MESSENGER-heritage Gamma-Ray and Neutron Spectrometers

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Surface Composition

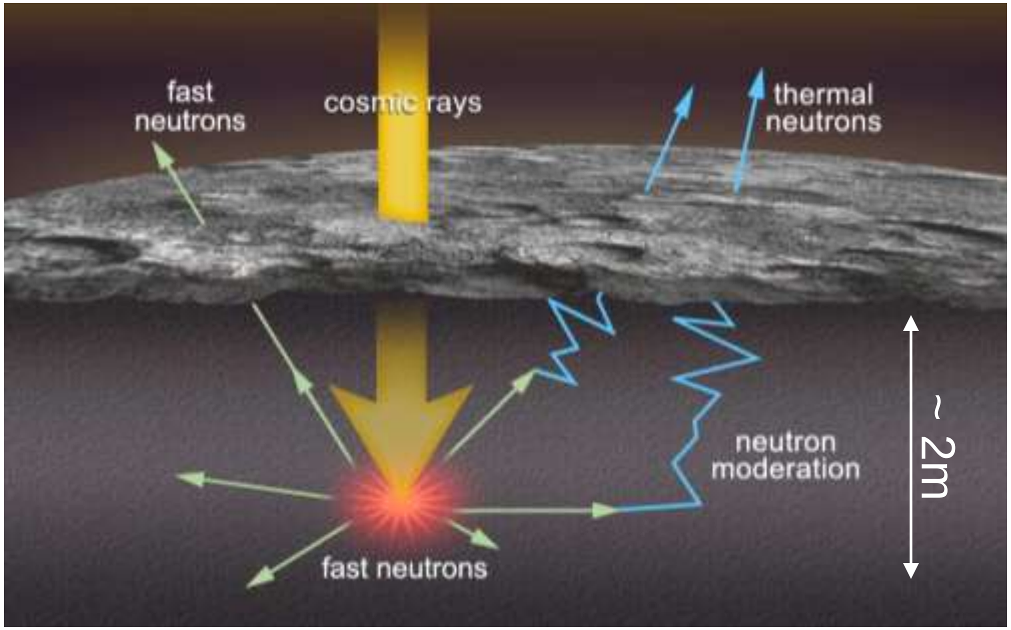
- ***The 2013-2022 Planetary Science Decadal Survey calls for measurements of the surface compositions of planetary bodies. A few examples include:***
  - Asteroid Tour, Trojan Tour and Rendezvous:
    - " … exploration of multiple asteroids could provide information on compositional gradients in the solar system."
  - Landed investigations of Phobos and Deimos:
    - "A major goal of in situ surface science on the martian moons is to determine their compositions in order to constrain their origins."
  - Lunar Polar Volatile Explorer:
    - "The nature of lunar polar volatile deposits … are not fully understood." "Also crucial is developing an inventory and isotopic composition of lunar polar volatile deposits to understand their emplacement and origin"
  - Additionally, sample return missions (Mars, Comet Surface, South Pole-Aiken Basin) would benefit from in situ measurements of compositional context.

Aspects of gamma-ray and neutron measurements

- These questions can be uniquely addressed by gamma-ray and neutron spectroscopy.
  - ***Passive***
  - ***Requires no sample preparation (drill, brush, scoop)***
  - ***Requires no special accommodation or operation (arm, placement, etc.)***
  - ***Sensitive to composition 10s of cm below the surface***
  - **Technique is sensitive to:**
    - ***Gamma rays: H, C, O, Na, Mg, Al, Si, S, Cl, K, Ca, Ti, Fe, Th, U***
      - **Depends of instrument composition (backgrounds) and elemental composition of target**
    - ***Neutrons: Moderators (H, C), absorbers (Fe, Ti, Gd, Sm), high-<A> (Fe, Ti)***
  - **Works from orbit (altitudes < 1 body radius) and on a surface**
  - **Acquisition times ~10 hrs (depending on desired sensitivity)**

Measurement Principles (1/2)

High-energy (> 10 MeV) Galactic Cosmic Rays (primarily protons) are incident on the surfaces of airless and nearly bodies.



- ***Fast (> 500 keV) neutrons are sensitive to <A>.***
- ***Epithermal (1 eV to 500 keV) neutrons are sensitive to neutron moderating elements (H).***
- ***Thermal (0.025 eV to 1 eV) neutrons are sensitive to the bulk abundance of neutron absorbing elements (e.g. Fe, Ti)***

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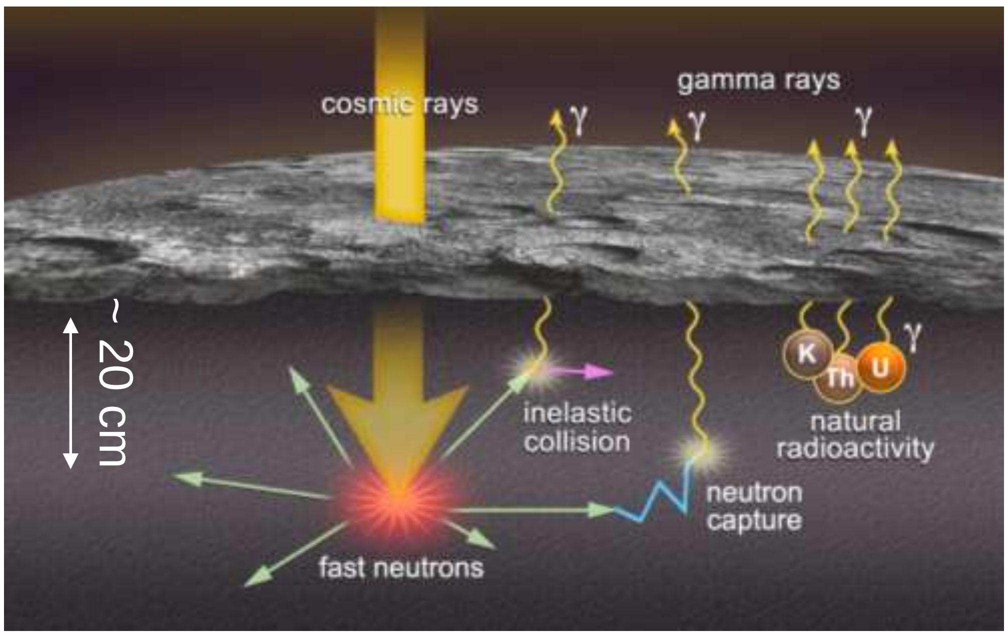

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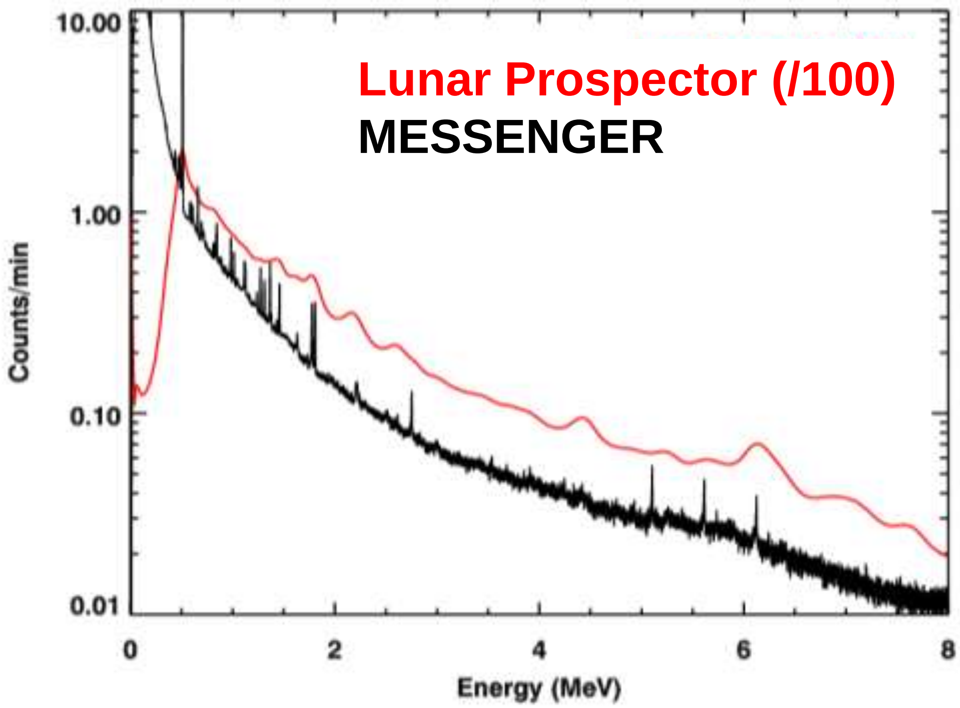
- ***Gamma rays are sensitive to:***
  - **Neutron excitation of stable elements (e.g. C, Na, Mg, Al, Si, S, Ca, Ti, Fe)**
  - **Decay of radioactive elements (K, Th, U)**

Gamma-Ray and Neutron Spectrometers

- *The information provided by gamma-ray and neutron spectroscopy has resulted in its use for many planetary science missions.*

- *Planetary gamma-ray spectrometers date back to the Ranger program and include:*
  - **Apollo 15 & 16, Venera/Vega Landers, NEAR, Lunar Prospector, Mars Odyssey, MESSENGER, Dawn**
  - **Typically utilize scintillator-based detectors w/ poor energy resolution**
    - *BGO has higher efficiency than HPGe*
  - **Recent instruments have used high-purity Ge (see Figure) which has superior energy resolution.**

- *Neutron spectrometers:*
  - **Lunar Prospector, Mars Odyssey, MESSENGER, Lunar Reconnaissance Orbiter, Dawn, Mars Science Laboratory.**
  - **Gas proportional counters (^{3}He) and Scintillators (Lithium Glass, Borated Plastic) have all been used successfully.**



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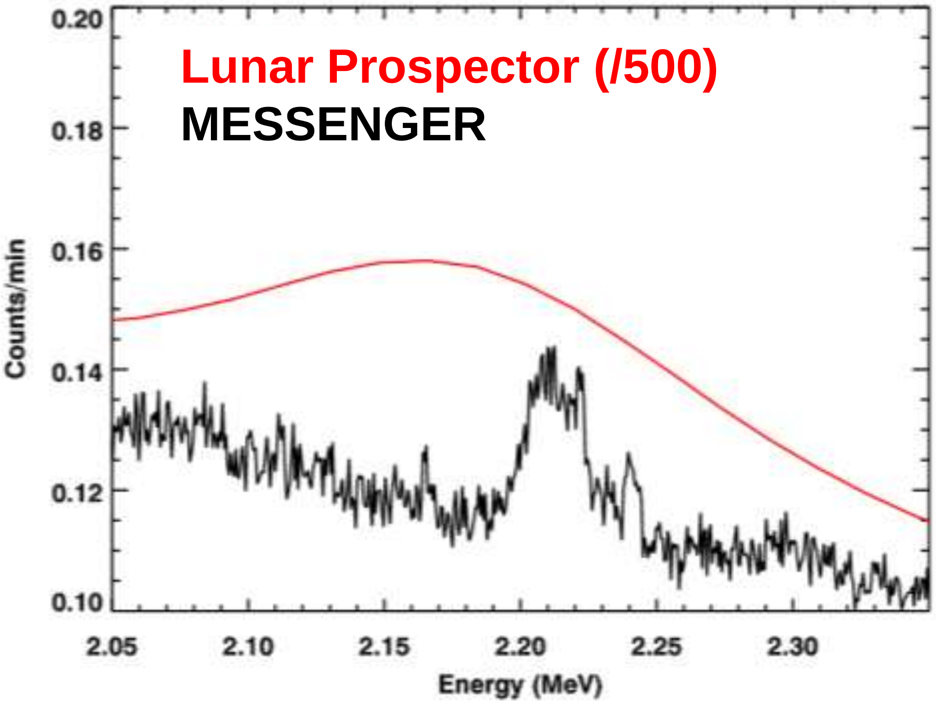
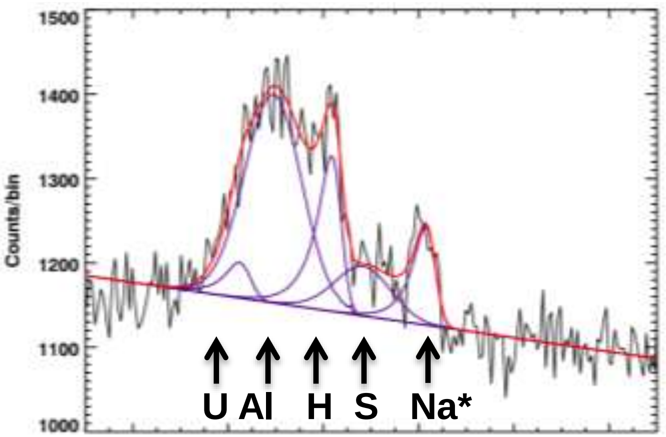
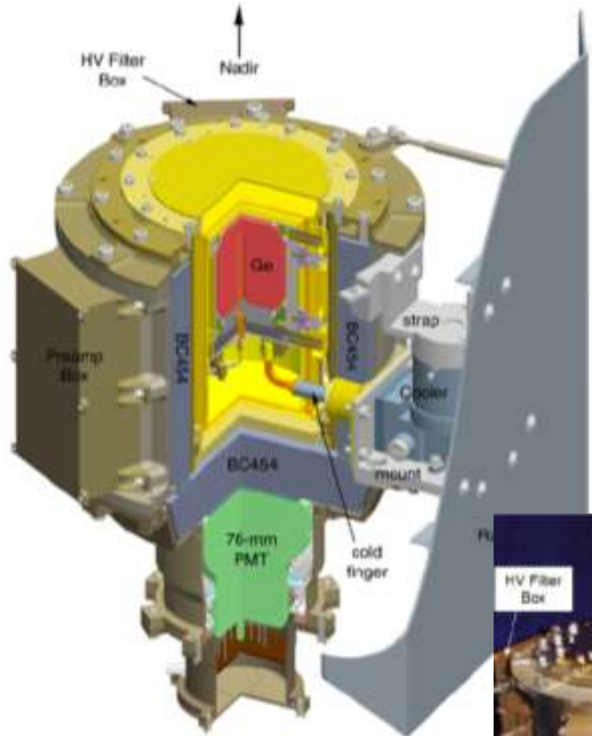
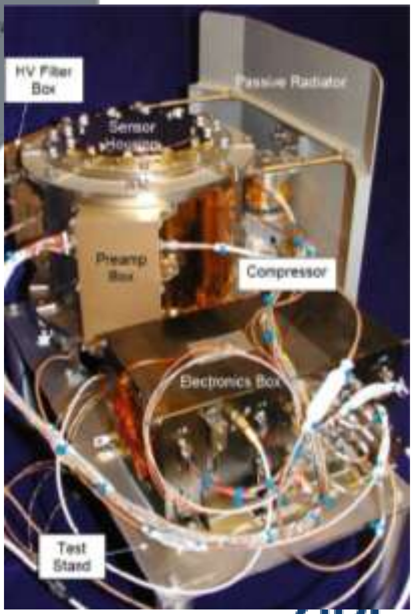




Instrument Details (1/2): Gamma-Ray Spectrometer

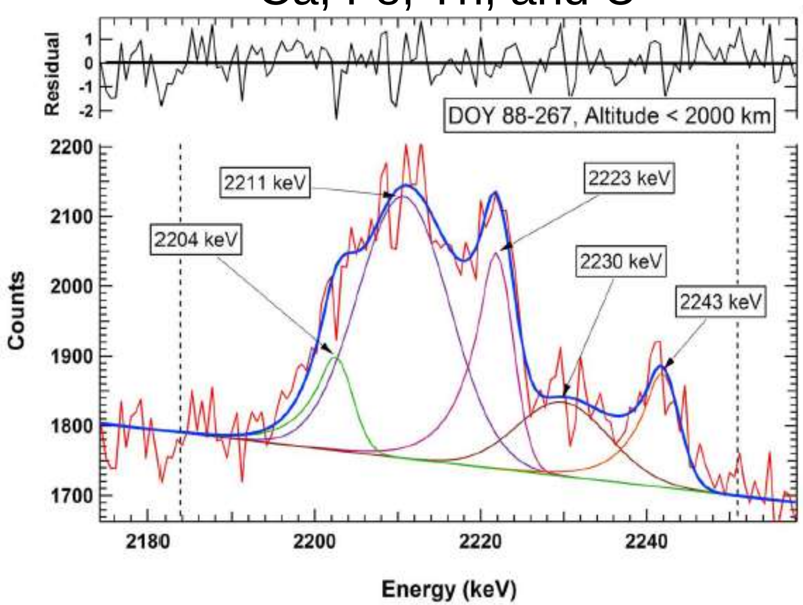
- *5 cm x 5 cm HPGe crystal (beveled cylinder)*
- *Borated plastic (BC454) anticoincidence shield*
- *Miniature mechanical cryocooler w/ 8,000 hr mean-time-to-failure*
  - Maintains detector at < 90 K
- *3.5 keV FWHM energy resolution (@ 1333 keV)*
  - Reduced to 4.5 keV by Mercury Orbit Insertion (following 6.6-year-long cruise)
- *9.2 kg (Total Mass)*
- *16.5 W*
- *< 180 bps average data rate.*

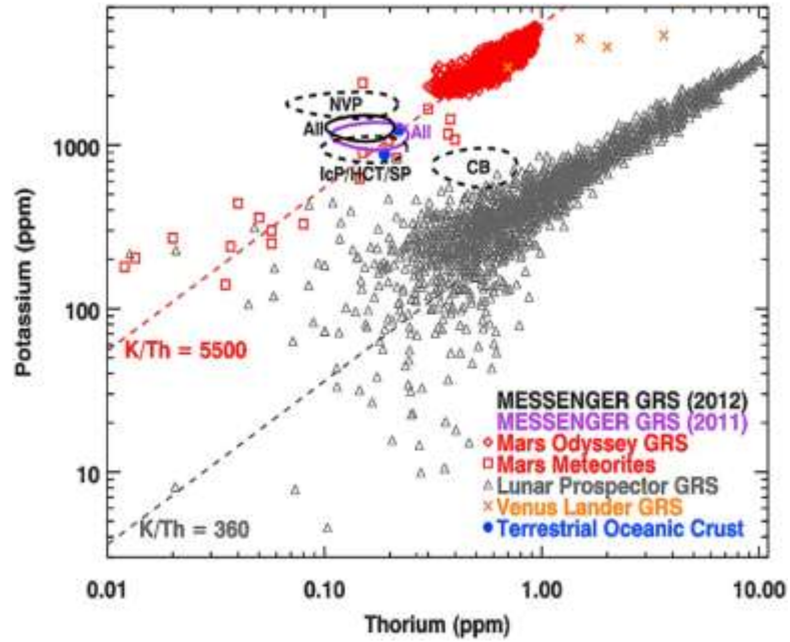


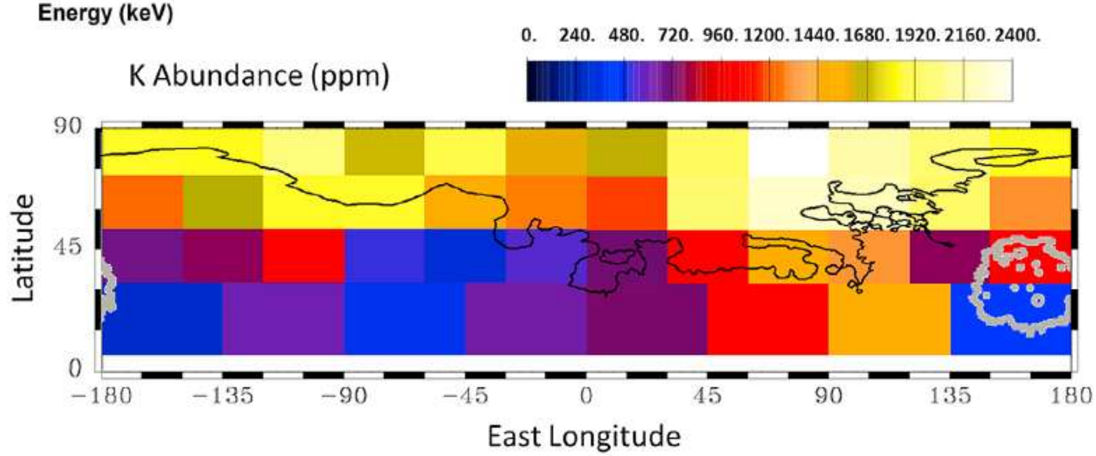


Measurements/Results from Mercury

Measurements of Na, Al, Si, S, K, Ca, Fe, Th, and U

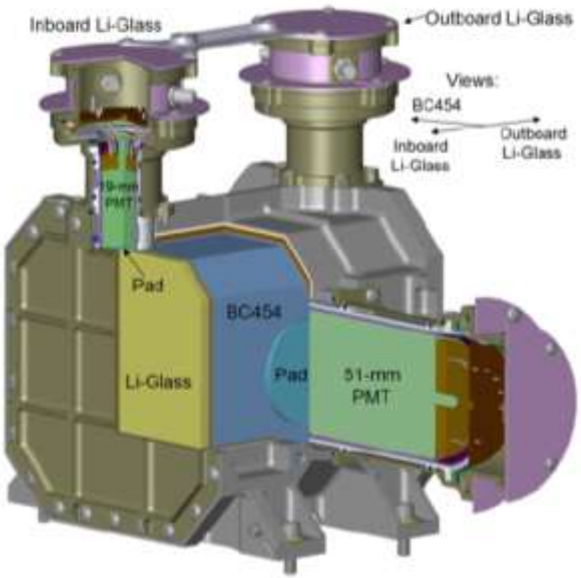


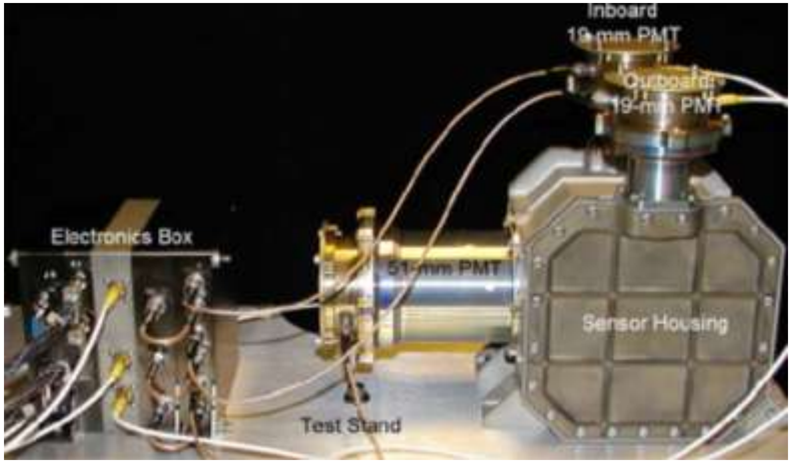




Instrument Details (2/2): Neutron Spectrometer

- ***10 x 10 x 0.4 cm Li Glass Scintillators (x2)***
  - **Thermal and epithermal neutrons**
  - **Separable via the Doppler filter effect**
- ***10 x 10 x 10 cm BC454 borated plastic scintillator***
  - **Epithermal and fast neutrons (thermals blocked by a Gd foil)**
  - **Fast neutrons from a double pulse technique.**
- ***3.9 kg***
- ***6 W***
- ***~70 bps average data rate***





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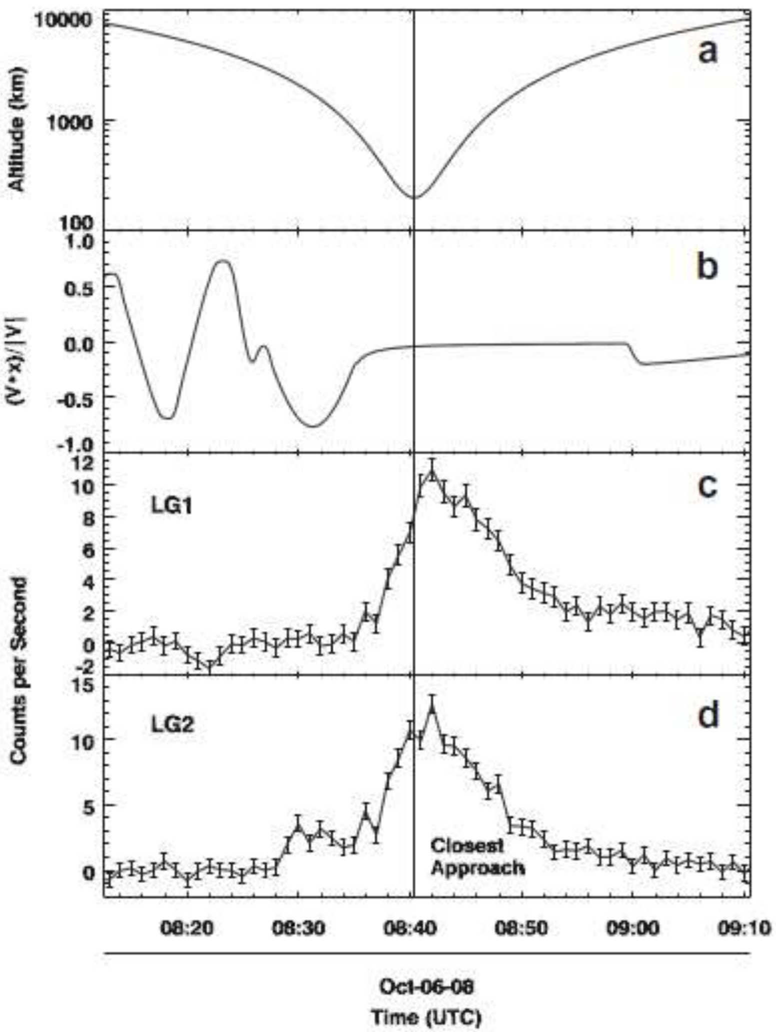

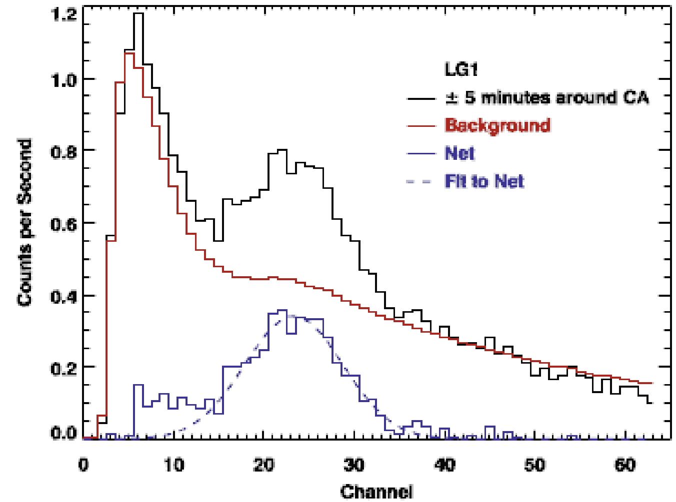

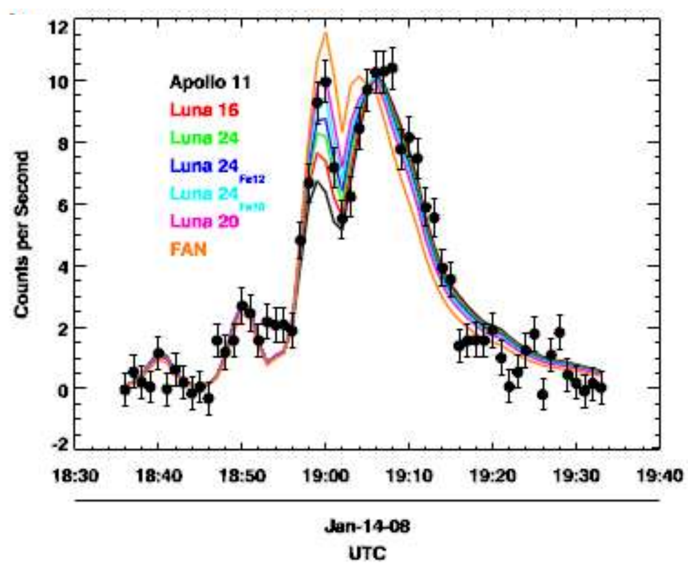

Results

- ***Composition***
  - Average near-equatorial abundances of neutron absorbing elements (*Lawrence et al.,* 2011)
  - First and only measurements of K, Th, U, and Na on the surface of Mercury (*Rhodes et al.,* 2011; *Peplowski et al.,* 2011; *Evans et al.,* 2012)
  - Map of K distribution across the surface (*Peplowski et al.,* 2012a)
  - Al/Si, Ca/Si, S/Si, and Fe/Si measurements in agreement with MESSENGER XRS results (*Evans et al.,* 2012; *Peplowski et al.,* 2012b)
- ***Polar hydrogen***
  - Initial results presented at LPSC (2012), new results will be presented at AGU.
- ***Solar neutrons***
  - Observation of solar-originating neutrons during the 31 Dec. 2007 flare (*Feldman et al.,* 2010).
  - New results from other flares to be presented at AGU.

Application to future missions

- ***Lessons learned during the operation of the MESSENGER GRNS include:***
  - **Improved procedures for maximizing energy resolution.**
  - **Innovative analysis techniques (e.g. background reduction methods) maximize the science return.**
- ***Development of future GRNS instruments:***
  - **Rigorously apply lessons learned from MESSENGER.**
  - **Develop a low-resource versions for resource-constrained missions.**
    - ***Low mass cryostat (GRS)***
    - ***Longer life cryocooler (GRS)***
    - ***Miniaturized, next-generation electronics (GRS + NS)***
- ***Extremely low-resource GRS and NS systems will be discussed by D. Lawrence on Friday morning.***