# Exploring the Galaxy at VHEs with H.E.S.S. 

P. Bordas (MPIK Heidelberg, Germany) for the H.E.S.S. Collaboration

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## Exploring the Galaxy at VHEs with H.E.S.S.

## outline

- the H.E.S.S. telescopes
- Galactic highlights
- H.E.S.S. - I
- H.E.S.S. - II
- summary


## the VHE window



Energy (eV) $10^{-6} 10^{-5} \quad 10^{-4} 10^{-3} 10^{-2} \quad 10^{-1} \quad 1$

Gamma-rays


VHEs

The Cherenkov technique in a nutshell


The stereo Cherenkov technique in a nutshell


## The High Energy Stereoscopic System of Cherenkov telescopes

## H.E.S.S. phase I (2002-2013)



Technical specs: snapshot
Telescopes: 4
Mirrors: 12 m diameter
Area: $107 \mathrm{~m}^{2}$
FoV: $\sim 5^{\circ}$ diameter
Camera: 960 pixels (PMTs)
Angular resolution $\geq 0.06^{\circ}\left(5^{\prime}\right)$
Electronics: fast $\sim 1$ ns
Energy range: ~100 GeV to ~100 TeV
Energy resolution ~15\%
Background rejection > 99\%
Duty cycle 10\%


## The High Energy Stereoscopic System of Cherenkov telescopes



## H.E.S.S. I highlights

## HESS Galactic Plane Survey


$\bullet>2800 \mathrm{~h}$ obs (2004-2013), $65^{\circ}<1<250^{\circ}$, $\mathrm{Ibl}<3.5^{\circ}$, [0.2-100] TeV, ~2\% Crab, 77 sources

## H.E.S.S. I highlights

## HESS Galactic Plane Survey





- adaptive ring bkg estimation with exclusion region masks

Galactic Longitude (deg)

- semi-automated, MLE-based source detection \& morphology fitting
- model sources as Gaussian plus an underlying "diffuse" component


## H.E.S.S. I highlights

## HESS Galactic Plane Survey



## ...featuring:

- H.E.S.S. catalog
- MWL associations


## A very hard spectrum TeV gamma-ray source in the Galactic plane




- one of the hardest gamma-ray spectra ever found at VHEs ( $\Gamma=2.07$ )
- detected only above few TeVs (contamination by nearby HESS J1640)
- no signature of cut-off, pp-preferred... PeVatron? (protons >100 TeV 99\% CL)


## First shell-type SNR ever detected in TeV gamma-rays


H.E.S.S. Collaboration (2006)
still, many questions remain...


Fermi-LAT Collaboration (2011)

- spectral cut-off shape? —> electrons vs. protons
- spatially-resolved spectra w/ unprecedented resolution $->$ resolve physical properties
- morphology \& radial profiles + comparison to X-rays $->$ particle diffusion + escape?


## H.E.S.S. high-precision measurements of RXJ1713-3946


H.E.S.S. Collaboration (2015, in prep.)

- exposure: 170 h
- angular resolution: 0.05 deg
- energy threshold: 250 GeV


| Spectral Model | $\Gamma$ | $E_{\text {cut }}$ <br> $(\mathrm{TeV})$ | $F(>1 \mathrm{TeV})$ <br> $\left(10^{-11} \mathrm{~cm}^{-2} \mathrm{~s}^{-1}\right)$ | $\chi^{2} / \mathrm{ndf}$ |
| :--- | :--- | :--- | :--- | :--- |
| $F_{0} E^{-\Gamma}$ | $2.32 \pm 0.02$ | - | $1.52 \pm 0.02$ | $304.2 / 118$ |
| $F_{0} E^{-\Gamma} \exp \left(-\frac{E}{E_{\text {cut }}}\right)$ | $2.06 \pm 0.02$ | $12.9 \pm 1.1$ | $1.64 \pm 0.02$ | $120 / 117$ |
| $F_{0} E^{-\Gamma} \exp \left(-\frac{E}{E_{\text {cut }}}\right)^{2}$ | $2.17 \pm 0.02$ | $16.5 \pm 1.1$ | $1.63 \pm 0.02$ | $113.8 / 117$ |
| $F_{0} E^{-\Gamma} \exp \left(-\frac{E}{E_{\text {cut }}}\right)^{0.5}$ | $1.82 \pm 0.04$ | $2.7 \pm 0.4$ | $1.63 \pm 0.02$ | $142.1 / 117$ |

## H.E.S.S. high-precision measurements of RXJ1713-3946




- use X-rays (XMM-Newton) convolved with HESS-PSF
- 24 regions defined, derivation of B-field in a synchrotron (X-ray) scenario


## H.E.S.S. high-precision measurements of RXJ1713-3946



## H.E.S.S. I highlights

## The Fermi-LAT and H.E.S.S. Views of the Supernova Remnant W49B



Fermi-LAT and H.E.S.S. Collaboration (2015, in prep.)

- H.E.S.S.:
- 75h live-time (2004-2013, no CT5)
- Model analysis, std cuts (Eth $\sim 290 \mathrm{GeV}$ )
- W49B detected at 12.9 $\sigma$ stat. level
- morphology: point-like (PSF ~ shell size)
- Fermi-LAT:
- 5 years of data (Pass7)
- morphology: point-like (PSF ~ shell size)
- slight offset position w.r.t. H.E.S.S

HESS J1534-571


HESS J1912+101

H.E.S.S. Collaboration (2015, in prep.)

- goal: extend small population of known TeV shells
- some sources may be faint in X-rays (intrinsically or due to absorption) -shell morphology: particles confined - albeit high-E may have escaped
- method: look for new shell candidates in the HGPS
- results: two new shell-candidates resolved, few more candidates...


## H.E.S.S. Observations of the LMC



## PWN N157B:

- Crab LMV "counter-part"
- but lower B-field ( $45 \mu \mathrm{G}$ ) and efficiency
- no GeV emitter (so far)


## 30 Dor C

- $1^{\text {st }}$ detection superbubble in $\gamma$-rays
- shell-bright in X-rays, TeV also there?

N 132D

- one of oldest TeV emitting SNRs
- first individual cosmic-ray sources in external galaxy $\rightarrow$ Science 347:6220 (2015)
- just the "tip of the iceberg"? -> future observations with CTA


## Pulsations from the Vela Pulsar down to 20 GeV with H.E.S.S. II



- High significance detection of the P2 pulse from the Vela PSR with H.E.S.S.II
- CT5 able to operate down to 20 GeV
- Excellent agreement with Fermi-LAT: crosscalibration check for CT5

H.E.S.S. Collaboration (2015, in prep.)


## Observations of Sgr A* with H.E.S.S. II




- GC with the H.E.S.S. II array down to $\sim 100 \mathrm{GeV}$
- Detection of central source (40б), PWN G0.9+0.1, HESS J1745-303 + diffuse emission
- smooth continuation from spectrum seen in H.E.S.S. I
- E-threshold not low-enough to fully describe Fermi-LAT-H.E.S.S. spectral break
- +50h obs. time coming soon (blinded for dark matter searches...) vs 58h so far...


## PSR B1259-63: a pulsar Y-ray binary system

- pulsar (P 48ms, $\left.L_{\text {sd }}=8 \times 10^{35} \mathrm{erg} / \mathrm{s}\right)+09.5 \mathrm{Ve} \operatorname{star}\left(\mathrm{L}_{\text {star }}=2.3 \times 10^{38} \mathrm{erg} / \mathrm{s}\right)+$ circ. disk
- binary system: $\mathrm{D}=2.3$, P orb $=3.4$ years, eccentricity $=0.87$, orbital inclination $\mathrm{i} \sim 24^{\circ}$
- variable/periodic emission in radio, optical, X-rays, GeV and TeV y-rays
- pulsations seen only in radio (and away from periastron)
- GeV flare in 2011; happening again in 2014


PSR B1259-63, credits: NASA archive


## H.E.S.S. Observations of PSR B1259-63 during its 2014 periastron passage



## H.E.S.S. II highlights

## H.E.S.S. Observations of PSR B1259-63 during its 2014 periastron passage




- analysis of both 2014 and previous data with new software tools
- confirmed double-peak pattern observed in the long-term light curve
- Local minimum at the periastron passage
- Source still active at VHEs at 40-50 days after periastron
- Differences between light curves w.r.t previous periastron events


## H.E.S.S. II highlights

## H.E.S.S. Observations of PSR B1259-63 during its 2014 periastron passage



- Comparison of results from
H.E.S.S., Fermi-LAT and Swift-XRT simultaneous observations
- X-rays: highest-ever flux recorded in 2014 (2nd disk crossing). Hints of variability during GeV flare?
- Fermi-LAT: reappearance of the gamma-ray flare (slight differences), marked variability
- H.E.S.S. (CT5): high emission state at VHEs during the GeV flare


## H.E.S.S. II highlights

## LS 5039: the "swiss-clock" gamma-ray binary

- First binary @ TeV (Aharonian et al. 2005)
- C.O.: 3.7 +/-1.5 Msun, O6.5V companion, Porb=3.9d
- long-term stability at VHEs (the exception)
- illustrates variability in VHE light-curves and spectra



H.E.S.S. Collaboration $(2005,2006)$


## LS 5039 - update of H.E.S.S - I data-set (2006-2012)

- excellent agreement with 2006 published results (swiss-clock)
- detection in every orbital phase ( 0.1 width)
- spectral features in some phase-bins
- broken PL preferred for INFC w.r.t. exp-cutoff-PL

P. Bordas, HESS Galactic, JPS-2015


## H.E.S.S. II highlights

## LS 5039 - new H.E.S.S - II observations (2013-2015)


H.E.S.S. Collaboration (2015, in prep.)


- about 14h live-time (more in 2015), >10 $\quad$ detection (stereo and mono)
- spectrum down to 120 GeV with only 14 h obs. time! (can go lower)
- First gamma-ray binary with real Fermi-LAT/H.E.S.S. overlap
- so far compatible within errors: existence of a break at 100 GeVs ?


## Summary (I)

- 12 years of extremely successful H.E.S.S. operations
> effectively opening up the VHE window as a new astro-particle physics discipline
> constraining the origin of Galactic cosmic-rays
- testing the paradigm of SNRs: spectral cutoffs at TeV energies
- through single new accelerators + diffuse emission: PeVatrons!
> revealing VHE properties in powerful Galactic accelerators:
- properties of SNRs, PWNs, binaries, stellar-clusters... at the highest energies
- yet many unidentified -> discovery of new source types?



## Summary (II)

- H.E.S.S.-II in operation since 2013
> first true "hybrid system" of Cherenkov telescopes (rather challenging!)
> lowering E-threshold down to $\sim 50-100 \mathrm{GeV}$
- entering the Fermi-LAT regime (but with 10^5 times collection area)
- well-suited for variable phenomena (~hours-days) given high-statistics
- no real analog system in the horizon: CTA offers 24 m , northern hemisphere
- hardware/software can be further improved => a true transients hunter!

P. Bordas, HESS Galactic, JPS-2015

BACKUP





