



Europlanet 2020 RI FINAL REPORT



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Contents

EXECUTIVE SUMMARY.....	3
OVERVIEW OF THE PROJECT	5
WP1 - MANAGEMENT.....	6
WP2 – TA1: PLANETARY FIELD ANALOGUES	7
WP3 – TA2: DISTRIBUTED PLANETARY SIMULATION FACILITY	8
WP4 – TA3: DISTRIBUTED SAMPLE ANALYSIS FACILITY.....	9
WP5 – VA1: PLANETARY SPACE WEATHER SERVICE	10
WP6 – VA2: VESPA.....	11
WP7 – JRA1: CHARACTERISATION OF LAKE TÍREZ & DANAKIL	12
WP8 – JRA2: IMPLEMENTATION OF NEW SPECTROSCOPIC AND SIMULATOR CAPABILITIES.....	13
WP9 – JRA3: OPTIMAL PLANETARY SAMPLE HANDLING, INVESTIGATION AND ANALYSIS	14
WP10 – JRA4: PLANETARY SPACE WEATHER SERVICES.....	15
WP11 – JRA5: VESPA.....	16
WP12 – NA1: INNOVATION THROUGH SCIENCE NETWORKING	17
WP13 – NA2: IMPACT THROUGH OUTREACH & INNOVATION	18
IMPACTS OF EUROPLANET 2020 RI	19
MEASURING IMPACT.....	20
EXPLOITATION AND DISSEMINATION OF RESULTS.....	20
TA IMPACTS.....	21
VA IMPACTS	22
NA IMPACTS	23
COMMUNITY IMPACTS	24
CASE STUDY 1: SUPPORTING WORLD-LEADING SCIENCE	25
CASE STUDY 2: SUPPORTING INNOVATION	26
CASE STUDY 3: BUILDING REGIONAL COLLABORATIONS.....	27
CASE STUDY 4: KNOWLEDGE TRANSFER AND OUTREACH	28
CASE STUDY 5: SUPPORTING STRATEGIC DEVELOPMENT.....	29
CASE STUDY 6: ACCESS TO CUTTING EDGE DATA.....	30
CASE STUDY 7: SOCIAL RESPONSIBILITY.....	31
CONCLUSIONS	32
ACKNOWLEDGEMENTS	33
IMAGE CREDITS.....	34

Executive summary

Europlanet received €9.95 million funding under the European Commission's Horizon 2020 programme to implement an advanced research infrastructure for planetary science. The Europlanet 2020 Research Infrastructure (RI) was coordinated by The Open University, UK, and included 34 beneficiary institutions from 20 European countries.

As a mature infrastructure, Europlanet 2020 RI placed particular emphasis on widening the participation of under-represented research communities and stakeholders, including the newer EU Member States.

Between 1 September 2015 and 31 August 2019, Europlanet 2020 RI provided:

- Free transnational access to world-class laboratory facilities that simulate conditions found on planetary bodies, as well as terrestrial analogue fields sites for Mars, Europa and Titan.
- Virtual access to diverse datasets and visualisation tools to compare and understand planetary environments in the Solar System and beyond.
- Networking activities, including meetings, workshops and personnel exchanges, to strengthen the community, develop industry-academic collaboration, discuss the latest scientific results, and set the strategy and goals for planetary science in Europe for decades to come.
- Outreach and education programmes to engage Europe's citizens, teachers, students and policy makers with cutting-edge planetary science and exploration.

Transnational Access impacts:

- The five calls during Europlanet 2020 RI for Transnational Access generated 320 applications and 194 completed visits to facilities.
- Over 1480 days of access were provided to state-of-the-art planetary laboratory facilities and field sites, resulting in high impact publications, including several in the Nature and Science family of journals.
- Europlanet 2020 RI assembled the world's largest coordinated collection of planetary simulation and analysis facilities.
- Sample return handling protocols and ultra-sensitive isotopic analysis techniques have been developed and validated through Europlanet 2020 RI.
- Capabilities have been extended at the Wind Tunnel Simulator at Aarhus for simulations under Mars and Titan environmental conditions.
- New spectro-goniometers have been developed at Grenoble with improved sensitivity down to very low albedos and the ability to measure small samples such as rare meteorites.

- DLR's high temperature chamber has been upgraded and is now the only facility worldwide capable of performing spectral measurements of Venus surface analogues at realistic surface temperatures.
- The Danakil Depression has been characterised as a terrestrial analogue for extreme hydrothermal environments on Mars, Venus, Io and Ganymede.
- 10^{13} Ohm resistors validated within Europlanet 2020 RI have been released by ThermoFisher as a commercial product, opening up new potential applications for a very broad range of planetary and non-planetary users.

Virtual Access Impacts:

- Over 50 planetary datasets and 18.3 million data products are now accessible through the VESPA (Virtual European Solar and Planetary Access) Virtual Observatory developed through Europlanet 2020 RI. <http://vespa.obspm.fr/>
- The Europlanet Table Access Protocol (EPN-TAP) developed for VESPA has been adopted as standard by the International Planetary Data Alliance and ESA's Planetary Science Archive.
- Planetary Space Weather Service (PSWS) toolkits created to track planetary or solar events through the Solar System have attracted over 15,000 users from academia and industry worldwide.
- The SSHADE database infrastructure, developed with support from VESPA, has been recognised by the Federation of Digital Object Identifier (DOI) Registration Agencies and is now authorised to assign a DOI to cite each dataset stored within the SSHADE database infrastructure.

Networking Activity Impacts:

- 84 workshops and training sessions organised during Europlanet 2020 RI have been attended by more than 3,000 researchers, industrial representatives, outreach professionals, teachers and policy makers.
- Over 1,200 EU companies have been identified with an interest in provision of solutions or services to planetary scientists, or with an interest in recruiting planetary graduates.
- Thousands of media stories on planetary results have been generated around the world.
- 60,000 Euros of seed-funding from Europlanet 2020 RI has supported outreach projects to engage citizens across Europe with planetary science.
- Around 300 Members of the European Parliament and policy makers have attended exhibitions, events and individual briefings on planetary science topics.

Europlanet 2020 RI was recognised as a Horizon 2020 success story by the European Commission in December 2018.

Overview of the project

WP1 - Management

The Europlanet 2020 Research Infrastructure (RI) operated from 1 September 2015 to 31 August 2019 and was coordinated by The Open University, UK. With 34 beneficiary institutions from 20 European countries, a further 22 partner institutions and more than 150 participating individuals, Europlanet 2020 RI was a large and complex project whose success depended on the effective management and integration of many diverse elements.

Europlanet 2020 RI has built on the heritage of an FP6 Co-ordination Action (EuroPlaNet) and an FP7 Research Infrastructure (Europlanet RI) to provide a pan-European advanced infrastructure to support world-leading planetary science.

Europlanet 2020 RI has placed strong emphasis on inclusiveness to build a larger, stronger and more collaborative European planetary community. It has engaged a wide range of stakeholders (including policy makers, industry, amateur astronomers and the general public) to highlight the achievements and ambitious goals of European planetary research.

The Europlanet 2020 RI project was organised around four types of activity: Transnational Access (TA) to field sites and laboratories; Virtual Access (VA) to diverse planetary datasets and tools; Joint Research Activities (JRA) to develop new field sites and facilities; and a set of Networking Activities (NA) to expand Europlanet's networks within the planetary science community and with external audiences, to promote the services offered by Europlanet 2020 RI and disseminate the project's achievements.

At the core of Europlanet 2020 RI, the TA programme offered free access to a comprehensive set of laboratory facilities and field sites tailored to the needs of planetary research community, with particular emphasis on delivering analogues for current and planned planetary missions. The TAs supported travel and local accommodation costs for researchers to visit their chosen facility for an approved period of time to conduct their own project. Announcement of calls, collection of applications and their subsequent independent peer review were managed by the European Science Foundation (ESF), France.

Europlanet 2020 RI was delivered through 13 work packages (WP), including the management and co-ordination of the Europlanet 2020 RI project (WP1). A series of Boards oversaw the day-to-day running of the project and provided democratic discussion, accountability and feedback on Europlanet 2020 RI and its services.

A summary of all Europlanet 2020 RI activities and public deliverables can be found on the project website at: <http://www.europlanet-2020-ri.eu>.

WP2 – TA1: Planetary Field Analogues

TA 1 (Planetary Field Analogues) provided European and international researchers with access to a set of well-characterized planetary analogue field sites to carry out cutting-edge science and support planetary missions.

The TA1 collection of sites comprised realistic terrestrial analogues of the surface and near surface geological/geomorphological environments of planetary objects - including areas of astrobiological interest - for Mars, Europa, Titan and the early Earth.

Three planetary field analogues - Rio Tinto (Spain), Ibn Battuta (Morocco) and cold and hot environments in Iceland - were offered for transnational access throughout the project. A further two new sites - the Danakil Depression (Ethiopia) and Lake Tirez (Spain) - were characterised through JRA1 (WP7) during the first two years of Europlanet 2020 RI and became available for access in late 2017.

Over the five calls issued by Europlanet 2020 RI, TA1 attracted 83 applications, of which 50 were approved by the TA Review Board, resulting in 44 completed visits to the field sites.

TA1 projects included studies related to:

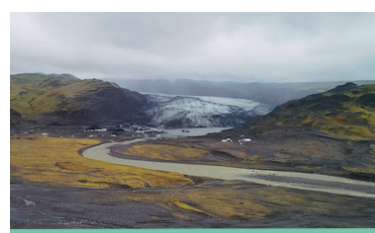
- The complex (bio) geo-chemical feedback processes that control planetary evolution to develop quantified models to explain observations made of planets in our Solar System.
- Processes that influence the survival of life under extreme conditions and the detection of records of past or present biological activity.
- Instrumentation under development for future planetary space missions.
- Concepts for analysis, operations and management in field settings.



Rio Tinto



Ibn Battuta Centre



Iceland



Danakil Depression



Lake Tirez

WP3 – TA2: Distributed Planetary Simulation Facility

TA2 (Distributed Planetary Simulation Facility – DPSF) gave researchers access to seven world-leading simulation facilities for the surface and atmospheric environments of Mercury, Venus, asteroids, comets, Mars, Jupiter, Saturn and the icy moons Titan, Enceladus, Ganymede and Europa.

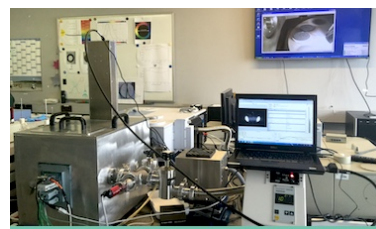
TA2 also enabled researchers to characterise the texture and mineral composition of samples in unprecedented detail as well as the ability to detect and characterise life, including Next Generation Sequencing.

The seven facilities included:

- The Planetary Emissivity Laboratory at DLR Germany.
- Planetary Environment Facilities at Aarhus University, Denmark.
- The Open University's Mars Chamber, UK.
- The high-pressure laboratory at VUA, Netherlands
- Cold Surfaces spectroscopy at IPAG, France.
- The Center for Microbial Life Detection at the Medical University Graz, Austria.
- The Petrology-Mineralogy Characterisation Facility at the Natural History Museum, London, UK.

Over the five calls issued by Europlanet 2020 RI, TA2 attracted 153 applications, of which 101 were approved by the TA Review Board, resulting in 100 completed visits to facilities.

Research enabled through TA2 visits included: tests of instrumentation for the ExoMars 2020 Rover, a survey of the microbial communities that developed during the isolation unit of the Mars500 simulated mission to Mars, and the generation of temperature-dependent laboratory spectra to interpret mission observations of salt deposits on the surface of Ceres and Europa.



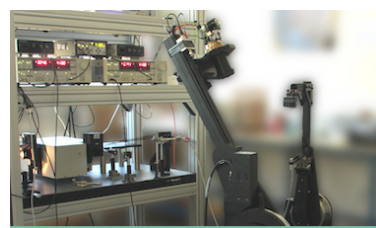
Planetary Emissivity Laboratory



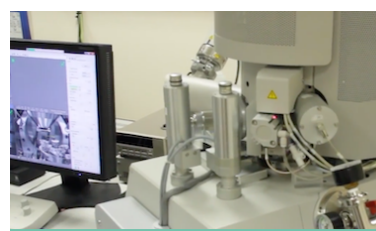
Wind Tunnel at Aarhus



Open University Mars Chamber, UK



Cold Surfaces spectroscopy, IPAG



Petrology-Mineralogy
Characterisation Facility, NHM

WP4 – TA3: Distributed Sample Analysis Facility

TA3 (Distributed Sample Analysis Facility – DSAF) provided users with access to four internationally renowned centres of excellence to enable state-of-the-art isotope geochemical analysis. TA3 offered a broad range of instrumentation required to quantify the complex (bio)geochemical cycles that control the formation and evolution of planetary bodies.

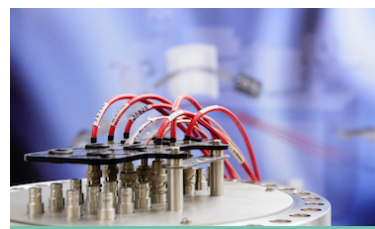
The four facilities included:

- The radiogenic and non-traditional stable isotope facility at VU Amsterdam, Netherlands.
- The radiogenic, non-traditional stable & rare gas isotopes at CRPG, Nancy, France.
- Stable Isotope Analytical Facilities and the NanoSIMS 50L Secondary Ion Mass Spectrometer at The Open University, UK.
- The radiogenic & non-traditional stable isotope facility at the Westfälische Wilhelms-Universität Münster, Germany.

The combined infrastructure available within DSAF represents a past investment of ~ €40 M (excluding buildings) mainly sourced from national funding agencies. The entire distributed facility offered unique capabilities to determine isotopic and elemental analyses at high spatial resolution (down to ~3 nanometres), high precision (down to 5 parts per million) and high sensitivity with samples less than a nanogram.

Over the five calls issued by Europlanet 2020 RI, TA3 attracted 84 applications, of which 51 were approved and resulted in 50 completed visits to facilities.

Research enabled through TA3 visits spanned the formation of planetary atmospheres, the shaping of planetary surfaces, and studies of the interior processes that lead to the differentiation of planetary bodies.



Triton plus at VU Amsterdam



Cameca ims 1280-HR at CRPG



NanoSIMS 50L at OU



Stable Isotope Analytical Facilities, OU



NeptunePlus at WWU Münster

WP5 – VA1: Planetary Space Weather Service

Space weather – the monitoring and prediction of disturbances in our near-space environment and how they are controlled by the Sun – is an important aspect of understanding Earth and protecting our vital assets such as orbiting satellites and power grids. VA1 (Planetary Space Weather Services – PSWS) has aimed to extend the science of space weather throughout the Solar System by developing five ‘toolkits’ to assist in planning for space missions. The toolkits covered:

- General planetary space weather
- Mars
- Comets
- Outer planets
- An event-diary for predicting/detecting planetary events (meteor showers, impacts etc).

The toolkits are made up of 12 services developed by PSWS, distributed over 4 different domains:

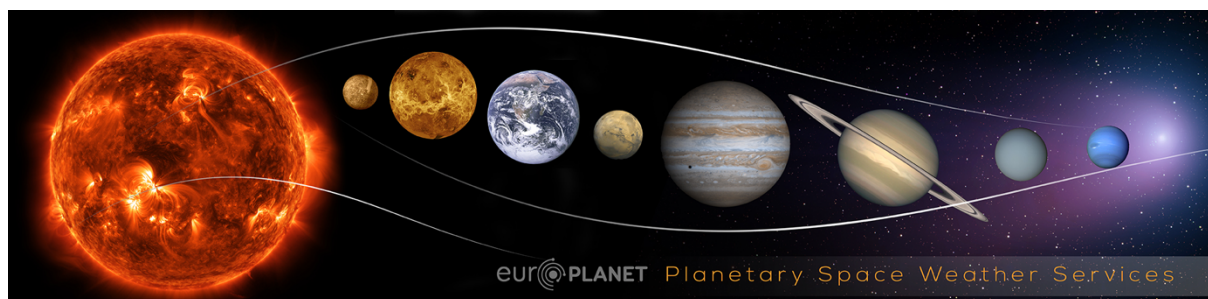
- A. Prediction
- B. Detection
- C. Modelling
- D. Alerts

All the services (see JRA4) can be accessed through the PSWS Portal:

<http://planetaryspaceweather-europlanet.irap.omp.eu/>

The PSWS portal website had 15,321 visitors during the Europlanet 2020 RI project and has a rapidly growing userbase. A topical issue on planetary space weather was published in the Journal of Space Weather and Space Climate in 2018.

PSWS’s Propagation Tool and Heliopropa prediction services have been integrated into the ESA Space Situation Awareness Space Weather Service Network portal. Ongoing, PSWS will form the basis of an expanded VA called “SPIDER”, which will include 4 new services with a particular emphasis on supporting the BepiColombo and JUICE missions.



WP6 – VA2: VESPA

WP6 VA2 developed the “Virtual European Solar and Planetary Access” (VESPA), a Virtual Observatory (VO) that provides a web-based portal to diverse planetary datasets derived from different instruments, missions and models. VESPA incorporates a series of standards and interoperable tools that enable users to share data and simultaneously visualise datasets to create a multi-dimensional view of the planetscapes under study.

VESPA also provides a light-touch, easy way for research teams to share their analysis results, helping them to reach a larger audience and prepare for the next generation of instruments or observations.

VESPA relies on:

- A set of metadata descriptors (EPNCore) that are both generic and specific to scientific themes including surfaces, atmospheres, magnetospheres, the dynamics of small bodies, exoplanets, heliophysics and laboratory spectroscopy.
- A new VO query protocol (EPN-TAP).

At the end of Europlanet 2020 RI:

- 52 online services have been made accessible through VESPA and more will continue to be added.
- There have been around 60,000 science accesses from the portal and tools over the duration of Europlanet 2020 RI.
- 20 VESPA related articles have been published.
- Over 20 papers on science enabled using VESPA have been published.
- ESA has implemented EPN-TAP access on the Planetary Science Archive, which includes 9 million files from 30 years of planetary science missions in Europe.



VESPA second mapping & VO workshop

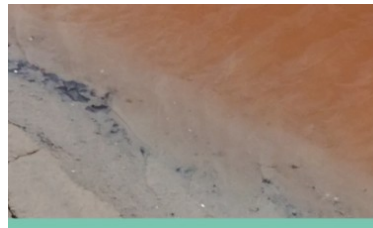
WP7 – JRA1: Characterisation of Lake Tírez & Danakil

JRA1 prepared two new planetary field analogue sites to offer through the TA1 activity in the final two years of the Europlanet 2020 RI project:

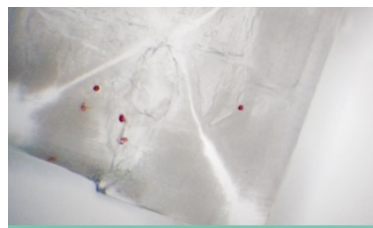
- Tírez Lake in Spain provides a good analogue for chloride deposits on Mars, such as the layered deposits discovered at the North Pole. For most of the year Tírez is composed of a sun baked, dry surface of deposited salt (NaCl) overlying sources of underground water. This extreme arid and saline environment hosts a wide biodiversity of photosynthesisers and extreme halophilic bacteria.
- Dallol in the Danakil depression in north-eastern Ethiopia is one of the hottest places on Earth and is an excellent planetary analogue for past hydrothermal activity on Mars and for astrobiological studies. Dallol is an intricately complex geological and biological setting constructed by volcanoes, hydrothermalism, salt flats, salt deposition, mineralisation, evaporation and extreme microbial communities.

The two sites were analysed and mapped, and a detailed biological survey was conducted using sequencing techniques to catalogue the biology at the different sub-habitats. Biological distribution maps (spatial and depth) were produced to help understand the processes that control interactions between the biology and geology of the sites.

Two peer-reviewed publications have resulted from the JRA1 characterisation of the field sites and there were 13 TA visits to the sites during the latter calls of the project. A newly discovered strain of salt-loving algae, which causes the vivid pink colour of Lake Tírez, was named “Dunaliella salina EP-1” after Europlanet 2020 RI.



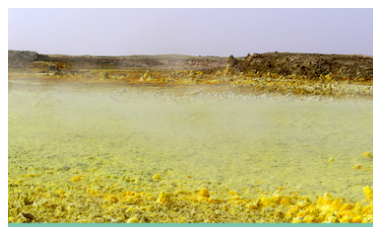
The pink waters of Lake Tírez



Algae in a salt crystal from Tírez



Salt deposits at Dallol



Danakil Depression



Characterising the site at Dallol.

WP8 – JRA2: Implementation of new spectroscopic and simulator capabilities

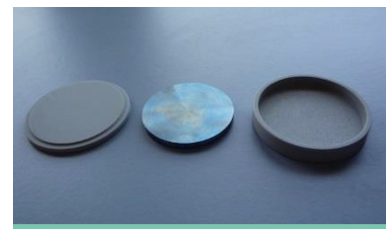
JRA2 upgraded the experimental capabilities at three of the TA2 facilities, improving capacity relevant to the planning and implementation phases of forthcoming missions to Mercury, Mars, asteroids and icy moons:

- High-speed imaging techniques, an air cooling system and a UV LED solar simulator were introduced at the Aarhus University Planetary Simulator Facility to enable a quantitative study of planetary dust and sand transport processes, and enhance understanding of surface-atmosphere interactions relevant to Mars, Earth, Venus and icy moons.
- Capabilities at the Planetary Spectroscopy Laboratory (PSL) at DLR were extended to cover the spectral range from 0.7 to 1.2 μm at Venus surface temperatures (460°C), enabling comparison of laboratory spectra with mission data gathered in the spectral windows near 1 μm , where Venus' CO_2 atmosphere is transparent and where important information on the redox state and transition metal contents on the surface can be acquired.
- A micro spectro-gonio radiometer was developed at CNRS-IPAG to enable reflectance spectroscopy for samples measuring less than one millimetre cubed and that reflect less than 0.03 percent of light illuminating the sample, offering the capability to analyse analogue comet/asteroid materials or samples from space that are mostly very dark or precious.

At least 12 TA visits have used the new capabilities at TA2 facilities during the latter TA calls.



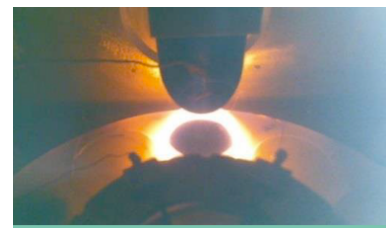
High-speed imager at Aarhus



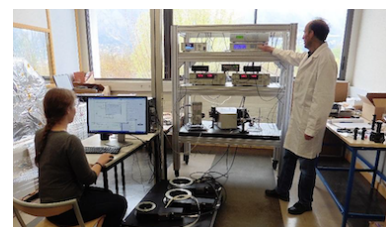
Ceramic case for sample at PSL



PSL Venus chamber testing



Sample at 700K in Venus chamber



Testing the spectro-gonio radiometer

WP9 – JRA3: Optimal planetary sample handling, investigation and analysis

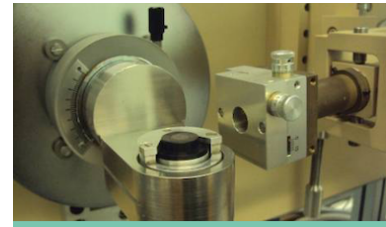
JRA 3 aimed to optimise the handling and characterisation of material from sample return missions and extra-terrestrial material such as meteorites. A road map on preparation protocols was produced¹ and techniques were evaluated to validate that sample characterisation is possible using non- or minimally-invasive preparation techniques. Using primitive chondritic meteorites, the following methodologies were validated:

- 3D image data from Computed Tomography (CT) scanning.
- X-ray diffraction measurements of powdered and unprepared rock chips of samples, as well as secondary electron microscope maps for unprepared chips and polished sections of the meteorites.
- An Electron Microprobe technique that requires no sample preparation other than carbon coating.

JRA3 has also addressed isotopic analysis of small samples by refining methods to develop and apply high resistance amplifiers to mass spectrometric analysis.

The success of the precision achieved using 10^{13} Ohm amplifiers has led to a number of publications and commercial exploitation of the technology by ThermoFischer, with applications to a diverse range of scientific disciplines that work with small samples (see Case Study 2).

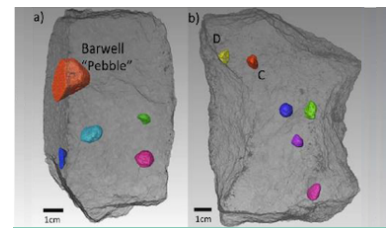
1. Road map on preparation protocols: http://www.europlanet-2020-ri.eu/sites/open.ac.uk.europlanet/files/deliverables/epn2020_ri_d9.1.pdf



CT scanner at NHM



Barwell meteorite analysed with JRA3



Analysis with JRA3 techniques



Electron microprobe images



Electron microprobe analysis

WP10 – JRA4: Planetary Space Weather Services

JRA4 has adapted and created 12 services for access through the Planetary Space Weather Services (PSWS) VA1 during Europlanet 2020 RI across the following domains:

A. Prediction

- **A1. The Heliopropa 1D MHD Solar Wind Prediction** Tool to provide real time and archive access to propagated solar wind parameters at planets, probes and comets.
- **A2. The Propagation Tool** to track solar storms, streams and energetic particles in the heliosphere.
- **A3. The Meteor showers** tool linking ephemeris of Solar System objects to predictable meteor showers.
- **A4. The Tailcatcher** tool to search for crossings of comets' ion tails by spacecraft.

B. Detection

- B1. The **ALFIE** tool to detect lunar impact flashes.
- B2. The **DeTeCt3.1** tool to detect impact flashes (fireballs) in video observations of Jupiter.
- B3. The **Windsocks** tool to estimate solar wind speeds from images of comets' ion tails.

C. Modelling

- **C1. The TRANSPLANET** ionospheric model to provide runs on request for Venus, Earth, Mars and Jupiter.
- **C2. The RADMAREE** Mars radiation surface environment model.
- **C3. The MAGNETODISC** tool for giant planet magneto-discs models connected to realistic, rapid solar wind compressions based on time-dependent predictions/observations.
- **C4. The Jovian Thermosphere Model** for Jupiter and its space environment connected to realistic, rapid solar wind compressions at Jupiter's orbit.

D. An Alerts service associated with solar wind prediction, detection of meteor showers, lunar flashes and cometary tail crossings.



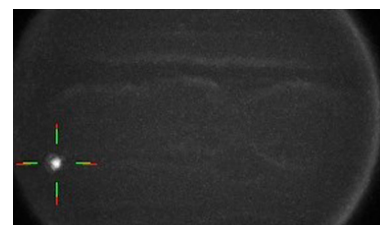
Heliopropa tool



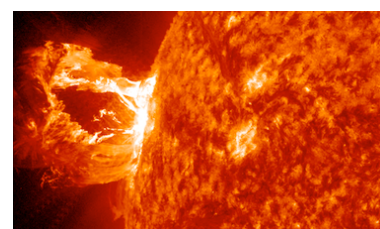
Tailcatcher & Windsocks comet tools



CDPP/Propagation tool



Jupiter fireball found with DeTeCt3.1



Coronal Mass Ejection from the Sun

WP11 – JRA5: VESPA

WP11 JRA5 developed the infrastructure underlying the VESPA VA2 facility, including data servers, access protocols, exchange standards, and tools to visualize and analyse the data. In particular JRA5 has:

- Extended the EPN-TAP access protocol developed during Europlanet-RI to support more science fields in planetary science.
- Upgraded the user interface and registry of data services, developed procedures to implement data services and laid the groundwork for sustainability.
- Prepared new VO-compliant data services with particular interest and impact in several thematic fields of Solar System studies, including spectroscopy, surface mapping, magnetospheres, atmospheres, small bodies and exoplanets.

Around 25 tools to display and process data have been developed or upgraded through the VESPA JRA5.

Collaborations on exoplanets and heliophysics are providing thematic extensions to EPNCore, which will help coordinate these fields and make future data services interoperable.

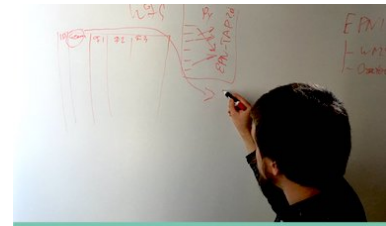
The International VO Alliance interoperability meeting in 2019, co-funded by Europlanet 2020 RI, was an important step in discussions and demonstrations of the inclusion of planetary science in the astronomy VO.

Tutorials have been developed around potential applications in many fields. These range from the identification of matching observations in non-related datasets to displaying surface data in either VO or Geographic Information System (GIS) tools to take advantage of both environments.

Procedures to support the sustainability of VESPA in the long-term have been trialled and refined through JRA5, including an installation procedure based on Docker and pilots with the European Open Science Cloud (EOSC).



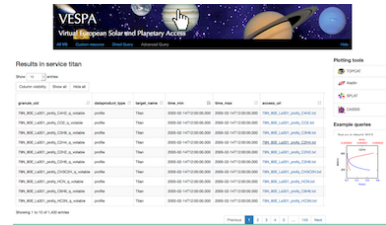
VESPA first mapping & VO workshop



Developing datasets for VESPA



VESPA first implementation workshop



VESPA portal query interface



VESPA Simulations JRA workshop

WP12 - NA1: Innovation through Science Networking

NA1 arranged meetings, topical workshops, summer schools and expert exchange visits to share best practice and expertise, expand the horizons of the ERA community, and enhance the ability of European planetary scientists to participate on the global scene.

Subjects addressed have ranged from the development of new TA and VA services to the identification of synergies between the Solar System and exoplanet science communities.

Over the four years of Europlanet 2020 RI NA1 has:

- Organised 84 workshops and/or meetings, including:
 - Two inclusiveness forums
 - Three International Space Science Institute (ISSI) workshops and two ISSI forums
 - 15 innovation and foresight workshops
 - 24 scientific workshops
 - 24 workshops to coordinate ground-based observations
 - 52% of the workshops were held in under-represented states during the last year of the project.
- Funded participation of 3390 members of the community in workshops, including:
 - 29% female participants
 - 29% early career participants
 - 16% under-represented state participants
 - 5% industry participants
 - 5% amateur astronomer participants
 - 18% participants from outside Europe.
- Funded 38 expert exchange visits over four regular calls, two special calls and one open call, with:
 - 50% female participation
 - 53% involving under-represented visitors or hosts.

Most significantly, a focused programme of inclusiveness has led to the development of an active network of planetary scientists and engineers working in under-represented states.



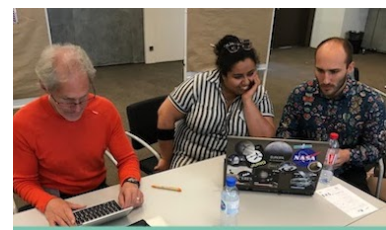
NA1 science workshop



Europlanet Summer School



Expert exchanges



VESPA workshop



Europlanet Summer School

WP13 - NA2: Impact through Outreach & Innovation

NA2 was responsible for engaging external communities with the activities of Europlanet 2020 RI and ensuring its results and achievements reach the widest possible audience.

Europlanet 2020 RI has supported the thriving planetary outreach community across Europe through:

- Three summer schools, in collaboration with NA1, to train early career researchers and amateur astronomers in communication skills.
- An annual prize and funding scheme to support innovation in public engagement and raise the profile of outreach within the scientific community.
- Teacher training and community engagement in Ethiopia, particularly in Afar, which hosts the Danakil planetary analogue site.
- Best practice workshops and sessions to promote knowledge transfer and sharing of resources.
- Development of an evaluation toolkit to help outreach providers and educators measure the impact of their activities.

Activities to engage with stakeholders have included:

- Two dinner debates and an exhibition in the European Parliament and over 20 individual briefings of MEPs.
- 81 press releases on planetary science stories and results from Europlanet 2020 RI.
- Social media presence on Twitter, Facebook, YouTube and Instagram.

Europlanet 2020 RI has also produced outreach resources including:

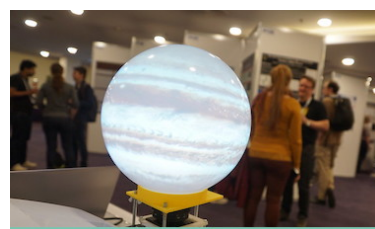
- 5 animations.
- 25 live webinars.
- 6 planetary-themed collections of educational resources.
- The "Planet P.I." Raspberry Pi climate sensor (see Case Study 7).



Afar Desert Class in Ethiopia



Exhibition in the European Parliament



Planets in a Room spherical projector



Best practice workshop



Europlanet Evaluation toolkit

Impacts of Europlanet 2020 RI

Measuring impact

Since its publication in spring 2019, Europlanet 2020 RI has started to use the framework defined by the OECD to assess its progress in working towards the following seven standard objectives for a research infrastructure:

1. Be a national or world leading scientific RI and an enabling facility to support science.
2. Be an enabling facility to support innovation.
3. Become integrated in a regional cluster/in regional strategies/Be a hub to facilitate regional collaborations.
4. Promote education outreach and knowledge transfer.
5. Provide scientific support to public policies.
6. Provide high quality scientific data and associated services.
7. Assume social responsibility towards society.

Over the course of the project, Europlanet 2020 RI has used a set of standard surveys to gather quantitative and qualitative user feedback on TA and NA activities. A range of Core Impact Indicators have been tracked, including user numbers (applications, approved TA visits, completed visits, accesses of VA services, NA workshop participation etc), publications (journal articles published, citations, impact factor of journals), dissemination activities (conference presentations, workshop organisation, press releases, exhibitions, promotional events, website visits, social media followings, video views, media coverage etc).

Data collected has been analysed within the 13 project work packages and outputs have been uploaded in the European Commission's Portal. A series of Case Studies addressing each of the seven objectives listed above have been compiled and are given at the end of this chapter.

Exploitation and dissemination of results

As of October 2019, 159 publications associated with Europlanet 2020 RI activities have been identified. These include 52 peer-reviewed articles in journals, resulting in 370 citations to date. 50% of the articles published have been in Q1 high impact factor journals, including Astronomy & Astrophysics, Geophysical Research Letters, Icarus, the Proceedings of the National Academy of Sciences of the United States of America and Nature Communications. Since much of the research undertaken is still in the process of being interpreted and new VA tools are still coming online, we expect many more publications to reference the project in the coming years.

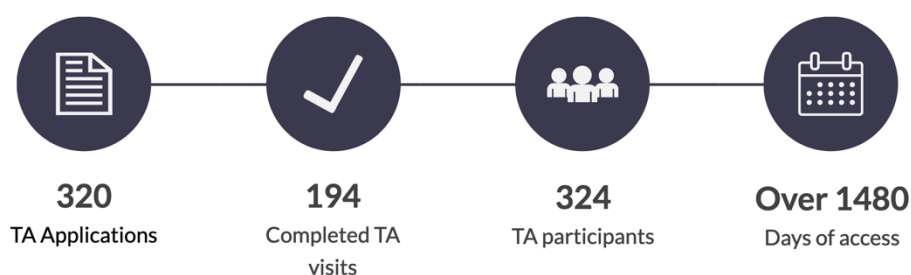
There have been over 250 conference presentations on the activities of Europlanet 2020 RI, including a series of special sessions organised at the European Planetary Science Congress (EPSC) 2018 in Berlin that highlighted the outputs of the three TAs, VESPA,

PSWS, NA1 and NA2 activities and projects supported by the NA2 Europlanet Public Engagement Funding Scheme.

TA Impacts



Over 1480 days of transnational access have been provided to over 300 research teams. As many of the visits involved 2 or more participants, the total access has significantly exceeded the 1427 days offered in the original Europlanet 2020 RI proposal.



Feedback was provided on 157 TA visits:

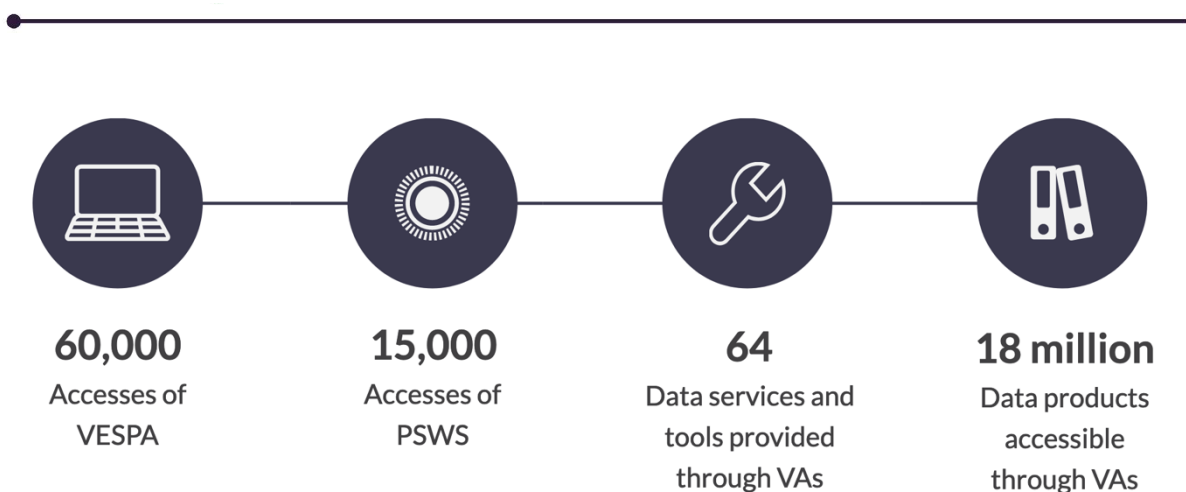
- 57% of participants had had no previous contact with the facility.
- 90% of visits were expected to lead to continuing collaborations.
- Technical capabilities of facilities met or exceeded expectations in 80% of cases.

Early feedback showed that almost 25% of respondents felt they had had insufficient time to complete their project within the ascribed visit length. In response, Europlanet 2020 RI adjusted the TA procedures to enable longer visits to be funded than initially planned. Overall, this has resulted in less visitors to the TA facilities than originally anticipated, although the number of guaranteed access days has been exceeded. However, the high impact papers that have arisen from subsequent visits demonstrates that this change has supported Europlanet 2020 RI in meeting its strategic objectives.

Main lessons learned from the TA Satisfaction Survey, which will be implemented in future TA calls include:

- Steps should be taken to cover as much of the costs directly at the host institution to assist early career and under-represented state researchers.
- More time is required for sample preparation and data interpretation and specific time for this should be included in the application.

VA Impacts



There have been an estimated 60,000 scientific accesses of VESPA services during the Europlanet 2020 RI project lifetime in addition to regular accesses from websites for large services. In October 2019, the current number of data products available within the VESPA network has reached 18.3 million.

The VESPA team has organised 26 sessions and training workshops at international meetings around the world. Metrics and feedback from participants show that, within the planetary science community, VESPA has reached a critical mass that will ensure usage beyond the lifetime of Europlanet 2020 RI or even future funded projects. Collaborations developed during Europlanet 2020 RI with the International Planetary Data Alliance (IPDA) are creating a bridge between VESPA data services and NASA's Planetary Data System (PDS4).

VESPA will continue to integrate new data services and the use of a standard VO protocol (TAP) will ensure sustainability. The EPNCore vocabulary has reached maturity and this standard set of keywords for scientific data products now has significant potential for

adaptation and use outside the VO access context, e.g. with private databases or data handling systems of space instruments in operation.

NA impacts

Europlanet 2020 RI has organised 84 meetings, workshops and training sessions, attracting over 3000 participants. NA1 workshops and summer schools have covered and combined all the different methods through which planetary science is facilitated: Earth-based observations, including those made by the amateur astronomy community, space-based observations, simulations, modeling, laboratory work and instrumentation.

The support of Europlanet 2020 RI has helped the planetary community to optimise the format of several workshops to a level that they have now been established as essential for the field, and the community has committed to maintain them beyond the Europlanet 2020 RI project. As an example, the meeting on outer planet moon-magnetosphere interactions held in February in Selfoss, Iceland, will be organised as a biennial conference henceforth.

In December 2018, Europlanet 2020 RI was selected by the European Commission as a Horizon 2020 success story. The project was featured in an article in Horizon, the EU Research and Innovation Magazine and promoted on the official Horizon 2020 and DG Research & Innovation Twitter channels

The Europlanet Media Centre issued 81 press releases on the results of Europlanet 2020 RI and planetary science topics, which have resulted in thousands of pieces of coverage in 61 countries worldwide. The Danakil site in particular has attracted significant interest from the media and several of the JRA/TA expeditions have been accompanied by journalists, photographers and artists. In 2017, a crew from the Nutopia television production company accompanied Europlanet 2020 RI researchers on a JRA field trip to Dallol. Footage was included in Gasp, the first episode of National Geographic's landmark series One Strange Rock. 81 million people worldwide have watched the series and the "Acidic Life" clip featuring researchers at Dallol has been viewed 1.1 million times on Facebook.

Outreach and educational resources produced in-house by Europlanet (including evaluation tools, videos, educational resource collections on astroEDU) and by the wider planetary community supported through the Europlanet Outreach Funding Scheme have been used by many thousands of citizens, teachers and students in Europe and around the world. Europlanet's Youtube channel has had over 100,000 minutes of watchtime and the project's videos, including animations, live webinars, short interviews with early career scientists, project team interviews and facility introductions have had an estimated 140,000 views (around 90,000 through Europlanet and Science Office channels and 50,000 through sharing of the videos at exhibitions and on other platforms e.g. [S]Cube and Space.com).

In July and August 2019, Europlanet 2020 RI funded a film crew to visit TA sites in Aarhus, Iceland and DLR, and the series of films will be released at the end of 2019. In addition to highlighting the impact of research from the Europlanet 2020 RI TA programmes, these films will be used to promote the facilities in the future.

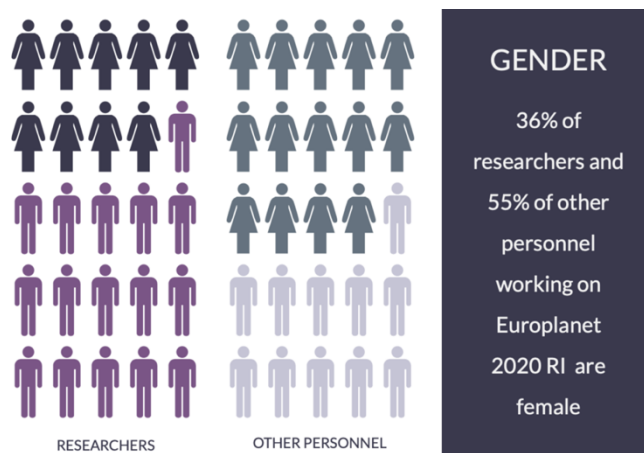
Community impacts

In measuring its success, Europlanet 2020 RI has made special efforts to monitor the participation from under-represented states (URS) and early career researchers. The proportion of early career participants in NA1 workshops grew from ~18% in the first year of the project to ~35% in year 4. Europlanet has prioritised URS applications for grants and bursaries to attend its workshops, summer schools and expert exchange programmes. It has developed specific mailing lists, targeted under-represented countries as hosts for key meetings (summer schools, training workshops, scientific meetings and EPSC 2017 was held in Latvia) and provided support for applications from URS in preparing TA submissions. This has led to some successes:

- 16% of all Europlanet 2020 RI workshop participants were from URS during 2018-19, compared to ~10% in 2015-16.
- 52% of the students and early career scientists participating in the Europlanet 2020 RI summer schools held at the Moletai Astronomical Observatory in Lithuania in 2017, 2018 and 2019 were from URS.

Feedback from students attending the Europlanet and Alpbach summer schools, and tracking of their subsequent engagement with the community, demonstrates that this type of early-career focused activity is a valuable tool to integrate URS scientists and engineers into the European community and to build capacity within URS. However, NA1 evaluation also shows the importance of holding meetings and workshops within under-represented countries and regions, as well as providing bursaries for URS researchers to travel internationally e.g. the URS participation at EPSC fell back to 7.6% in Berlin in 2018 after the 2017 high (18.3%) when EPSC was held in a URS (Latvia).

Europlanet 2020 RI introduced a diversity commitment in 2017, which is now upheld by all projects using the Europlanet brand. A gender breakdown of participants in Europlanet 2020 RI activities shows that 30% of visitors to TA facilities and 29% of participants in NA1 workshops were female. Of people funded directly to work on Europlanet 2020 RI activities, 36% of researchers and 55% of other personnel were female.



Case Study 1: Supporting world-leading science

Maximising impact through the Europlanet 2020 RI within the framework of international missions.

In April 2018, ESA and NASA signed a statement of intent to explore concepts for missions to bring samples of Martian soil to Earth, confirming sample return as one of the highest priorities for the international planetary community. The increasingly ambitious sample return missions coupled with technological and methodological breakthroughs are opening up new analytical fields that will constrain rates and timescales of processes controlling the formation and differentiation of planetary bodies.

Europlanet 2020 RI's TA programme has offered a suite of field and laboratory sites relevant for testing and preparing for future sample return missions, as well as access to four of the world's leading analytical laboratories to analyse meteoritic and sample returns with un-paralleled precision. The JRA3 programme augmented these capabilities with sample return handling protocols and ultra-sensitive isotopic analysis techniques, and produced an integrated methodology for optimising the handling, characterisation and analysis of rare samples, particularly in the context of future sample return missions.

Members of the Europlanet 2020 RI team led the European Curation of Astromaterials Returned from Exploration of Space (EURO-CARES) project, an H2020 project to develop a roadmap for a European Extra-terrestrial Sample Curation Facility (ESCF) to receive and curate samples returned from Solar System exploration missions to asteroids, Mars, the Moon, and comets. A follow up NA1 workshop involving participants from China, India, Japan, the USA, Canada, Australia and Europe reviewed the outstanding science questions that can only be answered via sample return missions, evaluated technological readiness for individual mission concepts and road-mapped engagement with sample curation communities across Europe to prepare for future sample return missions.

The outcomes of this meeting will be published in the Space Science Series of ISSI books, Volume 74: Role of Sample Return in Addressing Major Questions in Planetary Sciences, in 2020.

As both Europe and the US head back to Mars in 2020 with the ExoMars and NASA 2020 Rovers, Europlanet has a critical ongoing role to play in providing TA capabilities for the analysis of small and rare samples and a platform for inter-disciplinary, international discussions on the scientific, technical and societal implications of sample return missions.

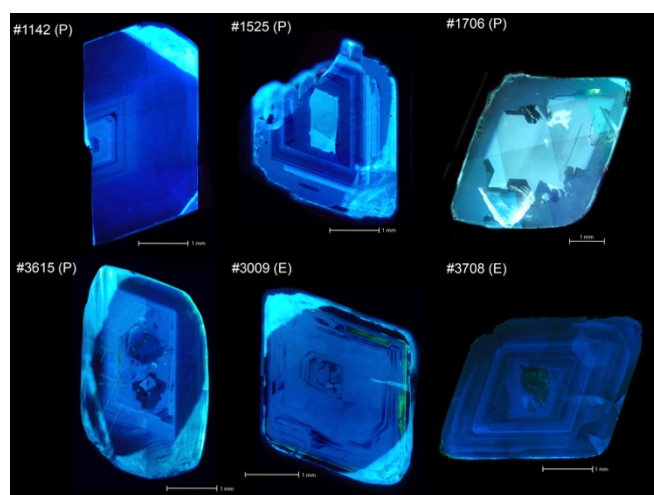
Case Study 2: Supporting Innovation

Collaboration across disciplines and with commercial sectors

A Europlanet 2020 RI JRA evaluated the use of 10^{13} Ohm amplifiers developed together with ThermoFisher to achieve very high sensitivity for exploring planetary processes.

This work resulted in a tenfold improvement in precision over conventional resistors allowing smaller samples to be analysed. ThermoFisher has released the 10^{13} Ohm resistors as a commercial product applied to a wide variety of instrumentation. The 10^{13} Ohm amplifiers have since been applied at both VUA and CRPG and offered for TA visits in the last TA three calls in Europlanet 2020 RI.

This ground breaking technology opens up new frontiers across the spectrum of analytical chemistry, with potential applications for a very broad range of non-planetary users for whom sample size is a key issue. A good example of this is an interdisciplinary study published in Nature Communications by VUA in 2017, which showed that diamonds retain records that certain volcanic events on Earth may still be able to create super-heated conditions previously thought to have only existed early in the planet's history before it cooled. These findings have implications for diamond prospecting.



Cathode luminescence image of diamond with inclusions

The team at VUA is also currently working with Pima County Office of the Medical Examiner to use isotopic analysis to assist in the identification of human remains for undocumented border crossers who do not survive the journey between Mexico and the United States. In 2017, researchers from the University of Oxford were awarded funding to apply micro-analytical techniques to museum quality artefacts to determine their place of origin (provenance).

The team at VUA has also been invited to join the IPERION CH Consortium, which is proposing the establishment of an ERIC for restoration and conservation science within Cultural Heritage.

Collaborations with ThermoFisher will be ongoing beyond the Europlanet 2020 RI project to develop further improvements in the technology. Practical applications of the analysis of small samples and the work is expected to open up new areas of research in planetary science and other disciplines.

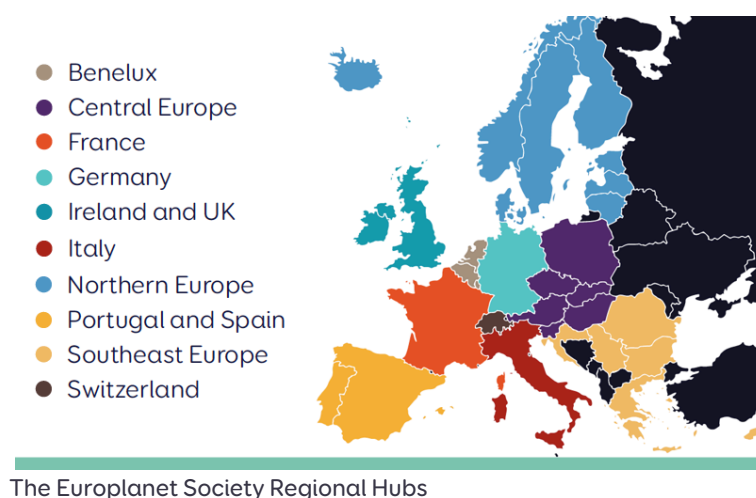
Case Study 3: Building regional collaborations

Supporting regional integration, strategy and growth

Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Poland, Portugal, Romania, Serbia, Slovakia and Slovenia represent around 25% of the EU's population, yet researchers from these under-represented states (URS) make up only around 6-8% of Europe's planetary science community. This under-representation is a significant problem that inhibits Europe's capacity to drive economic growth, secure its competitiveness on the world stage and develop the European Research Area.

A particular objective of Europlanet 2020 RI has been to widen participation from URS countries, and more than half of the Expert Exchanges during Europlanet 2020 RI involved URS participants. A number of these have led to ongoing collaborations, including a visit by Dr Mark Hofstadter, from NASA's Jet Propulsion Laboratory, to the Wigner Research Centre for Physics for one week in 2019. The two institutes had not had a close working relationship before and, if it were not for the Expert Exchange program, the visit would never have happened. Actions were identified for continued and expanded collaborations, including further exchanges with scientists at Wigner and opportunities for US researchers to co-supervise Hungarian graduate students. As a result of the Expert Exchange, specifications of the Wigner-designed FluxSet magnetometer have been shared with scientists at various US institutions, creating interest and opportunities within the US that may lead to flight-qualification of these new sensors.

In developing a sustainable structure for Europlanet 2020 RI and other EU-funded Europlanet projects, particular efforts have been focused on building capacity and more effective communication channels within less-represented communities. The Europlanet Society has set up 10 Regional Hubs to proactively develop networks, raise awareness and facilitate cooperation between the main institutions in each area. This support, particularly in Northern, Central and South-Eastern Europe, will enable Europlanet 2020 RI to cement its legacy and continue to grow regional collaborations beyond the lifetime of the project.



Case Study 4: Knowledge transfer and outreach

Building a wider user base through citizen scientists

Junocam is a wide-angle camera that provides the best spatial resolution ever acquired of Jupiter's cloud-tops. Data from Junocam shows convective clouds and lightning in thunderstorms and identifies unusual atmospheric conditions such as hotspots. There is no formal science team associated with Junocam: the instrument has an explicit remit to engage with citizen scientists. Amateur astronomers supply ground-based images and the public vote on images to acquire, and the amateur image processing community help process the data.

Workshops organised by Europlanet 2020 RI NA1, which brought together amateur astronomers and professional scientists, were critical in coordinating the observational campaigns for the JunoCam instrument and sharing techniques and best practice for processing data. Amateurs involved in the observational campaigns have uploaded their data to the Planetary Virtual Observatory and Laboratory (PVOL) data service, which is served from the VESPA portal using the EPN-TAP protocol and currently used by 351 data providers within the amateur community.

The campaign in support of Juno has had high-profile impact within the science community and in wider society. Three peer-reviewed publications on observations in support of Juno using data from PVOL have been published to date. The "New Views of Jupiter" workshop held in May 2018 trended on Twitter with the #RASJuno hashtag and a report was published in *Astronomy & Geophysics*. Europlanet 2020 RI issued 3 press releases related to the Juno campaign and workshops, resulting in worldwide media coverage and a feature on the BBC's *Sky at Night* programme.

To celebrate the arrival of Juno at Jupiter, and highlight European involvement in the mission, Europlanet held a public event in Athens with a panel of four leading European Jupiter scientists and a live link-up to JPL. The event was attended by 150 members of the public and teachers and was widely covered by the Greek national media. The event also featured the premiere of "Jupiter and its Icy Moons", a Europlanet animation on the Juno and JUICE missions, which was shortlisted for the European Science TV and New Media Festival and Awards 2017/18.

Case Study 5: Supporting strategic development

Developing global collaborations and supporting growth in new communities

Africa has enormous potential to contribute to planetary and space sciences, but is currently under-represented in the planetary community worldwide. From 2016-2017, Europlanet 2020 RI's JRA1 characterised the Danakil Depression as a planetary analogue. Since the site was made available for Transnational Access by external users in August 2017, 15 people have made TA visits to Danakil, with research projects ranging from providing ground-truth for Cassini observations of Titan, to characterising the microbiological community and using the Afar Depression to constrain the paleoclimatic evolution of Mars.

In December 2016, Europlanet 2020 held a workshop on the Danakil Depression attended by researchers from Europe and Ethiopia, as well as citizen scientists, outreach providers, industrial partners and representatives of Astronomy for Development. Following the meeting, participants signed a collaboration agreement and direct outcomes have included a successful application by the University of Bologna for an Erasmus+ grant to support staff exchanges. Europlanet researchers have also worked with communities around Ethiopia to pilot workshops to train teachers and engage local communities with the unique nature of the site, its international and scientific significance and its need for environmental protection.

The Danakil site will be a core facility of all future Europlanet TA programmes. TA visitors to Ethiopia will be integrated into a programme of outreach and training in East Africa, developed with the University of Mekelle.

Botswana also holds a number of planetary field analogue sites. The National Space Science and Technology Strategy for Botswana includes plans to support planetary research in the country through the creation of a Planetary Science Centre hosted by the Botswana International University of Science and Technology (BIUST). The Botswana Planetary and Space Science workshop, which took place in October 2018, was an opportunity to explore how Botswana could expand its involvement in planetary research and create a solid network of collaboration with international partners, including Europlanet 2020 RI. Outcomes included an agreement by delegates to promote a pan-African network of space and planetary science building on existing networks.

Going forward, Europlanet will build on experiences in Ethiopia to support the planetary science community in Botswana, as well as other emerging space programmes in Africa, by facilitating training, knowledge exchange and access to resources.

Case Study 6: Access to cutting edge data

Developing interoperable multi-database structures for a global community

The Solid Spectroscopy Hosting Architecture of Databases and Expertise – SSHADE (www.sshade.eu) provides spectral and photometric data over the whole electromagnetic spectrum from gamma to radio wavelengths. This interoperable database includes data on ices, minerals, rocks, organic and carbonaceous materials and liquids obtained in the laboratory, in the field at planetary analogue field sites or from extraterrestrial samples. The SSHADE infrastructure groups 20 databases (developed by non-Europlanet 2020 RI beneficiaries) worldwide in a central system; SSHADE is also the repository of the spectroscopic data recorded by participants in the TA2 programme.

Europlanet 2020 RI's JRA5 has developed SSHADE by creating a multi-database structure complete with data import tools, search/visualisation/export interfaces for users and data providers, templates and various conversion tools. The service was completed and delivered for open access in January 2018. A VO service has also been released, so that the SSHADE content is searchable and accessible from the VESPA portal.

A VESPA internal workshop held in Rome in November 2018 gathered specialists of experimental spectroscopy to identify a common basic Data Model to provide increased support for non-specialist observers who need to quickly identify possible materials matching observed spectral signatures in the optical-IR range, without detailed knowledge of the SSHADE interface. An EPN-TAP spectral and experimental extension finalised during this workshop has enabled richer, more consistent support for users in interpreting the composition of planetary surfaces observed by planetary missions, and will allow cross-searches between SSHADE and other spectroscopy services in VESPA.

Meetings to train and support 20 SSHADE data providers were hosted over the course of Europlanet 2020 RI, including 3 short SSHADE sessions for users during EPSC 2018 in Berlin.

The SSHADE database infrastructure has been recognised by the Federation of Digital Object Identifier (DOI) Registration Agencies and is now authorised to assign a DOI to cite each dataset stored within the SSHADE database infrastructure.

Case Study 7: Social responsibility

Applying planetary solutions to day-to-day living

NA2 developed a pilot outreach tool, Planet P.I. for use in formal and informal settings based around two of Europlanet's core science themes: planetary analogues and comparative planetology. Planet P.I. challenges students to compare climate data on Earth with data from the Rover Environmental Monitoring Station (REMS) instrument on the Curiosity Rover, which has been exploring the Gale Crater on Mars since August 2012.

Planet P.I. was successfully tested in the field, in urban and in extreme volcanic environments by scientists during planetary analogue field trips supported through Europlanet 2020 RI's JRA/TA programme.

The project has been piloted with schoolteachers and the Latvian interactive science museum, Zinoo, and there has also been commercial interest from the Latvian Commercialization Reactor in a spinoff. The Pi Pollution Detector aims to repurpose the Planet P.I. Raspberry Pi and sensors to address the social issue of pollution in the city of Riga caused by coal transfer from the shipyard and car exhaust. Because the Planet P.I. prototype has already demonstrated robustness in extreme field conditions in Ethiopia, the Pi Pollution Detector has been fast-tracked through early-stage processes to prove the hardware and qualified directly for Accelerator status. A social entrepreneurship company is being established to support the development of the device (<https://www.balticsinspace.eu>).



Planet P.I. in field tests at the Danakil Depression in Ethiopia

Conclusions

Europlanet 2020 RI has produced a step-change in research in Europe by providing the largest open access research infrastructure for planetary science in the world. The project has established the structures for longer term collaborations both within the European community and between Europe and international partners. The European Commission has recognised Europlanet 2020 RI as a Horizon 2020 success story.

Overall, Europlanet 2020 RI has had major impacts for the community:

- Europe's planetary simulation and analytical facilities have been upgraded through the JRA programme and the TA programme has led to the publication of high-impact research.
- Europlanet's VA activities, VESPA and PSWS, have evolved into mature, well-used facilities with protocols and tools that have become standards in the worldwide Virtual Observatory communities.
- Networking activities have been effective in disseminating the outputs of the project and developing capacity in under-represented states within the European Research Area and beyond.

The procedures implemented and lessons learned during the project have enabled Europlanet to refine the mechanisms and protocols necessary to enable mobilisation and collaboration within the community to maximise the impact of the talent and facilities within the European planetary community. The project's legacy, supported within the sustainable framework of the new Europlanet Society, will provide a solid foundation for a European planetary research infrastructure for decades to come.

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WP1 Management team: Nigel Mason (OU), Athena Coustenis (Obs. Paris), Barbara Pizzileo (OU), Louise Thomas (OU), Susmita Datta (OU), Beverley Bishop (OU), Nicolas Walter (ESF), Steve Miller (UCL), Marcell Tessenyi (BSSL).

WP2 TA1 team: Felipe Gomez (CAB-INTA), Gian Gabriele Ori (IRSPS) and Barbara Cavalazzi (University of Bologna), Viggó Þór Marteinsson (MATIS).

WP3 TA2 team: Jörn Helbert (DLR), Jonathan Merrison (Aarhus), Manish Patel (OU), Gareth Davies (VUA), Bernard Schmitt (IPAG), Christine Moissl-Eichinger (MUG), Sara Russell (NHM).

WP4 TA3 team: Gareth Davies (VUA), Albert Galy (CRPG), Ian Franchi (OU), Thorsten Kleine (WWM).

WP5 VA1 team: N. André (IRAP), M. Grande (Aber), N. Achilleos (UCL), M. Barthélémy (IPAG), M. Bouchemit (IRAP), K. Benson (UCL), P.L. Blelly (IRAP), E. Budnik (IRAP), S. Caussarieu (GFI), B. Cecconi (Obs Paris), T. Cook (Aber), P. Guio (UCL), A. Goutenoir (IRAP), B. Grison (CAS), R. Hueso (UPV/EHU), M. Indurain (IRAP), G. H. Jones (UCL), J. Liliensten (IPAG), A. Marchaudon (IRAP), D. Matthiä (DLR), A. Opitz (Wigner), I. Stanislawska (PAS), J. Soucek (CAS), C. Tao (NIICT), L. Tomasik (PAS), J. Vaubaillon (Obs Paris), V. Génot (IRAP), A. Rouillard (IRAP).

WP6 VA2 Team: S. Erard (Obs Paris), B. Cecconi (Obs Paris), P. Le Sidaner (Obs Paris), C. Chauvin (Obs Paris), A. P. Rossi (Jacobs Uni.), M. Minin (Jacobs Uni.), T. Capria (INAF), S. Ivanovski (INAF), B. Schmitt (IPAG), V. Génot (IRAP), N. André (IRAP), C. Marmo (GEOPS), A. C. Vandaele (BIRA-IASB), L. Trompet (BIRA-IASB), M. Scherf (OEAW), R. Hueso (EHU), A. Määttänen (LATMOS), B. Carry (IMCCE), N. Achilleos (UCL), J. Soucek (CAS), D. Pisa (CAS), K. Benson (UCL), P. Fernique (Obs Strasbourg).

WP7 JRA1 team: Felipe Gómez (CAB-INTA), Barbara Cavalazzi (U. Bologna), Gian Gabriele Ori (IRSPS), José Antonio Rodríguez (CAB-INTA), Ricardo Amils (CAB-INTA), Olga Prieto-Ballesteros (CAB-INTA), Juan Angel Vaquerizo (CAB-INTA), Nuria Rodríguez (CAB-INTA), Fernando Camps (CAB-INTA), Beatriz Flores (CAB-INTA), Goro Komatsu (IRSPS), Monica Pondrelli (IRSPS).

WP8 JRA2 team: Jörn Helbert (DLR), Jonathan Merrison (Aarhus), Bernard Schmitt (IPAG), Gareth Davies (VUA), Sandra Potin (IPAG), Pierre Beck (IPAG), Olivier Brissaud (IPAG), J.J. Iversen (Aarhus), Manish Patel (OU), Bernadett Weinzierl (DLR), Alessandro Maturilli (DLR), Jörn Helbert (DLR), Thomas Widemann (LESIA), Sabrina Ferrari (University of Padua), Dennis Wendler (DLR).

WP9 JRA3 team: Sara Russell (NHM) and Gareth Davies (VUA), Albert Galy (CNRS), Etienne Deloule, Laurie Reisberg (CRPG), Ian Franchi (OU).

WP10: N. André (IRAP), M. Grande (Aber), N. Achilleos (UCL), M. Barthélémy (IPAG), M. Bouchemit (IRAP), K. Benson (UCL), P.L. Blelly (IRAP), E. Budnik (IRAP), S. Caussarieu (GFI), B. Cecconi (Obs Paris), T. Cook (Aber), P. Guio (UCL), A. Goutenoir (IRAP), B. Grison (CAS), R. Hueso (UPV/EHU), M. Indurain (IRAP), G. H. Jones (UCL), J. Liliensten (IPAG), A. Marchaudon (IRAP), D. Matthiä (DLR), A. Opitz (Wigner), I. Stanislawska (PAS), J. Soucek (CAS), C. Tao (NIICT), L. Tomasik (PAS), J. Vaubaillon (Obs Paris), V. Génot (IRAP), A. Rouillard (IRAP).

WP11: VESPA JRA Team: Stephane Erard (Obs Paris), B. Cecconi (Obs Paris), P. Le Sidaner (Obs Paris), C. Chauvin (Obs Paris), A. P. Rossi (Jacobs Uni.), M. Minin (Jacobs Uni.), T. Capria (INAF), S. Ivanovski (INAF), B. Schmitt (IPAG), V. Génot (IRAP), N. André (IRAP), C. Marmo (GEOPS), A. C. Vandaele (BIRA-IASB), L. Trompet (BIRA-IASB), M. Scherf (OEAW), R. Hueso (EHU), A. Määttänen (LATMOS), B. Carry (IMCCE), N. Achilleos (UCL), J. Soucek (CAS), D. Pisa (CAS), K. Benson (UCL), P. Fernique (Obs Strasbourg).

WP 12 NA1 team: Ari-Matti Harri (FMI), Melinda Dosa (Wigner), Norbert Krupp (MPS), Elias Roussos (MPS), Manuel Grande (Aber), Rachel Cross (Aber), Gunther Kargl (OeAW), Manuel Scherf (OeAW), Maria Genzer (FMI), Harri Haukka (FMI).

WP13 NA2 team: Mariana Barrosa (SO), Anita Heward (SO), Thilina Heenatigala (SO), Sara Mynott (SO), Livia Giacomini (INAF), Veronika Raszler (SO), Eleni Chatzichristou (IASA), Pedro Russo (U. Leiden), Gražina Tautvaisiene (U. Vilnius), Rosa Doran (NUCLIO), Steph Tyszkla (NUCLIO), Amara Graps (Baltics in Space,), Felipe Gomez (CAB-INTA), Jen DeWitt (UCL), Karen Bultitude (UCL).

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P6. Europlanet 2020 RI, F Gomez, R Thombre, J Raack, MATIS

P7. DLR, Aarhus, OU, IPAG-CNRS, NHM

P8. VU Amsterdam, CRPG-CNRS, OU, NHM

P9. Europlanet 2020 RI, IRAP-CNRS, NASA, ESA, JPL-CALTECH

P10. Erica Luzzi

P11. Europlanet 2020 RI, F Gomez, R Thombre, CAB-INTA, B Cavalazzi, U. Bologna

P12. J Merrison, Aarhus University, J Helbert, DLR, IPAG-CNRS, B Schmitt

P13. L. Martel/NHM, London, N. Vasiliki Almeida, VU Amsterdam, J Koornneef et al

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