High-Energy Electrons, Positrons, and Gamma Rays from Geminga

Matt Kistler
Ohio State
Zwicky

Supernovae as source of cosmic rays

Neutron stars result from supernovae

What is the cosmic ray output of pulsars?
PULSAR WIND

\[ \dot{N}_{\text{GJ}} \sim B \Omega^2 R^3 / ec \]

GOLDRreich and Julian (1969)
VELA X

HESS (2006)

NEBULA NOT SHOWN

LARGER RADIO

290 PC

11,000 YR
VELA X

ELECTRON SPECTRUM
CONSISTENT WITH $E^{-2}$
WITH EXPONENTIAL
CUTOFF AT $\sim 70$ TEV

$\sim 2 \times 10^{45}$ ERG IN
TEV ELECTRONS

$\sim 4 \times 10^{48}$ ERG
INCLUDING RADIO NEBULA

(SEE DEJAGER 2007)

HESS (2006)

$$\mathcal{M} = \frac{\dot{N}_{e^\pm}}{\dot{N}_{GJ}}$$
HESS J1825–137

$>10^{48}$ ERG

$3.9 \pm 0.4$ KPC

21,400 YR

HESS (2006)
MULTI-TEV ELECTRONS
BEING MEASURED

HESS J1825–137
DEEP OBSERVATIONS
DUE TO NEARBY LS 5039

MULTI-TEV ELECTRONS
BEING MEASURED

HESS (2006)
Look to the TeV

MILAGRO (FROM TALK BY B. DINGUS)
MILAGRO (2009)

GEMINGA DETECTED IN ~35 TEV GAMMA RAYS

EXTENDED SOURCE

VERITAS CONSTRAINS POINT SOURCE

MILAGRO (2009)
\[ \geq 100 \text{ TeV } e^{\pm} \text{ needed} \]

\[ \tau_{IC} \sim 10^4 \left( \frac{100 \text{ TeV}}{E_e} \right) \text{ yr} \]

\[ t_G \sim 3 \times 10^5 \text{ yr} \]

\[ \dot{\mathcal{E}}_{\gamma, \text{TeV}} \sim 10^{32} \text{ erg s}^{-1} \]

\[ \frac{d\Phi}{dE_\gamma} = \frac{c}{4\pi r_G^2} \int d\gamma \int dE_b \frac{dN}{d\gamma} \ n_b(E_b) \sigma_{\text{KN}}(\gamma, E_b, E_\gamma) \]

\[ \dot{\mathcal{E}}_{e^{\pm}} \approx \dot{N}_{e^{\pm}} \langle E_{e^{\pm}} \rangle \approx \mathcal{M} \dot{N}_{\text{GJ}} \langle E_{e^{\pm}} \rangle \approx 2 \times 10^{30} \mathcal{M} \text{ erg s}^{-1} \]

\[ \mathcal{M} \geq 100 \]

PAIR PRODUCTION IS REQUIRED TO ACCOUNT FOR TEV GAMMA RAY LUMINOSITY
HESS J1825–137 DATA

~100 PC
HESS J1825–137 IF PLACED AT ~200 PC
TIME-DEPENDENT PROPAGATION FROM A POINT SOURCE

\[ Q(E) = Q_0 E^{-\alpha} \]

\[ \left( \frac{dE}{dt} \right)_r = -bE^2 \]

\[ E_{\text{max}} = (bt)^{-1} \]

\[ \tau_{\text{diff}}(E, t) \approx 2 \sqrt{D(E) t} \frac{1 - \left(1 - \frac{E}{E_{\text{max}}} \right)^{1-\delta}}{(1-\delta) \frac{E}{E_{\text{max}}}} \]

\[ f_e(r, t, E) = \frac{Q(E)}{\pi^{3/2} r^3} \left(1 - btE\right)^{\alpha-2} \left(\frac{r}{\tau_{\text{diff}}}\right)^3 e^{-\left(\frac{r}{\tau_{\text{diff}}}\right)^2} \]
Dotted, Solid, Dashed lines correspond to

\[ E_G = 1, 2, 3 \times 10^{48} \text{ erg} \]
\[ \delta = 0.4, 0.5, 0.6 \]
\[ r_G = 150 \rightarrow 250 \text{ pc, } 220 \text{ pc, } 250 \rightarrow 200 \text{ pc} \]

\[ \mathcal{L}_{e^\pm}(t) \propto (1 + t/t_0)^{-2} \]
Historical perspective

**Ginzburg:** I agree that it is extraordinarily difficult to disprove anything.

**Alfvén:** To disprove anything is very difficult, but also to prove it.

**Ginzburg:** Fortunately it is possible to do something. I have worked in the field for some years, and I can say in the course of time the argument slowly improves. So I hope during my lifetime I shall see the full victory of these things.

**Alfvén:** I hope you will live very long.

74. DISCUSSION ON COSMIC RAYS AND RELATED PROBLEMS

I.A.U. Symposium no. 31, 1967