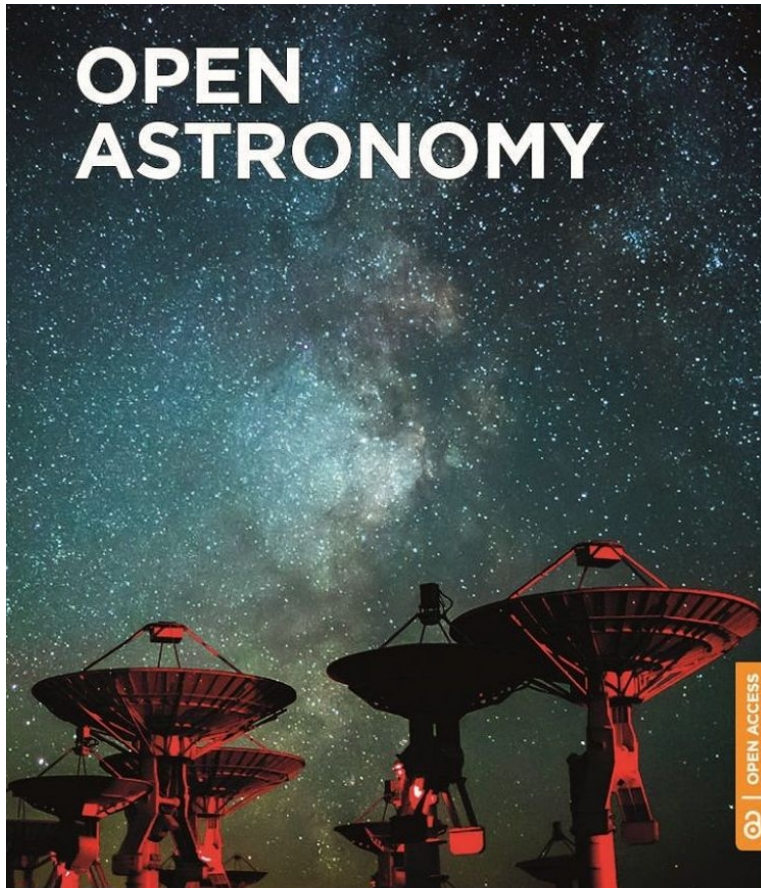


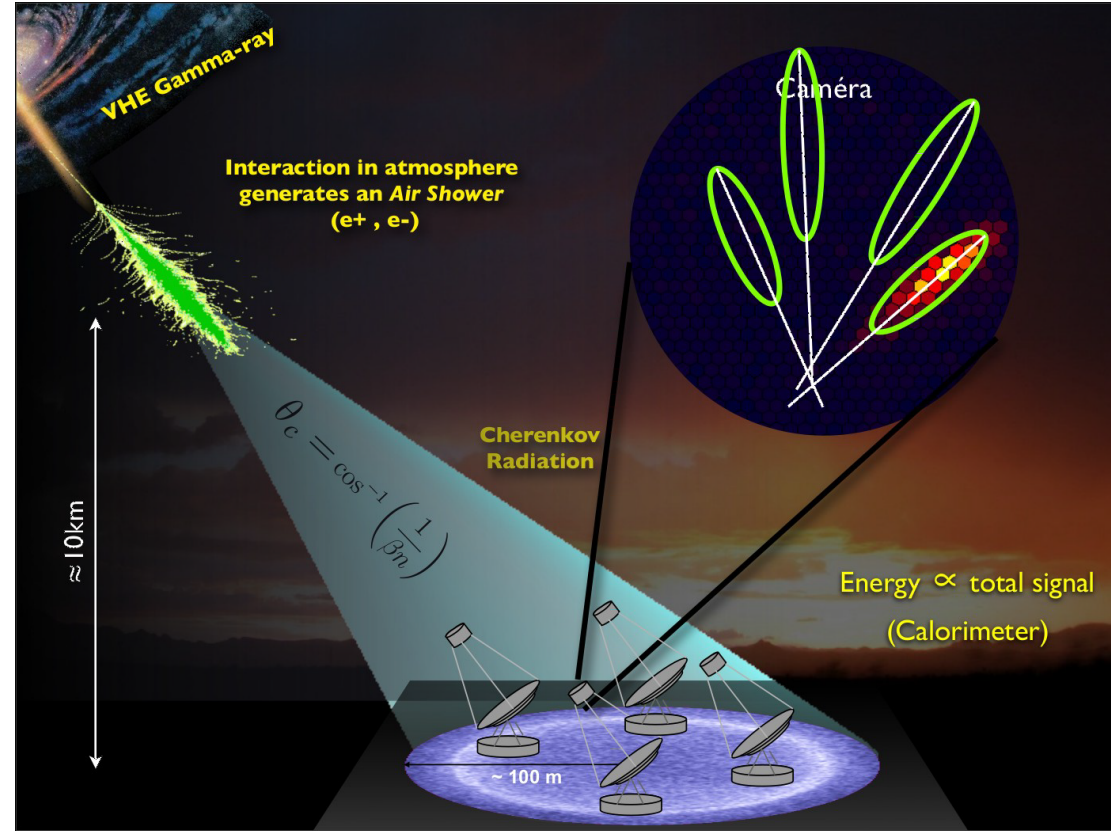


Open Science in the VHE energy domain

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

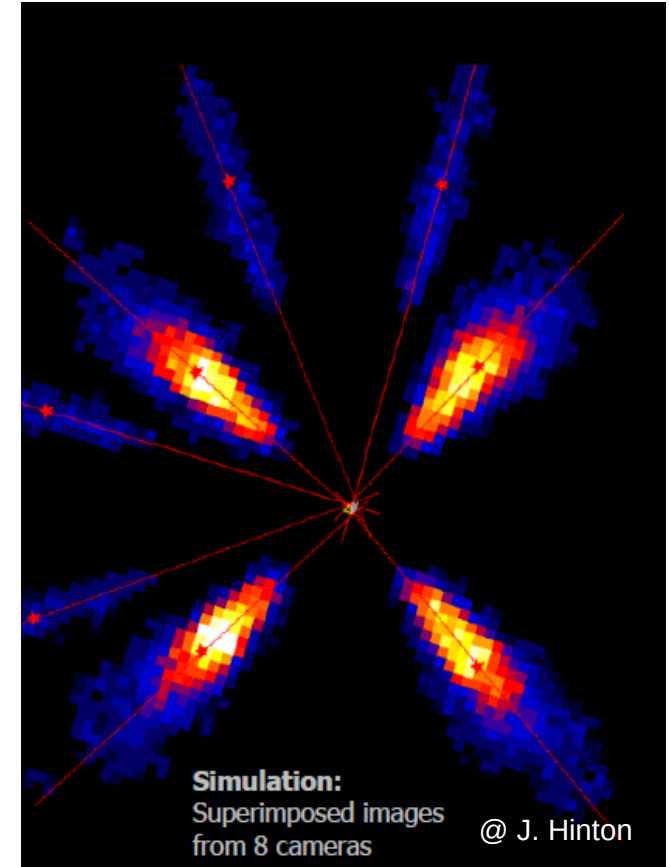
Introduction: Cherenkov Astronomy principles

- **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:

- 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 during an observation

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

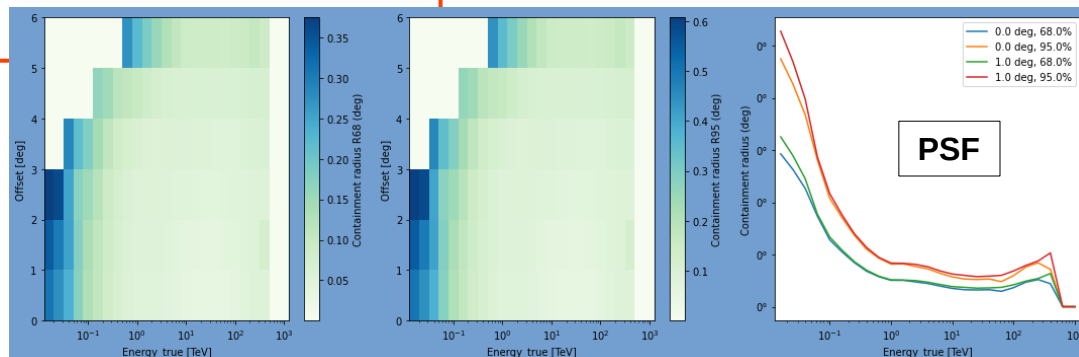
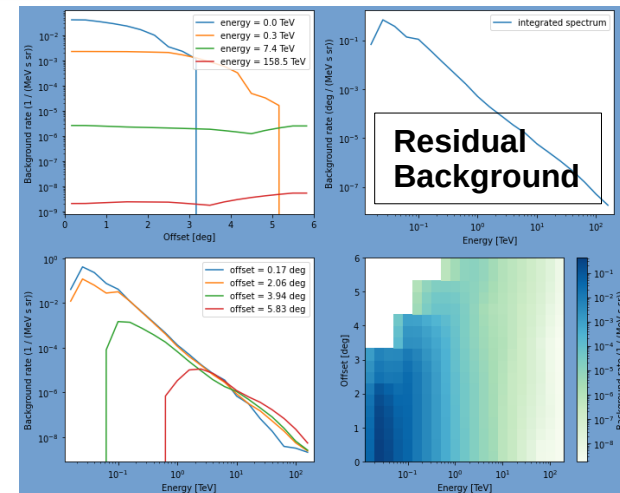
Change between observations

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

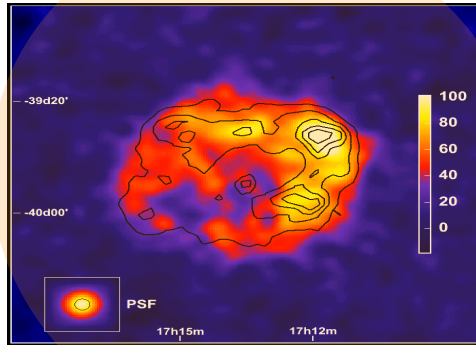
User' choices

- 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 ?

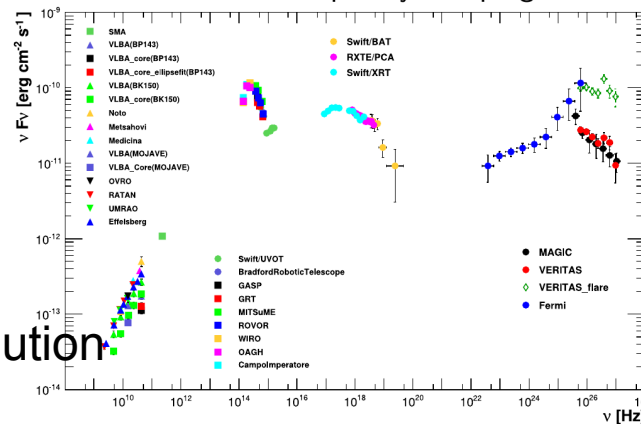
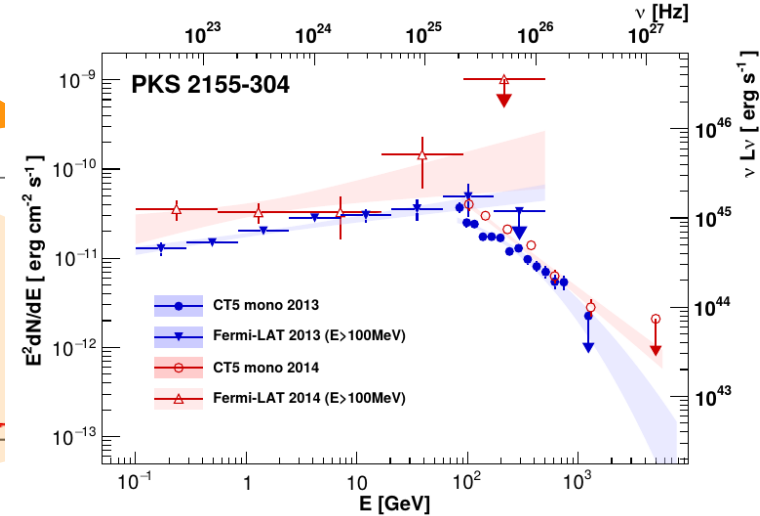
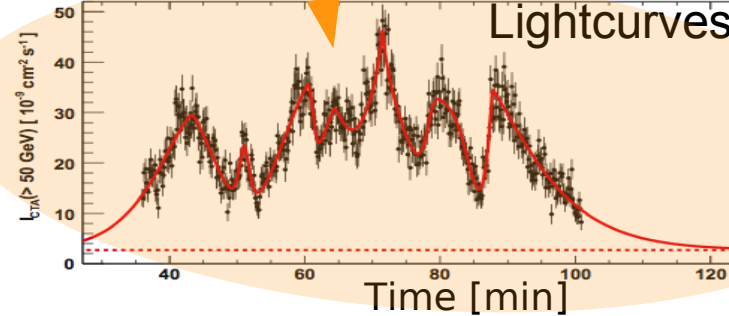


Astrophysics with multi-wavelength data



Images

Event lists
(coordinates, time, energy)



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

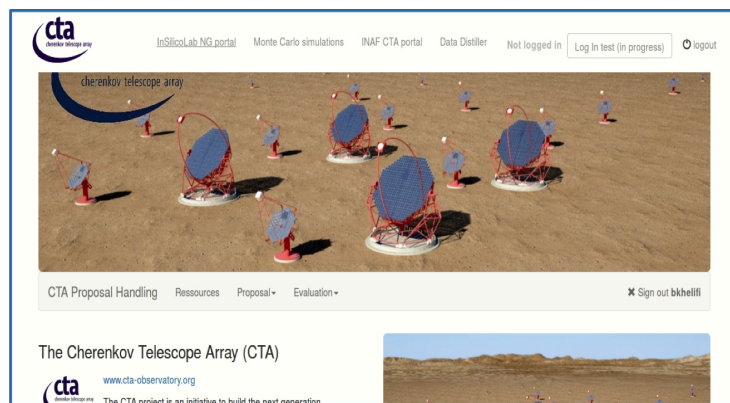
VHE Open Science progress

- 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)

My Draft Proposals [Daniel THIBAUT] +								
Id	Actions	Title	PI	Creation Date	Class	Category	Type	Targets / Time
7	 	Prop 1	Daniel THIBAUT	2019-02-27	GO	Scientific : ExtraGal/AGN	Triggered Observation Program	3 / 20.0
6	 	Prop 0	Daniel THIBAUT	2019-02-27	DDT	Scientific : Galactic	Monitoring	2 / 11.0

My Proposals as Co-I								
Id	Actions	Title	PI	Creation Date	Class	Category	Type	Targets / Time
5		Proposal Gemini I	Thanh-Tam Nguyen	2019-05-23	GO	Scientific : Galactic	Standard	1 / 0.0

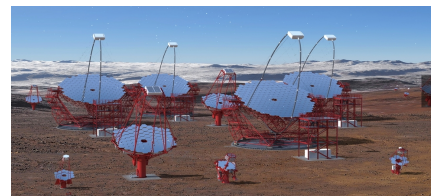
My Proposals Submitted as PI								
Id	Actions	Title	PI	Creation Date	Class	Category	Type	Targets / Time
16	 	Proposal for object type SEYFERT 1 GALAXY	Daniel THIBAUT	2019-05-27	GO	Scientific : Galactic	Standard	1 / 28.5
7	 	Prop 1	Daniel THIBAUT	2019-05-23	GO	Scientific : ExtraGal/AGN	Coordinated Observation Program	3 / 20.0



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

The screenshot shows the CTA Data Distiller web interface. At the top, it says "CTA Data Distiller" and provides a URL: <https://voparis-cta-test.obspm.fr>. Below the header, there are tabs for "Search", "Analyse", and "Visualisation". The "Search" tab is active, showing a table of results. The table has columns: "datapoint_type", "obs_collection", "obs_id", "target_name", "s_ra (deg)", and "s_dec (deg)". The table contains five rows of data for "Crab Nebula" observations. On the right side of the interface, there are sections for "SAMP" (Send Result Table, Send Selected Data), "Analysis tools" (Create Count Map(s), Extract Spectrum), and "Plotting tools" (TOPCAT, Aladin, VOSpec, SPLAT). The interface also includes a search bar, a "Send" button, and a "Sign out user" link.

datapoint_type	obs_collection	obs_id	target_name	s_ra (deg)	s_dec (deg)
☐ eventlist	1	23592	Crab Nebula	82.01333618164062	22.01444435119629
☐ eventlist	1	23559	Crab Nebula	85.25333404541016	22.01444435119629
☐ eventlist	1	23526	Crab Nebula	83.63333129882812	22.51444435119629
☐ eventlist	1	23523	Crab Nebula	83.63333129882812	21.51444435119629
☐ eventlist	3	5003499	CrabNebula	83.28087615966797	21.784133911132812

End User

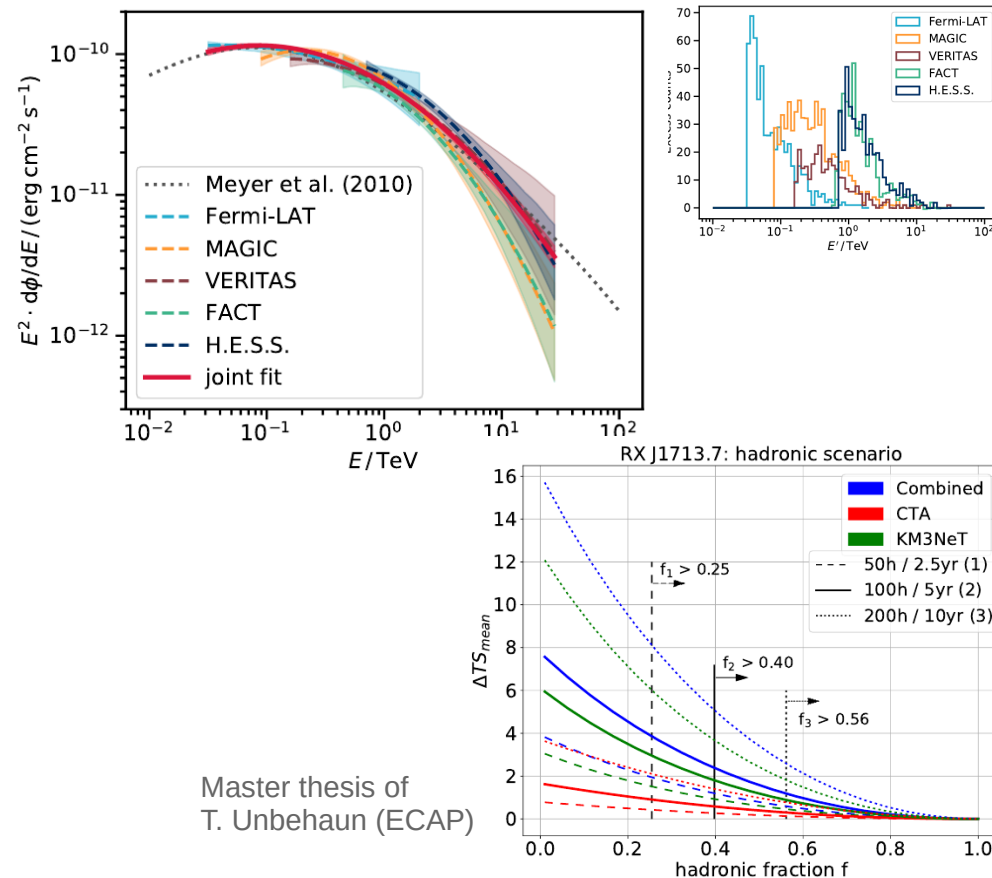
Project 'CTA Data Distiller' (LUTH)

Publications

Towards multi-wavelengths analyses



- Joint analysis of Crab data from Fermi-LAT, FACT, H.E.S.S., MAGIC, VERITAS ([arXiv:1903.06621](https://arxiv.org/abs/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 infinitely 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