On the Origin of the Gamma-ray Emission From the Andromeda Galaxy

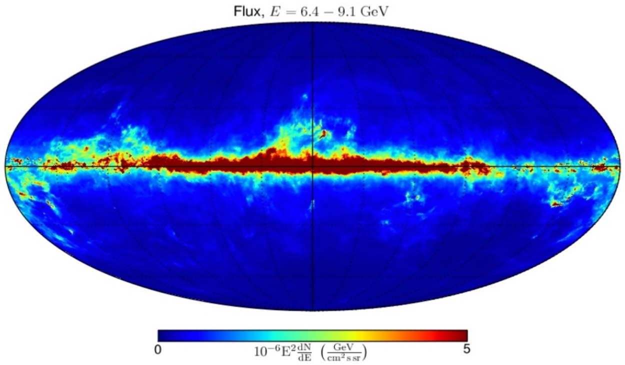
Xian Hou, Mattia Di Mauro, and Christopher Eckner

On behalf of the *Fermi*- LAT Collaboration

8th International Fermi Symposium
Baltimore, USA
18 Oct , 2018

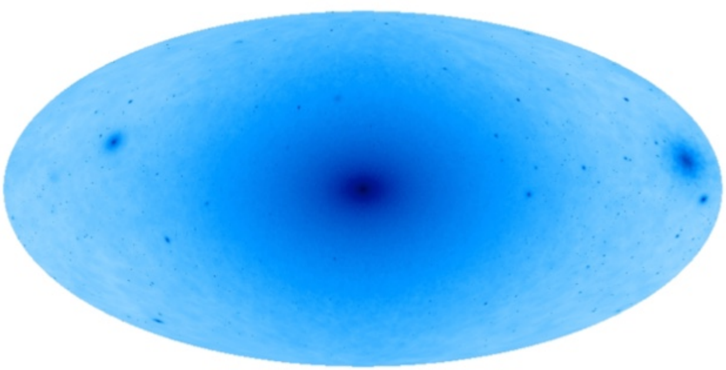
What make galaxies shine in gamma rays?

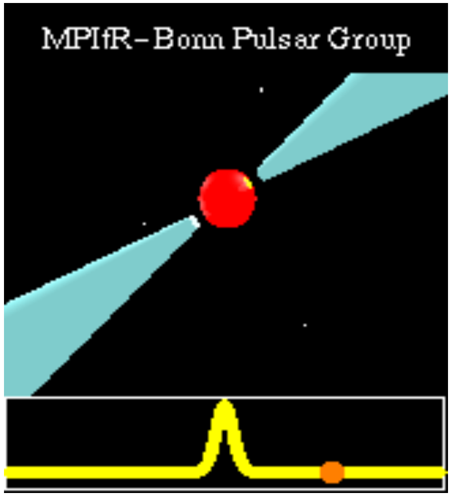
1. Cosmic rays interacting with interstellar medium
   - Pion decay
   - Inverse-Compton scattering
   - Bremsstrahlung (minor)

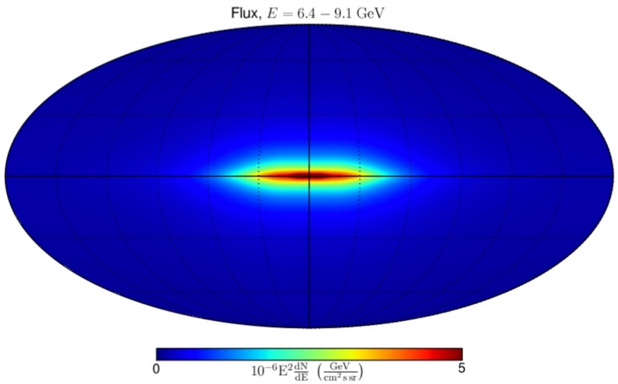


2. Populations of particle accelerators
   - Pulsars
   - Supernova remnants
   - Gamma-ray binaries …

3. Dark Matter





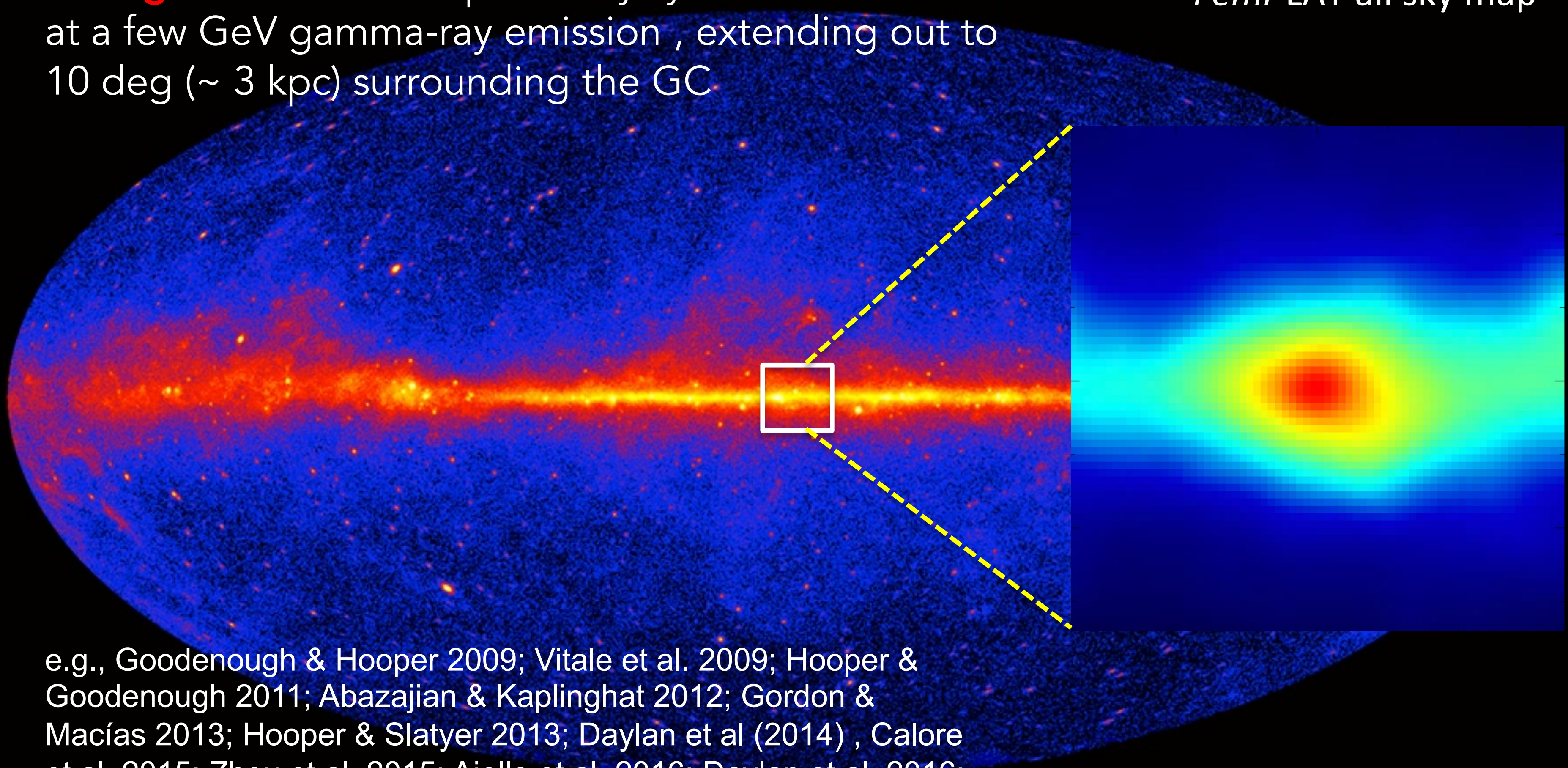


(Strong et al. 2010)

The Galactic Center Excess in the Milky Way

Strong evidence for a spherically symmetric excess at a few GeV gamma-ray emission , extending out to 10 deg (~ 3 kpc) surrounding the GC

Femi-LAT all sky map



e.g., Goodenough & Hooper 2009; Vitale et al. 2009; Hooper & Goodenough 2011; Abazajian & Kaplinghat 2012; Gordon & Macías 2013; Hooper & Slatyer 2013; Daylan et al (2014) , Calore et al. 2015; Zhou et al. 2015; Ajello et al. 2016; Daylan et al. 2016; Ackermann et al. 2017, etc.

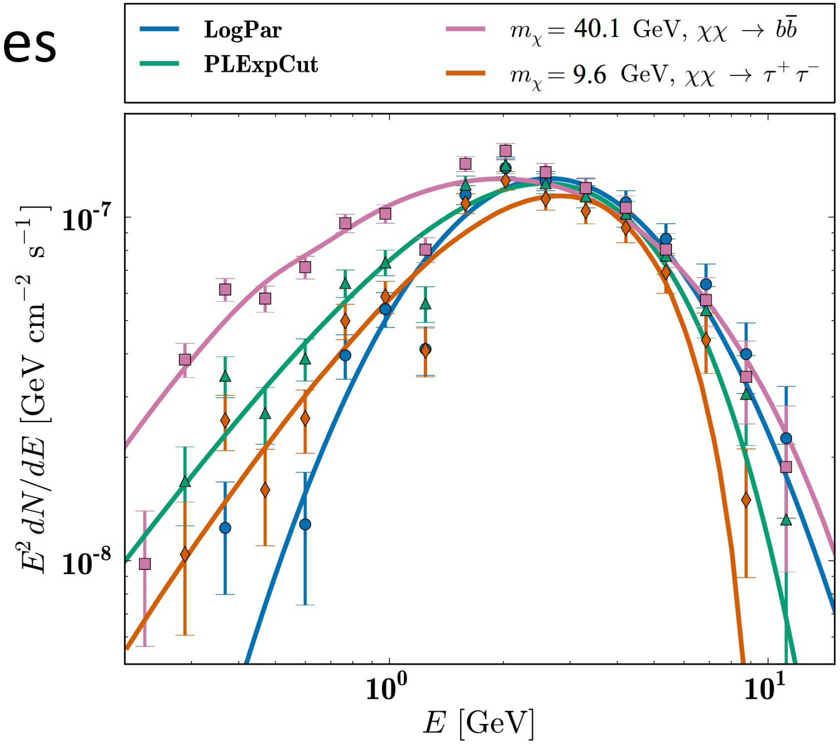
Origin of the GCE

1. Unresolved millisecond pulsars (MSPs)
2. Dark matter (DM)

Good: Spatial and spectral consistances

BUT:

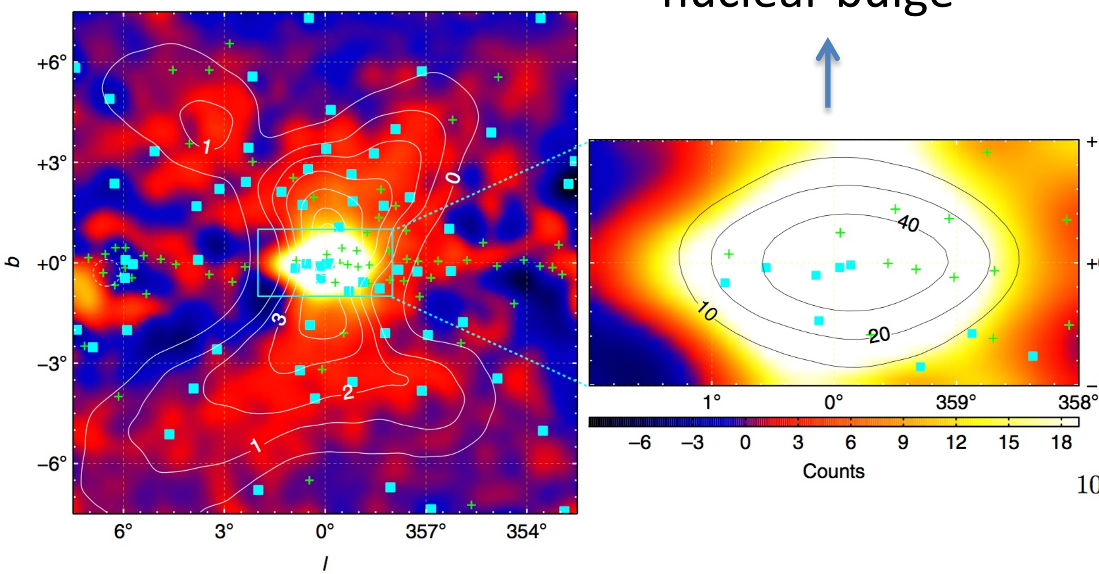
- MSPs: discrepancies between theoretical predictions and observations
- DM: strong tension with the DM limit from Dwarf galaxies



Origin of the GCE

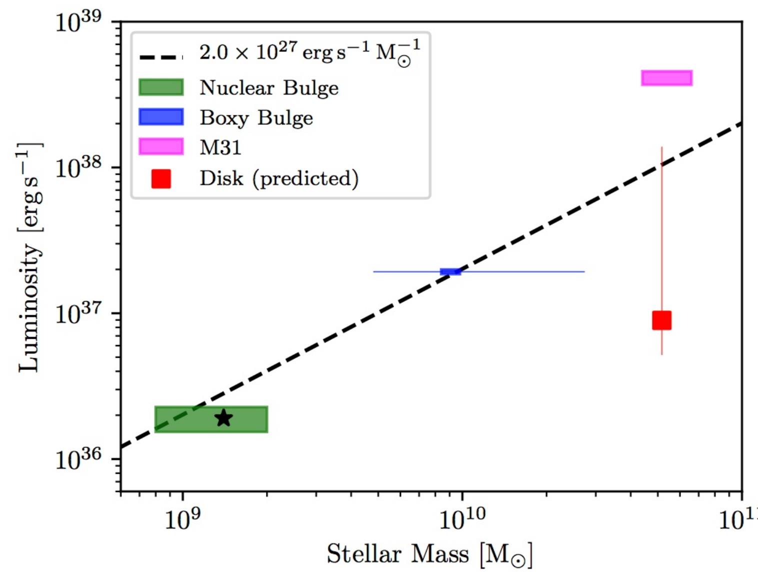
3. Stellar bulge

nuclear bulge



- Left: Residual (data-model) map matches the WISE IR X-bulge map (contours)
- Right: correlation with the near-infrared stellar density nuclear bulge data

(Macias et al. 2018)



- Stellar bulge model preferred over DM models
- GCE traces the stellar mass

(Bartels et al. 2018)

Origin of the GCE

3. Stellar bulge

Stellar density: $\rho_{\mathrm{MW,b}}(a) = \rho_{0,\mathrm{MW}} \frac{e^{-a^2/a_m^2}}{(1+a/a_0)^{1.8}}$ (Vanhollebeke et al. 2009)

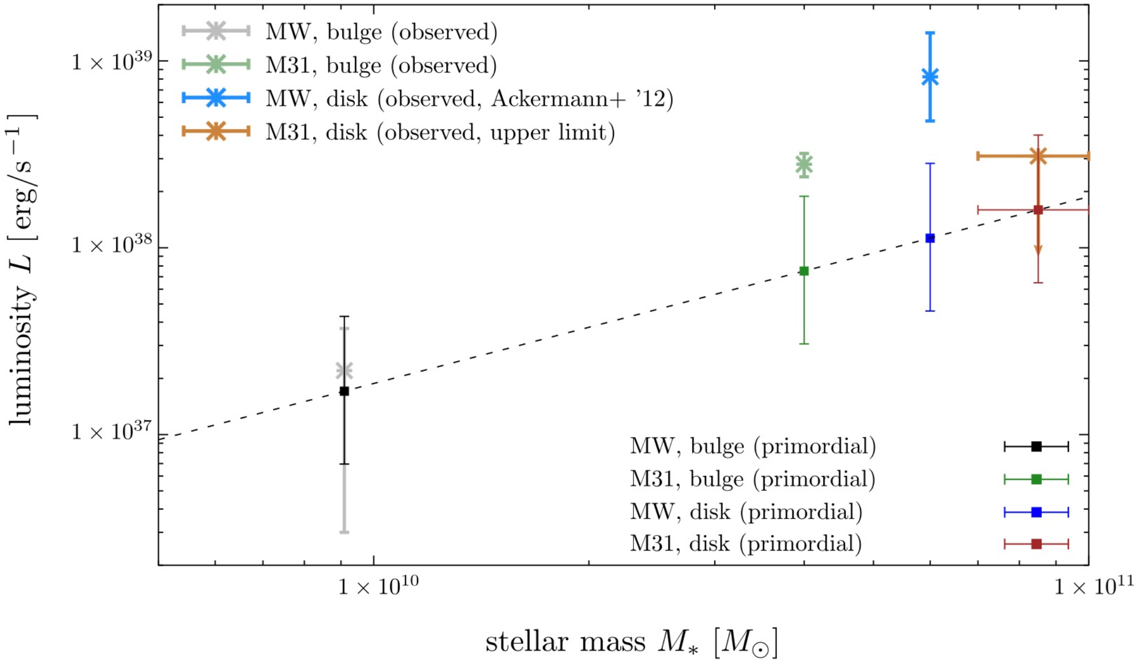
Using simple *scaling* between gamma-ray luminosity and stellar mass

$$L_{\mathrm{b}}^{\mathrm{MW}} = \frac{M_{\mathrm{b}}^{\mathrm{MW}}}{M_{*}^{\mathrm{MW}}} \int_{L_{\min}}^{L_{\max}} L_\gamma \left(\frac{dN}{dL_\gamma}\right)_{\mathrm{MW}} dL_\gamma$$

b: bulge *: disk

Fits remarkably well both the energetics and the morphology of the observed GCE

Similar result to Bartels et al. 2017

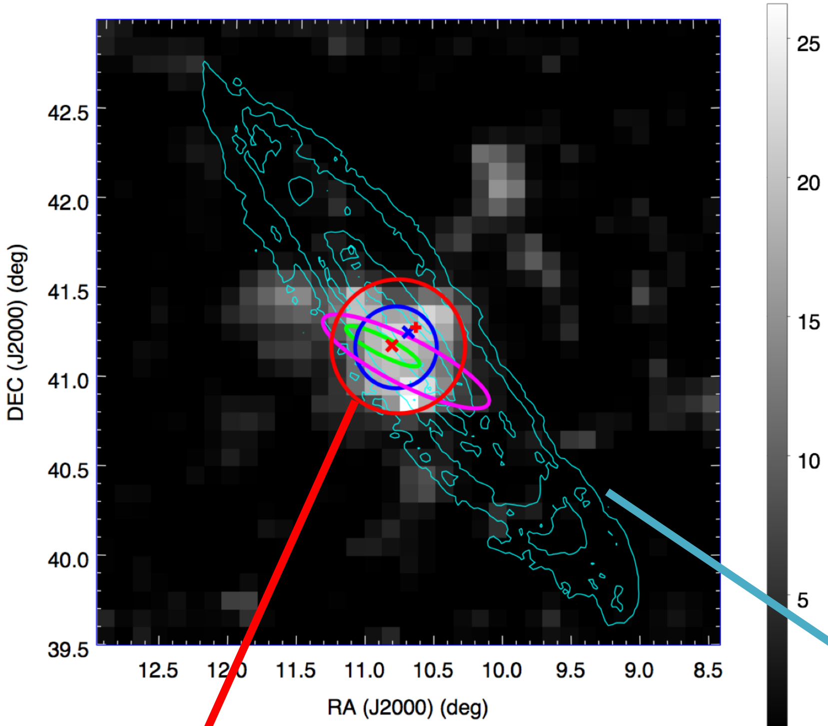


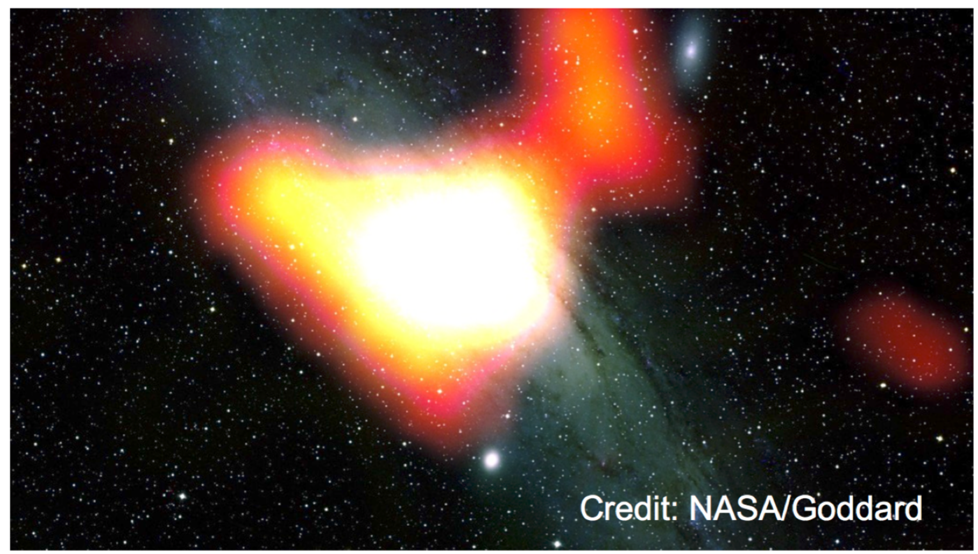
(Eckner et al. 2018)

Gamma-ray emission from M31

Only other large spiral local galaxy, close

→ **best target for resolved analysis**





Concentrated in the inner regions (0.4 deg) (uniform disk model)

Disk (plane) of the galaxy is not detected

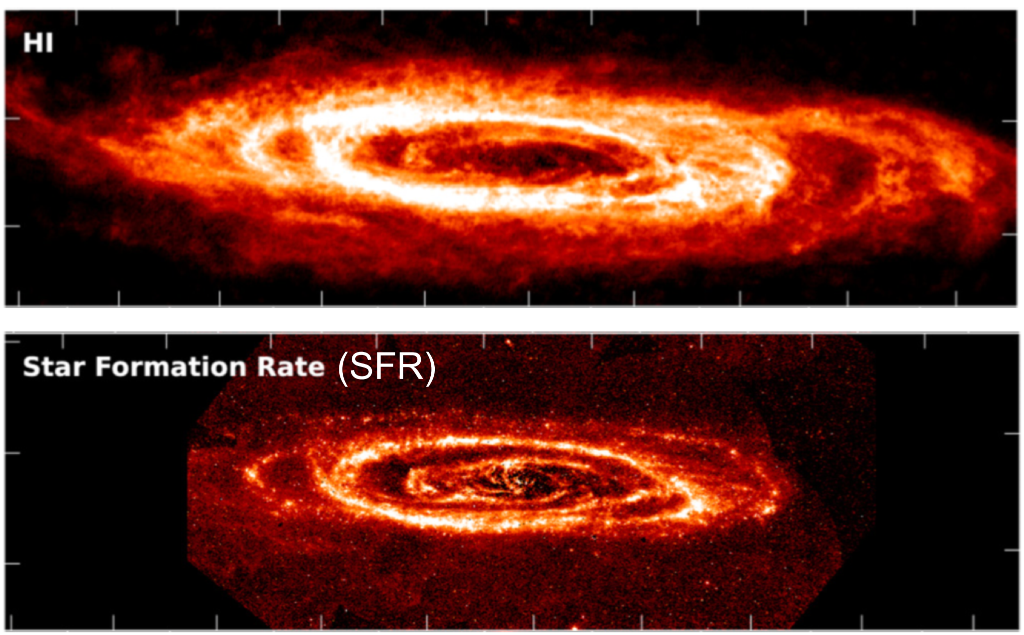
Not correlated with the galactic disk (NH map)

(Ackermann et al. 2017)

Origin of M31 emission

1. Interstellar emission

- π^0 decay
  - Low gas content to be compensated by high CR density at the galaxy center
  - But far from typical gas and star-formation regions (not detected in gamma rays)
- inverse-Compton (IC)
  - IC dominates the emission of M31: π^0 decay < 50% IC
  - Opposite to what is inferred for the MW: IC = 45% π^0 decay



Smith +12

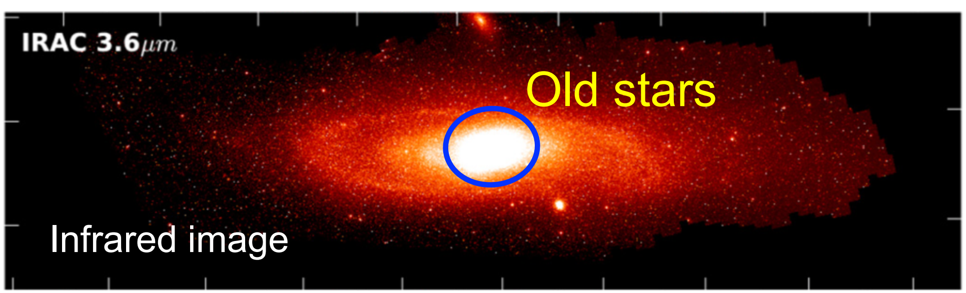
Possible solution:

High energy particles are not CRs resulting from recent star-formation activities, but from other sources?

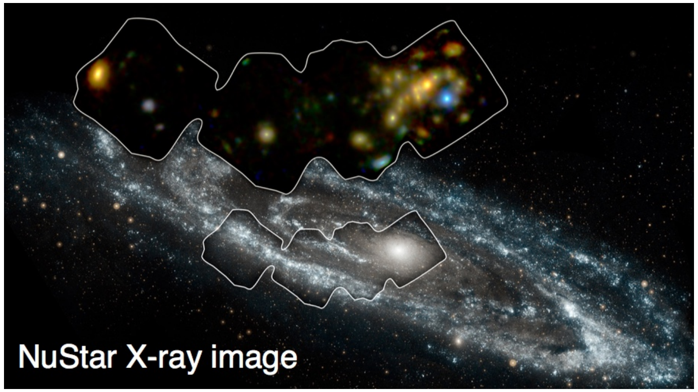
Origin of M31 emission

2. Population of MSPs

- M31 center: many old stars and X-ray binaries (Barmby+06, Voss&Gilfanov 07, Stiele+10)
- Possible large population of MSPs
- Star-formation rate in M31 is 1/10 of that in the MW -> disk emission decreased
- Mass of the M31 bulge is ~ 5-6 times that of the MW -> central emission increased



Smith +12

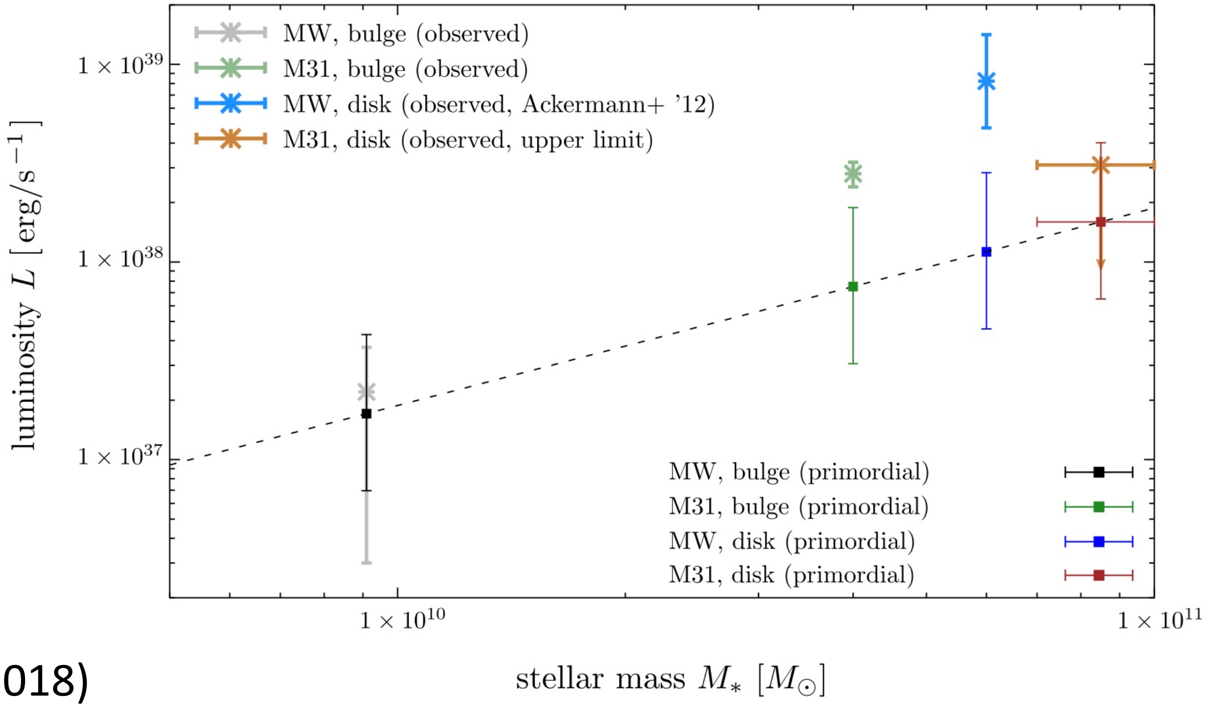


https://www.jpl.nasa.gov/news/news.php?feature=4811

Origin of M31 emission

2. Population of MSPs

- Using simple *scaling* between gamma-ray luminosity and stellar mass
- Bulge prediction: can only *marginally explain* the observed gamma-ray luminosity
- Disk prediction: *not far below* the present upper limit derived in Ackermann+17



(Eckner et al. 2018)

Origin of M31 emission

2. Population of MSPs

- MSPs deposited in the M31 bulge from globular cluster disruption can only reproduce 1/8 of the observed emission
- Either M31 differs significantly from the scaling relation
- Or additional sources would be needed

(Fragione et al. 2018)

➢ MSP population is possible candidate for gamma-ray emission in M31

➢ But improvements on the understanding of MSP population are needed

Origin of M31 emission

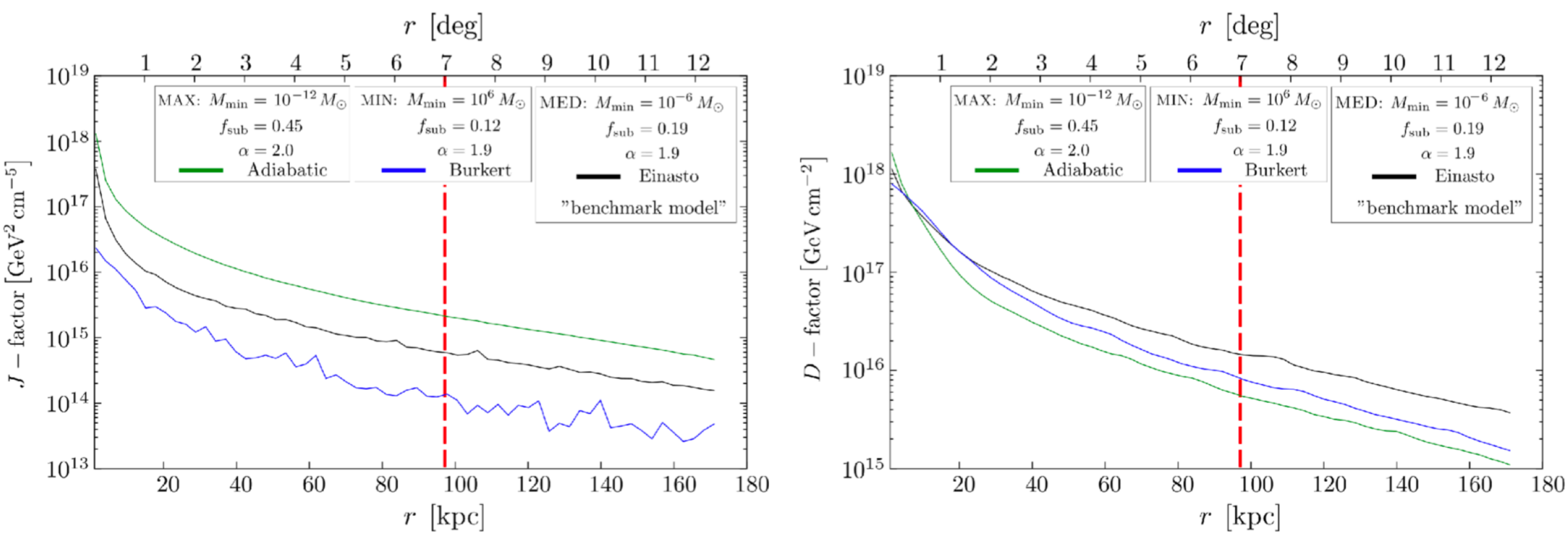
3. Dark matter (DM) annihilation/decay

Using **DMCat pipeline** (talk by Eric Charles)

Setup:

- ~10 years of LAT Pass 8 data, E=[0.1,100] GeV, 14°x14° ROI, FL8Y catalog
- ROI components: M31, DM, diffuse models, sources from FL8Y
- M31 template: Uniform disk with ext=0.30°, LogParabola spectrum (refitted using 10 year data, TS=122)
- DM templates: MAX, MED, MIN
- Fit the ROI components simutaneously

DM radial profiles



Left: J-factors (annihilation)

Right: D-factors (decay)

Same as in HAWC M31 DM paper: https://arxiv.org/pdf/1804.00628.pdf)

DM-only interpretation

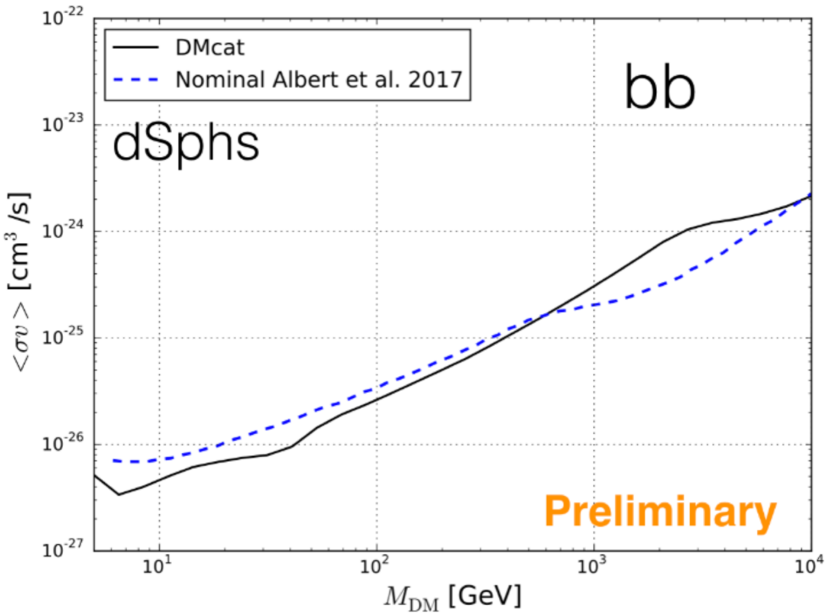
M31 extended source: TS=122 --> better than DM-only fit

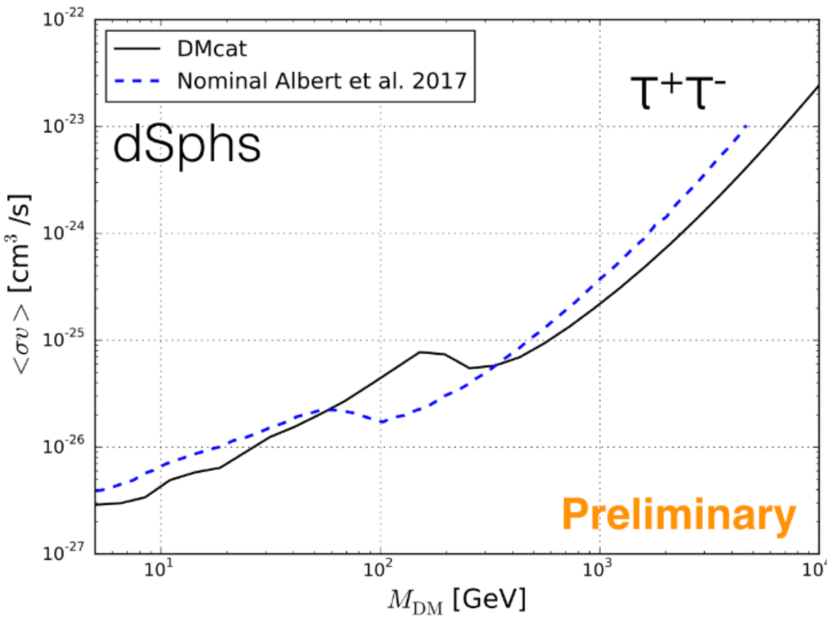
Example: MED

bb: TS=39, mDM=31 GeV and **<σv>= (6.7±2.8) 10^{-26}**

tau: TS=37, mDM=8 GeV and **<σv>= (1.7±1.3) 10^{-26}**

➢ In tension with dSphs limits derived in Albert et al. 2017 and DMCat

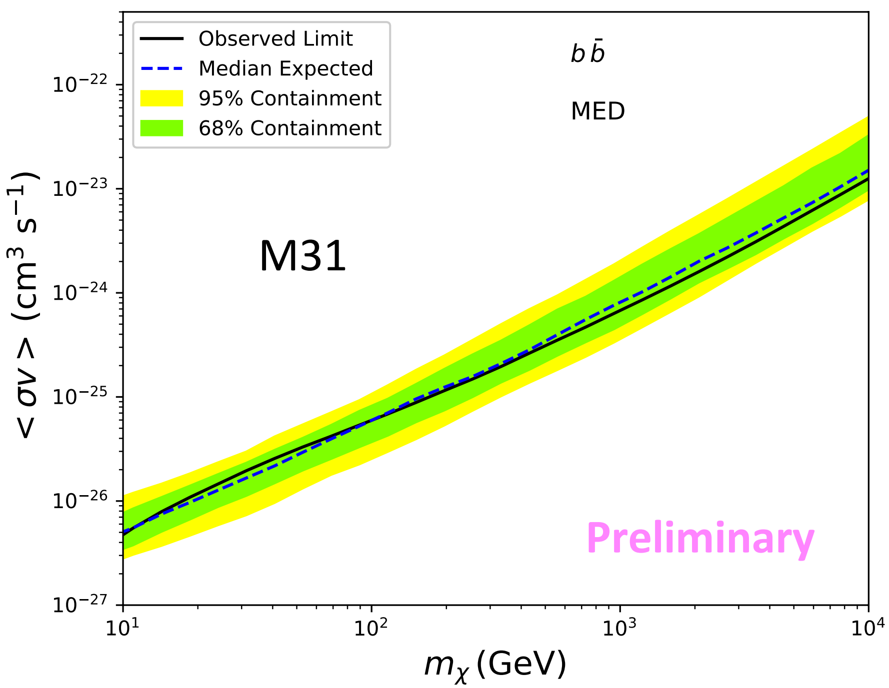


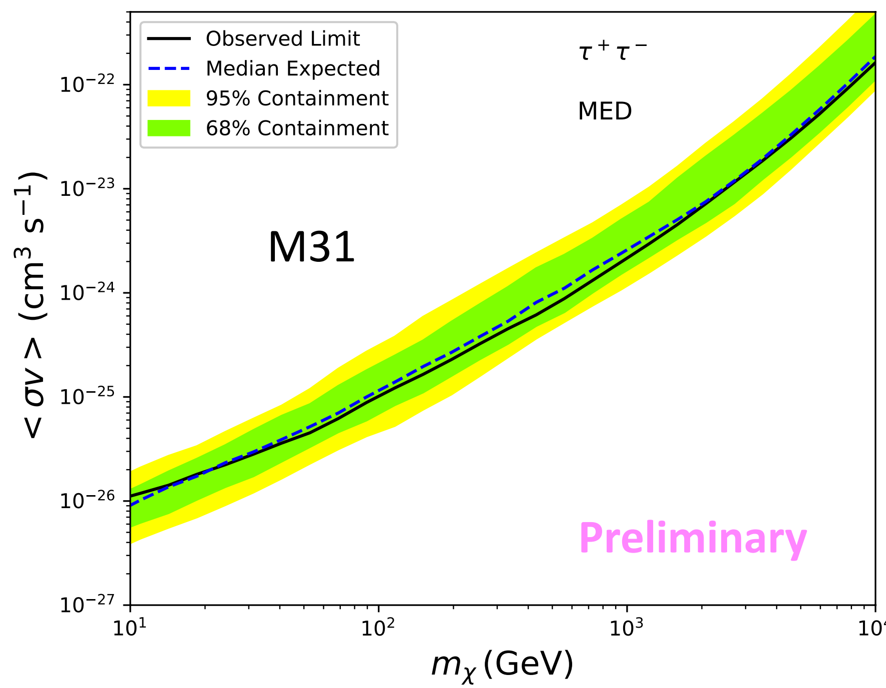


Mattia Di Mauro's talk: multiple targets DM search using DMCat

Limits: Sim null vs Obs.

annihilation

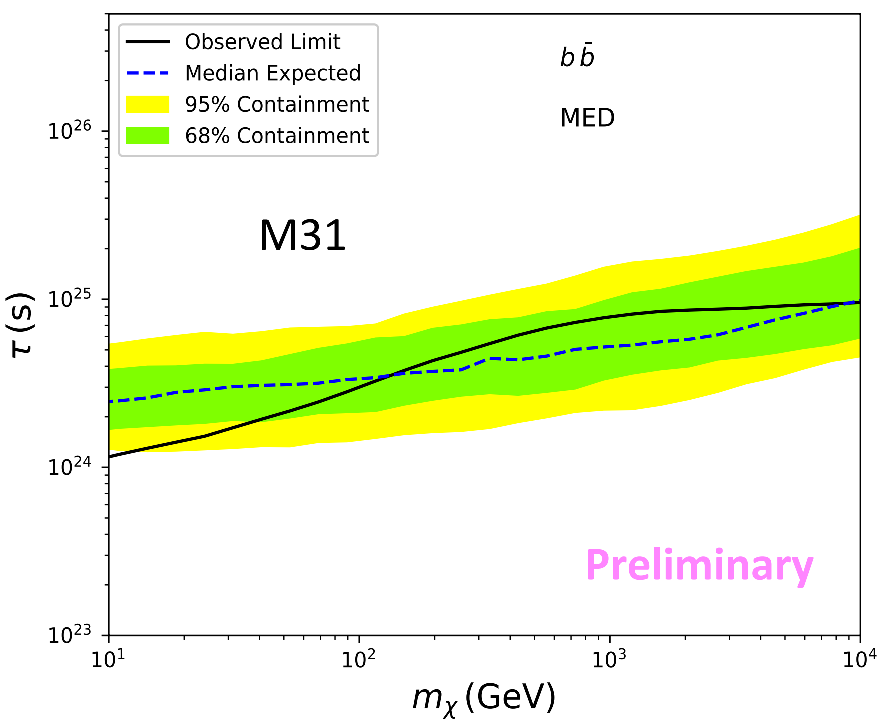


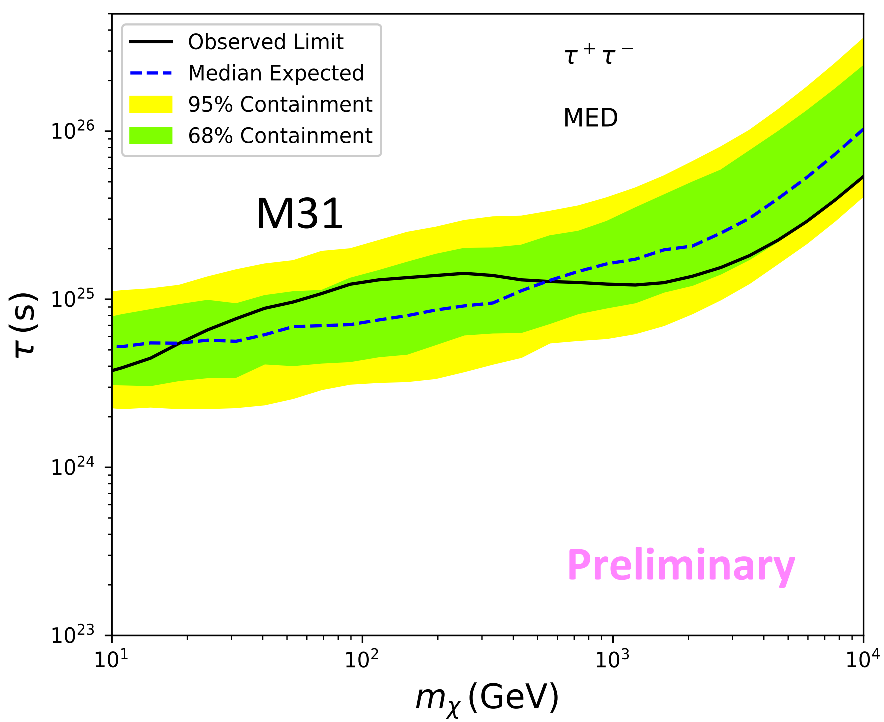


- Observed limit: M31 + DM at the position of M31
- Simulation: no DM at the position of M31 (sim null)
- Similar results for MAX and MIN templates

Limits: Sim null vs Obs.

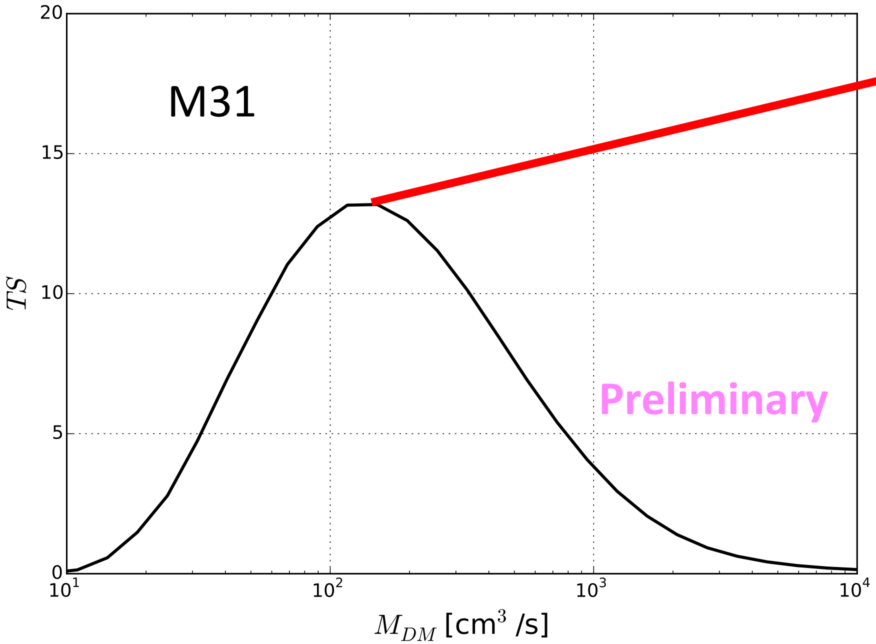
decay





- Observed limit: M31 + DM at the position of M31
- Simulation: no DM at the position of M31 (sim null)
- Similar results for MAX and MIN templates

Simulation: Injected Signal

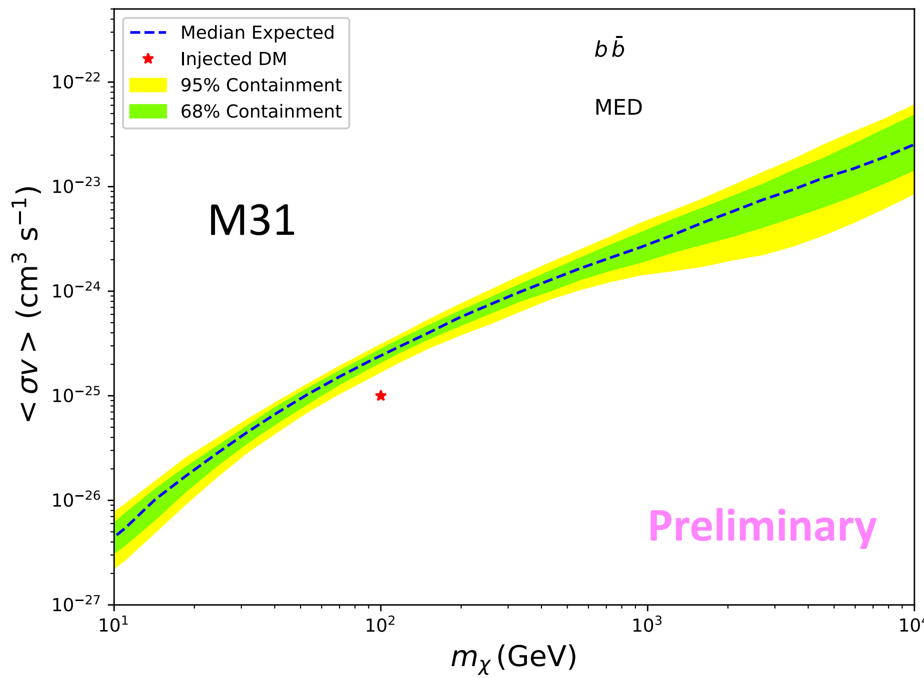


Best fit:

M= ~100 GeV

<**σv**>=(1.29+/-0.24)x10^{-25} cm^3/s

Compatible with the injected signal



- Signal: bb, M=100 GeV, <**σv**>=10^{-25} cm^3/s
- Similar results for MAX and MIN templates

Summary

- *Fermi*-LAT revealed significant central emissions in both the Galactic center and M31.
- The origin of both emissions are still subject of debate, but the Galactic center emission traces the stellar bulge better than M31.
- We search for DM in M31 using about 10 years LAT data assuming smooth component + substructure DM templates, and derive limits for DM annihilation/decay.
- We will test other DM profiles in the future.

Thank you!

BACKUP

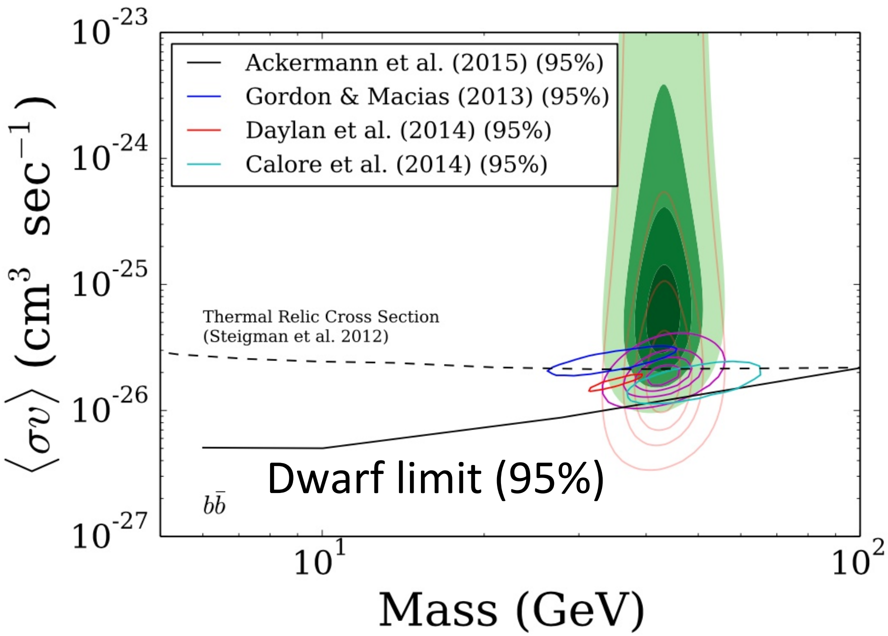
Origin of the GCE

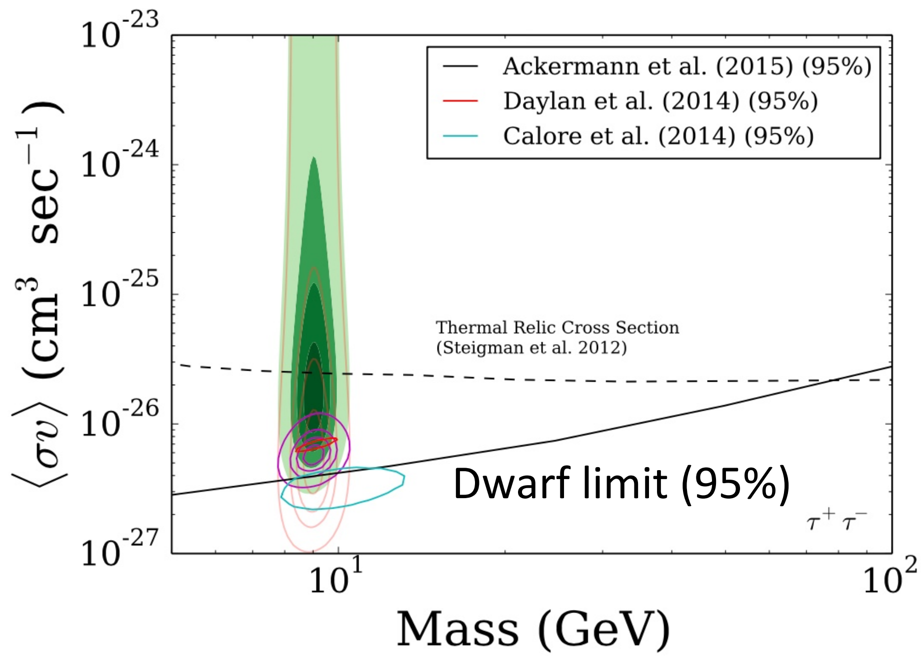
2. Dark matter

Bright GCE vs. Dim dwarfs

Difficulties:

- Strong tension with the DM limit from Dwarf galaxies.



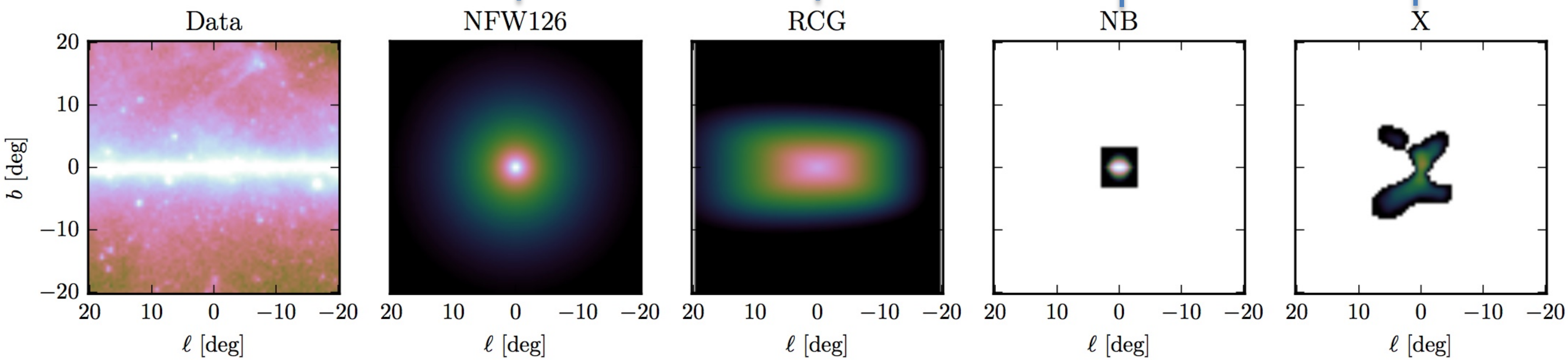


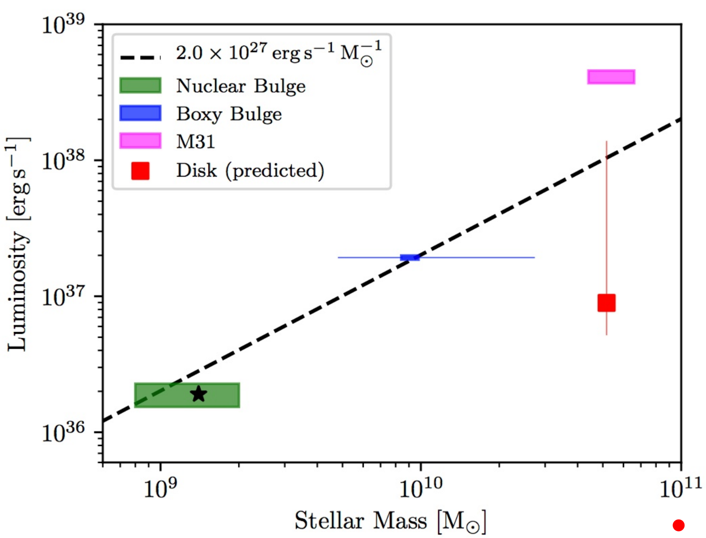
Abazajian et al (2016)

Origin of the GCE

3. Stellar bulge

DM | Boxy bulge | nuclear bulge | X-shaped bulge





Run	$-2 \ln \mathcal{L}$ free spectrum	$-2 \ln \mathcal{L}$ MSP spectrum
r5_RCG_NB_X	647808.1	648020.2
r5_RCG_NB	647831.2	648027.5
r5_RCG	647884.7	648061.7
r5_BulgeGC	647916.5	648140.3
r5_Einasto	647961.4	648188.6
r5_NFW126	648021.8	648242.4
r5_NFW100	648049.8	648278.6

Best fit: r5_RCG_NB

- Stellar bulge model preferred over DM models at >10σ
- GCE traces the stellar mass

(Bartels et al. 2018)

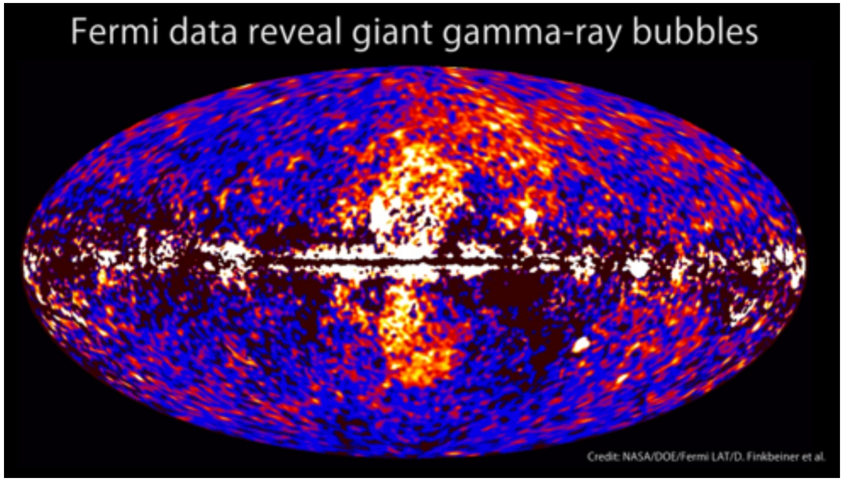
Origin of the GCE

4. Overall uncertainties

- Interstellar emission modeling (diffuse model): π^0 and IC
- Resolved point source modeling
- Additional CR sources near the GC
- Fermi bubbles (FB) modeling: spectrum and morphology of FB not known in the GC
- …

2-components interpretation:

- A spherical component with a spectrum that has a cutoff at a few GeV
- a bi-lobed component with a spectrum similar to the spectrum of the FB at high latitudes



Credit: NASA