High-energy Astrophysics in a single pixel

Michael R. Feyereisen
In collaboration with S. Ando, S.K. Lee, I. Tamborra, *et al.*

GRAPPA
GRavitation AstroParticle Physics Amsterdam

Motivation

Diffuse Backgrounds – How to analyse this data?

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

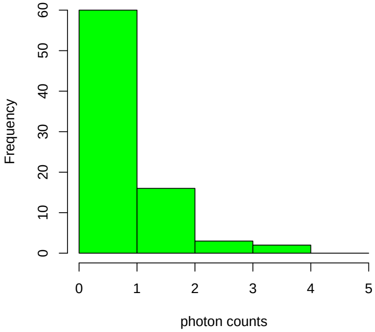
(#/pixel $\Longrightarrow$ count map)

- Mean Intensity $\langle I \rangle$
  - single number, limited
- variance $\sim \langle I^2 \rangle$
  - 2-point correlations!
  - mostly diffuse/isotropic
- higher moments? $\sim \langle I^n \rangle$
  - how to interpret?

Motivation

Study the probability distribution of counts/intensities/fluxes

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



Comparison to Zechlin *et al.* (1512.07190)

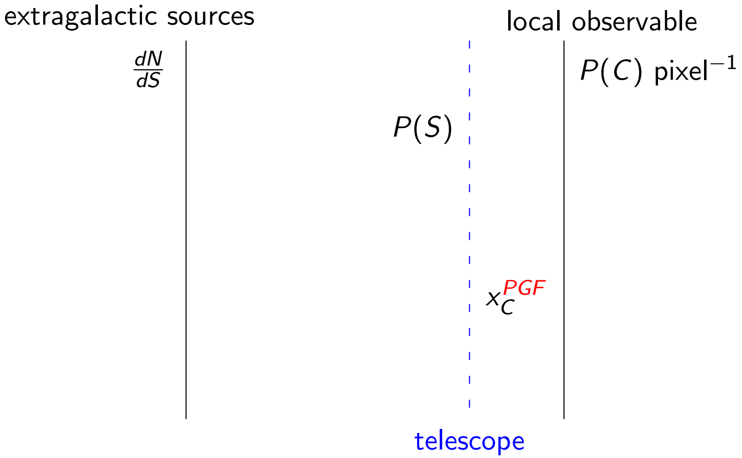
extragalactic sources

$\frac{dN}{dS}$

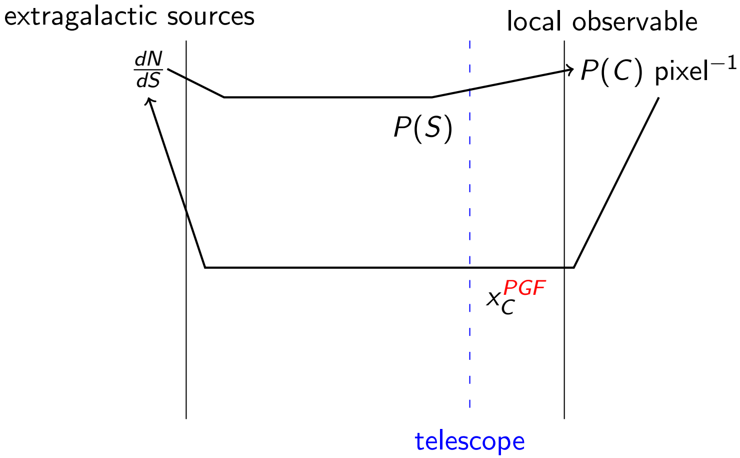
local observable

$P(C)$ pixel^{-1}

Comparison to Zechlin *et al.* (1512.07190)



Comparison to Zechlin *et al.* (1512.07190)



Example Problem

Dark Matter contribution to the diffuse extragalactic γ flux?

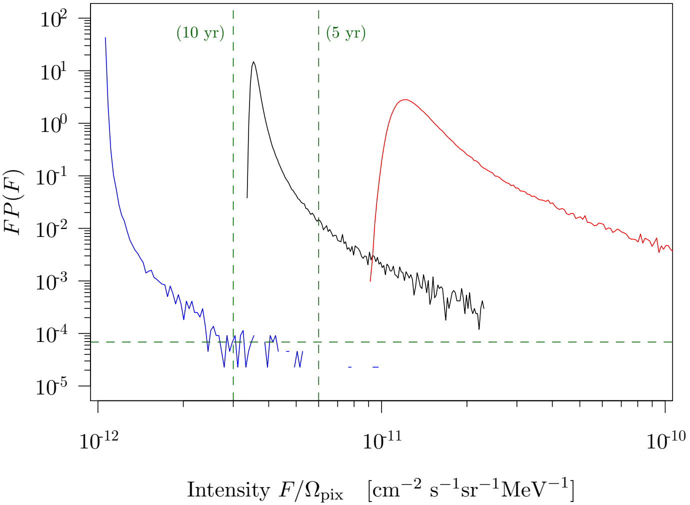
arXiv:1506.05118
MF, S. Ando, S.K. Lee

Model Inputs for dN/dF

- Fermi telescope's angular resolution ($\Longrightarrow N_{\mathrm{pixel}}$)
- theoretically-motivated, simulation fitted DM halo model
- 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 $m_\chi = 85\ \mathrm{GeV}$
- For now, simply work at 1 GeV only

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

Flux pdf of $m_\chi = 85$ GeV WIMP (at 1 GeV)



Qualitative Features (and physical interpretation)

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

What will knowing the DM $P(F)$ change for *us*?

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}

$\Longrightarrow$ Existing limits are only weaker by a percent-level factor (small correction, with Powerlaws it could have been MUCH more!)

Strategy 2: Use the diffuse background's anisotropy

For a Gaussian $P(F)$, Wiener-Khinchin says all info is contained in

- the mean (strategy 1)
- the variance (decompose into $C_\ell \implies$ anisotropy)

This is the case e.g. for CMB.

But the dark matter $P(F)$ is not a Gaussian

There is new information hidden in the higher moments...
(Monopole and Anisotropy *complementary* but not *complete*)

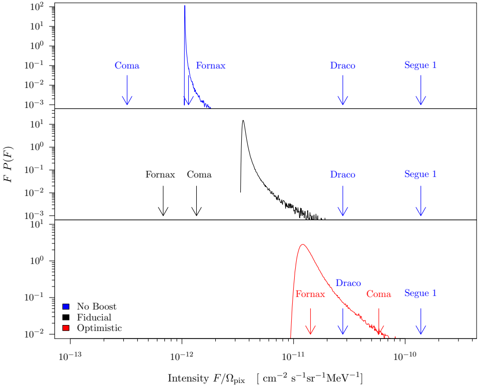
Flashback to 'Motivation'

How to analyse this data?
Predicting $P(F)$ guides our data analysis!

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

- Mean Intensity $\langle I \rangle$
  - corrections $\geq 5\%$
- variance $\sim \langle I^2 \rangle$
  - thinner than a gaussian
  - not complete story
- higher moments? $\sim \langle I^n \rangle$
  - yes, powerlaw tail!

Strategy 3: Look at promising sources



- diffuse DM background vs. potential DM sources
- thin $P(F)$ peak $\Longrightarrow$ well-determined F_{PS}/F_{BG}
- DSphs Challenging, worse with more boost(!)
- Cluster F_{PS}/F_{BG} bad even *without* astrophysics

Diffuse DM background is *very* relevant for DM point searches!

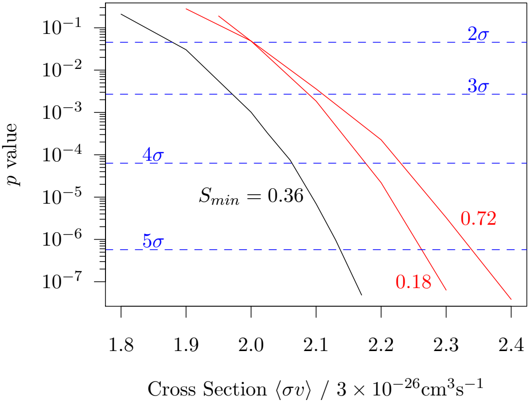
Strategy 4: One-Point Fluctuation Analysis

Compare the predicted $P(F)$ to the experimental $P(C)$

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

- Extrapolate Blazars to predict their $P(F)$, all else is Gaussian (model 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 Fluctuation analysis



1 GeV: 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!

Example Problem (II)

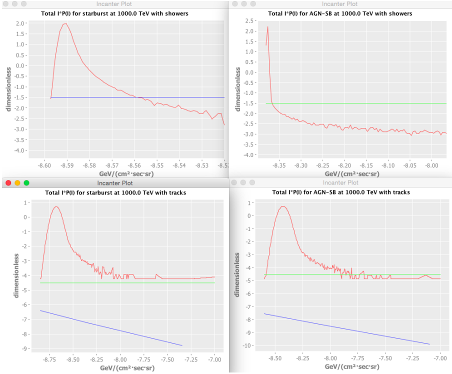
Star-forming galaxy contribution to the high-energy ν flux?

(Preliminary!!!)

Model Inputs for dN/dS

- Icecube has different responses for tracks and showers
- Infrared Luminosity Fn for SFG extrapolated to $dN/d(S\nu)$:
  - IR/γ correlation
  - two γ-to-ν models: leptonic and hadronic
  - $\Gamma = 2.2$ spectrum
  - No PeV cutoff
- Backgrounds: *Fermi* 2FHL gives $dN/d(S\gamma)$ of BL-Lacs
- etc.

(Preliminary!)



SB + SF-AGN indeed contribute to the observed flux.

High-Energy Neutrino Astronomy of SFGs

P(I) tells us about SFG Search Strategies (with ν telescopes)

Most SFG not visible as point sources over the diffuse background due to other SFGs, with *intrinsic* bound

$$F_{PS}/F_{BG} < 4 \text{ or } 5$$

due to the angular resolution of Icecube

Just like γ DM point searches: This does not account for other backgrounds, it will be even smaller in real data.

Summary

Methodology

We can (& should) model the origin of diffuse backgrounds
(we learn more than just fitting them!)

Science

- $P(F_{1\ GeV})$ for DM:
  - existing isotropic flux limits are a few % too optimistic
  - look for dwarfs, not clusters
  - 1-pt fluctuation analysis very promising
- $P(S_\nu)$ for SFG (Preliminary!!!)