Recent Results From H.E.S.S.
-and a look at the future!

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University of Durham
The Plan

- Some background information
- Recent H.E.S.S. results
  - The Galactic Plane survey
  - The Galactic Ridge
  - Dark matter searches
  - Starburst Galaxies
  - The PKS2155-30 flare and quantum gravity
  - Multiwavelength observations of M87
- CTA – the Cherenkov Telescope Array
Satellite-based: 511 keV to around 50 GeV

Ground-based: ~20 GeV+
• (Multiple) Images of showers
• Gamma rays form consistent pattern
• Showers located to ~0.1° at threshold
• Point source location to ~ 30"
• Excellent ability to get rid of the background
Important features of the technique.....

Excellent source location

Very large effective area

Cannot observe during full moon

IACTs are pointing instruments

Clouds are bad!

Energy threshold (and collection area) increase with zenith angle.
High Energy Stereoscopic System – H.E.S.S.

4 Telescopes since 2004
Namibia
M-PIK Heidelberg; Humboldt University, Berlin; University of Hamburg; Ruhr University, Bochum; Landessternwarte Heidelberg; Tübingen University; Erlangen-Nürnberg University

LLR Ecole Polytechnique; LPNHE; APC College de France; University of Grenoble; CESR Toulouse; CEA Saclay; Observatoire de Paris-Meudon; LPTA Montpellier; LAPP Annecy

Durham University; University of Leicester

Dublin Institute for Advanced Studies

Polish Academy of Sciences (Astronomical Center & Institute of Nuclear Physics); Jagiellonian University; Nicolaus Copernicus University

Charles University, Prague

Yerevan Physics Institute, Armenia

University of Namibia

North-Western University, South Africa

University of Adelaide, Australia

University of Innsbruck, Austria

University of Stockholm, Sweden
System Parameters

- Energy Threshold: 100 GeV
- Energy Resolution: 15%
- Field of View: ~5°
- Angular Resolution: 0.05°-0.1°
- Pointing Accuracy: ~10 arcsec
- Signal Rate: ~55/min (Crab Like)
- Sensitivity:
  - 1 Crab in 30 sec
  - 0.01 Crab in 50h

(All at zenith)
### Sources by Type

<table>
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<th>Type</th>
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<th>Subtype</th>
<th>Count</th>
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<tr>
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<td>PWN</td>
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<td>FRI</td>
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<td>Starburst Galaxies</td>
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<td>Diffuse</td>
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<td>FSRQ</td>
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<td>Gal. Centre</td>
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</table>

Fortuitously, that comes to 100 – but it’s subjective!
Science with VHE Gamma Rays

- SNRs
- Pulsars and PWN
- AGNs
- GRBs
- Dark matter
- Origin of cosmic rays
- Space-time & relativity
- Cosmology
- Dark matter
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The H.E.S.S. Galactic Plane Survey

The Extended H.E.S.S. GPS
2005 - 2008
Acceptance-corrected Exposure

**Extended H.E.S.S. GPS**
- $-85^\circ < l < 60^\circ$
- $-3^\circ < b < 3^\circ$
- Scan mode: 400 h
- Detected 50+ Galactic sources of VHE gamma-rays
- ICRC 2007, DPG 2008, Gamma08
Extended emission from the Galactic center region

Point sources subtracted

GC molecular clouds
Tsuboi et al. 1999

10 kyrs
H.E.S.S. Observations of Diffuse Emission in GC Region

Top-down: Annihilation of dark matter particles

\[ \chi \chi \rightarrow \gamma \gamma, \gamma Z, \gamma h \]

Matter distribution expected to have characteristic density profile:

\[ \sim r^{-1} \] (NFW)

to \[ r^{-1.5} \] (Moore)

sharp spike with long tail

and characteristic energy spectrum

Nicked from Werner Hofmann!
Galactic Centre

Sgr A East SNR

Sgr A*

TeV cog:
7\"±14\"_{\text{stat}} ±28\"_{\text{syst}}
from Sgr A*

DM Annihilation – angular distribution

Angular distribution of H.E.S.S. result consistent with a point source, once diffuse BG eliminated (16% of total emission). Assume a Gaussian centred on best-fit position → lower limit to slope of distribution -1.2 (i.e. cuspy)

Aharonian et al., PhRvL, 97, 22, id 221102 (2006)
DM annihilation - spectrum

$E^2 F(E) \text{ [TeV/cm}^2\text{s]}$

$E \text{ [TeV]}$

20 TeV Neutralino
20 TeV KK particle

proposed before H.E.S.S. data

proposed based on early H.E.S.S. data

The Position of the Galactic Centre Source

Radio contours of Sgr A East (VLA)

Previous H.E.S.S. best-fit centroid

New H.E.S.S. best-fit centroid

First H.E.S.S. result was compatible with Sgr A East, Sgr A* and PWN candidate G359.95-0.04. Using paraxial optical cameras on telescopes reduced pointing errors from 20 arcsec to 6 arcsec per axis. Sgr A East looks to be ruled out as source of emission.

Aharonian et al., *MNRAS*, Dec 2009 (astro-ph 0911.191v2)
Sgr Dwarf Spheroidal Galaxy

Has crossed Milky Way at least 10 times without being disrupted.

Good candidate for substantial amount of DM – not much gas, so low CR background too.

Handily, also off the Galactic Plane.

Signal is expected to come from a region ~1.5 pc, much smaller than the H.E.S.S. PSF. Profile (NFW…) doesn’t matter!
H.E.S.S. Observations

June 2006, 11 hours. Upper limit E > 250 GeV: 3.6 x 10^{-12} cm^{-2}s^{-1}. (95% c.l.)

For core model, a lower limit for the $B^{(1)}$ mass of 500 GeV can be derived.

100h observation would enable the exclusion of much more pMSSM parameter space and all KK space for the core model.
Canis Major ‘Overdensity’
From Strasbourg Observatory
No Signal!

Mass of system not well known, so this is assuming mass of $3 \times 10^8$ solar masses.

The Electron Spectrum

The ATIC experiment observed a peak in the electron spectrum between 300 and 800 GeV. Coupled with PAMELA excess, this has led to much speculation – e.g. dark matter, contribution from a local pulsar etc.

Measuring electron spectrum with a VHE gamma-ray experiment is tough – electrons and gamma rays both produce pure electromagnetic showers.

Have to use off-GP data and extensive simulations to derive an ‘electron likeness’ parameter, $\zeta$.

H.E.S.S. Measurements

Overall electron flux is compatible with ATIC within errors, but H.E.S.S. data exclude presence of a pronounced peak in the electron spectrum, though an energy shift could be possible, so it cannot be definitively ruled out. However, it’s hard to reconcile with a KK dark matter scenario.
Starburst Galaxies – why bother?

Compulsory picture!

Starburst galaxies = lots of star formation (in a small region) = lots of supernovae = lots of particle (proton) acceleration + lots of gas = lots of VHE gamma rays = confirmation of suspicions about galactic CRs (and maybe information about galaxy/star formation)
NGC 253

D = 3.9 ± 0.4 Mpc

SN rate ~ 10x Milky Way in starburst region

Mean density of gas in starburst region almost $10^3$ higher than MW

Radio, thermal X-rays show hot, diffuse halo consistent with galactic wind

Discovered by Caroline Herschel in 1783
H.E.S.S. Detection of NGC 253

Flux (E > 220 GeV): $5.5 \pm 1.0^{\text{stat}} \pm 2.8^{\text{sys}} \times 10^{-13} \text{ cm}^{-2} \text{s}^{-1}$

~ 0.3% Crab flux

119 hours of observation

No evidence for variability

CR density in starburst region ~ 2000x that near the Solar System, and ~ 1400 times that near the GC

Acero et al., Science, 326, 1080 (2009)
Fermi LAT detections of NGC253 & M82

Flux (E > 100 MeV):
1.6 ± 0.5_{stat} ± 0.3_{sys} x 10^{-8} cm^{-2}s^{-1}

Flux (E > 100 MeV):
0.6 ± 0.4_{stat} ± 0.4_{sys} x 10^{-8} cm^{-2}s^{-1}

No evidence for variability in either object

Gamma-ray luminosity best correlates with SN rate and the mass of gas in the galaxy – perhaps not surprising.

BUT distribution of CRs is unlikely to be uniform – e.g. the GeV emission in LMC mostly comes from 30 Doradus and does not trace star formation & total gas mass.
Emission models depend on many different parameters – agreement looks better for M82 than for NGC 253. In M82, the smooth power law connection between Gev & TeV emission suggests the same process produces both. Relationship less clear for NGC 253.
NGC 253 and Cosmic Rays

- 220 GeV generating protons need energy ~ 1300 GeV
- Given
  - CR energy production in equilibrium with losses from nuclear collisions;
  - Measured gas density and SN rate;
  - Production spectrum $\propto E^{-2.1}$
- Then calculate gamma ray flux to be factor of $10^2$ higher than observed; suggests CRs in NGC 253 more likely to escape than expected
- NGC 253 is not a perfect CR ‘calorimeter’ – ISM does not act as a perfect ‘beam dump’
- Nevertheless, conversion efficiency of protons to gamma rays is still ~ 10x higher than in the Milky Way
- Starburst nucleus should outshine the rest of the galaxy (consistent with H.E.S.S. point source)
**Interpretation III**

Assume protons (pion decay) gamma rays dominate

In M82: exploit uncertainties in SN explosion rate & efficiency of CR generation.

In NGC 253: exploit uncertainties in distance (2.5 Mpc has been quoted), diffusion timescales & cutoffs in the proton injection spectrum.

Cea del Pozo et al., 2009 Fermi Symposium (astro-ph 0912.3497v2)
Active Galactic Nuclei

The most common VHE-emitting AGN are the high-frequency peaked blazars – where we are looking almost directly down the jet.
In late July 2006, this AGN went crazy, and produced a burst that made the object 20 times brighter than the Crab Nebula. The burst contained over 60,000 gamma rays!
Energy Dependence of c

Broadly speaking (models vary), quantum gravity predicts an energy-dependence of the speed of light of the form:

\[ c' = c \left( 1 + \xi \frac{E}{E_p} + \zeta \frac{E^2}{E_p^2} \right) \]

where \( E_p \) is the Planck Energy, \( 1.22 \times 10^{19} \) GeV, and \( \xi \) and \( \zeta \) are free parameters to be determined. The correction is expected to be very small, but Amelino-Camelia et al. (1998) suggested that these modifications can produce significant time delays with energy over cosmological distances. The absence of such energy dispersion sets limits on \( \xi \) and \( \zeta \).

We can use the massive flare from PKS2155-304 to test this.
The MCCF (left) looks quite exciting, with an apparent 20s lag for higher energy. However, when you do 10,000 simulations varying the flux points of the oversampled light curve within measurement errors and create a cross-correlation peak distribution (right), you find an RMS of 28s and that simulations produce a negative delay for 21% of the time. The ‘lag’ is therefore consistent with zero.

$|\xi| < 17$ for linear dispersion & $|\zeta| < 7.3 \times 10^{19}$ for quadratic dispersion
M87 – a Radio Galaxy
Pinpointing the Emission Site

Combined observations of H.E.S.S., VERITAS, MAGIC & the VLBA 43 GHz team – the paper has 392 authors!

Emission is variable on ~ day timescales. Previous observations had shown an increase in VHE emission roughly contemporaneous with emission from the knot region HST-1 in the jet.

These observations show the emission is coming from the nucleus.

Acciari et al., Science, 325, 444 (2009)
Which came first??

The core seems to show a period of below-normal activity before the flare, and the radio flux increase actually starts before the VHE flare. This is followed by enhanced emission along the inner jet after the VHE flare.
Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, **but this is clearly only the tip of the iceberg**.
So what next???
The Cherenkov Telescope Array (CTA) a ‘real’ observatory with ~ 100 telescopes

- **25 MEuro**
  - Low-energy: energy threshold of few 10 GeV

- **35 MEuro**
  - Core array: mCrab sensitivity at 100 GeV–10 TeV

- **20 MEuro**
  - High-energy: 10 km² area at multi-TeV energies
## Work Packages

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<tr>
<th>WP</th>
<th>MNG</th>
<th>Description</th>
<th>Person(s)</th>
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<tbody>
<tr>
<td>WP1</td>
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<td>Management of the design study</td>
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<td>WP2</td>
<td>PHYS</td>
<td>Astrophysics and astroparticle physics</td>
<td>D Torres</td>
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<td>WP3</td>
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<td>J Hinton</td>
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<td>SITE</td>
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<td>G Vasileiadis</td>
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<tr>
<td>WP5</td>
<td>MIR</td>
<td>Telescope optics, mirrors, mirror alignment</td>
<td>M Mariotti &amp; M Doro</td>
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<td>WP6</td>
<td>TEL</td>
<td>Telescope structure, drive, control, robotics</td>
<td>M Panter</td>
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<td>WP7</td>
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<td>R Mirzoyan</td>
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<td>ELEC</td>
<td>Readout electronics and trigger</td>
<td>P Vincent</td>
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<td>S Nolan</td>
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<td>Observatory operation and access</td>
<td>A Sillanpää &amp; S Wagner</td>
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<td>WP11</td>
<td>DATA</td>
<td>Data handling, data processing, data management and access</td>
<td>C Stegmann</td>
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<td>WP12</td>
<td>QA</td>
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<td>M Punch &amp; M Benallou</td>
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(acting) Chair of the Consortium Board

J Knapp

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<td>medium-size telescopes</td>
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<tr>
<td>LST:</td>
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Opportunities for UK contributions, manpower needed everywhere.
Funding:

ASPERA Common Call CTA
mostly personnel
€2.6M
UK: £0.5M
£0.00

FP7 CTA Prep Phase call (EU) (€ 6M)
announcement spring 2010
mostly organisational
matching funds:
€2.93M
UK: ≈ €0.26M

FP7 Virtual research infrastructures (EU) (€ 4.2M)
announcement spring 2010
GRID, archiving, data handling, ... UK: ≈ 4 PD yrs

other funding:
€2.76M
UK: ≈ €0.24M