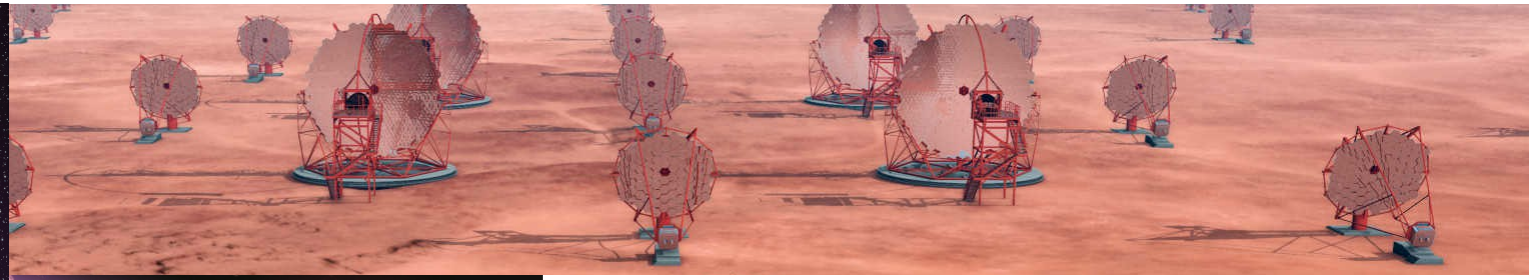
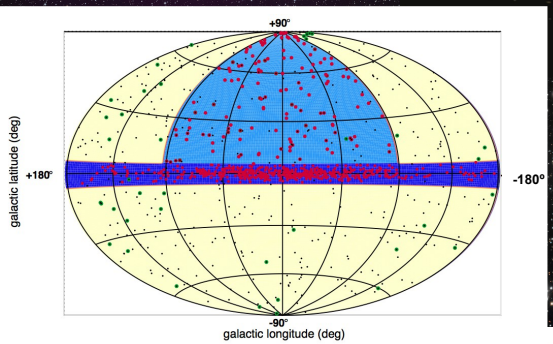
Extragalactic Science with CTA

Key Science Projects





Lucie Gérard
for the CTA Consortium

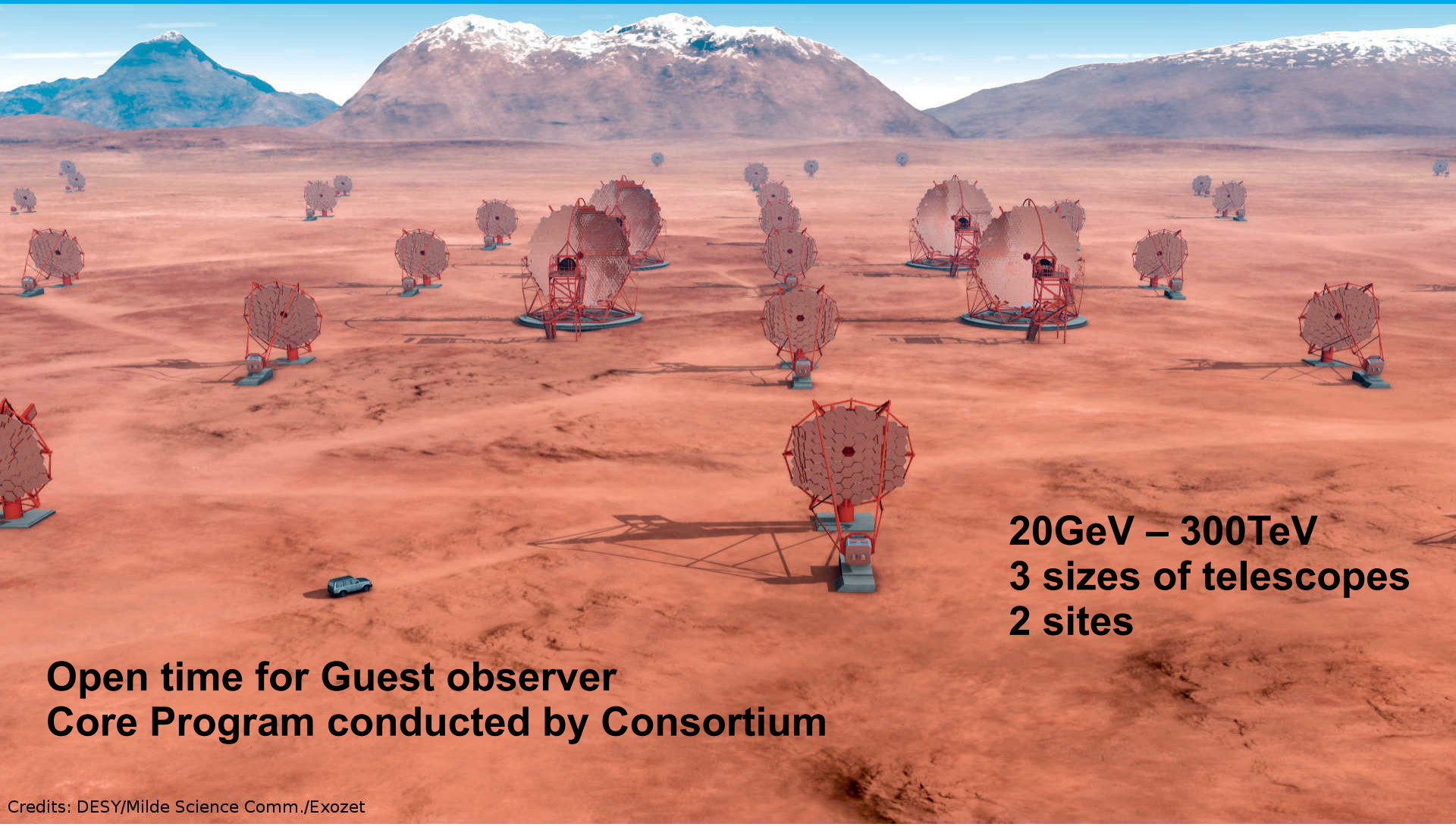
16-12-2015

HELMHOLTZ ASSOCIATION

cta cherenkov telescope array

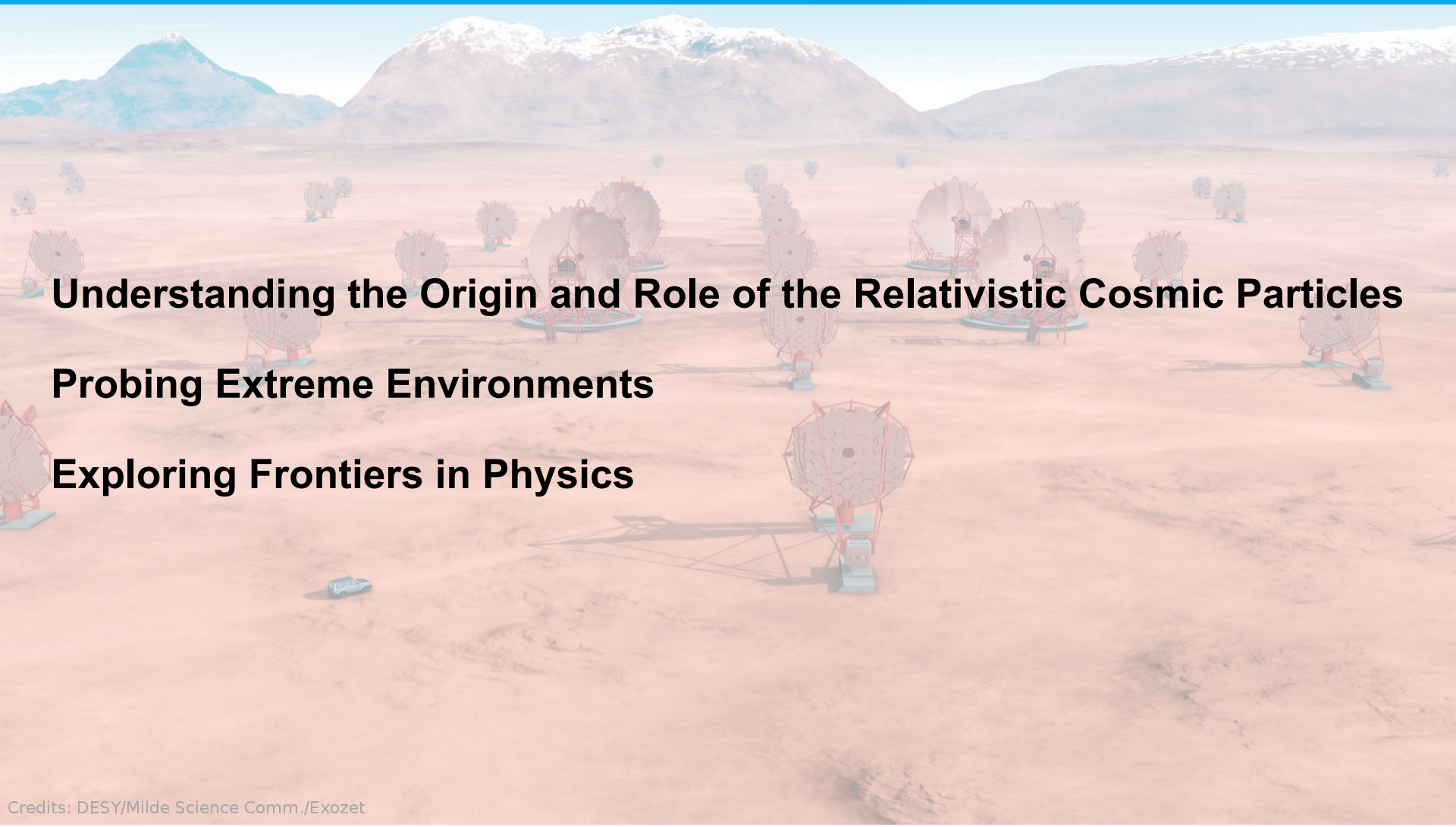
DESY

CTA: Very High Energy Gamma-Ray Observatory



See Michael Daniel's Talk: Thursday 14:00 (Session 20)

CTA Science Themes



Understanding the Origin and Role of the Relativistic Cosmic Particles

Probing Extreme Environments

Exploring Frontiers in Physics

Credits: DESY/Milde Science Comm./Exozet

CTA Key Science Projects

Extragalactic KSPs

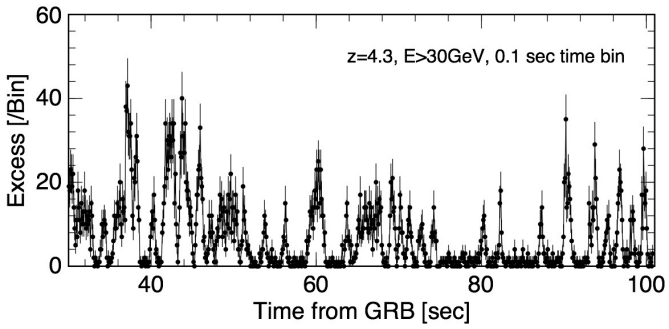
Theme		Question	Dark Matter Programme	Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra-galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔✔
	1.2	What are the mechanisms for cosmic particle acceleration?		✔	✔	✔		✔✔	✔✔	✔	✔✔	✔
	1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔		✔				✔✔	✔	✔
Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		✔	✔	✔			✔✔		✔✔	
	2.2	What are the characteristics of relativistic jets, winds and explosions?		✔	✔	✔	✔	✔✔	✔✔		✔✔	
	2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔	✔			✔✔	
Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔		✔						✔
	3.2	Are there quantum gravitational effects on photon propagation?						✔✔	✔		✔✔	
	3.3	Do Axion-like particles exist?					✔	✔			✔✔	

See talks from E. Moulin for DM project and Th. Stolarczyk for Galactic science

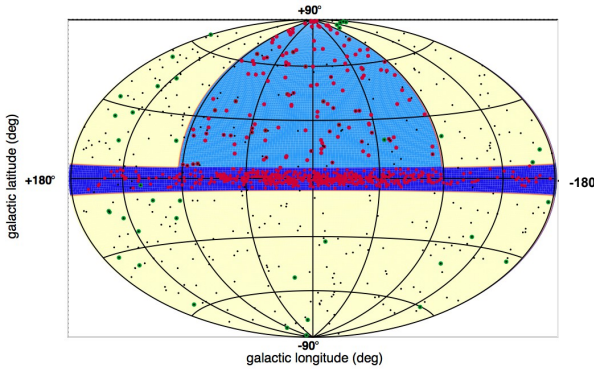
DESY

Extragalactic Key Science Projects

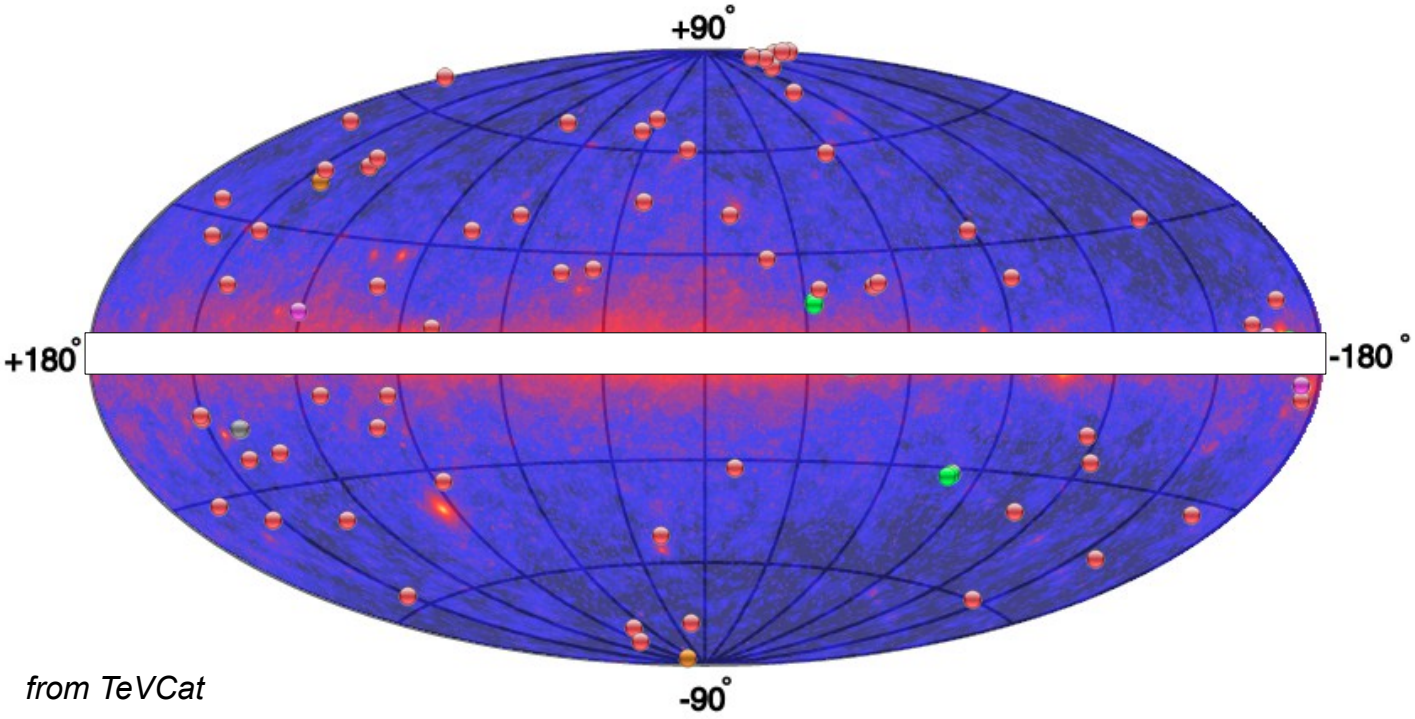
- **Targeted Observations**
  - **Active galactic nuclei**: VHE physic of AGN, cosmology, UHECRs, fundamental physic.
  - **Transients**: follow up on GRBs and extragalactic transients
  - **Galaxy clusters**: deep observation to probe cosmic rays in clusters
- **Extragalactic Survey**
  - **Unbiased survey of ¼ of the extra-galactic sky**: for population study and duty cycle, new and unknown sources.



Simulation *Inoue et al. 2013* (APh 43,252)



VHE extragalactic sky as of today



from TeVCat

- 67 sources. Strongly biased (most observations motivated by flux level at other wavebands)
- Mostly blazars, 4 radio galaxies, 5 FSRQs, 2 star burst galaxies

Active Galactic Nuclei KSP

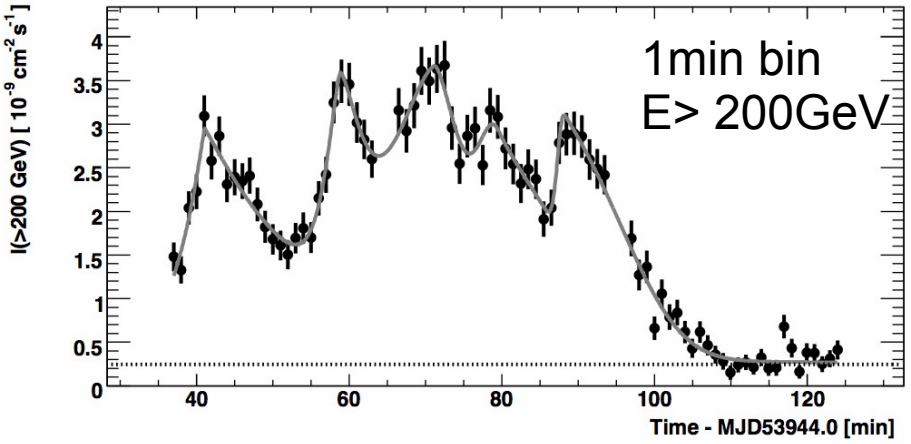
- What are the relevant particle acceleration and emission processes?
- How are the different blazar types related?
- What causes the observed variability?
- Where does the VHE emission from radio-galaxies come from?
- Is there other classes of AGNs emitting gamma-rays?
- What is the spectrum of the EBL and how does it evolves with redshift?
- What is the strength of the IGMF?
- Are AGNs a source of UHECRs?
- What can we say about Lorentz invariance violation?

Active Galactic Nuclei KSP: Variability

- Long term variation:
  - Duty cycle?
  - Quasi periodicity? ✳
  - Break in the power spectra?
- Short term variation:
  - Size, location and nature of the emission region?
  - Acceleration and cooling mechanisms?

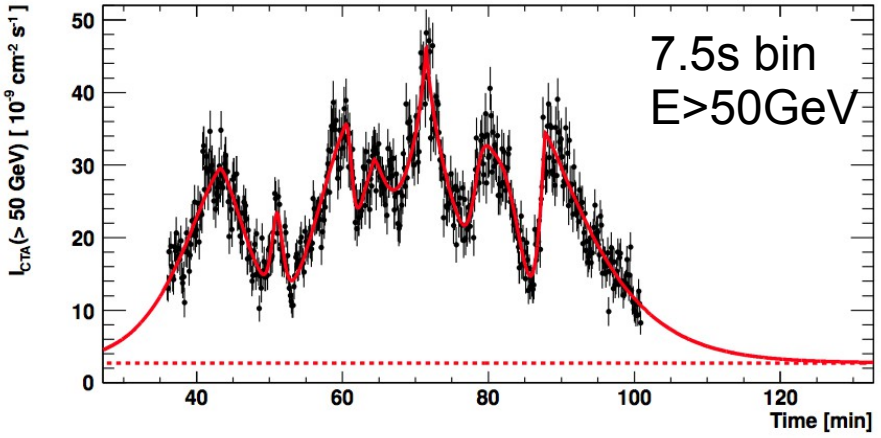
Flare of blazar PKS 2155-304 (2006)

H.E.S.S. data



Aharonian et al. 2007 (ApJ 664L 71A)

Simulated CTA observations



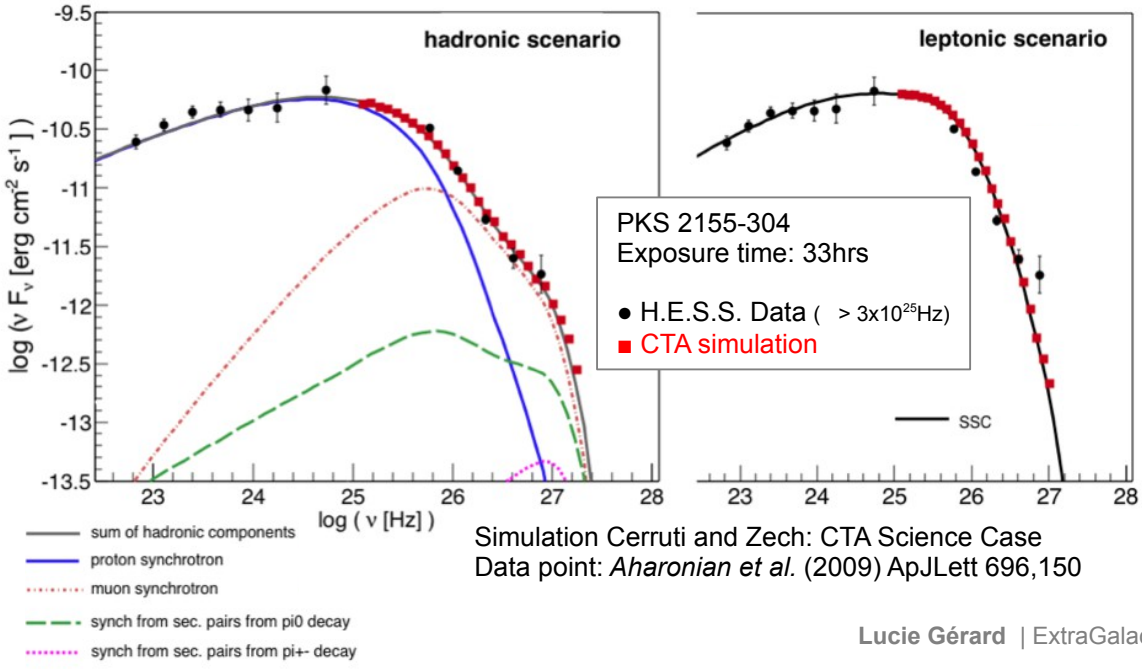
Sol et al. 2013 (APh 43 215S)

✳ see Stamerra et al., Hughes at al., Mendoza et al., this conference

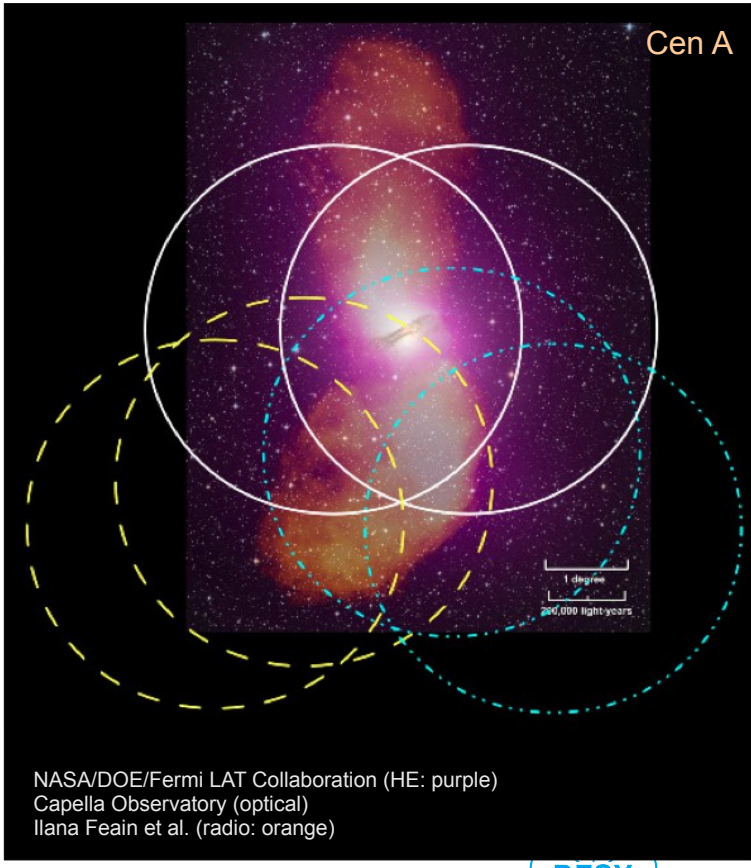
Active Galactic Nuclei KSP: Spectra

- High-frequency peaked blazars:
  - Leptonic or hadronic origin of the emission?
  - Signature of the interaction of gamma-ray with the photon fields?
  - Separate intrinsic features from propagation effects (wide range of redshift and source classes)

- Radio galaxies:
  - Where is the VHE emission coming from?
  - Does it fit the unification schemes? What is the link with blazars?



Simulation Cerruti and Zech: CTA Science Case
Data point: *Aharonian et al.* (2009) ApJLett 696,150



NASA/DOE/Fermi LAT Collaboration (HE: purple)
Capella Observatory (optical)
Ilana Feain et al. (radio: orange)

Active Galactic Nuclei KSP: Probing the Universe

> Extra-galactic background light:

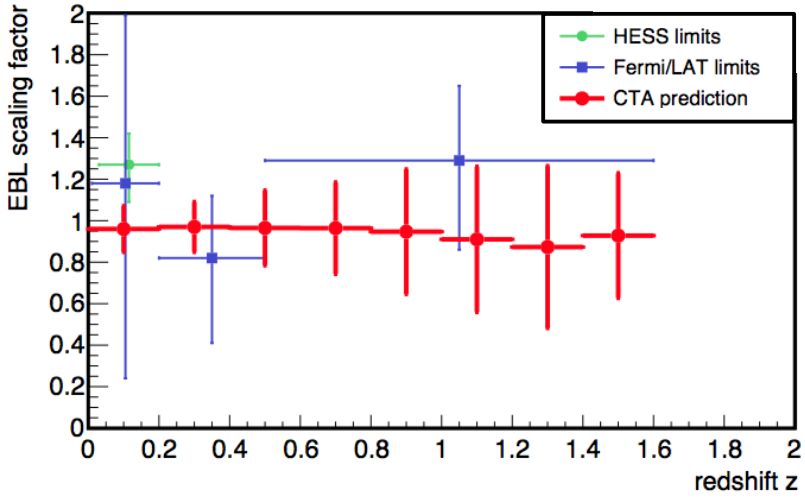
- Measurement from mid UV to far infrared with precision 20%
- Evolution up to redshift z>1
- Measurement of the cosmic γ-ray horizon
- Measurement of the Hubble constant

> Inter-galactic magnetic fields:

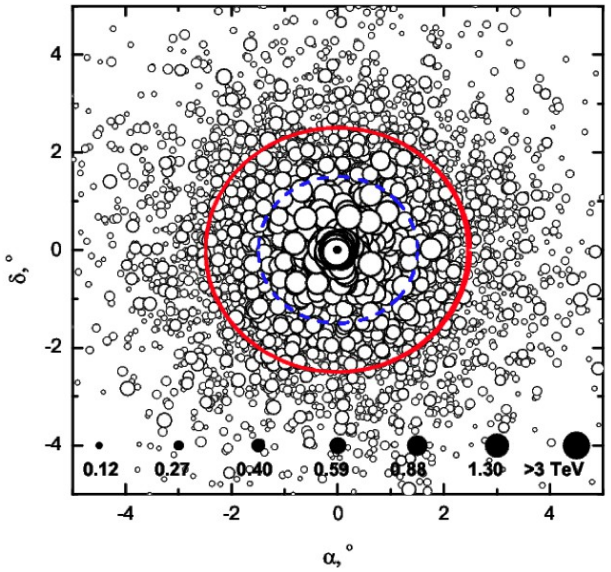
- Lower limit or detection?
- Imaging analysis:

  “pair halos” (IGMF > 10^{-16}G)
- Time resolved spectra:

  “pair echoes” (IGMF < 10^{-16}G)



Simulation D. Mazin (CTA Science Case)

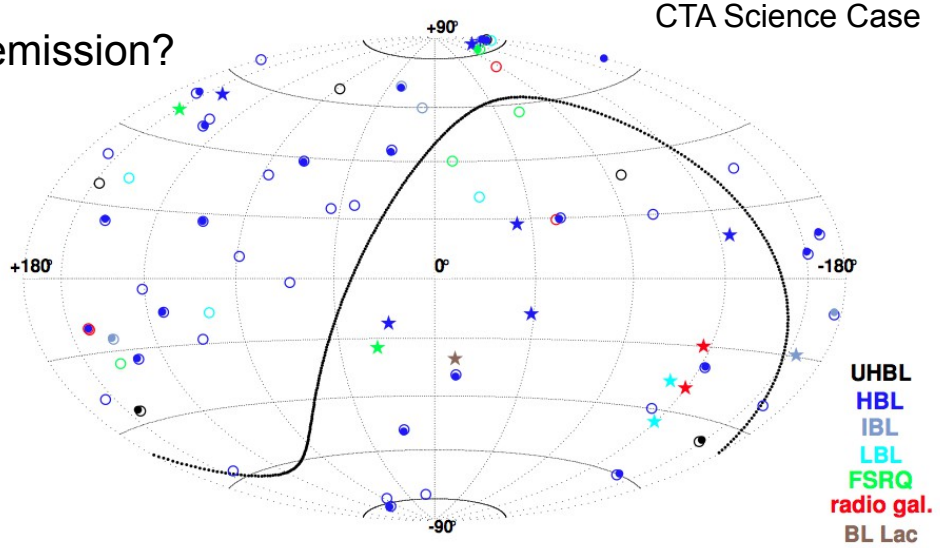


Elyiv et al. 2009 (Phys. Rev. D. 80,2)

Active Galactic Nuclei KSP: Strategy

- Long-term monitoring program
  - Regular observation of 15 VHE AGN of different classes
  - Goal: Light curves over 10 years minimum and time resolved spectra
- High Quality spectrum program
  - 40 AGNs of different classes with redshifts between 0.02 and 1.11
  - Goal: uniform set of high quality spectra
  - Deep observation of two radio galaxies
  - Goal: high resolution spectra, extended emission?
- Flare program
  - Follow up of external triggers
  - Regular monitoring of 80 AGNs of different classes and different redshifts
  - Goal: Catching flares

CTA Science Case



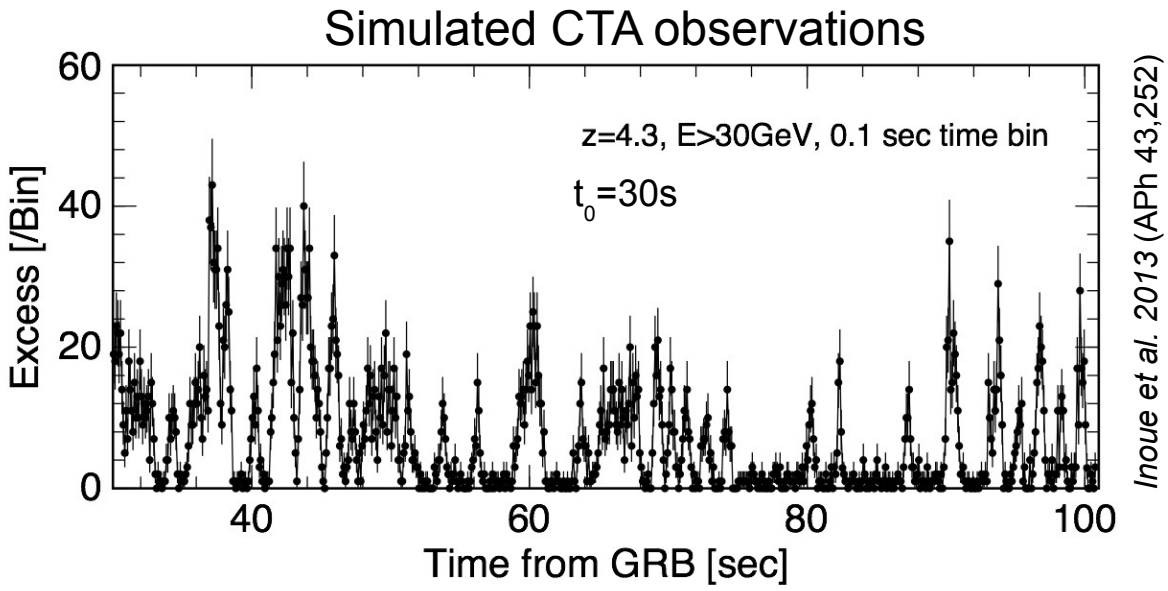
Transients: Focusing on GRBs

- What is the jet Lorentz factor?
- What can we say about the emission site based on γγ absorption and rapid variability?
- Probing particle emission and radiation for the prompt emission and the after glow.
- Probing EBL, IGMF and LIV

- Follow up on all promising GRBs

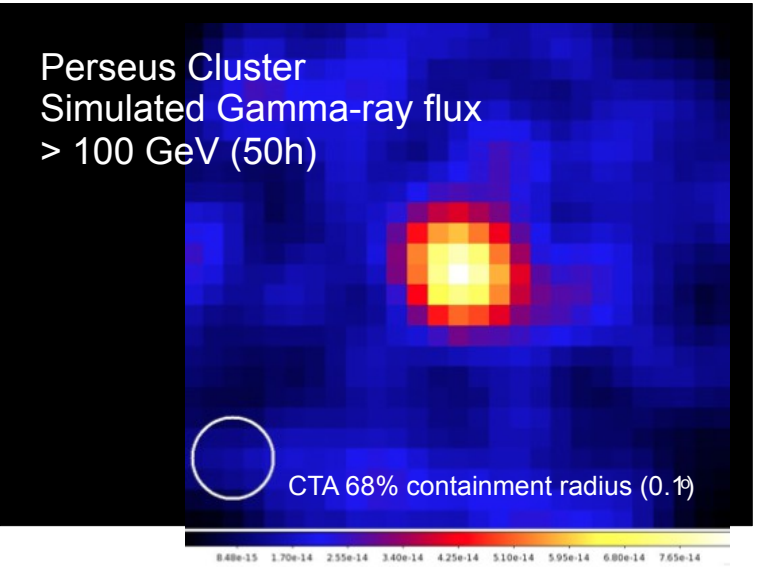
LST repositioning 20s

Serendipitous detection
More likely with a bigger FoV
Divergent pointing?



Clusters of galaxies KSP

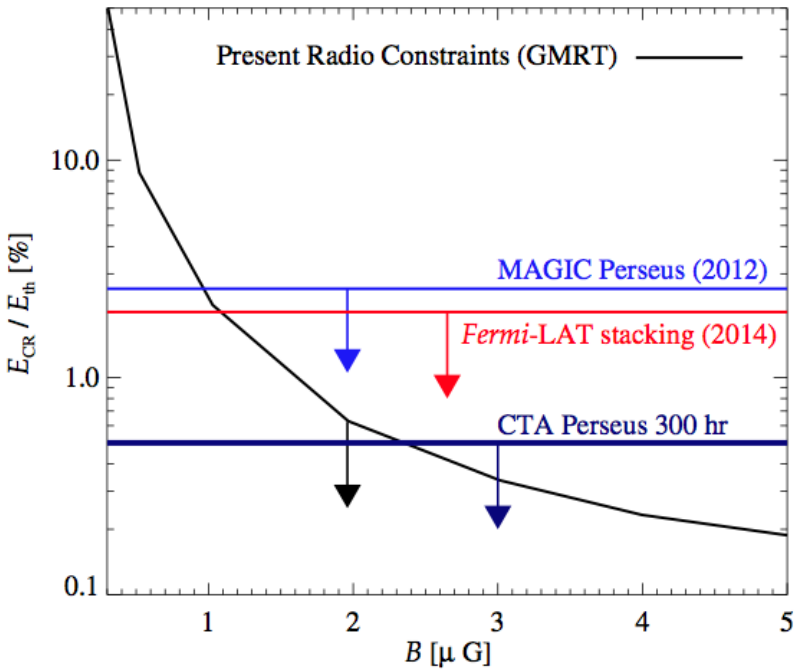
- Probing the origin, acceleration and propagation of CRs in clusters
- If detected: spectral and spatial distribution of diffuse component
- If not detected:
  - Hadronic origin of diffuse radio emission is ruled out
  - Limits on AGN injection of protons
- Prime target for DM searches



CTA Science Case

- Deep observation of the Perseus cluster
- Multi-purpose target:

  NGC 1275 and IC 310 in FoV
- With full CTA array

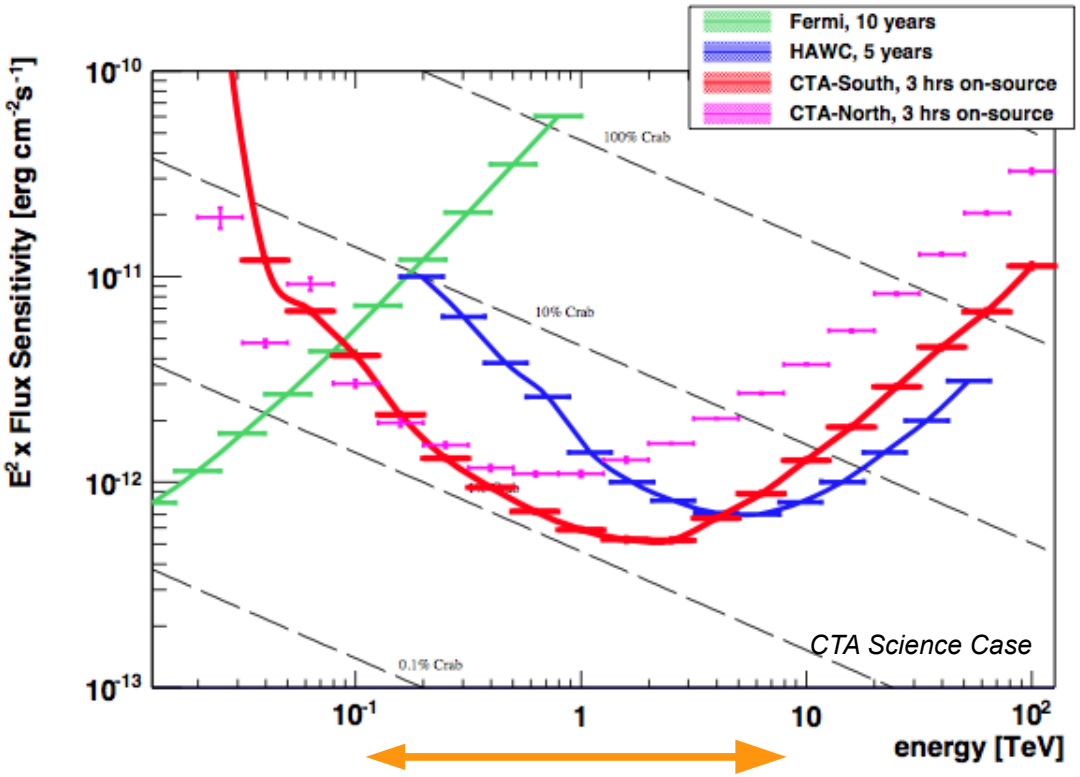


Brunetti et al. (2007), ApJl, 670, L5
Aleksic et al. (2012), A&A, 541, A99
Ackermann et al. (2014), ApJ, 787, 18
CTA Science Case

Extragalactic survey KSP

- Unbiased survey of ¼ of the extragalactic sky (10 000deg^2)
  - Unbiased catalogue of the VHE extragalactic sources
  - High resolution map between 50GeV and 10TeV

CTA FoV ~150 deg^2

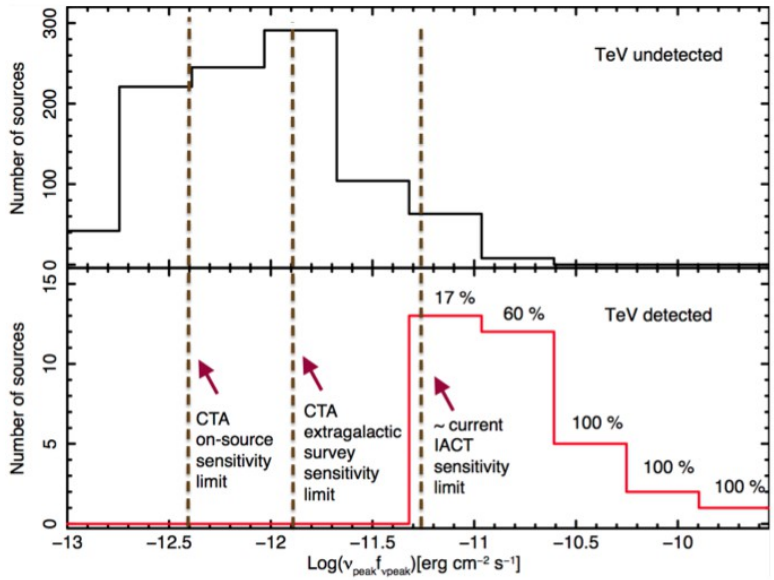


- 1000h
- Sensitivity 4-7mCrab
- Both sites
- CTA full array
- Completed within 3 years

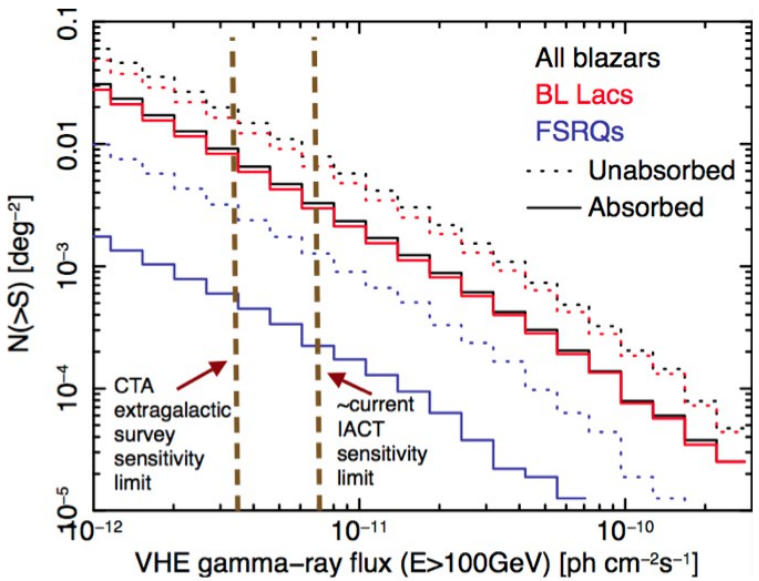
Unique survey in 100GeV-10TeV energy range

Extragalactic survey KSP: AGN physics

- Measurement of the nearby (z<0.2) BL Lacs luminosity function
  - Need at least 50 sources and an unbiased sample
  - 30-150 foreseen detections from Fermi or UV-Xray extrapolations
- Goal:
  - Probing the AGN unification scheme and the Blazar sequence
  - Estimate of the extragalactic diffuse gamma-ray background



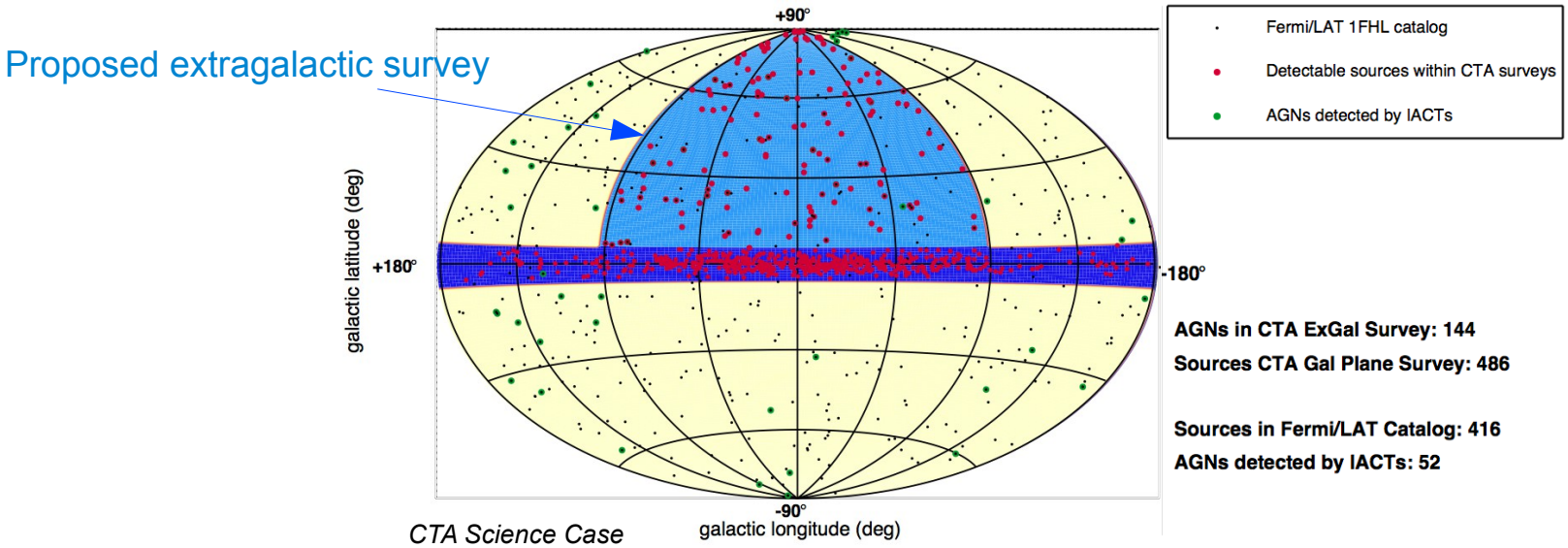
Arsioli et al. (2015). arXiv:1504.02801 (top)
CTA Science case



Padovani P. & P. G. (2015). MNRAS 446L 41P

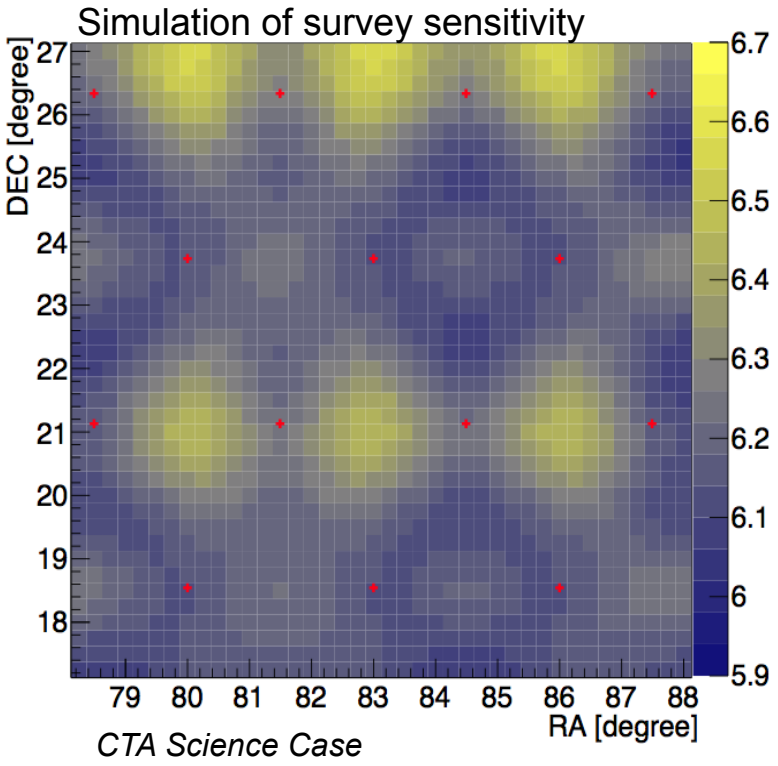
Extragalactic survey KSP: other benefits

- Reveal extreme blazars useful for EBL and IGMF studies
- New sources and new sources classes
  - Radio galaxies, star burst galaxies?
  - Clusters of galaxies, Seyfert 2 galaxies, ULIRGs?
  - Dark sources, signature of new physics?
- Large scale anisotropy of the electron spectrum



Extragalactic survey KSP: Strategy

- Uniform exposure ~6mCrab of 25% of the sky
- Each part of the sky observed several times to average over the sources activity states
- Several highly interesting regions covered (Virgo and Coma clusters, Northern Fermi bubble, Cen A)
- Serendipitous discovery during construction will be used to refine the strategy



Divergent pointing preliminary studies suggest:
- factor 4 increase in full array FoV
- factor 2 degradation in energy and angular resolution
- potential gain in sensitivity for same survey observation time

Very interesting for transient searches (GRBs in prompt phase?)

Multi-wavelength and multi-messenger support

- MWL follow up on transients: AGNs and active sources
- MWL long term monitoring campaigns targets
- Complete coverage of the extragalactic survey (at least optical)
- MWL and MM agreements and MoUs for alerts
- Redshift campaigns for blazars

- Possibility of CTA dedicated optical telescopes (photometry and polarimetry)
  - Systematic coverage of the targets to identify high and low states of the sources
  - Monitoring of AGNs for alerts of flaring states

Data products and release

- AGNs:
  - Continuous on line release of light curves and alerts from flaring monitored sources.
  - Regular release of full data set
  - Catalogue after first year and final catalogue and maps
- Transients:
  - Release of spectra and light curves for detected transients
  - Upper limits for all observed GRBs
  - Alerts
- Galaxy clusters:
  - Release of a preliminary and later final map and data
- Extragalactic survey:
  - Continuous release of alerts for transients events
  - Catalogue

All CTA data will be released to the public after the proprietary period (1 year)

DESY

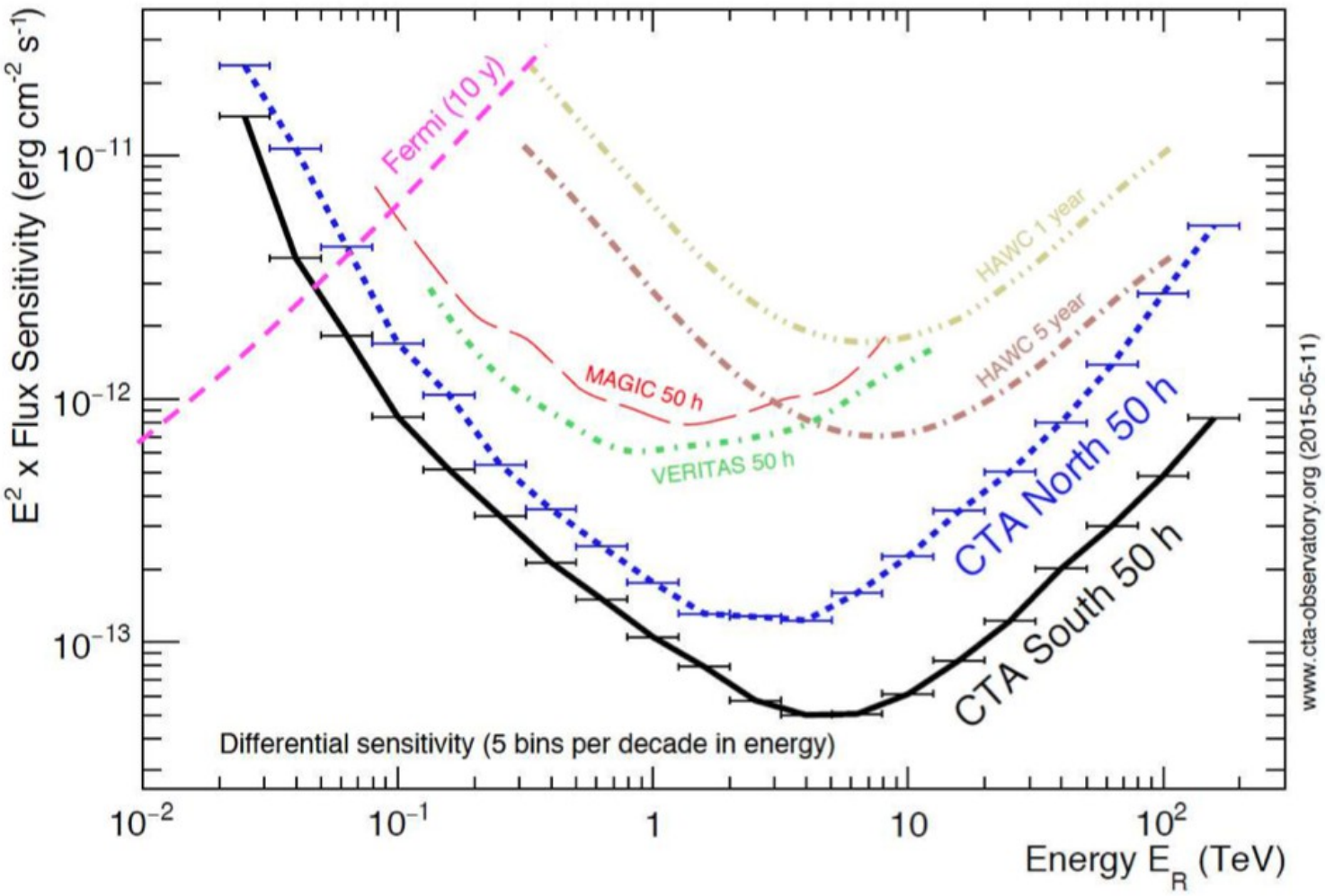
Summary

- Extragalactic KSPs explore CTA science themes in a coherent manner
- Data release to public after proprietary time (1 year)
- Strong Guest Observer program with ~50% of observing time over the first 10 years
- Legacy of use for the entire astronomical community
  - Catalogues
  - Maps
  - Light curves
- The KSPs will evolve according to the reviews before and during CTA operational period.

Thanks

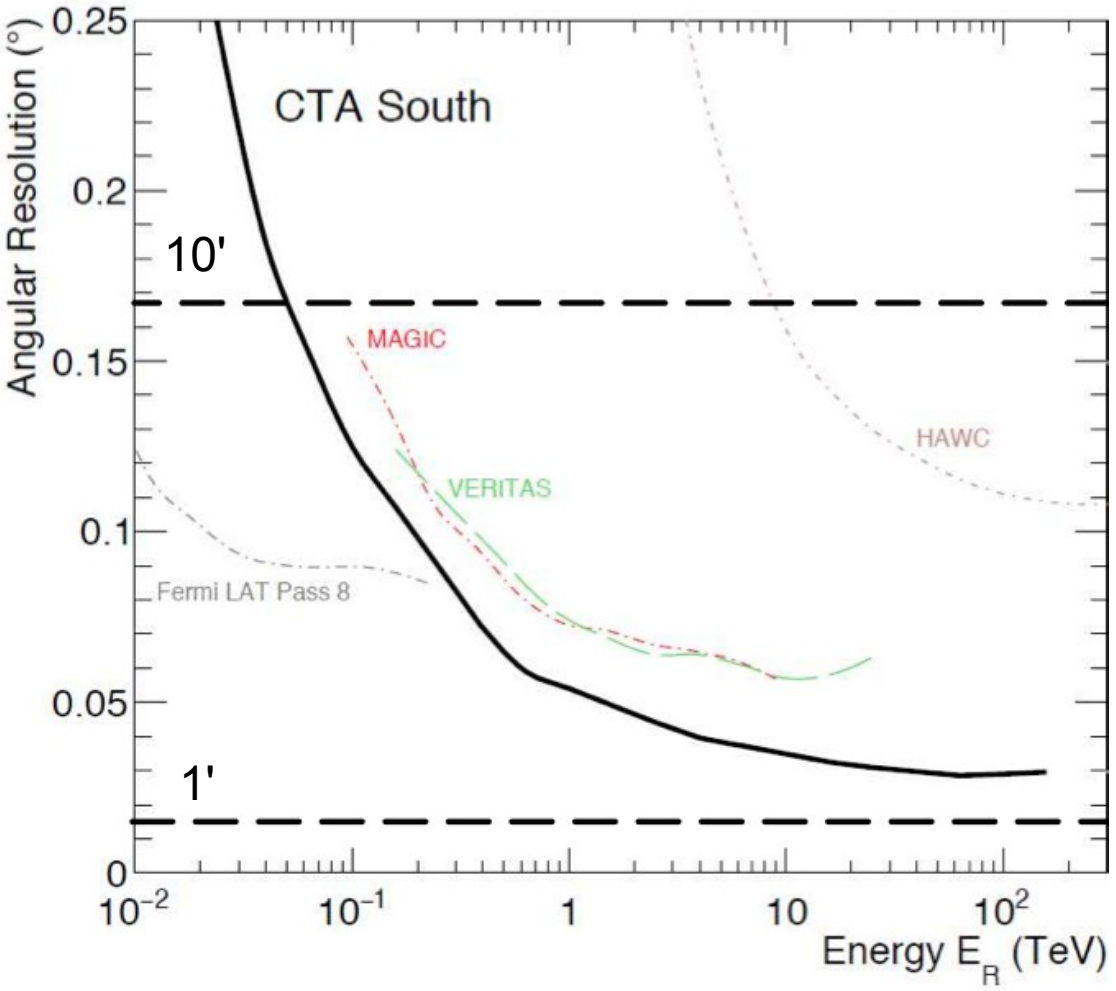
Back up

CTA Sensitivity



https://portal.cta-observatory.org/CTA_Observatory/performance/SitePages/Home.aspx

CTA angular resolution



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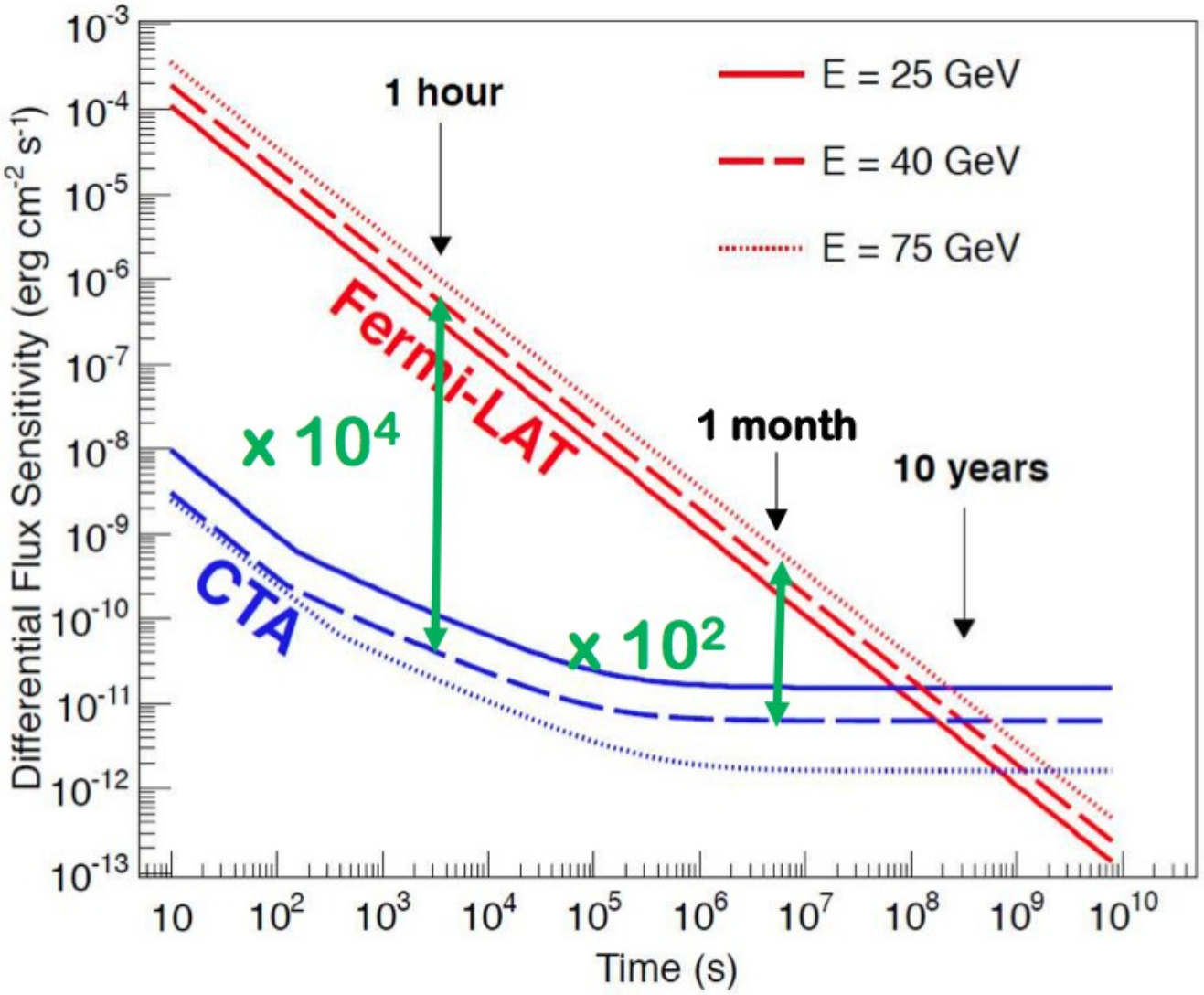
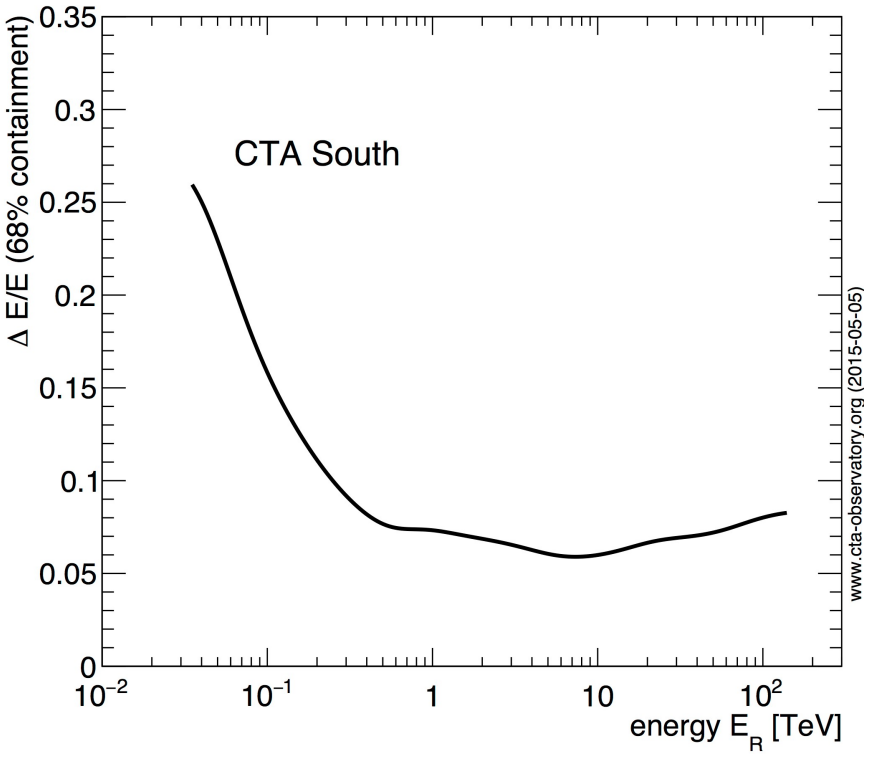
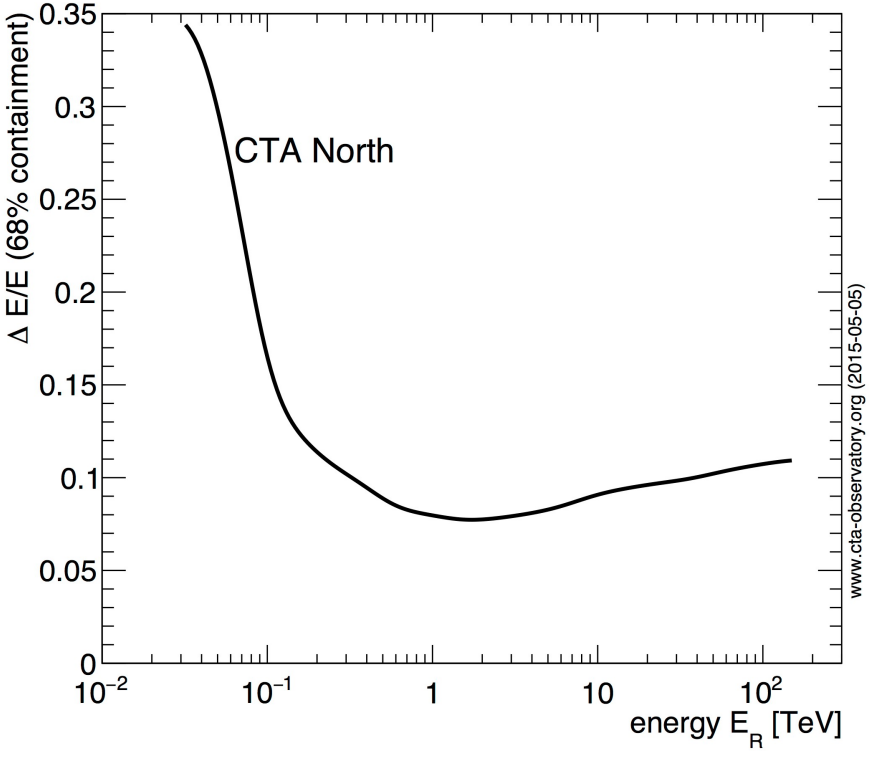
CTA timing capabilities



CTA angular resolution





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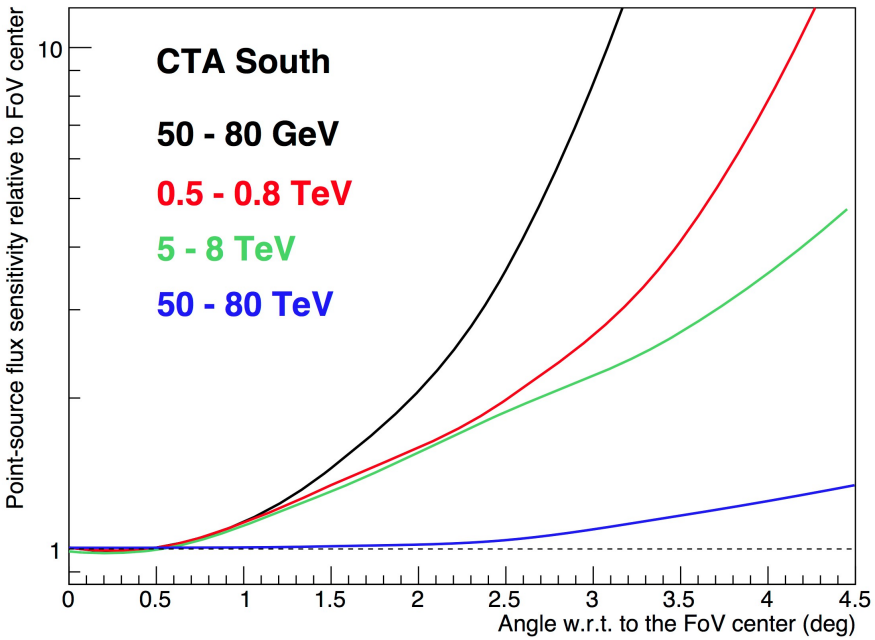
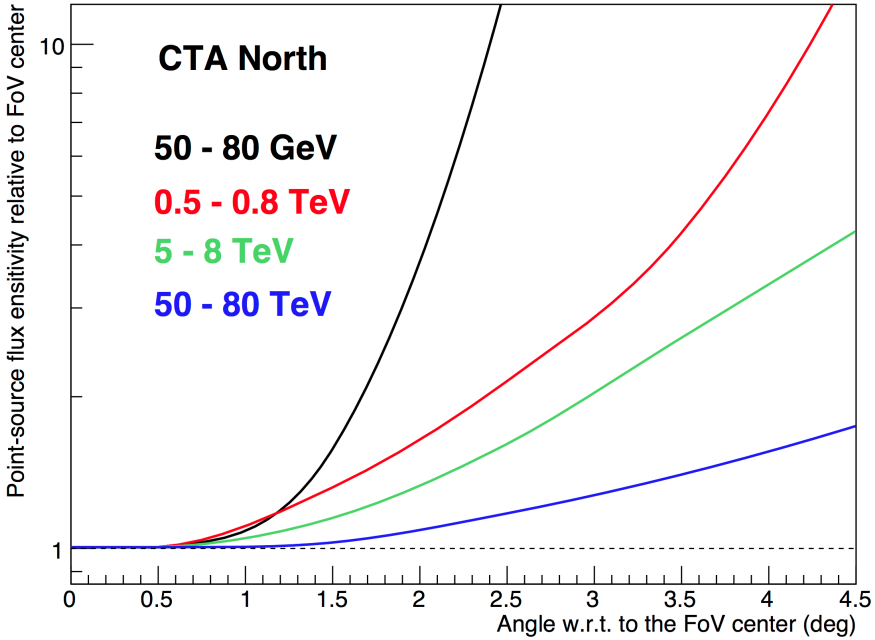
CTA Off axis sensitivity



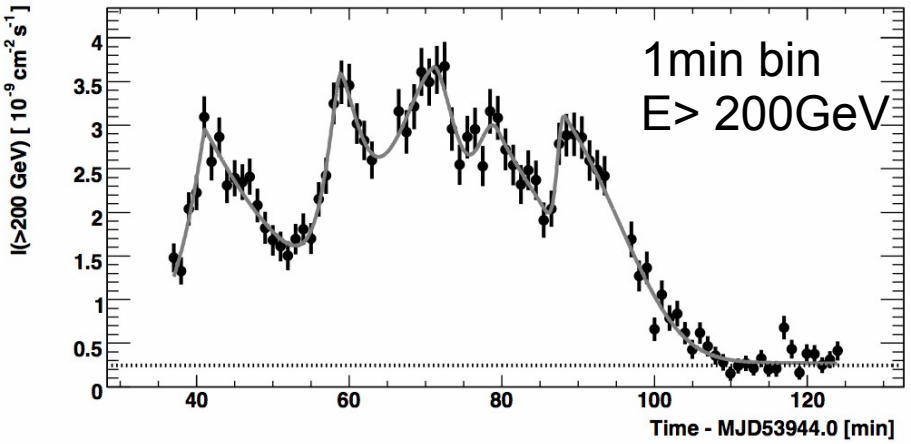


https://portal.cta-observatory.org/CTA_Observatory/performance/SitePages/Home.aspx

Short term variability with CTA

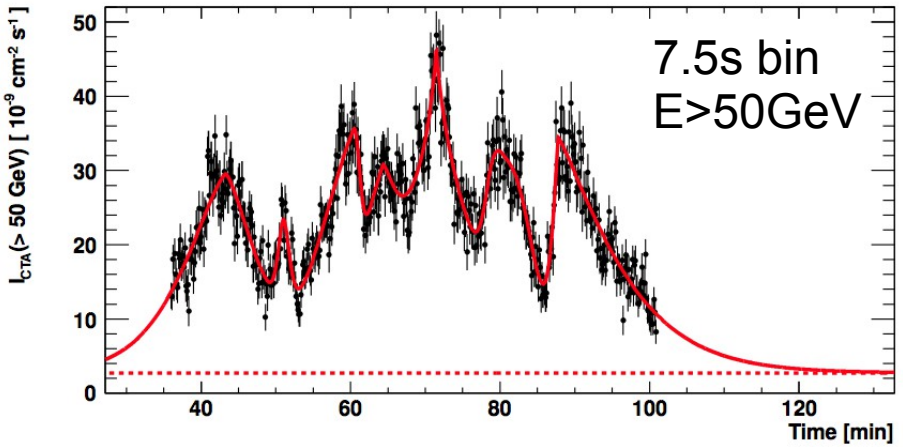
- PKS 2155-304 flare in 2006

H.E.S.S. data

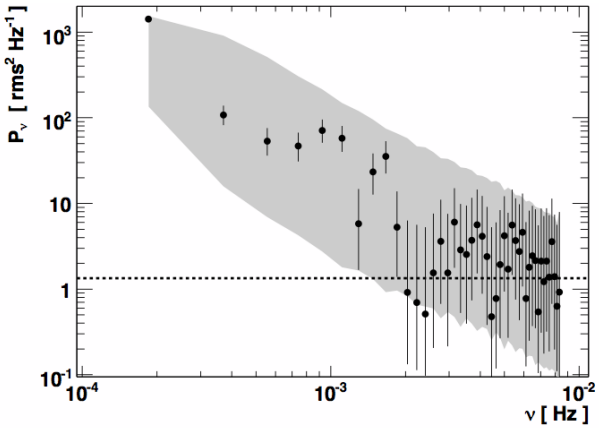


Aharonian et al. 2007 (ApJ 664L 71A)

Simulated CTA observation

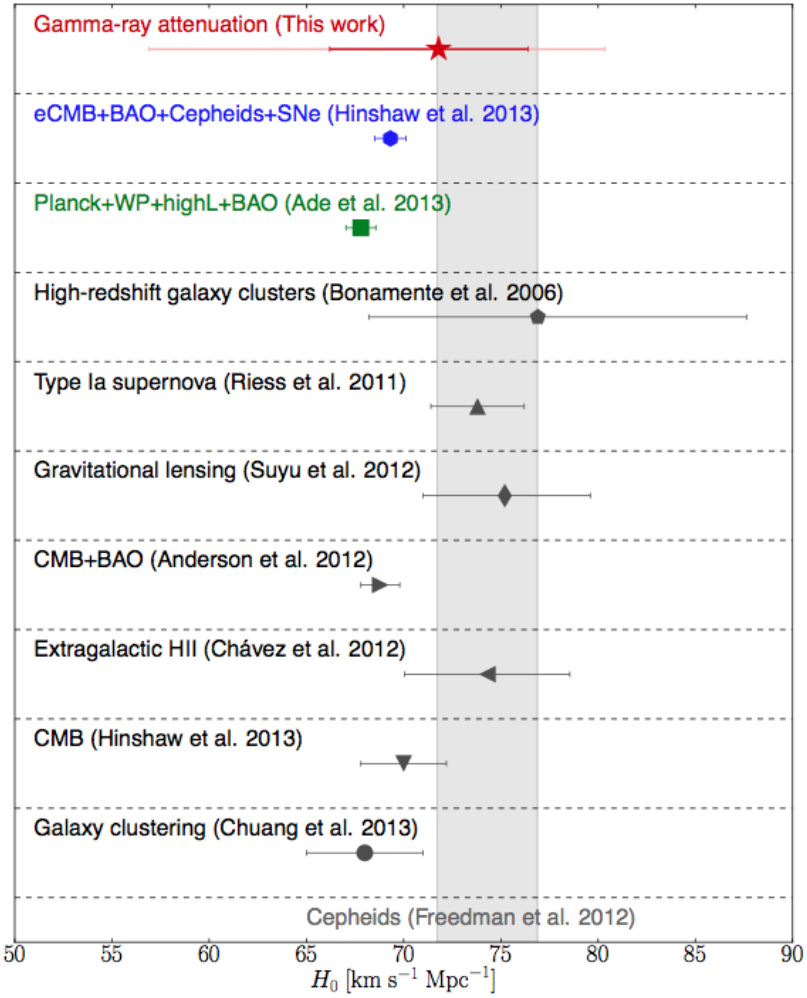


Sol et al. 2013 (APh 43 215S)



Simulation from extension of the red-noise behavior to high frequencies

Measuring Hubble Constant with Gamma-ray



Dominguez and Prada 2013