



The Neutron Spectrometer System on Peregrine Mission-1

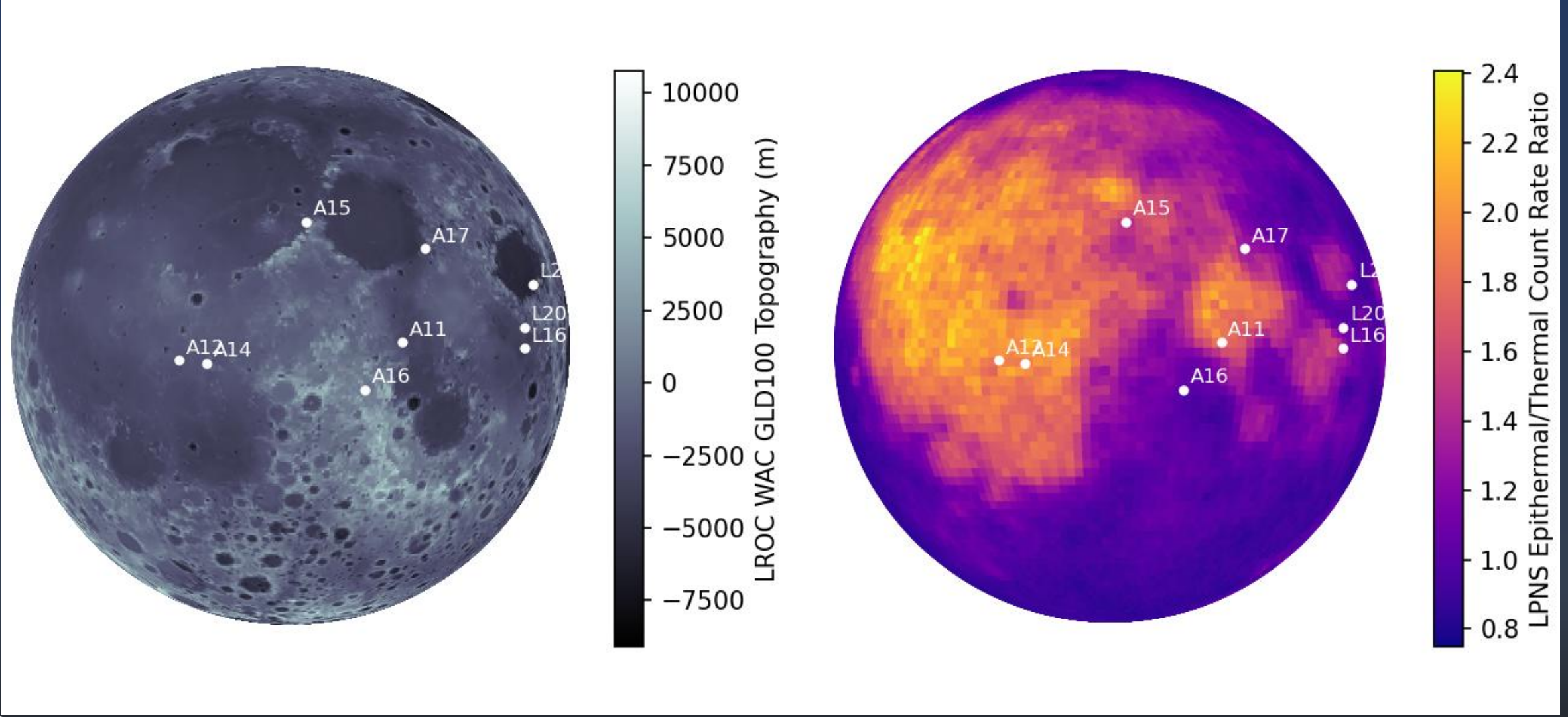
Steven Dobb¹, Richard Elphic¹, Bruce Clarke², Arwen Dave¹, Warren Davis³, Erin Fritzler³, Fritz Renema⁴, Lydia Schweitzer⁴

¹NASA Ames Research Center, ²SETI Institute, ³Astrion Group LLC, ⁴KBR Wyle

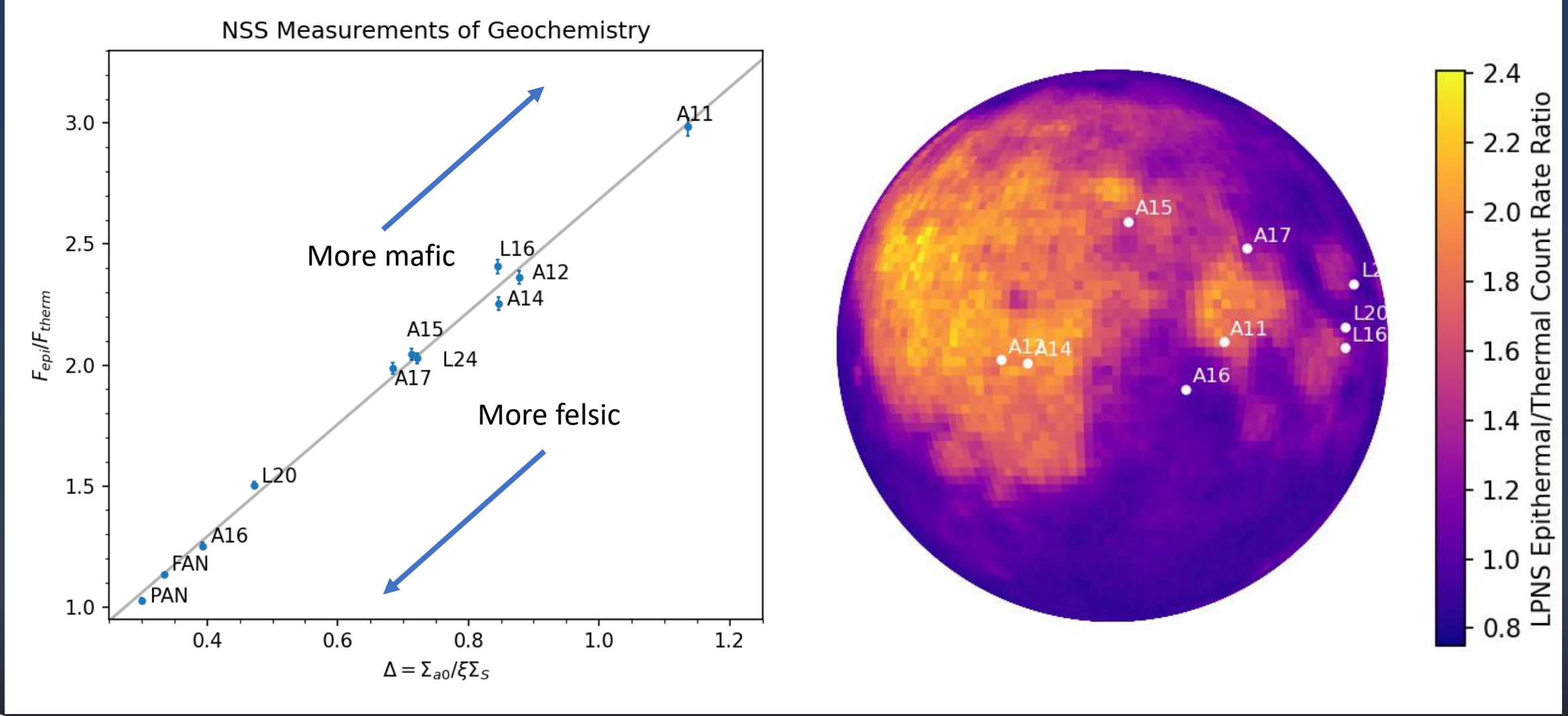
Patrick Peplowski, Jack Wilson, David Lawrence

Johns Hopkins University – Applied Physics Laboratory

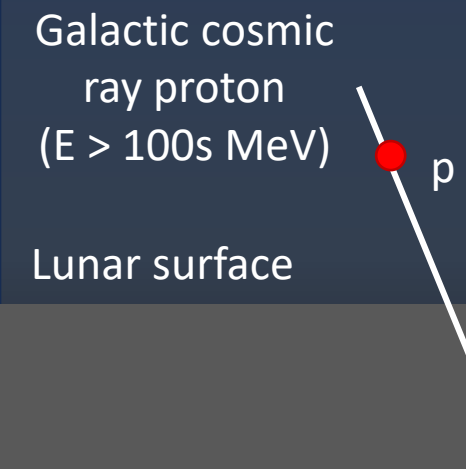
Neutrons in the lunar environment indicate bulk composition (Fe, Ti, H, REEs)



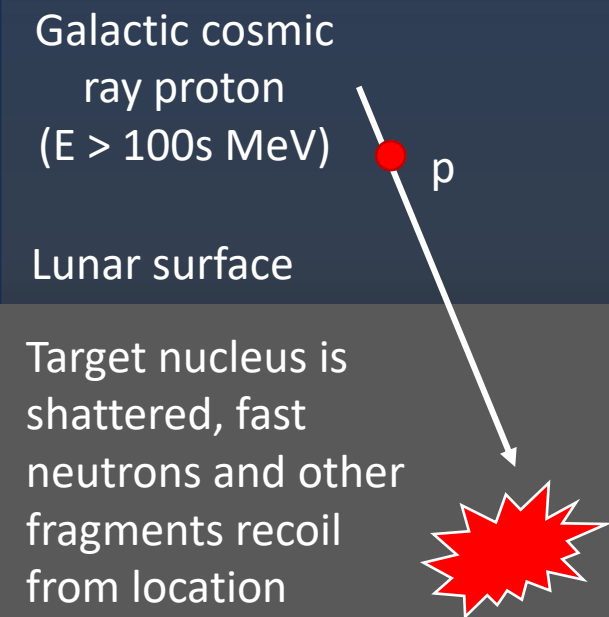
Neutrons in the lunar environment indicate bulk composition (Fe, Ti, H, REEs)



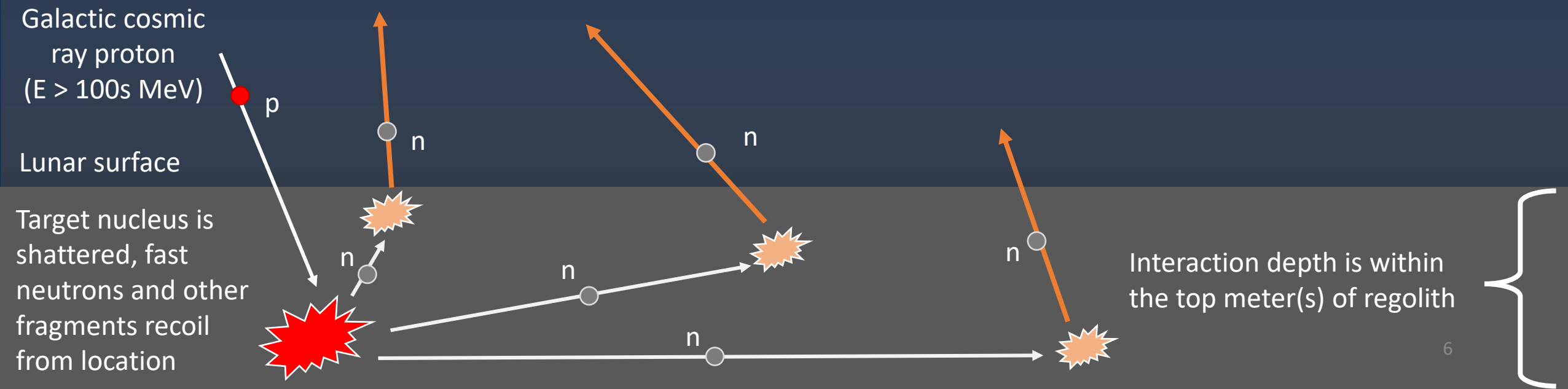
The Neutron Spectrometer System on Peregrine Mission-1



The Neutron Spectrometer System on Peregrine Mission-1



The Neutron Spectrometer System on Peregrine Mission-1



The Neutron Spectrometer System on Peregrine Mission-1

Neutron Spectrometer System:
Measures thermal and epithermal neutrons

^3He Gas Proportional Counters

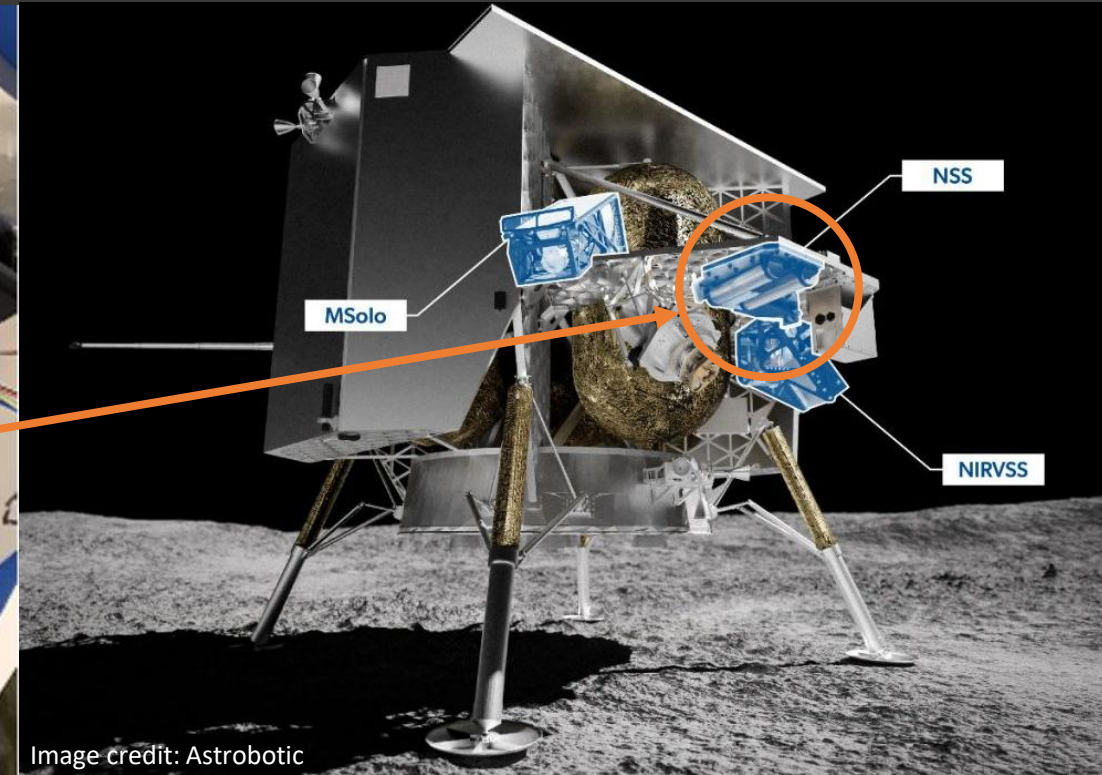
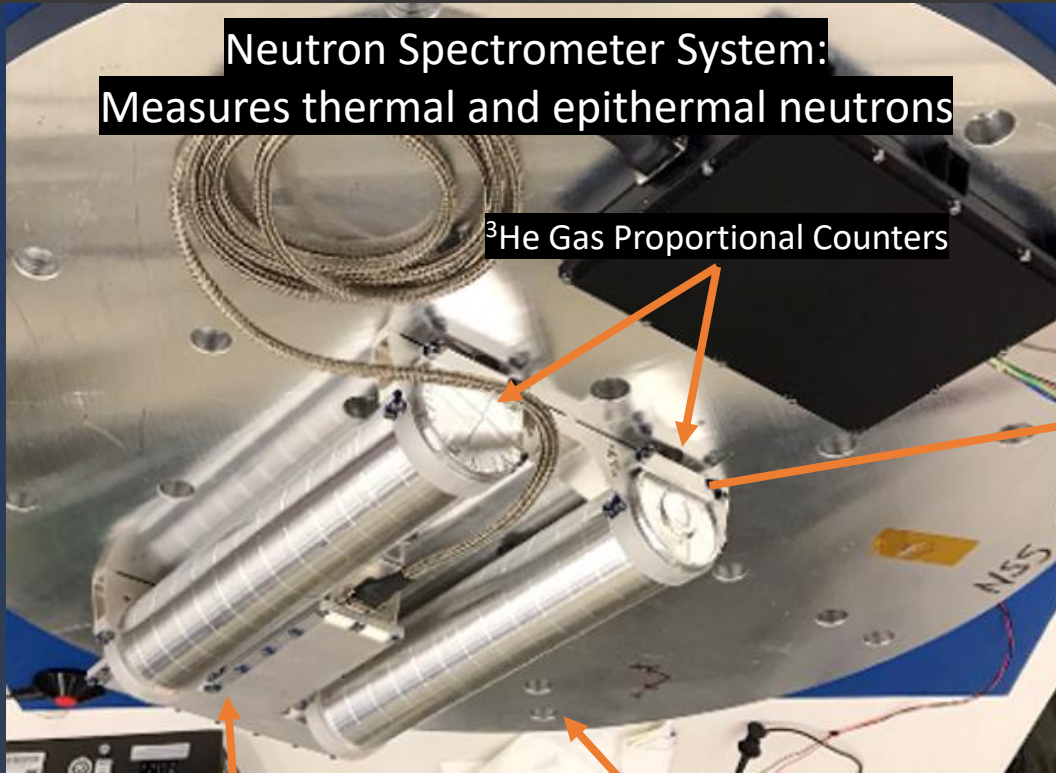
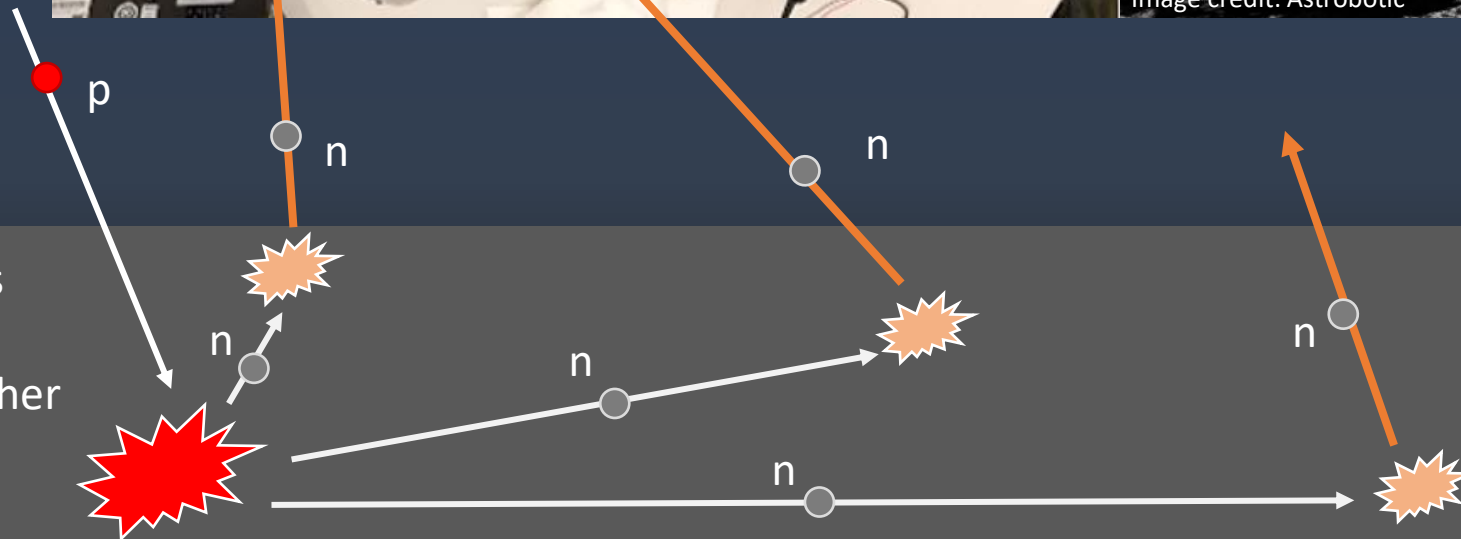


Image credit: Astrobotic

Galactic cosmic
ray proton
($E > 100\text{s MeV}$)

Lunar surface

Target nucleus is
shattered, fast
neutrons and other
fragments recoil
from location



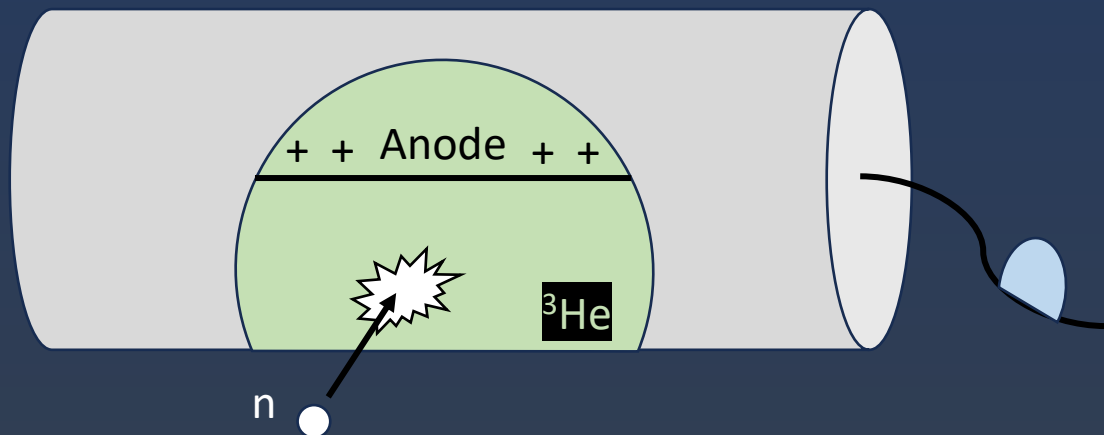
Interaction depth is within
the top meter(s) of regolith

Neutron detection with ^3He gas proportional counters

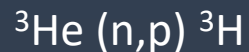
NSS measures neutrons over two energy ranges:

Detector 1 (Cd-wrapped): Epithermal ($0.4 \text{ eV} < E < 100 \text{ keV}$)

Detector 2 (Bare): Epithermal + Thermal ($E < 0.4 \text{ eV}$)



Reaction deposits energy in the gas:



$$573 \text{ keV} (p^+) + 191 \text{ keV} (^3\text{H}) = 764 \text{ keV}$$

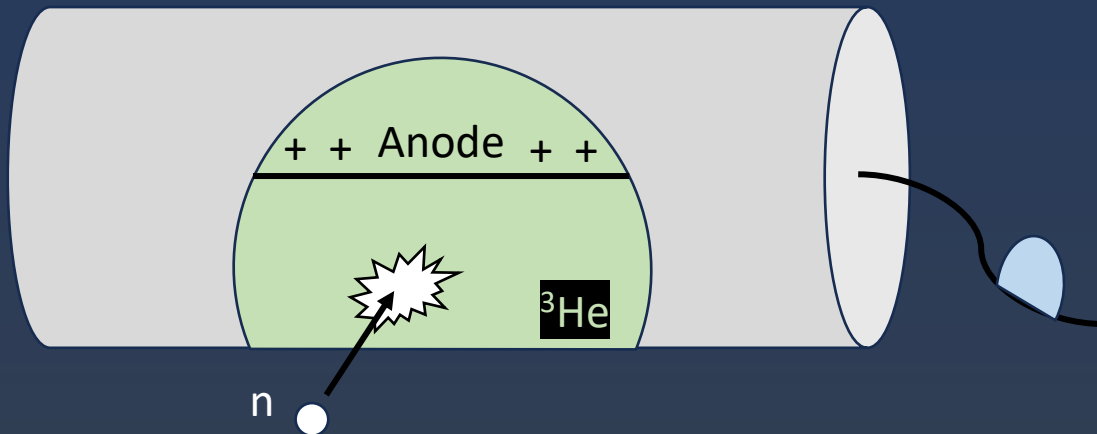
Products ionize ^3He gas,
 e^- collect on anode as current pulse

Neutron detection with ^3He gas proportional counters

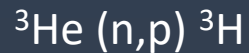
NSS measures neutrons over two energy ranges:

Detector 1 (Cd-wrapped): Epithermal ($0.4 \text{ eV} < E < 100 \text{ keV}$)

Detector 2 (Bare): Epithermal + Thermal ($E < 0.4 \text{ eV}$)



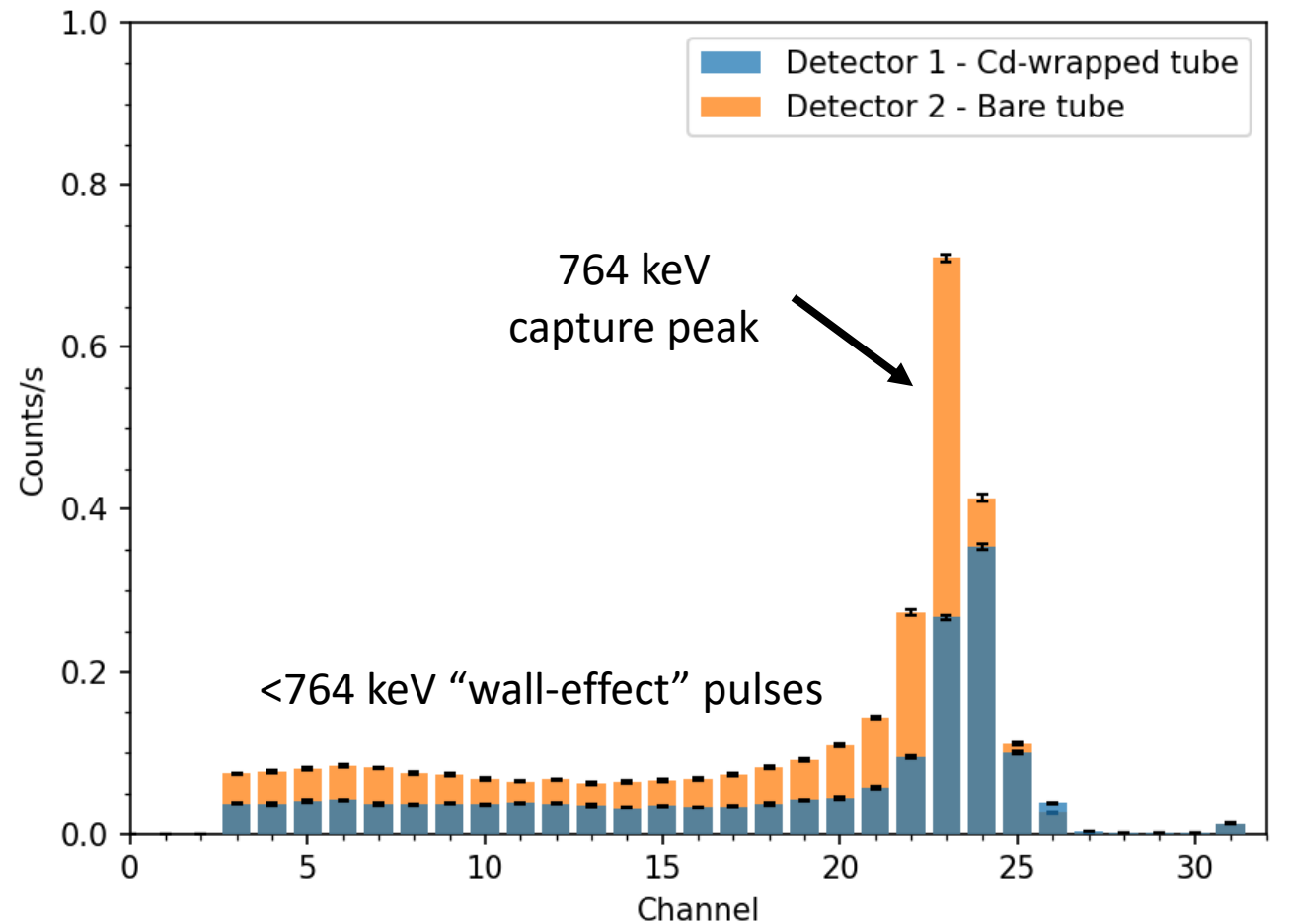
Reaction deposits energy in the gas:



$$573 \text{ keV} (p^+) + 191 \text{ keV} (^3\text{H}) = 764 \text{ keV}$$

Products ionize ^3He gas,
 e^- collect on anode as current pulse

A “nominal” NSS pulse height spectrum from pre-flight TVAC



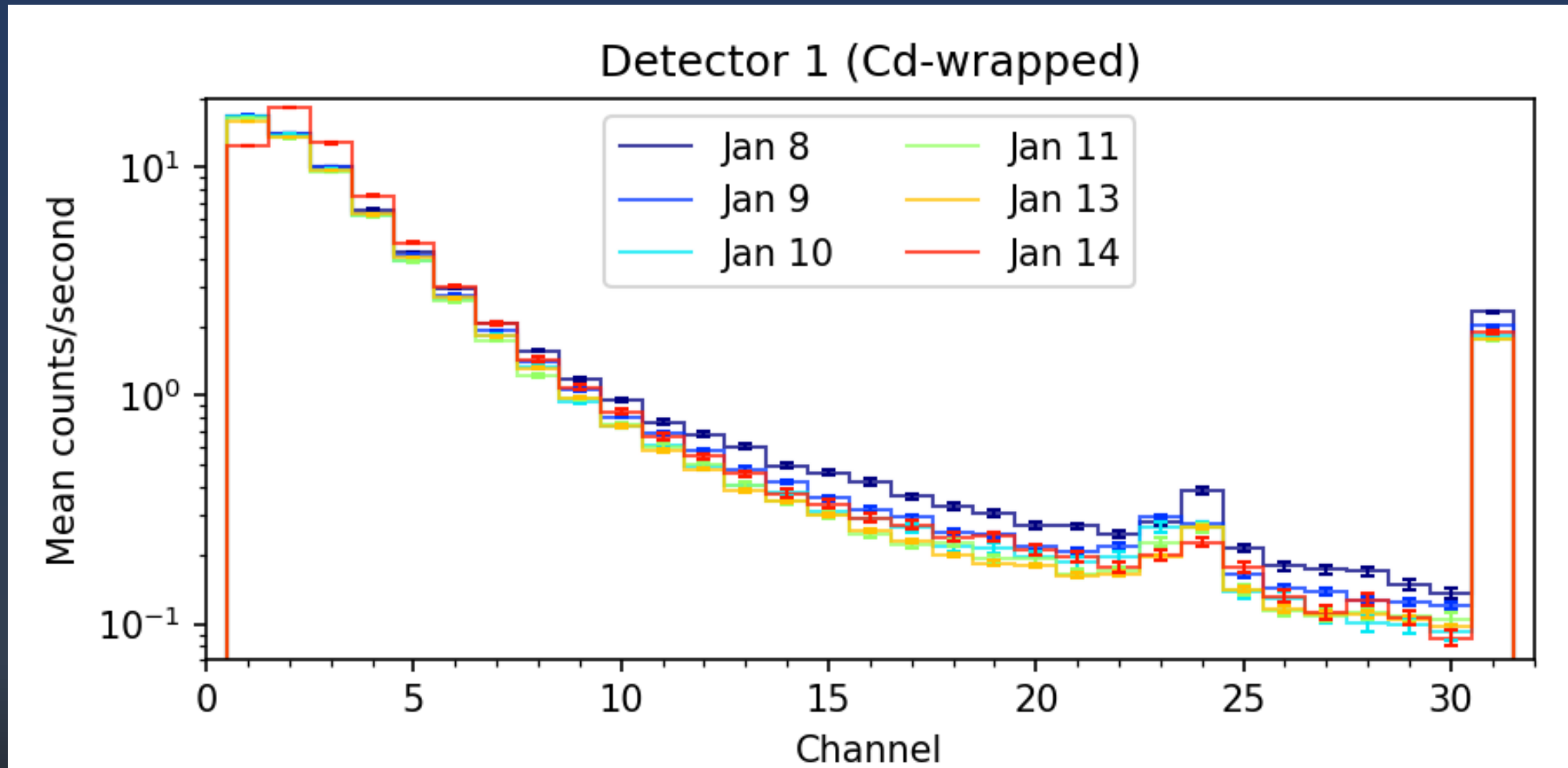
We didn't make it to the Moon... but still got 12.5 hours of data!

Ops Period #	Start (UTC)	End (UTC)	Powered-on duration (s)	# of Telemetry Frames Received	# of Commands Received
1	2024-01-08 14:02:31.595	2024-01-08 14:21:37.608	1146.013	1147	1
2	2024-01-08 17:08:37.732	2024-01-08 18:28:11.749	4774.017	4775	6
3	2024-01-09 09:08:18.961	2024-01-09 11:04:42.894	6983.933	6985	3
4	2024-01-10 15:35:07.418	2024-01-10 16:09:54.405	2086.987	2088	2
5	2024-01-11 15:08:37.002	2024-01-11 16:13:19.984	3882.982	3543*	3
6	2024-01-13 06:07:59.376	2024-01-13 13:00:59.352	24779.976	19226*	10
7	2024-01-14 20:51:50.521	2024-01-14 22:53:27.492	7296.971	7298	18
Total			50950.883 s / 14.15 hr	45062 (12.5 hr)	43

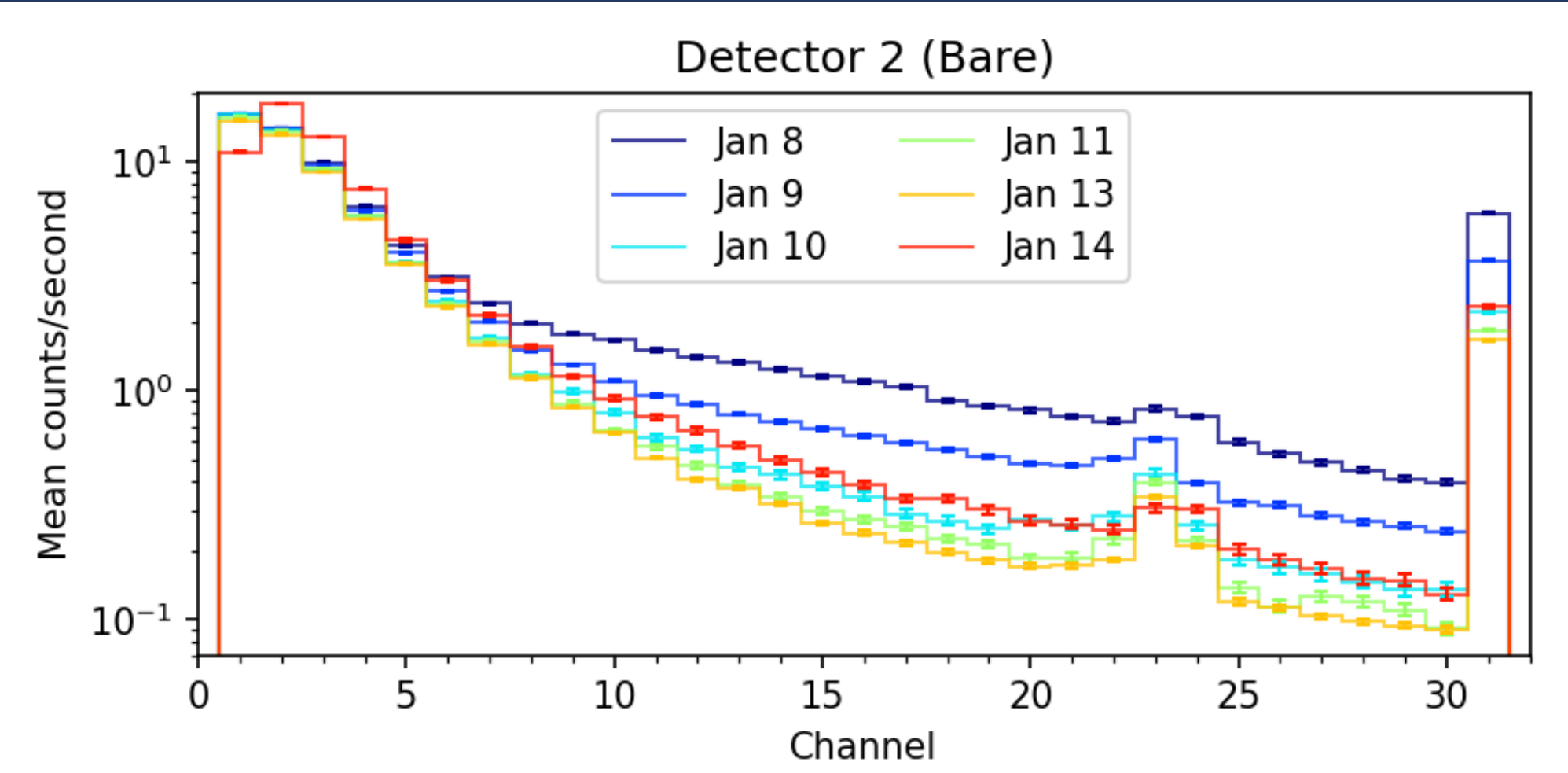
*DSN dropouts during periods 5 and 6 led to lost telemetry frames.

Nominal NSS checkout and background calibration activity in transit is only 2 hours.

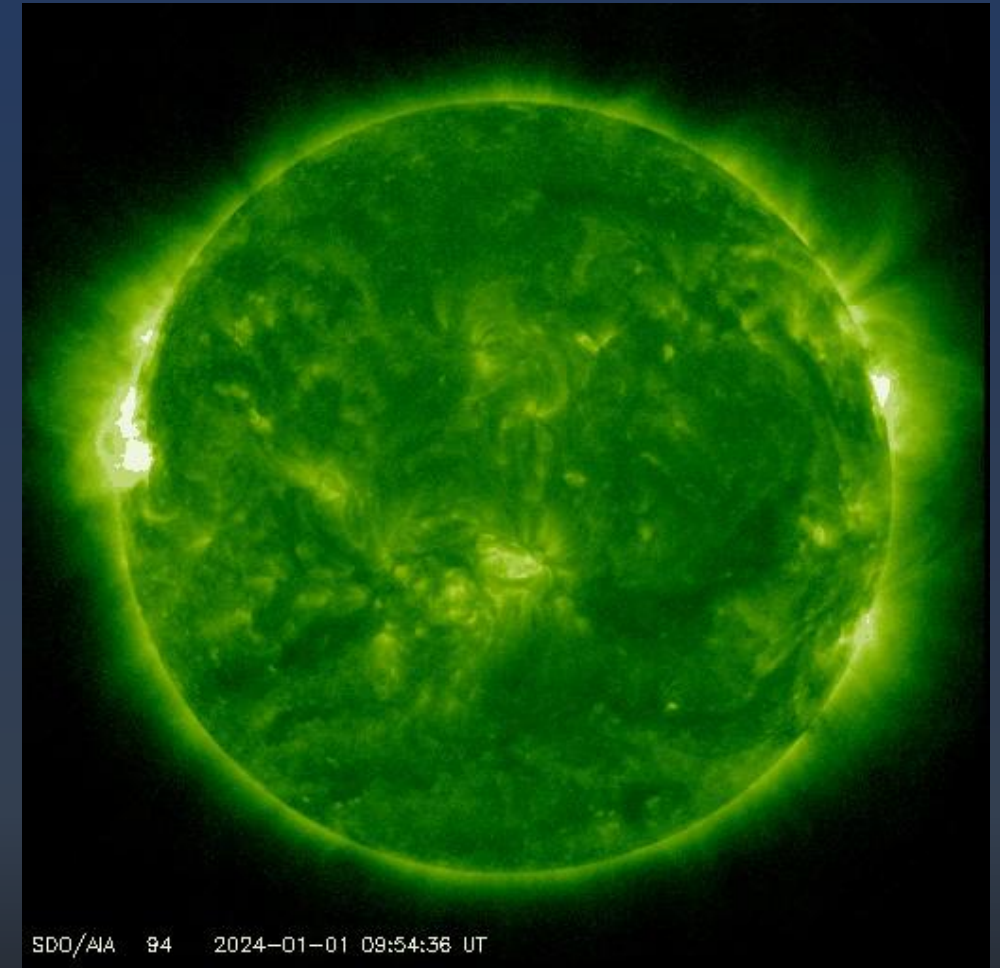
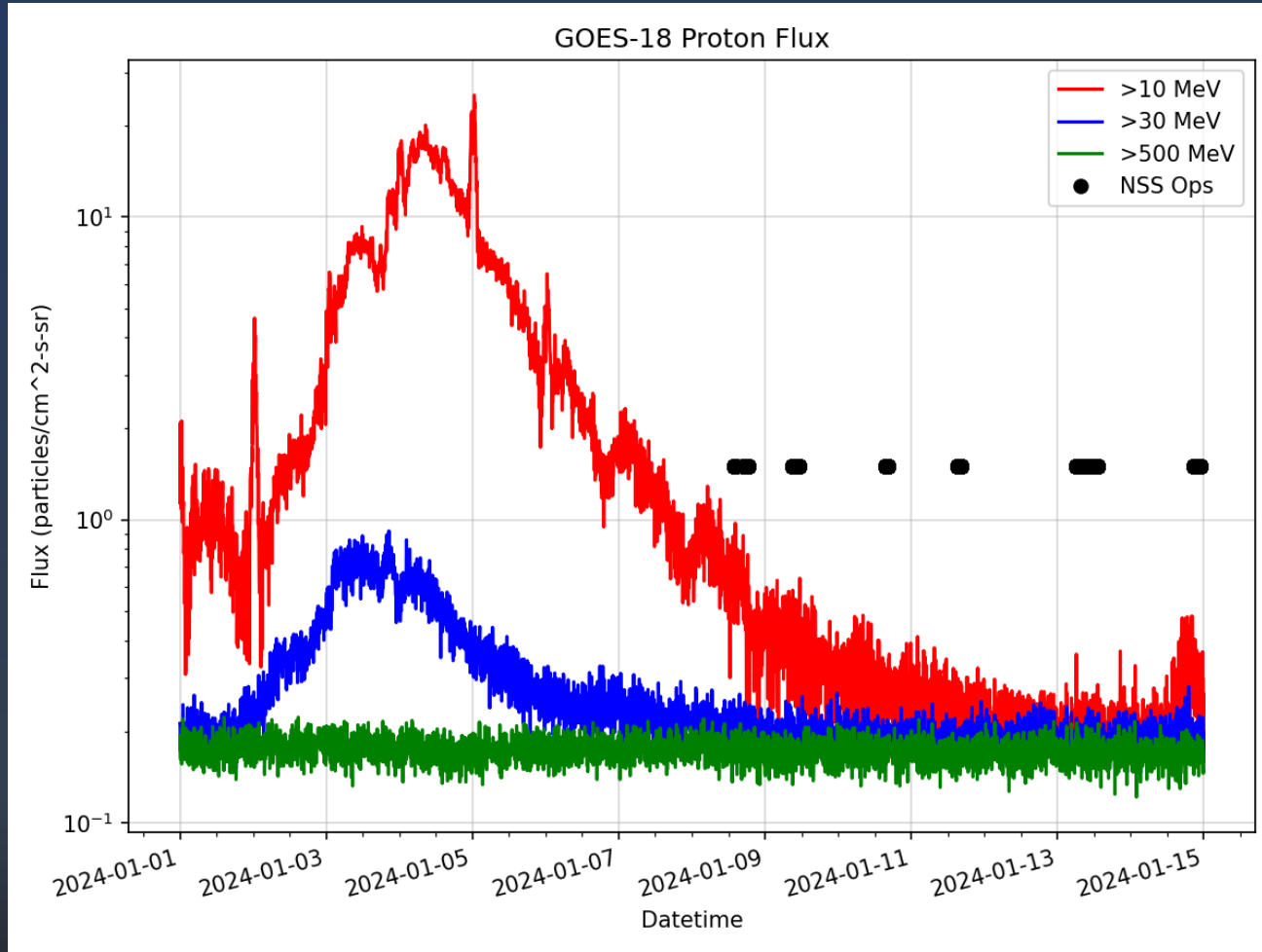
NSS measurements during Peregrine Mission show decreasing background



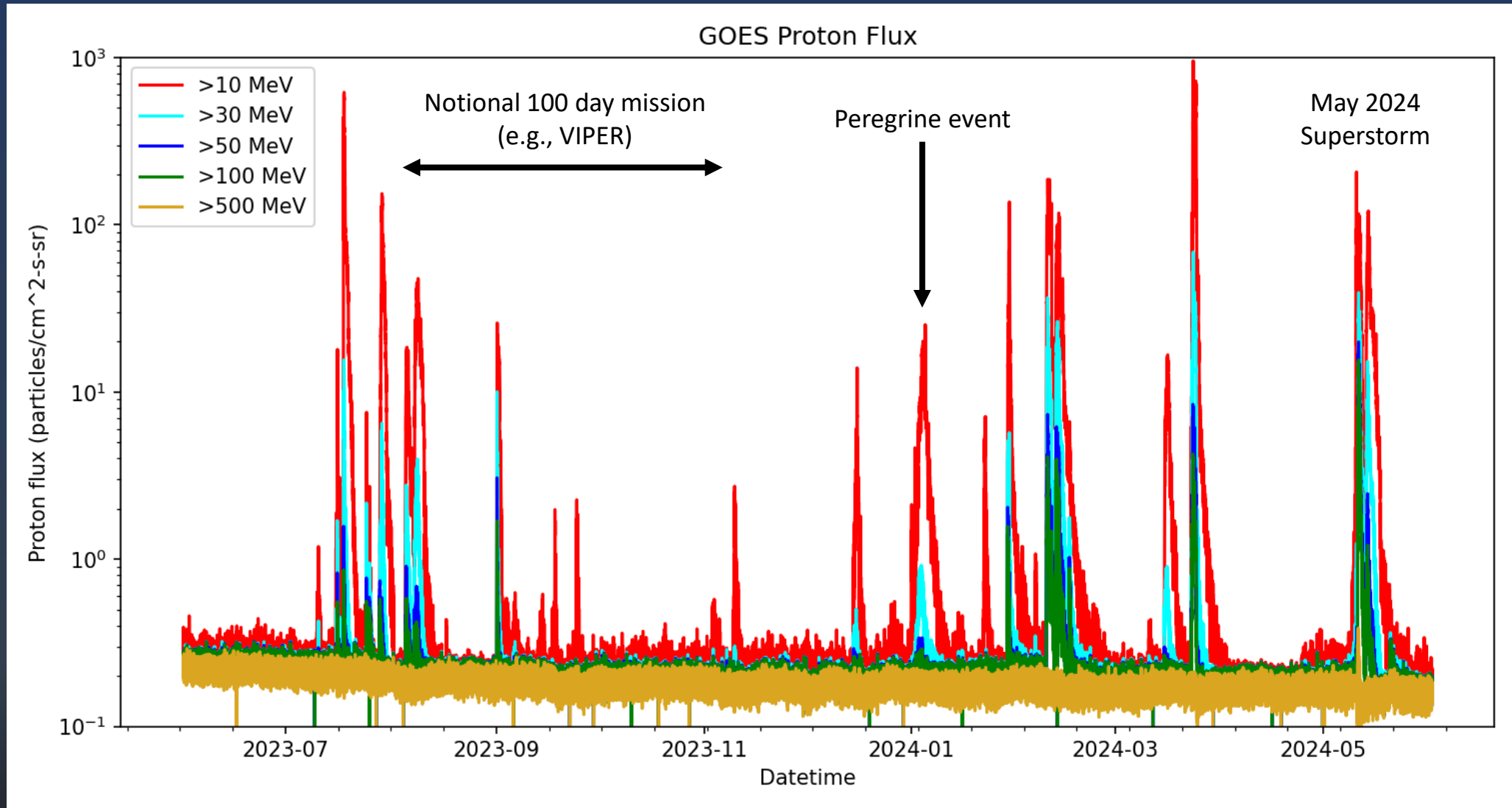
NSS measurements during Peregrine Mission show decreasing background



Peregrine mission was over the course of an ongoing Solar Particle Event (SPE)

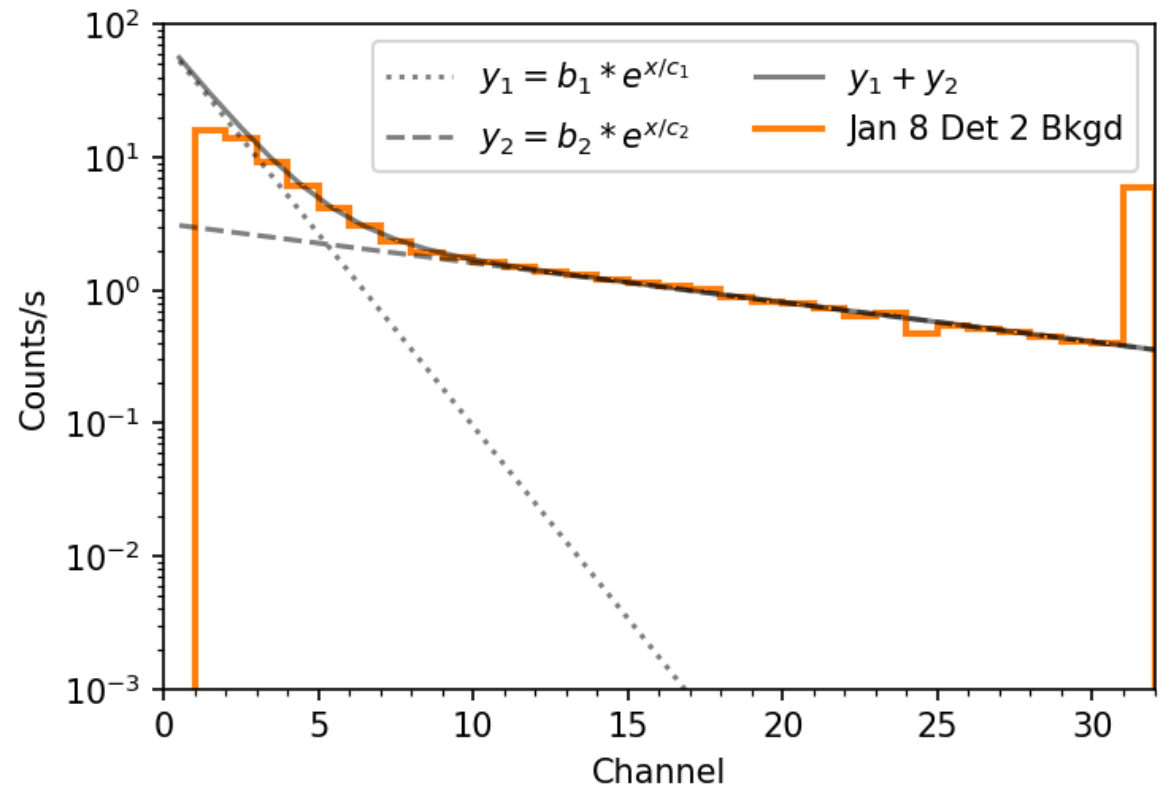
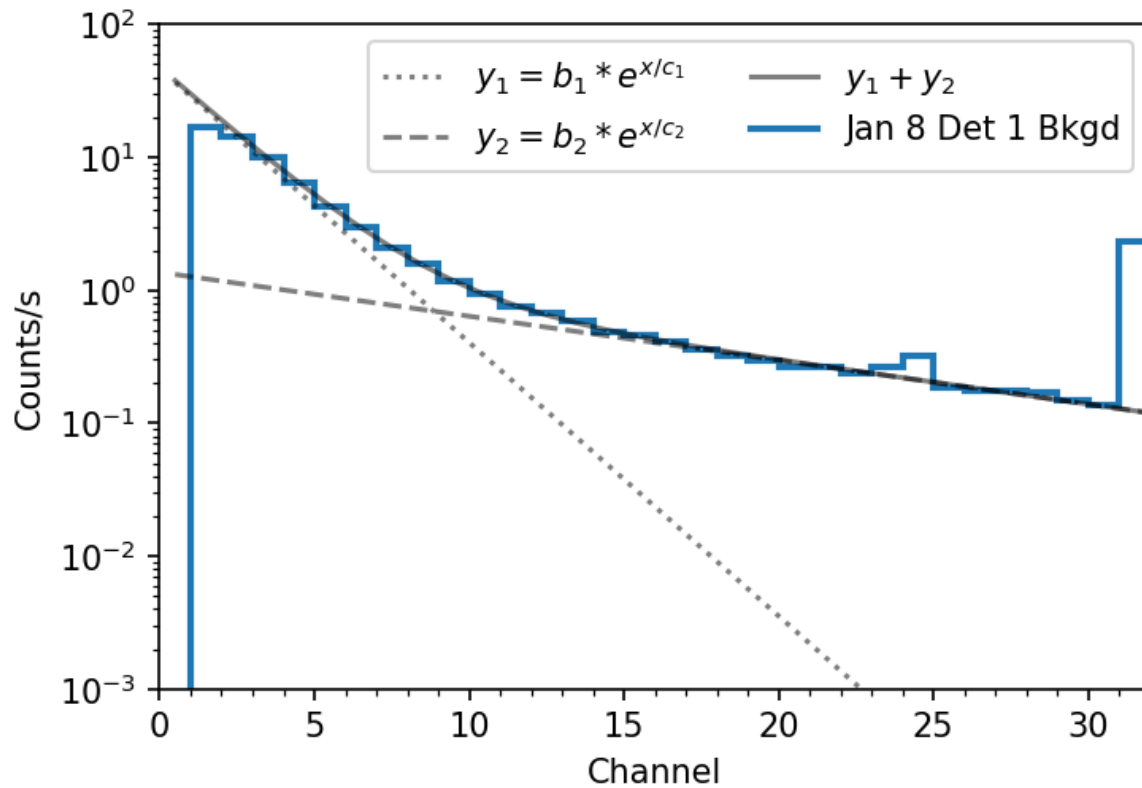


Peregrine-level events happen frequently during solar max



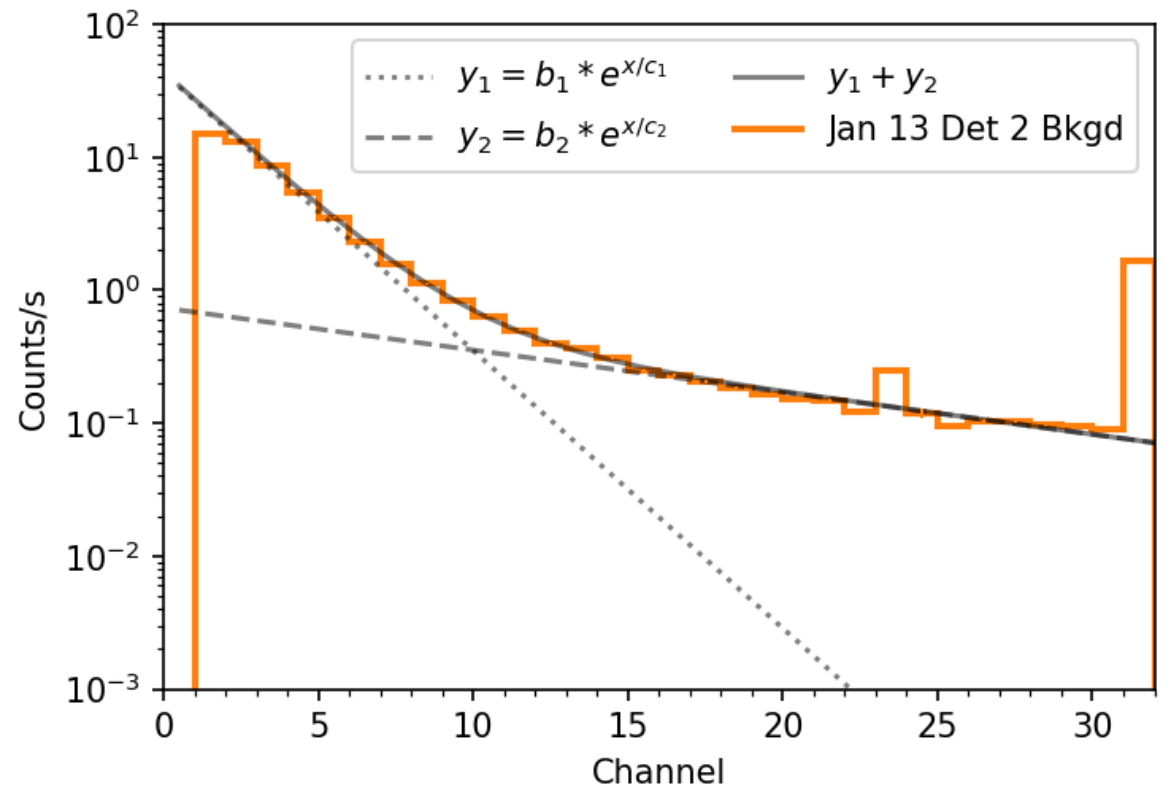
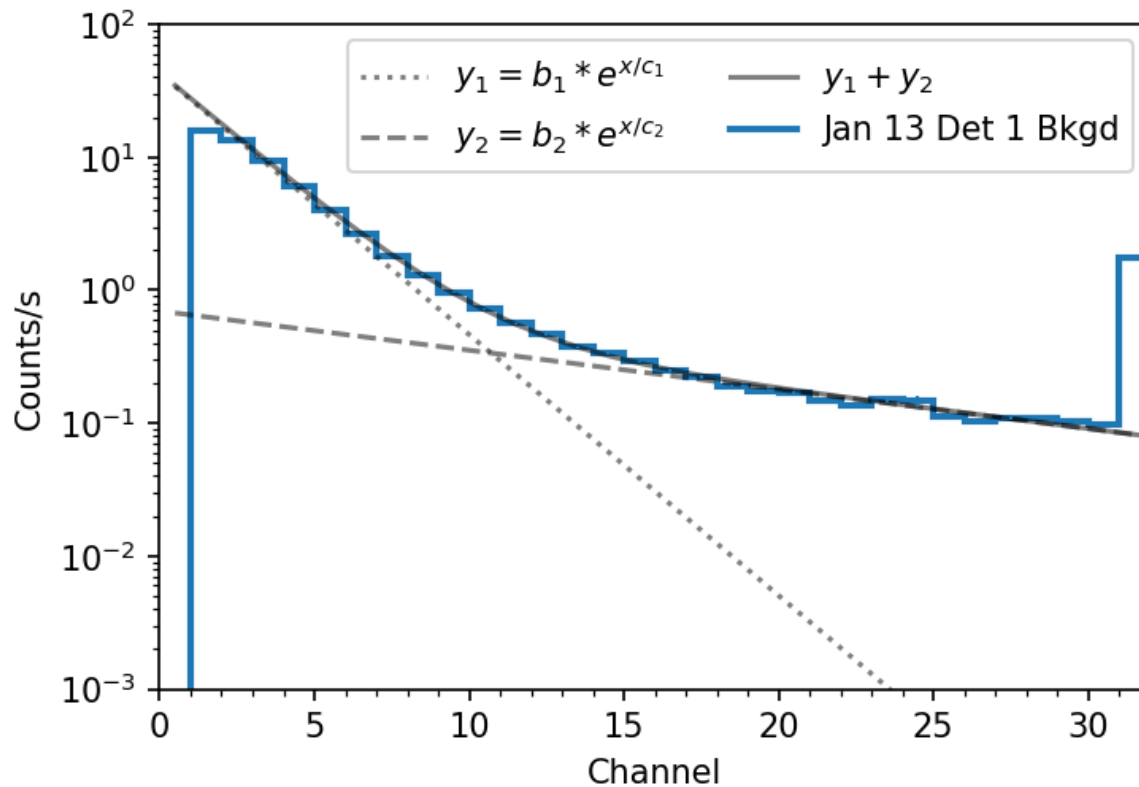
Background fitting – January 8th

Measured NSS background spectra can be fit using a sum of two power laws:
One component (y_1) describes high energy particle background (GCRs, gamma rays),
the other component (y_2) describes lower energy particle background (solar protons).

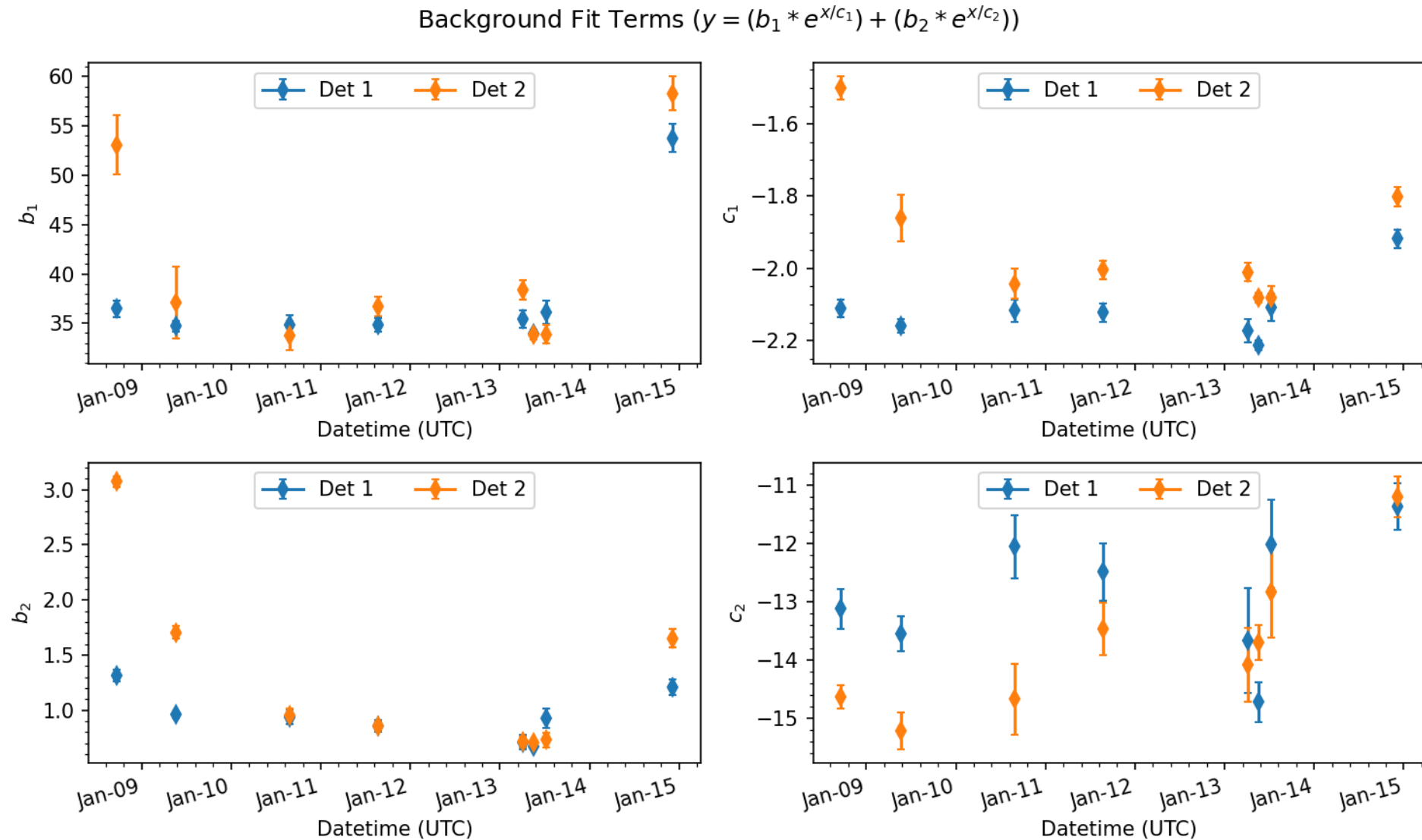


Background fitting – January 13th

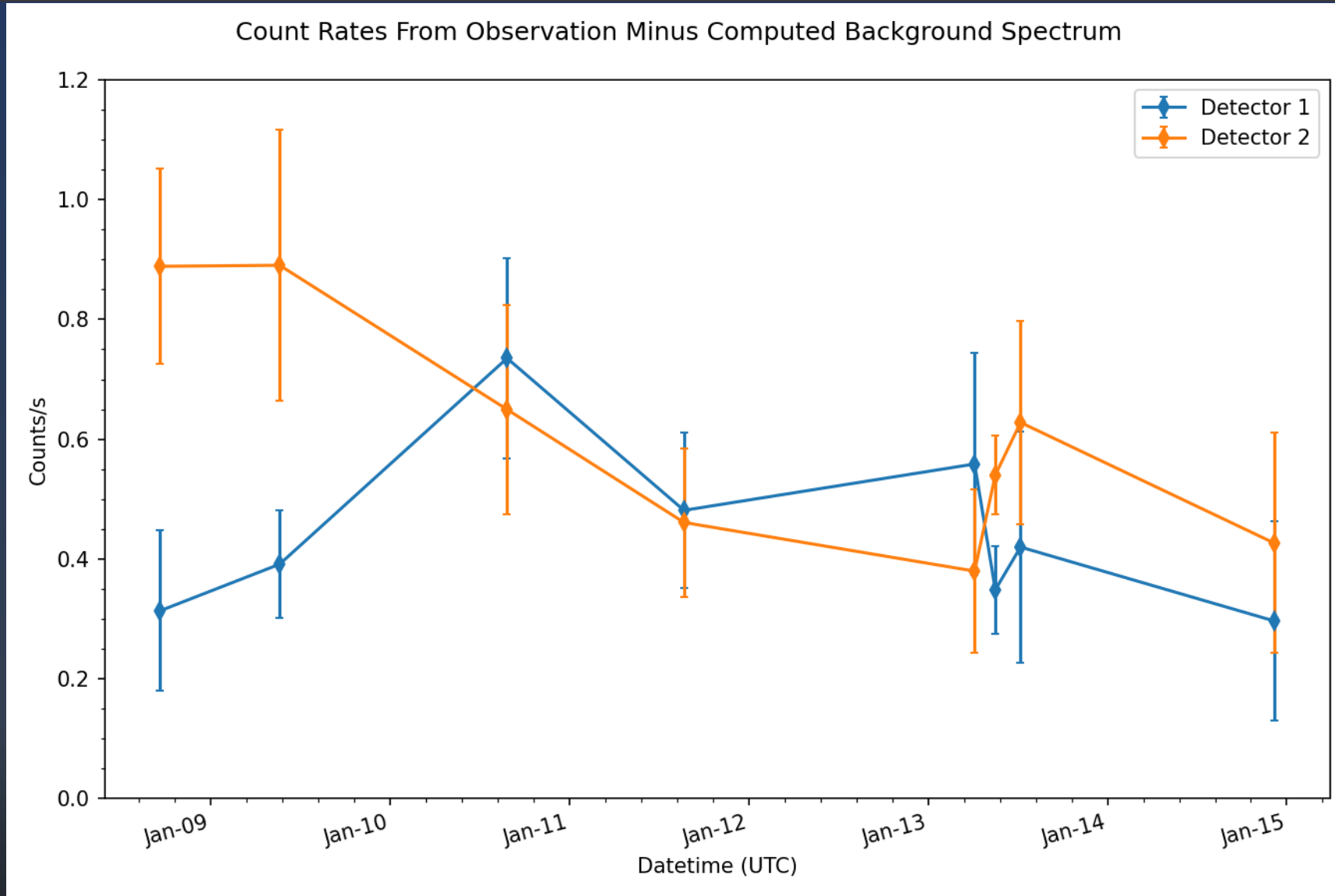
Measured NSS background spectra can be fit using a sum of two power laws:
One component (y_1) describes high energy particle background (GCRs, gamma rays),
the other component (y_2) describes lower energy particle background (solar protons).



Background fitting parameters track local space weather



Background fitting allows estimate of measured spacecraft-generated neutrons



- NSS Team has implemented software tools to perform real-time corrections to NSS data, reducing uncertainty in the search for polar volatiles across multiple missions.
- ARC Multi-Mission Operations Center has built partnership with NOAA Space Weather Prediction Center to get real-time space weather data from NOAA assets to NASA operators.
- NSS and VIPER Teams are implementing new Standard Operating Procedures regarding instrument and vehicle safety with respect to space weather on the lunar surface.

Summary

- The Neutron Spectrometer System (NSS) on Peregrine successfully returned 12.5 hours of data from cislunar space.
- A thorough checkout of the instrument under varying solar proton fluxes was performed.
- Returned data support improved science and space weather situational awareness for VIPER, MoonRanger, and LUPEX through analysis tools, SOPs, and operator training.

Backup

Neutrons in the lunar environment

Galactic cosmic
ray proton
($E > 100\text{s MeV}$)

p

γ

n

n

n

γ

Lunar surface

Inelastic collision

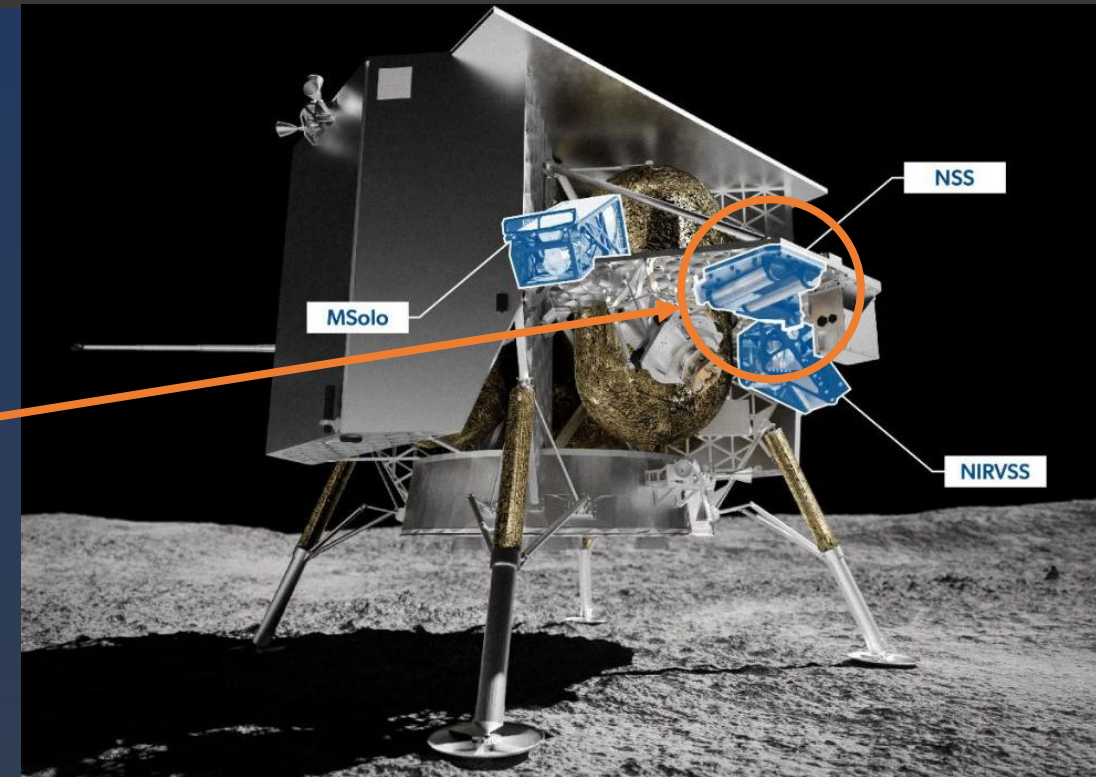
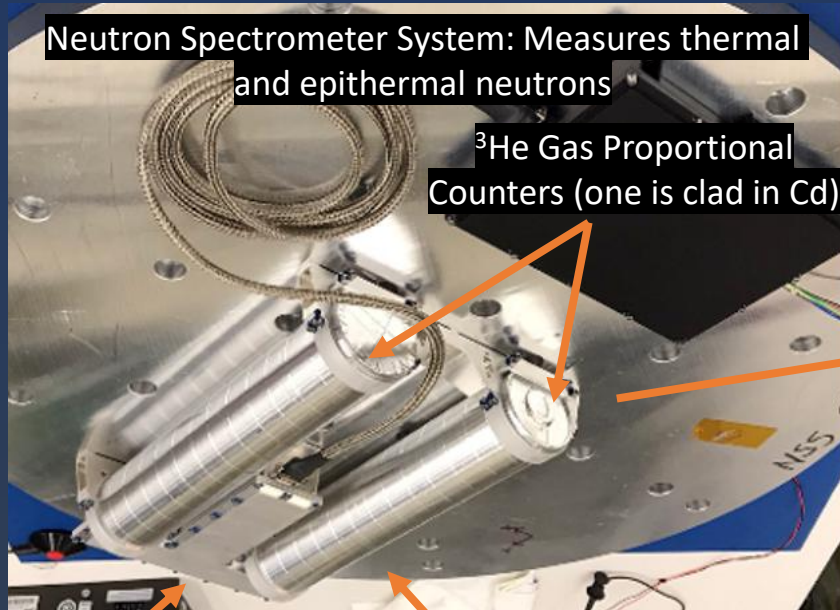
Elastic collision

Target nucleus (e.g., Si)

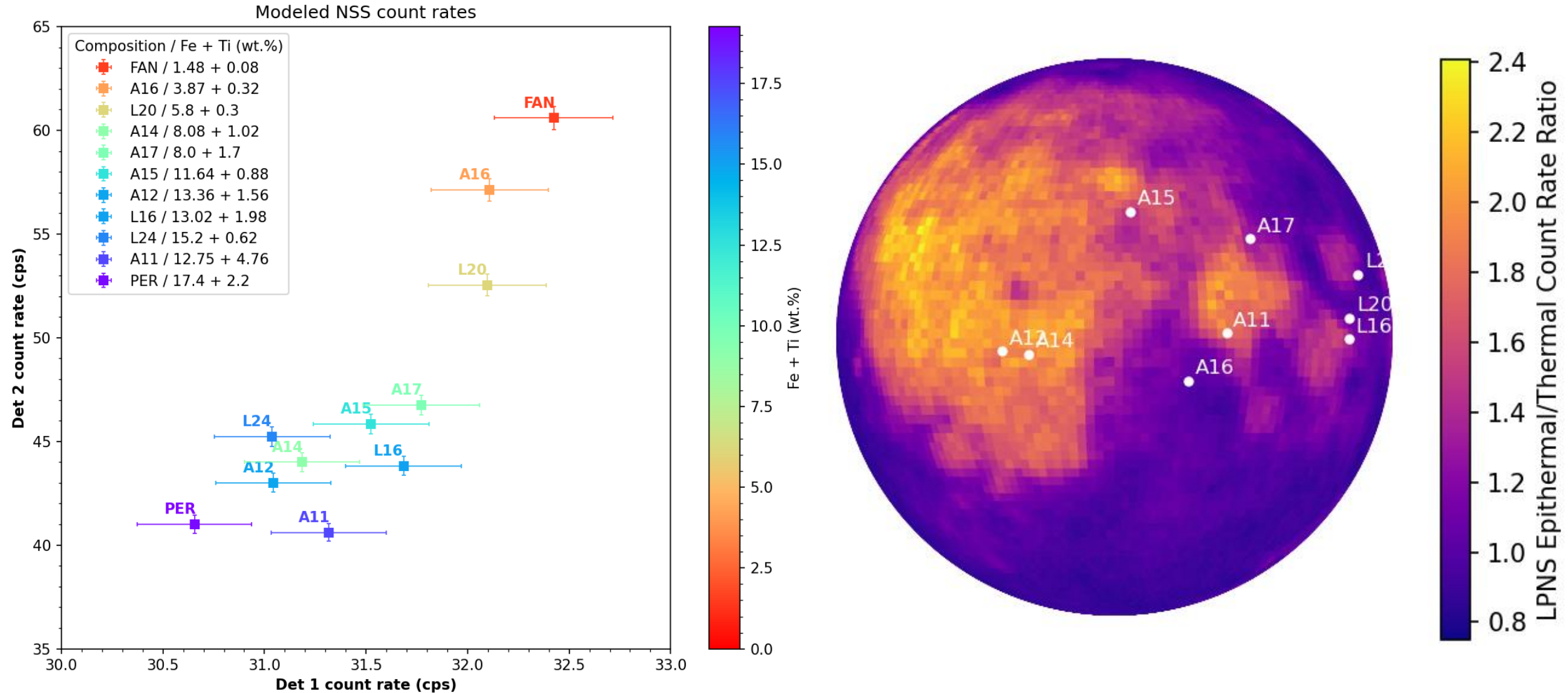
Target nucleus shattered, fast
neutrons and other fragments
recoil from location

Radiative capture

Interaction depth is $<100\text{s}$
of g/cm^2 (e.g., $1.7 \text{ g/cm}^3 * 100 \text{ cm} = 170 \text{ g/cm}^2$)

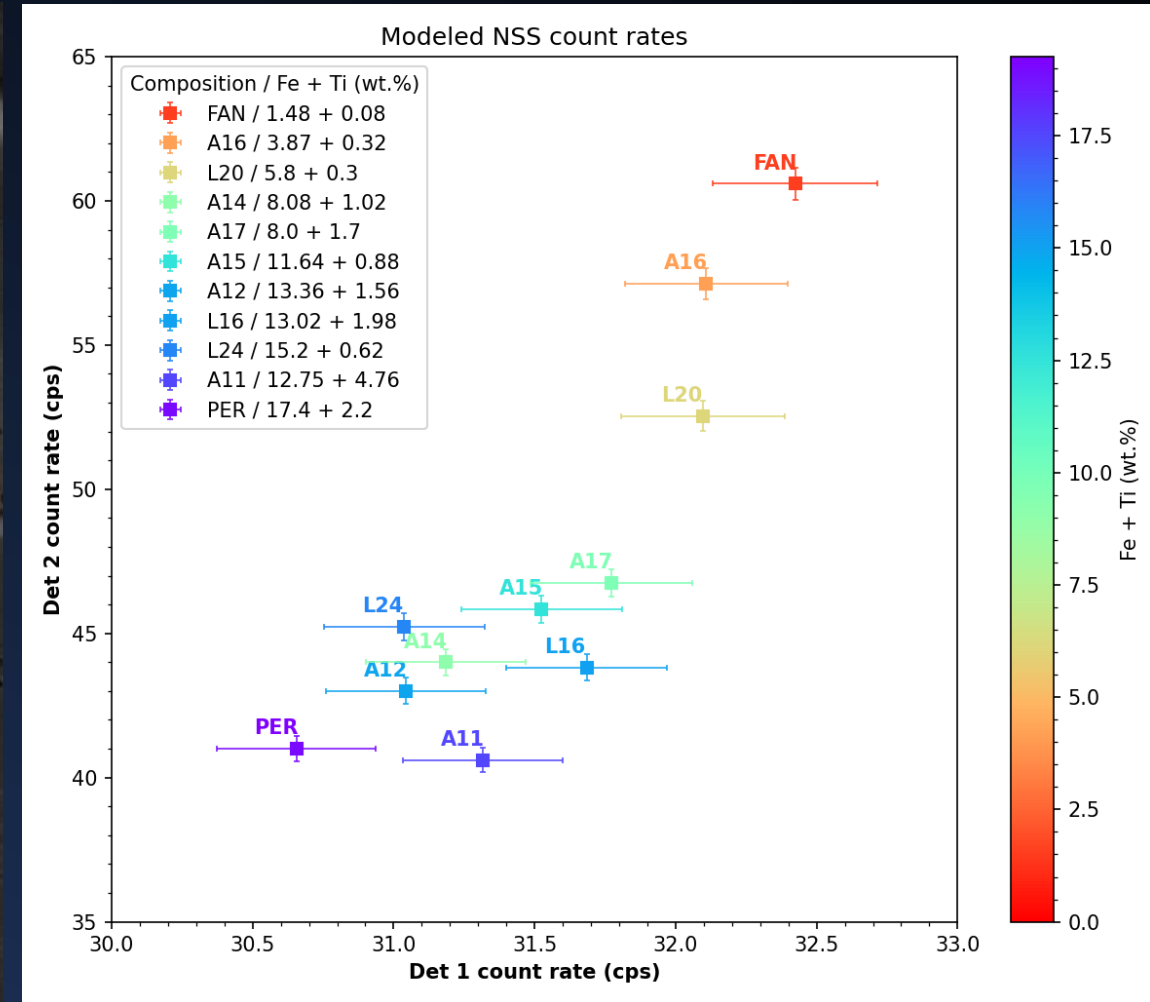
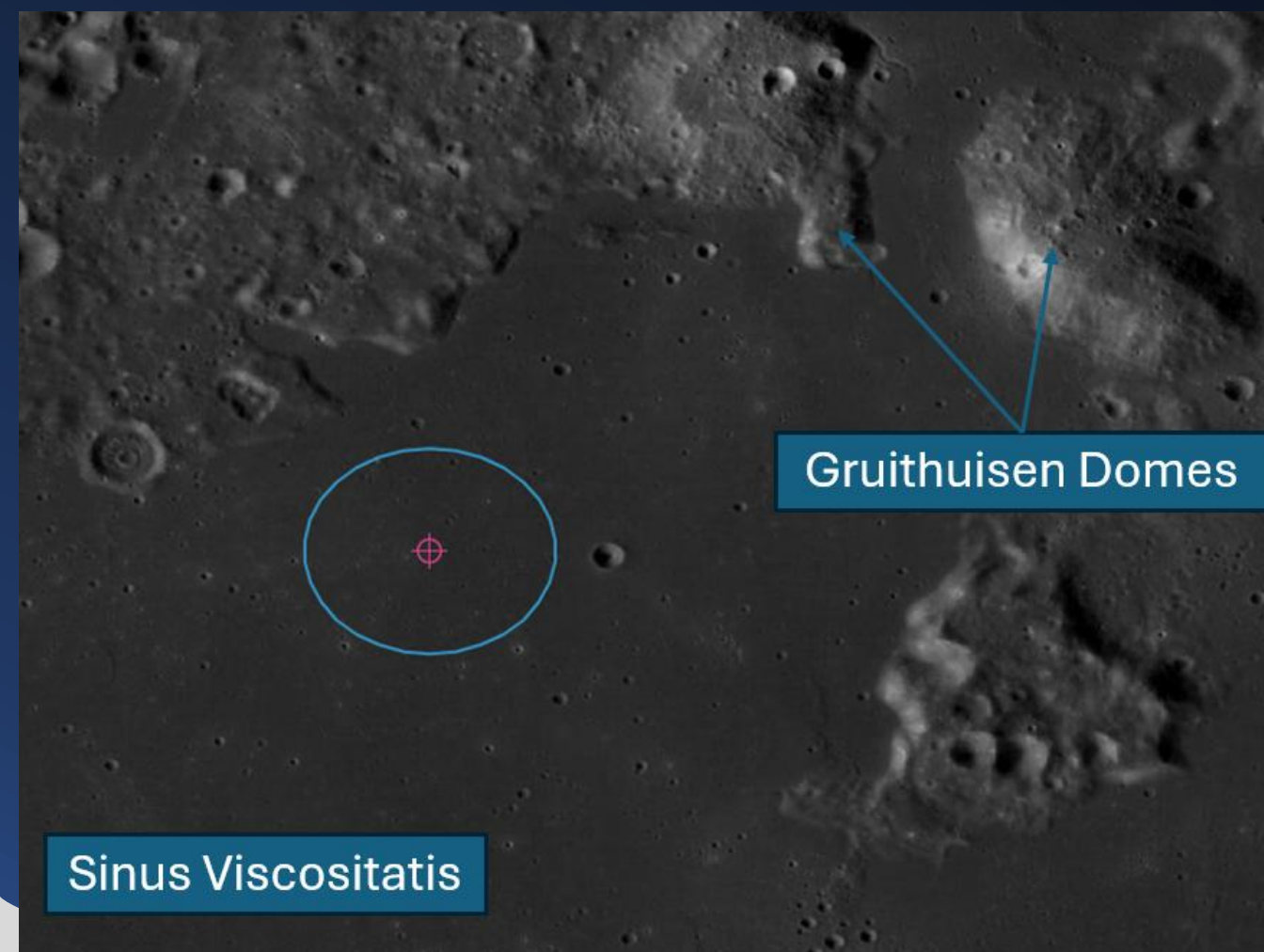


Neutrons in the lunar environment indicate bulk composition (Fe, Ti, H, REEs)

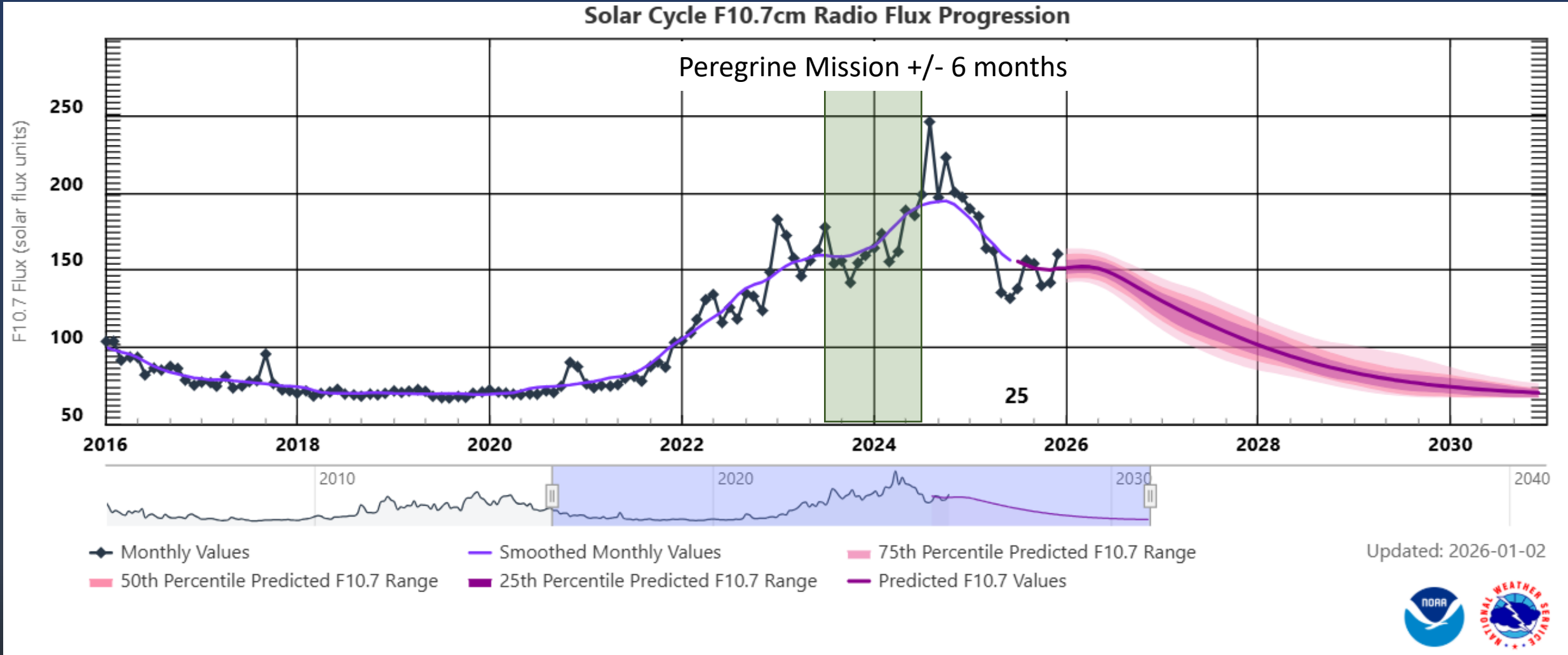


Expected Peregrine Measurements at Sinus Viscositatis Landing Site

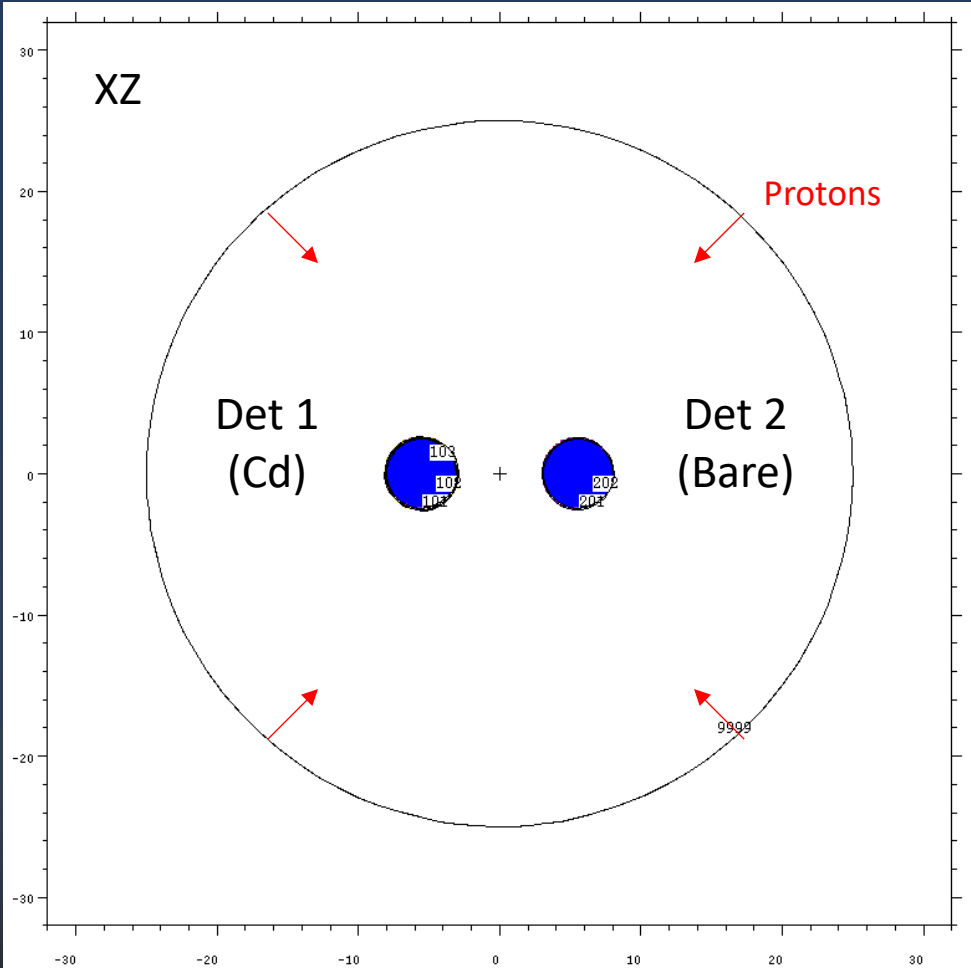
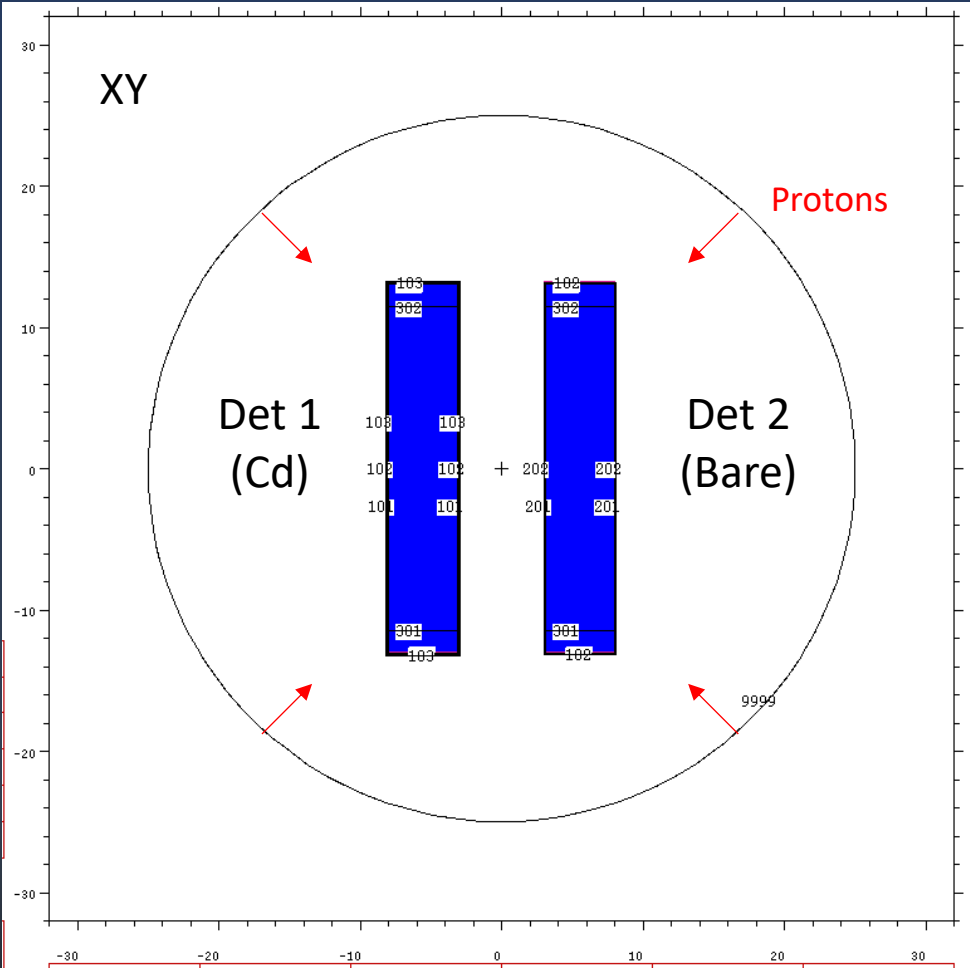
Landing site in Sinus Viscositatis was on Fe and Ti-rich basaltic mare material (strong neutron absorbers)



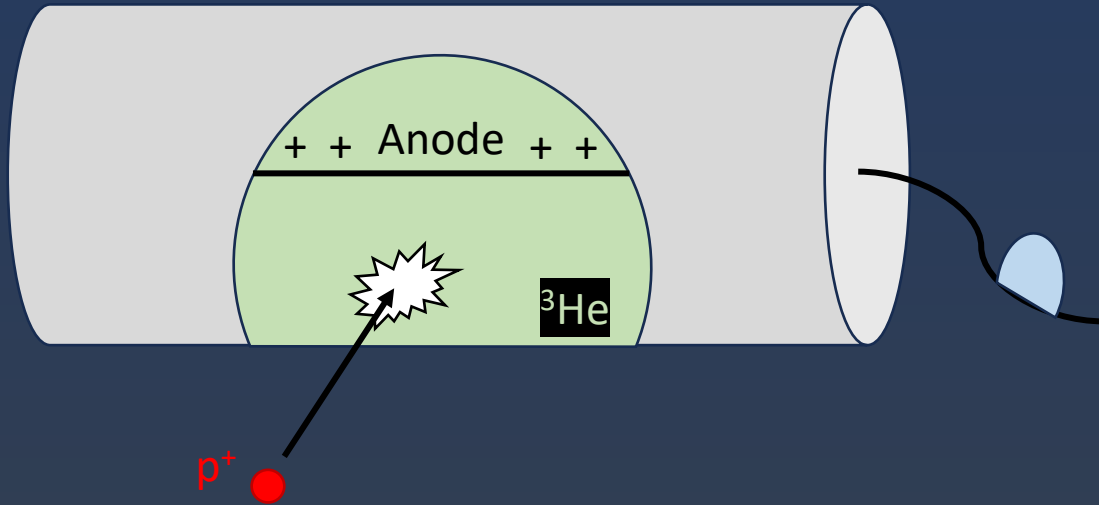
Peregrine-level events happen frequently during solar max



MCNP radiation transport models allow us to simulate proton bombardment on NSS

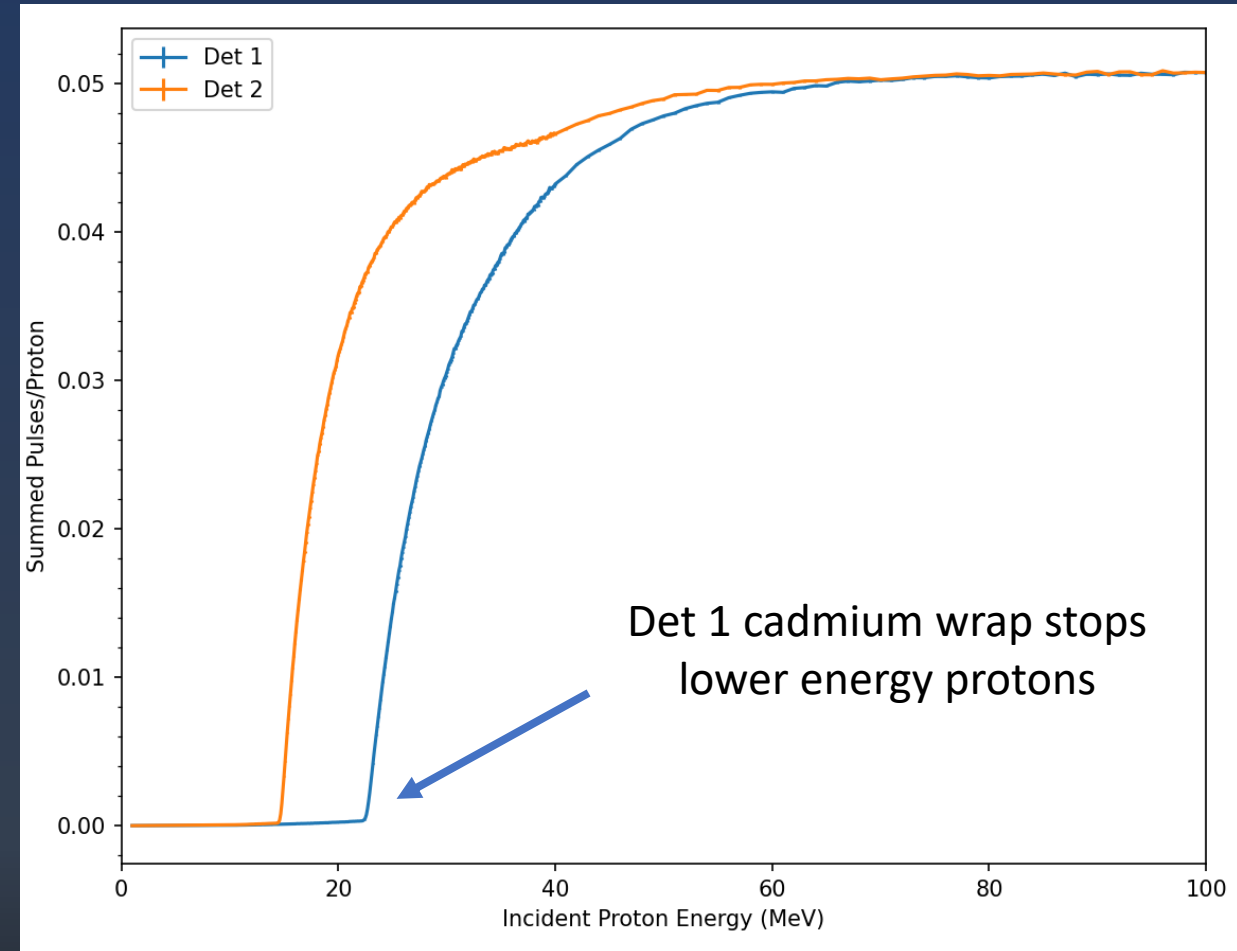


Proton Energy Deposition in ^3He gas proportional counters



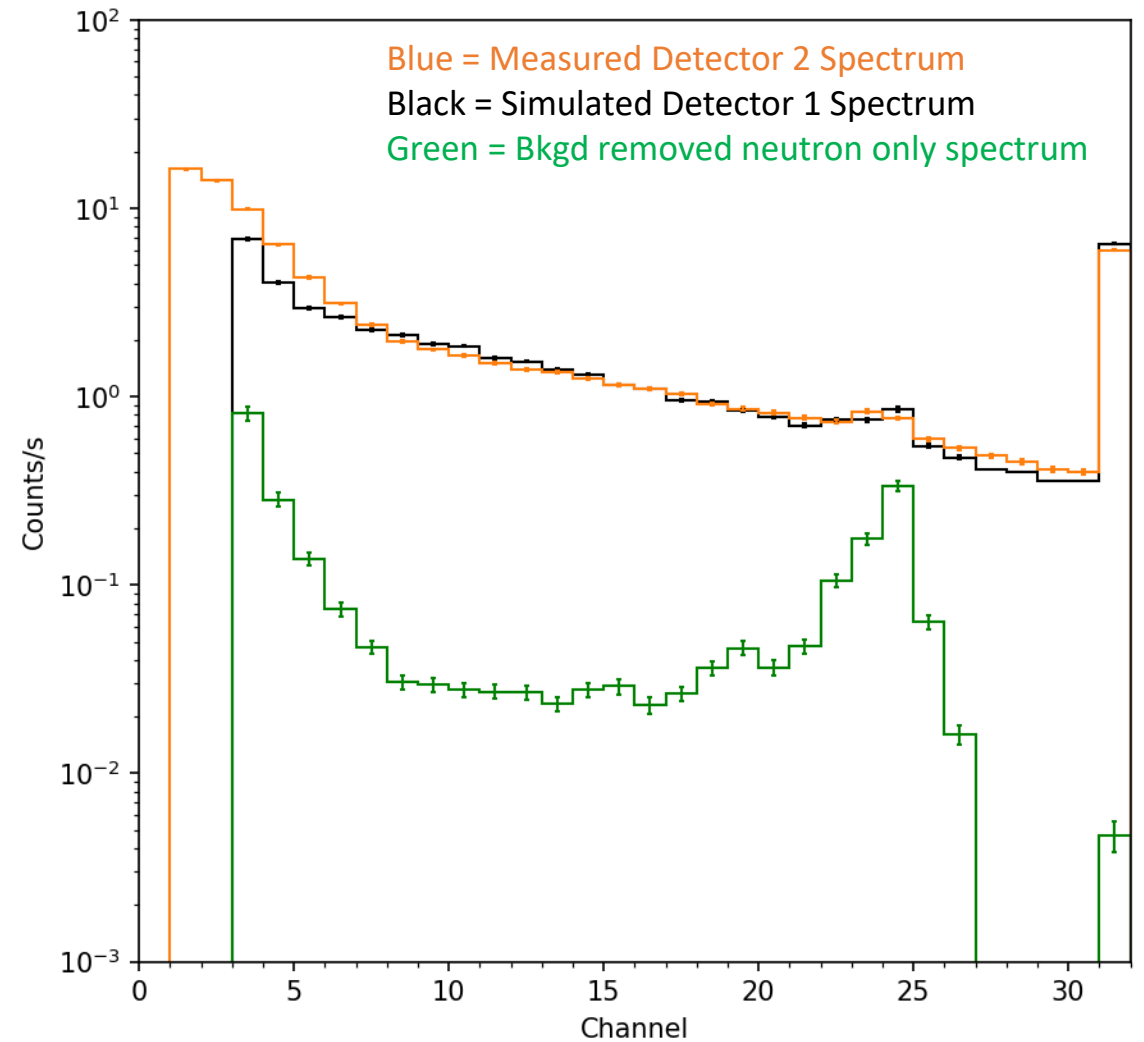
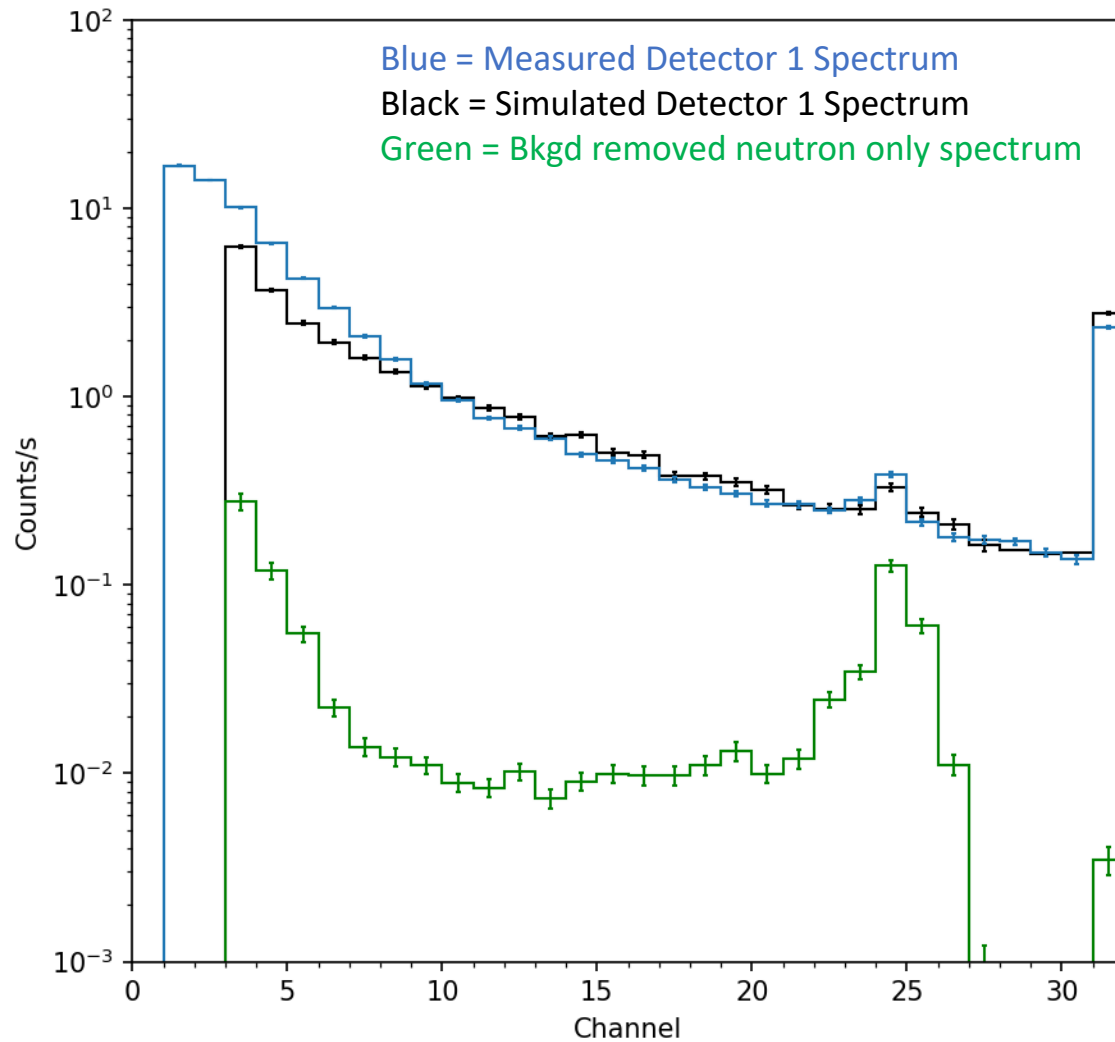
Energetic charged particles can also pass through the NSS housing and ionize the gas

Protons with $E > \sim 22$ MeV and $> \sim 14$ MeV can pass through the housing of NSS detectors



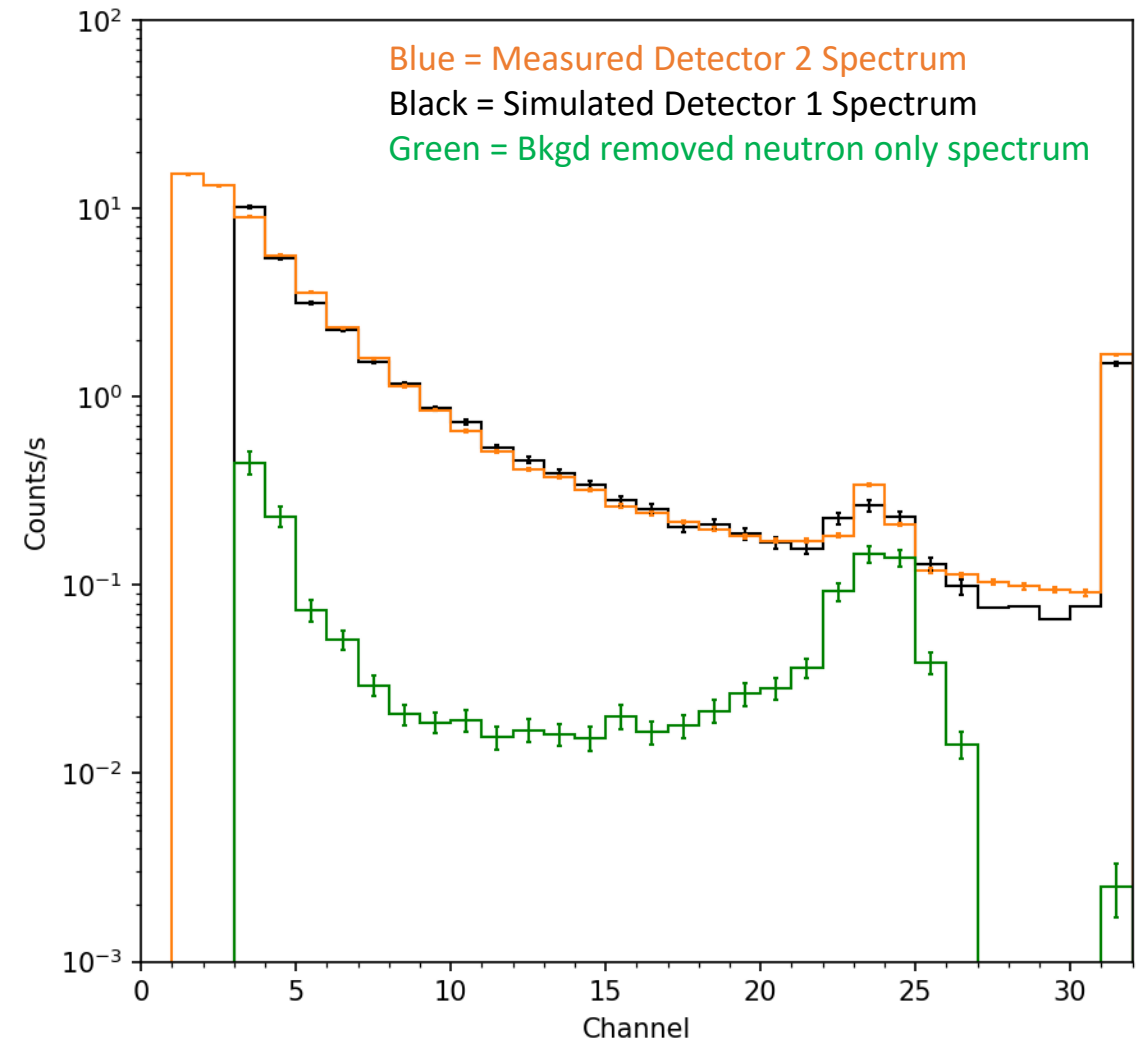
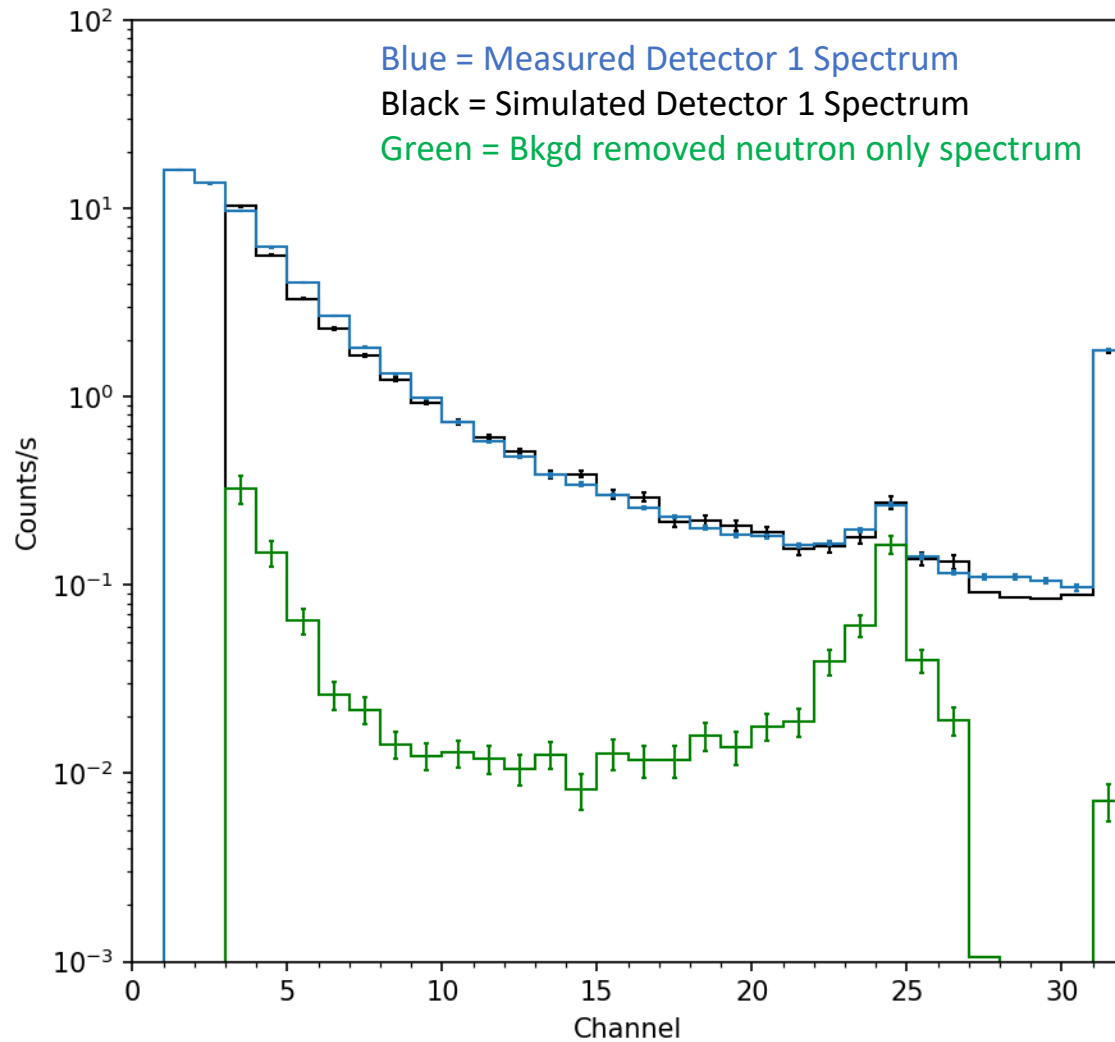
Build up synthetic NSS spectrum that includes neutron and proton pulses

2024-01-08T17:16:08.734, Grid Steps = 7, Obj Func Val = 0.5



Build up synthetic NSS spectrum that includes neutron and proton pulses

2024-01-13T09:00:02.354, Grid Steps = 7, Obj Func Val = 0.42



Elevated high energy ion fluxes from ARTEMIS

