Development of a Low-Resource Combined Gamma-Ray and Neutron Spectrometer for Planetary Science

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Outline & Acknowledgements

- Overview of planetary nuclear spectroscopy
- EPICS Instrument Development
- Simulated EPICS mission performance
- Summary

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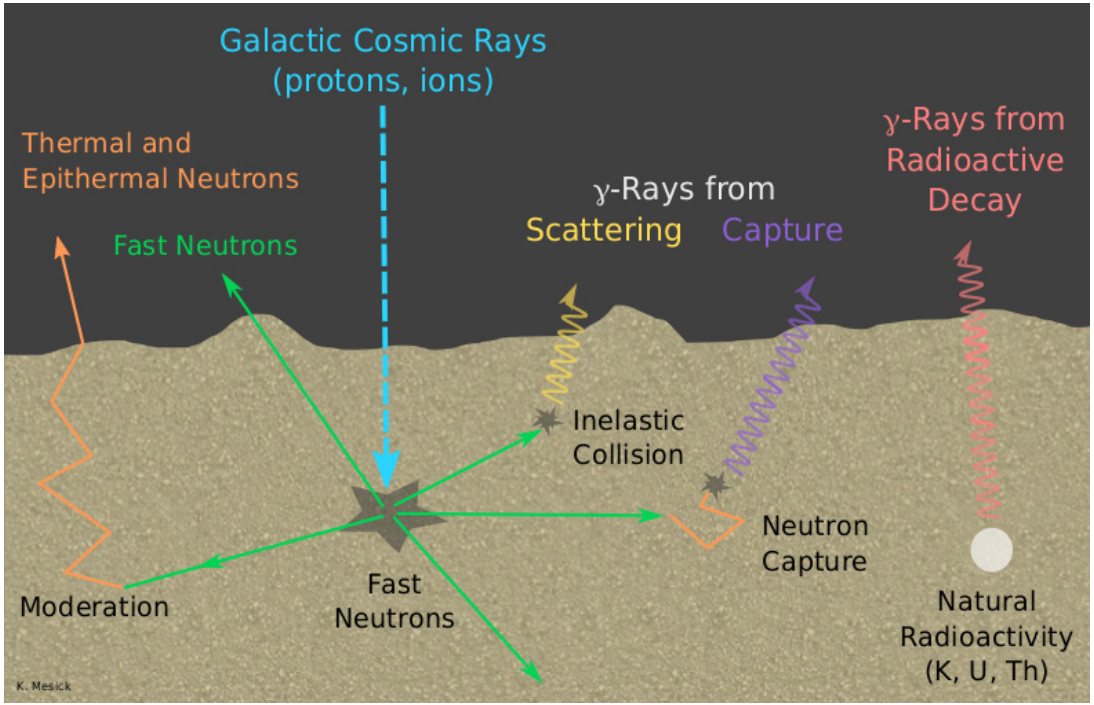
Planetary Nuclear Spectroscopy

Provides unique signatures of elemental and volatile abundance

- Galactic Cosmic Rays (GCRs) strike the surface of airless or near-airless planetary bodies
- Spalled neutrons interact in the sub-surface, resulting in neutron and gamma-ray albedo signals from the top meter
- **Neutron** energy spectrum reflects amount of moderation in the sub-surface, therefore extremely sensitive to H
- **Gamma rays** from neutron-inelastic and neutron-capture reactions or natural radioactivity emitted at distinct energies based on element



- The near sub-surface can also be interrogated by pulsed-neutron generator emitting 14.1 MeV neutrons

Planetary Missions and Science Questions

- Table shows some of the planetary missions that include nuclear spectroscopy instruments
  - International participation
  - Variety of target bodies
- Some questions nuclear spectroscopy can address:
  - Search for extraterrestrial life
  - Planetary structure, origins, and evolution
  - Planning for human exploration (in-situ resource utilization)

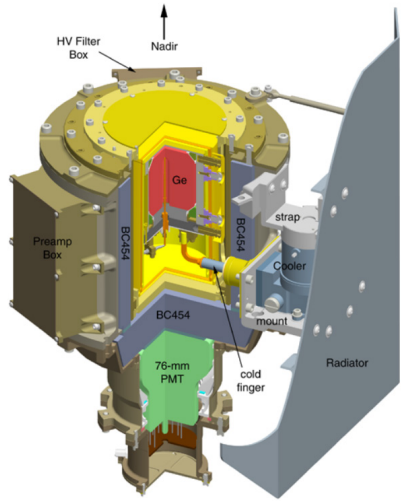
TARGET BODY	INSTRUMENT	MISSION	AGENCY	LAUNCH
Mercury	GRS, NS	MESSENGER	NASA	2004
	MGNS	BepiColombo	ESA	2018
Moon	GRS	Apollo 15, 16	NASA	1971, 1972
	GRS, NS	Lunar Prospector	NASA	1998
	GRS	Kaguya / SELENE	JAXA	2007
	GRS	Chang'e 1	CNSA	2007
	HEX	Chandrayaan-1	ISRO	2008
	LEND	Lunar Reconnaissance Orbiter	NASA	2009
	GRS	Chang'e 2	CNSA	2010
	LND	Chang'e 4 Lander	CNSA	2018
	MiniNS	*Lunar Polar Hydrogen Mapper*	*NASA*	*2021*
	ADRON-LF	*Luna 25*	*RFSA*	*2021*
	KGRS	*Korea Pathfinder Lunar Orbiter*	*KARI*	*2022*
Mars	GRS, NS, HEND	Mars Odyssey	NASA	2001
	DAN	Curisosity / Mars Science Lab	NASA	2012
	FREND	Trace Gas Orbiter	ESA	2016
	ADRON-RM	*Exo Mars Lander*	*ESA*	*2020*
Small Bodies	GRS	NEAR Shoemaker	NASA	1996
	GRaND	DAWN	NASA	2007
	GRNS	*Psyche*	*NASA*	*2022*
	MEGANE	*Martion Moons Exploration*	*JAXA*	*2024*
Outer Planets	*DraGNS*	*Dragonfly (Titan)*	*NASA*	*2026*

Upcoming

Previous Instruments

- Typically separate neutron and gamma-ray instruments
  - May share some components (anti-coincidence shield) and/or electronics
  - Neutron Detection: ^{3}He proportional counters, ^{10}B-loaded plastic, Li-glass, Stilbene
  - Gamma-Ray Detection
    - Gold standard is HPGe (exquisite gamma energy resolution, but requires cryo-cooling and frequent annealing)
    - Scintillators like BGO, CsI (~10% energy resolution)
  - Readout: Photomultiplier Tubes
    - Disadvantages are: bulky, susceptible to magnetic fields, kV bias

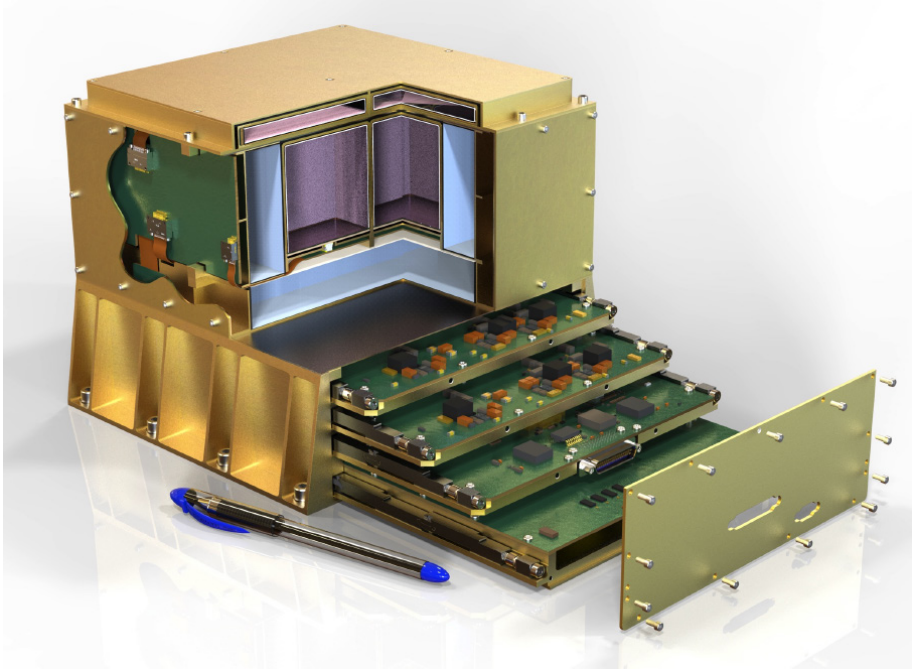
- NASA missions that have flown these instruments have been Discovery class – Flagship orbiter missions



MESSENGER Gamma-Ray Spectrometer

Elpasolite Planetary Ice and Composition Spectrometer (EPICS)

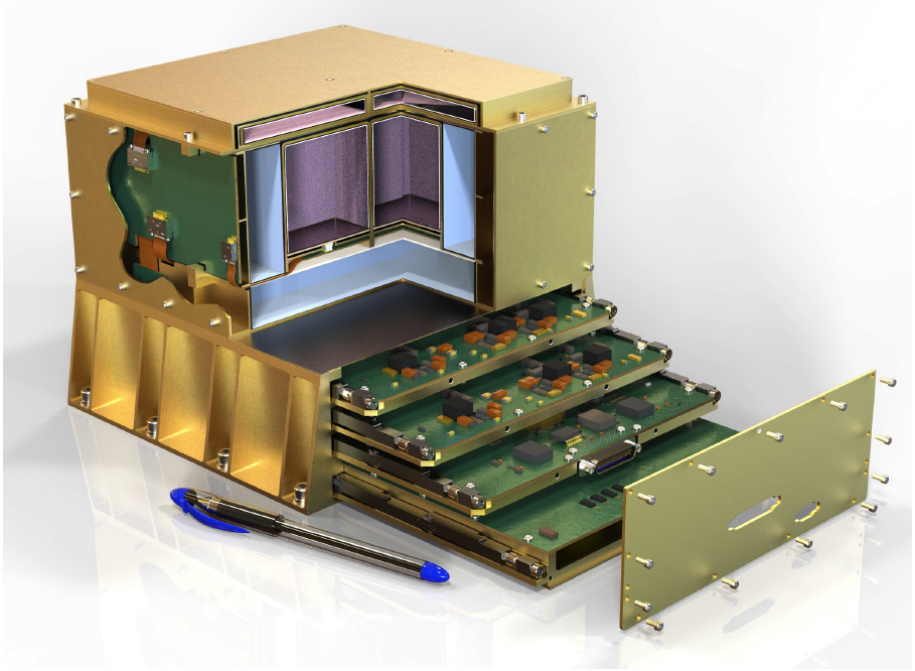
- Low-resource combined neutron and gamma-ray spectrometer under development at LANL
  - Utilizes elpasolite scintillators and silicon photomultiplier readout to reduce size, weight, and power (SWaP), and complexity
  - Modular design can be scaled for mission requirements
  - Orbiter sized version (2x2 array of modules) is estimated to be 7.4 kg, 13.9W, ~300 in^3 (4.9L)
    - 45% less mass and 35% less power then MESSENGER GRNS
    - 25% less mass and 8% less power than Dawn's GRaND GRNS



Rendering of EPICS optimized for high-altitude orbiter (2x2): 7.4 kg, 13.9W, ~300 in^3 (4.9L)

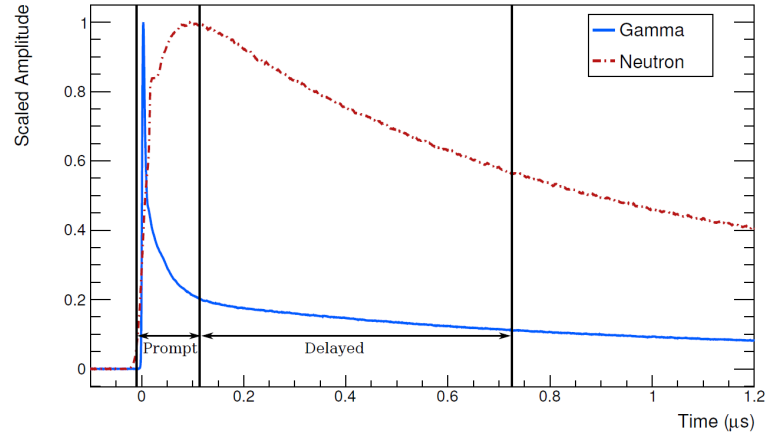
Elpasolite Planetary Ice and Composition Spectrometer (EPICS)

- Heritage of EPICS components
- CLYC Scintillator
  - Thermal characterization
  - Radiation damage assessment
  - Tested on high-altitude balloon
  - Upcoming LunaH-Map instrument on SLS Artemis-1 launch
- Silicon Photomultipliers
  - Thermal characterization
  - Radiation damage assessment
  - Flown on STPSat-5 (NRL SIRI)
- CLYC, SiPM, and processing electronics
  - Upcoming LANL experiment on STPSat-6

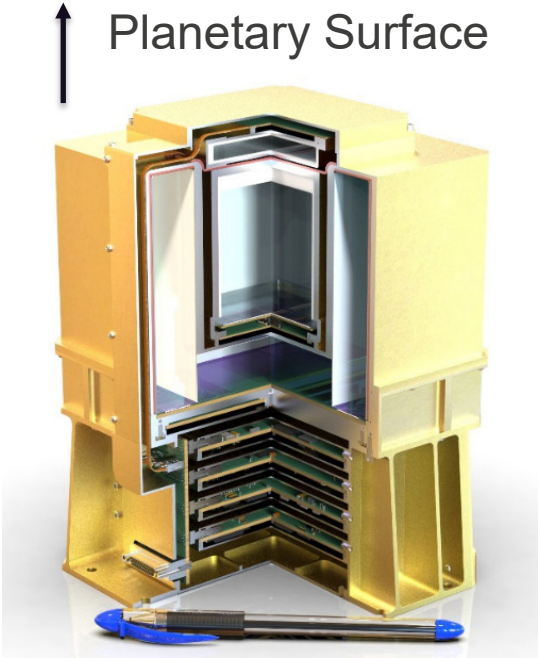


Rendering of EPICS optimized for high-altitude orbiter (2x2): 7.4 kg, 13.9W, ~300 in^3 (4.9L)

EPICS: Cs_2LiYCl_6:Ce (CLYC) Scintillator



- **Thin front CLYC** (0.6x5x5 cm^3) for thermal neutron detection
- **Central volume of CLYC** (5x5x5 cm^3) for gamma-ray spectroscopy and epithermal/fast neutron detection
- **Plastic scintillator** as anticoincidence shield and fast neutron tag

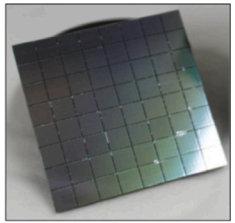


Rendering of single module EPICS for landed mission

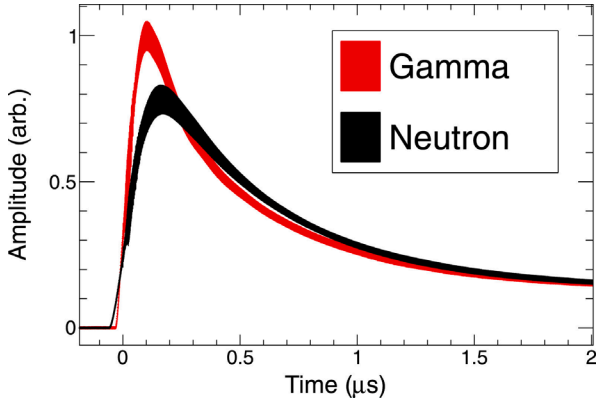
EPICS: Readout with Silicon Photomultipliers

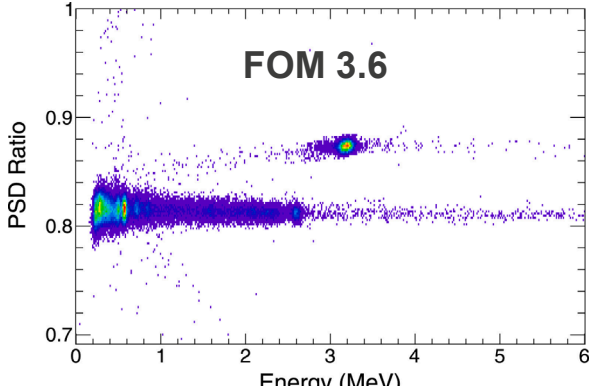
- Demonstrated readout of large CLYC volume with 64 element SiPM array achieving PMT-like performance

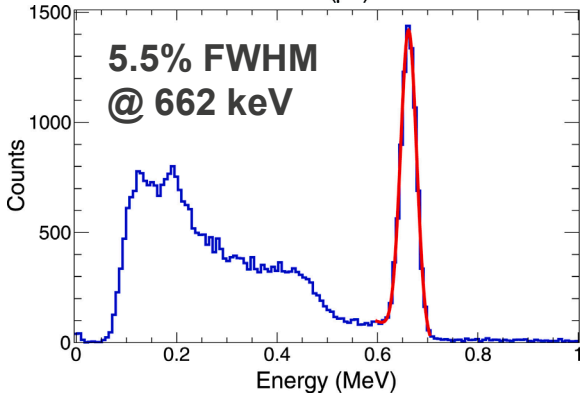
https://doi.org/10.1016/j.nima.2019.162928



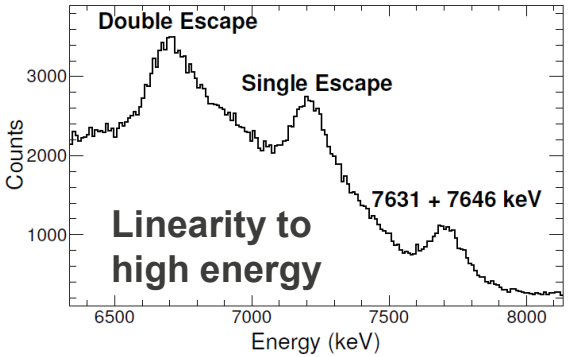
5x5x5 cm³ CLYC with PMT and SiPM array







Peaks from Fe-56 (n,γ)

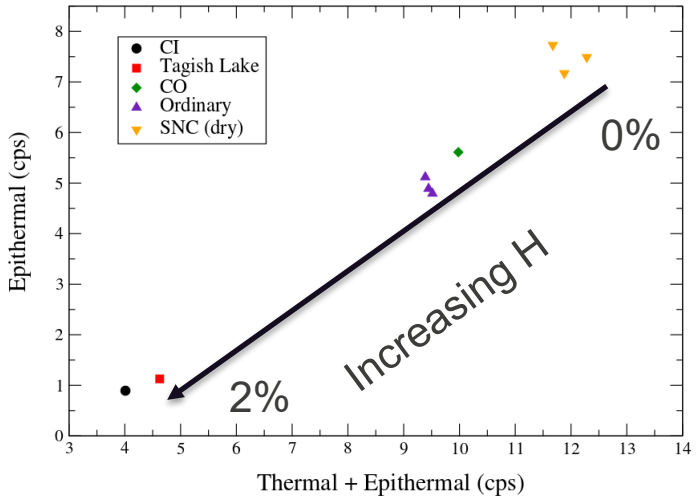


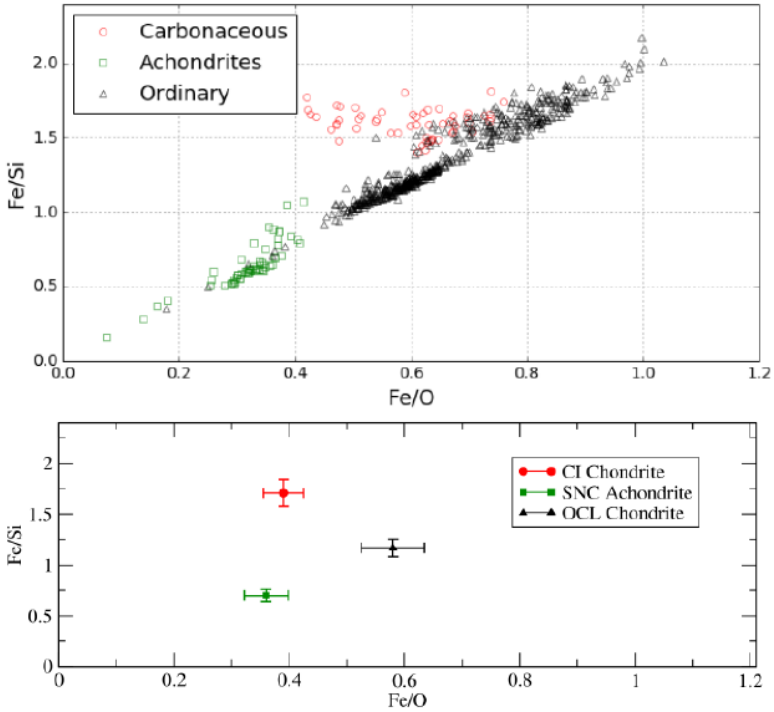
EPICS: Simulated Capabilities

Small planetary body surveyor

Detection of key elements to determine **composition of primitive bodies**

Abundance of water can be related to **origin of body** within the solar system





Asteroid classification based on Fe/Si versus Fe/O

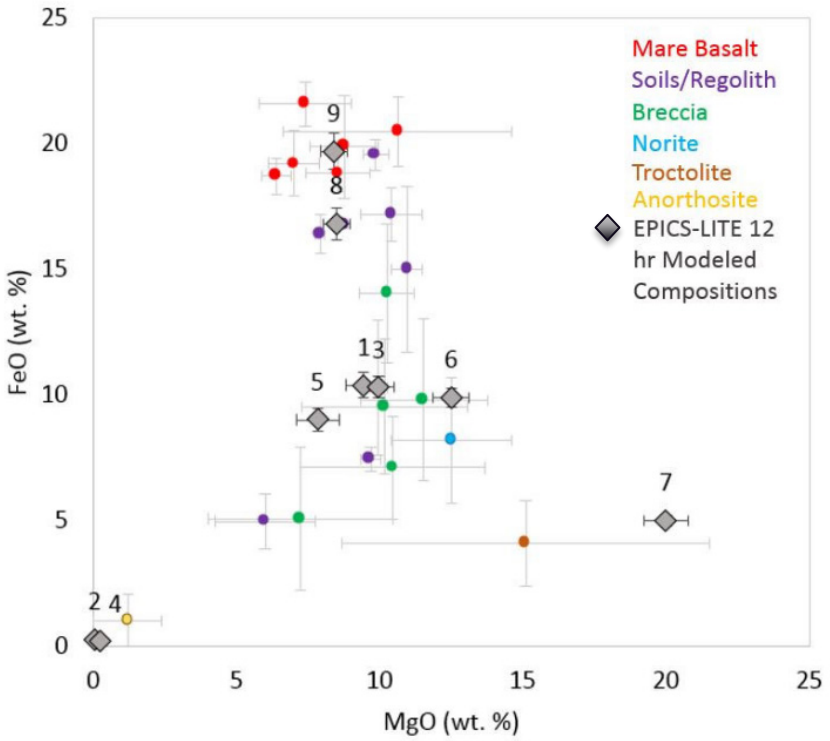
EPICS: Simulated Capabilities

Landed Lunar Mission

Detection of H, K, Si, Fe, Mg, Th, U in top tens of cm of lunar surface to **classify rock types** with respect to Apollo samples to assess local variability

Understand **lunar hydrological cycling** through the detection of H enrichments and diurnal variability.

Assess **in-situ resource utilization** potential: H (water source), Th and U (fuel source), Mg (building material)



FeO vs MgO for several classes of lunar material, with 12-hour EPICS measurements

Summary

- Planetary Nuclear Spectroscopy is a common technique used to study the near-surface composition of planetary bodies
  - Presence and abundance of hydrogen
  - Planetary structure, origin, and evolution
  - In-situ resource utilization
- Elpasolite Planetary Ice and Composition Spectrometer (EPICS) under development at LANL for a low-resource gamma-ray and neutron spectrometer for future missions
  - Utilizes elpasolite scintillator and SiPMs for reduced size, weight, power, and instrument complexity
  - Modularity makes instrument design accessible to different mission platforms, including cubesats and balloons

Questions or Comments?

- Please reach out with any questions or comments!

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