Virtual Research Presentation Conference

Using DSN X-band radar to measure spin states of satellites in near-geosynchronous orbits

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Tutorial Introduction

Abstract

Understanding and predicting the evolving spin states of defunct GEO satellites and rocket bodies is important for space situational awareness, active debris removal, satellite servicing, anomaly resolution, and small asteroid evolution.

There is clear evidence that many defunct GEO satellite spin states are predominantly driven by the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect. The YORP effect is spin state evolution due to solar radiation and thermal re-emission torques.

Observations are crucial to understand how YORP drives spin states and to validate dynamical models. We make use of the DSN X-band radar to illuminate GOES 8,9,11 and 12 GEO satellites to extract their spin states.

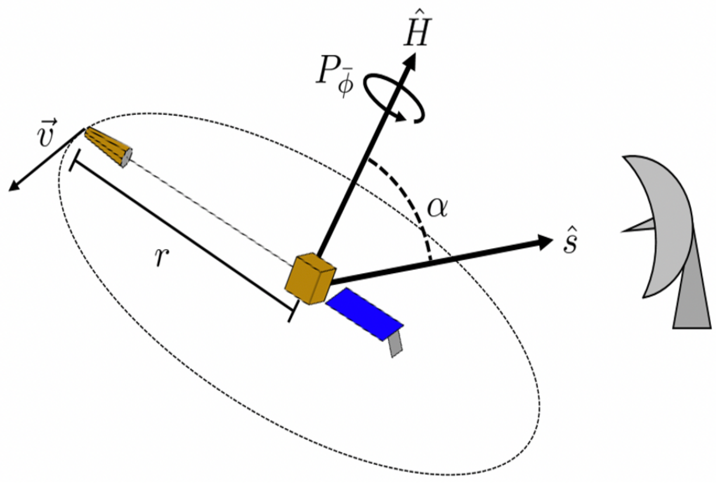


Figure 1: Geo Satellite reference frame using DSN X-band Radar

Problem Description

a) Context: Unfortunately, extracting spin states (spin periods, rotational angular momentum vector, instantaneous attitude) from ubiquitous photometric light curve data is challenging because GEO satellites are non-resolved from ground-based telescopes. Even for well-known objects, light curve inversion often yields several or more well-fitting spin state solutions within the modeling uncertainty. Also, there is strong evidence that the YORP effect drives satellites from uniform rotation to non-principal axis tumbling. Such tumbling states further complicate the light curve inversion process because tumbling motion is driven by two independent periods

b) State-of-the-art: To aid spin state analysis, particularly for the tumbling case, we incorporate Doppler radar observations obtained at the Goldstone Deep Space Communications Complex. Studying the family of well-known retired GOES weather satellites, we obtained spin period estimates for all targets and greatly narrow pole solutions, independent of light curve data

c) Relevance to NASA and JPL: The debris population near geosynchronous earth orbit continues to grow with ongoing launches and no natural deorbit mechanisms. Understanding the long-term dynamical evolution of these debris objects is necessary to protect active assets and preserve GEO for future use.

Methodology

Experiment description:

With the aim of obtaining spin rate and pole estimates for defunct GEO satellites, our experiment targets consisted of four retired GOES weather satellites: GOES 8, GOES 9, GOES 11, and GOES 12. These satellites have been studied extensively with optical observations showing diverse spin states with significant spin period variation over time, with strong indication of YORP-driven behavior [1-7]. These satellites are therefore dynamically interesting. Also, their significant asymmetry and known geometry and mass properties greatly aid Doppler echo analysis. Overall, these attributes make these satellites ideal targets for radar study.

Subsets of these GOES satellites were observed from Goldstone on December 6, 2019 and February 18-20, 2020. Avoiding radar illumination of all other catalogued spacecraft, two 34 meter Deep Space Network (DSN) antennas were used in a bi-static configuration with one antenna transmitting and the second receiving the reflected echoes. The transmitted signal consisted of fixed frequency, continuous wave carrier at X-band. We alternated periodically between several targets over the course of the night to sample different inertial viewing directions for each one.

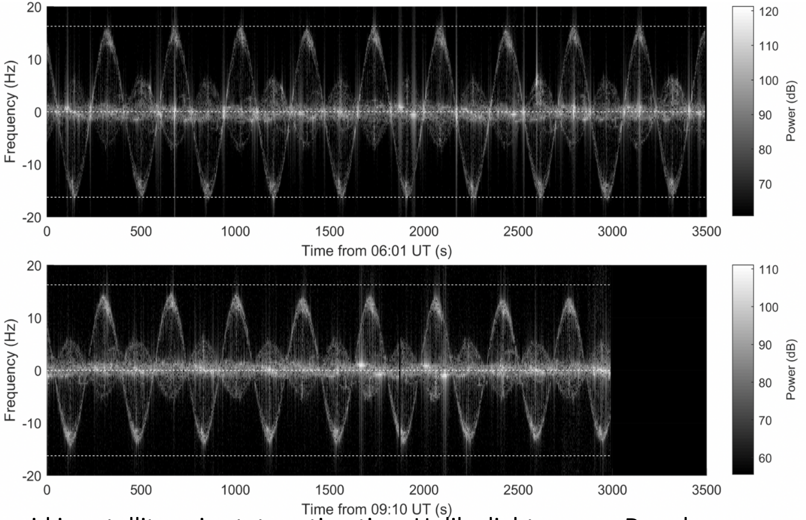
Results

Doppler echoes for GOES 8,9,11 and 12 were collected on December 6,2019, Feb 18’th and Feb 20’th 2020. 6,.

The Doppler echos for GOES 8 are shown in the Figure. We can clearly identify the solar sail, solar panel, and bus echoes.

The extracted precession periods for all GOES satellites can be seen in Table below.

	GOES 8	GOES 10	GOES 11	GOES 12
Dec. 6, 2019	*353 s (5.9 min)	-	*775 s (12.9 min)	882 s (14.7 min)
Feb. 18, 2020	*215 s (3.58 min)	30.5 s	-	462 s (7.7 min)
Feb. 20, 2020	*216 s (3.6 min)	30.5 s	-	454 s (7.6 min)



Overall, we developed and applied Doppler radar spin state estimation techniques that greatly aid in satellite spin state estimation. Unlike light curves, Doppler provides spatial resolution due to satellite rotation. This allows for clear identification of spacecraft features. Furthermore, Doppler vastly simplifies pole estimation as well as precession period extraction in the tumbling case. This is a huge improvement over light curve based inversion where accurate, high fidelity spacecraft models are often needed to replicate the observed specular reflections and glints.

Applying these radar-based estimation techniques, we obtained unambiguous precession periods for both tumbling and uniformly rotating GOES satellites. We found large diversity in precession periods and pole directions among the nearly identical GOES satellites with notable evolution over a 2.5 month span for GOES 8 and GOES 12. This spin state diversity and evolution is consistent with YORP-driven behavior. Furthermore, the rich diversity, pole motion, and tumbling resonances observed for these satellites motivates further observations and dynamical study.

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Publications

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