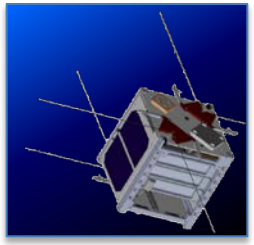

PROPCUBE
Science Mission Objectives

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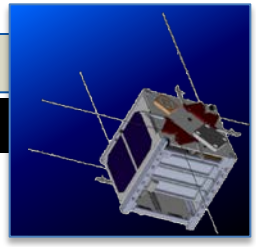
Giovanni Minelli, Dan Sakoda, Naval Post Graduate School, Monterey, CA

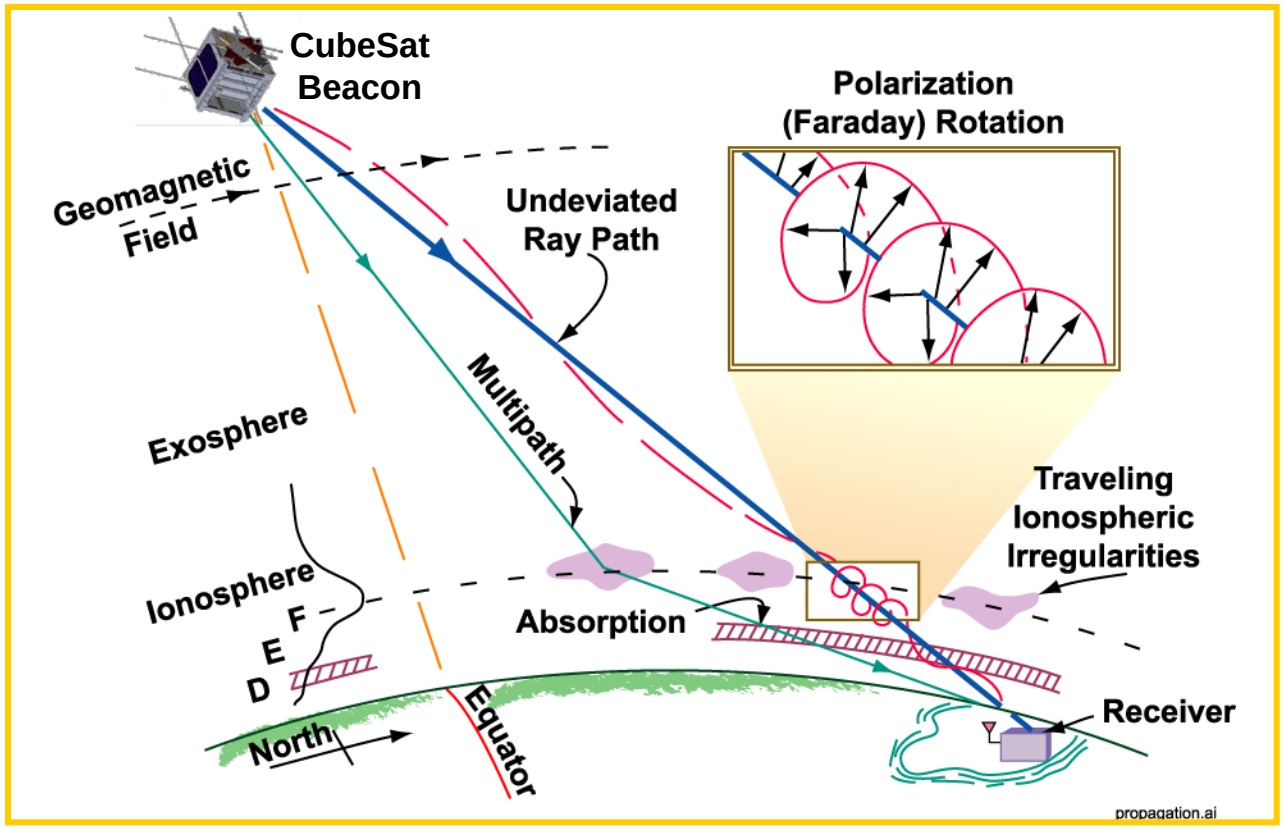
Frank, Lind, Juha Vierinen, Phil Ericson, MIT Haystack, Millstone Hill, MA

Mike Sulzer, Arecibo Observatory, Arecibo PR

Work Funded by NRL 6.1 Base Program

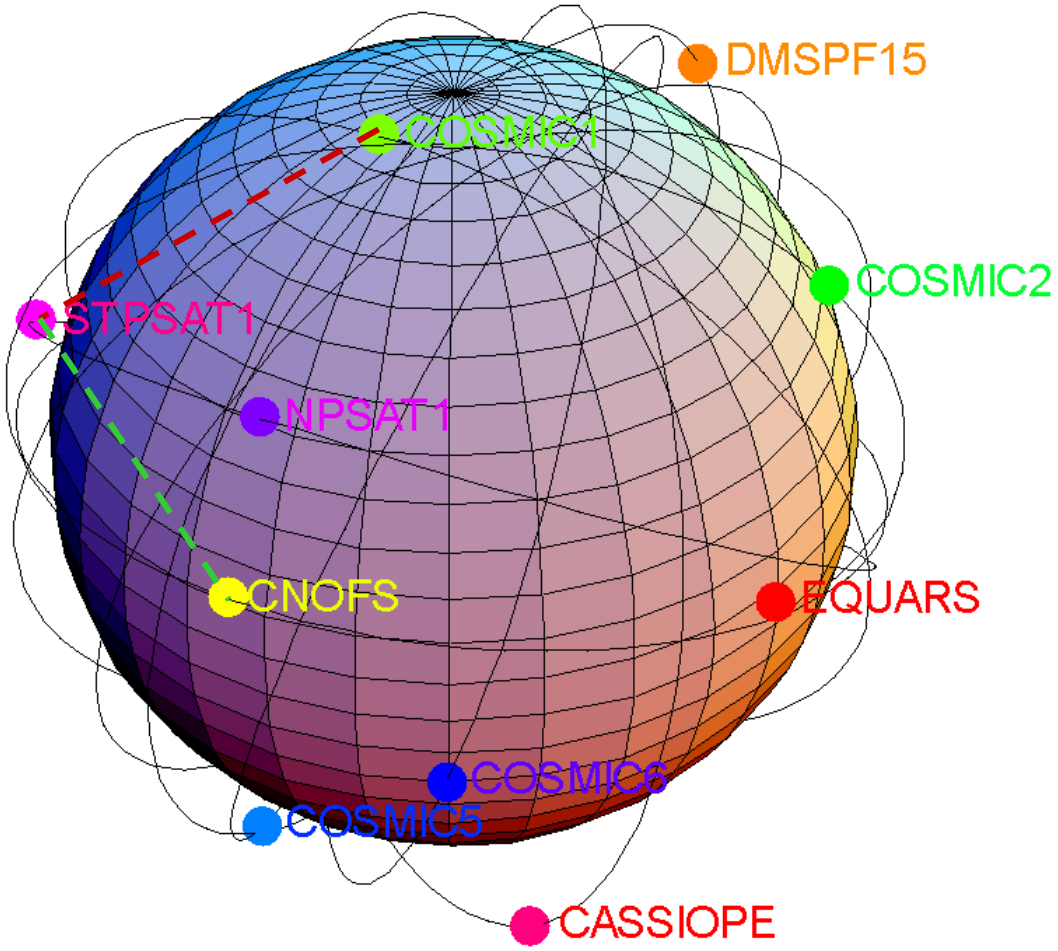
Major Ionospheric Propagation Effects on Space Beacon-to-Ground Links





- Phase Fluctuations
- Amplitude Fluctuations
- Absorption
- Frequency Shifts
- Faraday Rotation
- Group Delay
- Scattering
- Multipath

Recent NRL Beacons in Low Earth Orbit



- NRL CERTO Beacons
  - Fixed Frequency with No Modulation
    - VHF/UHF/L-Band
    - 150/400/1066 $^{2}/_{3}$ MHz
    - Right Hand Circular Polarization
  - **DMSP/F15 (In Operation)**
  - COSMIC (6 – Not Operating)
  - **ePOP CASSIOPE (In Operation)**
  - AFRL C/NOFS (Not Operating)
- NRL COMMX
  - TACSat4 (Not Operating)
  - UHF SATCOM Frequency Translator
  - Detection of Ionospheric Irregularities
- NRL Beacon Receivers
  - Ground Networks
    - Caribbean
    - South America
    - Alaska
  - Satellite Based Receiver
    - CITRIS on STPSAT1 (Not Operating)
    - Satellite to Satellite Irregularity Detection

DMSP/F15 (97.5 ° Inclination) and CASSIOPE/ePOP (81° Inclination) Satellites with Three Frequency CERTO Beacons

Satellite Beacon	UHF Frequency (MHz)	Other Frequencies (MHz)	Other Science Instruments	Contact Org.
DMSP/CERTO	400.032	150.012, 1066.752	SSIES, SSULI, SSUSI	NRL
ePOP/CERTO	400.032	150.012, 1066.752	RRI, GAP, IRM, SEI, MGF, FAI, NMS	NRL, U. Calgary

PROPCUBE Flor and Merryweather Beacon Satellites October 8 2015 Launch with 65° Inclination at 660 km Altitude

Beacon	UHF Frequency (MHz)	Other Frequencies (MHz)	Other Science Instruments	Contact Org.
PROPCUBE 1, 3	380-400	2340-2380	None	NRL

Future PROPCUBE Fauna Beacon Satellites TBD 2016 FORMOSAT-5 Launch 450 km x 720 km, 97.4°

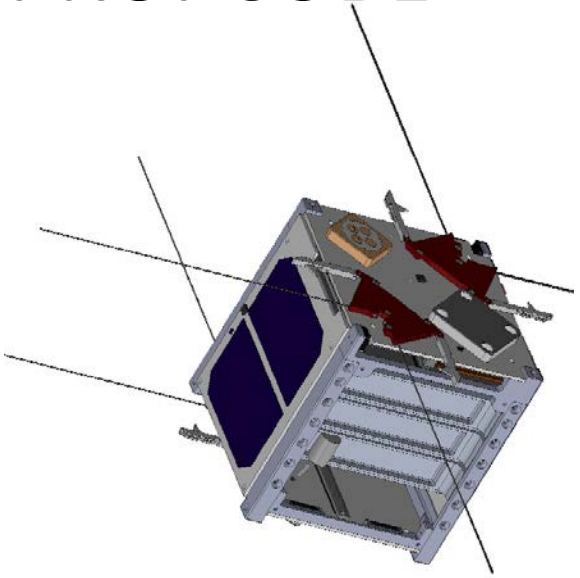
Beacon	UHF Frequency (MHz)	Other Frequencies (MHz)	Other Science Instruments	Contact Org.
PROPCUBE 2	380-400	2340-2380	None	NRL

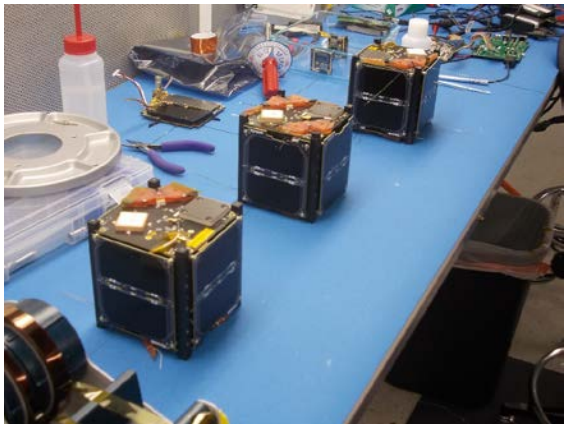
Satellites Released During STP-2 Mission
October 2016 Launch with 24.5° Inclination at 720 km Altitude
STP-2 Launch March 2017

Beacon	UHF Frequency (MHz)	Other Frequencies (MHz)	Other Science Instruments	Contact Org.
COSMIC II-1	400.90	965.5928, 2200.2702	GPS-RO, IVM	SMC/AFRL
COSMIC II-2	400	960, 2200	GPS-RO, IVM	SMC/AFRL
COSMIC II-3	400	960, 2200	GPS-RO, IVM	SMC/AFRL
COSMIC II-4	400	960, 2200	GPS-RO, IVM	SMC/AFRL
COSMIC II-5	400	960, 2200	GPS-RO, IVM	SMC/AFRL
COSMIC II-6	400	960, 2200	GPS-RO, IVM	SMC/AFRL
TBEx-1	400.032	150.012, 1066.752	None	SRII
TBEx-2	400.032	150.012, 1066.752	None	SRII
NPSAT1-CERTO	400.032	150.012, 1066.752	Langmuir Probe	NPG/NRL

Radio Propagation CubeSat: PROPCUBE

- PROPCUBE
  - 380 to 400 MHz UHF Band
  - 2375 to 2390 MHz S-Band
  - Frequency Pairs: (2376/396) = 6
- Launch Schedules
  - 8 October 2015 (PROCUBE-1 Flora and PROPCUBE-3 Merryweather) 64 Degree Inclination GRACE
  - October 2016 (PROPCUBE-2 Fauna) 97.4 Degree Inclination Space-X Falcon 9
- Ionospheric Electron Density and Irregularities
  - Total Electron Content by Differential Group Delay
  - Plasma Irregularities by Amplitude and Phase Scintillations
  - Detection of Artificial Irregularities from High Power HF Waves

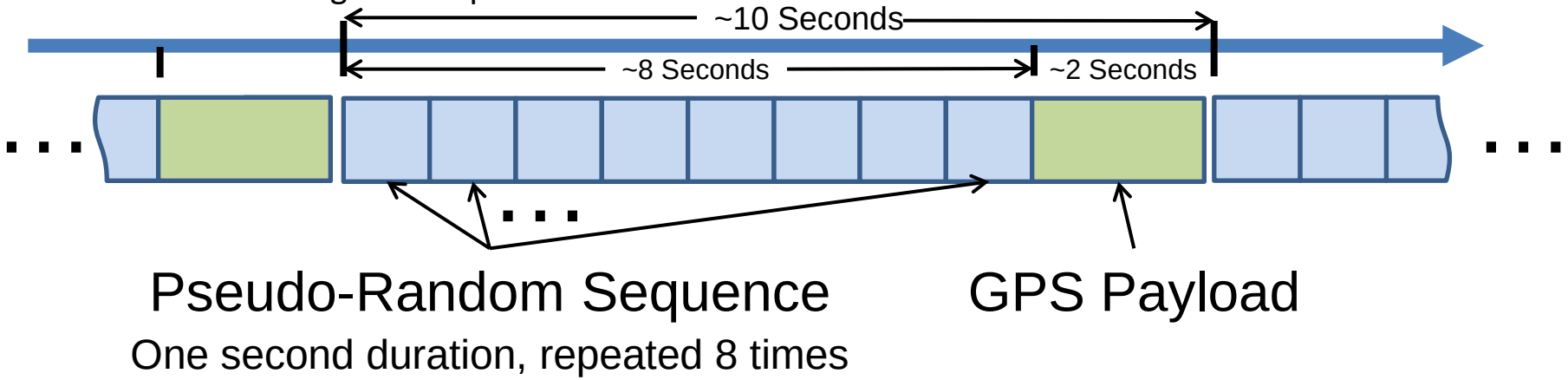




PROPCUBE Signal Architecture

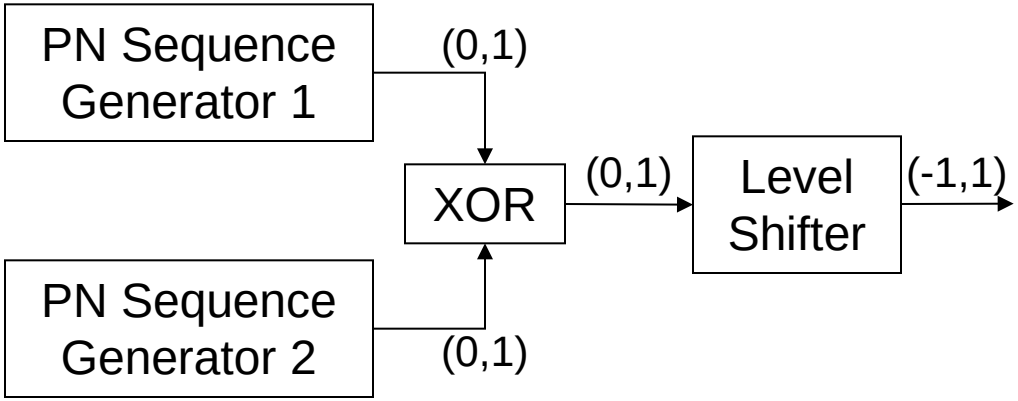
- Objectives
  - Design a transmitted waveform suitable for measuring Time Difference (Group Delay) and Frequency Difference (Differential Doppler) between a pair of frequencies.
  - Transmit a payload containing approximately 64 GPS location measurements
  - Repeat these transmissions every 9.84 seconds

- Method
  - Group Delay/Differential Doppler: Transmit a 1.016 Meg sample per second signal with duration of 0.984 seconds, repeated 8 times.
  - Payload: Transmit a 1.016 Meg sample per second signal with duration of 1.967 seconds containing 64 GPS packets



Radio Beacon Modulation

- Gold Code Generator



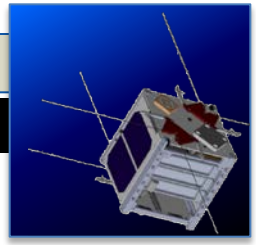
- Characteristics
  - Chip Rate 1.016118 Mbits/s (0.9841374 (3) micros)
  - Sequence Period 9,998,848 chips
    - 8 x 1,000,000 pseudo-random sequence chips
    - 1 x 64 GPS Messages x (61 x 8) bits per message x 64 spreading/Gold code chips per bit of message
  - Ranging Code: 7.8731 Seconds
  - Satellite Position Information: 1.96714 Seconds
  - Total Sequence: 9.84024 Seconds

PROPCUBE Mission Science

- Science Objectives
  - Ionospheric Electron Density and Irregularities
    - Total Electron Content by Differential Group Delay
    - Plasma Irregularities by Amplitude and Phase Scintillations
    - Detection of Artificial Irregularities from High Power HF Waves
  - Multiple CubeSat Location and Tracking
    - Early Detection of CubeSat Deployment
    - Separation of Satellites by Doppler Frequency Shifts
  - Precise CubeSat Position Determination
    - Spread Spectrum Precision Ranging to Satellites
    - Orbit Analysis to Provide Position and Satellite Ephemeris
  - Precision Characterization of the Arecibo “Big-Dish” Pattern
    - UHF and S-Band Sidelobe Characterization for Radio Astronomy
    - Intensity Recorded as PROPCUBEs Pass Through Dish Antenna Beam

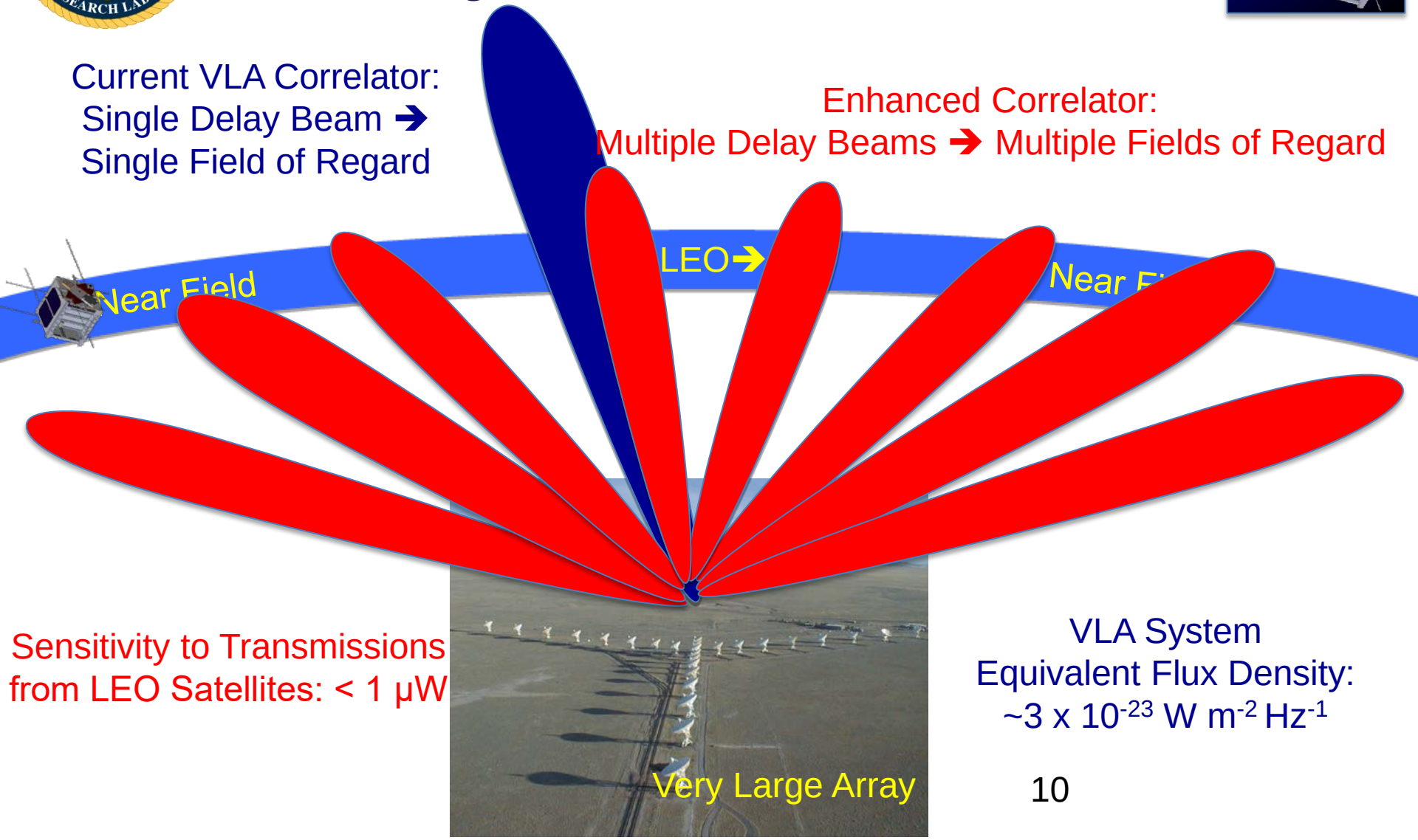
PROPCUBE Concept of Operation

Satellite Tracking and Antenna Pattern Characterization



Current VLA Correlator:
Single Delay Beam ➔
Single Field of Regard

Enhanced Correlator:
Multiple Delay Beams ➔ Multiple Fields of Regard



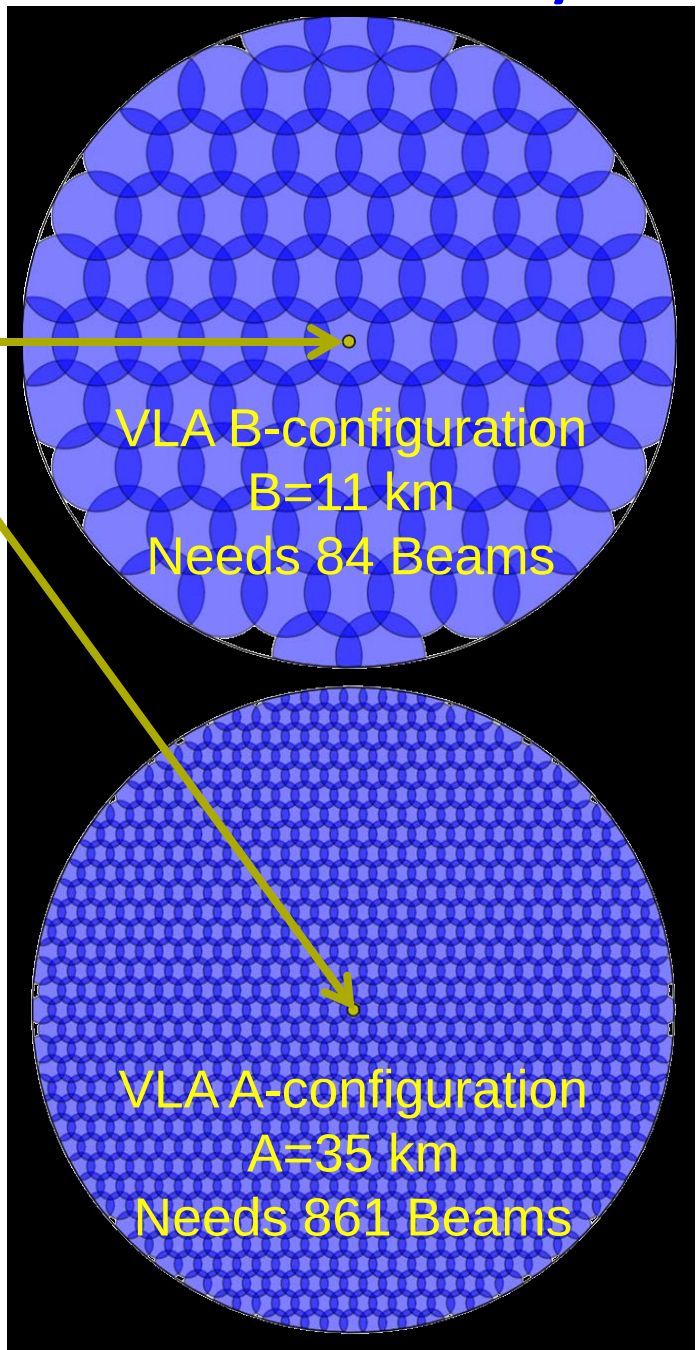
Sensitivity to Transmissions from LEO Satellites: < 1 μW

VLA System Equivalent Flux Density: ~3 x 10^{-23} W m^{-2} Hz^{-1}

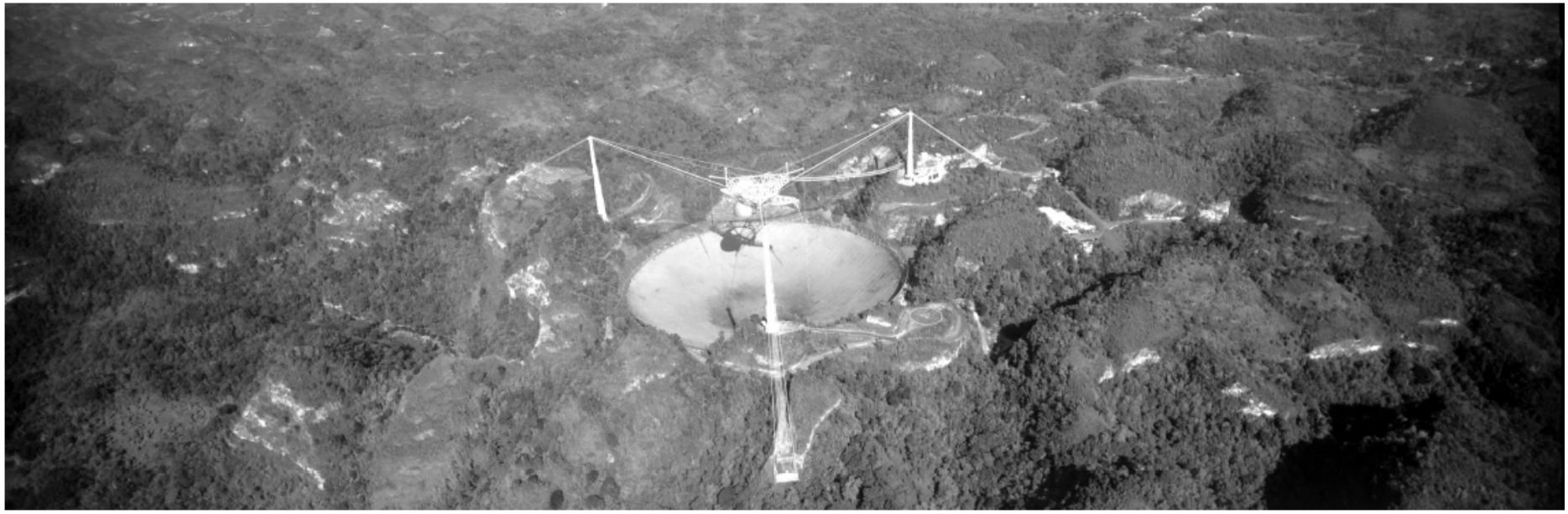
10

S&T Challenge: VLITE SSA Multi-beam System

- VLITE Primary Beam ~2° Full Width
- Bright Sources
  - Detected Beyond Primary Beam
  - Attenuated by Finite Bandwidth
- Bandwidth-Smeared Field of View
  Approximately c/(BΔf)
  - B or A = Longest Baseline
  - Δf = 100 kHz
  - Determines Number of Beams to Cover Sky
  - Large Number of Beams Yields Computational Challenge

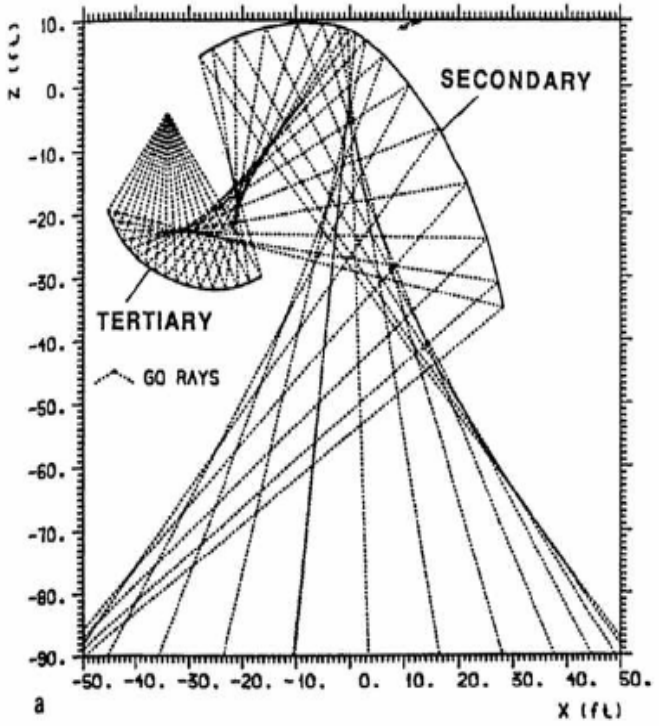


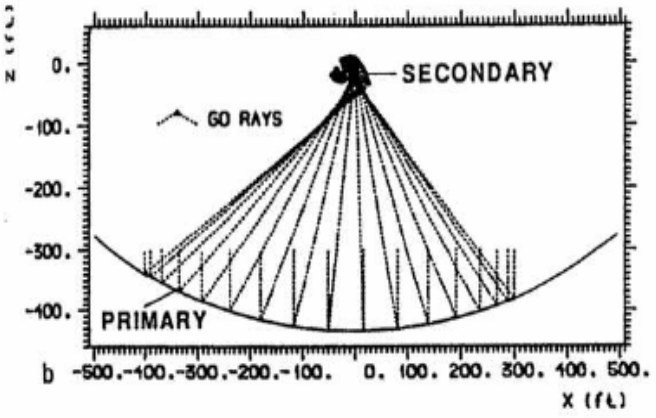
Characterization of the Arecibo Dish Antenna Pattern



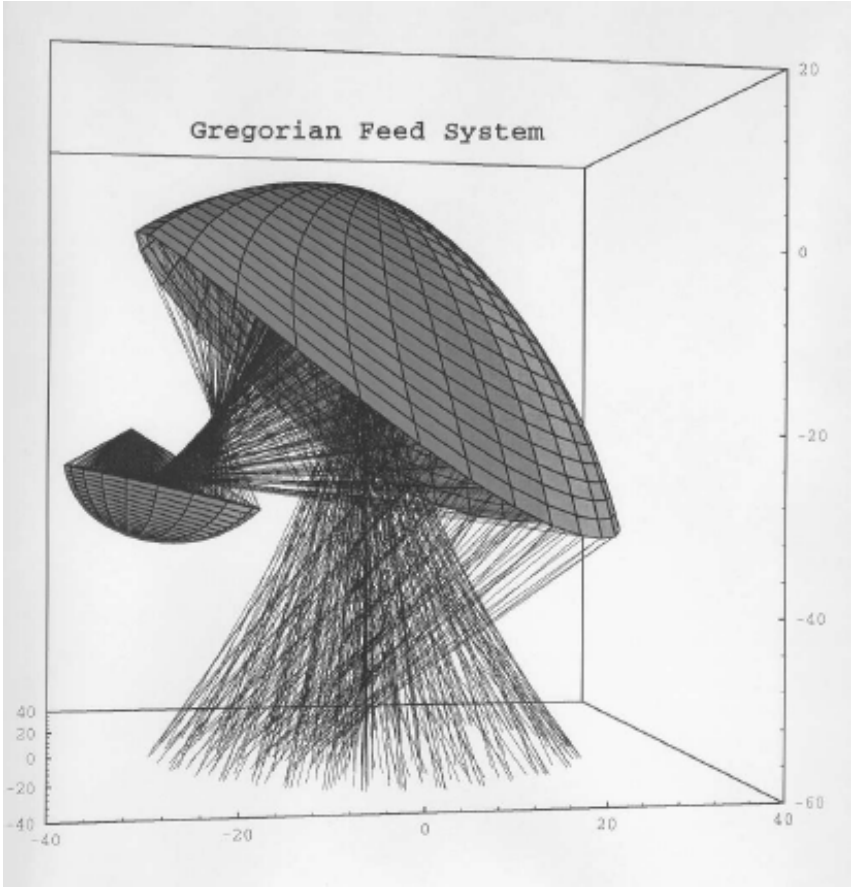
- Arecibo Observatory in the Karst of Northern Puerto Rico
- Gregorian Feed Supported by 265 to 365 foot Towers

Characterization of the Arecibo Dish Antenna Pattern

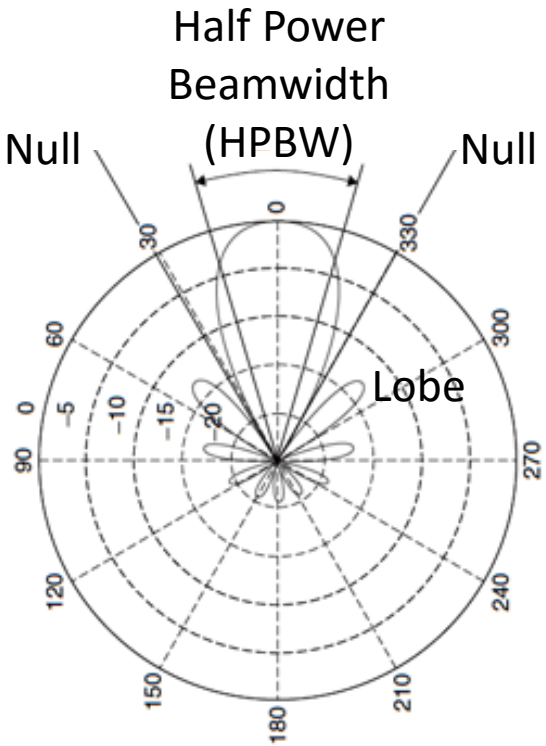




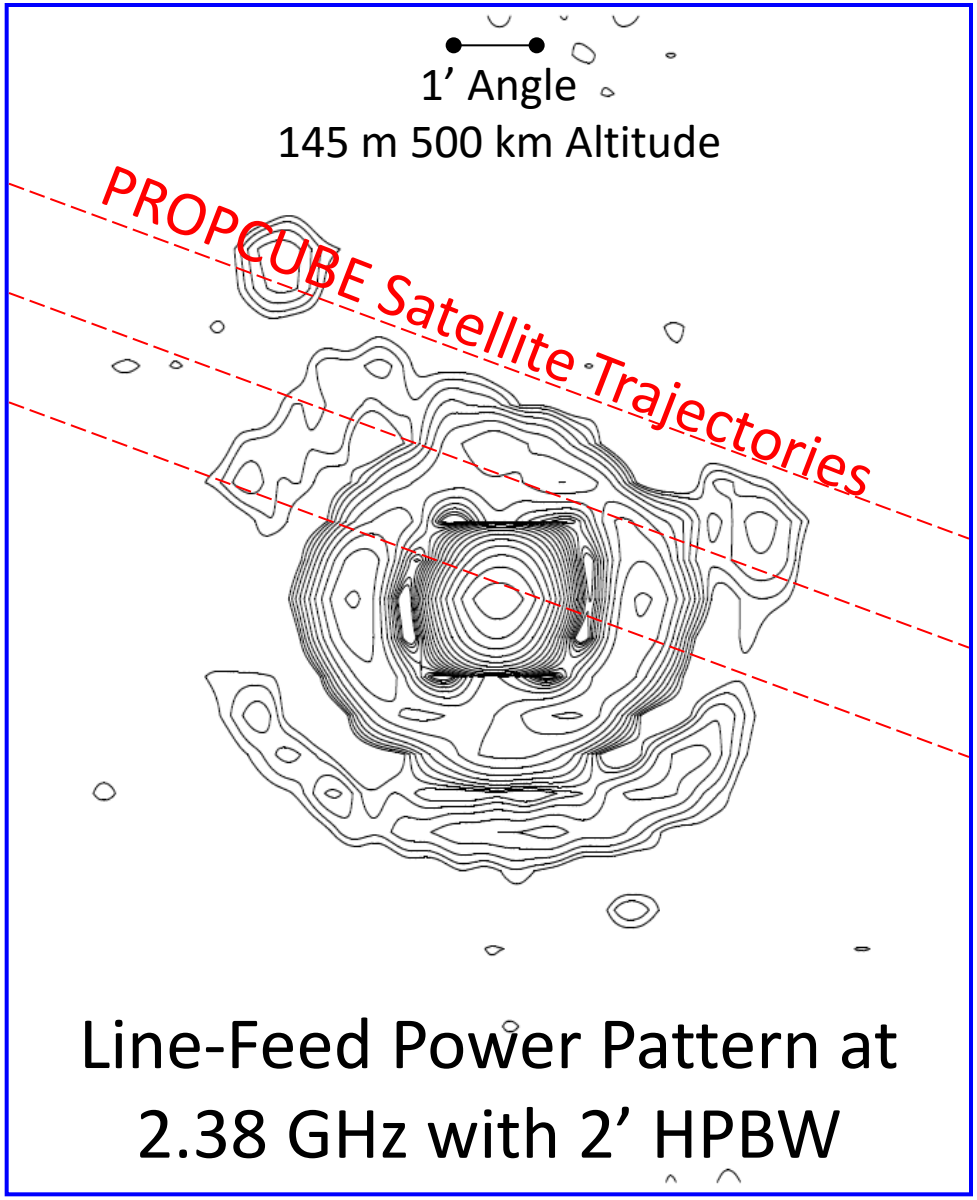
- Dual Reflector Feed Geometry
- Complete Gregorian System
- Two Sub Reflectors Correct for Spherical Aberrations of Primary



PROCUBES Measure Arecibo Dish Antenna Pattern

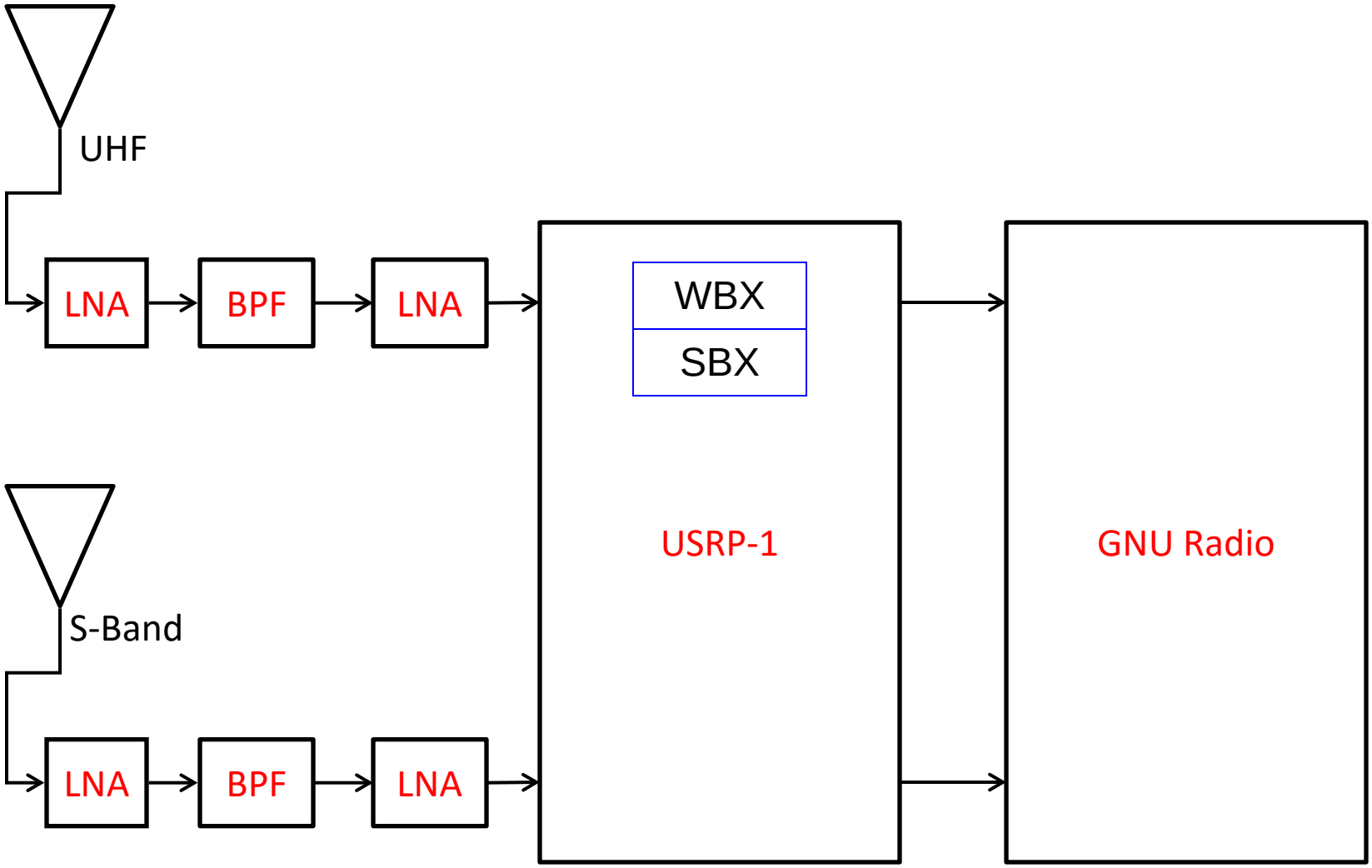


- Characteristics of Dish Antenna Patterns
- Extended Radio Source Employs Deconvolution of Antenna Pattern
- Desired PROPCUBE Position Knowledge 10 meters



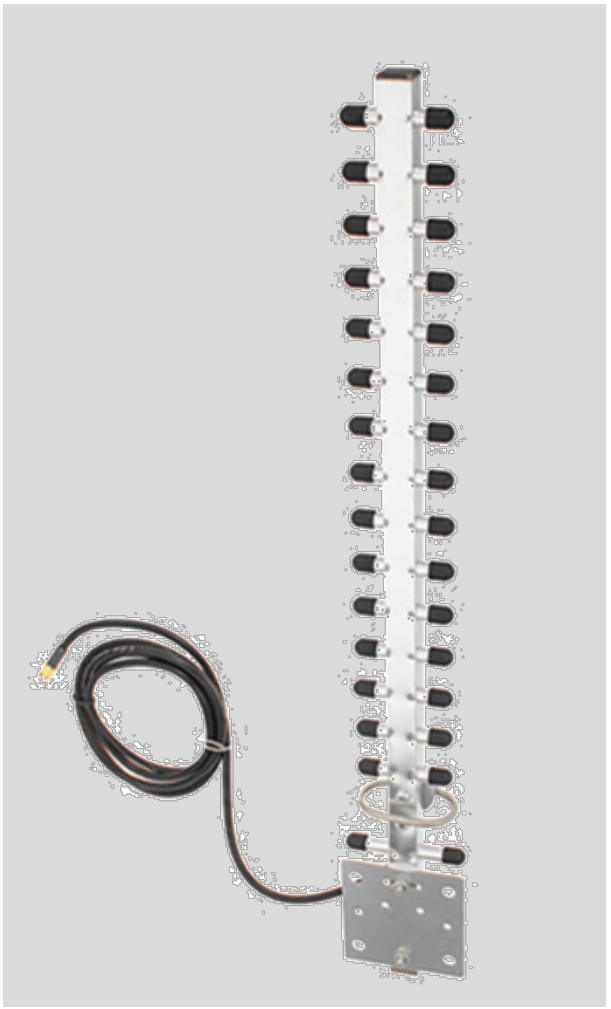
Line-Feed Power Pattern at 2.38 GHz with 2’ HPBW

GNU Radio Receiver System



Ground UHF and S-Band Antennas

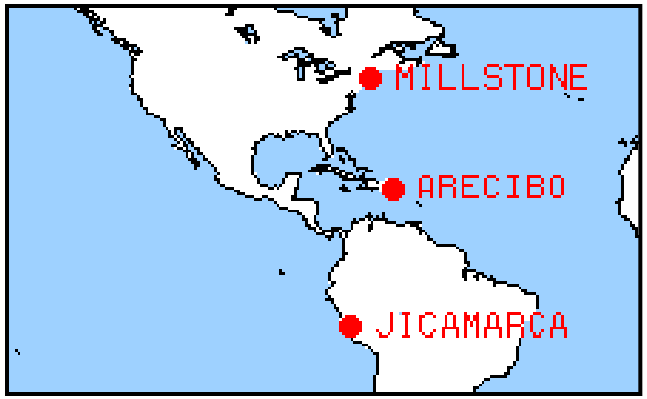
AV-2040, 11 dBc UHF Antenna
(240 to 400 MHz)



2.4GHz Yagi 25dbi Antenna

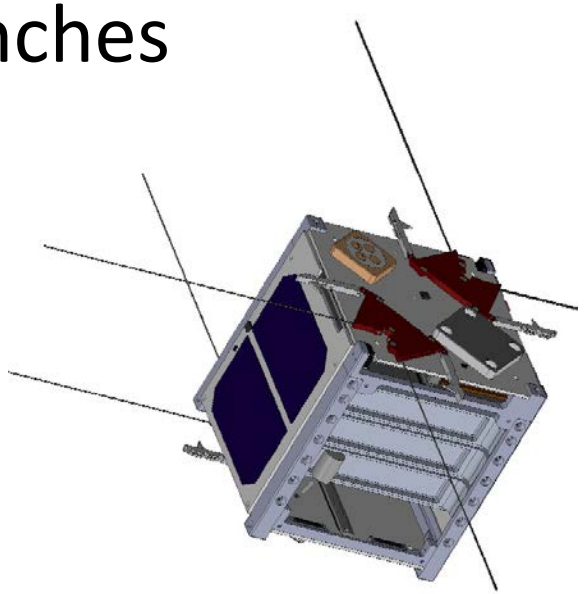
NRL Support of PROPCUBE Mission

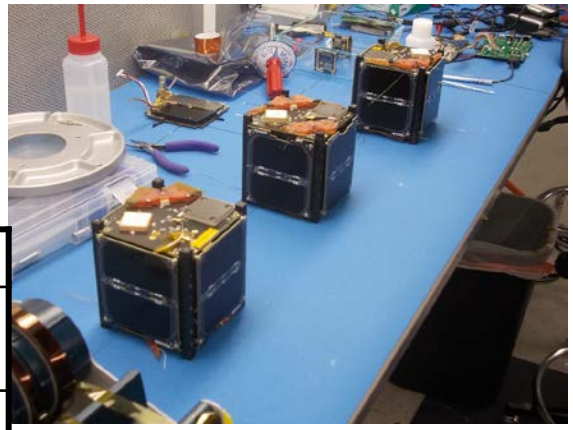
- Simulation of PROPCUBE Antenna Pattern
- Development of UHF/S-Band Coherent Receiver (USCR) System
- Experiment Implementation
  - Fielding of Ground Receiver Sites
    - HAARP, Alaska (62.4° N, -145.2° E)
    - Millstone Hill, MA (42.6° N, -71.5° E)
    - Arecibo Observatory, PR (18.3° N, -66.8° E)
    - Jicamarca Radio Observatory, Peru (11.9° S, -76.9° E)
  - Interface USCR with Arecibo Dish
    - Frequencies: 396 $^{2}/_{3}$ MHz, 2.380 GHz
    - Wide Band Waveform Receiver
- Data Analysis
  - Satellite Tracking Data Products (Range, Doppler Velocity, Position)
  - Ionosphere Data Products (Total Electron Content, Scintillations)
  - Arecibo Dish Antenna Pattern (UHF and S-Band)



PROPCUBE 1 and 3 Launches

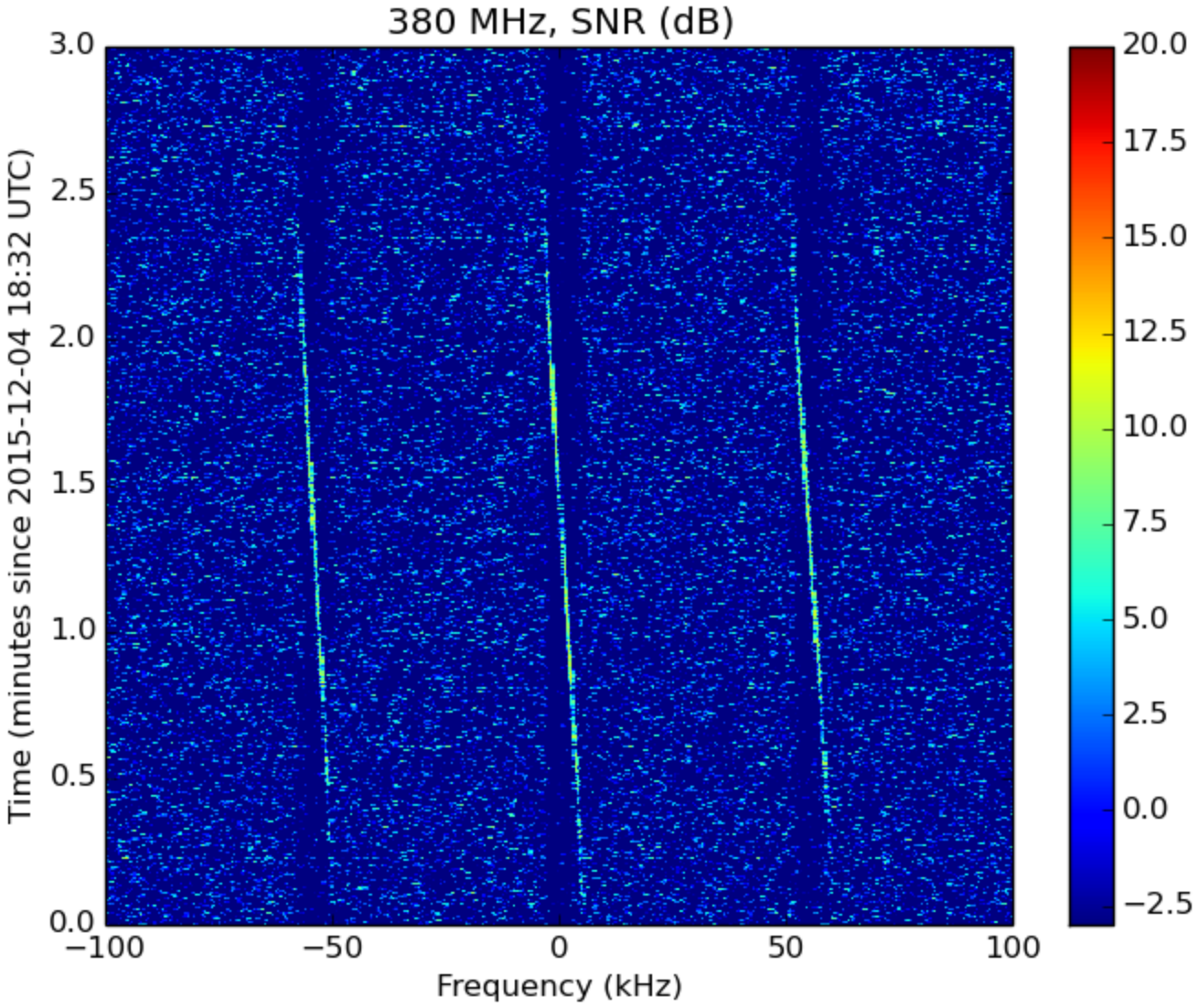
- PROPCUBE-1 and -3 Launch
  - Date: October 8 2015
  - Time: 1200-1600 GMT (08-12 EDT, 05-09 PDT)
  - Vehicle: Atlas 5 (401)
  - Launch site: SLC-3E, Vandenberg AFB, California
  - Mission: NROL-55 with GRACE Payload
  - Orbit: 63 Degree Inclination, 500 km Altitude
- Post Launch Activities
  - Initial Communications (2-3 weeks)
  - Payload Checkout (8 weeks)
  - Science Operations (2+ years)





Ground Site	(Latitude, Longitude)	Contact (Phone)	Transmit Frequency
Arecibo, Puerto Rico (2.38 GHz S-Band)	18.34° N, 66.75° W	Mike Sulzer (787-878-212 X255)	Primary: 2.38 GHz Secondary: 396 $^{2}/_{3}$ MHz
MIT/Haystack, MA	42.62° N, 71.49° W	Phil Erickson (781-981-5769)	UHF: 395 MHz S-Band: 2.37 GHz
VLA, NM (330-384 MHz UHF)	34.08° N, 107.62° W	Namir Kassim (202-767-0668)	Primary: 380 MHz Secondary: None
Jicamarca RO	12 S, 76 W	Edgardo Pacheco	Primary: 390 MHz Secondary: 2340 MHz

MIT/Haystack Observations of PROPCUBE I UHF Beacon



Summary

- PROPCUBE Status
  - Two In Orbit and One Scheduled for Launch Later This Year
  - 380 MHz and 2.38 GHz Transmissions Available on a Request Basis (CW or 1 MHz Modulation)
- Function Verification
  - MIT Haystack UHF Reception
  - NPG Monterey Receptions
    - UHF Spread Spectrum
    - S-Band CW
- Future Science Experiments
  - Ionospheric Scintillations
  - Beacon Orbit Determination with VLITE
  - Arecibo 12 meter and 1000 meter Dish Tests
  - Ranging Code Demodulations

Thanks to PROPCUBE Project Staff

- John Abel (TYVAK) PROPCUBE Project Manager
- Allen Tubbs (Aerospace) PROPCUBE Technical Advisor
- Paul Bernhardt (NRL) PROPCUBE Principal Investigator
- Giovanni Minelli (NPG) PROPCUBE Mission Operations with MC3