Satellite Observations of Nonlinear Interactions in the Ionosphere

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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

Satellite Orbit

- HIPAS
- HAARP
- Platteville
- Arecibo
- Jicamarca
- EISCAT
- SURA

Arecibo
Conjugate
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.
Electron Acceleration and Irregularity Formation 2\textsuperscript{nd} Harmonic of the Electron Cyclotron Frequency

- **HAARP Artificial Aurora**
  - 2.85 MHz
  - 3.6 MW Transmitter Power
  - March 2009
- **Artificial Plasma Layers**
  - 2\textsuperscript{nd} Harmonic Resonance
  - Electron Bernstein Wave Acceleration
- **Ref.:** Todd Pedersen (AFRL)
Artificially Produced Plasma Layers
Near 200 km Altitude

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 80° Inclination ORBIT
# Space-Based, Diagnostic Requirements for HAARP Measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Importance</th>
<th>Diagnostic</th>
<th>ePOP Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELF/VLF Waves</td>
<td>Very High</td>
<td>Receiver Covering 1 Hz to 30 kHz</td>
<td>RRI 10 Hz to 30 kHz</td>
</tr>
<tr>
<td>Field Aligned VLF Ducts Artificial and Natural</td>
<td>High</td>
<td><em>In Situ</em> Electron Density Probe</td>
<td>SEI (10(^2) to 10(^6) cm(^{-3}))</td>
</tr>
<tr>
<td>Elevated F-Region Electron Temperature as Duct Signature</td>
<td>Moderate</td>
<td>Thermal Electron Detector 0.0 to 0.3 eV</td>
<td>SEI (0 to 200 eV)</td>
</tr>
<tr>
<td>Optical Emissions from Precipitation</td>
<td>Moderate</td>
<td>Photo Detector N(_2)1P, 630, 557.7, 427.8, 777.4 nm</td>
<td>FAI (630 to 850 nm)</td>
</tr>
<tr>
<td>Suprathermal Electron Fluxes</td>
<td>Moderate</td>
<td>Energetic Electron Detector</td>
<td>SEI (0 to 200 eV)</td>
</tr>
<tr>
<td>Modulated HAARP Pump Wave</td>
<td>Moderate</td>
<td>HF Receiver/Antenna (3 to 9 MHz)</td>
<td>RRI (1-18 MHz, 30 kHz Bandwidth)</td>
</tr>
</tbody>
</table>

EPOP Booms – Deployed
(Looking at underside of lower deck plate)
Ionospheric Heating Simulations on Field Line Above Transmitter

Electron Density

Electron Temperature

Ion Temperature

1 Hour Heating Period

Satellite Altitude

Local Time (Hours-Minutes)
JOINT CERTO and GPS-GAP OPERATIONS ON CASSIOPE

From GPS Satellite

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

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

LEO ORBIT

Ground HF Transmitters

Ionosphere

Miniature HF RECEIVER
CubeSat Implementation of MiniHFR

(a) Stowed Configuration

HF Receiver Boards
DSP B2
ADC B1

10 cm

(b) MiniHFR Receiver

Short Antenna
19 cm

30 cm

To Ground HF Receivers
CubeSat Receiver Antennas
IRFU
Uppsala
PSI
Plasma
Science
Instruments
EFVS for PSI

EFVS Electric Field Vector Sensor 100 Khz – 16 MHz

Spacecraft Power, Timing, CAN bus
Deployable Electric Field

DEPLOYED (SCALE 1:10)

STOWED (SCALE 1:10)

NOTES:

1. M4AZ = 0.19 kg
2. SIZE OF EACH ANTENNA (LxWxH) - 460x65x54 MM
3. MASS OF EACH ANTENNA (WITHOUT ELECTRONICS) - 25 g
4. TUBULAR BOOM MATERIAL - ALLOY 6063, 5052/5083 MM STRIP

THERE WILL BE A SEPARATE CABLE FOR EACH OF CONNECTOR INSTALLS, CABLES LENGTH = TBD

MECHANICAL INTERFACE CONTROLLED DRAWING

RF-ANT (preliminary)

Spaced Research Centre
Palas Academy of Sciences
Barcelona, Spain
DG-719 MADIRAW

RF-ANT-06-100
LP for PSI

LP Langmuir Probe DC – 7.81 KHz

- Multiplexer
- 16 bit ADC 7.81 KHz
- FPGA
- Digital Signal Processing
- Memory Controller
- I/O
- Probe Bias ±5 V
- DC/DC Converter ± 12 V
- Microcontroller
- Timing CAN bus
- Numerically Controlled Oscillator 4 Hz-7.81 KHz

Spacecraft Power, Timing, CAN bus
SMILE for PSI

SMILE Small Magnetometer in Low-Mass Experiment

Sensor
- Excitation coils
- Compensation coils
- Pickup coils

FPGA
- Digital Signal Processing
- Timing
- Digital to analogue conversion logic

Microcontroller
- Timing
- CAN bus

Filters
- Spacecraft Power, Timing, CAN bus

ADC
SRC Ultra-Lightweight Antenna
Hanna Rothkeahl, Space Research Centre, Polish Academy of Sciences, Bartycka 18A, Warsaw, Poland 00-716
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