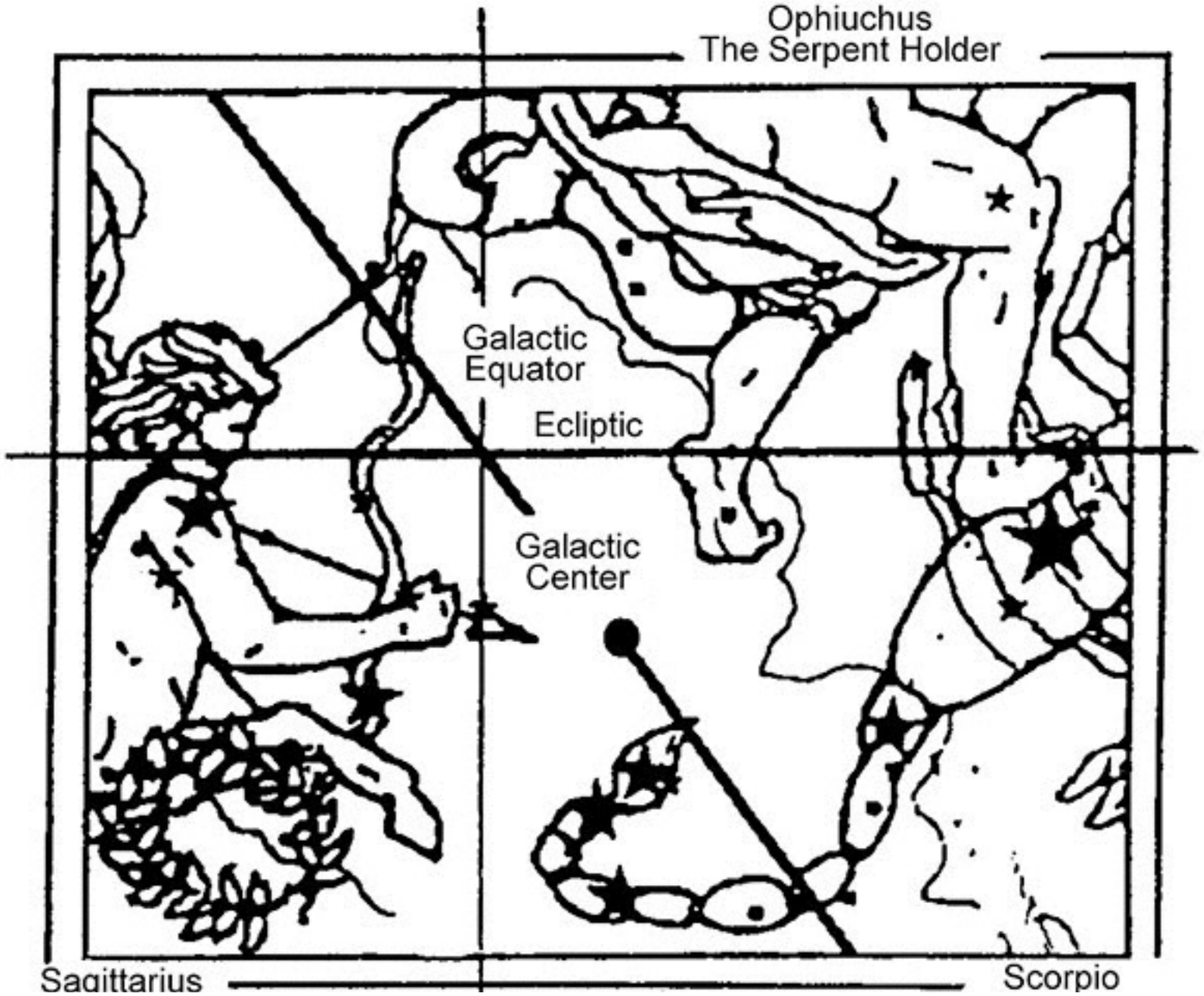
Fermi LAT's view on the centre of the Galaxy



Gabrijela Zaharijas

University of Nova Gorica and INFN, Trieste

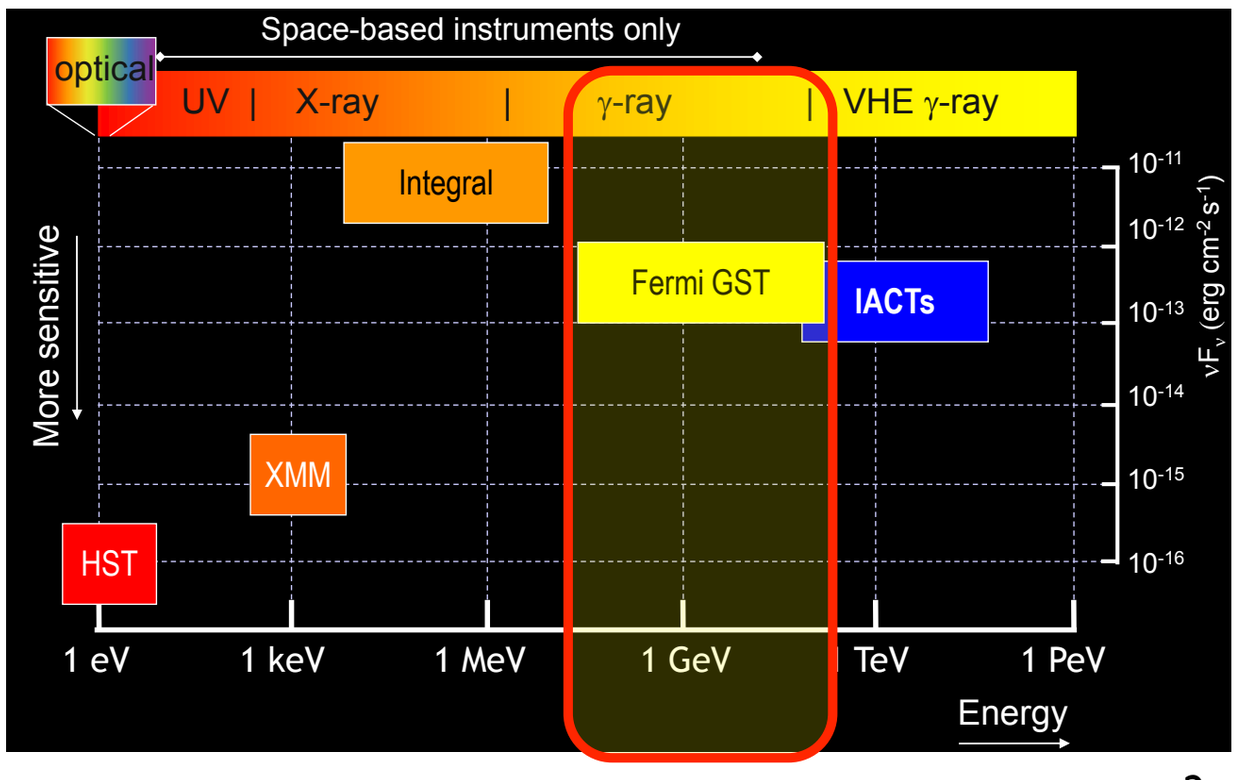
(on behalf of the Fermi LAT collaboration)

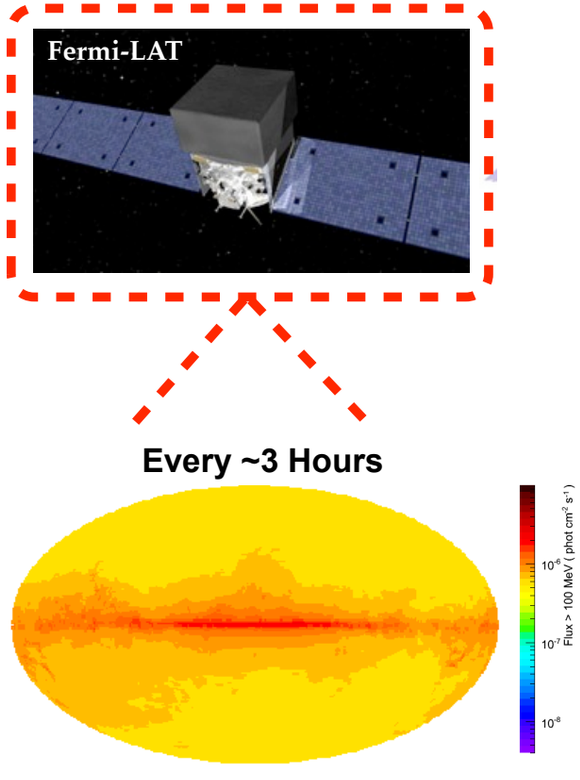
The Fermi LAT

Energy range: 20 MeV - 300 GeV

Field of view: 20% of the sky at any instant!

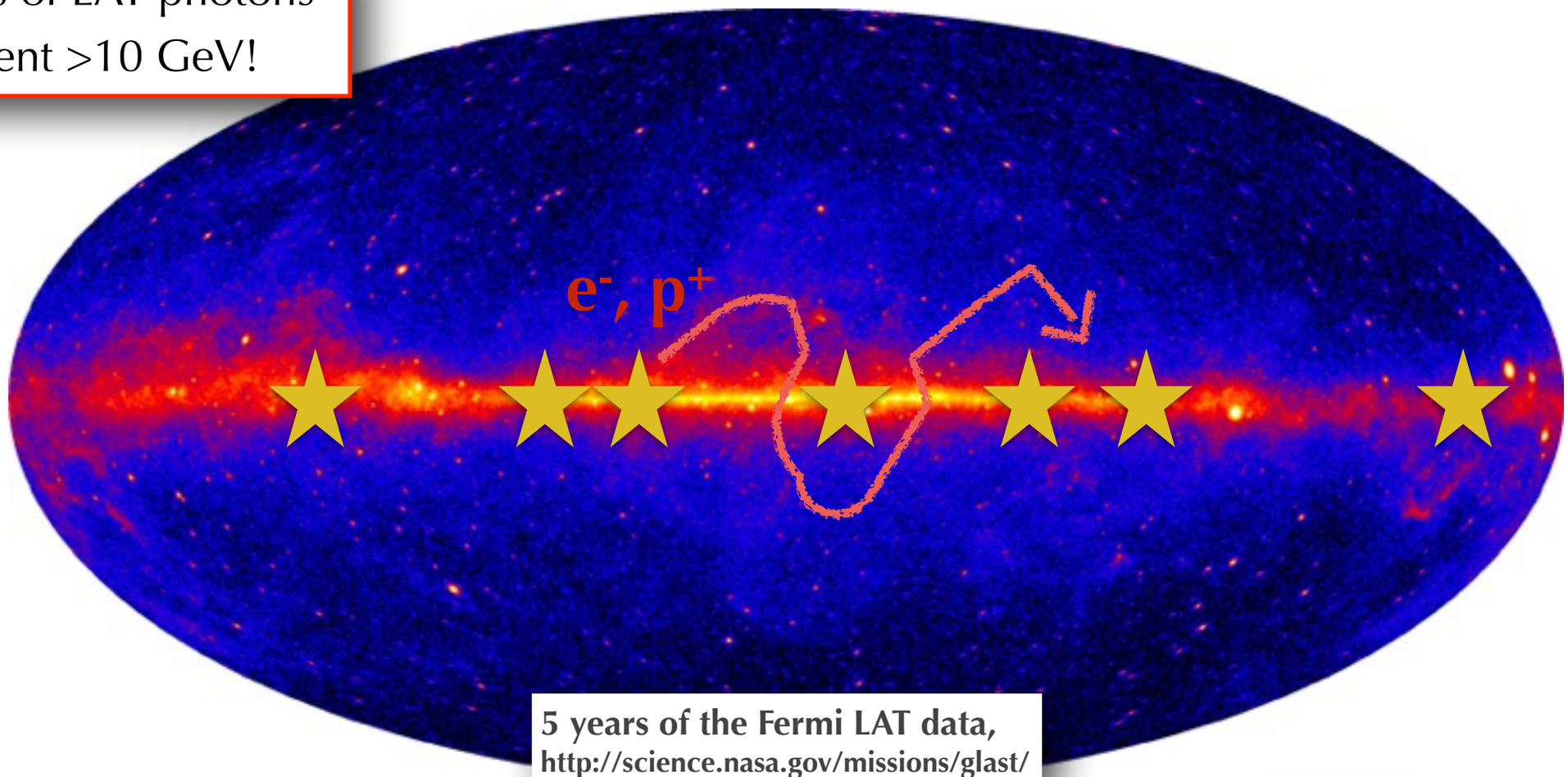
Angular resolution: 0.1deg, above 10 GeV



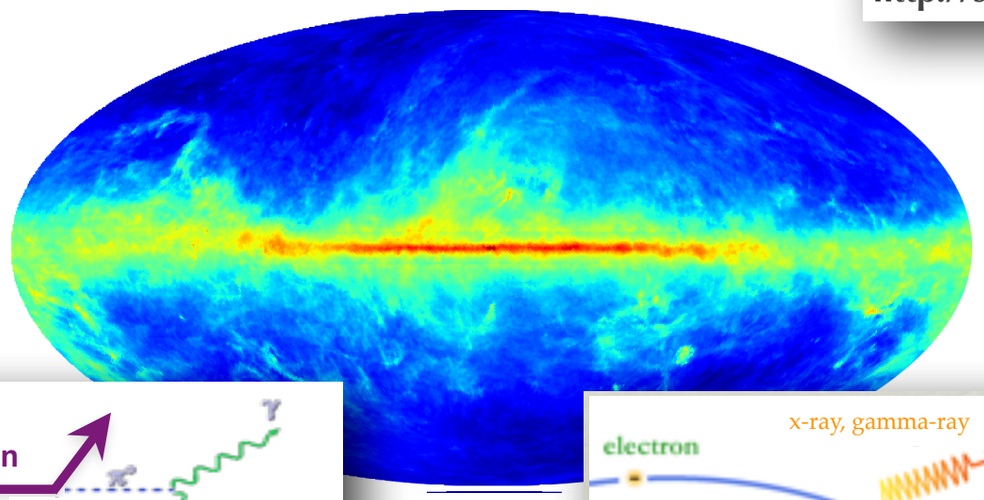


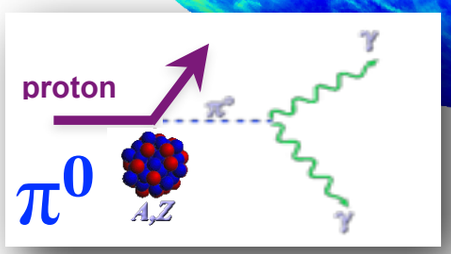
The Fermi LAT sky

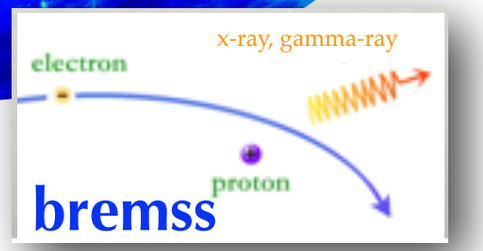
diffuse γs: 90% of LAT photons
first measurement >10 GeV!

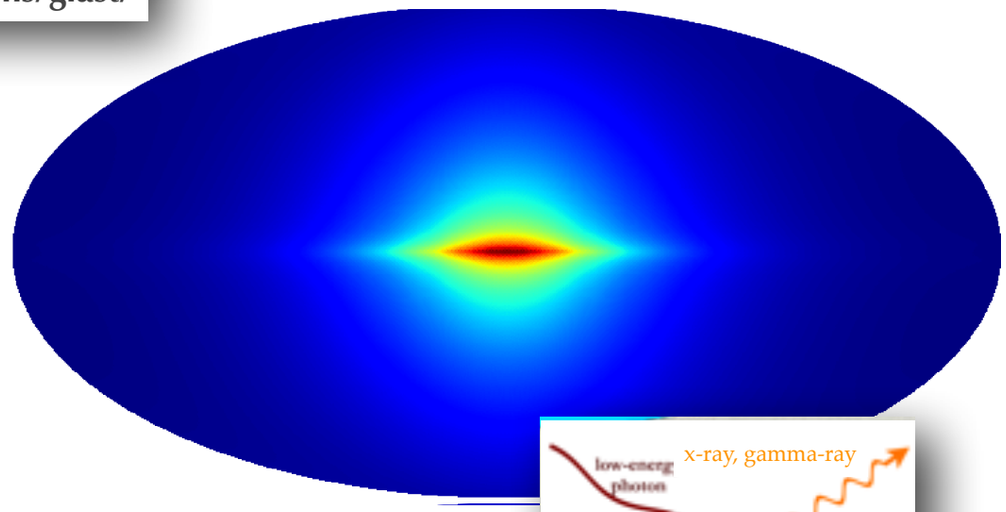


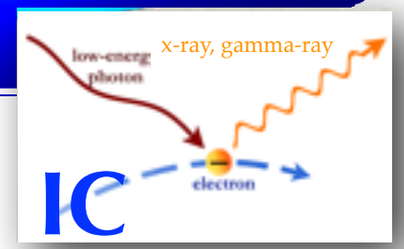
5 years of the Fermi LAT data,
http://science.nasa.gov/missions/glast/





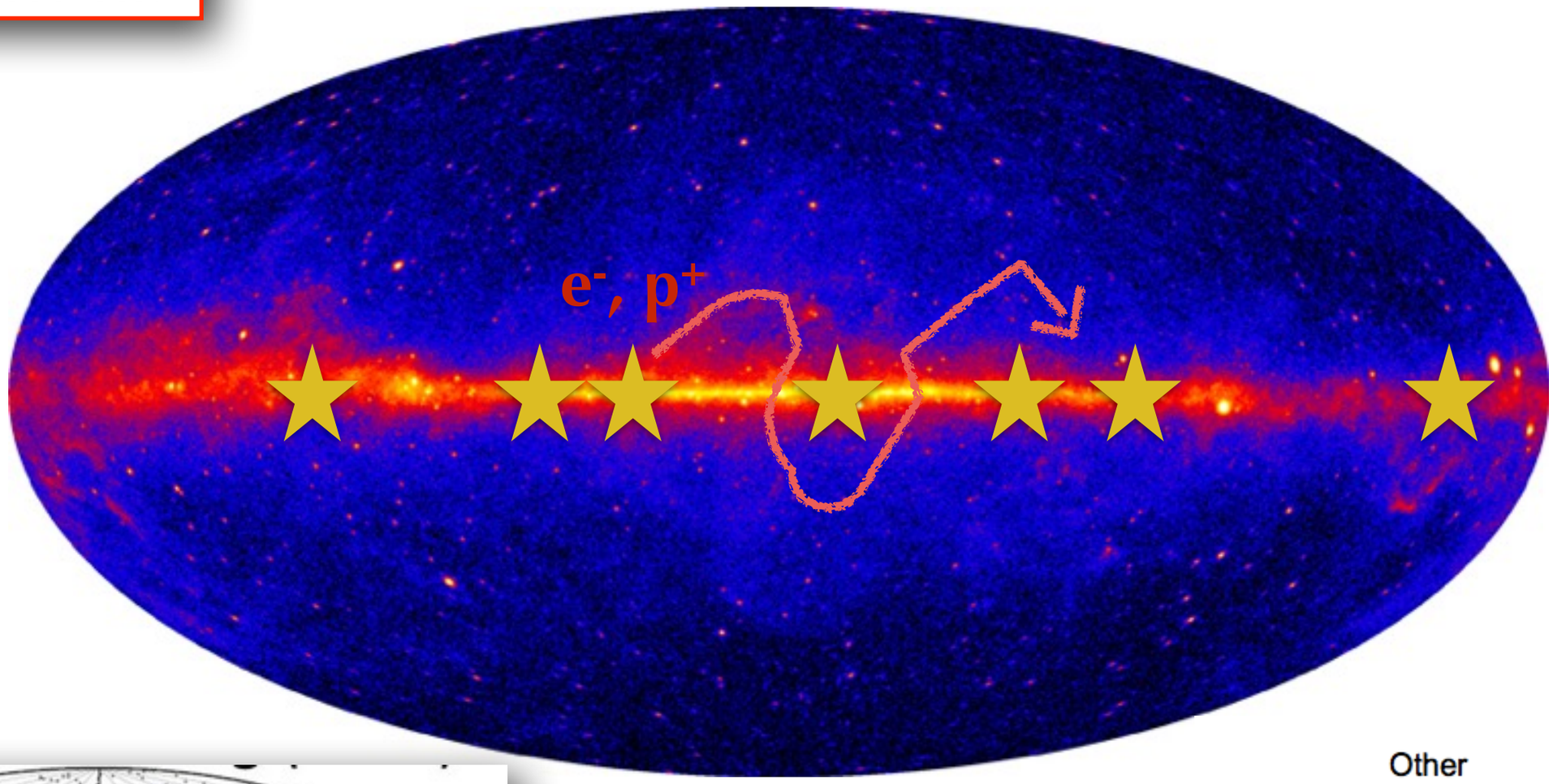


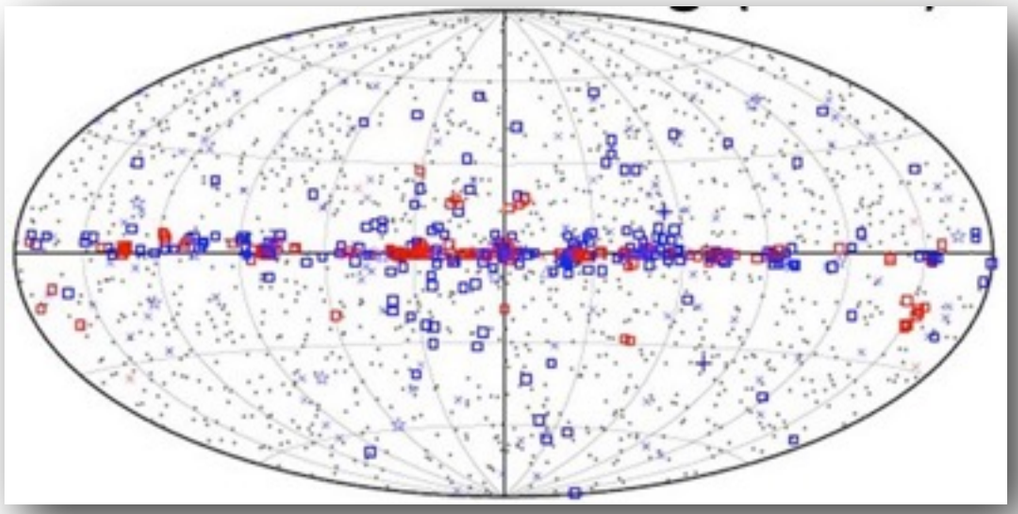




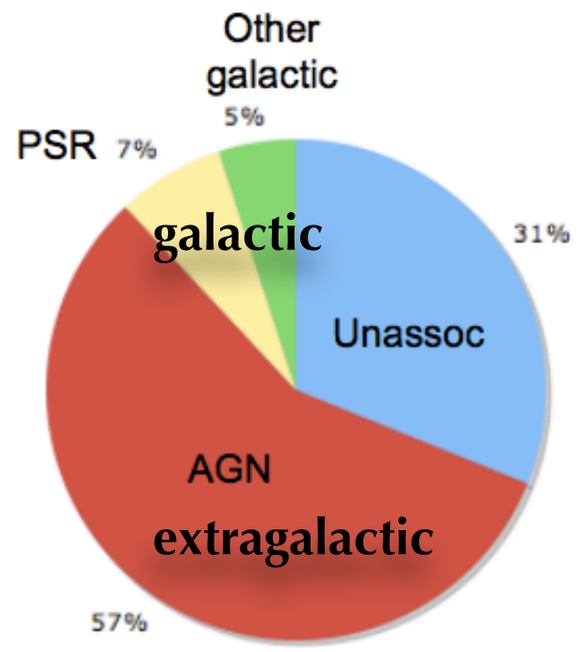
The Fermi LAT sky

3FGL: ~>3000 sources!





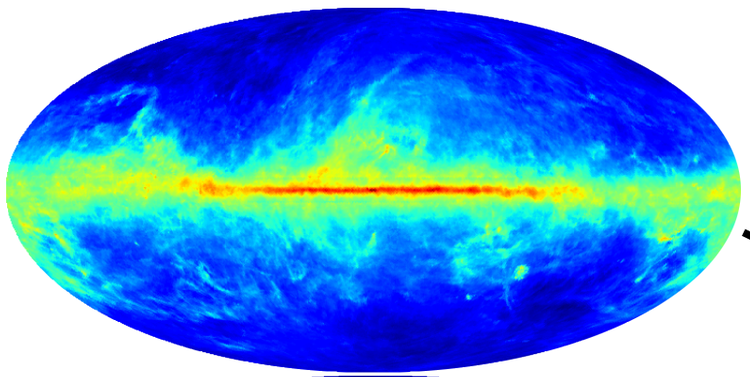
3FGL [Fermi LAT coll. 1501.02003]



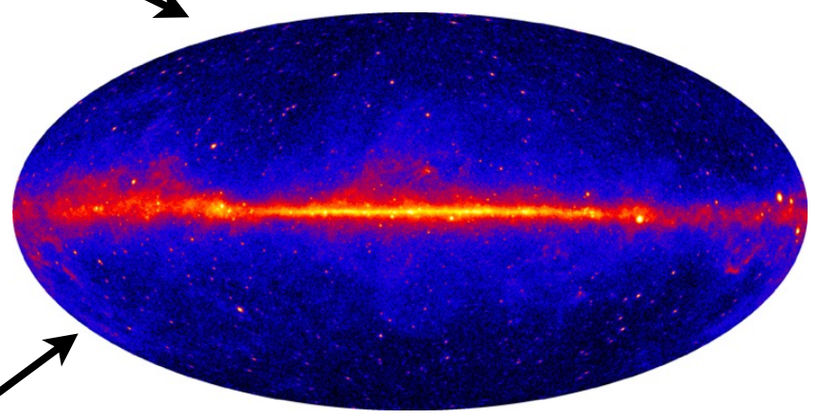
Extended signals in the Galaxy ?

‘template fitting’ procedure - in a nutshell

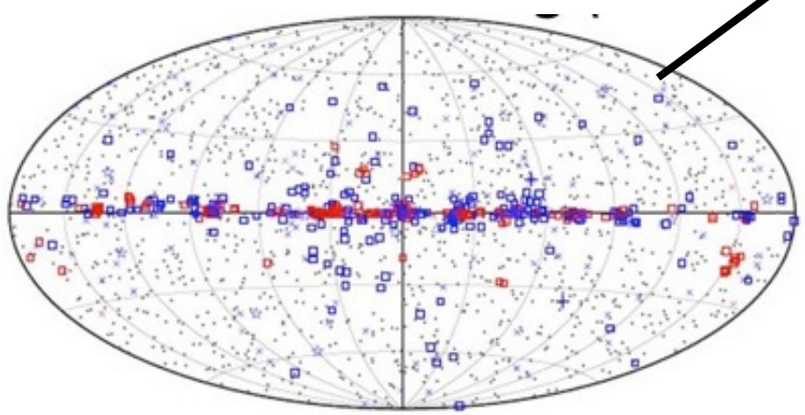
- chose templates of your emission components
- fit them to the data in each pixel and energy bin
- normalization of templates obtained using maximal likelihood approach



model(s) of the diffuse emission



LAT data



point sources from the 3FGL catalog

How to search for extended signals in the Galaxy ?

'template fitting' procedure - in a nutshell

- chose templates of your emission components
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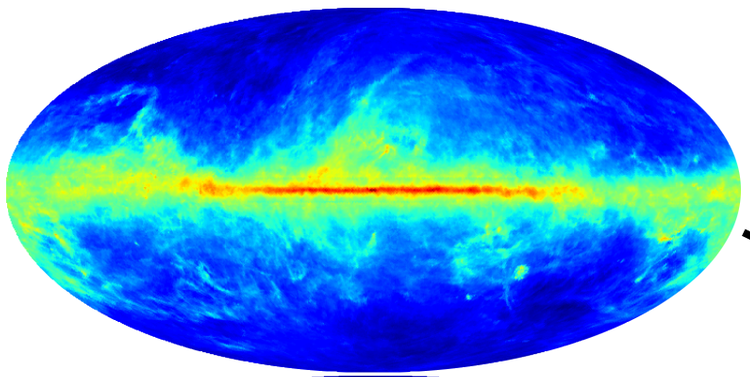
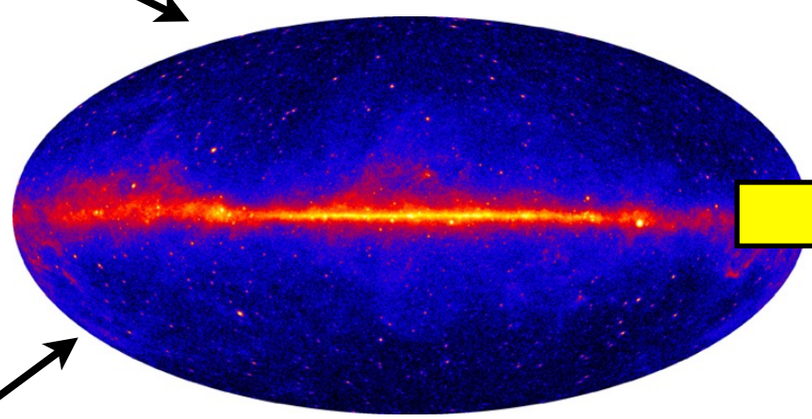
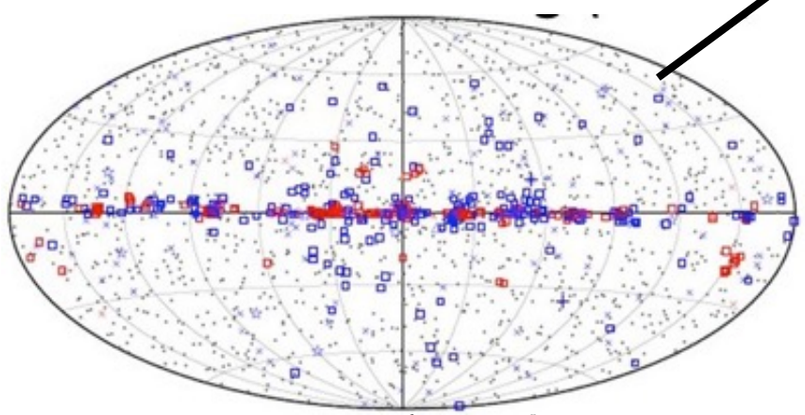


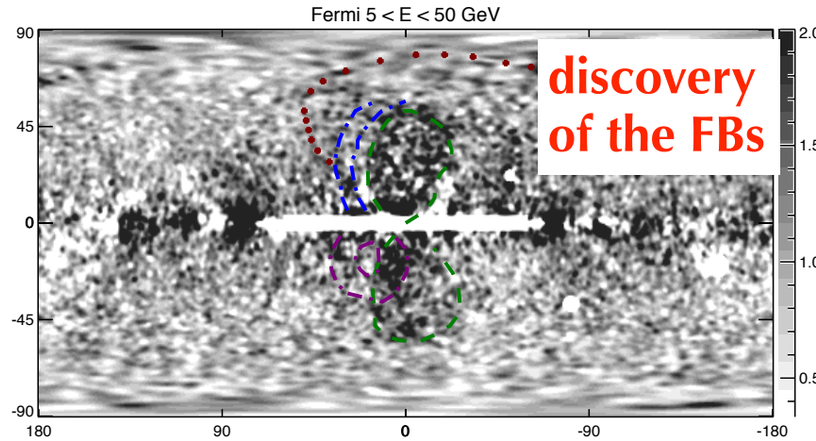
model(s) of the diffuse emission



LAT data



point sources from the 3FGL catalog



[Su+., ApJ, 2010, 1005.5480]

How to search for extended signals in the Galaxy ?

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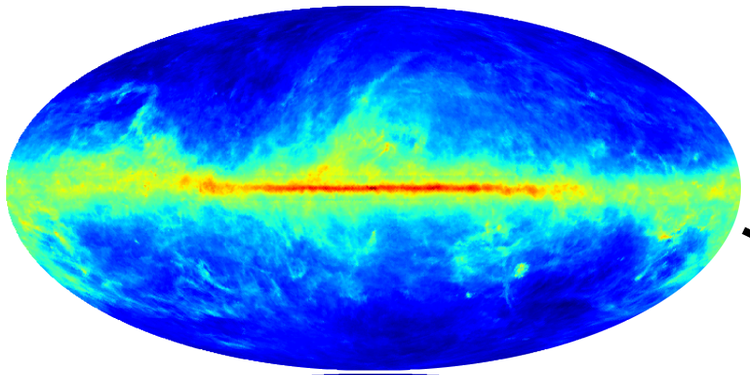
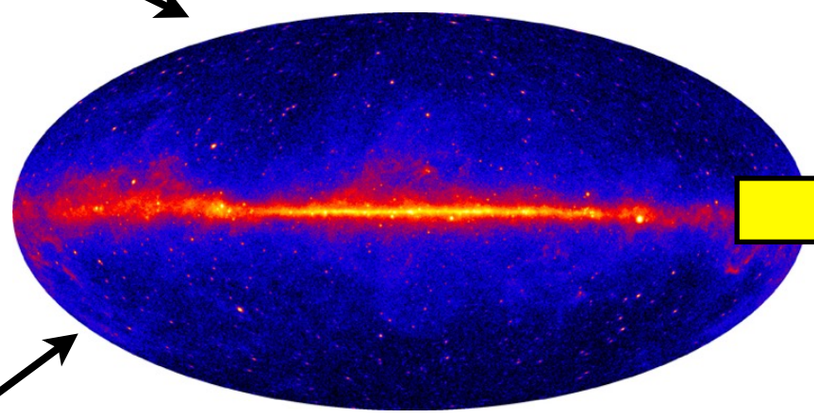
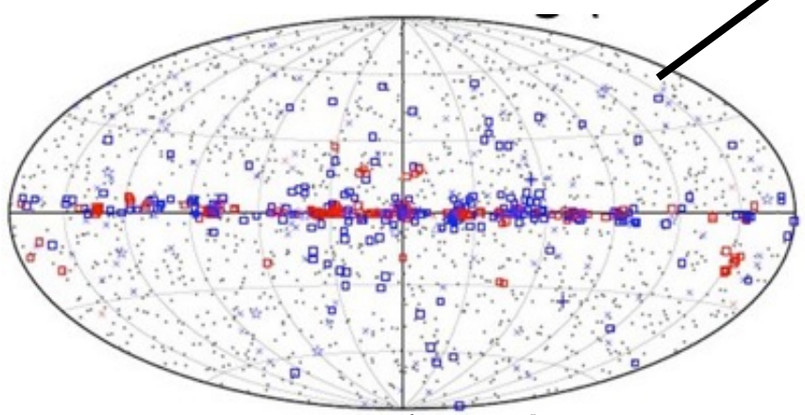


model(s) of the diffuse emission



LAT data



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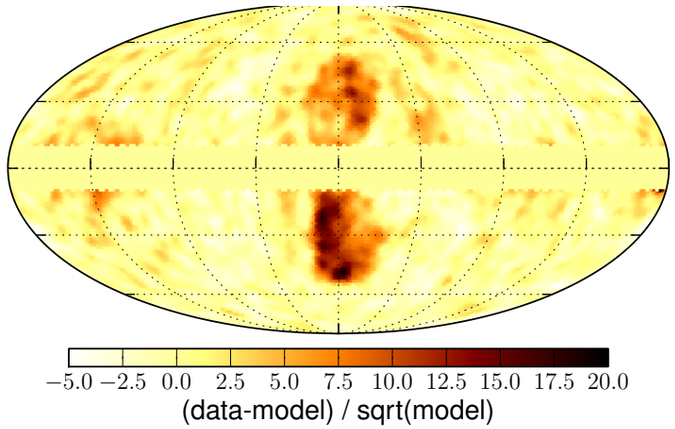
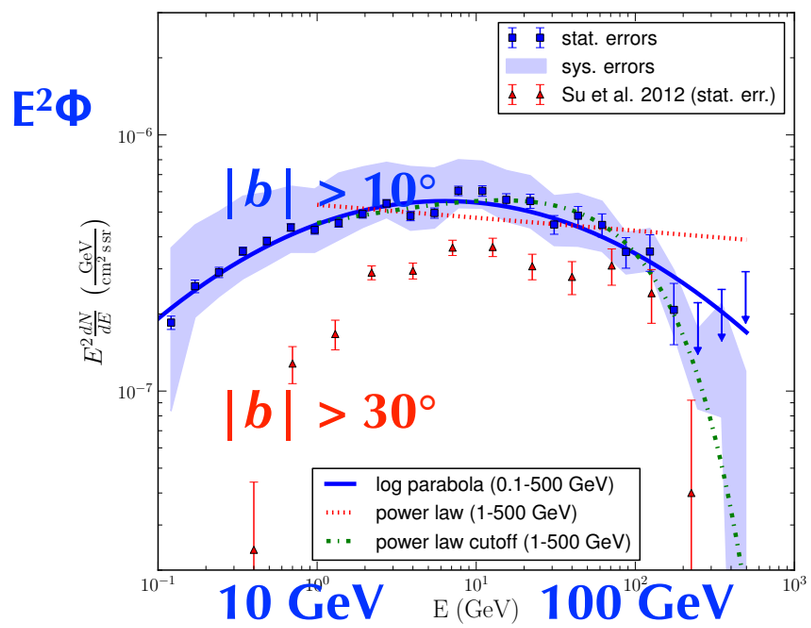
[Fermi LAT coll., ApJ, 2014,1407.7905]

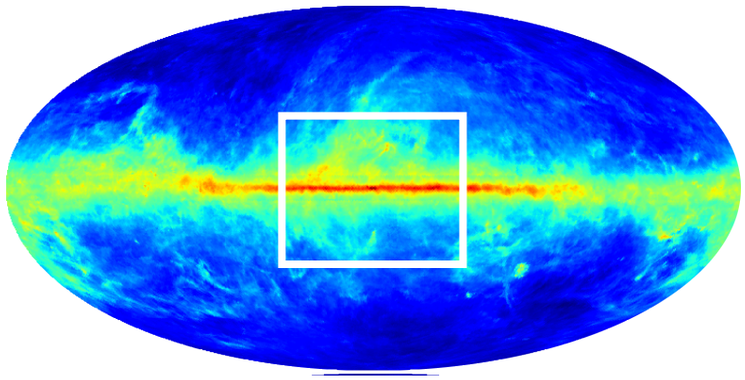


uniform brightness
hard spectrum
sharp edges

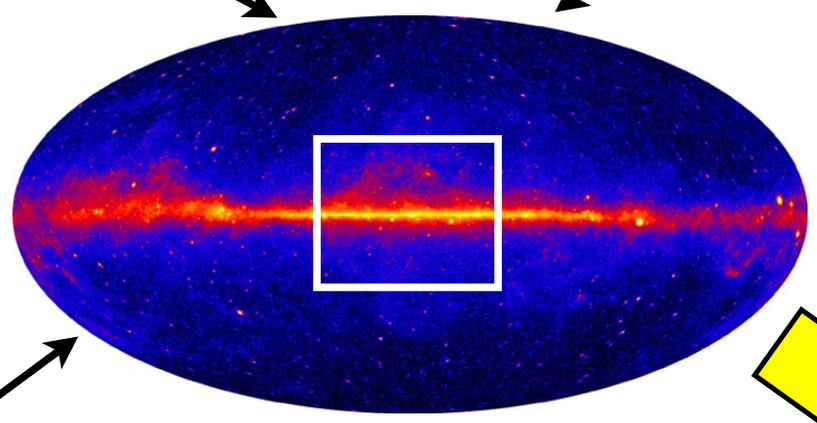


Galactic Centre Excess

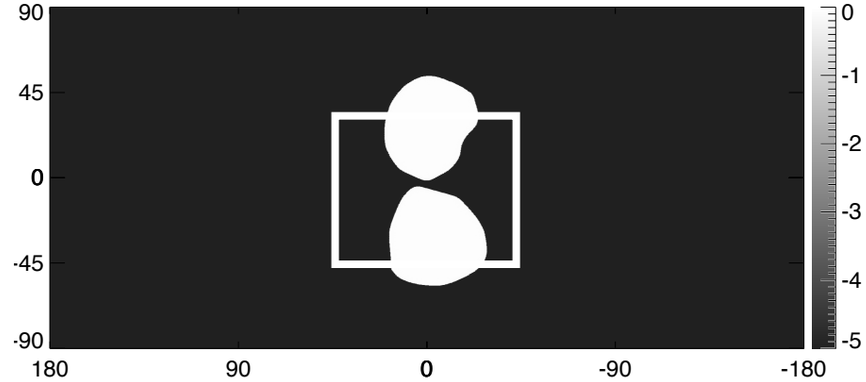
harder task!
apply ***template fitting*** procedure to the inner ~<20 deg with addition of the FBs



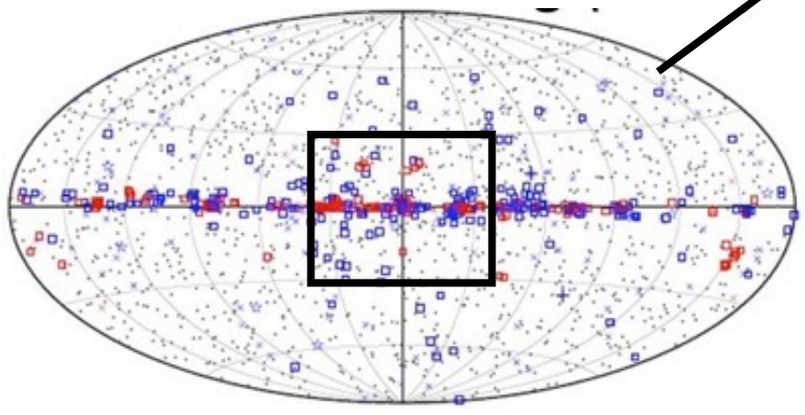
model(s) of the diffuse emission



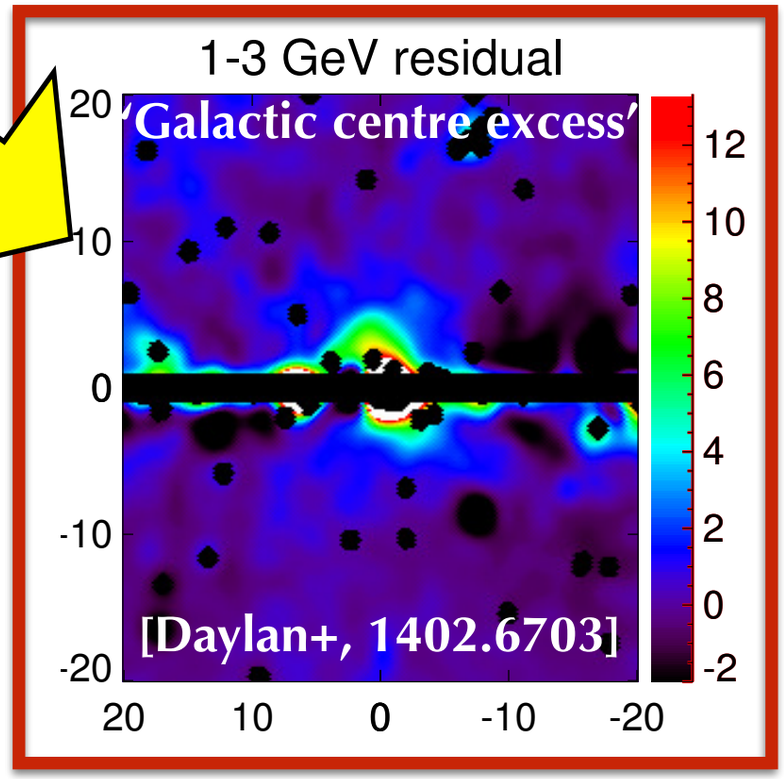
LAT data



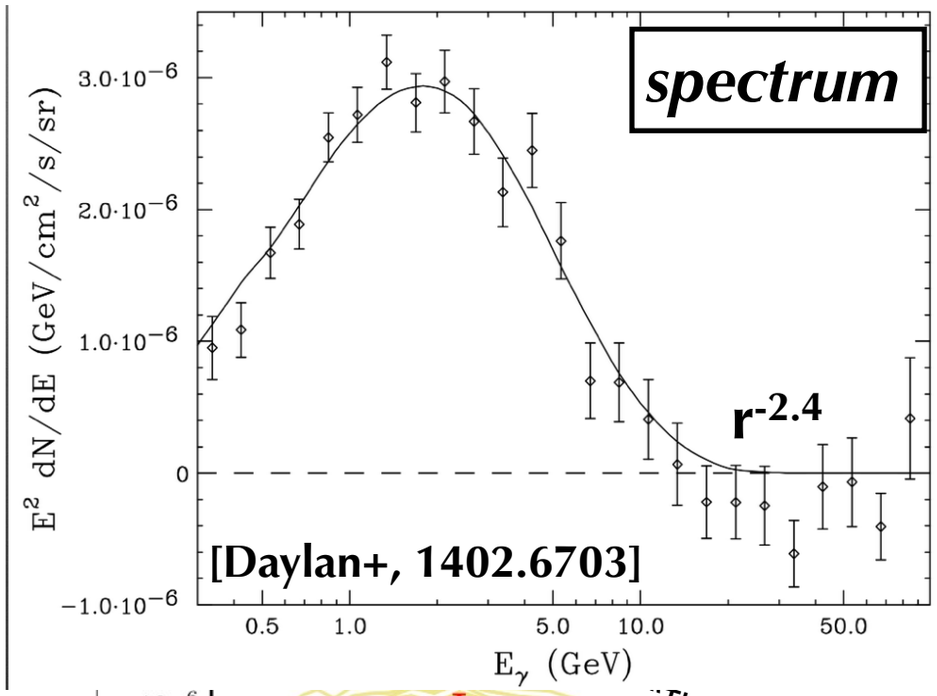
uniform-brightness template for the Fermi Bubbles

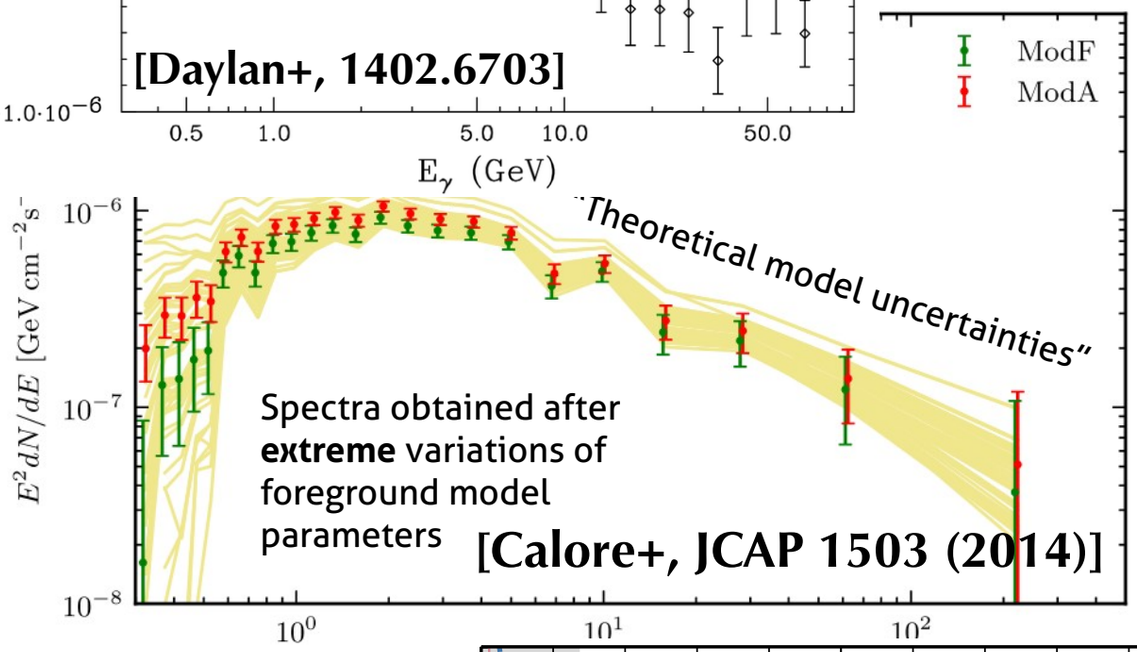


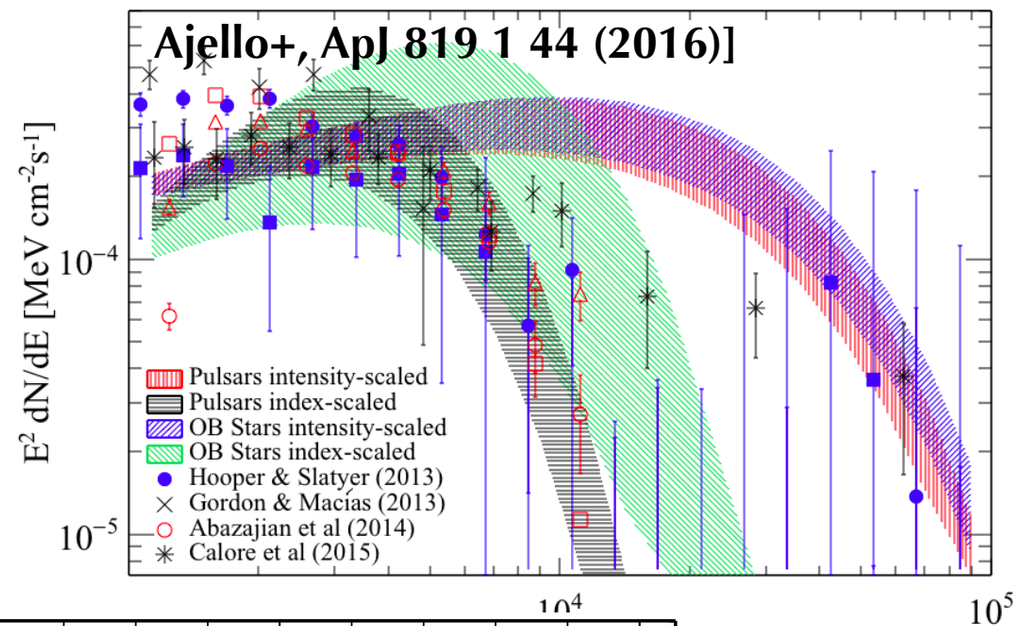
point sources from the 3FGL catalog

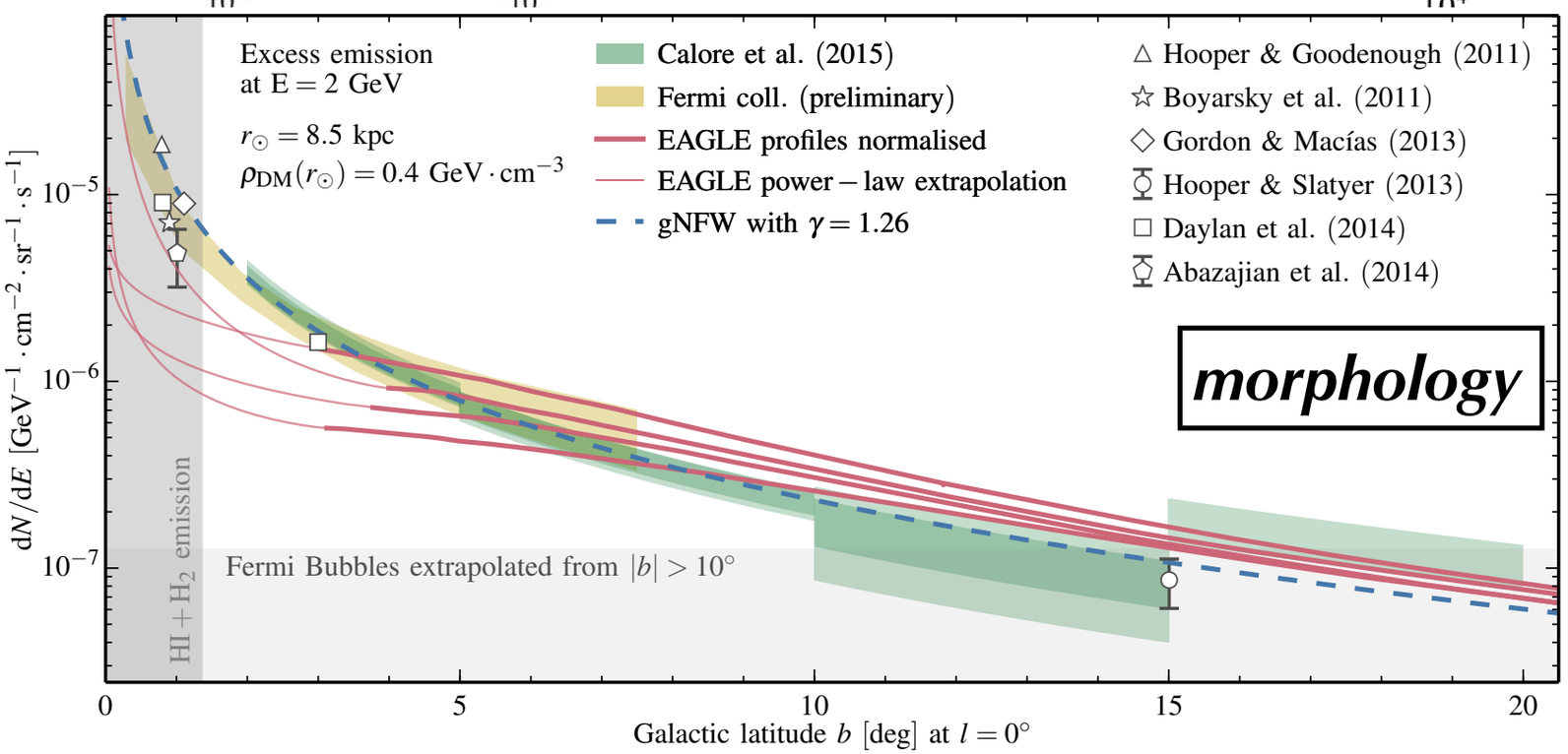


Many works reaching similar results: Vitale & Morseli (**2009**), Goodenough & Hooper (2009), Hooper & Goodenough (2011, PLB 697 412), Hooper & Linden (2011, PRD 84 12), Abazajian & Kaplinghat (2012, PRD 86 8), 1207.6047, Hooper & Slatyer (2013, PDU 2 118), 1302.6589 Gordon & Macias (2013, PRD 88 8) 1306.5725 Macias & Gordon (2014, PRD 89 6) 1312.6671, Abazajian et al. (2014, PRD 90 2) 1402.4090, Daylan et al. (2014) 1402.6703, 1407.5583 1407.5625 1410.1527



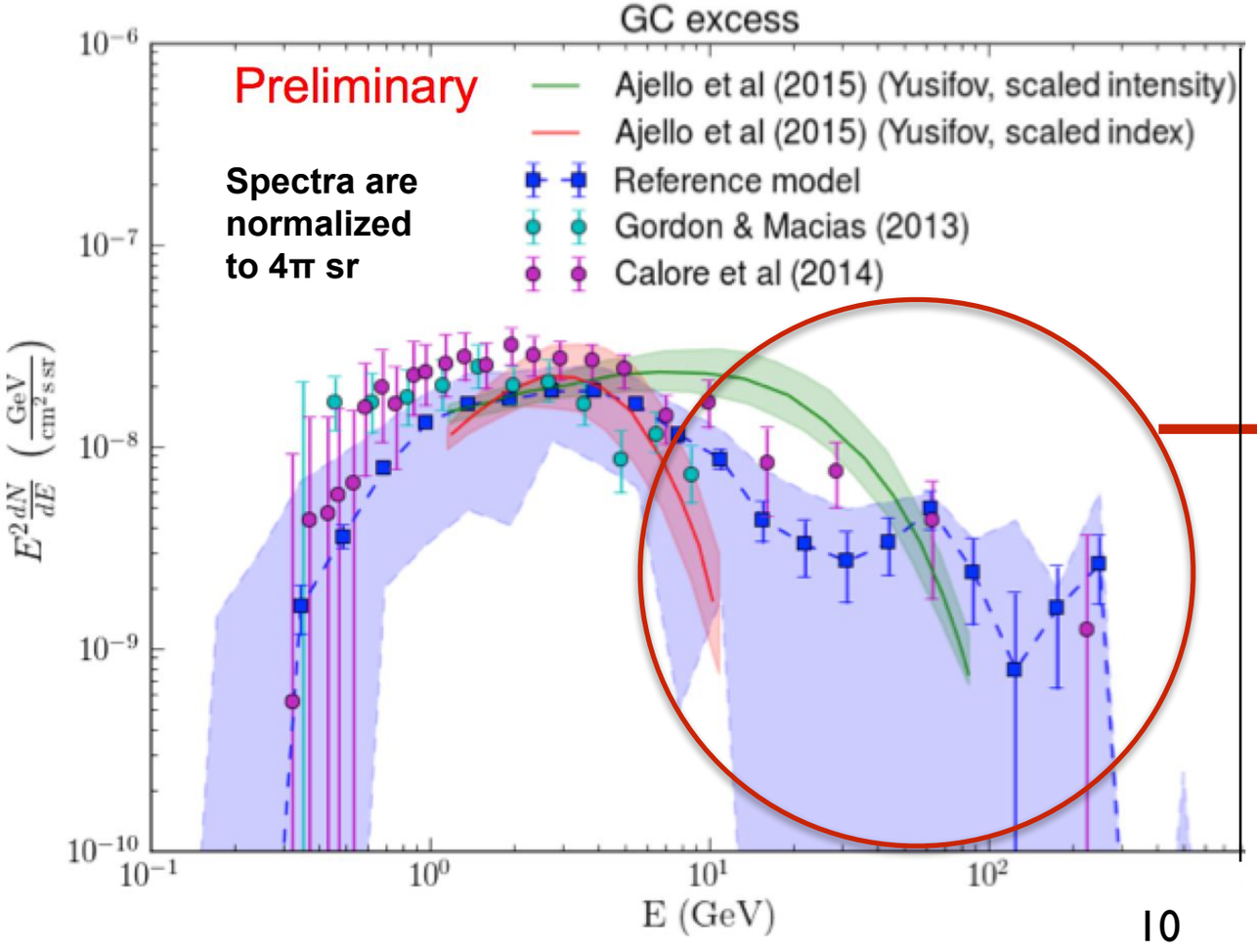


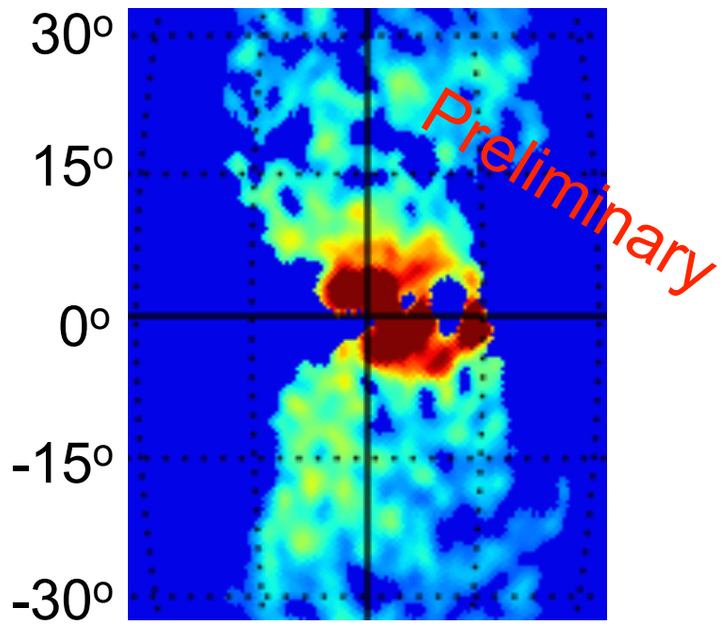




Updated Fermi LAT analysis (preliminary)

- uses more data (**80m)**
- uses improved event selection: **pass 8 (**improved angular and energy resolution, increased effective area at the high- and low-energy ends)
- checks additional systematic uncertainties:
  - GALPROP model parameters variations
  - **Alternative gas maps** (softer GCE spectrum < 1GeV)
  - Include additional sources of **CR electrons near the GC** (Gaggero+2015, Carlson+2015 ; GCE reduced)
  - add **data driven template of the Fermi Bubbles** (excess >10 GeV gone)





[A. Albert, APS 2016 meeting]

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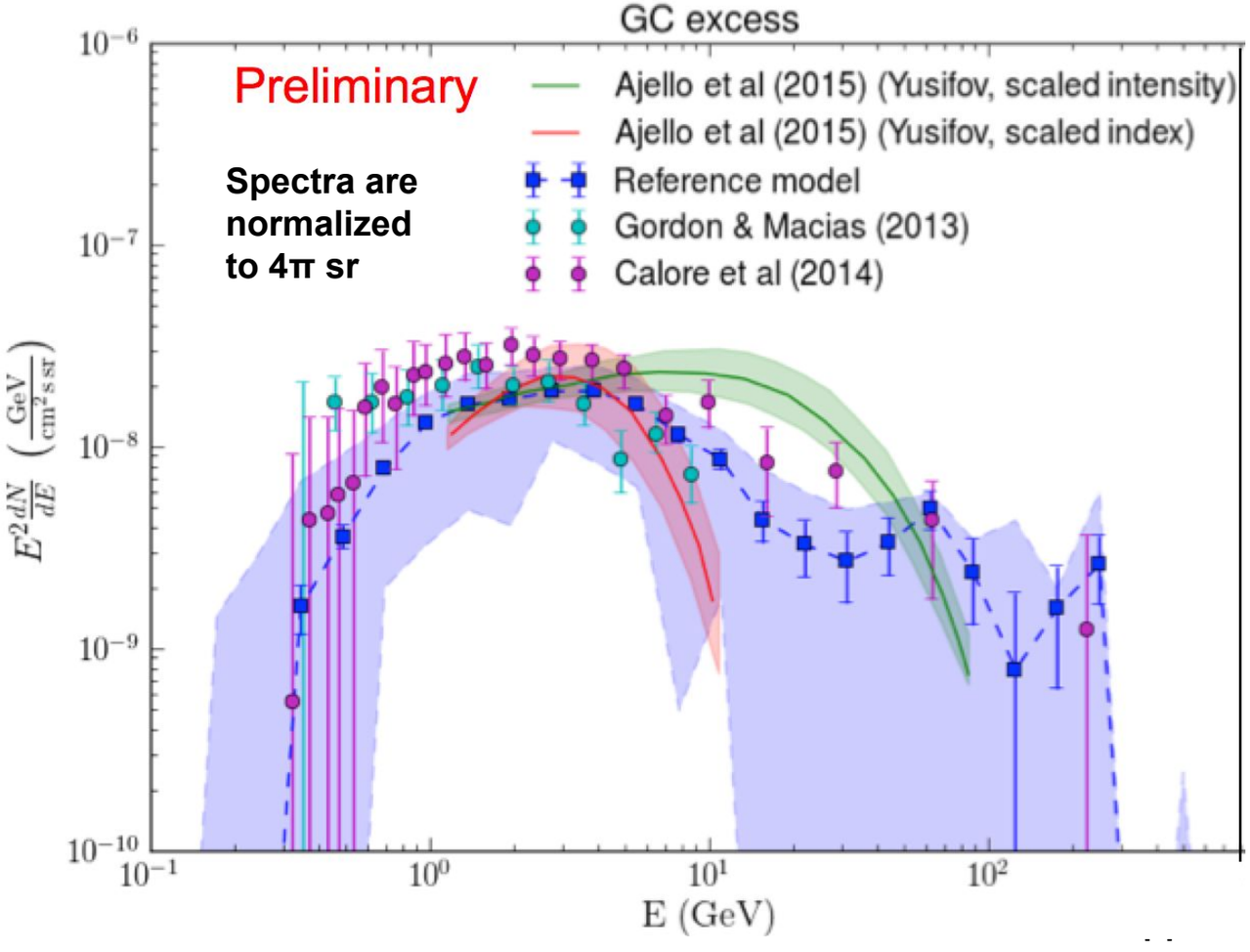
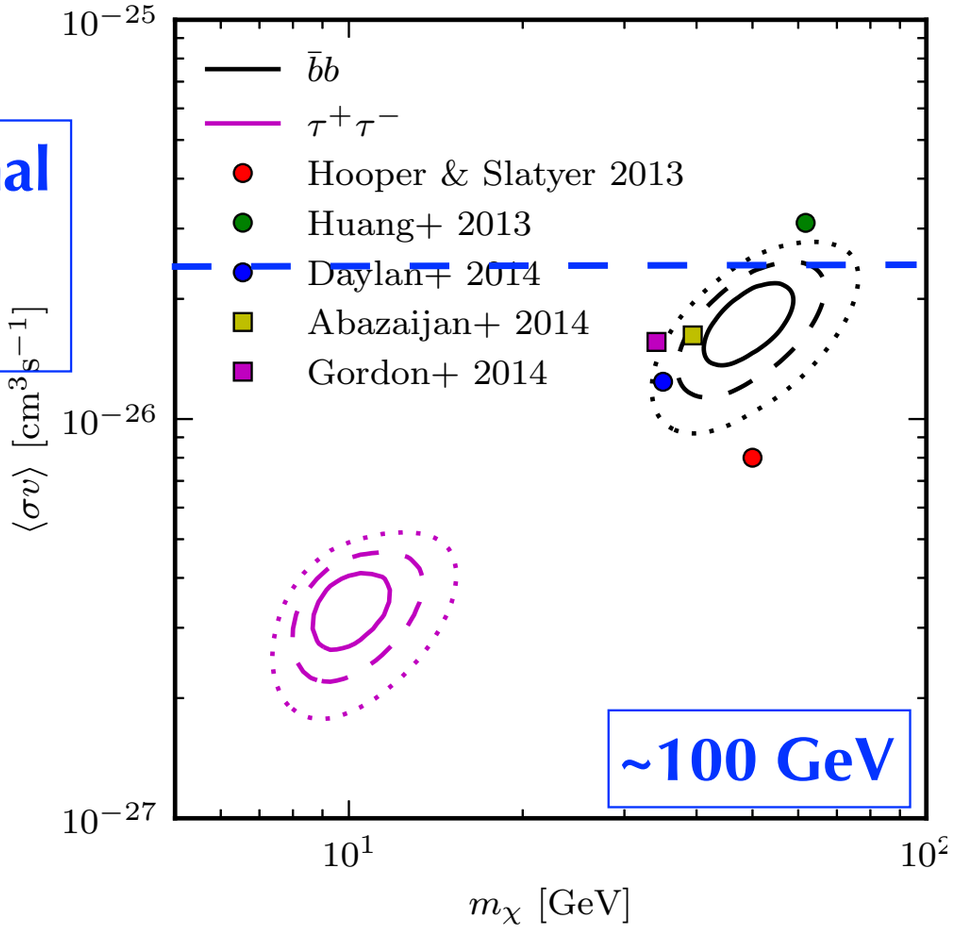


New emission component in the Galactic centre appears robust to various checks of the systematic uncertainty
its exact spectral features are model dependent

[A. Albert, APS 2016 meeting]

Origin of the excess?

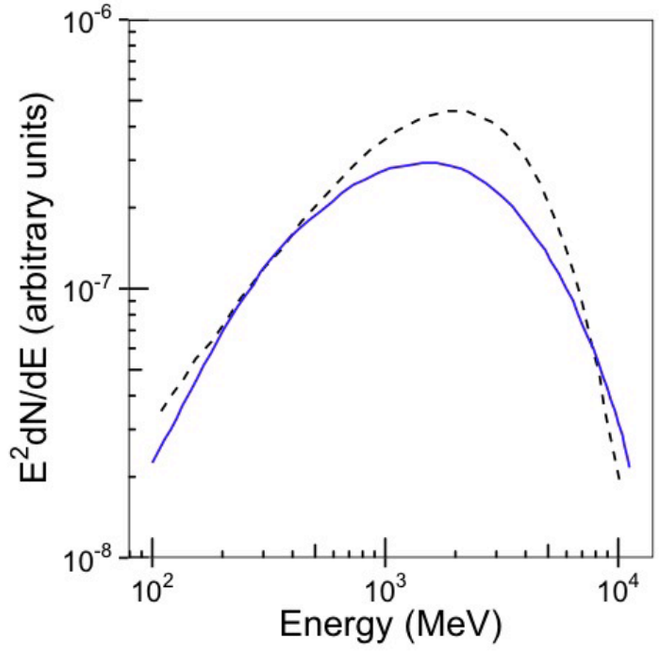


Right on the spot where WIMP dark matter is supposed to be!

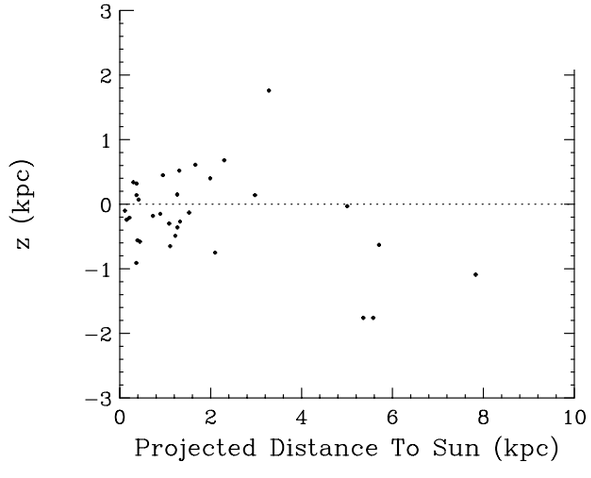
i) Individually unresolved point sources?

pulsars?

- spectral twins of ~50 GeV DM



Baltz et al (2007)



- Fermi LAT discovered 100+ of these objects in the Galaxy

[Abazajian, 2012, Mirabal, 2014; Macias, 2014, Petrovic +, 2015, Brandt+2015, Lee+, 2015, Bartels+, 2015…]

Origin of the excess?

A transient?

PROs:

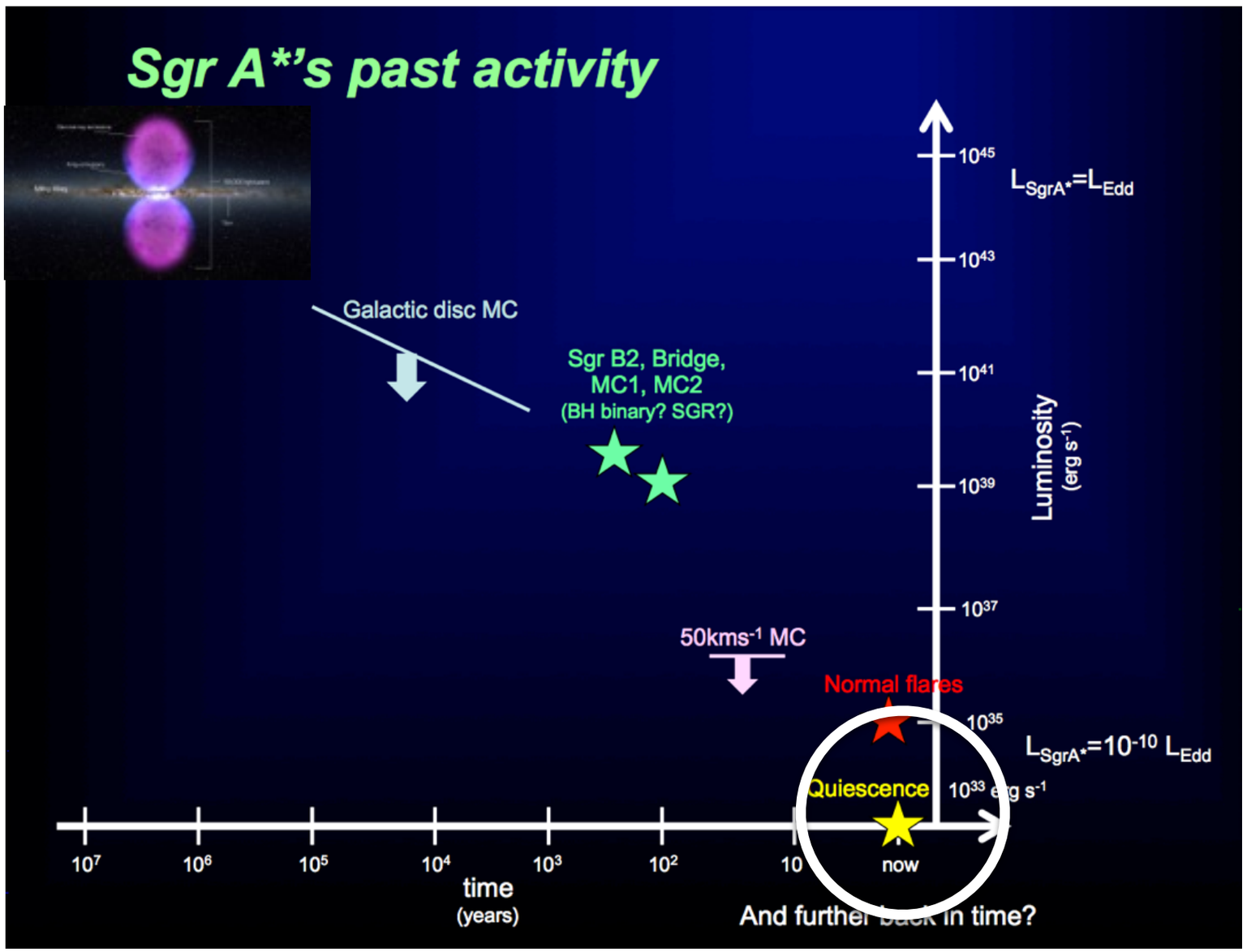
- we know that GC had periods of increased activity in the past
- energetics reasonable

$E_{tot,\ GCE} \sim 10^{51\text{-}52}$ erg

$E_{tot,\ Fermi\ Bubbles} \sim 10^{54\text{-}55}$ erg
[Su+,2010]

$(E_{tot,\ SNR}) \sim 10^{51}$ erg

Slide from G. Ponti



Could a burst like injection of *electrons* explain the GC excess?

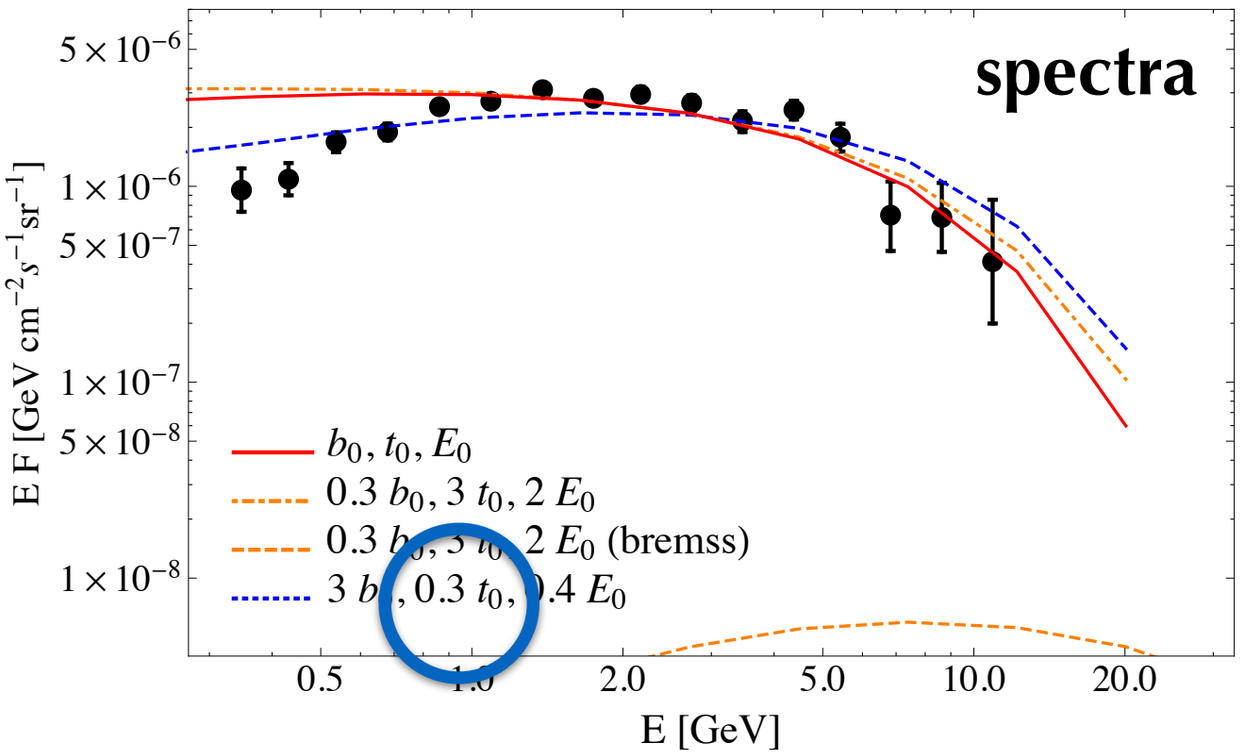
three parameters:

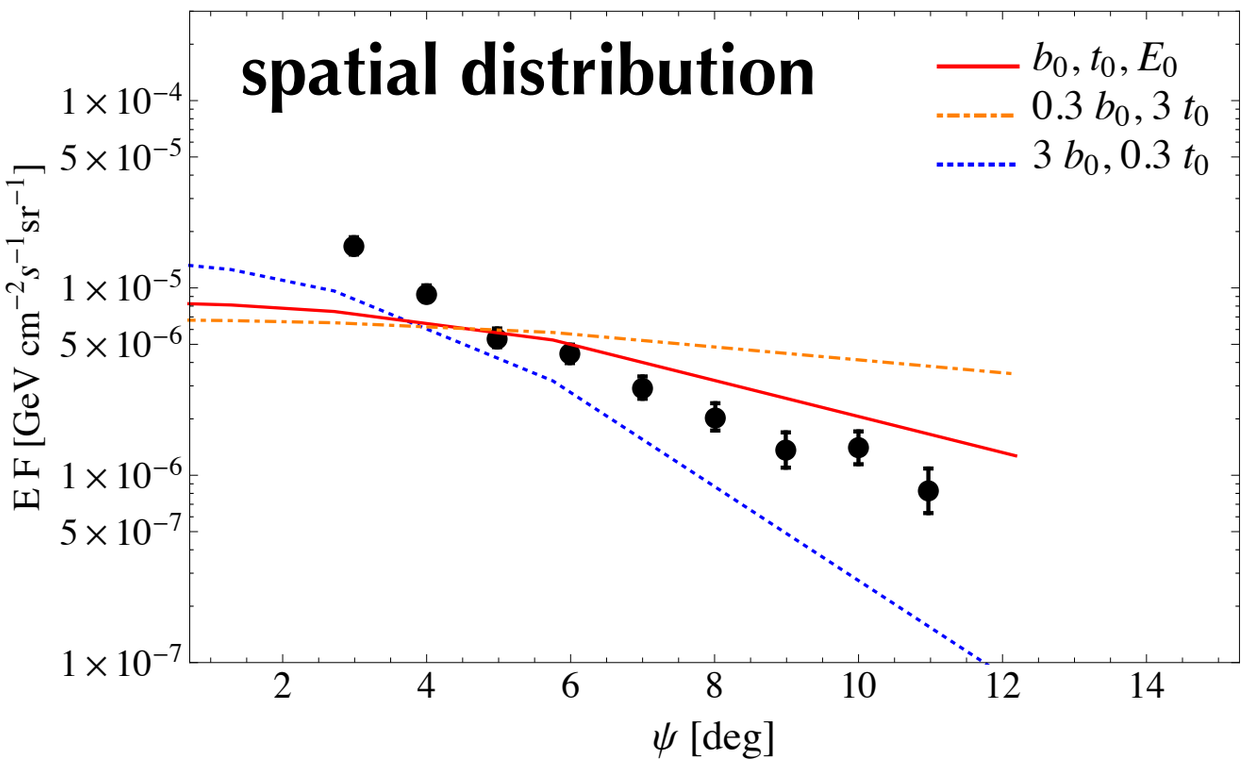
- energy loss parameter b,
- diffusion coefficient and
- time of the bursting event

} ⊳ set the energy cut-off and spatial scale!

⊳ ***3GeV Inverse Compton emission cut-off and 1 kpc scale*** ***have consistent solution in an event which happened a Myr ago!***

Flux normalization of the excess gives energy injection~**10^{52} erg.**





Petrovic, Serpico, GZ, 1405.7928

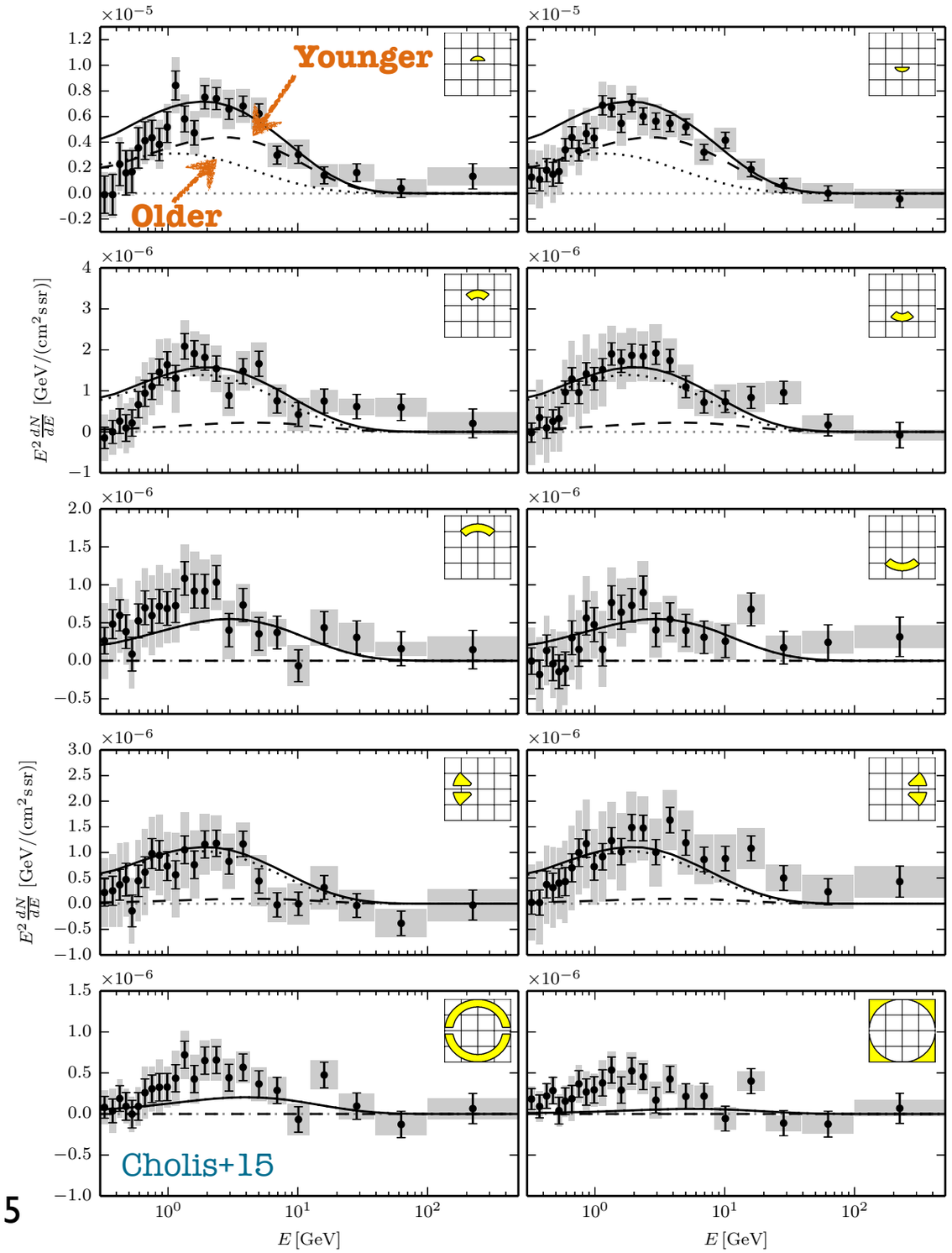
Could a burst like injection of *electrons* explain the GC excess?

numerical calculation: [Cholis+,2015]

-> could work, but:

- Hard injection indices (<2)
- At least two bursts Myr & 0.1 Myr
- High re-acceleration
- No excess in the inner 2 degrees
  (most analyses mask 2 deg, properties of GCE highly uncertain there)

Viable, though non minimal solution --
but we know that the GC environment is rich with astro events.



Origin of the excess?

How can we tell?

DM — multi-target and -messenger tests

MSPs — radio pulsar searches (e.g. w SKA [Calore+, 2016]), …

Transient event — detect a change of spectrum with latitude, single out the responsible past event, … ????

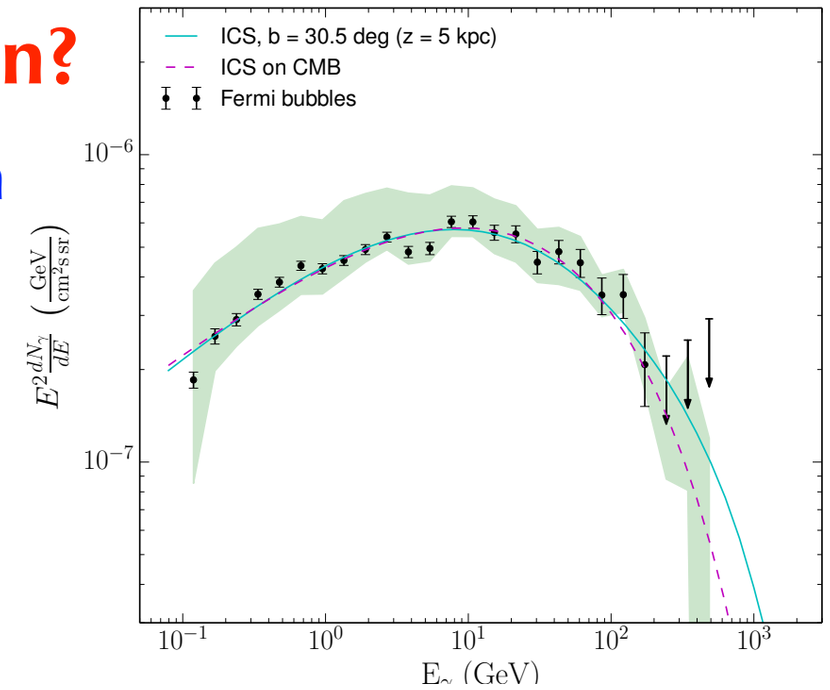
Ideas/comments are welcome!

Extra slides

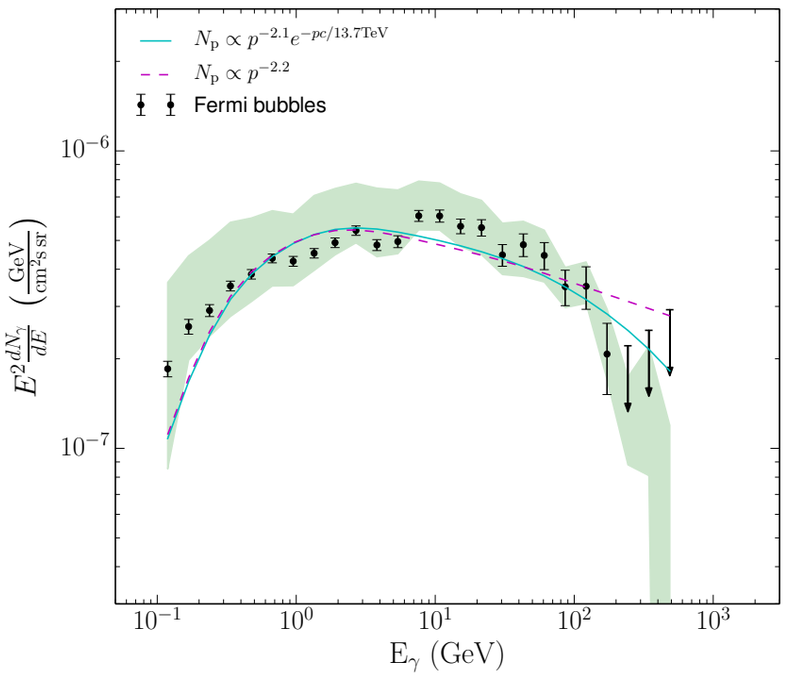
Fermi bubbles

origin of the emission?

1) leptonic (IC) emission
same population of electrons extrapolated to lower energies can explain WMAP/Planck 'haze'

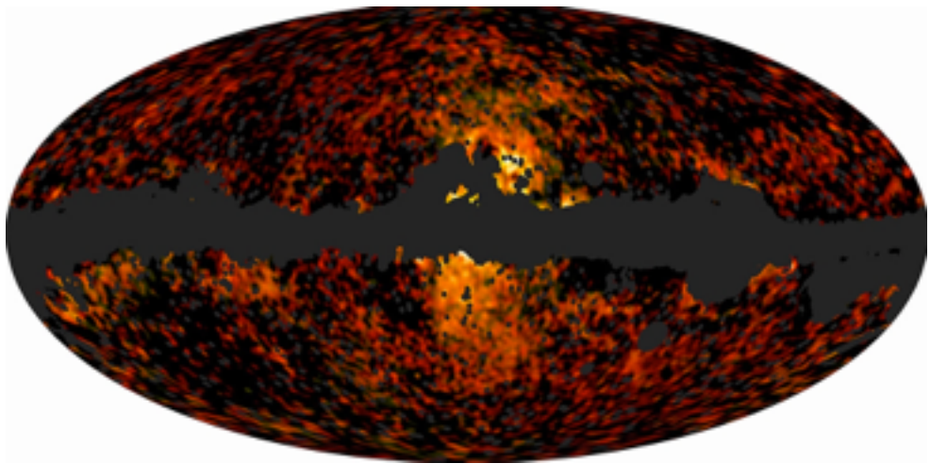


2) hadronic origin
interaction with ionized gas
time scale for interaction Gyr



Fermi LAT coll., ApJ, 2014, 1407.7905.

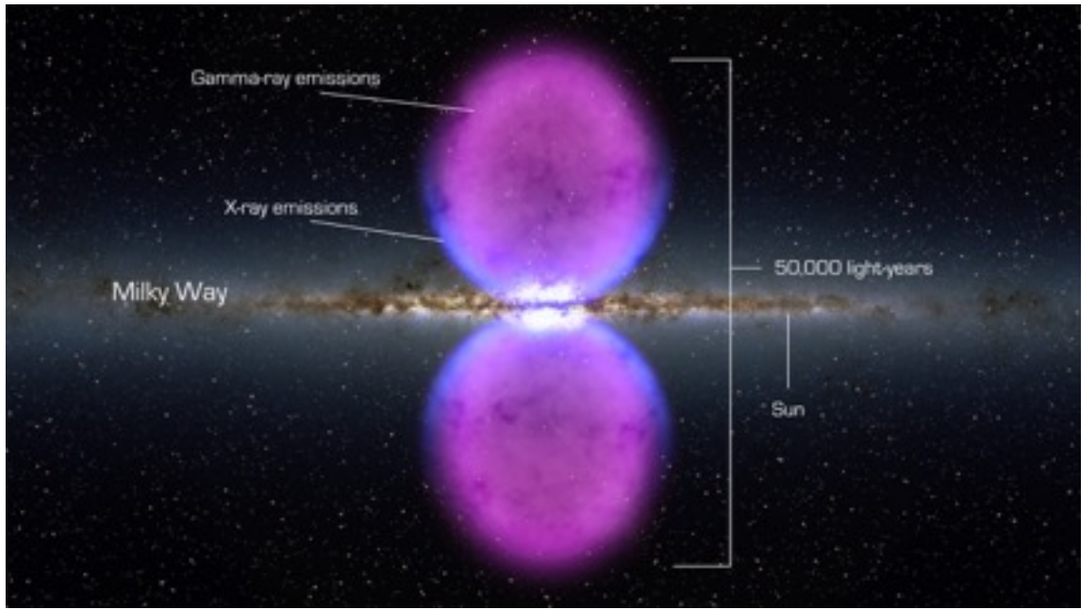
Planck map



[Planck coll., A&A, 2013]

many open issues still:
how are CRs transported with no energy losses,
sharp edges...

Origin of the excess?



FB likely originated in a past transient event

Independent evidence for more recent energy injections

Inverse Compton emission from electrons injected during an energetic burst event ~Myr ago could explain properties of the excess

[Petrovic, Serpico, GZ, 1405.7928]

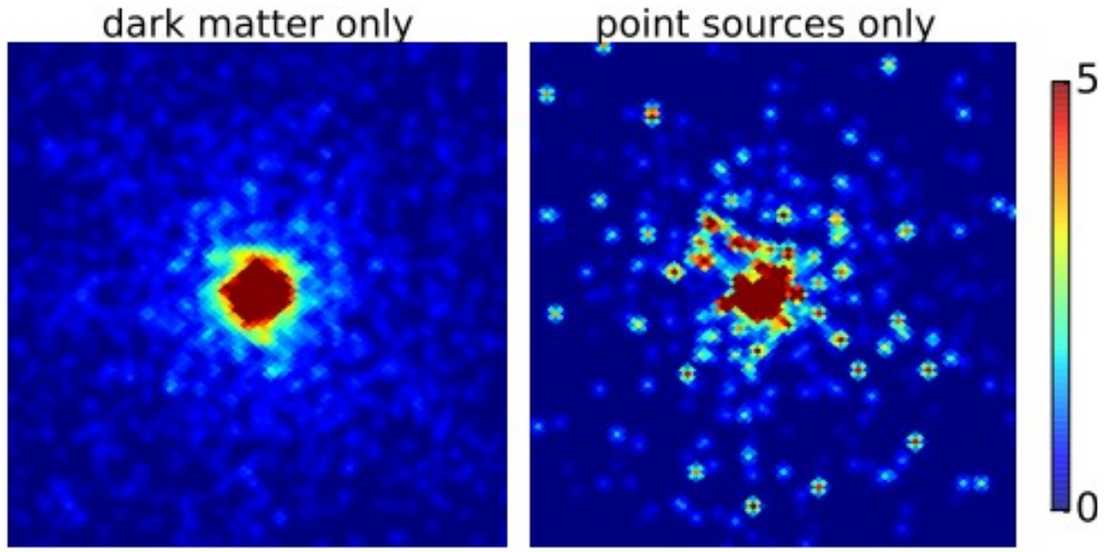
Individually unresolved point sources?

how can we tell?

discover gamma-ray pulsation - hard, too few photons

discover radio pulsation - might be possible with the SKA

use statistical properties of the LAT data to determine if the signal is 'point source-like'



(Credit: Lee+ 2014)

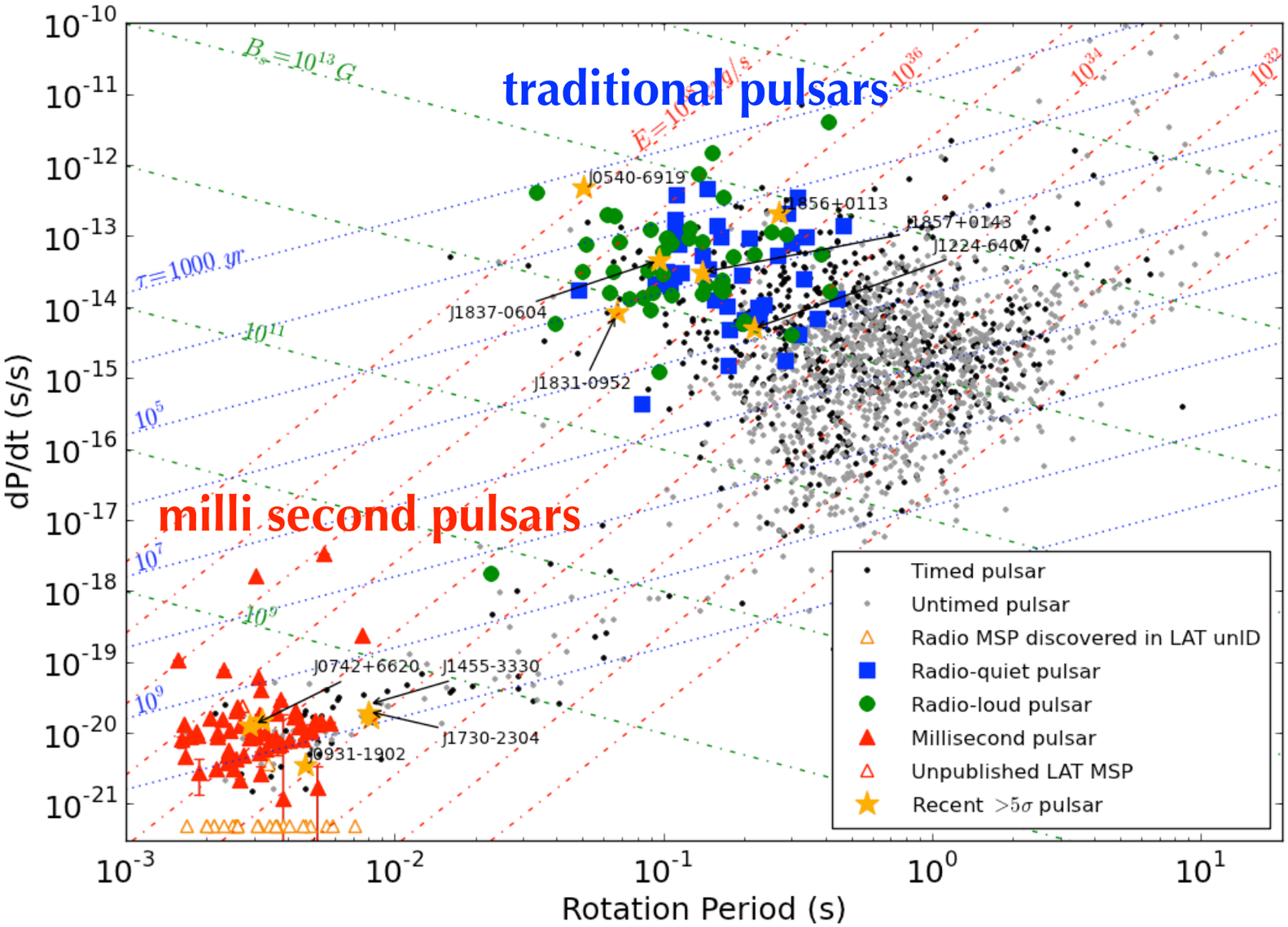
~**10σ** confidence that it is point source like

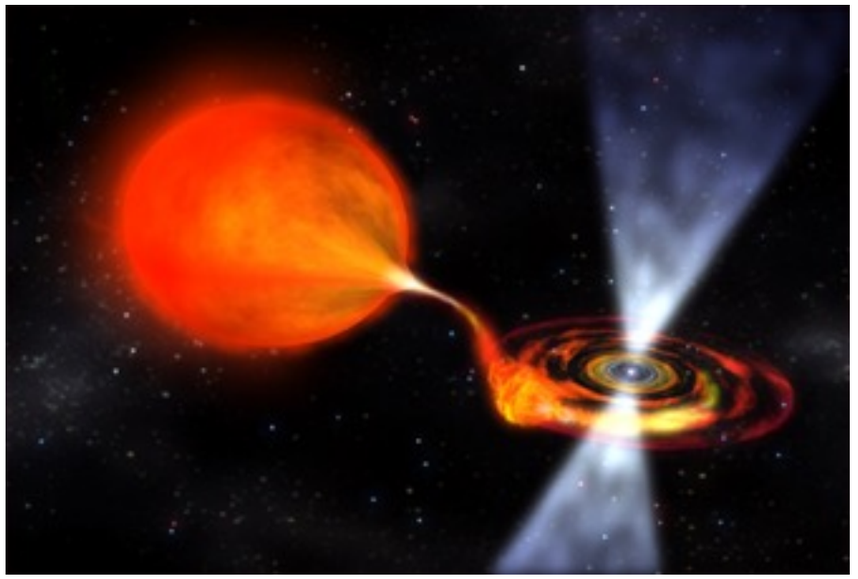
such population could explain the full excess

[Bartels+, 2015
Lee+, 2015]

What is the origin of the GCE?

pulsars come in two kinds





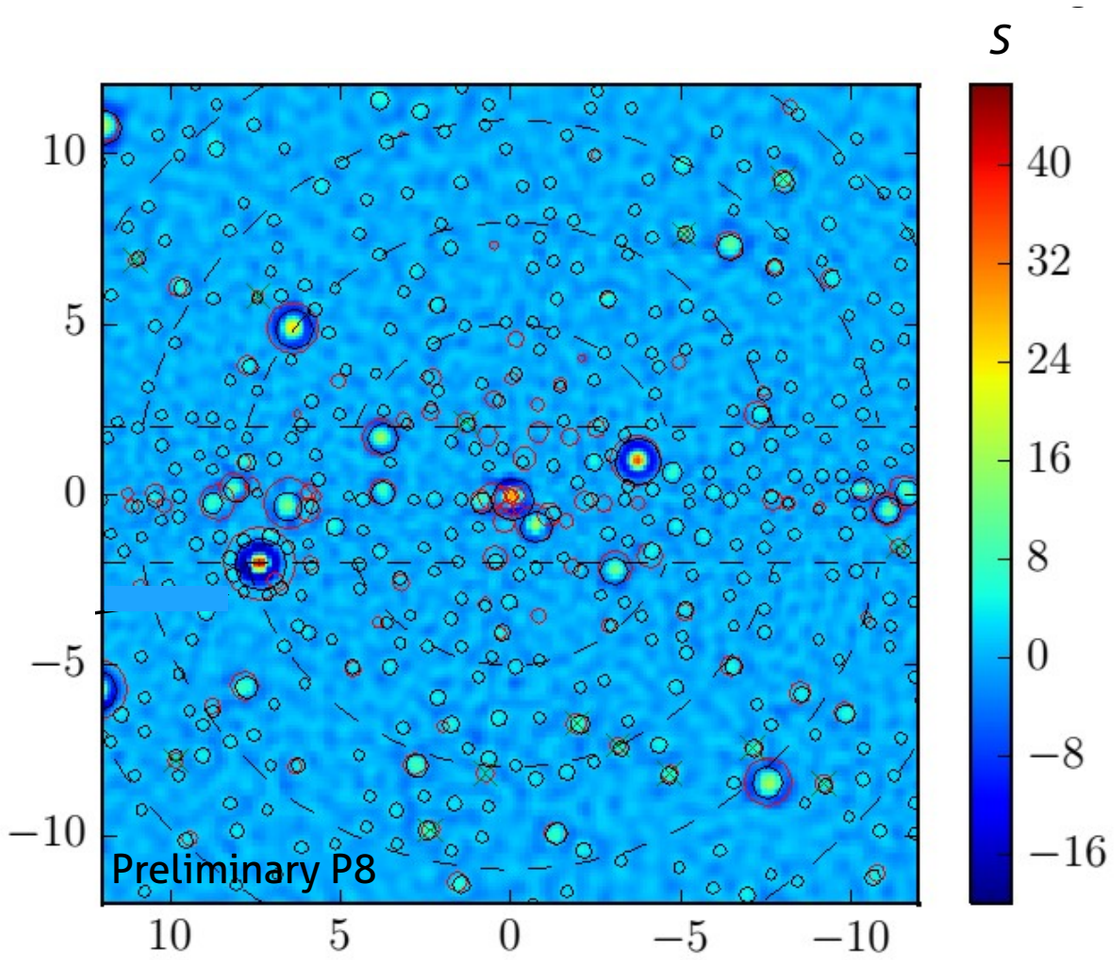
MSPs: older, 10^9yrs (vs 10^4yrs ordinary pulsars)

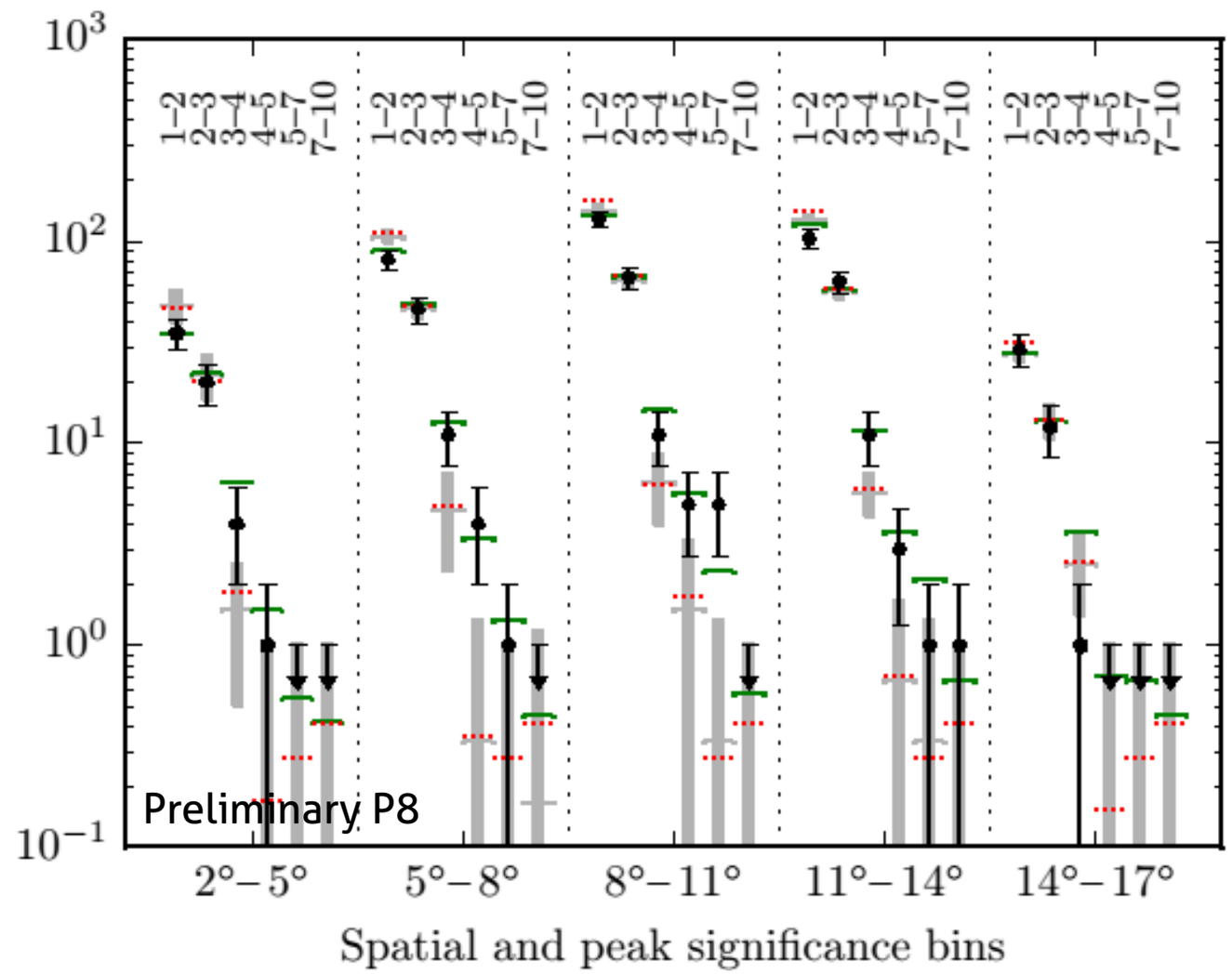
-> migrate further from the origin and spatial distribution less constrained

(astro) Interpretation 02:

Unresolved population of milli second pulsars

Bartels+: **Wavelet transform** (spatially constrained Fourier transform) of inner Galaxy data
-> filters out structures of a specific size (point sources) while removing diffuse emission.



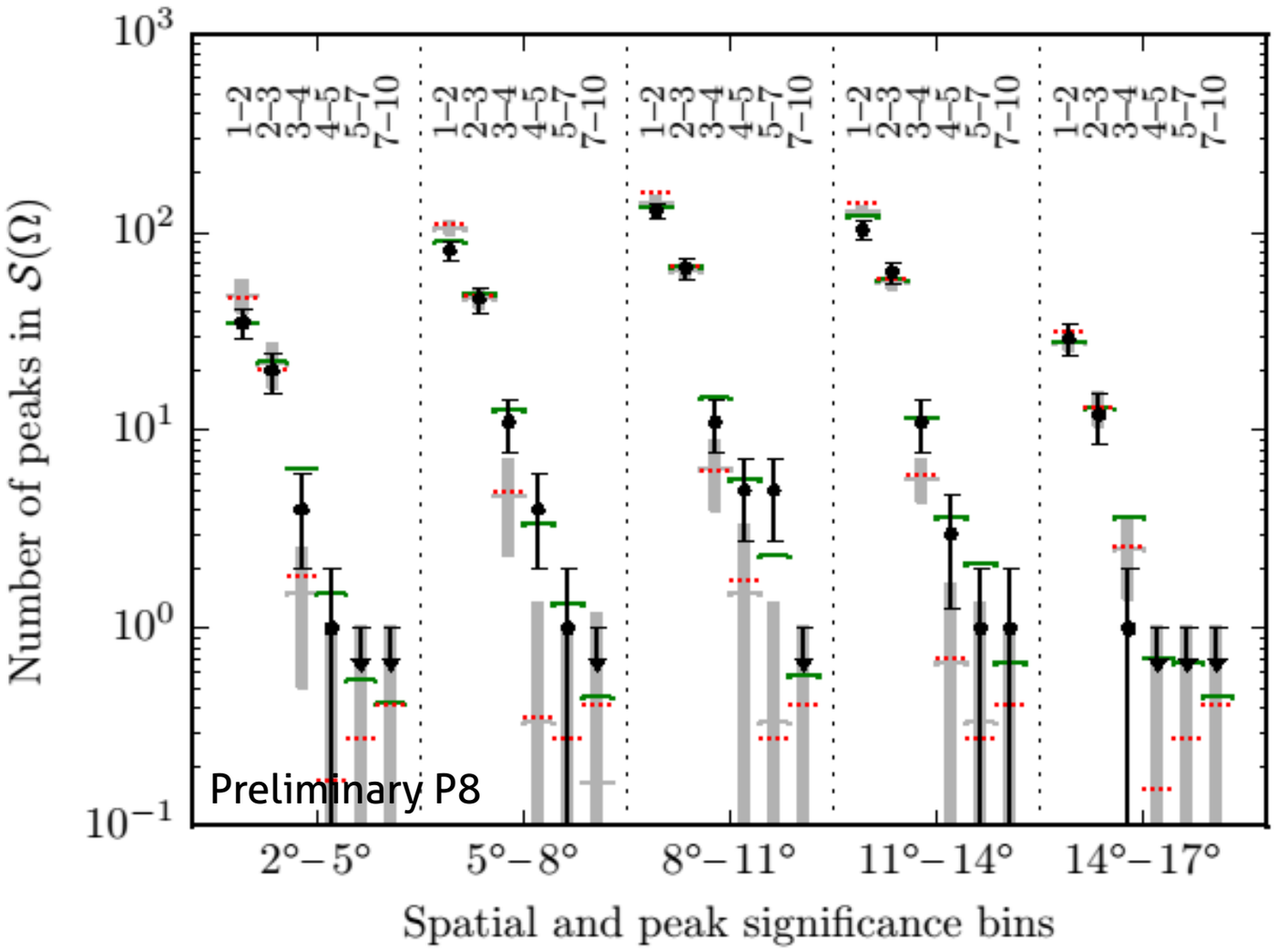


Histogram of peaks and MC results: point source like excess more high significance peaks and less low significance peaks.

(astro) Interpretation 02:

Unresolved population of milli second pulsars

Histogram of peaks and MC results: point source like excess more high significance peaks and less low significance peaks.



Histogram

- **Error bars:** inner Galaxy data

Null-hypothesis

- **Red**: null-hypothesis
- **Gray**: Control region results

Fit for norm and Lmax

- **Green**: best-fit

→ 8.3 sigma significance

MC predictions + simple estimates for disk population

We use a common maximum likelihood analysis (assuming that peaks are Poissonian distributed) to perform parameter estimation for the luminosity function:

$$\mathcal{L} = \prod_{i=1}^{n_r} \prod_{j=1}^{n_s} \mathcal{P}(c_{ij} | \mu_{ij}(L_{\max}, \Phi_5))$$

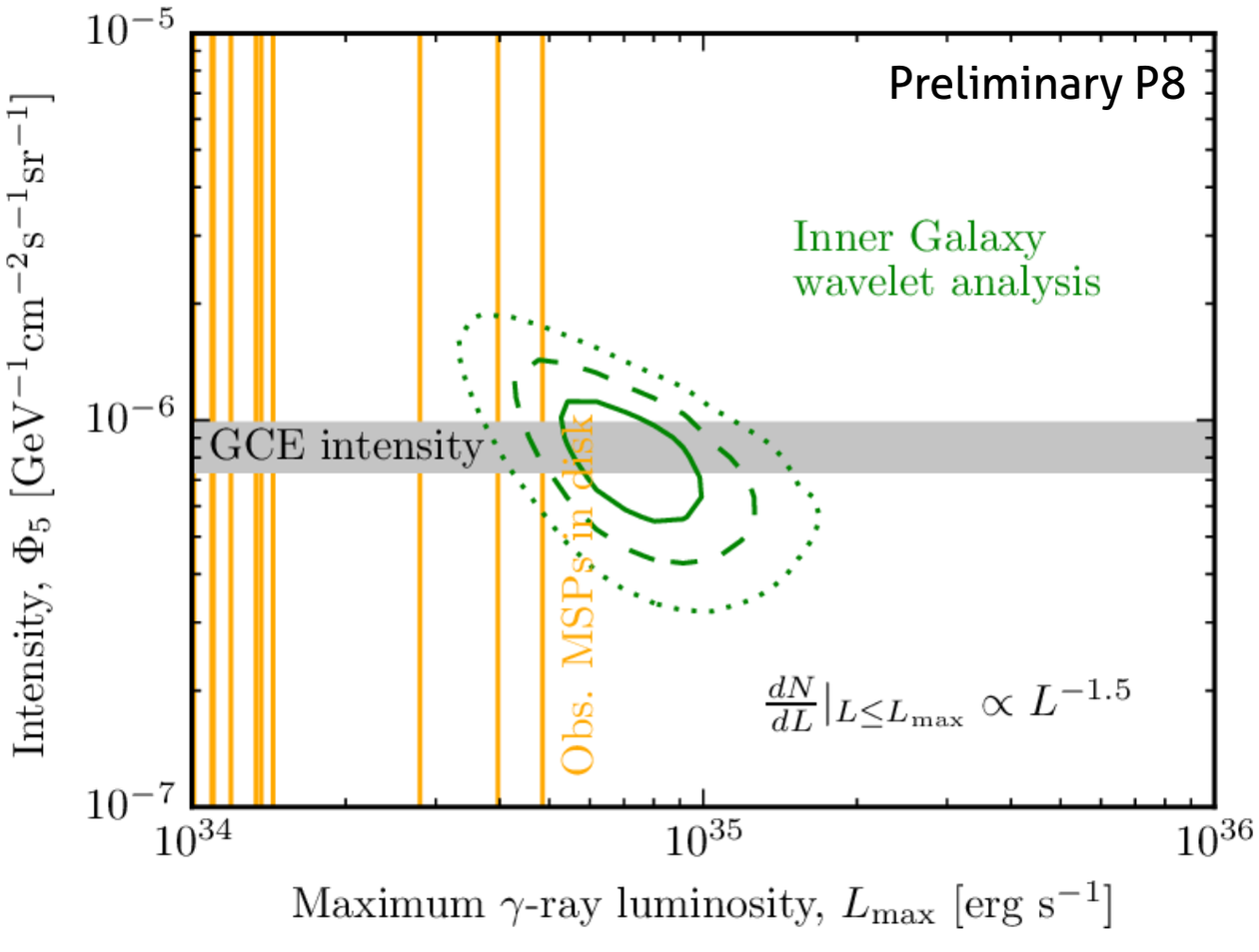
(astro) Interpretation 02:

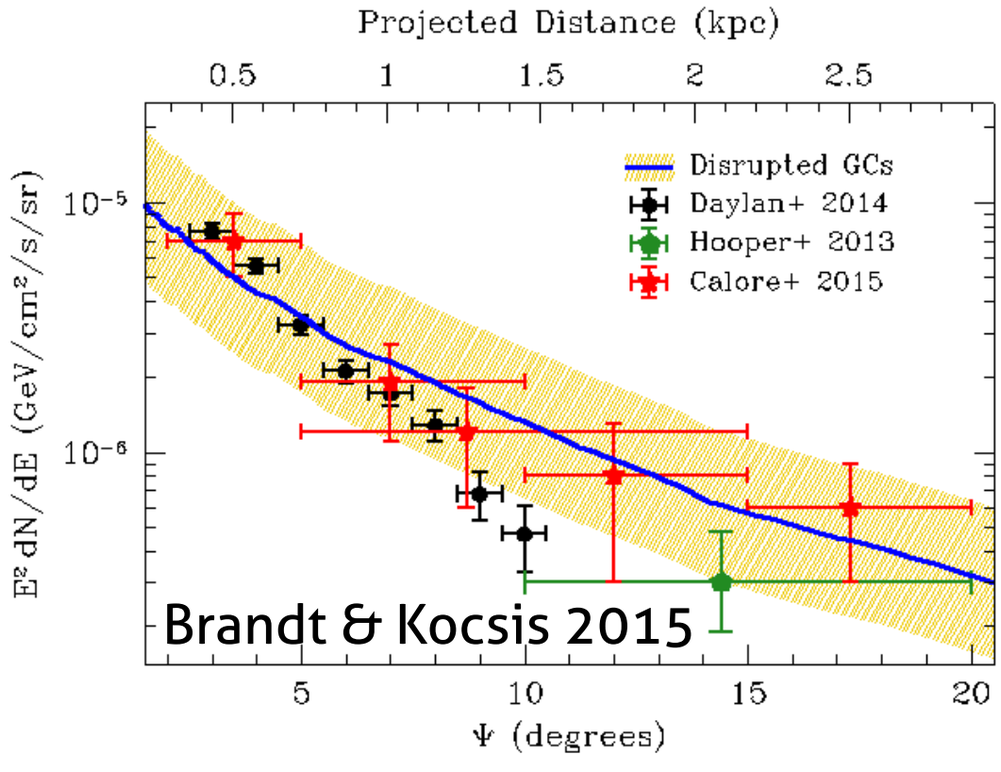
Unresolved population of milli second pulsars

Results:

- For a luminosity function index around 1.5, a MSP population with the best-fit normalization would reproduce 100% of the excess emission

- Lee+15, finds that ~60 MSPs just below the threshold cold explain the excess.





Bulge population

- Debris from disrupted globular clusters is enough to explain excess

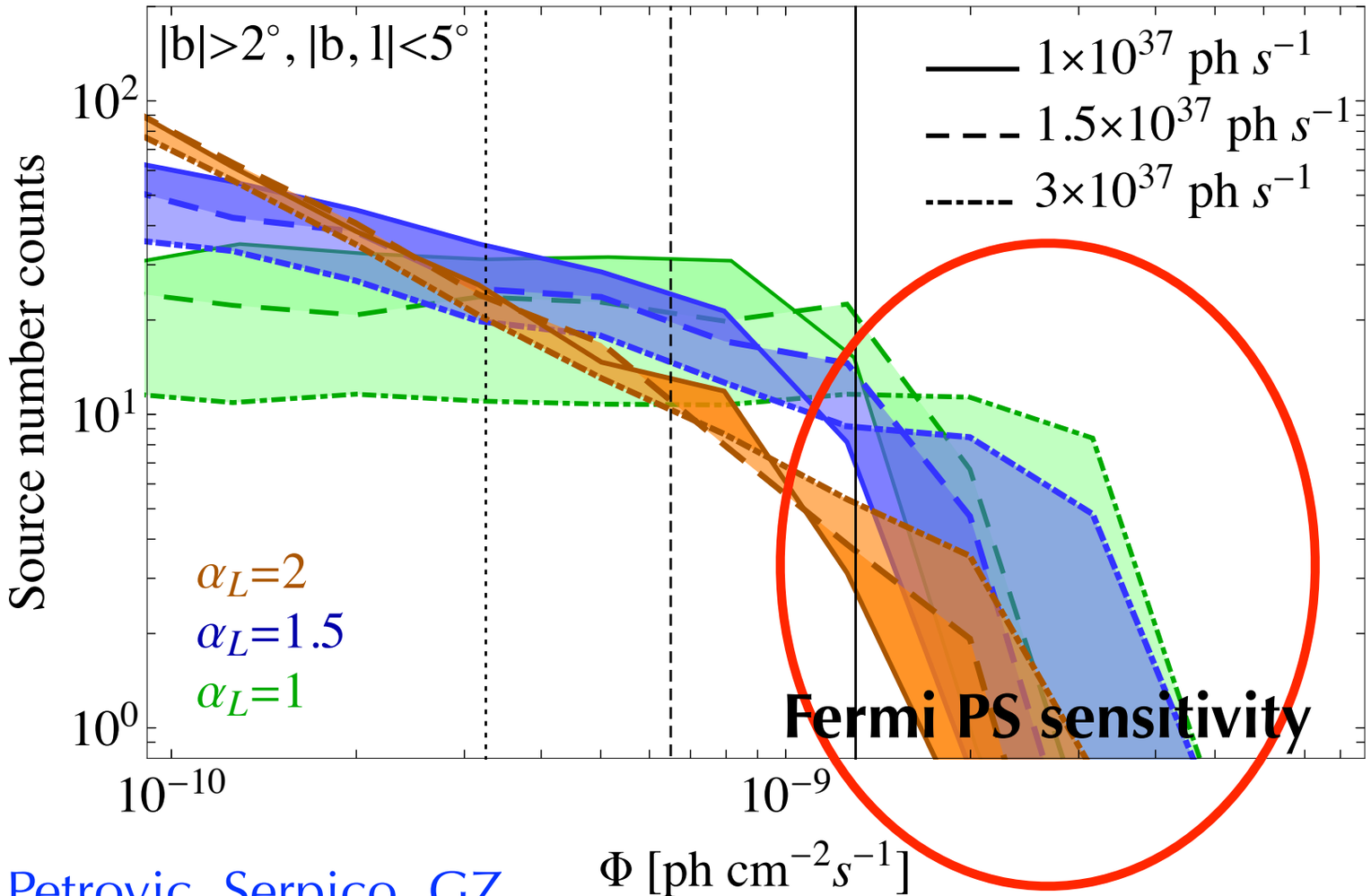
(astro) Interpretation 02:

Unresolved population of milli second pulsars

CONs:

2. too many MSPs should have been detected as point sources

Is this robust? We have only probed local population - have a complete sample only over a narrow range of luminosities.



Petrovic, Serpico, GZ, JCAP(2014),1411.2980

Simulate MSP population with parameters within their uncertainty ranges - and only **at the high luminosity end (most relevant, but incomplete sample)**.

find 1-20 MSPs above the threshold - (3FGL a dozen of pulsar like unIDs in that region)

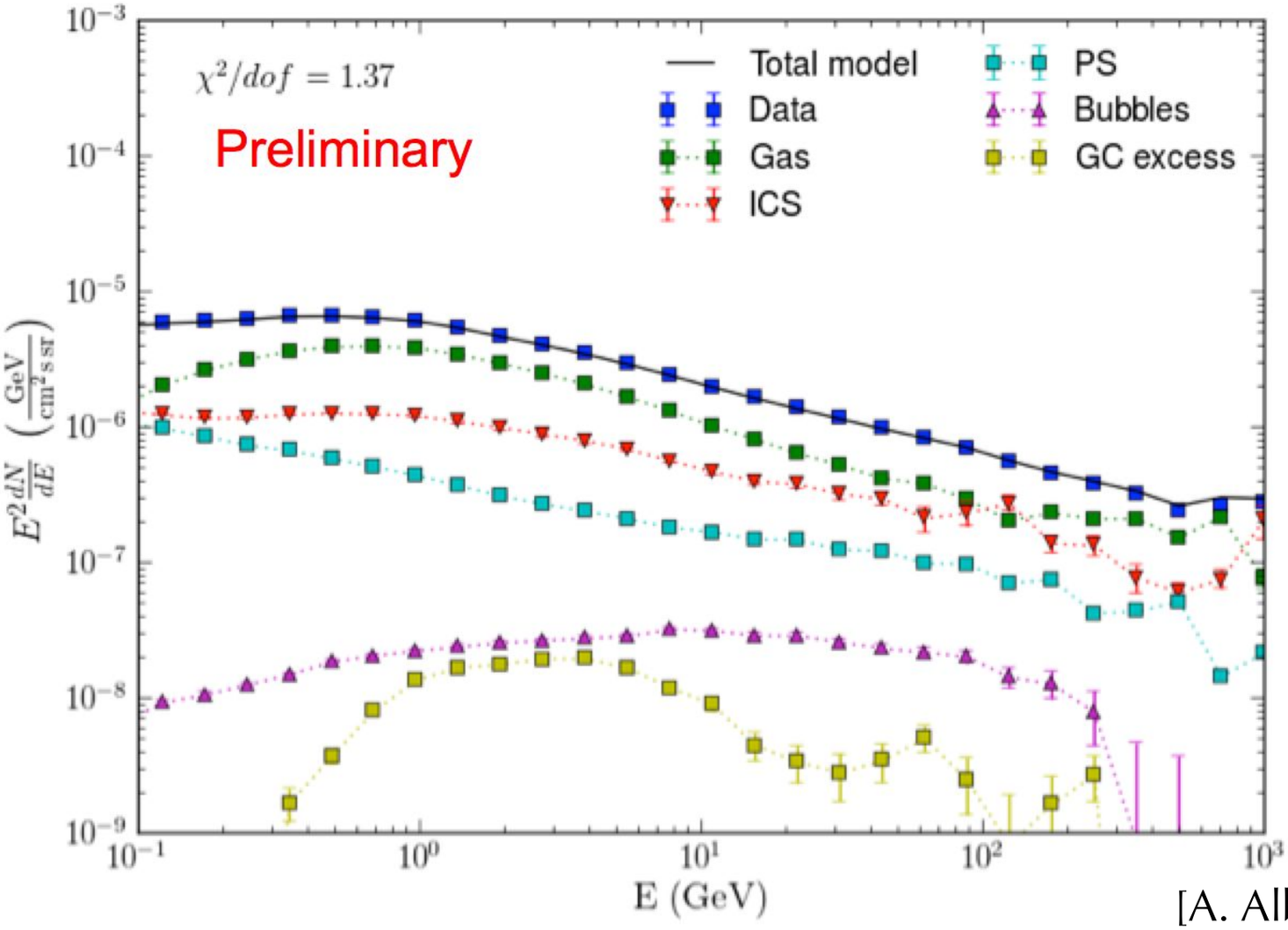
DM search in the inner Galaxy

updated Fermi LAT analysis (preliminary)

Fermi LAT analysis with the pass8 80m of data.

pass 8: improved direction and energy reconstruction, better background rejection, a wider energy range, and significantly increased effective area at the high- and low-energy ends.

- **Baseline templates:**



uncertainties due to the method used to partition the gas along the line of sight, as well as uncertainties related to the input interstellar tracer data and their angular resolution. This method is not 385 applicable toward the Galactic center (and anticenter) because in those directions the velocity from circular motion is almost perpendicular to the line of sight. Also, in the case of CO, for clouds in the central molecular zone (CMZ) tidal streams largely dominate over regular circular 388 motion

[A. Albert, APS 2016 meeting]