Radiation Hardened Opto-Atomic Magnetometer (RHOM)

Progress Update

DOE Funding Opportunity: DE-FOA-0001770
Grant Number: DE-SC0018586
Period of Performance: 4/4/22 – 4/3/2025

DOE Program Manager: Dr. Michelle D. Shinn
Office of Science – DOE
Phone: (301) 903-8363

Principal Investigator: Daniel Engelhart, Ph.D.
dengelhart@hedgefogresearch.com

Hedgefog Research Inc.
San Pedro, CA 90731
7/30/2025

Hedgefog Research Inc.

Areas of Expertise

- Laser systems
- Atomic interferometry sensors
- Custom optical sensors
- Dust mitigation and filtering
- Fluid dynamics sensing and simulations
- Vision testing
- Magnetic sensing
- Software development
- Machine learning

Manufacturing Capabilities

- Large area flex circuits
- Eye care devices

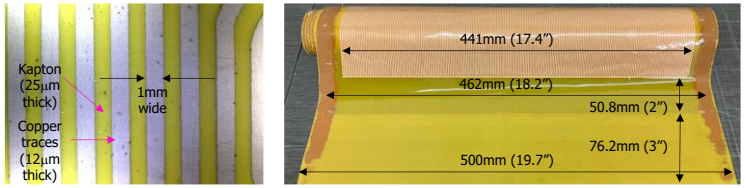
Certifications

- ISO 13485:2016

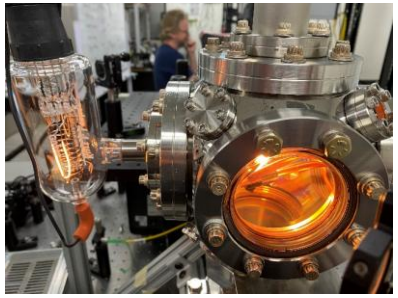
Our customers:

USAF, US Army, US Navy, NASA, DTRA, DLA, DoE

Automated Vision Tester presented at the 2022 Military Health Research Symposium

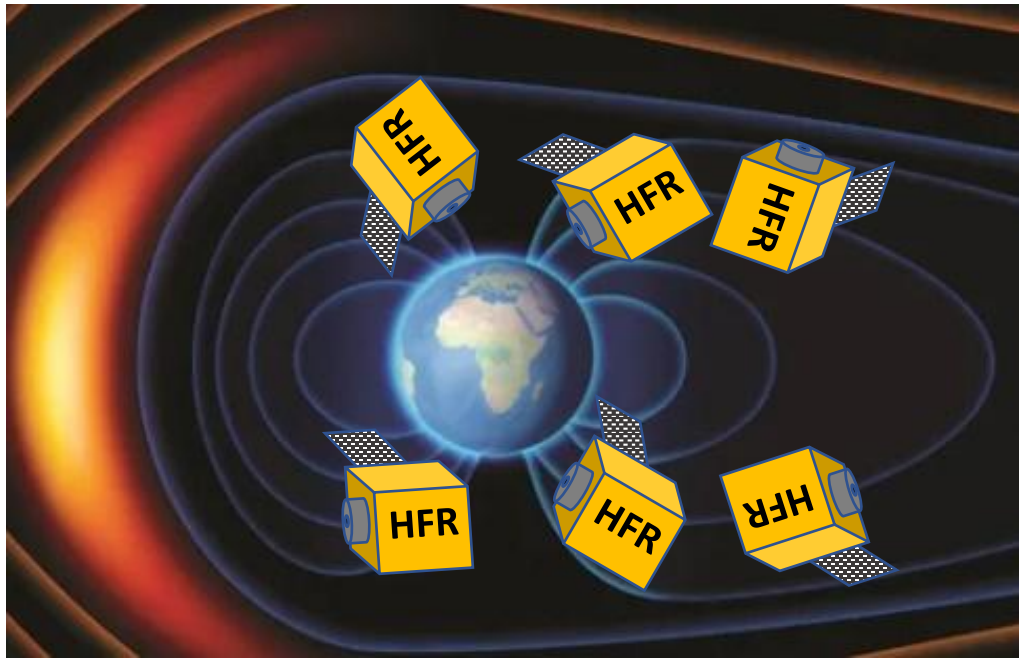


Large area flex circuit manufactured at HFR



HFR's state-of-the- art optics and vacuum lab

Hedgefog Research Inc. (HFR) is a full cycle R&D and manufacturing company located in San Pedro, California. HFR has a proven capability and expertise in every stage of product development process starting from generation of a novel idea all the way to production, sales, and service.



Space Weather Sensing (conceptual)

Contact Information
1891 N Gaffey St Ste 224
San Pedro, CA
www.hedgefogresearch.com
Phone: 310-935-2206

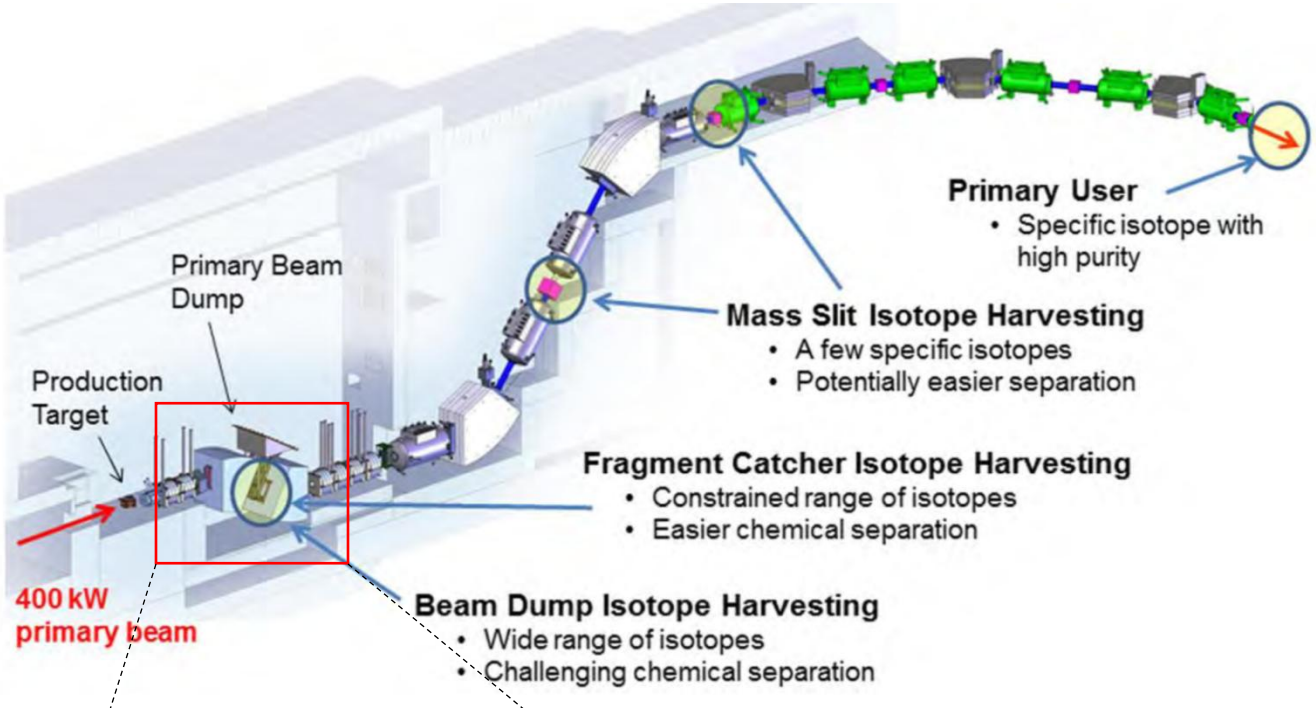
Accelerator Facilities for Nuclear Science

- In rare isotope beam (RIB) facilities, **production and manipulation of the reaction products**, including ionization, purification, acceleration, and transport, need to be optimized individually to achieve maximum production rate of target nuclei.
- **Precise electromagnetic manipulation of reaction products** is needed to deliver intense rare-isotope beams with good ion optical quality and desired timing/energy characteristics.
- **Magnetic-field probing** is one of the diagnostic tools routinely used in the operation of RIB facilities.
- Nuclear magnetic resonance (NMR) probes commonly used in these applications have **limited lifetime** (~ weeks) due to radiation-induced damage. This results in facility downtime and increased operation cost.

DOE Needs

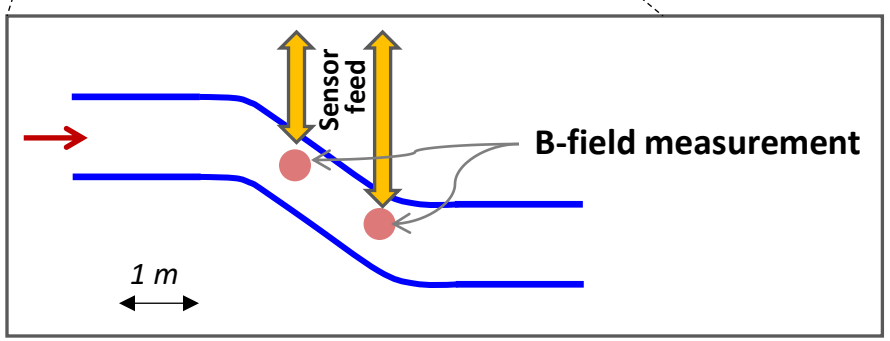
- Magnetic-field sensing in high-radiation environments (gamma ray and **neutron**, **0.1 ~ 10 MGy/yr**), replacing NMR probes
- Target operation lifetime **> 1 year**
- Field range: **0.2 ~ 3 T**
- Precision (ΔB/B) better than 10^{-4}, **10^{-5} desired**
- Field gradient (in one direction): 10^{-4} cm^{-1}
- Rep. rate: higher than 1 min^{-1}, **1 Hz desired**
- **Beam energy recently reached ~20 kW, ramping up to 400 kW, already seeing NMR probe failures**

Isotope Harvesting at FRIB



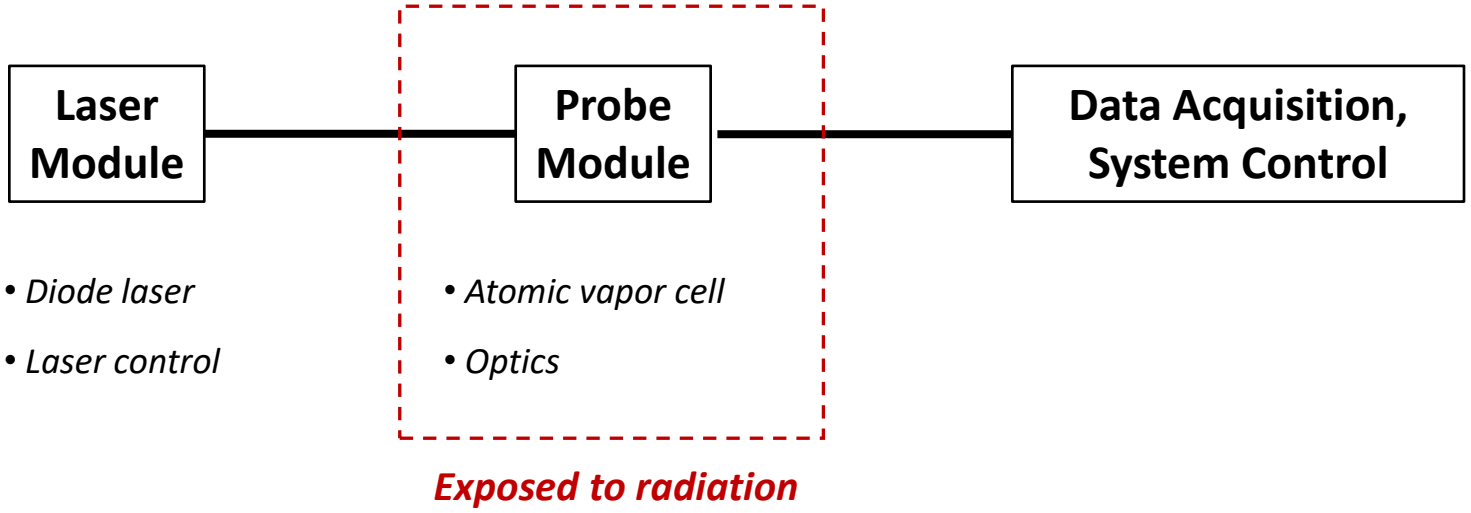
**** FRIB: Opening New Frontiers in Nuclear Science***
August 2012

Rare isotope & primary beam

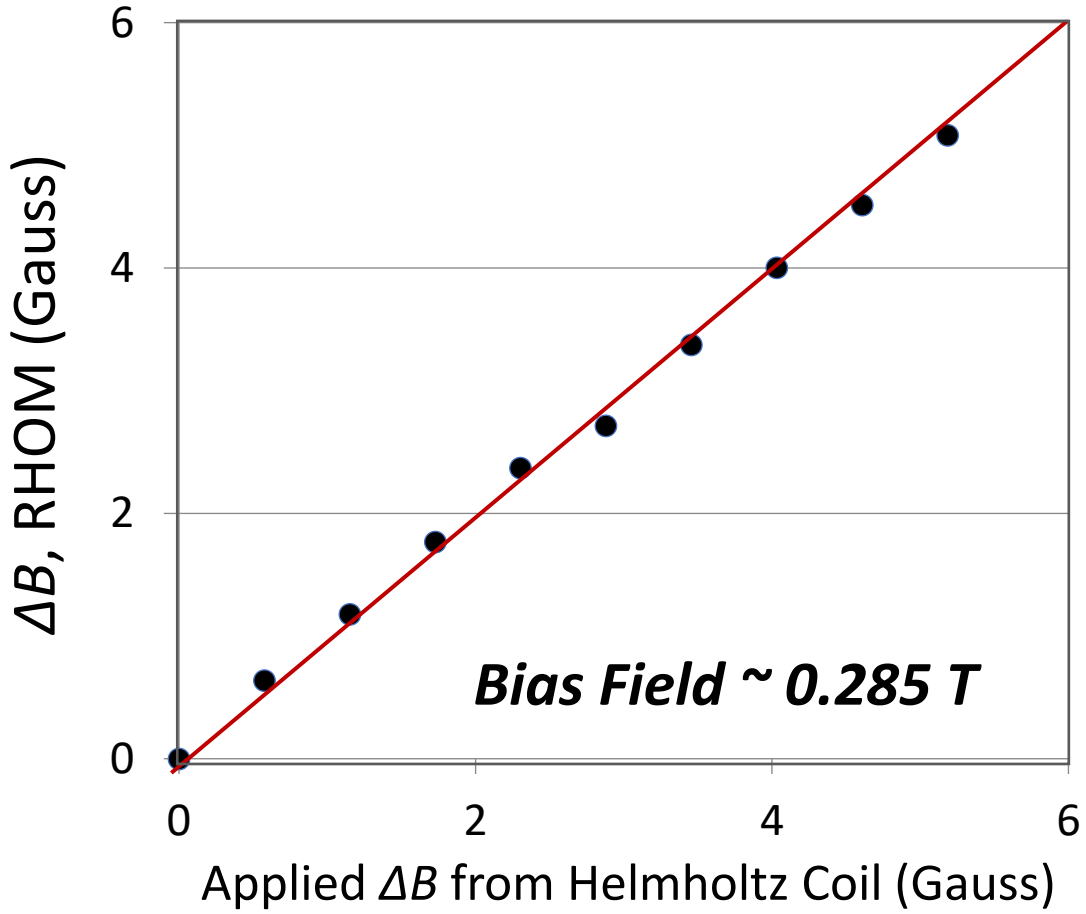


Radiation Hardened Opto-Atomic Magnetometer

- Contains **minimal number of radiation-hard components** exposed to radiation (glass cell, metallic mirror, mechanical housing)
- RHOM accuracy guaranteed by quantum mechanics; **no need for device calibration**
- Sensitivity better than **10^{-5} T**
- Relative precision **($\Delta B/B$) better than 10^{-5} at 1 T** (**~ 1 Hz** sampling rate)



Magnetic Field Measurement



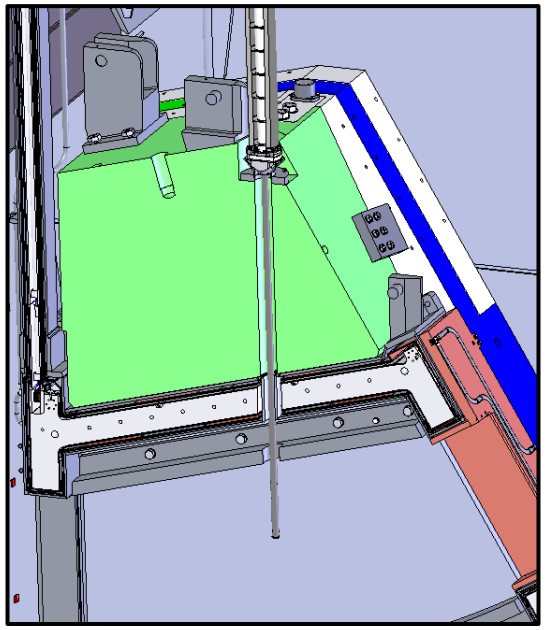
SI-traceable, calibration-free determination of magnetic field

Phase IIA Progress Summary (July 2025)

- Developed a new probe module design (1.5 in. × 1.3 in. × 1.5 in.)
- Devised and successfully tested a new optical system scheme
- Developed data acquisition and signal processing software, which, combined together, will provide a fully automated real-time magnetic-field sensing.
- Procured all system components
- Evaluated system performance with final components
- Integrated all components into two rack-mountable boxes
- Developed FRIB-compatible sample probe
- RHOM Phase IIA prototype tech demonstrations Feb/May 2025
- Delivered Phase IIA prototype to FRIB
- **Long-term radiation hardness testing currently underway**

RHOM Probe

53”



60”

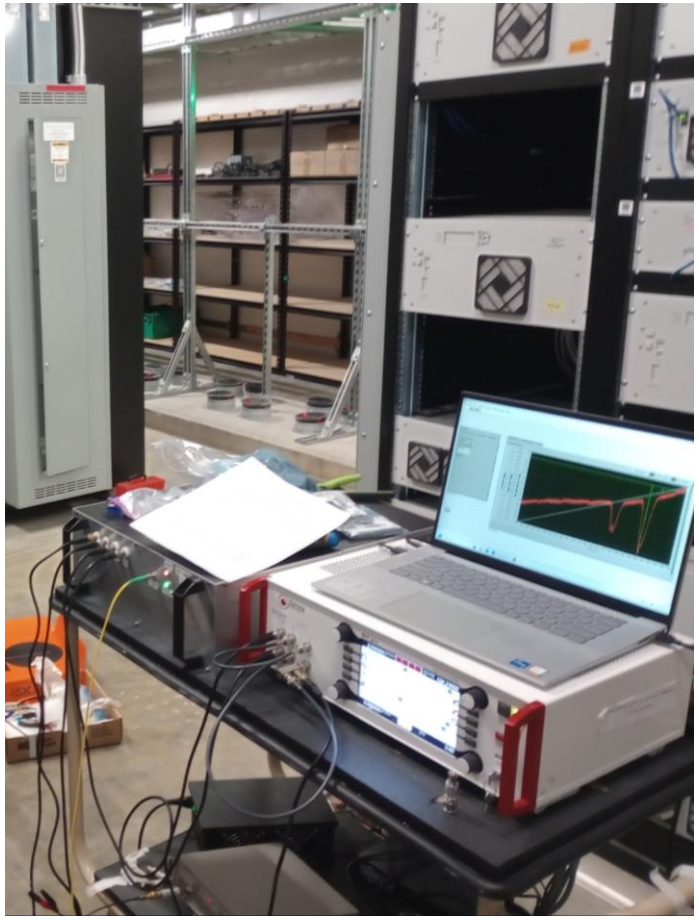
All sensitive components are located in upper (instrumentation) head of measurement fixture.

Lower (probe) module contains fused silica and metal optics and heater.

Technical Demonstration - FRIB

From Control Room:

- Laser Modulation
- Electronic Control
- Signal Analysis

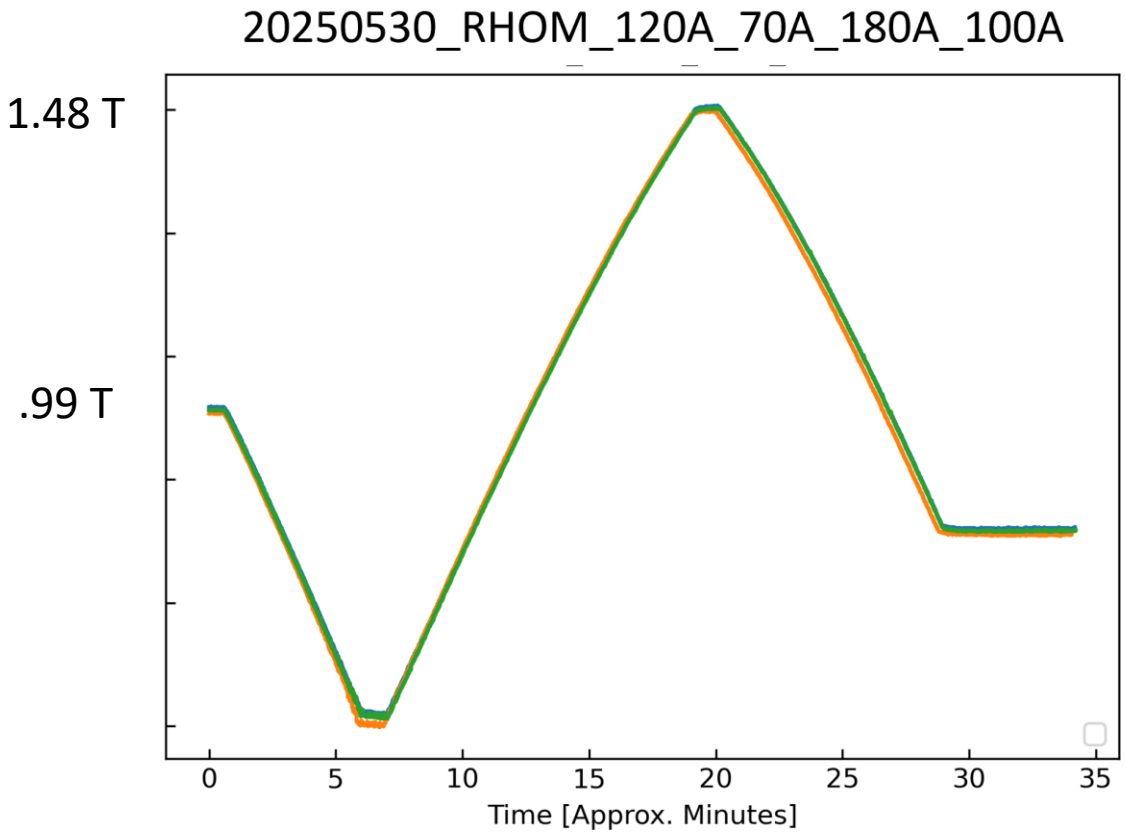


Probe Installation in
High-Radiation Separator Hall

Remote operation proceeded smoothly. RHOM probe was mounted in existing FRIB SCD1 measurement hardware (**no modification required**).

All electronic control, signal processing, and laser light generation performed in separate hall; all sensitive equipment well-removed from any radiation exposure.

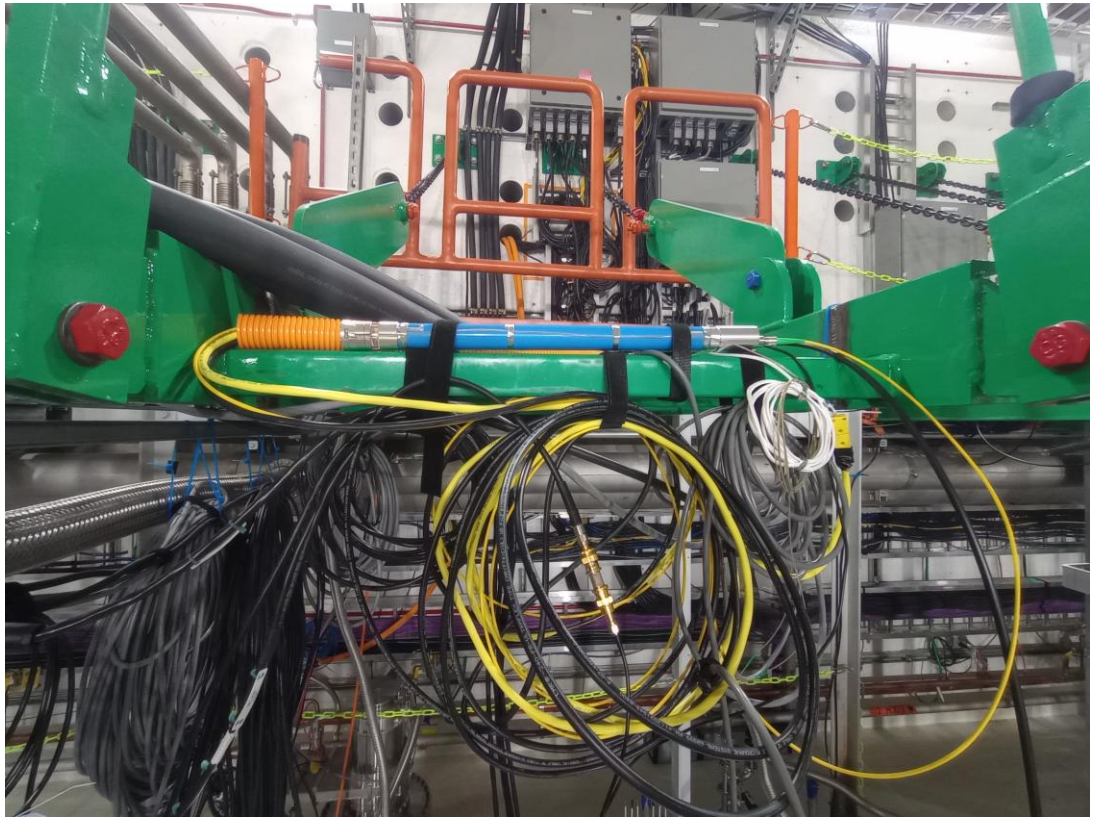
Results



- SUCCESS!
- Long term stable operation (>10 hrs)
- Prototype v1 precision **better than 10^{-4}** with design improvements for ×10-100 precision improvement for v2

Radiation Hardness Testing

Radiation testing finished on 7/23 (~2 months. Planned shutdown until October).
Post-irradiation performance evaluation scheduled for September



Post Phase II Tasks

- Commercialization!
- RHOM system recently finished initial radiation exposure (May 29-July 23)
- Requirements for commercial system are being discussed with FRIB personnel
- HFR is identifying other customers such as
  - Electron Ion Collider
  - European Spellation Source
  - Spellation Neutron Source (ORNL)
  - Fusion Accelerators?

Thank you!
Project Team: Matt Thompson, Denzal Martin, Adrian Avilla-Alvarez, Alex Kolessov, Gary Mikaelian
FRIB Team: Steven Lidia, Evan Daykin, Georg Bollen

Thank you! Questions?

Areas of Expertise

- Lunar in-situ Resource Utilization (ISRU)
- Atomic interferometry sensors
- Custom optical sensors
- Dust mitigation and filtering
- Fluid dynamics sensing and simulations
- Vision testing
- Magnetic sensing
- Nuclear Forensics

Manufacturing Capabilities

- Large area flex circuits
- Eye care devices
- Medical Devices

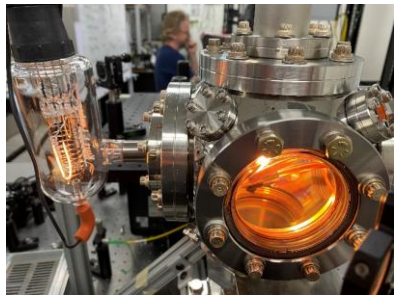
Certifications

- ISO 13485:2016

Our customers:

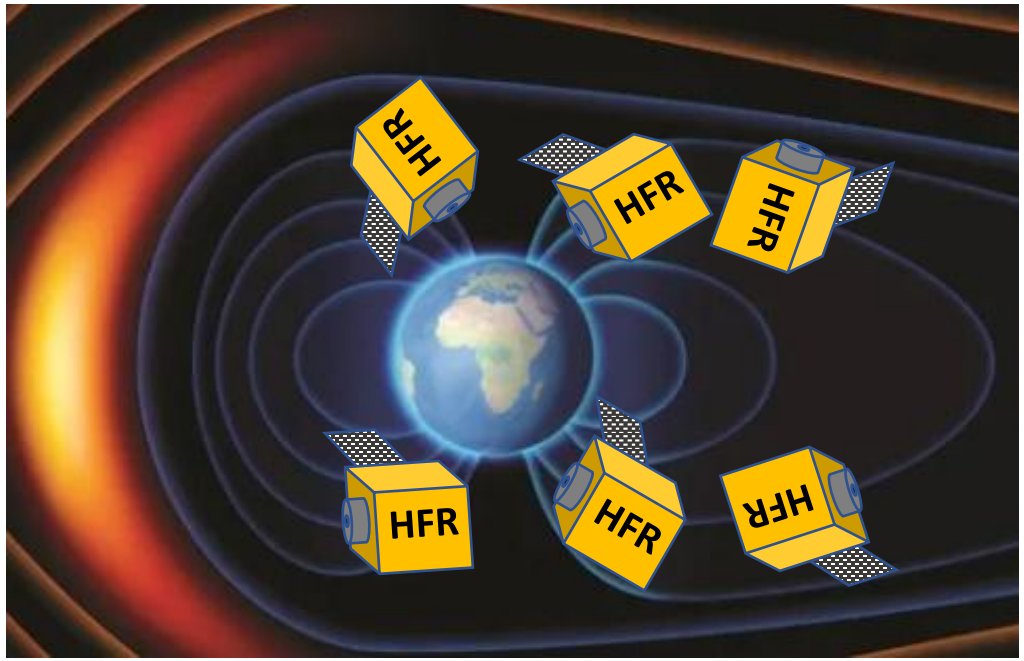
USAF, US Army, US Navy, NASA, DTRA, DLA, DoE

Automated Vision Tester presented at the 2022 Military Health Research Symposium



HFR's state-of-the- art optics and vacuum lab

Hedgefog Research Inc. (HFR) is a full cycle R&D and manufacturing company located in San Pedro, California. HFR has a proven capability and expertise in every stage of product development process starting from generation of a novel idea all the way to production, sales, and service.



Hedgefog Research Inc.
1891 N Gaffey St Ste 224
San Pedro, CA

www.hedgefogresearch.com
dengelhart@hedgefogresearch.com