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 Cassiopeia A

Chandra SN 1006
Cosmic Rays & SNRs

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

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

for steady state of CR with lifetime \(10^6\) years

observed energy density of galactic CR:
\[\sim 10^{-12} \text{ erg/cm}^3\]
galactic cosmic rays can be revealed by their interaction with the ISM
Supernova beam dump \rightarrow molecular clouds
galactic cosmic ray sources?

TeV γ rays in correlation with molecular clouds
hadronic acceleration?

Aharonian et al., Nature 439 (2006), 695
TeV photons trace the density of the molecular clouds

→ the accelerator
galactic plane

Southern Hemisphere Sky

Standard Deviations

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

210° 90° 65° 30°
MGRO J1908+06: the first Pevatron
galactic plane

Southern Hemisphere Sky

Standard Deviations

90°, 65°, 30°, 210°
cygnus region: Milagro and Tibet

Milagro
- contours are pion model with no sources
- crosses are EGRET unidentified sources
- TeV/matter correlation
- chance noncorrelation $1.5 \times 10^{-6}$

$3 \pm 1 \nu$ per year in IceCube per source
IceCube 5 years (E > 40 TeV)
neutrinos from the cosmos

- particle astrophysics instrumentation
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  - galactic cosmic rays
  - extragalactic cosmic rays
Cosmic Rays & GRBs

Gamma-Ray Bursts:
$10^{52}$ ergs x $300$/Gpc$^3$ x $10^{10}$ yr
$\sim 10^{-19}$ erg / cm$^3$

Observed energy density of extragalactic CR:
$\sim 10^{-19}$ erg / cm$^3$

GRBs provide environment and energy to explain the extragalactic cosmic rays!
Cosmic Rays & SNRs

Supernova remnants:

\[ 10^{50} \text{ ergs every 30 years} \]

\[ \sim 10^{-12} \text{ erg/cm}^3 \]

for steady state of CR with lifetime \( 10^6 \) years

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

Observed energy density of galactic CR:

\[ \sim 10^{-12} \text{ erg/cm}^3 \]
energy in extra-galactic cosmic rays

\[ \sim 3 \times 10^{-19} \, \text{erg/cm}^3 \text{ or} \]
\[ \sim 10^{44} \, \text{erg/yr per (Mpc)}^3 \text{ for } 10^{10} \text{ years} \]

\[ 3 \times 10^{44} \, \text{erg/s per active galaxy} \]
\[ 2 \times 10^{52} \, \text{erg per gamma ray burst} \]

energy in cosmic rays \( \sim \) equal to the energy in light!
ν and γ beams: heaven and earth

Black Hole

Radiation Enveloping Black Hole

\[ p + γ \rightarrow n + π^+ \]
\[ \sim \text{cosmic ray + neutrino} \]
\[ \rightarrow p + π^0 \]
\[ \sim \text{cosmic ray + gamma} \]
NEUTRINO BEAMS: HEAVEN & EARTH

black hole

radiation/gas envelope of black hole

\[ p + p \rightarrow \pi^+ + \pi^- + \pi^0 \]

\[ \pi^0 \rightarrow \gamma + \gamma \]

\[ \pi \rightarrow \nu_\mu + (e + \nu_e + \nu_\mu) \]
energy in extra-galactic cosmic ray

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

$\sim 10^{44}$ erg/yr per (Mpc)$^3$ for $10^{10}$ years

$3 \times 10^{44}$ erg/s per active galaxy

$2 \times 10^{52}$ erg per gamma ray burst

cosmic rays $\sim$ photons $\sim$ neutrinos
neutrinos associated with extragalactic cosmic rays

\[ \log(E^2 I(E)) / \text{GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \]

\[ \log(E/\text{GeV}) \]

AMANDA

IceCube
Auger: the sources revealed?
Cen A at < 4 Mpc !
active galaxy

Cen A $p + p$

supermassive black hole: $10^8$ solar mass

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

accretion disk

jet