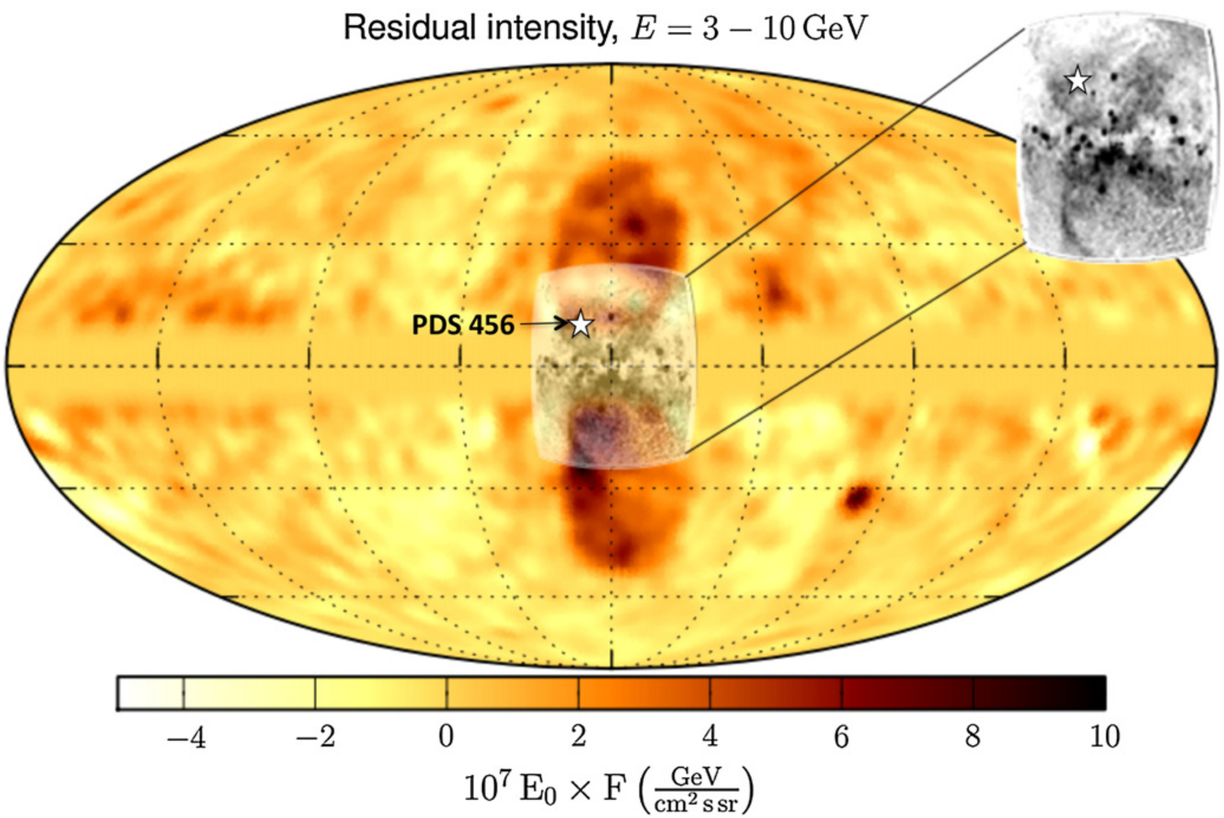
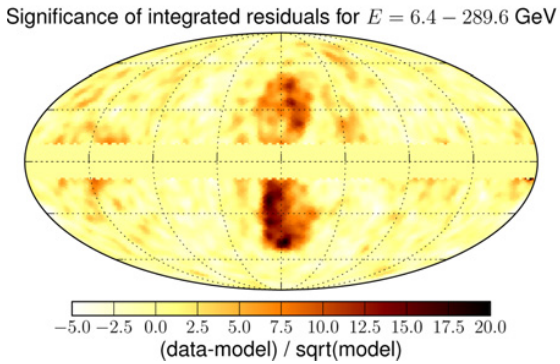
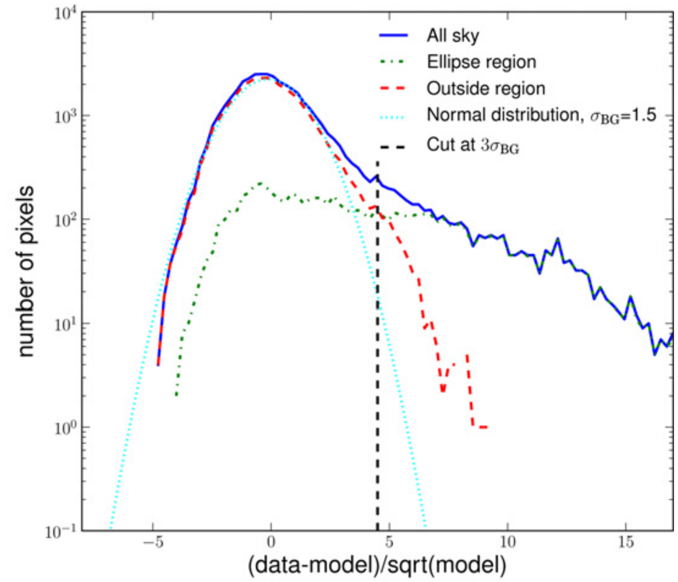
The Fermi Bubbles as Pair-Haloes

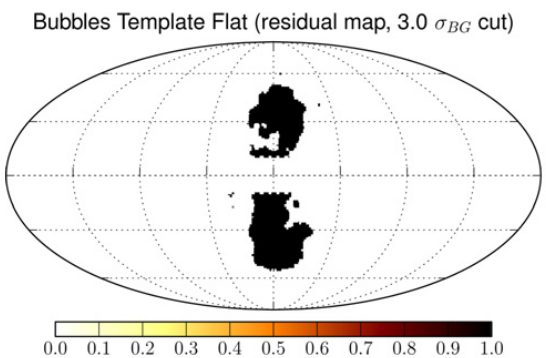
Demosthenes Kazanas & Tonia M. Venters
NASA/GSFC

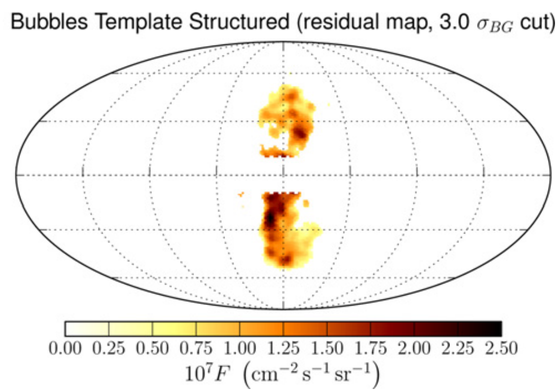


Ackermann et al. 2014, ApJ, 793, 64









Bubble Properties

- Their galactic center association and extent: ~ 10 kpc (indicating a finite time activity for their formation).

- Their (γ-ray) luminosity: ~ 4 x 10^{37} erg/s (implying a cooling life time of 1My and an energy content of 10^{51} – 10^{52} erg).

- The limited extent of their energy spectrum

Note the apparent low energy cut-off! Inconsistent with shock acceleration (typically invoked in these situations)

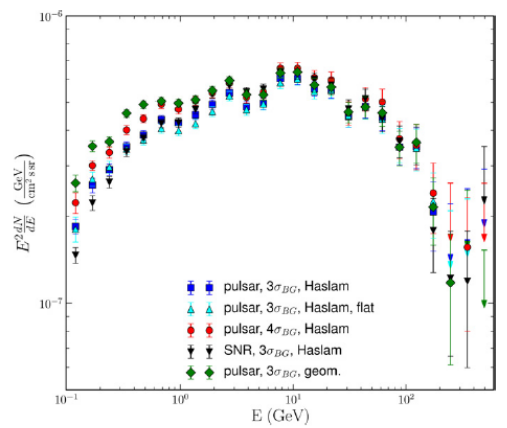


Figure 7. Spectra of the bubbles for different model configurations. The cases differ by the significance threshold used to define the template of the bubbles ($3\sigma_{\mathrm{BG}}$ or $4\sigma_{\mathrm{BG}}$), whether the CR source distribution is traced by pulsar or SNR distributions, and the use of the geometric Loop I template or the Haslam map.
(A color version of this figure is available in the online journal.)

Bubble Properties (continued)

- Their sharp edges! (on all sides)

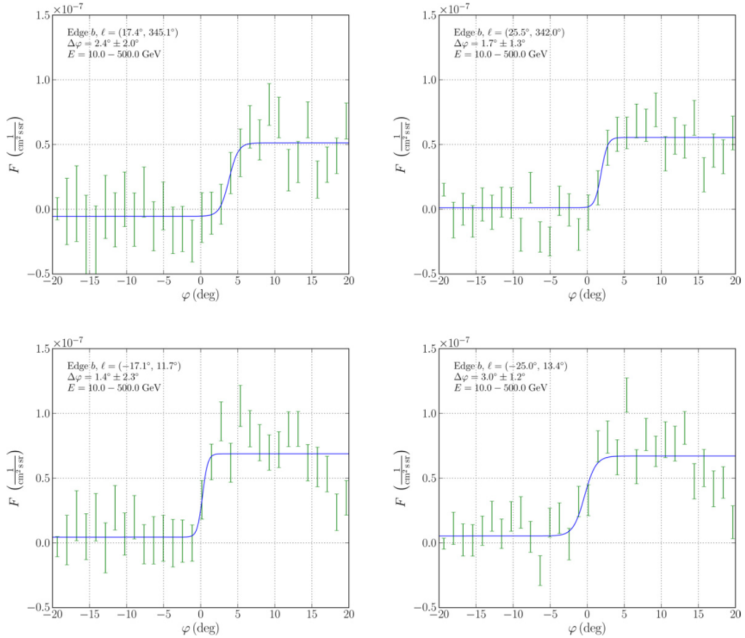


Figure 29. Examples of fitting the edges of the bubbles in the GALPROP residual map, integrated above 10 GeV (Figure 22).
(A color version of this figure is available in the online journal.)

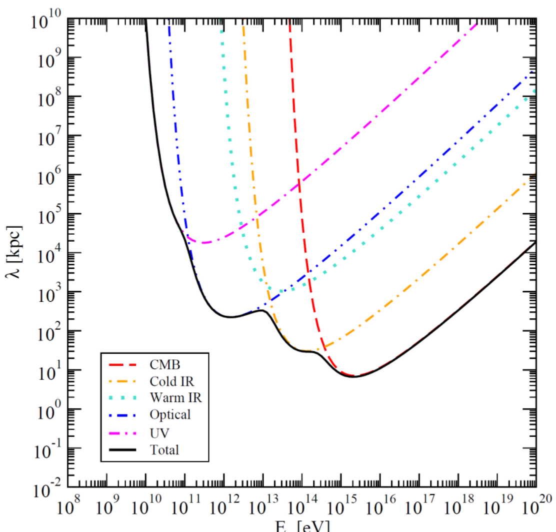
Origin

- Some activity in the galactic center at a prior time:
  - a jet from the black hole (Guo & Mathews 2012; Yang et al. 2012)
  - a spherical outflow from the black hole (Zubovas et al. 2011)
  - a wind from supernova (SN) explosions (Crocker & Aharonian 2011)
  - a sequence of shocks from several accretion events onto the black hole (Cheng et al. 2011)

All the above resort to shock acceleration to produce the radiating particles. As such they have problems with the absence of lower frequency radiation and the sharpness of the edges.

Pair Haloes

- Pair haloes are e+e- pairs created by high energy γ-rays interacting with ambient radiation away from their source. Generally thought to be related to TeV blazar emission in interactions with the EBL.
- Their length scale is of the order of the mean free path of γ-rays, generally thought to be of order of Mpc.
- The much more intense field of the Galaxy, offers the possibility that this process be associated with the much smaller galactic scales.



Some Simple Estimates

- We assume the presence of a BL Lac state of the Sgr A* black hole at the Galactic Center producing a significant fraction of its radiation in high energy (> 1 TeV) γ-rays.
- Their flux as a function of radius *r* and energy *E* will be (assuming conical geometry)

$$F(r,E) \simeq \left[\frac{f_0(E)}{r^2}\right] \times e^{-r/\lambda(E)}$$

- *λ(E)* is the γγ →e+e- mean free path

- The e+e- injection rate in *r, E* will be the divergence of the flux

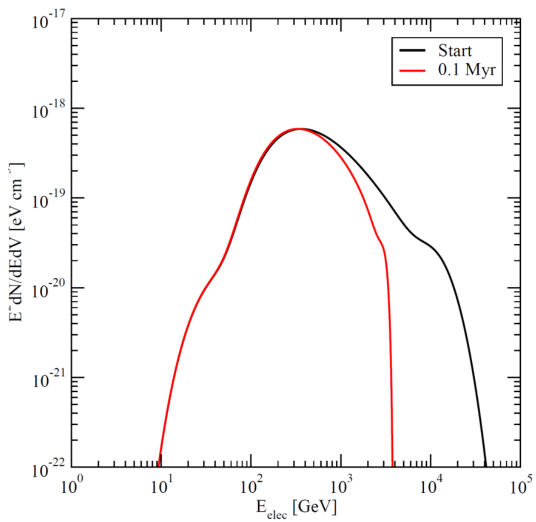
$$\begin{aligned} Q(r,E) &= \nabla \cdot F(r,E) \\ Q(r,E) &= \left[\frac{f_0(E)}{r^2\,\lambda(E)}\right] \times e^{-r/\lambda(E)} \end{aligned}$$

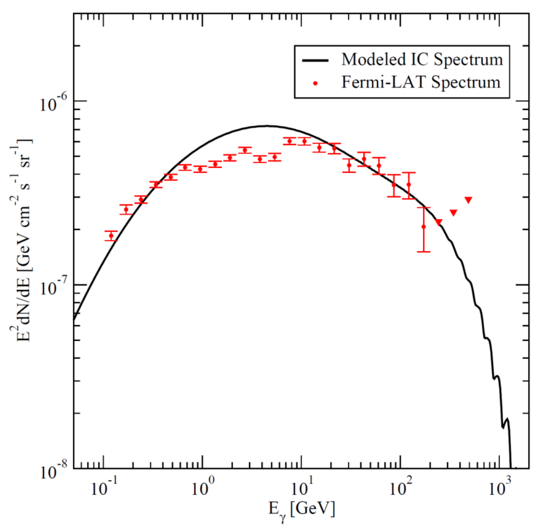
- The current value of the electron-positron density with the above injection rate can be easily calculated (assuming the injection of e+e- lasts for a time scale *Δt* shorter than the electron cooling time (~0.1- 1 M yr)

$$N(r,E,t) = Q[r, E/(1-\beta E t)] \times \frac{1}{(1-\beta E t)^2} \times \Delta t$$

- Where *E* in *Q(r,E)* has been replaced by *E/(1 – βEt)* and *Δt* is the duration of the injection time (~ 10,000 yrs, the light crossing time to the bubble edge; β the inverse electron cooling time).
- The luminosity and size of the bubbles is given by the luminosity and duration of the active state *Δt* and their sharp edges by this fact and the removal of all higher energy leptons by cooling.
- The γ-ray luminosity needed to provide the observed radiation is of order $L_\gamma \sim 10^{41}$-10^{42} erg/s, consistent with the sub-Eddington BL Lac emission.

- Preliminary calculations, *ignoring* (for the time being) *all dynamical and kinematic effects of the e+e- injection in inducing an outflow*, provide the following electron and γ-ray spectra (after adjusting a number of model parameters to obtain a good fit)





- The problem is currently under more detailed study.

- Thank you !!!