The Galactic Center:
A Model for Cosmic Ray Interactions in Starburst Galaxies?

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Figure 1. Hubble-Spitzer Color Mosaic of Galactic Center.
http://hubblesite.org/gallery/album/entire/pr2009002a/xlarge_web/

Introduction

The Galactic Center contains strong magnetic fields, high radiation fields, and dense molecular gas. These conditions are extreme when compared with those in the Galactic disk, as is also the case in starburst galaxies. The close proximity of the Galactic Center allows for more and better observations of the interstellar medium and surrounding environment than for extragalactic sources. This makes the Galactic Center an ideal place for testing models for cosmic ray interactions. We have developed and tested a semi-analytic model of cosmic rays for the starburst galaxy M82. Now, we compare the model to published data for both the Galactic Center and the starburst galaxy NGC 253. We present the predicted radio and gamma-ray spectra for the Galactic Center and compare the results with published measurements. In this way we provide a quantitative basis for assessing the degree to which the Galactic Center resembles a starburst system.

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Model Assumptions

Our single zone cosmic ray interaction model [1] is based on the following assumptions:

- Uniform mean density (80 cm^{-3}) containing three phases, magnetic field (50-200 μG), radius (200 pc), supernova rate (10^{-4} yr^{-1}) [2] and constant advection speed
- Equilibrium for particle injection and energy losses (no diffusion)
- A power-law injection spectrum (p~2.3)
- A constant particle acceleration efficiency from supernovae (10% of SN energy to protons and 2% of the proton energy to electrons)

Properties of Galactic Center

The components of the interstellar medium include:

- Hot Gas
  $n_{hot} \sim 1$ cm^{-3} , $T_{hot} \sim 6 \times 10^6$ K
- Ionized (HII) Gas
  $n_{ion} \sim 50 - 500$ cm^{-3}, $T_{ion} \sim 8 \times 10^3$ K
- Molecular Gas
  $n_{H2} \sim 5 \times 10^4$ cm^{-3}, $T_{H2} \sim 10^2$ K,
  $M_{H2} \sim 3 \times 10^7$ $M_{\odot}$ [2]
- Radiation Field
  $U_{rad} \sim 8$ eV/cm^3, $T_{dust} \sim 21$ K [3]

Independent Model Parameters:

- Magnetic Field Strength (B)
- Advection (Wind) Speed (v_{adv})
- Absorption Fraction (f_{ab})
- Ionized Gas Filling Fraction (f_{ion})

Conclusions

Although the model works well for NGC 253, from the excess of hadronic emission at TeV energies and lack of leptonic emission at GeV energies, it is clear that the starburst model fails for the Galactic center. The underestimated gamma-ray and radio spectra suggests the electron to proton ratio is too low by a factor of ~8. An excess of free-free emission in the radio spectrum is another difficulty for this model.

Modeling Gamma Ray & Radio Spectra

- Neutral pion decay, bremsstrahlung, and inverse Compton emission are the main mechanisms for production of gamma-rays. Our gamma-ray spectrum is built using the average density of the medium. ***Blindly applying the model to the Galactic center results in a spectrum which does not fit the observed Fermi data.***
- We fit the radio spectrum with synchrotron emission in the hot, diffuse medium with free-free absorption and emission from warm, ionized gas clouds. The goodness of the fit depends on ionized gas density, magnetic field strength, advection speed, and absorption fraction.
- Best-fit parameters for NGC 253 are (n_{ion} = 400 cm^{-3}, B = 225 μG, v_{adv} = 100 km s^{-1}, f_{ab} = 0.05). Parameters for the Galactic Center are (n_{ion} = 25 cm^{-3}, B = 200 μG, v_{adv} = 1000 km s^{-1}, f_{ab} = 0.05).

Galactic Center

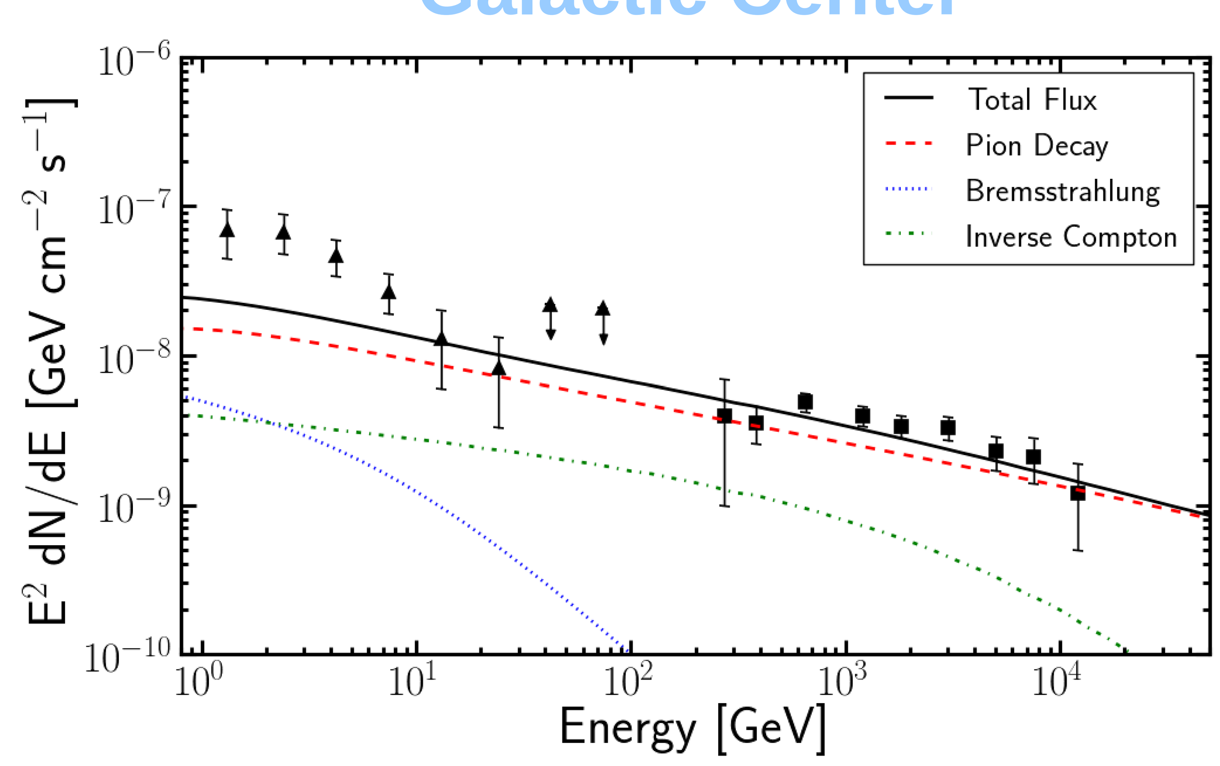

Figure 2. GC Gamma Ray Flux – Data from Yusef-Zadeh+ (2013) [4]

Starburst Galaxy NGC 253

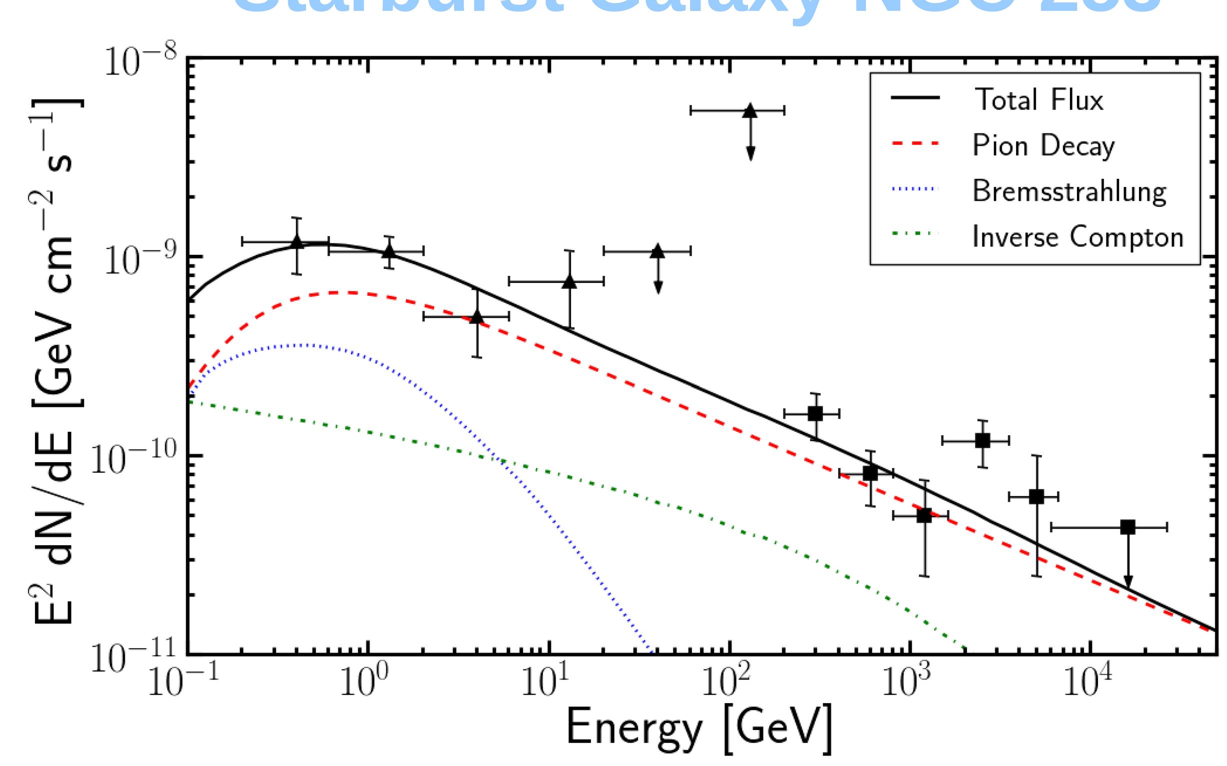

Figure 3. NGC 253 Gamma Ray Flux – Yoast-Hull+ (2013) [5] Data from Ackermann+ (2012) [6], Abramowski+ (2012) [7]

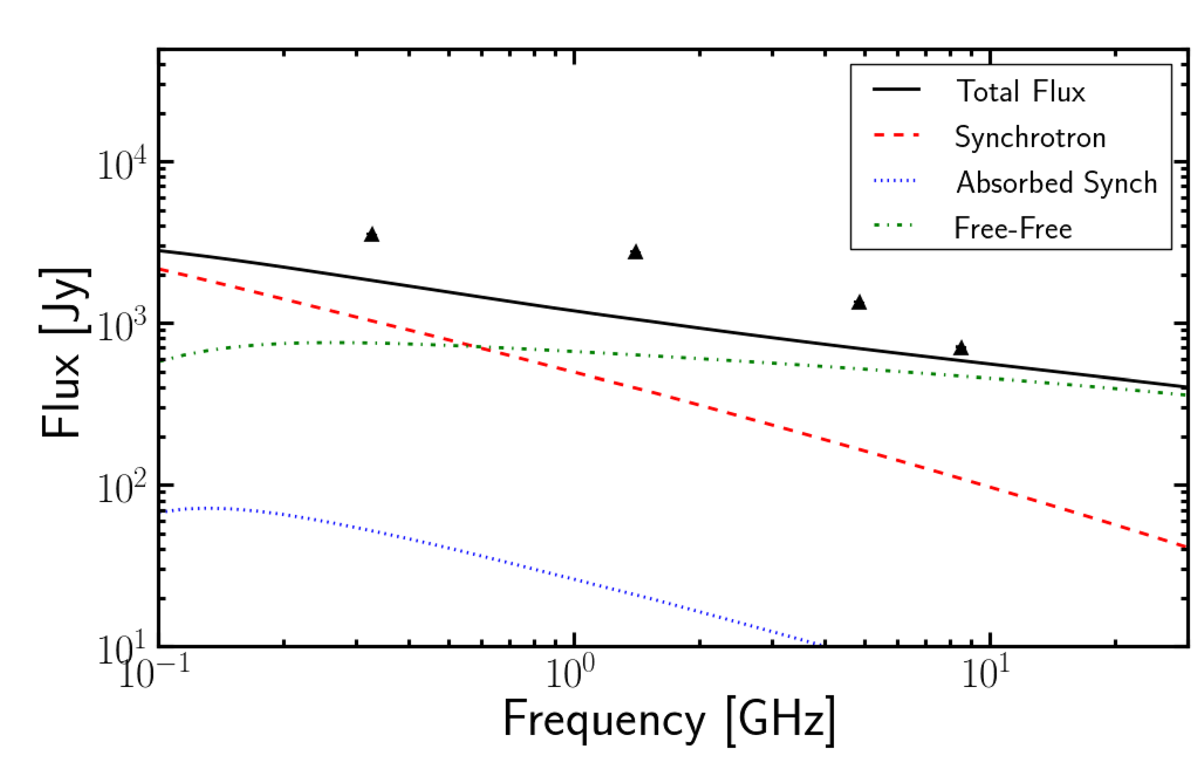

Figure 4. GC Radio Spectrum – Data from Yusef-Zadeh+ (2013) [4]

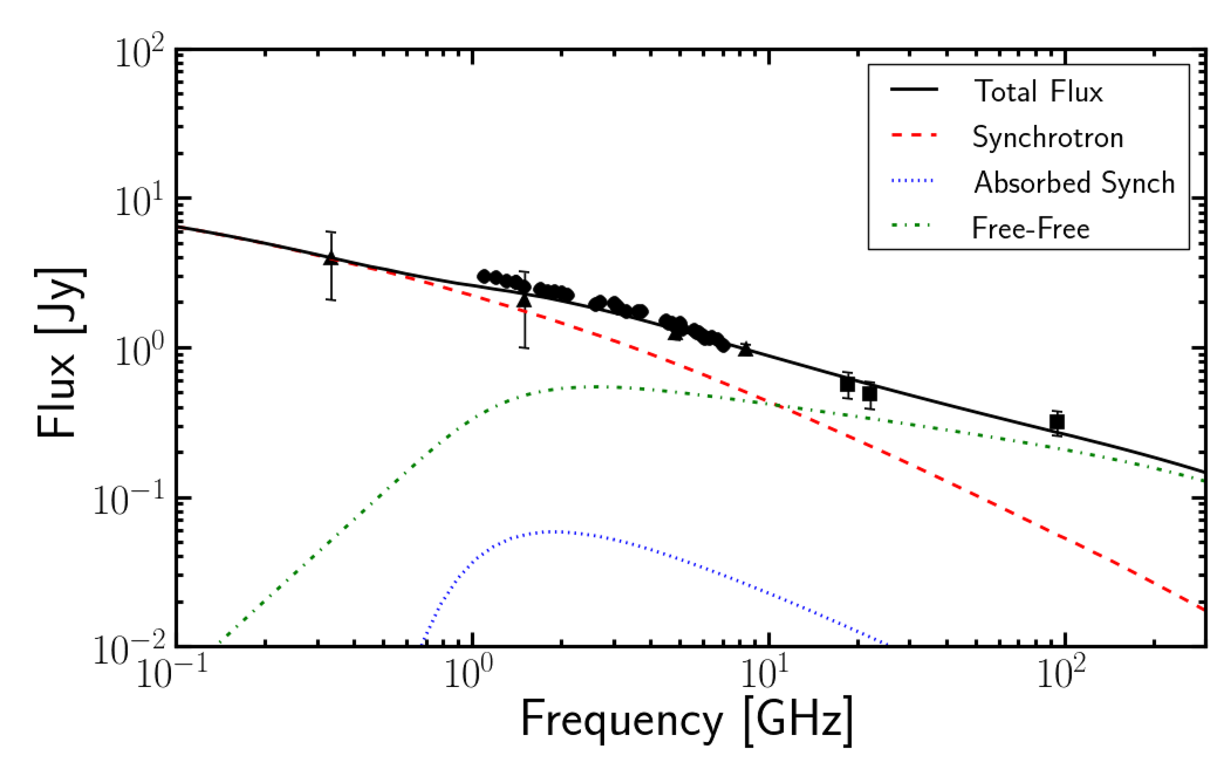

Figure 5. NGC 253 Radio Spectrum – Yoast-Hull+ (2013) [5] Data from Heesen+ (2009) [8], Ricci+ (2006) [9]

Acknowledgments & References

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