OSIRIS-REX ENCOUNTERS EARTH: SIGNATURES OF A HABITABLE WORLD. D.S. Lauretta[1], S.S. Balram-Knutson[1], C.A. Bennett[1], B.J. Bos[2], C. Drouet d'Aubigny[1], P.R. Christensen[3], E.C.A. Church[4], D.N. DellaGiustina[1], H.L. Enos[1], D.R. Golish[1], V.E. Hamilton[5], C.W. Hergenrother[1], E.S. Howell[1], J.N. Kidd Jr.[1], M.C. Nolan[1], D.C. Reuter[2], B. Rizk[1], A.A. Simon[2], and the OSIRIS-REx Team. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA (lauretta@lpl.arizona.edu). [2]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]Arizona State University, Tempe, AZ, USA. [4]Lockheed Martin Space, Littleton, CO, USA. [5]Southwest Research Institute, Boulder, CO, USA. Email: lauretta@lpl.arizona.edu

Introduction: OSIRIS-REx is an asteroid sample return mission [1]. The spacecraft is currently in interplanetary space and scheduled to arrive at asteroid (101955) Bennu [2] in November 2018. The mission design incorporated a gravitational assist at the Earth to match Bennu's orbital inclination of ~6˚. This encounter permitted observations of the Earth, allowing us to repeat the famous search for life that the Galileo mission team performed in 1990 [3], along with similar spacecraft-based campaigns [4,5].

Closest approach to Earth occurred on 22 September 2017 at a range of 17,237 km over the southern Pacific Ocean (Lat = 74.73˚ S, Lon 271.94˚ E). OSIRIS-REx approached Earth from its night side. All data were acquired post encounter as part of an extended instrument checkout campaign from 22 September through 2 October 2017. The OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS) [6], the OSIRIS-REx Thermal Emission Spectrometer (OTES) [7], the OSIRIS-REx Camera Suite (OCAMS) [8,9], and the Touch-and-Go Camera System (TAGCAMS) [1] acquired data.

Signatures of a Habitable World: The ultimate goal of exoplanet remote sensing is to detect atmospheric biosignatures remotely [10]. A necessary but not sufficient condition for the presence of life is a marked departure from thermodynamic equilibrium. Atmospheric biosignatures are chemical species in the atmosphere that are out of chemical equilibrium and are byproducts of life processes. In our analysis, we focused on identifying spectral features of chemical species that indicate habitability for a temperate rocky planet.

Imaging Data: The first images of the Earth were acquired with the TAGCAMS NavCam (Fig. 1). These panchromatic images reveal vast expanses of ocean with apparent continents and coastlines. A region of specular reflection is present at the sub-solar point, consistent with a spherical surface that is macroscopically smooth and suggestive of the presence of a liquid reservoir with planet-wide dimensions. High-albedo clouds cover much of the surface, but in transparent areas, extreme albedo contrasts are seen. Two distinct cyclonic storms are apparent, having likely formed due to latent heat driven by significant atmospheric convective activity.

The best OCAMS images are centered on a large ocean basin. Three land masses are visible. The four OCAMS-MapCam color filters were combined to visualize specific spectral contrasts in the clouds and on the surface. Band combinations are the most informative. First is (b', v, w) (equivalent wavelengths 0.473, 0.550, and 0.698 µm respectively), which gives a true-color composite (Fig. 2) [9]. The land masses have a reddish-brown color compatible with mineral-bearing surfaces. In high-resolution PolyCam images, small liquid reservoirs appear to exist within some land masses. As with the 1990 flyby, we found no unambiguous sign of technological geometrization.

We also produced false-color images to analyze features on the Earth further [9]. The most informative color index is (x - w)/(x + w), which is calculated using the near-infrared and red filters (at 0.847 and 0.698 µm). These data reveal a material associated with the land masses that strongly absorbs visible light (from 0.4 to 0.7 µm) and strongly reflects near-infrared light (from 0.7 to 1.1 µm). This compound is verified in the OVIRS spectral data and does not correspond to any known mineral (although mineral combinations have not been ruled out). It appears to be distributed along coastlines, with large concentrations in the continental mid-latitudes and on small islands in the ocean.

OVIRS Data: A representative OVIRS spectrum in the 0.5-2.5-µm range is shown in Fig. 3. OVIRS spectral and radiometric measurements indicate the presence of water. The average 1-µm albedo of the extensive ocean basins is ~4%, much smaller than the albedos of the clouds and land surfaces, and consistent with the low diffuse reflectance of dielectric liquid surfaces, including water. We find evidence of gas-phase H_2O over the entire planet. This spectrum also indicates the presence of a molecular oxygen absorption band at 0.760 µm. This transition is spin-forbidden, and the strength of the feature suggests a substantial concentration of O_2.

OTES Data: A series of OTES measurements are shown in Fig. 4. Spectral features in the Earth's atmosphere are readily apparent: CO_2, O_3, CH_4, and gaseous H_2O absorptions are present. The atmosphere is transparent between approximately 8.3 and 12.5 µm (800 and 1200 cm^{-1}), providing a probe of surface temperatures. In the central latitudes are extensive areas with higher, nearly uniform temperatures above the melting point of water. The spectra indicate an atmosphere with a warm stratosphere containing abundant O_3, above a somewhat colder lower stratosphere, from whence the CO_2 band arises. Over 99% of H_2O vapor is in the troposphere.

Conclusions: From the OSIRIS-REx fly-by, observers otherwise unfamiliar with the Earth could conclude that the planet is covered with large amounts of water present as vapor, in clouds, and as oceans. Because we did not image the poles, no direct evidence of ice is available. The atmosphere is dynamic, with large cyclonic storms in the equatorial and mid-latitudes. Land masses are present that contain mineral-bearing surfaces and a compound that strongly absorbs at the wavelengths emitted by the Sun. The atmosphere is out of equilibrium, with mechanisms that generate CH_4, O_2, and O_3 rapidly, leading to substantial steady-state abundances that outpace removal. If this flyby were a follow-on to the 1990 encounter, our observers would note that the methane abundance in the atmosphere had increased by ~12% and CO_2 by ~14%, indicating that the sources of these gases had accelerated their output over the past twenty-seven years.

Acknowledgements: This material is based upon work supported by NASA under Contract NNM10AA11C issued through the New Frontiers Program. NASA's Goddard Space Flight Center in Greenbelt, MD, provides overall mission management, systems engineering and the safety and mission assurance for OSIRIS-REx. Dante Lauretta of the University of Arizona, Tucson, is the principal investigator, and the University of Arizona also leads the science team and the mission's science observation planning and data processing. Lockheed Martin Space in Littleton, CO built the spacecraft and is providing flight operations. Goddard and KinetX Aerospace are responsible for spacecraft navigation. OSIRIS-REx is the third mission in NASA's New Frontiers Program. NASA's Marshall Space Flight Center in Huntsville, Alabama, manages the agency's New Frontiers Program for the Science Mission Directorate in Washington DC.

References: [1] Lauretta et al. (2017) *Space Science Reviews* **212**: 925-984. [2] Lauretta et al. (2015) *Meteoritics & Planetary Science* **50**, 834-849. [3] Sagan et al. (1993) *Nature* **365.6448**: 715-721. [4] Livengood et al. (2011) *Astrobiology* **11.5**: 393-408. [5] Christensen et al. (1997) *JGR: Planets* **102.E5**: 10875-10880. [6] Reuter et al. (2017) *arXiv preprint* arXiv:1703.10574. [7] Christensen et al. (2017) *arXiv preprint* arXiv:1704.02390 (2017). [8] Rizk et al. (2017) *arXiv preprint* arXiv:1704.04531. [9] Golish et al. (2018) 49th *LPSC*. [10] Rugheimer et al. (2013) *Astrobiology* **13.3**: 251-269.

Figure 1. TAGCAMS image of the Earth

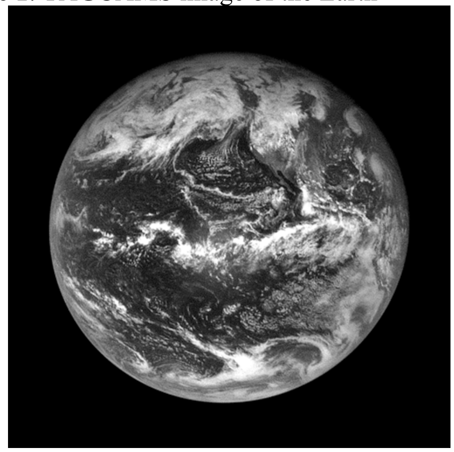

Figure 2. MapCam three-color composite of Earth

Figure 3. OVIRS spectrum of Earth

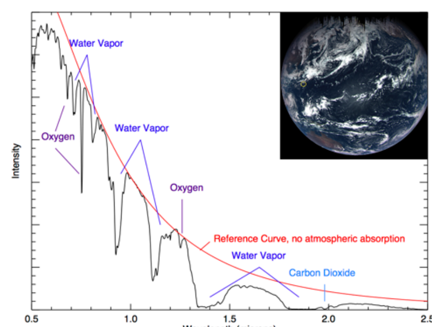

Figure 4. OTES spectra of Earth