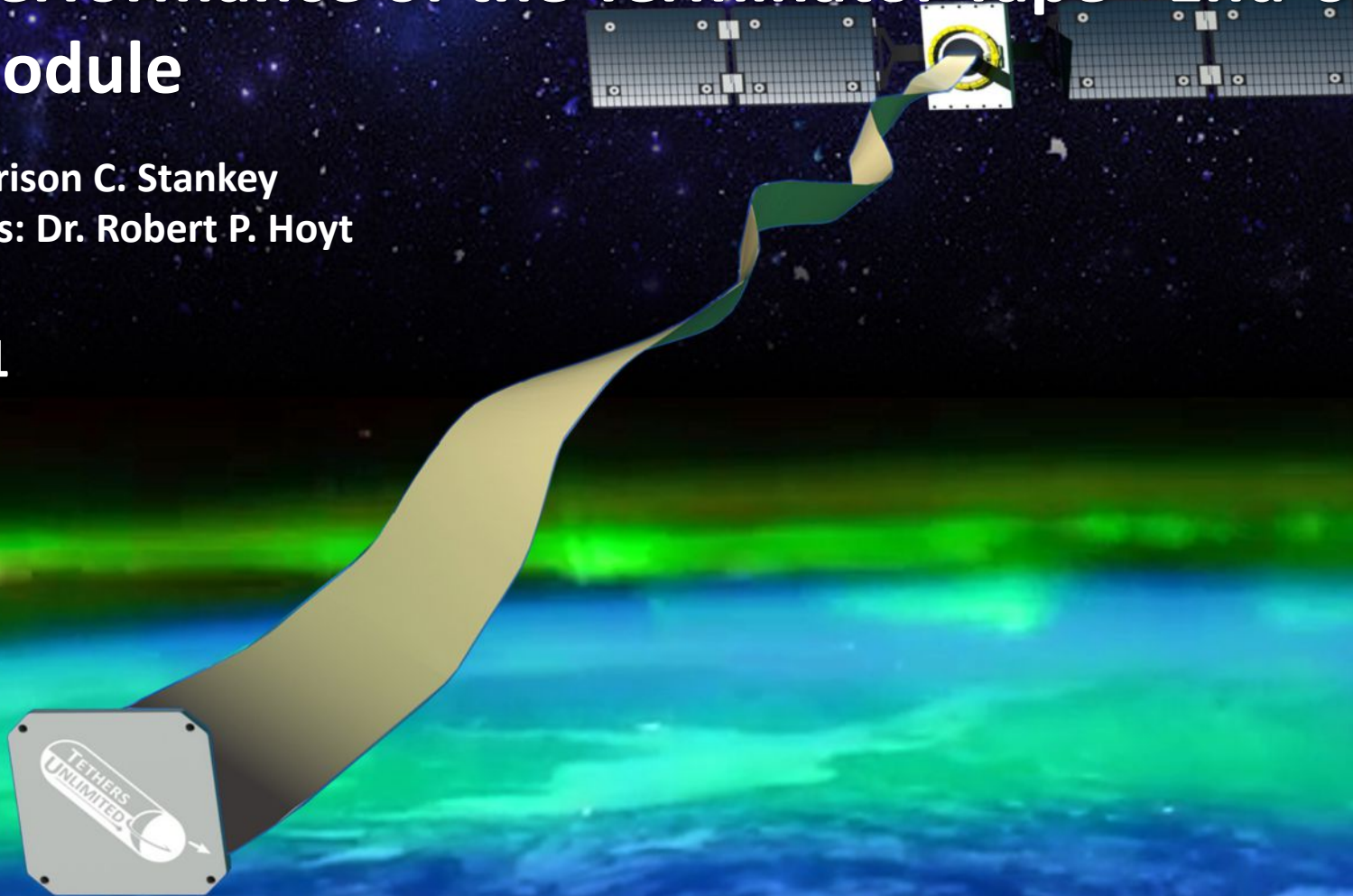


In-Flight Performance of the Terminator Tape[®] End-of-Life Deorbit Module

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SmallSat 2021



Outline

Terminator Tape[®] is a passive deorbit device that utilizes both aerodynamic and electrodynamic drag generated from a long, thin deployed conductive tape.

This presentation includes:

- The Space Debris Problem
- Theory and Design
- Flight Data
- Performance Analysis
- The Effect of Passive Deorbit Devices

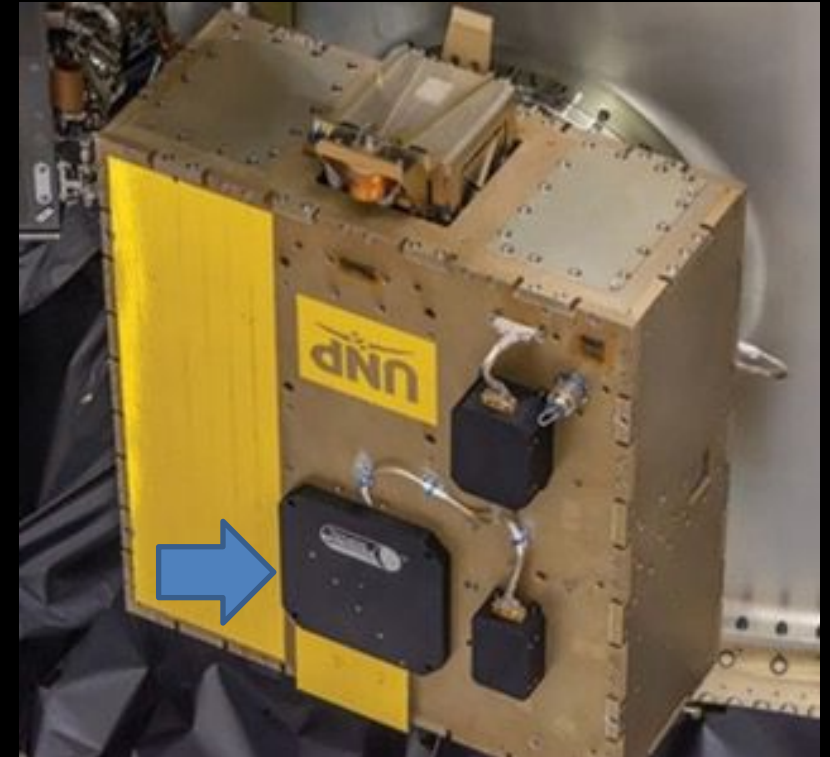


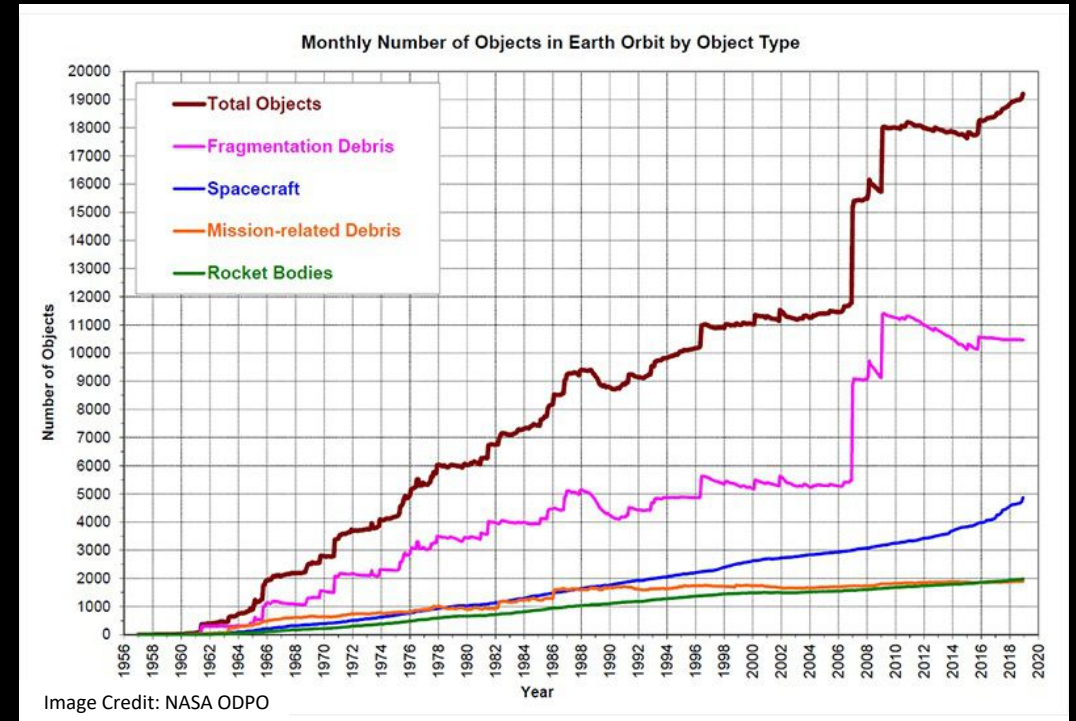
Image Credit: SpaceX

Terminator Tape on PROX-1

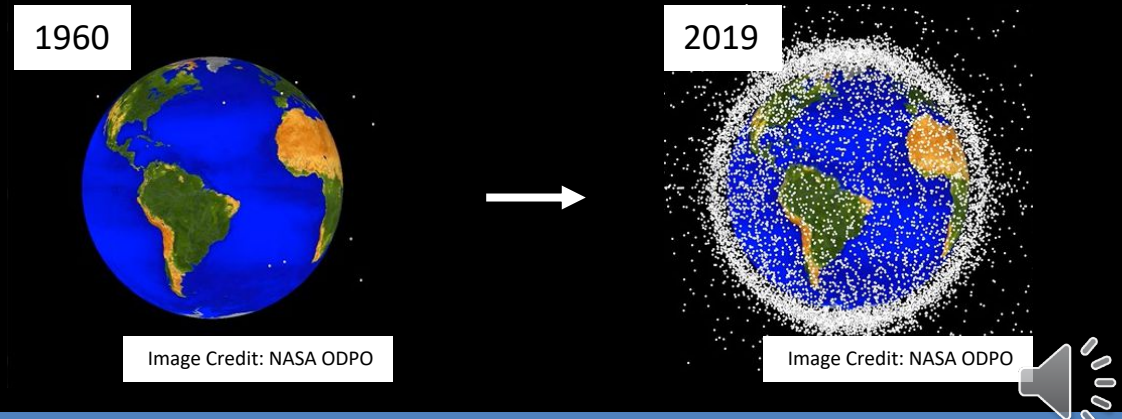


The Space Debris Problem

- Space debris is both manmade and natural
- As human activity in space has grown, so has debris in orbit around the earth.
- This debris poses risk to existing and future missions.
- Recent regulations have made attempts to address this problem by requiring satellite operators to remove their equipment from crowded orbits within a 25-year period after mission-completion.



Tethers Unlimited, Inc. developed the Terminator Tape passive deorbit module to address this issue.



Concept of Operations



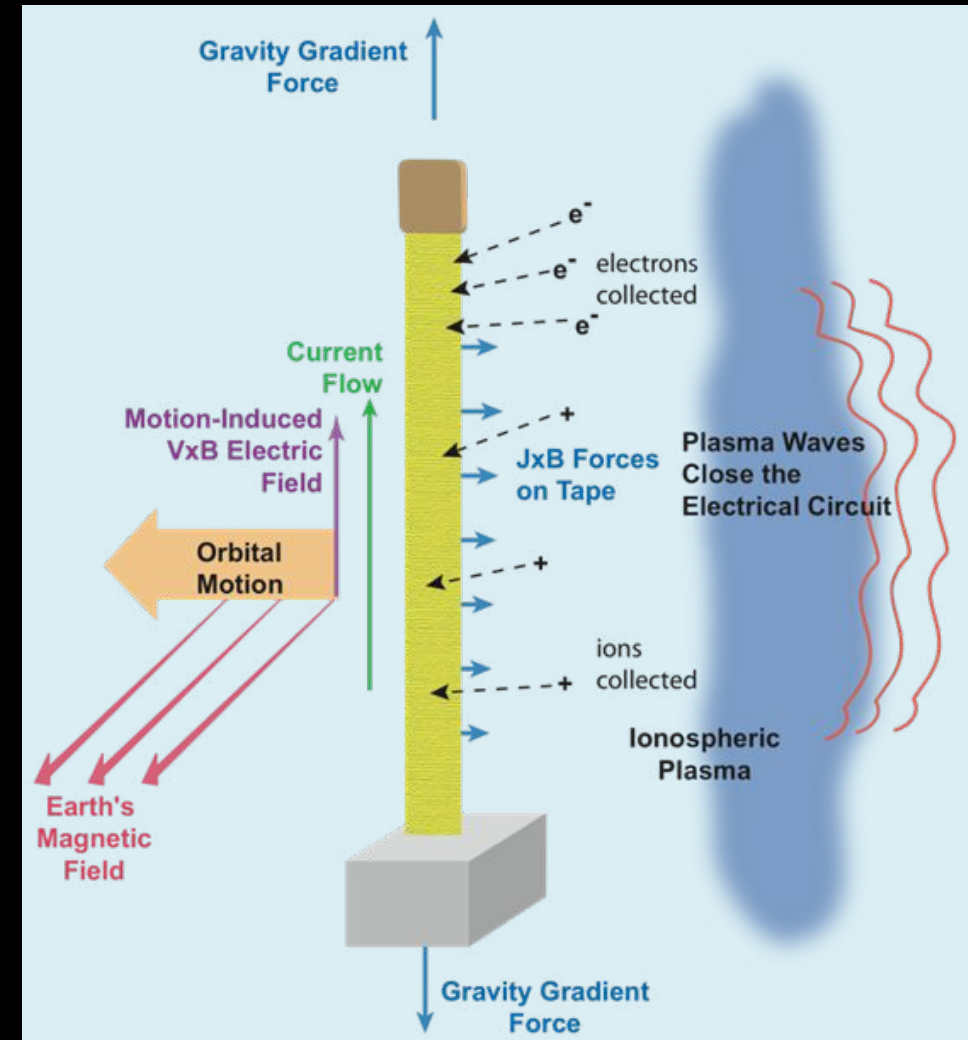
Concept of Operations

1. Terminator Tape is mounted to the craft
2. After the mission is completed, the module is commanded to deploy.
3. The module deploys a conducting tape, which generates neutral particle drag and passive electromagnetics drag to hasten the deorbit of the spacecraft



Terminator Tape Theory

- Terminator Tape leverages two physical phenomena
 - Electrodynamic force
 - Lorentz (EMF) Voltage: $V = \vec{L} \cdot (\vec{v} \times \vec{B})$
 - Lorentz Force: $\vec{F} = \int_0^L (\vec{I} \times \vec{B}) d\ell$
 - Aerodynamic (drag) force
- Performance is maximized through stable gravity gradient (up-down) orientation.



Terminator Tape Electrodynamic Theory



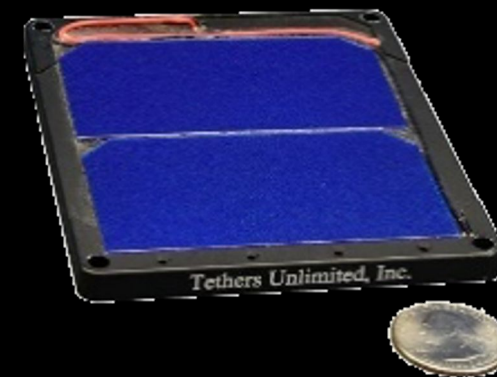
Configurations

Flight Heritage!



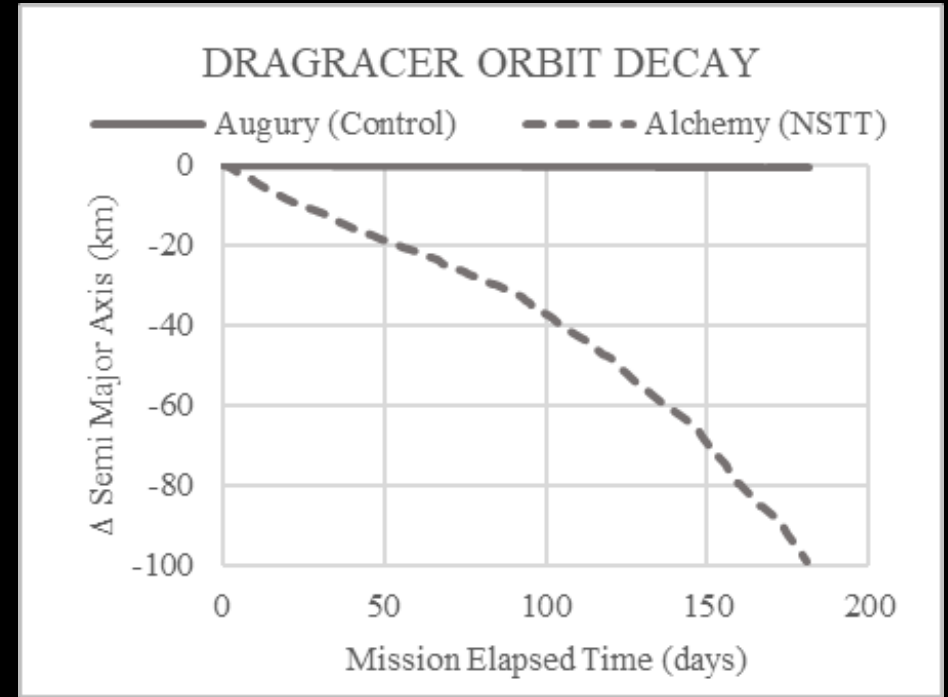
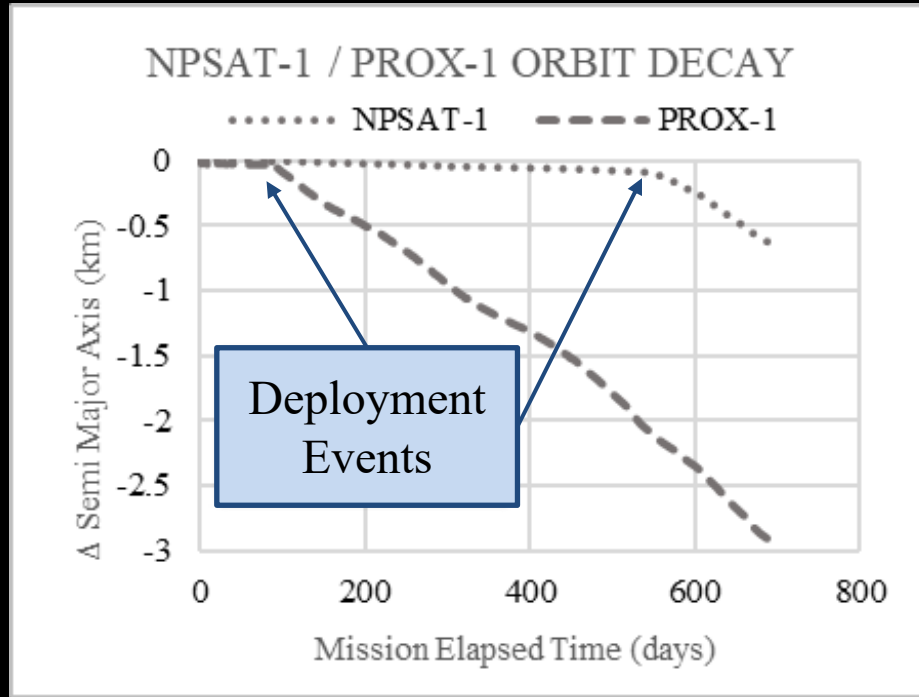
	NSTT		CSTT
	830	Mass [g]	83
180 x 180 x 18		Envelope [mm]	100 x 83 x 6.5
70 x 0.15		Tape Size [m]	10 x 0.08
9		TRL	9

Flight Heritage!



Flight Data

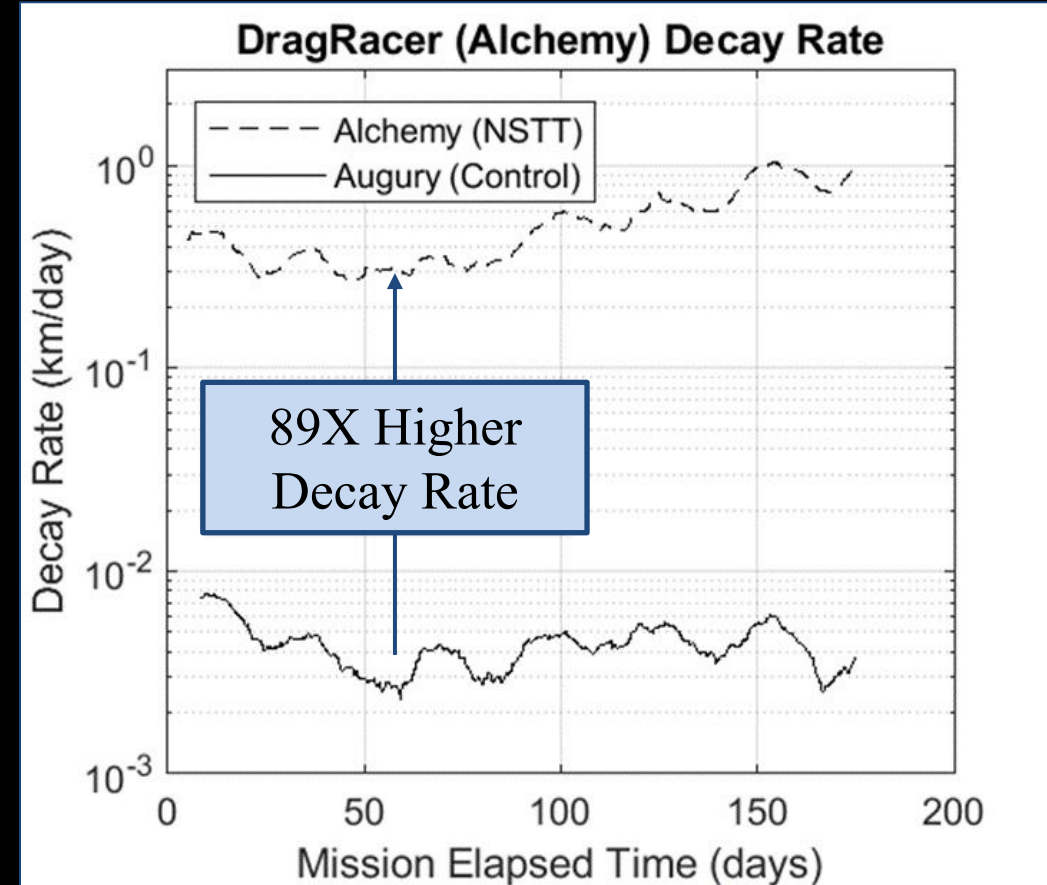
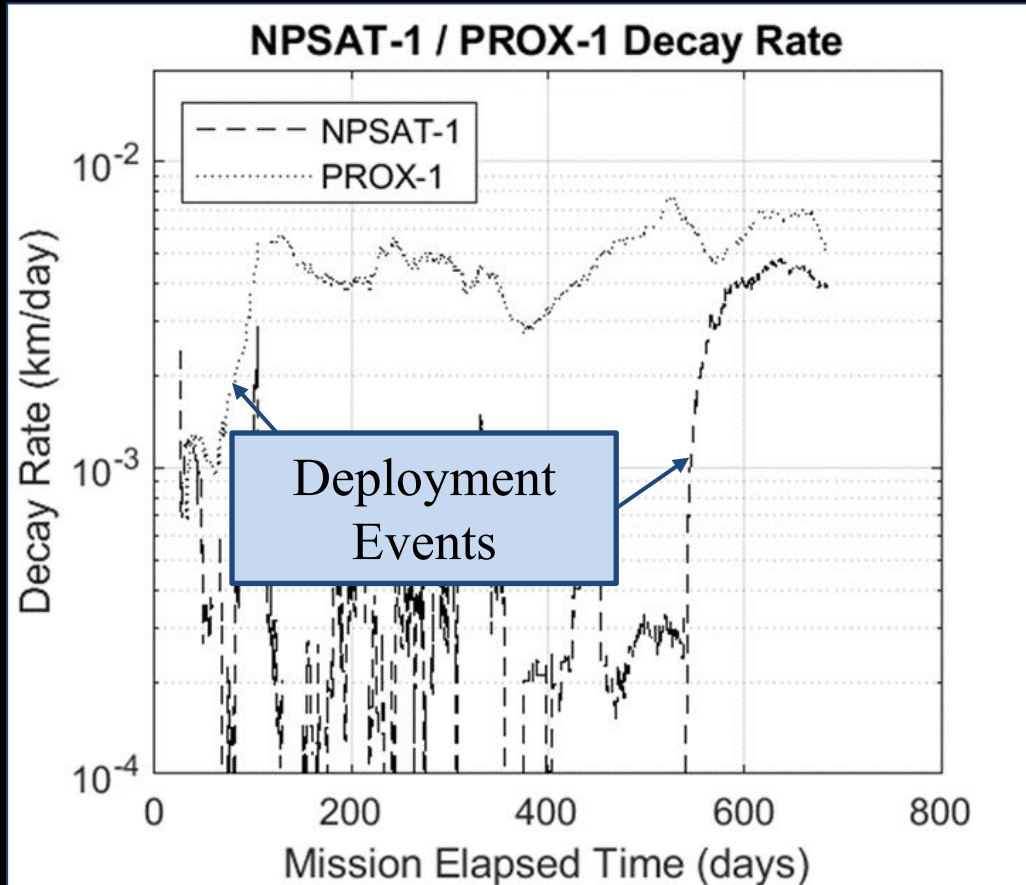
Flight data shows three successful on-orbit deployments (no failures)



Craft (Mission)	Deploy Date	CAT ID
PROX-1 (STP-2)	09/23/2019	44339
NPSAT-1 (STP-2)	12/24/2020	44340
Alchemy (DRAGRACER)	11/21/2020	46954



Decay Rate & Performance



The Effect of Passive Deorbit Devices

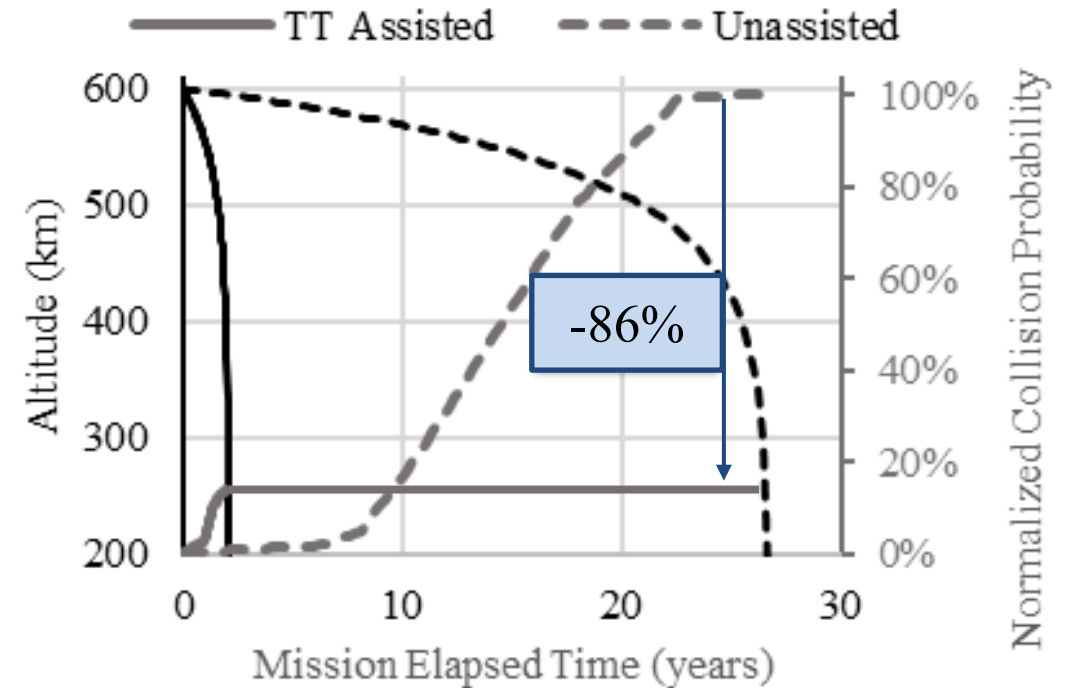
Area-Time Product

$$Risk_{collision} \propto (time_{deorbit}) * (area)$$

vs.

$$Risk_{collision} \propto area \int_0^T f_{growth}(t) dt$$

TIME-WEIGHTED COLLISION PROBABILITY



Present time spent on orbit carries much lower risk than future time on orbit.



The Case for Terminator Tape



Flight Proven



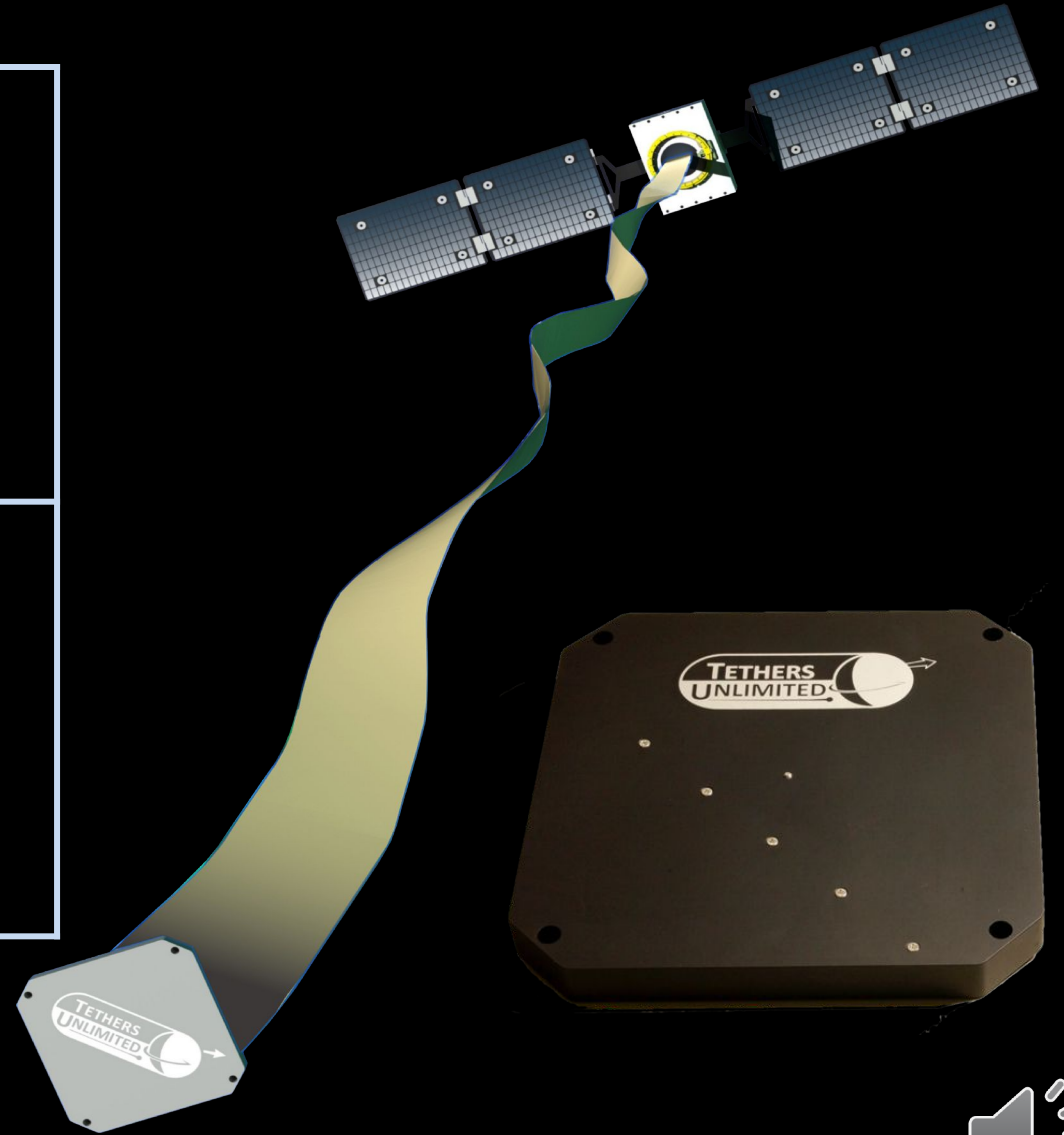
Reduces Cost



Single Command;
No Overhead



Timer Module
(Ease/Redundancy)



Regulatory Compliance



- In recent years, the USGOV Orbital Debris Mitigation Standard Practices (ODMSP) have been updated.
- Tethers Unlimited evaluates compliance with these standards on a case-by-case basis.

#	Description	Threshold	Terminator Tape Compliance
3-1	Collision with large objects during orbital lifetime	< 1 in 1000	1 in 209,604 (Alchemy/Dragracer) [DAS]
3-2	Collision with small debris during mission operations	< 1 in 100	Membrane is perforation survivable
4-1b	Atmospheric re-entry	25 years post-mission	NSTT increased initial decay rate 89X Will re-enter in seven months with NSTT (vs 12.2 years without)
4-2	Reliability of disposal	0.9 (0.99 goal)	100% success rate

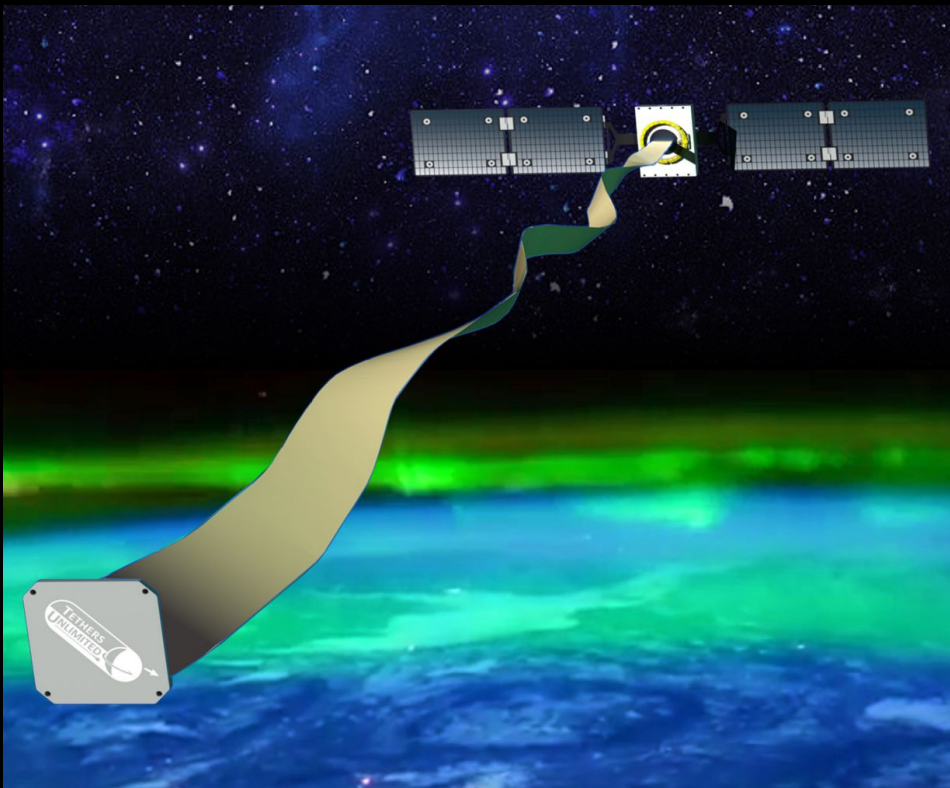


Closing Remarks



Summary of On-Orbit Performance

- Successful deployment of three Terminator Tape units.
- Performance characterization is underway with expected values in range of predictions.



Acknowledgements

- Millenium Space Systems (a Boeing Company)
- TriSept
- Rocket Lab
- SpaceX
- AFRL University NanoSat Program
- Naval Postgraduate School
- Georgia Tech

