Lunar Interior Temperature and Materials Suite (LITMS)

Testing the thermal evolution, differentiation, and asymmetry of the Moon

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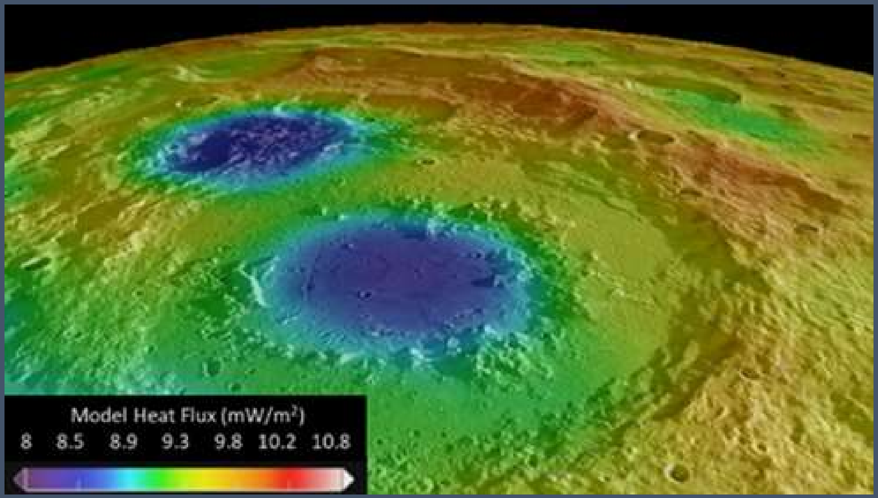
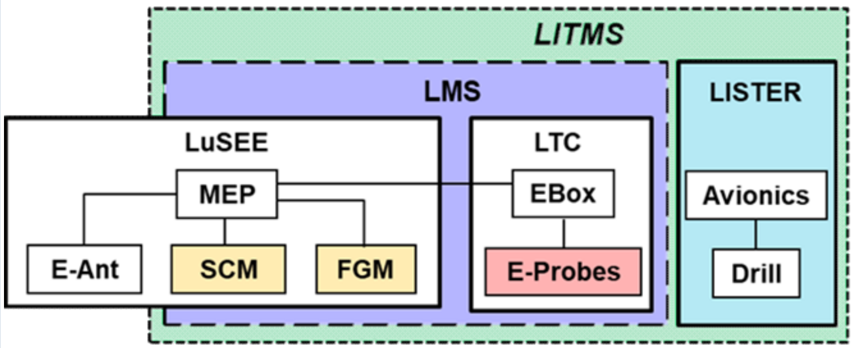
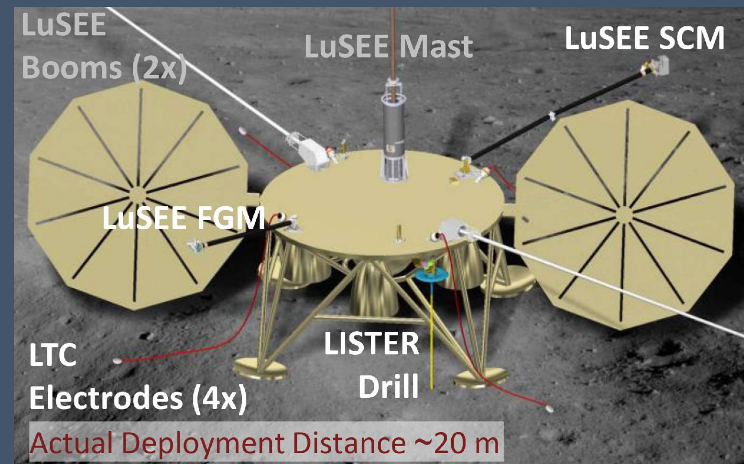


Planetary Science Decadal Survey
Mercury & Moon, June, 2021

LITMS



LITMS: Lunar Interior Temperature and Materials Suite = LMS + LISTER
LISTER: Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity
LMS: Lunar Magnetotelluric Sounder = LuSEE (part) + LTC
LuSEE: Lunar Surface EM Explorer.
LTC: Lunar Telluric Currents
MEP: LuSEE Main Electronics Package
E-Ant: LuSEE E-field Antennas
SCM: LuSEE Searchcoil Magnetometer
FGM: LuSEE Fluxgate Magnetometer
EBox: LTC Electronics Box
E-Probes: LTC E-field Probes (4x)

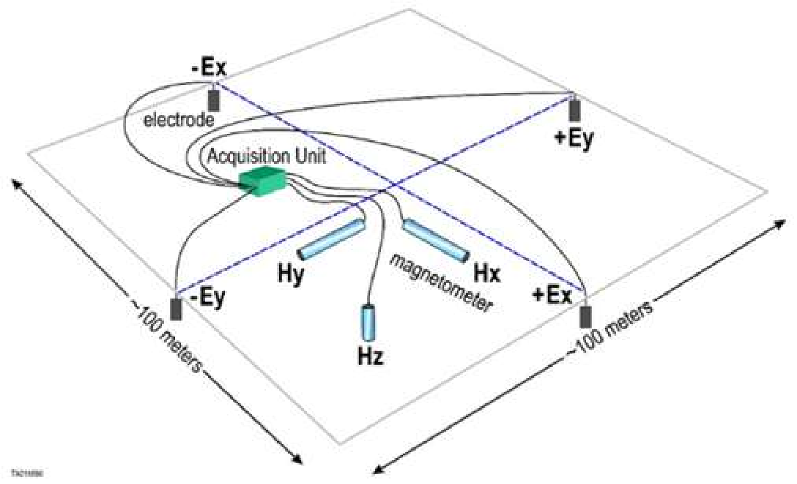


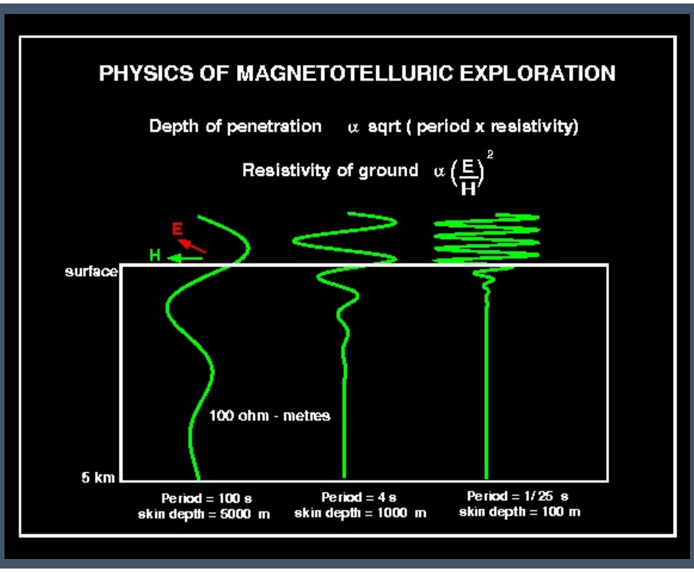
	Level 1	Level 2	Level 3	Level 4A	Level 4B
LuSEE: *FGM,SCM*	B(t)	LMS: $\sigma_a(f)$	$\sigma(z)$	$T_{MT}(z\|m)$	T(z) m(z)
LTC: *E-Probes*	E(t)				
LISTER	T(t, z<3m)		q	$T_{HF}(z\|m)$	

- Determine heat flow by measuring temperatures and thermal conductivity at depths up to 3 m.
- Determine electrical conductivity of the interior using the magnetotelluric (MT) method.

- Joint measurement of heat flow and electrical conductivity separates the temperature and compositional dependence of each.
- Single-station experiments can be completed in days.

The Magnetotelluric Method (MT)



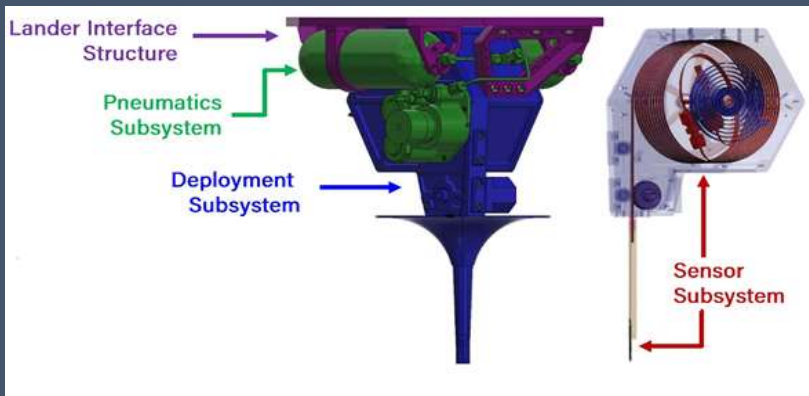


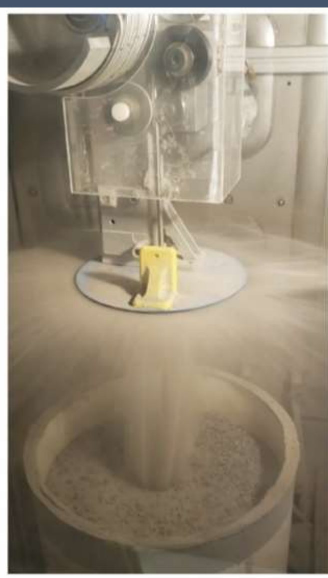
hearthweb.ess.washington.edu/booker/magnetotellurics/overview

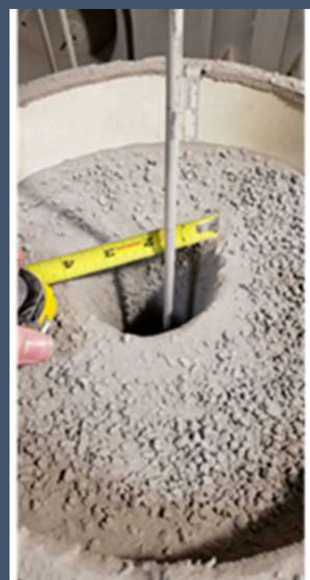
- Measure natural low-frequency electric and magnetic fields.
- Determine resistance from a version of Ohm's Law

  R = V / I = Electric Field / Magnetic Field
- Solve for the distribution of resistivity with depth, knowing that the skin-depth effect allows lower frequencies to penetrate deeper.
- MT is superior to magnetic-transfer function (Apollo 12-Explorer 35) because it
  - does not require a distant, reference observation.
  - is largely insensitive to plasma distortions, allowing measurement at higher frequencies and hence imaging at shallower depths << 500 km.

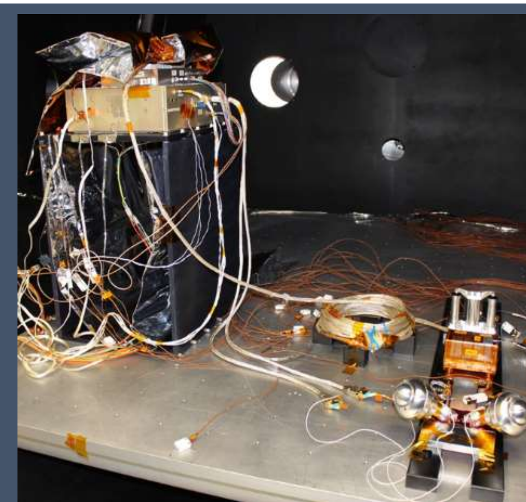
LISTER & LMS Development

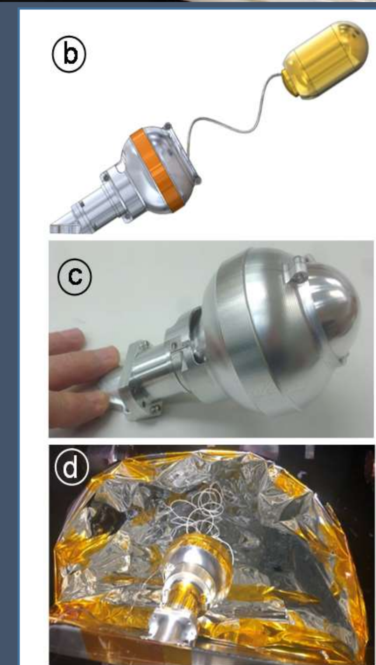






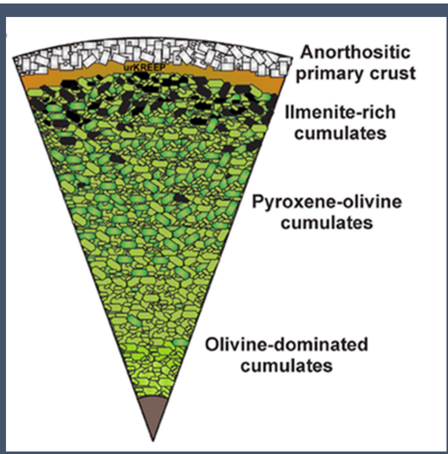
- Development on both instruments began with IRADs in 2008-9.
- LISTER continued under PIDDP, SBIR.
- LMS continued under COLDTech, ICEE-2.
- Separately selected for flight under LSITP.
    - LMS KDP 2/21.
    - LISTER KDP 10/21.



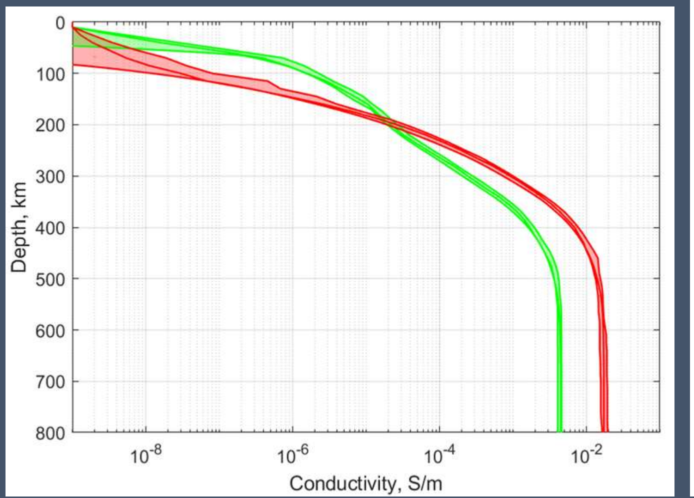


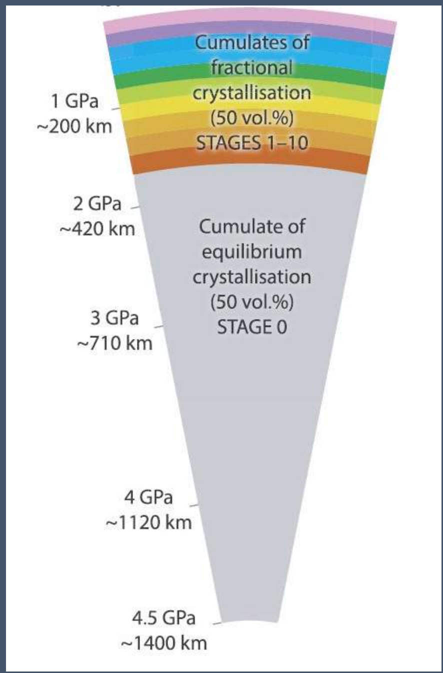
(1) Vertical Differentiation

- Primary differentiation into crust, mantle, & core following magma ocean.
- Fractional crystallization in mantle led to stratification.
- Gravitational instability caused overturn.
  - <u>But</u> surface composition of SPA suggests uppermost mantle was stratified ferroan cumulates & KREEP-rich (*Moriarty et al.,* 2020).
  - Suggests overturn was incomplete and KREEP was globally distributed.
- Electrical conductivity controlled by Fe content: very different profiles for end-members.
  - Heat flow constrains temperature profile.



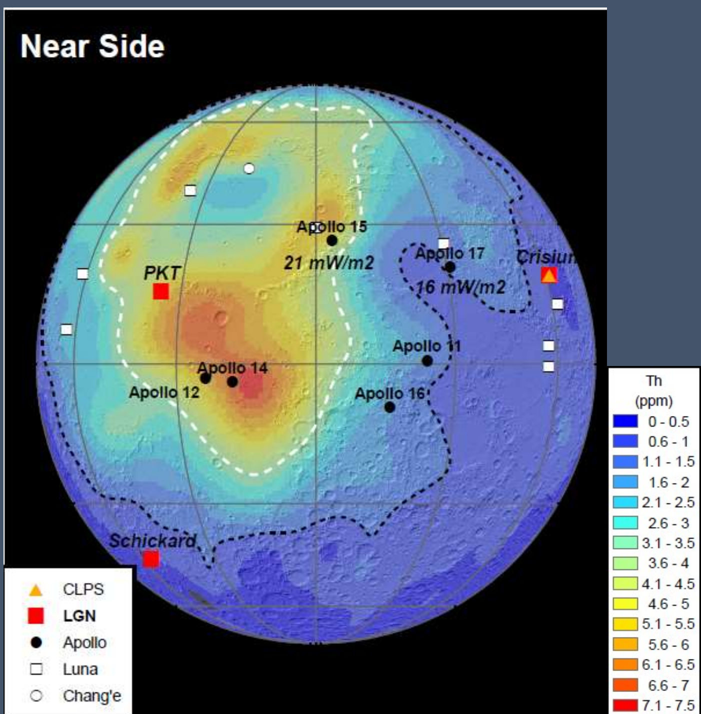
McCubbin et al., 2015





Johnson et al., 2021

(2) Lateral Asymmetry (Procellarum KREEP Terrane)

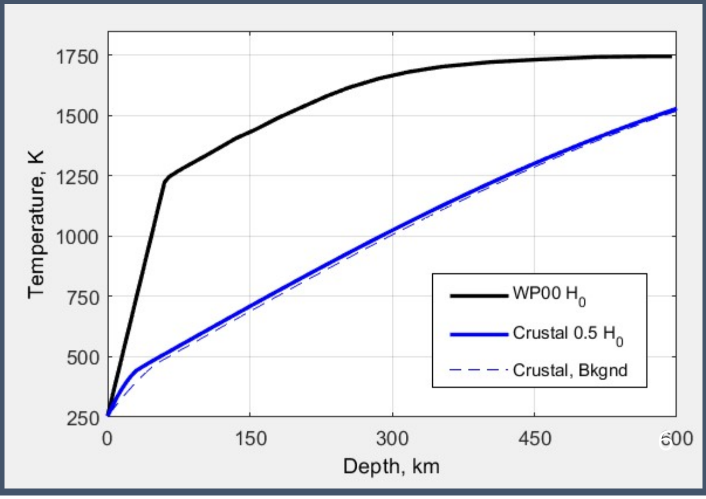


- Maria concentrated in western near side (Man in the Moon).
- Revealed by Lunar Prospector 1998 to be rich in incompatible elements "KREEP" – Procellarum KREEP Terrane (PKT).
- Dregs of magma ocean were concentrated in one part of the Moon, forming distinct crust and perhaps causing long-lived volcanism. Theories conflict about the distribution of heating and its effect on the surface.
- Measure heat flow and electrical conductivity **far** from PKT.
  - Calibrate prior Apollo measurements to new background.

Table 1. Alternative Models for PKT Interior

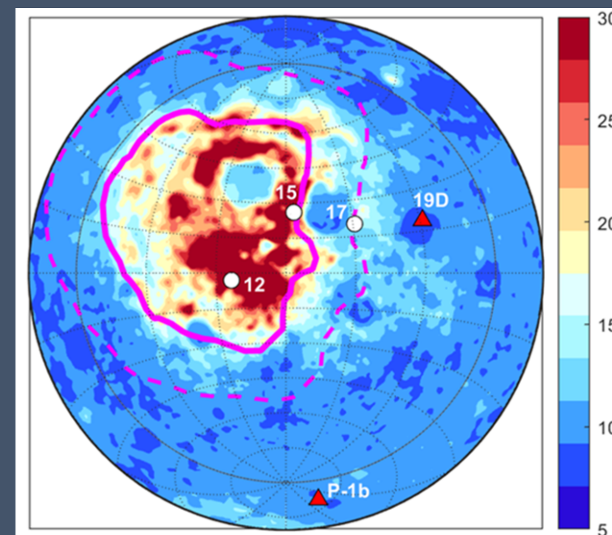
Interior Model	Apollo 15 & 17 Heat Flow	Gravity & Topography	Apollo 12 Electrical Conductivity	Long-Lived Volcanism
Hot Mantle[1]	Yes	Maybe	No	Yes
Cold Mantle[2]	Yes	Yes	Yes	Maybe

[1]*Wieczorek and Phillips*, 2000. [2]*Grimm*, 2013.

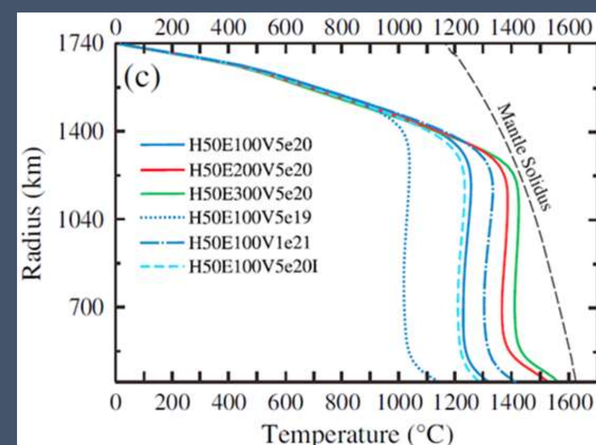


(3) Thermal Structure and Evolution

- Surface heat flow is sum of contributions from mantle, crust, and KREEP.
  - Unique separation A15, A17, Schrodinger for “cold” PKT.
  - Deconvolve incorporating electrical conductivity for “hot” PKT.
- Lunar temperature profile
  - Lunar thermal evolution models make specific predictions for temperature profile determined by heat budget and factors controlling mantle viscosity.
  - Slope of stagnant lid in mantle determined by heat flow.
  - Temperature of convecting interior (& viscosity) determined from electrical conductivity.



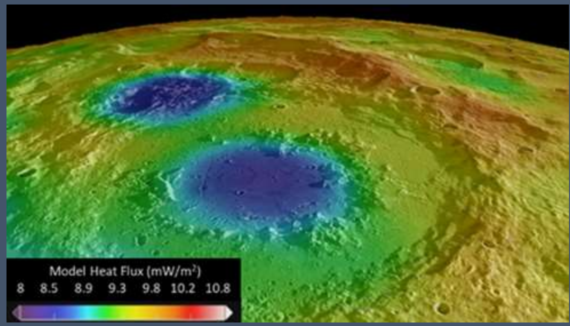
Based on Siegler & Smrekar, 2014

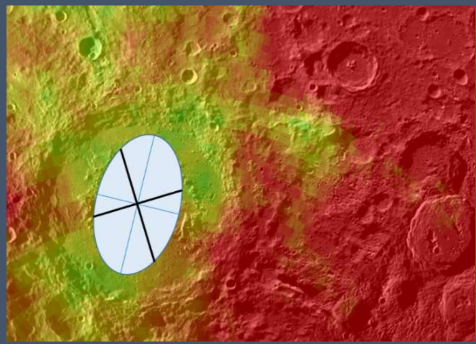


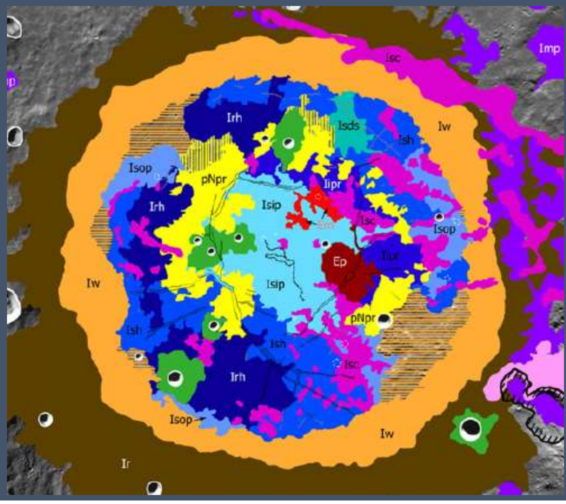
Zhang et al., 2013

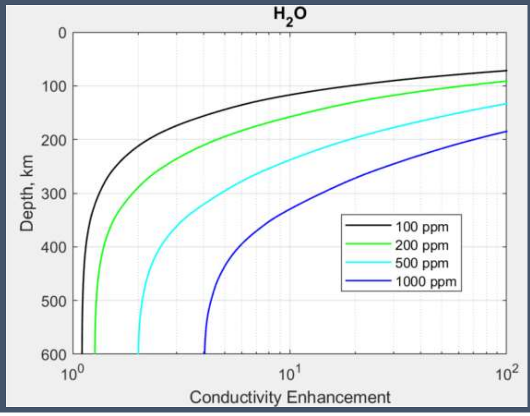
Schrödinger

- Selected by NASA, but useful for study of global differentiation and thermal evolution.
  - Far from PKT, needed to establish background properties of mantle.
  - Peak-ring structure presents choice of two different crustal thicknesses, both distinct from prior landing sites.
  - Rim of SPA, which itself is a large-scale geological probe of the non-PKT Moon.
    - Anisotropy of electrical conductivity may point toward different SPA structure, if present.
  - Local pyroclastic volcanism may have distinct, preserved source zone.
    - Electrical-conductivity activation energy for (residual) water is different than iron.
  - Unlike Reiner Gamma, no strong static magnetic fields that may disturb EM sounding.









Kramer et al., 2013

Outlook

- LISTER & LMS previously, independently selected for CLPS 19D mission!
  - Launch August 2023; landing in Mare Crisium.
  - Mission also has laser retroreflector (D. Currie, UMD).
- PRISM launch likely early 2025.
  - LuSEE requires Jupiter, Saturn below horizon.
  - Mission also includes seismic suite (M. Panning, JPL).
- Prototypes of principal payload suite of a New Frontiers Lunar Geophysical Network (Cohen et al., 2009; Shearer & Tahu, 2013; Neal et al., 2020) or Artemis geophysics (Weber et al., 2020) will have flown.
  - LGN optimizes geographic diversity & long-term monitoring.