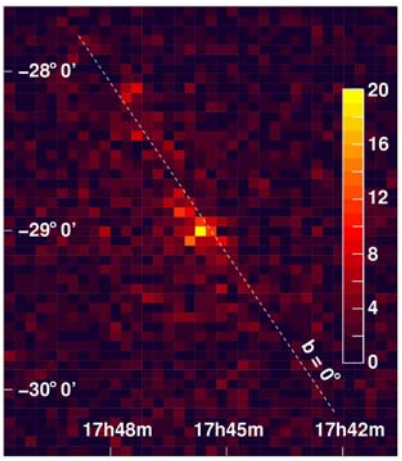
High Energy Gamma Rays from the region of Galactic Center

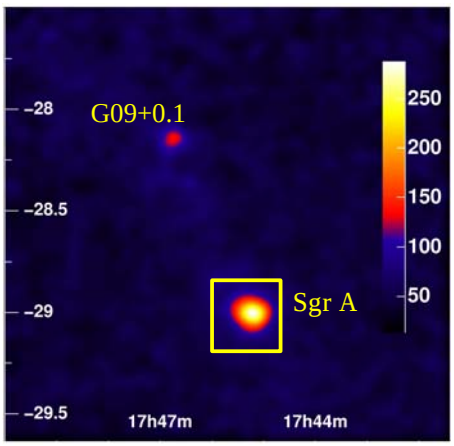
F.A. Aharonian (MPI-K, Heidelberg)

KITP, Santa Barbara, Apr 15, 2005

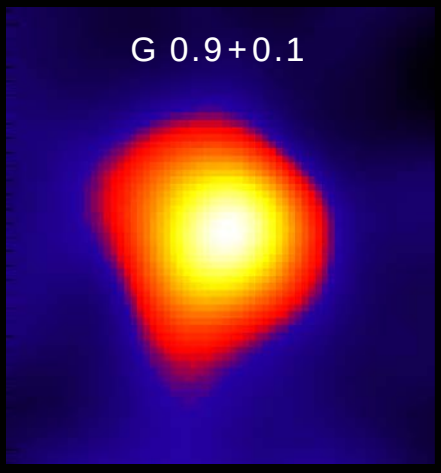
TeV ♑-rays from Galactic Center detected by HESS array of Cherenkov Telescopes

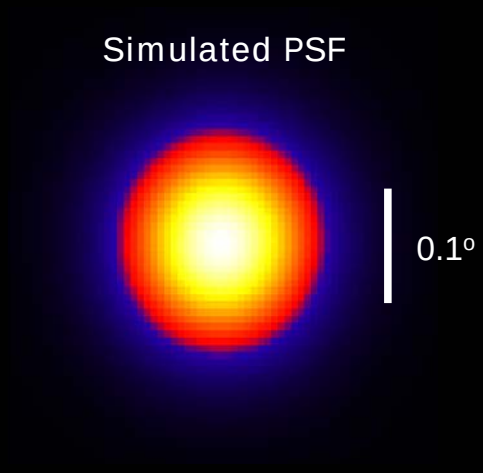
in 2003 and 2004



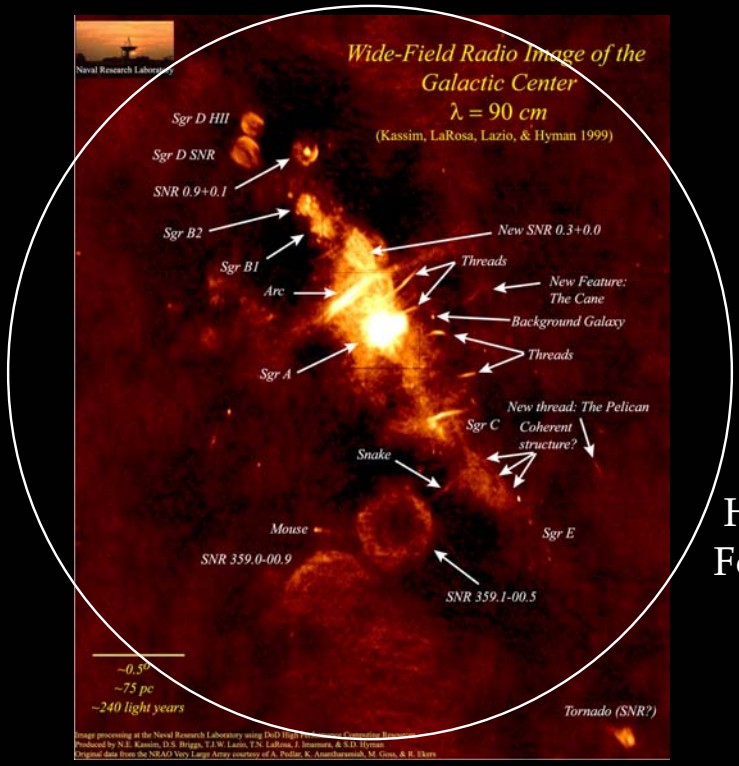


Source Size ?



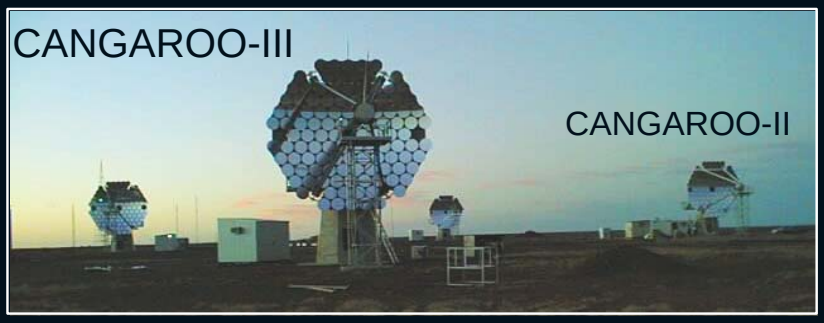


G09+01 looks a like a point source for HESS ...

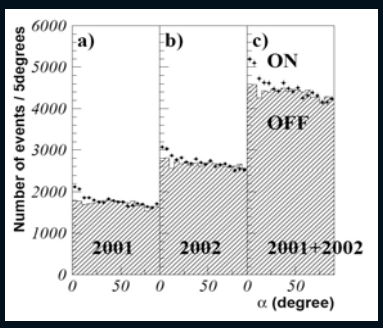


HESS:
FoV=5°

CANGAROO:

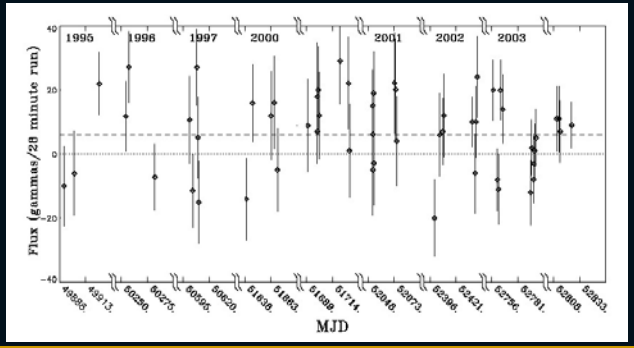


- Tsuchiya et al. 2004
- 67 hours of data, 10sigma
- 2001-2002
- no variability

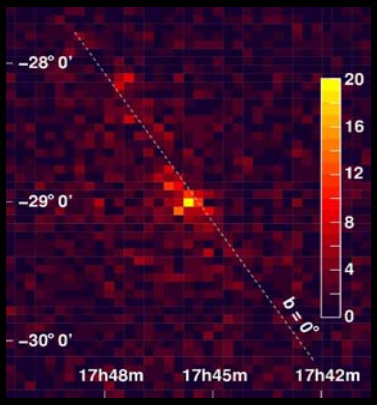


Whipple:

Kosack et al. 2004
26 hours of data taken over 8 years at large zenith angles 3.7 sigma



HESS: 2003 data



- 17 hours of data
- Taken with 2 telescopes during construction of the array
- 160 GeV threshold
- 11 sigma signal from close to Sgr A*
- See A&A 425, L13-16 (2004)

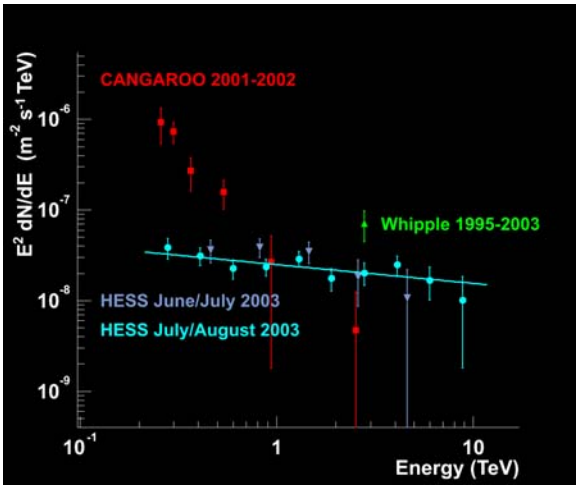
Energy Spectrum

- HESS:
  $dN/dE \propto E^{-2.2}$
- Flux > 160 GeV:
  $1.8 \pm 0.2 \times 10^{-11}$ cm^{-2} s^{-1}
  (5 % of Crab flux)

- CANGAROO:

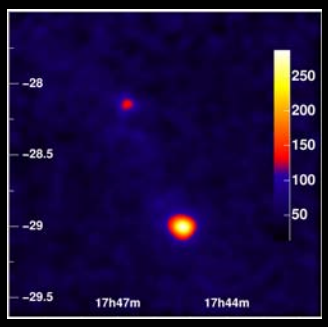
  $dN/dE \propto E^{-4.6}$

  Flux > 160 GeV:
  ~ 1 Crab



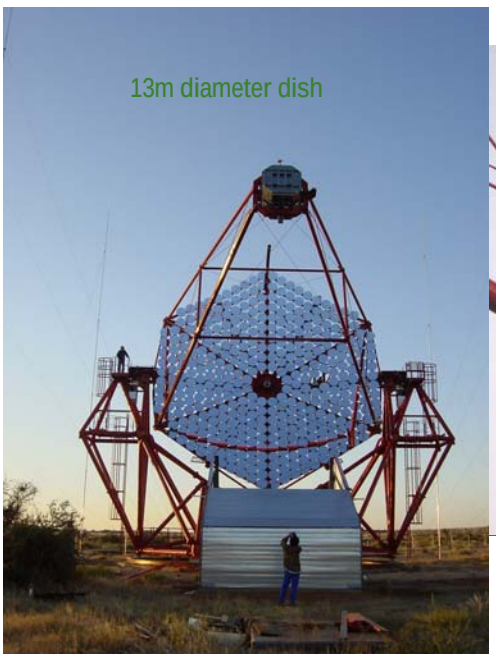
Jim Hinton

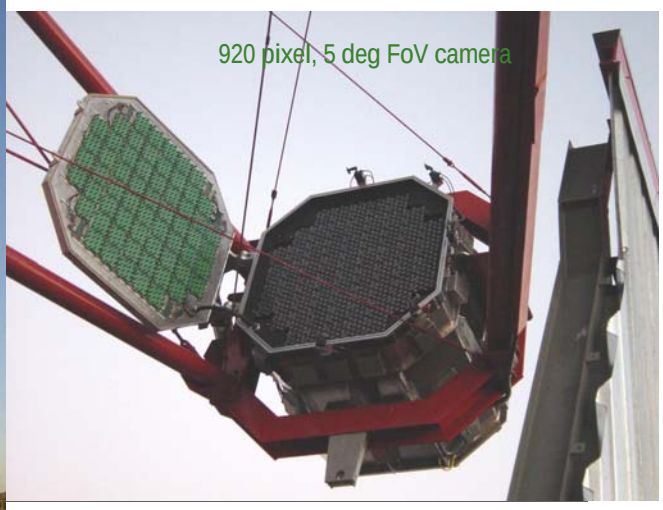
HESS : 2004 data



- 50 hours of data
  with full 4 telescope array
- Significance of HESS J1745-290 is 35 sigma
  5 s/√(hour) at quiescent level ➡ HESS has
  a power to resolve flares on 1 h timescales
- *Flux and Spectrum compatible*
  no details yet – paper in preparation
- New source detected in the same field of view

H.E.S.S. - *High Energy Stereoscopic System*





- Energy range
  100 GeV - 10 (30) TeV
- Energy resolution
  15 - 20%
- Angular resolution
  3 - 6 arcmin
- Sensitivity:

1 Crab	30 sec
0.1 Crab	20min
0.01 Crab	25 hours
10 Crab	1 sec

- Field of View 5^o

1 Crab = 3×10^{-11} erg/cm^2 s

✓ 0.1 Crab - min detection time
for Whipple – 50-100 hour

✓ 0.003 Crab requires 200 h
10^{-13} erg/cm^2 s level

better than Chandra/XMM for >0.1 deg objects !

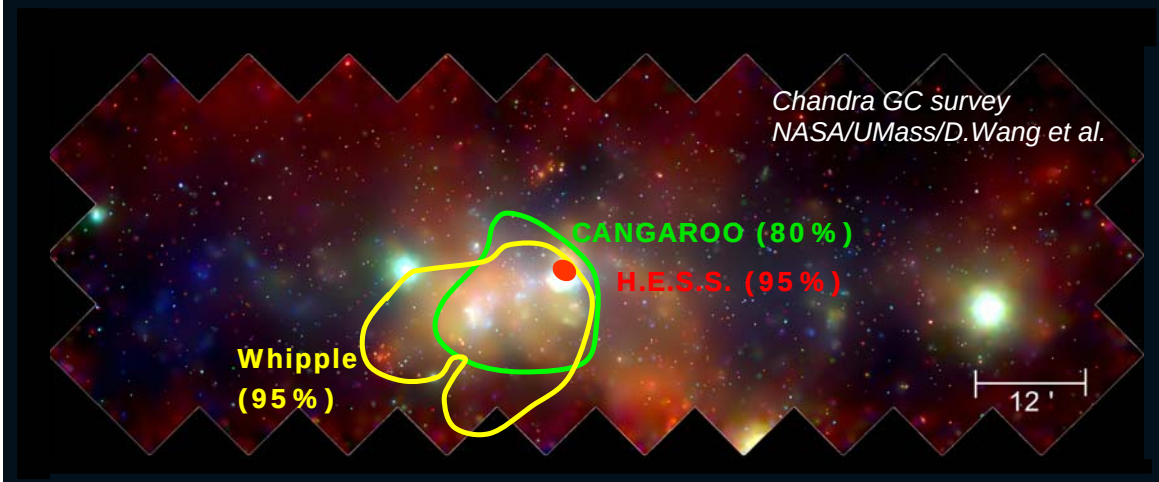
✓ 10 Crab (i) strong flares of Mkn 421/501
(ii) energy flux sensitivity of EGRET
(iii) several orders of magnitude
less than typical GRB fluxes

✓ 3 arcmin - angular resolution of ASCA

✓ 5^o FoV plus 0.1 Crab for < 1 h –
sufficient for effective surveys !

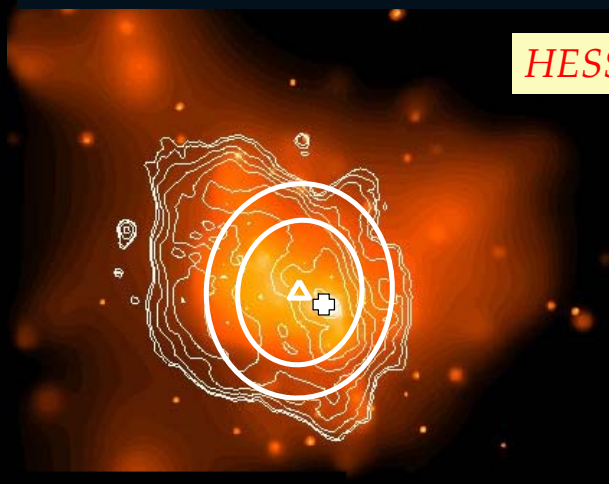
Position?

systematic and statistical errors on source location by HESS are comparable: 20-30 arcseconds



Contours from Hooper et al. 2004

Sgr A* and Sgr A East



Sgr A East
Chandra & Radio
NASA/G.Garmire (PSU)
F.Baganoff (MIT)
Yusef-Zadeh (NWU)

*HESS position very close to Sgr A**

but Sgr A East
not ruled out

call γ-ray source
HESS J1745-290

Sgr A*

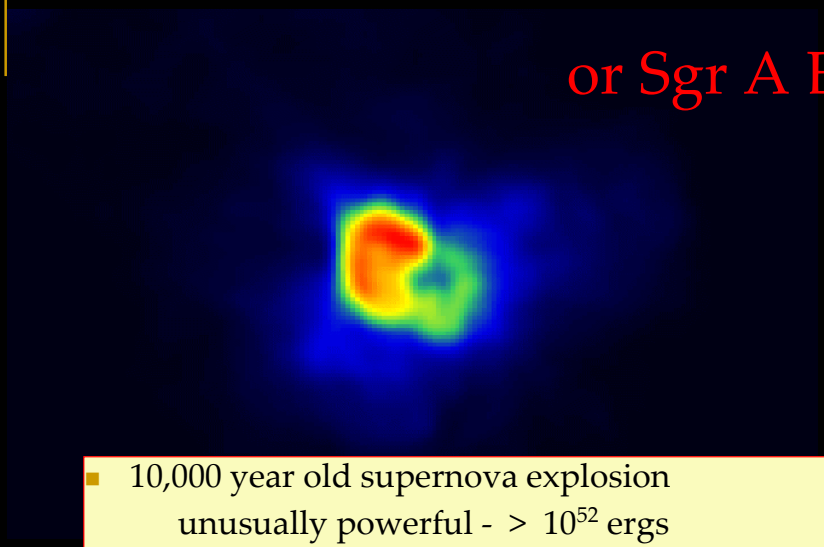
- 3×10^6 solar mass black hole
- very low luminosity
  $< 10^{-8}$ Eddington luminosity
- Highly variable non-thermal emission in IR and X-ray
- Extremely compact source
  < 0.1 milliarcseconds at mm
  variability timescale < 1 hour

transparent for gamma-rays
up to ~10 TeV !

can accelerate protons up to 10^{18} eV !

MPE / R. Genzel et al.

or Sgr A East ?



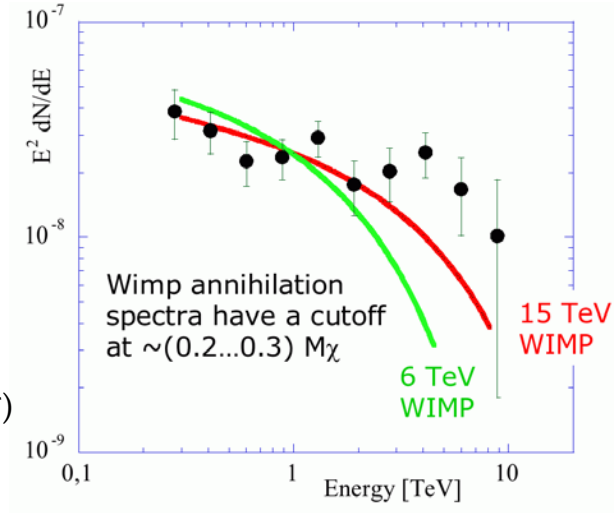
- 10,000 year old supernova explosion
  unusually powerful - > 10^{52} ergs
  and compact - 3 arcmin
- surrounds Sgr A* !
- Diffusive Shock Acceleration of Cosmic Rays

or Dark Matter ?

annihilation of SUSY or other DM candidate particles

DM Annihilation?

- HESS Spectrum requires a > 10 TeV DM particles
- most WIMPs models favour a < 2 TeV mass neutralinos
- other DM candidates ?
  - GMSB: *Gauge mediated Supersymmetry Breaking*
  - Kalusa-Klein Dark Matter
- also a rather cuspy profile and a high density of DM in the very central part (around SBH/Sgr A*)



or **Interactions of CR protons with ambient diffuse gas or photon fields**

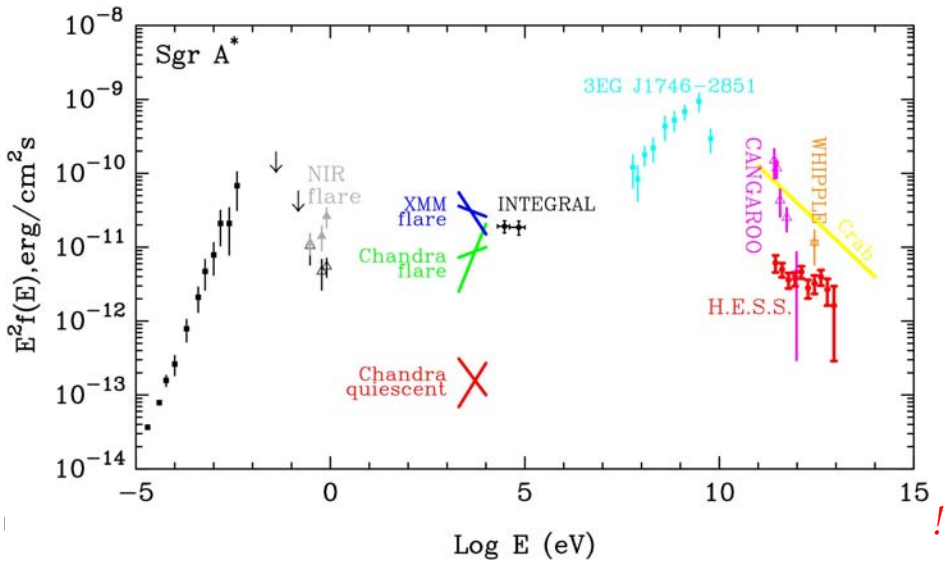
TeV γ-rays from central <10 pc region of GC *

- Annihilation of DM ? *mass of DM particles > 12 TeV ?*
- *Sgr A* :* $3\ 10^6\ M_o$ BH ? *somewhat speculative but possible*
- SNR Sgr A East ? *why not ?*
- Plerionic (IC) source(s) *why not* ?
- Interaction of CRs with dense molecular gas (clouds) ? *easily*

* *the center of gravity is within 30 arcsec around Sgr A* !*

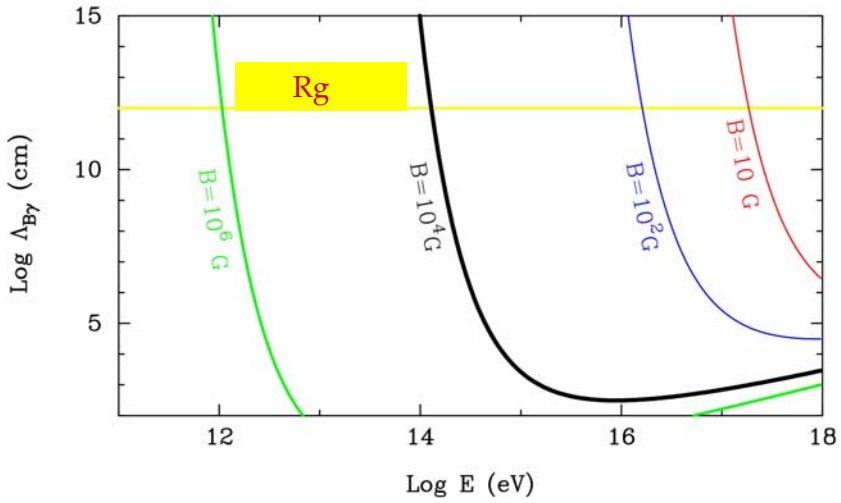
BH in GC – unique with extremely low luminosity

a nice present for (gamma-ray) astronomers …



!

transparent also in magnetic field if B < 10^5 G



Mean free path is a function of ♍🖬☎☜🖅$m_e c^2$)(B/B_{crit}); B_{crit}=4.4e13 G

Radiation Processes associated with *Protons*

maximum acceleration rate: $t_{acc} = \kappa r_g/c; \quad r_g = E/300B; \quad \kappa \geq 1$

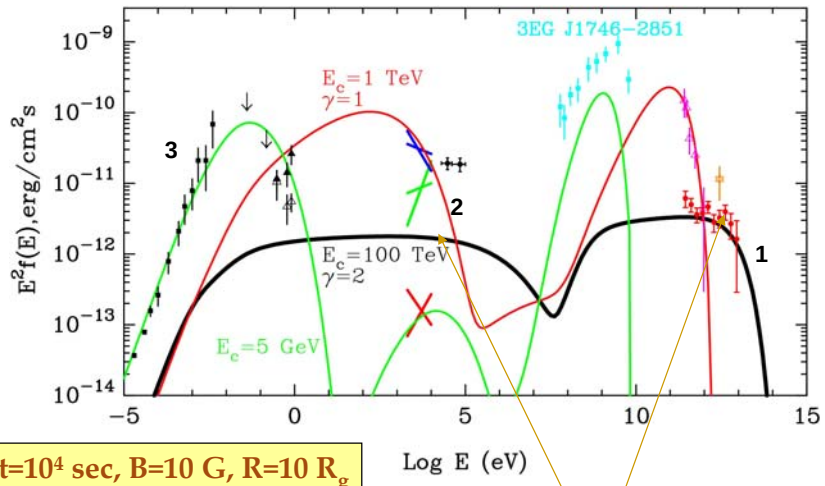
(i) in rotation-induced magnetic field (Levinson 2001) : k=1

(ii) by shocks (DSA): ks 10 (c/v)^2

$$E_p \approx 10^{18}(B/10^4 G)(M/3 \times 10^6 M_\odot)\ \kappa^{-1}\ \text{eV}\ .$$

- *Synchrotron radiation ?* $\epsilon_{max} = (9/4)\alpha_f^{-1} m_p c^2 \approx 0.3\kappa^{-1}$ TeV
  unlikely unless in the jet with ♎ 🕸 🗁🗀
- *Curvature radiation ?* $\epsilon \approx 0.2(B/10^4 G)^{3/4}(M/3x10^6 M_\odot)$ TeV
  possible if B >10^5 G , but in such fields TeV gamma-rays cannot escape
- pp interactions ?
- p ♍ (photomeson) interactions ?

p-p interactions in the accretion flow



n=10^8 cm^{-3}, t=10^4 sec, B=10 G, R=10 R_g

□=2, E_c=100 TeV, L_p=5e38 erg/s
■=1. E_c=1 TeV, L_p=1e40erg/s
■=0, E_c=5 GeV, L_p=1e40 erg/s

$(h\nu)_{synch}$ s 100 $(E_{\gamma_0}/1TeV)^2$ (B/10 G) keV

p-p interactions in the accretion disk ?

Broad-band radiation due to TeV protons

acceleration by induced electric field or by strong shocks in the accretion flow

correlated TeV-X-IR flares

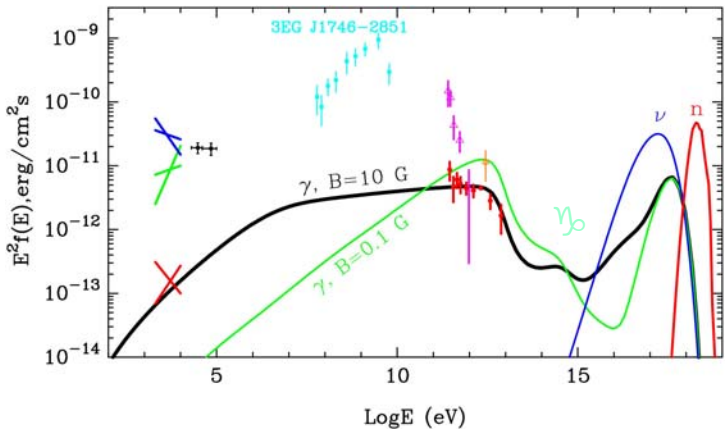
Can be easily checked by simultaneous X-TeV observations:
TeV energy flux can be only a factor of few higher than X-ray flux !
(unless B << 1G)

n=10^8 cm^{-3}, t=10^4 sec, R=10 R_g

Low efficiency: $t_{pp}= 10^7 (n/10^8 \text{ cm}^{-3})^{-1}$ sec => τ < 0.1 %

TeV neutrino fluxes detectable by km^3 class detectors ?

E-M cascades initiated by p-γ interactions



Acceleration to 10^{18} eV close to the gravitational radius ($10^{12} - 10^{13}$ cm)

interaction with IR and mm photons (and B) fields
=> E-M cascades

requires 10 kG B-field at 1-2 Rg

no conflict with X-rays !

UHE neutrinos – detectable by AUGER ?,
UHE neutrons and γ-rays detectable by AUGER

electronic models = IC models

1. SSC type models in relativistic jet ?

maximum electron energy in random field:

$$E_{e,max} \approx 5 \times 10^{13} (B/1G)^{-1/2} \kappa^{-1/2} \text{ eV}$$

=> random B-field << 1 G unless & s 1

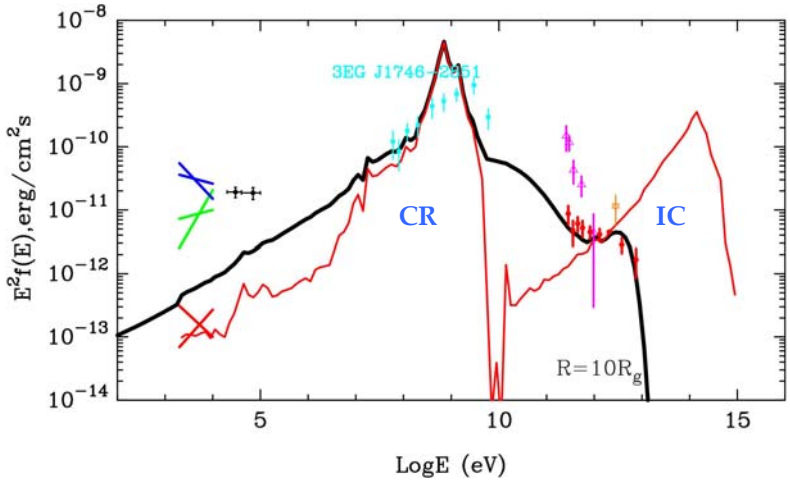
2. Curvature Radiation – IC model

acceleration in a regular B-field:

$$E_{e,max} \approx 10^{14} (B/10G)^{1/4} \text{ eV}$$

100 TeV IC gamma-rays initiate E-M cascade in IR source

electronic models: "IC/Curvature radiation" cascades)



no neutrons, no neutrinos, relatively weak X-ray emission

Summary

- At least 3 process can provide non-negligible fractions of the detected TeV flux

Tests:

- Variability on timescales less than 1 hour

  HESS detects every 1hour statistically significant signal from GC

- MWL campaigns

  planned observations with Chandra

Diffuse Emission of the central 10 pc region

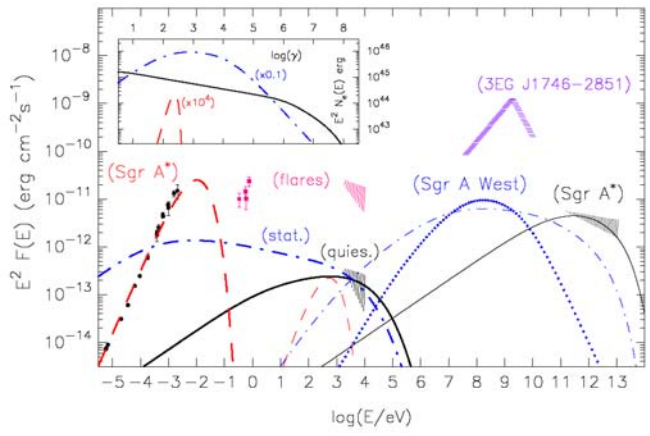
1. **due to pp interactions in dense (1000 cm^{-3}) gas regions**

2. **due to Inv. Compton in dense (2.5 keV/cm^{-3}) FIR regions**

A Black-Hole Plerion?

Accelerate electrons at termination shock of *wind*
(sub-relativistic outflow of particles and field) from Sgr A*

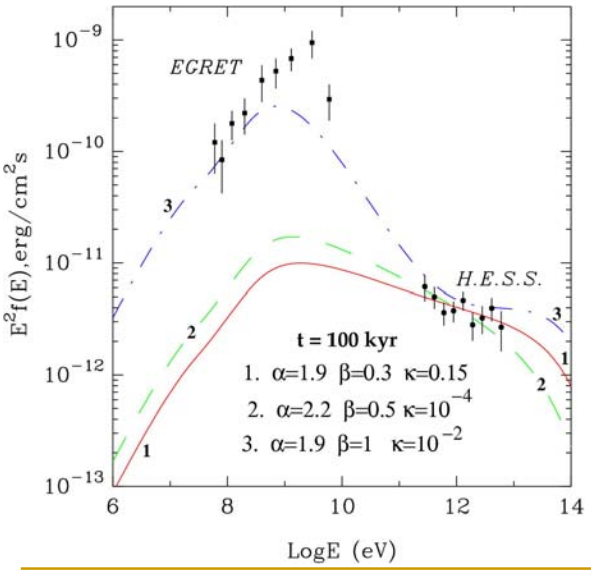
similar to a pulsar wind nebula



Atoyan & Dermer
astro-ph/0410243

pp gamma-rays in the central 10 pc region

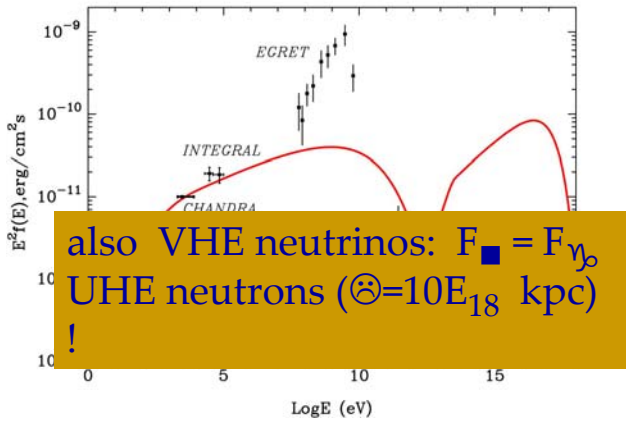
$Q_p(E)=Q_o\ E^{-\alpha}\ \exp(-E/1\ \text{PeV})$, $D(E)=10^{28}(E/1\text{GeV})^{\delta}\ \&\ \text{cm}^2/\text{s}$; $\&$ =1, δ=0.5-0.6 -diffusion in GD



if $t_{pp} < t_{esc}$ => π^0-decay γ-ray production in "saturated" regime => $L_\gamma = 1/3\ L_p$, otherwise the flux and spectrum of γs depend not only on CR injection power and spectrum, but also on the (energy dependent) propagation of CRs in ISM

1. fast diffusion : $\delta \rightarrow$ $L_p=7.5 \times 10^{37}$ erg/s
2. slow diffusion: $\delta \rightarrow$ $L_p=6.9$
3. Diffusion-to-rectlinear prop. $\delta \rightarrow$ $\Rightarrow$ $\alpha\ \delta$ $L_p=$

synchrotron radiation of secondary electrons …



also VHE neutrinos: $F_\nu = F_\gamma$
UHE neutrons (λ=$10E_{18}$ kpc)
!

α=1.5, E_1=2e14 eV/E_2=1.5e18 eV
Lp=1.5e38 erg/s, $\&$=0.001, δ=0.3

if Ep -> 10^{15} eV and B > 100 μG synchrotron radtaion of secondary ($\pi^{+/-}$ -decay) electrons extends to X-ray domain: for α=2 $L_X < \frac{1}{2} L_\gamma$

but for α < 1.5 and Ep -> 10^{18} eV synch. rad. appears at TeV energies and for a certain combination of parameter can explain HESS data

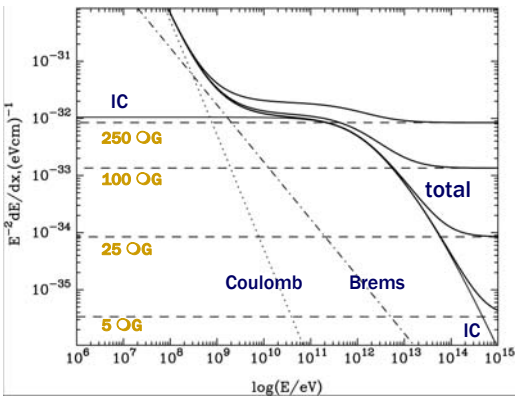
although the radiation is produced throughout the diffuse region (up to 10 pc), the observer would detect a point-source like signal centered on Sgr A* !

IC emission of plerionic or SNR origin*

Energy Losses of electrons in the Galactic Disk and the GC region

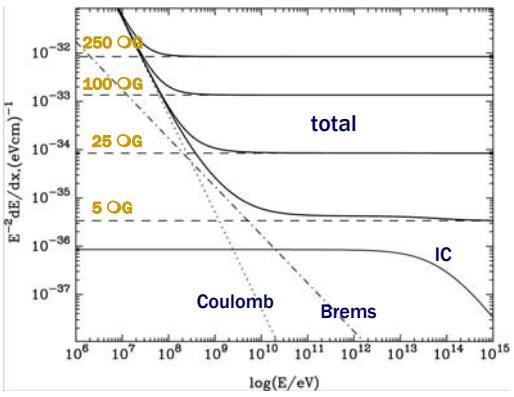
Central 1 pc region of GC

T=160K, w=2500 eV/cm^3, n=1000 cm^{-3}

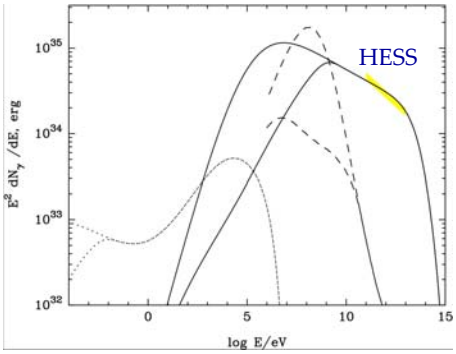


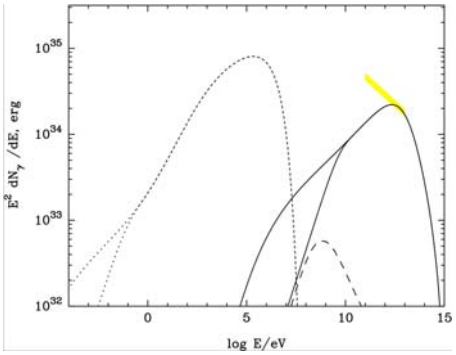
"standard" region of GD

T=2.7K, w=0.25 eV/cm^{-3}, n=1 cm^{-3}



Gamma Rays from GC of IC Origin ? *





Le=1.1e37 erg/s, B=25 ❍G, ✌=2.3

Le=1.2e36 erg/s, B=100 ❍G, ✌=1.6

- SNR Sgr A East
- or a PWN (plerion) close to GC
- or a "plerion" around Sgr A*