Astroparticle / high-energy community

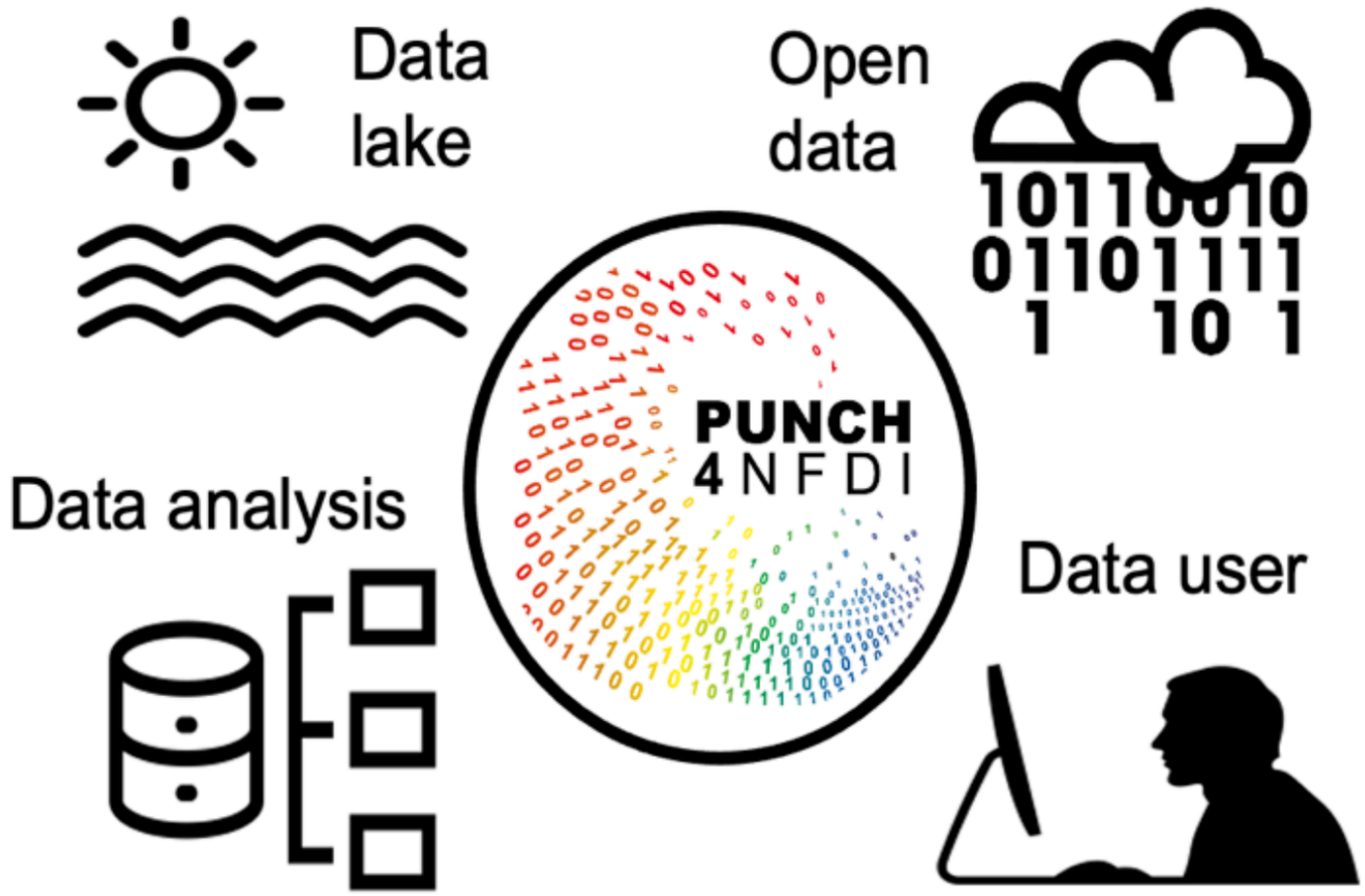
PUNCH4NFDI Open Data Workshop

2021, Feb 11

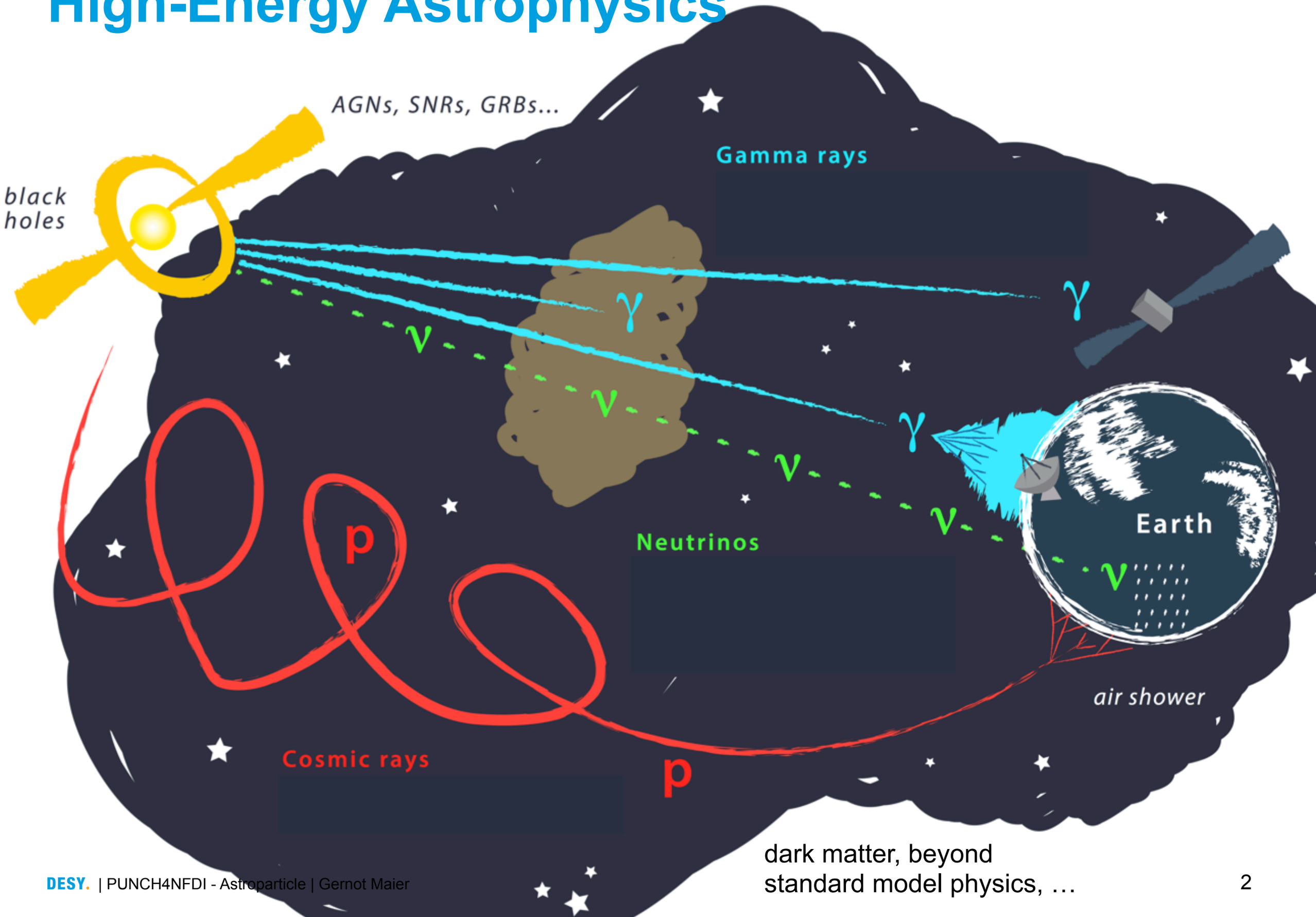
Gernot Maier

DESY.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES



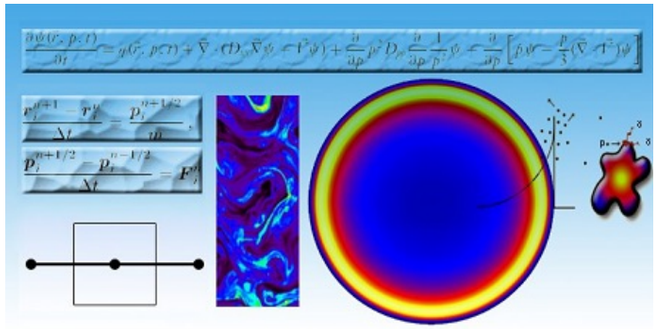
High-Energy Astrophysics

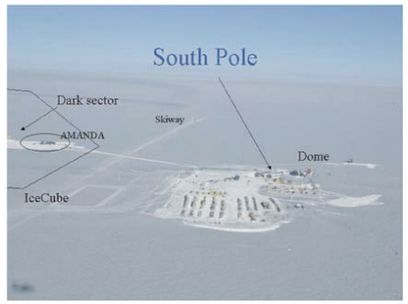


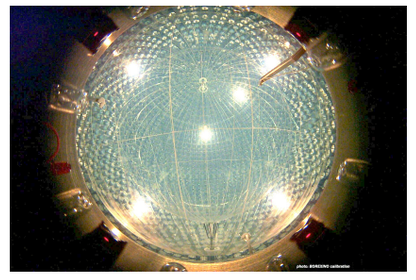
dark matter, beyond standard model physics, …

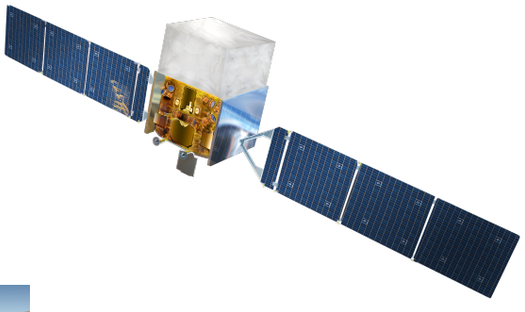
Astroparticle

Theory, Experiments, Observatories.

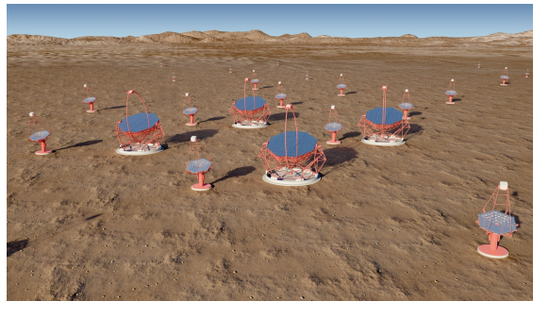








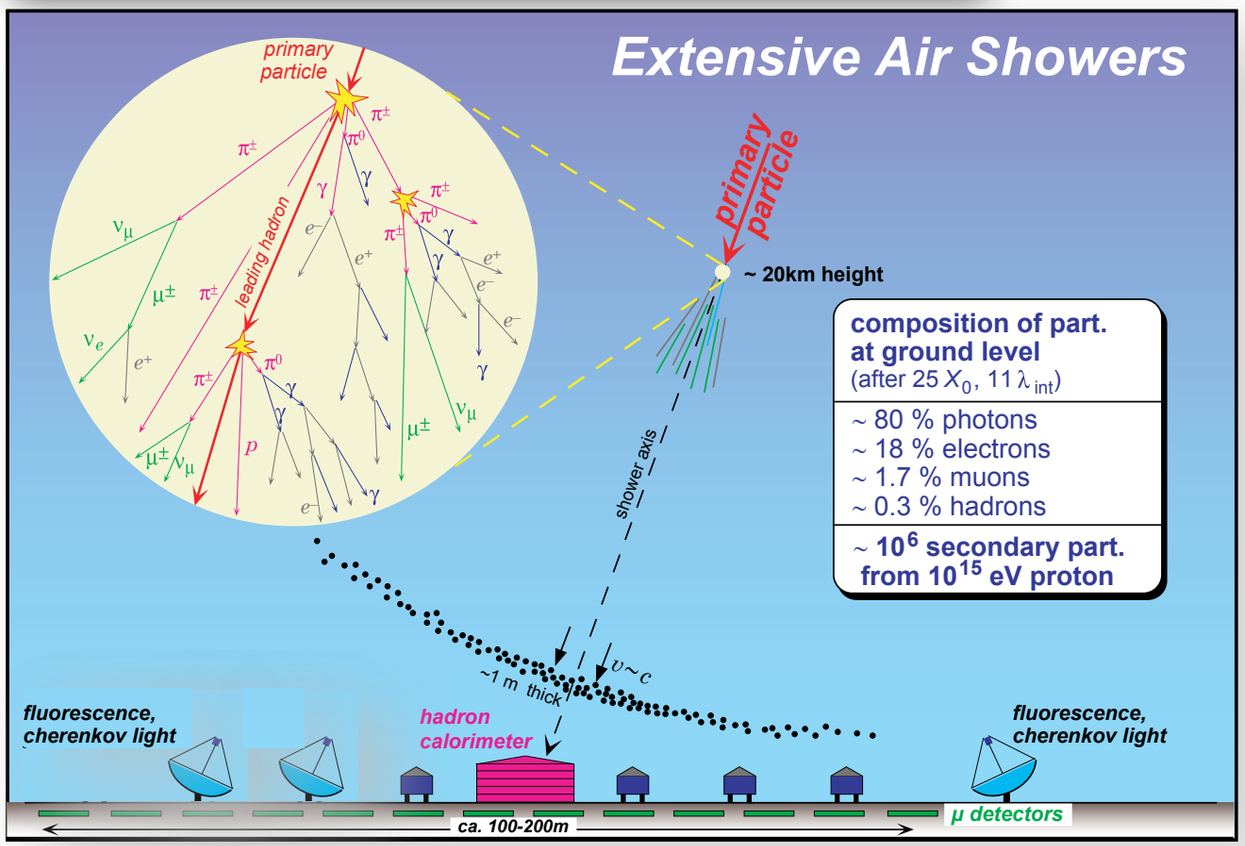
- **Theory and Simulations**
- **Experiments**
  - large international collaborations (IceCube, Auger, H.E.S.S., …)
  - national collaborations / groups (CONUS, neutron-monitors, …)
- **Observatories**
  - international organisations (NASA, ESO, CTAO, …)
- **Detector Development**
  - e.g. photodetector or optics development



Concentrate on high-energy / gamma-rays.

Data structures - Event lists + Instrument Response

Data structure for most physics analysis very simple.



Per Event:

- classification (p, Fe, gamma, ..)
- energy
- direction
- time
- detector state (e.g., pointing)

Observing period

- instrument response (effective detective area, energy migration, point-spread function)
- detector uptime

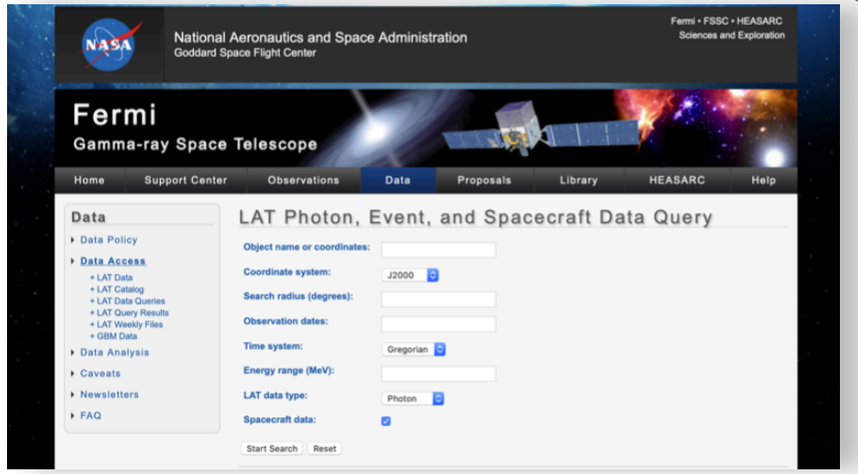
(obviously on DACQ level and intermediate levels much more complicated)

Fermi Gamma-ray Telescope

A showcase how observatories work

- Gamma-ray telescope operated by NASA —> survey instrument
  (+DOE, institutions in France, Germany, Japan, Italy and Sweden)
- All high-level data products available to the community (<1 day)
- Prompt data (e.g., GRBs) and notification (within <~15 s of detection)
- Services by NASA:
  - data (events+calibration) in common formats (FITS)
  - open source software tools
  - user support desk & documentation
  - cross-mission accessibility (e.g. through NASA's HEASARC archive)
  - catalogues

Simple web interface

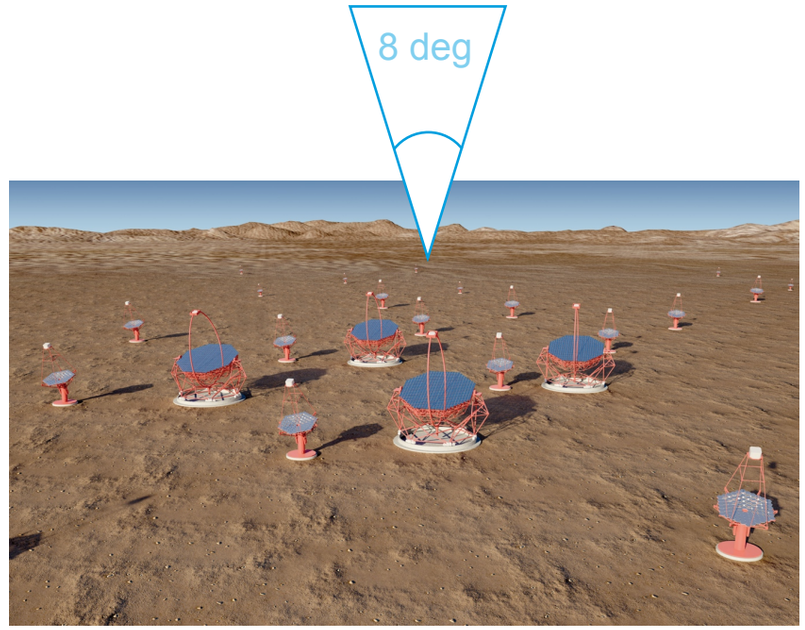


Most publications not by the Fermi Team

CTA Gamma-ray Telescope

Future observatory for gamma-ray astronomy.

- Gamma-ray telescope operated by CTAO
  —> pointed instrument
  +developed by a worldwide collaboration
  large German contribution
- All high-level data products available to the community (open data after proprietary period)
- Prompt data (e.g., GRBs) and notification (within ~100s of detection)
- Services by CTAO:
  - data (events+calibration) in common data formats (FITS)
  - open source software tools
  - user support desk & documentation
  - cross-mission accessibility (possibly through ESO archive)
  - catalogues



Key difference to Fermi!
Observation proposals led by Principal Investigators

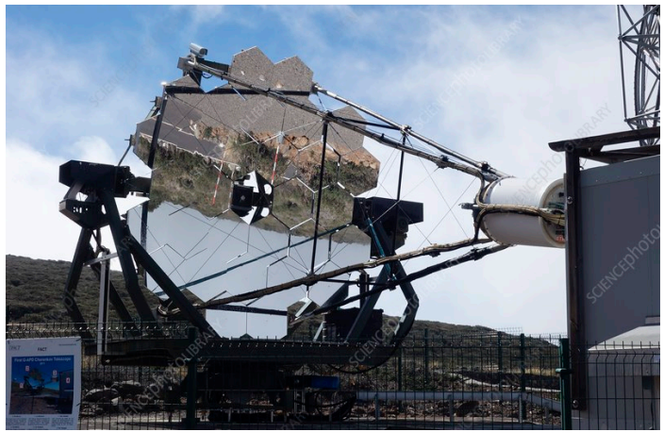
CTA Data policy not finalised yet
(e.g., 1 year of proprietary period; afterwards open).

Similar to X-ray telescopes
(XMM, Chandra)
>50% of all publications based on archival data

Gamma-ray experiments

How to access decades of valuable data.

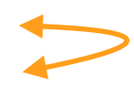
- Operating gamma-ray observatories
  H.E.S.S., FACT, MAGIC, VERITAS
  - operated by international collaborations
  - no sharing of data (and data model); no or limited sharing of software; expert knowledge required
  - legacy archives
  - multi-instrument and multi-wavelength analysis
- ongoing community effort
  - common high-level data formats
  - public software tools
  - workflows and archiving
  - ‘future proof’ - involvement of upcoming instruments (CTA Observatory)



Standardisation of data formats in gamma-ray astronomy

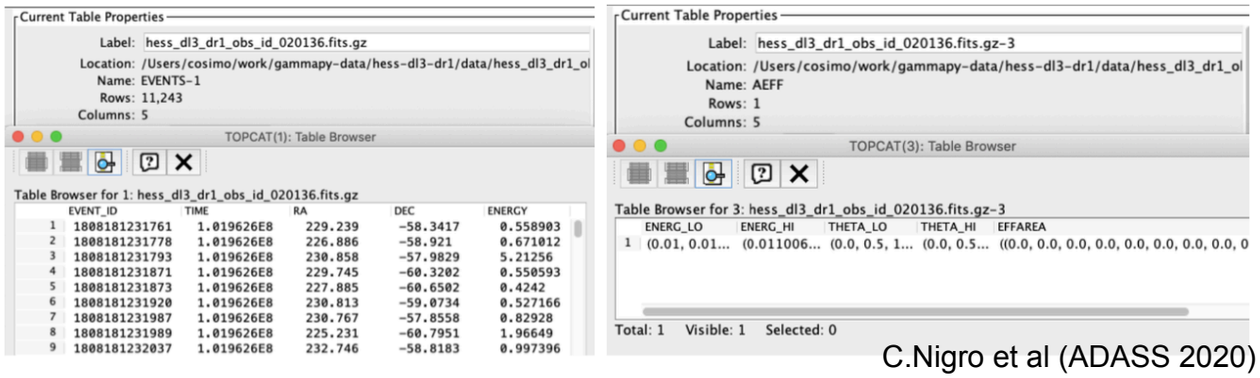
- event level plus instrument response functions

data level	description	size
DL0	**raw** output of DAQ	$\sim$ TB / tel. / night
DL1	**calibrated** quantities (charge, arrival time)	$\sim$ 10 GB / night
DL2	**reconstructed** shower parameters	$\sim 10^2$ MB / run
DL3	**reduced** γ ray candidates + response functions	$\sim 10^2$ kB
DL4	**science** data products: spectra, light curves, skymaps	$\sim$ 10 kB



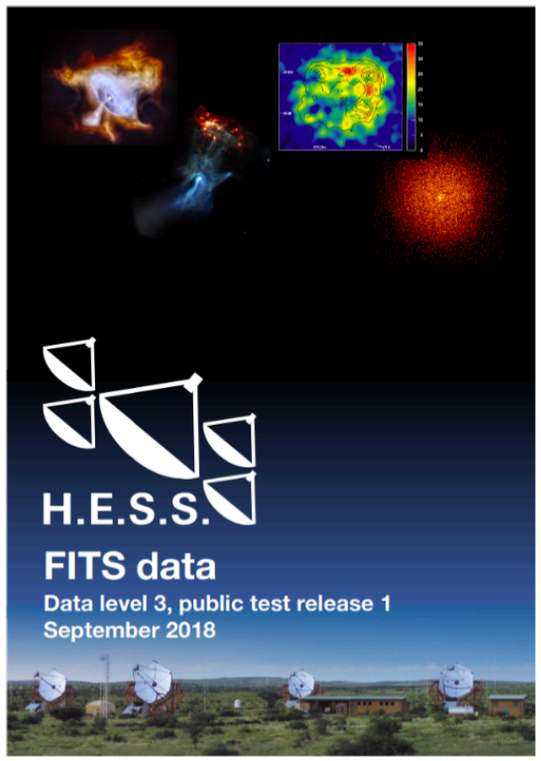
open source software tools

- based on existing standards in astronomy (see Fermi LAT) with all advantages and disadvantages

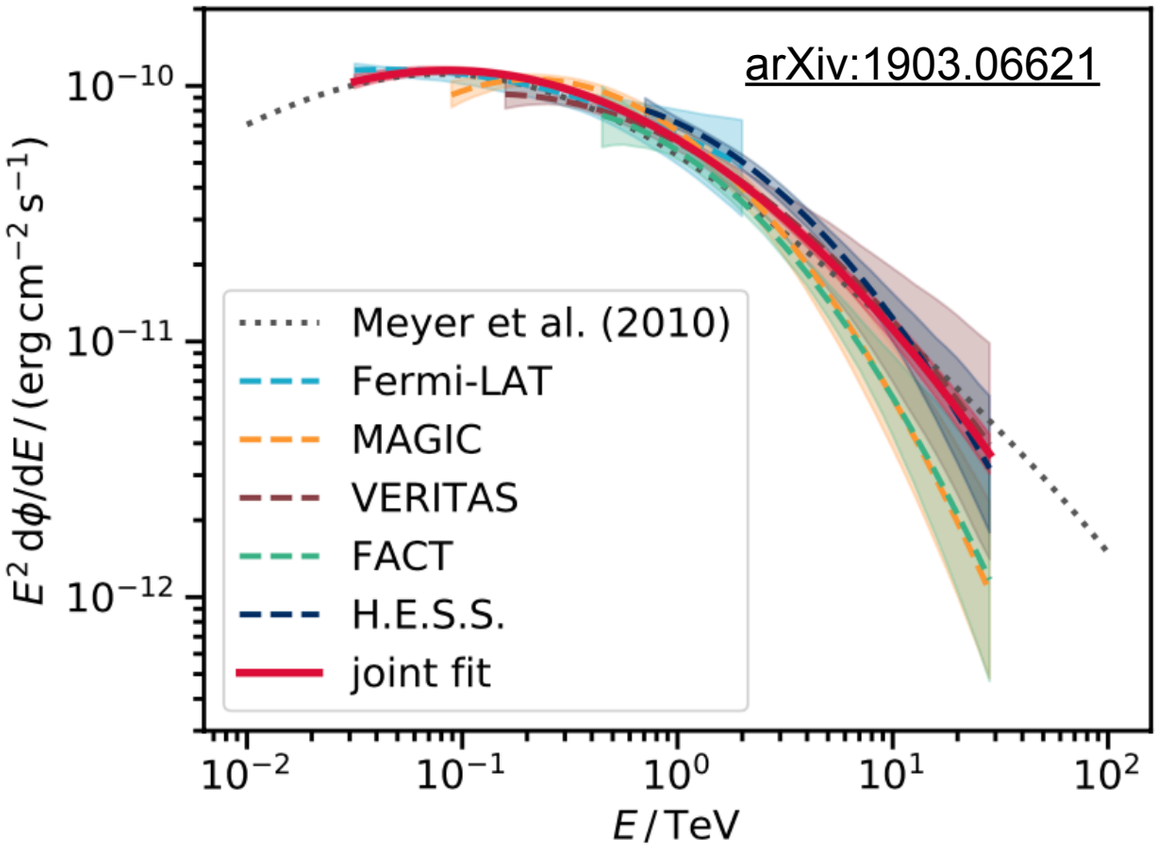


C.Nigro et al (ADASS 2020)

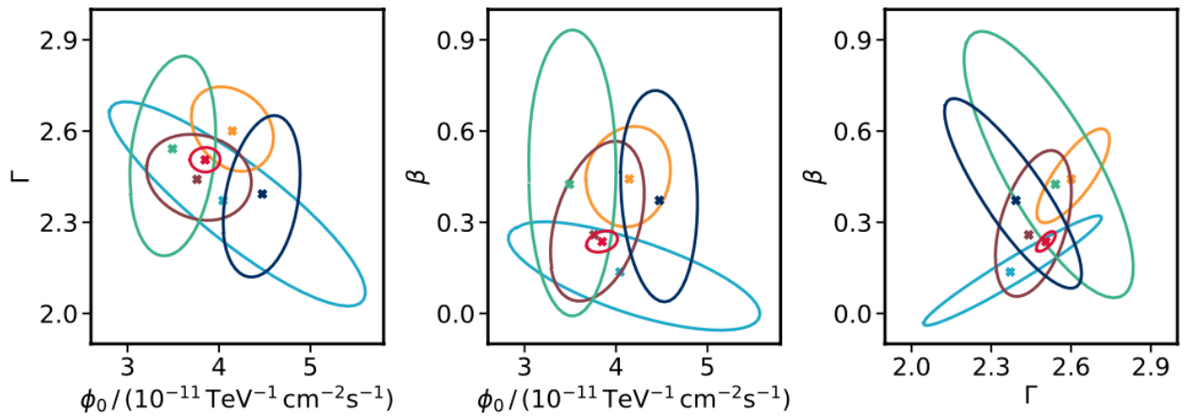
- open source software (e.g., gammapy, ctools) —> software used for future CTA
- realistic scenario for public data archives
  - e.g., first H.E.S.S. data release (arXiv:1810.04516, zenodo)



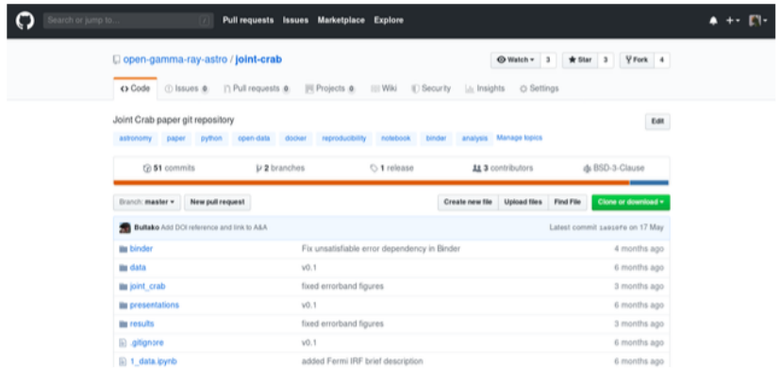
Multi-instrument analysis

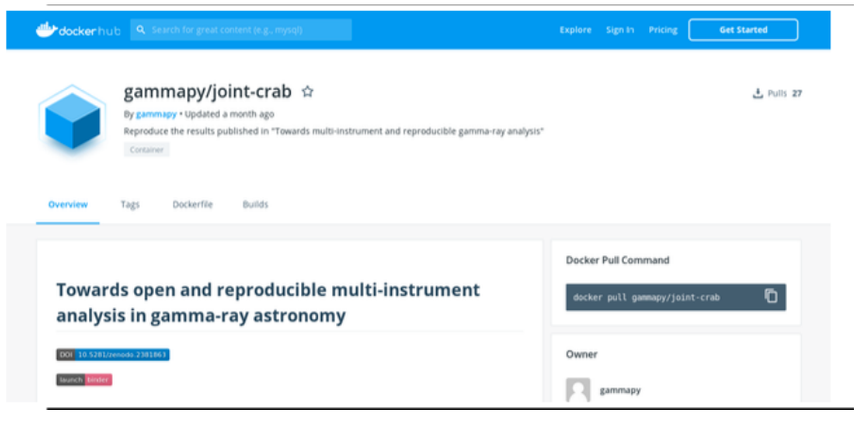


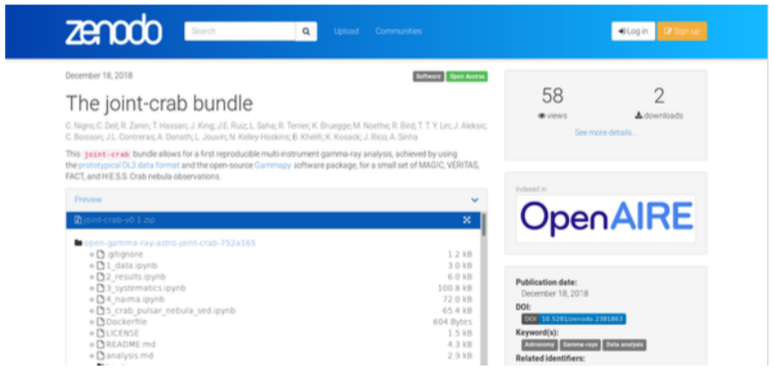
Combined energy spectrum of Crab Nebula obtained with data from **five** different instruments
—> joint likelihood taking systematics consistently into account



Reproducibility workflow based on git, docker, zenodo



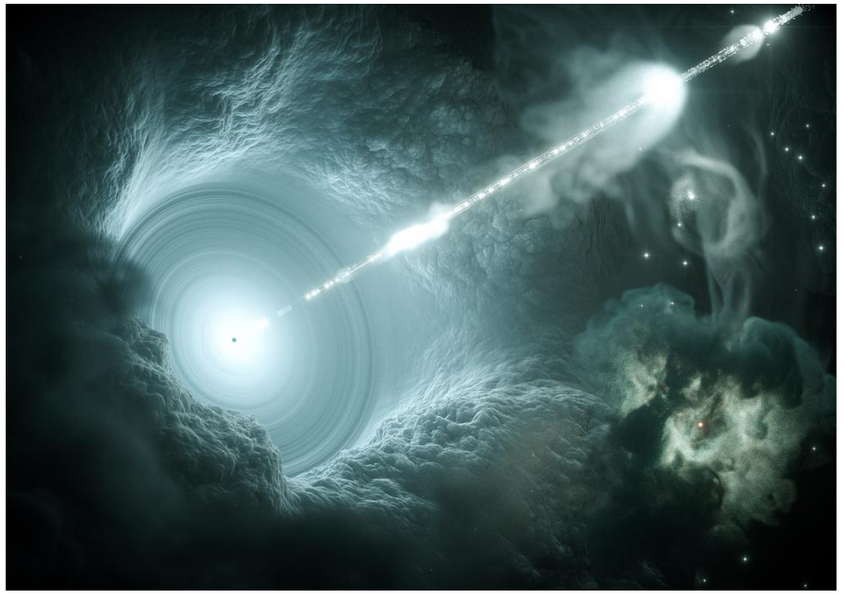


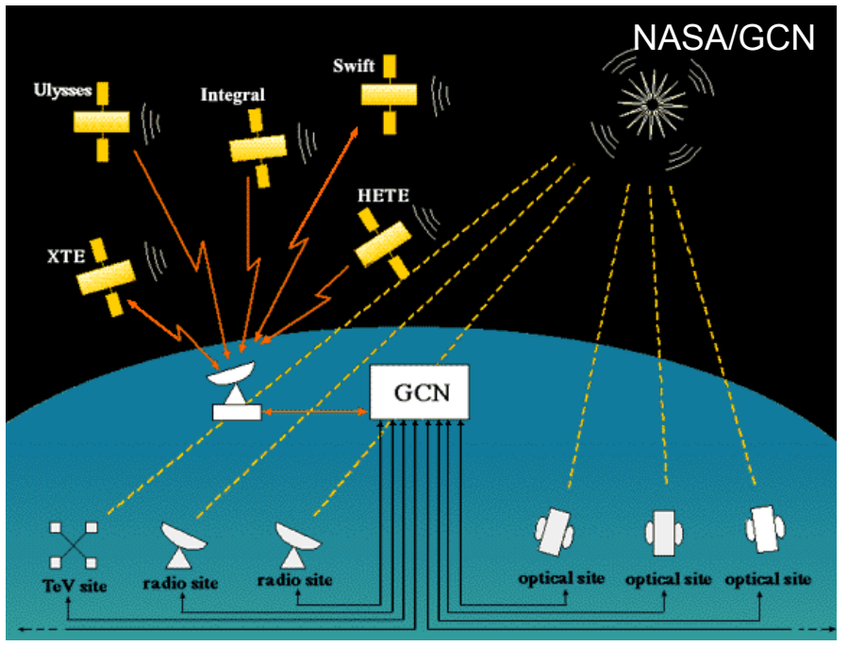


C.Nigro et al (ADASS 2020)

Transient Alert streams

- multi-wavelength and multi- messenger
  - gravitational waves, radio (SKA), optical (V.Rubin, ZTF), X-ray, gamma rays (CTA), neutrinos (IceCube), cosmic rays (Auger), …
  - few alerts per year to millions / day
- **alert streams almost by definition public data**
  (alternative: private with many bilateral MoUs)
- automatic & reprocessed alerts
  - automatic = telescope repointing without human interaction; real-time analysis and feedback
- alert processing increasing complex
  - (no) follow up, real-time results





VO Events = standard protocol for transient events (XML)

transient broker systems

alert processing, filtering, augmentation, prioritising, archiving (e.g., AMPEL)

Conclusions & PUNCH4NFDI

- science data portal & archives
  - data/software/documentation/support
  - MC / theory / modelling
- efficient management of research data products
  - observatory model
- data transformation & maximum exploitation by combination of data sets
  - standards for data and metadata
  - open analysis tools & community software
  - cross-disciplinary interest on data
- real-time decisions for transient science
- outreach, citizen science, training

Open-data activities

- Piere Auger Observatory: https://www.auger.org/index.php/science/data
- KASCADE (KCDC): https://kcdc.ikp.kit.edu/
- IceCube: https://icecube.wisc.edu/science/data
- KM3Net: https://www.km3net.org/km3net-infradev/open-access-to-km3net-data/
- ANTARES: https://antares.in2p3.fr/publicdata.html
- MAGIC: http://opendata.magic.pic.es/
- HESS: https://www.mpi-hd.mpg.de/hfm/HESS/pages/dl3-dr1/
- FACT: https://fact-project.org/data/
- ….