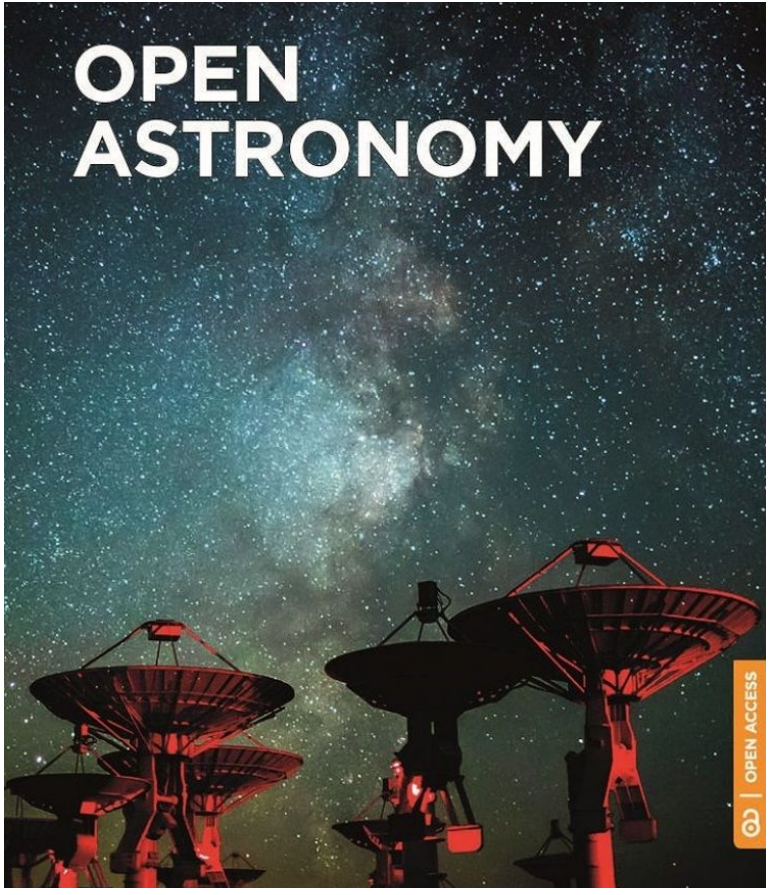
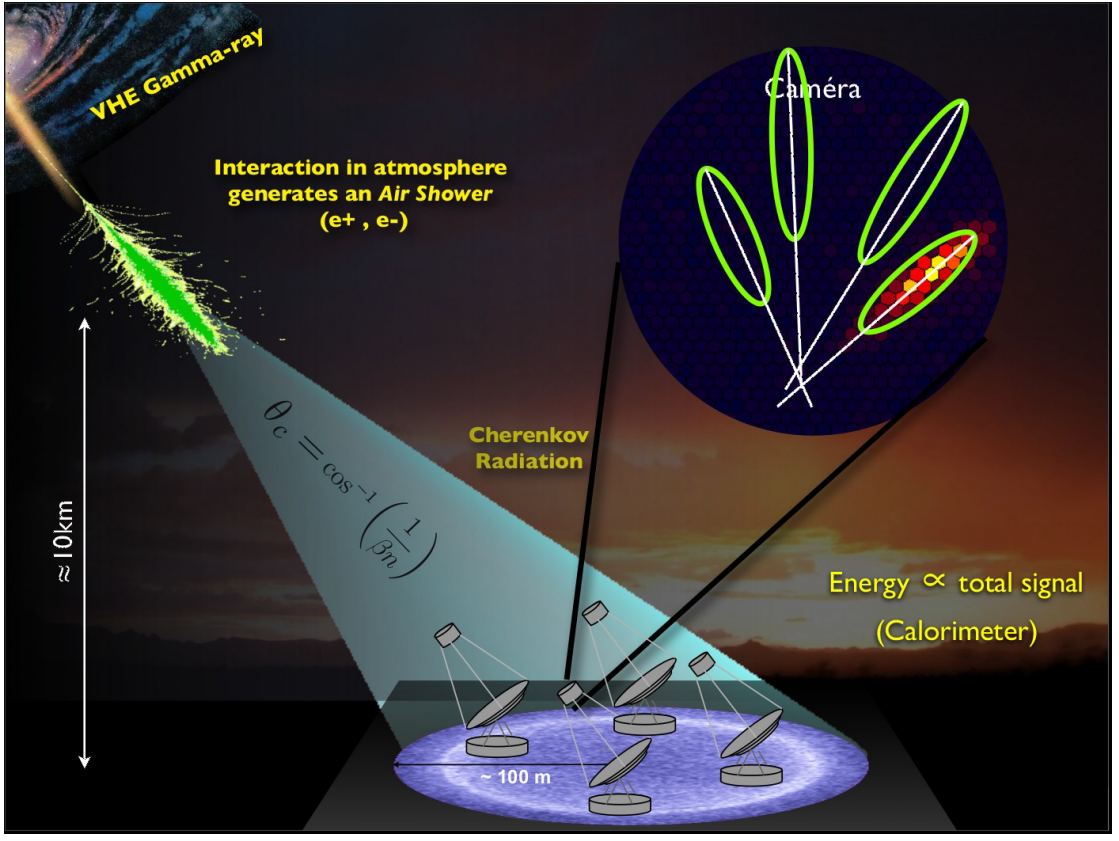


Open Science in the VHE energy domain

C. Boisson (LUTh), M. Servillat (LUTh),
B. Khélifi (APC)

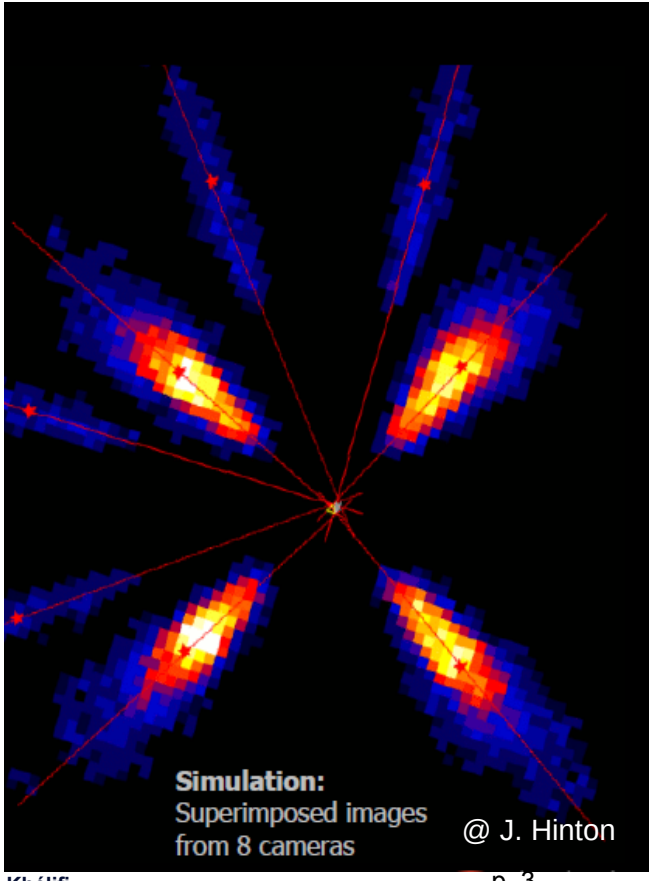
Introduction: Cherenkov Astronomy principles

- Dark nights (small duty cycle)
- Event reconstruction: photon, particle shower, Cherenkov light (faint, few nanoseconds)
- Atmosphere: calorimeter simulations, with assumptions
- Complex dataflow: complex chain of softwares with metadata that need to be structured



Introduction: Cherenkov Astronomy principles

- Why more telescopes in an array?
  - More events, more photons
  - Better spectra and images
  - Fainter sources
- Better events:
  - More precise measurements of atmospheric cascades and hence of primary gamma
  - Improved angular resolution
  - Improved energy resolution
  - Improved background rejection power



Challenge: complex instrument

- To model and fit VHE data, we need accurate Instrument Response Files that change with:

Change during an observation

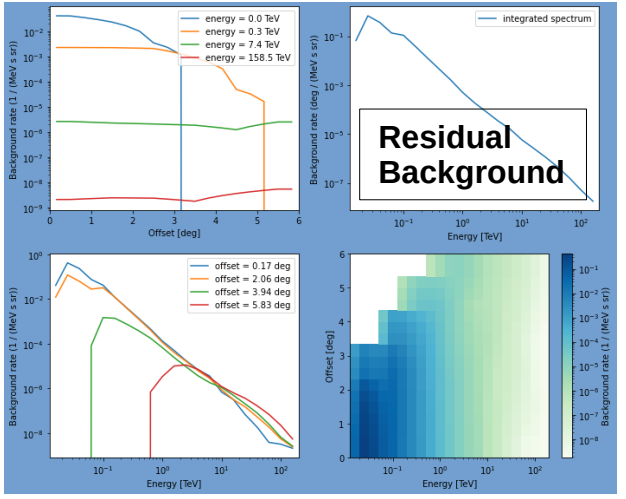
  - Gamma-ray energy
  - Position in Field of view
  - Zenith angle (elevation): atmosphere thickness
  - Ground position of shower relative to the array (Nb. of telescopes of each type that trigger)

Change between observations

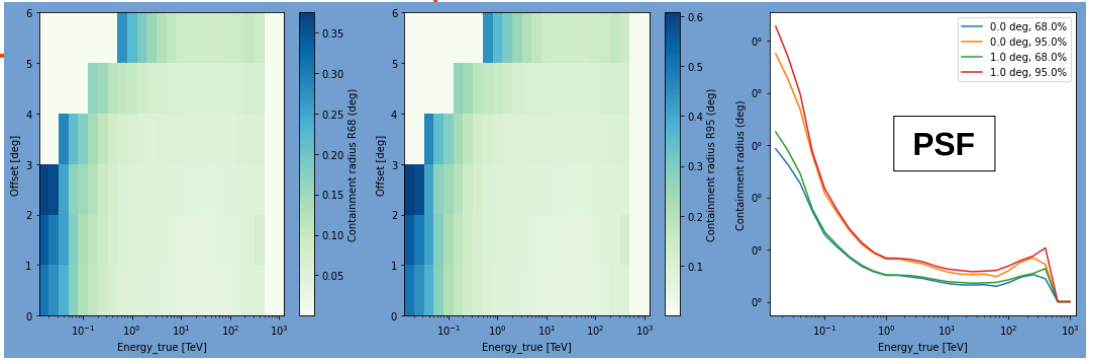
  - Subarray Choice
  - Atmosphere density profile
  - Atmosphere aerosol content profile
  - Optical Night-Sky Background light level (Moon, Zodiacal light, light pollution)

User' choices

  - Analysis configuration: reconstruction algorithm, discrimination strength, privileged observable, source-type characteristic

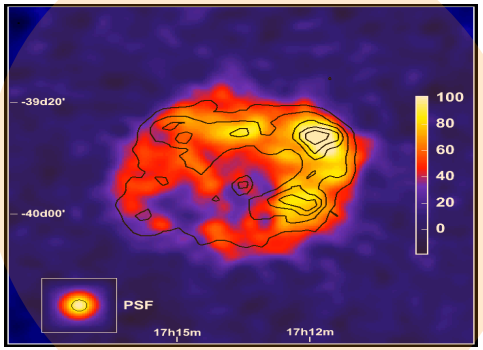


- Need of complex IRFs:
  - their accuracy: need of complex shapes (3→5D, lin/log/cos, true/reconstructed parameters)
  - the representation of systematic errors: bracketing envelope, pdf, simple asymmetric errors ?

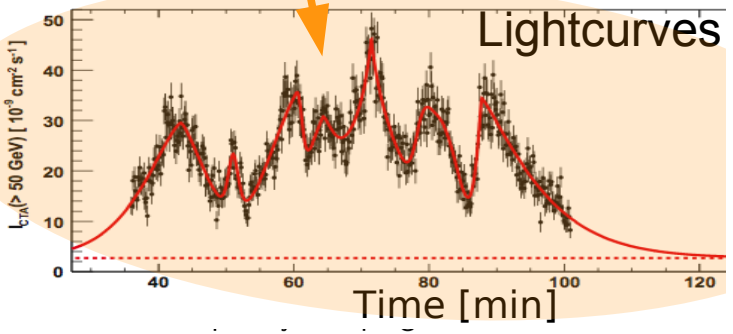


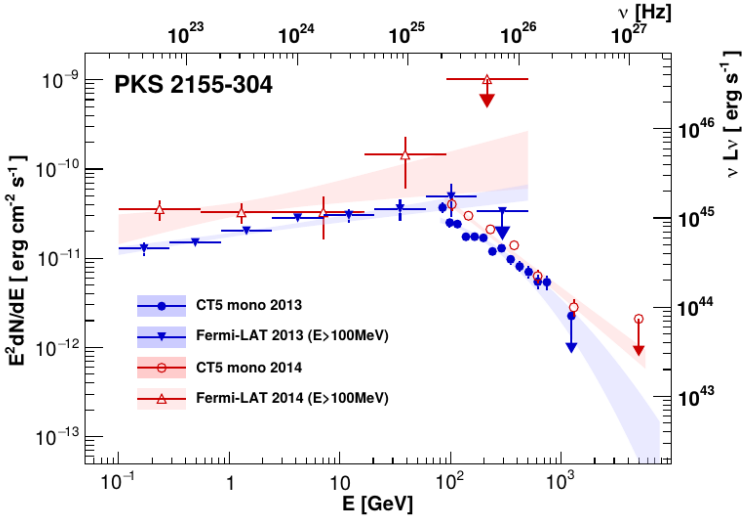
Astrophysics with multi-wavelength data

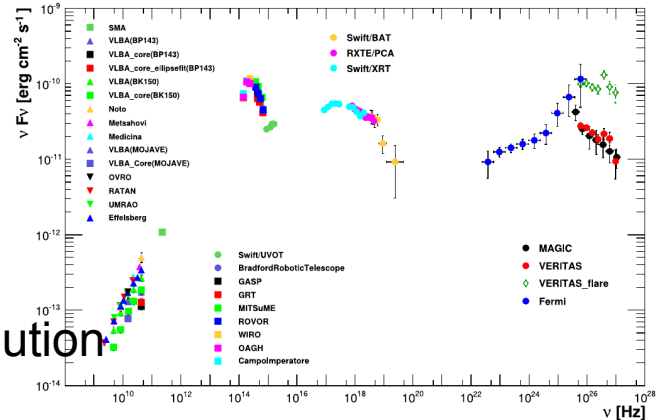
Event lists
(coordinates, time, energy)



Images







Spectral Energy Distribution

- **How to use data at other wavelengths?**
  - Simultaneous?
  - Calibrated?
  - Specific calibration?
  - Errors?
  - Context?

→ Provenance needed and a software that takes into account the data disparities

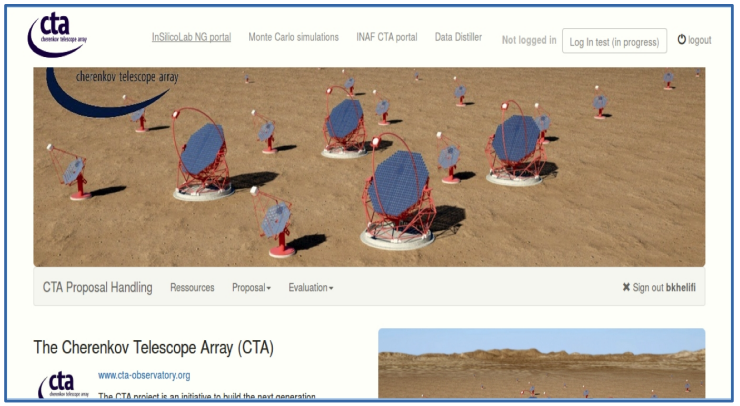
VHE Open Science progress

- ESA&NASA observatories are at the forefront of open-data provision since decades in the HE domain

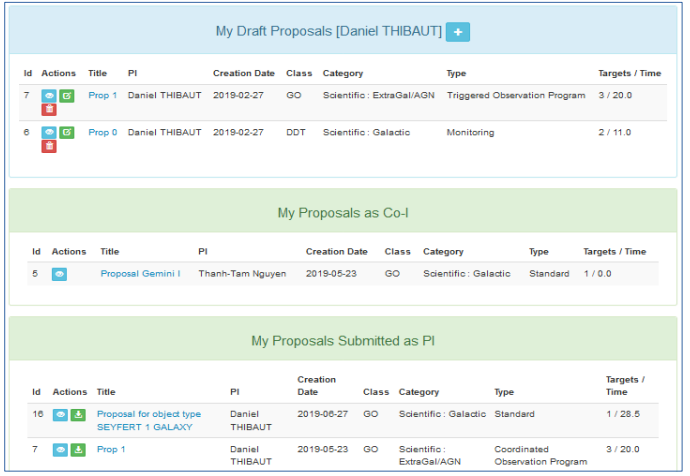
- VHE observatories have just started their shedding
  - Creation of the open initiative about a common VHE data format in 2015 (GADF)
  - Creation of the Gammapy structured open-source project at the end of 2017
  - H.E.S.S.: first public test data release (arXiv:1810.04516)
  - MAGIC: towards a public legacy data portal (arXiv:1909.01172)
  - ANTARES: access to some data sets for neutrino point sources (download page)
  - Gammapy selected as open-source software of choice for analysis of H.E.S.S. data (in the 2021 HESS news)
  - H.E.S.S. is working now on a legacy release of all good quality high-level data
  - IceCube(AMMADA-II) releases publicly their data
  - And CTA, KM3NeT and SWGO observatories will do after some proprietary period

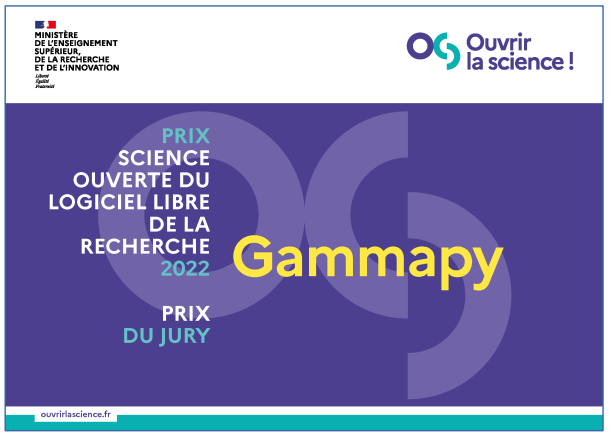
CTA Open Science progress

- CTA, the first VHE gamma-ray observatory:
  - Data will be released after some proprietary period
  - Call of observation proposals will be organised
  - Science Archive and Science Gateway
  - Delivery of an open Science Tools package (Gammapy chosen)



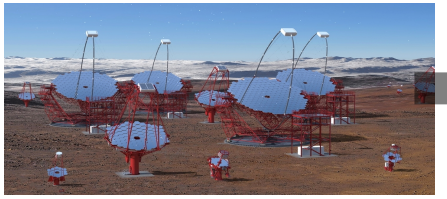
Project `CTA PHP' (APC, LUTh)





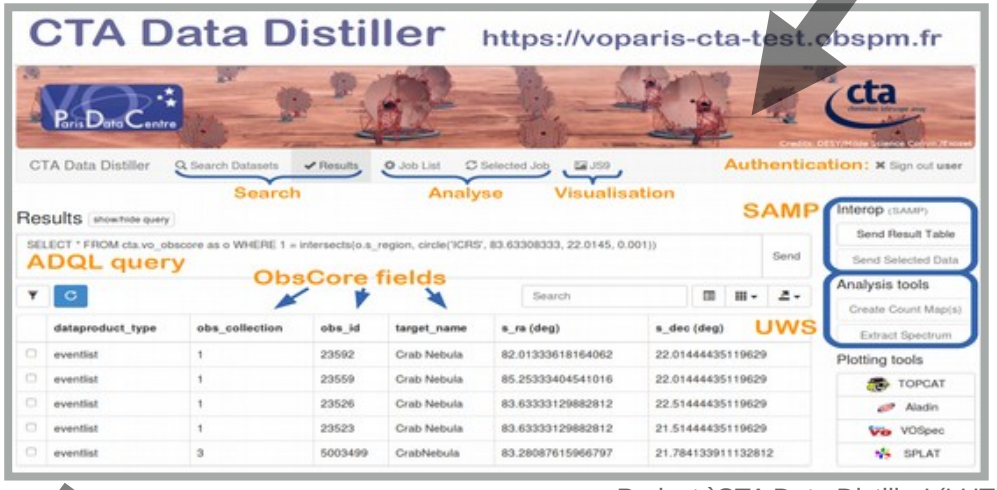
CTA Open Science progress

- CTA Science Archive and Science Gateway
- Conception of a CTA Master Configuration Data Model
- Compatibility with Virtual Observatory standards
- Science Gateway = collection of interconnected web services with common Authentication/Authorization system



Data Centers

Archive



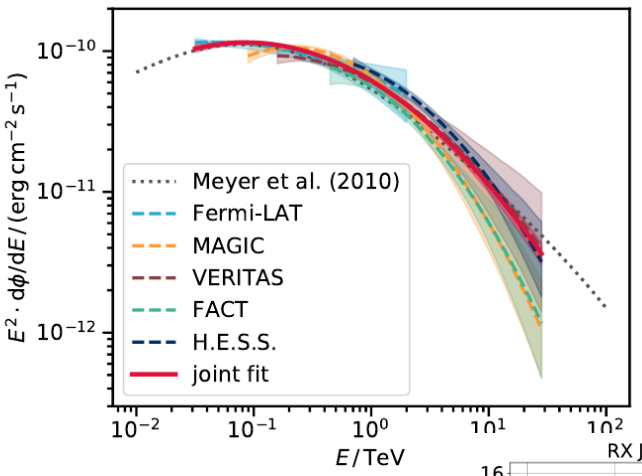
Project `CTA Data Distiller' (LUTh)

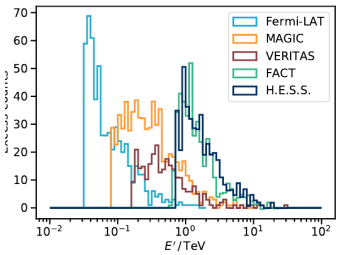
End User

Publications

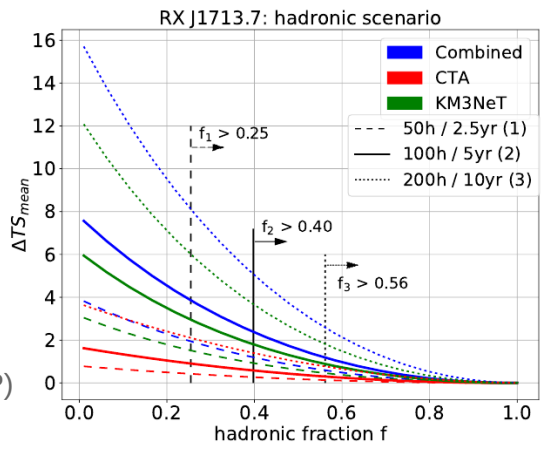
Towards multi-wavelengths analyses

- Joint analysis of Crab data from Fermi-LAT, FACT, H.E.S.S., MAGIC, VERITAS (arXiv:1903.06621)





- Ongoing work about joint analyses with:
  - XMM and H.E.S.S. data
  - KM3NeT and H.E.S.S./CTA simulated data



Master thesis of
T. Unbehaun (ECAP)

Towards multi-messengers analyses

- ML and MM joint analyses are infinitly simplified by the use of a common data format
  - Some other open analysis tools (e.g. 3ML, SkyLLH) have chosen a software design with experiment-based data readers
- Gammapy relies on the Gamma Astro Data Format
  - Format shared by H.E.S.S., MAGIC, VERITAS, FACT and CTA
  - But it is a format a bit associated with Imaging Atmospheric Cherenkov Telescopes

- Extension of this open initiative towards a “VHE Open Data Format”
  - Open initiative for IACT observatories, Water Cherenkov Detector instruments and neutrinos observatories
  - This new initiative will be structured with a coordination committee including official representatives of 11 experiments: ASTRI, CTAO, FACT, Fermi-LAT, HAWC, H.E.S.S., IceCube, KM3NeT, MAGIC, SWGO, Veritas

To conclude...

- For a long time, the complexity of the VHE data and IRFs, and of their associated softwares was used to restrict the data usage to collaborations
- As seen, the VHE panorama has changed the last decade and VHE experiments are and will release openly their data, with associated open-source softwares
- This turnover triggers also the development of open-source softwares about theoretical models (e.g. Naima, agnpy), such that their predictions can be adjusted on data with a more proper statistical treatment