Friedrich-Alexander-Universität
Erlangen-Nürnberg

ANTARES and KM3NET neutrino data and data analysis

Steffen Hallmann, FAU Erlangen (ECAP)

2nd AstroORDAS Workshop and ACME WP4 meeting
Lausanne, December 08–12, 2025

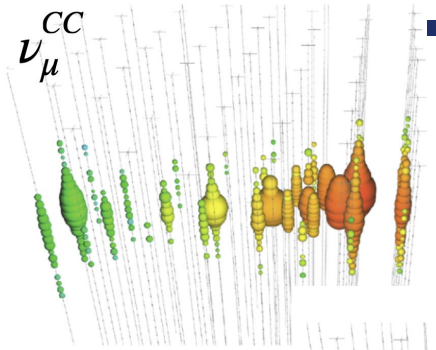
Funded by the European Union

KM3NeT-INFRADEV *(ID: 739560)*
KM3NeT-INFRADEV-2 *(ID: 101079679)*
ESCAPE *(ID: 824064)*
EOSC Future *(ID: 101017536)*
ACME *(ID: 101131928)*

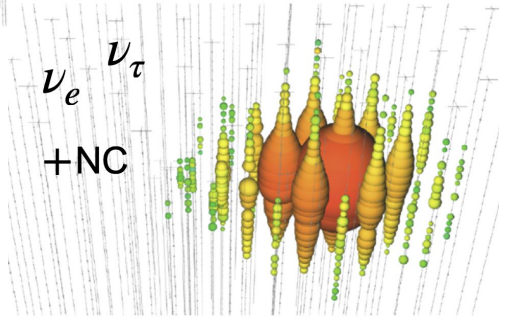
ANTARES and KM3NeT instruments and data

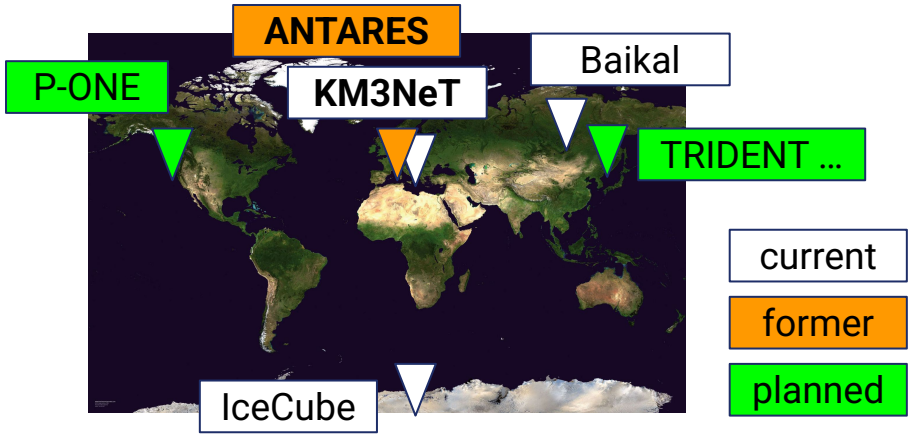
High-energy (>GeV) neutrino detection in a nutshell

- Neutrino interaction in matter produces secondary lepton (e, μ, τ) and hadronic cascade at the vertex
- Detection of (single) photon “hits” from Cherenkov radiation in transparent medium
- large-scale infrastructures O(km³) in water or ice with arrays of photodetectors → **direction & energy** reconstruction
- **low count rate**, **all-sky** observations using Earth as shield from atmospheric muon background
- Main astrophysics target:
  - neutrino emission from cosmic & galactic accelerators
  - constrain hadronic emission scenarios



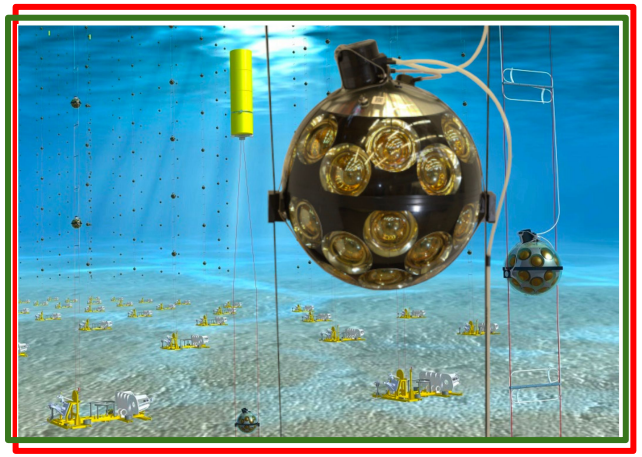
Credits: IceCube Collaboration

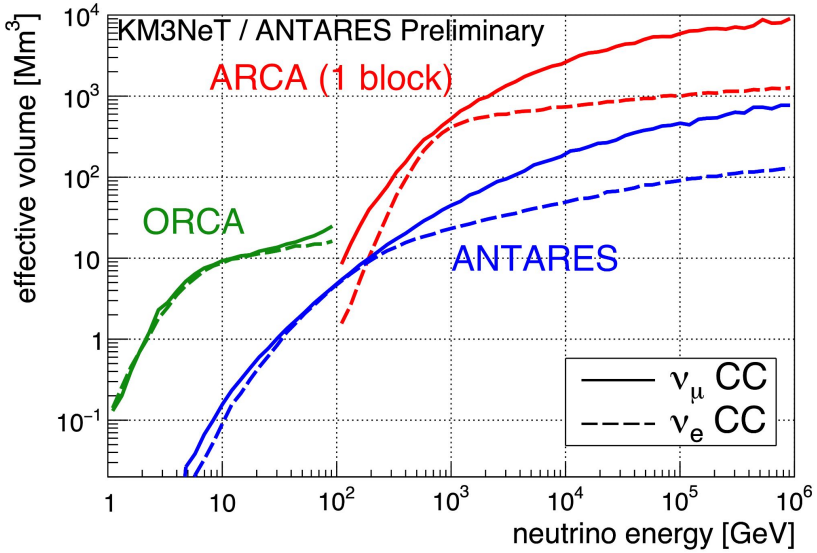




KM3NeT and ANTARES telescopes

→ deep sea research infrastructures in the Mediterranean Sea





- consists of 2 detectors:
  ARCA (astroparticle research) +
  ORCA (oscillation research)
- 230+115 detection units à 558 PMTs
- **under construction**
- currently ≧¼ of both detectors installed and taking data

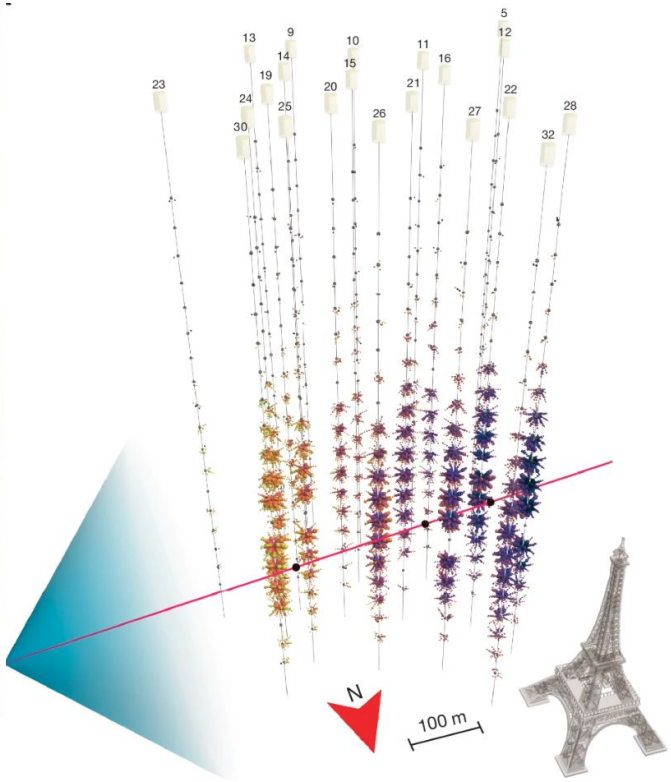
- operated between 2006 to 2022
- 12 detection lines / 885 PMTs total

→ 12+ years of **legacy data**

Recent highlights

from KM3NeT and ANTARES

- Ultra-high-energy neutrino detected by KM3NeT



[Nature volume 638, pages 376–382 (2025)]

@ time of UHE event: only ~10% of final KM3NeT/ARCA detector

- ANTARES legacy analysis published

Physics Reports

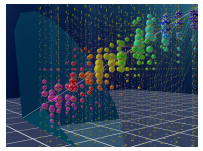
Volumes 1121–1124, 5 June 2025, Pages 1-46

Review Article

The ANTARES detector: Two decades of neutrino searches in the Mediterranean Sea

A. Albert [1 2], S. Alves [3], M. André [4], M. Ardid [5], S. Ardid [5], J.- J. Aubert [6], J. Aublin [7], B. Baret [7], S. Basa [8], Y. Becherini [7], B. Belhorma [9], F. Benfenati [10 11], V. Bertin [6], S. Biagi [12], J. Boumaaza [13], M. Bouta [14], M.C. Bouwhuis [15], H. Brânzaş [16], R. Bruijn [15 17], J. Brunner [6]...J. Zúñiga [3]

Data collection and processing



Detectors

Photon hit stream

filtering

triggered event

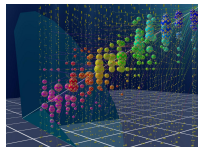
reconstruction

particle events (x, t, E)

"all data to shore"

dynamic calibration

Data collection and processing



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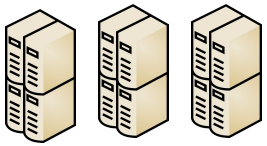


Simulation

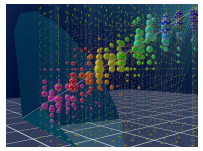
full particle & detector simulation

analogous filtering and reconstruction

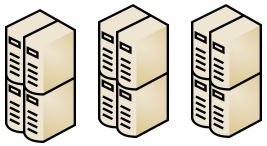
simulated data set

"run by run" accounting for backgrounds, active PMTs

Data collection and processing



Detectors



Simulation

Photon hit stream

filtering

triggered event

reconstruction

particle events (x, t, E)

full particle & detector simulation

analogous filtering and reconstruction

simulated data set

selection on target (source model)

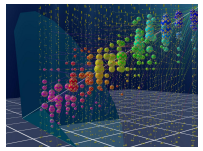
event lists

instrument response

sensitivity & flux limits

neutrino discovery

Data collection and processing



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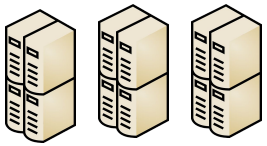


Simulation

Photon hit stream

filtering

triggered event

reconstruction

particle events (x, t, E)

full particle & detector simulation

analogous filtering and reconstruction

simulated data set

selection on target (source model)

event lists

instrument response

sensitivity & flux limits

neutrino discovery

mostly internal

open

custom, ROOT based data formats (contains all PMT hit information)

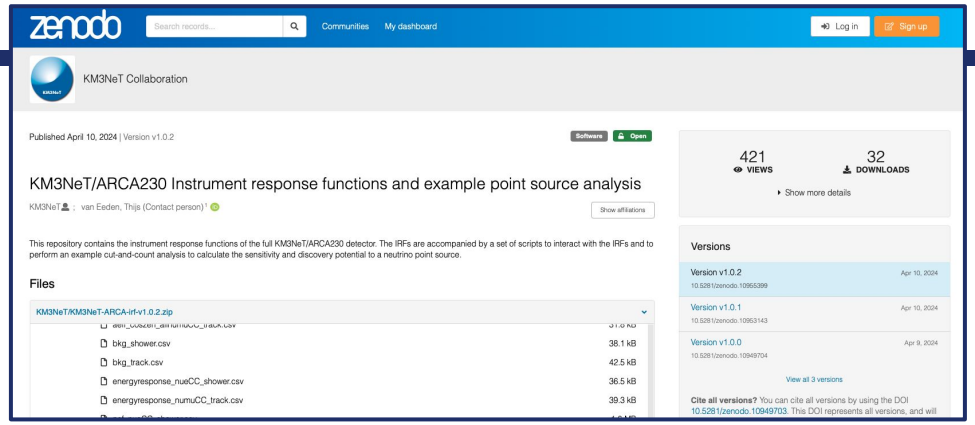
- O(2 PB/year) for KM3NeT/ARCA
- O(0.5 PB total) for ANTARES

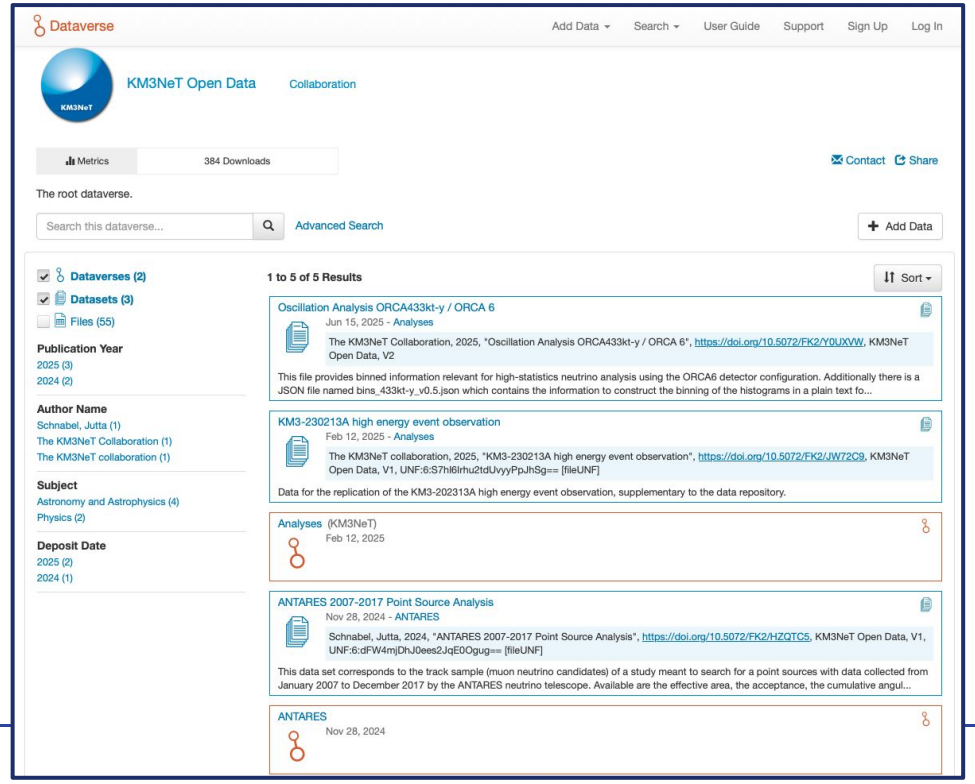
→ VO tables; eventually: VODF format

General data platform: The Open Data Center

Offering event lists, and instrument responses

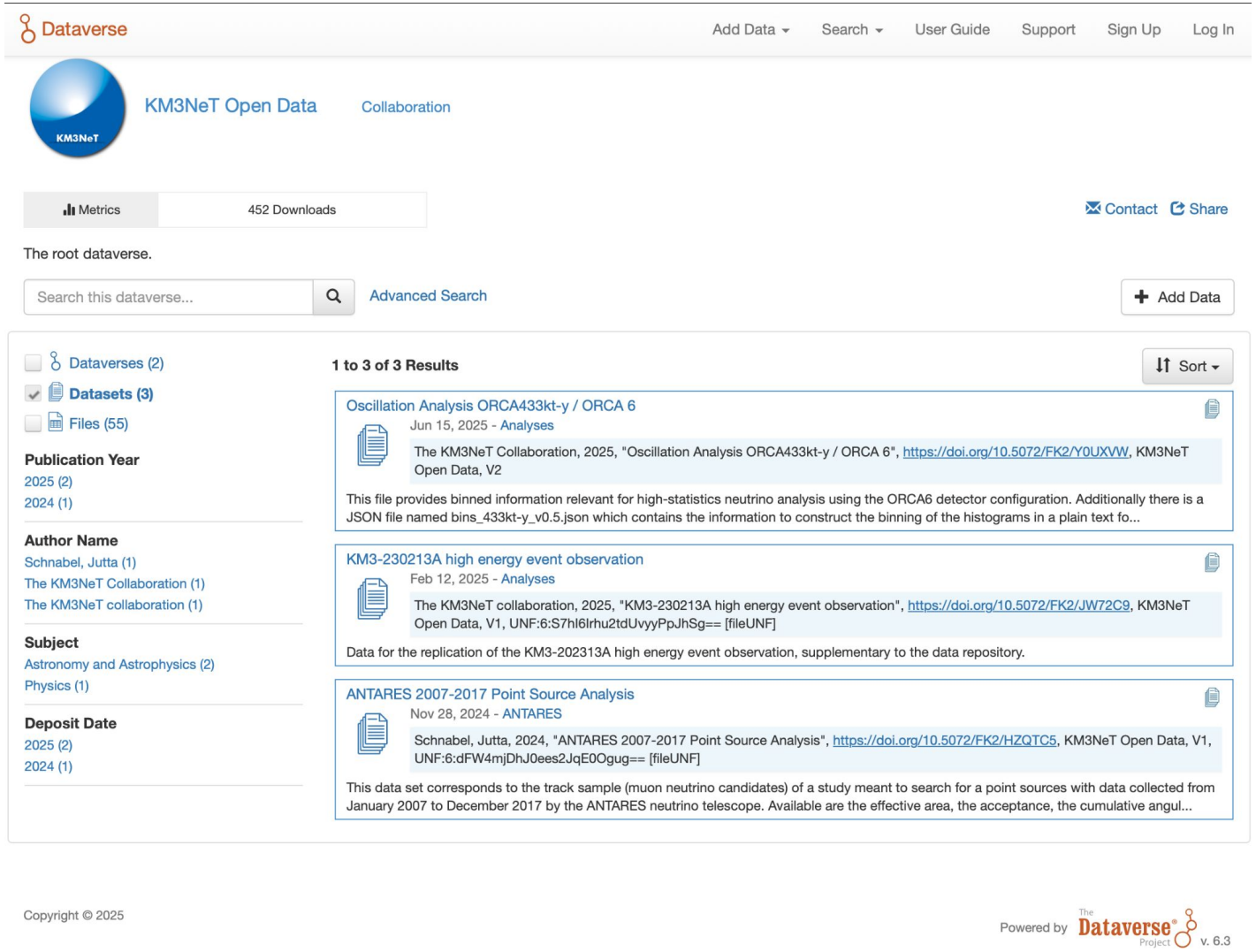
- Open Data Center: **main server** for all public science products by KM3NeT (data, software, papers …)
- Tested several alternatives (**Zenodo**, CKAN, **Dataverse**)
- Established a dataverse instance at opendata.km3net.de
- Can be used for both ***open and restricted*** data sharing!
  - including publications, plots, software …
  - to be developed as central science outcome registry!
- First public datasets available.
  Under construction! Will need to
  - set up authentication
  - establish standard entries for different entry types
  - further develop API interface
  - develop standards for metadata





Open data center

https://opendata.km3net.de/

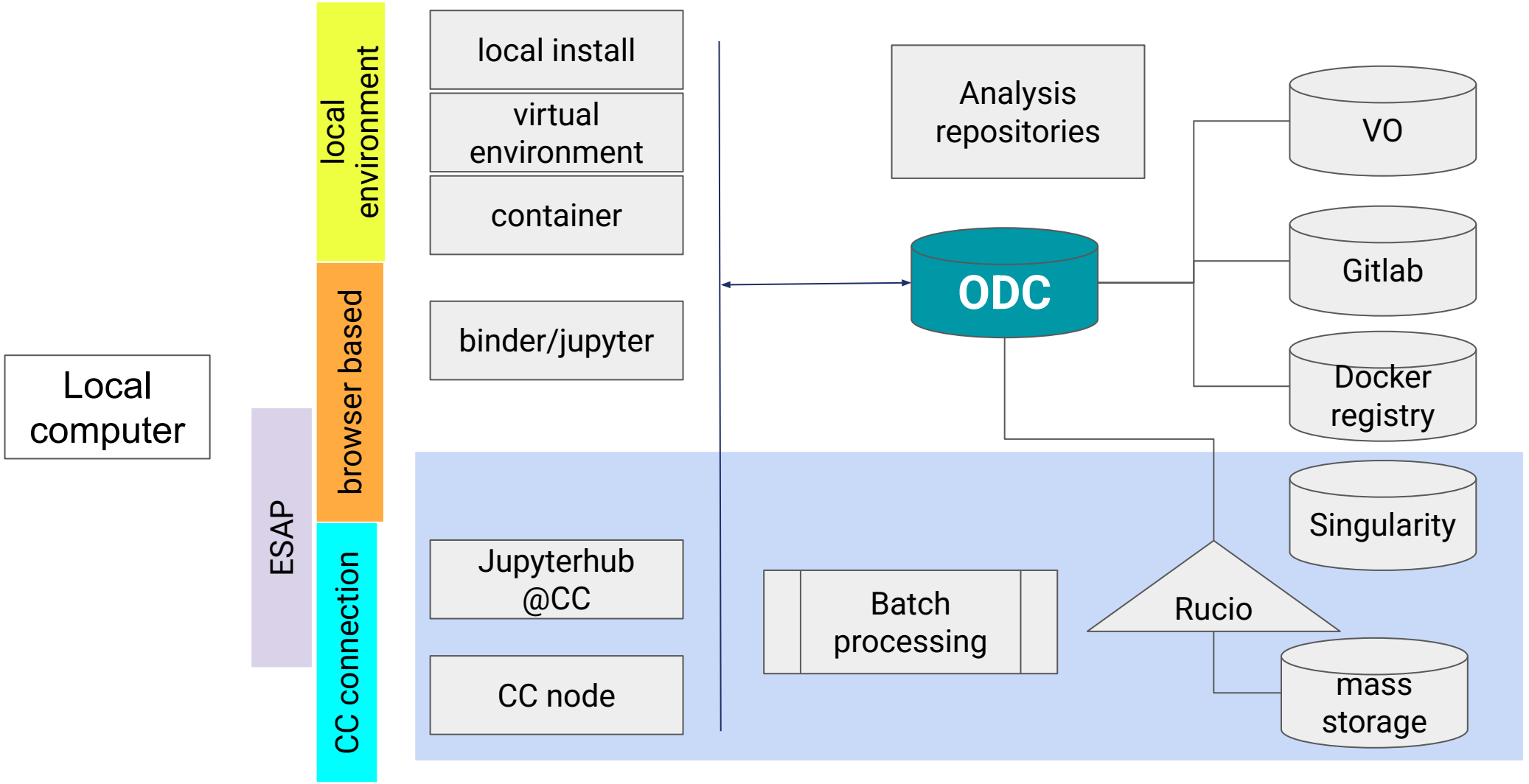


- Currently 3 datasets, covering:
  - neutrino oscillations
  - reproducing part of the UHE event publication (including hit-level data!)
  - event table (as a service from vo server) and instrument response for the 2007-17 point source analysis
    (Note: not yet full legacy dataset livetime, not VODF format)

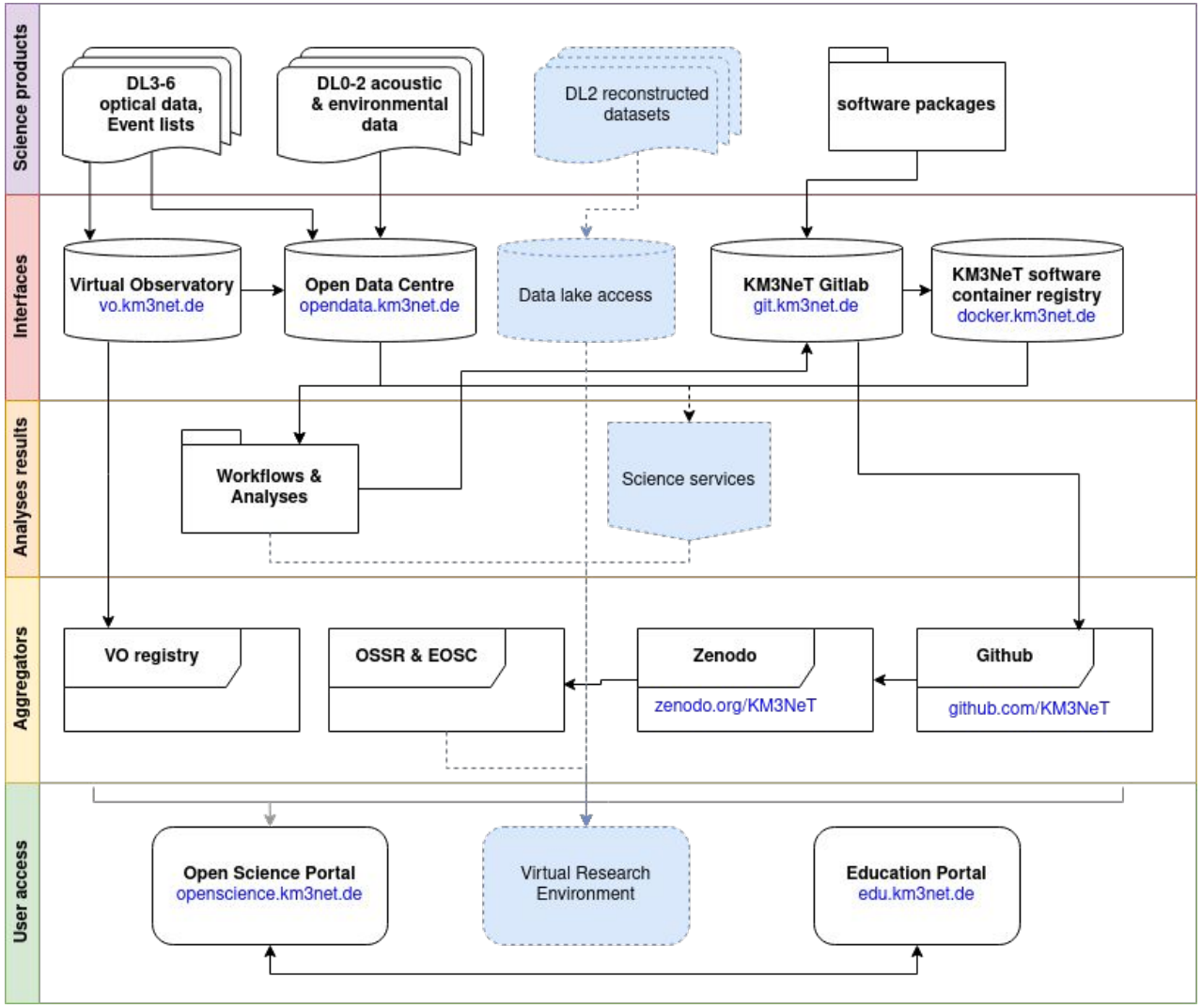
Possible to access via openkm3 python package (shown in tutorial part 1)

Integration of the interfaces

Connection of different services and entry types



Infrastructure: The KM3NeT Open Science System



- Defining data formats and standards for **science products**
- Provide KM3NeT-side **interfaces**
  - For astrophysics: Virtual Observatory
  - For “everything”: Open Data Center
  - For software & Repositories: Gitlab and (docker) containers
- Connection to **aggregators**: VO registry, Zenodo, Github, EOSC …
- Provide or integrate to **User platforms**
  - Open Science Portal, Education Portal

→ Constant development & Improvement

Tutorial Part 1:

ANTARES 2007-17 point source search

ANTARES data in the KM3NeT Open Data Center

- KM3NeT took over responsibility for the ANTARES legacy
- Provisioning of ANTARES datasets, software (containers) and analysis examples in the KM3NeT Open Data Center and VO are suitable use-cases for developing interfaces
- Definition of standard data and content descriptors / metadata under development

Demo: *Reproducing part of the 2007-17 point source search using data and IRFs from the KM3NeT Open Data Center*

-> Demo on binder

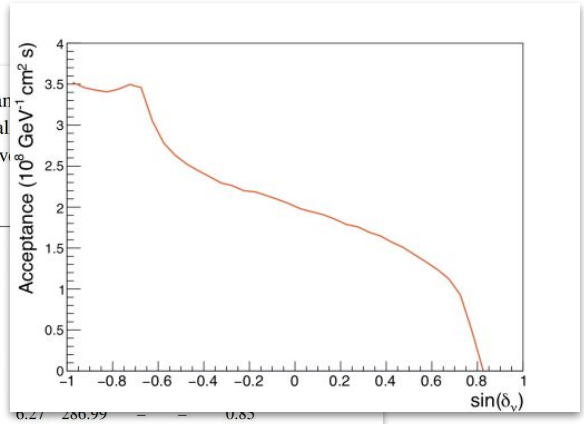
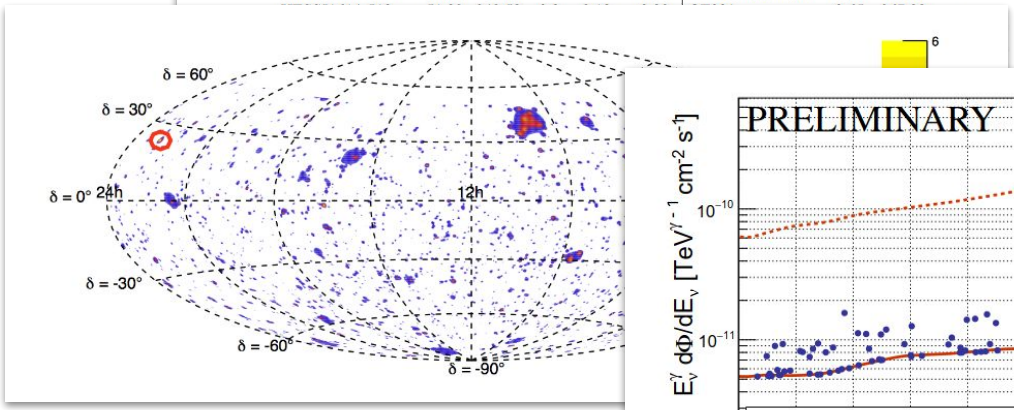
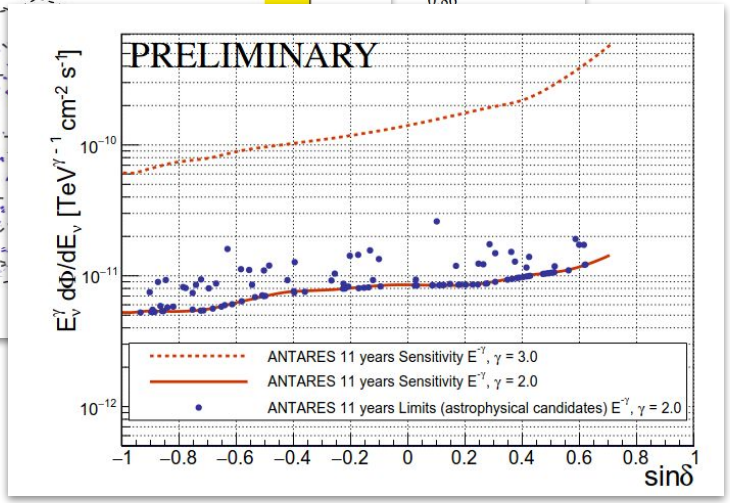


Table 1: List of analysed astrophysical objects. Reported are the source's nam
of signal events, pre-trial p-value and 90% C.L. upper limits on the flux normal
(in units of 10^{-8} GeVcm^{-2}s^{-1}). Dashes (-) in the fitted number of source ev
with null observations.

Name	δ[°]	α[°]	$\hat{\mu}_{sig}$	p-value	$\Phi^{90\%}_{E^{-2.0}}$	Name
LHA120-N-157B	-69.16	84.43	–	–	0.53	HESSJ1837-069
HESSJ1356-645	-64.50	209.00	0.2	0.67	0.75	2HWCJ1309-054
PSRB1259-63	-63.83	195.70	–	–	0.53	3C279
HESSJ1303-631	-63.20	195.75	–	–	0.55	2HWCJ1852+013*
RCW86	-62.48	220.68	–	–	0.53	W44
HESSJ1507-622	-62.34	226.72	–	–	0.53	PKS0736+017
HESSJ1458-608	-60.88	224.54	1.1	0.13	0.90	RGBJ0152+017
ESO139-G12	-59.94	264.41	–	–	0.59	2HWCJ1902+048*
Eta Carinae	-59.68	161.27	–	–	1.00	SS433
MSH15-52	-59.16	228.53	–	–	0.54	HESSJ0632+057
HESSJ1503-582	-58.74	226.46	–	–	0.54	MGROJ1908+06
HESSJ1023-575	-57.76	155.83	1.3	0.12	0.93	2HWCJ1829+070
CirX-1	-57.17	230.17	–	–	0.57	B1030+074
SNRG327.1-01.1	-55.08	238.65	–	–	0.58	2HWCJ1907+084*

6.27	286.99	–	–	0.85
7.03	277.34	–	–	0.85
7.19	158.39	–	–	0.85
8.50	286.79	–	–	0.87
				1.19
				0.86
				0.86
				0.86





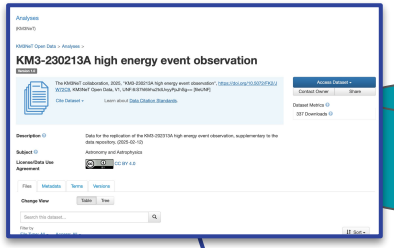
Tutorial Part 2:

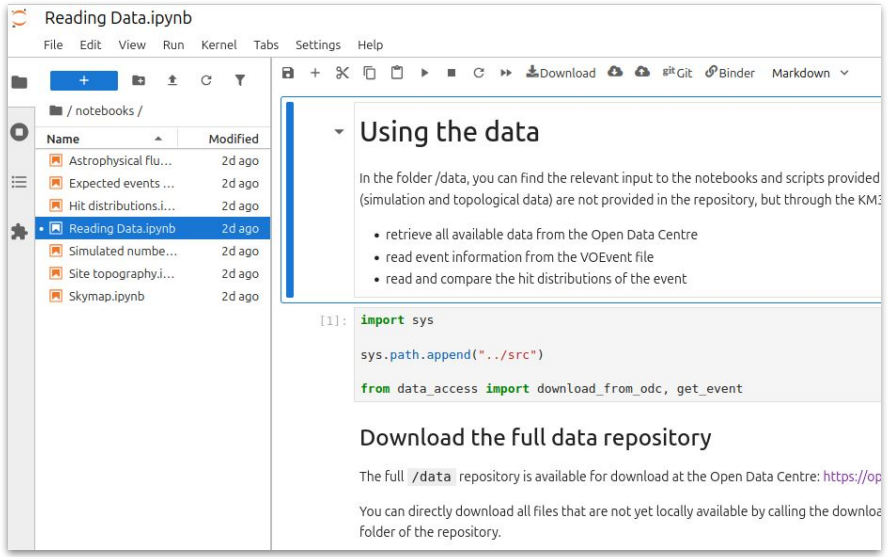
KM3NeT UHE neutrino event

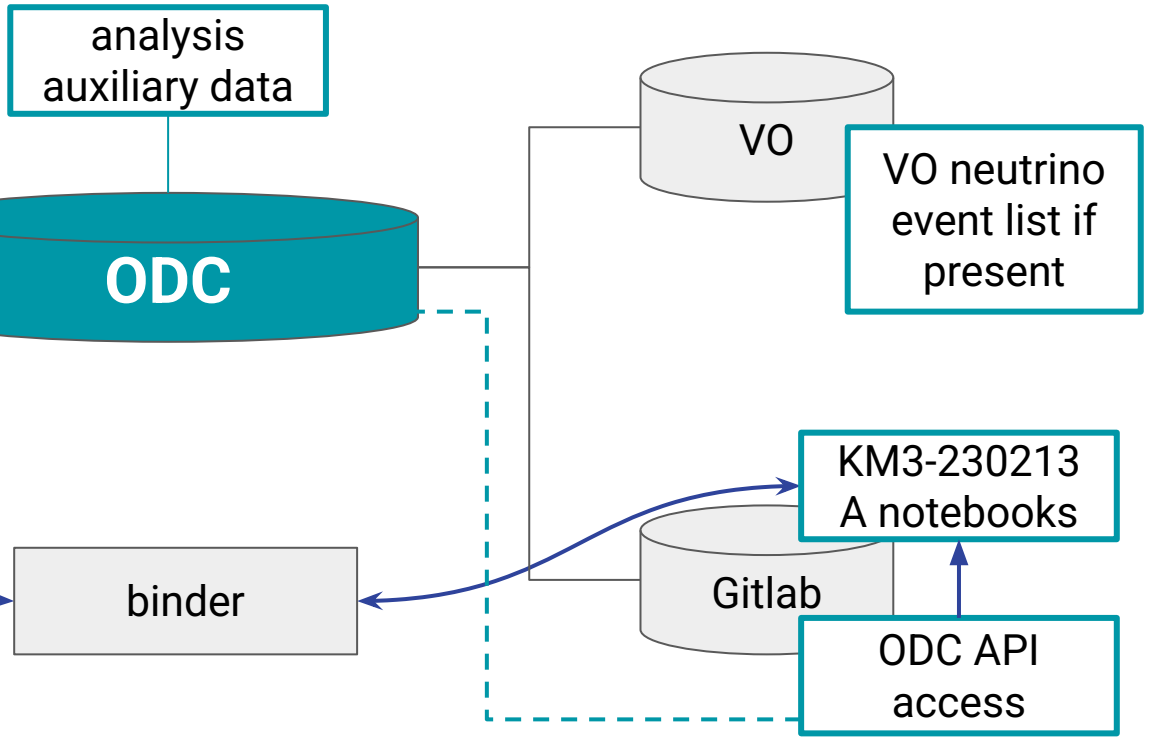
Example: Spinning up an environment

Launching a notebook accessing ODC data

KM3NeT UHE event
“KM3-230213A”,
launching mybinder







building standard interface with openkm3 python client
→ Access ODC entries and files
→ redirect to VO entries

definition /
standardisation of
storing metadata pending

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KM3NeT

ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

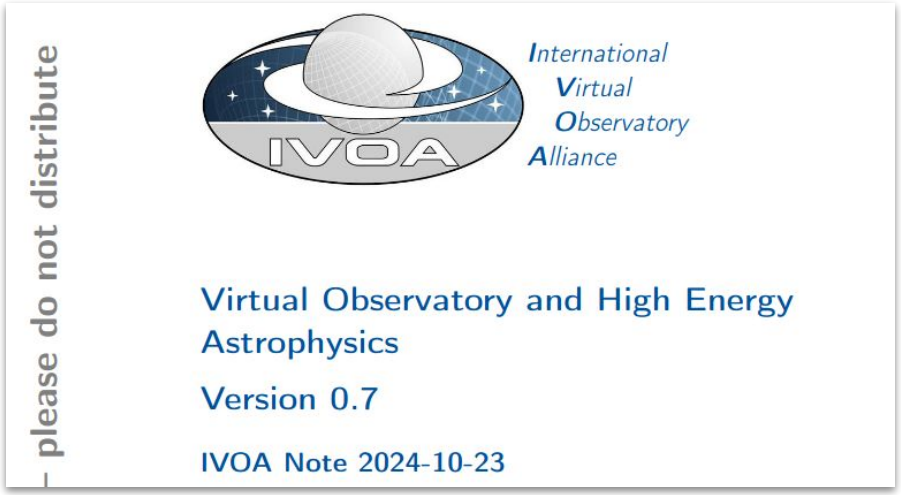
FAU

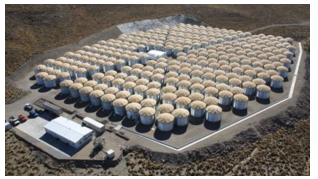
Thank you for your attention!

Data format developments

VODF & HEIG

- VODF based on Gamma Astronomy Data Format (GADF) used in gammapy
- Official structure established
  - VODF Steering committee: one representative per experiment, defining roadmap & goals
  - VODF Lead Editors: Format development
  - Conveners: Organization & Coordination of work

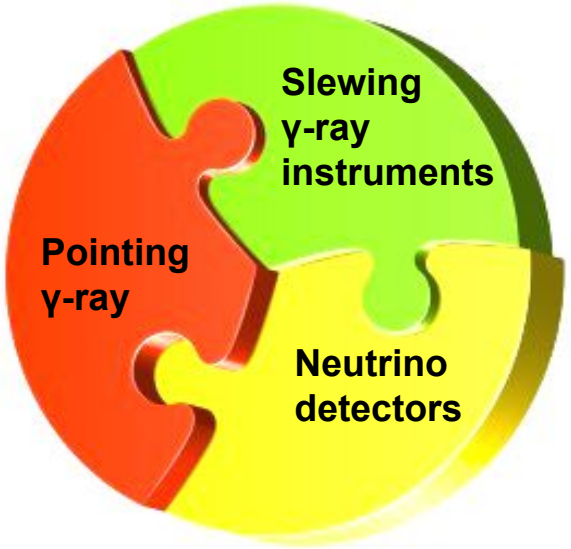


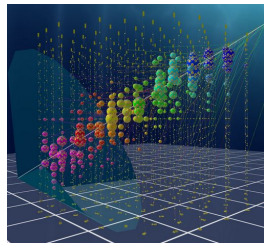


HAWC

Fermi-LAT

SWGO





IceCube

KM3NeT

FACT

H.E.S.S.

CTAO

ASTRI

MAGIC

VERITAS