USING VIRTUAL AND AUGMENTED REALITY FOR PLANETARY SURFACES INVESTIGATIONS – A CASE STUDY ON MARS AND THE MOON. S. Le Mouélic[1], G Caravaca[1], N. Mangold[1], J. Wright[2], C. Carli[3], F. Altieri[3], F. Zambon[3], C. H. van der Bogert[4], R. Pozzobon[5], M. Massironi[5], B. De Toffoli[5], A. P. Rossi[6]. [1] LPG, CNRS UMR6112, Univ.Nantes, France. [2] School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK; [3] INAF-IAPS, Romae, Italy; [4]Institut für Planetologie, Westfälische Wilhelms-Universität, Münster, Germany; [5] University of Padova, Dipartimento di Geoscienze, Padova, Italy; [6] Department of Physics and Earth Sciences, Jacobs University Bremen, Germany.

Introduction: Virtual Reality (VR) and Augmented Reality (AR) coupled with 3D terrain reconstructions are increasingly used for science, education and outreach applications. These techniques [1, 2] are becoming more widespread thanks to the release since 2016 of reliable, versatile and cost-effective hardware solutions accessible to the general public. In the field of planetology, VR and AR theoretically allow the possibility to simulate field trips to remote places that are otherwise inaccessible to humans. Using high-resolution imaging, coupled with spectral or morphological data gathered by robotic explorers (orbiters, landers, rovers), we can create integrated virtual environments that accurately represent the surface of planetary bodies and allow visualization and characterization of different datasets. These virtual environments provide the possibility to navigate on a global scale using orbital data, and move down to the surface when *in situ* data are available to explore and analyze local outcrops. This is particularly useful in the cases of the Moon and Mars, where both extensive orbital and *in situ* data are available [3, 4, 5].

Online Resources: The VR and/or AR rendering of simple orbital and/or ground-based 3D models can be first performed using a web-based solution such as Sketchfab. This offers the possibility to easily visualize, interact, and share medium-resolution 3D models derived either from photogrammetric or stereoscopic reconstructions (e.g. https://sketchfab.com/LPG-3D or https://sketchfab.com/planmap.eu, Fig. 1 and 2).

Fig. 1: Use of the Sketchfab online plateform to visualize digital outcrop models derived from Curiosity imaging data using a Virtual Reality headset (left), or using Augmented Reality with a smartphone (right).

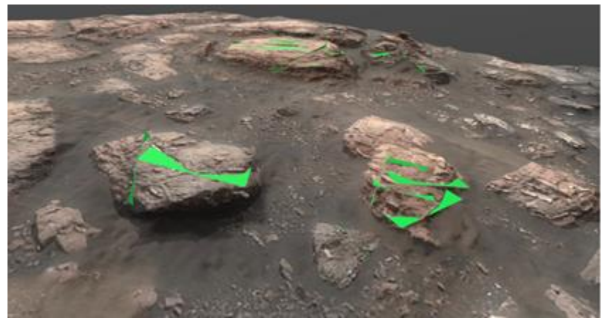

Fig. 2: Example of a structural analysis on sulfate vein networks in Gale crater described in [6] and viewable directly online on Sketchfab.

Stand-alone applications: We are also investigating how the information from various sources can be integrated into a single comprehensive way to display, manipulate, analyze and share both analytical data and results. The use of a more powerful and versatile solution based on a game engine [7] allows the development of such more complex solutions. An application has been developed to recreate common geological measurments tools in VR on the Kimberley area in Gale crater (Mars), allowing the detailed quantitative investigation of a layered outcrop of sedimentary origin (Fig. 3, see also [8]).

Fig. 3: Use of dedicated VR geological measurement tools on the Kimberley area.

On a second application, we have created an experience integrating visible high-resolution imagery, digital elevation and outcrop models, geomorphological maps and compositional maps derived from spectroscopic measurements on several test sites such as the Copernicus crater and Apollo 17 landing sites on the Moon, the Crommelin crater, Kimberley area (Gale crater), Jezero crater and Oxia Planum on Mars, and the Hokusai quadrangle area on Mercury (Fig. 4 and 5). For each of these cases, the use of a VR headset helps to better understand the environment, the scales, and the relationships between different morphological units.

In terms of hardware solutions, when high levels of details and significant data volumes are required, the VR headset has to be coupled to a high-end computer embarking a gaming-rated GPU to process the virtual environment. In the case of more optimized or focused application, a wireless headset such as the Oculus Quest might be powerful-enough to provide a comprehensive experience.

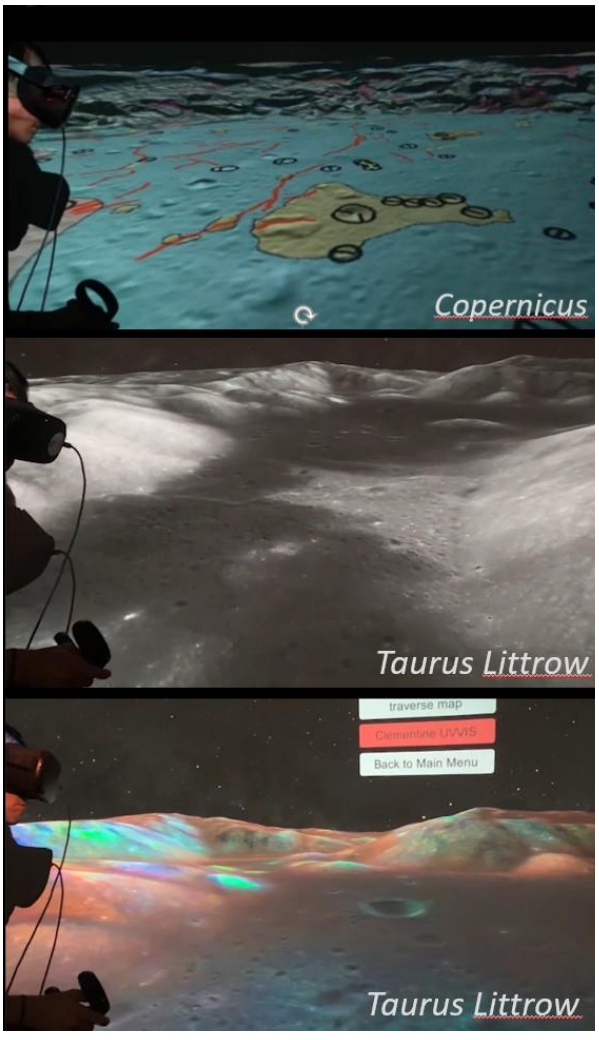

Fig. 4: The integration of orthoimages drapped on a digital elevation model into a VR environnement allows the user to freely explore and observe the structures from any point of view, without the deformations induced by reprojections on a traditional computer screen.

Conclusion and perspectives: These VR approaches offer new possibilities in terms of data exploration, analysis, and applications for research, education and outreach simulating "virtual planetary field-trips". One of the challenges in the forthcoming years will be to achieve a semi-automated integration and fusion of data sets reprensenting several Terabytes both of orbital and ground based images and digital elevation models, into the constantly evolving VR and AR hardwares. For orbiters and rovers, this integration possibly relies on the use of SPICE kernels to automatically register and integrate data taken from orbit and on the ground at scales up to few mm.

Acknowledgments: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776276 (PLANMAP). We also thank VR2Planets for the VR tools on Kimberley.

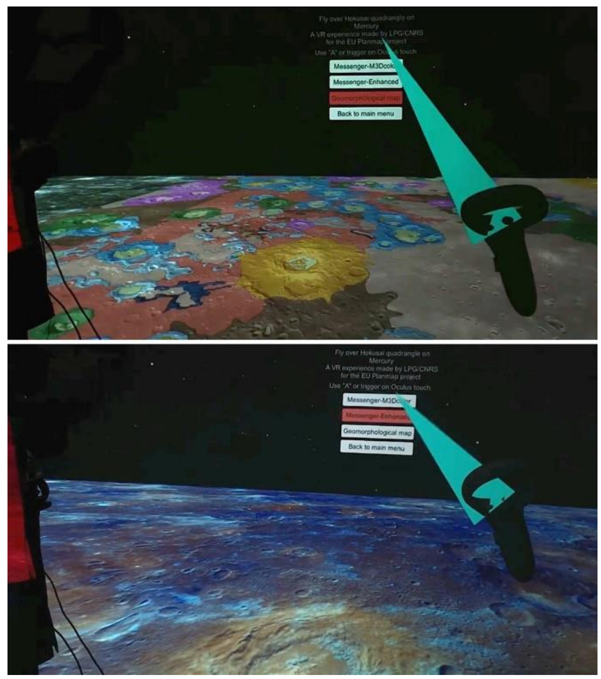

Fig. 5: Integration in VR of Messenger false color mosaics with a geomorphological map on the Hokusai region on Mercury.

Bibliography: [1] McGreevy (1993), M.W. Virtual reality and planetary exploration. In Virtual Reality; Elsevier: Amsterdam, The Netherlands,; pp. 163–197, ISBN 0-12-745045-9. [2] Favalli, M. et al. (2012), Comput. Geosci. 2012, 44, 168–176. [3] Ostwald, A. and Hurtado, J., Proc. of the 48th LPSC, The Woodlands, TX, USA, 2017. LPI Contribution No. 1964, id.1787. [4] Caravaca, G. et al. (2020) Planet Space Sci, 182, 104808, DOI: 10.1016/j.pss.2019.104808. [5] Le Mouélic, S. et al. (2020) Remote Sensing, 12 (11), DOI: 10.3390/rs12111900. [6] De Toffoli et al. (2020), J. Str. Geol., 137. [7] Nesbit, P.R et al. (2020), GSA Today, vol. 30, 4–10. DOI: 10.1130/GSATG425A.1. [8] Caravaca et al., This issue.