Paired Ionosphere-Thermosphere Orbiters

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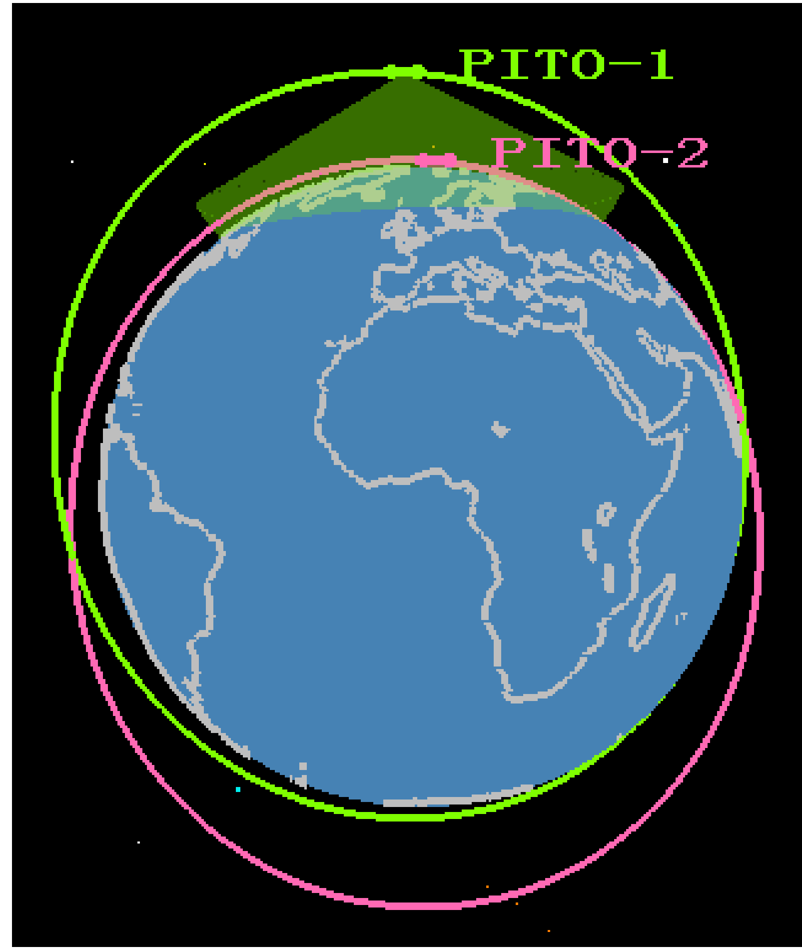
Overview

The Paired Ionosphere-Thermosphere Orbiters (PITO) mission combines comprehensive *in-situ* measurements with large field-of-view imaging and vertical sounding instruments to provide new insights into the physics of the ionosphere-thermosphere system.

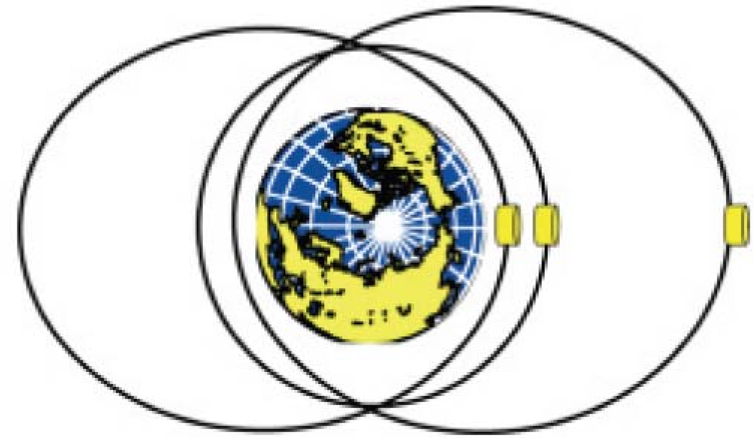
PITO packs strategic-impact science into a package about the size of a NASA Medium Explorer (MIDEX), or slightly larger mission.

The power of PITO is derived through its two-satellite orbital configuration, which provides for *in-situ*/imaging co-volume measurements twice per orbit. Addition of vertical sounding measurements give an overall picture that has aspects of a complete three-dimensional description.



The PITO orbital configuration. Here imaging on PITO-1 images the volume measured *in-situ* by PITO-2.

The PITO orbit has similarities to NASA’s 2005 Roadmap mission ITMC. Both missions incorporate co-volume *in-situ* and remote sensing measurements to provide a comprehensive measuring system. In contrast, however, PITO utilizes a high-inclination orbit to complete science goals from all latitudes, and has a relatively simpler two-satellite system.



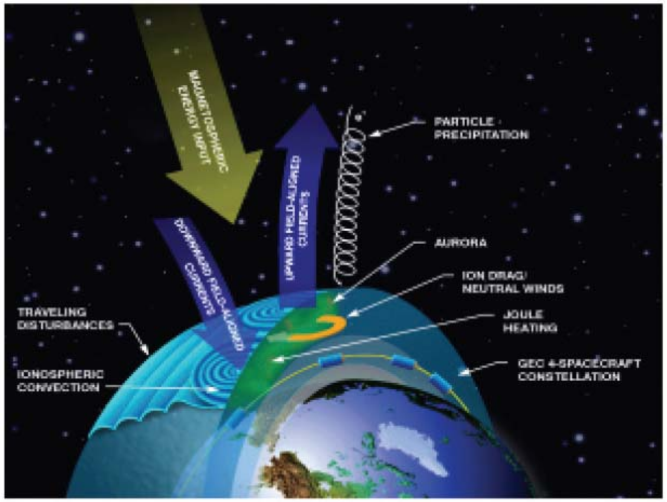
The ITMC orbital configuration from NASA’s 2005 Roadmap. PITO has similarities to this equatorial mission, but is simpler and encompasses science from all latitudes.

PITO’s orbits are designed to be “equal but opposite” in the sense that one spacecraft is directly below the other when they are at, respectively, perigee and apogee. In other words, their arguments of perigee differ by 180 degrees.

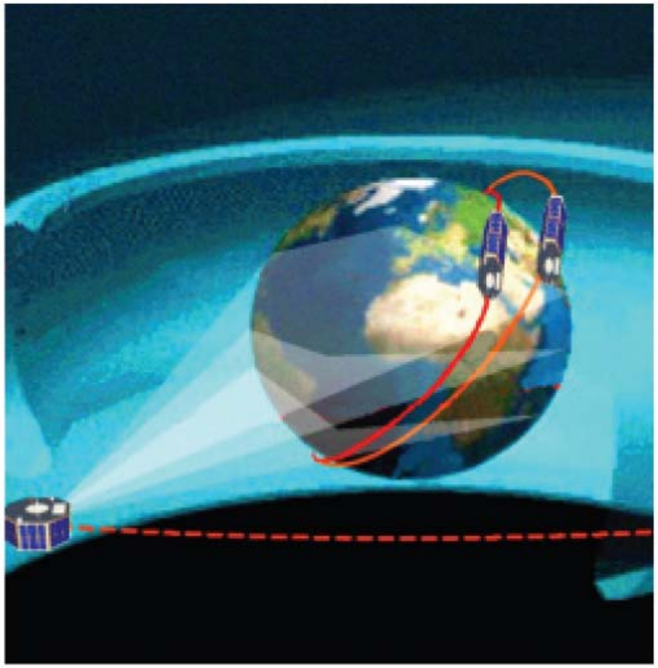
PITO Science Objectives

Using paired satellites for simultaneous observation of large and small scale ionosphere-thermosphere phenomena in two regions of the atmosphere and the coupling between them determine how on different scales

- The ionosphere-thermosphere (I-T) system responds to magnetospheric forcing
- Solar and geospace forcing causes ionospheric density irregularities below 1000 km
- Composition changes in the aurora are driven
- High-latitude electrodynamics exerts control on the global circulation of the atmosphere
- Equatorial depletions are related to atmospheric disturbances



PITO's science goals includes several of those in NASA's 2005 Roadmap missions GEC (top) and ITSP (bottom).



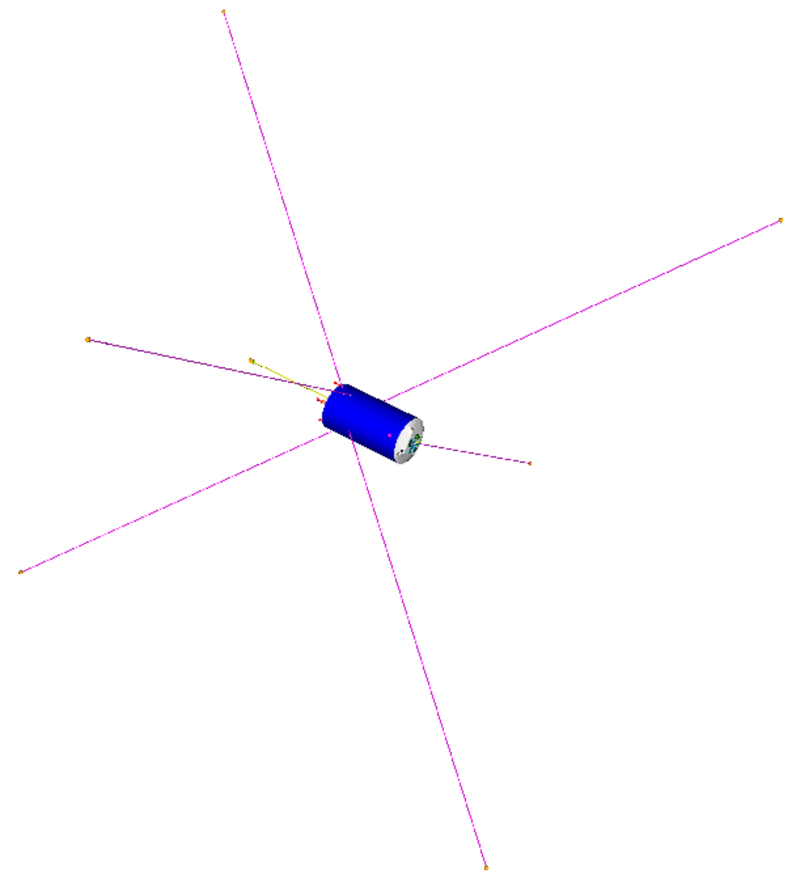
The PITO satellites are identical 3-axis stabilized spacecraft with instrument suites that measure

1) *In-situ* neutral and ionized gas parameters
2) *In-situ* electrodynamic and charged particle parameters
3) Remote sensing of aeronomic emissions
4) Vertical profiles of ionized and neutral gas densities

Combined in situ, imaging and profiling allow one to unravel the complex interplay between process on different scales and in different regions.

The PITO mission is currently under preliminary study at The Aerospace Corporation. A scenario that injects each satellite directly into a 200 × 2000 km, 82-deg orbit with its own modest (Taurus) launch vehicle is being completed.

The spacecraft buses are simple cylinders with body-mounted solar arrays. Power requirements then drive the size of the vehicles to 1-m diameter and 2-m length. Total mass at launch, including propellant and contingency, is 400 kg.



PITO’s spacecraft look much like this satellite, which is one of the elements of the GEC constellation.

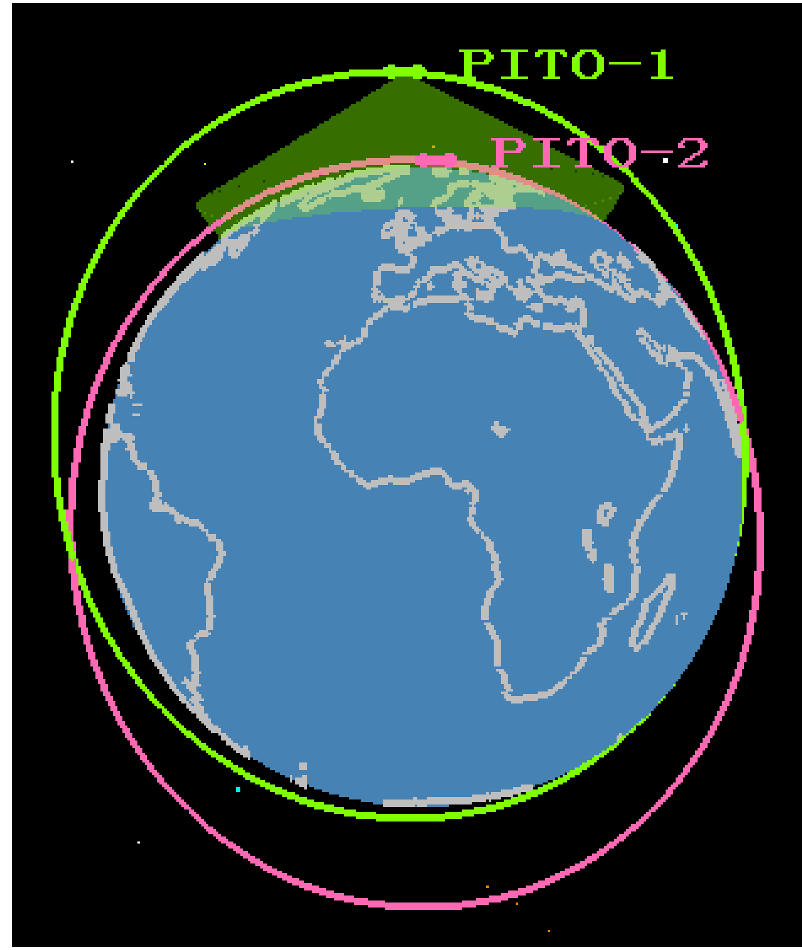
Science Investigation

PITO encompasses some of the science objectives from two of NASA's 2005 Roadmap missions, GEC and ITSP.

By virtue of its frequent co-volume measurements of *in-situ* and remotely-sensed parameters, multipoint measurements are made. This aspect allows progress to be made on the GEC science objectives:

- **How does the ionosphere-thermosphere (I-T) system respond to magnetospheric forcing?**
- **How is the I-T system dynamically coupled to the magnetosphere?**

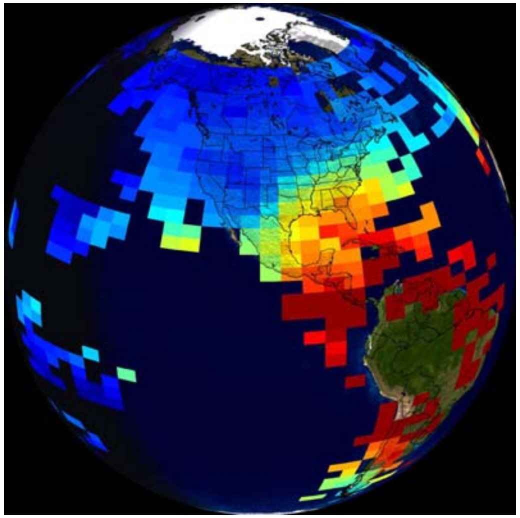
Progress on these objectives will be made during PITO's frequent high-latitude excursions.



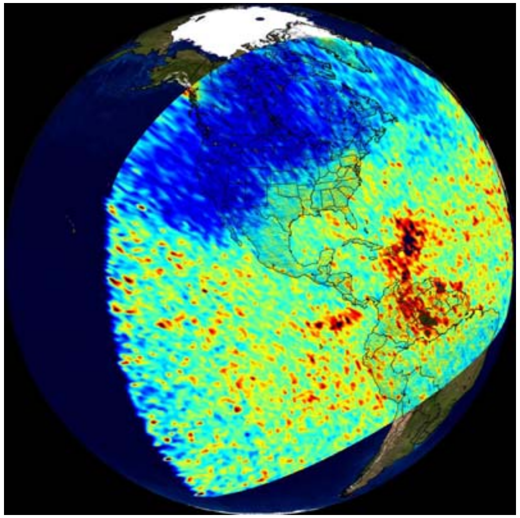
The PITO orbital configuration. Here imaging on PITO-1 images the volume measured *in-situ* by PITO-2.

Similarly, PITO will also make progress at lower latitudes on ITSP science questions. The combination of *in-situ* and remotely-sensed parameters will provide the multipoint measurements necessary. These objectives include:

- Determine the effects of long and short term variability of the Sun on the global-scale behavior of the ionospheric electron density.
- Determine the solar and geospace causes of small scale ionospheric density irregularities in the 100 km to 1000 altitude range.
- Determine the effects of solar and geospace variability on the atmosphere enabling an improved specification of the neutral density in the thermosphere.



(a)

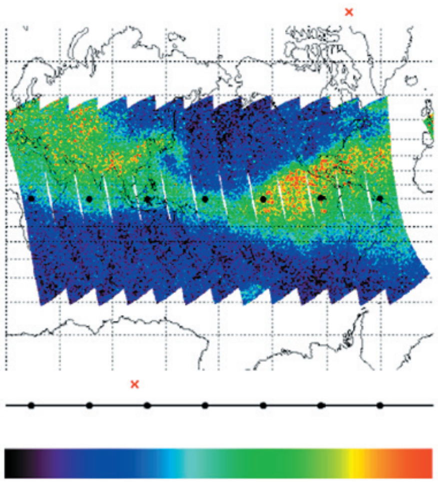


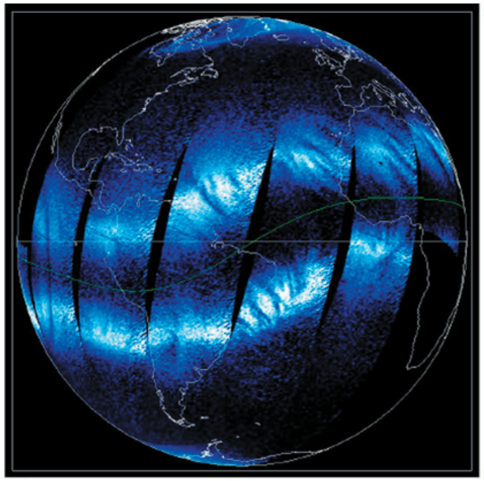
(b)

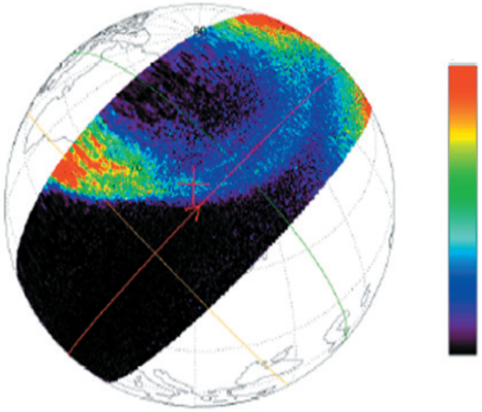
(a) TEC disturbances driven by Coronal Mass Ejections (Foster, 2004) and (b) composition disturbances (O/N2 ratio) driven by solar EUV (Polar VIS imager).

PITO will also enable the separation of locally driven changes from those on large spatial scales with different time scales. This determination requires more than single-point measurements, and PITO brings to bear dual *in-situ* measurements and the wide-area measurements of remote imaging on this problem. Questions that become answerable are:

- How are composition changes in the aurora driven?
- What is the role of high-latitude electrodynamics in the global circulation of the atmosphere through heating and wave generation?
- How are equatorial depletions related to small-scale atmospheric disturbances?







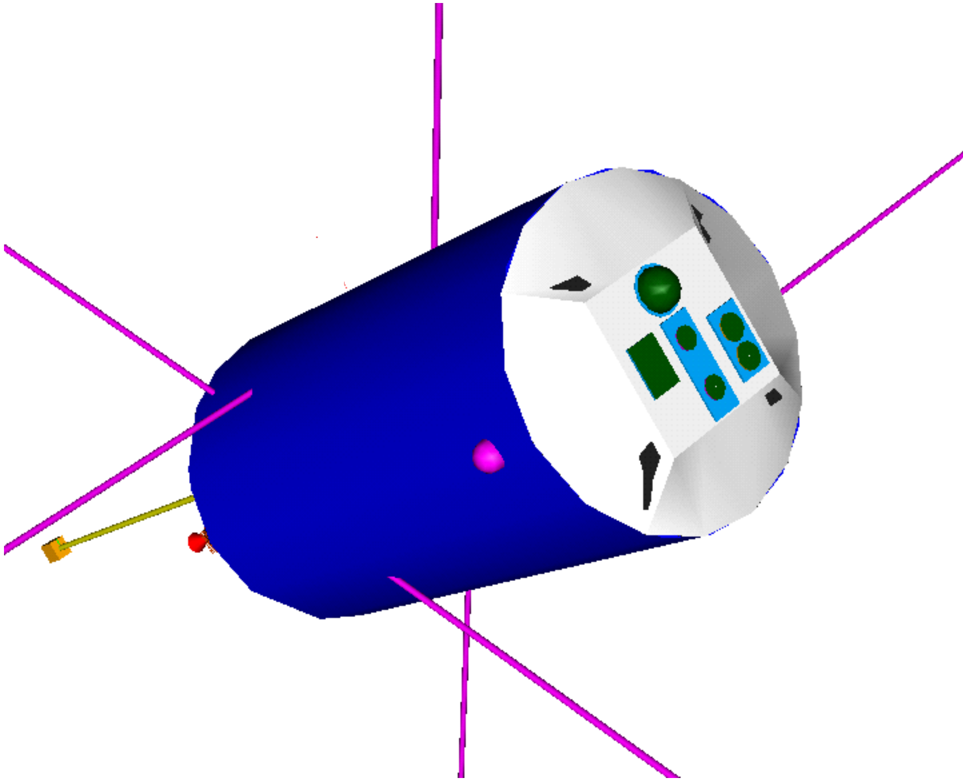
(a) 13-orbit composite image of GUVI observations of O/N2 composition change during a geomagnetic storm. The local time of the TIMED spacecraft was near noon and time elapses from right to left. Enhancements and strong depletions in composition are seen within the image. (b) A 6-orbit composite GUVI nighttime OI (135.6 nm) image of equatorial arcs containing structures associated with plasma instabilities. (c) A GUVI auroral OI (135.6 nm) image.

Science Implementation

The science suite is composed of four instrument packages:

1) *In-situ* neutral and ionized gas parameters
2) *In-situ* electrodynamic and charged particle parameters
3) Remote sensing of aeronomic emissions
4) Vertical profiles of ionized and neutral gas densities

The *in-situ* packages are much the same as those used in the GEC mission.



View of a GEC satellite showing booms of electrodynamics package and ram-facing apertures for neutral and ionized gas instruments. The PITO configuration is similar.

In-situ neutral and ionized gas parameters

The first three moments of the fluid distribution functions (density, flow speed, temperature) are to be measured. Neutral and ion composition is also to be measured.

Baseline instruments include:

- Langmuir probe for ionized gas density and temperature
- Ion drift meter and retarding potential analyzer for plasma flow velocity
- Ionization gauge for neutral gas density
- Cross-track and ram wind sensor
- Mass spectrometer for ion and neutral composition

In-situ electrodynamic and charged particle parameters

AC and DC electric and magnetic fields will be measured. Distribution functions of charged particles will be measured.

Baseline instruments include:

- Three-axis electric field double probe for DC and AC electric fields
- Boom-mounted three-axis fluxgate magnetometer for DC magnetic fields
- Boom-mounted three-axis search coil magnetometer for AC magnetic fields
- Electrostatic analyzer for charged particle distribution functions

Remote sensing of aeronomic emissions

Electromagnetic emissions will be remotely imaged to yield

- nightside total electron content
- dayside O/N2 ratio
- auroral energy input and characteristic energy

Baseline instruments include:

- Wide field-of-view ultraviolet imager imaging the following emissions
    - 135.6 nm
    - Lyman-Birge-Hopfield short
    - Lyman-Birge-Hopfield long

Vertical profiles of ionized and neutral gas densities

Profiles of electron density and neutral gas density will be measured

Baseline instruments include:

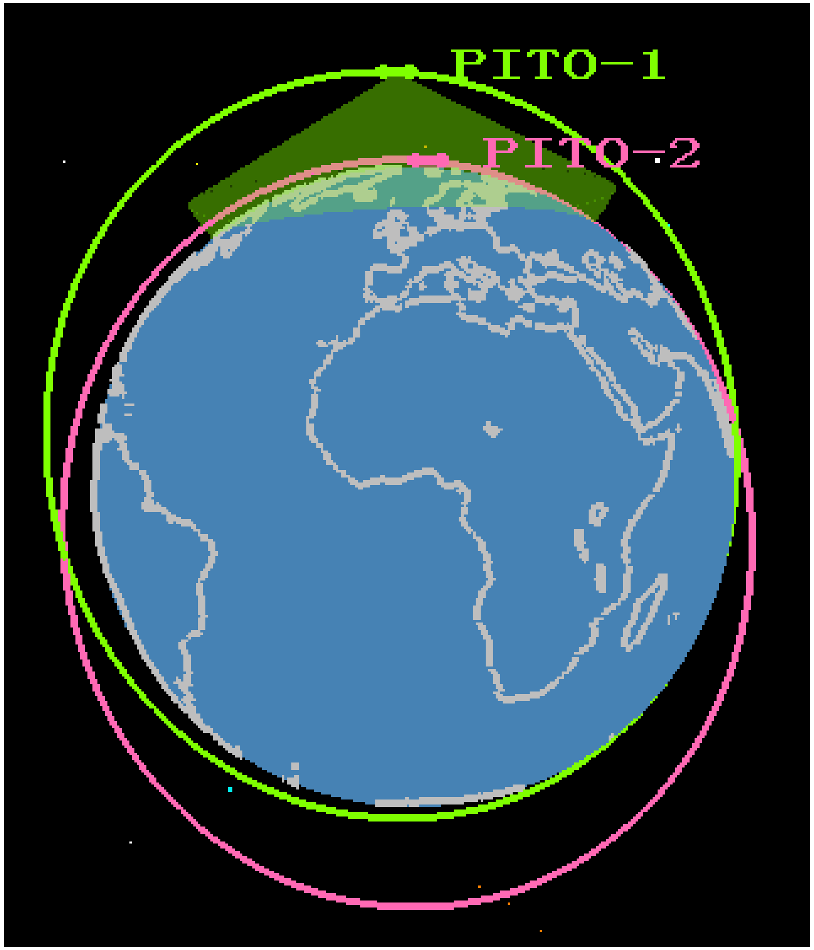
- Topside-bottomside sounder for electron density profiles
- Spaceborne lidar for neutral density profiles

Mission Implementation Study

A scoping study is being performed on PITO. The input parameters to the study include:

- Direct-inject to 200 X 2,000 km at 82 deg
- Single-manifest or dual-manifest
- Instrument suite modeled as single mass/power
- Booms modeled as single mass
- Two-year mission
- Launch in 2015 with technology frozen in 2008
- NASA class B/C – medium to high heritage, selected redundancy
- 100% payload duty cycle

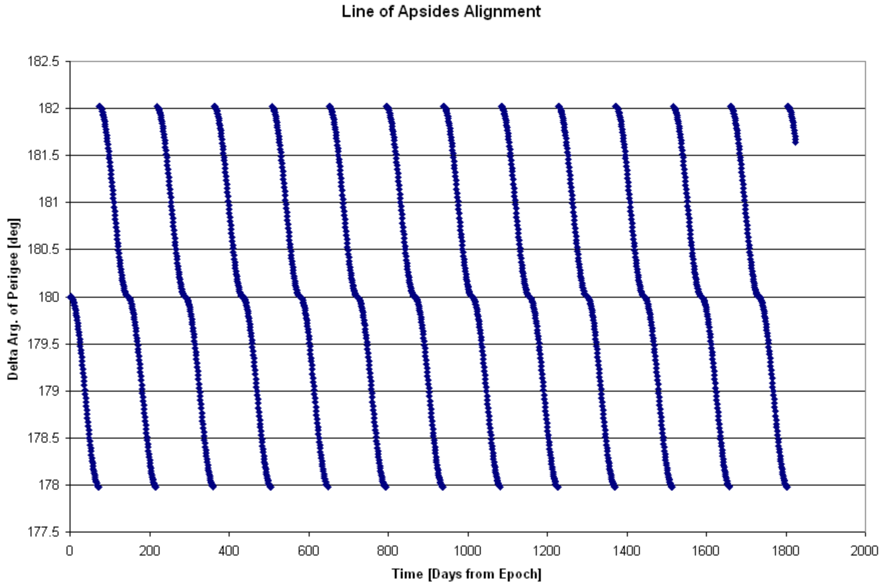
The current conclusion is that the mission can easily (>40% margin) be launched on a pair of Taurus 2110 launch vehicles (cost each: $28M)



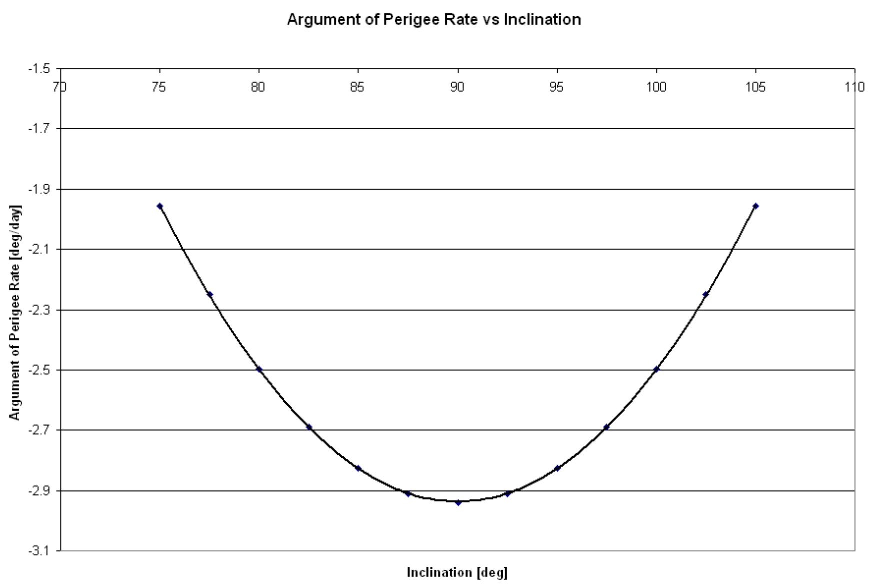
The PITO orbital configuration. Here imaging on PITO-1 images the volume measured *in-situ* by PITO-2.

Orbits

PITO's lines of apsides remain within 2 degrees of each other. The lines of apsides rotate at about 2.6 degrees per day. Thus the perigee-apogee combination covers the full range of latitudes (0 – 82 deg) about ten times per year.

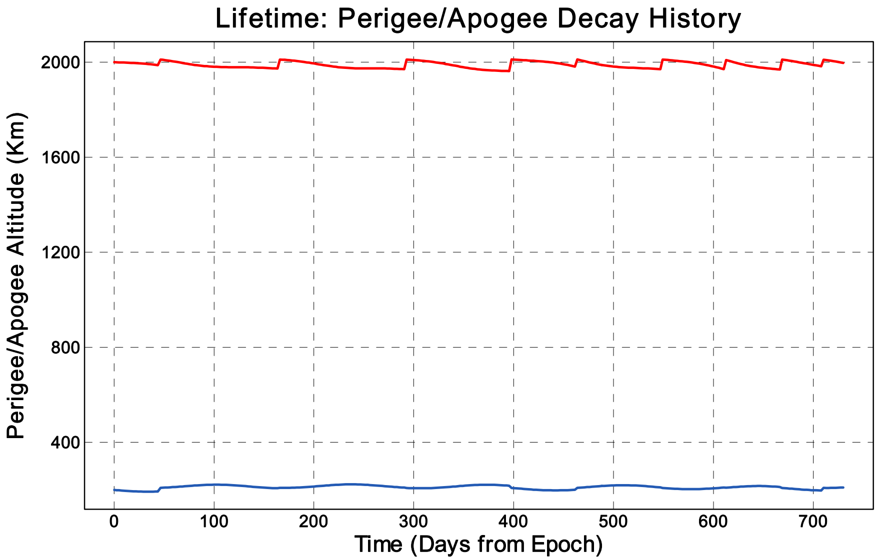


Alignment of lines of apsides.



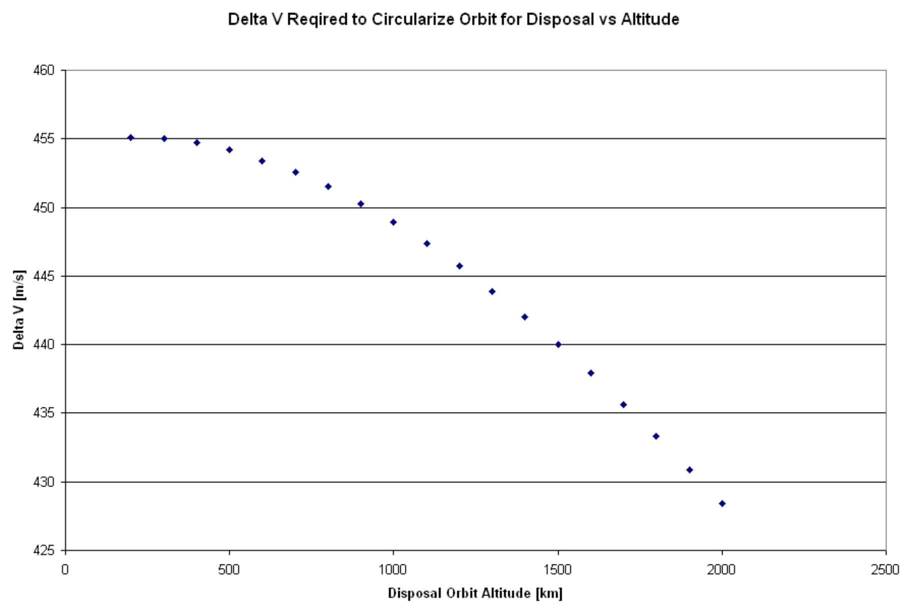
Variation of argument of perigee with inclination.

The PITO periapses stay within 10 km of its nominal orbit through the use of nine station-keeping maneuvers requiring a total of 88 m/s.



Perigee and apogee as a function of time

At the end of its prime mission, PITO goes to a circular orbit for disposal. About 450 m/s is required for an 800-km apogee (and perigee).



Amount of fuel needed to circularize to disposal orbit as a function of altitude.

Attitude determination and control

Requirements

- Pointing accuracy (3σ): 3 deg
- Attitude determination (3σ): 0.05 deg
- Slew rate: 0.36°/sec
- Jitter: TBD
- Boom stability: TBD

Design

- Requirements easily met by standard ADACS components.
- Standard reaction wheels work well
- Thruster-only system also would work
- Torquer-based system might also work
- Earth and Sun sensors could provide attitude determination accuracy
- Low-end star tracker easily achieves needed accuracy

	Component	# Units	Unit Mass (kg)	Mass (kg)	Unit Power (W)
TOTAL				**8.5**	
Reaction Wheels	Teldix 0.7 kg	4	0.7	2.8	4.0
Coarse Sun Sensors	Adcole 18394 2 deg	4	0.1	0.3	0.1
Star Tracker	Ball CT-633 6 arc sec	1	2.4	2.4	9.0
IMUs	Litton 1 - 10 deg/hr 0.04 - 0.1 deg/hr$^{0.5}$	1	0.7	0.7	10.0
GPS Receiver	Motorola Viceroy	1	1.3	1.3	4.8
ADACS Computer		1	1.0	1.0	10.0

ADACS componentry

Power system

Solar cell type	Multijunction	
Solar array type	Lightweight	
Solar array design / deployment	Body Mounted	
BOL inherent solar array degradation	0.77	%
EOL radiation degradation	0.845	
Solar array facesheet thickness	10	mil
Solar cell thickness	6	mil
Solar cell packing factor	0.909	
E-bar (efficiency factor)	1	
End-of-Life Required Solar Array Power	383.91	W
Solar Cell Performance Degradation	0.0024	%/year
EOL Solar Array Degradation	0.995	
Beginning-of-Life Required Solar Array Power	456.52	W
Solar Cell Efficiency	28.0%	%
Solar Array Area	6.20	m2
BOL Solar Array Provided Power	456.52	W
EOL Solar Array Provided Power	383.91	W
Number of panels for body mounted array	4.0	#
Solar array density	0.42	kg/m^2
Density factor for body mounted array	15.0%	%
Solar array mass	2.58	kg
Solar array deployment mass	0.00	kg

Bus Voltage	28	V
Maximum Load Power	234.8	W
Power Condition/ Regulation Mass	5.9	kg
Power Harness Mass	12.0	kg

Battery type	Li-ion	
Number of batteries	2	
Number of redundant batteries	0	
Number of redundant cells	2	
Battery voltage	28	V
Battery voltage regulated at	4	V
Maximum eclipse load	4.47	A-hr
Battery capacity required	29.81	A-hr
Battery capacity available	29.81	A-hr
Minimum battery voltage	24.80	V
Minimum number of required cells	9	9
Battery cell unit mass	0.47	kg
Battery unit mass	5.20	kg
Total Battery Mass	10.41	kg

Several other systems have been studied but not presented here due to space limitations:

- Propulsion system
- Command and data handling system
- Telemetry system
- Thermal system
- Structures
- Launch vehicle(s)

<u>Work in progress</u>

- Examine SV design impact of launching to circular 200 km park orbit and using onboard propulsion to raise apogee
- Trade apogee altitude vs. radiation dose vs. mission lifetime
- Investigate SV-to-Ground Comm opportunities and durations
- Examine dual manifest scenario
- Search NASA's Rapid Spacecraft Development Office (RSDO) catalog of suitable candidate commercial small satellite buses