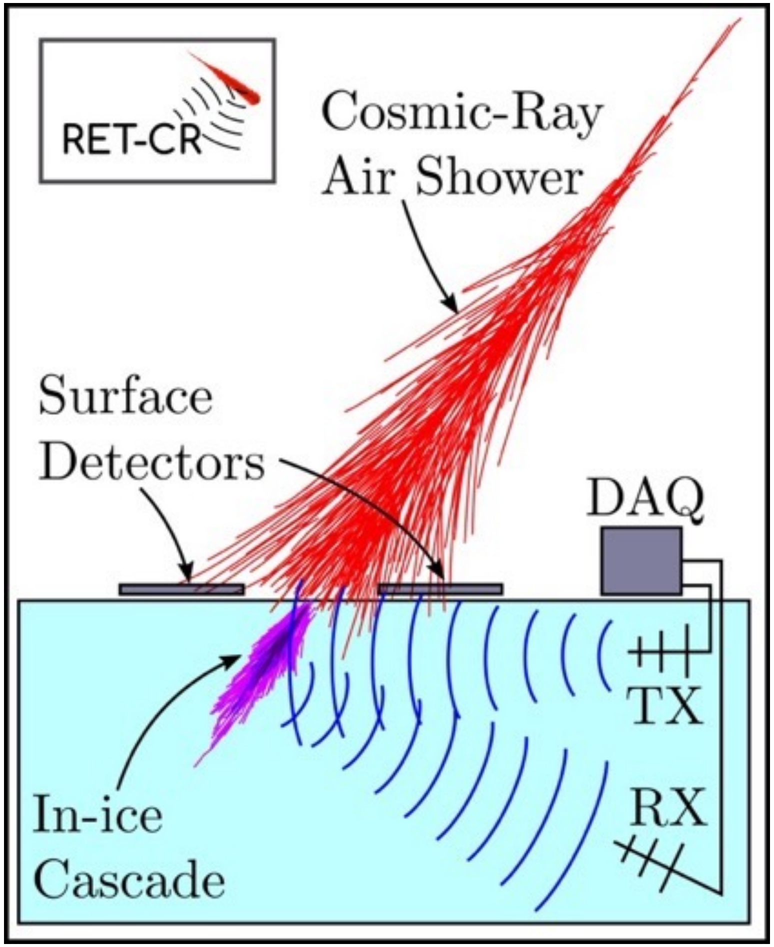
# Deployment and Status Update of the Radar Echo Telescope

**Dylan Frikken** on behalf of the Radar Echo Telescope collaboration

# Outline

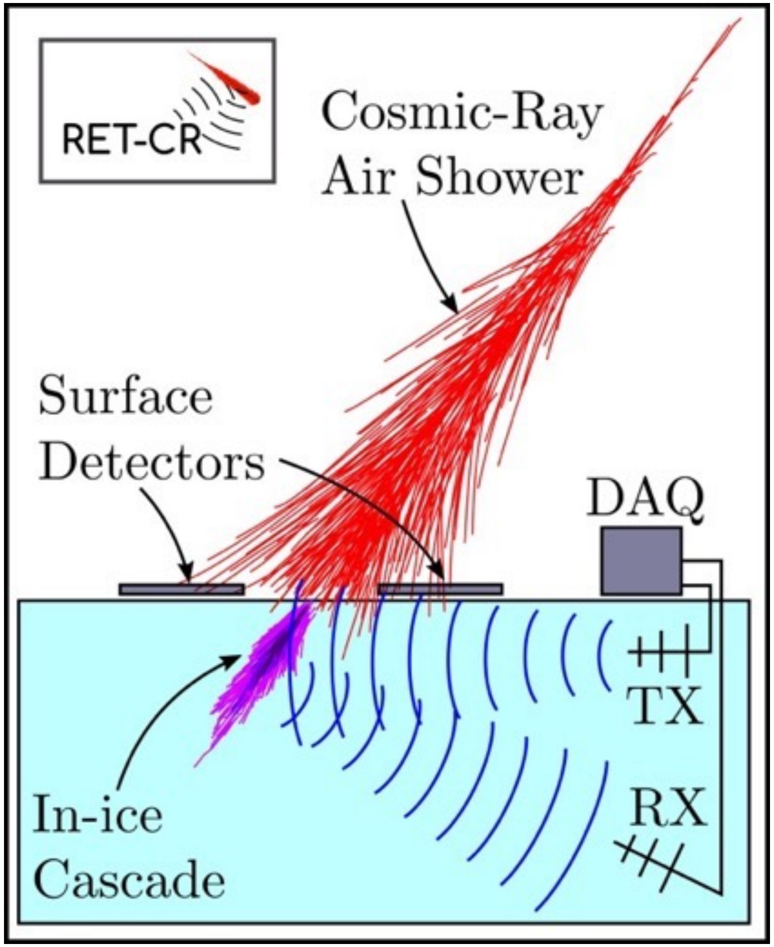
- Radar Echo Telescope for Cosmic Rays (RET-CR)
  - Big Picture
  - Method validation
  - Detector geometry
  - Deployment




RADAR ECHO TELESCOPE

# What is the Radar Echo Telescope for Cosmic Rays?

- Big Picture:
  - Detect the ionization trail from a in-ice cosmic ray shower via active radar sounding
  - Use in-ice cosmic ray showers to test the radar echo method for a future neutrino detector (RET-N)

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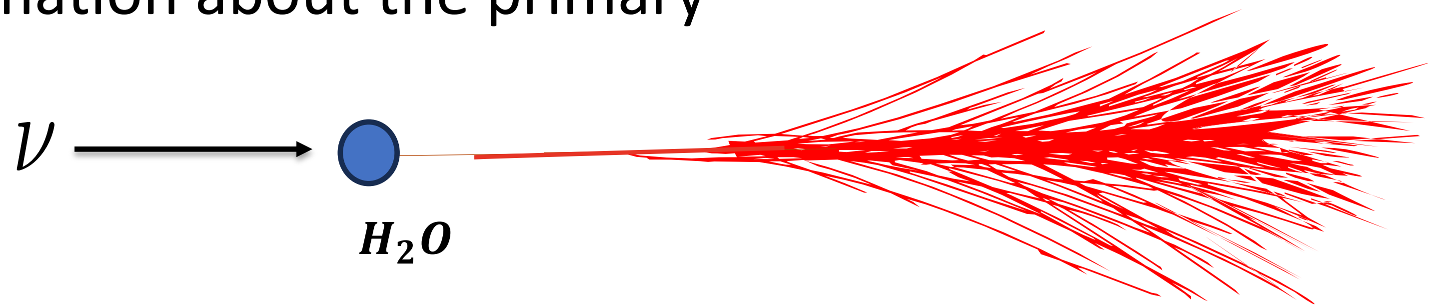
# Ionization Trail

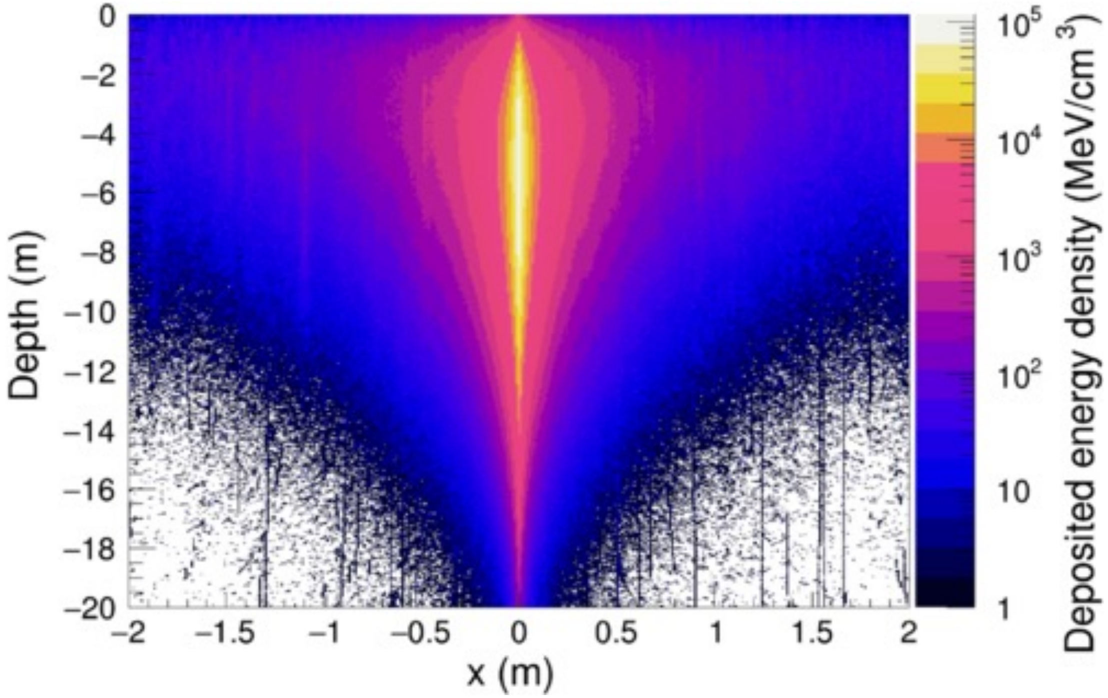
- High-energy particle interactions create a cascade of relativistic particles
  - These cascade particles lose energy to ionization leaving behind a short-lived blob of charge, called the Ionization Trail
    - The length of time this trail persists (the Free Electron Lifetime) depends on the material properties for free electrons
  - The length and direction of this Ionization trail can tell us information about the primary



# In-Ice Cosmic Rays

- At high elevation, the in-ice cascade contains a significant fraction of the total cosmic ray shower energy

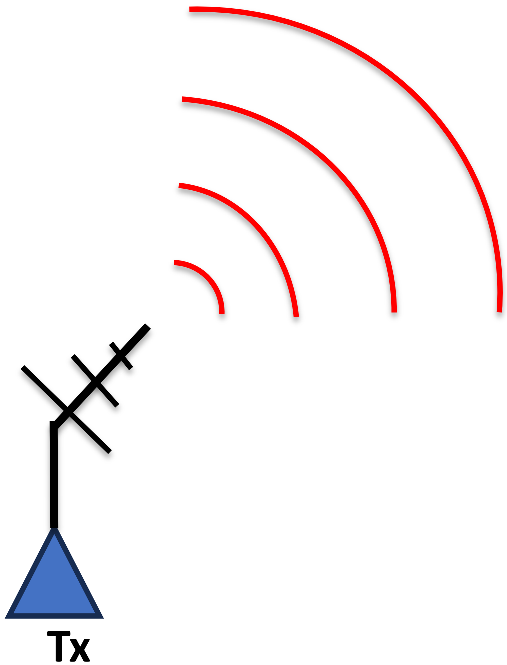
- There is a relative abundance of high-energy cosmic rays compared to UHE neutrinos (~1/day for cosmic rays, ~1/decade for UHE neutrinos)




https://doi.org/10.1103/PhysRevD.106.043023

# Radar

- Basic concept:
  - A transmitter (Tx) broadcasts radio waves into a volume



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- Basic concept:
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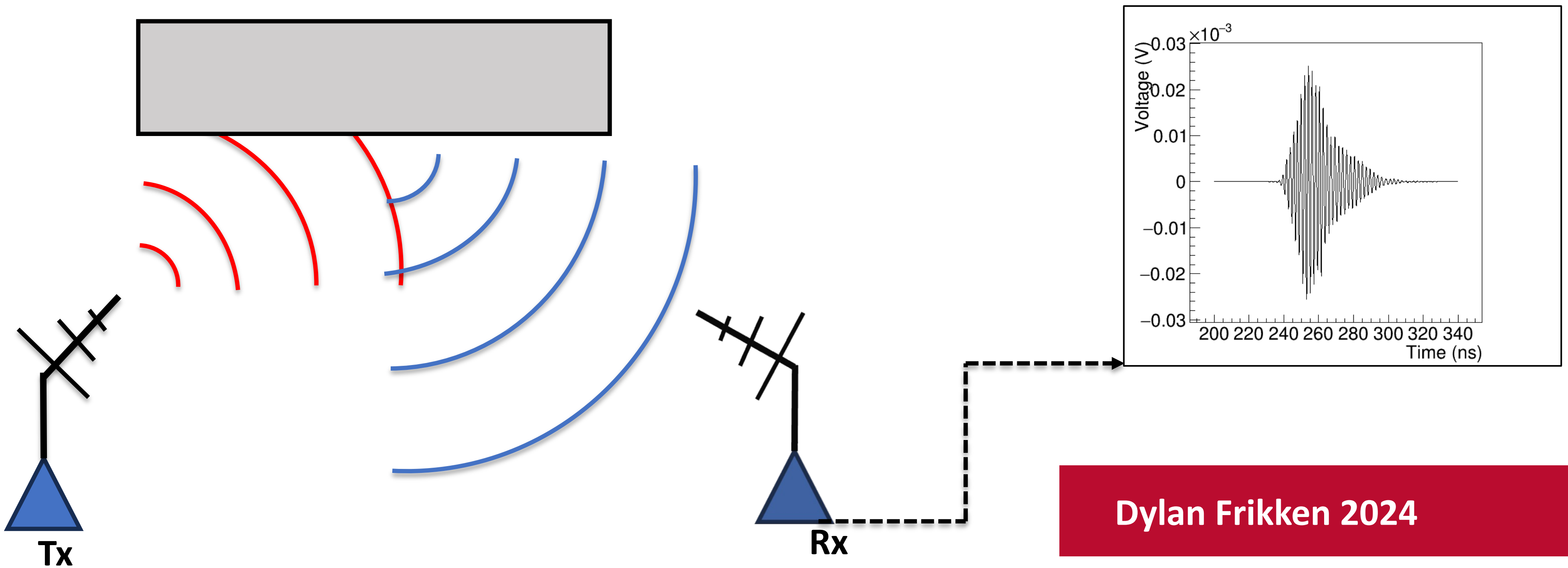
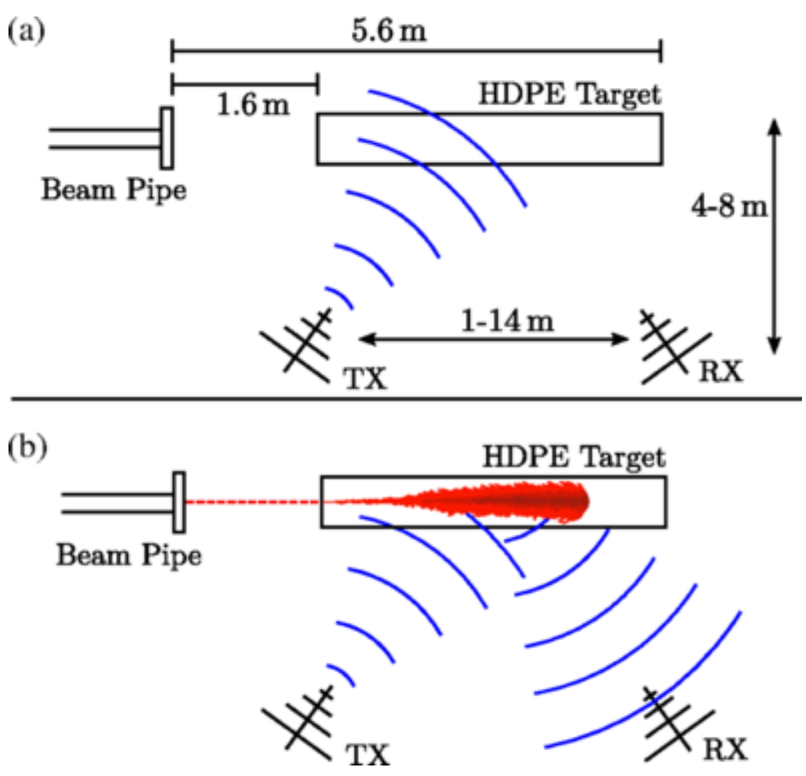
  - Receiver(s) (Rx) monitor that volume
  - If some object that reflects radio is present in the volume, the transmitted signal will reflect into the receiver



# Method Validation:
# SLAC T-576

- Several experiments ran over many decades, culminating in the T-576 experiment at SLAC
    - The beam of electrons had a similar energy density to the ionization trail expected for UHE neutrinos and in-ice high energy cosmic ray showers
    - High-density Polyethylene (HDPE) has similar radio propagation properties to polar ice
    - Interrogated a beam illuminated target with a radar system, attempting to measure a radar echo off the ionization trail



# Method Validation:
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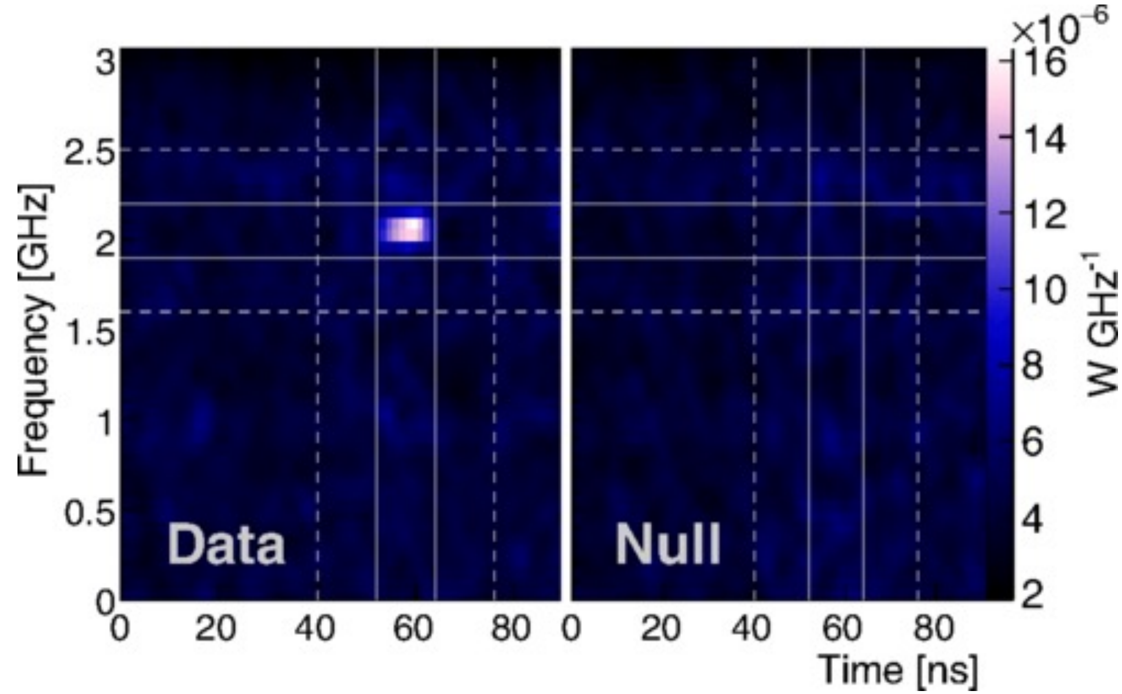
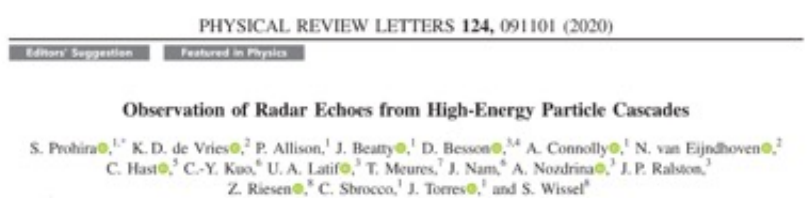



**First observation of a radar echo off a particle induced ionization trail!**



PHYSICAL REVIEW LETTERS **124,** 091101 (2020)

Editors' Suggestion | Featured in Physics

**Observation of Radar Echoes from High-Energy Particle Cascades**

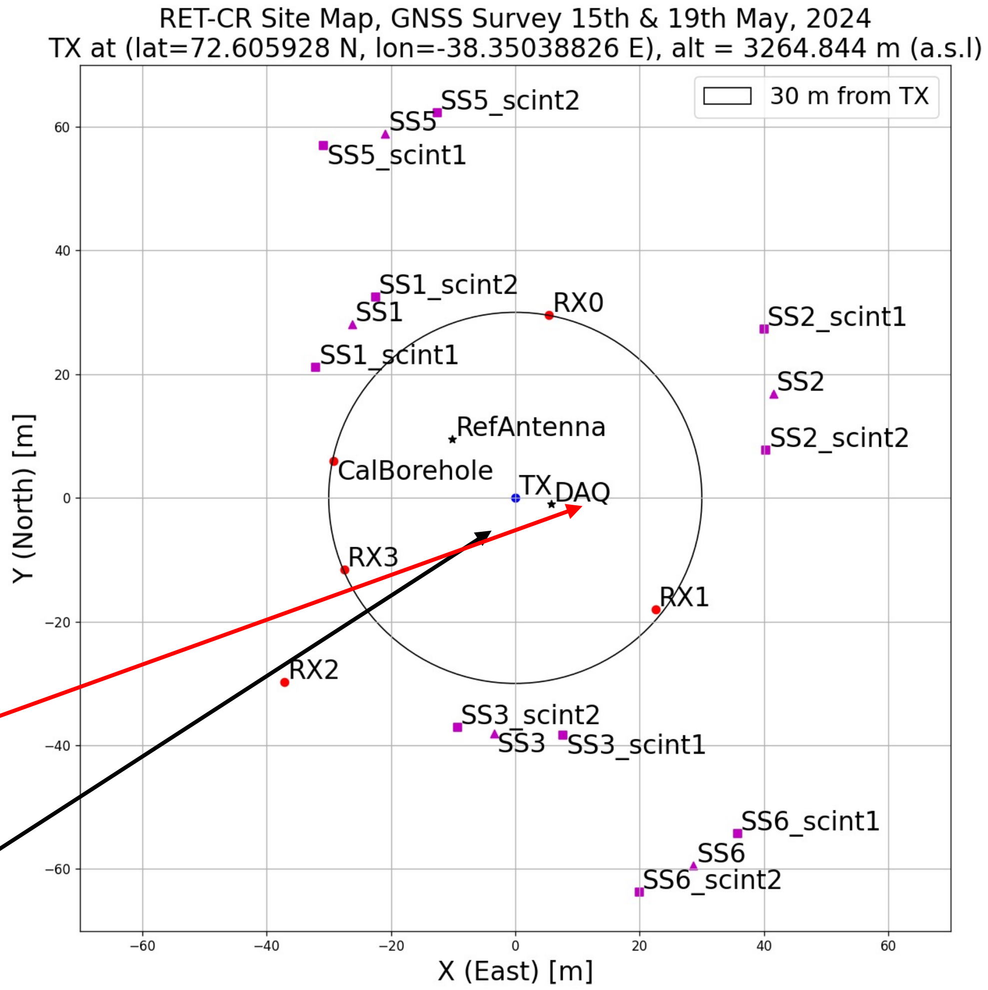
S. Prohira,[1,*] K. D. de Vries,[2] P. Allison,[1] J. Beatty,[1] D. Besson,[3,4] A. Connolly,[1] N. van Eijndhoven,[2] C. Hast,[5] C.-Y. Kuo,[6] U. A. Latif,[3] T. Meures,[7] J. Nam,[6] A. Nozdrina,[3] J. P. Ralston,[3] Z. Riesen,[8] C. Sbrocco,[1] J. Torres,[1] and S. Wissel[8]

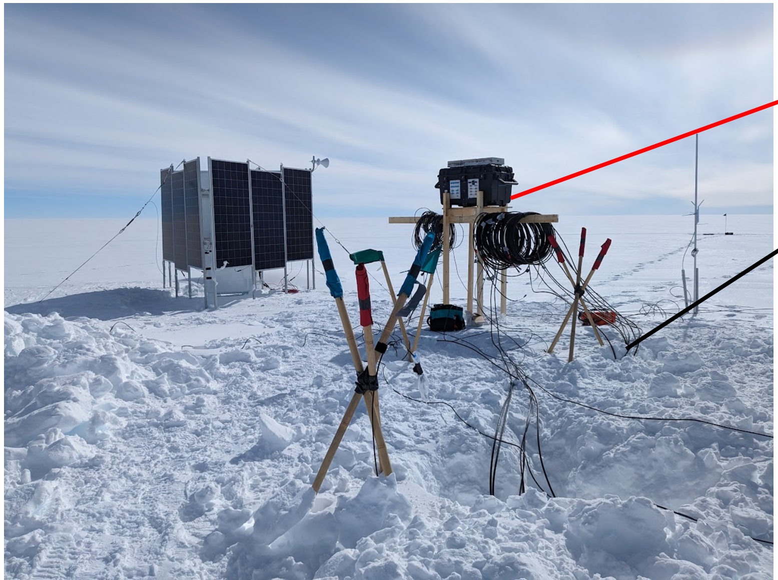
# RET-CR 2023 Season

- RET-CR was deployed in May 2023 and ran for just under a month
- The 2023 RET-CR season was cut short due to loss of DAQ resulting from overheating
- The main system enclosure (DAQ) was placed into a dug hole and covered with plywood to keep drifting snow from entering its filter system
- Excess heat from the Tx amplifiers caused the DAQ enclosure to melt the hole and break cables

# RET-CR Layout

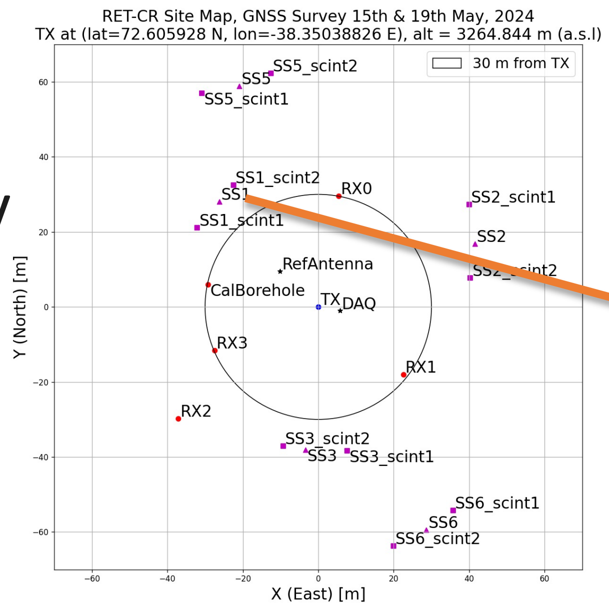
- Phased-Array Transmitter (Tx)
- Tx at center of geometry
- Tx broadcasting 180 MHz continuous sinewave (CW)
- Four receivers (Rx)
- Five surface stations

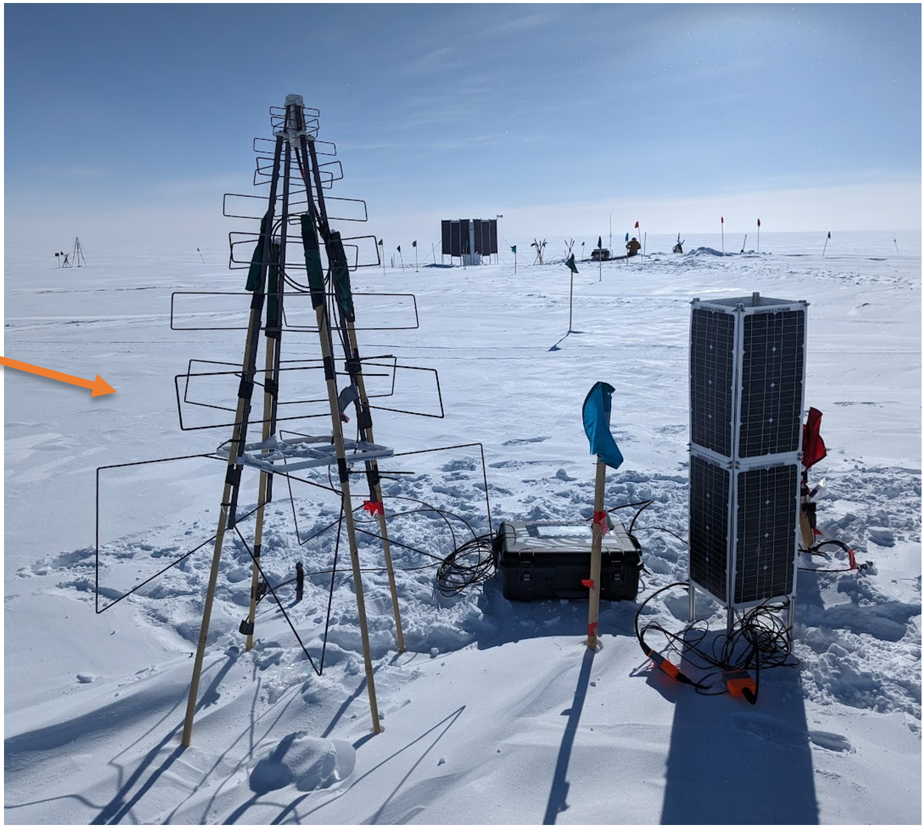


# RET-CR Surface Stations

- Five independent surface stations
- Two scintillator panels separated by 20 m
- One SKALA antenna
- The scintillator panels coincidence is sent to central station which forms low level trigger



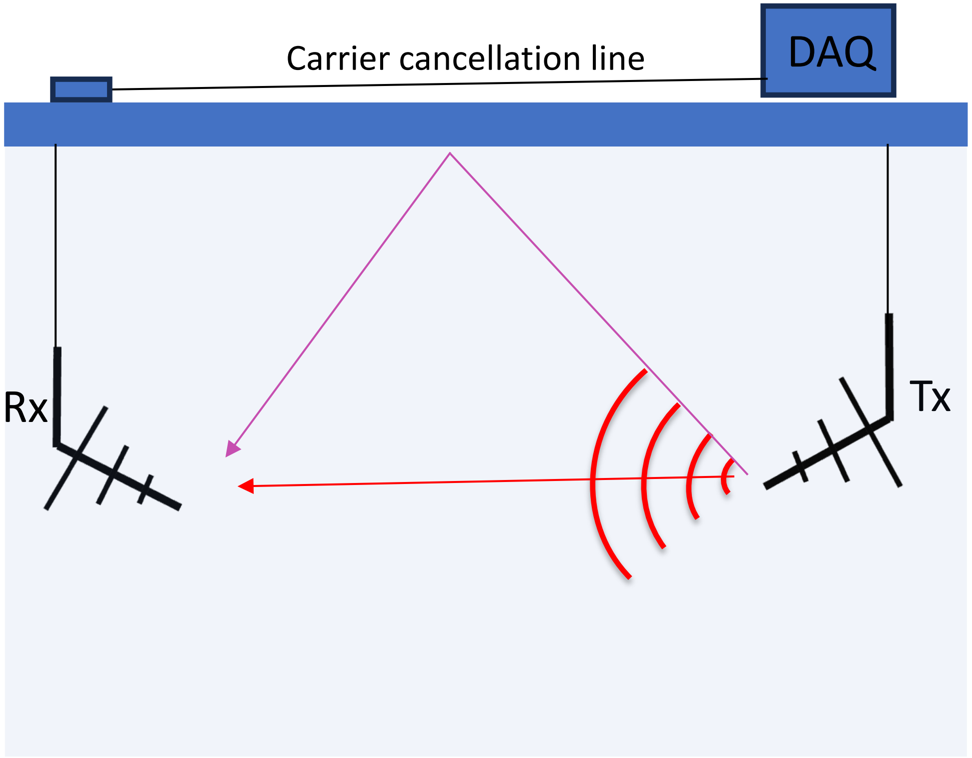



# RET-CR 2024 Season Improvements

- New thermal management system
  - DAQ crate is now above surface
  - Heatsink cools the Tx amplifiers
- New scintillator timing system
- New surface station electronics
- Two additional surface stations (far baseline outriggers)
- One additional receiver
- Various on-site ice property measurements taken

# RET-CR Transmitter Cancellation

- Problem: high power transmitter close to receivers will saturate amplifiers
- Solution: cancel the direct and reflected transmit signal out of the receiver path
- Cancellation signal is input to Rx line before amplification



# RET-CR Transmitter Cancellation

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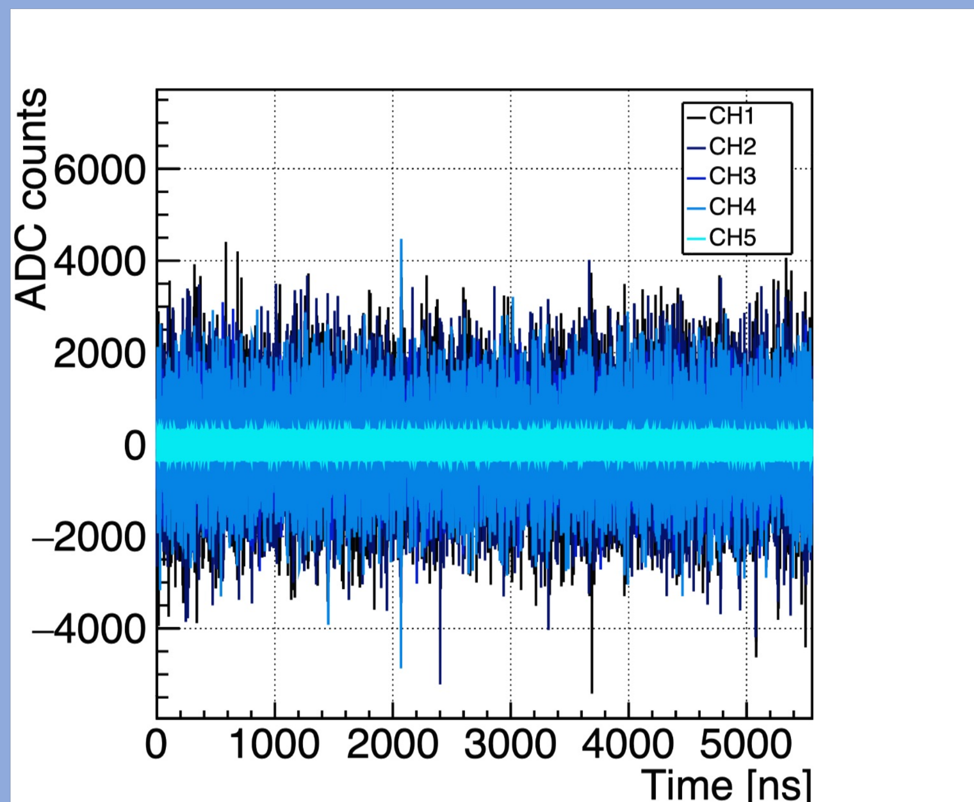
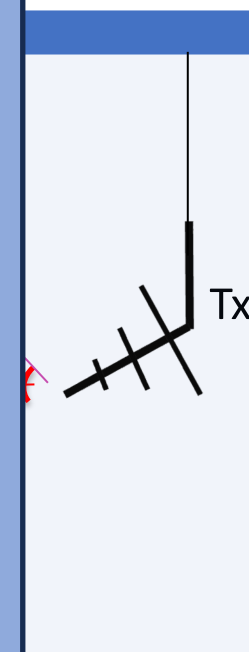
    line

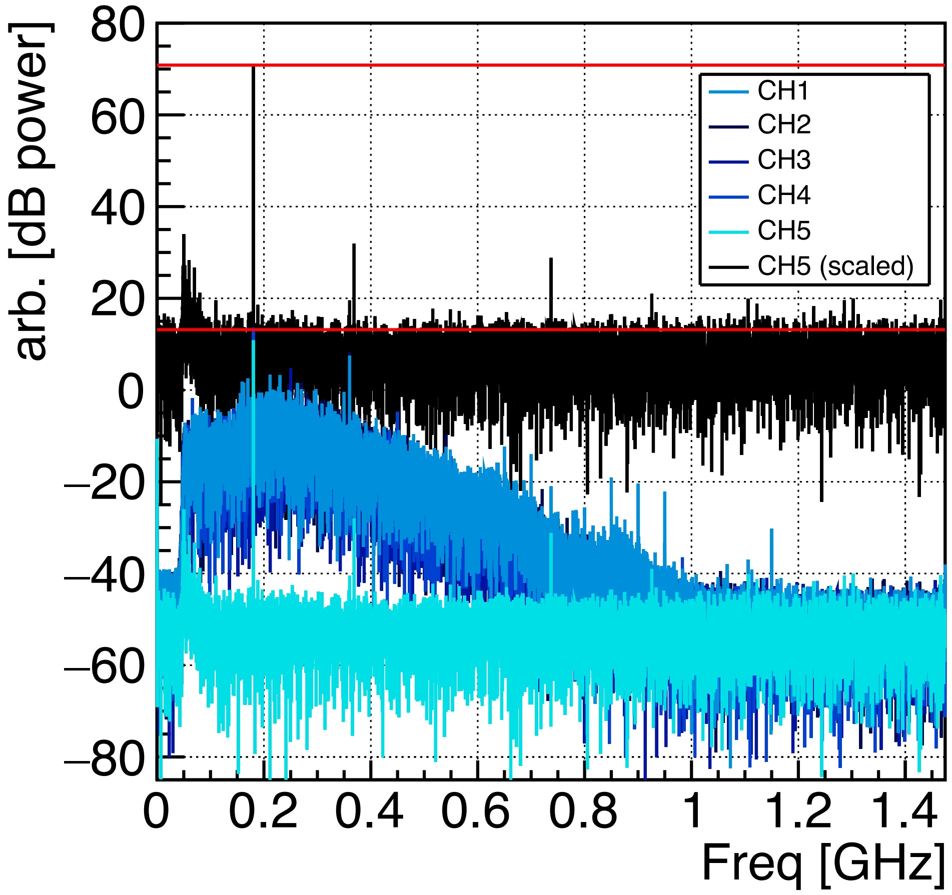
## Results: Thermal Noise!



# RET-CR Initial Performance

- Second stage of transmitter signal cancellation routine shows a ~60 dBm/Hz reduction of received power
- Prevents saturation of receiver antennas while allowing signal through uncancelled



# RET-CR 2024 Deployment

- May 2024 Deployment team:
  - Advanced Team (1 May – 22 May)
    - Steven Prohira – University of Kansas
    - Simon De Kockere - Vrije Universiteit Brussel
    - Dylan Frikken – Ohio State University
  - Late Team (9 May – 22 May)
    - Alex Kyriacou – University of Kansas
    - Curtis McLennan – University of Kansas

# RET-CR Deployment

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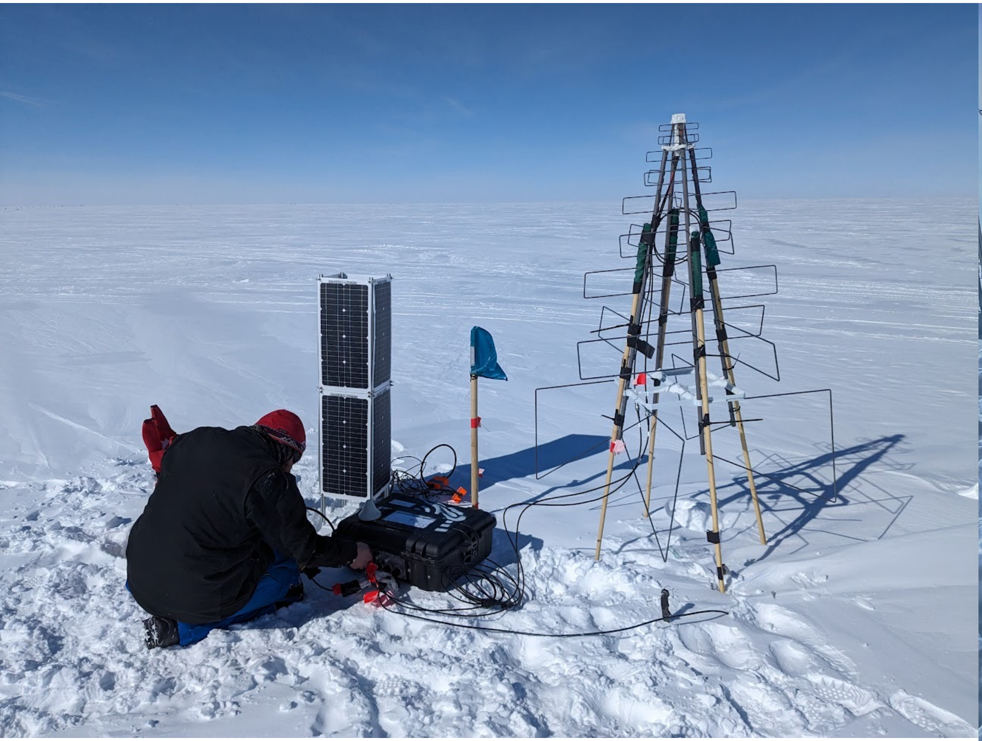
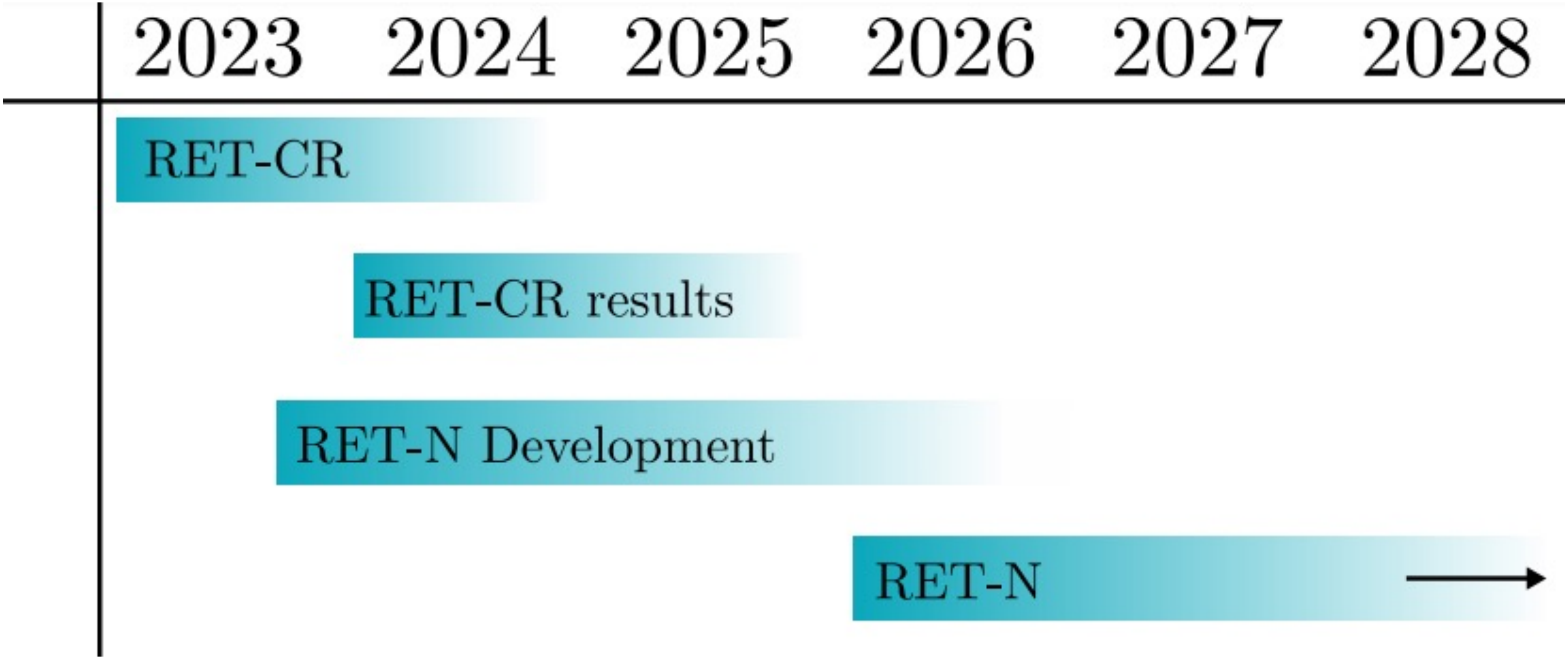


# Acknowledgements

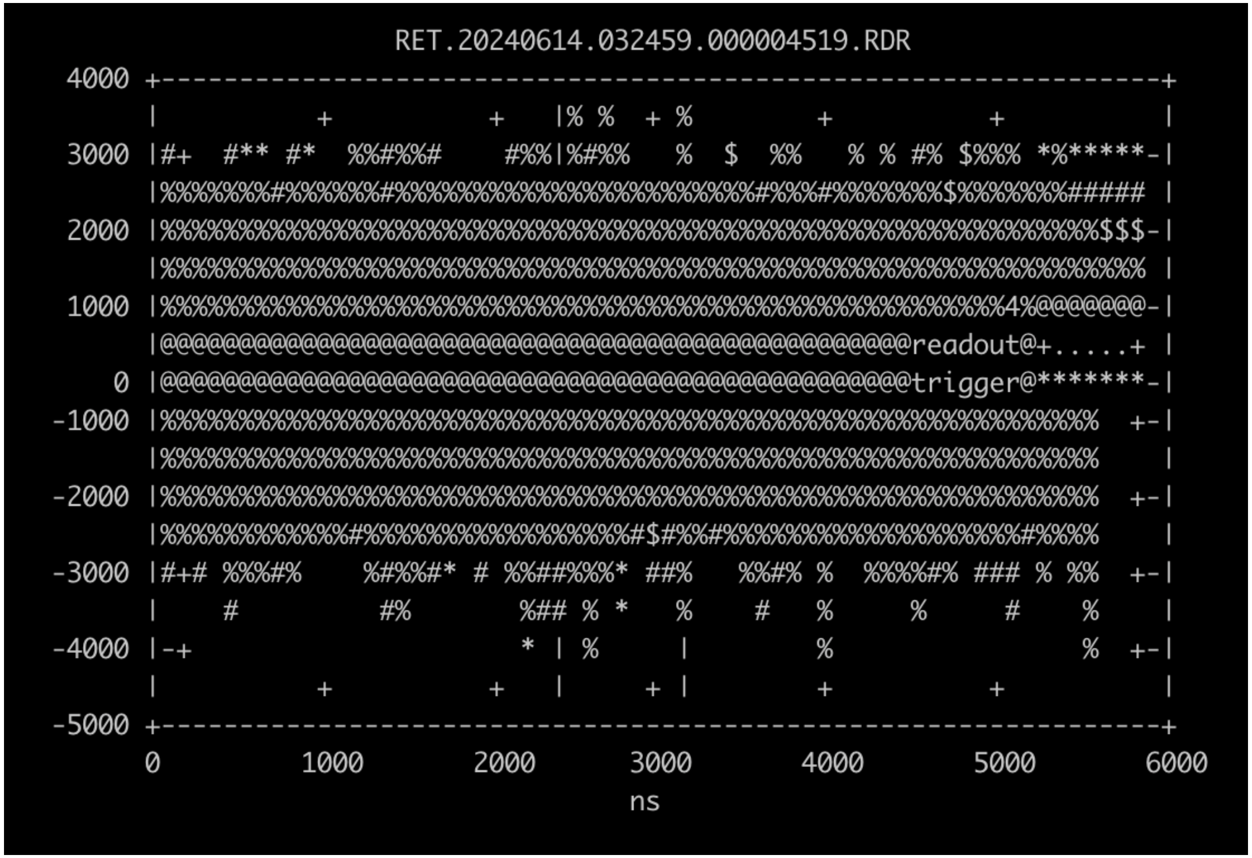
- We would like to acknowledge the following people/groups
  - The CODALEMA collaboration for providing the surface radio DAQs used for RET-CR
  - The IceCube collaboration for providing the scintillator panels
  - The Summit Station staff for providing us cargo logistics, food, warmth, and fun!

# Future Timeline



# RET-CR Status Update

- Even with the bandwidth limitations of a remote station, we can still monitor the experiment in real time!!
- The “waveform” on the right is a forced triggered event from last night



# Thank you!

- RET Collaboration
  - The Ohio State University
  - IIHE/Vrije Universiteit Brussel & Université Libre de Bruxelles
  - University of Kansas
  - Penn State University
  - UW Madison
  - National Taiwan University
  - SLAC National Accelerator Laboratory
  - University of Chicago
  - Radboud University

erc
European Research Council
Established by the European Commission

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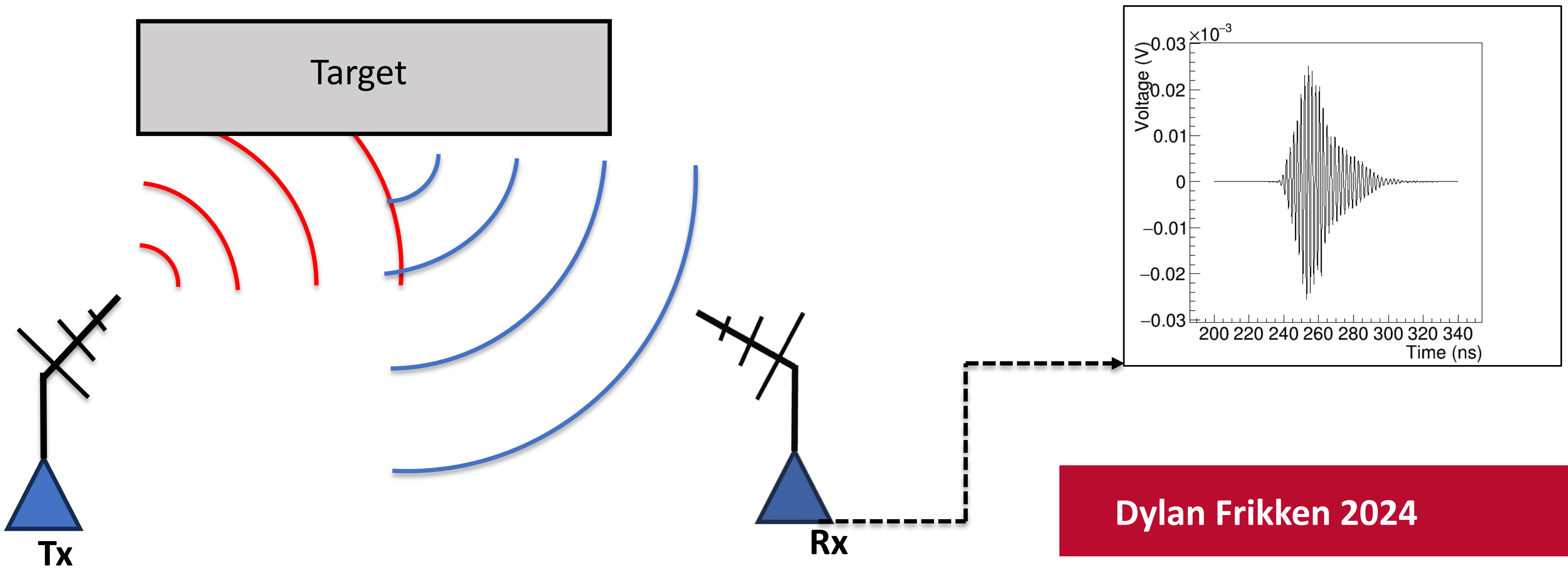
# Backup

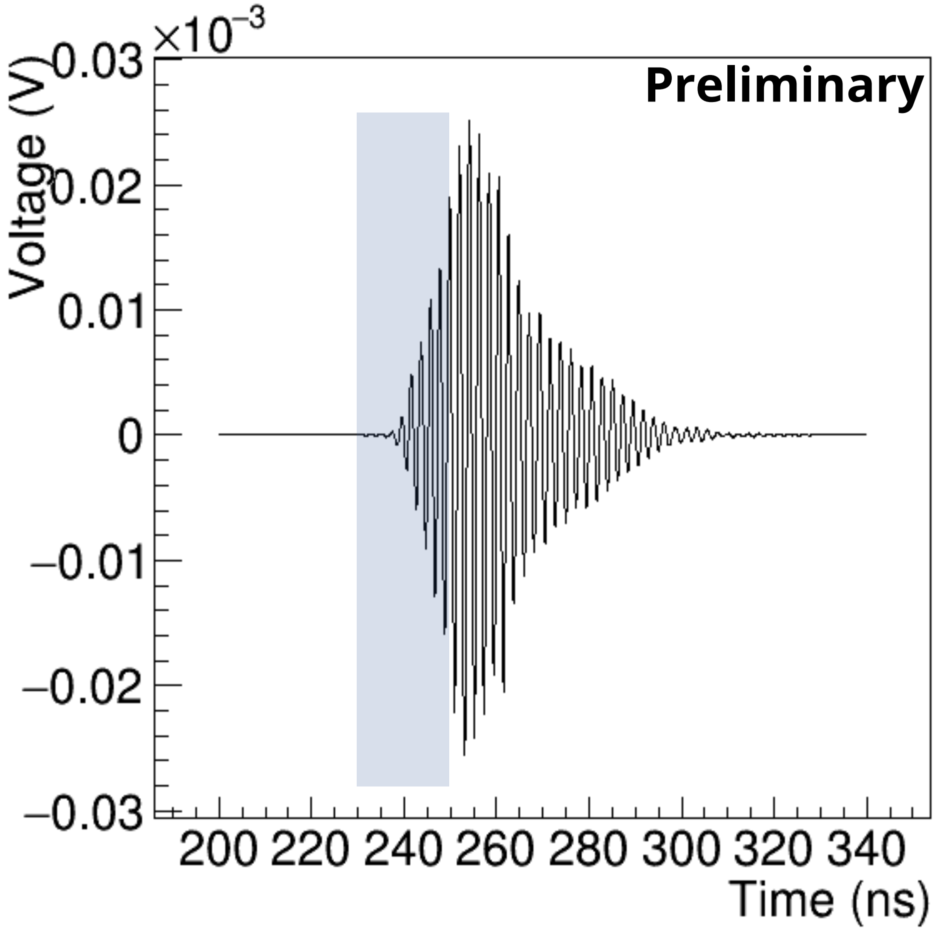
# Radar

- Radar Cross Section
  - How ”detectable” is the target using radar?
  - Dictates the amount of power of the reflected (blue) waves
  - Ignores transmitted signal properties, media effects, and baseline distance
  - Goal of stealth plane design is to minimize this value



# Investigation of Received Signal Properties

- RET simulated using RadioScatter (in-house radar reflection simulation with GEANT4) arXiv:1710.02883




Transmit frequency (450 MHz)

- Three phases of a RET event:
  - Cascade development

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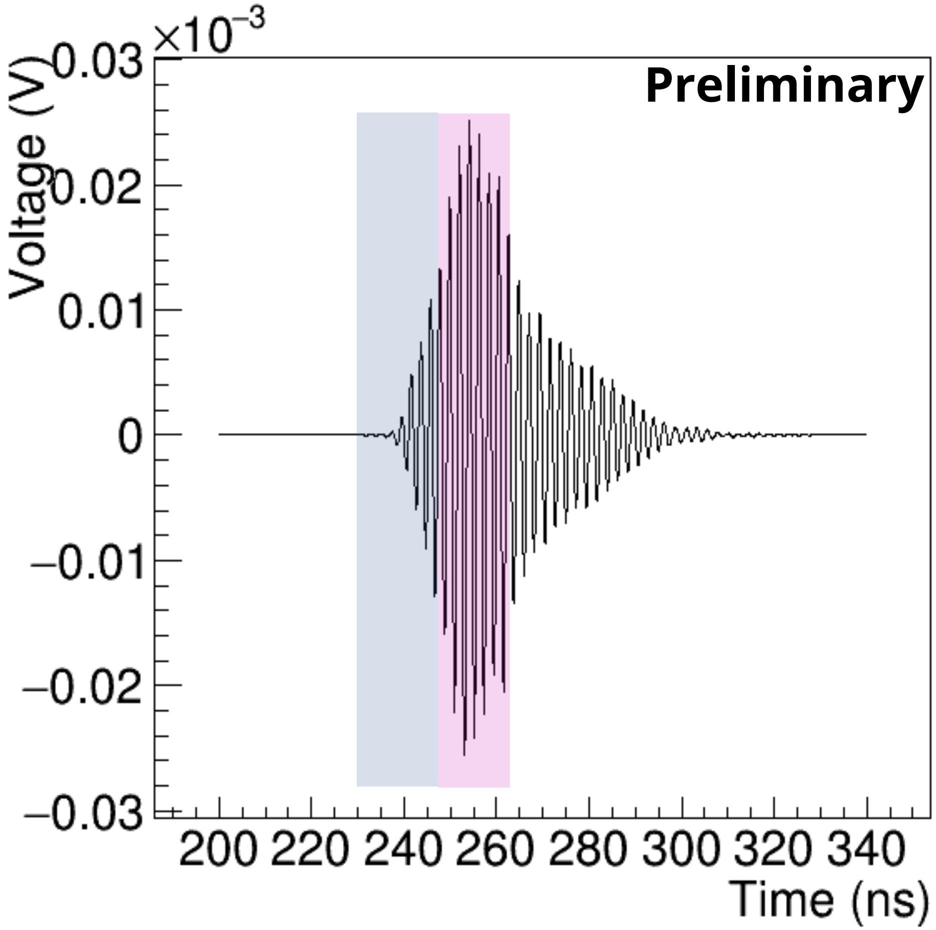


**Transmit frequency (450 MHz)**

- Three phases of a RET event:
  - Cascade development
  - Cascade as a static reflector

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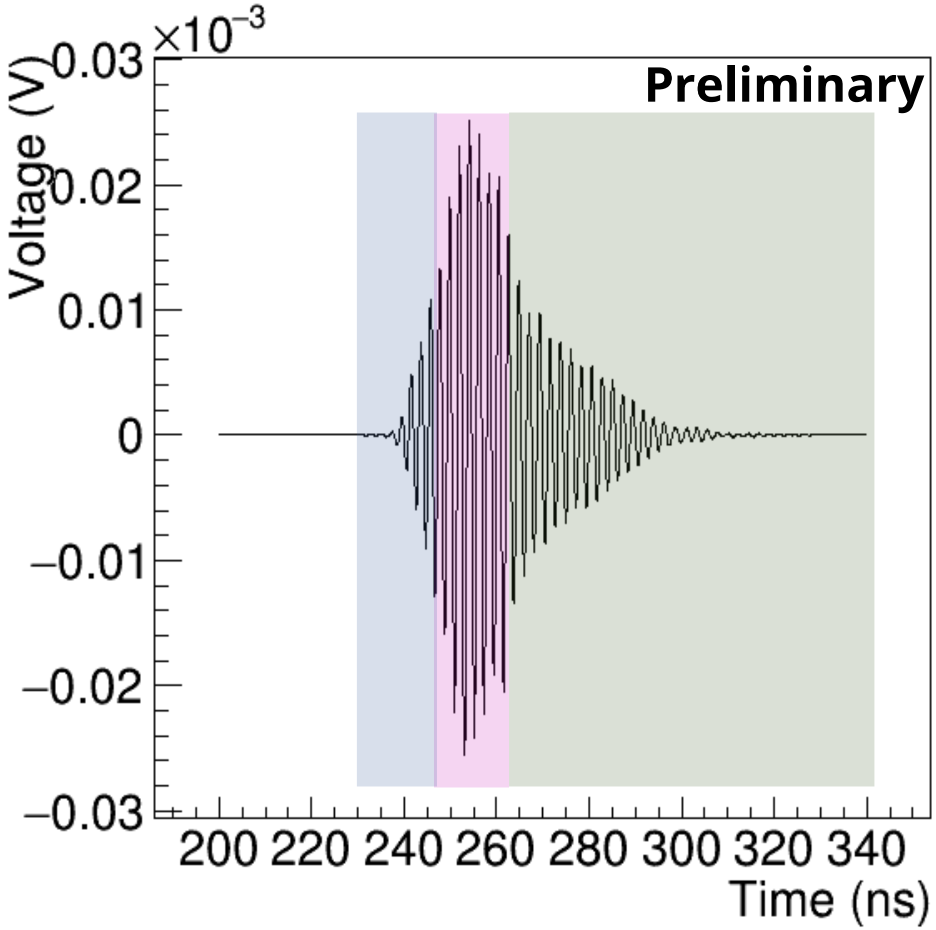


**Transmit frequency (450 MHz)**

- Three phases of a RET event:
  - Cascade development
  - Cascade as a static reflector
  - Recombination/Attachment