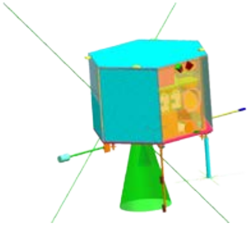
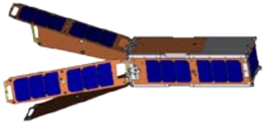


Satellite Observations of Nonlinear Interactions of in the Ionosphere



Carl L. Siefring, Paul A. Bernhardt

Plasma Physics Division, Naval Research Laboratory

Washington, DC 20735

Todd Pedersen, Air Force Research Laboratory

Kirtland AFB, NM

Andrew Yau, Department of Physics and Astronomy

Institute for Space Research

University of Calgary, Calgary, Canada

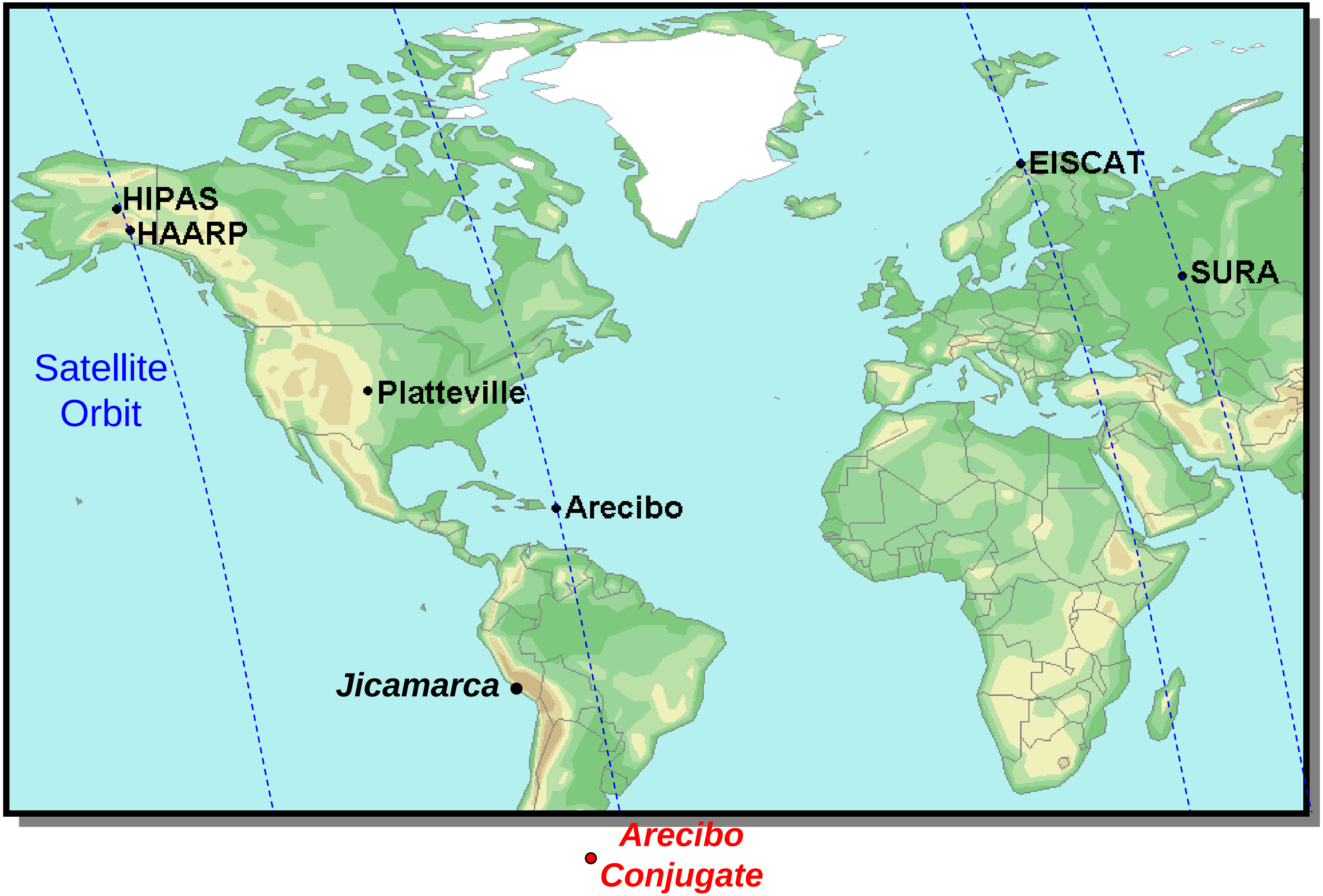
Jan Bergman, IRFU, Upsalla, Sweden

Hanna Rothkeahl, Space Research Centre, Polish Academy of Sciences, Warsaw, Poland

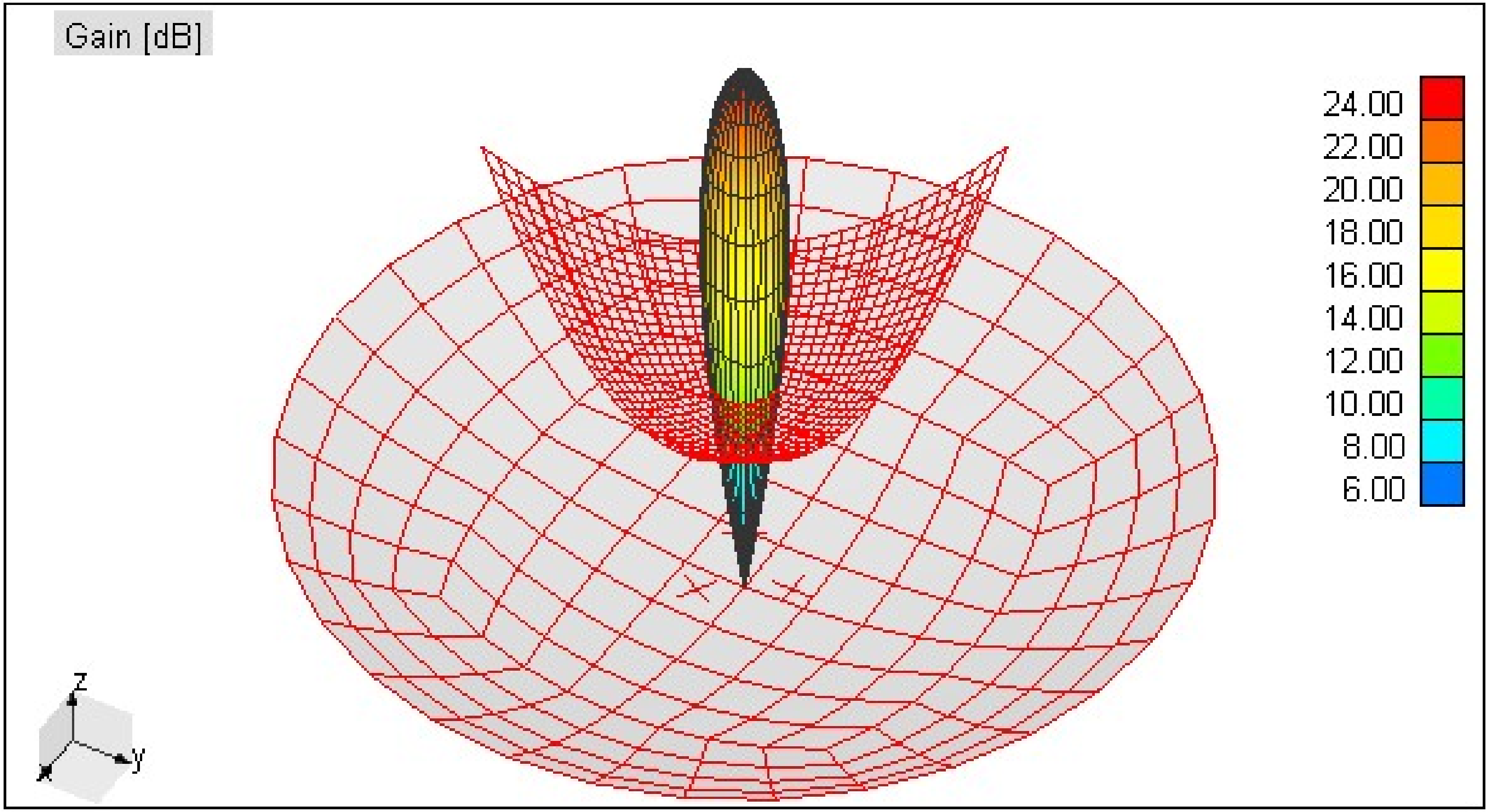
CubeSat Observations at 300 km Altitude

- HF Signal from High Power Radio Waves
  - Near Vertical Transmissions
  - Reflected Below F-Layer Peak
  - Low Altitude Expendable Satellites Needed
- Ionospheric Modification Effects
  - High Power Radio Waves
  - Enhanced Electron Densities
  - Elevated Energetic Electron Fluxes
  - Plasma Wave Generation
  - ELF/VLF Wave Detection
- Spacecraft Opportunities
  - Canadian ePOP
  - NRL MiniHFR
  - Swedish PSI

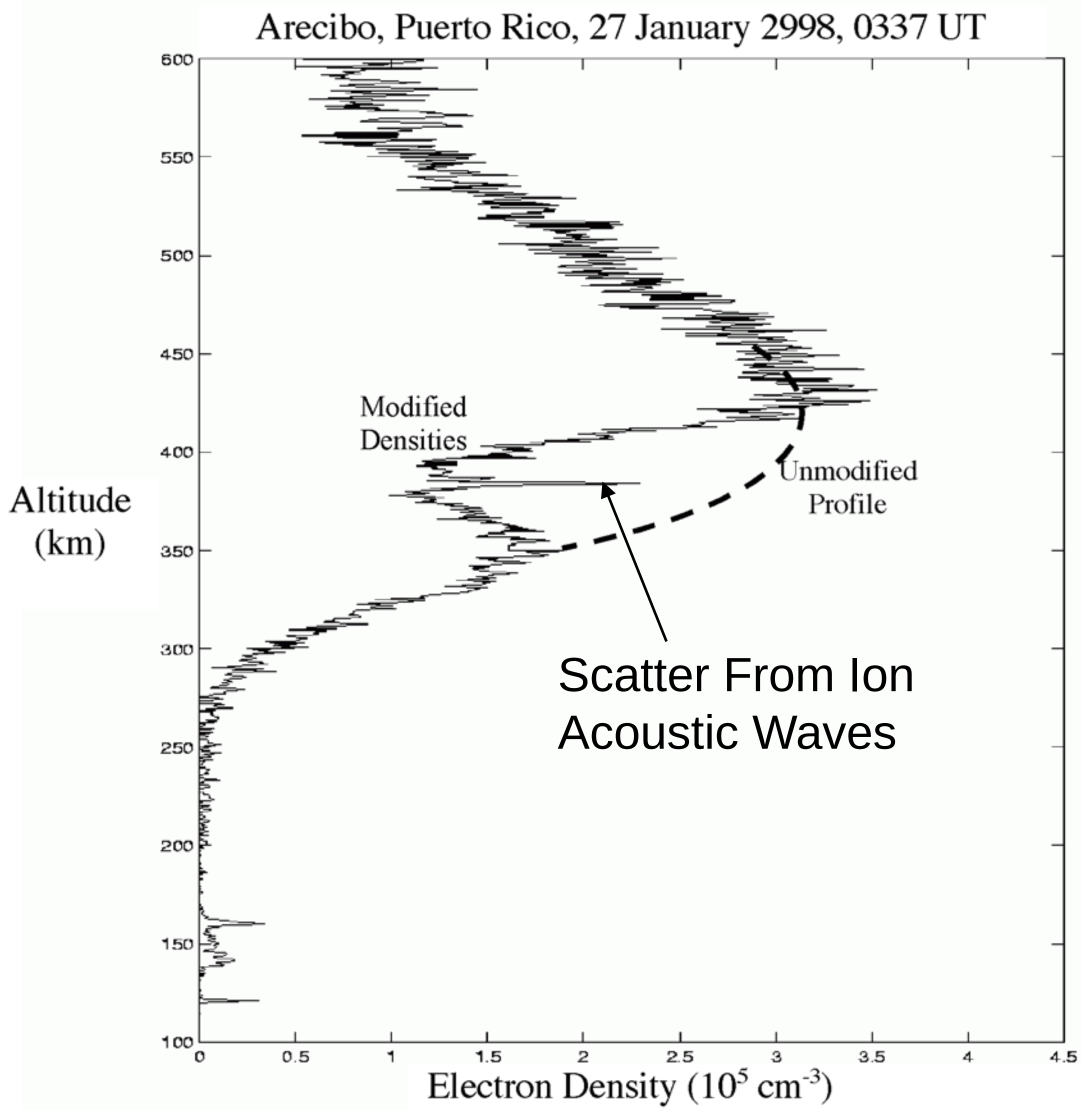
Satellite Observations of Current Ionospheric Modification Facilities



Arecibo HF Facility Antenna Gain at 8.175 MHz Giving 220 MegaWatts ERP



Incoherent Scatter Observations of F-Region Heating Showing Ionospheric Hole



In Situ Measurements by NRL IFH Rocket

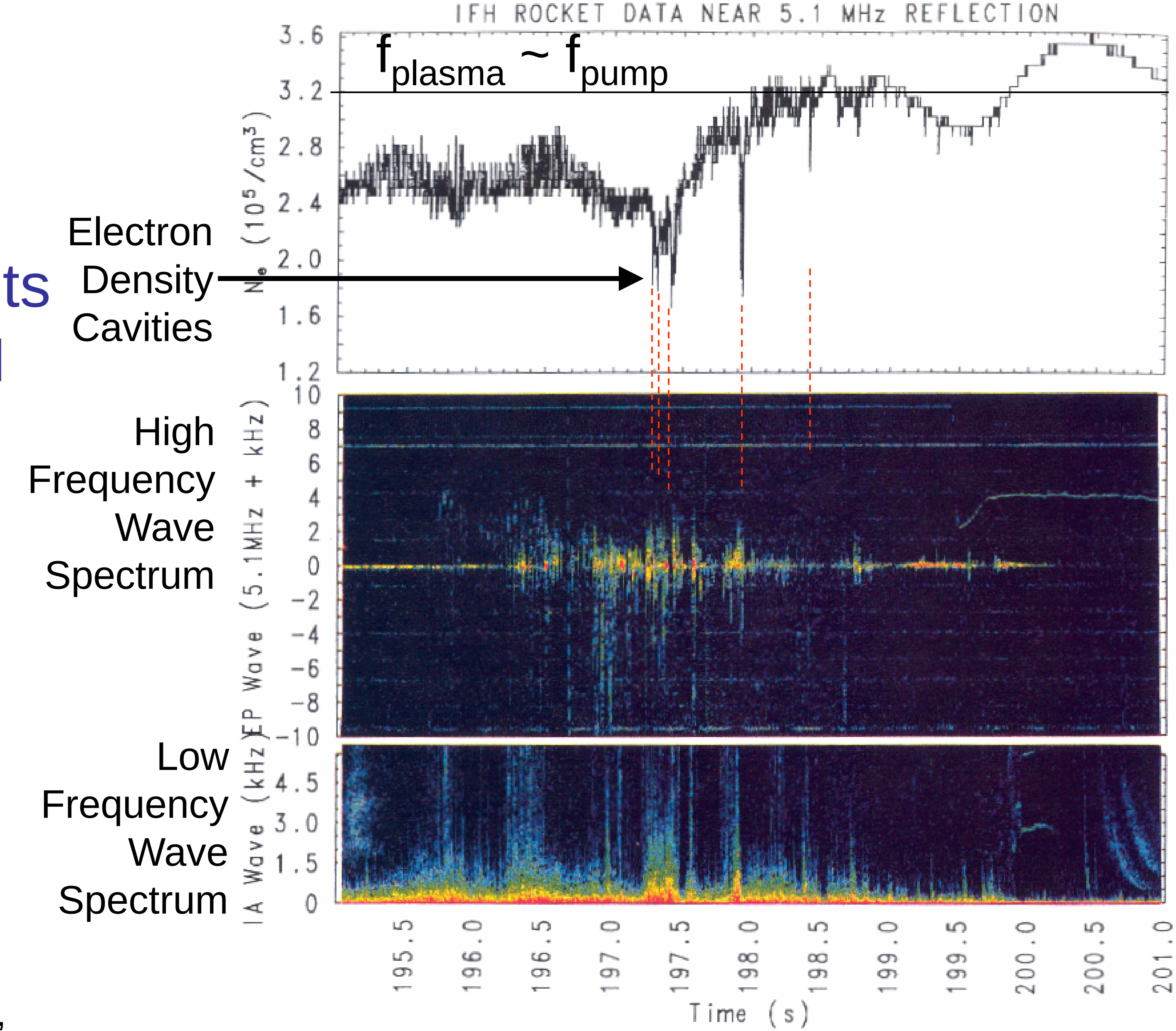
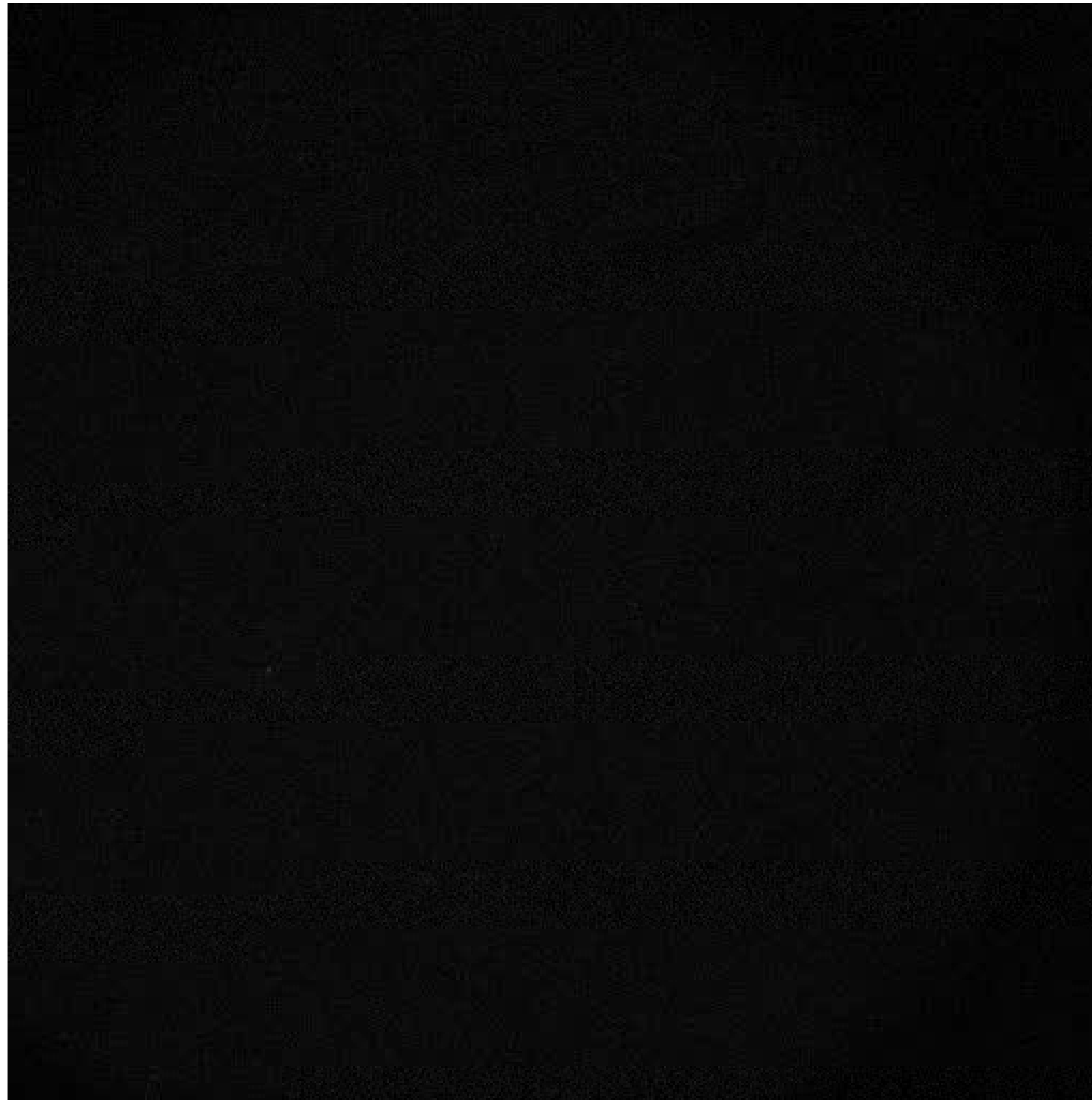


Plate 2. Detail of the electron density, Langmuir waves around 5.1 MHz and low-frequency ion acoustic waves near the HF reflection level. The Langmuir waves and ion acoustic waves seem to be trapped or guided by the density cavities. Spectra of low-frequency electric fields are measured between sensors EF1 and EF4 of Figure 2.

Reference:
Bernhardt, Siefring, Rodriguez, Haas, Baumback, Romero, Solin, Djuth, Duncan, Pollack, Sulzer, ***The ionospheric focused heating experiment***, **J. Geophys. Res.**, 100, 17,331-17,345, 1995.

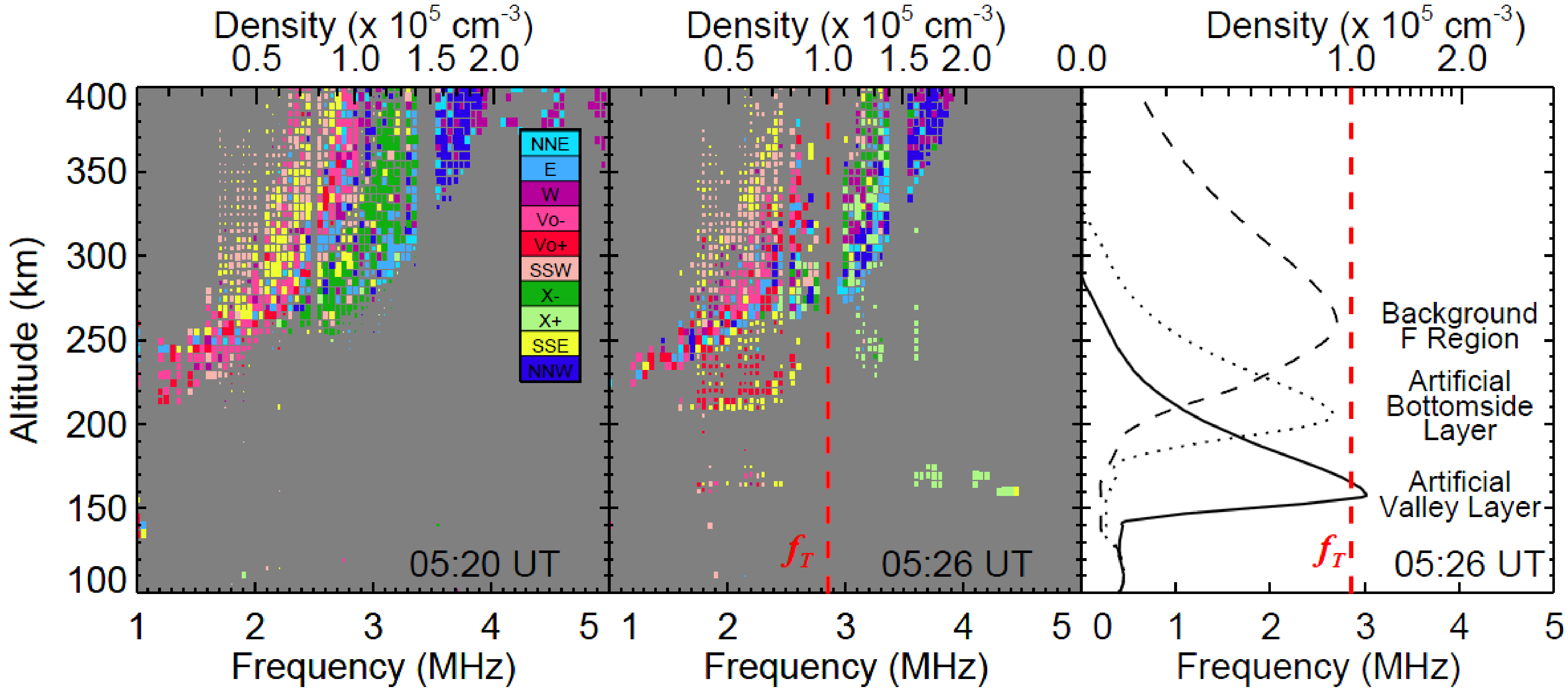
Electron Acceleration and Irregularity Formation 2nd Harmonic of the Electron Cyclotron Frequency

- HAARP Artificial Aurora
  - 2.85 MHz
  - 3.6 MW Transmitter Power
  - March 2009
- Artificial Plasma Layers
  - 2nd Harmonic Resonance
  - Electron Bernstein Wave Acceleration
- Ref.: Todd Pedersen (AFRL)

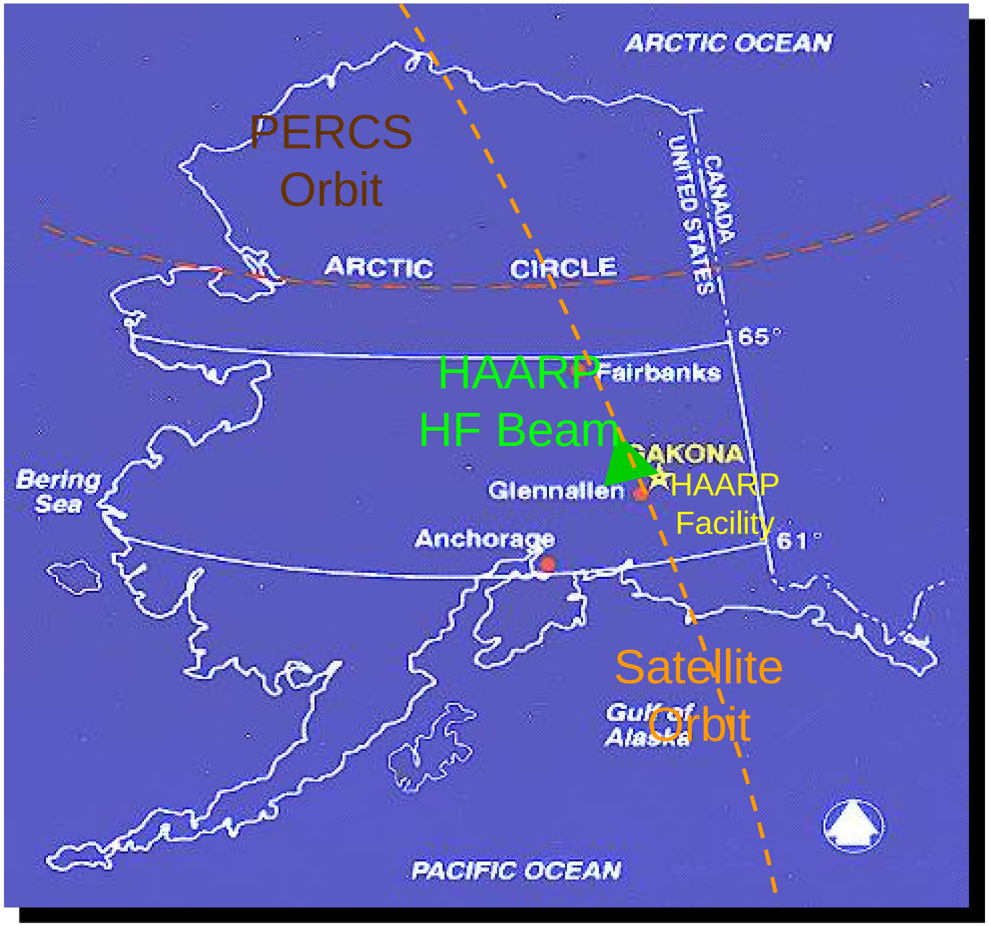


Artificially Produced Plasma Layers Near 200 km Altitude

Source: Todd Pedersen et al. 3009, Creation of Artificial Ionospheric Layers Using High-Power HF Waves



HAARP Instrument Experiments with Instrumented Satellites

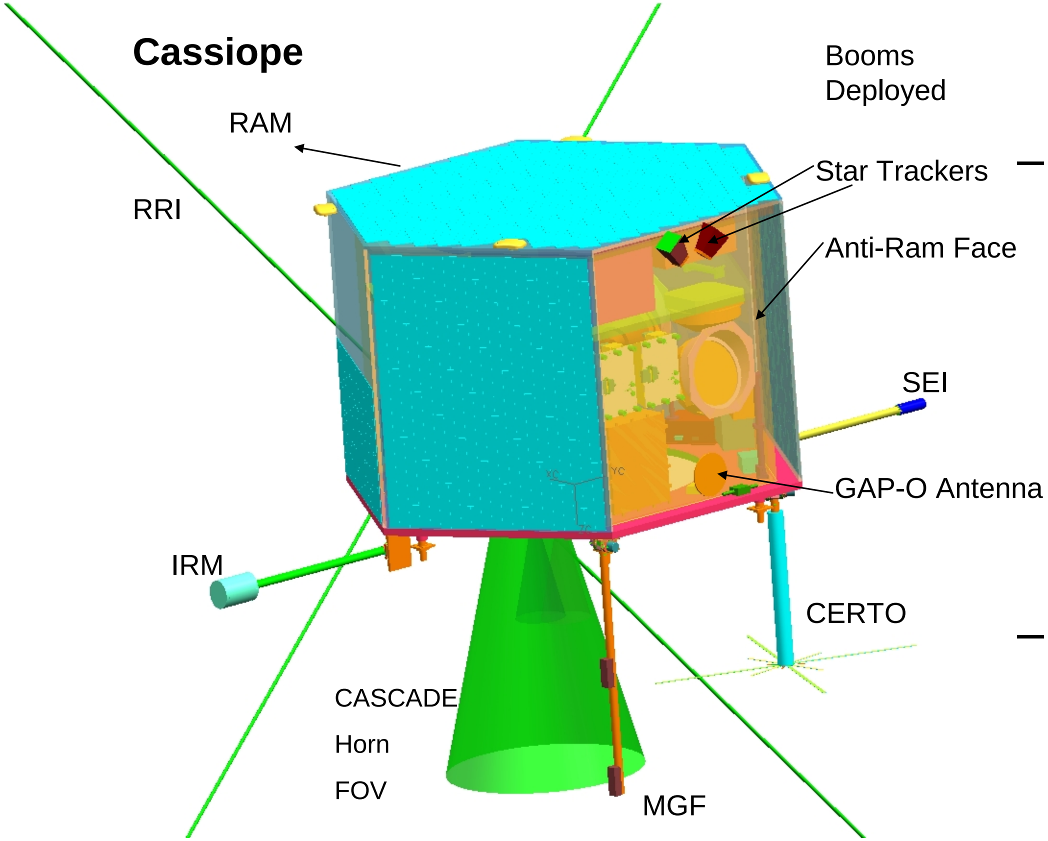


- PERCS Operational Utility
  - Absolute Measurement of HAARP Antenna Pattern from 2.8 to 10 MHz
  - Precise Measurements of Plasma Waves Generated by HAARP

Satellite Support of Nonlinear Excitation of the Ionosphere

- High Power Radio Waves
  - Stimulated Electromagnetic and Electrostatic Emissions (SEE) for Radio Receiver Instrument (RRI)
  - Electron Acceleration
  - Enhanced Airglow
  - Ion Acceleration
  - Electron Density Irregularities

e-POP/CASSIOPE Micro-Satellite: Instrument Payload



- Imaging particle instruments for unprecedented resolution on satellites
  - IRM: Imaging rapid ion mass spectrometer
  - SEI: Suprathermal electron imager
  - NMS: Neutral mass and velocity spectrometer
- Auroral imager and wave receiver-transmitter for first micro-satellite measurements
  - FAI: Fast auroral imager
  - RRI: Radio receiver instrument
  - CERTO: Coherent electromagnetic radio tomography
- Integrated instrument control/data handling, and science-quality orbit-attitude system data to maximize science return
  - MGF: Magnetometer
  - GAP: Differential GPS Attitude and Position System

ePOP CASSIOPE Mission Overview

- Inclination: 80 Degrees
- Orbit: 300 x 1500 km
- Lifetime: > 1 Year
- Initial Apogee Over Northern Latitudes
- Orbit Decay Over 2 Years
  - 110 km at Apogee
  - 12 km at Perigee
  - Initial Argument of Perigee: 270 degrees
- Launch: Late 2012
- 3-Axis Agile Spacecraft
- Noon/Midnight Orbit
- 2 kRad per year with 0.0825 Inch Shielding
- Spacecraft Critical Design Review April 2005

e-POP Payload Science Instruments

- **IRM** will detect 3D ions distribution at 1 to 100 eV for 1 to 40 AMU mass species.
- **SEI** will detect the 2D electron distribution function in the energy range of 2 to 200 eV.
- **NMS** will measure neutral particle constituents. It is capable of resolving both the neutral particle composition and the flow velocity.
- **FAI** will do simultaneous imaging of the near-infrared band in the range 650-850 nm, and the monochromatic wavelength of 630 nm.
- **RRI** will measure the electric fields of spontaneous waves in the frequency range of 100 Hz to 18 MHz
- **MGF** will measure the ambient magnetic field with a dynamic range of ±60,000 nT and a resolution of 1 nT.
- **GAP** will provide precision timing and time-of-day information in real time, as well as high-resolution spacecraft position and velocity.
- **CER** will emit coherent EM radiation to an array of ground receivers clustered along -75° E longitude. The measured signals would be used for tomographic analysis.

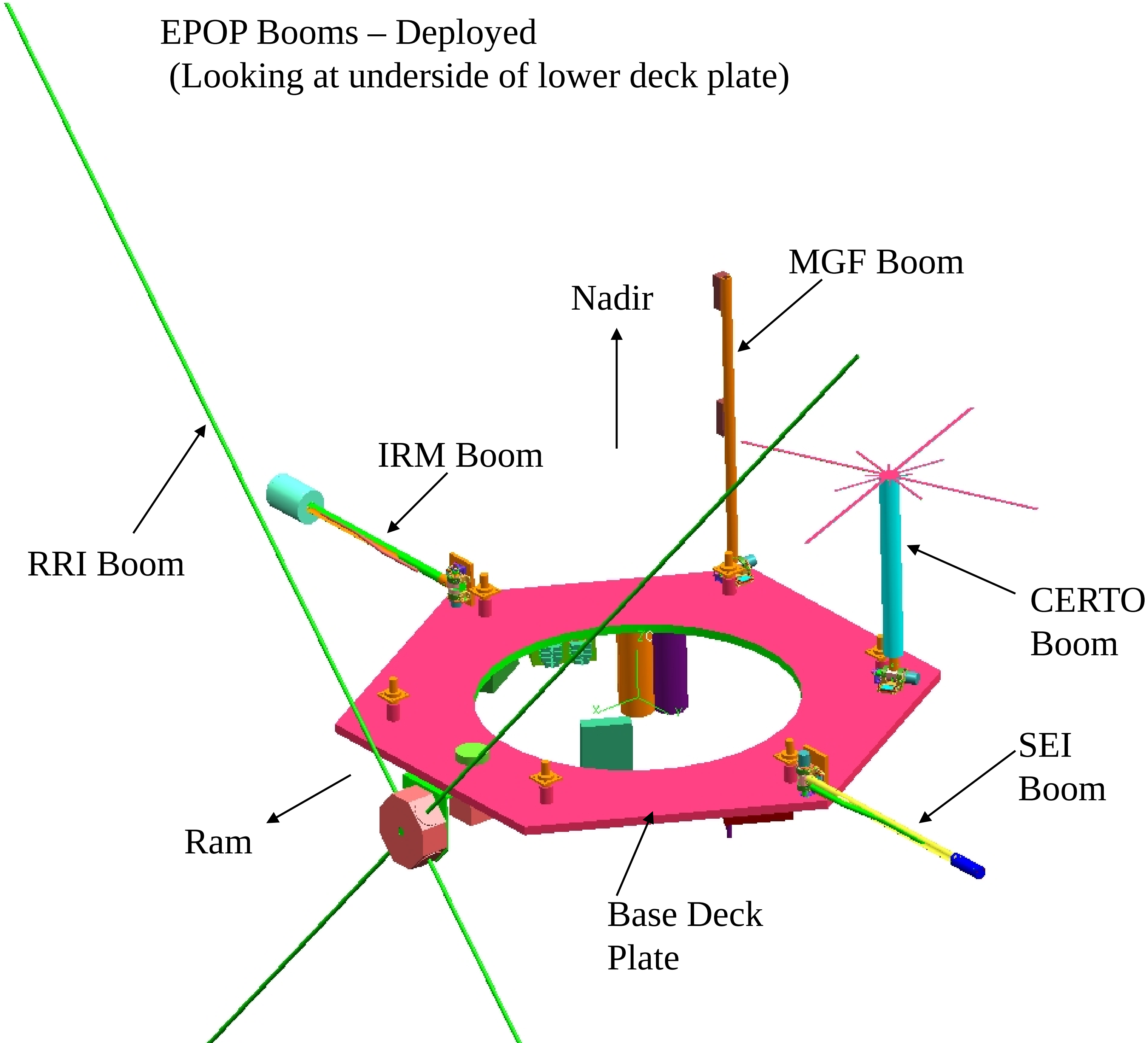
Earth Coverage by ePOP/CASSIOPE in a 80º Inclination ORBIT

Space-Based, Diagnostic Requirements for HAARP Measurements

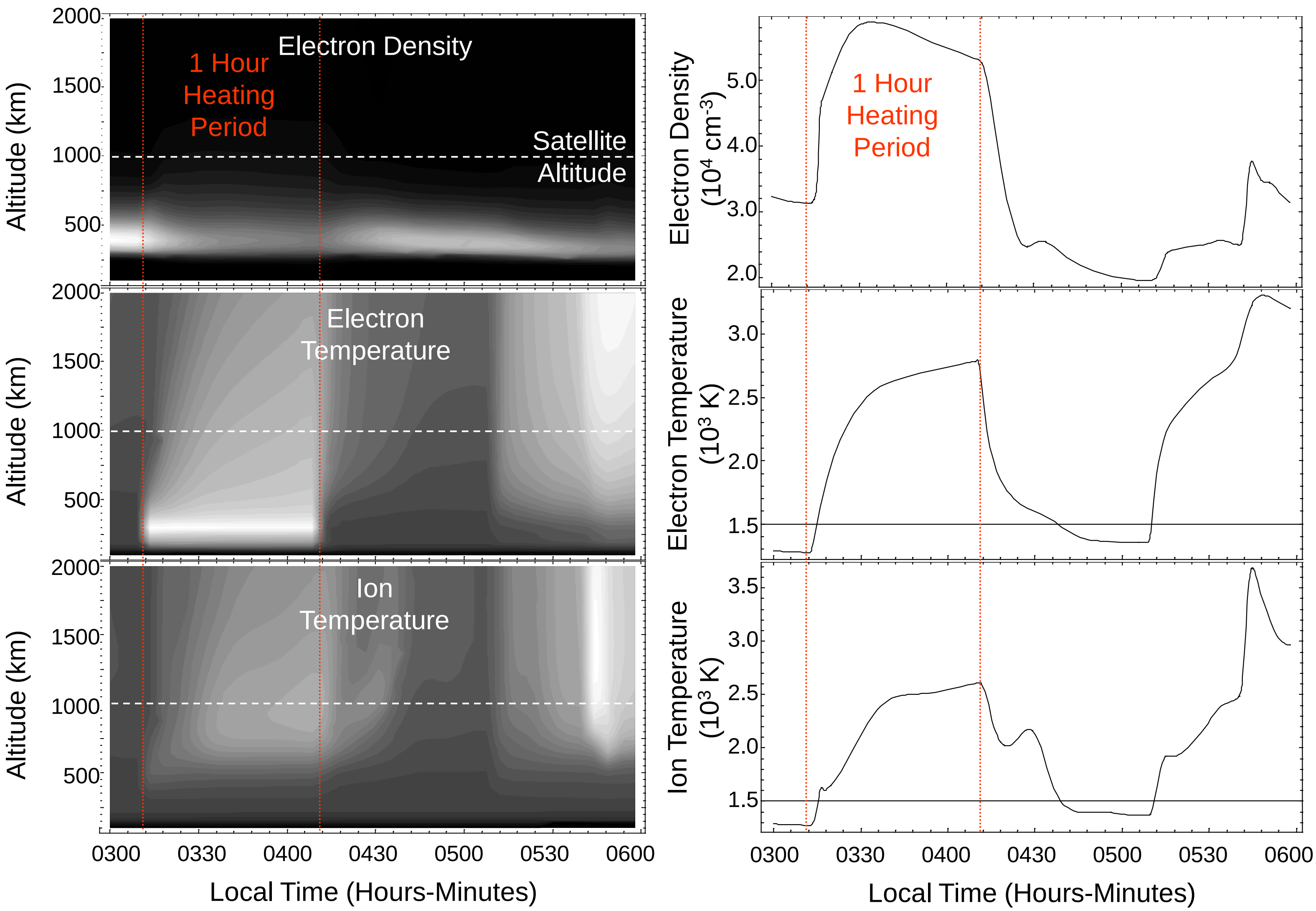
Measurement	Importance	Diagnostic	ePOP Instrument
ELF/VLF Waves	Very High	Receiver Covering 1 Hz to 30 kHz	RRI 10 Hz to 30 kHz
Field Aligned VLF Ducts Artificial and Natural	High	*In Situ* Electron Density Probe	SEI (10^2 to 10^6 cm-3)
Elevated F-Region Electron Temperature as Duct Signature	Moderate	Thermal Electron Detector 0.0 to 0.3 eV	SEI (0 to 200 eV)
Optical Emissions from Precipitation	Moderate	Photo Detector $N_2$1P, 630, 557.7, 427.8, 777.4 nm	FAI (630 to 850 nm)
Suprathermal Electron Fluxes	Moderate	Energetic Electron Detector	SEI (0 to 200 eV)
Modulated HAARP Pump Wave	Moderate	HF Receiver/Antenna (3 to 9 MHz)	RRI (1-18 MHz, 30 kHz Bandwidth)

Note: RRI = Radio Receiver Instrument, SEI = Suprathermal Electron Imager, FAI = Fast Auroral Imager, CERTO = Coherent Electromagnetic Radio Tomography, IRM = Rapid Ion Mass Spectrometer

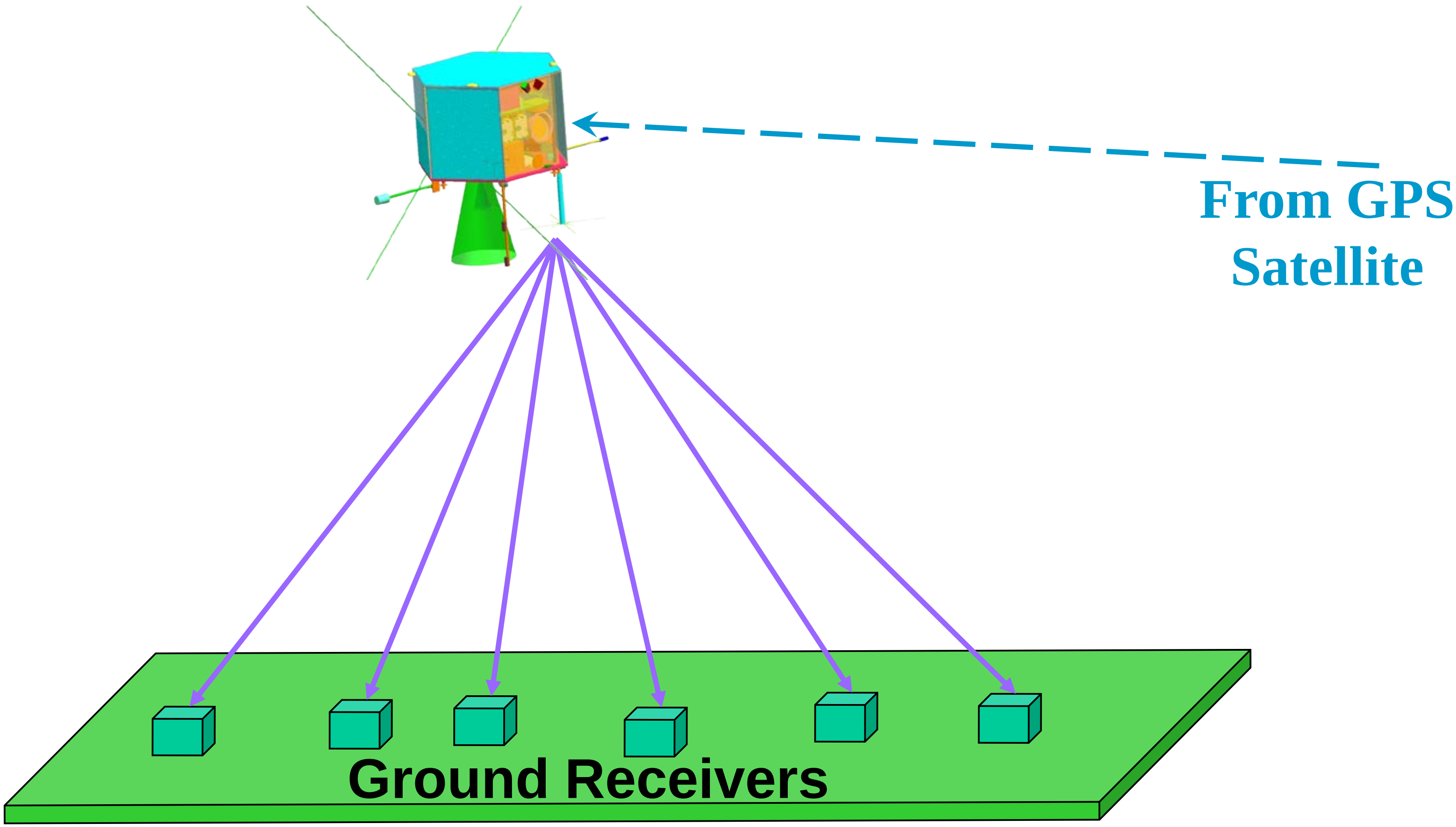
EPOP Booms – Deployed
(Looking at underside of lower deck plate)



Ionospheric Heating Simulations on Field Line Above Transmitter



JOINT CERTO and GPS-GAP OPERATIONS ON CASSIOPE



Active Experiments ePOP Experiment Modes
Paul A. Bernhardt, NRL

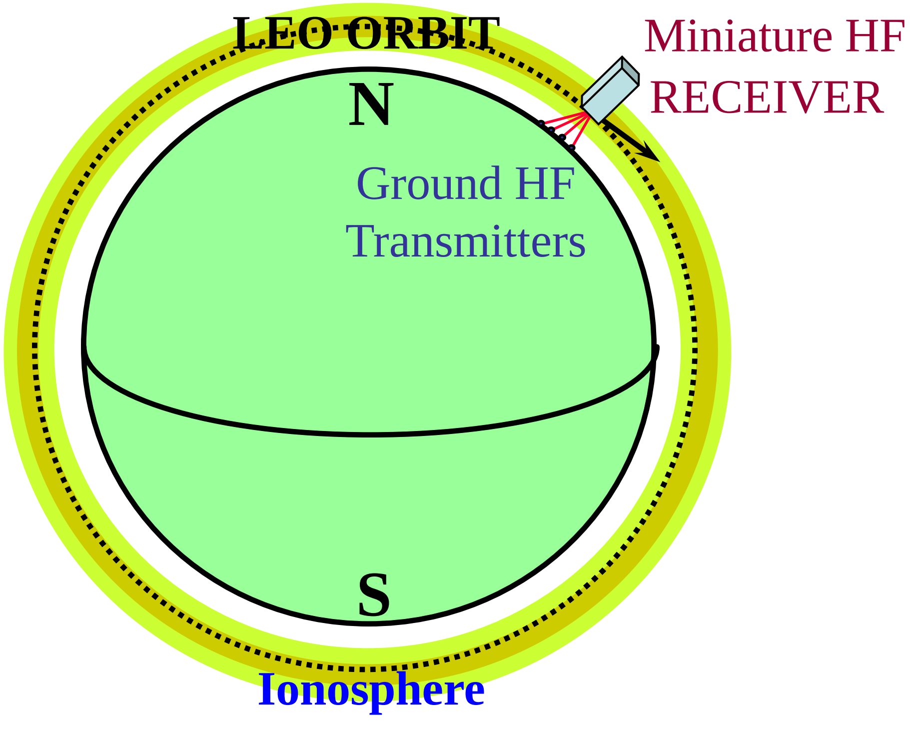
Experiment / Instrument	Modulated Heater Wave Generation (MHWG)	HF Heater Artificial Aurora (HAA)	HF Heater Stimulated Electromagnetic Emission (SEE)	HF Heater Plasma Temperature Enhancements (PTE)
RRI	VLF/ELF	0~5 MHz	0~5 MHz	HF Waves
SEI	Yes	WPI	WPI	IonMode
FAI	No	Yes	No	No
CER	No	CERALLC	No	No
IRM	No	No	No	IRMTIS
NMS	No	No	No	No
GAP	No	No	No	No
MGF	No	No	No	No
Altitude Requirements	< 800 km	< 800 km	< 350 km	Any
Pointing	At Event	At Event	Event	Z-Nadir

Note: RRI = Radio Receiver Instrument, SEI = Suprathermal Electron Imager, FAI = Fast Auroral Imager, CERTO = Coherent Electromagnetic Radio Tomography, IRM = Rapid Ion Mass Spectrometer, GAP = Differential GPS Attitude and Position System, MGF = Magnetometer

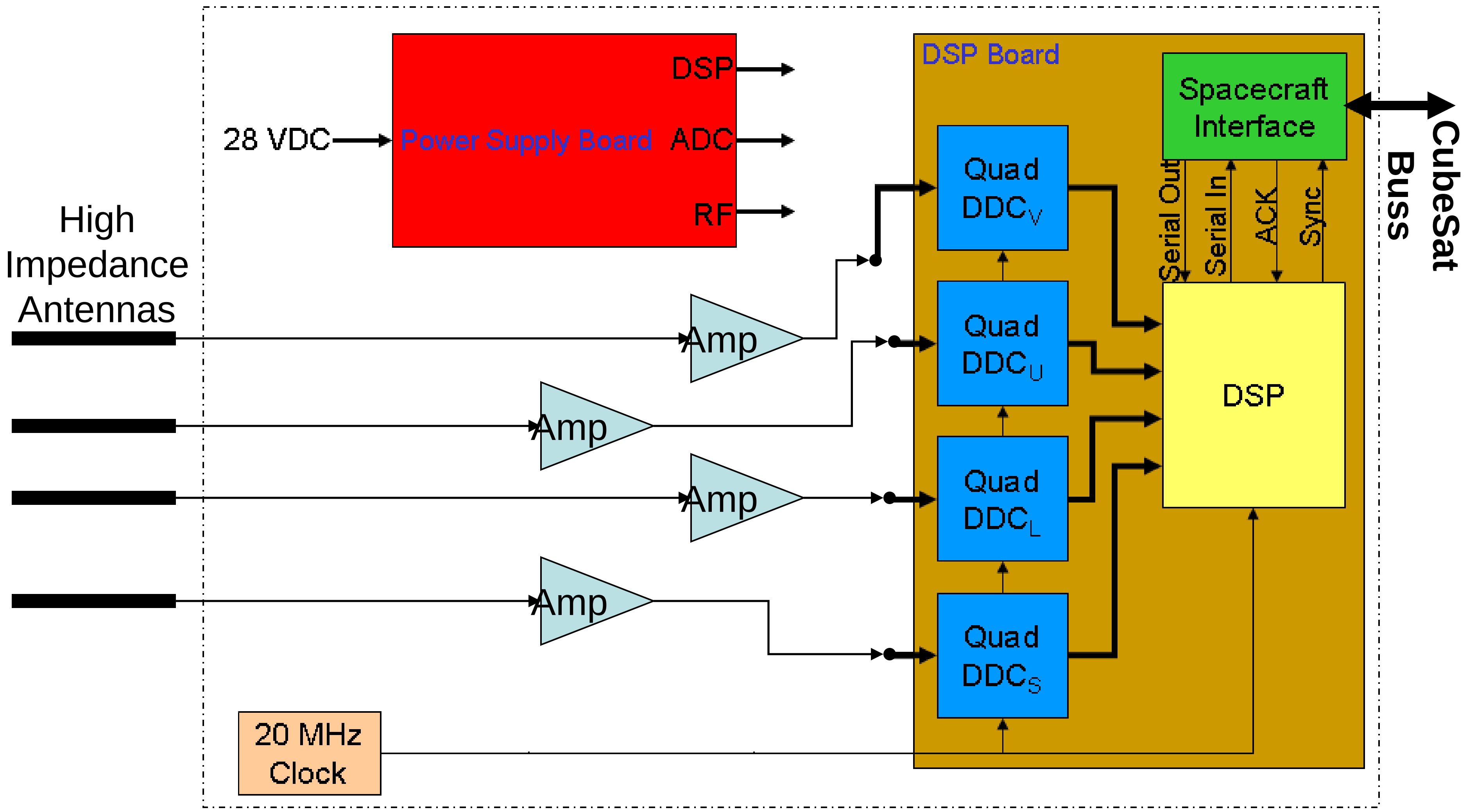
Miniature HF Receiver (MiniHFR)

- Miniature HF Receiver
  - Power: 5 and 3.3 V available @ 5 W total power (continuous operation)
  - Volume – 3 boards = 3 to 5 cm of stack
  - Mass – 800 g
  - Pointing accuracy need – 20 deg (dependent on link margin analysis)
  - Pointing direction
    - highest gain of antennas collinear with the ram direction
    - highest gain in nadir direction for receiving ground beacons
  - Shadowing/ field of view/aperture size – no deployables within the highest gain of antennas
  - TT&C need through C&DH/Radio and down to the ground – TBD bps

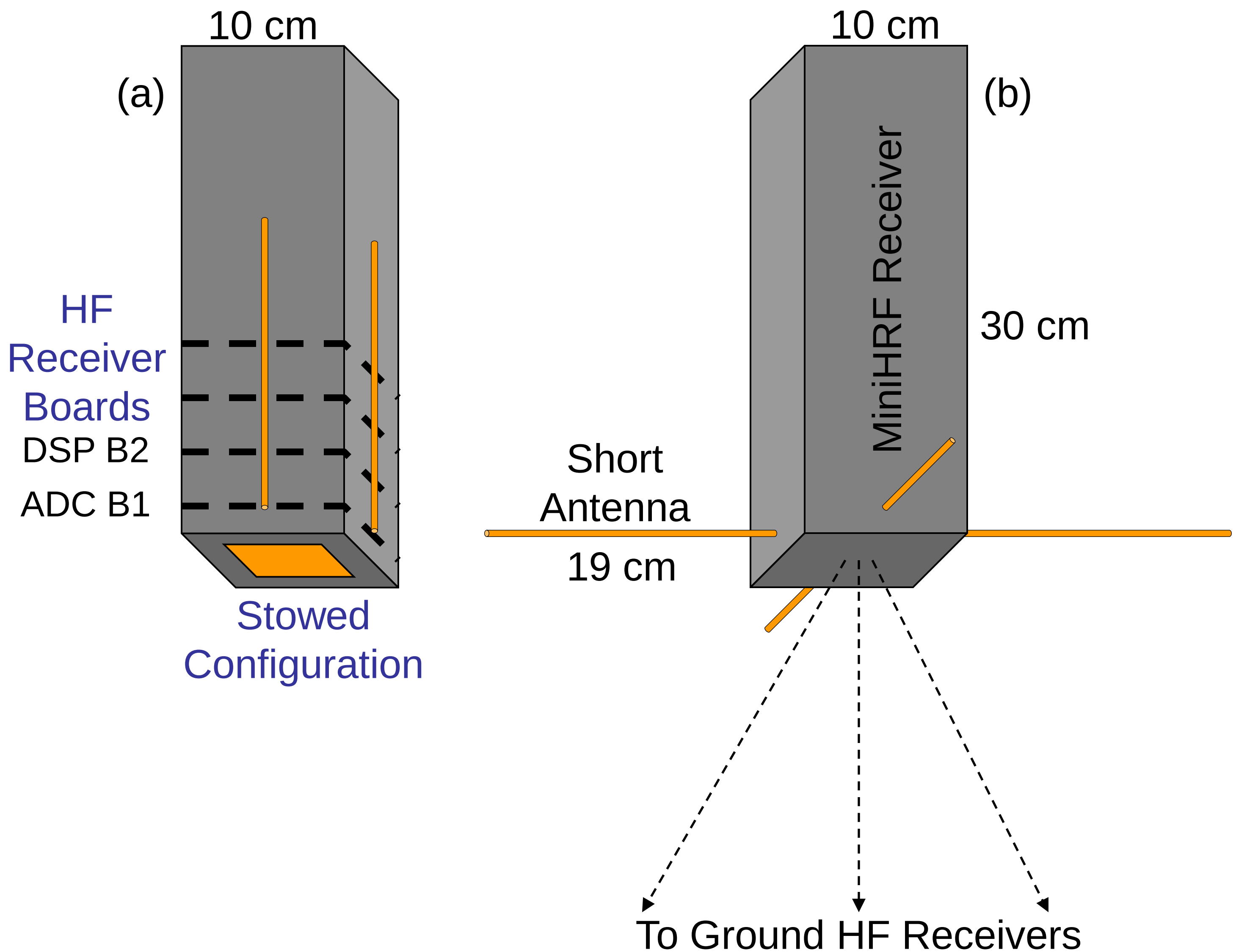
GEOMETRY FOR
HF CubeSat MEASUREMENTS



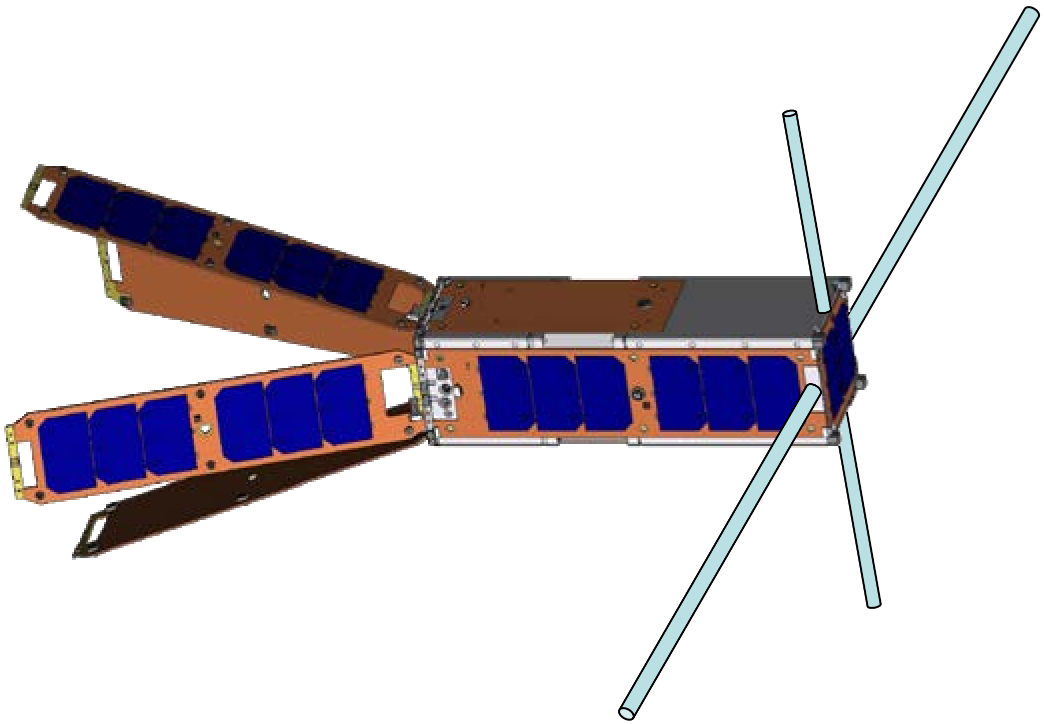
MiniHFR Design



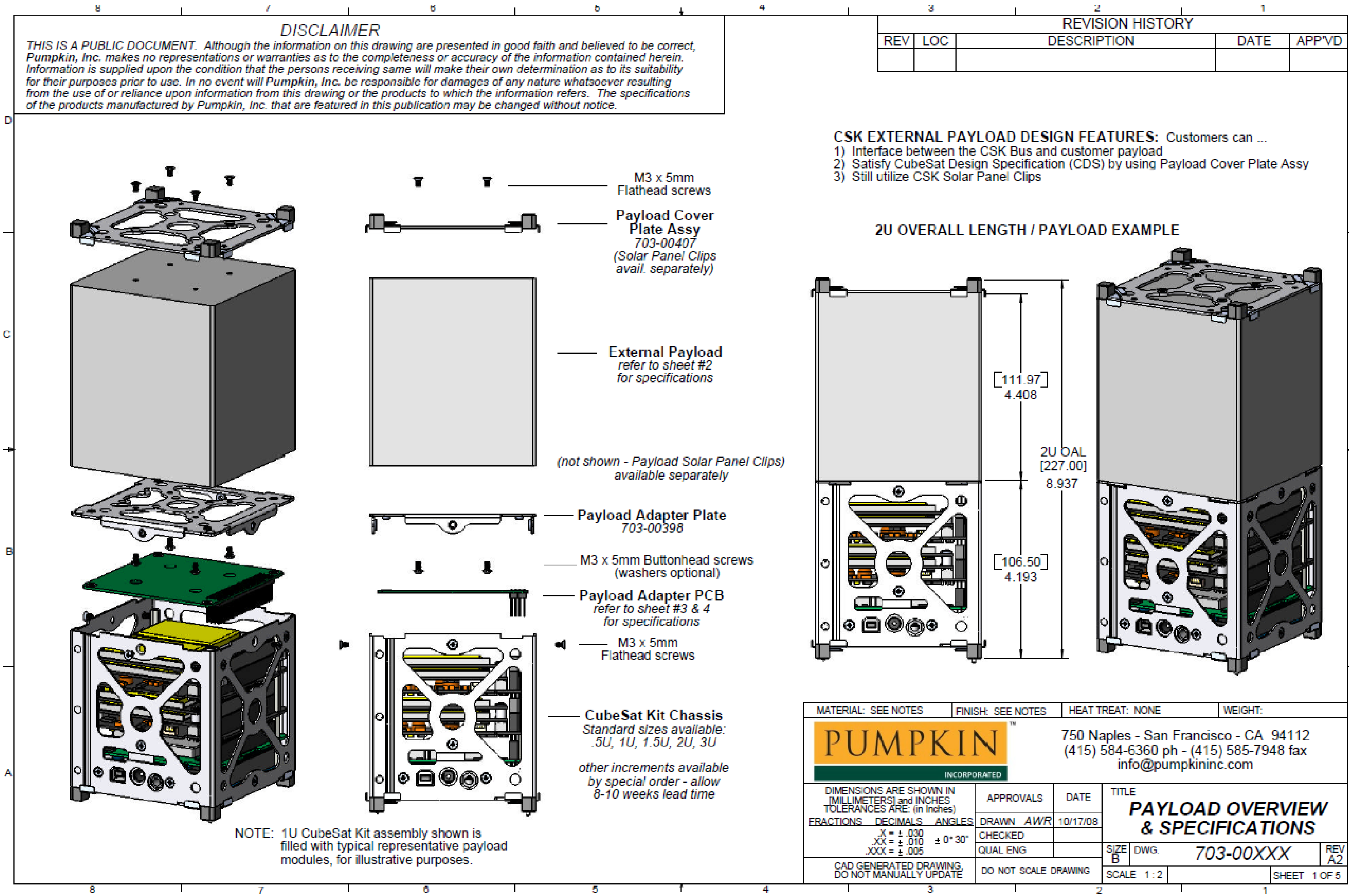
CubeSat Implementation of MiniHFR



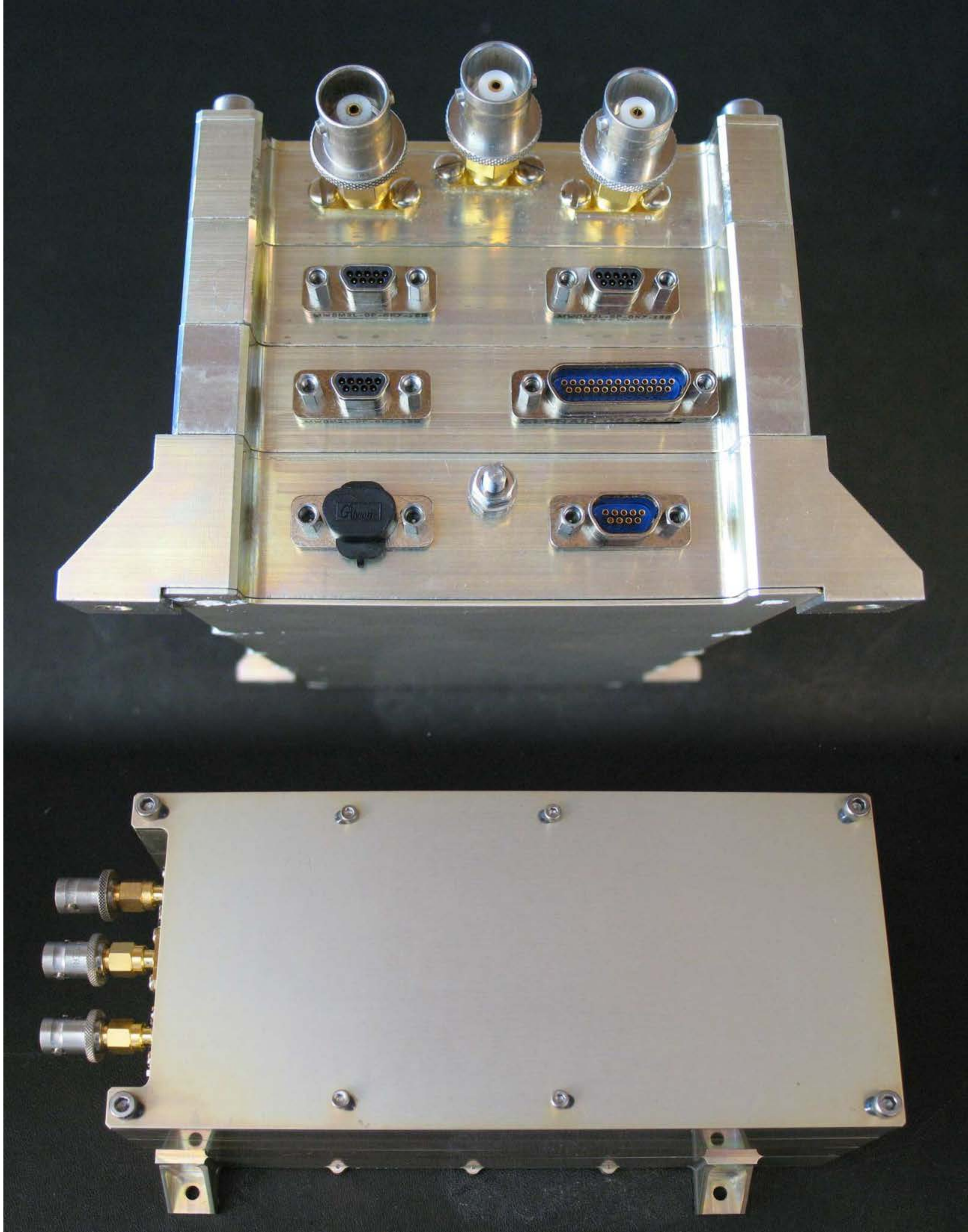
CubeSat Receiver Antennas



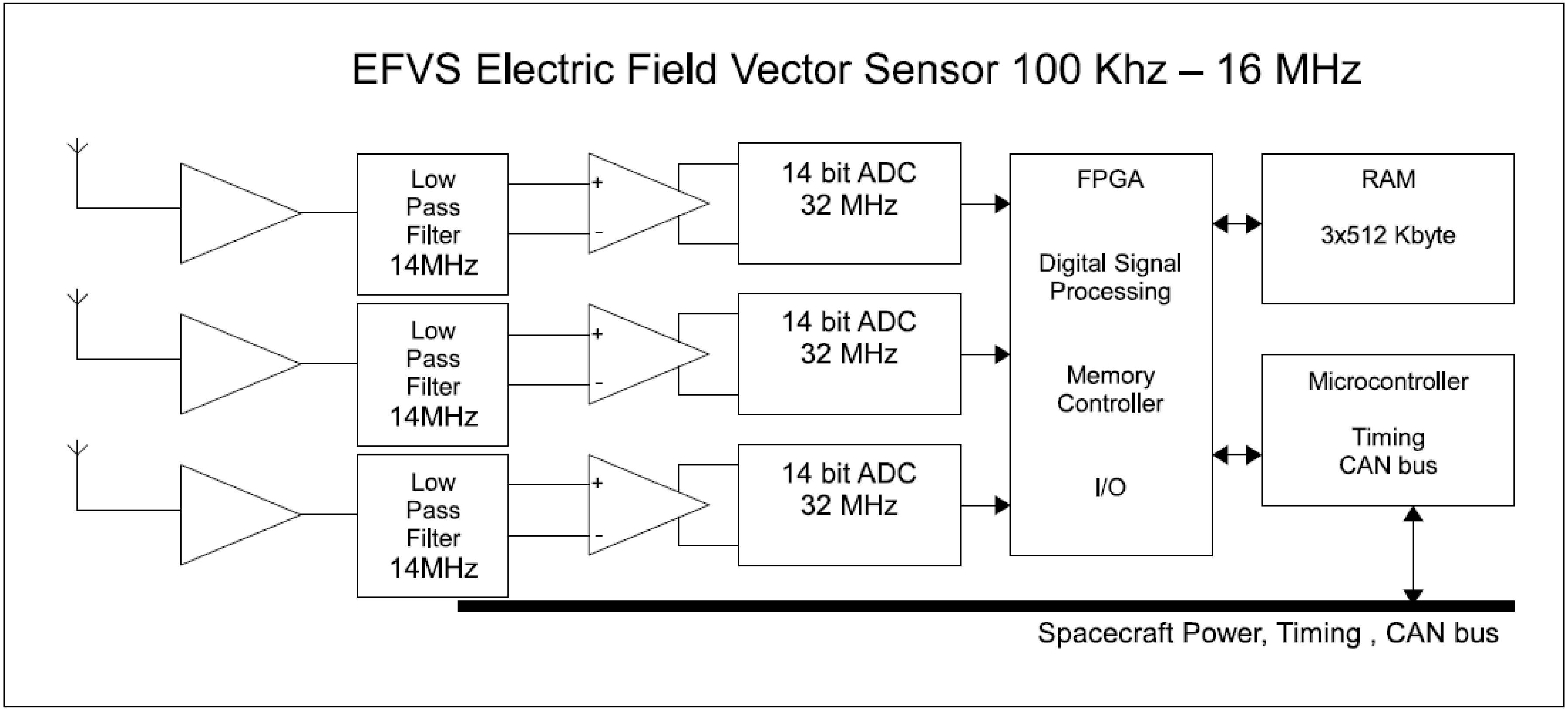
CubeSat Payload Guide



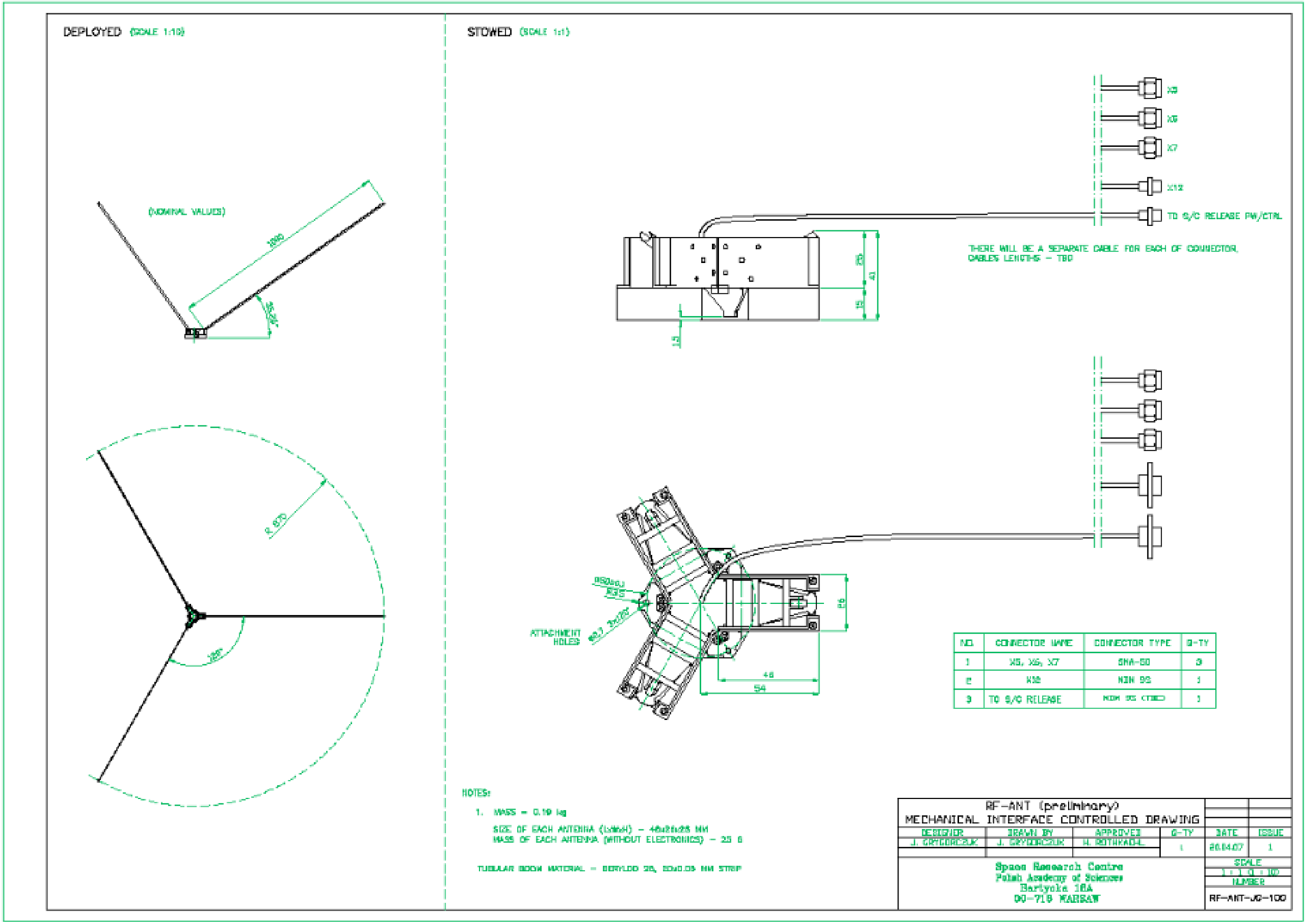
IRFU
Uppsala
PSI
Plasma
Science
Instruments



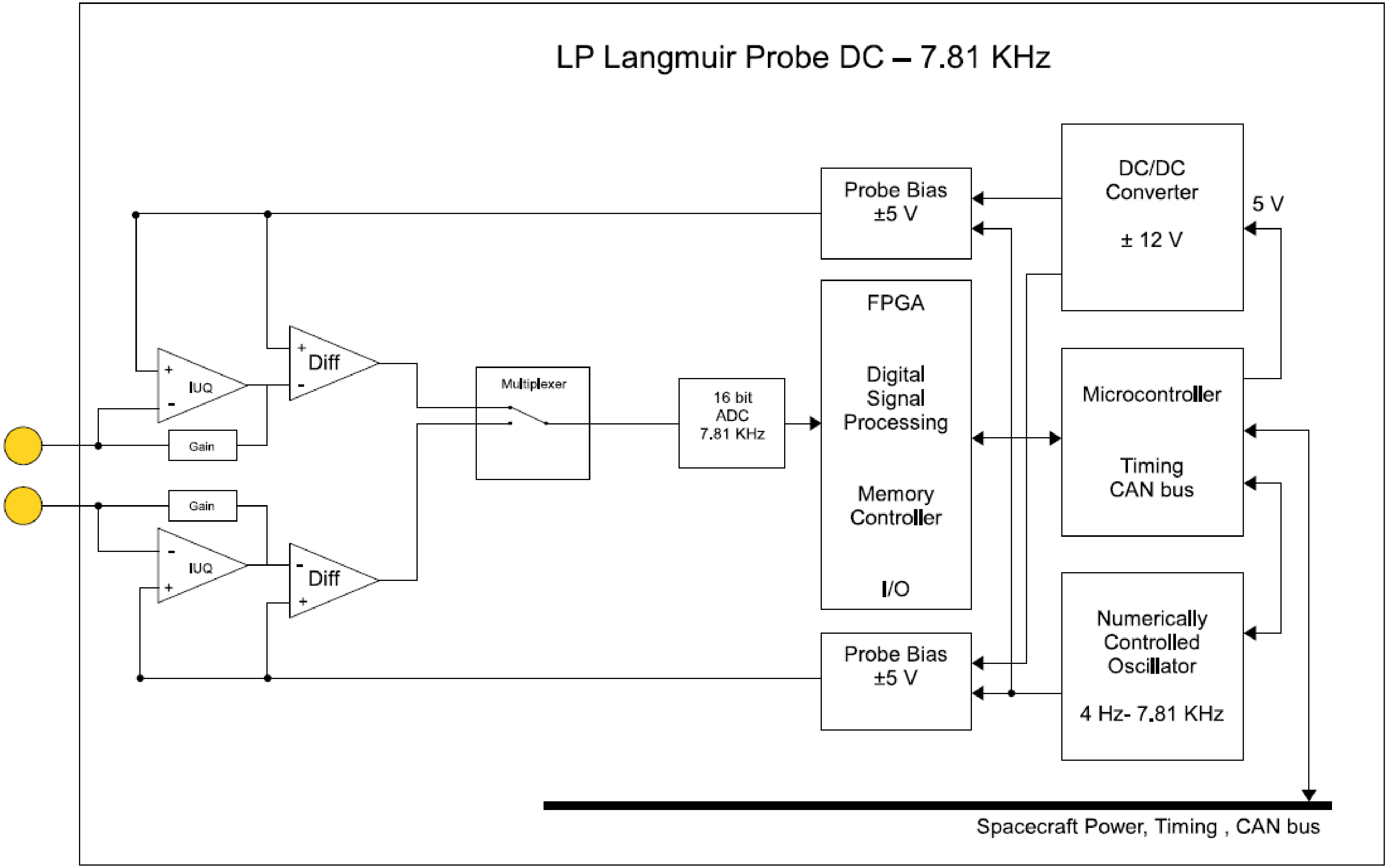
EFVS for PSI


EFVS Electric Field Vector Sensor 100 Khz – 16 MHz
Low
Pass
Filter
14MHz
Low
Pass
Filter
14MHz
Low
Pass
Filter
14MHz
+
-
14 bit ADC
32 MHz
14 bit ADC
32 MHz
14 bit ADC
32 MHz
FPGA
Digital Signal
Processing
Memory
Controller
I/O
RAM
3x512 Kbyte
Microcontroller
Timing
CAN bus
Spacecraft Power, Timing , CAN bus

Deployable Electric Field

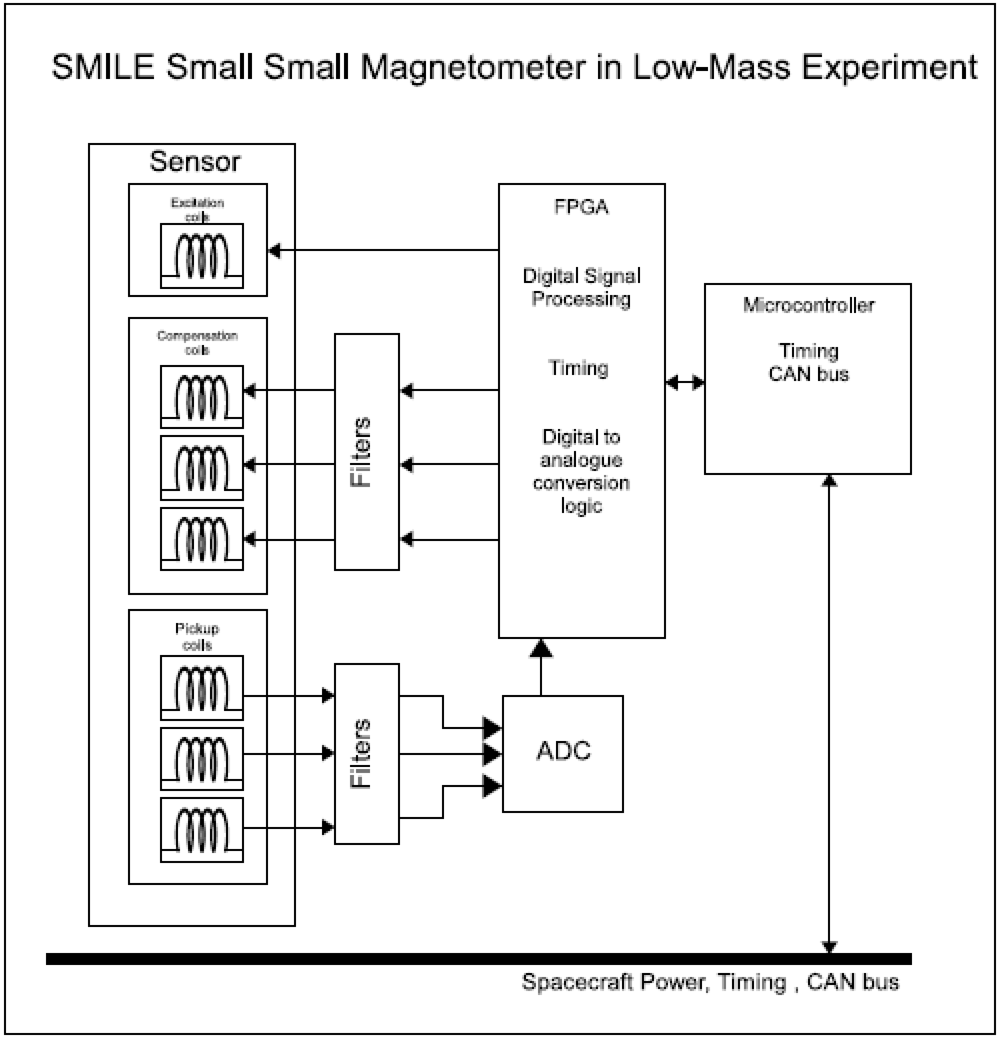


LP for PSI



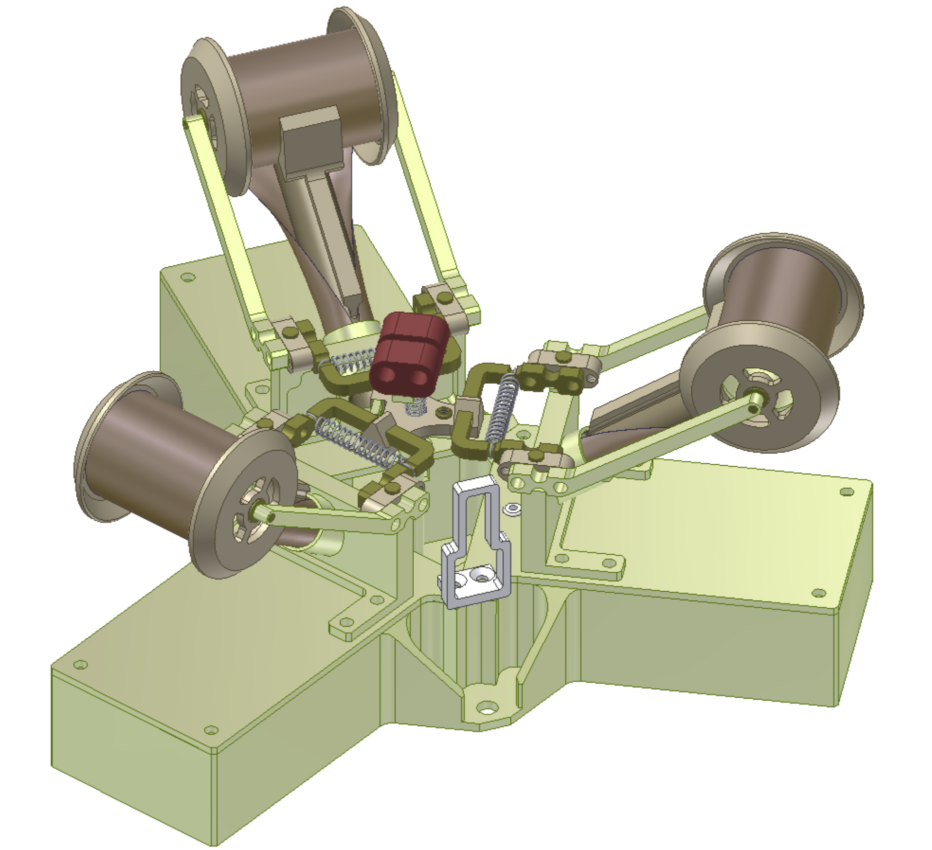
LP Langmuir Probe DC – 7.81 KHz
Probe Bias
±5 V
DC/DC
Converter
± 12 V
5 V
FPGA
Digital
Signal
Processing
Memory
Controller
I/O
Microcontroller
Timing
CAN bus
Numerically
Controlled
Oscillator
4 Hz- 7.81 KHz
Probe Bias
±5 V
16 bit
ADC
7.81 KHz
Multiplexer
Diff
IUQ
Gain
Gain
IUQ
Diff
Spacecraft Power, Timing , CAN bus

SMILE for PSI



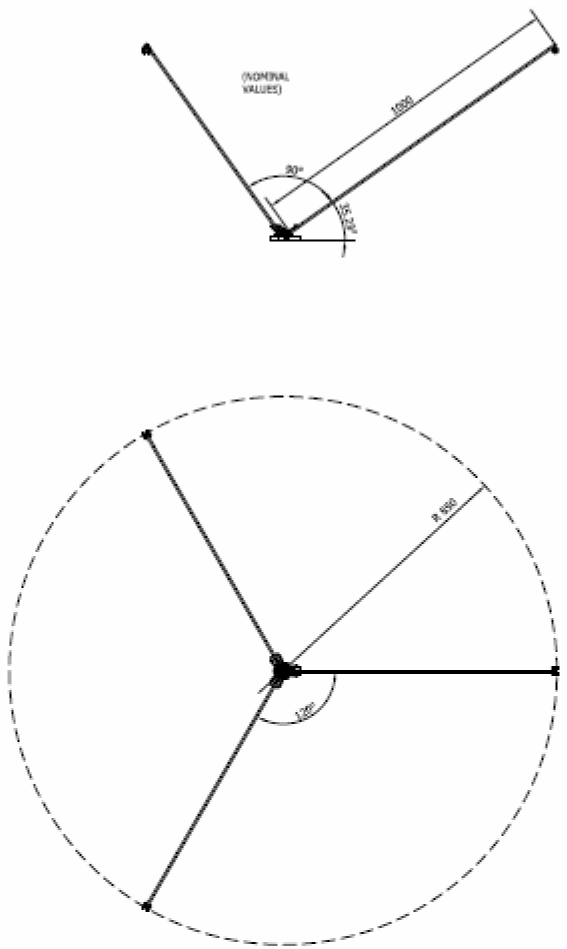
SRC Ultra-Lightweight Antenna

Hanna Rothkeahl, Space Research Centre, Polish Academy of Sciences,
Bartycka 18A, Warsaw, Poland 00-716



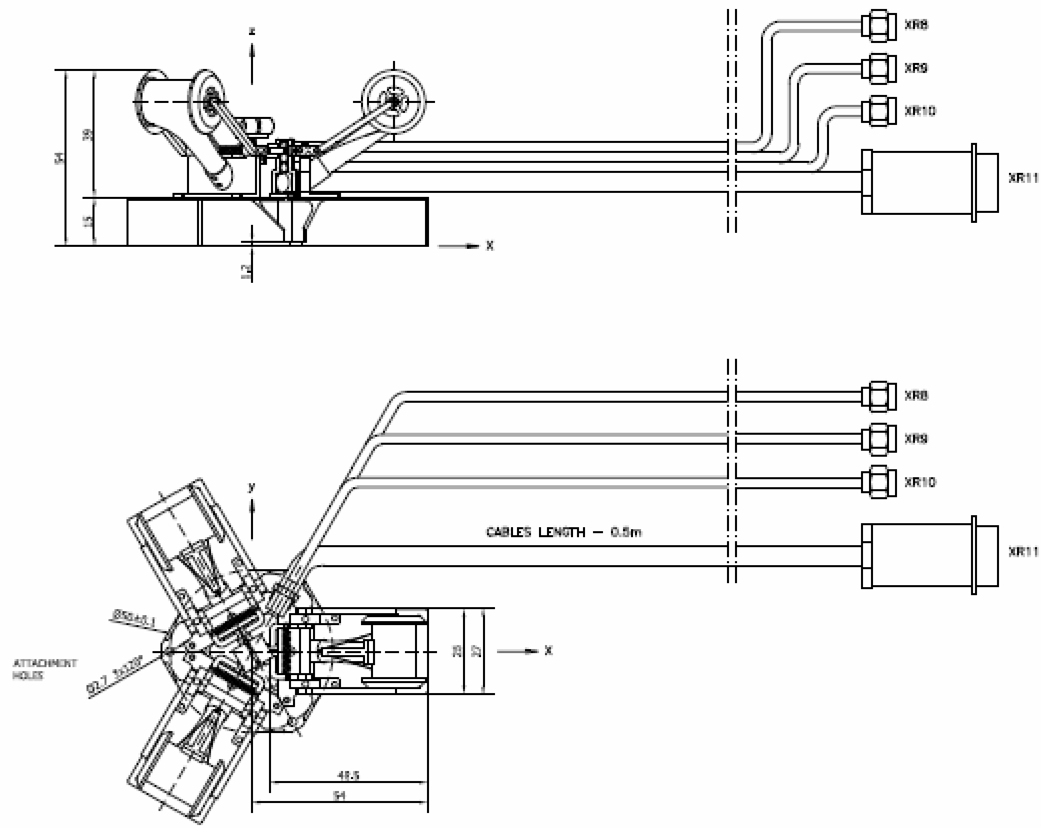
SRC Ultra-Lightweight Antenna

DEPLOYED (SCALE 1:10)



STOWED (SCALE 1:1)

NO.	CONNECTOR NAME	CONNECTOR TYPE	Q-TY
1	XR8, XR9, XR10	SMA-50-PAG0302	3
2	XR11	PC19ATB	1



NOTES:

1. MECHANICAL INTERFACE
   - 1.1 TOTAL MASS – 0.2±10%
   - 1.2 SIZE OF EACH ANTENNA (LxWxH) – 48.5x27x39 mm
   - 1.3 MASS OF EACH ANTENNA (WITHOUT ELECTRONICS) – 0.015±10% kg
   - 1.4 TUBULAR BOOM MATERIAL – BERYLCO 25, 20x0.05 mm STRIP
   - 1.5 MOMENTS OF INERTIA (WITH RESPECT TO CS):
     - I_x = 100 $kgmm^2$
     - I_y = 100 $kgmm^2$
     - I_z = 90 $kgmm^2$

RELEC-RFA-AE
MECHANICAL INTERFACE CONTROLLED DRAWING

DESIGNER	DRAWN BY	APPROVED	Q-TY	DATE	ISSUE
J. GRYGORCZUK	H. TOKARZ	H. ROTHKAEHL	1	01.06.11	1

Space Research Centre
Polish Academy of Sciences
Bartycka 18A
00-716 WARSAW

SCALE: 1 : 1 (1 : 10)
NUMBER: RE-ANT-MT-500

Summary

- High Power HF Waves in the Ionosphere
  - Nonlinear Wave Interactions
  - In Situ ES and EM Wave Generation
    - High Frequency
    - Low Frequency
- MiniSat Sensor Platform
  - ePOP (2012 Launch)
  - 8 Plasma, Neutral and Wave Sensors
- PicoSat (CubeSat) Sensors
  - NRL Miniature HF Receiver (MiniHFR)
  - 30 Day Lifetime
- Nano Sat or MicroSat Sensors
  - IRFU PSI
  - SRC Antennas