Moonba, a micro-rover for a targeted investigation of lunar surface dust. Timothy A. Livengood[1,2], Michael K. Barker[2], Dina M. Bower[1,2], Tilak Hewagama[1,2], Justin Ward[3]. [1]University of Maryland, timothy.a.livengood@nasa.gov; [2]NASA Goddard Space Flight Center; [3]Newton Engineering.

Introduction: Moonba will be a small tele-operated rover transporting a microscope and lighting system for the purpose of characterizing photometric properties and physical structure of undisturbed lunar dust and regolith at a scale of ~10 µm per pixel over an imaging patch of ~4 cm width, along a transect of ~200 m. Astronauts will transport and deploy the rover and base station to a remote location to separate it from the blast zone surrounding the lander vehicle. **Moonba** could be operated from Earth for most purposes or by astronauts from within a habitat to augment human operations at the landing site. The high data volume may require astronauts to retrieve a data-storage device from the base station while telemetering only a critical subset of data to Earth during the mission.

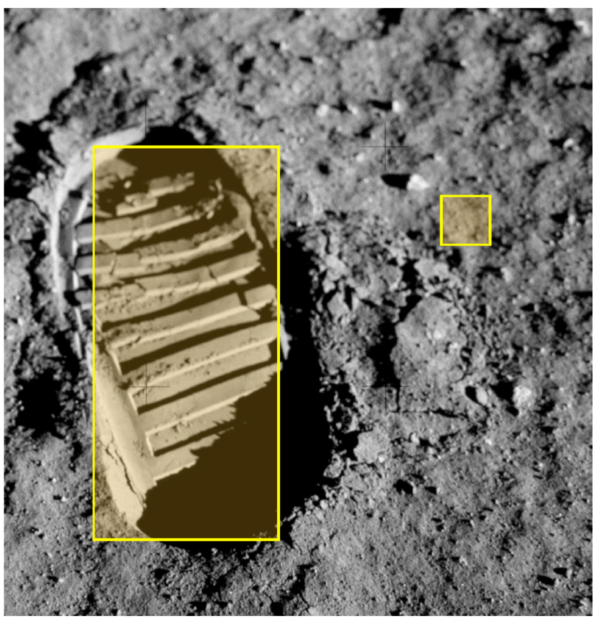

Fig. 1: Moonba will obtain microscopy of undisturbed lunar regolith. Photometry of airless bodies returns parameters describing the average physical structure of planetary surfaces. The **Moonba** microscope, PhoROM (Photometry of Regolith by Optical Microscopy), will capture the actual structure of the lunar surface with ~10 µm/pixel resolution over an image patch of ~4 cm width. **Moonba** will operate outside the region disturbed by human activity and can probe into shadowed regions to investigate frosts. Image of Neil Armstrong's bootprint, Apollo 11, photo credit NASA.

State of the art: Moonba is intended, literally, to go where no one has gone before and to do so slowly and carefully.

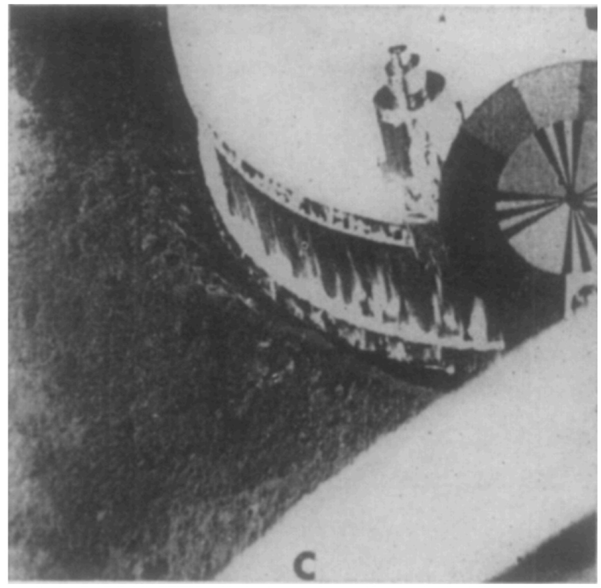

Fig. 2: Existing imagery and samples constrain particle size distributions and composition, but not undisturbed surface structure or texture. Photography targeting the surface from Surveyor and Apollo is in the vicinity of a major disturbing influence – rocket exhaust, astronauts, lunar roving vehicle [1]. High-quality surface images from Chang'e 3 or 4, if they exist, have not been made widely available. Image by Surveyor 1 [2].

Available photography at the lunar surface that can resolve individual grains and structures composed of grains consists of incidental images by the Apollo astronauts (Fig. 1) and limited targeted imagery (Fig. 2) at greater than millimeter scale. Such data has been analyzed to yield statistical properties of the surface at 0.1-millimeter and larger scale [1,2] and to constrain laboratory models for surface texture formation [3]. Photometry of the surface from orbit has investigated submm scale statistical properties of the regolith surface [4,5]. Investigations of permanently shadowed regions (PSRs) have yielded challenging results that invoke a range of poorly constrained surface properties [6,7]. What is lacking is direct *in situ* validation of the physical structure of untouched regolith at relevant resolution, as well as sampling the diversity of the surface over a transect comparable to orbital pixel scale.

Moonba significance and goals: Moonba will meet a need for high-quality ground truth imagery of undisturbed regolith as a touchstone to interpret photometry of airless surfaces throughout the Solar System. The opposition effect, or opposition surge, is particularly significant in characterizing surface texture as it results from interference phenomena as a well as shadow-hiding [8]. Special regions such as PSRs and temporarily shadowed regions (TSRs) can undergo unique processing by formation and sublimation of frosts from minute quantities of volatile species. **Moonba** will image the surface at resolution of ~10 µm (0.01 mm), with a range of illumination phase angle and color to develop detailed high-fidelity models for surface structure and topography/texture. By moving very slowly and methodically, **Moonba** will enter previously untouched regions without scattering grains or initiating significant vibrations that could disturb fragile surface structures.

Moonba methodology: Moonba will be implemented as a small wheeled rover carrying no batteries, minimal power distribution, no data system, and no wireless communication, operated on a tether from a fixed base station that supports communications with Earth. Offloading power, control, and communications to the base station enables a low mass rover. The base station can be deployed by an astronaut or a lander, with power and two-way communication over a lightweight tether incorporating fiber-optic data transmission, power delivery, and strain-relief that carries current to warm the tether and keep it flexible in shadow. The tether will deploy from motorized reels on the base station and on the rover to minimize drag. The tether can enable **Moonba** to venture into PSRs at <30K and increase power to heaters to maintain operating temperature. A rescue option for steep slopes will be to winch the rover upslope, using the tether. **Moonba** thus can execute riskier drives than a self-contained rover.

Moonba primary instrumentation will be a down-looking monochrome microscope with a ring-lighting system to control illumination angle, including direct coaligned lighting, with commandable color distribution. The microscope system is designated **PhoROM**, for Photometry of Regolith by Optical Microscopy (Fig. 3). Using a 16 megapixel camera, PhoROM can image a patch ~4 cm on a side with 10 µm resolution. High f/ number will enable deep depth of field to minimize focusing requirements. **PhoROM** can produce a very high data volume with only a selected fraction of data able to be telemetered to Earth. With astronaut deployment, the full data set can be stored on a device retrieved by astronauts and returned to Earth.

Additional instrumentation includes moderate resolution (~1–2 Mpxl) cameras, forward-looking and reverse and on the base station for context. These cameras provide additional information on topography. A fraction of the engineering camera data will be telemetered to enable remote driving control.

Choosing a 200m range tether as a reasonable arbitrary guess, **Moonba** need only drive at about 0.33 mm/sec on average to cross 200 m in a 7-day mission. **Moonba** can stop every ~50 cm to conduct microscopy, or more often, on some planned schedule to achieve a systematic sampling of regolith structure and diversity. Faster driving modes can facilitate deployment to desirable locations.

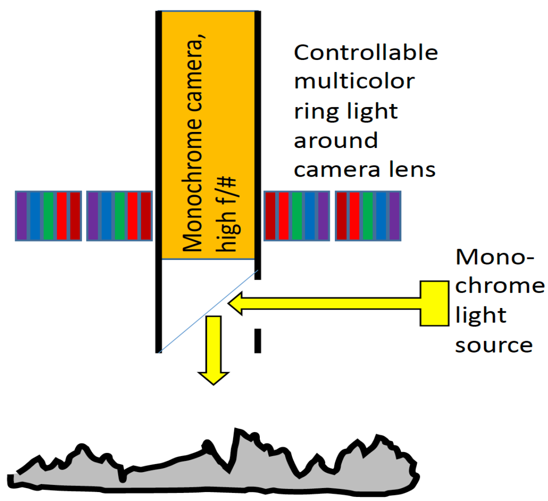

Fig. 3: PhoROM microscope with commandable lighting to control illumination angle and color. Changing the off-axis angle and direction of lighting will support determining topography as well as measuring phase angle dependence of photometry and wavelength-dependence. Images will show actual texture in detail and at diverse sites.

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