European Commission

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Project Acronym: ASTERICS

Project title: Astronomy ESFRI & Research Infrastructure Cluster

Periodic Technical Report

Part B

Period covered by the report: from 01/11/2016 to 30/04/2018

Periodic report: 2nd

[1] The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation

Astronomy ESFRI & Research Infrastructure Cluster

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1 November 2016 – 30 April 2018

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1 Explanation of the work carried out and overview of the progress

The ASTERICS project is set up around four astronomy ESFRI facilities (SKA, CTA, KM3NeT and ELT). The ASTERICS Consortium consists of universities and research institutes with groups of researchers and developers that are linked to one or more of these ESFRI facilities. One major task at the beginning of the project was to bring together people from these four distinct research areas, as they had not worked together on such a large scale before. These groups have evolved very different cultures and ways of collaborating. The Virtual Observatory (VO) meetings started with a well-defined core around several observatories and data sets and expanded quickly in the first project period with new groups to their meetings. Collaborations were extend around Citizen Science experiments and new collaborations resulted in new Citizen Science experiments at the end of PP1. The integration within the overall project of the various groups progressed and participants were, in parallel to the developments for their own facility, more and more thinking about the possible implementation of their work in other facilities. This was a big achievement so early into the project and a nice starting point for the second project period. The VO meetings included more data providers and developers and users from new wavelengths and messengers. Around data and software development two well attended and appreciated schools and workshops were organised, attracting industry and young researchers from outside the project partners. Citizen Science experiments were successfully launched and concluded. A Multi-messenger astrophysics meeting was organised around timing and alerting around gamma and radio astrophysics. For the integration within the project an all-hands meeting was organised, where participants exchanged knowledge and ideas in diverse groups. The most awarding message we received was during the Gravitational Wave Town Hall meeting in April 2018 in Amsterdam, where when some challenges with coordination of multi-messenger alerts were recognised, multiple persons in the audience suggested ASTERICS as the first place to look for coordination of solutions. We must have left a positive impression at earlier meetings. This was at the end of the project period. With the initiative to lead this coordination we will ensure a productive third project period for multi-messenger astroparticle physics.

On technical activities, progress is made in all work packages. The work is mostly in line with the description of action. Details on results and progress are given per work package.

This chapter describes the work carried out during the reporting period (1 November 2016 - 30 April 2018) in line with the Annex 1 to the Grant Agreement (Description of Action (DoA)). In Section 1.1, a list of specific ASTERICS objectives is followed by a description of the progress towards the achievement of those objectives during the second 18 months of the project.

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1.1 Objectives

The main objective of ASTERICS is to establish a single collaborative cluster of next generation ESFRI telescope facilities in the area of astronomy, astrophysics and astroparticle physics by identifying, addressing and solving key challenges of common interest, adopting cross-cutting solutions with mutual and wide-ranging benefit to all concerned.

ASTERICS facilitates the process of identifying areas of rapid technology development, where the adoption of a complementary and synergetic approach across the ESFRI projects can lead to significant added value in their operational phase. Moreover, as the ESFRI projects sharply focus on their own design requirements, ASTERICS looks towards enabling interoperability between the facilities, minimising fragmentation, encouraging cross-fertilisation, developing joint multi-wavelength/multi-messenger capabilities, and opening-up the next generation.
During the third year of the ASTERICS project, we positively concluded that the goal of the project, to bring astronomers and astroparticle physicists together and have them develop tools together and learn from each other where possible, was almost reached. We had broken the four silos (radio, optical, gamma-rays and neutrinos) and people were now working together on the four topics in data generation, data integration, data analysis, the Virtual Observatory, timing and scheduling, and citizen science, but we felt we had created new silos on these topics (see figure 1).

Figure 1. Astronomy silos within ASTERICS.

Therefore, we wanted to organise a meeting to bring all persons working on ASTERICS subjects together to exchange results, successes, developments and questions and create what we called diagonal links through the collaboration. Vertical were the original 'messenger' silos, horizontal the ASTERICS WPs and tasks. The diagonal links would create an optimal fabric for collaboration and continuing collaboration after the project (figure 2).

Figure 2. The diagonal links create an optimal fabric for collaboration and continuing collaboration after the project.

To achieve the ASTERICS main goal, a set of objectives have been set. These are described in the DoA and reported below (italic text):

- *Maximise software re-use and technology co-development for the robust, scalable and flexible handling and exploitation of the huge data streams and distributed petascale database systems associated with the ESFRI facilities - identifying best practice, defining open standards, design patterns and benchmarks, generating prototypes, constructing use-cases, and optimising frameworks and software libraries in an open innovation environment.*

  A collection of statistically robust and domain independent open source software libraries for data analysis and data mining on Peta-scale datasets were released on OBELICS software repository http://repository.asterics2020.eu/software.

  The open repository is the way that we have chosen to guarantee the open access to ASTERICS-OBELICS results. Furthermore it is a main obejctive for WP3 through which we have supported fruitful convergence of complementary expertise and we have built a community based innovation environment for all ESFRI and other RIs involved in ASTERICS. Thus, anticipating a path to FAIR data, software and service solution preservation, as it will be set up in the European Open Science Cloud (EOSC).

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WP4 DADI contributes by providing building blocks from the Virtual Observatory framework of open standards and tools. These have initially been developed for enabling interoperability and are now more and more used by projects including them in their data pipelines.

- *Investigate and demonstrate data integration across the ESFRI facilities, using data mining tools and statistical (e.g. Bayesian) analysis techniques, introducing adaptable and evolving work management systems that will permit deployment on existing and future e-science infrastructures.*

  ESFRI projects face many challenges in the processing and integration of their data. Original solutions were developed and tested by members of the ASTERICS Collaboration to overcome these challenges. In this report, numerous tests on data format, data storage and transfer and data processing in an automated pipeline and in large databases were performed. These tests were presented and discussed in the D-INT technology benchmark report (D3.9). In addition, many tests were performed on innovative hardware with low power consumption within the ASTRI for CTA and DOME for SKA projects. Dedicated data analysis software were developed in order to perform tests and benchmarks on new architectures, also in collaboration with hardware producers. These results were presented in the D-GEX technology benchmark report (D3.8).

  A repository of services (http://repository.asterics2020.eu/services) providing a framework for the analysis and integration of data for large-scale infrastructures was developed under WP3. These services have been developed or evaluated under the ASTERICS-OBELICS work package. The repository also includes services developed by collaborating projects with applications in astronomy ESFRI projects. Eleven workflow management services software were developed under task D-ANA of OBELICS workpackage. These software products are publicly available on http://repository.asterics2020.eu/software.

- *Coordinate and harmonise the joint and efficient scheduling, operation and interoperability of the ESFRI facilities (and indeed other ground and space based telescopes) via a high-level policy forum and through technical developments such as innovative time synchronisation that enable multi-messenger astronomy via a rapid exchange and evaluation of VOEvent messages alerts, taking into account all necessary book-keeping logistics such as interchange formats, authorisation, prioritisation and identity methodology.*

  After a number of preparatory meetings with a growing number of participants, we had the First ASTERICS Policy Forum on 17 and 18 January 2018 in Nice. The following four main topics were discussed in science cases that were provided by the ESFRI RIs and their science working group members:
    1. Joint time allocation;
    2. Observing strategies for multi-messenger campaigns;

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3. Data access and sharing;
4. General policies of common interest (towards next generation ESFRI RIs).

The participants discussing these main topics consisted of ASTERICS work package leaders, external advisory board (AEAB) members and science working group members from the different ESFRIs. Activities during the meeting, conclusions and future actions will be presented in the WP1 section.

DADI collaborates with CLEOPATRA to gather requirements on VOEvent and works in the IVOA Time Domain Interest Group to update the standard if required.

- *Adapt the VO framework and tools to the ESFRI project needs, gathering requirements from the community and making the data interoperable in a homogeneous environment, enabling discovery and re-usage by the entire astronomical community and accessibility via a set of common tools and standards.*

  The four kinds of complementary events organised by DADI contribute to this objective. The Technology Forums (two during the period) are devoted to the discussion of the partners' relevant technological activities and are used to strengthen cooperation and collaboration, and to prepare European input to the International Virtual Observatory (IVOA) meetings - the IVOA develops the astronomical interoperability standards. The ESFRI Forums and Training Events (one during the period) are dedicated to gathering the ESFRI and pathfinder requirements and feedback. The European Data Provider Forums and Training Events extend the concept to all data providers, and allow us to check the general relevance of the VO developments (the one foreseen during the period was organised earlier, during the first reporting period). The yearly DADI Schools (two during the period) also gather science usage requirements and feedback on VO-enabled tools. In addition, specific meetings are organised as required to progress in the gathering of requirements and technological discussion.

  Requirements and feedback drive the DADI technological activities on the development of the VO framework of standards and tools. These activities are performed in the context of the IVOA Working and Interest Groups, and the results are presented during the IVOA Interoperability meetings. The DADI first priority, interoperability standards for multi-dimensional data, was completed with the adoption of the last relevant standard in May 2017. The second priority, time domain data, is actively pursued in DADI and in the IVOA, under the leadership of DADI staff.

- *Disseminate the results of ASTERICS to as wide an audience as possible, via the production of high quality outreach materials and direct engagement with all relevant stakeholders. Open-up the ESFRI facilities to the general public via a suite of Citizen Scientist Mass Participation Experiments (MPEs) that will capture the interest of the general public, especially the next generation of future engineers and scientists.*

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WP2 DECS has produced a set of promotional tools. In collaboration with WP1, an updated website has been created that is the introductory point of ASTERICS for a wide range of audience, from the general public to stakeholders (see figure 3). An ASTERICS brochure and pull-up banners are more specific tools that helped to disseminate ASTERICS results during international events. A new version of the brochure highlighting a selection of results obtained in ASTERICS in the first three years of the project was finished at the end of April 2018 and published shortly afterwards. The renewed website and brochure focus more on the topics related to ASTERICS and less on the work packages than the previous versions and are more adapted for exploitation of the results. The use of social media by means of Twitter and a Facebook page has allowed the project an instantaneous interaction and feedback.

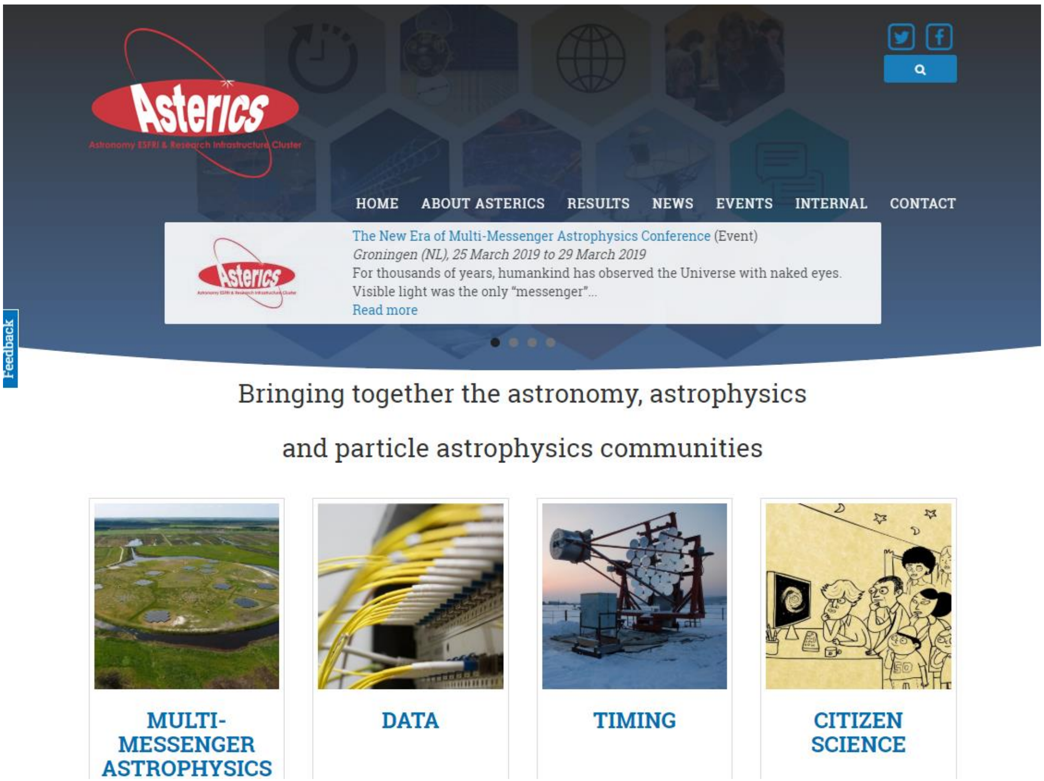

Figure 3: Screenshot of the renewed ASTERICS website.

The project manager, project scientist and work package leaders attended several conferences and meetings to present ASTERICS there, or made sure to send a delegate.

One of the main aims of DADI is the implementation of the ESFRI and pathfinder data in the Virtual Observatory. This will open the data that is produced by the ESFRI facilities to usage by the global astronomical community and the general public, as well as enabling this data to be available for use in citizen science projects.

- *Train and educate the community in the usage and implementation of the ASTERICS products (e.g. the VO framework and tools), and make ESFRI staff active participants in*

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the use of new cross-domain Big Data software solutions, processor architectures and citizen science applications. Build capacity in the field, to train and develop the next generation of scientists and engineers that will be the future users of the ESFRI astronomy facilities.

This objective was addressed through a number of general workshops as well as thematic training events organized during the reporting period. Along with invited talks, the first ASTERICS-OBELICS workshop included live demos with tutorials on QServ architecture, MonetDB database systems and Apache Spark computing framework. These live demos provided participating researchers a walkthrough of these systems, for example, QServ has potential applications for SKA and LOFAR.

The second ASTERICS-OBELICS workshop emphasized on the Machine Learning sessions with live demos. Machine Learning techniques are already being tested in various ESFRI projects such as KM3NeT, CTA as well as world class projects such as LSST.

The first ASTERICS-OBELICS thematic training on advanced software programming for astrophysics and astroparticle physics provided theoretical and hands-on training to acquire efficient and fast computer programming techniques, as well as skills for improving scientific data analysis software.

The second ASTERICS-OBELICS international school scientific programme focused on training Masters students, PhD students, postdocs, as well as senior researchers on python libraries and machine learning applications for astronomy and astroparticle physics.

Furthermore, partners of ASTERICS-OBELICS have conducted original developments, in certain case in cooperation with industrial partners. Such developments have concerned new paths to improve the sensitivity of analysis software, and the efficiency of processor exploitation. The results of such works have also been presented in conferences, in ESFRI RI collaboration meetings as well as published in review journals.

DADI ESFRI and pathfinder participants are enabled to implement the VO standards and to use VO tools, through DADI workshops, specific meetings, participation in IVOA meetings, and technical discussions when needed. They are progressively involved as active participants in technological work on the development of the VO framework. One highlight is the definition of the Provenance Data Model, which is on the IVOA Recommendation path and was adopted by CTA for its pipeline. DADI Schools are open to early career scientists and staff from the ESFRIs and pathfinders, to train them to use VO-enabled capabilities for their own needs.

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1.2 Explanation of the work carried out

1.2.1 WP1 Management

This work package establishes the ASTERICS Management Support Team (AMST), thus guarantees the smooth execution of all financial, administrative and reporting elements of the project. It also permits the AMST to exercise central control and oversight of the scientific and technical progress of the project, as measured by the successful receipt of deliverables and secured milestones. A high-level Policy Forum (involving the ESFRI projects and other large astronomy research infrastructures) has been established in order to coordinate and agree new models for joint time allocation, observing and data access/sharing, in addition to other more general policy matters of common interest. The culmination of ASTERICS will be a grand Integrating Event to show-case the results of the project and their relevance to the ESFRI telescopes and all other relevant stakeholders.

1.2.1.1 Management and Administration

Two new team members joined the management support team in 2017. A project assistant started in May 2017 and is providing support to the members of the management support team. A project liaison officer joined in October 2017 and is working on tasks related to the exploitation and collaboration plan.

The management support team oversees smooth execution of the financial elements of the project by monitoring the partner's expenses on a six-month cycle. This way we noticed early on that some partners started their activities slower than expected. This was addressed in the first periodic review. In the second period, partners increased the activity and in the previous cycle (M30) most partners indicated they would finish around the agreed budget.
In addition, the management support team keeps track of Deliverables and Milestones, lists of publications, dissemination etc. Some deliverables had a considerable delay. This was communicated with the Project Officer. For two deliverables, this was hardware related and for one hiring the required postdoc was late. These deliverables were planned relatively early in the project and have no follow-up, so there are no consequences for the overall project.

The work package leaders continued to have meetings (mostly teleconferences) every two months. The ASTERICS General Assembly (AGA) Chair is also invited to these meetings.

Three activities during the second reporting period were not planned:

- An amendment was started to include OPNT as a new partner. The staff member from the VU continued ASTERICS activities in the start-up SME OPNT and it was agreed that tasks and funding would be moved from the VU to OPNT. This amendment was started at the end of the period and should be completed soon.

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- The ASTERICS team is investigating the inclusion of the European Solar Telescope (EST) as a partner. The AGA had no objections to this amendment and the management support team is looking into the available funding needed to include EST.
- The new general director of ASTRON took over the coordinator role of ASTERICS. The continuation to the project was guaranteed by the project manager and project scientist that have been involved from the beginning of the project.

1.2.1.2 Governance

AGA

There were three ASTERICS General Assembly (AGA) meetings during Project Period 2:

- 29 November 2016 (Month 19)
- 20 June 2017 (Month 26)
- 19 January 2018 (Month 33). This meeting was following the Policy Forum.

At these meetings, the AGA was informed by the coordinator and WP leaders about the project status and the AGA discussed activities and policies.

AEAB

The ASTERICS External Advisory Board (AEAB) met for the second time during the AGA on 19 January 2018 and also participated in the AGA. The AEAB presented their findings to the AGA. The AEAB were positive about the project achievements and recommend to strengthen the interconnect between the work packages. The written report of the AEAB is in Annex 1.

In April 2018, one member from the AEAB resigned due to a lack of time. A new AEAB member, representing the same field (APPEC) was proposed to replace the departing member and was accepted by the AGA.

1.2.1.3 Collaboration and Exploitation

The Collaboration and Exploitation plan are aimed at looking for new collaborations and promoting ASTERICS at meetings, events and with other stakeholders. Part of the work on these plans was taken up by the new project liaison officer.

The following activities took place in the second reporting period:

- Participation in a meeting on multi-messenger astrophysics organized by WP5 in September 2017.
- The EOSC initiative has many related topics with the ASTERICS activities. Therefore, the ASTERICS project manager presented the ASTERICS activities and plans at several EOSC events.

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- Members from the management support team participated in the Second ASTERICS – OBELICS Workshop on EOSC in Astronomy and Astrophysics in October 2017.
- An inventory was made of existing collaborations in the project by asking feedback from the partners.
- Contacts with SMEs S&T, Triopsys and Common Workflow Language (CWL) were made in the context of the Industrial Collaboration Call organised in WP3.
- Members from the European Solar Telescope (EST) participated in their first ASTERICS event (the Second ASTERICS – OBELICS workshop in October 2017) and in the AGA in January 2018.
- There are continuing contacts with APPEC and ASTRONET. Two persons of the AMST attended the APPEC Roadmap presentation in January 2018.
- There is contact with H2020 projects EMBRIC, ENVRIplus, CORBEL, PARTHENOS, RISCAPE, SERISS and SINE2020 on dissemination activities.
- Contacts with EGI crystalized into two EOSC project collaborations.
- There were several contacts with the gravitational wave community, via email and meetings. We received questions whether it was possible to strengthen the multi-messenger tools and communication through the ASTERICS activities. We are developing plans to use the ASTERICS website for this.

1.2.1.4 Events

Policy Forum

After a number of preparatory meetings with a growing number of participants, we had the First ASTERICS Policy Forum on 17 and 18 January 2018 in Nice. In the preparatory meetings a list of topics was defined and four working groups started to describe use cases and the attached foreseen challenges. The following four main topics were addressed in the science cases of each science working group:

1. Joint time allocation;
2. Observing strategies for multi-messenger campaigns;
3. Data access and sharing;
4. General policies of common interest (towards next generation ESFRI RIs).

The goal of this meeting was to present use cases from the four ESFRI facilities in ASTERICS, discuss the implications of the study results, to define issues and challenges and decide on necessary activities in the next months in order to develop a policy to be presented and discussed in the next meeting.

Four working groups had been established in September 2017. Their findings were discussed by the Policy Forum organising group in December 2017 as preparation for the January meeting. For the January meeting only people closely involved in the work connected to the use case working groups were invited. We limited the group to be able to have a discussion on a selected number of subjects and find common issues that needed more than technical

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solutions. We explained to other people that wanted to participate that they were welcome, but that we had a closed agenda. They understood our point and decided to wait for the next meeting.

The use case working groups mostly consisted of scientist, not data scientists, computer scientist, or software developers. One of the findings of the meeting was that that the scientist have nice plans to use data from several observatories, but that they do not always see what is needed to get where they want to go. The same was concluded about the volume needed for data storage and compute for analysis for the new ESFRI facilities. It was no even assumed that volume would be catered for, it was not in the equation. We concluded that a lot of work to find the requirements for all the future science would need a combined effort of scientists and technicians from all fields.

Actions until summer and fall 2018 are described in the detailed report
The following Policy Forum will possibly be in November 2018, where the findings of the working groups will be presented to all interested parties, followed by an open discussion what else we should include in the expanding study.

There will also be Policy Forum activities during the Grand event

<u>All-hands meeting</u>

When the AEAB, at the end of the January 2018 meeting, recommended better interconnection between the work packages, we were already organising an All-hands meeting for March 2018 to make everyone in the project aware of the work in other work packages. All collaborators working on ASTERICS were invited. Participants presented their work in 5-minute pitches, following which there was the opportunity to further discuss their work in a round-table setting. In addition, a team-building event was organised.

Overall, the participants were very positive about the 5 minutes pitches and 60 minutes breakout sessions. This programme concept allowed the participants to focus on what they are interested in and gave them a good perspective on the work done by other members of the project. The small-group discussion held encouraged attendees to talk to new people and made the meeting very interactive. Chairs and attendees of the breakout sessions indicated that the discussion at their table were informative. For a future similar meeting it is recommended to make the concept of the program more clear to all the attendees and describe the format of the meeting better and upfront.

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Grand Event

The culmination of ASTERICS will be a grand Integrating Event to show-case the results of the project and their relevance to the ESFRI telescopes and all other stakeholders.

The location and dates for the Grand Event at the end of the project are decided. The event will take place from 25 to 29 March 2019 in Groningen and will have the title “The New Era of Multi-Messenger Astrophysics conference”.

We plan to organise the meeting along the following strategy.

Rationale

- Integrating event
- Showcase the final results
- Engage with stakeholders

Deliverable 1.5 of the ASTERICS Grant Agreement is the "Integration Activity", described as a "grand Integrating Event to showcase the final results of the ASTERICS project and engage with all relevant stakeholders". The audience is to be found outside the ASTERICS partners and among the stakeholders that will use ASTERICS results. scientists, developers, astronomical facilities and e-infrastructures, policymakers, and relevant industries.

Integrating

- Integrate ASTERICS results in context. The most relevant context is multi-messenger astrophysics research.
- Integrate audiences.
- Integrate plenary sessions around common themes for science, technology and policy.
- Integrated sessions with proactive chairpersons who will provide introduction, connections and bridges between presentations and conclusion to the sessions.
- Each plenary session should contain something of interest for different audiences, to stimulate the integration of audiences.

The plan is to have a conference (originally proposed as IAU Symposium) on multi-messenger astrophysics with a strong technological component represented by ASTERICS results. The need for such an event became evident to WP1 by attending a number of meetings where scientists and other stakeholders regretted the lack of the coordination and technology drive between different communities, which is something that ASTERICS could deliver. The astronomy and astroparticle physics communities urge for the kind of support that ASTERICS provides.

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Themes

Themes could be scientific topics like:

- highly energetic phenomena;
- dynamic sky;
- nature of astrophysical neutrinos,
- gravitational waves and their follow-ups.

This would serve the ASTERICS ESFRI facilities and other large instruments such as VIRGO/LIGO and the ESFRI pathfinders. (To include EST would require other themes.)

In order to showcase the ASTERICS results in the field of multi-messenger astrophysics, one first needs to set the stage for the needs of the communities in this field. At the event, scientists will present their work in high energy phenomena, transient astronomy, astrophysical neutrinos, and gravitational waves with their multi-messenger follow-ups. The ESFRI facilities, and pathfinders, will show their potential in addressing the open scientific questions. ASTERICS partners will demonstrate the technological advances of the past years. The ASTERICS Policy Forum will open the discussion on the status and future of multi-messenger coordination.

Meeting structure

- Conference type
- Full week, allowing travel on Monday morning and Friday afternoon.
- Mostly one-way communication in large plenary sessions, to inform the participants about results and developments.
- Some dedicated parallel sessions:
    - Group sessions for more in depth
        - teaching or training;
        - discussion at equal level;
        - communication to learn from the participants.
    - Booths for demonstrations, outreach and Q&A
    - Posters for introducing new ideas, outreach and Q&A
    - Ad-hoc meetings for discussion, communication, and Q&A

The meeting will have a structure similar to other events that have a comparable size and range of topics, such as EWASS or the European Planetary Science Conference, with plenary and parallel sessions. The plenary sessions concentrate on presenting an integrated story around science, technology and policy.
The parallel sessions can be dedicated to subjects that require more time.

Monday 25/03	Tuesday 26/03	Wednesday 27/03	Thursday 28/03	Friday 29/03
	plenary 1	plenary 5	plenary 9	plenary 11
	plenary 2	plenary 6	plenary 10	plenary 12
	lunch	Lunch	lunch	lunch
	plenary 3	plenary 7	parallel 1-4	parallel 9-12
registration	plenary 4	plenary 8	parallel 5-8	parallel 13-16
registration	reception	dinner	public lecture	

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We aim for 350 participants, which corresponds to a total expense of 170k Euros. With a proposed registration fee of 250 Euros, the cost claimed from the project will be around 80 k€. This is within the remaining conference and meeting budget in the project.

The meeting location is a conference center (MartiniPlaza) in the university city of Groningen, in the north of the Netherlands. A number of faculties, institutes and companies in Groningen have strong ties to astronomy and astrophysics. The city is connected to Amsterdam airport by frequent direct trains.

Preparations for the logistics and content have started in September 2017. The Local Organizing Committee (LOC) is composed of the full AMST with the addition of ASTRON personnel. The Scientific Organizing Committee (SOC) has also been defined. It consists of a number of scientists, including ASTERICS people, who are expert in multi-messenger astrophysics, and it is coordinated by the Project Coordinator and the Project Scientist.
The SOC with their respective expertise is listed here:

- Sera Markoff – University of Amsterdam (Netherlands) - *high energy astrophysics*
- Eric Chassande-Mottin - CNRS (France) - *gravitational waves*
- Patrick Woudt – University of Cape Town (South Africa) - *transient phenomena*
- Anna Franckowiak - DESY (Germany) - *high energy neutrinos*
- Enrico Ramirez-Ruiz – University of Santa Cruz (USA) – *high energy phenomena*
- Gemma Anderson - Curtin University (Australia) - *transient phenomena*
- Aart Heijboer - Nikhef (Netherlands) - *high energy neutrinos*
- Marica Branchesi - INFN (Gran Sasso, Italy) - *gravitational waves*
- Dipankar Bhattacharya - Inter-University Centre for Astronomy and Astrophysics (India) – *instrumentation and high energy astrophysics*
- Mansi M. Kasliwal - Caltech (USA) - *transient phenomena*
- Zsolt Paragi - JIVE (Netherlands) - *transient phenomena - VLBI*
- Tara Murphy - University of Sydney (Australia) – *transient phenomena*
- Feng Yuan - Shanghai Observatory (China) - *high energy astrophysics*
- Alessandra Corsi - Texas Tech University (USA) – *gravitational waves*
- Fabio Pasian - INAF (Italy) - a*stronomical e-infrastructure and VO*

We will follow an equal opportunity policy regarding diversity and non-discrimination. Therefore, we plan to actively seek contributions from underrepresented parts of the astronomical community. Also, we will take into account gender balance for invited and contributed talks. As the next generation of facilities, and a mature multi-messenger astrophysics environment, will only be available in the next decade, we will pay special attention that early career researchers are given the opportunity to present their work.

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1.2.2 WP2 DECS

The objective of WP2 DECS is to promote ASTERICS, with the final goal of opening up the ESFRI astronomical facilities to all relevant stakeholders and the widest possible audience. The following progress has been made towards this objective.

- Muon Hunters ASTERICS citizen science project launched and is an outstanding success. 1.3 million classifications were made by volunteers in the first five days. The project has now reached over 2 million classifications and is essentially complete.
- Facilitated the creation of the Galaxy Nurseries citizen science experiment.
- Open access publications: Feng, Q., et al., 2017, arXiv:1708.06393 (in Proceedings of the 35th International Cosmic Ray Conference (ICRC 2017), Busan, South Korea); Dhital, N., et al., 2017, arXiv:1709.05196; Sushchov, O., et al., 2017, arXiv:1709.05230.
- ASTERICS represented at EWASS and ESOF in 2016, 2017.
- Quarterly ASTERICS email newsletter launched.
- Presented ASTERICS results and citizen science at United Nations/Italy UNOOSA Open Universe Initiative conference, held at the United Nations in Vienna in November 2017.
- Presented some results of ASTERICS to delegations from the Ethiopian Embassy in the UK, including former deputy prime minister His Excellency Mr. Tefra Walwa who is also patron of the Ethiopian Space Science Society. These visits occurred in November 2016 and again in November 2017.
- Second Citizen Science workshop held in Trieste in January 2018.
- Co-organised a symposium on Software in Astronomy at the April 2018 European Week of Astronomy and Space Science conference in Liverpool, UK, including open and transparent data and software services.
- We have completed our promotional animation deliverable: Sixty Second Adventures in Collaborative Science
    - Episode 1 - Citizen Science,
    - Episode 2 - Messengers from Space,
    - Episode 3 - Multimessenger Science.

The following deliverables have been delivered in this reporting period, following workshops and inputs from all beneficiaries in WP2 DECS:

- D2.3 Educational resources for mass participation experiment
- D2.4 Mass participation experiment
- D2.5 Public and stakeholder engagement via video resources
- D2.6 Open-access publications from mass participation experiment
- D2.7 Educational resources for mass participation experiment
- D2.8 Mass participation experiment

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1.2.3 WP3 OBELICS

The OBELICS work package aims to enable interoperability and software re-use in data generation, integration, and analysis. The OBELICS work package is organized around the following four different task groups to efficiently address these common challenges.

- **Task 3.1 Management, user engagement and data dissemination (MAUD):** This task concerns overall management of the work package, user engagement & data dissemination through thematic training events and general workshops. In addition, the task also engages with industries to address innovation related objectives of the work package.
- **Task 3.2 Data generation & information extraction (D-GEX):** The target of this task is the first stage of the scientific data flow concerning data generation and information extraction. During the reporting period, D-GEX produced technology benchmark report addressing green computing as well as a survey report on Real-Time Data Streaming Architecture (D3.13) already applied or envisaged by the ESFRI projects.
- **Task 3.3 Data systems integration:** The task D-INT (3.3) is targeting the challenges in the data management of the large ESFRI infrastructures. During the reporting period a number of services were developed by task members to enable the integration of analysis software. In addition, a technology benchmark report was produced, presenting tests on data format, data storage and transfer and data processing in an automated pipeline and in large databases.
- **Task 3.4 Data analysis /interpretation (D-ANA):** This task addresses the common challenge to assess the quality of Petascale datasets and execute automatic analysis to reduce their size by developing a collection of statistically robust and domain independent open source software libraries for data analysis and data mining on Peta-scale datasets.

1.2.3.1 Management, user engagement and dissemination (MAUD)

This task concerns all management, user engagement & data dissemination activities of the OBELICS work package. MAUD acts as an interface between H2020-ASTERICS management (WP1) and WP3. This includes ensuring timely submission of deliverables, periodic reporting, as well as support for communication and dissemination. Over the reporting period MAUD undertook various intiatives for knowledge sharing with other H2020 projects such as HNSciCloud, Indigo DataCloud, XDC, EOSCpilot, EOSC-Hub.

Between November 2016 and April 2018 MAUD organized one co-located event merging a general workshop and a thematic training event, one general workshop and two thematic training events.

The First ASTERICS – OBELICS workshop and training event (D3.2+D3.6) on Science Data Cloud & Computing models in Astronomy and Astroparticle Physics addressed high priority subjects of ESFRI projects such as Authorization and Authentication, Data Storage, Transfer & Preservation, Large Databases, Workflow management and Interoperability. The format of the event included invited talks and panel discussions and live demonstrations and tutorials on services and software that are aimed to be explored and evaluated for likely being used in the ASTERICS ESFRI Projects. The event observed participation of over 80 participants from ASTERICS partner institutes, partner H2020 projects, EU consortia as well as major industries, all the workshop sessions were addressed from different perspectives. A call for expression of interest for industrial cooperation was launched to benefit from industrial presence at the workshop.

Figure 4: First ASTERICS-OBELICS workshop, December 2016, Rome, Italy.

The Second ASTERICS-OBELICS workshop (D3.11) was dedicated to Astronomy & Astroparticle Physics assets in building the European Open Science Cloud and took place in Barcelona from 16-18 October 2017. The workshop served as a platform for H2020-ASTERICS to present its activities under WP3-OBELICS and to bring together the ESFRI representatives and other

Figure 5: Second ASTERICS-OBELICS Workshop, October 2017, Barcelona, Spain.

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stakeholders to discuss potential contributions from the Astronomy community to building a European Open Science Cloud. The workshop also provided an opportunity to demonstrate new technologies such as machine learning and deep learning with some use cases in astronomy.

The First ASTERICS-OBELICS International School on Advanced software programming for astrophysics and astroparticle physics was organized from 6-9 June 2017 in Annecy, France. This four-day training event brought together over 80 PhD students, postdocs, senior researchers from the domain of astrophysics and astroparticle physics, and the gravitational waves community from renowned research institutes in Europe as well as the USA. The school provided theoretical and hands-on training to acquire efficient and fast computer programming techniques, as well as skills for improving scientific data analysis software.

Figure 6: First ASTERICS-OBELICS International School, June 2017, Annecy, France.

The 2nd ASTERICS-OBELICS international school was originally planned to take place in Month 36, but due to availability of rooms and avoiding clashes with other events, it was decide to organise it in the same month as the first school (June). Since the intention was to organise it in the reporting period, we report on the school here. The school was dedicated to machine learning and python programming for astrophysics & astroparticle physics. In its second edition this year – the school gathered over 70 PhD students, postdocs, senior researchers from all over Europe - from beyond Europe, from Kenya and Morocco - and is especially

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intended for a broad audience from this domain. The school was hosted and organized by CNRS-LAPP from 4 -8 June 2018 in Annecy, France. More information on this event is available on https://indico.in2p3.fr/event/16864/

Industrial calls for expression of interests were announced during the WP3-OBELICS general workshops. In 2017 CNRS-LAPP formalized industrial cooperation with an italian company Orobix for GammaLearn proposal which aims at developing a high performance system for gamma ray signal classification, primary arrival direction reconstruction and primary energy estimation from IACT data by leveraging on deep learning techniques. The intention was to realise five industrial contracts, so the call was advertised again and new parties were contacted. The response was still very low. In 2018, four proposals were received with participation from three Dutch companies, one Lithuanian company and an Italian company. As the deadline for proposals was end of March 2018, the reviewing partly took place just after the reporting period. The results of the review are relevant for the continuation of the project work and are therefore reported here. The Following two proposals have been selected for funding in 2018

- **ASTRON Data Portal**: It has two Dutch industrial partners Triopsys and S&T . The project will be executed in collaboration with ASTRON one of the WP3- OBELICS partner.
- **Modular data reduction on pipelines for astronomy data:** It has a Lithuanian industrial partner VIDE. The project will be executed in collaboration with two WP3-OBELICS partners INAF and ASTRON.

Reviews on one of the proposal are pending at the moment for evaluation.

During the reporting period, the workpackage also joined hands with Trust-IT services ltd. to further improve and strengthen dissemination of WP3 activities to the relevant communities and stakeholders. This collaboration is realized by contracting out the communication and dissemination activities of the OBELICS workpackage in particular the support for OBELICS workshops as well as thematic training events.

1.2.3.2 Data generation and information extraction (D-GEX)

During the reporting period, D-GEX task members produced the Technology Benchmark Report (D3.8). The report summarizes the results obtained so far in investigating solutions to match the issue of green computing in the ASTRI/DOME frameworks. Here green computing is referred to the technologies to radically reduce the power needed to perform computationally intensive work on extremely large amounts of data.

A complete pipeline from trigger, acquisition, reduction, calibration up to stereoscopic reconstruction was implemented with a software stack tuned on small size telescopes of ASTRI-CTA. It is supposed to run on a GPU platform, which will be located close to the telescope site. The power consumption was reduced by more than an order of magnitude (actually a factor around 20).

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INAF (ASTRI) and ASTRON (DOME) groups have designed systems targeting the requirements of low power consumption, thus realising a sort of data center in a box; the ASTRI team focused mainly on software (ASciSoft) and algorithms, to be run on embedded boards (Nvidia Jetson, ARM + Nvidia GPU processors) attached to ground telescopes, while the ASTRON team focused on hardware integration. During the ASTERICS project lifetime, some improvements can be achieved by both exploiting new generation computing platforms and improving the software reconstruction algorithms. Various tests have been conducted with expected results, while leaving room for improvements, both in hardware selection and integration and in software development.

OBELICS has provided the framework to test and share largely results about the benchmarking efforts and computing architectures for Gamma ray astronomy. The software in use in this work was adapted to the hardware instead of redesigning. The software development objectives are also shared by D-ANA task group of WP3-OBELICS.

At the same time OBELICS partner institutes have been working on other aspects related to its main goal, which is the first steps of the data flow.

- ASTRON has developed algorithms for "Fast convolutional resample" of data that are able to split the work among many processors in parallel architectures. The code generated is publicly available at https://gitlab.com/astron-idg.
- IFAE and UCM have been investigating the use of common data formats in event based observatories. The HDF5 format for low level data and the CTA DL3 for high level data. As foreseen in the Grant Agreement a contract has been finalized to collaborate with private enterprises in the comparison of low level data formats and further test the HDF5 alternative. Concerning the DL3 format, it is at the border of D-INT and D-GEX, since high level formats for one observatory constitute the basis for integrating their results with those of other facilities. Its specifications can be found at the Open-gamma-ray-astro github site. More details are provided in the D-INT section of the report.
- LAPP has developed a data format generator for high performance computing (HPC) applications. This generator is able to automatically produce a data format with HPC specifications given a human readable configuration file, as well as all the complete libraries to handle this data format (functions to read and write data) in C++ and in Python. This work is now being proposed as a solution for the CTA raw data format and will be tested and compared to other solutions in the near future. This work goes hand-in-hand with the data compression work that is presented in more details in the D-INT section of the report and can be found at https://gitlab.in2p3.fr/CTA-LAPP/PLIBS_8_UTILS/.
- INFN has been testing the implementation of the BeeGFS parallel file system on a low power test bed consisting of both ARM and x86 SoCs in a work that is also at the border of DGEX and DINT.

A survey report on Real-Time Data Streaming Architectures (D3.13) already applied or envisaged by the ESFRI projects was produced during the reporting period. In this survey, they

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analysed different approaches adopted by many ongoing research facilities or envisaged for the upcoming ones. The panorama emerged is quite diverse, but some common trends were noticed as well. The architectures for real-time data streaming surveyed are usually staged in many levels with lower levels, the ones closer to the detectors, very specific with very little chances to be replaced by common solutions. Higher levels instead share more commonalities, both hardware and software, that could be exploited to develop solutions that could be shared by different facilities. Often, the online processing of data is performed on dedicated processor, like FPGA, or highly parallelized processors like GPUs, which allow accelerating the data analysis. Another trend emerged from this survey is the increasing demand for data transfer with low latencies over long distances, for example from the observatories located in some remote areas to computing centres in North America or Europe.

1.2.3.3 Data systems integration (D-INT)

Data Integration is an important part of the data processing life. After its generation, and in order to be correctly analysed, data have to be stored in such a way to be easily and quickly retrieved, without alteration (preservation of its integrity). After studying the challenges faced by the ESFRI infrastructures based on their specific data models and resource requirements and presenting them in the Analysis Report on Resource Requirements, the D-INT task aims at tackling them.

Some of these challenges being tackled in WP3-OBELICS are

- Data storage and retrieval
- Preservation of workflows
- Open data access

There are huge differences in the data integration challenges between ESFRI projects. OBELICS members involved in ESFRI and world class experiments are currently developing and testing specific solutions to the challenges they are facing. This process includes benchmarks of existing solutions as well as the ones under development to test their viability. The ongoing developments of followed solutions were presented in the Technology Benchmark Report (D3.9) that was produced during the reporting period.

Capabilities and performance tests of the LSST database solution Qserv are being conducted. Qserv shall store all the data directly used for scientific results. This is especially important to link the LSST data processing pipeline and the science pipelines that are developped by different LSST teams (from France and US) and further constrain the Qserv developments. A Python library that is capable of converting the output of the LSST data processing pipeline into a data format that can be ingested by Qserv has been developed. This library is in constant evolution in parallel with the developement of Qserv. Current tests give identical and consistent results on a regular MySQL database and on the Qserv database. Next steps involve increasing the size of the dataset to test Qserv performances in a more realistic environment. This work is being conducted by the LSST team at LAPP.

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Evaluation of several virtual systems has been conducted in order to ensure the result reproducibility of data processing pipelines over time. Such reproducibility is at the core of any scientific activity but is difficult to achieve with data analysis and the fast evolution of systems and architectures. These considerations therefore impact all ESFRI experiments. As a result of this evaluation, Docker has been selected to be deployed and used for KM3NeT data processing. Efforts in this direction have already started and should be further extended in the future. This work is being conducted at FAU.

A first prototype of a common high-level data format (DL3) for gamma-ray astronomy is being investigated. The purpose of this initiative is to perform different Imaging Atmospheric Cherenkov Telescopes (IACT) experiments to share data in order to perform combined analysis, cross-calibrate their instruments and build a common archive. In the future, it could also include other event-based infrastructures such as neutrinos or gravitational waves infrastructures. A test has been successfully conducted by converting MAGIC data and running a consistent analysis with the official one. An article on this open data format and its advantages is being written. In this context, UCM and IFAE are also collaborating in the development of the gamma-py package (http://gammapy.org), and open code to produce high level results from event data stored in DL3 format. This work is being conducted at IFAE and UCM.

The development of a process management system, STOA, to ease observational astronomy pipelines is being developed in relation with the ALMA observatory and in preparation of the SKA. This work is motivated by the need to do cross analysis between different observation catalogs, which is especially important for multi-wavelength analysis and with the birth of multi-messenger analysis. Analysis scripts that have been developed on different environments and for different catalogs can be integrated in STOA in order to have a single and convienent working tool. It is also designed to ease collaborative work and analysis so that specialists from different domains can join forces. STOA has been successfully tested on ALMA data analysis compared to data published in the Veron catalogue. Future steps involve a more advanced integration of STOA with other tools such as Jupyter notebooks and direct access to online services of the Virtual Observatory. This work is being conducted at UCAM.

The data volumes at hand in future ESFRI experiments is one of the main challenges to deal with. In order to reduce the costs of data transfer and storage, data compression is essential. A lossless (as opposed to lossy that would deteriorate data, which is not acceptable in most physics experiments) compression algorithm has been developed for digitized signals stored as integers (this kind of signal is very common in physics). The algorithm has been optimized for CTA data to reach the state-of-the-art in terms of compression ratio but reducing the compression time by a factor of almost 20, making it applicable in real use-cases. These results have been submitted for publication. The next step is to bring these developmenents at scale for CTA simulated and real data. This work is being conducted at LAPP.

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The developments and benchmarks realised concern all the stages in the life of the data - data format, data storage and transfer, integration into large databases - and processes to help its integration - automated pipelines and virtualization environments.

A repository of services has been developed to ease the data integration, retrieval and analysis by end-user

Raw data arising from astronomy and astroparticle infrastructures cannot be retrieved and analysed on the final user computer or computing infrastructure. Therefore, solutions to deal with data on large scales must be used and with them, services to help the users have to be provided. A repository of services listing technologies to enable the integration of analysis software. This repository of services (D3.14) is available on http://repository.asterics2020.eu/

INAF has developed the Jupyter for Gamma (J4G) service. J4G combines a multi-user version of notebooks with Gamma Ray Astronomy tools. It provides remote single-user Jupyter notebooks and it is integrated with the INAF-CTA Authentication and Authorization Infrastructure (INAF-CTA AAI). It makes available user data by deploying Jupyter Notebooks in user space close to user's data thanks to an integrated cloud data service environment (based on owncloud). J4G is a user-friendly and reproducible computing in HPC/HTC environments.

ASTRON has developed an integrated Rule-based Data management System (iRODS). It has been adopted in the context of APERTIF long-term archive upgrade of the Westerbork Radio Synthesis Telescope. It maintains one global namespace to retrieve files (data-objects) stored in several locations. It maintains metadata separately, and provides some form of Authentication and Authorization (A&A). The ALTA implementation relies on external components providing A&A.

CNRS-LAPP members have been contributing to the development of the Qserv system, a petascale distributed database for the Large Synoptic Survey Telescope (LSST). The Qserv system relies on several production-quality components, including MariaDB and XRootD.

UCM partners have contributed to the Gammapy package. It is an open-source Python package for gamma-ray astronomy built on Numpy and Astropy. Gammapy is a candidate to the science tools for CTA. It starts from High Level data preferentially, but not restricted to, in the open DL3 format.

1.2.3.4 Data analysis/ interpretation (D-ANA)

The task 3.4 (D-ANA) addresses common challenge to assess the quality of Petascale datasets and execute automatic analysis to reduce their size by developing a collection of statistically robust and domain independent open source software libraries for data analysis and data mining on Peta-scale datasets. During the reporting period, task members also put together a software repository dedicated to workflow management services (D3.15). This repository is available on http://repository.asterics2020.eu/software.

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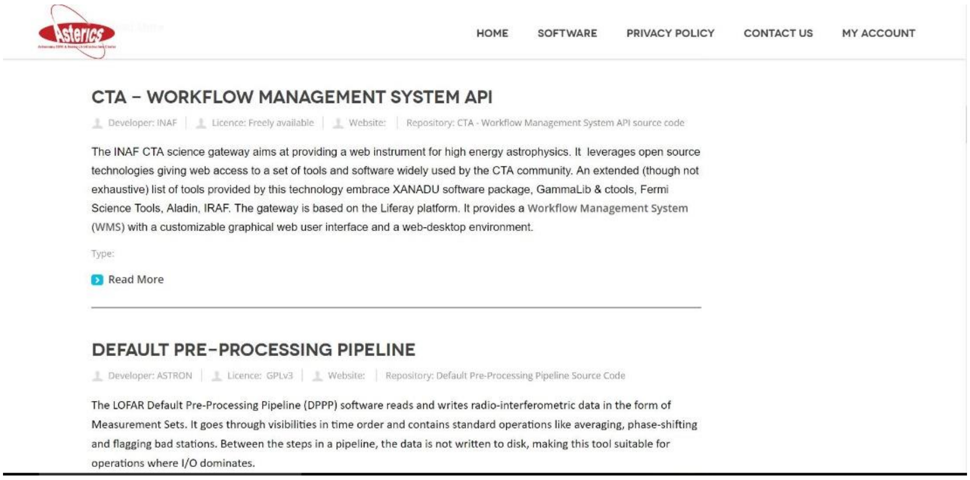

Figure 7. OBELICS software repository.

D-ANA task members also produced the Technology Benchmark Report (D3.10) during the reporting period. This report presented a relatively diverse set of results and work in progress, but nevertheless some clear and very important commonalities and themes were identified. These were:

- Commitment and the acknowledgement of value of making the tools fit into existing frameworks, in particular Python and its package eco-system and the ROOT framework.
- Focus on computational efficiency, as in all of the facilities supported by ASTERICS there is a realisation that the scientific capabilities will to some extent be limited by the available computing power.
- Focus on advanced statistical techniques, including Bayesian statistics, wavelet analysis, high performance software programming, machine learning and compressed representations of likelihood functions to best extract faint signals from the observed data.
- The essential aspect of remote and distributed scientific work and data analysis and the consequent requirements for authentication and authorization.

A complete report on the benchmarking activities on A&A technologies performed in the framework of D-ANA is available on the open ASTERICS wiki at "Authentication & Authorisation Technology Benchmarking Report" (draft 0.3, 04 Apr 2017).

In addition to the Technology Benchmark Report, a Jupyter kernel was created for CASA. CASA is a widely-used software package for processing astronomical data. The kernel allows all CASA tasks to be run from inside a Jupyter notebook, albeit non-interactively.

- **UCAM** members have produced a source detection/characterisation code, building on an in house code at Cambridge (BayeSys). Compared to many other source finding methods, it produces a more detailed description of the shapes of sources and does not require maps to be run through CLEAN first. It is still in development and we have

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already got some promising results applying it to ALMA data. This code is available on https://bitbucket.org/PeterHague/basc.

- **UCAM and JIVE** produced a Minimal Recomputation framework for astronomy and wrote a paper, which has been presented at ADASS, Santiago, 2017. The code and paper are published at: http://www.mrao.cam.ac.uk/~bn204/sw/recipe. UCAM also produced a task-based parallelisation framework for Astronomy with focus on the CASA package. It is described in the following SKA-SDP memo Practical Distributed Data Processing using SWIFT/T & CASA by B. Nikolic avalable at http://www.mrao.cam.ac.uk/~bn204/publications/2017/2017-08-casaswift.pdf.
- **UCAM** partners have developed STOA (Script Tracking for Observational Astronomy) and SWIFTCASA. STOA is a workflow management software with both command line and web interfaces that permits the efficient handling of large, heterogeneous data sets, and provides a fast run-test-rerun work cycle for these situations. SWIFTCASA is a task-based parallelisation of the standard radio astronomy data reduction package "CASA". It allows easy distribution of processing on conventional HPC clusters through the use of a shared file system, and is able to scale CASA up to the limits of storage throughput relatively easily.
- **CNRS-CPPM** members have developed JPP and OMGsim (Optical module Geant4 simulation). Jpp is a java-inspired collection of C++ classes and applications for PDF creation, multidimensional interpolation, function minimisation and plotting. Based on a much broader KM3NeT software framework, developed by Maarten de Jong, it is released in a more generic, experiment-independent format. The package uses a flexible, templated class structure, which avoids the use of global variables, such as in Minuit. OMGsim software objective is to provide an easy to use simulation of the optical modules containing PMTs, in particular, muli-PMT optical modules of KM3NeT. More attention has been given to the simulation of the photocathode, using a dedicated thin layer and complex refraction index to determine photon absorption, reflection and transmission. Photoelectron emission is simulated using Spicer's three-step model.
- **CEA** contribution to D-ANA task was in the context of the CTA consortium. The main goal is to probe the capability of sparse methods (wavelet transforms) to distinguish the atmospheric shower against the diffuse sky and electronic background in the camera images, and compare the obtained performance with the classical methods used so far in CTA. The 'image recognition' code has been made generic and is delivered as a standalone package named PYWI. The performance was measured through various observables, and the optimisation of the detector sensitivity. This code - named IRB- was made generic and is usable to estimate the sensitivity of any instrument delivering a signal and background particle list.
- **INFN** efforts were focused on the ROOT analysis framework. It is one of the most used programmes for the analysis and indeed it is the "de facto" standard for high-energy physics. The goal of the ROAst library (ROot extensions for ASTronomy) is to extend the ROOT capabilities adding packages and tools for astrophysical research. ROAst comes with three feature sets: access to astronomical catalogues; coordinate conversion tools;

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high-precision Moon and Sun position models relative to the Earth; and graphical tools to produce commonly used plots (general and partial skymaps).

In addition **INFN** activities were dedicated to the development of Cosmic Ray Event Library (CORELib). CORELib is a collection of simulated events of cosmic ray showers. The production is currently based on CORSIKA featuring a common set of physical parameters in order to achieve a general purpose high statistics production. The CORELib production is now using more than 1000 CPU cores, allocated to the KM3NeT collaboration, but its technical specifications exceed the needs of KM3NeT, in the spirit of serving the community of astroparticle experiments and potentially also other fields of applications.

- **INAF** developed Yabi, a 3-tier application stack to provide users with an intuitive, easy to use, abstraction of compute and data environments. Yabi has been used in high performance computing environments across the disciplines such as IA2 Data Center to allow accredited users to run HARPS-N and GIANO-B data reduction pipelines on private and public data from TNG archive.
- The **INAF** CTA science gateway aims at providing a web instrument for high energy astrophysics. An extended (though not exhaustive) list of tools provided by this technology embrace XANADU software package, GammaLib & ctools, Fermi Science Tools, Aladin, IRAF. The gateway is based on the Liferay platform. It provides a Workflow Management System (WMS) with a customizable graphical web user interface and a web-desktop environment.
- **ASTRON** team developed LOFAR Default Pre-Processing Pipeline (DPPP) software. It reads and writes radio-interferometric data in the form of Measurement Sets. It goes through visibilities in time order and contains standard operations like averaging, phase-shifting and flagging bad stations. Between the steps in a pipeline, the data is not written to disk, making this tool suitable for operations where I/O dominates.
- Imaging Atmospheric Cherenkov Telescopes (IACT) such as CTA need a complex event reconstruction based on a set of images to produce a list of photons that will later be derived into science products such as flux, sky maps, etc. Current algorithms giving the best physical results can hardly scale to the data volumes produced by CTA. New algorithms, based on state-of-the-art methods for image analysis, are being explored for the analysis of IACT data. The objective of these developments is to both improve the computing performances and the physics results of the most advanced methods used nowadays. In particular, methods based on image reduction like the Singular Value Decomposition or machine learning methods based on deep neural networks are being developed. This work is being conducted at **CNRS-LAPP.**
- **CNRS-LAPP** team is producing a High Performance Computing framework, implemented in C++, that provides fast mathematical kernels.This Framework produces C++ and Python (thanks to C++ wrappers based on Python C API) libraries for Intel processors. The main characteristic of these libraries is that they contain mathematical kernels automatically designed for vector registers (Single Instruction Multiple Data) of the computer on which they are compiled, and thus allow code vectorization. In addition, these mathematical kernels are implemented to maximize the use of CPU cache and

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branch predictor. The output is almost 100% CPU usage. These libraries are composed of fast elementary functions, those meeting the requirements for actual big experiments (CTA, SKA, …), to guarantee the reusability of those functions.

- **CNRS-LAPP** team also contributes to a "High Performance Computing" Hillas algorithm for CTA experience based on the above Framework. This Framework is available here https://gitlab.in2p3.fr/CTA-LAPP/PLIBS_8 . This work was also published in *Polynomial data compression for large-scale physics experiments, P. Aubert et al, Computing and Software for Big Science (2018), https://arxiv.org/abs/1805.01844*
- Furthermore, **CNRS-LAPP** team also developed ctapipe.flow. It is a Python implementation of the flow-based programming paradigm for the ctapipe framework. In flow-based programming, applications are defined as networks of black-box components that exchange data across predefined connections. These components can be reconnected to form different applications. ctapipe-flow executes ctapipe processing modules in a sequantial or multiprocess environment. User implements steps in Python class. This work was published in proceedings of International Cosmic Ray Conference 2017 that took place in Busan, South Korea

  - *High Performance Computing algorithms for Imaging Atmospheric Cherenkov Telescopes, ICRC, July 2017 https://pos.sissa.it /301/771/*
  - *pschitt! - APython package for themodelling of atmoSpheric Showers and Cherenkov Imaging Terrestrial Telescopes, ICRC, July 2017. https://pos.sissa.it/301/772/*
- **CNRS-APC** is developing a software package with Machine learning algorithms for transient signal classification for gravitational wave astronomy. Gravitational wave observations are limited by a background of transient signals from instrumental and environmental origin. This package includes a set of machine learning tools that allow to classify those transient signals, in order to better characterize their large population, give hints about their source, and provide new ways for mitigating this background. The algorithms take a labelled set of transients, extract features from the time series, and learn a classifier (neural network) using standard ML libraries. While this toolbox is intended for gravitational wave data specifically, it is general enough to be adapted to problems in other scientific disciplines. This software package is expected to be released on the OBELICS repository by September 2018.

All the above listed software developments are publicly available on the OBELICS repository http://repository.asterics2020.eu/software.

Within task D-ANA the INAF team is analysing workflow architectures for the orchestration of data- and compute-intensive analysis on distributed computing infrastructures, together with how they can be efficiently linked with authentication and authorisation (A&A) systems.

The elements of this analysis are in continuous evolution: within an European framework, the utilities provided by the new emerging EOSC-related activities need to be taken in

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consideration. In particular, three H2020 projects (EGI, EUDAT, Indigo-DataCloud) have produced a set of A&A systems that will be harmonised within the new EOSC-Hub project.

Within OBELICS, the approval of the expressions of interest for commercial collaboration related to the Common Workflow Language (CWL) is also changing the perspective: portable workflows described using the CWL open standards, combined with modern software packaging and software container technology, are expected to greatly increase the portability and reusability of complicated and complex scientific computing data analysis workflows. The integration of CWL-compliant workflows with EOSC-provided A&A utilities is an important step to implement.

It is important that all these activities, being included in an astronomy environment, are compliant with the standards defined by the International Virtual Observatory Alliance (IVOA). It is necessary to build stable systems capable of performing in a data management and computation infrastructure providing IVOA-compliant interoperable storage resources (VOSpace) and wide cloud access.

For the above reasons, a slight change of focus will be implemented in Task 3.4.2 in the final year of the project: the design and testing of data processing workflows on compute-intensive systems will be performed, using existing workflow engines and A&A protocols (with particular attention to those provided by EOSC plus CWL). The main goal is to assess the requirements for the connection of the ESFRI and other astronomy Research Infrastructures to the EOSC through the Virtual Observatory standards.

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1.2.4 WP4 DADI

ASTERICS WP4 DADI objectives are to make the ESFRI and pathfinder project data available for discovery and usage by the whole astronomical community, interoperable in a homogeneous international framework, and accessible by a set of common tools. More specifically:

- Task 4.1, led by INAF and UHEI (Section 1.2.4.1)
  Train and support ESFRI project staff in the usage and implementation of the Virtual Observatory framework and tools, and make them active participants in the development of the VO framework definition and updates, thus contributing to relevance and sustainability of the framework.
- Task 4.2, led by CNRS/UMR 7550-CDS and INTA (Section 1.2.4.2)
  Train and support the wider astronomical community in scientific use of the framework, in particular for pathfinder data, and gather their requirements and feedback.
- Task 4.3, led by CNRS/UMR 7550-CDS and UEDIN (Section 1.2.4.3)
  Adapt the VO framework and tools to the ESFRI project needs, and make sure European astronomers remain lead actors in the International Virtual Observatory Alliance (IVOA), influencing it in the interest of the European infrastructures and the European scientific community.

All DADI deliverables during the first reporting period, and all but one during this second one, have been *workshops*. The meetings are held at or close to the scheduled date, or several months before for the two Data Provider Forum and Training Events (D4.6, D4.13). Then several weeks are needed to prepare and review the "text deliverable" submitted to the European Commission. The other deliverable was the initial version of the *Repository of WP4 products* (Section 1.2.4.4), which was delivered as expected in April 2017[2]. DADI Milestones are "Progress and Priorities" at the IVOA Interoperability meetings, which are held twice a year. Other important meetings are the yearly Astronomical Data Analysis Software and Systems (ADASS) conferences, which are held back-to-back with the "Northern Fall" IVOA meetings, and the Plenary meetings of the Research Data Alliance. The meeting web sites are linked to from DADI wiki page[3], which also provides a link to the Repository of WP4 products.

The meetings play complementary roles to reach the WP objectives and are interconnected. Some of the connections are represented in the schema in figure 8.

[2] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:dadiproductrepository
[3] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:start

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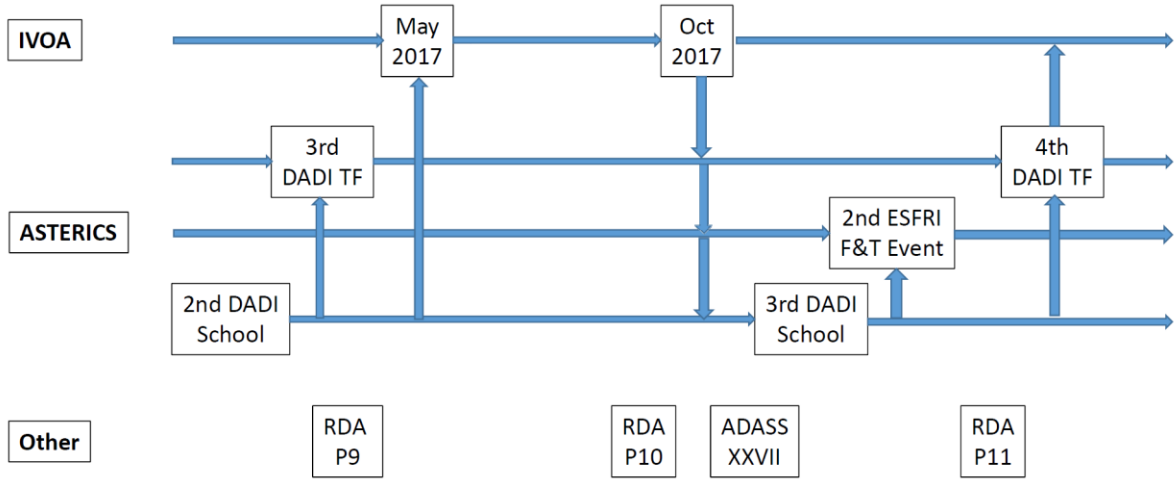

Figure 8. Schema displaying some of the connections between the meetings relevant to DADI. For instance, requirements gathered from some of the events trigger developments, then discussed in the Technology Forum.

1.2.4.1 Task 1: Training and support of ESFRI staff, and gathering their feedback and requirements

One meeting was held within this task during the period: the Second ESFRI Forum and Training Event[4] (D4.10), organised by INAF in Trieste, 13-14 December 2017. The First European Data Provider Forum and Training Event[5] (D4.6) was originally scheduled in December 2017, but it was organised earlier (15-17 June 2017) by UHEI in Heidelberg and reported in the First Periodic Report.

The ESFRI Forums are aimed at gathering ESFRI requirements and feedback on the VO, and to discuss relevant technical activities in DADI (whereas the Data Provider Forums are open to the wider European data provider community with similar aims). The Trieste Forum was an important milestone, because several representatives of the EST project participated in the meeting, and discussed how solar data could be taken into account in the VO framework. There are already examples of extension of the VO framework, for instance to deal with planetary data, with a long term participation of that community in IVOA meetings and the recent creation of a Solar System Interest Group in the IVOA. This possible model was discussed, as well as specific topics of interest for the solar community. The project presented later by EST to join ASTERICS takes these discussions into account. One can also note among many other topics input from SKA and discussion of how to include radio data in the VO.

[4] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4esfriforum2
[5] http://www.g-vo.org/edp-forum-2016

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The afternoon before the meeting was devoted to an induction meeting for Newcomers, which had been requested as a feedback from the First Data Provider Forum, and was particularly timely because of EST participation.

The Forums are completed by meetings organised for further discussion of specific topics, which in general combine gathering requirements and technical discussions, and thus are relevant to Tasks 2.1 and 2.3 with different weights on the two aspects depending on the meeting. These meetings are linked to from the WP4 wiki page. Most of those organised during the period included significant technical discussions, so they are listed under Task 2.3 (Section 1.2.3, table 1) in this document.

1.2.4.2 Task 2: Training and support of the wider astronomical community and gathering their feedback and requirements

The main activity in this domain continued to be the organisation of the annual School, open to participants from all over Europe, targeted to early career researchers and to ESFRI team members. Two were held during the period:

- The Second ASTERICS European School[6] (D4.5), organised by CNRS/CDS in Strasbourg, 15-17 November 2016;
- The Third ASTERICS European School[7] (D4.9), organised by INTA in Villafranca del Castillo near Madrid, 14-16 November 2017.

The Schools are targeted to early career researchers. They follow a successful template, with a short introduction on the Virtual Observatory and ASTERICS, hands-on tutorials including a ‘treasure hunt’, participant work on using the VO for their own research needs, and report in the last plenary by some of the participants on their practical scientific cases. Participants are supported by tutors, who also gather feedback which is shared with the VO tool and service developers. The Schools require lots of preparatory work, with a systematic test and update of all the tutorials and also to identify possible topics for the participant use cases.

A remarkable point of these schools are the tutorials on VO usage for gravitational wave follow-up studies, prepared and conducted by an “ESFRI” partner (EGO/VIRGO/ET). A first version of the tutorial was introduced in the 2016 school, and it was substantially modified and updated in the 2017 version "Electromagnetic follow-up of gravitational-wave events”[8], including now the identification using VO tools of electromagnetic counterparts of the recently discovered gravitational waves produced by the collapse of two neutron stars.

[6] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:school2
[7] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:school3
[8] http://htmlpreview.github.io/?https://github.com/ggreco77/Electromagnetic-follow-up-of-gravitational-wave-events/blob/master/Electromagnetic_followup_gravitational-wave_events_v5.html

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The updated tutorials are made available for reuse in the Repository of WP4 products and in the sustainable Euro-VO web pages[9]. Tutorials developed by DADI teams for other events are also posted. In addition, DADI staff are invited to act as tutors in events in partner countries or elsewhere. One can cite during the period the Tenth Spanish Virtual Observatory School[10], held in La Laguna, Tenerife 6-8 March 2017 and Observatoire Virtuel @ OCA[11] (Observatoire de la Côte d'Azur), Nice 26-27 September 2017. The Third Cosmology School[12] (Krakov, Poland, 10-23 July 2017) included a VO mini workshop, with two days of tutorials on the scientific usage of the VO by DADI staff.

Task 4.2 activities are regularly reported at the IVOA Interoperability meetings, as shown e.g. by the agenda of the Education Interest Group session at the Shanghai IVOA meeting (http://wiki.ivoa.net/twiki/bin/view/IVOA/InterOpMay2017-EDU). E. Heinl (UHEI) was designated vice-chair of the Interest Group in May 2017.

1.2.4.3 Task 3: Adaptation of the VO framework and tools to the ESFRI project needs, and impact in the IVOA

Two deliverable meetings were organized within this task during the reporting period:

- The Third ASTERICS DADI Technology Forum[13] (CNRS/CDS,D4.7, 22-23 March 2017, Strasbourg)
- The Fourth ASTERICS DADI Technology Forum[14] (UEDIN, D4.11, 16-17 April 2018, Edinburgh). This meeting, originally planned in March 2018 in the Description of Work, was slightly delayed for logistical reasons.

These meetings fully fulfilled their role: sharing of information on and discussion of the technological activities of the partners, preparation of following May Interoperability meetings (Shanghai in May 2017, Victoria in May 2018). They were built on the successful model of plenary talks complemented with so-called hack-a-thon sessions, which allow informal discussions of topics of interest for several partners. This enabled in-depth discussion in particular, but not only, of ASTERICS priority topics, which are also IVOA ones. Two priorities, *multi-dimensional data* and the *time domain*, had been identified at the beginning of the project. The Fourth Forum also addressed the emerging priority of Science Platforms/Portals. The interoperability standards are defined in the frame of the IVOA, with significant participation of ASTERICS staff. IVOA standards[15] are open for use, and openly

[9] http://www.euro-vo.org/?q=science/scientific-tutorials
[10] http://svo.cab.inta-csic.es/meetings/escuela_svo10/
[11] https://www.oca.eu/fr/ecoles-thematiques/1319-ecole-vo-2017
[12] https://cosmology-school.ujk.edu.pl/
[13] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4techforum3
[14] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4techforum4
[15] http://www.ivoa.net/documents/

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discussed in the IVOA Working and Interest groups. The ones which are more relevant to ASTERICS are listed in the Repository of WP4 products.

Defining interoperability standards for *multi-dimensional data* required to agree at the international level on several standards, which led to lively discussions between sometimes conflicting points of views. The "caravan" of Data Access Layer standards for multi-dimensional data was successfully completed in May 2017, with the approval of SODA (the Server-side Operations for Data Access (SODA) web service capability) by the IVOA Executive Board. The lively discussions during the Third Technology Forum had been instrumental in the progression towards an agreement. Emphasis is now on implementation and feedback from implementation, which was one of the main topics of the Fourth Technology Forum.

ASTERICS/IVOA time domain activities have two aspects: one is to gather requirements from projects dealing with diverse kinds of time series to develop standards to model and access time data in the VO; the other one is to update the existing VOEvent standard, which is already widely used to represent, transmit, publish and archive information about a transient celestial event, in particular to upgrade it to deal with LSST data. The latter work is done in collaboration with CLEOPATRA. The time domain topic, which had been somehow stalled for several years in the IVOA, is now moving forward vigorously under the leadership of the new chair and vice-chair of the IVOA Time Domain Interest Group, A. Nebot (CNRS/CDS, since May 2017) and D. Morris (UEDIN, since May 2016). Several specific meetings listed below have been organised by DADI in this domain.

Another high impact DADI technological work is the development of the *Provenance Data Model*, which is of high interest in particular for CTA, which includes it in their data pipeline and gathers requirements from a range of use cases. It is one of the standing topics of the Technology Forums, and the theme of a series of specific meetings, the "Provenance Days", also listed below. *Interferometric data* was discussed with LOFAR during a specific meeting and was one of the topics of the Second ESFRI Forum & Training Event.

Time Domain	DADI/CLEOPATRA meeting on the Time Domain[16]	CNRS/CDS, 21 March 2017, Strasbourg, France
	GAPS[17] Time Series face-to-face[18]	INAF, 22 June 2017, Padova, Italy
	Strasbourg Time Series Data Meeting[19]	CNRS/CDS, 5-6 December 2017, Strasbourg, France

[16] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4wp5timedomain
[17] Global Architecture of Planetary Systems
[18]https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4gapsinaf
[19] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:timeseriesdatameeting

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Provenance	Provenance Day[20]	CNRS/CDS, 13 December 2017, Strasbourg, France
	Provenance Day[21]	LUPM, 3-4 May 2017, Montpellier, France
	Provenance discussion	Potsdam, 20 March 2018
Interferometric data	LOFAR/VO[22]	CNRS/CDS, 18 November 2016, Strasbourg, France

Table 1. Specific meetings organised by WP4 during the period.

Task 2.3 also includes the development of VO-enabled tools, including pre-existing ones such as Aladin or TOPCAT. GWsky[23] is a Python tool developed in the framework of the LIGO-VIRGO collaboration and proposed to the Gravitational Wave community for gravitational wave follow-up. GWSky uses the VO to gather information and display results. The localisation of GW170814 in Aladin Light is shown in figure 9.

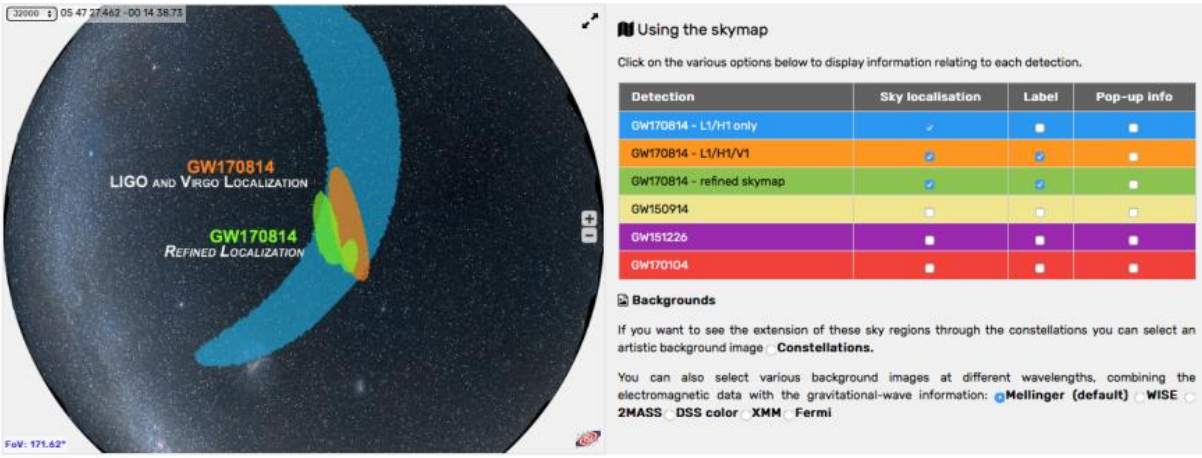

Figure 9. Localisation of GW170814 displayed in Aladin Light.

<u>IVOA and ADASS meetings during the period</u>

Two IVOA meetings were held during the period, in Shanghai[24] (China), 14-19 May 2017 and Santiago[25] (Chile), 27-29 October 2017, back-to-back with the ADASS XXVII Conference[26] (22-26 October 2017). Progress and Priorities at these IVOA meetings are ASTERICS Milestones 16

[20] http://wiki.ivoa.net/twiki/bin/view/IVOA/ProvDayDec2016
[21] http://wiki.ivoa.net/twiki/bin/view/IVOA/ProvDayMay2017
[22] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4lofarstrasbourg2016
[23] https://docs.google.com/presentation/d/1xBCXg4apU6FMxnbzlbYdynrXuQENYqb00wk2p2UShGs/edit#slide=id.g2492664a96_0_11 , https://github.com/ggreco77/GWsky
[24] http://ivoa2017shanghai.csp.escience.cn/dct/page/1
[25] http://www.adass.cl/#ivoa
[26] http://www.adass.cl/

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and 20 respectively. They are shortly described in the Milestone texts provided to the European Commission. The talks presented by staff working in Europe are listed in the Repository of WP4 Products[27]. ASTERICS DADI participation in the Shanghai meeting is also assessed in D4.7 (Section 6), with respect to the contributions to standards, scientific session, education and outreach, and cross-project aspects.

During the Shanghai IVOA meeting, which marked the fifteenth birthday of the IVOA, the IVOA (and ASTERICS!) reached a milestone with the completion of the set of standards dealing with multi-dimensional data. The second priority, time domain, was very actively tackled (two dedicated plenary session and one splinter session, plus input to other sessions), input from DADI partners and activities (in particular the Technology Forums and the specific meeting held in March in Strasbourg) being key for the endeavour. A. Nebot (CNRS/CDS) was designated as chair of the IG during the Shanghai Interop. The Hierarchical Progressive Survey HiPS and a new version of the IVOA Single Sign On standard were also approved as IVOA Recommendations during the meeting. These standards are of high interest for the DADI community and were made possible by work done within the project. The Science session included a Time Domain talk. The Education and Outreach session included as explained well received presentations of DADI activities. H. Heinl (UHEI) was designated vice-chair of the IVOA Education Interest Group. As usual, the Interoperability meeting was also used to discuss the RDA activities and their interest for astronomy.

During the Santiago IVOA meeting, DADI staff provided again significant contribution to most Working Group (WG) and Interest Group (IG) sessions. One can cite in particular the session of the Time Domain Interest Group, which was common with the Data Model and Data Access Layer Working Groups: the Time Domain IG brings specifications, and the WGs are in charge of defining the standards with active participation of the IG members. Input from DADI again played a prominent role during the session, both for the discussion of use cases to derive requirements, and for the development of data models and data access protocols. Provenance, which is a major topic of DADI thanks to the CTA partner, was also discussed: M. Servillat (CNRS/LUTH) presented in particular the Provenance Data Model Proposed Recommendation. As usual, RDA status, and its relevance for the IVOA community, was discussed during the session of the Data Curation and Preservation IG, including information on the discussions held at the RDA Montréal Plenary meeting (September 2017).

Like all the “Southern Spring” IVOA Interoperability meetings, this one was attached to the annual Astronomical Data Analysis Software and Systems conference, this year ADASS XXVII, which was also held in Santiago, 22-26 October 2017. The VO was present in many contributions to the Conference, and several persons involved in DADI presented a contribution. Among them, G. Iafrate (INAF) and M. Taylor (U. Bristol) were invited to present

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27 https://www.asterics2020.eu/dokuwiki/lib/exe/fetch.php?media=open:wp4:ivoa_shanghai_asterics_dadi_final.pdf
https://www.asterics2020.eu/dokuwiki/lib/exe/fetch.php?media=open:wp4:ivoa_santiago_asterics_dadi.pdf

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talks, respectively "VO for education: virtual and remote observing" and "TOPCAT: working with data and working with users". Many of the talks in particular from the session *Human-Computer Interaction, user interfaces design guidelines and interfaces projects to Big Data* were presented by active DADI participants, and many other presentations made reference to the VO. Two posters were directly linked to DADI: "Provenance as a requirement for large-scale complex astronomical instruments" (M. Servillat, CNRS/LUTH) and "What can Open Clouds do for Astronomy? Interaction between the ASTERICS and EOSCpilot" (F. Pasian, INAF).

RDA meetings during the period

Relationship with the RDA is one of WP4.3 subtasks. Three RDA Plenary meetings were held during the reporting period:

- RDA Ninth Plenary meeting[28], Barcelona, Spain, 5-7 April 2017
- RDA Tenth Plenary meeting[29], Montreal, Canada, 19-21 September 2017
- RDA Eleventh Plenary meeting[30], Berlin, Germany, 21-23 March 2018

Several DADI partners participated in these meetings, which enabled exchange of knowledge between the IVOA and the RDA. The IVOA Provenance model is for instance of interest for the RDA Provenance Patterns Working Group[31] to which it is planned to provide a use case. Reciprocally, the Data Curation and Preservation Interest Group session at each IVOA meeting is mostly dedicated to reporting and discussion of RDA activities and outputs in the astronomical context. One DADI partner (INAF) also participated in the RDA EU – ENVRI Summer School on Data Management and Data Science[32], which was held 12-16 June 2017 in Helsinki, to gather hands-on experience on RDA recommendations and outputs.

1.2.4.4 Repository of WP4 Products

The Repository of WP4 Products[33] is the only DADI deliverable which is not a Workshop. It is hosted by the DADI wiki pages. Its initial version (D4.8) was delivered as expected in April 2017.

DADI has several kind of "products", including some that have been developed totally or partially with DADI support and some that are key components of the project with respect to the ESFRI and science needs. They are classified into several categories in the Repository:

- Scientific tutorials describing real use cases of VO-enabled data and tools, prepared and updated in particular in the framework of the annual DADI Schools

[28] https://www.rd-alliance.org/plenaries/rda-ninth-plenary-meeting-barcelona
[29] https://www.rd-alliance.org/plenaries/rda-tenth-plenary-meeting-montreal-canada
[30] https://www.rd-alliance.org/plenaries/rda-eleventh-plenary-meeting-berlin-germany
[31] https://www.rd-alliance.org/group/provenance-patterns-wg/wiki/prov-patterns-wg-collaboration-tools
[32] http://blogs.helsinki.fi/rdasummerschool/
[33] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:dadiproductrepository

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- VO-enabled tools in support to the ESFRI and science needs identified by the project
- VO standards in support to the ESFRI needs identified by the project
- Tools in support to data publishing in the VO
- Other results of collaborative work

Presentations of DADI participants in the Interoperability meetings organised twice a year by the International Virtual Observatory Alliance IVOA can also be considered as DADI “products”, and are listed in the Repository.

The Registry of WP4 Products has been continuously updated since its delivery to remain up-to-date, in particular to display the new or updated tutorials, and to keep track of the evolution of proposed IVOA standards on the Recommendation track. The final version (D4.15) will be delivered at the end of the project.

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1.2.5 WP5 CLEOPATRA

The activities in the work package CLEOPATRA aim at synergetic observing modes, and fast and reliable access to large data streams. These aspects are addressed in the following tasks:

1. Development of technology for the enabling of long-haul and many-element time and frequency distribution over fibre connections. This has the potential to increase the efficiency and affordability of all radio astronomy facilities (SKA, LOFAR, VLBI). Such developments are also highly relevant for astroparticle facilities (CTA, KM3NET) and can enable novel real-time multi messenger observations.
2. Developing methods for relaying alerts that will signal transient event detections between the facilities and enable joint observing programmes. The focus will not just be on interchange formats but on scientific strategies and methods for joint observing.
3. Further development of existing data streaming software, building on the success of previous e-VLBI projects, and providing tools for robust and efficient data dissemination for all facilities in the user domain, including ESO facilities such as ALMA and the ELT.
4. Fostering the development of advanced scheduling algorithms, using AI approaches for optimal usage of the ESFRI facilities.

During the first 18 months of the project Cleopatra performed very well, getting up to speed quickly both with respect to the hiring of new personnel and starting the actual work. In spite of a number of organisational changes (task leaders changing affiliation), work in the second period continued very much at the same pace, producing many excellent technological results and deliverables that were (mostly) on time. One partner (DESY), faced with difficulties hiring a full-time engineer for an 18 month period, re-evaluated the way they would implement their work plan, which led to a shift of their deliverables. However, also here the work is making excellent progress and will be concluded well within the timeline of the ASTERICS project.

Towards the end of this reporting period, it became apparent that some partners would underspend. In one case the reason was that the leader of task 1a, J. Koelemeij, left the VU to work full-time for his commercial enterprise OPNT. As his student, who also was involved in Cleopatra, moved along, nobody was actually left at the VU to work on the project. The solution to this was to make OPNT a full partner in ASTERICS and to have the VU transfer the remaining funds to OPNT. This was agreed upon by all involved and submitted in a request for an amendment to the EC and accepted.

The second partner underspending was SURFNet, who found they would need less funds than anticipated for their part of the project, due to work efficiency. This money was redistributed among DESY and IEEC, based on proposals to enhance the output of their contributions.

1.2.5.1 Task 1: Synchronization

This task is centred around the White Rabbit Ethernet (WR) technology, with two quite distinct purposes. The first is to upgrade WR to generic technology for deployment on long-haul public telecom networks, and to increase its frequency stability by three orders of magnitude in

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order to achieve the hydrogen maser level stability required by the SKA and other (commercial) applications. The second focuses on new calibration and characterisation tools for WRE equipment, providing a faithful and accurate timing source to the many element detector arrays of the CTA and KM3NeT, while at the same time upgrading WR to 10Gbps data transport capability. J. Koelemeij, formerly of the VU, now OPNT, heads the first sub-package (5.1a), and D. Berge, formerly of UvA, now DESY, the second (5.1b).

The work on **Task 5.1a** revolved around the two deliverables D5.4, *Hardware for maser-level time & frequency distribution in public networks* and D5.7, *Time transfer in SURFnet/LOFAR network & general design rules for network implementation*. For D5.4, measurements of the short-term stability of out-of-the-box WR ZEN equipment showed that the phase noise was insufficient to support maser-level frequency transfer, as required for the project. This led to the decision to build a low-jitter WR switch, as developed previously at CERN. VU and OPNT applied upgrades to two default CERN WR switches to reduce the phase noise and improve the short to medium-term stability by

- Implementing a low-jitter daughterboard (LJD)
- An ultralow noise clean-up oscillator
- Using wavelength-stabilized DWDM SFP transceivers.

The low-noise WR switches were commissioned, the performance of various configurations were tested and compared with tests done at the University of Granada/Seven Solutions. Effects of wavelength variations of CWDM versus DWDM SFPs on the long-term stability of WR were studied. All results are reported in the deliverable report, and, the NRAO being very interested in these techniques for a possible upgrade of the current Very Large Array (VLA) in New Mexico, in an NRAO memo

https://library.nrao.edu/public/memos/ngvla/NGVLA_22.pdf.

For D5.7, VU, JIVE, ASTRON and OPNT worked together with SURFnet on the network design (a WR link Westerbork – Groningen – Westerbork – Dwingeloo). At the same time, SURFnet was preparing the roll-out of their new DWDM network, SURFnet8. In order to ease the implementation, SURFnet requested a change of the DWDM Optical Supervisory Channel (OSC) from 1510 to 1590nm. Although the impact on the WR link would be minimal, there were some consequences:

- A new network design was needed
- The wavelength change had to be implemented by OPNT in the bi-directional optical amplifiers
- The deliverable was delayed by about six months (with no impact on the final goals of the project, as most of the work for dependent deliverables could proceed without any delays).

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The WR link was staged at the SURFnet headquarters in Utrecht, the Netherlands, and tested in a link that closely resembled that of the SURFnet8 network, including optical data traffic, multiplexers and network management. The equipment for the link Westerbork – Groningen – Westerbork – Dwingeloo is scheduled to be installed and commissioned by May 2018. From then on, test measurements will take place of various configurations (with and without additional switch at Groningen for a separate WR branch to the LOFAR stations at Buinen). After completion of the test, a VLBI trial will follow. Finally, the CAMRAS radio telescope at Dwingeloo was equipped with a Software Defined Radio (SDR) backend and first commissioning observations were done, while the planning for fiber works in Dwingeloo are ongoing.

A large part of the effort in **task 5.1b** was aimed at the completion of deliverable D5.6, *Tools and methods for delay calibration before installation and in situ*. The general layout of the CTA and KM3NeT arrays can be considered large Ethernet networks with hundreds to thousands of widely distributed nodes. Nanosecond-level synchronisation of all these detector elements is required to reconstruct high-energy gamma rays and neutrinos. For this purpose WR technology was adopted early on in the projects, however the calibration of hundreds of telescopes and thousands of optical modules needed completely new tools and methods. Tools for relative calibration measurements of hundreds of WR nodes prior to their installation were developed, as well as complete timing calibration procedures. Both relative and absolute timing calibration were detailed, as well as methods to monitor and cross-check the stability of the system in situ.

WR hardware was tested in real field conditions in the context of the Tunka Advanced Instrument for Gammy ray and cosmic ray Astrophysics (TAIGA) project in Siberia, 50 km from Lake Baikal. The TAIGA project combines Imaging Atmospheric Cherenkov Telescopes (IACTs) with an array of wide-angle non-imaging optical detectors of the TAIGA High Sensitivity Cosmic ORigin Explorer (HiSCORE) array to proof a new, cost-efficient technology for very large area Gamma ray telescopes, for energies beyond the CTA range.

The TAIGA-HiSCORE stations each contain four large area photomultiplier tubes (PMTs) and WR nodes that allow for subnanosecond time alignment of all stations distributed over an area of 0.4 km^2. The setup in Siberia allows to do a comparison of various types of WR hardware under harsh circumstances and to perform an extended monitoring of the stability of such a complex setup in long-term exposure. Testing of the WR hardware in field conditions is ongoing during the winter of 2017-2018.

At UGR much effort went into the 10G development of the WR technology, with very good results. Some key IP modules were received from Xilinx and Seven Solutions, which were found to be critical for further progress. As yet, sub-ns accuracy has not yet been reached, but the 10 ns mark has been passed and improvements are ongoing.

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1.2.5.2 Task 2: Multi-messenger methods

After a somewhat troublesome start, with several changes of task leader, activities in task 2 picked up considerably during the second period. Deliverable D5.2, *Multi-messenger alert handling design document,* was completed, specifying the requirements and technology solutions for alert handling for LOFAR, EVN and GW detectors.

The LOFAR Responsive Telescope 1.0 was rolled-out, bringing an impressive improvement of response time to less than 3 minutes, with an even shorter response time in the planning. As LOFAR will use telescope-specific XML triggers, a VOEvent filter is being implemented, converting the GW triggers to XML. More software will then use these messages to trigger EVN e-VLBI observations, in which a number of likely sources in the large field of view of LOFAR will be targeted at high resolution.

Through the personal contacts between the participants of Cleopatra, an MoU was signed between VIRGO-LIGO and a group of JIVE and EVN scientists, to get early notifications of GW events. This led to a number of Target of Opportunity observations with the EVN (unfortunately without any direct detections).

An important highlight was the ASTERICS workshop on Radio – γ-ray: Transient Alert Mechanisms (deliverable D5.8), held in Amsterdam on 26 -28 September 2017:

http://indico.astron.nl/event/rgammatamThe workshop had approximately 40 participants, bringing together a good mix of representatives from various instruments: Radio (LOFAR, ATCA, MWA), γ-ray (CTA, MAGIC, HESS, FERMI, SWIFT), neutrino (IceCube), GW (LIGO) and optical (BlackGEM/MeerLICHT). Also present were Virtual Observatory and scheduling experts. Talks provided an interesting mix of science and technical information. It became clear that there is a common set of problems that needs to be solved, and much eagerness to collaborate. One problem that kept coming up was cross-matching events to various catalogues in order to identify targets for follow-up. The workshop also featured a special afternoon session on scheduling organised by task 5.4. The general consensus was that the workshop was extremely timely and useful, and that follow-up workshops, possibly on a yearly schedule, should be considered.

1.2.5.3 Task 3: Post-detection data streaming

Based on the successful tests with the Python prototype of the data streaming software, as reported in the previous periodic report, the decision was made to code the actual deliverable in a compiled language. For this the ISO C++11 language was chosen, because of its many new and useful features. Those features were used extensively, resulting in the on-time delivery of D5.5, *Data streaming software client*. A technical report explaining the features and possible uses cases of the delivered daemon/client pair of programs accompanied the public release of the source code.

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During development of the software, a module was created to enable command line parsing in quite a novel way. This code was found to be useful enough in its own right to make it available as a stand-alone library, called “argparse11”. The code was properly isolated and released to the popular open source code sharing community hosted by GitHub.com.

1.2.5.4 Task 4: Scheduling of large astronomical infrastructures

In the second period of ASTERICS this task continued to make excellent progress. IEEC and GTD worked on algorithms and simulations of observation scheduling, while STFC concentrated on the observation planning aspects. The work, which will be described in deliverable D5.9, *Report on scheduling algorithms for large infrastructures using subarrays and infrastructure for cross-facility scheduling*, deals with scheduling issues on scales ranging from local arrays to subarrays to global infrastructures comprising different facilities. Special emphasis is placed on the benefits of multi-facility scheduling for nominal scientific programmes (based on common execution and access policies: open time, key programmes, etc.) and also for transient events. In addition, a proposal for promoting collaborative exploitation of infrastructures has been included in the 5.9 deliverable, as an initiative of the STFC team.

AI technologies for scheduling operations are described in the report, together with a performance analysis. An analysis of scientific use cases for the multi-observatory scheduling was also initiated. CTA and SKA infrastructures were used for an initial test case in order to simulate coordinated programmes and evaluate the benefits of multi-observatory scheduling. This was complemented by publicly available surveys done by SKA precursors (in particular the GASKAP survey). These scientific programmes, together with the operational strategy for CTA and SKA, were modelled and are now being used in a simulation platform that checks the performance of both observatories working in a coordinated manner. A formal analysis of the simulation runs will be described in the second deliverable, D5.12.

As coordinated and multi-messenger observing is a new field, whose workers are separated by specialism and by geography, the suggestion is made that a portal be constructed as a conduit for “coordinated” news, and to provide some continuity for the community, especially after ASTERICS has ended. An analysis of how collaborations of different types form, and what could be done to make that process easier suggests the use of a Facebook group as a portal for coordinated observation news. Private, in some cases bespoke, webapps as areas for messaging, transient curation, observation planning and display can be highly efficient. An investigation into the development of general tools to replace the `bespoke' element and make such webapps easier to construct could be very useful.

1.3 Impact

For all Work Packages the information on impact remains relevant.

As stated in the DoA, *"ASTERICS places significant value on engaging the paying public with the astronomical facilities their taxes have helped to realise. Mass Participation Experiments (MPEs) have already played an important role in democratising research, demonstrating that a large fraction of the public is interested and willing to contribute. In the past few years, citizen science has increased the numbers of active participants in astronomy research by much more than an order of magnitude [...] ASTERICS aims to attract an already science-inclined public to a more formal science education. A further impact of ASTERICS is in harmonising citizen science practice across the ESFRI facilities, spreading good practice and avoiding parallel development of divergent solutions in open research data access for the general public. Our programme is in tune with the times - we are anxious to get started and see large-scale facilities such as the ESFRI telescopes really connecting with the paying public, creating and enthusing a new generation of scientists and engineers."*

This aspiration has been realised through our very successful Muon Hunter experiment, which achieved 1.3 million classifications in the first five days, and had educational resources built in. We have also launched promotional animation videos that have had many thousands of views each.

The European Solar Telescope, EST, became an ESFRI Project after the start of ASTERICS. Researchers and developers connected to the EST have since visited ASTERICS meetings and the ASTERICS General Assembly has approved a proposal for development of tools for EST in the ASTERICS environment.

The impact on tools for multi-messenger astrophysics is larger than expected as developers outside the ASTERICS cluster are teaming up with ASTERICS teams. We will act on this opportunity to make the impact as large as possible.

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2 Update of the plan for exploitation and dissemination of results

The Exploitation and Collaboration plans were updated in March 2017. No further updates of the plans will be made in the remaining time of the project. Both plans are in execution phase. We did not see a reason to deviate from the plan. An overview of contacts is shown in the below table.

Action / Sector	Passive (conference)	Reserved active (meetings)	Collaborative (working on common projects)	Active (fully working together at a distance; exchange of ideas, processes, procedures, results, personnel)
Other projects (including other EC-funded projects) - European Solar Telescope - Aeneas - EuroPlanet - Opticon - RadioNet - Km3NeT2.0	- European Solar Telescope - Aeneas - EuroPlanet - Opticon - RadioNet	- European Solar Telescope - Aeneas	- European Solar Telescope	
Industries - Orobix (IT) - E4 (IT) - Quasar SR (ES) - Triopsys (NL) - S&T (NL)	- Orobix (IT) - E4 (IT) - Quasar SR (ES) - Triopsys (NL) - S&T (NL)	- Orobix (IT) - E4 (IT)	- Orobix (IT) - E4 (IT)	
Research organisations - TU Delft, Shahrzad Naghibzadeh (NL) - Polish Academy of Science, Piotr Homola (PL) - Auckland University of	- TU Delft, Shahrzad Naghibzadeh (NL) - Polish Academy of Science, Piotr Homola (PL) - Auckland University of Technology, Stuart Weston (NZ)	- TU Delft, Shahrzad Naghibzadeh (NL) - Polish Academy of Science, Piotr Homola (PL) - Auckland University of Technology, Stuart Weston (NZ)	- TU Delft, Shahrzad Naghibzadeh (NL) - Polish Academy of Science, Piotr Homola (PL) - Auckland University of Technology, Stuart Weston (NZ)	

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Technology, Stuart Weston (NZ) - Radboud University Nijmegen, Paul Groot (NL) - University of Geneva, Renaud Jolivet (CH) - Byurakan Astrophysical Observatory, Areg Mickaelian (AM)				
Yet unidentified interested parties - National Representative Portugal for H2020 European Research Infrastructures, José Antão (PT)				

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3 Deviations from Annex 1 and Annex 2

WP1 – AMST

The All-hands meeting was not foreseen in the DoA, but fits the overall activities and the event budget for the project. The Project Officer approved the idea for the meeting.

WP2 – DECS

We are writing a new massive open online course, to be presented at the Open University as a "Badged Open Course" on its OpenLearn platform. It will feature the VO-enabled Stellarium software and we aspire to feature more advanced VO technology. We have designed the learning outcomes and study schedule. Video material was shot in Tenerife in October 2017. The course is aimed at entry-level e.g. suitable to 14+ year olds and interested adult learners. This is in addition to the obligations of the DOA and goes beyond our formal requirements.

WP4 – DADI

D4.6, initially foreseen in November 2016, was organised 5 months early in June 2016, and reported in the first periodic report. D4.11 was organised in April 2018 instead of March for logistics reasons.

WP5 – CLEOPATRA

Some deliverables have suffered delays, for various reasons, however the work package is on track and all deliverables will be completed before the end of the project.

3.1 Tasks

3.1.1 WP2 DECS

Unfortunately, during the development of our materials for Deliverable 2.7 and 2.8, one of our ASTERICS-funded staff had to be granted long-term sick leave due to a serious illness, and as a result Deliverables 2.7 and 2.8 were one month late.

For this reason, we unfortunately also had to descope our ambitions for the projects that could be made available by the time of this deliverable deadline, though still nevertheless meeting the formal requirements of the project deliverables.

Going beyond the requirements of these deliverables, we have facilitated the creation of a further citizen science experiment, the Cosmic Ray Extremely Distributed Observatory (CREDO) and its associated crowdsourced analysis the Dark Universe Welcome. The aim of this project is to use people's mobile phones as charged particle detectors. These charged particles

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could be caused by Cherenkov showers of extremely high energy cosmic rays (e.g. 1-10 Joules) impacting on the interplanetary medium and solar wind in our own Solar System. The incidence rate of extremely high energy cosmic rays, with energies 1-10 Joules, is still unknown. Cherenkov showers from such high energy cosmic rays would result in a worldwide, synchronous set of charged particle detections. The idea of this experiment is to use mobile phones as a worldwide network of charged particle detectors. When a charge particle impacts on the Charged Coupled Device in a mobile phone, it appears as a glitch in the image that is read out. When mobile phones are charged they are typically left horizontally, and the data can be tagged with location and timing information, so a charging mobile phone can be used as a very effective cosmic ray detector. An Android app has already been developed to be run while a phone is charging. The Dark Universe Welcome project aims to crowdsource the analysis of the worldwide data set that will be compiled from this app, and this component of the project is still under development and review. The lead on Dark Universe Welcome was the staff member who is now on long-term sick leave but this work will be resumed by other staff in the ASTERICS project.

3.1.2 WP5 CLEOPATRA

Some deliverables have suffered delays, for various reasons, however the work package is on track and all deliverables will be completed before the end of the project.

3.2 Use of resources

3.2.1 WP2 DECS

There are no deviations on the use of resources, except that a saving was made in the third-party costs on project developer time, by facilitating the development in other, cost-neutral ways.

3.2.1.1 Unforeseen subcontracting

No unforeseen subcontracting was done. We were able to save third-party resource for development of the Zooniverse platform by facilitating the creation of a new mobile functionality at no cost to the project.

3.2.1.2 Unforeseen use of in kind contribution from third party against payment or free of charges

No unforeseen use was made of in kind contributions.

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3.2.2 WP5 CLEOPATRA

As already mentioned, funds were transferred from the VU to the new ASTERICS partner OPNT, which means that the same effort is spent on Cleopatra by the same people.
The underspending by SURFnet, due to work efficiency, has led to a redistribution of funds to DESY and IEEC, where it will be used for equipment and engineering effort.

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4 ANNEX 1

ASTERICS
External Advisory Board
Report 2
ASTERICS General Assembly 5
19th January 2018

AEAB: Simon Berry (SKA), Rene Ong (CTA), Jan Palouš (CAS – Chair person), Ronald Stark (ASTRONET), Michael Sterzik (ESO), Els de Wolf (KM3Net)

1. The AEAB recognizes that ASTERICS is having a very positive impact in fostering collaboration between four ESFRI astronomy / astrophysics / astroparticle projects – CTA, SKA, KM3NeT, and ELT. We appreciate the project management effort in general that keeps the different activities coordinated and on track. We recommend to explore a stronger connection to EST, and to other global projects such as LSST. At the strategic level, we suggest the expansion of contact and dialogue between ASTERICS and APPEC to ensure alignment of interests.

2. The AEAB congratulates the ASTERICS project for the positive outcome of the mid-term review by the EC. In general, the AEAB would appreciate that important material is distributed earlier, and the AEAB meeting time slots better coordinated, to be able to provide proper feedback / evaluation on time. The ASTERICS project is complex and fast moving. We also request that a more rigorous approach is taken to progress reports, providing more clearly-presented detail in each workpackage to enable the AEAB to do its work. We therefore suggest that the AEAB should meet more frequently in final project phase, coordinated with AGA meetings.

3. Observations of the progress of the work packages presented during

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the AGA:

- Asterics Policy Forum: The report on the meeting, immediately preceding the AEAB and AGA meetings, suggests it is a productive forum where useful conclusions are emerging. It now needs a sustained effort to ensure that common requirements emerge from interaction between the different stakeholders on key issues.
- WP1: Coordinated project management is important in the last part of the project. The spending profiles show significant volatility, due to delays in both the delivery of products in the final stages, and personnel hiring. Resource planning in relation to hiring personnel, and then what can be achieved in the final stages of the project needs to be realistic. The AEAB notes the proposal to bring activities involving the EST within the ASTERICS project. We support the proposal, and urge the ASTERICS Management team to identify a viable route to providing resources that will enable the new programme.
- WP2: The DECS citizen science projects appear to be very successful and provide active dissemination into a broad public.
- WP3: Successful individual projects were highlighted. However, their ability to connect across different ESFRIs remains unclear. The AEAB has some concerns about effort gaps in the tasks (Cambridge etc.), but also note that effort is underway to resolve the issue.
- WP4: The VO-centric approach brings added-value to the data management tasks in the different ESFRIs. They clearly benefit from the work done and the deliverables provided.
- WP5: We noted substantial progress for time synchronization using the White Rabbit technology, and its pilot implementation.

4. In general, we note that all WPs seem to be showing good progress individually, but it is less obvious if there is coherence and major internal collaboration among them. An effort to better interconnect them will be appreciated. The participation in schools/conferences/forums could benefit from more coordination between individual WPs with respect to timing and topics.
5. For the remainder of the project a strong scientific leadership is considered crucial. A clear picture and vision on the final outcome of the project and its lasting impact needs to be conceived and communicated. We recommend to keep a strong focus on the further growth of the collaboration between astronomy / astrophysics and

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astroparticle communities. We urge continued efforts to ensure that the visibility of ASTERICS in the community and general public is maximized. The visibility of ASTERICS to the general public needs to be increased. We welcome the discussion in the ASTERICS project team about their future role in the European Open Science Cloud.

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