Galactic center excess analysis with Pass 8 data

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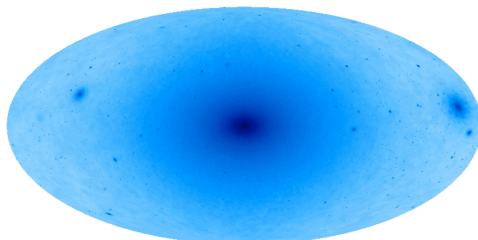
DESY, Zeuthen

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on behalf of the Fermi LAT collaboration

6th Fermi Symposium
Arlington, Nov 9 - 13, 2015

Fermi · Gamma-ray Space Telescope

National Aeronautics and Space Administration

NASA

www.nasa.gov/fermi

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Dark matter annihilation in the Galactic center?
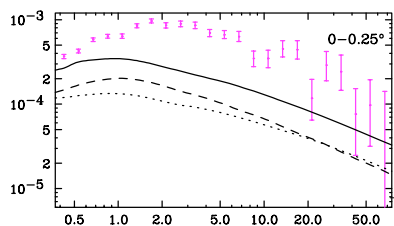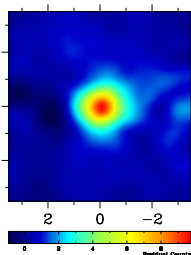

Via Lactea II, Kuhlen et al, arxiv:0907.0005
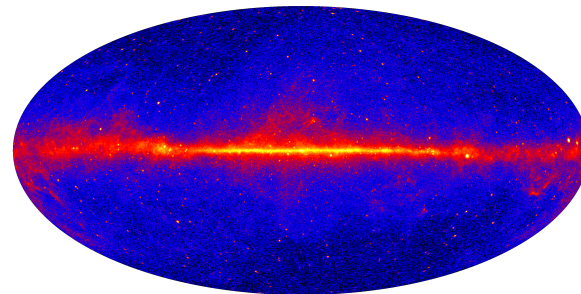
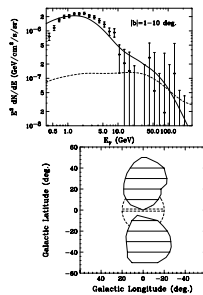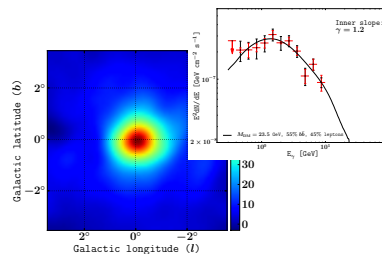Fermi LAT, 6 years, Pass 8 data

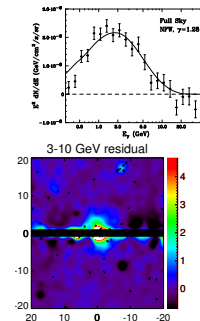## Excess emission

Goodenough & Hooper
arxiv:1010.2752

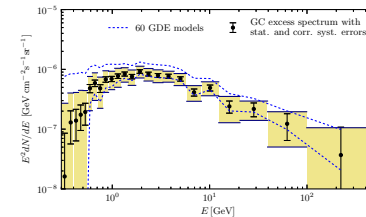Abazajian & Kaplinghat
arxiv:1207.6047

Hooper & Slatyer
arxiv:1302.6589

Gordon & Macias
arxiv:1306.5725

Daylan et al.
arxiv:1402.6703

Calore et al.
arxiv:1409.0042

and counting

Dark matter annihilation, unresolved sources, CR electrons?

– **Mirabal (arxiv:1309.3428), Petrovic et al. (arxiv:1411.2980), Cholis et al. (arxiv:1506.05119), Lee et al. (arxiv:1506.05124), Bartels et al. (arxiv:1506.05104), Brandt & Kocsis (arxiv:1507.05616), Carlson et al. (arXiv:1510.04698) etc.**

Fermi LAT collaboration Pass 7 analysis

- **Construct interstellar emission model (IEM) with a combination of templates from GALPROP**
  - **Test different CR distributions (pulsars, OB stars)**
  - **Refit intensity of components**
  - **Refit both index and intensity**
- **Find and characterize the point sources near the GC for each IEM**
- **There is a residual near the GC with a spectrum peaking at a few GeV (NFW template) – strong dependence on IEM**
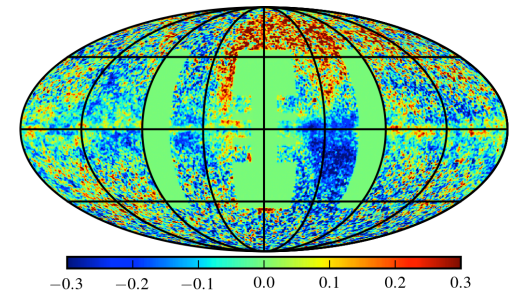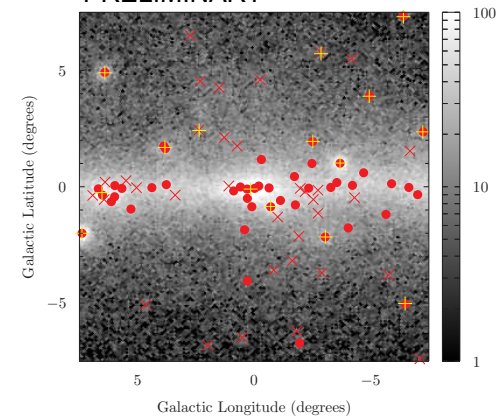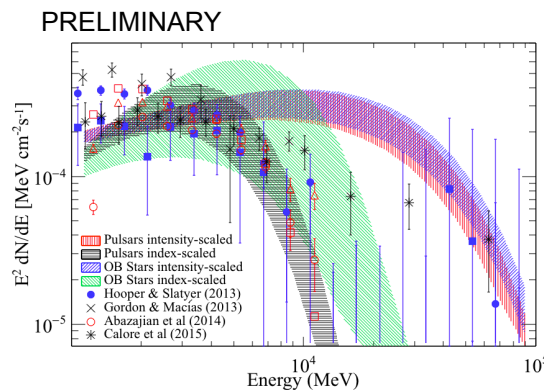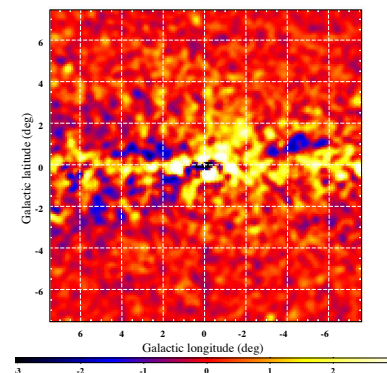
Ajello et al.,
arxiv:1511.02938

PRELIMINARY

PRELIMINARY

PRELIMINARY

PRELIMINARY

Outline of the talk

- **Data used for this analysis**
  - **Pass 8**
- **Analysis method**
  - **Template fitting**
- **Variations of GALPROP parameters**
- **Alternative distribution of gas along the line of sight**
  - **Derived with starlight extinction data**
- **Additional source of CR electrons near the GC**
- **Derivation of the Fermi bubbles at low latitudes**
  - **Use the spectral information to derive a template for the bubbles**
- **Summary**
  - **the band of the GC excess flux**

Data Set

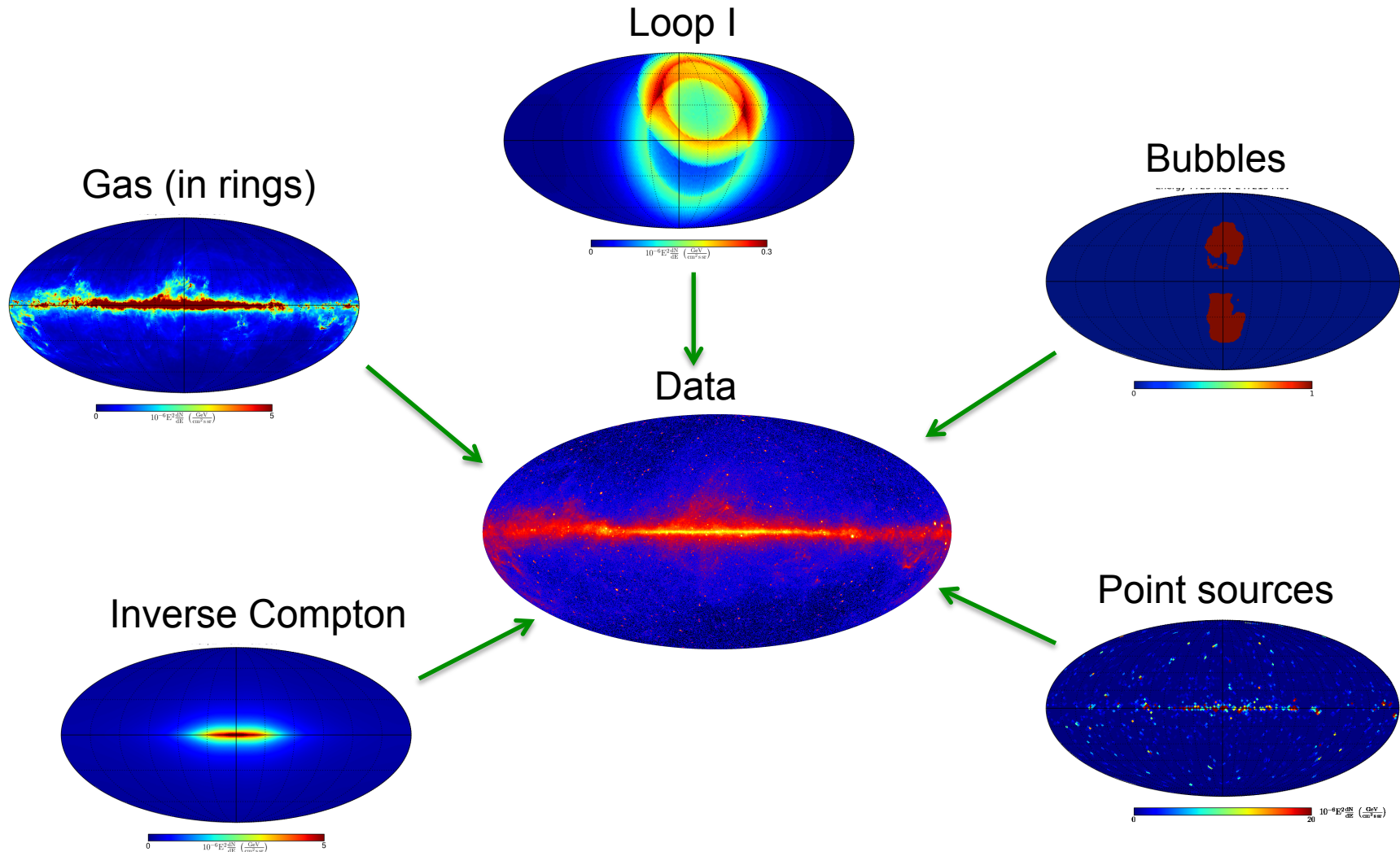- **6.5 years of Pass 8 data (Aug 8, 2008 – Jan 31, 2015)**
- **Pass 8, Ultracleanveto Class, zenith angle less than 90°**
- **27 energy bins from 100 MeV – 1 TeV**
- **Binned into HEALPix maps of order 6 / 7 (resolution 1° / 0.5°)**

Order 6 resolution for small flux areas

Order 7 resolution for large flux areas

Preliminary

Adaptive resolution order

5.9 7.1
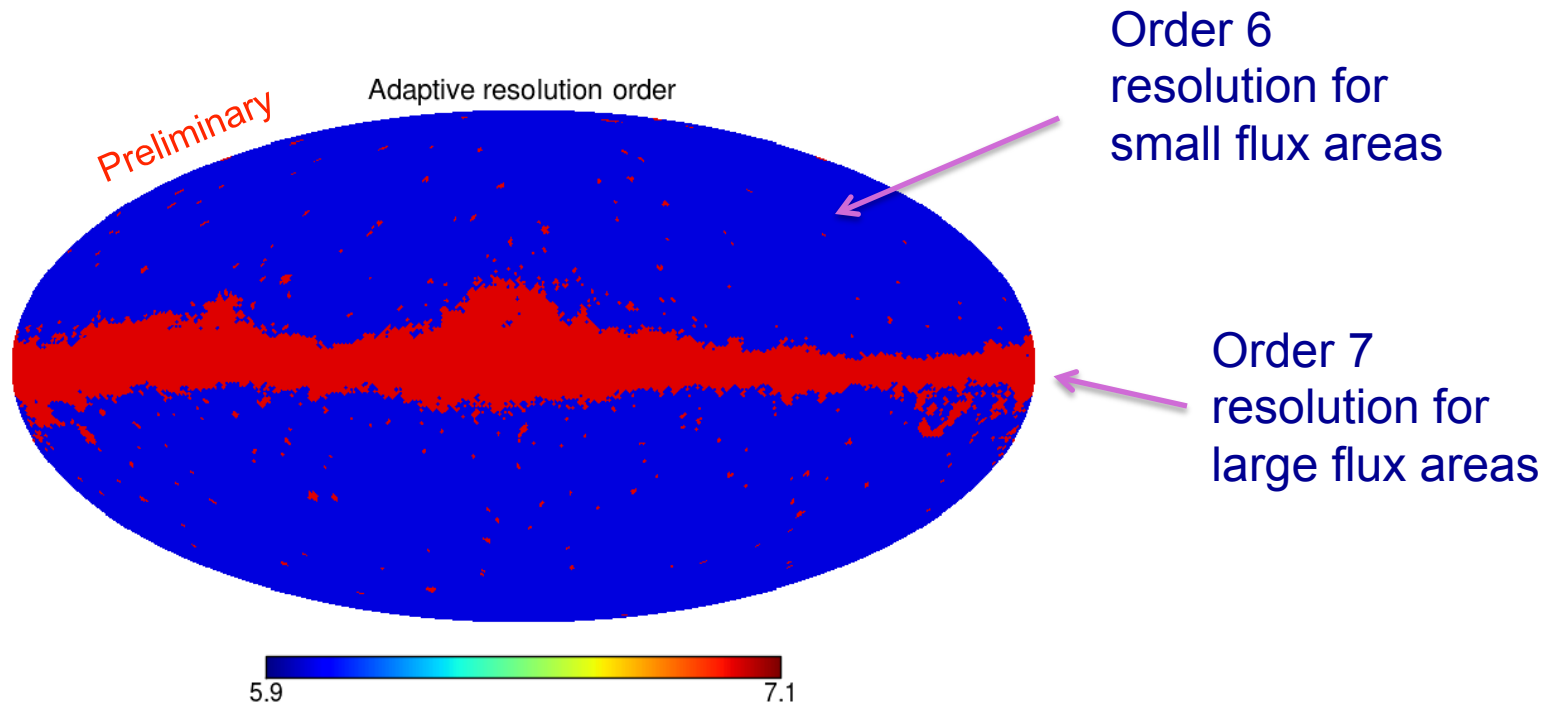
- **Fit templates to the data in energy bins (bin by bin fitting)**

Loop I

Gas (in rings)

Bubbles

Data

Inverse Compton

Point sources

Reference model templates

- **Baseline templates:**
  - **Gas correlated (π^0 decay, bremsstrahlung) – GALPROP in 5 rings**
    - **Separate H I and CO templates (trace atomic and molecular hydrogen)**
  - **Inverse Compton (starlight, IR, CMB) - GALPROP**
  - **Loop I** **(Wolleben, arxiv:0704.0276)**
  - **Isotropic**
  - **Fermi Bubbles** **(Fermi collaboration, arxiv:1407.7905)**
  - **Point Sources** **(T. Burnet presentation on Wednesday)**
    - **Derived with Pass 8 data**
    - **The cores of 300 bright PS are masked**
  - **Sun / Moon (Fermi science tools)**
- **Excess template:**
 - **Contracted NFW DM annihilation (index 1.25)**

R [kpc]
0 – 1.5
1.5 – 3.5
3.5 – 8
8 – 10
10 – 50

Inner: 0 – 1.5, 1.5 – 3.5, 3.5 – 8
Local: 8 – 10
Outer: 10 – 50

# GALPROP parameters and alternative gas distribution

- **Use models from Fermi LAT diffuse analysis** (arxiv:1202.4039)

- **Cosmic-ray source distribution:**
  - **Pulsars** (Lorimer et al., astro-ph/0607640)
  - **SNR** (Case & Bhattacharya, astro-ph/9807162)
  - **Pulsars** (Yusifov & Kucuk, astro-ph/0405559)
  - **OBStars** (Bronfman et al., astro-ph/0006104)

- **CR propagation volume**
  - **Radius: 20/30 kpc**
  - **Height: 4/10 kpc**

- **Spin Temperature**
  - **150K/optically thin**

- **We derive an alternative distribution of gas along the line of sight to the GC using starlight extinction** (Schultheis et al, arxiv: 1405.0503)
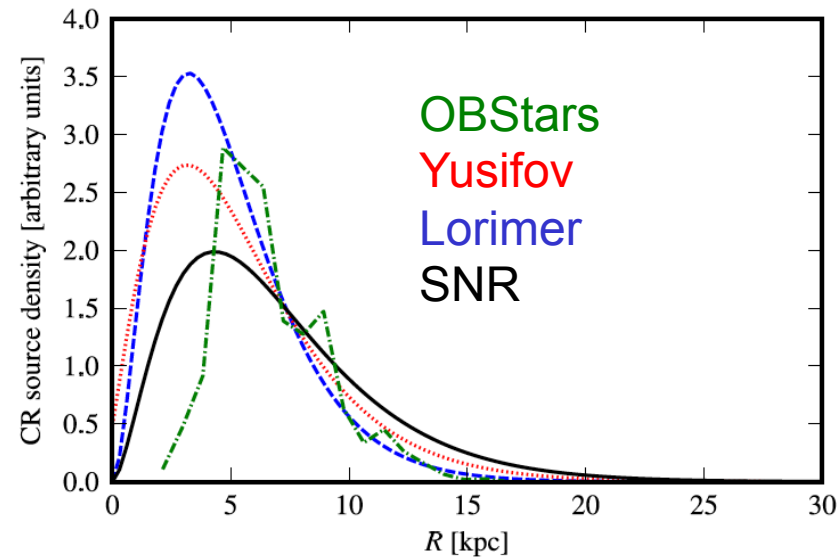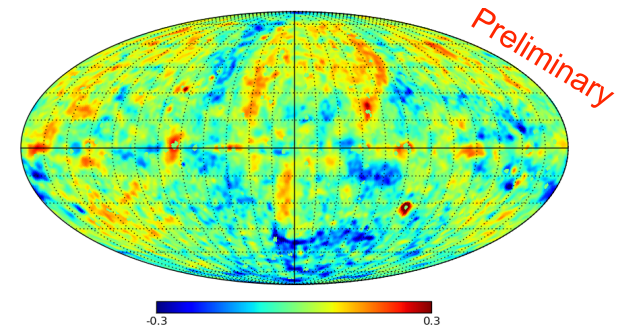
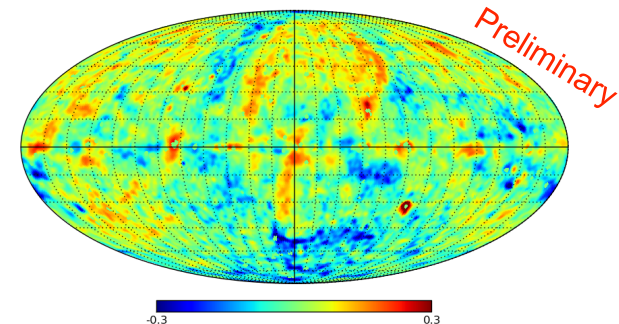**Reference model parameters shown in blue**

OBStars
Yusifov
Lorimer
SNR

- **Contracted NFW, n = 1.25**
  - **All sky-fit**
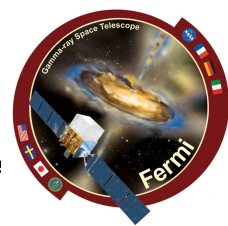 - **Fit normalization in each energy bin for each template**
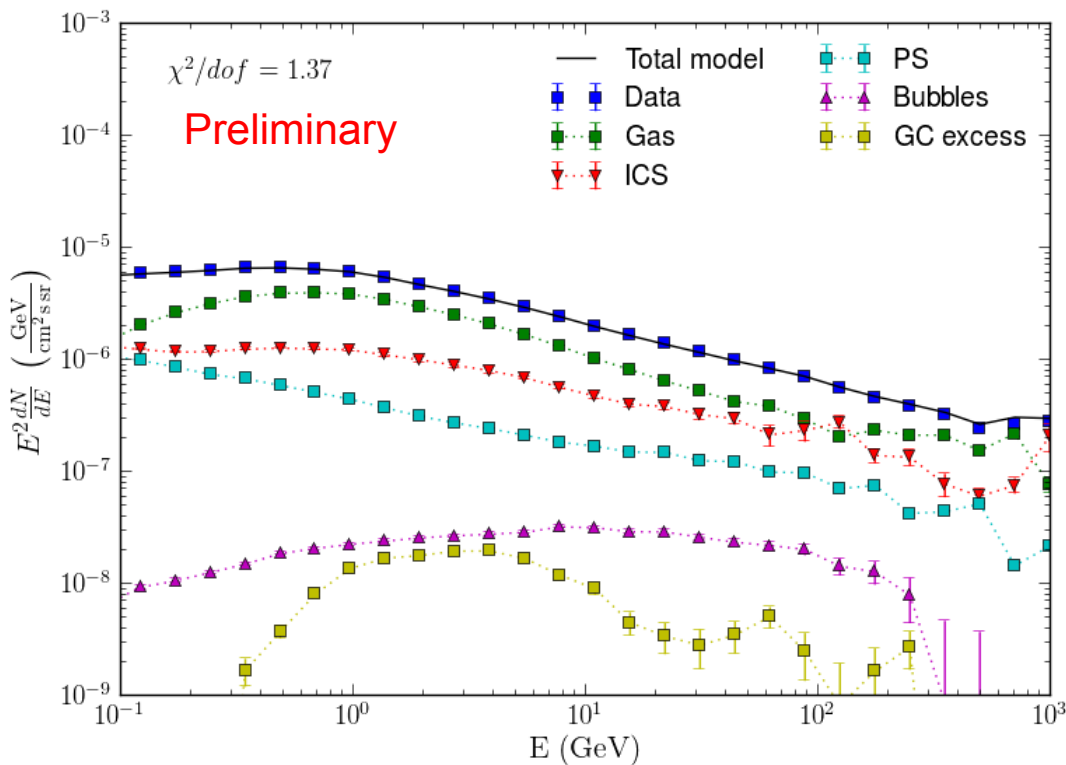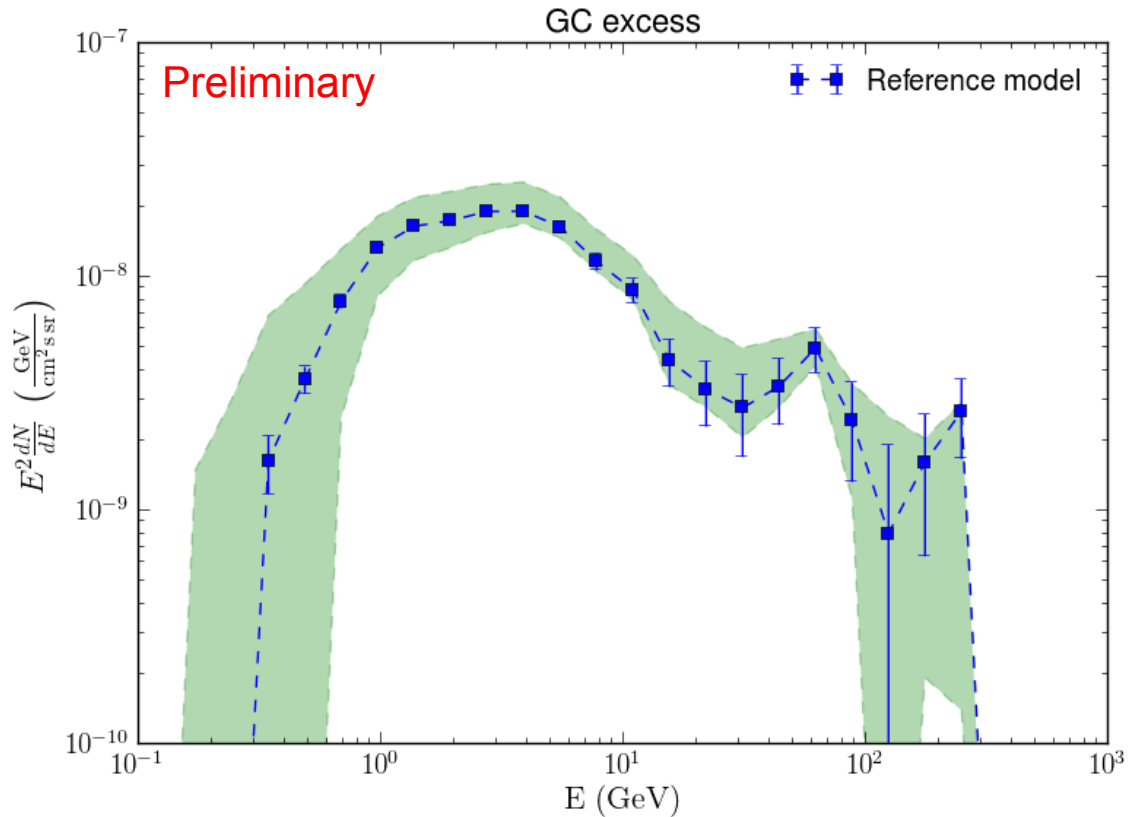

Fractional residual, 1.1 – 6.5 GeV

Add back the GC excess signal

- **Variation of GALPROP parameters and the distribution of gas along the line of sight**

- **CR electron sources in the bulge** (Petrovic et al. arxiv:1411.2980)

  - **electrons are produced by MSPs in the bulge**

- **Star formation in molecular clouds near the GC**

  - **Burst-like emission from the GC nucleus** (Cholis et al. arxiv: 1506.05119)

  - **Stationary CR production by molecular clouds** (Carlson et al. arXiv:1510.04698)

- **Similar to Carlson et al (2015), we find that a source of CRe electrons in the CMZ region can reduce the flux associated with NFWc template:**
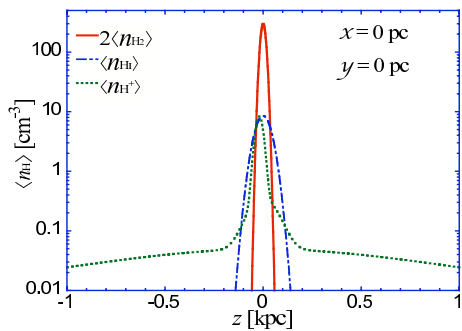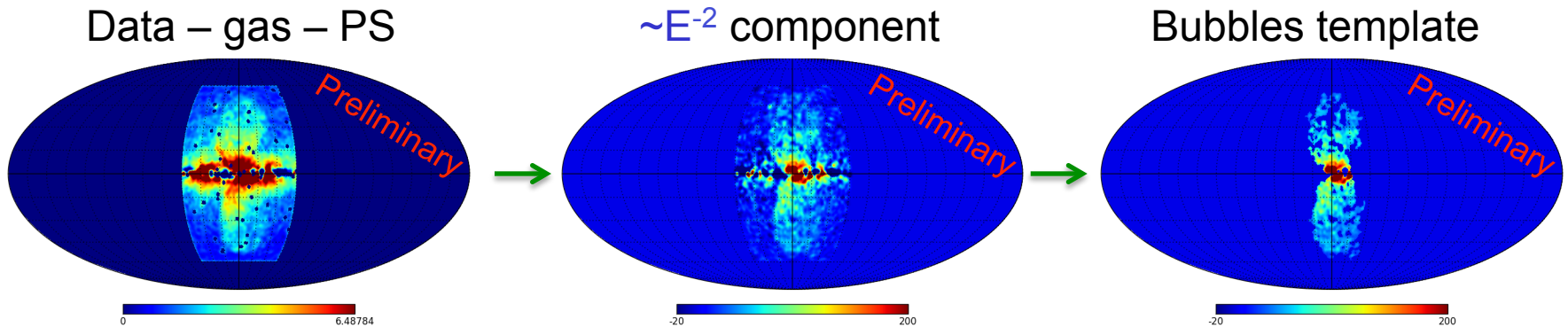

Ferriere et al., astro-ph:0702532
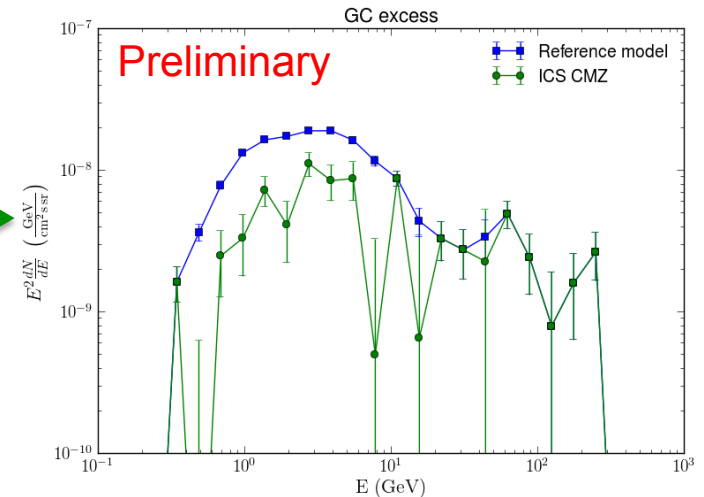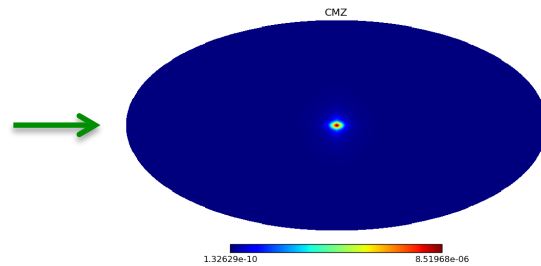
Bubbles template

- **Assume that the bubbles have the same spectrum near the GC as at high latitudes ~E^{-2} between 1 and 10 GeV**

- **Cut on significance to obtain the bubbles template**

Data – gas – PS   →   ~E^{-2} component   →   Bubbles template
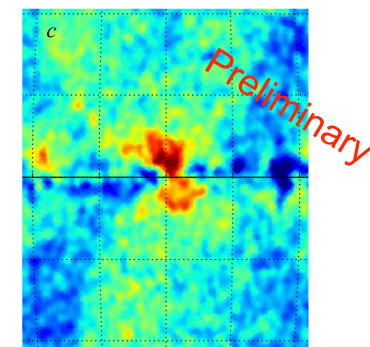
- **Fermi bubbles template in the inner Galaxy looks similar to the template found in Casandjian (2014)**
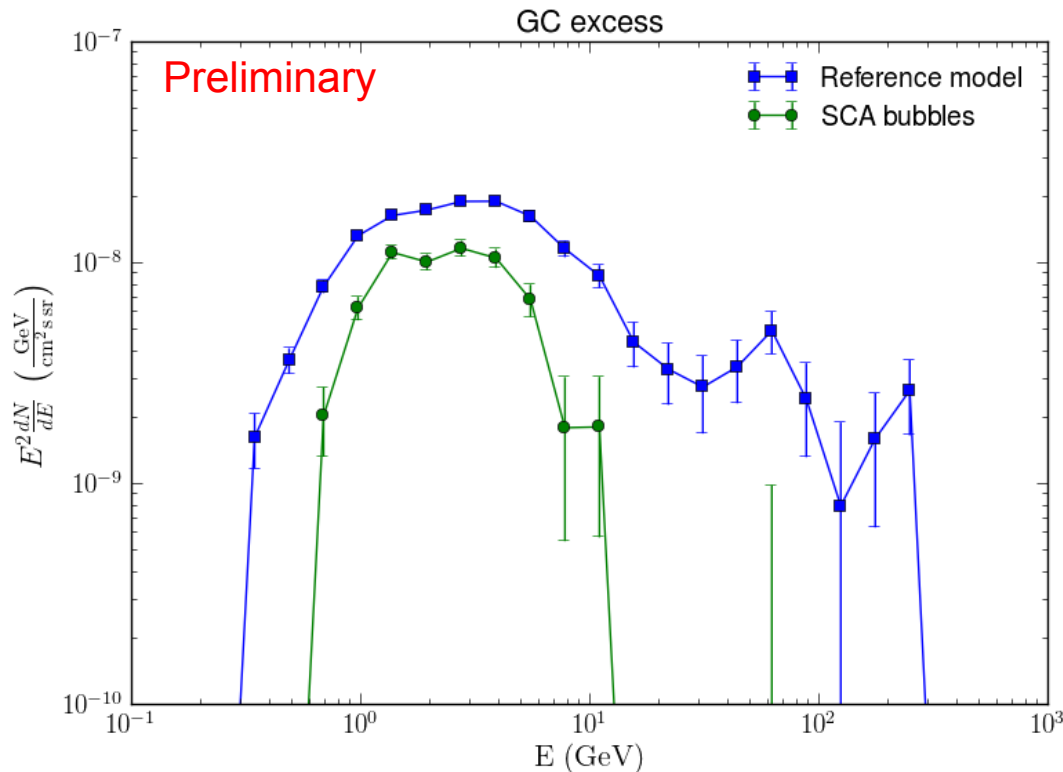
- **But beware of modeling uncertainties**
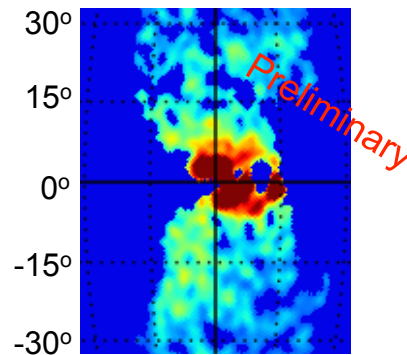
This work

J.-M. Casandjian for the Fermi LAT collaboration, arxiv:1502.07210

- **Fit the NFWc profile together with the all-sky bubbles determined with Spectral components analysis (SCA)**
  - **The high-energy tail of the GC excess is gone**
 - **Overall normalization is reduced**

- **The spectrum uncertainty band**
  - **Variations of GALPROP models and gas distribution**
 - **CMZ source of CR electrons**
  - **Fermi bubbles at low latitudes**
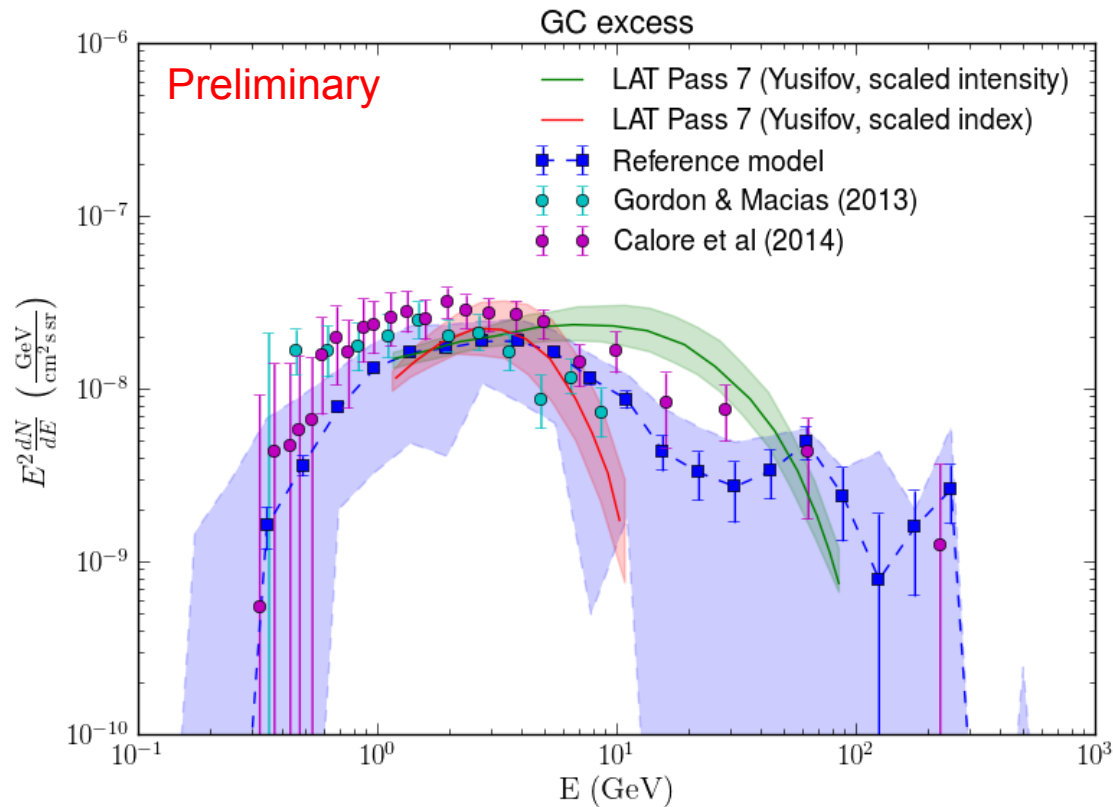

Spectra are normalized to 4π sr

Conclusions

- **Some model-related uncertainties on the GC excess were investigated using Pass 8 data**

- **The following uncertainties have relatively small effect on the excess spectrum:**
  - **Variation of GALPROP models**
  - **Distribution of gas along the line of sight**

- **Most significant sources of uncertainty are**
  - **Fermi bubbles morphology**
  - **Sources of CR electrons near the GC**

- **Since the astrophysical explanations of the excess, e.g., MSPs cannot be excluded at the moment, we put limits on DM annihilation (Andrea Albert's talk on Thursday)**
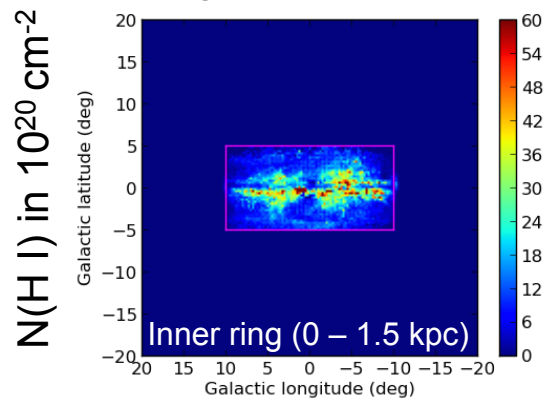
Backup slides
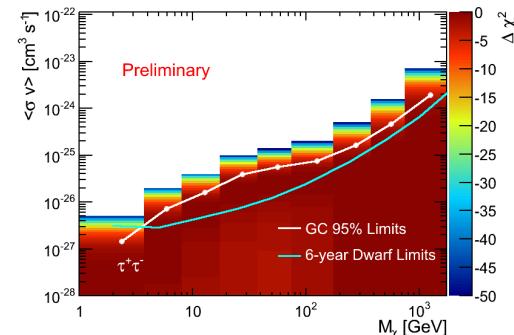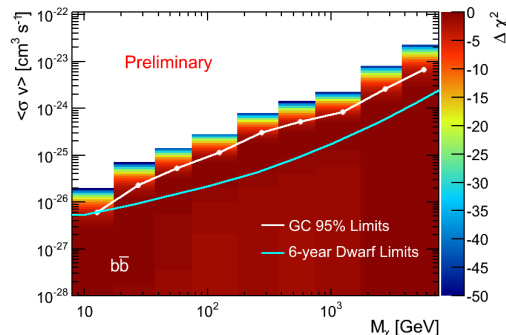
Alternative Gas Maps
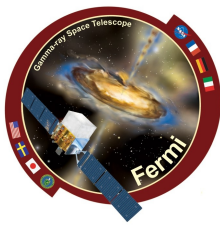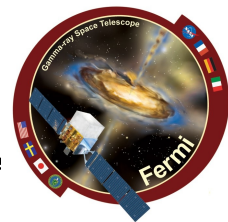
- **Hard to model distribution of gas towards the GC due to lack of Doppler shift information**
  - **Gas distribution is interpolated from |Lon| > 10°**
- **Use starlight (SL) extinction (Schultheis et al, arxiv:1405.0503) to find the distribution of dust along the LOS towards the GC**
  - **Derive the distribution of gas assuming homogeneous mixing of dust and gas**
- **Not meant to be a substitution for the current gas maps**
  - **useful for estimation of modeling uncertainties**

Using SL extinction   Original gas maps

Inner ring (0 – 1.5 kpc)

$N(H\,I)$ in 10^{20} cm^{-2}

Galactic latitude (deg)   Galactic longitude (deg)

GC excess

Preliminary

Reference model
SL extinction gas

$E^2\frac{dN}{dE}$ $\left(\frac{GeV}{cm^2 s\, sr}\right)$

E (GeV)