A CubeSat-Based Instrument for Calibrating Ground-Based Millimeter-Wave Polarimeters (CalSat)

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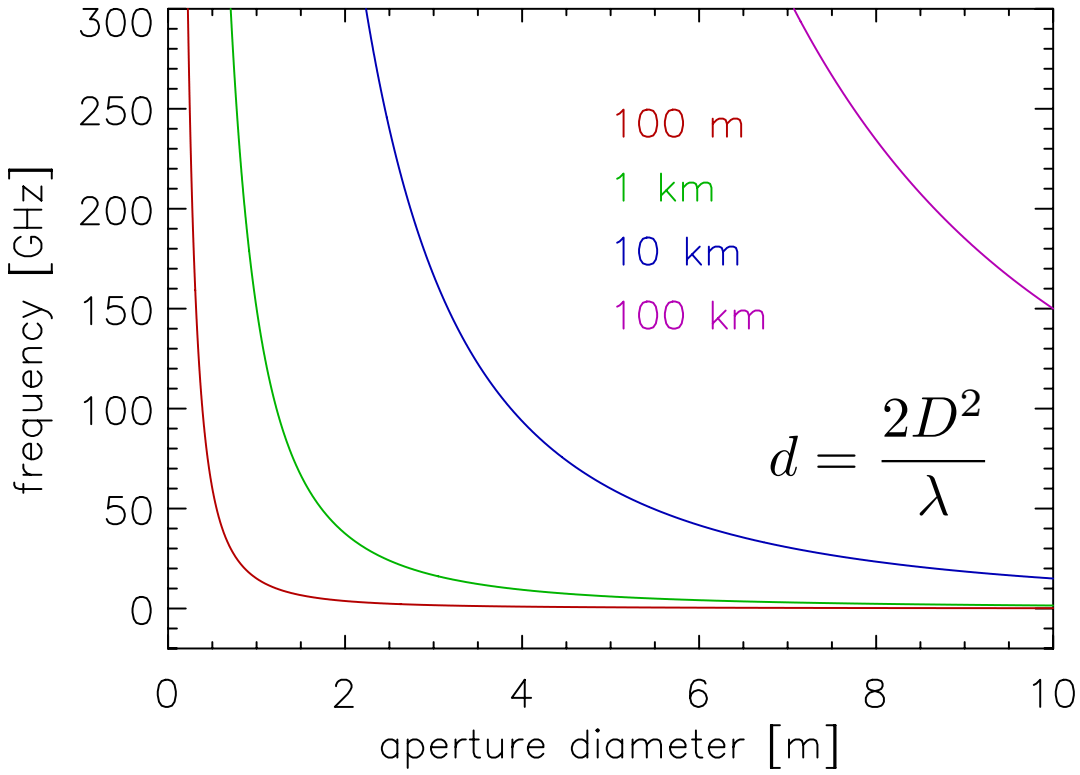
Associate Professor

Department of Astronomy

University of Virginia

November 5th, 2024

Ground-Based Calibration Sources



Ground-based sources should ideally be placed in the far field and the Fraunhofer distance is ***far*** for medium and large apertures.

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A CubeSat for Calibrating Ground-Based and Sub-Orbital Millimeter-Wave Polarimeters (CalSat)

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Precision tests of parity violation over cosmological distances

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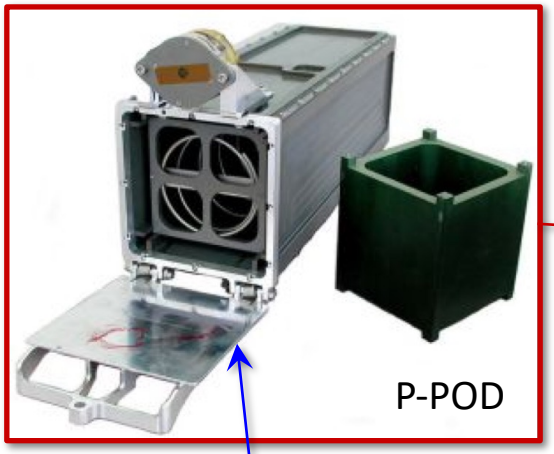
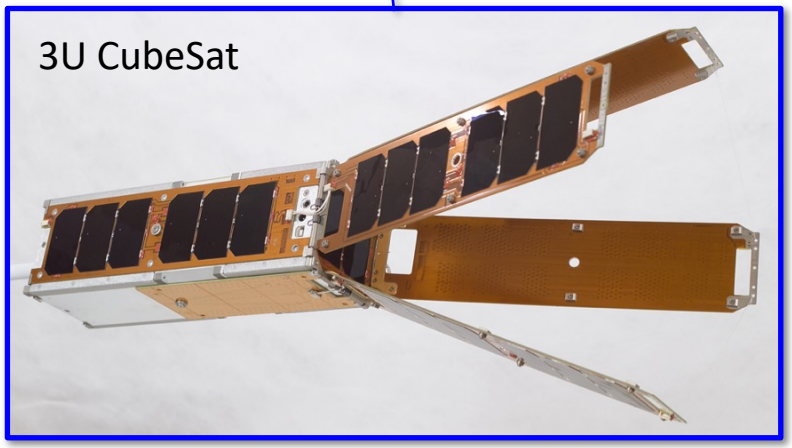
Buchalter Cosmology Prize 2014

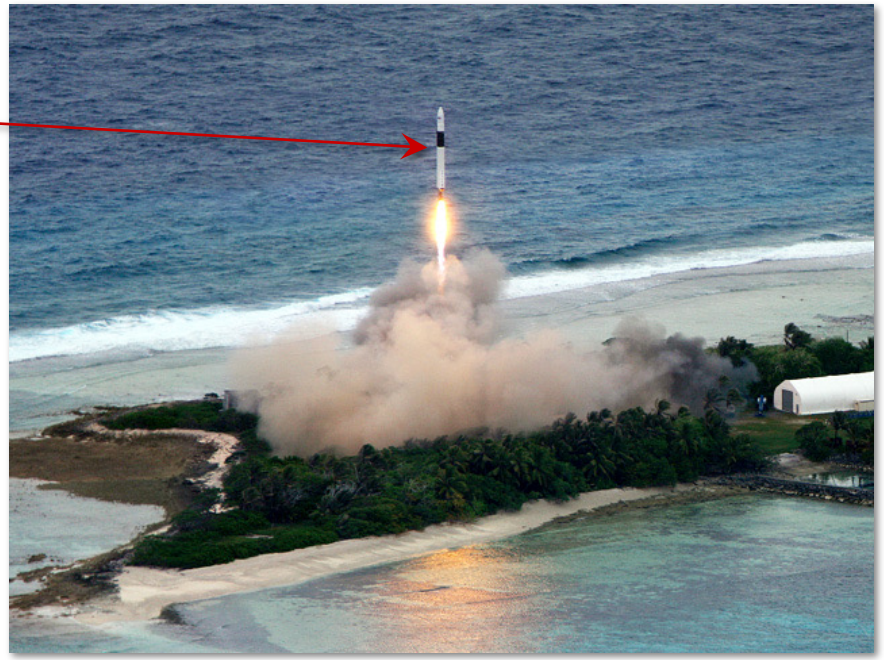
ABSTRACT

Recent measurements of the cosmic microwave background (CMB) *B*-mode polarization power spectrum by the BICEP2 and POLARBEAR experiments have demonstrated new precision tools for probing fundamental physics. Regardless of origin, the detection of sub-μK CMB polarization represents a technological *tour de force*. Yet more information may be latent in the CMB's polarization pattern. Because of its tensorial nature, CMB polarization may also reveal parity-violating physics via a detection of cosmic polarization rotation. Although current CMB polarimeters are sensitive enough to measure one degree-level polarization rotation with $>5\sigma$ statistical significance, they lack the ability to differentiate this effect from a systematic instrumental polarization rotation. Here, we motivate the search for cosmic polarization rotation from current CMB data as well as independent radio galaxy and quasar polarization measurements. We argue that an improvement in calibration accuracy would allow the unambiguous measurement of parity- and Lorentz-violating effects. We describe the CalSat space-based polarization calibrator that will provide stringent control of systematic polarization angle calibration uncertainties to 0.05° – an order of magnitude improvement over current CMB polarization calibrators. CalSat-based calibration could be used with current CMB polarimeters searching for *B*-mode polarization, effectively turning them into probes of cosmic parity violation, 'for free' – i.e. without the need to build dedicated instruments.

What is a CubeSat?

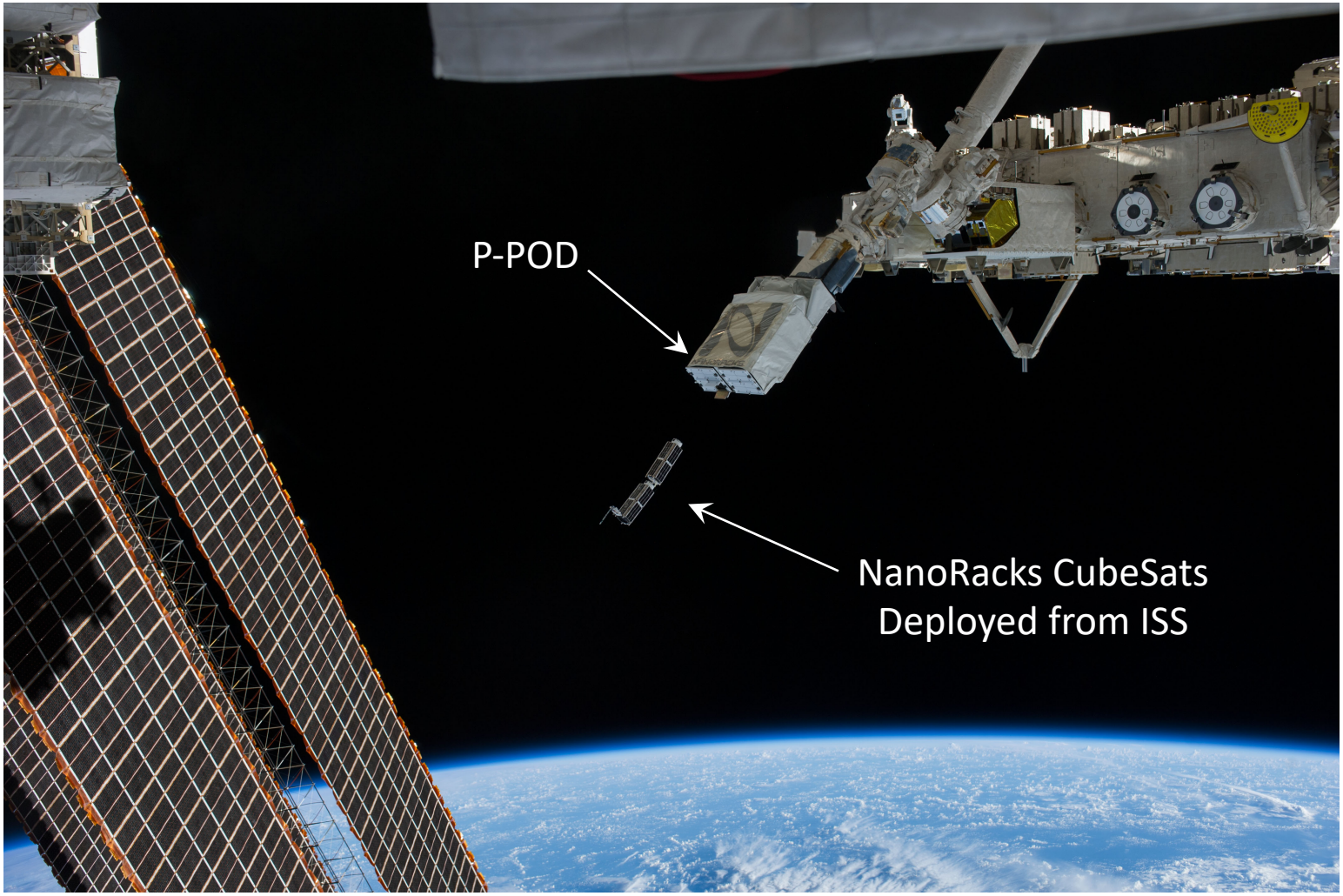






The Falcon 1 rocket lifting off at Omelek Island on July 14, 2009.

What is a CubeSat?



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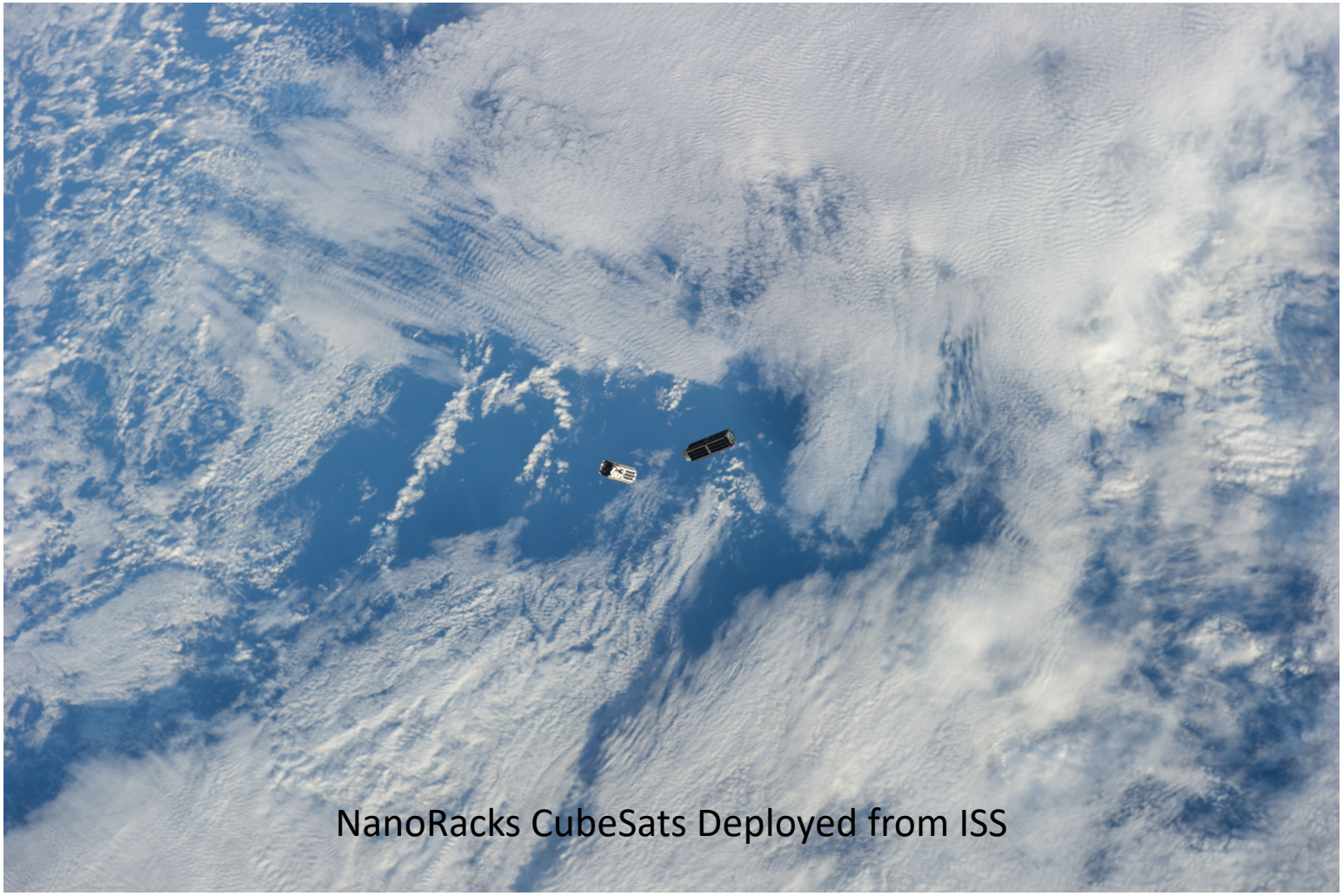
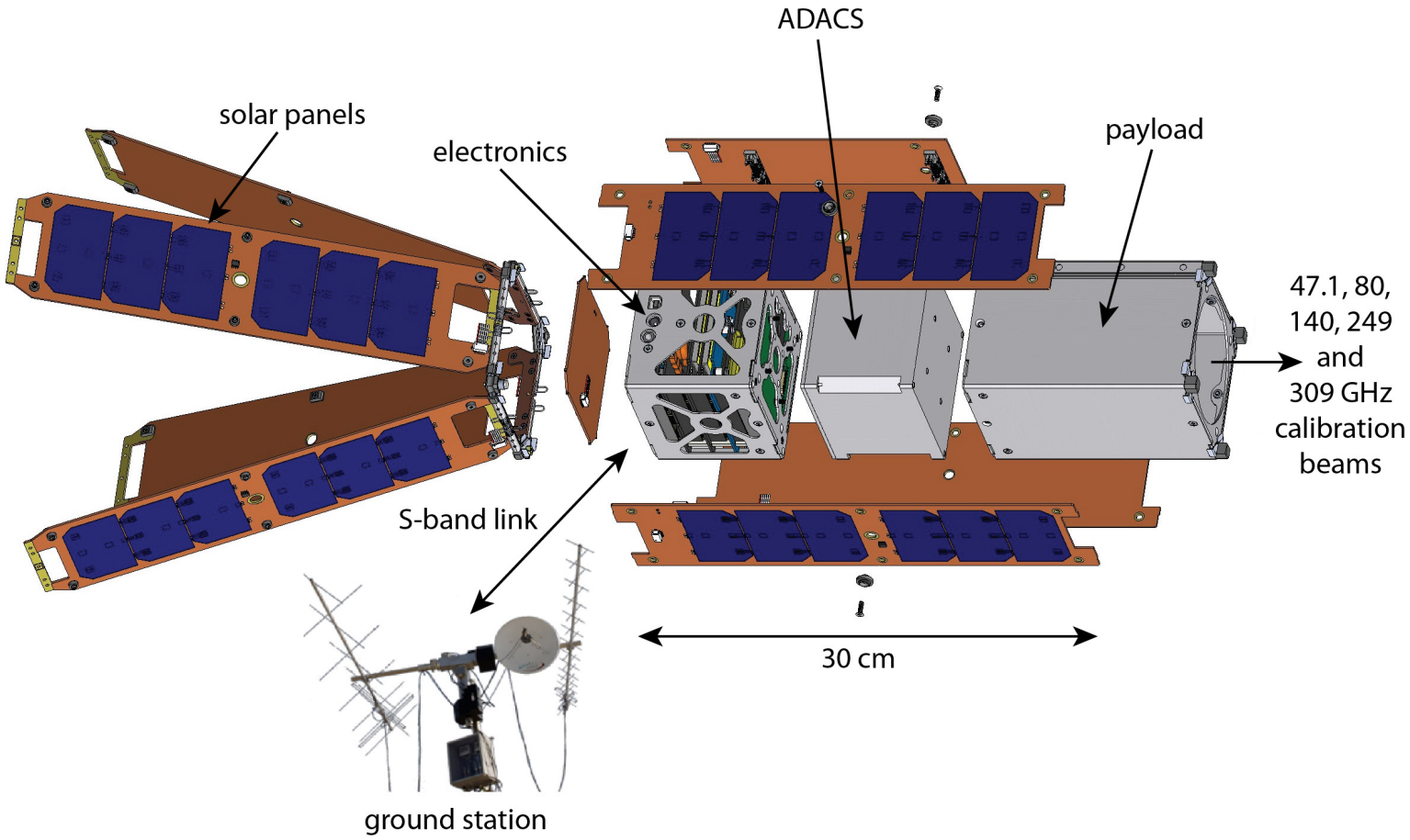


NanoRacks CubeSats Deployed from ISS

Exploded View of CalSat v1.0



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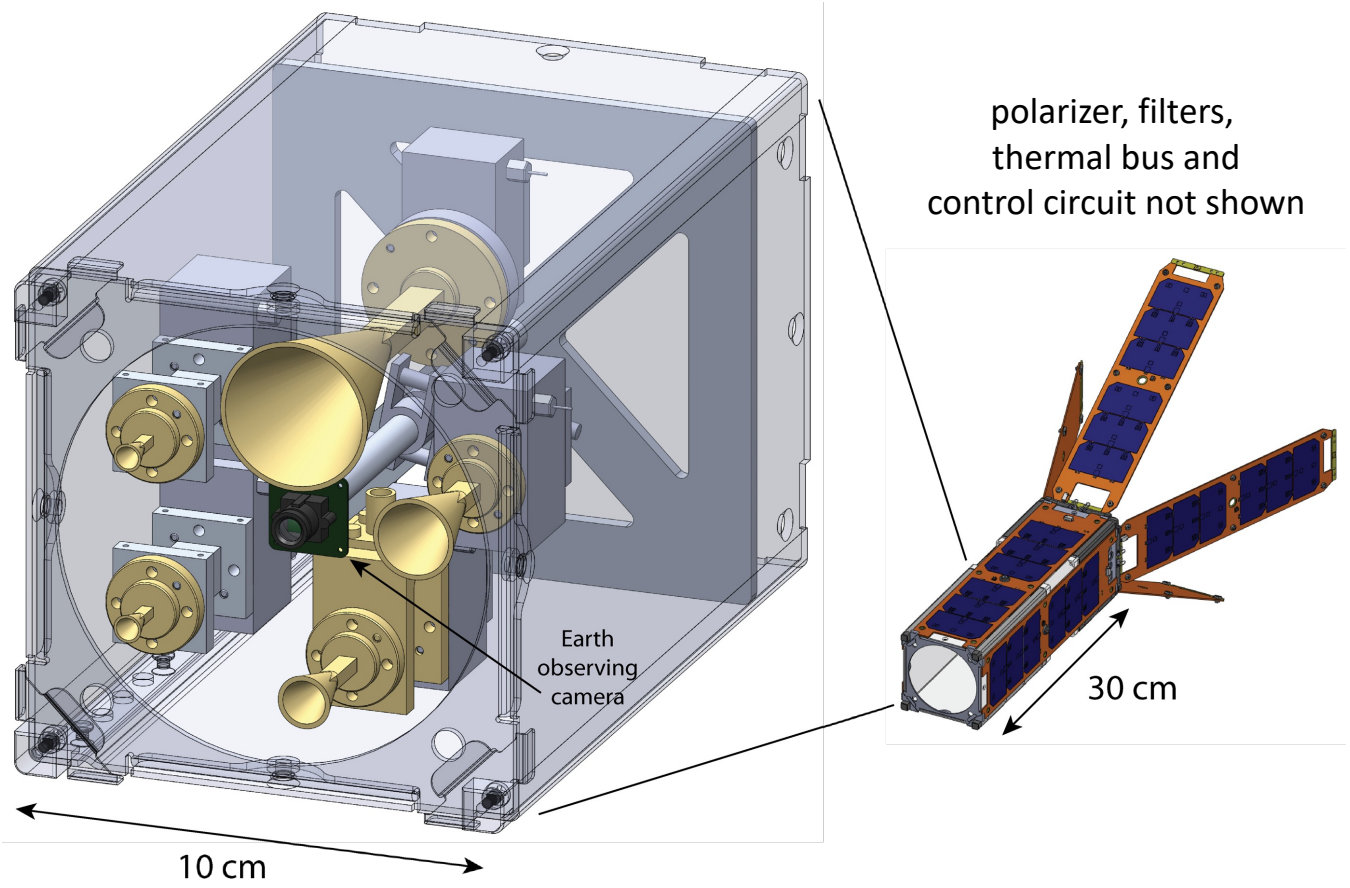
The CalSat Payload



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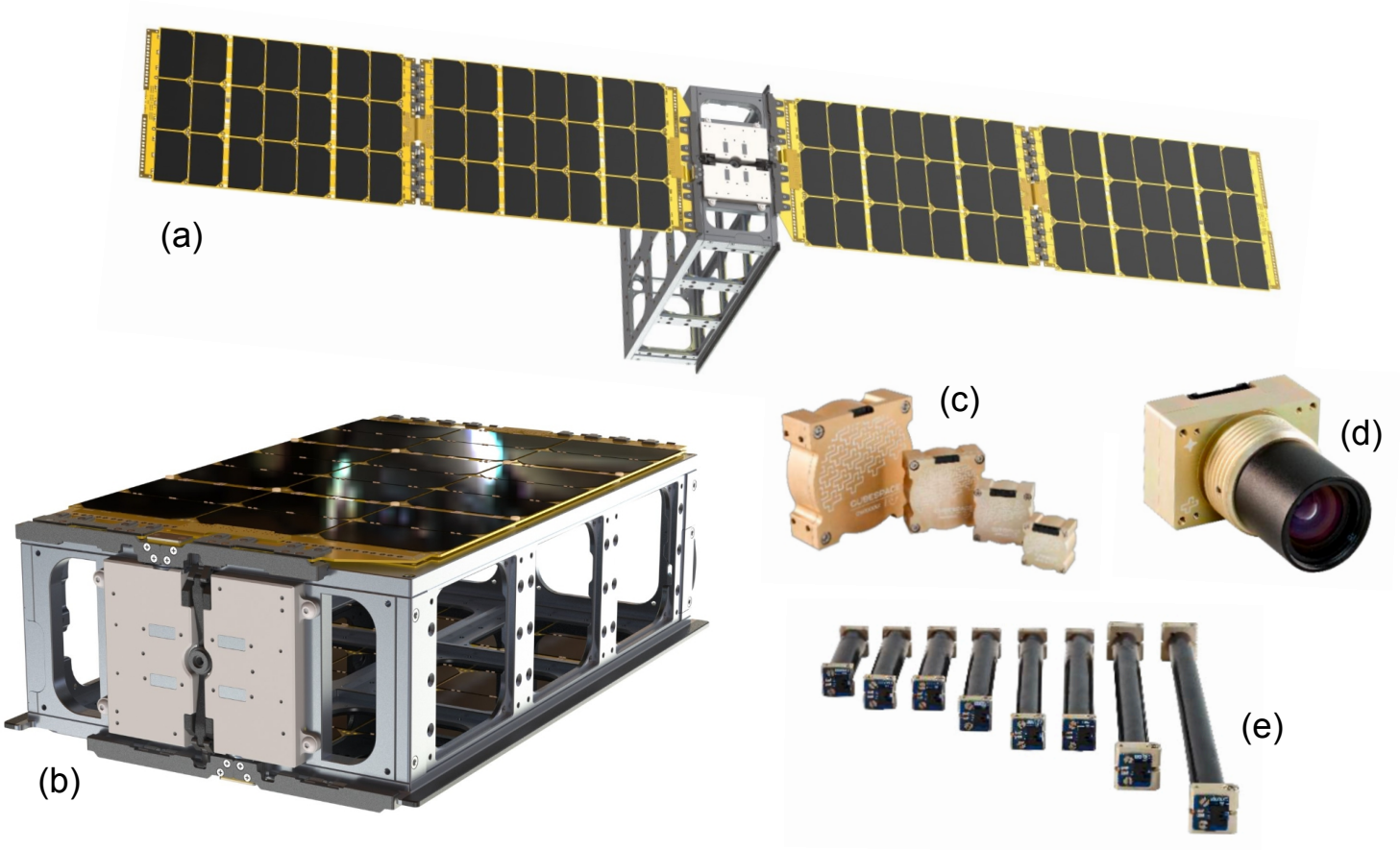
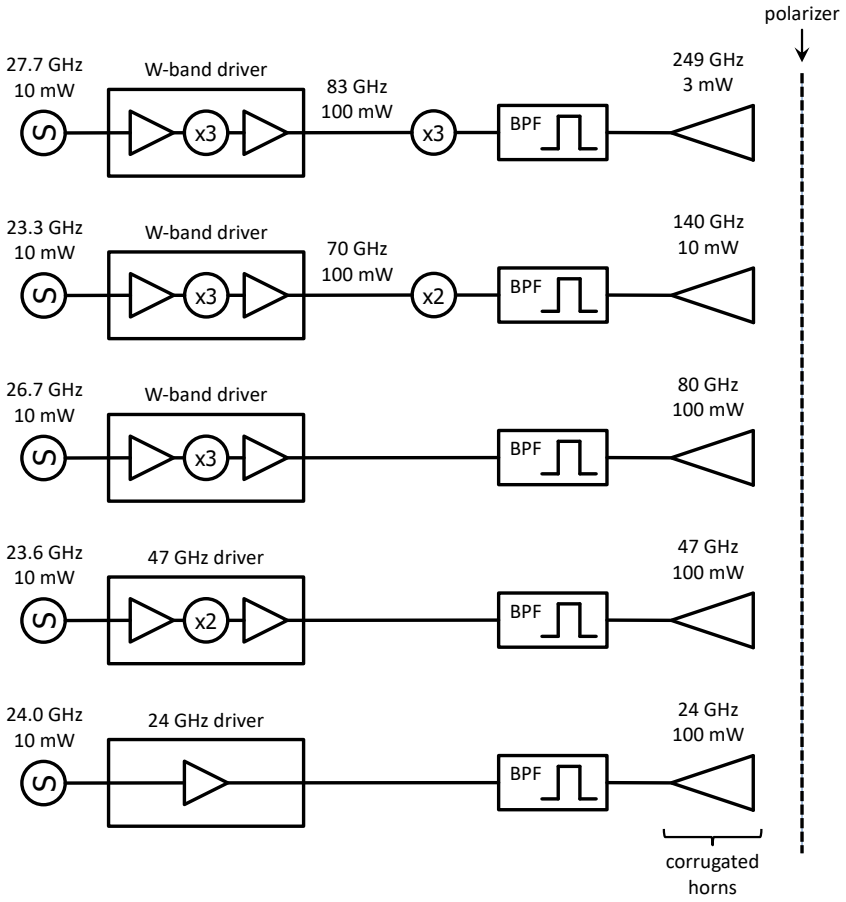
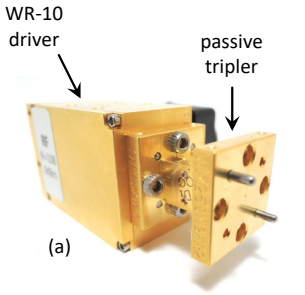
CalSat v2.0

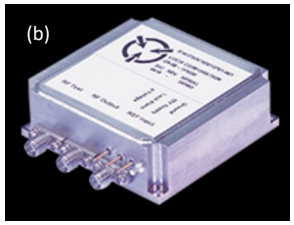


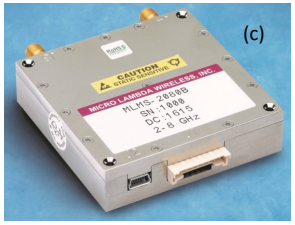
Bus from Pumpkin, ADCS from Cube Space.

Calibration Sources from TK and VDI



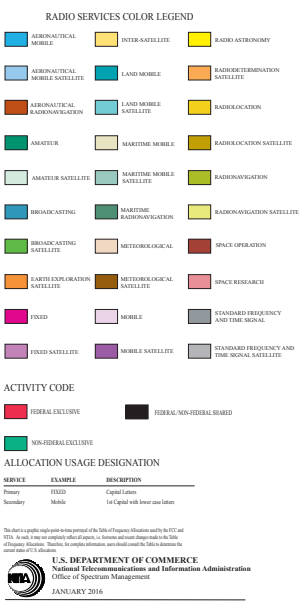


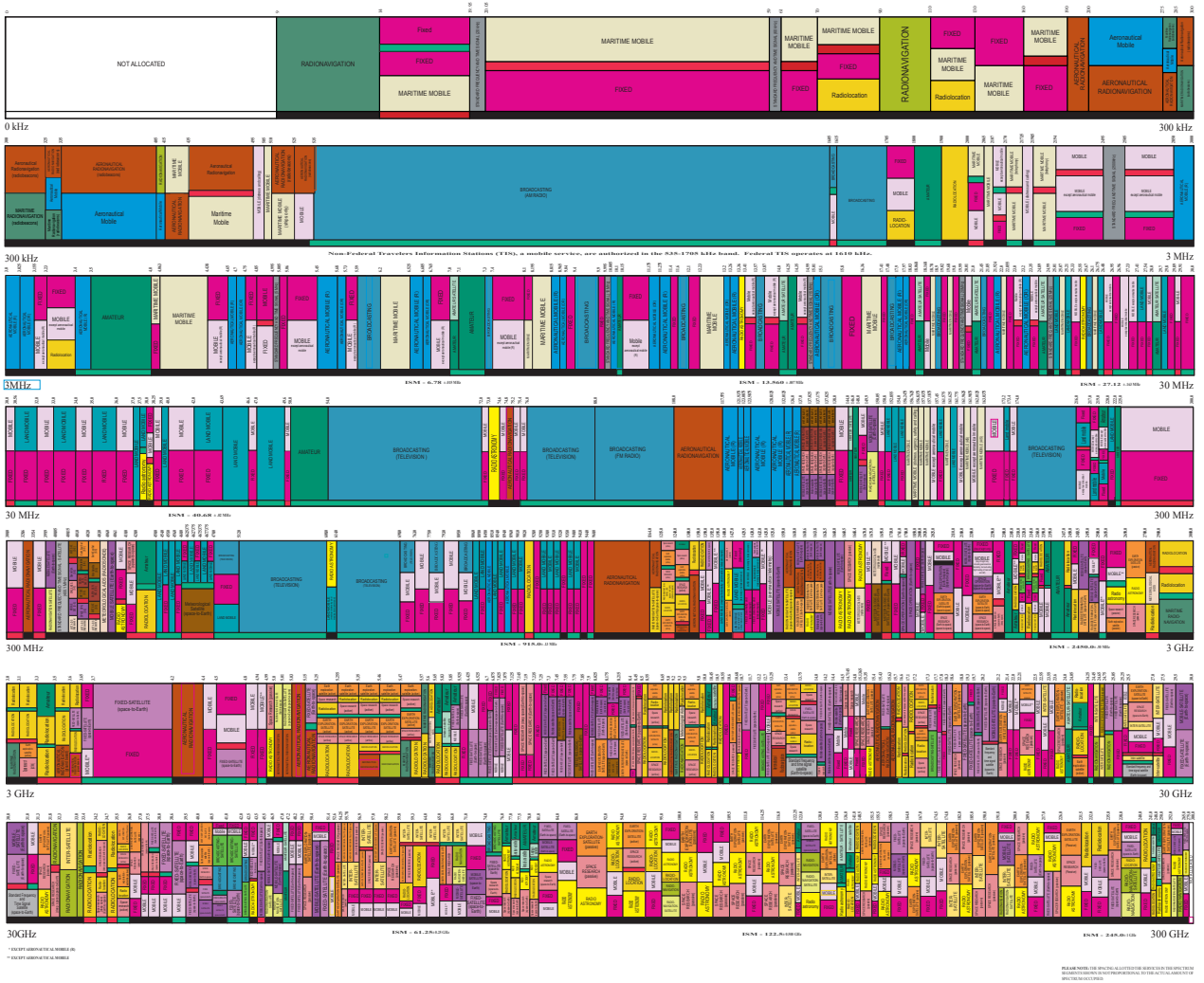




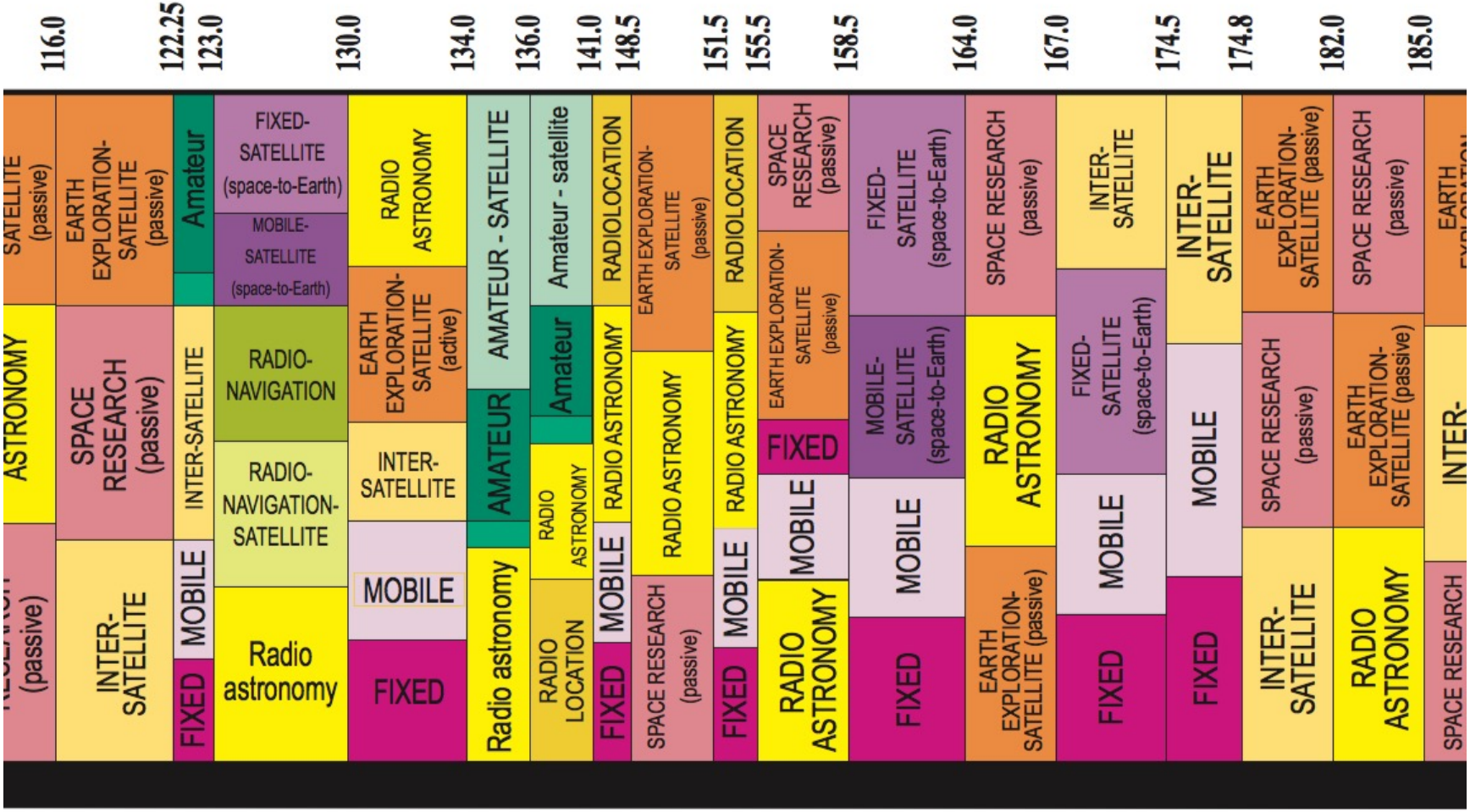
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM





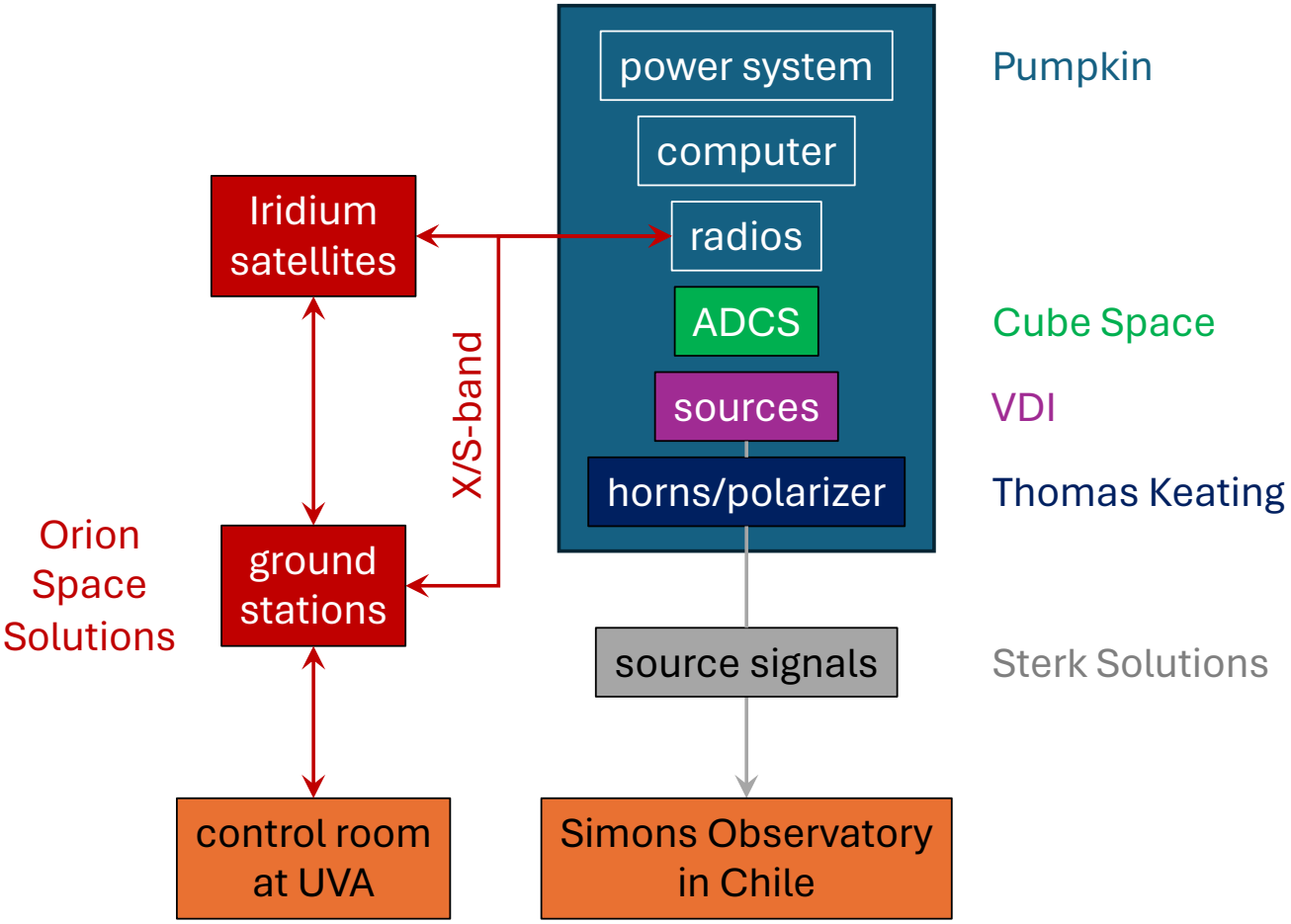
150 GHz Spectral Band

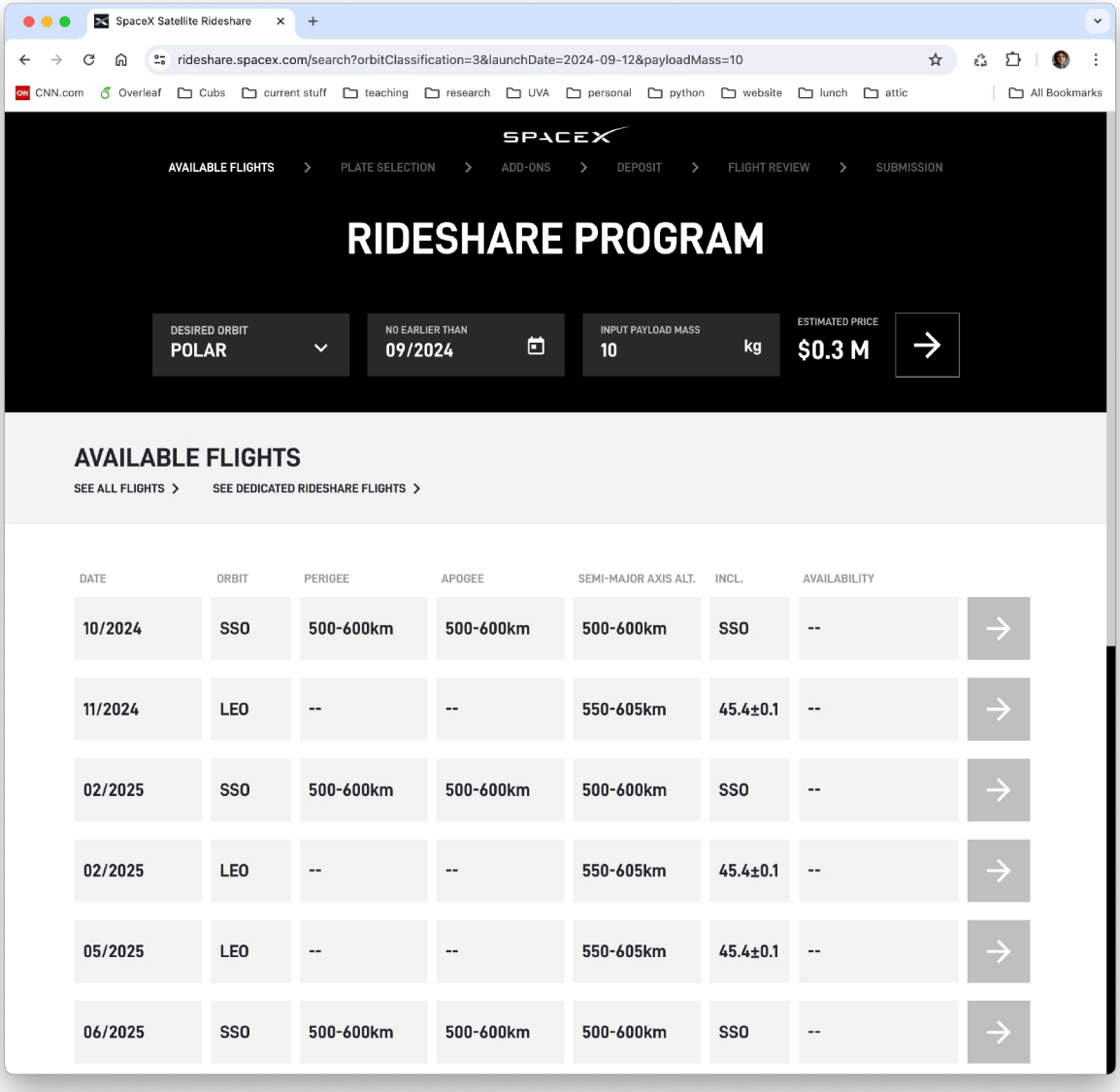


CalSat Characteristics

Characteristic	Value
source frequencies [GHz]	24.0, 47.1, 80.0, 140, and 249
source spectral width [MHz]	< 1
output millimeter-wave power [mW]	50
polarization	linear
cross-polarization level [dB]	-60
horn type	corrugated
input waveguide on horn	rectangular, single-moded
horn gain [dBi]	approximately 20
ADACS steering uncertainty [deg]	< 1
ADACS roll uncertainty [deg]	0.02 (1σ)
polarization orientation uncertainty [deg]	0.02 (1σ)
estimated payload mass [kg]	2
estimated total CubeSat mass [kg]	8
calculated operating temperature [°C]	10 (night) to 30 (day)
orbit altitude [km]	500
orbital period [hours]	1.6
orbits per day	14.2

Mission Organization

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Overleaf
Cubs
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teaching
research
UVA
personal
python
website
lunch
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All Bookmarks
SPACEX
AVAILABLE FLIGHTS
PLATE SELECTION
ADD-ONS
DEPOSIT
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NO EARLIER THAN
09/2024
INPUT PAYLOAD MASS
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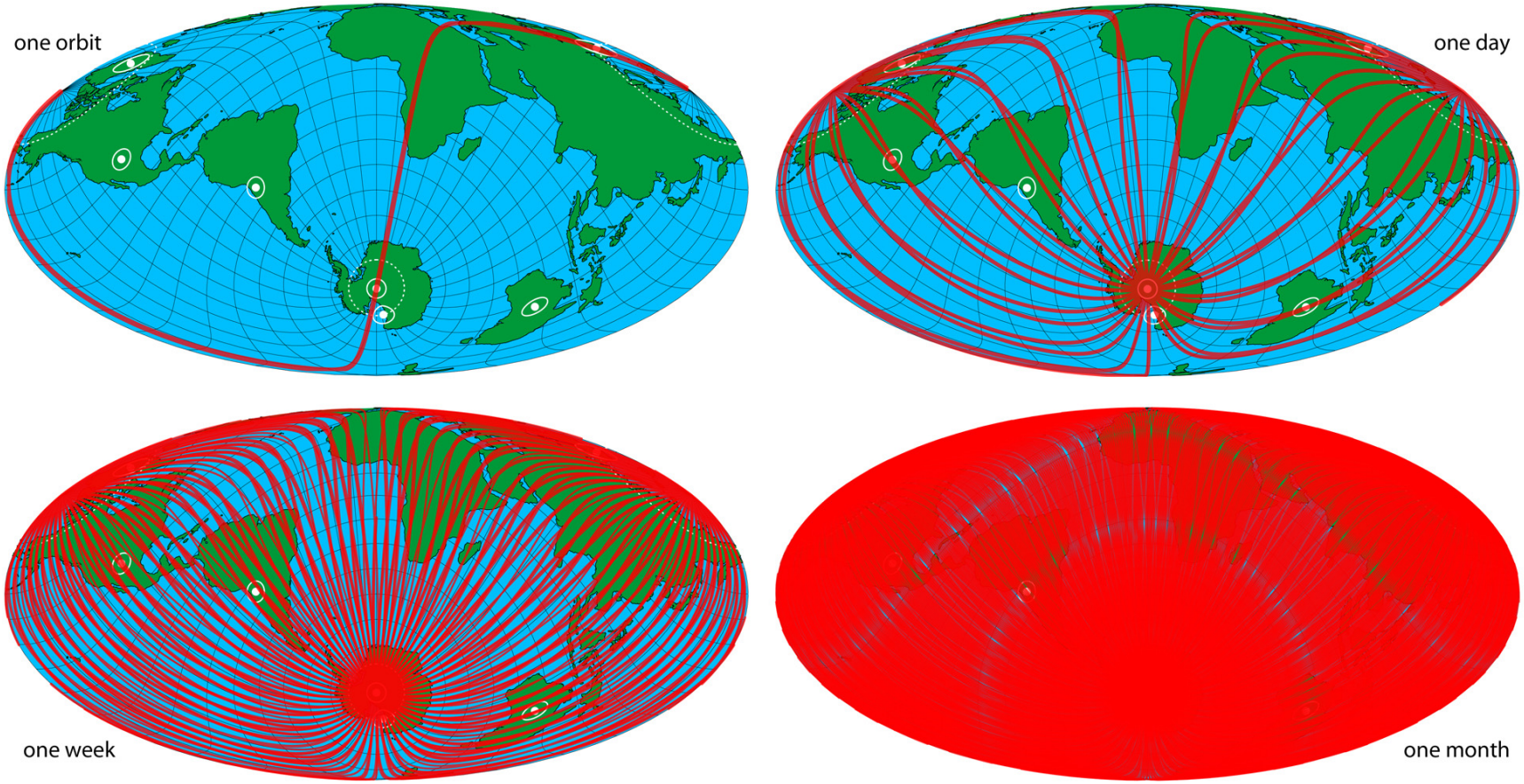
INCL.
AVAILABILITY
10/2024 SSO 500-600km 500-600km 500-600km SSO --
11/2024 LEO -- -- 550-605km 45.4±0.1 --
02/2025 SSO 500-600km 500-600km 500-600km SSO --
02/2025 LEO -- -- 550-605km 45.4±0.1 --
05/2025 LEO -- -- 550-605km 45.4±0.1 --
06/2025 SSO 500-600km 500-600km 500-600km SSO --

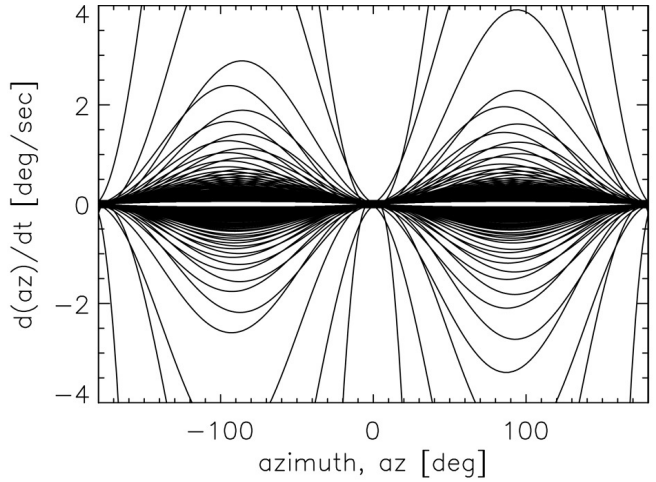
CalSat: Polar Low Earth Orbit

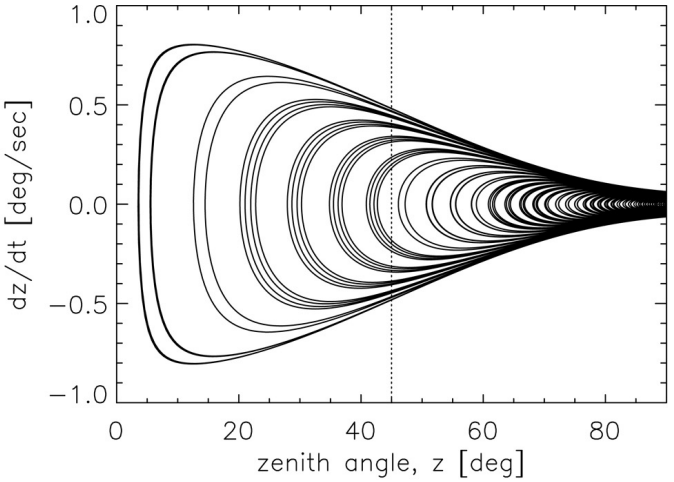


With polar orbit, CalSat is observable from all ground-based observatories.

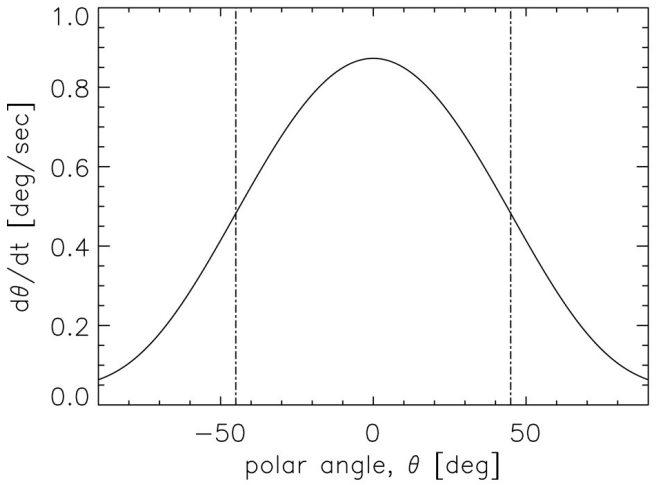
CalSat: Observability

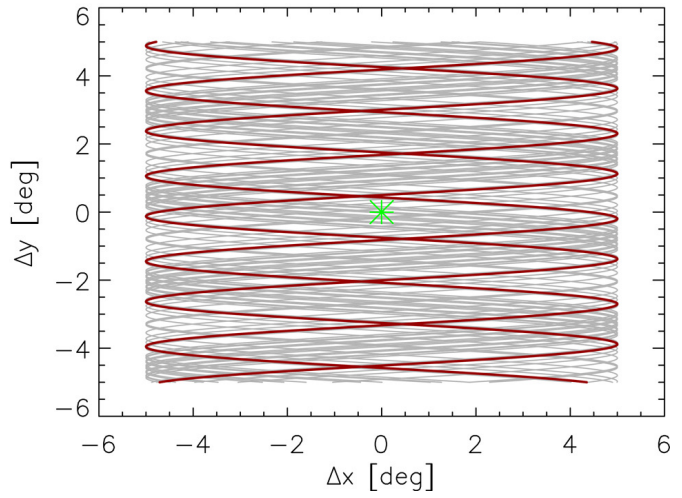
Atacama Desert



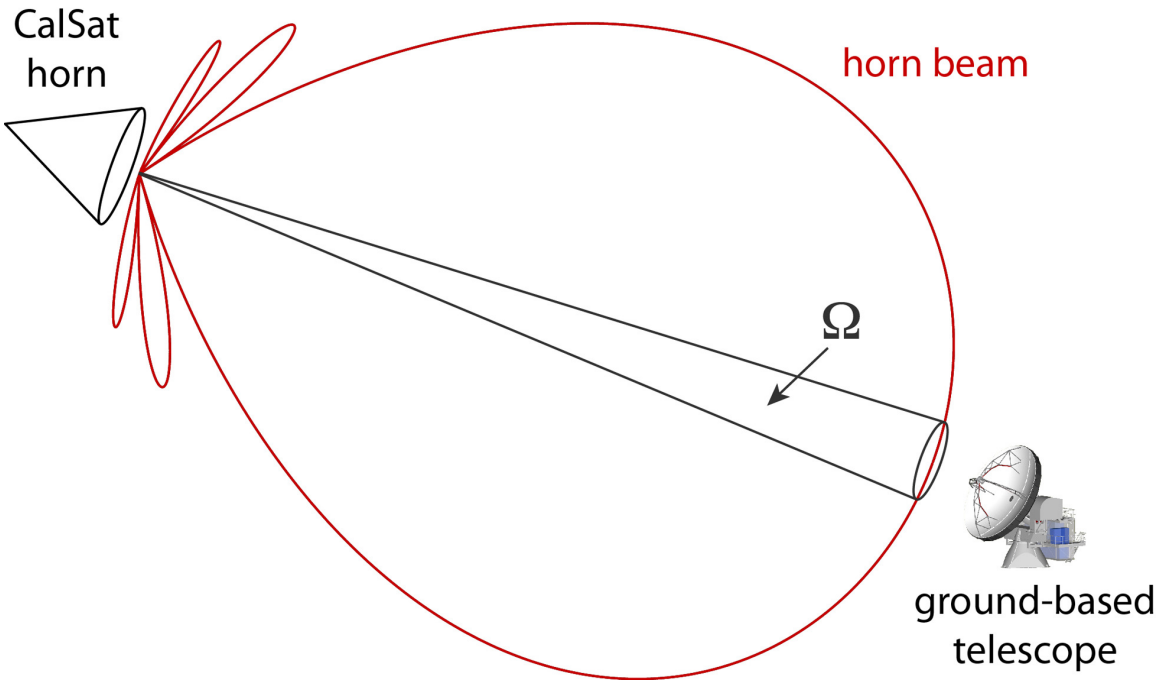


South Pole





Beam Coupling



CalSat Power and Atmospheric Loading