**The Problem:**

As Cislunar traffic increases in volume, particularly transits from Earth orbits to Lunar orbits and return, maintaining the location/position, velocity, time, trajectory and proximity data essential for situation awareness for both crewed and autonomous spacecraft will become an increasingly more critical issue.

The top level objectives are:

1. Tracking to project and prevent collisions with other spacecraft, orbital debris, and other Cislunar space crossing objects.
2. Assist in autonomous navigation to intended destinations, including docking in space

**A Potential Solution:**

The ability of a spacecraft to obtain a near real-time navigation fix which can be readily correlated with other traffic analogous to terrestrial maritime and aviation applications requires in-space aids to navigation.

There are currently four Global Navigation Satellite Systems (GNSS) that are active:

* Global Positioning System (GPS) – United States – The baseline satellite constellation consists of 24 satellites positioned in six earth-centered orbital planes with four operation satellites and a spare satellite slot in each orbital plane. The system can support a constellation of up to thirty satellites in orbit.
* Galileo – European Union – The fully deployed Galileo system will consist of 24 operational satellites plus six in-orbit spares, positioned in three circular Medium Earth Orbit (MEO) planes at 23,222 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees to the equator.
* GLONASS – Russia – The GLONASS space segment consists of 24 satellites, in three orbital planes, with eight satellites per plane. The GLONASS constellation geometry repeats about once every eight days.
* BeiDou Navigation Satellite System (BDS) -- China -- BeiDou-3 will eventually consist of 35 satellites, which include 5 geostationary orbit (GEO) satellites and 30 non-GSO satellites. It is expected to provide global services upon completion in 2020.

These systems allow the highly accurate determination of the absolute position of an object near the Earth to varying degrees of accuracy.

By using side lobe signals it appears to be possible to obtain reliable data from GPS and possibly the other GNSS; however signal strength and dilution of precistion effects will degrade the usefulness of these signals with distance from the Earth.

By determining the highest Earth orbital altitude that will allow for an assured 4+ GNSS satellite fix (additional satellites beyond four provide for redundancy in the event of loss of signal or for better position dilution precision) and locating active aids to navigation in the corresponding orbit equipped with appropriate retroreflectors, autoresponder, and/or signal broadcast capability (for passive receivers) along with the ubiquitous availability of highly accurate time, very low cost (e.g., resource cost including mass, volume, power, complexity, etc.) reliable instantaneous navigation fixes can be obtained. The aids to navigation, which XISP-Inc refers to as Visible and Active Space Tracking (VAST) could be CubeSats/SmallSats that are part of a Technology Development, Demonstration, and Deployment (TD3) mission. The VAST aids to navigation will obtain their absolute position in an Earth centric coordinate system and will serve as active and passive triangulation objects allowing the relative position of any spacecraft in Cislunar space capable of viewing at least three satellites, provided a highly accurate, stable, and consistent onboard time reference can be maintained.

The use of the NASA Atomic Clock improvement project and other government/commercial investments should provide assured access to time.

XISP-Inc would like to leverage our existing TD3 mission development investment to design and field a VAST system using some form of public/private partnership.

To accomplish this, XISP-Inc would like to work with the NASA Space Communications and Navigation (SCaN) Program and Office to accomplish:

1. **VAST Requirements**: Research and help determine the Cislunar positional accuracy requirements, as well as other derived requirements needed to satisfy the the top level objectives for navigational accuracy in Cislunar space (Karman line of 100 km LEO through to the surface of the Moon).
2. **VAST Technology Development, Demonstration, and Deployment (TD3)**: Define and conduct, in collaboration with NASA SCaN, in-space tests which would involve at least three VAST aids to navigation located at known positions plus a ubiquitous, highly accurate time reference.
3. **VAST Architecture**: Determination of optimal number of VAST aids to navigation and their placement to ensure accurate relative cislunar position accuracy for customers in different addressable markets in Cislunar space.
4. **VAST In-Service Testing**: Faciliate Cislunar customer tests, including independent cross-correlation of positional accuracy using laser retroreflectors and other means independent of the VAST navigation solution.

References:

1. Autonomous Spacecraft Navigation Using Above-the-Constellation GPS Signals Dr. Luke Winternitz, NASA Goddard Space Flight Center, SCaN Navigation Workshop February 16, 2017
2. Emerging Technologies for Autonomous Space Navigation Opportunities for Technology, Development, Demonstration, and Deployment (TD3) Missions with XISP-Inc NASA Headquarters SCaN Office Briefing February 17, 2017

**Signal Availabilty**

* Satellite not broadcasting
  + Satellite Outage File helps mitigate DOP issues
* Terrain
  + Use terrain models & urban propogation models
* Jamming
  + Multi-spectral jammer modeling
  + Dynamic, phased-array antenna
  + GPS signal characteristics
* Antenna gain pattern
  + Multiple antennas to get best signal gain
* Dropped signals
  + Different channels, different encodings
* Receiver noise
  + Non-constant receiver noise modeling, per channel
  + Higher fidelity noise models improve system modeling
* Receiver processing
  + Model time to first fix (TTFF)
* Lack of signal drives up DOP
* Almanacs expire after about two weeks
* STK models GPS, GLONASS, and GALLIEO
* Help.agi.com/stk

**Dilution of Percision (DOP)**