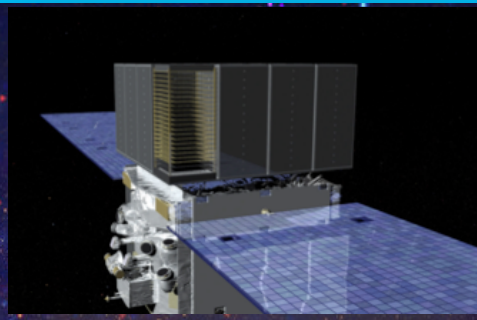
Overview of γ-ray related activities

Recent highlights and a glimpse into the future

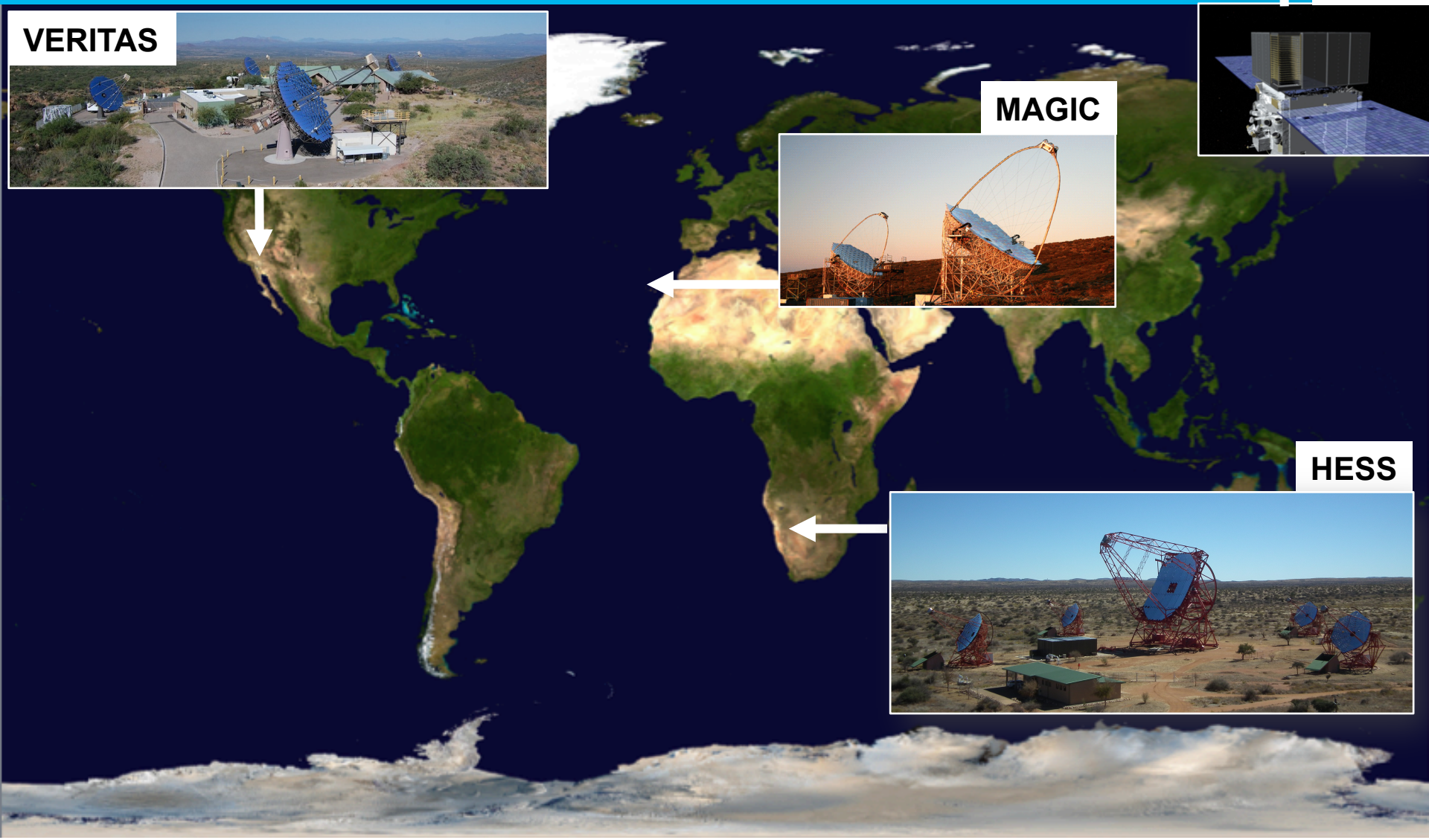


NASA/JPL-Caltech/ESA/CXC/STScI

Stefan Ohm (DESY, Zeuthen)

HAP workshop, Erlangen, 21/09/2016

Major instruments for the detection of γ rays (2011)

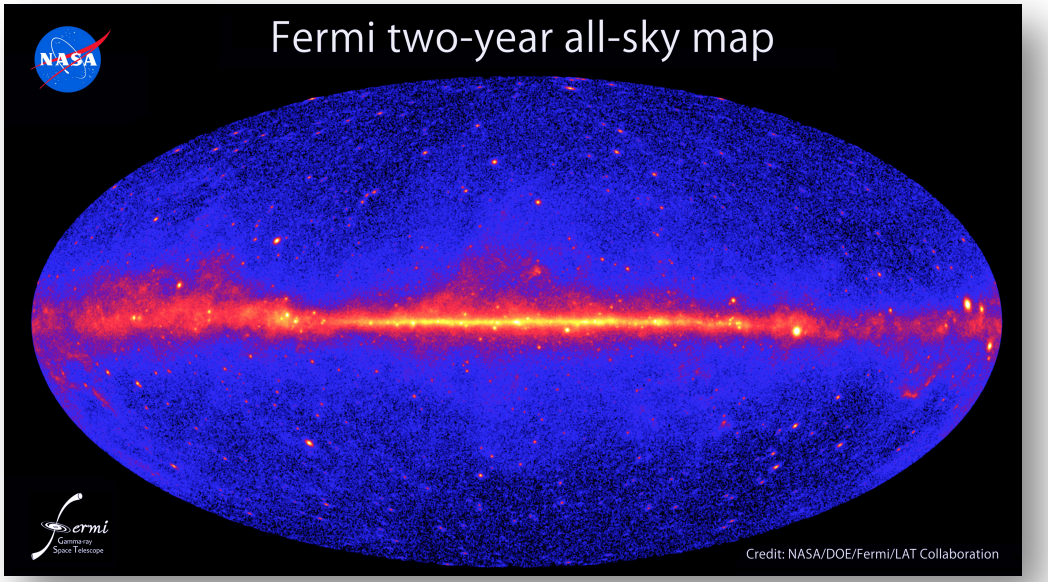


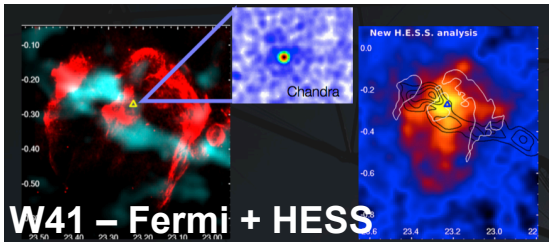
The γ-ray sky in 2011 (at the ICRC in Beijing)

Fermi-LAT

> Highlights

- Catalogues (2FGL, AGN)
- New source classes (e.g. Novae, Globular clusters, Starburst galaxies)
- Large γ-ray PSR population
- Crab flares
- High-energy GRBs



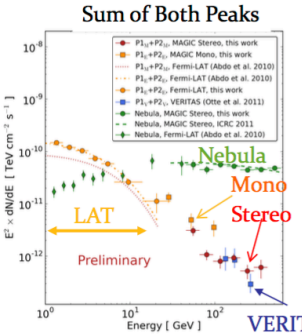


IACTs

> Highlights

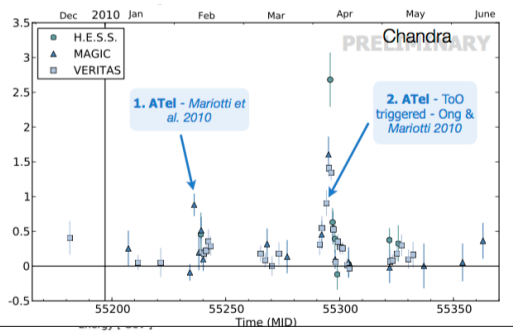
- Source populations increase (e.g. AGN, SNRs, PWNe)
- Detailed source analysis including MWL information
- Extragalactic background light measurements
- Crab pulsation up to 400 GeV (MAGIC)
- IACT cooperations increase (binaries, radio galaxies)

Crab – MAGIC

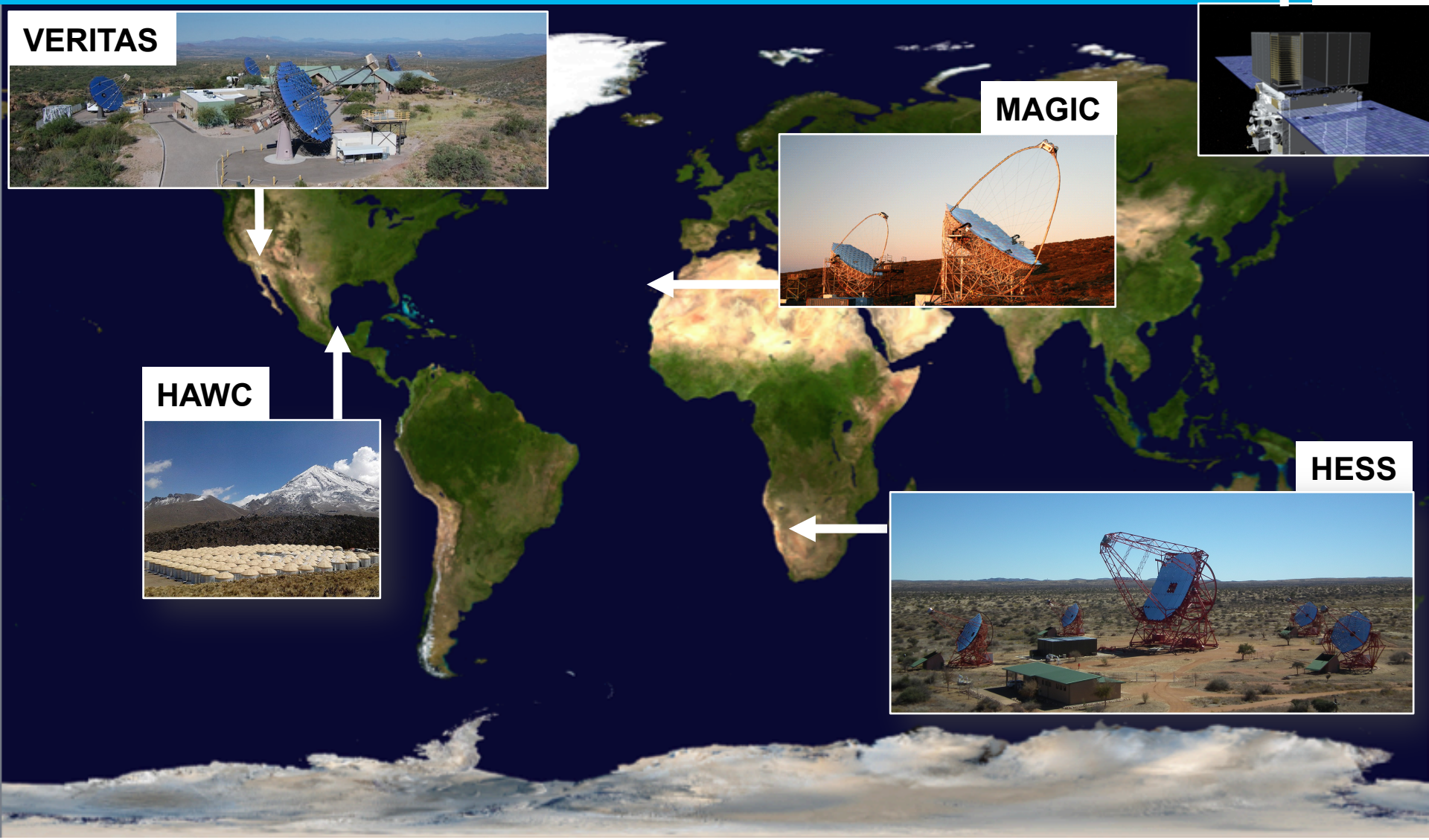


VERITAS (McCann et al, this conf)

M87 – all IACTs

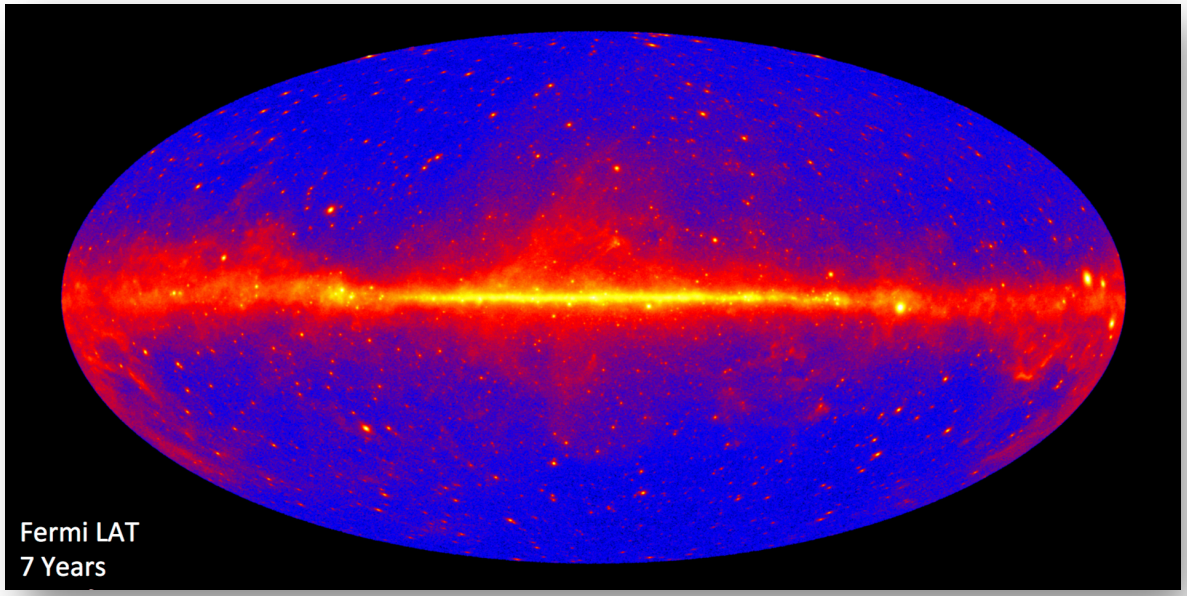


Major instruments for the detection of γ rays (2016)



The γ-ray sky in 2016 (at the Gamma in Heidelberg)

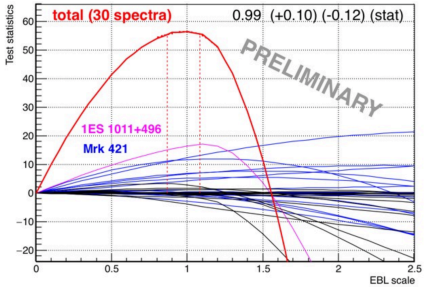
Fermi-LAT



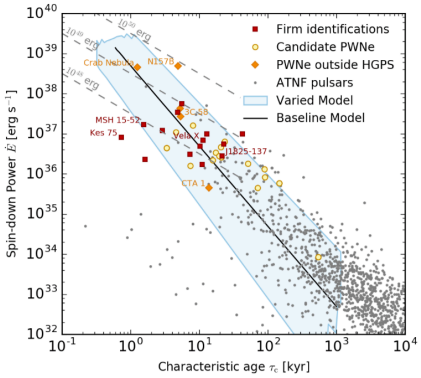
> Highlights

- More catalogues (3FGL, 3FHL, 1FIG)
- Transient monitoring, rapid variability, multi-messenger searches
- Fermi triggering IACTs
- Galactic Centre (line, excess)
- Fornax A, LMC, high-z AGN (EBL)

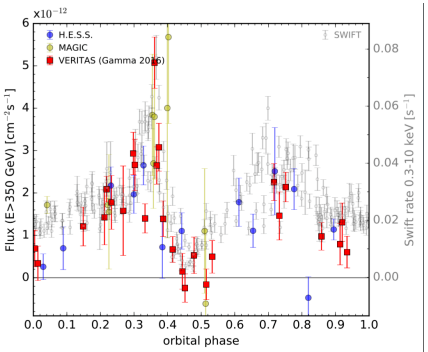
EBL – MAGIC



PWNpop – HESS



HESS J0632 – all IACTs



IACTs

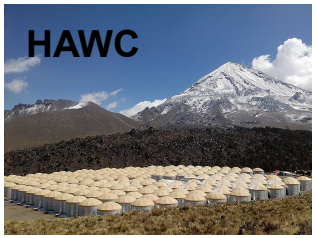
> Highlights

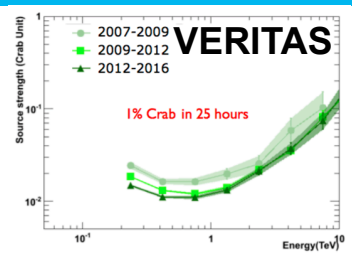
- More sources
- Better measurements of existing sources
- More multi-messenger and multi-wavelength studies
- Regular IACT cooperations (+ HAWC)

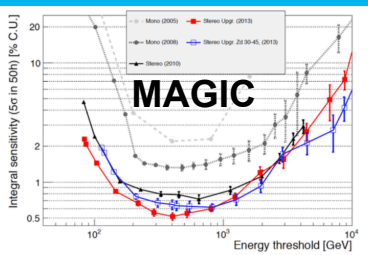
Evolution of the field: Instruments and Analysis

> Instruments

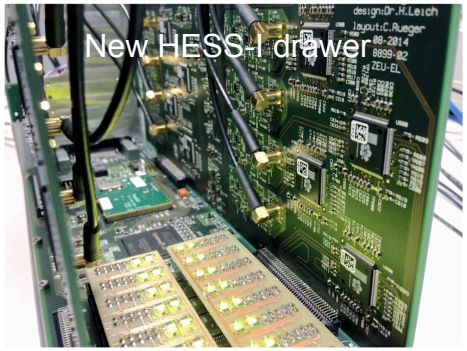
- New instruments (HAWC)
- New telescopes (MAGIC-II, HESS-II)
- New hardware (VERITAS PMT, and HESS-I camera upgrade)
- New trigger and readout schemes








New VERITAS PMTs



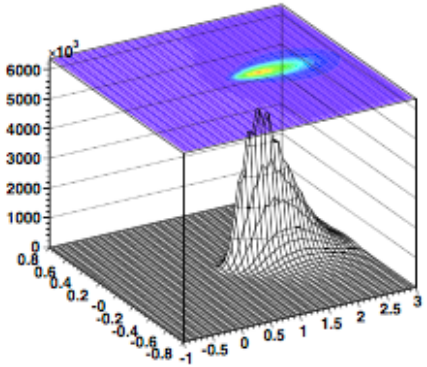
> Analysis

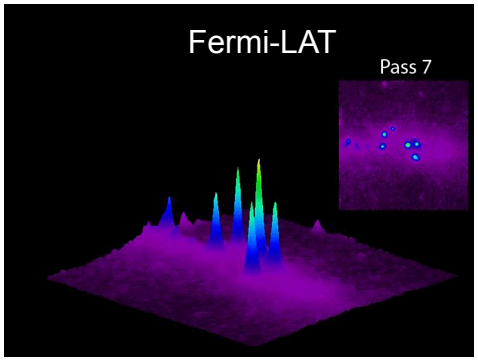
- Improvements on all fronts

→ up to factor ~2 in sensitivity

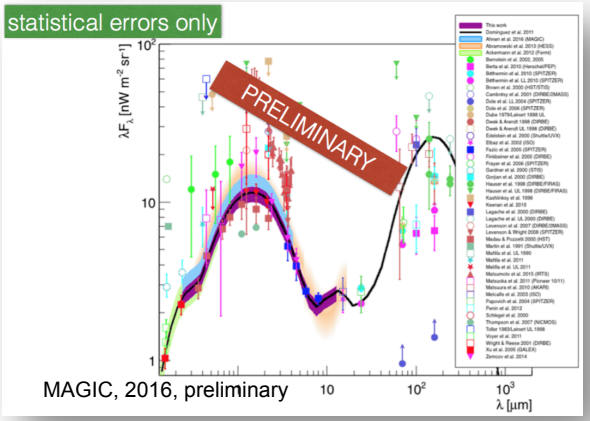
- Pushing to lower and higher energies
- Operation at the sensitivity limit

→ Systematics becomes more of an issue


de Naurois & Rolland



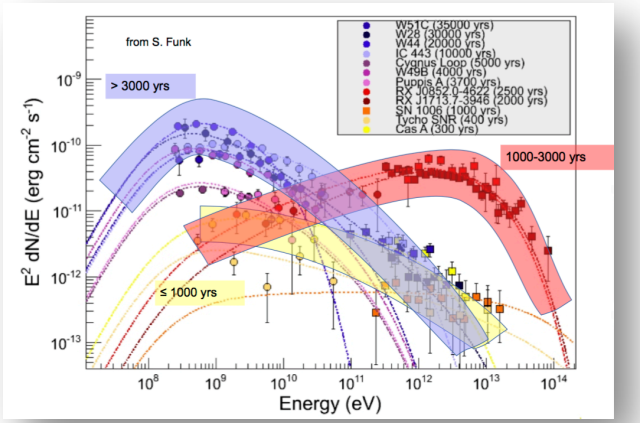
Evolution of the field: Observation strategies



Key science

Deep exposures

Precision measurements



Surveys

Population studies

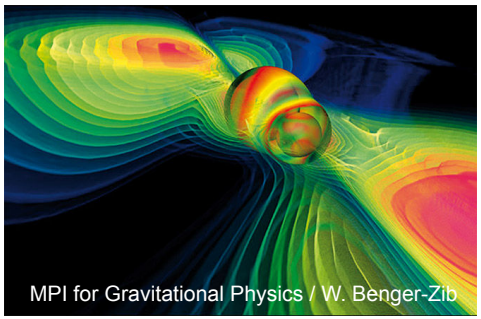
Initial discoveries
(first years of operation)

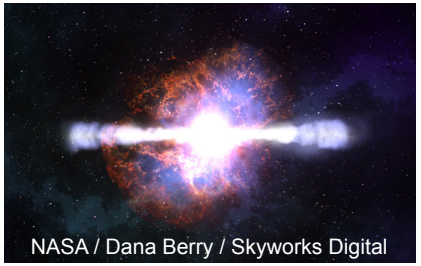
Time-domain

Transients

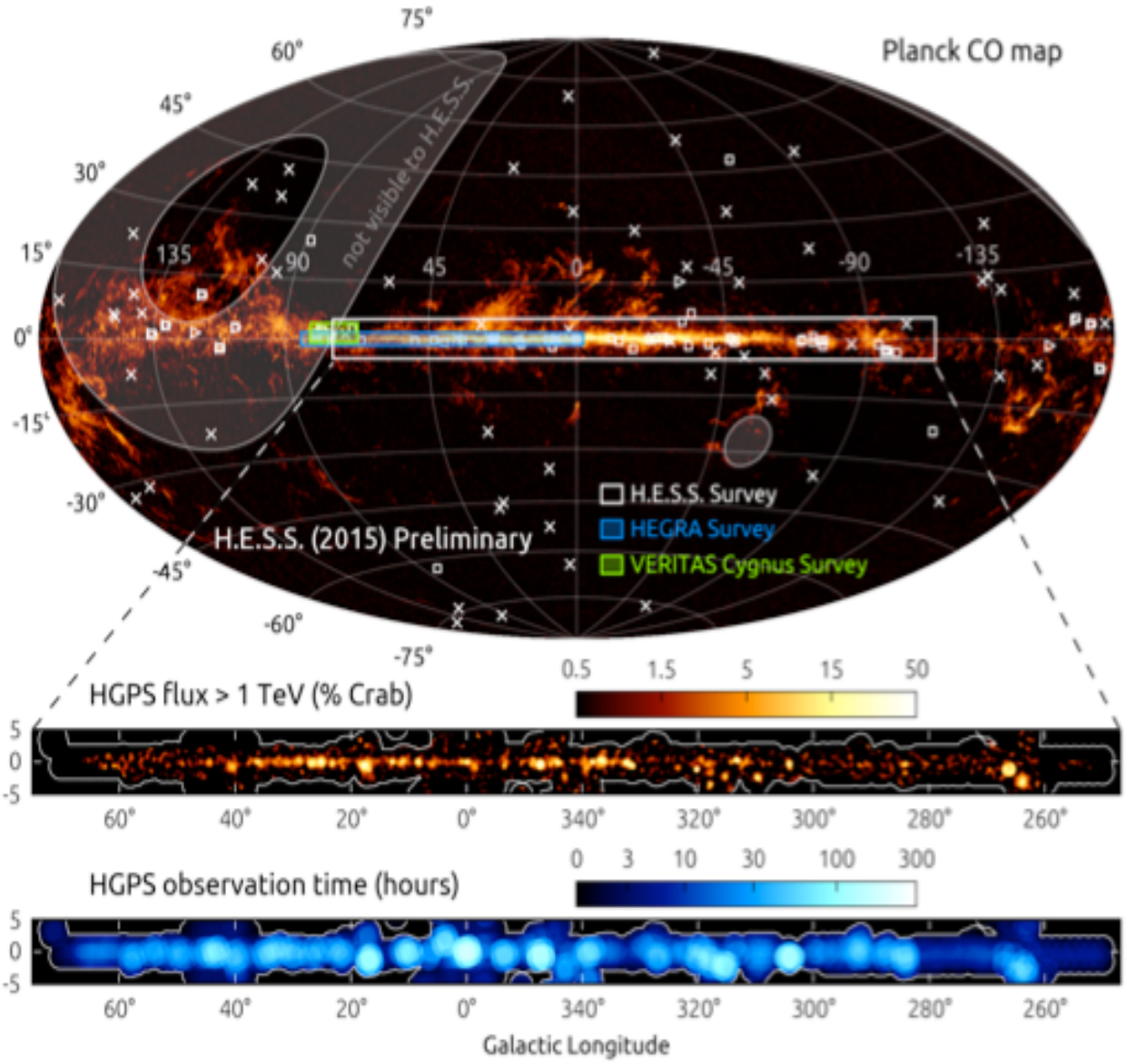
Multi-messenger

Multi-wavelength



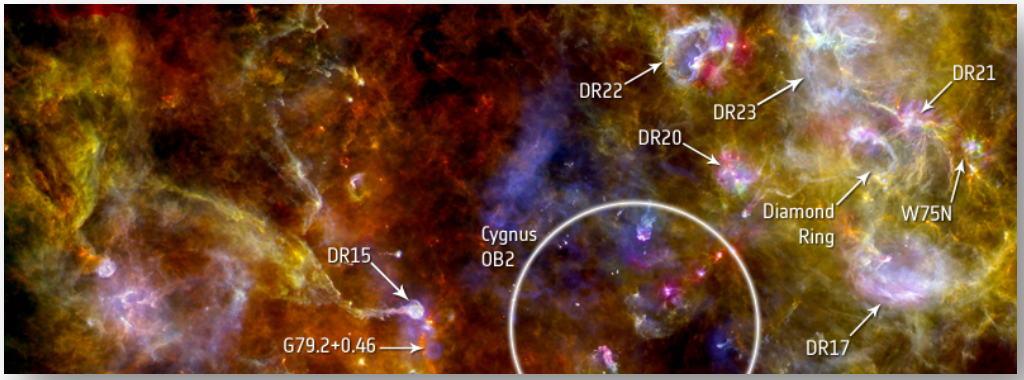


Surveys: The H.E.S.S. Galactic Plane Survey

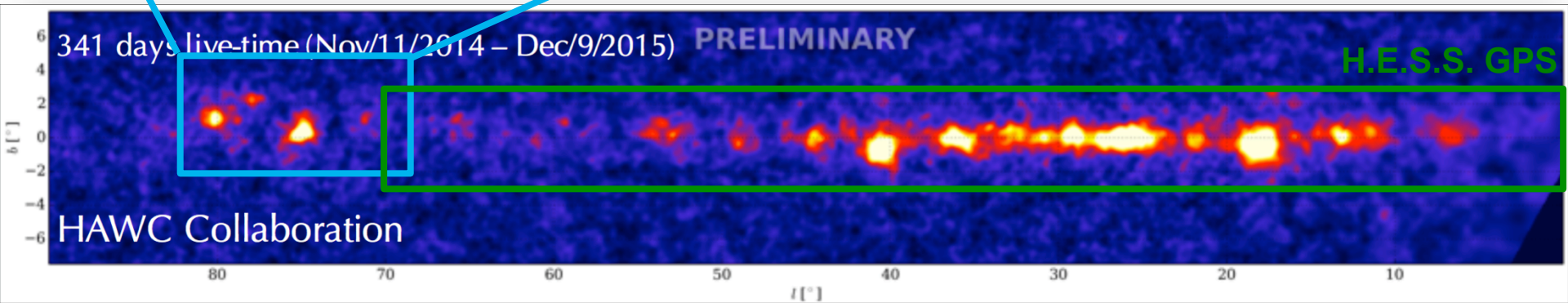


- 10-year survey
- 78 VHE sources
- Many objects extended
- Publication in preparation
- Data release to the public in the form of maps

Surveys: The northern hemisphere (Cygnus)

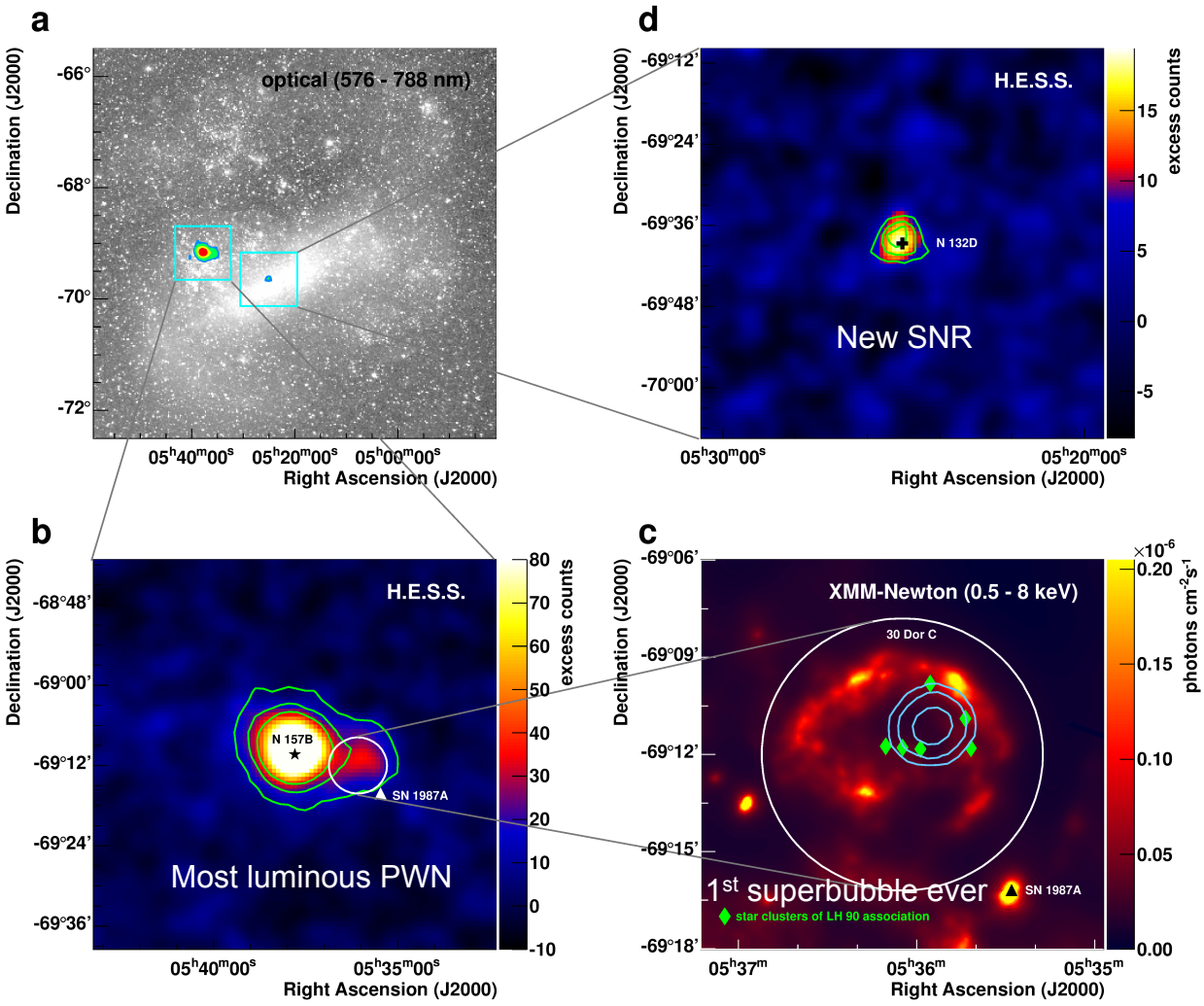


- HAWC perfect for surveys
  - ~95% duty cycle, ~2 sr FoV
- Cygnus region
  - close, massive star-forming region
  - full of potential particle accelerators
  - very complex region
- VERITAS Cygnus survey
  - Deep observations (>300 hrs)
  - Reveals PWNe and SNR
  - No emission from Cygnus cocoon
  - MWL studies underway



Surveys: Large Magellanic Cloud

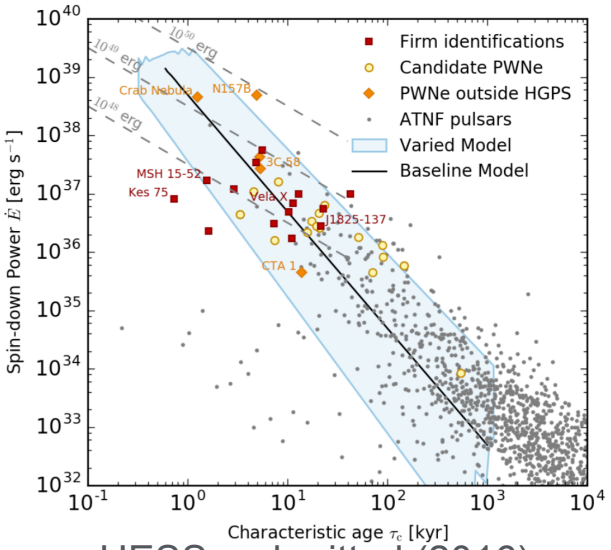
- 1st extragalactic detection of stellar-type objects at VHE
  - Independent probe of Galactic accelerators
  - Extreme environment (SFR, radiation fields, CR densities)
- New TeV source class discovery: superbubble 30 DorC
- VHE survey continues
- Also Fermi finds stellar-type objects in LMC:
  - PSR
  - PWN
  - SNR
  - γ-ray binary
  - + diffuse emission



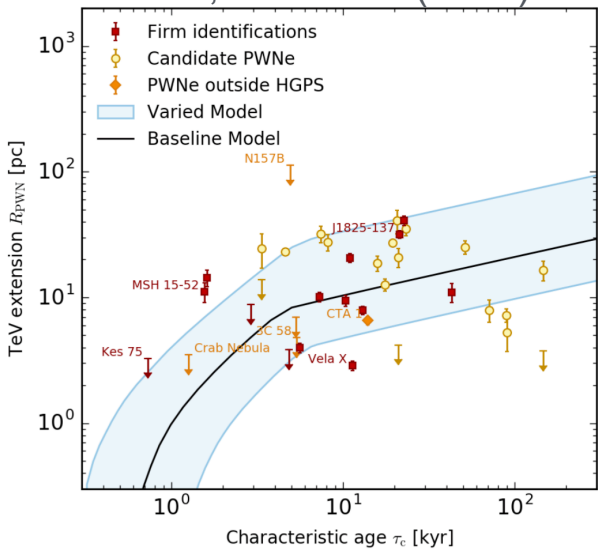
H.E.S.S., Science 2015

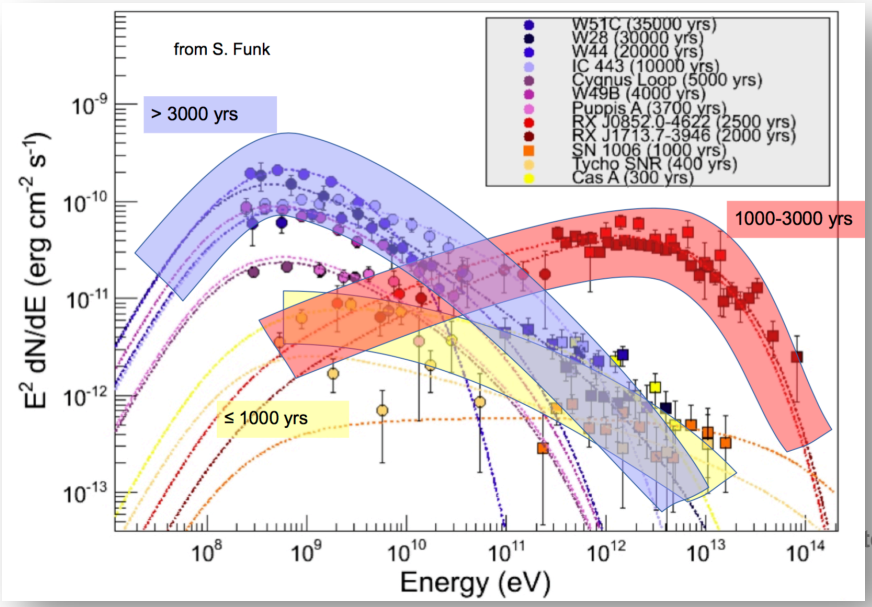
Population studies: PWNe and SNRs

- PWNe population to study
  - particle properties
  - PWN evolution (e.g. B-fields, NT particles)
  - importance of environment
- Spectra of γ-ray SNRs probe
  - ambient medium
  - particle acceleration, interaction and escape
  - underlying particle population



HESS, submitted (2016)

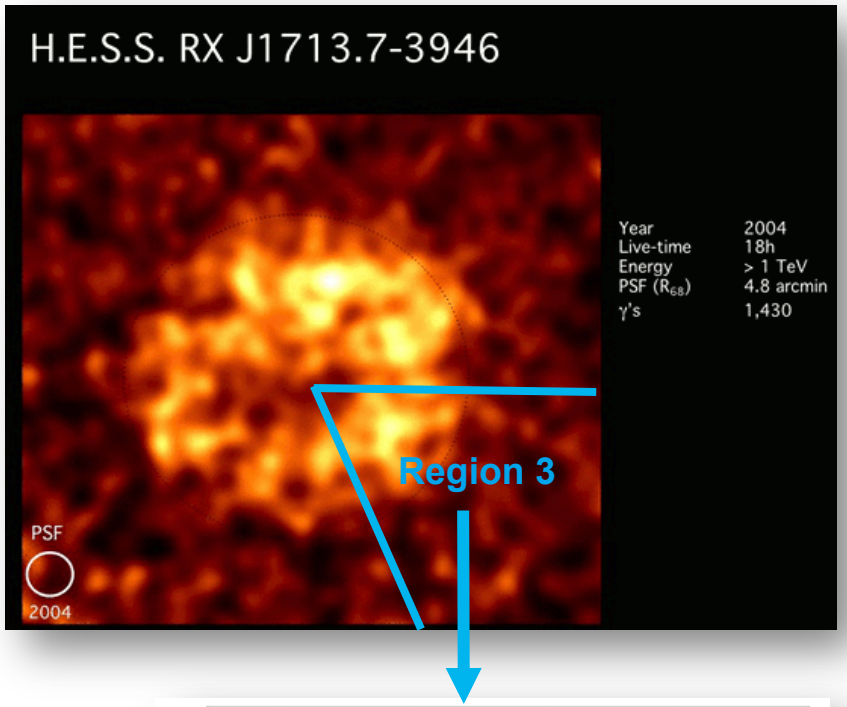


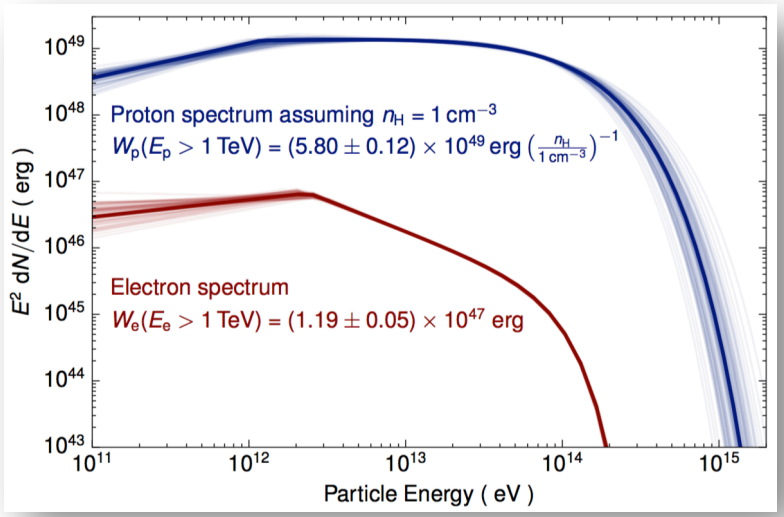


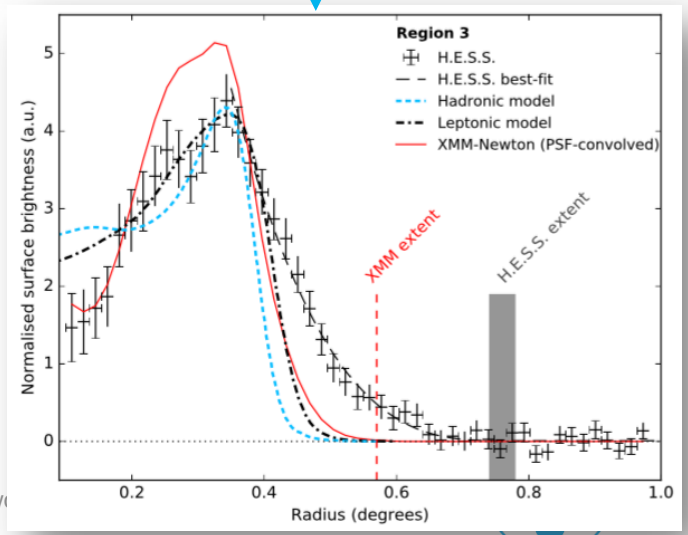
Precision Measurements: Young SNRs

- RX J1713-3946
  - ~2000 yr old SNR
  - One of the most important sources at VHE
  - first resolved shell of a SNR in γ rays (2005)
- By now (Abdallah et al., 2016 subm.)
  - More data, much more sensitive analyses
  - Probing particle properties (B-fields, E_{max})
  - TeV shell more extended than X-ray shell

→ Prove of particles leaving the shock region!

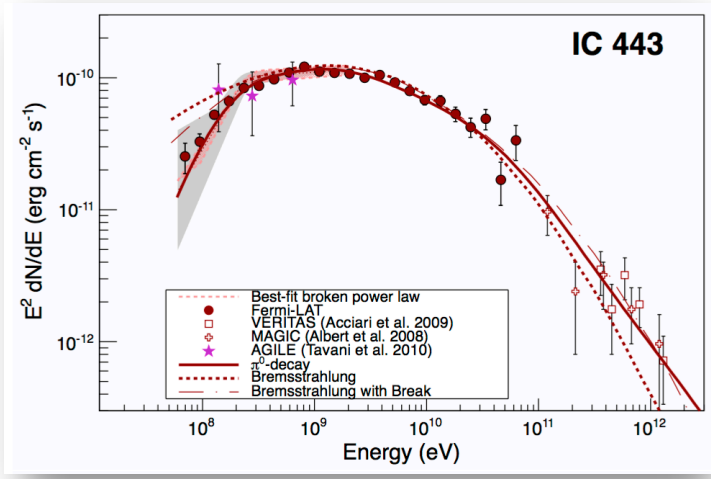


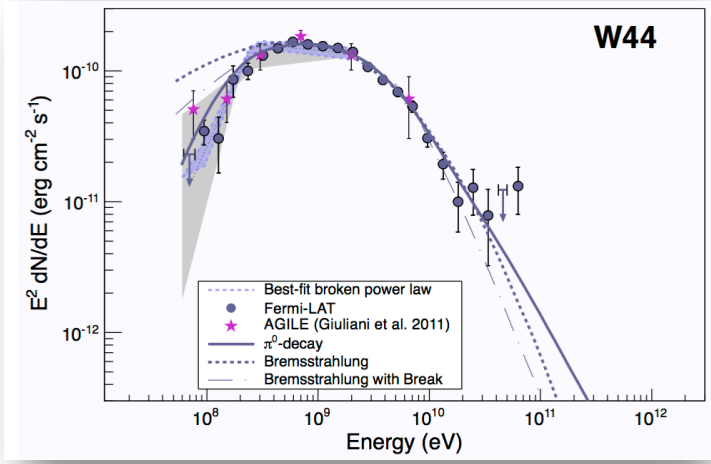


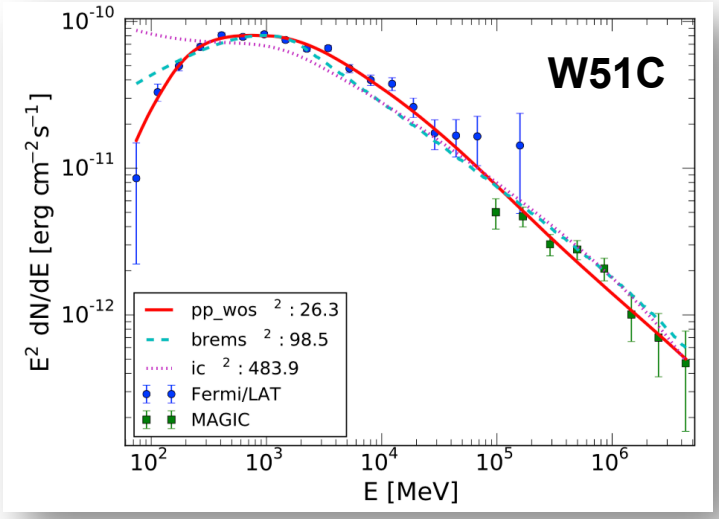


Precision Measurements: Middle-aged SNRs

- Origin of Galactic CRs
  - Characteristic π^0-decay cutoff seen in IC 443 and W44
  - Hard to detect in VHE γ rays
  - Prove of proton acceleration to high energies in SNRs
- W51C (Jogler & Funk 2016)
  - ~30kyr old SNR interacting with molecular cloud
  - Break at ~300 MeV indicative of π^0-decay
  - Connection between Fermi and MAGIC hints at single particle population (i.e. protons)

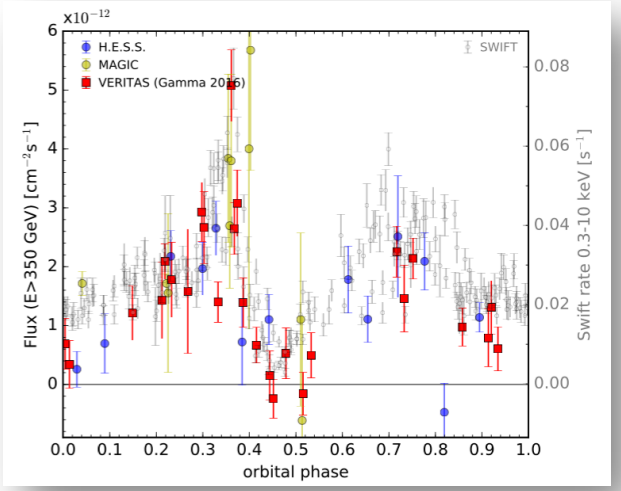




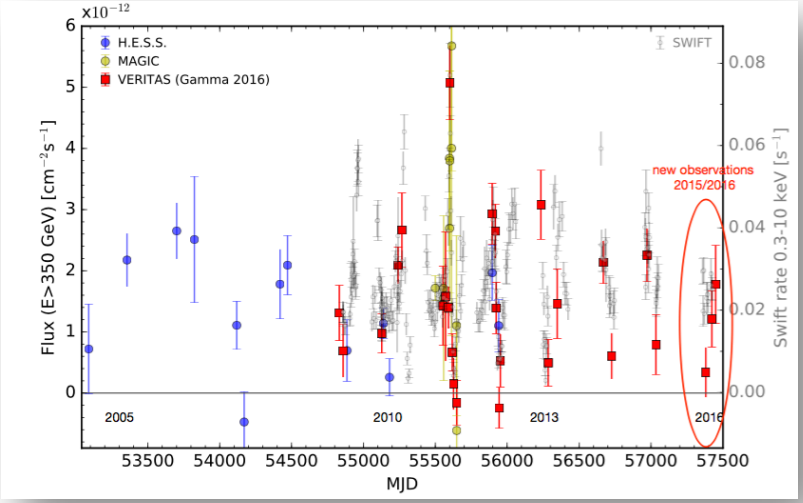


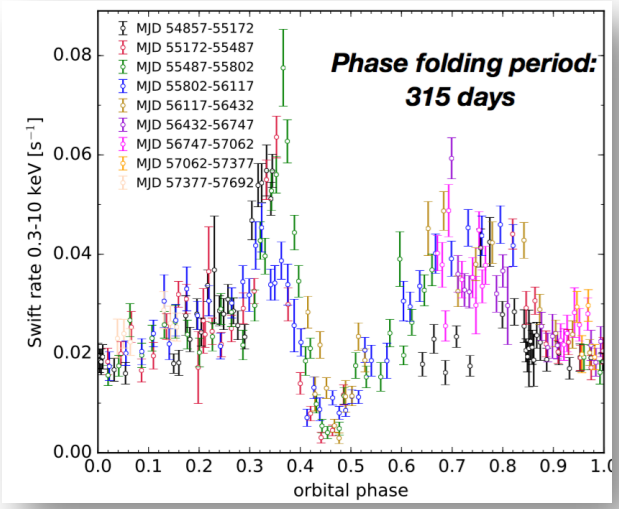
Long-term monitoring: γ-ray binary HESS J0632+057

- HESS J0632+057
  - γ-ray binary (massive star + compact object)
  - nearby (1.1 – 1.7 kpc), eccentric (e ~ 0.8) system in 315-day orbit
- More than 10 years of IACT observations
- Search for (intra-)orbit variability and study of particle acceleration and interaction in extreme environment



Schlenstedt, Maier (VERITAS), 2016

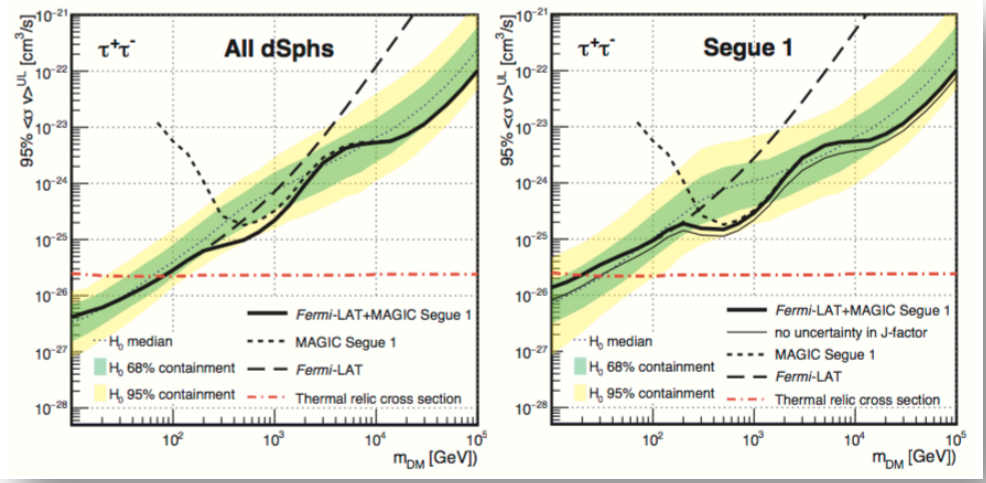




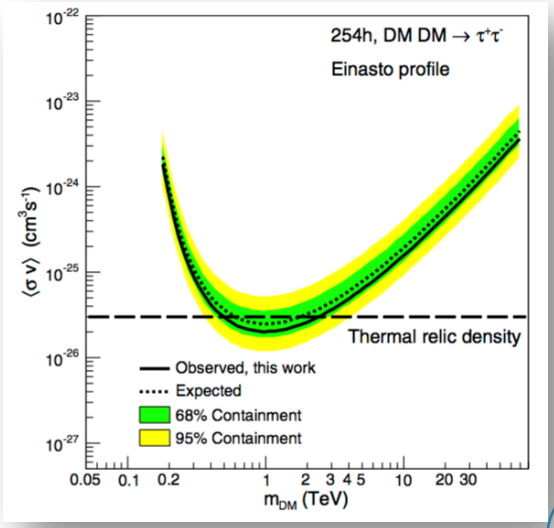
Fundamental physics: Dark Matter searches

- Ongoing efforts to search for DM in dwarf galaxies, Galactic Centre, Galaxy clusters
- Different approaches
  - Stacking, Combination of data sets
  - New likelihood techniques
- Examples
  - Fermi-LAT + MAGIC observations of Segue 1 dwarf → improve in overlap region between instruments
  - A decade of HESS Galactic Centre observations → First time probing thermal relic cross section

Fermi-LAT stacking + MAGIC (Ahnen et al. (JCAP, 2016) 039



HESS, (Abdallah et al., PRL, 117, 111301)



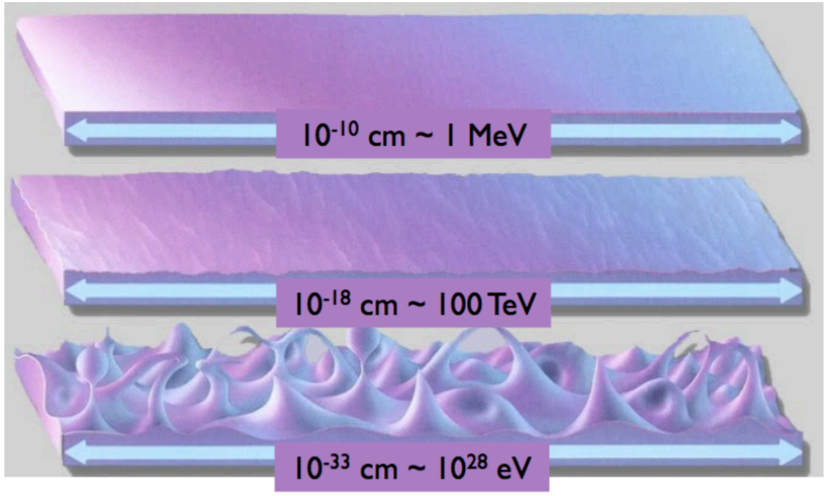
Fundamental physics: Lorentz Invariance Violation (LIV)

> Quantum structure of space-time can produce **energy dependence of speed of light:**

$$v = c\left(1 \pm \xi\left(\frac{E}{M_P}\right) \pm \zeta\left(\frac{E}{M_P}\right)^2 \pm \ldots\right)$$

- Access to Planck scale via large distances and/or high energies
- GRBs, AGN flares or PSRs provide good test-bed
- Different objects probe different phase space

Source family	d [pc]	E [GeV]	δt [s]	Expected limits E_{QG1} [GeV]	E_{QG2} [GeV]
GRB	10^{10}	10^{1}	$10^{0} - 10^{2}$	$10^{17} - 10^{19}$	$10^{9} - 10^{10}$
AGN	10^{8}	10^{4}	$10^{2} - 10^{5}$	$10^{15} - 10^{18}$	$10^{9} - 10^{11}$
Pulsar	10^{3}	10^{2}	$10^{-4} - 10^{-2}$	$10^{17} - 10^{19}$	$10^{10} - 10^{11}$



> Global efforts

- MAGIC, VERITAS and HESS are teaming up for global LIV search

→ Improve sensitivity, combine different source types, reduce systematics

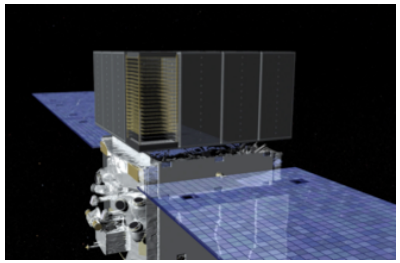
- Agreement signed by all parties, groups established, work started

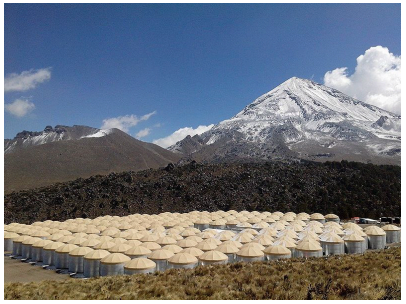
J. Rico, (MAGIC), Gamma2016

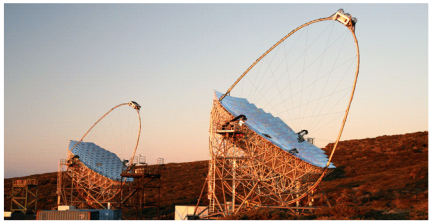
The future: Time domain and multi-messenger prospects

- Importance of the time domain
  - ~20% of Fermi 3FGL sources variable (+ GRBs, short transients, novae, periodic sources)
  - Transient sources are among the ones with the highest scientific impact
- Compact objects and physics under the most extreme conditions in the universe
  - Crab flares probe particle acceleration mechanisms
  - GRBs and AGN flares probe fundamental physics (e.g. LIV)
  - AGN flares probe emission site, probe cosmology and star-formation history
- Origin of astrophysical neutrinos (steady vs. flaring sources)
- Electromagnetic counterparts to gravitational wave events (e.g. GRBs)
- (Not to forget UHECRs that probe the very local universe)

The future: Time domain and multi-messenger prospects







- >90% duty cycle
- ~half-sky
- ~1 – 100 deg ang. res.
- ~10 triggers per year

- >90% duty cycle
- ~half-sky
- ~0.1 – 10 deg ang. res.
- modest sensitivity

- ~15% duty cycle
- ~5 deg FoV
- ~0.1 deg ang. res.
- excellent sensitivity

→ Communication, event filtering and fast response are key!

Summary and Outlook

- γ-ray astronomy made a huge leap forward in the past decade
- Shift from initial source discoveries to key science
  - Deep exposures, precision measurements, surveys, catalogues, population studies
  - Reaching the limits for current instruments in core energy range (for steady sources)
  - Still room for improvements at high energies (recent PeVatron discovery)
  - new instruments (e.g. TAIGA) operating at high energies being commissioned
- Multi-messenger and time-domain astroparticle physics era started
  - Communication is key
  - Next decade will see explosion of triggers (optical surveys, radio, etc.)
- Next generation CTA for ground-based γ-ray astronomy on the horizon