The gamma-ray sky seen with H.E.S.S.

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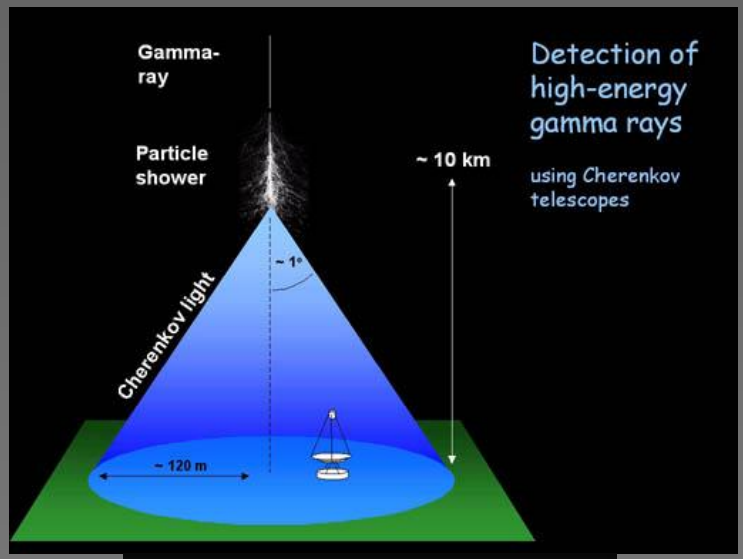
for the H.E.S.S. collaboration

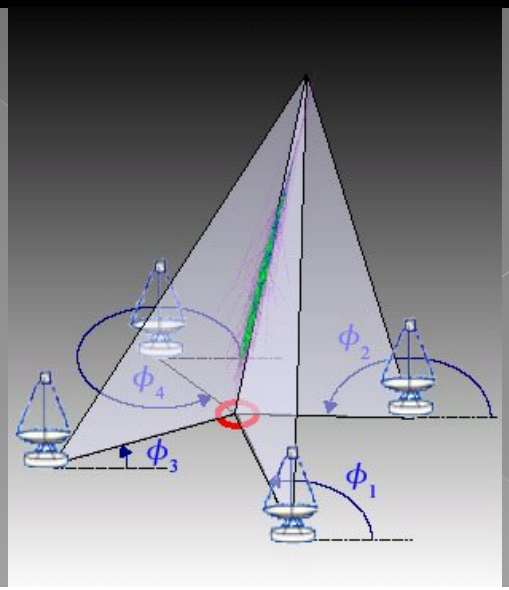
Outline

- The Cherenkov technique
- Diffuse Emission
- Galactic sources (selected results)
- Extragalactic sources (selected results)
- Search for Dark Matter (see talk of B. Opitz)
- Next-generation instruments
- Conclusions

The Imaging Atmospheric Cherenkov Technique

- Conical wavefront with a timespread of ~ns
- Illuminates a cirle of ~120m radius on ground (TeV gamma-rays)
- All telescopes within the light cone detect the shower -> effective area ~10^5 m^2
- An array of telescopes can reconstruct the shower in 3D (stereoscopy)





The High-Energy Stereoscopic System (H.E.S.S.)

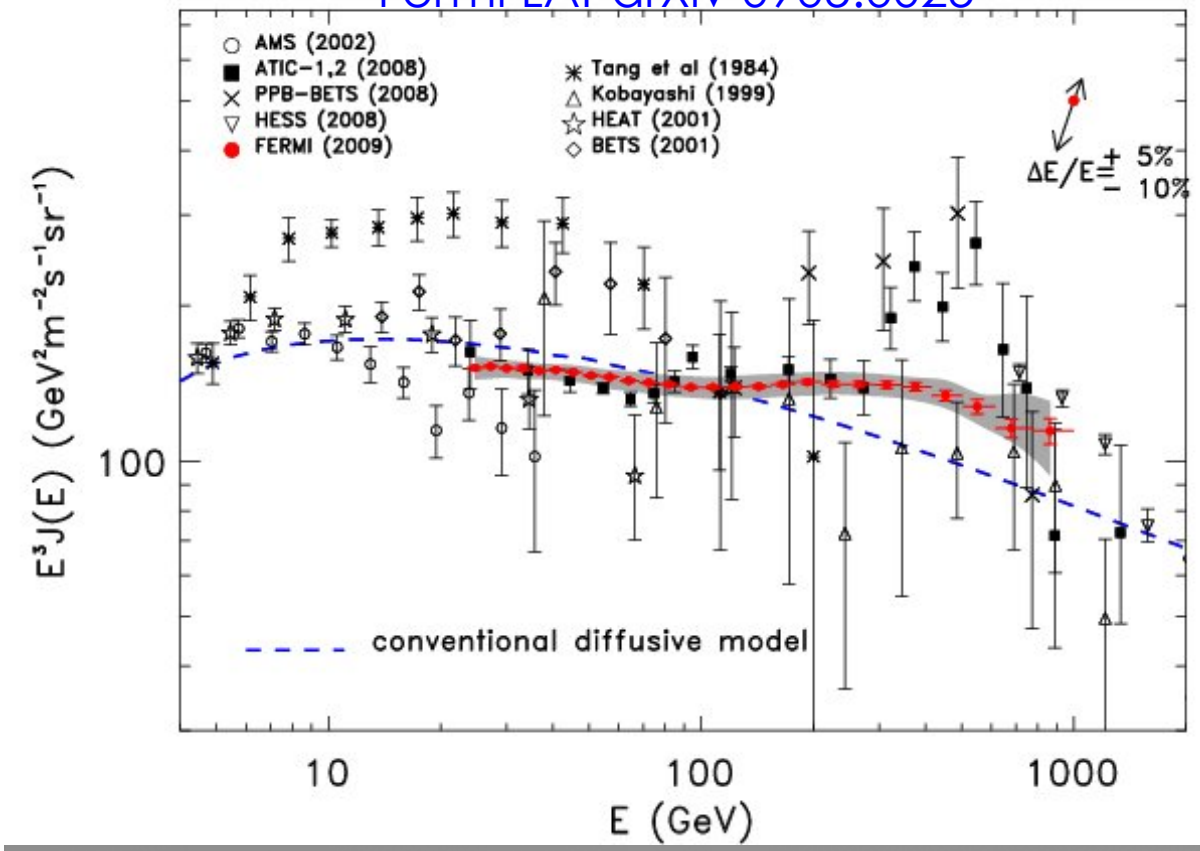
- Field of view: 5°
- Energy threshold: ~120 GeV at zenith
- Angular rersolution: <0.1°

Diffuse Emission

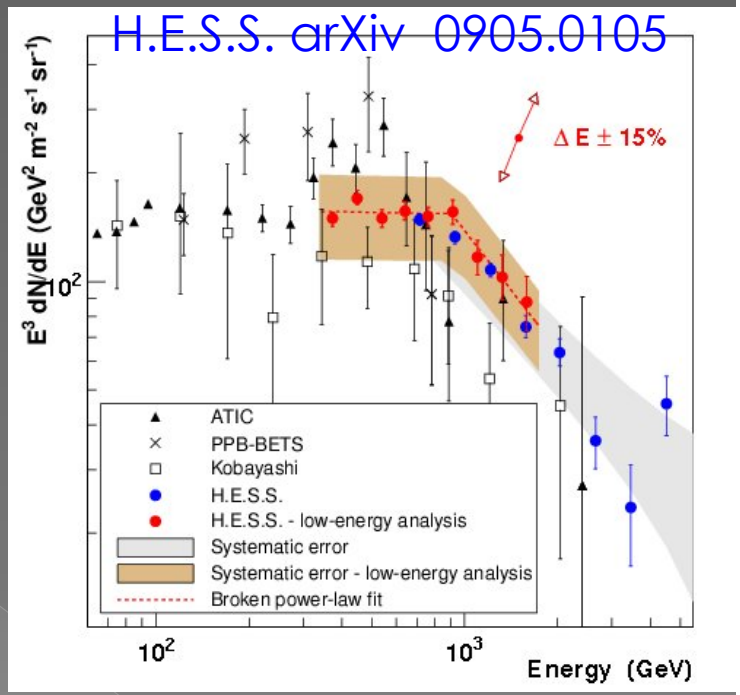
The electron spectrum
The LMC
Starburst galaxy NGC 253

The CR electron spectrum

Fermi LAT arXiv 0905.0025



H.E.S.S. arXiv 0905.0105

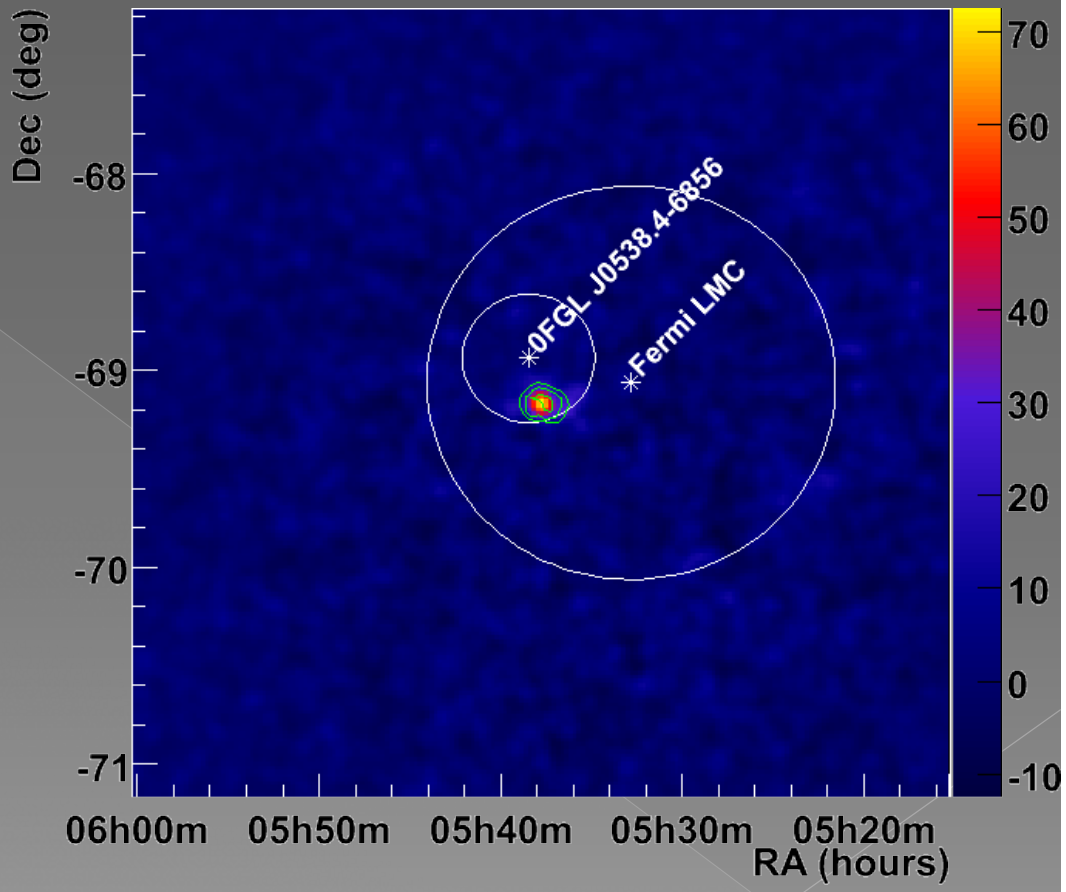


Slight deviation with respect to the diffuse emission model can be due to pulsars (D < 1 kpc)

The anomaly claimed by ATIC (Nature ***456*** (2008) 362, ballon experiment) is not confirmed

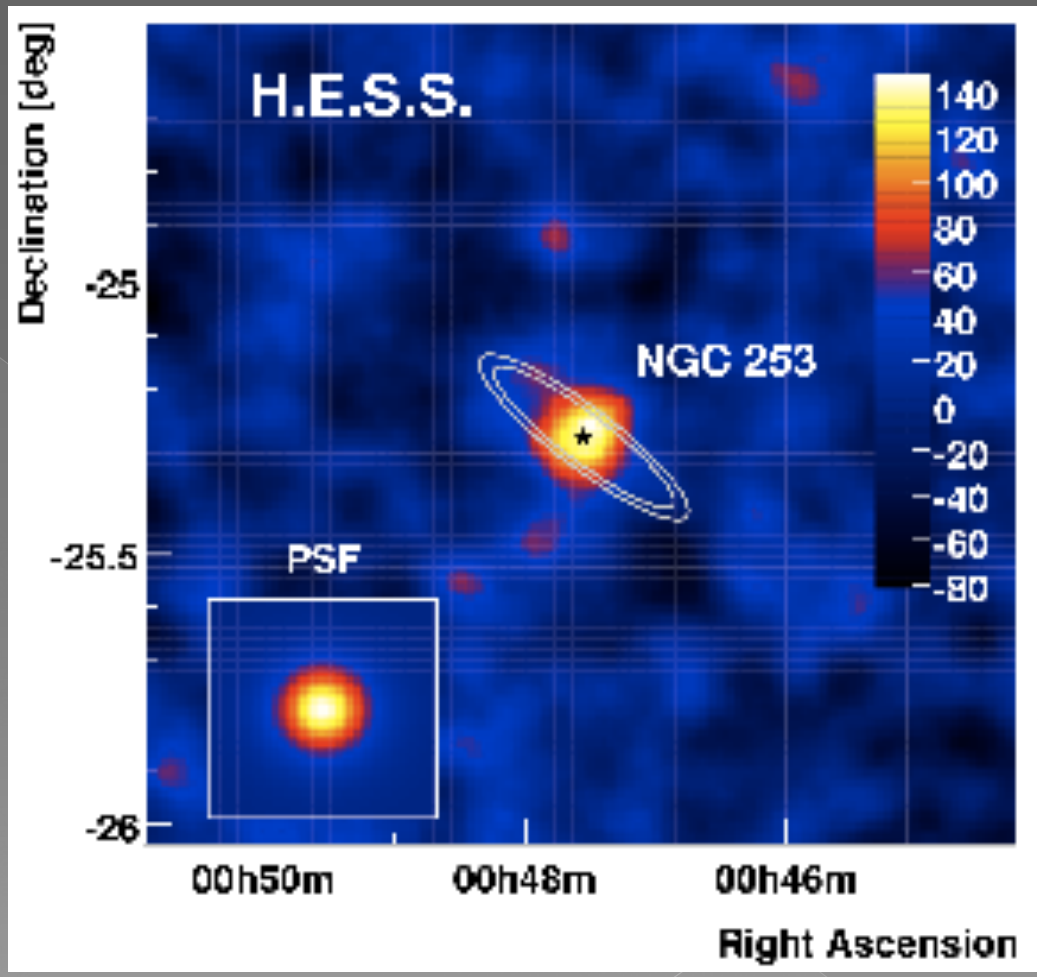
Emission from the LMC

- Detected as point-like source (44 h)
- Consistent with SNR 157B/PSR J0537-6910 (highest Edot)=most distant VHE-PWN detected
- Upper limit on SN1987A
- No detection of 30 Doradus



Starburst galaxy NGC 253

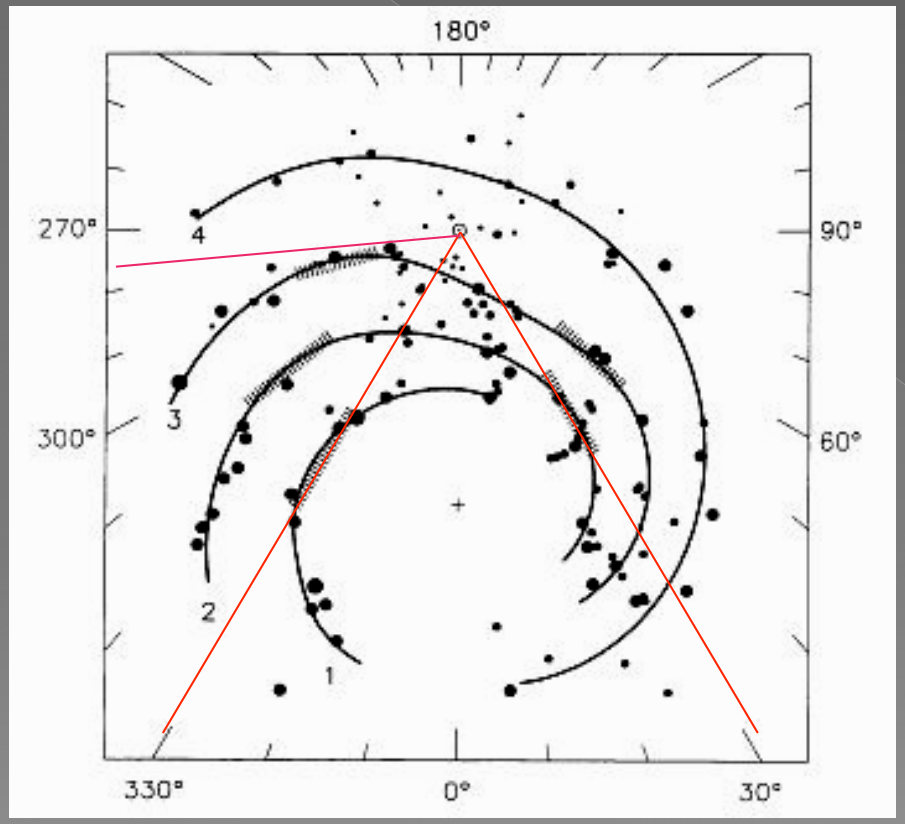
- Starburst galaxy at 2.5 – 3.9 Mpc
- H.E.S.S. observations between 2005-2008: 119 h good livetime
- Detection: 5.2 s
- Point-like
- Faintest source so far: 0.3% of Crab flux



Galactic sources

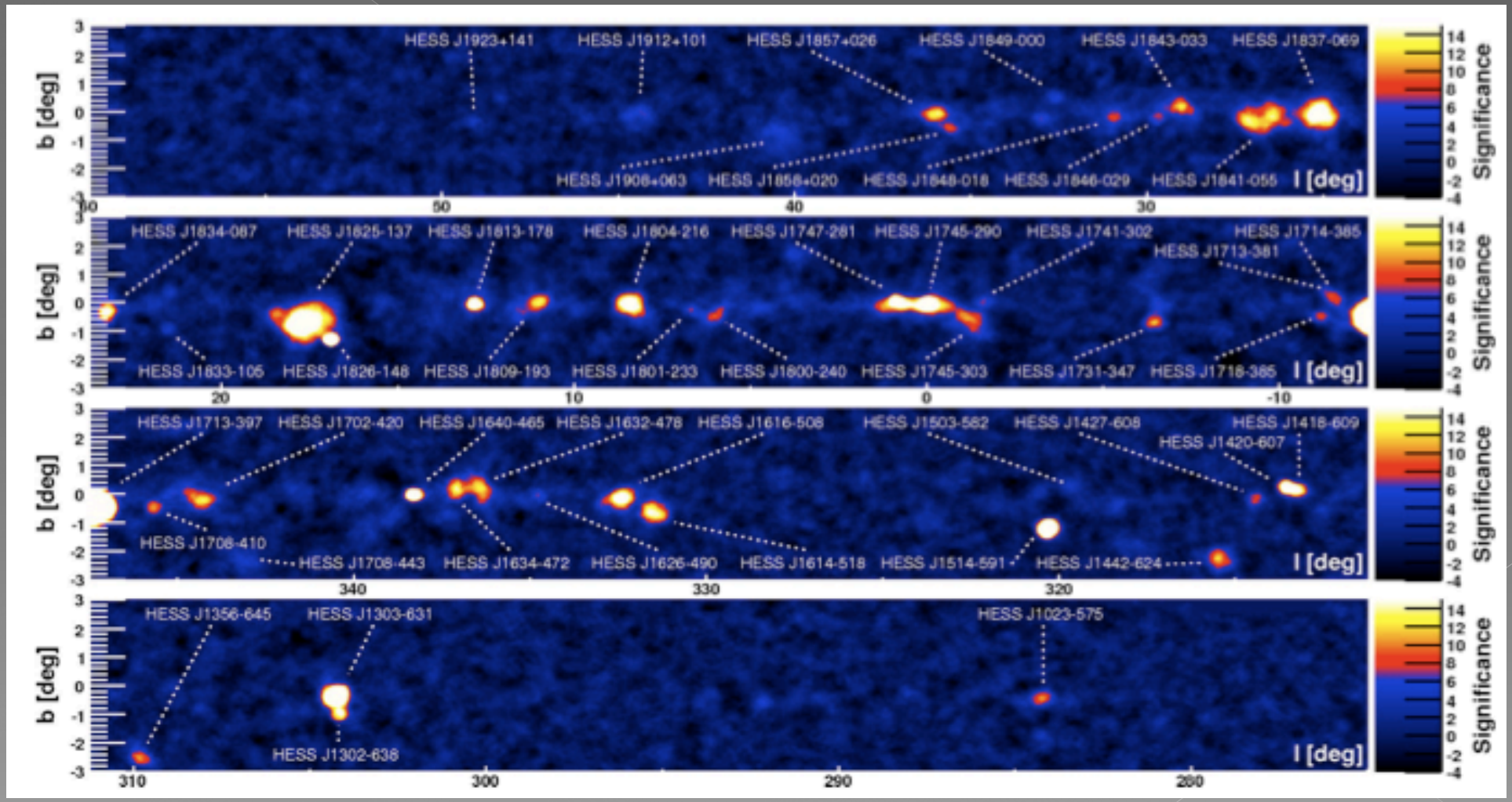
Survey discoveries
Supernova remnants (SNR)
Pulsar Wind Nebulae (PWN)
Binaries

The galactic plane survey

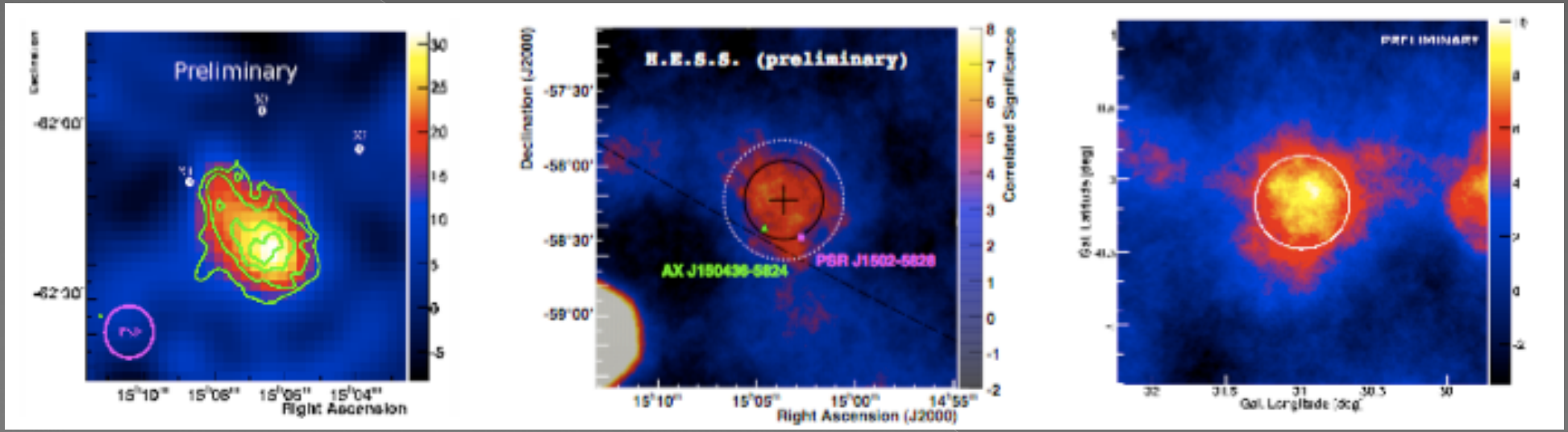


- Inner Galaxy (2004) + extension (2005-2008)
  from ℓ = -85° (or 275°) to ℓ = +60° and $|b|<3°$
- Survey is complete for fluxes > 0.09 Crab (+ deeper observations)
- Low diffuse flux (≠ Fermi/AGILE) → Individual sources appear clearly
- Most of the revealed sources are mildly extended (D > 3 ' to 4 ')

Surveying is discovering



Extended sources without counterparts



HESS J1507-622

- Bright source: 8% of Crab
- 3.5 deg off the gal. plane
- Extension 0.11
- Spectral index 2.2

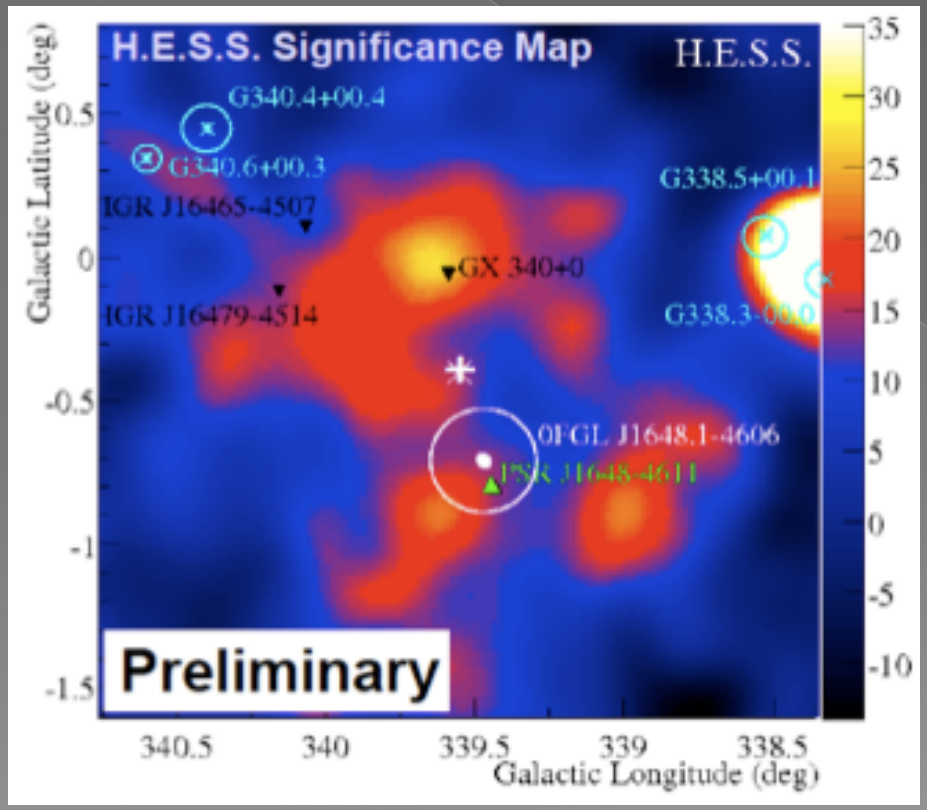
HESS J1503

- Bright source: 6% of Crab and extended
- No obvious counterpart (PSR with low Edot, AX is a cataclysmic binary)
- A forbidden velocity wing ?

HESS J1848-018

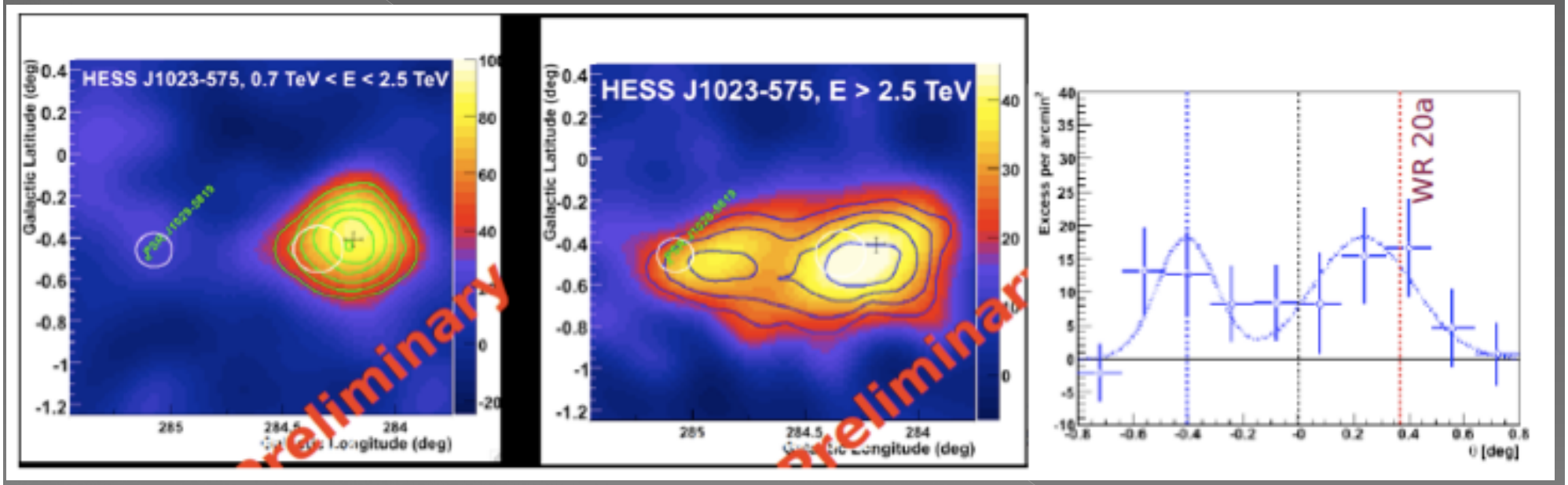
- 2% of Crab
- no obvious counterpart (star-forming region W43, WR 121a ?)

Stellar cluster: Westerlund 1 discovered!



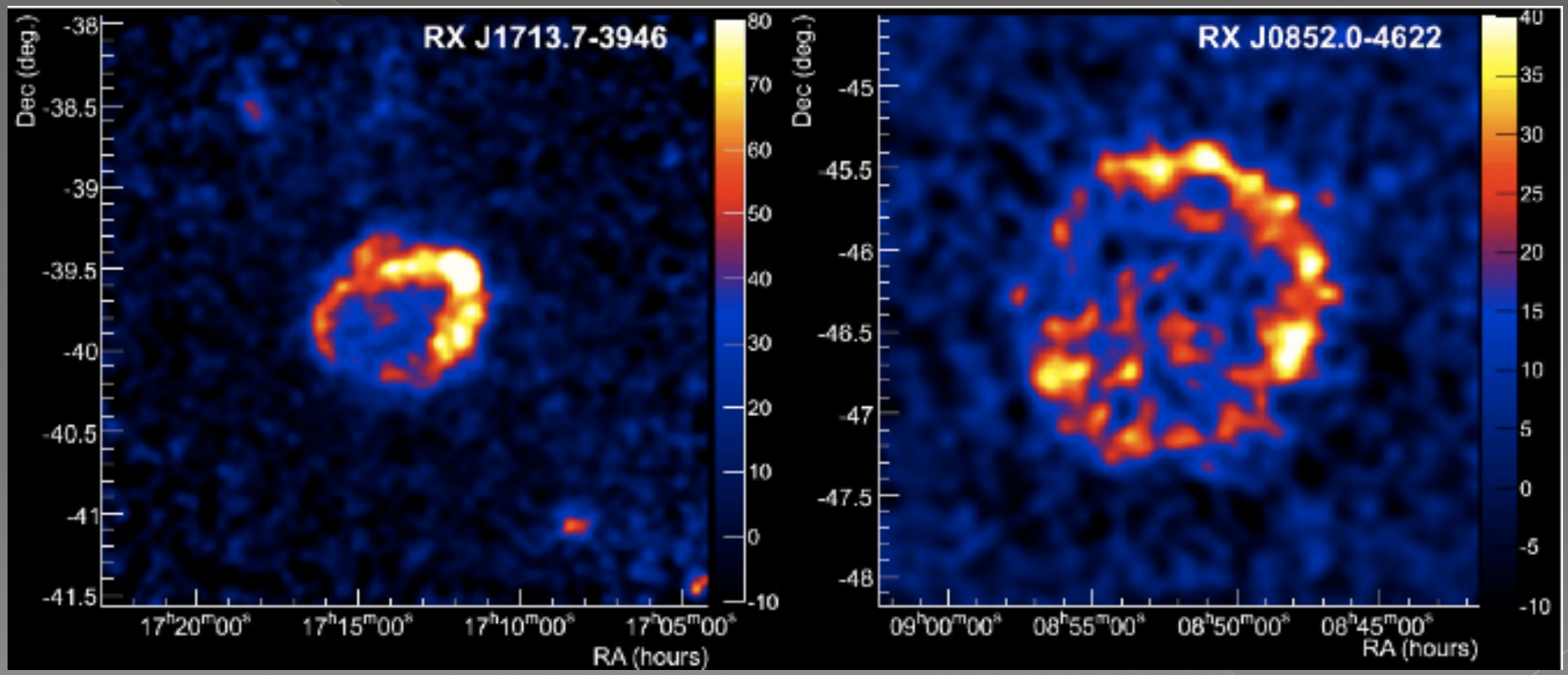
- The most massive stellar cluster with >24 WR stars, 4-5 kpc, 5 Myears
- 10^{39} erg/s in kinetic energy
- 34 h live time, E_{th} = 680 GeV
- Possible acceleration sites: colliding wind binaries, collective winds, supernovae

Wd2 energy-dependent shape



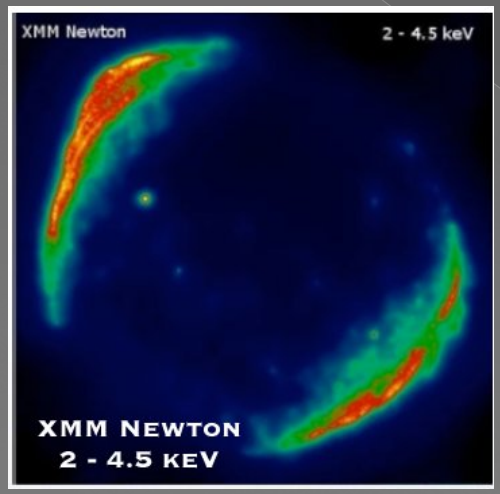
- Wd2 reobservation: energy-dependent morphology and a new source HESS J1028-581 coincident with Fermi detection 0FGL J1028.6-5817 of a pulsar
- HESS J1023-575 low X-ray emission + molecular clouds, Fermi counterpart 0FGL J1024.0-5754

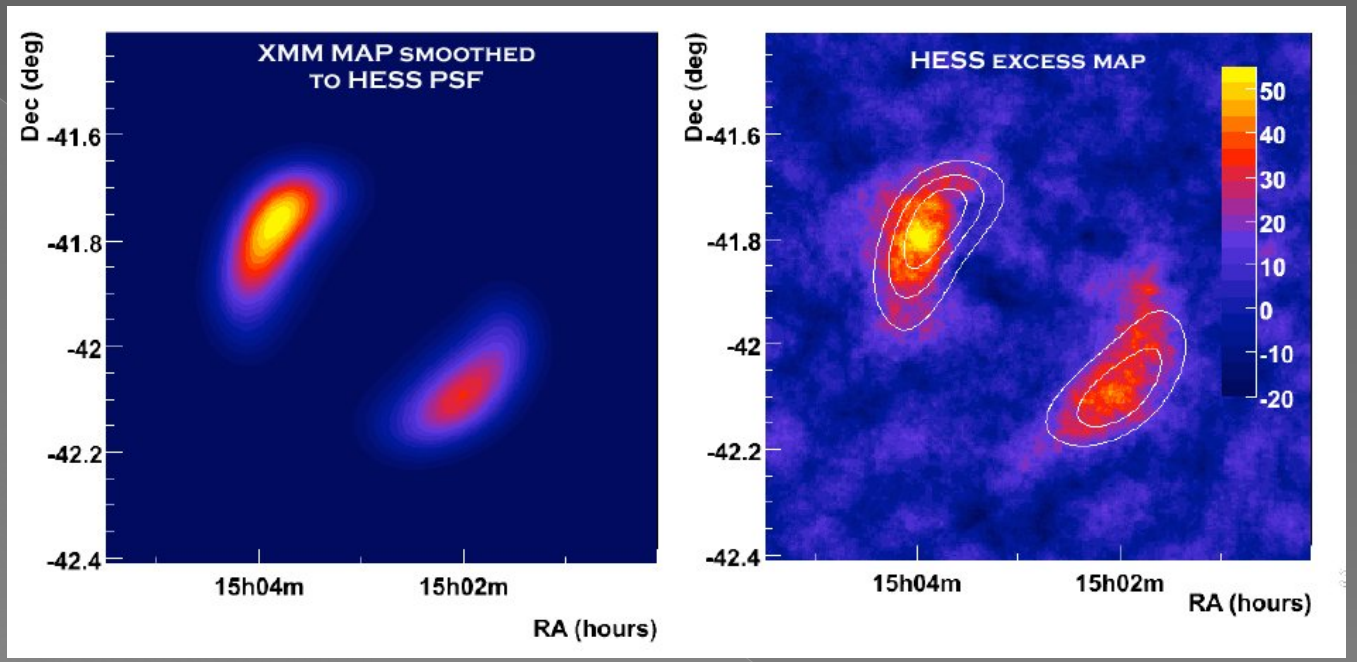
Shell-type SNR: Classic hits



- Shock wave acceleration up to 100 TeV
- Primary particle type (electrons and/or hadrons) still uncertain

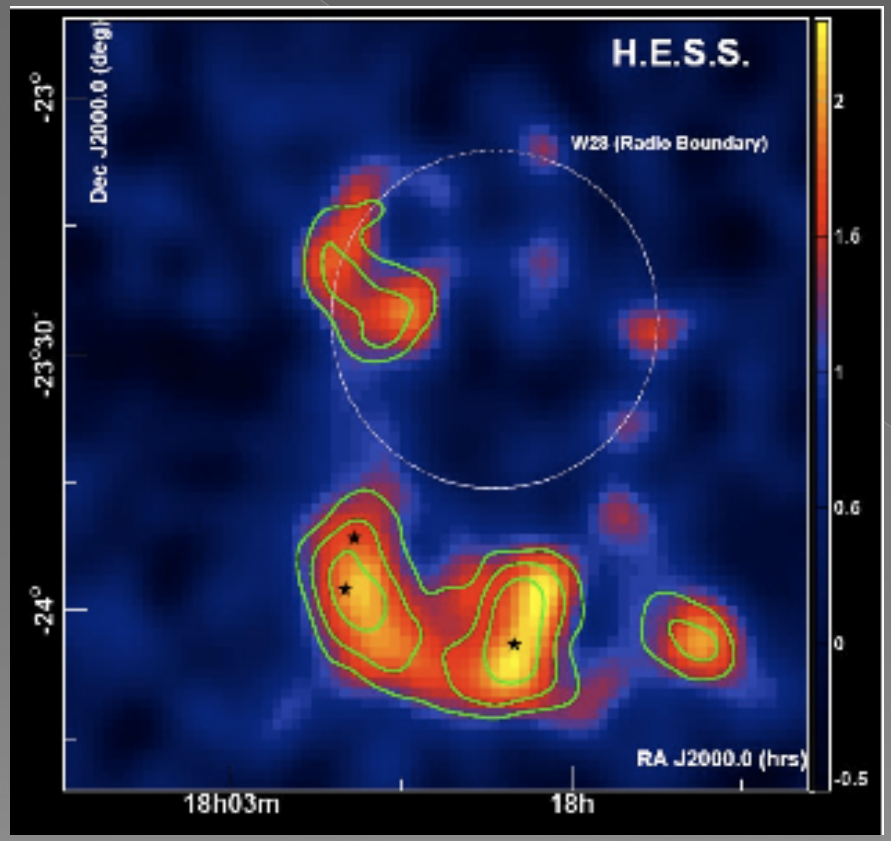
Shell-type SNR: SN 1006

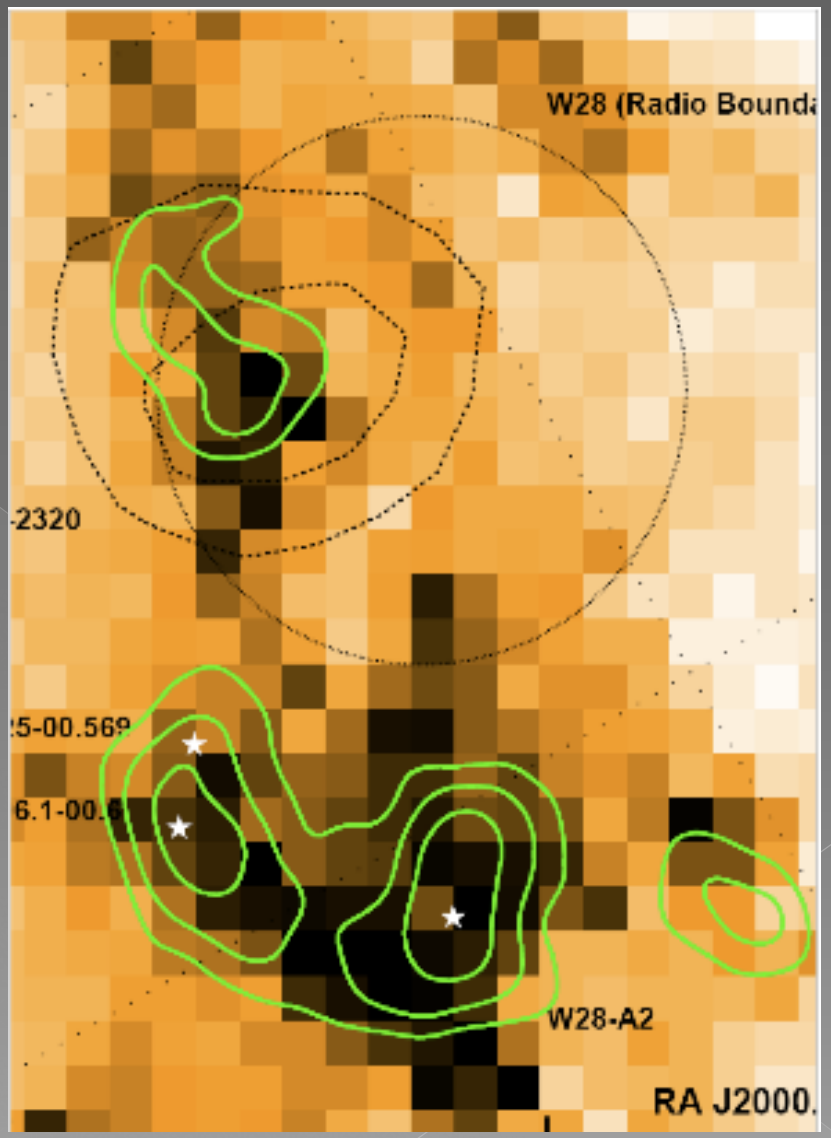




- More than 100 h of live time
- Very faint (1% of Crab) and extended source
- Bimodal morphology coincident with non-thermal X-ray morphology

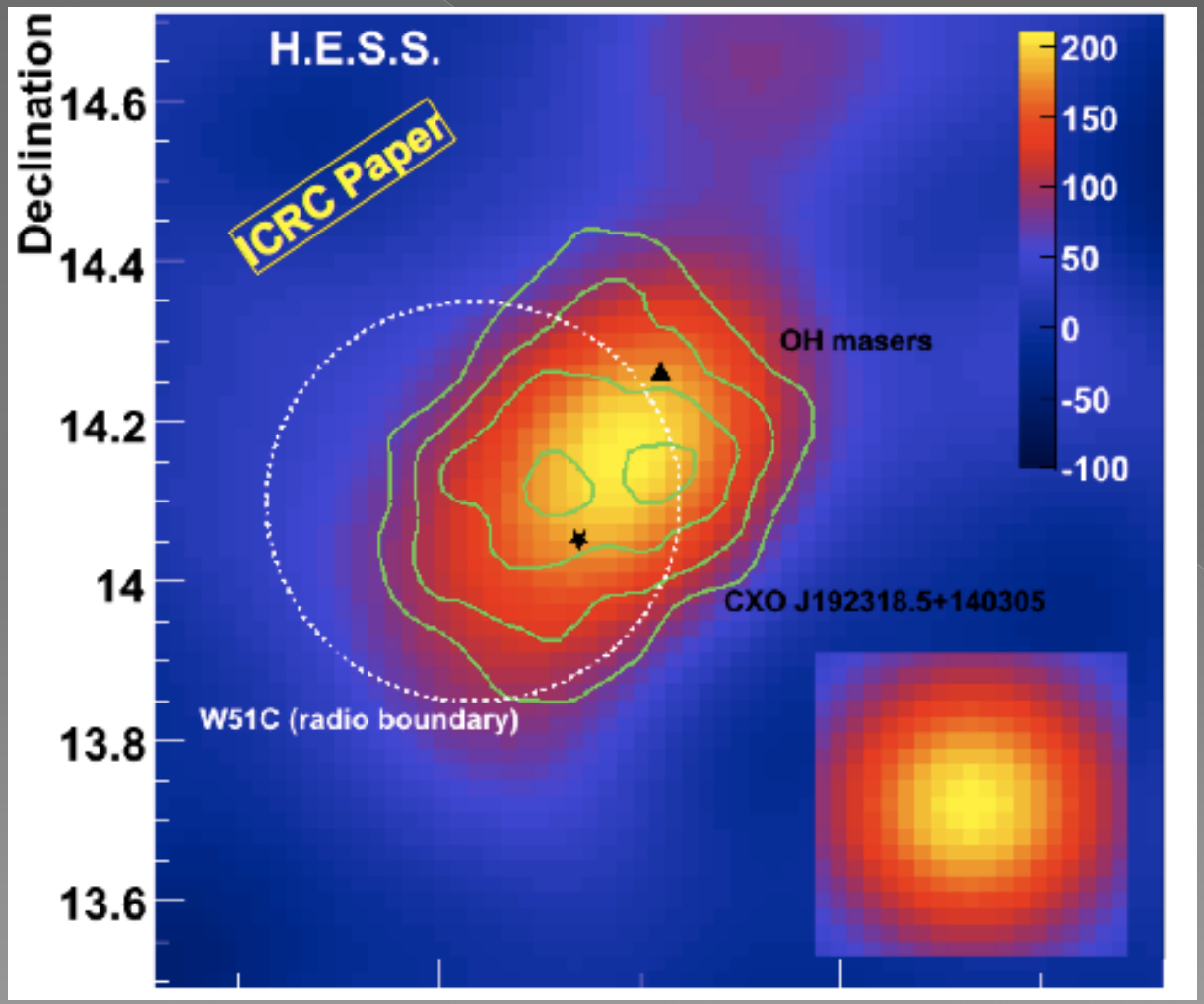
Old SNR: interaction with clouds





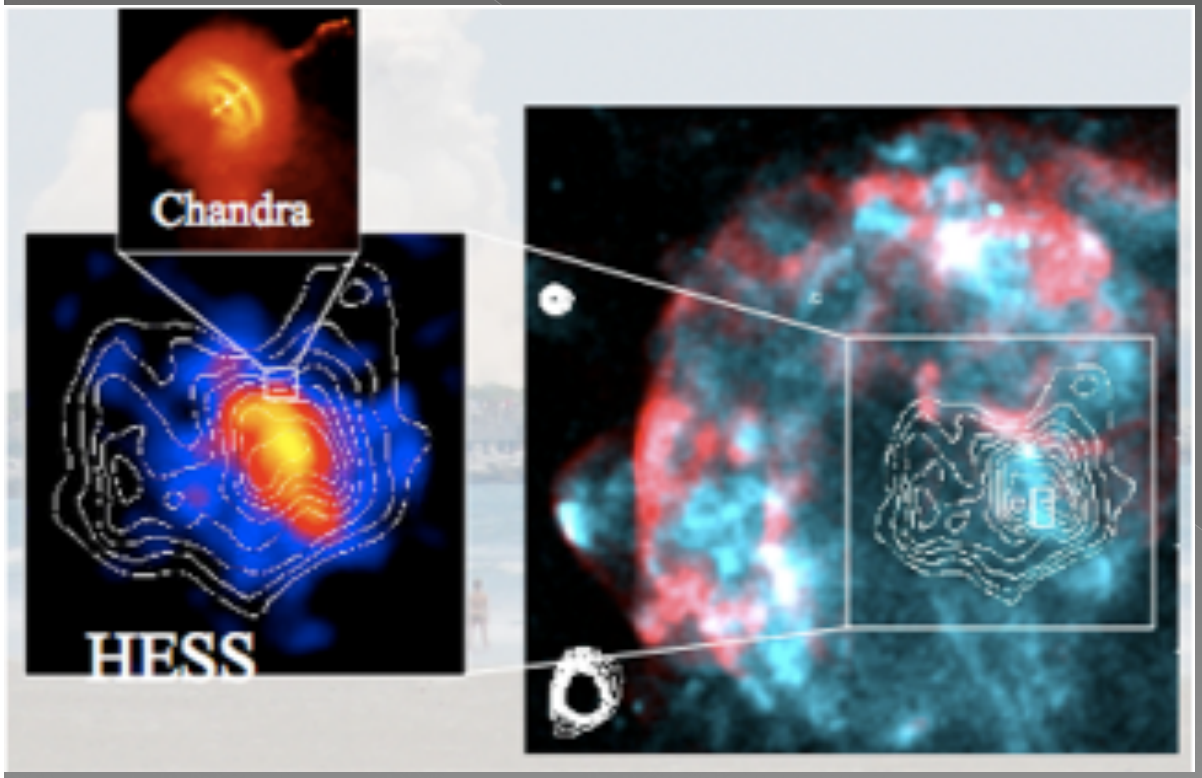
- W28:
  - Distance: 2 – 3 kpc
  - Age: 35 – 150 kyrs

The GeV-TeV connection in SNR: W51



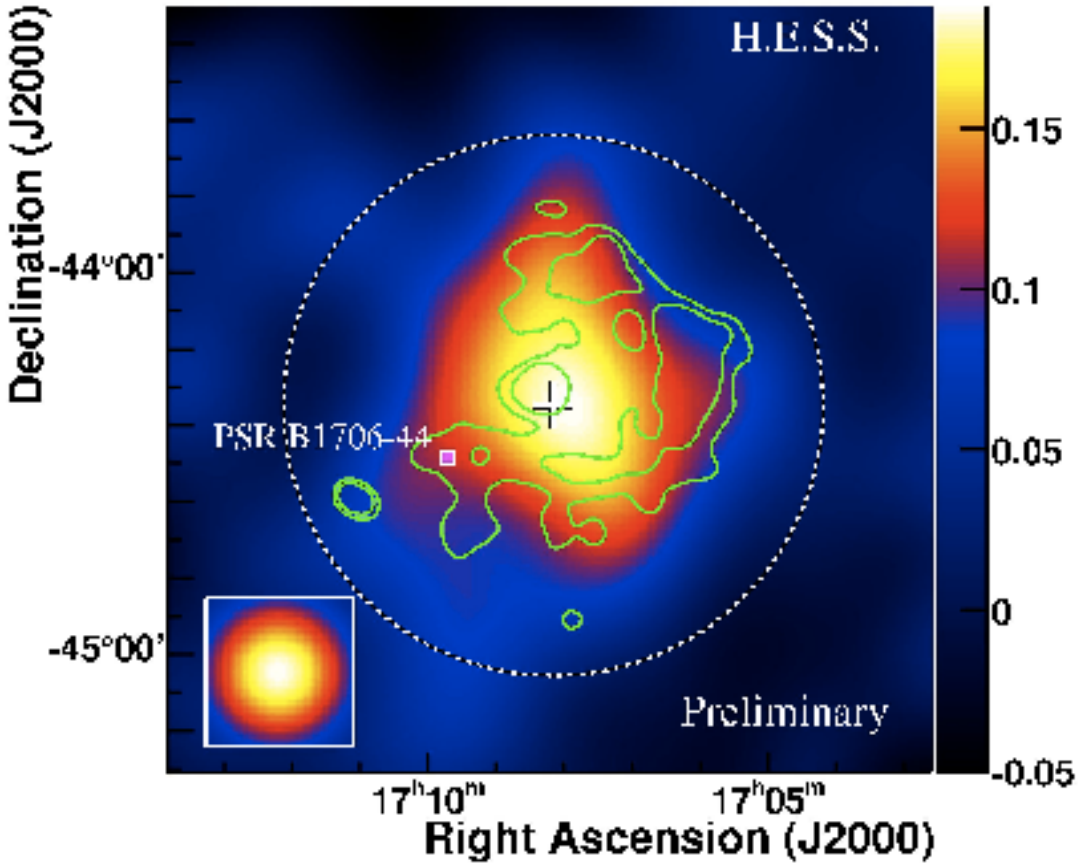
- 6 kps, 30kyears
- Interacting with molecular clouds
- CXO source is possibly a PWN, non-thermal emission

The GeV-TeV connection in PWN: Vela X and Vela pulsar



- Vela X is the brightest flat-spectrum radio component of the Vela SNR
- D = 290 pc
- Size: 3° x 2°
- Earlier H.E.S.S. observations found 5% of its volume (cocoon <0.8 deg)
- 58h more live time -> emission up to 1.2 deg
- Fermi found the pulsar and extended Vela X emission

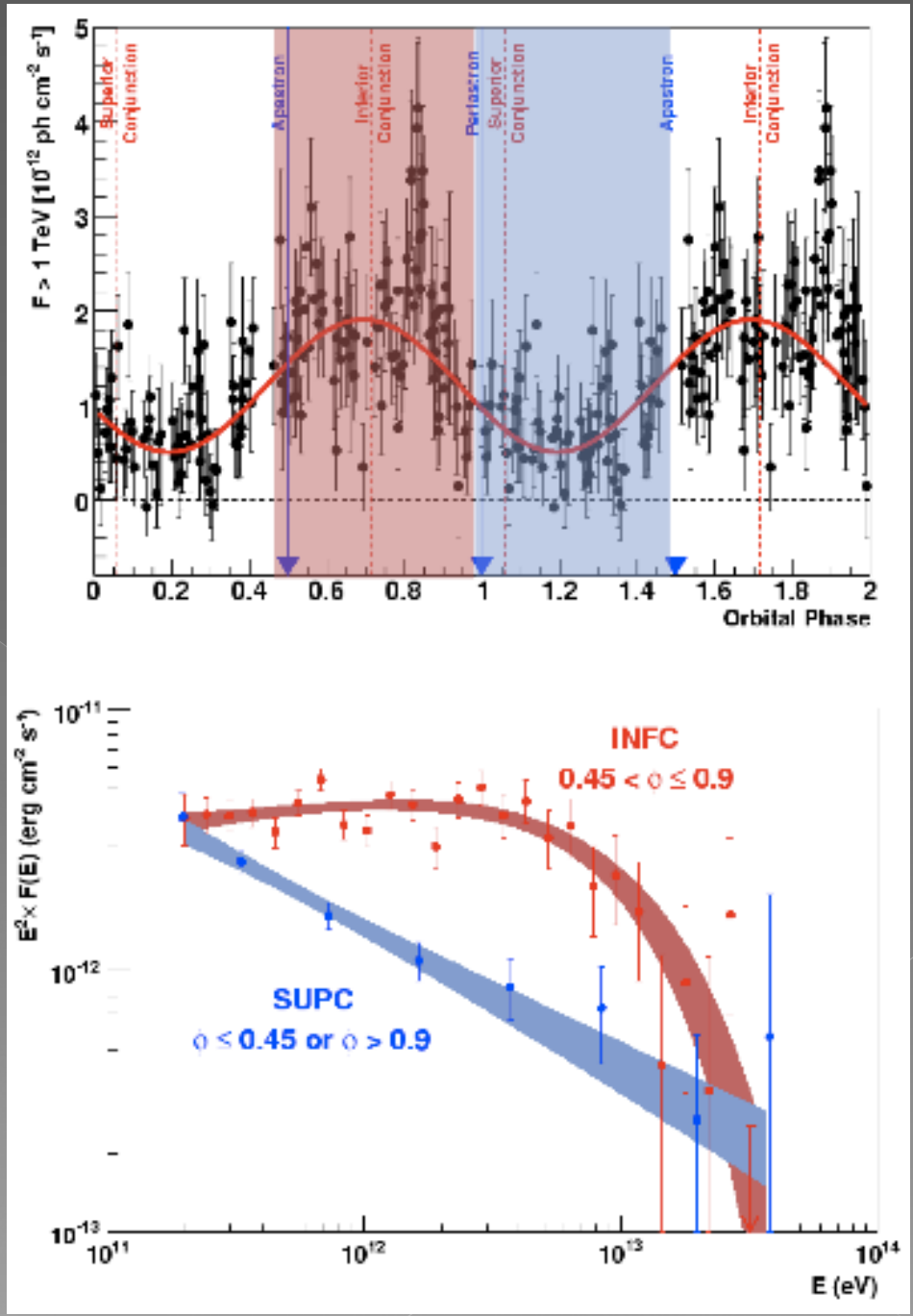
HESS J1708-443



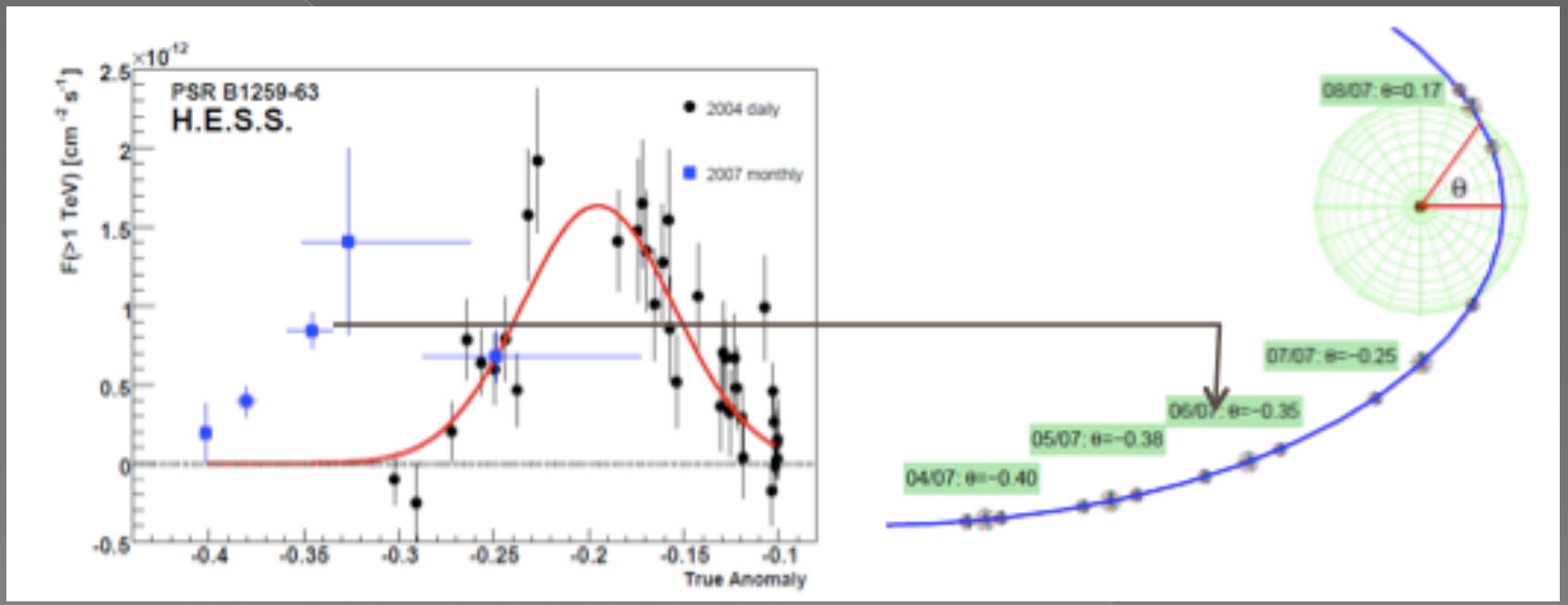
- Nearby PSR B1706-44
- No excess at pulsar position (pulses detected by Fermi, glitch, up to 50 GeV detection)
- Extension 0.29°
- Hard source (Γ=2), integral flux above 1 TeV is 17% of Crab
- Not easy to interpret

Binaries: LS 5039

- A few High-Mass X-ray Binaries are γ-ray emitters
  - Massive bright star + compact object
- LS 5039
  - Distance: 2.5 kpc
  - Orbital period: 3.9078+-0.0015 days
  - Modulation strength strongly energy-dependent



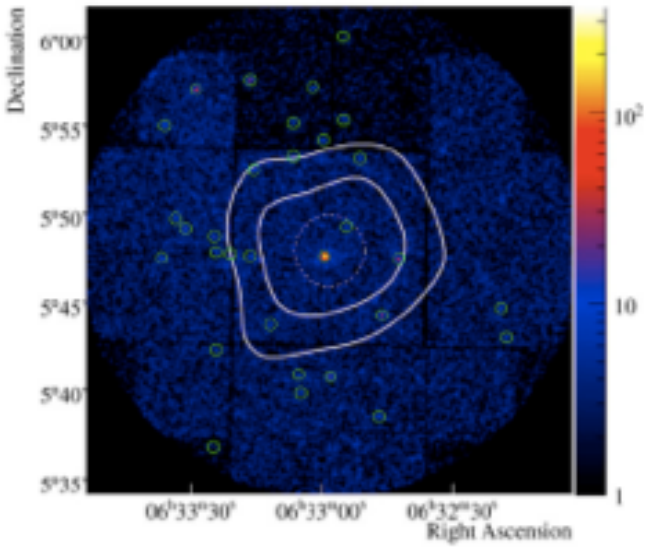
News on PSR B1259-63

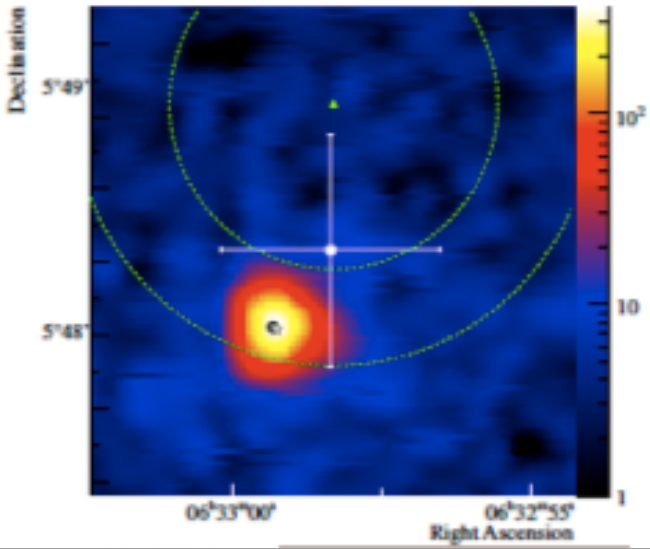


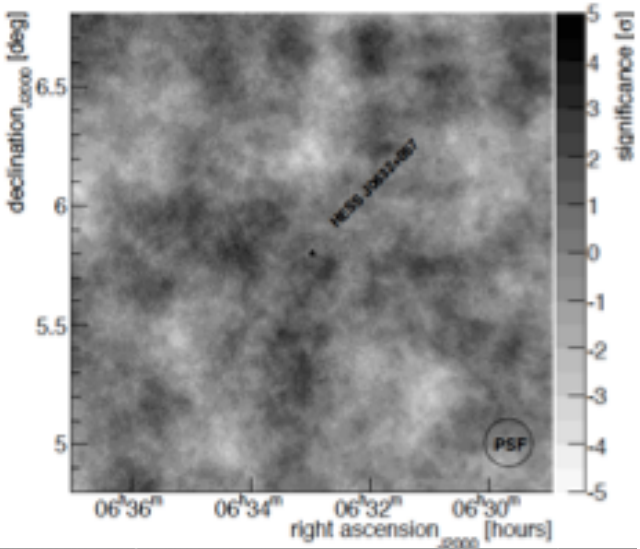
- Reobserved in 2005/06 at large orbital separation and in 2007 at periastron passage
- Resulting lightcurve indicates significant emission out of circumstellar wind, not only interaction between wind and disc
- IC with stellar wind photons ?

HESS J0632+057: a new γ-ray binary?

- One out of 2 H.E.S.S. unidentified point-like sources
- Possibly associated with MWC 148
- VERITAS found the source to be variable: upper limits only







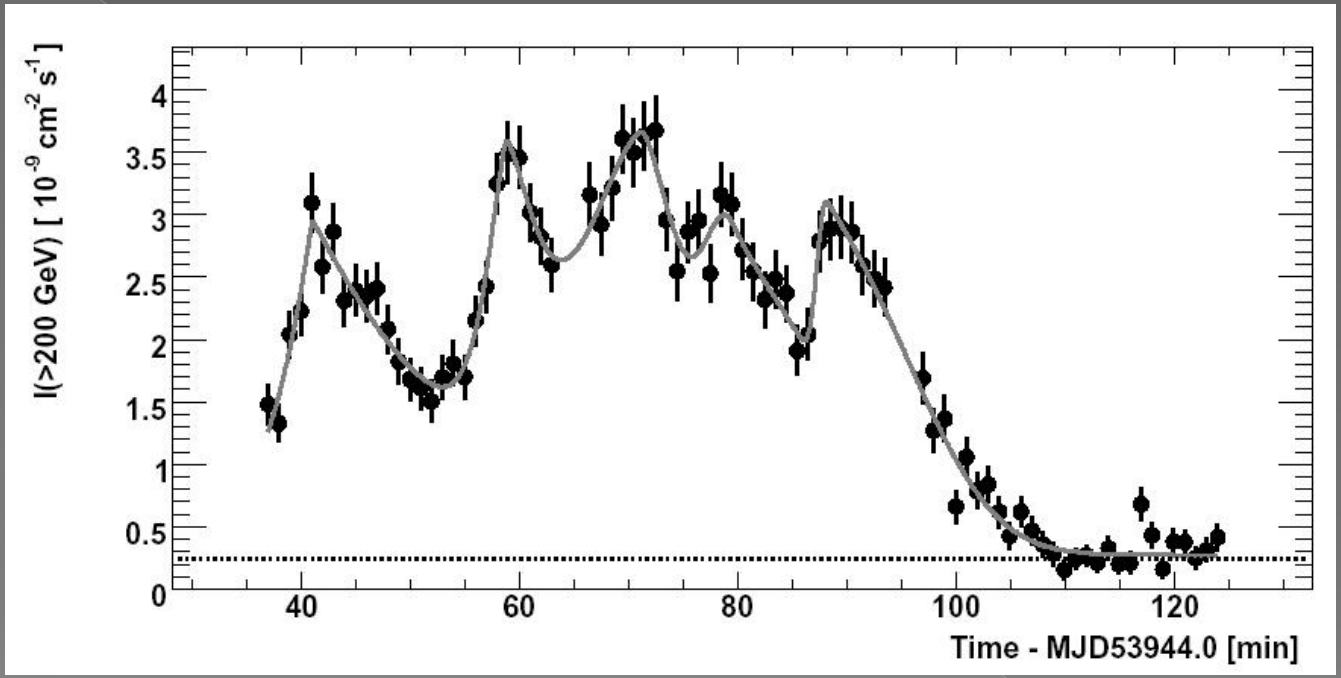
The Extragalactic Sky

New blazars
Multi-wavelength campaigns
Energy-dependent photon velocity ?
Radio galaxies

AGN detected by H.E.S.S.

object name	redshift	class	discovery at VHE	Flux level (in % Crab)	observed photon index	shortest variability time scale
Centaurus A	0.0018	FR I	2008 (H.E.S.S.)	0.8	2.7±0.5	
M 87	0.004	FR I	2003 (HEGRA)	~1.4	2.20±0.15	~1 day
Mrk 421	0.030	HBL	1992 (Whipple)	300 (high state)	2.1±0.1 (Ec = 3.1 TeV)	<1 hour
PKS 0548-322	0.069	HBL	2007 (H.E.S.S.)	1.4	2.8±0.3	
PKS 2005-489	0.071	HBL	2005 (H.E.S.S.)	2.8	4.0±0.4	~1 month
RGB J0152+017	0.080	HBL	2007 (H.E.S.S.)	2	2.95±0.36	~1 month
PKS 2155-304	0.116	HBL	1999 (Mark VI)	15 (up to 1500)	3.32±0.06 (low state)	~3 min
1ES 0229+200	0.139	HBL	2006 (H.E.S.S.)	1.8	2.50±0.19	
H 2356-309	0.165	HBL	2006 (H.E.S.S.)	2.3	3.09±0.24	~1 month
1ES 1101-232	0.186	HBL	2006 (H.E.S.S.)	2.3	2.94±0.20	~1 year
1ES 0347-121	0.188	HBL	2007 (H.E.S.S.)	2	3.10±0.23	~1 year
PG 1553+113	>0.250	HBL	2006 (H.E.S.S./MAGIC)	3.4	4.5±0.3	

Most VHE-AGN are blazars

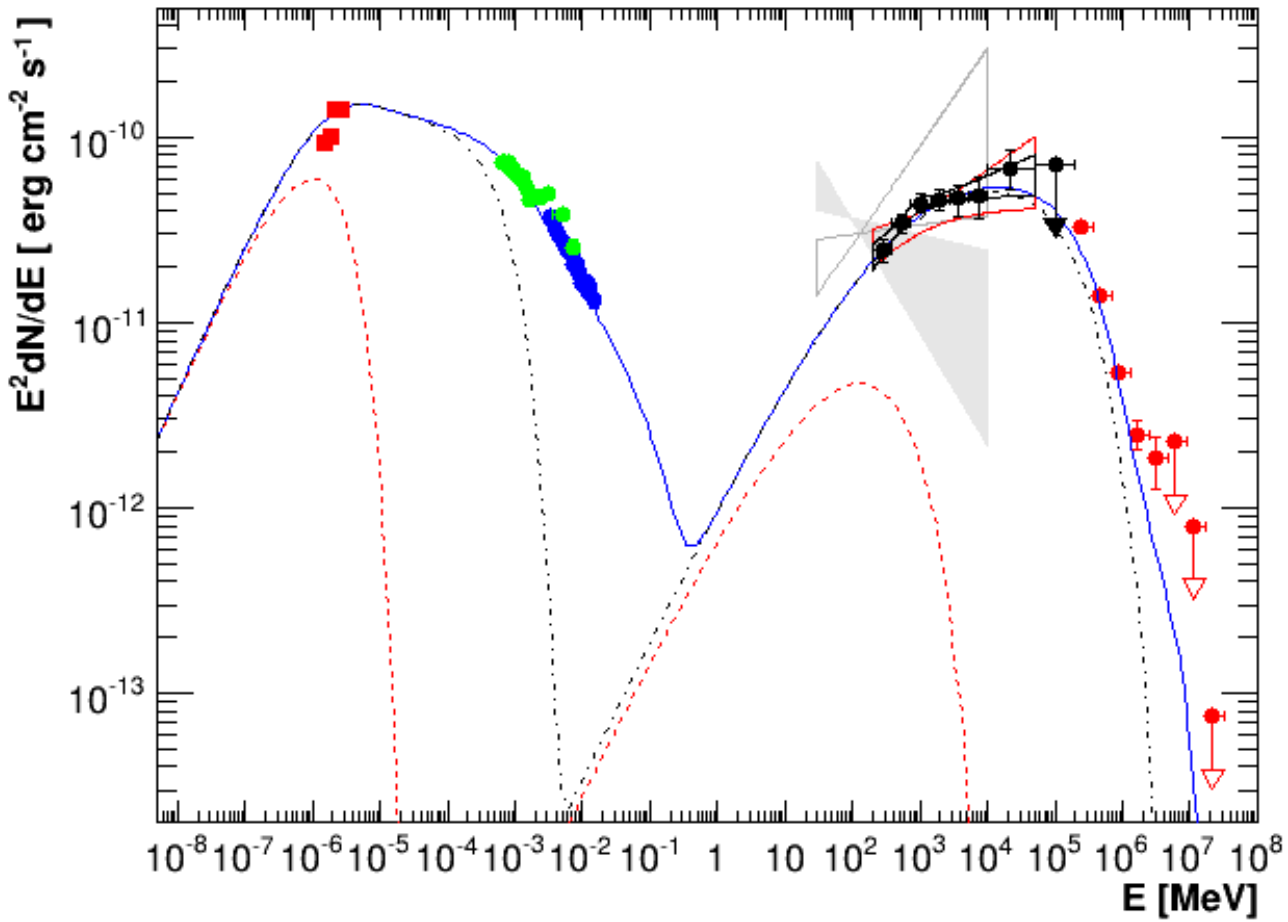


- Blazars are variable sources which exhibit:
  - Very high γ-ray luminosity during flaring periods (> 10 times the Crab flux for PKS2155-304 in July 2006)
  - Short timescale variability (~ few minutes for PKS2155-304 in July 2006) → constraint on the size of the emission zone
- In order to avoid opacity ($\gamma + \gamma \rightarrow e^+ + e^-$) → constraint on the Lorentz factor of the jet: $\Gamma > \approx 10$

Multiwave-length campaigns

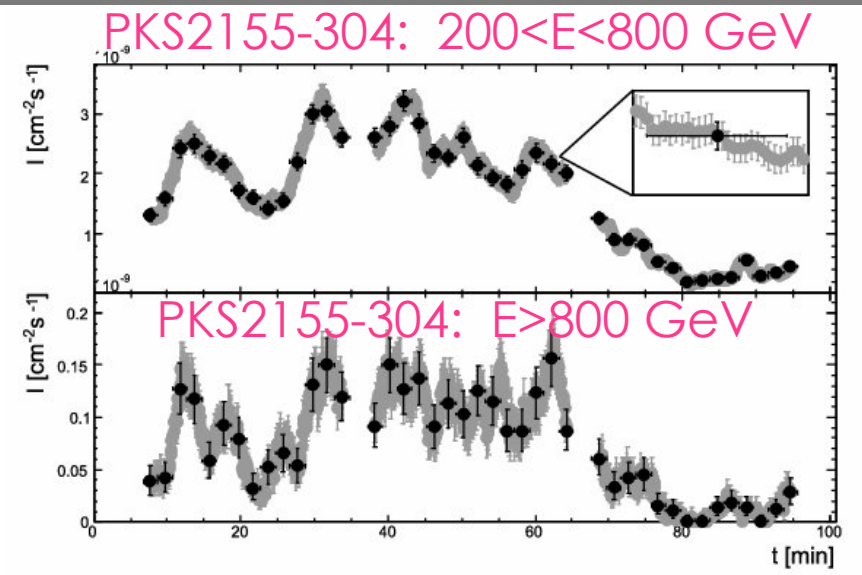
Optical (ATOM)-X-ray (Swift, RXTE)-Fermi and H.E.S.S. on the blazar **PKS 2155-304** (z=0.117) in a low state

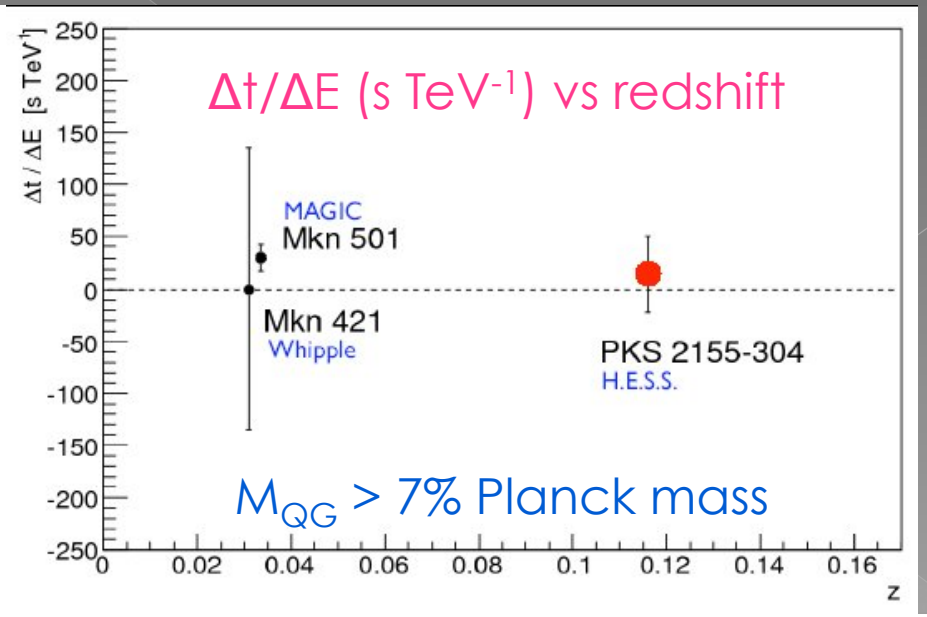
- In the low state, no correlation between X-rays and VHE γ-rays (≠ flares)
- The most energetic electrons (responsible for X-rays) do not significantly contribute to the Inverse Compton bump (extreme Klein-Nishina regime)



Energy-dependent photon velocity ? $v = c(1-E/M_{QG})$

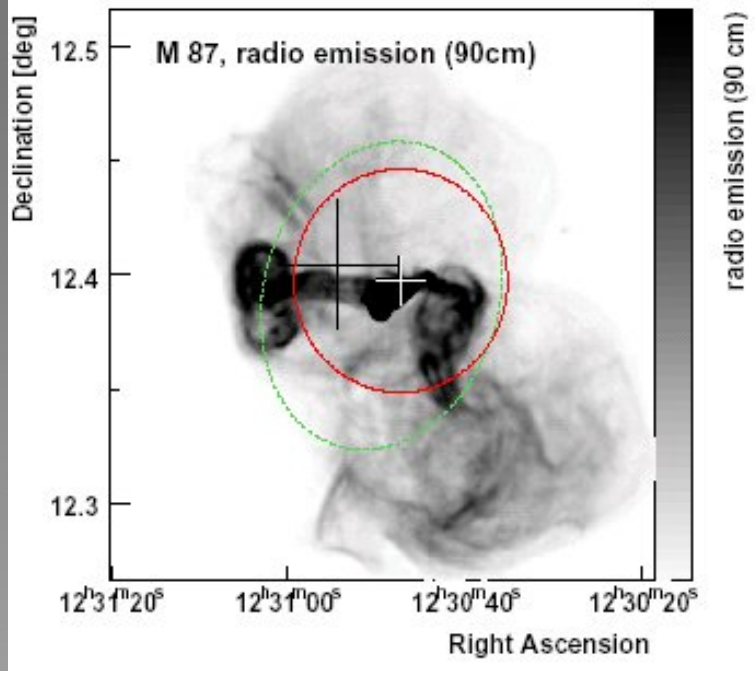
- Blazars are located at cosmological distances and show rapid variability
  - Whipple Observatory: Mkn 421 in May 1996,
  - MAGIC: Mkn 501 from May to July 2005,
  - H.E.S.S.: PKS 2155-304 in July 2006
- Search for differences (time-lags) between light-curves in different energy ranges

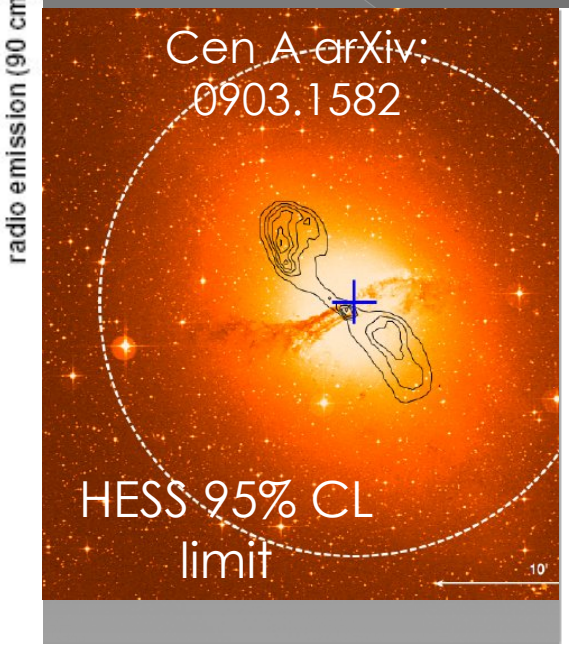


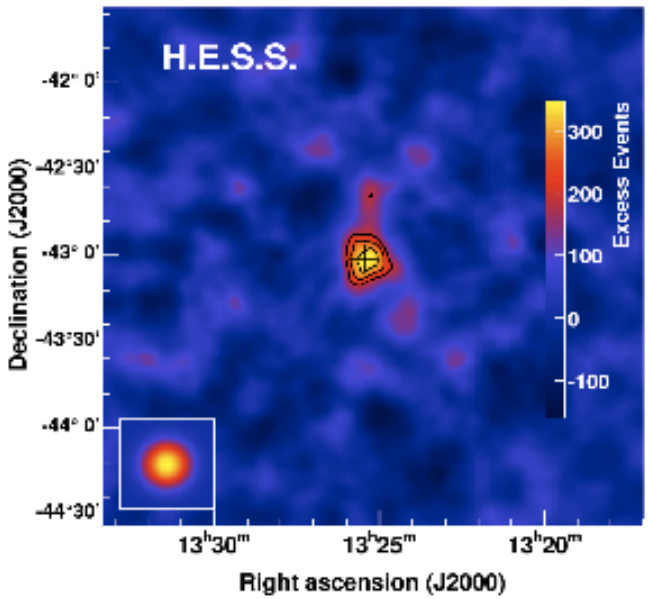


The raise of radio galaxies: M87, Cen A

Galaxy	Distance (Mpc)	Angle (jet-l.o.s.)	Black hole mass (solar masses)	Photon index	Detection
M87	16.	30°	3.2×10^9	2.62±0.35 (2004) 2.22±0.15 (2005)	HEGRA,HESS, VERITAS, MAGIC
Centaurus A	3.8	15°-80°	$(5.5\pm3)\times 10^7$	2.73±0.45±0.2	HESS







Future instruments

H.E.S.S. phase II

CTA

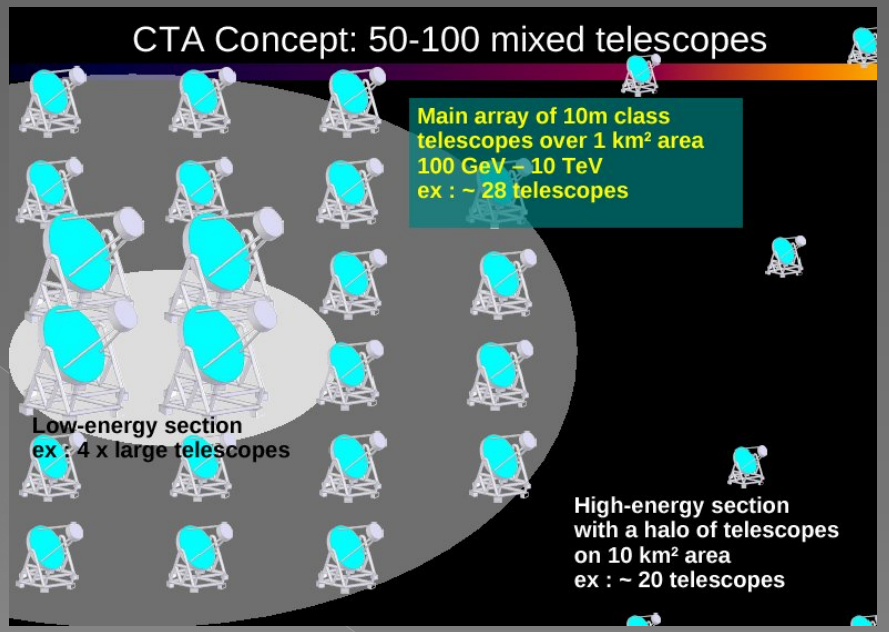
H.E.S.S. phase II

H.E.S.S. II: a very large telescope (28 m diameter) in the centre of the present array (2010) + camera comprising 2048 pixels →

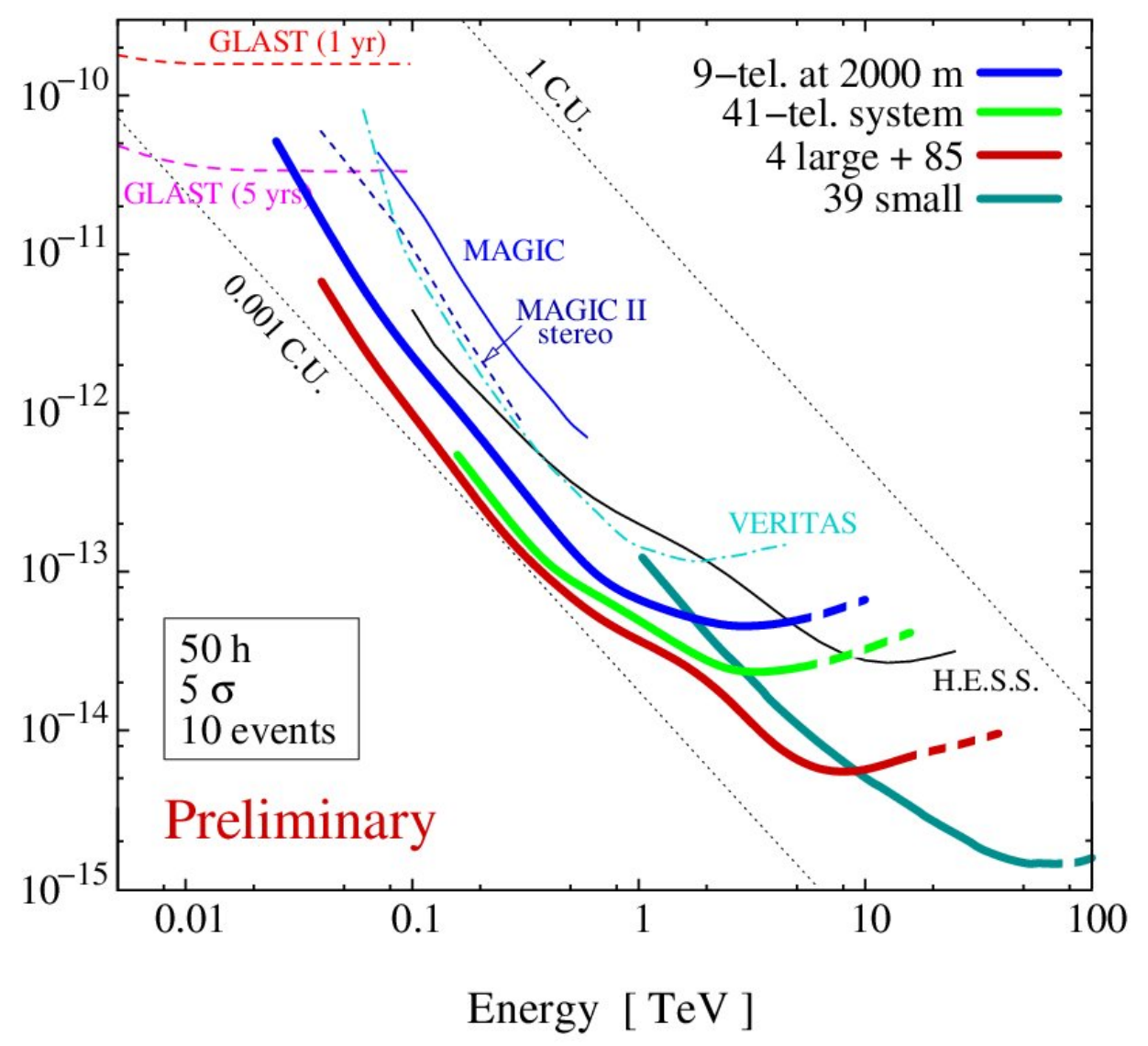
- 30 GeV threshold with the very large telescope
- 80 GeV threshold with the very large telescope + one of the other 4
- Sensitivity × 2 for E > 200 GeV

CTA

- 3 types of Cherenkov telescopes :
  - a few very large telescopes for lower energies 30 GeV – 100 GeV
  - about 40 telescopes (HESS I – type) spread over ~ 1 km^2 → a milli-Crab sensitivity in the TeV range
  - about 25 smaller telescopes spread over a larger area (~10 km^2) should explore the energy domain E > 10 TeV
- Angular resolution ~ 2 arc minutes
- ≈ start building in 2014 ? full array in 2018 ?
- Should operate as observatory

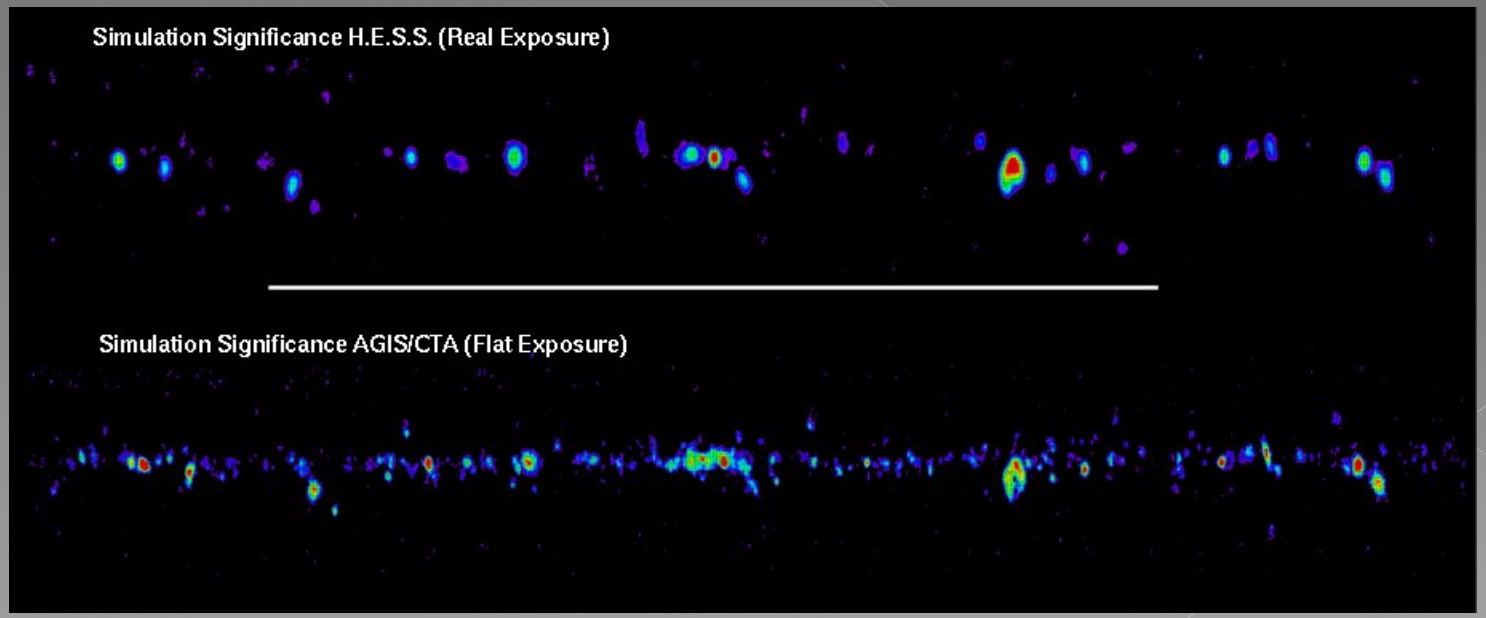


CTA – seaking the milli-Crab



CTA – Visions of the future

- An angular resolution of ≈ 2 arc-minutes → better separation of sources in the Galactic Plane → easier identification with a radio or X-ray source
- The expected sensitivity of the array will result in a catalogue of about 1000 sources, both galactic and extra-galactic → population studies
- New types of sources of VHE γ-rays are likely to be detected, e.g.:
  - Ultra-Luminous InfraRed Galaxies « ULIRG » (star formation, strong stellar winds)
  - Galaxy clusters
  - « Exotic » sources (e.g. annihilation of Dark Matter particles)



Conclusions

- Imaging Atmospheric Cherenkov Telescopes have now produced a catalogue of almost 100 sources:
  - > 60 galactic sources : shell-type supernova remnants, pulsar-wind nebulae, binary systems, OB associations
  - 12 extra-galactic sources : blazars, radio-galaxies
- In the following years, H.E.S.S. II should usefully complement satellite observations in the GeV range (Fermi, AGILE), particularly on variable sources (e.g. AGN).
- In the long term, observatories based on large arrays of Cherenkov Telescopes (CTA) should reach the milli-Crab sensitivity and still improve the angular resolution, opening the way to population studies and to the discovery of new types of cosmic accelerators.