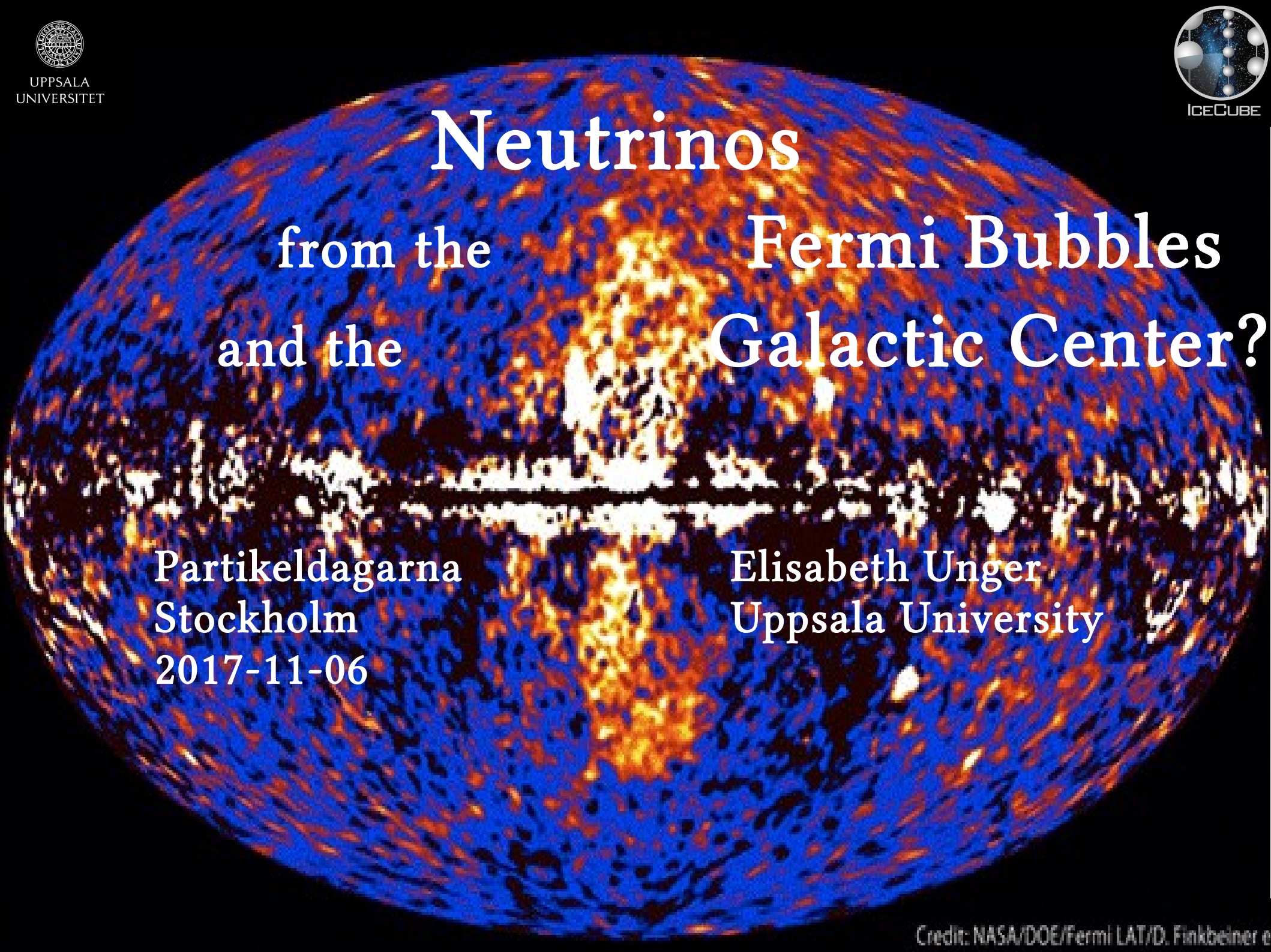
UPPSALA UNIVERSITET

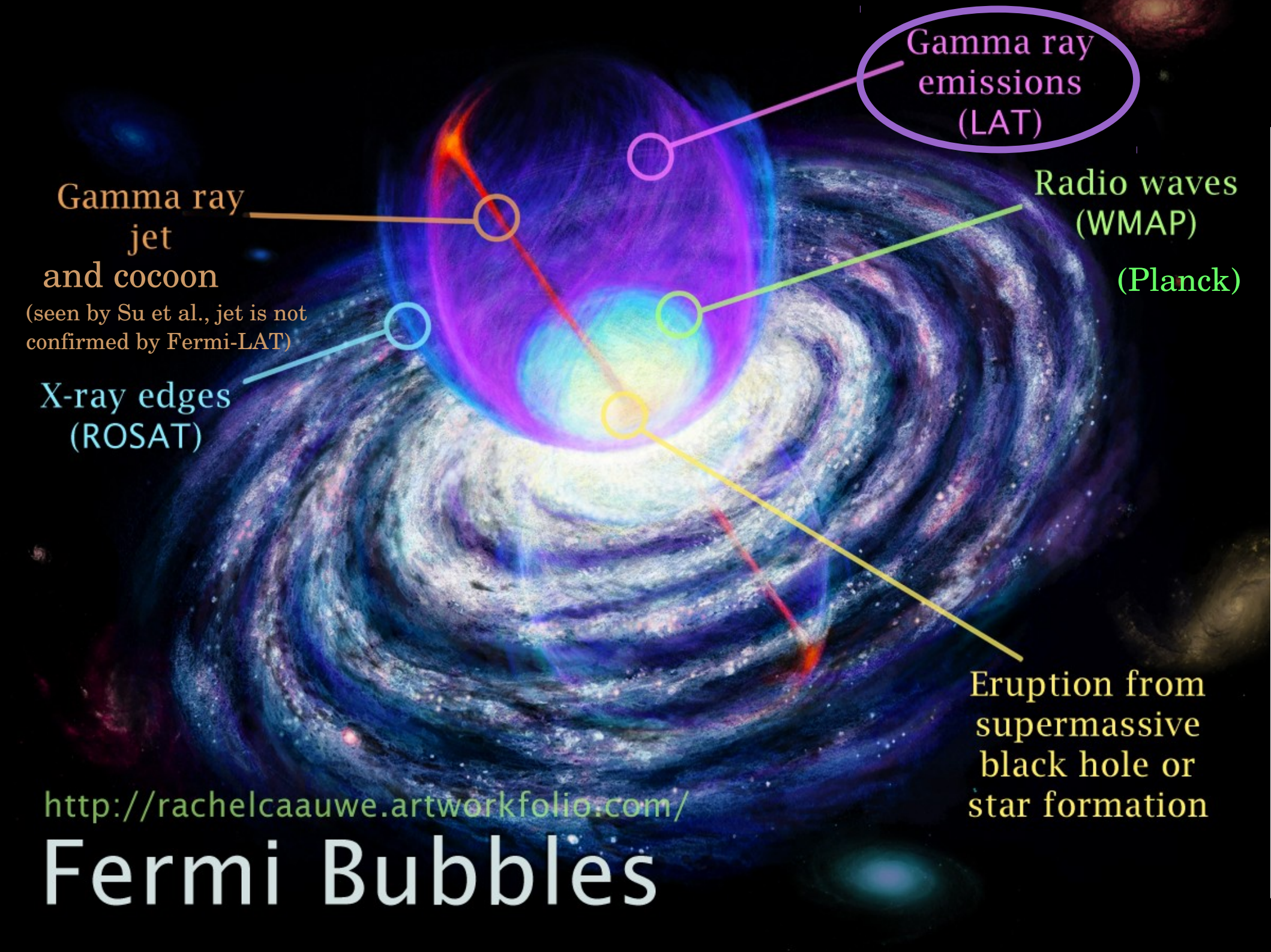
IceCube

Neutrinos from the Fermi Bubbles and the Galactic Center?



Partikeldagarna
Stockholm
2017-11-06

Elisabeth Unger
Uppsala University

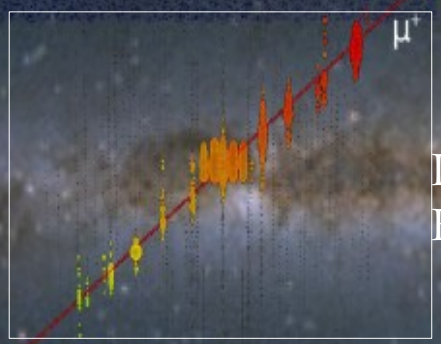

Gamma ray emissions (LAT)
Radio waves (WMAP)
(Planck)
Gamma ray jet and cocoon
(seen by Su et al., jet is not confirmed by Fermi-LAT)
X-ray edges (ROSAT)
Eruption from supermassive black hole or star formation
http://rachelcaauwe.artworkfolio.com/
Fermi Bubbles

Hadronic model:

1. Cosmic Ray (CR) production and acceleration due to star formation and supernovae explosions

2. Injection of CRs in FB due to Galactic wind from Galactic center region. CRs are trapped in FB for ~10^{10} years

3. ν and γ production due to CR interaction in Fermi Bubbles (FB)



IceCube, Earth

R. Crocker et al., Phys. Rev. Lett. 106 (2011) 101102.

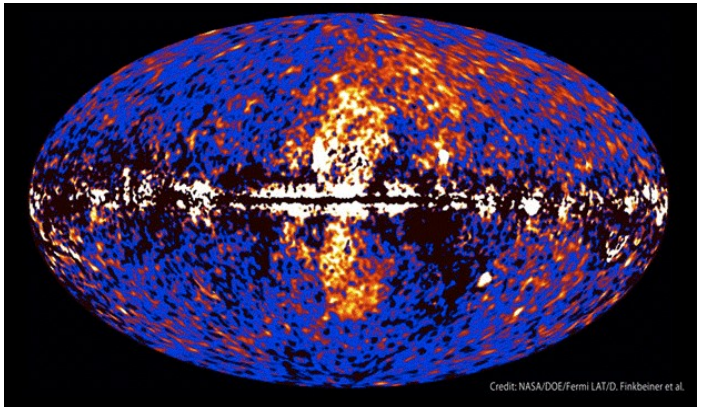
Fermi Bubble γ-ray spectrum

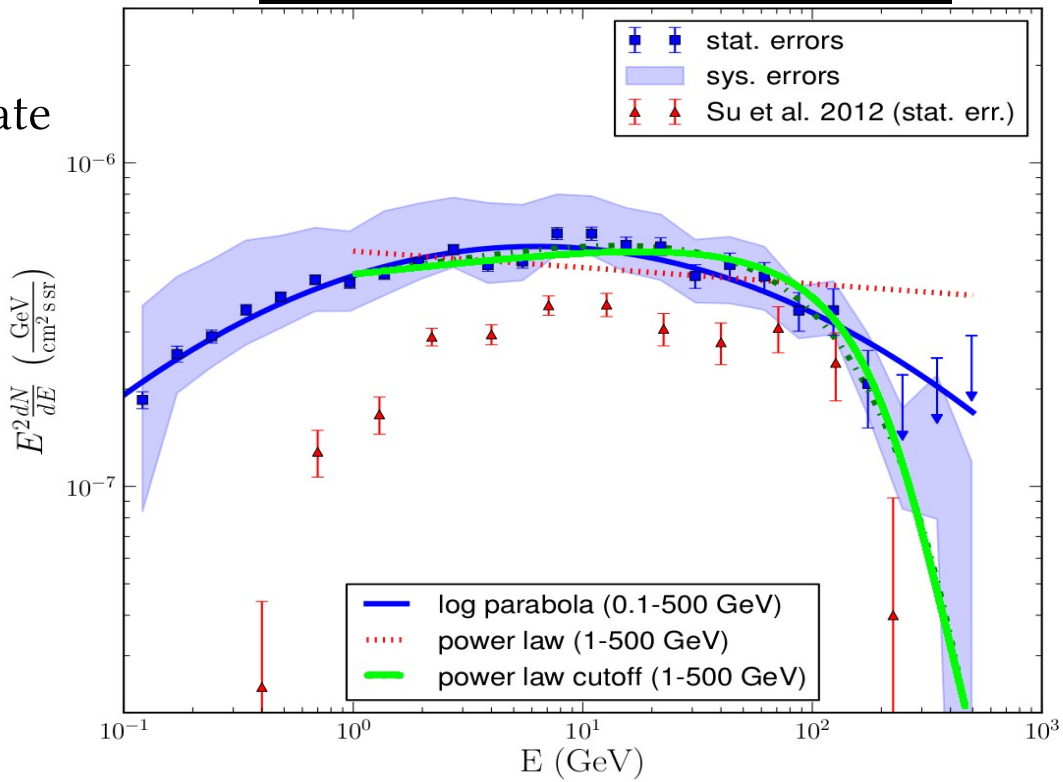
- Constant intensity over emission region
- Normalization shift between Fermi-Lat (blue squares) and Su et al. (red triangles):
  - different foreground modeling
  - different definition of FB shape template
  - different Galactic plane mask
- If power law spectrum:
  - index:

$$\gamma = 1.87 \pm 0.02[\mathrm{stat}]^{+0.14}_{-0.17}[\mathrm{syst}]$$

  - exponential cutoff:

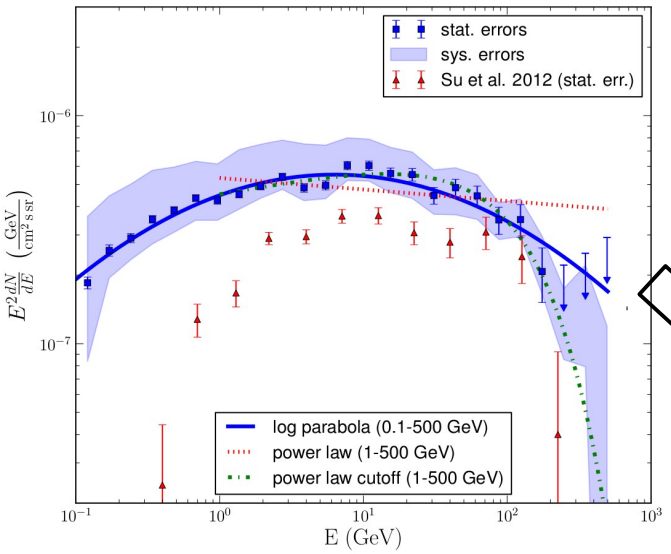
$$E_{cut} = 113 \pm 19[\mathrm{stat}]^{+45}_{-53}[\mathrm{syst}]\ \mathrm{GeV}$$





Fermi-LAT collaboration,The Astrophysical Journal, Volume 793, Issue 1, article id. 64, 34 pp. (2014)

Signal spectrum estimation



Neutrino oscillations: [1:1:1]

All three flavours included
→ 3x this flux used

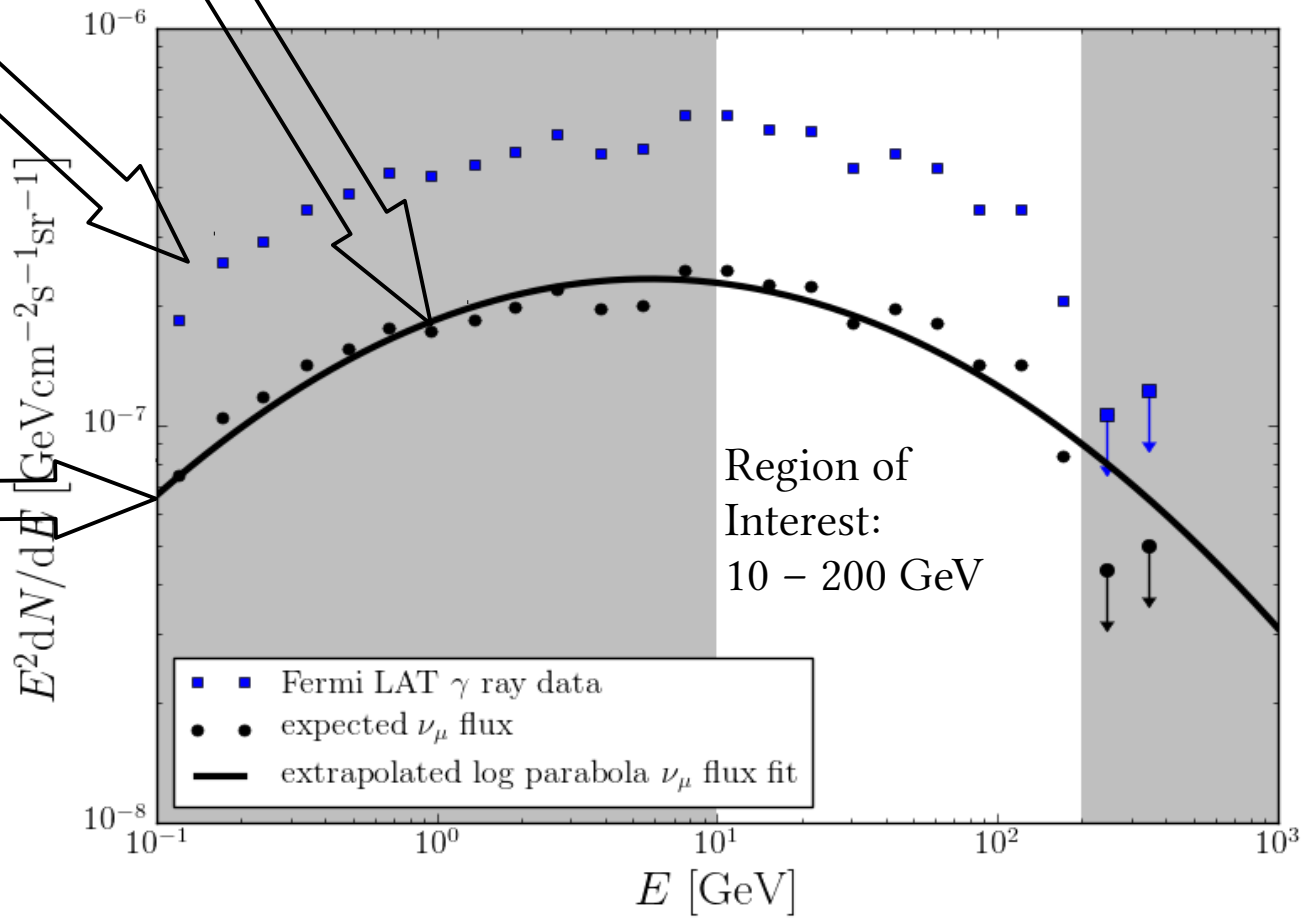
	ν_e	ν_μ	ν_τ
CC	cascade	track	cascade*
NC	cascade	cascade	cascade

*at low energies

Neutrino flux calculation from: F. L. Villante et al., Phys. Rev. D 78, (2008) 103007

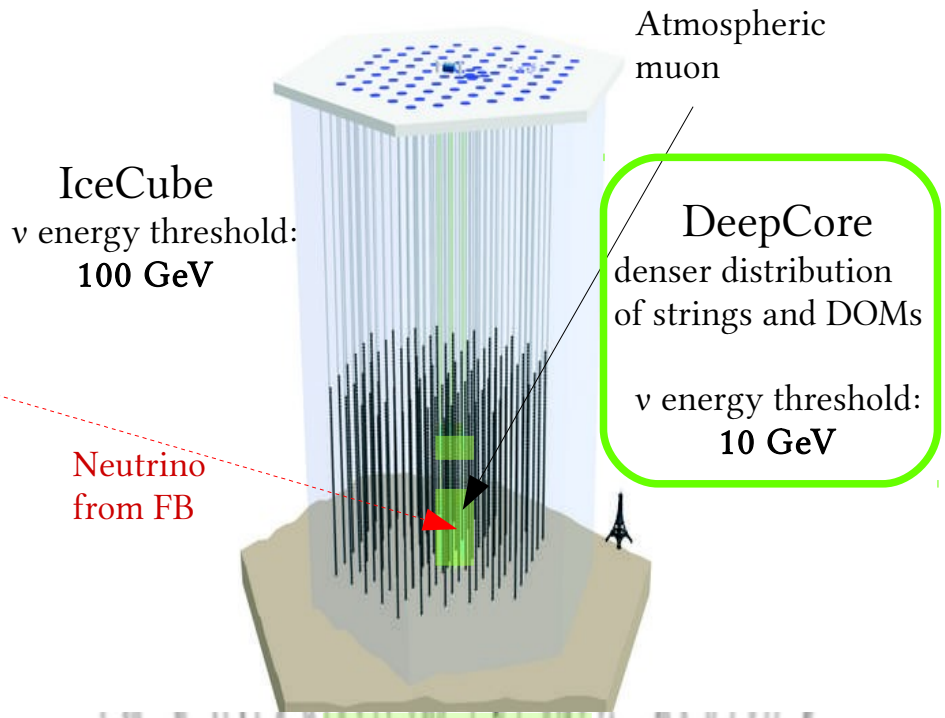
$$\Phi_{\nu_e} = \Phi_{\nu_\mu} = \Phi_\gamma \cdot (0.211 + 0.195)$$

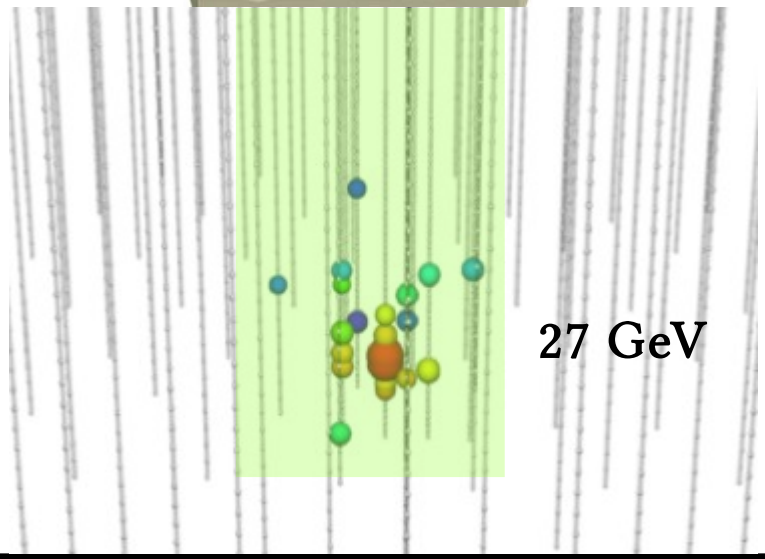
ν_μ $\bar{\nu}_\mu$



Event selection

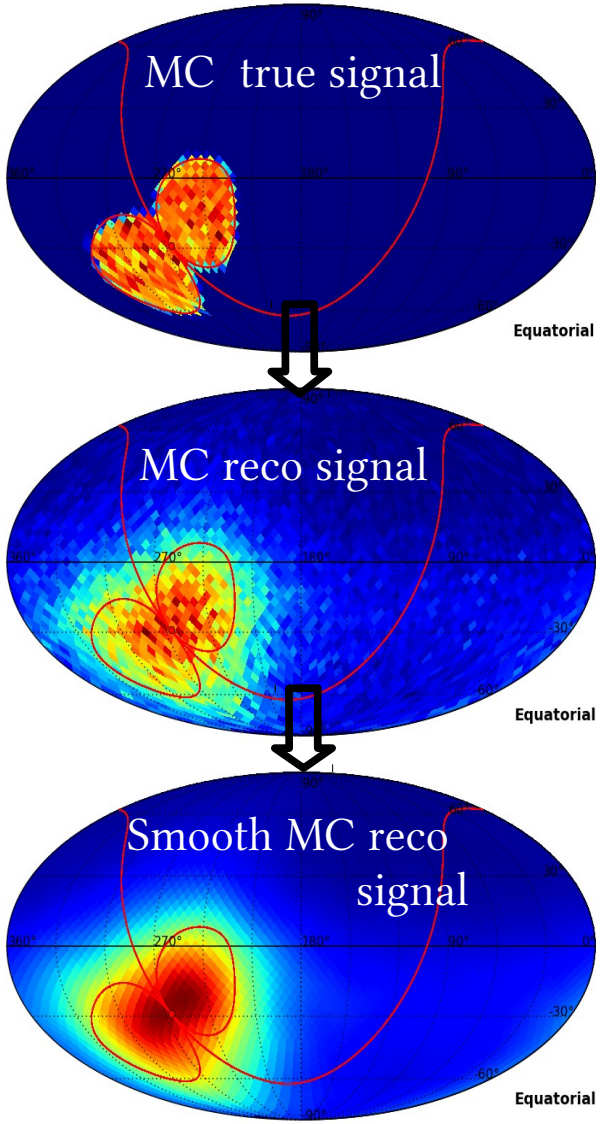
- All neutrino flavors
- All directions (full sky)
- Low energies: 10 GeV – 200 GeV
- Select only Cascade-like events (muon & tauon events look like cascade events at these low energies)
- Background reduction:
  - substantial by using IceCube's top and side layers as veto
  - by investigating different variables e.g.:
    - event topology
    - timing
    - direction





Signal expectation

- Simulated Monte Carlo events are weighted with expected ν - flux from FB per flavor and moved into the FB area
- Reconstruction of the signal
- Smoothing of the signal for a more realistic Probability Density Function (PDF)

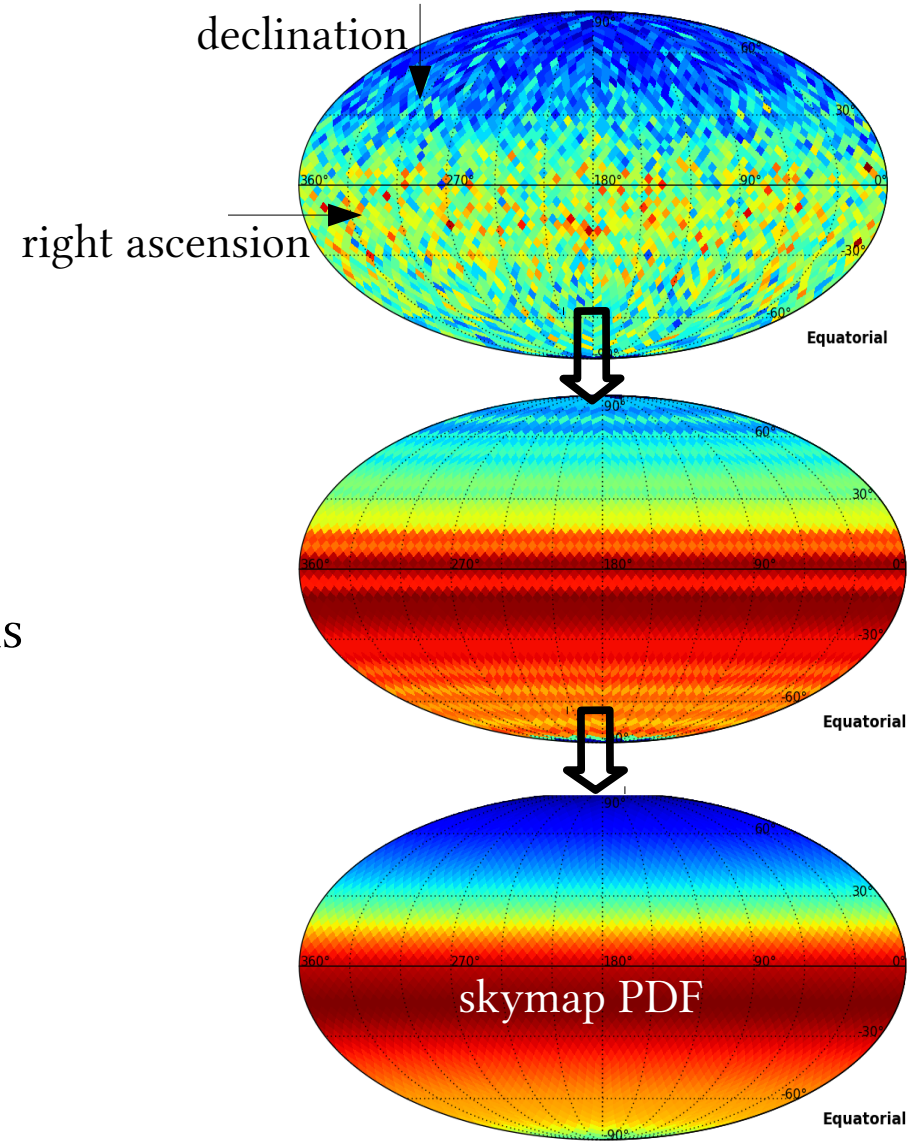


Background expectation

- 2086 days of observed data
  from May 2011 to April 2017

- averaging over right ascension
  for all declinations to hide real directions

- smoothing of the data
  for a more realistic PDF



Hypothesis Testing

- Maximum Likelihood Analysis
- Construct a likelihood function using above created skymap PDFs
- Include possibility of signal in the data background

$$\mathcal{L}(b) = \prod_{i=1}^{n_{obs}} f(b_i|\mu)$$

bins — signal events

$$f(b|\mu) = \frac{\mu}{n_{obs}} f_S(b) + \left(1 - \frac{\mu}{n_{obs}}\right) f_B(b|\mu)$$

signal PDF — background PDF

$$f_B(b|\mu) = f_{sd}(b|\mu) - \frac{\mu}{n_{obs}} f_{ss}(b)$$

scrambled data PDF — scrambled signal PDF

- Using likelihood ratio as a test statistic as in the method developed by Feldman and Cousins

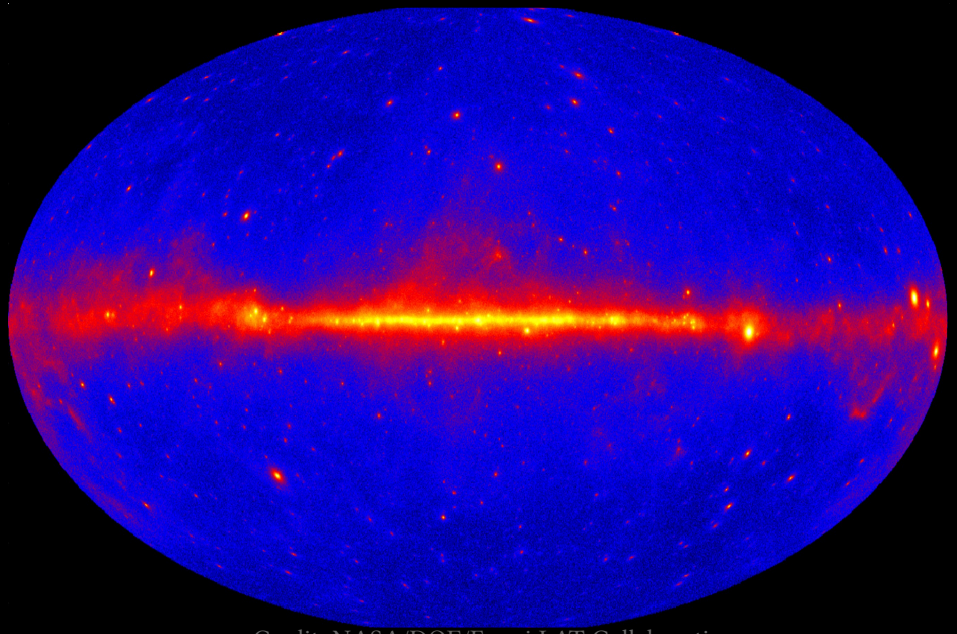
$$R(\mu) = \frac{\mathcal{L}(\mu)}{\mathcal{L}(\hat{\mu})}$$

likelihood of signal events

likelihood of best fit of signal events

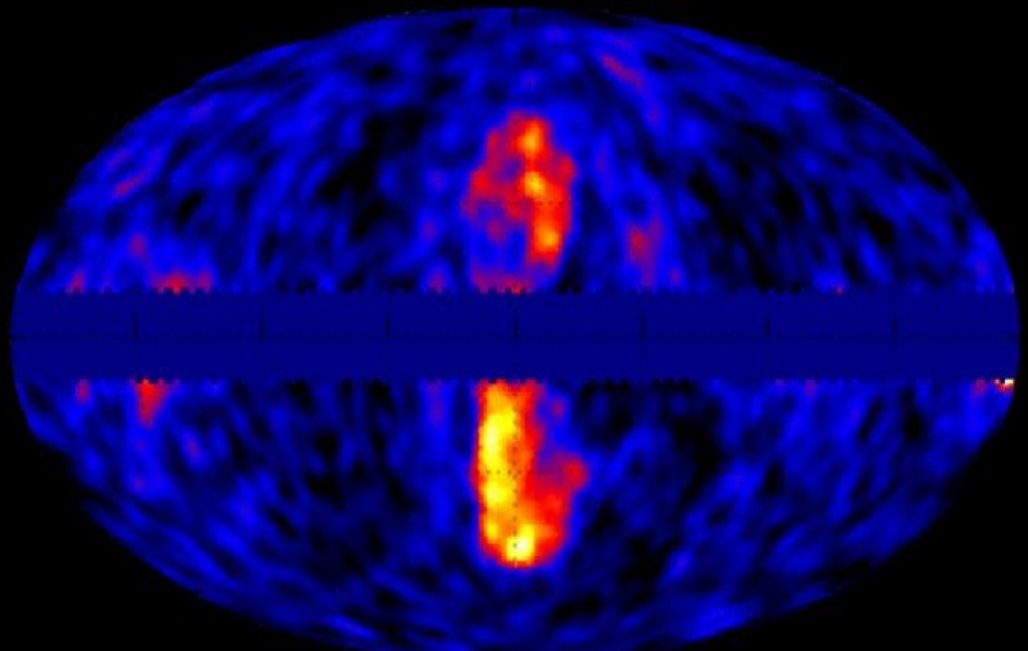
Galactic Center?

γ-ray skymap



Credit: NASA/DOE/Fermi LAT Collaboration

Fermi Bubbles



Credit: NASA/DOE/Fermi LAT Collaboration

Galactic Center and Plane have too much radiation ⟶ cut away for visibility of Fermi Bubbles

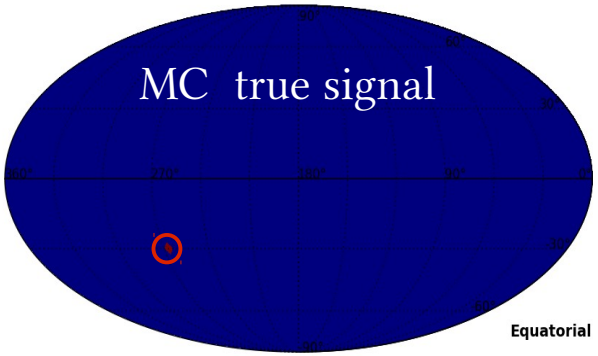
Ansatz: Equivalent spectral distribution as for FB expected also from the Galactic Center (GC)

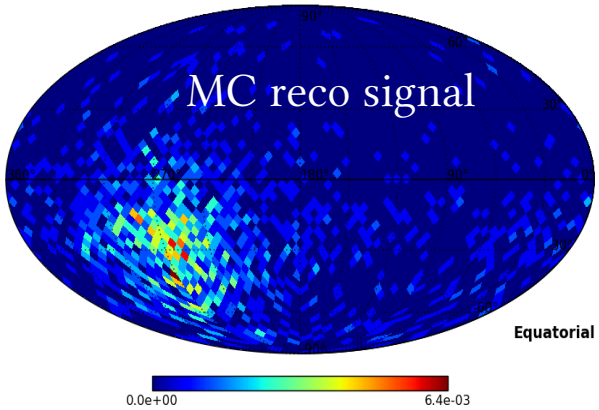
First IceCube analysis of GC without Dark Matter expectation at these low energies.

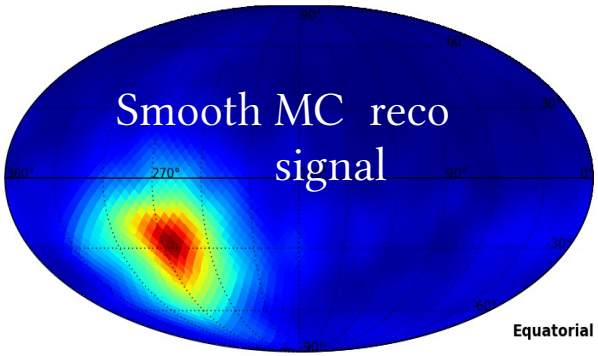
Galactic Center PDFs

Same analysis method for GC, with FB flux expectation

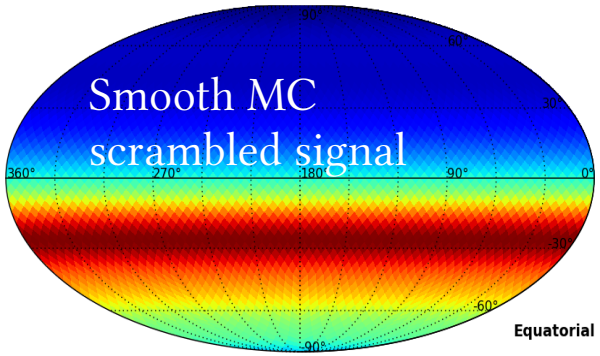
Events distributed within 0.5 degrees radius around the Galactic Center



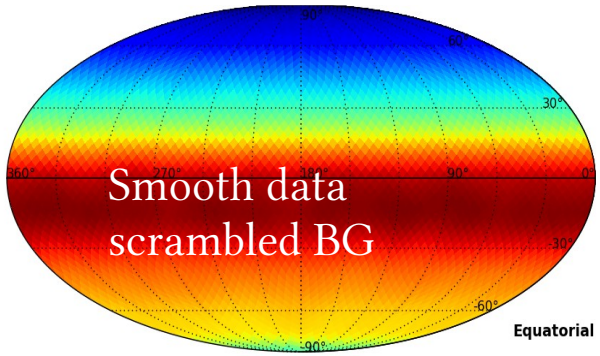




$f_S(b)$



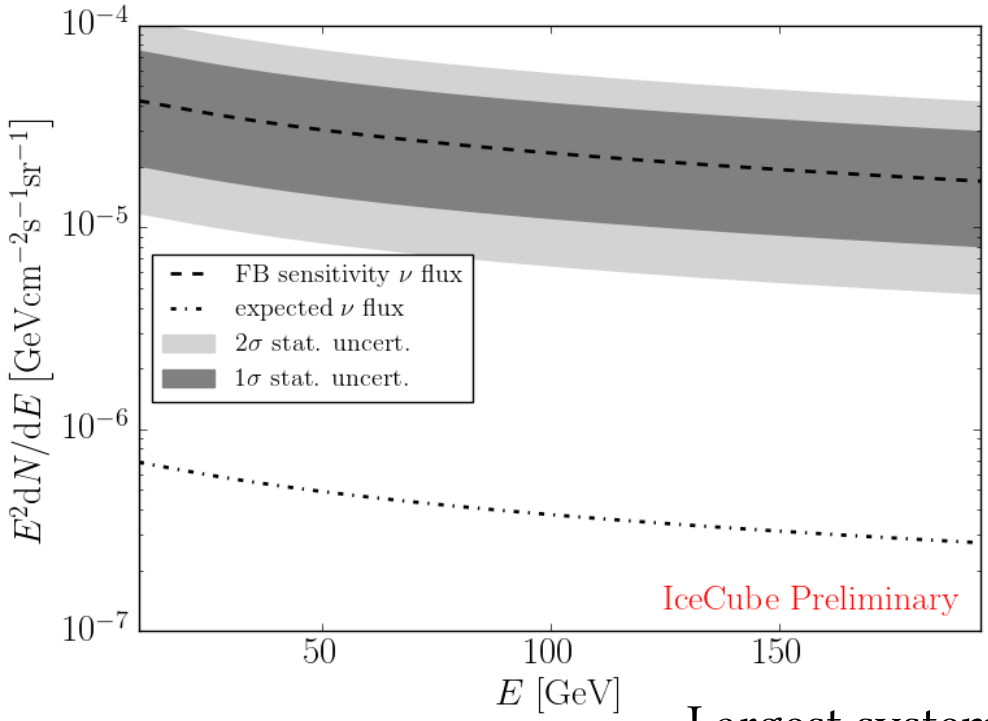
$f_{ss}(b)$



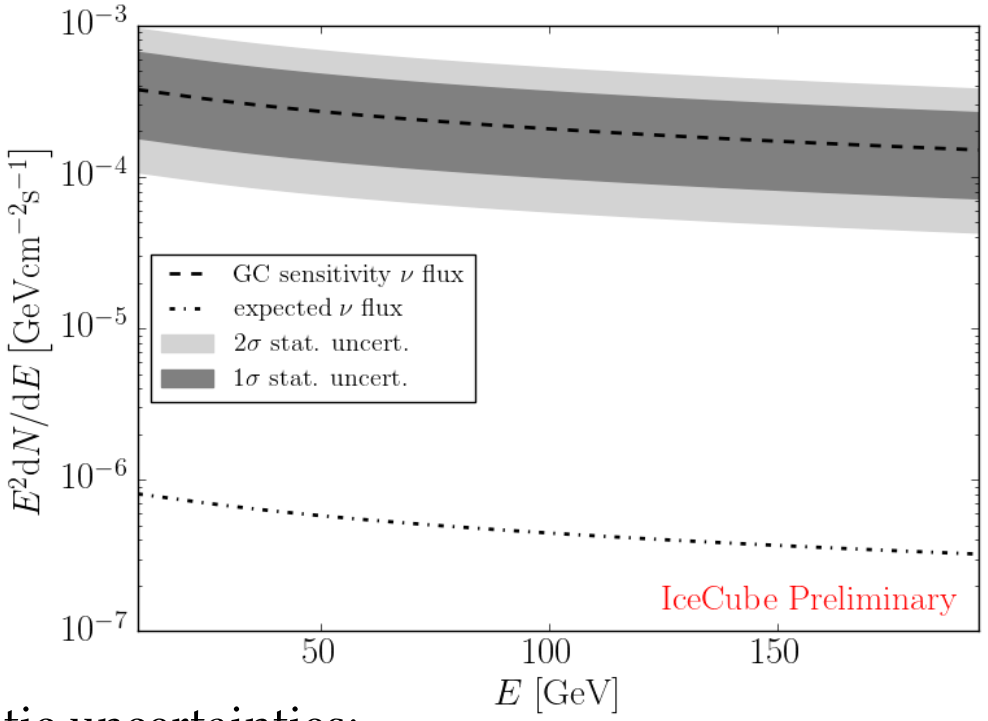
$f_{sd}(b|\mu)$

Sensitivities

Fermi Bubbles



Galactic Center



Largest systematic uncertainties:

11%	DOM efficiency	16%
10%	Ice model	12%
11%	Noise model	16%

Statistical uncertainties exceed systematics.

FB comparison to ANTARES

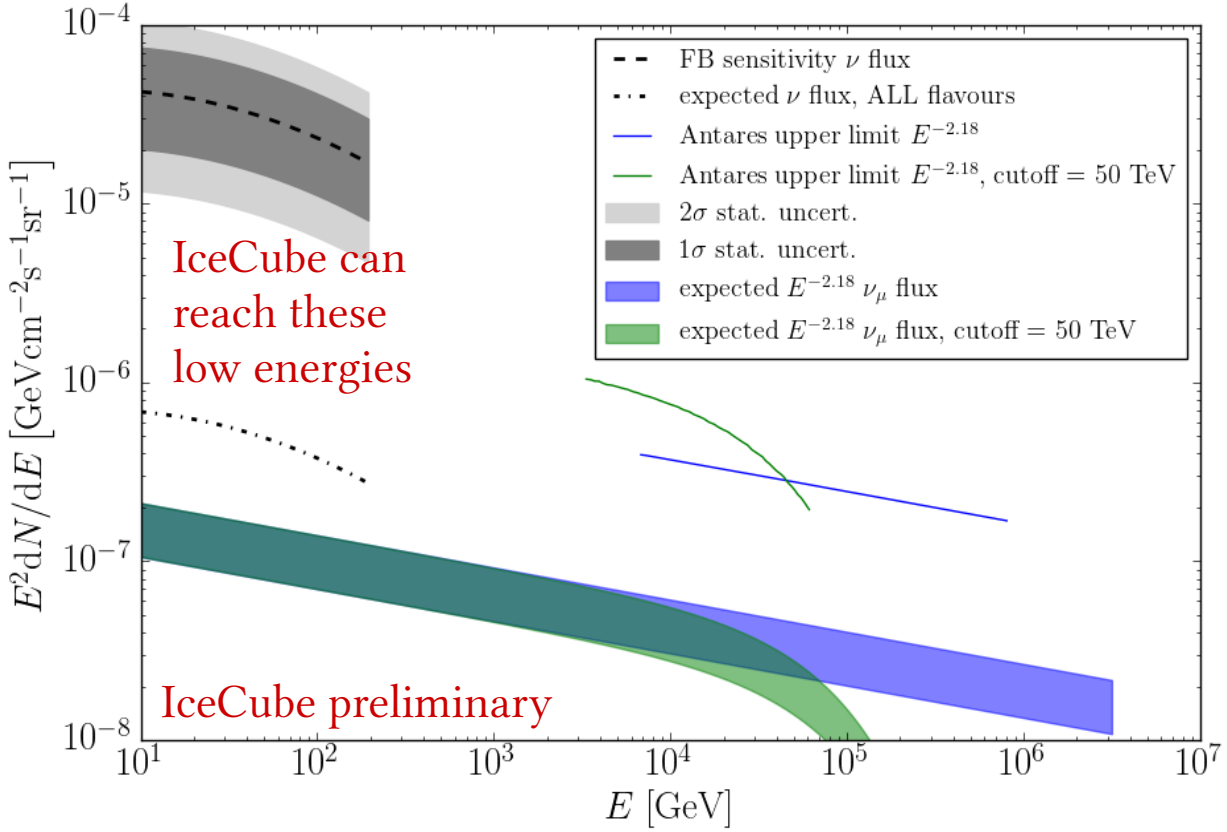
ANTARES

- 2096 days livetime, data: 2008-2015
- Cut and count analysis performed
- 1.5σ excess for tracks, 0.6σ excess for cascades of events in the Fermi bubble regions

ICECUBE

- 2086 days livetime, data: 2011-2017
- Maximum likelihood analysis
- Analysis will be unblinded soon
- $E^{-2.18}$ sensitivity same as for log parabola

- $E^{-2.18}$ fit starting at 10 GeV
- Results: S. Hallmann, 35thICRC2017



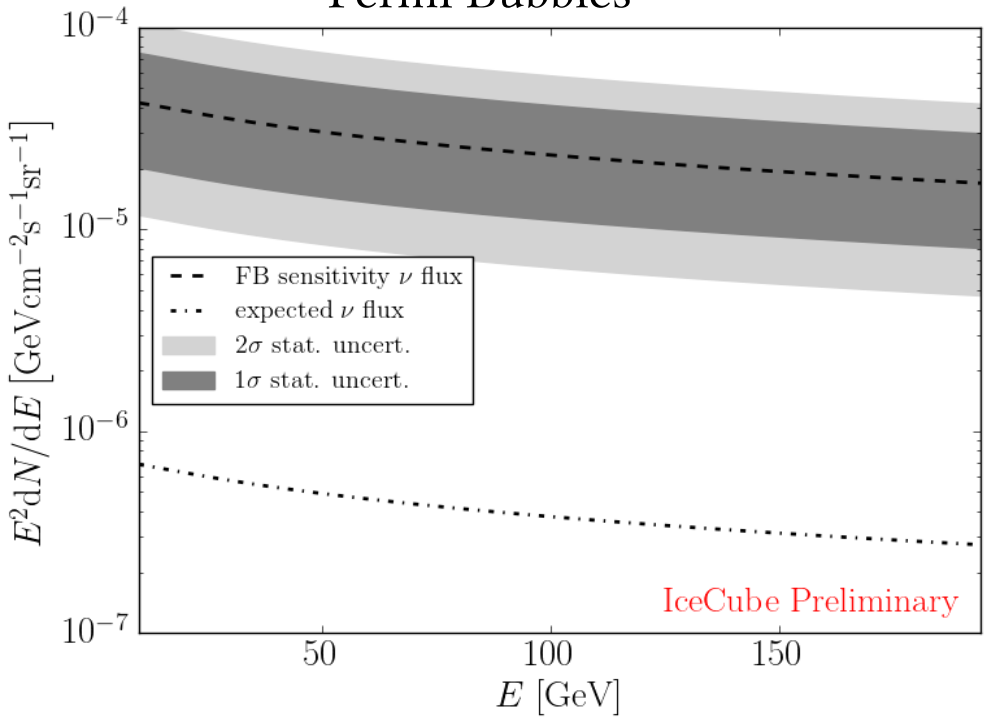
- Log parabola: best fit of measured flux in complete energy range

Thank you for your attention!

First neutrino telescope analysis probing at these low energies

- the Fermi Bubbles
- the Galactic Center without Dark Matter expectation

Fermi Bubbles



Galactic Center