THE NEW CANGAROO TELESCOPE AND THE PROSPECT OF VHE GAMMA RAY OBSERVATION AT WOOMERA

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Abstract

A summary of the observations of very high energy gamma rays at Woomera, South Australia is presented to discuss the current status and prospect of gamma ray astronomy. Emission of gamma rays are due to copious production of electron and positron, in contrast to apparently “silent protons”. Electrons radiate into multi-wavelengths from radio to gamma rays, linking the gamma ray data to the other bands.

A new telescope for VHE gamma ray astronomy is to commence operation at Woomera in 1999. The telescope of light-collecting area of 7m diameter has a threshold energy of detecting gamma rays near 100 GeV. Also discussed is the next step we plan to take, in which a system of four telescopes of 10m size will be constructed. With the telescopes in the next generation, more number of Galactic sources will become detectable as well as extragalactic ones at larger distances. We expect that there will appear new types of gamma ray sources, shedding a new light on the long-standing puzzle of the “origin of cosmic rays” by extending the study beyond our Galaxy.

Keywords: very high energy gamma rays, pulsar, active galactic nuclei, gamma ray burst

1 INTRODUCTION

High Energy (HE; at 100 MeV - 10GeV energies) and Very High Energy (VHE; in the region of 100 GeV to TeV energies) gamma rays are linked to energetic particles. They are produced through the non-thermal mechanism of those elementary particles as progenitor. Gamma rays are to suffer from the absorption through the pair creation of electron and positron, $\gamma + \varepsilon \rightarrow e^- + e^+$, where ε stands for ambient photon of longer wavelengths. The gamma ray interactions characterize the

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feature of VHE gamma ray astronomy that provides us with the probe for the nonthermal high energy phenomena in the Universe. Gamma ray astronomy has found that the Universe at the present time is rich in high energy phenomena. However, the early Universe has much higher temperature than any high energy processes of the present time. The relics of earlier Universe such as gamma rays from anti-matter annihilation on matter or from primordial black holes has acted to some extent as the impetus of promoting gamma ray astronomy. Attempts to detect the relic phenomena have failed so far and remain as potential targets that gamma ray astronomy needs to keep aiming at.

The window of seeing the Universe with gamma rays at the shortest wavelengths of electromagnetic radiation was established in HE region by Compton Gamma Ray Observatory (CGRO) launched in 1991, and remarkably progressed in VHE by the success of ground-based technique to detect TeV gamma rays. The current status of gamma ray astronomy in rapidly growing stage is explained in Fig. 1, by plotting the number of point sources detected in the gamma ray bands to compare with those in X-rays. The increase of the discovered sources is as rapid as what happened in X-ray astronomy in 1970's. The detection of gamma rays has less opportunities than X-rays,

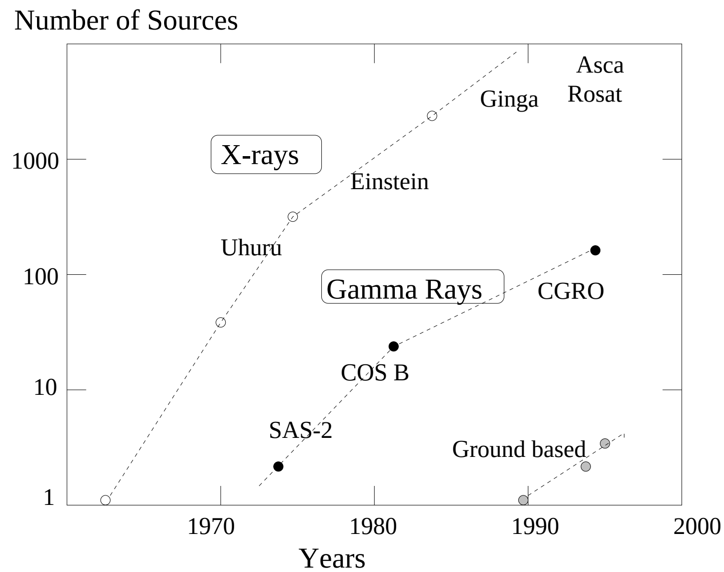

Figure 1: The number of point souces plotted against the year of observation

because of the larger and heavier gamma ray satellites. The ground-based telescope for VHE region is much less expensive, and provides more and easier opportunities of gamma ray observation. An increasing number of groups are to work in IACT (imaging air Čerenkov telescope).

The review of gamma ray astronomy is found in the invited talks of the 4th CGRO Symposium. In particular, the results and prospect of VHE gamma ray astronomy are presented in Weekes et al. 1997 in the Proceedings and references are therein, as well as CANGAROO (Collaboration between Australia and Nippon for a GAmma Ray Observatory in the Outback) results in Kifune et al. 1997. In this paper, we summarize the results from CANGAROO, by taking these as example to discuss VHE gamma ray astronomy.

The travelling distance of VHE gamma rays, *i.e.* the depth of VHE observation into the earlier Universe, is determined by the density of the extragalactic background photon. VHE photons are converted into a pair of electron and positron when they encounter the ambient background photons. The collision mean free path increases with decreasing energy of VHE gamma rays.

Thus, lower threshold energies of detecting gamma rays are attempted by many groups, in order to cover the region of 10 GeV to 300 GeV which has been left unexploited. The new CANGAROO telescope of 7m diameter is scheduled to commence observation of gamma rays at about 100 GeV at the beginning of 1999 (phase II of CANGAROO project). Construction of three more telescopes of 10m size are proposed as CANGAROO III for lower threshold energy and better resolution in energy and direction angle.

2 RESULTS of VHE OBSERVATIONS

The first object established as VHE source is the Crab nebula. The detection by the Whipple group, or a break-through achieved by IACT (imaging air Čerenkov telescope) after a long "dark age", was almost simultaneous with the launch of CGRO, and has stimulated the search for VHE signals in the gamma ray pulsars of EGRET detection. The CANGAROO commenced observation in 1992 by using the 3.8m IACT (Hara et al. 1993). Observation of the Crab from Woomera at zenith angles larger than 50° enabled us to detect several tens TeV gamma rays (Tanimori et al. 1997) with sensitivity better than other techniques currently available in 10 TeV - 100 TeV energy region. Two more EGRET pulsars, PSR B1706-44 (Kifune et al. 1995) and Vela pulsar (Yoshikoshi et al. 1996) were found to emit VHE gamma rays. These signals are, however, unpulsed, not modulated by the pulsar spin period as detected in HE band. The GeV gamma rays from the EGRET pulsars originates in the pulsar magnetosphere which corotates with the neutron star. At higher energies, however, the site of dominant emission moves to the pulsar nebula which is formed around the pulsar of high spin-down luminosity. It has been known that a

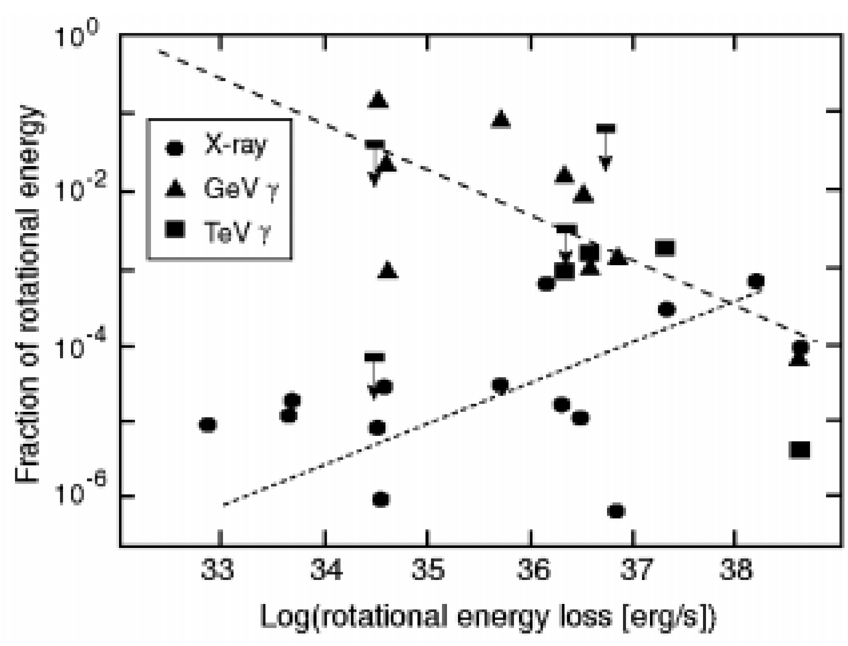

Figure 2: Brightness in X-ray, HE and VHE gamma ray bands of young pulsars. The luminosity relative to spin-down luminosity (horizontal axis) is plotted for individual pulsars versus spin-down luminosity. The data for X-ray (circle) and HE gamma rays (triangle) is from the pulsed signal, and VHE ones (square) are unpulsed luminosities.

much larger fraction of rotational energy loss of EGRET pulsars is spent into HE gamma rays than radio and X-rays, as demonstrated in Fig. 2. The VHE emission appears to have luminosity as high as HE data. However, the number of sources is limited and too small to infer the dependence on the rotational energy loss as indicated by the dot and the dash line in Fig. 2 for the X-ray and HE cases.

Evidence of VHE gamma ray emission was obtained on supernova remnant SN 1006 (Tanimori et al. 1998). The CANGAROO observation was motivated by the detection of non-thermal X-rays from the region of the supernova shell that suggests shock acceleration takes place in the shell to produce high energy electrons (Koyama et al. 1995). The result that VHE gamma rays are also detected from the same site of the non-thermal X-ray emission provides direct evidence of electrons accelerated to as energetic as ~100 TeV, as well as a clue to clarify the origin of cosmic rays, which has long remained as a puzzle. Supernova remnants are generally believed to be the most likely site of shock-acceleration of cosmic ray protons. If the VHE gamma rays from SN 1006 are of proton origin, the gamma rays from π^0 decay would have a monotonously decreasing spectrum of power law. The flux of CANGAROO detection at TeV energy then predicts GeV gamma rays above the EGRET upper limit. Thus, electrons are more likely to explain the VHE gamma rays of SN 1006. However, the direct evidence of ~100TeV electrons in the supernova shell strongly suggests that protons are also shock-acceletated at the shell of the supernova.

VHE radiation from the pulsar nebulae and the supernovae as well as active galactic nuclei are consistent with the inverse Compton process by electrons, which also emit synchrotron radiation into the bands at longer wavelengths of radio to X-rays. Thus, observation of VHE gamma rays is linked to the other energy bands, and the ananlysis of comparing the data over multi-wavelengths is necessary and useful. The luminosities L_{sync} and L_{ic} of synchrotron and inverse Compton radiation, respectively, are proportional to the energy density of magnetic field (W_B) and seed photons of the Compton scattering (W_{photon}) given as $L_{sync} = \frac{4}{3}\sigma_T c\gamma^2 W_B$ and $L_{ic} = \frac{4}{3}\sigma_T c\gamma^2 W_{photon}$, where σ_T is the Thomson cross section and γ the Lorentz factor of electrons. Thus, we can infer the strength of magnetic field from the ratio of the two luminosities. The detection of VHE gamma rays from the pulsar nebulae PSR B1706-44 and Vela as well as from SN 1006 suggests a few to 10 μG at the emission region of similar strength to the interstellar space. However, it should be noted that the estimation is based on a simplified view that the magnetic field is uniform ignoring the spatial distribution of progenitor electrons. Modification on such assumptions may give intenser magnetic field (Aharonian et al. 1997).

Efforts of CANGAROO for detecting VHE signals from active galactic nuclei are so far with negative results (Roberts et al. 1998). Observation of several EGRET unidentified sources and supernova remnants have been made and analyses are now underway as well as about 'after glow' of southern gamma ray bursts which BeppoSAX satellite detected with about one arcminute accuracy.

3 CANGAROO II and III

An IACT of light collection area of 7m diameter has been under construction since 1995, and will be installed at about 100m distance from the existing two telescopes of the 3.8m diameter and BIGRAT in Woomera. The start of observation is scheduled at the beginning of 1999 year. The 7m telescope has light collection area of about 30m^2 trippling that of 3.8m telescope for the purpose of achieving detection of ~200 GeV gamma rays. We use the design of commercial 'radio antenna' for the main body of the 7m telescope and install sixty spherical mirrors of 80cm diameter onto the parabolic frame of the radio antenna. In order to reduce the weight, we use plastic material with aluminum foil on the surface of the spherical mirrors. The fine-tuning of each spherical mirror to the parabolic envelope is remote-controlled by driving two motors which are installed at the screws for holding each mirror.

The focal length of the composite, parabolic mirror of 7m diameter is 8m. In the main focal point, a camera of 512 photomultiplier tubes is installed. Hamamatsu R4124 tube of 13mm diameter is used, each pixel covering, with the aid of light collecting cone, the area of 1.6cm×1.6cm in the focal plane, which aims at $0.115° \times 0.115°$ of the sky.

The signal of each photomultiplier tube carries two independent informations corresponding to the number of Čerenkov photons received onto the tube and their arrival time, which the electronics circuits work to decompose. In addition, the circuits produce discriminator signal when the light yield in the individual photomultiplier tube is larger than a preset value. Summation of the light yields and the discriminated signals is taken and used to generate a trigger signal to record the data. The details of the CANGAROO II system will be described elsewhere. The width of gating the synchroneous atmospheric Čerenkov lights from gamma rays will be about 20 ns, improving the current system of CANGAROO I by a factor of 4∼5. The shorter time-width of the gate can more efficiently reject background light which are incident uniformly and randomly in time, and when combined with the effect of increased surface area of the telescope, we expect to reduce the threshold energy of gamma rays down to near 100 GeV.

The 7m telescope has 'geometrical diameter' of 10m and we can furhter increase the light-collection area by installing more number of the small spherical mirrors. By this relatively inexpensive improvement, we plan as soon as possible to achieve even lower threshold energy. The detection sensitivity better than 10^{-12} erg cm^{-2} s^{-1} is expected, which is not very far from the case of X-ray detection and even better than GeV gamma rays of satellite instruments.

There are several proposals for the "next generation" of IACT, such as VERITAS, HESS and MAGIC projects. VERITAS and HESS plan to construct many IACTs. The concept of having a system of telescopes is mainly (i) to achieve a 'stereoscopic" observation by multiple (usually, 2 to several) telescopes of air Čerenkov lights from common gamma ray events. Such stereoscopic measurement provides us with detailed information of the gamma ray showers such as the production height of Čerenkov light and the distance of the telescopes to the line of gamma ray trajectory. These knowledges are useful to estimate the energy and arrival direction of gamma rays with better accuracy as well as to achieve a larger signal to noise ratio of gamma rays against the cosmic ray background. It is also aimed (ii) to enable the scan of wider area of the sky during limited observation time by using a more independent number of telescopes. We consider that the purpose (i) is more important and urgent, and have a proposal of constructing three telescopes of 10m diameter, to which the 7m telescope of CANGAROO II (with enlarging the collection area to 10m diameter) is added to provide a system of 4 telescopes as CANGAROO III (as illustrated in Fig. 3).

4 PROSPECT OF VHE GAMMA RAY ASTRONOMY IN WOOMERA

The "inverse Compton" nebulae of VHE gamma ray detection are formed around the pulsars that have the highest values of spin-down luminosity. Most of the pulsars having high spin-down luminosity are discovered to accompany a synchrotron nebula of hard X-rays (Kawai 1998), suggesting that more number of 'inverse Compton nebuae' are to be detected by VHE gamma rays with CANGAROO II and III of improved detection sensitivity. The systematic study of the luminosities at multi-wavelengths from these nebulae will provide us with better understandings of the pulsar wind and its particle acceleration.

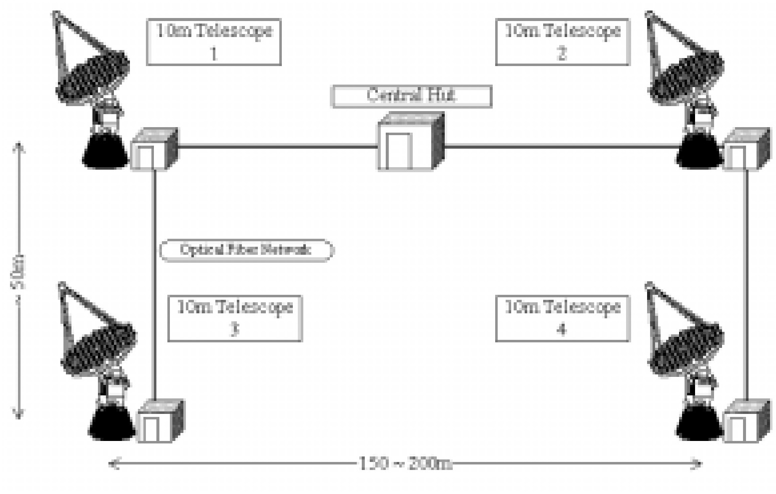

Figure 3: A system of four telescopes of CANGAROO 3

The blazars so far known in the southern sky are at larger distances than the redshift ~ 0.03 of Mrk 421 and 501 of emitting VHE gamma rays. The fact is consistent with the short travelling distance of VHE gamma rays expected from the collision with infrared photons in the extra-galactic space to produce a pair of electron and positron, as well as with no positive detection of AGN by the 3.8m telescope of CANGAROO I. The lower threhsold energy of CANGAROO II is hoped to expand the Woomera survey for VHE gamma rays to further distances.

Copious production of electrons is likely associated with intense radiation field, which generally prevents escape of VHE gamma rays by electron-positron pair creation. However, as is found in the case of AGN, relativistic jets can enhance gamma ray luminosity to be proportinal to δ^4, where the beaming factor $\delta \approx 10$ (Kubo et al. 1998). The jet phenomena appear to be associated with violent time variation, and from this view point, it is interesting to note that some of the unidentified EGRET sources which are probably within the Galaxy seem to exhibit violent time variation (Tavani et al. 1997). These feature can be argued to suggest new population of Galactic gamma ray sources and might be related to hard non-thermal emission up to MeV energy from compact objects. Burst phenomena of such objects are worth watching also in VHE region. It is to be noted that better detection sensitivity will give us more chances of detecting the sources of violently time-varying nature, which may characterize the sky seen with VHE gamma rays.

5 CONCLUSION

HE and VHE gamma ray astronomy has discovered unexpectedly rich, energetic phenomena from copious electron-positron production in various objects such as AGN and pulsars. The electron progenitor of gamma rays implies the importance of multi-band observation and a close link of VHE gamma ray astronomy with the other band such as radio and X-ray astronomy.

Gamma rays from the decay product of π^0 meson of proton progenitor have not been discovered yet from point-like sources of gamma rays. Further efforts remain to be done for clarifying the origin of cosmic rays. On the other hand, the study is expanding beyond our Galaxy as found in the detection of HE gamma rays from Large Magellanic Cloud. Improved sensitivities of VHE gamma ray observation would detect other near-by galaxies as sources, and we expect that the comparison among different galaxies would shed a new light on the study of energetic particles in galaxies.

The next generation satellite detector GLAST of HE gamma rays is hoped to uncover thousands of gamma ray sources when we extrapolate the source number to brightness relation from EGRET to GLAST senstivity. Such a bright prospect will be also true in VHE gamma ray domain. The ground-based telescope of less expense has a merit of easier opportunities of observations than the case of satellite instruments. CANGAROO has enjoyed the advantage of site location in the southern hemisphere. The EGRET observation has been still biased to the northern sky, probably due to the less number of ground-based telescopes having observed and discovered a less number of interesting objects in the southern sky. The next 'hop' of CANGAROO steps is soon to be taken to uncover more Galactic and extragalactic VHE sources in the southern sky, and we hope to develope the collaboration between University of Adelaide and a consortium of Japanese institutions into a larger size.

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