UNASSOCIATED GAMMA-RAY SOURCES AS TARGETS FOR INDIRECT DM DETECTION WITH FERMI-LAT

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BASIC SCHEME: DARK MATTER (DM) SUBHALOS AS TARGETS

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- N-body cosmological simulations → What do we expect?
- We do not have a clear signal of DM annihilation → **constraints on** $\langle \sigma v \rangle$, m_χ

DM ANNIHILATION IN THE WIMP MODEL

$$\chi\chi \to \begin{cases} \tau^+\tau^- \\ b\bar{b} \\ W^+W^- \\ ?_1\,?_2 \end{cases} \to \cdots \to \gamma\gamma$$

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Astrophysics (Density profile, distance…)

Particle Physics (channel, annihilation spectra…)

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$$J_{factor} = \frac{1}{4\pi} \int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho_{DM}^2 [r(\lambda)] d\lambda$$

$$f_{pp} = \sum_f B_f \frac{dN_f}{dE_f} \frac{\langle \sigma v \rangle}{2 m_\chi^2}$$

Branching ratio taken as 1

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$$\langle\sigma v\rangle \propto \frac{m_\chi^2 \cdot F_{min}}{J_{factor} \cdot \int_{E_{th}}^{E} \left(\frac{dN}{dE}\right) dE} = \frac{m_\chi^2 \cdot F_{min}}{J_{factor} \cdot N_\gamma}$$

DM ANNIHILATION IN THE WIMP MODEL

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Instrument

Theory

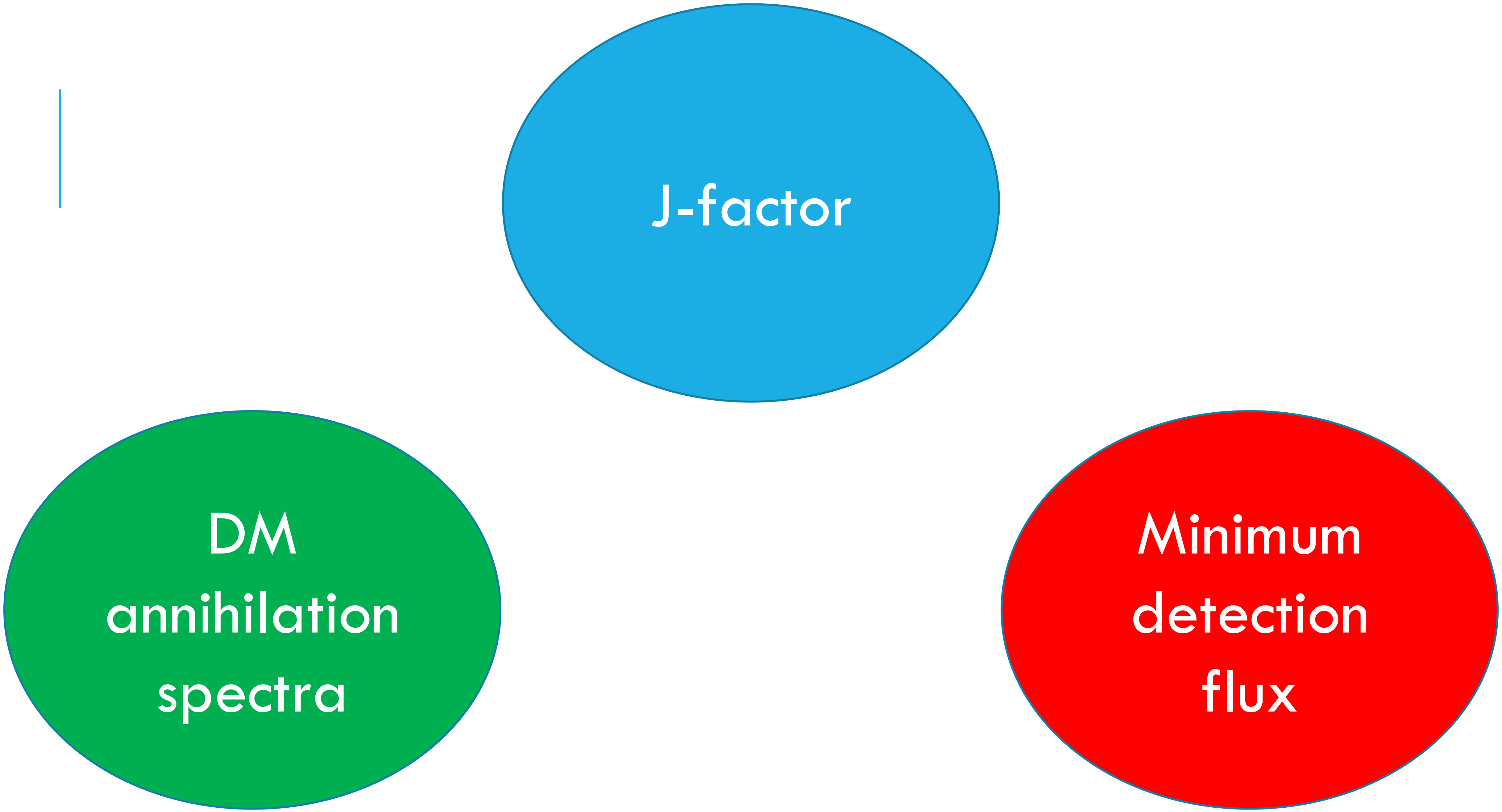
Simulations

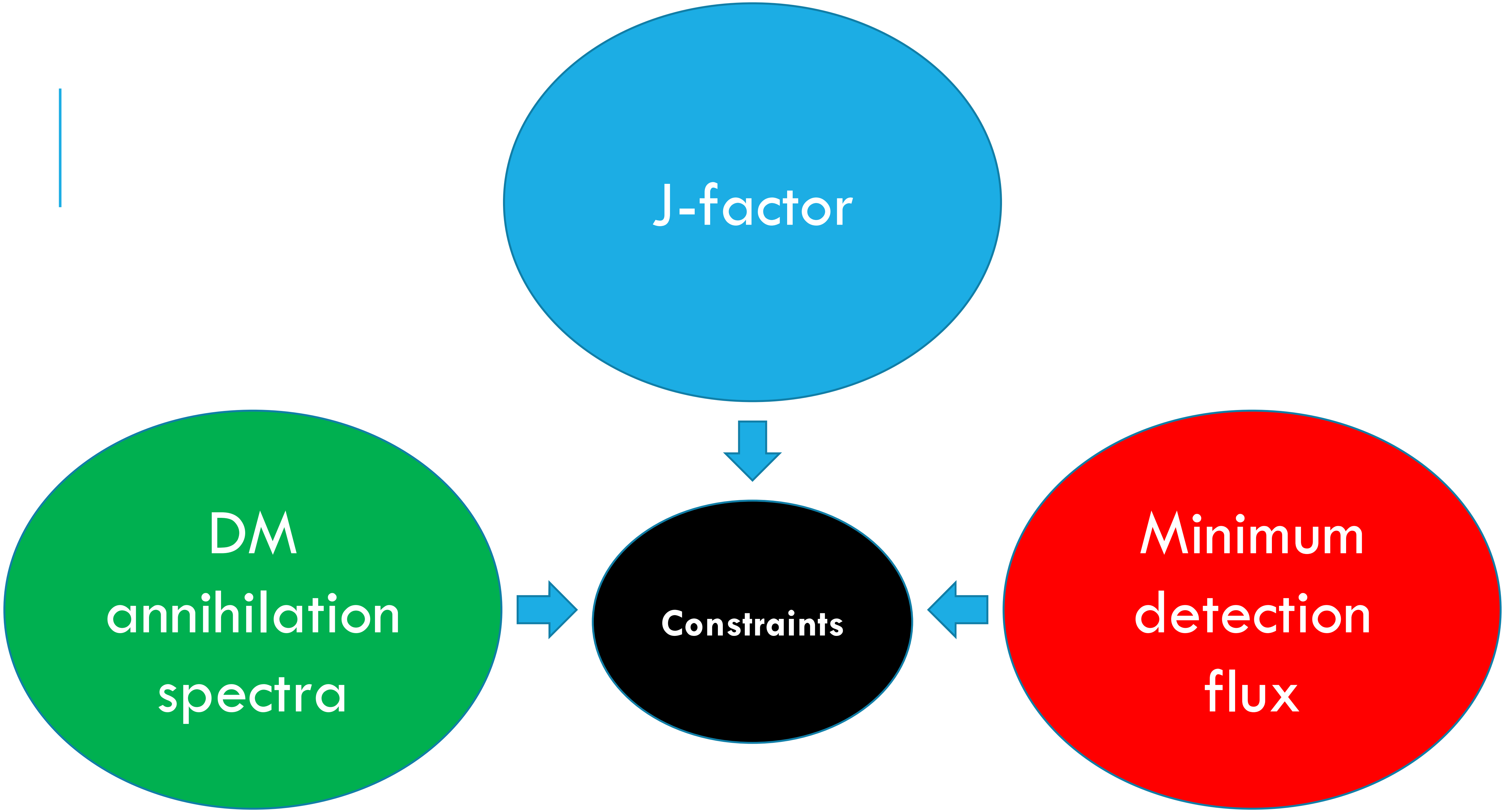
We want to probe the lowest possible $\langle\sigma v\rangle$ values to rule out WIMP candidates

J-factor

J-factor

DM annihilation spectra

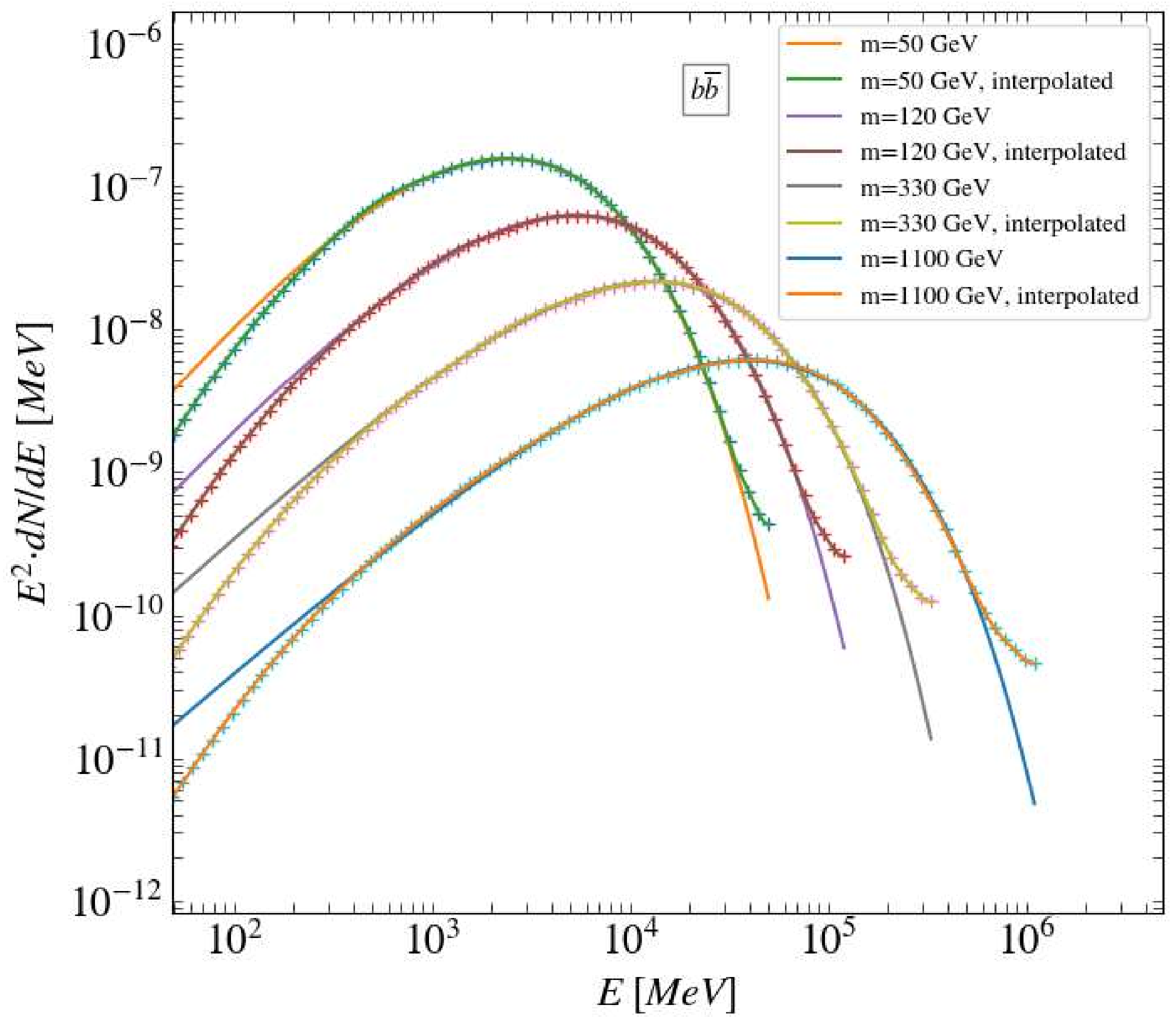

J-factor
DM annihilation spectra
Minimum detection flux


J-factor
DM annihilation spectra
Constraints
Minimum detection flux

DM INTEGRATED SPECTRA

- From Cirelli PPPC4 (PYTHIA8), including EW corrections
- For usual channels $(b\bar{b}, \tau^+\tau^-, W^+W^-, etc.)$
- From 5 GeV up to 100 TeV
- Parametric fit to Power Law with SuperExponential Cutoff:

$$\frac{dN}{dE} = K \cdot \left(\frac{E}{E_0}\right)^{-\Gamma} e^{-\left(\frac{E}{E_{cut}}\right)^{\beta}}$$

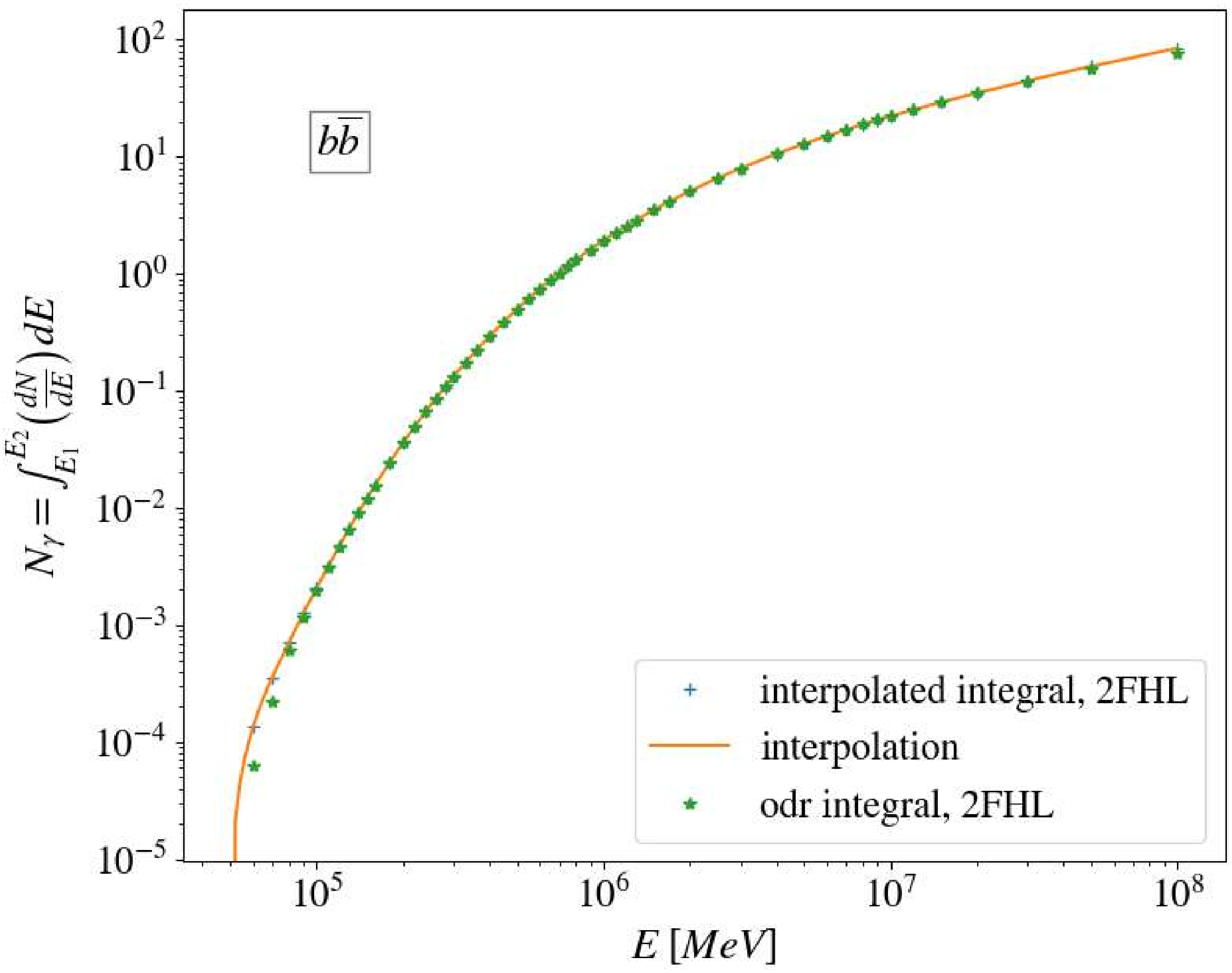


DM INTEGRATED SPECTRA

- We want the integrated spectra,

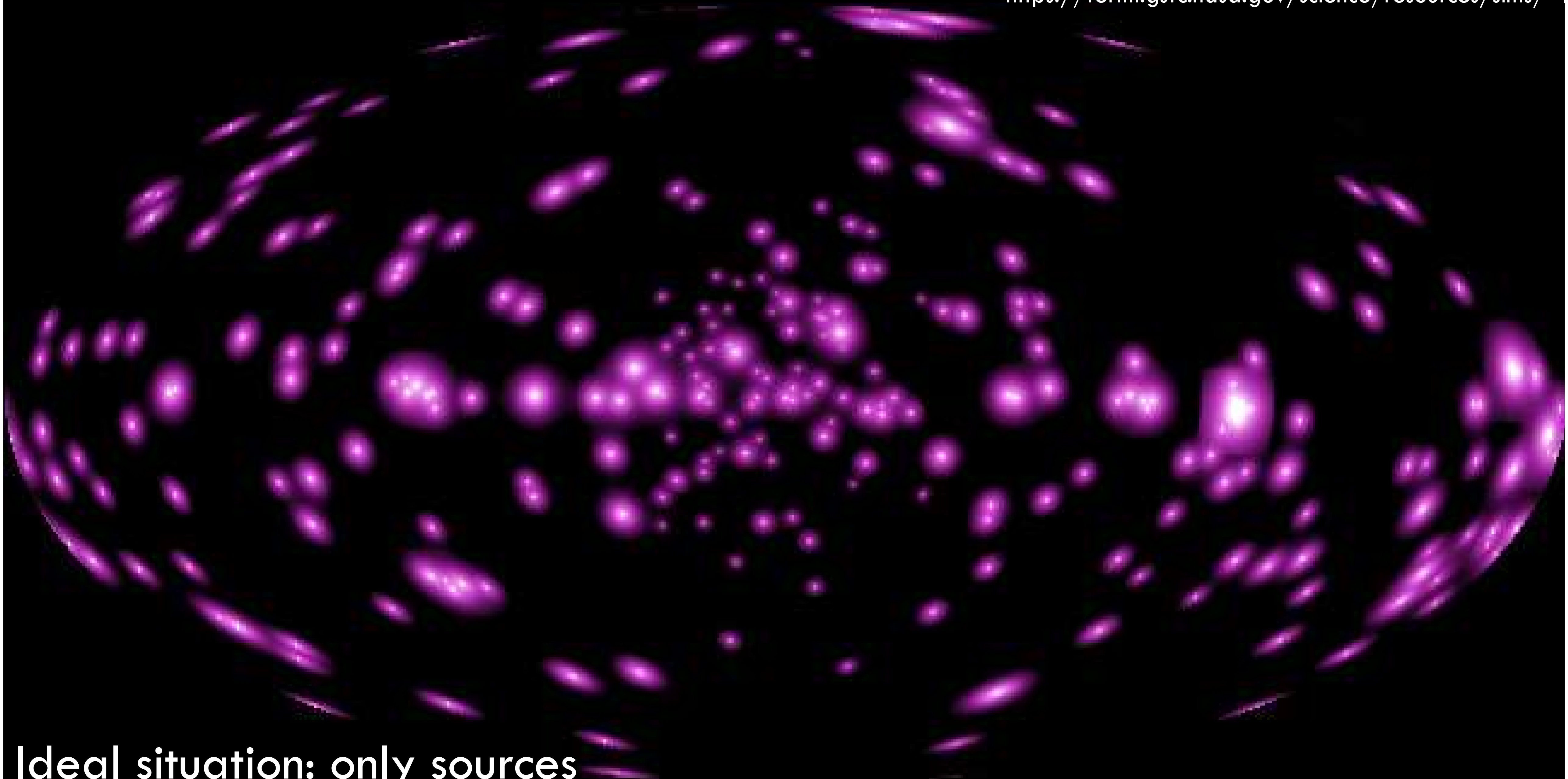
$$N_\gamma = \int_{E_{th}}^{E} \left(\frac{dN}{dE}\right) dE$$

- Dependance on the experiment's energy threshold



MINIMUM DETECTION FLUX

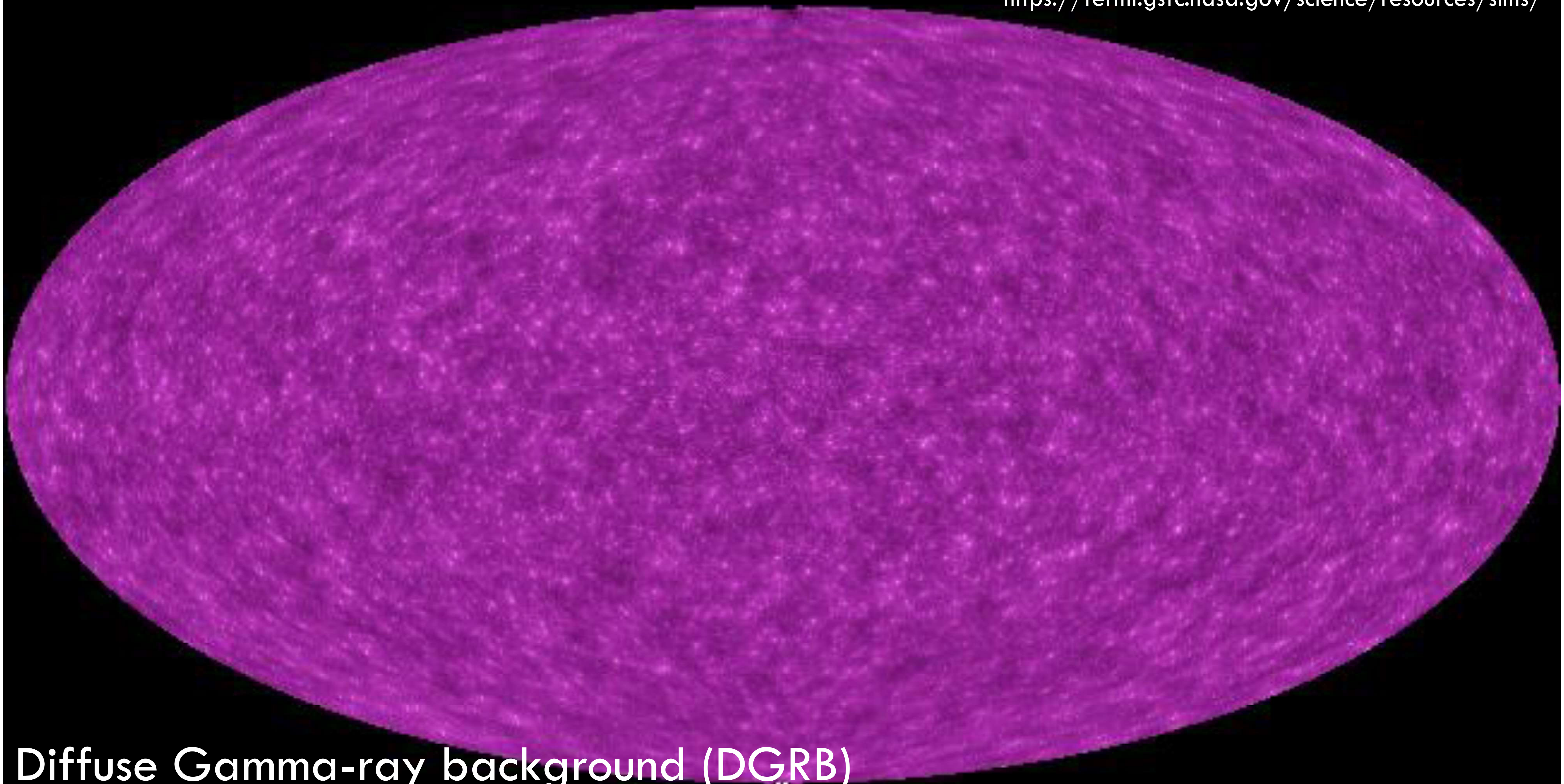
- Minimum flux to have a 5-sigma detection over background
- Normally taken as the threshold flux of the catalog
- BUT, important dependance on **annihilation channel**, **source sky position** and **catalog setup**



https://fermi.gsfc.nasa.gov/science/resources/sims/

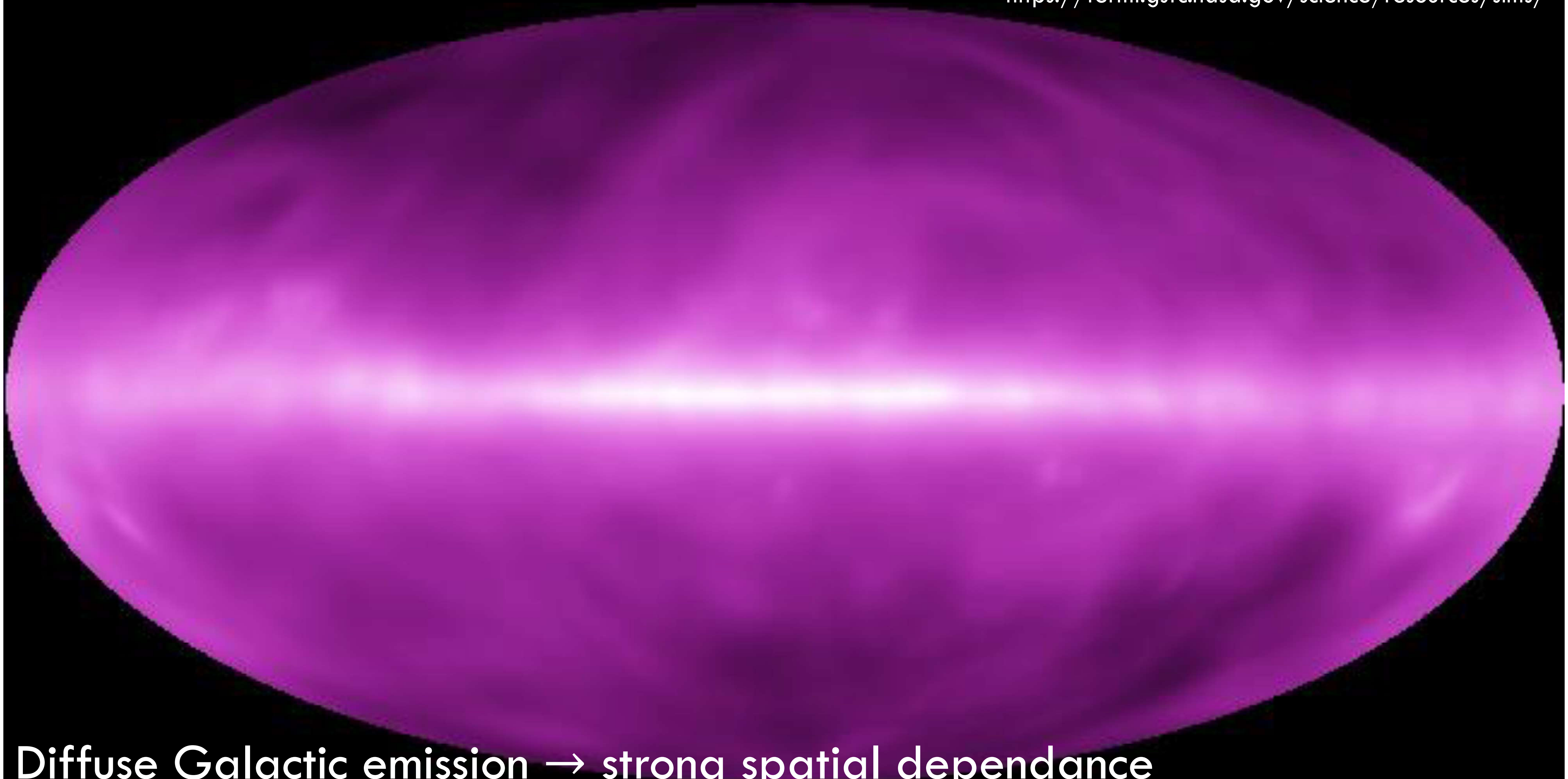
Ideal situation: only sources

https://fermi.gsfc.nasa.gov/science/resources/sims/

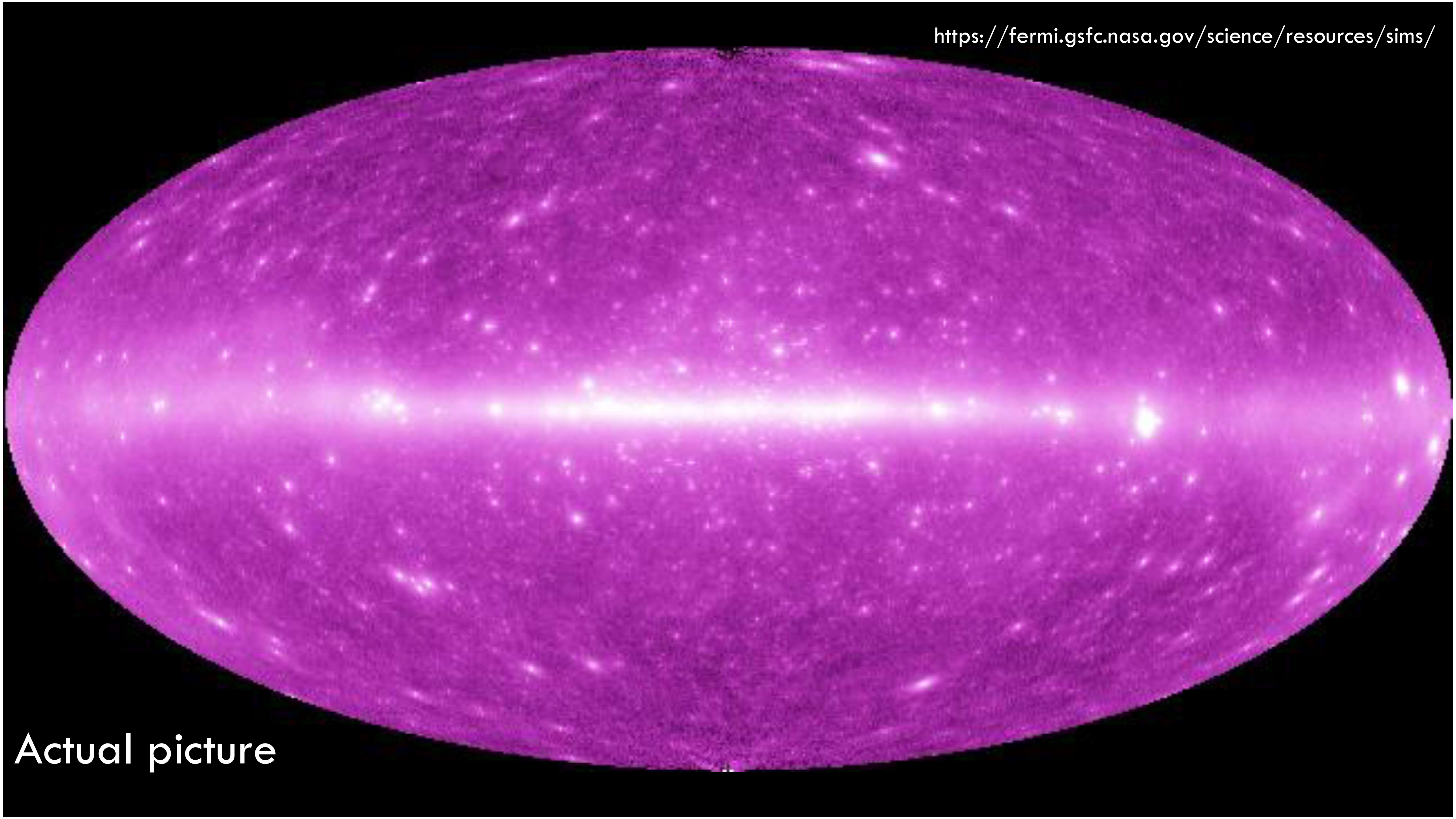


Diffuse Gamma-ray background (DGRB)

https://fermi.gsfc.nasa.gov/science/resources/sims/



Diffuse Galactic emission → strong spatial dependance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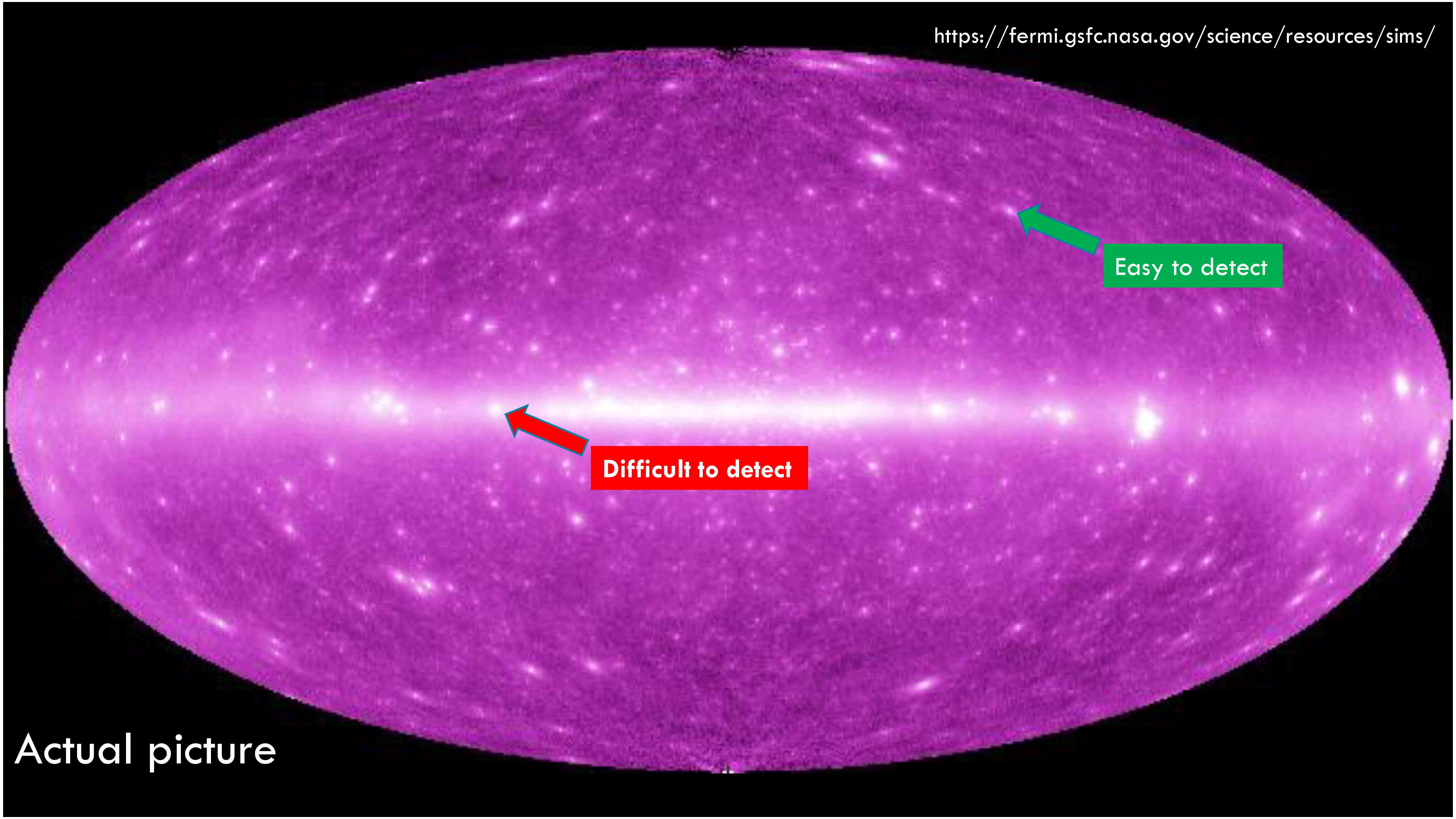
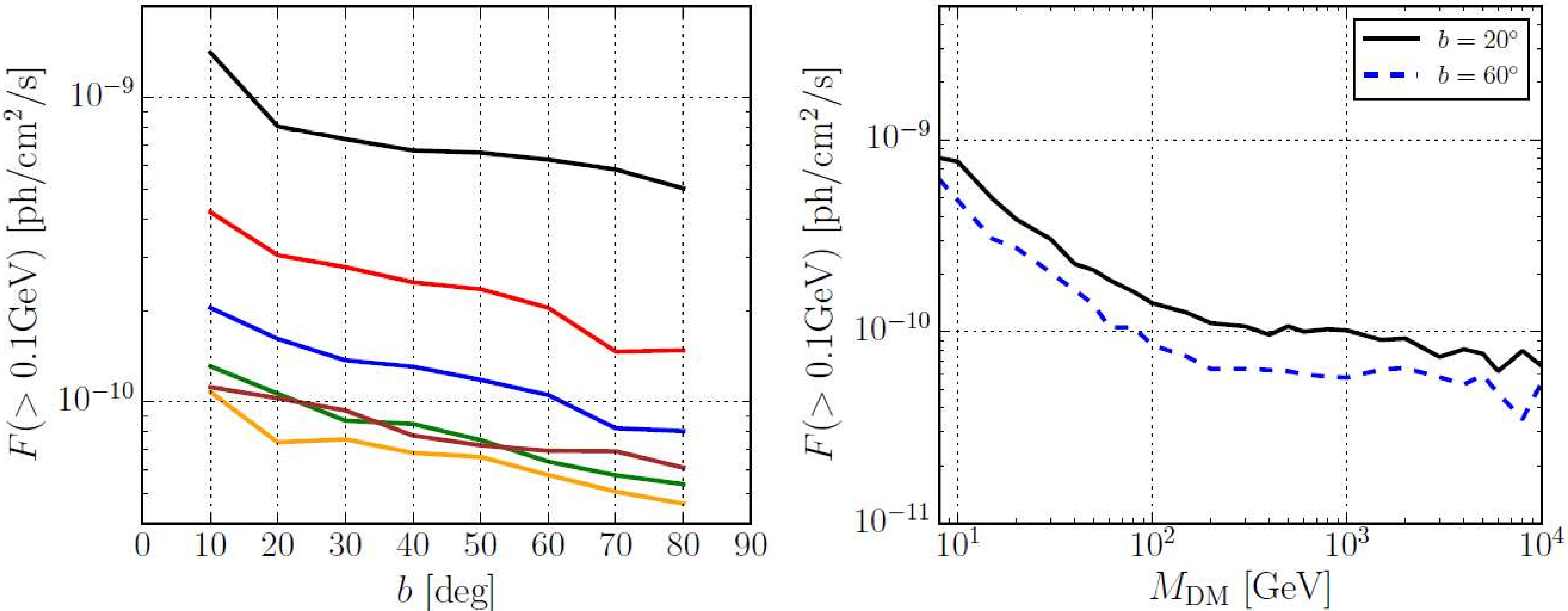
Actual picture

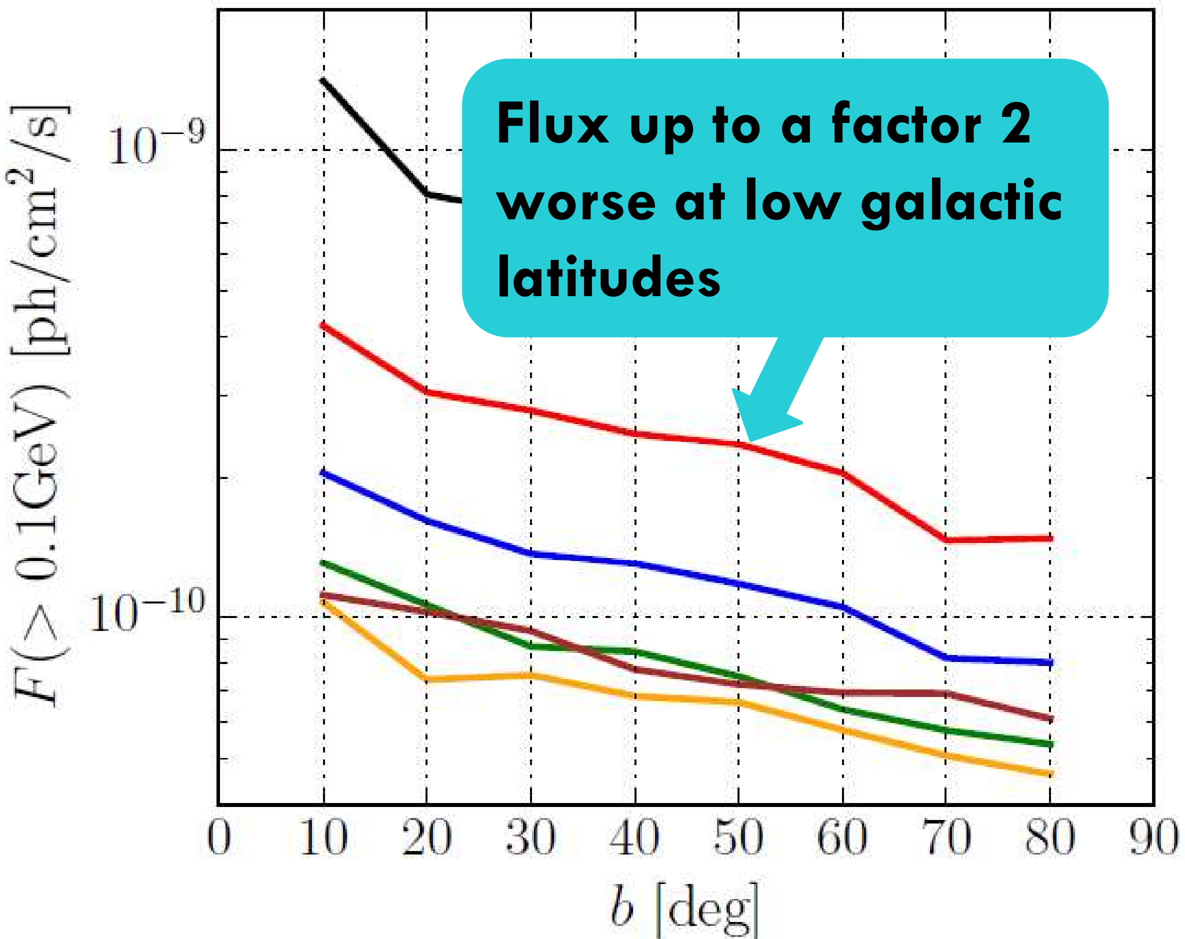

https://fermi.gsfc.nasa.gov/science/resources/sims/
Easy to detect
Difficult to detect
Actual picture

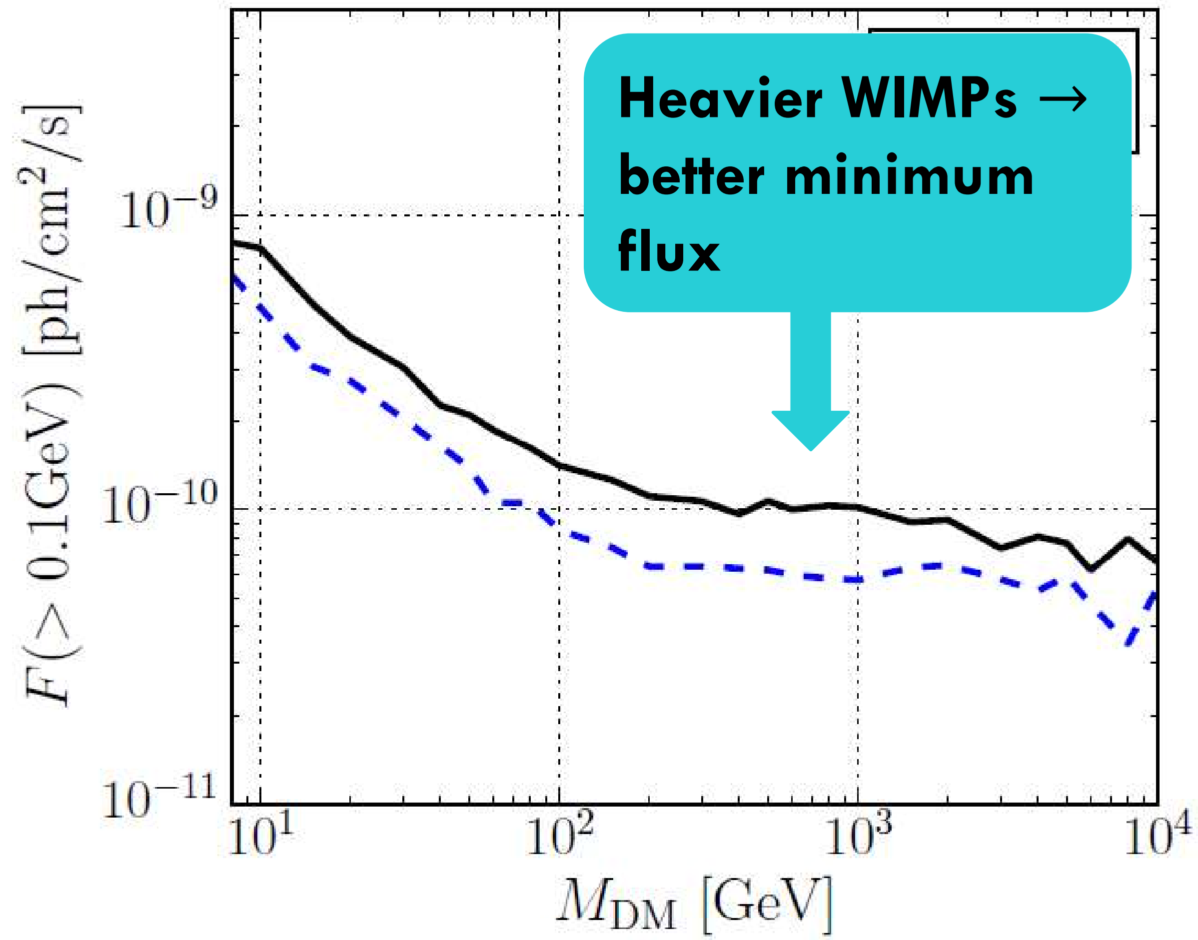
MINIMUM DETECTION FLUX



Calore+17 (1611.03503)

MINIMUM DETECTION FLUX





Calore+17 (1611.03503)

MINIMUM DETECTION FLUX

Also depends on the catalog

Catalog	Release year	Total sources	unIDs	Energy threshold
3FGL	2015	3033	1010 (33,3%)	100 MeV
2FHL	2015	360	48 (13,3%)	50 GeV
3FHL	2017	1556	177 (11,3%)	10 GeV
4FGL	2018?	>5000	? (30-40%)	100 MeV

J-FACTOR

- Via Lactea II (VL-II) simulation, DM only, Milky Way size
- Resolve subhalo masses down to $\sim 10^{6.2} M_{\odot}$

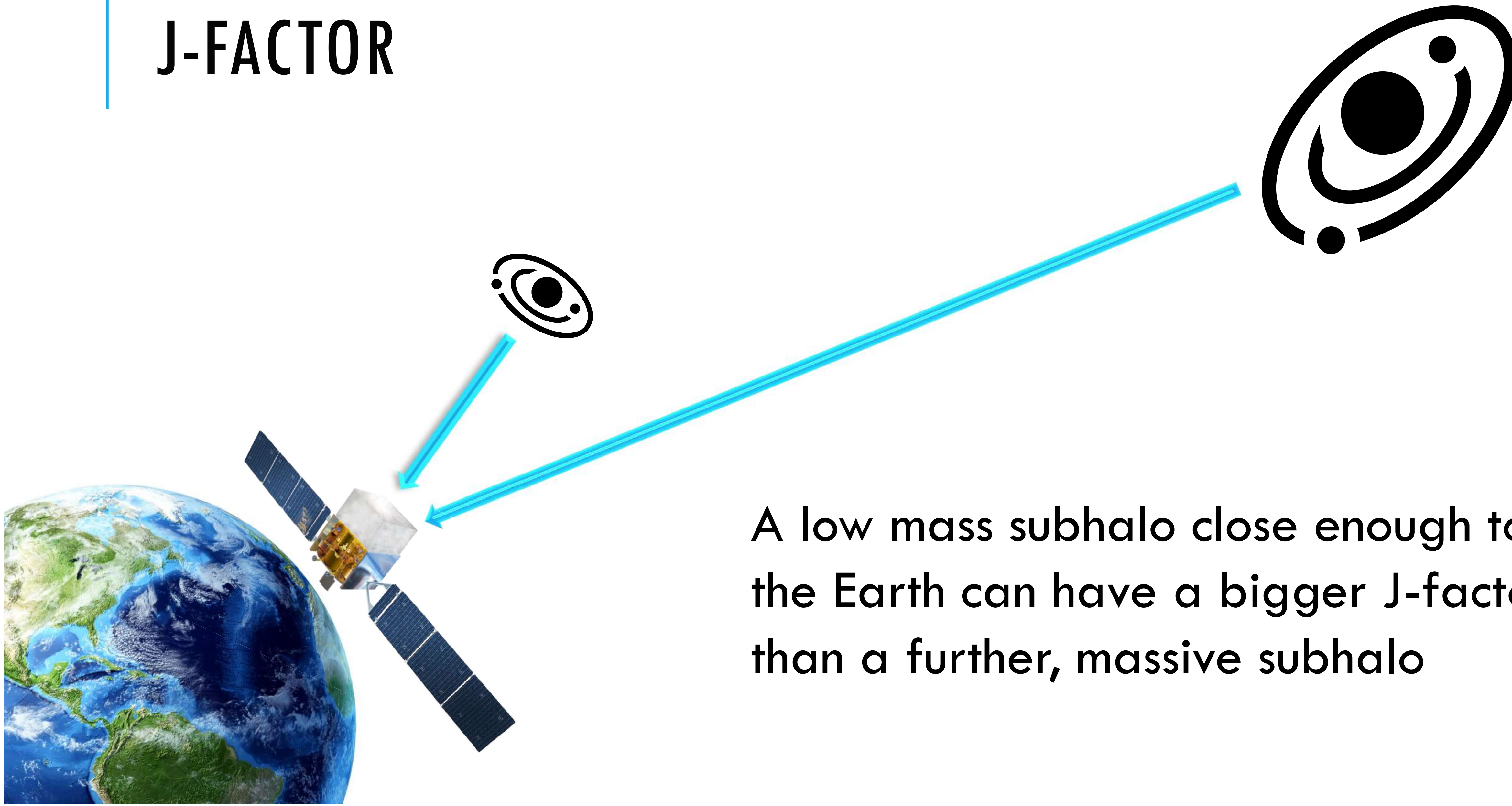
- Every order or magnitude lower in mass is exponentially harder to compute

- **Are unresolved low-mass subhalos important for DM subhalo searches?**

YES

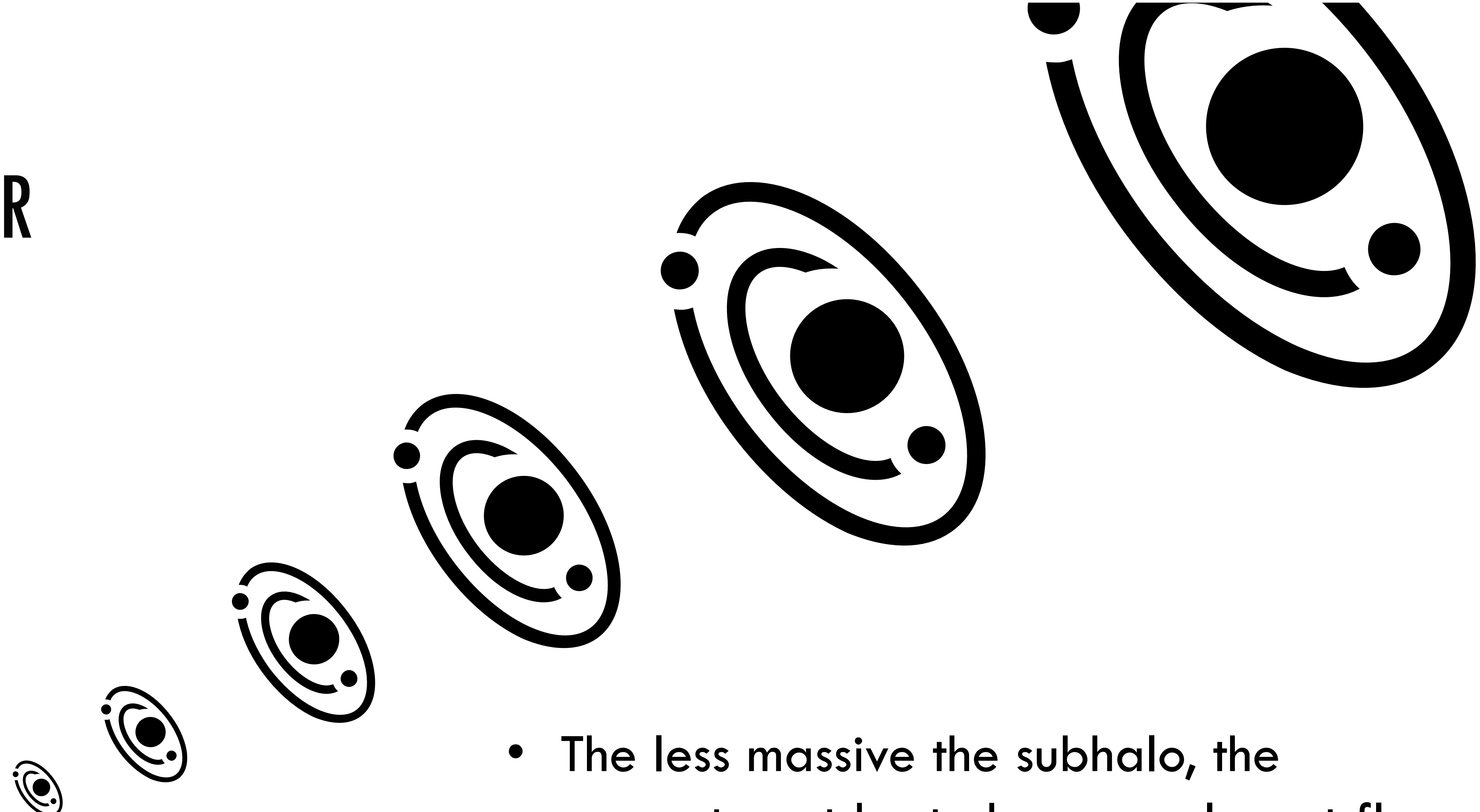
Diemand+08 (0805.1244)

J-FACTOR



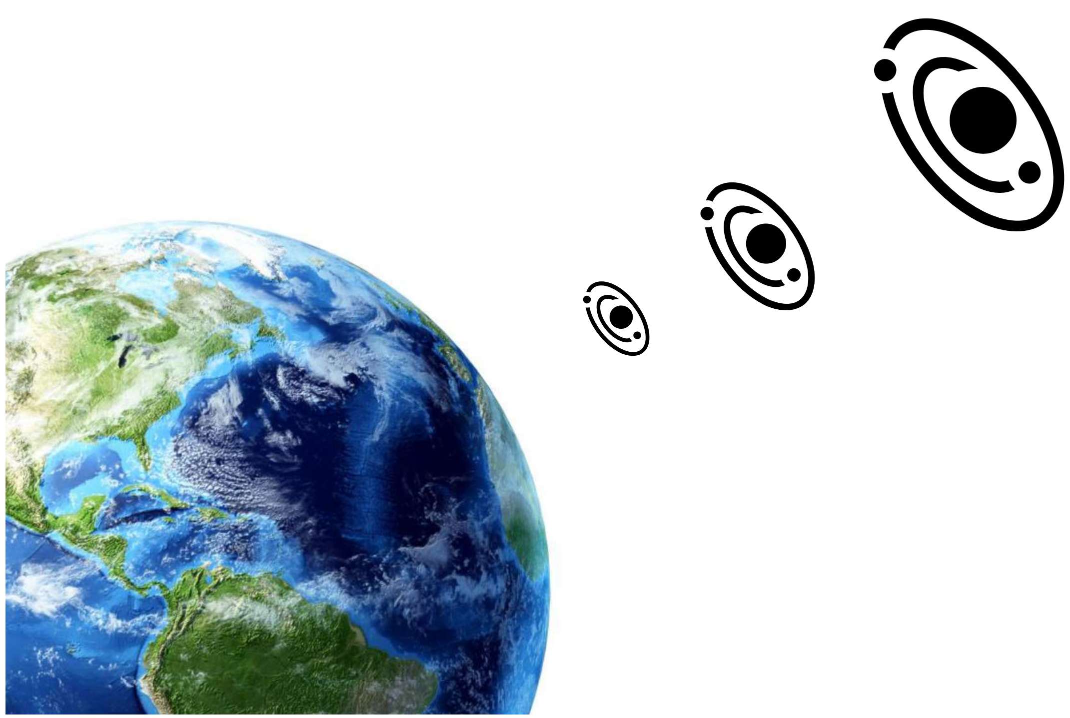
A low mass subhalo close enough to the Earth can have a bigger J-factor than a further, massive subhalo

J-FACTOR



- The less massive the subhalo, the nearest must be to have a relevant flux
- Also, $J \propto c^3 \propto M^{-3}$ (c ≡concentration, bigger for lower masses)

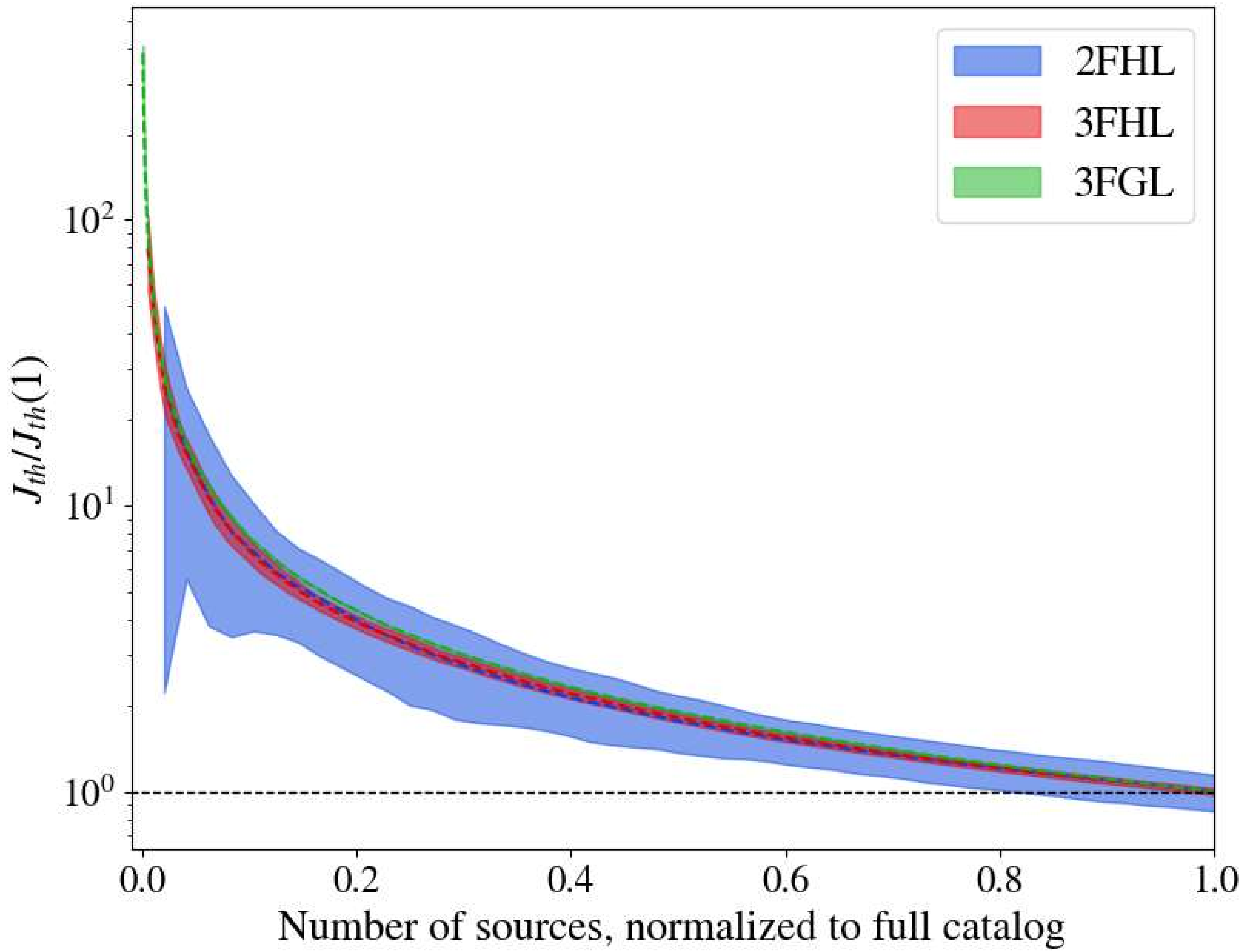
J-FACTOR



- We repopulate the simulation in a realistic yet computationally feasible way
- We reach $\sim 10^{-2} M_{\odot}$

J-FACTOR

- The subhalos with the largest J-factors could be some of the unIDs in Fermi catalogs!
- As $\langle \sigma v \rangle \propto J^{-1}$, the higher the J-factor, the better the constraints
- Therefore, we want to have the **lowest possible number of unIDs candidates**
- We apply **selection cuts** based on expected DM subhalo properties



SELECTION CUTS

1. Association
2. Latitude
3. Variability
4. Machine learning
5. Multiwavelength
6. Spectral bump

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Improved observational campaigns provide new associations of unIDs (to known astrophysical objects), which are removed from our sample

SELECTION CUTS

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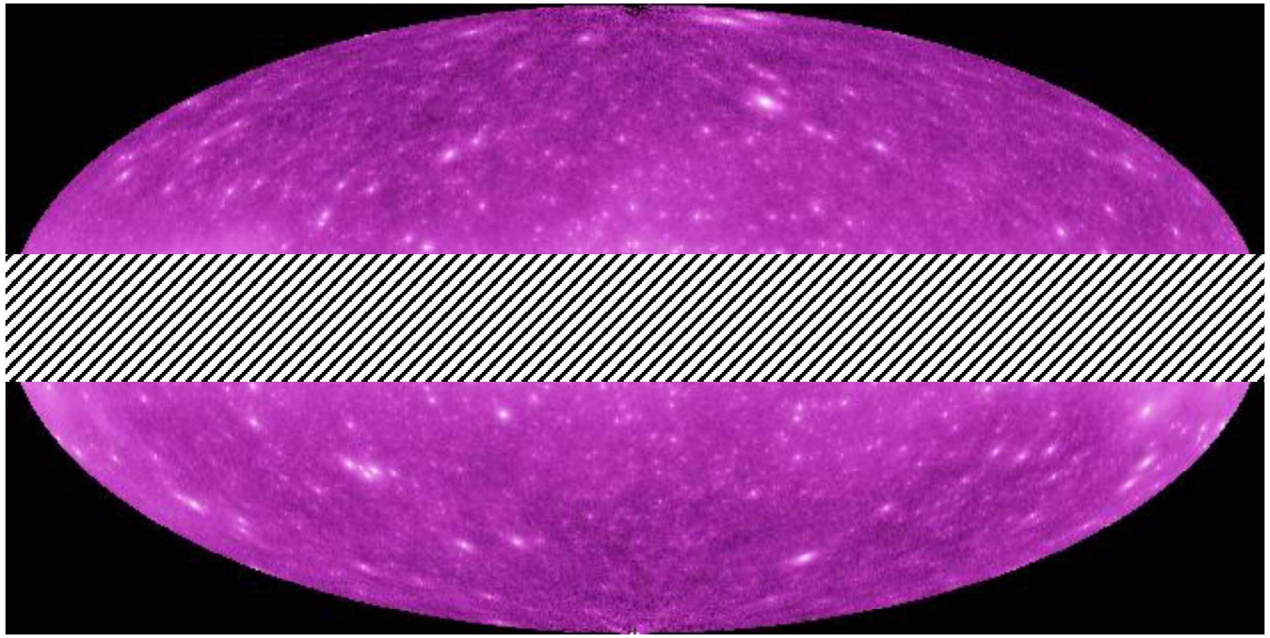
The Galactic plane is a complex region with lots of astrophysical objects (e.g. pulsars) → cut out $|b| \leq 10°$



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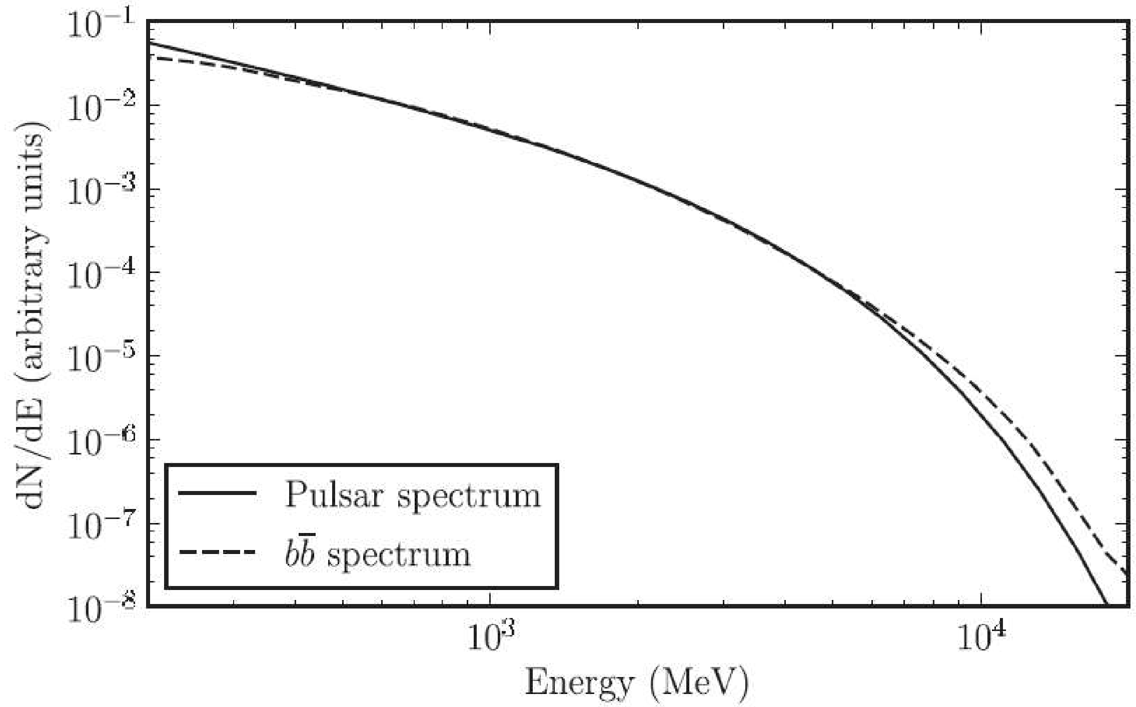

Ackermann+12 (1201.2691)

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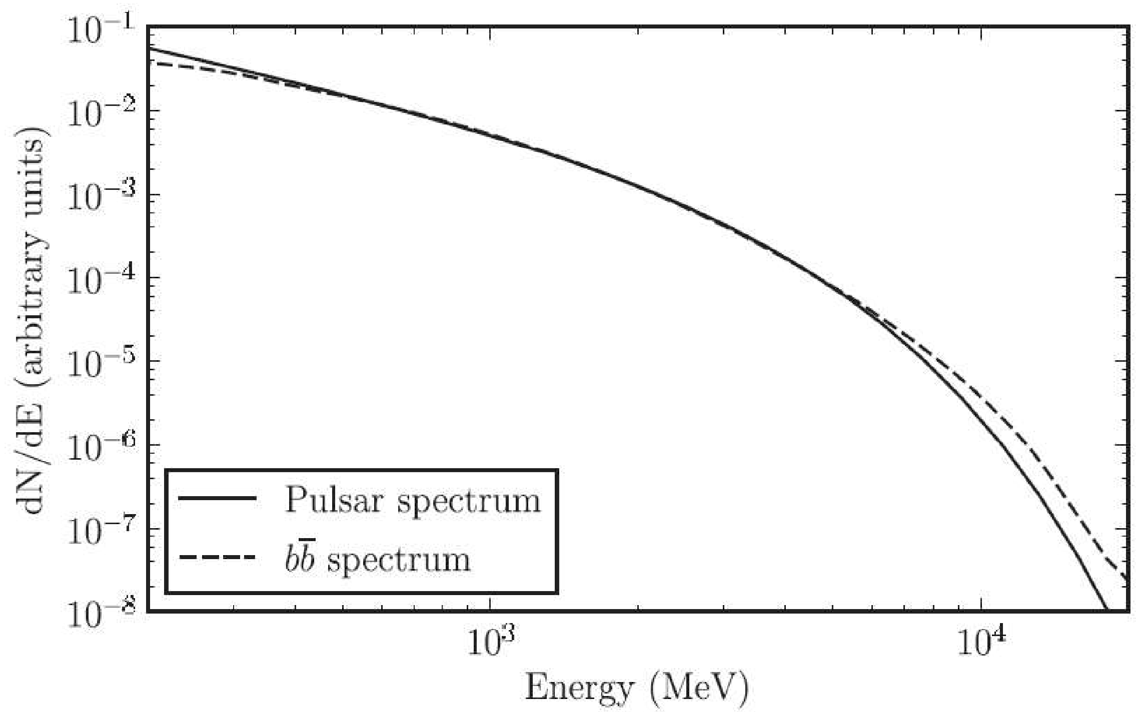
DM subhalos expected to have a steady flux → no variability (FAVA)



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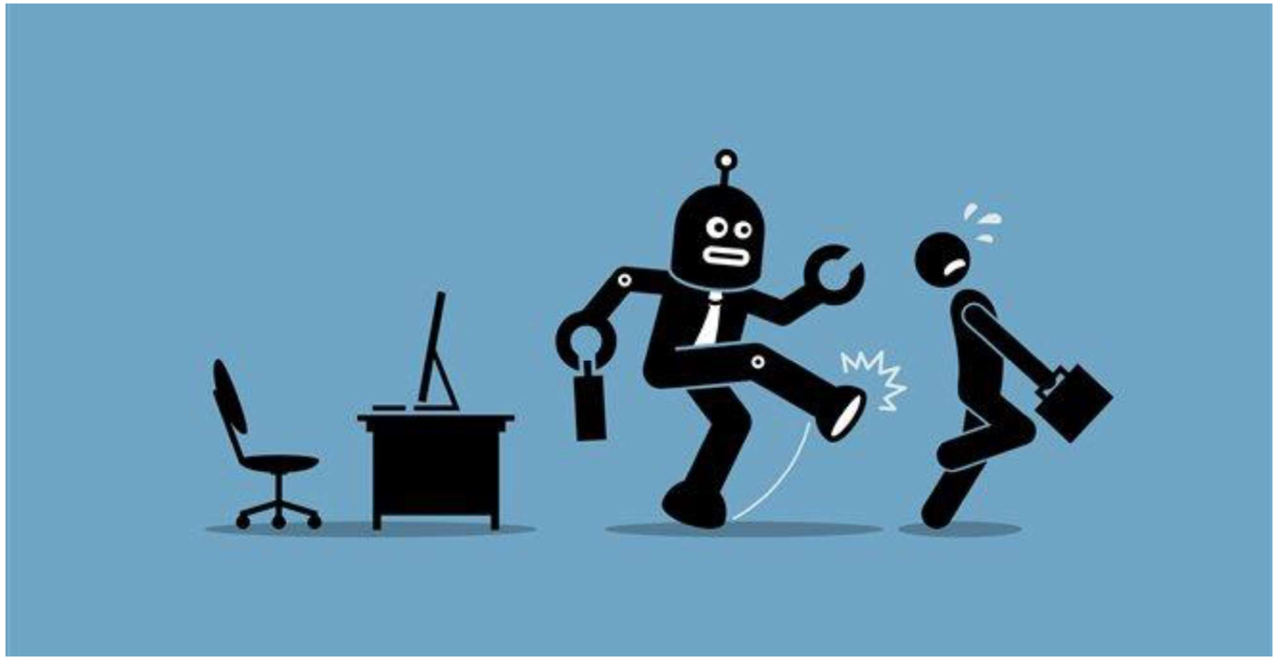
Trained with the associated objects, a machine learning can predict with great accuracy the type of source

Salvetti+17 (1705.09832), Lefaucheur+17 (1703.01822)



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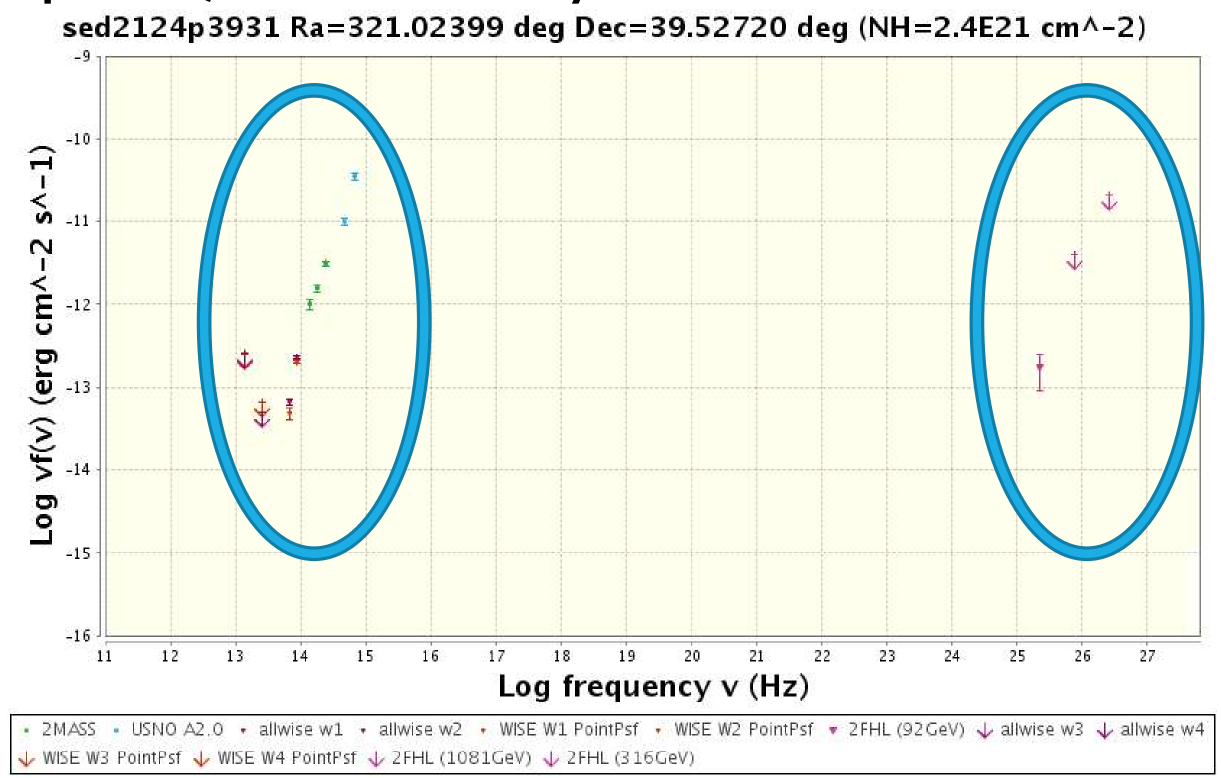
DM is not expected to emit in any other wavelength, so exhibiting emission in IR, optical, UV or X-ray is a cut



tools.asdc.asi.it

SELECTION CUTS

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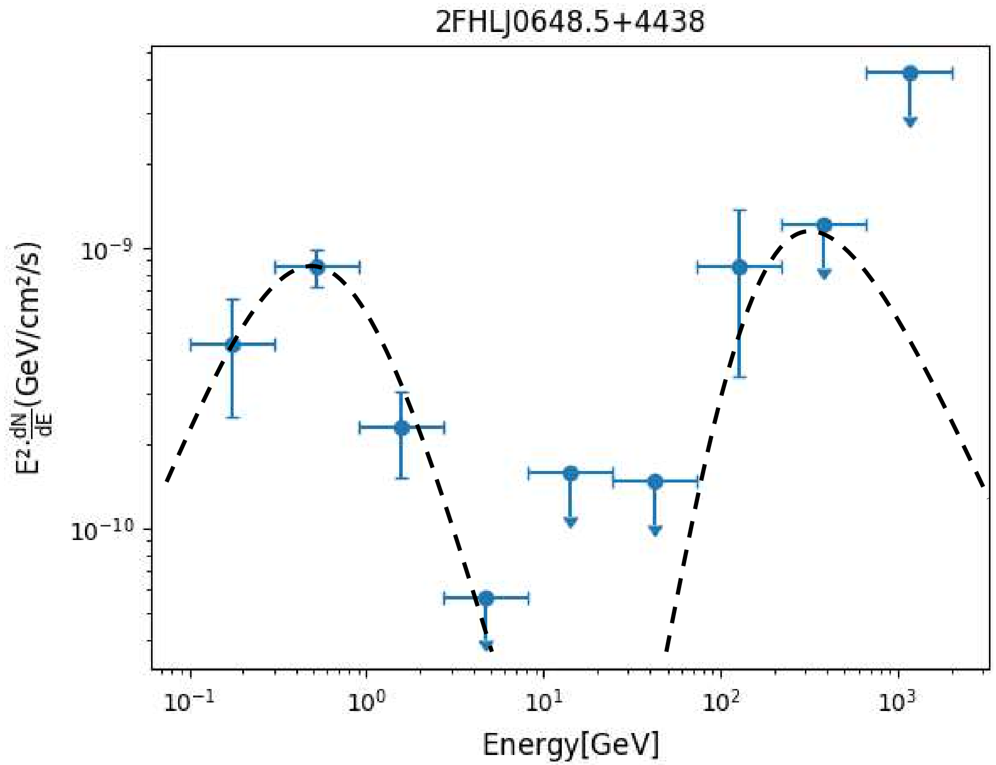
6. **Spectral bump**

We expect a smooth spectrum, i.e., with no "bumps"



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	Original	Result
2FHL	48	10
3FHL	177	54
3FGL	1010	60

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- The method proves to be complementary and competitive to other indirect searches
- Conservative yet realistic constraints
- CAVEAT: The repopulation assumes this low-mass subhalos $(\lesssim 10^7 M_\odot)$ are not disrupted – Reasonable, but not 100% sure
- More source associations and new gamma-ray catalogs $\rightarrow$ improvement
- Future CTA is competitive where Fermi-LAT is not, closing the gap for high masses

Thank you very much!

BACKUP SLIDES

(AKA ANSWERS FOR NON-EXISTENT QUESTIONS)

GALACTIC LATITUDE DISTRIBUTION