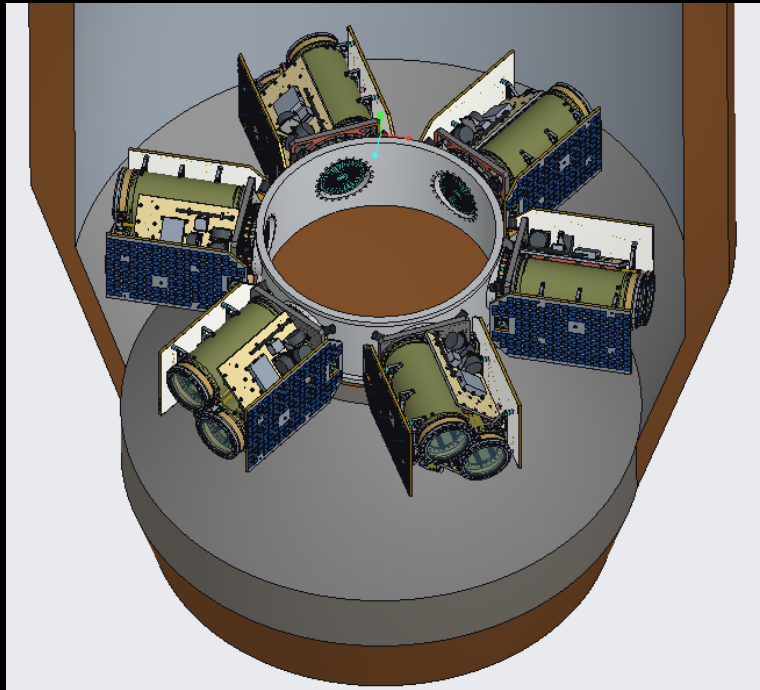


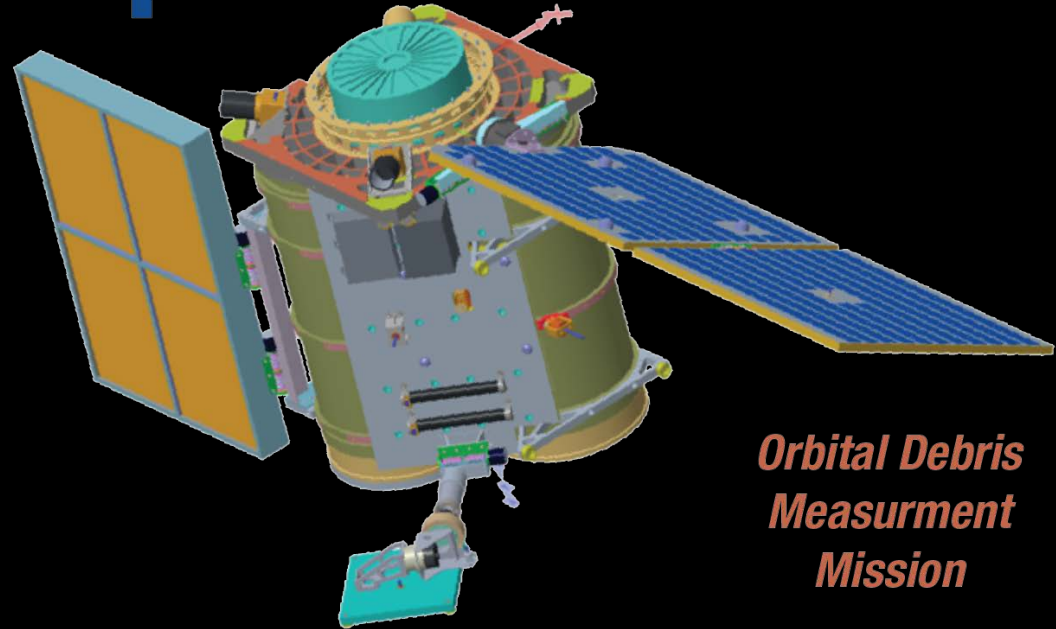


Capsulation Satellite: CapSat

21st Annual Small Payload Rideshare Symposium



CapSat-DRAGONS



*Orbital Debris
Measurement
Mission*

NASA • GSFC • JSC • MSFC

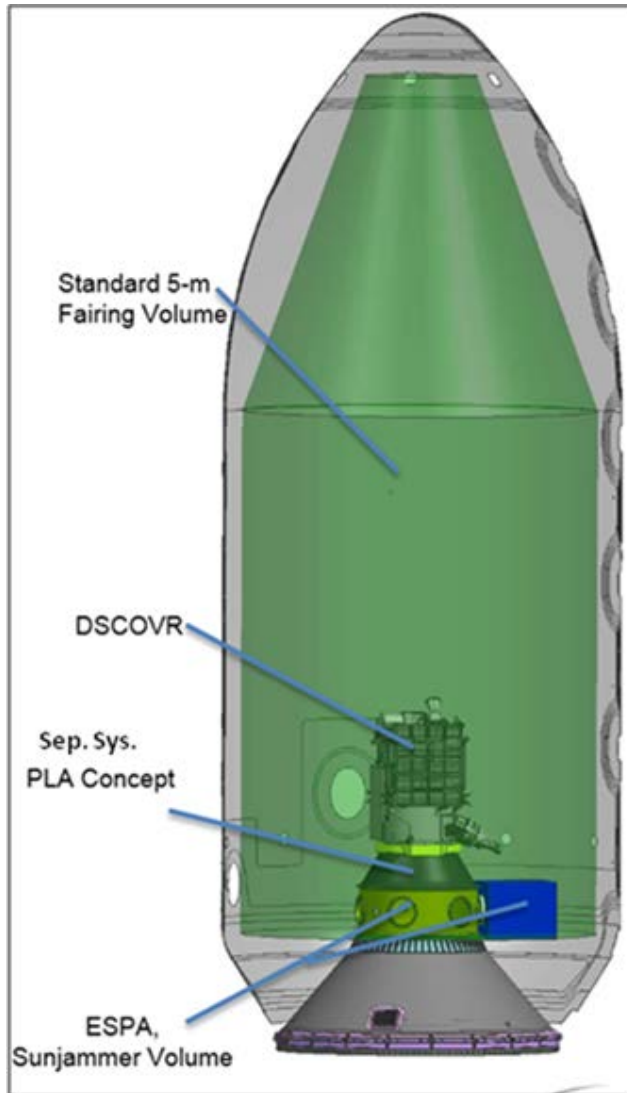
Joe Burt

June 5, 2019

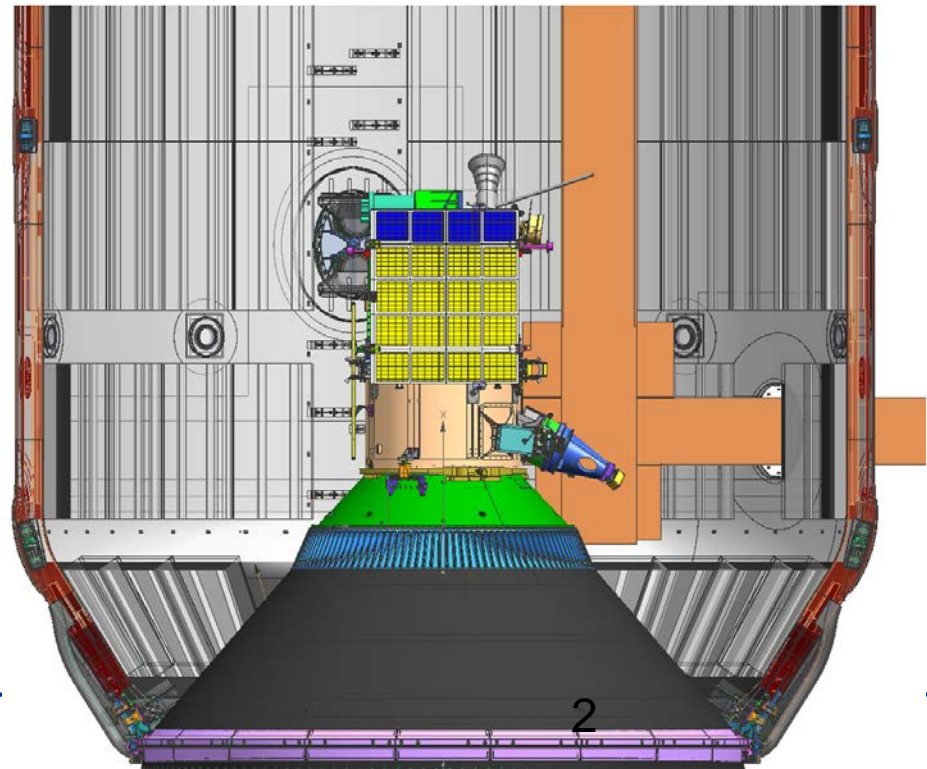
Goddard
Space Flight Center



Exhibit One : Falcon 9 Launch of DSCOVR



- DSCOVR launched February 11, 2015
- 2500 kg of unused mass went to L-1
- And just a little bit of unused volume
- NASA had a secondary payload on an ESPA ring but it was cancelled.
- Falcon 9 capability to LEO is ~15,000 kg and ~3500kg to escape velocity



Rideshare / ESPA Heritage: Capacity v. Flown

... the lost opportunity of empty slots



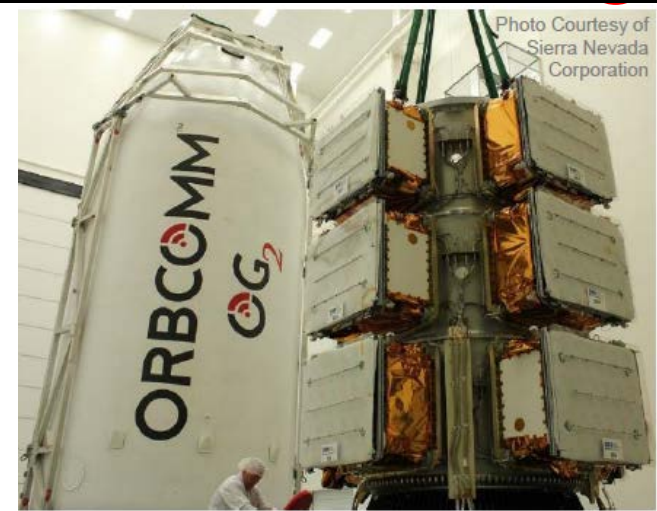
Mission	L/V	Carrier	Launch Date	S/C Capacity	S/C Flown	Empty Slots
STP-1	Atlas 5	ESPA	March 2007	6	4	2
LCROSS	Atlas 5	Propulsive ESPA	June 2009	1	1	0
OG2- 1	Falcon 9	ESPA Grande (2ea)	July 2014	8	6	2
AFSPC-4	Delta IV	ESPA/ANGELS	July 2014	6	1	5
OG2-2	Falcon 9	ESPA Grande (3ea)	December 2015	12	11	1
AFSPC-6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



STP-1



LCROSS



OG2-2

Photo Courtesy of Sierra Nevada Corporation



NASA Missions That Could Support Rideshare

Candidate Primary Mission	Launch Date	Orbit	Rideshare Adapter	# Rideshare Spacecraft	Rideshare Mass (kg)
Sentinel-6 (JPL)	11/2020	Polar, Cir.	ESPA Ring	6	2,057
Restore-L	11/2020	Polar	ESPA Ring	6	2,057
Landsat-9	12/2020	Polar, Cir.	ESPA Ring	6	2,057
SWOT (JPL)	4/2021	Polar, Cir.	ESPA Ring	6	2,057
LUCY (GSFC)	2021	Earth Esc.	ESPA Ring *	6	2,057
JPSS-2	7/2021	Polar, Cir.	ESPA Ring	6	2,057
PSYCHE	2022	Earth Esc.	ESPA Ring *	6	2,057
PACE	2022/23	Polar, SSO	ESPA Ring + ESPA Grande	10	4,068
IMAP	12/2024	L-1	ESPA Grande	5	2,461
New Front-4	2024	TBD	ESPA Ring *	6	2,057
GDC	2025	TBD	ESPA Ring *	6	
EVM-3	2026	Polar, Cir?	ESPA Ring *	6	2,057
JPSS-3	2026	Polar, Cir.	ESPA Ring *	6	2,057
Landsat-9	2026	Polar, Cir.	ESPA Ring *	6	2,057
Sentinel-6b	2026	Polar, Cir.	ESPA Ring *	6	2,057
Discover-15	2026	TBD	ESPA Ring *	6	2,057
Total:				81	33,270



Right-sizing the technical endeavor

Now that there's more mass available than dollars to pay for it. Missions can be right-sized primarily for cost.

Small doesn't always equate to low cost. CubeSat's can still average ~\$1M/kg not unlike full size spacecraft.

Note: use of contributions, student labor, etc. can drive these cost significantly down but robust science CubeSat's are still not cheap per kg.

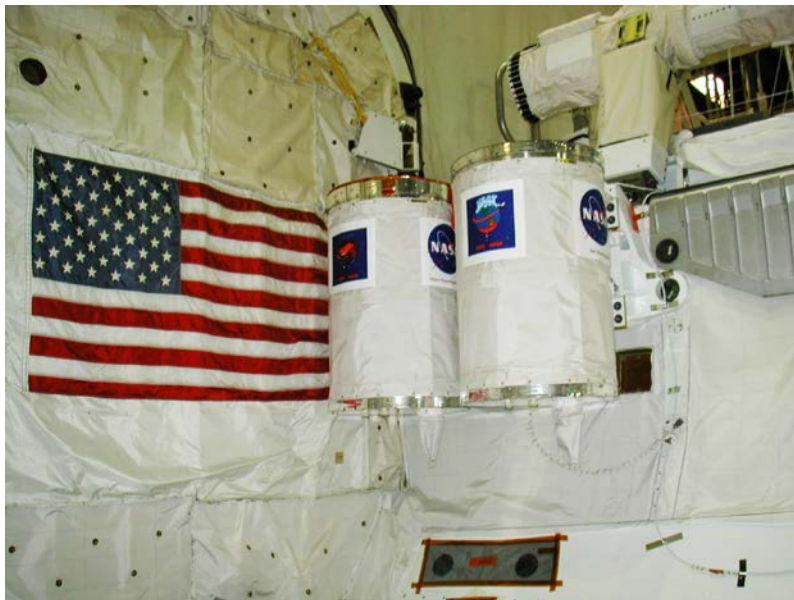


A good watch often cost more than a small clock.



Last time NASA had this much extra mass they created the Hitchhiker Program

CapSat builds on NASA's tradition of Hitchhiker Get Away Special-GAS Cans that flew on the shuttle. Hitchhiker flew over 200 missions over 2 decades managed out of Goddard Space Flight Center. CapSIT allows independent development of instruments and spacecraft decoupling funding, contracts and science. "If it fits, it flies!" and when its ready it can go. Interchangeable tubes allow slipping and leapfrogging of instruments and substitution of a dummy mass if needed to insure no impacts to the primary mission launch date.



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.



Unified Formfactor

- **Hitchhiker and CubeSats share a common thread; a unified formfactor.**
 - **There are no 6½ U CubeSat launchers or Can and ½ Get Away Specials.**
- **It is the common formfactor that allows interchangeability and separation of build schedules and decoupling of funding- that builds broad success.**
- **A common formfactor leads to increased reliability through refinements while not mandating completely fixed interfaces.**
- **CapSAT has two form factors**
 1. **The first being the Spacecraft formfactor as specified in the USAF Rideshare User's Guide for a 180kg, 15" diameter ESPA attached payload. This is a formfactor that many have built buses for already.**
 2. **The second is the new instrument formfactor for the CapSIT- CapSat Science Instrument Tube.**



Standardizing the instrument interfaces

- **Standardizing the instrument interfaces makes instruments interchangeable**
 - This is a major paradigm shift in and of itself
 - Given a maximum mass, maximum power, maximum volume and a CG location range plus a standard data interface including software, (ie. Mil-Std-1553, USB, Spacewire, 422, Ethernet ,etc)
 - Tubes can be placed in an assortment of tube carrying spacecraft which will then be programmed for pointing and observing requirements
- **True separation of instrument and spacecraft design and build**
 - Schedules are completely decoupled. Instruments can be integrated at the at the launch site.
 - AO's can go out for instrument tubes and separate contracts for tube carriers can be managed on IDIQ contracts.
 - Spacecraft can be bought in bulk and repurposed at the launch site as needed.
 - The requirement for mass simulators will be reduced to instrument tubes and a supply of viable instruments will all but eliminate the need to fly a mass simulator.

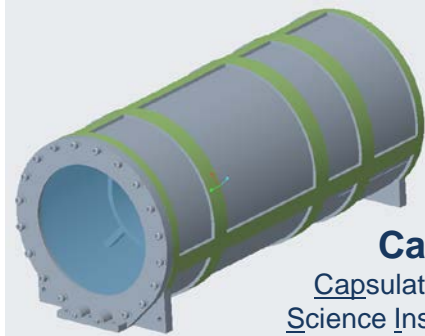
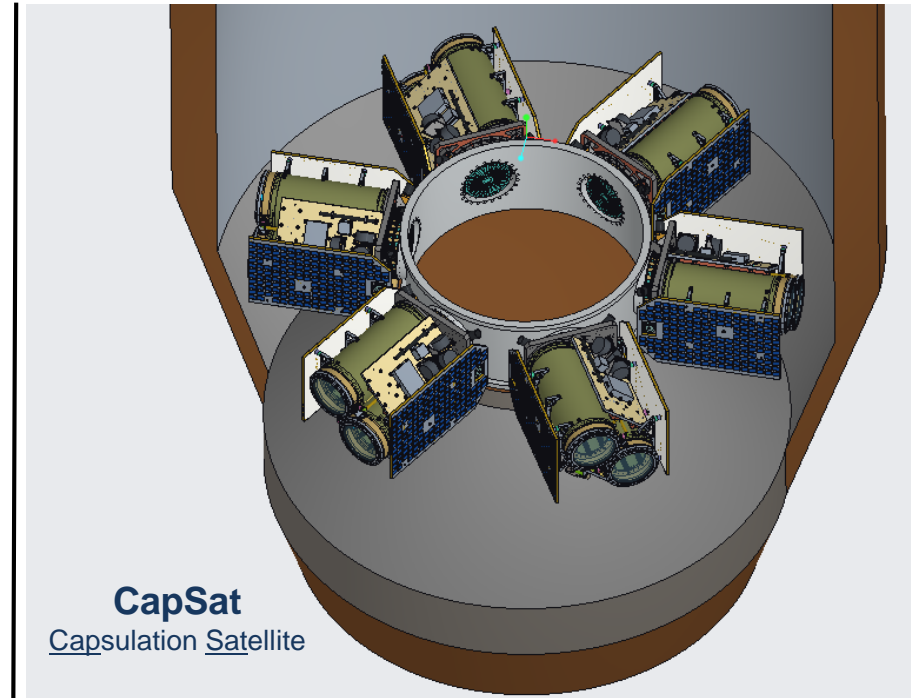


CapSat-Capsulation Satellite

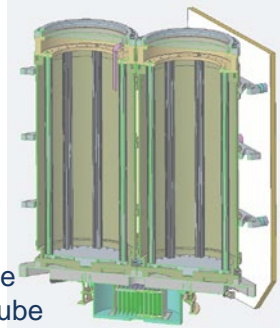
ESPA Class Spacecraft taking advantage of unused launch vehicle mass to orbit

- **Mission Description:**

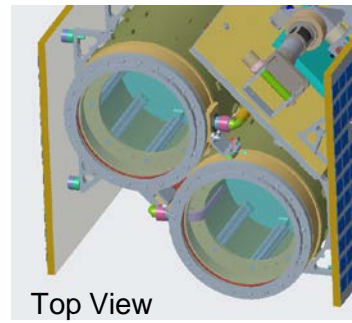
- Capsulation Satellite or CapSat is a low cost, 3 axis stabilized, modularized and standardized spacecraft, based on using pressurized volumes which allow ruggedized COTS hardware to be flown reliably in space in a manner similar to the NASA Hitchhiker-Get Away Special or GAS Can Program.
- The Capsulation Satellite Science Instrument Tube or CapSIT is a standardized interface allowing independent development of multiple instruments/technology demonstrations that can be integrated quickly into the bus.
- CapSIT is fully qualified for flight independent of the CapSat spacecraft and maybe fully pressurized or not as desired.



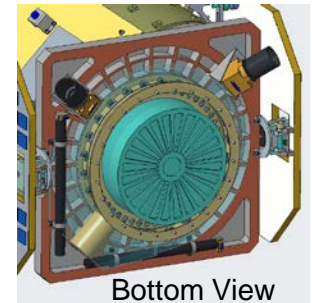
CapSIT
Capsulation Satellite
Science Instrument Tube



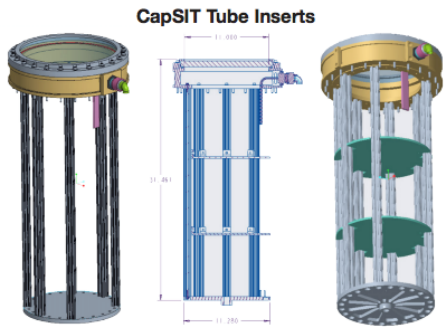
Cutaway view



Top View



Bottom View



- CapSIT Tubes are approximately 1 ft in diameter and 2.5 ft tall.
- Tubes can be flown pressurized, unpressurized, or partly pressurized.
- Tubes provide an instrument volume equal to ~53-U per tube or 106-U for a pair.
- The Tubes are designed to contain 17.5 kg of instrument mass and provide 20+ Watts of power.
- Tubes are designed with a standard interface for rapid interchangeability.
- The mechanical ICD will specify the CG location & frequency response.
- Tubes are intended to use this entire mass, adding weight if needed in order to maintain direct interchangeability with other tubes or a replacement dummy mass in order to not affect coupled loads.
- A single instrument can span 2 tubes by placing electronics in one tube and detectors/optics/etc. in the other.
- Standard tubes can also be flown on other host spacecraft; simplifying interfaces, coupled loads, lead times, contracts, and cost.



"IF IT FITS, IT FLIES!"

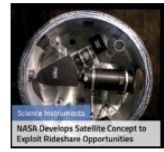
Paper presented at The 20th Annual Small Payload Rideshare Symposium June 12-14, 2018
 "CapSat - An ESPA Class CubeSat Model" <https://www.sprsa.org>



Paper presented at the 2017 IEEE Aerospace Conference
 "Capsulation Satellite or CapSat: A Low Cost Reliable Rapid Response Spacecraft Platform"



September 27, 2016: CapSat article makes top page of www.nasa.gov and www.nasa.gov/goddard



October 2016 CapSat inputs approved for next edition of NASA Technology Innovation Magazine
<https://viewer.aemmobile.adobe.com/index.html#project/20151817-e5ce4721-aff0-65bc-38c9679b/view/ti.17.3/article/17.3.Space.for.Everyone>



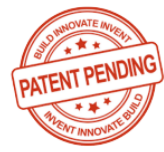
July 2016 CapSat article makes the cover of Cutting Edge

<https://www.nasa.gov/sites/default/files/atoms/files/summer16current.pdf>



<https://www.nasa.gov/feature/goddard/2016/nasa-develops-satellite-concept-to-exploit-rideshare-opportunities>

CapSat is currently in Patent pending status with the US Patent Office:



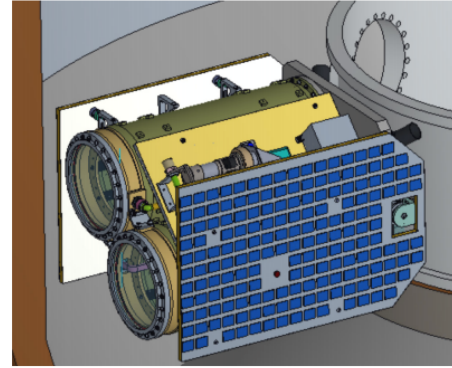
For more information Contact JOE.BURT@NASA.GOV
 301-286-2217

National Aeronautics and Space Administration

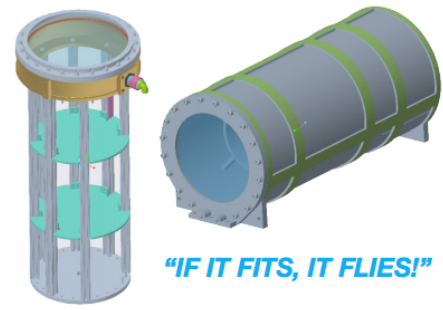


CapSat

Capsulation Satellite or CapSat is a low cost, 3 axis stabilized, modular, standardized spacecraft, based on a pressurized volume allowing ruggedized COTS hardware to be flown reliably in space at a cost per Kg 20 times cheaper than the average CubeSat.



CapSIT: Capsulation Satellite Science Instrument Tube



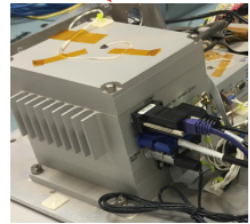
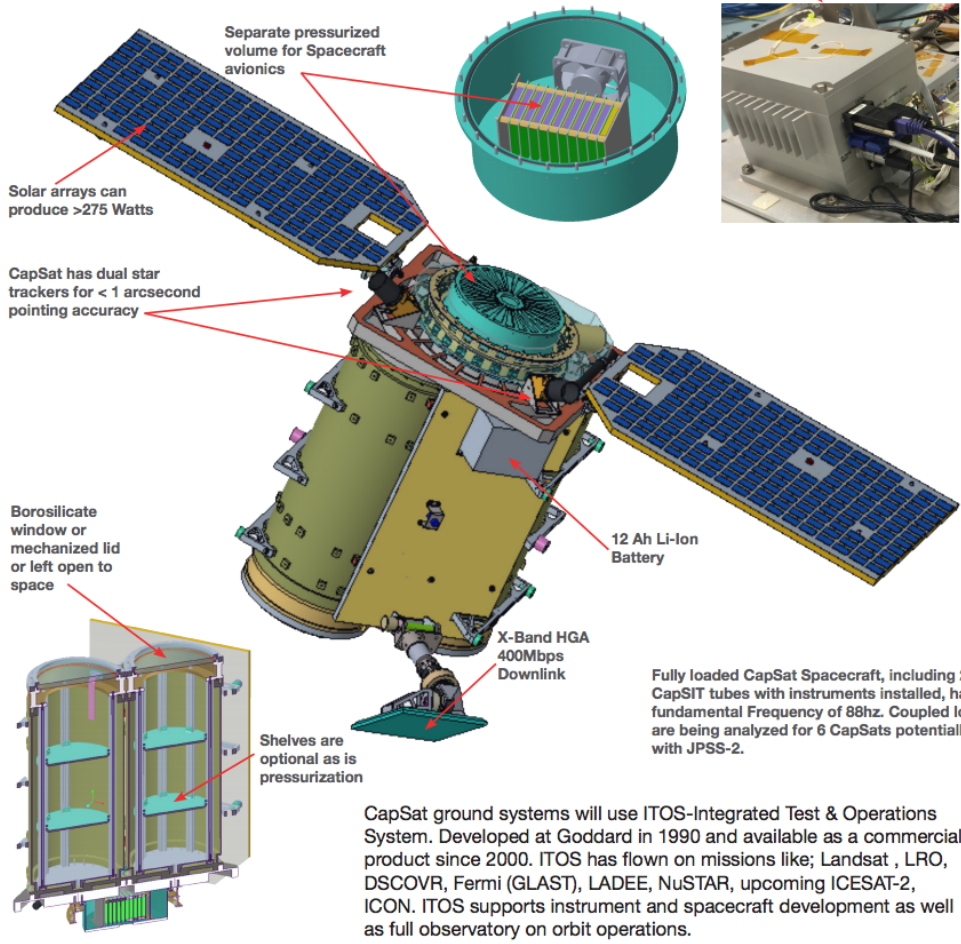
"IF IT FITS, IT FLIES!"

www.nasa.gov

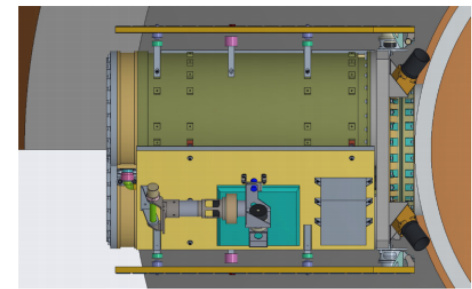


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CapSat Flight software uses NASA's open source core flight executive cFE; developed with decades of Goddard heritage and now approved for Class A human rated use. A version of Microsoft Windows was successfully run on a CapSat C&DH within the cFS to demonstrate plug and play instrument software integration for a new type of Landsat Thermal Imaging Sensor instrument in 2016.



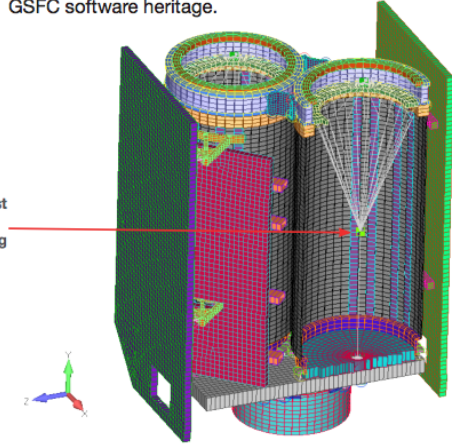
CapSat supports Motorized Lightband-MLB attachment to a standard 6 port ESPA with 180 kg per port.



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 Ring.

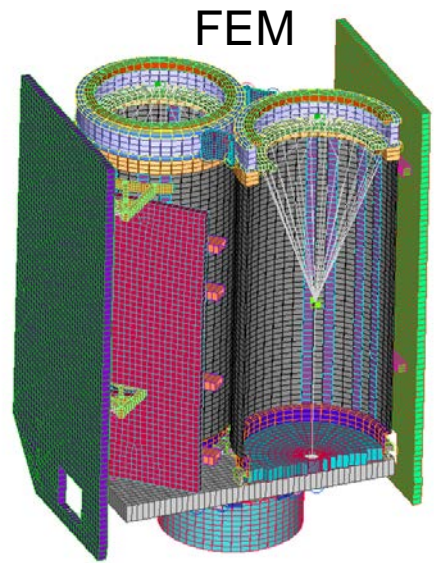
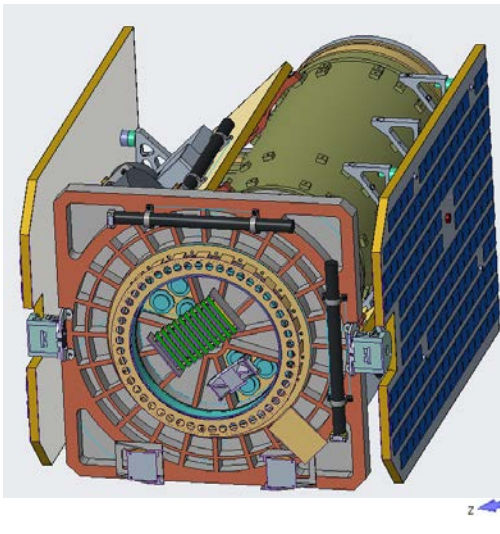
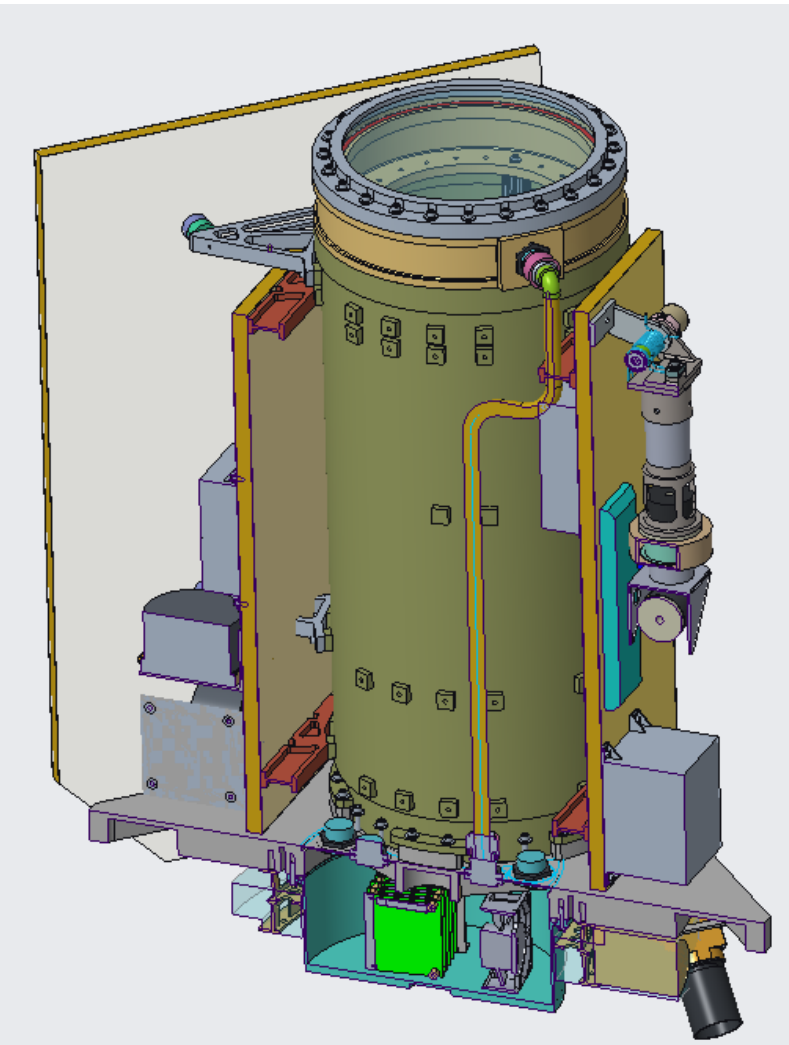
Almost all future NASA missions will be providing rideshare opportunities. This capacity typically goes unused largely do to cost. Typical CubeSat's are still nearly \$1M/kg. A single CapSat can provide 180kg of on-orbit mass at a cost >20 times cheaper.

CapSat achieves this by leveraging proven SmallSat and CubeSat hardware combined with decades of GSFC software heritage.





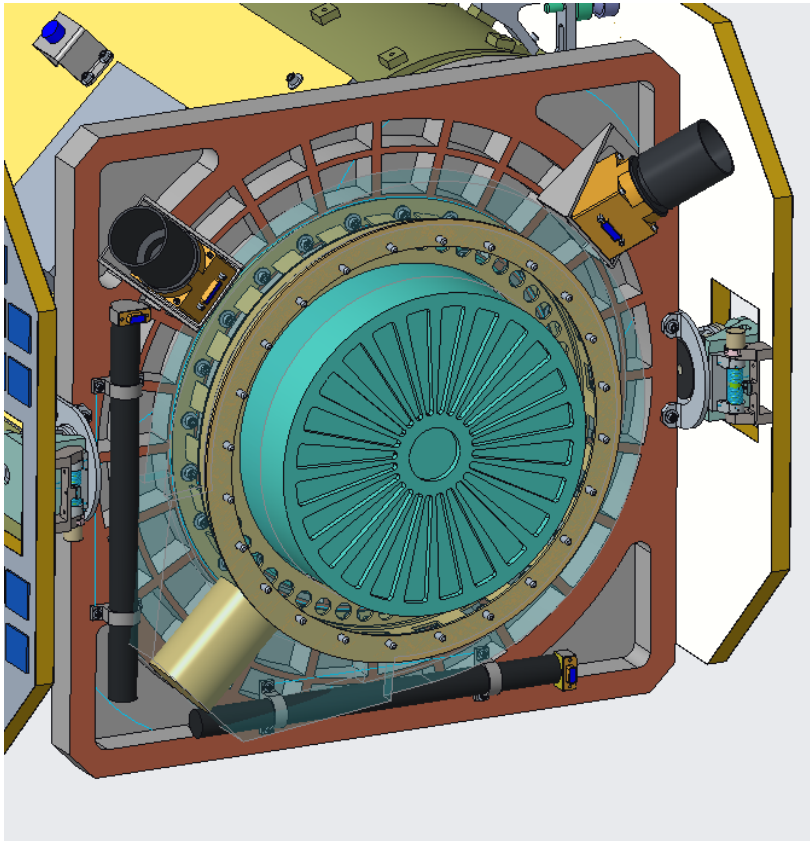
CapSIT Tube Interchangeability



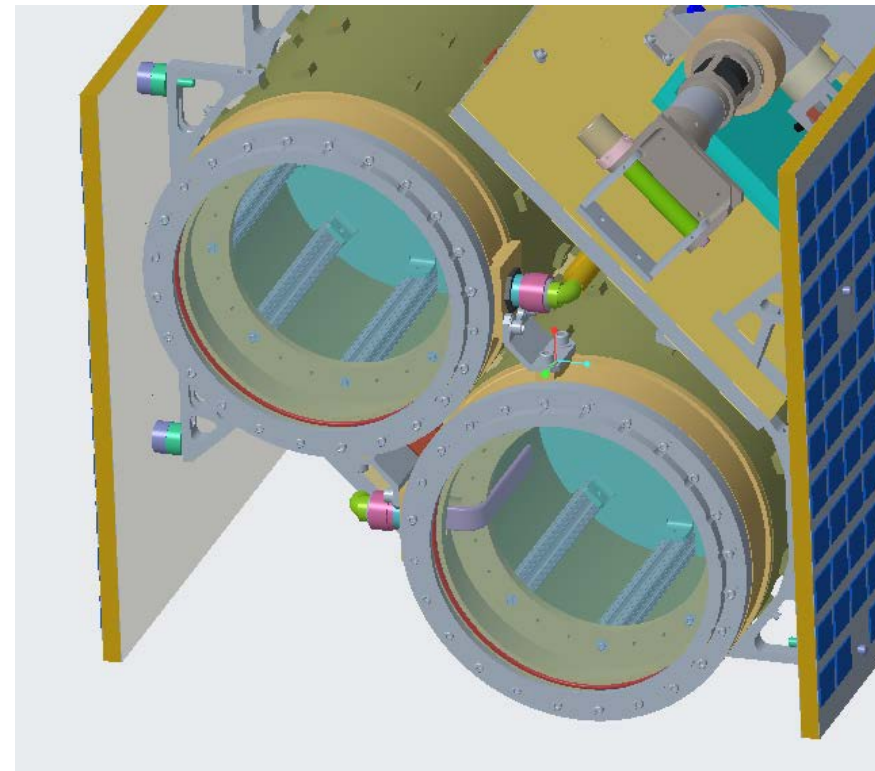
Fully loaded CapSat Spacecraft, including 2 CapSIT tubes with instruments installed, has a 1st fundamental Frequency of 88hz. Coupled loads are being analyzed for 6 CapSats potentially flying with JPSS-2. The CapSIT interchangeability allows for a single coupled loads analysis regardless of which tubes are selected for launch.



Capsat isometric stowed views



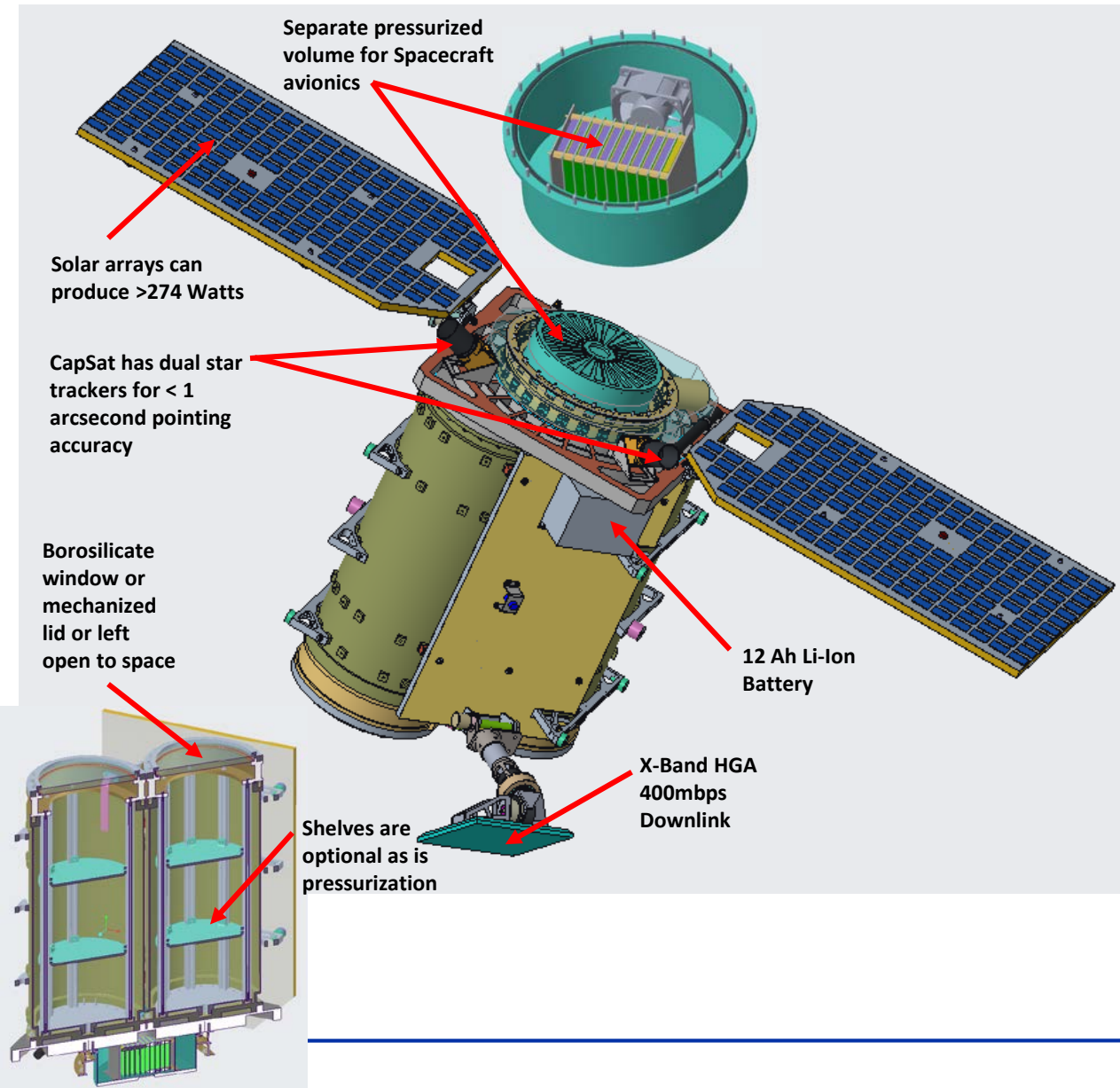
Bottom View



Top View

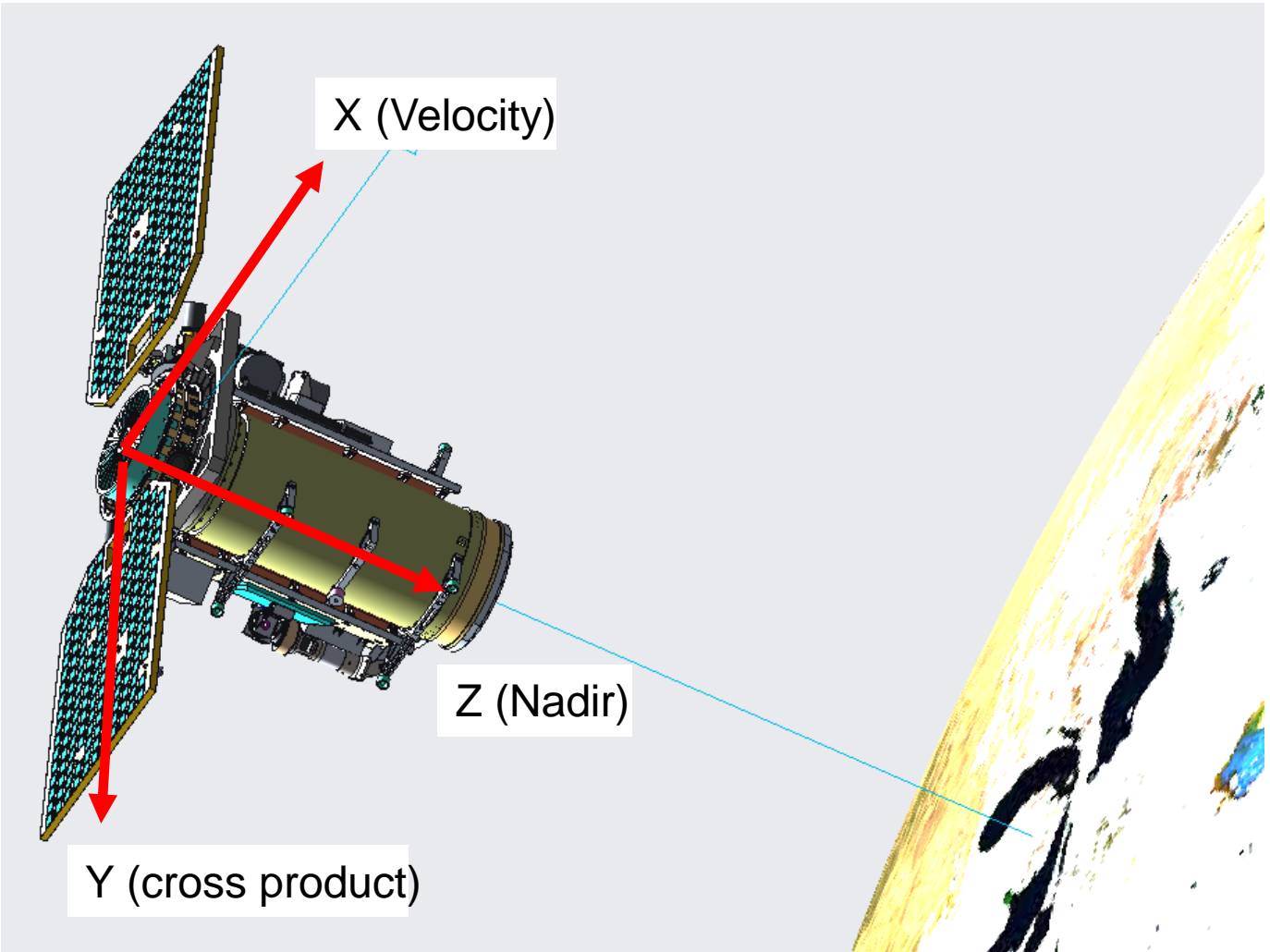


Capsat isometric deployed





CapSat on orbit

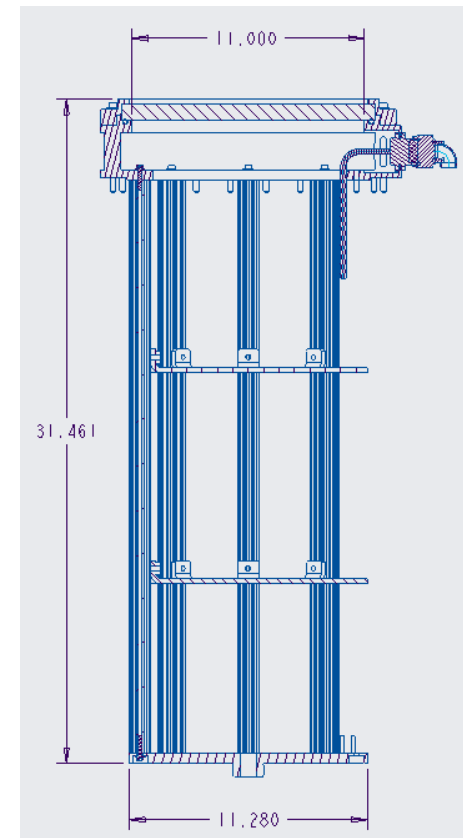


Note: CapSat can point in all directions



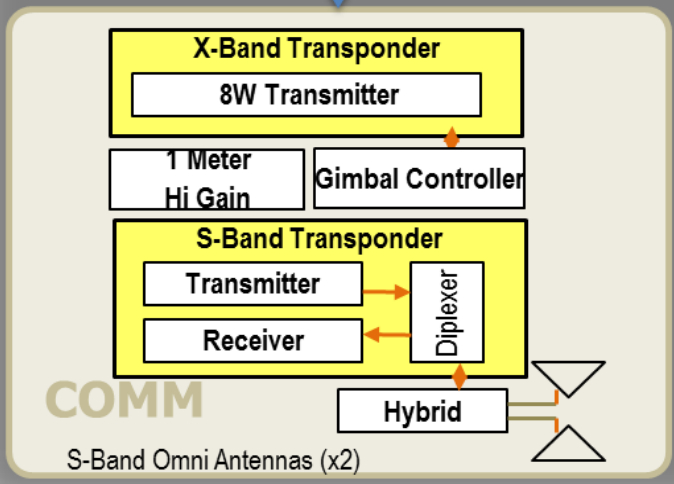
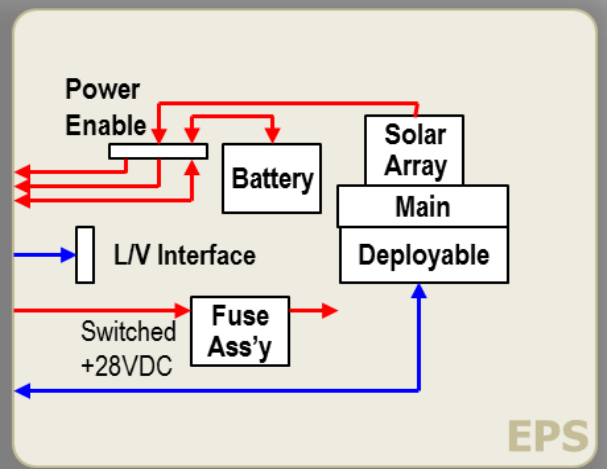
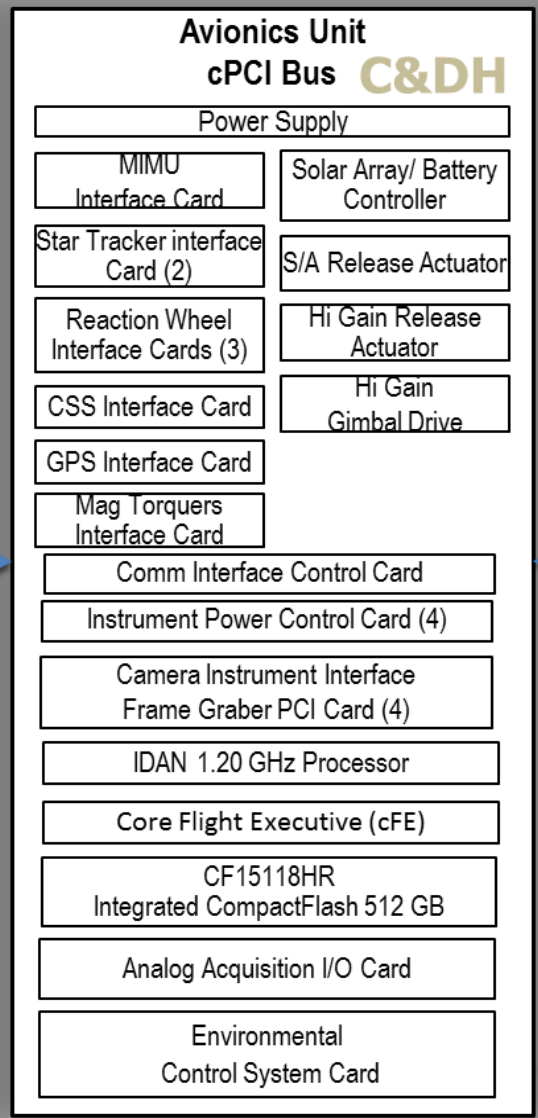
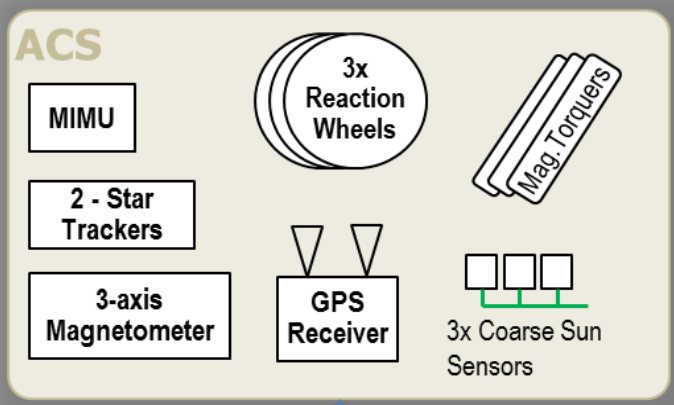
CapSIT: “If it fits it flies”

- CapSat Science Instrument Tubes or CapSIT’s are roughly 1 ft x 2.5 ft
- They provide an instrument volume equal to ~53U per tube or 106U for a pair
- They are designed with a standard interface for rapid interchangeability
- The Tubes are designed to contain 17.5 kg and provide 20+ Watts of power
- For Safety the Tubes are designed for complete containment of the 17.5 kg place within just like the Hitchhiker GAS cans were.
- They are intended to use this entire mass, adding weight if needed in order to maintain direct interchangeability without affecting coupled loads
- Tubes will be delivered to an instrument developer in a kit form
- The Kit will include software to allow testing through commercial standard data interfaces
- The mechanical ICD will specify the CG location & frequency response
- The electrical ICD will include EMI/EMC and inrush current requirements
- There is a design for an all-in-one tester that could be delivered to the instrument building institution for a complete mechanical, thermal, EMI/EMC/ and data flow verification.
- Qualified tubes can be delivered or swapped out very late in the I&T flow
 - Possibly up to the last minutes if there is an appropriately placed fairing door
 - This is intended for certain biological experiments but allows for maximum flexibility and quick response to space that other payloads could take advantage of
- Tubes can be flown pressurized, unpressurized or partially pressurized.
- A single instrument can span two tubes buy placing electronics in one tube and detectors/optics/etc. in the other, both of which can be pressurized or not independently.
- Standard tubes can also be flow on other host spacecraft. Simplifying interfaces, coupled loads, lead times, contracts, and cost.



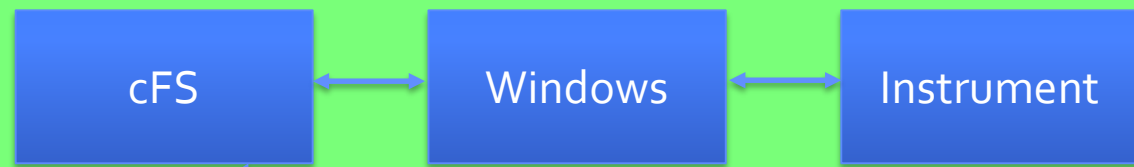
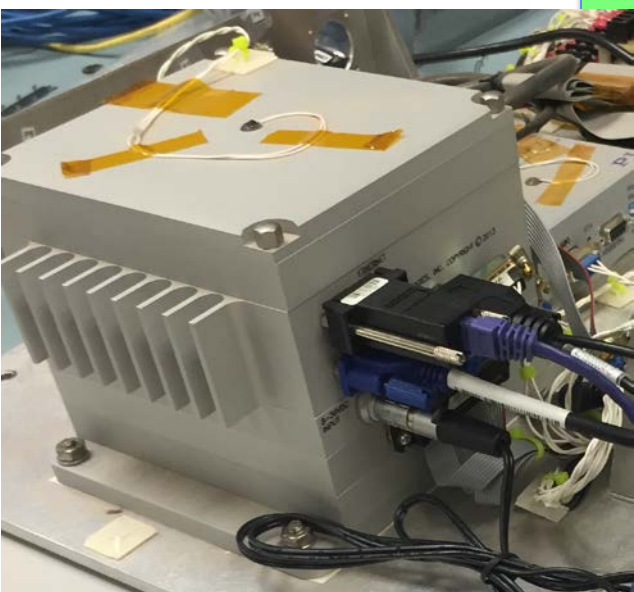


CapSat Block Diagram



NASA CapSat- Software Configuration

CapSat Flight software uses NASA's open source core flight executive cFE; developed with decades of Goddard heritage and now approved for Class A human rated use. A version of Microsoft Windows was successfully run on a CapSat C&DH within the cFS to demonstrate plug and play instrument software integration for a new type of Landsat Thermal Imaging Sensor instrument in 2016.



CapSat Flight System



CapSat ground systems will use ITOS-Integrated Test & Operations System. Developed at Goddard in 1990 and available as a commercial product since 2000. ITOS has flown on missions like; Landsat , LRO, DSCOVR, Fermi(GLAST), LADEE, NuSTAR, upcoming ICESAT-2, ICON. ITOS supports instrument and spacecraft development as well as full observatory on orbit operations.



Flight & Ground Software

- 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. (The ISS has over 80 laptops running windows.)

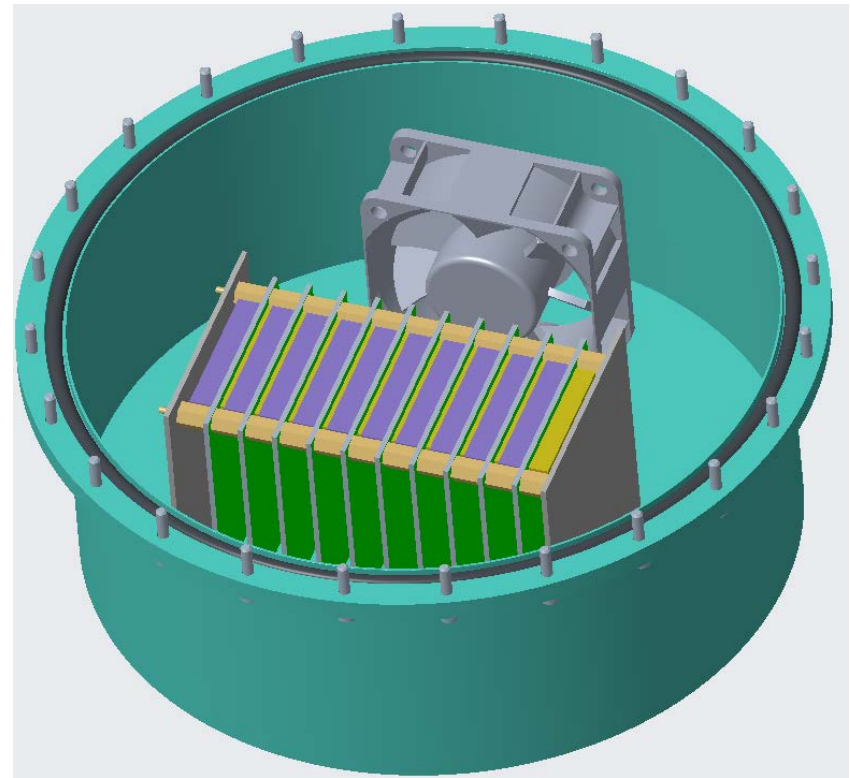


Pressurized Spacecraft Avionics Compartment

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 at low cost. CapSat utilized such a system in its development unit in 2016.

CapSat is upwards compatible. Should an application/customer wish to upgrade; there is always the option to upgrade to a high reliability flight proven avionics system of which Goddard actively builds and fly's. This would allow for a quick and smooth transition to a higher quality system.



VOLUME = 8.6251531e+01 INCH³
SURFACE AREA = 1.3560890e+03 INCH²
AVERAGE DENSITY = 9.9576561e-02 POUND / INC
MASS = 8.5886308e+00 POUND



Ruggedizing & Radiation

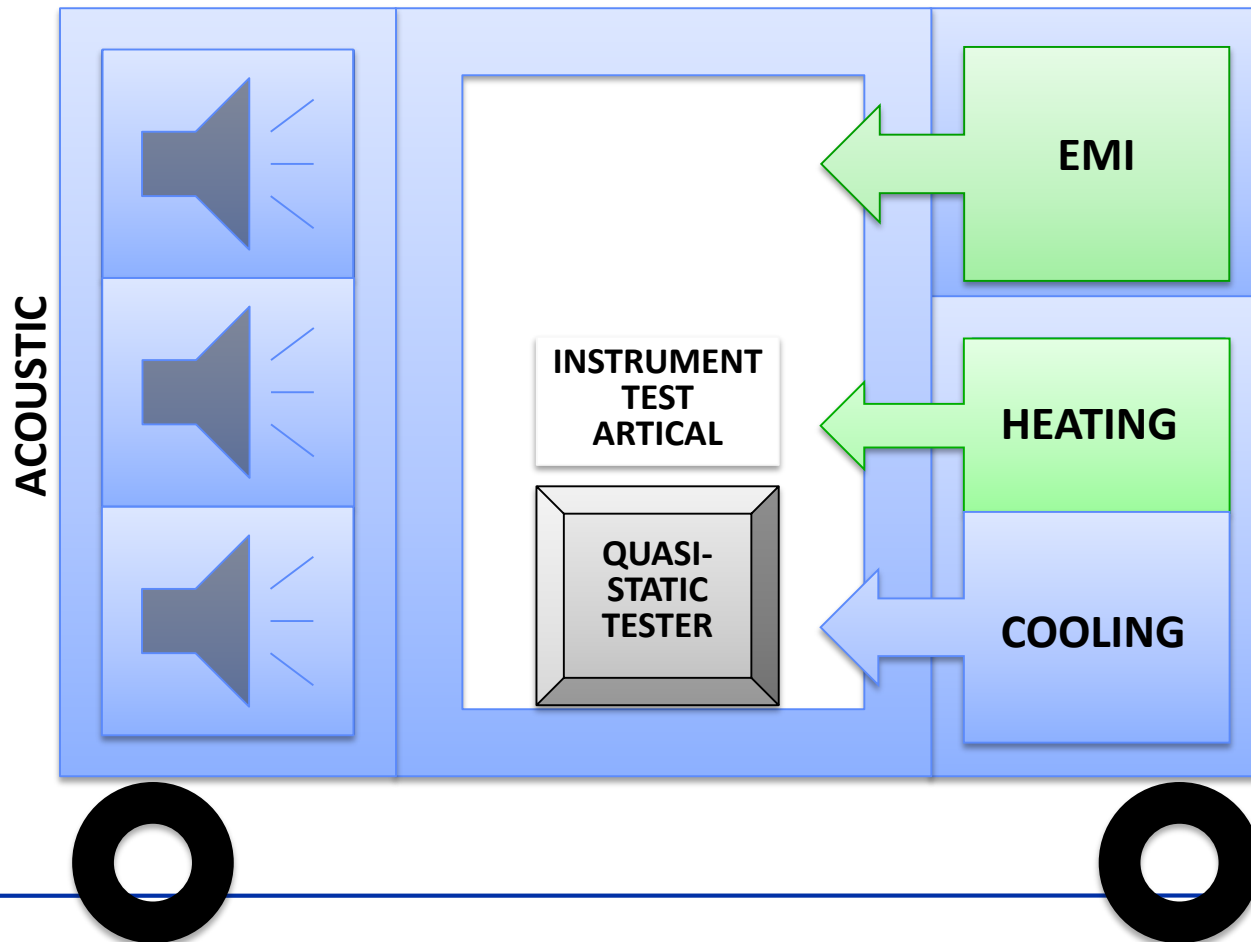
- Ruggedizing a payload may include the following:
 - removing things like connectors, moving parts, switches, etc. and replacing them with flight quality hand soldered parts and direct wiring.
 - Adding stiffeners and brackets to electronics boards
 - Adding EMI and/or radiation shielding.
- **Total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



All-in-One Portable Environmental Test Facility

- Instrument inserts can be fully tested without a vacuum chamber
- This makes possible the development of a portable all-in-one environmental tester
- Such a tester can reduce costs, simplify testing, and repeat testing improving reliability

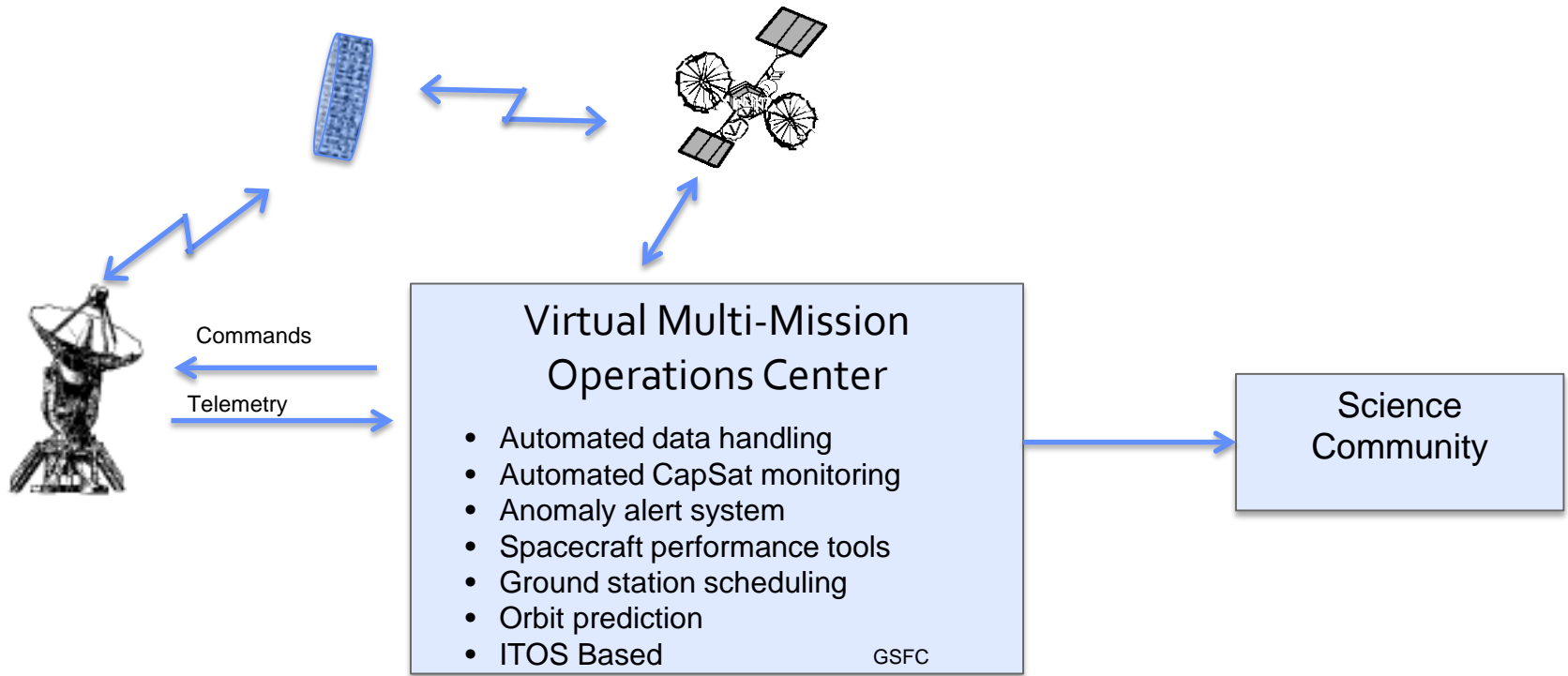
Acoustic, EMI, Thermal Cycle, Quasi-Static, and Contamination



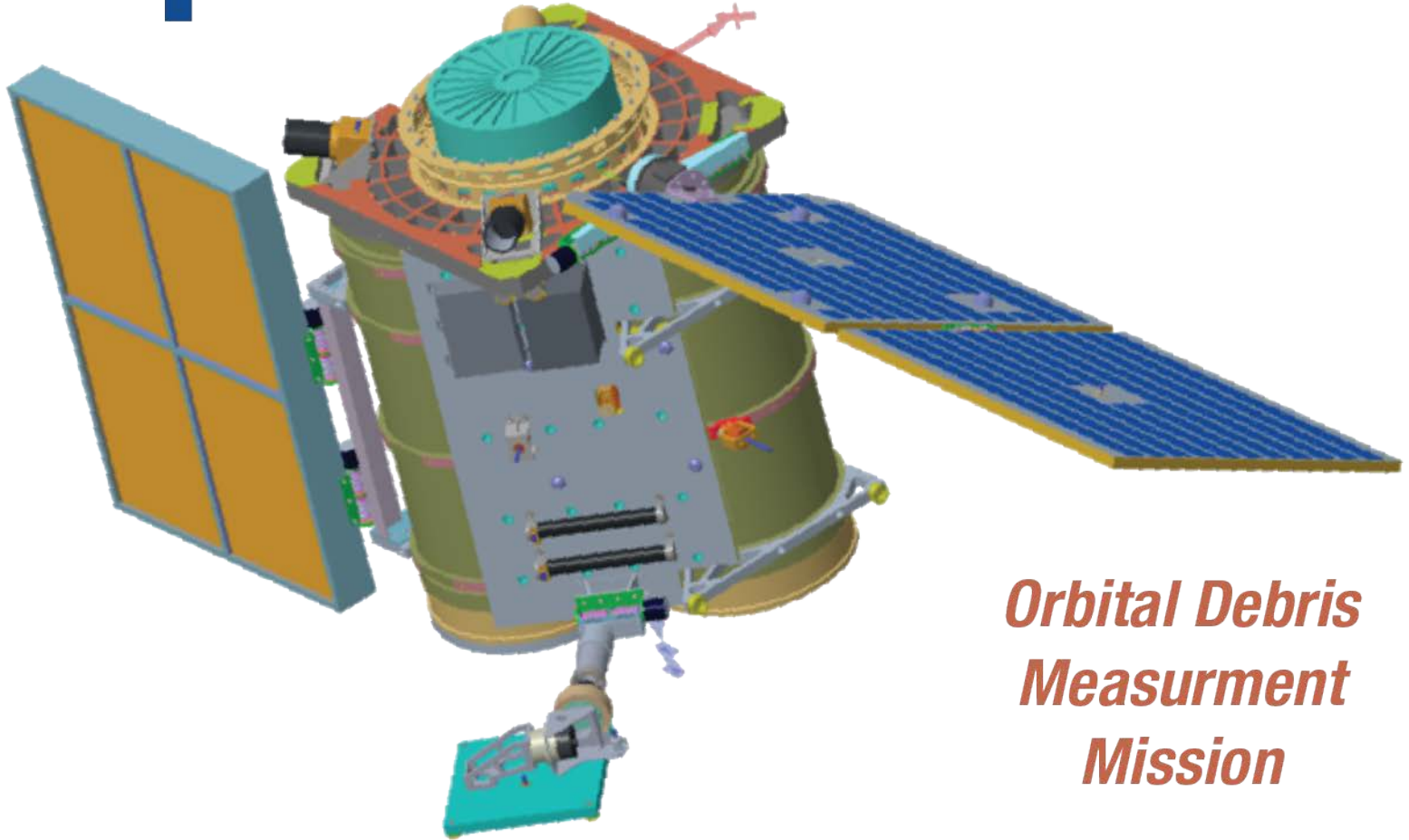
Test levels of all tests are only to what is experienced within the tube not the full spacecraft levels; heating, cooling, acoustics and EMI will be significantly reduced inside the tube.



CapSat Ground System



CapSat-DRAGONS



*Orbital Debris
Measurement
Mission*

NASA • GSFC • JSC • MSFC

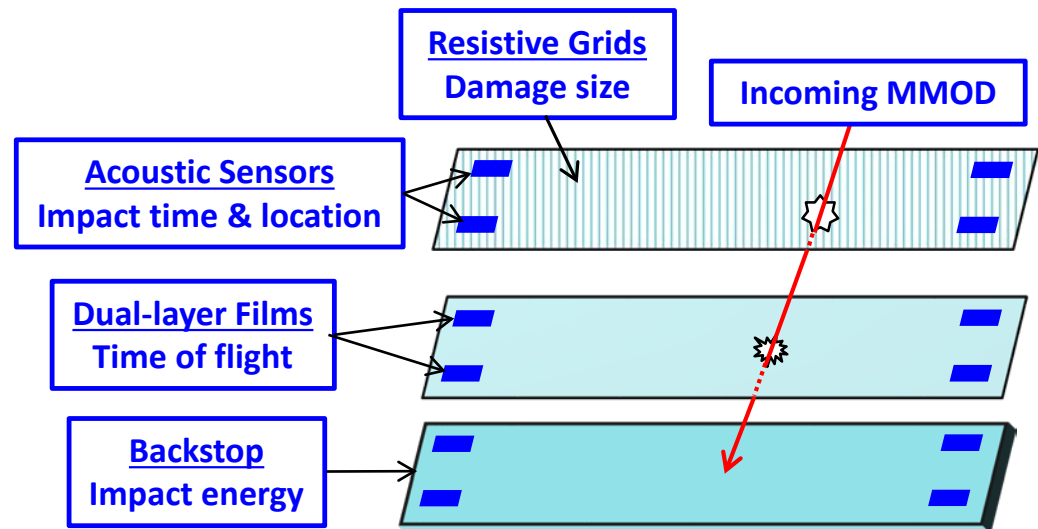


DRAGONS

- **DRAGONS (Debris Resistive/Acoustic Grid Orbital NASA-Navy Sensor)**

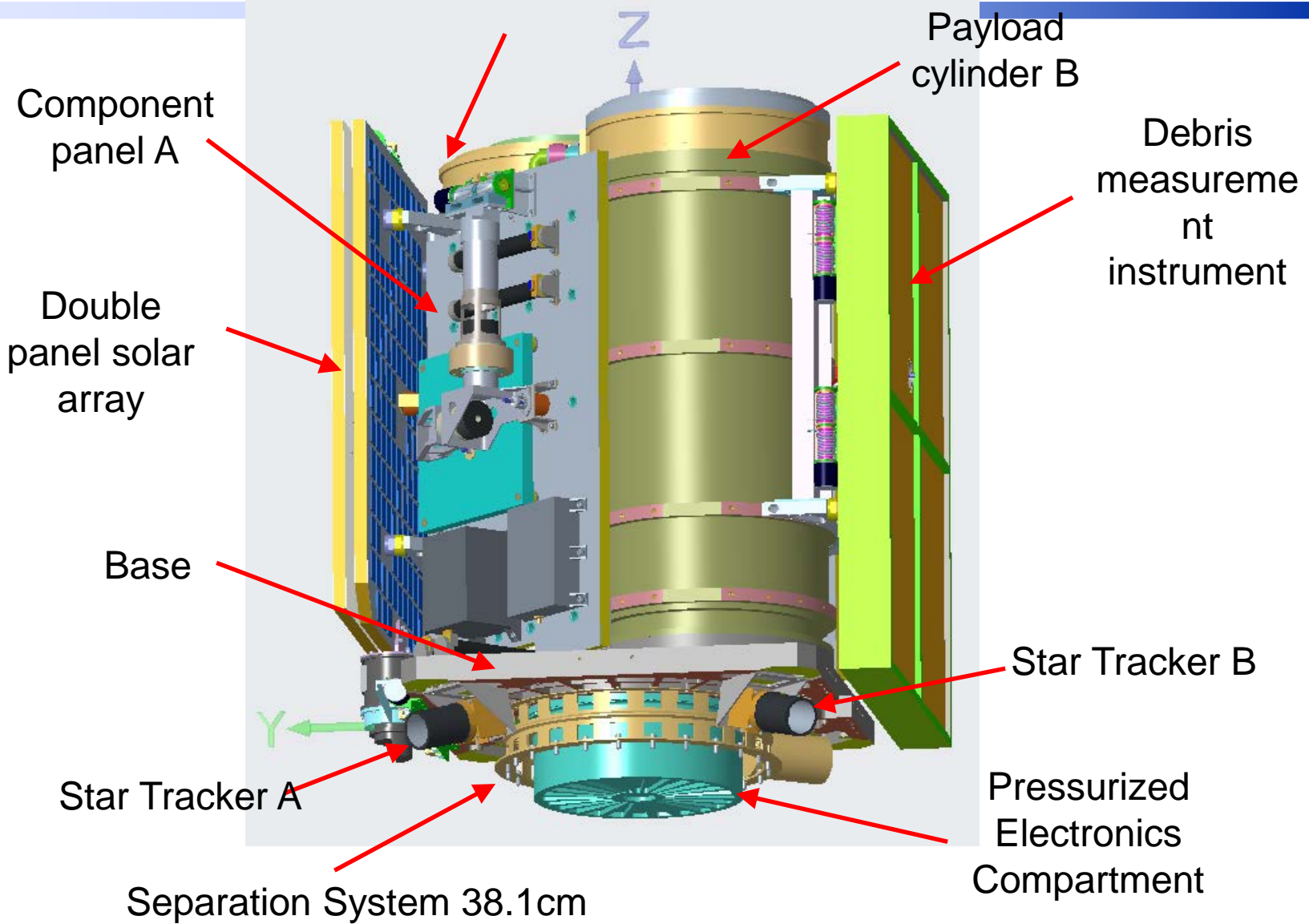
- Is designed to detect/measure MMOD in the ~millimeter size regime
- Combines several impact detection technologies to maximize information that can be extracted from the detected impact events

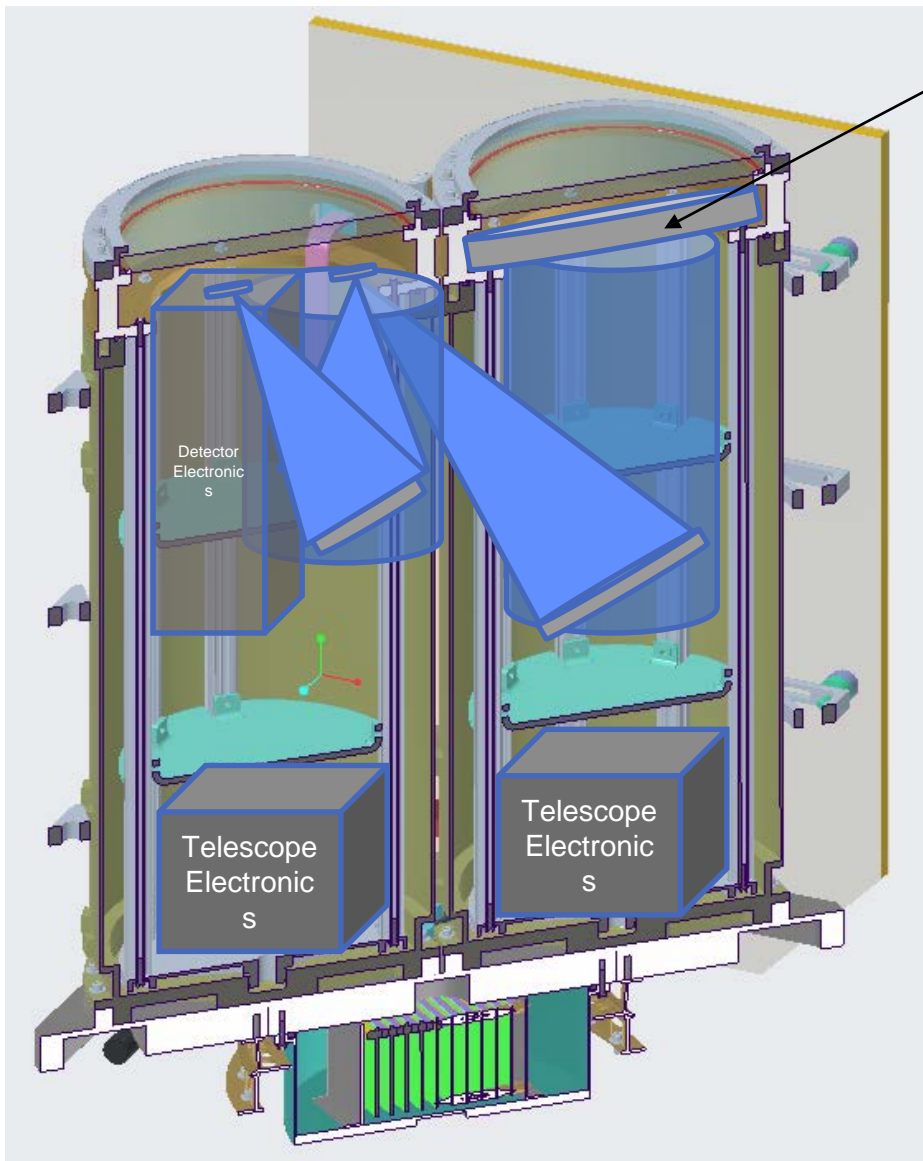
- **impact location**
- **particle size**
- **impact speed**
- **impact direction**
- **impact energy / particle density**





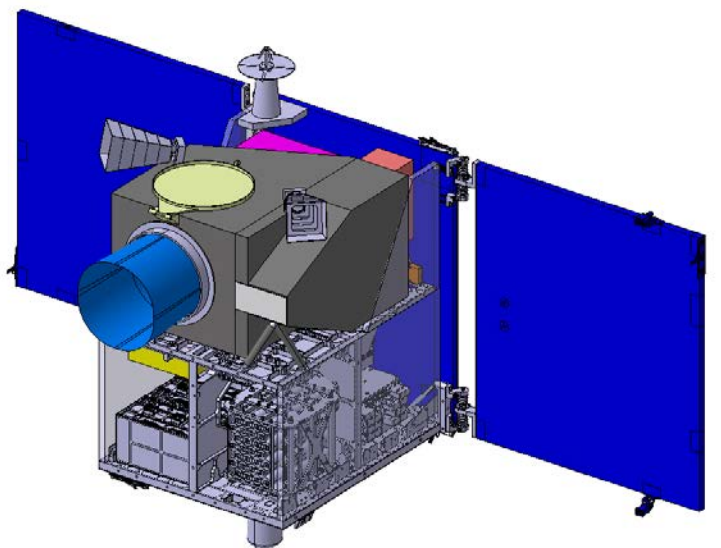
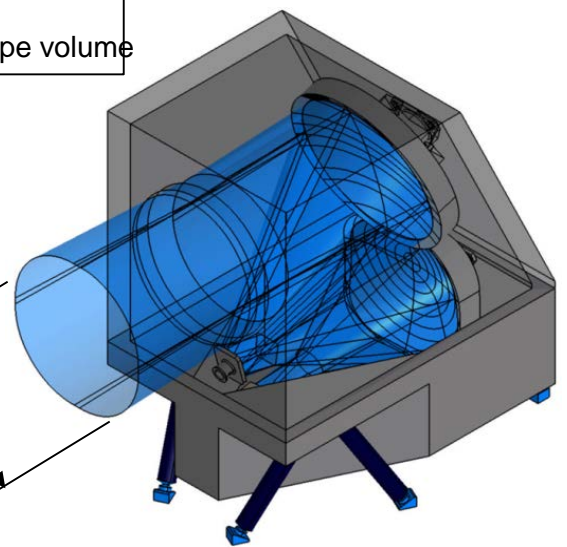
Debris-Sat Stowed Configuration

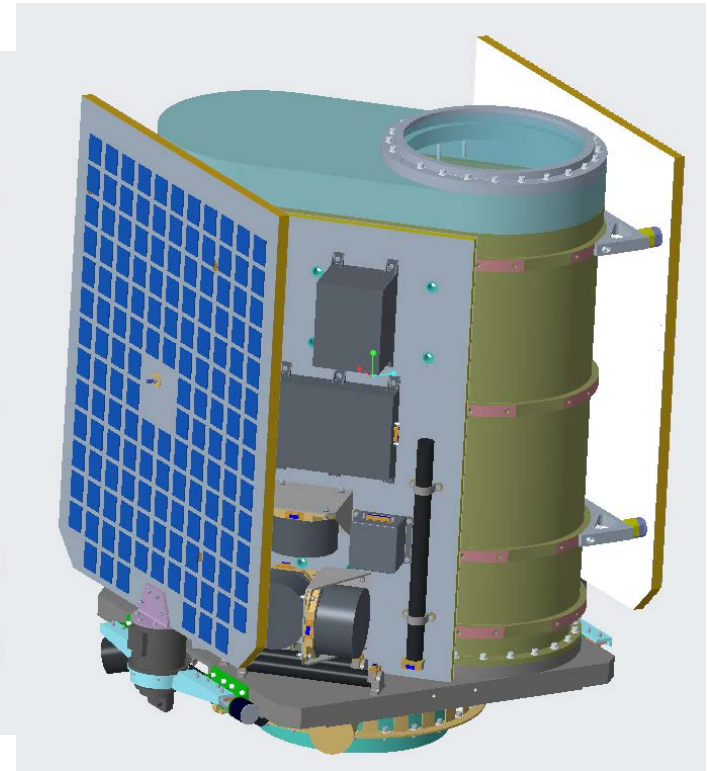
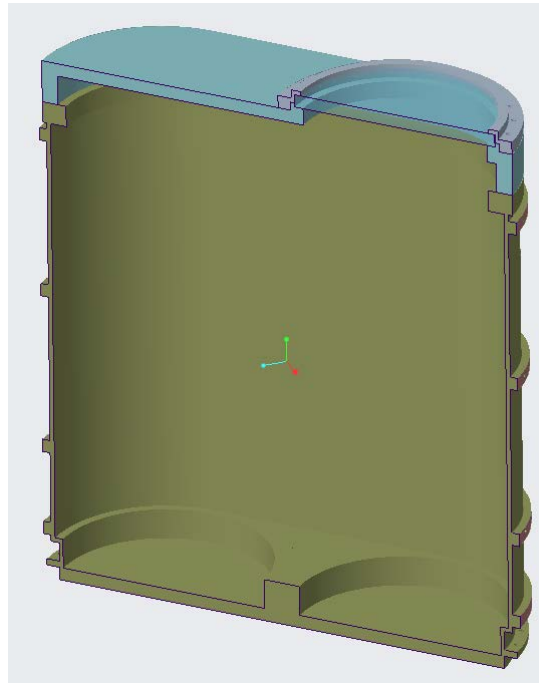
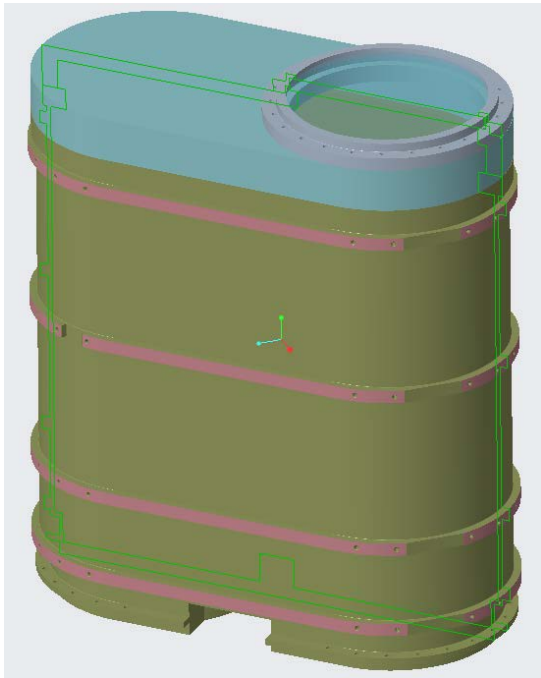




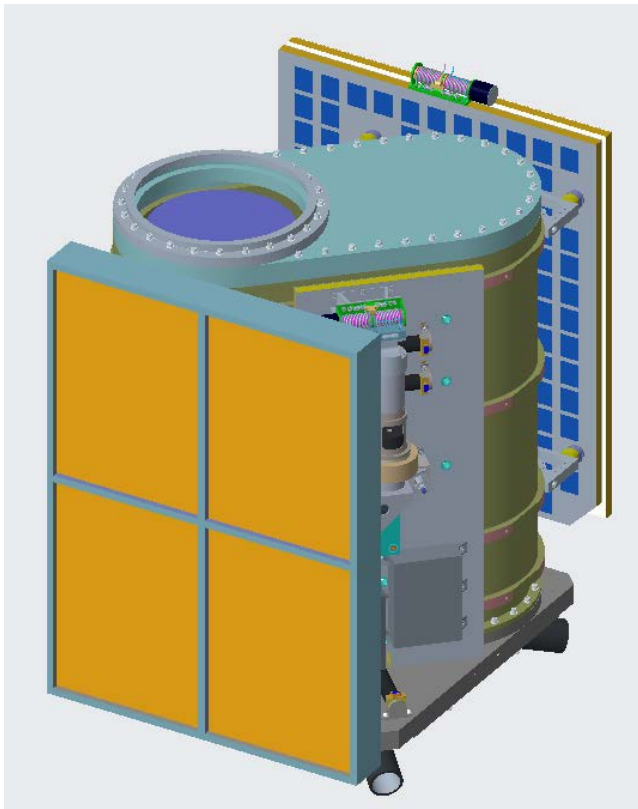
Optical lens
Seals telescope volume

Diameter
200mm ≈ 8 inches

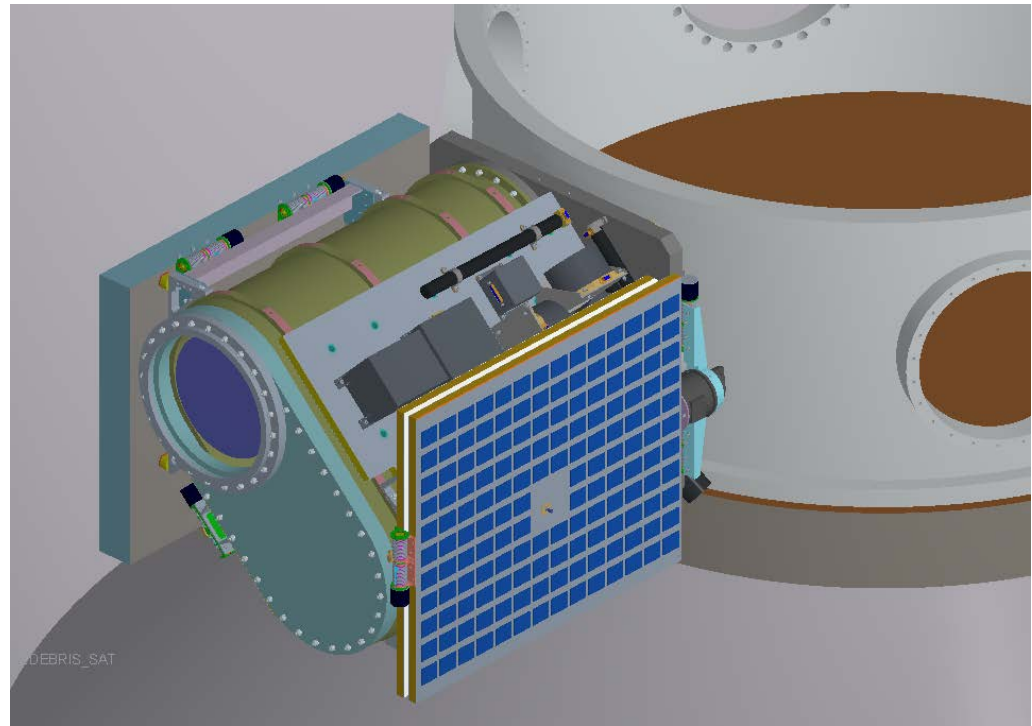




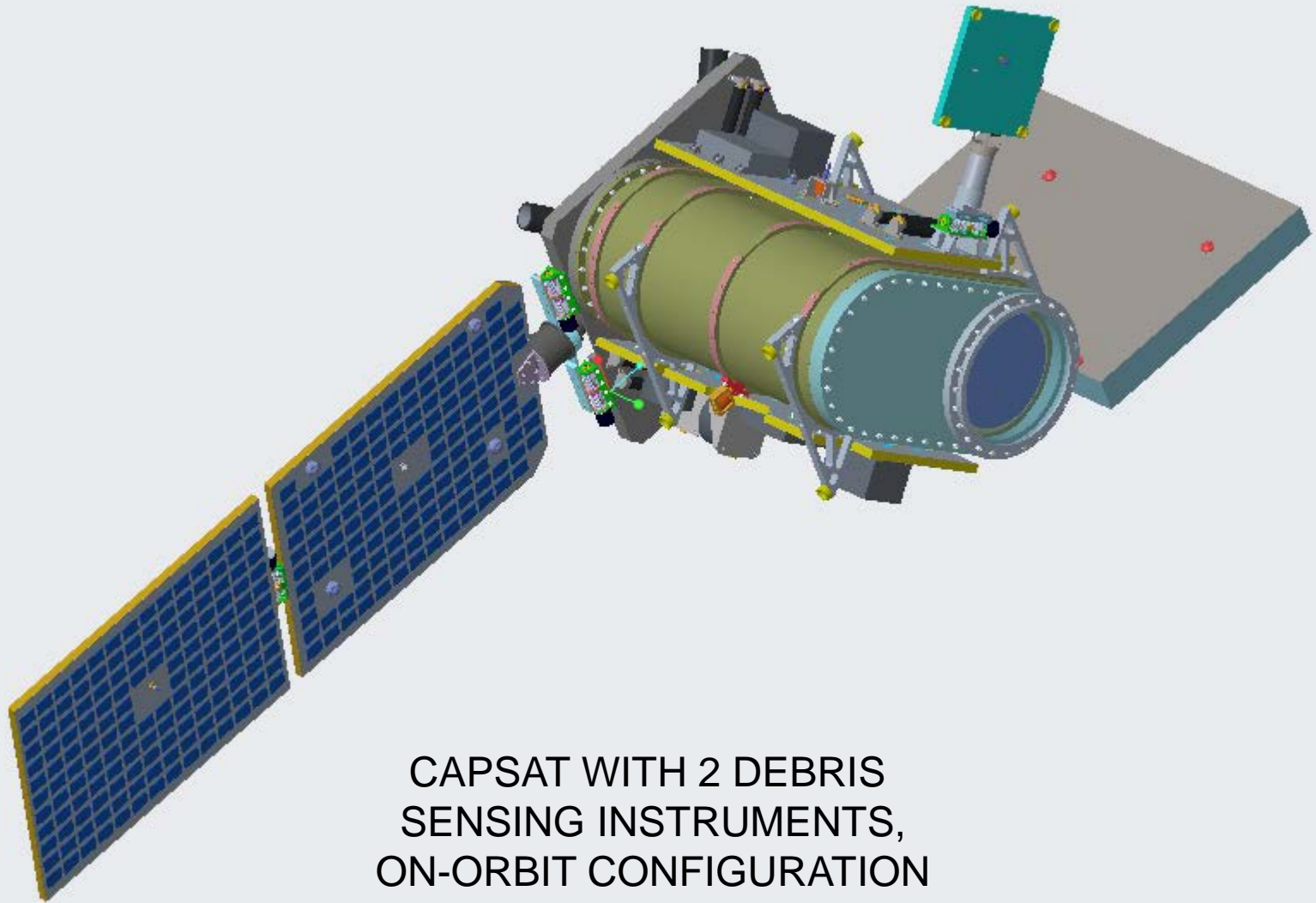
CAPSAT WITH COMBINED CYLINDER ASSEMBLY
HOUSING THE ESA DEBRIS INSTRUMENT



CAPSAT WITH 2 DEBRIS
SENSING INSTRUMENTS,
STOWED CONFIGURATION



CAPSAT WITH 2 DEBRIS
SENSING INSTRUMENTS,
STOWED ON ESPA CONFIGURATION



CAPSAT WITH 2 DEBRIS
SENSING INSTRUMENTS,
ON-ORBIT CONFIGURATION



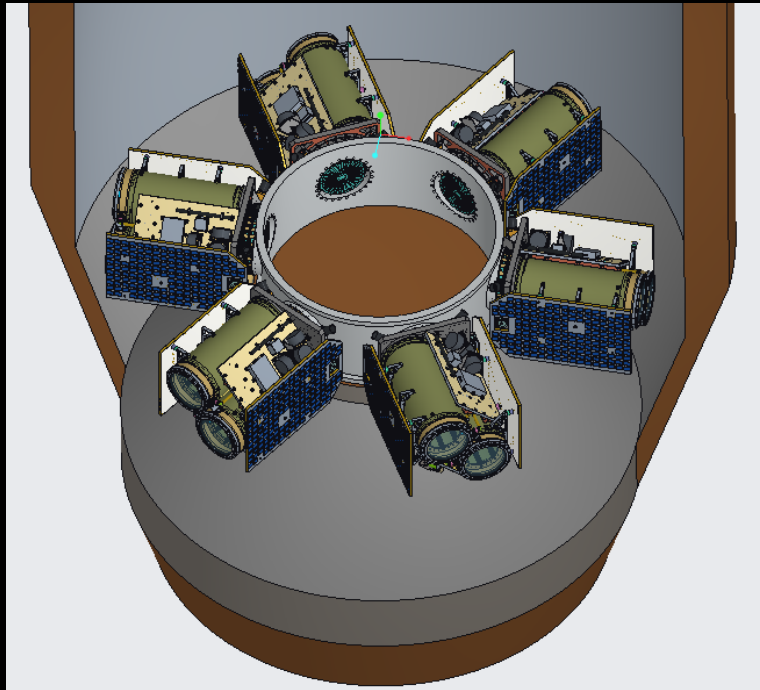
CapSat Conclusion

- **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. CapSat intends to provide an architecture with small sat mass and capability at CubeSat prices.**
- **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. It is the ability to conduct significant science, engineering, and operational spaceflight missions that are 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.**

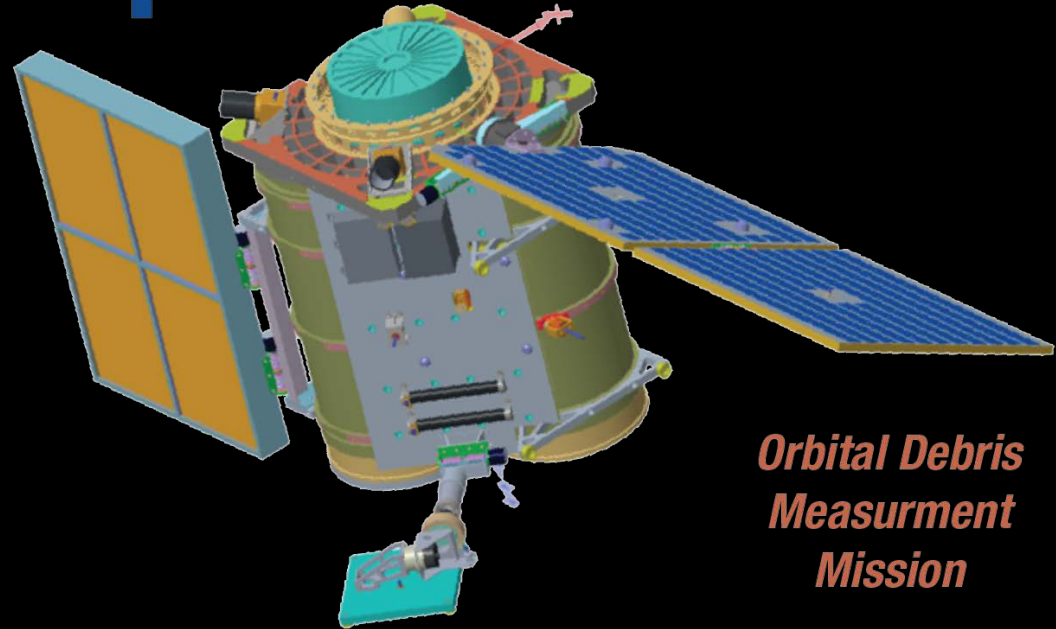


Capsulation Satellite: CapSat

21st Annual Small Payload Rideshare Symposium



CapSat-DRAGONS



*Orbital Debris
Measurement
Mission*

NASA • GSFC • JSC • MSFC

Joe Burt

June 5, 2019

Goddard
Space Flight Center