Earth imaging from the Moon with the EPIC-type camera

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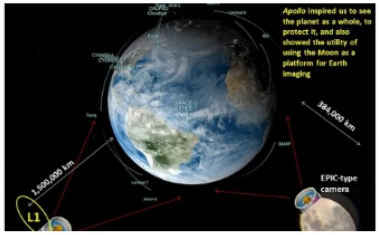

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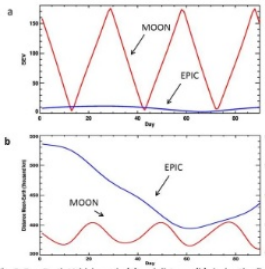


The L1 location restricts phase angles to "2°-12° (a nearly backscattering direction), depriving the observer of any information on bidirectional surface reflectance factors (BRFs) or on cloud/aerosol phase functions. A compact, lightweight, autonomous EPIC-type camera on the Moon's surface offers a unique opportunity to expand EPIC observations and advance Earth science in novel and potentially unanticipated ways (*Marshak et al.*, 2020, *Gorkavyi et al.*, 2021).

Fig. 2. Sun-Earth-Vehicle angle (a) and distance (b) during the first 3 months of 2021 (data for the Moon from *Espenak*, 202; for DSCOVR/EPIC - from https://epic.gsfc.nasa.gov/) See: https://www.frontiersin.org/articles/10.3389/frsen.2021.724074/full

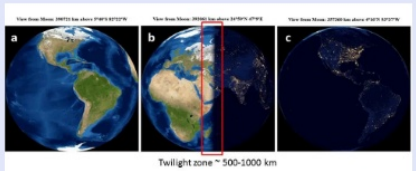


Figure 3. View of the Earth from the Moon at three points of the lunar orbit with phase (SEV) angles of (a) 0°, (b) 90° and (c) 180°. The image of the Earth was obtained by J. Walker based on MODIS/TERRA and Suomi/NPP images (*Walker*, 2021). Observations from the Moon of PMC and volcanic clouds in the twilight zone, where the Earth' surface has SZA>90, but clouds still illuminated (SZA<90), can effectively determine the heights of clouds.

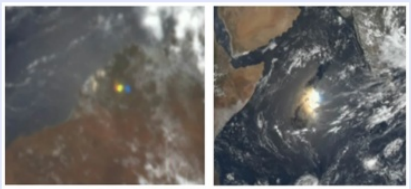
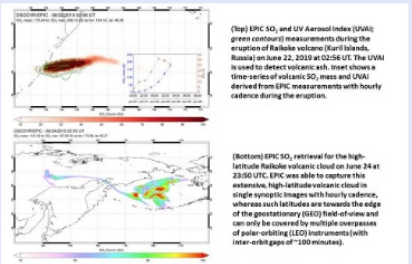


Fig. 4. Three examples of glints captured by DSCOVR/EPIC in 2018. The Solar-Earth-Vehicle (SEV) angle is around 9 degrees. (left) Terrestrial glint over Australia from cloud ice crystals on February 13, 2018 (see https://epic.gsfc.nasa.gov/?date=2018-02-13); (right) Ocean surface glint on September 17, 2018 (see https://epic.gsfc.nasa.gov/?date=2018-09-17).

Motivated by EPIC observations of solar glints off the terrestrial atmosphere, it is also important to explore the impact of starlight glints on the detection and characterization of exoplanets. This idea goes back to 1993 when Carl Sagan and colleagues used the Galileo spacecraft's fly-by observation of Earth as an exoplanet control experiment. Based solely on observations of specular reflection, they deduced that Earth was covered in part by liquid oceans. If some preliminary estimates of the frequency and brightness of solar glints from EPIC are confirmed, specular reflection observations from the Moon's surface could have a longer-term consequence for exoplanet science.



(Top) EPIC SO_2 and UV Aerosol Index (UVAI); green contour) measurements during the eruption of Raikoke volcano (Kuril Islands, Russia) on June 22, 2019 at 02:56 UT. The UVAI is used to detect volcanic ash. Inset shows a time-series of volcanic SO_2 mass and UVAI derived from EPIC measurements with hourly cadence during the eruption.

(Bottom) EPIC SO_2 retrieval for the high-latitude Raikoke volcanic cloud on June 24 at 23:50 UTC. EPIC was able to capture this extensive, high-latitude volcanic cloud in single synoptic images with hourly cadence, whereas such latitudes are towards the edge of the geostationary (GEO) field-of-view and can only be covered by multiple overpasses of polar-orbiting (LEO) instruments (with inter-orbit gaps of ~100 minutes).

Fig. 5. Volcanic and aerosol clouds from EPIC. An EPIC-like instrument on the Moon would provide synoptic imaging of the high latitude regions with higher spatial resolution and higher cadence than provided by DSCOVR/EPIC at L1.

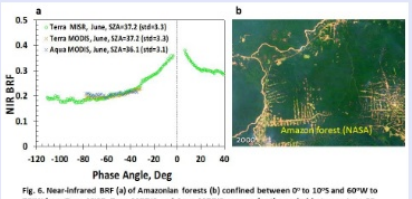


Fig. 6. Near-infrared BRF (a) of Amazonian forests (b) confined between 0° to 10°S and 60°W to 70°W from Terra MISR, Terra MODIS and Aqua MODIS sensors for the period between June 25 and July 10 accumulated over a 7-year period from 2001 to 2008.

An EPIC-like camera on the Moon's surface can provide frequent observations of every region of the Earth in the full range of scattering directions. The availability of such data will undoubtedly advance our ability to model evapotranspiration, snowmelt, and retrospective reconstruction of the snow water equivalent, which are critical for accurate description of the surface radiation balance (NAS, 2018).

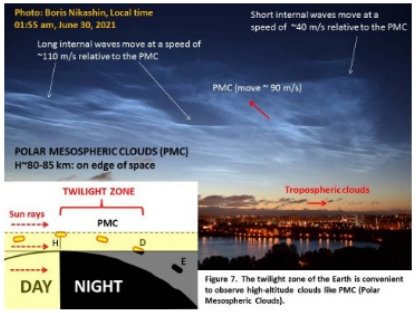


Figure 7. The twilight zone of the Earth is convenient to observe high-altitude clouds like PMC (Polar Mesospheric Clouds).

Conclusion

Deploying an **analog of DSCOVR/EPIC on the Moon's surface** would offer a unique opportunity to image the full range of Earth phases, potentially advancing Earth science in many ways:

1. observing **ocean/cloud glint reflection** for different phase angles;

2. comprehensive whole-globe monitoring of transient **volcanic and aerosol clouds** (smoke, dust), including the strategically important (for climate studies) polar regions not covered by GEO missions;

3. detecting of **polar mesospheric and stratospheric clouds** via whole-Earth limb imaging;

4. estimating surface BRF and full phase-angle integrated **albedo**;

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