CONCENTRATION AND CROWDING FOR LUNAR SITES. M. Elvis[1], A. Krolikowski[2], and T. Milligan[3]. [1]Center for Astrophysics | Harvard and Smithsonian, 60 Garden St., Cambridge MA 02138, USA, melvis@cfa.harvard.edu, [2] Department of History and Political Science and Center for Science, Technology, and Society, Missouri University of Science and Technology, 500 W 14th St., Rm 122, Rolla MO 65409, akro@mst.edu, [3]Department of Theology and Religious Studies, King's College London, Virginia Woolf Building, 22 Kingsway, London WC2B 6NR, anthony.milligan@kcl.ac.uk

Introduction: The large number of lunar missions planned for the next decade are likely to target a relatively limited number of small sites with concentrated resources on the Moon's surface, creating risks of crowding and interference at these locations.

Reserving the use of these concentrations of lunar resources for science is far from ensured and brings up a number of practical and near-term issues that fall into the territory of ELSI, i.e. problems of Ethics, Law and Societal Impact [1]. This paper generalizes our earlier work on the Peaks of Eternal Light [2] to other concentrated lunar resources, and is published elsewhere [3].

Lunar Resources: There are three classes of lunar resource we consider: (1) *Features* [the (so-called) Peaks of Eternal Light, the cold traps of the permanently dark regions, lunar pits, far-side 100 km-scale smooth terrain (for radio telescope arrays)]; *(2) Materials* (e.g. Thorium Uranium, Rare Earth Elements in the KREEP terrane [4], iron rich areas [5], ^{3}He rich areas [6,7]; (3) *Cultural sites* (e.g. Apollo landing sites) [8].

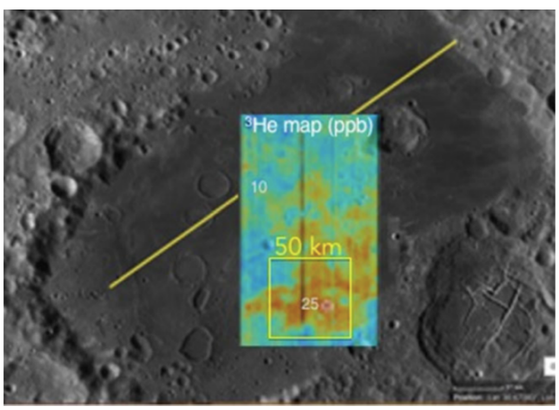

Figure 1: Mare Moscoviensis (gray scale). The yellow bar shows a length of 250 km, suitable for a full-scale far-side radio telescope array. The color overlay shows the ^{3}He concentration in ppb (white labels [7]).

The cultural sites are clearly few in number and small. More surprisingly, mapping of features and materials over the past decade has shown that they too are quite few in number and quite limited in extent, typically 1-30 km across. Even the ^{3}He distributions are clumped by factors of a few (figure 1). Similarly, although there are over 200 known lunar pits [9], the small subset of ones that have substantial overhangs or lead into lava tubes, that also have easy access, and are near to useful locations will be of prime interest.

Based on the announced destinations for forthcoming landers, it is the highly illuminated peaks and permanently shadowed regions near the South Pole that are likely to experience crowding first. The total area of >70% illumination 2 meters off the local surface is only 0.8 km^2 within 25 km of the South Pole, rising to 4.5 km^2 at 10 meters [10]. Maintaining distances of >1 km between landers will thus be challenging.

"Harmful Interference": Keeping a substantial distance between landers is important as many scientific sensors are necessarily extremely sensitive to electrical signals, light, vibration, dust, and mechanical damage. Experiments may require avoidance zones for any other nearby activity, and these zones may be quite large, kilometers across. The most discussed problem is that of lunar regolith dislodged and sent outward at high velocity by the rocket plume of a descending lander. "Lunar soil is highly abrasive and effective as a sandblasting medium" [11].

Studies of the Apollo 12 landing find that several tons of regolith were removed by its rocket plume, and that small dust particles achieved escape velocity from the Moon. Slightly larger particles will still travel large distances. It is thus impossible to avoid *all* contamination of an emplaced lander by a later lander, however far away it touches down.

Article IX of the Outer Space Treaty allows measures to prevent "*potentially harmful interference with activities of other States*" when the states in question are conducting research which may be used to justify exclusion of others. Real situations, where significant resources are at stake, will require adjudication to resolve disputes. Unlike the Antarctic Treaty on which it was based, the Outer Space Treaty has no mechanism for adjudicating disputes.

Determining a safe size for an exclusion zone will depend on the physics of how much dust of what size travels what distance, but also on the legal questions of what reasonable mitigation measures the new and the already emplaced landers could have taken. At a minimum, estimates calculated from both physics and engineering perspectives should inform how these limits are set, although a broader range of disciplines will need to be drawn upon in drafting recommendations.

Policy Considerations: Unlike the first lunar explorations in the 1960s and 1970s, the coming decade will involve multiple actors and will include both traditional state agencies and commercial companies, leading to a complex regime for resolving disputes.

From the perspective of policy studies, lunar sites of interest present analogs to global "common-pool resources" or "commons" [12]. These are resources over "which no single nation has a generally recognized exclusive jurisdiction" [13]. Studies of how commons work in practice, notably by Elinor Ostrom and her collaborators [12], have resulted in the recognition of a number of effective ways to govern them collectively. We summarize them as:

(1) Identify shared interests; (2) Define the problems; (3) Lengthen the time horizon, so that multiple interactions are expected; (4) Design accommodating platforms; (5) Establish habits of cooperation; (6) Create with-holdable carrots.

Issues of Timeliness and Justice: In a multi-player environment, such as is imminent on the Moon (Table 1), and where there is competition for limited resources, arriving at an effective solution requires building a framework that can be a basis for consensus, or at least for widespread acceptance. Without such agreement, any framework is liable to lack stability and to break down. For stability to be secured, standards of justice are required. Actors will not look favorably upon arrangements that disadvantage them in ways that they regard as clearly unfair. This is where policy and ethics meet.

The Moon presently falls into the "goldilocks zone" for deliberation. This is the period during which, just outcomes are more likely to be secured. Too early, and an approach is liable to be under-informed; too late and patterns of behavior become almost impossible to change. The right time to deliberate about these matters, from an ethical point of view, is when we know enough, but not everything that we will eventually need to know, about lunar resources. As regards the Moon we are, for now, behind a genuine "veil of ignorance", an idealized state never really encountered on Earth [14]. In the absence of such detailed knowledge about lunar conditions, interested actors may be more motivated to tackle the risks of crowding and interference in reasonably just, opportunity sharing, ways in order to safeguard future opportunities for themselves. In doing so, they will be more likely to arrive at a stable framework for governance, one which can last "long enough" to protect future opportunities.

Conclusions: The useful and valuable resources on the Moon are concentrated into a modest number (tens) of quite small regions (in the order of a few km). Over the next decade, forms of interference and related disputes and conflicts over these concentrated resources may arise, as many actors, sovereign, philanthropic, and commercial, descend onto just a handful of small, high-value sites on the lunar surface. Responsibly coordinating these diverse actors' activities requires recognizing and accommodating their distinct interests and purposes. Any proposed governance arrangement may have to contend with irreducible practical and conceptual tensions between different actors' designs: scientific, commercial, and human-exploration activities may often be incompatible with each other. Moreover, it is likely that these varied actors' plans are best served by different governance arrangements [15].

Now is an appropriate time to begin developing a governance framework guided by these lessons from Earth. Efforts at managing forthcoming disputes are most likely to succeed if they are undertaken *before* vested interests gain too firm a foothold.

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