

“There is no strife, no prejudice, no national conflict in outer space as yet”.

President John F. Kennedy, (1962, Rice University, Sept 12.)



Credit: NASA

Concentrated Resources on the Moon

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ASTROPHYSICS

HARVARD & SMITHSONIAN

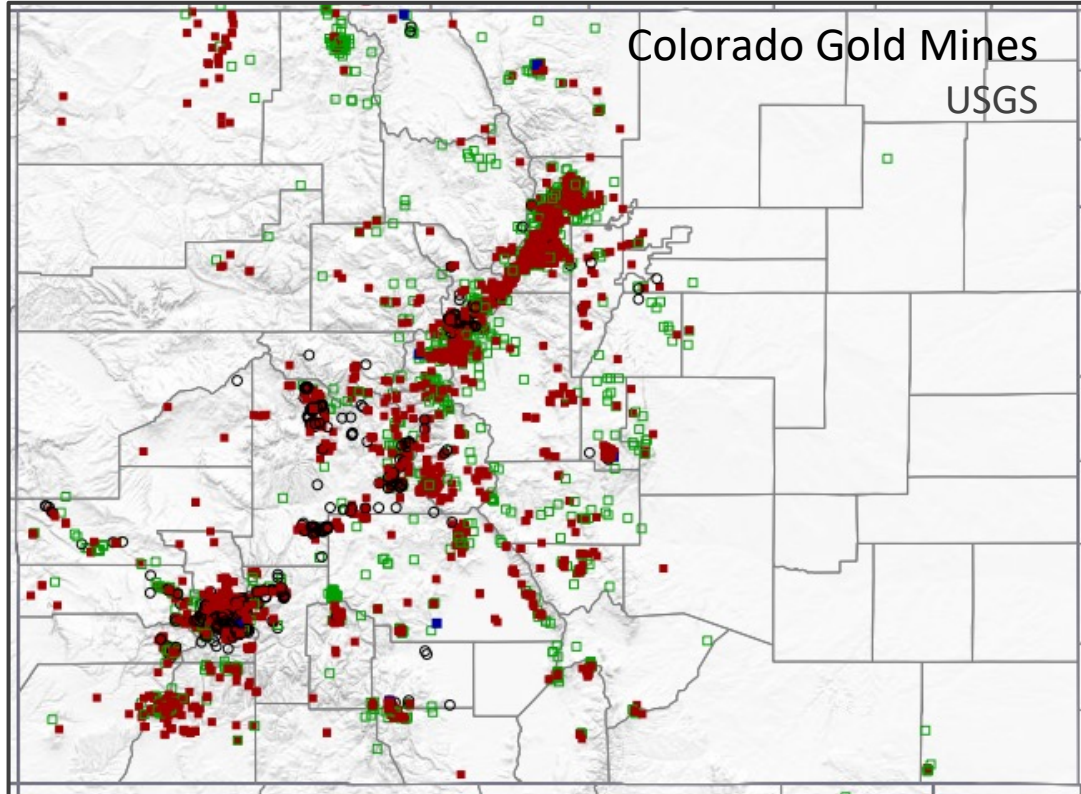
published in Elvis, Krolikowski, & Milligan
Phil. Trans. Roy. Soc. A, 379:20190563

[arXiv:2103.09045](https://arxiv.org/abs/2103.09045)

Our thanks to the
National Space Society
For this opportunity to
address UN COPUOS



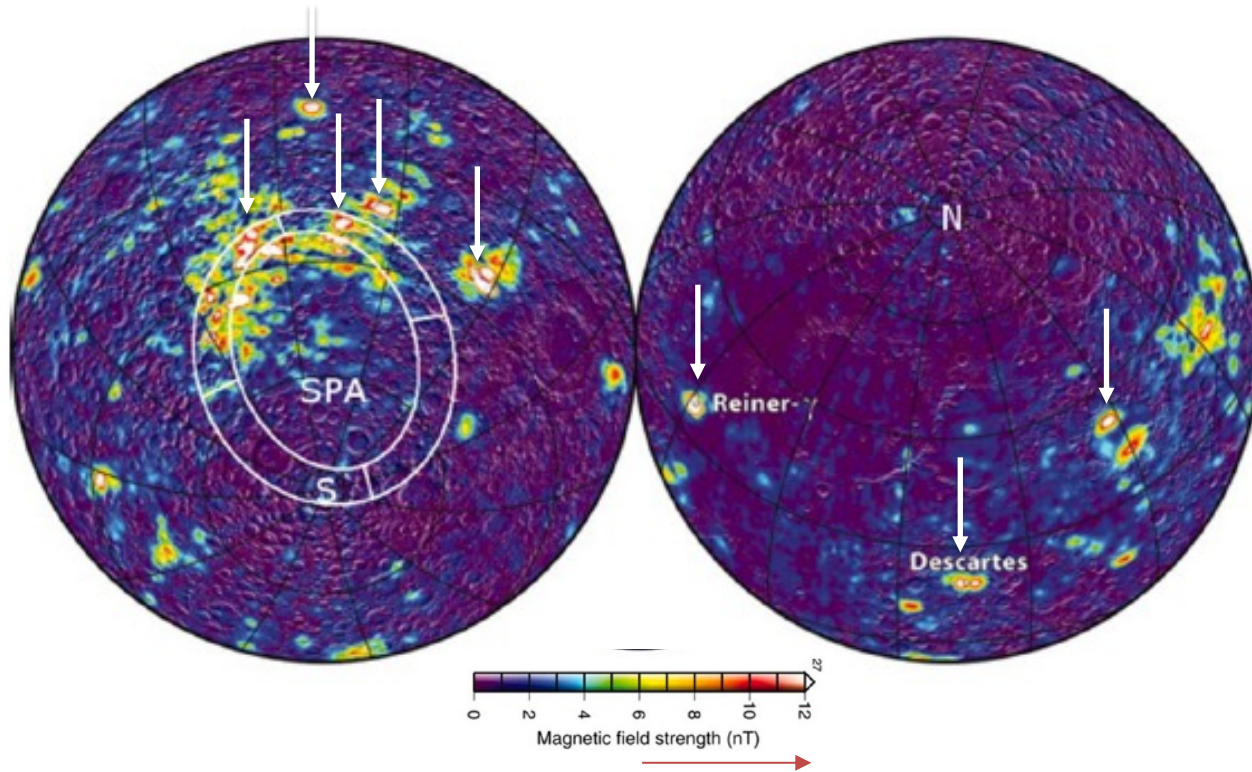
not every mountain is a gold mine



clustered, highly localized
desirable real estate is rare in space
the Moon is not uniform
“magnificent desolation”
one exception: oxygen
from silicate rock of
regolith

iron - Lunar Magnetic Anomalies

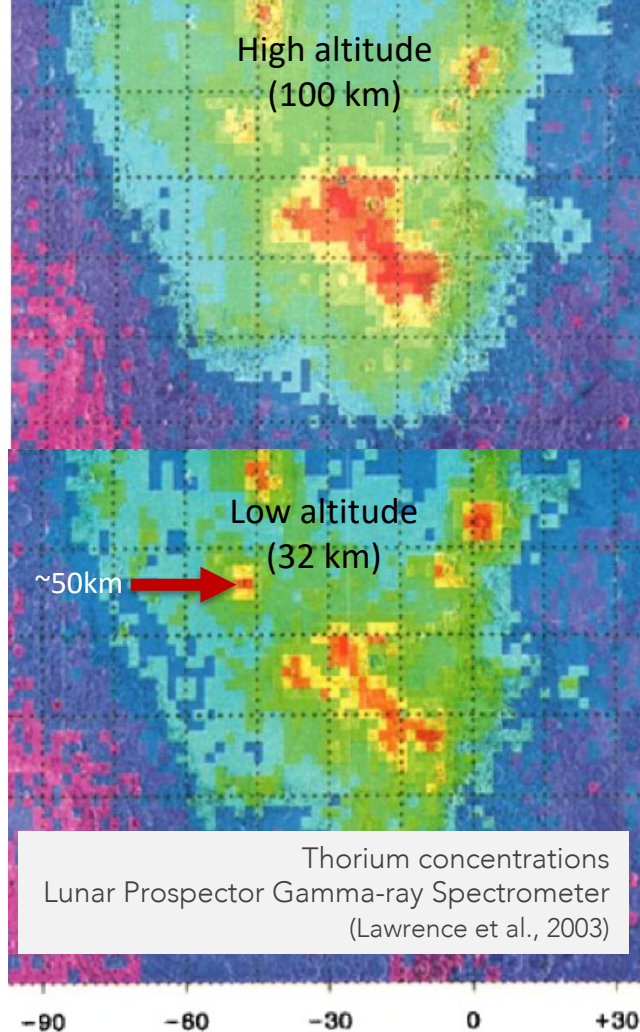
Wieczorek, Weiss & Stewart (2012)
Science, Vol.335, Issue 6073, pp. 1212



Lunar Prospector magnetometer

small fraction of Moon's surface
localized doublings ~50 km dia.

Concentrated Regions could be even smaller

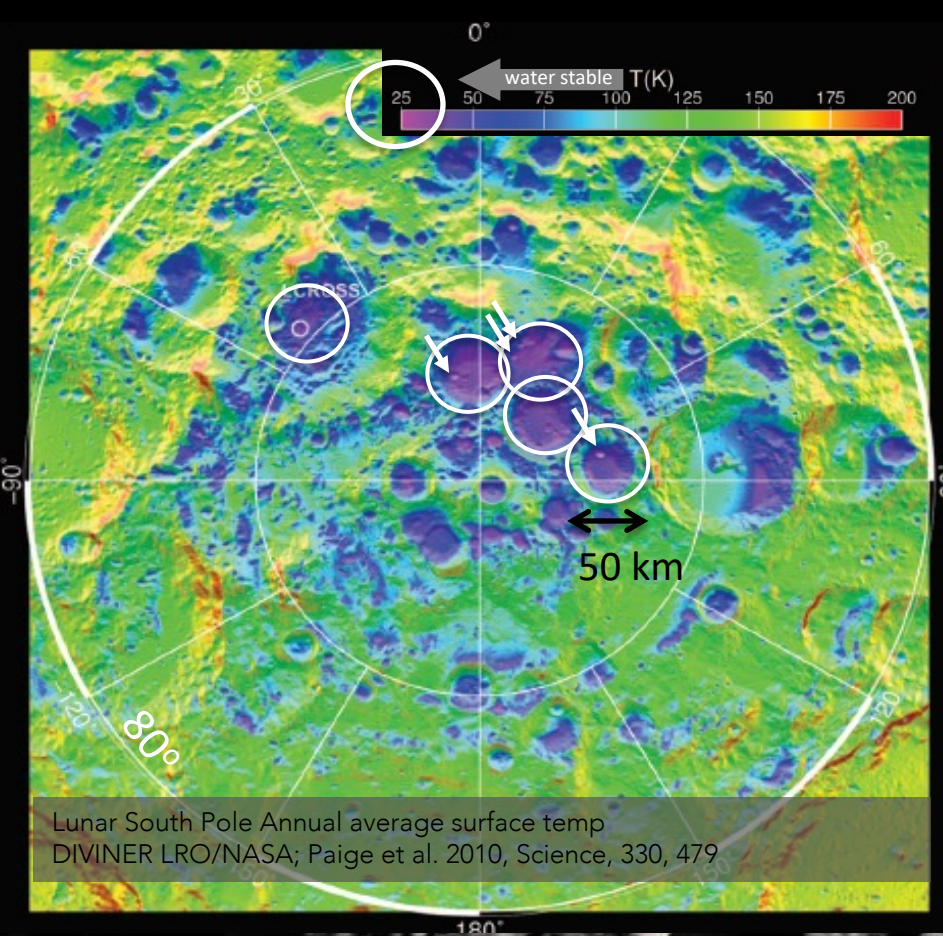


Limited resolution of instruments ~10s km
Large pixels dilute signal.

Any smaller scale features will have higher concentrations

E.g. Thorium from High altitude vs Low altitude

polar cold traps



- Permanently Shadowed Regions (PSRs)
- Cold: <173 C (110K) water ice is stable
- Cold traps retain volatiles for billions of years
- Billion tonnes [TBR] of water
- Key to lunar industry & settlement
- Only a few 50 km-scale cold traps
- Oldest (25 K) traps are few km scale

The Peaks of Eternal Light[§]

Elvis, Milligan & Krolikowski 2016, Space Policy

[arXiv:1608.01989](https://arxiv.org/abs/1608.01989)

Not all resources are material

Lunar poles have peaks in nearly permanent sunlight*

Located next to permanently shadowed regions (PSR)

i.e. **continuous power near a valuable resource.**

Rare resource. total area ~1 sq. km.

Peaks of Eternal Light

Sun circles the horizon near the poles



* W. Beer, J.H. Maedler, *Der Mond nach seinen Kosmischen und individuellen Verhaeltissen oder allgemeine vergleichende Selenographie*, Simon Schropp and Co, Berlin, 1837.

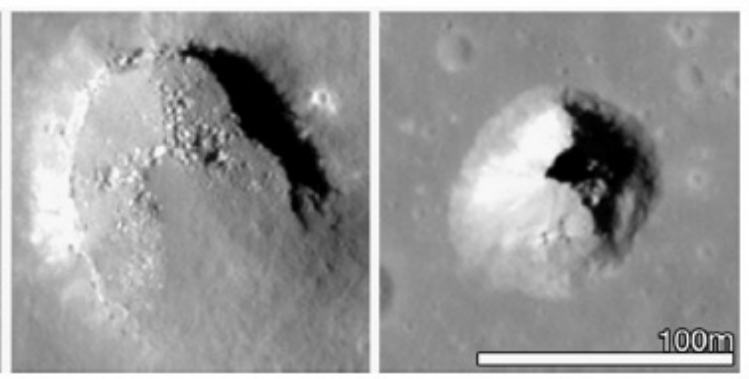
[§] C. Flammarion, *Astronomie Populaire: description general du ciel*, Marpon and Flammarion, Paris, 1880, p. 159.

lunar pits

best sites for human habitation?

LROC map, Wagner & Robinson (2014) 2014Icar..237...52W

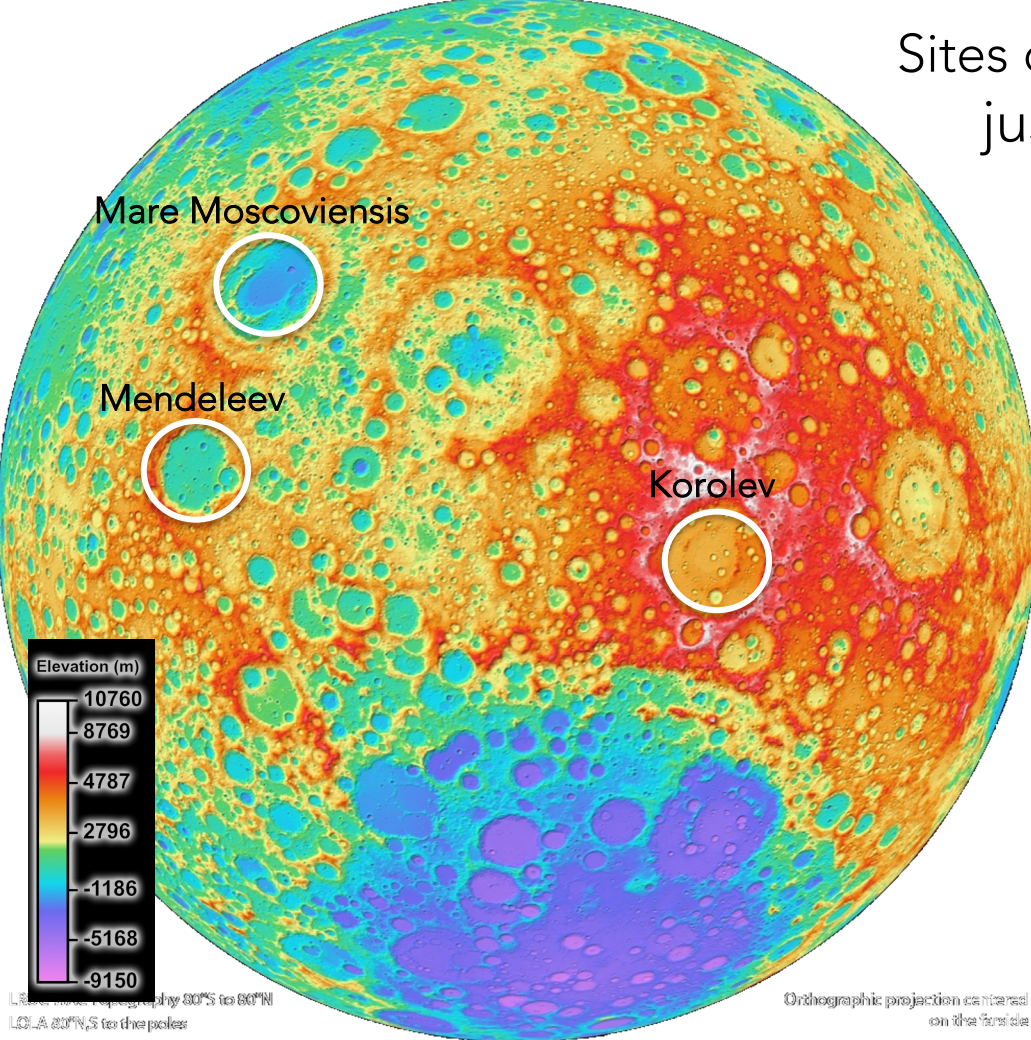
221 known pits
those with easy access
+ large overhangs, tubes
+ near resources
will be the most valuable.



Rutherturd

Sites of Extraordinary Scientific Importance just 3 sites for cosmology telescope

Le Conte, Elvis & Gläser, 2023
Royal Astronomical Society Techniques &
Instruments, submitted.



- Lunar far-side is solar system's radio quiet zone
- Enables study of a time before stars and galaxies
- Requires large low frequency radio telescope array
- Only ~3 sites >200 km dia., with smooth terrain
- Most uses will conflict with radio quiet zone
- E.g., navigation, communication constellations



Most lunar resources are highly concentrated

Elvis, Krolikowski, & Milligan
Phil. Trans. Roy. Soc. A, 379:20190563
[arXiv:2103.09045](https://arxiv.org/abs/2103.09045)

typically a dozen sites

typically a few kilometers across

rare, valuable real estate

Leads to disputes and conflicts

Many players about to enter

Problem for governance



For more examples and some mitigation options see backup slides

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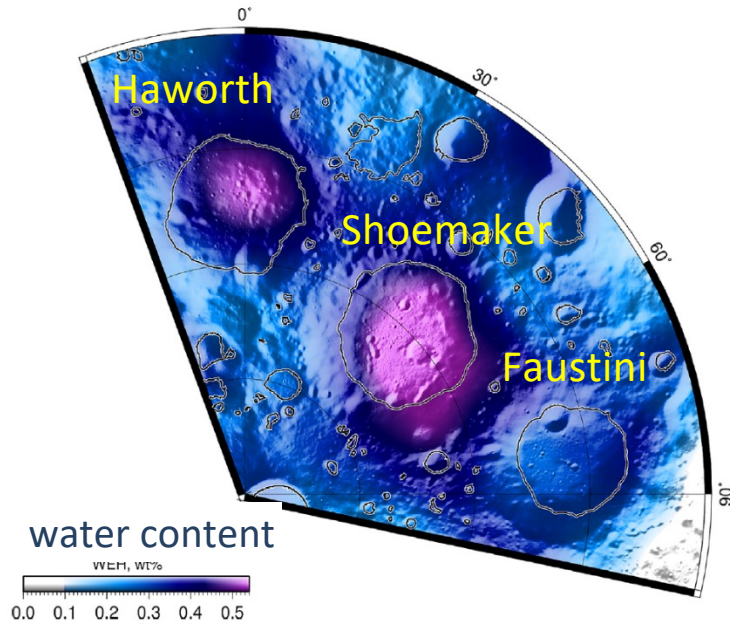


Back-up slides

1. more examples of concentrated resources
2. some mitigation options

1. Gravitational Wave Observatory

A.B. Sanin et al./Icarus 283 (2017) 20–30



Map of the WEH abundance in wt% in the vicinity of the Shoemaker, Haworth and Faustini craters. Contours of PSRs are shown.

LION: Laser Interferometer on the Moon

Amaro-Seoane+2021

40 km triangle

cryogenic temperature

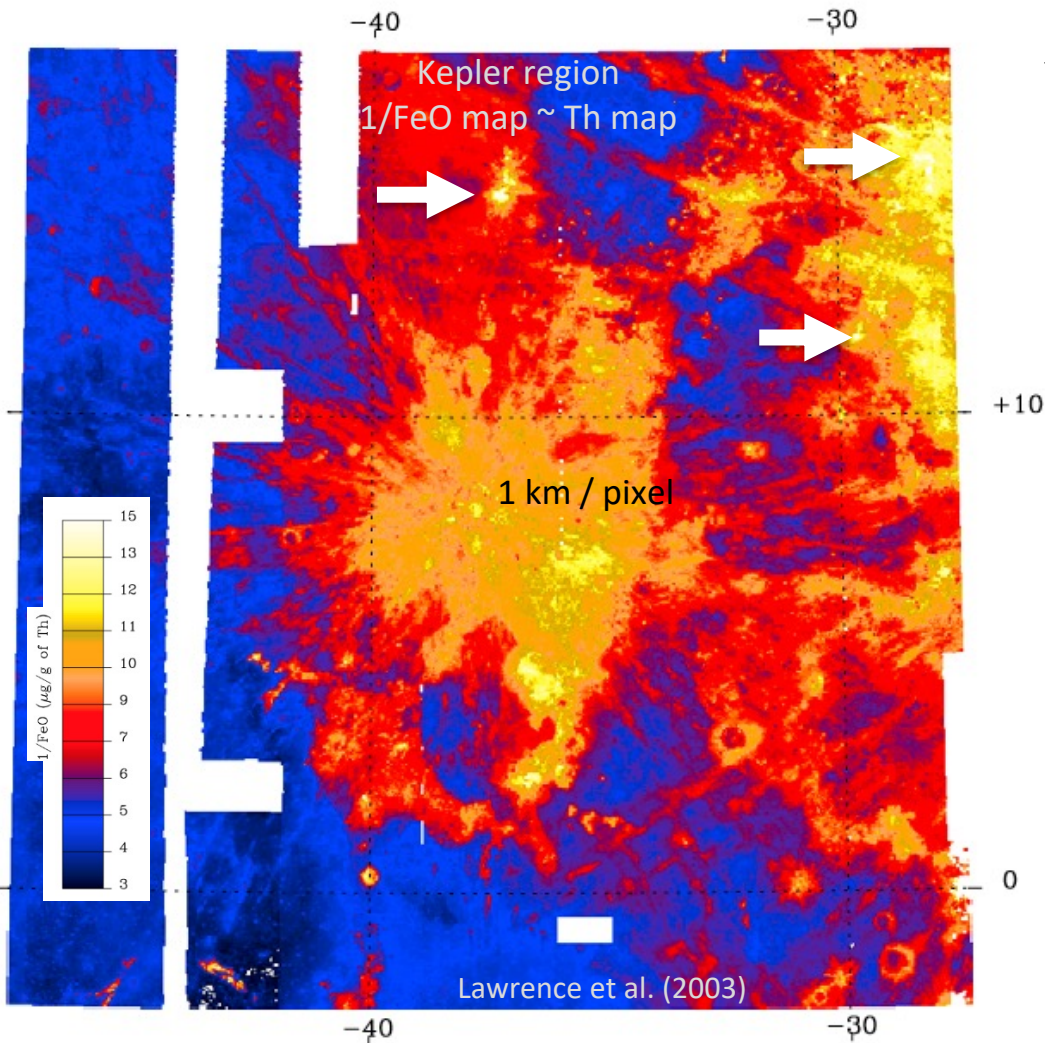
3 large enough Permanently Shadowed Regions
sensitive to seismic disturbances

→ avoid water rich PSRs (mining)

→ just 1 site: Faustini crater

1. thorium concentrations

Lunar Prospector Gamma-ray Spectrometer data
(Lawrence et al., 2003)



appear widespread

in detail far more concentrated

15 g/tonne vs 10 g/tonne

2. Mitigation Steps: Technical

Elvis, 2023, IISL submitted

Example: Sites of Extraordinary Scientific Importance

Radio: suppress side-lobes, harmonics, and electronics noise
both on the surface and in lunar orbit

Infrared: identify and map coldest “dry” PSRs;
minimize dust lofting from landing/take-off

Gravitational Waves: minimize vibration from mining,
ground traffic, launches

INCENTIVES: why invest in tech if others won't use it?

2. Mitigation Steps: Policy

Elvis, 2023, IISL submitted

Sites of Extraordinary Scientific Importance

Banning other users won't help:

astronomers need the HSF infrastructure

Radio: set standards for electronics noise

both on the surface and in lunar orbit

Infrared: limit non-science use of dry PSRs.

set dust lofting standards

Gravitational Waves: set vibration standards.

reserve a large dry PSR (Faustini?)

sharing of landing/launch pads near poles

ALL: mechanisms for enforcement: carrots and sticks

easy within Artemis Accords countries? others?

2. Mitigation Steps: A Broader View

Elvis, 2023, IISL submitted

Sites of Extraordinary Scientific Importance

astronomy is just a convenient example

other science will have different SESIs

need to define these SESIs pro-actively, together