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Results from Observations of AGNs with the H·E·S·S· Telescope System and Future Plans

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Abstract. The H·E·S·S· (High Energy Stereoscopic System) Phase-I is comprised of four Imaging Atmospheric Cherenkov Telescopes (IACTs) for observation of galactic and cosmic sources of Very High Energy (VHE) gamma rays, with a significant improvement in sensitivity and a detection threshold below that of previous IACTs. Observations of Active Galactic Nuclei (AGNs) since the start of operations in June 2002 are presented, in particular for PKS 2155-304 and Mkn 421, along plans for Phase-II.

1 The H·E·S·S· Telescope System

The H·E·S·S· detector for observation of > 100 GeV γ-rays has been operating since June, 2002 in the Khomas highlands of Namibia (23°S, 15°E, 1.8 km a.s.l.). It captures the Cherenkov light emitted by cascades of particles in the atmosphere initiated by a γ-ray or charged cosmic ray incident on the atmosphere. The Cherenkov pulses ($\lambda \sim 350$ nm) are brief (few ns), faint, and illuminate a light-pool of diameter ~ 250 m on the ground for vertical cascades. The Cherenkov images of these cascades, roughly cometary in shape with an angular extent of a few mrad, can be seen by a detector anywhere in the light-pool equipped with a sufficiently fast and sensitive camera. This permits the estimation of the nature of the initiating particle (signal γ-ray or background cosmic-ray) and the measurement of its angular origin and energy. The Atmospheric Cherenkov technique intrinsically has a large (~ 50000 m^2) collection area, though with a small field of view (few degrees). Observations must take place on clear, moonless nights.

The detector, in its Phase-I, consists of four IACTs in a square of side 120 m. Each telescope mount has a tessellated mirror of 107 m^2 area with a camera in the focal plane at 15 m. The camera contains 960 photo-multipliers (PMs) with 0.16° pixel-size, 5° field of view. The read-out electronics, all contained within the camera, is triggered when the signal from a number of PMs exceeds a trigger threshold in an effective ~ 1.3 ns trigger window. The PM signals, which are stored in an analogue memory while awaiting the trigger, are then read out, digitized, and integrated within a 16 ns window. The results are then sent from the camera's data-acquisition system to the control room via optical fibres.

Soon after the second telescope became operational in January 2003, a 'Stereo' central trigger was implemented (June 2003), by which events are only retained if multiple telescopes see the same cascade. This decreases the dead-time for the individual telescopes, allowing the trigger threshold to be decreased (thus decreasing detector's energy threshold), while the multiple images of each cascade provide a increase in the background-rejection capability and the angular and energy resolution of the system.

The Phase-I of H·E·S·S· was completed in December, 2003, with the addition of the fourth telescope, since which time the system has been operating at its full sensitivity. The energy threshold of the system is ~ 120 GeV for sources close to Zenith after background rejection cuts (~ 400 GeV for single-telescope mode) with an angular resolution improved to $0.06°$ (from $0.1°$) and allowing spectral measurements with an energy resolution of $\simeq 15\%$. Observations of the Crab nebula have confirmed the system's performance, with a rate of 10.8 γ/minute and a detection significance of 26.6 $\sigma/\sqrt{\text{hr}}$, which when extrapolated for a sources close to Zenith give a 1 Crab-level sensitivity (5σ detection) in only 30 seconds (1% Crab in 25 hrs). See [1,2] for further details.

2 Observations of AGNs with H·E·S·S·

Since the first operation of the H·E·S·S· detector, many galactic and extragalactic sources have been studied. The observation of AGNs at the highest energies is a probe of the emission mechanisms in the jets of these sources, and studies of the their multi-wavelength spectral energy distributions (SEDs) and correlated variability over wavelength enable emission models (leptonic or hadronic) to be tested. In addition, as these VHE photons interact with the intergalactic Infra-Red (IIR) background (to give an electron-positron pair) and are thus absorbed, they can also serve as a probe of this background (resulting mainly from early star formation) which is difficult to measure by direct means. However, this absorption limits the distance at which we can see AGNs to a redshift 0.5 at the H·E·S·S· detector threshold energy. The large detection area of H·E·S·S· allows us to measure spectral and temporal characteristics on hour timescales (depending on the strength of flares) for the sources seen.

Among the extra-galactic targets (with observing time up to Summer, 2004 in parentheses) are: PKS 2155-304 (92h), PKS 2005-489 (52h), M87 (32h), NGC253 (34h). Here we present results from two AGNs: PKS 2155-304 and Mkn 421.

2.1 The AGN PKS 2155-304

PKS 2155-304 is the brightest AGN in the Southern Hemisphere, and has been well studied in many energy bands over the last 20 years. It has been previously detected at VHE energies [3]. With a redshift of $z = 0.117$ it is one of the most distant VHE blazars, and therefore of interest not only for studies of this class of object, but also for IIR studies.

Initial observations were taken over all the installation phase of H·E·S·S· Phase-I from July 2002 to October 2003, with an evolving detector threshold and sensitivity. Clear detections ($> 5\sigma$) are seen in each night's observations, and an overall signal of 44.9σ in 63.1 h of this mixed data, with ~ 1.2 γ/min, 10-60% Crab level, with variability on time-scales of months, days, and hours.

The energy spectra are characterized by a steep power law with a time-averaged photon index of $\alpha = -3.31 \pm 0.06$.

Owing to a particularly high level seen by H·E·S·S· in October, 2003, we triggered our RXTE "target of opportunity" proposal on this source, enabling quasi-simultaneous observations to be taken between the two instruments. Short-term variations (< 30 min) are seen in both these datasets, and multi-wavelength correlations will be published in a forthcoming paper.

A H·E·S·S· multi-wavelength campaign with the PCA instrument on board the Rossi X-ray Timing Explorer (RXTE) has been successfully completed in August, 2004, with the full four-telescope Phase-I array, and therefore full sensitivity, and these data are under analysis. This intense study of this source should yield insights into its inner workings.

2.2 The AGN Mkn 421

Mkn 421 was the first extra-galactic source detected at VHE energies [4]. It is the closest such source (at $z = 0.03$) and so is little affected by IIR absorption. With a declination $\delta \sim 38°$, it is still accessible to H·E·S·S·, though culminating at a Zenith angle above 60°. Under these conditions, observations with the H·E·S·S· detector have a higher threshold, but a compensatory larger effective area (as the light-pool is geometrically larger for showers developing at a greater atmospheric slant distance), and so gives access to the highest energies of the spectrum.

In April of this year, a great increase in activity from this source was seen by the all-sky monitor aboard RXTE, reaching an historically-high level of 110 mCrab in mid-April. A multi-wavelength campaign was therefore triggered on this source, including other IACTs, radio and optical telescopes, and RXTE.

The H·E·S·S· observations, at an average Zenith angle of 62°, provided a very clear signal in April, with 66σ in 9.71 h of data, yielding ~ 5.1 γ/min, and an estimated 1-2 Crab level. The flux clearly increases from the January level (6σ in 2.12 h, ~ 0.8 γ/min, 10-50% Crab level), and was also seen by other IACTs in the Northern hemisphere (Whipple, MAGIC). Shorter-term variations and correlations with other energy domains are currently under study.

3 Future Plans for expansion to H·E·S·S· Phase-II

Plans for Phase-II of the experiment are comprised of a large telescope in the centre of the current Phase-I providing a lowered threshold and increased sensitivity. This will provide access to a number of astrophysical phenomenæ, such as the spectral cut-offs in pulsars, microquasars, GRBs, and dark matter in the form of WIMPs. As concerns this paper, AGNs can be observed up to redshift of 2-3 with H·E·S·S· Phase-2 (vs. 0.5 with H·E·S·S·), provided that they are sufficiently bright, as the optical depth due to absorption in the intergalactic infra-red background is smaller at lower energies. With detections of a larger number of AGNs at varying redshifts, the effect of IIR absorption may be disentangled from the intrinsic spectra of the sources.

Technical plans for this very-large telescope are well advanced. The mount and dish structure (30m Ø) are well within the capabilities of industry, since much larger radio-telescopes have been built. The camera, using the same technology as Phase-I, with some improvements in order to decrease the dead-time and readout speed, will have ~ 2000 pixels of size $0.05°$($\sim 3°$field of view). An improved Analogue Memory ASIC (Application-Specific Integrated Circuit) is being prototyped, and the associated camera and read-out electronics are being designed, based on the experience gained with the Phase-I.

In operation with the four telescopes of Phase-I, Monte Carlo simulations indicate that, in coincidence mode the '4+1' system would have a detection threshold of $\sim$ 50GeV with fine-grained and photon-rich image in the central telescope providing improved background rejection and angular and energy resolution. In stand-alone mode, a threshold as low as $15-25$ GeV may be achieved, though with lower background-rejection capability.

4 Conclusions

Phase-I of H·E·S·S· has already provided many interesting new results, of which some of those from extra-galactic sources are presented here. Based on the experience gained with H·E·S·S· Phase-I, a Phase-II extension consisting of a very large Cherenkov Imaging Telescope is being designed, which will provide an unprecedentedly low threshold IACT, while greatly increasing the sensitivity at current energies. H·E·S·S· Phase-I will continue to provide exciting new results in the future, while the Phase-II is being designed and installed.

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Fig. 1. Photo of the current four-telescope H·E·S·S· Phase-I array, with an artist's impression of the Phase-II 30m Ø telescope in the centre of the array superimposed.