HESS Highlights and Status

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Overview

The Instrument

- Technique
- Specifications

Goals

Scientific Results

- The Galactic Plane Survey
- Galactic Sources
- Extra-galactic Sources
- Other

Future and Status

- HESS Phase II
H.E.S.S.
Details

- **Wide energy range**
  - Very High Energy \( \approx 100 \) GeV - 100 TeV

- **Angular Res:** <0.1° per event
  - improves with telescope multiplicity and shower intensity

- **Effective Area:** > \( 10^5 \) m\(^2\)

- **Energy Res:** 15 %

- **Pointing** accurate within 10"

- \( \approx 1000 \) hrs observation/year

- Fully operational since 2003
4 Telescopes
- 120 m spacing
- 107 m² mirror

Cherenkov Cameras
- 960 pixels, 0.16° / pixel
- 5° Field of View

Central Array Trigger
- Requires 2 telescope coincidence
- Better sensitivity + ang. resolution
Interaction in atmosphere generates an Air Shower (e+, e-)

\[ \theta_c = \cos^{-1} \left( \frac{1}{\beta n} \right) \]

Energy \( \propto \) total signal (Calorimeter)

\( \approx 10 \text{ km} \)
Sensitivity

- HESS I (predicted)
- MAGIC I

1% Crab
10% Crab
5 sigma 50 hours > 10 events
Crab-like spectrum hard cuts

GLAST (steady sources)

<table>
<thead>
<tr>
<th>% Crab</th>
<th>Obs. Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>30 s</td>
</tr>
<tr>
<td>5%</td>
<td>1 h</td>
</tr>
<tr>
<td>1%</td>
<td>25 h</td>
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Goal:

- Identify and study the sources of cosmic rays
- Which processes can accelerate particles up to $10^{20}$ ev?
- VHE (GeV-TeV) Gamma rays provide a direct view of VHE parent particle population
Predicted VHE Sources

Active Galactic Nuclei

Shell-type Supernova Remnants

Polar Wind Nebulae

Supermassive Black Holes

Microquasars/Binaries

Star forming Regions + Wolf-Rayet Stars

Gamma-ray Bursts

Galaxy Clusters
Shock acceleration produces relativistic particles

Electron population:
- + B-field
- synchrotron emission (Radio–X-ray)
- Inverse-Compton scattering produces VHE Gamma

Proton population:
- + target material
- produces Pions + ...
- \( \pi^0 \)-decay produces VHE gammas
So far nearly all VHE sources can be explained with electrons.

leptonic sources exhibit 2-humped spectrum
What do we expect?

- **Proton scenario** produces the following:
  - Relative height depends on target density, distance to source, B-field

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### Graphical Representation

- **dN/dEdAdt**: Proportionality of particle density with energy and area
- **E^2**: Energy squared

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- **Synchrotron from secondary leptons**: Diagrammatic representation of energy distribution
- **π^0-decay + Bremsstrahlung**: Additional particle decay processes

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- **VHE Gamma**: Very High Energy Gamma radiation
- **GeV Gamma Ray**: Gigaelectron Volts Gamma rays
- **TeV Gamma Ray**: Teraelectron Volts Gamma rays

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VHE Spectra

Spectra we measure in the VHE energy range have very few “features”

- **No lines** at these energies*
- Only get:
  - Flux, Spectral slope
  - Cutoff energy (sometimes)
  - Peak energy (rarely)

Multi-wavelength data are crucial for understanding the sources!

*unless we detect dark matter, e.g. annihilating Neutralinos
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VHE Astronomy in the recent past...

- Only a handful of sources
- No extended sources, morphological studies
- Focused on AGN Science
The Galaxy is full of VHE Gamma-ray Sources!
Galactic Sources

- Shell-type Supernova Remnants
- Pulsar Wind Nebulae
- Microquasars
- The Galactic Center
- Diffuse Emission
- Unidentified sources
- Molecular Cloud associations
Supernova Remnants
First resolved extended TeV source!
Correspondance with X-Ray morphology: implies gamma/X-ray production mechanism linked
RCW 86: New VHE Shell?
CTB 37B

- Chandra + HESS
- VHE + Non-thermal X-Ray discovery

*Accepted A&A (May 2008)*
Breaking News: SN 1006

“New” VHE SNR?
SN 1006 HESS/Chandra

- Smooth (degrade) Chandra image to the HESS PSF
- Compare with HESS excess map
Pulsar Wind Nebulae
correlate HESS scan with PSRs from Parkes survey

★ can start to predict which PSRs will produce VHE PWNe!

Svenja Carrigan, MPI-K
HESS J1825

Fig. 4. Energy spectra in radial bins. The left panel shows the photon index as a function of the distance from the pulsar. A clear increase of the photon index for larger distances from the pulsar position is apparent; the photon index seems to level off at a distance of $\pm 0.6^{\circ}$.

Fig. 5 summarises the findings of Fig. 4 by plotting the fits to the different wedges are compared. Table 2 summarises the different spectral parameters determined in the wedges using different distribution of offsets.

For all regions the energy spectrum has been determined as described in the text and has been fitted by a power-law in a restricted energy range between 0.25 TeV and 10 TeV.

The right panel shows the differential energy spectra for the regions illustrated in the inset, scaled by powers of 10 for the purpose of contrast. H.E.S.S. excess map as shown in Fig. 1. The wedges show the different wedges.

Error bars denote statistical errors. Systematic errors of $20\%$ on the flux and $0.15$ on the photon index are to be added for each data point in addition. However, since all spectra do not start at exactly the same energy, threshold changes slightly, thus some of the different spectra do not agree within errors to a value of $2.4$.

For all regions the energy spectrum has been determined as described in the text. The innermost region is centred on the pulsar PSR J1826–1334. Main Figure: $\gamma$-ray morphology in HESS J1825–137.
Microquasar LS 5039
**LS 5039 Periodicity**

**Period:**
- HESS: $3.908(2)$ d
- Optical: $3.9060$ d

**Chance probability:** $<10^{-15}$ (incl trials)

*implies emission region $\sim$1 AU (rules out jets/outflows)*
The Galactic Center

Coincident with Sgr A* (supermassive Black Hole)?

Best Fit HESS J1745–290 (Aharonian et al. 2004)
Best Fit HESS J1745–290 (van Eldik et al. 2007)
- preliminary-
$E^2 dN/dE$ (m$^{-2}$ s$^{-1}$ TeV)

- CANGAROO-II (2001/02)
- HESS June/July 2003
- HESS July/August 2003
- MAGIC (2004/05)

Energy (TeV)
Dark Matter?

WIMPs

Candidate: Neutralino

- Stable, Mass in the GeV - 10s of TeV range
- Would produce gamma-rays via annihilation
  - Intensity $\propto \rho^2$

*If...*

- Density profile in galaxy has a cusp at GC, could be detected!
search also made for dark matter signal + power-law external signal
- no signal detected (upper-limit at 10% source flux)
Courtesy the H.E.S.S. Collaboration
Aharonian et al., in preparation
GC Variability?

- Simultaneous HESS/Chandra observation
  - X-ray flare
    - 9x quiescent level
    - 1700 ksec
  - No increase in Gamma flux
    - 100% flux increase ruled out at 99% confidence level

Preliminary
The Galactic Center

Galactic Center Source:
Whipple: $4\sigma$ (26 h)
H.E.S.S.: $38\sigma$ (50h)

G0.9+0.1 SNR
GC + G0.9 Subtracted: Diffuse emission!

Interaction of CRs with molecular clouds

not consistent with passive illumination (spectral index $\approx 2.3$)
close correlation between $\gamma$-rays and molecular clouds

deficit in TeV $\gamma$-rays: source too young?
simulation: $10^4$ years old source @ GC
GC accelerates (nucleonic) cosmic rates!
Molecular Cloud Interactions

- **W28 region** - old SNR interacting with molecular clouds?
  - age ≈ 35000 - 150000 years, propagating into dense clouds
  - e- acceleration inefficient: hadronic cosmic rays
More MC Interactions...

- HESS J1745-303: unidentified galactic center source

CTB 37a
Coincidence with HI Structure: Forbidden Velocity Wing?
Star forming regions?
A new type of VHE Gamma-ray emitter: Star-forming region! Wolf Rayet star? Wind Blown Bubble?

Extension much larger than WR system => bubble blown in ISM?

shocks/turbulence in wind-blown bubbles accelerate CRs
Possibly associated with W 43 star-forming region (including WR 121a, a Wolf-Rayet star)
10 h of data, 9 sigma significance
**Multiwavelength view**

- **RECALL**: Two-peaked emission predicted $I_x/I_\gamma \approx 1$

- We expect VHE sources to have obvious counterparts in Radio and X-rays.

- Sources with no obvious X-ray/Radio counterpart are thus harder to explain...
Some Unidentified Sources

Recently:
Likely new SNR!
[Tian et al. 2008]

New energetic PSR!
[Hessels et al, 2008]
Extra-Galactic Sources

Active Galactic Nuclei

- Blazars
  - Variability studies
- Non-blazars (M87)
  - Variability studies
Active Galactic Nuclei (AGN)

- Powerful object at the center of some galaxies
  - Supermassive Black Hole
  - Relativistic Jet
  - Variable emission

Blazars:
- Jet is pointed at us
  - 15 known TeV blazars as of 2008
  - 7 Observed by HESS
  - 5 Discovered by HESS
PKS 2155 Flare

- First major AGN flare for Southern hemisphere source
- 15x Crab Nebula flux!
- Variability on 200s timescales! (fastest ever in the field)
- Spectra on same timescales!
- Very small emission region or very high Lorentz factor!

F(>200GeV) in 5 minute bins

Extragalactic Background Light

Assume: AGN intrinsically not harder than $\Gamma = 1.5$

Measurements of distant AGN provide Upper-Limit on EBL absorption


- HESS measurements imply:
  - EBL lower than previously thought!
  - Universe is more transparent to TeV emission! - we can see further...

Recently discovered by:
- H.E.S.S.
- MAGIC

1ES 2356-309 1ES 1101-232 show relatively hard spectrum
A new class of TeV object: a non-blazar AGN!
Variability (flux doubling) on Day timescales

NOTE: no boost from jet

Faster in TeV than in other wavebands!

Emission close to $R_s$
- Rules out core of Virgo cluster and jet!

Challenges models!

M87: Variability

Science 314 (2006)
Other Results

- Cosmic Ray Spectrum
- Electron Spectrum
- Extended extragalactic objects?
Can we measure the Cosmic Ray Iron spectrum with HESS?

Direct Cherenkov light:

\[ I_{DC} \propto Z^2 \]
\[ I_{shower} \propto E \]

The H.E.S.S. Iron spectrum

Rolf Bühler, MPI-K

Aharonian et al, 2007, Phys Rev D
Use random-forest method to develop cuts which select electron events.
Looking to the Future...

Extended Extragalactic Objects?

e.g.: Galaxy clusters
powerhouses for high E cosmic rays!

- Don’t leak out over time as in a galaxy
- Hadronic interactions with target material seen in X-rays, should produce gamma rays too!

★ Not yet detected in VHE gamma rays
Detected VHE Sources

- Active Galactic Nuclei
- Shell-type Supernova Remnants + Molecular clouds
- Pulsar Wind Nebulae
- Supermassive Black Holes
- Microquasars/Binaries
- Starforming regions/WR Stars
- Gamma-ray Bursts
- Galaxy Clusters

* possibly

+ ...?
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HESS Phase II

- Single 30m telescope
- Mirror area: 600m²
- FOV: 3°
- 2000 pixel camera
- Rigid steel structure
  - Height: 40m
  - Weight: 560 tons

Construction started

First light: end of 2008+
HESS Phase II

H.E.S.S. Phase II stereoscopy + monoscopy

- **HESS II Standalone**
  - 15–25 GeV

- **HESS Hybrid**
  - ~50 GeV
  - ~100 GeV

- **HESS Phase I**
  - possible exploration
  - guaranteed exploration
  - enhanced sensitivity
Conclusions

- HESS has discovered a wide variety of VHE sources:
  - extended, point-like, diffuse, periodic, variable, ...
  - the total number of VHE sources is now greater than 50! (close to 100 including unconfirmed hotspots)

- VHE astrophysics is in a golden age of discovery ushered in by HESS and other next-gen ACTs

- Future upgrades and observatories will probe larger energy ranges and deeper