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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 01/05/2015 to 31/10/2016

Periodic report: 1st

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

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01 May 2015 – 31 October 2016

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For the ASTERICS consortium
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1 Explanation of the work carried out and overview of the progress

Introduction

The ASTERICS project is set up around four astronomy ESFRI facilities (SKA, CTA, KM3NeT and E-ELT). The ASTERICS Consortium consists 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. As the Virtual Observatory (VO) had already a well-defined core around several observatories and data sets, they were the first to welcome the new groups to their meetings. In the Citizen Science workshop, the early adopters were also more prominently present than the ones with no previous Citizen Science experience. This was good for starting the information flow and new collaborations. The integration within the overall project of the various groups is progressing. Participants are now, in parallel to the developments for their own facility, more and more thinking about the possible implementation of their work in other facilities. This is something one cannot easily enforce and is a big achievement so early into the project.

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.

In this chapter, we describe the work carried out during the reporting period (1 May 2015 – 31 October 2016). 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 first 18 months of the project. Section 1.2 contains the details of the work carried out in each Work Package.

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

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between the facilities, minimising fragmentation, encouraging cross-fertilisation, developing joint multi-wavelength/multi-messenger capabilities, and opening-up the next generation of observatories to discovery and data re-usage by the entire astronomical community.

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.*

  Since the beginning of the project, we made substantial progress towards enabling interoperability and software re-use for the data generation, integration and analysis of the ASTERICS ESFRI and pathfinder facilities. This started with the creation of an open innovation environment for establishing open standards and software libraries for multi-wavelength/multi-messenger data. OBELICS is developing common solutions for streaming data processing and extremely large databases, as well as studying advanced analysis algorithms and software frameworks for data processing and quality control. In particular, in the reporting period, a data format survey was performed to find synergies between ESFRI experiments producing similar types of data. Low and mid-level data generated by all event-based experiments have a hierarchical structure and therefore hierarchical formats as HDF5 are suitable for them.

  A number of innovative solutions have been produced over the first 18 months. A library for fast, vectorised, array reductions and moment calculations was written in C++ with Python binding. A notebook-style interface was designed for cloud-based reduction of interferometric data. Wavelet denoising was implemented for discriminating a Cherenkov signal versus the sky background. New interfaces now enable the extension of the ROOT framework for Astroparticle projects. The initial general-purpose library of simulated primary cosmic ray, written during the reporting period, already improve the efficiency of new investigations without the need to re-generate the events each time.

  Also, an innovative and efficient algorithm of lossless compression for digitalised signals (which is usually the kind of data produced by ESFRI experiments) was produced. This achieves reasonable compression ratios with comparatively small compression duration.

  WP4 DADI also contributes by providing building blocks from the Virtual Observatory framework of standards and tools. For instance, the IVOA Provenance concepts have been adopted in the CTA pipeline (see Section 1.2.4.3).

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- *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.*

  WP3 OBELICS has set up a repository of existing and new under-development (or extension) libraries to address this objective. The repository is publicly available and it provides, so far, thirteen software libraries for statistically robust analysis of Petabyte-scale datasets in astronomy.

- *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.*

  In the effort to harmonize the interactions between facilities, a high-level Policy Forum (involving the ESFRI projects and other large astronomy research infrastructures) has been established. The first meeting took place in February 2016.

  More technical aspects concern the development of the technology for enabling long-haul and many-element time and frequency distribution over fibre connections, for relaying alerts, and for streaming data. As a first step, a report on scheduling algorithms for large infrastructures was prepared (see section 1.2.5.4). This takes into account cross-facility scheduling from subarrays to a global infrastructure.

  A number of high-bandwidth transfer tests were done between New Zealand and the Netherlands, using various commercial and non-commercial applications. A working e-transfer prototype was delivered.

  Scheduling algorithms dealing with multiple constraints were studied for the CTA, though care is being taken to make sure the solution will not be only suitable for CTA.

  With regard to time and frequency distribution, ASTERICS CLEOPATRA has demonstrated a new and very precise dispersion delay measurement method. Simultaneous transmission of an optical supervisory channel (OSC) signal and two additional wavelength channels for time and frequency transfer, was successfully demonstrated at SURFnet.

- *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.*

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Three kinds of complementary events organized by DADI concur to this objective. The Technology Forums are devoted to the discussion of the partners' relevant technological activities, and of collaborations, and to the preparation of the International Virtual Observatory Alliance (IVOA) meetings. The ESFRI Forum and Training Events are dedicated to gather the ESFRI and pathfinder requirements and feedback. The European Data Provider Forums and Training Events extend to concept to all data providers, and allow us to check the wider relevance of the VO developments.

The First Technology Forum, the first event organized by DADI, was important for team building and information sharing. It also allowed the participants to discuss important topics in preparation of the Sydney IVOA Interoperability meeting. It was designed to enable discussions between VO and ESFRI (and pathfinder) partners about the development and implementation of the Virtual Observatory framework, and allowed to identify a preliminary list of topics of common interest.

The First ESFRI Forum & Training Event was then organized to gather a first set of requirements from the ESFRIs and pathfinders with respect to the Virtual Observatory framework.

The Second Technology Forum was fully devoted to the discussion of technological activities and collaborations, and to the preparation of the Cape Town Interoperability meeting, with plenary discussions and the so-called 'Hack-a-thon' sessions during which small groups discuss specific topics of interest for them in more details.

The ASTERICS Data Provider forum and Training event gathered astronomers and engineers on the topic of on-line publishing of astronomical data and services. An open training session was organized on June 17th, with tutors available on several data publication packages.

The topics identified as of common interest are regularly discussed during the meetings, and also fed the technological activities on the development of the VO framework and tools, which are performed in the context of the IVOA, discussed in the IVOA Working Groups and Interest Groups and presented during the IVOA Interoperability meetings.
WP4 DADI has established collaborations through initial discussions during the DADI workshops. This has concrete results such as the publication of ANTARES data in the VO by UHEI and the usage of Aladin Lite (CDS) for gravitational wave follow-up in the so-called GWSky tool. The code is stored in the official LIGO/Virgo gravitational wave astronomy repository to support the effort of electromagnetic follow-up of gravitational waves (https://gw-astronomy.org/wiki/LV_EM/TechInfo). Meetings have been organised on specific topics at the request of the ESFRI representatives, including one with the Gravitational Wave community that also included a representative of the LIGO project.

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- *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.*

  WP2 DECS has produced a set of promotional tools. A website is the introductory point of ASTERICS for a wide range of audience, from the general public to relevant stakeholder. An ASTERICS brochure and pull-up banners are more specific tools that helped to disseminate ASTERICS results during international events. The use of social media by means of Twitter and a Facebook page has allowed the project an instantaneous interaction and feedback.

  WP4 DADI is continuously working on the implementation of the ESFRI and pathfinder data in the Virtual Observatory. This will open the data produced by the ESFRI facilities to usage by the general public and inclusion 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 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*

  WP4 DADI organizes a yearly School on the scientific usage of the VO, open to participants from all over Europe, mostly earlier career astronomers. ESFRI staff are invited to participate in Schools, to understand the VO usage and be able to refine their requirements. ESFRI staff who had participated in the First School as students were involved in the preparation of the second one, updated or prepared tutorials, and participated as tutors, making them active participants in the dissemination of knowledge about the VO framework.

  DADI ESFRI and pathfinder participants are progressively involved in technical work on the development of the VO framework. For instance, the definition of the IVOA Provenance standard is of particular interest for CTA. A series of dedicated meetings was organized to prepare the discussion in the IVOA. During the last "CTA Pipeline Developer" meeting in October 2016, the decision to follow the IVOA Provenance concept was made. This decision is a direct consequence of the tight collaboration established with CTA members, and their direct participation in the definition of the IVOA Provenance Data Model.

  To train the community on citizen science tools, such as Zooniverse, WP2 DECS organised a workshop (see section 1.2.2) that has identified a number of Mass Participation Events (MPEs), and started the development of a web-based interfaces for Science 2.0.

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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

The management support team was established shortly after the start of the project. The smooth execution of all financial elements of the project is guaranteed by monitoring the partners' expenses on a six-month cycle. While some negotiation with partners was required in order to agree on the six-month cycle, both the first and second report reached the required budgetary actions on time.

The administrative part covers the Deliverables and Milestones and the lists of publications, disseminations, etc. Although a quality control policy was implemented from the beginning, there were some issues with timely delivery of Deliverables. We have now adapted the policy to allow for earlier corrective actions if needed.

The Deliverables of WP4 during the reporting period are all meetings, so no document is promised in the DoA. It is however evident that the results of the meeting should be well documented and disseminated, so a report is provided as result of the meeting. These reports usually arrive three months after the meeting, thus the EC participant portal registers these Deliverables as late. It is worth noticing the meetings were timely and very successful.

The central control over scientific and technical progress is established by meetings of the WP-leaders every two months; the AGA Chair is invited permanently. This improves the communications with partners. These meetings have a formal agenda and minutes. The WP leaders attach their written two-month progress report to the agenda. Most of these meetings are telecons.

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Two activities during the first reporting period were not planned:

- An amendment was needed to bring GTD from third party to IEEC into the project as a full beneficiary. For the project and the project plan this was a very minor change and was expected to be a light administrative change as well. It proved to be a major technical operation on the administrative portal.
- The general director of ASTRON, personally involved as coordinator of the project, moved to another institute. In consultation with the project Consortium and the Project Officer in Brussels, the ASTRON managing director accepted the coordinating position. There were no changes in the project management team or the support team, so the continuation of the project management was guaranteed.

1.2.1.2 Governance

AGA

There were two ASTERICS General Assembly (AGA) meetings during Project Period 1, one at the kick-off meeting in May 2015 (Month 1) and one on 11 February 2016 (Month 10), where the AGA was informed with a formal 9 month report by the coordinator and WP leaders about the project status and the AGA discussed activities and policies.

AEAB

During the 2nd AGA meeting the ASTERICS External Advisory Board (AEAB) met for the first time. At the end of the day they presented their findings. They were happy with the work done so far and gave some recomendations. The written report of the AEAB is in Annex 1.

1.2.1.3 Collaboration and Exploitation

The Collaboration plan and the Exploitation plan in this stage of the project aim at promoting ASTERICS at meetings and events and presenting the ASTERICS message and plans. This has been done by various persons distributed over all work packages. The more important task is to gradually increase the number of persons and organisations that are interested in collaborating with ASTERICS partners on ASTERICS activities, either to adopt the results or to contribute to the development.
To name a few activities and results:

- ASTERICS Participated, on invitation, (in the stakeholder meeting with High Level Expert Group of the European Open Science Cloud (EOSC) EC initiative.
- The European Solar Telescope (EST) consortium expressed interest to collaborate with ASTERICS partners.
- A University group from Armenia expressed their interest in VO activities (development and schools).

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- There are initiatives for new projects with EGI.
- There is close contacts with APPEC and ASTRONET. Next to that, both organisations have an observer in the AGA meetings.
- There is contact with the H2020 projects EU-T0, AARC2, Indigo DataCloud, HNSciCloud to find common development possibilities.
- Contact with industries ATOS, ORACLE, NVIDIA have been established in the preparation for the OBELICS General Workshop and thematic training event in December 2016.

1.2.1.4 Events

The first Policy Forum was organised to investigate expectations, wishes and opportunities on how to organise a well-attended and valued Forum. The results gave a handle to determine audience, subjects and frequency. Many persons are at the moment working on the technical development of new models for joint time allocation, observing and data access/sharing. This will serve as input for the discussion during the next Forum.
The Grand Integrating Event at the end of the project seems far away. Initial thoughts on how to set up an event that could have great impact have started.

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.

1.2.2.1 Production of promotional materials:

DECS has designed and delivered an ASTERICS brochure for general public and decision-makers. In-house graphic artists at the Open University designed the brochure. The first draft of the text was written by DECS, and was then iterated to approval with the other work package leads. A version in Adobe InDesign format has been sourced for brochure translation. 1500 English-language versions have been printed and distributed to WP leads.

DECS has also used in-house professional artists and editors to design and print pull-up banners that have been used by the consortium and for which online PDF versions are also available internally. These promotional materials have been used extensively e.g. at professional meetings (EWASS, ESOF, and the worldwide ADASS) and at public engagement events.

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1.2.2.2 Create web-based interfaces for Science 2.0 citizen science:

DECS held the first ASTERICS Citizen Science workshop in July 2016 at St. Catherine's College Oxford. There was representation from the SKA, CTA, E-ELT and other astronomical facilities. Four candidate citizen science experiments were identified for further development, as follows:

- *Searching for faint cosmic rays with CTA* (lead Lucy Forston). The science goal is to detect fainter Cherenkov events by visual classification. The anticipated activity is to classify hadron vs. photon events in the CTA telescopes, morphologically and in the time domain. This will be applied first to simulations and to e.g. HESS.
- *CREDO, the Cosmic Ray Extremely Distributed Observatory* (lead Piotr Homola, see their website at credo.ifj.edu.pl). The science objective is to detect ultra-high-energy charged particles with a whole-Earth Cosmic Ray detector. The activity is to use mobile phones as charged particle detectors, either while charging (so the device is horizontal) or while playing a game such as Pokemon Go (so the orientation is known). Following the ASTERICS workshop, CREDO held an inaugural meeting in August 2016. The CREDO PI asked for the following quote to be passed on: “Please feel free to convey my view of the importance of ASTERICS action in the case of CREDO: inspiration, practical know-how, valuable interpersonal exchange.”
- *An expansion to the existing Pulsar Hunters* (lead Rene Breton). The science goal is to extend the successful Pulsar Hunters Zooniverse project (featured on BBC Stargazing Live) to harder-to-find pulsars. The activity is interactive data visualization of pulsar time and frequency domain data. The same experiment and methodology is applicable in future to SKA data.
- *Deblending slitless spectra from HST and Euclid* (lead Claudia Scarlatta). The science objective is a spectroscopic survey of star-forming galaxies and AGN, quantifying star formation rates and black hole accretion diagnostics. The activity is to interactively deblend objects in confused slitless spectroscopy, for application on HST data (WISH) and future use in Euclid.

A technical requirement of several of these crowdsourcing experiments is the ability within the Zooniverse Panoptes platform to perform interactive examination of data, rather than just view static images. Part of the DECS software developer resource will be deployed to create this new functionality. As the projects are developed and ready to beta-test, they will be released to the Zooniverse beta-testing community through a web interface, which will be linked to and promoted from ASTERICS's own site.

In discussions at the St. Catherine's College workshop, it was agreed that E-ELT is not well suited to surveys that can be mined through crowdsourcing, but crowdsourcing can identify rare populations in survey data sets to supply E-ELT with targets.

The public engagement videos will be commissioned once MPEs are approximately three months from launch. The executive producer of the Open University's Sixty Second

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Adventures has left the OU to work for the BBC, but is still available to produce animations on a freelance basis at no difference in cost to ASTERICS.

1.2.2.3 Dissemination and promotion and engagement internally and with the wider community:

The ASTERICS website has been designed and went live on time. The website wireframe design was created by DECS, then discussed and iterated within the AEB. The initial content was populated by DECS into a website authoring tool at ASTRON, with subsequent minor modifications requested and implemented by other work packages. The website was then migrated to Drupal by Giuseppe Cimo at ASTRON and updated. ASTERICS publications are published on the externally-facing website.

The Publications of the Astronomical Society of Australia have agreed in principle to publish the Citizen Science workshop outcomes. PASA has impact factor 3.245 (c.f. PASP 2.62, Icarus 3.161), has no page charges and encourages immediate arXiv postings, in keeping with our "Science 2.0" open science aspirations. There is also free data archiving up to 50 Tb, and the data gets its own DOI separate to the paper. The papers must be useful and citable, should contain verifiable statements and novel content, and for experiments should have passed a critical design review (which here means results from the Zooniverse beta testers).

DECS has also created a Twitter profile to promote and publicise the project progress.
National contact points for ASTERICS press releases were identified, following a call for volunteers. These contacts will facilitate timely communication of ASTERICS results. The contacts are: Giuseppe Cimò (ASTRON) for The Netherlands; Francoise Genova (Strasbourg University) and Giovanni Lamanna (LAPP) for France (with requests to include Denis Mourand and Elizabeth Kohler in CNRS to coordinate press activity); Fabio Pasian and Massimo Ramella (INAF) for Italy; Enrique Solano (INTA) for Spain; Stephen Serjeant (OU) for the UK.

In 2016 the UK House of Lords Science and Technology Select Committee held an inquiry into the relationship between EU membership and the effectiveness of UK science publications, inviting contributions of evidence from throughout the sector. Evidence was received from "national academies, professional institutions, universities, research institutes, funding bodies, campaign groups, Government departments and agencies, scientific advisers and individuals with experience of leadership roles in the EU" (Report: EU Membership and UK Science, House of Lords). Given the strategic benefits that ASTERICS brings to ESFRIs and to European astronomy, it was felt appropriate to provide this parliamentary committee with written expert factual evidence, while remaining strictly neutral on political matters including the coming UK referendum on the membership of the EU. The select committee's report was published on the 20th of April 2016, and the report was debated in the UK House of Lords on 10 June 2016.

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1.2.3 WP3 OBELICS

WP3 OBELICS supports the ESFRI projects in Astronomy and Astroparticle Physics by building a collaborative framework among scientists and ICT technical experts, and following the data flow from observations to scientific data products. In the course of the first 18 months of the project, OBELICS has started the development and prototyping of common solutions for: streaming data processing, extremely large databases, advanced analysis algorithms, software and middleware frameworks for data management, data processing and data access.

Given the size and the number of beneficiaries in the OBELICS work package, management, user engagement and dissemination have been addressed in a number of ways, such as the implementation of a detailed workplan and two in-person OBELICS meetings. During the first 18 months, OBELICS activities initially involved building up teams, and subsequentially carrying out the activities towards the deliverables promised under the grant agreement and optimizing the work plan based upon the feedback received from the ESFRI projects. The WP3 is organized into four complementary tasks addressing different objectives of the work package.

1.2.3.1 Task 3.1: MAnagement, User engagement and data Dissemination (MAUD)

This task concerns all management, user engagement & data dissemination activities of the OBELICS work package. This primarily involves organizing regular meetings with the ASTERICS partners to ensure timely submission of deliverables with support of task leaders of the WP3. A project plan (Deliverable D3.1) providing a guide to all the work package members was delivered during the first four months of the project. This deliverable also described scope, roles of partners and stakeholders; schedule and resources; work breakdown structure (WBS) and deliverables; management plan and finally risk analysis and management.
Following Deliverable D3.1, two in person meetings of WP3 members were organized in Rome in February 2016 and in Madrid in September 2016. These meetings brought together the OBELICS task leaders as well as task participants to review the current status of the various tasks and to decide next steps in view of upcoming deliverables. MAUD also followed up with the WP3 members for the hiring process, which has been challenging for some of the partners. This issue has been further discussed under risk management. To address the user engagement and data dissemination the following activities were carried out under MAUD.

- Preliminary contacts established with computing and data centres, e-infrastructures such as EGI, policy forums (e.g. ASTRONET, APPEC) and ESO, consortia such as EU-T0.
- First in person OBELICS meeting held in Rome on 26—27 January 2016. It was dedicated to “users engagement” which has enabled among others the establishment of: a forum of ESFRI contacts, external users and partners, e.g. from AARC2-H2020 project concerning the issue of Authorisation and Authentication infrastructure; the engagement of external partners together with OBELICS partners around High Performance Computing

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programming and new low-power computing platform; the potential cooperation explored with other H2020 e-infrastructure project, e.g. Indigo DataCloud, HNSciCloud.

- At M12 the delivery of the first open-source original ASTERICS HPC software (developed in the CTA context) and included in the D3.4 OBELICS software libraries, has allowed to set up the inputs and practical orientation for the first main OBELICS International School foreseen in April 2017 at M23.
- At M12 a first training course on the data challenges in Astronomy and Astroparticle Physics given by the OBELICS coordinator G. Lamanna on invitation at IHPCSS 2016 (ihpcss2016.hpc.fs.uni-lj.si) allowing MAUD to establish a mutual engagement with PRACE on the preparation of the first OBELICS International School and to disseminate OBELICS activities internationally.
- Two poster presentations by T. Vuillaume, LAPP and P. Bacon, APC at the 26th Edition of ADASS conference in Trieste, Italy in October 2016. Such participation in the international seminars and conferences from WP3 members will further increase with advancing recruitment process.
- WP3-ASTERICS members are also involved in the CTA Authentication and Authorisation (A&A) case one of the funded pilots of the multidisciplinary AARC2 project approved by H2020.
    - Under the auspices of ASTERICS OBELICS and DADI an A&A federation meeting was held on 18 October 2016 during the ADASS Conference in Trieste with the participation of several projects including CTA, SKA, Euclid, and IVOA. The major agreements included the need to separate clearly Authentication from Authorization: while for the former inter-project federation mechanisms can be found, the latter are responsibility of the individual projects, in which specific intra-project federation mechanisms may be devised. All participants agreed to continue sharing the information on their A&A activities; for the European participants, this activity can be considered as part of the coordination tasks to be carried out within ASTERICS. A&A is also a regular topic of discussion in DADI and in the IVOA.
    - During the IVOA Interoperability Workshop held in Trieste on 22 October 2016, the Grid and Web Services WG (GWS) reached an agreement on standardization of Group Authorization: the GWS will draft an IVOA standard that will follow the usual IVOA path, with the goal of getting approval in 2017.
- Thanks to the second OBELICS face to face meeting, the topics of common interests and issues for ESFRI projects were identified. The discussion also allowed WP3 task leaders to define the future directions and identifying commonalities and complementarities within WP3 tasks. This meeting also provided inputs for the general workshop and thematic training events.
- Drafting of a call for expression of interest for industrial participation has also advanced well to encourage the partnering process with the industries on innovation-related objectives of the OBELICS work package. This call shall be launched at the OBELICS thematic event and workshop, organized for 12—14 December 2016 in Rome.
- New insights coming both from the OBELICS partners and the ESFRI project offices and/or

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the ESFRI representatives in ASTERICS during the start-up phase of the WP3 have convinced the OBELICS management to merge D3.2 (expected at M12), namely "First OBELICS thematic training event", with D3.6 First OBELICS general workshop, organized for December 2016. This deviation in the GA is discussed in detail under the section 3.1. The thematic training event and workshop will allow ASTERICS to establish collaborative networking within H2020 projects (HNSciCloud, AARC2, Indigo DataCloud) Consortia (EU-T0, APPEC, EGI) as well as industries (ATOS, ORACLE, NVIDIA).

1.2.3.2 Task 3.2: Data Generation and information eXtraction (D-GEX)

The target of this task is the first stage of the scientific data flow, that is, the Data GEneration and information eXtraction (D-GEX). One of the main challenges at the beginning of the project was to share and analyze the characteristics of the data generation in the various ASTERICS experiments with the aim of identifying possible synergies and commonalities in this stage of the data flow, which are not obvious especially between different fields. Over the last 18 months D-GEX activities were dedicated to the provision of innovative solutions that are flexible enough to be adopted by the different ESFRI experiments. The objectives of this task have been further categorized into four transversal subtasks.

- **Data format survey**: ASTERICS will benefit ESFRI projects and other related major research infrastructures, including ESFRI-precursor experiments. The use of common formats for low-level data is less clear, since this data depends on the particularities of each experiment, i.e. signal based, event based and image based experiments. A Data format survey (Deliverable D3.3) to seek synergies between these experiments with the aim of fostering the use of open data standards that would enable interoperability and software re-use was performed. This deliverable has identified two areas where synergies among different experiments, mainly event-based (e.g., CTA and KM3NeT) are more promising: defining standards for low-level data and pushing for common high-level data formats.
- **Open data format**: The UCM and IFAE groups have been contributing to a recent initiative to define specifications of an open data format within the gamma-ray community (see http://gamma-astro-data-formats.readthedocs.io/en/latest). In addition, this initiative was proposed to be extended to encompass neutrino and cosmic-ray observatories. In particular, this data format may be suitable to deliver public data from KM3Net.
- **High performance formats for data streaming**: Other developments in data formats have been the adoption of the open FITS format by the INAF group for handling ASTRI/CTA data and the studies by the ASTRON group to move from the domain specific 'casa tables' system towards HDF5 for data products other than images and measurement sets (visibilities). The UCAM group is the representative of SKA and its activities within D-GEX are devoted to the data streaming and architecture of the data processing unit in SKA. Apache-Spark (JAVA based framework) is being investigated to handle streaming, iterative streaming, quality assessment and databases.

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- **Low power computing (LPC) platforms**: INAF introduced LPC platforms in the ASTRI/CTA pipeline in order to test first steps of the data calibration and reduction. Some benchmarks of new hardware solutions, in particular ARM processors plus GPUs (Graphics Processing Units), have been performed for this kind of analysis and compared with traditional hardware. ASTRON has focused on developing efficient algorithms for data reduction, mainly calibration and imaging, at a low power budget. It has investigated how various GPUs can be used to perform the IDG-algorithm developed as part of work stream D-ANA. INFN focused on the benchmarking of low power computing architectures taken from the mobile and embedded worlds. In particular system-on-chips (SoC) belonging to both the Intel and ARM ecosystems were acquired and tested in collaboration with the INFN COSA project (http://www.cosa-project.it). Connecting both worlds, LAPP activities have concentrated on developing high performance computing (HPC) solutions. With computing performances in mind, LAPP also developed a data format generator (a library of functions to create and handle a data format) adapted to vectorisation for simulation files in Imaging Atmospheric Cherenkov Telescopes such as CTA. This results in a speed up of 40 during the analysis of those files and allows vectorization with a total speed up of at least 300.

The work conducted on Open Data Format under D-GEX task will be particularly useful for ESFRI Project KM3NeT to open-source its data.

1.2.3.3 Task 3.3: Data systems INTegration (D-INT)

The task D-INT (3.3) aims at studying the challenges in the data management of the large ESFRI infrastructures. The problem of transferring and storing large amounts of data can be addressed in diverse manners. One of them is to compress the data. However, physics is understandably reluctant to lossy compression as crucial information could be lost. Lossless compression is much harder to achieve however, and often require important compression times. An innovative algorithm of lossless compression for digitalized signals (which is usually the kind of data produced by physical experiments) has been developed at LAPP. The algorithm achieves reasonable compression ratios with comparatively small compression times. The result of those developments will result in a scientific publication under review.

FAU focused on two main topics: a) collecting the data management plan and computing needs of the KM3NeT project and b) working on preservation of scientific analyses over long periods with the possibility to reproduce results up to 10 years after a publication. A survey of possible solutions has been conducted and the most promising candidates investigated: virtual machines and containerisation. Finally, the *docker* (https://www.docker.com) containerisation solution was chosen for its wide use and performance. Innovative solutions, including the *docker*, are under discussion and tests in the concerned infrastructures. In the best-case scenario, these will be adopted by the ESFRI projects. In most of the cases, these results have triggered discussions within collaborations and therefore improved the current development of the ESFRI projects.

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ESFRI projects in general have to deal with unprecedented amount of generated and/or reconstructed data. The major challenges concern the storage and the transfer of those data, their access through complex but efficient databases and their analysis on distributed computational resources, in a reasonable amount of time.

The resources and requirement analysis report (Deliverable D3.5) described the data model of each instrument and focused on the resources required to manage the large data volumes, from their generation, to their archive and their analysis. The inputs on data storage and computing needs from LAPP (CTA & LSST), UCAM (SKA), ASTRON (LOFAR), FAU (KM3NeT), INAF & IAP (EUCLID) were used to estimate the evolution of total storage needs (Figure 1) and computing needs (Figure 2: Evolution of the Computing needs for the ESFRI projects) of ESFRI projects over a period of 10 years (2015-2026). In both the cases the scale is logarithmic.

This deliverable will serve as a comparison basis between the ESFRI projects to better understand their common ground and differences in their data and computing models.

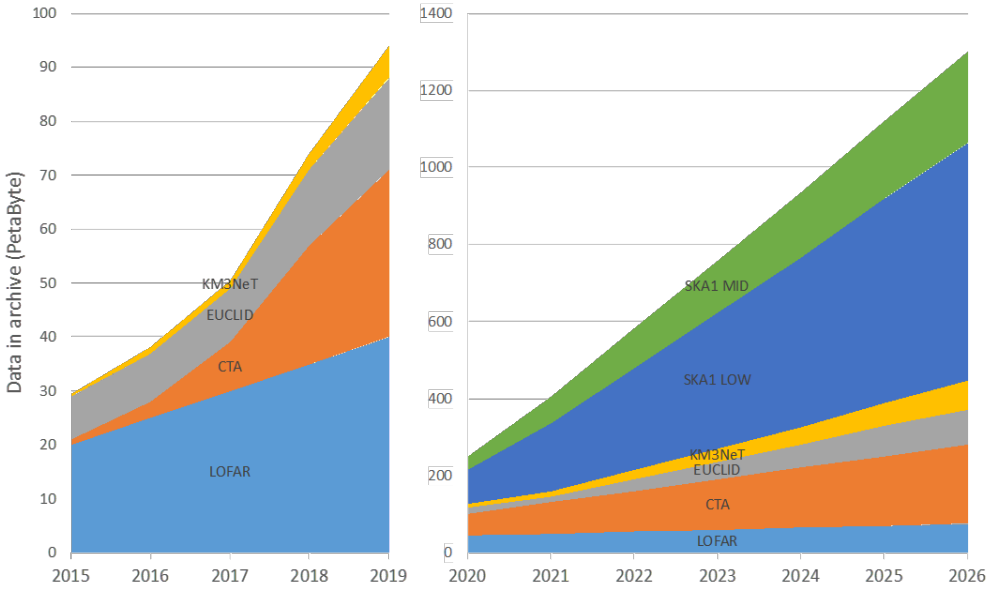

Figure 1: Evolution of the storage needs for the ESFRI Projects.

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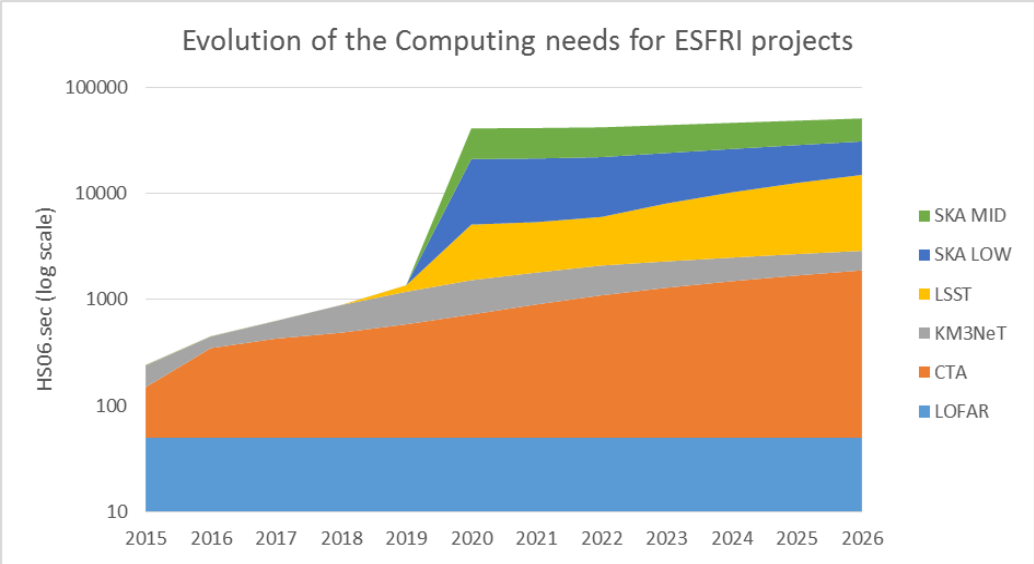

Figure 2: Evolution of the Computing needs for the ESFRI projects.

Task 3.4: Data ANAlysis / Interpretation (D-ANA)

Task 3.4 aims at developing a collection of statistically robust and domain independent open source software libraries for data analysis and data mining on Peta-scale datasets. UCAM has the task leadership and coordination responsibilities of D-ANA.
A number of innovative solutions have been produced over the first 18 months. These tend to be focused on single observatories but investigation of combining these and use in multiple projects is already work in progress. These are presented here along with task partners involved:

- **UCAM**: Prototyping of Statistical Analysis planning tool (StatPLAN) & Multi-wavelength inference (MW-INFERENCE). These tools allow combination of data from different facilities, different wavelengths and potentially multi-messenger astronomy.
- **ASTRON**: Development innovative algorithms for calibration and imaging. For imaging, a new method for putting measured correlations on a grid to perform an FFT. This method, Image Domain Gridding (IDG), has proven to work well on both CPUs and GPUs, and is being ported to software for imaging LOFAR data.
- **LAPP**: A library for fast, vectorised, array reductions and moment calculations written in C++ with Python binding. These developments are part of an open source library accessible at https://gitlab.in2p3.fr/CTA-LAPP/CTA_Analysis
- **JIVE & UCAM**: Design for a notebook-style interface to cloud-based interferometric data reduction for radio astronomy. This design allows a modern notebook-style approach to post-processing VLBI data, to enable users to develop and run their

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pipelines code on remote (to them) systems close to the data, in order to minimize costs of shipping and processing large data sets.

- **CEA**: Wavelet denoising for discriminating a Cherenkov signal versus the sky background. In parallel de-noised events are reconstructed to get the direction of the incoming gamma-ray or cosmic-ray in the atmosphere.
- **CPPM**: Robust direction and energy reconstruction algorithms which are crucial for the interpretation and analysis of astroparticle signatures, with which to perform low energy astronomy. This work will integrate all new developments and their prerequisites into a common format which can be used for large-scale data analysis and event characterisation.
- **INFN**: Interfaces which allow extension of the ROOT framework for Astroparticle projects.
- **INFN**: An initial general-purpose library of simulated primary cosmic ray allowing new investigations to be done efficiently without the need to re-generate these events each time.
- **INAF**: Agreement across projects on the need to separate clearly Authentication from Authorization, building inter-project Authentication federation mechanisms.
- **INAF**: Group Authorization standardization agreement within IVOA, to be used within the project.
- **INAF**: Initial general-purpose library of A&A and workflow management systems have been delivered as part of deliverable D3.4.
- **APC**: End-to-end simulation of the second and imminent LIGO/Virgo science run were carried out. This simulation includes the simulation of a population of binary neutron star mergers, the generation of the associated gravitational-wave signal, the recovery of this signal in synthetic Gaussian noise with LIGO/Virgo expected noise curve, the reconstruction of the source position using BAYESTAR method and the computation of a high-energy counterpart according to a selection of models (based on typical prompt and afterglow emissions from gamma-ray bursts)

The full list and status of software being developed within this OBELICS task form D3.4, which was delivered at M12 and is publicly available at:
https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp3:d-ana_software_repository
The innovative libraries produced under D-ANA task for fast computation (PLIBS, PLISA) can potentially have an impact outside of astronomy since they implement fairly generic operations with wider usage (a scientific publication to a computing research related journal will be submitted). In addition, the notebook interface (VLBI in the Cloud) can be of use for all radio interferometric data analysis (including e.g., ALMA, eMERLIN, JVLA and potentially initial versions of SKA). The multi-wavelength inference library (MW-INFERENCE) is intended for the start to allow combination from multiple astronomical facilities.

The ongoing work is also looking for integration possibilities between the modules being produced under this task. This potential integration is represented through the diagram in figure 3:

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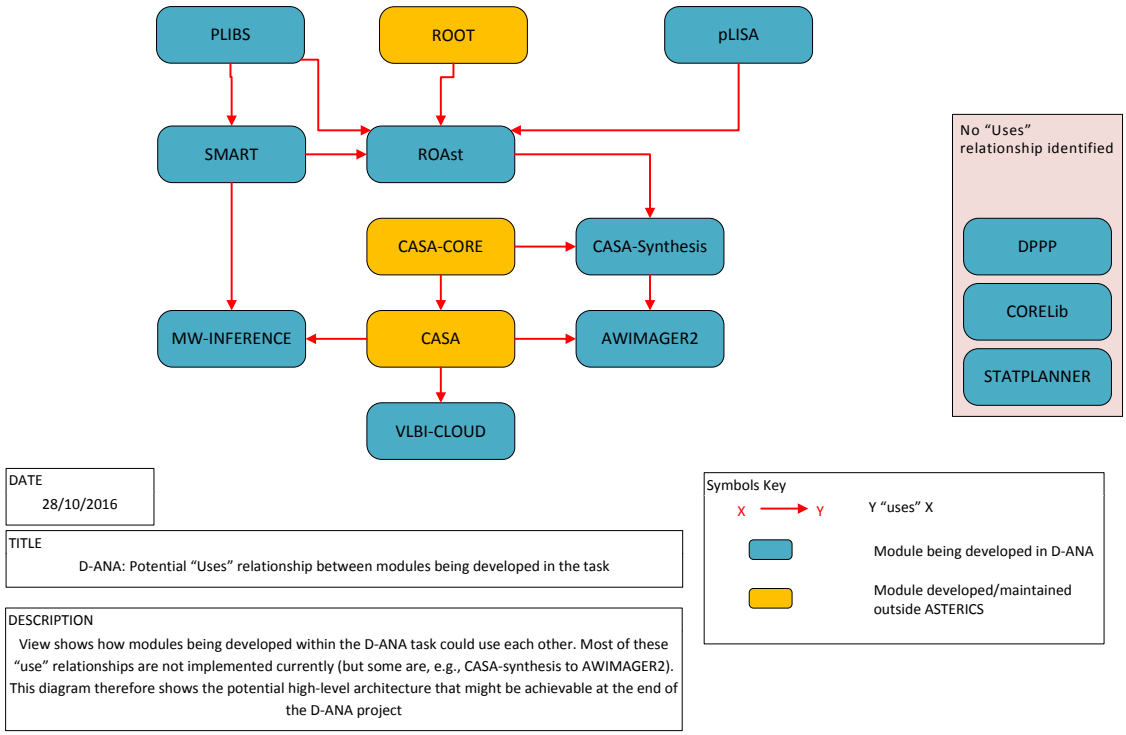

Figure 3: The diagram represents the potential integration between the modules that are being produced in the OBELICS work package.

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 with a set of common tools. More specifically:

- Task 4.1, led by INAF and UHEI
  Train and support ESFRI project staff in the usage and implementation of the Virtual Observatory (VO) 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
  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 and UEDIN
  Adapt the VO framework and tools to the ESFRI project needs, and make sure European astronomers remain lead actors in the International Virtual Observatory

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Alliance (IVOA), influencing it in the interest of the European infrastructures and the European scientific community.

DADI gathers VO specialists from CNRS/UMR 7550/UNISTRA (CDS, WP lead), INAF, INTA, UEDIN and UHEI and representatives of the ESFRI and ESFRI-like projects and their pathfinders, CTA (CNRS/LUTH/OBSPARIS), EGO/VIRGO/ET (CNRS/APC), KM3Net (CNRS/CPPM) and SKA (ASTRON). ESO is an associate partner, and participates in the Workshops. The long-term collaboration established with ESA on the VO development continues in this project. All partners participate in all tasks. DADI activities had an early start since the definition of standards and agreeing on them is a long-term process. Also, gathering the ESFRI and pathfinder requirements had to begin as early as possible.

Most DADI deliverables are *workshops*, including all the deliverables scheduled for the first reporting period. The meetings are held at or close to the scheduled date. Then several weeks are needed to prepare a "text" deliverable submitted to the European Commission. D4.6 was initially foreseen in November 2016, i.e. after the end of the reference period, but it was decided to hold it in June 2016 because there were too many competing meetings near the initial date, so it is included in this report. DADI Milestones are the IVOA Interoperability Meetings, which are held twice a year. Other important meetings are the ADASS yearly meetings and the RDA Plenary meetings. The meetings are described in the DADI wiki page https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:start.

The meetings play complementary roles to reach the WP objectives and are interconnected. Some of the connections are represented in the schema in figure 4.

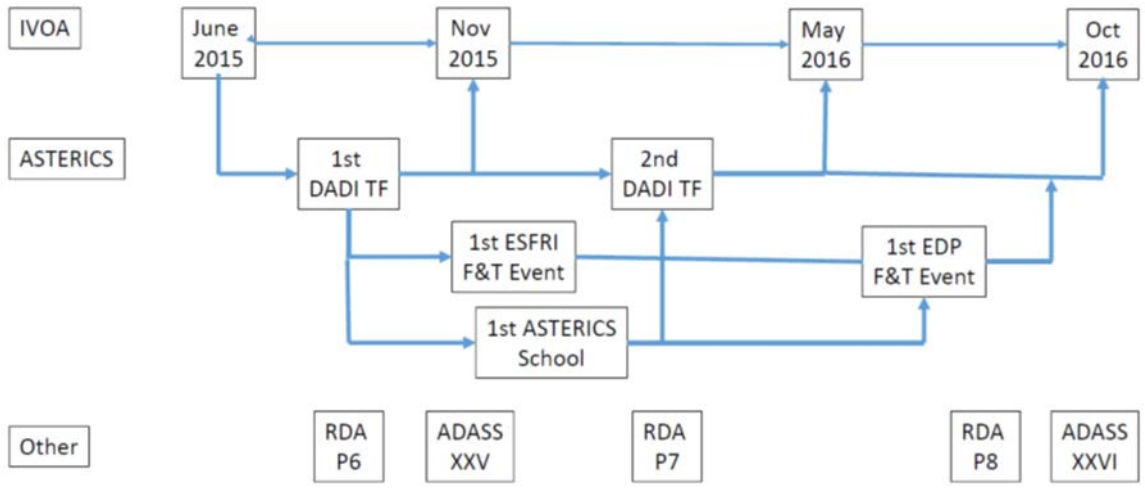

Figure 4: The WP4 DADI meetings play complementary roles to reach the WP objectives and are interconnected. This overview gives some of the connections. Requirements from one meeting trigger developments, which go into other meetings.

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

The meetings organized within this task are:

- First ESFRI Forum and Training Event (D4.3, Trieste, 3—4 December 2015, Trieste)
  The meeting was organized by INAF. The link https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4esfriforum1 contains the list of the 25 participants and their affiliations, as well as the programme and a link to the slides and to the summary of the discussions.
- First European Data Provider Forum and Training Event (D4.6, Heidelberg, 15—17 June 2016)
  The event (http://www.g-vo.org/edp-forum-2016/) was organized by UHEI. It had been initially planned in November 2016, but was organised earlier in June 2016 as explained.

The first ESFRI Forum and Training Event, D4.3, was held at an early phase of the project, and it was decided to focus it on gathering requirements and continue team building, and to postpone the training aspects so that the ESFRIs could better identify their needs in that domain. It was particularly aimed at gathering the large projects' requirements and feedback on the VO framework, in particular on topics of interest identified during D4.1. This was then pursued on an international scale during the Cape Town IVOA meeting (MS7), during which 'focus sessions' with the same aim were organised, under the responsibility of M. Allen (CDS). Two of the large projects, CTA and EGO/VIRGO/LIGO, were represented by people actively involved in DADI, and SKA was also presented in details, as could be expected in South Africa.

Tasks 4.1 includes one activity aimed at reaching European data providers beyond the large projects directly involved in DADI, in the form of two European Data Providers Forum and Training Events. The first of such meetings, D4.6, was a success, gathering a wide range of data providers, from the ESA and ESO international organisations to smaller data centres, eager to share their practices, lessons learnt on the usage of the VO and requirements, and to learn how to use VO publishing tools. It is important to note that representatives of the EST project, which was included in the ESFRI Roadmap in 2016, participated actively in the meeting.

DADI ESFRI partners are regularly polled for their needs, and additional meetings are organised as requested. The "Provenance Days" are discussed in Section 1.2.4.3. Another result was the organization of the DADI - Gravitational Wave Community meeting described in Section 1.2.4.2. The second round of discussions between DADI lead and the ESFRIs during Summer 2016 led in particular to organise a meeting with LOFAR staff at CDS on 18 November 2016, just after the end of the reporting period, to identify their specific needs and gather their feedback.

It is finally worth noticing that data of the ANTARES experiment, one of the KM3Net pathfinders, was included in the German Astrophysical Observatory service through

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collaboration between CNRS/LPPM and UHEI, following the Trieste ESFRI Forum and Training Event. They are thus now available in the VO. Also, the collaboration on the usage of Aladin Lite (CDS) for gravitational wave follow-up in the so-called GWSky tool started during the First ESFRI Forum & Training Event and has been going on since then.

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 is the organization of an annual School, open to participants from all over Europe, targeted to early career colleagues and to ESFRI team members.

The First DADI School (D4.2, 15—17 December 2015, Madrid) was for the participants to become familiar with the VO tools to use them in their own research. The school webpage is https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:school1#program and the updated tutorials have been posted in the sustainable Euro-VO web site at http://www.euro-vo.org/?q=science/scientific-tutorials.

The school set up a successful template that has been used for the second one (D4.5), which was held in Strasbourg 15—17 November 2016, just after the end of the reporting period. The tutorials can also be used in other contexts. It is worth noting that ESFRI staff are actively involved in the preparation of the Second School in addition to the VO teams, which demonstrates that they are becoming actors of the VO landscape.

In addition to the DADI School, a meeting DADI-Gravitational Wave Community[2] was held at CDS on 31 May – 1 June 2016. The meeting was organised by Eric Chassande-Mottin (CNRS-APC) and Françoise Genova (CNRS-CDS, WP4 lead). The event combined information exchange about the VO and gravitational wave projects on their data aspects, discussion of possible collaboration, and tutorials on the scientific usage of the VO. The topics were the time domain (coordinated by UEDIN in DADI) plus themes mostly relevant to CDS expertise: skymap visualisation and tiling; galaxy catalogues and usage for prioritization; tutorial on the scientific usage of the VO in a relevant scientific domain. The meeting was attended by 10 persons belonging to the European Gravitational Wave community, from CNRS-APC (France), Eötvös University (Hungary), INFN Firenze and Pisa (Italy), and Radboud University (The Netherlands), plus Roy Williams (LIGO/CalTech). The European and US teams work in close collaboration and share data, software and tools, and it proved to be very useful to have a US presence at the meeting, all the more so because R. Williams already collaborates with the CDS on LIGO/EGO visualisation tools. D. Morris (UEDIN), the technical contact for time domain in DADI and newly appointed vice-chair of the IVOA Time Domain Interest Group, attended the meeting, as well as CDS scientists and experts of visualisation tools and methods and of catalogues. In addition

[2] https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4gwstrasbourg2016.

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to the excellent collaboration set up previously on GWSky, another one was initiated on galaxy catalogues and cross-match, in particular on the completeness of the GLADE galaxy catalogue using GWSky and MOC. Another important topic will be to gather the Gravitational Wave community needs and use cases for the evolution of the IVOA time domain standards. Possible participants in the Second School were identified, as well as the possibility to prepare a tutorial relevant to gravitational waves (the tutorial was prepared by an EGO staff, who presented it at the Second School).

This meeting can be taken as a successful prototype of meeting focussed on a specific community, thus allowed to speak its own language and come with its own needs and concerns, with an inducing role towards this specific community beyond the teams involved in WP4, both as an introduction to the VO and a place to discuss further activities.

Moreover, preparation has started for organising a meeting on time domain involving all the interested WP4 and WP5 parties. This is clearly a domain in which ASTERICS has the capacity to move the lines, and to bring critical input for the evolution of IVOA standards by bringing needs which will complement the LSST ones. A preliminary discussion involving the ASTERICS Project Scientist, the WP4 and WP5 leads, and DADI representatives of CTA and EGO, was held during the Trieste ADASS meeting to organise the collaboration in the domain. It is likely that a common meeting will be organised during the first half of 2017, eventually in Strasbourg back-to-back with the Third DADI Technology Forum (D4.7).
Finally, E. Solano (INTA) volunteers to lead an activity to define real science cases with the ESFRI partners, which would eventually produce refereed VO-Science papers, in the framework of Task 4.2. This will be discussed with the other DADI participants to see if there is interest for this kind of activity, and to check who may want to involve staff in the activity if it is decided to start it.

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

Meetings organized within this task are:

- First ASTERICS DADI Technology Forum (D4.1, 17—18 September 2015, Strasbourg)
  The meeting program and participants, as well as the slides presented, can be found on the meeting page
  https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4techforum1

- Second DADI Technology Forum (D4.4, 7—8 March 2016, Edinburgh)
  The meeting web site:
  https://www.asterics2020.eu/dokuwiki/doku.php?id=open:wp4:wp4techforum2,
  displays all the slides presented during the meeting and a report on the subjects discussed during the two Hack-a-Thon sessions.

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The impact of collaborations between the ESFRIs and the VO teams in DADI framework is well illustrated by DADI Provenance activities. Following an initial informal *CTA and Provenance Meeting* (6—7 July 2015, Paris, France) organized by C. Boisson (CNRS/LUTH) to discuss CTA requirements on provenance, was presented at the 6th RDA Plenary, at the ADASS conference (poster) and at the Sydney and Cape Town IVOA meetings. Three Provenance Days were held afterwards, in Paris[3] (14 April 2016), Heidelberg[4] (14 June 2016) and again Paris[5] (20 July 2016), and discussions were also held during the DADI Workshops and the IVOA meetings. The starting point was that the IVOA Provenance model, inspired from the W3C, was too general. CTA was an excellent initial use case to check project needs. Discussion of the IVOA Provenance model now includes the RAVE survey and Pollux synthetic stellar spectra database as additional use cases. The recent meetings allowed the participants to discuss the use cases, to refine the model, to discuss its serialisation, and to discuss the draft standard document and the sharing of tasks, as well as possible contributions to the coming ADASS and Interoperability meetings. The Riebe et al. contribution proposed by the team for the ADASS XXVI meeting has been accepted as an oral talk and M. Servillat also presented a poster. It is also noticeable that this activity made a large fraction of the RDA Provenance Interest Group during the Paris RDA Plenary meeting. This collaboration has an impact both on the IVOA and on CTA: the corresponding IVOA standard is being written and will enter in the IVOA Recommendation track, and as explained, during the last "CTA Pipeline Developer" meeting in October 2016, the decision to follow the IVOA Provenance concept was made. The contribution of CTA requirements to the definition of the IVOA Provenance standards also demonstrates that the ESFRIs can become main actors in the definition of the IVOA framework.

DADI technological contributions to the development of the VO framework of standards and tools will be described in Section 1.2.4.4, which describes DADI contribution to the IVOA Interoperability meetings, which are ASTERICS Milestones. In addition to the many crucial contributions of ASTERICS-DADI to the IVOA activities, the impact of ASTERICS in the IVOA can also be seen when looking at the leadership of IVOA Working Groups and Interest Groups. At the beginning of the Cape Town meeting (May 2016), all the IVOA Working Groups and Interest Groups, except one, the Time Domain Interest Group, had at least one Chair from Europe, with the Data Access Layer Working Group and the Theory Interest Group having their two Chairs from Europe. Chairpersonship of the Groups is regularly renewed, and after the meeting the Time Domain Interest Group has a Vice-Chair from UEDIN, D. Morris, who is also the technical contact person for time domain in DADI. DADI boosts the European participation in the IVOA by providing the direct link with the ESFRI projects, which had been needed for a while to ensure the full relevance of the VO developments to their needs, and to make them active participants, and not only consumers of the VO.

[3] http://wiki.ivoa.net/twiki/bin/view/IVOA/ProvDayApril2016
[4] http://wiki.ivoa.net/twiki/bin/view/IVOA/ProvDayJune2016
[5] http://wiki.ivoa.net/twiki/bin/view/IVOA/ProvDayJuly2016

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Task 4.3 also has to ensure liaison with the projects that deal with the generic aspect of scientific data sharing, in particular the RDA. DADI presence has been ensured in all the RDA Plenary meetings organized since the beginning of ASTERICS:

- RDA Sixth Plenary meeting, 23—25 September 2015, Paris (France) (https://rd-alliance.org/plenary-meetings/rda-sixth-plenary-meeting.html)

- Seventh RDA Plenary Meeting, 1—3 March 2016, Tokyo (Japan) (https://rd-alliance.org/plenaries/rda-seventh-plenary-meeting-tokyo-japan)

- RDA 8th Plenary meeting (Denver, 15—17 September 2016) (https://rd-alliance.org/plenaries/rda-eighth-plenary-meeting-denver-co)
  It was held in Denver, USA, in the frame of the International Data Week (http://www.internationaldataweek.org/), together in particular with SciDataCon 2016 *Advancing the Frontiers of Data in Research* (http://www.scidatacon.org/2016/, 11—13 September 2016), convened by the WDS and CODATA.

DADI lead, who had been in member of the RDA Technical Advisory Board (TAB) and of the RDA Europe projects since the beginning of the RDA, was elected co-chair of TAB in October 2015. Topics of interest for astronomy are regularly discussed in the RDA meetings. DADI/IVOA Provenance Data Model activity has for instance been a highlight of the RDA Provenance Interest Group at the Paris RDA Plenary in September 2015. Liaison between the RDA and the IVOA is ensured through the IVOA Data Curation and Preservation Interest group, which is also chaired by DADI lead, and is also regularly discussed during meetings of the IVOA Executive Board. It does not seem necessary to create a specific Astronomy Interest Group in the RDA, because we have the IVOA to discuss discipline-specific interoperability questions, but we have lots to learn from and lots to bring to the RDA. Certification of data repositories, DOIs, dynamic data citation and scholarly data publication were among the RDA themes discussed during the Interoperability meetings.

Finally, it is also worth to notice that the IVOA Registry of Resources was included in EUDAT B2FIND Registry. EUDAT (http://eudat.eu) is a major European project which builds generic building blocks for the scientific data infrastructure. A public release is available, thanks to a collaboration with Heinrich Widmann, Hannes Thiemann and Damien Lecarpentier (EUDAT): http://b2find.eudat.eu/group/ivoa.

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1.2.4.4 IVOA interoperability meetings and ADASS conferences

The IVOA Interoperability meetings are DADI Milestones. DADI participated in the following IVOA Interoperability meeting:

- 14—19 June 2016, Sesto/Sexten (Italy) **Milestone 2**
- 30 October – 1 November 2015, Sydney (Australia) **Milestone 5**
- 8 –13 May 2016. Cape Town (South Africa) **Milestone 7**
- 21—23 October 2016, Trieste (Italy) **Milestone 11**

ASTERICS was first brought into the IVOA discussions during the first IVOA Executive Board meeting in Sesto on May 14th 2015. The current IVOA priorities, multi-dimensional data and time domain, fit very well with the initial priorities of ASTERICS. Technical work in these domains was pursued, in particular by staff engaged in ASTERICS. Integrating big projects' requirements in the VO development is a continuous process. The role of the IVOA Committee for Science Priorities (CSP), chaired by M. Allen (ASTERICS, CDS), was updated as part of defining the processes to best engage with these projects. ASTERICS of course was expected to play a major role, which was confirmed by the input provided to the Focus Sessions of the May 2016 IVOA meeting. It is for instance noticeable that the CTA and the Gravitational wave projects representatives in the Cape Town 'Focus sessions' aimed at gathering large project requirements were people involved in ASTERICS, just one year after the beginning of the project. M. Ramella (INAF), who is currently the chair of the IVOA Education Interest Group, also participates in DECS, thus ensuring a liaison between ASTERICS WP2 and the VO.

Here we identify a number of the highlights on topics of particular interest for ASTERICS-DADI, which are also discussed in DADI Workshops and tackled by DADI teams, organised with respect to the relevant IVOA Working Group or Interest Group:

- Applications Working Group (WG): HiPS has been a major topic of discussion at the Interoperability meetings, as it was at the ADASS conference. As prepared during the Strasbourg DADI Technology Forum, consensus was reached within IVOA to "promote" the HiPS Note to a Working Draft (WD) as a step towards a future IVOA Recommendation

- Data Access Layer WG: Multi-dimensional science is an IVOA priority, with a "caravan" of standards being developed to deal with it. This is also one of DADI top priorities. The set of relevant standards is nearly completed: DataLink has been an IVOA Recommendation since 17 June 2015; the so-called Simple Image Access Protocol SIAPv2.0 was endorsed as an IVOA Recommendation on 24 December 2015; SODA (Server-Side Operations for Data Access, previously called AccessData) is in the final stage of the recommendation process. The VOEvent Transport Protocol V2.0, also of key interest for ASTERICS, is in the Request for Comment phase.

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- Data Model WG: Discussion of Provenance, with the production of a Working Draft, mostly based on the discussions held in DADI, which was released in November 2016.
- Grid & Web Service WG: Authentication & Authorisation discussions within the VO framework build on the discussion held DADI Workshops in collaboration with OBELICS.
- Registry WG: Work on pgsphere (UHEI); HiPS registry extension
- Data Curation and Preservation Interest Group (IG): The status of the RDA and the IVOA/RDA interaction are a standing item of the IG sessions.
- Digital Object Identifiers (DOIs) are a hot topic, which led to lot of discussions in particular during the Sydney Interoperability Meeting (Data Curation and Preservation and Registry sessions).

The "Northern Fall/Southern Spring" IVOA meeting is attached to the Annual Astronomy Data Analysis and Software System (ADASS) Conference, which gathers astronomical data providers from all around the world, including astronomical data providers from large ground- and space based projects. It is thus important that DADI staff also participates in the ADASS conference. A significant ASTERICS presence was ensured in the Sydney ADASS XXVth and Trieste ADASS XXVIth conferences, held respectively on 25—29 October 2015[6] and 16—20 October 2016[7].

[6] Sydney ADASS XXV (2015): Staff from CDS (including WP4 lead), CTA, LOFAR, INAF, INTA, UHEI, and of the UK VO team (as well as from Euclid), participated actively in the meeting, as well as ESO and ESA. Fabio Pasian (ASTERICS GA Chair, WP3, WP4) presented a talk on behalf of ASTERICS at the Conference, and Christophe Arviset one about the IVOA. The VO was ubiquitous in the talks and posters presented by space and ground-based projects, and was very positively mentioned in the keynote address presented by Nobel Prize winner Brian Schmidt Big Data and Big Astronomy. An ASTERICS DADI talk was presented by Allen (CDS) et al. Two ASTERICS DADI posters were displayed by Sanguillon et al. (CTA and CDS), and by Bonnarel (CDS), Dowler, Noddle (UEDIN), Tody.

[7] Trieste ADASS XXVI (2016): E. Chassande-Mottin (CNRS/APC), M. Louys (CDS) and G. Taffoni (INAF) presented invited contributions, respectively on the *search for gravitational waves with low latency*, *Data Models in the IVOA*, and *numerical astrophysics in the era of exascale computing*, as introductory reviews to the Surveys for Transient Objects in the era of Gravitational Wave Astronomy, Data Models in Astrophysics, and New Trends in HPC and Distributed Computing sessions respectively. Several oral contributions on topics discussed in the DADI context were presented by a number of active members of DADI: P. Fernique (CDS), F. Genova (CDS), M. Nullmeier (UHEI), K. Riebe (AIP-GAVO),), A. Schaaff (CDS). Two posters on DADI-related activities were displayed by F. Bonnarel, D. Teodori, P. Fernique, C. Bot, M. Louys – CDS, and by M. Molinaro, INAF and F. Bonnarel, CDS. The ASTERICS demo booth and the CDS one were also privileged means to disseminate information about the project. Another excellent point for ASTERICS' visibility is that A. Szomoru (JIVE) presented WP5 CLEOPATRA as an oral contribution in the session devoted to Transients. There were also two posters directly related to OBELICS activities.

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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:

- 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.

- 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.

- 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 E-ELT.

- Fostering the development of advanced scheduling algorithms, using AI approaches for optimal usage of the ESFRI facilities.

In spite of ASTERICS kicking off just before the summer period, Cleopatra got off to a flying start. First personal contacts between the partners were made during the ASTERICS face-to-face kick-off meeting on the 27th of May 2015, and the first WP-wide telecon took place on the 30th of June. A preliminary wiki was set up, as well as a Cleopatra mail exploder. After the summer, activities picked up, several more telecons were held and at several of the institutes the process of hiring new staff started. Within the individual tasks telecons and in-person meetings took place as well. During the first 18 months of the project, two deliverables and one milestone were due, two of which were reached well on time. One deliverable, due in month 18, will be delayed by five months for reasons which will be explained (see sections 1.2.5.2 and 3.1).

1.2.5.1 Task 5.1: 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 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 WR equipment, providing a faithful and accurate timing source to the many element

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detector arrays of the CTA and KM3NeT, while at the same time upgrading WR to 10Gbps data transport capability. Because of this clear division, the decision was made to formally split this task, with J. Koelemeij of the VU heading the first sub-package (5.1a), and D. Berge of FOM the second (5.1b).

Task 5.1a has made excellent progress. No new hires were needed, which meant work could start nearly immediately. Discussions with SURFnet resulted in a choice of suitable hardware, after which amplifiers and lasers were ordered. Design rules for fibre-optic time distribution were defined, and a choice of wavelengths for the timing distribution meant that optical amplifiers could be assembled Deliverable D5.1 (General design rules for implementation in existing optical networks) was completed and submitted on time, and may in fact prove to be of real value for other network providers considering deploying this technology.

After a great deal of preparations (delay calibration, WR software modifications, part of deliverable D5.6) a laboratory setup with 100 km fiber spools was used to demonstrate a new and very precise dispersion delay measurement method. This will allow correcting for differential delays due to dispersion in existing fiber-optic links, needed to reach sub-nanosecond clock synchronisation over 250 km distances. This will be followed by a field trial. For the VLBI demo (deliverable D5.14), the frequency stability of WR needs to be improved by a factor 10-100. A lot of insight was gained in the noise properties of current WR, and first steps towards mitigation of the noise were taken through hardware and software modifications. These are important steps towards deliverable D5.4. A factor of 10 improvement is feasible, and a factor of 100 improvement seems not unrealistic. Performance tests of WR equipment inside a temperature-controlled chamber at JIVE/ASTRON are in progress (parts of deliverables D5.6 and D5.7).

Simultaneous transmission of an optical supervisory channel (OSC) signal and two additional wavelength channels for time and frequency transfer, all three advantageously making use of the OSC transmission band around 1510 nm of a DWDM system, was successfully demonstrated in a test setup at SURFnet. This method will be used to synchronize radio telescopes through SURFnet´s DWDM network along the path Dwingeloo – Assen – Groningen – Assen – Dwingeloo, for the VLBI demonstration later on during the project.

The Cleopatra postdoc at VU Amsterdam started working half-time for a VU spin-off company on the first of September 2016. This means he will continue working for Cleopatra for 6 more months, which will not cause any delays of the deliverables of the project. This has been discussed with and approved by the ASTERICS management.

Task 5.1b was slightly slower in the uptake, but also here good progress has been made. At Nikhef, an absolute time calibration procedure is being commissioned, and a document for discussion within the expert community (CERN White Rabbit) has been produced.

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For CTA, a calibration procedure has been written up, and a common CTA timing board is being tested in the lab. Field tests of this board at the HESS site in Namibia will follow soon, to check its performance in a real harsh environment.

Work at DESY has started up in June. A mid-size White Rabbit setup is being prepared, including GPS, Rubidium clock and White Rabbit switches. The lab tests are going well, and the installation at the first site will occur before the end of 2016. Hardware will be ordered soon and first test runs are anticipated before the end of this year.

Good progress is being made towards 10G capability for WR. A multifrequency WR protocol implementation is under development, which will help to parametrize the WR code. In order to support high bandwidth together with WR timing capabilities over the same optical link, DMA support of WR-ZEN nodes is being implemented.

UGR developed and completed gateware for WRCORE on Zynq devices, and is currently developing a Linux DMA driver for WRCORE. A scalability analysis of the White Rabbit technology for cascade-chain networks is being done, as is the setup of a new platform for 10G WRCORE.

Close contact is being kept between the two sub-tasks, in order not to re-invent any wheels. A Cleopatra-WR mail exploder was set up beside the general mail exploder, for technical discussion. A code repository was also created to facilitate the exchange of code between the various partners. A very well-attended WR workshop was organised in Amsterdam at NIKHEF, in March, involving many other groups also working on WR:
www.ohwr.org/projects/white-rabbit/wiki/Mar2016Meeting.

Several presentations were given by members of the CLEOPATRA team. The work in ASTERICS has received much attention in the international WR community, and many useful contacts were made.

1.2.5.2 Task 5.2: Multi Messenger Methods

The aim of this task is to develop standards for the generation, dissemination, distribution, and reaction to multi-messenger events. This will take the form of a design document, leading to software being implemented for one or two facilities (LOFAR & EGO). A demonstration is planned in which e.g. radio facilities follow-up an event generated by a gravitational wave detector. Part of the project is to investigate potential scientific synergies for implementing methods for automated follow-up observations.

The first task-wide telecon was held on the 15th of February 2016. Originally, CNRS and UVA were planning their contribution to start in 2017, however both decided to move this forward to early 2016, because of developments within LIGO and CTA. At the UVA, a postdoc has been

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hired in August, who will work on deliverable D5.11 (Scientific studies of transient event observing).

Unfortunately, the first task leader, appointed by ASTRON, could not find enough time to effectively lead the task. He was then replaced by another ASTRON staff member, who also found he had too many other obligations. Eventually, with the approval of the ASTERICS management and exec, the lead was handed over to JIVE (M. Kettenis). This however means the project suffered a delay, and deliverable D5.2, due in month 18, has been postponed until February 2017.

A telecon with all task participants was held in September 2016, leading to a basic work division to define the multi-messenger protocols for the first deliverable D5.2 (Multi-messenger alert handling design document). With all partners up to speed, further delays are not expected.

1.2.5.3 Task 5.3: Post-detection data streaming

This small task only involves the task leader, H. Verkouter. Activity in this task focussed on the definition of a high-level design and discussions with several NREN representatives with regard to protocol and architectures for a data transfer client. A number of high-bandwidth transfer tests were done between New Zealand and the Netherlands, using various commercial and non-commercial applications. A working e-transfer prototype was delivered as milestone M5.2. Currently, this prototype is being re-written from Python to C++, for added robustness and speed.

1.2.5.4 Task 5.4: Scheduling of large astronomical infrastructures

This task, led by P. Colome, will research how the SKA and CTA could maximise their science return with AI scheduling solutions. The programme will also incorporate multi-frequency, multi-messenger astrophysics at the scheduling level.

Also, this task got off to an excellent start, with their first face-to-face meeting in July 2015 in Barcelona. As the deliverables occur quite late in the project, intermediate milestones were defined. Several telecons were held, and a second meeting took place during the SPIE conference in Edinburgh in June 2016. Quite early on, it was found that GTD had to change their status from third party to full member. In spite of some problems with the EC portal, this was eventually accomplished.

An initial version of deliverable D5.9 (Report on scheduling algorithms for large infrastructures using subarrays and infrastructure for cross-facility scheduling) was prepared by the STFC

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team. Some changes were proposed during the meeting, in order to describe the main issues starting from a local solution dealing with subarrays to a global infrastructure dealing with cross-facility scheduling.

IEEC did research into AI technologies, showing that Genetic Algorithms perform far better than Neural Networks, by a factor of 4 – 5. An additional increase of efficiency with a factor of 1.5 could be achieved by the use of Multi-Objective Evolutionary Algorithms. Care is being taken to make sure the solution will not be only suitable for CTA. The constraints that are treated simultaneously are the maximum time allocated for on-source tracking, minimum time spent on slewing, maximum number of completed programmes and their relative priority. GTD has assigned a software engineer to the project in September 2016. A draft version of D5.9 will be ready before the end of 2016.

1.3 Impact

The information on expected impacts as described in the DoA is still relevant and up to date.

2 Update of the plan for exploitation and dissemination of results

The plan for exploitation and dissemination as described in the DoA is expanded and developed in the Exploitation Plan D1.1 and the Collaboration Plan D1.2. These plans are in the execution phase at the moment. There will be an update to these plans in M23 in D1.3 and D1.4. Progress on the execution of the current plans is described in the WP results (section 1.3.1.2).

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3 Deviations from Annex 1 & 2 of Grant Agreement

3.1 Deliverables

WP1 - AMST

Milestone 6: First AEAB evaluation + acceptance of annual reports.
At the 2nd AGA meeting on 11 February 2016 (month 10) a 9 month report had been presented, the AGA decided that Milestone M6 would only be completed after the report on the full first year had been approved. The first annual report was delayed over the summer holiday and officially approved during the 3rd AGA meeting in November. No project activity was impacted by the report delay.

WP3 - OBELICS

Deliverable D3.2 and D3.6.
The original plan aimed at three annual thematic meetings at months 12, 24, 36 and three annual WP3 general workshops at months 18, 30, 42. The thematic meetings were intended to inform the project partners on a specific WP3 related subject. Where possible, other communities and disciplines outside those covered by ASTERICS would be invited to the meetings.
In order to organize a successful thematic training event, all items had to be optimal: the definition of the subject, the preparation of the presenters and material, and the advertising invitations to partners and interested parties outside ASTERICS. When preparing the event in detail, all parties involved, the OBELICS partners as well as the ESFRI project offices and/or the ESFRI representatives in ASTERICS, concluded organizing the training for month 12 was too early to ensure the sought open innovation environment with industry and partners, due to the very early phase of the collaboration, where not all industrial participants were identified. Postponing the training event would allow to exploit the results of ongoing research on software libraries and resource requirements. The best option seemed to be to merge the "first OBELICS thematic training event" (D3.2, M12) with the first OBELICS general workshop (D3.6, M18). It was decided that off-line continuation of the preparatory work was needed, followed by a second face-to-face meeting in September 2016 in Madrid. Therefore, the combined training event and General workshop is organized for 12 – 14 December 2016 (M20) in Rome.

At the moment of writing the periodic report (this document) we can conclude that the meeting was very successful with about 90 participants, well distributed over research infrastructures and industry.

A logical conclusion was to merge the reports on both meetings, too. The report will be

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uploaded early in 2017.

Consequences: The integration of D3.2 and D3.6 will provide us with a series of invited talks, tutorials and panel discussions to address the challenges of D3.4, D3.5 and will also help in optimizing approach for D3.7, D3.8, D3.9 and D3.10. The integration will also serve as first step towards upgrading the software libraries in an open innovation environment with industrial collaboration. Therefore, we strongly believe the impact of the delayed deliverable D3.2 and its integration with D3.6 will prove to be beneficial for upcoming deliverables and it will bolster innovations in WP3 through collaborations with industrial participation along with partnering projects and consortia. D3.2 and D3.6 will also catalyze collaborative networking with partner H2020 projects, partner consortia and industry to work together in future common areas of interests which was also one of the scopes of the INFRADEV4 -4-2014/2015 call.

WP4 – DADI

In the preparation of the meetings related to D4.2 and D4.3, scheduling problems were encountered. Therefore, D4.6 was organized four months early.

WP5 – CLEOPATRA

D5.2: Multi-messenger alert handling design document
Task 5.2 suffered a delay because of problems with the lead of the task. This has been resolved, and apart from a delay of 4 months of deliverable D5.2 no further delays are to be expected. This delay will not impact other project activities.

In task 5.1b, the final definition of the exact implementation of the work at DESY took some careful considerations. As a result, the work itself has started a bit later than originally anticipated. However, as the 18-month contribution of DESY will still easily fit within the overall timeline of the project, this delay poses no threat to the overall timeliness of the project.

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3.2 Resources

First year hiring has advanced quite good despite of some unforeseen delays. Recruitment process at some of the partner institutes (UCAM, CNRS-APC, CNRS-IAP) has not been fully implemented. Hiring technical engineers proved to be a very difficult task due to the shortage of people willing to leave industry for public projects. This led to another challenge, which is to train non-specialists to the issues at hand in ASTERICS in general. It has also caused over commitment of leads at partner institutions.

At DESY, the person to work on task 5.1b was hired later than originally anticipated. However, as the 18-month contribution of DESY will still easily fit within the overall timeline of the project, this delay poses no threat to the overall timeliness of the project.

The financial resources used in the first 18 months of the project are just over 3.1 M€ (See financial report). This if roughly in line with the expected spending for this period. Now that most staff is in place, the partners estimate the cost at completion of the project to be close to the project budget. We will monitor this closely and implement corrections when needed.

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APPENDIX 1 Asterics External Advisory Board (AEAB)

The report of the ASTERICS External Advisory Board presented at Asterics General Assembly 2 on 11 February 2016.

Asterics External Advisory Board (AEAB) Report at Asterics General Assembly 2 11th February 2016

Jan Palouš

AEAB chair person

Czech Academy of Sciences Prague

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

1. AEAB recognizes that the project has made a positive start. Its leadership under Mike Garrett as Coordinator, supported by an experienced project management team at ASTRON and the project Executive seems strong. We noted the news that Mike will leave ASTRON for a new role and thank him for his effort in preparing and then establishing ASTERICS as a functioning project. We hope that the transition to a new project coordinator can be made smoothly.

2. The AEAB welcomed the detailed WP leader reports. They showed good progress with all early deliverables of excellent quality, submitted on time. The current underspending is due to delay with hiring of relevant staff in some areas. We urge the team to continue their efforts to reach the proposed profile of spendings. At an appropriate point (perhaps early in the project) it may be necessary to discuss a no-cost extension with the EC. The AEAB looks forward to continuing its oversight role through the process of annual or periodic reviews as the progress towards deliverables increases over the next 12 months.

3. AGA2 proved that much of the work is directly relevant to the implementation of ESFRI facilities, their exploitation and introduction to general public. However, the AEAB recommends to improve the direct visibility of ASTERICS activities by staff in the ESFRI projects. In particular for the technically-focused work packages that would be beneficial. This

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might be simply achieved by enabling wiki access or occasional participation in telecons or meetings. As they report on the excellent start being made by ASTERICS to their teams, the AEAB will assist with this process by identifying appropriate ESFRI project technical contacts (where required) and transmitting them to ASTERICS WP leaders. More generally, the AEAB welcomes the effort being made in external communication, and proposes to increase the visibility of various activities including ASTERICS workshops, schools and publicly accessible experiments.

4. The AEAB recommends to increase the contacts with other relevant projects. Their representatives should be invited to ASTERICS actions to enable cross-fertilization of separate fields and to increase the synergy with other scientific endeavors, industry and SMEs. While the ambition to aggregate new fields of interest and to go beyond the formally required deliverables is appreciated, the effort and timing should be carefully chosen

and not distract from the ramp-up of core activities.

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APPENDIX 2 TERMINOLOGY

A&A	Authentication and authorisation (or vice versa)
AARC2	Authentication and Authorisation for Research and Collaboration
ADASS	Astronomical Data Analysis Software and Systems conference
AEAB	ASTERICS External Advisory Board
AEB	ASTERICS Executive Board
AGA	ASTERICS General Assembly
ALMA	Atacama Large Millimeter/submillimeter Array
AMST	ASTERICS Management Support Team
Aladin	An interactive sky atlas
Aladin Lite	A lightweight version of Aladin running a web browser
ANTARES	Astronomy with a Neutrino Telescope and Abyss environmental RESearch project
APC	AstroParticule et Cosmologie
APPEC	AstroParticle Physics European Consortium
ASTERICS	Astronomy ESFRI & Research Infrastructure Cluster
ASTRON	Astronomisch Onderzoek in Nederland (The Netherlands' Institute for Radio Astronomy), coordinator
ASTRONET	Astronomy Network
ATOS	industry
CDS	Centre de Données astronomiques de Strasbourg (Strasbourg astronomical Data Centre)
CEA	Commissariat a l'energie Atomique aux Energies Alternatives, partner 12
CLEOPATRA	WP5: Connecting Locations of ESFRI Observatories and Partners in Astronomy for Timing and Real-time Alerts
CNRS	Centre National de la Recherche Scientifique, partner 2
CPPM	Centre de physique des particules de Marseille (Centre for particle physics of Marseille)
CREDO	Cosmic Ray Extremely Distributed Observatory
CTA	Cherenkov Telescope Array
DADI	WP4: Data Access, Discovery and Interoperability
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D-ANA	Data ANAlysis / Interpretation
DECS	WP2: Dissemination, Engagement and Citizen Science
DESY	Stiftung Deutsches ElektronenSynchrotron, partner 21
D-GEX	Data GEneration and information eXtraction
D-INT	Data systems INTegration
DoA	Description of Action
DOI	Digital Object Identifier
DWDM	Dense Wavelength Division Multiplexing
E-ELT	European Extremely Large Telescope
EGI	European Grid Infrastructure
EGO	European Gravitational Observatory
eMERLIN	e-MERLIN is an array of seven radio telescopes in the UK
ESA	European Space Agency
ESFRI	European Strategy Forum on Research Infrastructures
ESO	European Organization for Astronomical Research in the Southern Hemisphere
ESOF	EuroScience Open Forum
ET	Einstein Telescope
EST	European Solar Telescope
Euclid	ESA's Euclid space mission
EUDAT	Collaborative Pan-European infrastructure for research data
Euro-VO	European Virtual Observatory
EU-T0	European Tier 0 Data Research and Innovation Hub
EWASS	European Week of Astronomy and Space Science
FAU	Friedrich-Alexander-Universität Erlangen Nurnberg, partner 10
FFT	Fast Fourrier Transform
FITS	Flexible Image Transport System
FOM	Stichting voor Fundamenteel Onderzoek der Materie, partner 15
GA	Grant agreement
Gaia	ESA space observatory for astrometry
GPU	Graphics Processing Unit
GTD	GTD Sistemas de Informacion SA, partner 23
H2020	Horizon 2020, (8th) Framework Programme for Research and Innovation of the European Union
GW	Gravitational Wave

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GWS	Grid and Web Services WG
HDF5	Hierarchical Data Format (version 5)
HESS	High Energy Stereoscopic System (Cherenkov telescope array)
HiPS	Hierarchical Progressive Survey
HPC	high performance computing
HST	Hubble Space Telescope
IAP	Institut Astrophysique de Paris
IDG	Image Domain Gridding
IEEC	Institut d'Estudis Espacials de Catalunya fundacion, partner 16
IFAE	Instituto de Fisica de Atlas Energias, partner 17
IG	Interest Group
IHPCSS	International HPC Summer School
INAF	Istituto Nazionale di Astrofisica, partner 3
INFN	Istituto nazionale di fisica nucleare, partner 19
INTA	Instituto Nacional de Tecnica Aeroespacial (National Institute for Aerospace Technology), partner 6
IVOA	International Virtual Observatory Alliance
JIVE	Joint Institute for VLBI in Europe, partner 5
KM3NeT	Cubic Kilometre (km^3) Neutrino Telescope
LAPP	Laboratoire d'Annecy-le-Vieux de Physique des Particules
LIGO	Laser Interferometer Gravitational-Wave Observatory, USA
LOFAR	LOw Frequency Array
LPC	Low power computing
LSST	Large Synoptic Survey Telescope
M [nr]	Month or Milestone
MOC	IVOA Multi-Order Coverage map
MPE	Mass Participation Experiment
NVIDIA	industry
OAS	Observatoire Astronomique de Strasbourg (Strasbourg Astronomical Observatory)
OBELICS	WP3: Observatory E-environments Linked by common ChallengeS
OBSPAR	Observatoire de Paris, Third Party of CNRS
ORACLE	industry
OSC	optical supervisory channel

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OU	Open University, partner 9
PASA	Publications of the Astronomical Society of Australia
PDF	Portable Document Format
PLIBS	High Performance Computing software libraries (LAPP) in D-ANA software repository.
PLISA	Parallel Library for Identification and Study of Astroparticles (INFN) in D-ANA software repository.
RDA	Research Data Alliance
ROOT	Object-oriented program and library for data processing, born at CERN
SKA	Square Kilometre Array
STFC	Science and Technology Facilities Council, partner 20
SURFnet	SURFnet BV, partner 22
TAB	Technical Advisory Board (of RDA)
UCAM	University of Cambridge, partner 4
UCM	Universidad Complutense de Madrid, partner 18
UEDIN	University of Edinburgh, partner 7
UGR	Universidad de Granada, partner 14
UHEI	Ruprecht-Karls-Universität Heidelberg, partner 8
UNISTRA	Université de Strasbourg, Third Party of CNRS
UVA	University of Amsterdam, partner 13
Virgo	European Gravitational Observatory or EGO, Pisa, Italy
VLBI	Very Long Baseline Interferometry
VO	Virtual observatory, cf. IVOA
VOEvent	IVOA Sky Event Reporting Metadata
VU	Free University, Amsterdam, partner 11
WDS	ICSU World Data System
WG	Working Group
WP	Work package
WRE	White Rabbit Ethernet

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