# VHE gamma-ray astronomy @IN2P3 in the 2020s

S. Fegan (LLR), on behalf of D. Horan

Prospectives of IN2P3 (Astroparticle) - Annecy, Nov 2019

# Summarising GT04 contributions…


CTA Science Prospective at IN2P3

Contributors:

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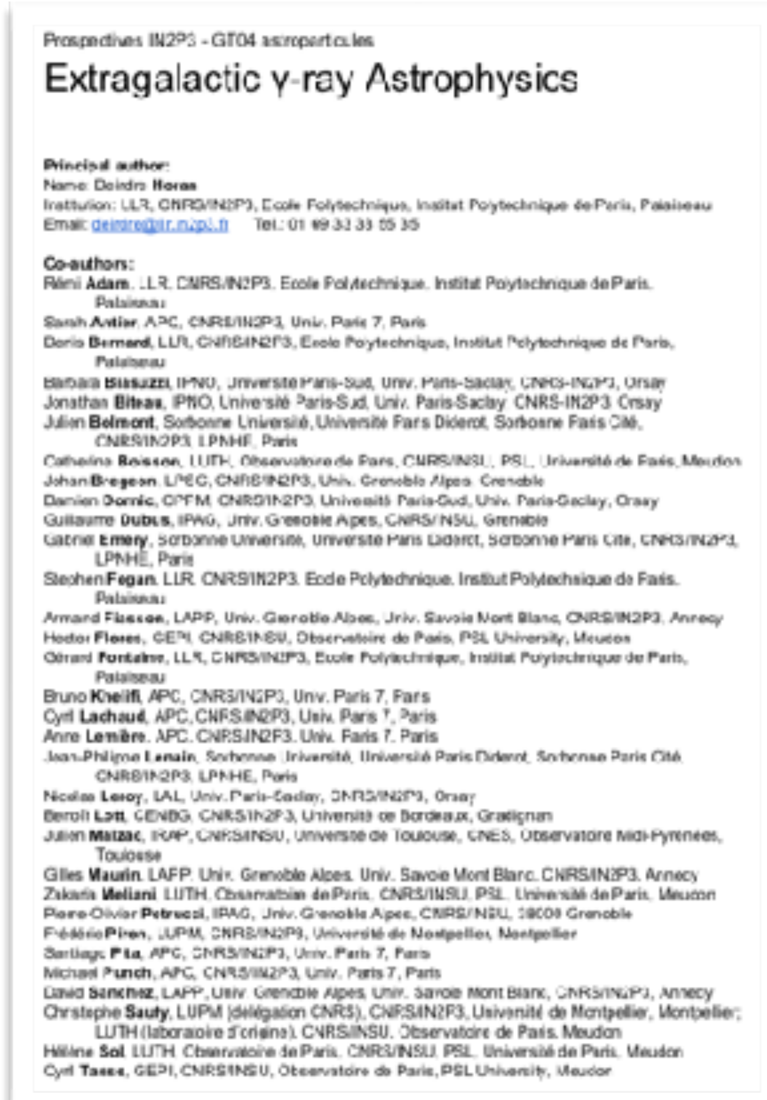
Abstract

**Suomijärvi et al.**


Prospectives IN2P3 - GT04 astroparticules

Extragalactic γ-ray Astrophysics

Principal author:

Name: Deirdre Horan

Co-authors:

**Horan et al.**


Contribution Prospectives IN2P3 2020 - GT-04

γ-ray cosmology

Principal Author:

Name: Jonathan Biteau

Co-authors:

**Biteau et al. (§1–3)**

1 : https://indico.in2p3.fr/event/19952/attachments/55568/73294/ProspectiveIN2P3_2019_CTA_Suomijarvi.pdf
2 : https://indico.in2p3.fr/event/19952/attachments/55568/73288/Prosp2020_IN2P3_Extragalactic_gamma-ray_astrophysics.pdf
3 : https://indico.in2p3.fr/event/19952/attachments/55568/73287/Prosp2020_IN2P3_Gamma_ray_cosmology.pdf

# Cherenkov Telescope Array

## About

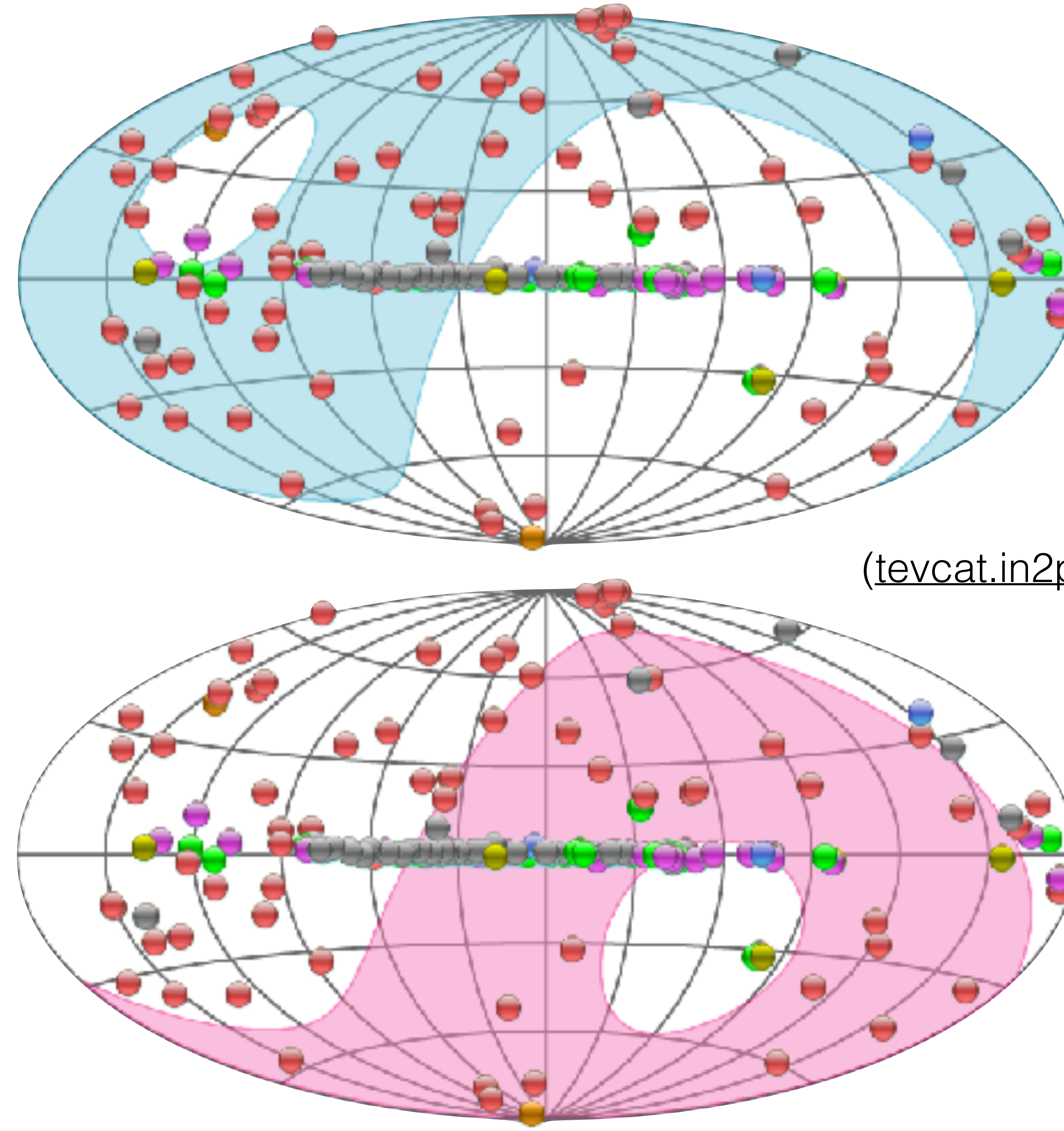
The Cherenkov Telescope Array (CTA) is the next generation ground-based observatory for gamma-ray astronomy at very-high energies. With more than 100 telescopes located in the northern and southern hemispheres, CTA will be the world's largest and most sensitive high-energy gamma-ray observatory.

READ MORE

# One observatory, two sites

CTA-N : 4 LST, 5–15 MST
Effective area @10TeV : $8 \times 10^5$ m$^2$
Focus on extra-galactic sources

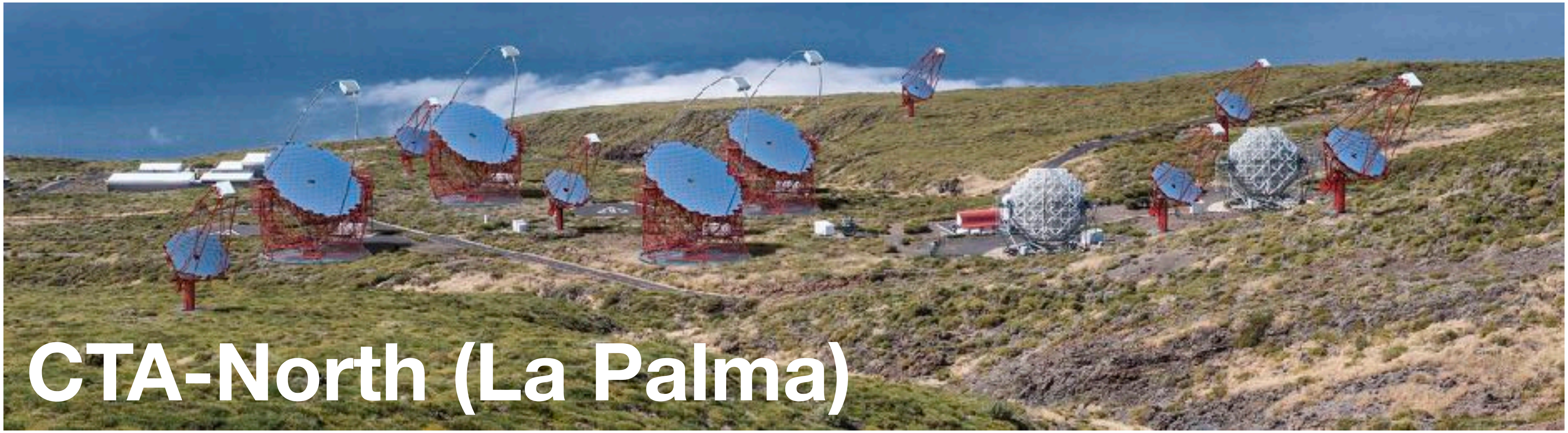

CTA-S : 0–4 LST, 15+ MST, 50 SST
Effective area @10TeV : $3 \times 10^6$ m$^2$
Optimised for observation of Galaxy

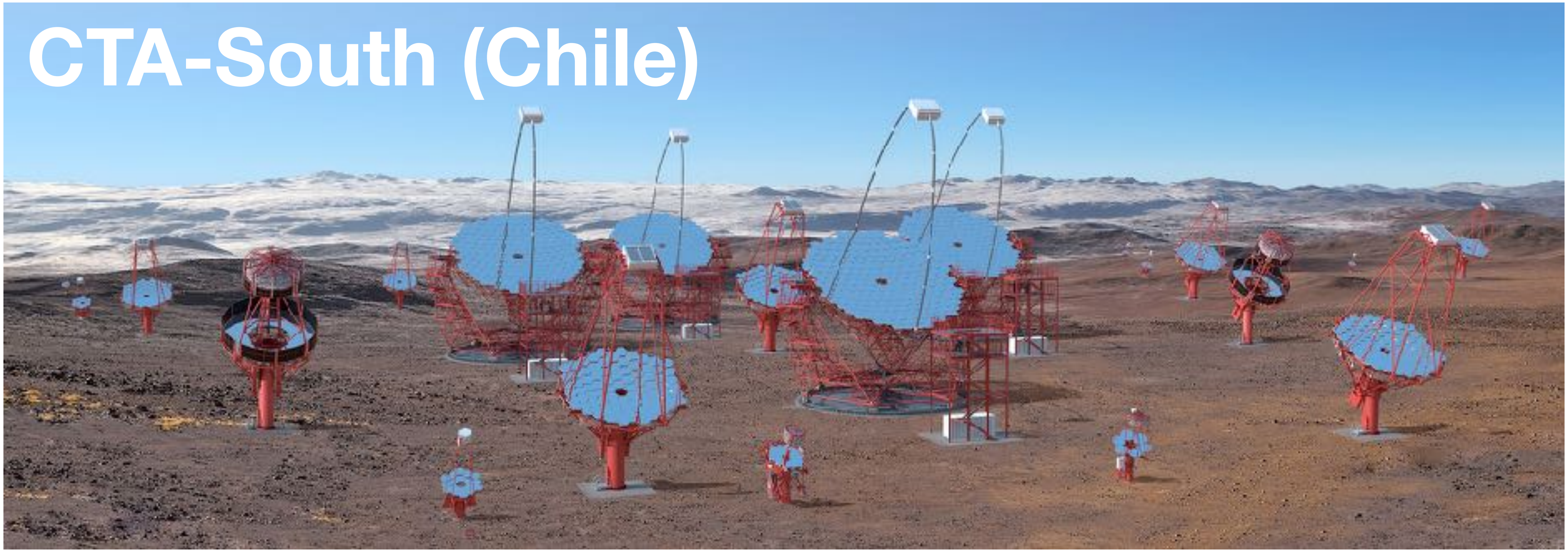


(tevcat.in2p3.fr)

- Some sources accessible to both sites - ~4 hour offset in longitude will allow these to be observed for somewhat longer periods if necessary.
- Same analysis & simulations tools for both sites. Ideally some common hardware.

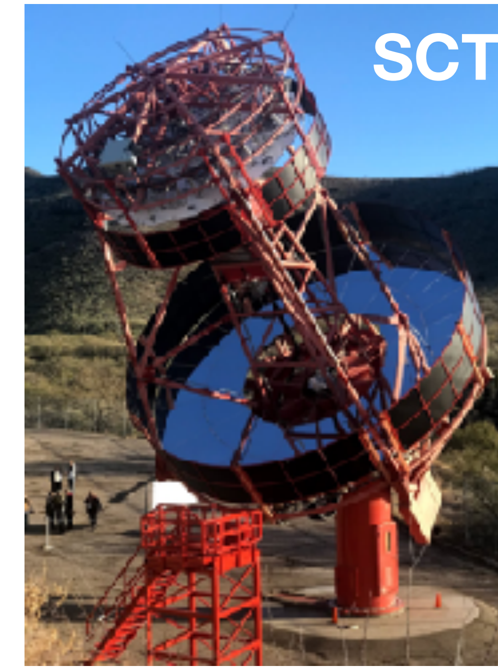
# One observatory, two sites

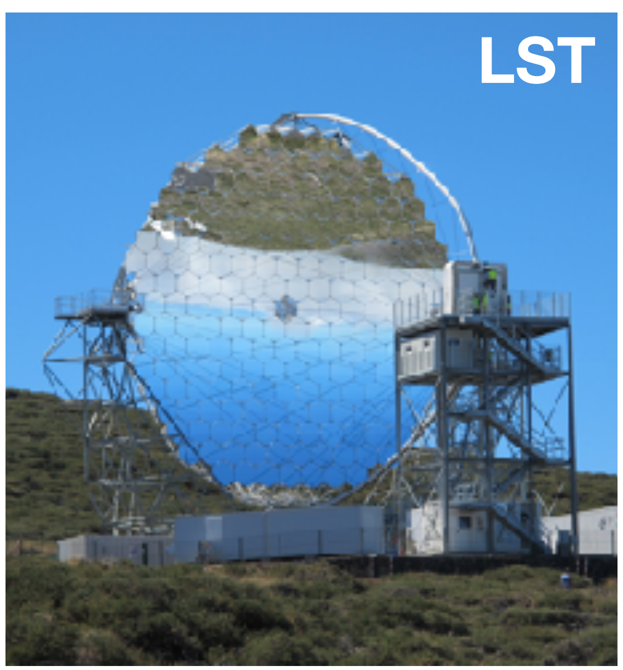


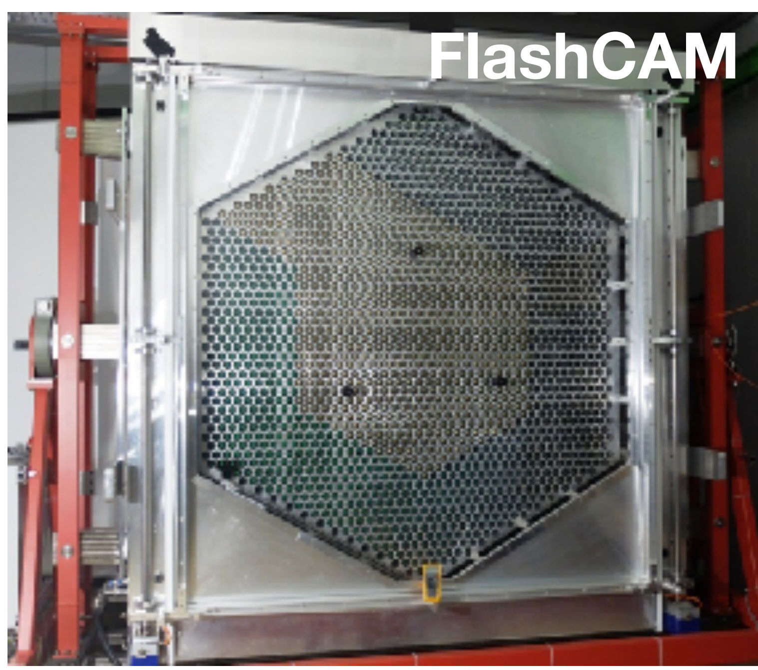



# 2010s : design and prototyping





# Principal advances of CTA

- **Two sites** — full sky visible, double available science. First extra-galactic survey (1/4 sky) will complement deep Galactic survey.
- **Large area** — more gamma rays gives improved instantaneous sensitivity; particularly important for transients.
- **Many telescopes** — improved reconstruction, proton rejection and angular resolution, particularly at high energies. Flexibility.
- **Large field of view** — increased science efficiency - particularly for survey and for serendipitous detection of transients (GRBs).
- **Energy range** — three telescope classes extend energy range. Understand spectra & variability at highest energies. Deep z
- **Focus on "quality"** — requirement for larger telescope availability improves science yield and uniformity of data taking.
- **Faster electronics, data processing, rapid pointing, high quantum efficiency detectors…**

# CTA timeline

## Level-1 Milestones for Construction

- We plan to use the following Level-1 milestones. The milestone dates are very ambitious and assume no limitations, e.g. funding
- Note: So far these milestones have been discussed CTAO internally only and not yet with the project participants, potential providers or Council
- Final milestone dates will be determined by the project and funding reality

| No. | Level-1 Milestone | CTA-North | CTA-South |
|---|---|---|---|
| 1 | Hosting agreements signed | Q3 2016 | Q4 2018 |
| 2 | Begin Initial Infrastructure Works | Q2 2020 | Q2 2020 |
| 3 | Complete Initial Infrastructure Works | Q4 2022 | Q2 2022 |
| 4 | First telescope acceptance on site | Q4 2020 | Q3 2022 |
| 5 | Begin Phase 1 Early Science | Q4 2022 | Q3 2023 |
| 6 | End Phase 1 and begin Phase 2 (Operations of Ph1 configuration) **4/5/0** | Q1 2025 | Q1 2025 **0/15/50** |
| 7 | Completion of Phase 2 Construction Project | TBD | TBD |

*CTA project manager, June 2019*

# CTA science themes


★ Understanding the Origin and Role of Relativistic Cosmic Particles

- Nature of cosmic accelerators
- Propagation of accelerated particles
- Interaction with their environment

★ Probing Extreme Environments

- Black holes and jets
- Neutron stars & relativistic outflows
- Exploring cosmic voids (EBL & EGMF)

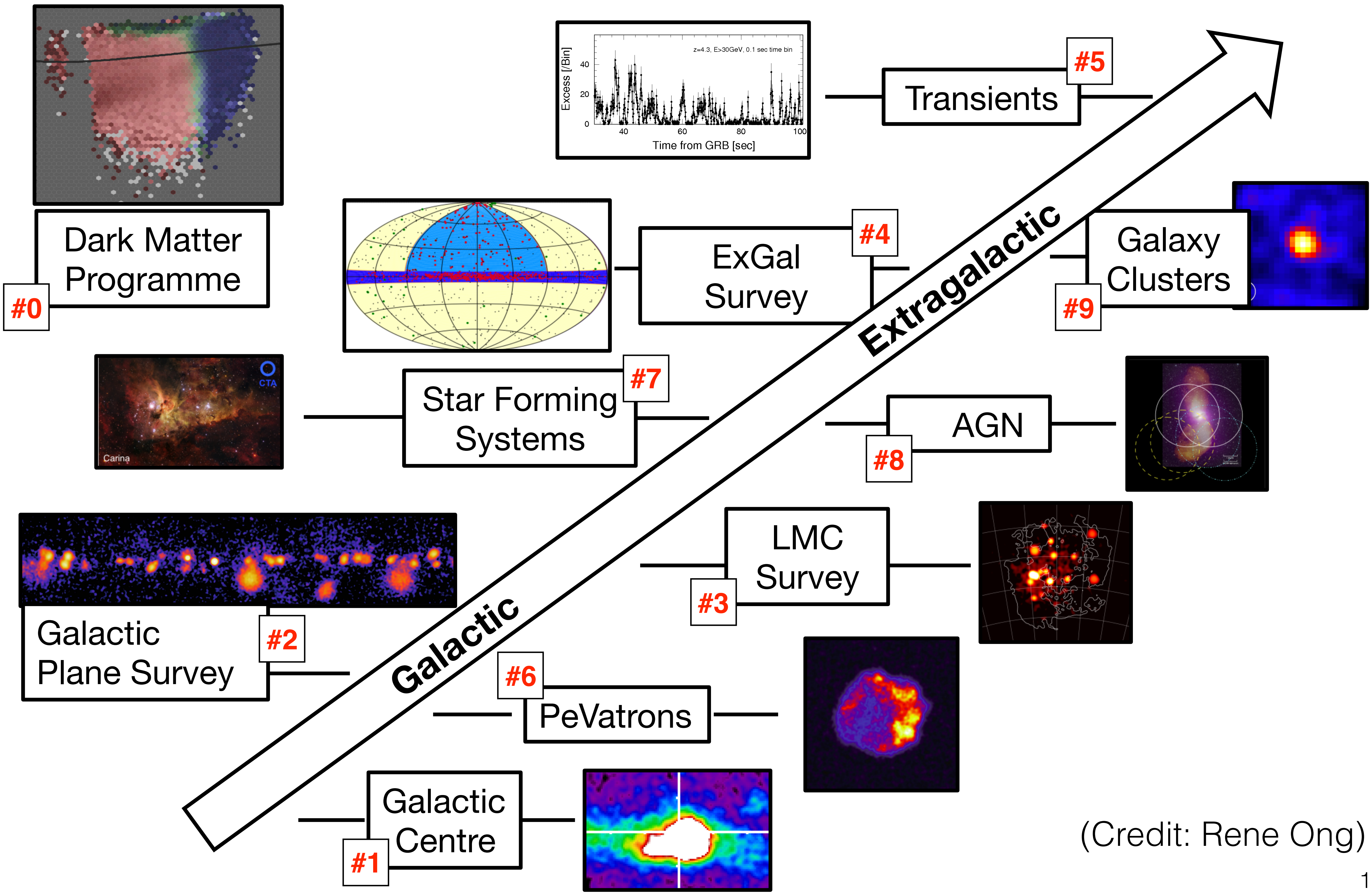
★ Exploring Frontiers in Physics

- Dark matter : nature & distribution
- Quantum gravity : Lorentz symmetry near Planck energy
- Do axion-like particles exist?

# Science gathering phases

- **Key science projects** — initially observatory time will be dedicated to Key Science Projects as discussed next. In this phase CTA collaboration will direct observations, perform analysis and publish the results - catalogs, science papers, etc.
- **Open observatory** — as time goes on, and in particular as the Galactic and extra-galactic surveys are completed, CTA will operate as the first open, proposal-driven observatory for VHE astronomy. The observatory-mode operation of CTA is expected to significantly boost scientific output by engaging a research community much wider than the historical ground-based gamma-ray astronomy community. Proposals from the community will be reviewed by a time-allocation committee, observations scheduled at the appropriate site, data collected, reduced, and made available to the proposer, with appropriate tools.

# CTA key science projects (KSPs)



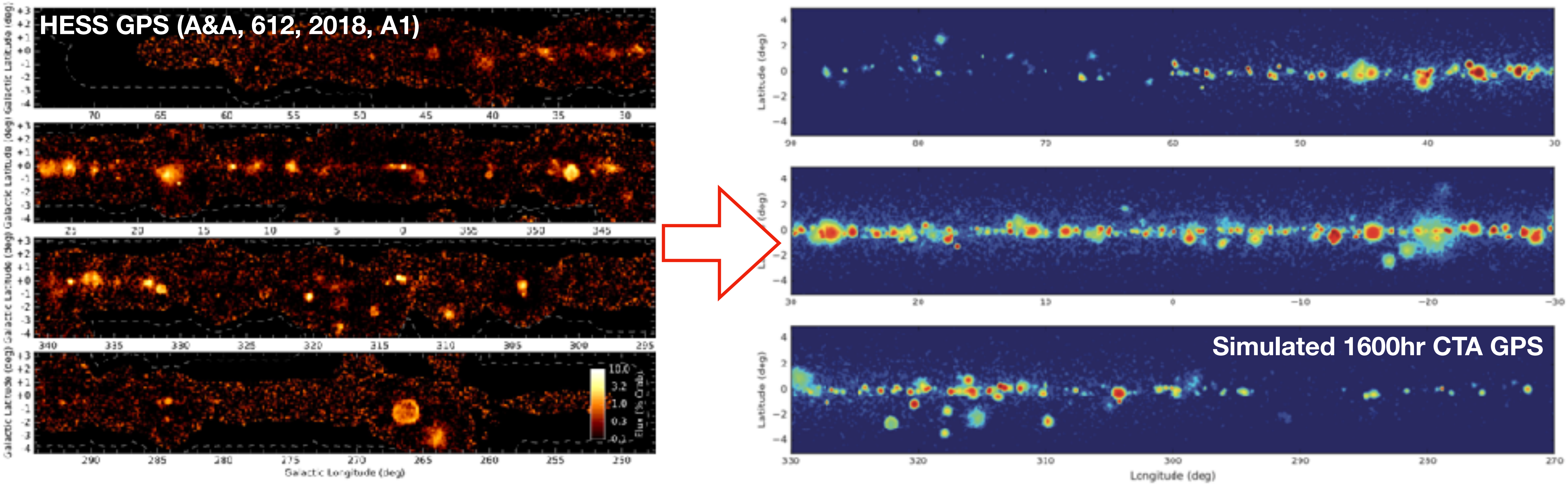

(Credit: Rene Ong)

# CTA science @ IN2P3

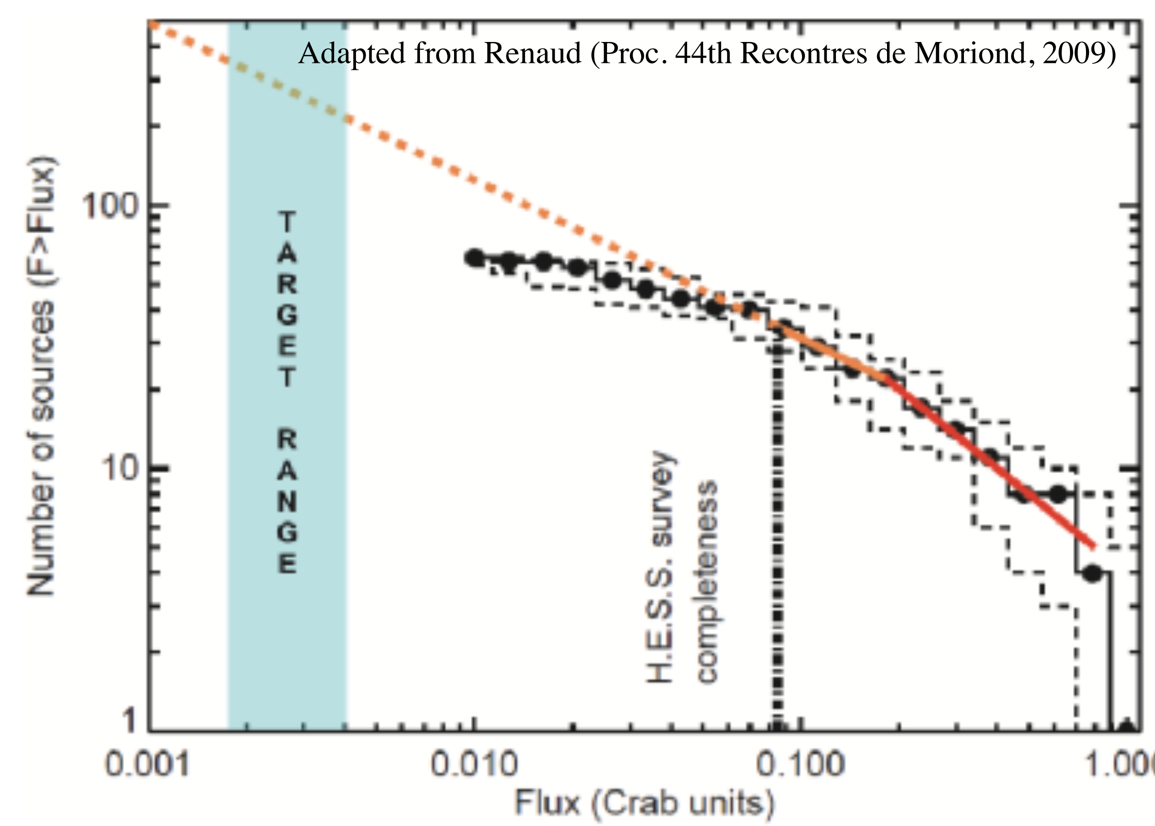
| | APC | CENBG | CPPM | IPNO | LAPP | LLR | LPNHE | LUPM |
|---|---|---|---|---|---|---|---|---|
| Galactic centre | | | | | | | | |
| Gal. plane survey | | | | | | | | |
| LMC survey | | | | | | | | |
| Ex.Gal. survey | | | | | | | | |
| γ-ray cosmology | | | | | | | | |
| Transients | | | | | | | | |
| PeVatron | | | | | | | | |
| Magnetospheres | | | | | | | | |
| Star form. region | | | | | | | | |
| AGN | | | | | | | | |
| Galaxy clusters | | | | | | | | |
| DM & Exotic | | | | | | | | |

*Table 1: KSP and other science-topic participation matrix for IN2P3 labs. Red indicates primary interest of a lab; the lab expects to lead CTA investigations in this area. Blue indicates a secondary interest in the topic; the lab expects to participate in studies in this area.*

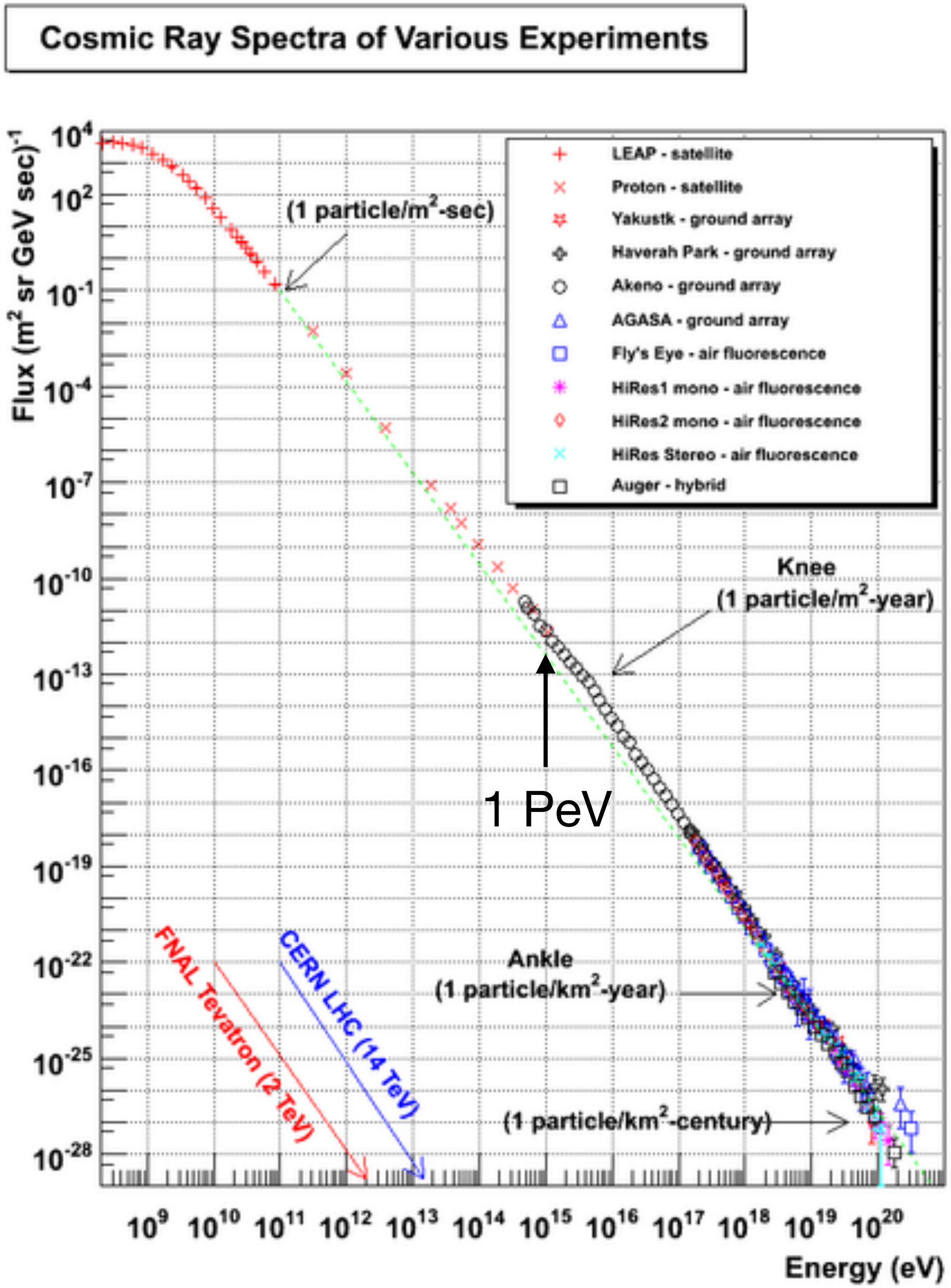
# Galactic plane survey (GPS)




- GPS is major KSP of CTA including 1,000 hr of observation in South and 600 hr in North.
- Target the few milli-Crab flux
- Expect few 100s of sources, or more if new source classes emerge
- **Springboard to other new science**



# PeVatrons




- The "origin of CRs" has long been a motivation for VHE astronomy.
- Galactic objects are presumed sources of CRs below knee, with pop. of SNRs capable of providing required power of $10^{41}$ ergs/s.
- But would like to clearly detect the presence of PeV protons in the sources - "PeVatrons"
- Look for unattenuated spectra that in the 10-100 TeV regime ; which would strongly suggest presence of 1PeV protons (KN cutoff for $e^-$).
- CTA : target GPS sources with few TeV emission. Observations with SSTs particularly important.

# Gamma-ray AGN : open questions

- After 30 years of studying AGN at GeV-TeV energies (and >45 years at MeV-GeV) there are still many open questions.
- How are jets launched and collimated, and where are particles accelerated in the jets ?
- What are the constituent particles that radiate gamma rays ? Where are the UHECRs ?
- What is the nature of variability in AGNs ? What are the limits on the shortest timescales ? What about long period “breaks” ?
- How does the quiescent (non-flaring) state differ from the flaring ?
- How do orphan flares fit into the picture of acceleration in AGN ?
- Is there really a blazar sequence (more power = lower energy) ?
- Are radio galaxies the parent population of blazars ? How are the different classes related ?
- What is the luminosity function for TeV AGN ? How does it evolve ?

# What capabilities does CTA bring

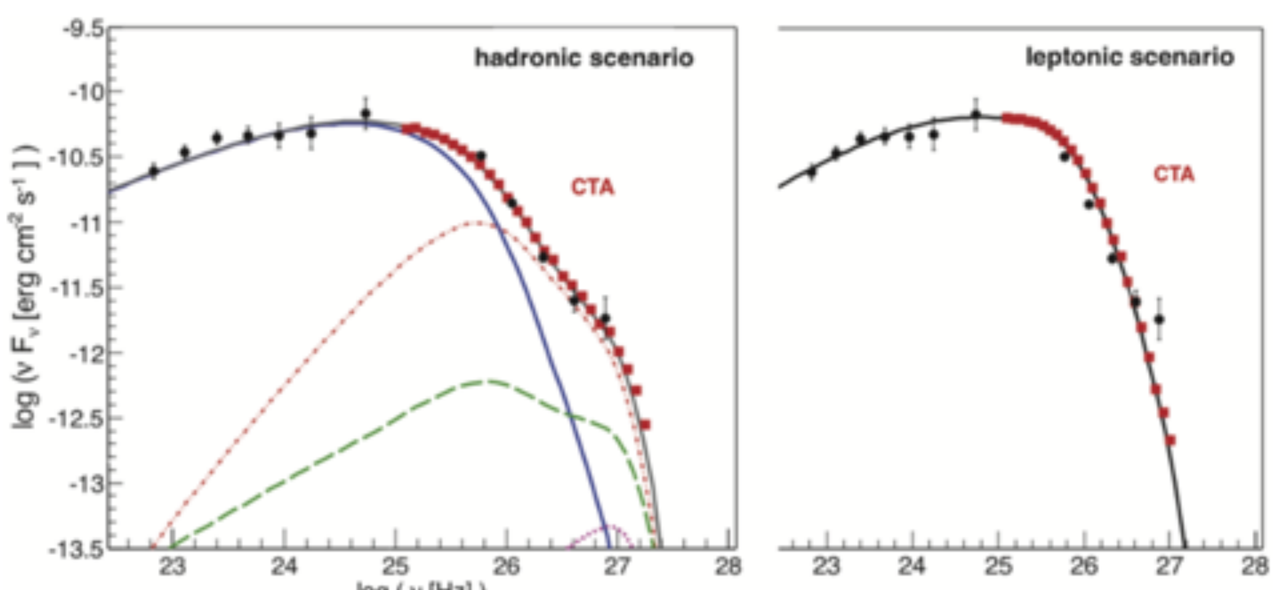
- CTA will be major instrument for **fourth decade** of extragalactic VHE astronomy (detection of Mrk 421 by Punch et al, 1992).
- **Larger instantaneous sensitivity** : critical to understanding fast flaring and transients in general. Opens phase space of variability inaccessible to current observatories.
- **Higher spatial resolution** : addresses morphology of close-by sources (radio galaxies) such as Cen A, where extended emission has been seen at $>5\sigma$. Detailed spectro-morphology with CTA may show evolution of VHE particles in jet (as for SNR in HESS).
- **Large field of view** : of the MST telescopes makes the first extragalactic survey covering 10,000 deg$^2$ feasible (compared with 1,000 deg$^2$ of HESS GPS).
- **Flexibility** : to observe in new ways, exploiting sub-arrays where appropriate (e.g. SST observe PeVatrons while MSTs observe AGN*, or subset of MST do long-term snapshot monitoring).



* but don't forget UHECR cascades

# The targeted AGN KSP

- Derive spectra and lightcurves of known AGN with unprecedented accuracy : address presence of hadrons in jet, probe emission region to smaller scales through shorter variability timescales.
- Long term lightcurves to complement Fermi - are there breaks in the temporal spectra of the flares at long periods.
- Search for high-redshift blazars, radio galaxies, NLSy1, radio-quiet AGN, and “extreme” (high $E_{peak}$ - low L) blazars on the sequence with “reasonable” exposures.
- Understand the behaviour of the different AGN subclasses.




Zech et al. A&A, 602, A25 (2017)

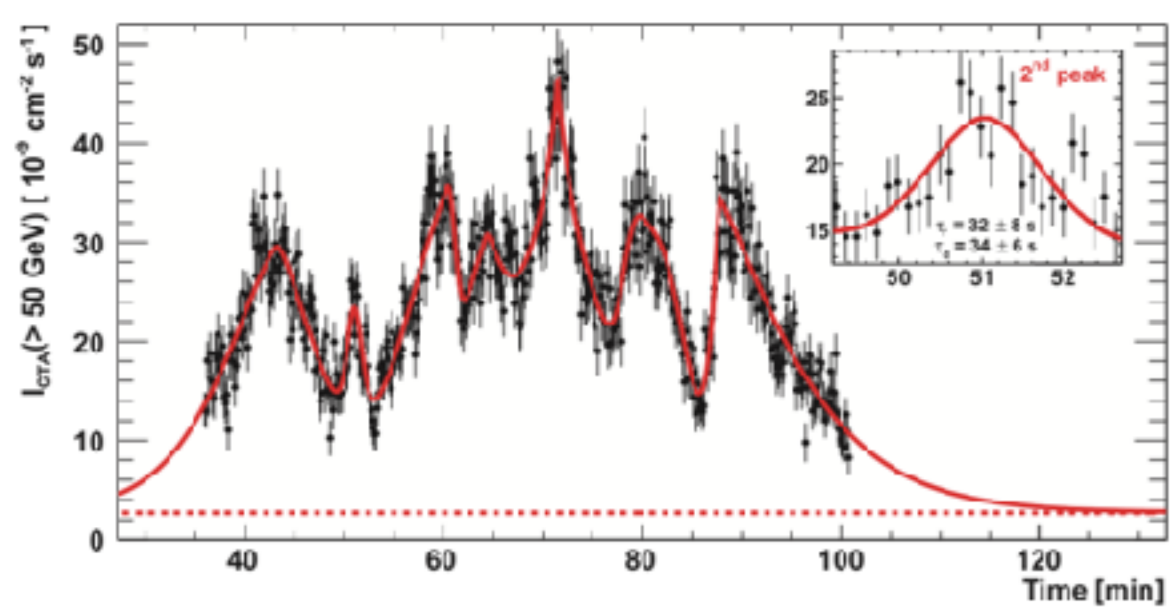



Figure credit : J Biteau

# The extra-galactic survey KSP

- Current view of extragalactic sky with 78 known AGN is heavily biased by observation strategy.
- First <u>unbiased</u> survey of extragalactic sky with VHE instrument : 1/4 sky down to flux of 5 milli-Crab (use N & S sites).
- Expect at least 50 to 150 new sources, depending on assumptions.
- Detect VHE emission from new AGN types or from extreme AGNs
- Understand properties of population
- Reconstruct luminosity function
- Understand AGN flaring duty cycle ; optimise strategy for flaring sources

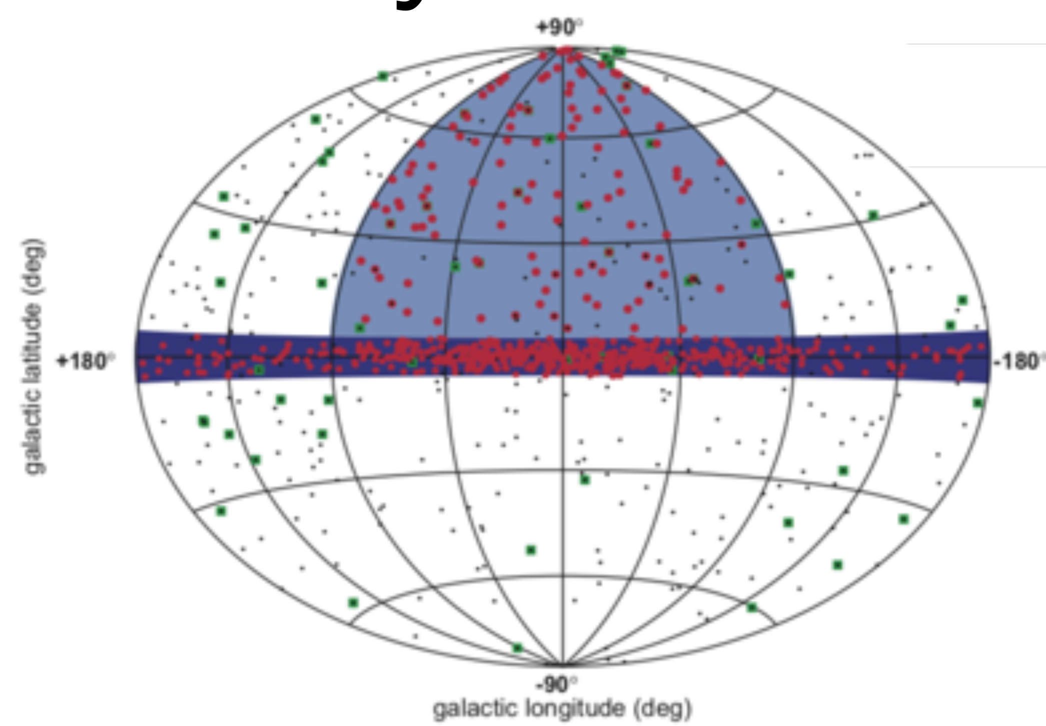
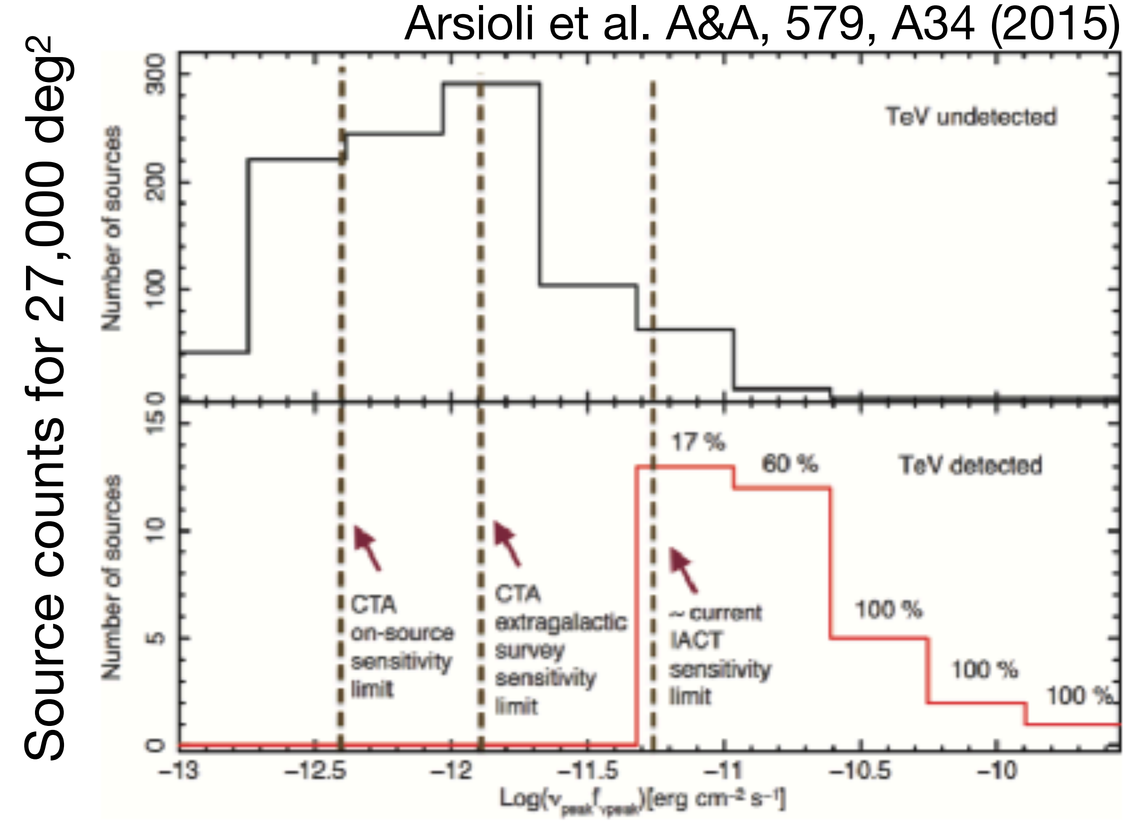



Figure credit : CTA

Arsioli et al. A&A, 579, A34 (2015)



# GRBs and transients

- After more than 25 years of looking for GRBs with ground-based gamma-ray telescopes 3 were discovered over last 2 years (MAGIC & 2 x HESS). Details of detections not yet published !

**First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C**

ATel #12390; *Razmik Mirzoyan on behalf of the MAGIC Collaboration*

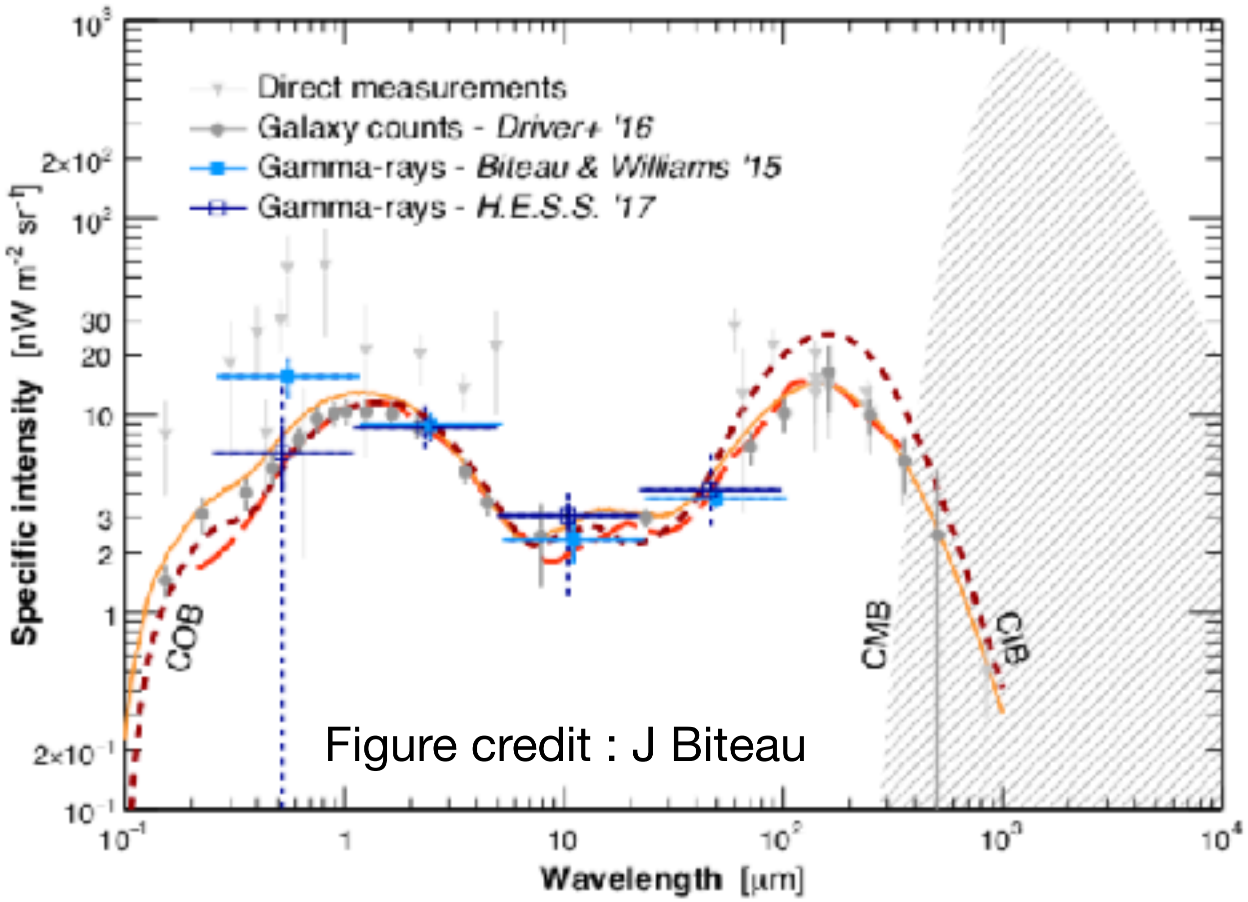
| | |
|---|---|
| Discovery of Late-Time Very High Energy Emission from a Gamma-ray Burst Afterglow | *Edna L. Ruiz Velasco* |
| *Teatro Cuse, Italy, Bologna* | 13:11 - 13:24 |

**GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.**

ATel #13052; *M. de Naurois (H.E.S.S. Collaboration)*

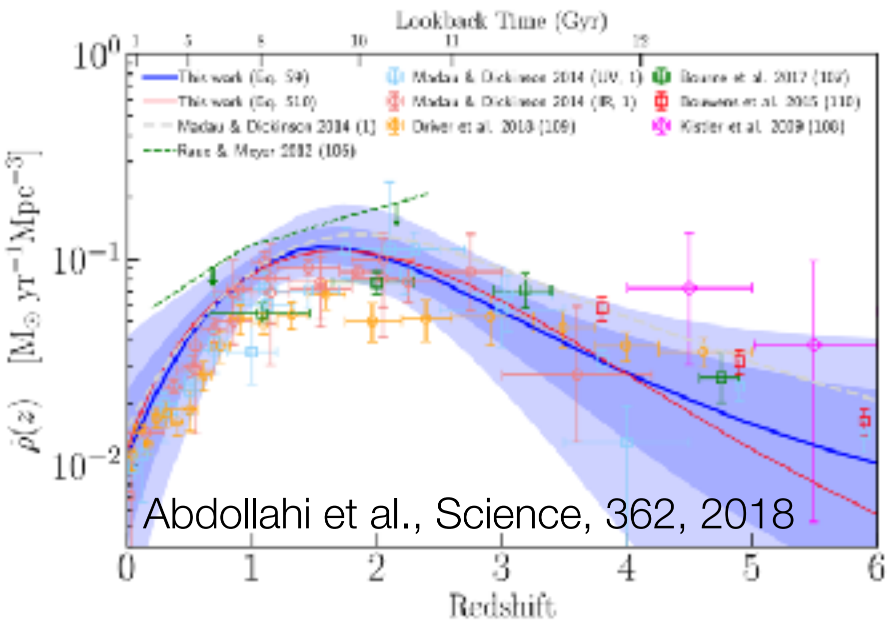
- The 10-year LAT : 17 short & 169 long. Energies above 100 GeV.
- Prediction (prior to TeV detections) are that rates of at least 1 detection/yr could be possible with CTA.
- How high in energy can emission go (opacity) ? What are timescales for acceleration and cooling & how do these depend on energy ?
- <u>Prompt emission</u> : certain observation programs can be optimised to also increase detection of prompt transients (at cost to sensitivity) : divergent pointing where telescopes look in different directions
- <u>Fast response & high sensitivity</u> : are of primary importance in responding to transient alerts. CTA has been designed for this.

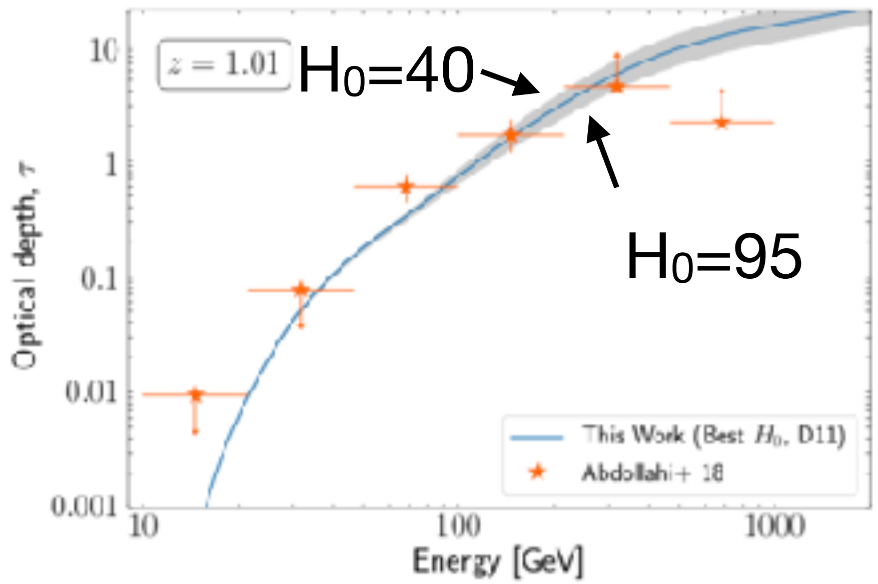
# Gamma-ray cosmology : EBL

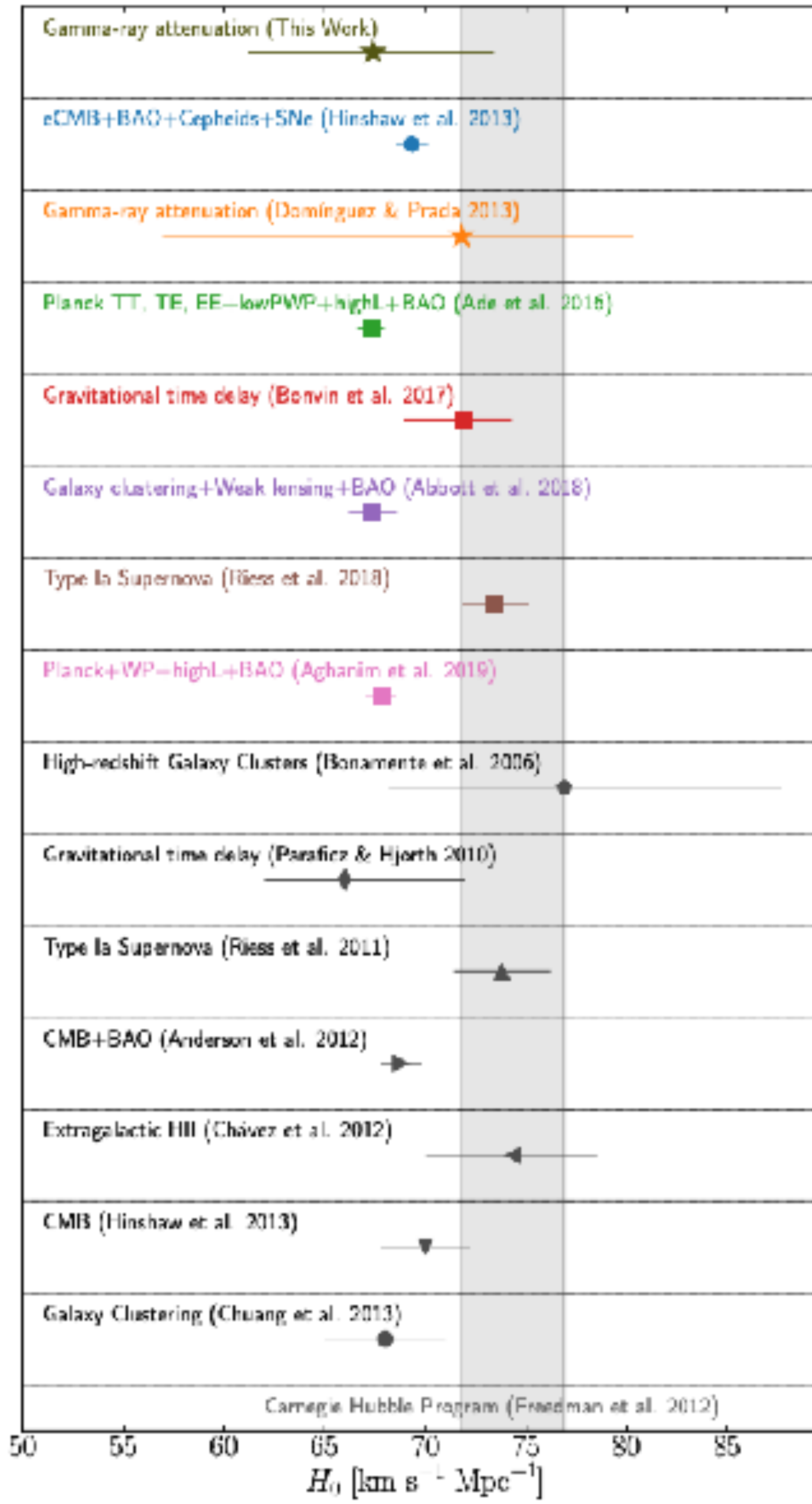



- Attenuation of gamma-ray spectra from pair production interactions over cosmic distances leaves identifiable imprint on spectra of distant sources as $\exp\{-\tau(E,z)\}$
- Density of background optical (star light) and IR (dust emission) light from history of star formation provide major backgrounds.
- GeV-TeV photons from distant sources constrain these photon fields to be close to values required from galaxy counts ; lower than values given by the difficult direct measurements.
- CTA will bring : precision calibration of energy scale, more sources, out to higher redshifts, better spectra.
- Expect to probe EBL evolution out to z=2.5.

# Gamma-ray cosmology : SFH & $H_0$




Domínguez et al., in press, arXiv:1903.12097

- Evolution of optical & IR field densities depend on star formation history (SFH) and cosmology of Universe ($H_0$)
- Gamma-ray opacity measurements can be interpreted in context of a consistent SFH model to give constraints on $H_0$.
- CTA will provide more sources in the range out to z=1 which will better constrain these parameters.

# Beyond the gamma-ray spectrum

- Determination of the redshift of TeV blazars of extreme importance for source studies & gamma-ray cosmology. CTA task force with partner observatories in place but continued support important.
- Multimessenger observations with GW, neutrino and cosmic-ray telescopes will provide for a much deeper understanding of many astrophysical sources. See dedicated session.
- SVOM will provide invaluable alerts to CTA for GRB, and also provide MWL observations of afterglows and of AGN.
- Radio imaging of extragalactic jets are needed to address location of gamma-ray emission in the jets of local sources, in combination with the improved PSF from CTA.
- Participation in an MeV instrument is also highly desirable for the future, and in particular one with capabilities for polarimetry. Search for (extreme) MeV blazars. Possibly resolve hadronic and leptonic models on basis of polarisation.