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Astrophysics with HESS

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Abstract

HESS is a next-generation large Imaging Atmospheric Cherenkov Telescope (IACT) system of up to 16 telescopes, to be built in the Southern Hemisphere in the Khomas Highland in Namibia. The schedule foresees to start with scientific operation of the first 4-telescope subsystem in the year 2002 (Phase 1). HESS will permit gamma-ray astronomy above 40 GeV with a sensitivity about one order of magnitude better than current experiments. The dramatic increase in sensitivity will allow a detailed study of the Nonthermal Universe, and will contribute to long-standing astrophysical problems such as the origin of Cosmic Rays.

1 Introduction

The HESS project is a joint effort of collaborators from Germany, France, Italy, Ireland, the Czech Republic, Armenia, Namibia, and South Africa. HESS is a next-generation IACT system of up to 16 telescopes, to be built in the Southern Hemisphere in the Khomas Highland in Namibia. Each telescope has a segmented 80 m^2 reflector with 15 m focal length, and a high-resolution camera with a $\sim$4.3 degree field of view (extendable to 5 degrees) and a pixel size of 0.16 degrees. The schedule foresees to start with scientific operations of a first 4-telescope subsystem in 2002 (Phase 1). More details of the HESS project can be found in Aharonian et al., 1997a, and Hofmann, 1997. The design goals of HESS are high sensitivity, low energy threshold, good angular resolution, good energy resolution for determining reliable energy spectra, and a large field of view for the observation of extended sources.

After a brief summary of the HESS performance, the astrophysical aims of HESS are detailed.

2 HESS Performance

The HESS performance has been determined with detailed Monte Carlo studies of low-energy showers. More details can be found in these proceedings, in Aharonian et al., 1997b, and in Konopelko, 1999.

HESS will have an energy threshold of 40 GeV for detection, and 100 GeV for spectroscopy and spatial resolution. The angular resolution will be 0.1 degree per photon, the energy resolution will be 20 % per photon. The integral flux sensitivity above 100 GeV will be 10^{-12} ph/(cm^2 s), the minimal detectable energy flux at 100 GeV will be 10^{-13} ergs/(cm^2 s) (100 h observation). This sensitivity presents an order of magnitude improvement in sensitivity compared to existing IACT experiments. The low energy threshold allows deep (z $\sim$ 1) cosmological observations.

The HESS sensitivity is compared to the Crab energy flux spectrum in Fig. 1. HESS makes it possible to search for emission in the 100 GeV - TeV energy range at a flux level of a few milli-Crab.

3 Astrophysical aims of HESS

The improved sensitivity will permit the detection of a larger number of objects *known* to emit VHE gamma rays such as Pulsar Nebulae and Blazar-type AGNs. Improved photon statistics for strong VHE sources will permit spectroscopic analysis on short time scales, important for variability studies. The expected observation of Supernova Remnants (SNRs) will probably settle the open question of the origin of Cosmic Rays. One will also search for VHE emission from objects with predicted fluxes below those of current instruments. Nearby Starburst Galaxies, nearby Clusters of Galaxies, and Compact Binaries are examples of such objects which are expected to be GeV/TeV emitters. A survey of the Galactic plane and other potentially interesting sky regions with unprecedented sensitivity becomes possible. The site in the Southern Hemisphere is favourable for the observation of the Galactic Centre region. We will learn more about the Diffuse Extragalactic Background Radiation (DEBRA) fields by the observation of GeV/TeV energy spectra modified by DEBRA extinction and

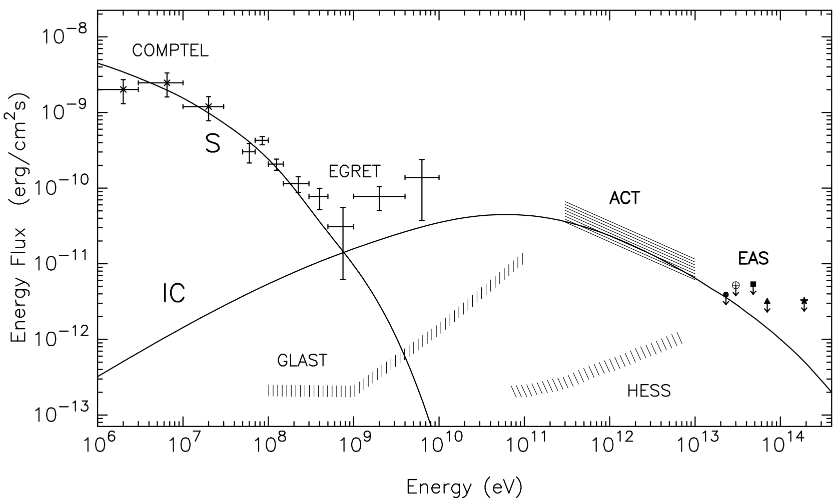

Figure 1: *The plot shows the Crab energy flux from gamma ray to VHE energies, as measured by satellite and ground-based detectors, with a synchrotron-self-Compton model fit to the data. The HESS sensitivity is given by the shaded area.*

by the study of Pair Halos. Finally, a search for gamma-rays of non-accelerator origin, such as from the decay of Topological Defects and Dark Matter candidates, will be carried out. Table 1 summarizes the presently foreseen observation targets of HESS and the associated physics questions adressed by these observations.

The expected contribution of HESS to some of these areas is briefly summarized below:

3.1 Shell-Type SNRs Shell-type SNRs are the prime candidates for the origin of Cosmic Rays below 10^{15} eV. To date, there is only little observational evidence for hadron acceleration in SNRs. A non-thermal tail is observed in some X-ray spectra, and TeV gamma-ray emission has been reported from SN 1006. There is a possible identification of some EGRET sources with SNRs. The detection of VHE gamma rays from SN 1006 with HESS would be a confirmed detection of a shell-type SNR in this energy band. Observations of gamma rays from hadrons accelerated in SNR are a prime objective of HESS.

Detailed modeling of shock acceleration in SNRs has led to predictions of the expected gamma-ray fluxes. The fluxes are at the limit or below the limit of current instruments, and the fact that the sources are extended ($\sim$1 degree) makes the observation difficult. Phenomenological estimates show that more than 10 SNRs during the Sedov phase at an age of 10^3 - 10^4 years should be detectable at the HESS sensitivity level. This number could be much higher if one considers the possibly enhanced emission resulting from the interaction of Supernova ejecta with dense interstellar regions such as nearby Molecular Clouds.

3.2 AGNs The positive detection of a number of Blazar-type AGNs, the extreme flux variability on time scales as short as hours, and the correlations with flux variability in other wavelength bands have shown the importance of AGN observations at VHE energies.

The synchronous flaring activity of these sources in the keV and TeV energy regions supports the belief that both components originate in a jet due to synchrotron emission and Inverse Compton scattering of one population of relativistic electrons. Multiwavelength observations and good photon statistics for spectroscopic analysis at short time intervals will make it possible to study the acceleration mechanism and the gamma-ray production in the jets. The positive detection of a larger sample of blazars at different redshifts will yield information about conditions in the jet and will constrain the DEBRA density by estimating the extinction of the GeV/TeV radiation due to Infrared/Optical photon fields.

At present, all gamma-ray AGNs detected at VHE energies are Blazars. However, VHE emission is an

Localized Objects	
Galactic	
Supernova Remnants	Sources of Galactic Cosmic Rays?
Pulsars, Pulsar Nebulae	Physics of Pulsar winds, Particle acceleration Structure of Nebulae
Accreting Neutron Stars, Stellar Black Holes, Microquasars	Accretion, Jet Formation, Emission Mechanism
Giant Molecular Clouds	Targets for Galactic Cosmic Rays
Extragalactic	
Nearby Starburst Galaxies	Cosmic Rays in External Galaxies
Rich clusters of Galaxies	Formation, Accretion
AGNs, Radio Galaxies, Quasars	Accretion, Gamma Rays from Jets and Radio Lobes, Diffuse Background Radiation Fields
Pair Halos	VHE luminosity, Diffuse Background Radiation Fields
Diffuse Radiation	
Charged Cosmic Rays	Energy Spectra, Composition
Galactic Plane	Diffuse VHE gamma rays
Topological Defects	Dark Matter, Galactic Halo models

Table 1: *Presently foreseen observational targets for HESS and associated physics motivations.*

expected property also of other types of AGNs such as Quasars, including AGNs with no visible jet-like features such as Seyfert Galaxies. Furthermore the so-called "Microquasars", Galactic superluminal objects proposed to be scaled-down versions of AGNs, are possible emitters of VHE gamma rays.

3.3 Clusters of Galaxies A sizable fraction of the energy of clusters of galaxies should be contained in the nonthermal component of the intracluster medium. Nucleonic Cosmic Rays in the intracluster medium are thought to originate mainly from termination shocks of the galactic winds during the formation of the early type galaxies in the clusters. Gamma rays are then produced via π^0 decay in interactions of the Cosmic Rays with the intracluster gas. Ongoing cluster accretion might also generate IC gamma-ray fluxes from freshly produced energetic electrons. Predicted fluxes are at the limit of the HESS sensitivity: estimating the total energy in relativistic protons of the Perseus cluster to $\sim 10^{62}$ erg gives an integral energy flux F($>$100 GeV) $\sim 10^{-12}$ erg / (cm^2 s) over a few degrees spatial extent.

3.4 Formation of Pair Halos The interaction of high energy photons ($\gg$ 10 TeV) from VHE sources with photons of the Infrared/Optical and the cosmological 2.7 K diffuse extragalactic background radiation can lead to the formation of extended VHE halos (see Fig. 2). The high energy photons create electron-positron pairs which are isotropized by the intergalactic magnetic field. Subsequent Inverse Compton interactions with the microwave background photon field then lead to lower energy gamma rays. The angular size of the resulting pair halo depends on the mean free path, i.e., the strength of the diffuse Infrared/Optical background photon fields and the absolute source distance. An assumed VHE luminosity of the central source above 10 TeV of L=10^{46}(d/1Gpc)^2 erg/s gives an integral halo flux of the order of 10^{-11} ph/(cm^2 s) (see Fig. 2).

Determining the spectrum and the intensity of the VHE emission as a function of the angular distance from

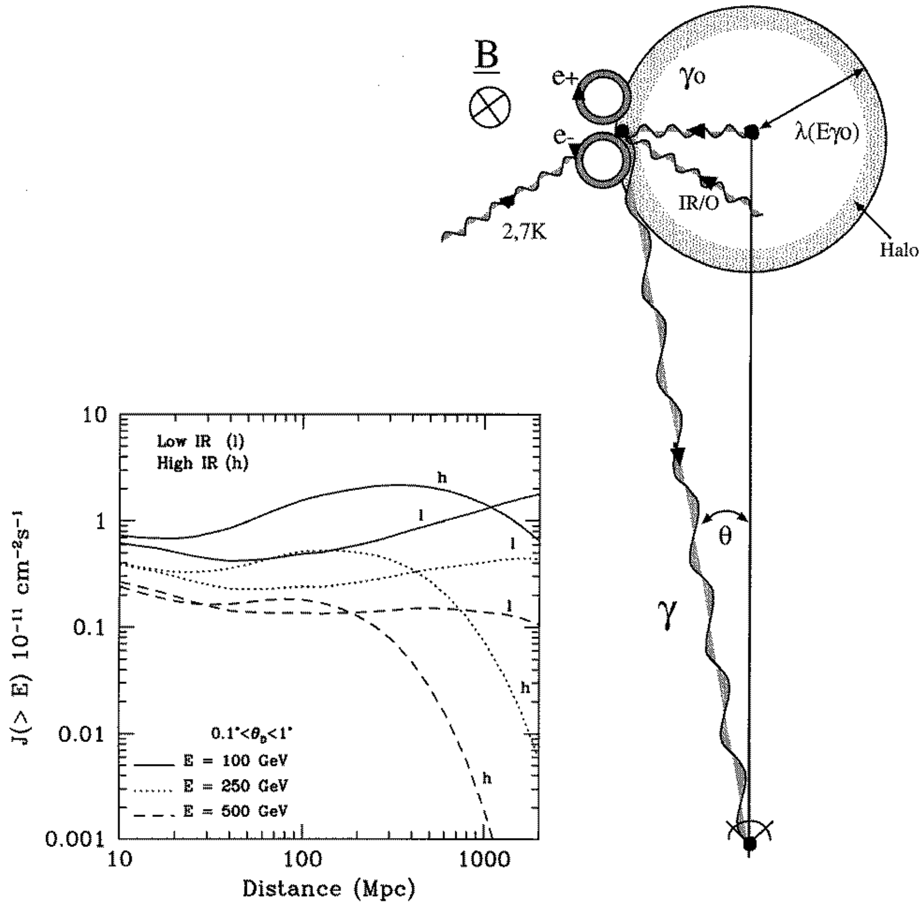

Figure 2: *The physics of pair halos: the right part shows the interaction process of a "primary" gamma photon with photons of the background radiation fields (see text). The left part shows the expected halo radiation fluxes integrated within $\theta = 1^\circ$ above 100 GeV, 250 GeV, and 500 GeV as a function of source distance for two different levels of the Infrared/Optical background: 'Low' ($n(\varepsilon) = 10^{-3}\varepsilon^{-3} ph/cm^3 eV$) and 'High' ($n(\varepsilon) = 10^{-3}\varepsilon^{-2} ph/cm^3 eV$). The assumed VHE luminosity of the central source above 10 TeV is $L=10^{46}(d/1Gpc)^2$ erg/s.*

the halo would allow a direct determination of the DEBRA fields and the total VHE power of the source. By comparing the characteristic physical sizes of pair halos with their observed angular sizes, one obtains information on source distances and the redshift-distance relation, i.e., on the value of the Hubble constant, that does not rely on the distance-ladder technique ("observational cosmology").

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