TeV Emission from the Galactic Center Black Hole Plerion

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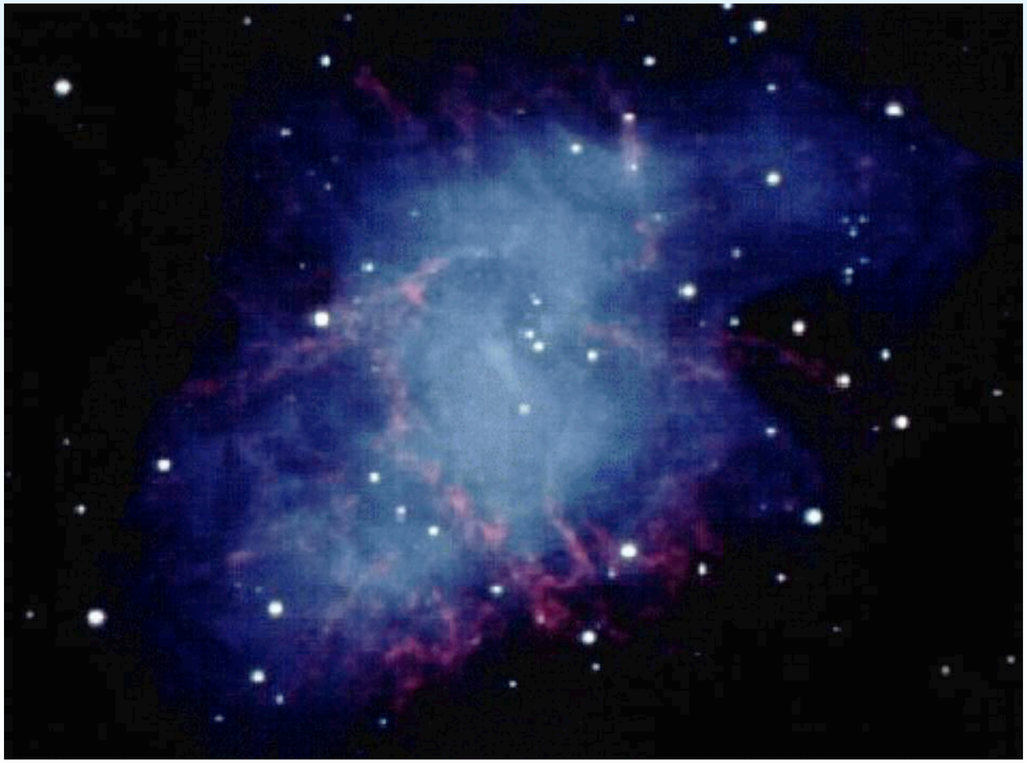
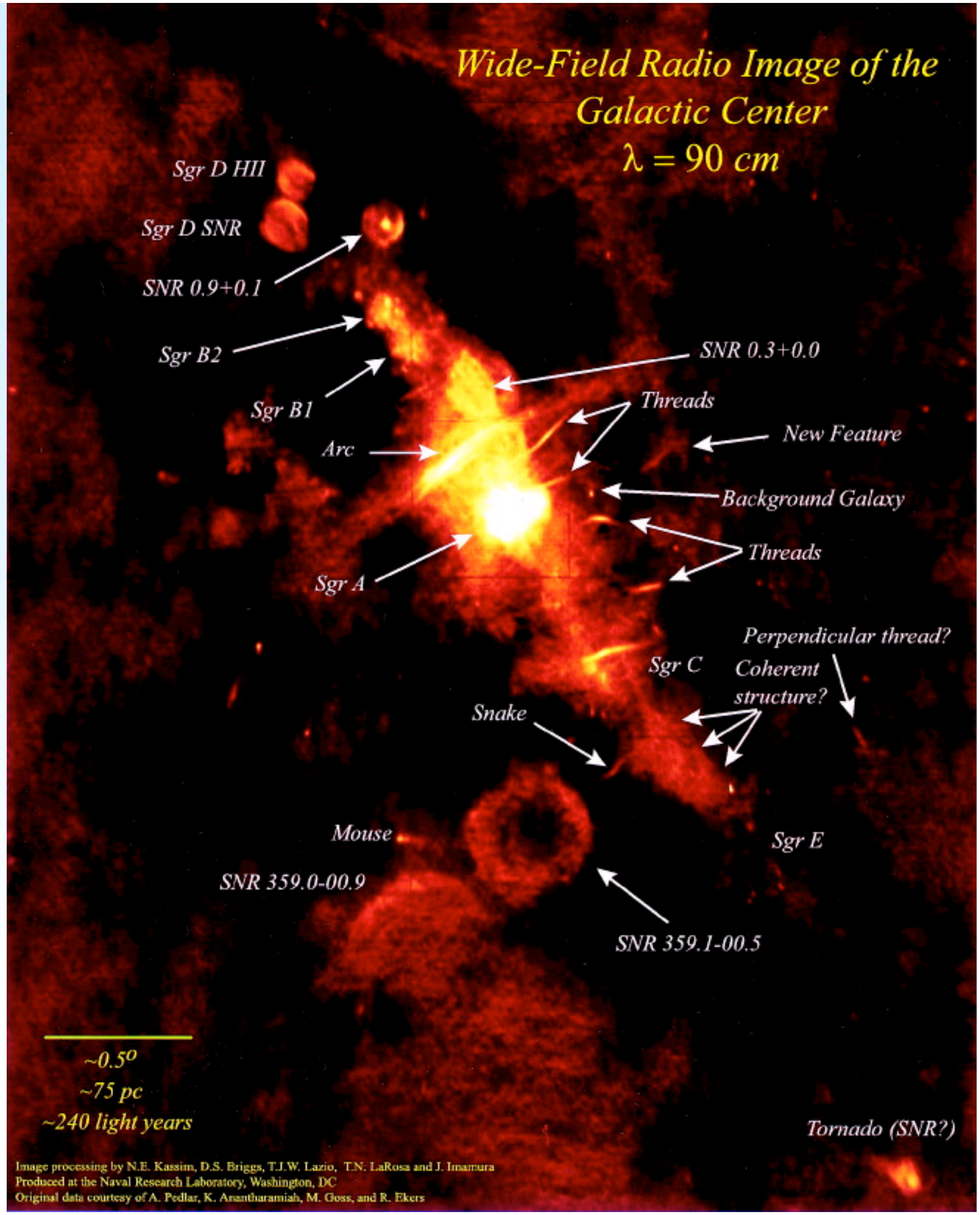


Crab Plerion

Galactic Center Region at 90 cm (330 MHz)

- 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 source at nucleus of Milky Way

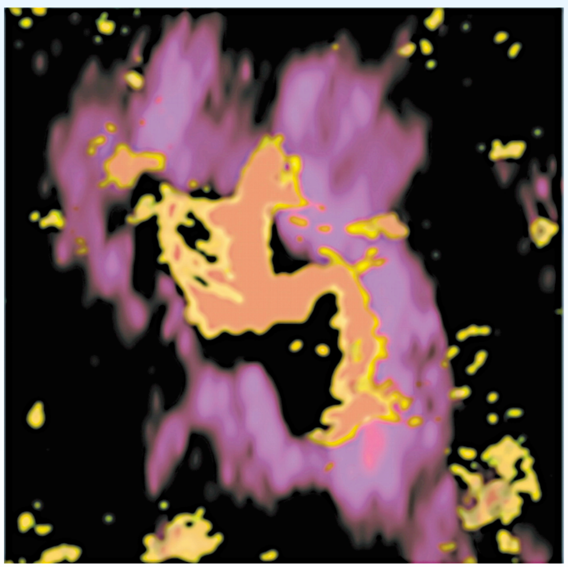
LaRosa et al. (2000)



Sgr A East (blue): extremely energetic ($\approx 10^{52}$ ergs) emission region

Sgr A West (red): Three-arm spiral of gas and dust streamers

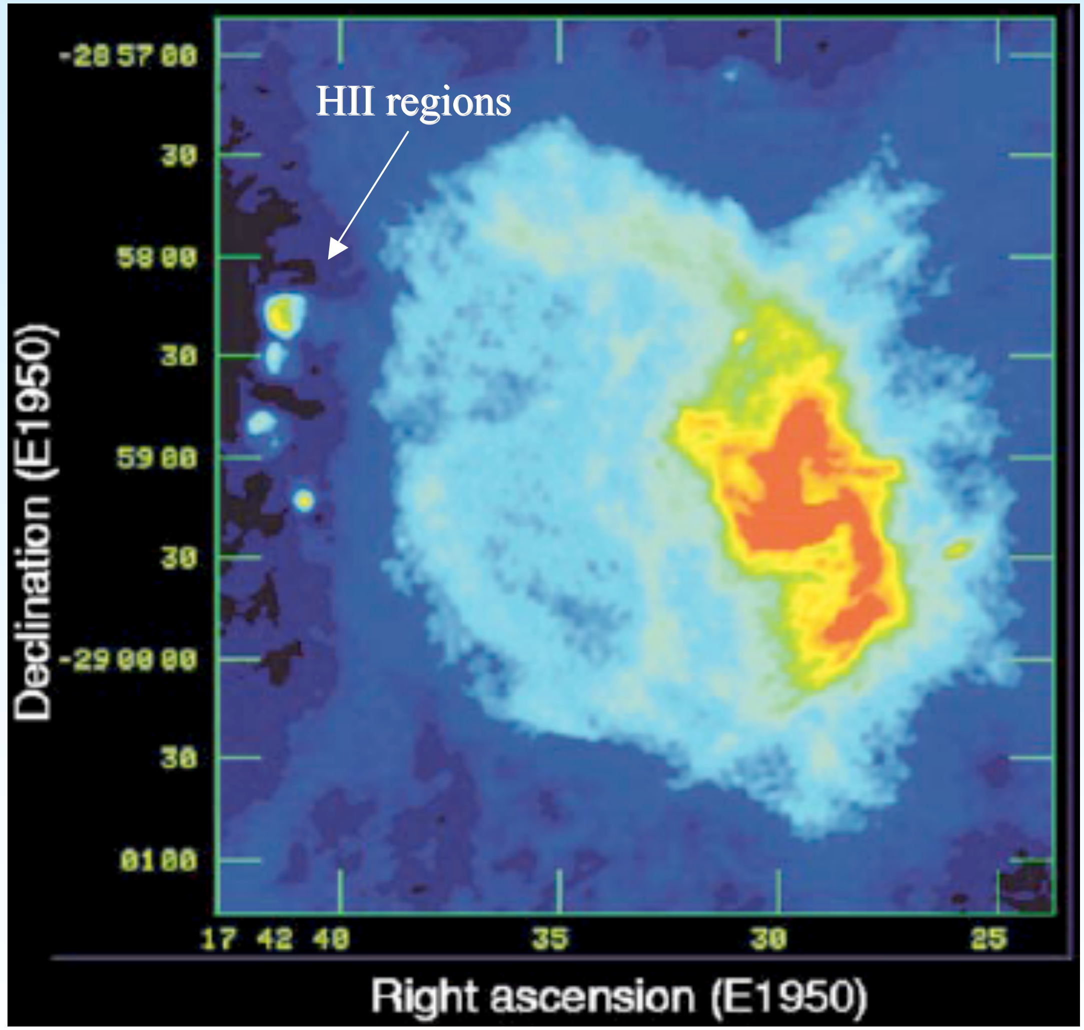
Molecular Ring: Circumnuclear disk of HCN and 1.2 cm Sgr A West radio emission



(4 pc × 4 pc)

(Wright et al. 1993)

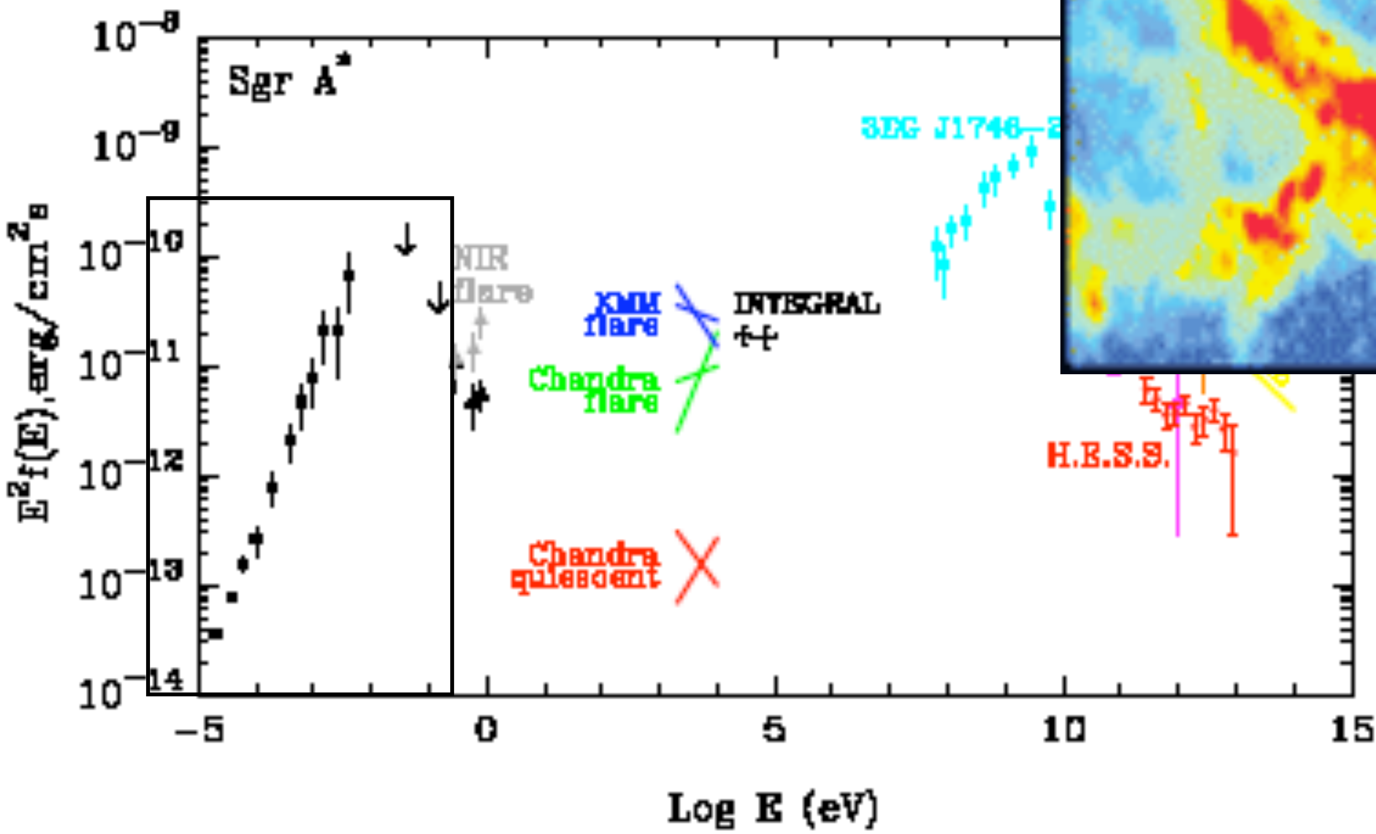
Inner Sagittarius region (4 ′×3 ′, or 9.3×7 pc)



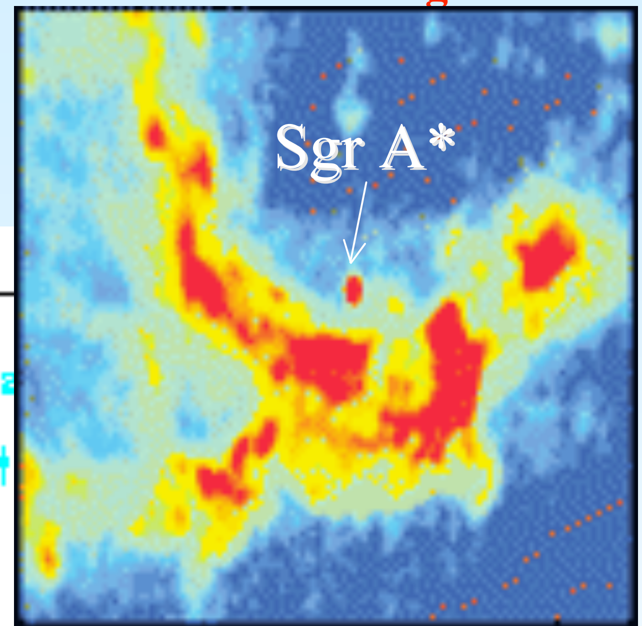
6 cm VLA radio of Sgr A East and Sgr A West

(Yusef-Zadeh, Melia, & Wandle 2000)

Multiwavelength Observations of Sgr A*



2 cm VLA radio of Sgr A West

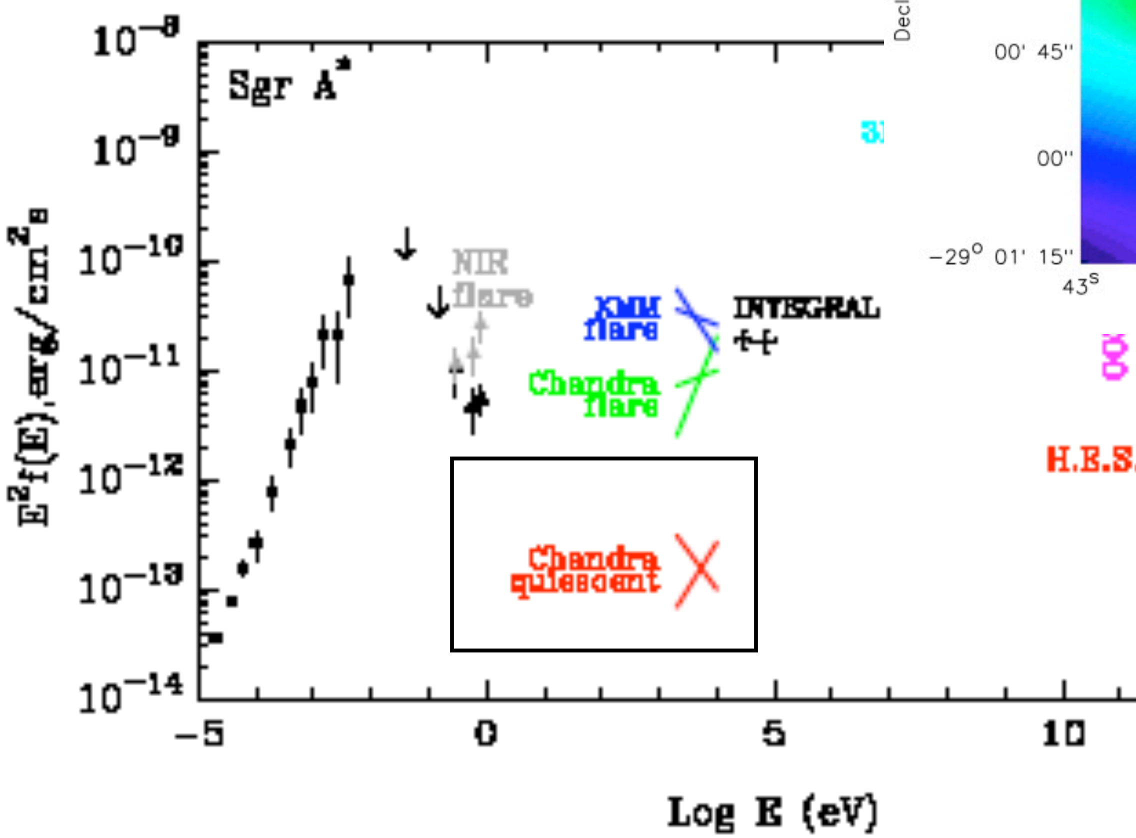


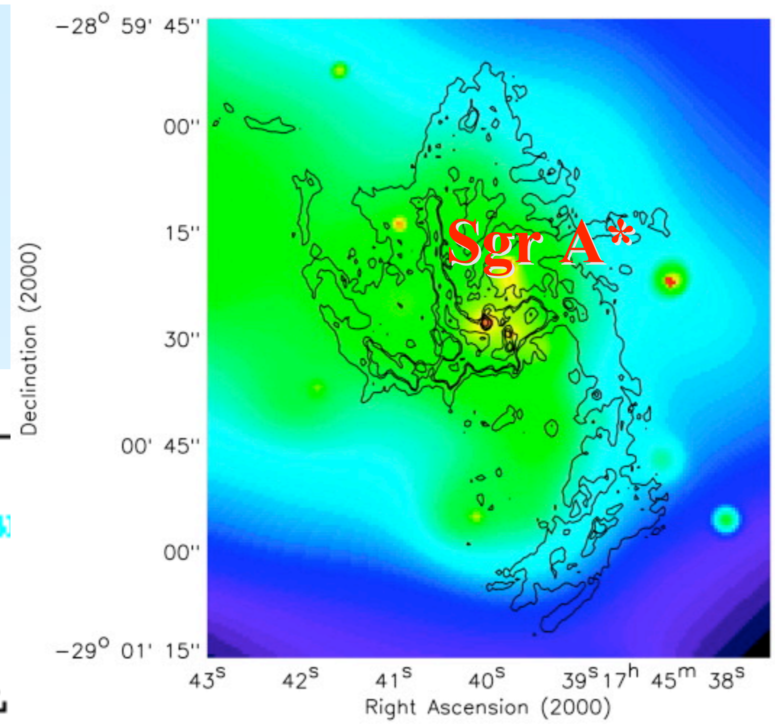
(Yusef-Zadeh & Wandle 1993)

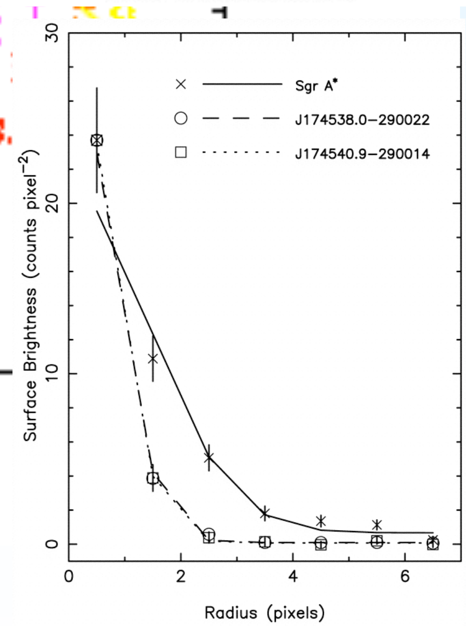
Aharonian and Neronov 2004

Multiwavelength Observations of Sgr A*

Chandra Obs. of Sgr A*



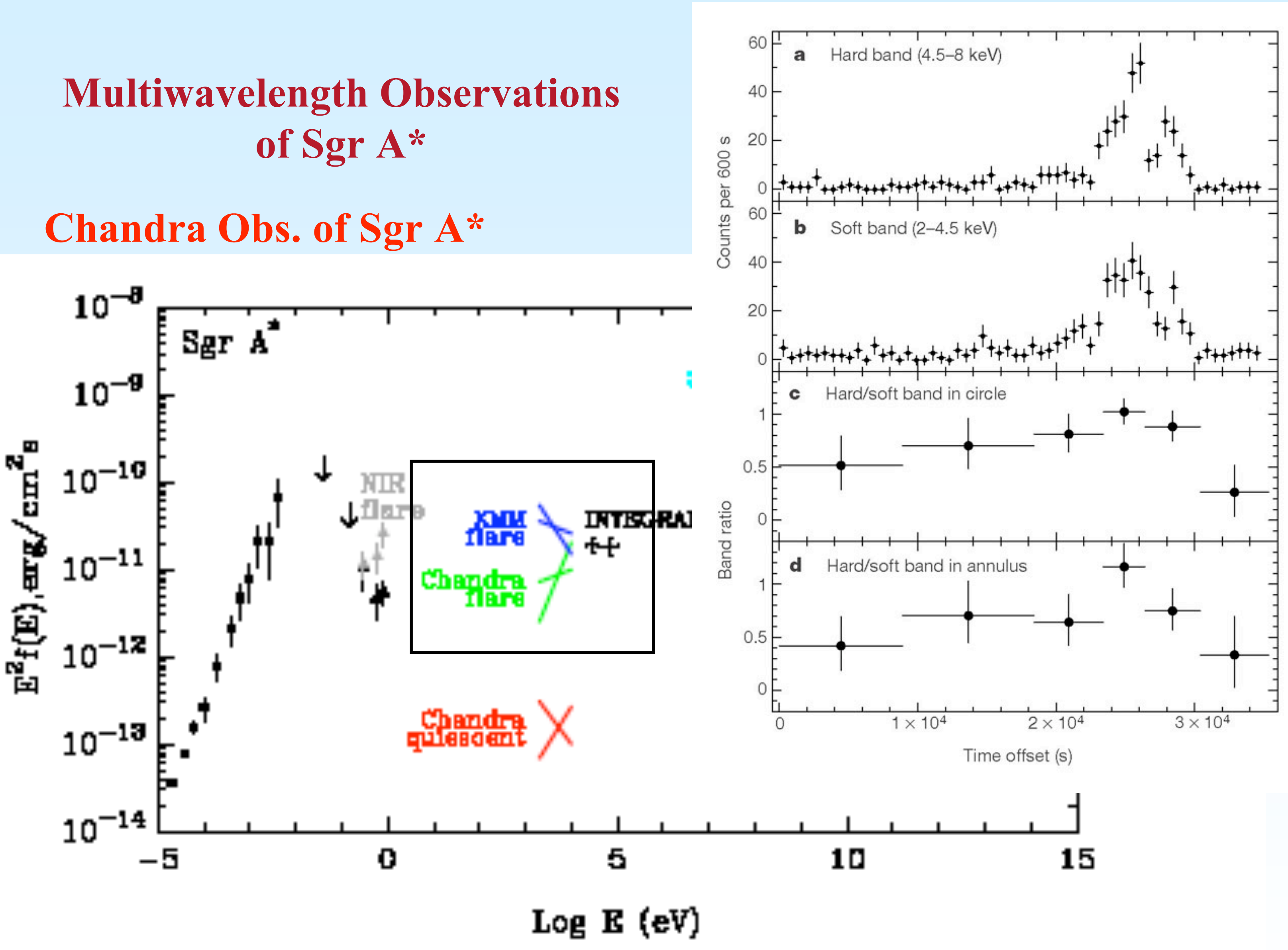




Baganoff et al. 2003

Multiwavelength Observations of Sgr A*

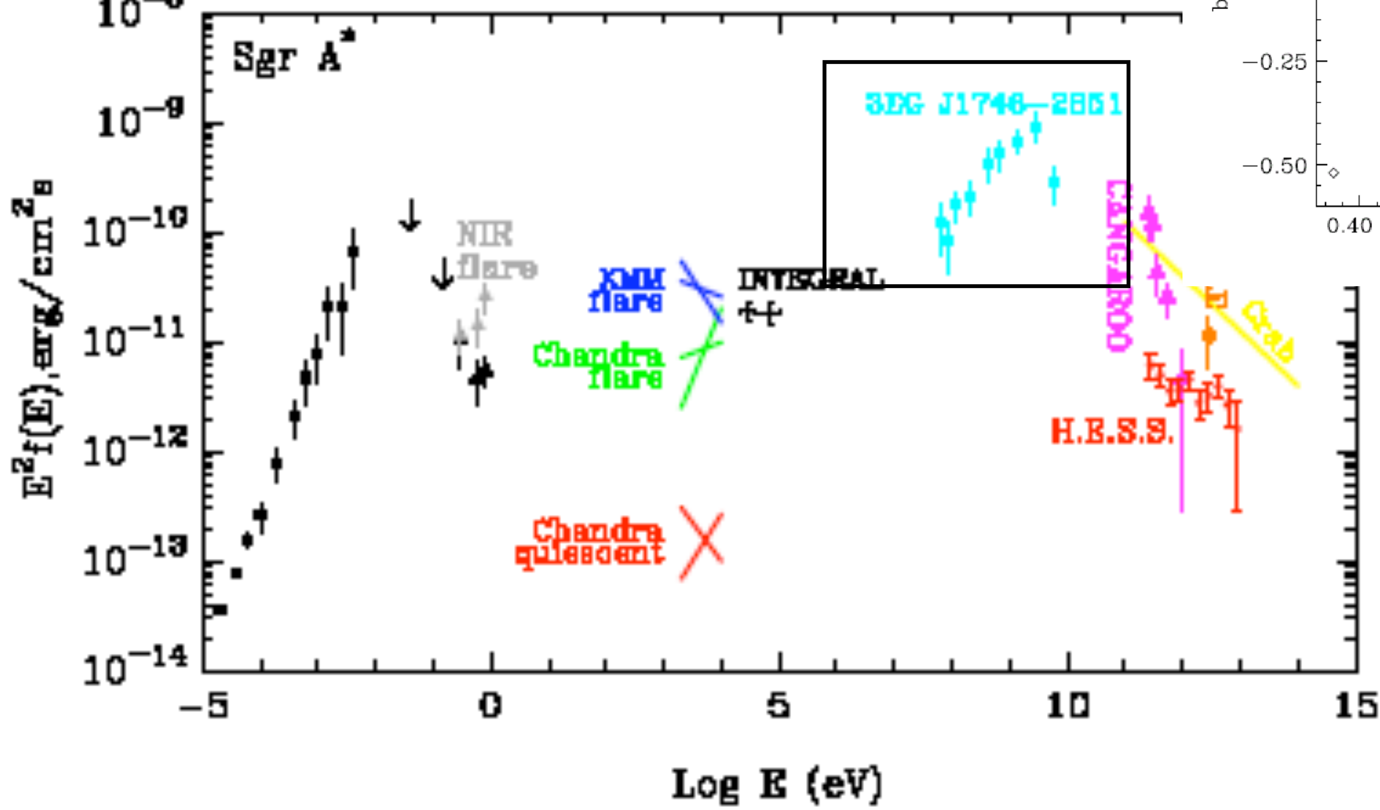
Chandra Obs. of Sgr A*

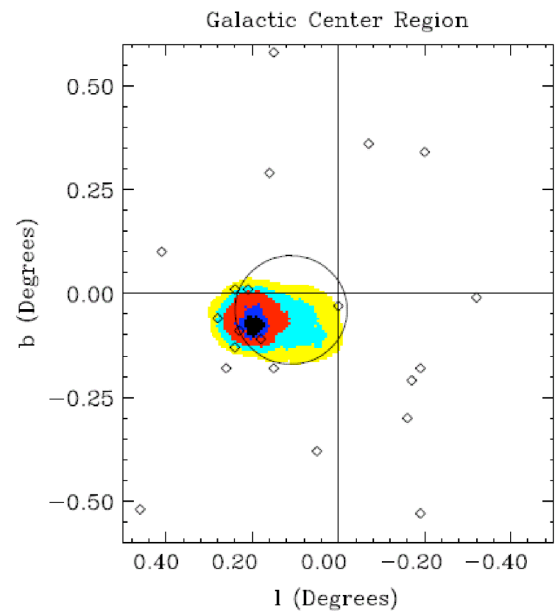


Baganoff et al. 2001

Multiwavelength Observations of Sgr A*

EGRET Obs of Galactic Center





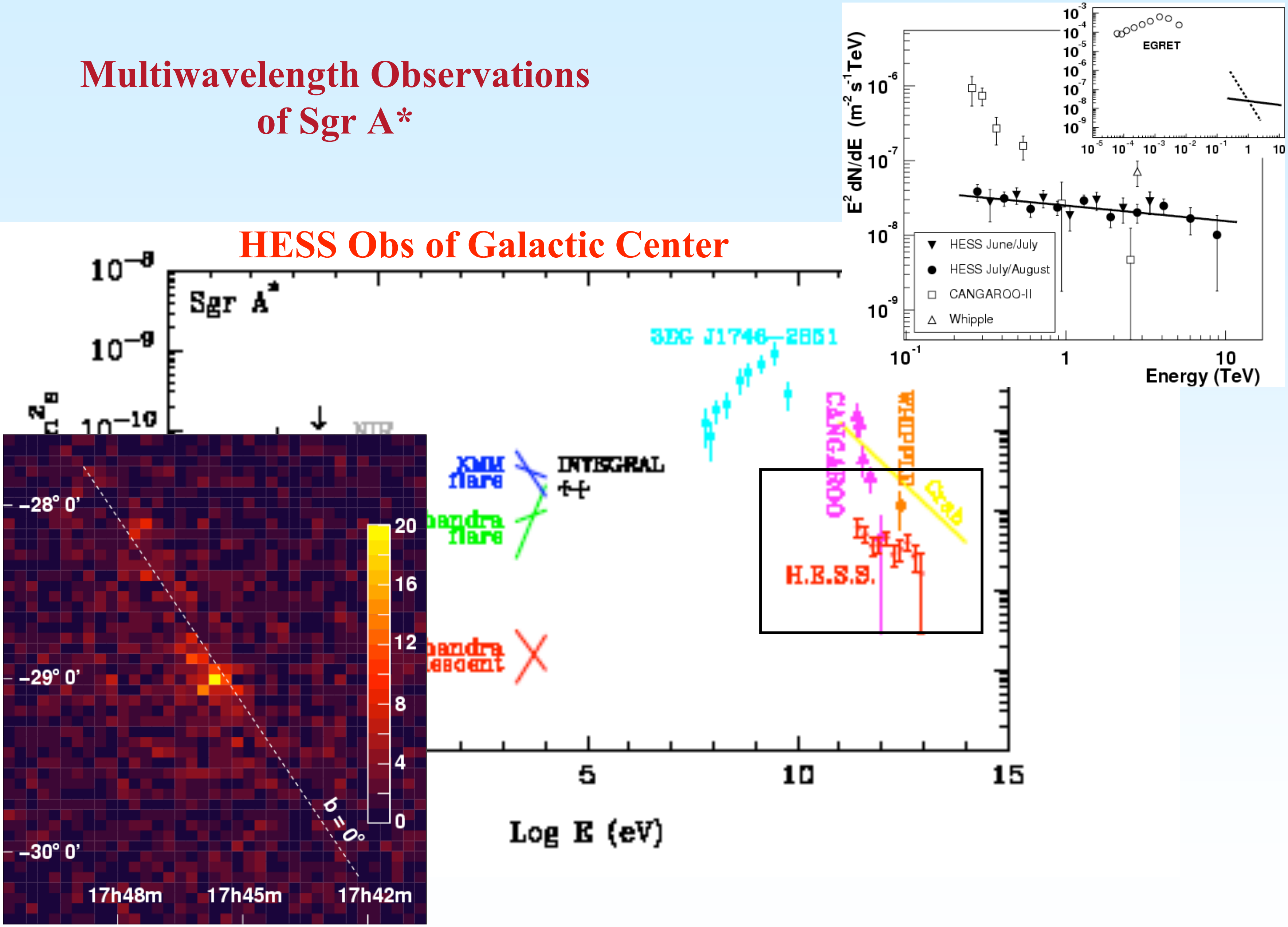
Vela-like Pulsar?

EGRET emission displaced from direction to GCBH

Dingus and Hooper 2002; Pohl 2005

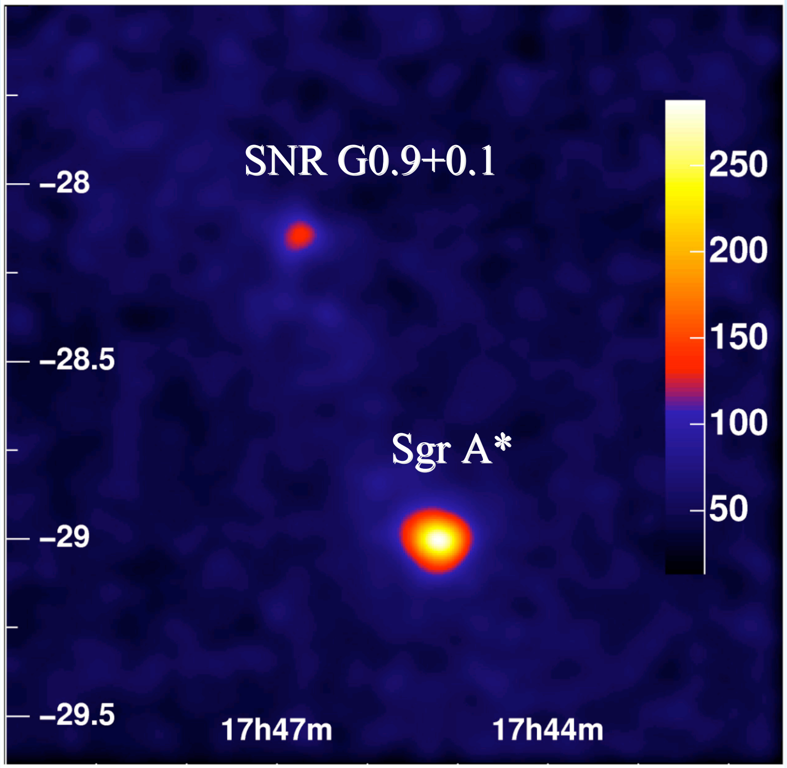
Multiwavelength Observations of Sgr A*

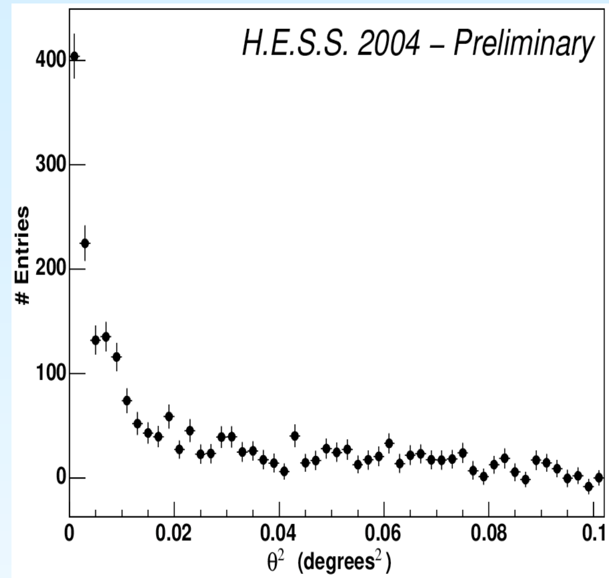
HESS Obs of Galactic Center



Aharonian et al. (2004)

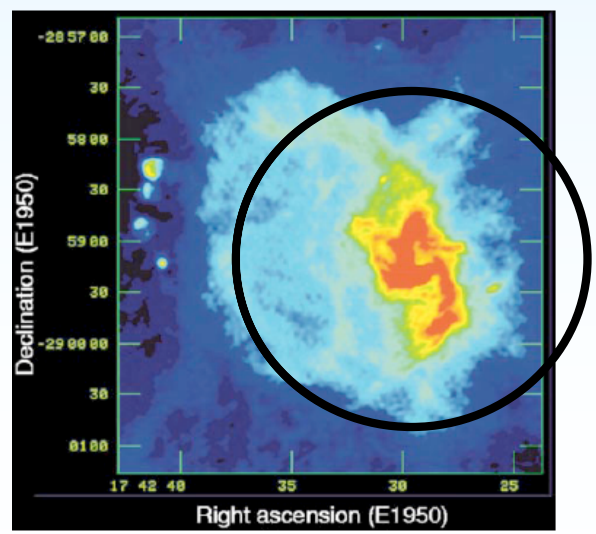
HESS Measurements of TeV Angular Distribution





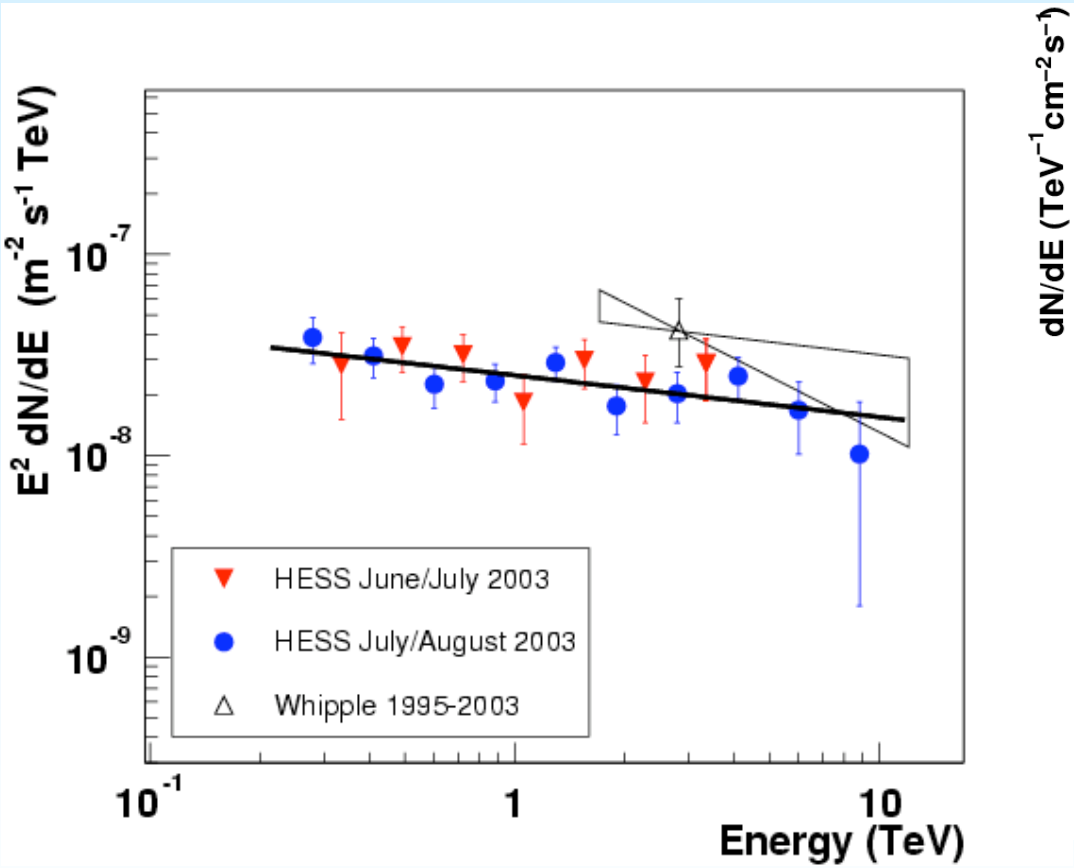
HESS measurements 2004-2005

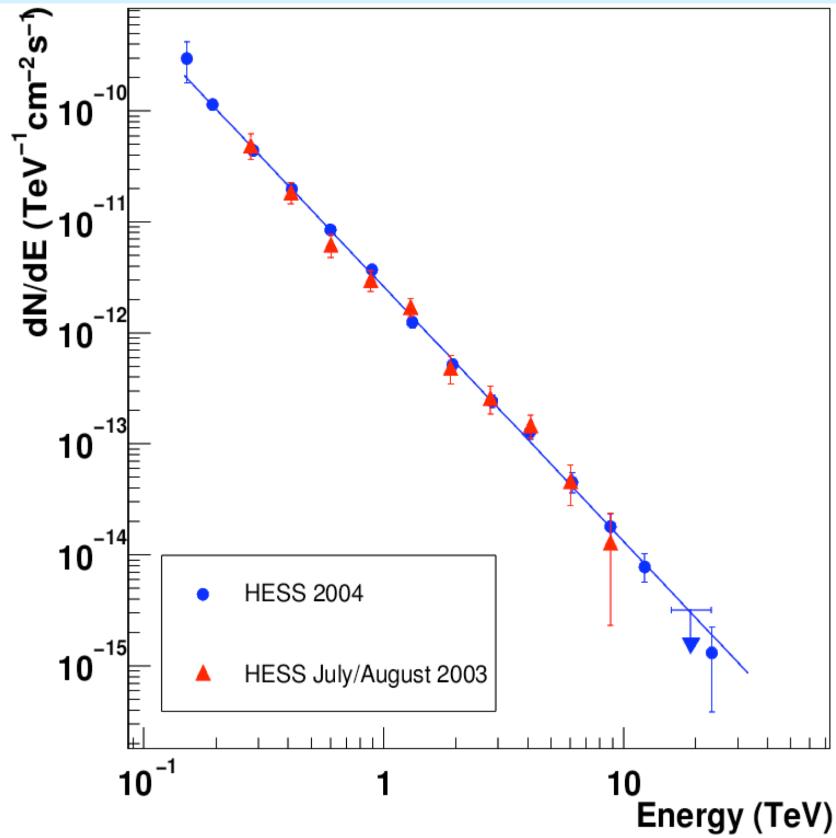
Hofmann (2005)



Upper limit to source size (95% CL)
< 3' ⇒ < 7 pc

HESS Measurements of TeV Spectrum of Galactic Center Source





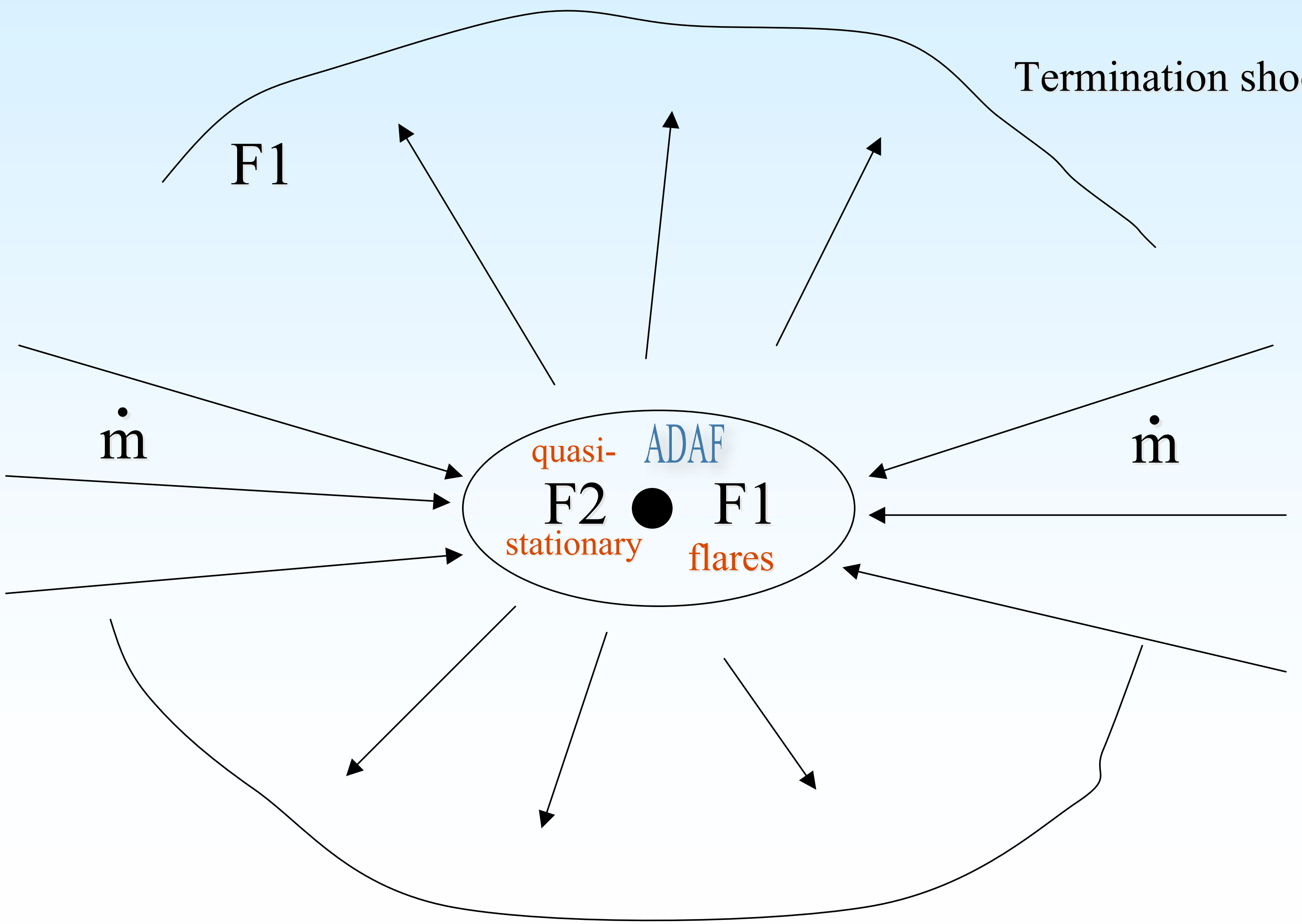
E^2dN/dE spectrum for June/July, July/August campaigns

dN/dE$\propto E^{-2.21\pm0.21} \times 10^{-8}$ m^{-2} s^{-1}TeV^{-1} (≈5% of the Crab)

Agrees with Whipple (Kosack et al. 2004); disagrees with Cangaroo-II (Tsuchiya et al. 2004)

No significant variability on any time scale

TeV Radiation from the Galactic Center Black-Hole Plerion



Accretion Physics in the ADAF Regime

Advection-dominated accretion flow (ADAF) model for compact objects accreting at low Eddington accretion rate

$$\dot{m} \equiv \eta_{BH} \dot{M} c^2 / L_{Edd}$$

When $\dot{m} << 1,$ radiant luminosity

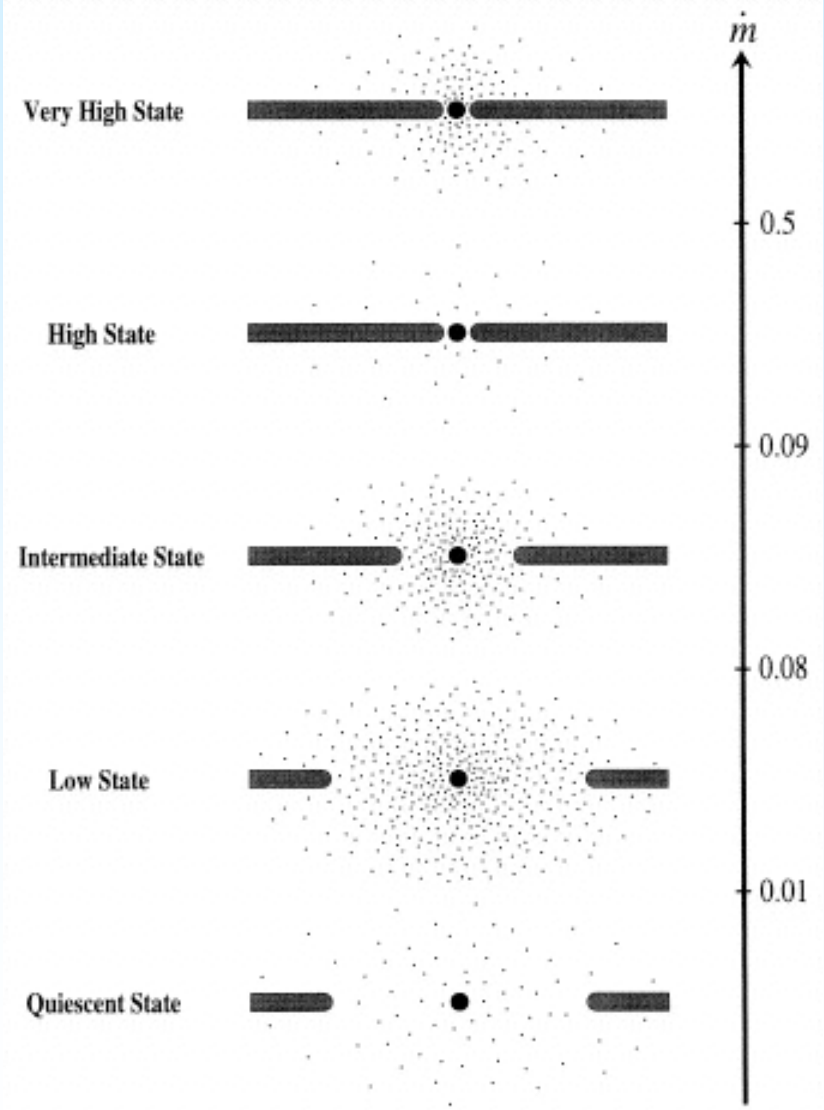
$$L_{rad} = \dot{m} L_{Edd} (\dot{m} / \dot{m}_*) \, ,$$

$$\dot{m}_* \approx 0.1$$

$(\dot{m} / \dot{m}_*)$ is fraction of accretion power that is advected into black hole or convectively escapes

$$L_{th} = L_{rad} = 10^{36} \; ergs \, s^{-1} \Rightarrow$$

$$\dot{m}_{GCBH} \approx 1.5 \times 10^{-5}$$



Esin, McClintock, & Narayan (1997)

Second-order Fermi Acceleration in the ADAF

No optically thick accretion disk

Second-order stochastic Fermi acceleration
for radio-sub mm emission

$$\frac{B^2}{8\pi} = \varepsilon_B \left(\frac{\eta_{BH}\dot{M}c^2}{4\pi R^2 c}\right) \Rightarrow B(G) \approx 30\varepsilon_B^{1/2} L_{36}$$

for a region of size 20 r_S

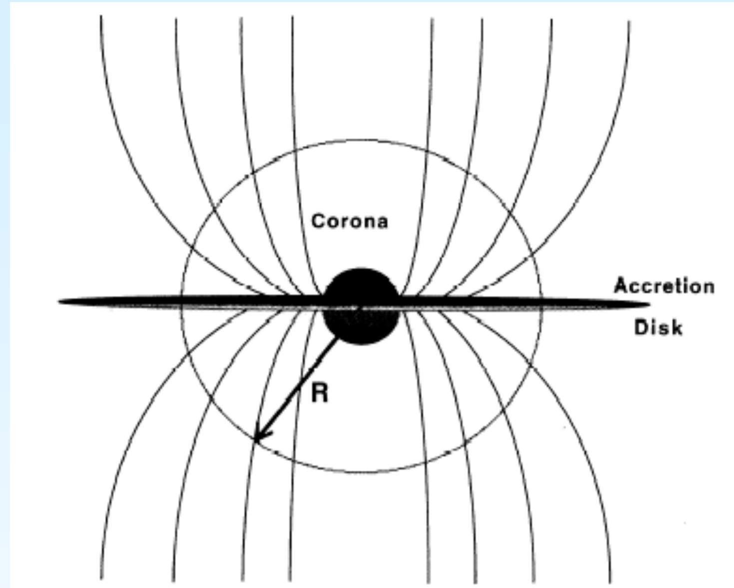
Equating acceleration rate of electrons by Whistler turbulence to synchrotron loss rate:

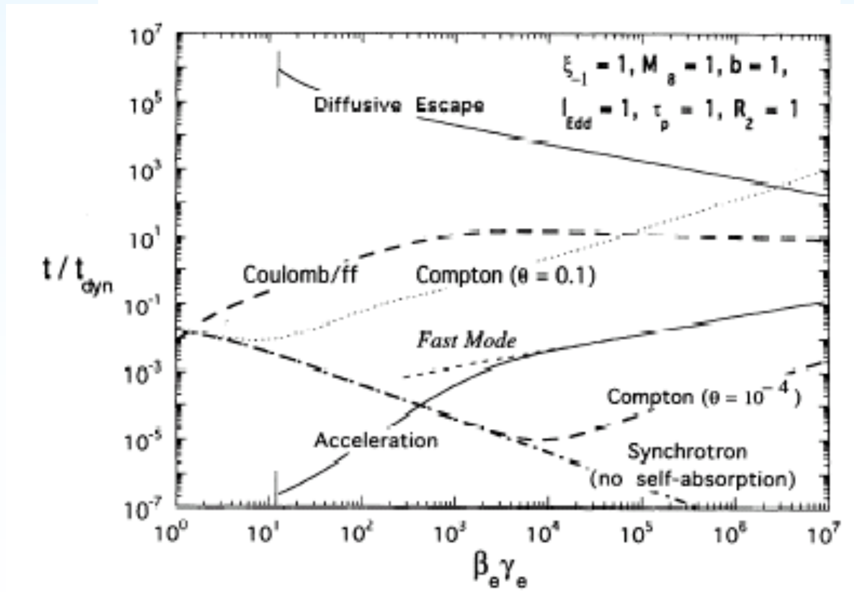
$$\gamma_0 \approx 200(\varsigma_{-1}\varepsilon_{B,-1})^{1/3} L_{36}^{1/2} \left(\frac{\tau_T}{2\times10^{-4}}\right)^{-11/18}$$

Dermer, Miller & Li 1996; Liu, Petrosian, & Melia 2004

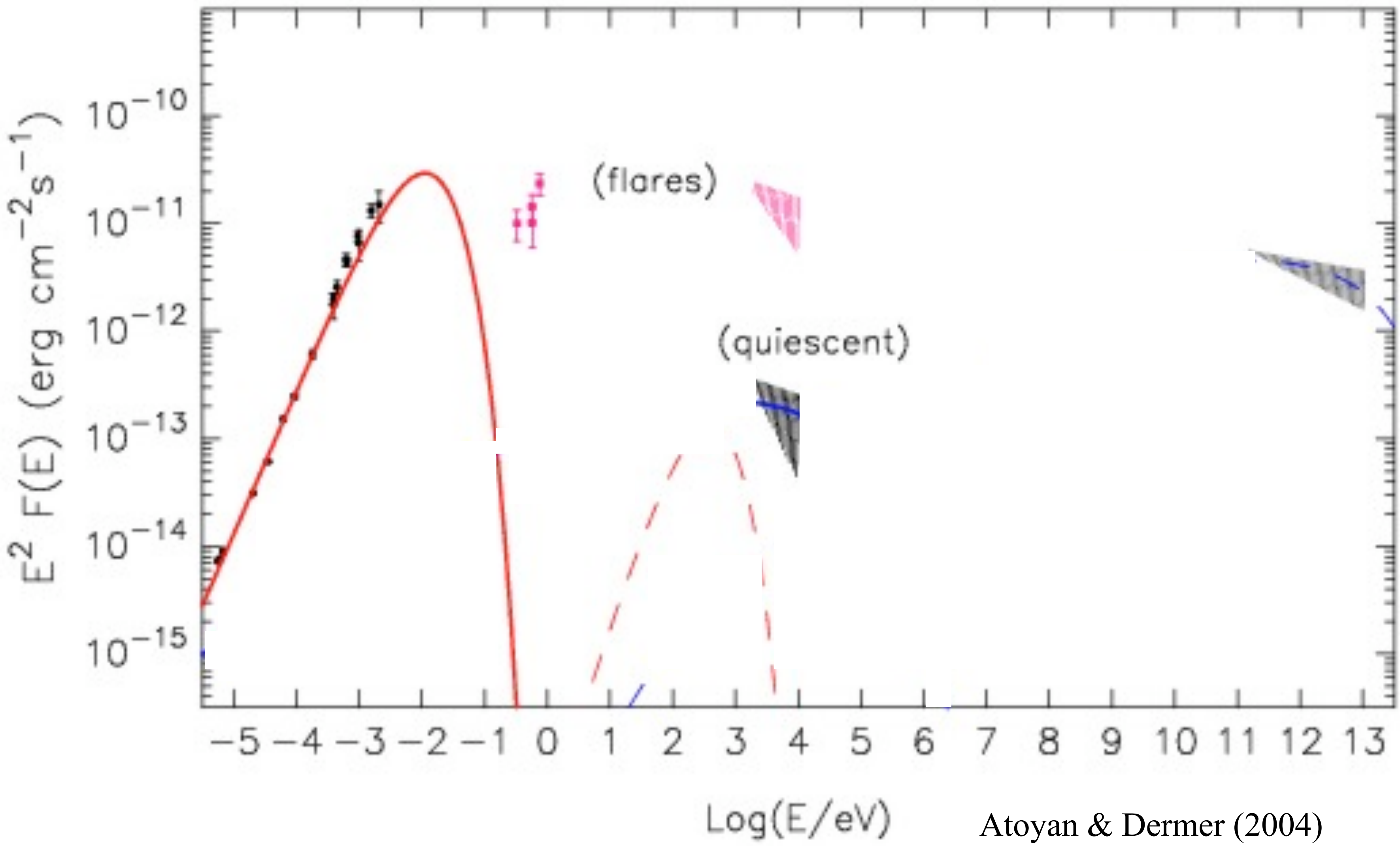
Steady-state electron spectrum:

$$N(\gamma) \propto \gamma^2 \exp(-\gamma/\gamma_0)$$



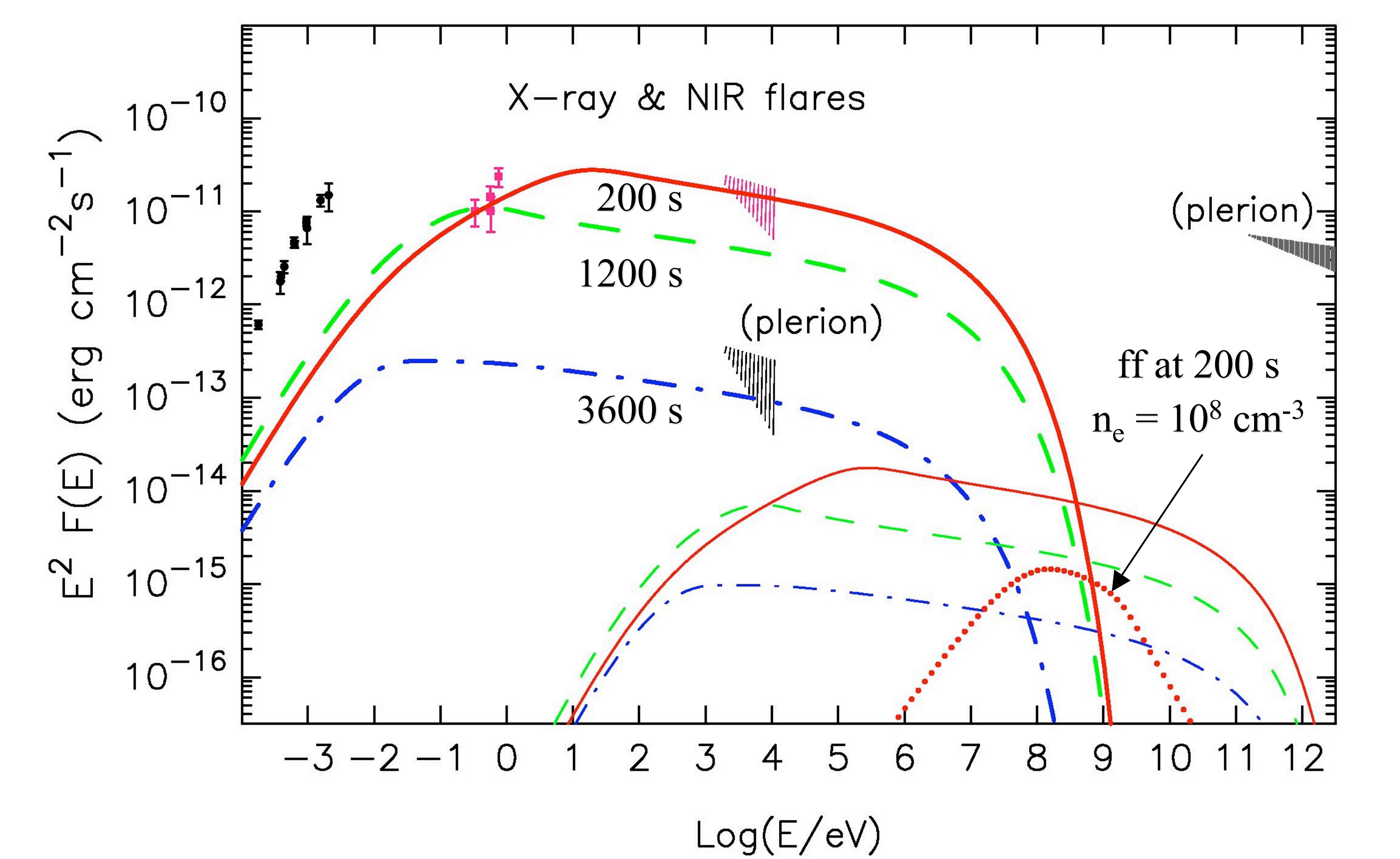


Stochastic acceleration model for radio/sub-mm emission



Atoyan & Dermer (2004)

Flaring Emissions from Inner Region



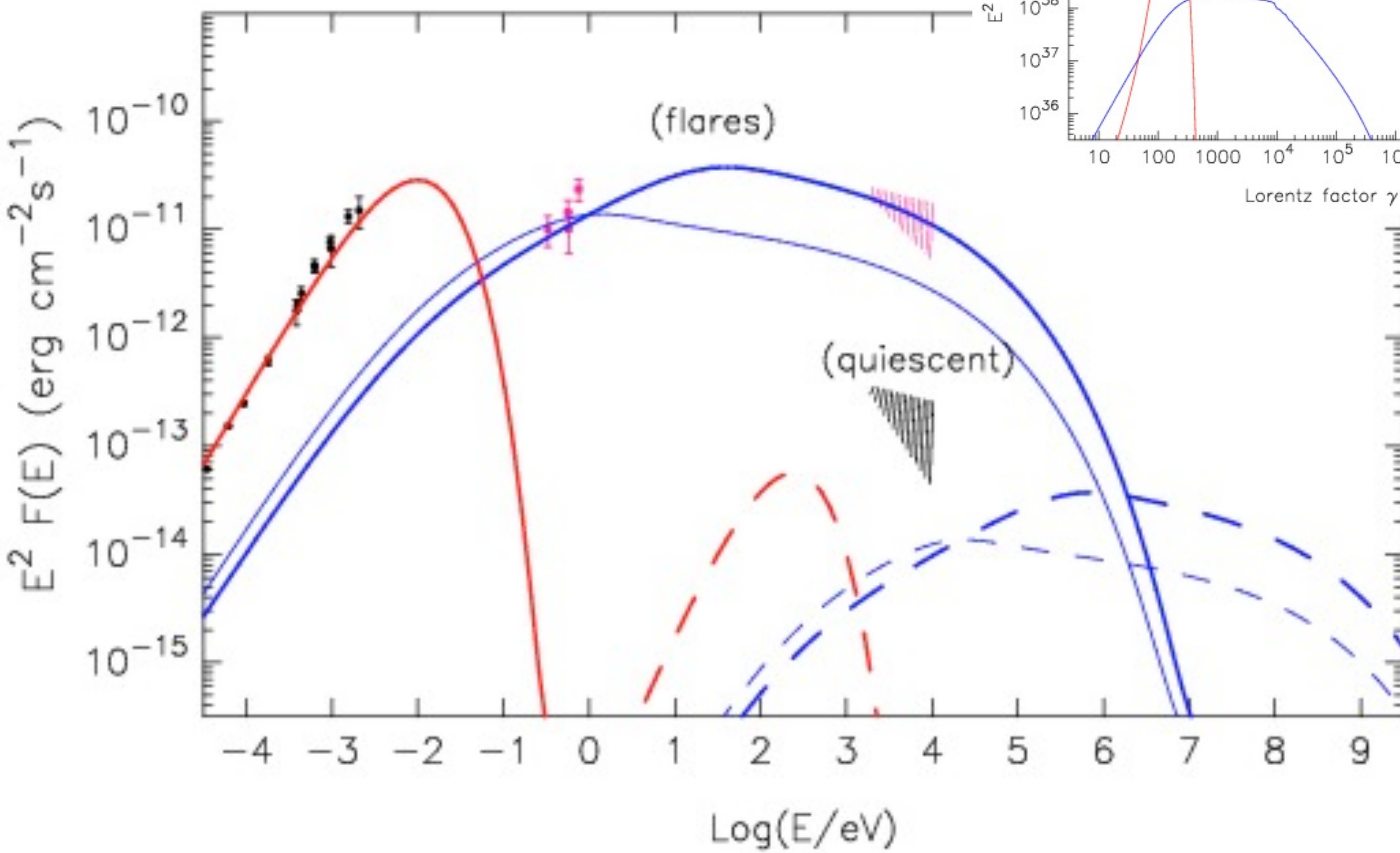
Flares from instabilities in accretion flow that form shocks at few r_S

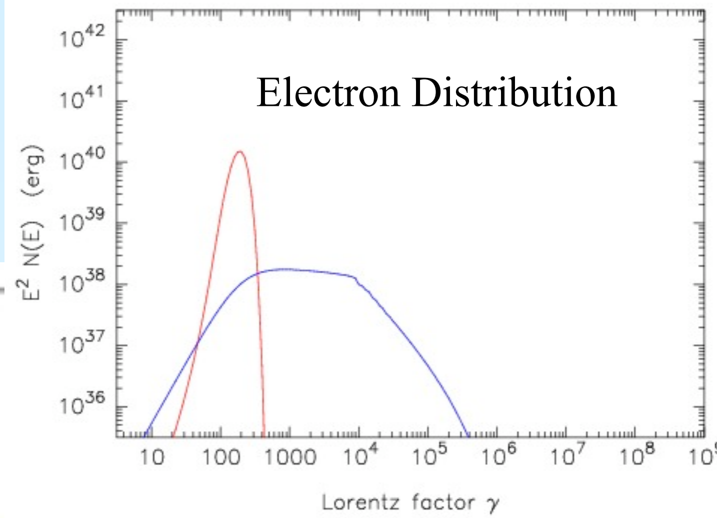
First-order Fermi shock acceleration injects electrons with $\gamma < 10^6$, -2.2 injection index

Explains X-ray/NIR flares and short variability timescales from cooling and expansion

Self-absorbed flares at < 100 GHz from same electrons in "expanding source" scenario

Multiwavelength Emission from Sgr A*





Very weak > 100 MeV γ-ray emission

The Black Hole Plerion

Particle escape by convective outflow in advection-dominated inflow-outflow source (ADIOS) extension (Blandford & Begelman 1999) of ADAF model.

Assume a wind power

$$L_{wind} = 10^{37} L_{37}\ ergs\ s^{-1}$$

With speed $v_{wind} \approx c/2$ directed into solid angle $\Omega \approx 1$ sr

Wind terminates at a subrelativistic shock at

$$R_{shock} \cong 3 \times 10^{16} L_{37}^{1/2}\ \Omega_w^{-1/2} cm$$

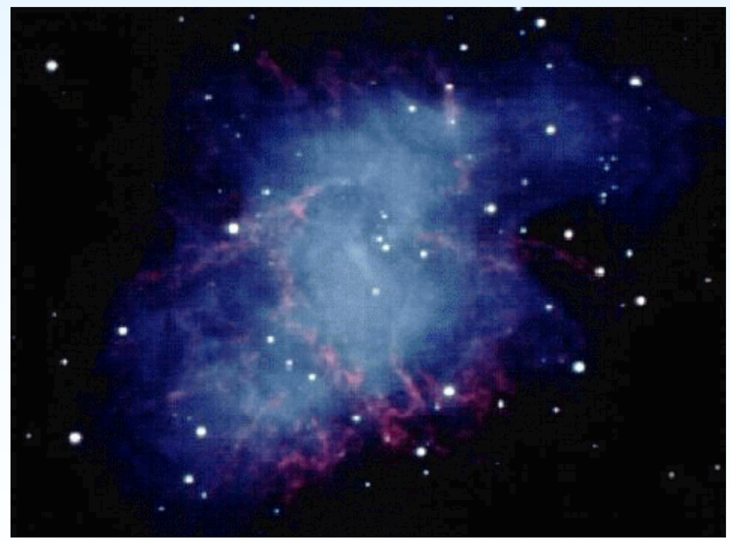
found by equating thermal gas pressure with energy density of wind

Electrons and protons accelerated by first-order (shock) Fermi acceleration.

Electrons emit X-ray synchrotron radiation to form quiescent X-ray emission

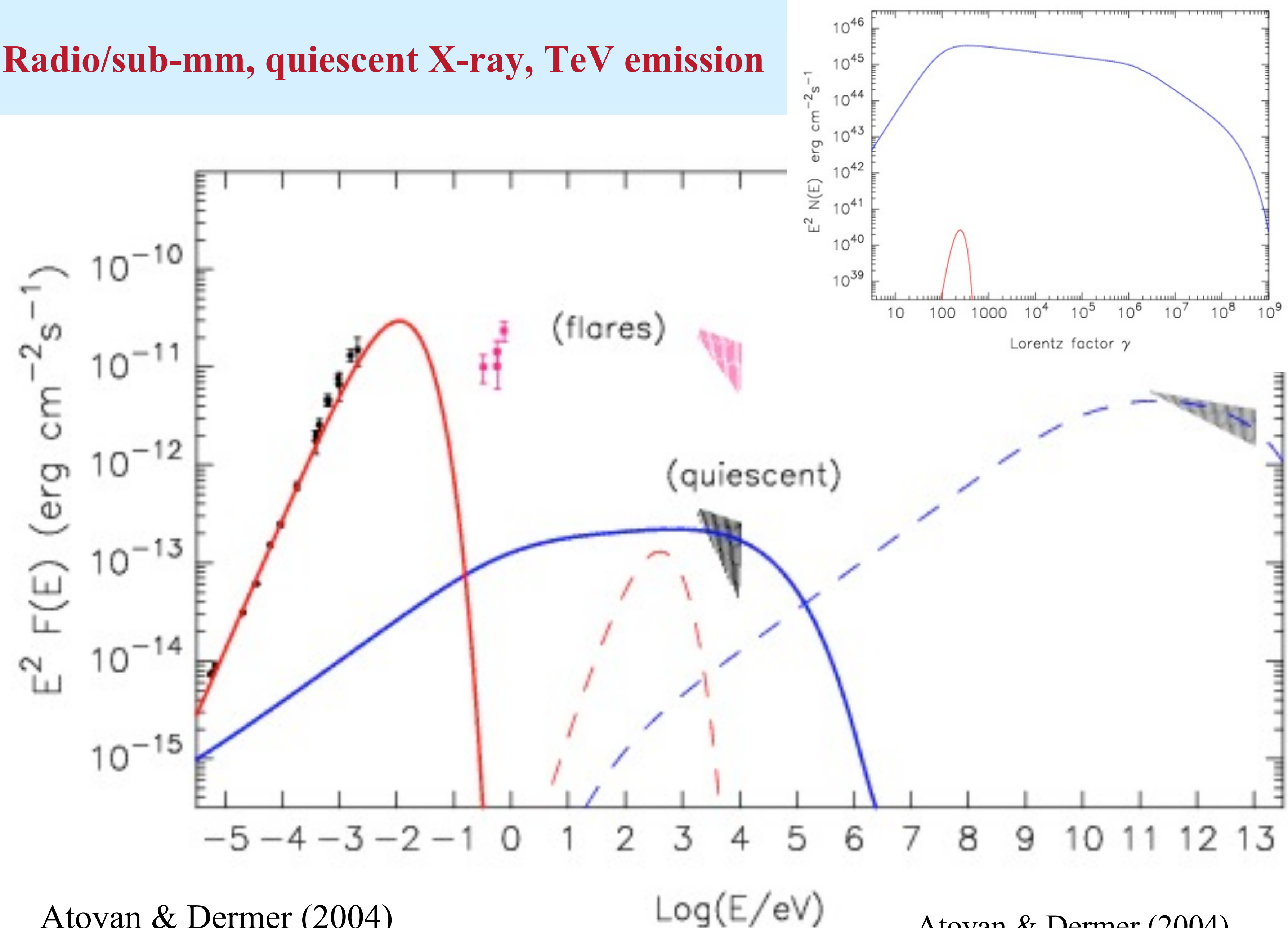
and Compton scatter

- ADAF emission
- 10^{13} Hz emission from cold dust ring around Sgr A*



Neutron Star Plerion: Crab Nebula

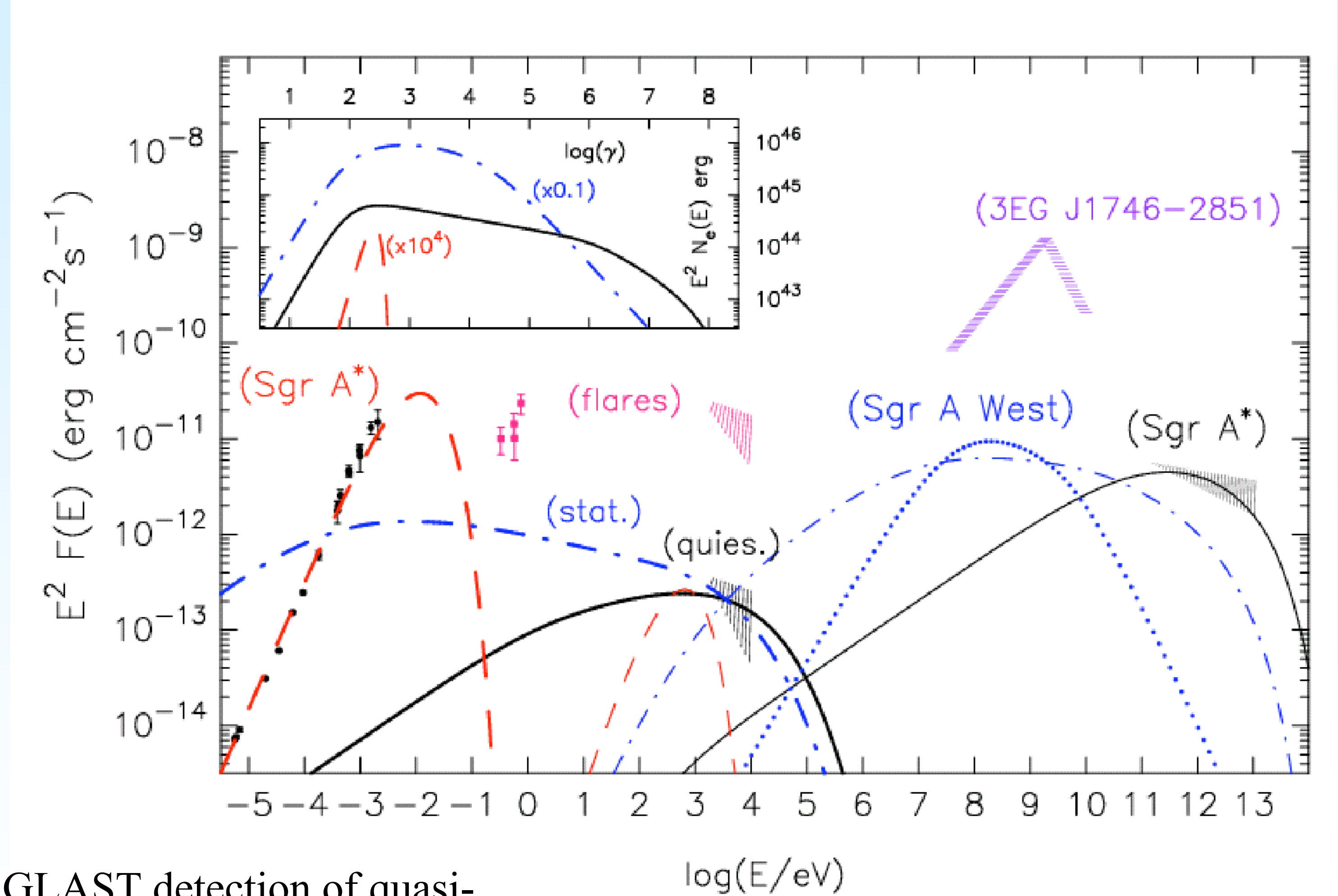
Radio/sub-mm, quiescent X-ray, TeV emission



Atoyan & Dermer (2004)

Atoyan & Dermer (2004)

Galactic Center Black Hole Emission:
Sgr A* ADAF + Black-Hole Plerion + Sgr A West, a black-hole remnant



Predict GLAST detection of quasi-stationary Compton and bremsstrahlung fluxes from pc-scale plerion.

Propagation of GeV electrons to power Sgr A West

Previously Proposed Models for TeV Emission

1. π^0 decay γ rays from secondary nuclear production by cosmic rays (possible accelerated by Sgr A West SNR)

2. Annihilation of supersymmetric dark matter particles
   (Requires neutralinos of mass > 4-10 TeV)

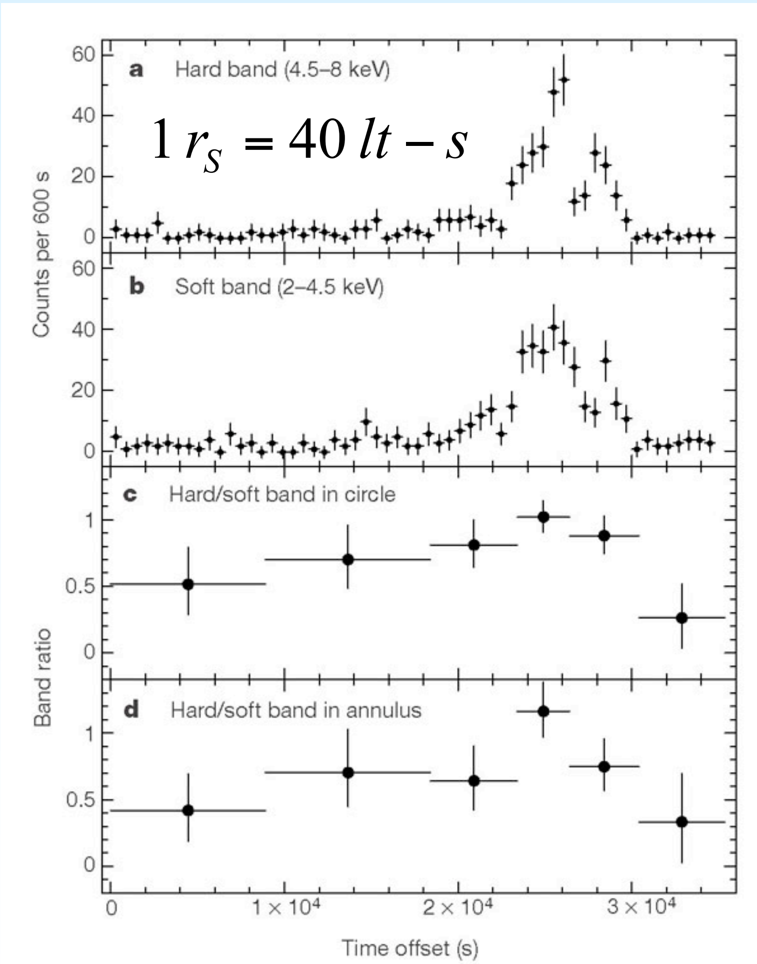
3. Proton curvature radiation

4. TeV jet models (where is the jet?)
   acceleration in the inner jet from shocks; would expect significant variability

Summary

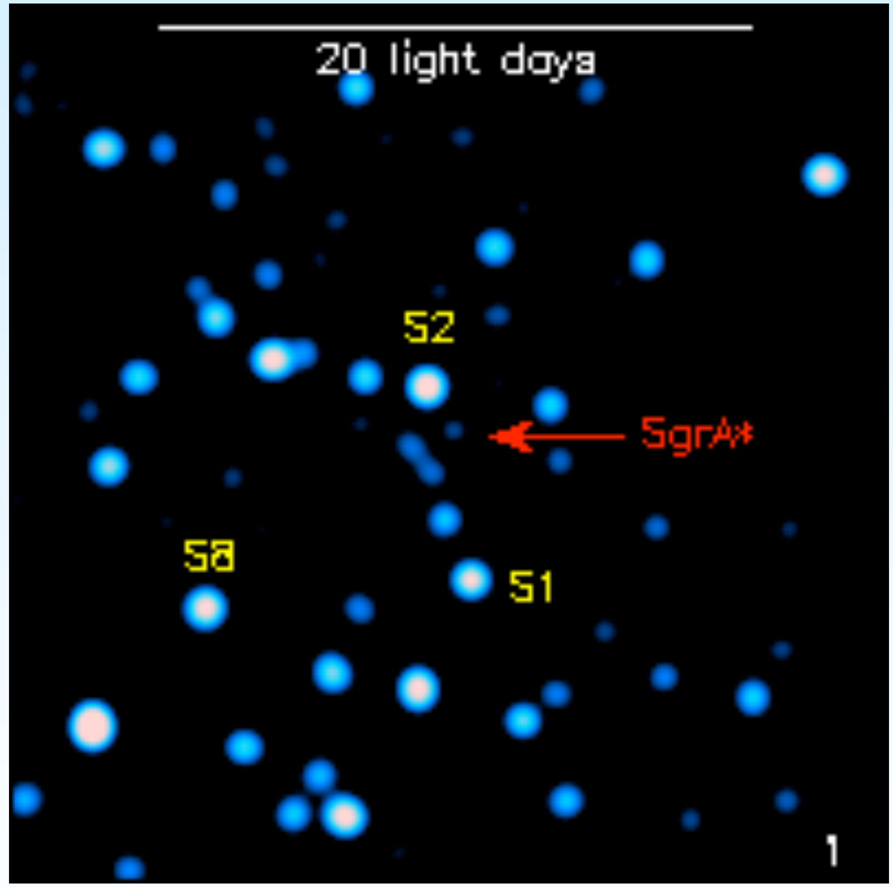
1. TeV radiation from Galactic Center Region: Important Discovery from new generation Imaging Air Cherenkov Telescopes
2. Observations imply two emission regions:
   - (i) Inner region near black hole
   - (ii) Black hole plerion at the termination shock
3. New insights into black-hole accretion in the extreme ADAF regime for GCBH; advection and convective outflow in central accretion flow
4. X-ray flares are synchrotron emission within ~10 r_S of GCBH
5. TeV γ rays made by black-hole plerion, first of a new class of nonthermal emitters

2. X-ray flares with a period of about one per day, rising by factors up to 100 during several tens of minutes. Distinctive point source becomes visible at the location of SgrA*.



$$1\, r_S = 40\, lt - s$$

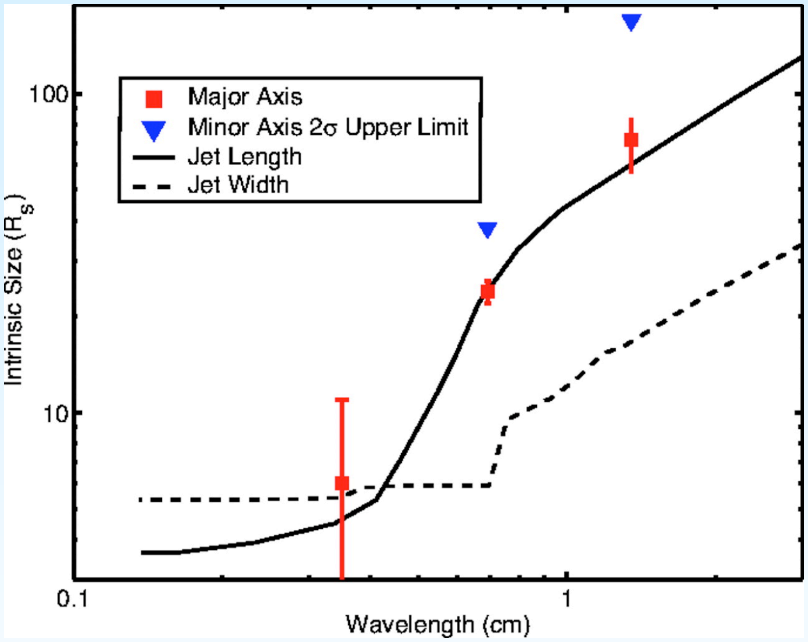
Flaring X-ray Emission from Sgr A*



The short rise-and-decay times of the flares suggest that the radiation must originate from a region within less than tens of r_S

Baganoff et al. (2001)

Resolving Sgr A*

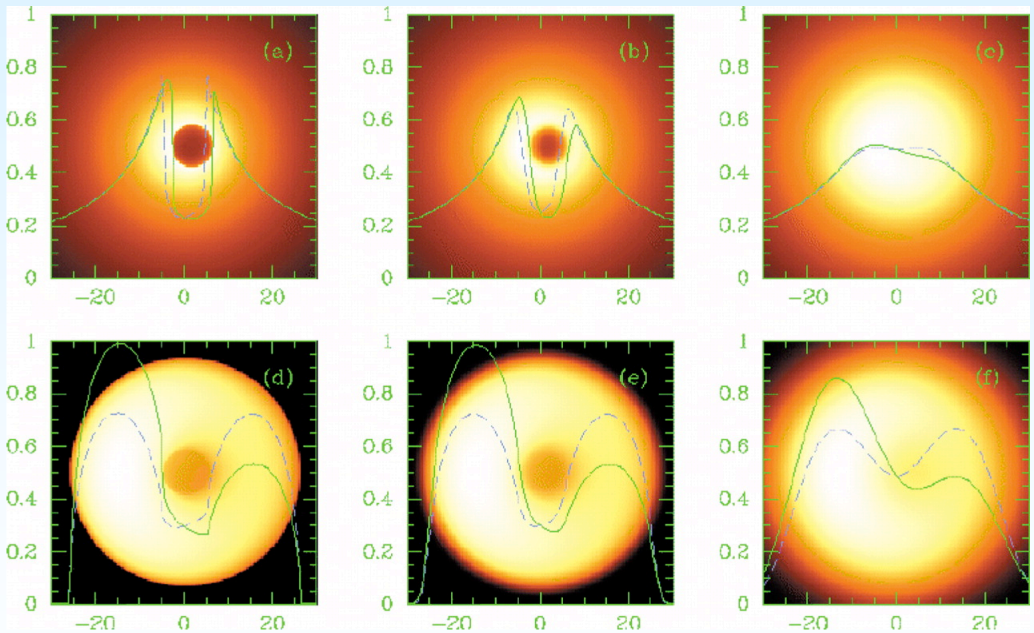


Bower et al. (2004)

Intrinsic size of Sgr A* measured using VLBA

24(±2) r_S at 7 mm (43 GHz)

Theoretical simulations of 1.3 cm images of Sgr A*



Falcke, Melia, & Agol (2000)