THE SCIENCE MISSION OF SPACEIL'S BERESHEET LANDER: PLANS AND RESULTS Oded Aharonson[1,2], Christopher T. Russell[3], James W. Head III[4], Mark Wieczorek[5], Ian Garrick-Bethell[6,7], Benjamin P. Weiss[8], David E. Smith[8], Kathryn Rowe[3], Ariel Gomez[9], Asaf Grosz[10], Shai Amrusi[10], Alexander Novoselsky[1], Nadav Nahaman[1], Yuval Grossman[1], Yonatan Shimoni[1], [1]Weizmann Institute of Science, Rehovot, Israel, (Oded.Aharonson@weizmann.ac.il) [2]Planetary Science Institute, Tucson, AZ, USA, [3]University of California Los Angeles, Los Angeles, CA, USA, [4]Brown University, Providence, RI, USA, [5]Observatoire de la Côte d'Azur, Nice, France, [6]University of California Santa Cruz, Santa Cruz, CA, USA, [7]Kyung Hee University, Republic of Korea [8]Massachusetts Institute of Technology, Cambridge, MA, USA, [9]SpaceIL, Tel-Aviv, Israel, [10]Ben-Gurion University, Be'er Sheva, Israel

Introduction: SpaceIL's lunar lander mission named Beresheet (meaning 'in the beginning' or 'Genesis' in Hebrew) is the first Israeli mission beyond Earth orbit [1]. Originally conceived as an entry in the Google Lunar XPRIZE competition, Beresheet was launched on February 22, 2019 from Cape Canaveral onboard a SpaceX Falcon 9. The mission included several science investigation goals [2], and consisted of three phases: multiple Earth orbits followed by lunar orbit insertion, a soft-landing maneuver, and stationary operation on the Moon's surface [3].

The scientific payload of the Beresheet lander is comprised of two instruments. The primary instrument is a triaxial fluxgate magnetometer (SILMAG), provided by the University of California, Los Angeles [4,5]. The second is the Lunar Retroreflector Array (LRA), provided by NASA Goddard Space Flight Center. The position of the instruments installation on the spacecraft is shown in Figure 1. In addition, six 8-megapixel CCD cameras (5 panoramic cameras and a self-pointing camera) were integrated on the spacecraft, providing images intended for public engagement as well as scientific interpretation of the landing site. Measurements by SILMAG were planned and performed during the orbital and landing maneuver phases of the mission. Additional magnetic measurements as well as ranging from the Lunar Orbiter Laser Altimeter to LRA were planned post landing.

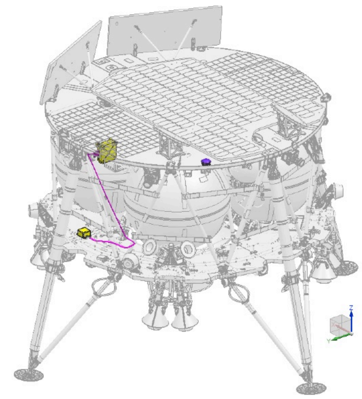
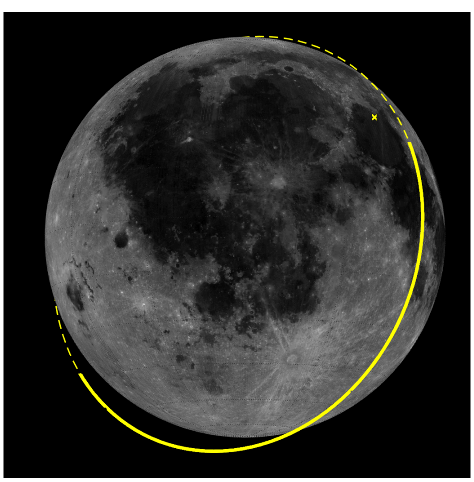


Figure 1: A perspective drawing the Beresheet lander showing location of the integrated science instruments including the SILMAG electronics and sensor head (yellow), tether (magenta), and LRA (purple).

a)



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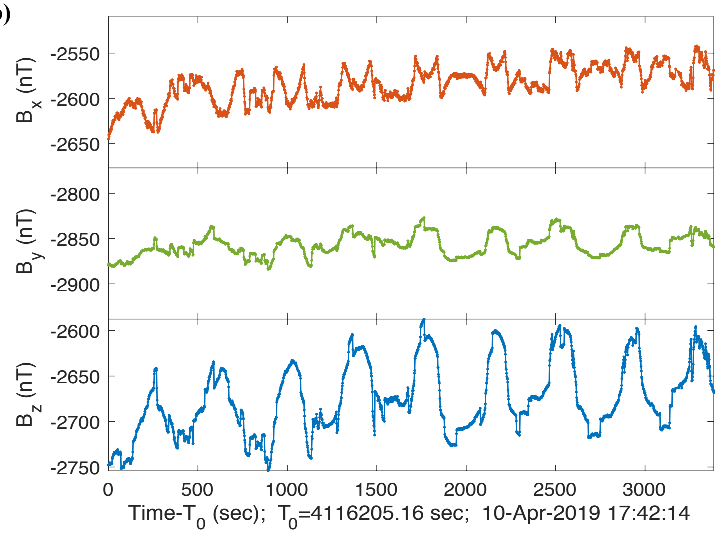

Figure 2: a) The position of the final orbit and landing trajectory of the Beresheet spacecraft around the Moon (dashed) as well as an interval during which SILMAG measurements were obtained and downlinked (solid). b) The magnetic field measurements along each of the three axes.

Results: Orbital measurements of the magnetic field from Kaguya and Lunar Prospector [6] guided the selection of the final sites to a location West of Posidonius crater in Mare Serenitatis, satisfying constraints [2] based on lunar topography [7], surface roughness [8,9], and rock abundance [10], among others. Figure 2 shows the position of the final orbit around the Moon, as well as the location of the spacecraft impact point on the surface. A time interval during which SILMAG data were acquired is indicated, along with the magnetic measurements derived along each axes during this time. These data, as well as calibration measurements acquired in Earth orbit, show that the instrument successfully responded to variations in the local field. However, our analysis indicates that the signal was dominated by the spacecraft field, which may have exceeded the designed dynamic range of the sensor in one axis. In this field regime, laboratory tests verify the SILMAG control electronics allow detection of field variations as seen in the data, but the value of the field reported may not be reliably interpreted.

During the spacecraft's final descent maneuver, a fault indication from one of the two IMUs and an attempt to command a power-on of this unit led to the mission computer reset, main thruster shutdown, landing system failure, an uncontrolled, low angle (<10°), high speed impact on the lunar surface, and communication loss [3]. Figure 3 shows the Beresheet impact site as imaged by the Lunar Reconnaissance Orbiter Camera [11] on April 22, 2019. Both bright and dark brightness variations are seen surrounding the impact point at the center of the image (32.5956°N, 19.3496°E), owing to the disturbance of lunar regolith and dust cover.

References:

[1] Gibney E. (2019) *Nature*, *566*, 434–436. [2] Aharonson O. et al. (2019) *50th Lunar and Planetary Science Conference*, Abstract #2290. [3] Shyldkrot H. et al. (2019) *AAS/AIAA Astrodynamics Specialist Conference*, 1–13. [4] Strangeway R.J. et al. (2002) *AGU Spring Meeting*, Abstract #GP51A–09. [5] Russell C.T. et al. (2019) *50th Lunar and Planetary Science Conference,* Abstract #1728. [6] Tsunakawa H. et al. (2015) *J. Geophys. Res. Planets*, *120 (6)*, 1160–1185, [7] Barker M. et al. (2016) *Icarus*, *273*, 346–355, [8] Smith D. et al. (2010) *Space Sci. Rev.*, *150 (1)*, 209–241. [9] Rosenburg M.A. et al. (2011) *J. Geophys. Res. Planets*, *116 (E2)*, E02001. [10] Bandfield J.L. et al. (2011) *J. Geophys. Res. Planets*, *116 (E12)*, E00H02. [11] Robinson M. et al. (2010) *Space Sci. Rev.*, *150 (1-4)*, 81–124.

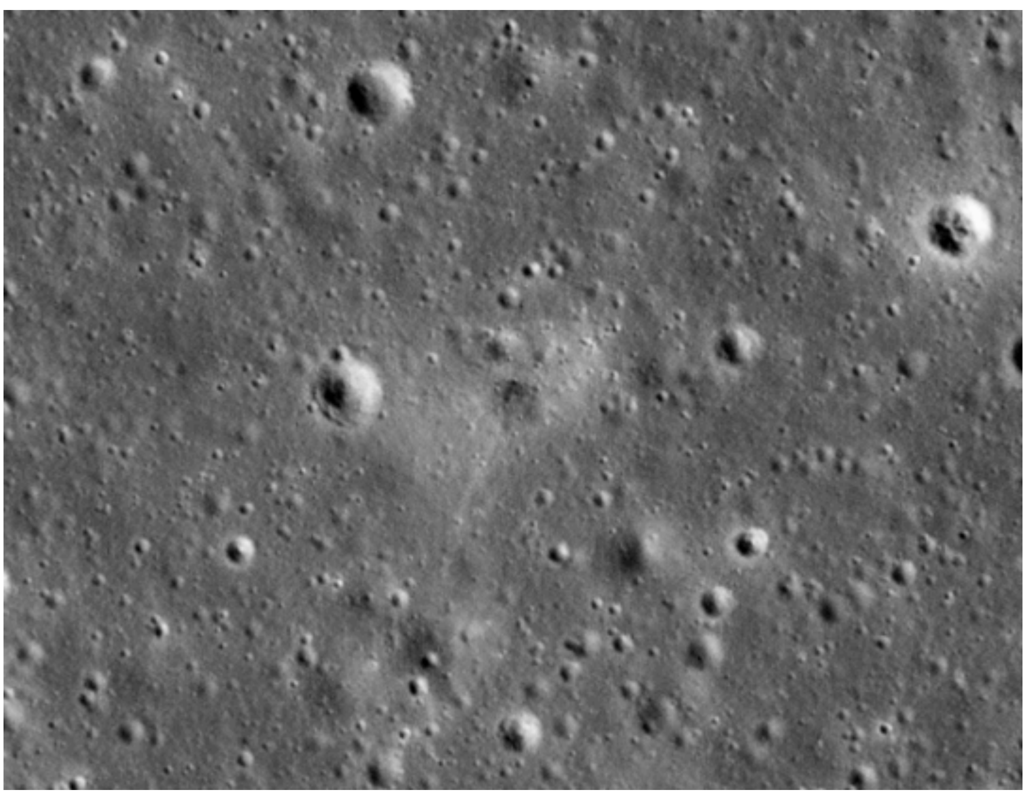

Figure 3: A portion of LROC image M1310536929R showing the Beresheet crash site in Mare Serenitatis. The image is ~450 m across. Image Credit: NASA/GSFC/ASU.