Modelling the extragalactic flux distribution from dark matter

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Motivation

5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5

4	2	6	5	7	1	3	9	8
8	5	7	2	9	3	1	4	6
1	3	9	4	6	8	2	7	5
9	7	1	3	8	5	6	2	4
5	4	3	7	2	6	8	1	9
6	8	2	1	4	9	7	5	3
7	9	4	6	3	2	5	8	1
2	6	5	8	1	4	9	3	7
3	1	8	9	5	7	4	6	2

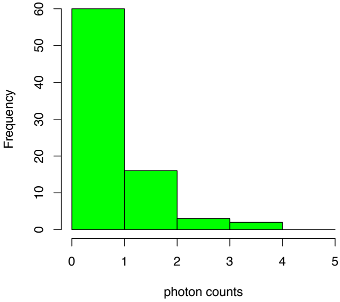
Both of these photon count maps have the same mean intensity

But one clearly has more information!

Motivation

We should care about the probability distribution of intensities

1	2	0	1	0	1	1	0	2
1	1	2	0	2	1	0	1	0
1	0	1	2	3	1	2	1	4
0	1	0	0	0	2	1	2	0
0	2	1	0	0	1	1	1	1
2	1	0	1	1	1	0	3	0
1	3	0	0	1	1	2	0	1
2	0	2	1	4	0	0	0	0
1	1	2	0	1	2	1	1	2



Motivation

- Objective: Use the photon count distribution over many pixels as our observable.
  1. This information is currently unexploited.
  2. This "one point-function" is *complementary* to anisotropy!
- More precisely:
  1. Model/predict the count distribution due to both DM annihilations and astrophysical backgrounds (this talk)
  2. Compare it to the experimentally observed distribution (future)
- Read all about it in

arXiv:1506.05118
MF, S. Ando, S.K. Lee

The only slide with maths

$$\text{Observed Flux} = \sum_{\text{all halos}} \text{Flux from one unresolved halo}$$

$$\text{Flux from one halo} = \iint_{L,z,\cdots} \text{horribleFn(unknown parameters)}$$

But we want the Flux *Distribution*

$$P(F) = P_1(F) \star P_1(F) \star \cdots \star P_1(F)$$

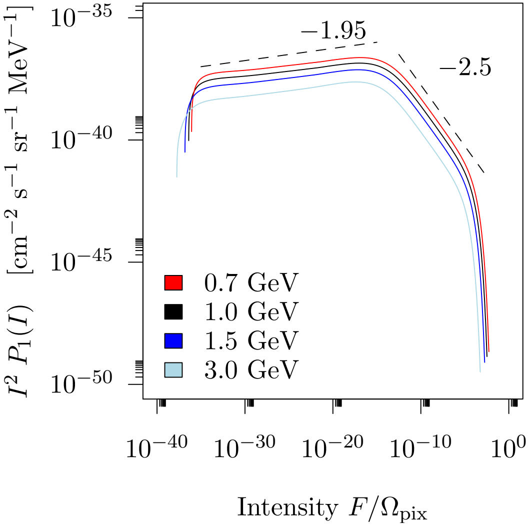
$$P_1(F) = \text{marginalise away uncertainties}$$

Model Inputs

- Fermi telescope's angular resolution ($\implies N_{\mathrm{pix}}$)
- theoretically-motivated, simulation fitted mass function
- NFW profile with low-mass flattening of $c(M, z)$
- three substructure boost models:
  - conservative – no boost
  - sensible – fit to simulation, (Sánchez-Conde + Prada, 2014)
  - optimistic – powerlaw (Gao et al., 2012)
- WIMP with thermal cross-section and $m_\chi = 85\ \mathrm{GeV}$

The mean DM intensity between 0.2% and 2% of the EGB (at 1 GeV) depending on optimism regarding substructure boost.

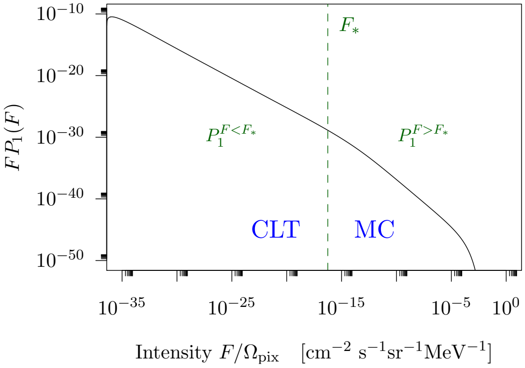
Flux distribution $P_1(F)$ of a single halo



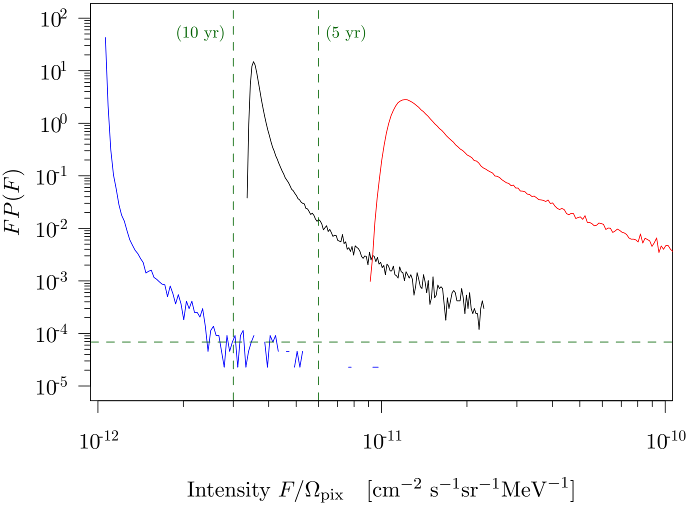
Methodological digression

The method from arxiv:1506.05118 in one sentence

We use probability-theoretical arguments to justify a binomial expansion that 'divides and conquers' the problem.



Flux distribution $P(F)$ of the entire background



$P(F)$

Qualitative Features:

1. The distribution is *not a Gaussian*.
2. At high flux we reproduce the $F^{-2.5}$ 'tail' from $P_1(F)$.

A single bright source dominates the flux from the pixel.

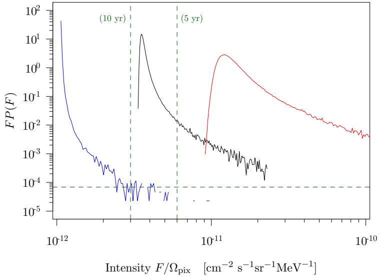
3. At low flux we have a roughly Gaussian peak.

This is characteristic of a diffuse background.

4. The peak is *much thinner* than a Gaussian of equal (μ, σ)

$P(F)$

1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	2	1	1
1	1	1	1	1	1	1	1	3
1	1	1	1	1	1	1	1	1
1	1	2	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	2	1



- "1" = diffuse background of unresolved point sources
- "2 or more" = a single unresolved point source is as bright as everything else in that pixel
- Remember to add shot noise on top of this!

Quick half-way summary

We modelled the γEGB flux due to DM *distributionally*.
Distribution's features have sensible interpretations
Studied dependence on modelling choices (Boost, $c(M)$, LSS, ...)

TODO: How does knowing $P(F)$ affect DM search strategies?

Many indirect detection strategies, $P(F)$ relevant for *all* of them!

Strategy 1: Use the Mean EGB Intensity

SKEWNESS $\Longrightarrow$ The mean is NOT the most likely value.

Boost model	Mean	Most Likely	Ratio
No boost	1.0	1.0	
Fiducial	3.68	3.52	$\sim 5\%$
Optimistic	15.2	11.9	$\sim 25\%$

Table: Intensities at 1 GeV in units of $10^{-12} cm^{-2} s^{-1} sr^{-1} MeV^{-1}$

Existing limits are only weaker by a percent-level factor
(just a correction, but it could have been MUCH more!)

Strategy 2: Use the diffuse background's anisotropy

For a Gaussian $P(F)$, all info is contained in

- the mean (strategy 1)
- the variance (decompose into C_ℓ, strategy 3)

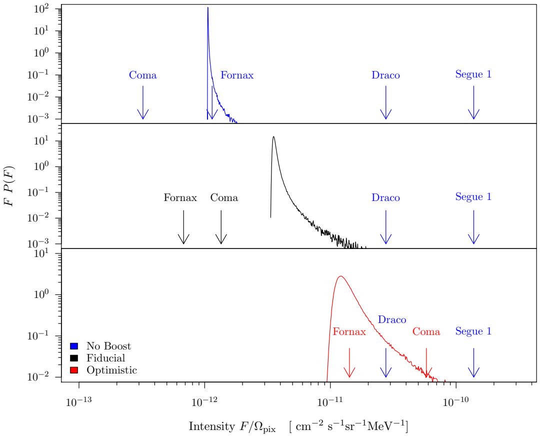
This is the case e.g. for CMB.

But, our $P(F)$ is not a Gaussian

There is new information hidden in the higher moments too...

Complementarity!

Strategy 3: Look at promising sources



- diffuse DM background vs. DM sources
- thin peak $\Longrightarrow$ precise S/N
- DSphs Challenging, worse with more boost(!)
- Cluster S/N bad even *without* astrophysics

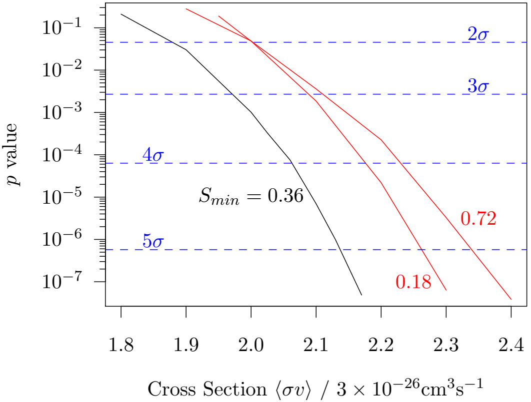
Strategy 4: One-Point Function analysis

Compare the predicted $P(F)$ to the experimental $P(\mathrm{Counts})$

We need to model the astrophysical backgrounds' $P(F)$ too!

- Blazars contribute $15 \pm 1\%$ of the EGB flux at 1 GeV
  Extrapolate dN/dS to predict the blazar $P(F)$.
- The remaining diffuse component has a Gaussian $P(F)$ (improvements underway)
- Various $P(F)$ combinations to get
  - a prediction for no DM signal (null hypothesis), and
  - predictions for various values of $\langle \sigma v \rangle$ (mock data)
  - χ^2 poorness-of-fit to forecast our statistical power.

Strategy 4: One-Point Function analysis



No energy spectrum in this analysis (yet!)

We're still *ignoring* most of the available data. Even then, our projections are already competitive with e.g. Fermi Dwarfs!

Summary

What we did

The probability distribution of DM halo fluxes was characterised:

- Single-source distribution *and* EGB contribution distribution.
- $P(F)$ not just a Gaussian, but has a powerlaw tail.

Why it matters

- existing $\langle I_{\mathrm{EGB}} \rangle$ limits weakened by *only* a few percent.
- extragalactic diffuse background is an irreducible background for point searches; Galaxy clusters less promising than DSphs.
- one-point analysis can be competitive with other methods – even *without* using energy spectra.