"NEW" OBSERVATION OF TEV GAMMA RAY SOURCES:
Relation to Origin of Matter and Early Universe

Tadashi Kifune
*Institute for Cosmic Ray Research, University of Tokyo,*
*Midori 3-2-1, Tanashi, Tokyo 188, Japan*

The observation of TeV gamma rays from celestial objects has recently come onto a firmly founded stage that has several "established" sources with the sensitivity at the level of $\sim 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. A quantitative argument has become available about the underlying process by comparing the high energy gamma ray flux with the other wavelengths, providing a direct clue to uncover non-thermal high energy features of the Universe.

## 1 Introduction

The Universe appears to show a wealth of nonthermal phenomena. Non-thermal radiation has dominant contribution to the total luminosity of the gamma ray sources. Gamma rays are linked with matter by interactions of elementary particles, and gamma ray detection verifies the processes of particle acceleration taking place in bright gamma ray sources, such as AGN (active galactic nuclei) and pulsars.

Mechanism of the non-thermal emission, characterized by a power law energy spectrum, gives a monotonously decreasing number of gamma ray photons with increasing energy. Large collection area is necessary for detectors as well as a considerable thickness of material to fully absorb a cascade shower that gamma rays generate in the instruments. The requirement limits the opportunities of launching gamma ray satellites, and has made high energy gamma ray astronomy to be the last band of electromagnetic radiation to join the modern astronomy. The EGRET instrument of CGRO (Compton Gamma Ray Observatory) was launched in 1991 to discover more than 150 gamma ray sources at 100 MeV to 10 GeV energies (1). Ground-based observation that utilizes the atmosphere as a calorimeter of absorbing gamma rays has a large detection area of more than $10^8$ cm$^2$ and could establish, also recently in 1990's, several sources of VHE (very high energy) gamma rays at $\sim 1$ TeV. The breakthrough of the ground based detection was enabled by the angular resolution of $\sim 0.1°$ of IACT (imaging air Čerenkov telescope), being followed by the next generation of IACT systems for persuing better sensitivities and lower threshold energies below 100 GeV. The present paper discusses the current status of VHE gamma ray astronomy (*e.g.* see (2), references therein), paying atttention to the relevance of gamma ray astronomy to the title of the present Conference, "Origin of Matter and Early Universe".

## 2 Current status of VHE gamma ray astronomy

The number of gamma ray sources in the energy range of 100 MeV to 10 GeV is shown in Table 1. Most of the sources are not identified yet with the objects seen with the other wavelengths. The unidentified EGRET sources of galactic latitude $\leq 10°$ are probably of Galactic origin and some of these appear within the error circle of detection to be associated with known objects such as supernova remnant. However, the angular resolution typically of 1°, is not as good as those in the other wavelengths to conclude that the associated object is responsible for the observed GeV gamma rays. A typical example of unidentified gamma ray source was Geminga that had remained long as a riddle for about 20 years, and the time-modulated signal of gamma ray data could identify Geminga to be a "middle age" pulsar (3) which is quiet in radio and X-rays. Many other such pulsars can be hidden in the region of dense matter. Table 2 is the current list of the objects reported as VHE gamma ray sources. Requirement of the confirmation by independent detections would conclude six "established sources" at present. Ater Crab nebula was established by Weekes et al. (4) in 1989, VHE gamma ray observation has experienced a rapid rise in the number of sources; yielding three (Crab, Mrk 421 (5) and PSR B1706-44 (6)) several years ago and still increasing.

Table 1: Number of high energy gamma ray sources (EGRET sources)

| pulsar | normal galaxy | active galaxy | unidentified source | | EGRET catalogue |
|---|---|---|---|---|---|
| | | | $b^* < 10°$ | $b^* > 10°$ | |
| 6 | 1 (LMC) | 38 | 37 | 43 | 2nd (1) |
| | | 3 | 8 | 17 | Supplement of 2nd |
| * b is galactic latitude; LMC stands for Large Magellanic Cloud | | | | | |

Efforts in the VHE gamma ray band to observe EGRET gamma ray pulsars has failed to detect signals modulated with pulsar period, instead, discovering unpulsed signals (*e.g.* for review, see (7)) from the plerions of Crab, PSR B 1707-44 and Vela pulsars. Multiple groups have reported VHE detection of the Crab nebula. The earlier detection of PSR B1706-44 was confirmed by Durham group (8) at 300 GeV threshold. Evidence of VHE gamma rays from Vela pulsar direction was repeatedly obtained in the 1993 - 1997 data of CANGAROO group (9), which indicates that the emission region is the birth place of the Vela pulsar (10) and is displaced by about 0.13° from the pulsar.

Table 2: List of Claimed VHE Sources

| objects | confirmation by | | EGRET | Note |
|---|---|---|---|---|
| | other groups | repeated observations | Detection | (Object type) |
| Crab | √ | √ | √ | plerion |
| PSR B1706−44 | √ | √ | √ | plerion |
| Vela | | √ | √ | plerion |
| SN 1006 | | √ | | shell type SNR |
| PSR B1509−58 | | | | plerion |
| PSR B1259−63 | | | | binary pulsar |
| J1105−6107 | | | possibly | 62 ms pulsar |
| GRS1915+105 | | | | micro quasar |
| Cen X−3 | | claimed in the past | possibly, time variable | X-ray binary |
| Mrk 421 | √ | √ | √ | AGN |
| Mrk 501 | √ | √ | √ | AGN |
| 1ES2304+514 | | | | AGN |
| PKS 2005−61 | | | √ | AGN |

Preliminary evidence was reported on PSR B1509-58 (11), and PSR J1105-

in one viewing period of EGRET data (20). The fact that Cen X-3 is a time-variable GeV source might support the speculation in 1980's that close X-ray binaries have VHE activity. The time-variable signals from these objects, if true, suggests new types of VHE Galactic sources from the vicinity of neutron stars in binary systems or black holes.

## 3 Implication of VHE gamma ray data

While the diffuse emission from the Galactic disk is generally understood to be from cosmic ray protons, the point(-like) sources so far discovered as bright in GeV and TeV gamma rays are due to abundant energetic electrons (and positrons). Thus, VHE gamma rays are closely tied with X-ray band, because the observed emissions in the two bands are explained, respectively by synchrotron and inverse Compton effect of common progenitor electrons.

### *3.1 Inverse Compton and synchrotron radiation*

Energy loss by synchrotron and inverse Compton processes of electrons is described respectively by $\mathrm{L_{sync}} = -(\mathrm{dE/dt})_{\mathrm{sync}} = (4/3)\sigma_{\mathrm{T}}\mathrm{c}\gamma^2\mathrm{W_{mag}}$ and $\mathrm{L_{ic}} = -(\mathrm{dE/dt})_{\mathrm{ic}} = (4/3)\sigma_{\mathrm{T}}\mathrm{c}\gamma^2\mathrm{W_{rad}}$, where $\mathrm{L_{sync}}$ and $\mathrm{L_{ic}}$ are the luminosity of synchrotron and inverse Compton radiation, $\sigma_T$ is Thomson cross section and $\mathrm{W}_{mag}$ and $\mathrm{W}_{rad}$ are the energy density of magnetic field and the the ambient photon field, respectively. The ratio, $\mathrm{L_{sync}/L_{ic}} = \mathrm{W_{mag}/W_{rad}} = \mathrm{B}$, gives strength of magnetic field B in the emission region. The 2.7K MWB(microwave background) is dominant as the target photon of the inverse Compton effect, in most of Galactic VHE sources except for the bright source of Crab nebula, in which self-synchrotron photons, *i.e.* synchrotron radiation by the same progenitor electrons, is Compton scattered. In AGN, either self-synchrotron or external photons from clouds or accretion disk near the central nuclei of galaxy is more abundant than 2.7 K MWB. From the target photon of energy $\epsilon$, the energy of Compton-boosted gamma ray photons is calculated to be $\sim \gamma^2\epsilon$, where $\gamma$ is the Lorentz factor of progenitor electrons.

### *3.2 Pulsar nebula and plerion*

In the case of Crab nebula, the whole energy spectrum of synchrotron and inverse Compton radiation are measured. The inverse Compton flux can be compared in detail with the expected one from synchrotron X-rays to give magnetic field $\sim 300\mu$G, close to the equi-partition value. The strong magnetic field allows synchrotron radiation in the energy range beyond 100 MeV, and explains why the Crab nebula appears as a plerion of unpulsed GeV gamma

Table 3: Pulsars of ASCA Observation

| * | VHE | pulsar | associated object | nebula |
|---|---|---|---|---|
| (1) | √ | Crab | **** | √ |
| (2) | √ | Vela | **** | √ |
| (3) | | Geminga | | √ |
| (4) | √ | PSR B1706−44 | | √ |
| (5) | ? | PSR B1509−58 | MSH15-52 | √ |
| (6) | | PSR B0437−4715 | (5.8 msec pulsar) | |
| (7) | | PSR B1951+32 | EGRET/CTB80 | √ |
| (8) | | PSR B1046−58 | | √ |
| (11) | | PSR B1929+10 | | √ |
| (14) | | PSR B1821−24 | (3 msec pulsar) | |
| (17) | | PSR B0656+14 | EGRET?/Monogem | √ |
| (18) | | PSR B0540−69 | in LMC | |
| (21) | | PSR J1105−6107 | 2EGJ1103-6106 ? | √ |
| (24) | | PSR B1853+01 | W44 | √ |
| (25) | | PSR B1259−63 | binary pulsar | |
| (27) | | PSR B1610−50 | Kes 32 | √ |
| (33) | | PSR B1055−52 | EGRET | √ |
| * the number in the order of $L_{sd}/d^2$ (see text) | | | | |

rays as detected by EGRET. Gamma rays of higher energies can provide more direct evidence of the maximum energy of accelerated electrons, putting a constraint on theoretical models. The CANGAROO data (21) appears consistent with the spectrum continueing with a constant power index up to at least 50 TeV and possibly to ∼100 TeV. In the cases of PSR B1706-44 and Vela, the energy spectrum of gamma ray emission is less well measured yet, but the emission in VHE relative to X-ray band restricts magnetic field as well as confinement condition of energetic electrons. The magnetic field of $\sim 3\mu$G as weak as the ISM (interstellar medium) one, inferred from the comparison of X-ray and TeV gamma ray intensities, implies higher energy density of electrons, by an order of magniutde, than that of magnetic field, $W_{mag} = B^2/8\pi$, indicating that the two energy densities are not in equi-partition. However, magnetic field is generally not uniform. The intensity of VHE gamma rays and X-rays from PSR B 1706-44 can be also compatible with $B \sim 20\mu$G stronger near the center of nebula than the peripheral region, if we assume the escape time $\tau_{escape}$ from the central region is $\sim 10 \cdot (E/20\mathrm{TeV})^{-\delta}$ yrs with $\delta = 0 \sim 0.5$ (Aharonian et al. 1997 (22)). X-ray data of many of the pulsar nebulae listed in Table 3 shows a spatial extent more than 0.1°, just as large as the angular resolution of IACT. VHE gamma rays are likely more extended than X-ray synchrotron nebula.

When we list pulsars in the order of fluence, $L_{sd}/d^2$ where $L_{sd}$ and d are spin down luminosity and distance, unpulsed X-ray emission is observed from most of the high ranked ones, suggesting the existence of synchrotron nebula around the pulsars(see *e.g.* (23)). Among those ranked within the top four, Crab, Vela and PSR B1706-44 except Geminga are VHE sources. We can expect that more number of inverse Compton nebulae will be discovered. It is useful, in addition to the work available from the synchrotron X-ray data (Shibata et al. 1997 (24)), to have systematic investigation also on inverse Compton nebulae to draw a view on the general feature of pulsar and its nebula, such as the depencence of magnetic field in nebula, wind velocity and total number of electron-positron pairs, on the spin-down energy loss of pulsars.

### *3.3 Supernova remnant*

The detection of VHE gamma rays from SN 1006 gives a direct evidence that particles are accelereted up to ~100 TeV in the supernova shell. The nonthermal radiation from SN 1006 is consistent with the view of inverse Compton and synchrotron radiation to explain the flux of TeV gamma and X-rays as well as the upper limit of flux in 100 MeV - 10 GeV region by EGRET.

In those SNRs which are located within the error circles of EGRET unidentified sources, the observed GeV gamma rays can be due to proton progenitor. The acceleration model in the supernova shock gives protons of a hard power law spectrum of index near to $-2$, predicting a detectable flux of TeV gamma rays when we extrapolate the observed GeV flux to higher energies (25) (26). Extensive efforts (27) (28) have, however, failed to detect VHE gamma rays. The fact may indicate that the GeV gamma rays are not from proton progenitor but, for example, due to bremsstrahlung process by electrons from plerion activity which is possibly associated with those SNRs of EGRET detection. The relative intensity between VHE gamma rays from electron and proton progenitors can vary from object to object, depending on the maximum energy of accelerated electrons and the morphological complexity of supernova in association with molecular clouds etc. Comparison with GeV flux and more accurate spectral information as well as investigation on more number of SNRs is necessary to infer the contribution from proton progenitor.

### *3.4 Origin of matter and of cosmic rays*

Gamma rays are closely related to "matter" in the Galaxy. Hayakawa (29) discussed in 1952 high energy gamma rays from $\pi_0 \rightarrow \gamma\gamma$ decay produced by cosmic rays in collision with ISM. Detection of such gamma rays can tell us the density of matter, irrespective of its state to be as neutral or ionized atoms or molecules, while radio waves of 21cm and millimeter are to infer the density of neutral atom and molecular of hydrogen, respectively. The region of the dense ISM in the Galaxy is where young stars are born to synthesize nuclear species and to result in frequent supernova explosions, and is also where energetic "particle beam" and "target material" is abundantly prepared for generating gamma rays. A considerable portion of EGRET sources is still unidentified (Table 1), and some of these are apparently embedded in the dense matter region (30). High penetrating power of high energy gamma rays through dense matter is thus useful to exploit unkown phenomena still hidden from observation.

The spectrum of cosmic rays extends at least to $10^{20}$eV. Galactic cosmic rays of energy lower than $\leq 10^{15}$eV are generally believed to be shock-accelerated in supernova remnants. VHE gamma ray astronomy is expected to uncover the "origin of cosmic rays", by tracing the interactions of cosmic rays. The acceleration of cosmic rays to their relativistic energies is in principle by transferring and deviding the energy of a bulk motion of a macroscopic system into protons or nuclei. Cosmic rays are strongly coupled to their environmental medium, as is shown by the fact that the energy density of cosmic rays appears in equi-partition with that of magnetic field in the Galactic disk, $\mathrm{W_{cosmic\,ray}} \sim \mathrm{W_{mag}}$. The matter synthesized in stars is supplied to ISM through stellar winds and supernova explosions, which are also the most likely processes of the Galactic cosmic ray acceleration. Cosmic rays are confined in the Galactic disk and their propagation process is affected by the general structure of the matter in the Galaxy.

The Lorentz factor $\gamma$ of accelerated electrons, or the maximum energy possibly achieved in candidate objects of the origin of cosmic rays, can be inferred from comparison of synchrotron and inverse Compton radiation. In the case of gamma rays of TeV energy generated by Compton scattered 2.7K photons, the Lorentz factor $\gamma$ of progenitor electrons is $\sim 10^8$, *i.e.* $\sim 10^{14}$ eV of electron energy. Infrared to optical photons are considered to be the target of inverse Compton process in the intense radiation field of AGN, implying that electrons of lower energies produce TeV gamma rays than in the case of Galactic sources. In addition, the progenitor electrons are in a bulk motion of jet having a Lorentz factor $\Gamma$. This fact causes a Doppler shift in the frequency of radiation; $\nu_{\mathrm{obs}} = \nu_0 \delta$, where the suffix "obs" and "0" designate the observer's and jet frame. The beaming factor $\delta$ is $\delta = 1/\Gamma(1 - \beta\cos\theta)$, where $\beta = \mathrm{v/c}$, velocity of jet, $\Gamma = 1/\sqrt{1-\beta^2}$, and $\theta$ the viewing angle of the jet direction. A typical value is $\delta \approx 10$ (*e.g.* see (31)).

Thus, the maximum value of $\gamma$ seems smaller in blazars than the Galactic gamma ray sources such as Crab (*e.g.* (32)). We need deeper survey of VHE gamma ray sources for the place where particles of $\gamma \sim 10^{11}$ are accelerated somewhere in extragalactic objects of a large scale of spatial extension (32), in order to explain the cosmic rays of $10^{20}$ eV. Rich clusters of galaxies can be a source of VHE gamma rays if strong wind from early type galaxies is converted into non-thermal acceleration energy (33), which should be detectable by the next generation of IACT, such observation providing evidence of locating the origin of the highest energy cosmic rays and of investigating cosmological history of these objects.

### *3.5 Towards early Universe*

Extragalactic cosmic rays could tell us about non-thermal activity in early Universe. However, cosmic rays suffer from deflection by magnetic field and are confined within a limited travelling distance. Instead, gamma rays provide us with knowledges on high energy particles in remote objects. The gamma ray flux from LMC detected by EGRET has demonstrated that cosmic ray intensity in the neighboring galaxy is weaker than ours. The result also suggests that the cosmic ray intensity varies from galaxy to galaxy, and has enabled us to see the cosmic rays beyond our Galaxy. Detection of gamma rays from AGN has pushed the horizon even further to red shift z $\sim$ 2.5 by GeV and to the distance of $\sim$100 Mpc by TeV gamma rays.

High energy gamma rays also suffer from absorption due to creation of a pair of electron and positron when they collide with ambient background photons, *i.e.* $\gamma + ambient\ photon \rightarrow e^{+} + e^{-}$. With increasing energy of gamma rays, softer photons can exceed the threshold energy of about 1 MeV for the pair creation in the center of mass system of the collision. The 2.7 K MWB can become the target for gamma rays of energy $\geq 10^{14}$ eV, with the absorption length of gamma rays as short as $\sim$10 kpc. Infrared and optical photons are most effective in the extragalactic space for TeV gamma rays, giving the travelling distance of about 100 Mpc (*e.g.* Stecker et al. 1992 (34)). By observing VHE gamma rays, we can thus extend the study on high energy non-thermal phenomena beyond our Galaxy, but the reach is limited within the Universe not much earlier than the present time. The attenuation length of VHE gamma rays is schematically shown in Fig. 1. Travelling distance of cosmic rays is also estimated from a simplified view of the diffusion during the life time of cosmic rays as calculated from $\sqrt{\mathrm{cRT}}$, where c, R and T are the light velocity, gyro radius of protons and diffusion time (for more careful treatment, *e.g.*, see (35)). The Galactic case (a) corresponds to magnetic field $3 \cdot 10^{-6}$G

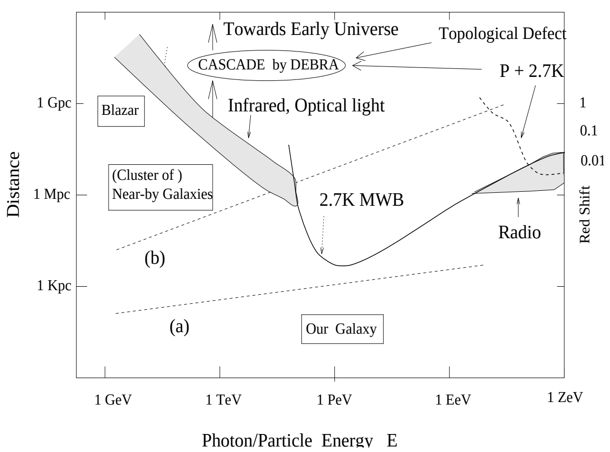


Figure 1: Travelling distance of gamma rays and cosmic rays is schematically shown against energy. Solid and dashed curves are for gamma ray and cosmic ray, respectively. Ambient photons collide with gamma rays to produce a pair of electron and positron when the center of mass energy exceeds twice of the energy of electron rest mass. The ambient photon contributing to the process is infrared and star lights for ∼1 TeV, and 2.7K MWB for ∼1 PeV gamma rays. Distance cosmic rays can reach by diffusion are to be as large as (a) and (b), respectively in the Galactic and extragalactic cases (see Text).

and T assumed to be $10^7 \cdot (\mathrm{E}/1\mathrm{TeV})^{-0.7}$ yrs and in the extragalactic case (b) magnetic field of $3 \cdot 10^{-9}$G and T $= 10^{10}$ yrs are assumed. The life time of cosmic ray protons is determined by their collision with matter, and can be as long as 10y10 us about DEBRA. (ii) Pairs of electrons and positrons from absorbed gamma rays then emit secondary high energy gamma rays through inverse Compton collision with MWB to form a halo emission around AGN. The relaxation time of the secondary processes is determined by the life time of electrons, to be comparable with the accretion life time ~1 Gyr of AGN having a massive black hole of $10^8$ solar mass. Such 'pair halos' of gamma rays (see *e.g.* Aharonian et al. 1992 (36)) can be also formed around those AGN which are presently quiet but were active in the past. (iii) The gamma rays and cosmic rays of energies $\gg$ 1 TeV that are generated at a site farther than 100 Mpc suffer from successive cascades of photo-nuclear interaction and electromagnetic processes, of which space and time scale is characterized by the travelling distances shown in Fig. 1, and would finally produce copious gamma rays in the energy region of 10 GeV to 100 GeV, contributing to diffuse extragalactic gamma rays (*e.g.*, see (37)). Thus, the study of diffuse and/or granularly extended extragalactic VHE gamma rays provide information on high energy activity in early Universe of producing highest energy cosmic rays or gamma rays, to discover or put constraint on the exotic processes such as the topological defects. The observation with next generation IACTs attempts to cover the energy region, which remains still unobserved with both the two methods of satellite and ground-based instruments.

## 4 Conclusion

The VHE gamma ray sources have copious production of accelerated electrons and positrons. The energy spectrum of pulsar nebulae and SN 1006 as well as the time variable emission from AGN over radio to TeV bands is consistent with the scheme of synchrotron and inverse Compton radiation by electron progenitor. Most of the pulsars with high value of fluence $L_{sd}/d^2$ accompany X-ray synchrotron nebula and suggest the inverse Compton counterpart of the nebulae. Detection of the gamma rays will inform us of the strength of magnetic field and spatial characteristics in the plerions. Contribution of protons to VHE gamma rays remains to be investigated for the site of "origin of cosmic rays" in both the Galactic and extragalctic cases.

The current sensitivity of VHE observation is shown in terms of fluence *i.e.* energy flux, plotted for Galactic objects in Fig. 2. The next generation of IACT with sensitivity better than $\sim 10^{-12}$ergcm$^{-2}$s$^{-1}$ and reduced threshold energy below 100 GeV will be capable throughout whole the Galaxy of detecting the sources of VHE luminosity $\sim 10^{33}$ erg s$^{-1}$. Extragalactic gamma rays, for example, from Perseus cluster of galaxies is estimated to be $(5.1 - 0.5) \times 10^{-12}$ photons cm$^{-2}$ s$^{-1}$ ($\geq$ 1 TeV) (33) (which corresponds to $\sim 1 \cdot 10^{-12}$ erg cm$^{-2}$

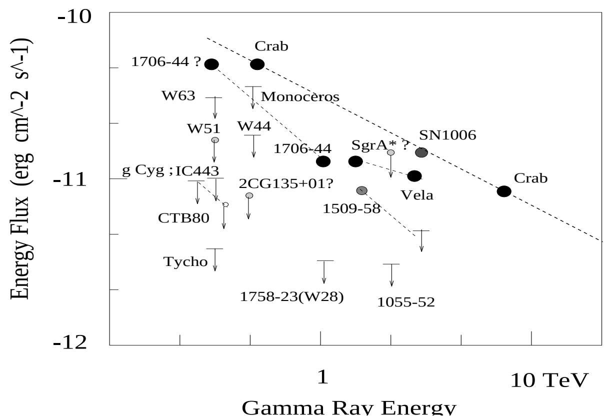


Figure 2: Fluence from varous galactic objects. The sensitivity of VHE detection has reached a level somewhat below $10^{-11}$ erg $s^{-1}$ $cm^{-2}$, better than that in GeV region, which corresponds to the luminosity $10^{33}$ erg $s^{-1}$ at a distance of 1 kpc.

$s^{-1}$) and would become detectable. New types of VHE gamma ray sources will appear to show us a rich variety of non-thermal features of the Universe, to extend our scope towards earlier Universe, as well as into the region of dense matter where young stars are being formed and of extreme environmental conditions in the vicinities of black holes and neutron stars.

**Acknowledgments** I appreciate the discussions with a number of colleagues during recent conferences, which were helpful to prepare this paper.

## References

[1] Thompson, D.J. et al., *Astrophys. J. Suppl.* **101**, 259 (1995)

[2] Weekes, T.C., Aharonian, F.A., Fegan, D.J., and Kifune, T., to appear in *Proc. of the 4th Compton Symposium* (1997).

[3] Halpern, J.P. and Holt, S.S., et al., *Nature* **357**, 222 (1992).

[4] Weekes, T.C. et al., *Astrophys. J.* **342**, 379 (1989).

[5] Punch, M., et al., *Nature* **358**, 477 (1992).

[6] Kifune, T. et al., *Astrophys. J. Lett.* **438**, L91 (1995).

[7] Kifune, T., *Pulsar: Problems and Progress (IAU Colloquium 160) Eds. S. Johnston, M.A. Walker and M. Bailes. Publ. ASP Conf. Series* **105**, 339 (1996)

[8] Chadwick, P.M. et al., *Proc. 25th ICRC (Int, Cosmic Ray Conf.) (Durban)* **3**, 189 (1997).
[9] Yoshikoshi, T. et al., *Astrophys. J. Lett.* **487**, L65 (1997).
[10] Harding, A.K., De Jager, O.C., and Gotthelf, E., *Proc. 25th ICRC (Durban)* **3**, 325 (1997).
[11] Sako, T. et al., *Proc. 25th ICRC (Durban)* **3**, 193 (1997).
[12] Turver, K.E. et al., to appear in *Proceedings of Kruger Workshop "Towards Major Atmospheric Cerenkov Detector V"* (1997).
[13] Kaspi, V.M. et al., *Astro. Ph. 9703115* , (1997).
[14] Tanimori, T. et al., *IAU Circular* **6706**, 2 (1997).
[15] Koyama, K. et al., *Nature* **378**, 255 (1995).
[16] Pohl, M., *Astr. Astrophys.* **307**, 57 (1996).
[17] Mastichiadis, A. and de Jager, O.C., *Astr. Astrophys.* **305**, 153 (1996).
[18] Quinn, J., et al., *Astrophys. J. Lett.* **456**, L63 (1996).
[19] Aharonian, F.A. and Heinzelmann, G., *to be published in Nucl. Phys. B (astro-ph/9702059)*(1997).
[20] Vestrand, W.T., Sreekumar, P. and Mori, M., *Astrophys. J. Lett.* **483**, L49 (1997).
[21] Tanimori, T. et al., *Astrophys. J. Lett., in print* (1997).
[22] Aharonian, F.A., Atoyan, A.M., and Kifune, T., *Mon. Not. R. Astron. Soc.* **291**, 162 (1997).
[23] Kawai, N. and Tamura, K., *Pulsar: Problems and Progress (IAU Colloquium 160) Eds. S. Johnston, M.A. Walker and M. Bailes. Publ. ASP Conf. Series* **105**, 367 (1996)
[24] Shibata, S. and Kawai, N., *submitted for publication* (1997).
[25] Drury. L.O'C., Aharonian, F.A., and Völk, H.J, *Astron. Astrophys.* **287**, 959 (1994).
[26] Naito, T. and Takahara, F., *J. Phys. G:Nucl. Part. Phys.* **20**, 477 (1994).
[27] Lessard, R.W. et al., *Proc. 25th ICRC (Durban)* **3**, 233 (1997).
[28] Hess, M. et al., *Proc. 25th ICRC (Durban)* **3**, 229 (1997).
[29] Hayakawa, S., *Prog. Theor. Phys.* **8**, 517 (1952).
[30] Kaaret, P. and Cottam, J., *Astrophys. J. Lett.* **462**, L35 (1996).
[31] Inoue, S. and Takahara, F., *Astrophys. J.* **463**, 555 (1996).
[32] Makishima, K., *personal communication*(1997).
[33] Völk, H.J., Aharonian, F.A. and Breitschwerdt, D., *Space Science Review* **75**, 279 (1996).
[34] Stecker, F.W., De Jager, O.C. and Salamon, M.H., *Astrophys. J. Lett.* **390**, L49 (1992).
[35] Ptuskin, V.S., Völk, H.J., Zirakashvili, V.N., and Breitschwerdt, D., *Astron. Astrophys.* **321**, 434 (1997).
[36] Aharonian, F.A., Coppi, P.S., and Völk, H.J., *Mon. Not. Roy. Astron. Soc.* **264**, 191 (1993).
[37] Coppi, P.S., and Aharonian, F.A., *Astrophys. J. Lett.* **487**, L9 (1997).