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Report on the United Nations/Italy Workshop on the Open Universe initiative

(Vienna, 20–22 November 2017)

I. Introduction

1. The Office for Outer Space Affairs of the Secretariat has the mandate to promote international cooperation in the peaceful uses of outer space and to assist Member States with capacity-building in the use of space science, space technology and space applications. For that purpose, the United Nations Programme on Space Applications, implemented by the Office for Outer Space Affairs, was established in 1971.

2. The United Nations Programme on Space Applications soon recognized that activities related to space science and access to astronomical facilities and data could offer a cost-effective, entry-level path for capacity-building and science and technology education. To that end, the Basic Space Science Initiative was launched in 1991. Since then, the Programme has implemented a series of activities and projects related to basic space science.

3. The Italian Space Agency (ASI) has a long-standing history of contribution to space science and applications through national and international programmes. In line with the mission and goals of the United Nations, ASI shares the vision of open data as a driver for knowledge and development.

4. Working together with ASI, the Government of Italy proposed the Open Universe initiative at the fifty-ninth session of the Committee on the Peaceful Uses of Outer Space, to be established under the auspices of the Committee and under the leadership of the Office for Outer Space Affairs in close cooperation with the Government of Italy (see A/AC.105/2016/CRP.6).

5. The Committee welcomed the proposal and agreed that the initiative would be included in the preparations for the fiftieth anniversary of the United Nations Conference on the Exploration and Peaceful Uses of Outer Space, in 2018 (UNISPACE+50) (A/71/20, para. 299). UNISPACE+50 will be a dedicated segment of the sixty-first session of the Committee. The Open Universe initiative is part of thematic priority 7 of UNISPACE+50, on capacity-building for the twenty-first century.

6. The present document contains a summary of the outcomes and recommendations of the United Nations/Italy Workshop on the Open Universe initiative, held in Vienna from 20 to 22 November 2017.

A. Background and rationale

7. In the space science domain, various organizations in the past decades have developed sets of standards and good practices that are widely used in the scientific community. The organizations involved in such development include the Flexible Image Transport System Working Group of the International Astronomical Union (IAU), the International Virtual Observatory Alliance (IVOA), the International Planetary Data Alliance, the Planetary Data System of the National Aeronautics and Space Administration (NASA), the Virtual Solar Observatory and, with a focus on interdisciplinary standards, the Research Data Alliance.

8. In recent years, several initiatives have also developed interactive, user-friendly platforms in order to provide access to products and services in astronomy, demonstrating an evolution towards a more transparent and inclusive ecosystem of tools and services.

9. Generally speaking, education in astronomy and space science has a demonstrated record of developing capacity in science and technology and in promoting rational thinking and the scientific method. Furthermore, the study of the universe has the potential to inspire both scientists and the general public alike, and outreach projects in educational institutions, planetariums, observatories and museums cater to this growing interest among the general public.

10. In addition, the number of citizen scientists and citizen science projects associated with astronomy and space science is increasing, and each one has different requirements. As a result, there is a growing public need for personalized services, including services accessible to mobile devices, a fact which may influence the evolution of data services in those domains.

11. Efforts are necessary to dramatically increase the use of space science data, in order to satisfy the needs of not only those target groups, but anyone interested in astronomy and space science. In merging project data from providers with both the data-delivery capabilities and the creative power afforded by the Internet, the potential of scientific discovery for research, education and inspiration could be made available to all humankind.

12. Recognizing those needs, the United Nations intends to take an active role in the promotion of open data-sharing arrangements, which will also serve as a way to connect with new and upcoming players in the field of space science around the world, including developing nations and emerging space actors.

13. In order to define the scope of the initiative, the following series of events was organized:

(a) Open Universe legal aspects panel, 30 March 2017, Vienna;

(b) Expert meeting on the Open Universe initiative, 11 and 12 April 2017, ASI headquarters, Rome;

(c) Briefing on the status of the Open Universe initiative and call for support, 13 June 2017, Vienna;

(d) United Nations/Italy Workshop on the Open Universe initiative, 20–22 November 2017, Vienna.

14. The initiative is in line with UNISPACE+50 thematic priority 7, on capacity-building for the twenty-first century. Ties are also established with Sustainable Development Goal 4 (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all) by further advancing knowledge and increasing the level of sharing of scientific discoveries among user communities in all parts of the world. In addition, the open-source philosophy and the proposed collaborative approach in the development of the platform are aligned with thematic priority 1, on the global partnership on space exploration and innovation. Finally,

access to planetary science data, including on solar activity, could tentatively support thematic priority 4, on the international framework on space weather services.

B. Objectives of the Workshop

15. The main objectives of the United Nations/Italy Workshop on the Open Universe initiative were as follows:

(a) Review the status of current initiatives in space science with regard to data sharing, including lessons learned and ongoing activities;

(b) Promote the universal adoption of established standards and good practices in the field of astronomy and planetary science, and of the FAIR (Findable, Accessible, Interoperable, and Reusable) principles in data sharing;

(c) Discuss the long-term sustainability of astronomy and space science data archives as an enabler for the robust provision and preservation of science-ready data and its links to UNISPACE+50 thematic priority 7, on capacity-building for the twenty-first century, and in the implementation of Sustainable Development Goal 9 (Building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation);

(d) Examine the opportunities for education and capacity-building in the field of space science data, linked to thematic priority 7 and Sustainable Development Goal 4;

(e) Exchange views on the design of a strategy to satisfy in a timely fashion the various requirements of an ever more diverse clientele, and on any expansion plans needed for service provision;

(f) Explore the potential to foster citizen innovation through open access to science-ready, astronomical data, and, in that regard, discuss the coordination of the international efforts of providers of space science data on the basis of a set of criteria on ease of access, quality, robustness, transparency, completeness and timeliness;

(g) Discuss the way forward, building upon these objectives and upon related capacity-building and international cooperation activities, in preparation for UNISPACE+50.

C. Attendance

16. The Workshop was organized by the Office for Outer Space Affairs and, on behalf of the Government of Italy, ASI. In meeting the objectives, the Workshop brought together experts from the space science and astronomy sectors, as well as decision makers, educators, practitioners and other end users to discuss the most recent advances in and methods for accessing and utilizing space science and astronomy data.

17. The Workshop was attended by 92 experts, professionals and end users from the following Member States: Argentina, Armenia, Australia, Austria, Azerbaijan, Brazil, Bulgaria, Canada, China, Colombia, Costa Rica, Ecuador, France, Germany, India, Iran (Islamic Republic of), Italy, Kenya, Mexico, Nigeria, Russian Federation, Spain, Switzerland, Turkey, United Kingdom of Great Britain and Northern Ireland and United States of America. Participants represented 47 national, regional and international organizations, including agencies and organizations of the United Nations system, the space community, academic institutions, private companies and non-governmental organizations.

II. Programme

18. The co-organizers developed the programme of the Workshop with the support of a programme committee composed of experts in the field of astronomy and space science. The programme included opening remarks by the Permanent Representative of Italy to the international organizations in Vienna, the Director of the Office for Outer Space Affairs and the President of ASI, followed by two keynote presentations, one by each of the original proponents of the Open Universe initiative, from ASI and the University of Sheffield, United Kingdom. Furthermore, there were five technical sessions, a technology demonstration session, a poster session, splinter group and plenary discussions, a final round table to discuss the way forward and closing remarks.

19. The keynote speaker from ASI gave an overview of the status of the Open Universe initiative, providing information on the foundation and principles of the initiative and the main motivation for it. The initiative is aimed at reducing the barriers to data access and, ultimately, at fostering the knowledge that can result from such access. The operation of the initiative needs to take into account the existing infrastructure and networks, such as IVOA, in order to best contribute to the achievement of the Sustainable Development Goals. The speaker gave a brief introduction to the prototype web portal under development at ASI, in order to illustrate how a multi-discipline facility can increase the level of transparency and openness in space science data. That prototype was later demonstrated in the demonstration session.

20. The keynote speaker from the University of Sheffield discussed the potential of the Internet in all aspects of life and explained how the astronomy community would benefit from using modern tools to reach a larger number of people. The speaker gave a historical perspective of the evolution of good practices for archiving, from the database of the European X-ray Observatory Satellite (EXOSAT) in the 1980s, to the future Large Synoptic Survey Telescope Science Platform, which will include the use of social media for promotion and outreach. He argued for the involvement of a larger user base in the work of scientific discovery.

21. The contents of the Workshop presentations and discussions, as summarized by the rapporteurs of each session, are contained below. The presentations are available online at the website of the Office for Outer Space Affairs.

A. Current status and perspectives in space science data

22. The first session of the Workshop was dedicated to a review of the existing space and ground facilities in the field of space science and astronomy. Data archives and services and infrastructures for data dissemination were emphasized. Speakers representing major space agencies and national and international organizations presented the status of activities in the field.

23. The Head of the Data and Engineering Division at the European Space Astronomy Centre (ESAC) of the European Space Agency (ESA) presented information on ESA's fleet of spacecraft for space science; the services provided by ESAC covering astronomy, planetary science and fundamental physics; and the challenges associated with their archives and their long-term preservation. ESA has an open data policy, typically with a one-year period of exclusive use of the data allocated to the principal investigators and mission teams. ESAC data archives are now built using virtual observatory standards and infrastructures. Collaboration is a key factor for providing good services and avoiding duplication. ESASky is a good example of a collaboration with IVOA and the Centre de Données astronomiques de Strasbourg (CDS).

24. The Head of the Department for Physics of Stellar Systems of the Institute of Astronomy of the Russian Academy of Sciences gave an overview of the astronomical

facilities and data archives in the Russian Federation, their various catalogues and past and future space science missions. Those activities are carried out across a number of observatories and institutions involving approximately 1,400 researchers. Astronomical data archives are hosted and maintained by astronomical institutions in the Russian Federation, following virtual observatory standards. At present, their six-metre optical telescope provides an online archive, while other facilities will follow that approach in the future. The Russian Federation is implementing a standard open policy of releasing data to the world community after a one-year proprietary period.

25. A representative of the China National Space Administration gave a comprehensive description of the deep space exploration programme in China, including their China Lunar Exploration Programme. The Lunar Exploration and Space Engineering Centre is responsible for the management of scientific data from lunar and deep space missions, while the National Astronomical Observatory is responsible for receiving, processing and storing scientific data. The scientific data policy of China is in the process of adopting openness and sharing as a guiding principle.

26. The Chair of IVOA made a presentation on the Alliance's activities, developing standards and encouraging good data practices in astronomy that follow the FAIR principles. The virtual observatory is a framework for data centres to provide data archives and services and for software providers to offer a variety of compatible analysis and visualization tools and user interfaces. The virtual observatory can be thought of as an evolving ecosystem in which IVOA defines interoperability standards, while data centres and member organizations provide various services, applications, registries, interfaces and various other software layers built upon those standards. The alliance was founded in 2002 and currently includes 21 members that meet regularly.

27. A representative of the European Organization for Astronomical Research in the Southern Hemisphere (ESO) made a presentation about the organization, which manages four observing sites in Chile that operate 19 telescopes with 46 instruments. The organization is committed to open data with a standard policy that all observational data become public after a one-year proprietary period. The data volume of the archive and its usage are constantly growing, thus requiring the data to be processed to higher levels utilizing software pipelines and data mining and machine learning techniques. The representative stated that a new archive interface was to be released soon. The organization provides extensive user support, organizes user workshops and runs joint observing programmes with other facilities, making data available to planetariums as well.

28. The Director of the Space Science Data Centre of ASI made a presentation about the Centre, which is dedicated to the observation of the universe, information and computing technologies, and Earth observation, and follows the FAIR principles. The Centre was formerly known as the ASI Science Data Centre and has supported more than 25 space missions since its establishment in 2000. The speaker gave an overview of several existing services of the Centre and a plan for providing Earth observation data. Some of the services have been integrated into the Open Universe portal developed by ASI.

29. A representative of the Brazilian Centre for Research in Physics made a presentation about the work of the Brazilian Science Data Centre, a novel initiative supported by the Brazilian Centre for Research in Physics and the Brazilian Space Agency and developed under the framework of the International Centre for Relativistic Astrophysics Network in Brazil. The Brazilian Science Data Centre, based on the concepts proposed by the Open Universe initiative, responds to the needs of the Brazilian community for a regional data centre for astrophysics. It is built within a context of cooperation with virtual observatory initiatives and the Governments of Brazil, the Russian Federation, India, China and South Africa (the BRICS countries). The Centre has been in development since 2016 and constitutes a

distributed cost-effective model for developing countries. Their activities include the production of a number of astronomical catalogues and the provision of services based on the virtual observatory standards, including for data sets that are currently not available to the public. The first release of the tools and interfaces is expected at the end of 2017.

30. A representative of the Harvard-Smithsonian Center for Astrophysics made a presentation on the main characteristics of the Chandra Source Catalog of the Chandra X-ray observatory, including a preview of the upcoming second release, which provides an innovative view of the X-ray sky and includes the visualization of stacks of observations. Furthermore, several virtual observatory interfaces of the Center were showcased. It is expected that the Centre will be a rich virtual facility for X-ray astronomy and a long-lasting legacy of the Chandra programme.

B. International cooperation and policy and legal aspects

31. The session presented perspectives on the role of international cooperation and of various policy and legal aspects of the Open Universe initiative.

32. A representative of the European Commission made a presentation on the status of a European Union initiative to develop the European Open Science Cloud, which is aimed at addressing several key challenges in the European research arena. Those challenges include a lack of awareness about data standards; limited hardware for storage and computing; fragmentation and lack of coordination across research disciplines; and various issues regarding data privacy, protection and copyright. The European Open Science Cloud plans to build upon and integrate the past two decades of progress and to provide 1.7 million European researchers with free, open services for data storage, management, analysis and use across disciplines.

33. A representative of the Italian National Institute of Astrophysics discussed the extent to which the FAIR principles are satisfied by the standards currently used by the astronomical community. The components of the virtual observatory were mapped to the FAIR principles, showing that data compliant with virtual observatory standards abide by the principles. However, not all data are compliant with the virtual observatory standards, and sometimes use of the FAIR principles is not enough. A recommendation was made that the Open Universe initiative should take the form of a distributed mechanism of shared services, endorsed and supported by the Office for Outer Space Affairs. For data that are not compliant with the virtual observatory standards, significant development is needed to create conversion layers. To that end, IVOA and data providers should make efforts to jointly extend standards to deal with new classes of data. For cases in which the FAIR principles are not enough, data providers will also need to become science service providers.

34. A presentation was made on the role of the National Commission on Space Activities (CONAE) of Argentina as the space agency of that country, as well as its space science and earth observation data provider. The presentation focused on the new data portal (GeoPortal), which incorporates various layers of information for the benefit of local community users in Argentina. Information was presented on the role of training in the use of the system and its data. In addition, the incorporation of the Deep Space Network antenna of ESA and the installation of a deep space antenna for the Moon mission of China, which could also be used for scientific purposes in Argentina, were discussed. Several initiatives related to the use of astronomical data supported by the Ministry of Science, Technology and Productive Innovation of Argentina were explored.

35. A representative of the Sapienza University of Rome made a presentation on several legal aspects of the Open Universe initiative of relevance, considering that space science continues to be a gateway to national space activities for many countries. The norms and principles on the availability and accessibility of science data in general, and space science data in particular, have evolved since the 1990s and have acquired the status of consolidating legal principles. The representative

concluded that all space science data should promptly be made publicly available, in accordance with the policies on validation periods and periods of exclusive use of individual agencies. That approach is contained in various international legal principles and doctrines, including the Outer Space Treaty, the Convention for the Establishment of a European Space Agency, and the guidelines of the Organization for Economic Cooperation and Development.

36. A representative of the Astrobiology Centre of the National Institute for Aerospace Technology (INTA) and the Spanish Virtual Observatory made a presentation on the advantages and achievements of the virtual observatory from the perspective of an astronomer. The virtual observatory allows seamless sharing of open data, accessible worldwide, through a common set of standards. Virtual observatory tools take advantage of this standardization to carry out analysis tasks that would be very inefficient or altogether impossible outside of the virtual observatory environment. This scenario opens the era of a new branch in astronomical research: virtual observatory science.

37. A representative of the National Centre for Scientific Research (CNRS) of France and the European Virtual Observatory provided the historical context of the virtual observatory as a pioneer of international collaboration aimed at enabling the sharing of scientific data. The virtual observatory framework of standards and tools ensures that astronomical data observe the FAIR principles, and the worldwide scientific community is using virtual observatory enabled data and tools in its daily research work. Moreover, it is a powerful vehicle for the democratization of science, making data and tools available to scientists worldwide, and access is also provided for educational and training purposes. In this context of the rapid developments seen in open science, it was highlighted that elements of the virtual observatory framework were used by other disciplines. This is not limited to closely related disciplines, such as the planetary sciences and astroparticle physics, but also to the Virtual Atomic and Molecular Data Centre and the Research Data Alliance groups working on interoperability of materials science and engineering.

38. A representative from the Square Kilometre Array presented an overview of the initiative, including the scientific goals and technical challenges, and emphasized its achievements. Several key challenges drive the need for global collaborative models for regional science centres of the Square Kilometre Array. First, the science data products that emerge from the observatory of the Square Kilometre Array are not in the final state required for scientific analysis and publication. Second, the data volumes are so large that direct delivery to end users is unfeasible. Lastly, the community of scientists working on science data products of the Square Kilometre Array will be geographically distributed. The presentation concluded with an evaluation of the socioeconomic impact that will be realized by the Square Kilometre Array.

C. Software and platform demonstrations

39. Three software demonstrations were provided on the first day of the Workshop:

(a) ESASky: all the skies in your browser;

(b) The CDS portal: a unified way to access the services of the Centre de Données astronomiques de Strasbourg;

(c) The portal of the ASI Open Universe initiative and the prototype AGILE-LV3 web tool.

D. Educational, social and economic benefits of open data

40. The technical session focused on the benefits of open data in the areas of education, society and economy. Different experiences in various countries around the world demonstrated the efforts of research centres and universities, with a view

to fostering astronomical research and education and their future sustainability. A cost-benefit analysis was presented as a successful method of measuring the economic benefits of space science investments and of the open access approach to space data.

41. The General Secretary of IAU made a presentation about the Astrophysical Virtual Observatory as a learning tool. The Observatory is used by IAU for its sponsored educational activities for both students and teachers, and it is adapted according to cultural and knowledge levels in different countries. Training sessions of the Astrophysical Virtual Observatory are an integral part of the schools and training seminars organized by IAU, including in countries where there are no astrophysics professors. Relevant activities have included the training of teachers and the courses organized by the regional offices of the Office of Astronomy for Development of IAU, the International School for Young Astronomers, the Network for Astronomy School Education and the Galileo Teacher Training Programme. The presentation concluded with the expectation that the Open Universe initiative could support activities incorporating the needs and interests of the general public.

42. A representative of the Italian National Institute of Astrophysics made a presentation on the Institute's successful use of virtual observatory for education (VO4Edu). The main goal of the initiative was to spark the interest and enthusiasm of students in astronomy and allow them to experience what the research work of an astronomer is really like. The target group included high school and university students. The initiative is indicated as a method for the democratization of access to space science, assessing the needs of schools and trying to engage students on how to solve astronomical problems using a step-by-step guide. The products developed by the Institute are aimed at narrowing the gap between experts and the general public, making it possible for the latter to experience the excitement of research, even if on a smaller scale.

43. A representative of New York University in Abu Dhabi made a presentation about the university, which attracts students from 115 countries. The interests of the science faculty focuses heavily on astronomy and astrophysics, including galaxy formation, exoplanets, helioseismology, water masers, supernova remnants, compact objects and dark matter. The representative stressed that the Open Universe approach to data sharing was in line with the university's philosophy of learning, and it was proposed that the university should be a hub of the initiative.

44. A representative of the Material Measurement Laboratory of the National Institute of Standards and Technology made a presentation on the influence of the virtual observatory standards on data discovery, access and use in other disciplines. Virtual observatory access protocols enable reuse and interoperability through the specification of standard data models and uniform metadata. The architecture allows for the data to remain federated despite its distribution. As a result, data can be managed and curated by experts, but the integrated resource registry enables researchers, educators, students and the public to find data of interest regardless of physical location. It has now been used as the model for distributed and federated data services in a number of other diverse disciplines, including materials science, metrology, biomedicine and neuroscience. The virtual observatory architecture and approach are both attractive to other disciplines and amenable to the exposure of research data to a diverse community of users.

45. The Director of the Astronomical Observatory of the Sergio Arboleda University in Colombia made a presentation on the establishment and work of the Andean regional office of the Office of Astronomy for Development, called ROAD-Andina. In the Andean region, with about 150 million people, 10 projects have been carried out through the work of task forces on astronomy for university and research, astronomy for children and schools, and astronomy for the public. In order to incorporate the experience of the Office of Astronomy for Development into the Open Universe initiative, the representative of ROAD-Andina proposed the further developing of activities such as workshops, gatherings and meetings; the use of platforms and technological aids for information exchange and online education; the

promotion of studies in areas such as near-Earth object monitoring; and the building of astronomical facilities in dark and quiet sites.

46. A representative of the Inter-University Centre for Astronomy and Astrophysics made a presentation about making astronomy and astrophysics data more accessible to universities in India. The Centre is a unique institution that is aimed at fostering connections between university departments in India and increasing the profile of astronomy and astrophysics through teaching, research and development. At present, a total of 150 faculties are participating and are able to use the centralized observing and data facilities. The Centre hosts the Virtual Observatory-India project, which has developed many tools for astronomy data analysis, and the Astrosat Science Support Cell (the multiwavelength space telescope of India). It has a vibrant outreach wing, which takes steps to use open data to inspire younger students and amateur astronomers to gain confidence in research aspirations. Such activities are carried out with the annual participation of 50,000 people.

47. A professor of the University of Milan made a presentation on the socioeconomic benefits of data in the context of the Open Universe initiative. The initiative matches some of the components of the Research Infrastructures of the European Union Horizon 2020 Programme, including flexible accessibility to multiple users, shared management, public involvement and the generation of an unprecedented amount of digital information, among others. In that context, social benefits include the expansion of data availability to the global community of space science, the engagement of citizen scientists and derived added value of scientific discoveries for the general public. Different kinds of externalities are generated by an open access approach, and they can be measured, valued and utilized in a social cost-benefit analysis. Two approaches for estimating the economic value of such an initiative were presented. The empirical study of public preferences in the valuation of public goods in other domains could provide valuable lessons for the field of science.

E. Outreach and space citizen science projects

48. The technical session concentrated on possible applications for outreach and citizen science, and featured two different approaches to encouraging the involvement of the general public in the fields of astronomy and space science.

49. A representative of the Open University of the United Kingdom made a presentation on two open data and citizen science initiatives that have had success in the field of astronomy. The Astronomy European Strategy Forum on Research Infrastructures and Research Infrastructure Cluster (ASTERICS) project has enabled broad access to data acquired by the Forum telescopes by means of an interface to the virtual observatory framework. Some of those data were successfully analysed using a distributed citizen science initiative called the Muon Hunters project. The presenter highlighted the potential of citizen science as a tool and put forward his vision to make data available and to democratize the processes of discovery by directly involving the public. In addition, the work of the OpenScience Laboratory for education was introduced, which makes available online tools, tutorials and hardware teaching materials for classes on science, technology, engineering and mathematics. The view was expressed that the Office for Outer Space Affairs should endorse IVOA.

50. A representative of the Maulana Azad National Urdu University in India made a presentation on outreach and education in India in the field of astronomy. She underlined the urge to educate children in India not only to strengthen the scientific mindset but also to foster rational thinking. Among the main challenges, the presenter highlighted the lack of inspiring teachers, the focus on grading, insufficient syllabuses, the lack of trust and the discrepancy between the expectations of educators and students. The representative emphasized the need to cultivate the interests and diverse talents of young people. The representative presented activities in India that are aimed at making astronomy more popular among the public. Those activities

included Olympiads, winter schools, exposure camps, exhibitions, movies, shadow days and encouraging undergraduate students to use available data for their own observations and publications.

51. A presentation was made by the representative of the Space Academy in Bulgaria. The Space Academy consists of an educational and inspirational space programme, held in the biggest space and science museum in the Balkans ("Muzeiko"). The programme for children aged 8 to 12 serves to foster curiosity and interest, in particular in the field of space sciences. The programme is carried out in a total of 6 sessions with 12 modules, which address, inter alia, the solar system, celestial bodies and the protection of our planet, and includes practical activities to support this aim in everyday life.

52. A representative of the Shamakha Astrophysical Observatory in Azerbaijan highlighted a long tradition of astronomical research in that country. The presentation touched on a number of the Observatory's publications, its facilities and its astronomical instruments, including several telescopes. The presentation focused on outreach goals aimed at students of secondary and high schools, and the general public. The main goal was to improve the propagation of knowledge on space science by developing astrotourism in the observatory and the museum that is established within the facility and exhibits astronomical samples. Activities planned include summer schools, public lectures, astrofestivals, workshops, as well as the publication of books, brochures, calendars or other souvenirs and the preparation of a new web page.

53. The Director of Astrovisualization at the American Museum of Natural History made a presentation on OpenSpace as a Digital Universe 3D atlas, which is the foundation for creating space shows at the Hayden Planetarium in New York, using the most accurate scientific data available. OpenSpace can visualize the latest simulations of fundamental processes of the universe. The institution is aiming to create an algorithm to explore space in 3D and share it around the world from planetariums to schools, relying on the capabilities of networks and numerous international partners. The project is funded by NASA and began in 2016. It forms the backbone of the show that was displayed in the side event at the planetarium of the Natural History Museum of Vienna.

54. The Director-General of the Natural History Museum of Vienna provided an overview of the history of the imperial collection that constituted the genesis of the collections in the museum, and highlighted its present development and future plans. In relation to the topics of the Workshop, the museum's meteorite collection is the oldest — and one of the largest — in the world. Two of the museum's citizen science projects were highlighted, namely, involvement in Asteroid Day activities, and participation in initiatives for the protection of the night sky and reduction of light pollution. As a side event to the Workshop, the speaker extended an invitation to attendees to see a show in the museum's new digital planetarium and visit the meteorite display.

F. Poster session

55. The poster session included a lightning round in which poster presenters pitched the theme and contents of their posters to the participants. This was followed by a traditional poster session, in which presenters answered detailed questions in front of their posters.

56. Poster presentations were made by ASI, the Department of Astronomy of the University of the Republic in Uruguay, the Indian Institute of Space Science and Technology, the International Centre for Relativistic Astrophysics Network in Armenia, the Kenya Space Agency, the National Polytechnic School of Ecuador, the Northwestern Polytechnic University of China, the Space Academy in Bulgaria, Space Agenda from Turkey, Space Generation Advisory Council headquarters and Space Generation Advisory Council Nigeria.

G. Beyond the current paradigm: new initiatives and services

57. This session explored what the future of science data archiving and dissemination might look like and included proposals for future products and services.

58. The representative of National Research Council of Canada made a presentation on developing international infrastructure for data-intensive science, introducing the work and evolution of the Canadian Astronomy Data Centre and its cloud ecosystem, which provides integrated services beyond archiving. In that context, the Centre collaborates with various partners to develop an infrastructure to support data-intensive research activities available for a large number of uses worldwide. A fresh new approach would be needed in order to realize a substantial transfer of the benefits of astronomy data and the supporting infrastructure to the public. Such an effort could be accomplished, with a focus on developing nations as the highest priority, by means of education, outreach and citizen science, all areas where the involvement of the United Nations could play a key role. In addition, the representative put forward a potential recommendation on the importance of investments in supporting new and existing services.

59. The representative of the Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences made a presentation on the potential contribution of the International Scientific Optical Network observation project to the Open Universe initiative in developing countries. The Network comprises over 80 optical telescopes in 16 countries. The speaker proposed possible forms of collaboration and cooperation of the project with the Open Universe initiative. Those included the donation of telescopes to developing countries to help enlarge the network, training courses for experts in those countries, coordinated observation campaigns and capacity-building among international researchers, with a view to elaborating technological solutions for observation of space objects.

60. A representative of the Smithsonian Astrophysical Observatory made a presentation on the future of the astronomical archive in the era of the virtual observatory, focusing on the promotion of data sharing in all communities. The representative emphasized that good practices and procedures were required. One example of mission archive is the Chandra Data Archive, which provides comprehensive access from proposals to publications. Such interfaces need to cater to anticipated data needs, necessitating a continuous increase in complexity. The representative suggested that comprehensive public interfaces should not be the responsibility of archives, and that they should concentrate on developing a rich interoperable data environment, which researchers can access using various external interfaces.

61. The representative of the University of Geneva in Switzerland argued that providing access to space science does not end with the data, and highlighted the importance of legacy data sets for generating new discoveries, in particular when analysed in ways the original researchers could not have anticipated. The representative explained that straightforward interfaces with complex data analysis capabilities were needed in order to make the process of generating science available to all target groups. For that purpose, cloud computing and artificial intelligence are required and will be the future of science data processing, following the fourth industrial revolution. The representative concluded by mentioning that such interfaces should allow for the seamless generation of new results, a fundamental step towards evolving into a knowledge society.

62. The representative of the University of Sheffield presented a proposal on the Open Universe initiative with regard to consolidated archive obligations in astronomy and space science. The presentation examined the principles underlying tools such as the recently developed ESASky or the proposed Large Synoptic Survey Telescope Science Platform, and compared their speed, utility and ease of use to the long and manual processing of scientific data required a few decades ago. The presenter discussed a proposed set of Open Universe obligations, which can be mapped to the

FAIR principles. Together with the underlying use of IVOA standards, the obligations are essential to the efficiency and cost-effectiveness of data-driven science.

III. Outcomes and recommendations

63. In addition to the technical sessions, splinter discussions were held on the following topics: (a) increasing transparency of already available resources, (b) resurfacing data and other hidden or otherwise hardly accessible resources, and (c) broadening the user base of astronomy and space science data.

64. The first plenary discussion covered a series of tentative projects within the context of the Open Universe initiative, including proposed collaborations with ASI, the Committee for Space Research and the International Scientific Optical Network. Additional open proposals and calls for support on the topics of citizen science, hackathons, advisory missions and the facilitation of archiving solutions were presented. The participants of the Workshop expressed their view that the projects could be challenging and would need further development.

65. The final panel discussion reviewed a possible road map for the Open Universe initiative and discussed its scope and objectives. The invited panellists shared their views on the initiative and the floor was then opened up for discussion in the plenary.

66. On the basis of the discussions, the following observations and recommendations were made.

A. Observations and general recommendations

67. The participants of the Workshop noted the background of the proposal for the Open Universe initiative and the objectives of the associated Workshop, acknowledged the outcomes and recommendations of the expert meeting held in April 2017 in Rome (see A/AC.105/2017/CRP.22), and recognized the challenges of the evolving ecosystem of players in the astronomy and space science data domains.

68. The participants of the Workshop noted the central role of IVOA as the main standards organization for data interoperability in astronomy, and also noted the contributions from other stakeholders and networks. It was stressed that the duplication of efforts should be avoided. In that regard, it was important to disseminate and promote the adoption of existing established standards among data providers and data exploitation applications developers, and to extend those standards, including metadata, to new data sets when needed. The FAIR principles for data management and stewardship should inform any new development.

69. It was recognized that Governments had already invested substantial resources to create the existing network of astronomy data services. The powerful science capabilities provided by the network are the foundation upon which the Open Universe initiative relies. Those investments should continue in order to support the maintenance of existing services and new developments, such as those proposed under the Open Universe initiative.

70. Furthermore, it was highlighted that a great deal of astronomical data from space missions and ground facilities were collected by principal investigators on the basis of open calls and that those investigators had proprietary rights on the calibrated data products based on the observations for a defined time period (usually one year).

71. It was expressed that the final calibrated data, together with complete ancillary data that characterize the observations, should be stored in online archives, following established standards, and that the data should be made available to the public, without the need of further data processing, after the required proprietary periods.

72. To that end, it was essential to facilitate collaboration and coordination among data centres for the provision not only of data, but also of sufficient computing power

and appropriate server-side tools to fulfil user requirements. The provision of a new category of web-ready data services suitable for portable devices and flexible user-interfaces should be encouraged, thereby maximizing the usability and the scientific and sociological value of the data.

73. In addition, actions should be taken, as appropriate, towards resurfacing data worldwide, guaranteeing that such actions result in data products that would remain useful for the foreseeable future. When possible, a survey of the status of data availability for all space science missions and ground-based facilities should also be undertaken. Specific actions needed for resurfacing high-value data sets should be identified.

74. It was expressed that a substantial transfer of the benefits of astronomy data and supporting infrastructure to the public through education, outreach and citizen science was needed, in particular with a focus on supporting developing nations and emerging space actors, and among women and young people. The use of social media platforms should be encouraged to promote initiatives and raise public awareness.

75. In that regard, it was noted that outreach and educational efforts of the Open Universe initiative should be carried out in close collaboration with relevant stakeholders. Such stakeholders could include governmental authorities; intergovernmental and non-governmental organizations; partners in academia, industry and the private sector; and, in particular, the existing capacity-building networks in the domain of astronomy and space science. Through its Office of Astronomy for Development and its Office for Astronomy Outreach, IAU should be an important partner in pursuing those objectives.

76. The Office for Outer Space Affairs took note of the observations and general recommendations and committed to taking them into consideration in developing the Open Universe initiative.

B. Recommendations for the Office for Outer Space Affairs

77. The participants of the Workshop recommended establishing, under the auspices of the Committee on the Peaceful Uses of Outer Space, an initiative to promote and facilitate access to high-quality extraterrestrial scientific data for the benefit of all potential users. The initiative, to be called the Open Universe initiative, is to be created under the leadership of the Office for Outer Space Affairs, in close cooperation with the Government of Italy, and in particular with the Italian Space Agency, and other potential partners whose support should actively be sought.

78. The Open Universe initiative was in that regard seen as a way of promoting transparency by creating projects to broaden and facilitate access to space science data for everyone, everywhere, and in reaching space and non-space sectors. The development and sharing of good practices for education and outreach, incorporating diverse developmental, cultural and linguistic perspectives, was seen as particularly important.

79. The main objective of the Open Universe initiative is to promote and facilitate the visibility, free accessibility and ease of utilization of space science data, and in particular astronomical data, collected by space- and ground-based facilities.

80. To that end, the Office for Outer Space Affairs and the Open Universe initiative should work towards:

(a) Enhancing and completing the online availability and visibility of astronomical and space science data, following internationally agreed standards;

(b) Promoting the development of software applications and educational and outreach environments for astronomy and space science, with the objective of furthering the progress of society in terms of culture and knowledge, in particular among young people and women, irrespective of the level of development of a country.

81. In the context of the Open Universe initiative, and with the above observations and considerations in mind, the participants of the Workshop recommended that the Office for Outer Space Affairs should:

(a) Promote at decision-making levels cooperation between countries and relevant stakeholders, including space agencies, astronomical observatories, data centres, for the driving of innovation in space science data archiving and dissemination, encouraging the sharing of good practices and the adoption of established standards;

(b) Liaise and foster partnerships among the research community in the development, extension and provision of visibility for the above-mentioned data, services, applications and standards for a broad user base and at all available levels — including raw data, calibrated data and upper-level data products, provided by both established and emerging providers;

(c) Promote the establishment and dissemination of good practices in outreach; science, technology, engineering and mathematics (STEM) education; and citizen science, encouraging the translation of resources and tutorials to ensure enhanced access to all users, irrespective of their level of development, origin, gender or age;

(d) Foster new opportunities for young scientists and engineers, and encourage the organization of workshops at local schools, museums, observatories, planetariums and other facilities, in cooperation with existing capacity-building efforts.

C. The way forward

82. The Office for Outer Space Affairs will continue working with its partners on the Open Universe initiative with a view to refining and consolidating the recommendations that have been outlined.

83. The initiative is aimed at contributing to the overall capacity-building strategy of the Office, the UNISPACE+50 thematic priorities and the Sustainable Development Goals.

84. Member States and other organizations interested in supporting activities under the Open Universe initiative are encouraged to contact the Office for Outer Space Affairs.