Capsulation Satellite or CapSat:

A Low-Cost, Reliable, Rapid-Response Spacecraft Platform

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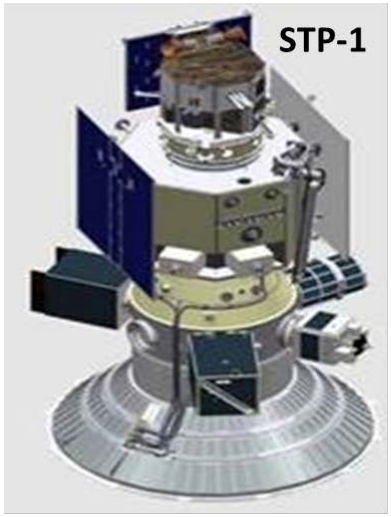
Goddard
Space Flight Center

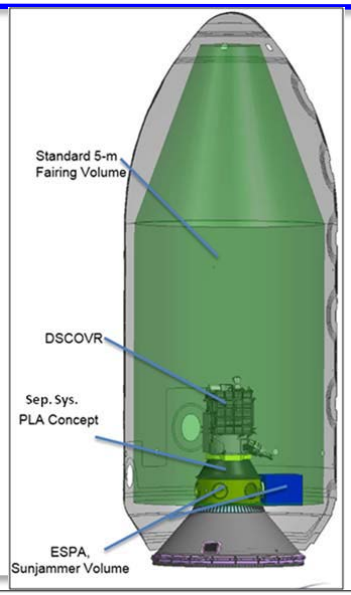
Problem Statement

- The National Aeronautics and Space Administration (NASA) Goddard's Rideshare Office estimates that between 2013 and 2022, NASA launches of primary satellites will have left unused more than 20,371 kilograms of excess capacity.

Goddard Rideshare Office

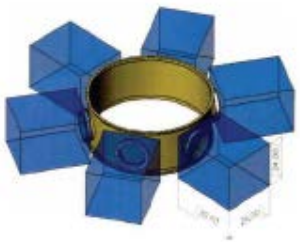


Air Force



NASA

Commercial



ESPA
200 kg

Some Potential NASA Rideshare Opportunities

Mission	Launch Date	Orbit	L/V	Mass (kg)	Excess Mass (kg)	No. of extra S/C
Landsat-8	Feb 2013	Sun Sync	Atlas 5		4400	
DSCOVR	Feb 2015	E-S L2	Falcon 9		2500	
TDRS-M	Oct 2017	GTO	*AV401*		271	
TESS	Dec 2017	TL1	Falcon 9		3000	
Landsat-9	Dec 2021	Polar	Delta IV		4400	
SWOT (JPL)	2021	Polar	TBD		TBD	
PACE	2022	Polar	AV401		5800	
TOTAL:					20,371	

ESPA Grande

24-inch Bolted
Interface (Four places)

Standard ESPA: 6 each 15” dia ports 180 kg/port 24”x24”x38”

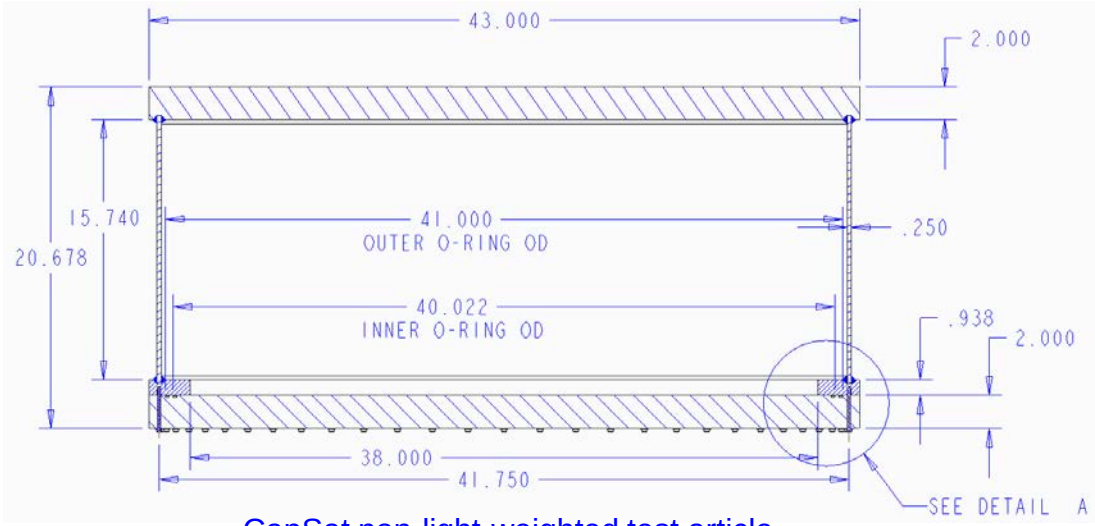
ESPA Grande : 4 each 24” dia ports 318 kg/port 42”x46”x56”

Historical Rideshare Data

Mission	L/V	Carrier	Launch Date	S/C Capacity	S/C Flown	Empty Slots
STP-1	Atlas 5	ESPA	March 2007	6	4	2
LCROSS	Atlas 5	Propulsive ESPA	June 2009	1	1	0
OG2- 1	Falcon 9	ESPA Grande (2ea)	July 2014	8	6	2
AFSPC-4	Delta IV	ESPA/ANGELS	July 2014	6	1	5
OG2-2	Falcon 9	ESPA Grande (3ea)	December 2015	12	11	1
AFSPC-6	Delta IV	ESPA	July 2016	6	0	6
			Total:	39	23	16

CapSat Solution

- Capsulation Satellite or CapSat is a low cost, 3 axis stabilized, modularized and standardized spacecraft, based on a pressurized volume with active thermal control allowing ruggedized COTS hardware to be flown reliably in space.
- CapSat takes advantage of unused launch vehicle mass to orbit capabilities via the USAF Ride Share program; being specifically designed to mate to an ESPA Grande Ring.
- Capacity goes unused in large part do to cost. Typical CubeSat's are still nearly $1M/kg. A single CapSat can provide over 300kg of on-orbit mass at a cost 20 times cheaper; ~$50K/kg.
- CapSat achieves this by leveraging proven SmallSat and CubeSat hardware combined with decades of GSFC software heritage in the cFS-Core Flight System and ITOS-Integrated Test & Operations System.



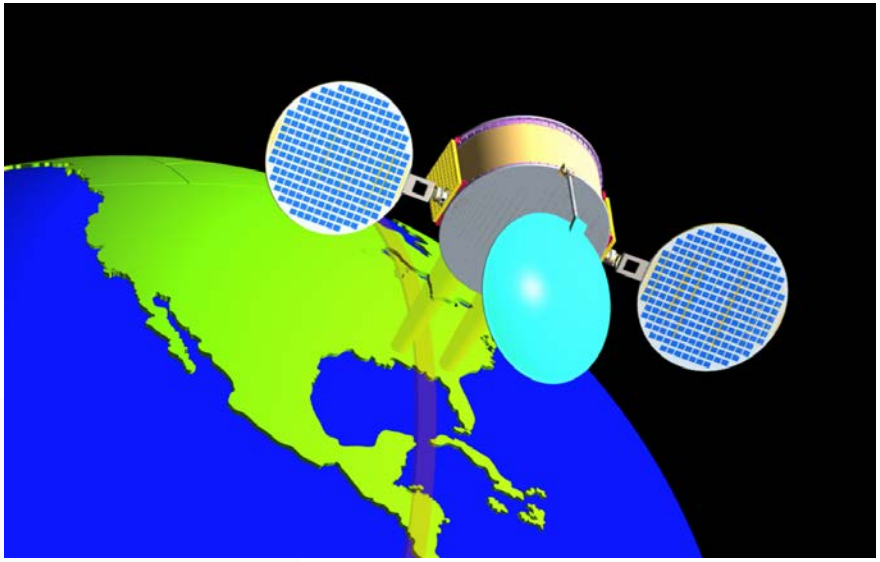
CapSat non-light-weighted test article
Dimensions in inches

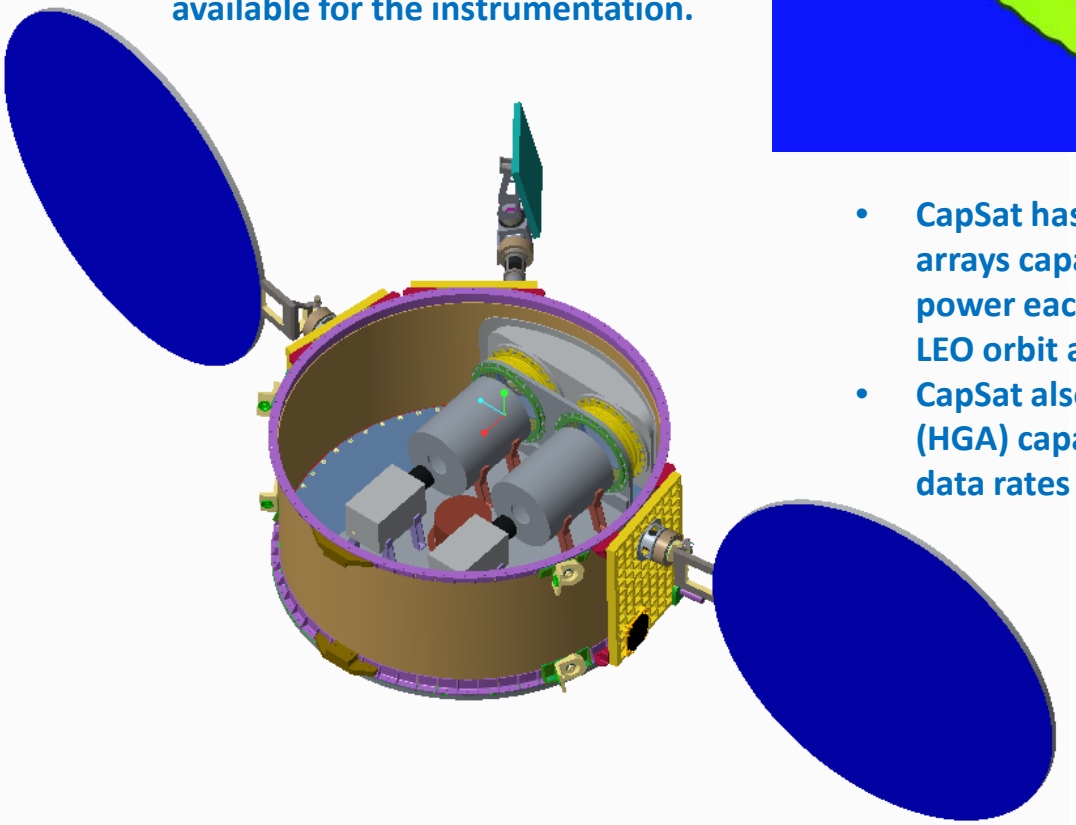
- NASA's Hitchhiker program, which began in 1984 and ended in 2003, flew hundreds of successful experiments, many with a pressurized volume called a Get Away Special (GAS) can. Commercial-off-the-shelf or COTs electronics — almost all worked successfully — were placed inside these GAS cans.

CapSat ESTO Mid-Term Lab

Capsat Dual Viewport Arrangement

- CapSat is a hockey puck-shaped spacecraft bus that measures approximately 40 inches in diameter and 20 inches in height. Its mass is approximately 300 kilograms, with more than 100 kilograms and 100 watts available for the instrumentation.

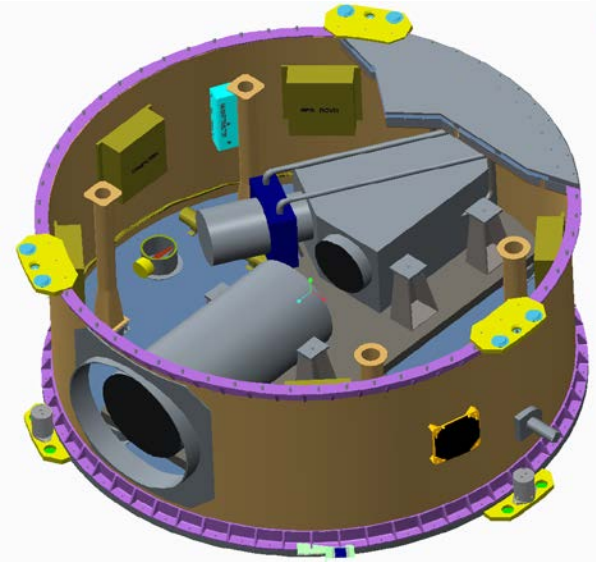


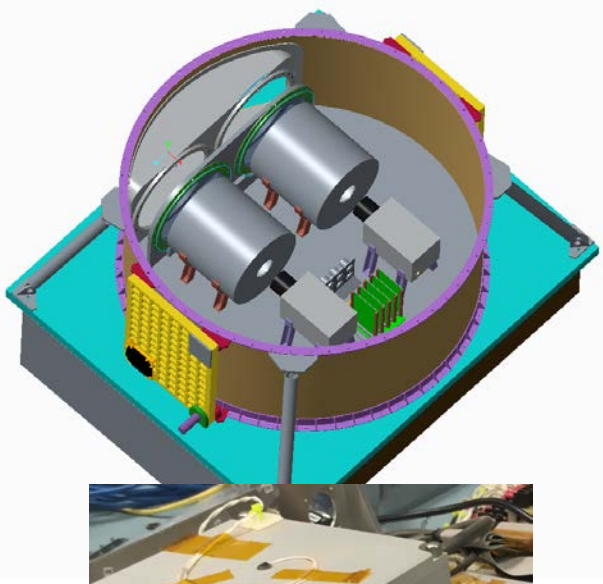


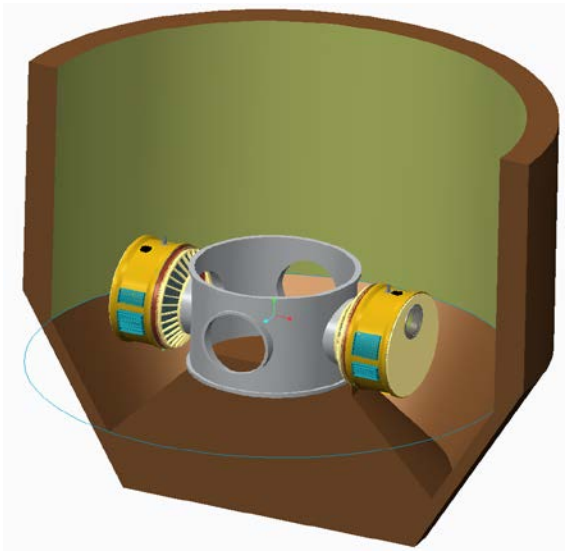
- CapSat has two 0.78 square meter solar arrays capable of producing 138 watts of power each for a total of 276 watts and a LEO orbit average power of 135 watts.
- CapSat also has a 1-meter high gain antenna (HGA) capable of producing X-band downlink data rates in excess of 400 Mbps

CapSat Avionics

- CapSat will take advantage of a pressurized volume for both the spacecraft and the payload.
- Highly capable commercial- and military-quality instrumentation systems designed for aviation and other purposes are readily available for thousands of dollars. CapSat utilized such a system in its development unit in 2016.



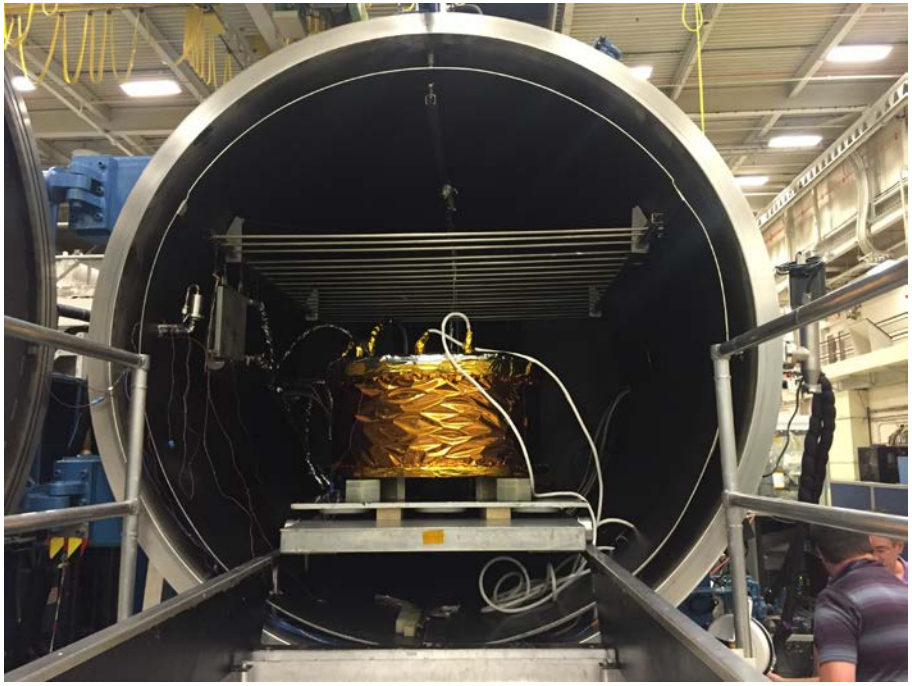


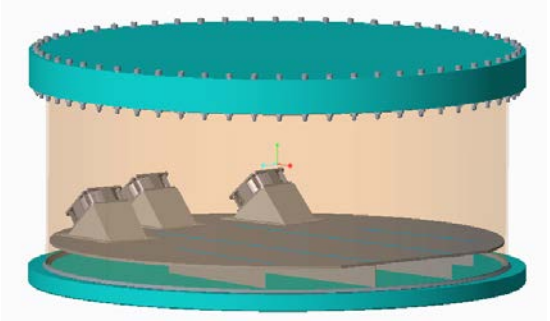


Thermal Accomplishments

Goddard Space Flight Center

- The CapSat thermal design relies on multiple fans and a particular arrangement of hot and cold wells (under review for patent) to achieve an active thermal-control system.
- This system will provide better thermal control for the onboard electronics — even while flying through low-earth orbit (LEO) eclipses — than they might see in a terrestrial lab during diurnal fluctuations.

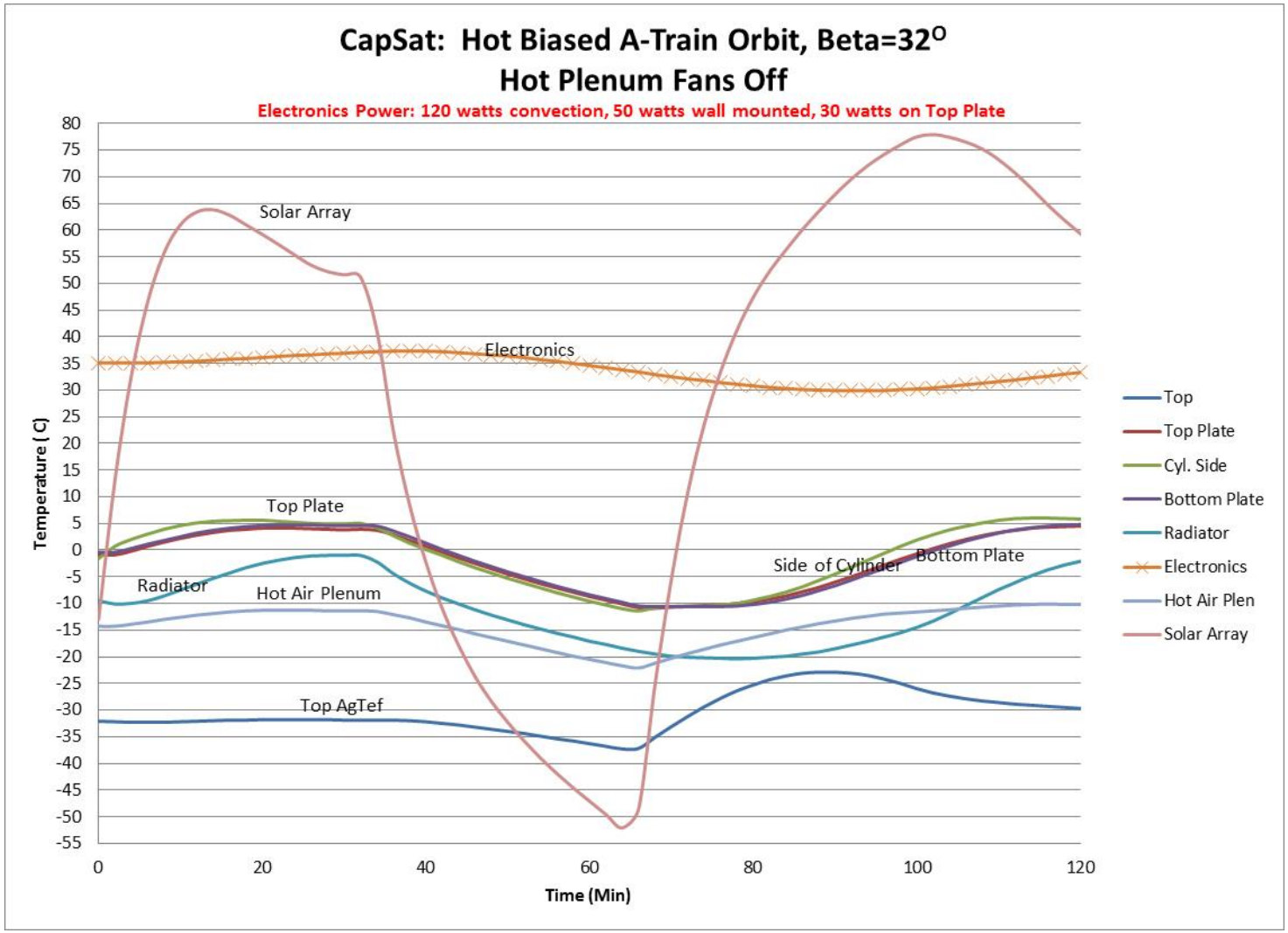


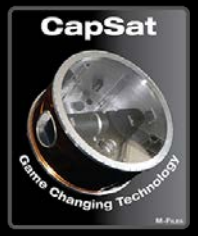


- Thermal model for CapSat with airflow was created in TSS and SINDA-Multiple cases, multiple modes
- Fans were selected and tested for flow rates Thermal mass models were fabricated
- Heaters, thermistors and control systems were designed and fabricated.
- Room temperature ambient testing as well as full thermal vacuum testing was performed.
- Data was collected and models were correlated

Thermal Accomplishments

Goddard Space Flight Center





Ruggedizing & Radiation

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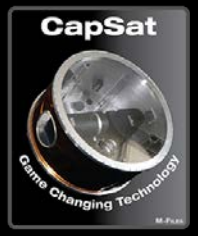
- Ruggedizing a payload may include the following:
  - removing things like connectors, moving parts, switches, etc. and replacing them with flight quality hand soldered parts and direct wiring.
  - Adding stiffeners and brackets to electronics boards
  - Adding EMI and/or radiation shielding.

- Total dose levels for LEO orbits are manageable with reasonable parts selection and shielding.
- CapSat has significant aluminum structure in all directions providing inherent shielding plus plenty of additional mass available for localized shielding as needed.
- Single event upset and latch up events will need to be addressed separately.
  - A robust watchdog timing and reset system will need to be employed. Fortunately, the cFS software system is well designed for this.
- Parts selection may not always be an option, however, many commercial parts are capable for LEO.
  - Parts with unknown capabilities require testing or incur additional risk.
  - Known outliers can be replaced or shielded.



Flight & Ground Software

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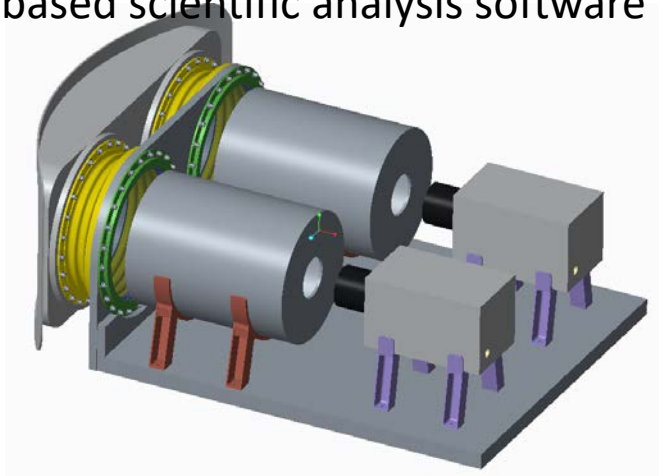
- CapSat will use the NASA GSFC's Core Flight System. For decades Goddard has delivered flight software to its satellite builds. In 2005 a system for reuse was developed called the core Flight System or cFS. Developed at NASA GSFC with heritage from SMEX and MIDEX missions (SAMPEX, SWAS, TRACE, WIRE, DSCOVR, Swift, RXTE, TRMM, WMAP, SDO) and used on these GSFC missions LRO, GPM, MMS, LADEE, RBSP, Morpheus, Solar Probe Plus, and more. This software is available open source.

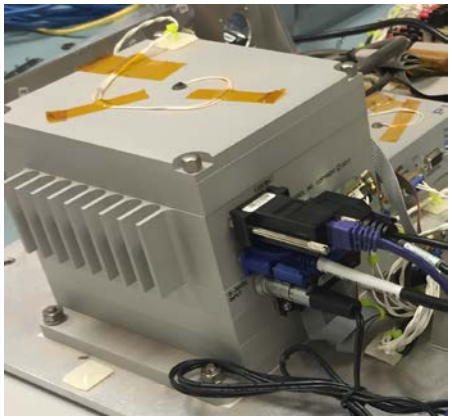
- In addition to the heritage flight software CapSat will also use the Integrated Test & Operations System (ITOS) ground system software. ITOS builds of heritage going back to the small explorer missions in 1990. ITOS is now available commercially. ITOS supports from board and box development all the way through to on orbit mission operations.

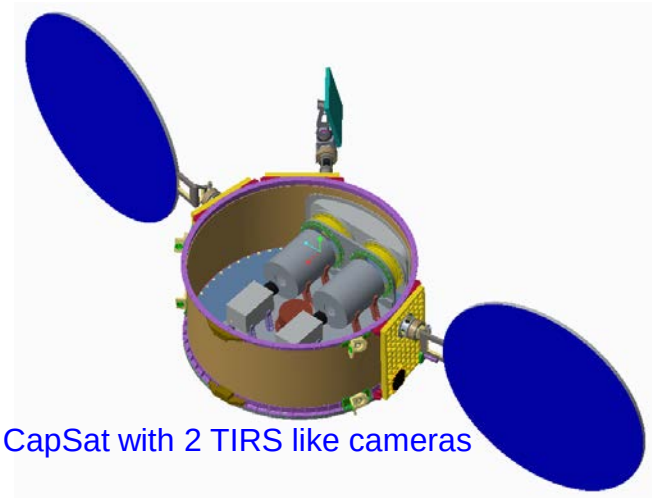
- To be even more compatible with lab instruments a version of Microsoft Windows was also incorporated into the flight computing system. All of the command and telemetry handling, time tagging, command verification, etc. is handled by the cFS. Windows is able to run separately in such a manner that if it hangs up the spacecraft bus remains unaffected.

Strained-Layer Superlattice Infrared Detector Camera

- The ESTO funded Strained-Layer Superlattice Infrared Detector Camera also known as SLS was integrated into CapSat. The SLS camera was relocated to the inside of a CapSat and connected via Ethernet to the flight computer running a version of windows as well as the core Flight Executive (cFE) from cFS. Commands for the camera were created using the original vendor provided lab software running in the Windows environment on a laptop that acted as the Science Operations Center (SOC). These commands including mouse strokes were captured and sent via ITOS to the onboard computer where they were converted back to the same inputs to another copy of the vendor supplied windows software and executed onboard by the camera residing in CapSat. The image data was captured and returned to the ITOS ground system and then analyzed via the windows based scientific analysis software from NIST.



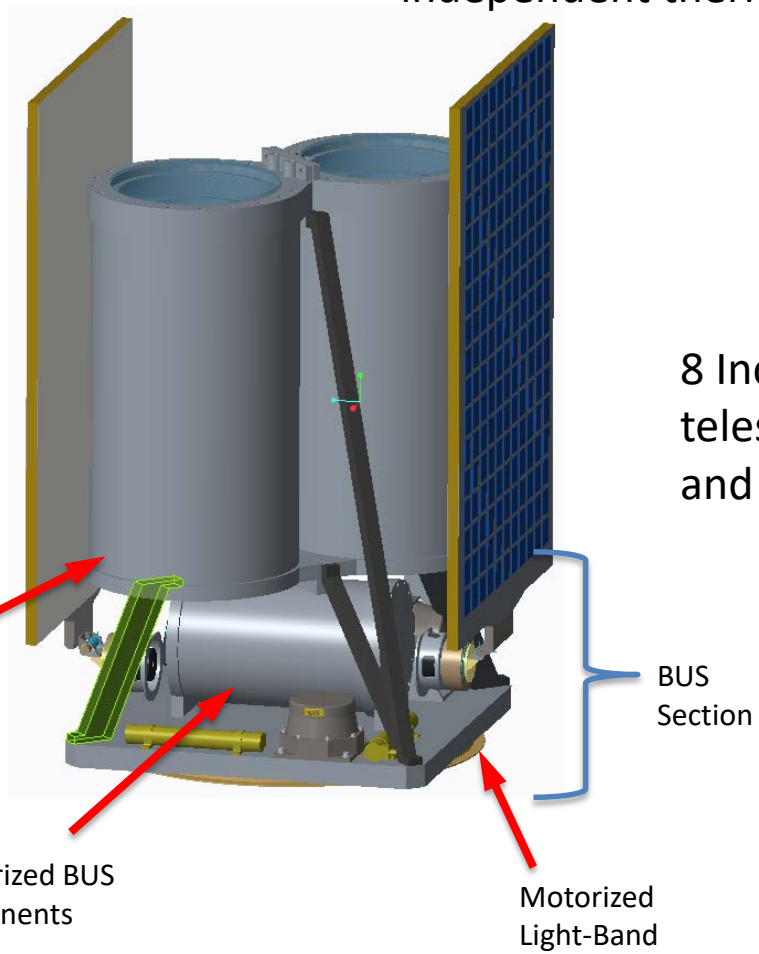




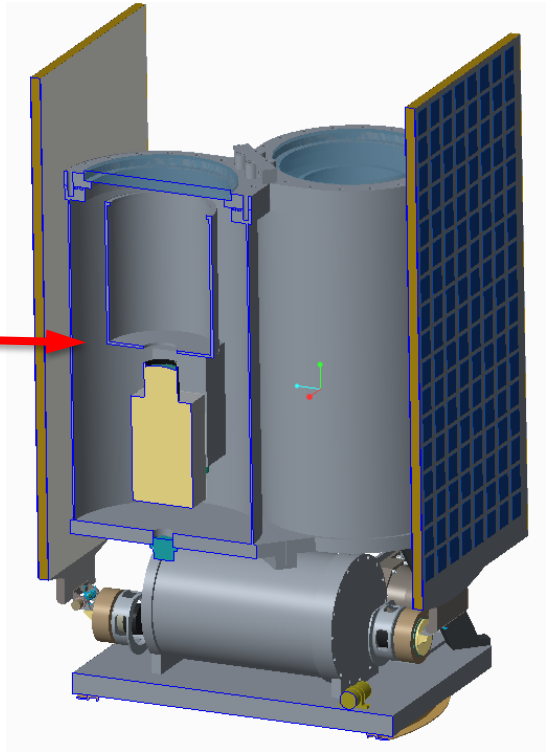
CapSat with 2 TIRS like cameras

CapSIT: CapSat Science Instrument Tube

Open architecture allows for easy I&T and independent thermal design



8 Inch telescope and camera



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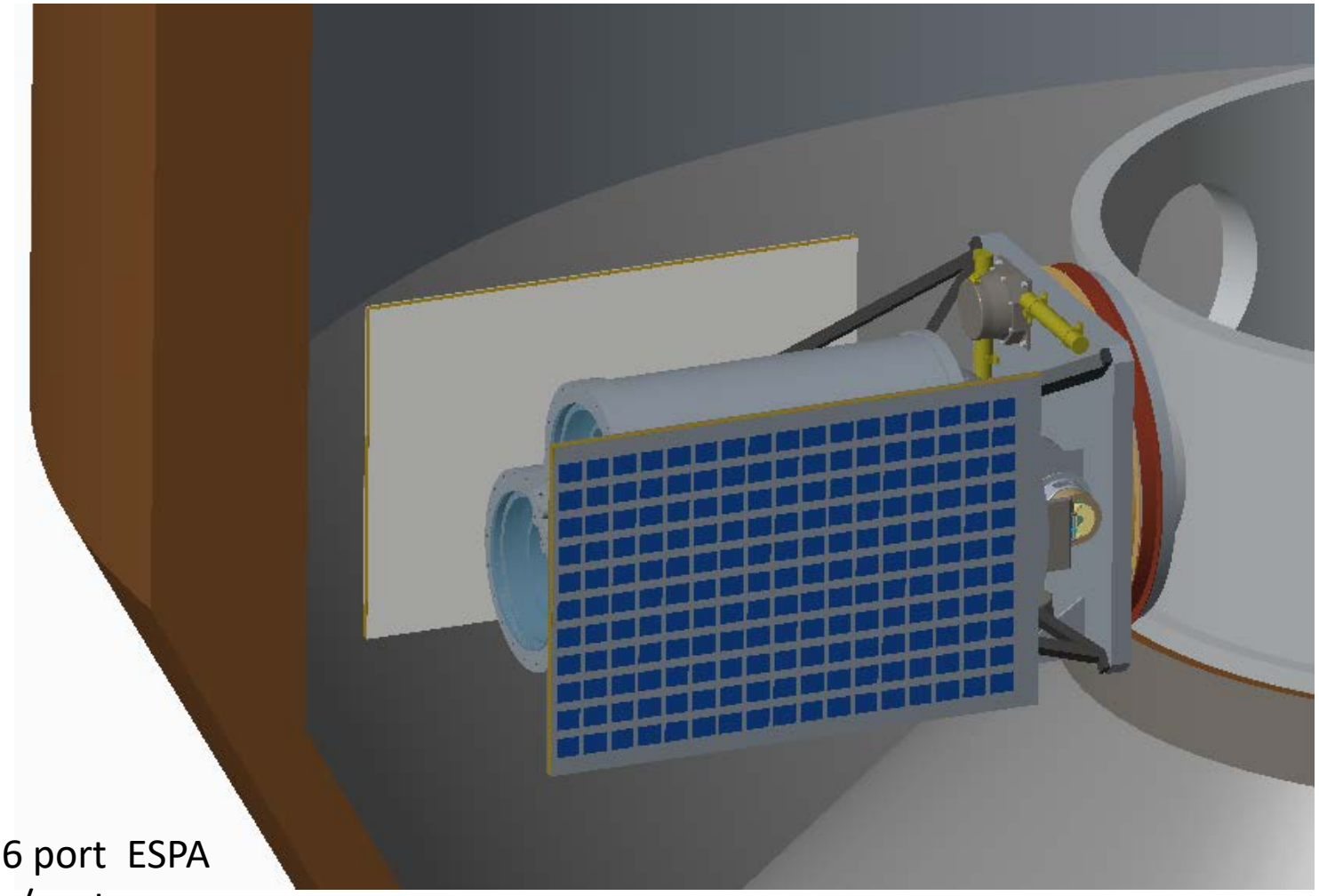
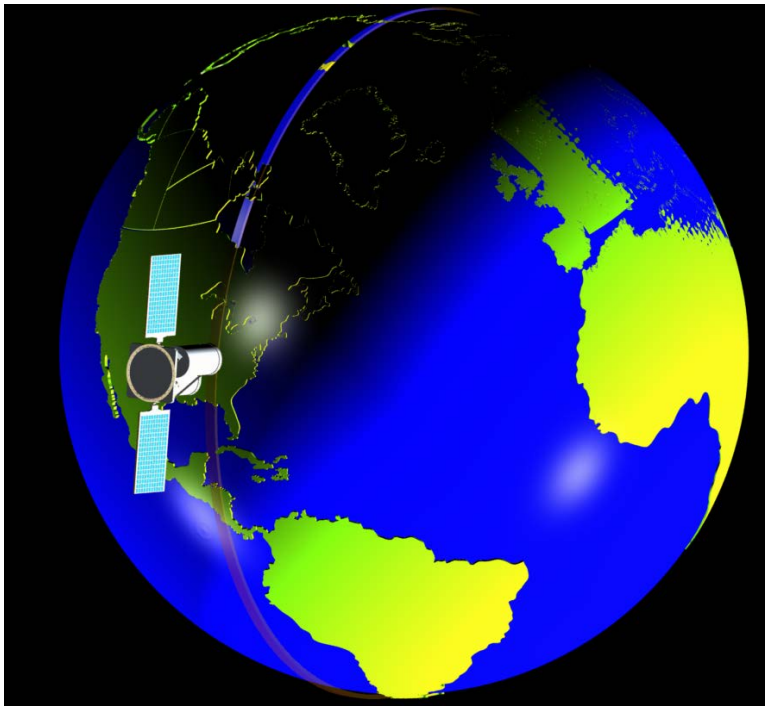
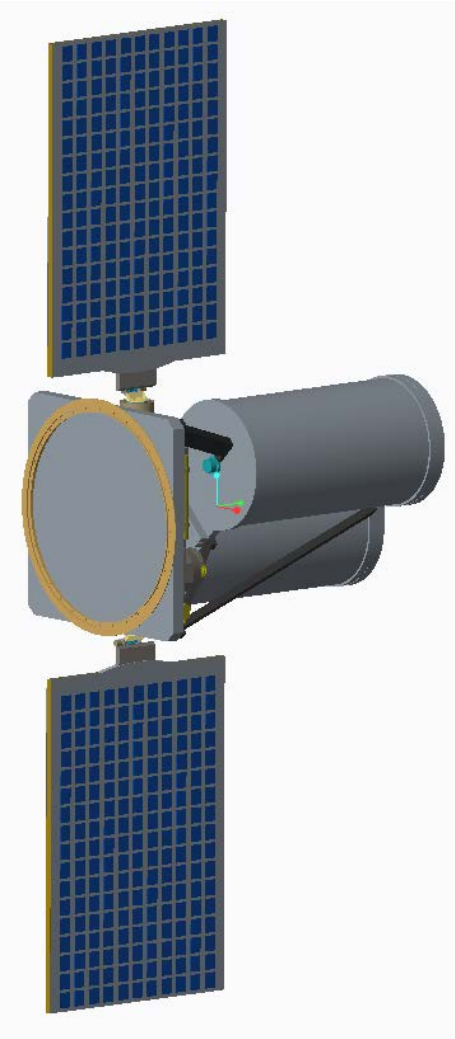


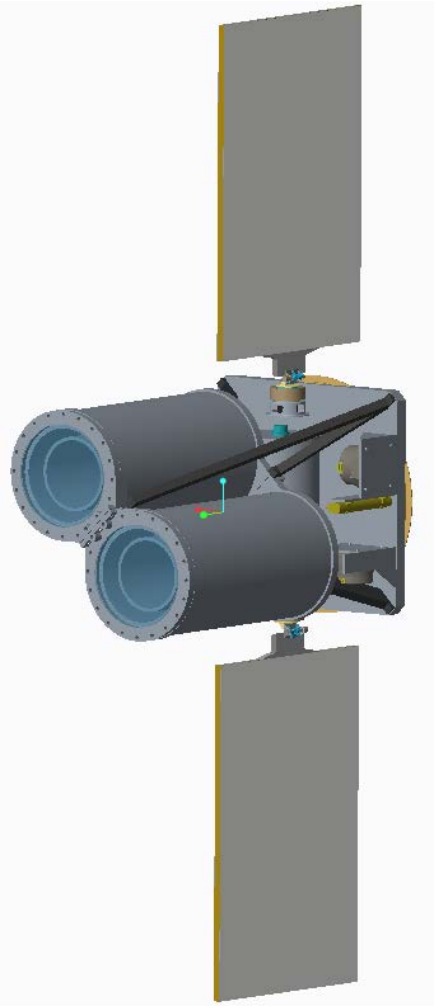
- Fits a 6 port ESPA
- 180 kg/port

CapSIT: CapSat Science Instrument Tube



Solar Arrays oriented for a 6 AM sun synchronous orbit





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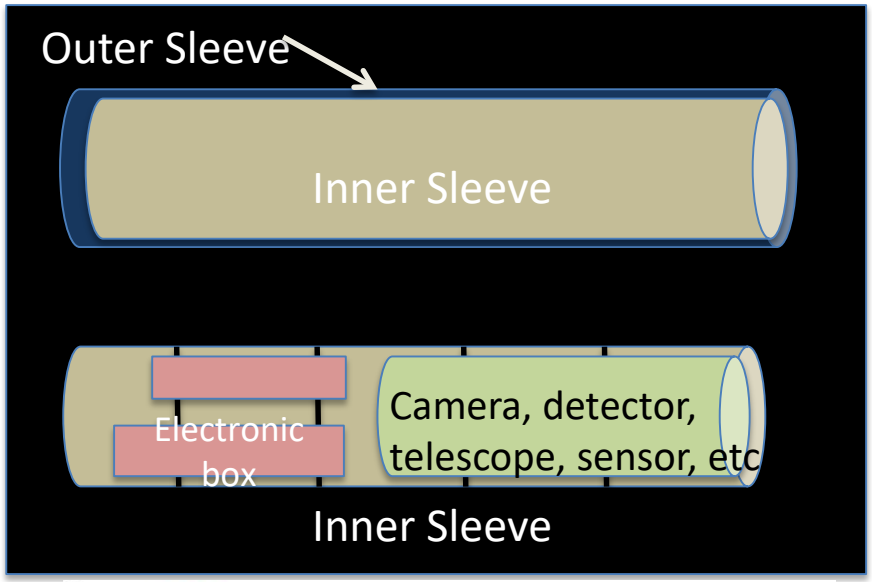
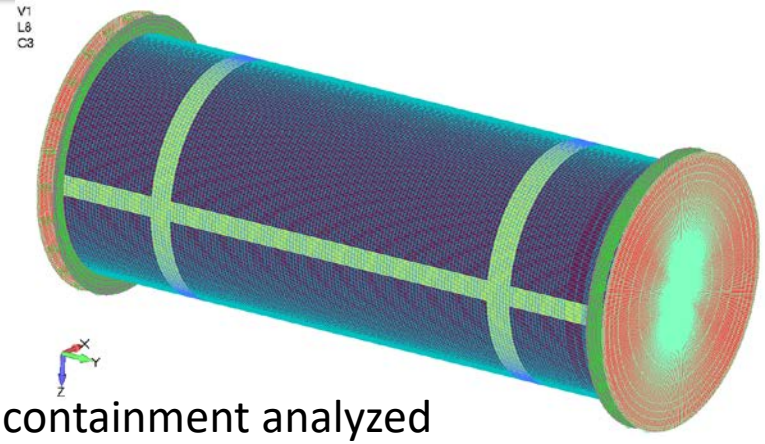




containment analyzed

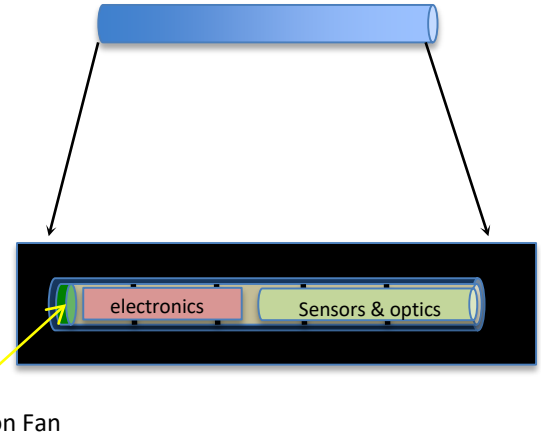
- Tube is 60 cm x 30 cm
- 17.5 kg inside tube mass
- Tube is prequalified so CapSIT can be qualified for flight w/o a thermal vacuum chamber
- Inner sleeve can be drilled and screwed into to hold an assortment of components while the outer sleeve maintains pressure wall integrity

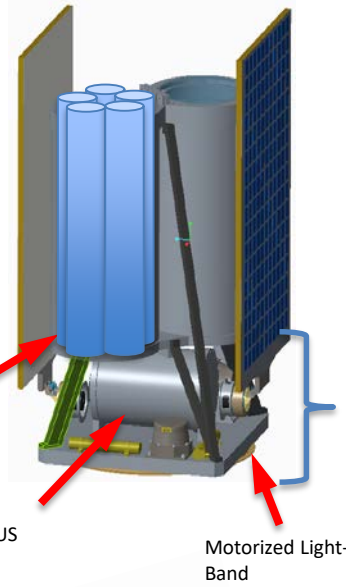
CapSat Science Instrument Tube: CapSIT

CapSIT mini-tubes

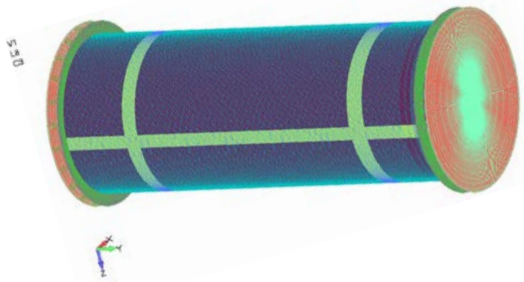
An 6U class pressurized instrument accommodation.
All spacecraft functions are provided external to the 6U mini-tube.
Including pointing, power, data storage and communications.

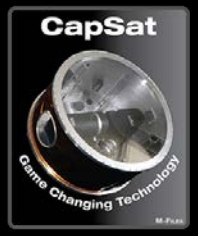
10 cm diameter
80 cm tall
~6 U equivalent
8 kg internal
11 kg total
55 kg bundle of 5





5 mini tubes ≅ 1 CapSIT tube





CapSat- DRAGONS

Goddard Space Flight Center

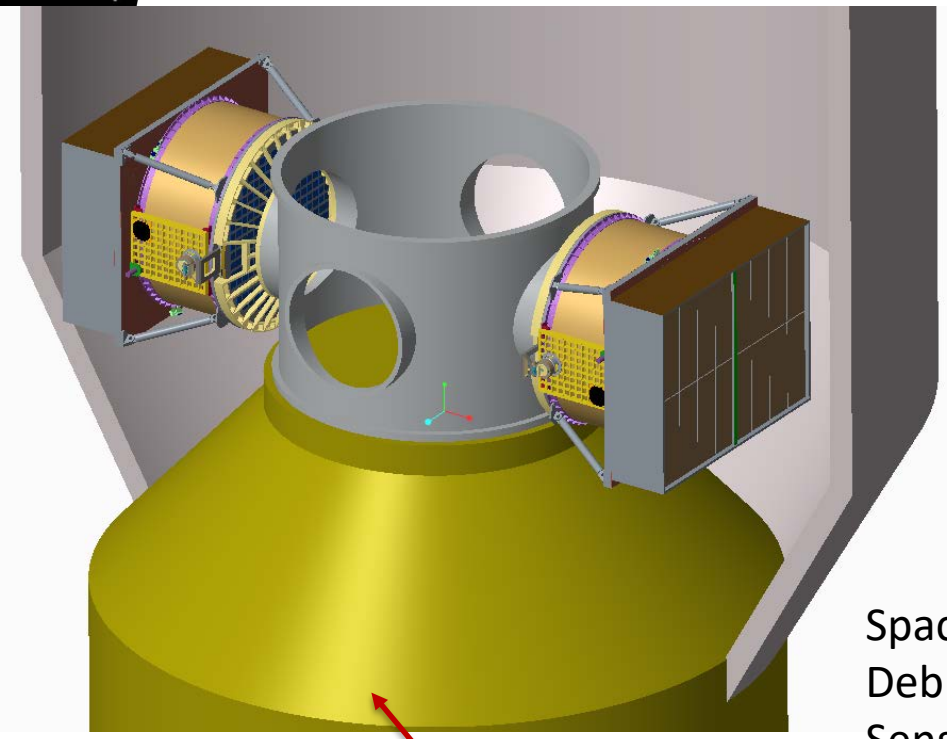
- The sensor is called DRAGONS, short for Debris Resistive Acoustic Grid Orbital Navy-NASA Sensor. The NASA Orbital Debris Program Office at the Johnson Space Center is managing the project. DRAGONS is scheduled to fly on the ISS in 2018. However, several NASA earth science spacecraft, threatened by orbital debris, are flying in the so-called A-Train orbit between 700-1000 kilometers above Earth. This is where NASA would like to deploy new sensors potentially via CapSat.

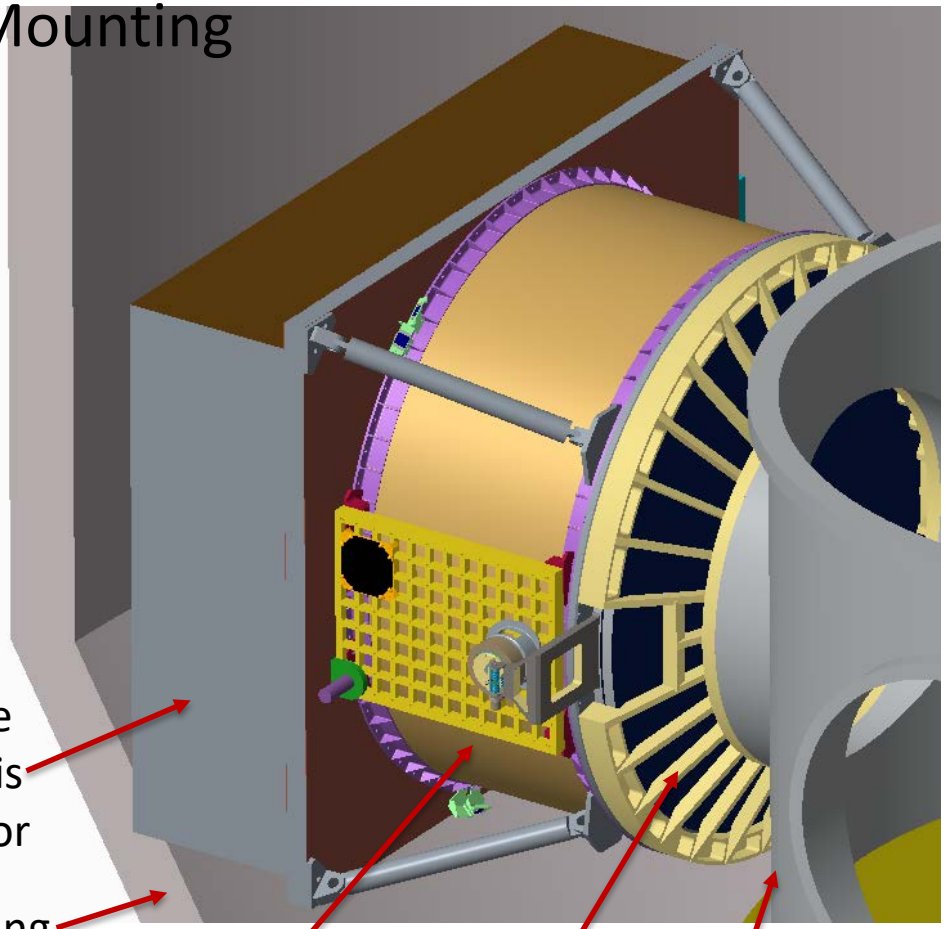
- While a pressurized spacecraft volume is not required for this type of sensor, CapSat will make available a pressurized volume for the sensor electronics. This will maximize the options for the use of lower-cost COTS devices while providing an enhanced thermally stable on-orbit environment to promote longevity.

CapSat-DRAGONS Configuration

Capsat - Orbital Debris Configuration

ESPA/Falcon-9 Mounting





Space Debris Sensor

Fairing

Stage Vehicle

Capsat

ESPA to Capsat Adapter

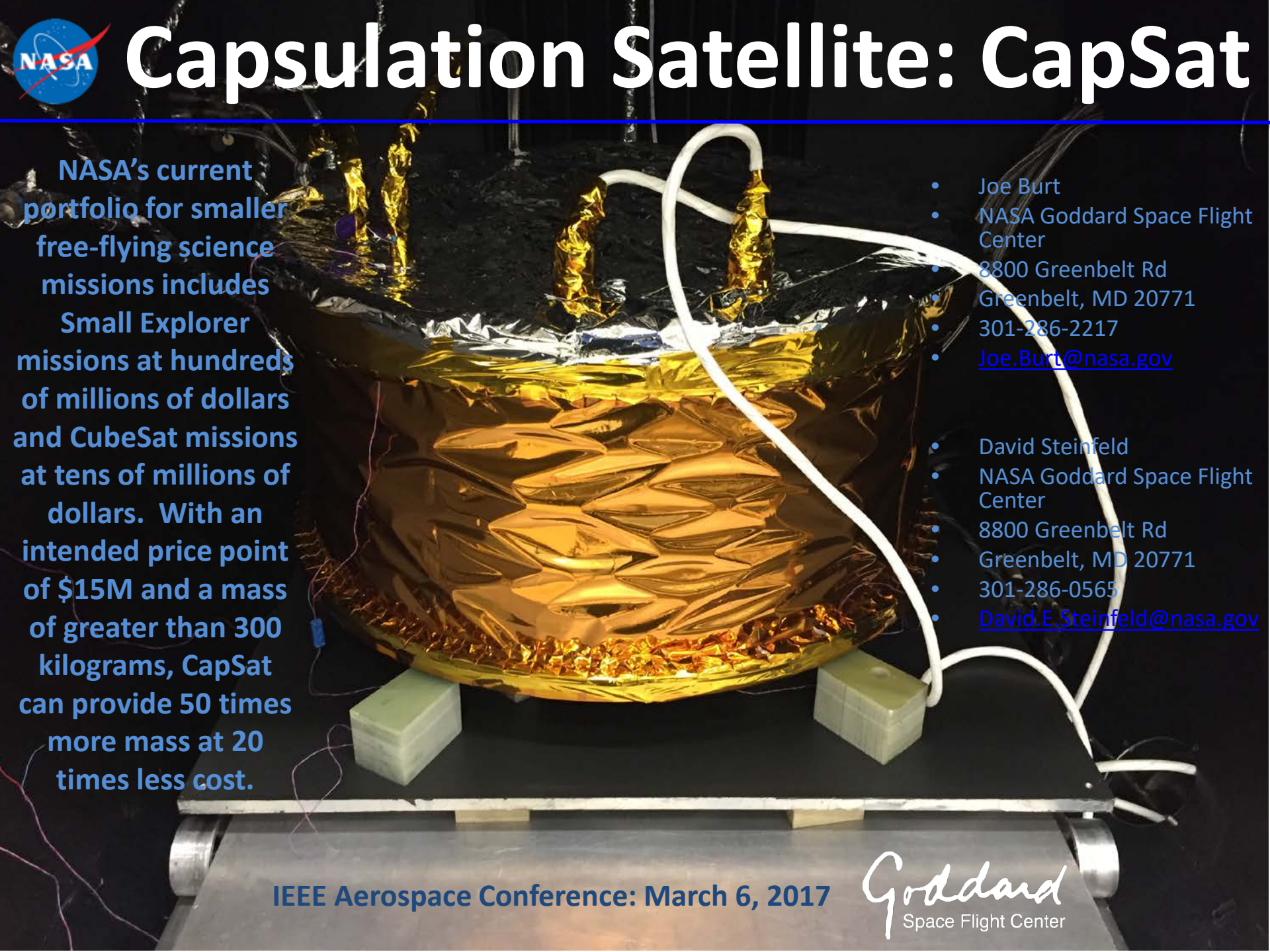
ESPA Grade

CapSat & CapSIT

- Imagine going into the lab and creating new measurement systems with readily available COTS hardware and then simply repackaging and ruggedizing them for flight using the same software that was used in the lab. This could all be completed without the long lead times and costs associated with traditional spaceflight hardware.

- This is the true power of the Capsulation Satellite concept. Whether in the CapSat or CapSIT form, it is the ability to conduct significant science, comparable to a single instrument on a full-sized satellite or a dedicated SmallSat, at a price that is more comparable to that of a CubeSat mission.

Capsulation Satellite: CapSat



NASA's current portfolio for smaller free-flying science missions includes Small Explorer missions at hundreds of millions of dollars and CubeSat missions at tens of millions of dollars. With an intended price point of $15M and a mass of greater than 300 kilograms, CapSat can provide 50 times more mass at 20 times less cost.

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