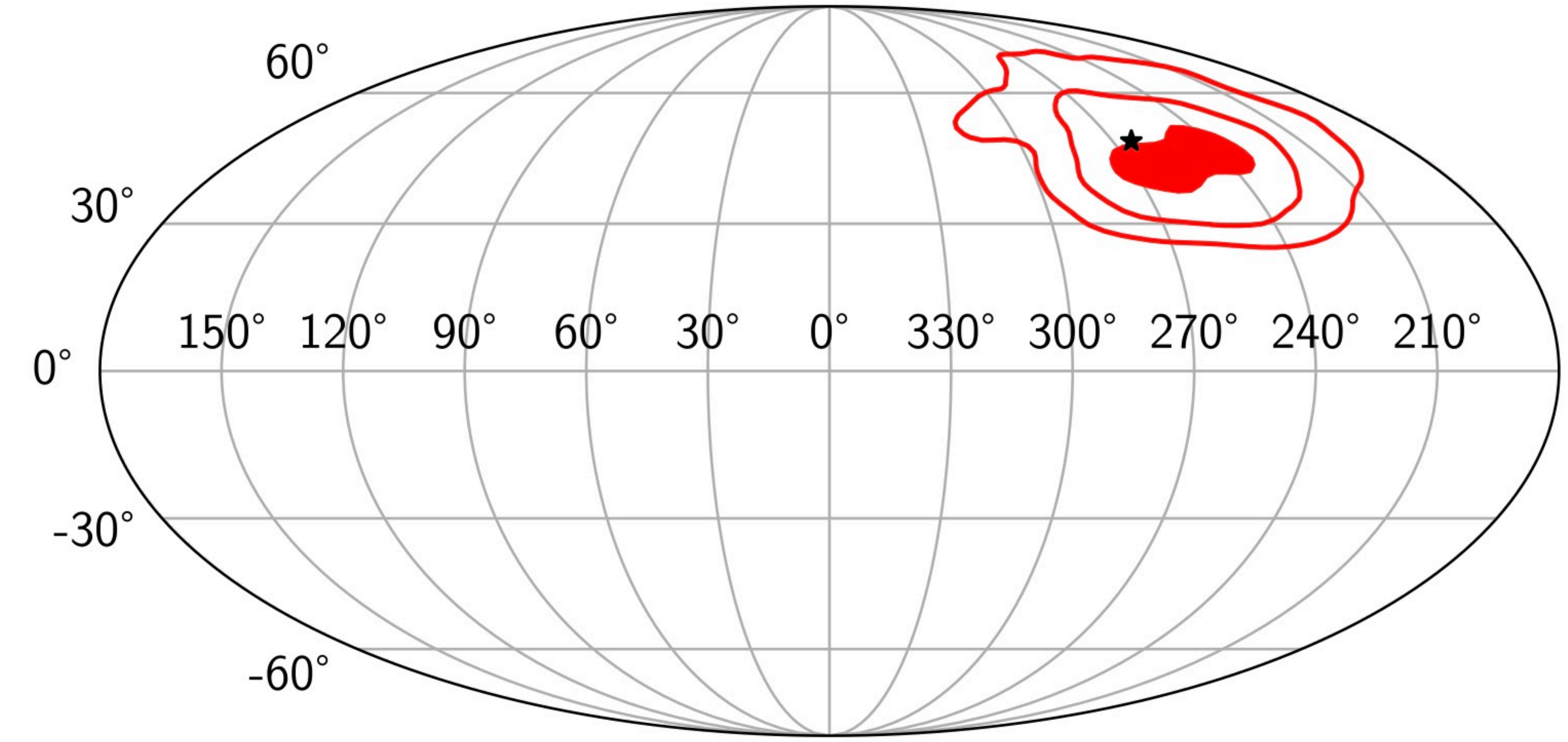
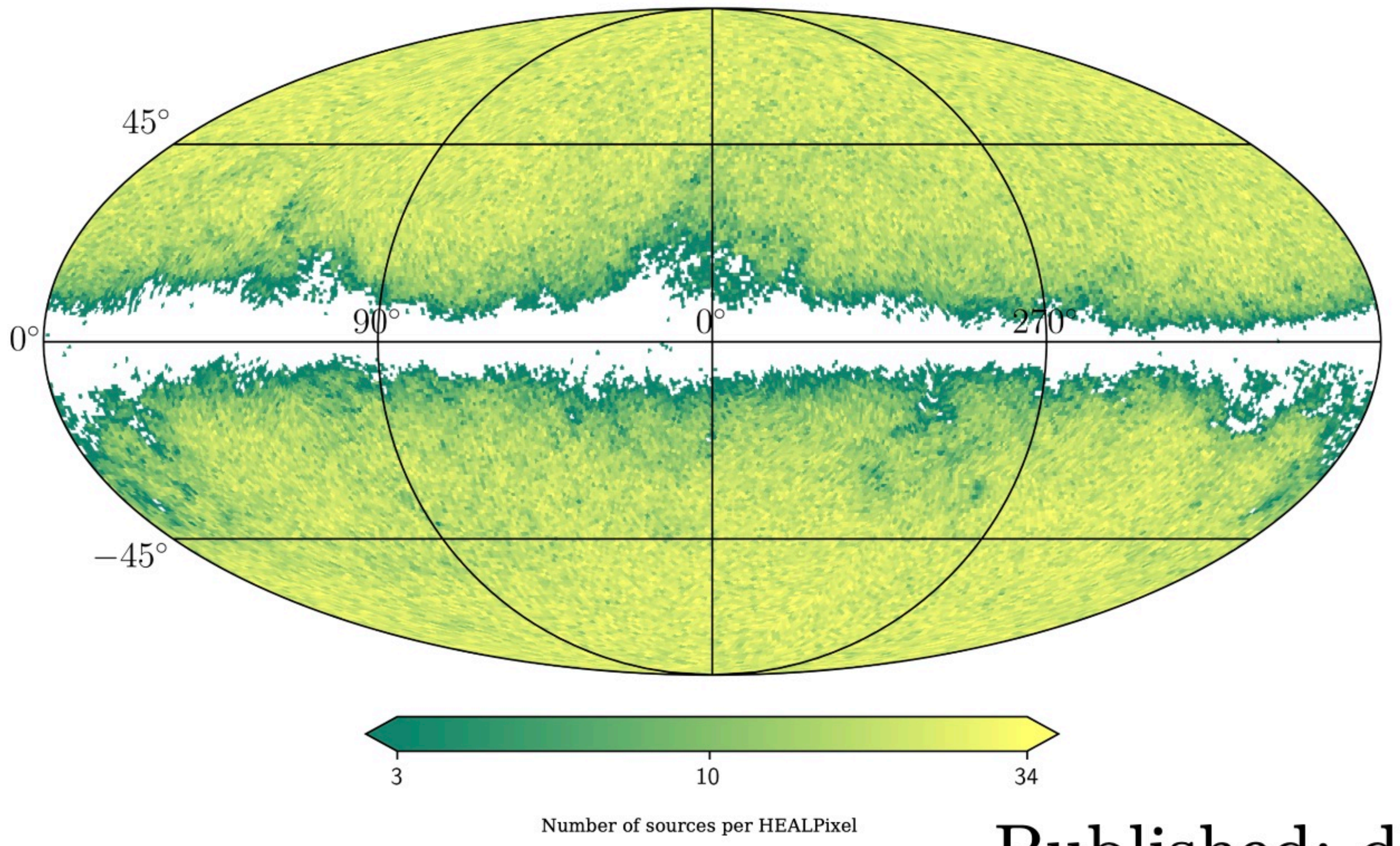


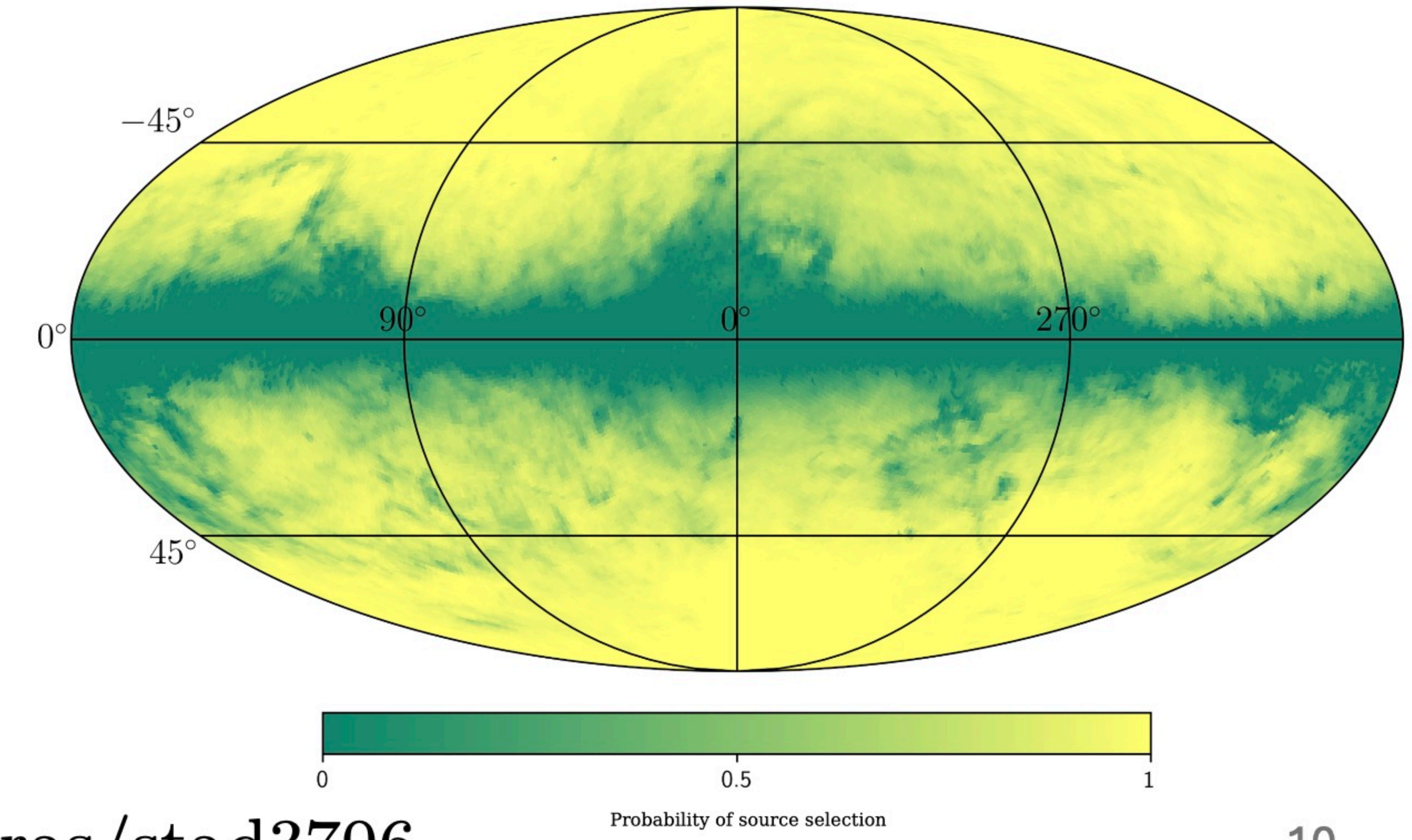
$\mathcal{Z} = \sum_k \mathcal{L}_k(\xi_{k-1} - \xi_k)$ and $P(\xi) = \frac{\mathcal{L}(\xi)}{\mathcal{Z}}$

Results: Quasars

Amplitude
$0.011^{+0.006}_{-0.005}$
0.0048



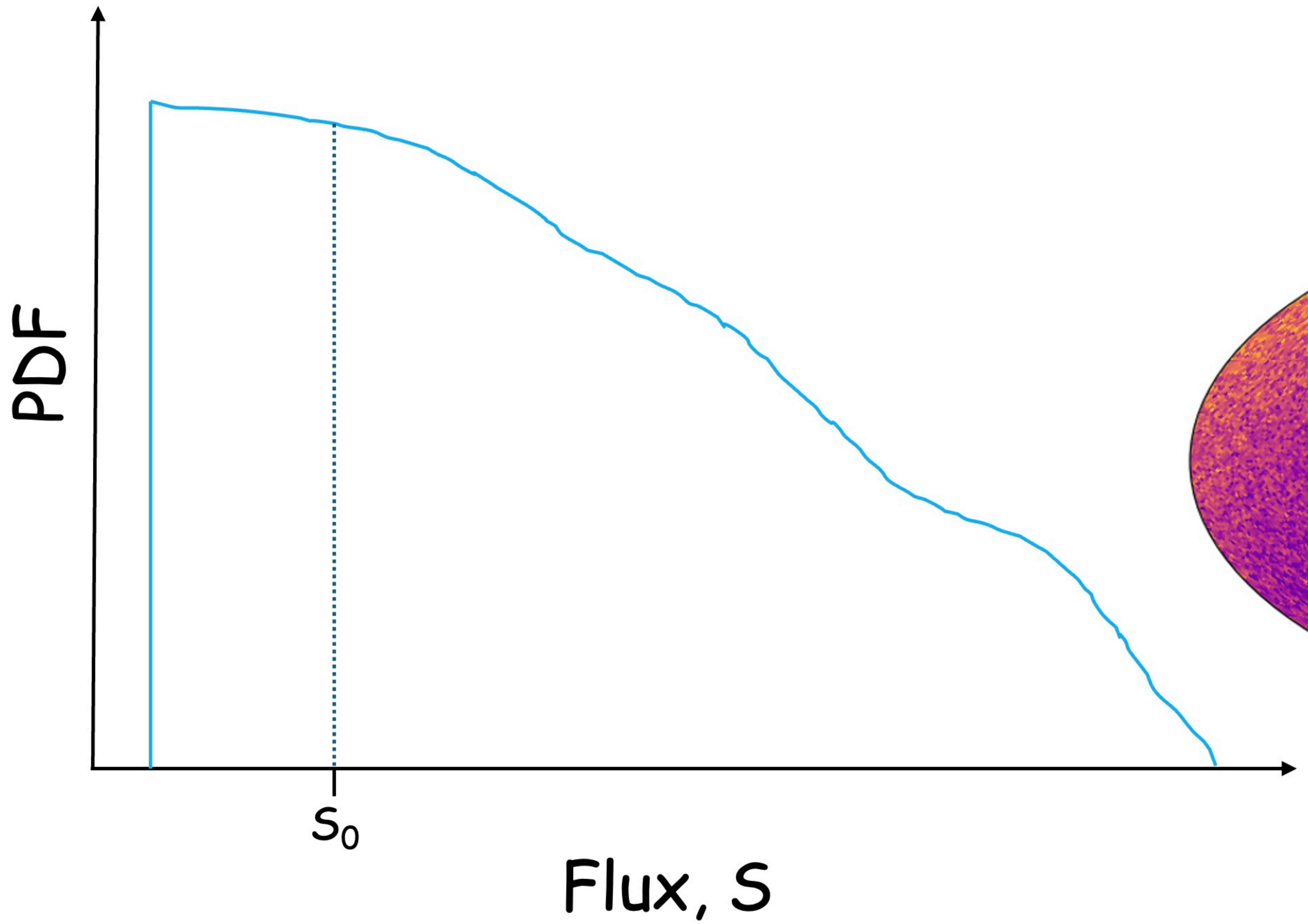


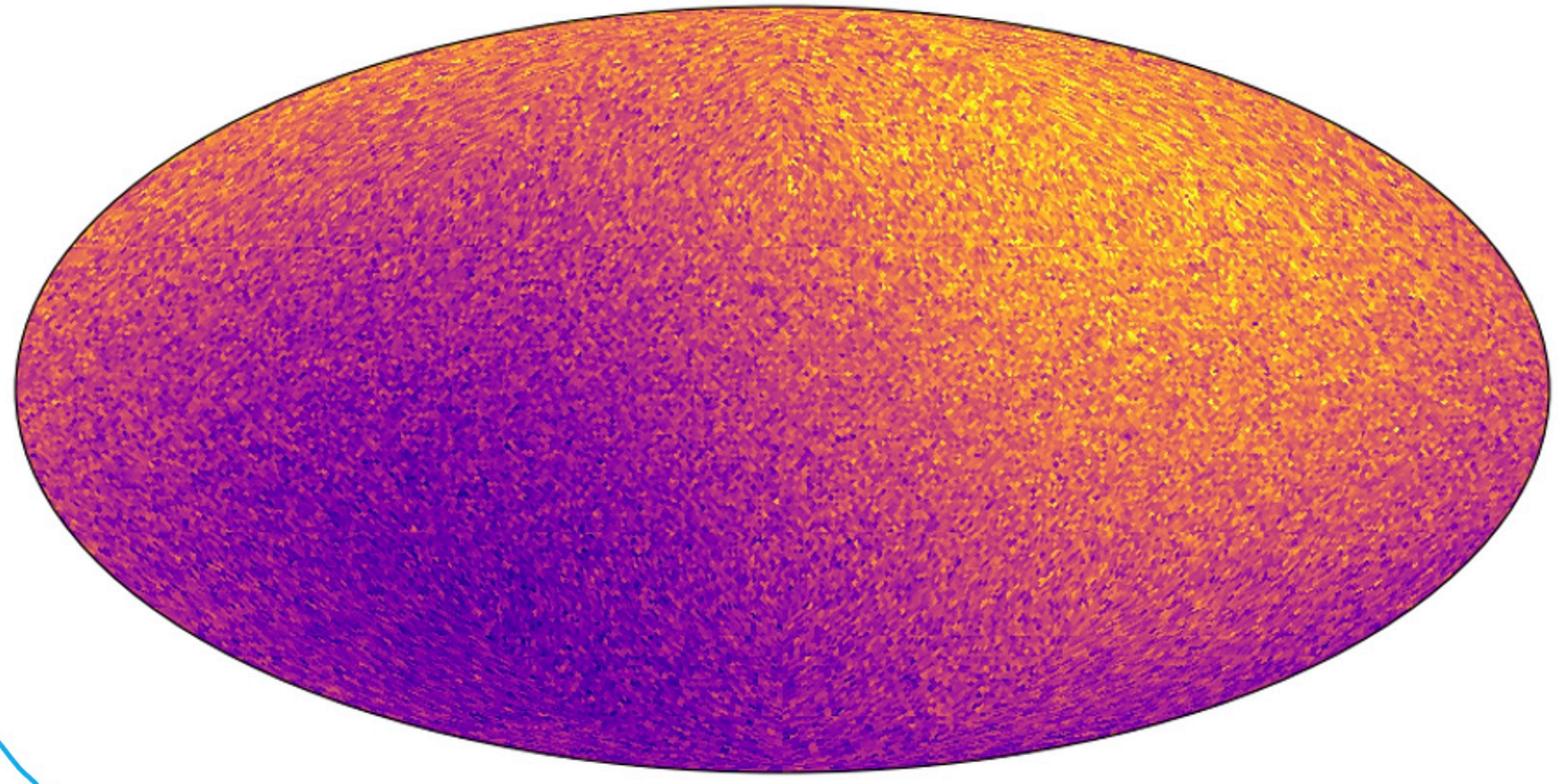


Published: doi.org/10.1093/mnras/stad3706

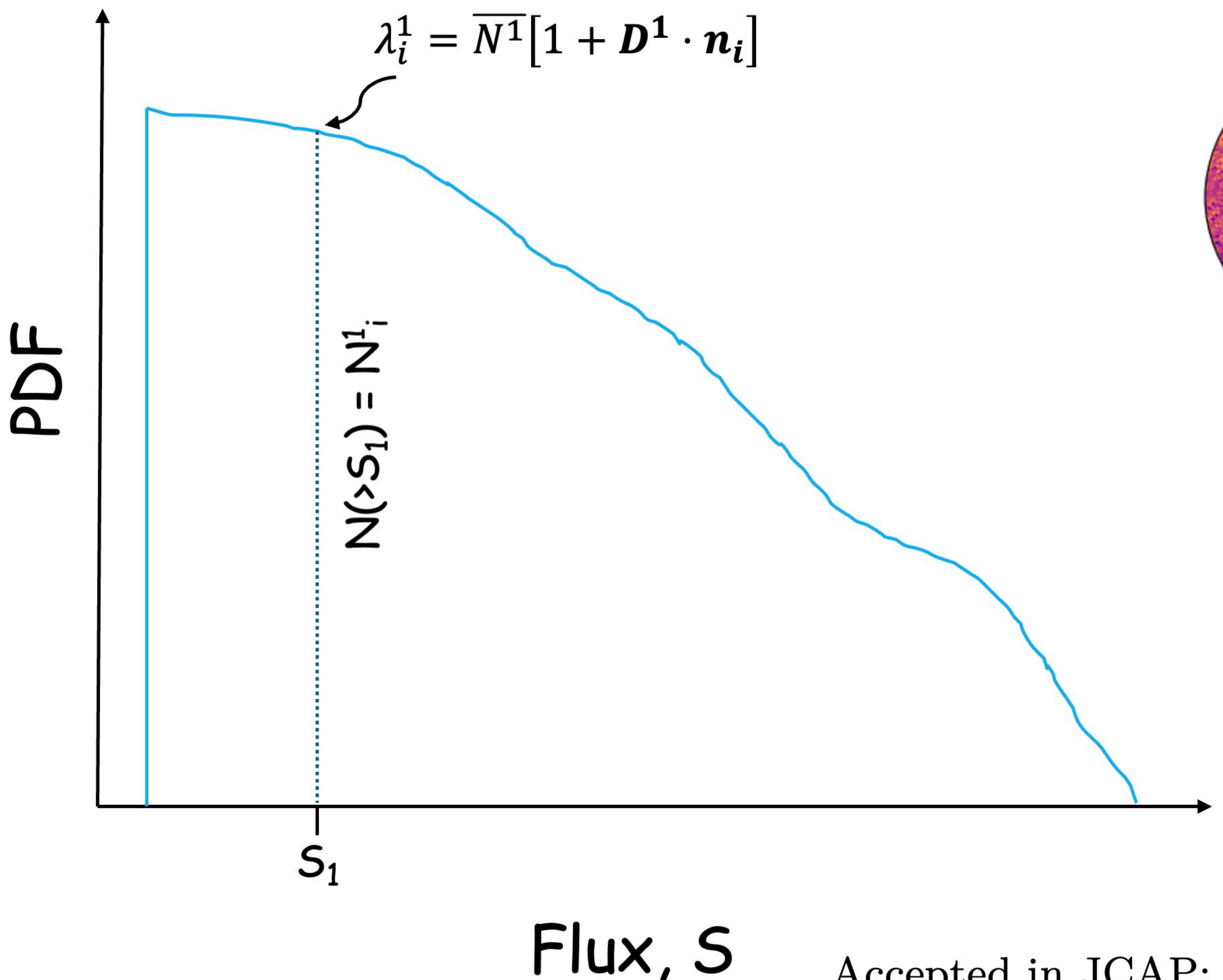
The Future

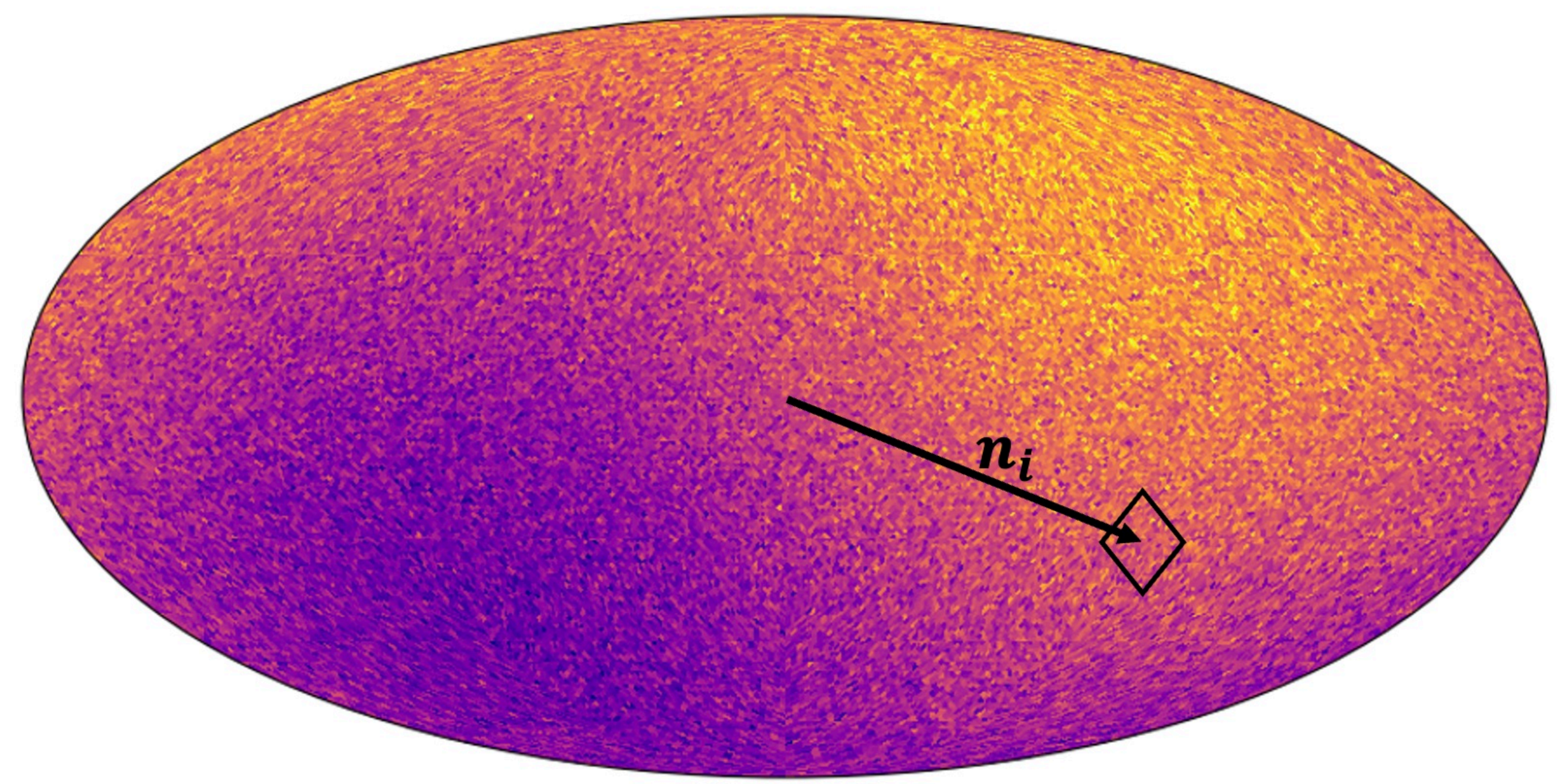
Can we utilize the full Luminosity function?





Multiple Flux Bins



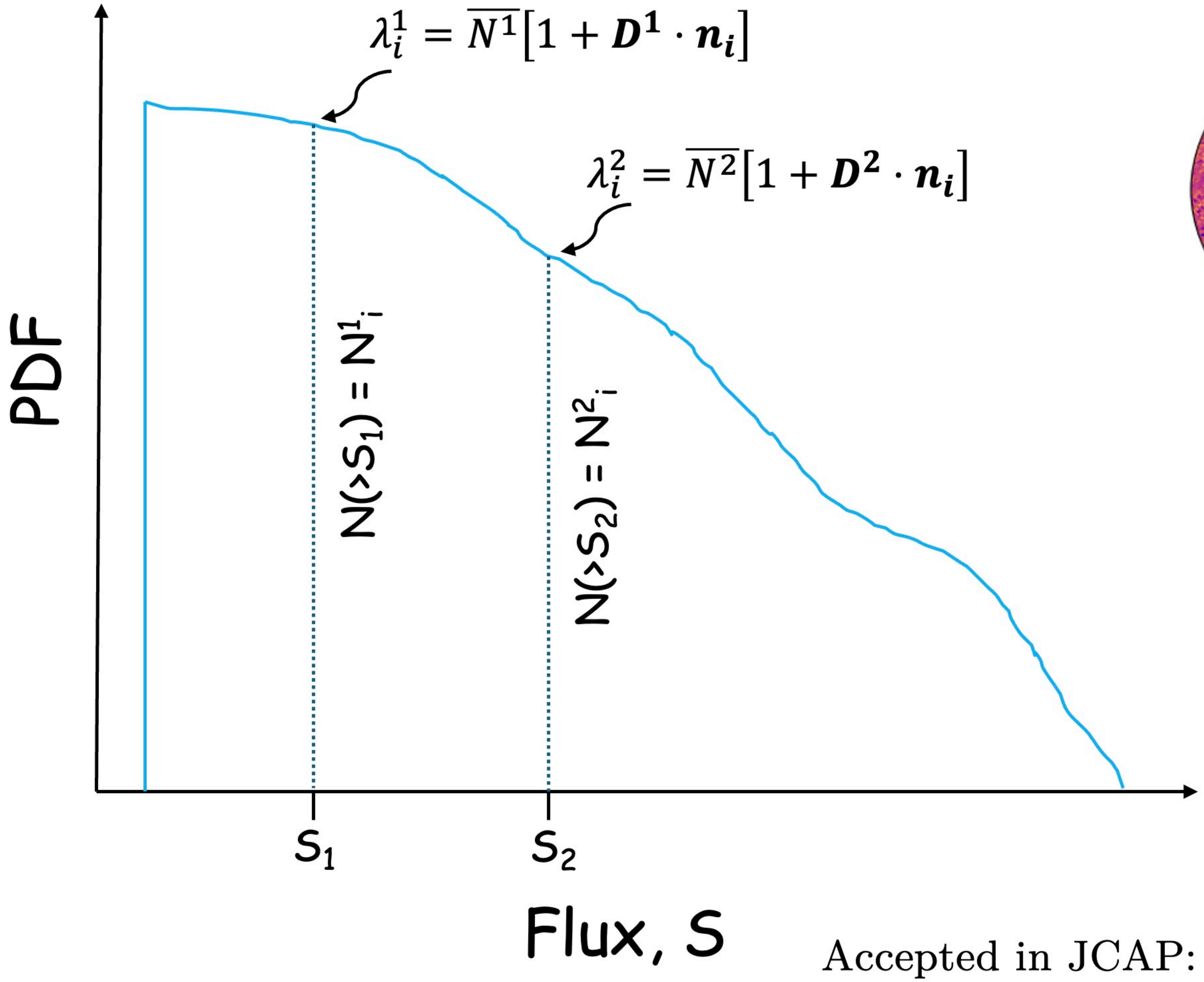


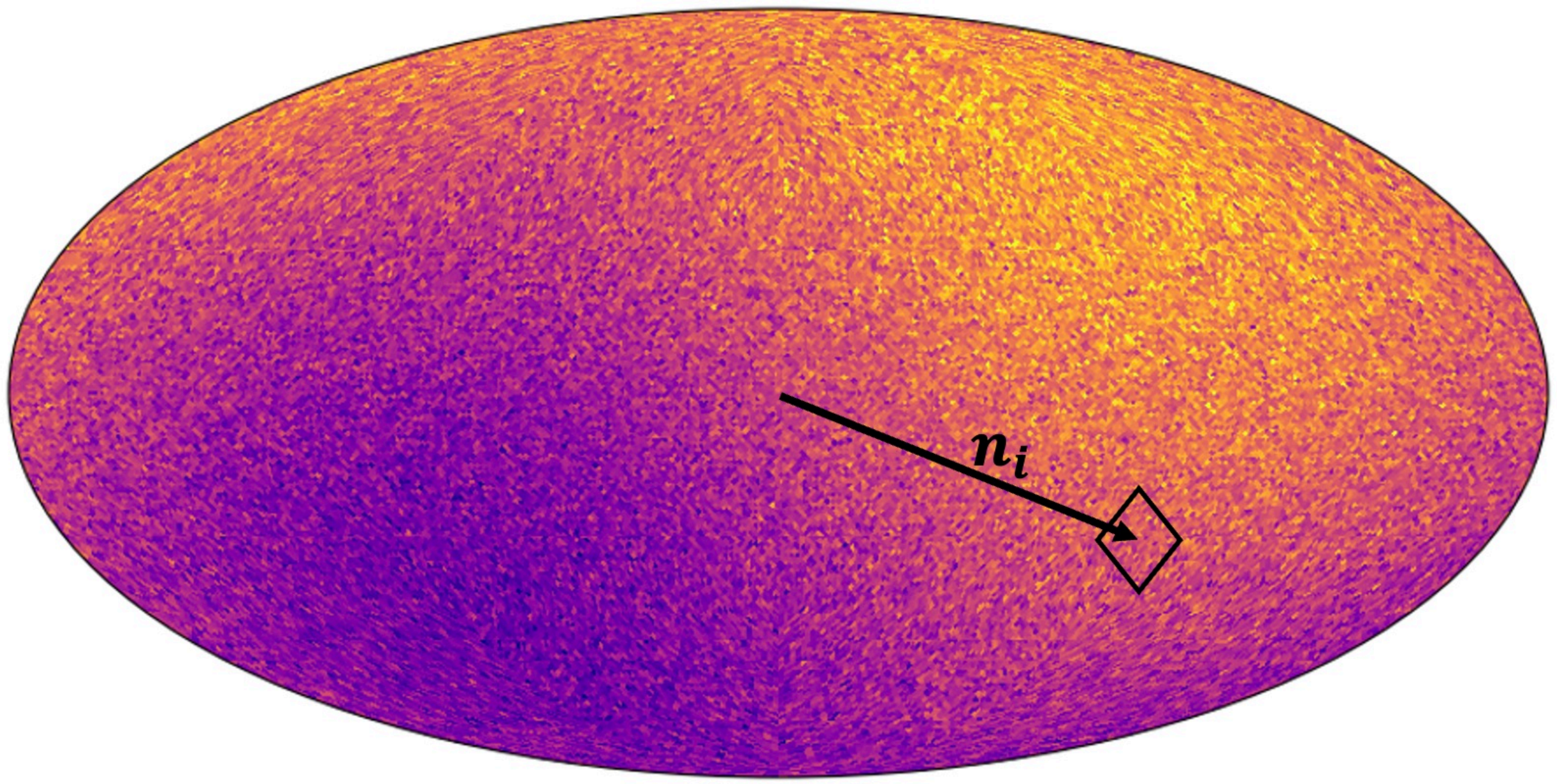
$$\mathcal{L}(D|\theta, M)$$

$$\prod_i \mathcal{L}(N_i^1|\lambda_i^1)$$

Accepted in JCAP: 2605.27520

Multiple Flux Bins





$$\mathcal{L}(D|\theta, M)$$

$$\prod_i \mathcal{L}(N_i^1 - N_i^2 | \lambda_i^1 - \lambda_i^2) \mathcal{L}(N_i^2 | \lambda_i^2)$$

Accepted in JCAP: 2605.27520

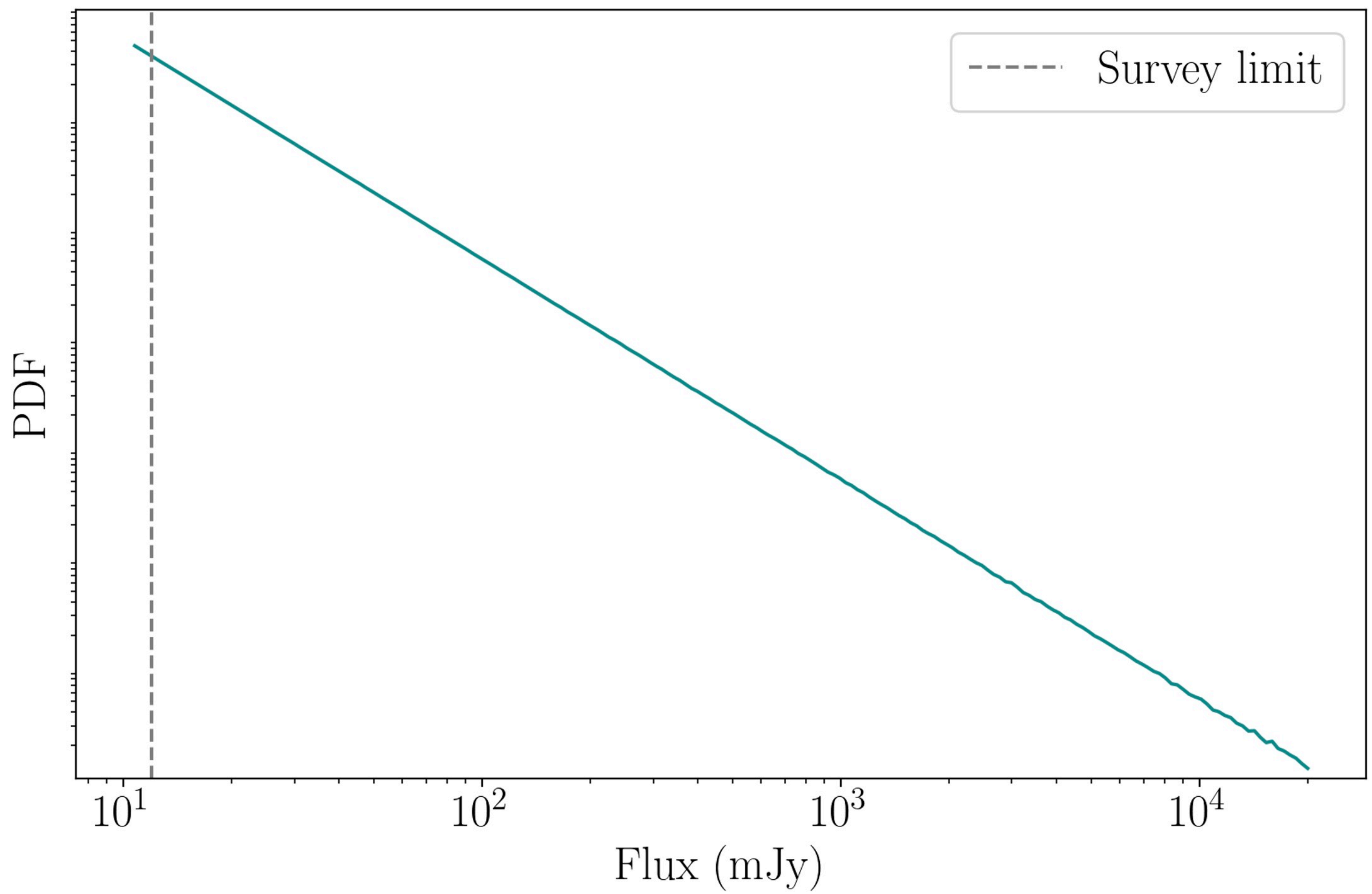
Proof of Concept: Mocks

Create an isotropic distribution of sources.

Sample flux from a luminosity function.

Add dipole by injecting aberration and Doppler shift.

LF 1: Power Law



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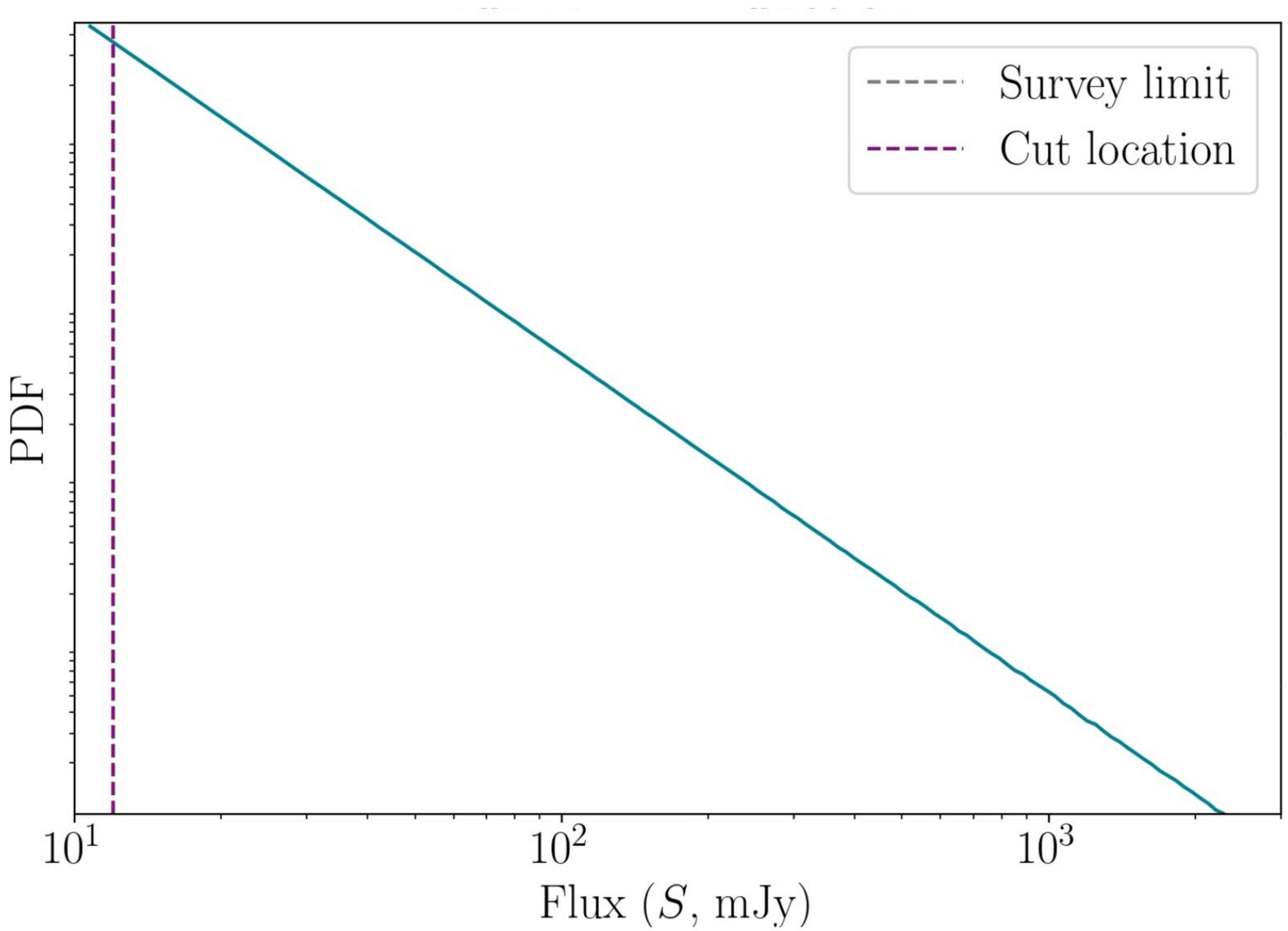

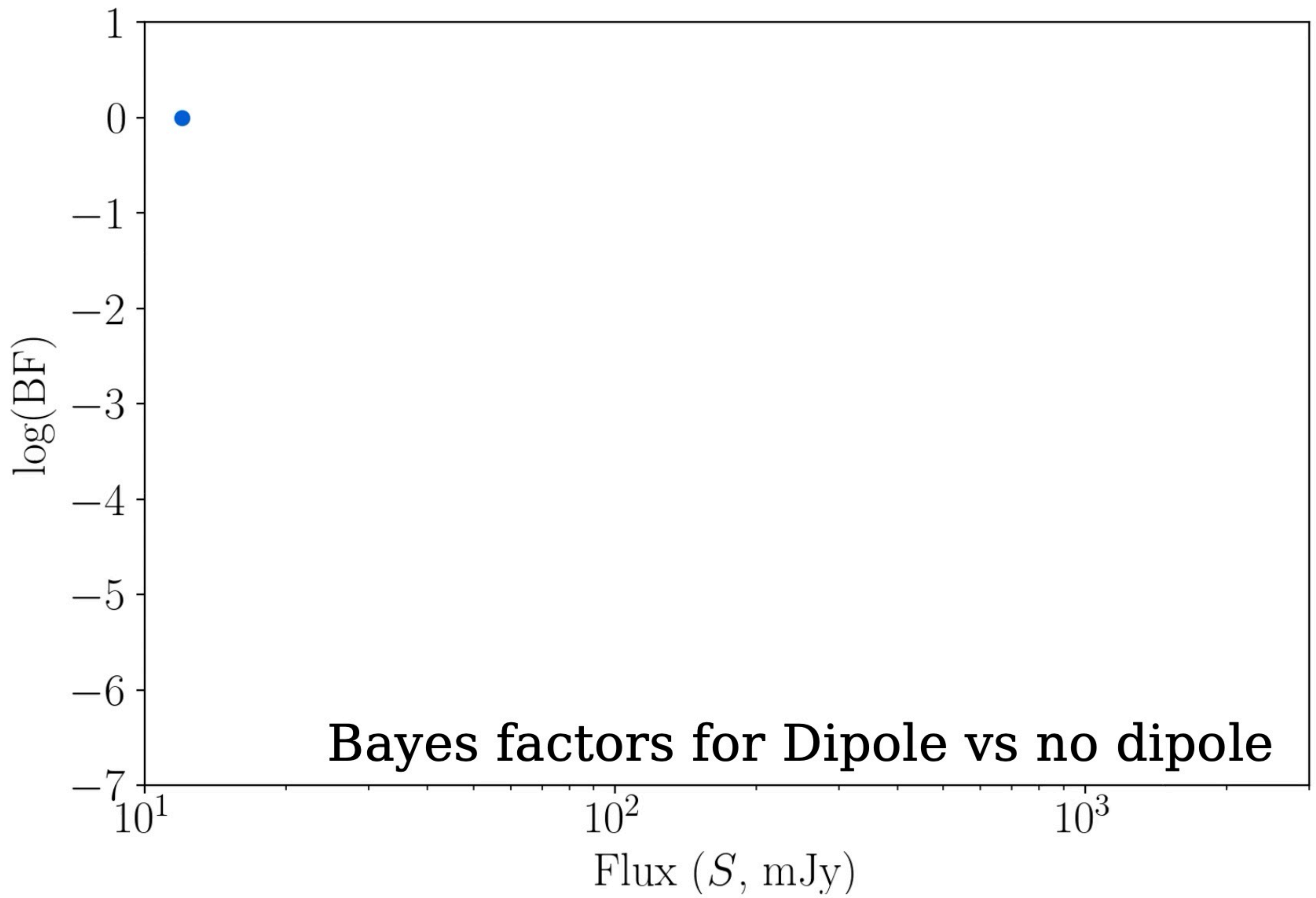

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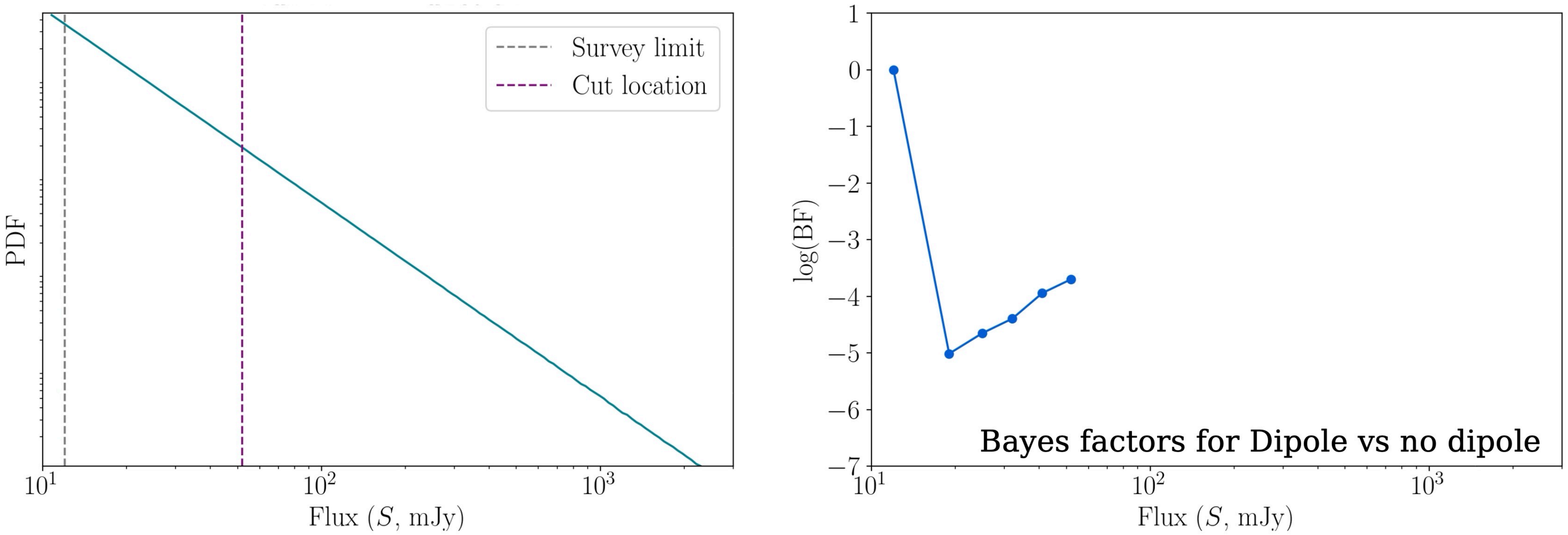

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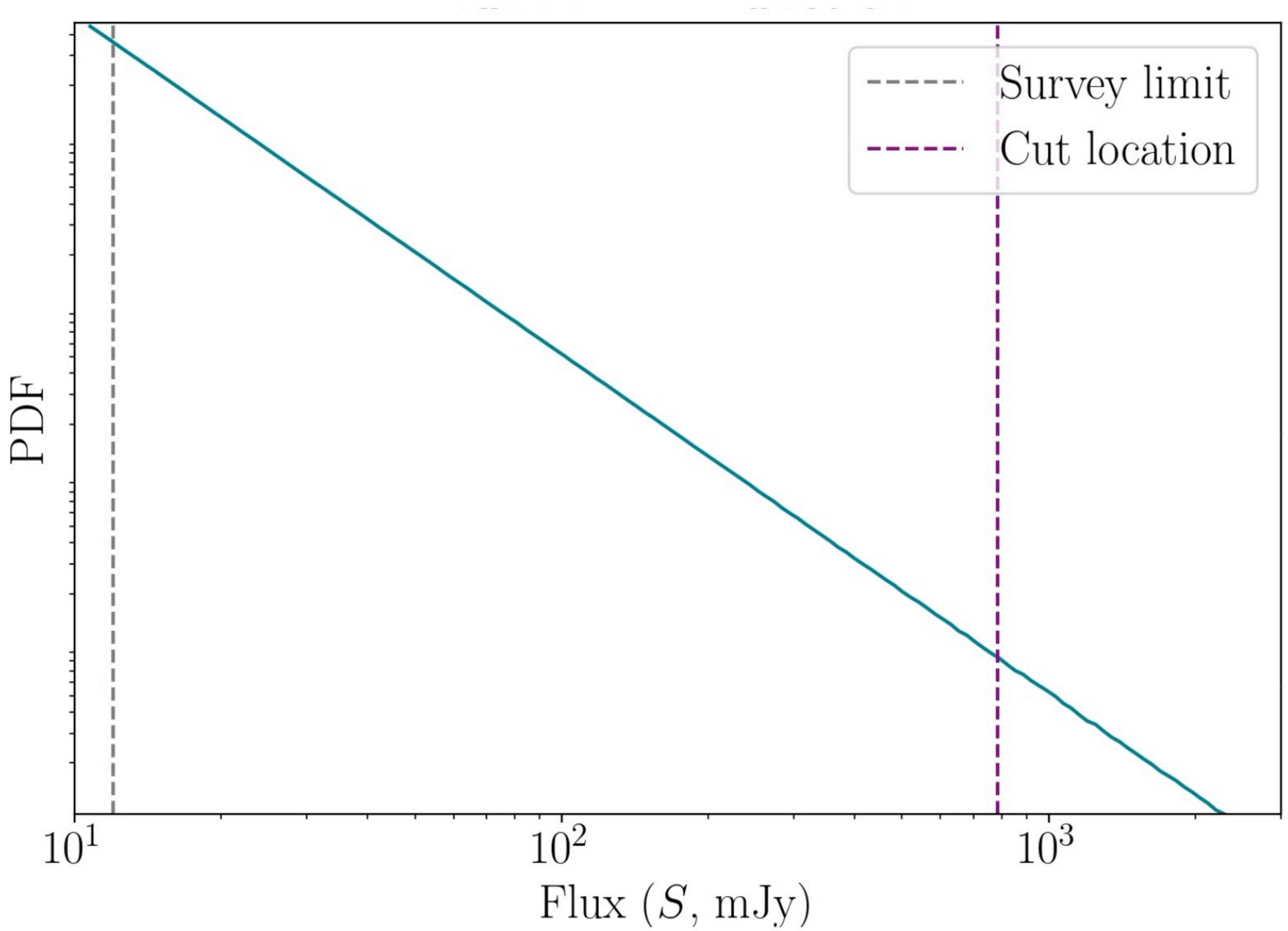

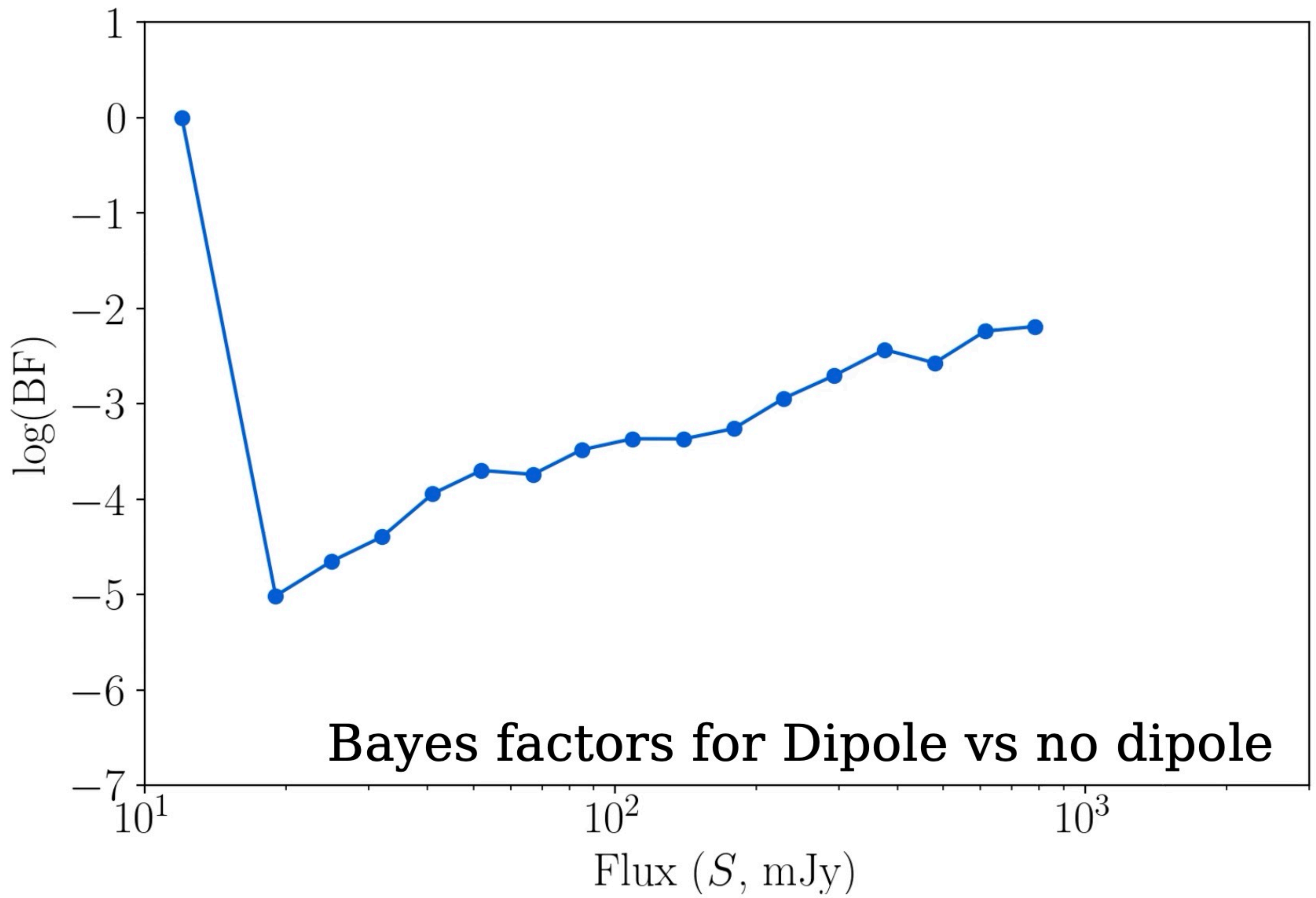

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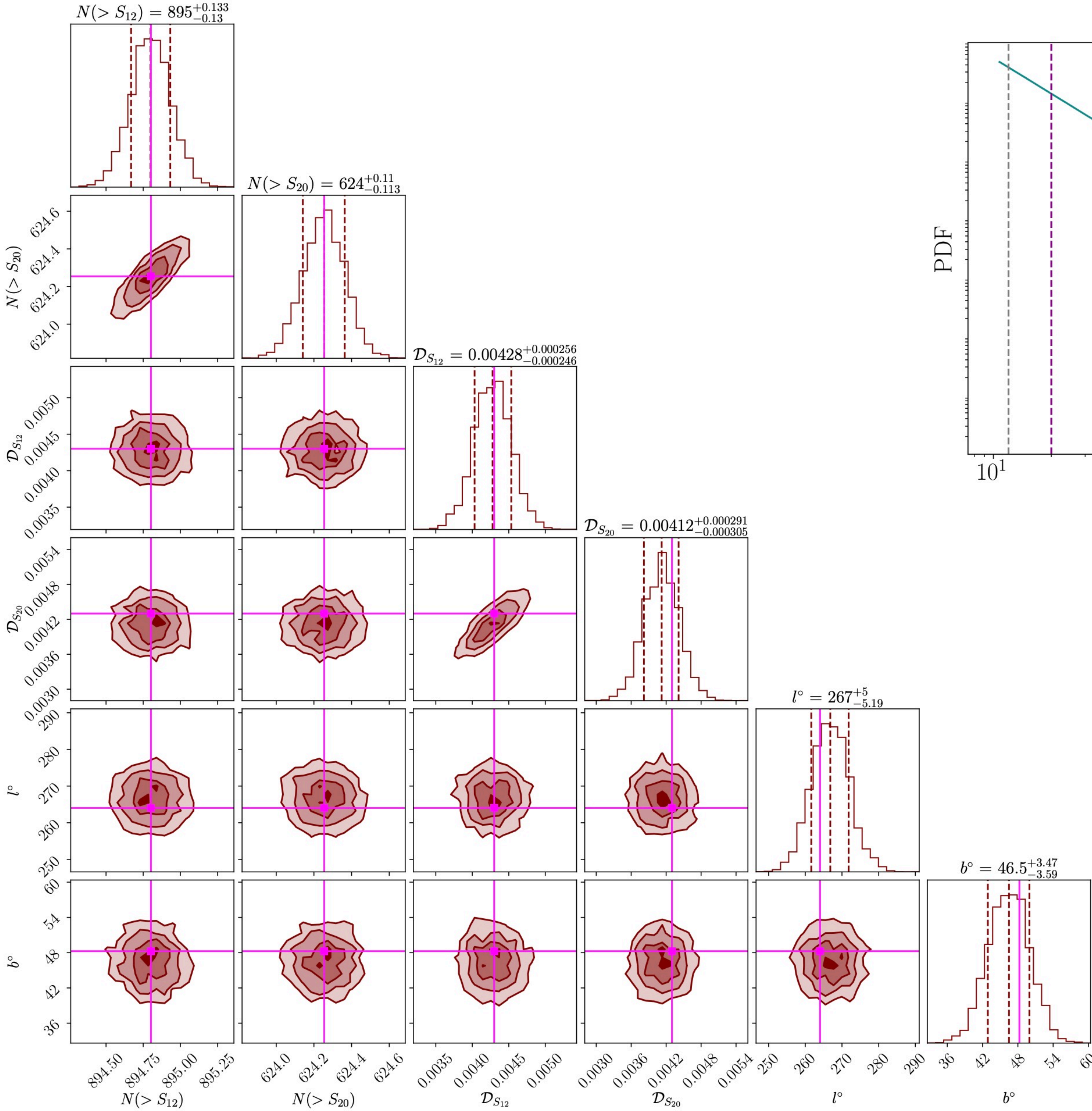
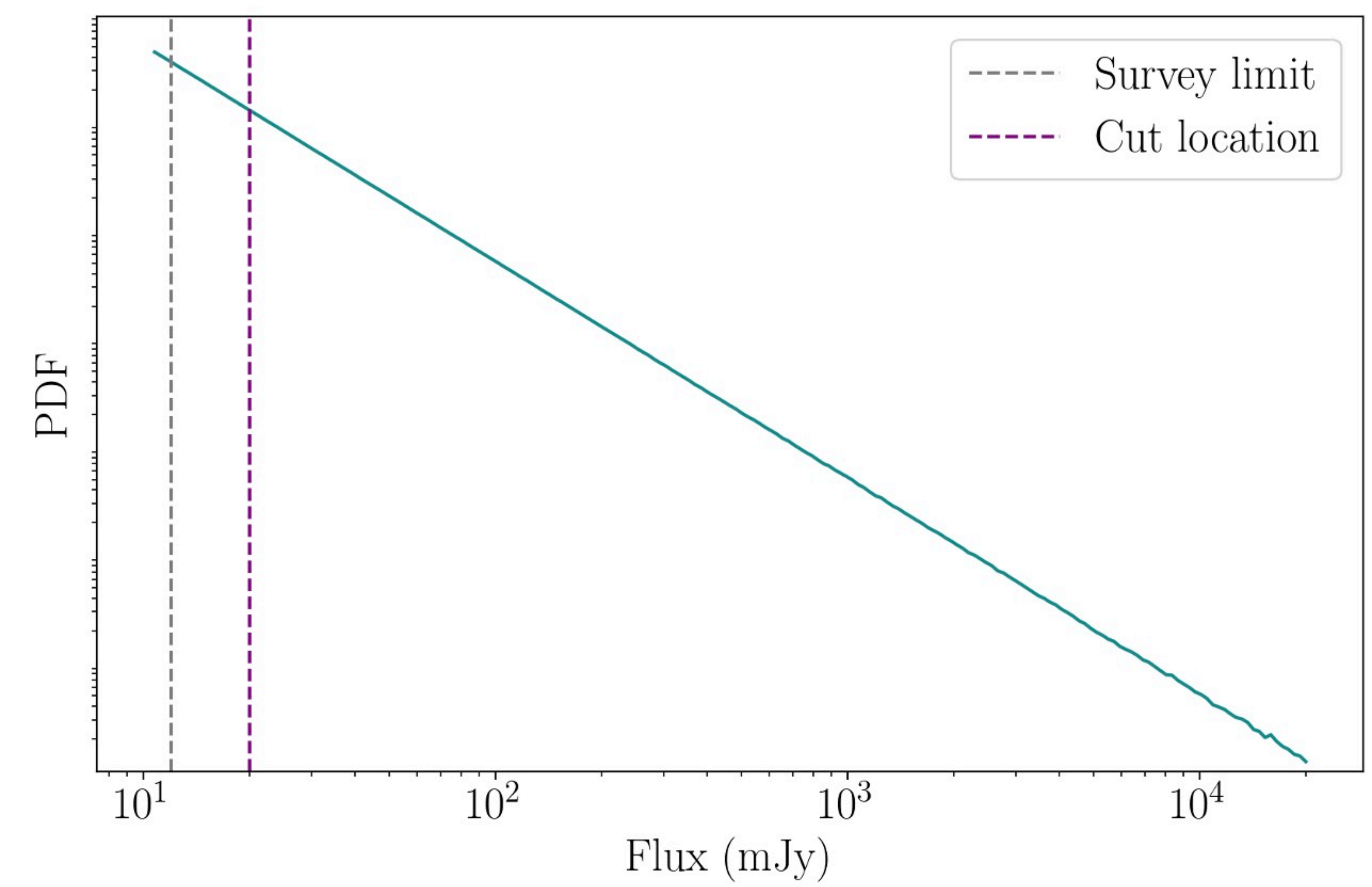
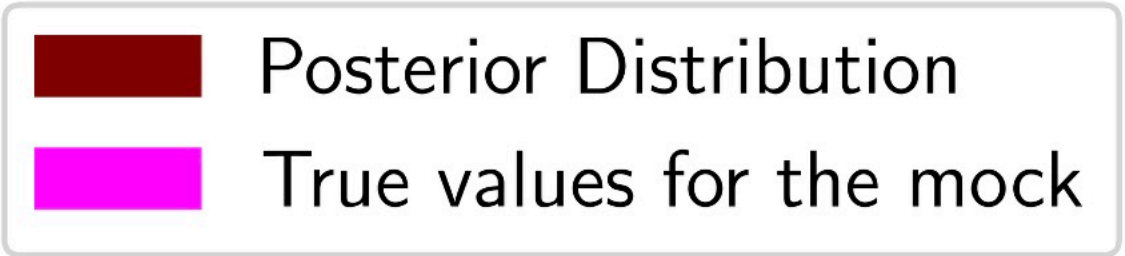


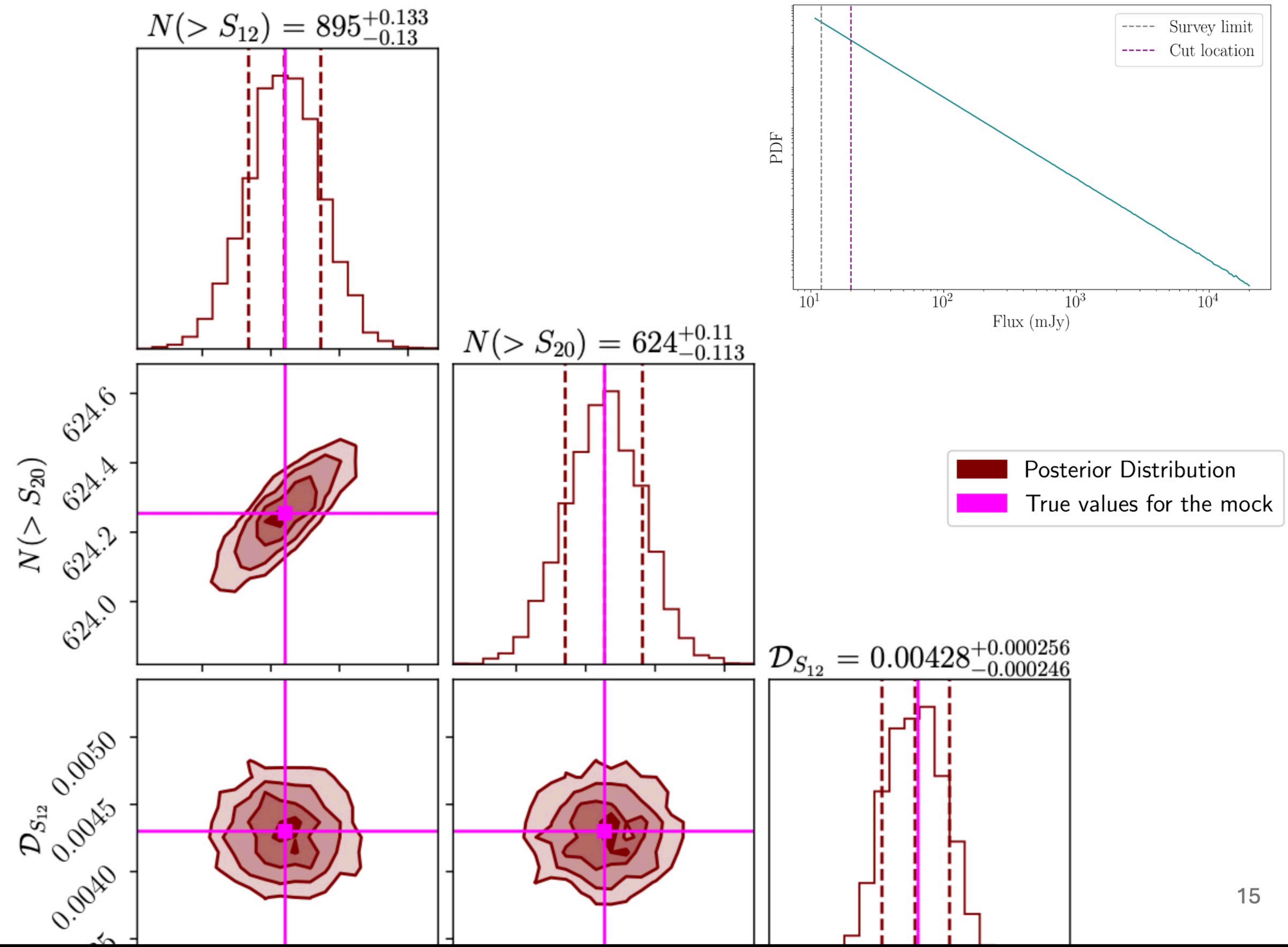
$N(> S_{12}) = 895^{+0.133}_{-0.13}$
$N(> S_{20}) = 624^{+0.11}_{-0.113}$
$\mathcal{D}_{S_{12}} = 0.00428^{+0.000256}_{-0.000246}$
$\mathcal{D}_{S_{20}} = 0.00412^{+0.000291}_{-0.000305}$
$l^\circ = 267^{+5}_{-5.19}$
$b^\circ = 46.5^{+3.47}_{-3.59}$
$N(> S_{12})$
$N(> S_{20})$
$\mathcal{D}_{S_{12}}$
$\mathcal{D}_{S_{20}}$
l°
b°

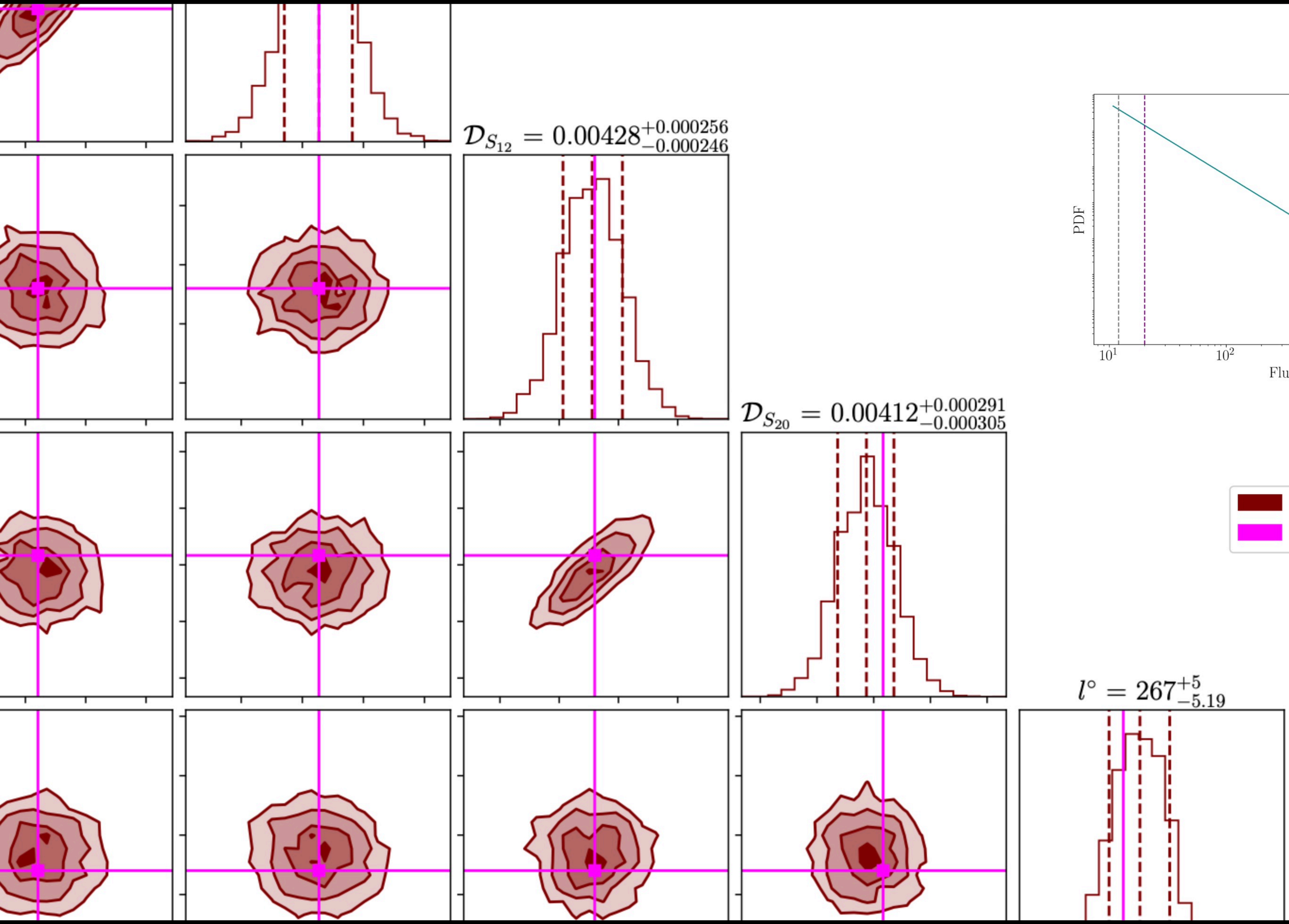


Survey limit
Cut location
PDF
Flux (mJy)

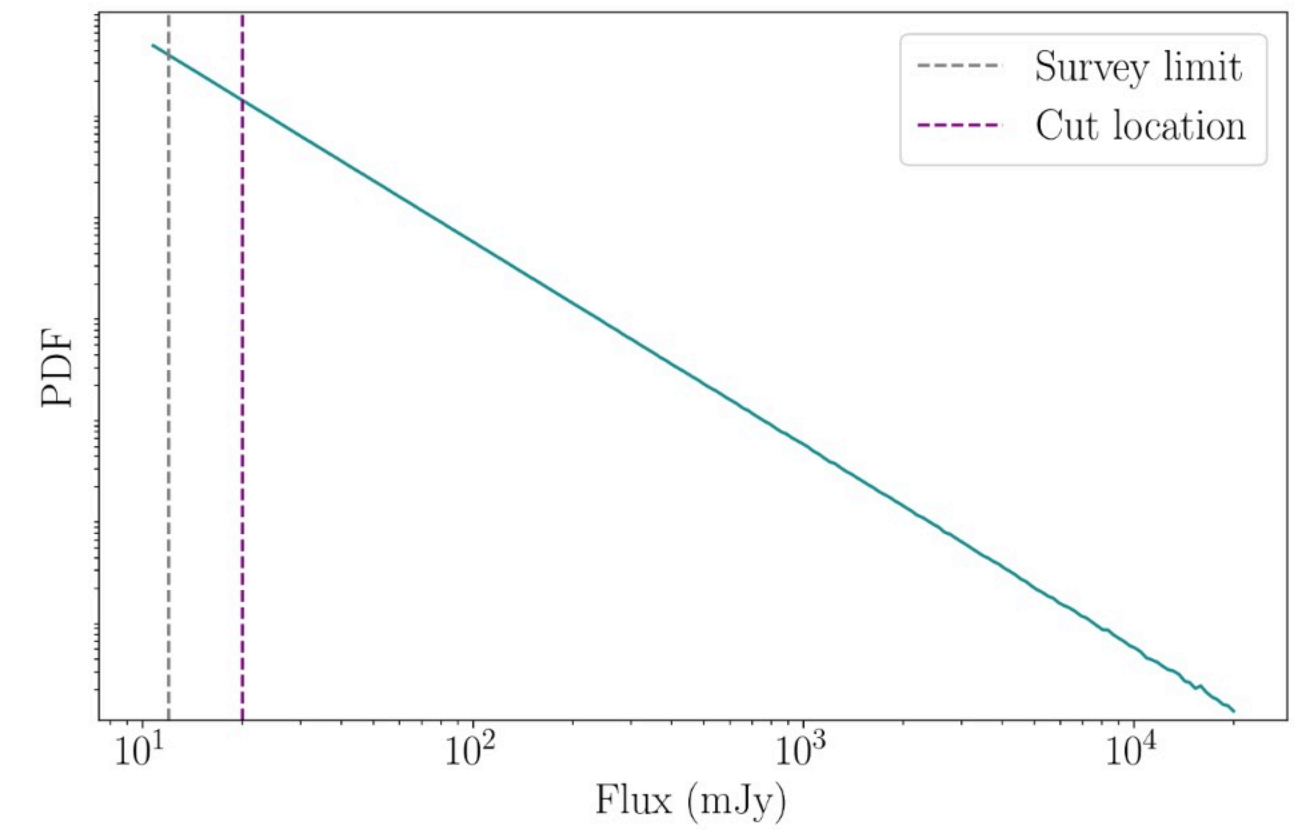


Posterior Distribution
True values for the mock


$N(>S_{12}) = 895^{+0.133}_{-0.13}$
$N(>S_{20}) = 624^{+0.11}_{-0.113}$
$\mathcal{D}_{S_{12}} = 0.00428^{+0.000256}_{-0.000246}$
$N(>S_{20})$
624.0
624.2
624.4
624.6
$\mathcal{D}_{S_{12}}$
0.0040
0.0045
0.0050
Survey limit
Cut location
PDF
Flux (mJy)
10^1
10^2
10^3
10^4
Posterior Distribution
True values for the mock



$\mathcal{D}_{S_{12}} = 0.00428^{+0.000256}_{-0.000246}$
$\mathcal{D}_{S_{20}} = 0.00412^{+0.000291}_{-0.000305}$
$l^\circ = 267^{+5}_{-5.19}$
Posterior Distribution
True values for the mock



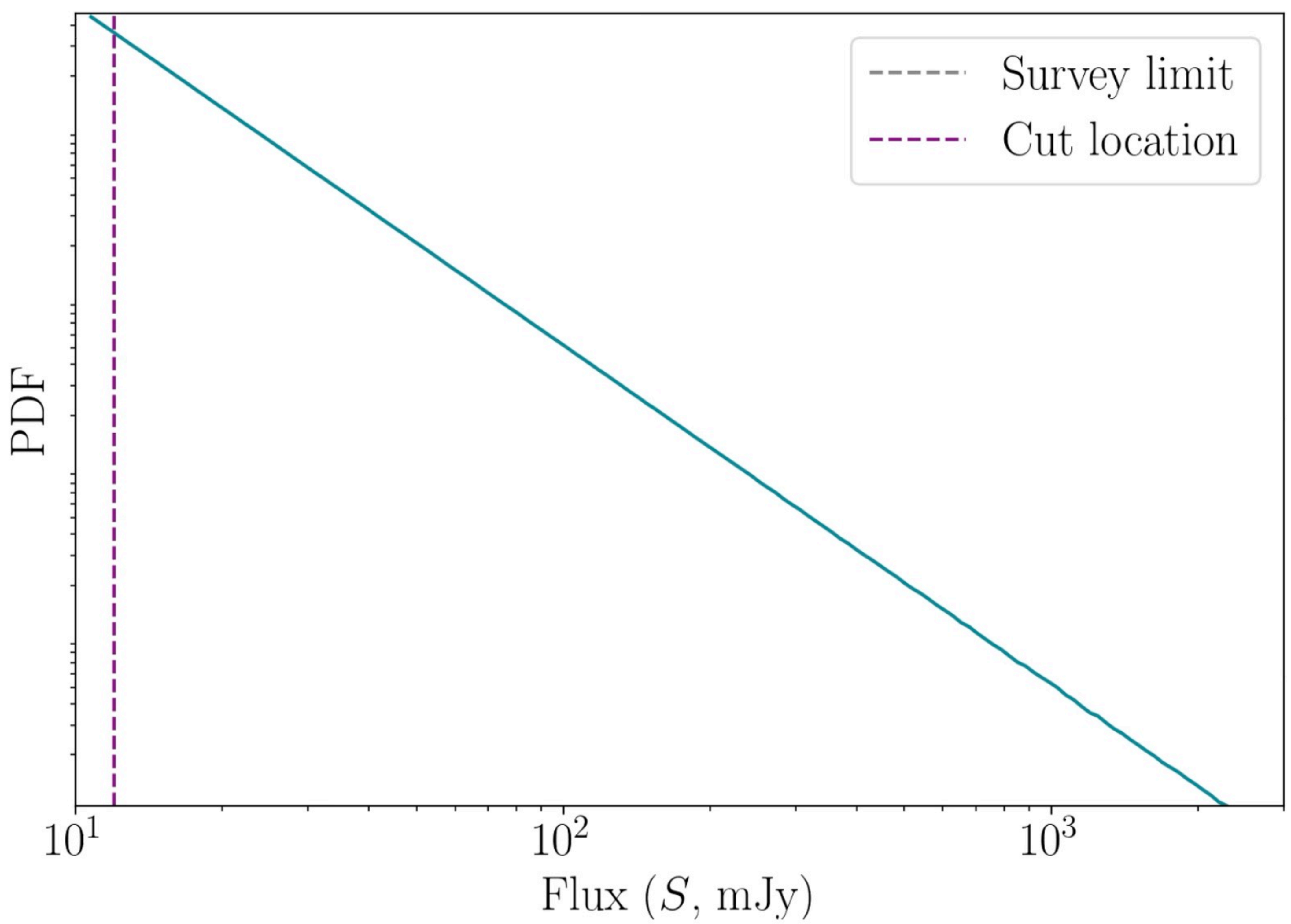
Survey limit
Cut location
PDF
Flux (mJy)

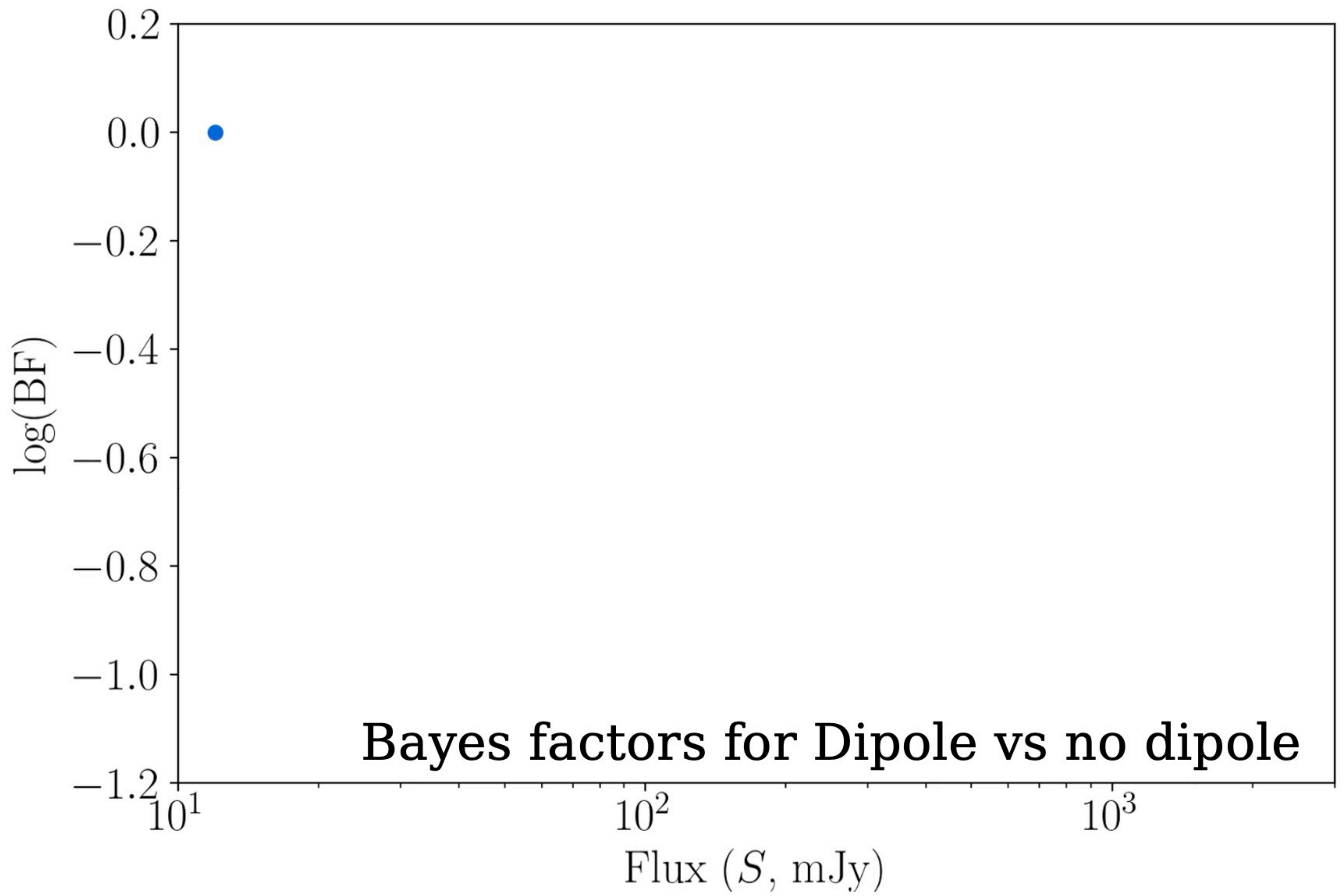
LF 1: Power Law (Contd.)

$D_{S_i} = [2 + x_i(1 + \alpha)]\,\frac{v}{c} \Rightarrow$ rescale the amplitudes.

$$\Theta = \{\{\bar{N}\}_i, \{D_{S_i}\}_i, l^\circ, b^\circ\} \Rightarrow \{\{\bar{N}\}_i, v, l^\circ, b^\circ\}.$$

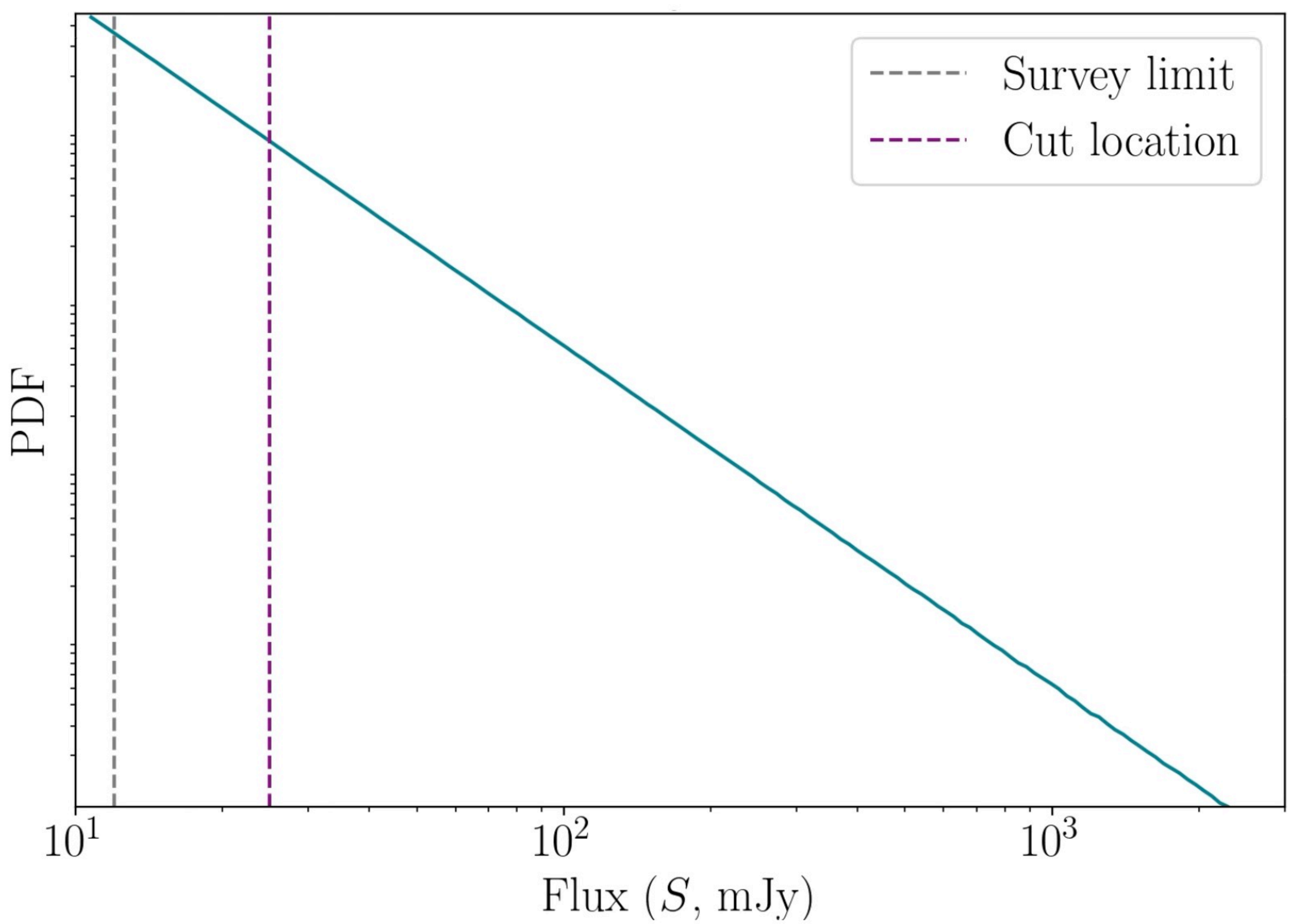
LF 1: Power Law (Contd.)

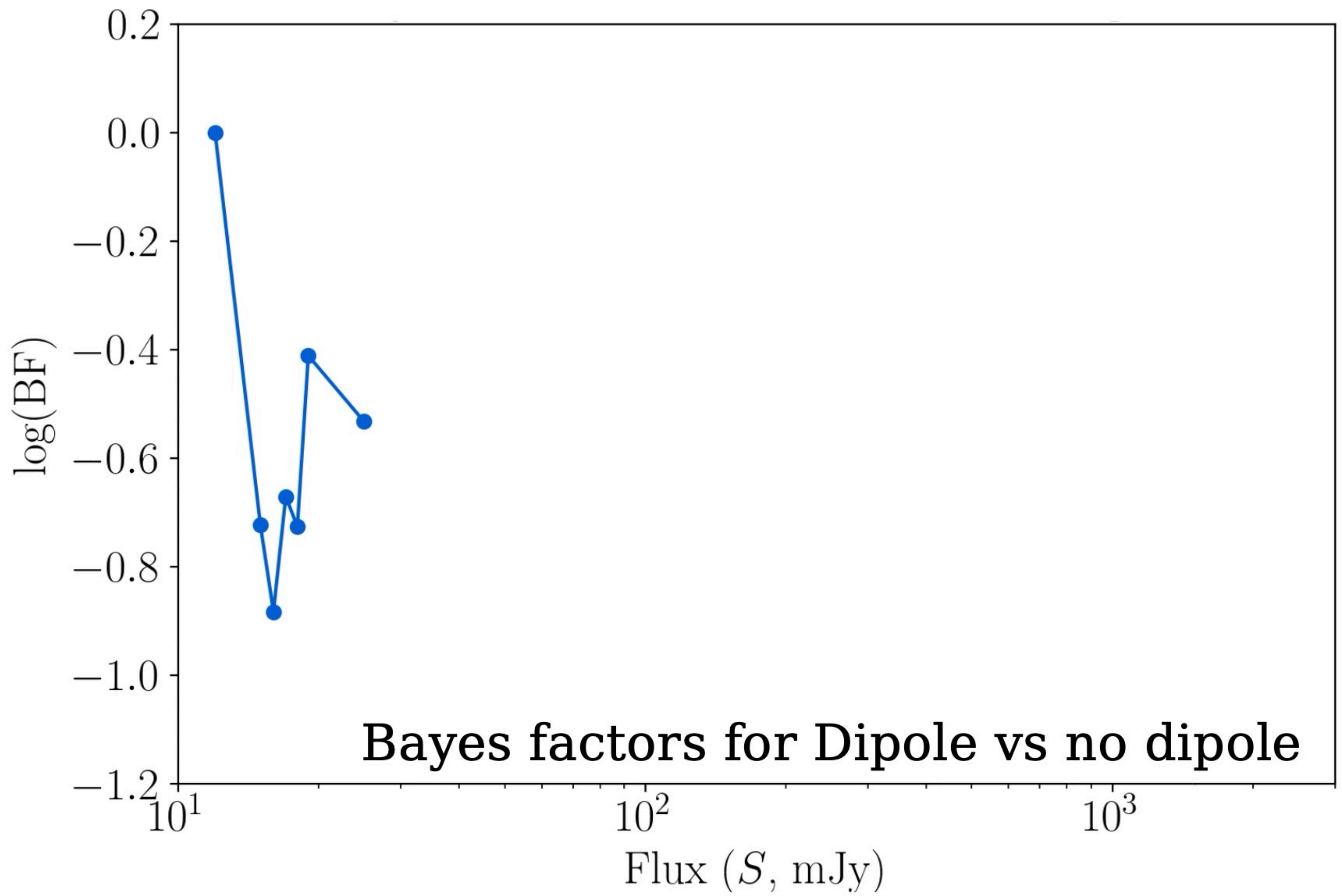




Accepted in JCAP: 2605.27520

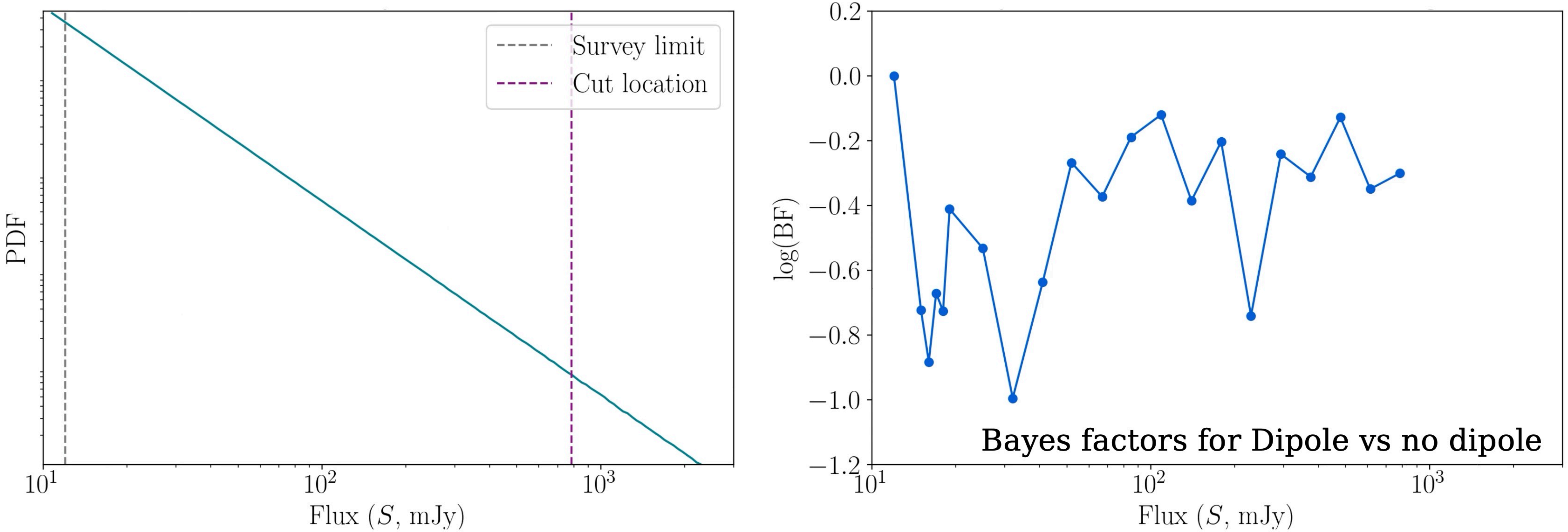
LF 1: Power Law (Contd.)





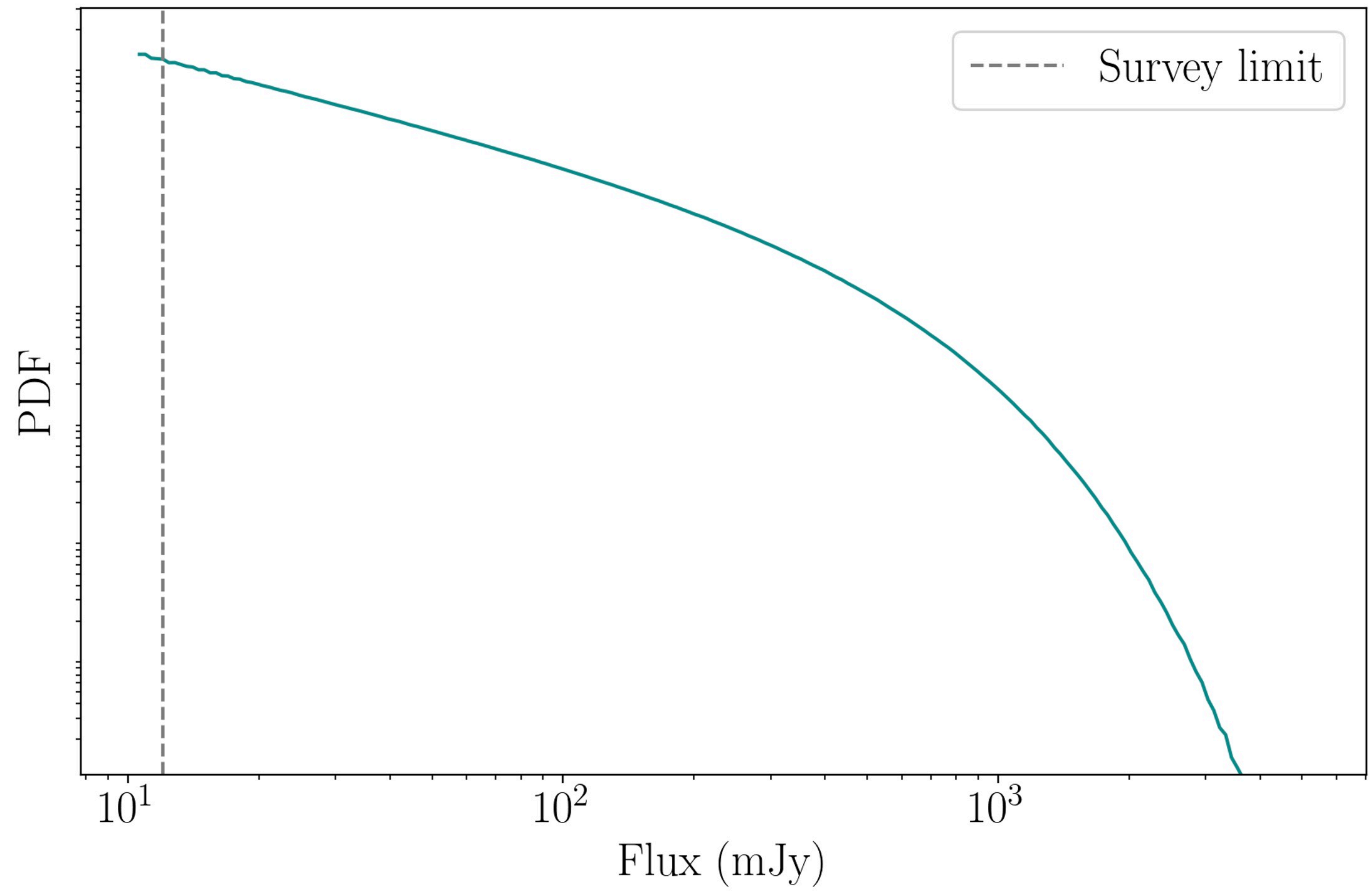
Accepted in JCAP: 2605.27520

LF 1: Power Law (Contd.)



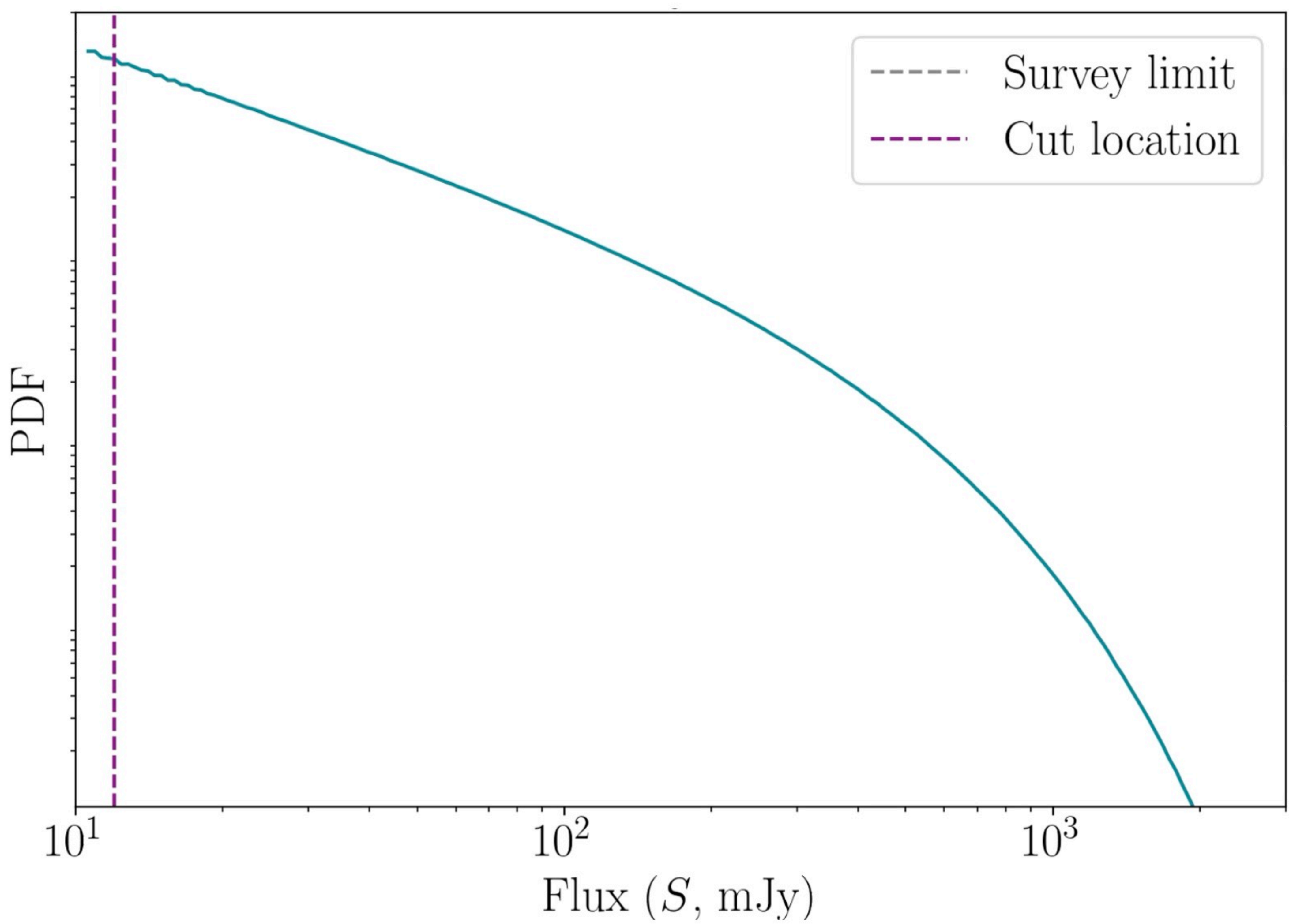
Accepted in JCAP: 2605.27520

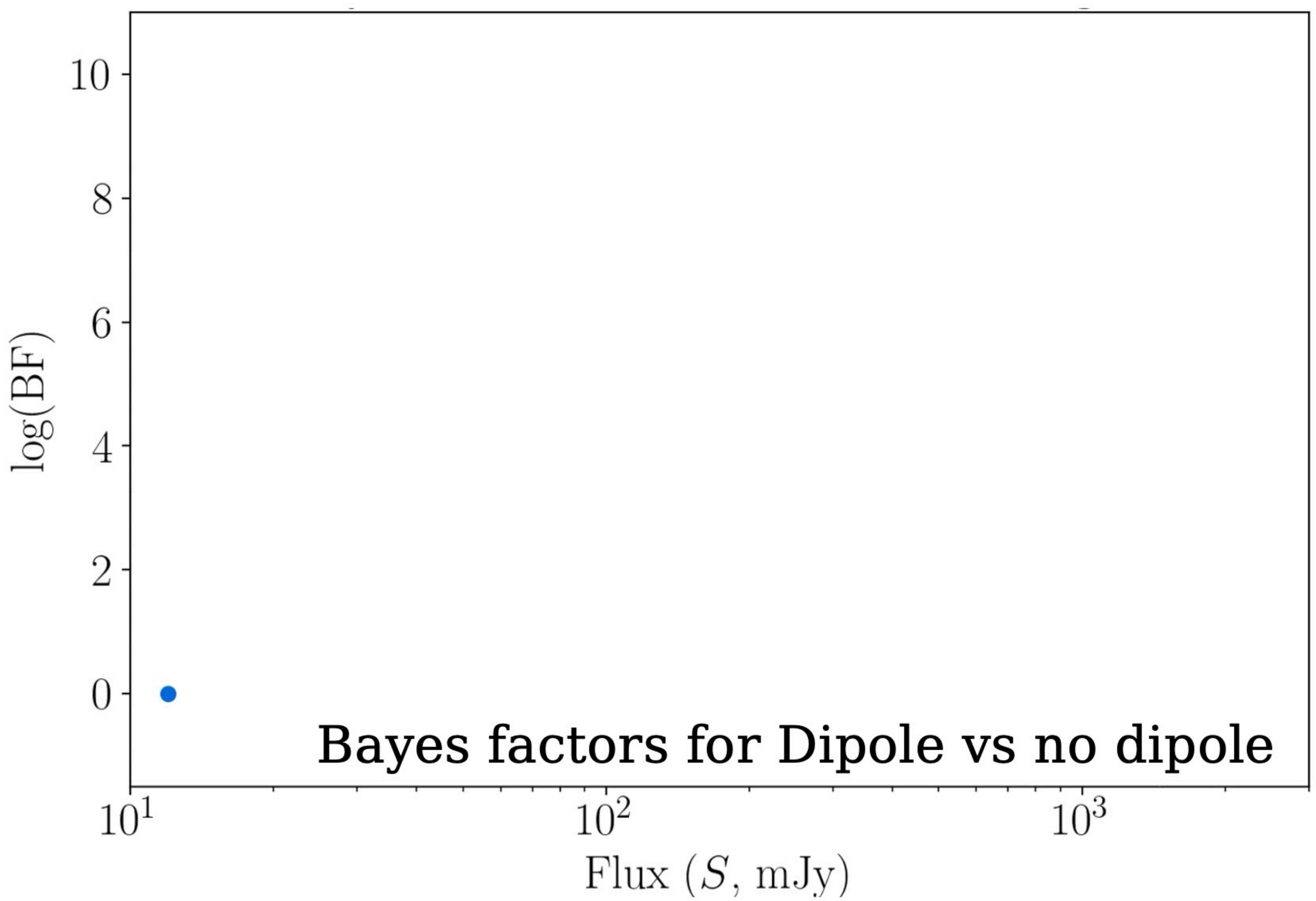
LF 2: Schechter



Accepted in JCAP: 2605.27520

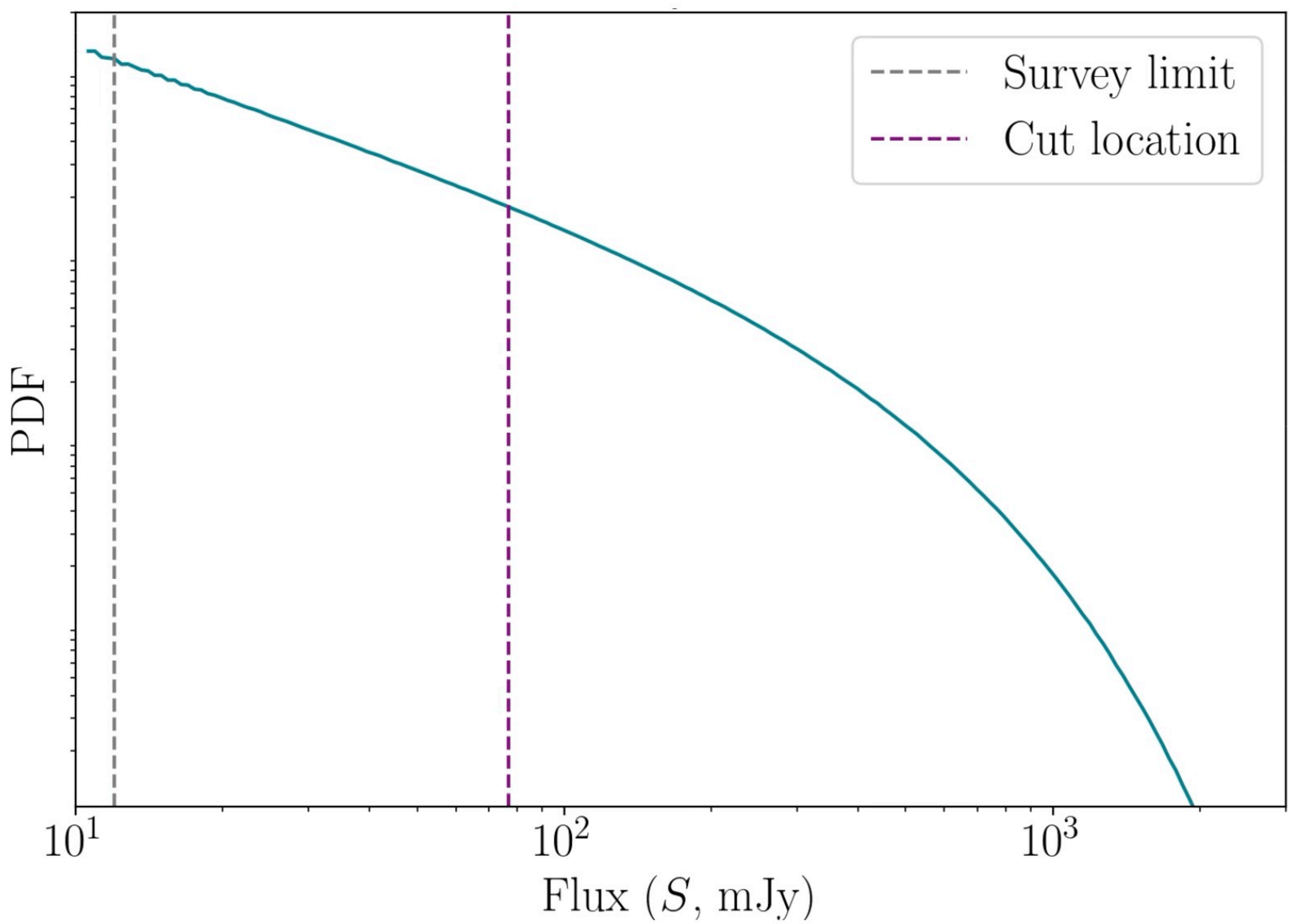
LF 2: Schechter

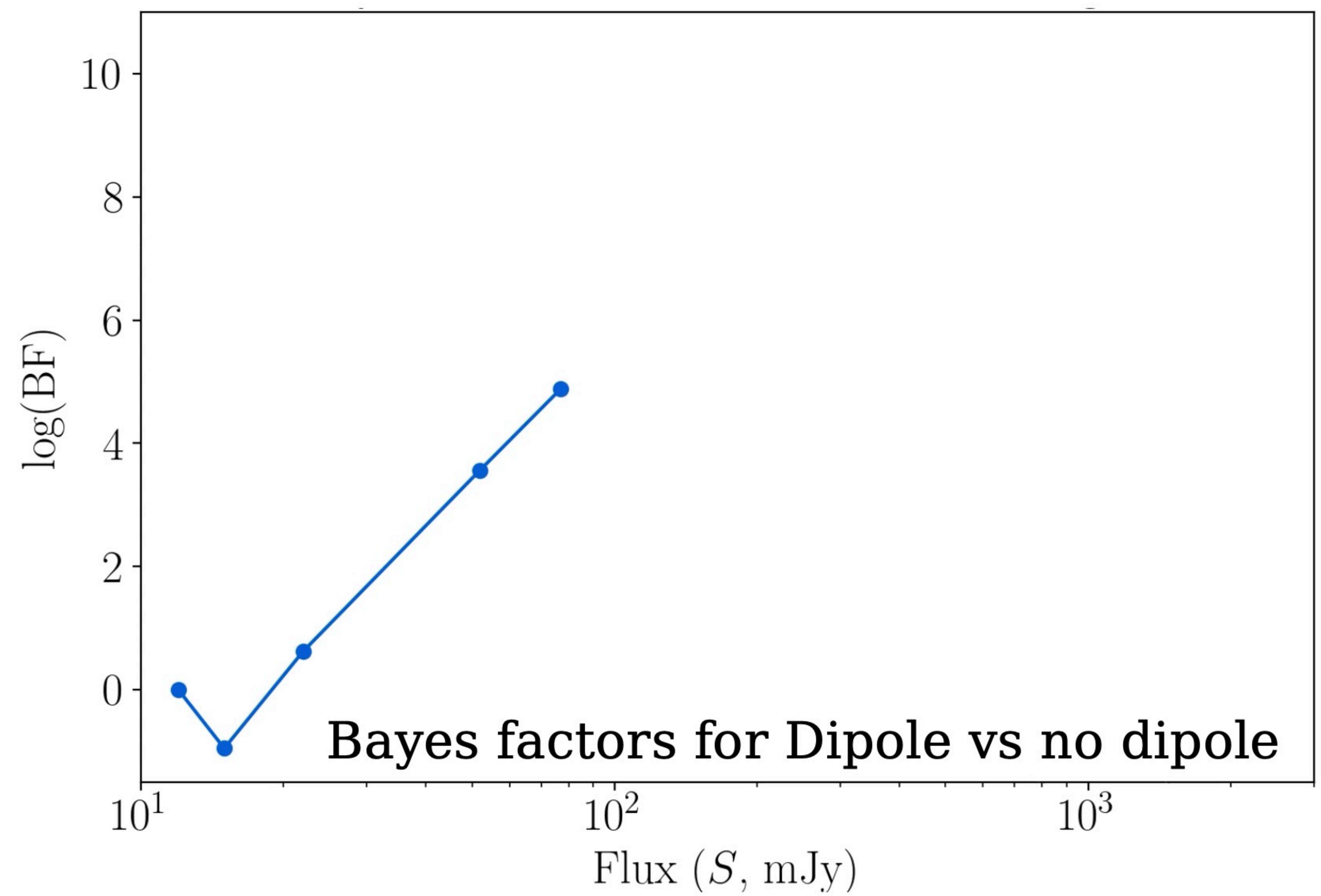




Accepted in JCAP: 2605.27520

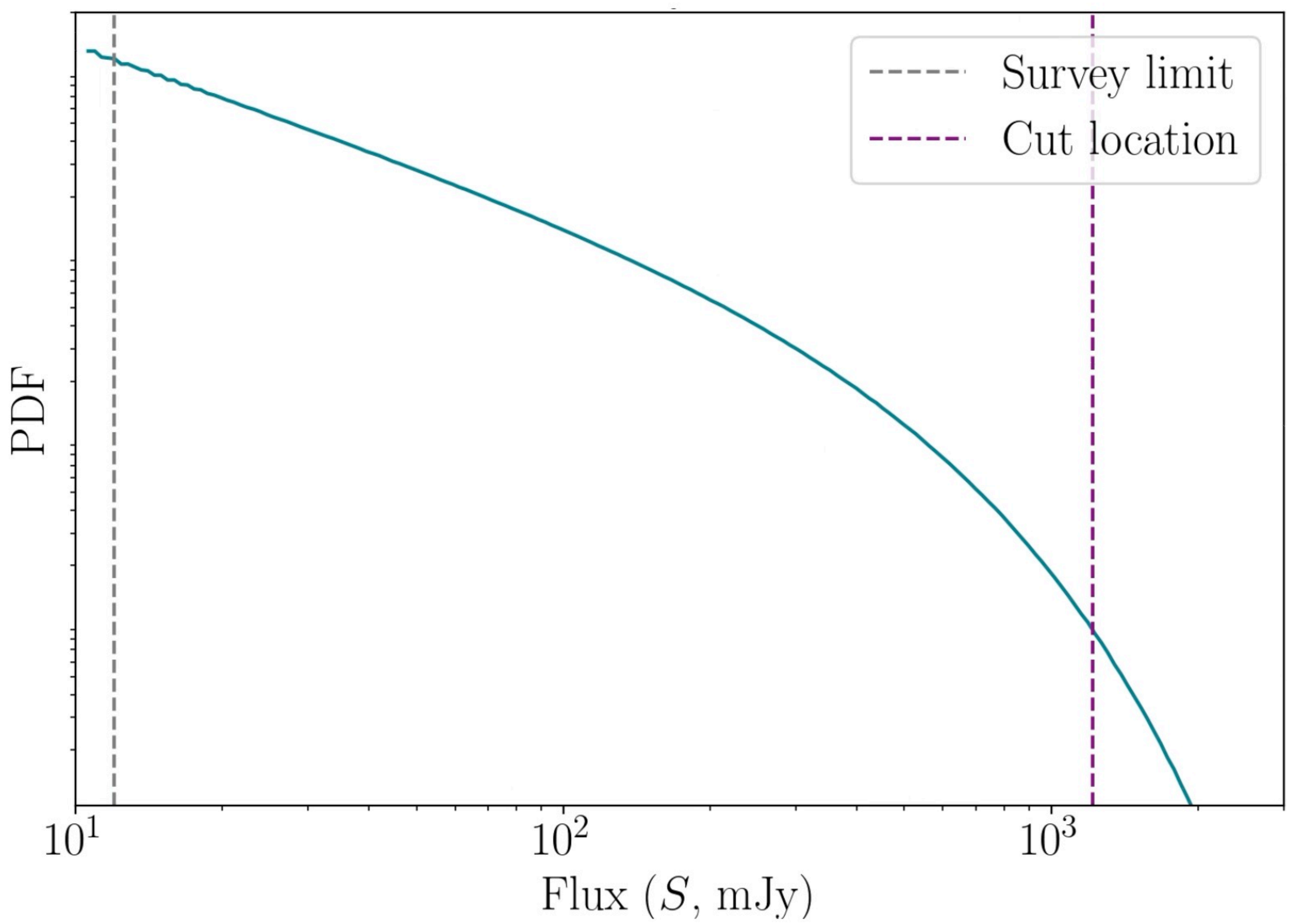
LF 2: Schechter

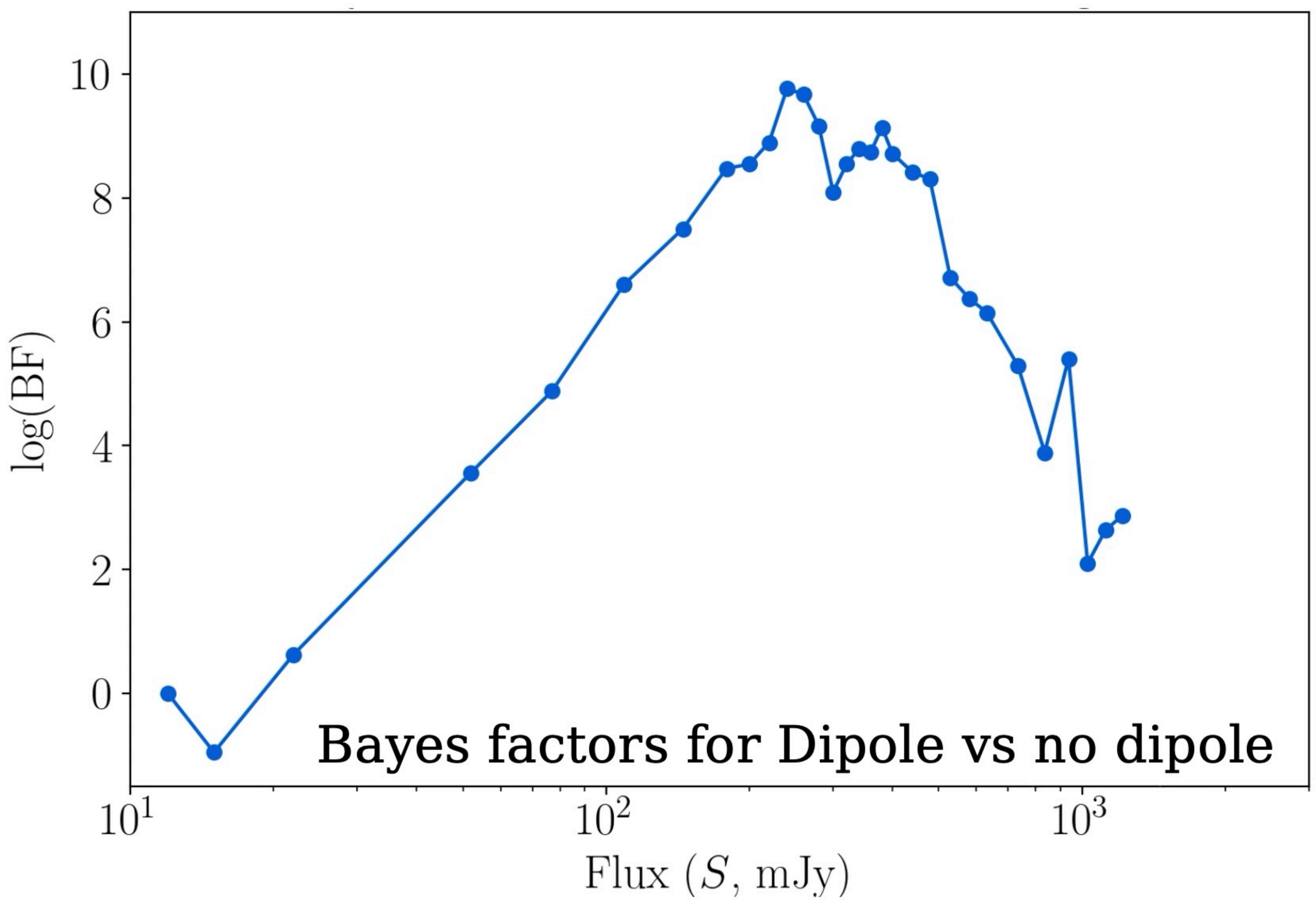




Accepted in JCAP: 2605.27520

LF 2: Schechter

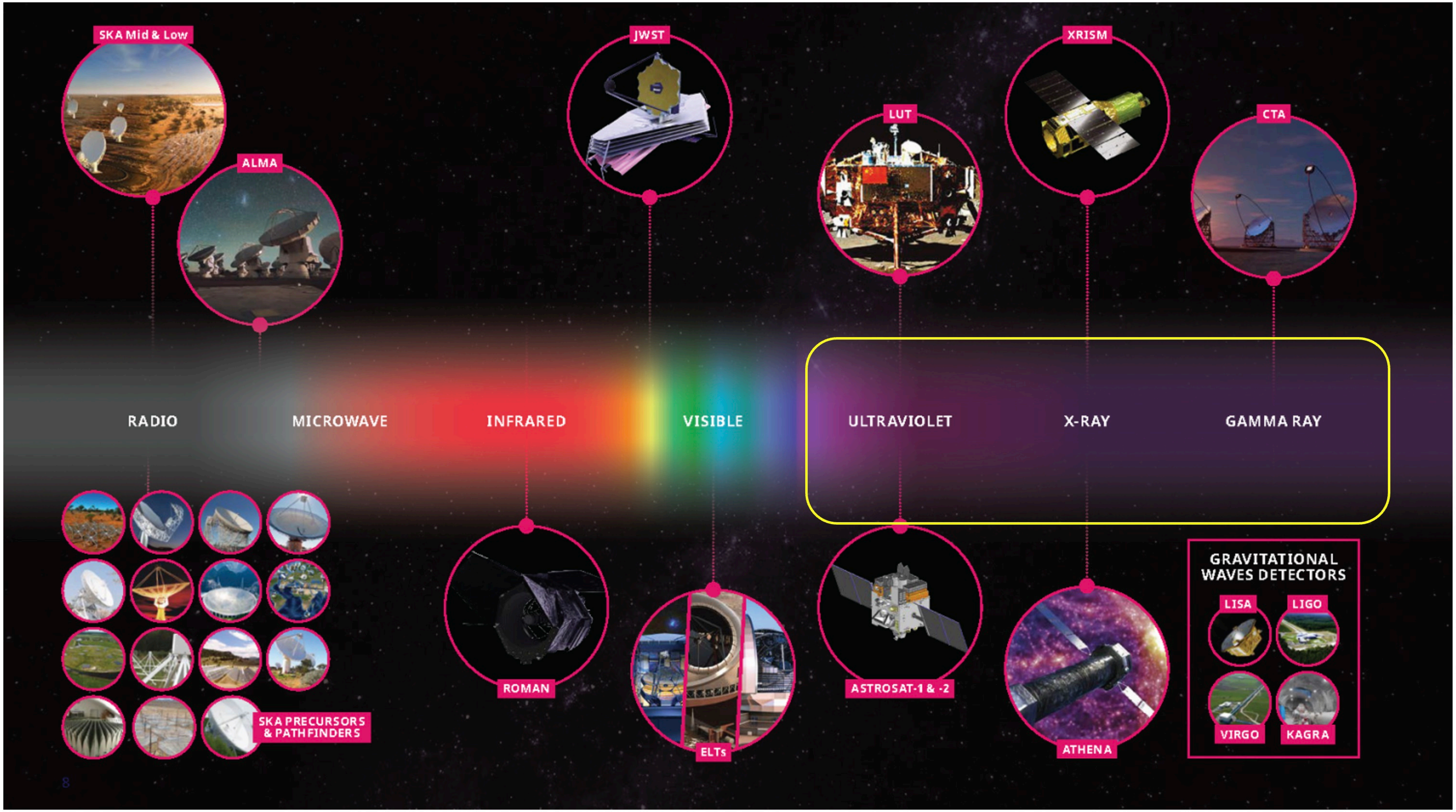




Accepted in JCAP: 2605.27520

Conclusions

- Excess matter dipole amplitude question the kinematic interpretation of the CMB dipole.
- Currently working to check how much information can we squeeze from the Luminosity function.
- Future work involves extending to higher frequencies.


SKA Mid & Low
JWST
XRISM
LUT
CTA
ALMA
RADIO
MICROWAVE
INFRARED
VISIBLE
ULTRAVIOLET
X-RAY
GAMMA RAY
ROMAN
ASTROSAT-1 & -2
GRAVITATIONAL WAVES DETECTORS
LISA
LIGO
VIRGO
KAGRA
SKA PRECURSORS & PATHFINDERS
ELTs
ATHENA