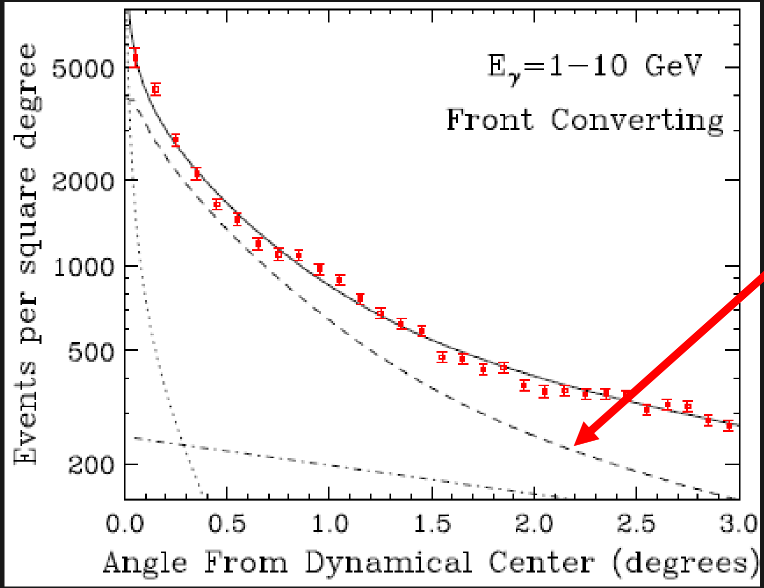
Assessing the Impact of Hydrogen Absorption on the Characteristics of the Galactic Center Excess

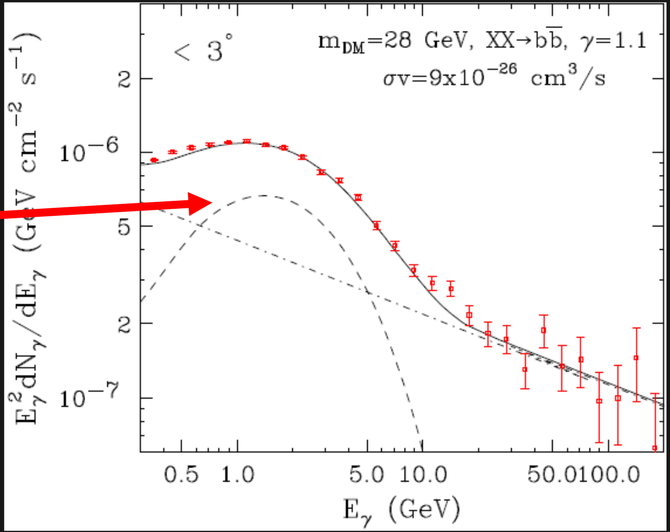
Martin Pohl
with Oscar Macias and Chris Gordon

Introduction

Back in 2009 Lisa Goodenough and Dan Hooper published on the arXiv



Dark matter



Introduction

Later analysis confirmed that there indeed is an excess.

Questions remain:

- Is the cosmic-ray induced diffuse emission properly modelled?
- What is the spectrum of the excess?
- What is the intensity distribution of the excess?

Galactic diffuse emission

Intensity depends

1. on the cosmic-ray flux
2. and the density of interstellar gas and radiation,
3. all integrated along the line of sight

Gas density is the decisive input for modelling

and is measured through line emission and its Doppler shift

Galactic diffuse emission

Normal assumption: circular rotation in the Milky-Way galaxy

$$V_{\mathrm{LSR}}(l, b, P) = \left[\frac{R_0}{r} V(r) - V(R_0)\right] \sin l \cos b$$

Zero velocity toward the Galactic center (l=0)

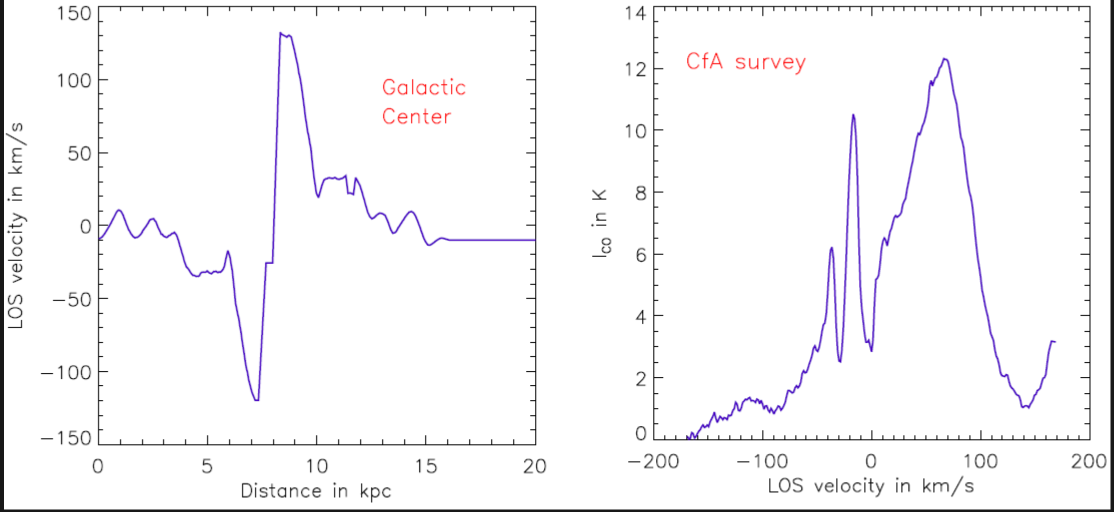
Standard assumption of circular motion does not work for inner Galaxy

→ no velocity resolution

Galactic diffuse emission

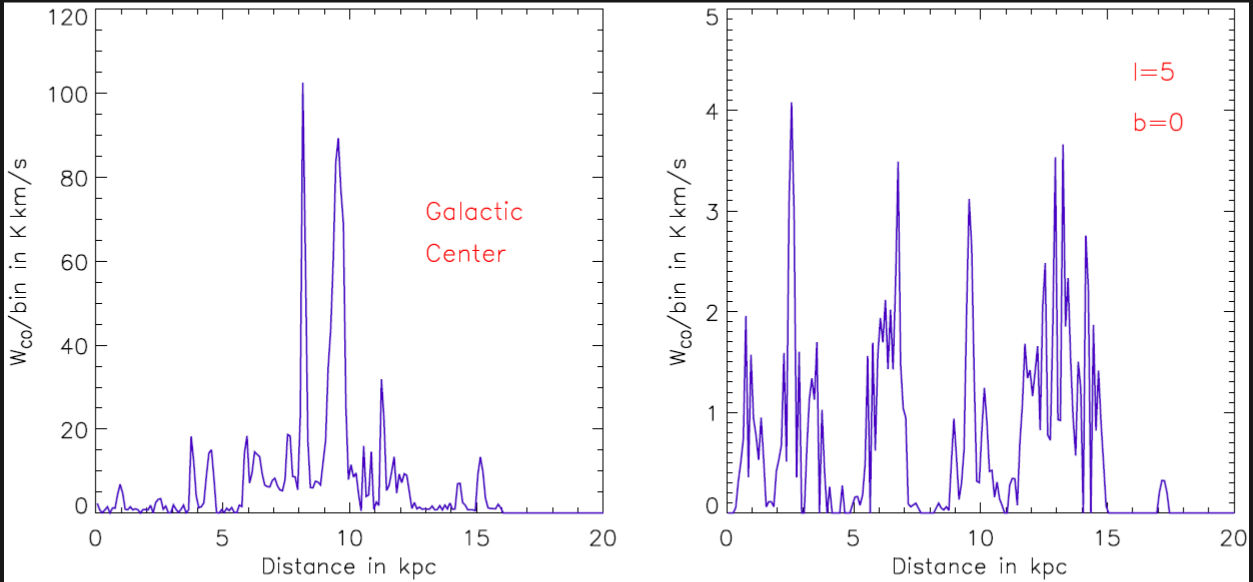
Simulate gas flow in barred gravitational potential with SPH (Bissantz et al.2003)

➔ non-radial flow (Pohl et al. 2008)



Galactic diffuse emission

CO deconvolution for 2 lines of sight



Newer models available, e.g. Mertsch et al.

2018 LAT reanalysis

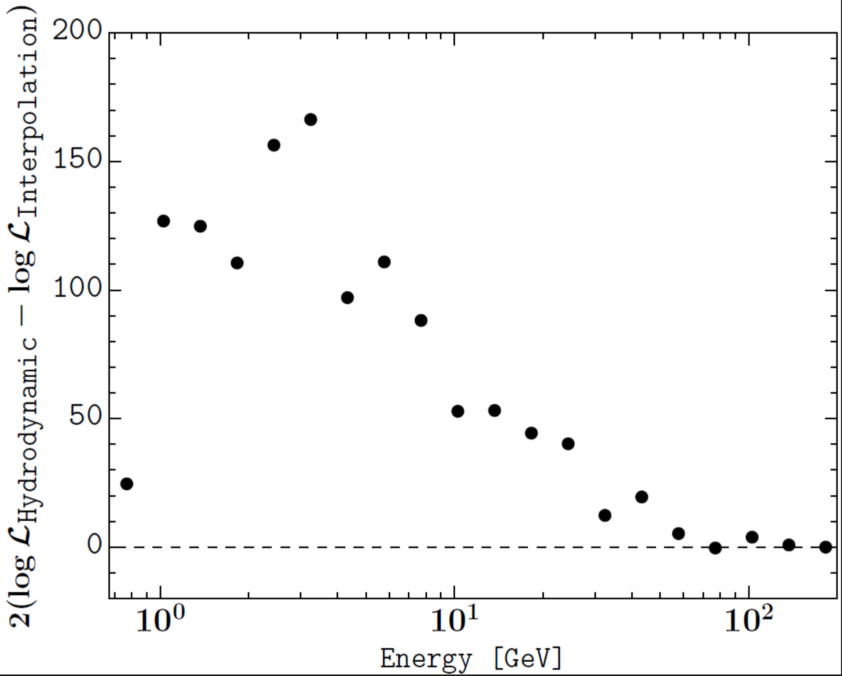
Improved map of H_2

Fit to data in 15° x 15° GC field

Total improvement TS=354

Seems to work at all energies

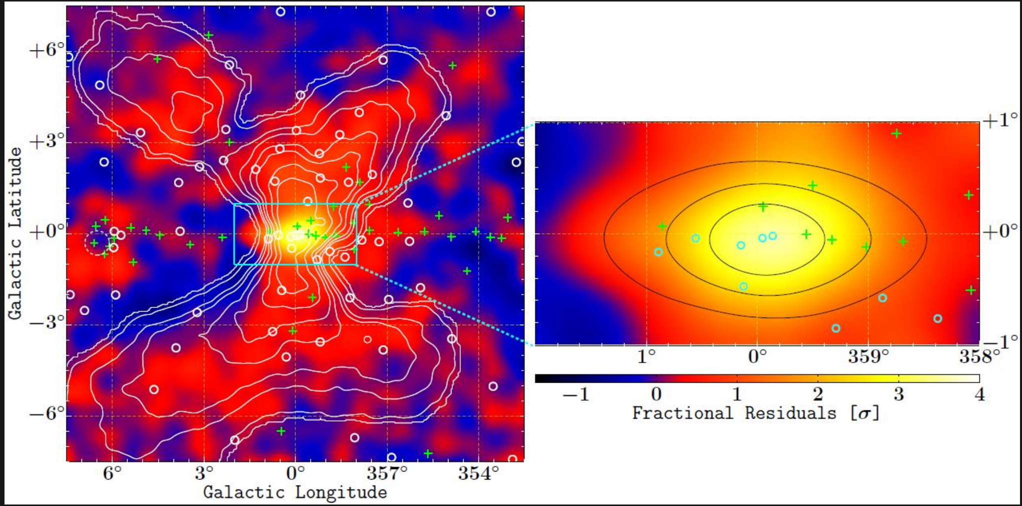
(Macias at al. 2018)



2018 LAT reanalysis

Residuals of revised diffuse model and 43 new point-source candidates (+)

DM template provides mimimal fit improvement



White contour: X bulge seen in NIR

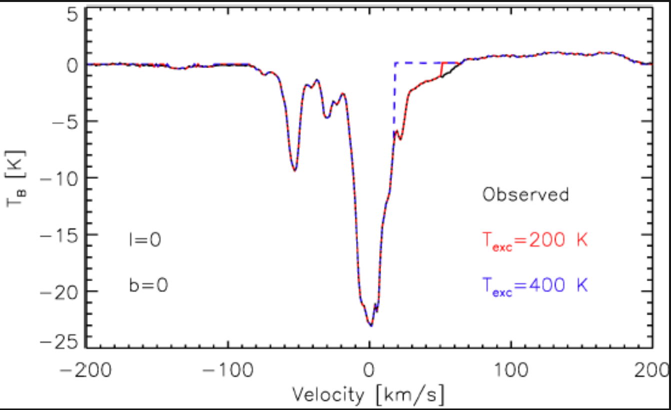
Black contours: Nuclear bulge

2021

How can we improve?

Idea:

- Revise model for HI deconvolution
- Account for absorption
- Perform radiation transport calculation



Radiation transport

Line emission and continuum emission $\frac{dI}{ds} = j_c + j_l - \alpha_l I$

For each segment Δs of the line of sight with optical depth $\tau = \Delta s\, \alpha_l$

$$I(\Delta s) = I_0 e^{-\tau} + \frac{j_c + j_l}{\alpha_l}\left(1 - e^{-\tau}\right)$$

Increment in brightness temperature

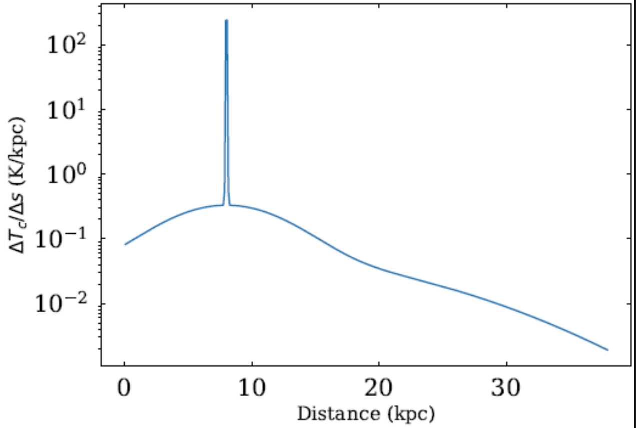
$$\Delta T = \left(\frac{\Delta T_c + \Delta T_l}{\tau} - T_0\right)\left(1 - e^{-\tau}\right) \quad \text{with } \Delta T_l = \tau T_{exc}$$

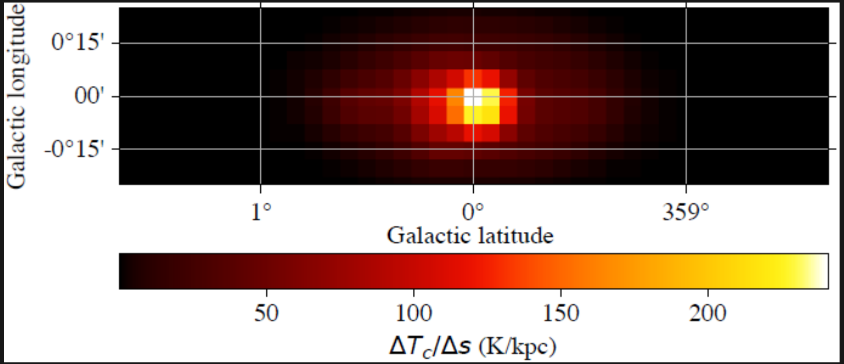
Gas data from HI4PI survey

Radiation transport

Continuum model based on CHIPASS survey and axisymmetry

strongly peaked at the Galactic Center





LOS towards Galactic Center

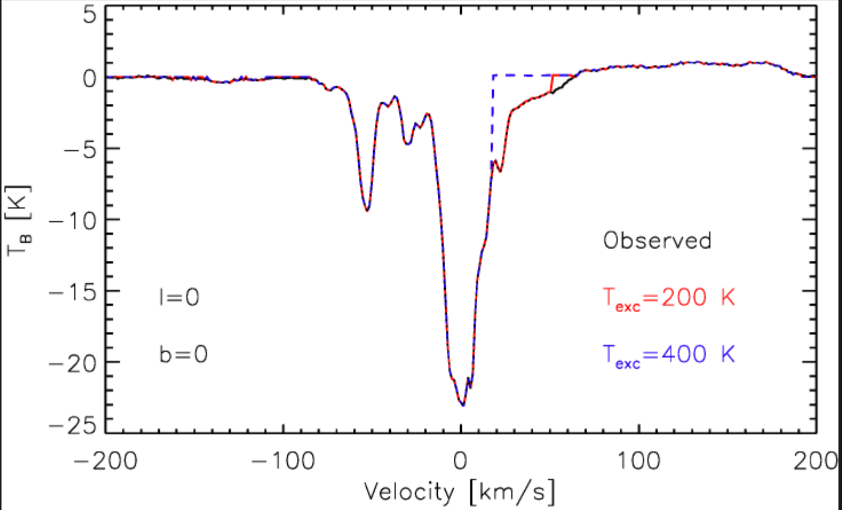
at 8 kpc distance

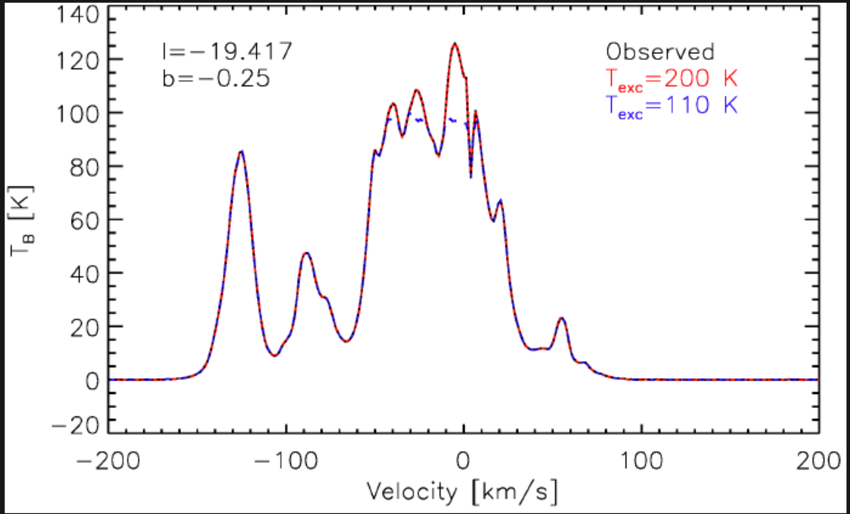
Radiation transport

Solution depends on assumed excitation temperature,

T_{exc}=200 K is best compromise

Locally, smaller temperatures are better





Radiation transport

New model with continuum emission and absorption

- Much more realistic than previous analyses
- The variety of observed HI spectra is well reproduced
- Same gas-flow model as was used 15 years ago

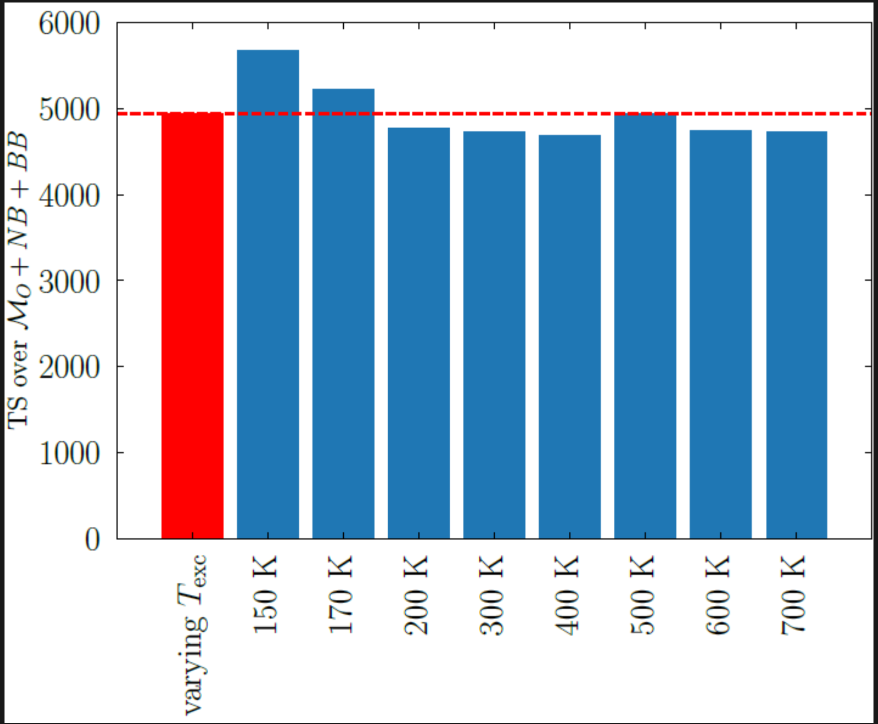
How does that affect analysis of Galactic diffuse emission?

Application to LAT data

Also include a revised model of the X bulge (Coleman et al. 2020) tracing Red-Clump stars and marked as „BB“.

„NB“ stand for the nuclear bulge

We henceforth use varying T_{exc}



Application to LAT data

Sequential analysis

Baseline model	Additional source	ΔTS	Significance
Basel.	Cored ellips.	0.0	$0.0\,\sigma$
Basel.	Cored	0.1	$0.0\,\sigma$
Basel.	BB	282.2	$15.3\,\sigma$
Basel.	NFW ellips.	647.2	$24.2\,\sigma$
Basel.	NFW	807.1	$27.3\,\sigma$
Basel.	NB	1728.9	$40.8\,\sigma$
Basel.+NB	Cored ellips.	0.1	$0.0\,\sigma$
Basel.+NB	Cored	0.7	$0.0\,\sigma$
Basel.+NB	NFW ellips.	1.0	$0.0\,\sigma$
Basel.+NB	NFW	3.4	$0.2\,\sigma$
Basel.+NB	BB	261.0	$14.7\,\sigma$
Basel.+NB+BB	NFW ellips.	0.1	$0.0\,\sigma$
Basel.+NB+BB	Cored ellips.	0.4	$0.0\,\sigma$
Basel.+NB+BB	Cored	0.7	$0.0\,\sigma$
Basel.+NB+BB	NFW	2.6	$0.1\,\sigma$

Only gas maps

Gas maps + NB

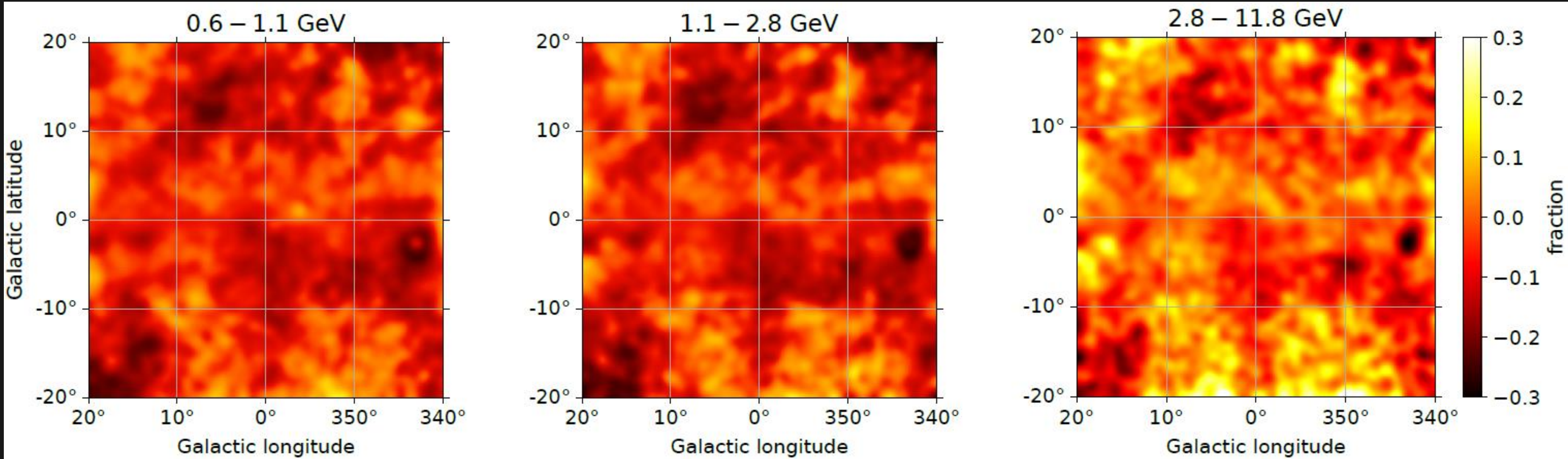
Gas maps + NB + BB

No DM-like signal

Application to LAT data

Not a fluke: true data are well compatible with a MC-based fake data

Residuals are small, possibly except where the Fermi bubbles appear



Conclusions

- A new HI gas deconvolution based on full radiation transport
- Very good reproduction of the variety of observed line spectra
- Reanalysis of Fermi-LAT data strongly prefers the new gas model
- It also prefers the nuclear bulge
- It likes the boxy bulge, a revised model of the X bulge

ΔTS~5000

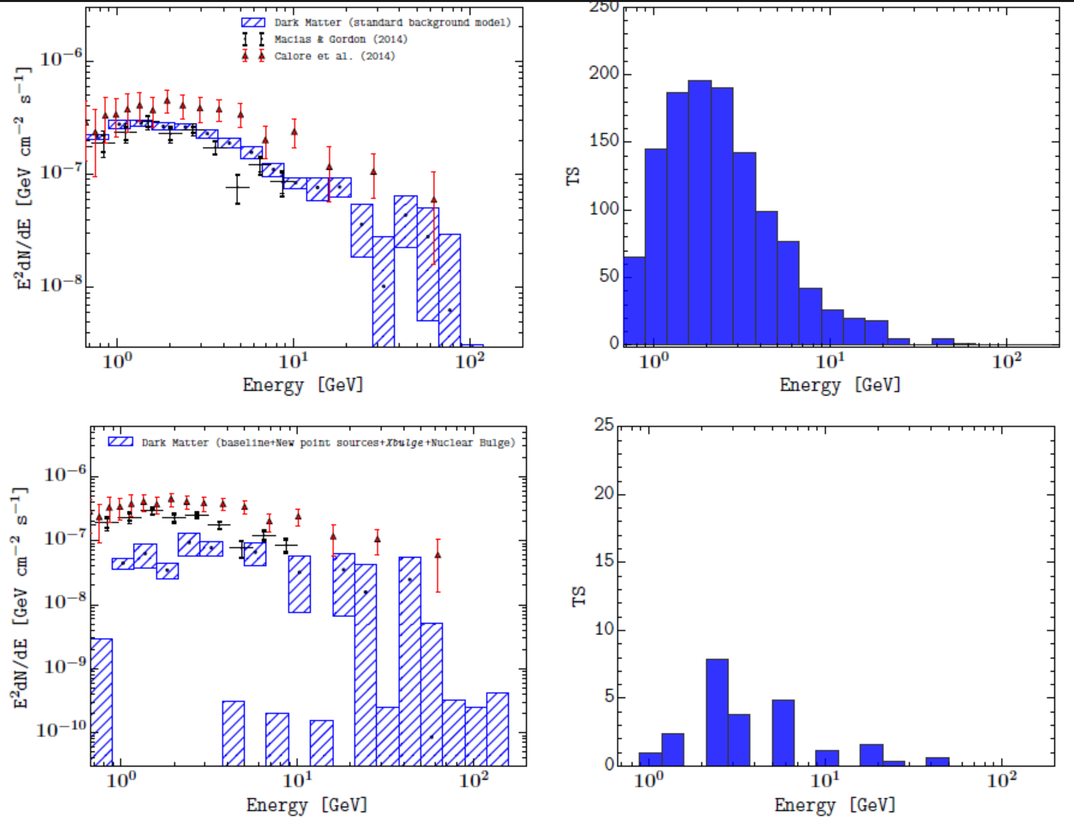
- No evidence whatsoever for a dark-matter scenario

2018 LAT reanalysis

Old

DM model

33σ



New

1σ

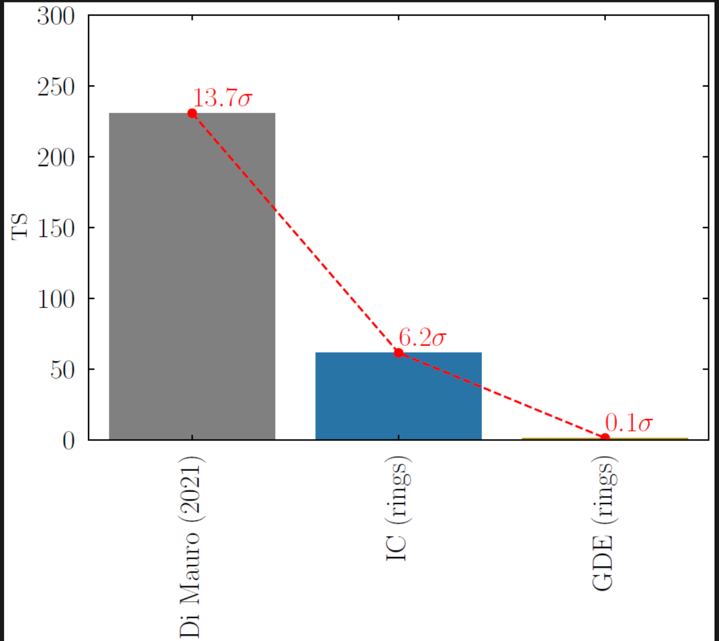
Application to LAT data

Poor models of diffuse emission yield a gamma-ray excess

TS for DM template

1. Base model of Di Mauro
2. Reorganize IC in six rings
3. Also reorganize hadronic model in four rings

Lack of flexibility is critical



Clues on MSP scenario

Slope of BB profile should depend on MSP production scenario

Primordial:
NS formation in massive binaries retains them in globular clusters, etc.

Dynamical:
NS are captured and form binaries