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Title: The Search for Water on Planetary Bodies using Neutron Science

Author(s): Shin, Tony Heong Shick

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The Search for Water on Planetary Bodies using Neutron Science

Tony H. Shin, Ph.D
Scientist
Intelligence and Space Research Division
Space Science and Applications (ISR-1)

Undergraduate Seminar
University of Illinois Urbana-Champaign
Nuclear, Plasma & Radiological Engineering
03/08/2022

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My path to where I am now

Born in Seoul, South Korea

Grew up in Northwest Suburbs of Chicago (Barrington, IL)

University of Michigan – Ann Arbor,
Department of Nuclear Engineering & Radiological Sciences

- B.S.E 2014, M.S.E 2015, Ph.D 2019
- Detection for Nuclear Nonproliferation Group (DNNG)
- Thesis: Fast-neutron multiplicity counting for nuclear safeguards applications

Los Alamos National Laboratory, Space Science and Applications (ISR-1)

- Director's Postdoctoral Fellow 2019-2021
- Entrepreneurship Postdoctoral Fellow 2020-2021
- Staff Scientist 2021-Present

BARRINGTON
HIGH SCHOOL

UNIVERSITY OF
MICHIGAN

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A few projects I’ve worked on…

At University of Michigan:

Organic scintillator characterization for fast-neutron detection

Fast-neutron multiplicity counting for safeguards applications

Time-interval analysis of subcritical systems

At Los Alamos National Laboratory:

Smart mobile sensor platform for radiation contamination

Neutron spectroscopy for nuclear emergency response

High-fidelity atmospheric radiation transport

Data fusion algorithm development for Space Nuclear Detonation Detection (SNDD)

Edge intelligence for homeland security applications

Search for water content on planetary bodies

In 2014, I got my Bachelor’s Degree… what now?

Get a job? Graduate School?

I choose graduate school (obviously) because I really enjoyed conducting research

However, there are many options outside of graduate school at LANL!

Think about what *you* really want to do

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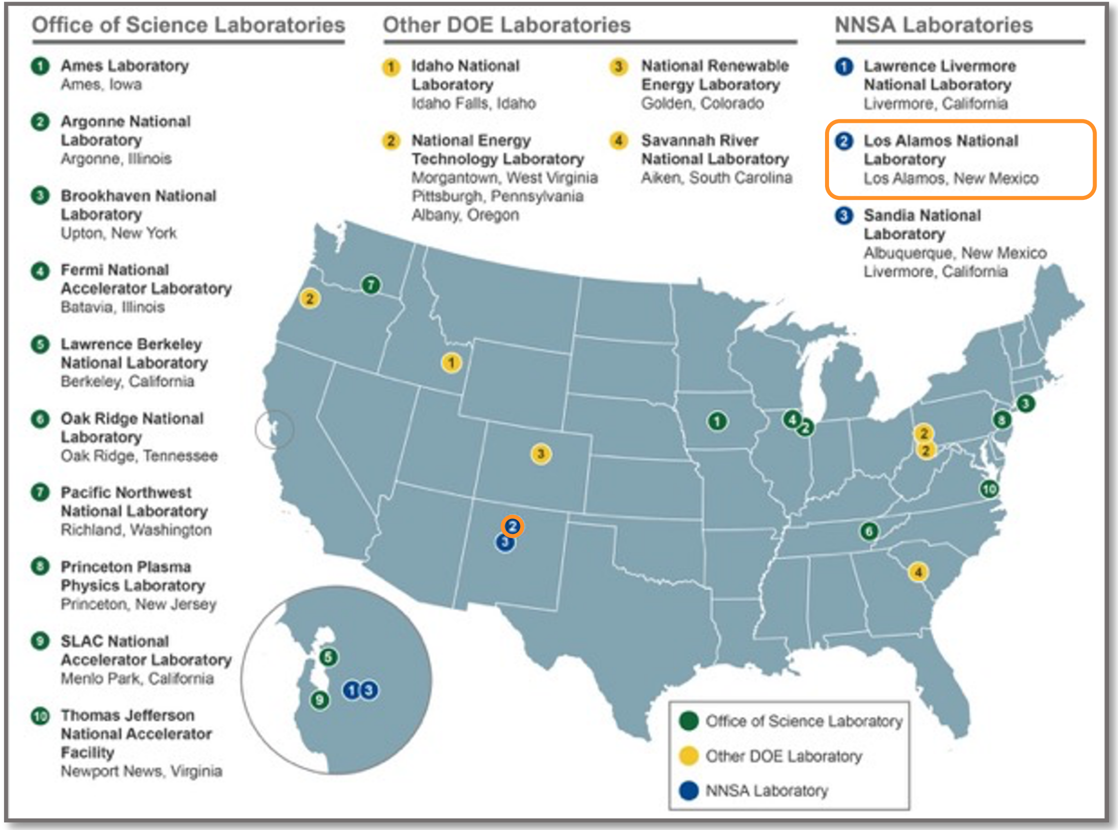
DOE Laboratory in NNSA Enterprise



Kansas City Plant

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

Nevada National Security Site

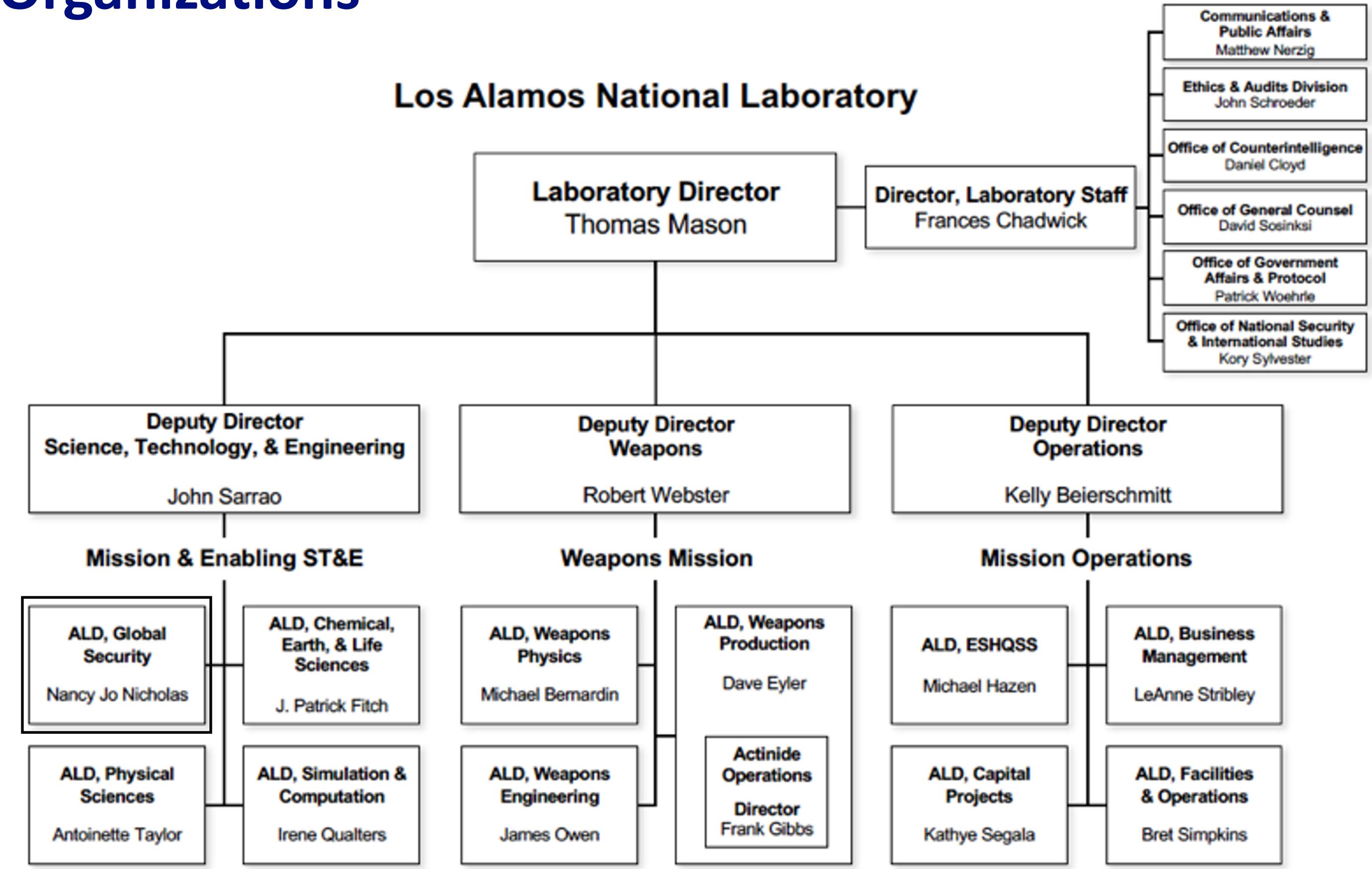
Pantex Plant
Z

Sandia National Laboratories

Savannah River Site

Y-12 National Security Complex

LANL Organizations



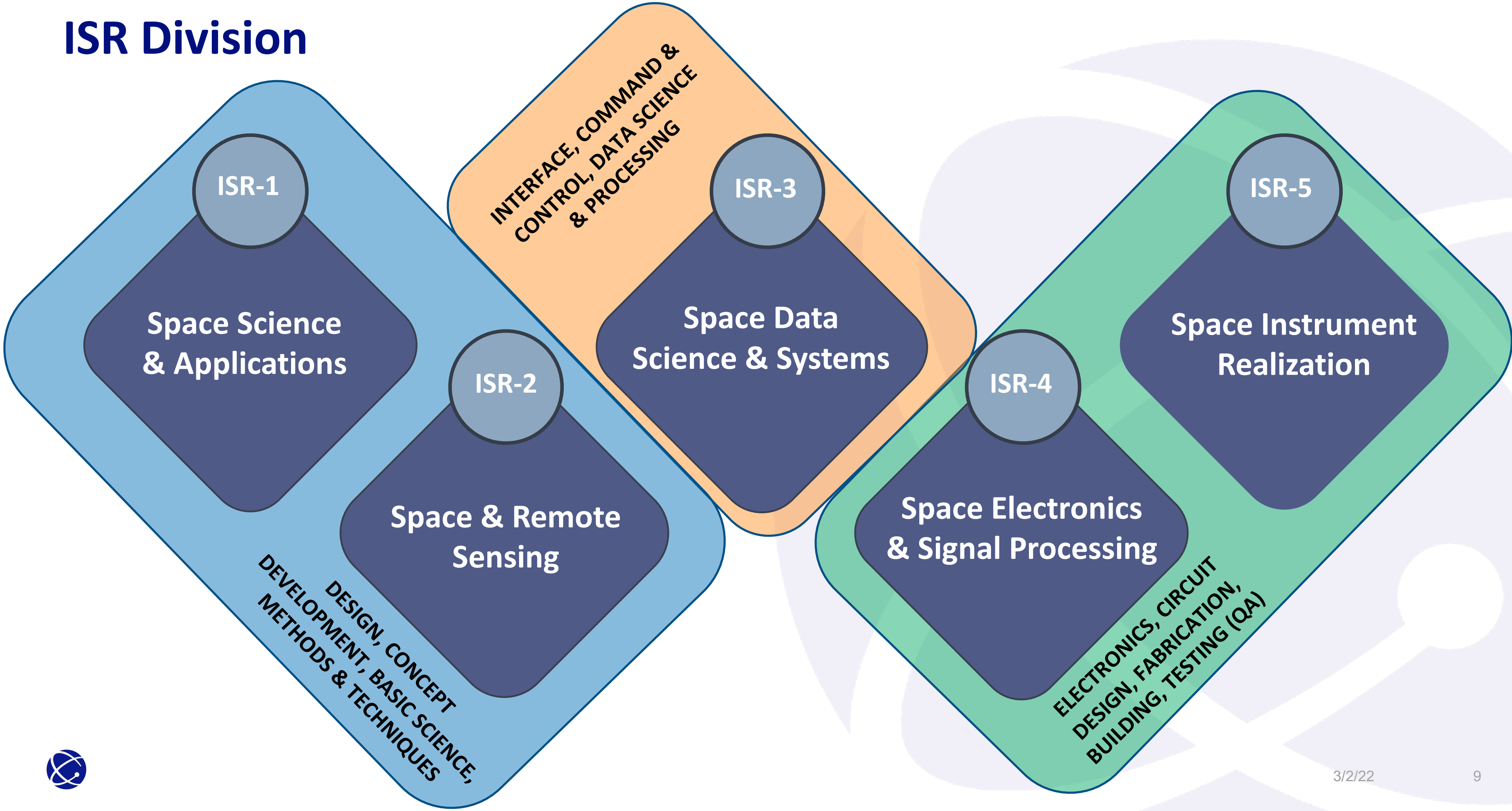
ISR

Intelligence and Space Research

Los Alamos National Laboratory

From Space, In the Air, On the Ground

ISR Division



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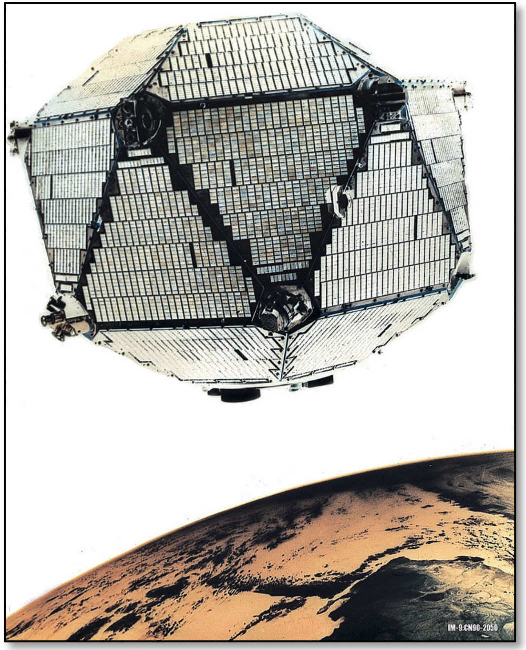
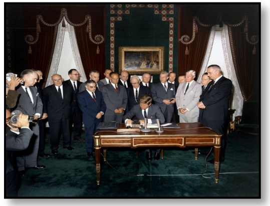
How does a lab that does this?



Get involved in this?

50+ Years of Treaty Verification

Limited Test Ban Treaty



1963

Outer Space Treaty

1967

Nuclear Nonproliferation Treaty

1968

Threshold Test Ban Treaty

1974

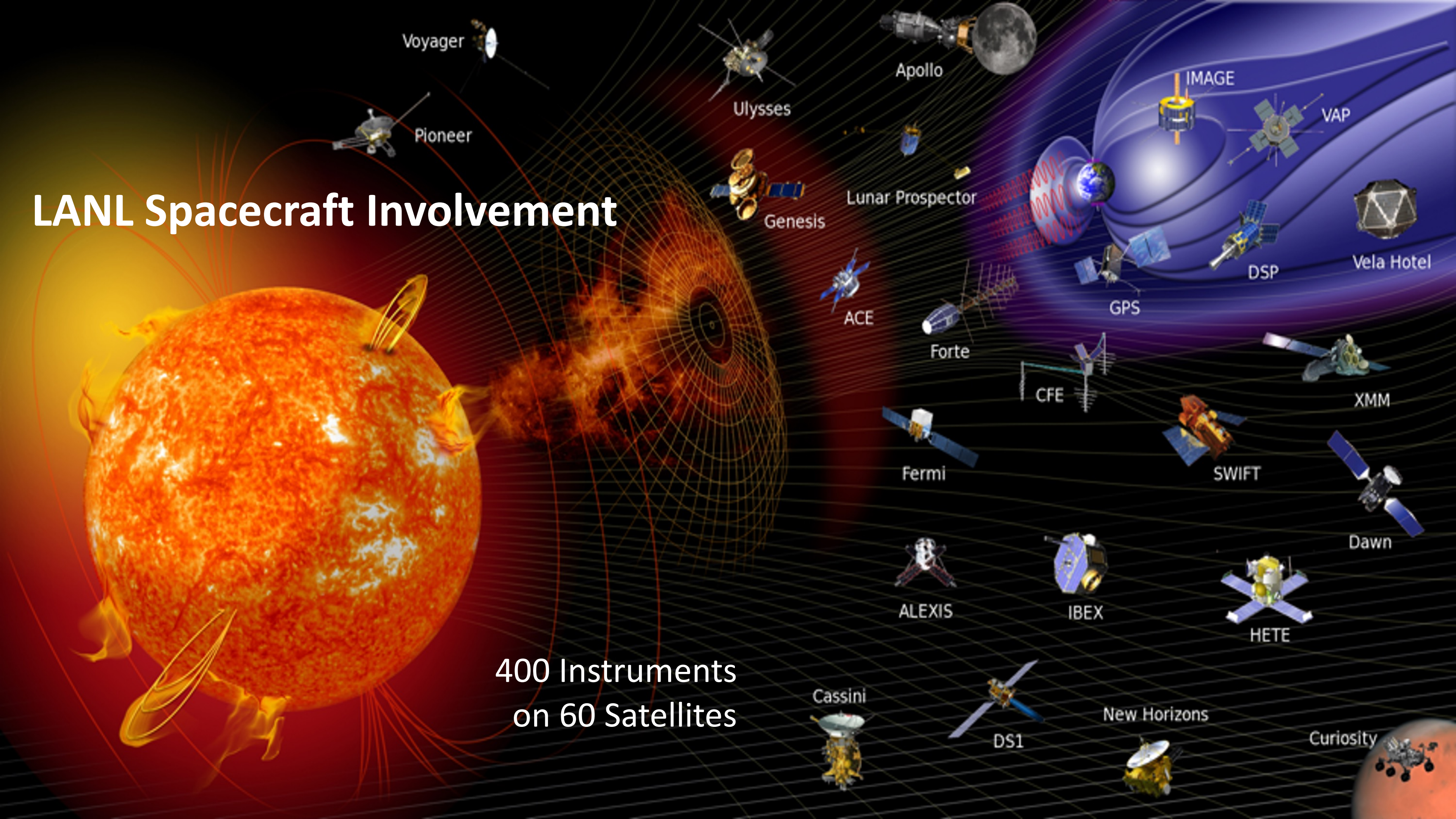
1990

Peaceful Nuclear Explosions Treaty

Comprehensive Test Ban Treaty

1996

LANL Spacecraft Involvement



400 Instruments
on 60 Satellites

Nuclear engineering applies to space science!

Radiation is everywhere in space!

We leverage our expertise in:

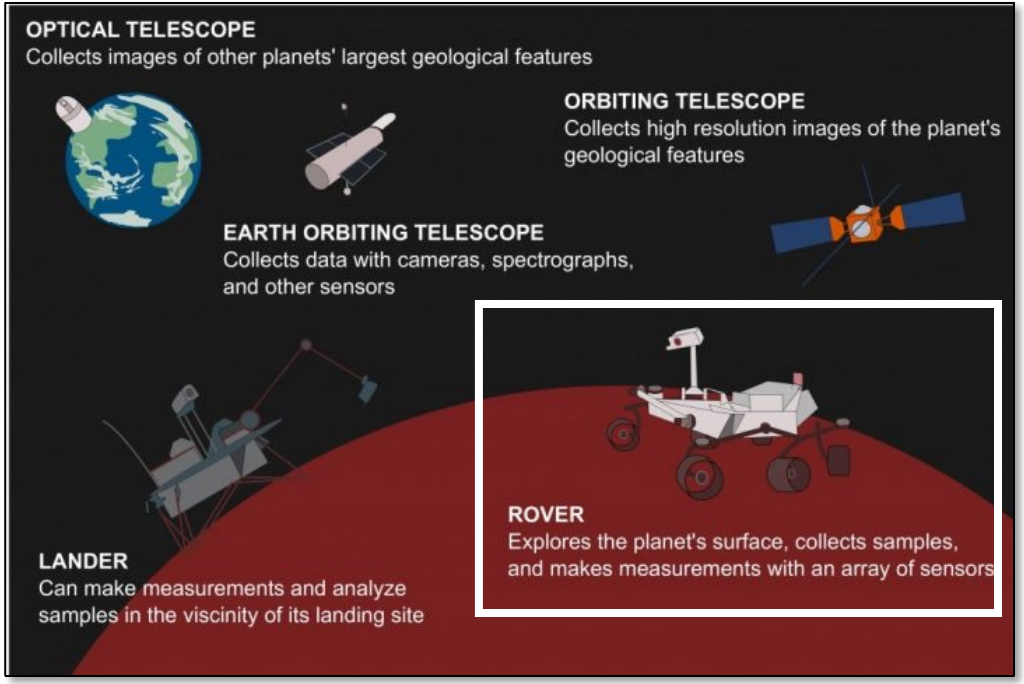
1. Radiation detection (neutron, gamma ray, charged particles, plasma, x-ray)
2. Modeling and simulations (MCNP and Geant)
3. Data analysis (statistical analysis, anomaly detection, performance assurance)

Allows us to apply nuclear science to solve unique problems

The search for water on planetary bodies

Water is **essential** to the formation of all known life, and is a primary driver for exploration of the solar system

LANL has a rich history of developing radiation detection systems for Mars exploration missions (Odyssey, Curiosity, and Perseverance)



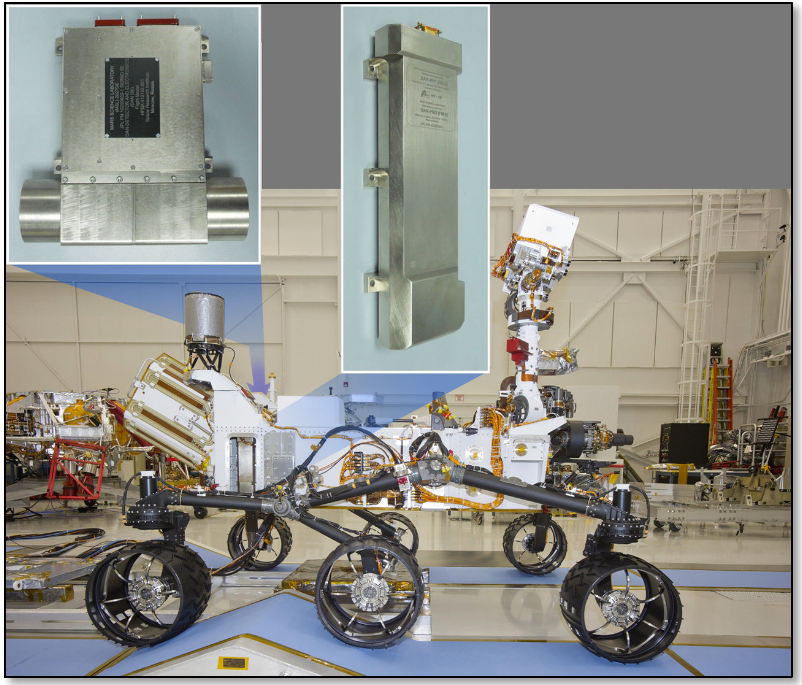
https://sitn.hms.harvard.edu/flash/2019/water-beyond-earth-the-search-for-the-life-sustaining-liquid/

How do we measure water content?

Neutrons can be used to quantitatively characterize absorbed water and hydrated materials

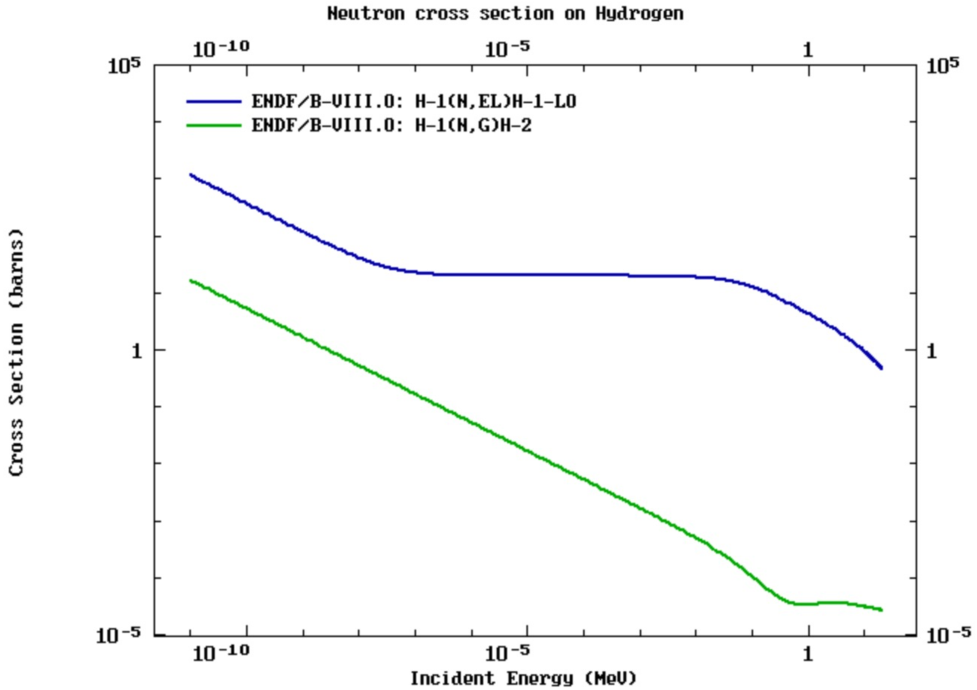
The Dynamic Albedo of Neutron (DAN) instrument is an example of a system that leverages neutrons for this purpose

Consists of a DT pulsed neutron generator, and a a pair of ^{3}He proportional counters



https://mars.nasa.gov/msl/spacecraft/instruments/dan/for-scientists/

Basics of neutron physics: looking at neutron cross section on hydrogen

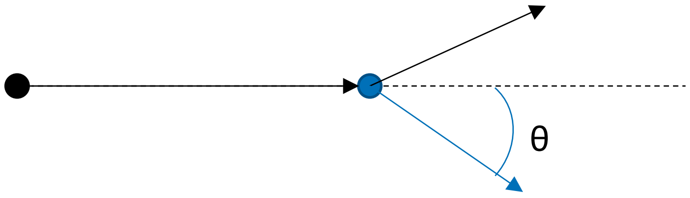


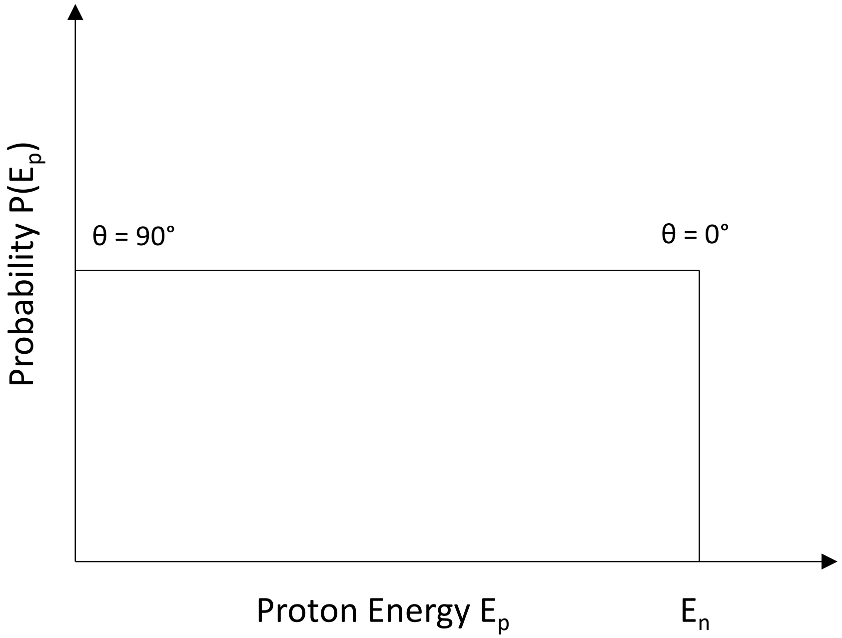
Primarily elastic scattering with some contribution from radiative capture, particularly at lower neutron energies

What happens when a neutron interacts with hydrogen?

Neutron elastic scatters on hydrogen

Neutrons have the same mass as hydrogen (i.e., a proton)





Therefore, a neutron can deposit up to ALL of its initial energy in a single elastic scatter on a proton

Hydrogen is great at "slowing down" neutrons due to this behavior

Neutron radiative capture on hydrogen

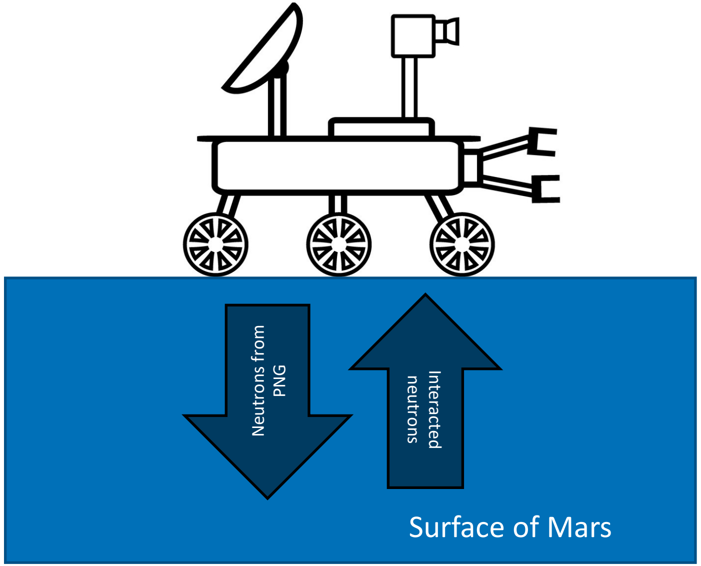
Neutron is completely absorbed by a nucleus

$$^{1}H(n,\gamma)^{2}H \qquad Q = 2.2\ \text{MeV} \qquad E_\gamma = 2.2\ \text{MeV}$$

A 2.2 MeV gamma ray is emitted for neutron captures on hydrogen

Typically occurs only at lower neutron energies (thermal range)

From physics to implementation: DAN instrument



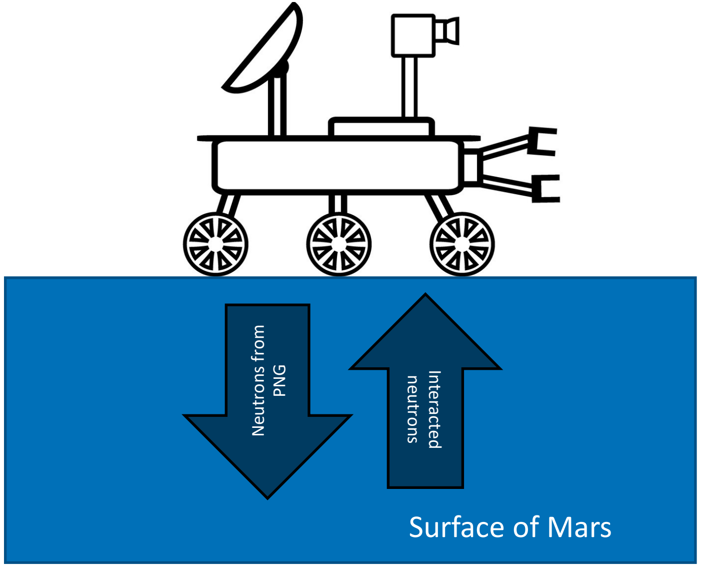
Pulsed neutron generator (PNG) produces 14.1 MeV neutrons

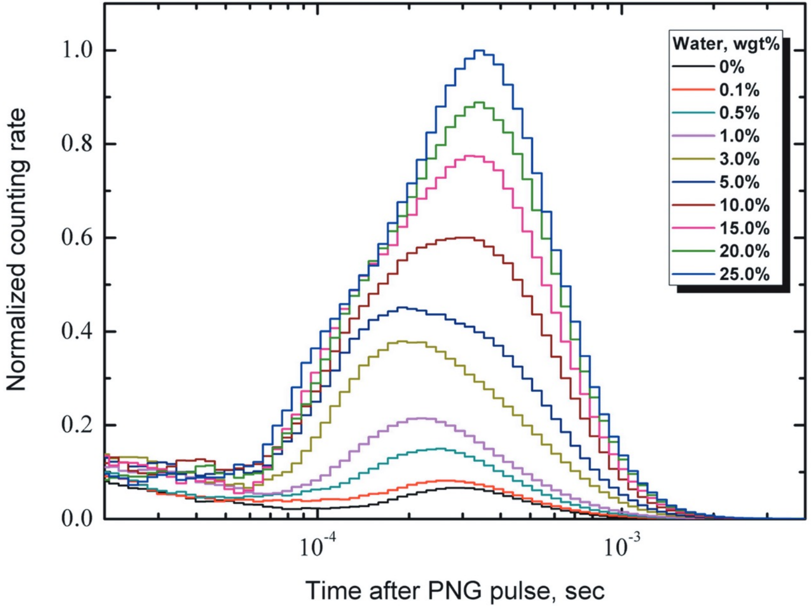
Neutrons interact with sub-surface hydrogen

We can analyze the time behavior of interacted neutrons relative to the PNG start signal

Time behavior should be directly tied to hydrogen content

From physics to implementation: DAN instrument





Future systems: Dragonfly Mission

Future systems: DragGNS instrument

Dragonfly Gamma-ray and Neutron Spectrometer (DraGNS) instrument currently under development, and will include:

1. Pulse neutron generator
2. Two high-purity Ge (HPGe) gamma-ray detector
3. Two ^{3}He neutron detectors (thermal and epithermal)

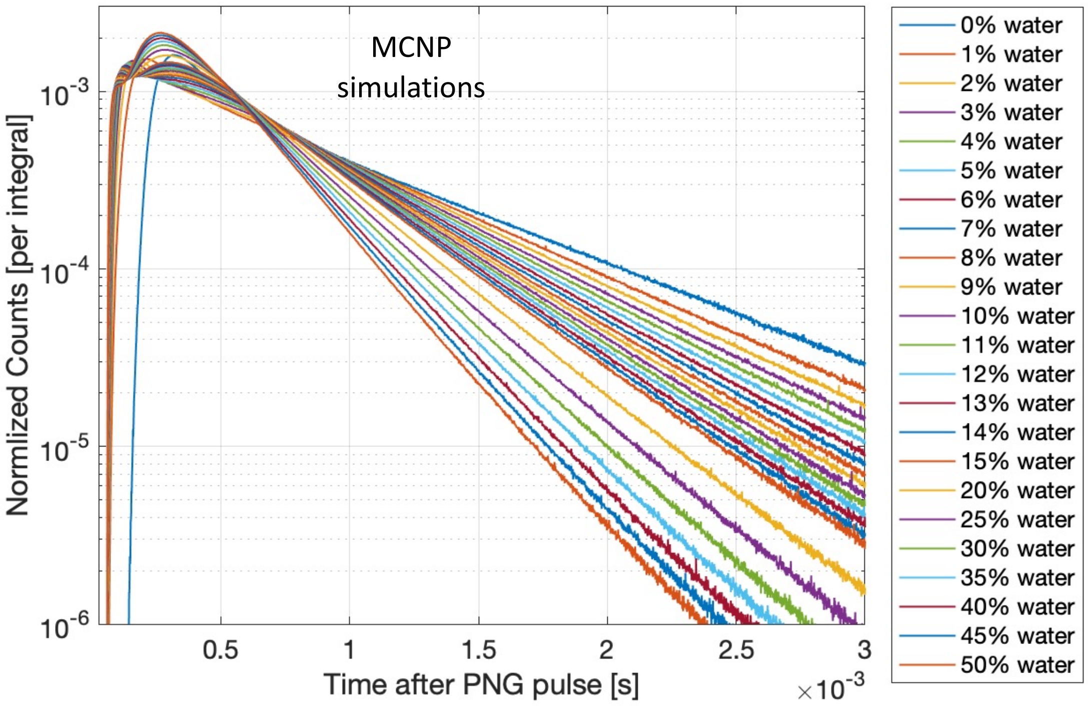
Future systems: DragGNS instrument

A major challenge: depending on the orbital positioning of Titan, there can be significant latency (70-90 mins) with direct line of sight and no means of communications (eight Earth days) without direct line of sight

Can we introduce autonomous rover controls to mitigate lost time, providing a more fruitful mission outcome?

What advantages come from having more than one rover?

Data interpretation, how do we correlate what we see to water content?



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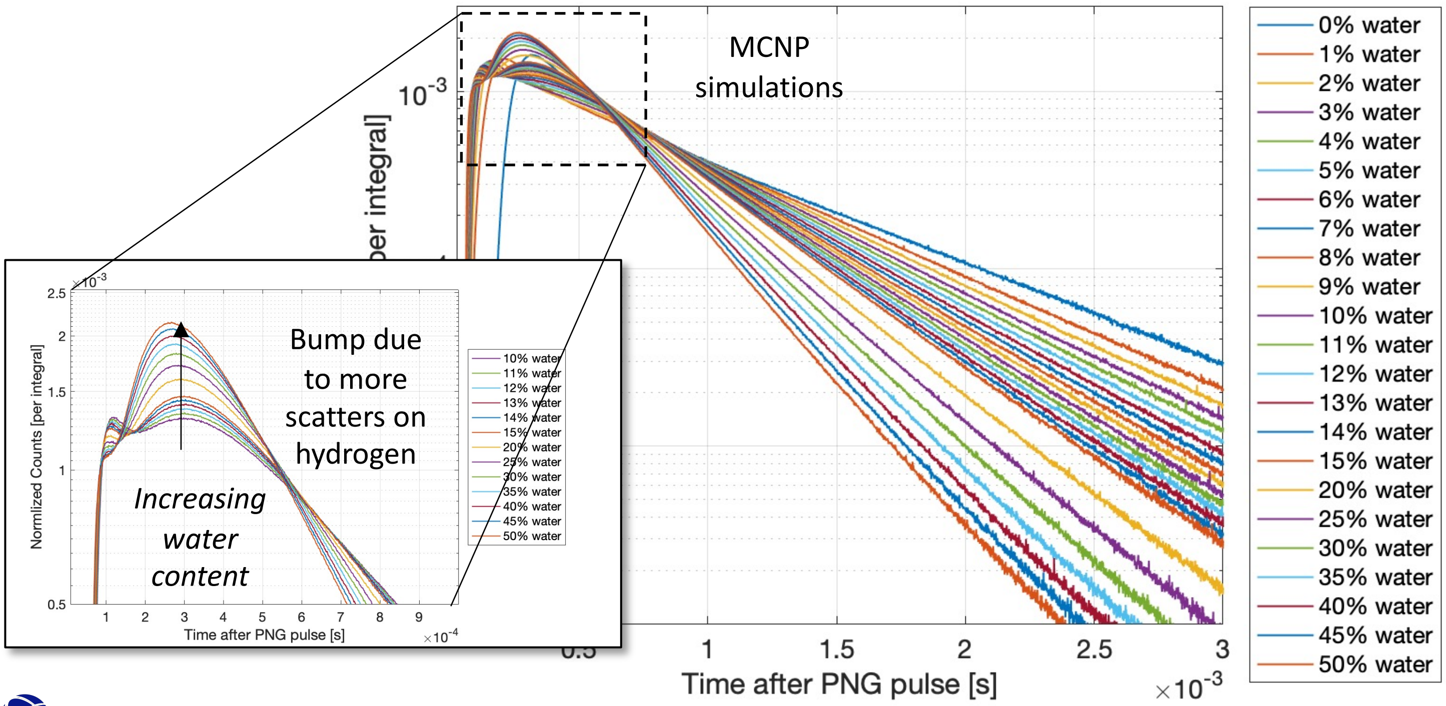

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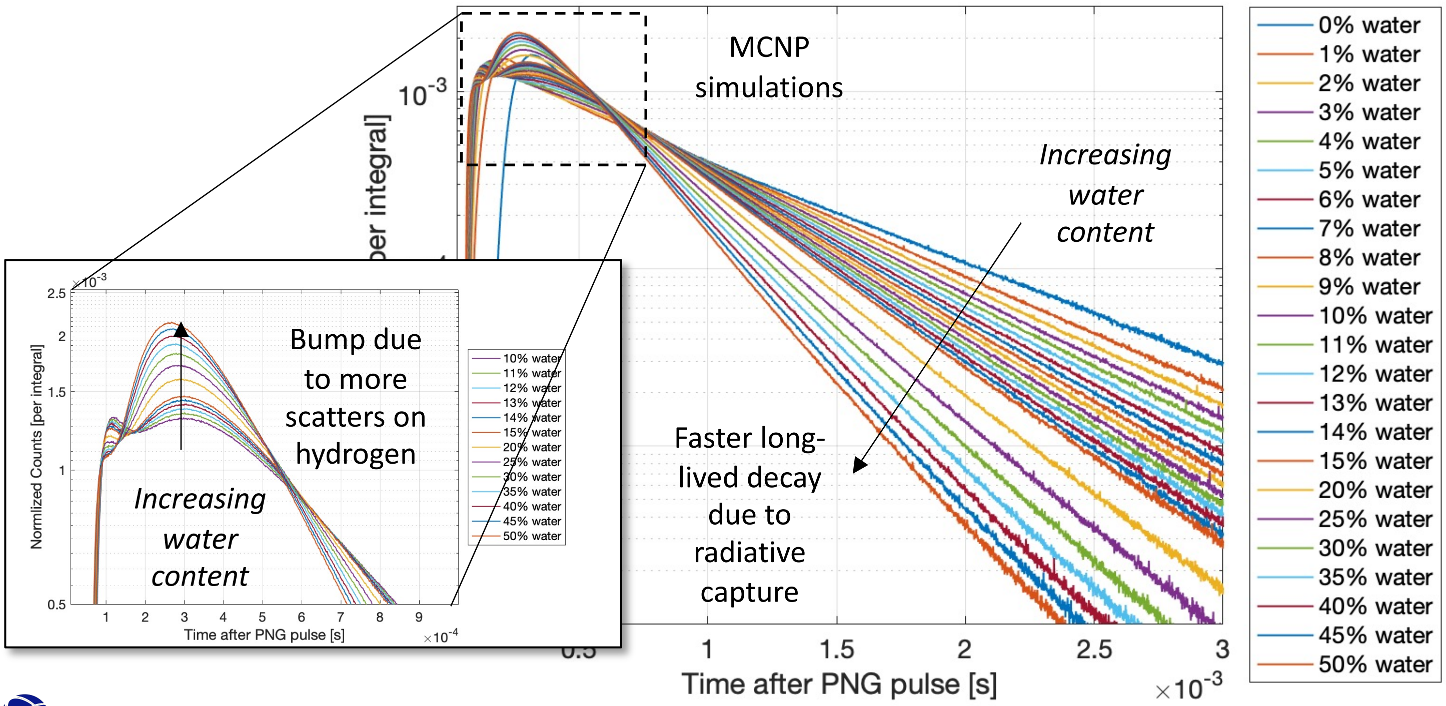
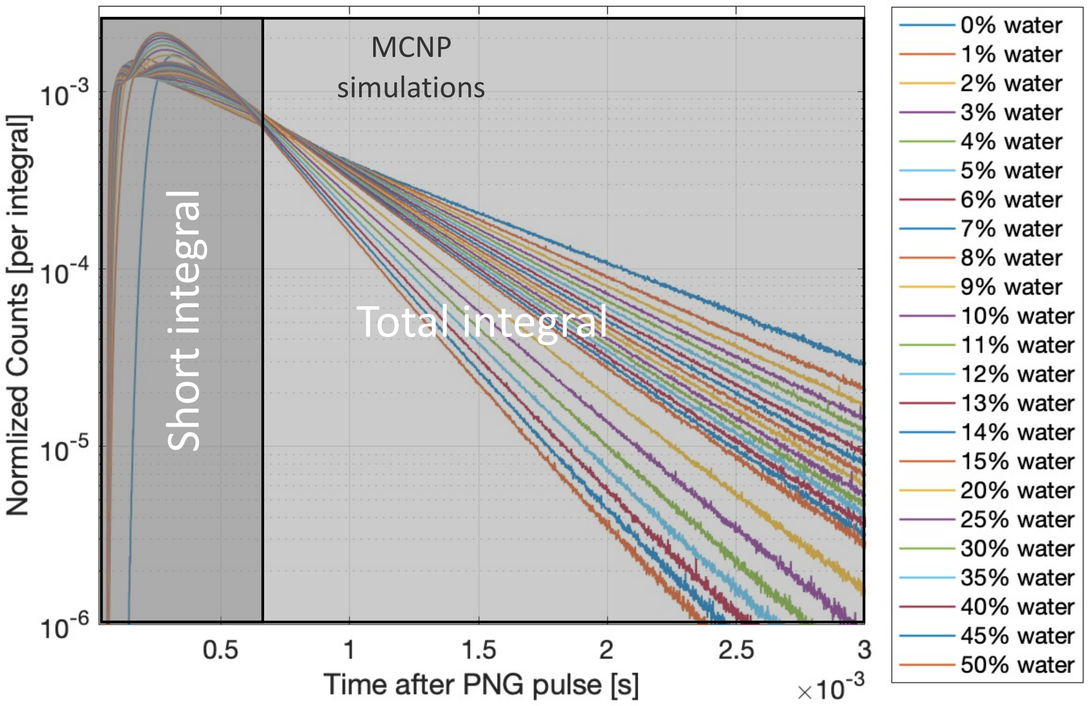


Data interpretation, how do we correlate what we see to water content?

Calculate ratio of short and total integral to provide metric relating shape and water content



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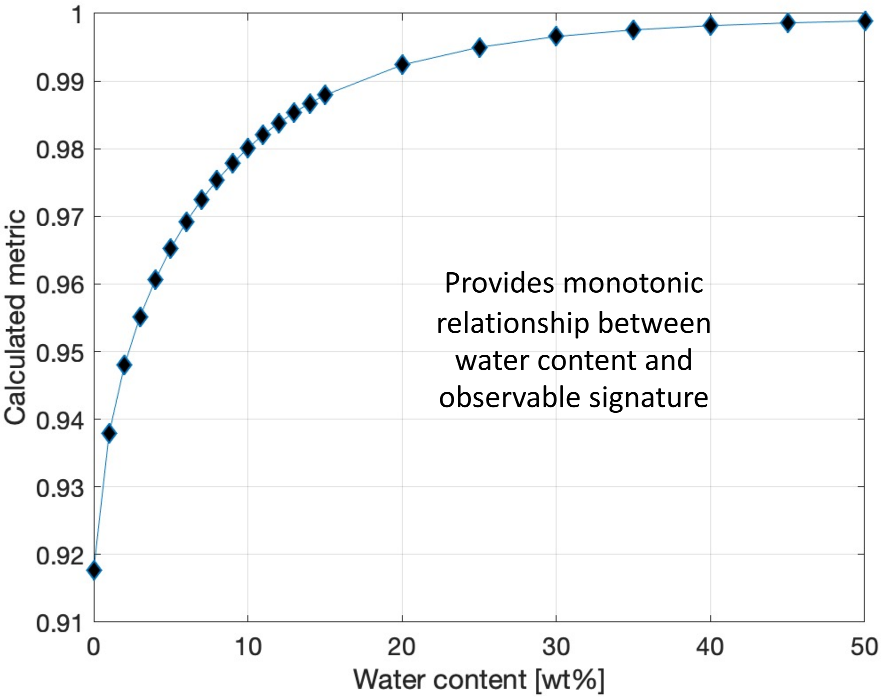
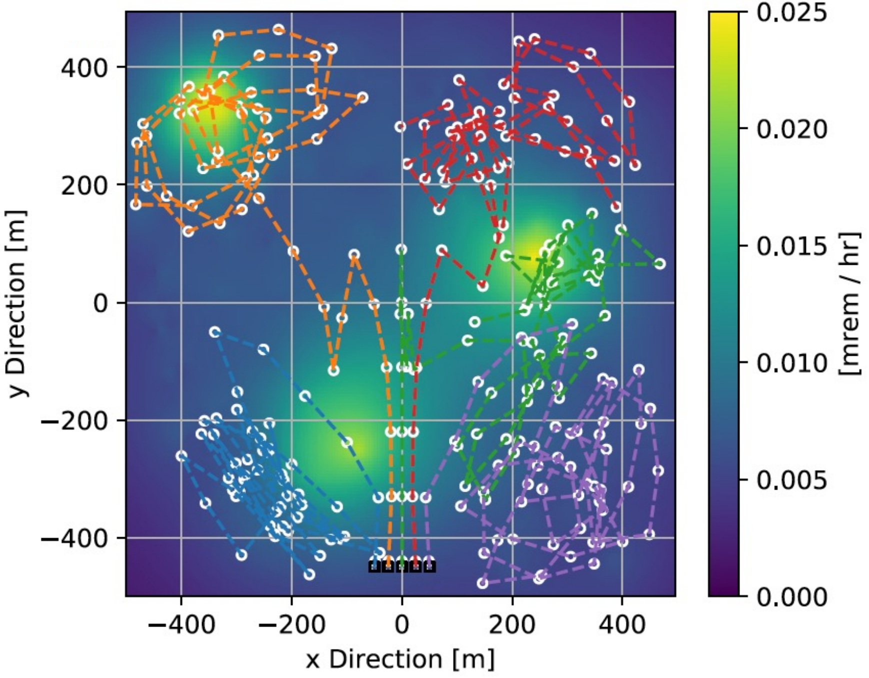


Previously developed algorithm for optimizing trajectories of mobile sensor networks

In previous work, we have developed a fully autonomous mobile sensor platform for radiation contamination mapping

Takes real-time radiation data and dynamically optimizes motion paths

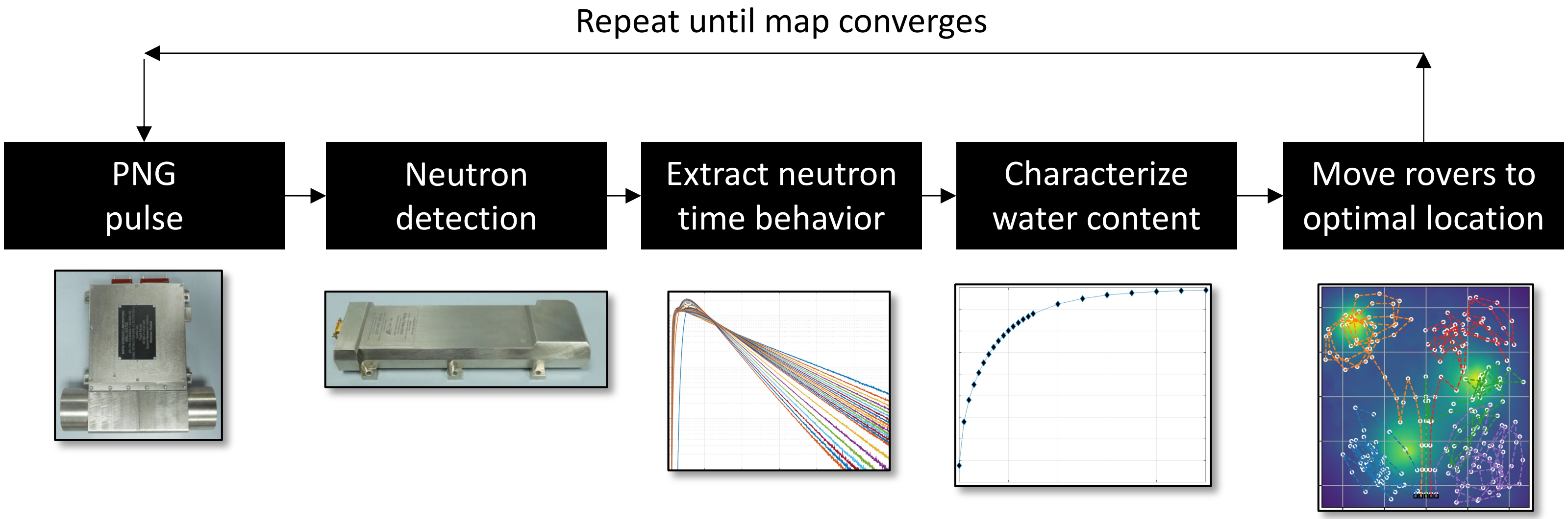
T.H. Shin, et al., “Multi-sensor optimal motion planning for radiological contamination surveys using prediction-difference maps” LA-UR-20-26153, 2021



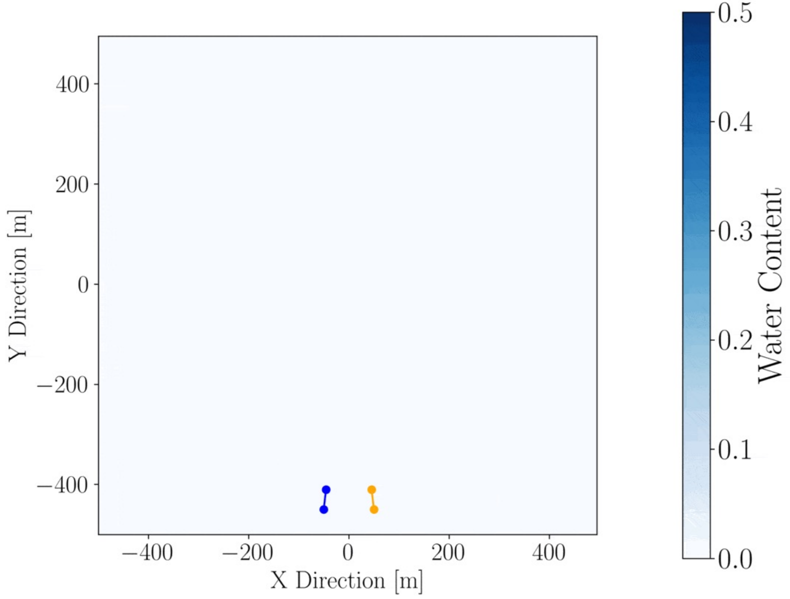
Applying algorithm to search for water content

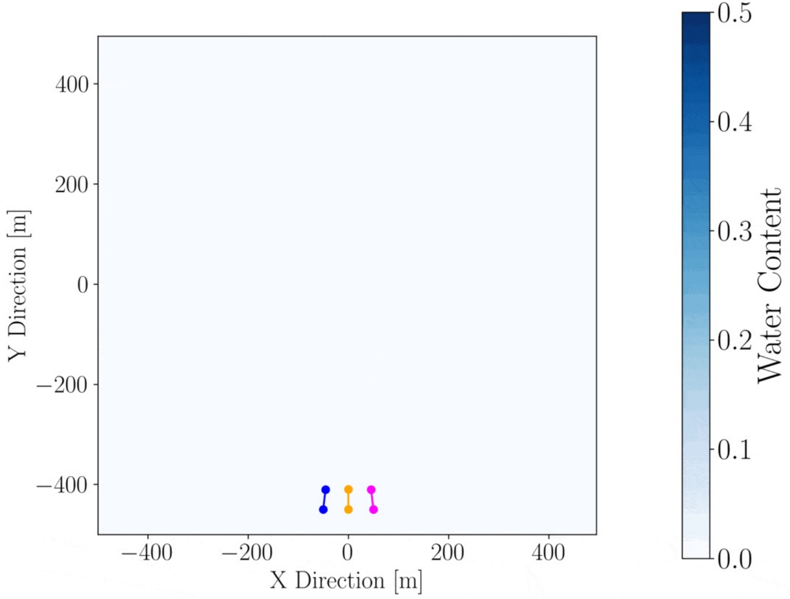
Rather than using radiation detection count rates to characterize contamination, we implement the PNG-detector data to characterize water content

Allows us to map the water content in an area with no human-in-the-loop controls



Putting everything together:
An example with a two- and three-rover survey





What's next?
From proof-of-concept to demonstration

We are currently implementing detectors onto three ground rovers for field demonstrations

July 2022: Experiment in the Artic to measure perma-frost using PNG-CLYC system

2022 and beyond: Implement space-grade hardware and develop highly optimized software for real-time data analysis

Conclusions

Nuclear engineering incredible relevant for space science applications!

We demonstrated that neutron science can be used to characterize water content in current and future space missions

ISR-1's involvement in space missions will continue for the years to come

Student Research Opportunities

We are always seeking opportunities for summer intern and post-bac positions

If you are interested, please come talk to me!

We have interests in space applications, computer science, nuclear security, and many more!

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Tony H. Shin, Ph.D
Scientist
ISR-1: Space Science and Applications
thshin@lanl.gov
(505) 667 4136

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