Lagrange Point 1 Orbit Observatory Communication with Earth via Earth Orbiting Satellites

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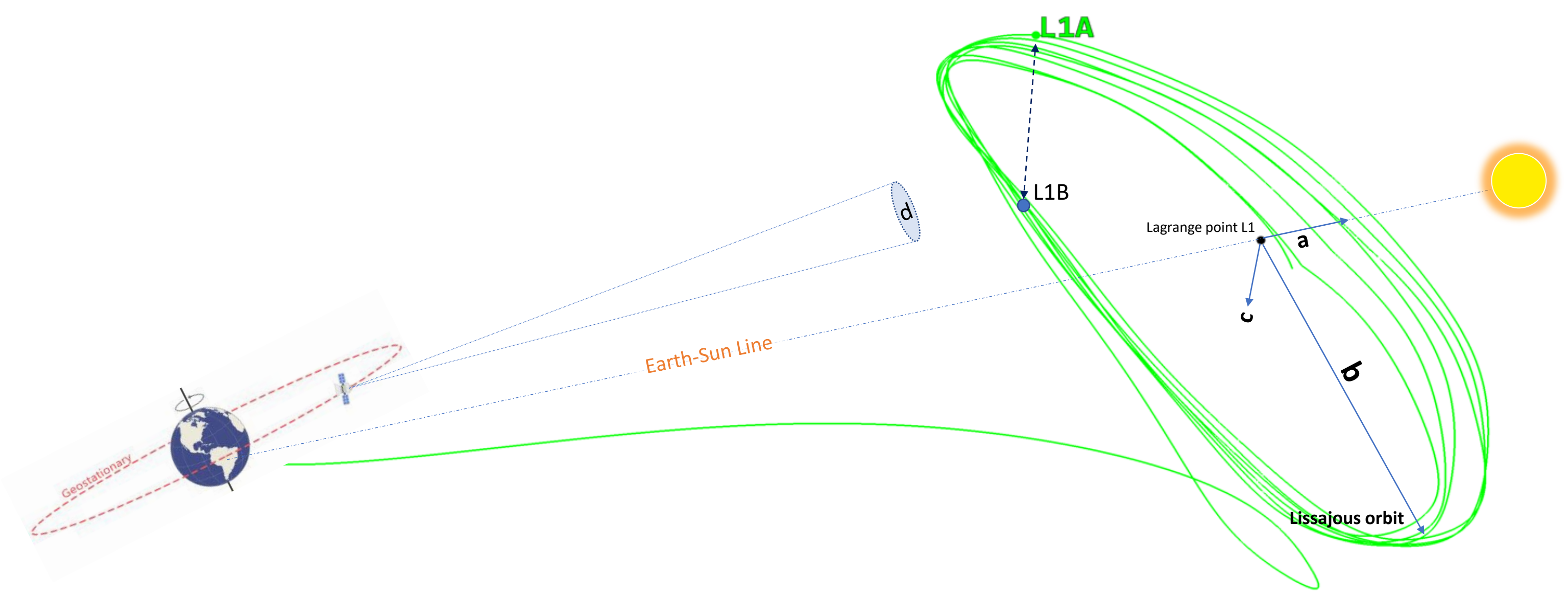
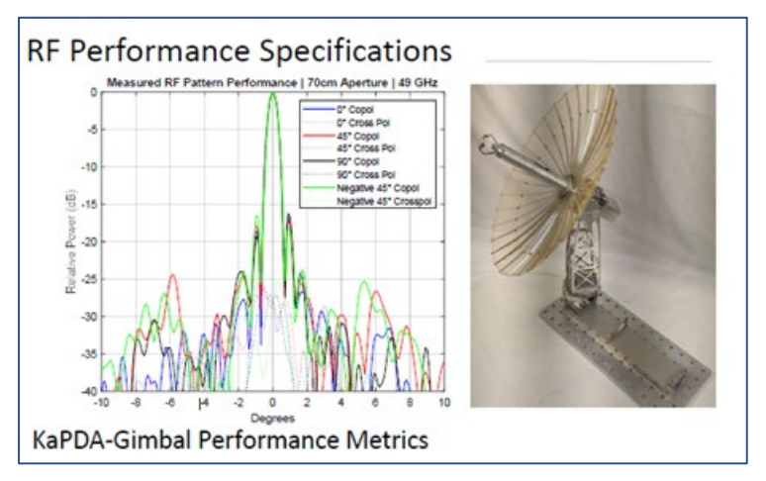
ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) Space Weather Next (SW Next) Program's primary objective is to provide timely and accurate space weather measurements (e.g., Sun coronal imaging and solar wind measurements) to operational users. The SW Next Program is funding the development of multiple space weather observatories in multiple orbital regimes (e.g., Sun-Earth Lagrange Point 1 (L1), Geosynchronous Equatorial Orbit, and Low-Earth Orbit). Space weather observation's baseline architecture includes observatories that are placed at L1 with the goal of providing continuous measurements of the space environment and observations of the Sun. Continuous communication of the L1 observatories is one of the highest priorities of space weather observations for NOAA. The first of SW Next L1 observatories is anticipated to be launched in 2028 and the next one in two years later. This study explores the key aspects of an alternative communication approach of disaggregating the L1 observatory communication using an orchestrated combination of Geostationary (GEO)/Medium-Earth Orbit (MEO)/LEO relay satellites to Ground Entry Point (GEP) networks. This integrated space network will provide cost-effective performance for NOAA, and it can provide the same balance of performance and cost for Space-Based Data Relay (SBDR). We are exploring the latest trend in radio frequency (RF) and Laser coms space terminal, which are at a Technical Readiness Level of 6 or higher, and which provides low-latency, low-cost, resilient, assured connectivity for the space terminal supports both LEO-to-MEO and LEO-to-GEO relay comms and extending it to L1 observatories. In this disaggregated approach, NOAA could choose to operate multiple observatories at L1 and downlink all observations to preferred GEPs terminal via relay satellites. Such a disaggregated communication architecture would provide NOAA's top priority measurements in a more robust, reliable, and cost-effective system. This architecture offers the potential elimination of the expensive global dedicated ground station antenna network and its dependency. The study evaluates one promising RF approach; the use of High-Gain Antenna (HGA) or phased array antenna mounted on the relay satellites' solar panels to provide continuous tracking of L1 observatory for a stable communication links. In addition, we are exploring a Do-No-Harm (DNH) enabling technology demonstration as a Payload of Opportunity with SW Next current Program constellations of satellites and with commercial space-to-space communication relay and direct-to-Earth (DTE) as a service network provider vendor.

GEO Satellites to L1 Observatories Communication Distance and Geometry Context





RF Performance Specifications

KaPDA-Gimbal Performance Metrics

L1A Launch Sequence	
Launch	1 Jan 2028 00:00:00.000
L1 Injection	8 Apr 2028 13:49:00.000

L1B Launch Sequence	
Launch	1 Feb 2028 00:00:00.000
L1 Injection	8 May 2028 05:49:00.000

Lissajous orbit size (notional)		
a	200 k km	Ecliptic in Earth-Sun direction
b	650 k km	Ecliptic perpendicular to the Earth-Sun direction
c	200 k km	Out of ecliptic
d	52.38 k km	2 deg GEO antenna coverage at L1
	~ 6months	Orbital Period
	~500 k km	L1A - L1B range

A geostationary orbit, also referred to as a geosynchronous equatorial orbit (GEO), is a circular geosynchronous orbit 35,786 km in altitude above Earth's equator (42,164 km in radius from Earth's center) and following the direction of Earth's rotation.

A Lissajous orbit, in the Sun-Earth-Moon system at Lagrange point 1 is a quasiperiodic orbital trajectory that an object can follow around a Lagrangian point of a three-body system without requiring any propulsion.

Notional Lissajous orbit size, 200k km ecliptic in Earth-Sun direction, 650k km ecliptic perpendicular to the Earth-Sun direction and 200k km out of ecliptic and have an orbital period of ~6 months.

A RF beam width, 2 deg cone angle of a KaPDA (Ka band Precision Deployable Antenna) antenna on GEO satellite can cover ~53k km of L1 Lissajous orbit

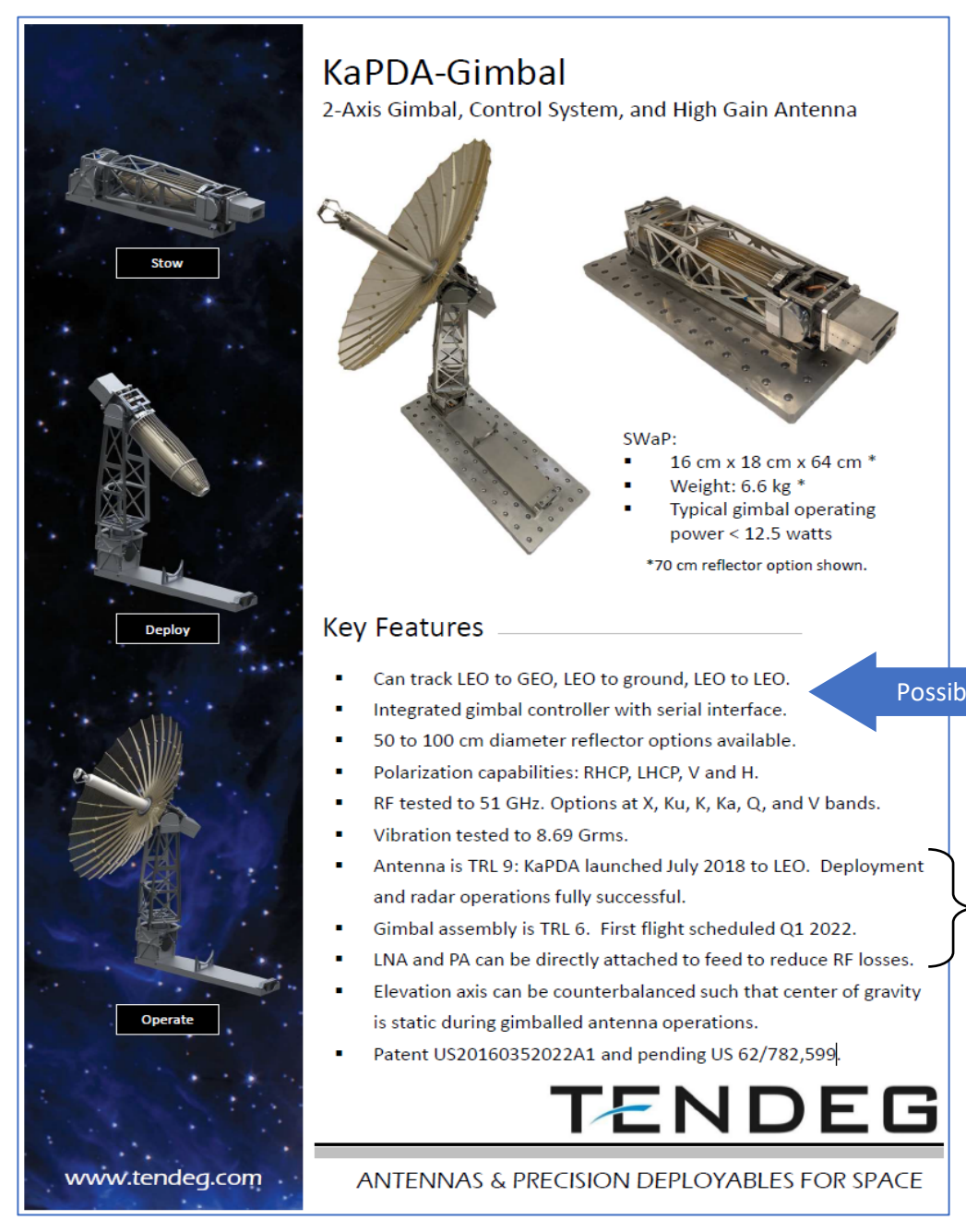
Approximate Ground Station Cost Analysis

Approximate Antenna Cost ($M) over 5 years of mission life				
Item	Type	Acquisition	Annual O&M	Total Cost
A	5m Full Motion Fixed Satcom Antenna	3	3	18
B	13m Full Motion Fixed Satcom Antenna	7	5	32
C	Leasing 5m Full Motion Fixed Satcom Antenna		1	5
D	Leasing 13 m Full Motion Fixed Satcom Antenna		2	10
E	Leasing for ranging		2	10

Total cost for a SW Next L1 mission due to ground antennas

- Required 24x7 data downlink and commands uplink
- Need 2 of (B) types for command and downlink during CONUS coverage ➔ 64M
- Need 3 of (C) types for downlink during OCONUS coverage ➔ 15M
- Ranging cost ➔ 10M
- Total ➔ ~ 90M

Gimbal HGA to Support the Concept



KaPDA-Gimbal

2-Axis Gimbal, Control System, and High Gain Antenna

SWaP:
- 16 cm x 18 cm x 64 cm *
- Weight: 6.6 kg *
- Typical gimbal operating power < 12.5 watts

*70 cm reflector option shown.

Key Features
- Can track LEO to GEO, LEO to ground, LEO to LEO.
- Integrated gimbal controller with serial interface.
- 50 to 100 cm diameter reflector options available.
- Polarization capabilities: RHCP, LHCP, V and H.
- RF tested to 51 GHz. Options at X, Ku, K, Ka, Q, and V bands.
- Vibration tested to 8.69 Grms.
- Antenna is TRL 9: KaPDA launched July 2018 to LEO. Deployment and radar operations fully successful.
- Gimbal assembly is TRL 6. First flight scheduled Q1 2022.
- LNA and PA can be directly attached to feed to reduce RF losses.
- Elevation axis can be counterbalanced such that center of gravity is static during gimballed antenna operations.
- Patent US20160352022A1 and pending US 62/782,599

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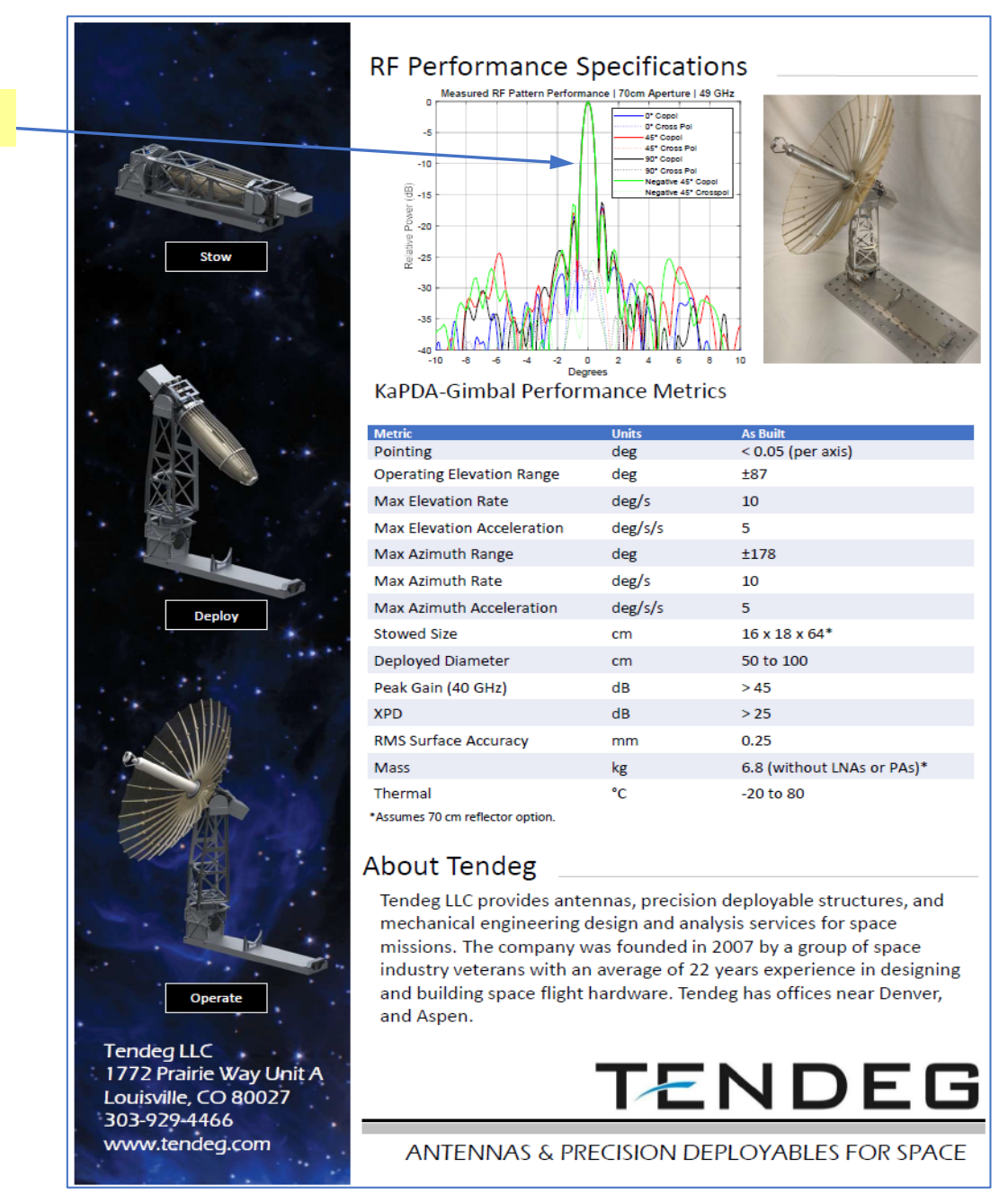
Possible to extend to L1 orbit

High Technology readiness levels (TRLs)

2 Deg Beam Width



RF Performance Specifications

KaPDA-Gimbal Performance Metrics

Metric	Units	As Built
Pointing	deg	< 0.05 (per axis)
Operating Elevation Range	deg	±87
Max Elevation Rate	deg/s	10
Max Elevation Acceleration	deg/s/s	5
Max Azimuth Range	deg	±178
Max Azimuth Rate	deg/s	10
Max Azimuth Acceleration	deg/s/s	5
Stowed Size	cm	16 x 18 x 64*
Deployed Diameter	cm	50 to 100
Peak Gain (40 GHz)	dB	> 45
XPD	dB	> 25
RMS Surface Accuracy	mm	0.25
Mass	kg	6.8 (without LNAs or PAs)*
Thermal	°C	-20 to 80

*Assumes 70 cm reflector option.

About Tendeg

Tendeg LLC provides antennas, precision deployable structures, and mechanical engineering design and analysis services for space missions. The company was founded in 2007 by a group of space industry veterans with an average of 22 years experience in designing and building space flight hardware. Tendeg has offices near Denver, and Aspen.

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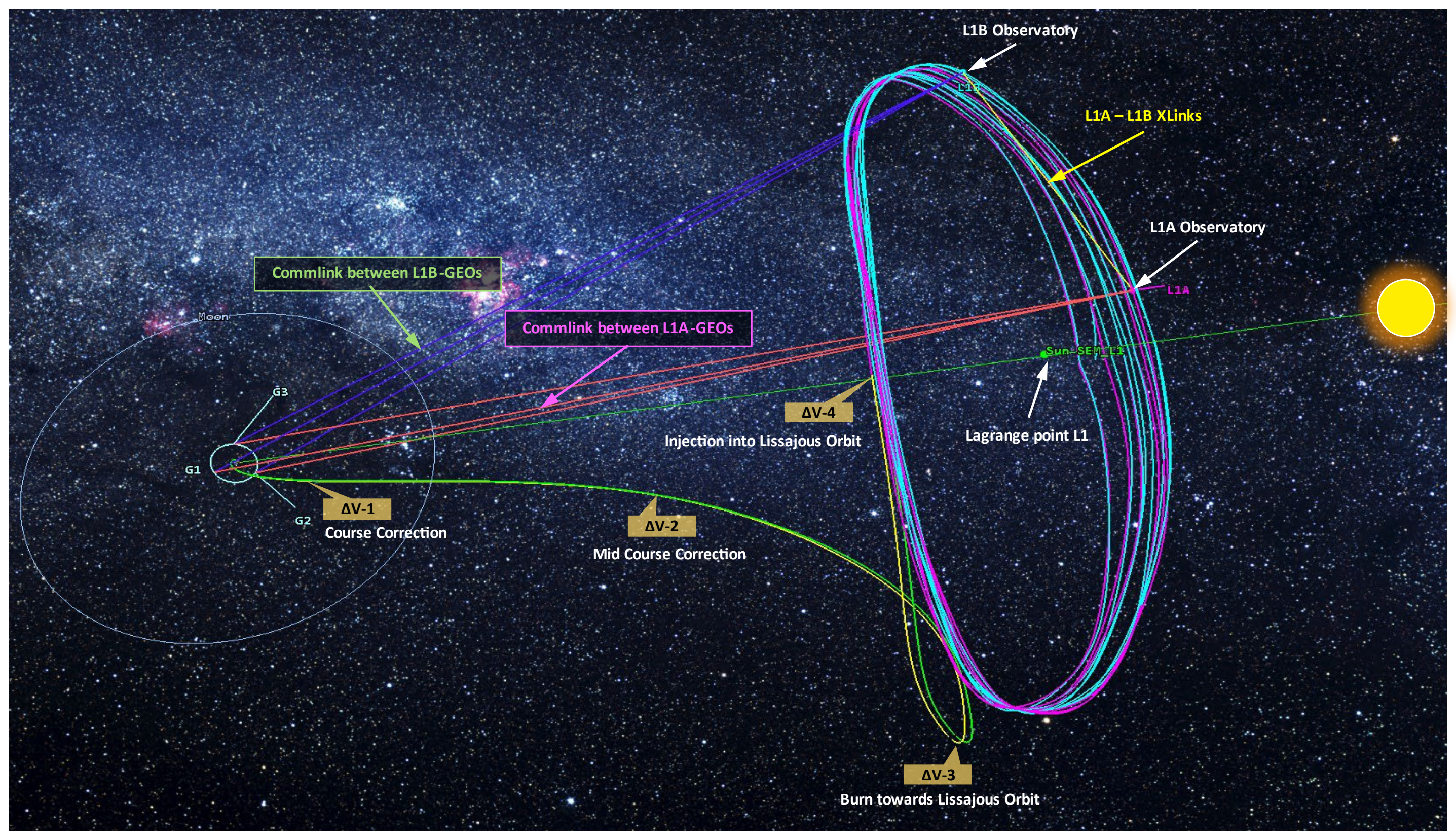
Earth Orbits and Sun-Earth L1 Lissajous Orbit



The National Oceanic and Atmospheric Administration (NOAA) Space Weather Observations (SWO) program division's Space Weather Next (SW Next) L1project primary objectives are to provide timely and accurate space weather measurements (e.g., Sun coronal imaging and solar wind measurements) to operational users. SWO's baseline architecture includes observatories that are placed at the Sun-Earth Lagrange Point 1 (L1) with the goal of providing continuous measurements of the space environment and observations of the Sun. Continuous Communication of the L1 observatories is one of the highest priorities of space weather observations for NOAA. The NOAA SW Next Program is funding the development of multiple L1 observatories. The first of SW Next L1 observatories is anticipated to be launched in 2028 and will provide continuity of space weather observations beyond the Space Weather Follow-On (SWFO) L1 mission lifetime. This study explores the key aspects of an alternative communication approach of disaggregating the L1 observatory communication via Geosynchronous Earth Orbit satellites (at locations similar to those of commercial ViaSat constellations). Viasat working with NASA on their Commercial Services Program (CSP) to provide SATCOM services to near-Earth space vehicles. As part of CSP, they are in the process of demonstrating the Space transport services using an orchestrated combination of ViaSat-3 and direct-to-Earth (DTE) ground-segment-as-a-service network. This integrated space network will provide cost-effective performance for NASA/NOAA, and we believe it can provide the same balance of performance and cost for Space-Based Data Relay (SBDR).

Earth Satellites and L1 Observatories Communication Context

KaPDA-Gimbal

2-Axis Gimbal, Control System, and High Gain Antenna
- 16 cm x 18 cm x 64 cm *
- Weight: 6.6 kg *
- Typical gimbal operating power < 12.5 watts
- 50 to 100 cm diameter reflector options available.
- Polarization capabilities: RHCP, LHCP, V and H.
- RF tested to 51 GHz. Options at X, Ku, K, Ka, Q, and V bands.
- Antenna is TRL 9: KaPDA launched July 2018 to LEO.
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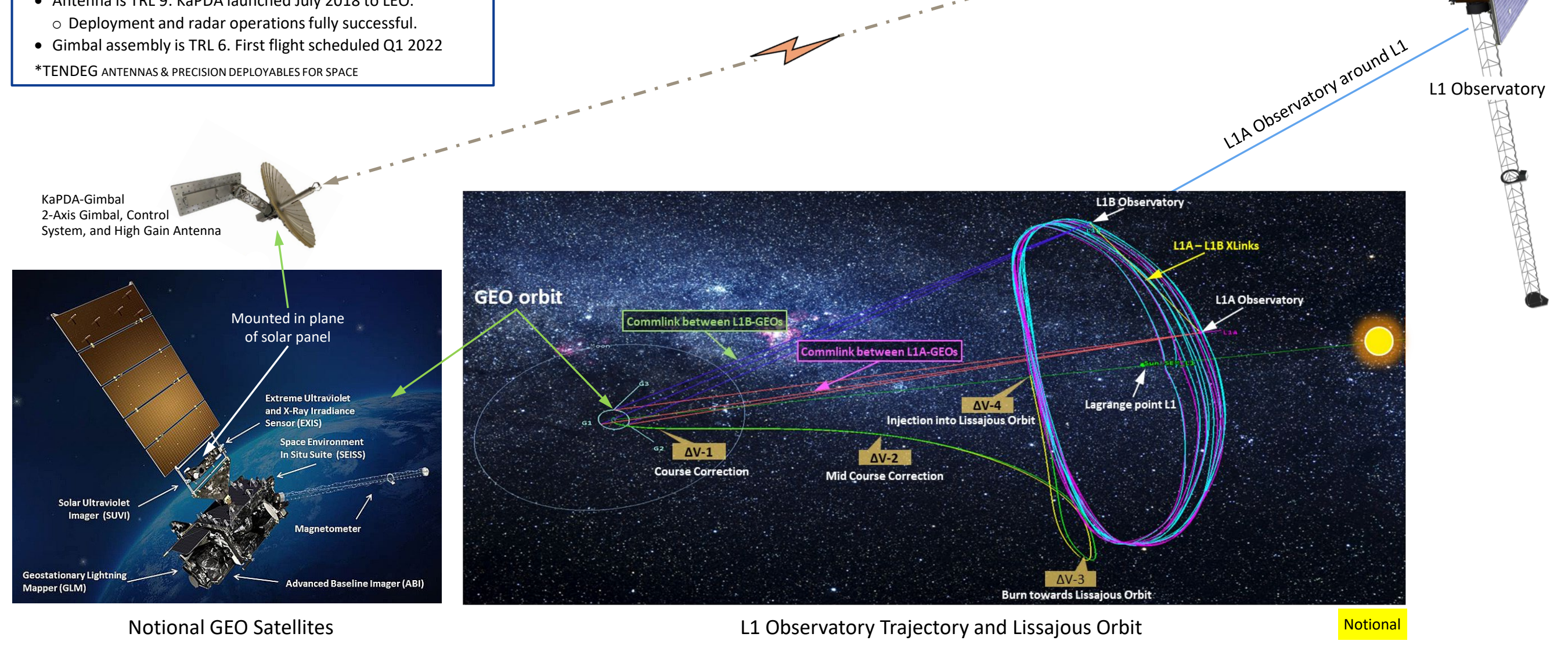
*TENDEG ANTENNAS & PRECISION DEPLOYABLES FOR SPACE



Notional GEO Satellites

L1 Observatory Trajectory and Lissajous Orbit

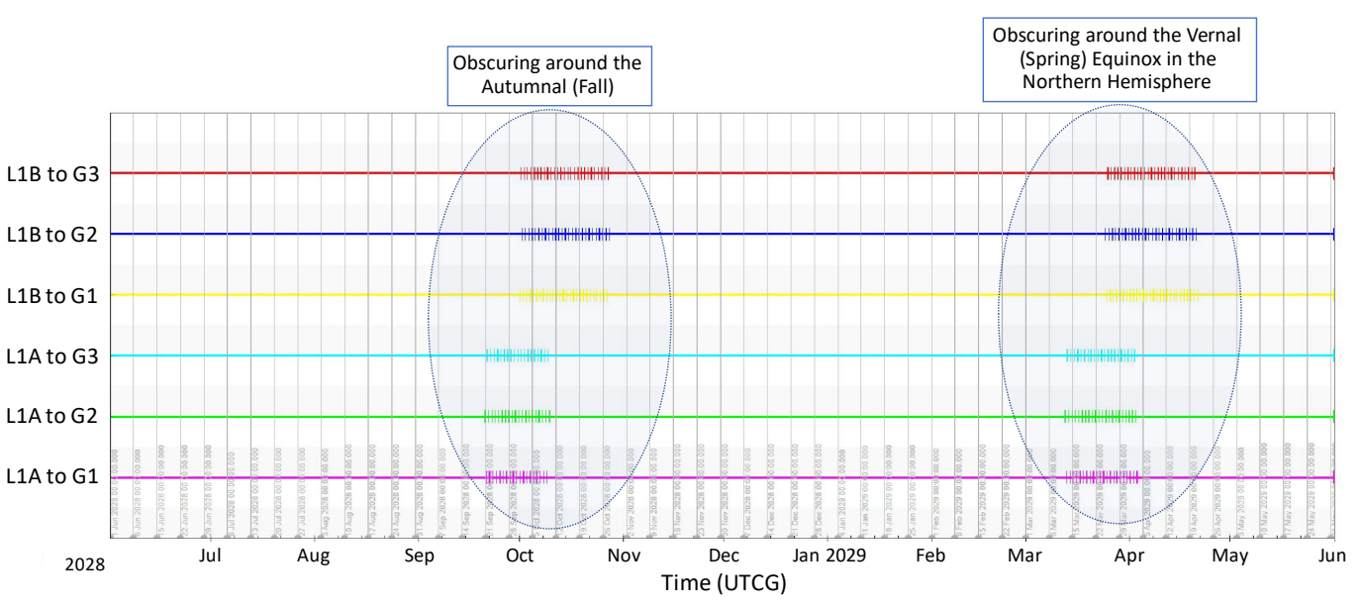
Notional

NOAA could choose to operate observatories at L1 and downlink all observations to Earth orbiting (GEO,MEO,LEO) satellites. Having the High Gain Antenna (HGA) like KaPDA (Ka band Precision Deployable Antenna) or phased array antenna mounted in the plane of the satellites' solar panels provides continued tracking of L1 observatory and stable communication links. Such an architecture would provide NOAA's top priority measurements in a more robust, resilient, and cost-effective system without the use of expensive global use of ground station antenna network.

Removing the direct ground stations communications requirements from the L1 mission (except ranging requirement) would significantly reduce the cost of ground-based antenna networks. A smaller, less expensive SW Next L1 program would potentially free-up resources for other priorities including technology demonstrations.

GEO to L1 Observatory Access Over a Year

Earth Obscuring GEO to access L1 Observatory around Equinoxes



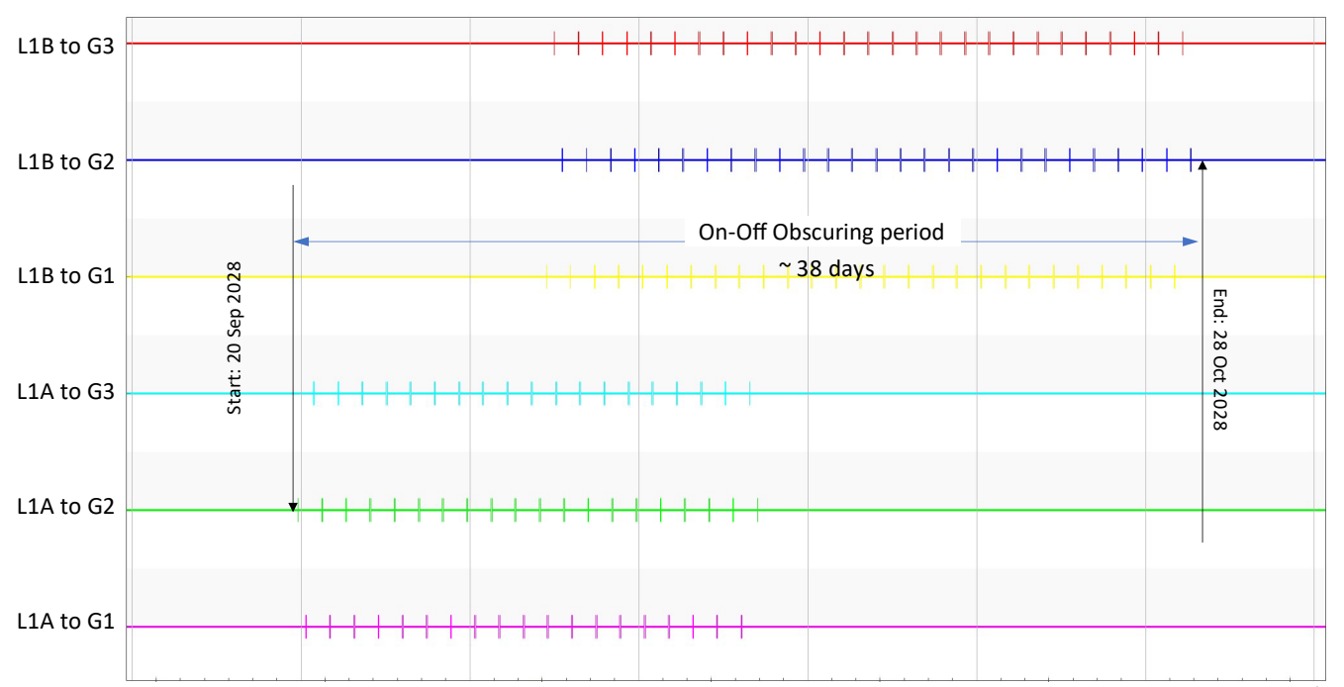
Nearly all orbit configurations about the Earth including GEO experience occasional eclipse intervals during which the view of the Sun's L1 Lissajous orbit is obstructed by the Earth, interrupting otherwise continuous communication to L1. For the case of a satellite in a geostationary orbit, obstruction occurs most prominently when the Earth's equatorial plane lies close to the ecliptic plane (i.e., during the Earth equinoxes). In case of LEOs, MEOs, HEOs the obscurations happen almost every orbits.

Solar equinox is a moment in time when the Sun crosses the Earth's equator, which is to say, appears directly above the equator, rather than north or south of the equator. This occurs twice each year, around 20 March and 23 September.

One of the primary issues for communications to L1 observatory via GEO orbit is that there are periods of time in the year where the Earth is in the Field of View (FOV) of the communication leading to partial or full obscuration of the communication and degradation or loss of data.

The analysis presented here shows that simultaneous communication from both the GEO constellations of 3 equally spaced GEOs locations fully compensates for these eclipse periods, enabling continuous L1 observatory communication via GEO satellites.

Period of Earth Obscuring 3 GEOs to access 2 L1 Observatories around Fall Equinox



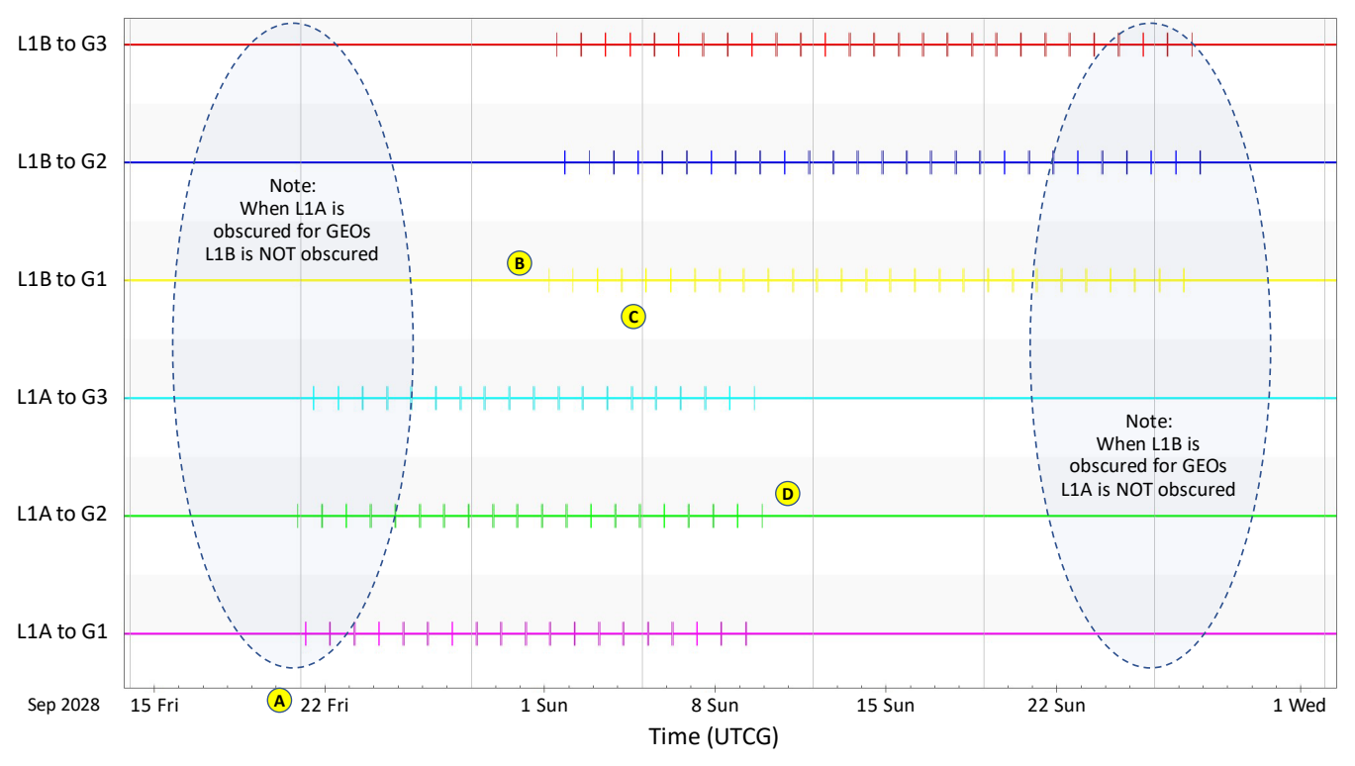
Fall equinox, in the year when the Sun is exactly above the Equator and day and night are of equal length; also, either of the two points in the sky where the ecliptic (the Sun's annual pathway) and the celestial equator intersect. In the Northern Hemisphere the fall equinox falls about Sep 20 or 21, as the Sun crosses the celestial equator going south.

One of the primary issues for communications to L1 observatory via GEO orbit is that there are periods of time in the year where the Earth is in the Field of View (FOV) of the communication leading to partial or full obscuration of the communication and degradation or loss of data.

The analysis presented here shows that simultaneous communication from 3 GEO constellation locations fully compensates for these eclipse periods, enabling continuous L1 observatory communication via GEO satellites.

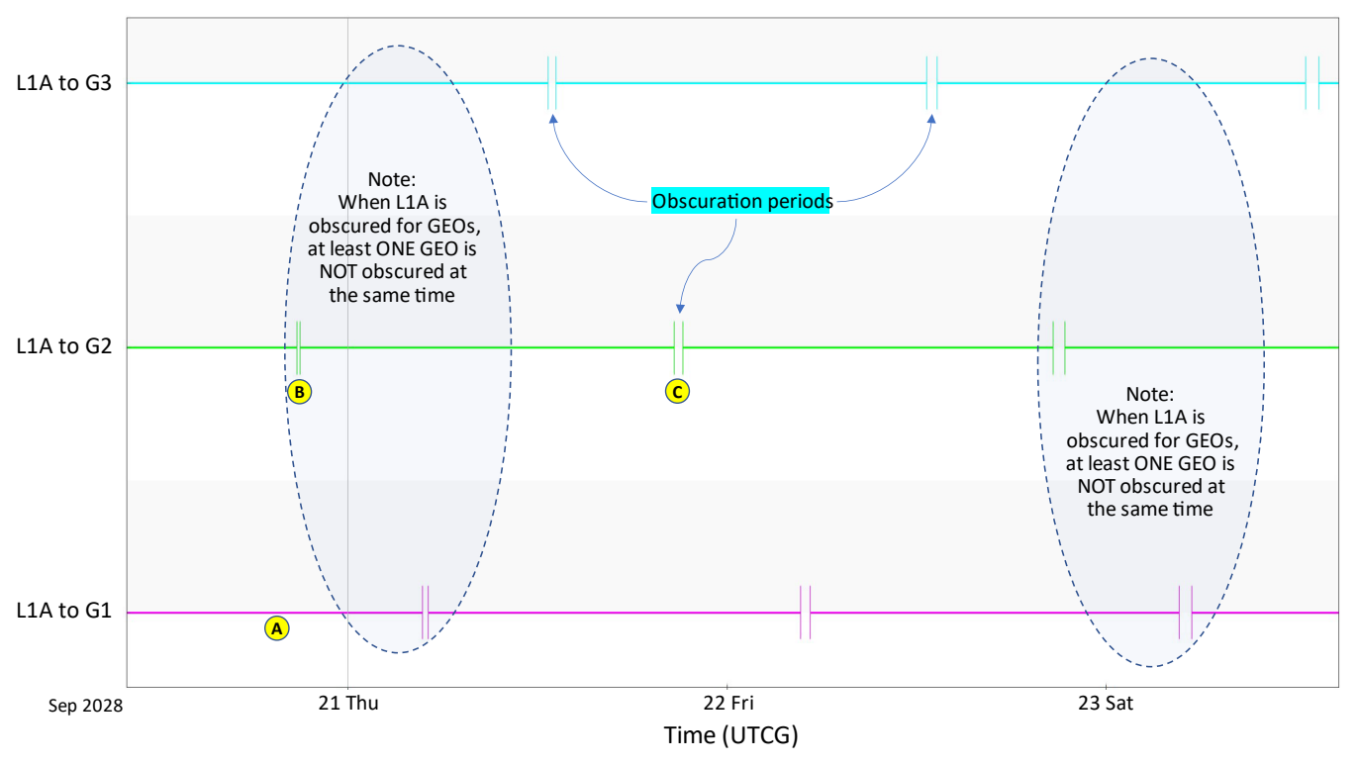
On/off Obscurations last for about 38 days

Details of Earth Obscuring GEOs to access L1 Observatories around Autumn (Fall) Equinox



- Ⓐ Initial condition: Assume, We have a continuous access between GEOs constellation and L1 Observatory constellation up to this point and then we have start of L1A and GEO obscuration
- Ⓑ Up to this point L1B was not obscured for the GEOs, so then use the L1A-L1B X-links capabilities of the observatories, to collect the data from L1A and combined with L1B data, and then downlink to GEOs
- Ⓒ During this period, we have multiple obscurations events for both observatories and GEOs, during this period, use the L1A-L1B X-links capabilities to collect the data from either observatories and combined with its own data, and then downlink to GEOs
- Ⓓ At this point L1A is no longer obscured for the GEOs, so then use the L1A-L1B X-links capabilities of the observatories, to collect the data from L1B and combined with L1A data, and then downlink to GEOs

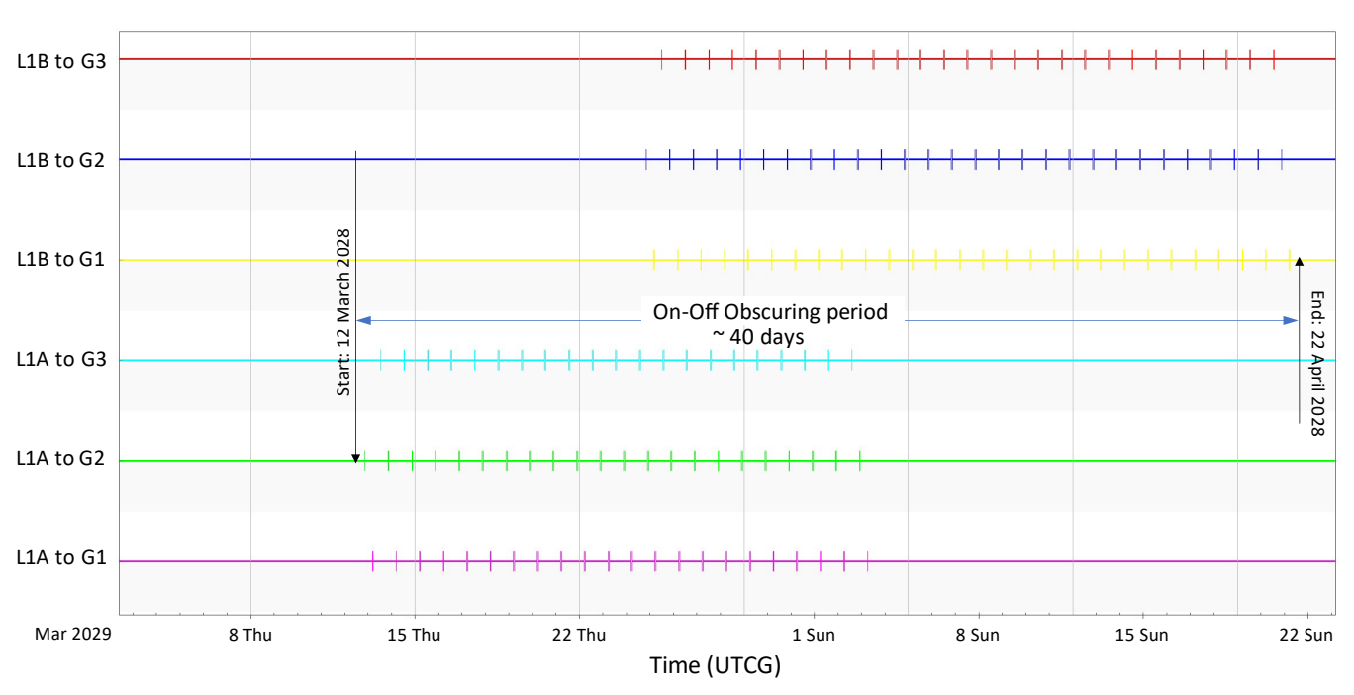
Details of Earth Obscuring GEOs to access L1 Observatories around Autumn (Fall) Equinox



- Ⓐ Initial condition: Assume, We have a continuous access between GEOs constellation and L1 Observatory constellation up to this point and then we have start of L1A and GEOs obscuration
- Ⓑ At this point G2 is obscured for L1A but G1 and G3 are not obscured, use G1 or G3 to downlink the data from L1A
- Ⓒ During all obscuration's periods, use the GEOs which are not obscured, to downlink the data from L1A

Use unobscured GEO to downlink L1 observatories data around Autumn (fall) Equinox

Period of Earth Obscuring 3 GEOs to access 2 L1 Observatories around Vernal Equinox



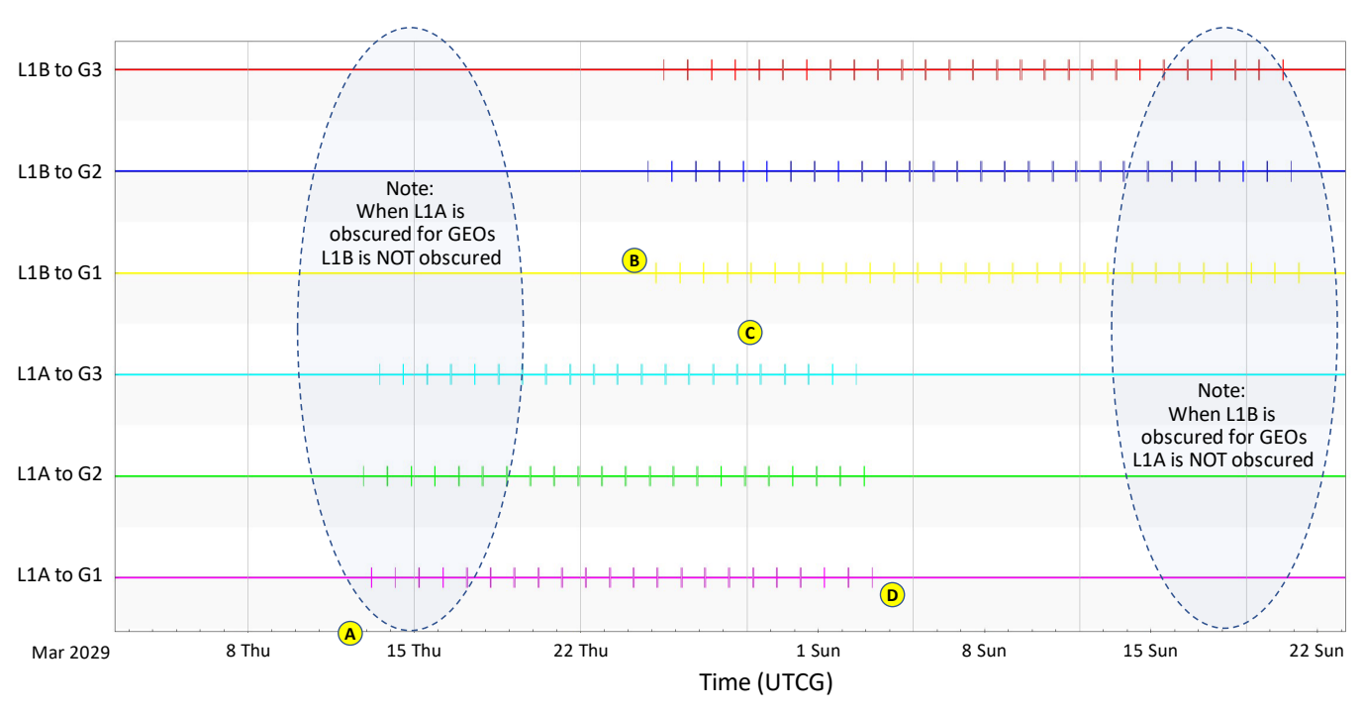
Vernal equinox, which occurs twice in the year, is when the Sun is exactly above the Equator and day and night are of equal length and either of the two points in the sky where the ecliptic (the Sun's annual pathway) and the celestial equator intersect. In the Northern Hemisphere the vernal equinox falls about March 20 or 21, as the Sun crosses the celestial equator going north.

One of the primary issues for communications to L1 observatory via GEO orbit is that there are periods of time in the year where the Earth is in the Field of View (FOV) of the communication leading to partial or full obscuration of the communication and degradation or loss of data.

The analysis presented here shows that simultaneous communication from both the GOES-East and GOES-West locations fully compensates for these eclipse periods, enabling continuous L1 observatory communication via GEO satellites.

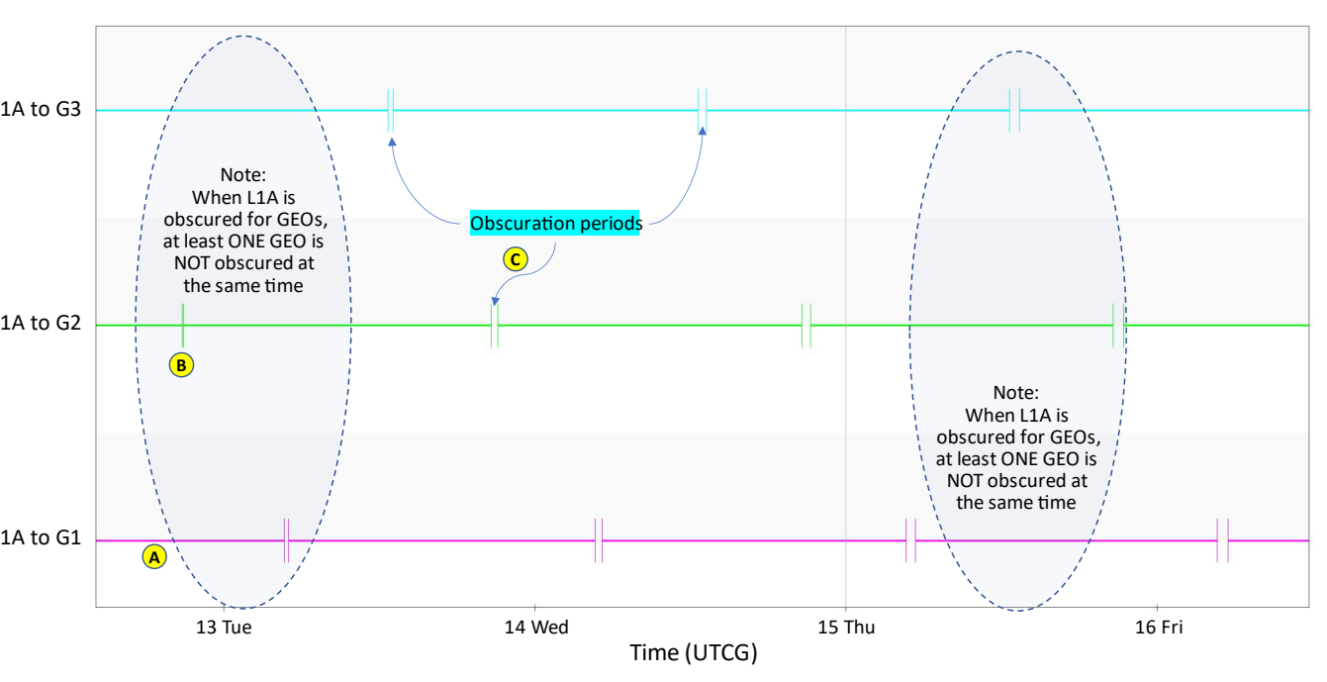
On/off Obscurations last for about 40 days

Details of Earth Obscuring GEOs to access L1 Observatories around Vernal Equinox



- Ⓐ Initial condition: Assume, We have a continuous access between GEOs constellation and L1 Observatory constellation up to this point and then we have start of L1A and GEO obscuration
- Ⓑ Up to this point L1B was not obscured for the GEOs, so then use the L1A-L1B X-links capabilities of the observatories, to collect the data from L1A and combined with L1B data, and then downlink to GEOs
- Ⓒ During this period, we have multiple obscurations events for both observatories and GEOs, during this period, use the L1A-L1B X-links capabilities to collect the data from either observatories and combined with its own data, and then downlink to GEOs
- Ⓓ At this point L1A is no longer obscured for the GEOs, so then use the L1A-L1B X-links capabilities of the observatories, to collect the data from L1B and combined with L1A data, and then downlink to GEOs

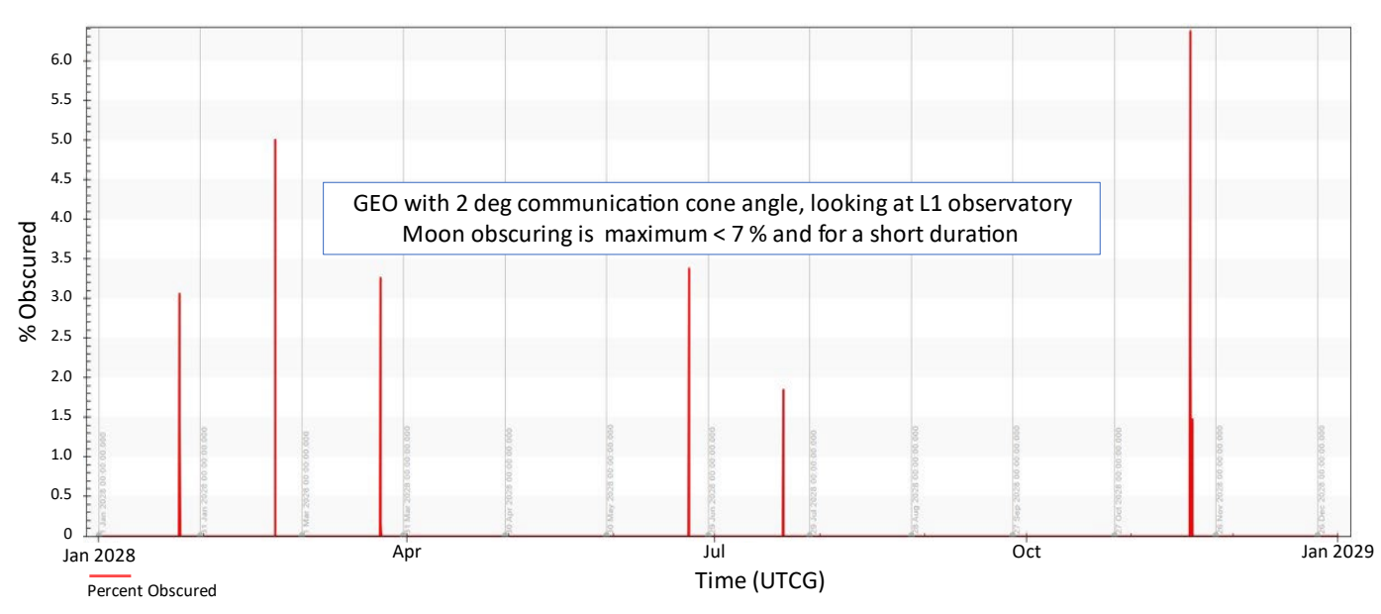
Details of Earth Obscuring GEOs to access L1 Observatories around Vernal Equinox



- Ⓐ Initial condition: Assume, We have a continuous access between GEOs constellation and L1 Observatory constellation up to this point and then we have start of L1A and GEOs obscuration
- Ⓑ At this point G2 is obscured for L1A but G1 and G3 are not obscured, use G1 or G3 to downlink the data from L1A
- Ⓒ During all obscuration's periods, use the GEOs which are not obscured, to downlink the data from L1A

Use unobscured GEO to downlink L1 observatories data around Vernal Equinox

Moon Obscuring GEO to access L1 Observatory Around the Year

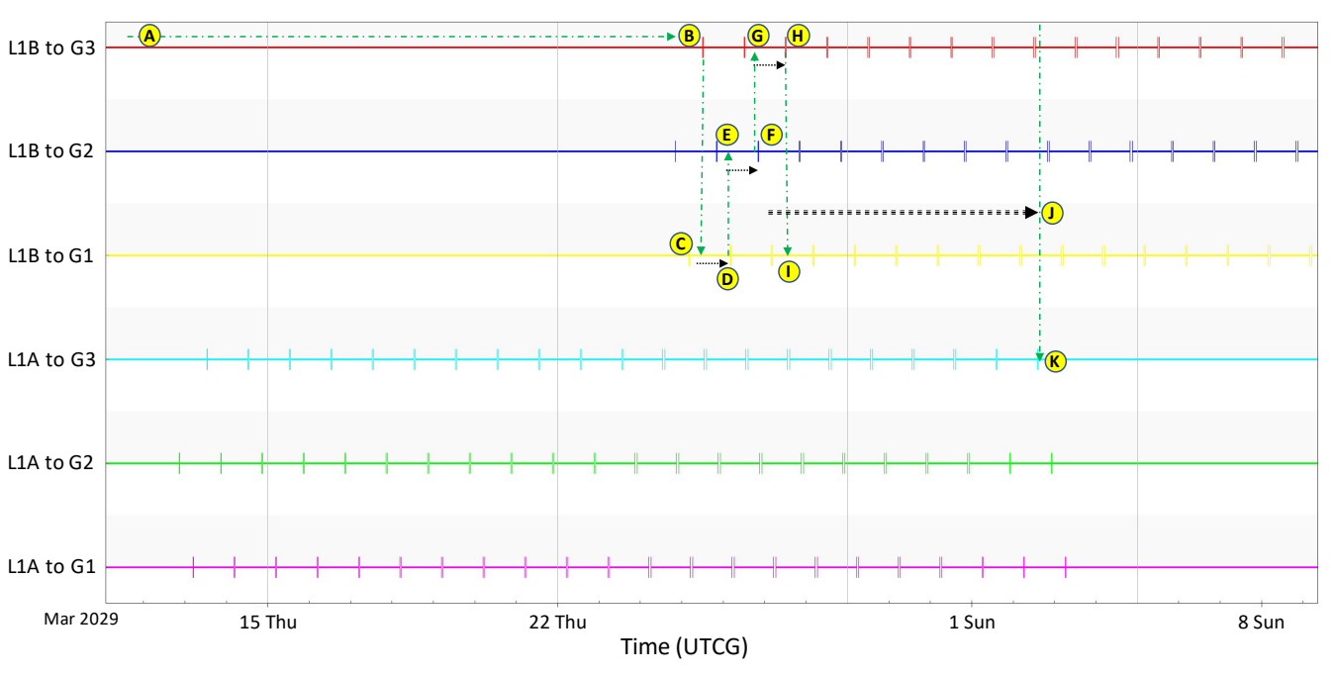


GEO orbit occasional eclipse intervals during which the view of the Sun's L1 Lissajous orbit is obstructed by the Moon, for a brief periods in the year interrupting otherwise continuous communication to L1.

One of the primary issues for communications to L1 observatory via GEO orbit is that there are periods of time in the year where the Moon is in the Field of View (FOV) of the communication leading to partial or full obscuration (max < 7 %) of the communication and degradation or loss of data.

The analysis presented here shows that simultaneous communication from both the GEOs locations fully compensates for these eclipse periods, enabling continuous L1 observatory communication via GEO satellites.

Mission Operation During Obscuring



- Ⓐ Initial condition: Assume, We have a continuous access between GEOs constellation and L1 Observatory constellation up to this point and then we have L1A and GEO obscuration
- Ⓑ Around first L1B-G3 obscuring event, switch to L1B-G1 for communication access to the L1B-G1 Observatory; During this obscuration period, use L1A – L1B X-links to collect the data from the L1A observatory
- Ⓒ Stay with L1B-G1 communication access until the L1B-G1 Obscuration period starts.
- Ⓓ Switch to L1B-G2 communication access
- Ⓔ Continue the communication access until the L1B-G2 Obscuration period starts.
- Ⓕ Switch to L1B-G3 communication access
- Ⓖ Continue the communication access until the L1B-G3 Obscuration period starts
- Ⓗ Switch to L1B-G1 communication access
- Ⓘ Repeat the above scenario until L1A and GEO obscuration ends
- Ⓙ Switch to L1A-G3 communication access
- Ⓚ Use L1A – G3 communication access until next obscuring period starts.

Acknowledgment

- Thanks are due to Ms. Marisa Exnicious of the AGI support team of the Ansys Company for knowledge and assistance with the Ansys STK tool
- Thanks are due to our NOAA SWO colleagues for inspirational discussions and support

Summary and Future Space-to-Space Communication

- Estimated NOAA ground station cost for a life of a SW Next L1 Observatory mission is estimated at $90M USD
- In the future, NOAA has plans to launch multiple SW Next L1 observatories
- With the presented concept, if we can properly design and use technically advanced HGA antennas (or phased arrays) into GEOs and L1 observatories communication systems, we can drastically reduce the NOAA ground station cost
- This space-to-space communication can be extended to include a cross-link between two SW Next L1 observatories
- The potential benefits of adding this cross-link enhancement mitigates the communication issues identified by one SW Next L1 observatory and reduces the operational requirement that each GEO is to track two SW Next L1 observatories.