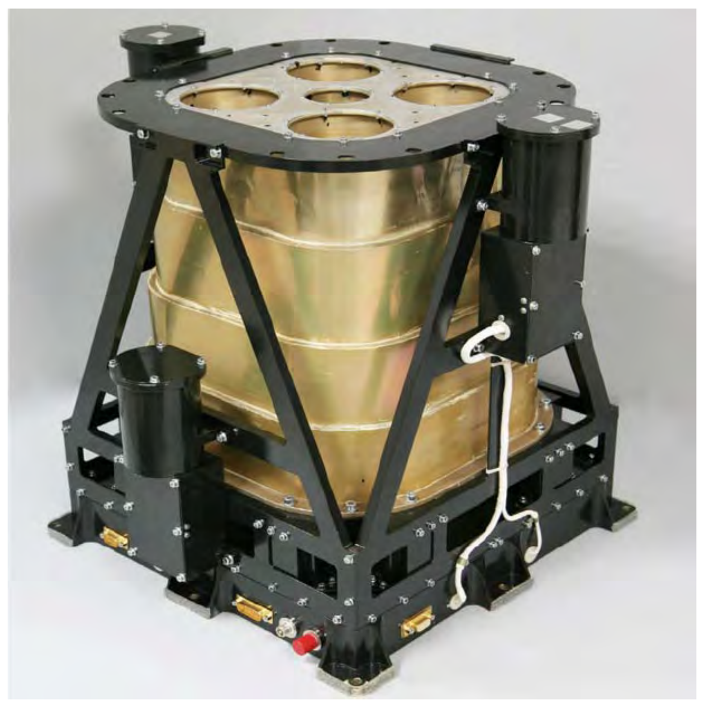
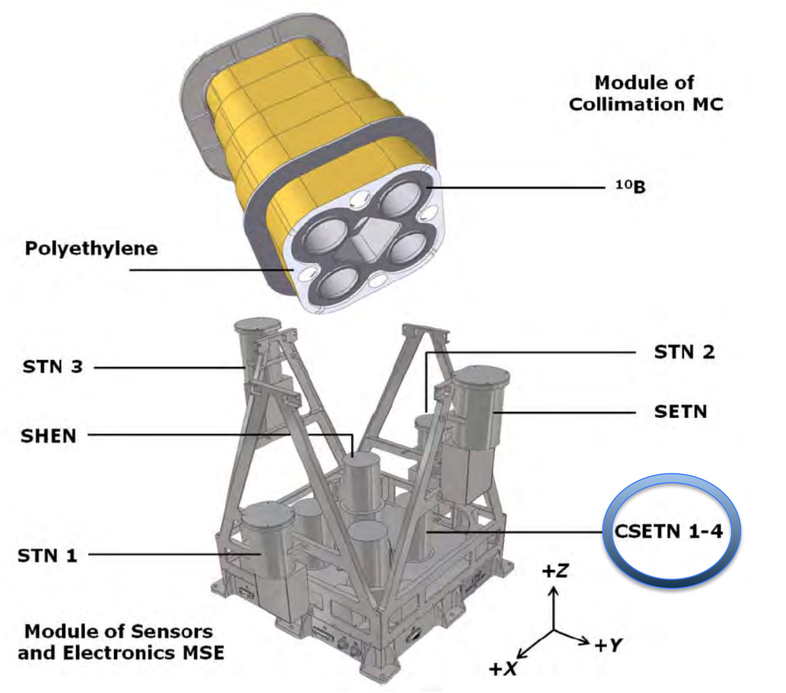
NEUTRON REMOTE-SENSING AT THE MOON: VARIATION WITH ALTITUDE OF NEUTRON FLUX FOR THE LUNAR EXPLORATION NEUTRON DETECTOR (LEND)

T. A. Livengood, CRESST/UMD/GSFC; W. V. Boynton, LPL U. of Arizona; G. Chin, NASA/GSFC; L. G. Evans, Computer Science Corp.; M. Litvak, Inst. for Space Research; T. P. McClanahan, NASA/GSFC; I. G. Mitrofanov, Institute for Space Research; R. Sagdeev, U. of Maryland; A. B. Sanin, Inst. for Space Research; R. D. Starr, Catholic U. of America; J. J. Su, U. of Maryland

The Lunar Exploration Neutron Detector (LEND) instrument on the Lunar Reconnaissance Orbiter (LRO) employs a collimator to improve the spatial resolution for neutron remote-sensing of hydrogen-rich volatile deposits on the Moon, with the primary goal of mapping deposits of water at the Moon's cold high latitudes [1]. The collimator reduces the flux of lunar neutrons reaching the detector element from off-nadir directions so that neutrons reaching the detector through the narrow acceptance angle of the collimator opening contribute the primary signal. Verifying the component of epithermal neutrons that is detected in collimation is essential to estimating the actual concentration of water stored in localized deposits.





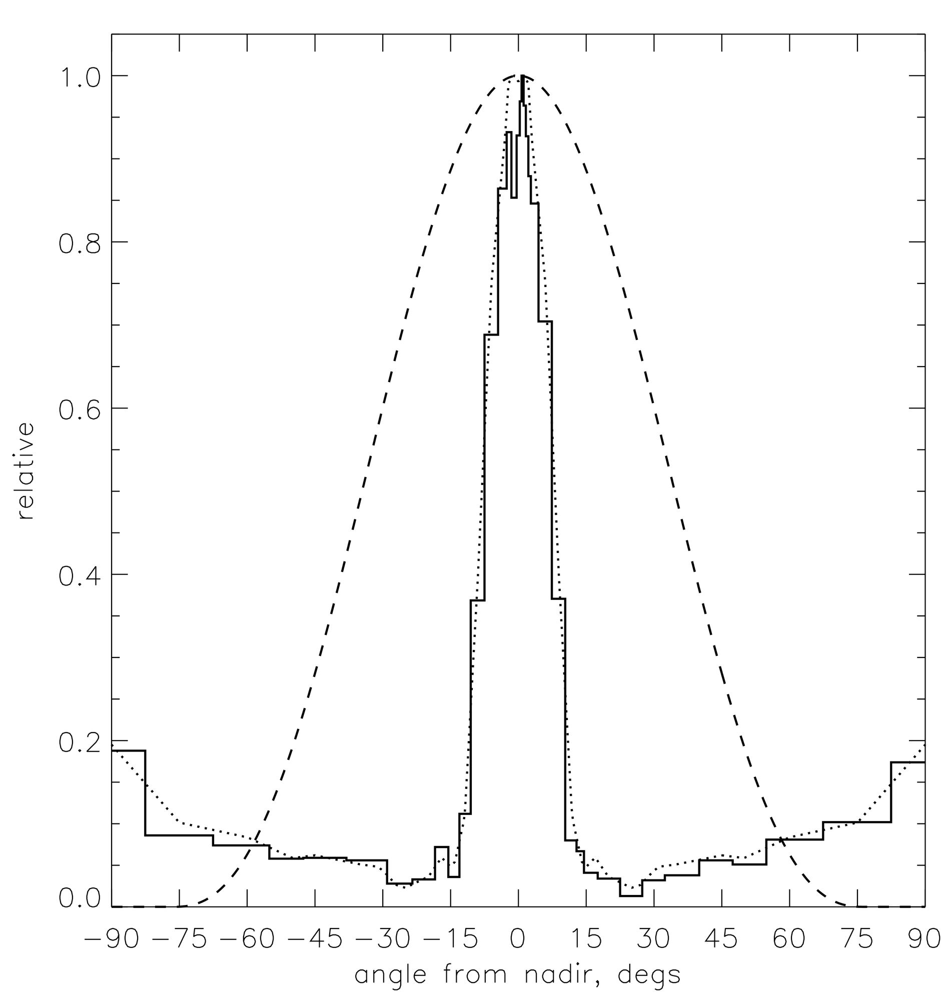
LEND Instrument Description:

- Lunar Exploration Neutron Detector (LEND) on LRO is sensitive to buried hydrogen [1]:
  - Galactic cosmic rays eject neutrons from regolith
  - Epithermal neutrons (~1 eV to 1 MeV) are moderated by H, depleting flux in this interval [4] .
  - LEND probes H content without solar illumination by measuring epithermal neutron flux.
- We use LEND data from Sep 2009 through 2012, accessible from the PDS (LEND DLD format).
- Collimated CSETN detectors combine four epithermal neutron detectors. Leakage through collimator wall biases detected energy spectrum to higher energy than SETN.
- Detector background flux estimated from modeling mapped flux using linear combination of maps from other LEND detectors and the Lunar Prospector Neutron Spectrometer (LPNS) [2].
- Neutron population detected by CSETN biased to higher energy by leakage through collimator wall.

This project is to distinguish neutrons detected in collimation from neutrons detected by penetration through collimator walls.

Measured Angular Response:

- Angular response of LEND collimated detectors measured using neutron point source [3] (solid histogram). Calculations use mirror-symmetric interpolation (thin dotted line).
- Analytic integration for lunar neutron emission at depth shows anisotropic emission due to finite opacity of regolith, approximately proportional to cosine of angle from normal, confirmed by estimated resolution of omnidirectional detectors on LPNS [2]. Sensitivity to precise estimated form of anisotropy remains to be tested.
- Opening angle of lunar limb from nominal LRO altitude of 50 km [4] is ±76°. Angle observed from spacecraft scaled to angle of emission from surface: 76° from nadir = 90° emission angle (bold dashed line).

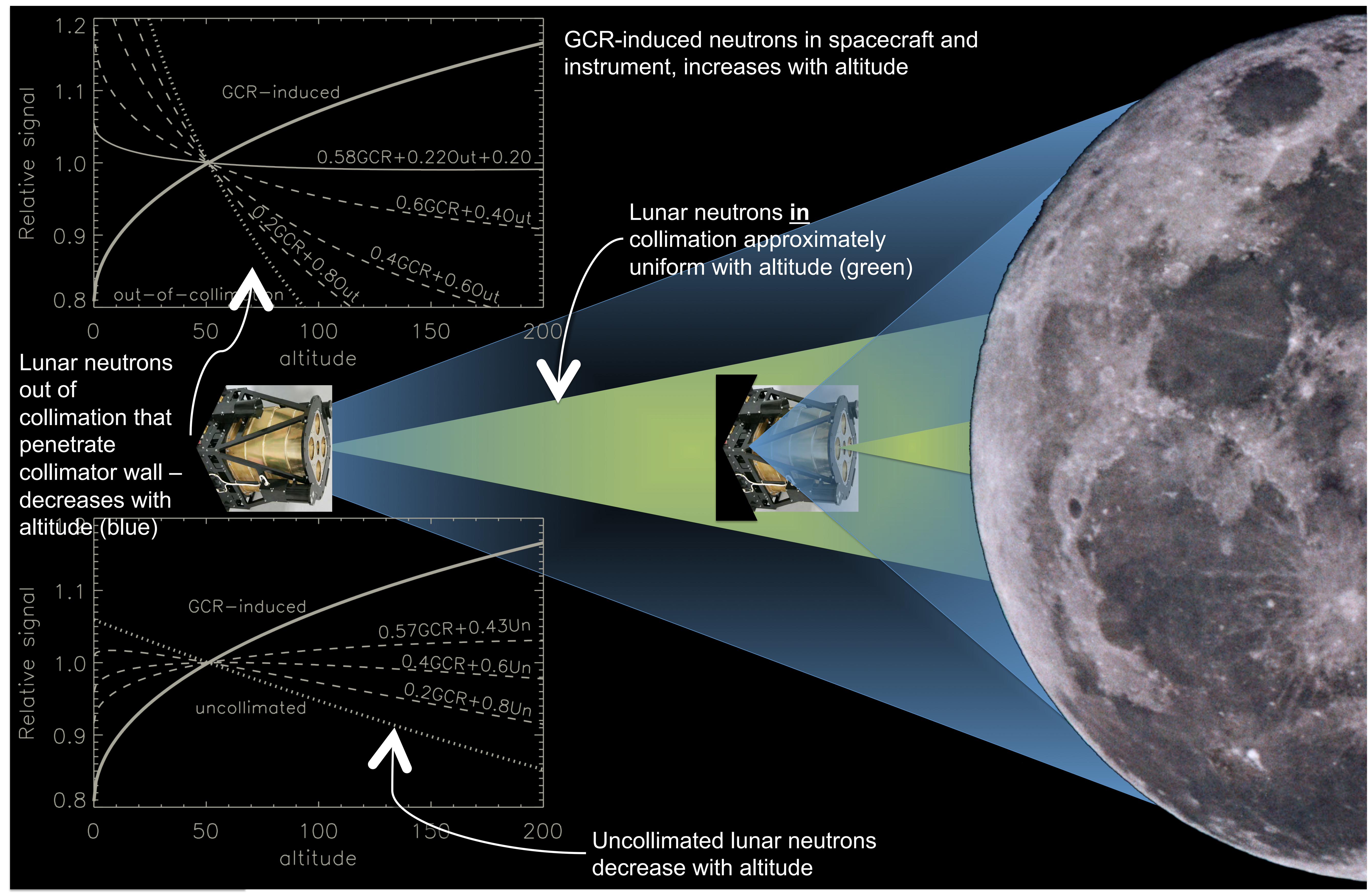


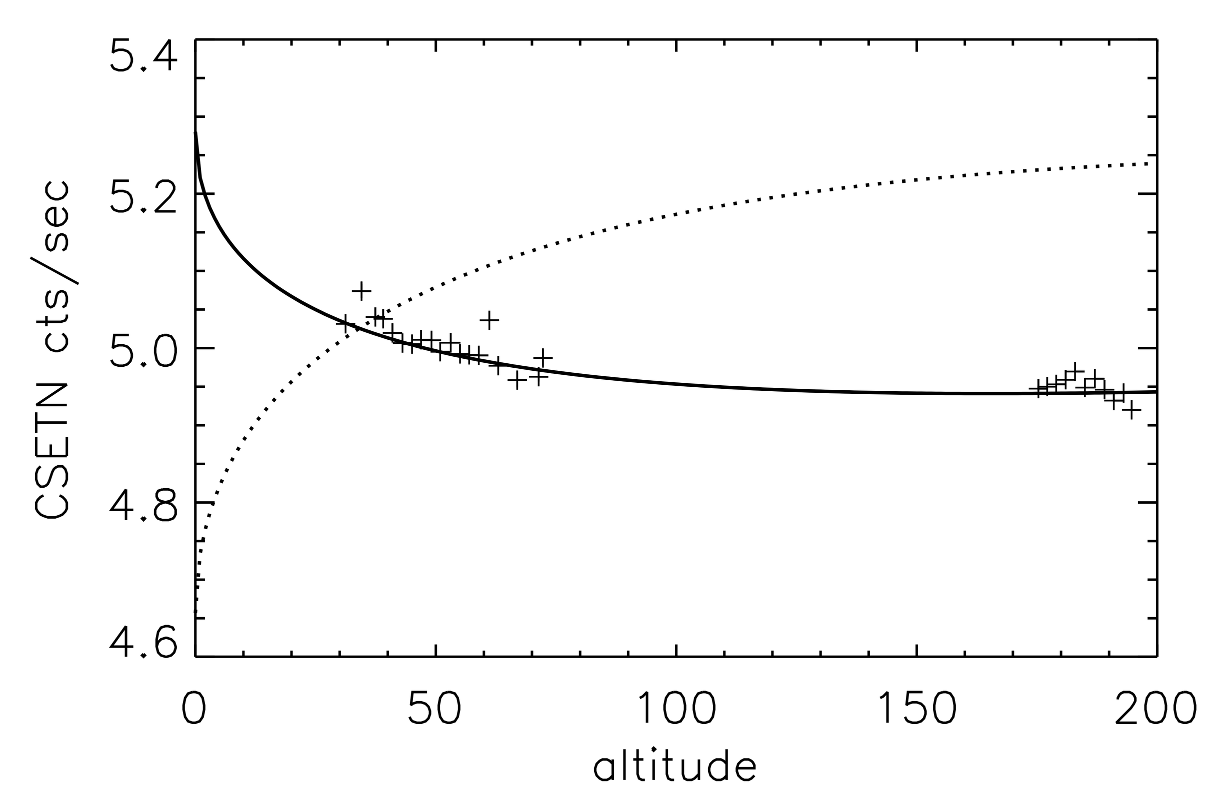
References:

[1] Mitrofanov, I. G., *et al.* (2010) *Space Sci. Rev.* **150**, 183–207.
[2] Maurice, S., *et al.* (2004) *JGR-Planets* **109**, E07S04.
[3] Litvak, M. L. *et al.* (2012). *JGR-Planets* **117**, E00H32.
[4] Vondrak *et al.* (2010) *Space Sci. Rev.* **150**, 7–22.
[5] Eke, V. R. *et al.* (2012). *Astrophys. J.* **747**, 6.

Contributions to neutron fluence with altitude:

1. Instrument background ('dark current'): neutrons induced in spacecraft structure by galactic cosmic ray (GCR) impacts. Neutron fluence is proportional to solid angle of sky that is not obscured by the Moon. Increases with altitude.
2. Collimated lunar neutrons: lunar emission within the narrow field of view of the LEND collimator (central transmission peak of angular response function). Filled field of view implies approximately constant signal as a function of altitude; actual deviation due to nonzero emission angle at edge of field is ignored in this analysis.
3. Out-of-collimation lunar neutrons: neutrons from outside collimator field of view, moderated by passage through finite (high) opacity of collimator wall, reducing energy to sensitivity range of epithermal neutron detectors. Increasing altitude reduces opening angle of lunar limb and reduces angle relative to nadir for neutrons reaching LEND, where collimator is more opaque. Causes rapid reduction in detectable flux with altitude.
4. Uncollimated lunar neutrons: assumed population of high-energy neutrons moderated by LEND collimator sufficient to be detectable below energy threshold but otherwise collimator is effectively transparent [5]. Decreases with altitude less steeply than out-of-collimation neutrons.





Observed variation with altitude:

- Neutron count rates within 20° of north pole – approximately uniform source, average count rates over life of mission within ±1 km intervals in altitude. **Uncertainties are displayed!**
- Nominally circular orbit, Sep 2009 to Dec 2011, 50 km altitude.
- Elliptical orbit since Dec 2011, aposelene above north pole
- Fit model forms for signal variation with altitude, least-squares optimization.
- GCR-induced background is degenerate with other parameters – assume from other evaluations.
- Bold solid line: best fit to data.
- Dashed line: assume 57% background, 43% uncollimated (not fine-tuned for partial flux suppression due to polar hydrogen). Clearly not an effective fit. Fitted value for this component is zero for every assumed value of background.
- Example case assumes 2.9 cps background (58%), fit yields 1.0±0.3 cps collimated, out-of-collimation 1.1±0.1 cps, uncollimated 0.0±0.4 cps. Forcing uncollimated component to zero, reduces uncertainties to ±0.1 cps.