POPACS

Spheres in Space: Sensors for the Impact of Solar Storms on Our Atmosphere

The Polar Orbiting Passive Atmospheric Calibration Sphere (POPACS) satellites are now in orbit and ready to carry out their mission.

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1. What Exactly is POPACS?

The main objective of Project POPACS (Polar Orbiting Passive Atmospheric Calibration Spheres) is to measure the changes in density of the auroral zone upper atmosphere, in response to various solar stimuli, such as flares and CMEs. The mission consists of deploying three 10 cm spheres whose external appearances are identical but whose masses differ. The three masses are 1 kg, 1.5 kg, and 2 kg. The different masses result in differing ballistic coefficients, which will cause them to spread out in right ascension along the original orbit. Tracking the spheres allows the atmospheric density to be calculated.

In their launch configuration, the three spheres are separated by a set of two spacers and two end plates. The entire assembly fits into the standard CubeSat Peapod deployment device. When deployed, all spheres, spacers, and end plates are ejected into space at relatively low velocities. Hence the initial orbit of POPACS is that of the payload from which the Peapod deployed the satellites and other hardware.

Figure 1 shows schematically the deployment configuration. The entire payload of spheres and spacers has a cross section of 10 cm which is needed for accommodation in the Peapod. A second figure shows the hemispheres that were paired and filled with Bismuth and Sand–each filled to achieve each satellite's required net weight of 1, 1.5, and 2 kg, respectively. To mitigate concerns about overpressure once the satellites are in space each has a very small hole in its spherical shell.

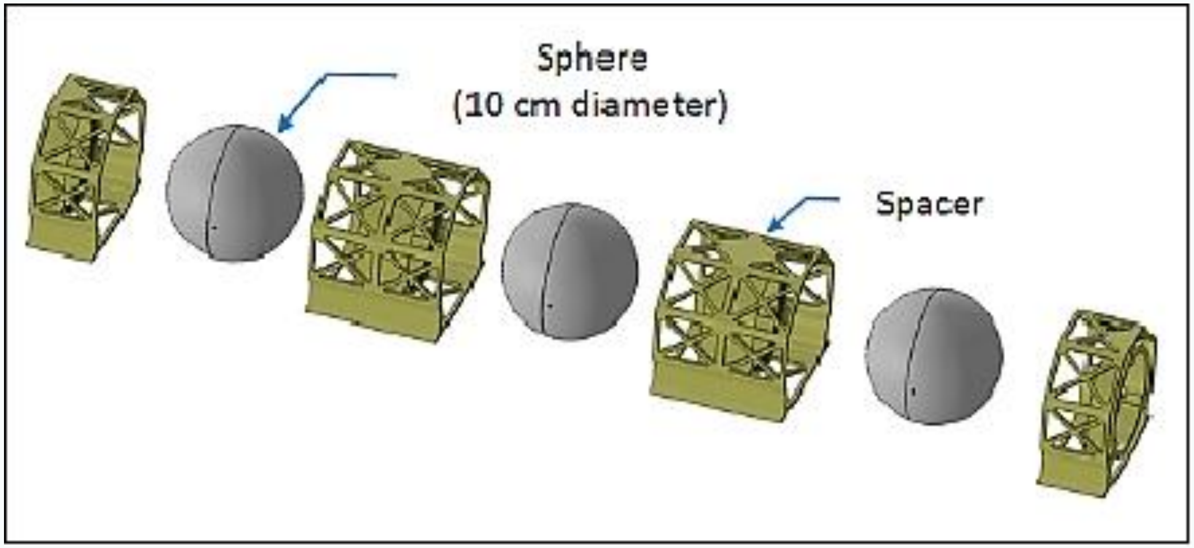

Figure 1.

Figure 2.

2. Whose Brain-Child is POPACS?

It is with great pleasure that we can identify Gilbert ("Gil") Moore as the sole individual responsible for the POPACS concept. Beyond that, he has followed through on the design and fabrication of POPACS. This he has done by providing young science researchers at several universities unique technical opportunities to bring his concept to fruition. Given that the spheres are now in orbit, these teams have been completely successful in their endeavors.

Gil nurtured this concept and its fabrication along for over a decade and together with his wife, Phyllis, financially provided for the launch by the SpaceX Corporation. The last step in this venture has been completed in collaboration with Utah State University.

3. When and Where Was POPACS Launched?

Figure 3.

The Peapod deployment package was a secondary payload on a SpaceX Falcon 9 rocket. This rocket was launched from the Californian launch site of Vandenberg on Sunday, September 29, 2013. The launch occurred exactly on schedule at 0900 hours Pacific Coast time. The assembled and ready for launch Falcon 9 rocket and payload is shown here.

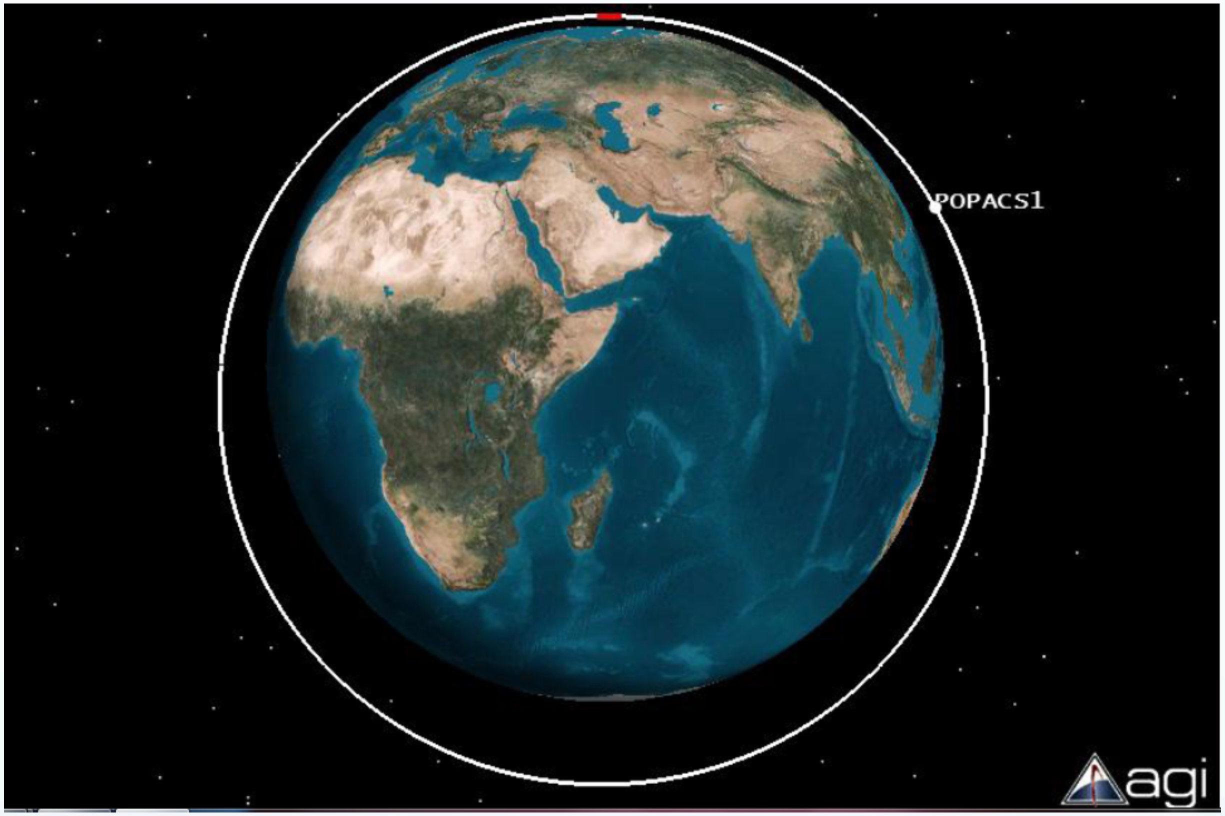

Figure 4.

The initial polar orbit has a perigee of 355 km and an apogee of 1455 km. This orbit is ideal for scientific investigations associated with the Earth's auroral zones. The auroral zones are where the majority of solar storm energy is deposited in the Earth's atmosphere. Figure 4 shows the orbit around the Earth. The perigee location is placed over the north pole, however, this is simply for presentation purposes. An exact location for the perigee awaits more detailed orbit parameter evaluation.

4. What Science Governs POPACS?

The key POPACS Science is an investigation into Thermospheric Satellite Drag. A very important population of satellites have orbits in what is called Low Earth Orbit (LEO). The major advantage of LEO is that its distance to ground-based receiving stations is small (a few hundred kilometers), but at a cost. This is because the satellites travel in an atmospheric environment that "drags" the satellites. Accumulated drag over years gradually reduces apogee and eventually the orbit decays into the atmosphere proper with an end-of-life experience. The environment of acceptable drag is called the thermosphere to distinguish it from the more dense lower atmospheric layers of the troposphere, stratosphere, and mesosphere.

If the Sun was quiescent and its solar wind and irradiance never changed, the problem of satellite drag in LEO would be entirely understood, but as life has it, variability and solar weather and storms do change the thermospheric density. The basic thermospheric dependence upon the Sun is associated with the solar cycle, a nominally 11-year period for the thermosphere.

The physics of this dependence is readily understood by knowing that the difference between solar minimum and solar maximum is that ultraviolet (UV) solar irradiance is stronger during solar maximum. In the thermosphere, the UV irradiance is the heat source. Hence, during solar maximum the thermosphere is hotter and the simple fact that hotter gases expand more than cold ones is the physics mechanism that causes the thermosphere to have higher density in the LEO environment. This then leads to more drag and shorter lifetimes. The Hubble space telescope is a good example where NASA made several trips to give its orbit a "boost" by firing the space shuttle's main engines to change Hubble's orbit.

In addition, much shorter periods of solar variability (27 days for a solar rotation and hours for storms) all lead to heating. The most dynamic solar storms are associated with the solar wind which cannot directly deposit energy in the LEO environment. Instead, the solar wind energizes the magnetosphere and this complex region of space eventually deposits energy into the auroral regions of the LEO environment.

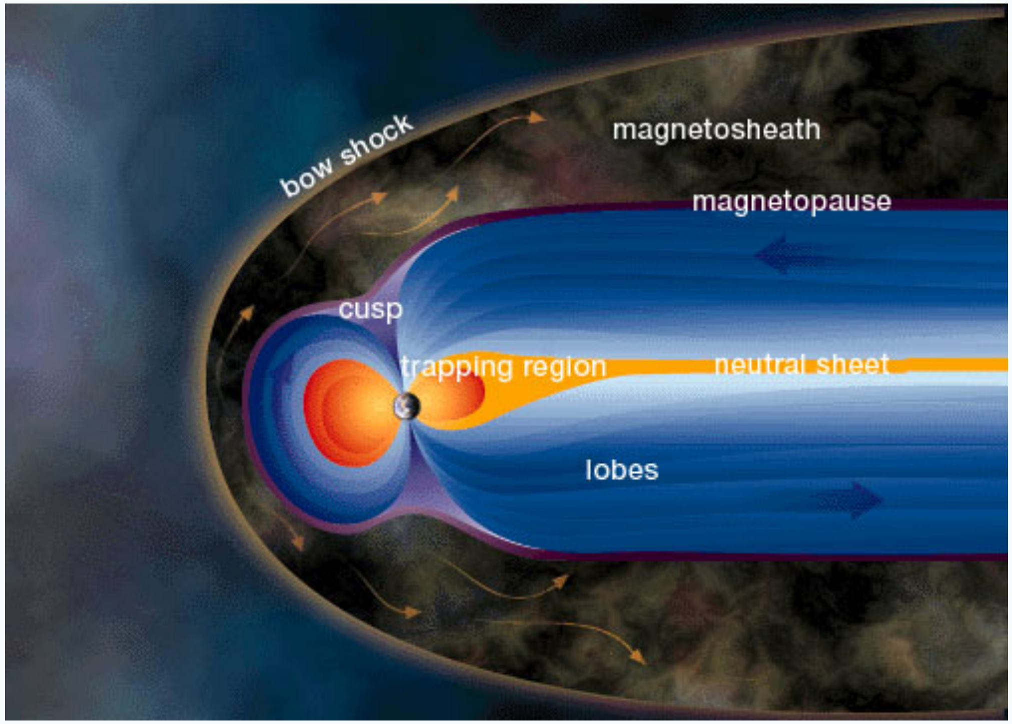

Figure 5.

Figure 5 shows a schematic cross section through the magnetosphere with the key regions labeled. The Sun is located at the left and as the solar wind impinges on the bow shock, energy can by various mechanisms enter the magnetosheath through the magnetopause and eventually end up in the neutral sheet where energization of electrons and protons lead to populations of hot particles that deposit their energy in the thermospheric auroral zones. The magnetosphere introduces a complicated time history and variable energy deposition rate that is poorly predicted. This is why missions like POPACS are crucial for the forecast application for LEO communities. POPACS will sense the thermosphere's response to storms each time a POPACS satellite passes through its perigee—approximately once every 100 minutes.

5. Who is Involved in Doing POPACS Science?

Scientists and engineers including high school students, undergraduate students, graduate students, professors, national laboratory researchers, and space industrial researchers and very dedicated individuals such as Gil Moore. The research tasks fall into several categories:

i. At the national level where government laboratories are responsible for tracking space objects, including space junk, a very extensive program of radar tracking is used to check the orbits of all objects above a certain size. To these researchers, the POPACS satellites provide a unique target object that will immediately provide information on changes in satellite drag.

ii. Another aspect of research at national laboratories, in this instance the Naval Research Laboratory (NRL), is research that involves maintaining the most accurate empirical model of the thermospheric density. This is achieved by using orbit changes from many LEO satellites being incorporated in deducing changes in thermospheric densities over the entire globe.

iii. Amateur scientists and academic researchers form a global network of observers who capture satellites in their telescopes. These satellite locations are then combined to update the orbit parameters of the satellite. The universal standard for exchanging orbital parameters is the two line element (TLE). Figure 6 shows an example of a satellite TLE.

iv. At Utah State University a team of undergraduate and graduate students along with research faculty will carry out studies of how POPACS satellites can be used to determine the thermosphere's response to specific solar storms. This will be done by a group carrying out analysis of the TLEs as the three POPACS satellite orbits change differently to the thermospheric changes. Observationally, the group will also field telescopes to observe the satellites. This component of the research provides unique field experience in fundamental aspects of orbital mechanics, observational tracking, and photographic data reduction. The exercise is further complicated by the fact that the POPACS light signature is sub-visual and is only seen in the photographs if indeed the tracking computations, both position and timing, are accurate.

6. What is a TLE?

The two line elements describe the satellite orbit as deduced from various observations and propagation of expected drag based on modeling the thermospheric impact on the orbit. An orbit is defined in several different versions of the following information in different coordinate systems. The position of the satellite which is a set of three coordinates; then at that location what is the direction and speed of motion of the satellite, hence three more parameters; and finally the time of this satellite position. At USU, there are classes available that educate the students on orbital mechanics. The first class on this subject is MAE5560 Dynamics of Space Flight. The USU team will include instructors for this class as mentors for the team's efforts on POPACS orbital analysis.

The JSPOC will periodically publish Two Line Element sets (TLEs), similar to those below, that define each sphere's orbital elements at the start of a given epoch

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1 25544U 98067A 12207.23435663 .00012087 00000-0 18559-3 0 9948
2 25544 51.6432 292.2604 0000709 323.9012 131.3736 15.54710176783935
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Figure 6.

7. POPACS Updates

We still await the first set of TLEs of the three POPACS spheres. In order to distinguish between the three spheres, they are named as follows:

MOORE: POPACS 1 kg Sphere

PHYLLIS: POPACS 1.5 kg Sphere

GILBERT: POPACS 2 kg Sphere