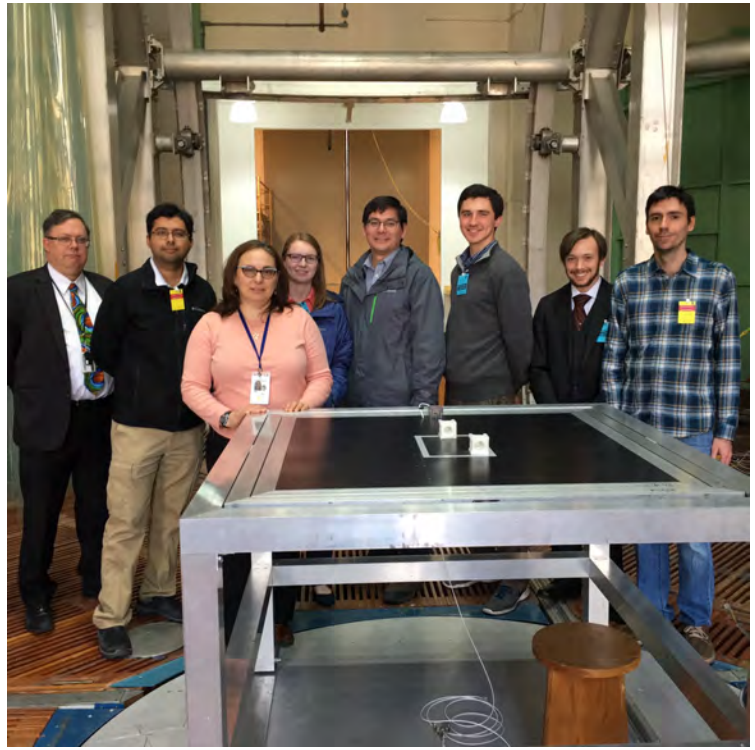
Development of new AC and DC magnetometers for small satellites



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UM and NASA Team

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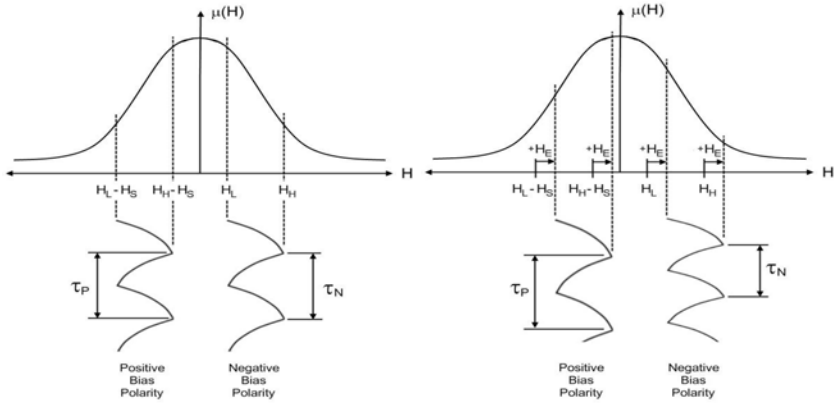
- Arie Sheinker (Postdoc, now at SOREQ in Israel)
- Leonardo Regoli (Postdoc in CLASP now at JHU/APL)
- Srinagesh Singh (PhD in EE now at Microsoft Research)
- Brandon Ponder (undergrad, now PhD student)
- Jacob Thoma (Class of 2020 EE, now at NASA JPL)
- Matt Pellioni (Class of 2019, now at Northrup Grumman)
- Geoff Jenkins (Class of 2020 in Space Science, now PhD student)
- Connor Raines (Class of 2021 in EE, now in grad school)
- Todd Bonalsky (GSFC, Code 549)

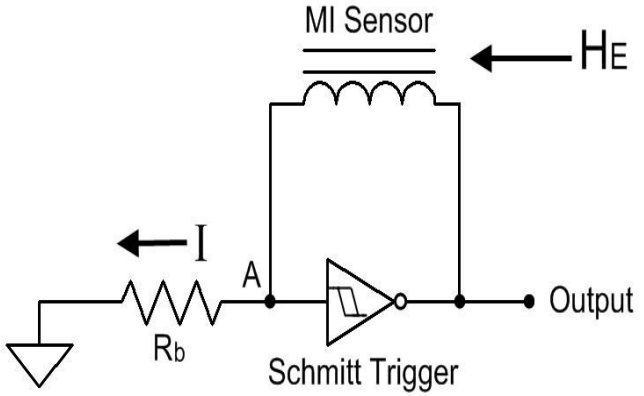
Objectives of Project

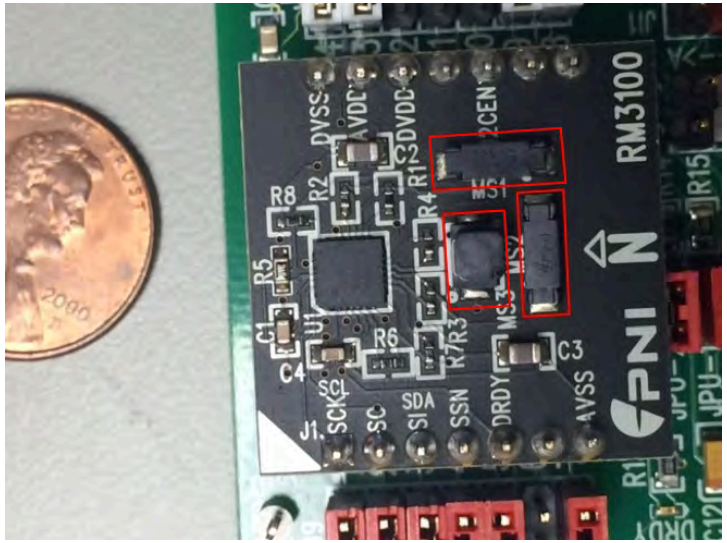
1. Space Qualify modified PNI RM3100 Magneto-Inductive (MI) Magnetometer
2. Develop more sensitive MI Magnetometer system
3. Develop algorithms for boom-less small satellite magnetometry
4. Develop concept for a Hybrid MI/Torque Rod/Search Coil Attitude Determination and Control System (ADCS)

Magneto-Inductive Magnetometer

- Technology is a simple LR circuit that works similar to a fluxgate in that it drives the core into saturation, but essentially measures the time difference between going up and down the curve. The time difference is proportional to B.

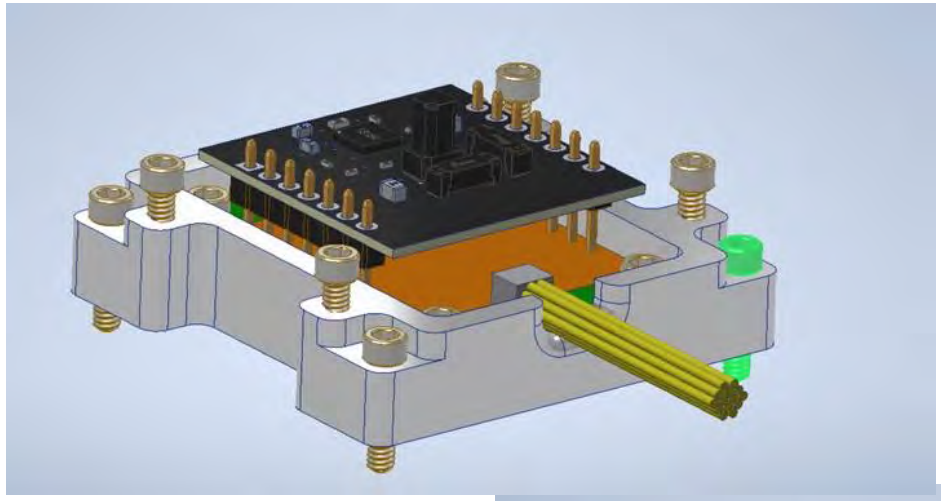




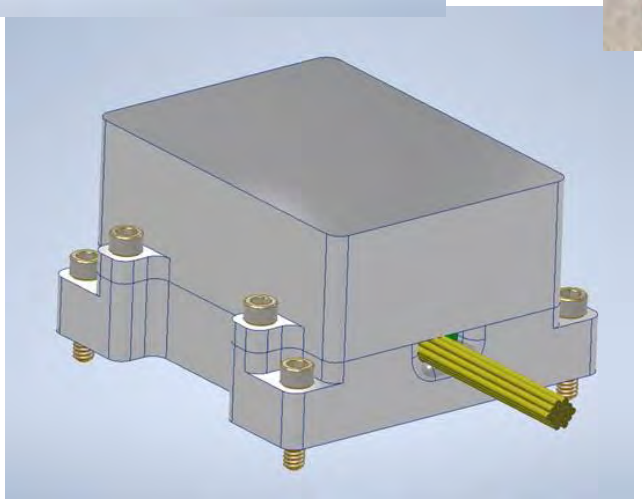


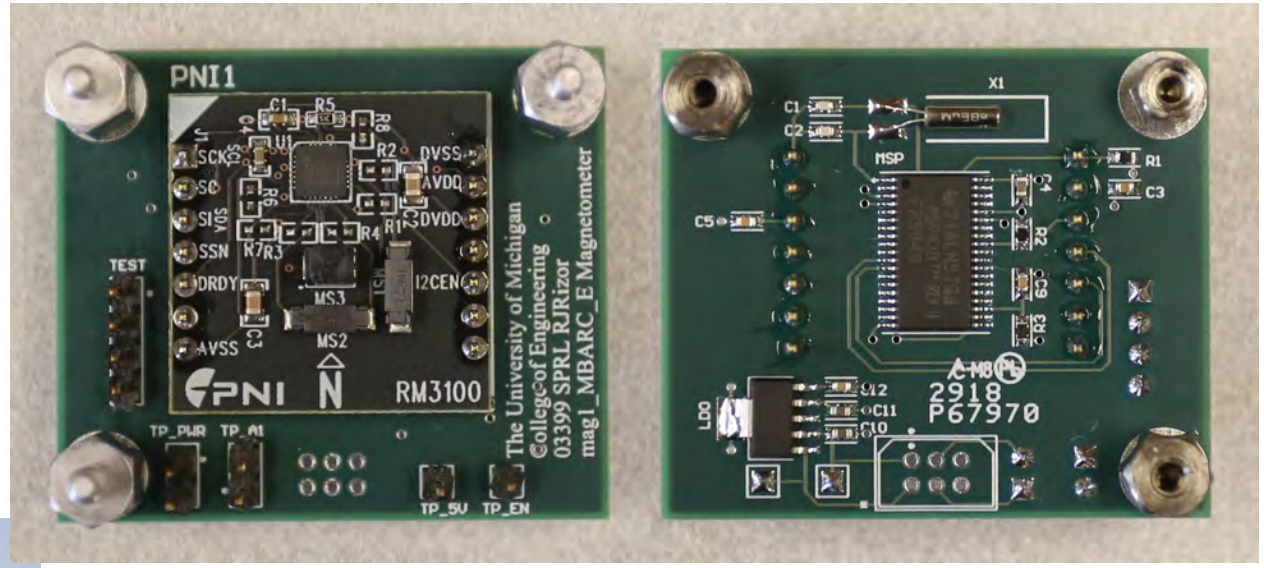
Goal is to design an extremely low SWAP+C++

(Size, Weight and Power + Cost +Telemetry + Accommodation) and magnetic noise algorithms to enable magnetometery on any satellite without a boom



24 x 24 x 30 mm; 20 g; 10 mW; $1M; 2 kbps; no boom. Sensor, transorbs, electronics, thermometer in 100 mil AL for surface mounted on spacecraft bus

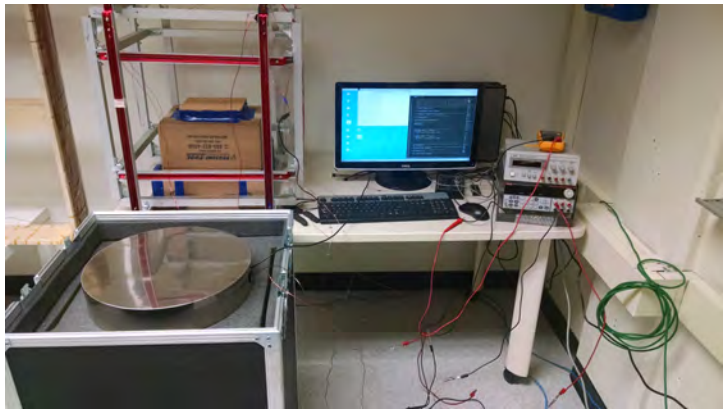


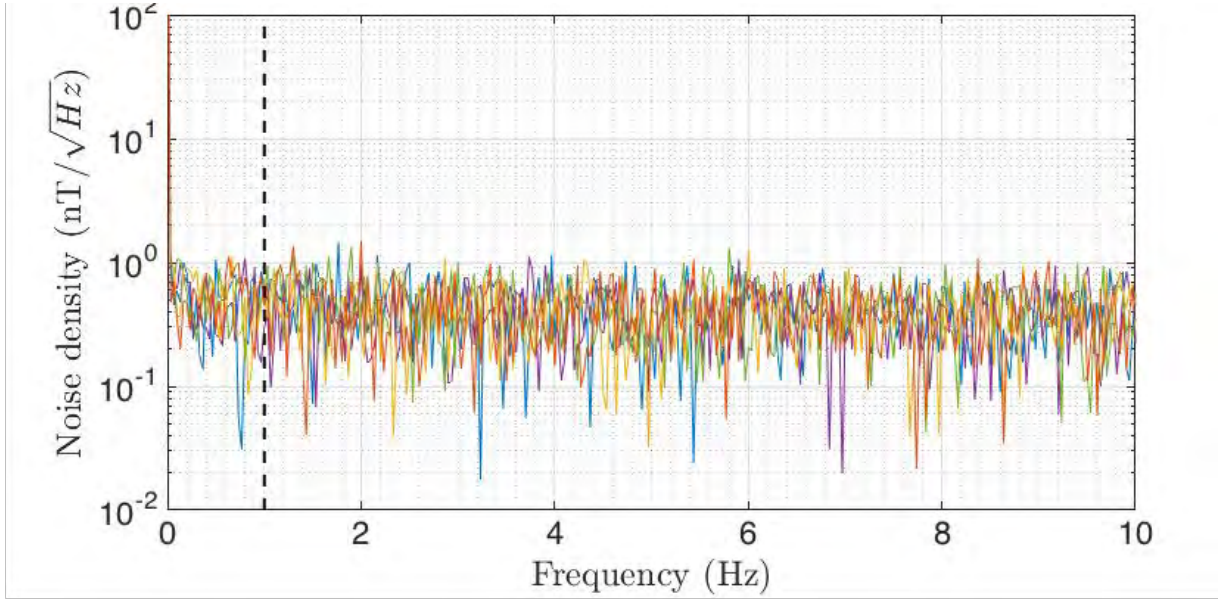


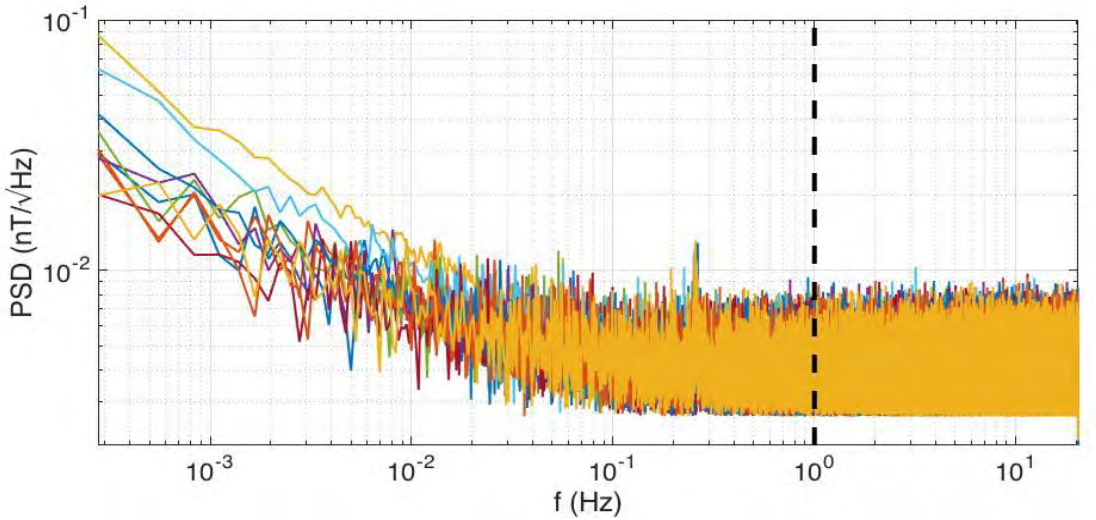
Integrated electronics, sensor and processor design for inside the spacecraft bus

Performance

- Noise floor (4 pT/root(Hz) @ 1 Hz)
- Resolution < 1 nT at 1 Hz
- Good performance up to 10 Hz
- Good linearity
- Stable Thermal Off-set
- Linear Thermal Off-set







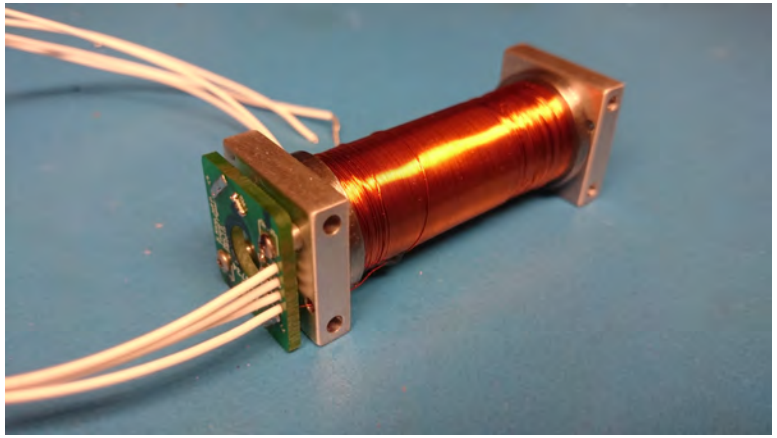
UM PNI RM3100 Environmental Testing

(All tests passed with worst case ~1% gain change)

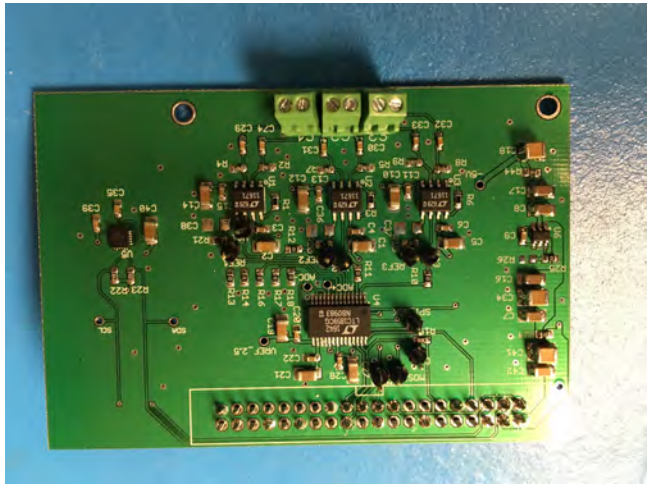
Thermal Shock	**Mil STD 202-107G** **Sample Plan Mil STD 105E -Tested 100 sensors out of lot of 1000**	**Cycle -65 ºC for 15 min then +125 ºC for 15 min, then back to -65 ºC transition less than 20 seconds between temperature chambers.**
Mechanical Shock	Mil STD 202 – 213 Condition C	Modified > 100 g, 6 ms, half-sine Tested mounted samples in 3-axis, six times per axis (total 18 shocks)
Vibration	PNI Qual Plan @UM Cal-Poly Vibration Profile	Random vibration for 20 minutes per axis at 5 g from 10 Hz to 2000 Hz
Low Temp Storage		-65 ºC for 500 hours tested at room temperature one day later.
High Temp Storage		1000 hours at +100 ºC, unpowered
Thermal Cycles	JEDEC-JESD22-A104	500 cycles at -40ºC for 15 minutes, then 90ºC for 15 minutes, then back to -40ºC with transition time less than 10 minutes
Radiation Testing	TID testing at Michigan, GSFC and LBNL (Sample of 10 Sensors)	Passive and Active testing up to 500 kRad. No SEL (LET > 75 MeVcm^2/mg @ 85 C)

Hybrid AC/DC+ADCS (low TRL Concept)

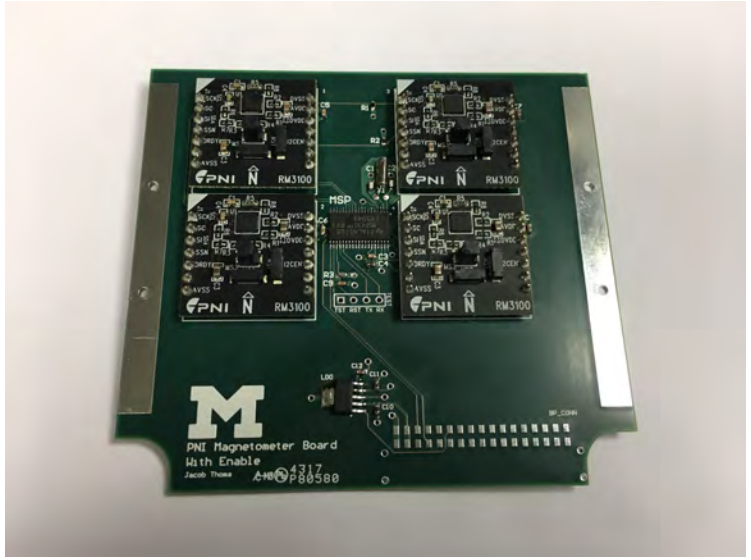
- Use a torque rod as a search coil (AC) with the UM-PNI-MI (DC) magnetic measurements and for Attitude Determination (AD) with Attitude Control (AC)



UM Torque Rod



Search Coil Electronics

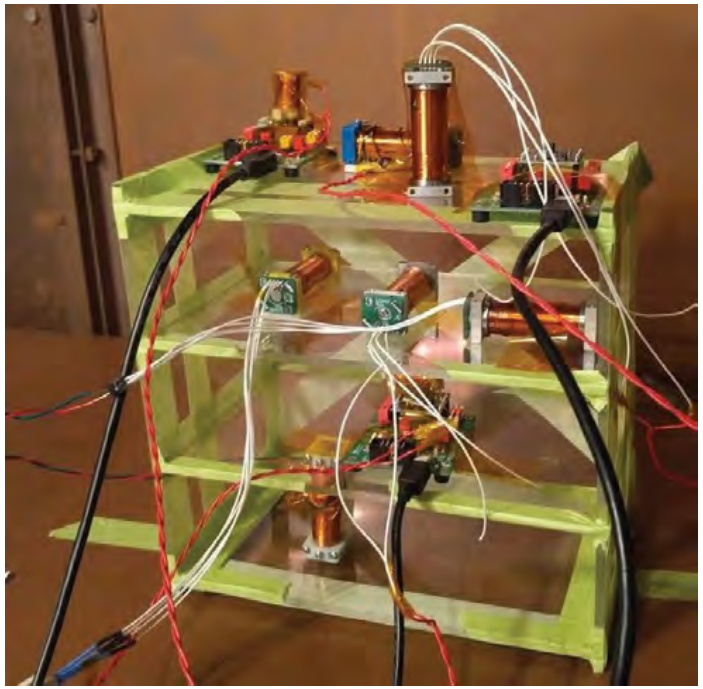


UM Quad Mag (4 PNI sensors for a CubeSat)

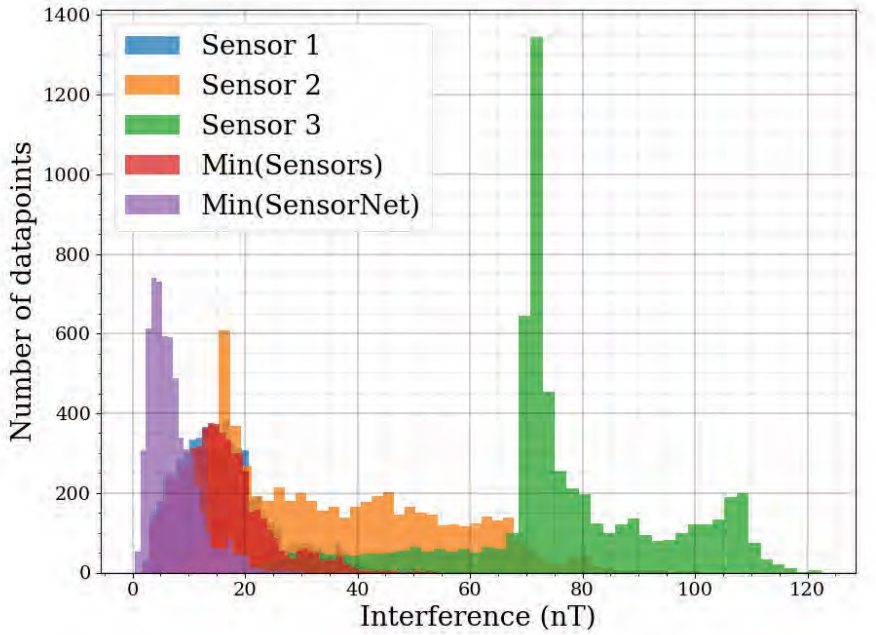
Noise Cancellation: Machine Learning

Machine Learning

Deshmukh et al. (2019) improves upon traditional analytic algorithms
by using machine learning statistical approaches (conceptual bandits)
to combine housekeeping data of subsystems with 3 magnetometer data to
”learn” the magnetic signatures of “noise” to enable optimization
and minimization of sets of magnetometer data.

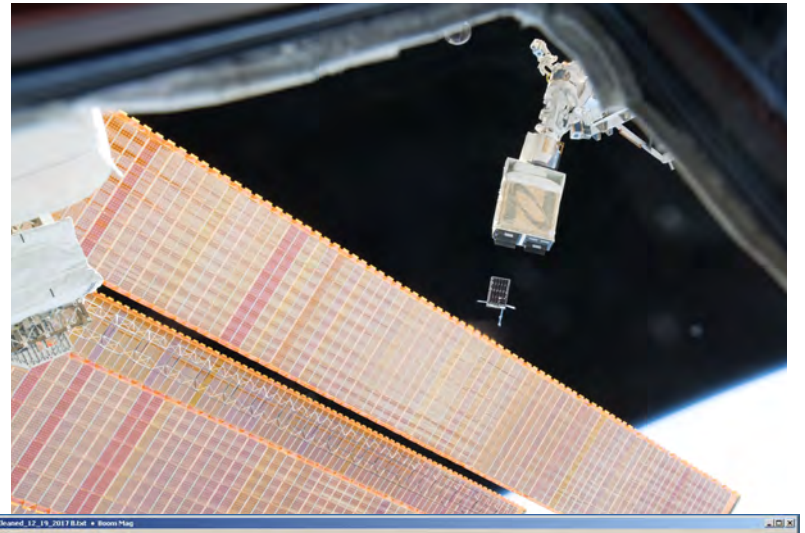


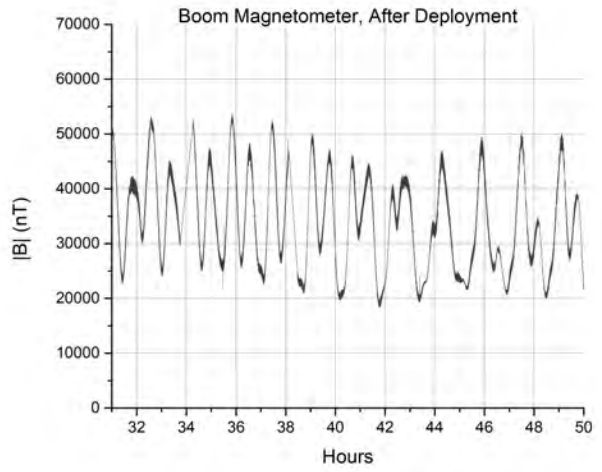
Magnetometers=3 and Noise=6

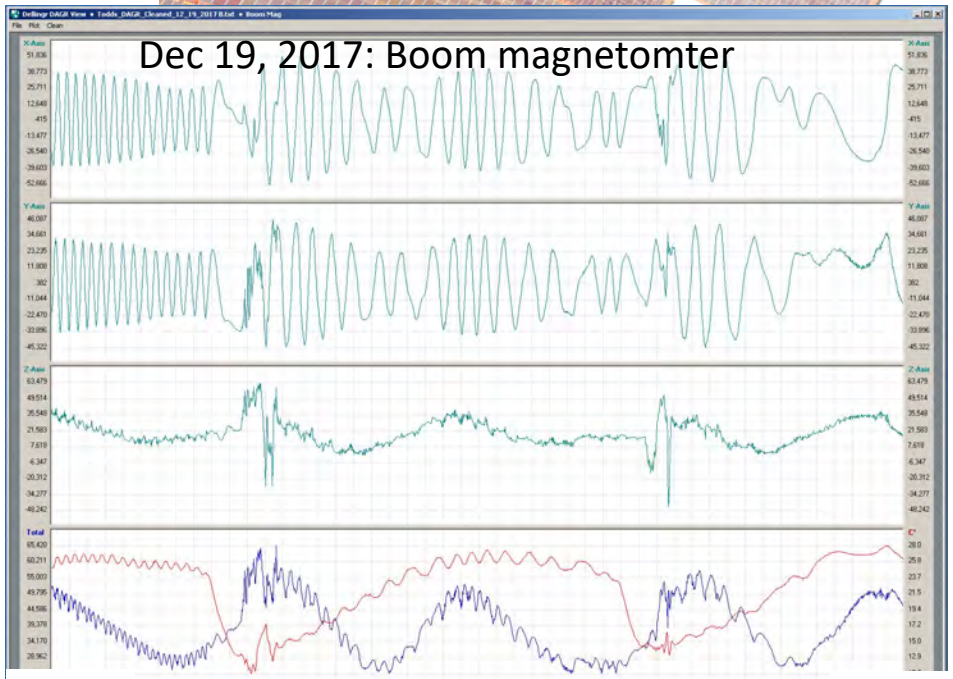


Test data IMF-like data and “purple” ML results show reconstruction.

NASA GSFC Dellingr deployment and Initial data







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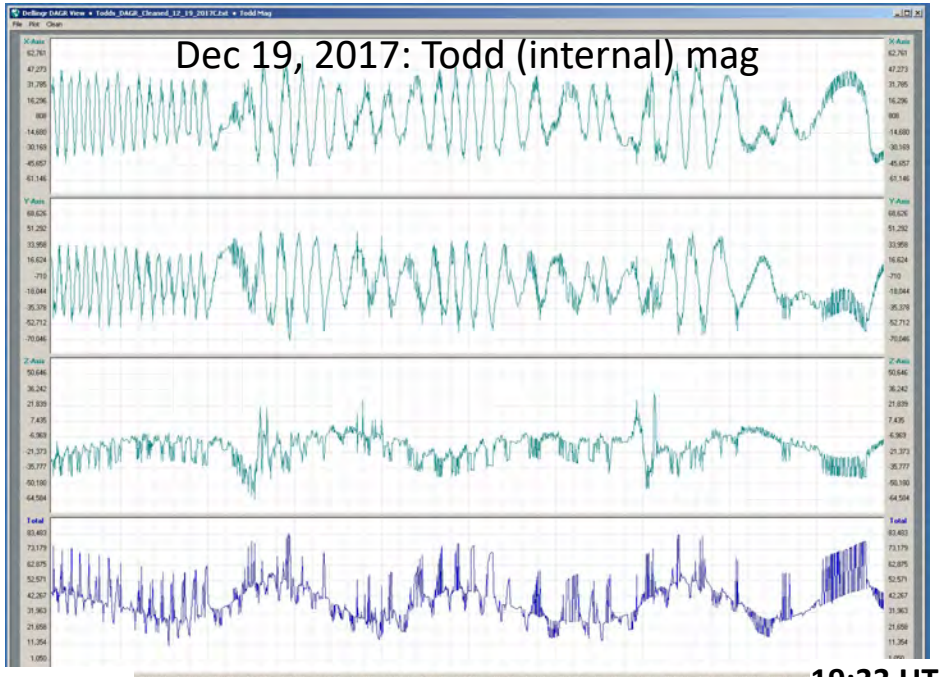

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NASA Artemis Lunar Gateway HERMES NEMISIS

- HERMES: Heliophysics Environmental and Radiation Measurement Experiment Suite
- NEMISIS: Noisy Environment Magnetometer in a Small Integrated System