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April 14, 2017

Jose P. Albuquerque
Chief, Satellite Division
International Bureau
Federal Communications Commission
Washington, D.C. 20554

Re: Response of Theia Holdings A, Inc.
File No. SAT-LOA-20161115-00121 (Call Sign S2986)

Mr. Albuquerque,

Please find attached the response of Theia Holdings A, Inc. ("Theia") to the questions provided in your letter of March 15, 2017.[1]

As described in the attached response, Theia has concluded that a minor change to the satellites in the Theia Satellite Network ("TSN") would substantially enhance the physical coordination of the TSN constellation with other NGSO systems and space objects. Specifically, Theia believes that it can and should de-orbit its satellites under affirmative control. To facilitate the controlled de-orbit of its satellites, Theia seeks to include additional propellant in the existing oversized fuel tank on the spacecraft. This minor change does not affect the DAS analysis included with Theia's original application.

Theia intends to develop and submit an application amendment at the appropriate time to effect this minor change to its satellite design. Other participants in the Commission's NGSO processing rounds may consider similar improvements to their constellation or satellite designs as a result of developments within the processing rounds. Accordingly, Theia respectfully requests Commission guidance on the following matters:

i. Whether the FCC will afford applicants within an NGSO processing an opportunity to submit application amendments by a uniform date certain (to be determined later) to effect proposed changes that may result from processing round comments, consultations,

[1] See Letter from Jose P. Albuquerque, Satellite Division, International Bureau, to Tom W. Davidson, Akin Gump Strauss Hauer & Feld LLP, File No. SAT-LOA-20161115-00121 (Call Sign S2986) dated March 15, 2017 ("FCC Letter").

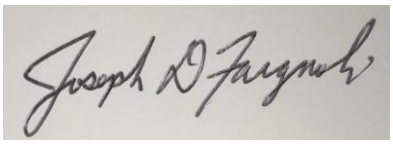
negotiations or other factors, along with any supporting argumentation and appropriate waiver requests, as it has done in prior satellite processing rounds;[2] and

ii. Whether the Commission should or must grant a waiver or forbear from applying of Section 1.65, Section 25.116 or such other provisions of the Commission's rules as necessary to permit applicants considering changes to their proposed systems to file a consolidated amendment on a uniform date certain, rather than potentially filing multiple application amendments throughout the processing round as potential changes are developed.

Theia submits that these approaches in the Commission's pending NGSO processing rounds would serve the interest of administrative convenience and preserve scarce Commission resources, while at the same time serve the public interest by enabling applicants to make necessary improvement to the proposed satellite systems and giving full effect to the Commission's application processing and amendment rules.

Finally, while this response does not constitute an amendment to its pending application, Theia would note that its desire to implement the change described herein could potentially implicate Section 1.65's continuing accuracy and completeness of information requirements and Section 25.116(c)'s amendment provisions. Theia believes that there is good cause to accept this response as an update of information of decisional significant under Section 1.65 and that the addition of fully controlled de-orbit capability should not be considered a major amendment under Section 25.116(c) because it would significantly improve physical coordination of the TSN constellation without requiring changes to the basic spacecraft design. Nonetheless, Theia reserves the right to formally request a waiver of the Commission's rules and other appropriate relief while the Commission considers the important application processing issues noted above.

Respectfully submitted,



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[2] *See, e.g.*, Public Notice, *International Bureau Invites Applicants to Amend Pending V-Band Applications*, Report No. SPB-199, DA 04-234 (January 29, 2004).

THEIA HOLDINGS A, INC.
RESPONSES TO FCC QUESTIONS

The Federal Communications Commission's ("FCC" or "Commission") letter of March 15, 2017 poses a number of questions. The Commission's questions and responses of Theia Holdings A, Inc. ("Theia") follow below.

1. **Please provide an analysis of collision risk for satellites during the passive disposal phase, i.e., after all propellant is consumed. Recognizing that satellites in this phase are planned for varying initial orbits, please provide an analysis for both a worst case (all satellites at 540 km perigee) as well as an anticipated range of orbits. Please provide an assessment of how many conjunctions and/or collision avoidance maneuvers might be required of the International Space Station (ISS), assuming it is in operation throughout the period in which Theia satellites would transit the ISS orbit.**

In Theia's November 15, 2016 application,[1] end-of-life disposal of satellites from the Theia Satellite Network ("TSN") was described as a series of orbit lowering maneuvers, culminating in the final disposal orbit with 610 km apogee and 540 km perigee. This plan meets FCC and NASA regulations and guidelines for satellite disposal, with a fully passivated satellite with a remaining lifetime of less than 10 years,[2] and a probability of collision with orbital debris of 0.00078.[3] Additional analysis shows that the average number of conjunctions between a Theia satellite in disposal orbit and the International Space Station ("ISS") to within 10 km is less than one event throughout the full term of the remaining satellite orbit.

Notwithstanding Theia's compliance with established FCC and NASA rules, and in recognition of the issue of the proliferation of orbital debris and the attendant increase in collision risk, Theia has concluded that it should adopt an updated plan to deorbit all satellites fully under control to atmosphere. The fully controlled deorbit plan requires an additional 145 kg of propellant on each TSN satellite, which can be accommodated in the existing tank and design.

The additional fuel will permit a fully controlled descent though a series of 5 Hohmann transfers, with a transition from a next-to-final orbit with a 170 km perigee into a final orbit with a 30 km perigee, resulting in targeted atmospheric re-entry. Further, the additional fuel permits this fully controlled descent to avoid the ISS, the Hubble Space Telescope, and all other active or passive space objects whose orbits are known. This plan obviates any ISS avoidance maneuvers and effectively eliminates collision risk with orbital debris. As the propellant tank in the original design is of sufficient volume to accommodate the additional propellant, Theia is able to make the addition of the fuel without modification to the basic architecture of the spacecraft.

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[1] Theia Holdings A, Inc., IBFS File No. SAT-LOA-20161115-00121 (Call Sign S2986) at Technical Narrative, Appendix 4.

[2] *See id.* (analysis employing NASA Debris Assessment Software 2.0.2).

[3] *See id.*

2. **Please provide an analysis of collision risk, assuming rates of satellite failure resulting in the inability to perform collision avoidance procedures of 10, 5 and 1 percent. This analysis should include a study performed assuming all failures occur at the mission altitude, but may also include additional studies specifying alternative assumptions concerning the orbital locations (such as injection altitude) at which failures might occur**.

Theia has examined the collision risk at mission altitude using the NASA Debris Assessment Software ("DAS"), the Analytical Graphics Incorporated Systems Tool Kit ("STK") and the Aerospace Debris Environment Protection Tool ("ADEPT"), a proprietary software package. Reasonable agreement was achieved among all of them.

Should a Theia satellite in mission orbit fail in a manner that would result in the inability to perform collision avoidance procedures, and other measures are not employed to remove the unmaneuverable satellite from orbit, then the satellite would undergo orbital decay and descend out of the mission "shell"[4] in a period of between 20 and 25 years from failure. A failed Theia satellite would continue its orbital decay over a substantial period of time, and ultimately re-enter the atmosphere in an uncontrolled manner. DAS has limitations that prevent full lifetime and collision risk assessment for this scenario, however the results of the studies employing the other tools indicate lifetimes prior to re-entry of between 165 and in excess of 200 years, depending on assumptions about the drag-state of the satellite under consideration. Collision risk with an operational Theia satellite is negligible because operational satellites can readily perform avoidance maneuvers.

The collision risk of 1%, 5% and 10% of the TSN constellation (120 operational satellites and in-orbit spares) becoming unmaneuverable and subsequently beginning natural decay was studied (1, 6 and 12 satellites, respectively). For a single satellite, within an initial 30-day period of becoming unmaneuverable, the probability of a collision in the existing space environment is approximately 0.00009 (9×10^{-5}). The collision risk for one satellite which is unmaneuverable over its natural decay lifetime of approximately 165 years was found to be approximately 0.26 (26%), assuming that no other large LEO constellations ("LLCs") were in deorbit.

Theia also considered the collision risk for one TSN satellite which is unmaneuverable over its natural decay lifetime in a more complex space environment posed by the inclusion of the other LLCs proposed in this processing round. In this case, our study assumed that during LLC operations (a) 2% of the satellites in the LLCs fail, and then (b) during disposal transition 5% of the remaining LLC satellites fail to complete a maneuver to drop the LLC satellites down to a 5-7 year coasting re-entry, leaving approximately 93% of the satellites from the LLCs in a 5-7 year coasting re-entry profile, all of which would be available for consideration of collision with the unmaneuverable TSN satellite, and that (c) the LLC constellations are continuously refreshed for at least 165 years. In that case, the probability of collision with a single TSN satellite which was unmaneuverable and left to natural decay rose to approximately 0.54 (54%).

[4] The mission orbit "shell" is the range of nominal stationkeeping accuracy of +/- 10 km of nominal mission altitude.

The collision risk statistics for 1, 6 and 12 TSN satellites, for 30 day, average annual and decay lifetime, and both with and without the space environment including the LLCs, is presented in Table 1.

TABLE 1 - PROBABILITY OF AN UN-MANEUVERABLE TSN SATELLITE COLLISION FOR VARIOUS TIME PERIODS AND CONDITIONS	NUMBER OF UN-MANEUVERABLE THEIA SATELLITES								
	1			6			12		
	PERIOD OF CONSIDERATION			PERIOD OF CONSIDERATION			PERIOD OF CONSIDERATION		
	FIRST 30 DAYS	365 DAY AVERAGE	165 YEAR DECAY LIFETIME	FIRST 30 DAYS	365 DAY AVERAGE	165 YEAR DECAY LIFETIME	FIRST 30 DAYS	365 DAY AVERAGE	165 YEAR DECAY LIFETIME
COLLISION RISK ASSUMING NO PROPOSED LLCs ARE PLACED IN THE SPACE ENVIRONMENT	**0.00009** (0.009%)	**0.00130** (0.130%)	**0.26** (26%)	**0.00054** (0.054%)	**0.00777** (0.777%)	**0.83579** (84%)	**0.00108** (0.108%)	**0.01549** (1.549%)	**0.97304** (97%)
COLLISION RISK ASSUMING ALL PROPOSED LLCs ARE IN SPACE WITH DEORBIT TO A 5-7 YEAR COASTING PHASE TO RE-ENTRY	**0.00011** (0.011%)	**0.00270** (0.270%)	**0.54** (54%)	**0.00066** (0.066%)	**0.01609** (1.609%)	**0.990526** (99%)	**0.00132** (0.132%)	**0.03192** (3.192%)	**0.99991** (100%)

The Commission may note that there are already many other objects of comparable size to the TSN satellites studied, which are presently in space with similar uncontrolled orbits and similar decay lifetimes. The statistics in Table 1 are computed specifically for the TSN satellites, but are not directionally unique – any satellite in LEO orbit at or below 800 km, or which enters the sub-800 km region, and which either is, or becomes, not affirmatively maneuverable would experience similar risks of collision, adjusted for satellite cross-sectional area.

Theia has not performed an analysis of the consequences of Theia satellites being unable perform collision avoidance maneuvers prior to orbit injection, because a launch provider has not yet been selected, and therefore the conditions prior to orbit injection are unknown at this time.

In the design of the Theia satellites, Theia has carefully considered, and will continue to carefully consider, the risk of an unmaneuverable satellite at mission orbit. In the satellite design, Theia has included redundancy for critical components, and elements that enhance survivability and reliability. Theia continues to examine the space debris and deorbit issue, and is investigating additional measures to reduce the probability of, as well as limit the consequences of, on-orbit satellite sub-system failures, including potentially the addition of dedicated independent deorbit thrusters, ultra-reliable electrical and attitude control systems, improved tracking, telemetry, and control ("TT&C") communications, and the potential implementation of automated deorbit programs, if certain satellite conditions are present.

In the matter of collision risk, Theia's interests are aligned with those of the U.S. Government and the space community as a whole. Theia continues to keep the reliability of safe, controlled deorbit as a priority in its satellite and mission design.

3. Any additional information you may wish to provide concerning human casualty risk resulting from satellite disposal, such as any risk or loss mitigation strategies under development.

While Theia's deorbit procedure as described in the original application is compliant with FCC and NASA regulations and guidelines, Theia is acting to further reduce human casualty risk resulting from atmospheric re-entry of Theia satellites. As described in Theia's response to Question 1 above, Theia has concluded that it should adopt a deorbit plan for the rapid, controlled descent to a target area in the South Pacific Ocean within nominally less than 3 days from deorbit initiation.

The initial target area proposed for disposal is indicated in Figure 1. The re-entry will take place in the direction of travel indicated by the red arrow, and will nominally conclude on the ascending portion of the disposal orbit. The region indicated in blue is approximately 7% of the earth's surface area (36,000,000 square km), is also of a length exceeding 26% of the earth circumference (10,500 km), and contains less than 100 people on average per day. In addition, the buffer between the initial proposed target area and any settlements with over 100 people are more than 1200 km in the cross-track direction, and in excess of 5,000 km along the orbit track in each direction.

The choice of the transition of the second to last orbit at a 170-km perigee to a final orbit with a 30-km perigee also provides for a steep descent into the atmosphere on re-entry. A steeper descent results in a higher accuracy of targeting and a smaller debris field than shallower orbits. The sun synchronous orbits of the TSN satellites naturally take every satellite nearly precisely along the disposal track, further enhancing the ease of implementing and assuring the deorbit plan.

Initial Monte Carlo simulations performed indicate a less than a 1:1,125,000 chance of a satellite's reentry debris field falling outside of the indicated zone. This assumes that the satellite remains within nominal functional limits, and the reentry orbits prior to the final atmospheric capture orbit are known to accuracies commensurate with present-day tracking capabilities. Theia is continuing to study the reentry debris field spread and statistics.

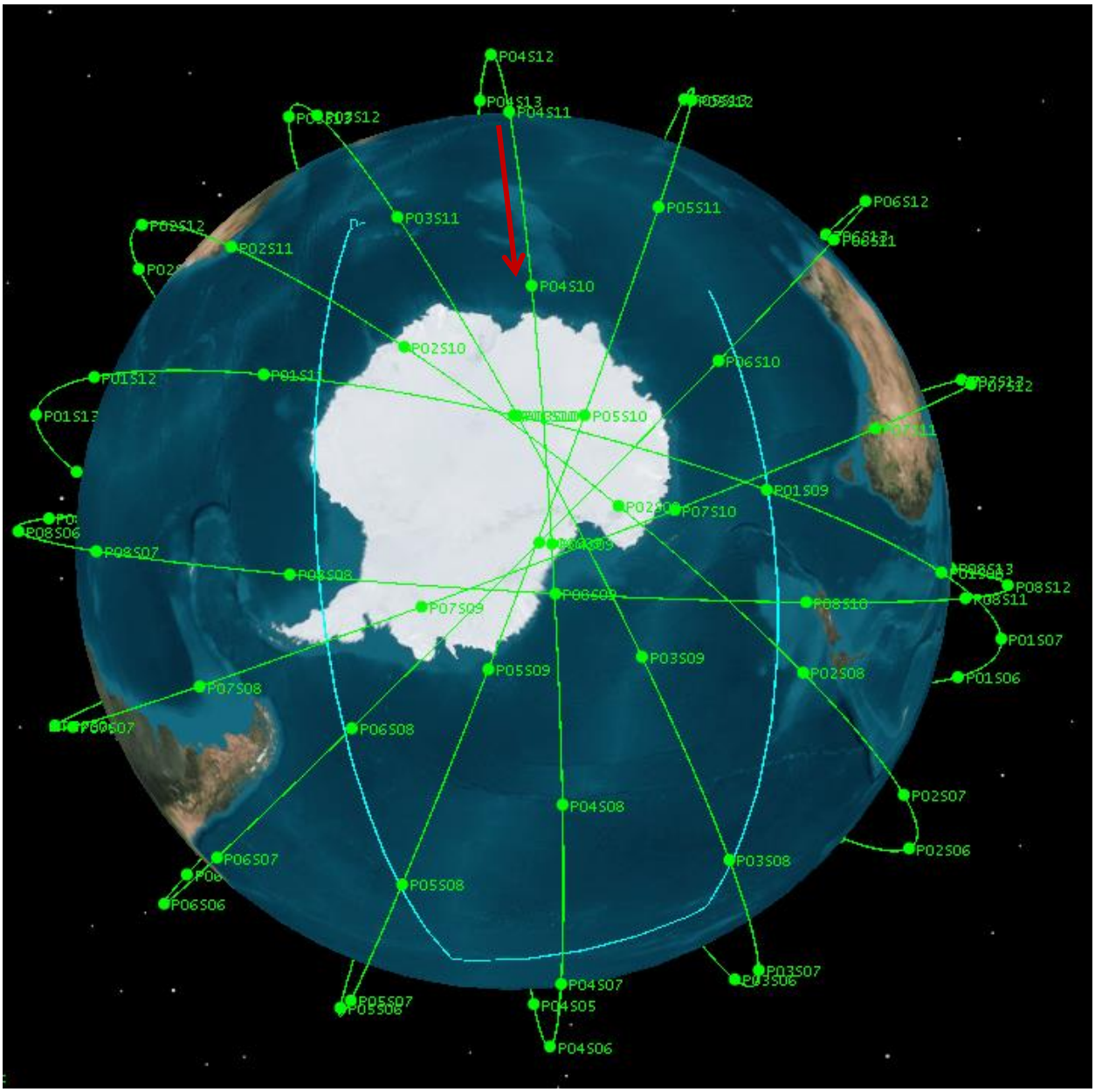

Figure 1 – Theia Satellite Deorbit Target Region

4. Any information or analysis you may wish to provide with respect to treatment of this application under the Commission's environmental processing rules.

THEIA RESPONSE:

With respect to 47 CFR 1.1301-1.1309 of the National Environment Protection Act of 1969, ground infrastructure facilities for the TSN include: gateways, satellite operation centers, network operation centers or supporting data centers. Although locations for these facilities

have not yet been selected, Theia shall comply with the Commission's environmental processing rules as stated in 1.1307 including:

- No facilities will be located in an officially designated wilderness area, a wildlife preserve area, or a flood plain.
- No facilities will physically or visually affect a property significant in American history that is listed, or is eligible for listing, in the National Register of Historic Places, as determined in accordance with the Nationwide Programmatic Agreement or the Collocation Programmatic Agreement.
- No facilities will affect Native American (Indian) religious sites.
- No facilities will affect listed threatened or endangered species or designated critical habitats; or are likely to jeopardize the continued existence of any proposed endangered or threatened species or likely to result in the destruction or adverse modification of proposed critical habitats.
- No facilities construction will involve significant change in surface features (e.g., wetland fill, deforestation or water diversion).
- Facilities will not be equipped with high intensity white lights and will not be located in a residential neighborhood (as defined by the applicable zoning law).
- No facilities will cause human exposure to levels of radiofrequency radiation in excess of limits defined by the Commission.
- No facilities will be constructed taller than 450 feet above ground level (AGL).

Theia will prepare and Environmental Assessment if a facility operation or transmission would cause human exposure levels of radiofrequency radiation in excess of the limits specified in 1.1210 and 2.1093.

With respect to the issues raised in the Space Data decision cited in this question, the circumstances in the Space Data case were fundamentally different than those presented by the proposed TSN operations. That case involved a circumstance where all of the large number of proposed balloon-borne repeaters would return to Earth at indeterminate locations because they were not under the control of Space Data, but here the TSN satellites burn up upon re-entry and thus would not implicate the same environmental concerns.

Specifically, Theia submits that its relatively small number of NGSO satellites and compliant DAS analysis establish that launch and operation of the TSN do not give rise to material environmental or safety concerns. Moreover, Theia's conclusion that it should adopt a fully controlled re-entry approach further mitigates and potential concern regarding these issues.

5. **For optical inter-satellite links, please provide the wavelength, power, duty cycle, beam diameter at emitter, and beam divergence. In addition, please provide the power margin at the receiver at maximum operating distance.**

THEIA RESPONSE:

The current design of the optical inter-satellite links employs optical systems using a wavelength of 1064 nanometers for the bi-directional communications signal. The transmitted optical power is expected to be approximately 2 watts (33 dBm), and would operate with 100% duty cycle during crosslink activities. The space-borne beam diameter will nominally be 10 centimeters in diameter at the emitter. The beam divergence will be approximately 14.5 micro-radians measured at the 1/e points on the beam, and 29.1 micro-radians at the $1/e^2$ points. At maximum range and data rate, the power margin is expected to be approximately 9.4 dB at beginning-of-life and 5.3 dB at end-of-life.

The same configuration is expected to be used for space-ground bi-directional links, however the ground terminal will have a larger aperture.

In addition, the TSN optical crosslinks and downlinks may include provision for a much lower power beacon at a different wavelength to assist in the acquisition and tracking of the link. If such a beacon is employed, it would also have a larger beam divergence. Studies are ongoing to determine if such a beacon will be necessary.

6. **Please indicate whether optical inter-satellite links will be coordinated with other systems proposed in Commission applications and with the U.S. Department of Defense's laser clearing house, and, if such coordination has commenced, please address the status of coordination.**

Theia has contacted Department of Defense Laser Clearing House, Operations Officer CPT Austin Baker. Theia has been advised that since it is a commercial organization, Theia does not submit to the Registration process. Theia will nevertheless keep the Laser Clearing House advised of the Theia laser-link activities.

Theia commits to coordinate with other applicants, and will pursue the matter further as the processing round progresses.