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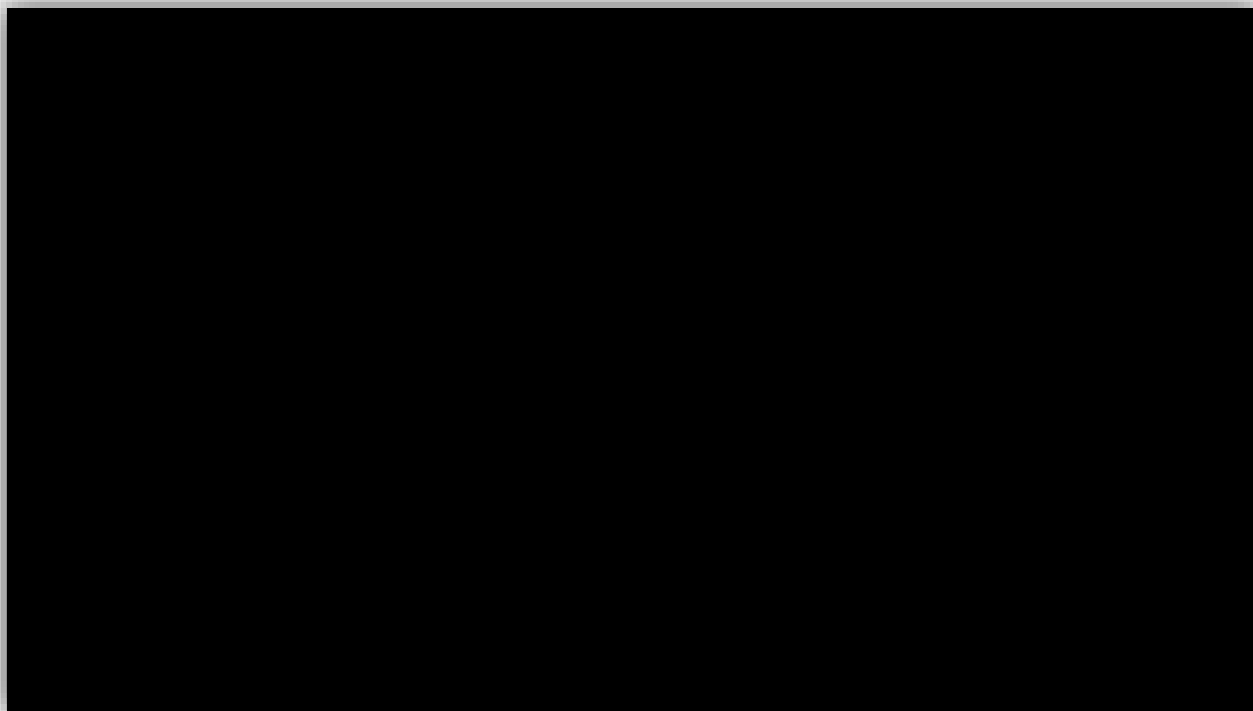
From earth to outer space: surface composition analysis with neutron-induced gamma rays

WANDA 2020

03/04/2020

MAURICIO AYLLON UNZUETA

NASA: DRAGONFLY/DALI



DRAGONFLY: NASA mission to explore Titan, perhaps the most exciting moon of our solar system.

One of the onboard instruments is DraGNS (Dragonfly gamma-ray and neutron spectrometer).

<https://dragonfly.jhuapl.edu/index.php>



DALI: Development and advancement of lunar instrumentation.

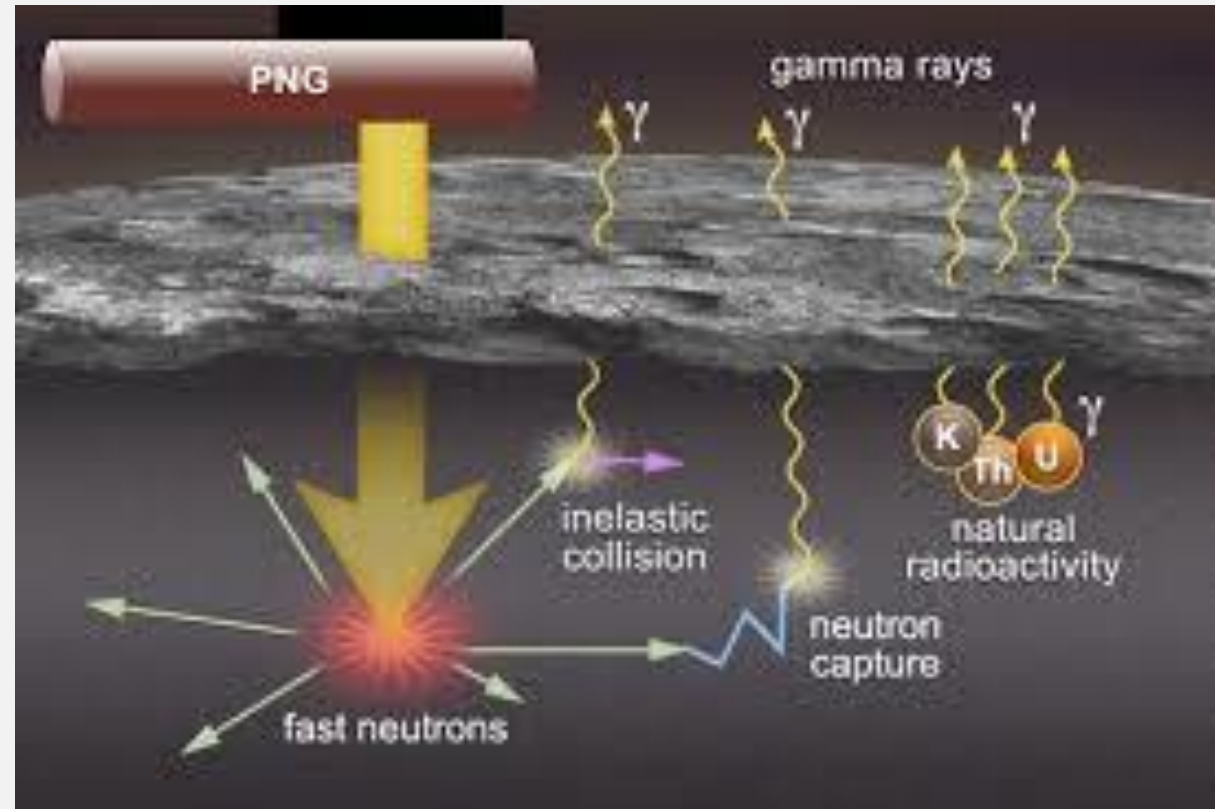
Maturation of the Bulk Elemental Composition Analyzer (BECA) for surface and sub-surface lunar studies.

PI: Dr. Ann Parsons from Goddard Space Flight Center.

<https://www.nasa.gov/feature/goddard/2019/five-teams-win-nasa-dali-awards-to-advance-future-lunar-missions>

DRAGONFLY/DALI INSTRUMENTATION

- **Pulsed neutron generator** (Schlumberger)
- **Gamma-ray detection system**
 - Thermal neutron capture (TNC)
 - Inelastic Scattering (INS)
- **Neutron detector**
 - Neutron albedo



NOVEL METHOD TO MEASURE CARBON IN SOIL: ROOTS

Developed at Berkeley Lab

PI: Arun Persaud – apersaud@lbl.gov

API is a neutron/gamma imaging technique that allows for:

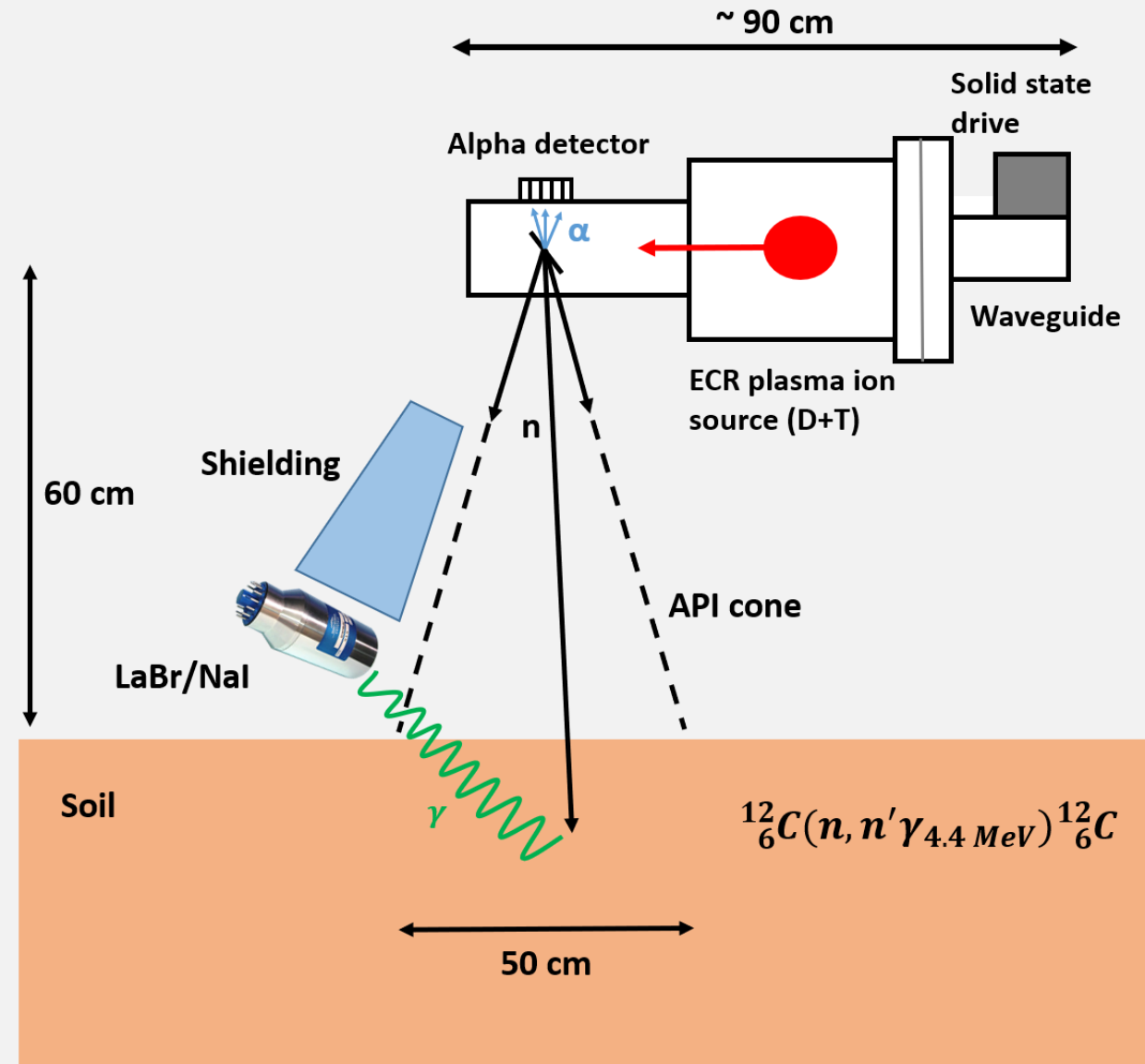
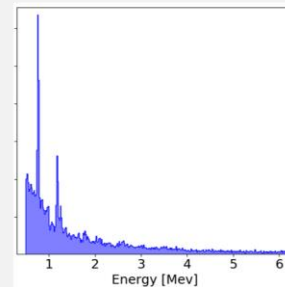
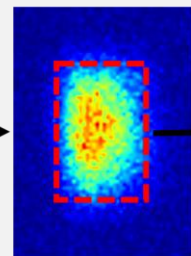
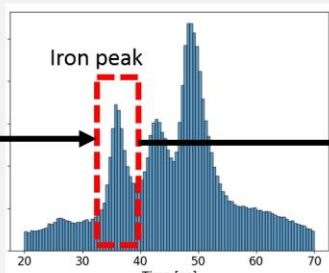
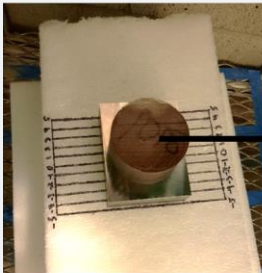
1. Determination of isotopic distributions in **3D**
2. “**Background-free**” gamma spectra
3. Material identification and absolute elemental abundances

Iron sample (SS1018)

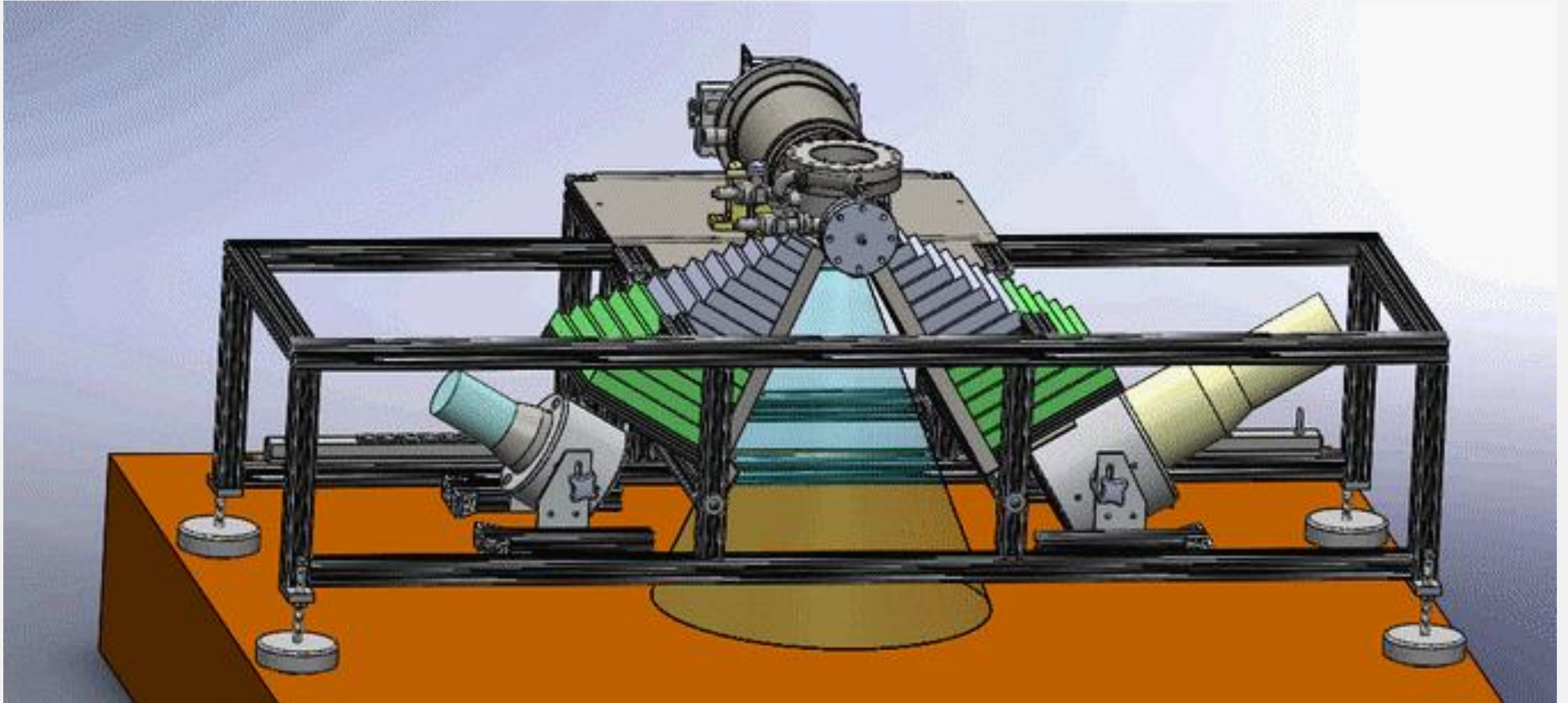
Time histogram

XY counts density map filtered in time

Iron gamma energy spectrum

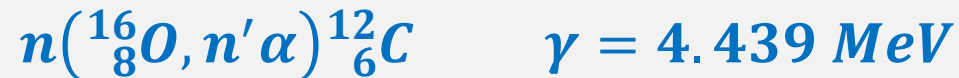


ROOTS API SYSTEM

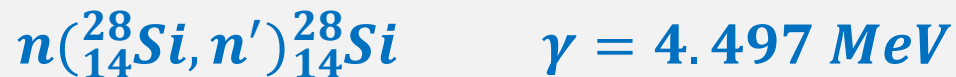


INTERFERING REACTIONS ON C-12 GAMMA LINE

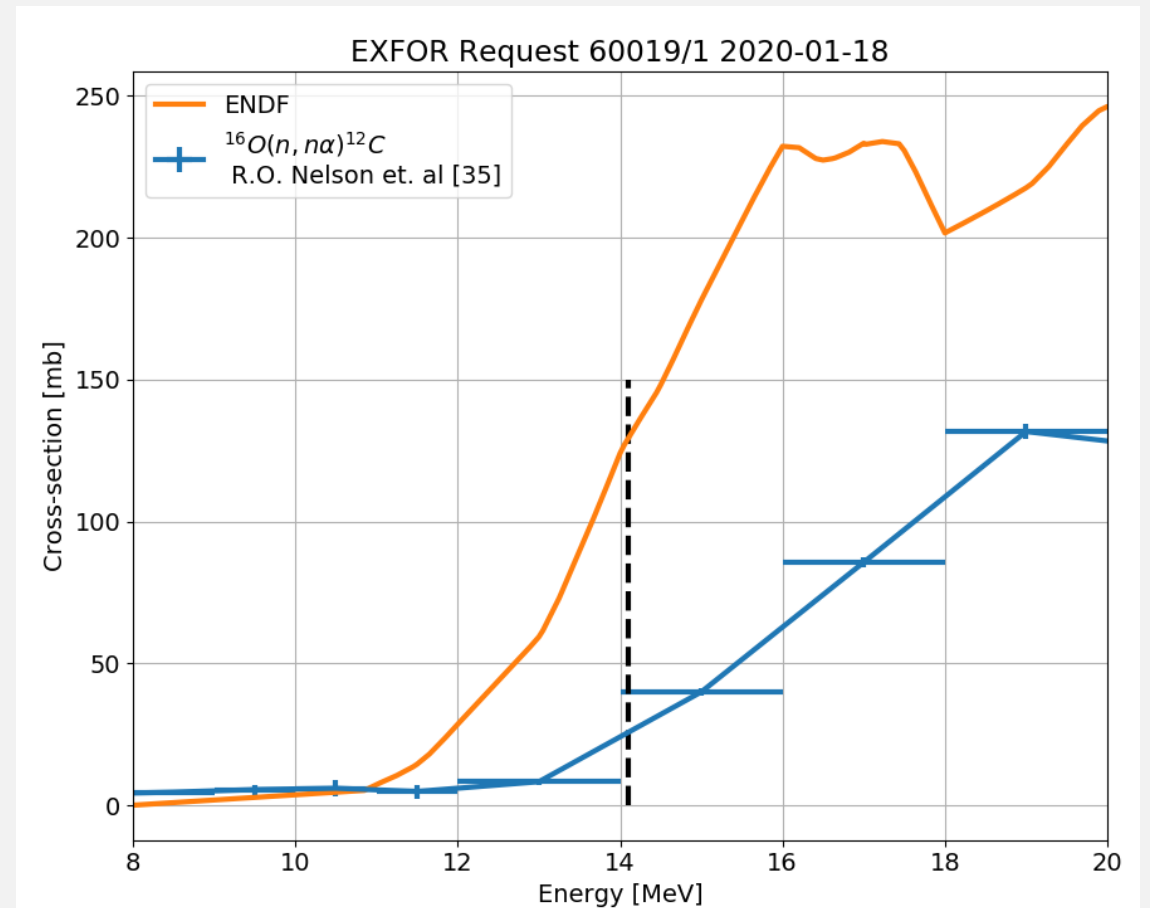
Two important interfering reactions:



- Experimental cross-section at 14.1 MeV incident neutron energy not available.
- Large discrepancy $\sim X5$, and experimental data suggests this value may be closer to ENDF.

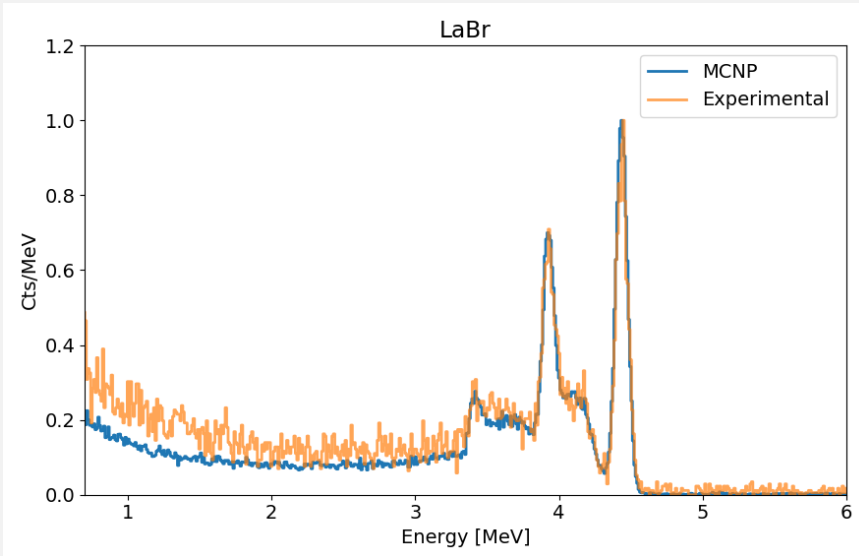


- Result of a nuclear cascade transition $6.276\text{MeV}(3+) \rightarrow 1.779\text{MeV}(2+)$
- Not resolvable with LaBr (resolution $\sim 120 \text{ keV}$)



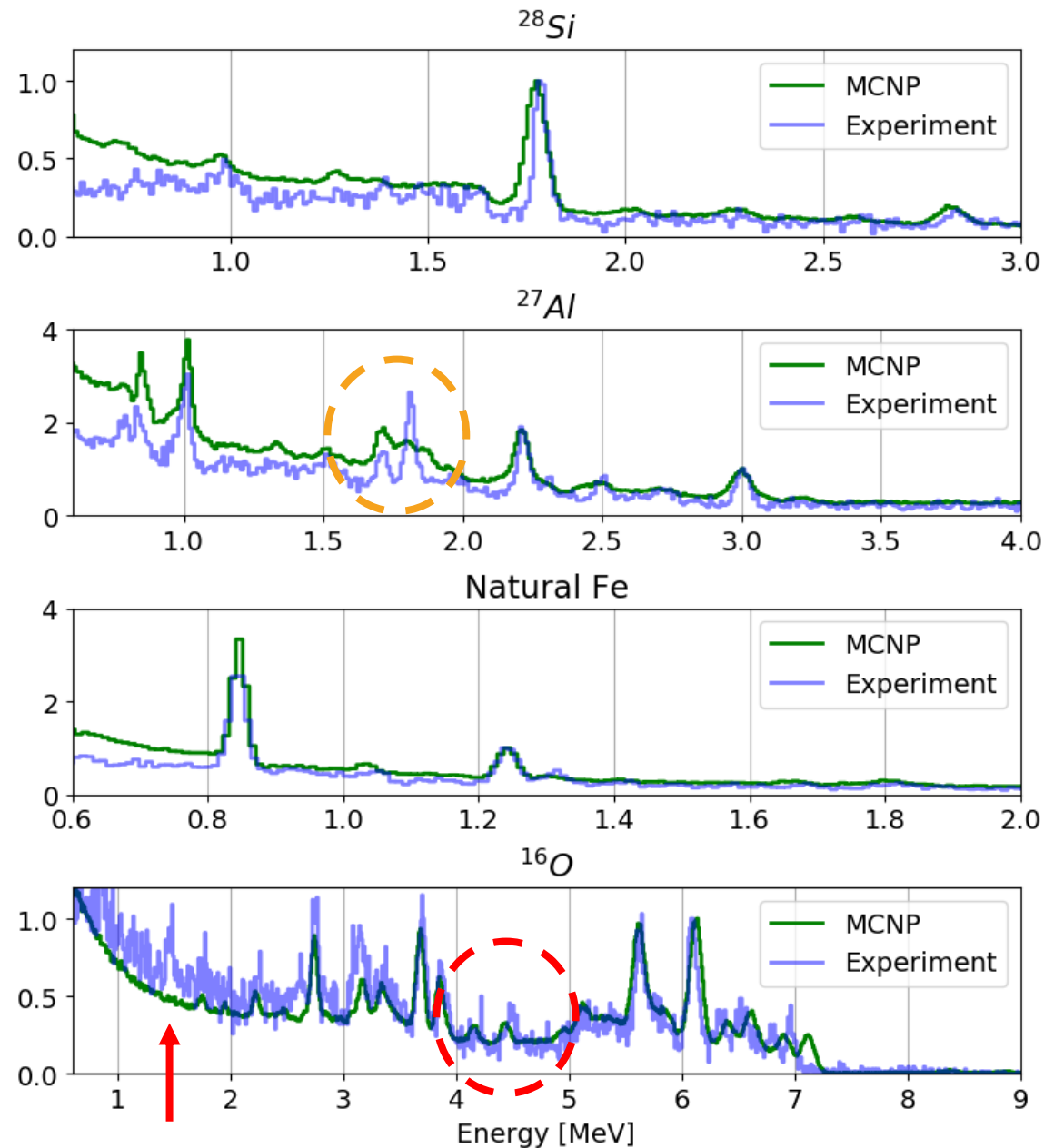
R. O. Nelson et al. High-Resolution Measurements and Calculations of Photon-Production Cross Sections for ${}^{16}\text{O}(n,x)$ Reactions Induced by Neutrons with Energies between 4 and 200 MeV". In: Nuclear Science and Engineering 138 (2001), p. 105. doi: 10.13182/NSE01-A2205. url: <http://dx.doi.org/10.13182/NSE01-A2205>.

SINGLE-ELEMENT SPECTRA: EXPERIMENTAL VS. MCNP



LaBr detector

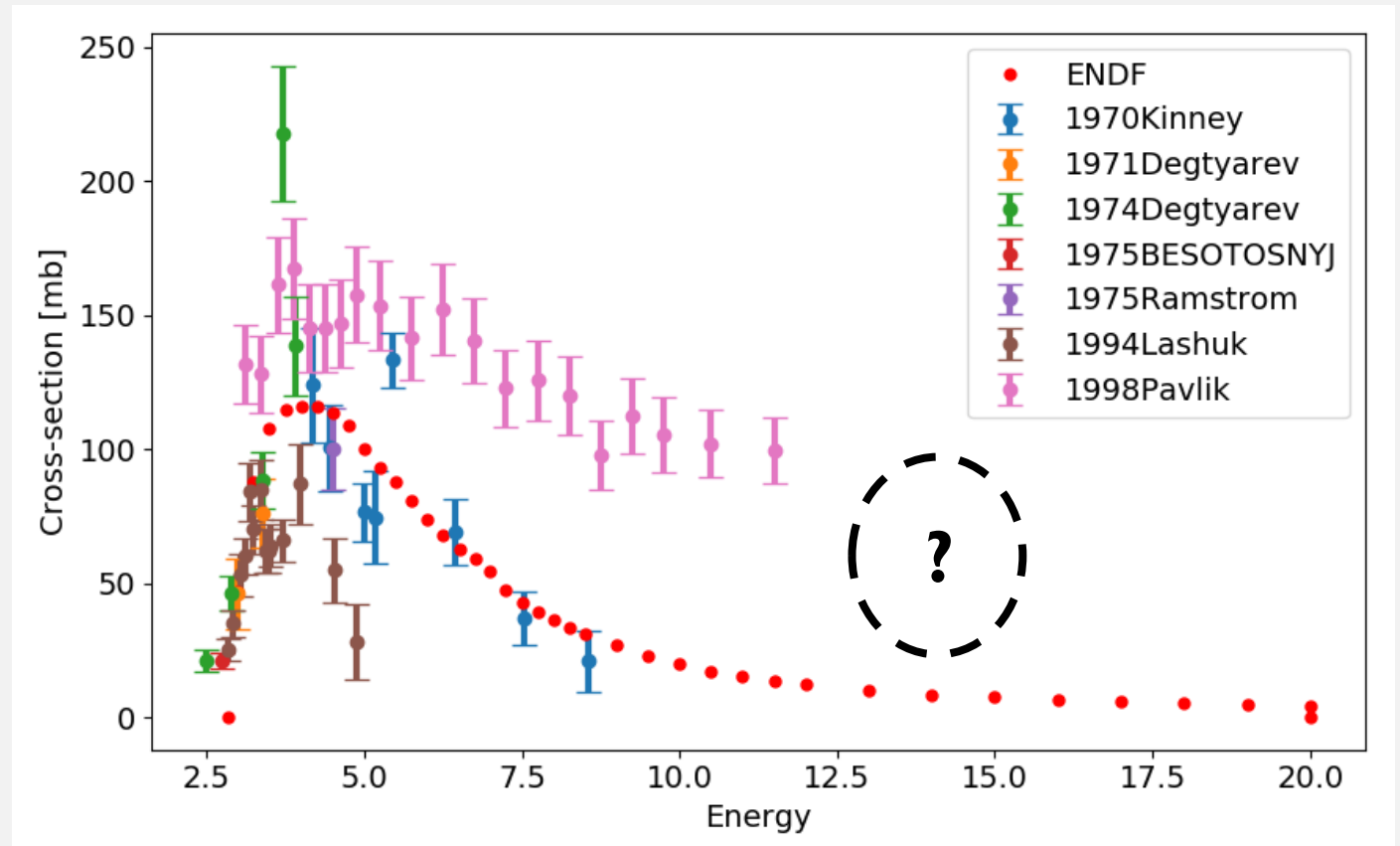
1. C-12 is an example of a **“well known”** cross-section at 14.1 MeV
2. Experiment suggest a **higher value** than both ENDF and measured for $n(^{16}_8\text{O}, n'\alpha)^{12}_6\text{C}$ (red circle)
3. Al-27 line at 1720 keV **underrepresented?** (yellow circle)



1720 KEV LINE OF AL-27 AS ANOTHER EXAMPLE OF MISSING DATA

Level 2734 keV emits the 1720 keV gamma

1. Post-1970 level and gamma data in EXFOR
2. Might indicate a trend of ENDF **underpredicting** this level
3. Current Al-27 cross section evaluation for fast region below 20 MeV was done in 1994 and **has not been revised since**



Special thanks to Amanda Lewis who looked into this isotope for me 😊

CONCLUSIONS

- API as a potential tool to measure 14.1 MeV neutron induced gamma-ray cross sections / gamma branches
- Important reaction cross section to be measured: $n(^{16}_8\text{O}, n'\alpha)^{12}_6\text{C}$ for earth and space applications
- Some O-16 lines not present in ENDF at the moment
- Al-27 cross section evaluation below 20 MeV can be updated (1994)

Some important isotopes for earth/space exploration:

Element	Isotopic abundance (%)	Main gamma energies (MeV)
Carbon	^{12}C : 98.9	4.439
Aluminum	^{27}Al : 100	0.844, 1.72, 2.21, 2.98
Oxygen	^{16}O : 99.76	2.74, 3.089, 3.68, 3.854, 4.439, 6.13
Iron	^{54}Fe : 5.85, ^{56}Fe : 91.75, ^{57}Fe : 2.12	0.847, 1.238, 1.81
Silicon	^{28}Si : 92.2, ^{29}Si : 4.7, ^{30}Si : 3.1	1.78, 2.838, 4.489

Table 5.1: Most common elements present in soil, their natural isotopic abundance (greater than 2%), and their main prompt non-elastic gamma-ray energies.

Mauricio Ayllon Unzueta, PhD Thesis, Spring 2020, UC Berkeley

Cross section data at 14.1 MeV of critical importance for many NASA missions: GRNS (asteroid Psyche), MEGANE (Mars and moon), DraGNS (Titan), etc.

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