Space Object Identification by *In Situ* Measurements of Orbit Driven Waves SOIMOW Capability Briefing

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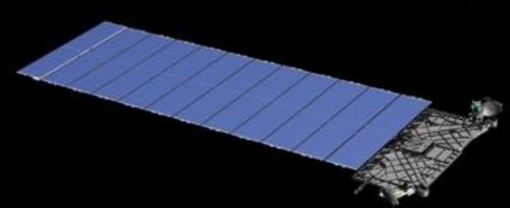
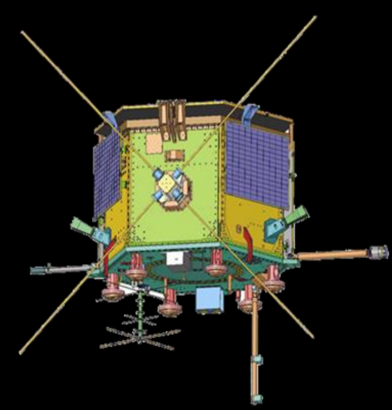
Iridium



Starlink

Waves

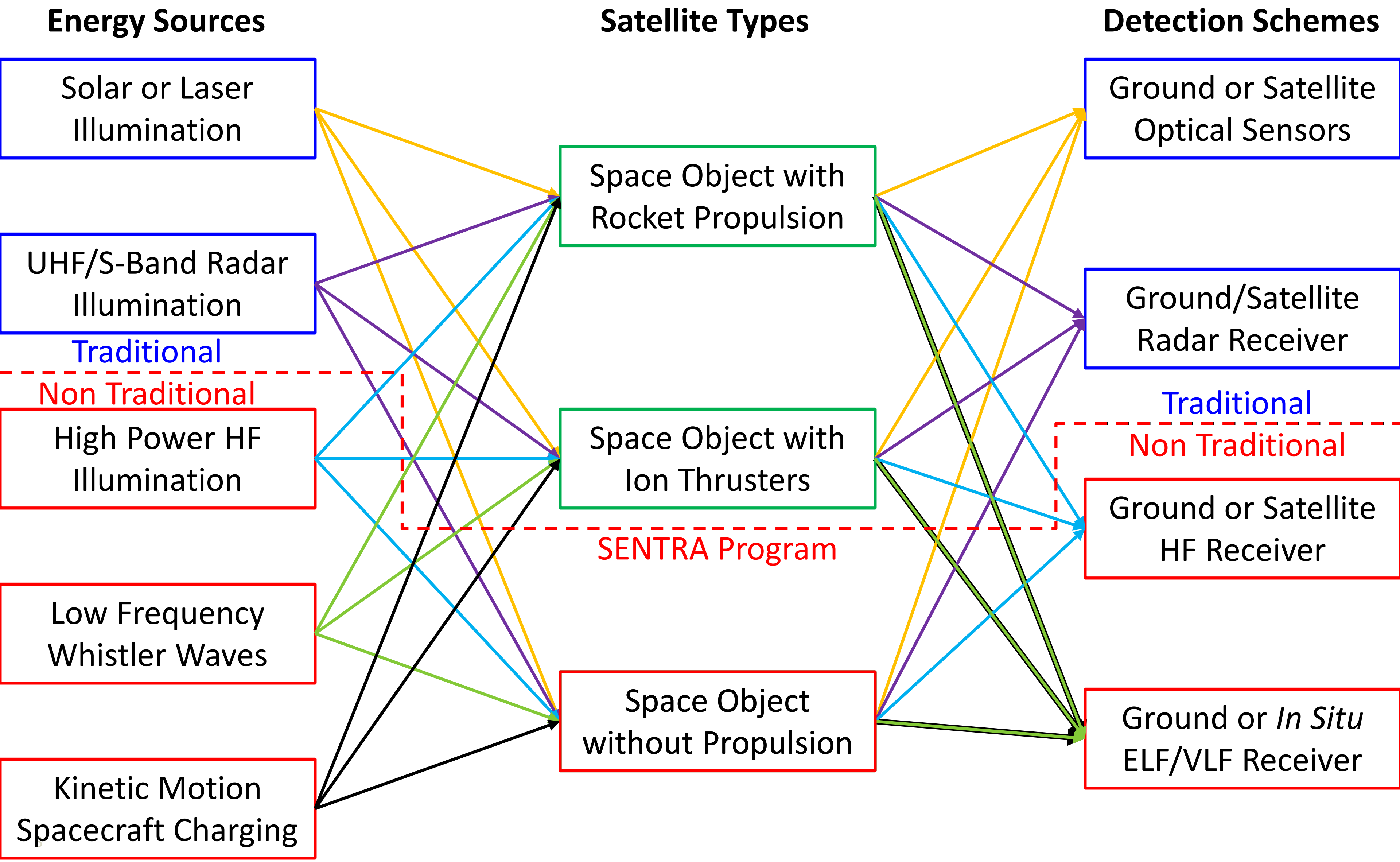


e-POP

- SOIMOW Technology Overview
  - **Program Objectives:** Detection, Classification, Recognition, and Identification (DCRI) of Space Objects for Space Situational Awareness (SSA)
    - Track Space Debris Less Than 10 cm in Size
    - Develop Satellite Damage Mitigation by Collision Avoidance
    - Identify Unexpected Plasma Wave Emission Events in Space
    - Determine Effects of satellite shape, orbit, tumbling, and thrusters
  - **Tools for Detection** of Satellites and Space Debris by Plasma Waves
    - **Arecibo UHF Incoherent Scatter Radar** Data of Satellite Plasma Waves
    - **SWARM-E Satellite** with Electric and Magnetic Field Sensors in Low Earth Orbit
    - Illumination by **HAARP** High Power HF Transmitter for Excitation of EM Plasma Waves
    - **Experimentally Validated Theories** on Stimulated Scatter of Plasma Waves
    - **Mission Planning Tools** for Space Object Tests and Technique Evaluation
  - Examples of **SOIMOW Successes** for Space Object Detection
    - Close Conjunctions of Inert Space Debris and Satellites with Electric Field Sensors
    - Detection of High Power HF Excited Emissions for Electrostatic Waves in Space
    - Spacecraft Detection by Passage Through VLF Transmitter Ray Paths
    - Transient Excitation of Magnetosonic Solitons and Whistlers by On Orbit Events
    - Plasma Wave Turbulence in Long-Distance Neutral Clouds from Satellites
  - Conclusions

Detection of Plasma Waves from Orbiting Satellites and Space Debris

Satellite Sensor Operations Chart for SOIMOW

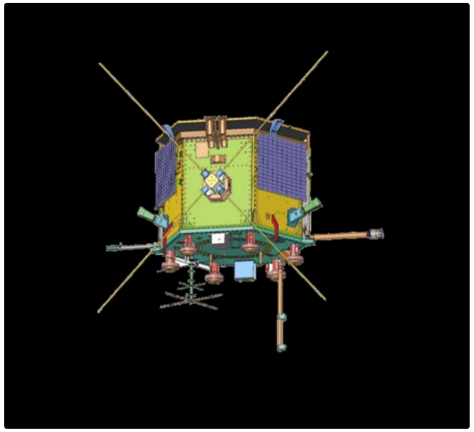


University of Alaska Fairbanks and University of Calgary Facilities for Space Debris Identification and Tracking with SOIMOW

HAARP High Power HF Illuminator

Active Environmental Research Array

SWARM-E Plasma Inst.



PFISR UHF Space Weather Radar

UAF Cameras and LIDARs

Poker Flat Rocket Range

Conjunctions of Target Satellites with Host Electric Field Sensors

Visionary Science for Detection of Small Objects in Space

Past

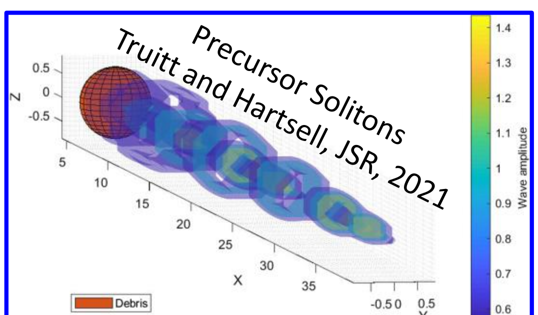
Concept: Orbiting Debris Launches Plasma Waves for Detection → **Theory and Simulation**: Plasma Wave Disturbance Generation →

Present

Concept Testing: Space Sensor Observations of Satellite Encounters → **Focused Modeling**: 3-D Fluid and Particle Codes with Electromagnetics →

Future

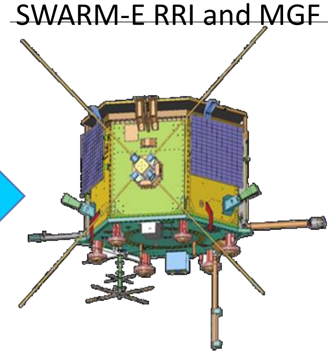
Dedicated Space Hardware: Microsats with Wave and Particle Sensors → **Operational Space System**: Sensor Interpretations and Machine Learned Signatures



Plasma Wave Predictions

Past

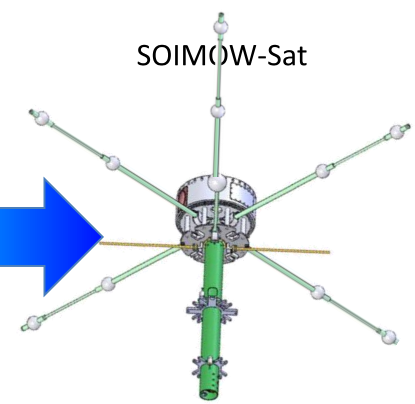
SWARM-E RRI and MGF



In Situ Field Measurements

Present

SOIMOW-Sat



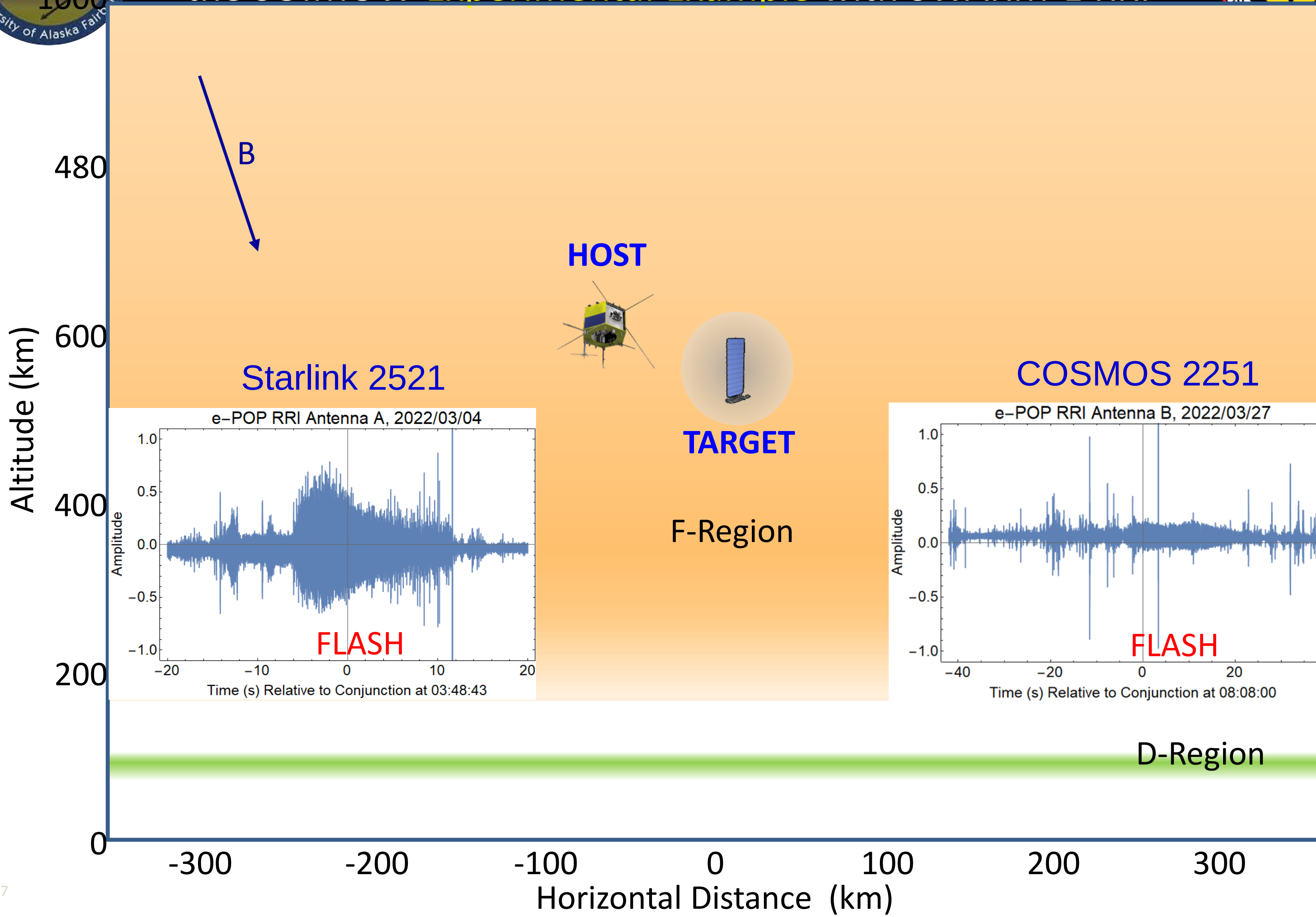
Dedicated Sensors

Future

Key Features of Low and Medium Frequency Plasma Waves for Space Debris Identification and Tracking (SINTRA)

Mode	Alias	Frequency Range	Speed	Group Direction	Polarization
Fast Magnetosonic	Compressional Alfven Wave	Low Frequency $0 < \omega < \Omega_i$ or ω_{LH}	Fast	Isotropic	$\mathbf{E}\cdot\mathbf{B}_0 = 0$
Alfven	Shear Alfven Wave	Low Frequency $0 < \omega < \Omega_i$	Fast	Along $\mathbf{B}_0$	$\mathbf{E}\cdot\mathbf{B}_0 = 0$
Slow Magnetosonic	Magnetized Ion Acoustic Wave	Low Frequency $0 < \omega < \Omega_i \cos\theta$	Slow	Along $\mathbf{B}_0$	$\mathbf{E} \parallel \mathbf{B}_0$
Whistler	Electron Whistler, Helicon Wave	Medium Frequency $\Omega_i < \omega < \Omega_e \cos\theta$	Fast	19.5° of $\mathbf{B}_0$	$\mathbf{E}\cdot\mathbf{B}_0 = 0$
Electrostatic Ion Cyclotron	First Ion Cyclotron	Low Frequency $\omega^2 = \Omega_i^2$	Zero	Isotropic	$\mathbf{E}\cdot\mathbf{B}_0 = 0$
Ion Cyclotron	Second Ion Cyclotron	Low Frequency $\omega^2 = \Omega_i^2 \cos^2\theta$	Zero	Along $\mathbf{B}_0$	$\mathbf{E} \parallel \mathbf{B}_0$
Ion Acoustic	Unmagnetized Ion Sound Waves	Medium Frequency $\Omega_i < \omega < \Omega_e \cos\theta$	Slow	Isotropic	$\mathbf{E} \parallel \mathbf{B}_0$
Lower Hybrid	Finite-k_z Lower Hybrid Waves	Low Frequency Fixed $\omega_{LH}^2 = \dfrac{\Omega_i \Omega_e + \Omega_e^2 \cot^2\theta}{1 + \Omega_e^2 / \omega_{pe}^2}$	Slow	Perpendicular to Phase Velocity	$\mathbf{E}\cdot\mathbf{B}_0 = 0$

Satellite Detection by EM Wave Generation During the SOIMOW Experimental Example with SWARM-E RRI



Detection of Plasma Waves from Orbiting Satellites and Space Debris

End-to-End Resources at the Geophysical Institute/UAF and U/Calgary

Program Asset	Name	Source	Purpose	Data Product
Alaska Satellite-Tracking Ground Station	ASF	UAF	**Realtime Tracking**	Synthetic Aperture Radar Satellite Tracking
Satellite Orbits and Target Conjunction Predictions	SOAP	Aerospace	**Mission Planning**	Satellite and Space Debris Trajectories
Magnetic Field Vectors and Satellite Velocity Geometries	IGRF+	UAF	**Mission Planning**	Favorable Geometries for SINTRA Tests
SWARM-E Satellite with Plasma Wave Receivers	e-POP RRI/MGF	Univ. of Calgary	**Space Data Acquisition**	Electric and Magnetic Fields from SWARM-E
High Power HF Transmitter: Electrostatic Wave Generator	HAARP	UAF	**Target Illumination**	Stimulated Scatter from Space Targets
Ground HF, VLF, and ELF Receivers	AERA	UAF and DOD	**Emission Detection**	Plasma Wave Fields from Spacecraft
Multimode Plasma Wave Propagation and Generation	WIPL-D+	WIPL-D and UAF	**Observation Analysis**	Identification of Host Wave
Space Plasma Laboratory	SPLE	WVU	**Experiment**	Scaled Plasma Physics
Ionospheric Specification Simulation and Tools	SAMI-3	JD Huba	**Background Ionosphere**	Ambient Plasma Wave Environment

Plasma Waves from Orbiting Satellites and Space Debris

Summary of SOIMOW Team Capabilities

- Satellite Motion Produces Waves and Wakes
  - Orbital Plasma Waves Provide a New Means of Space Object Detection
  - Ionospheric Waves from Spacecraft Impact the Space Weather Environment
- Factors Affecting Plasma Wave Disturbances from Space Objects
  - Trajectory Relative to Magnetic Field Direction
  - Size, Orientation, and Tumbling of Spacecraft or Debris
  - Propulsion System Operation Injecting Neutral or Ion Beams
- Space Object Detection Systems
  - Close Encounters between Hypersonic Target and Sensors on Host Satellite
  - Target Flight Through High Power HF Beams Near Ionospheric Critical Regions
  - Passage of Target Between Ground VLF Transmitter and Whistler Receivers
- Current SOIMOW Activities
  - Continuing Conjunctions of HOST SWARM-E Sensors with Targets of Opportunity
  - Scheduled Flights of High-Inclination, Low-Altitude Targets Though the HAARP Beam
  - Target Flights Over Ground VLF Transmitters with Satellite and Ground Sensor Support
  - Mission Planning to Execute On-Going Experiments
  - Theory, Simulation and Laboratory Experiments to Explain Observations
  - Identification of Benefits and Hazards for Multiple Spacecraft and Debris in LEO