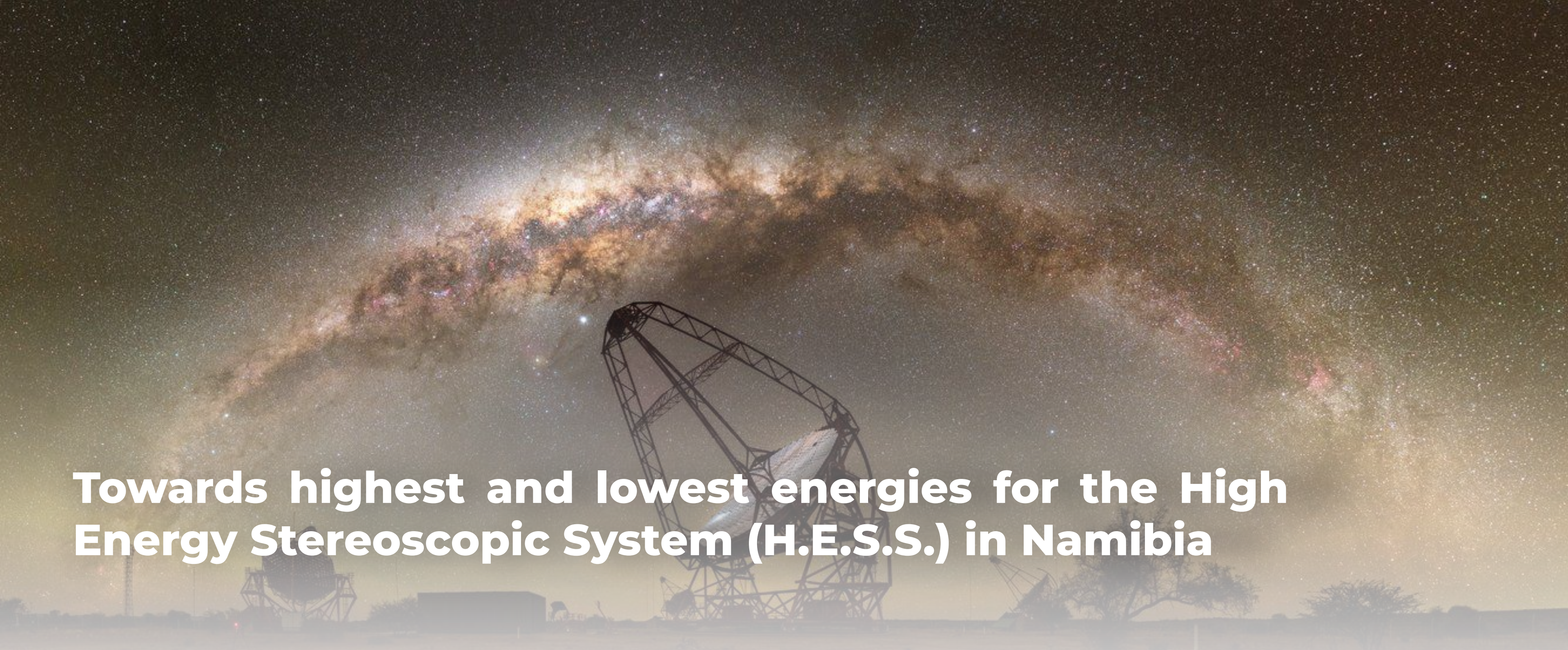


Towards highest and lowest energies for the High Energy Stereoscopic System (H.E.S.S.) in Namibia

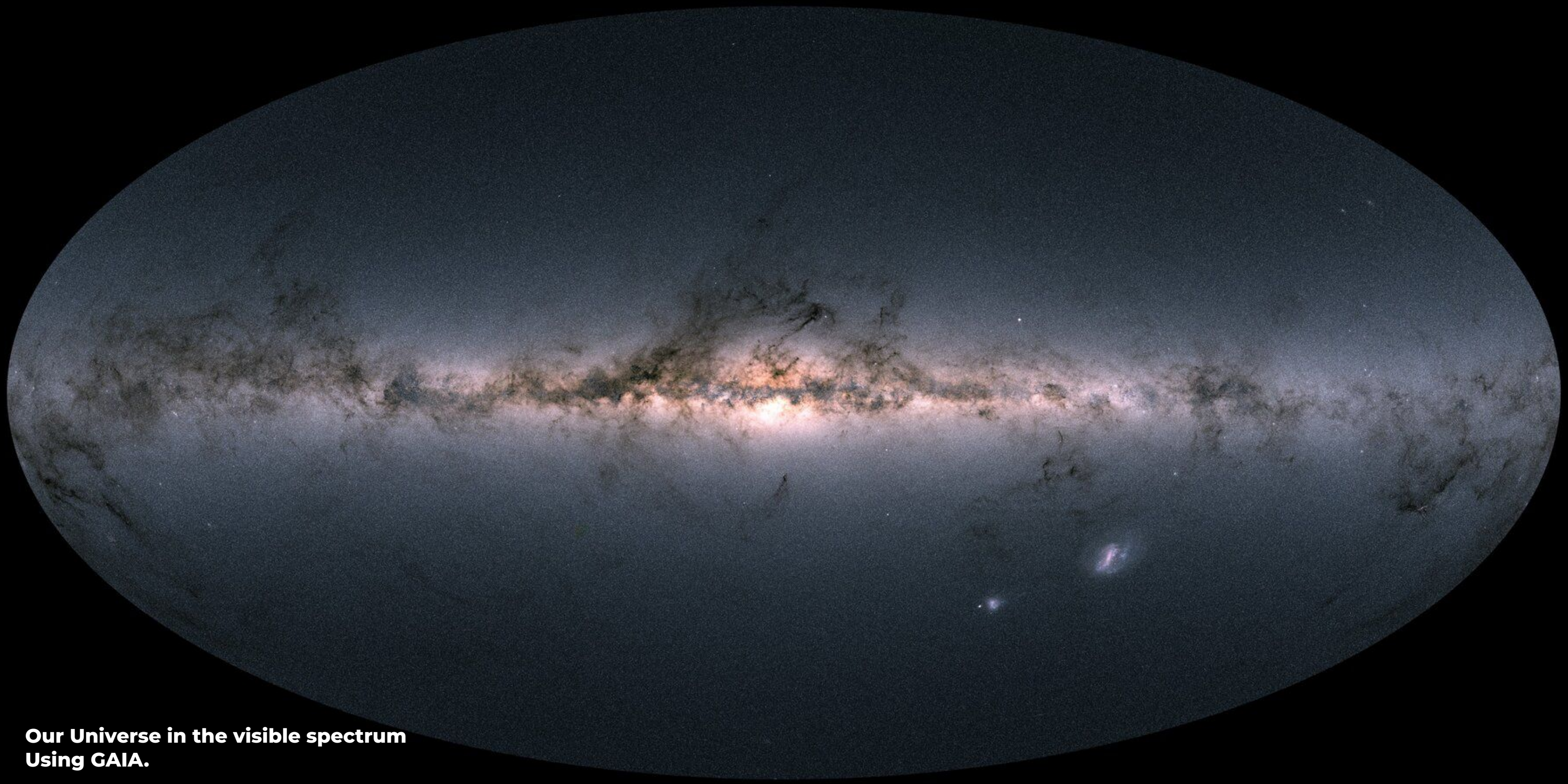
PhD student : Wassim A. SI SAÏD
Supervisor : Mathieu De Naurois
Laboratoire Leprince Ringuet, Palaiseau | CNRS/UMR 7638

For the JRJC 2024 - Cote d'armor, France - 27 Novembre 2024

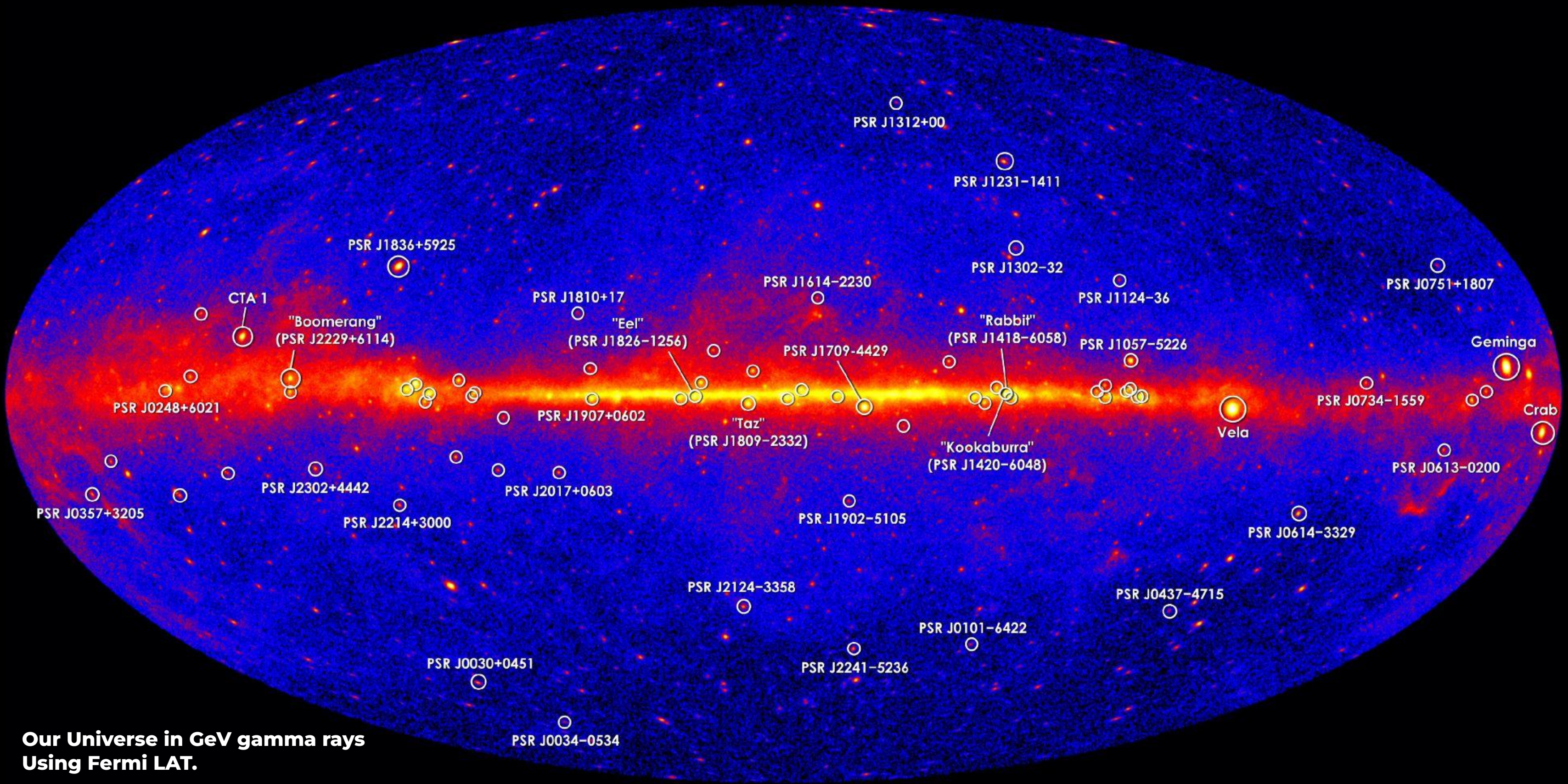
H.E.S.S. Laboratoire Leprince-Ringuet cnrs ÉCOLE POLYTECHNIQUE IP PARIS

1. **General introduction on gamma-astronomy**

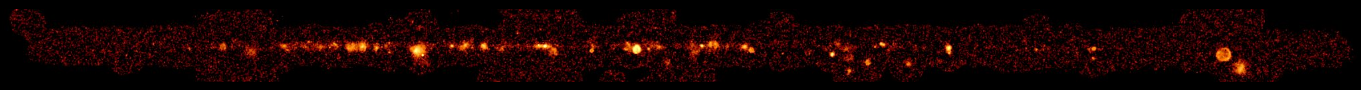
2. The High Energy Stereoscopic System (H.E.S.S.)



Our Universe in the visible spectrum
Using GAIA.



Our Universe in GeV gamma rays
Using Fermi LAT.



Our Galactic plane in TeV gamma rays - (HGPS 2018)
Using H.E.S.S Telescope.

The origin of cosmic Gamma-rays ?

Cosmic gamma rays are produced in catastrophic and most extreme environments in the universe. The nature of the processes are non-thermal.

Key Gamma-Ray Production Mechanisms:
Bremsstrahlung, Inverse Compton Scattering, Synchrotron Radiation.

What are these space cataclysms ?

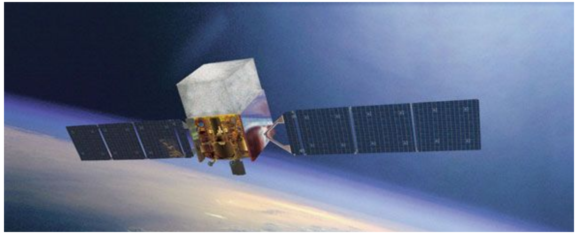
Pulsars and compact objects (Neutron stars, Black holes) (Maxime Regeard's talk).
Relativistic jets of Active Galactic Nuclei (more details in Samantha Lopez's talk)
Gamma-ray Bursts (Supernova explosion, Gravitational waves from mergers)
Supernovae remnants outer shells
…

How do we observe Gamma-rays ?

With Space Telescopes :

Fermi, Swift-BAT, Integral… (More in Samantha Lopez talk)

MeV-GeV Domain

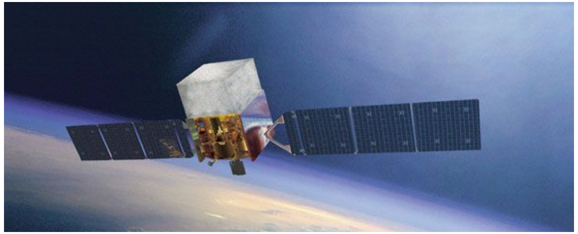


How do we observe Gamma-rays ?

With Space Telescopes :

Fermi, Swift-BAT, Integral… (More in Samantha Lopez's talk)

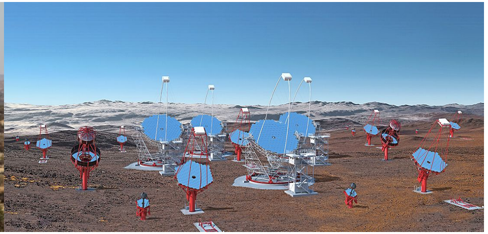
MeV-GeV Domain



Ground Based detectors :

Veritas, MAGIC, H.E.S.S. (This presentation), and Cherenkov Telescope Array Observatory (CTAO)

GeV-TeV Domain

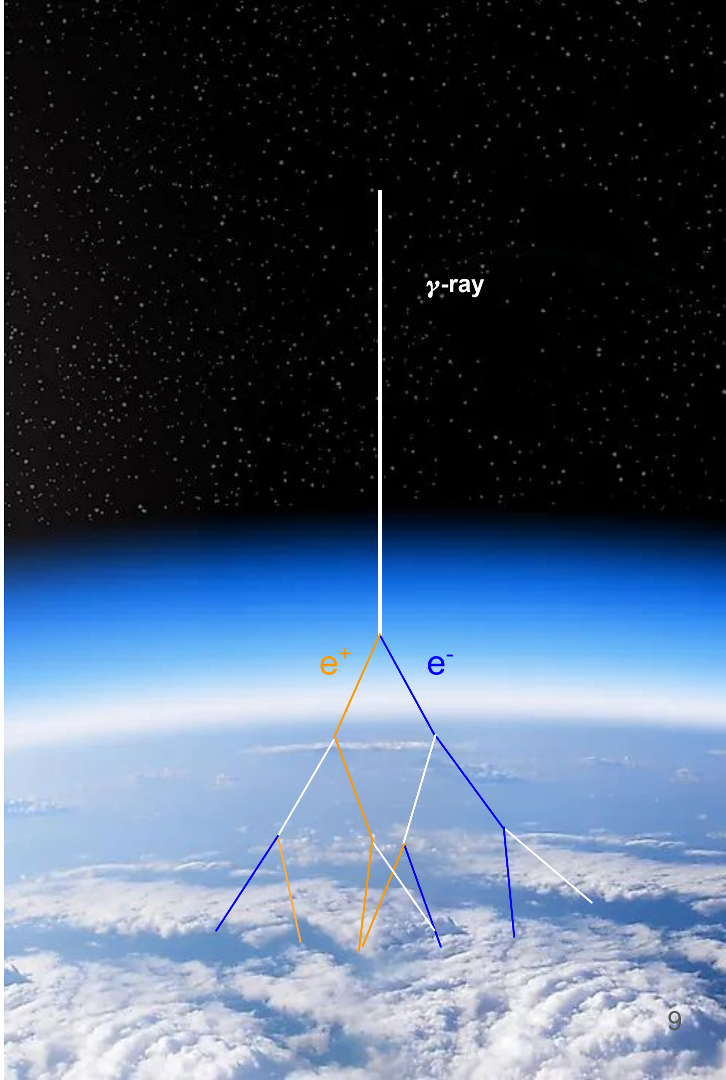


Ground based detections

Ground-based gamma-ray astronomy field is made possible by utilizing Earth's atmosphere as a naturally available calorimeter.

Cosmic gamma photons interact with the columbian field of the atoms and molecules in the atmosphere producing an electron-positron pair ($e+$,$e-$) that initiate an electromagnetic cascade.

The em-shower is detected through atmospheric Cherenkov effect from charged secondary particles created in the shower.

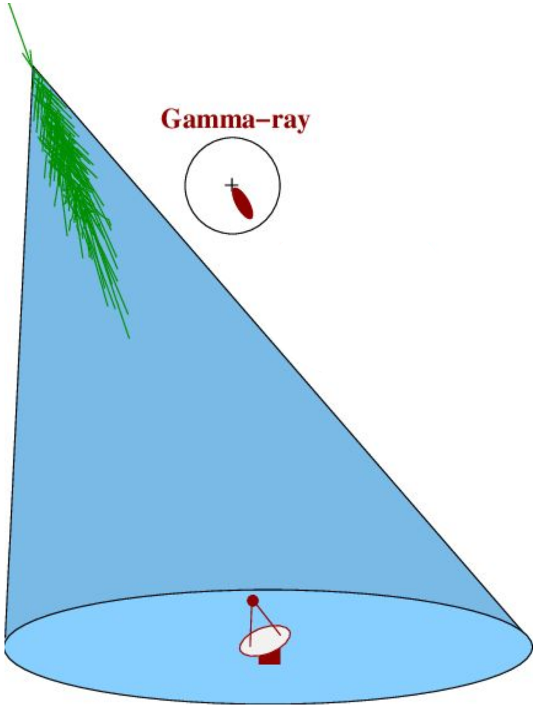


Ground based detections

Depending on the initial photon energy, the Cherenkov light from the cascade can be :

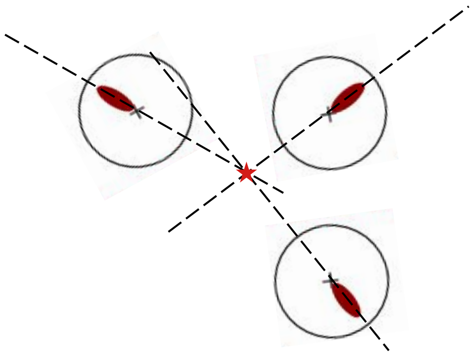
- Prominent in **Blue** (~300–450 nm).
- faint ~100 photons/m^2.
- short < 1 ns.
- within a 130 m distance from the shower center.

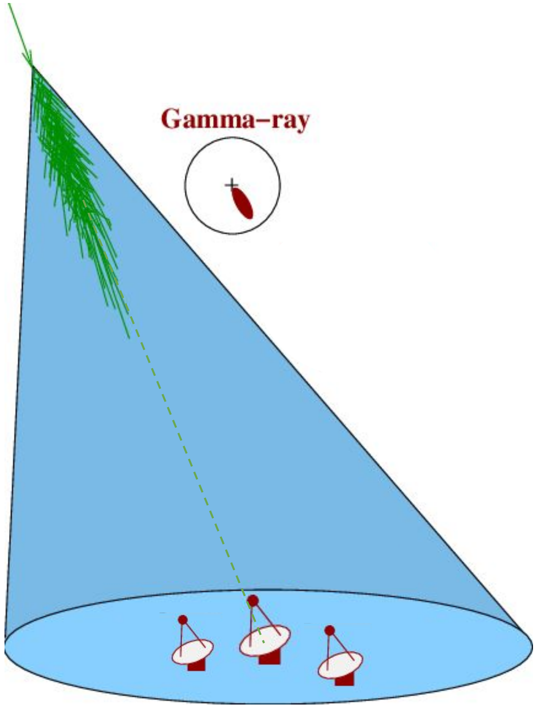
Imaging these blue Cherenkov flashes allow an indirect measurement of the the primary particle of the shower - **Imaging Atmospheric Cherenkov Technique (IACT).**



Ground based reconstruction

The initial particle energy, and direction can be reconstructed using the geometry of the Cherenkov image and the parallax with multiple telescopes.





1. General introduction on gamma-astronomy

2. **The High Energy Stereoscopic System (H.E.S.S.)**

3. Expanding H.E.S.S. capabilities to lower energies

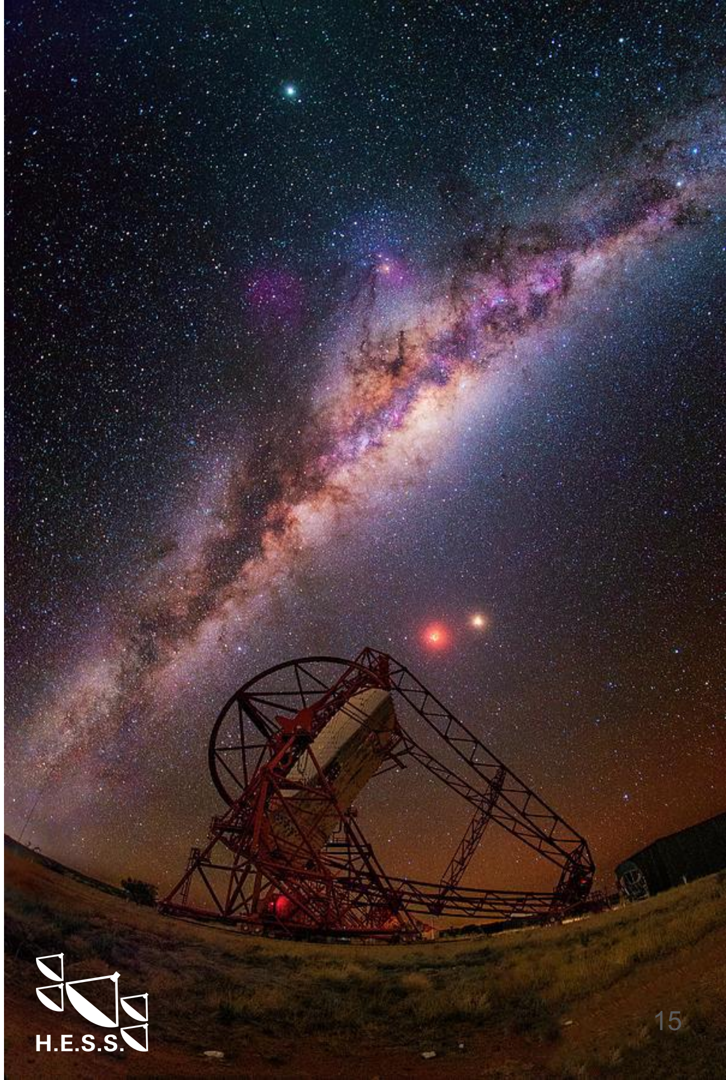

H.E.S.S
1000 - Achievement unlocked
You placed the word Krampouz in the JRJC.

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

Array of 5 Cherenkov Telescopes. CT1-4 with a 12 m Ø mirror and CT5 the largest Cherenkov Telescope with a mirror of 28 Ø m. in operation since 2002 at 1800 meters asl in the Khomas Highlands in Namibia.

H.E.S.S. system is capable of :

- Observe and study galactic and extragalactic sources in the Southern Hemisphere.
- Survey dense regions of the Milky Way (H.E.S.S. Galactic Plane Survey).
- Follow up on alerts from multi-messenger networks to detect gamma-ray emissions.
- Detect transient phenomena like GRBs, AGN flares, and X-ray binary outbursts.
- Characterize low-energy gamma-ray spectra with CT5.



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

3. Expanding H.E.S.S. capabilities to higher and lower energies

4. FlashCAM implementation in French Analysis Pipeline

H.E.S.S. I

2002

4 Telescopes commissioned CT1-4

~100 GeV to 10 TeV.

H.E.S.S. I

2002

H.E.S.S. II

2012

4 Telescopes commissioned CT1-4

~100 GeV to 10 TeV.

CT5 the 28m mirror telescope was built

Expanding H.E.S.S. capabilities to lower energies ~30 GeV.

Raising the Higher limits to tens of TeV.

Main motivations : Extragalactic science and Transient observations.

H.E.S.S. I

2002

H.E.S.S. II

2012

H.E.S.S. IU Camera upgrade

2015

2017

4 Telescopes commissioned CT1-4

~100 GeV to 10 TeV.

CT5 the 28m mirror telescope was built

Expanding H.E.S.S. capabilities to lower energies ~30 GeV.

Raising the Higher limits to tens of TeV.

Main motivations : Extragalactic science and Transient observations.

Camera upgrade to the small telescopes HESS-I → H.E.S.S. IU.

Faster and more reliable electronics.

H.E.S.S. I — **2002**

H.E.S.S. II — **2012**

H.E.S.S. IU Camera upgrade — **2015** – **2017**

CT5 NamCAM era — **2019**

4 Telescopes commissioned CT1-4

~100 GeV to 10 TeV.

CT5 the 28m mirror telescope was built

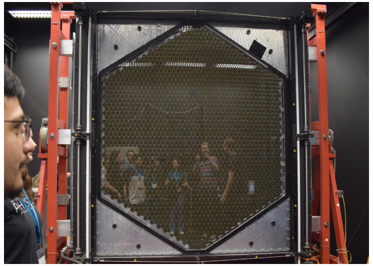
Expanding H.E.S.S. capabilities to lower energies ~30 GeV.

Raising the Higher limits to tens of TeV.

Main motivations : Extragalactic science and Transient observations.

Camera upgrade to the small telescopes HESS-I → H.E.S.S. IU.

Faster and more reliable electronics.



CT5 camera was replaced by NamCAM, a FlashCAM prototype camera Medium sized telescopes of CTAO-south.

Improved data acquisition speed and time resolution, enhancing capabilities for detecting transients like GRBs and fast extragalactic flares.

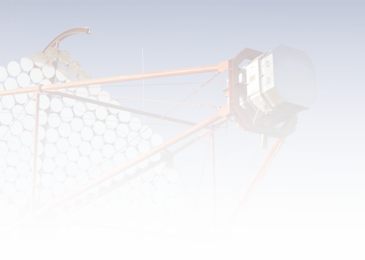
H.E.S.S. I

H.E.S.S. II

H.E.S.S. IU Camera upgrade

CT5 NamCAM era

2002 — 2012 — 2015 — 2017 — 2019



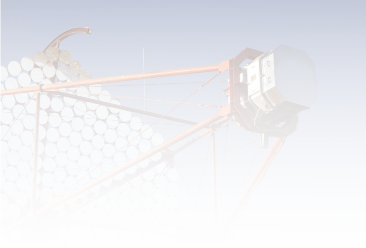
5 years into NamCAM era… **not a single** paper including NamCAM data are **yet published.**

H.E.S.S. I — 2002

H.E.S.S. II — 2012

H.E.S.S. IU Camera upgrade — 2015, 2017

CT5 NamCAM era — 2019



5 years into NamCAM era... **not a single** paper including NamCAM data are **yet published.**

Multiple calibration and analysis pipelines **coexist** within H.E.S.S. with different paradigms.

To ensure the scientific relevance of the results a **cross-checks** between two different pipelines is **mandatory** before publication by the collaboration.

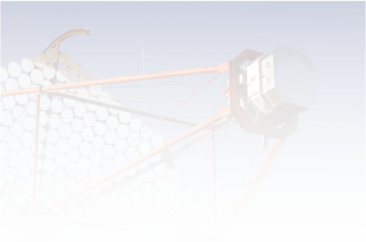
H.E.S.S. I

H.E.S.S. II

H.E.S.S. IU Camera upgrade

CT5 NamCAM era

2002 — 2012 — 2015 — 2017 — 2019



NamCAM implementation in **German Calibration**, **German Analysis** was already been done.
Implementation of NamCAM in **French Calibration**, **French Analysis** started last March of this year with this project.

3. Expanding H.E.S.S. capabilities to higher and lower energies

4. implementation in the French Analysis Pipeline

5. NamCAM potential in H.E.S.S.

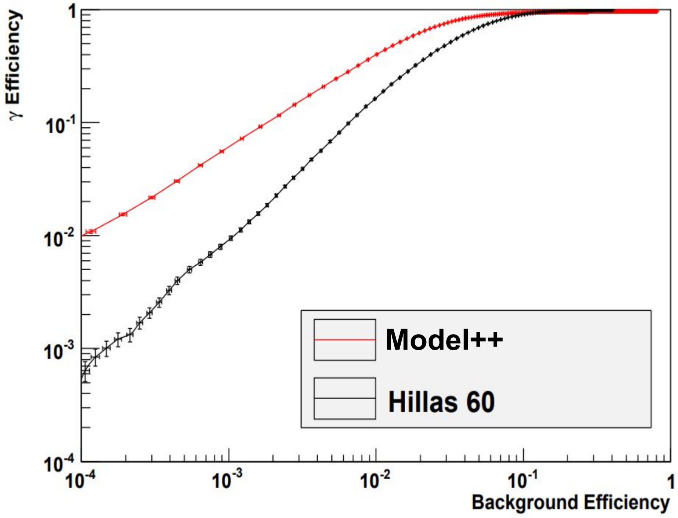
French Analysis pipeline

Is one of the two main calibration and analysis pipelines in the H.E.S.S. Collaboration.

One key features of French Analysis is its in house reconstruction model : Model++ (10.1016/j.astropartphys.2009.09.001)

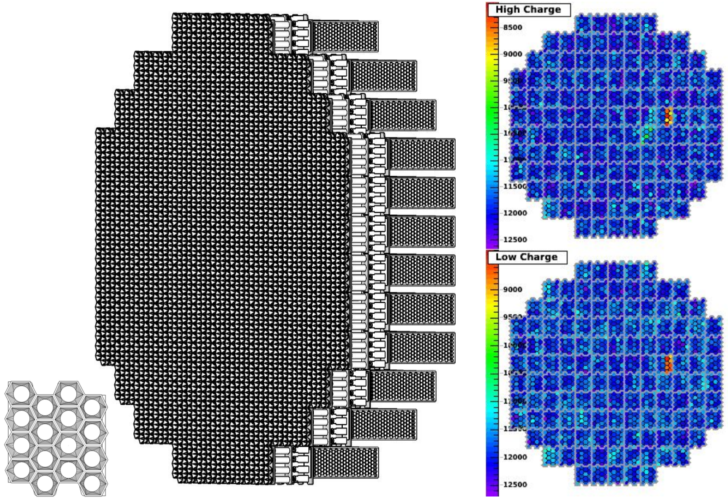
a sophisticated template based reconstruction model, that utilize a detailed Monte Carlo simulation templates for different shower parameters, combined with maximum likelihood estimation on the Cherenkov images and templates.

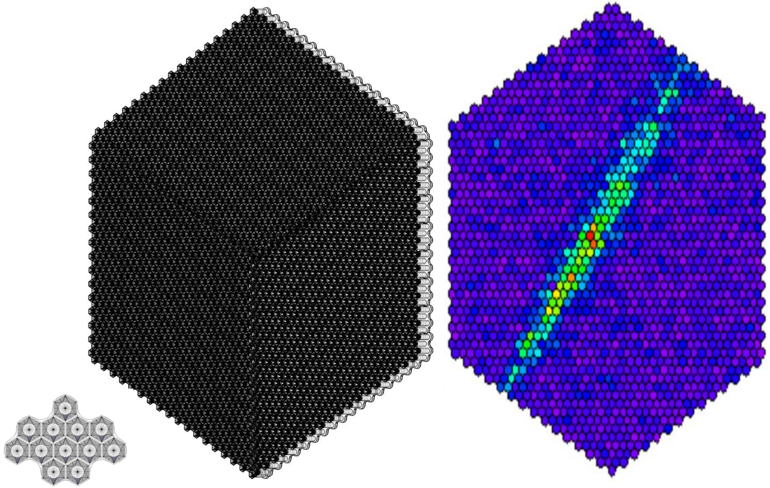
Model++ provide a more precise direction and energy reconstruction of the photon induced shower compared to other models and shines at low energies with a high background rejection power.



10.1016/j.astropartphys.2009.09.001

Where is the challenge ?





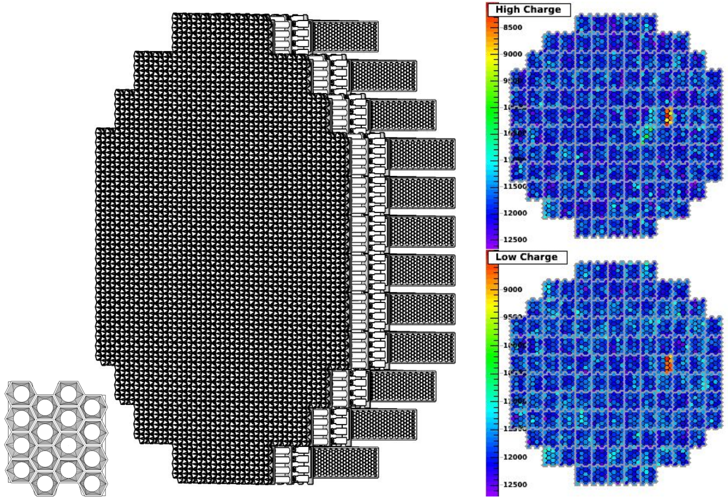
HESSII characteristics (Old)

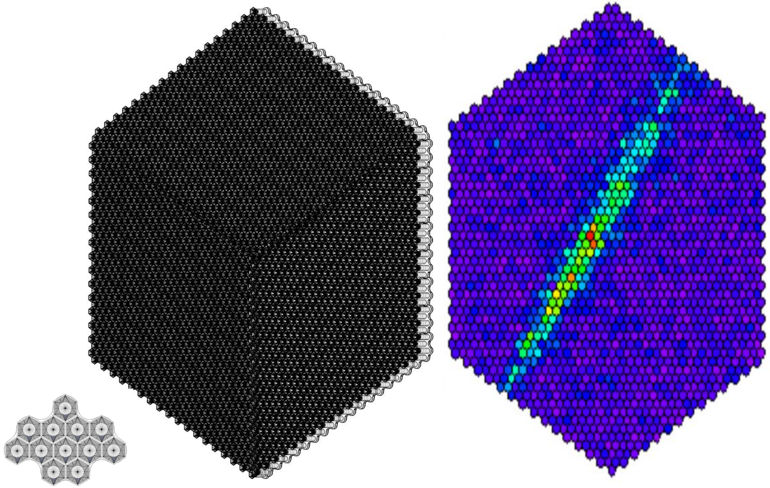
2048 pixels camera, ~30% peak quantum efficiency
Dynamic range : 0.2 p.e - 3000 p.e
Classical two gain / pixel setup. a High and Low gain.
Fixed 16ns integration window.

NamCAM characteristics (New)

1764 pixels camera, 40% peak quantum efficiency
Dynamic range : 0.2 p.e - 3000 p.e
One single gain / pixel with two behaviours :
Linear between 0.2 - 200 p.e / exponential above 200 p.e.
Adjustable 9ns integration window.

Where is the challenge ?





HESSII characteristics (Old)

Camera output raw **ADC counts** for both channels, conversion from ADC count to p.e is done in the calibration pipeline.

NamCAM characteristics (New)

Camera output **signals in p.e** after an autocalibration inside the camera.

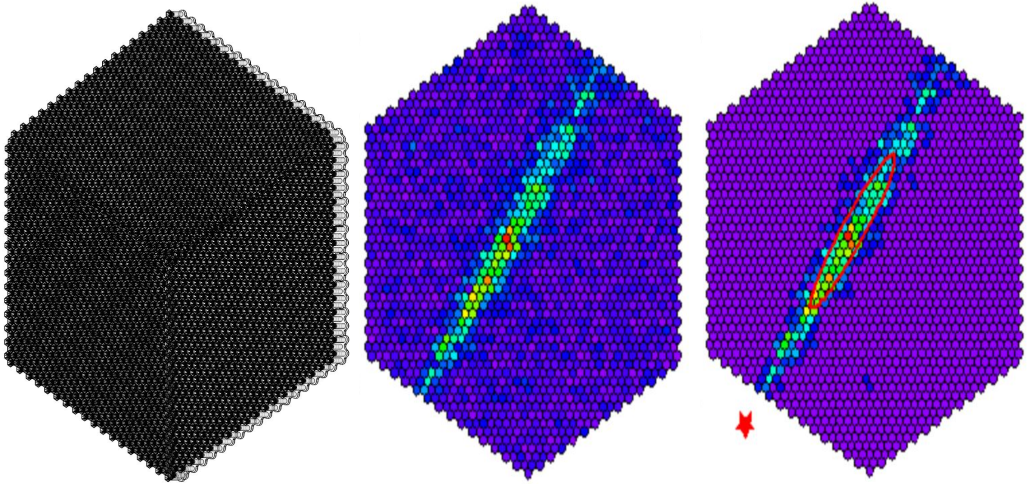
NamCAM implementation outline

1. Read and display NamCAM charges - Adapt if necessary classical Hillas reconstruction.
2. Adapt the Calibration Pipeline to NamCAM single gain design.
3. Adapt Model++ to NamCAM.

NamCAM Hillas reconstruction

A dedicated intensity calculation script was developed for NamCAM to read the camera raw data (in p.e) and display them.

The French pipeline image cleaning algorithm worked perfectly with minor changes. The classical Hillas shape reconstruction method was applied in the same way as the old camera with success.



Adaptation of The French Calibration

French Calibration is a consequent source code split into different calibration algorithms modules to simplify the calibration.

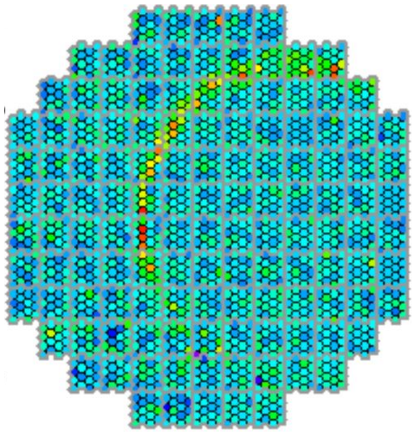
As of today 4 of the pipeline algorithms were adapted for NamCAM :

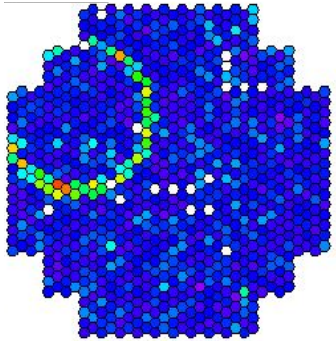
- **Muon efficiency algorithm** (partially - explanation just after).
- **Electronic pedestals estimation** (done).
- **Run pedestals** (recently adapted - verification in progress before production).
- **Flatfield coefficient algorithm** (Done by Jimmy Shapopi - PhD at UNAM).

Adaptation of French Calibration
Muon efficiency

French Calibration computes a muon efficiency parameter for Model++ by identifying muon candidates from observation runs.

Muon Cherenkov images are characterized by their nearly perfect circular "O" shape. Since the Cherenkov light produced by muons is independent of the initial particle energy driving the shower, it provides a robust natural calibration parameter for assessing the instrument's response to Cherenkov light.



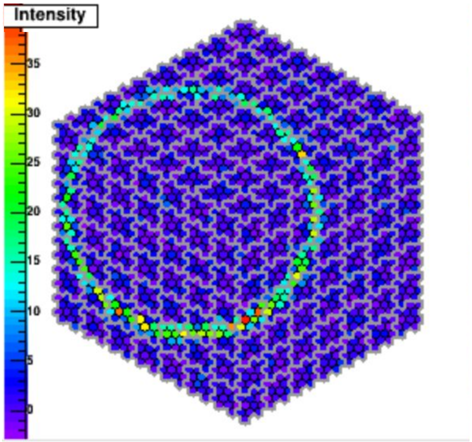


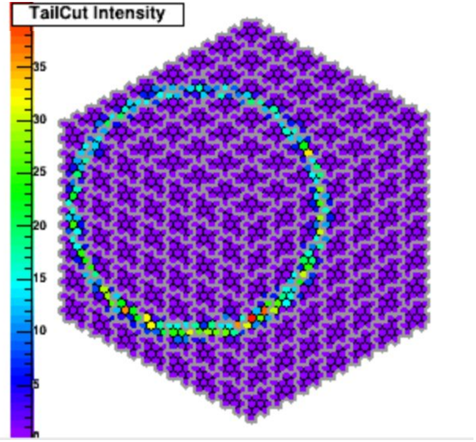
1. Muon images are cleaned.
2. Cercle fitted using Karimaki method (doi.org/10.1016/0168-9002(91)90533-V).
3. Parameters (Radius, impact location on camera, light intensity…) are then extracted.
4. The best fit of the muon is performed with a maximum likelihood.

Adaptation of French Calibration
Muon efficiency

For NamCAM, modification to the Muon efficiency maker was done in a first part. Applying the same cleaning as for Hillas reconstruction. The muon candidate fitter can select muons from NamCAM images.

The likelihood algorithm, requires a detailed description of noise of the camera. And no advancement can be made before estimating the camera pedestals.



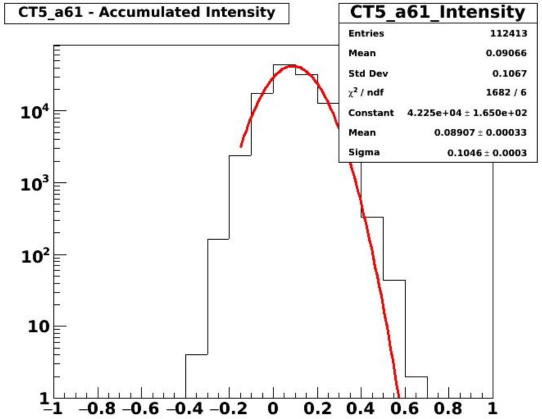


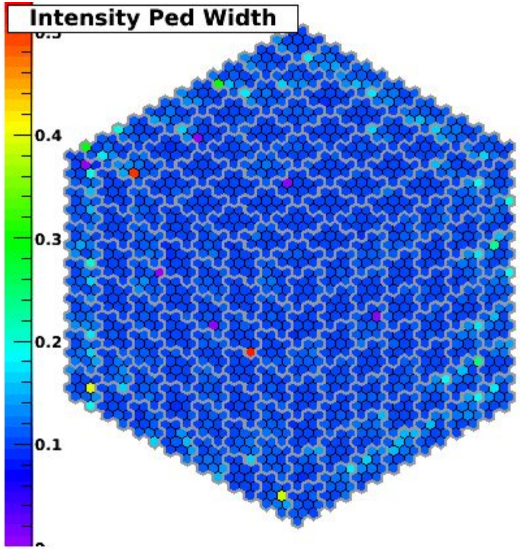
Adaptation of French Calibration
Electronic-dark pedestals

Electronic pedestals runs are done by H.E.S.S. to extract the electronic baseline with camera lid closed in the dark.

Pixel by pixel signal is accumulated in histograms, and fitted to extract the electronic pedestal width. Broken pixels are flagged in the process accordingly.

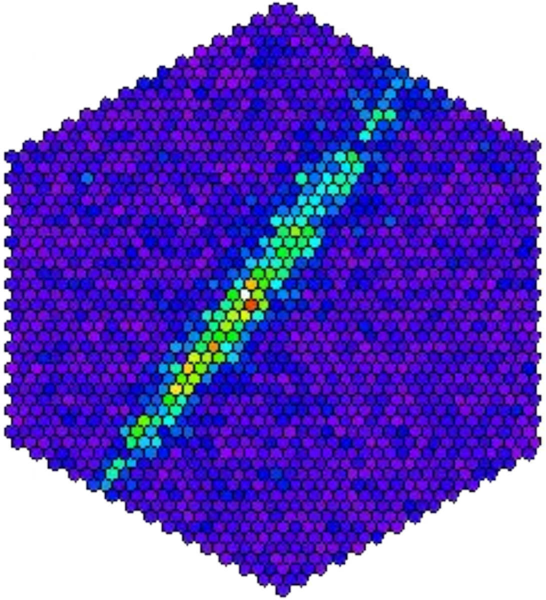
Electronic pedestals are then saved in a calibration database per pixel.





Adaptation of French Calibration
Run pedestals

French Calibration perform a pedestal estimation in observation run, to probe the electronics baseline for proper calibration for Model++.



Adaptation of French Calibration
Run pedestals

French Calibration perform a pedestal estimation in observation run, to probe the electronics baseline for proper calibration for Model++.

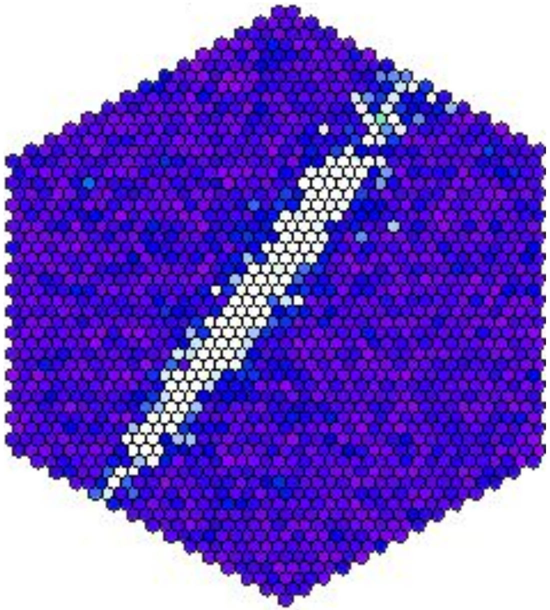
Two methods are being used to separate cherenkov image from the background, and both were adapted for NamCAM.

- Highest Amplitude method.

$$I_p = \{I_p | I_p \in Top_k(I_{all}))\} \quad k = 150.$$

- by Neighbor.

$$I_C = \{I_p | \mu - n\sigma \leq I_p \leq \mu + n\sigma, I_p > Threshold\}$$



Adaptation of French Calibration
Run pedestals

French Calibration perform a pedestal estimation in observation run, to probe the electronics baseline for proper calibration for Model++.

Two methods are being used to separate cherenkov image from the background, and both were adapted for NamCAM.

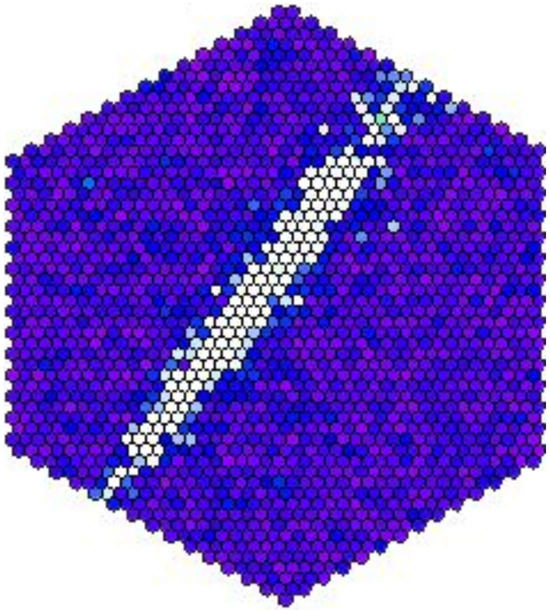
- Highest Amplitude method.

$$I_p = \{I_p | I_p \in Top_k(I_{all}))\} \quad k = 150.$$

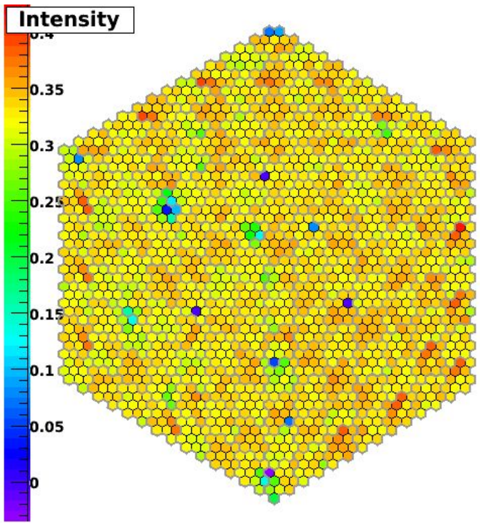
- by Neighbor.

$$I_C = \{I_p | \mu - n\sigma \leq I_p \leq \mu + n\sigma, I_p > Threshold\}$$

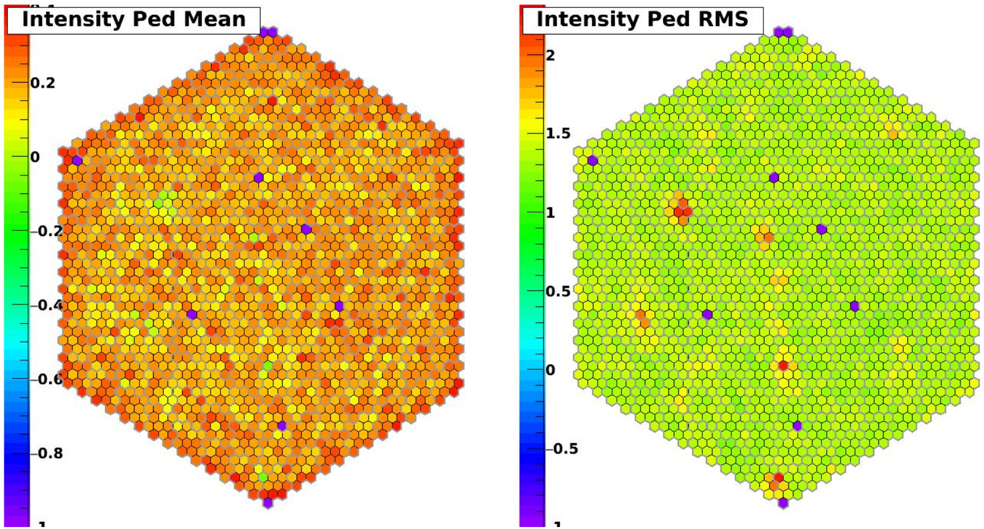
The safe pixels after the Cherenkov cuts are then accumulated and fitted to extract the pedestal width. And then saved in the calibration database per pixel.



Adaptation of French Calibration
Run pedestals



Accumulated intensity (p.e) after cherenkov cuts.



Pedestals Mean and RMS after Cherenkov cut.

NamCAM implementation outline

1. Read and display NamCAM charges - Adapt if necessary classical Hillas reconstruction.
2. Adapt the Calibration Pipeline to NamCAM single gain design.
3. **Adapt Model++ to NamCAM single gain design (coming soon).**

4. NamCAM implementation in French Analysis

5. NamCAM potential in H.E.S.S.

Questions

Preliminary implementation:
These are the first 8 months results and advancements in the project, with much still to be done.

NamCAM in French Analysis:
The integration of NamCAM into the French pipeline is highly anticipated by the H.E.S.S. collaboration and the wider gamma-ray astronomy community.

Unlocking New Insights:
This work will provide access to five years of archived observational data, enabling the production of new scientific publications and cross check what was already prepared waiting for this software implementation.

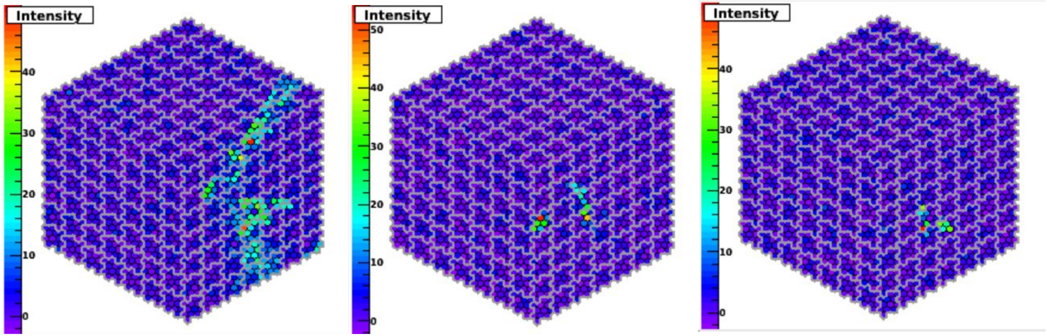
- Analyse a 100 of GRBs and future GRB follow-up (new science for core collapse supernovae, gw…)
- Time based gamma-ray astronomy (AGN flaring…)
- More statistics in lower energies.
- First scientific results with the FlashCAM type camera (Future CTAO).

Questions ?

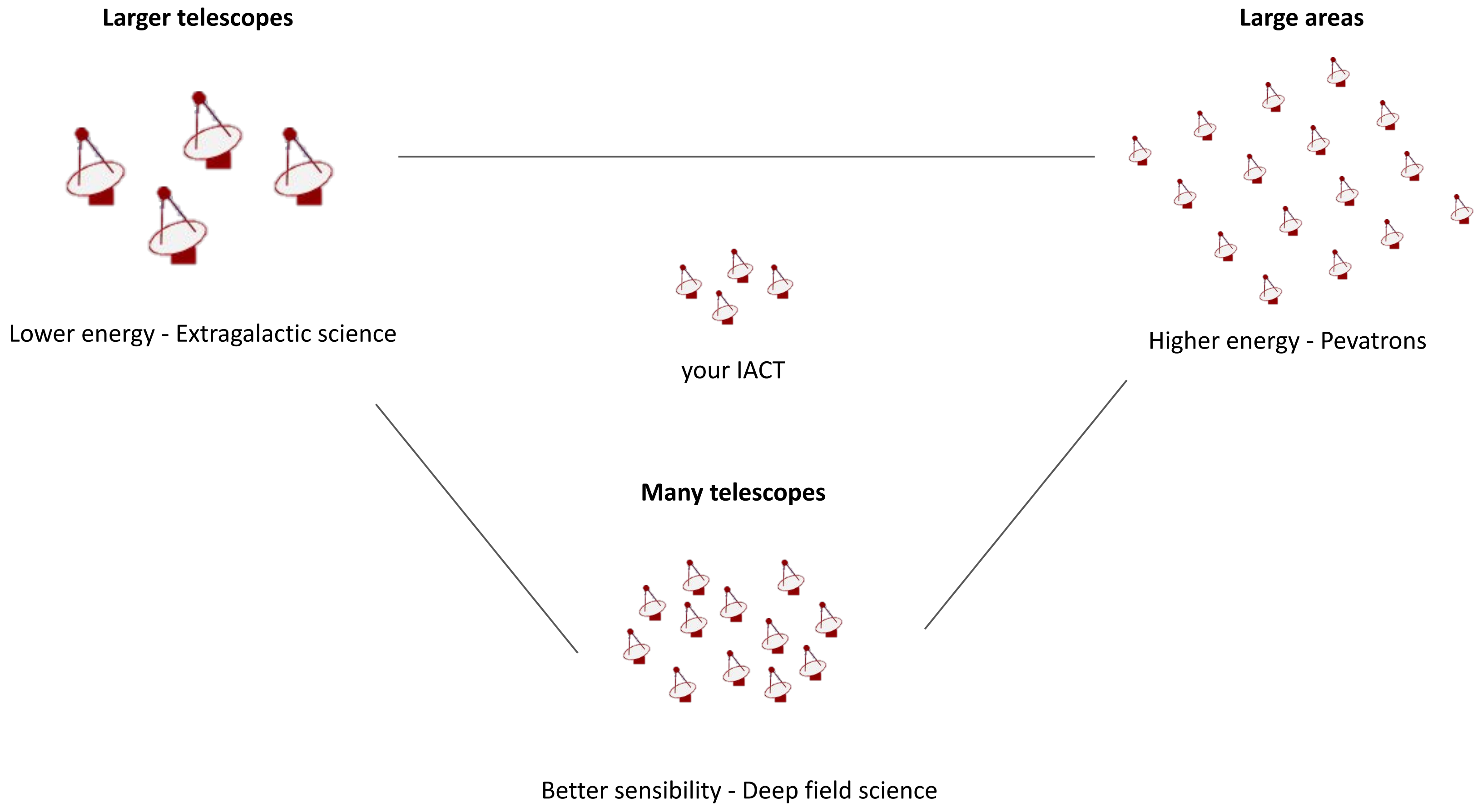
Questions

Backup slides

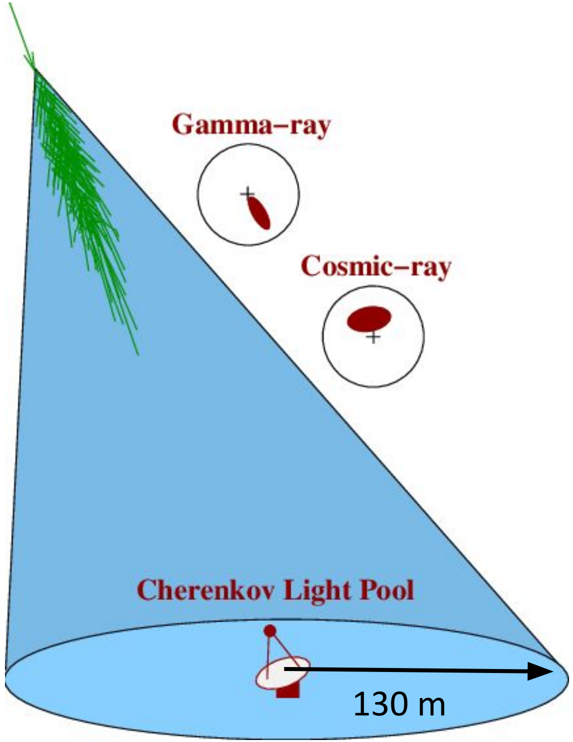
Background (Hadronic showers) :

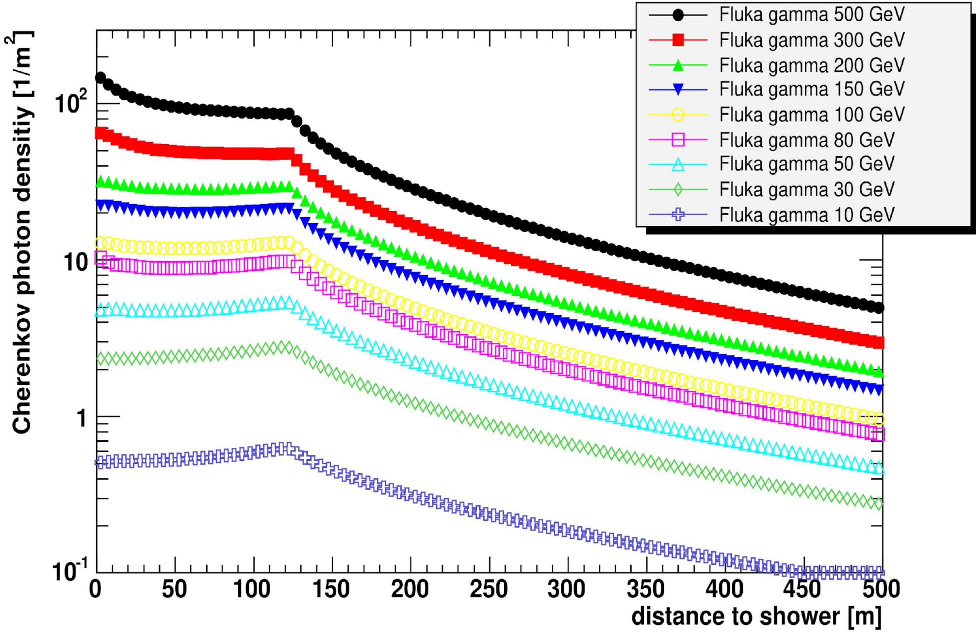


IACT geometries

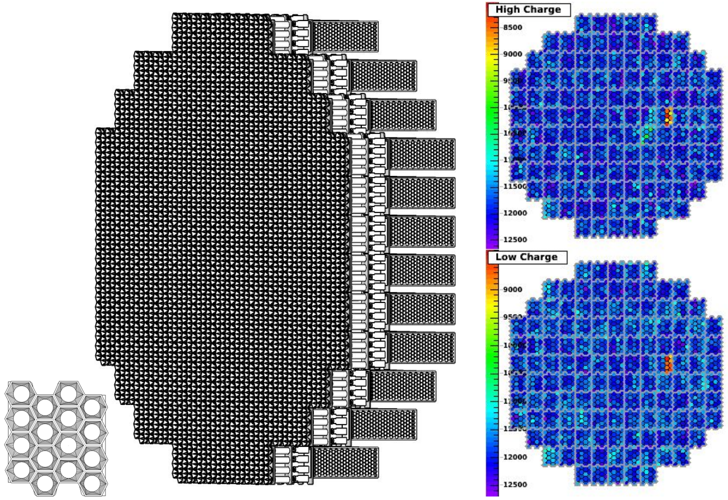


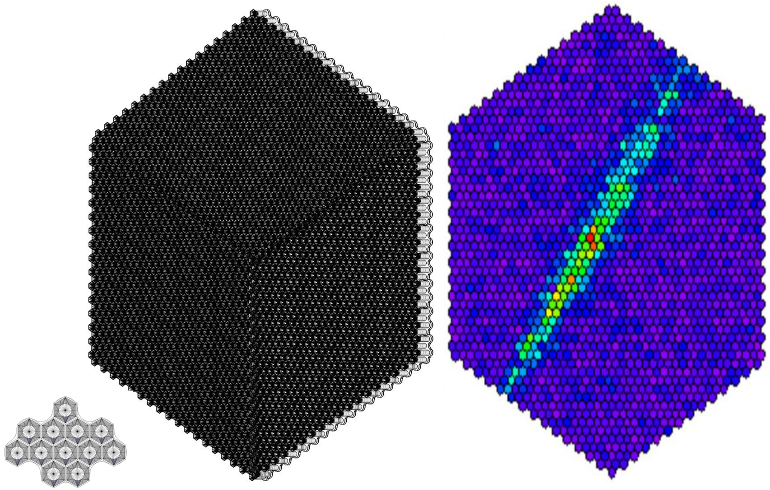
IACT geometries





Calibration process :





HESSII calibration (Old)

$$C_i^{HG} = \frac{ADC_i^{HG} - P_i^{HG}}{G_i^{HG}} \times FF_i \times B_i^{HG}$$

$$C_i^{LG} = \frac{ADC_i^{LG} - P_i^{LG}}{G_i^{HG}} \times (HG/LG)_i \times FF_i \times B_i^{LG}$$

NamCAM Calibration (New)

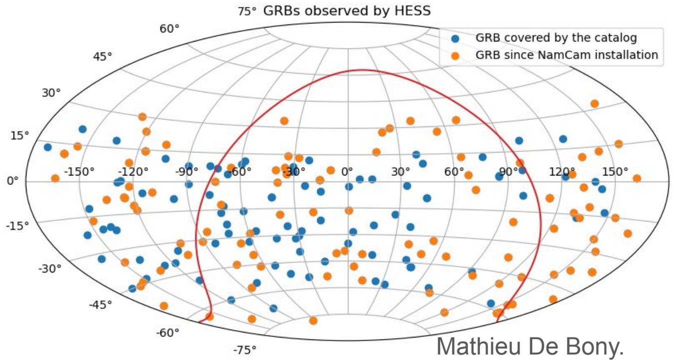
$$C_i = \left(\tilde{C}_i - P_i\right) \times FF_i \times B_i$$

One of the consequences

Public H.E.S.S. GRB observation List

https://grbhess.github.io/

+93 GRB follow-up after NamCAM installation yet to be studied with the French calibration.



Mathieu De Bony.