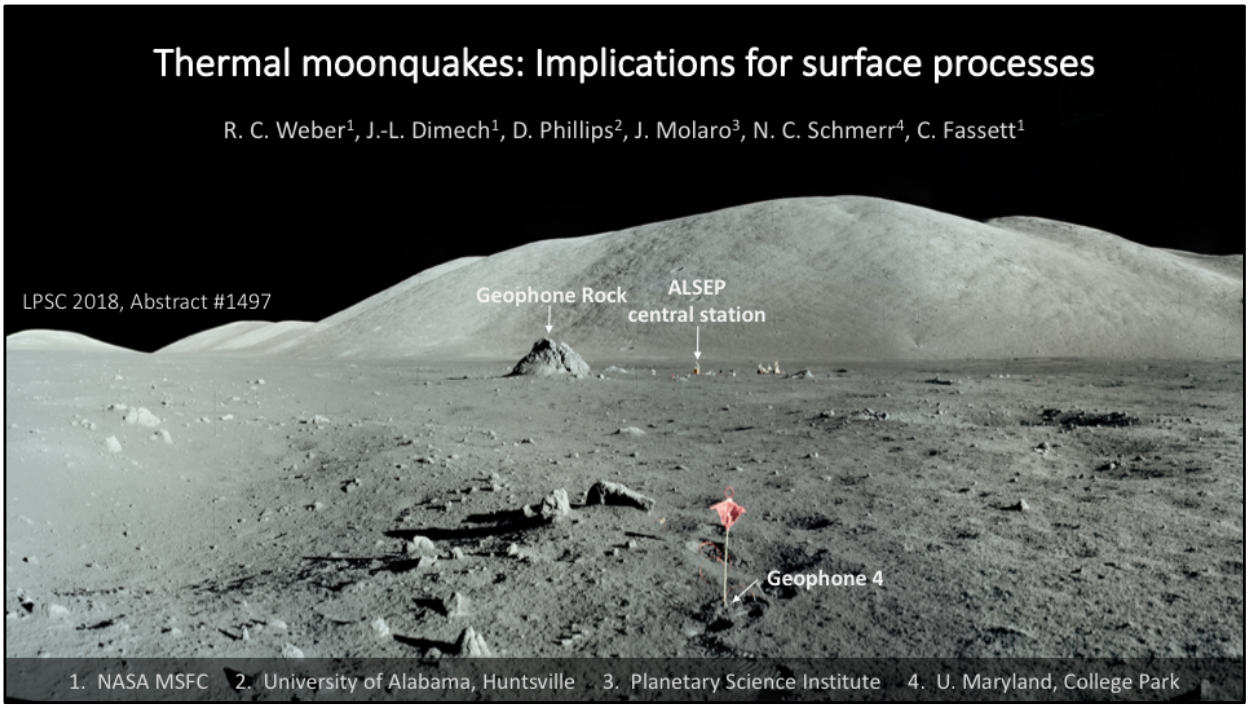
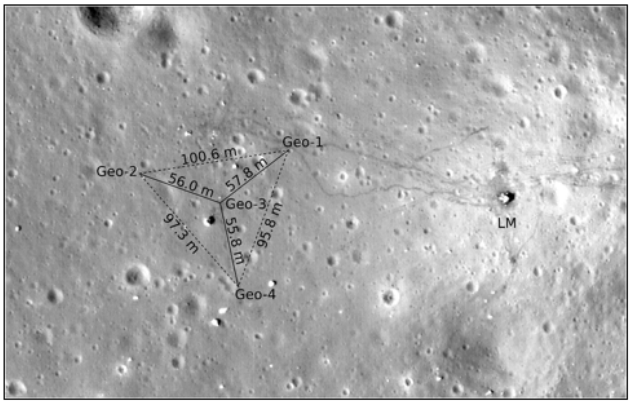


Apollo image AS17-147-Geophone 4 partial pan
Frames 22528 to 22532.
Source: NASA

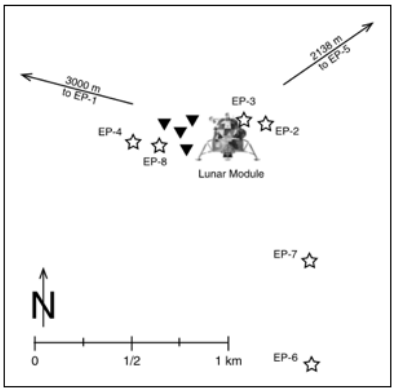
Background

Lunar Seismic Profiling Experiment (LSPE)
was part of the
Apollo Lunar Surface Experiment Package (ALSEP)



Heffels et al., 2017 (PSS)

Sollberger et al., 2016 (GRL)

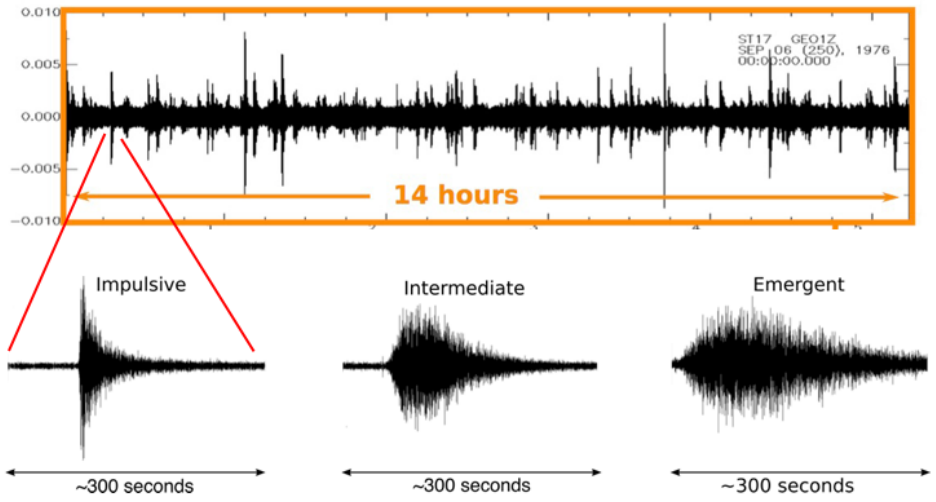


Primary modes of operation:
1. Active experiment
2. "Listening" mode

Left image: Heffels et al., 2017 "Re-evaluation of Apollo 17 Lunar Seismic Profiling Experiment data." Planetary and Space Science 135, 45-54.
Right image: Sollberger et al., 2016 "The shallow elastic structure of the lunar crust: New insights from seismic wavefield gradient analysis" Geophysical Research Letters *43*, 10,078–10,087.
Fair use

Thermal Moonquakes

Continuous “listening mode” data contain many small “noise” events



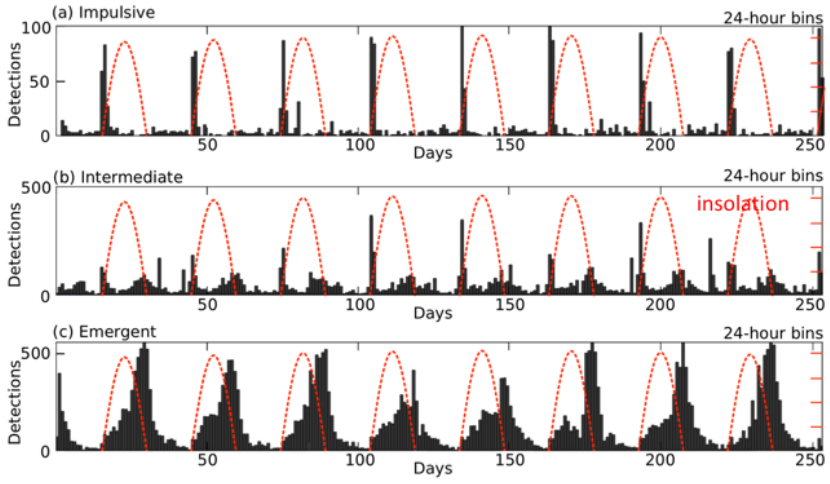
Author-generated images.

Notes: What do we know about them from previous work?

- Observed on all Apollo seismic experiments
- Occur periodically according to diurnal sunrise/sunset cycle
- Have predictable amplitudes and waveforms
    - Original event detection performed only on small portion of data
    - Original event classification performed by eye

Thermal Moonquakes

HMM event detection algorithm identified >50k events showing strong diurnal occurrence patterns consistent with previous observations. Work by Dimech reported at AGU 2016 & LPSC 2017, Results in Physics (in press).

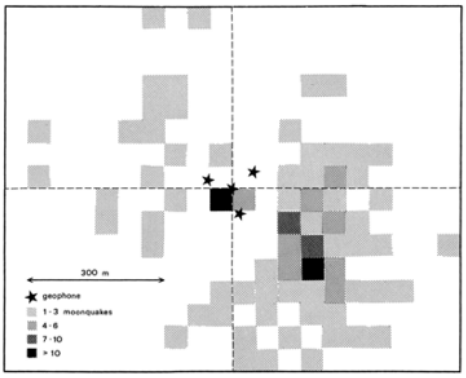


Author generated

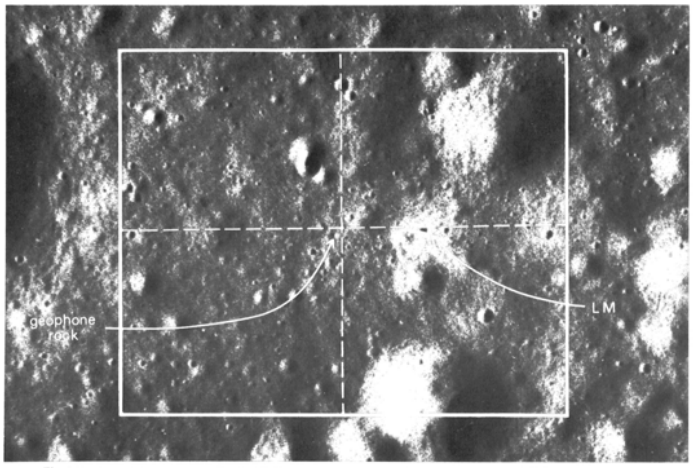
Thermal Moonquakes

Early work used signal amplitudes to locate thermal moonquakes detected by LSPE

- Locations accurate to ~50m



Duennebier 1976, Proc. Lunar Sci. Conf.



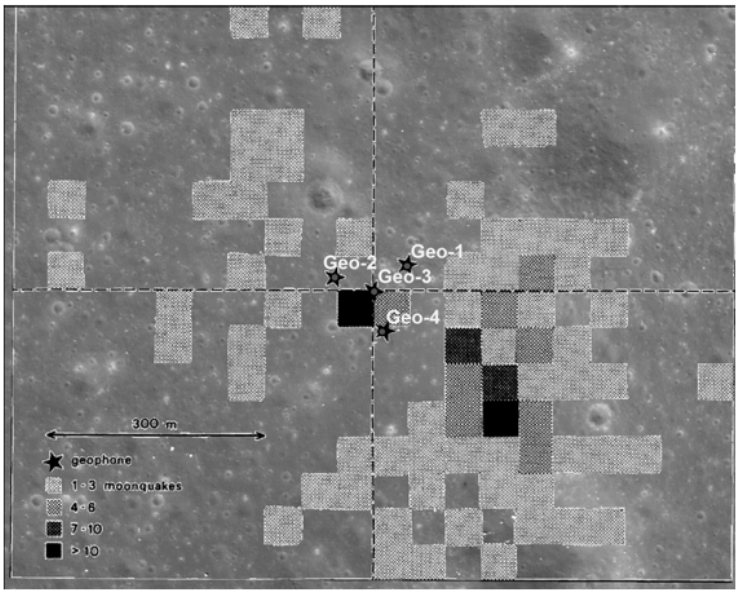
Apollo PanCam image

Images from Duennebier 1976, Proc. Lunar Sci. Conf. 7th, p. 1073-1086 "Thermal Movement of the Regolith"
Fair use

Apollo PanCam image AS 17-2309. Source: NASA

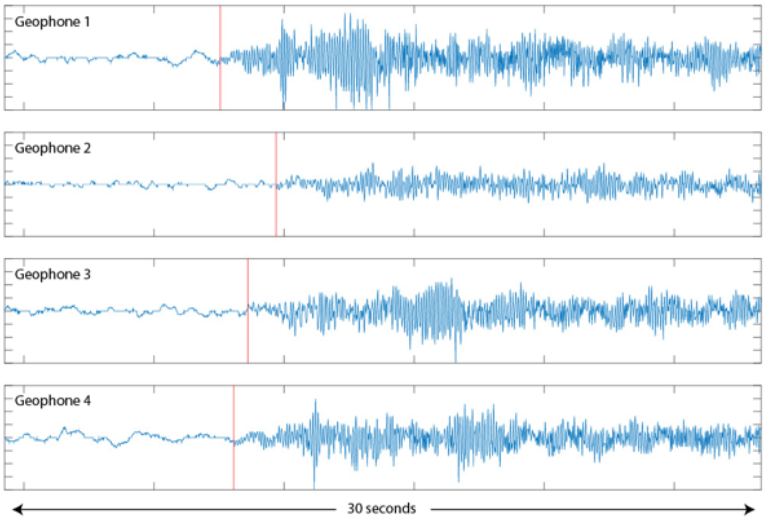
Thermal Moonquakes

LROC image



LROC image. Source: NASA
Click image: Image from Duennebier 1976, Proc. Lunar Sci. Conf. 7th, p. 1073-1086 "Thermal Movement of the Regolith" overlaid on LROC image. Source: NASA
Fair use

Event location

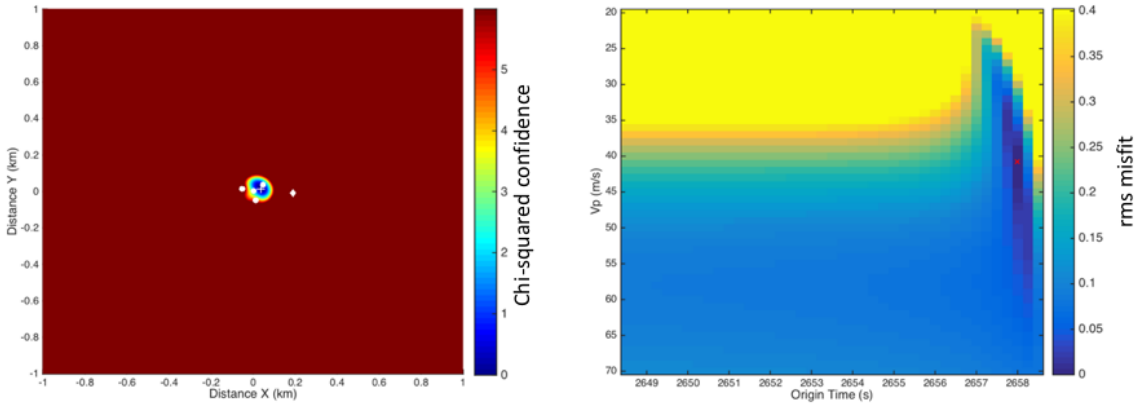


Author-generated

Event location

Method by Schmerr:

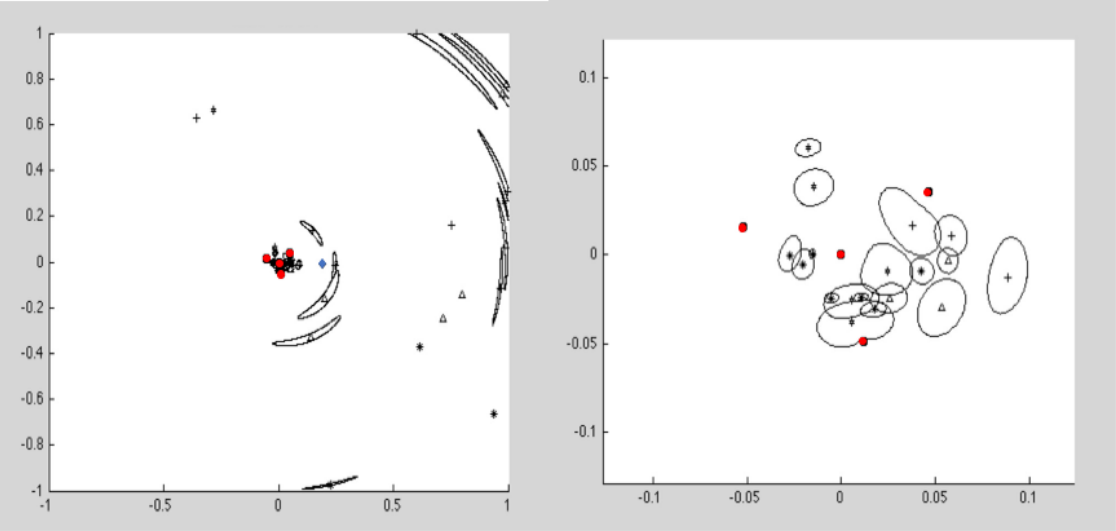
1. Assume a single 1-D layer velocity model, waves travel in a straight line along the surface
2. Input initial guess for velocity and origin time (grid search over values)
3. Input arrival times at 4 geophones
4. Minimize misfit between observed and calculated arrivals



Author-generated

Event location

Location results:



Author-generated

Event location

Analysis 1:

What do we see inside those contours?

Features mapped by Haase et al. 2012 (JGR)

rocks

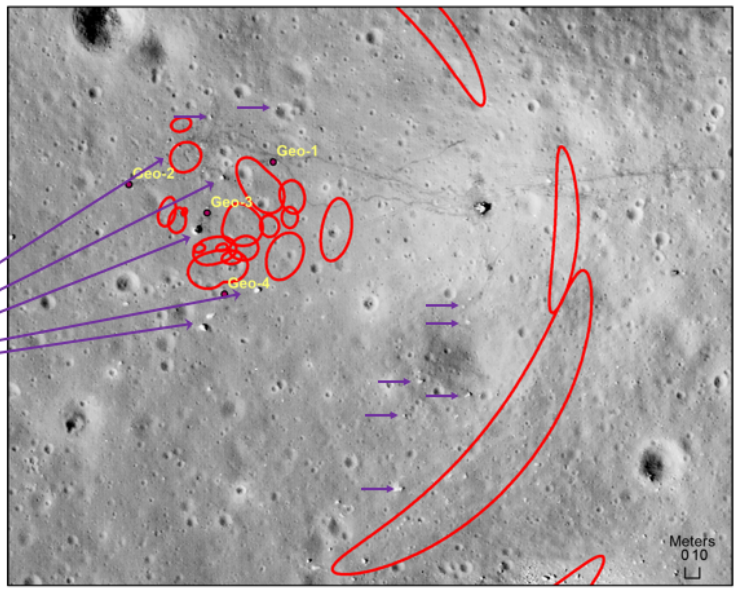
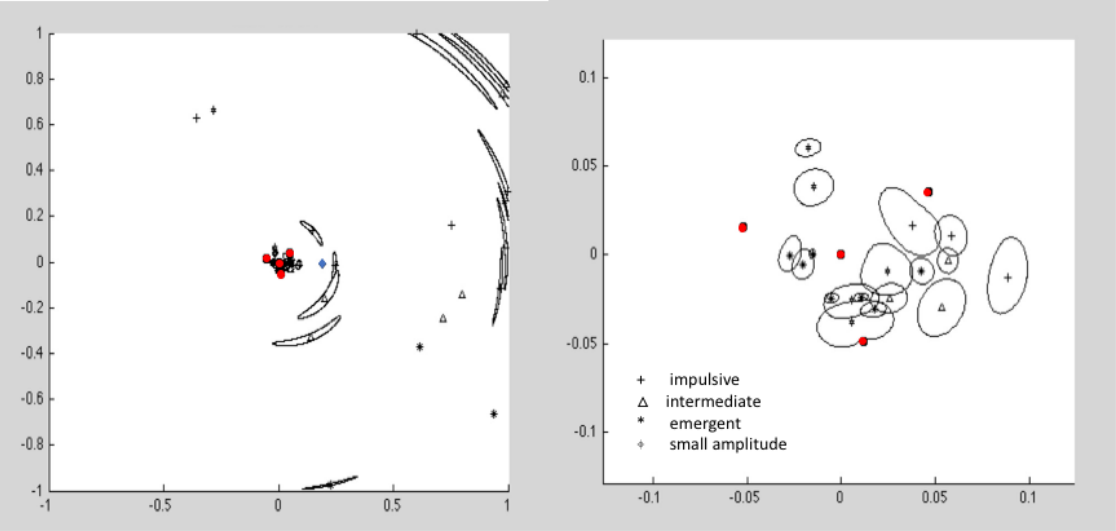


image: LROC imagery (source: NASA) with author generated points and contours
Rocks mapped by Haase et al. (2012) “Mapping the Apollo 17 landing site area based on Lunar Reconnaissance Orbiter Camera images and Apollo surface photography”. Journal of Geophysical Research Vol. 117. Fair use

Event location

Analysis 2: Are there any obvious patterns based on waveform type?



Author-generated

Thermal modeling

What do thermal moonquakes tell us about regional surface processes?

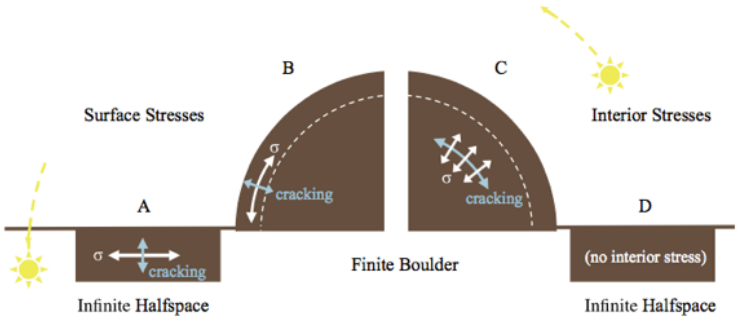
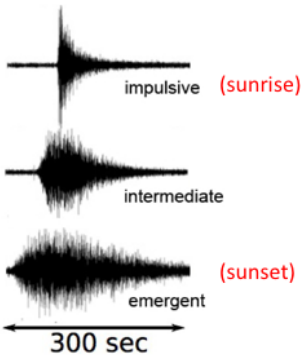


Figure from Molaro et al., 2017 (Icarus)

~~Do waveform rise times indicate distance from array?~~

Do waveform rise times indicate type of cracking?



Left: Figure from Molaro et al., 2017 (Icarus) “Thermally induced stresses in boulders on airless body surfaces, and implications for rock breakdown” Volume 294, Pages 247-261. Fair use

Right: author-generated

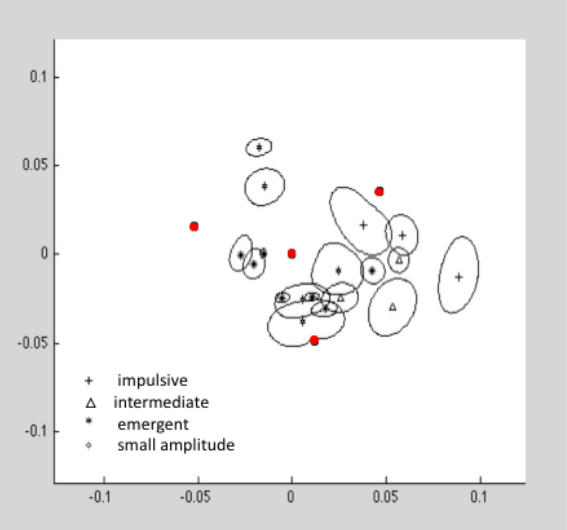
Conclusions & future work

Conclusions from pilot study:

1. Thermal moonquake arrival times can be used to improve precision of recovered locations
2. Waveform type is likely indicative of failure type rather than distance from array
3. Distribution suggests diffuse events throughout the lunar regolith, but because of large separations in the delay times between events, we can't rule out contributions from rocks and boulders

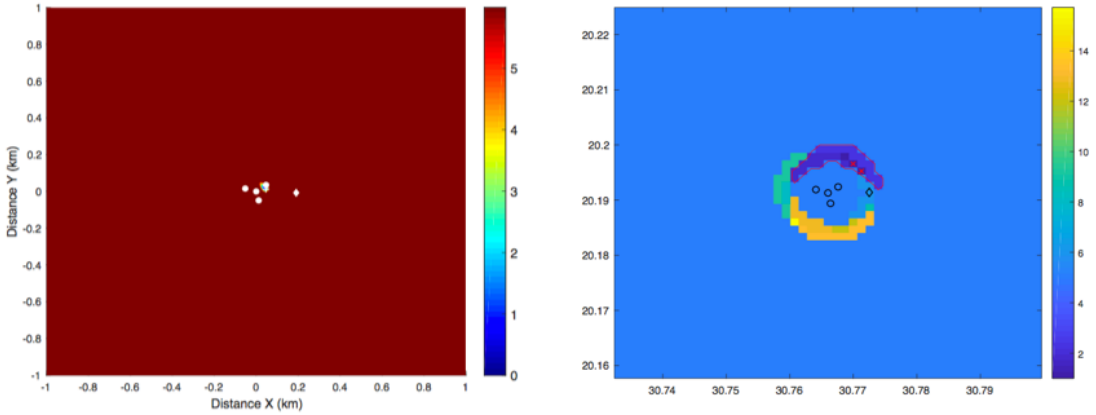
Future work:

1. Map pick uncertainty onto location uncertainty
2. Perform spatial and statistical analysis on larger event sample over a full lunation. Attempt to match event types and locations to features, time of day, temperature, and stress state.
3. Perform quantitative assessment of the contribution of thermal moonquakes to regolith production



Author-generated

Location refinements



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