The Galactic centre at 10^{12} eV

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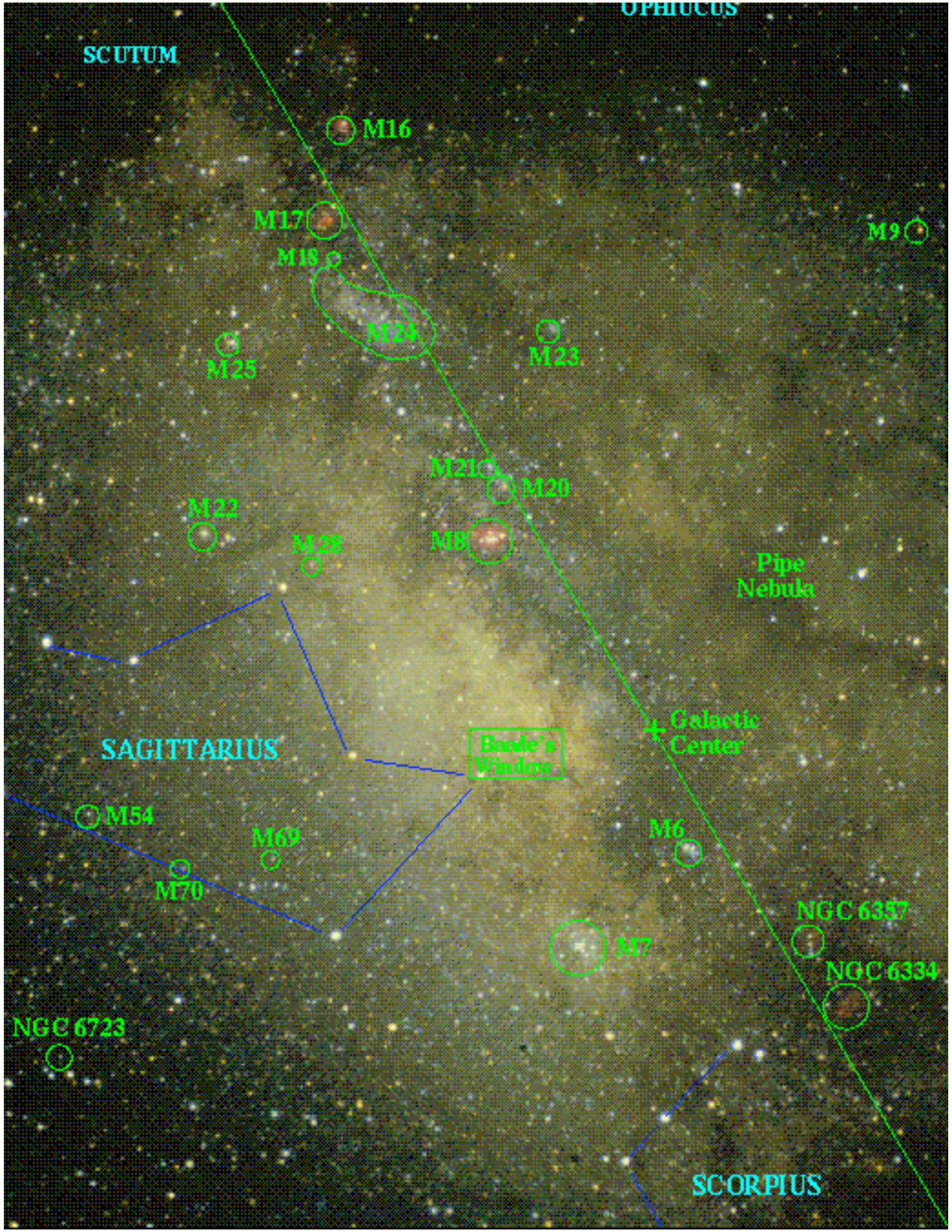
- Work in tera-electronvolts: TeV = 10^{12} eV ~ erg

- I have stolen material from talks available on line by:

1. Dermer and Attoyan
2. Andrea Goldwurm
3. HESS Collaboration



GC at Optical Wavelengths

- We can observe the GC at radio, sub-millimeter, infrared, X-ray and γ-ray wavelengths

Credit: UCLA Galactic Center Group

GC - NIR

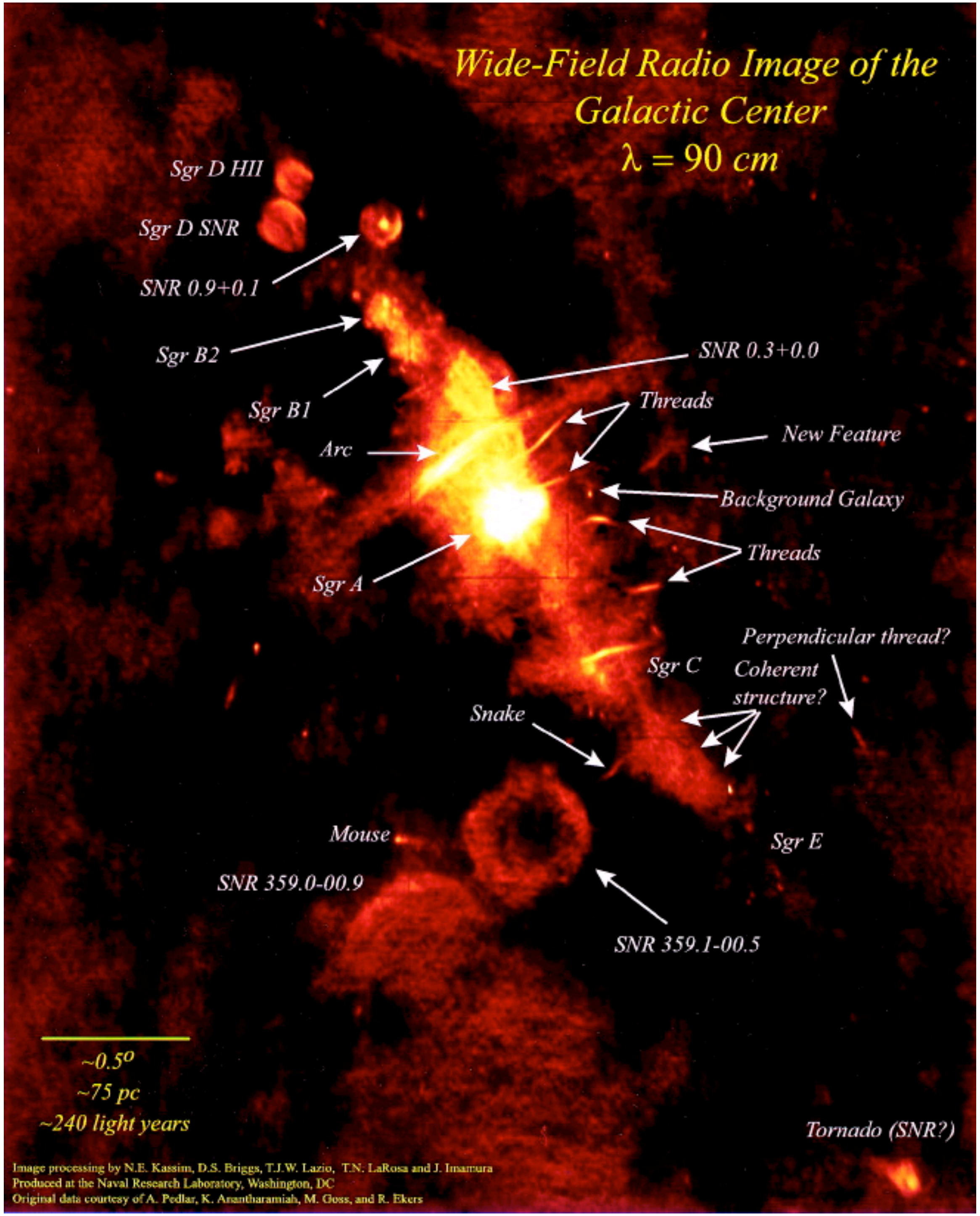
- From NIR monitoring with VLA and Keck of stars in close orbits (periods ~ few decades), it is now conclusively determined that:

1. the distance to the GC, R_0, is ~ 8 kpc
2. at the dynamical GC there is a ~4 x 10^6 solar mass black hole

Radio Zoom

Galactic Center Region at 90 cm ~ 300 pc

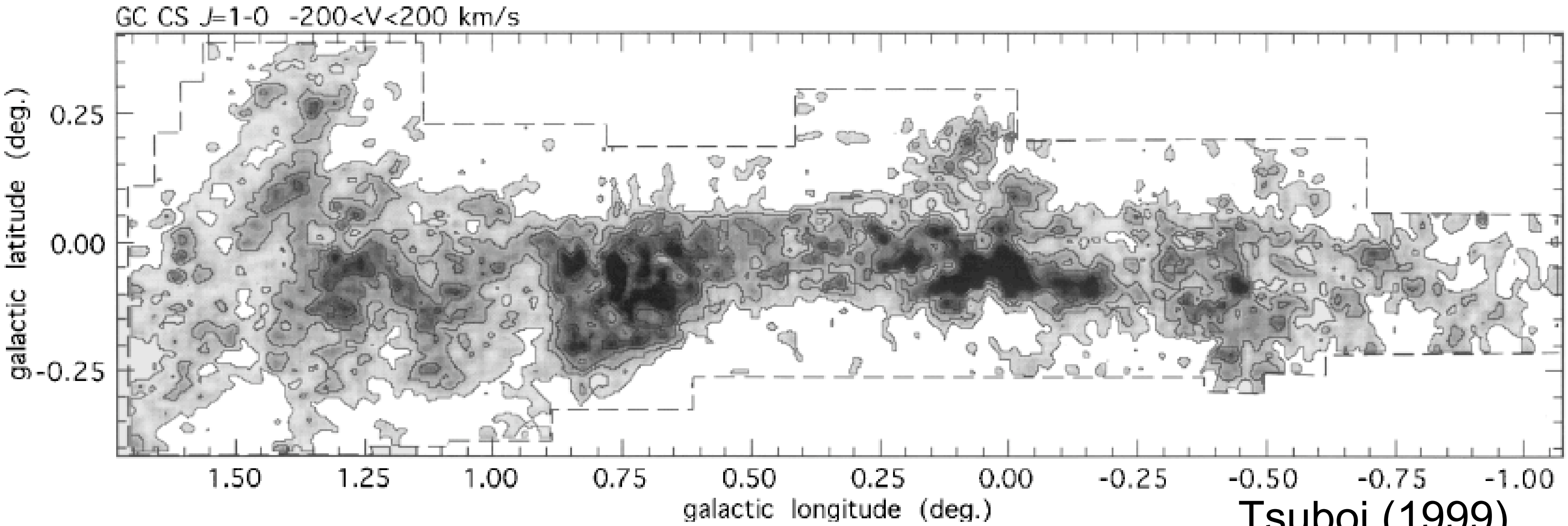
- Nonthermal radio-emitting filaments
- Large scale magnetic fields and relativistic electrons
- SNRs, HII regions
- Poloidal magnetic field within ~100 pc of nucleus
- Sgr A: compact radio sources at nucleus of Milky Way



LaRosa et al. (2000)

Credit: Dermer and Atoyan

Gas Density Through GC



Tsuboi (1999)

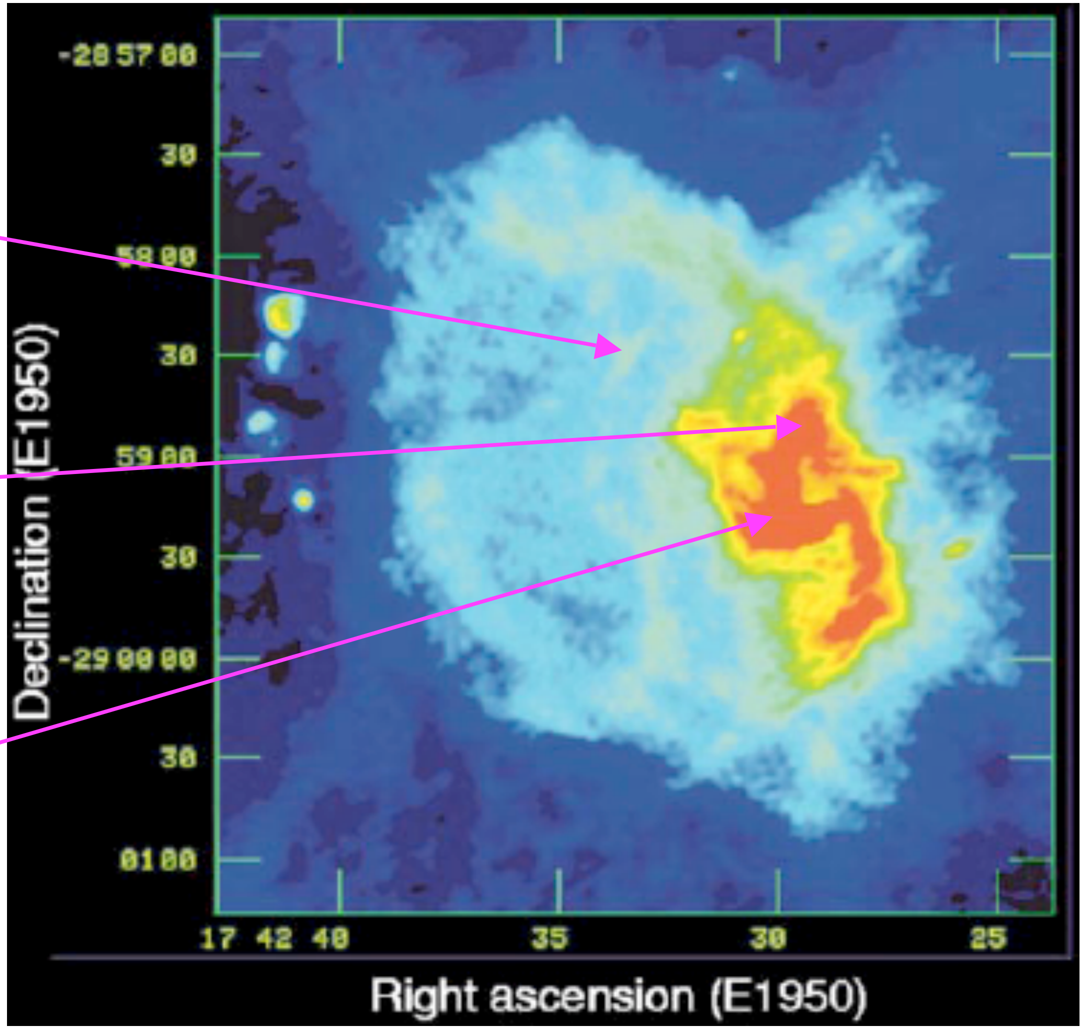
- Molecular line observations trace gas density and show up central molecular zone of giant molecular cloud complexes bound in tight orbits (~100 pc) around Sgr A - these contain ~ 10% of the Galaxy's molecular gas (3-8 10^7 solar mass) in densities of n_{H2} ~ 10^4 cm^{-3}

Sgr A Resolved: Radio Features of Inner 10 pc (4 ′×3 ′, or 9.3×7 pc)

Sgr A East (blue): extremely energetic (≈10^{52} ergs) region occurring ≈ 50,000 yrs ago from chain of SNRs, a GRB, or star swallowed by BH. Diffuse X-ray emission.

Sgr A West (red): Gas and dust streamers ionized by stars and spiraling around the Galactic center, possibly feeding the nucleus.

Sgr A*: A bright compact radio source at intersection of the arms of the Sgr A West, coincident with Gal dynamical centre



6 cm VLA radio of Sgr A East and Sgr A West

(Yusef-Zadeh, Melia, & Wandle 2000)

Other components:

1. cluster of evolved and young stars
2. dusty molecular ring (circumnuclear disk)
3. ionized gas streamers

Credit: Dermer and Atoyan

Sgr A* in Radio

- GC contains bright radio source, Sgr A*, first identified in the 1970s and coincident with dynamical centre of Galaxy…~ 1 Jy and variable (tens of days)
- @ 3mm size: δt x c ~ 1 AU ~ 20 R_{Sch}…emission associated with accretion disk

~TeV Observations of GC

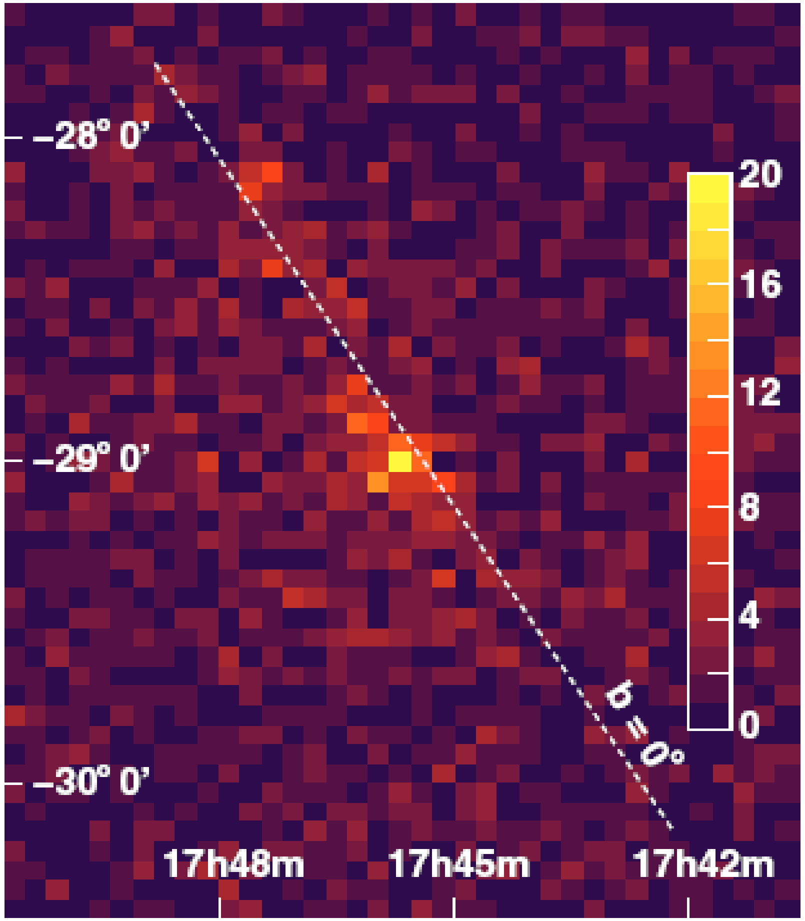
- In 2004, definite detections of the GC at ~TeV energy was reported by:

1. CANGAROO (Tsuchiya et al. 2004)
2. Whipple (Kosack et al. 2004)
3. HESS (Aharonian et al. 2004)

- Observation of GC with MAGIC has since been reported (Albert et al. 2006)

HESS Observation of GC

Aharonian et al. 2004



- Consistent with point source, radius < 3 arcmin ~ 7 pc
- Located within 1 arcmin of Sgr A* -- Hard spectrum:

  -2.25 ± 0.04(stat.) ± 0.10(syst.)
- This spectrum confirmed by MAGIC which found -2.2 ± 0.2
- Data consistent with steady source

What is the mechanism for γ-ray production?

- Broadly two classes of model:

1. *leptonic* - high-energy electrons (10 TeV+) inverse-Compton scatter ambient light to TeV energies

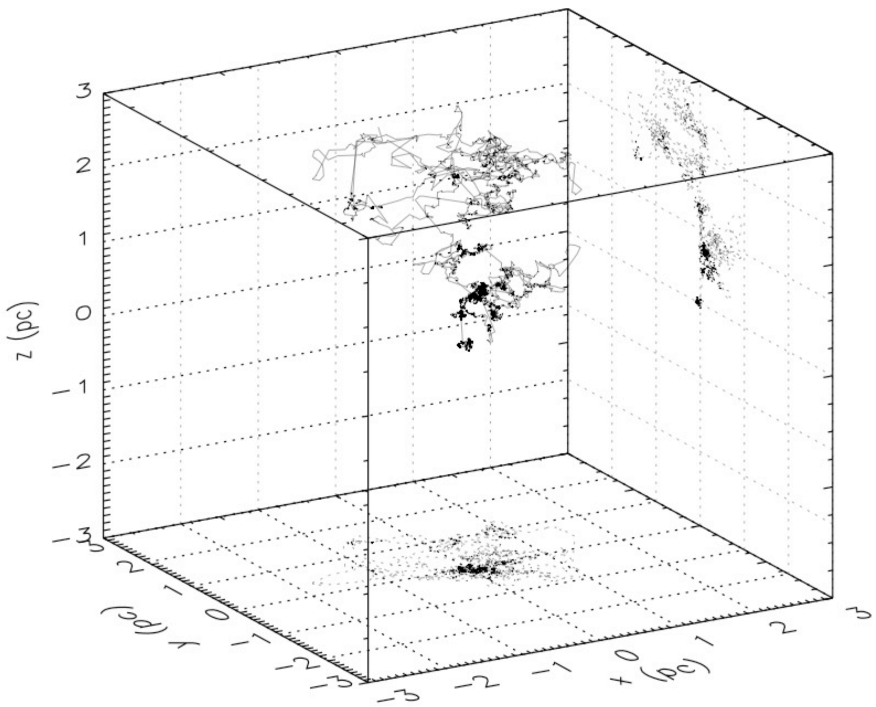
2. *hadronic* - protons (and heavier ions) collide with ambient matter and produce pions (cf. LHC)

A diffuse, hadronic model for the TeV point source at the GC

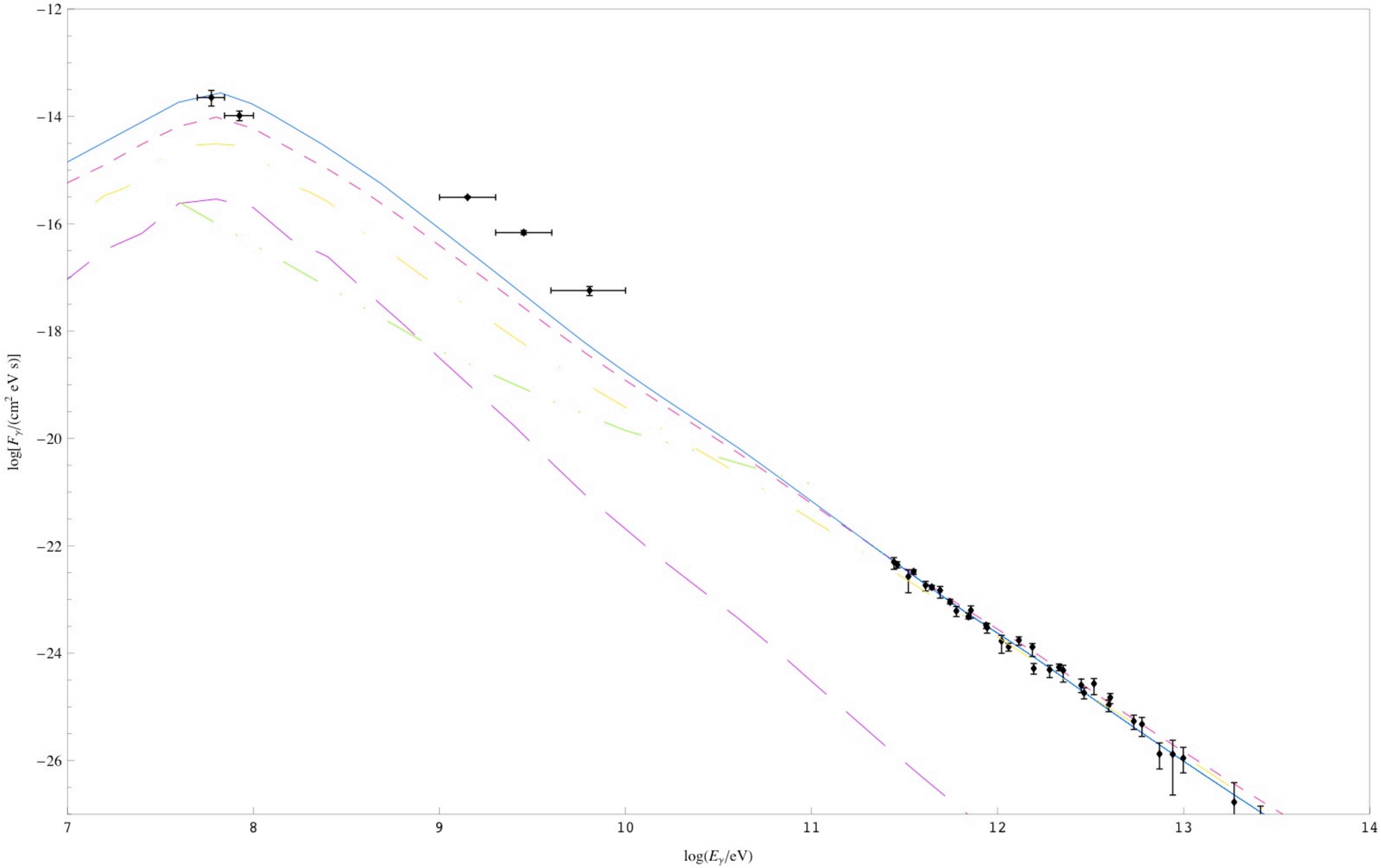
Ballantyne et al. 2007 ApJL 657,13

Crocker et al. 2007 ApJL 664, 95

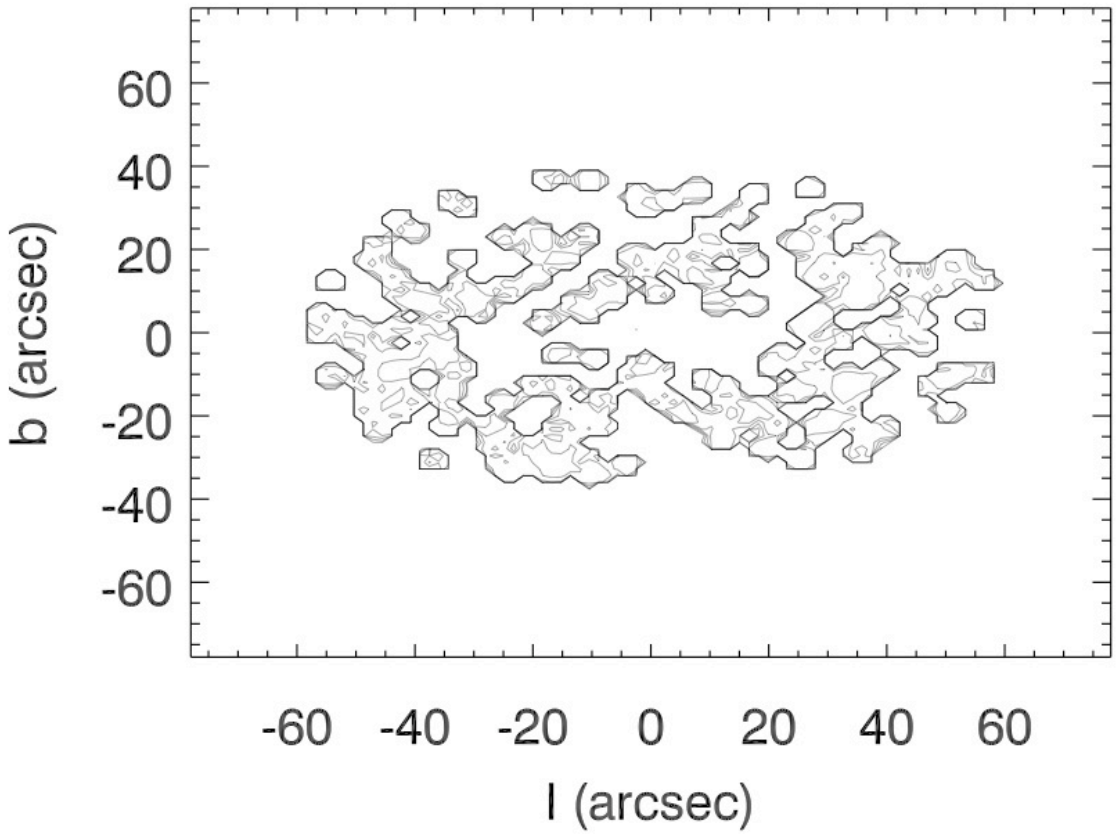
Computational model



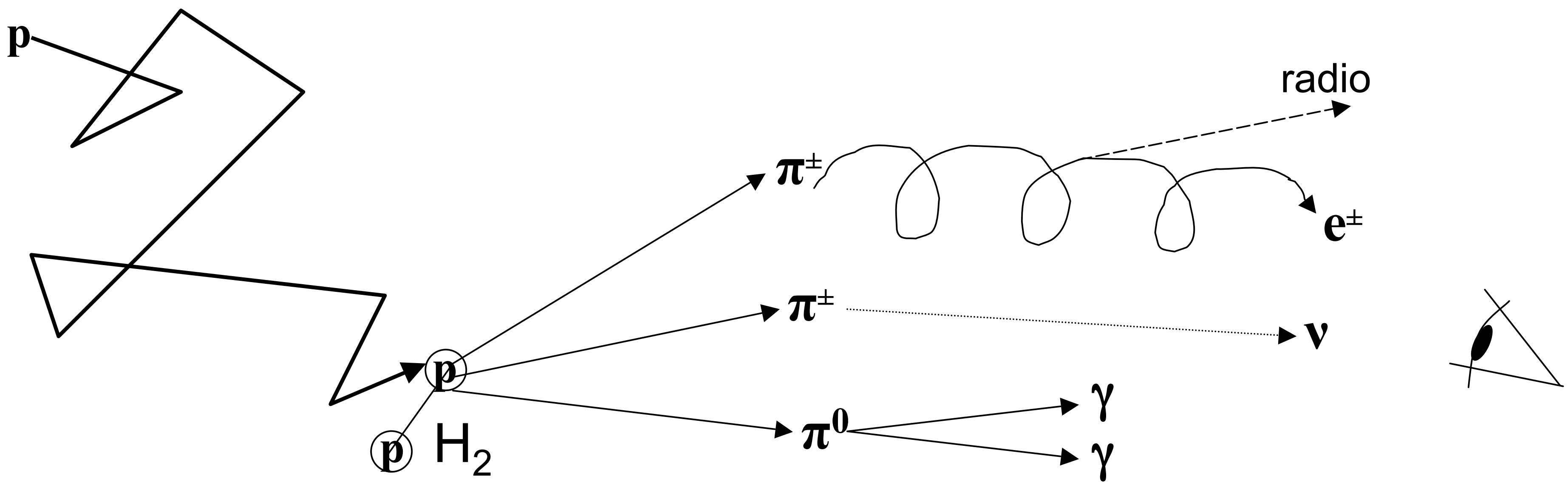
- A ~2 TeV proton is injected close to Sgr A* and scatters on magnetic field inhomogeneities
- It leaves the computational volume after reaching 3 pc.



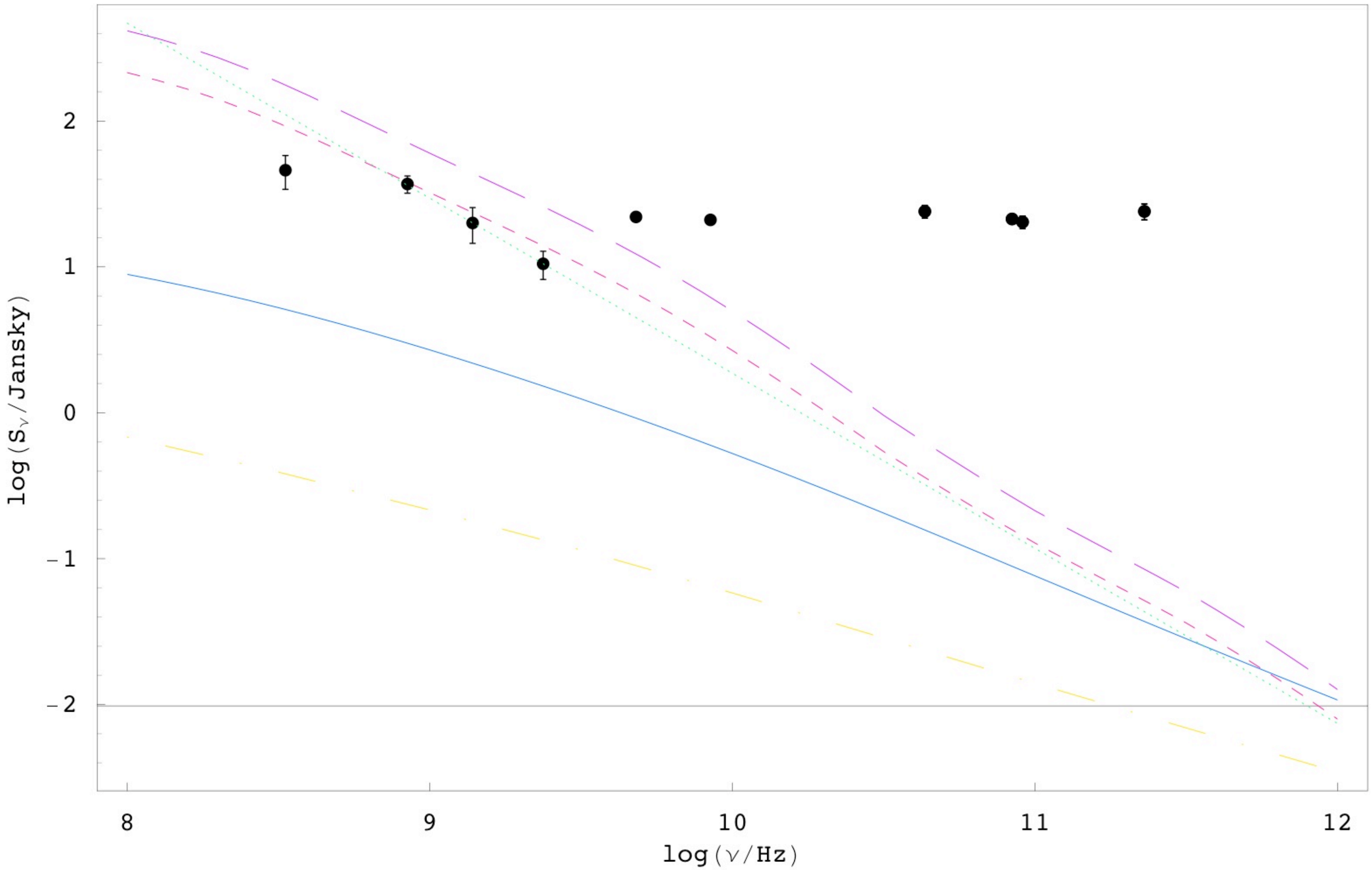
10 MeV - 10 TeV spectrum predicted by modelling



The circum-nuclear disk illuminated by cosmic ray impacts
(contours of integrated 1-10 TeV emission)



Schematic: a HE proton enters from left scatteting on magnetic field inhomogeneities. It collides with an H_2 molecule creating a shower of pions. We can detect some of the decay products of these pions with various detectors.

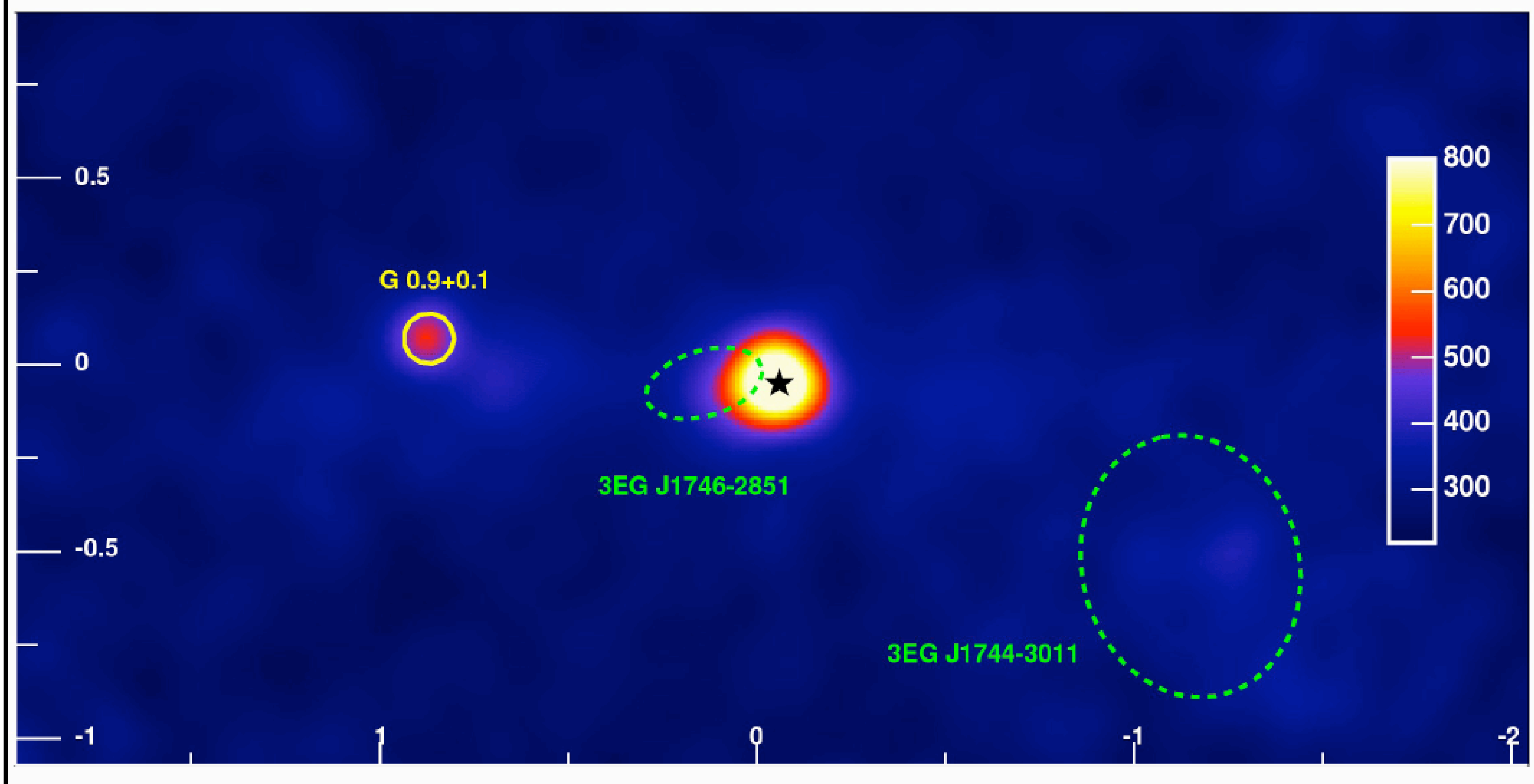


Predicted radio spectrum vs data for inner 2’ x 1’ around Sgr A*: *the hadronic model is self-consistent*

- Neutrinos: a smoking gun for the hadronic model for TeV gamma-rays from the GC? …the GC source should be detectable within two years by a Mediterranean-based neutrino telescope and, perhaps, over a similar timescale by IceCube at the South Pole

Diffuse Emission

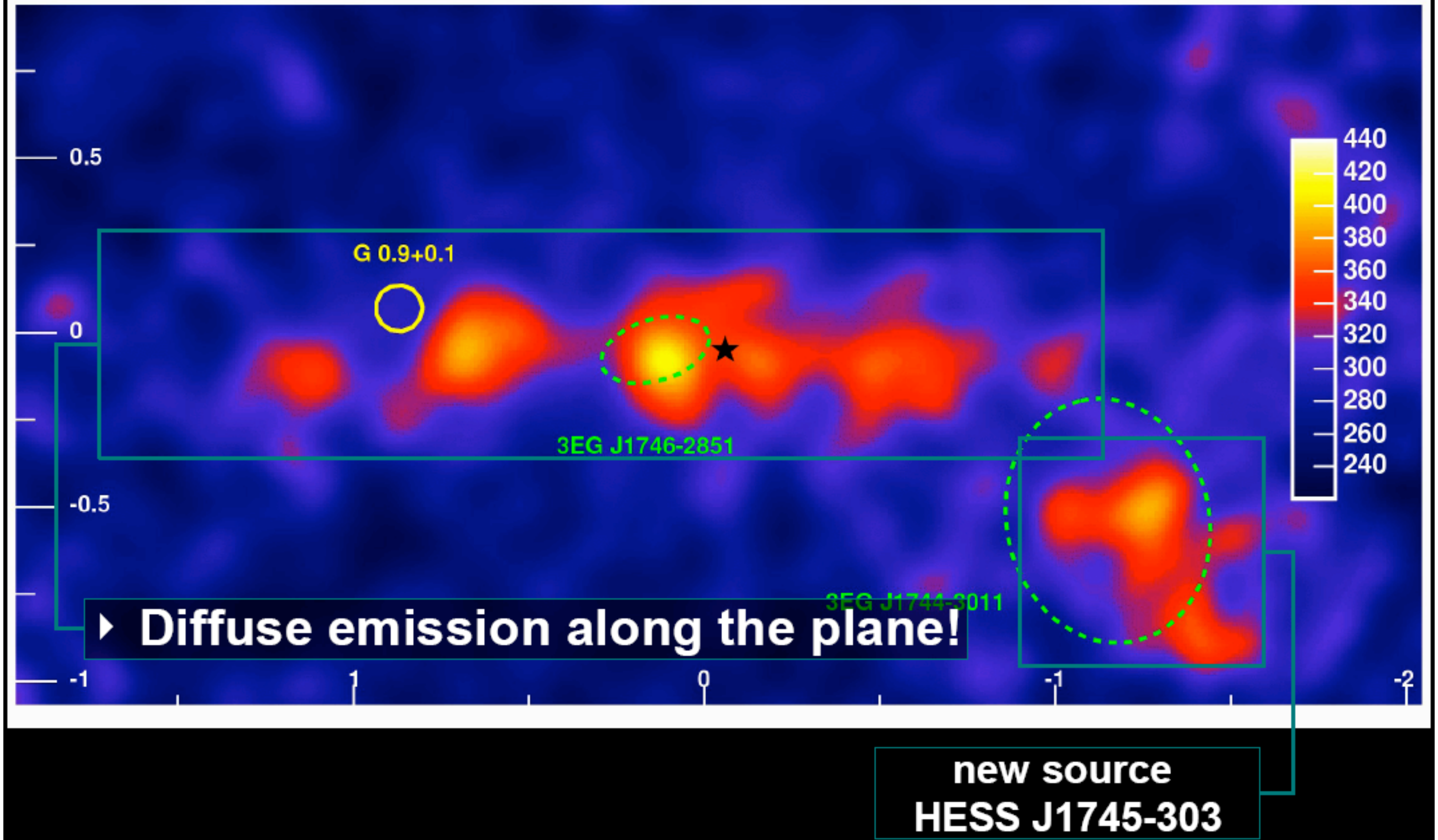
Diffuse γs in H.E.S.S. data?



- 50 hour H.E.S.S. Observation of GC in 2005
- Need to subtract the two bright sources

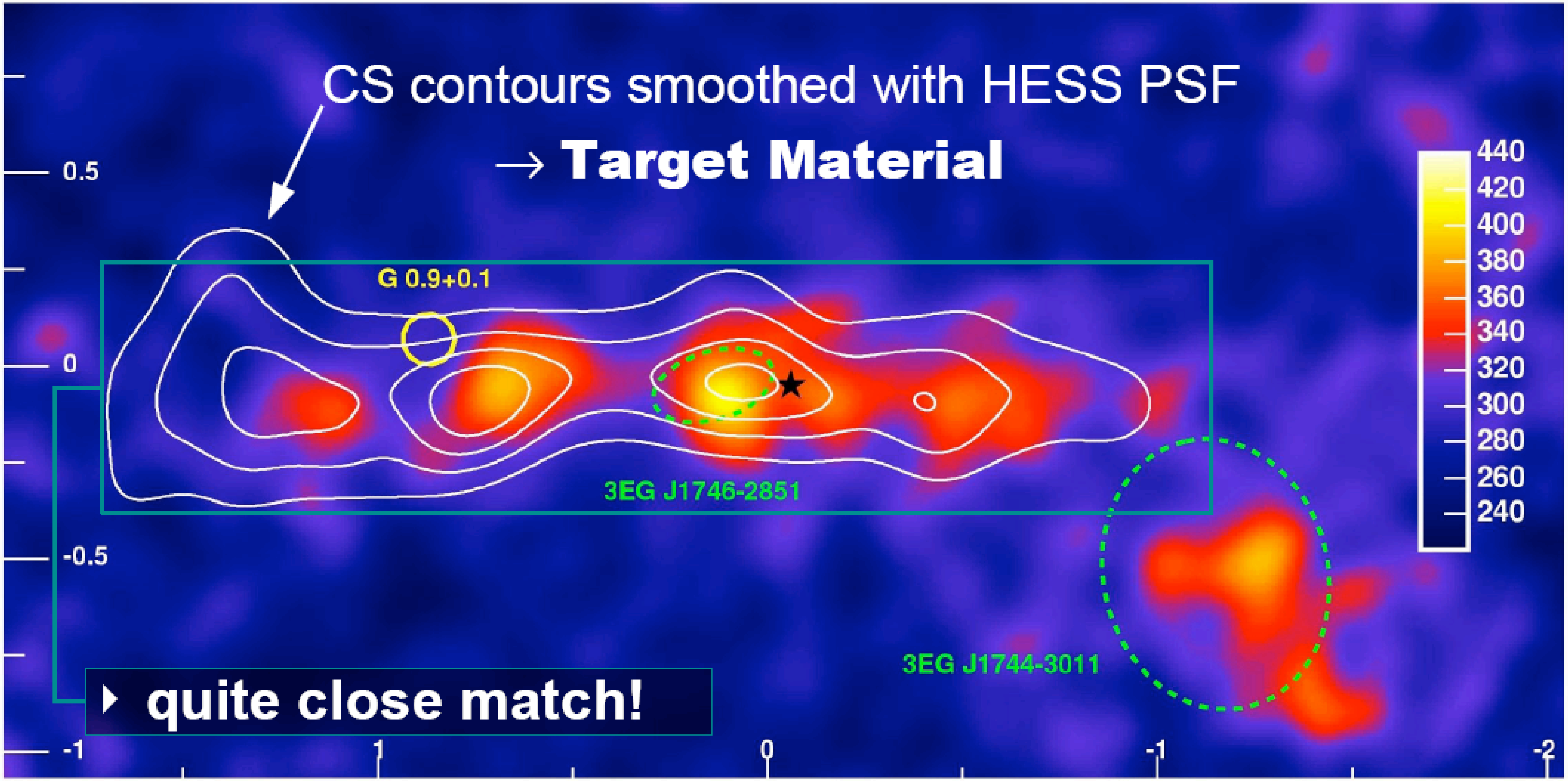
Credit: HESS Collab

Residuals after source subtraction



Credit: HESS Collab

CS contours over H.E.S.S. map

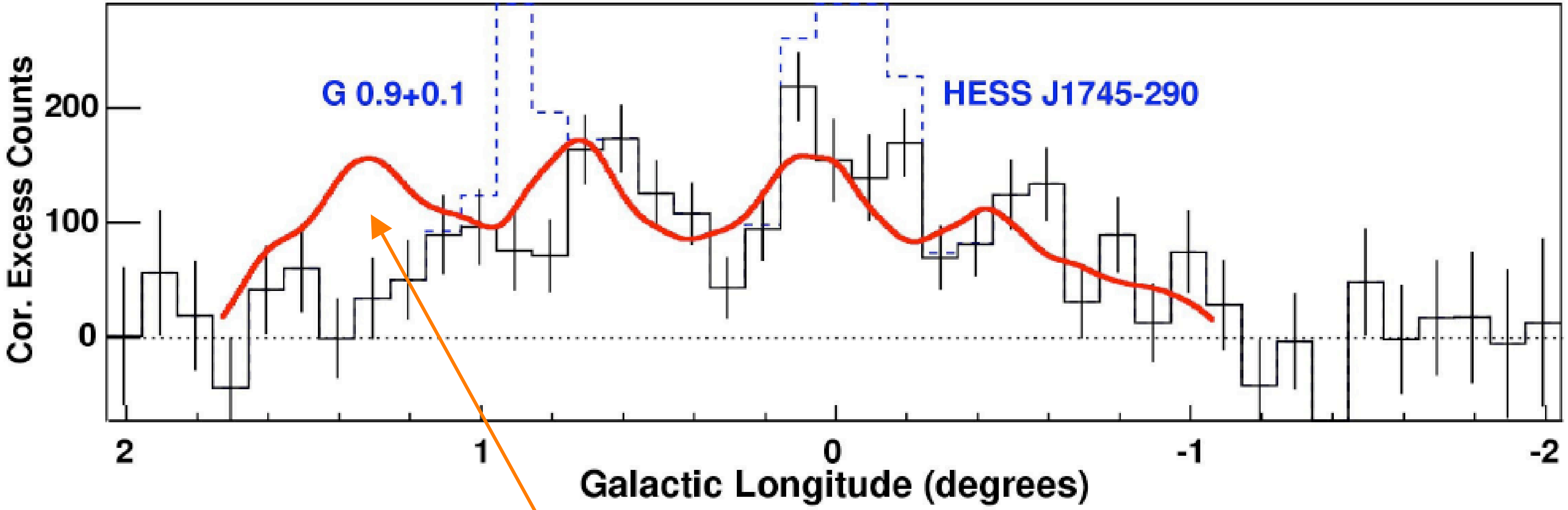


Credit: HESS Collab

Explaining Emission

- HESS collaboration, noting correlation between γ-rays and molecular density, posit hadronic collisions as source of emission – implies 10^{50} ergs in CR hadrons through the CMZ
- Yusef-Zadeh et al. (2007 ApJ 656, 847) noting independent correlation between Fe K α line emission and γ-rays suggest origin in IC scattering of IR background by primary electrons

Longitudinal Slice



- **Reasonable agreement overall but**
  - **Deficit around l = 1.3°**

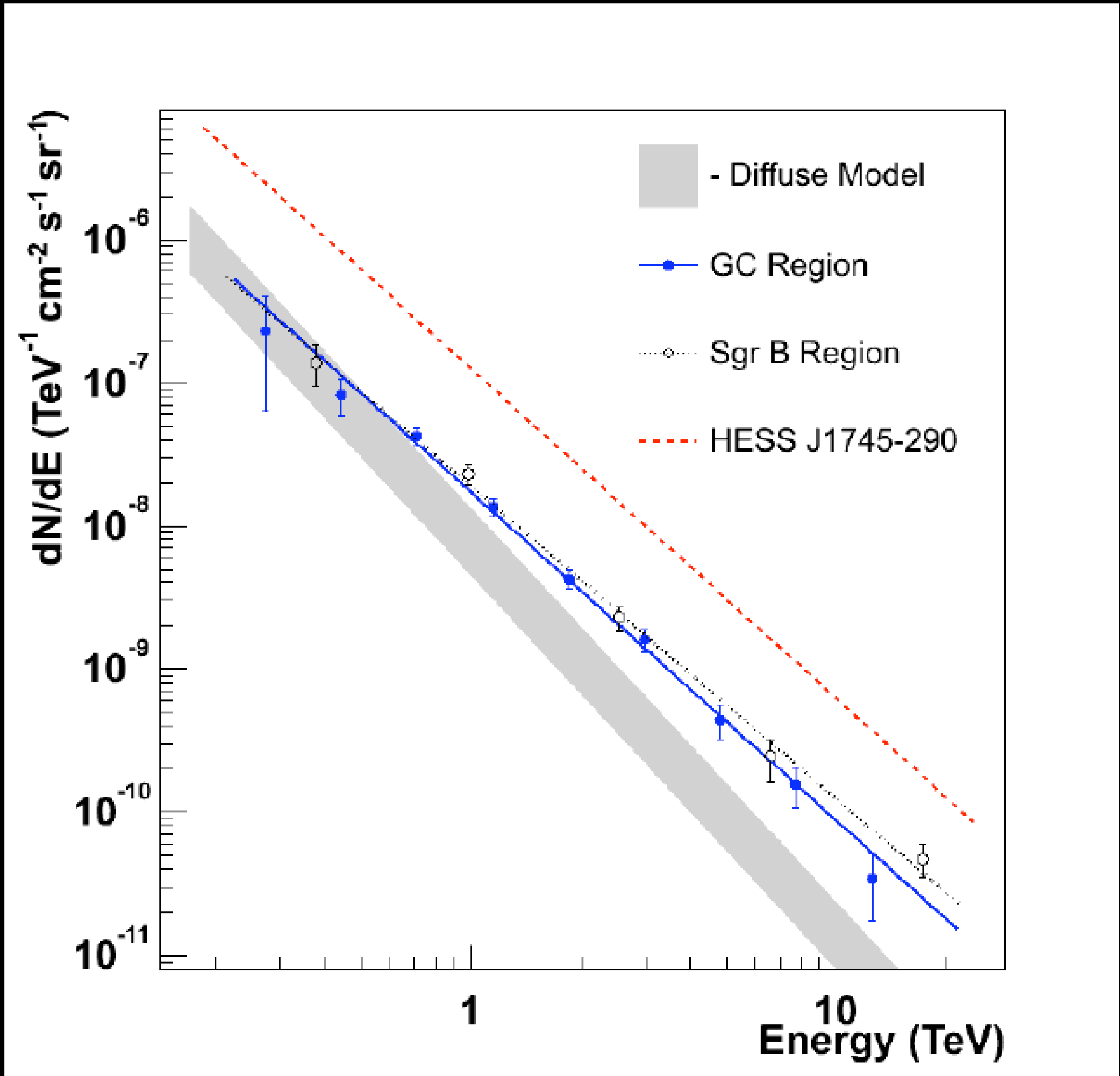
Credit: HESS Collab

Interpreting γ-ray/gas Correlation

- HESS Collaboration suggests that break-down of correlation at angular scales ~ 1° suggests NSS scenario where CR hadrons injected at central source
- Assuming diffusion coefficient typical for Galactic disk, viz., 10^{30} cm^{2}s^{-1} @ TeV, diffusion time to 1° is ~10^4 years – close to some estimates of age of Sgr A East SNR

Energy Spectrum

- The Galactic Centre Source: HESS J1745-290
  - (solid angle is integration radius used – source looks point-like)
- All emission in the GC has
  - $\Gamma_\gamma \approx 2.2$



Credit: HESS Collab

Couple of Points Concerning Spectral Index

- Spectrum much harder than would be produced by local CR population interacting in GC gas
- On the one hand, the fact that the SPIN of the diffuse emission and the GC point source are so similar might argue for a common accelerator (at Sgr A*, Sgr A East?)
- On the other hand, the fact that the spectral index of the diffuse emission does not vary across the region poses some problems for a model invoking diffusion: why doesn't the SPIN harden at large distances?

Current work

- Propagation modelling over size scales of diffuse emission ~200 pc diameter region (seems to show that a truly diffuse source mechanism is required)
- Looking at diffuse radio emission from entire region (prediction from gamma-rays agrees with observed radio emission if the ambient field is **~mG**).