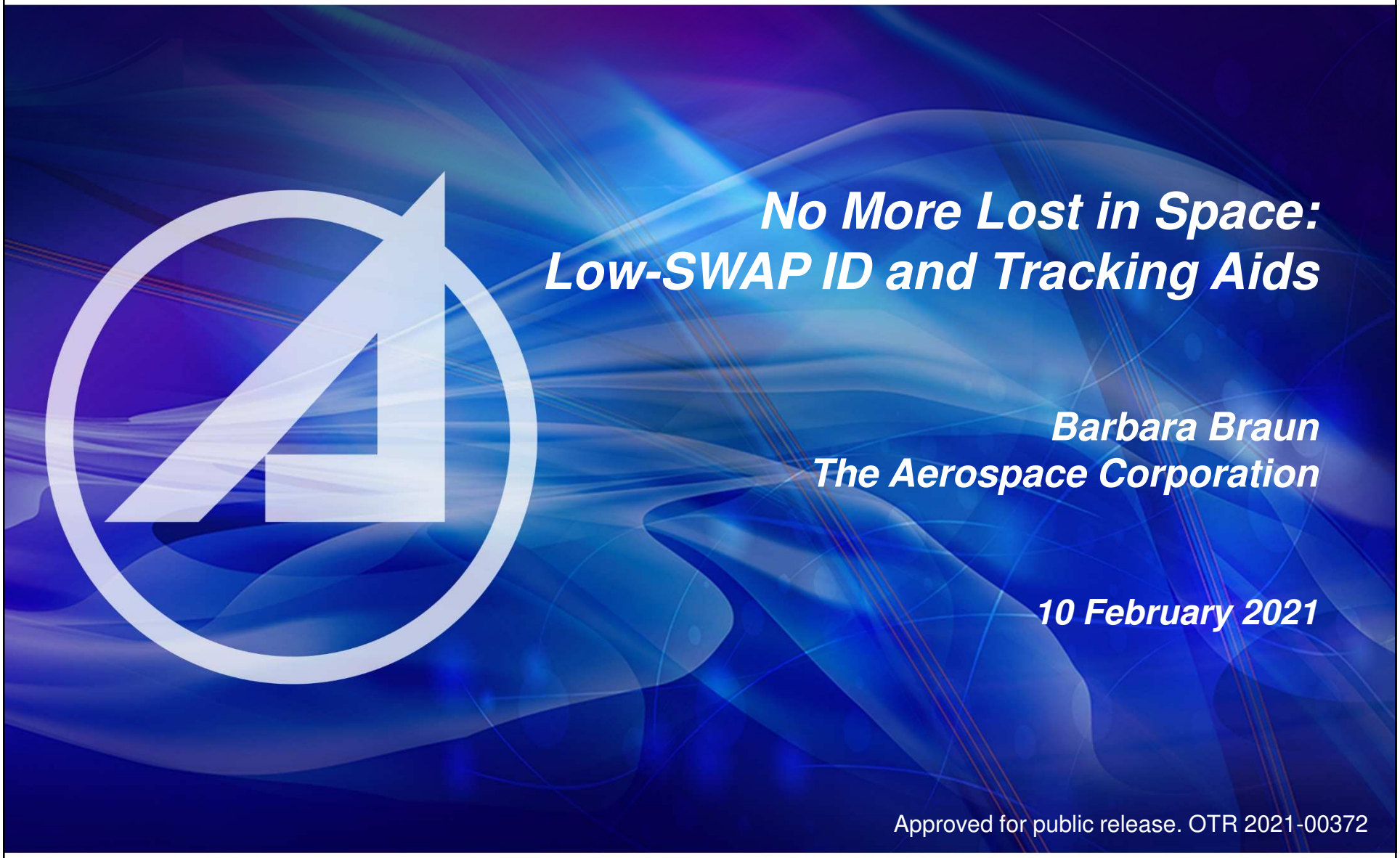


No More Lost in Space: Low-SWAP ID and Tracking Aids

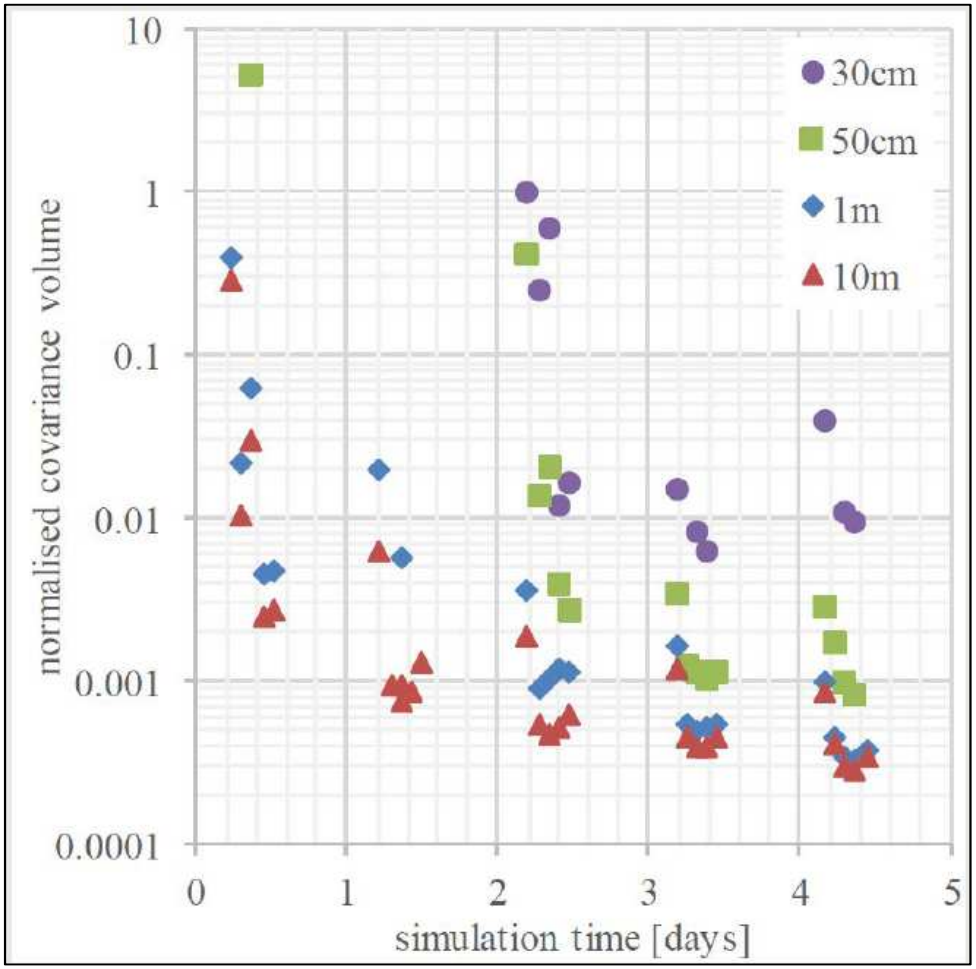
Barbara Braun
The Aerospace Corporation

10 February 2021

Approved for public release. OTR 2021-00372

The Problem

- CubeSats and other very small satellites can be hard to identify
  - *Smaller and less trackable*



Letizia, Francesca, *Results from ESA's Annual Space Environment Report, July 2019*, presented as a key-note address at the Advanced Maui Optical and Space Surveillance Technologies Conference, held in Wailea, Maui, Hawaii, September 2019

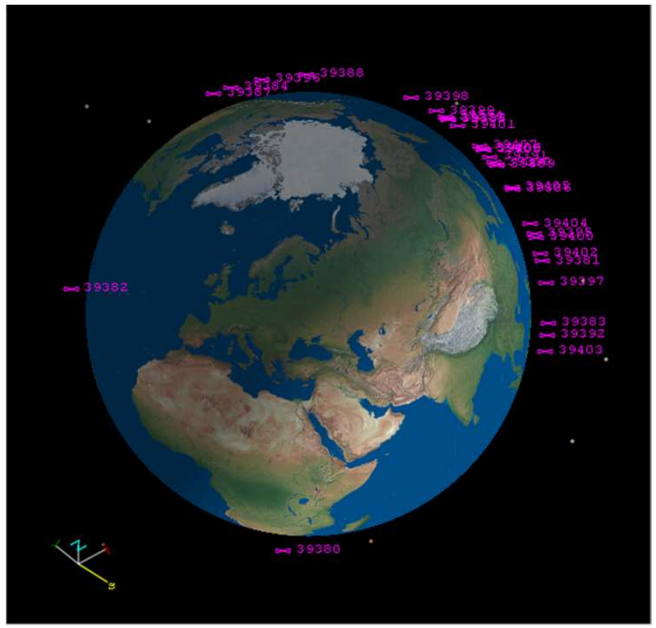
The Problem

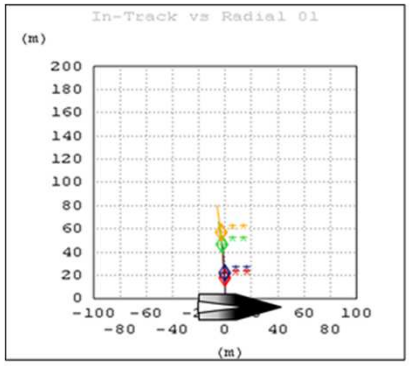
- CubeSats and other very small satellites can be hard to identify
  - *Smaller and less trackable*
  - *Standardized size – hard to distinguish on orbit*

Credit: NASA

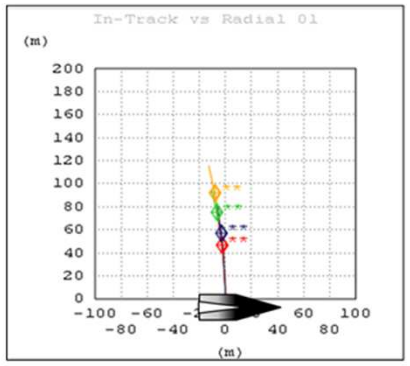
The Problem

- CubeSats and other very small satellites can be hard to identify
  - *Smaller and less trackable*
  - *Standardized size – hard to distinguish on orbit*
  - *Often deployed in large numbers from a single vehicle, with little separation*

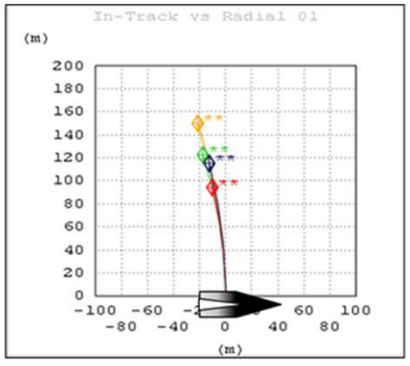




~20s after deployment of 2nd pair of CubeSats



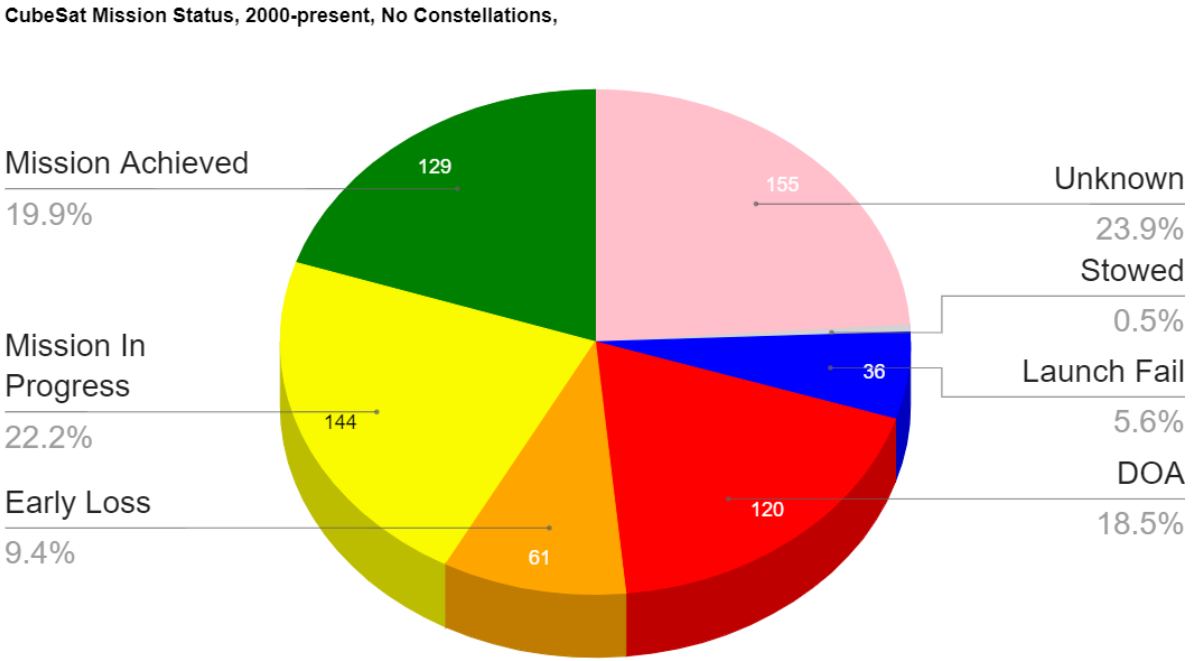
~50s after deployment of 2nd pair of CubeSats



~100s after deployment of 2nd pair of CubeSats

The Problem

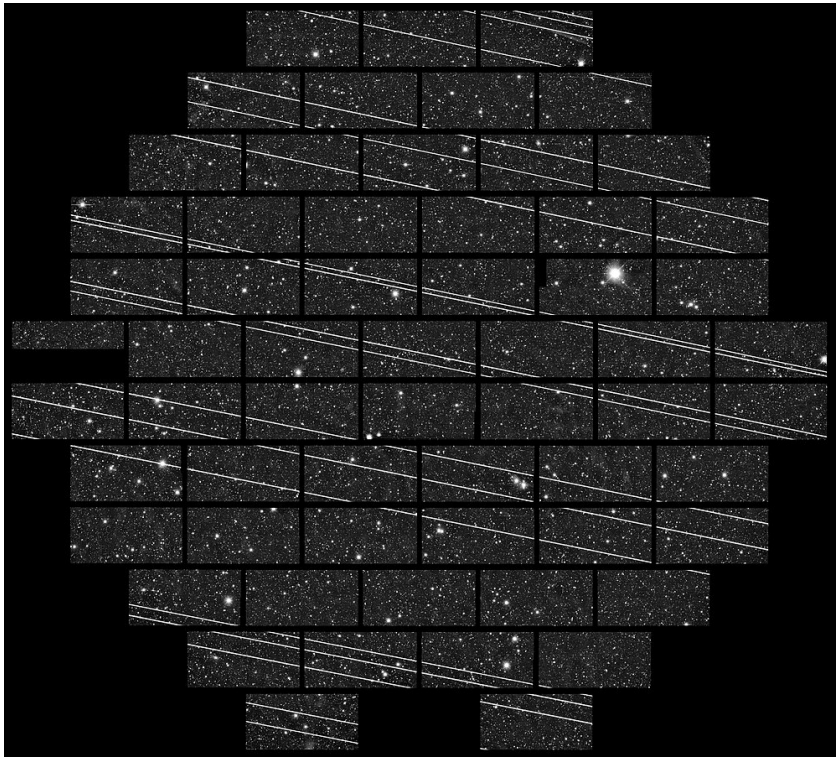
- CubeSats and other very small satellites can be hard to identify
  - *Smaller and less trackable*
  - *Standardized size – hard to distinguish on orbit*
  - *Often deployed in large numbers from a single vehicle, with little separation*
  - *Sometimes dead on arrival*



Credit: M. Swartwout, https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

Another, Newer Problem?

- Constellations are starting to conduct autonomous maneuvers
  - *Using uploaded conjunction information*
  - *This allows efficient collision avoidance*
  - *But it means that a satellite's current trajectory might change without notice*

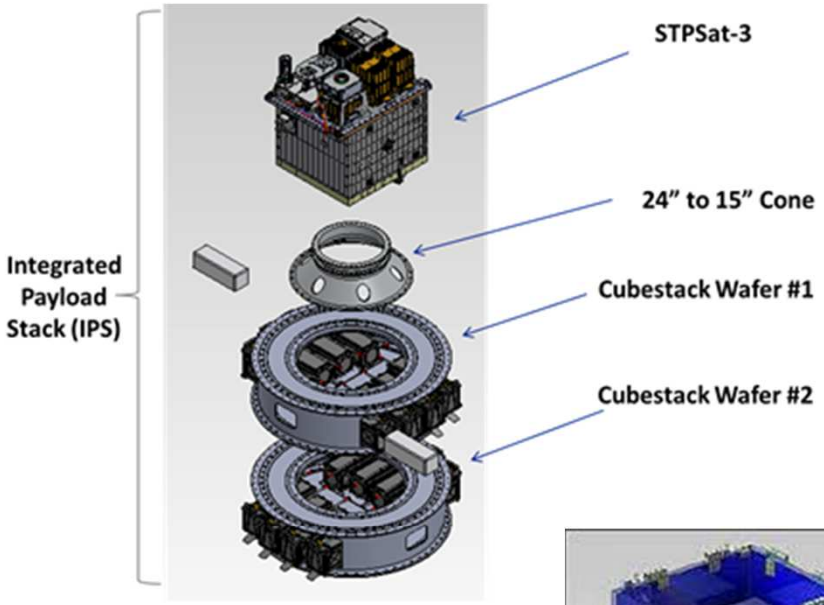


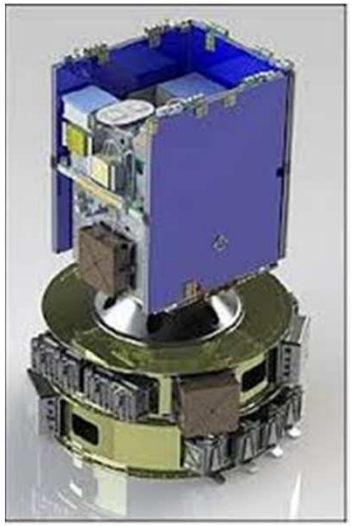
Credit: CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey

An Early Example

ORS-3 Mission

- Partnership between STP and the Operationally Responsive Space (ORS) office
- Launched on a Minotaur I on 19 November 2013
- Manifest included STPSat-3 and 28 CubeSats
  - *CubeSats deployed from two "wafers" mounted beneath STPSat-3*
  - *CubeSats provided by many organizations, from high schools to the DoD*





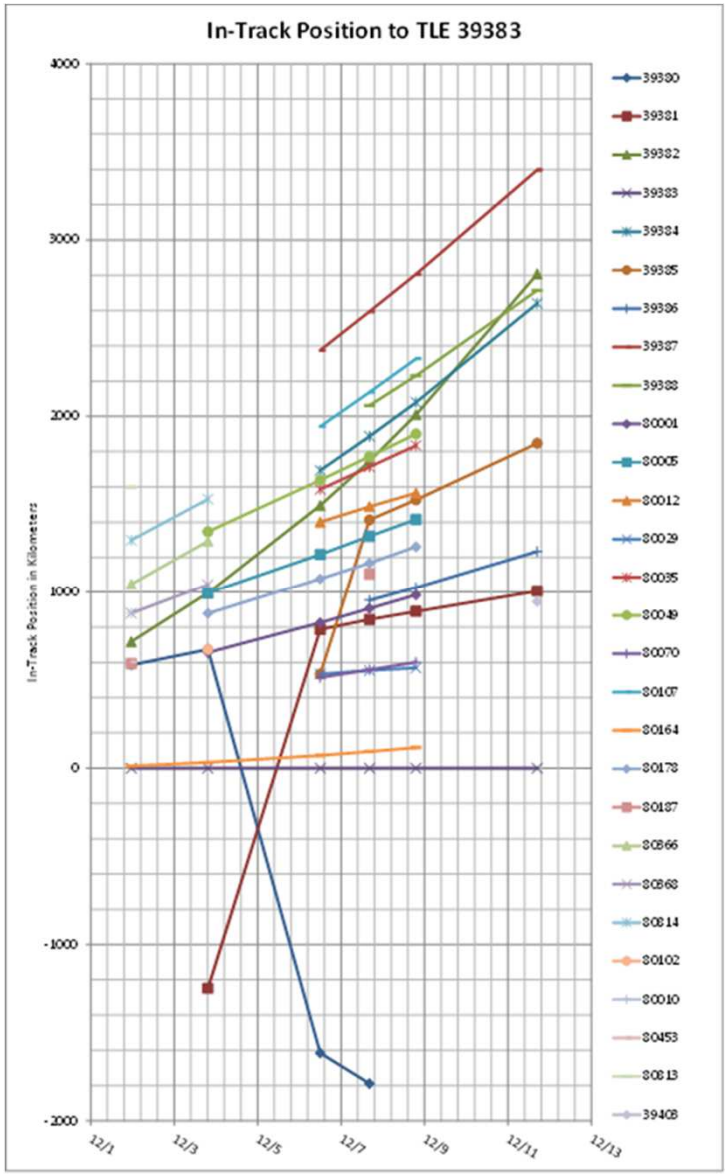
Braun, B. & S. Herrin. (2016). *The more, the messier: ORS-3 lessons for multi-payload mission deployments*. 1-10. 10.1109/AERO.2016.7500582.

Held the record for the most satellites deployed from a single rocket – for one day

An Early Example

ORS-3 Mission

- Issues with
  - *Cross-tagging*
  - *Mis-tagging*
  - *Unresponsive satellites*
  - *Identifying "owners" of TLEs*
- Took almost three months to identify all satellites



More Recent Examples

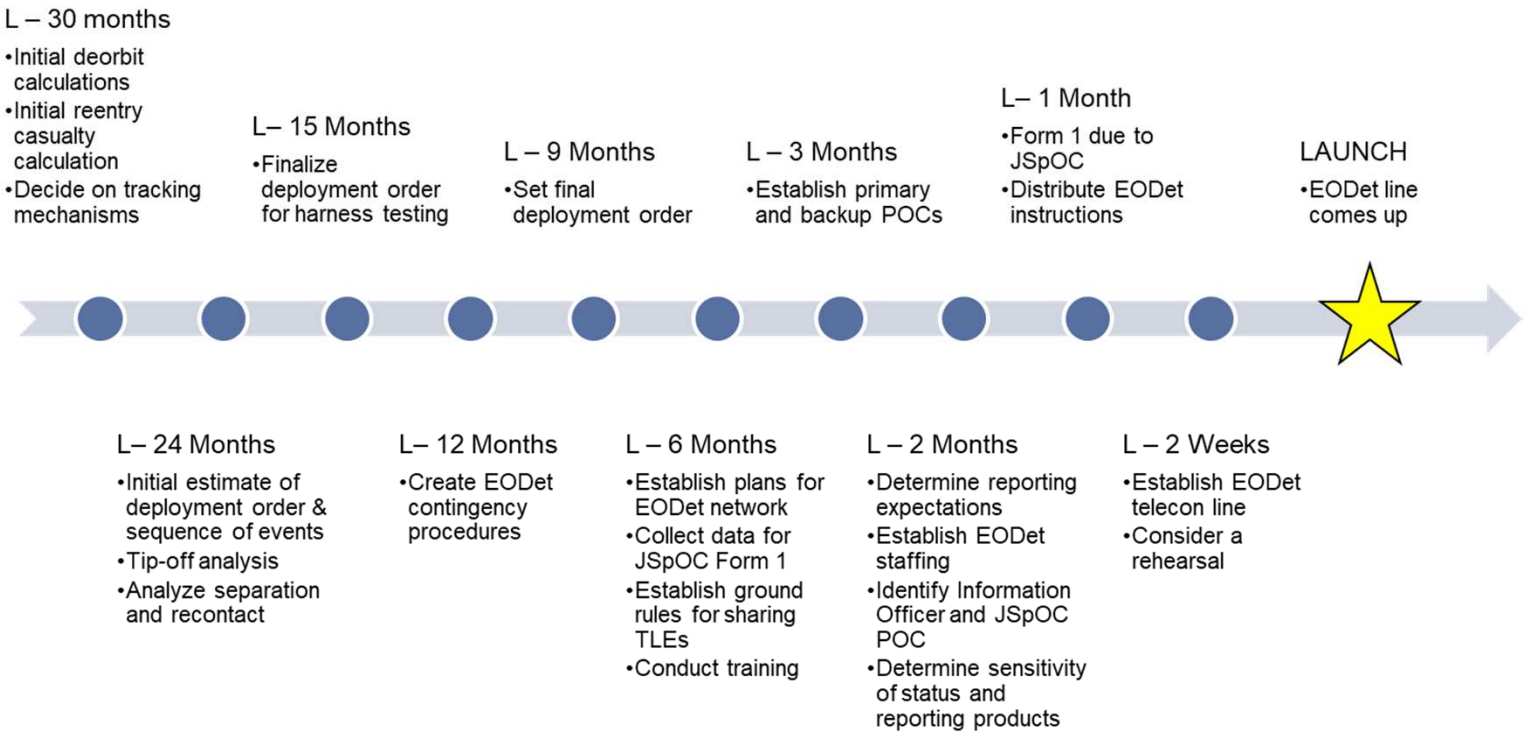
- SSO-A
  - *55 tracked objects*
    - 15 Micro Satellites
    - 48 CubeSats
    - Two free-flying deployment platforms
  - *87% of spacecraft contacted by their owner within 24 hours of launch*
  - *94% of spacecraft ultimately contacted by owning agencies*
  - *As of 26 June 2019, 12 unclaimed objects*
- Recent SpaceX Starlink Launch

Credit: SpaceX

Improving Identification

Process Improvements

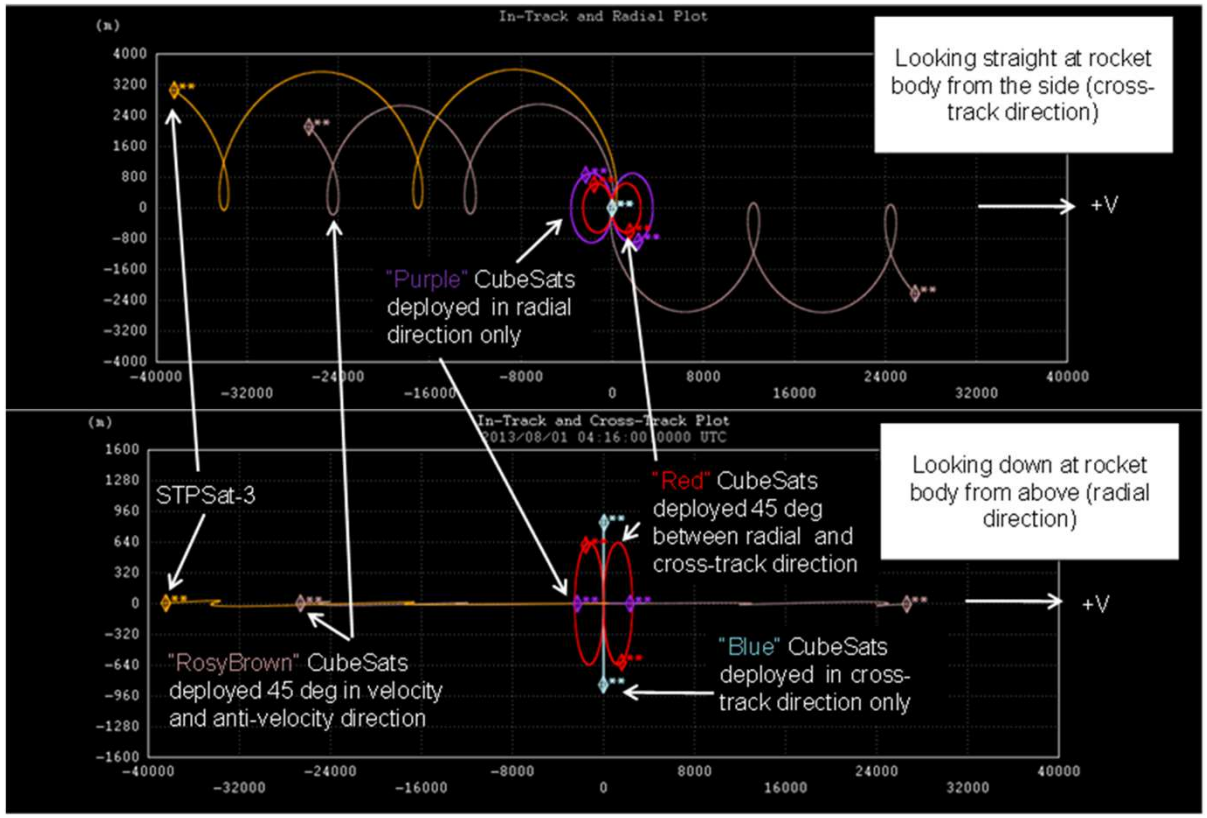
- Good coordination with tracking agencies pre-launch
- Community sharing of TLEs and other position data in clearly-defined, consistent formats
- Careful consideration of deployment direction and timing
- Post-launch coordination



Improving Identification

Design Improvements

- Good design and development choices
  - *Understand the scope*
  - *Test, test, test*
  - *Design for simplicity*
  - *Overdesign*
  - *Have robust safe modes*
  - *Consider backup communication systems*
- Good launch choices
  - *Delays between deployments*
  - *Deployment with along-track components*



Braun, B. & S. Herrin. (2016). *The more, the messier: ORS-3 lessons for multi-payload mission deployments*. 1-10. 10.1109/AERO.2016.7500582.

Low-SWAP ID and Tracking Aids

Several Technology Schemes

- **CubeSat position and ID via radio**
- **Coded light signals from light source on exterior of CubeSat**
- **Radio frequency interrogation of an exterior Van Atta array**
- **Laser interrogated corner cube reflectors (CCR)**
- **Passive increase of albedo**

CubeSat Position and ID via Radio

- A position, navigation, and timing (PNT) receiver is attached to a CubeSat, along with a radio to transmit the information via a LEO communications provider
  - *Pros: most complete data*
  - *Cons: most complex, highest SWAP*

BlackBox, by by NearSpace Launch, Inc

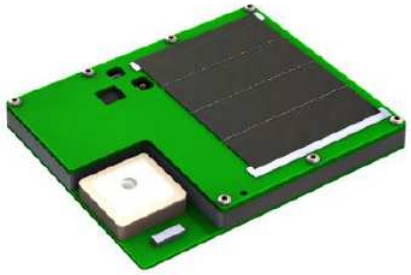


Fig. 4a. Thin Patch or Stamp Black Box for side mounting

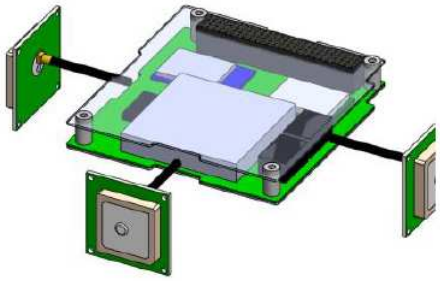


Fig. 4b. PC104 Black Box for internal stack mounting

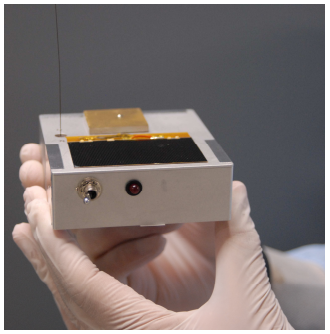
Fig. 4c. "Standard" Black Box for larger satellites. TRL 9: flown on Spaceflight launch. Solar Array and Antennas not shown.

Voss, H.D. et. al., "Black Box" RF Sat-Link for Space Debris, Mission Success and Risk Mitigation¸ First International Orbital Debris Conference, Sugar Land, TX (2019).

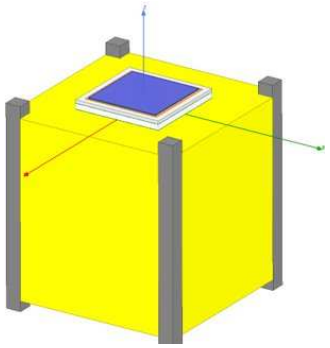
CubeSat Position and ID via Radio

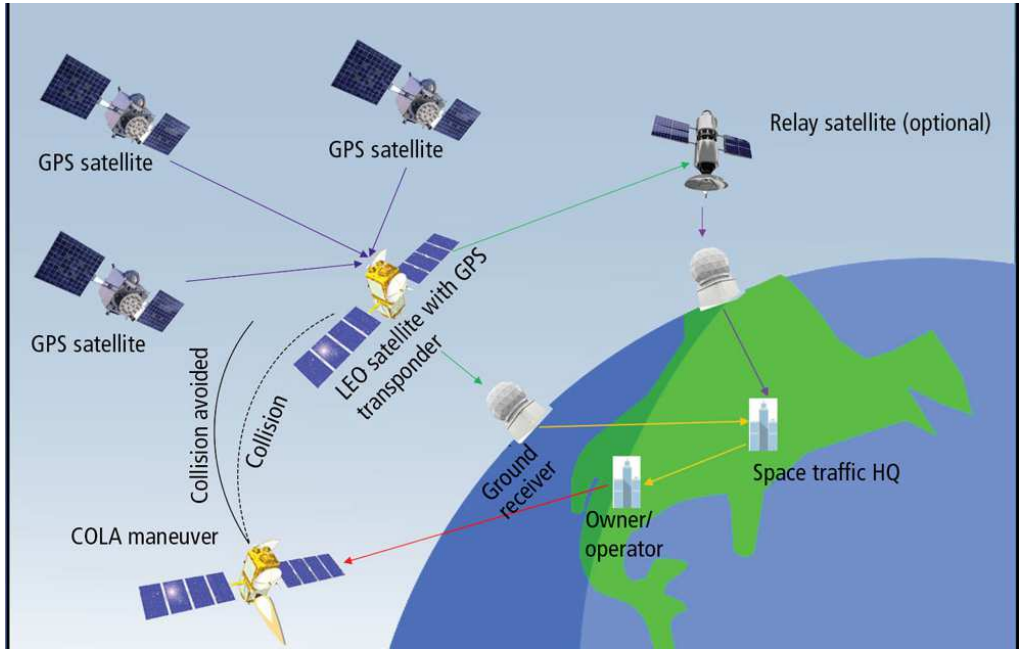
- Blinker (Aerospace Corporation)
  - *Transmits positive ID and GPS state often*
  - *Survives independently from host for years*
  - *Can provide host with real-time measurements*
  - *Includes event-triggering via IMU chip*
  - *Encryptable data*
  - *Prototype v1.0 to be flown in 2021*

GPS Transponder Prototype v1.0



GPS Transponder Prototype v2.0 mounted on 1U





Abraham, A.J., "*GPS Transponders for Space Traffic Management*," Center for Space Policy & Strategy, Aerospace Corporation, April 2018.

Coded Light Signals

- Exterior-mounted LEDs using larger aperture telescope to receive; or
- Diffused LED laser using ground-based photon-counting camera
  - *Pros: Can identify satellite through LED flash pattern, low power*
  - *Cons: Current implementations are large, requires power (can be independent of main satellite), specific ground-based sensor, clear skies, attitude control?*

ELROI, Los Alamos National Laboratory

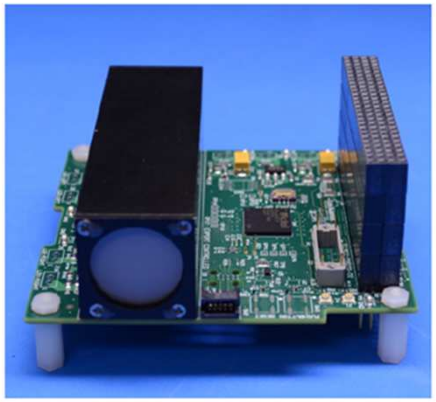


Figure 3 The ELROI-PC104™ beacon unit that was installed on NMTSat.

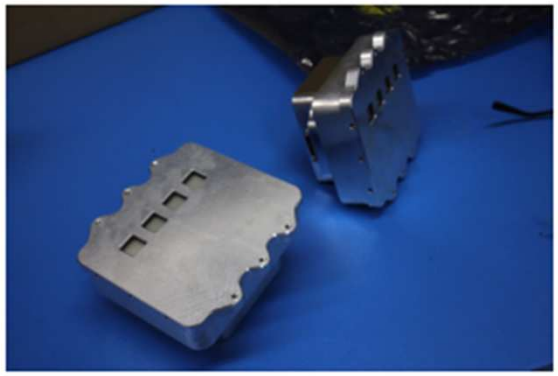
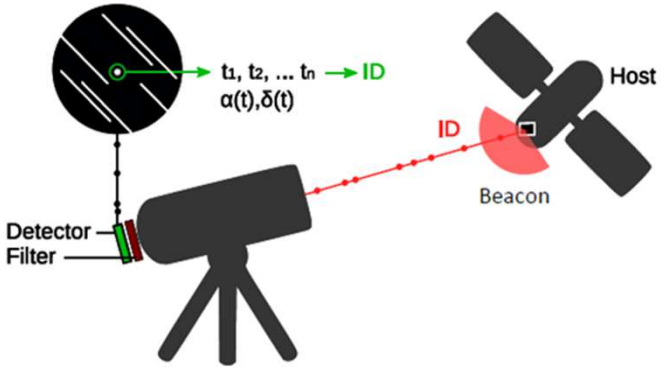


Figure 4 Two ELROI™ beacon units delivered for a launch in 2021.



Palmer, D.M., et. al., "*Progress Towards the ELROI™ Satellite License Plate",* SSC20-VI-05, 34th Annual Conference on Small Satellites, Logan, UT (2020).

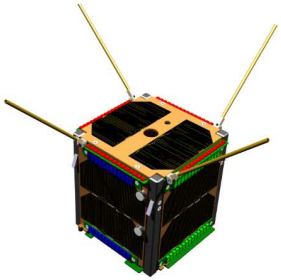
Coded Light Signals

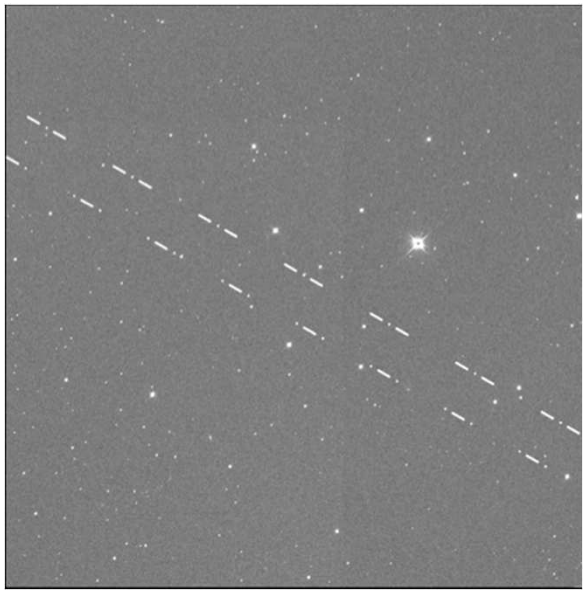
LEDSat

LEDSat

Sapienza

University of Rome





Simulation of two LEDsats crossing astronomical image.

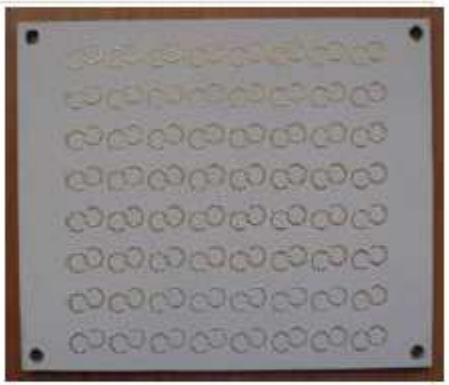
- **Track optically while in Earth shadow.**
- **Small telescopes – lots of amateur and professional facilities worldwide.**
- **Telescope tracks stars – simpler!**
- **Optical resolution of a few arc-seconds.**
- **Different flash patterns for different satellites means distinguish different satellites immediately after deployment.**
- **If system independent of main payload, continue to work if main payload fails. Use LEDs to transmit telemetry.**
- **Encode time in flash pattern for orbit determination – short flashes have same width as stars – excellent astrometry!**
- **No radio, no FCC license required.**

*Seitzer, P. et al., "*LEDsats: LEO Cubesats with LEDs for Optical Tracking", *AMOS 2016 Technical Conference*

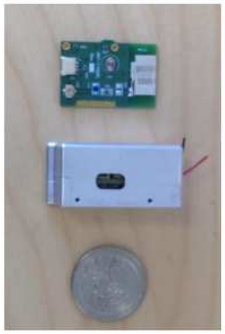
Van Atta Arrays and RF Interrogation Receivers

- A small RFID tag (or tags) is affixed to the outside of the CubeSat, and then a coded signal is received when the tag passes through a beam of radio frequency energy with the appropriate wavelength
  - *Pros: Low (or no) power required, works day or night*
  - *Cons: Requires RF ground source of appropriate wavelength*

Nanosatellite Tracking Experiment (US Navy)



Van Atta array Retro-reflector in the Ku-band, fits standard 1U panel, tuned to HAX RADAR frequency.



(Above) CUBIT tag with quarter as size comparison.

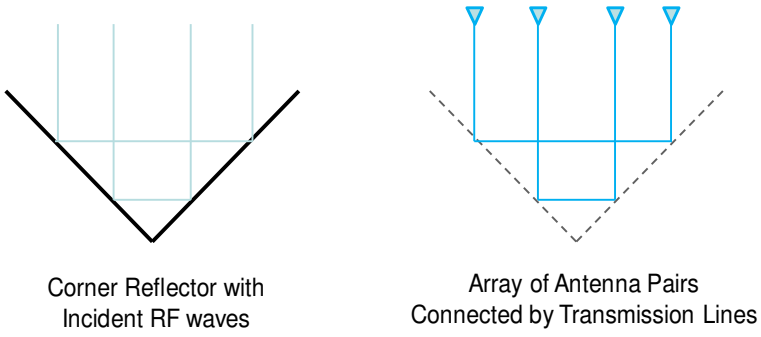
(Right) CUBIT components assembled for operation.

CUBIT (SRI International)

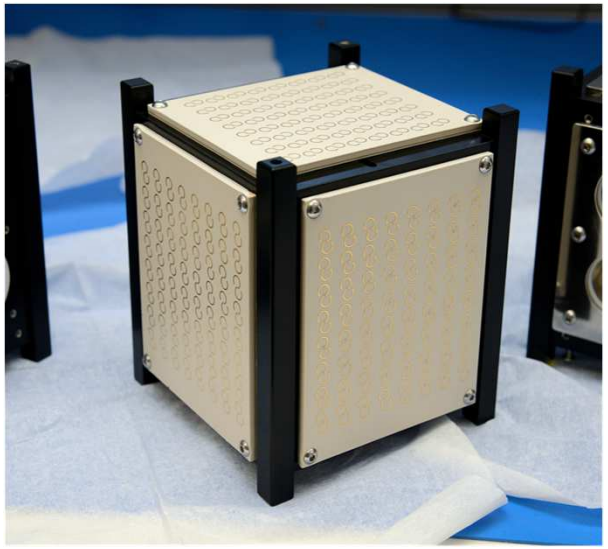
CUBIT "SRI International's CubeSat Identification Tag (CUBIT): System Architecture and Test Results from Two On-Orbit Demonstrations," SSC19-XI-05

Passive Retro-Reflectors

- Passive Retro-Reflectors
  - *NTE is based on a novel Van Atta Array design*
  - *Behaves similarly to a three-dimensional corner reflector, but with a flat form factor*
  - *May be attached to the underside of solar panels and/or unused external surfaces on a smallsat chassis*
  - *Improves Radar Cross Section at all aspect angles*
    - The radar return of a flat metal plate drops off significantly at only a few degrees from normal (90 degrees)
    - Retroreflectors provide similar return at normal, but the drop off is much less



A corner reflector (left) and a Van Atta Array Retro-reflector (right).



1U STAR-3 satellite with NTE retro-reflector panels.

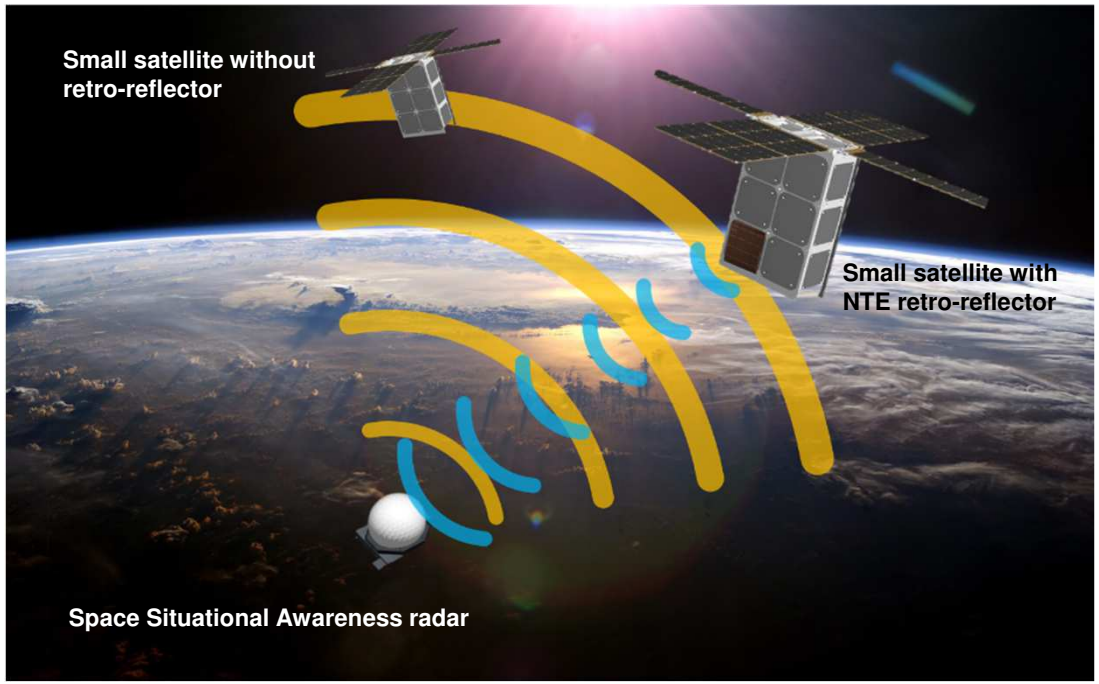
Passive Van Atta Array retro-reflectors are flat, and small enough in the Ku- and X-band that they may be easily integrated into small satellites to improve tracking for SSA

Courtesy: Naval Information Warfare Center

Nanosatellite Tracking Experiment (NTE)

Objective: Develop and test passive retro-reflectors for improved detection, tracking and identification of small satellites for improved Space Situational Awareness (SSA)

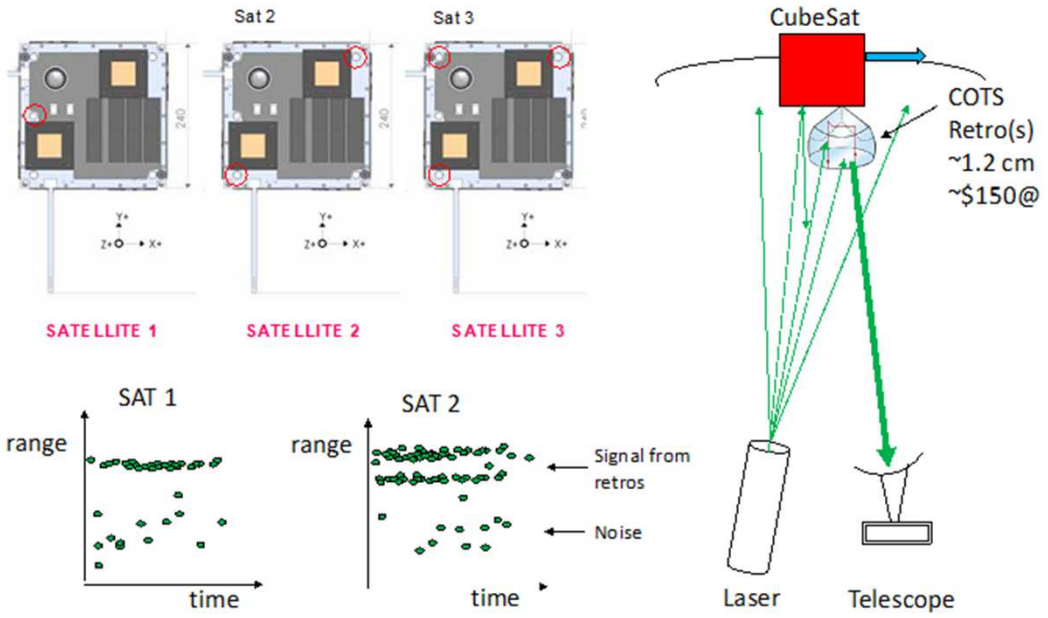
1) *A Ku-band retro-reflector is integrated onto a small satellite and launched in to Low Earth Orbit*
2) *A ground based radar (MIT Lincoln Laboratory Haystack Observatory) illuminates the small satellite*
3) *The radar return is collected and analyzed*
4) *The ability to track a smallsat with a retro-reflector is compared against one without*
5) *Currently developing a modulation capability for the radar return to be used as a unique identifier*



Courtesy: Naval Information Warfare Center

Corner Cube Reflectors and Increasing Albedo

- Corner Cube Reflectors:
  - *A special mirror designed to reflect laser light back in the direction from which it arrived*
  - *Pros: Very common, high-TRL, low SWAP, no power required*
  - *Cons: Does not uniquely ID all satellites, requires laser illumination for best results*
- Use of tapes, high-albedo paint, etc. to increase visual magnitude
  - *Pros: Simple, low or virtually no SWAP*
  - *Cons: Does not uniquely ID satellite, may not be sufficient to compensate for small size*



Credit: The Aerospace Corporation

The Future?

- Identification on every satellite
- GPS data autonomously reported over space links
- Data fusion merges ground-based, space-based, and self-reported tracking info
- Norms of behavior for resolving conjunctions (“both turn to the right”)
- VFR and IFR-style “flight rules”
- Autonomous collision avoidance
- Rapid removal after mission life

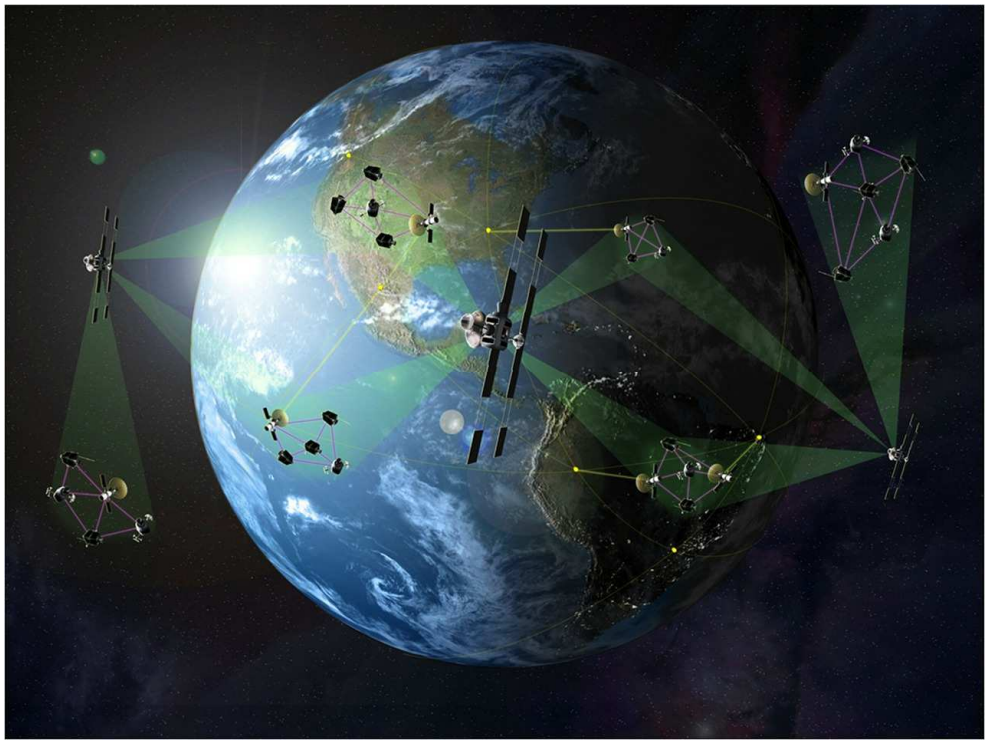


Image from Pixabay

The Present

How to Make Things Better Right Now

- Improve coordination with tracking agencies
- Consider deploying for trackability
- Improve reliability of CubeSats – at least for basic functionality
- Consider low-SWAP tracking aids
- Improve ground-based interrogation systems
- Implement common standards for data sharing
- Develop norms of behavior
- Communicate!

Credit: The Aerospace Corporation

References and Credits

- Letizia, Francesca, *Results from ESA's Annual Space Environment Report, July 2019*, presented as a key-note address at the Advanced Maui Optical and Space Surveillance Technologies Conference, held in Wailea, Maui, Hawaii, September 2019
- Swartwout, Michael, Cubesat Database, https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database, accessed 25 January 2021
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- Phan, Samson, "Spaceflight Industries' SSO-A Flight Launches with SRI International's CUBIT Technology Onboard, Developed to Track and Identify Low Earth Orbit Satellites," https://www.sri.com/blog/spaceflight-industries-sso-flight-launches-sri-internationals-cubit-technology-onboard, retrieved 10/30/2019.

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