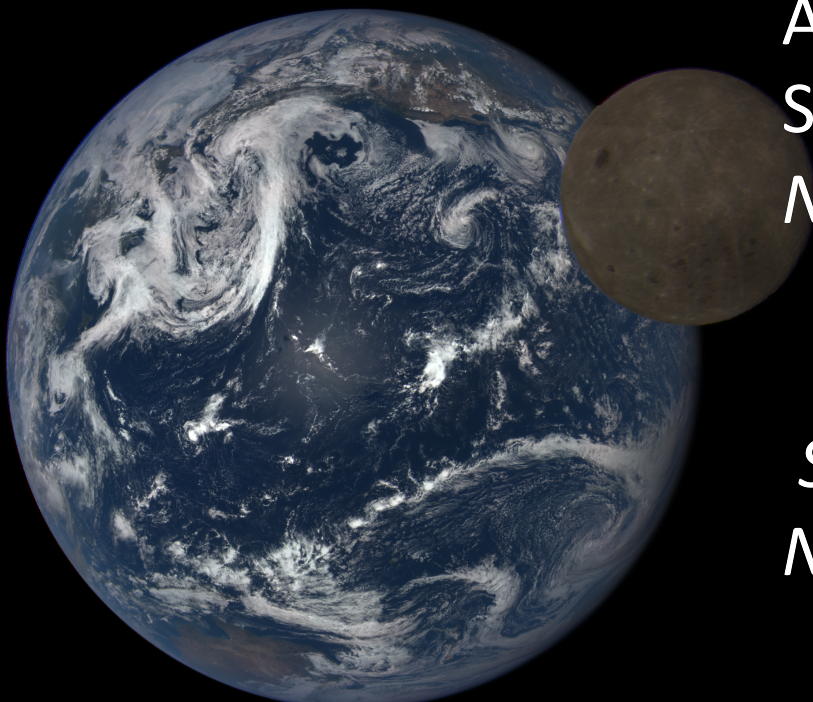
LEIA: Lunar Explorer Instrument for space biology Applications



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in collaboration with

SwRI
NASA AES RadWorks

Space Biosciences
NASA AMES RESEARCH CENTER

LEIA Objectives:

- Identify genetic factors impacting cellular response to lunar surface radiation and gravity

- Characterize the lunar surface radiation environment at a south pole landing site

LEIA Specific Aims

Aim 1. Combine yeast genetics with metabolic modeling to determine cellular sensitivity to the lunar environment.

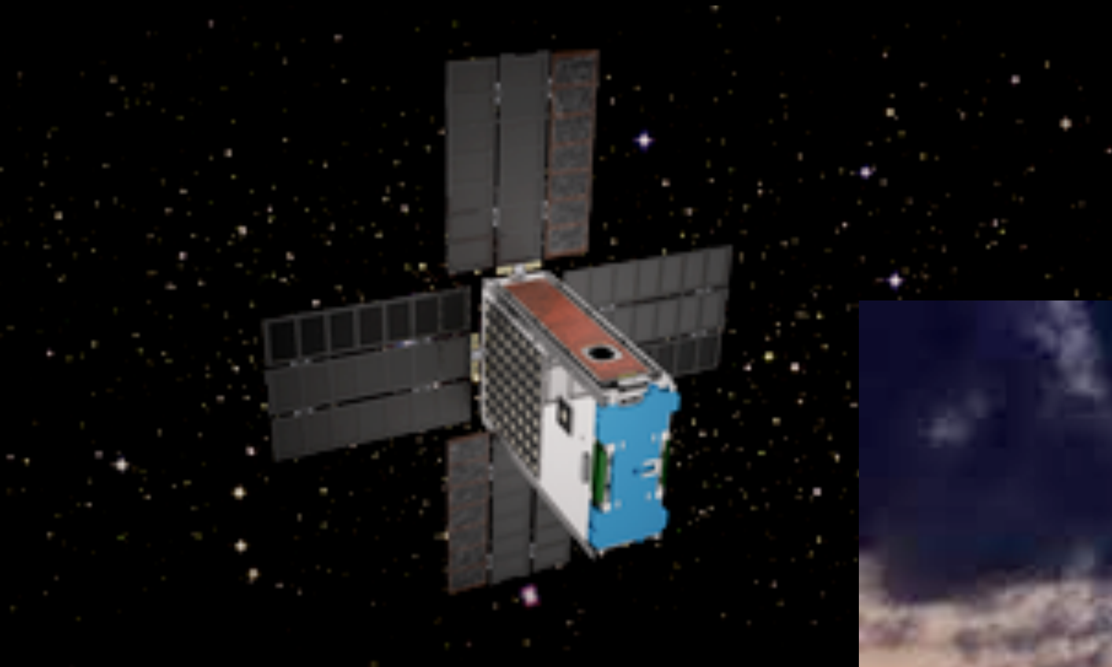
Aim 2. Evaluate synthetic biology-enabled production of antioxidant nutrients and proteins under lunar surface conditions.

Aim 3. Evaluate genetically engineered yeast for enhanced tolerance to the lunar environment.

Aim 4. Measure and characterize biologically relevant radiation on the lunar surface.

BioSentinel: a CubeSat for deep space biological investigation

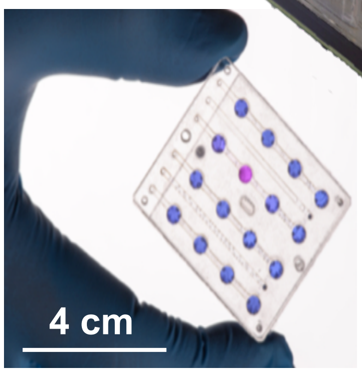
(https://www.nasa.gov/centers/ames/engineering/projects/biosentinel.html)



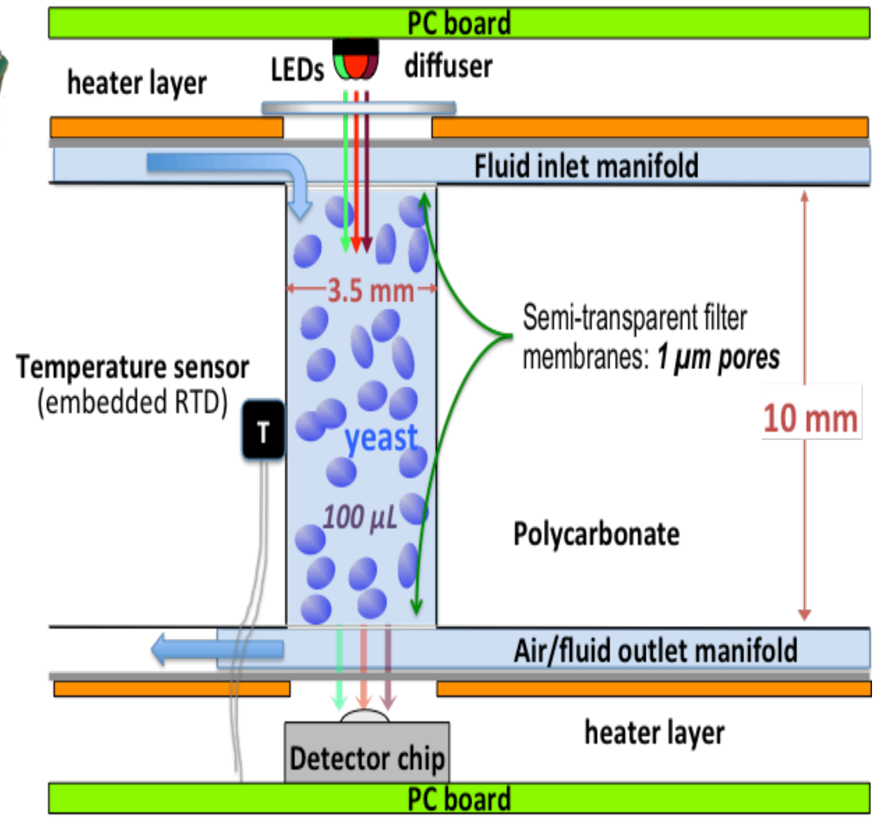
BioSentinel biological payload is housed in the BioSensor

4U BioSensor

Microfluidic Card



Individual Cell Culture Well



For LEIA:

- BioSensor will contain 16 microfluidic cards
- Each card has 16 culture wells (256 wells total)
- Pumps and valves control medium addition through 2 separate manifolds
- Each well can record light absorbance data at 3 LED wavelengths

BioSensor optical detection system

3-color optical system at each well tracks

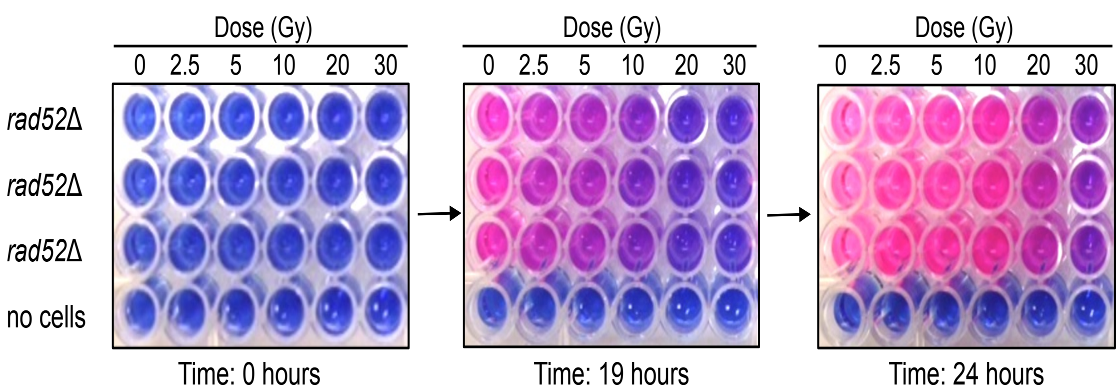
- cell growth *via* infrared optical density
- cell metabolic activity *via* alamarBlue dye color changes

<u>LEDs</u>:

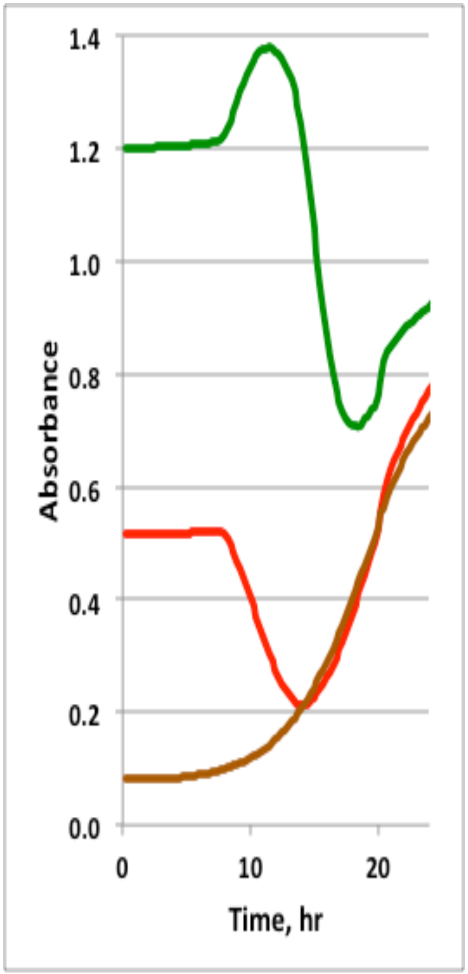
570 nm - green, measures pink alamarBlue

630 nm - red, measures blue alamarBlue

850 nm - infrared, measures cell growth



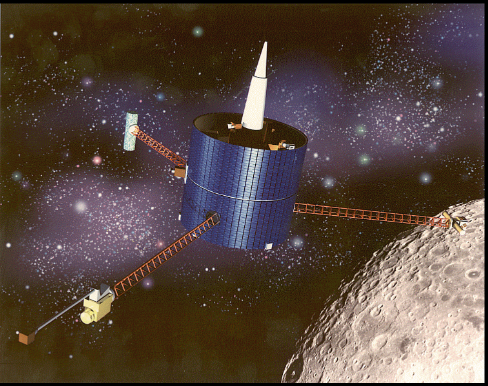
alamarBlue turns pink when cells are metabolically active



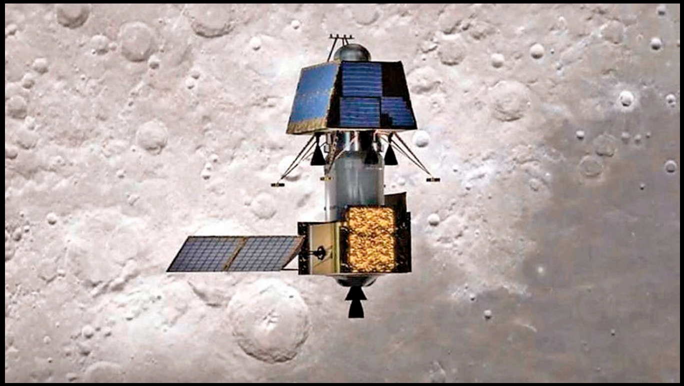
Yeast growth with flight-like optical unit

Expected outcomes

- Determine cellular sensitivity to the lunar environment.
- Test genetic strategies to enhance cellular tolerance to the lunar environment.
- Ground truth radiation measurements.

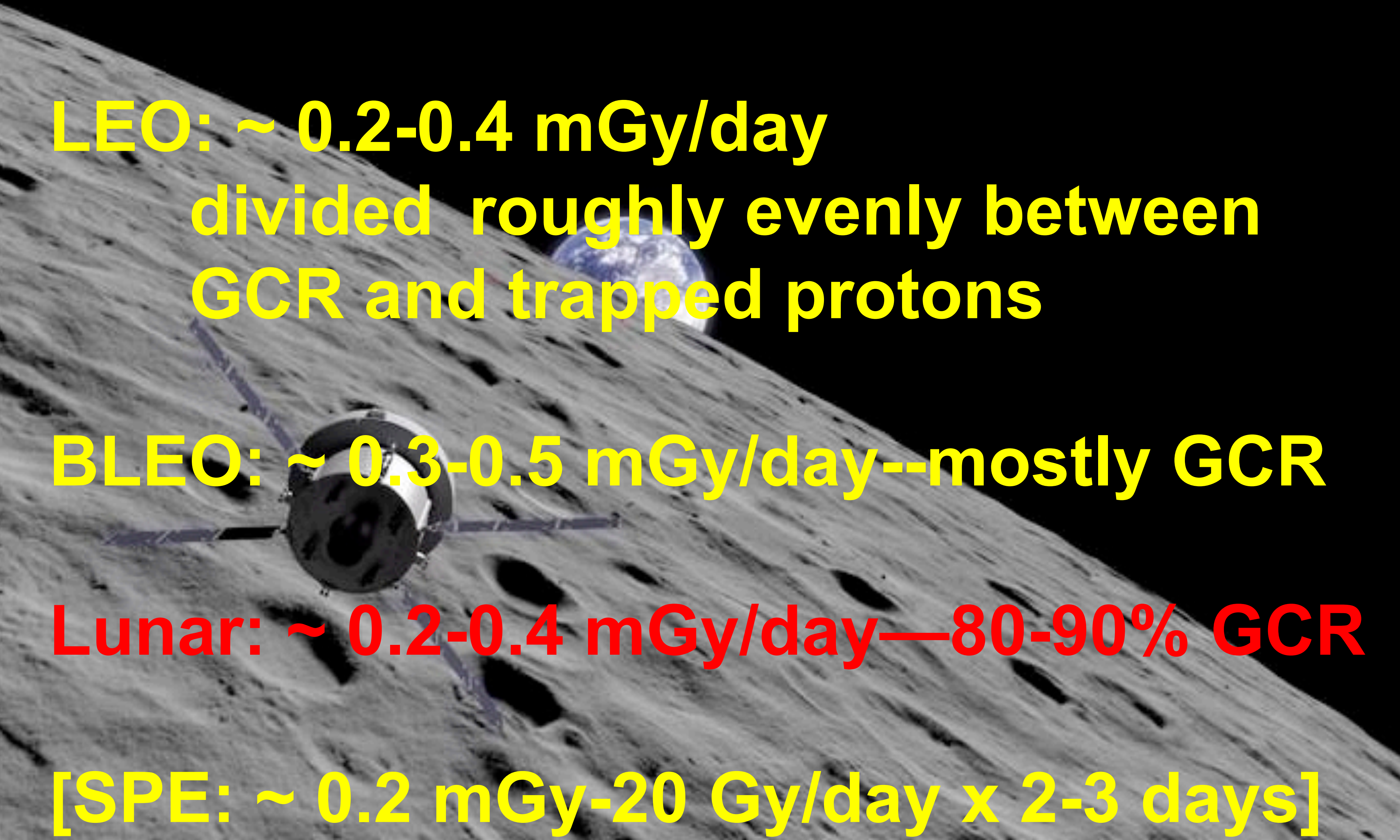


Lunar Radiation Environment



- GCR, SPE
- albedo particles (p, HZE, n)
- modulated by solar cycle, lunar shadowing, surface composition

Comparative doses



LEO: ~ 0.2-0.4 mGy/day
divided roughly evenly between GCR and trapped protons

BLEO: ~ 0.3-0.5 mGy/day--mostly GCR

Lunar: ~ 0.2-0.4 mGy/day—80-90% GCR

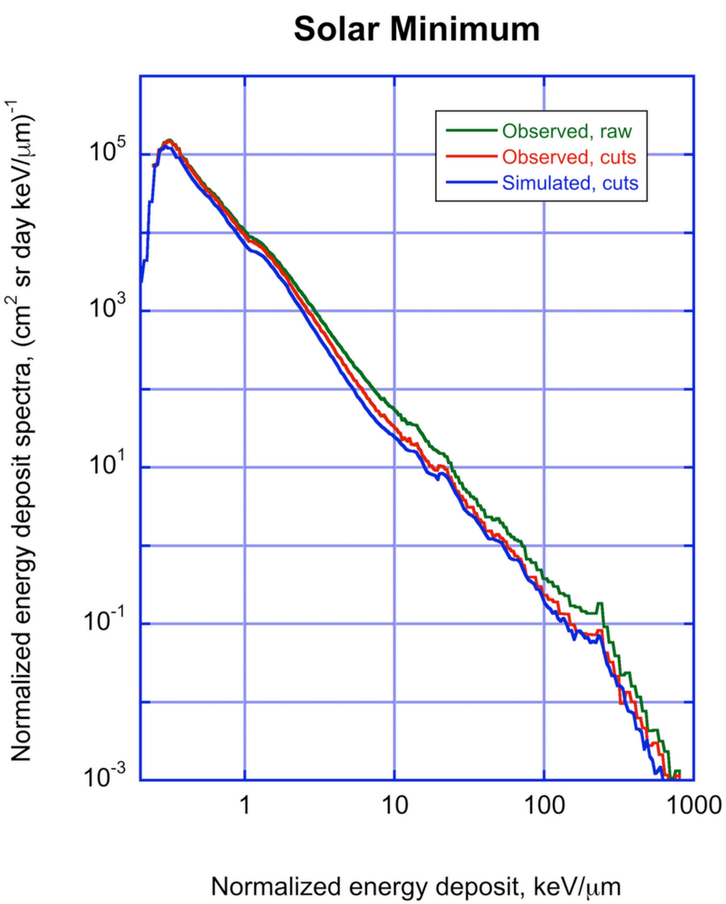
[SPE: ~ 0.2 mGy-20 Gy/day x 2-3 days]

LEIA Projected Doses

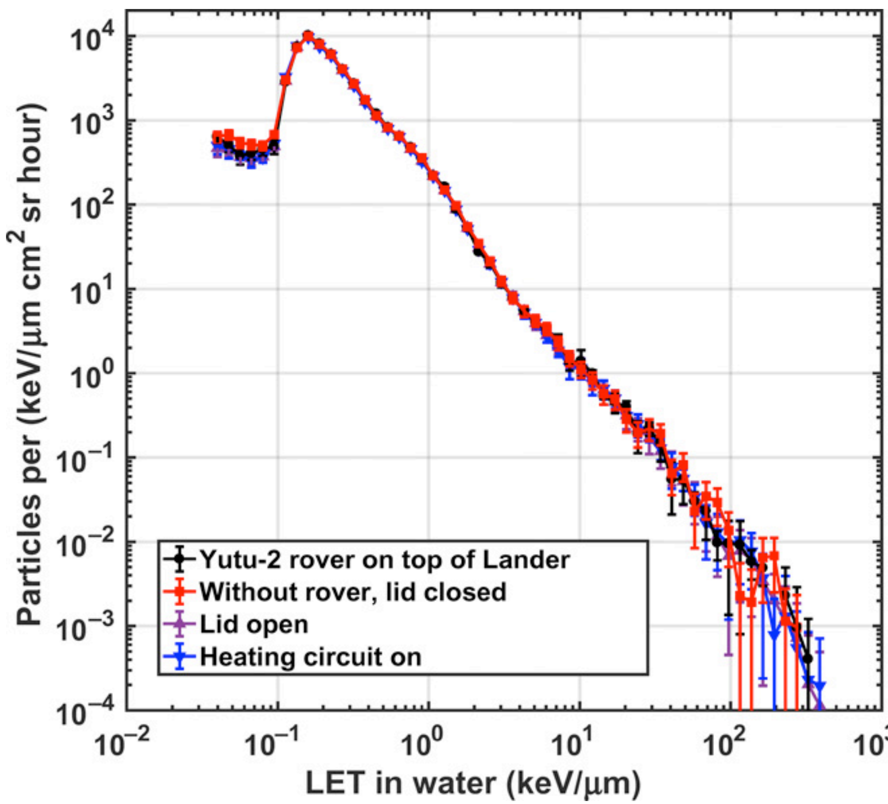
- **GCR + lunar albedo**
  - Lunar transit (including trapped belts)
    ~ 0.2 mGy /day
  - Lunar surface (GCR+albedo)
    ~3-6 mGy/*lunar* day
- **SPE**
  ~ 10 mGy/day

CRaTER (LRO)
(50 km)

LND (Chang'E 4)
(surface)



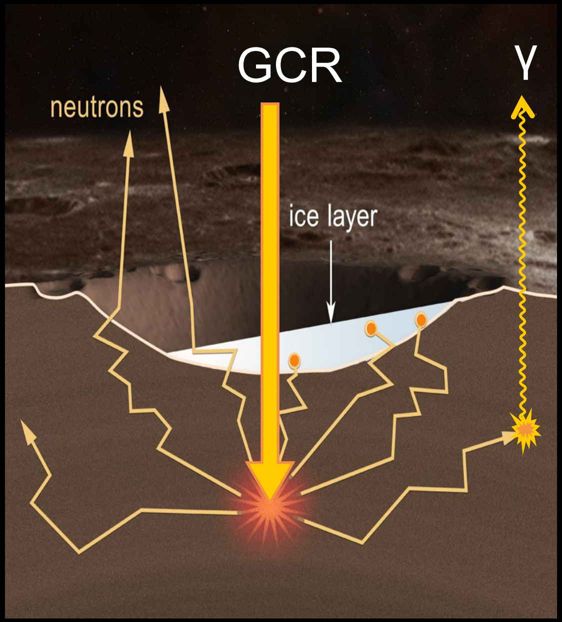
Looper *et al*. *Space Weather* **18(12)** (2020).



Zhang *et al., Sci. Adv.* **6** eaaz1334(2020)

Dose rate (charged particles in Si) (**01:30, 2/2/19**):
LND – **10.2(1.1) μGy/hr**; CRaTER – **10.0 μGy/hr**

Lunar surface radiation environment differs from deep space

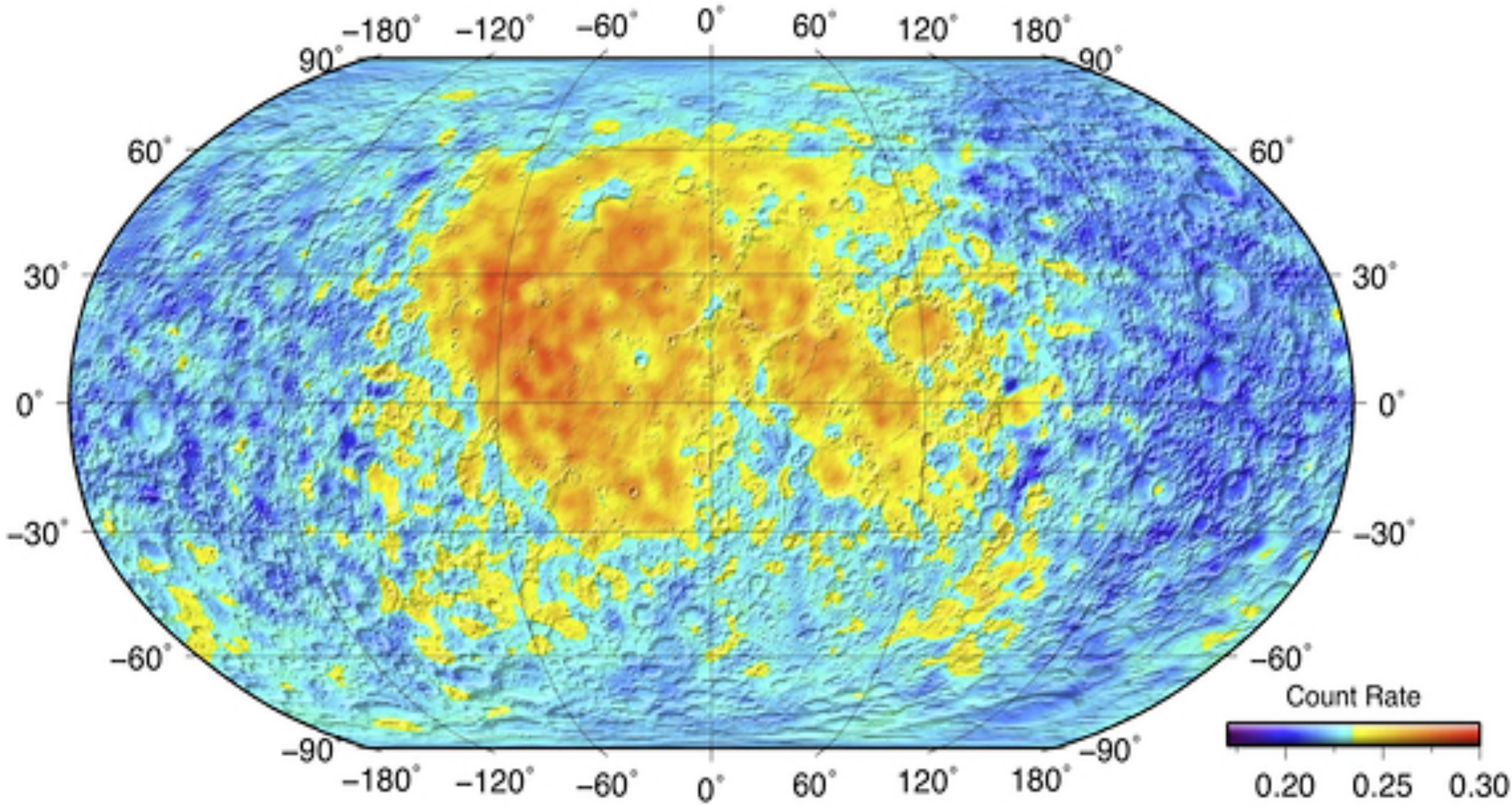


Interactions of GCR with lunar regolith produce secondary albedo neutrons

- Fast neutrons cause direct cellular damage
- Fast neutrons also produce ionizing radiation
- Estimates of surface neutron doses vary widely

LEND (LRO) Fast Neutron Flux

(Litvak, M. L., *et al., J. Geophys. Res*. **117,**E00H22 (2012))



Consistent with LP data (Maurice *et al., J. Geophys. Res.,* **105** 20 365 (2000))
Fe-rich mare soils produce more fast neutrons than Al-rich highland soils)

CRaTER (LRO) – 50 km

(Spence *et al.*, *Space Weather* **11**, 643–650 (2013))

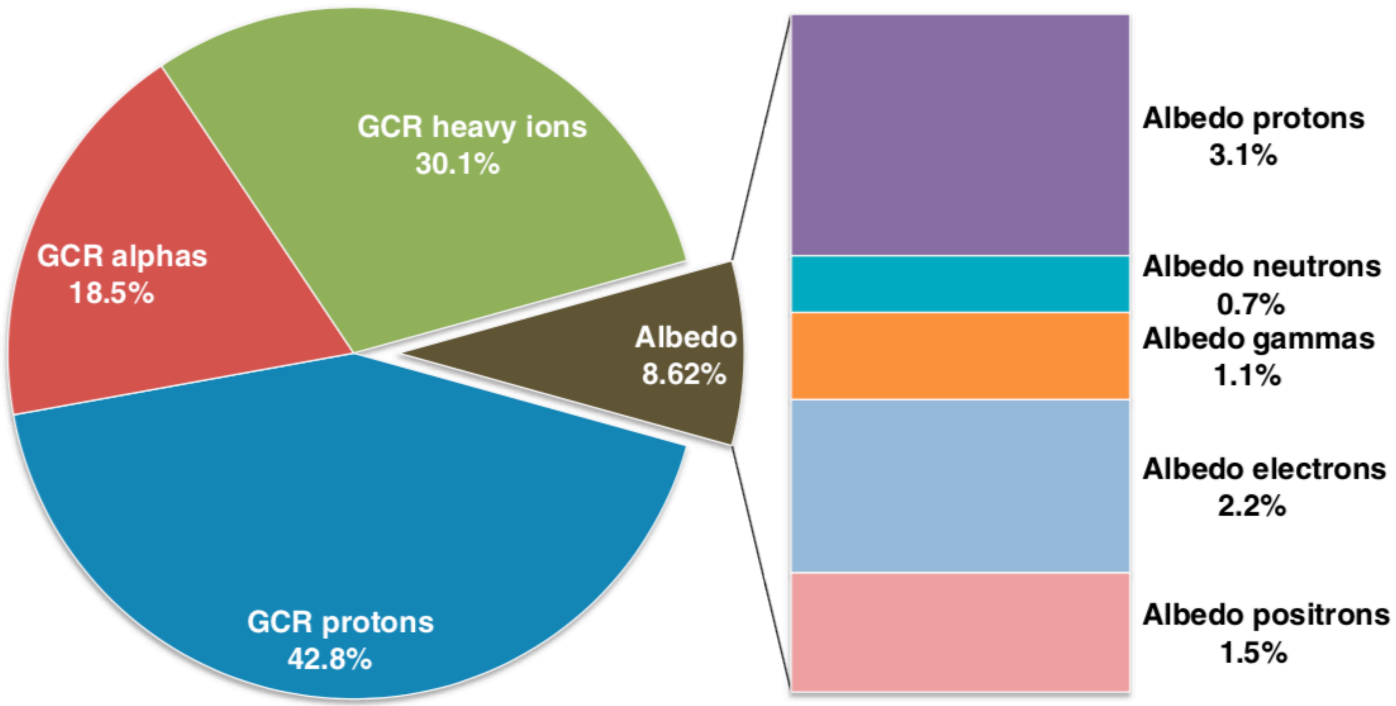


Figure 4. Relative percentage contribution of primary GCR and albedo species to the total absorbed dose rate (and dose) at LRO altitudes derived from the Looper et al. Geant4-derived and validated model.

Lunar surface radiation is primarily extrapolated from lunar orbiter data.

There is as yet no consensus for the fast neutron contribution to total dose.

Mission	Instrument	Dose Type	% Fast Neutron
Chandrayaan-1	RADOM	Effective	2-20%
Lunar Prospector	LP	Effective	16-18%
LRO	CRaTER	Absorbed	0.7%
Chang'E 4	LND	Absorbed	23%

Direct measurement of charged particles and fast neutrons will provide ground truth data at a south polar landing site.

Biological Effectiveness

Radiation type and energy range	Radiation weighting factor, w_R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons, energy <10 keV	5
Neutrons, energy 10–100 keV	10
Neutrons, energy > 100 keV–2 MeV	20
Neutrons, energy > 2–20 MeV	10
Neutrons, energy > 20 MeV	5
Protons, other than recoil protons, energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Motivation for LEIA radiation measurements:

- Most lunar radiation data to date are from orbiters; limited surface data from Apollo and Chang'E 4.

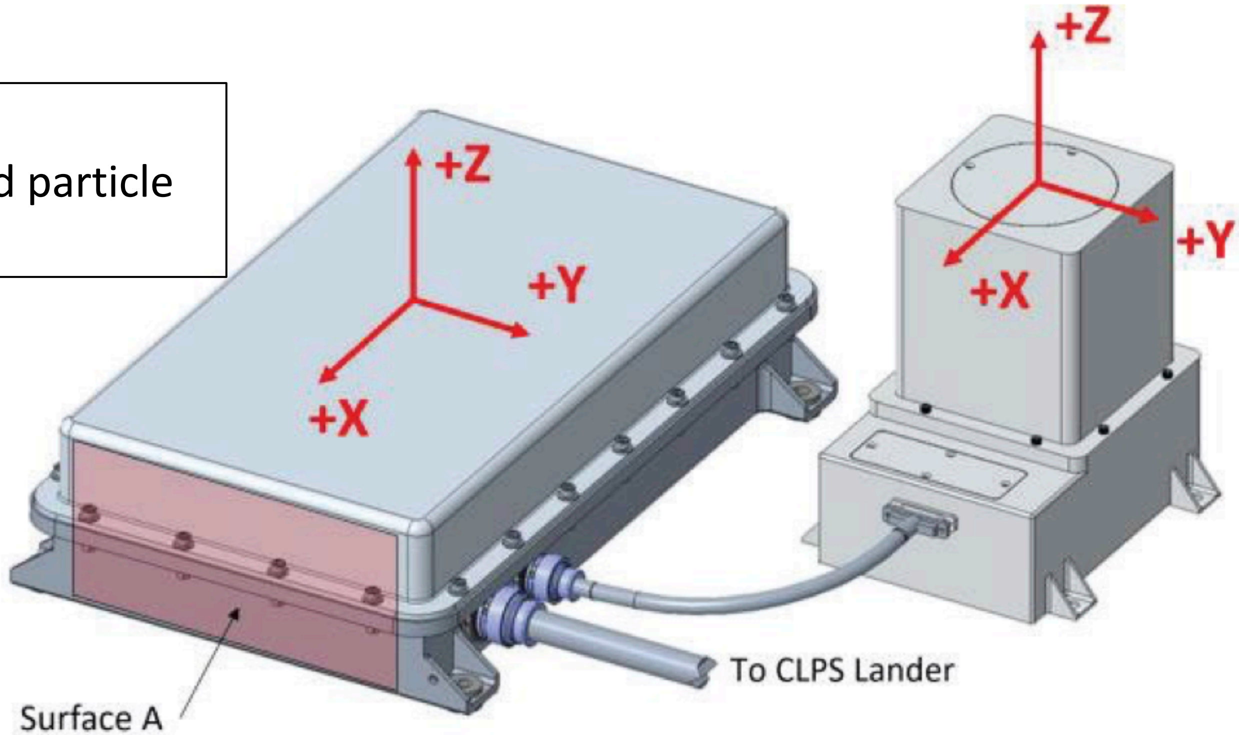
- Surface radiation measurements depend on instrument sensitivity, surrounding spacecraft structures, solar cycle, surface location and biological weighting (which in turn depends on organism and endpoint).

- **The ambiguities and uncertainties introduced by these factors can be reduced by measurements, *specific to each lander*, of the time resolved charged particle and fast neutron energy spectra and the absorbed dose *(i.e*. the unweighted energy deposition per unit mass)**.

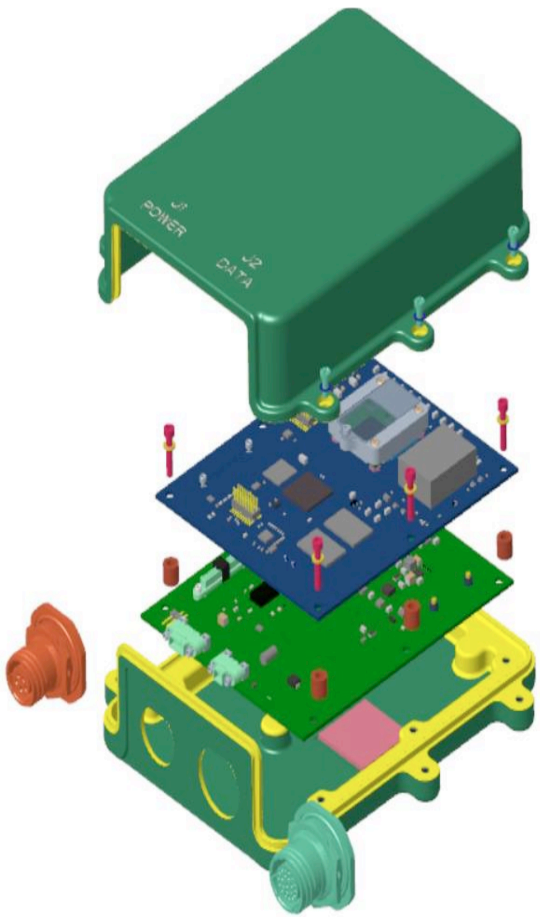
LEIA Payload

Mini-FND fast neutron detector

Biosensor;
ARES charged particle detector

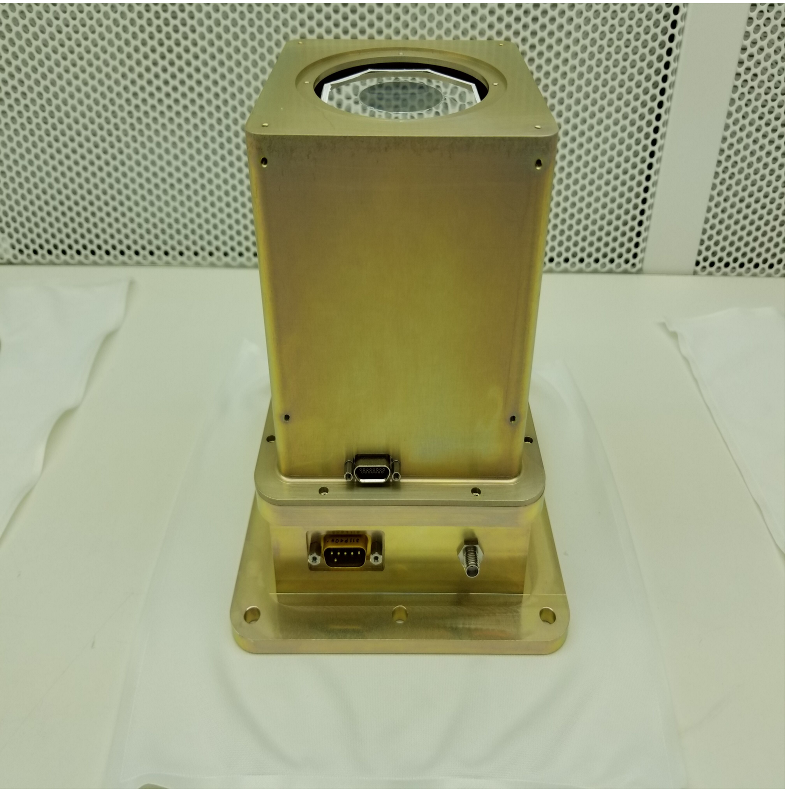


ARES (protons, GCR heavy ions)



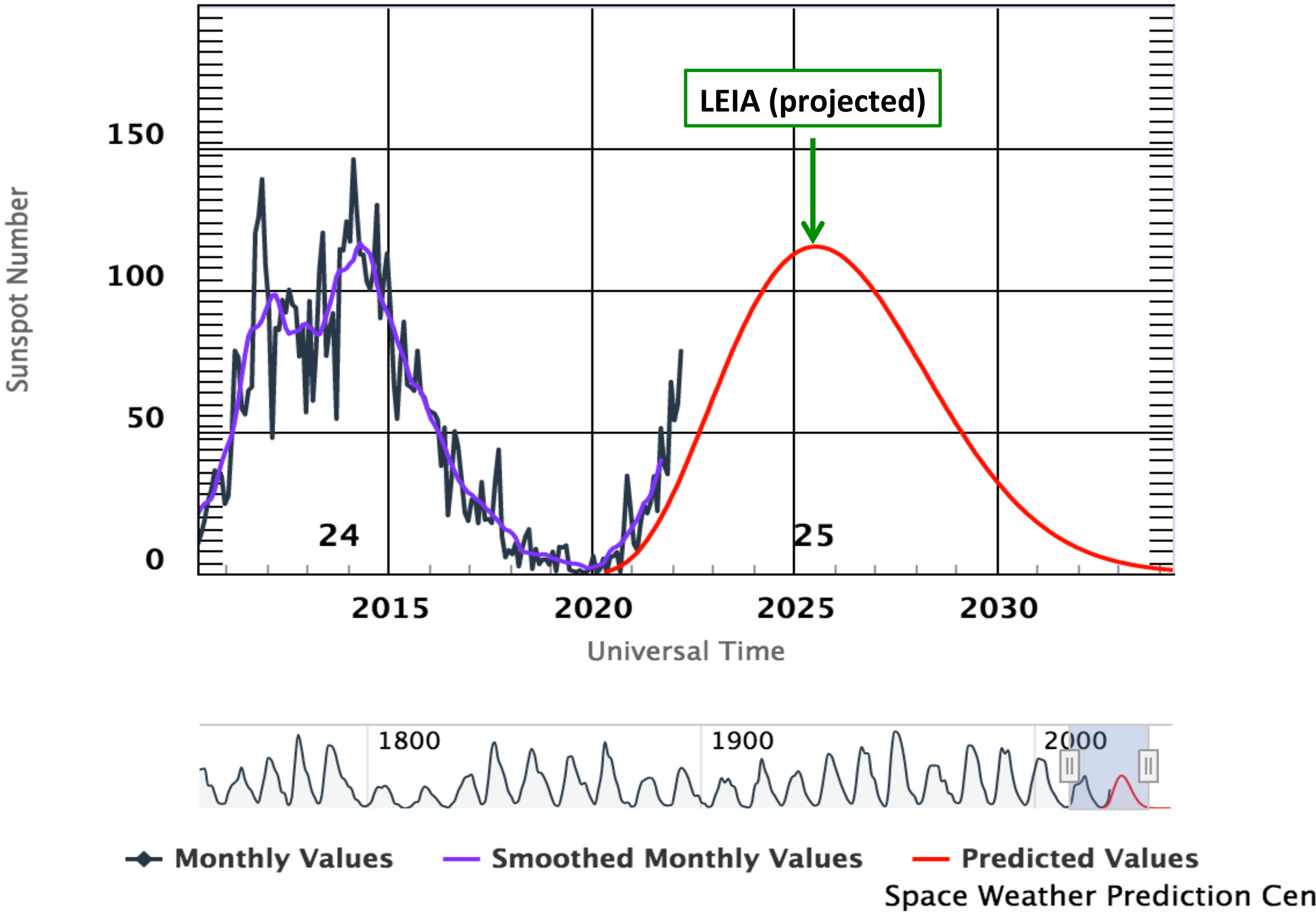
- Developed by AES RadWorks for lunar missions including Artemis
- “Timepix” silicon detector technology currently in use on ISS and BioSentinel
- dose, dose rate, LET spectrum
- Range in particle charge and energy covers biologically-significant components of lunar surface radiation field
- 155 gm; 13 x 10 x 3.8 cm;   <2.5 w

Mini-FND (fast neutrons)



- Designed by Southwest Research Institute (SwRI)
- Miniaturized version of the ISS/RAD FND currently operating on ISS.
- Neutron energy, dose, dose equivalent
- Neutron energy range: 0.5 to 10 MeV
- 1.3 kg
- 1650 cm^3 (10.5 x 10.5 x 15.0 cm)
- 5.1 w

SC 25 Prediction



- Payload radiation exposure is modulated by solar cycle, location on the lunar surface, spacecraft structure

- Measurements vary depending on a number of factors, including instrument sensitivity, shielding by spacecraft materials and, for biological effects, how the data are weighted

- Ideally, want measurements specific to each payload of the time resolved charged particle and fast neutron energy spectra and the absorbed dose (*i.e.* the unweighted energy deposition per unit mass)

- In practice, can use a combination of existing orbiter and lander radiation data, knowledge of the landing site, detailed descriptions of the spacecraft shielding distribution, and radiation transport models to estimate the radiation dose to the payload with relatively low uncertainty

Questions?