Tracking the Orbits of Small Space Debris with Ionospheric Plasma Waves

P.A. Bernhardt[(1)], B.E. Eliasson[(2)], W.A. Scales[(3)], A. Howarth[(4)], V. Foss[(4)], R.L. Scott[(5)], S. McKay[(1)]

(1)Geophysical Institute, Univ. of Alaska, Fairbanks, AK, USA; e-mail: pabernhardt@alaska.edu
(2) Dept, of Phys., SUPA, Univ. of Strathclyde, Glasgow, UK, (3) ECE, Virginia Tech, Blacksburg, VA, USA,
(4) University of Calgary, Calgary, AB, Canada, (5) Defence R&D Canada Ottawa, Ottawa, ON, Canada

Tracking and detecting small objects in space can now employ plasma waves produced as these objects pass through the ionosphere. Computer simulations and laboratory measurements predict that this technique, called Space Object Identification with Measurements of Orbit Driven Waves (SOIMOW) will find objects that are not seen by optical and radar systems. In situ observations have confirmed the presence of these plasma waves, during space sensor conjunctions with known space objects. Small space objects, when they pass through a structured environment, can generate whistler mode waves observable with both ground sensors and remote satellite instruments. Space debris and satellites moving through plasma irregularities excite electric and magnetic emissions such as whistler, compressional Alfvén, or lower hybrid waves. A whistler wave disturbance is generated by conversion of orbital kinetic energy into an electromagnetic plasma oscillation when a charged space object encounters a region of field aligned density irregularities (FADIs). Whistlers propagate undamped at around 9000 km/s from the source regions and can be detected by the e-POP RRI at large ranges over 100 km from the space debris target. Similarly, fast magnetosonic waves with Alfven speeds have been detected out to these ranges of 100 km with the in situ, electric field probes on the Canadian CASSIOPE/Swarm-E spacecraft. The spectral "FLASH" signatures of space debris are uniquely found between the local ion cyclotron and the upper hybrid frequencies (Figure 1).

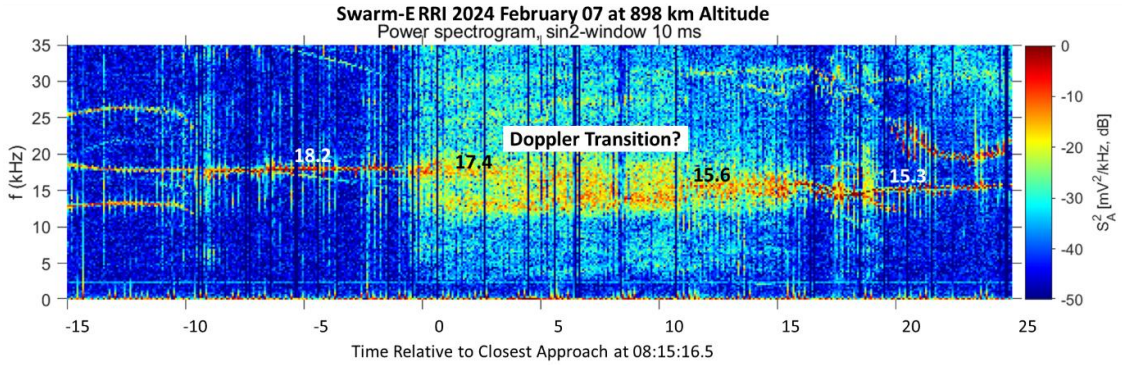

Figure 1. FLASH signature with CA-6A Space Debris (8 cm radius) coming within 2.5 km of Swarm-E RRI. The observed Doppler frequency shifts can provide the velocity of the object.

After detection, space debris tracking is required to update orbit prediction models. In situ measurements from host sensors need to provide the angle of arrival (AOA), vector distance (**L**), and vector velocity (**V**) of the space debris target for estimation of a predictive state vector. The AOA requires a vector sensor of the EM fields to give both the electric (E) and magnetic (H) vector components of the incident signal from the space debris target to the host sensor platform. Forming the E x B Poynting flux from the target object, yielding the source direction. The range and velocity influences the rapid Doppler frequency shifts near the time of closest approach between the two objects. Finally, transient disturbances from the target can become dispersed by propagation in the magnetized plasma much as a lightning falling tone is formed with whistlers. Matched filter processing of these signals with wavelet-like, plasma waveforms allows estimation of the range of the source for specific generation time.

1. P.A. Bernhardt et al. (2023) Observations of plasma waves generated by charged space objects, Phys. Plasmas 30, 092106.
2. Matthew Idso, Wayne Scales, Bhuvana Srinivasan (2024), Modeling Lower Hybrid Waves Generated by Charged Space Objects, Radiation Effects and Defects in Solids.
3. B. Eliasson, P.A. Bernhardt (2025) The generation of whistler, lower hybrid and magnetosonic waves by satellites passing through ionospheric magnetic field aligned irregularities, Phys. Plasmas, 32, 1.