# GNSS[1] Geospace Constellation (GGC): A Cubesat Space Weather Mission Concept

Anthony J. Mannucci, Jeff Dickson, Coutney Duncan, Ken Hurst
Jet Propulsion Laboratory, California Institute Of Technology

**THEME:** Atmosphere-Ionosphere-Magnetosphere Interactions

**EXECUTIVE SUMMARY**

Investment in radio occultation science using GPS receivers in low-Earth orbit is bringing enormous scientific benefit to the Atmosphere-Ionosphere-Magnetosphere community. Recent technology developments permit highly miniaturized receivers that provide high quality science data for ionospheric studies. Such receivers are compatible with the Cubesat form factor, raising the possibility of swarms of Cubesats providing unprecedented global coverage of ionospheric electron density measurements throughout the E and F-region ionosphere and up into the plasmasphere. In this white paper, we describe the science and technology needed to achieve this result. ***We recommend technology investment in miniaturized GPS receivers for ionospheric remote sensing.*** Such Cubesat swarms, either as a dedicated constellation or an ad-hoc constellation deployed via launches of opportunity, would be a profoundly useful resource for advancing AIM science, providing plasma measurements to accompany other measurements of the forces that influence ionospheric structure such as solar EUV, thermospheric winds and composition, and ionospheric electric fields.

## 1. Science

Applying GPS technology to ionospheric measurement has produced an explosion of new science results. The reason is relatively simple: GPS has provided a quasi-imaging capability for ionospheric total electron content. This capability has revolutionized our field because it allows scientists to visualize ionospheric structure on a range of spatial scales, from 100s to 1000s of km, globally and continuously. This has produced discoveries and new science in a range of areas, from extreme ionospheric storms to long-term trend studies and studies of ionospheric irregularities.

The earliest GPS work used receivers on the ground. Starting in 2001, with launch of the CHAMP and SAC-C satellites, a continuous stream of ionospheric data became available from GPS receivers in low-Earth orbit. Using the radio occultation (RO) technique, first pioneered on GPS/MET (1995-1997), the community has demonstrated the feasibility of retrieving electron density profiles from the total electron content measurements obtained from the receivers. Electron density is retrieved using an "onion peeling" (Abel transform) retrieval approach. See Figure 1. While the accuracy of unaided retrievals will vary, it is clear there is a wealth of scientific information in the profiles and in the rawer total electron content measurements obtained in limb viewing

[1] GNSS: Global Navigation Satellite System

geometry. As an added bonus, GPS measurements from ground and space are now being used as input data to assimilative models for research and operations, bringing a new capability to space weather that is analogous to the numerical weather prediction capabilities existing in terrestrial weather.

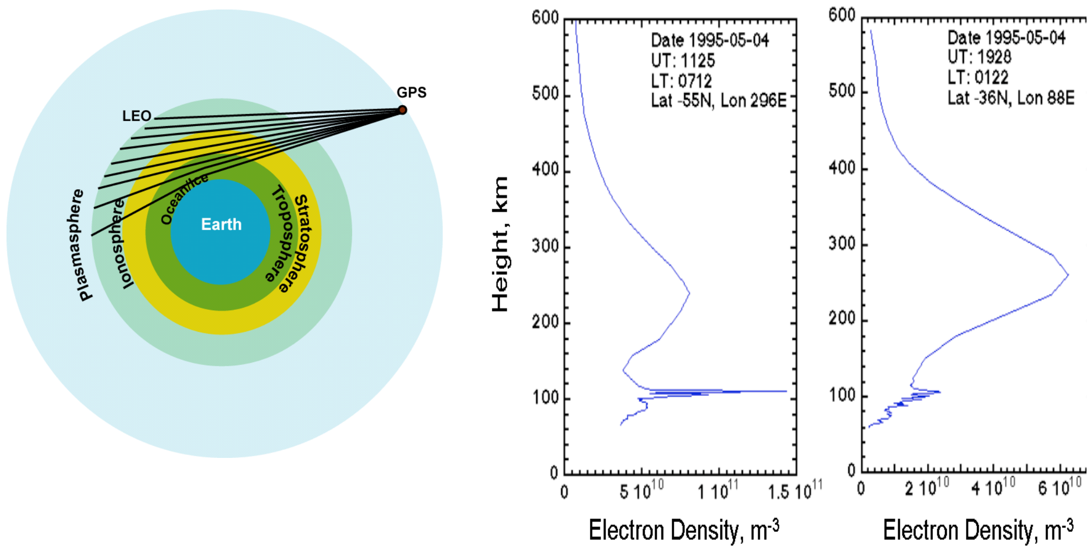


Figure 1. Radio occultation acquisition geometry (left). Retrieved electron density profiles from GPS/MET (right) should strong E-layer signatures. The GPS receiver is onboard the Low Earth orbiting satellite (LEO) tracking the transmissions from the GPS satellite (GPS).

It is clear the scientific community will benefit from increasing numbers of orbiting GPS receivers. Increased numbers of receivers increases the spatial and temporal resolution of the quasi-images that are obtained. To quantify this benefit, we refer to Figure 2 [Schreiner, 2009]. This shows the number of occultations (electron density vertical profiles) that will occupy a 500x500 km$^2$ region on average per day from the COSMIC-2 constellation of 12 satellites. Depending on latitude, the 7-10 available profiles per day available represents a historic advance in global coverage for ionospheric studies. However, considering the importance of mesoscale structure, the strong diurnal variations in the ionosphere that significantly affect its vertical structure, and the rapid changes with UT occurring during disturbed periods (e.g. TEC doubling and lifting of a few hundred km in 2-3 hours) it is clear that additional satellites would provide significant scientific benefits enabling new science investigations. We believe that deploying 100-200 receivers on orbit will produce the next quantum advance in scientific capability and new science.

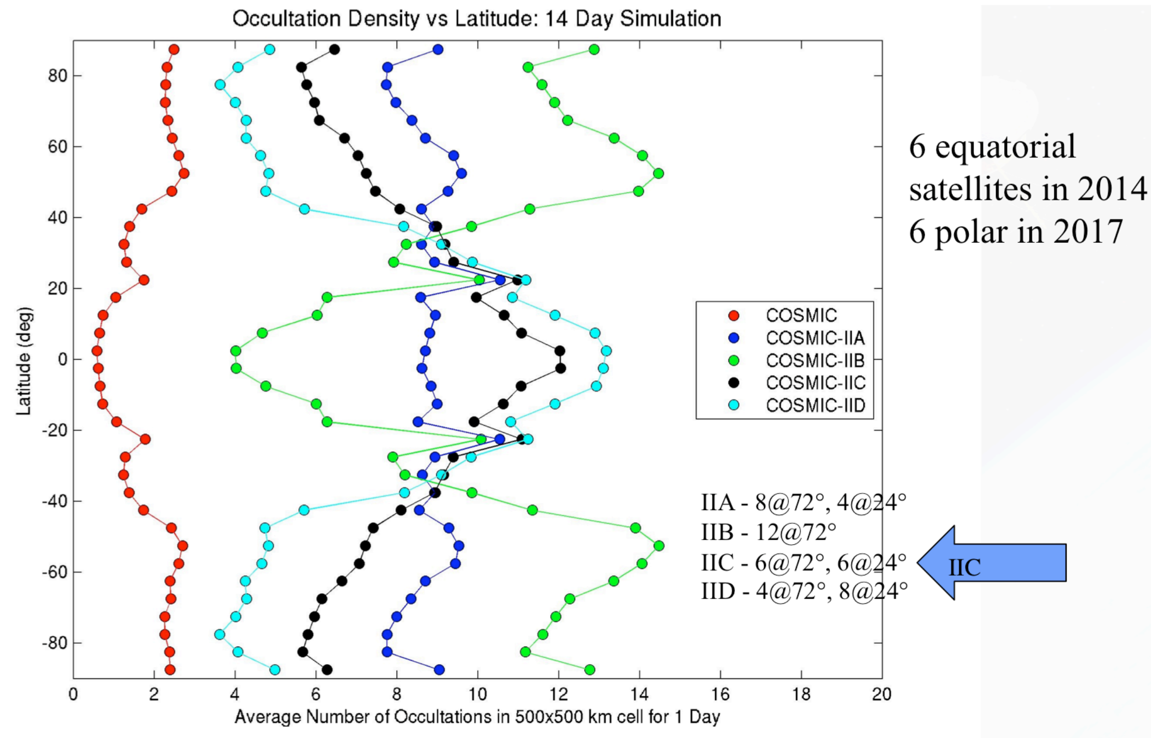


Figure 2. Number of occultations per 500x500 km$^2$ region, by latitude, for candidate COSMIC-2 constellations. From a presentation by W. Schreiner, UCAR, presented at the OSSE COSMIC Workshop, Taiwan, August 2009.

## 2. Technology

The enabler of new science is the possibility of deploying a sufficient number of GPS receivers in low Earth orbit so that the quasi-imaging capability that has been so successful from ~1000 ground-based receivers is brought to the vertical dimension (altitude). Reducing the power, size and mass of ionospheric radio occultation instruments offers the best hope of increasing the resolution of the images and increasing the probability of maintaining the data continuity through time, sampling a wide variety of solar cycle and atmospheric conditions.

Technology is within reach to produce a low power (<3W) low cost (< $50K each in quantity) instrument for ionospheric remote sensing from space. We base our assessment on the availability of commercial receivers such as the Novatel OEMV-3 board. Table 1 has relevant engineering data for this board. The Novatel receiver board is compatible with a Cubesat power budget and form factor.

**Table 1: Novatel OEMV-3 GNSS Receiver**

| Characteristic | Value |
|---|---|
| Power | 2.1 W |
| Mass | 75 g |
| Dimension | 85x125x13 mm |

The Novatel GNSS (Global Navigation Satellite System) receiver has a number of features well suited for our targeted science measurements. Unlike most commercial GNSS receivers, which only produce position outputs based on single (L1) frequency tracking, the Novatel produces the carrier and code phase observables necessary for science. It supports all current and planned GNSS signals such as Galileo and modernized GPS L2C (new codeless[2] second frequency), L5 (new codeless third frequency), as well as tracking of the current encrypted L2 signal. Access to the receiver version that supports operation in space is possible by NASA centers such as JPL, including the capability to track at high altitudes and high speed.

Radiation testing on Novatel receivers indicates they are suitable for a Cubesat orbit and mission lifetime (Markgraf et al., 2004). In a technology demonstration effort, we recommend leveraging commercial off the shelf parts to keep costs low.

Figure 3 is a sketch of the Cubesat concept. The following characteristics of the system are favorable for Cubesat also:

***Spacecraft accommodation:*** Pointing requirements are modest: 5-10 degrees knowledge and control suffices due to the use of hemispherical patch antennas in the RAM and anti-RAM velocity directions. RO requires three-axis stabilization. Cubesats are rapidly evolving to achieve such stability.

***Antenna:*** two patch antennas could be used (one fore/RAM and one aft/anti-RAM), at ~100g each with dimensions 40x40x10 mm. Cables might add an additional 100-300g of mass, depending on configuration.

[2] "Codeless" refers to the fact that the signal is not encrypted, available for civilian use.

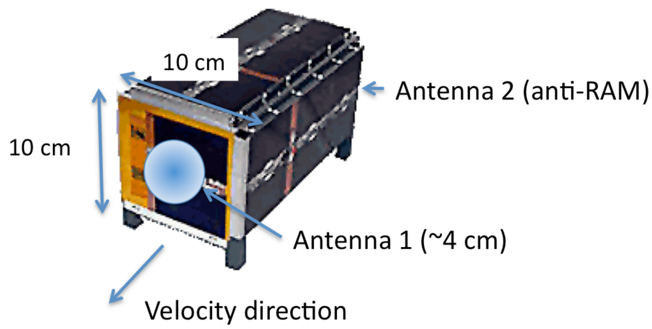


**Figure 3.** Schematic of the Cubesat with radio occultation capability.

## 3. Conclusions And Recommendations

We recommend technology development to enable GNSS receivers compatible with the Cubesat form factor for remote sensing of the Earth's ionosphere and plasmasphere. A radio occultation receiver should be considered for deployment on all future NASA and NOAA space weather and Earth science missions (see National Research Council, 2007 for a similar recommendation).

## 4. Acknowledgement

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

## 5. References

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