VHE Gamma-ray astronomy from the ground - Highlights

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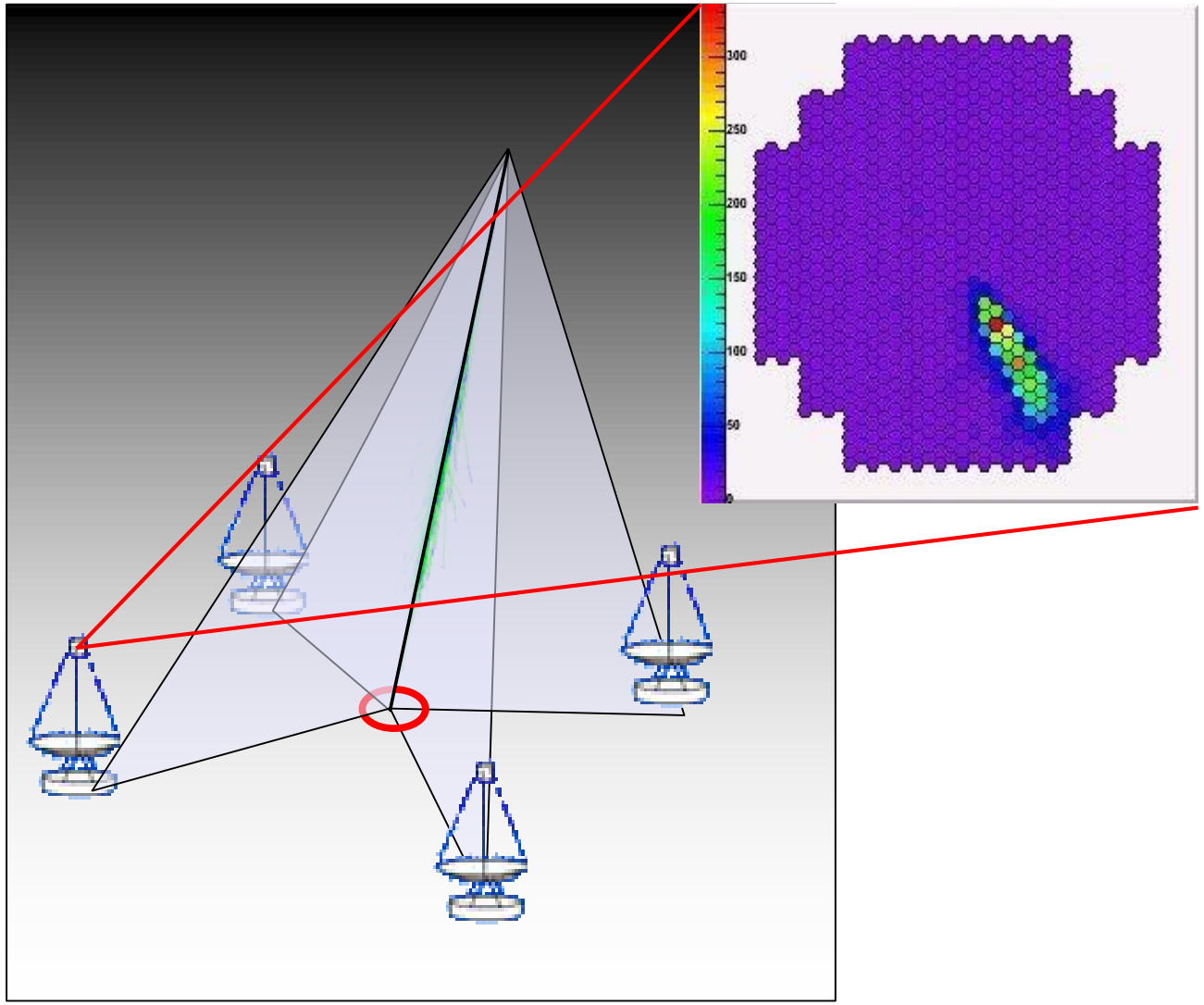
Introduction

- More than 200 contributions from Atmospheric Cherenkov Telescopes submitted
- Personal, biased selection of results
- Many thank to the MAGIC and VERITAS collaboration for providing me their results

Detection Technique in a nutshelll

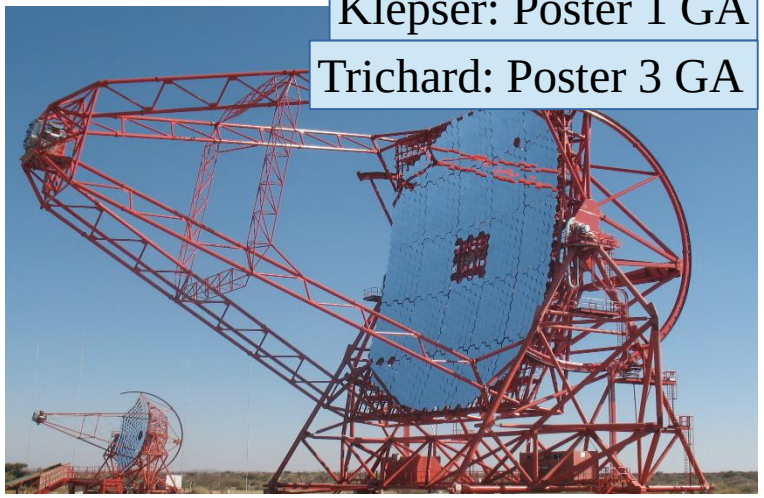
- Shower develop in the atmosphere
- Ultra relativistic e± emit Cherenkov light ~10km above ground
- Fast camera (1 ns) image the shower
- Stereoscopy greatly improve reconstruction and identification of particles



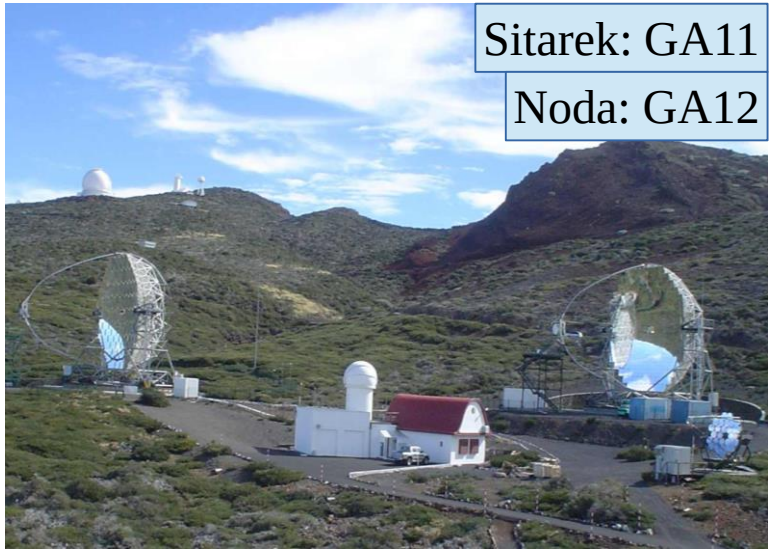
Instruments

- MAGIC stereo upgrade: 2012
- HESS-II
  - New 28m telescope: 2012
  - Major H.E.S.S. I Camera Upgrade 2015-2016
- VERITAS upgrade: 2012

Gottschall: Poster 3 GA
Klepser: Poster 1 GA
Trichard: Poster 3 GA



Sitarek: GA11
Noda: GA12

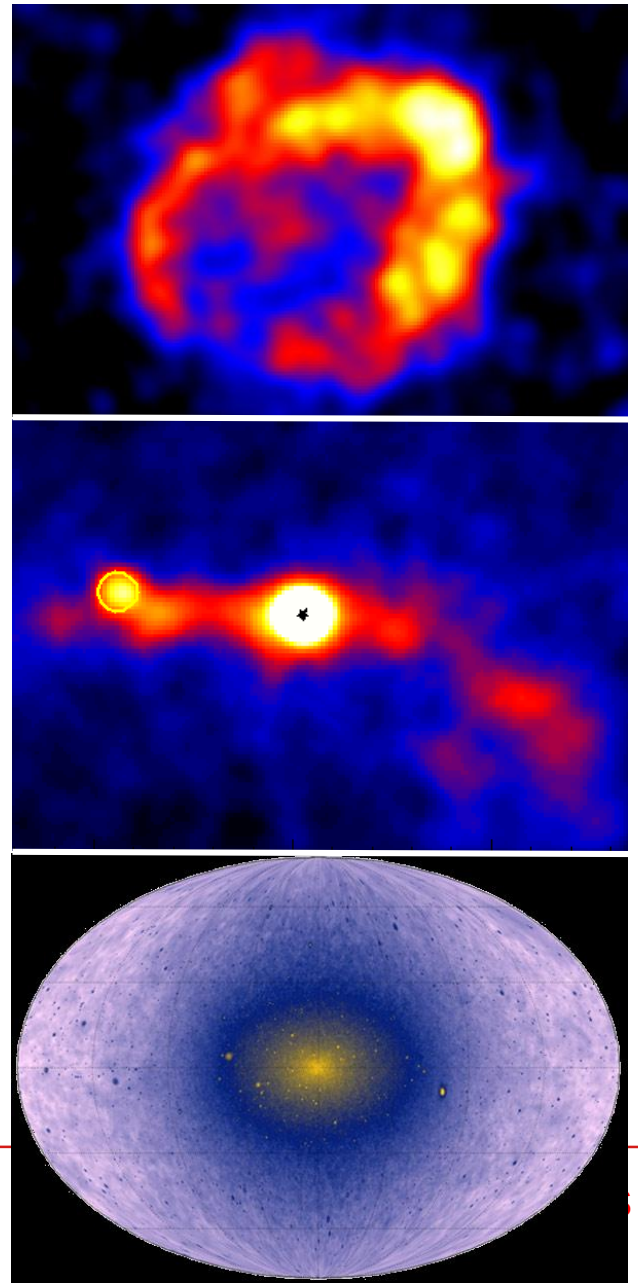


Park: Poster 3GA
Staszak GA10

Science Case

- Imaging of cosmic particle acceleration sites
- Physics of pulsars and pulsar winds
- Full sky surveys
- Probing the extragalactic background light
- Extreme variability of AGN
- Limits on dark matter and new physics

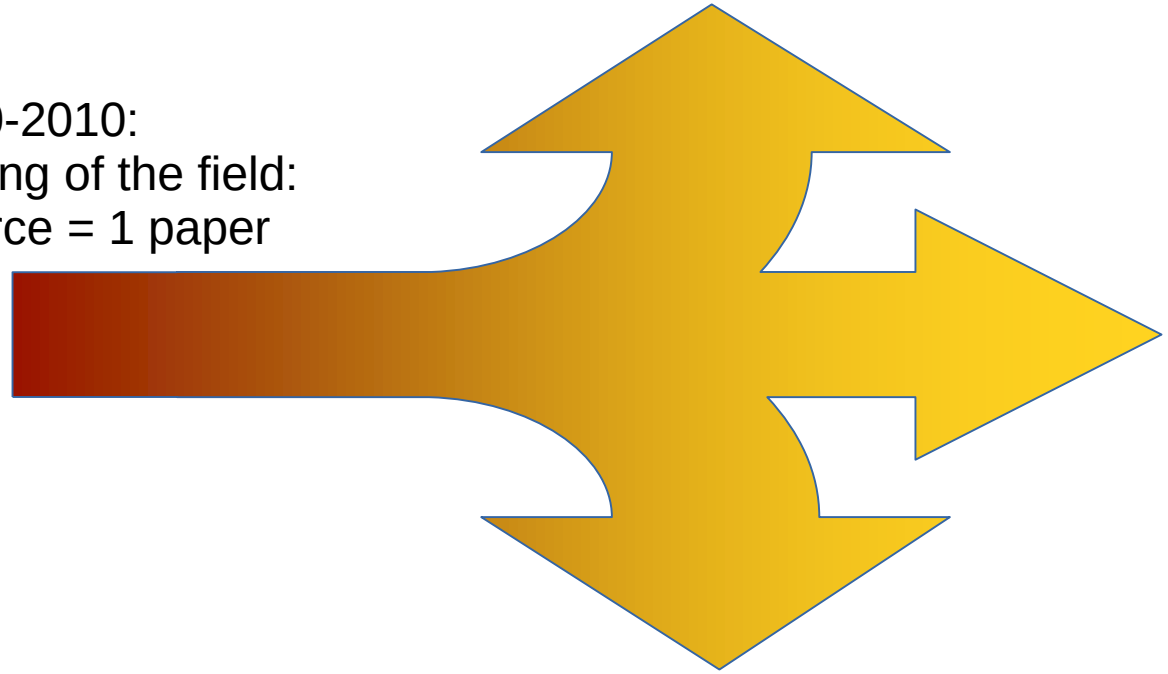
- Major contributions from all current instruments



Evolution of the Field

Surveys, populations studies

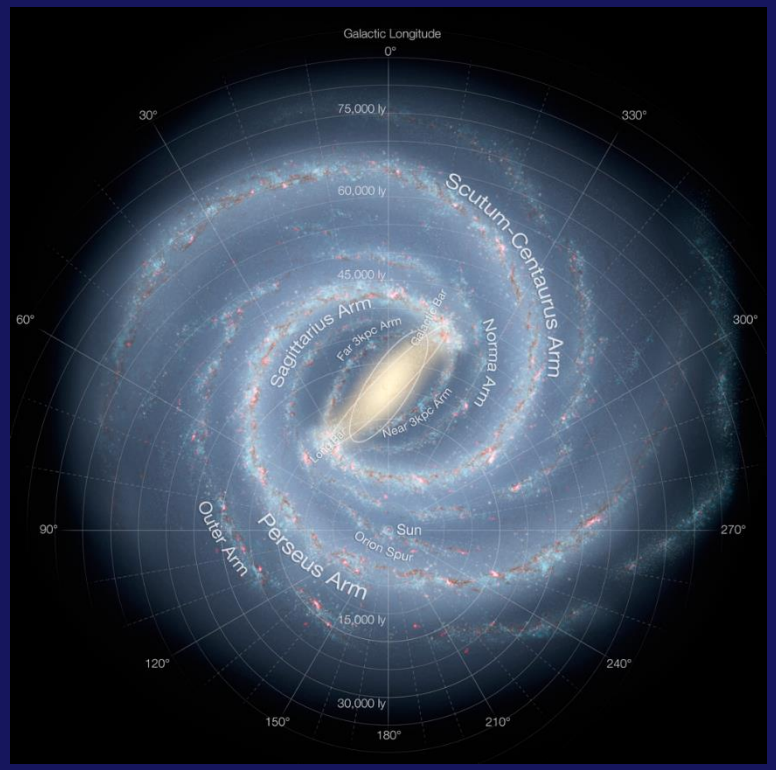
~2000-2010:
Opening of the field:
1 source = 1 paper

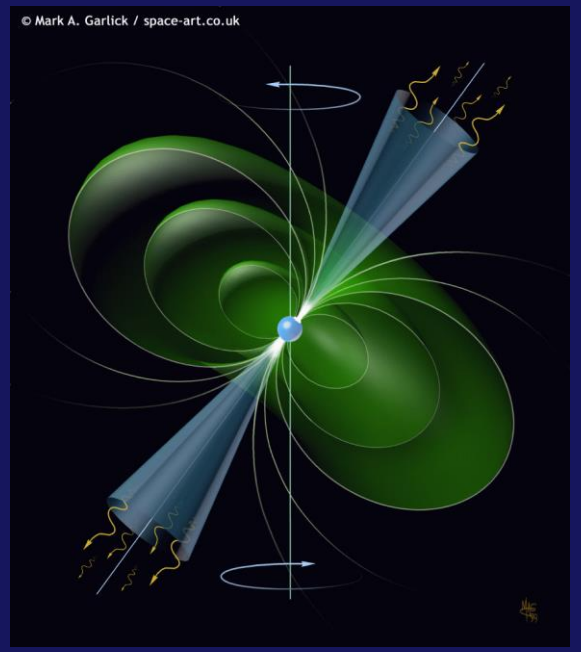


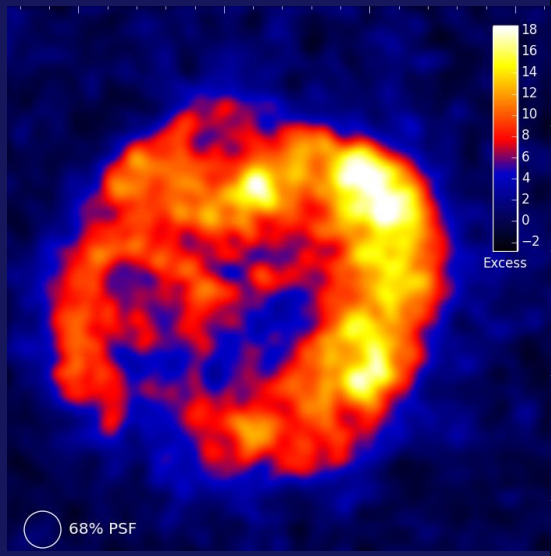
Key Science projects,
Deep investigation
of specific objects

The Unknown, still searching for
- Dark Matter
- Exotic Physics

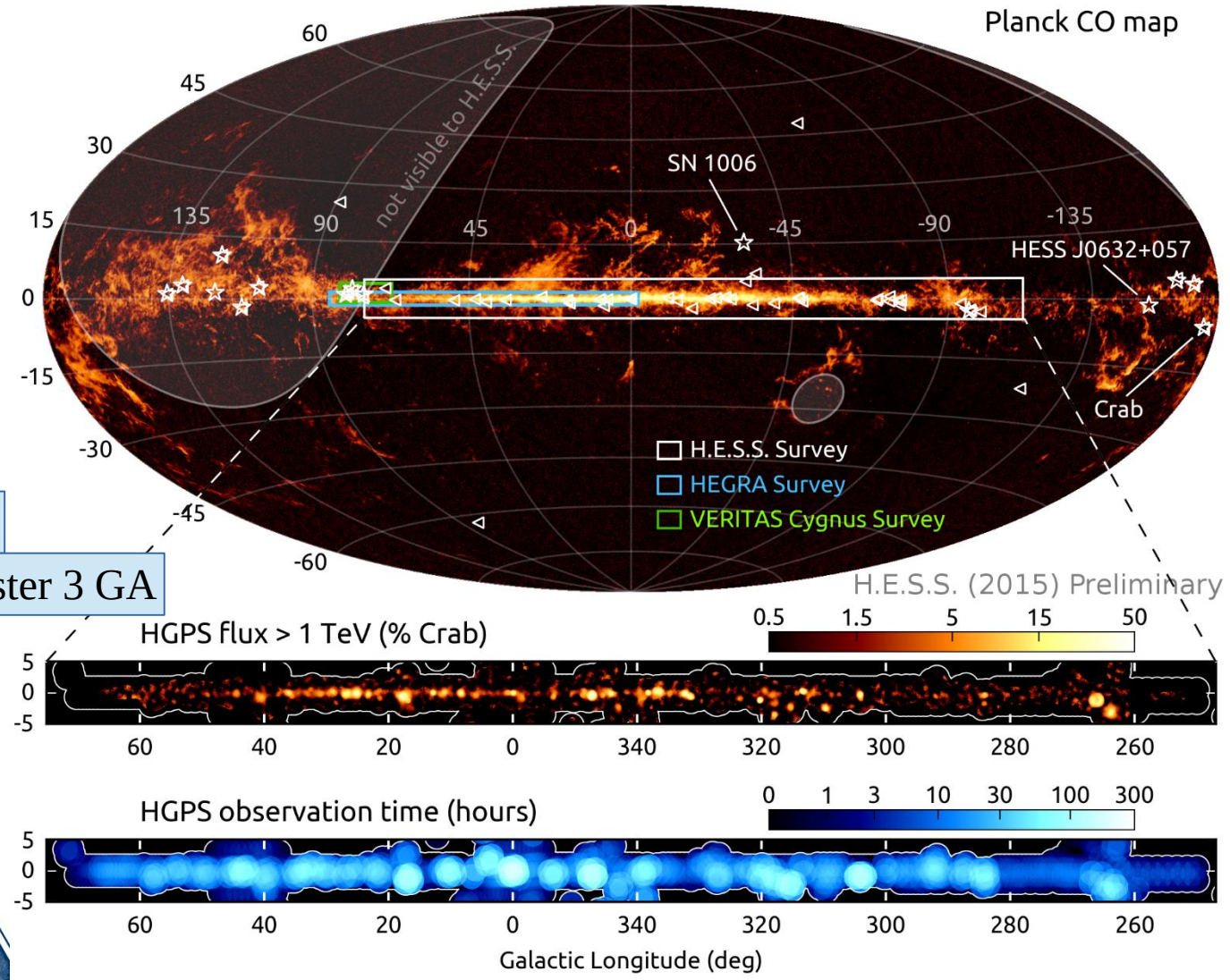
Galactic Science







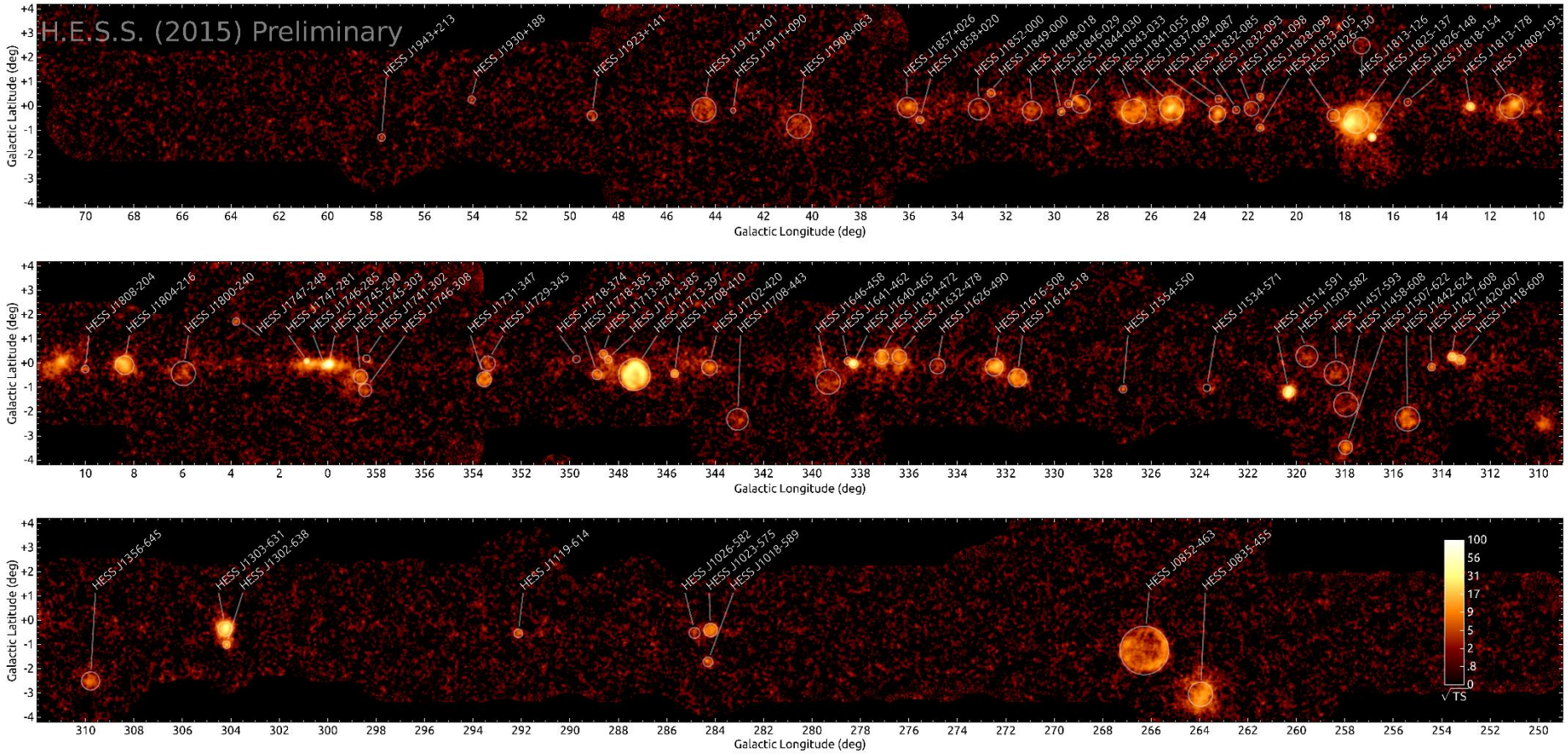
HESS Legacy Survey



Deil: GA16

Donath: Poster 3 GA

HESS Legacy Survey

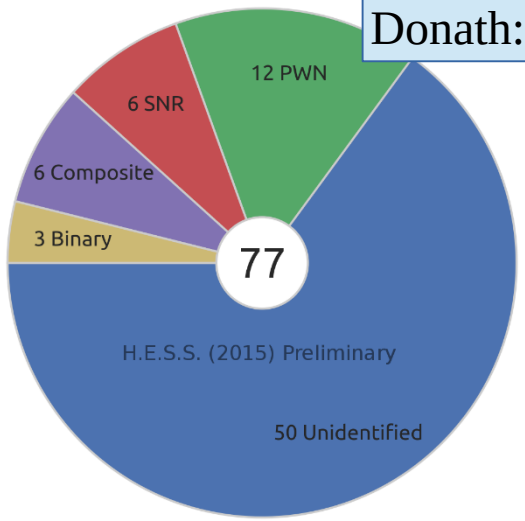


HESS Legacy Survey

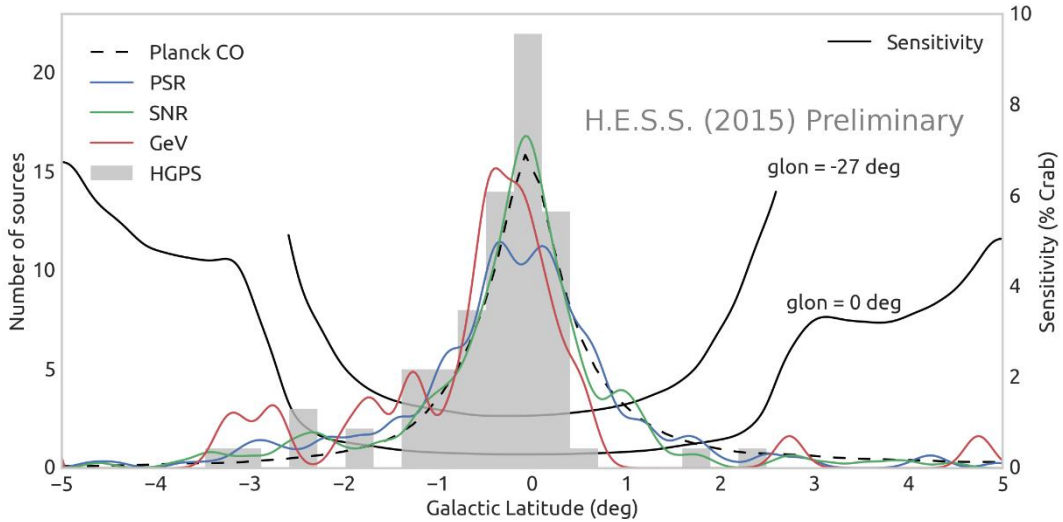
- "Final" HESS catalog of survey sources
  - Data collected 2004 – 2013
  - 2673 h after quality selection
  - Significance and flux maps
  - Automatic pipeline for source extraction
  - Likelihood fit : Gaussian components plus diffuse background

Deil: GA16

Donath: Poster 3 GA

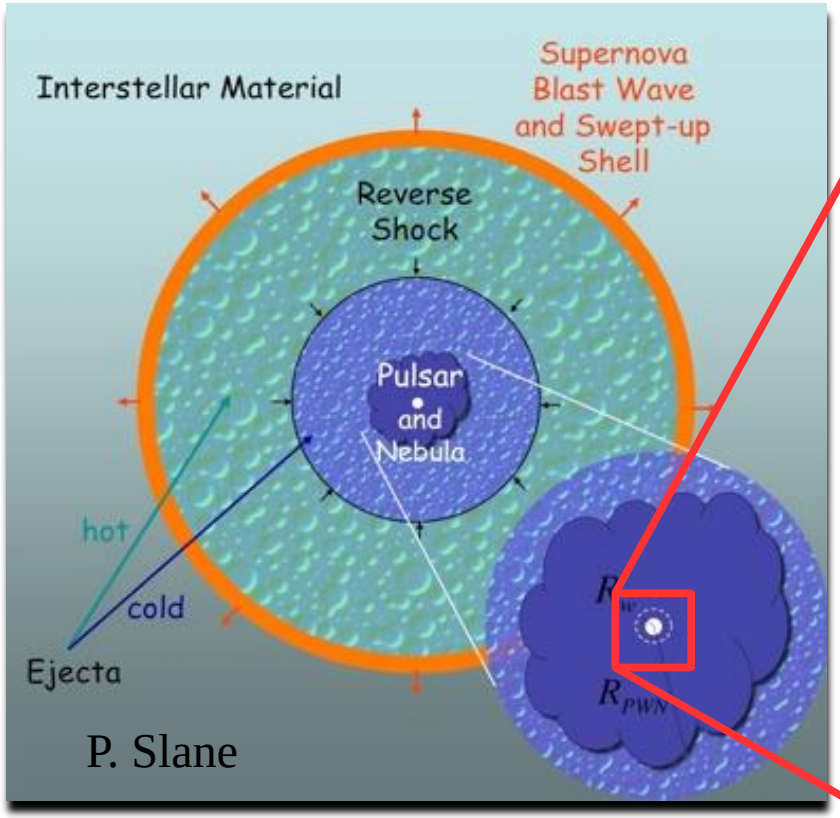


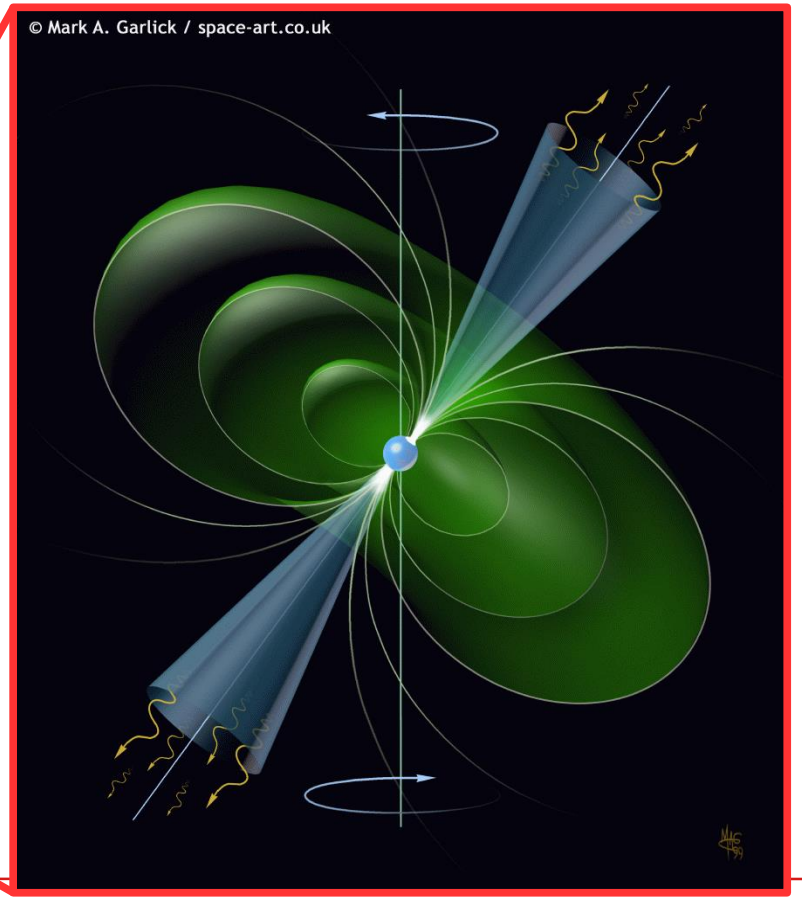
- 66 VHE sources +
  11 complex sources
  (e.g. shell SNR) excluded from pipeline



Pulsars and Nebulae

- Majority of identified source in the Galaxy are associated with young pulsars
- Synchrotron Nebula fed by the pulsar wind



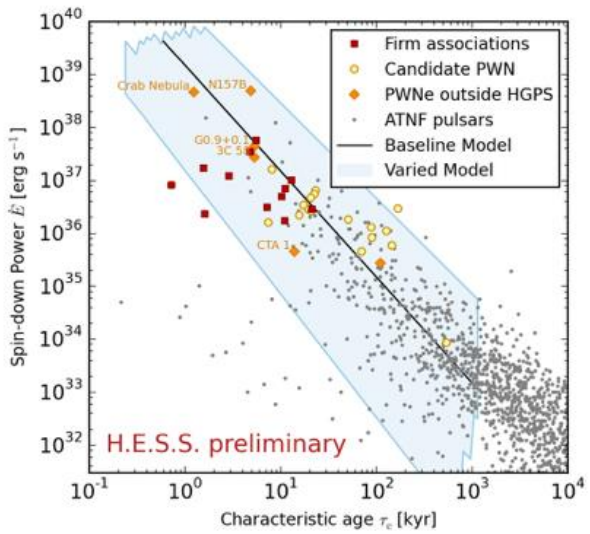


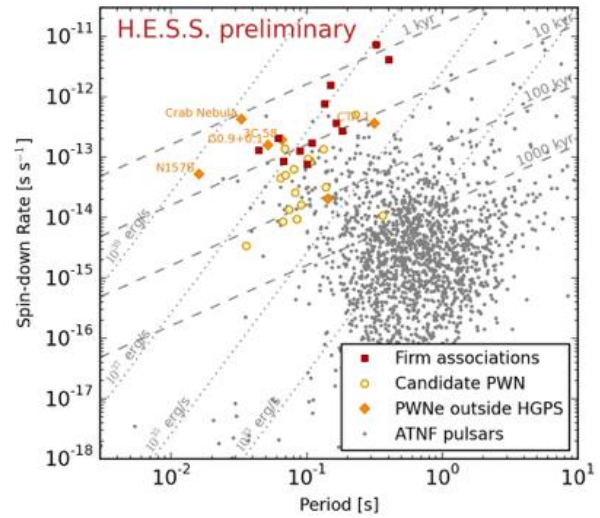
Surveys: PWN population studies

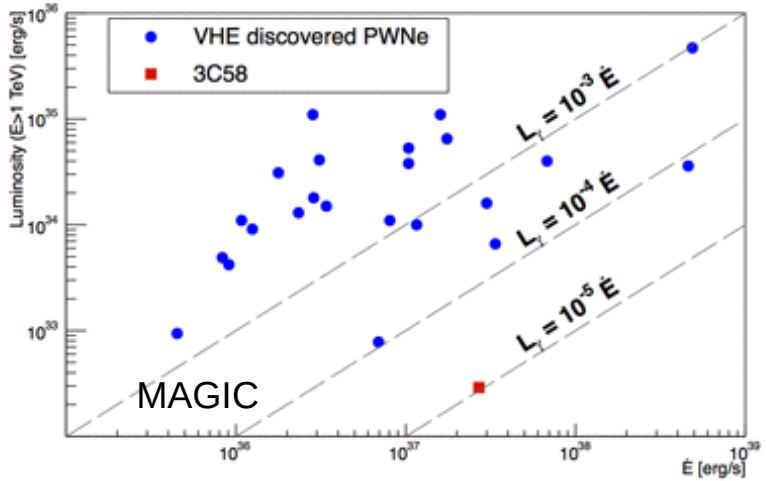
- Surveys are good for populations studies
- PWNs exhibit complex morphologies (reverse shock interaction)
- Statistical behaviour:
  - Most young pulsars associated with PWN
  - Extension, offset vs age
  - Fading with power
  - ...
- Some PWN exhibit peculiar characteristics
  - 3C58: very low luminosity (Least luminous TeV PWN) compared to spin-down power

(Not efficient accelerator? Weak B Field?)

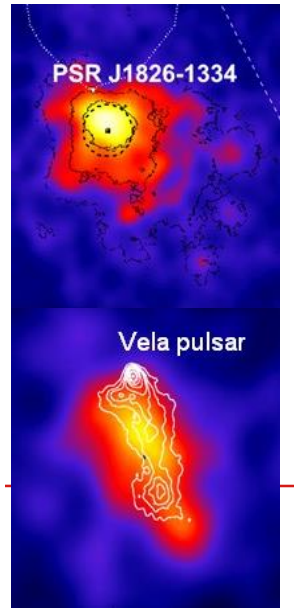
Klepser: GA03







Lopez-Coto: GA07

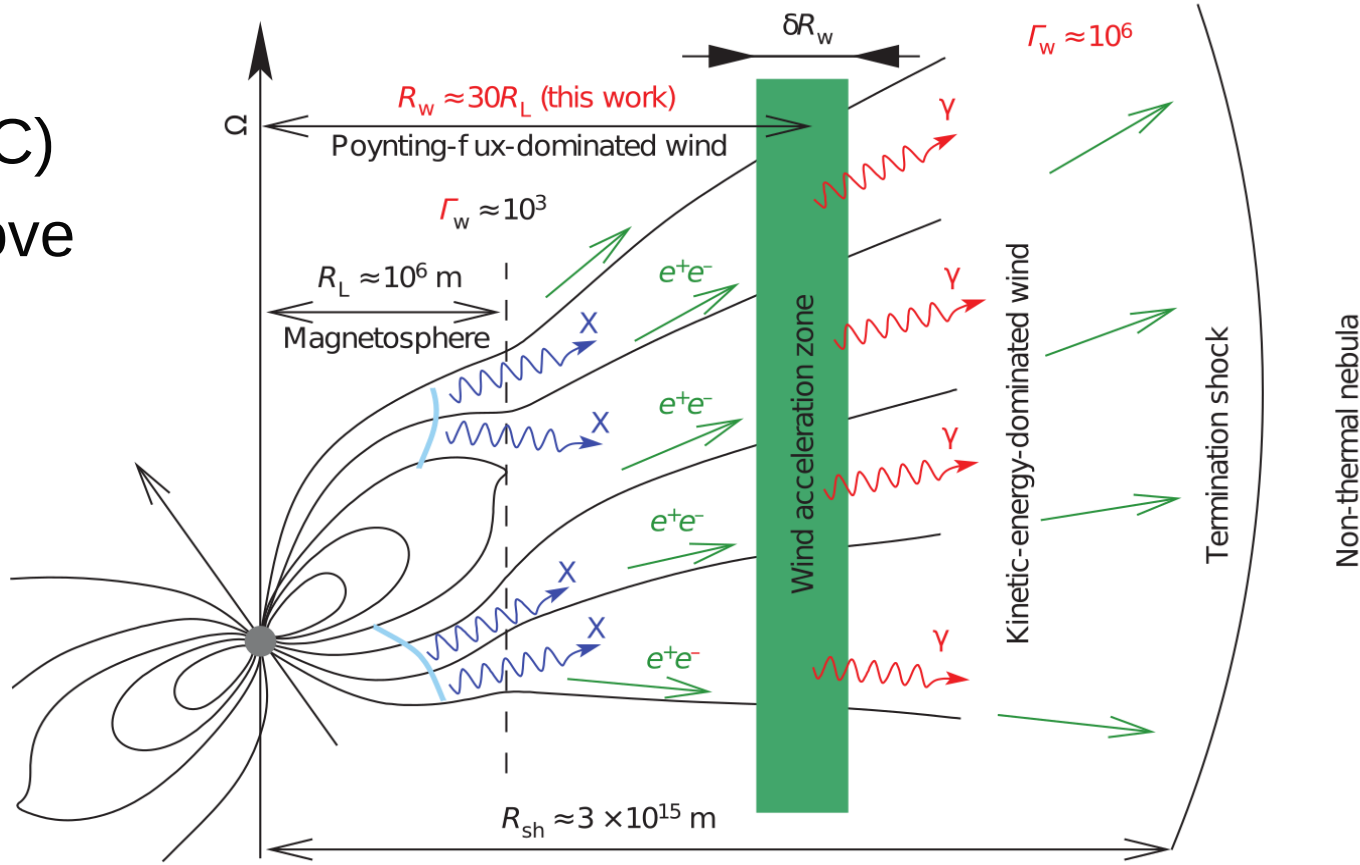


Mathieu de Naurois

VHE emission from Pulsars...

VHE History of Crab Pulsar:

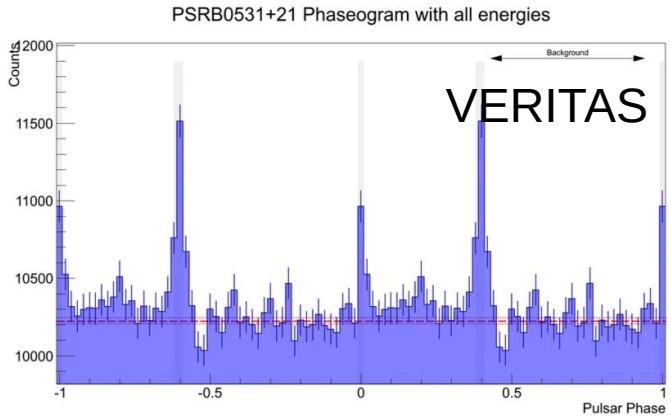
- 2008: First detection of emission above 25 GeV from a pulsar (MAGIC)
- 2011: First detection of emission above 120-250 GeV (VERITAS)
- 2011: First spectrum 25-100 GeV (MAGIC)
- 2012: First spectrum 50-400 GeV (MAGIC)
- 2014: Bridge Emission ≥ 50 GeV (MAGIC)



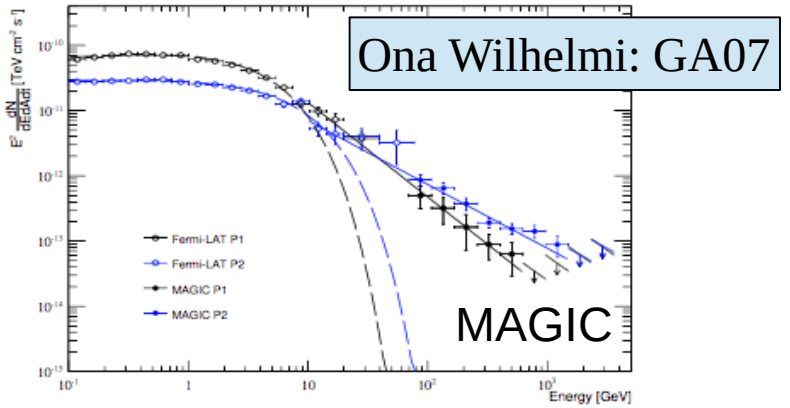
Crab Pulsar

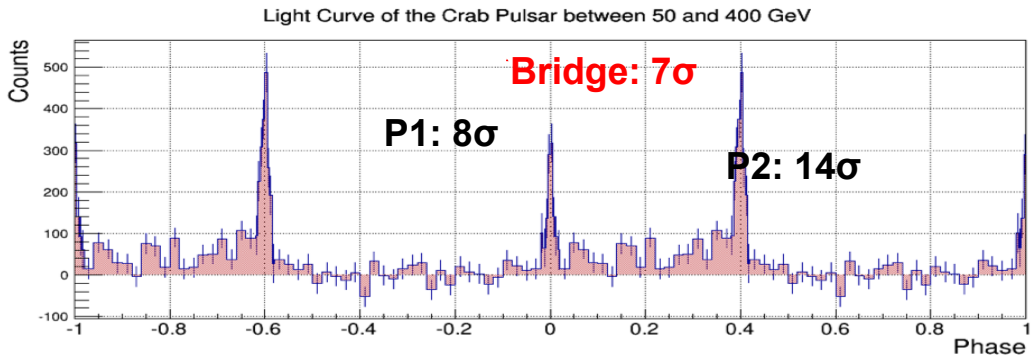
Thanh: Poster 1GA

- Deep observations
- MAGIC (320h) + Fermi-LAT
  - Pulsed Emission from 10 GeV to > 1 TeV
  - Emission from the bridge (toroidal bending of B lines?)
- VERITAS (195h)
  - Confirmation of Pulsed Emission > 400 GeV
- Era of precision measurement
- Challenges for pulsar models
  - emission from the neighbourhood of the Light Cylinder (r ~1600km)
  - Likely IC emission
  - Most compact accelerator so far



Ona Wilhelmi: GA07



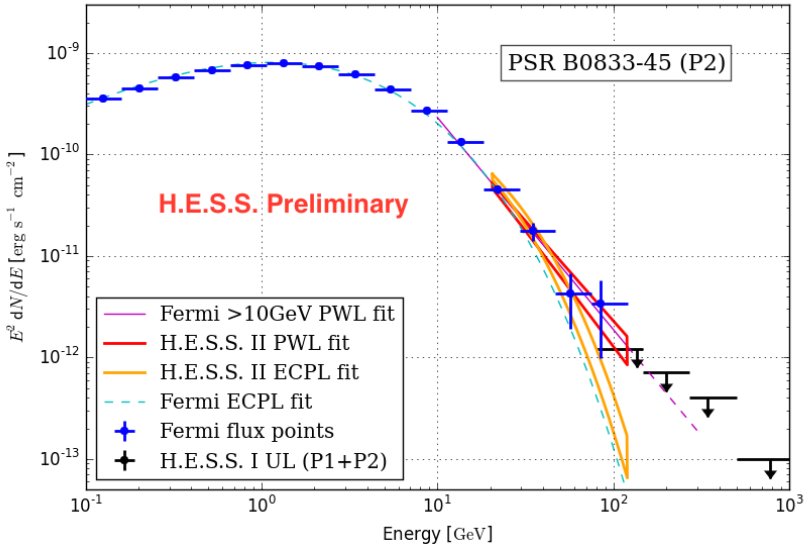


Highest energy pulsation

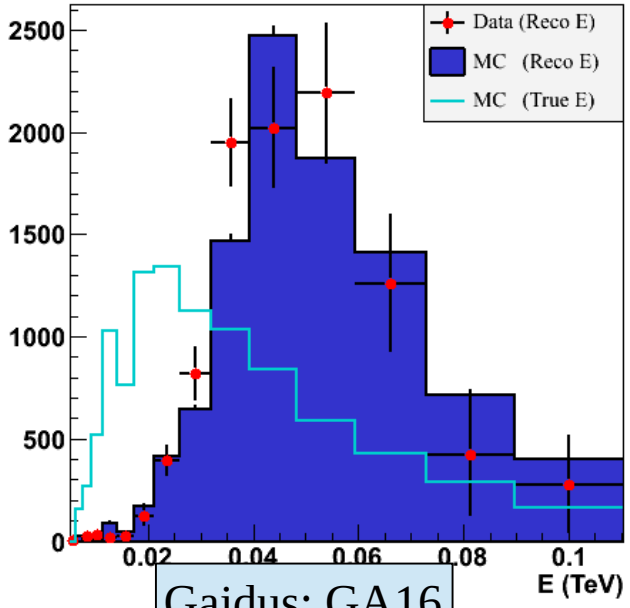
Vela Pulsar

Second VHE pulsar

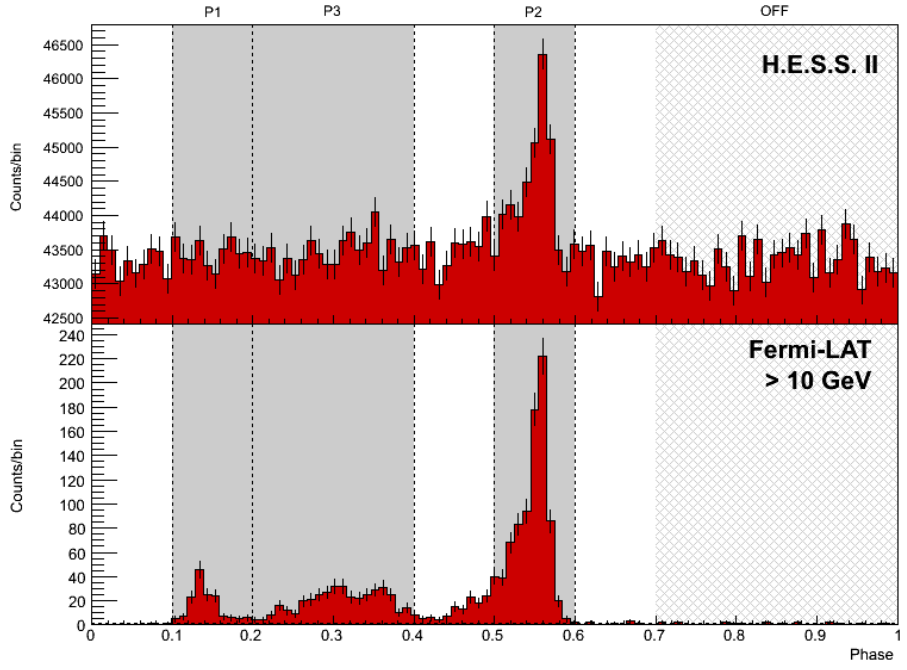
- Second VHE pulsar (H.E.S.S.)
  - calibration source at the threshold in standard observation mode
  - Deep observation campaign needed to investigate maximum energy and variation of pulse profile with energy
  - γ-rays as low as 10 GeV!



Energy distribution

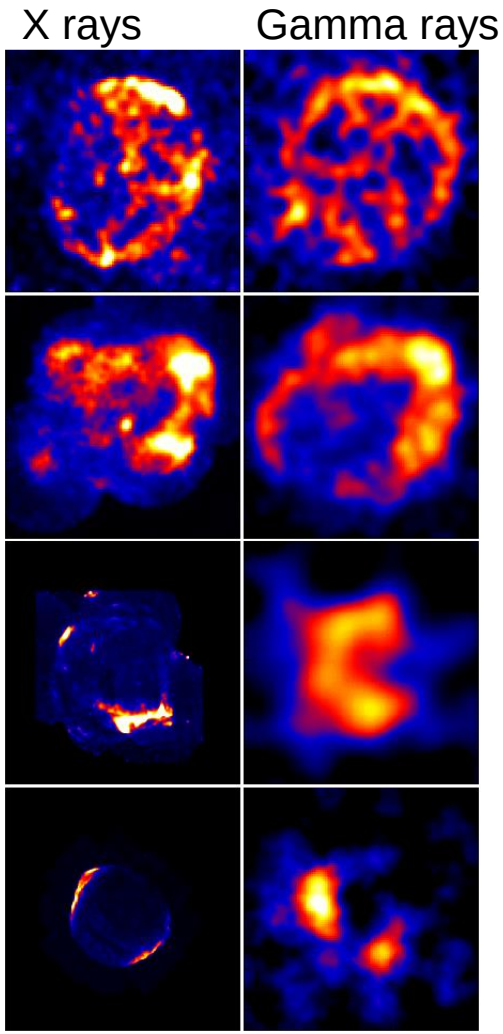


Gajdus: GA16



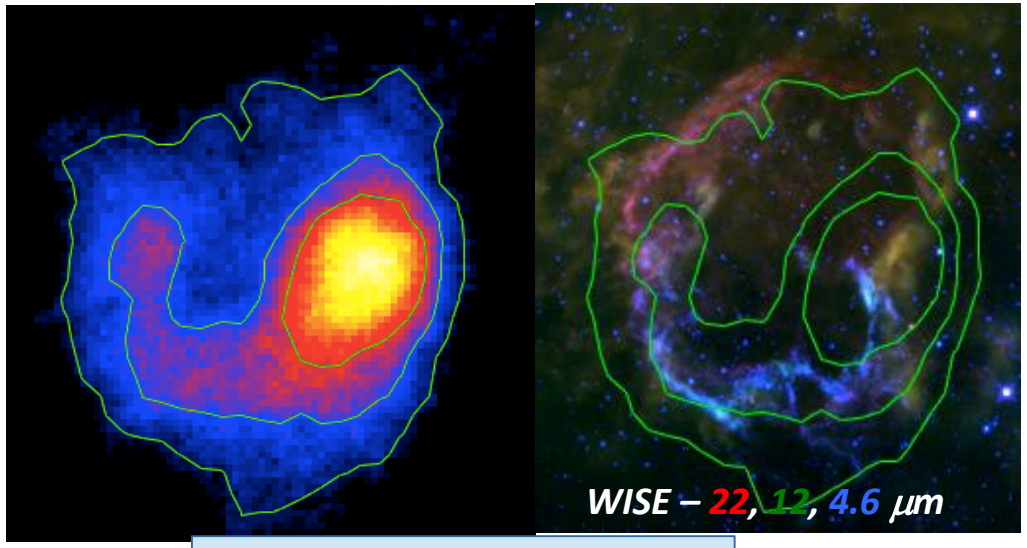
Supernova Remnants

- Second population of VHE sources in Galaxy
- Young, historical supernova, in different evolution stages
  - High quality images, MWL data
- Olders SNRs proven to accelerate protons
  - In interaction with molecular clouds
- High energy often dominated by leptonic processes
  - Due to different efficiency of radiation mechanisms
  - Hadrons need target to be revealed
- SNRs can be pevatrons only during a short time



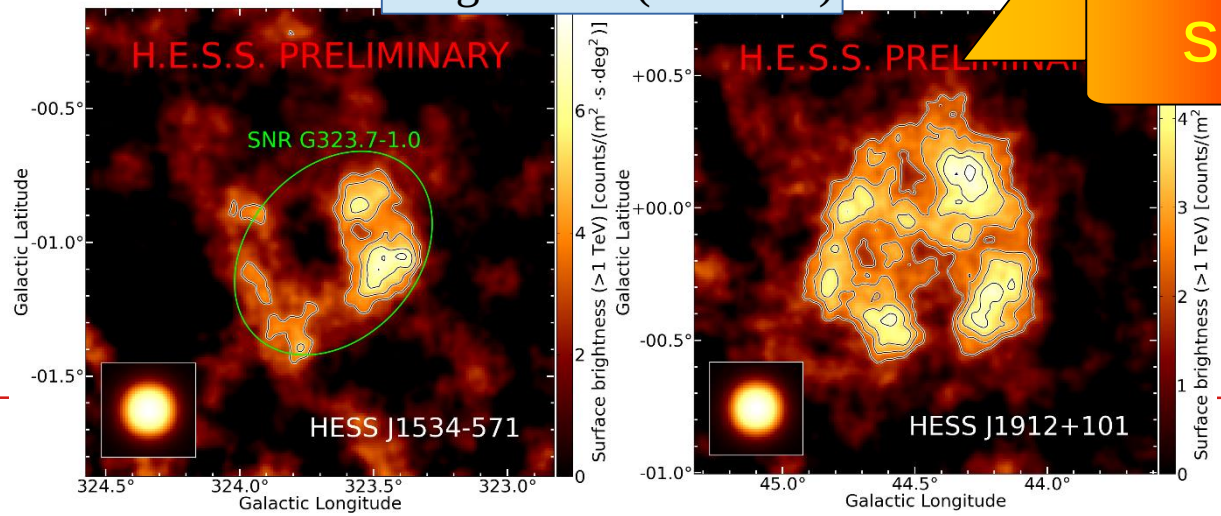
New TeV Shell-type SNRs

- IC 443 shell resolved by VERITAS
  - Spectra from different regions probe the environmental dependence of cosmic-ray diffusion
  - Evidence for hadronic acceleration in old SNRs
- New shell-type SNRs resolved by HESS
  - HESS J1534-471 & HESS J1912+101
  - Shell identification (RCW 86)

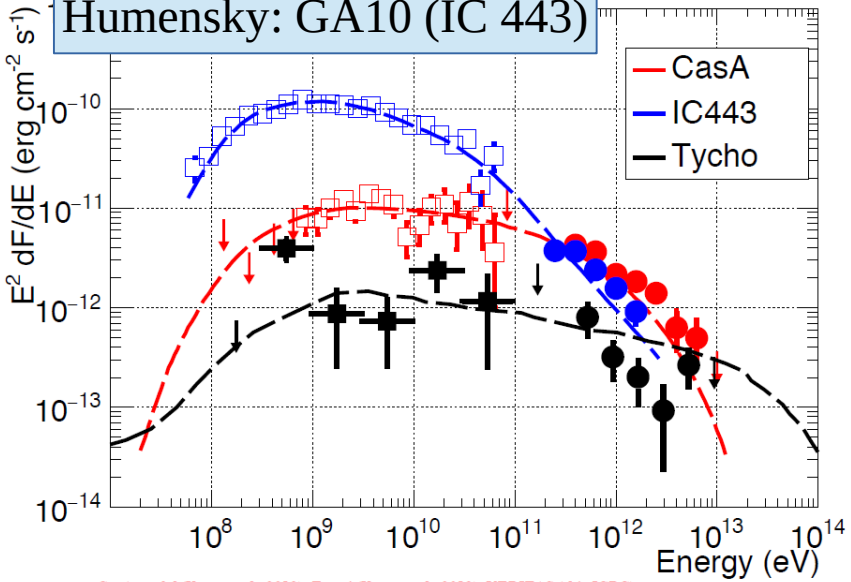


Pühlhofer: GA02
Jung: GA02 (RCW 86)

Increasing sample



Humensky: GA10 (IC 443)

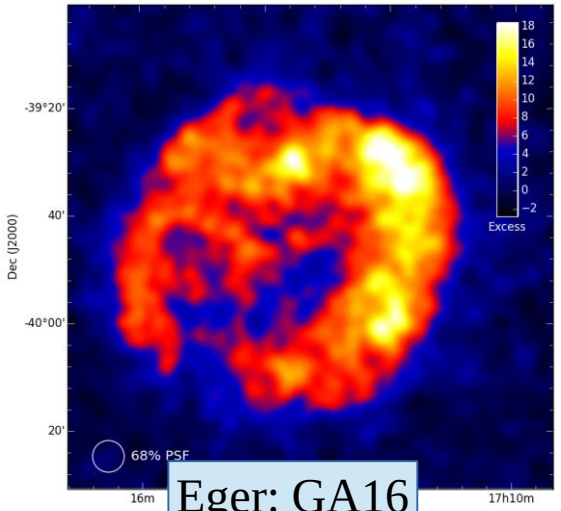


CasA model (Yuan et al., 2013), Fermi (Yuan et al., 2013), VERITAS (this ICRC)
IC443 model (Ackermann et al., 2013), Fermi (Ackermann et al., 2013), VERITAS (this ICRC)
Tycho model (Slane et al., 2014), Fermi (this ICRC), VERITAS (this ICRC)

Spectro-Imaging of RXJ 1713-3946

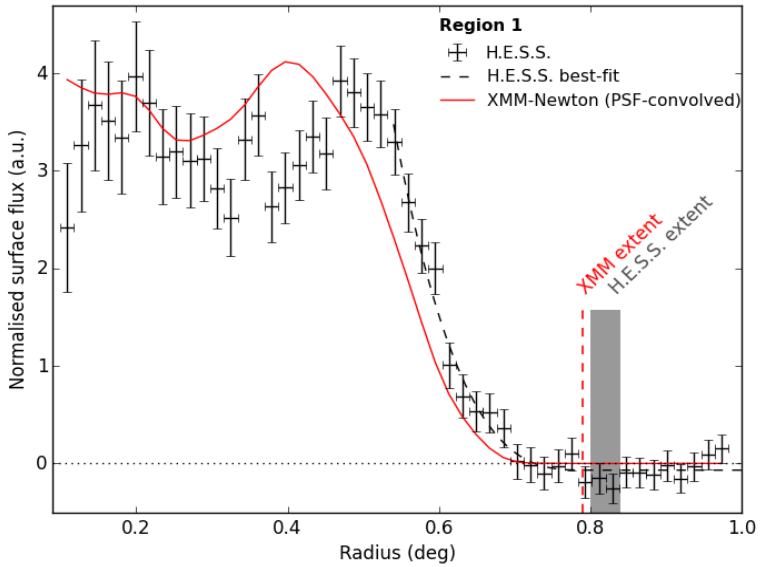
10 years of H.E.S.S. data

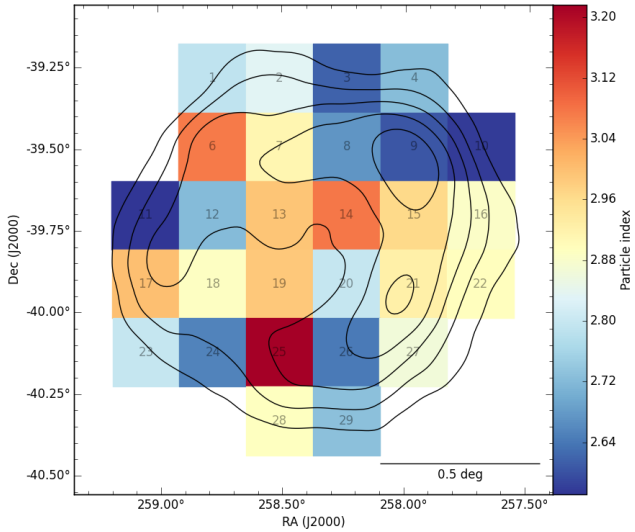
- Factor 2 improvement in statistics
- Spatially resolved spectra
- Difference in X/γ radial profiles: Particle escape and/or B field geometry
- VHE astronomy can probe acceleration regions!



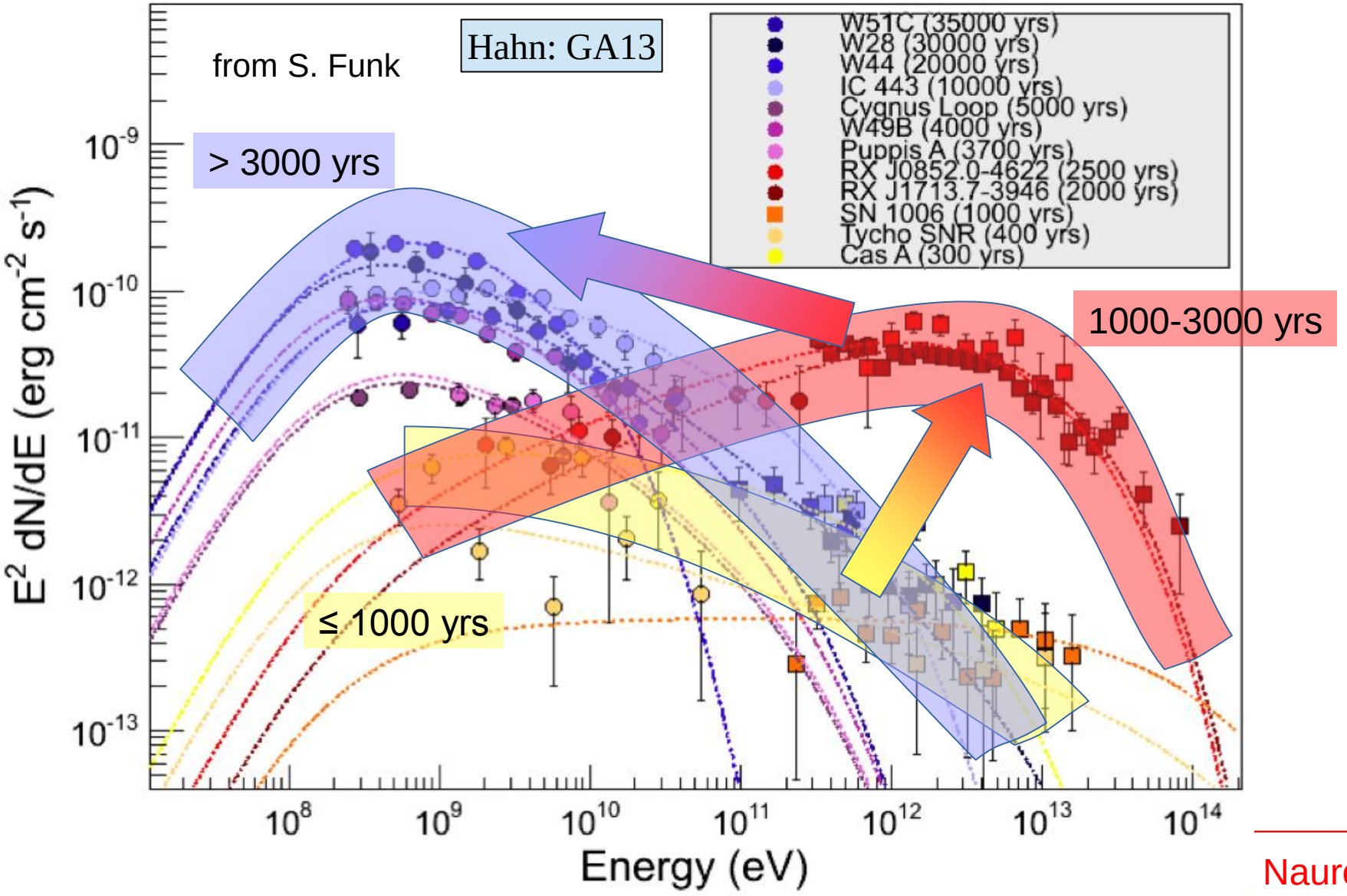
Eger: GA16

Particle escape?





Large sample → evolution of supernova remnants

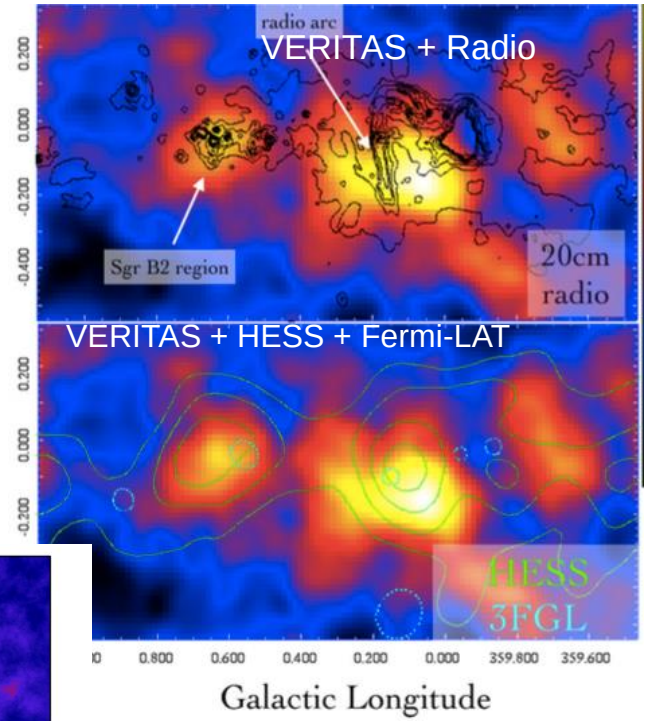


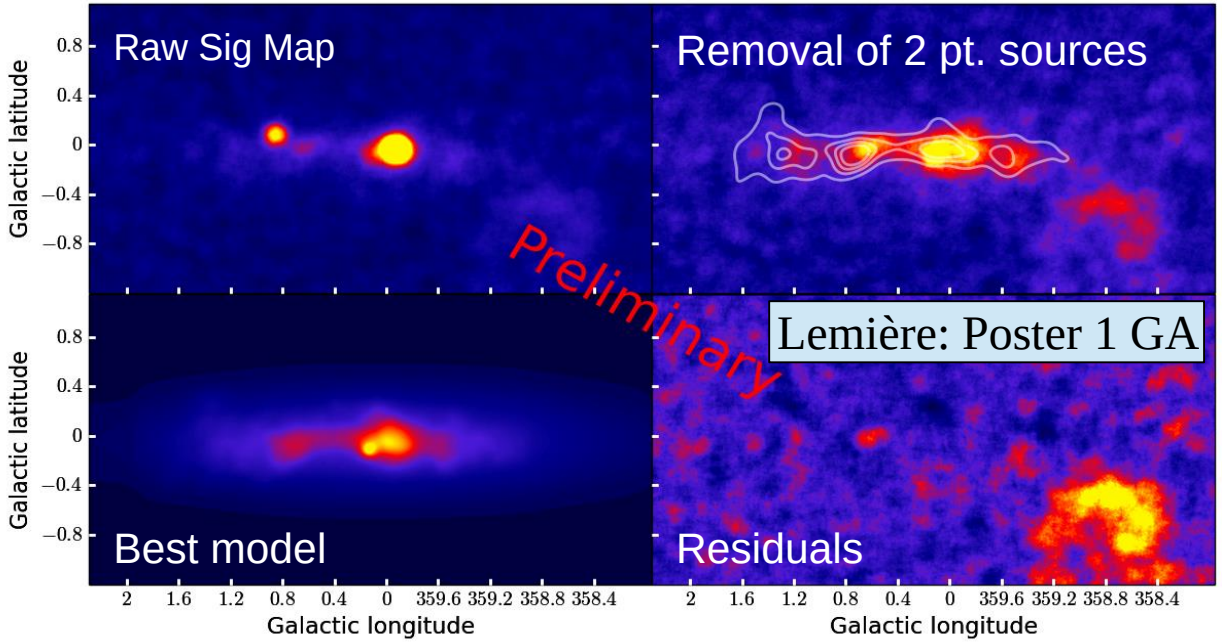
Galactic Centre

- Complex morphology
  - VERITAS: correlation with radio, 3FGL & HESS
  - MAGIC observations at high zenith angle
  - HESS: Deep observation (250h)
    - Diffuse emission (interaction of CRs with Molecular clouds)
    - Detection of Arc Source (HESS J1746- 285) above CMZ contribution (likely PWN)

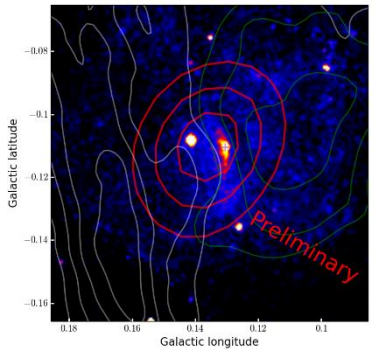
Fruck: GA14

Smith: GA10





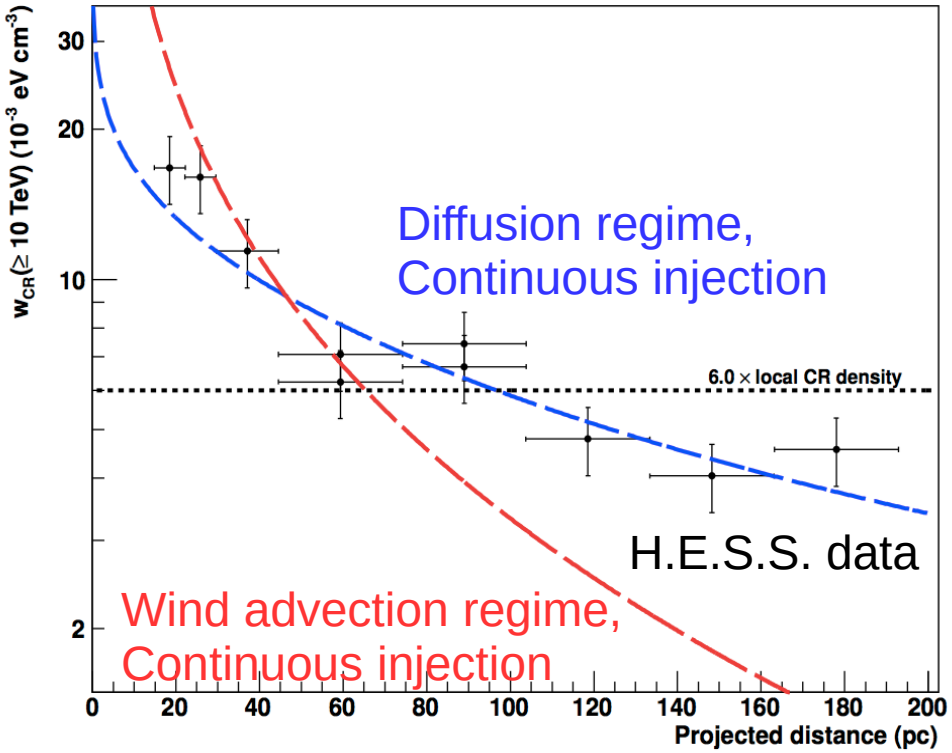
Lemière: Poster 1 GA



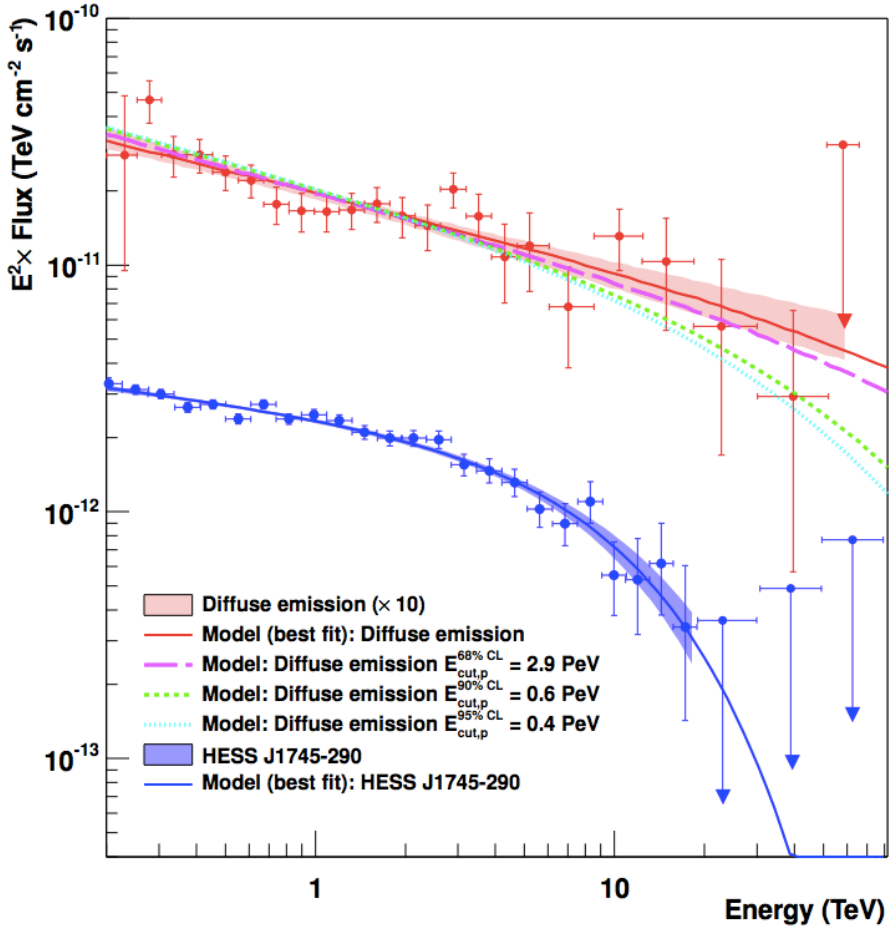
Galactic Centre with H.E.S.S.

First Pevatron

- Central source: cut-off @ 10 TeV
- Diffuse emission shows no cut-off well > 10 TeV
- Emission likely due to propagation of protons accelerated around central black hole and diffusing away (projected radial distribution matches)
- Parent proton population up to 1 PeV (2.9 PeV @ 68% CL)

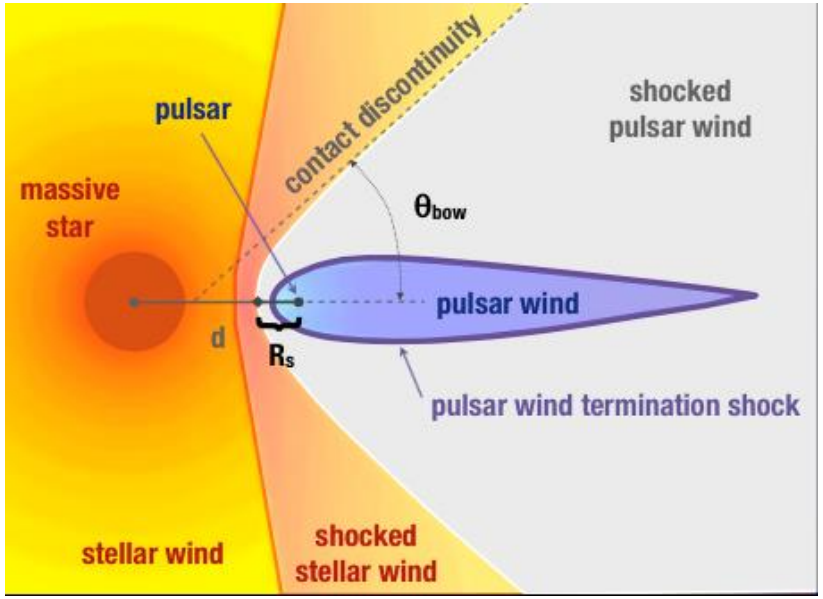


Viana: GA16



TeV gamma-ray binaries

- Extreme environment
- Complex physics:
  - Accretion/ejection in binary systems
  - Anisotropic radiation fields
  - Absorptions by pair creation
  - Variable conditions
- Very different periods
- Very different phenomenology
- Laboratories for acceleration & radiation mechanisms on human timescales



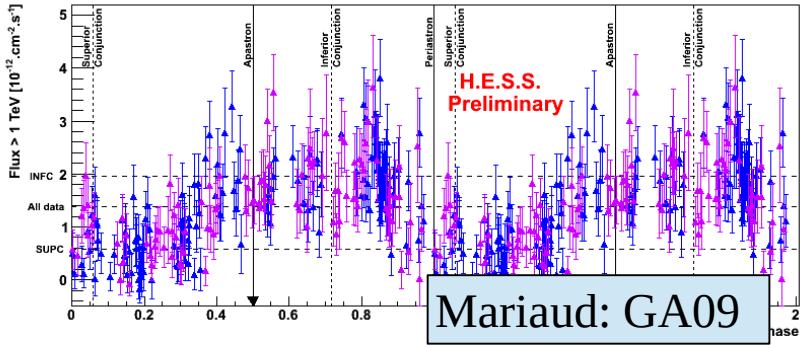
G. Dubus, ArXiv: 1307.7083

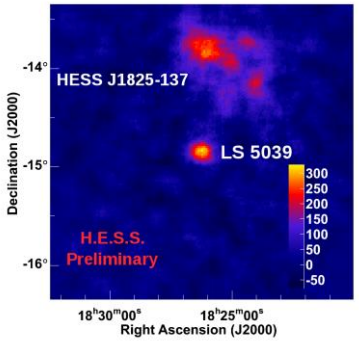
	Period (days)	$M_*(M_\odot)$
PSR B1259-63	1236	31
LS 5039	3.9	23
LS I +61 303	26.4	12
HESS J0632+057	315	16
1FGL J1018.6-5856	16.6	31

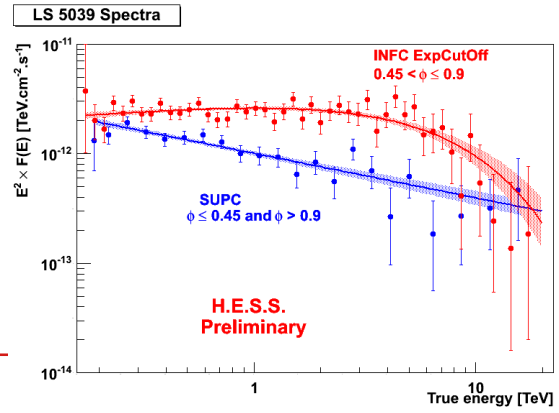
Swiss clocks ?

LS 5039

- New H.E.S.S. II data
- Perfectly periodic (10 yrs)

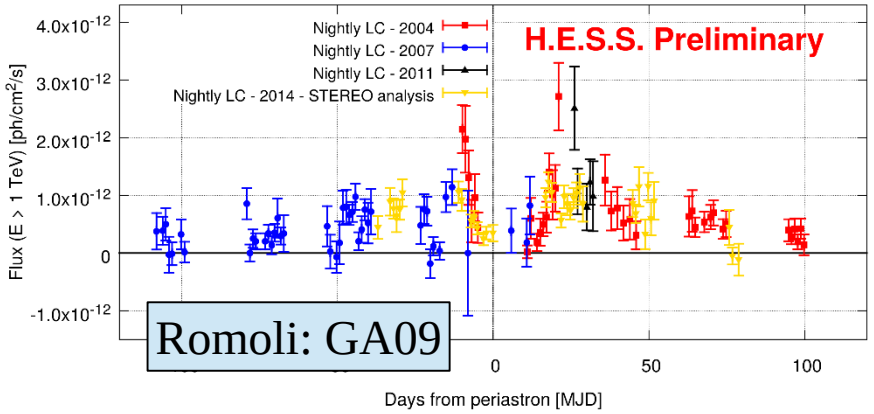


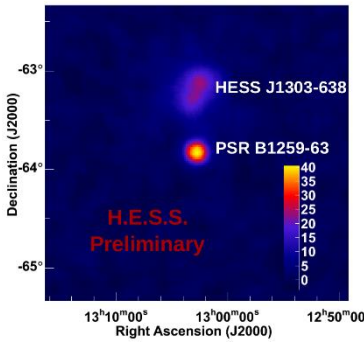




PSR B1259-63

- New H.E.S.S. II data
- Consistent with previous observations
- Fermi Flare not detected



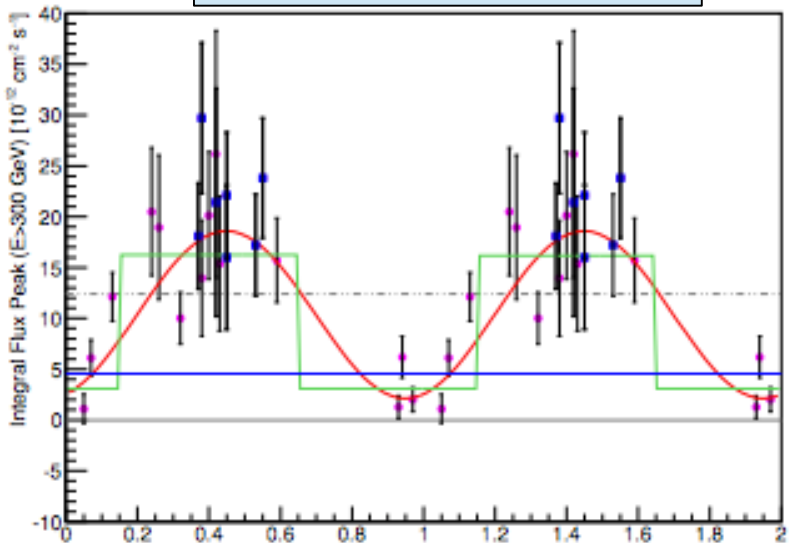


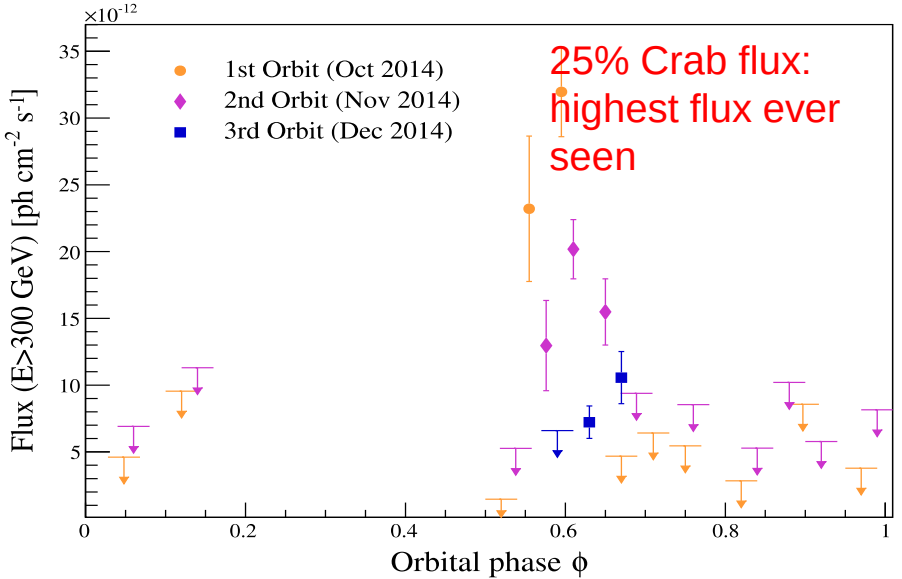
- Origin of Fermi Flare still puzzling

LSI +61 303 – The fuzzy clock

- Compact object + Be star
- Orbital period: (26.496 ± 0.0028 days)
- MAGIC: Super-orbital period: (1667 ± 8) day (variation of accretion rate?)
- October 2014: VERITAS detection of exceptionally bright (> 25% of the Crab Nebula flux) and fast (< 2-day rise time) flares
  - rapidly changing conditions (possibly due to turbulent mixing of stellar and pulsar winds, a structured stellar wind, or interaction with stellar disk

Fernandez-Barral: GA09





O'Faolain de Bhroithe: GA10
Kar: Poster 3GA

Extremes objects in the LMC

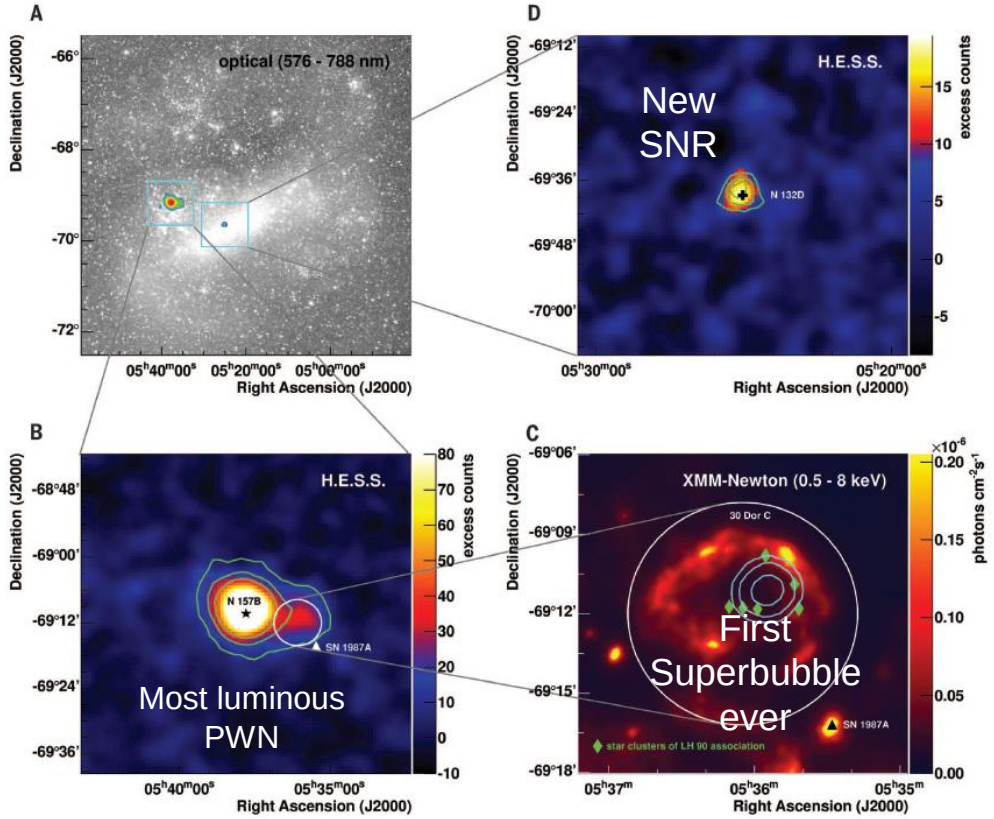
- First glimpse of the LMC population of (stellar-type) particle accelerators
- Extreme environment:
  - Large CR density
  - Large IR

  → Very efficient radiation mechanisms
- First TeV supperbubble
  - Possible sources of UHECRs

First extragalactic Stellar Sources

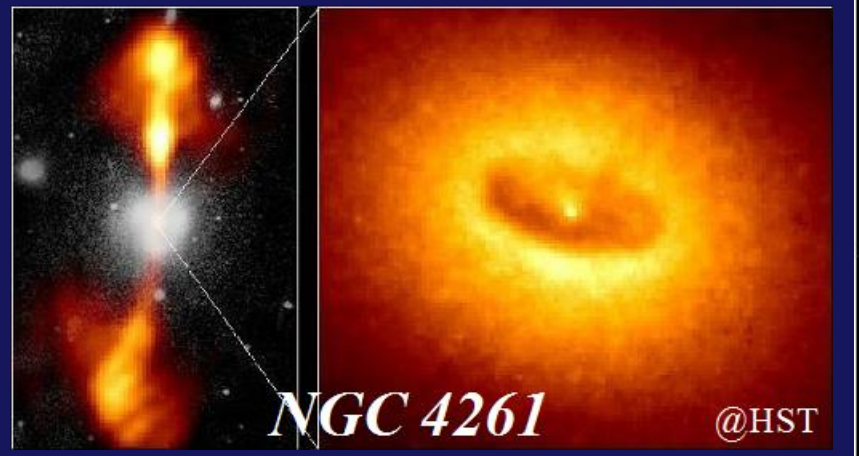
First Superbubble

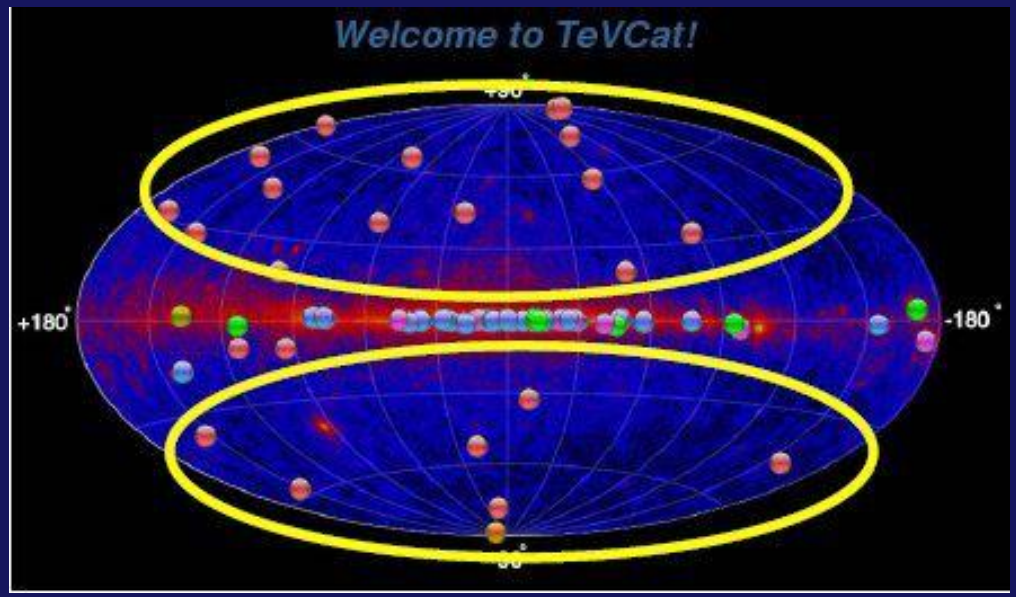
Komin: GA16



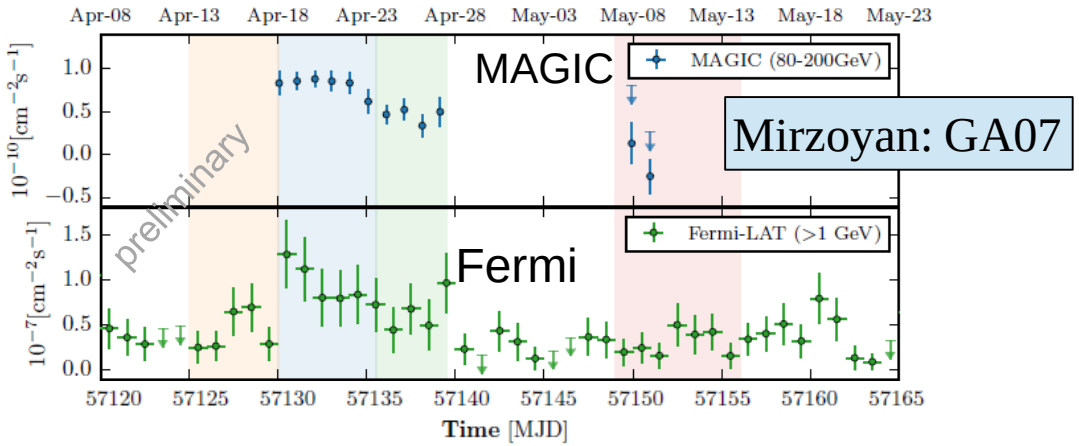
H.E.S.S. MAGIC VERITAS

Extragalactic Science

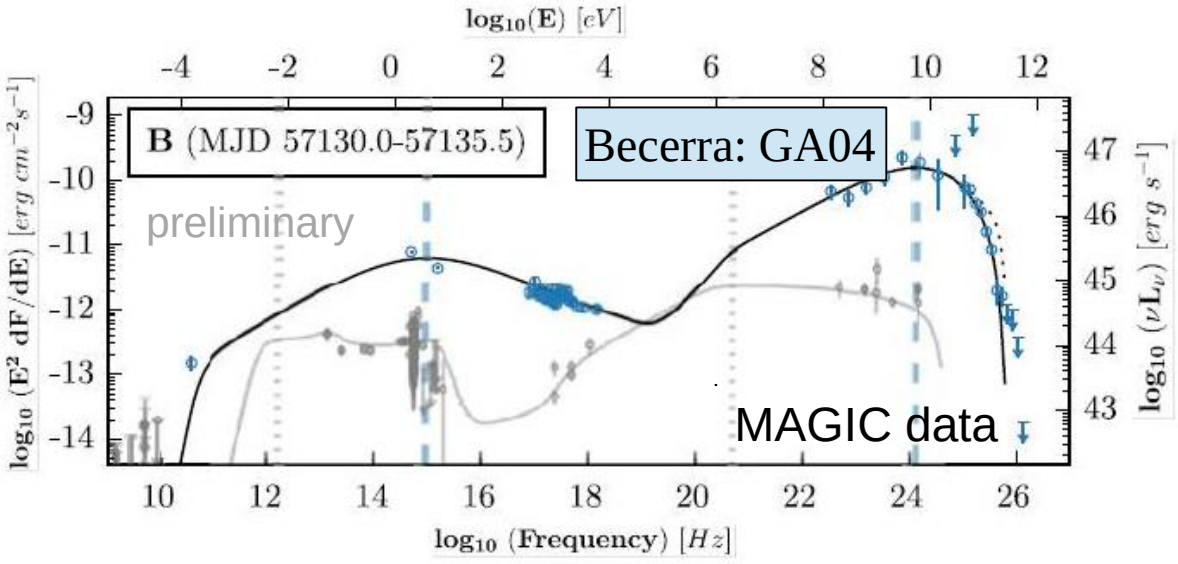




A quasar half a Universe away: PKS 1441+25 @ z = 0.939 !

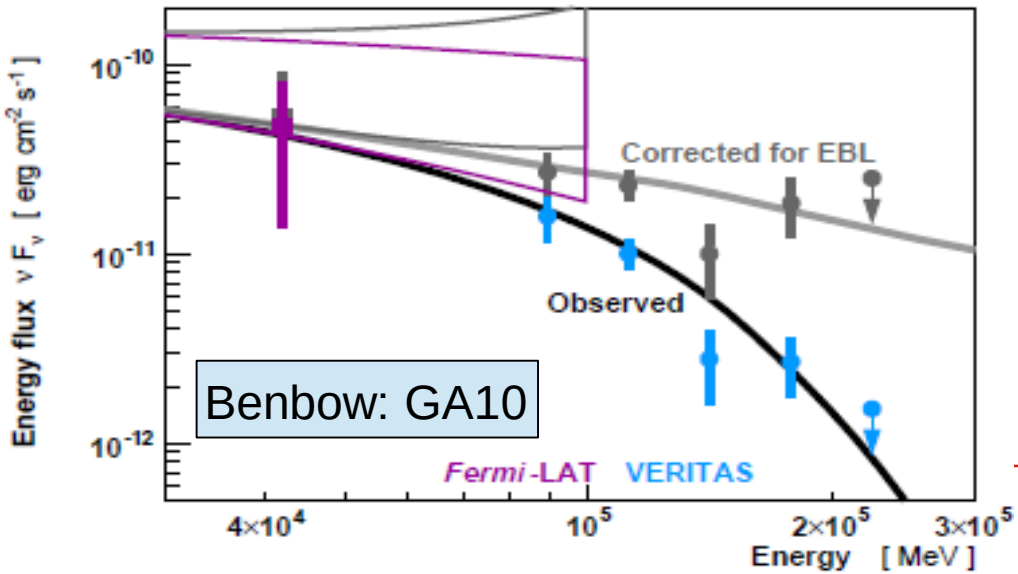


Mirzoyan: GA07



Becerra: GA04

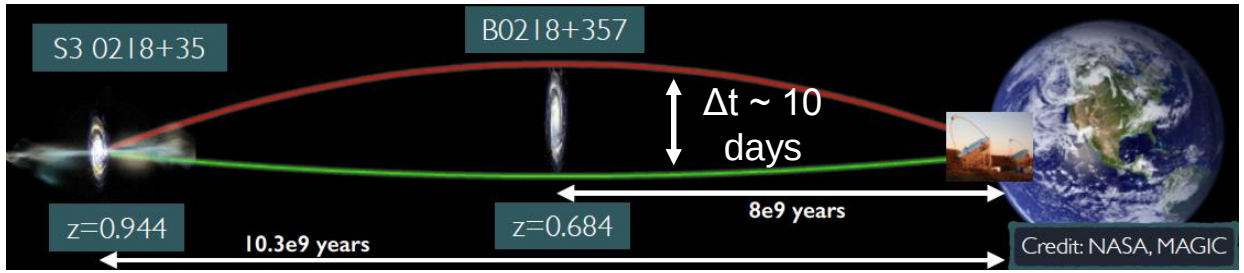
- FSRQ @ z = 0.939
- MAGIC detection @ 25 σ
- VERITAS Confirmation
  - Up to 200 GeV
  - ~400 GeV accounting for z!
- Stringent constraints on the EBL < 1 μm from a single source



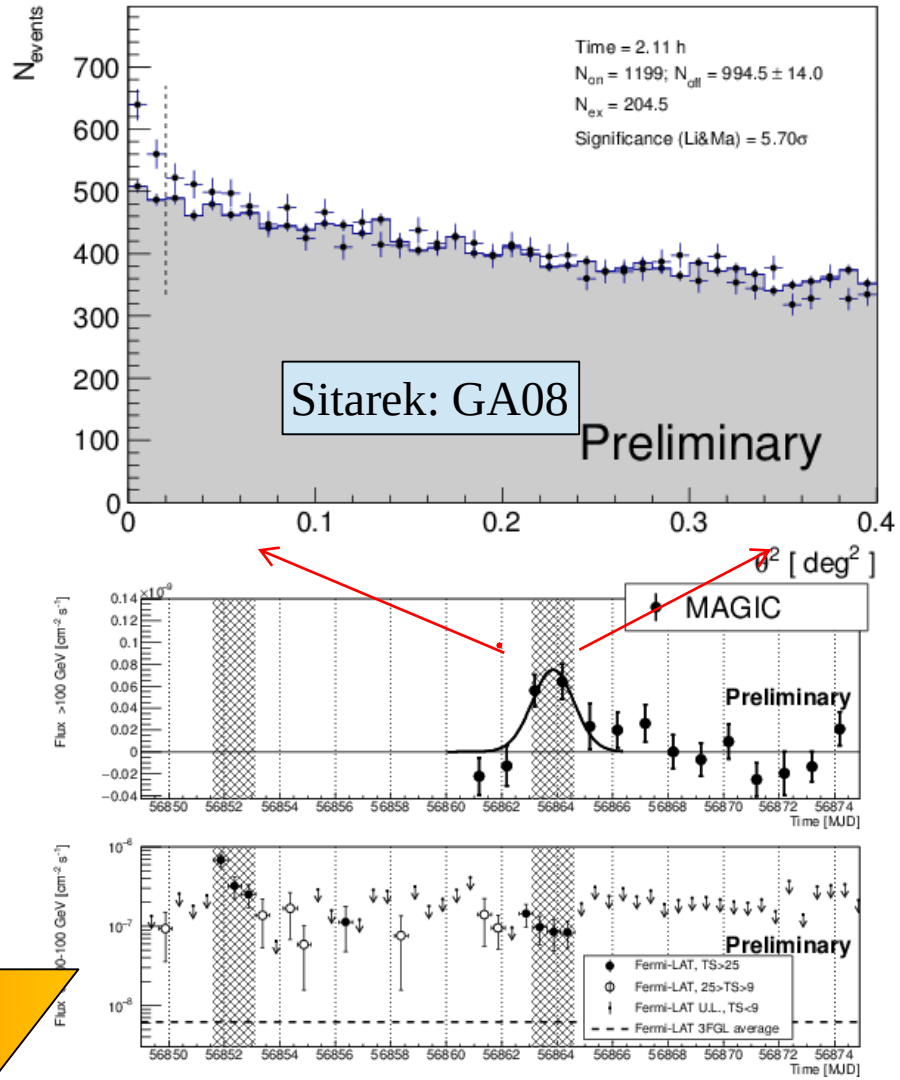
Benbow: GA10

Redshift record

QSO B0218+357: Gravitationally lensed blazar @ z = 0.944 !



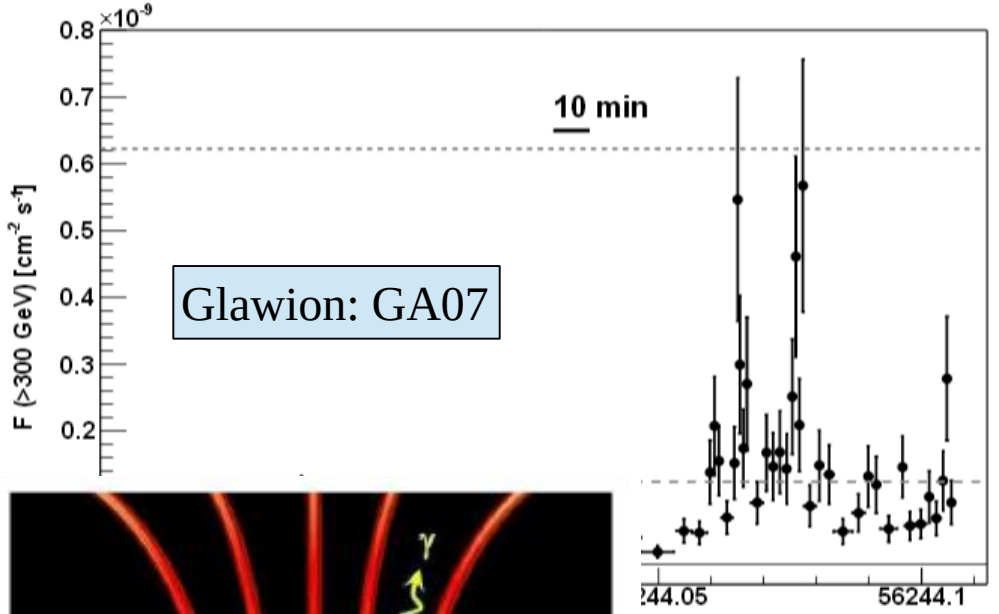
- ~11.5d delay between the direct & lensed components (Fermi – 2012)
- Observations with MAGIC performed during the 2nd flare: detection of sub-TeV lensed emission
  - much more prominent emission than by Fermi
  - VHE emission from z~1 is strongly attenuated above ~100 GeV
  - GeV + sub-TeV observations can put constraints on the EBL models at z ≤ 0.94
  - impact on cosmology models

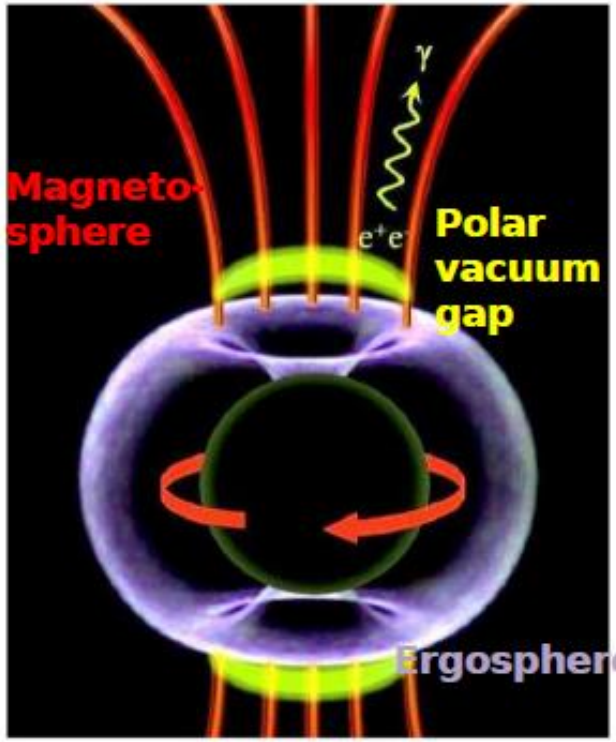


First lensed TeV blazar

Lightening of a black hole: IC 310

- Viewing angle 10° ≤ θ ≤ 20° (EVN Image)
  - Not a blazar, no strong Doppler Boost
- TeV Variability < 4mn (MAGIC)
  - Emission region constrained to < 0.2δRG
- Huge optical depth for γ-γ pair production due to small Doppler boost
  → inconsistent with shock-in-jet model
- Magnetospheric model similar to pulsar models (e.g. Levinson & Rieger, 2011)
  - Acceleration of particles close to black hole in vacuum gaps
  - hard γ-ray spectrum due to electromagnetic cascading



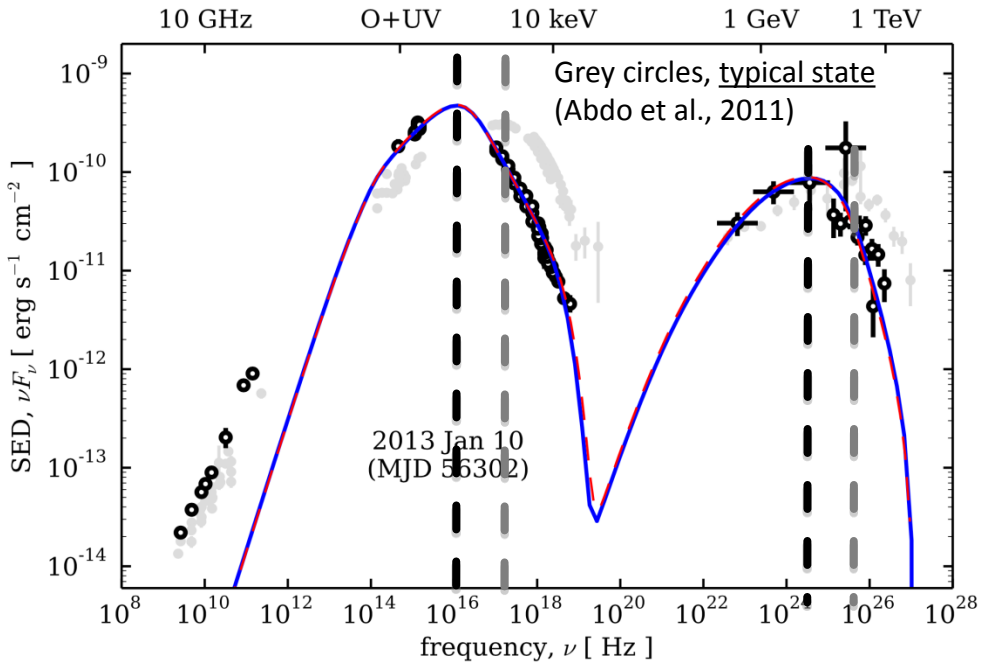


First object of this type!

Extensive MWL campaigns on Mrk421

- Mrk421 and Mrk501 : “easiest” blazars: nearby, bright at all energy bands and no broad line region effects
- More than 25 instruments participate, from radio to VHE
  - Regular observations by MAGIC and VERITAS
  - Monitoring regardless of activity, also in “low states”
- Peculiar flare (January 2013):
  - Synchrotron and IC peak shifted to ~ 10 times lower energies
  - Never seen before for any blazar
  - “HBL moving towards IBL”
  - Low activity softened the X-ray and VHE spectra, but did not show spectral cutoffs

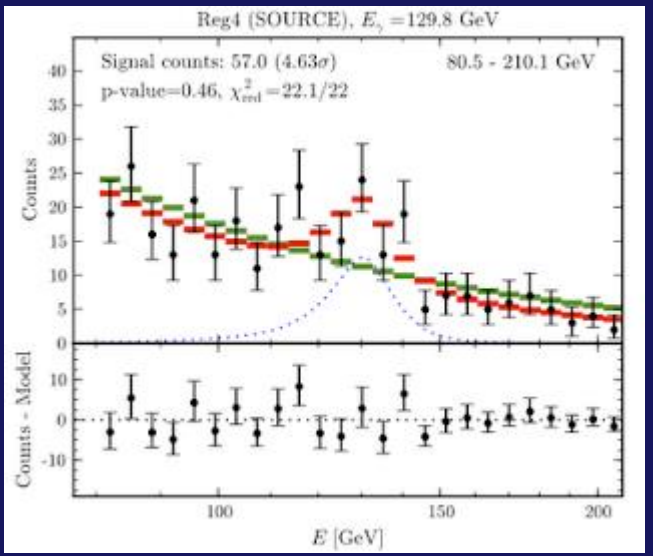
SED of Mrk421 in January 10, 2013



Noda: GA 12

Mirzoyan: GA07

Astroparticles

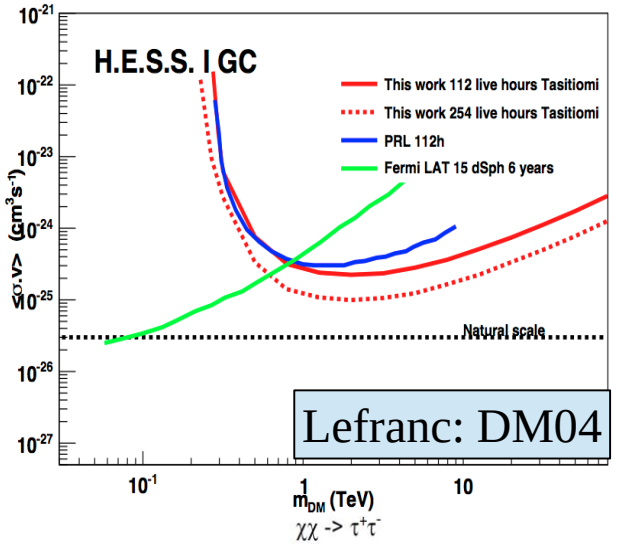


Dark Matter Searches

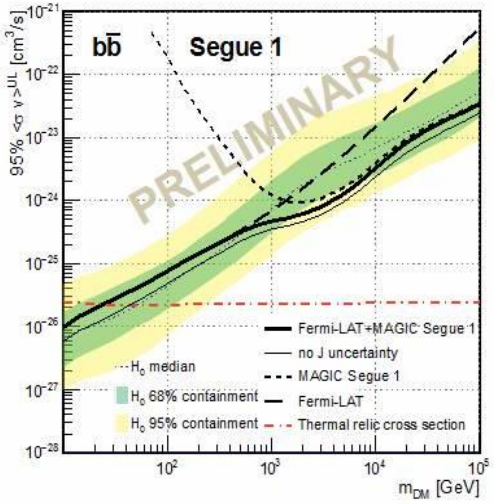
- Current target:
  - Galactic Centre Halo (H.E.S.S.)
  - Dwarf spheroidals
- Strategies
  - Deep observations (≥200 h)
  - Optimal statistical treatments
  - Search for annihilation lines
  - MAGIC: Combination with Fermi-LAT

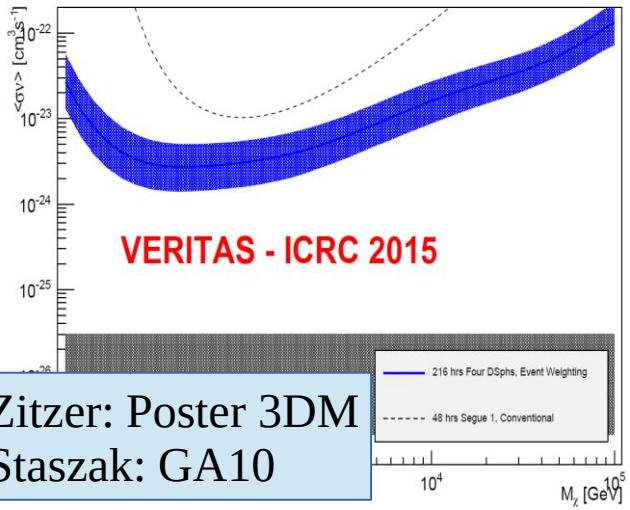
Kieffer: GA05

- Next step: combine results from H.E.S.S., MAGIC, VERITAS & Fermi-LAT

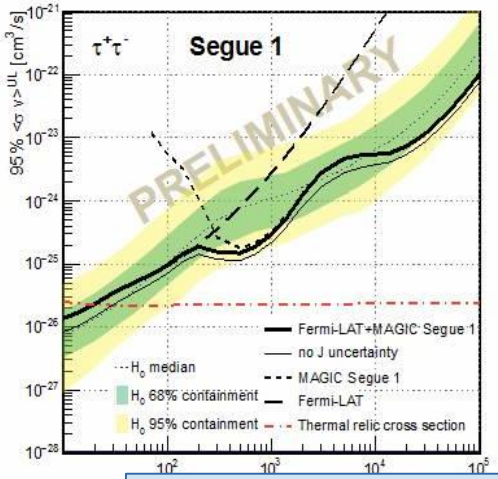


Lefranc: DM04





Zitzer: Poster 3DM
Staszak: GA10



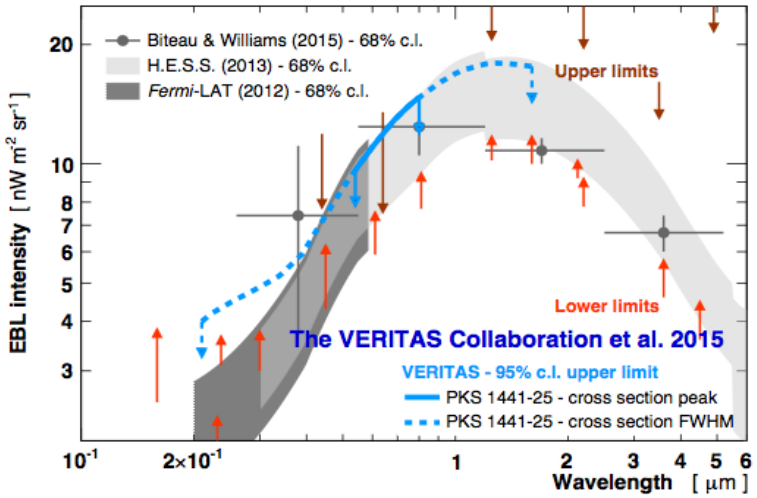
Wood: Poster DM04

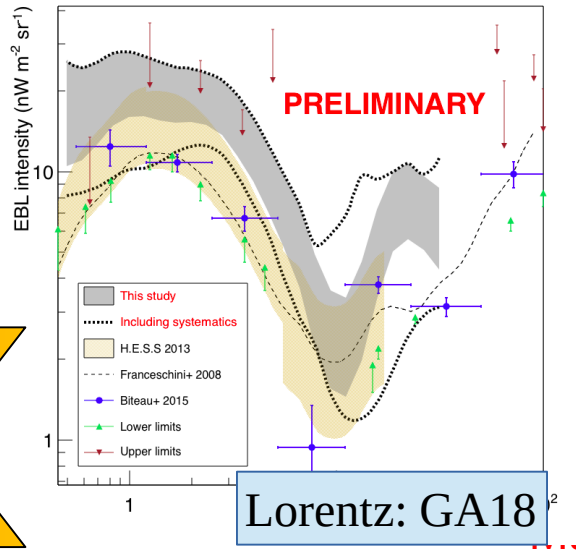
Most constraining limits

EBL constrains

- Absorption of VHE γ-rays by pair creation on EBL/CMB
- Achievable Constrains:
  - Single sources at large distance provide upper limits
    - PKS 1441-25 (VERITAS & MAGIC)
    - 1ES 1101+496 (MAGIC)
  - Measurement of several sources at different distances allow to measure the EBL (HESS)

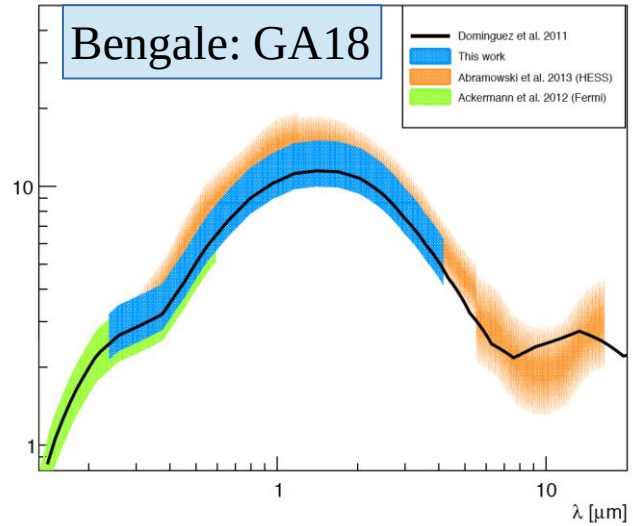
Benbow: GA10





Lorentz: GA18

Bengale: GA18



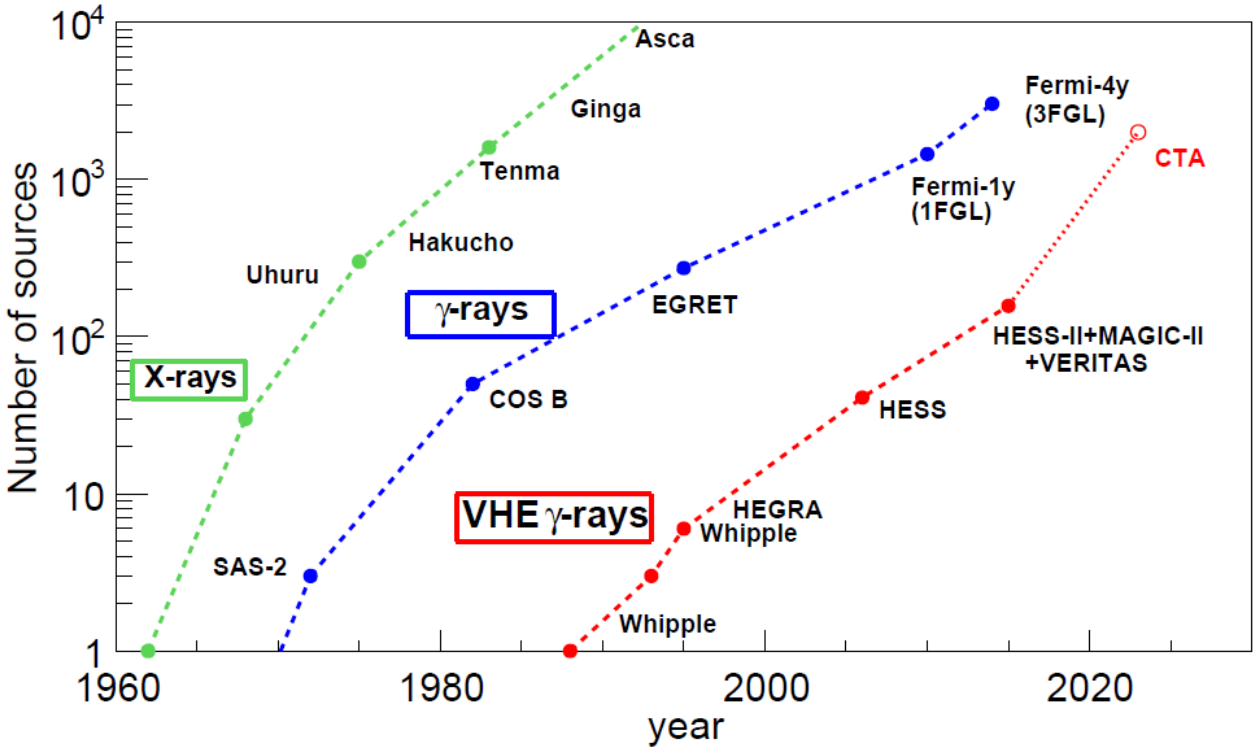
First actual measurement of EBL

Conclusions

- Many NEW results presented in the next days – attend the sessions!
- VHE astronomy is experiencing a phase transition: key science projects, requiring deep (>100 h) exposure

Fishing-in-the dark time is over, precision measurement era is starting

"Kifune" plot 2015



Backup