Whole Earth imaging from the Moon South Pole (EPIC-Moon)

A. Marshak[1], N. Krotkov[1], N. Gorkavyi[2], S. Marchenko[2], A. Vasilkov[2], Y. Knyazikhin[3], M. Kowalewski[1], O. Torres[1], M. DeLand[2], M. Ramsey[4], P. Christensen[5], V. Realmuto[6]
[1]NASA/GSFC, [2]SSAI, [3]Boston University, [4]Univ. of Pittsburgh, [5]Arisona State Univ., [6]NASA/JPL

Numerous LEO/GEO Earth-observing platforms provide a broad spectrum of viable data; however, it is at the expense of a limited geographical (GEO) or temporal (LEO) coverage (Fig. 1, left panel). The Earth Polychromatic Imaging Camera on the Deep Space Climate Observatory (DSCOVR/EPIC) imager [1] clearly stands apart, observing the entire sun-illuminated Earth from the Lagrange L1 point. The L1 location, however, restricts the phase angles to ~2°-12° (a nearly backscattering direction, see the right panel in Fig. 1), depriving the observer of any information about the bidirectional surface reflectance factor (BRF) and/or a cloud/aerosol phase function. A compact, lightweight, autonomic camera on the Moon's surface offers unique opportunity to overcome these limitations and advance Earth science in ways difficult to predict. We propose to extend the EPIC's spectral coverage (~317-780 nm), by adding TIR channels. This polychromatic imaging camera can provide frequent observations of every Earth region for the full range of the phase angles (Fig. 1, right panel) that the existing Earth orbiting satellites cannot.

Earth science goals are to extend and improve the current DSCOVR/EPIC whole-Earth imaging by enhancing spectral coverage, spatial resolution, increasing image cadence and expanding the coverage of circum-polar regions. The acquired data will enable retrievals of aerosol scattering phase functions and Earth surface properties. Recent Earth Science Decadal Survey prioritized aerosols, clouds, convection, precipitation and surface albedo studies in connection with climate change [2]. As stated in IPCC AR5 Chapter 7: "*Clouds and aerosols continue to contribute the largest uncertainty to estimates and interpretations of the Earth's changing energy budget*" [3].

Realizing the importance of cloud and surface albedo studies [2], we propose to add TIR channels; thus going beyond the UV-NIR full-disk Earth imaging from EPIC. The combination of UV-TIR imaging from the lunar surface will allow:

- comprehensive (both in time and space, compared to LEO) whole-globe monitoring of transient volcanic [7,8] and aerosol clouds (smoke, dust), including the strategically important for climate studies polar regions not covered by GEO missions;
- simultaneous imaging of the day and night parts (thus, the twilight zone);
- better detection of circum-polar, high-altitude clouds via the whole-Earth limb imaging;
- subpixel image processing, allowing ~1 km vertical resolution of stratospheric aerosol limb profiles synergistically with ESD LEO missions: SNPP/OMPS-LP and ISS/SAGE-III [5,6];
- monitoring of the vegetation characteristics and plant physiology (BRF), as well as vegetation stress and evapotranspiration (TIR channel), thus contributing to the global carbon cycle studies;
- better (full phase-angle integrated) surface albedo estimates [2].

Lunar environment goals: The lunar dust exosphere is an important factor for the long-term stay of astronauts on the Moon, as well as for the functioning of scientific equipment on the moon surface and orbiters [9]. Telescopic limb observations of the scattering of sunlight (or starlight) from a lunar dust cloud should help build a 3D model of the lunar dust exosphere. A similar program was implemented for the zodiacal dust cloud [10]. Observations from the Moon will help improve the existing models of the zodiacal cloud, which is important for astronomical observations, JWST in particular.

Even a small meteoroid with a mass of 5 kg can excavate a ~10 m crater, hurling 75 tons of lunar regolith and rock on ballistic trajectories above the Moon [11]. However, "*The lunar impact rate is very* *uncertain because observations for objects in this mass range are embarrassingly few*" [12]. For the effective and safe implementation of the Artemis program, an accurate assessment of the meteorite hazard is required [9]. Using the Earth's atmosphere as a detector, the EPIC-Moon imaging of night-side as well as limb of the Earth will detect atmospheric impacts (either by a flash or dispersion of meteoritic dust clouds [5]) from the potentially threatening small (<10 m) asteroids in the circum-Earth space, thus improving the current highly uncertain estimates.

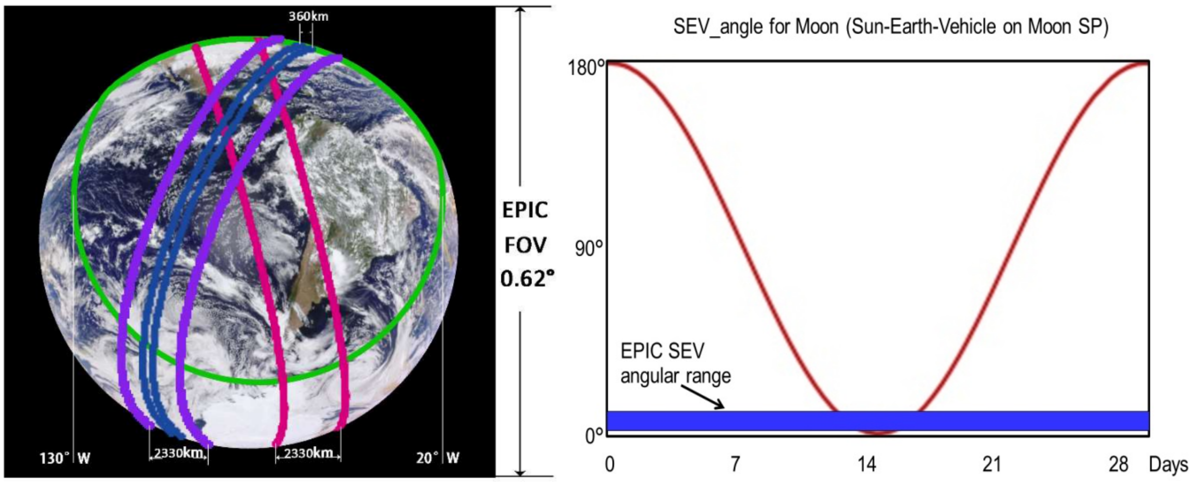

Figure 1. **Left panel:** Enhanced RGB EPIC image of the sunlit Earth taken on 15 January 2017 at 18:37:04 UTC. Areas between purple and red lines are Terra and Aqua MODIS 2330 km wide swaths. Blue lines depict a 360 km swath of the MISR sensor on the Terra platform. Terra MODIS and MISR cross the equator at 10:30 local solar time (LST) while Aqua MODIS sees the Earth at 13:30 LST. A fixed sampling area of the NASA's GOES-East is bounded by a green line. MODIS and MISR sensors on LEO platforms acquire radiance data over swaths at a specific LST. Biases in LEO estimates of the Earth's reflectivity due to sampling limits may amount up to 8% depending on a sampling area, observation time and wavelength [4]. **Right panel**: Solar-Earth-Vehicle (SEV) angle for any daylight Earth's object from the Artemis location near Moon South Pole during lunar month, compared to the EPIC's 2°-12° yearly range.

References

[1] Marshak, A. *et al*., *BAMS*, https://doi.org/10.1175/BAMS-D-17-0223.1 , 2018.
[2] National Academies of Sciences, Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space. Washington, DC: The National Academies Press (doi:10.17226/24938), 2018.
[3] IPCC, Fifth Assessment Report (AR5), https://www.ipcc.ch/assessment-report/ar5/.
[4] Song, W.J. *et al*., *Remote Sensing*, 10, https://www.mdpi.com/2072-4292/10/10/1594/htm, 2018.
[5] Gorkavyi, N. *et al*., *GRL*, 40, 4728, https://doi.org/10.1002/grl.50788, 2013, 2013.
[6] Gorkavyi, N. and DeLand, M. In: Deep Space Gateway Concept Science Workshop, LPI Contribution No. 2063, [#3155], https://www.hou.usra.edu/meetings/deepspace2018/pdf/3155.pdf, 2018.
[7] Krotkov N.A., *et al*. In: Deep Space Gateway Concept Science Workshop, LPI Contribution No. 2063, [#3076], https://www.hou.usra.edu/meetings/deepspace2018/pdf/3076.pdf, 2018.
[8] Ramsey, M. and Christensen, P.R., ibid, LPI Contribution N. 2063, [#3164], https://www.hou.usra.edu/meetings/deepspace2018/pdf/3164.pdf , 2018.
[9] Elphic, R.C. *et al*., *Space Sci. Rev*., 195, 3-25, https://doi.org/10.1007/s11214-014-0113-z , 2014.
[10] Gorkavyi, N. *et al*. NGST Science and Techn. Exp. Eds. E.P. Smith & K.S. Long, 462-467, 2000.
[11] About Lunar Impact Monitoring, https://www.nasa.gov/centers/marshall/news/lunar/overview.html.
[12] Speyerer, E.J. *et al*., *Nature*. 538(7624): 215-218, https://doi.org/10.1038/nature19829, 2016.