Recent results from H.E.S.S.

Emmanuel Moulin for the H.E.S.S. collaboration
50th Rencontres de Moriond EW
14 - 21 March 2015
The H.E.S.S. collaboration

- MPI Kernphysik, Heidelberg, Humboldt Univ. zu Berlin, Ruhr-Univ. Bochum, Univ. Erlangen-Nuremberg, Univ. Hamburg, LSW Heidelberg, Univ. Potsdam, Univ. Tübingen, DESY
- Stockholm University, Royal Institute, Linnaeus University, Durham Univ., Univ, Leicester, Dublin Inst. for Adv. Studies, GRAPPA U. Amsterdam
- Polish Academy of Sciences; Jagiellonian University, Cracow; Nicolaus Copernicus University, Torun; University of Warsaw, Warsaw
- Univ. Adelaide, North-West Univ., Potchefstroom, Wits Univ., Johannesburg, Univ. of Namibie, Windhoek
A γ-ray enters the atmosphere. The electromagnetic cascade results in Cherenkov light. A 10 nanosecond snapshot shows a 0.1 km² "light pool", with a few photons per m².
γ-ray enters in the atmosphere

Electromagnetic cascade

Current IACTs:
- 2 - 5 Telescopes
- 500-2000 pixel cameras
- 3.5 - 5.0° FoV
- ~0.1° angular res.
- ~15% energy res.
- Sensitivity <1% Crab
- ~30 GeV < E < ~50 TeV

10 nanosecond snapshot

0.1 km² “light pool”, a few photons per m²
The H.E.S.S. experiment

- **H.E.S.S. phase I**
  - four 12m telescopes
  - FoV 5 deg
  - energy threshold 100 GeV
  - angular resolution < 0.1 deg
  - Operating since 2003

- **H.E.S.S. phase II**
  - four 12m telescopes
  - one 28m telescope (FoV 3.5 deg)
  - energy threshold $O(30 \text{ GeV})$
  - angular resolution from 0.4 deg to less than 0.1 deg
The H.E.S.S. experiment

- H.E.S.S. phase I
  - more than 10000 hours of data
  - discovered over 80 new VHE gamma ray sources
  - published over 100 scientific papers, plus numerous conference contributions

- H.E.S.S. phase II
  - towards lower threshold and transients

H.E.S.S. phase I

H.E.S.S. phase II
Indirect dark matter search

\[
\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_{DM}^2} \frac{dN_\gamma}{dE_\gamma} \times \int_{\Delta\Omega} \int_{l.o.s.} \rho^2(r[s]) ds
\]

Particle Physics:
- Cross sections
- Differential photon yield
- DM particle mass

Astrophysics
- DM distribution in the target

SM: $b, W^+, Z, \tau^+, \ldots$

Primary channels
- SM: $\bar{b}, W^-, Z, \tau^-, \ldots$

Hadronisation and/or decay
- $\gamma, e^+, p, \nu, \ldots$

Final states
- $\gamma, e^-, p, \nu, \ldots$
Spectral signatures in gamma-rays

Continuum emission
(“Secondary photons”) → from fragmentation of quarks/massive gauge bosons (via $\pi_0$ decay)

Gamma-ray lines → from two-body annihilation into photons → forbidden at tree-level, generically suppressed by $O(\alpha^2)$

Virtual Internal Bremsstrahlung (VIB) → radiative correction to processes with charged final states → generically suppressed by $O(\alpha)$
Dark matter targets gamma-ray searches

- DM density profile matters
- Astrophysical background matters as well

Galactic Centre
- Proximity (~8kpc)
- Possibly high DM concentration:
  - DM profile: core? cusp?
- High astrophysical background

Galaxy satellites of the Milky Way
- Many of them within the 100 kpc from GC
- High M/L
- Low astrophysical background


Substructures in the Galactic halo
- Lower signal
- Cleaner signal (once found)

Galactic halo
- Large statistics
- Galactic diffuse background

Emmanuel Moulin . H.E.S.S. Moriond EW 2015
Dwarf satellite galaxies of the Milky Way

- Most DM-dominated systems in the Universe
- Stellar dynamics allows to control the DM distribution
- Environments with favorably low standard gamma-ray backgrounds
- No standard VHE signal detected so far

- Rich observational program in H.E.S.S., MAGIC and VERITAS
- Both classical (Draco, Sculptor, Fornax, …) and ultra-faint (Segue 1, Coma Berenices, …) dSphs
Dwarf galaxy observations by H.E.S.S.


- No significant excess
  → upper limits on the DM flux vs. DM particle mass

Significance map

Sagittarius dSph FoV
- 90 obs. time
- RoI: 0.1°
Dwarf galaxy observations by H.E.S.S.

*Phys. Rev. D 90, 112012 (2014)*

- No significant excess
  → upper limits on the DM flux vs. DM particle mass

- 5 dSphs observed by H.E.S.S. 1
  → Combined analysis

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<table>
<thead>
<tr>
<th>dSph</th>
<th>Mean Zenith (°)</th>
<th>$E_{th}$ (GeV)</th>
<th>Live-time (hrs)</th>
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<tr>
<td>Sagittarius</td>
<td>15.99</td>
<td>196</td>
<td>90.0</td>
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<td>Coma Berenices</td>
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<td>Fornax</td>
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<td>Carina</td>
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<td>Sculptor</td>
<td>14.21</td>
<td>264</td>
<td>12.5</td>
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</tbody>
</table>
Dwarf galaxy observations by H.E.S.S.


- No signal so far only upper limits, only large flux enhancement can be excluded
- Complementary to Fermi-LAT limits
Dwarf galaxy observations by H.E.S.S.

- No signal so far only upper limits, only large flux enhancement can be excluded
- Complementary to Fermi-LAT limits
- New dSph galaxy candidates from the DES survey in the Southern hemisphere
Galactic Centre region seen by H.E.S.S.

- Largest H.E.S.S. dataset
  - Most detailed view of GC @VHE: Pointlike sources (PWN, SNR, Unid) and diffuse emission

- DM density in the central region of the Milky Way expected to be large
Inner Galactic halo observations by H.E.S.S.

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- N-body simulations predict almost universal DM profile
  → density DM cusp towards the centre of galaxies
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- Avoid sky regions with strong astrophysical gamma ray background
- Focus at the same time on regions with an expectedly large DM density
  → search region: 45-150 pc around GC, Galactic plane excluded
Inner Galactic halo observations by H.E.S.S.

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- Strongest gamma-ray contraints to date for TeV DM: $3 \times 10^{-25} \text{ cm}^3 \text{ s}^{-1}$ @1 TeV
- About one order of magnitude above thermal relic cross section @1 TeV
Inner Galactic halo observations by H.E.S.S.

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- N-body simulations predict almost universal DM profile
  → density DM cusp towards the centre of galaxies
- Baryons influence the DM
  → tend to flatten the DM distribution in the central kpc of Milky Way like galaxies  
  \[A. \text{Pontzen and F. Governato, Nature (2014)}\]

Given the limited FoV of IACTs, this requires dedicated observational strategy to probe DM annihilation signal
→ ON-OFF observations
Inner Galactic halo observations by H.E.S.S.

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- Limited FoV: ~2 deg. in radius
  → signal and background cannot be taken at the same time to allow for enough DM gradient between the signal and background region
  → require dedicated observational strategy
Inner Galactic halo observations by H.E.S.S.


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- Strongest gamma-ray constraints to date for TeV DM for core DM halo at GC $3 \times 10^{-24} \text{ cm}^3 \text{ s}^{-1}$ @1 TeV
Search for monochromatic gamma-ray line

- Strongest gamma-ray constraints to date for TeV DM line
- H.E.S.S. will fill the gap between Fermi-LAT and H.E.S.S. 1

HESS PRL 110, 041301 (2013)
The Crab with CT5

- \(<\text{zenith}> = 48 \text{ deg}\)
- Standard analysis
  - photon rate = 12.6 ± 0.1 \(\gamma/\text{mn}\)
  - MC expectation = 13 \(\gamma/\text{mn}\)
The Galactic Centre with CT5

- The Galactic Centre is one of the most complicated regions

- Observation and analysis
  - Life time 68.8 h
  - Signal with 25 $\sigma$
  - extended emission

- Background needs to be further studied
Summary

- H.E.S.S. II is
  - continuing to contribute to our understanding of the high-energy Universe
  - measuring point sources and extended sources
  - filling the gap between Fermi-LAT and IACTs

- Dark Matter:
  - Combined analysis towards 5 dSph galaxies
  - Strongest TeV constraints so far from the inner Galactic halo
  - Together with Fermi-LAT constraints towards dSph galaxies, HE.S.S. 2 will curb the parameter space from a few tens of GeV to a few tens of TeV

- HESS II is accumulating observations in the Galactic Centre region

- Exciting times ahead of us
Strongest gamma-ray constraints to date

Nearby (~100kpc) dwarf galaxies

Inner Galactic halo

15-dpsh stacking
100% tautau

Natural scale