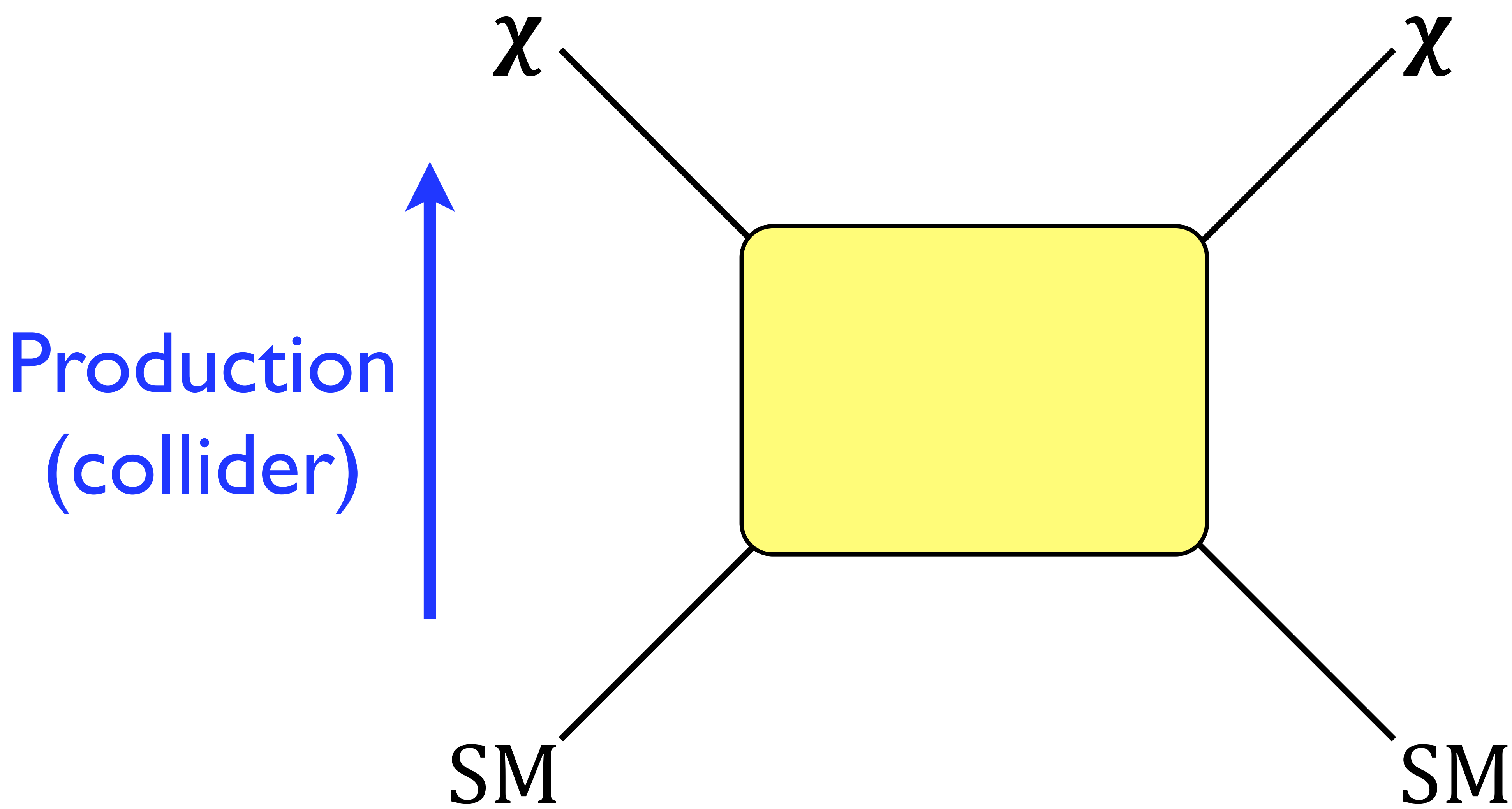
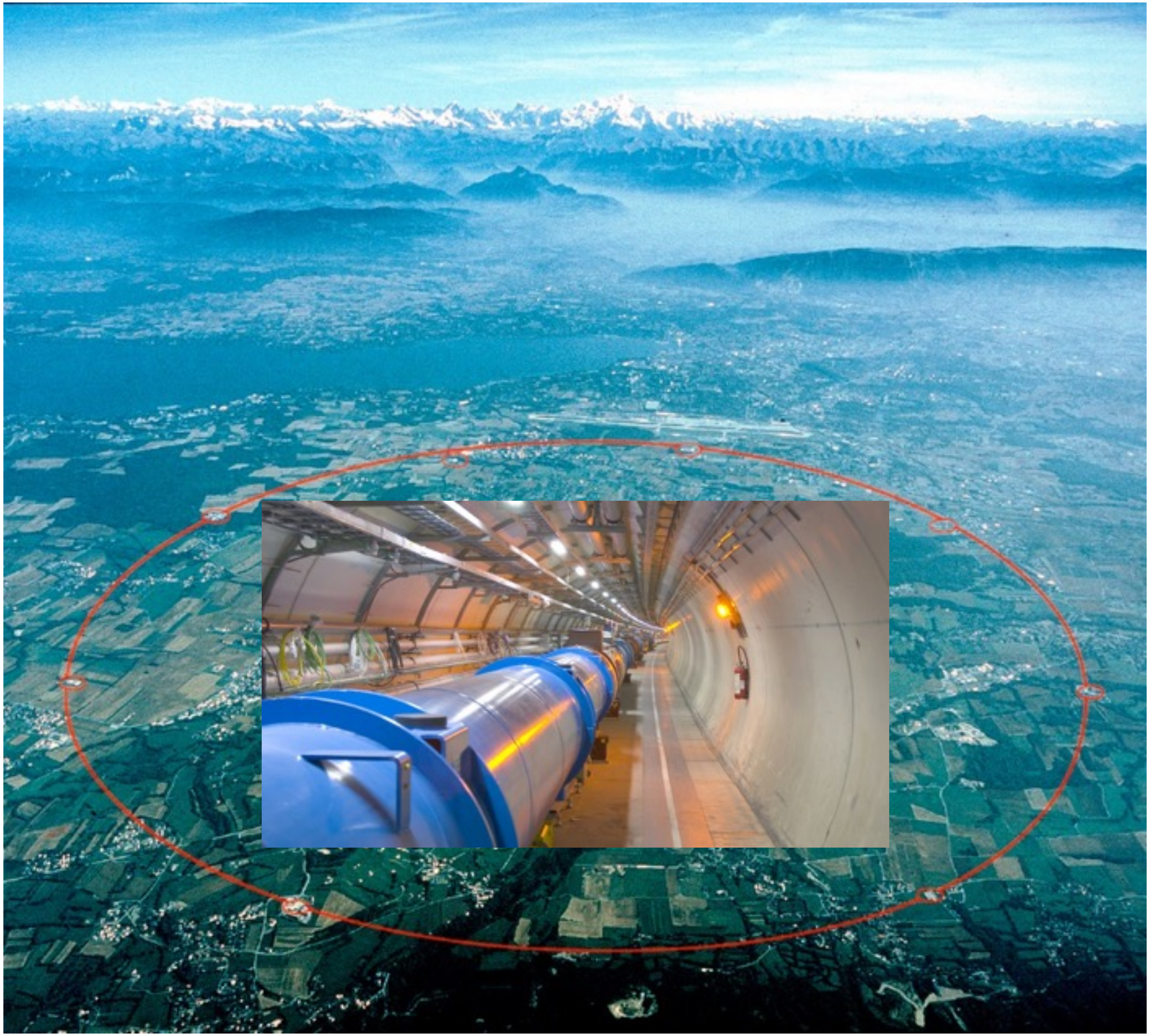
Indirect dark matter searches: recent results and excitement

Jennifer Gaskins
GRAPPA, University of Amsterdam

How to detect particle dark matter?

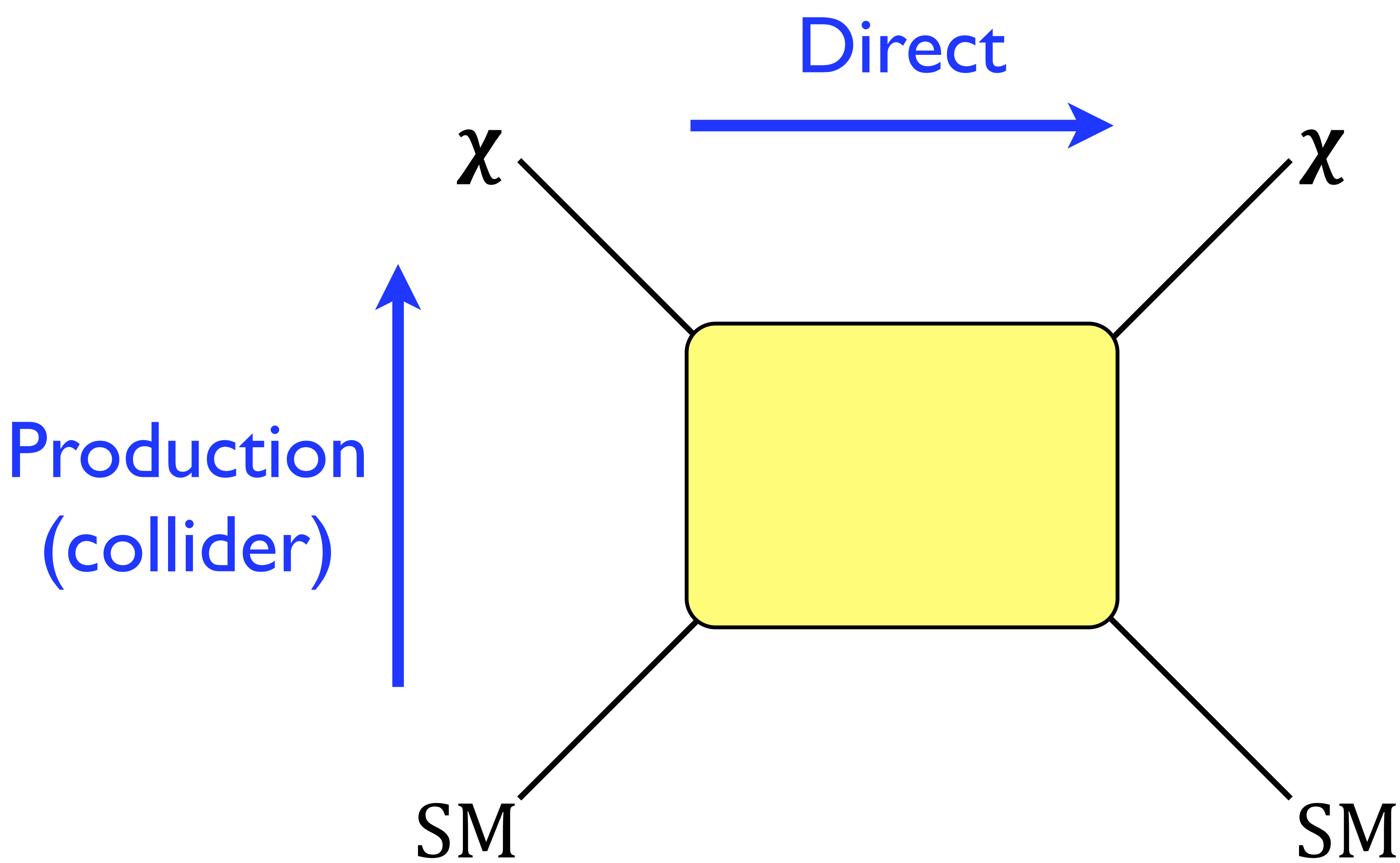


Production at a collider



(Large Hadron Collider)

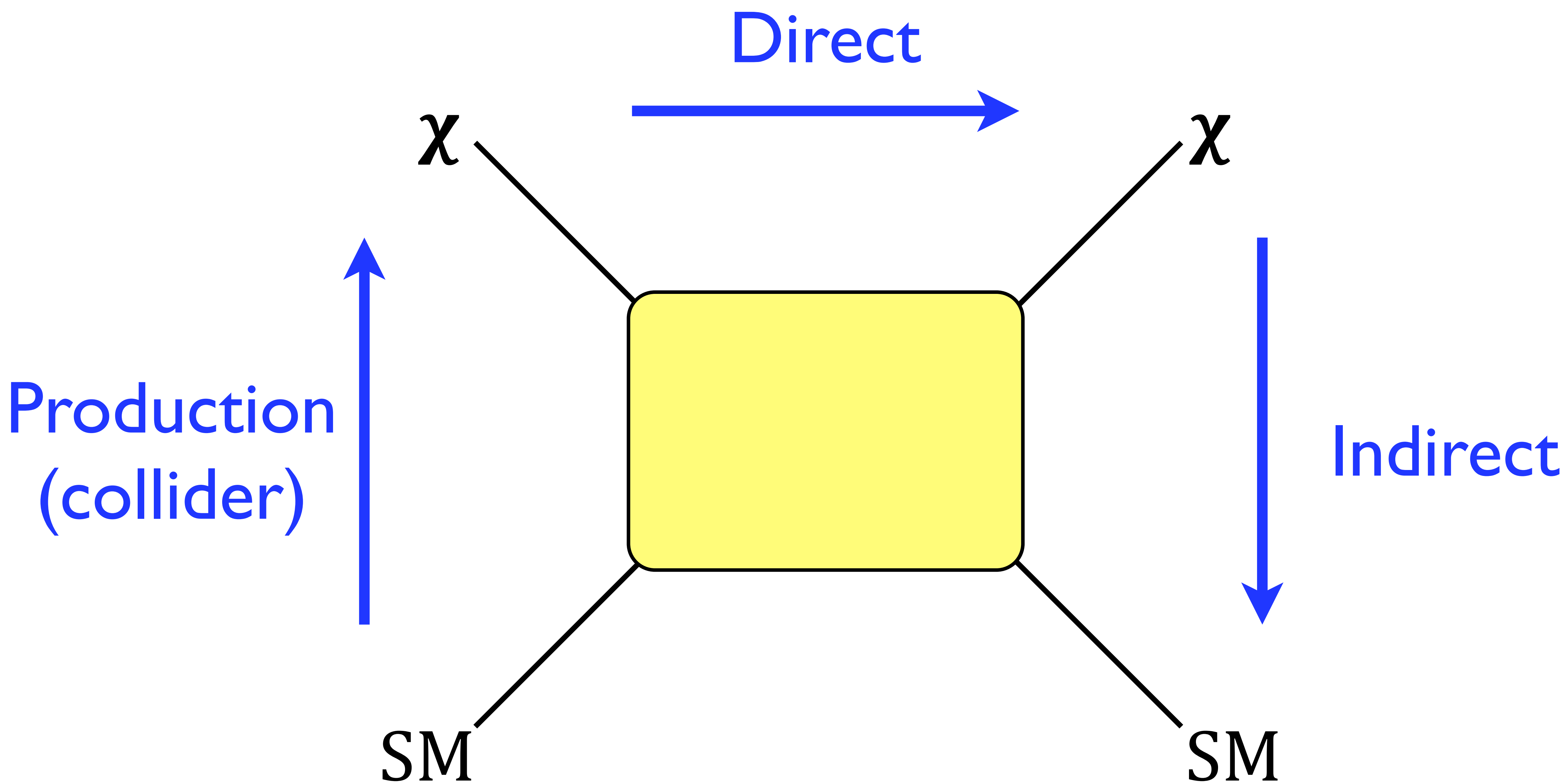
How to detect particle dark matter?



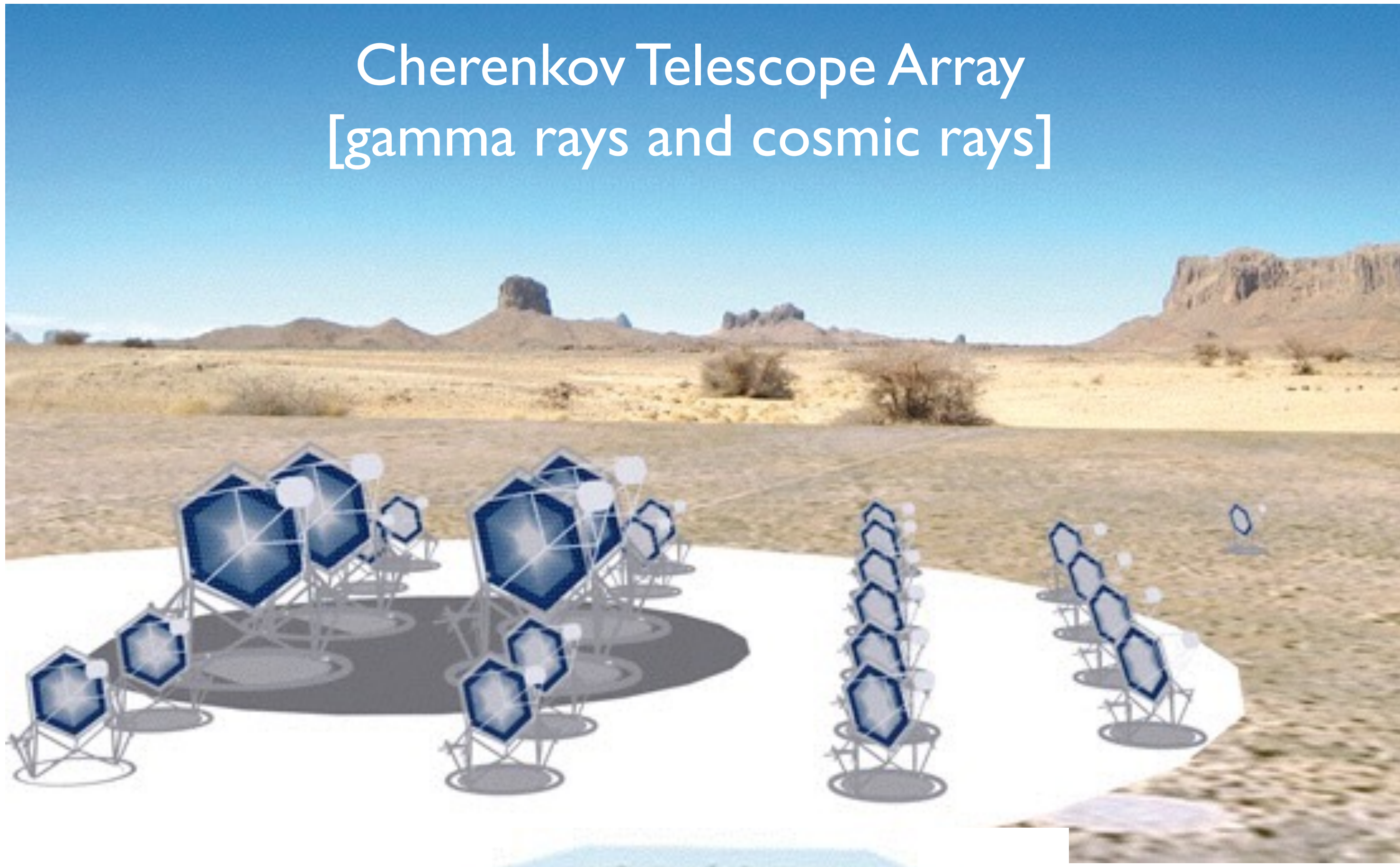
Direct detection

LUX experiment

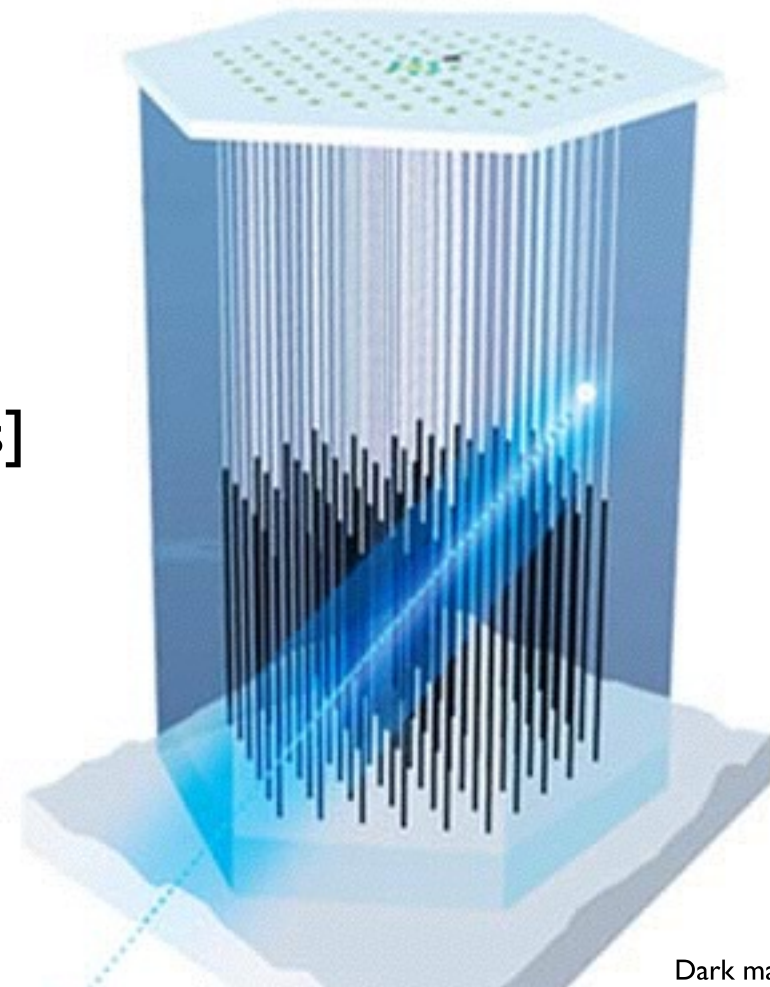
How to detect particle dark matter?



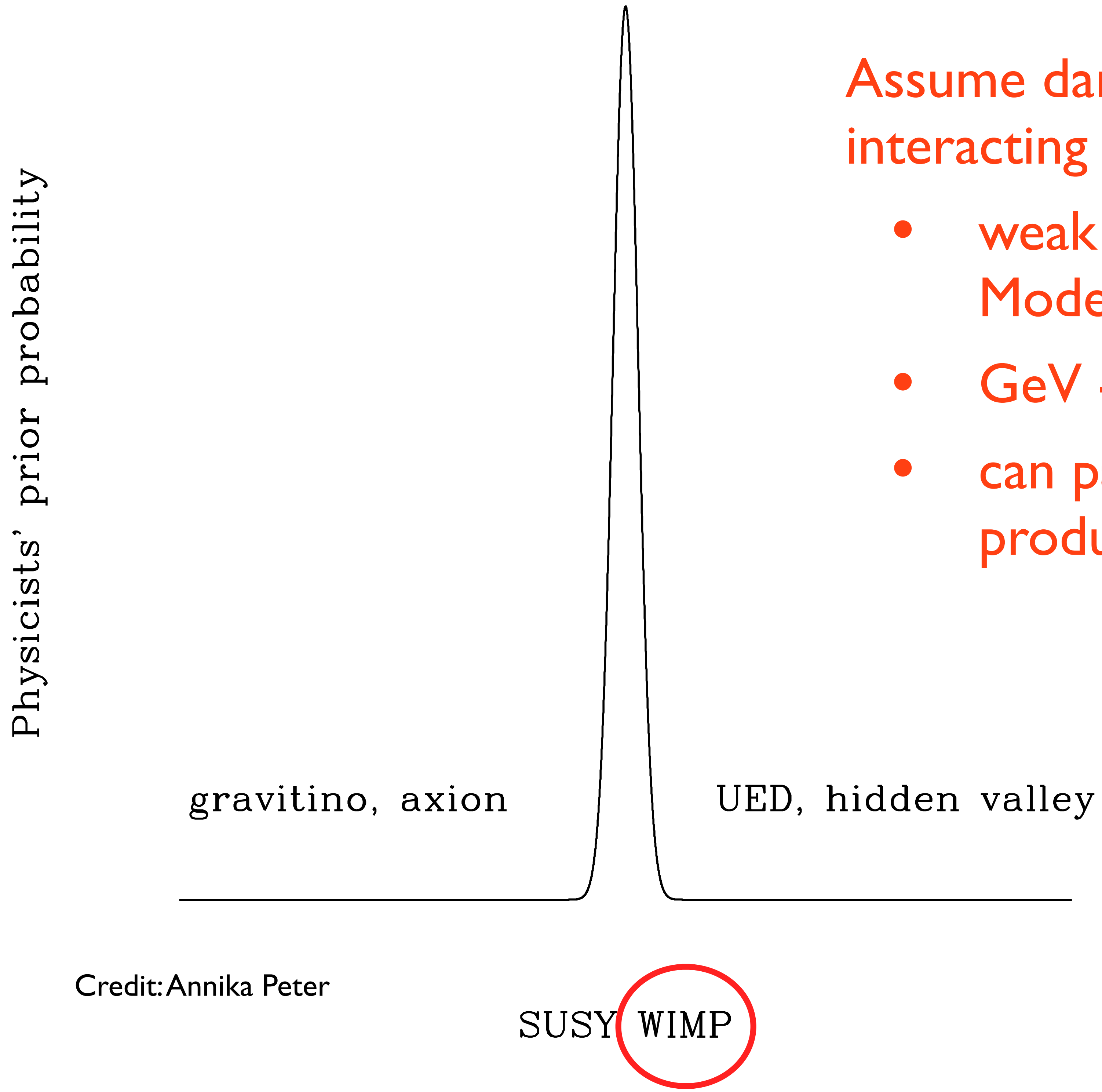
Indirect detection



IceCube
[neutrinos]



Particle dark matter candidates



Credit: Annika Peter

Assume dark matter is a WIMP (weakly-interacting massive particle):

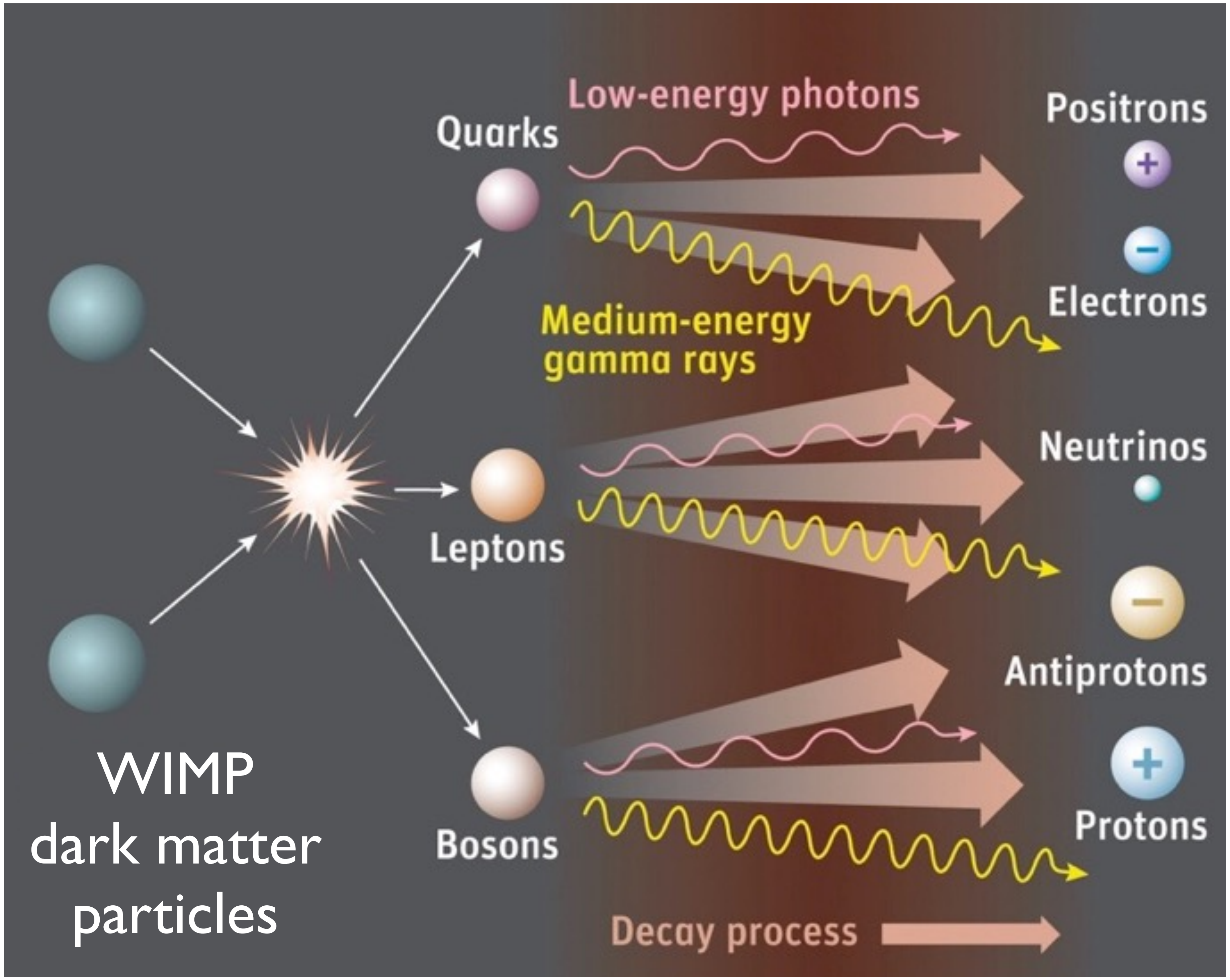
- weak interactions with Standard Model
- GeV - TeV mass scale
- can pair annihilate or decay to produce Standard Model particles

Other candidates for indirect searches

- Sterile neutrinos
  - viable warm or cold DM candidate depending on production mechanism
  - radiatively decay to active neutrinos producing a photon line at half the sterile neutrino mass
  - most currently viable parameter space is for 1-100 keV mass (X-ray energies)
  - responsible for claimed 3.5 keV line?

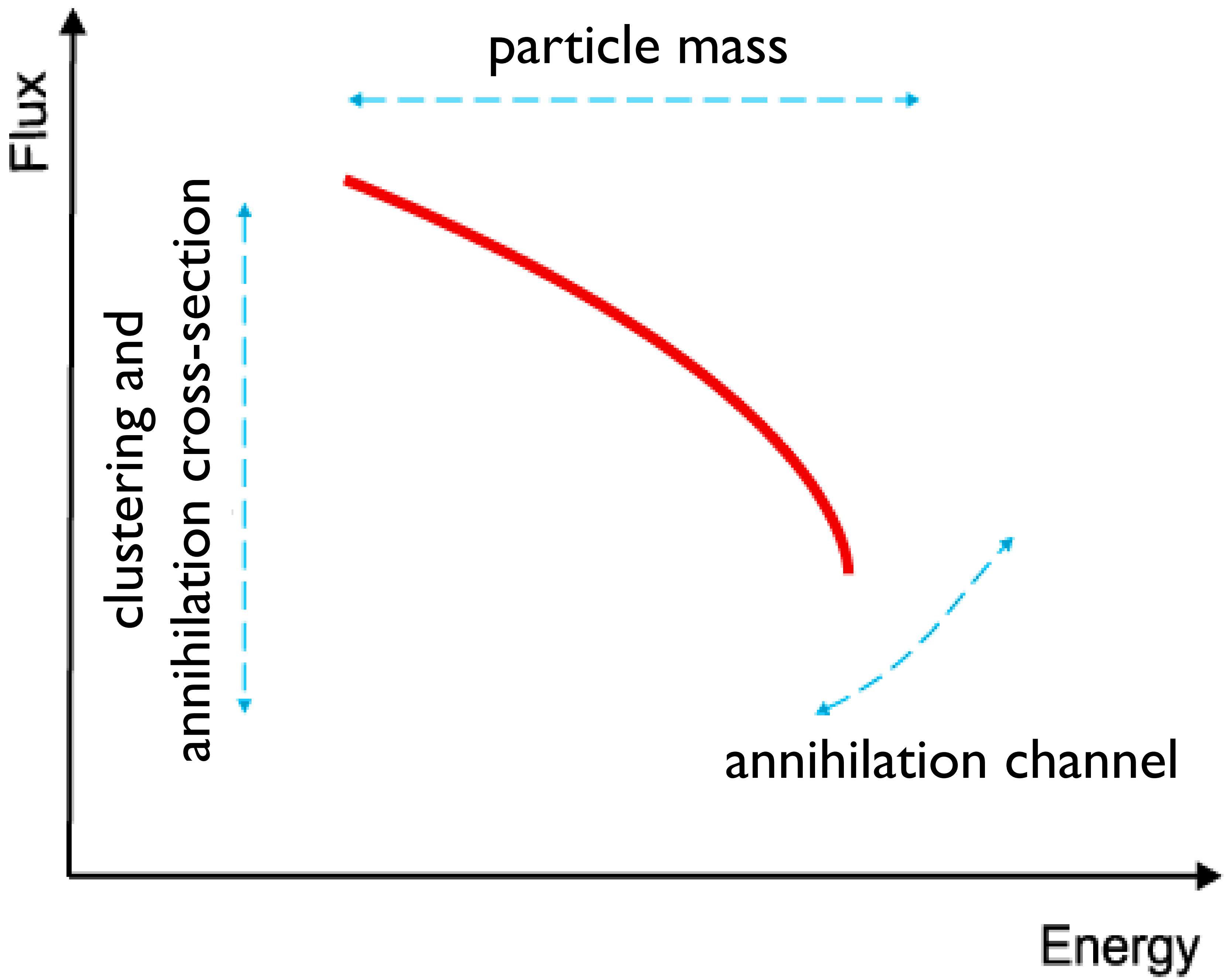
- Superheavy dark matter (mass > 10^{12} GeV)
  - non-thermal relic
  - can annihilate or decay to SM particles, such as ultra-high-energy cosmic rays or neutrinos

Indirect dark matter signals



Credit: Sky & Telescope / Gregg Dinderman

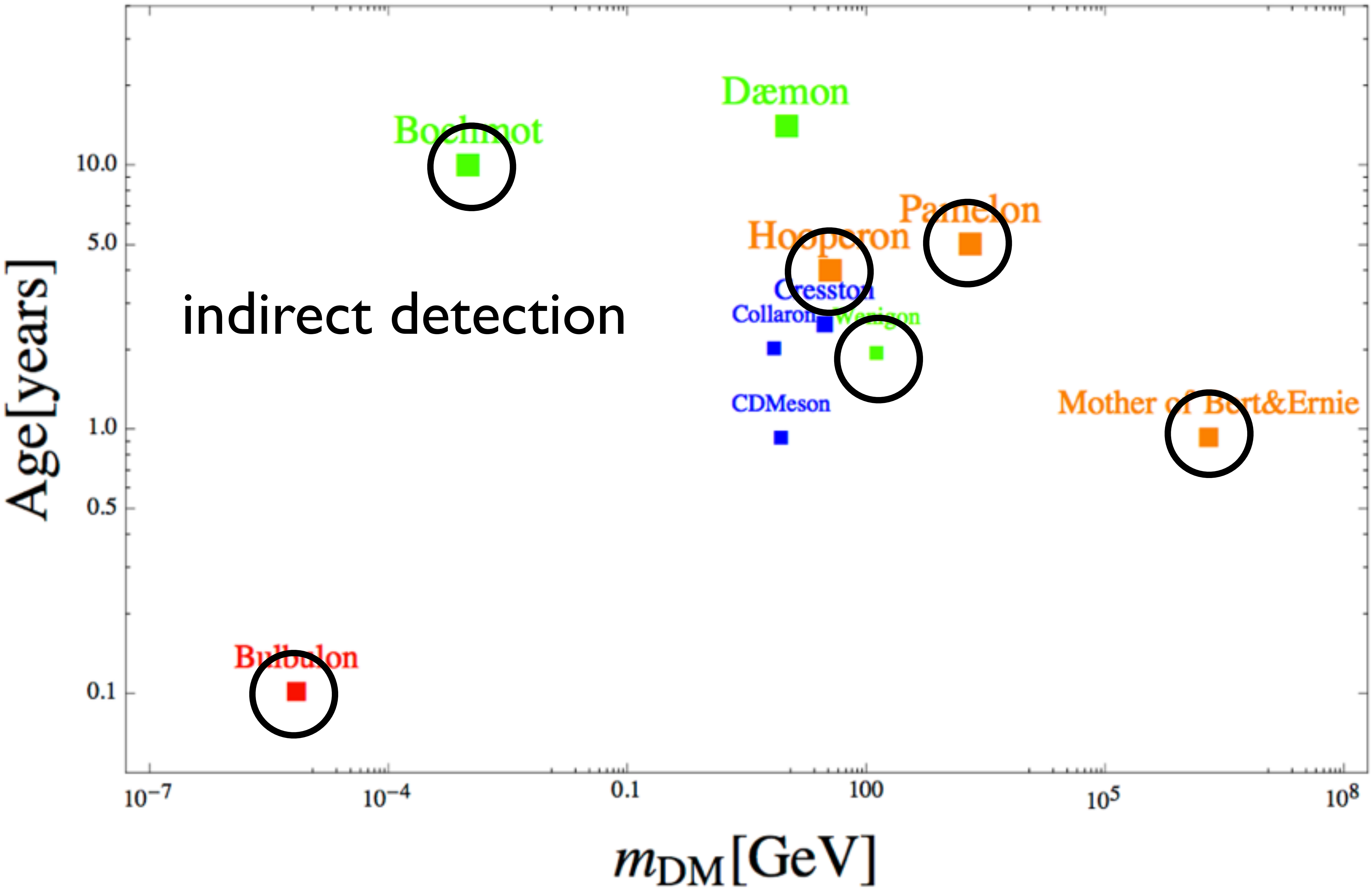
Indirect dark matter signals



adapted from Bertone 2007

Anomalies!

Credit: Jester @ http://resonaances.blogspot.com



Indirect detection: selling points

- only way to identify *particle* DM in an astrophysical context
- needed to show that a DM candidate detected at a collider or in a lab indeed is the cosmological DM and is stable on cosmological timescales
- for WIMPs, there is a theoretical prediction for the total annihilation cross section
- anomalies!

Indirect messengers

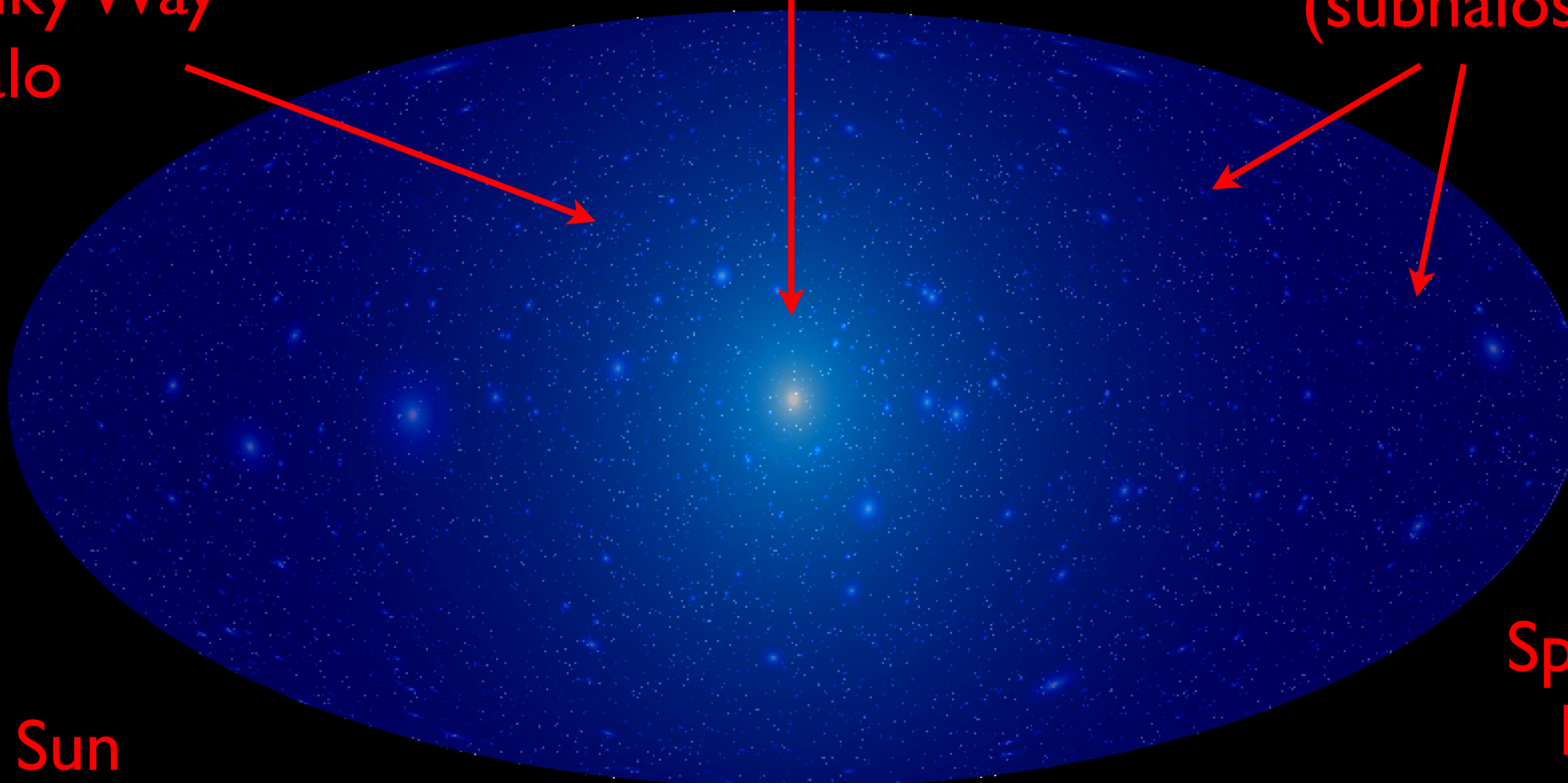
	Instruments	Advantages	Challenges
Gamma-ray photons	Fermi, HESS(-II), VERITAS, MAGIC, CTA, GAMMA-400, DAMPE, ASTROGAM	point back to source, spectral signatures	backgrounds, attenuation
Neutrinos	IceCube/DeepCore/PINGU, ANTARES, KM3NET, Super-K, Hyper-K	point back to source, spectral signatures	low statistics, backgrounds
Charged particles	PAMELA, AMS(-02), ATIC, ACTs, Fermi, CTA, CALET, GAPS	antimatter hard to produce astrophysically	diffusion, propagation uncertainties, don't point back to sources
Multiwavelength emission	[radio to X-ray telescopes!]	often better angular resolution, more statistics, different backgrounds	depends on assumptions about environment for secondary processes

Dark matter in the gamma-ray sky

The inner galaxy

The Milky Way halo

Unassociated sources (subhalos?)



Galaxy clusters

Dwarf galaxies

The Sun

Spectral lines

The isotropic gamma-ray background

Anisotropies

Image Credit: JG 2008

The Fermi LAT gamma-ray sky

5 years, E > 1 GeV

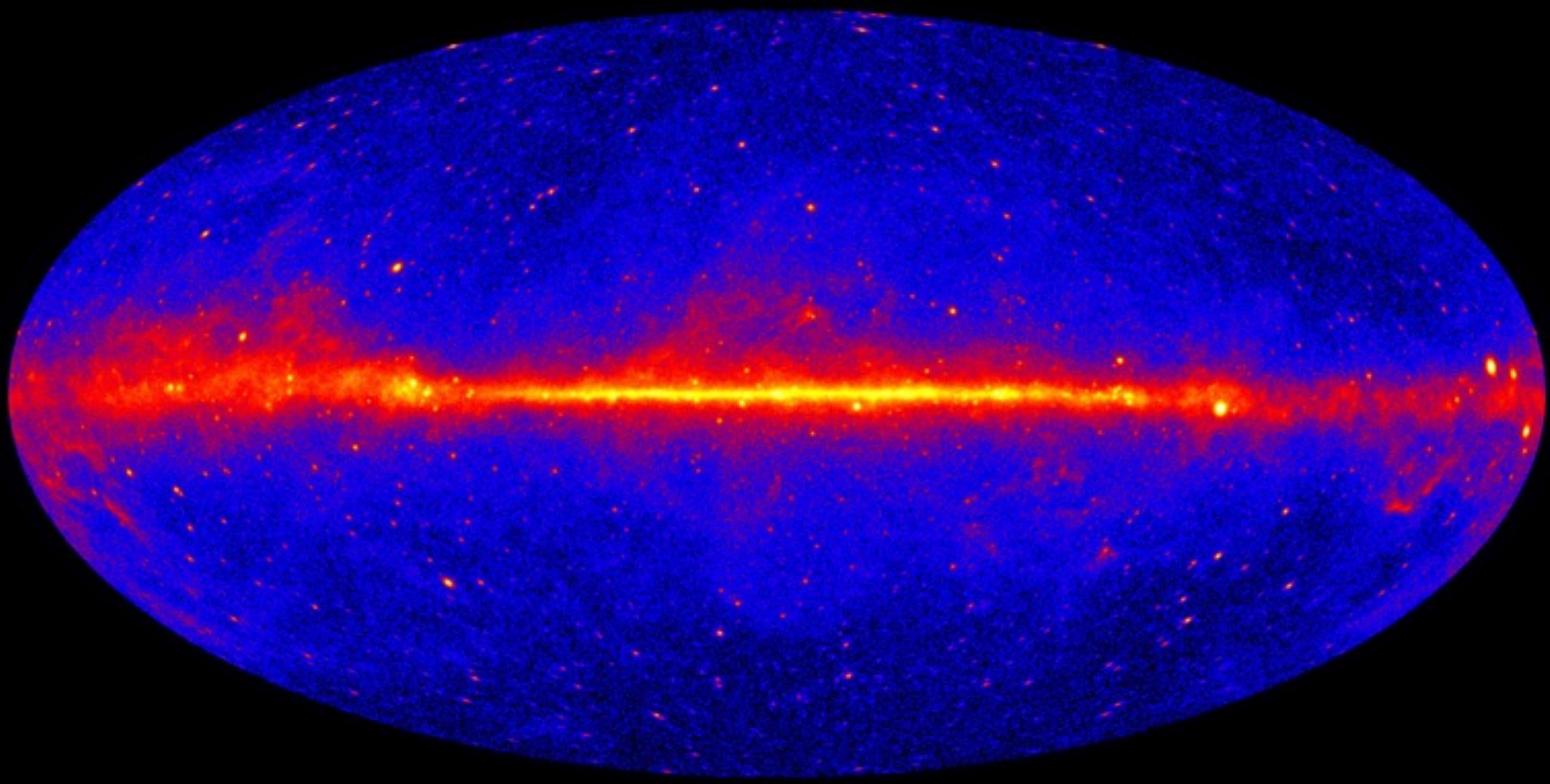
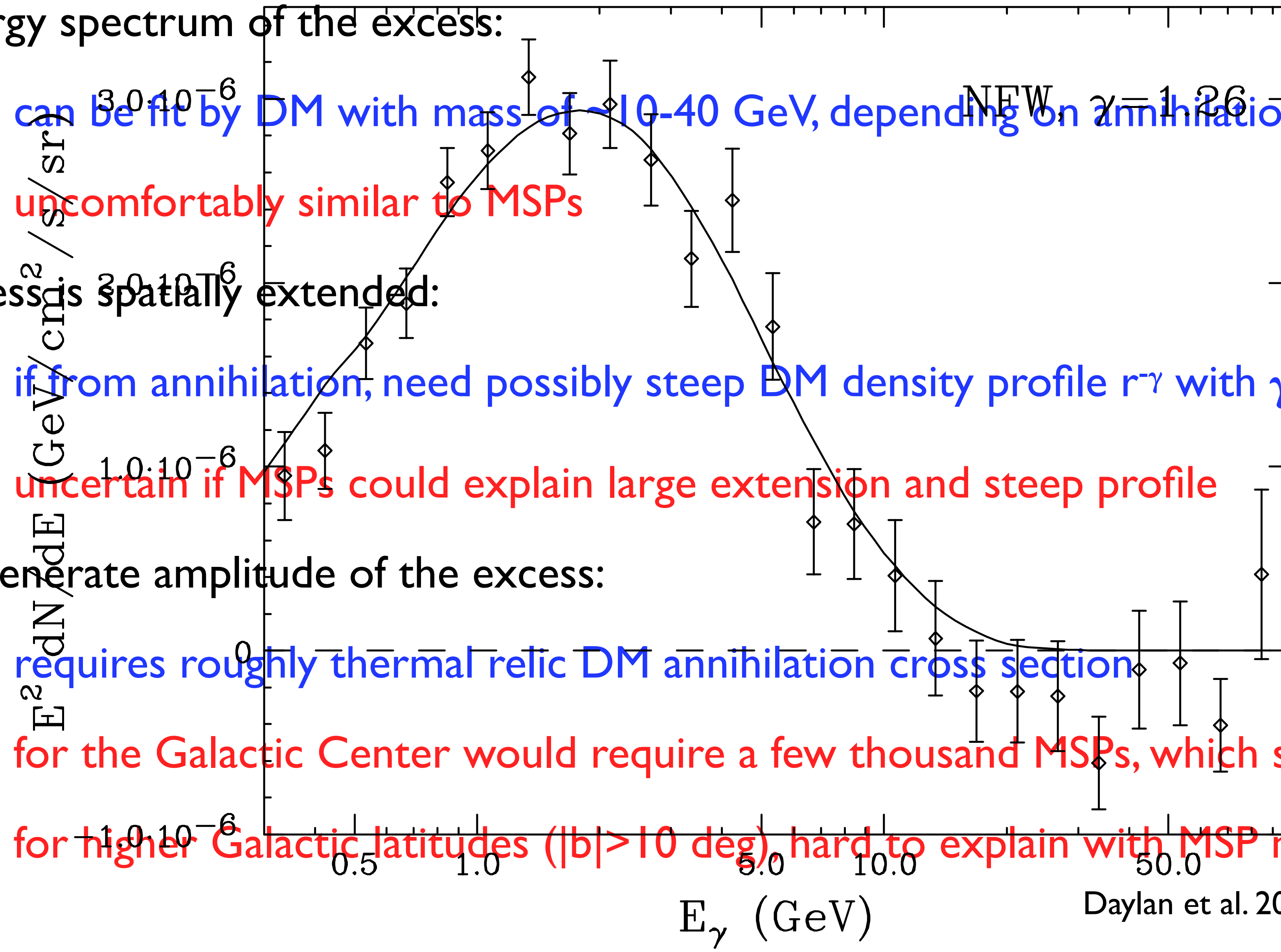


Image Credit: NASA/DOE/International LAT Team

A dark matter signal in the Inner Galaxy?

- Using Fermi LAT data, multiple groups have claimed an excess at a few GeV from the Galactic Center and higher Galactic latitudes. The excess has been interpreted as emission from dark matter (DM) annihilation and/or unresolved millisecond pulsars (MSPs).
- Energy spectrum of the excess:
  - can be fit by DM with mass of ~10-40 GeV, depending on annihilation channel
  - uncomfortably similar to MSPs
- Excess is spatially extended:
  - if from annihilation, need possibly steep DM density profile $r^{-\gamma}$ with γ = 1.0-1.4
  - uncertain if MSPs could explain large extension and steep profile
- To generate amplitude of the excess:
  - requires roughly thermal relic DM annihilation cross section
  - for the Galactic Center would require a few thousand MSPs, which seems plausible
  - for higher Galactic latitudes (|b|>10 deg), hard to explain with MSP models



Daylan et al. 2014

see: Hooper & Goodenough 2011, Morselli, Cañadas, Vitale (Fermi LAT) 2011, Abazajian & Kaplinghat 2012, Hooper & Slatyer 2013, Gordon & Macías 2013, Abazajian et al. 2014, Daylan et al. 2014, Calore et al. 2014, and others

Excess over what?

What's in the model:

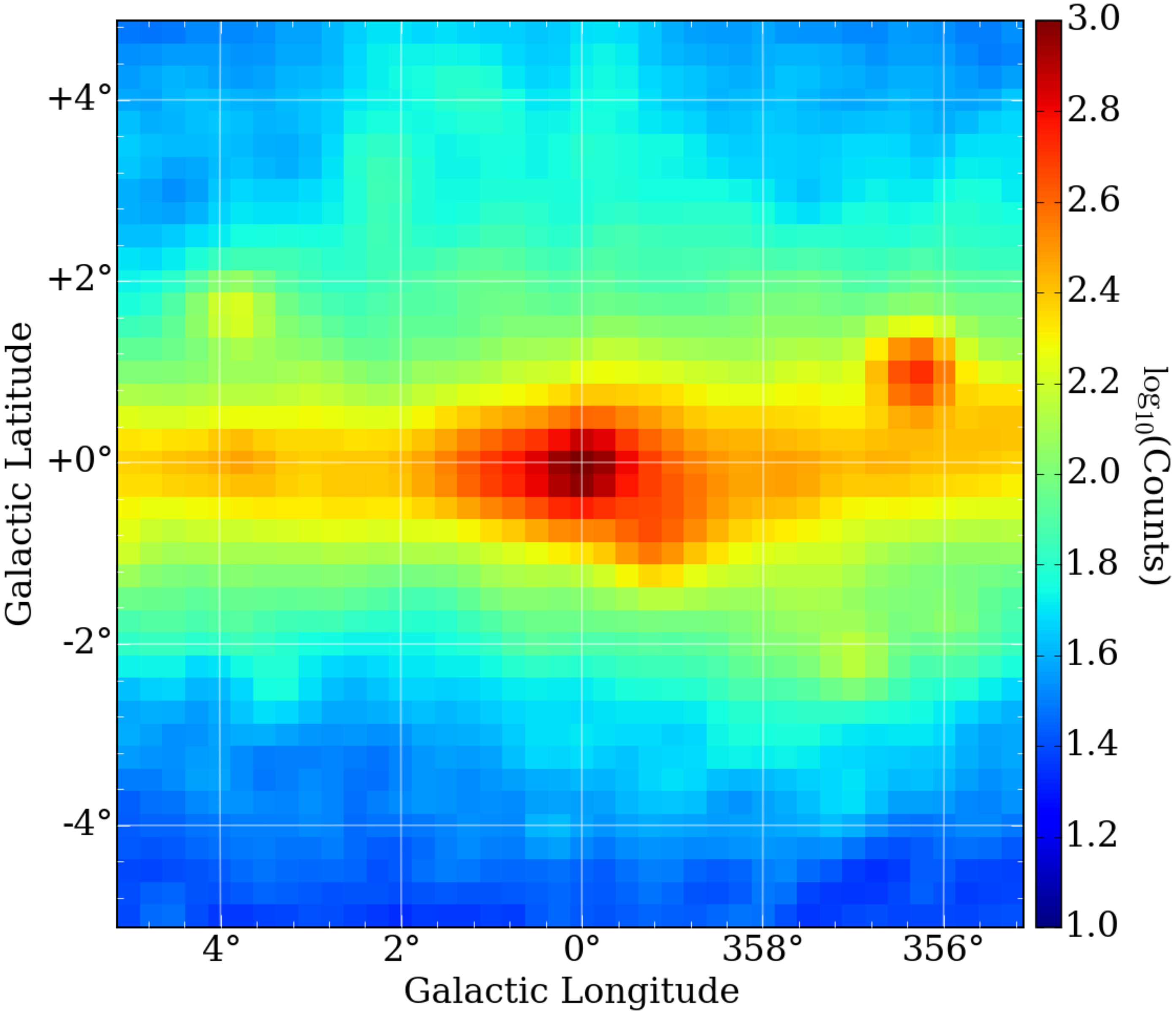
- Galactic diffuse emission associated with cosmic-ray interactions (sum of many processes)
- isotropic gamma-ray background (measured)
- detected gamma-ray sources (e.g., pulsars, supernova remnants)

What's not in the model:

- unresolved gamma-ray sources
- dark matter

Fermi LAT data

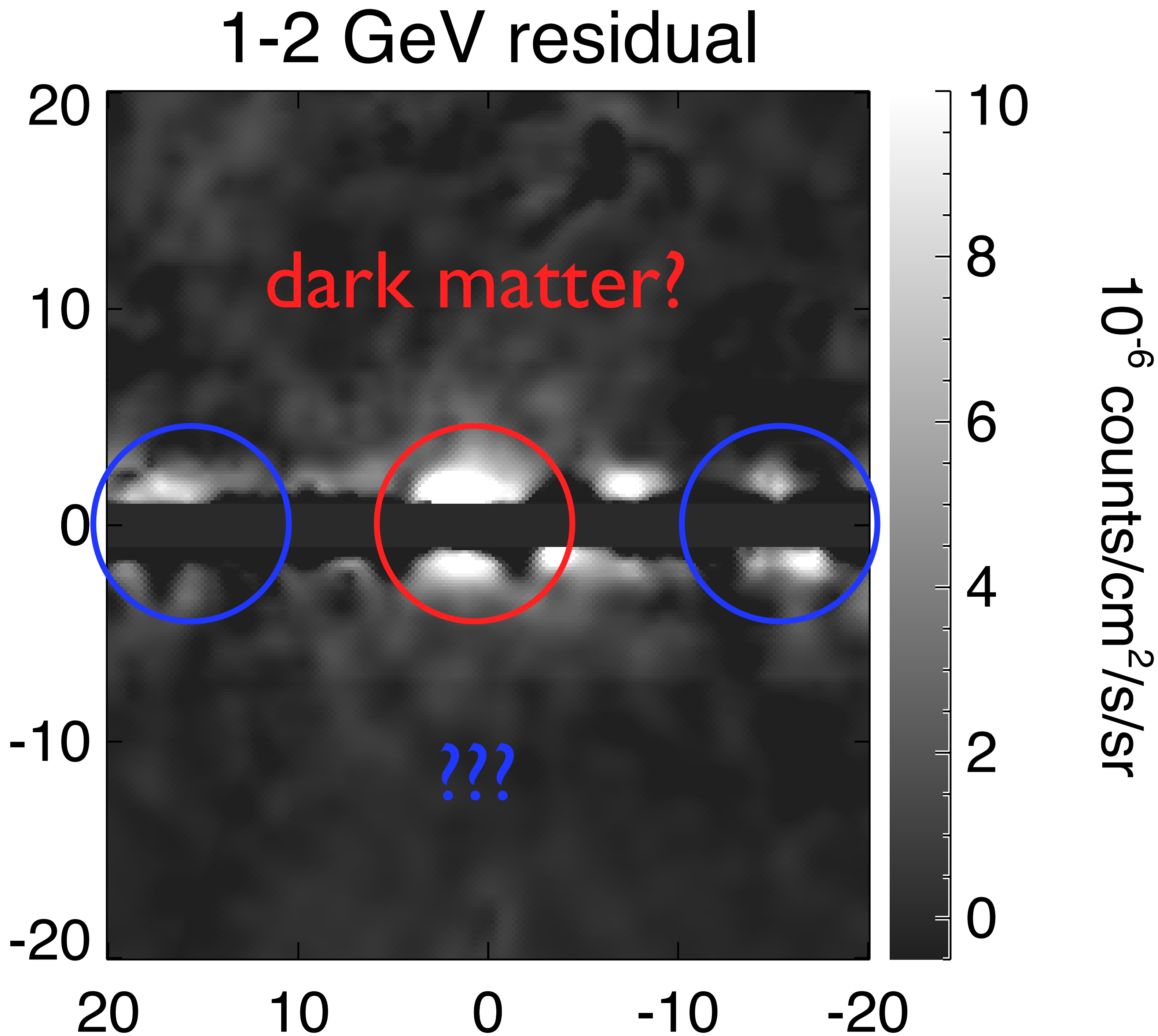
observed counts (1-35 GeV)



JG 2015 (in prep)

Residuals

(for best-fit model w/o dark matter component)



Daylan et al. 2014

Can the GeV excess be millisecond pulsars?

Can unresolved MSPs produce the high-latitude excess?

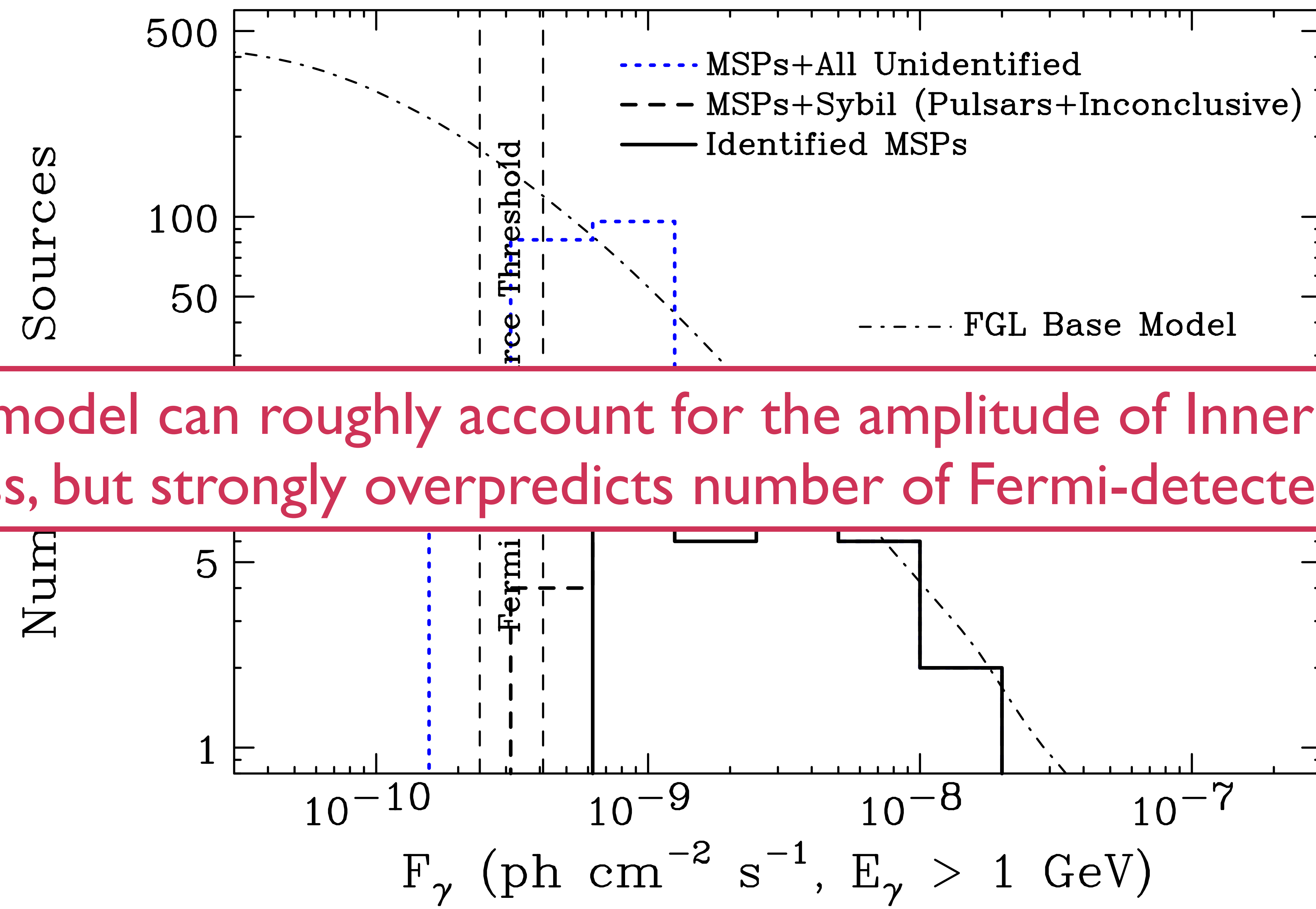
- first, note that only a few dozen MSPs have been detected in gamma rays; Galactic MSP population could be ~ 10k! We've only seen the tip of the iceberg.
- adopt a spatial model and luminosity function for the MSPs, calibrated to detections in radio (start with base model of Faucher-Giguere & Loeb 2010)
- from model, calculate flux distribution of MSPs for $|b|>10$ deg
- (at low Galactic latitudes, model and observational uncertainties are larger)

Can the GeV excess be millisecond pulsars?

Unresolved sources
(contribute to diffuse)

Resolved sources

source count distribution (|b|>10 deg)

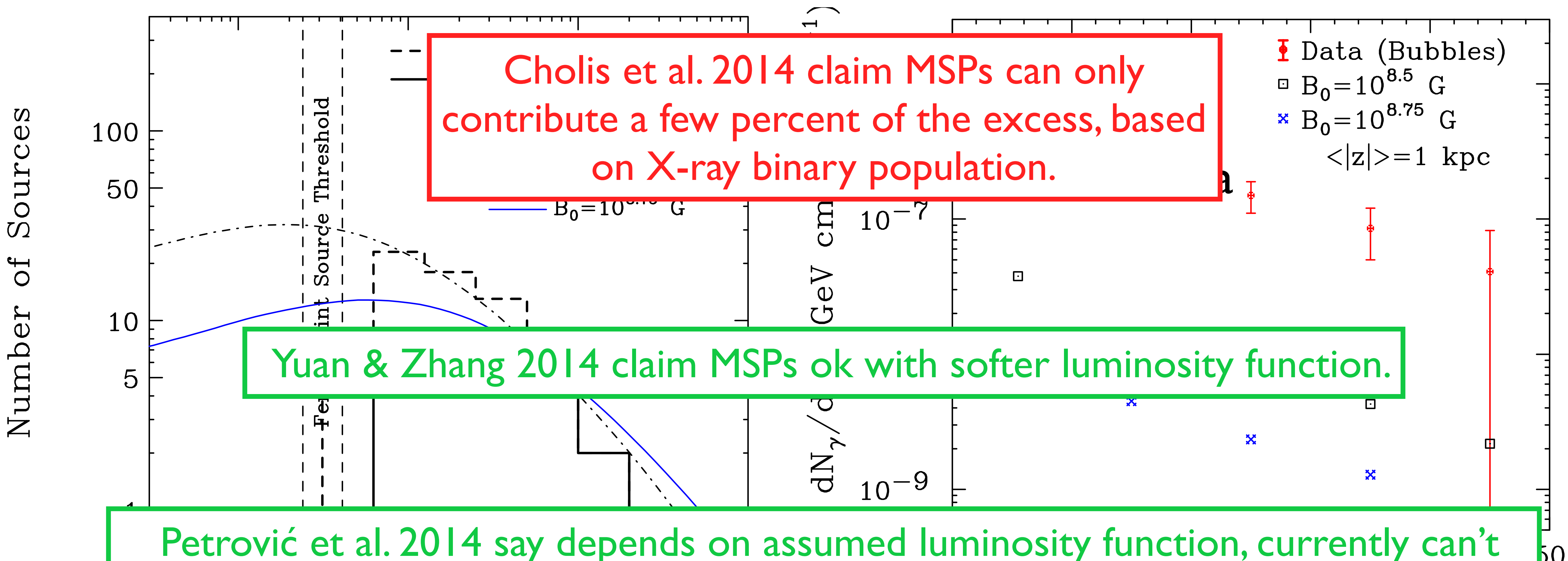


base model can roughly account for the amplitude of Inner Galaxy excess, but strongly overpredicts number of Fermi-detected MSPs

Hooper, Cholis, Linden, JG, Slatyer 2013

Can the GeV excess be millisecond pulsars?

Source count distribution | Latitude dependence of excess



Cholis et al. 2014 claim MSPs can only contribute a few percent of the excess, based on X-ray binary population.

Yuan & Zhang 2014 claim MSPs ok with softer luminosity function.

Petrović et al. 2014 say depends on assumed luminosity function, currently can't exclude MSPs.

adjusting MSP model parameters to better reproduce the observed source counts leads to models that cannot explain the *amplitude* of the observed excess

Hooper, Cholis, Linden, JG, Slatyer 2013

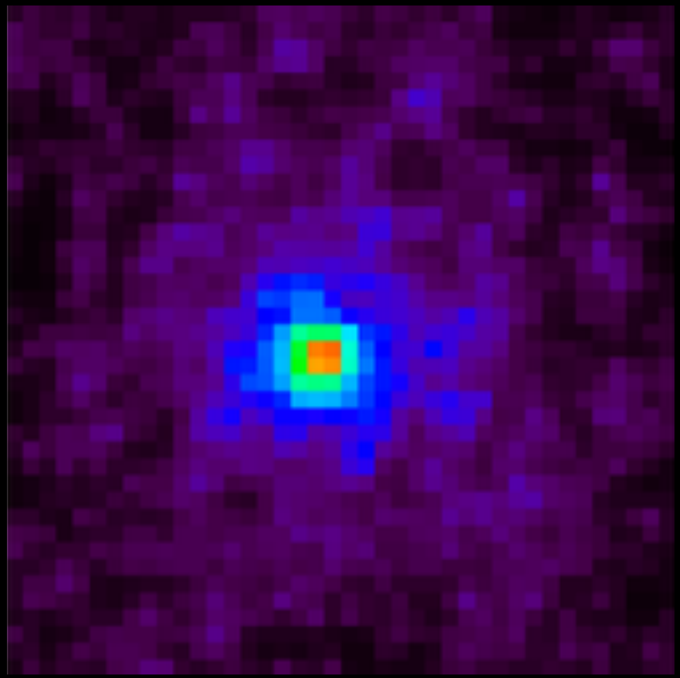
Bed of Procrustes

Statistics of the Inner Galaxy emission

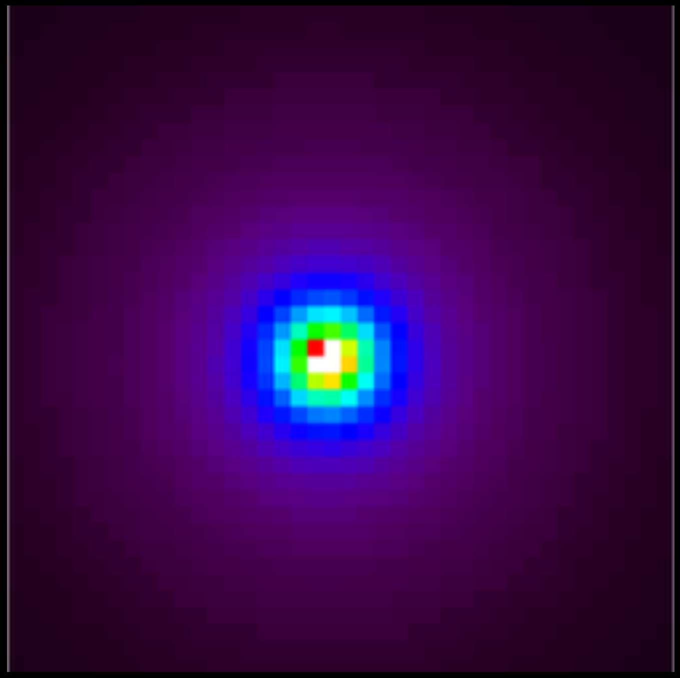
- GeV excess analyses to date have used spatial templates based on the *average* properties of the emission from DM or sources because we do not know the locations of unresolved sources
- real data contains information that is lost in spatial models which represent average source emission
- we will use *statistical information* in the emission to constrain the properties of its contributors

Statistical properties of diffuse emission

sources map



DM map

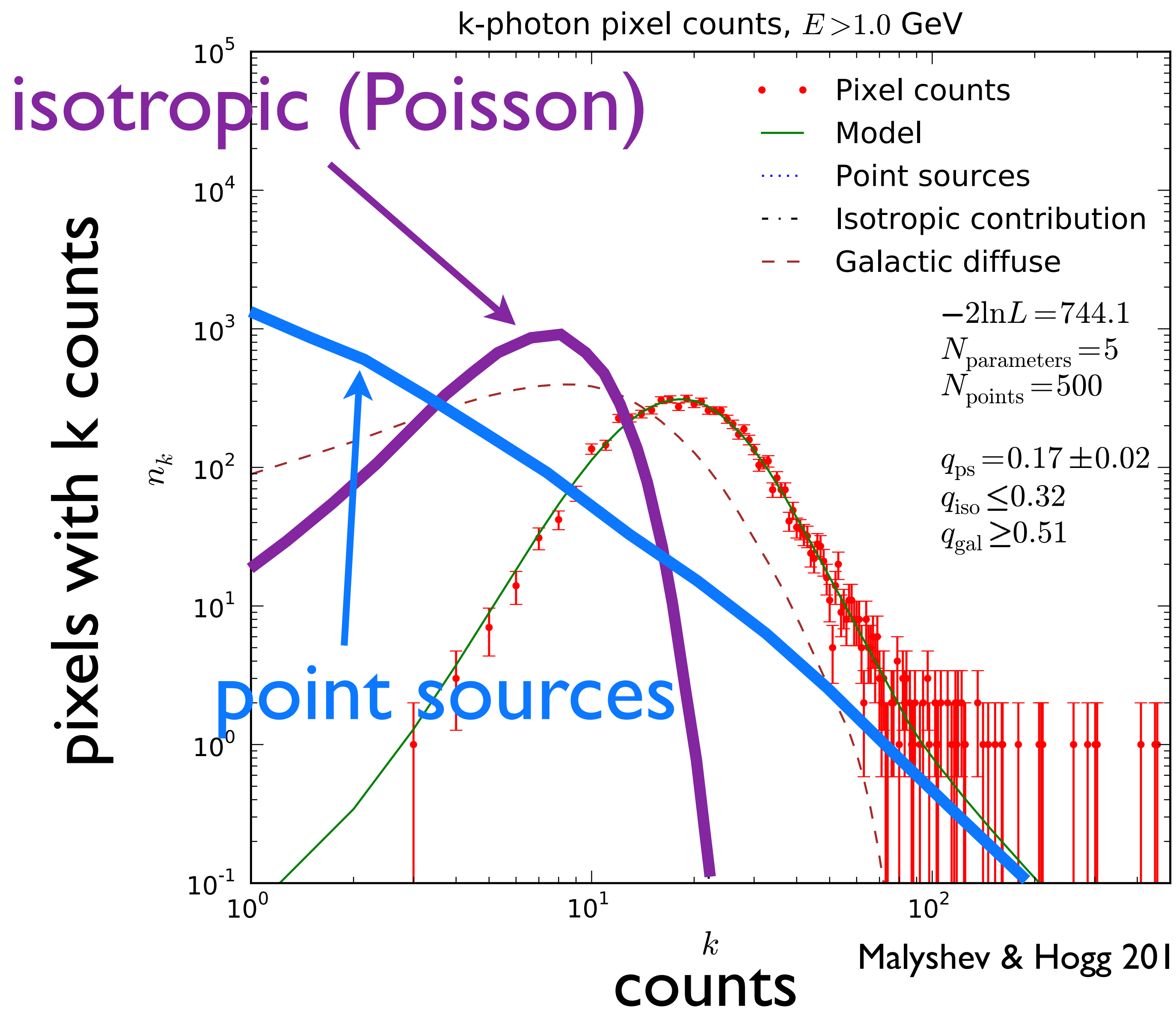


- diffuse emission arising from point sources has different clustering properties than emission from a smooth source (such as DM annihilation in the Inner Galaxy)
- can use the 1pt-PDF (# of pixels with k counts vs k counts) to characterize the clustering properties

The 1pt-PDF

- in the case of uniform exposure, the 1pt-PDF for a truly isotropic source will be Poisson-distributed
- sources feature a larger high-count tail and larger low count tail at the expense of the moderate-count regime

1pt-PDF of the Fermi gamma-ray background



Malyshev & Hogg 2011

NB: 1pt-PDFs are NOT additive

1pt-PDF analysis of the Inner Galaxy

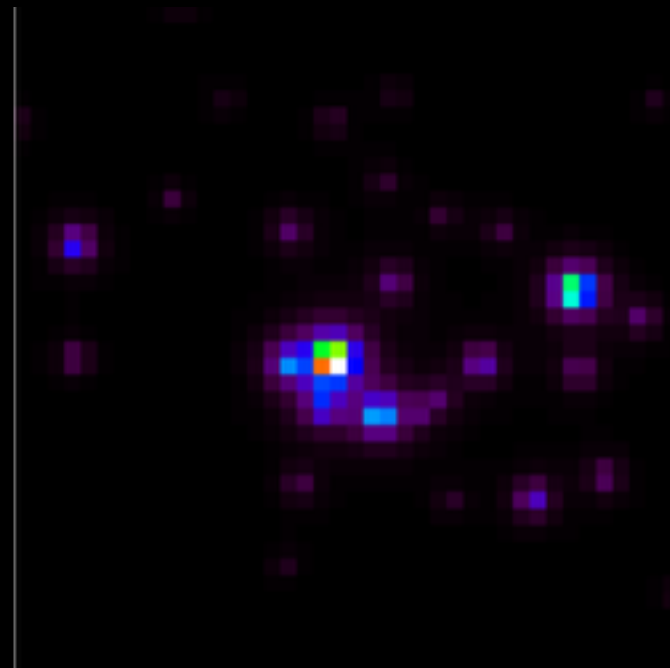
Natalie Harrison
(UChicago undergrad)

- to date we have performed a preliminary, proof-of-concept analysis based on simulated data only
- results today focused on understanding the origin of the GeV excess, method is generally applicable and analysis is being extended to test for possible dark matter signals over a wider range of masses and channels

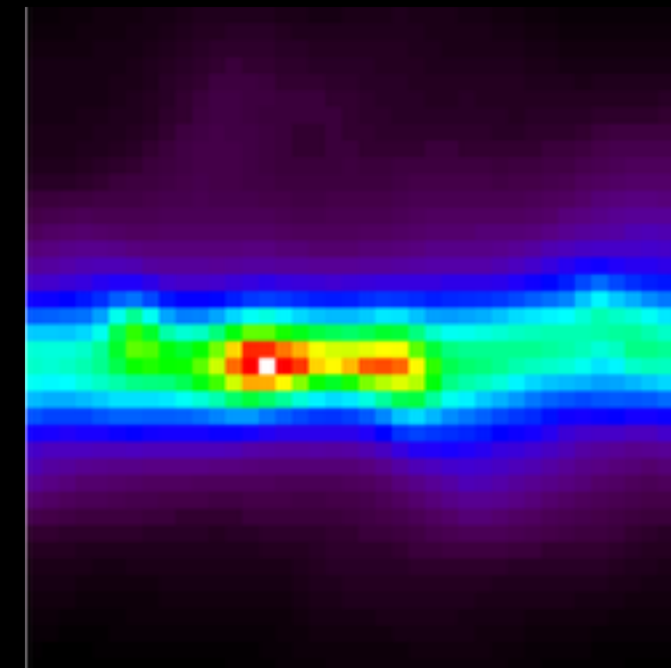
Inner Galaxy Components

- resolved sources (2FGL catalog)
- Galactic diffuse
- unresolved sources
- dark matter
- IGRB (included in model, but subdominant and not shown here)

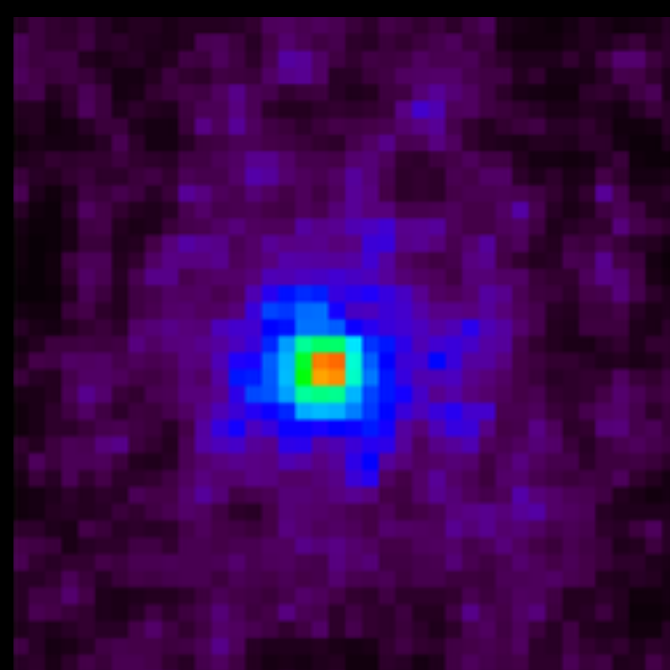
resolved sources (2FGL)



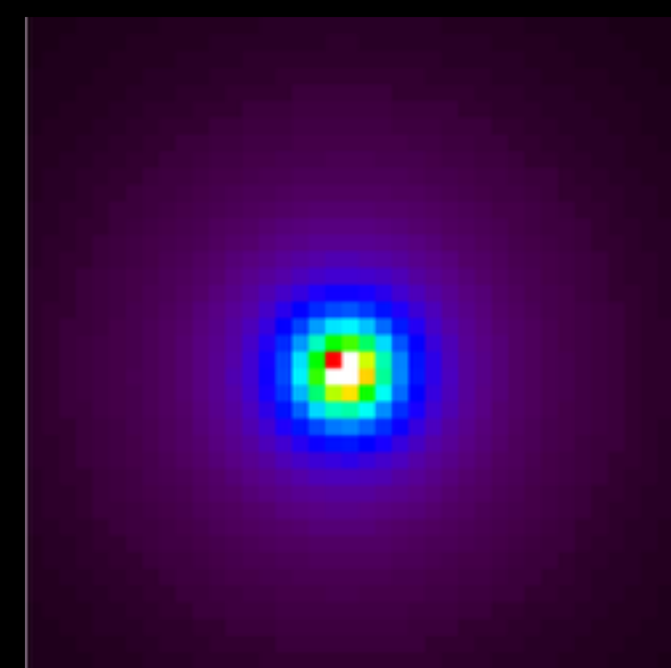
Galactic diffuse



unresolved sources

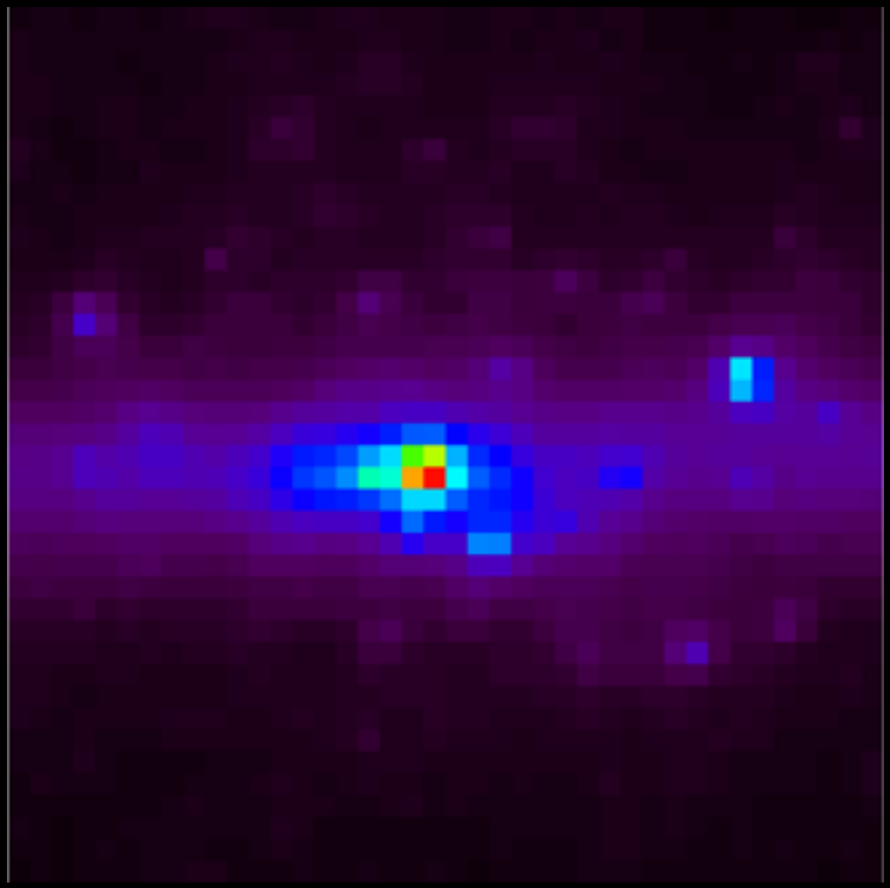


dark matter

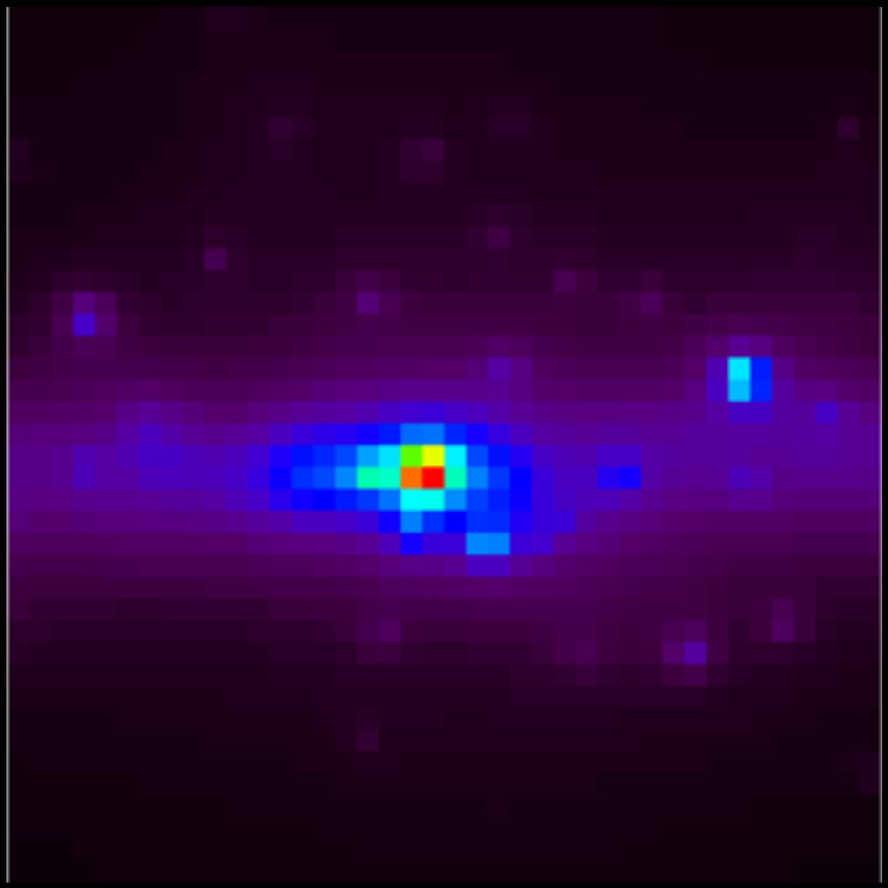


Total emission models

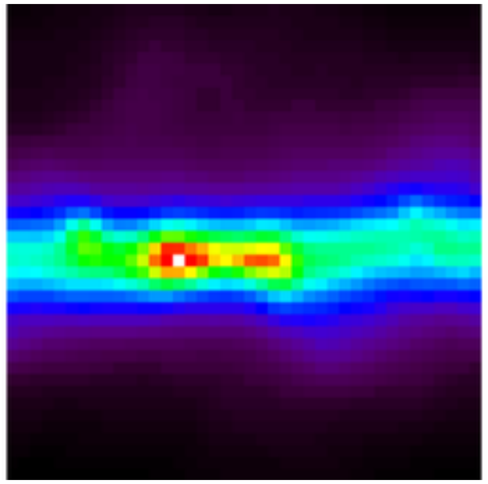
GAL+2FGL+ISO+
unresolved sources

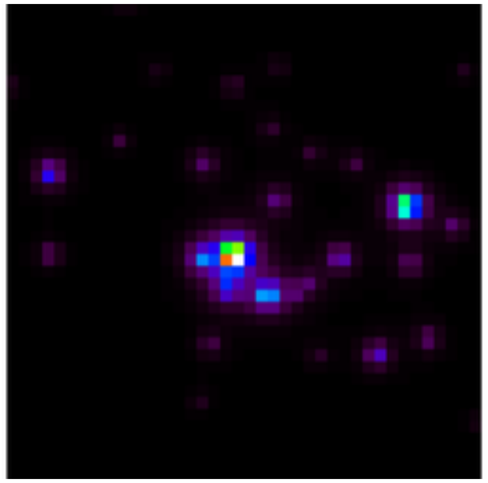


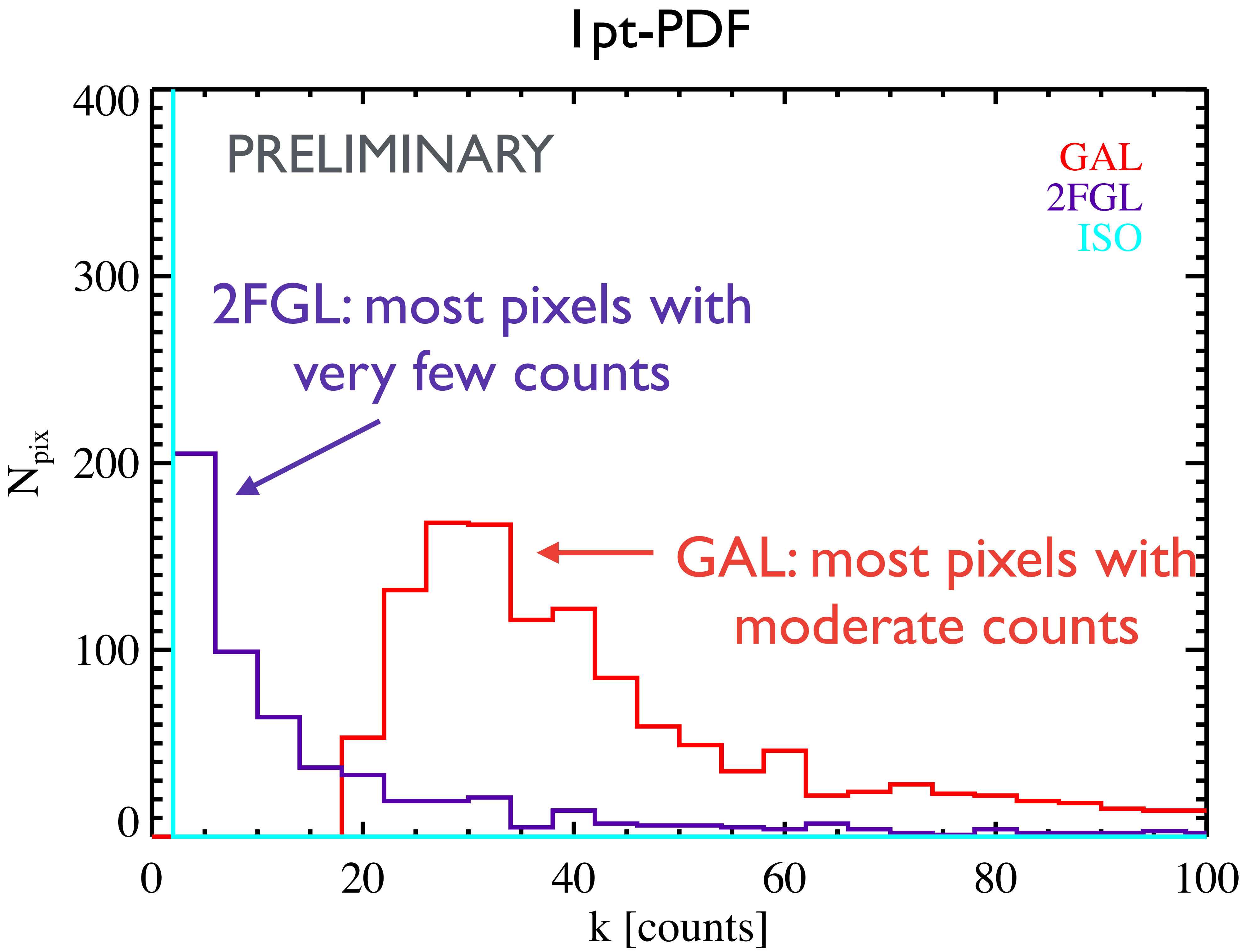
GAL+2FGL+ISO+
dark matter



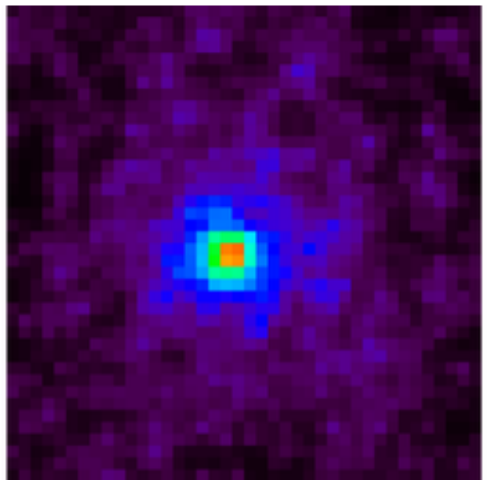
Inner Galaxy: components I

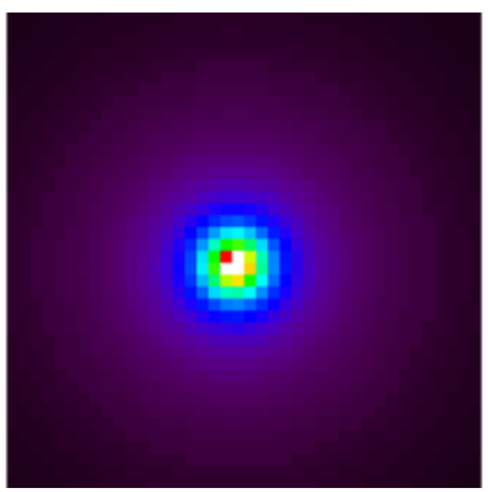




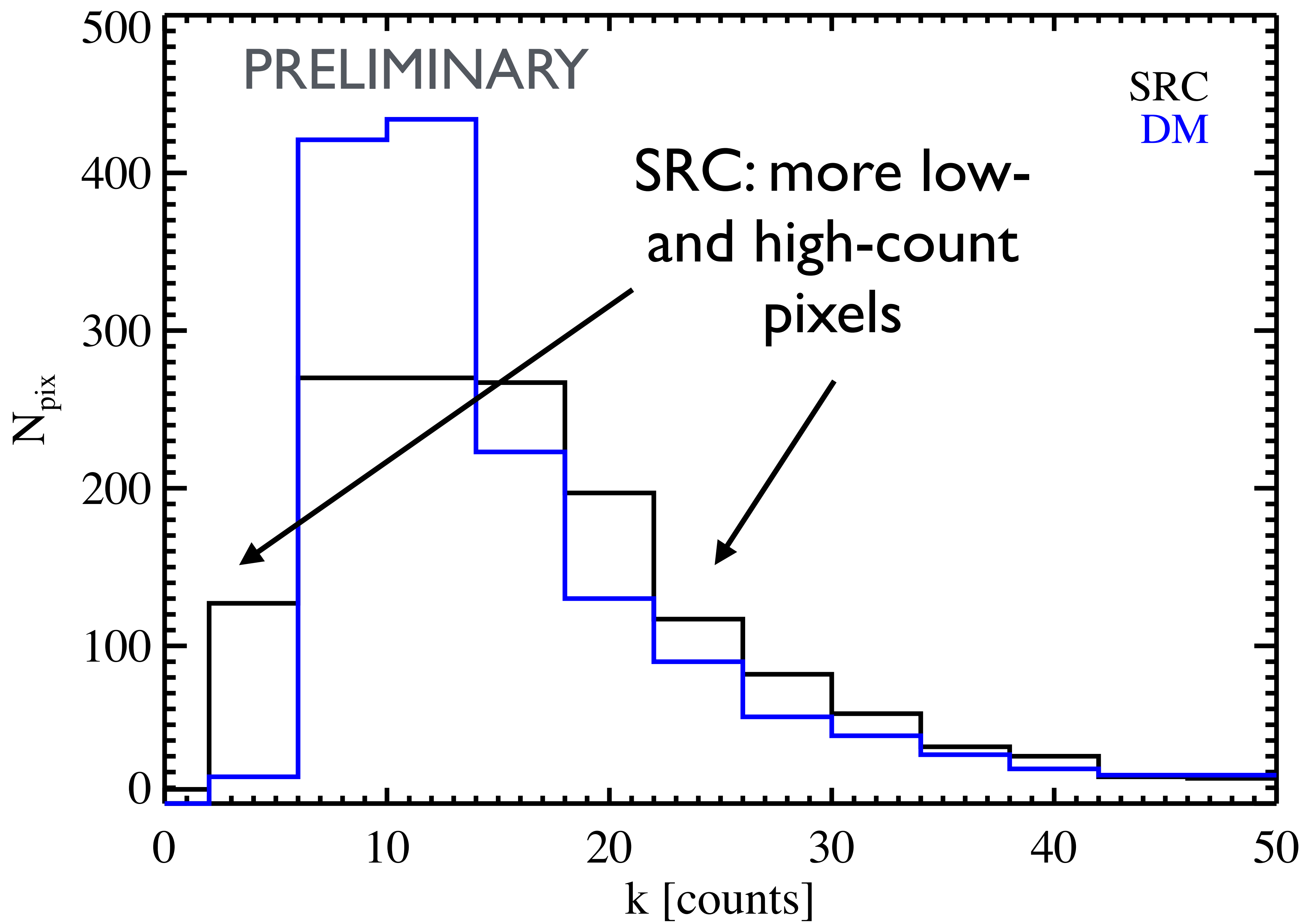


Inner Galaxy: components II



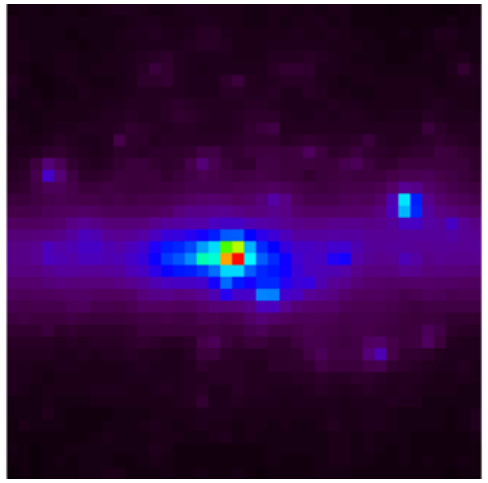


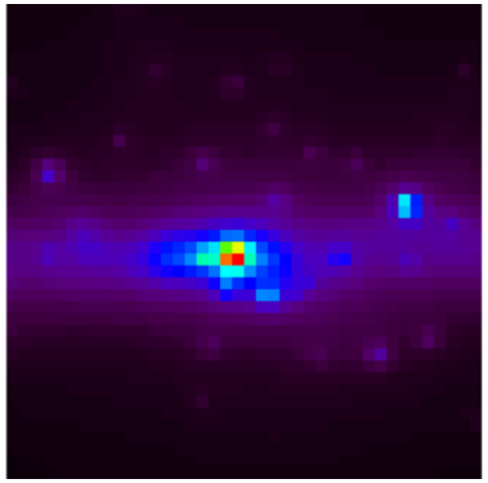
1pt-PDF



DM vs sources, with GAL+CAT+ISO

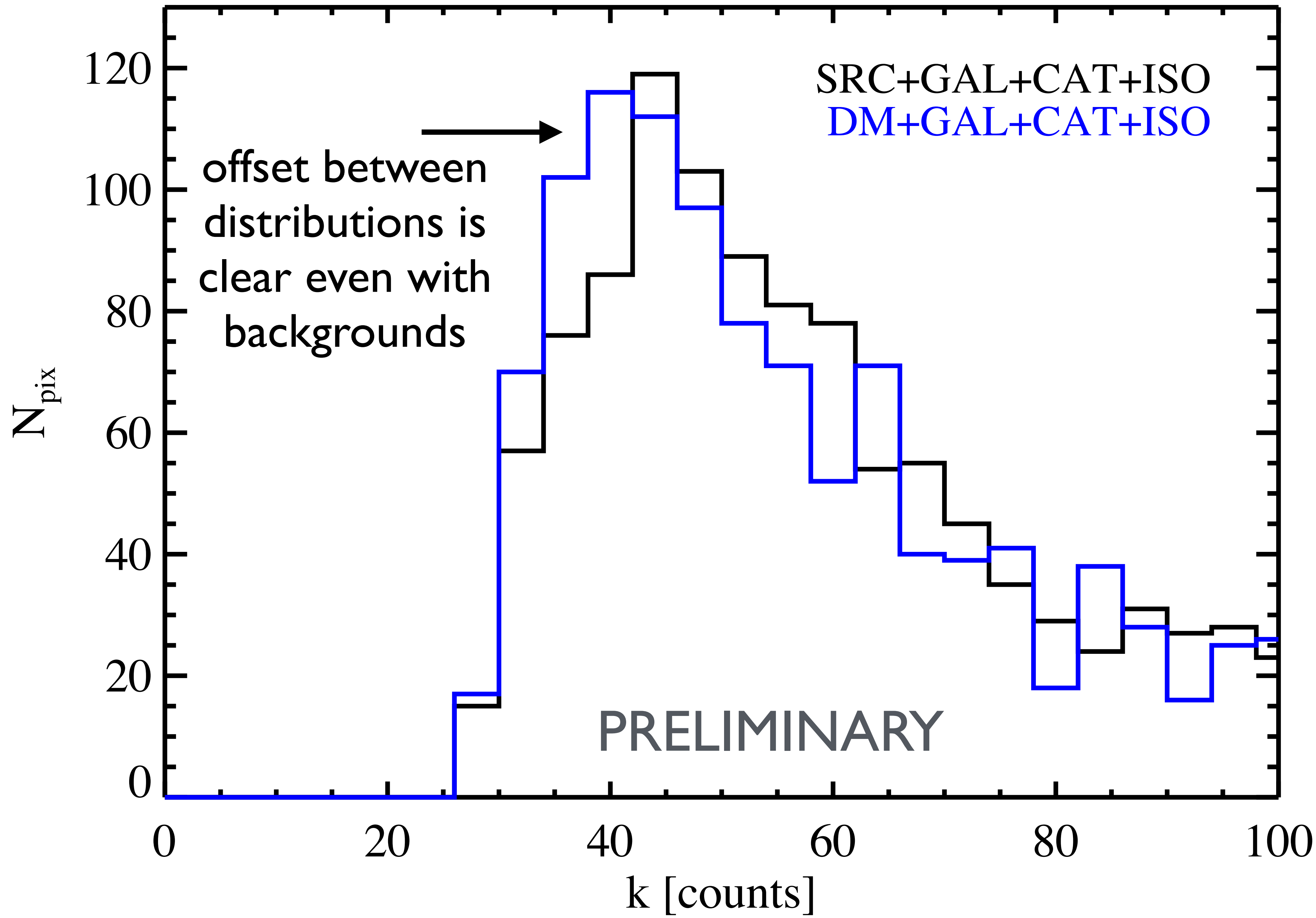
w/ sources





w/ DM

1pt-PDF (zoomed on low-count range)



Comments

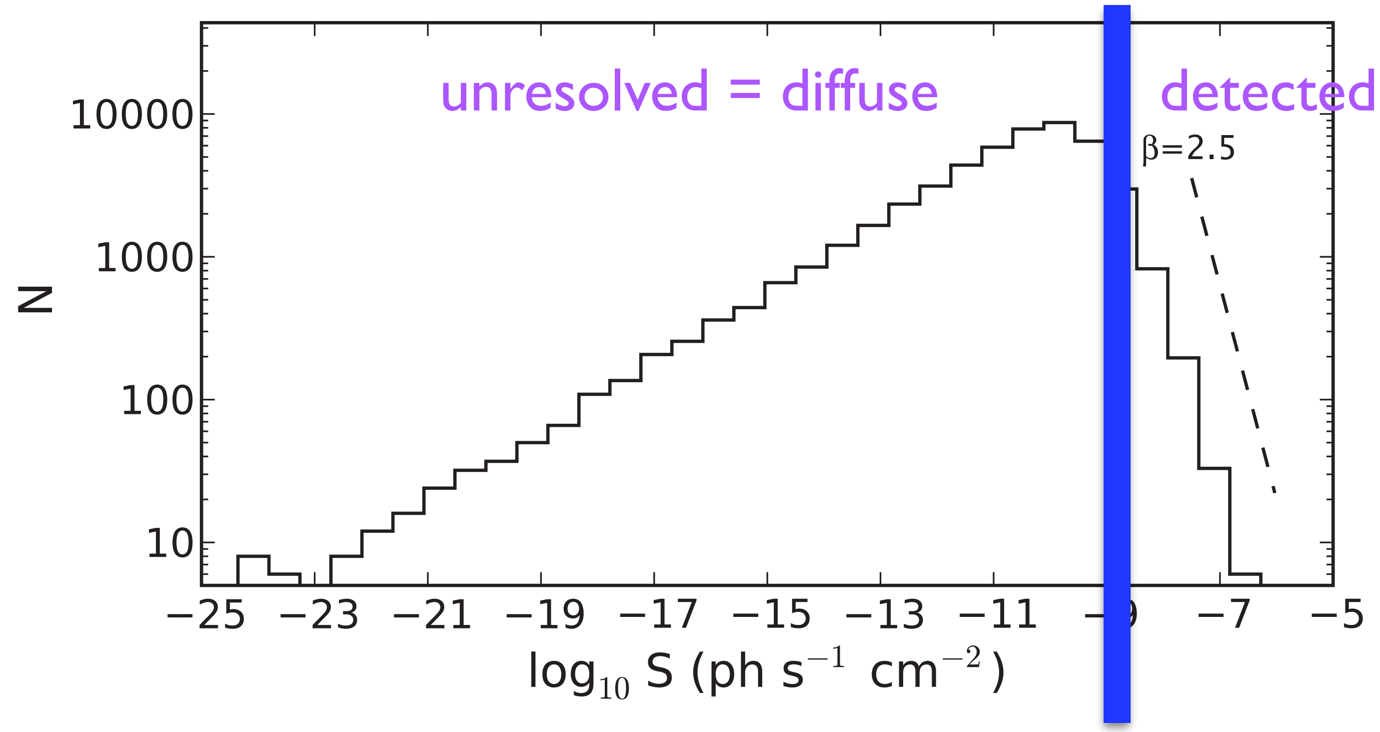
- current implementation of sources is somewhat optimistic (steep slope of logN-logS, so most sources near threshold)

- however, *for MSPs this is not so far from reality*: models predict that most undetected MSPs are close to flux threshold

- naturally, the limit of many, many sources with small fluxes is indistinguishable from a smooth component

MSP model logN-logS

Faucher-Giguère & Loeb 2010



approx 2FGL threshold
(E>100 MeV, Gamma=1.5)

Summary

- the Galactic Center GeV excess is a very intriguing possible dark matter signal
- important to rule out non-exotic explanations before claiming a dark matter origin
- the 1pt-PDF may offer a unique and robust means of distinguishing between sources and a smooth distribution