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Istituto Nazionale di Fisica Nucleare

Searches for dark matter signals in the gamma-ray sky with photon count statistics

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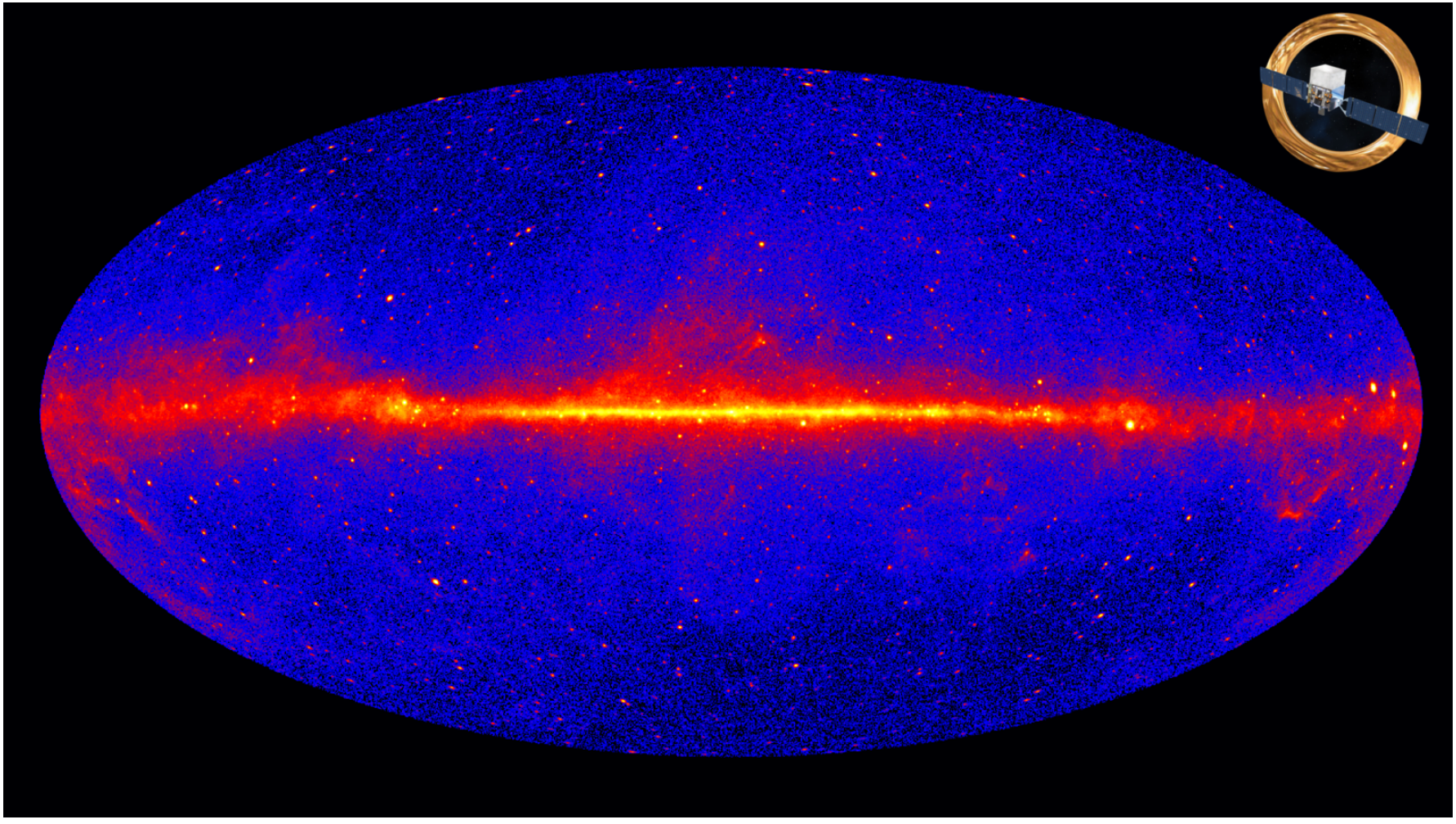
The γ-ray sky seen from Fermi-LAT

[Fermi-LAT 5 years, energy $>$ 1 GeV]



Fermi-Large **A**rea **T**elescope: high-energy γ -ray telescope,
data from $E = 20$ MeV to more than 300 GeV, 11 years of operation

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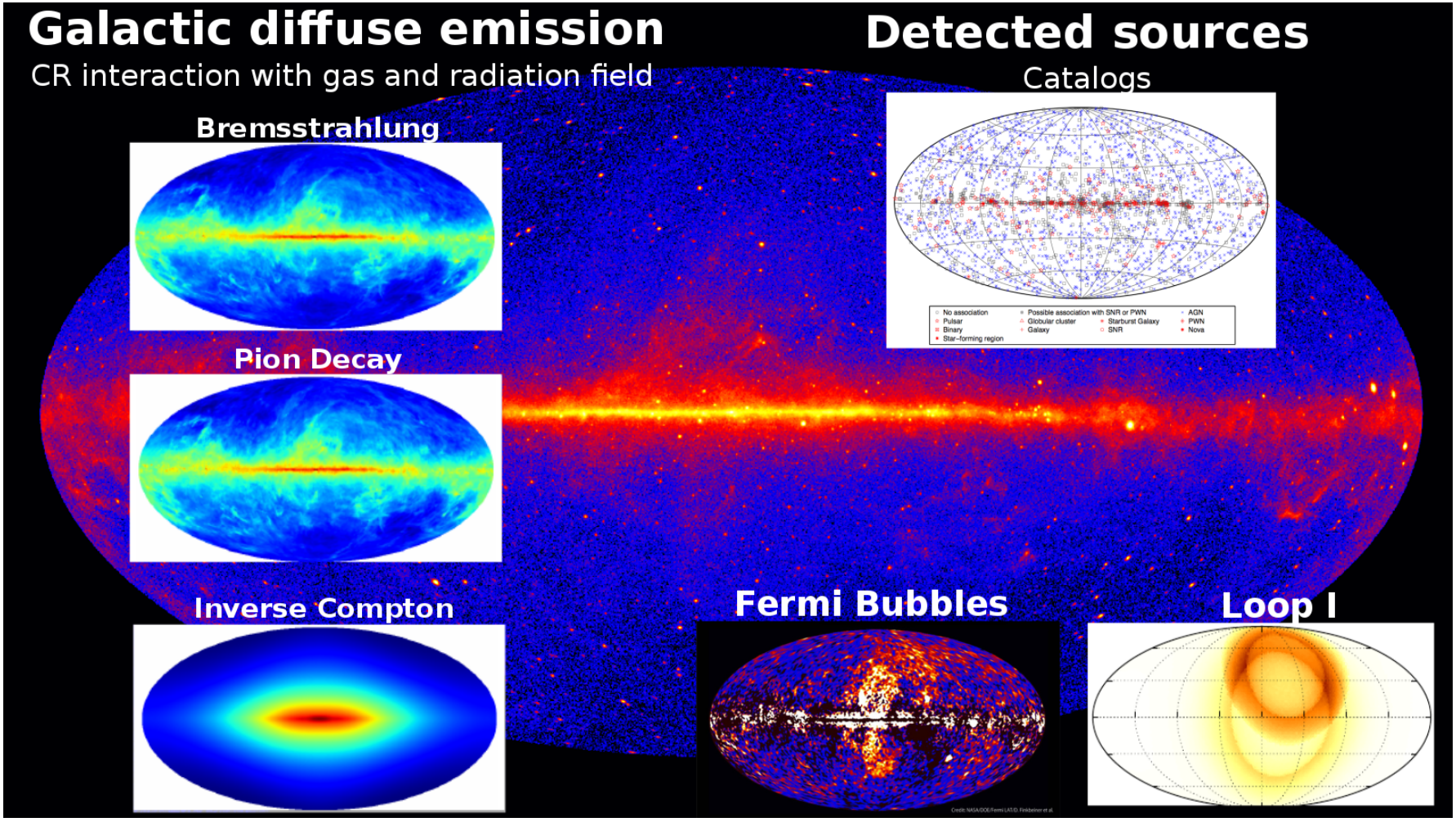

+ **isotropic emission** from unresolved sources and truly diffuse processes

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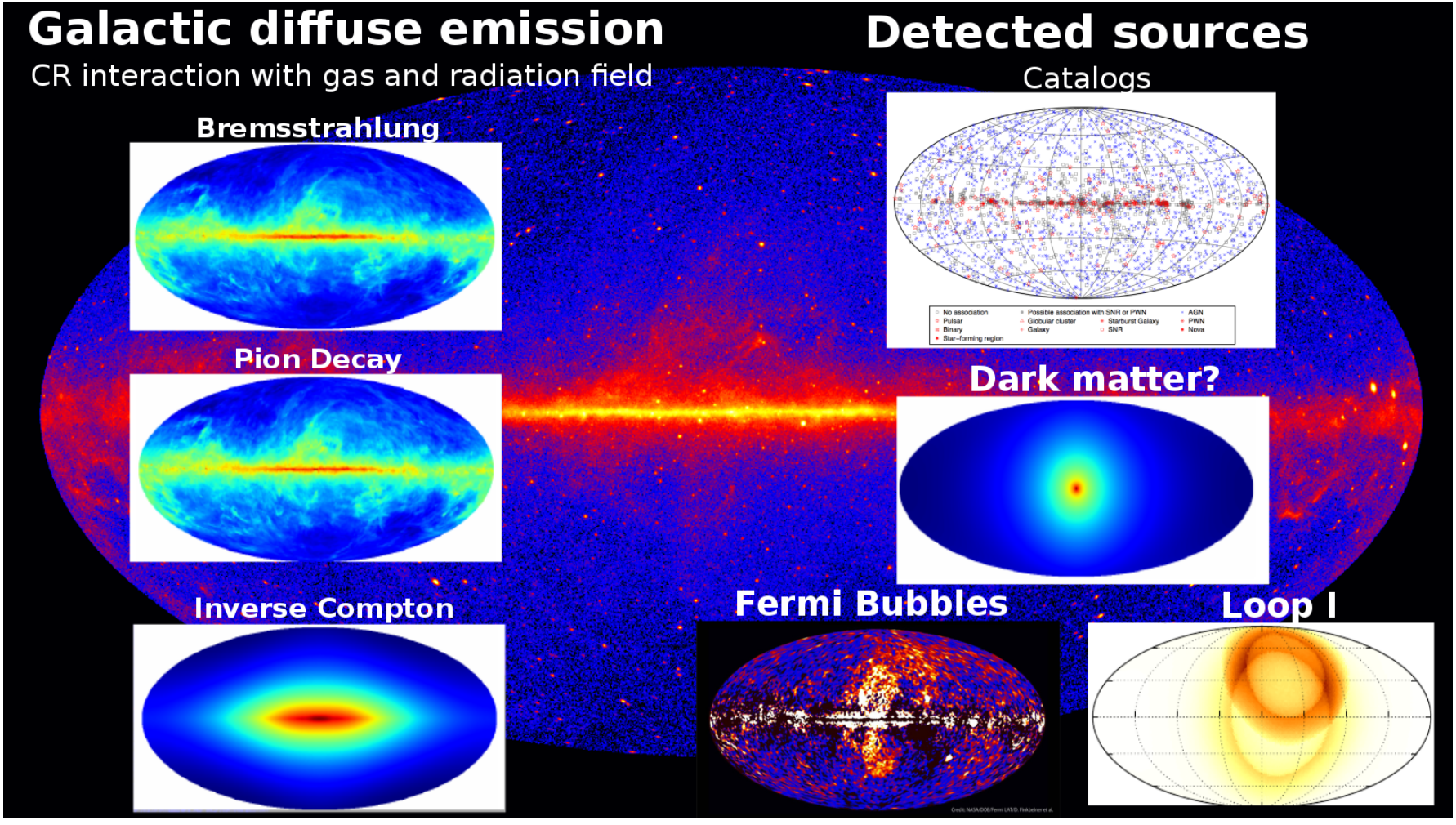
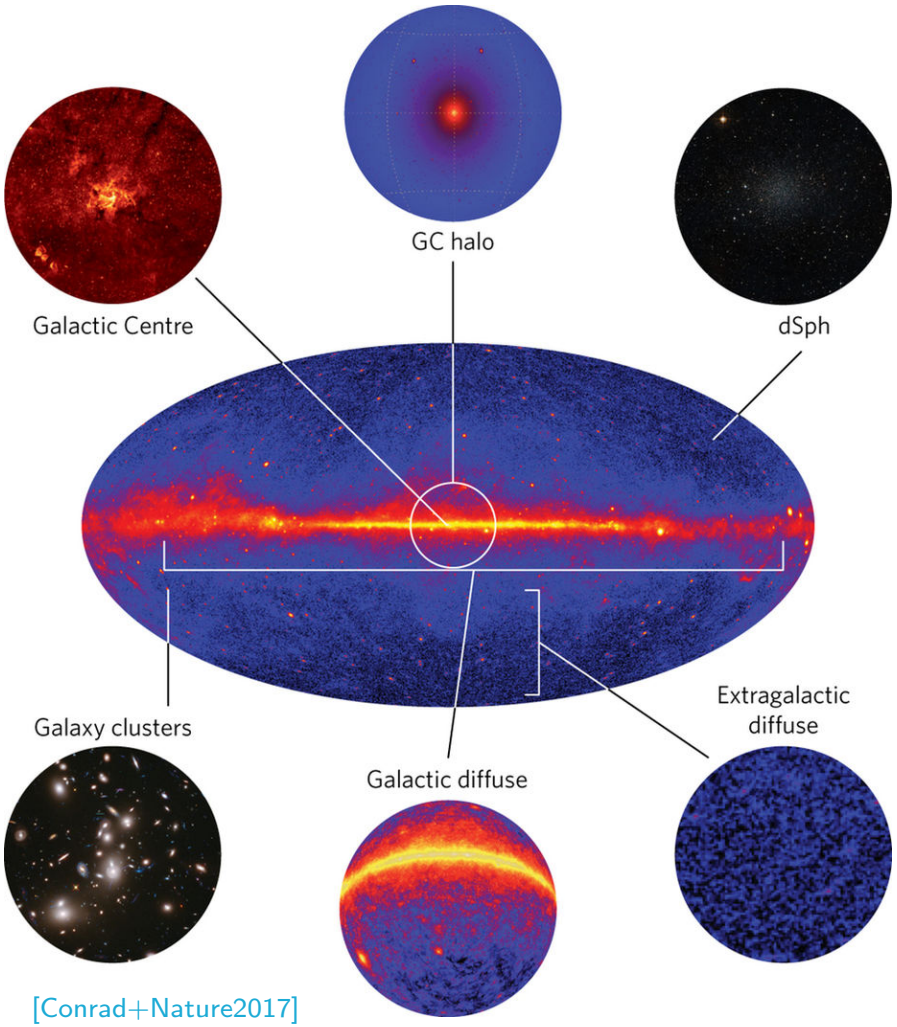


+ **isotropic emission** from unresolved sources and truly diffuse processes... Dark Matter?

→See M.Lisanti talk on Monday

Targets for indirect dark matter searches with γ rays



[Conrad+Nature2017]

This talk:

Galactic DM halo, high latitudes

see also: [Fermi-Lat Coll., Apj11] (1 year of data)

[Chang+PRD18] (template fitting)

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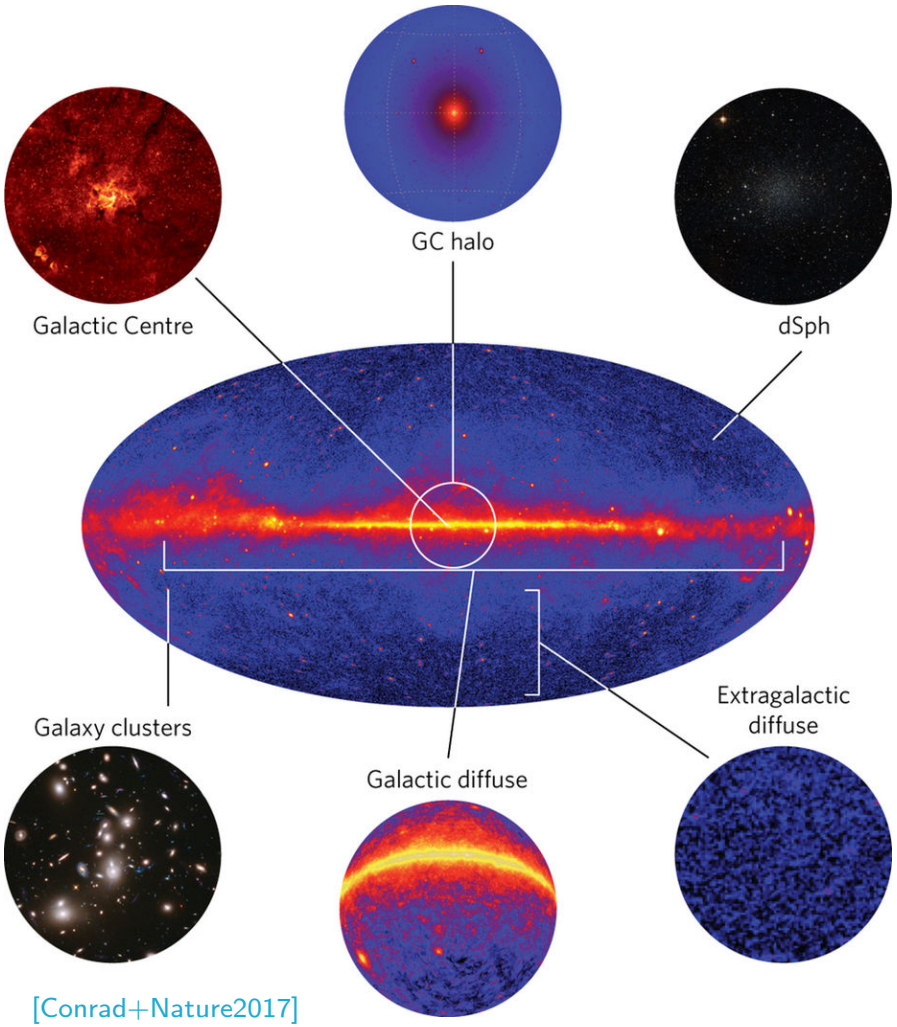

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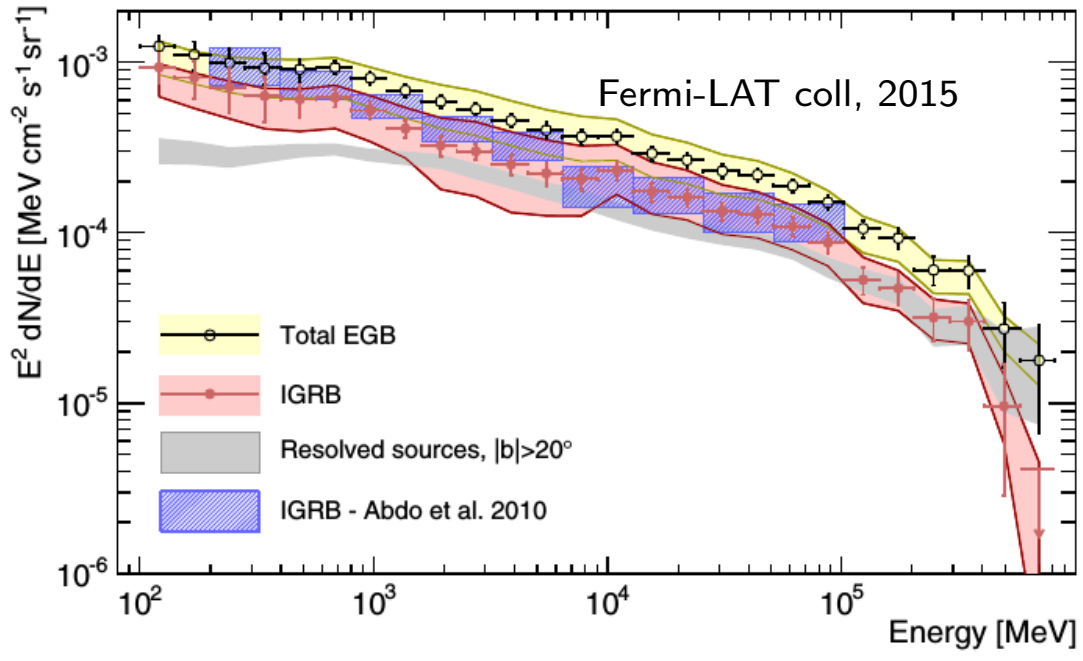
J factor at high latitudes is still high:
See M.Lisanti talk on Monday

Dissecting the γ ray sky at high Galactic Latitudes

γ-ray sky = Galactic diffuse + **E**xtragalactic γ-ray **B**ackground (**EGB**) emissions.

EGB= **point sources** + **isotropic γ ray background** (IGRB)



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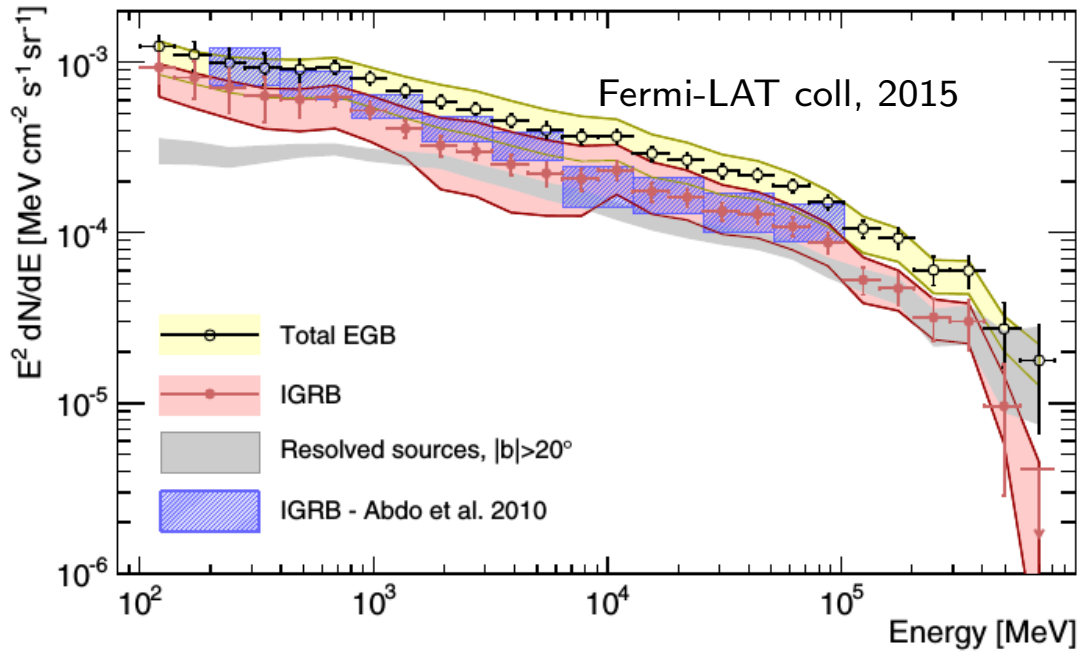

IGRB: **global contribution of unresolved** (too faint to be detected) sources:
extragalactic sources (blazars) + more exotic, e.g. dark matter

Unique tool to search for dark matter signals/ characterize unresolved γ-ray sources

See also Poster #232:
Probng gamma-ray source populations with photon count statistics and anisotropies

The source count distribution of γ-ray sources

Source count distribution dN/dS: # of sources N per $d\Omega$ with integral flux in $(S, S + dS)$.

Contribution to EGB from γ-ray sources is quantified by:

1. Source catalogs: limited by detection threshold (efficiency) of the instrument
2. Extrapolation/correlation with other wavelength: significant uncertainties
3. This talk: **Statistical properties of photon counts**

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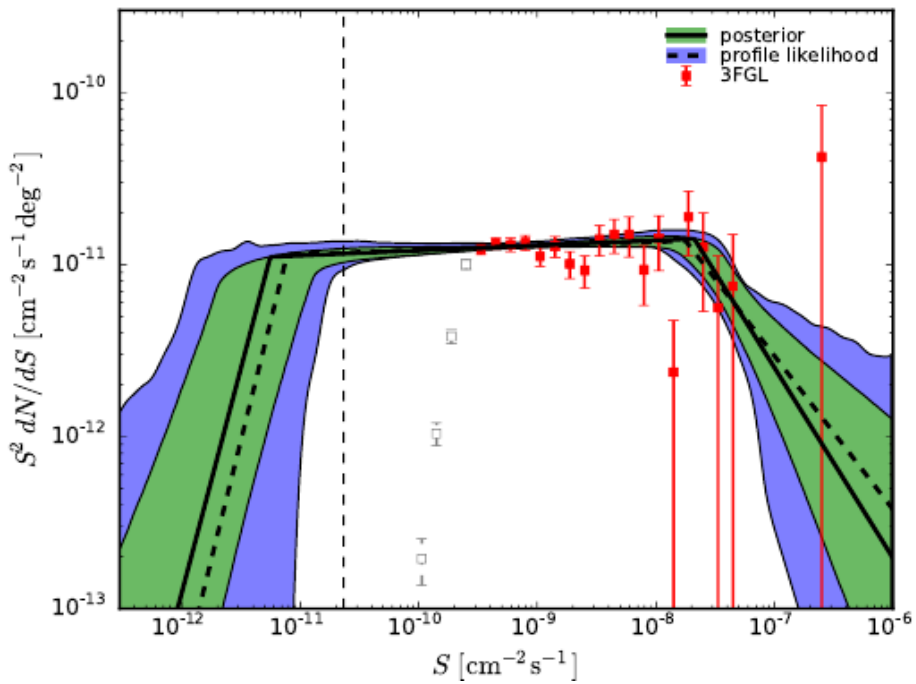
Catalog (3FGL) $\rightarrow$
Detection efficiency < 1
Statistical analysis results



[Zechlin+ApjS2016, 1-10 GeV]

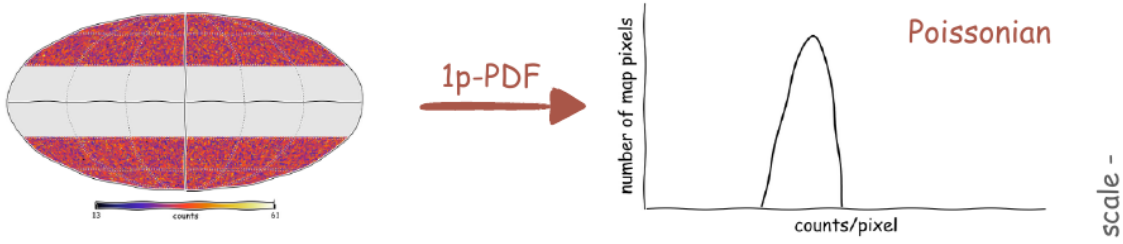
Pixel count statistics with the 1-point Probability Distribution Function (1pPDF)

Statistical analysis of intensity to decompose the γ-ray sky [Malyshev+ApJ2011]

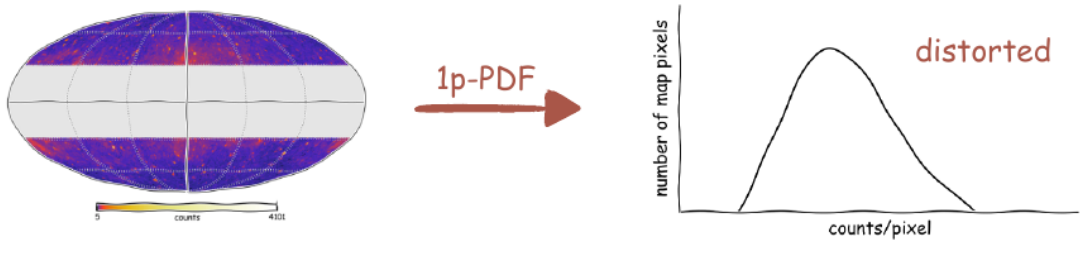
courtesy of H. Zechlin

Examples:

(A) diffuse isotropic background



(B) adding point sources, Galactic foreground, …



- not to scale -

- Applied to measure dNdS at high and low latitudes [Zechlin+ApjS2016], [Zechlin+ApjL2016], (1pPDF) [Lisanti+Apj2016], [Lee+PRL16] (NPTF)
- **This talk**: *extend this framework* to account for dark matter Galactic halo

1pPDF applied to Galactic Dark Matter searches

Analysis from Zechlin, Manconi, Donato, PRD 2018.

Investigate sensitivity reach of 1-point statistics for constraining a diffuse Dark Matter component at *high latitudes*

⇒ Unresolved point sources: flux **subdominant BUT comparable** to DM component
⇒ 1pPDF is **independent** from source catalogs
⇒ First time 1pPDF is tested for constraining Milky Way DM halo
⇒ Exploratory for low-latitude analysis (see later)

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Overview: (see also backup slides)

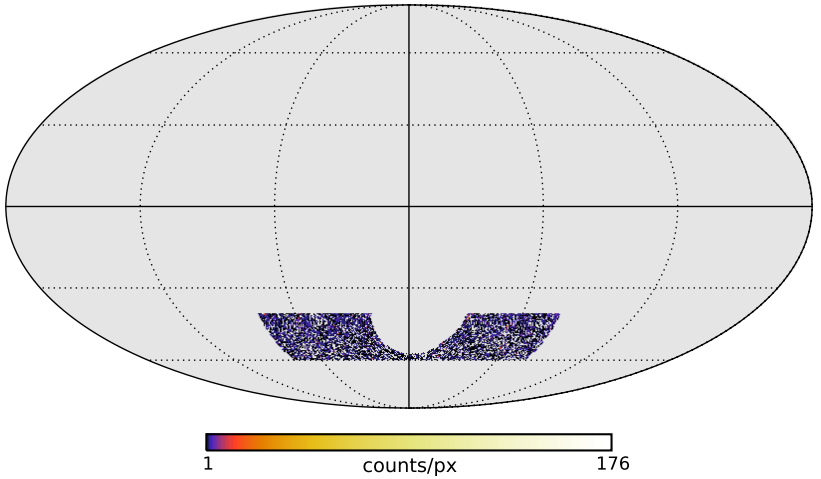
1. **Data**: Fermi-LAT 8yrs, 3 energy bins from 1 GeV to 10 GeV
2. **Dark Matter profile**: Einasto, $\rho_\odot = 0.4$ GeV cm^{-3} [Catena+JCAP2010]
3. **Dark Matter spectra**: dN_f/dE from [Cirelli+JCAP2010], $b\bar{b}$, $\tau^+\tau^-$ final states
4. **Main systematics**: Galactic diffuse emission
   ⇒ high latitudes $|b| > 30$ deg
   ⇒ different benchmark templates
   ⇒ ROI optimization
5. **Simulations**: to validate analysis framework

Region Of Interest (ROI) optimization

Zechlin, Manconi, Donato, PRD 2018

- Mask galactic plane: $|b| > 30 - 40$ deg
- Mask stuctures: Fermi Bubbles, Loop I
- Simulations w/o DM, expected sensitivity

⇒ **DM_ROI at high latitudes where real sky results consistent with simulations in all bins:**



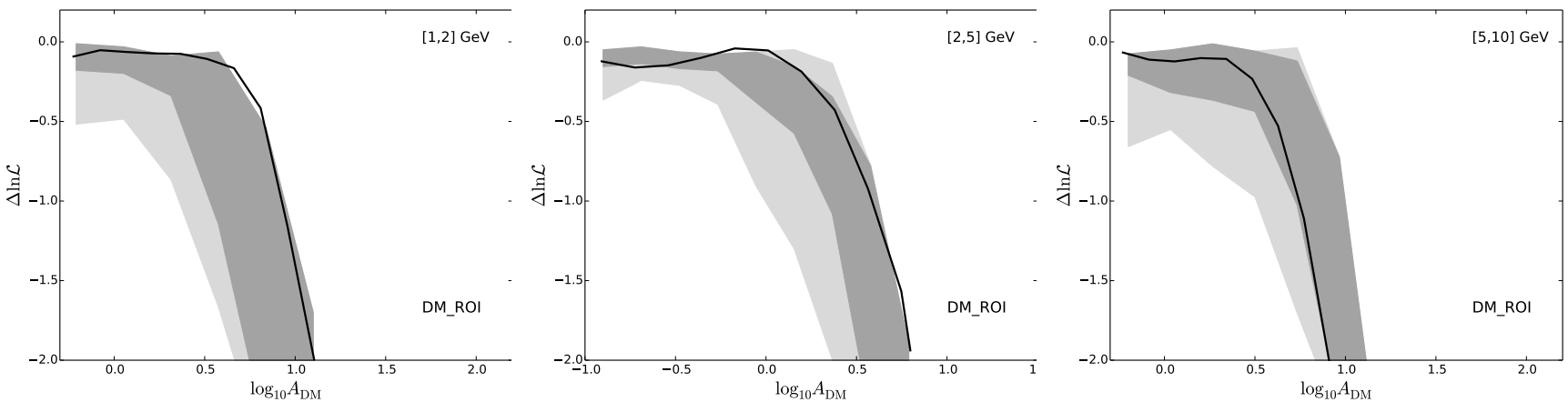


figure: Profile likelihood for $A_{\rm DM}$, rescaling parameter for $\langle \sigma v \rangle_0 = 10^{-26}$ cm^3 s^{-1} for $m_{\rm dm} = 15$ GeV.

Colors: 95% CL from simulations Real sky

More stable ROI, but not the only one

Signal injection and recovery on simulations

8 years of Fermi-LAT data simulated with Fermi Science Tool *gtobbsim*:

1. **Point sources** following dNdS of real sky
2. **Galactic diffuse** background
3. **Isotropic** background
4. **DM smooth halo**
   $m_{\rm DM} = 15$ GeV, $\tau^+\tau^-$,
   different $\langle \sigma v \rangle$

Simulated events are processed according to proper instrument response functions.

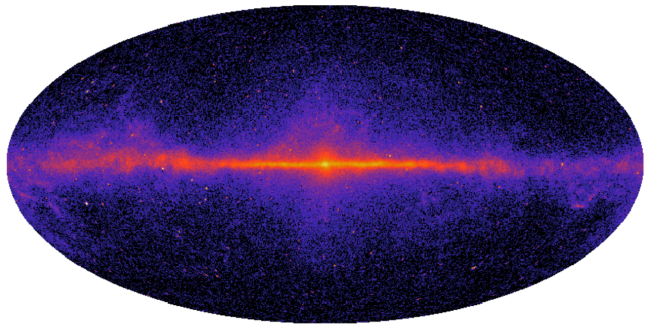


figure: Simulated counts for $\langle \sigma v \rangle_{\rm injected} = 10^{-25}$ cm^3/s

We recover injected DM signal within 1σ for values of $\langle \sigma v \rangle$ higher/between expected sensitivity.

Lower $\langle \sigma v \rangle$: consistenly obtain upper limits

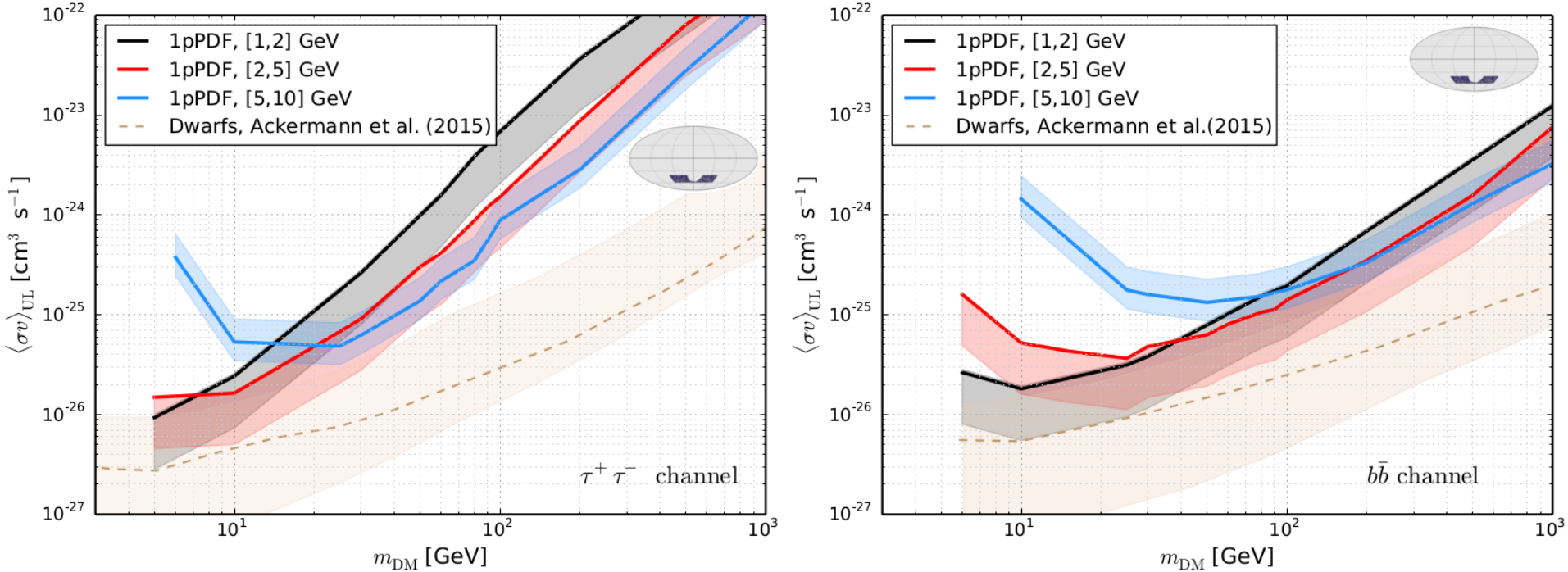
DM_ROI, [2,5] GeV

$\langle \sigma v \rangle_{\rm injected}$ [cm^{3}s^{-1}]	$\langle \sigma v \rangle_{\rm recovered}$ [cm^{3}s^{-1}]
10^{-25}	$8.08^{+2.3}_{-4.07} \cdot 10^{-26}$
10^{-26}	$2.33^{+1.62}_{-3.08} \cdot 10^{-26}$
10^{-27}	$< 4.32 \cdot 10^{-26}$

Results: upper limits on $\langle \sigma v \rangle$

Zechlin, Manconi, Donato, PRD 2018

Upper limits on $\langle \sigma v \rangle$ for two benchmark dark matter annihilation channels:



- Sensitivity of 1pPDF for dark matter searches at high latitudes is comparable with Dwarfs for $m_{\rm DM} < 50$ GeV for τ channel and $m_{\rm DM} < 100$ GeV for b channel
- The [1,2] GeV ([5,10] GeV) bin is more sensitive to low (high) dark matter masses

Main systematics: Galactic Diffuse Emission

Complex modeling, e.g. possible degeneracy Inverse Compton $\Longleftrightarrow$ DM halo

Different benchmark templates:

1. *Official* released with pass8 Fermi-LAT data
2. *models A,B,C* from [Ackermann+ApJ2015]

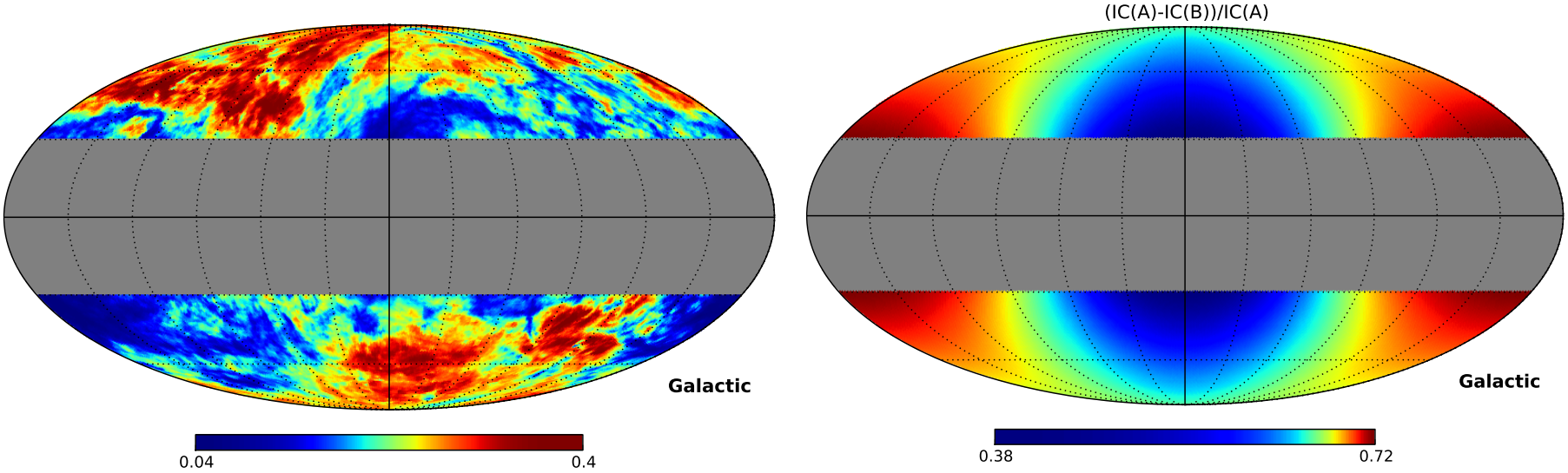


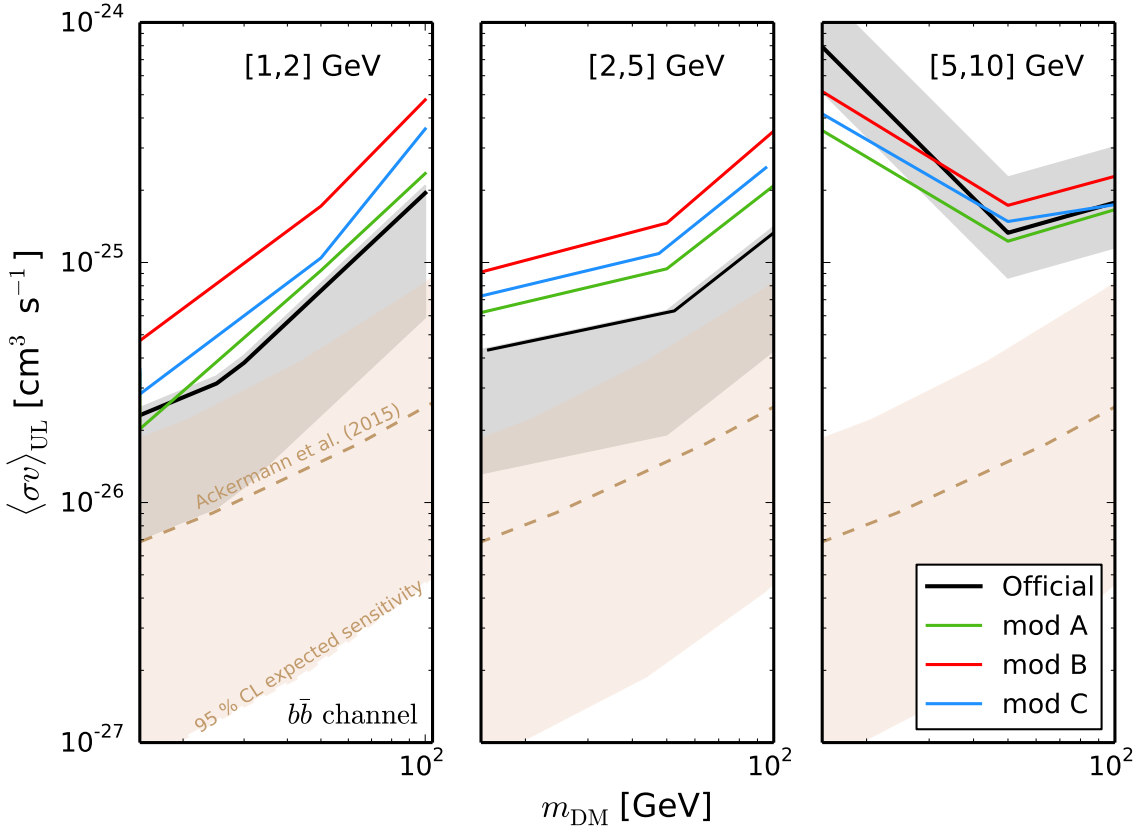
figure: Relative difference between Galactic diffuse emission (left) and Inverse Compton components only (right) from **mod A** and **mod B** integrated in [2,5] GeV for $|b| > 30$ **deg**

$\Rightarrow$ **Region of interest search depends from the galactic diffuse emission**

Better modeling: ongoing effort, e.g. SkyFact [Storm+17], [Porter+17,Gaggero+15, Selig+15]

Systematics on Galactic Diffuse Emission

Zechlin, Manconi, Donato, PRD 2018



$\Rightarrow$ **Scatter between models: factor** $\sim 2-5$ in $\langle\sigma v\rangle$

model B from [Ackermann+2015] has lower inverse Compton for $|b| > 30$ deg

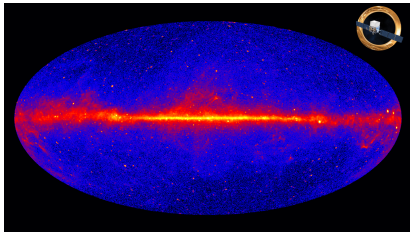
Summary - DM searches with γ -ray pixel count statistics

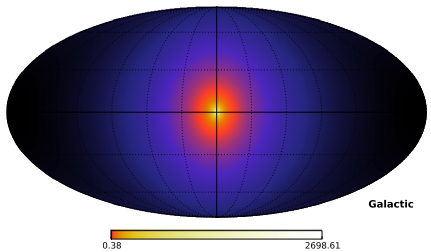
- The **1**-point **P**robability **D**istribution **F**unction is a **powerful statistical method** to:
  - ⋆ resolve faint point sources
  - ⋆ dissect γ-ray sky components

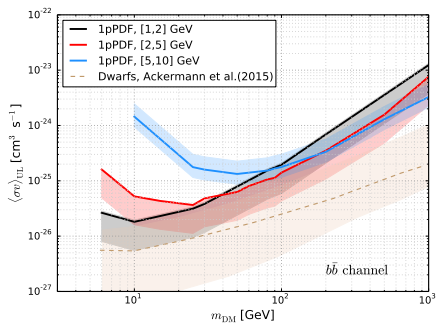
- **1pPDF sensitivity for Galactic DM halo signals at high latitudes was explored in simulated and real data**
  - ⋆ 8 yrs of Fermi-LAT data
  - ⋆ 3 energy bins in from 1 GeV to 10 GeV
  - ⋆ optimazed region of interest

Results:

1. **Sensitivity is comparable with other searches and methods**
2. Limited by systematics from background Galactic emission modeling







Perspectives: working on lower latitudes, dark matter subhalos