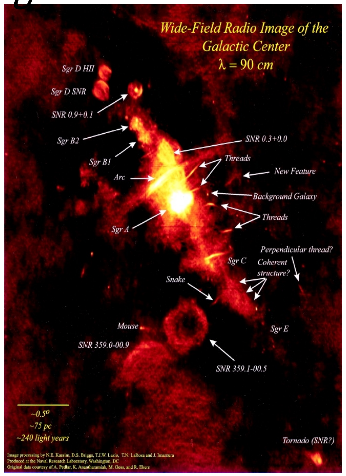
Targets

(where to search a DM-induced electromagnetic signal)

Targets

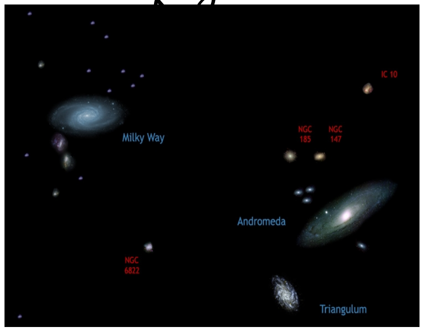
Galactic Center



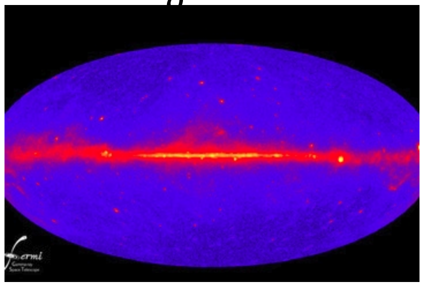
Subhalos

Clusters

Halo of Galaxies



Cosmological emission



Criteria:

DM signal as **bright** as possible
(large DM content + short distance)

Standard cosmic-ray emission as **faint** as possible

Spatial features

Good experimental coverage

Computation

SOURCE FUNCTION

Annihilating DM $Q_i^a(r,E) = \langle \sigma_a v \rangle \frac{\rho(r)^2}{2\,M_\chi^2} \frac{dN_i}{dE}(E)$

Decaying DM $Q_i^d(r,E) = \Gamma_d \frac{\rho(r)}{M_\chi} \frac{dN_i}{dE}(E)$

EMISSIVITY

Prompt $j_\gamma(E,r) = Q_\gamma(E,r)E$

Radiative $j_i(\nu,r) = 2\int_{m_e}^{M_\chi} dE P_i(r,E,\nu) n_e(r,E)$

$Q_e \xrightarrow{\text{transport equation}} n_e$

MEASURED INTENSITY

$$S_i(\nu,\theta,\theta_d) = \int d\Omega' \exp\left(-\frac{\tan^2\theta'}{2\tan^2\theta_d}\right) \int_{\text{l.o.s.}} dI_i(\nu,s,\tilde{\theta})$$

$$\frac{dI_i(\nu,s,\tilde{\theta})}{ds} = -\alpha(\nu,s,\tilde{\theta}) I_i(\nu,s,\tilde{\theta}) + \frac{j_i(\nu,s,\tilde{\theta})}{4\pi}$$

absorption: if negligible → $dI_i(\nu,s,\tilde{\theta}) = ds\, j_i(\nu,s,\tilde{\theta})/(4\pi)$

J-factor

Ball-park of expected J-factors for the different targets (for a solid angle corresponding to 1 deg)

$$\underbrace{\int_{\Delta\Omega}\left\{\int_{\rm l.o.s.}\rho^2(\boldsymbol{r})\mathrm{d}l\right\}\mathrm{d}\Omega'}_{\text{J-factor}}$$

1. Dwarf Spheroidal Galaxies
   - Draco, $J \sim 10^{19}$ GeV^2/cm^5
   - Ursa Minor, $J \sim 10^{19}$ GeV^2/cm^5
   - Segue, $J \sim 10^{20}$ GeV^2/cm^5
2. Local Milky-Way-like galaxies
   - M31, $J \sim 10^{20}$ GeV^2/cm^5
3. Local clusters of galaxies
   - Fornax, $J \sim 10^{18}$ GeV^2/cm^5
   - Coma, $J \sim 10^{17}$ GeV^2/cm^5
   - Bullet, $J \sim 10^{14}$ GeV^2/cm^5

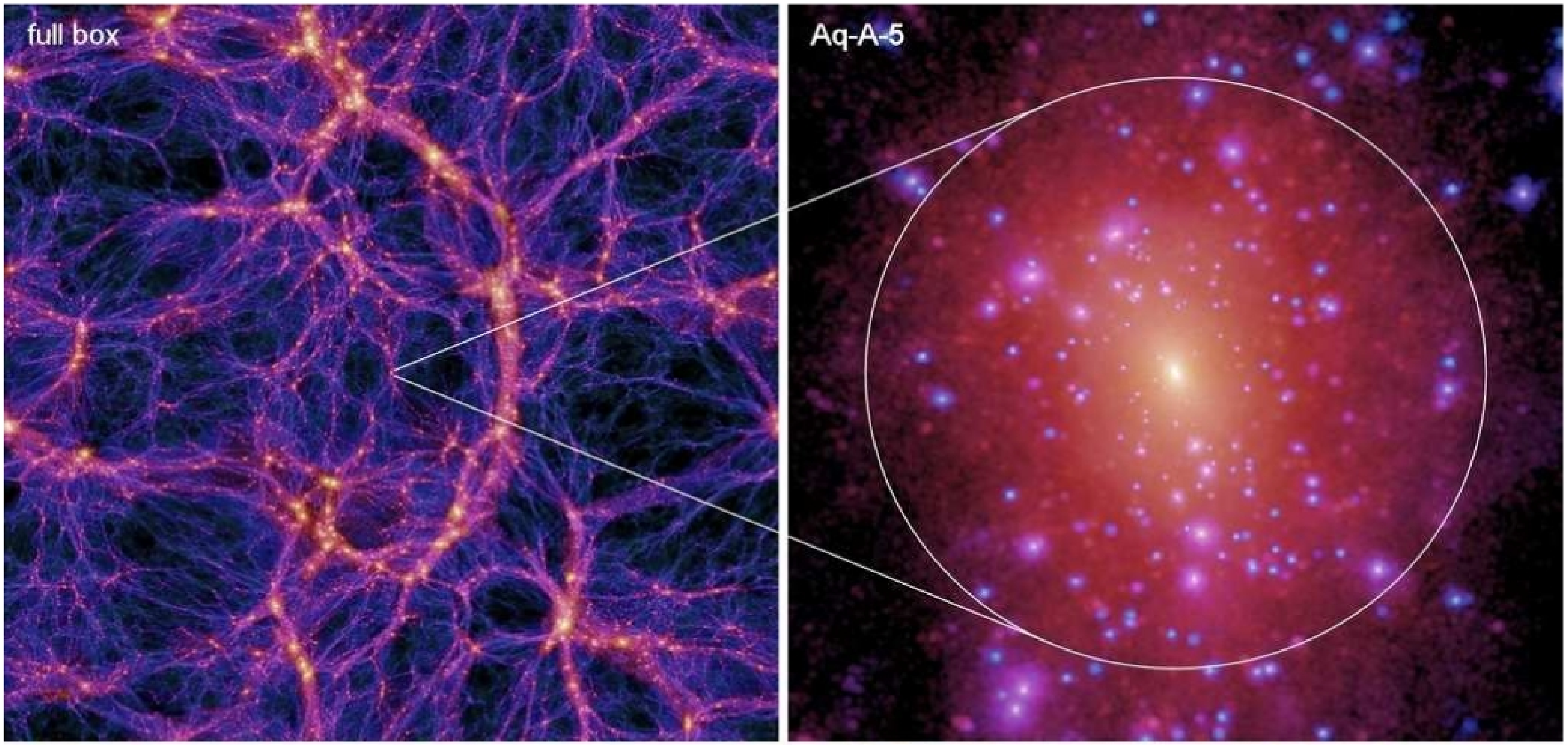
   + substructure boost
4. Galactic center
   - $0.1°$: $J \sim 10^{22} \ldots 10^{25}$ GeV^2/cm^5
   - $1°$: $J \sim 10^{22} \ldots 10^{24}$ GeV^2/cm^5

taken from S. Profumo's 2012 TASI lectures

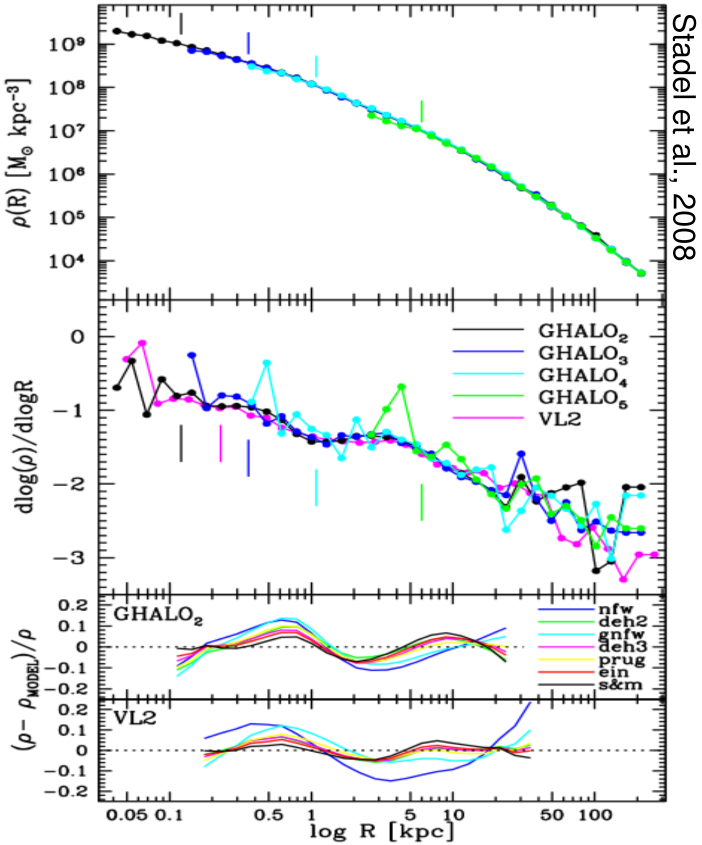
Galactic Center

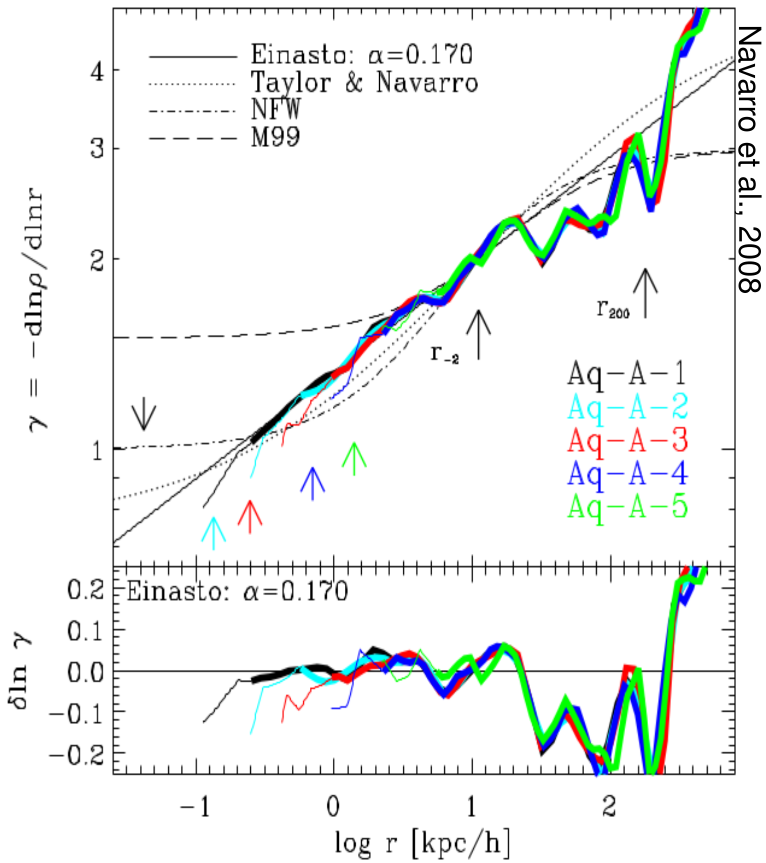
PROS: the Galactic Center (GC) is one of the prime targets in WIMP indirect searches, given the large DM overdensity predicted by N-body numerical simulations of galaxy formation.

Springel et al., 2008



Galactic Center





Inner slope **ρ** ~ $r^{-\gamma}$, with **γ** ~1 → cuspy profile

Galactic Center

CONS:

- Clean disentanglement of a DM signal from astrophysical emissions is rather complicated.
- Uncertain DM profile and description of propagation.

Effects of baryons are not included in N-body simulations:

Erase the cusp? (e.g. Governato et al., 2009)

or

Adiabatic contraction due to the supermassive BH? (e.g., Gondolo&Silk, 1999)

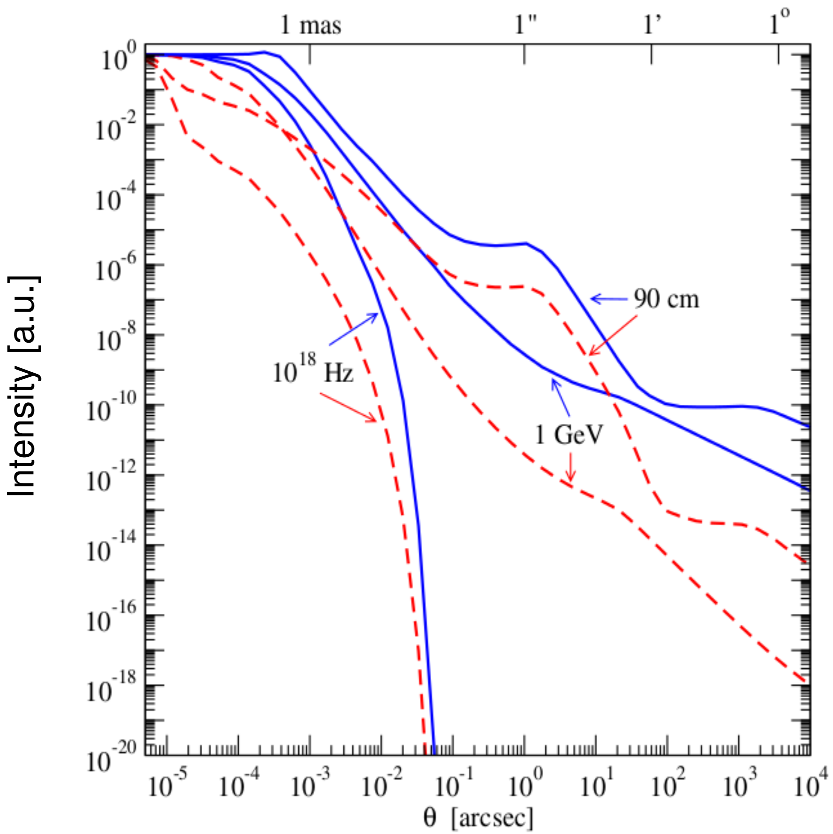
Which ingredients in the transport equation?

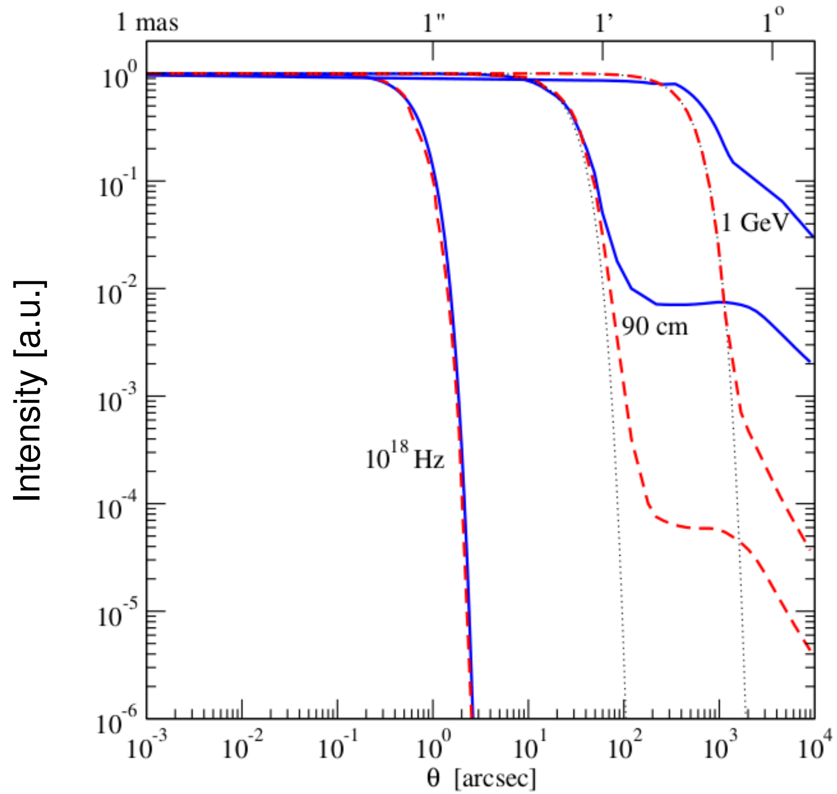
$$-\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 D\frac{\partial f}{\partial r}\right]+v\frac{\partial f}{\partial r}-\frac{1}{3r^2}\frac{\partial}{\partial r}(r^2 v)\,p\frac{\partial f}{\partial p}+\frac{1}{p^2}\frac{\partial}{\partial p}(\dot{p}p^2 f)=q(r,p)$$

Galactic Center

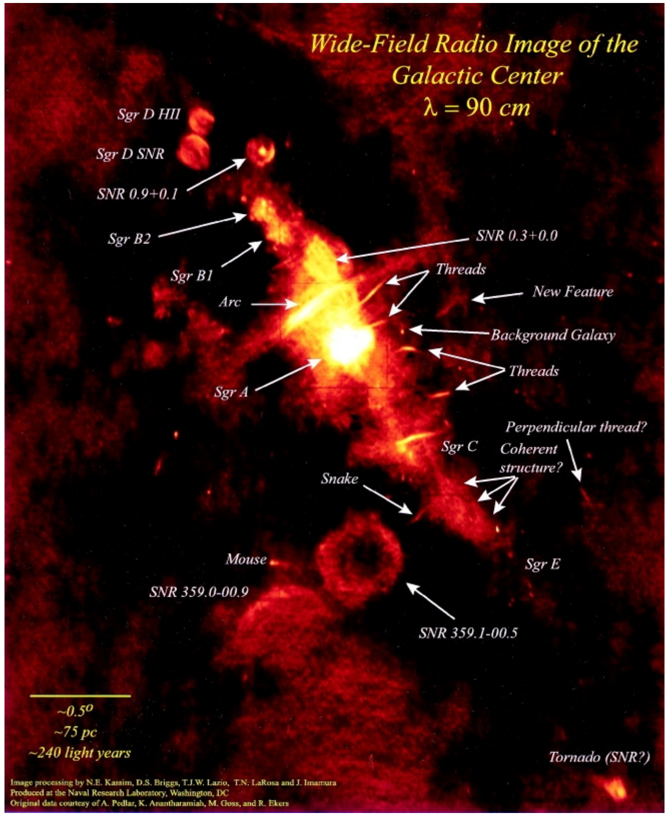
First of all: what is the GC scale?

And what angular sizes can observations probe?

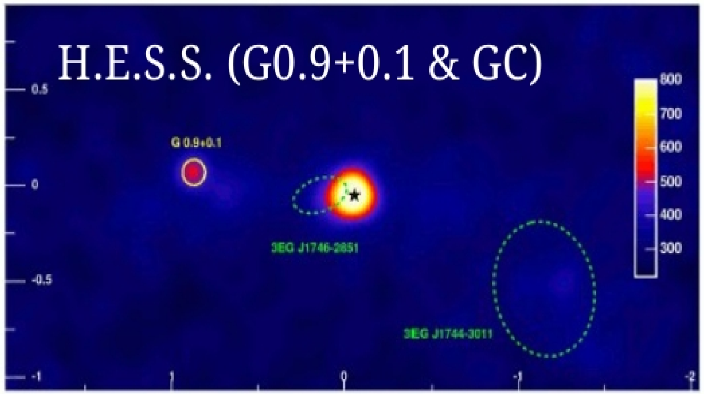


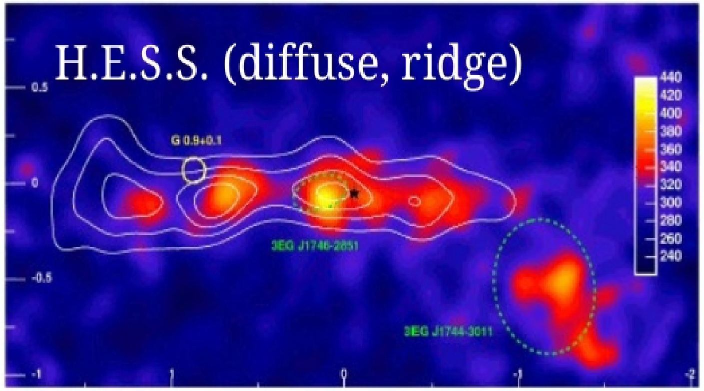


Galactic Center

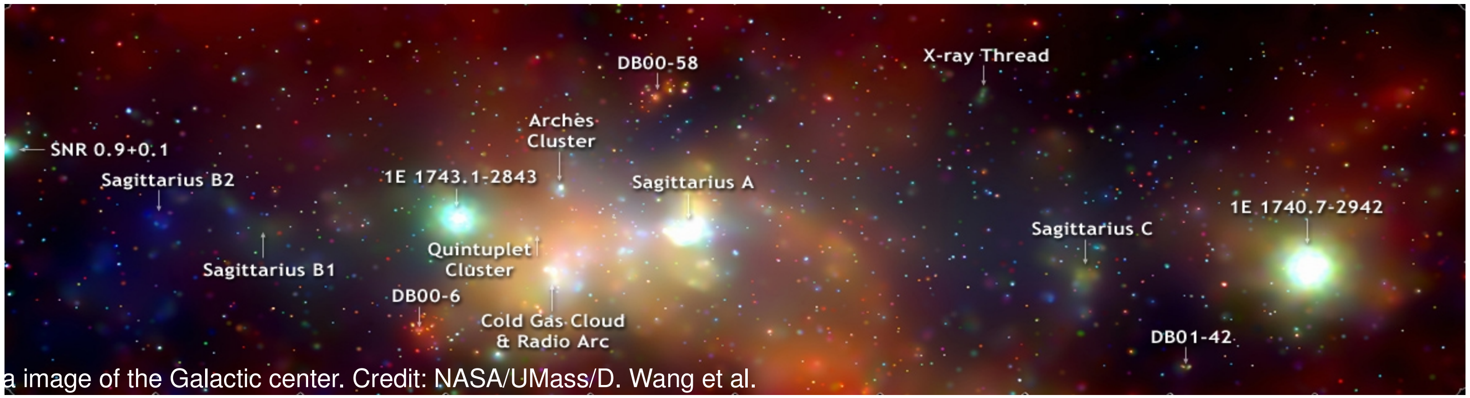


The nucleus of our Galaxy is a very rich system (“starburst-like”), with higher supernova rates, stronger magnetic fields, more intense radiation fields, and larger amounts of dense molecular gas than in the Galactic disk.





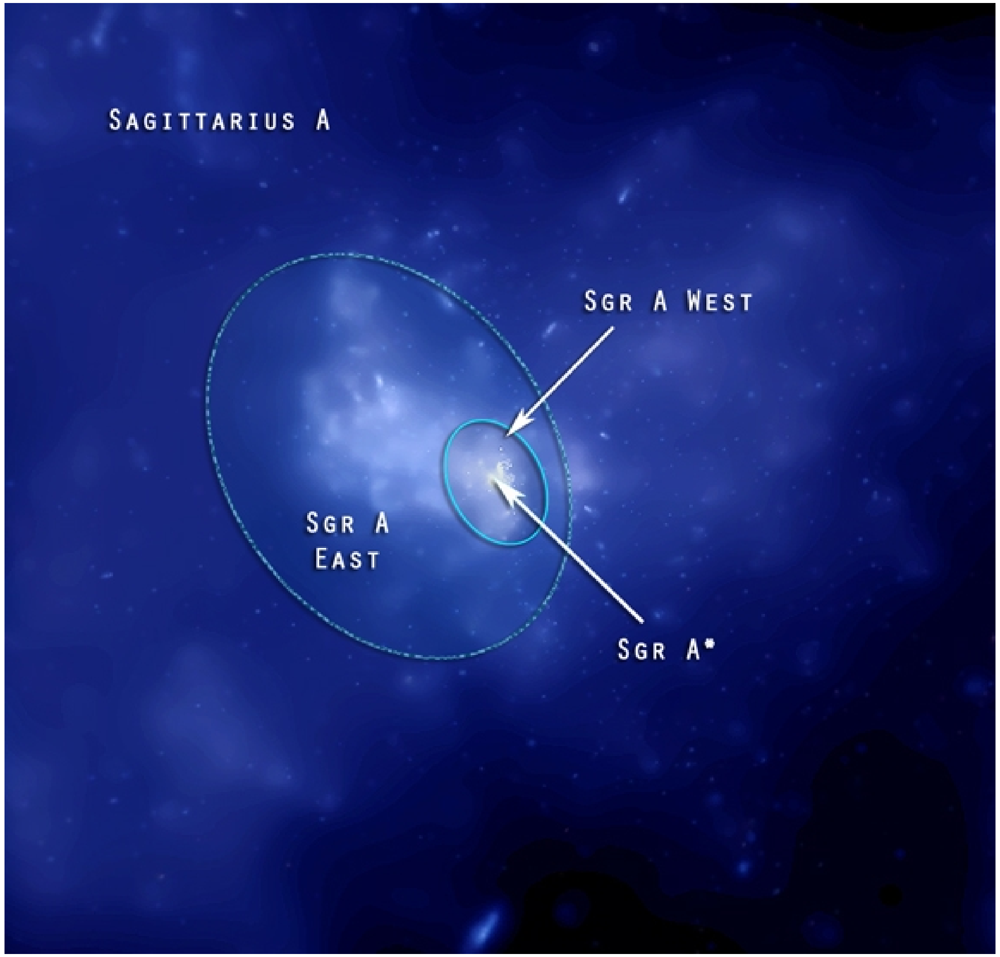
Aharonian, et al. (2006)



a image of the Galactic center. Credit: NASA/UMass/D. Wang et al.

Galactic Center

Let's start with the innermost region ~ 10 pc ~ few arcmin



CHANDRA image:NASA/G.Garmire (PSU)/F.Baganoff (MIT)

Sgr A is a complex radio source composed by:

EXTENDED EMISSION

Sgr A East: supernova remnant

Sgr A West: spiral structure

STRONG POINT SOURCE

Sgr A*: compact source associated to the supermassive black hole located at the GC

$M_{BH} = 3\ 10^6\ M_{sun}$

SIZE: < 0.1 mas radio

~ 0.6 arcsec X-ray

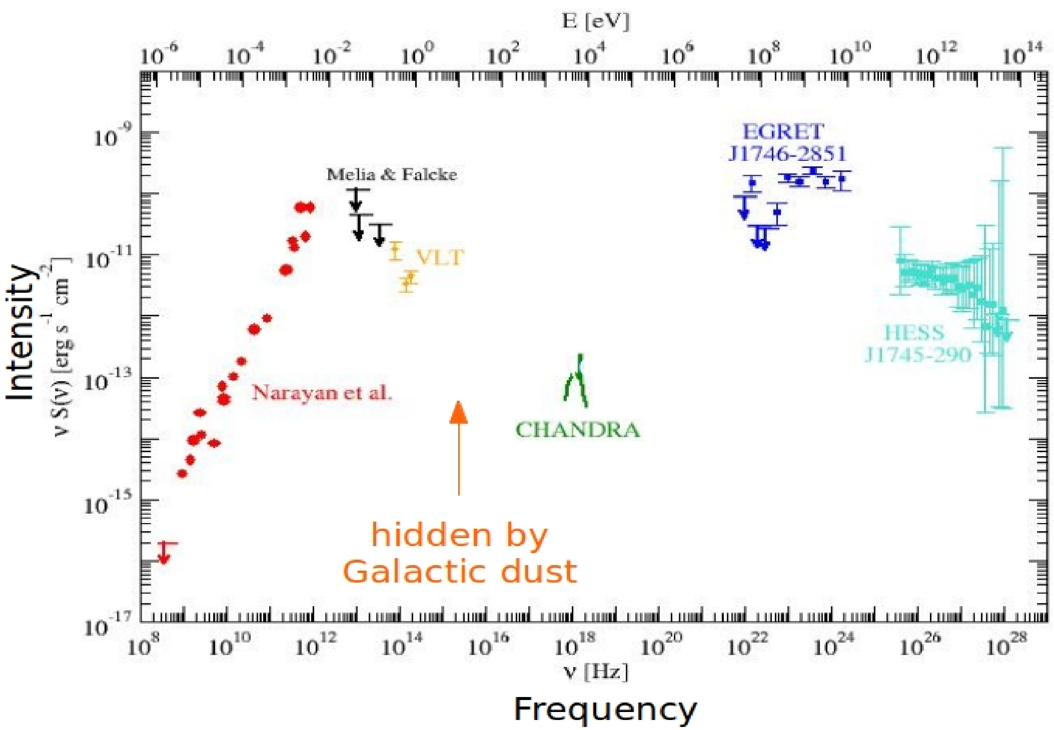
Galactic Center

STRONG POINT SOURCE detected at different wavelength.

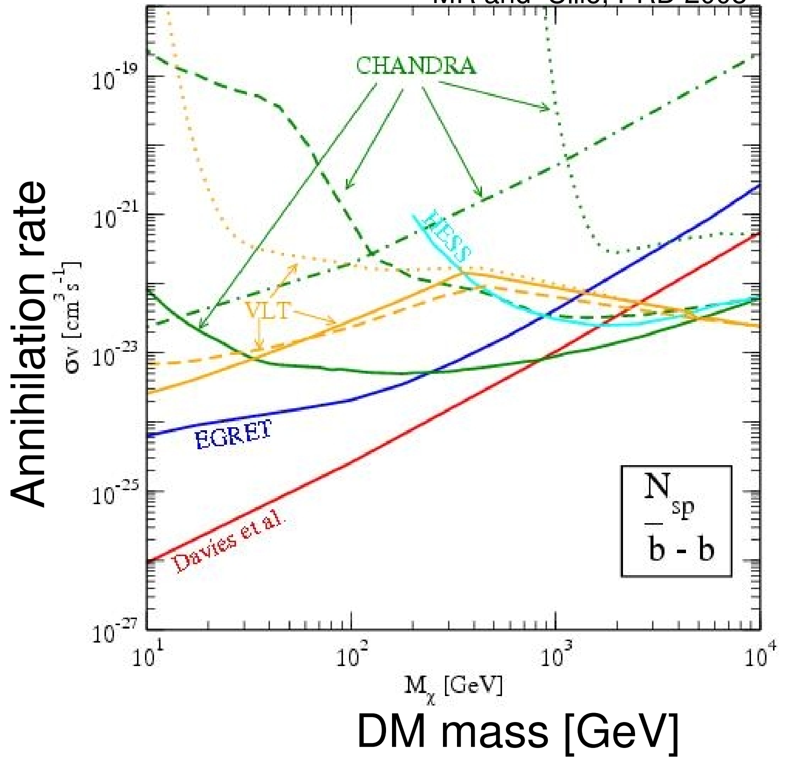
Spectrum and size incompatible with a DM interpretation,

but constraining.

MR and Ullio, PRD 2008



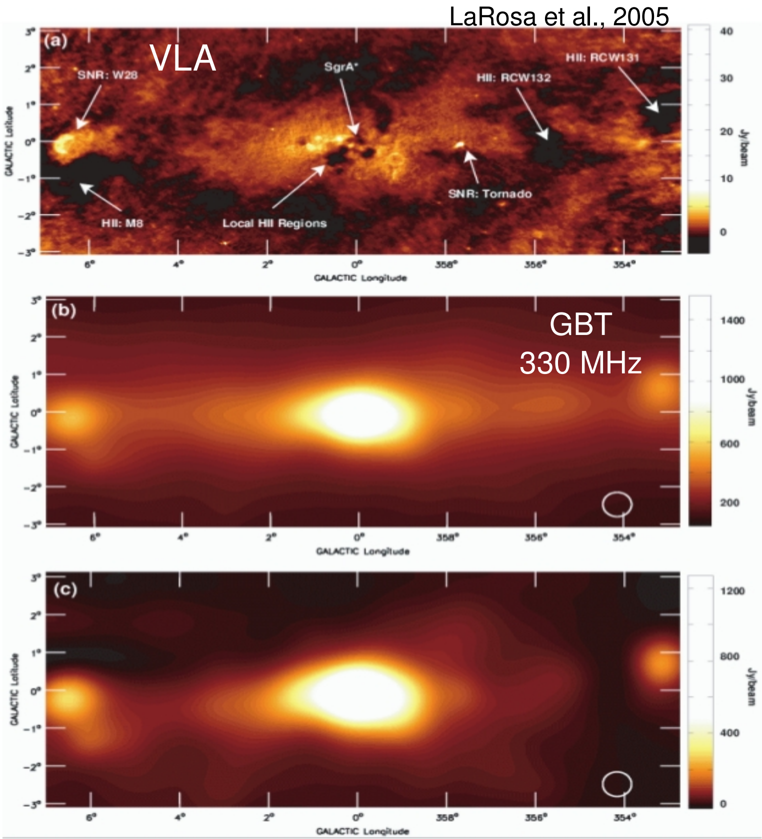
MR and Ullio, PRD 2008

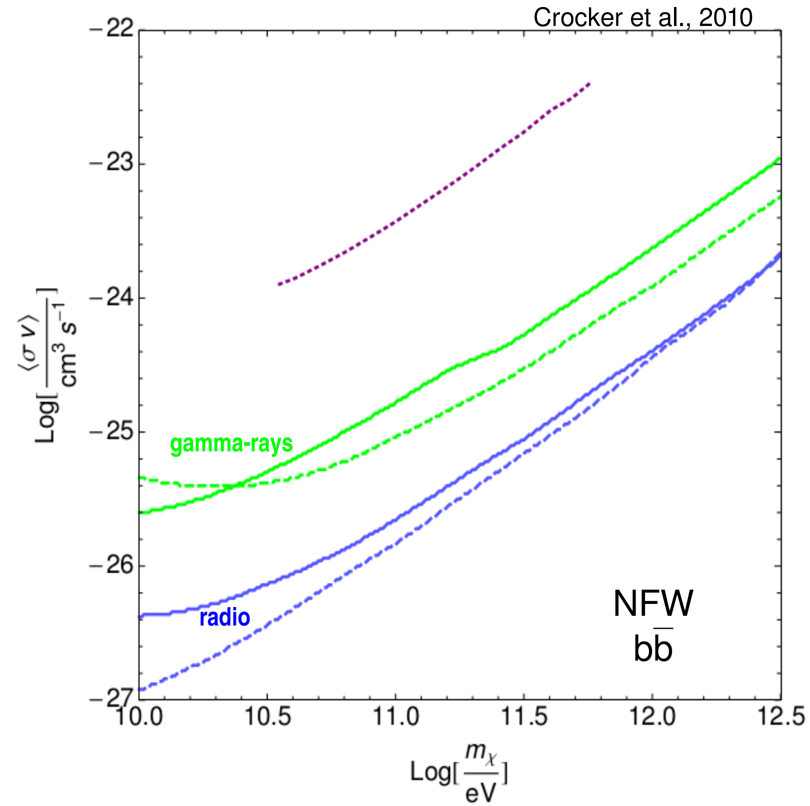


Galactic Center

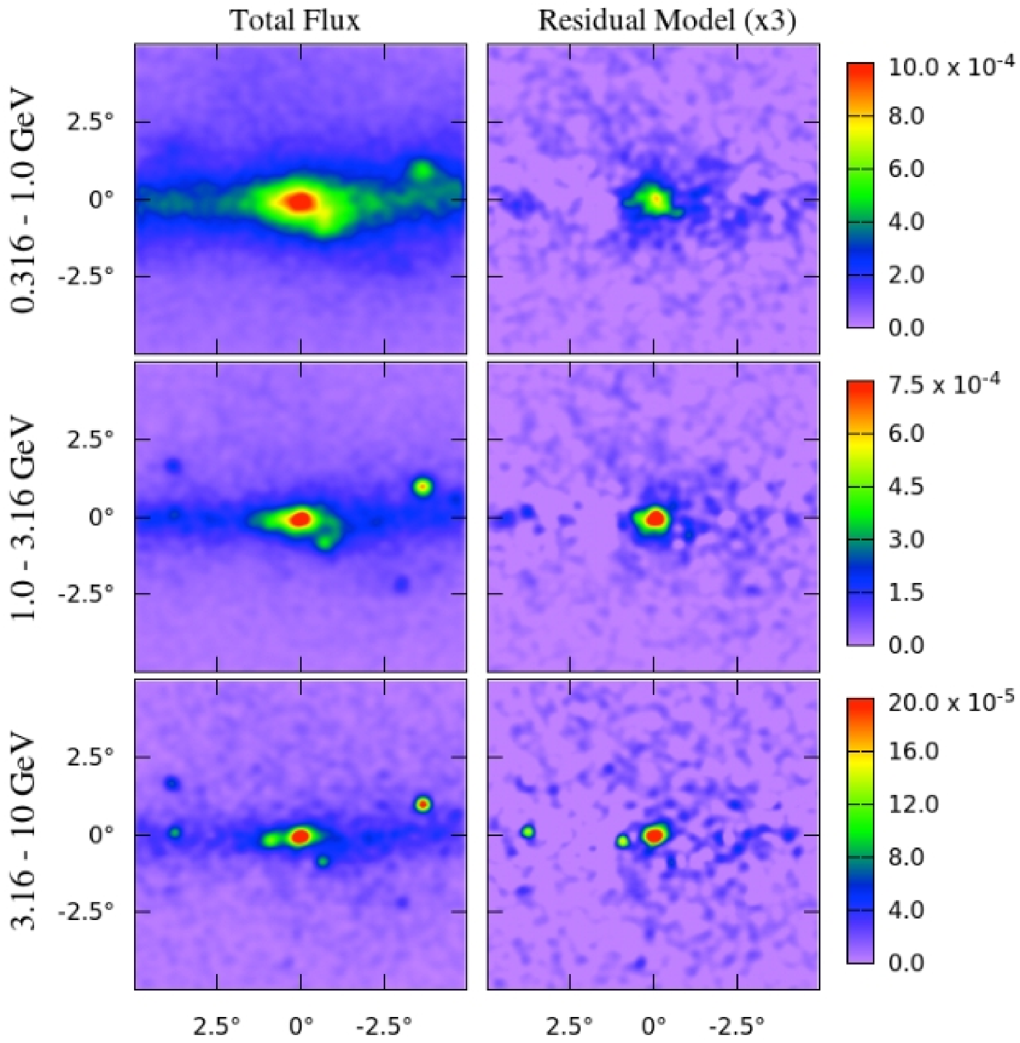
On larger scales ~ 100 pc ~ 1 deg

The supermassive BH may ultimately be responsible for powering many of the high-energy phenomena seen around the GC region





Galactic Center

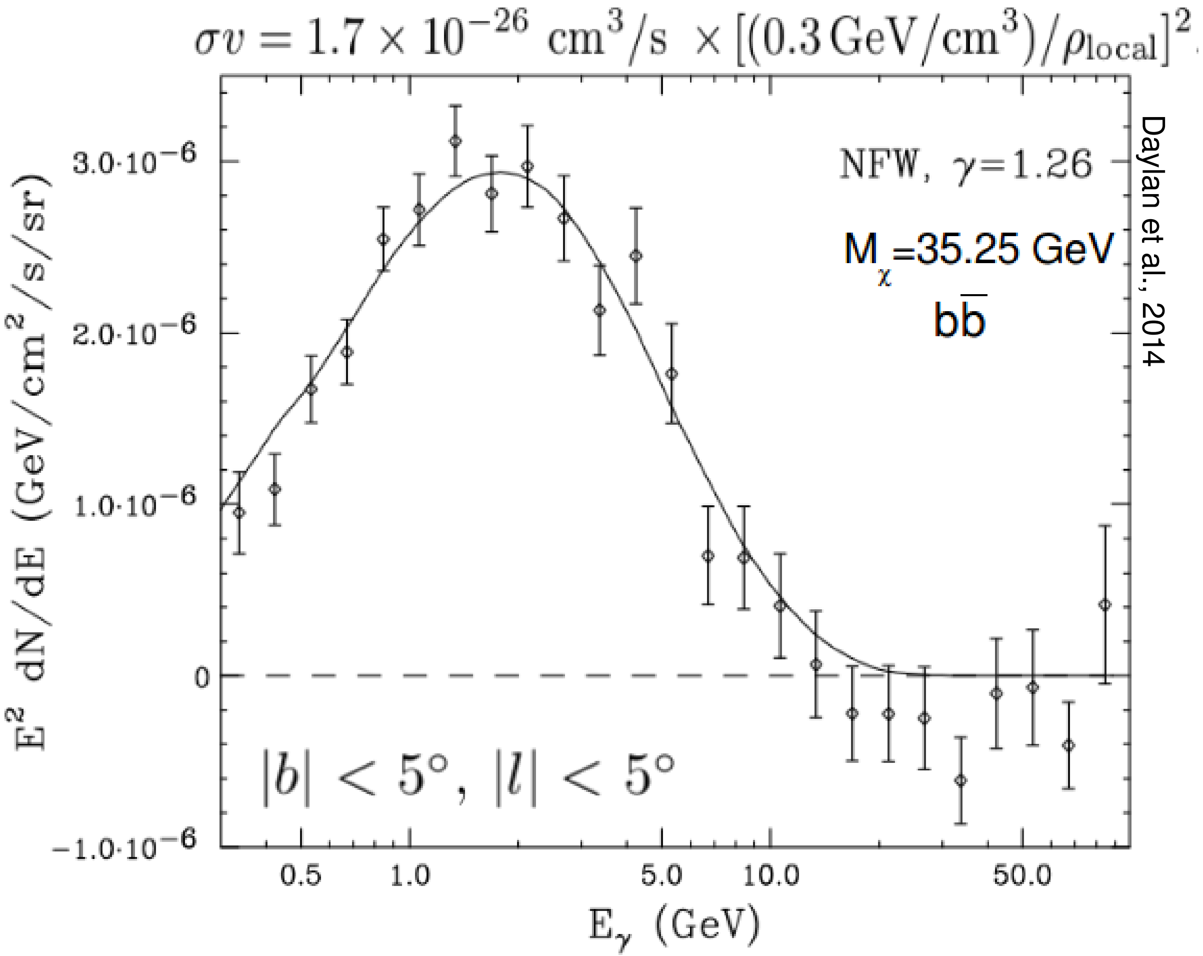


Right panel: residual maps after subtracting the best-fit Galactic diffuse model, 20 cm template, point sources, and isotropic template

(Daylan et al., 2014)

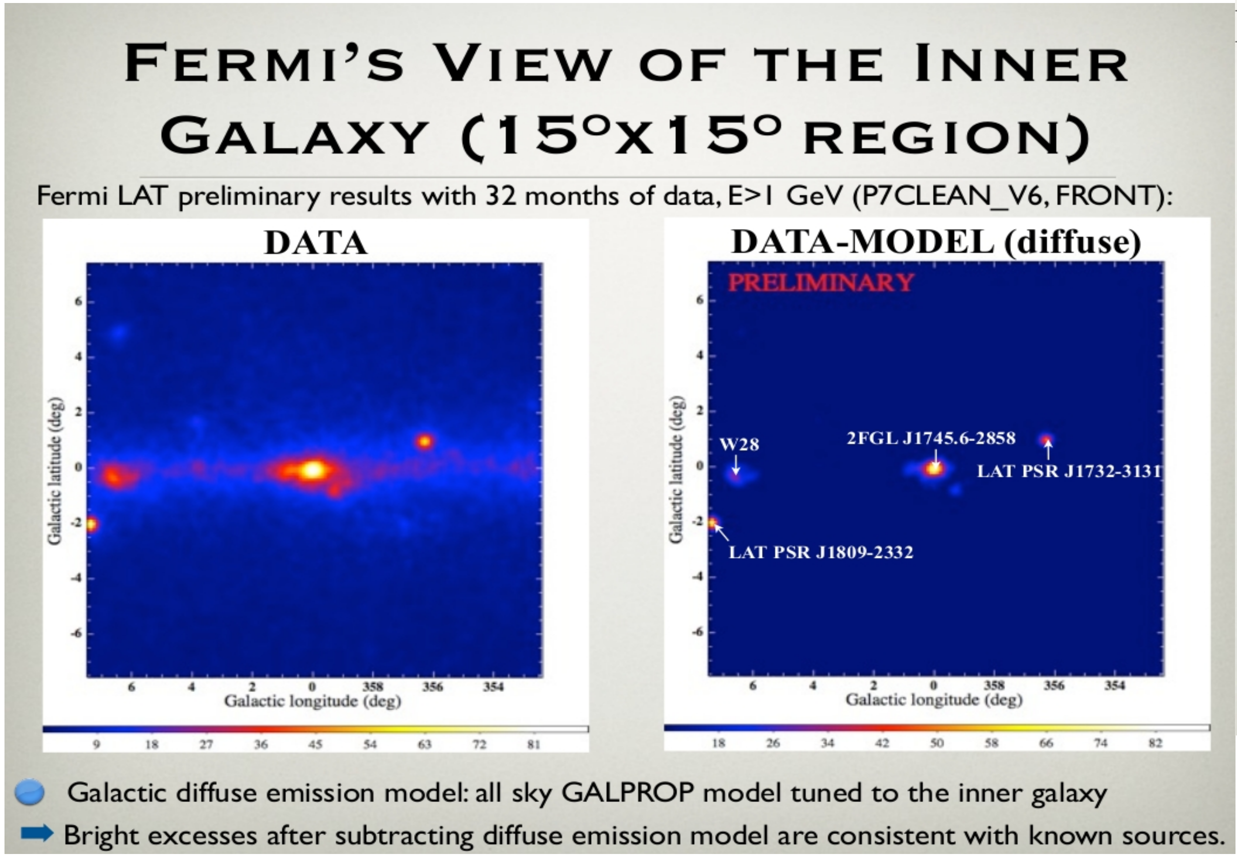
Galactic Center

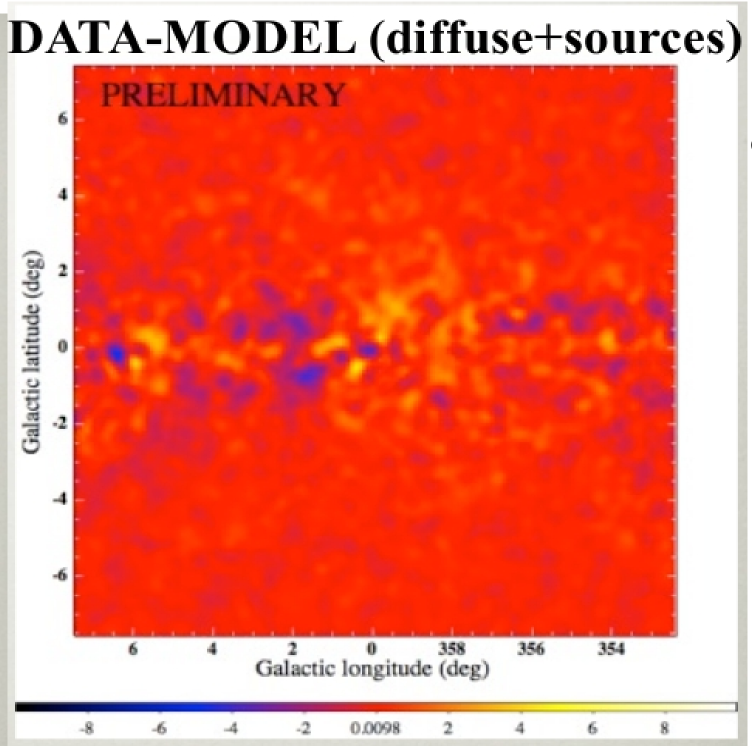
On ~ 1 kpc scale ~ few degrees



A spherical spatially extended (on about 10 degrees) excess of ~ 1-3 GeV gamma-rays has been claimed.

Galactic Center





S. Murgia's talk, 2014

Source confusion and uncertain diffuse emission modeling

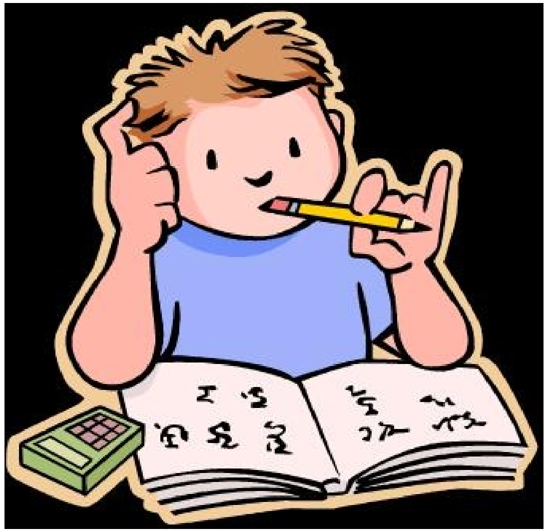
Petrovic et al., 2014:

Inverse Compton emission from high-energy electrons injected in a burst event of ~ 10^{52}-10^{53} erg roughly $O(10^6)$ years ago.

Carlson and Profumo, 2014:

π^0 decay of cosmic ray protons injected by SN remnants in episodes $O(10^6)$ years ago

Homework exercise



Take the model of slide 59.

↓

Compute the synchrotron emission at 330 MHz.

Approximations:

- $dN_e/dE \sim A\, x^{-B}\, e^{-Cx}$
- no spatial diffusion
- monochromatic description of synchrotron

↓

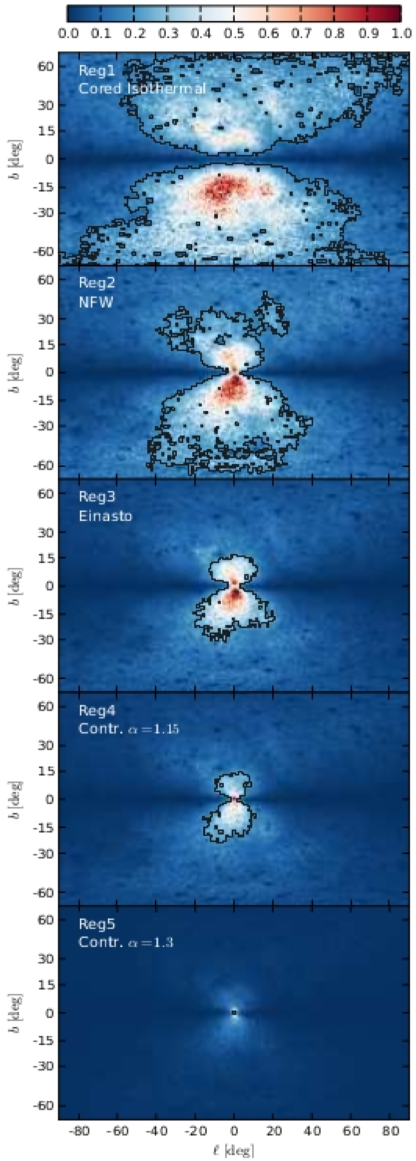
Compare with image of slide 57 (LaRosa et al., 2005).

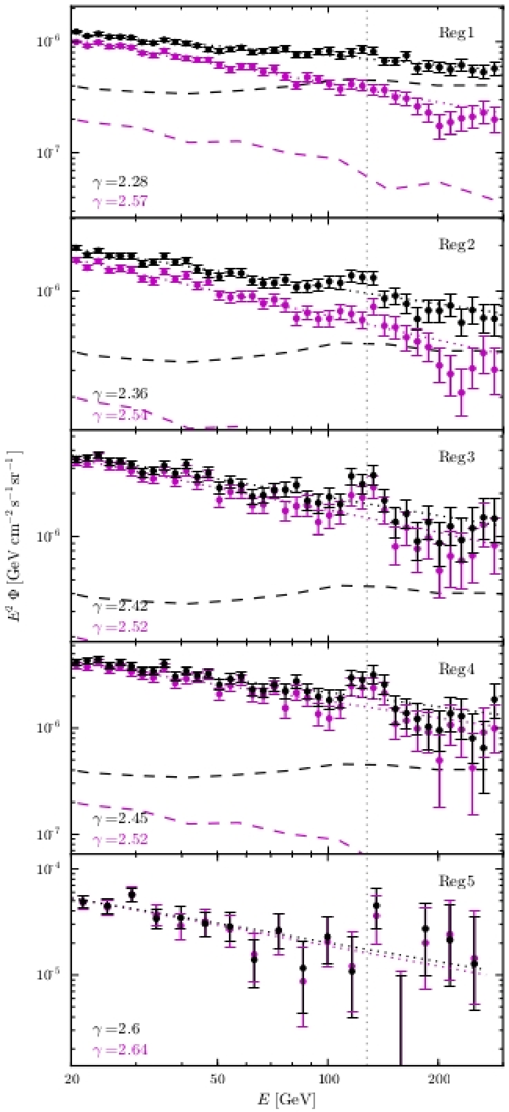
Can you match the emission?

What kind of **magnetic field** you need?

If you want to go further, look also at the spectrum of the radio emission (e.g., Crocker et al., 2010)

Line at the GC





Weniger, JCAP 2012

Signal to noise ratio in each pixel:

$$\mathcal{R}_i = \mu_i / \sqrt{c_i}$$

μ_i=expected events

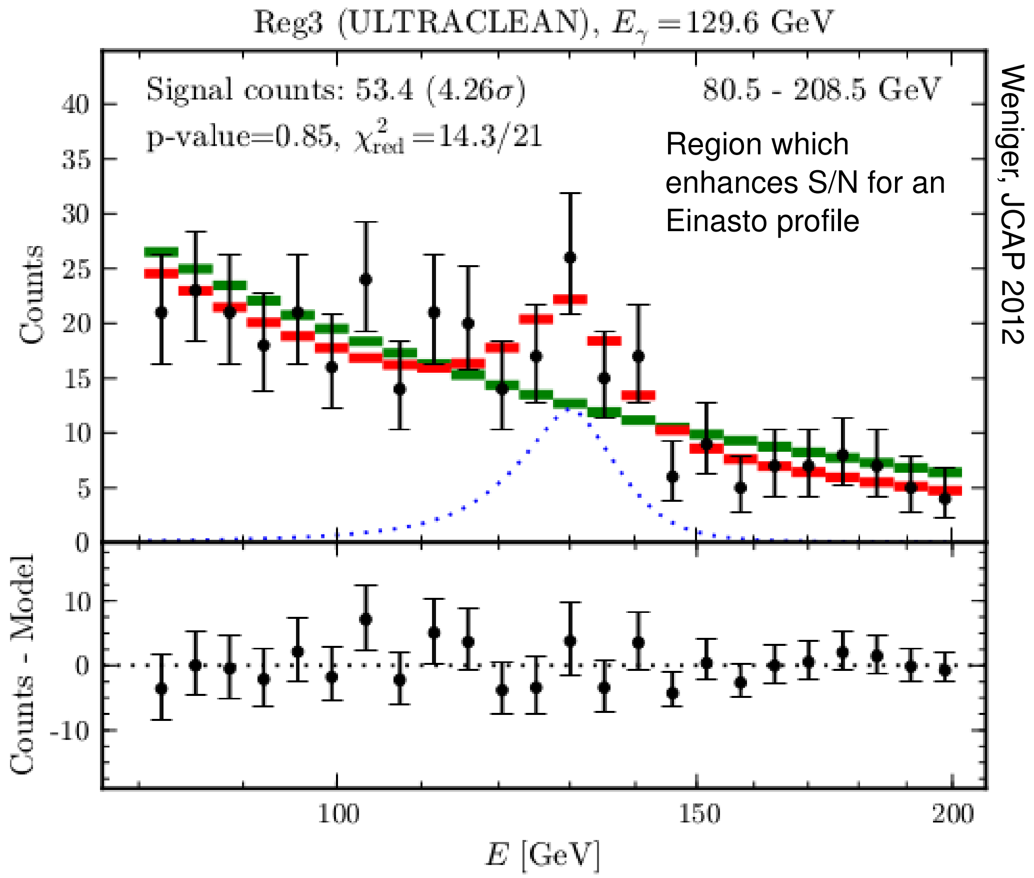
c_i=observed events

Optimal target region T_0 which maximizes:

$$\mathcal{R}_{\mathcal{T}_o} = \frac{\sum_{i \in \mathcal{T}_o} \mu_i}{\sqrt{\sum_{i \in \mathcal{T}_o} c_i}}$$

The significance of the excess found in this work is 3.2**σ**

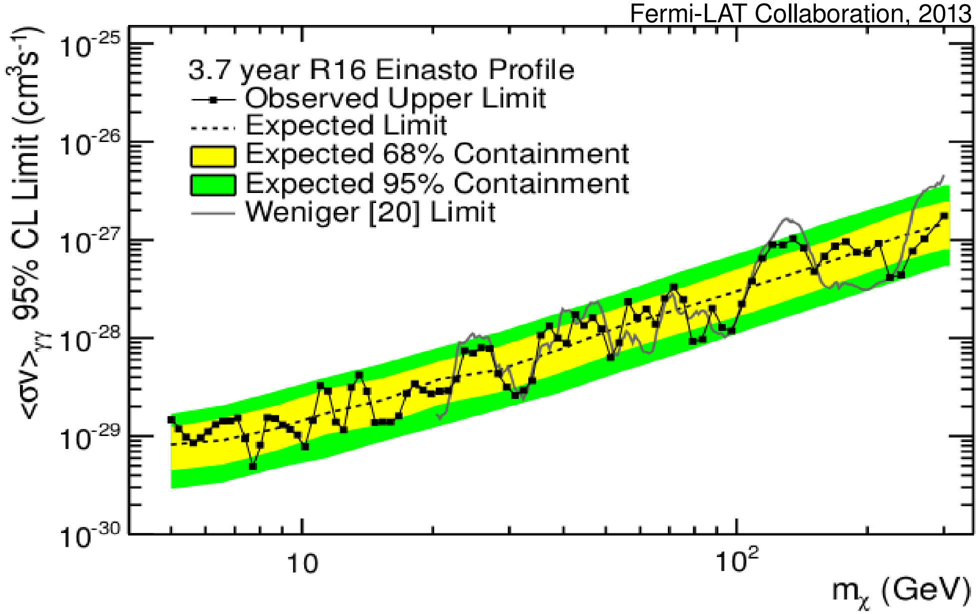
Line at the GC



Challenging large annihilation rate: $\langle \sigma v \rangle_{\chi\chi\to\gamma\gamma} = (1.27 \pm 0.32^{+0.18}_{-0.28}) \times 10^{-27}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$

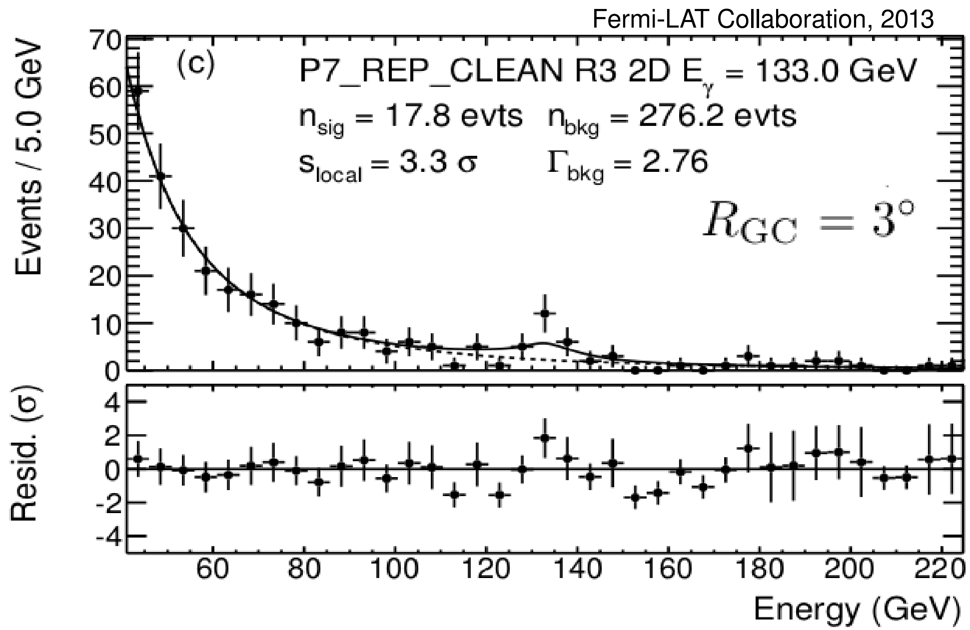
Puzzling, but good for theoreticians!

Line at the GC

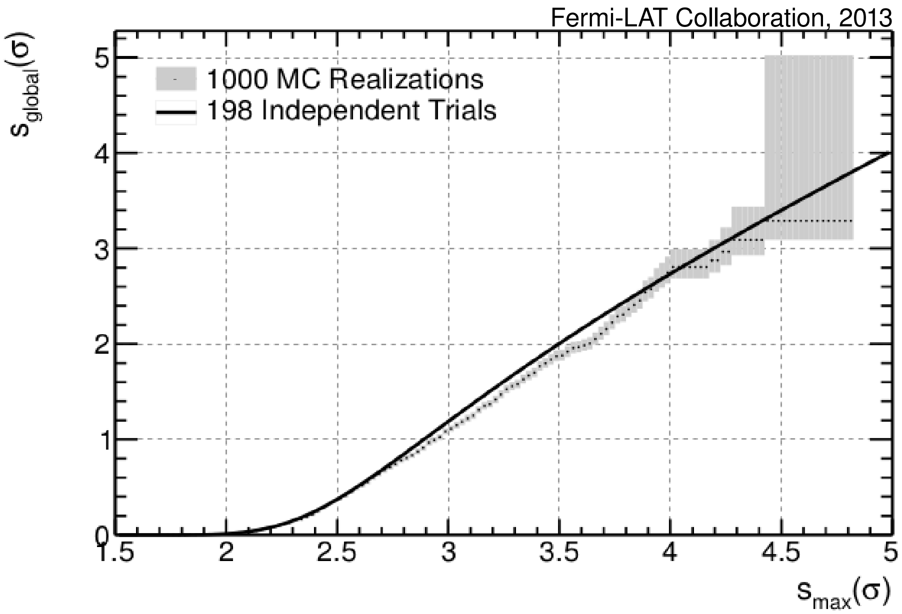


Re-analysis and careful evaluation of systematic effects by the Fermi-LAT team.

Still non-negligible local significance, that cannot be explained in terms of known systematic effects.



Line at the GC



Global significance of the excess is only 1.5σ

Other issues:

Suspicious excess of similar significance at the same energy in a subset of **Earth's limb data** (Finkbeiner et al., 2012), although cannot probably entirely explain the GC line.

Signal appears **offset from the (dynamical) GC** by ~ 1.5 deg (Su&Finkbeiner, 2012)

Better assessment of systematics and more statistics with PASS8 from the Fermi-LAT Collaboration and with forthcoming telescopes (HESS-II, GAMMA-400, CTA).