Introducing VODF

The Very-high-energy Open Data Format

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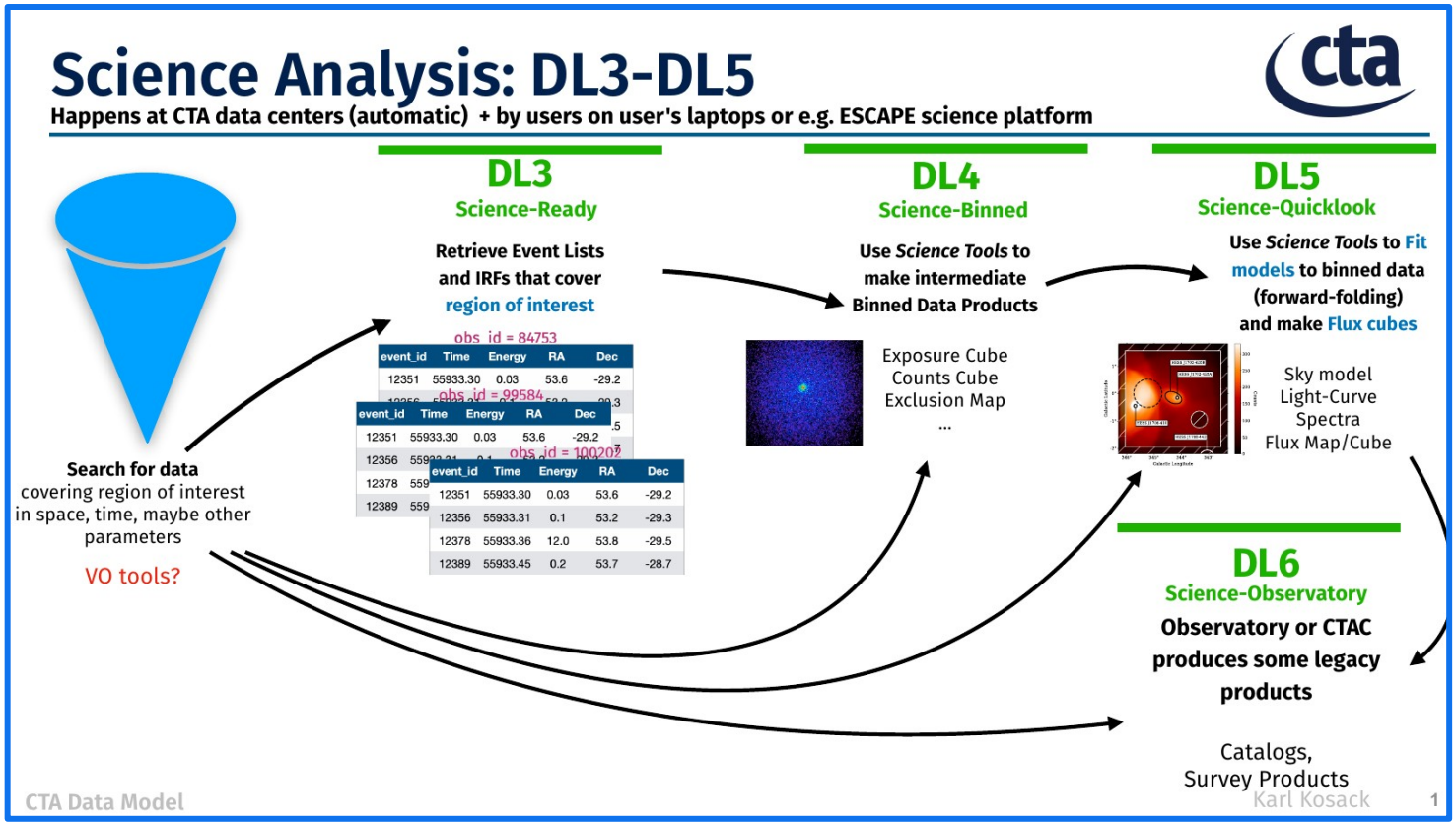
High Energy in the Virtual Observatory workshop

29th April 2025, Observatoire de Paris

What is it about: Data levels...



from Karl Kosack

Gamma Astro Data Format (GADF)

VODF
very-high-energy open data format

A format validated and used for MWL/MM astrophysics

GADF @Gammapy

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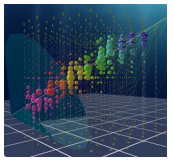


"Validation of standardized data formats and tools for ground-level particle-based gamma-ray observatories" (2022) doi:10.1051/0004-6361/202243527

"Prospects for combined analyses of hadronic emission from γ-ray sources in the Milky Way with CTA and KM3NeT" (2023) arXiv:2309.03007

The current shared open format: GADF

VODF
very-high-energy open data format

Gamma Astro Data Format: V0.3

A (short History of GADF)

2011 Prototypes for the CTA data format and science tools

2016
- Establishment of the Gamma-ray Astronomy Data Formats (GADF) initiative
- First preliminary release version (0.1), mainly focused on IACTs

2018
- Version 0.2 released
- Support implemented in the science tools Gammapy and ctools
- H.E.S.S. releases ≈ 50 h of observations of different sources using the format

2019
- FACT, Fermi-LAT, H.E.S.S. MAGIC and VERITAS observations of the Crab Nebula are used to perform the first multi-instrument analysis [doi:10.1051/0004-6361/201834938]
  `https://github.com/open-gamma-ray-astro/joint-crab`
- `ctools` based analysis of the H.E.S.S. data release [doi:10.1051/0004-6361/201936010]
- Comparison of Gammapy and ctools using the H.E.S.S. data release [doi:10.1051/0004-6361/201936452]

from Maximilian Linhoff

A consensus about its limitations

From feedbacks of the CTAO ASWG, DM group, Gammapy team, experiments, …

- Current standard is often very vague instead of descriptive
- Additional IRF parametrizations needed (e.g. FoV coordinates)
- Uncertainties and validities of IRFs
- Multiple IRFs for one observation
- Different IRFs for different event categories (“event types”)
- Additional specifications for simulated datasets
- Interoperability with other entities, especially the VO
- Lack of metadata (general and specific) → format is not FAIR-compliant
- Missing coordination with the major experiments

And the initiative lacks of a clear working organisation…

A consensus about its limitations

From feedbacks of the ASWG, DM group, Gammapy team, experiments, …

- C
- A
- U
- M
- D
- A
- In
- Lack of metadata (general and specific) → format is not FAIR-compliant
- Missing coordination with the major experiments

The core team of GADF takes the decision to go over…
by willing to create a new initiative which is based on the major facilities

We contacted all the VHE astroparticle experiments

An the initiative lacks of a clear working organisation…

From gamma rays to high energies particles

VODF
very-high-energy open data format

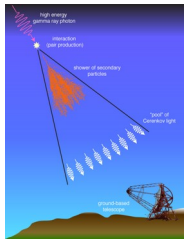
GADF
Data Formats for
Gamma-Ray Astronomy

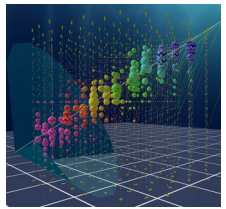
VODF
Very-high-energy
Open Data Format

F Findable
A Accessible
I Interoperable
R Reusable

IVOA

gammapy
A **Python** package for
gamma-ray astronomy





VODF, an open initiative around 11 large facilities

VODF
very-high-energy open data format

ASTRI - Astronomia a Specchi a Technologica Replicante Italiana, (IACT telescope)

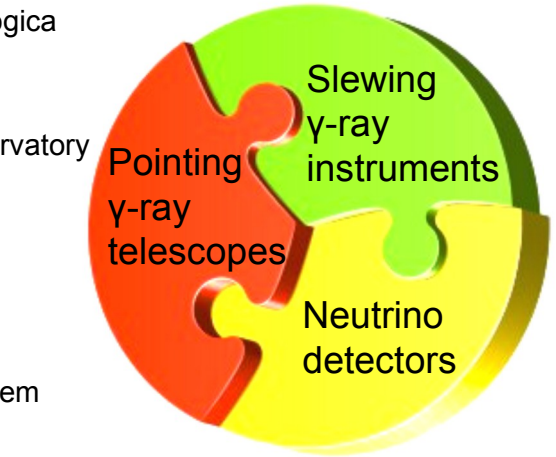
CTAO - Cherenkov Telescope Array Observatory (IACT observatory)

FACT - First APD Cherenkov Telescope (IACT telescope)

H.E.S.S. - High Energy Stereoscopic System (IACT Array)

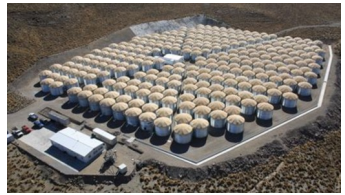
MAGIC - Major Atmospheric Gamma-ray Imaging Cherenkov telescope (IACT array)

VERITAS - Very High Energy Radiation Telescope Array System (IACT array)



Fermi-LAT - Large Area Telescope on the Fermi Space Telescope (High-energy Space Observatory)

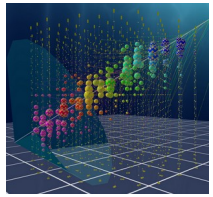
HAWC - High-Energy Water Cherenkov telescope (WCT)



SWGO - Southern Wide-Field Gamma-Ray Observatory (WCT)

IceCube - Neutrino Observatory

KM3NeT - The Cubic Kilometre Neutrino Telescope (neutrino telescope)



VODF: new structure for new Open Science

VODF Steering committee

one official representative per experiment, defining roadmap & goals

Established in 2022

VODF Lead Editors (3)

Format development

Conveners (2)

Organization & Coordination of work

Documentation:
https://vodf.readthedocs.io
Source & Community:
https://github.com/VODF/

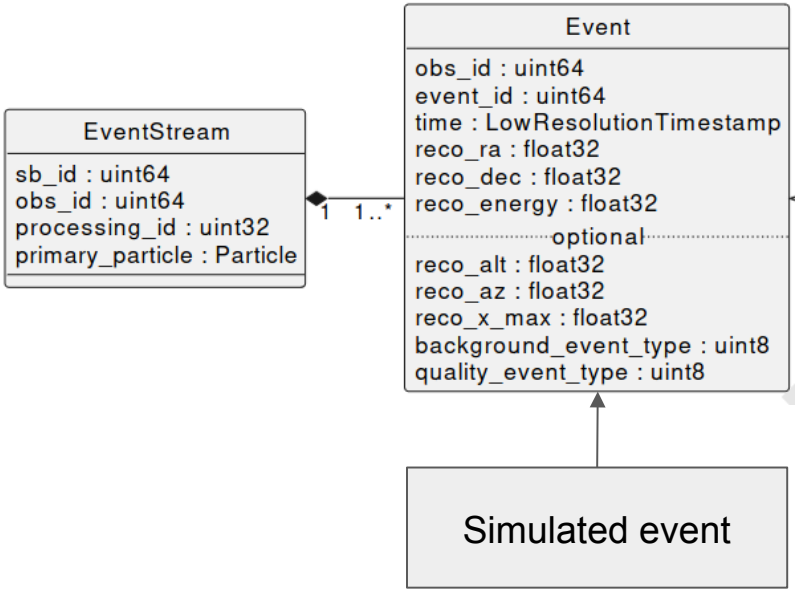
Steering Committee: F. Pintore (ASTRI), R. Zanin (CTAO), M. Lindhoff (FACT), N. Omodei (Fermi-LAT), X. Wang (HAWC), B. Khélifi (H.E.S.S.), M. Santander (IceCube), K. Graf (KM3NeT), C. Nigro (MAGIC), A. Smith (SWGO), A. Weinstein (VERITAS)

Lead Editors: K. Kosack (IACT), L. Olivera-Nitto (WCD), J. Schnabel (neutrino)

Conveners: R. Zanin (CTAO), B. Khélifi (H.E.S.S.)

Basic data format: “Events” and “service data” (L1)

event = particle detection (gamma, neutrino)



Information derived from simulation: Instrument Response Functions (IRFs)

- Stable Time Interval
- Effective Area
- Energy Dispersion
- Point Spread Function
- Background
- Radius of On region for point-like IRFs

From CTAO DL3 data model

Higher levels: Science results

VODF
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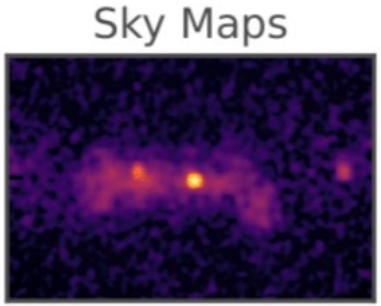
L2 (Science binned)

- exposure maps
- counts maps
- exclusion maps
- significance maps
- excess maps



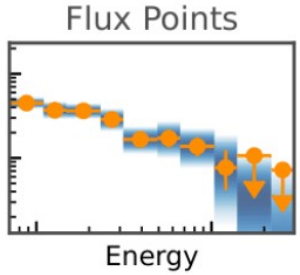
L3+ (Science products)

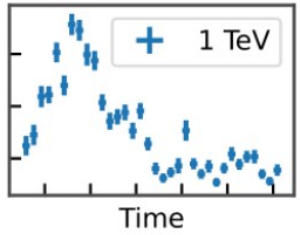
- Flux maps & fit models
  - data cube (3D,4D)
  - 2D sky map
  - light curve
  - spectrum
  - spatio-spectral cube
  - …

Potential future developments with VODF

Source Catalogs

Name	Flux	Size
SNR	1e-12	1 deg
PWN	1e-11	0.2 deg
GRB	1e-10	0 deg

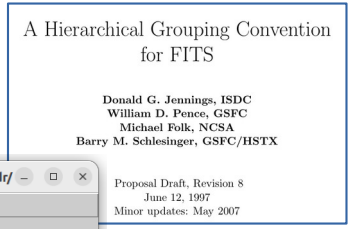


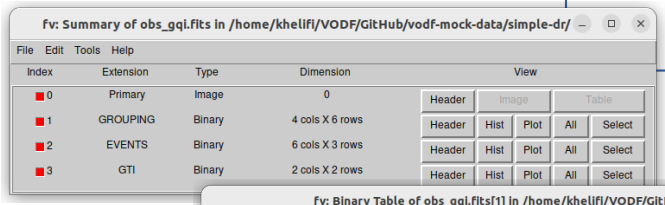


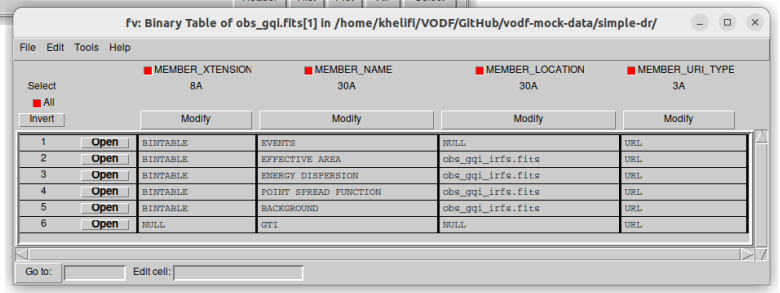
The VODF Data Model for L1

- Core element: Observation
- Key requirement: event/IRFs relationship
- Important requirement: mapping with IVOA standard

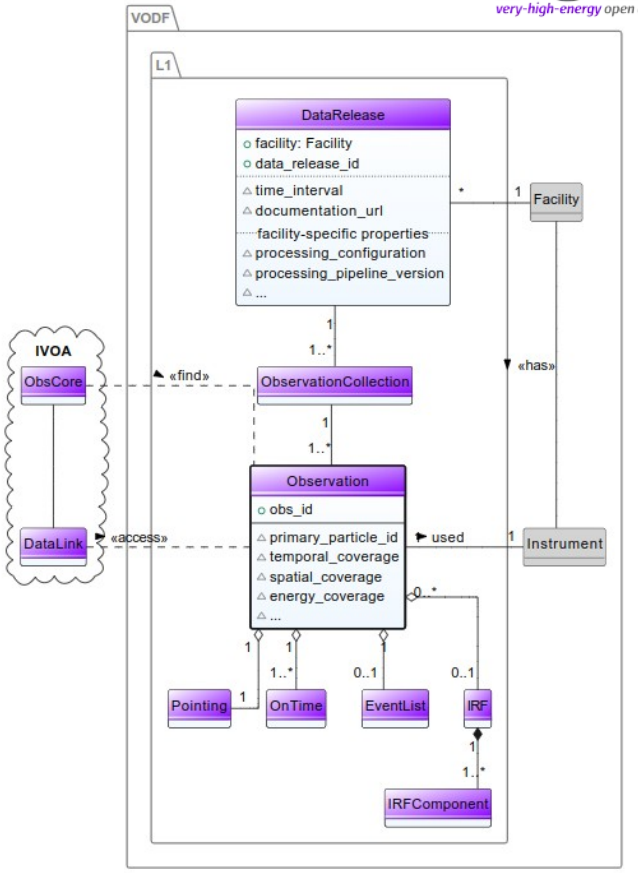
- Use of a technical standard:







https://github.com/bkhelifi/vodf-mock-data



VODF Level-1 Data Model

Summary: converging efforts

VODF
very-high-energy open data format

Data Formats
FITS, OGIP, GADF

VO

Users
Physicists&Folks

Science Portals
ESO, CXS, NRAO, etc

Data Release

CTAO

KM3NeT

SWGO
The Southern Wide-field Gamma-ray Observatory

Facilities under construction

Data Producers

Facilities preparing their archive

H.E.S.S.

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Science Analysis Tool
Gammapy, CIAO, etc

Summary: converging efforts

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Radio ObsCore 2025

HEIG 2024

VO

IVOA

Data Formats
FITS, OGIP, GADF

VODF Sept 2025

CTAO

CTAO SDC 2026

SWGO
The Southern Wide-field Gamma-ray Observatory

Data Release

Facilities under construction

Data Producers

Facilities preparing their archive

Users
Physicists&Folks

CTAO Prototype 2026

Science Portals
ESO, CXS, NRAO, etc

CTAO SAT 2026

Science Analysis Tool
Gammapy, CIAO, etc

OSCARS
Open Science Clusters' Action for Research & Society

ESCAPE

H.E.S.S.

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Legacy Archive 2027/28?

Thank you for your attention and looking forward to curating!

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