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# The Virtual Observatory Ecosystem Facing the European Open Science Cloud

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## ABSTRACT

The International Virtual Observatory Alliance (IVOA) has developed and built, in the last two decades, an ecosystem of distributed resources, interoperable and based upon open shared technological standards. In doing so the IVOA has anticipated, putting into practice for the astrophysical domain, the ideas of FAIR-ness of data and service resources and the Open-ness of sharing scientific results, leveraging on the underlying open standards required to fill the above. In Europe, efforts in supporting and developing the ecosystem proposed by the IVOA specifications has been provided by a continuous set of EU funded projects up to current H2020 ESCAPE ESFRI cluster. In the meantime, in the last years, Europe has realised the importance of promoting the Open Science approach for the research communities and started the European Open Science Cloud (EOSC) project to create a distributed environment for research data, services and communities. In this framework the European VO community, had to face the move from the interoperability scenario in the astrophysics domain into a larger audience perspective that includes a cross-domain FAIR approach. Within the ESCAPE project the CEVO Work Package (Connecting ESFRI to EOSC through the VO) has one task to deal with this integration challenge: a challenge where an existing, mature, distributed e-infrastructure has to be matched to a forming, more general architecture. CEVO started its works in the first months of 2019 and has already worked on the integration of the VO Registry into the EOSC e-infrastructure. This contribution reports on the first year and a half of integration activities, that involve applications, services and resources being aware of the VO scenario and compatible with the EOSC architecture.

**Keywords:** Virtual Observatory, European Open Science Cloud, Interoperability, Distributed e-Infrastructures, FAIR principles, Open Science

## 1. INTRODUCTION

ESCAPE Work Package 4 *Connecting ESFRI projects to EOSC through VO framework* (CEVO, see also Sec. 2.2), plans to make the seamless connection of ESFRI and other astronomy and astroparticle research infrastructures to the EOSC through the Virtual Observatory (VO) framework. CEVO Task 4.1 (see Sec. 2.3) has been investigating and applying solutions to integrate data and service resources, based upon the IVOA architecture (see Sec. 3), into the EOSC (see Sec. 5) one.

Progress so far has worked out more easily on the technical side, where the technologies involved have proved to be compatible, like it is the case of integrating the IVOA Resource Registry (Sec. 6.1.1). The developments on other aspects have been slower due to the challenges of interfacing with the evolving structure of the EOSC platform, for instance for service provision (Sec. 6.1.2), or due to not-yet-provided features of the architecture, for instance for the integration of semantics and vocabularies (Sec. 6.1.3). Participation in relevant EOSC project events has been of great help in identifying interfaces and contacts to allow the integration activities.

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Connecting to other EOSC-related projects (activity done in connection with CEVO Task 4.2) allowed describing the Open and FAIR<sup>1</sup> approach, envisioned in the IVOA, to other research domains and to projects whose purpose is to define building blocks for FAIR data sharing. This helped with the clarification of concepts with respect to data policies, licensing, user identification and permission granting. These concepts are a major consideration when providing resources but should not impede the easy access to public data holdings that form the predominant case in astrophysics.

Task activities involved connections to the other ESCAPE Work Packages (see Sec. 7.1):

- to make available a portfolio of software and services through EOSC, also through containerisation (WP3 - OSSR);
- to contribute to the EOSC Hybrid Cloud with technical standard solutions for the ESCAPE Science Platform (WP5 - ESAP);
- also considering the need for this latter service to have a standardised access to the Data Lake solution (WP2 - DIOS).

The outcome of the investigations done during the first half of the project (that updates the initial report ADASS XXIX<sup>2</sup>) is analysed in Sec. 8 and the open questions and challenges in Sec. 9.

## 2. ESCAPE

### 2.1 Project Overview

ESCAPE (*European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures*)\* addresses the Open Science challenges shared by ESFRI facilities (SKA, CTA, KM3Net, EST, ELT, HL-LHC, FAIR) as well as other pan-European research infrastructures (CERN, ESO, JIVE) in astronomy and particle physics.

The investigated solutions shall:

- connect ESFRI projects to EOSC ensuring integration of data and tools;
- foster common approaches to implement open-data stewardship;
- establish interoperability within EOSC as an integrated multi-messenger facility.

To accomplish these objectives ESCAPE unites astrophysics and particle physics communities and their expertise in computing and data management in support of the FAIR principles. ESCAPE supports existing infrastructures such as the astronomy VO (represented by the EURO-VO coordination effort, Sec. 4) to connect with the EOSC. With the commitment from various ESFRI projects in the cluster, ESCAPE will develop and integrate the EOSC catalogue with a dedicated catalogue of open source analysis software and services developed by the astronomy and particle physics communities. Through this catalogue ESCAPE will strive to provide researchers with consistent access to an integrated Open Science platform for data-analysis workflows.

### 2.2 CEVO Work Package Description

Within the Work Packages (WPs) of the ESCAPE project, WP4 *CEVO – Connecting ESFRI projects to EOSC through VO framework* – is meant to:

- assess and implement the connection of the ESFRI and other astronomy Research Infrastructures to the EOSC through the Virtual Observatory framework;
- refine and further pursue implementation of FAIR principles for astronomy data via the use and development of common standards for interoperability including the extension of the VO to new communities, and

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\*<https://projectescape.eu/>

- establish data stewardship practices for adding value to the scientific content of ESFRI data archives.

ESFRI facilities from astronomy and astroparticle physics in the VO were already part of the collaboration between ESFRI pathfinders and European VO teams in the ASTERICS DADI (*Data Access, Discovery and Interoperability\**).

The CEVO objectives build on that background expertise to make the seamless connection of ESFRI and other astronomy research infrastructures to the EOSC through the VO, extending them by the inclusion of new partners in the wider context of ESCAPE, and the new opportunities provided by EOSC. CEVO aims to map the VO framework to the EOSC so that the VO enabled archive services from ESFRI will be interoperable. The diagram in Fig. 1, inspired by the EOSC-hub<sup>†</sup> data lifecycle, shows elements of the mapping of IVOA standards to different EOSC concepts in the lifecycle. The connection of the VO registry will be key for discovery and reuse, and other standard map to the access, deposition and sharing of data, as well as for data management curation and preservation. CEVO will also enable the implementation of FAIR principles for ESFRI data via the adoption and development of common standards for interoperability (with Task 4.2). Another CEVO Task (Task 4.3) will pursue the application of machine learning to add value to ESFRI archives and will identify best practices in data stewardship.

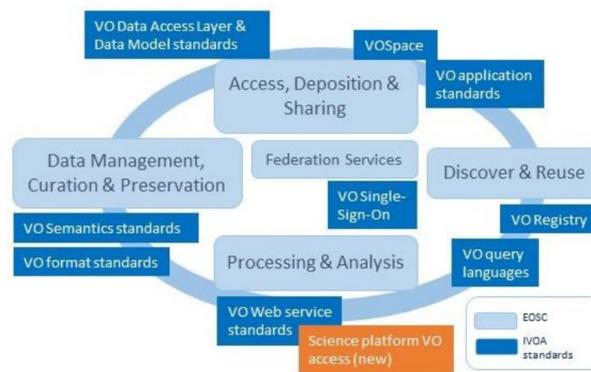


Figure 1. VO mapping onto the EOSC data lifecycle.

### 2.3 CEVO Task on Integrating the VO Architecture in EOSC

CEVO is focused on connecting ESFRI research infrastructures to the EOSC through the VO framework. Task 4.1 – *Integration of astronomy VO data and services into the EOSC* – is dedicated to identifying the relevant domain specific data access, discovery and manipulation standards and integrating them with the EOSC platform. To map the VO framework to the EOSC, attempting to include the VO enabled archive services from ESFRIs in the latter, task activities will focus on four main points:

- interfacing the VO framework with the EOSC;
- build an Astronomy portfolio of VO services;
- contributing to the EOSC Hybrid Cloud;
- containerising domain-specific services.

These integration areas have been defined into activities, reported in the CEVO Project Plan (ESCAPE Deliverable document D4.1<sup>3</sup>), and their progress is also summarised in an intermediate analysis report (ESCAPE Deliverable document D4.4<sup>4</sup>). This proceeding reports them to a larger community.

\*<https://www.asterics2020.eu/work-package/dadi>

†<https://www.eosc-hub.eu/>

### 3. IVOA

The International Virtual Observatory Alliance\* is an organisation, formed in June 2002, that focuses on the development of technological standards with the vision that astronomical datasets and other resources should work as a seamless whole. Its members are projects that embrace national level communities or super-national institutes or organizations. It currently has 21 members, plus a couple that expressed interest in joining.

The architecture<sup>5</sup> of the IVOA (briefly reported in Fig. 2) describes how the endorsed technical standards place themselves in the scenario of users searching for astrophysical resources, accessing them through interoperable, standardised interfaces while being helped by formats, languages, semantic description and models that are shared by the VO community.

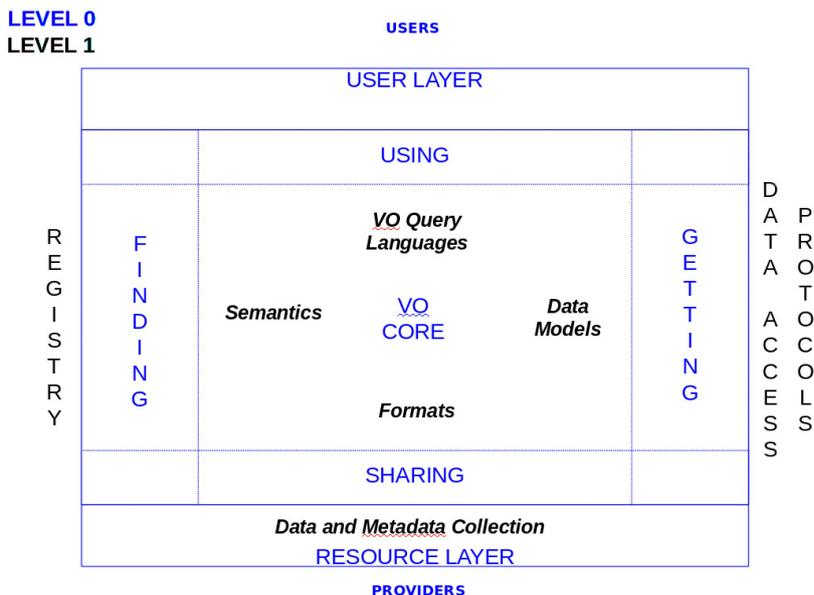


Figure 2. Levels 0 (black) and 1 (blue) of the IVOA Architecture superimposed. Users, on top, find the resources they need querying the Registry, once they have the description(s) of the relevant data and service they need for their analysis, they access them by means of interfaces defined by the access protocols. All of this is standardised by IVOA Recommendations that has a core of formats, languages, models and semantic annotations to make to process interoperable.

While the works of the IVOA started in 2002, the architecture itself shows quite clearly that the VO vision for astronomical resources embeds already the nowadays common concepts described in the FAIR principles (see Fig. 3).

### 4. EURO-VO

In Europe, the VO community got together at the beginning of the history of the VO and coordinated around a sequence of *EURO-VO*<sup>†</sup> projects up to the currently running ESCAPE project (partly presented in this contribution, Sec. 2.1). From the initial projects that touched directly one or another aspect of the interoperable scenario that was the goal of the overall activities, the VO effort in Europe became later a part of a larger cluster project that started to bring the VO expertise to other sibling communities: that was the case of the ASTERICS project and its Work Package DADI. Currently, the EURO-VO coordination is present with its members in ESCAPE and is leading the efforts in integrating the VO data and services within the EOSC.

\*<http://www.ivoa.net>

<sup>†</sup><http://www.euro-vo.org/>

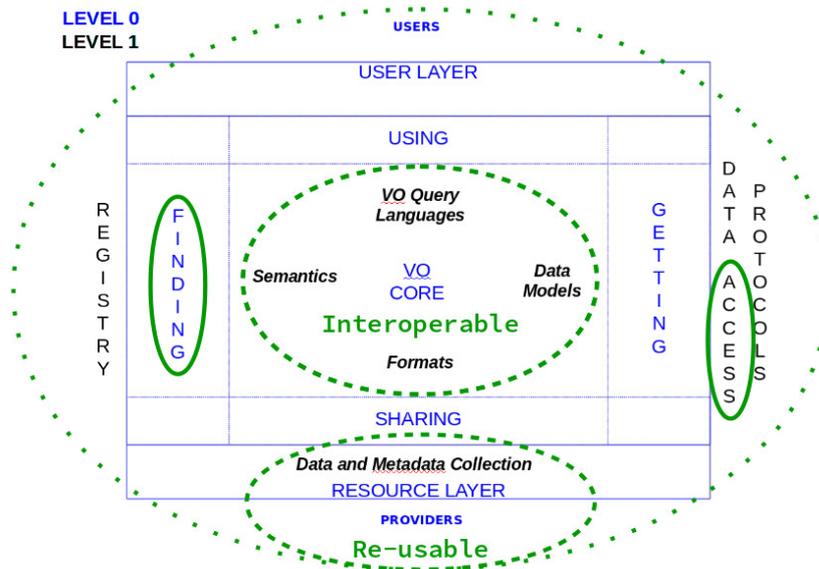


Figure 3. Areas of the IVOA architecture highlighted with respect to their support of the FAIR principles main concepts.

## 5. EOSC

The European Open Science Cloud (EOSC<sup>\*</sup>) is an environment for hosting and processing research data to support EU science.

The process to create the EOSC was initiated by the Commission in 2015. It aimed to develop a trusted, virtual, federated environment that cuts across borders and scientific disciplines to store, share, process and re-use research digital objects (like publications, data, and software) following FAIR principles.

The EOSC brings together institutional, national and European stakeholders, initiatives and data infrastructures to develop an inclusive open science ecosystem in Europe.

This can lead new insights and innovations, higher research productivity and improved reproducibility in science.

## 6. PROGRESS OF INTEGRATION ACTIVITIES

The activities described in this section have taken advantage of the networking activities, reporting and knowledge acquired by participating in relevant EOSC project events. Progress report is subdivided following the main activity blocks identified by the CEVO work plan; however, activities can be overlapping or cross the borders of the WPs themselves.

### 6.1 VO to EOSC Interfacing

This section is further subdivided in the several aspects of the interfacing of the VO with EOSC: the registry of resources, resource on-boarding, and semantics vocabularies.

<sup>\*</sup>[https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/open-science/eosc\\_en](https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/open-science/eosc_en)

### 6.1.1 Registry of resources

The first activity towards integrating the IVOA architecture within EOSC has been to test the compatibility of and then include the IVOA Registry of Resources in the EOSC service catalogue. This activity started immediately at the beginning of the ESCAPE project, with the identification of contacts to check the technical details and the compatibility of metadata models. Contact was established with B2FIND, and the resources of the IVOA Registry were then actually included into the B2FIND catalogue\*, taking advantage of the fact that the IVOA Registry of resources is OAI-PMH compliant. This activity is described in [2].

Reports on the relevant activity during the IVOA Registry Working Group sessions in the IVOA meetings are captured in the Milestones documents M20 and M21 of ESCAPE CEVO ([6] & [7]). The IVOA Relational Registry Schema standard interface (RegTAP [8]) proved to be an efficient tool for this task. The technical bases for B2FIND-IVOA interaction are the OAI-PMH transport protocol (already in use in both communities) and the DataCite metadata schema, which is an extension to the IVOA registry protocol. This extension is available on the GAVO (UHEI managed) full registry, which enabled the records to be harvested by B2FIND.

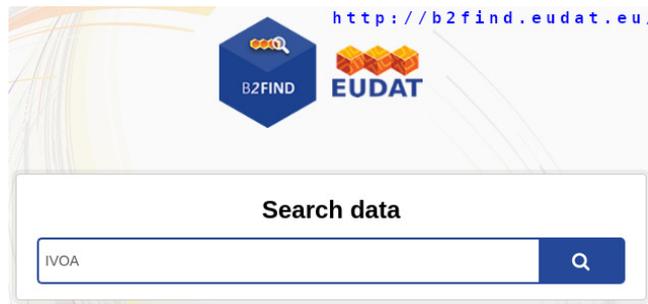


Figure 4. EUDAT B2FIND search box, initialised with a search using the term *IVOA*.

Figure 4 shows how to start a quick-look of VO resources within EUDAT. A simple search driven by the *IVOA* word yields the results page shown in Figure 5.

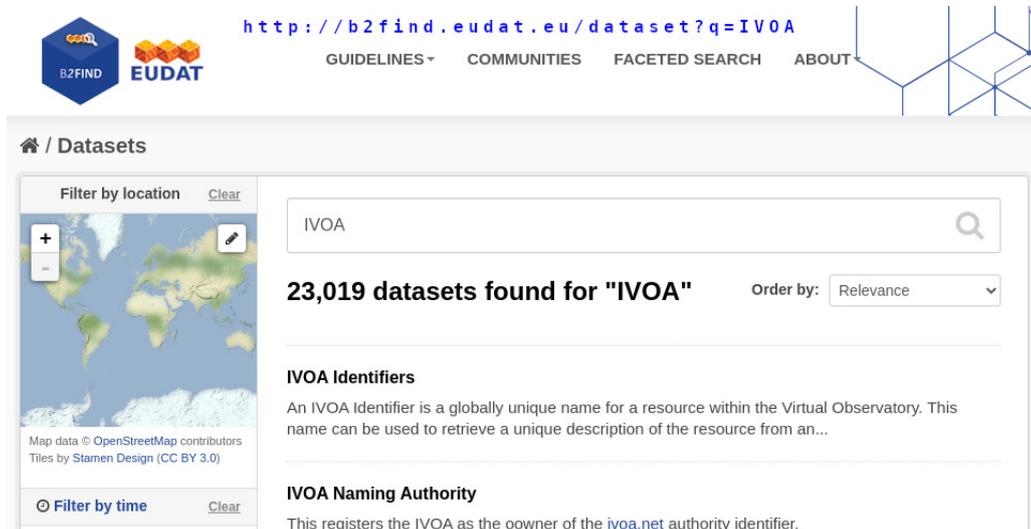


Figure 5. B2FIND *IVOA* results. The dataset count displays the actual content of the IVOA Registry at the moment the inclusion took place and the snapshot was taken.

\*This inclusion is visible at <http://b2find.eudat.eu/group?q=ivoa> (or <http://b2find.eudat.eu/group/ivoa>), and illustrated by Figures 4, 5, 6 & 7.

The plain result listing of the IVOA Registry content in B2FIND shown in Fig. 5 can then be filtered by features, that are taken from the metadata elements of the resources description. As shown in Fig. 6, the mapping of the metadata content between VOResource metadata and B2FIND metadata works well on the high-level description (*Publisher* or *Keywords* in Fig. 6) but starts to be less informative the more one enters into the domain specific details (e.g., *ResourceType*).

Feature	Value	Count
Keywords	Galaxies	3521
	Stars	3503
	Photometry	3079
	Photometry wide band	2709
	Spectroscopy	2346
	Velocities	2148
	Stars variable	2099
	Redshifts	1905
	Abundances	1616
	Open_Clusters	1329
Publisher	CDS	20147
	NASA/GSFC HEASARC	1064
	NASA/IPAC Infrared ...	490
	The GAVO DC team	198
	Space Telescope Sci...	119
	WFAU, Institute for...	119
ResourceType	AstroObjects	1648
	AstroImage	290
	Spectrum	117
	AstroData	89
	SpectralLines	3
	StillImage PRESERVE...	1

Figure 6. The leftmost panel shows the features that B2FIND allows filtering upon. The other three panels, Keywords, Publisher and ResourceType, show the available values for each of the three features expanded (including the count of resources for each value).

The filtering applied by B2FIND resembles the basic requirements answered by the IVOA Registry – the fact that the metadata schema of the IVOA Registry includes the Dublin Core is an asset in that respect – but does not allow for the subsequent machine-actionable interaction that the standardised interfaces provided by the IVOA standards allow. This is, of course, a known barrier when matching domain and general purpose repositories, because the depth of insight given by the descriptive metadata depends a lot on the semantic content of the metadata documents. Part of this is taken into account by the Metadata Access direct reference to the IVOA Registry full record (Fig. 7).

### Michigan Catalogue of HD stars, Vol.4 (Houk+, 1988)



Please refer to the "adc.txt" file by Wayne H. Warren Jr.

Spectral\_Classifica...

Identifier	
Source	<a href="http://cdsarc.u-strasbg.fr/cgi-bin/Cat?III/133">http://cdsarc.u-strasbg.fr/cgi-bin/Cat?III/133</a>
Metadata Access	<a href="http://dc.g-vo.org/rr/q/pmh/pubreg.xml?verb=GetRecord&amp;metadataPrefix=oai_datacite&amp;identifier=ivo://CDS.VizieR/III/133">http://dc.g-vo.org/rr/q/pmh/pubreg.xml?verb=GetRecord&amp;metadataPrefix=oai_datacite&amp;identifier=ivo://CDS.VizieR/III/133</a>

Figure 7. B2FIND, single resource description. The Identifier metadata shows the Metadata Access that connects to the IVOA Registry content.

Further work towards cross-disciplinary integration has involved a study of cross domain user stories for resource discovery. The latter is a challenging task, which is not directly included in the ESCAPE work plan and its follow up will depend on potential connections to other cluster projects.

### 6.1.2 Service on-boarding

Besides proving the technical feasibility of integrating the IVOA Registry content within the base repository structure of EOSC, our activities have also started to compare the concept of service onboarding, as described by EOSC, with the IVOA scenarios for service description and the deployment architecture. The *Adding a service to EOSC\** report, presented at the CEVO Technology Forum 1 by André Schaaff (CNRS-ObAS), was a first attempt in this direction. It was used to report the experience in the EOSC-Enhance survey. While continuously checking on the EOSC updates about service onboarding, for instance in the EOSC-Hub Week 2020 report<sup>†</sup>, a further attempt will be made through cross-project connection with H2020 NEANIAS<sup>‡</sup>.

### 6.1.3 Semantics

Another set of resources to be tested for inclusion in the EOSC services are the IVOA-standardised semantic vocabularies<sup>§</sup>. The activity of checking how this integration could be done has already started, however progress on the EOSC side is currently not defined well enough to provide a clear connection at this stage of the project.

## 6.2 VO Service Portfolio

This sub-section reports on the status of activities for actually providing resources to create a portfolio of services dedicated to astronomy within the EOSC. These activities are at an early stage, given the complexity of the EOSC architecture. The EOSC-Hub Week 2020 showed an inclusion plan for national, cluster and domain managed repositories. In CEVO we are following the evolution of that harvesting scenario while keeping awareness of other astronomy efforts, like the Europlanet VESPA containerised solution using the DaCHS resource and service software. The idea of operating a custom marketplace for astronomy is probably better pursued in connection with ESCAPE WP3. This solution will be followed up.

## 6.3 EOSC Hybrid Cloud Contribution

Another activity meant to integrate the VO architecture with the EOSC is through the federation of Research Infrastructure (RI) and connecting them to the EOSC itself. Here, the work has progressed in connection with ESCAPE WP5 ESFRI Science Analysis Platform in two main directions. On the one hand the UEDIN partner who leads the interactive data analysis work in WP5, is developing components to discover and access data analysis facilities based on agreed standardised APIs between the facility providers. To do so they are working on developing use cases, notebooks and containers for the WP5 platform. Specific requirements for astrophysics sub-domains (time domain, radio astronomy, ...) are collected and worked upon by all WP4 partners. On the other hand work is progressing for a possible implementation of the IVOA VOSpace standard [9], the IVOA interface to distributed storage, to contribute as a service to the ESCAPE/EOSC Cloud solution, possibly on top of the ESCAPE Data Lake (WP2). A solution has been identified, both by INAF and UEDIN, to test VOSpace on top of RUCIO. It will be discussed with WP2.

## 6.4 Service Containerisation

A final activity taken up to integrate and contribute to the EOSC cloud investigated the containerisation of web applications and other VO software to be integrated into the ESCAPE software repository. This activity will see a follow-up with WP3 Open-source scientific Software and Service Repository, and the harmonisation of these containers with the science platform will see an interaction among WP4, WP5 and WP2 in the second half of the project.

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\*<https://indico.in2p3.fr/event/20005/#18-adding-a-service-to-eosc>

†<https://www.eosc-hub.eu/eosc-hub-week-2020/agenda/service-onboarding-catalogue-services>

‡<https://www.neanias.eu/>

§<https://ivoa.net/rdf/>

## 7. PROJECT INTERNAL & EXTERNAL INTERACTIONS

### 7.1 Internal Cross-WP Interactions

Progress on the integration activity described above has involved building connections between the WPs of the ESCAPE project.

Activities led to provide software packages and services to the community through a FAIR repository solution, which complement CEVO Task 4.1 to connect services directly to EOSC through the VO, are managed in ESCAPE WP3 Open-source scientific Software and Service Repository. Task 4.1 got in connection with WP3 to contribute requirements to the ESCAPE repository. That repository, as shown during the EOSC-Hub Week 2020 (Fig. 8), should flow into the general EOSC repository. The WP3-WP4 collaboration should facilitate the contribution of VO resources to the ESCAPE repository and requirements gathering on media type annotations from the VO scenario.

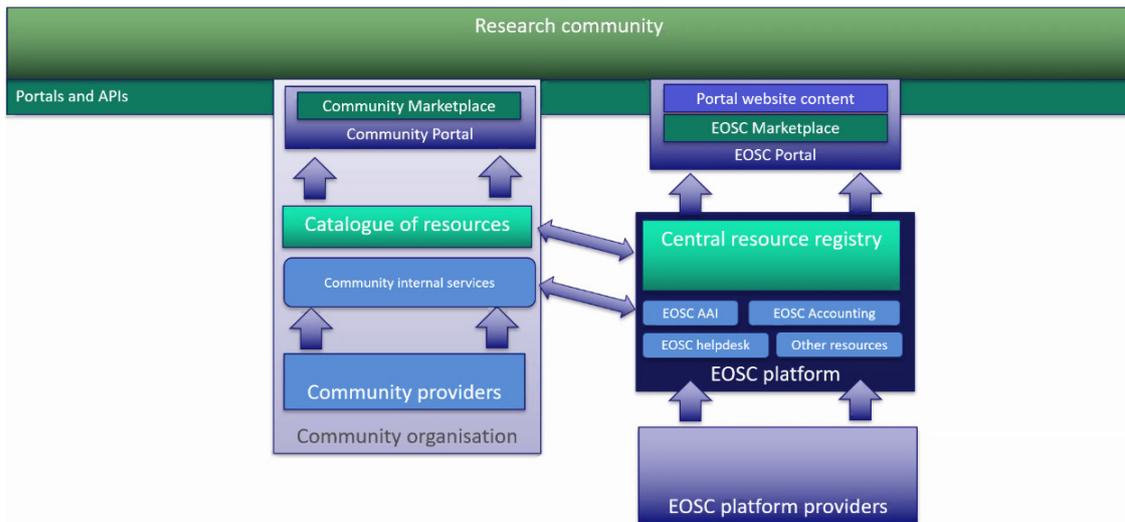


Figure 8. EOSC architecture's foreseen catalogue integration. O. Appleton presentation at the EOSC-hub Week 2020.

Another point of connection is between CEVO EOSC integration activities and WP5 on containerisation and hybrid cloud contributions. On the CEVO side this means porting IVOA derived technologies and having astronomy RIs implement or use them, while on the WP5 (ESAP) side it touches the integration of the Science Platform with the data resources. A specific aspect connected to this integration is the discussion of the AAIs (Authentication and Authorization Infrastructures) and how they affect the existing landscape of VO resources and services. Discussions held during the CEVO Technology Forum 1 and the ESCAPE Progress Meeting proved useful not only to make the above connections clear, but also to understand how the ESCAPE efforts in federating its RI resources could connect with the EOSC platform.

### 7.2 Interactions with EOSC-related Projects

In addition to connecting internally with other ESCAPE WPs and following the evolving FAIR best practices (e.g. through the RDA FAIR Data Maturity Model WG), our activities for integrating the VO expertise within the EOSC landscape have also involved the interaction with other EOSC-related projects, particularly FAIRsFAIR and FREYA.

Mark Allen (CNRS-ObAS) is one of FAIRsFAIR Champions. He participated actively in the Second FAIRsFAIR Synchronisation Force Workshop, which was held as a series of sessions in April-June 2020, during which he represented ESCAPE. The meeting was aimed at identifying the on-going activities related to the Action Plan of the “Turning FAIR into Reality” report, and to identify gaps and possible additions to the Action Plan. Another FAIRsFAIR activity in which CEVO participated actively is the two workshops on metadata catalogue

integration (9 September and 11 October 2020), and its follow-up DDI-CODATA Workshop (20 November 2020). This allowed us to explain the IVOA metadata framework, and to participate in the discussion on the possible generic solutions and how disciplinary frameworks could interface with them.

CEVO participated in a meeting organised by FREYA on persistent identifiers in research disciplines (5 August 2020), which allowed us to present the way the IVOA defines and uses identifiers.

One also has to cite here the active participation of CEVO in the tests and discussions of the RDA FAIR Data Maturity Model. The tests were performed jointly by Task 4.1 and Task 4.2: they enabled an assessment of how the IVOA framework was aligning with the proposed RDA Maturity Model and to identify discrepancies. The conclusion is that we can live with the maturity criteria, but that there are issues with the priorities: in particular, there is no “Essential” priority on Interoperability, whereas it is an essential element for astronomers, hence in the VO. The tests and the conclusions from them, were reported during the Technology Forum and the IVOA meeting in May 2020. This work brings useful information for the integration of the VO-enabled resources in EOSC, since the FAIR Metrics proposed by the EOSC FAIR WG are a subset of the RDA FAIR Data Maturity Model.

Attendance at the EOSC related meetings has been valuable both to showcase astronomy interoperability solutions, to present the developing astronomy requirements for EOSC, to understand the requirements and solutions from other research domains, and to get knowledge of the work performed by other projects and how astronomy could fit in.

## 8. ANALYSIS OF THE INTEGRATION STATUS

Considering the progress shown in Sections 6 and 7.1, the integration of the IVOA-based open architecture of standards for astronomy into the connected ecosystem of data resources and services in the EOSC is identified as being mostly feasible, but there are still challenges that need to be tackled to actually bring this integration to a mature level.

A definitely positive conclusion regards the high level description of data holdings and browser based services, leveraging the heritage and work of communities like the Open Archive Initiative, foundations like DataCite, DOI, ORCID and similar. The careful initial choice of the IVOA community to base its registry of resources on the generic OAI-PMH protocol, and to include the Dublin Core as mandatory elements of the metadata schema, has made it relatively simple to map the basic annotations and concepts of the IVOA into metadata models and universal identifiers. This made feasible the integration of the IVOA Registry into the EOSC repository provided by EUDAT that also relies on OAI-PMH and DataCite.

The challenge is more on the machine actionability of the discovery and access services attached to the data resources. The VO Registry uses standardised URIs to annotate the standard interfaces as well as to identify the relationships among resources. It has discipline-specific metadata for the coverage (e.g., in spatial and temporal coordinates) and scope of the data resources. EOSC, being the portal environment meant to be more general and abstract in terms of research domains, has a more abstract approach to data access and thus makes it difficult to reproduce the machine actionability level available in the IVOA. On the other side, IVOA, having developed its own URI schema for identifiers (IVOID) lacks somewhat on the take up of more general identifiers for its resources, i.e. the DOI nowadays more commonly used (although DOIs are commonly implemented by data providers, in particular for citation in publications). Another example of a difference emerging from the domain versus general repository behaviour are the tessellation solutions (HiPS [10] and MOC [11] IVOA standards, based on HEALPix) provided by the VO for sky positional and time coverage of the observations. Those are a valuable support in filtering the growing number of registered available resources and could be a technical feature to be reported alongside the other metadata also in a general portal solution like the EOSC one, being the natural counterpart of the geolocation of general web or earthbound resources.

A more challenging integration task has been comparing the user authentication and authorization (A&A) solutions available within the astrophysical community and the interface architectures made available by the projects developing the EOSC.

On the one hand, the standardisation efforts within IVOA regarding A&A have not seen a high level of implementation. This is due to the public approach to data and service delivery that represents the majority of

VO registered holdings, as well as to the lack of a safely funded, globally operating identity provider. Moreover, IVOA standards, and VO contents consequently, deal more with resource filtering, operations on catalogues (i.e. metadata annotated listings of astrophysical sources) and direct access to datasets, with a relatively minor support for providing computing operations. This means that, besides being only partially concerned by data access policies because of the public data and resources approach, the VO community has, up to now, not been concerned with accounting, because storage and computational resources made available to provide astrophysical data holdings for the community are usually enough to make them available and usable.

On the other hand, FAIRness and Openness requirements in the VO architecture were, since the beginning, answered by interface protocols that were meant to be machine consumable. Thus the A&A stress was more on the credential delegation technical aspects than the actual identification of the user and the permissions given to them.

For these reasons, the AAI (Authentication and Authorization Infrastructure) solutions being developed by the EOSC projects were initially not well aligned with the requirements of the VO data providers: because on the one hand they pointed towards a licensing system where the only possible solution for most heritage data was a plain CC-0 (and that also felt difficult to attach in some cases), and on the other hand they lacked the machine actionability that full credential delegation would allow.

Things have progressed in that respect since the start of the ESCAPE project, which can be seen by comparing the outcomes of EOSC Symposium (November 2019)<sup>1</sup> with those of the EOSC-Hub Week 2019 (April 2019)<sup>2</sup> on the AAI aspects. Convergence and interoperability of the main A&A solutions provided by the EOSC services (EGI Check-In, EUDAT B2ACCESS, GEANT eduTEAMS) has been provided to the benefit of the users. First discussions and awareness of machine-to-machine credential delegation were raised.

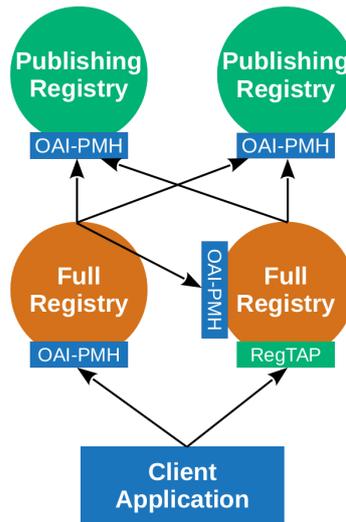


Figure 9. IVOA Registry ecosystem: publishing, harvesting, cross-domain interoperability and domain specific interface solutions.

There is also a difference in the way data resources and services are included in the VO Registry (and thus made available to VO-aware users and tools) with respect to what happens currently in the EOSC onboarding scenario. On the IVOA side a data/service provider has to be aware of the available typed-resources and how to describe them. The steps to perform then to publish a resource can be summarised as:

- identify (or implement) a publishing registry and create an authority resource in it. This means providing an identifiable (it will have its own IVOID) root resource under which all the resources provided will be placed and could be uniquely identified by their ID;

- generate the appropriate (VO)Resource descriptions for its data collections and services and publish them through the registry.

The publishing registry, exposing its OAI-PMH interface, will be harvested by the full registries that form the actual resource repository known as the IVOA Registry. The data collections and services are made available to the VO community when the publishing registry is harvested. The above steps can be fully automated and human interaction is more on the operational side to check the health status of the Registry as a whole, following up on corrupted records, invalid resource descriptors, and unreachable resources.

Figure 9 illustrates the way the IVOA Registry works. It shows how the OAI-PMH interface allows for resource harvesting among the different registry instances and how the dedicated RegTAP solution can be used by applications (and proves more actionable). RegTAP [5] defines an interface for searching the resource metadata stored in the registry using the IVOA Table Access Protocol. The same RegTAP interface is the one that facilitated the IVOA Registry mapping to the B2FIND repository.

On the EOSC side, the service onboarding solution is based on human interaction through web forms and contact points until the resource/service is validated and released through the portal.

This difference might be a temporary one while EOSC tools and architecture become more mature. It cannot be considered a challenge from the technical point of view because, as reported above for the registry integration, the metadata models and FAIR approach are comparable. It is, however, a potential hurdle which could produce a slower take up of astrophysical resources within the EOSC ecosystem when progress will have been made on the service onboarding in EOSC.

Another challenging difference between the VO landscape and the EOSC proposed architecture is related to how service provision is handled.

On the IVOA side, the contribution of data collections, services and other resources, is provided by the deployment of resources and services following the agreed standards (and often by autonomous systems). This leads to an ecosystem where the validation of the deployed resources in the VO is an operational activity focusing only on providing reliable resources to the end user.

In the EOSC architecture, where the governance is different, the data providers have to go through a different process, where metadata standards and interfaces are not automatically a means of creating an interoperable solution, and thus the onboarding process fills this gap by a preliminary validation of the resources that tends more to a preservation of the content and access points to information holdings, rather than being a check of actionable interoperability.

The challenge here is to find a way to automatise as much as possible the on-boarding process for a resources that are already registered in the IVOA, to reduce the amount of additional effort required on the providers side: the domain-specific technical one for the VO landscape, the general-purpose EOSC repository controlled validation on the other.

Last but not least important, a topic where integration is required is the interpretation on the FAIR principles applied to data resources and services already living in the VO landscape. This is an activity that crosses borders in CEVO between tasks 4.1 and 4.2 and a direct connection to FAIR initiatives at the EOSC, but also global, level. The IVOA vision, which has been developed starting in 2001-2002, was already following the FAIR principles, since its aim was to enable astronomers to find, access and interoperate data, a reuse capability being provided by the usage of a common format including data and metadata, and to provide seamless access to astronomical resources. of the concept of openness of data resources and services and always worked keeping in mind machine actionable interoperability. It can be seen from the IVOA architecture schema shown in Fig. 3. IVOA developed a disciplinary framework of FAIR practices which fulfils the community science needs but does not follow step by step all the fine grained details of the FAIR principles, as for instance defined in the RDA FAIR Data Maturity Model [12]. The activities to be brought on, in connection to EOSC and the other EOSC-related project will require testing the VO FAIR-ness with respect to EOSC FAIR Metrics and to continue on the work already started for the RDA FAIR Data Maturity Model.

## 9. NEXT STEPS

The integration of the VO architecture into the EOSC seems not an impossible task. Still it requires to tackle a few challenges that are currently discussed within the EOSC development bodies and projects.

From the point of view of the astrophysical community the main concern seems to be about how the existing machine-actionable and data providing semi-automated solution can be replicated in the EOSC without having to duplicate efforts in management and research technologies.

The effect of facing a multi-disciplinary environment has proven a challenge mostly because the astrophysical community concentrated on its science needs with respect to data sharing and reuse, which led it to skip hurdles like the authentication and authorization of users to access discovery and retrieval service. This allowed for a direct path in maturing a re-usable and interoperable paradigm of the VO that consequently brought into its architecture the findability, accessibility and interoperability aspects, thus completing the FAIR principles scenario in an operational framework at an early stage.

Within ESCAPE, considering the progress made so far, the goal for the second part of the project would be to investigate a solution for ESFRIs and RIs within the EOSC (and/or a domain specific, ESCAPE provided, cloud) to build their data resources and services adopting a VO aware vision and, as seamlessly as possible, find those same resources available in EOSC itself and able to use the other resources provided within the EOSC such as computing resources.

To do so the challenges to tackle are currently the following:

- attach data holdings to resource descriptions (not only PIDs for metadata);
- provide relationships among data resources and attached services;
- test, and make easier, the integration of VO-enabled data providers managed resources in the portal;
- deal with current AAI services and solution without preventing public content access;
- work at providing actionability for domain specific services and annotations through the EOSC portal;
- evaluate the position of VO-enabled data with respect to EOSC FAIR Metrics.

All the above challenges, building on the activities reported in this deliverable, will be tackled during the remaining part of the project. How far they proceed will depend on the actual status of the EOSC development and finalisation, and on the amount of resources necessary with respect to the tasks to perform.

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