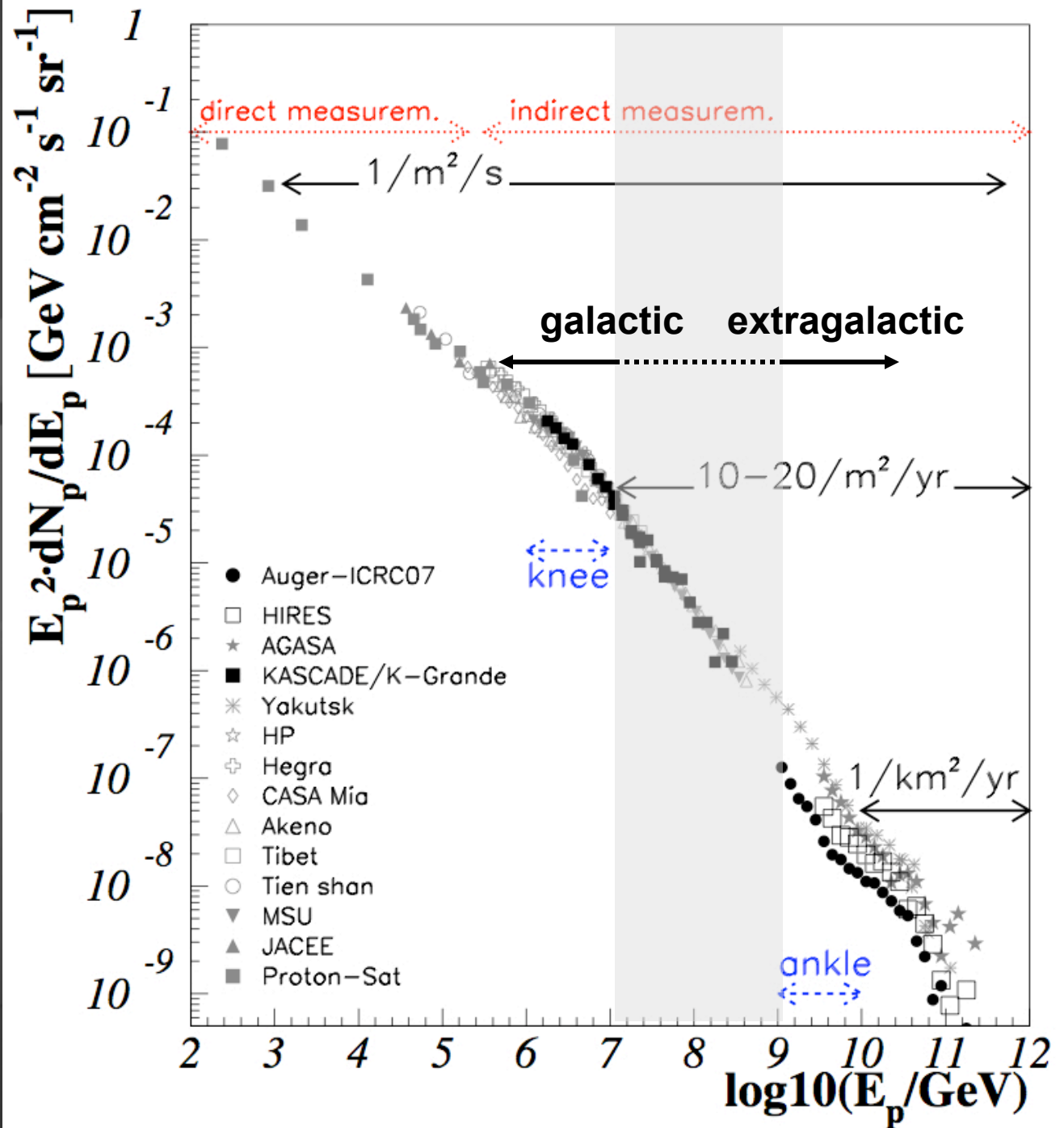galactic
and
extragalactic
cosmic rays
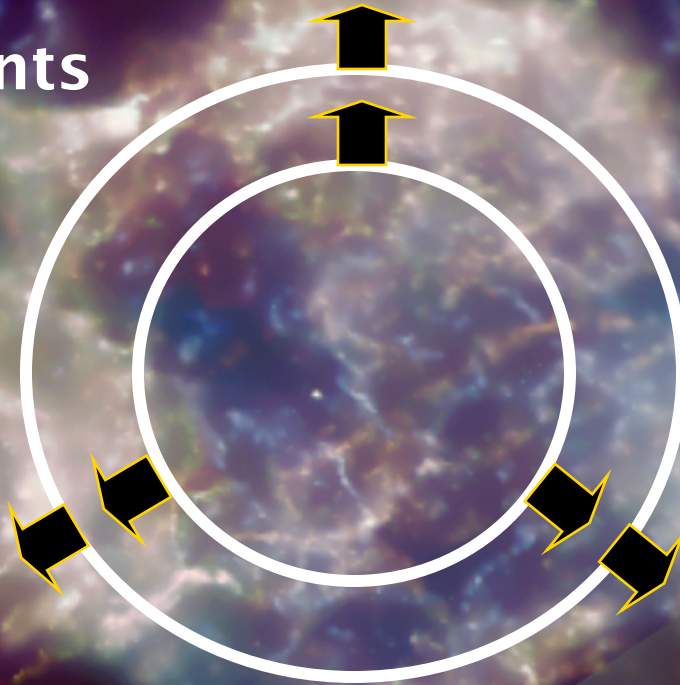
neutrinos from the cosmos

- **particle astrophysics instrumentation**

- **closing in on the cosmic ray puzzles**

  → **galactic cosmic rays**
  → **extragalactic cosmic rays**
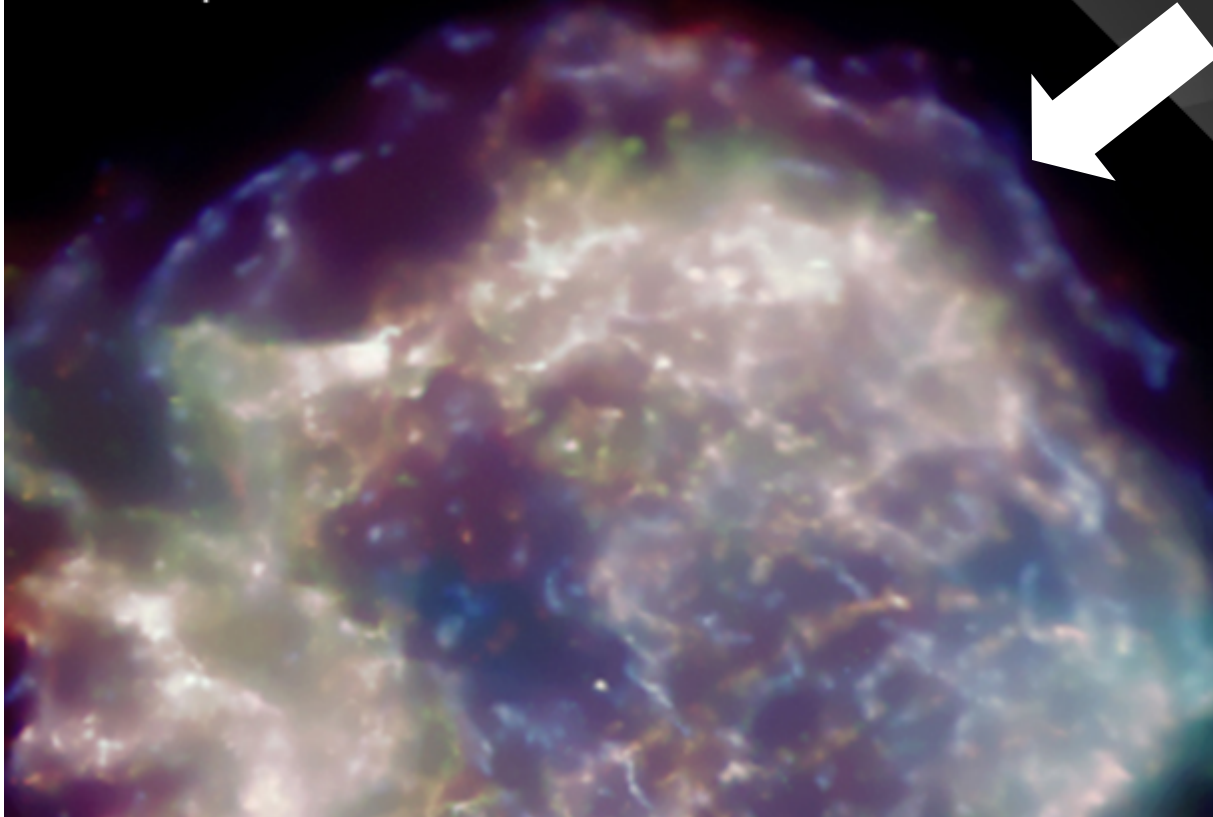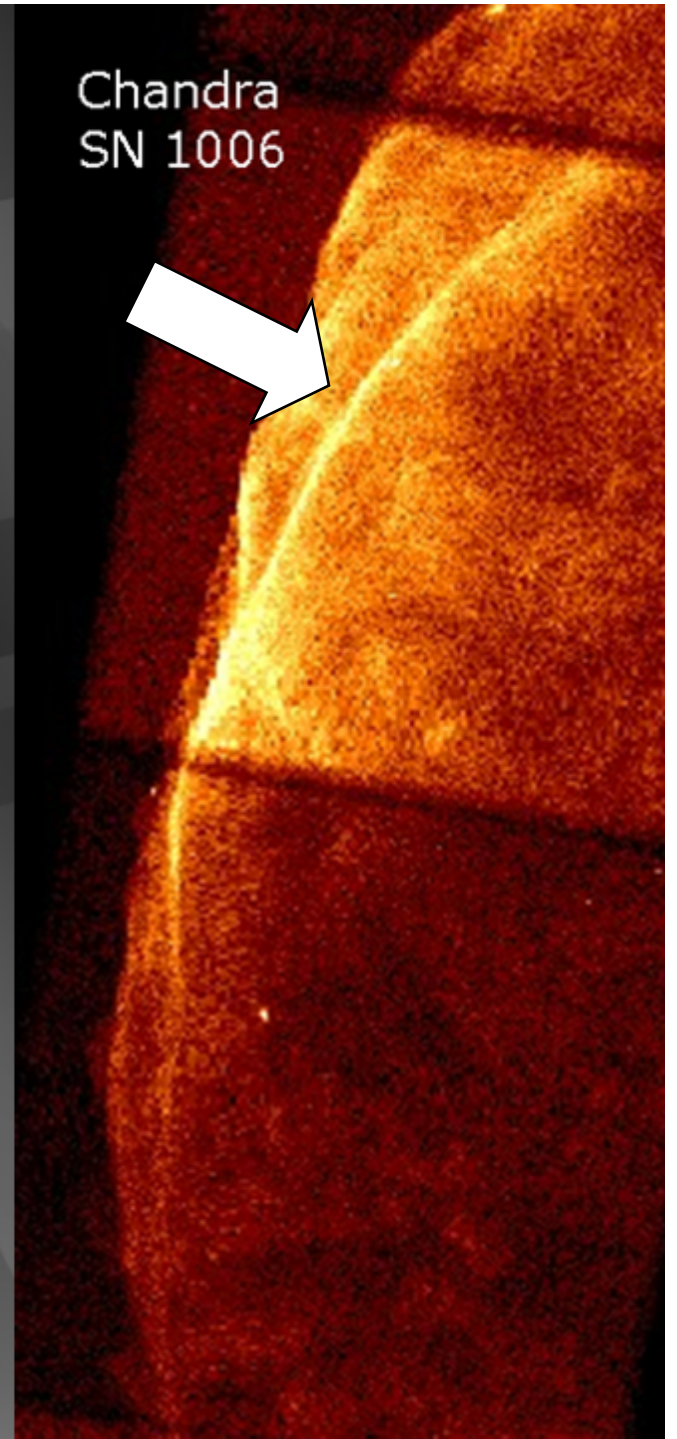
Cas A supernova remnant in X-rays

shock fronts

Fermi acceleration when particles cross high B-fields
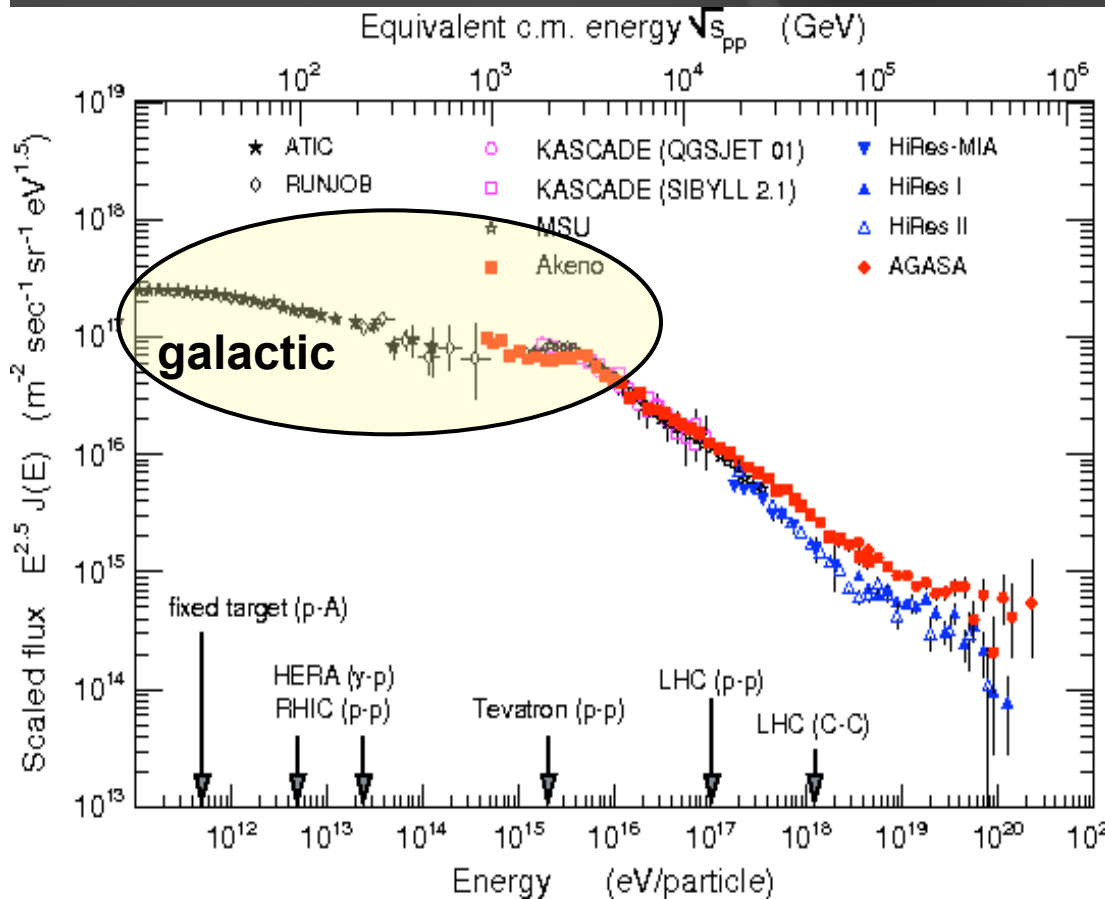
large
magnetic field

Chandra
SN 1006

Chandra
Cassiopeia A

Cosmic Rays & SNRs

observed energy density of galactic CR:

$\sim 10^{-12}$ erg/cm^3

supernova remnants:
10^{50} ergs every 30 years
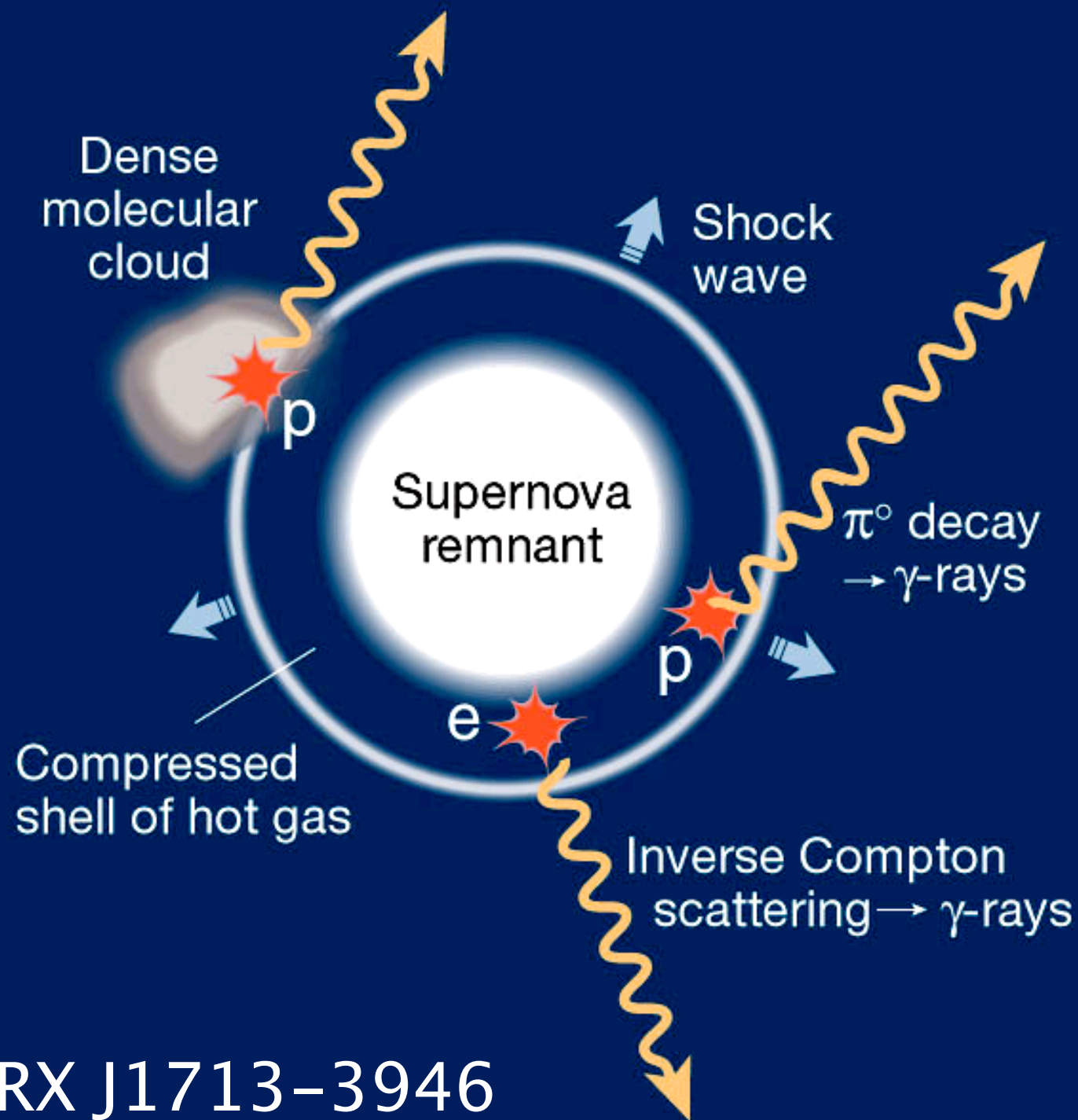
$\sim 10^{-12}$ erg/cm^3

for steady state of CR
with lifetime 10^6 years

**SNRs provide the environment and energy
to explain the galactic cosmic rays!**

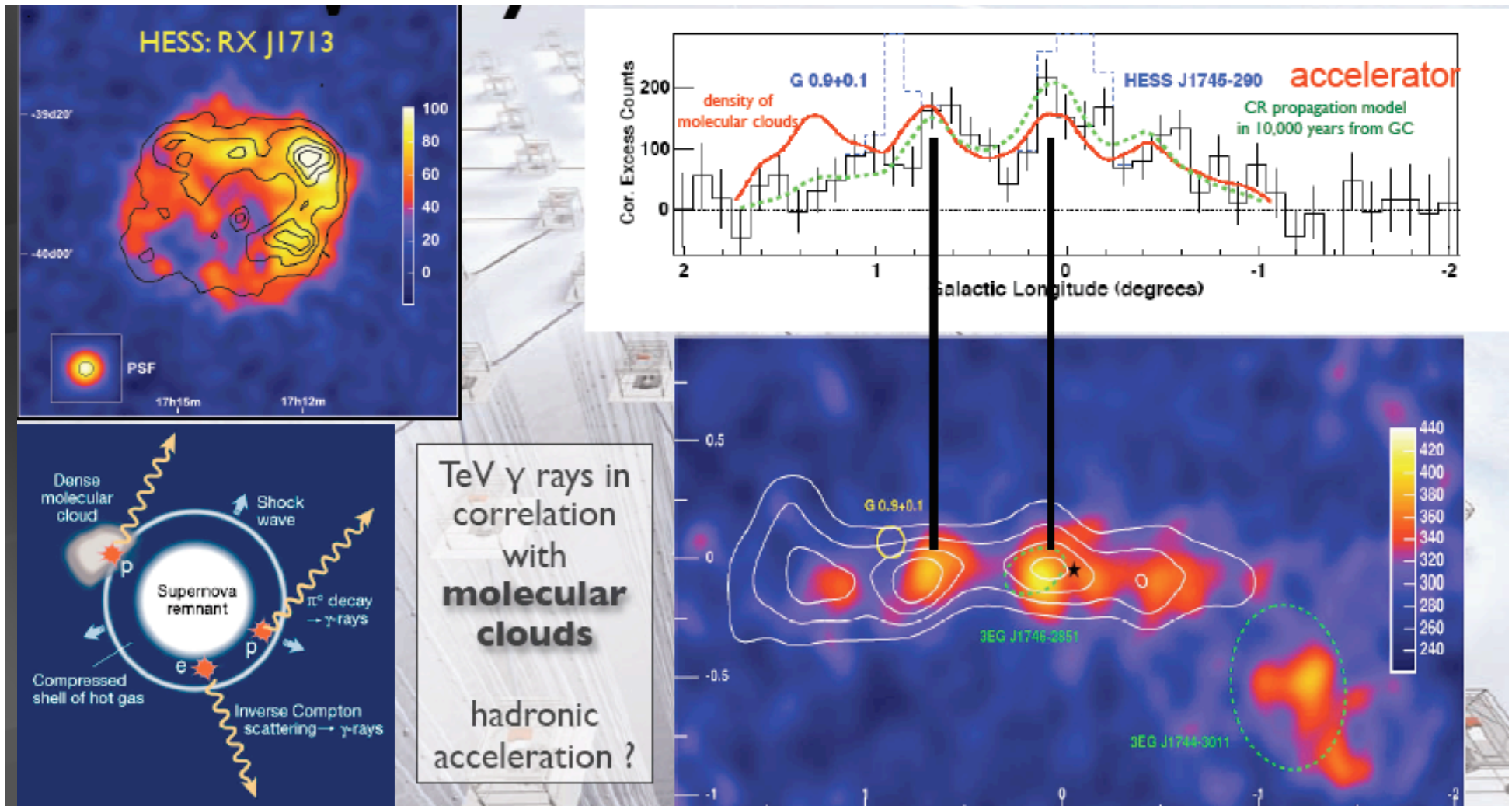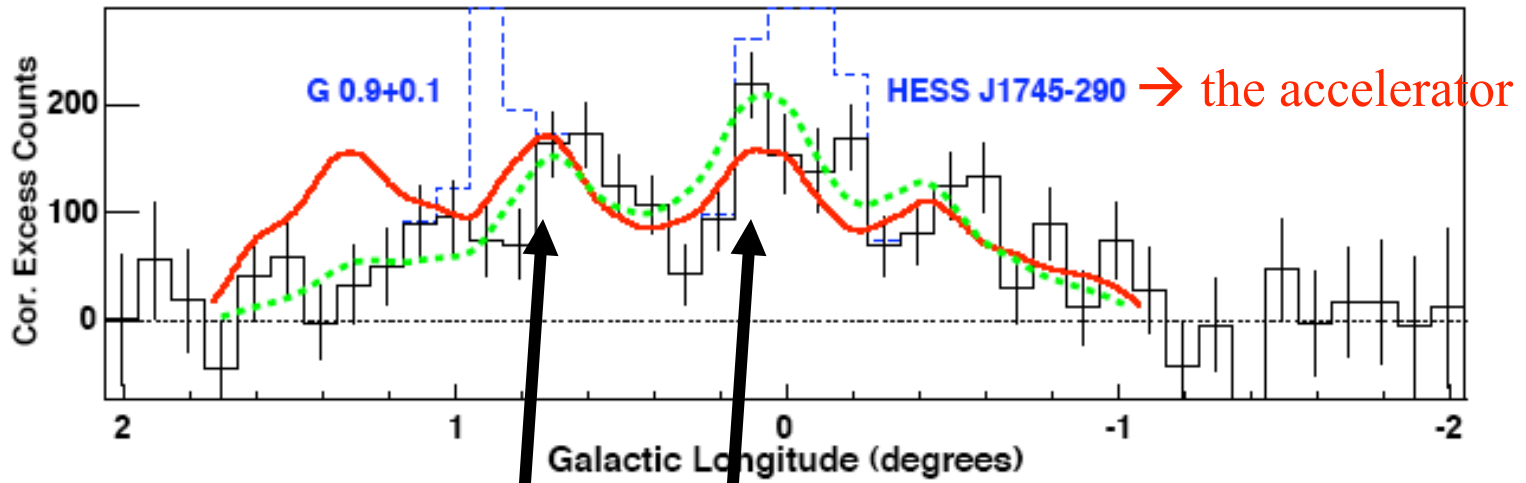# galactic cosmic rays can be revealed by their interaction with the ISM

supernova
beam
dump
→
molecular
clouds

Dense molecular cloud

Shock wave

Supernova remnant

π° decay $\rightarrow \gamma$-rays

p

e

p

Compressed shell of hot gas
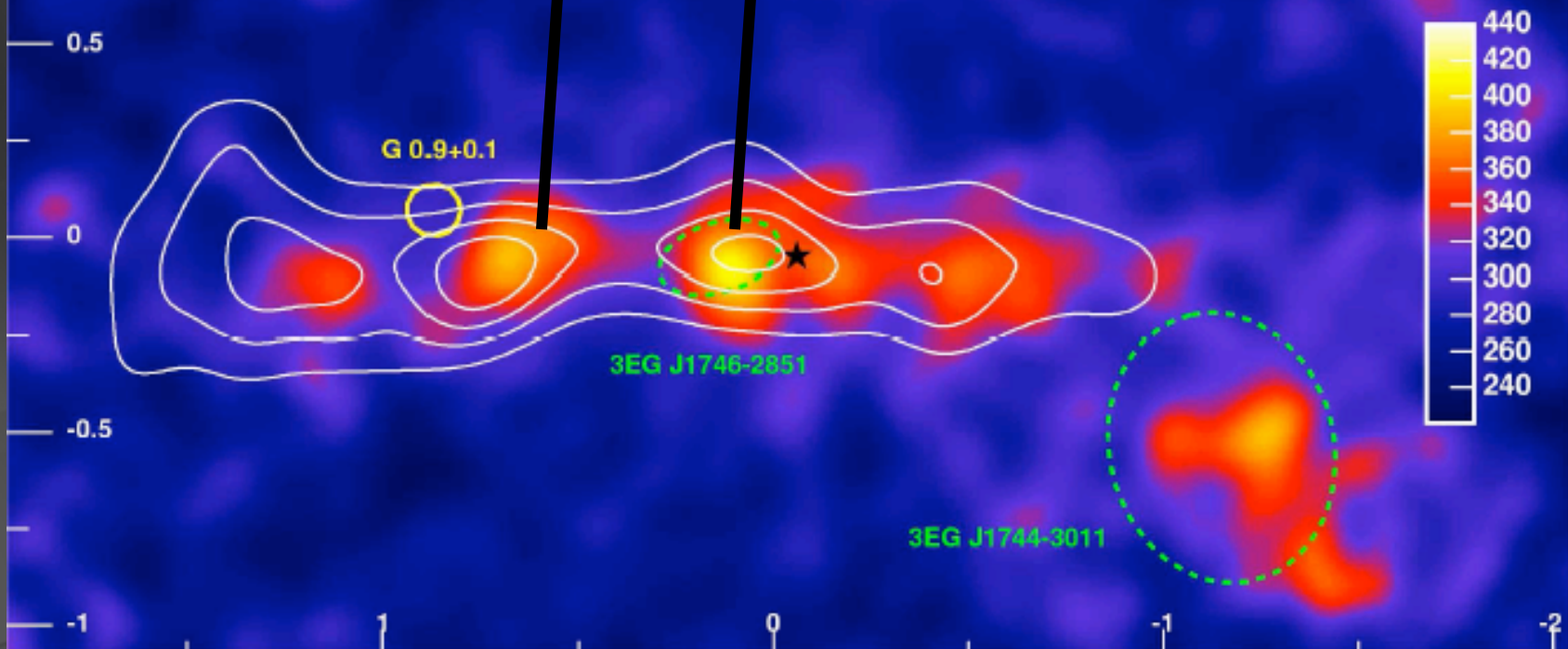
Inverse Compton scattering $\rightarrow \gamma$-rays

RX J1713–3946

galactic cosmic ray sources ?

Aharonian et al., Nature 439 (2006), 695

G 0.9+0.1   HESS J1745-290 → the accelerator
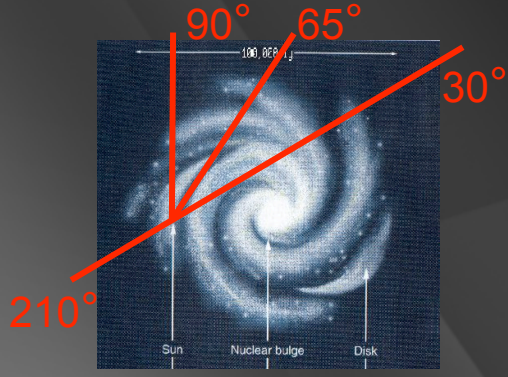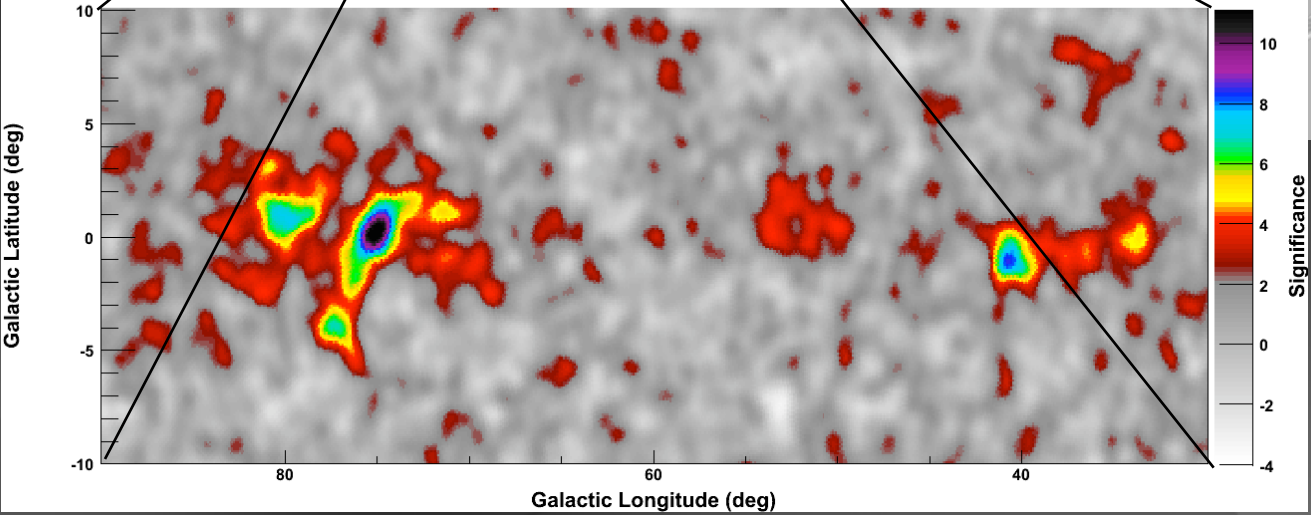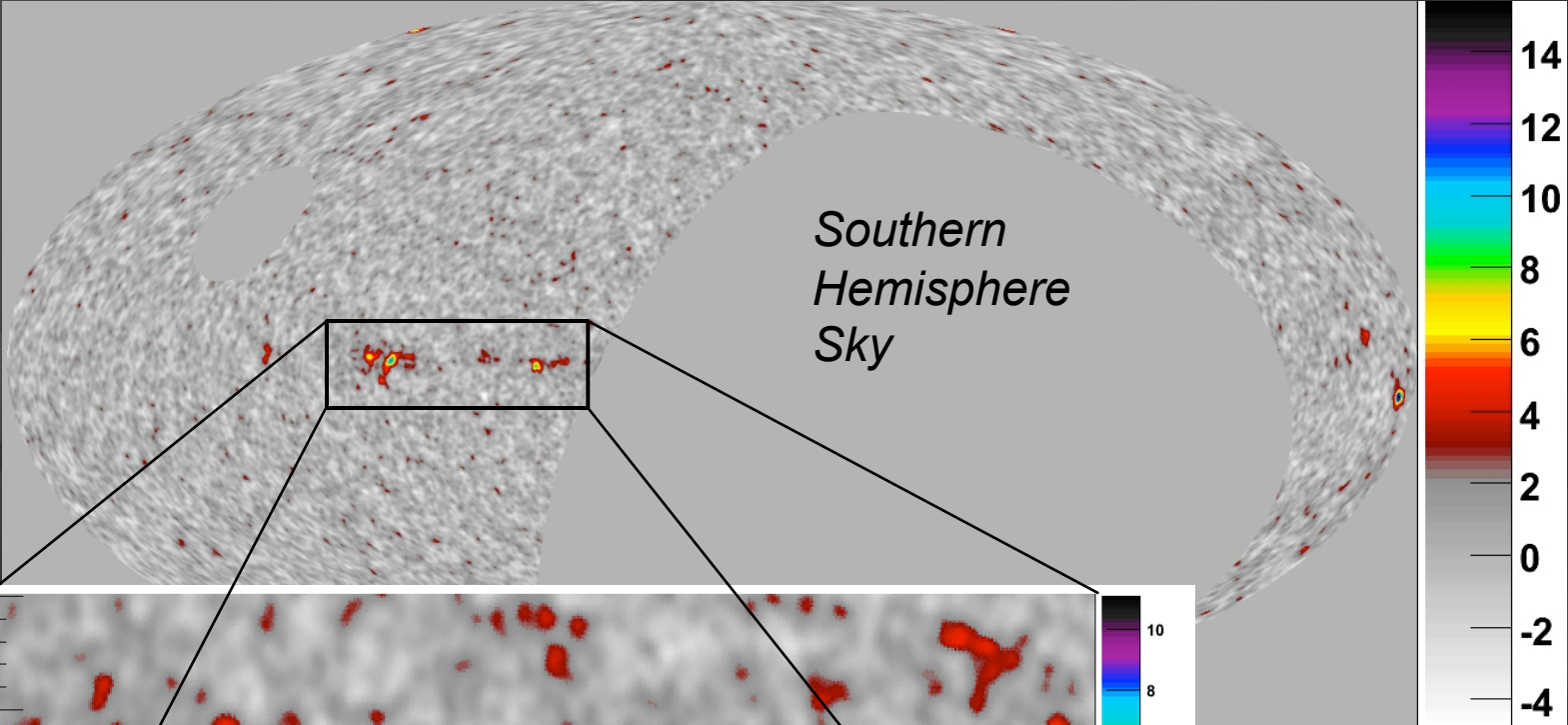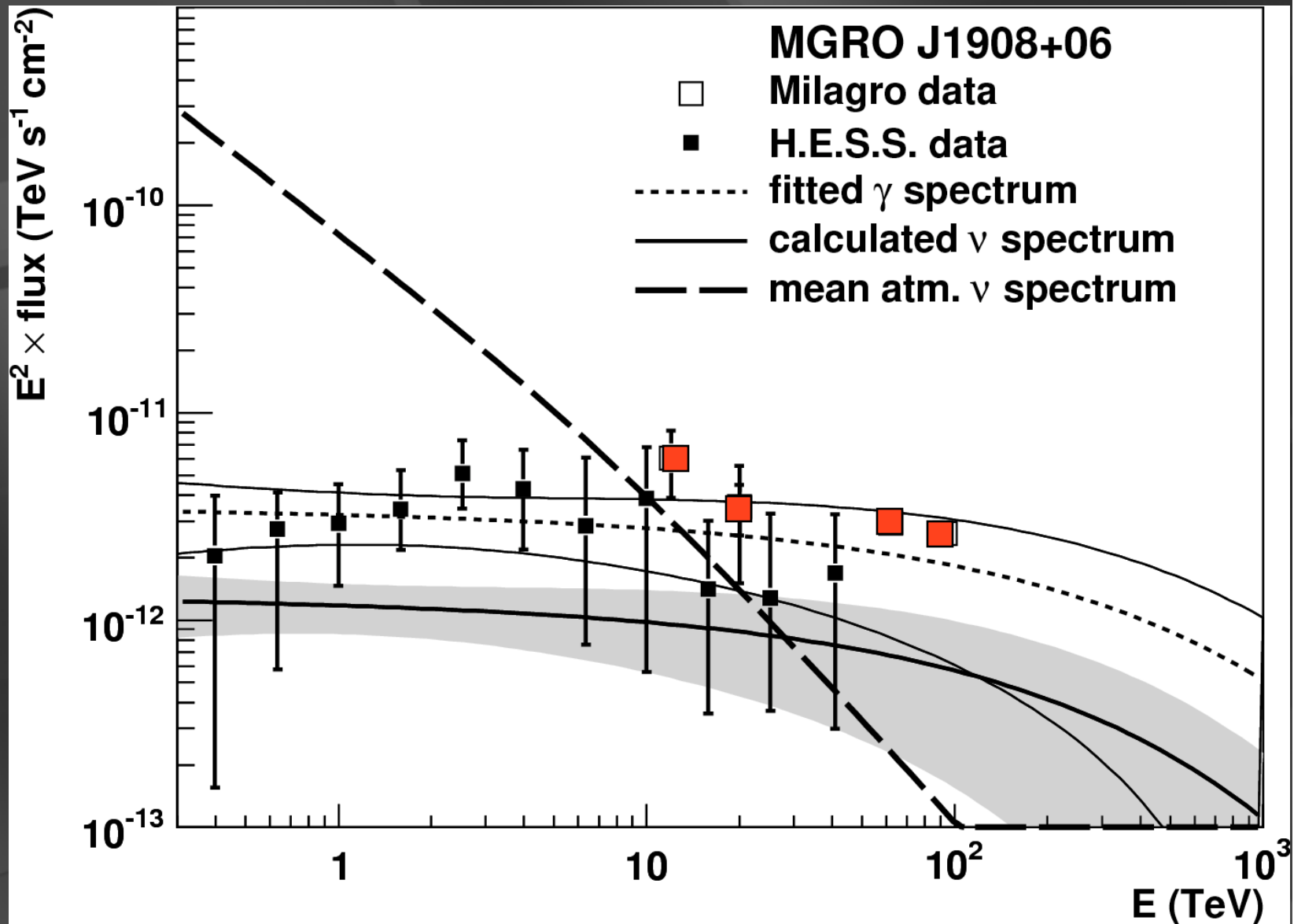
TeV photons trace the density of the molecular clouds

G 0.9+0.1
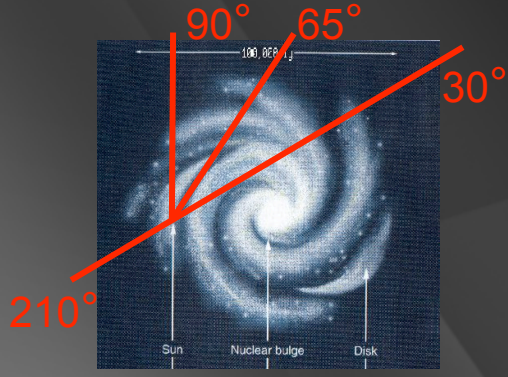
3EG J1746-2851

3EG J1744-3011

galactic plane

Southern Hemisphere Sky

Standard Deviations

14
12
10
8
6
4
2
0
-2
-4

MGRO J1908+06: the first Pevatron

galactic plane

Southern Hemisphere Sky
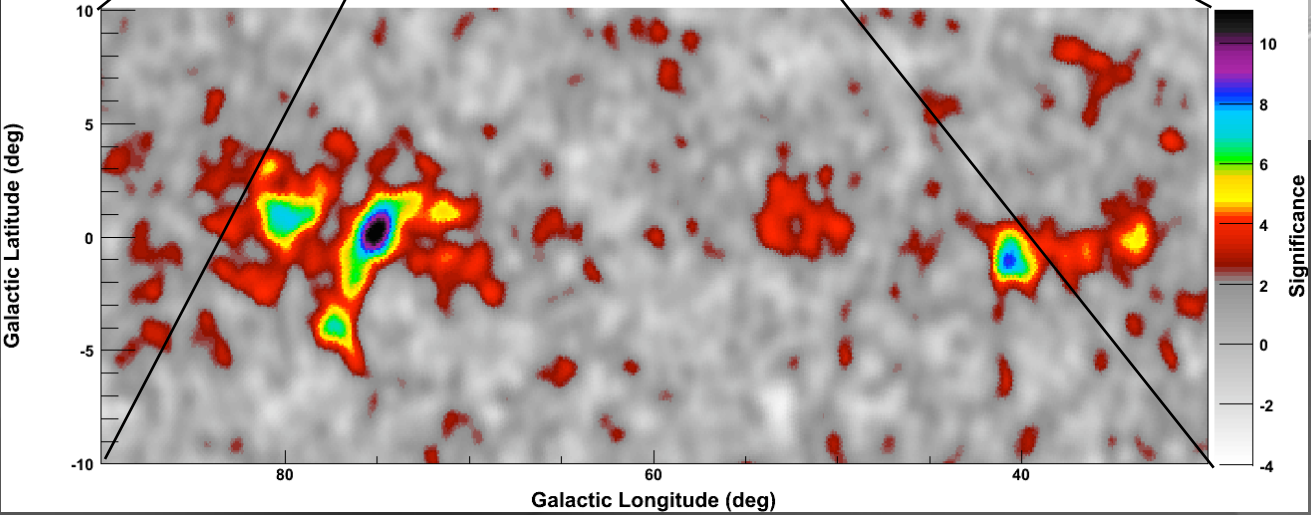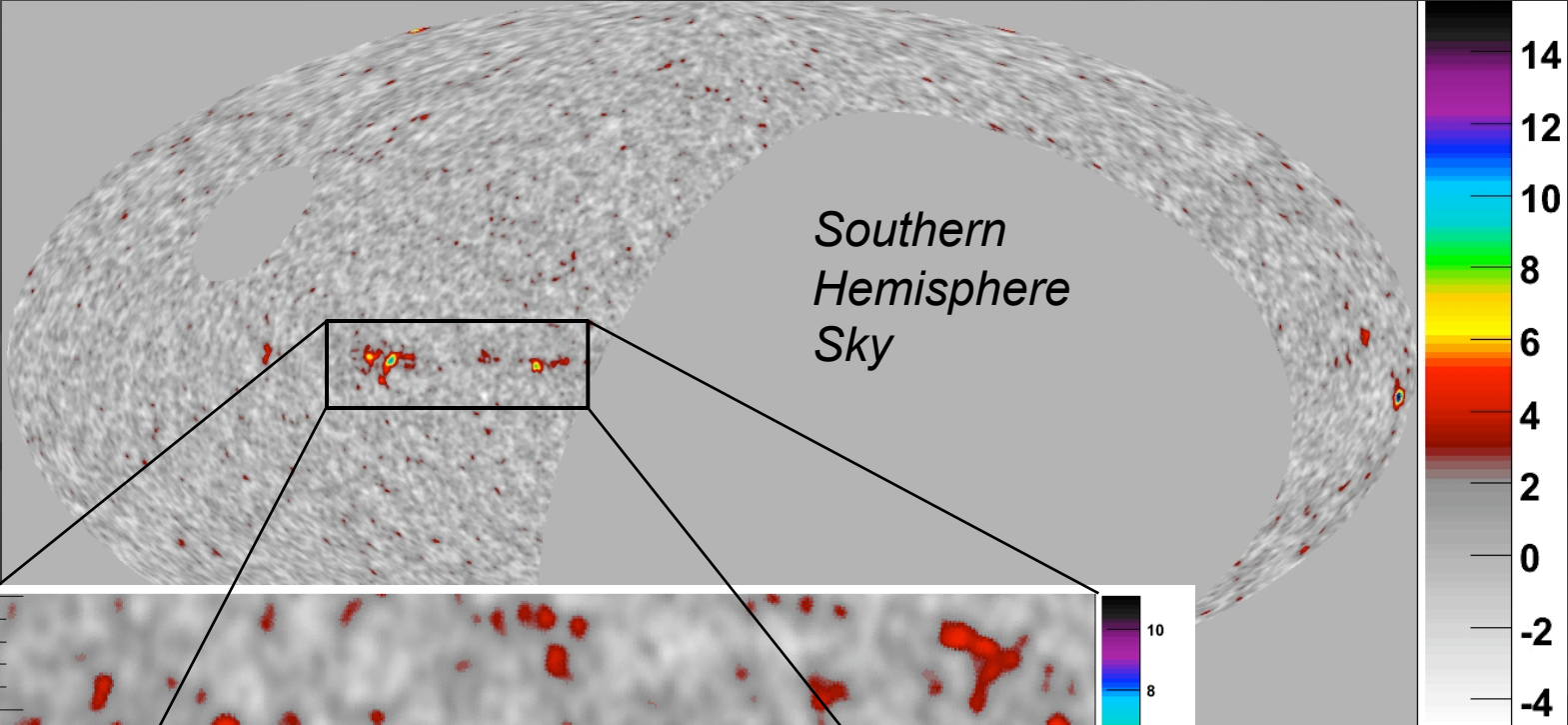
cygnus region : Milagro and Tibet
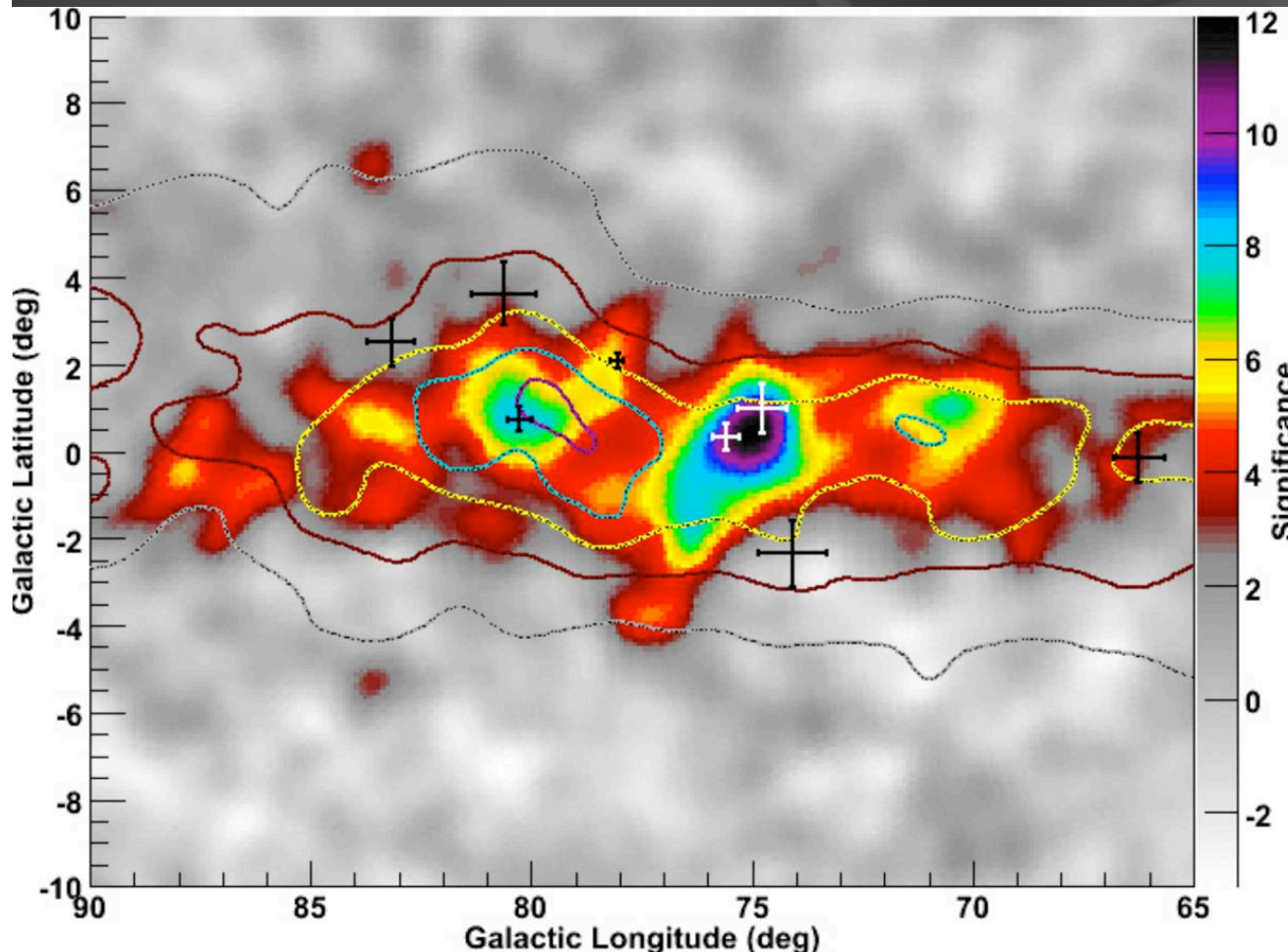
Milagro

contours are pion model
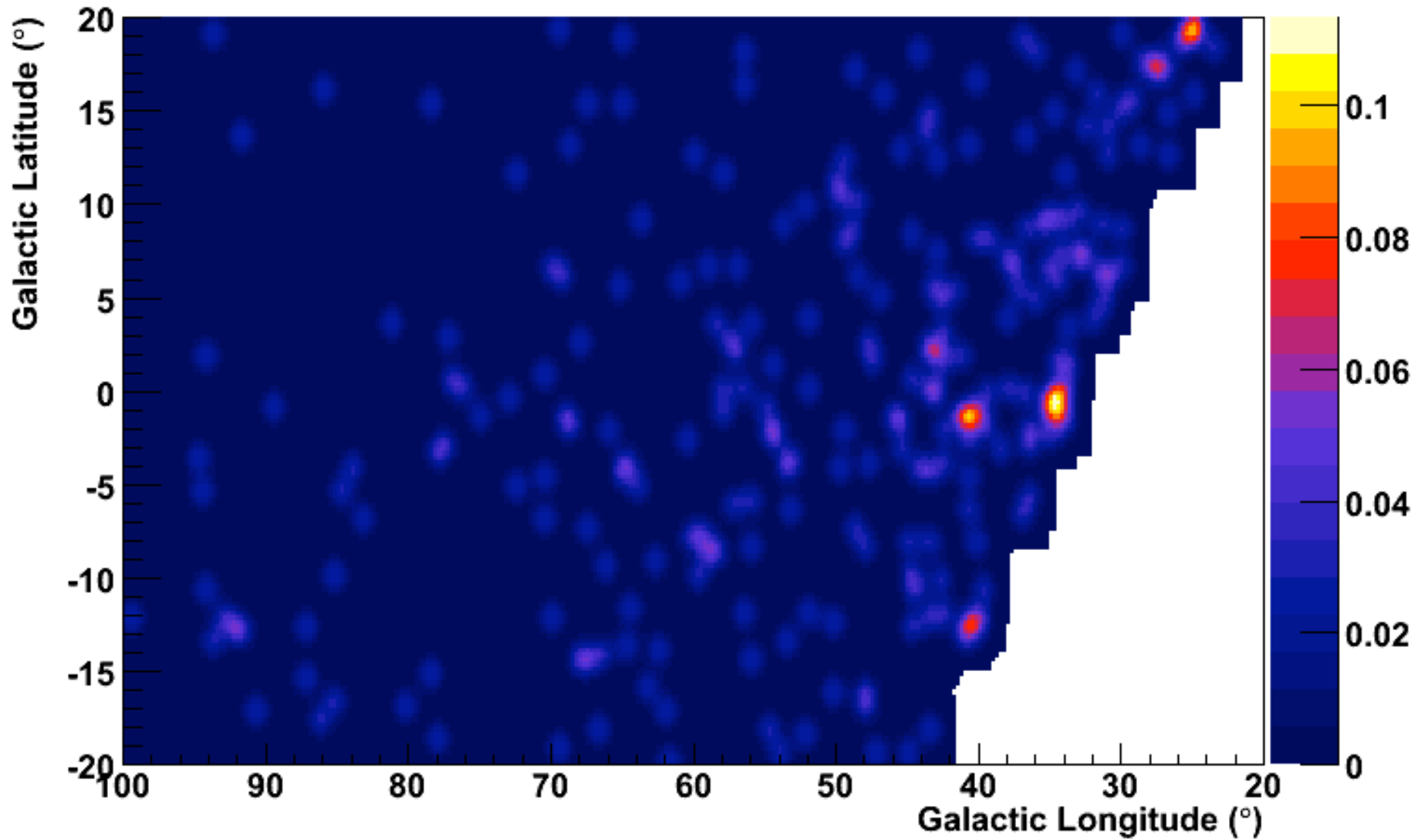with no sources

crosses are EGRET
unidentified sources

TeV/matter correlation

chance noncorrelation
1.5×10^{-6}

3 ± 1 ν per year in IceCube per source

IceCube 5 years (E > 40 TeV)

neutrinos from the cosmos

- **particle astrophysics instrumentation**

- **closing in on the cosmic ray puzzles**

     → **galactic cosmic rays**
     → **extragalactic cosmic rays**

Cosmic Rays & GRBs
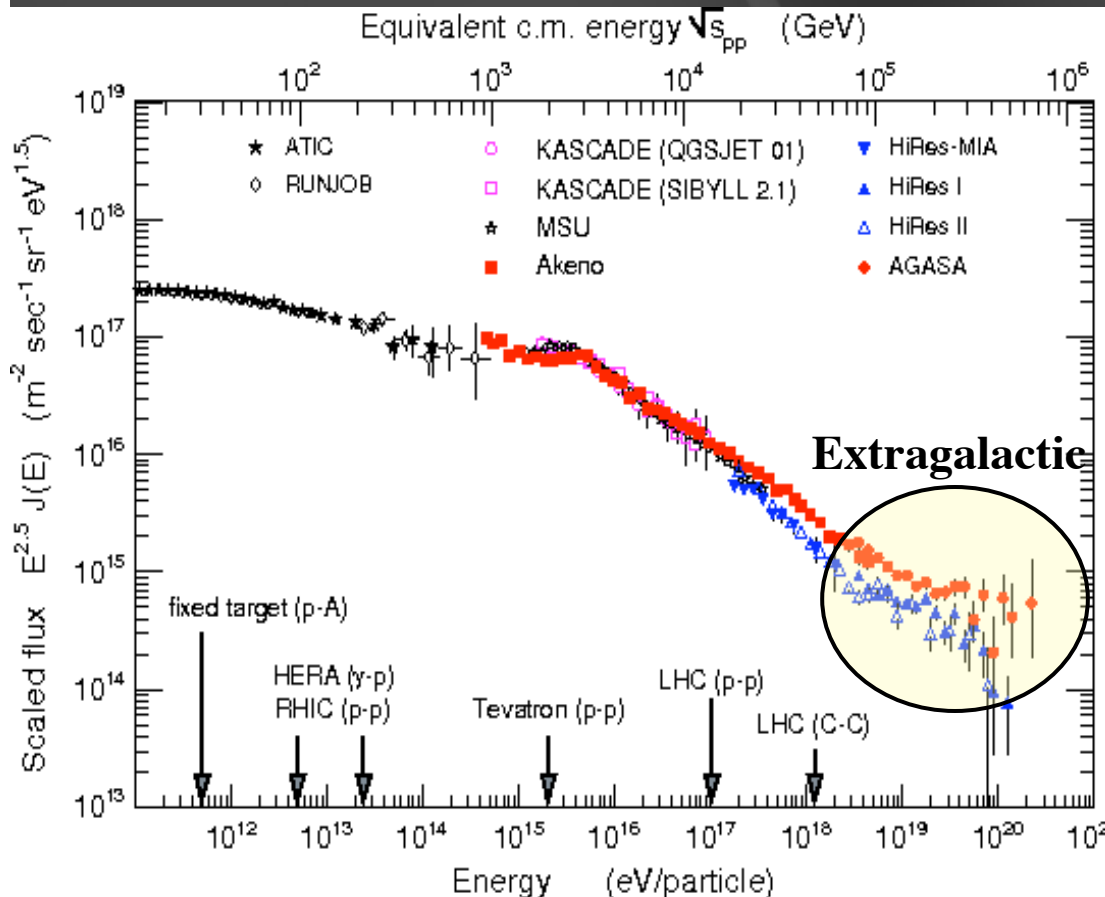
observed energy density of extragalactic CR:

$\sim 10^{-19}$ erg / cm^3

Gamma-Ray Bursts:
10^{52} ergs x 300/Gpc^3 x 10^{10} yr

$\sim 10^{-19}$ erg / cm^3

GRBs provide environment and energy to explain the extragalactic cosmic rays!

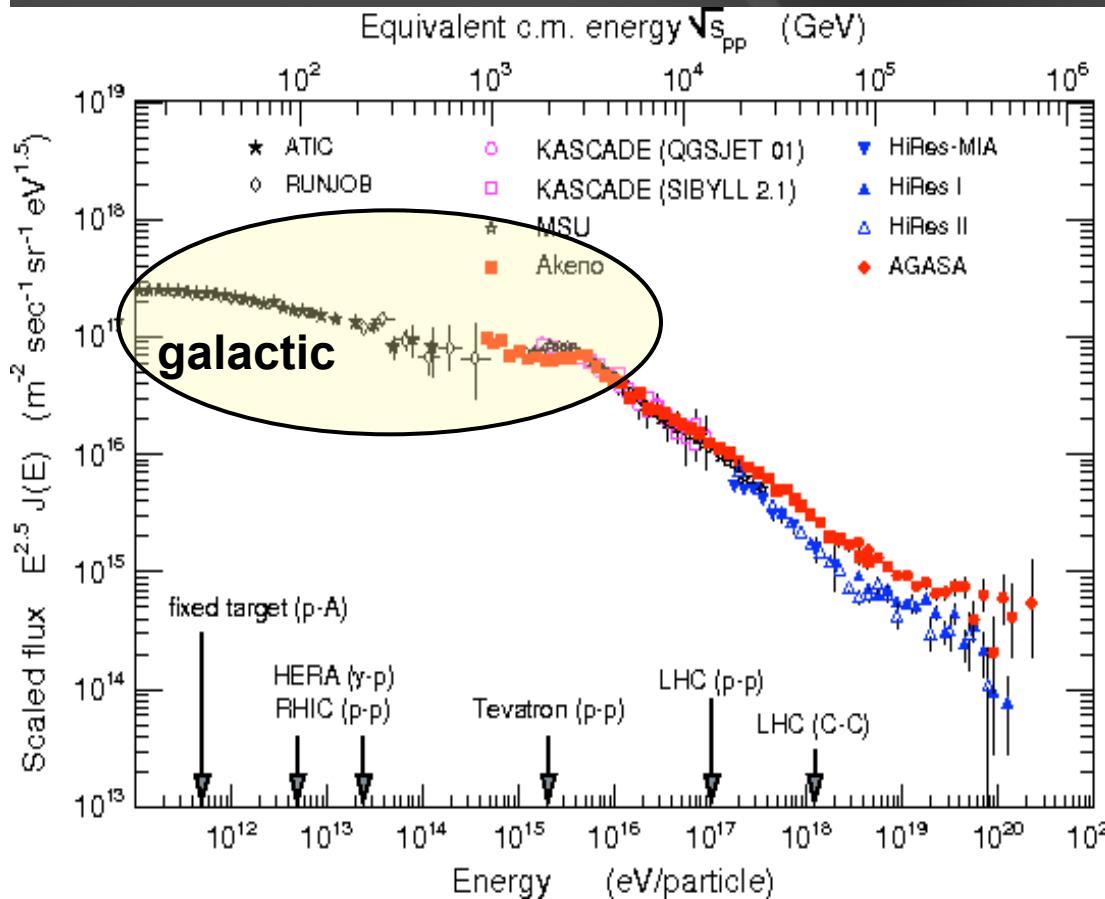# Cosmic Rays & SNRs

observed energy
density of galactic CR:

$\sim 10^{-12}$ erg/cm^3

supernova remnants:
10^{50} ergs every 30 years

$\sim 10^{-12}$ erg/cm^3

for steady state of CR
with lifetime 10^6 years

**SNRs provide the environment and energy
to explain the galactic cosmic rays!**

→ **energy in extra-galactic cosmic rays**

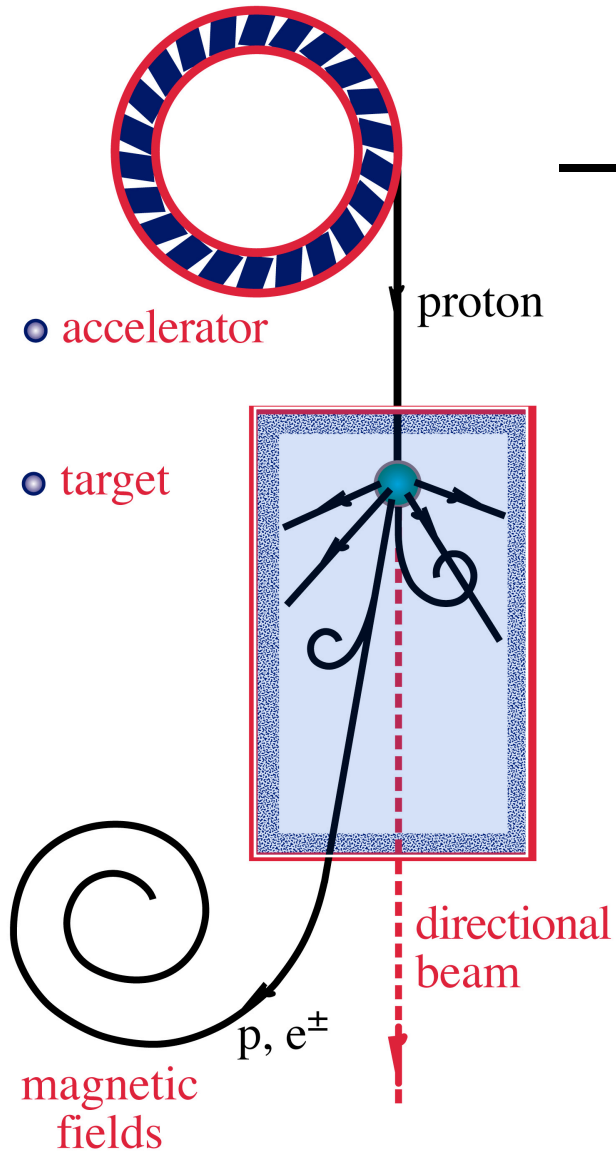 ~ 3×10^{-19} erg/cm^3 or
  ~ 10^{44} erg/yr per (Mpc)^3 for 10^{10} years

3×10^{44} erg/s per active galaxy !!!
2×10^{52} erg per gamma ray burst

→ energy in cosmic rays ~ equal to
   the energy in light !

accelerator

proton
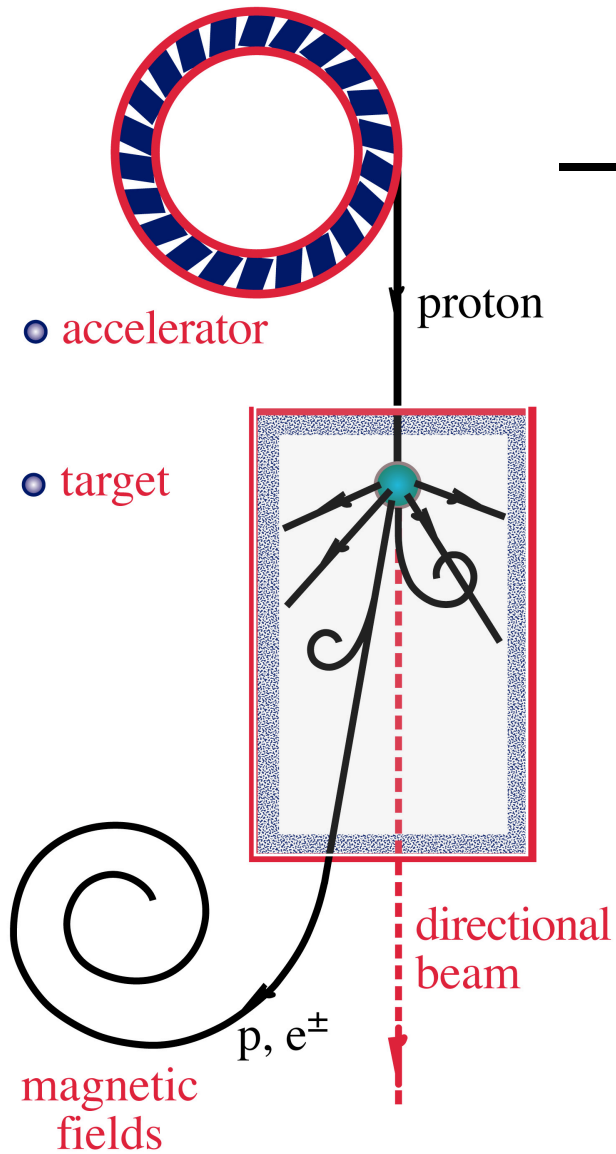
target

magnetic
fields

p, e$^\pm$

directional
beam

Black Hole

**Radiation
Enveloping
Black Hole**

$$p + \gamma \rightarrow n + \pi^+$$
~ cosmic ray + neutrino

$$\rightarrow p + \pi^0$$
~ cosmic ray + gamma
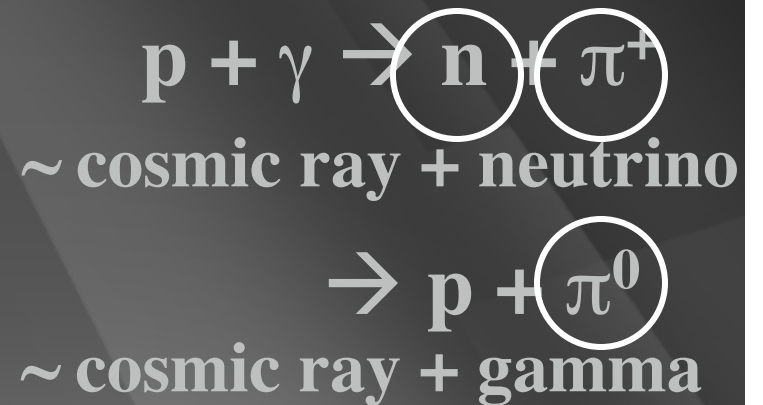
NEUTRINO BEAMS: HEAVEN & EARTH

proton

- accelerator

- target

directional
beam

p, e±

magnetic
fields

black hole

**radiation/gas
envelope of
black hole**

$$p + p \rightarrow \pi^+ + \pi^- + \pi^0$$

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi \rightarrow \nu_\mu + \left(e + \nu_e + \nu_\mu\right)$$
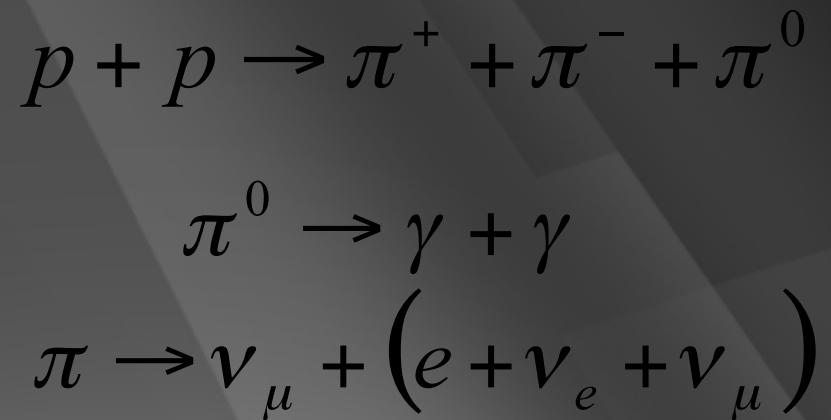
→ **energy in extra-galactic cosmic ray**

~ 3×10^{-19} **erg/cm³ or**
~ 10^{44} **erg/yr per (Mpc)³ for 10^{10} years**

3×10^{44} **erg/s per active galaxy**
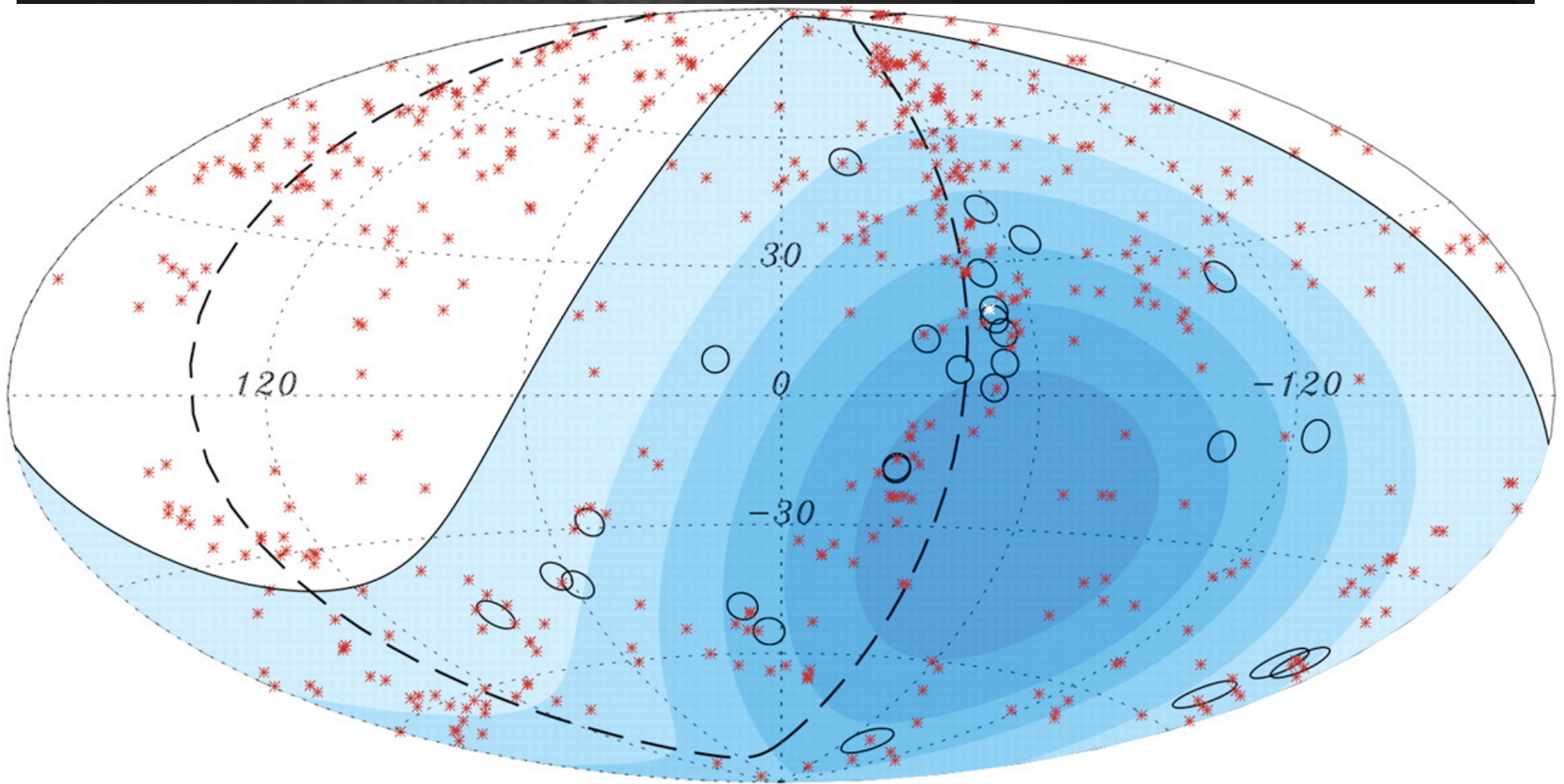2×10^{52} **erg per gamma ray burst**

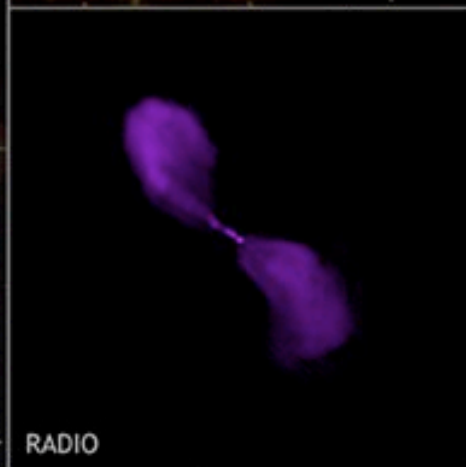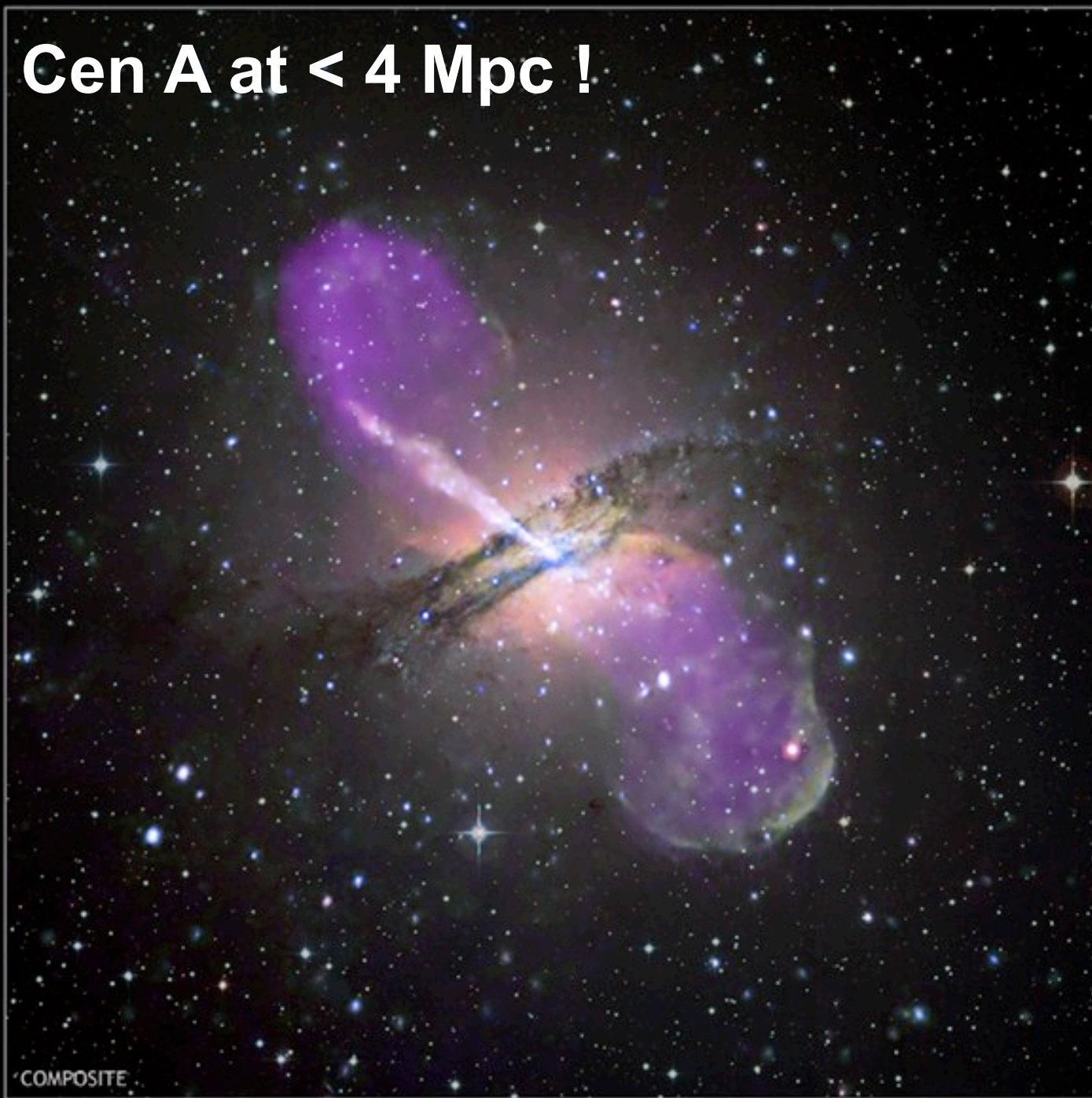→**energy in**

cosmic rays ~ photons ~ neutrinos

neutrinos associated with extragalactic cosmic rays
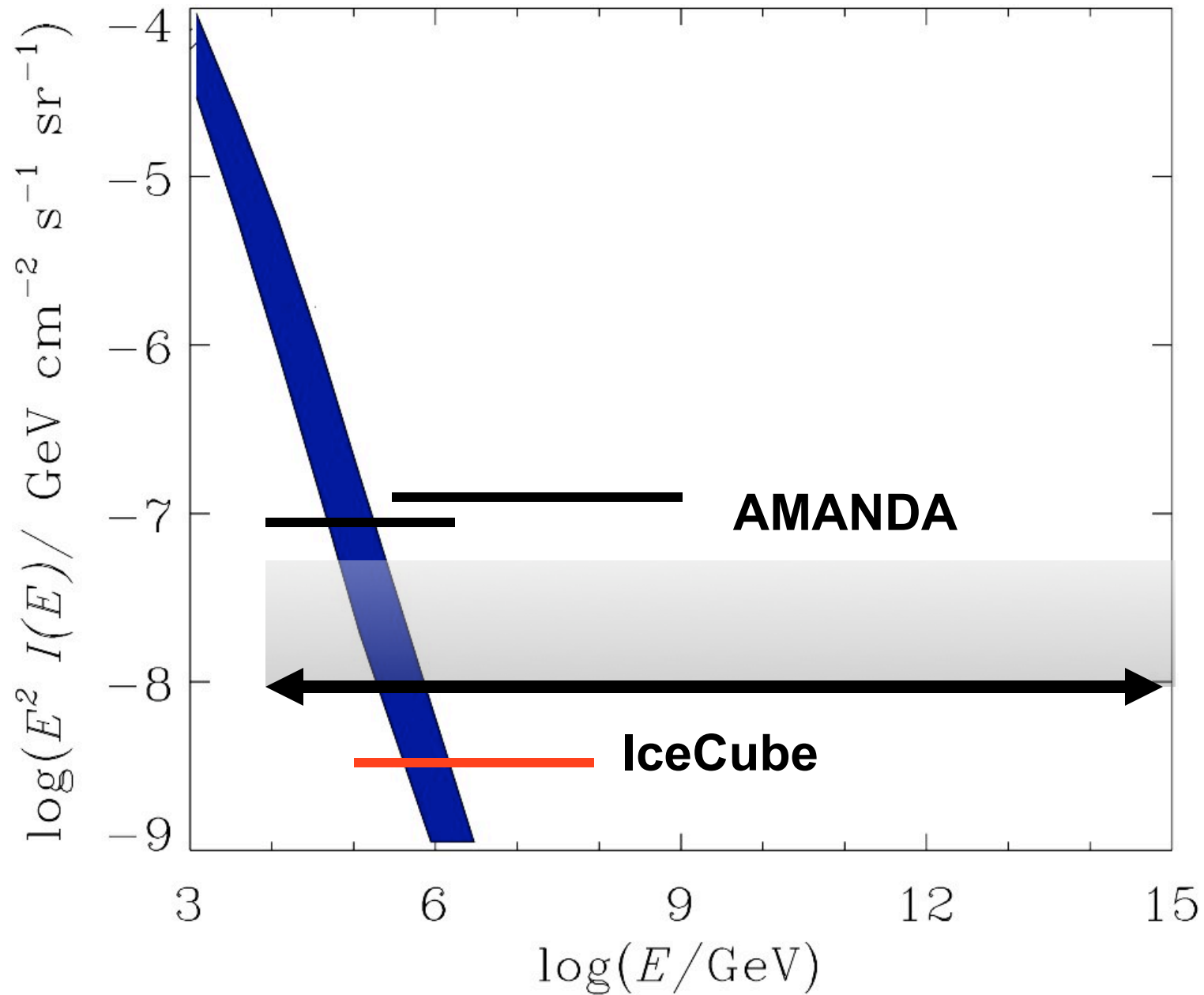
Auger : the sources revealed ?

Cen A at < 4 Mpc !

COMPOSITE

X-RAY

RADIO

OPTICAL

active galaxy

Cen A *p+p*

gas density
$n \sim 10^6 \ cm^{-3}$

supermassive
black hole :

10^8 *solar mass*

accretion disk

jet