High Energy Astrophysics by ASHRA

Y. Aita[1], T. Aoki[1], Y. Arai[2], Y. Asaoka[1], T. Browder[3], C. Fukunaga[4], T. Hayashino[5], Y. Higashi[2], J. Hisano[1], W. S. Hou[6], Y. B. Hsiung[6], S.Inoue[7], M. Ieiri[2], M. Jobashi[1], C. Jui[8], J. Learned[3], E. Loh[8], N. Manago[1], S. Matsuno[3], J. Matthew[8], K. Nakai[10], S.Nagataki[11], S. Nakamura[12], S. Ogawa[13], A. Okumura[1], S. Olsen[3], K. Sakurazawa[14], M. Sasaki[1], N. Sugiyama[15], Y. Tanaka[16], V. Vladimir[8], M. Z. Wang[6], Y. Watanabe[14], S. Yamada[1], and K. Yoshimura[2]

(1) Institute for Cosmic Ray Research, Univ.Tokyo, Japan, (2) High Energy Accelerator Research Organization, Japan, (3) University of Hawaii, USA, (4) Tokyo Metropolitan University, Japan, (5) Tohoku University, Japan, (6) National Taiwan University, Taiwan, (7) Max Planck Institute for Astrophysics, Germany, (8) University of Utah, USA, (9) Osaka University, Japan, (10) Tokyo University of Science, Japan, (11) Dept. of Physics, Univ.Tokyo, Japan, (12) Yokohama National University, Japan, (13) Toho University, Japan, (14) Tokyo Institute of Technology, Japan, (15) National Astronomical Observatory, Japan, (16) Nagasaki Institute of Applied Science, Japan

Abstract

All-sky Survey High Resolution Air-shower telescope project, ASHRA, is newly proposed international joint collaboration efforts. ASHRA is designed to detect three different high energy particle species, i.e., high energy gamma rays (> 1TeV), very high energy cosmic rays ($> 10^{18}$eV) and high energy neutrinos ($> 10^{16}$eV). Here we discuss impacts on astrophysics to measure these particle species.

1. Introduction

ASHRA (All-sky Survey High Resolution Air-shower telescope project) is a newly proposed air fluorescence and Cerenkov detector of joint collaboration efforts between Japan, US and Taiwan [2]. Due to its high angular resolution (1 arcminute) and wide field of view (50 deg. ×50 deg.), ASHRA can observe high energy gamma rays (> 1TeV), very high energy cosmic rays ($> 10^{18}$eV) and high energy neutrinos ($> 10^{16}$eV). Detailed designs are discussed in separate contributions of this conference [1]. Using these quite unique characteristics, we can reveal high energy astrophysical phenomena such as super-GZK cosmic rays, TeV gamma-ray, astrophysical jets, gamma-ray bursts (GRBs) and so on. In this contribution, we argue these major scientific targets of ASHRA.

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2. Ultra high energy cosmic rays

The ultra high energy cosmic rays which exceeded the GZK bound were observed by AGASA [5]. AGASA detected 8 events of cosmic rays above 10^{20}eV. However, we must beware that the total number of observed ultra high energy cosmic ray events is still small so that more observations are necessary to put confidence on the above conclusions. Indeed, recent reports from the American HiRes experiment support the existence of the GZK bound and are in conflict with the AGASA results. Resolving the situation requires experiments on larger scales such as the Auger project under construction in the southern hemisphere. A northern hemisphere counterpart is also strongly desired to obtain all sky data on arrival directions, which can be achieved with ASHRA.

ASHRA can prospectively detect around 33 events per year above 10^{20} eV, easily overwhelming the AGASA database. Its arcminute localization accuracy should provide important information on the candidate source objects, especially for cosmic rays of neutral composition like gamma-rays which are unaffected by Galactic magnetic fields. It should also clarify possible clustering of these cosmic rays on the sky. For charged particle cosmic rays, observation of the energy dependence of arrival directions may constrain the identity of the sources, as well as the the ill-understood structure of Galactic and intergalactic magnetic fields. Such considerations may simultaneously allow us to infer the cosmic ray composition, i.e. whether they are protons, heavy nuclei such as iron, or neutral particles like gamma-rays or neutrinos.

Let us now discuss on the possible astrophysical sources of ultra high energy cosmic rays [4]. In order to accelerate cosmic rays to ultra high energies, a necessary condition is that the product of the magnetic field and the size of the system reaches a certain value, which can be illustrated as the “Hillas diagram” [3]. The most promising physical mechanism for particle acceleration is thought to be the diffusive shock acceleration mechanism. However, electrostatic acceleration in global electric fields is also conceivable. Some potential candidate sources are (1) Active galactic nucleus jets: Radio galaxies and radio quasars, a subset of AGNs, are known to eject fast, powerful outflows called jets. Shocks forming in these jets are believed to be favorable for acceleration of ultra high energy cosmic rays. (2) GRBs: Recent observations of afterglow emission accompanying GRBs have demonstrated that they involve ultrarelativistic outflows. Shocks formed in these outflows satisfy the Hillas diagram criterion, and are promising sources of ultra high energy cosmic rays. (3) Cluster formation shocks: In the currently standard theory of hierarchical structure formation in the universe, shocks are thought to form in the associated gas when large scale structure such as clusters of galaxies form through the merging of smaller structures. Under certain conditions, cosmic rays accelerated in these shocks can achieve ultra high energies.

Besides the main candidate sources discussed above, numerous other ones exist. To identify the true source out of these diverse possibilities, a multi-faceted observational approach is necessary, including not only detailed studies of ultra high energy cosmic rays, but also those of gamma-rays and neutrinos. The outstanding features of ASHRA with regard to cosmic ray observations are as described above; ASHRA is also a powerful observatory for gamma-rays and neutrinos.

3. Very high energy gamma-rays

The most noteworthy characteristic of ASHRA is its capacity to observe not only cosmic rays through atmospheric fluorescence, but also gamma-rays in the TeV energy range using the same telescope, through the very different atmospheric Cerenkov technique. Its ability to conduct all-sky monitoring observations should open a new frontier in TeV gamma-ray astronomy, potentially revolutionizing this field alone.

There are three important aspects of observing TeV gamma-rays. First, as remarked in the previous section, a diversified observational approach is required in order to pin down the source of ultra high energy cosmic rays. One promising method is to search for secondary gamma-rays and neutrinos that are expected to accompany the acceleration of ultra high energy cosmic rays in the source object. Because such secondary neutral emission do not change their direction during propagation, they would allow the direct identification of the cosmic ray source objects. They should also exhibit spectra and variability characteristic to the type of astrophysical object such as AGNs or GRBs, making them particularly effective diagnostics of the cosmic ray source.

The second important issue is monitoring observations of transient objects by ASHRA. Although the presently operating TeV gamma-ray Cerenkov telescopes may have adequate sensitivity, energy and angular resolution, their greatest drawback is the narrow field of view, making them impotent to transient astrophysical objects. A major impact that ASHRA can have on TeV gamma-ray astronomy is providing persistent all-sky monitoring observations and efficient coverage of transient gamma-ray sources.

The final issue is TeV gamma-ray all-sky survey. Aside from transient objects, extensive TeV gamma-ray observations are crucial for studying many different high energy astrophysical phenomena. TeV gamma-ray all sky surveys, which can be performed effectively for the first time with ASHRA, should lead not only to deeper understanding of known types of gamma-ray sources, but also to solving the mystery of unidentified GeV gamma-ray sources, and to discoveries of new classes of high energy objects.

4. Ultra high energy neutrinos

ASHRA also possesses the unique ability to detect high energy neutrinos above 10^{16} eV. Observation of electron and muon neutrinos should uncover crucial information for understanding astrophysical phenomena. Detection of tau neutrinos may also be possible utilizing the earth-skimming effect.

Astrophysical jets can be possible sources of ultra high energy neutrinos. A crucial question regarding the physics of jets in AGNs is their main composition, whether they are electron-proton or electron-positron. In the case of electron-proton jets, a clear diagnostic may be offered by the high energy neutrino emission, which is expected to occur through photo-pion reactions, provided that the protons can be accelerated to ultra high energies. Detections of such neutrinos should then serve a dual purpose: determining the composition of jets as electron-proton, and also identifying them as ultra high energy cosmic ray accelerators. In the case of electron-positron jets, such neutrino emission is obviously not expected. The identification of the jet composition should be a crucial step towards understanding the still mysterious jet formation mechanism.

GRBs are also anticipated to be sources of neutrinos in various energy ranges. As with AGE jets, characteristic high energy neutrino emission should arise through photo-pion interactions if they accelerate cosmic rays to ultra high energies, providing a valuable means of identifying them as cosmic ray sources. Another important prospect is detection of neutrino emission from "failed GRBs". Observing the high energy neutrino emission from successful and failed GRBs should lead to valuable clues on the origin of GRBs (e.g. their connection with supernovae), and the physics of GRB formation.

Other proposed high energy neutrino sources include supernovae, Galactic pulsars in binaries and the Galactic center black hole. Although the predicted fluxes from these objects are below the nominal ASHRA sensitivity, the theoretical uncertainties are large. The prospects for their detection may be improved by cross-correlation with observations of lower energy neutrinos or gravitational waves. Such a multi-pronged approach using novel observational windows leads to a new revolution in astronomy, in which ASHRA can play an important part.

5. References

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