UF5 – Synergies in Research at Underground Facilities

UF Co-Conveners

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Outline

- Goals of UF5 – Synergies in Research at Underground Facilities
- Outline of report
- Key conclusions

Goals of UF5 – Synergies in Research at Underground Facilities

- Identify the breadth and nature of scientific and engineering research conducted in underground research facilities
- Place in context needs and requirements for these research efforts
- Identify synergies and/or conflicts as they present themselves
- Integrate awareness of the breadth of underground science into the strategic plan for underground facilities and infrastructure

Outline of report

- Introduction
- Accelerator-based nuclear astrophysics
- Experiments in fundamental symmetries
- Gravitational wave detection
- Geology and geophysics
- Quantum information science

- Desirable additions:
  - Geothermal science, Biology, Geobiology, Atom interferometry

Introduction

A broad range of scientific and engineering research is possible in underground laboratories, beyond the physics-focused activities described in the other Underground Facilities and Infrastructure Topical Reports. These areas of research include nuclear astrophysics, geology, geoengineering, gravitational wave detection, biology, and perhaps soon quantum information science. This UF Topical Report will survey those other scientific and engineering research activities that share interest in research-orientated Underground Facilities and Infrastructure. In most cases the breadth and depth of research aims is too large to cover in completeness and references to surveys or key documents for those fields are provided after introductory summaries. Additional attention is then given to shared, similar, and unique needs of each research area with respect to the broader underground research community's Underground Facilities and Infrastructure needs. Where potential conflicts of usage type, site, or duration might arise, these are identified.

Accelerator-based nuclear astrophysics

- Science goals:
  - Understand the synthesis of the elements in the stellar environment
- Method/Facilities:
  - Controlled nuclear reactions through accelerator-based reactions
- Status:
  - U.S. – CASPAR at SURF
  - Europe – LUNA at LNGS
  - China – JUNA at CJPL
- Outlook:
  - Promising science upgrades in existing experimental facilities are planned

Three facilities/experiments lead the field.
Report contains detailed underground usage and needs

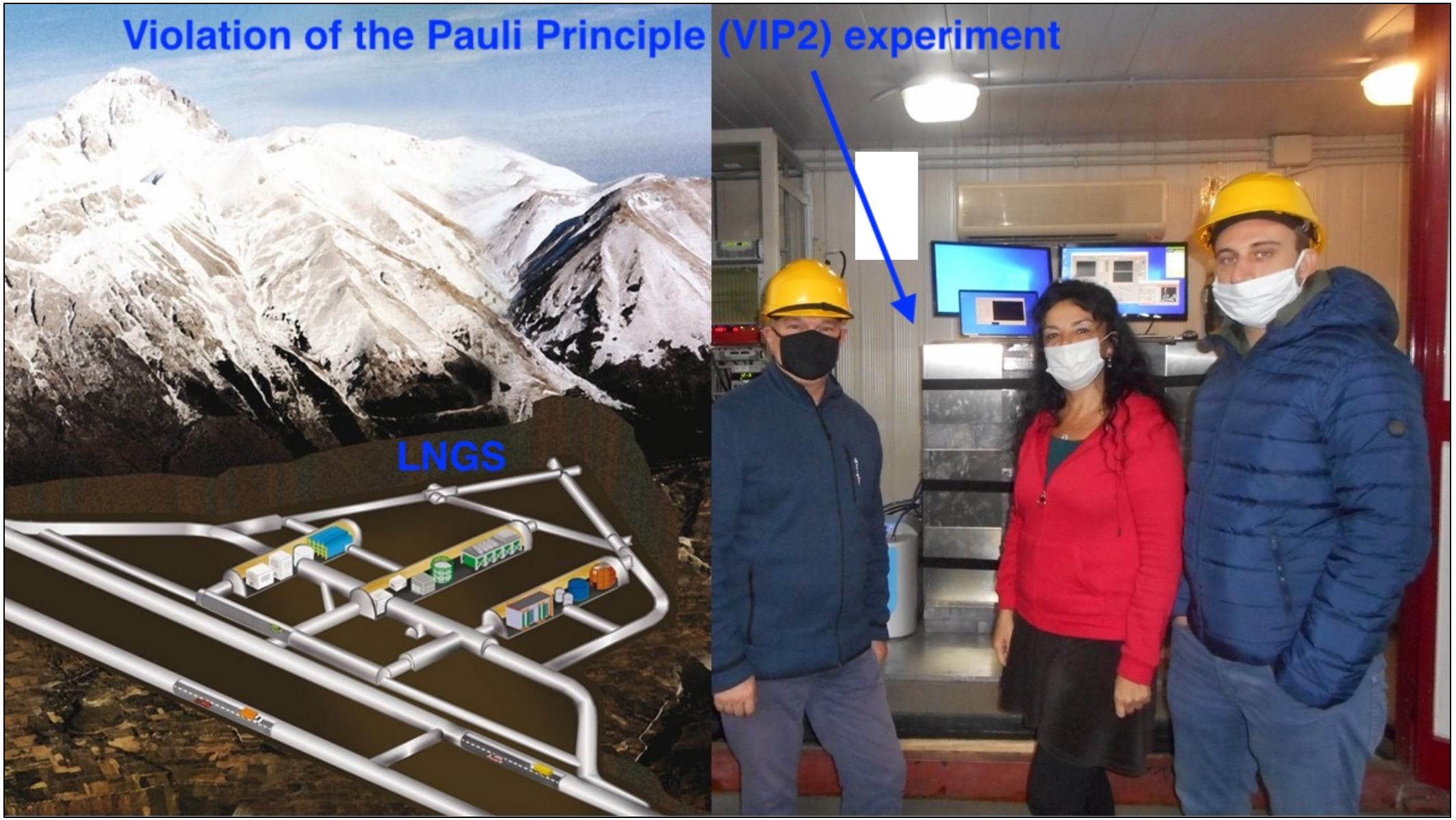
Compact Accelerator System for Performing Astrophysical Research

Measurement of stellar reactions with the use of accelerator based technology is also driving sensitivity requirements for current detector technology

A whole new realm of reaction measurements is opened to Nuclear Astrophysics underground

Experiments in fundamental symmetries

- Science goals:
  - Investigate space-time related symmetries and wavefunction collapse
- Methods/Facilities
  - Precision measurements of X- and γ-rays in atomic & nuclear transitions
- Status:
  - Dedicated experiments: Violation of Pauli Principle (VIP2)
  - Complementary measurements: DAMA/LIBRA and BOREXINO
- Outlook
  - Precision experiments will progressively test fundamental symmetries and are synergistic with other underground measurement infrastructure

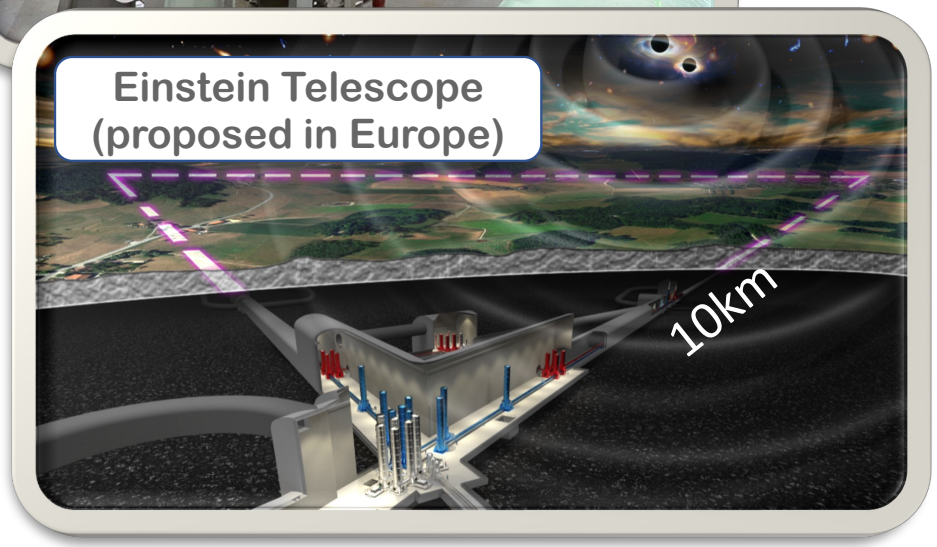

Violation of the Pauli Principle (VIP2) experiment
LNGS

Gravitational wave detection

- Science goals:
  - Expand the range and distance of searches for gravitational wave events
- Methods/Facilities:
  - Escape noisy environments (i.e., seismic, atmospheric, and electromagnetic phenomena) by going underground to enhance low-frequency detection
- Status:
  - KAGRA (Japan) is likely only underground GW detector for next decade
- Outlook:
  - Einstein Telescope is a future concept with 10 km interferometer arm lengths
  - Evaluation of infrastructure noise in other UF sites (SURF, LNGS, etc.) key

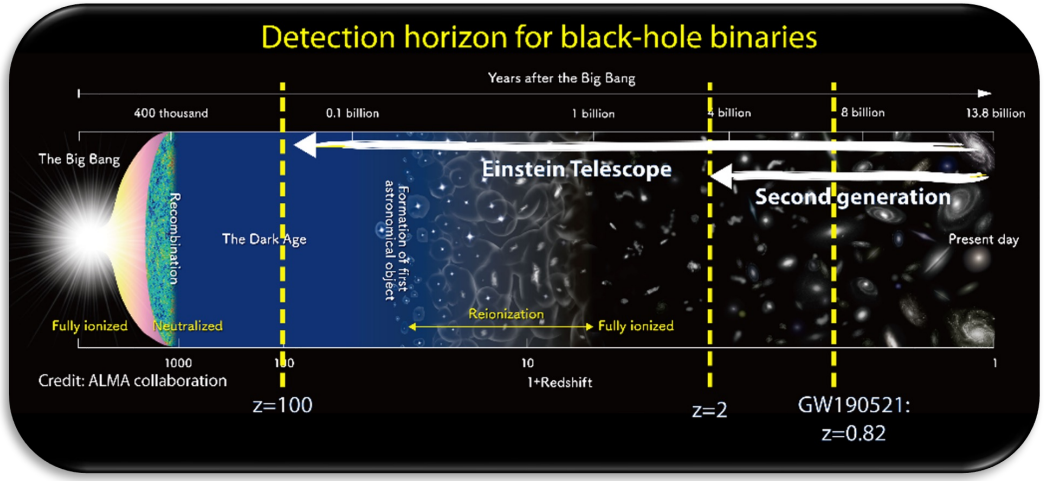
Underground Gravitational Wave (GW) detectors

KAGRA, Mount Ikenoyama, Japan



Low-noise underground environment
→ low-frequency GW observations, which means:

- Detect binary black holes with **larger masses** and at **higher redshift** (up to several 1000 solar masses and out to z=100 with Einstein Telescope)
- **Long observation of neutron-star binaries** until they merge (several hours with Einstein Telescope)



Geology and geophysics

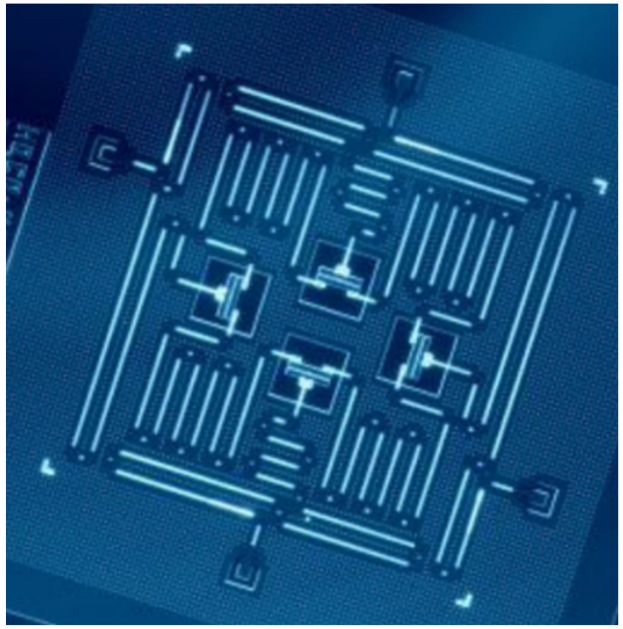
- Science goals:
  - Physics-based understanding of controls on permeability, stress, temperature, and chemical and biological processes across time and length scales
- Methods/Facilities:
  - Controlled borehole drilling and subsequent instrumentation for geologic host
- Status:
  - See: “A Global Survey of Deep Underground Facilities”, 2018 (via OSTI.OGV)
- Outlook:
  - Respectively, DOE and NSF are actively supporting and developing research in geothermal energy and carbon sequestration at SURF

Stimulation and flow controls for injection into boreholes of Test Bed 2, Site B,
of the Enhanced Geothermal Systems (EGS) Collab experiment on the 4100 Level of SURF.

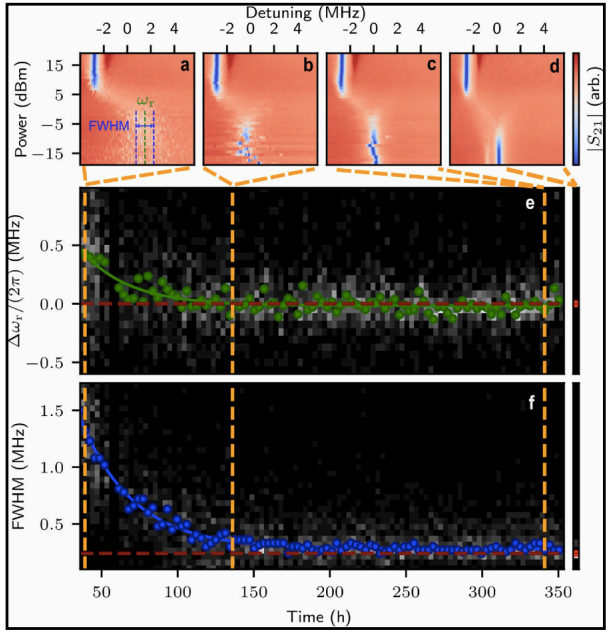
The inset to the lower right shows two of the boreholes with geophysical instrumentation installed.

Quantum information science (QIS)

- Science goals:
  - Improve understanding and performance of superconducting devices for quantum sensing & computing in face of environment-induced quasiparticles
- Methods/Facilities:
  - Deploy low radioactivity techniques for neutrino and dark matter science to superconducting quantum devices in radiation-shield underground labs
- Status:
  - Numerous institutions are installing QIS-oriented dilution refrigerators in UF
- Outlook:
  - Tantalizing opportunities to improve quantum computing in UF systems

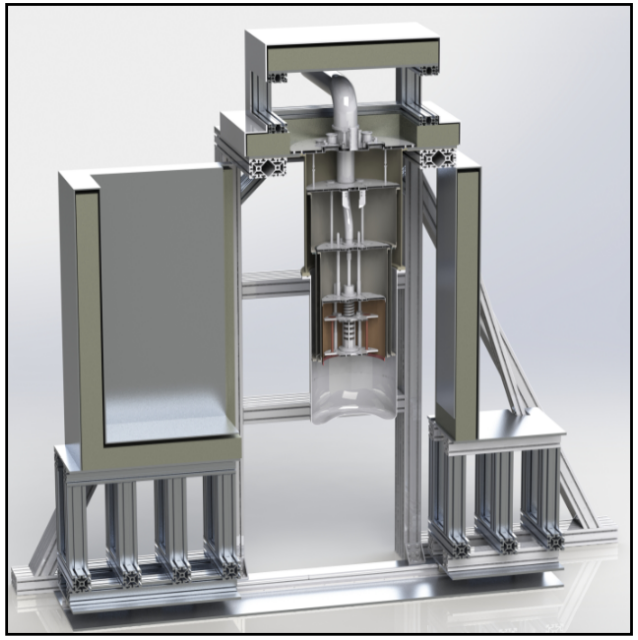


superconducting qubits



Decoherence of coherence from ionization

NEXUS Facilitity (Fermilab)



PNNL Shielded Facility

Summary

- Goal is to wrap-up UF5 – Synergies in Research at Underground Facilities – Topical Report
  - Are we missing things that will impact UF's ability to report to Snowmass?
- No out-right conflicts in research programs have been identified (or appropriately tailored facilities are available and in use)
- In several cases, smaller research programs benefit from economy-of-scale associated large particle physics programs
  - Recommends holistic assessment of total science impact from UF investments