ASTERICS is a project supported by the European Commission Framework Programme Horizon 2020 Research and Innovation action under grant agreement n. 653477
KM3NeT & ASTERICS

KM3NeT
Water Cherenkov in deep sea

**Building block:**
115 DUs

**Detection Unit (DU):**
18 evenly spaced DOMs

**Digital Optical Module (DOM):**
31 PMTs (+ other instruments)
Astroparticle Research with Cosmics in the Abyss

km³ size building blocks (2×) z DOM spacing 36 m

Oscillation Research with Cosmics in the Abyss

1 building block z DOM spacing 9 m

Phase 1 (fully funded - deploy 2018/19)
Phase 2 (partially funded - deploy 2019/21)


C. Bozza for the KM3NeT Collaboration – Workshop INFN CCR 2018
KM3NeT & ASTERICS

Bringing together the astronomy, astrophysics and particle astrophysics communities

MULTI-MESSSENGER ASTROPHYSICS

Multi-messenger astrophysics is an emerging area of space-time astrophysics that seeks to understand the emission of gravitational waves and high-energy cosmic rays in common sources. This involves the study of neutron stars, black holes, and other exotic objects in the universe.

DATA

The astrophysical ESFRI projects will support the development of new technologies and methods for data analysis, enabling the study of complex phenomena across different astrophysical domains.

TIMING

The astrophysical ESFRI projects will support the development of new technologies and methods for data analysis, enabling the study of complex phenomena across different astrophysical domains.

CITIZEN SCIENCE

Part of our mission is to engage with the general public as well as technical audiences. That is why we are developing public outreach programmes that address astrophysics questions, whilst educating the public in knowledge discovery.

UPCOMING EVENTS

Second European Data-Driven Forum and Training Event

30 - 31 June 2020, Heidelberg (Germany)

This workshop is dedicated to the second European Data-Driven Forum and Training Event held in 2020. It will focus on recent advances in the field of data-driven and data-driven models for the analysis of astrophysical data and their applications.

Very Large Volume Neutrino Telescope Workshop

26 - 28 October 2019, Villa d'Este (Italy)

The workshop is dedicated to the study of very large volume neutrino telescopes, exploring their potential for high-energy astrophysics and cosmology.

Data Analytics and Management in Data-Visible Society Conference 2019

28 - 30 October 2019, Munich (Germany)

Data Analytics and Management in Data-Visible Society Conference 2019 is aimed at providing a multidisciplinary forum for researchers and professionals from various domains of computational science, including astrophysics, cosmology, and high-energy physics.

ASTTronomy ESFRI and Research Infrastructure Cluster

C. Bozza for the KM3Net Collaboration – Workshop INFN CCR 2018
ASTERICS WPs and KM3NeT involvement

- WP 2: Dissemination, Engagement and Citizen Science (DECS) *
- **WP 3: OBservatory E-environments Linked by common ChallengeS (OBELICS)**
- WP 4: Data Access, Discovery and Interoperability (DADI) *
- WP 5: Connecting Locations of ESFRI Observatories and Partners in Astronomy for Timing and Real-time Alerts (CLEOPATRA) *

Task 3.3 D-INT: Data systems INTegration
Task 3.4 D-ANA: Data ANAlysis/interpretation

* Other KM3NeT involvements, not in this presentation
**CORELib (Task 3.4)**

**Cosmic Ray Event Library**: a service from KM3NeT to the scientific community

Cosmic ray showers are a common background source, but may also be the subject of observation depending on the experiment/application

CORELib includes events in a broad energy spectrum and with inclination up to 89° (focus not only on KM3NeT!)

Input to reconstruction/analysis algorithms (in particular, ML models: as good as the input data are!)

A common benchmark with well-documented and controlled conditions to evaluate algorithms and analysis techniques

Currently using CORSIKA as generator
CORELib (Task 3.4)

Pilot production - completed

<table>
<thead>
<tr>
<th>Energy range (GeV)</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>200-1000</td>
<td>$10^7$</td>
</tr>
<tr>
<td>$10^3$-10$^4$</td>
<td>$10^7$</td>
</tr>
<tr>
<td>$10^4$-10$^5$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>$10^5$-10$^6$</td>
<td>$10^5$</td>
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<tr>
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<td>$10^3$</td>
</tr>
<tr>
<td>$10^8$-10$^9$</td>
<td>$10^2$</td>
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</tbody>
</table>

Spectral index -2

Interaction models

<table>
<thead>
<tr>
<th>High energy model</th>
<th>Low energy model</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>QGSJET01</td>
<td>GHEISHA</td>
<td></td>
</tr>
<tr>
<td>QGSJET01</td>
<td>GHEISHA</td>
<td>X</td>
</tr>
<tr>
<td>QGSJETII-04</td>
<td>GHEISHA</td>
<td>X</td>
</tr>
<tr>
<td>EPOS LHC</td>
<td>GHEISHA</td>
<td>X</td>
</tr>
</tbody>
</table>

• Proton-induced showers
• Nuclei-induced showers
• With and without Cherenkov radiation

Observation station: sea level
Atmosphere: Standard European Binary (CORSIKA) and ASCII format

γ-initiated  p-initiated  He-initiated
Energy matters!

Computation time and output file size as a function of energy
**CORELib (Task 3.4)**

**Full production – ongoing (~4 months to go)**

<table>
<thead>
<tr>
<th>Energy range (GeV)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>200-1000</td>
<td>$15 \times 10^5$</td>
</tr>
<tr>
<td>$10^3$-$10^4$</td>
<td>$15 \times 10^5$</td>
</tr>
<tr>
<td>$10^4$-$10^5$</td>
<td>$15 \times 10^5$</td>
</tr>
<tr>
<td>$10^5$-$10^6$</td>
<td>$15 \times 10^5$</td>
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<tr>
<td>$10^6$-$10^7$</td>
<td>$15 \times 10^5$</td>
</tr>
<tr>
<td>$10^7$-$10^8$</td>
<td>$15 \times 10^5$</td>
</tr>
<tr>
<td>$10^8$-$10^9$</td>
<td>$15 \times 10^5$</td>
</tr>
</tbody>
</table>

**Using 1064 cores at ReCaS**

<table>
<thead>
<tr>
<th>High energy model</th>
<th>Low energy model</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>QGSJET01</td>
<td>GHEISHA</td>
<td>TAULEP</td>
</tr>
<tr>
<td>QGSJET01</td>
<td>GHEISHA</td>
<td>CHARM</td>
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<td>QGSJETII-04</td>
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<td>X</td>
</tr>
<tr>
<td>EPOS LHC</td>
<td>GHEISHA</td>
<td>X</td>
</tr>
</tbody>
</table>

**Flat (log) spectrum**

3 M high energy events (vs. 1100 of pilot production)

32x size increase!

Binary and ASCII format (ASCII output files already split by particle types)

$(\nu, \gamma e^+ e^-, \mu^+ \mu^-, \tau^+ \tau^-, \text{hadrons/nuclei, Cherenkov } \gamma)$

Done, “EPOS” remaining
Accessing data

Pilot production: SFTP to Salerno server (corelib@193.205.188.227 pwd Asterics2020) ~600 GB

Full production: currently hosted in ReCaS GRID SE, underway to be moved to CNAF ~50 TB expected
Access via Indigo-DataCloud, DIRAC, other?

Next steps:
• Starting discussions to involve other Collaborations (possible joint work in ESCAPE)
• Increase number of stations (2200m, 4000m) to match possible sites
• Simulate below 200 GeV
• Consider different atmospheres
**ROOT extensions for Astronomy**

ROOT is the standard tool for HEP analysis but does not offer much related to Astronomy.

Our goal: a library for many Astronomy-related activities that is natively developed in ROOT:

- Unified and seamless access to catalogues
- Coordinate transformations
- Sky Map
- Precise modeling of Moon and Sun position

Find everything at [https://gitlab.com/Spisso/ASTERICS-ROAst](https://gitlab.com/Spisso/ASTERICS-ROAst) (including docs/tutorial)
ROAst (Task 3.4)

Access to catalogues

Offline catalogues:
• UCAC4 (USNO CCD Astrograph Catalog v.4)
• URAT1 (USNO Robotic Astrometric Telescope v.1)

Online catalogues:
• Virtual Observatory (VO) catalogues
• VizieR catalogue repository (> 17,000!)

A core set of properties common to all catalogues are provided + extended properties that depend on each catalogue (e.g. proper motion info)
Dynamic property browsing ensures flexibility

Regions of various shapes can be extracted from each catalogue (Rectangle/Circle/Ellipse)
ROAst (Task 3.4)

Access to catalogues

Welcome to ROOT 6.87/87
(c) 1995-2016, The ROOT Team
Built for Linux-x86_64-gcc
From heades/master/96-07-06-745-g07ce61, giu 27 2016, 17:57:06
Try 'help', 'demo', 'license', 'credits', 'quit'/.q'

root [0] .L libAstroCatalogue.so
root [2] ROAst::T AstroCatalogue::graphics VOCatalogueGraps
This is the ROAst-Astro Catalogue Graphics Class, V 1.0
(ROAst::T AstroCatalogueGraphics & Name: Title:
root [3] ROAst::T AstroCatalogue* Test
(ROAst::T AstroCatalogue *) multpar
This is the ROAst-Virtual Observatory Catalogue Class, V 1.0
(ROAst::T AstroCatalogue *) 0x233c7b0


United States Naval Observatory Flagstaff Station 28Sep2017 01:35:48
Astronomical Image and Catalogue Server:
http://www.nofs.navy.mil/data/fchpix/
Please send questions and problem reports to:
sett@nofs.navy.mil

(Int_t) 302
Info in <TCanvas::MakeDefCanvas>: created default TC canvas with name cl
Info in <TCanvas::MakeDefCanvas>: created default TC canvas with name cl
root [8]
## Coordinate transformations supported

<table>
<thead>
<tr>
<th>Astronomical coordinate system</th>
<th>Geographical coordinate system</th>
<th>Time coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equatorial</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Galactic</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Lat-Long/UTM</td>
<td>Unix time/UTC/Local Sidereal</td>
</tr>
<tr>
<td>Equatorial rectangular</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Ecliptic</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
ROAst (Task 3.4)

Skymaps and plotting

<table>
<thead>
<tr>
<th>Astronomical coordinate system</th>
<th>Flat plot</th>
<th>Aitoff projection</th>
<th>Aitoff skymap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equatorial</td>
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<td>OK</td>
<td>OK</td>
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<tr>
<td>Galactic</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Horizontal</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

+ Precise Moon position model (ELP-2000-82)
+ Precise Sun position model (VSOP87)
CONTAINERISATION (Task 3.3)

Requirements

• Check old analyses
• Run similar analyses on own data for comparison
• Preserve “legacy” software (e.g. no Scientific Linux 6 in several computing centres!)
• Fulfill reproducibility (e.g. in FAIR principles in grant agreements)

Exploring possible solutions

<table>
<thead>
<tr>
<th>Virtual Machines</th>
<th>Docker</th>
<th>Singularity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow, un flexible</td>
<td>Not supported on HPC clusters</td>
<td>Looks OK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Commits</th>
<th>Contributors</th>
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<tbody>
<tr>
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<tr>
<td>Nix</td>
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<tr>
<td>rkt</td>
<td>5167</td>
<td>177</td>
</tr>
</tbody>
</table>
CONTAINERISATION (Task 3.3)

Singularity Status:
- Works on Linux (native), Windows & Mac (Vagrant), several HEP-related computing centres
- Easy installation on own machine
- Highly compatible with Docker

Service to community: ANTARES (KM3NeT progenitor) main data processing tool chain fully containerised

KM3NeT applications ported so far
- Jpp (Data processing framework)
- KM3Pipe (Python-based data management and processing framework)

Next steps: containerisation also in continuous software integration
• Participation in ASTERICS project proved beneficial to KM3NeT

• Dedicated HR for specific long-term tasks

• Setting up “bridges” with other Collaborations

• Set the foundations for possible evolutions and joint work

• KM3NeT contributions helped earning leading/coordination positions in future projects