CENTER FOR SPACE STANDARDS & INNOVATION

CubeSat Orbital Debris Policy Solutions and SSA

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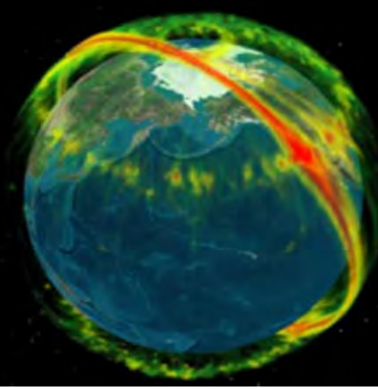


Committee on Achieving Science Goals with CubeSats
National Academy of Sciences, Engineering and Medicine
30 October 2015

Discussion topics

- Key CubeSat vs debris policy issues & solutions
  - Cheap to manufacture ≠ Cheap to [properly] fly
  - CubeSats & space debris: perception vs reality
  - Why avoid collisions? What's the big deal?
  - Role of international & university standards & norms
- Role of the private sector
- Policy lessons drawn from other domains

In what sense are small satellites low cost ?

- Cheap to manufacture ≠ Cheap to fly
- Smallsats enable cost-constrained organizations to fly S/C
  - Cheap to make: mass-producible, repetitive, simple design
  - Kits available at component, subsystem, and satellite level
- Reality: satellite operations & debris mitigation using best practices & norms are not cheap
  - Low-thrust deorbit technology not fully mature and costs $$
  - CubeSat and small satellite operators often don't know, or know well, their own orbits and attitude; doing so costs $$
  - Dedicated launches, Safety-of-Flight (SoF) screening, RFI avoidance and responsible deorbit cost $$

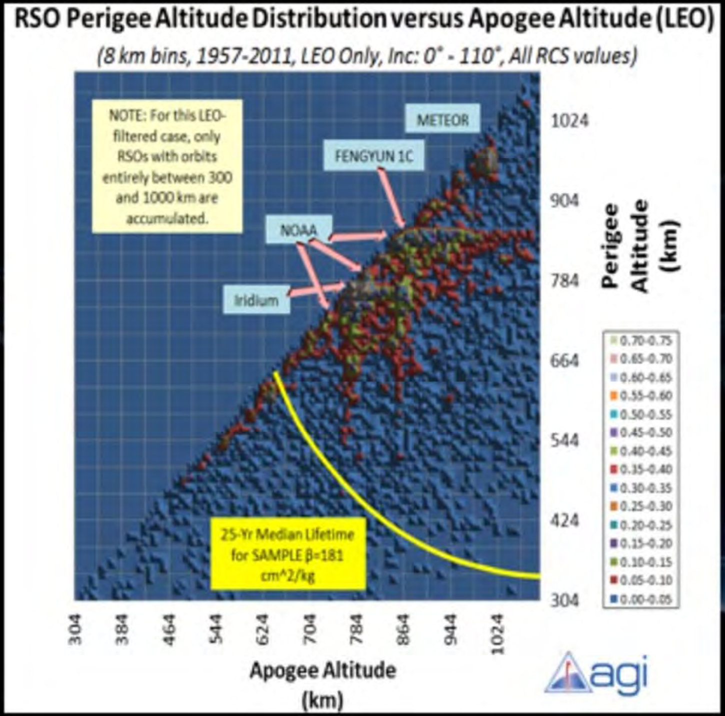
CubeSats & debris: perception vs reality

Issue	Misperception	Reality	Why?
CubeSats = high percent of catalog	✓		0.7% of current RSO catalog, yet only 0.07% of 2 cm catalog. But must improve our CubeSat record!
CubeSats are just debris	✓		True if not properly disposed of post-mission, but they can serve vital missions just as large S/C can. Large S/C have much more mass & will generate more debris if hit
CubeSats have flown inappropriate secondary payload orbits		✓	By 2011, half of CubeSats were placed in > 25 yr orbits. Yet larger space actors had 40% > 25 yr from 2000-2012*
CubeSats have much lower collision risk due to their small size	✓		Collision probability a function of combined hardbody radius; infinitesimally-small S/C still have collision risk
CubeSats don't impinge on others	✓		Any space object, whether large or small, can impinge on other space operators
CubeSats are built & operated by novices	✓	✓	Some CubeSat designers, builders and operators are extremely experienced and prudent; others not as much
CubeSats are like a "bullet" w/longer lifetimes than larger S/C	✓		For equivalent-density shapes, drag is inversely proportional to lineal dimension

Oltrogge and Leveque, "An Evaluation of CubeSat Orbital Decay," SmallSat Conference, SSC11-VII-2, Logan UT

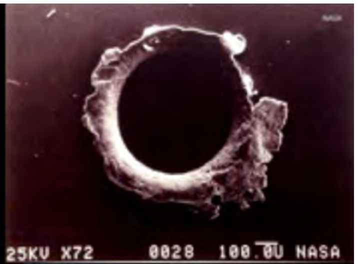
Resident Space Object (RSO) Distribution

- CubeSats coexist with a "backdrop" of LEO RSOs

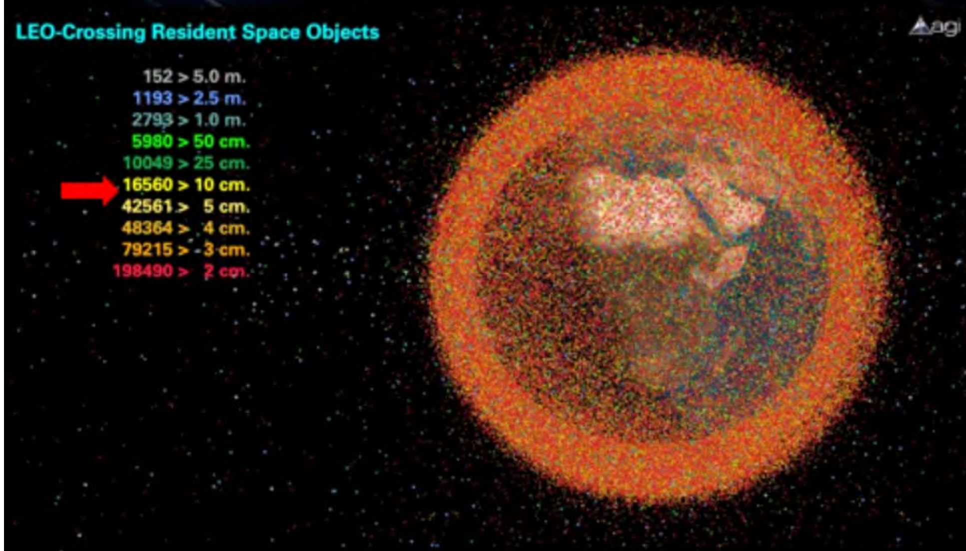


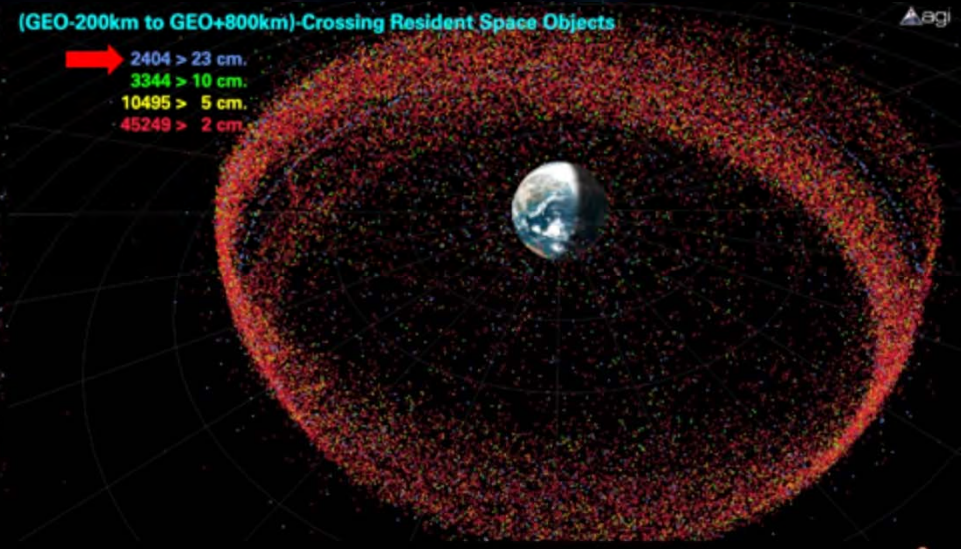
Oltrogge and Kelso, "Getting To Know Our Space Population From The Public Catalog, AAS 11-413

Current public catalog is incomplete



- Based on MASTER 2009, current RSO catalog
  - Contains only 6.6% of LEO-crossing objects > 2 cm
  - Contains only 3.6% of GEO-crossing objects > 2 cm





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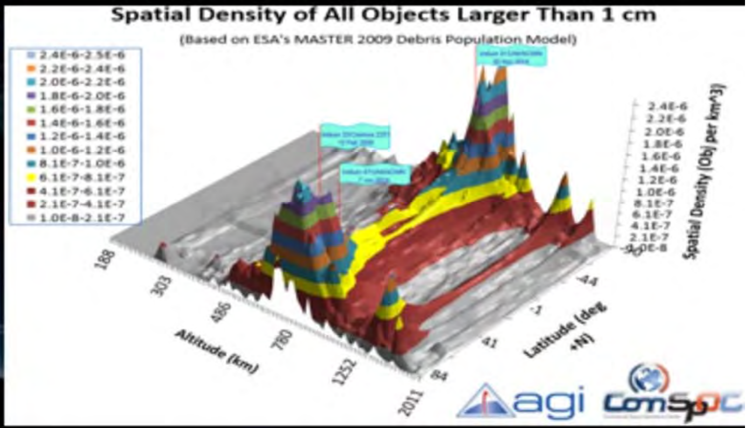
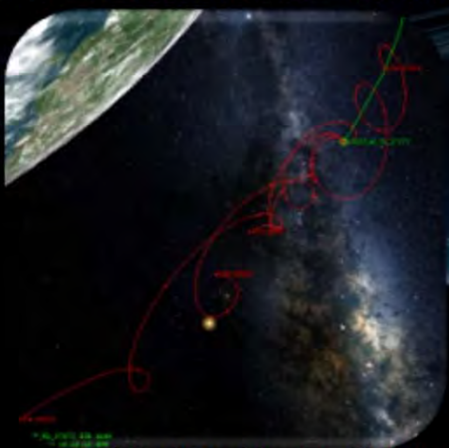
Iridium's Experience Post-Iridium33/Cosmos

- Twelve 2014 debris-generating events
  - Two were Iridium fragmentations
  - Iridium-47 & -91 collisions occurred in high spatial density post-Iridium-33 kill zone
  - No publicly-tracked "colliders" found

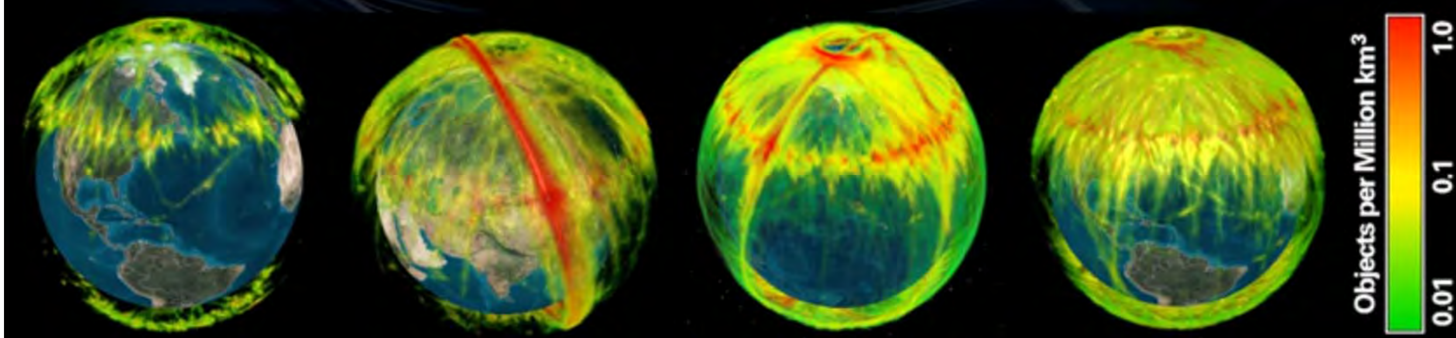


Once created, such high-density zones are ≈ permanent



On the slippery slope…

- In the past decade, RSO spatial density has increased by two orders-of-magnitude
- The time to set a new course is <u>now</u>



2005 | 2007: Feng Yun 1C | 2009: Iridium/Cosmos | 2015

https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0CAcQjRxqFQoTCN7u7-DH6cgCFUcWPgod4hkKrA&url=http%3A%2F%2Fwww.ejectionsite.com%2Fthunderbird6.htm&psig=AFQjCNEjXQSxewevfmj3XFI-XK9RWDvnaQ&ust=1446272679319716

CubeSat and smallsat standards & norms of behavior can start us on that new course

- University-led standards
  - CubeSat Design Spec devel by 60 universities & high schools
    - Covers deployment systems, testing, board interfaces, mass prop.
  - Configuration controlled yet responsive
  - Free, dynamic & evolved to a mature state
- International norms & stds (UN, IADC, ISO, CCSDS, ANSI)
  - Rigorously developed and internationally-coordinated
  - Multi-year development cycles
  - Purchasing standards may be cost-prohibitive for universities

A Regulatory Wrinkle: What is a small satellite?

- No international set of demarcations or definitions achieve consensus reflecting what constitutes a "small satellite"
  - Dimensions
  - Mass
  - Complexity
  - Capabilities and functionality
  - Performance & reliability
  - Developer or operator flight experience, heritage
- Standards w/demarcations invite gamesmanship & unfairness
  - Two satellites a gram apart could be treated very differently!

ISO small satellite standards development

- CubeSat operators seeking greater legitimacy must adhere to norms for space operations, space safety and RFI mitigation
- When codifying such norms, must decide whether to:
  1. Enhance overarching standards to address unique smallsat aspects;
  2. Develop smallsat-unique standards in parallel w/big satellite versions

Special Small Satellite Standards

- More approachable by universities
- May be cheaper to procure standards
- More concise, less repetition, easier to navigate

?

Consolidated, unified standards

- Easier to develop, maintain and evolve standards
- More complete
- Less confusion about which standards apply

What smallsat-unique standards are useful?

- Small satellite form factor, hardware, interfaces
  - CubeSat Design Spec 16 Apr 2015 (1U – 12U, etc.)
  - PocketQube
  - But we recognize university/HS success w/CubeSat Design Spec
- Small satellite testing

(?)

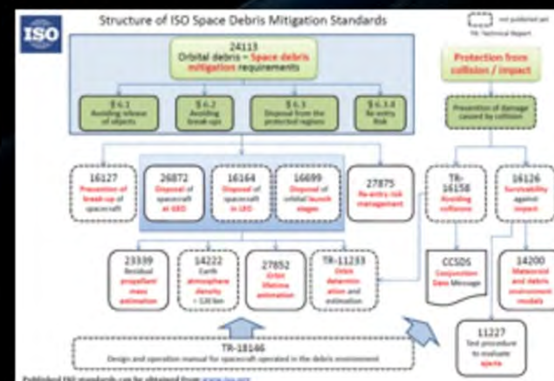
  - Smaller objects have fewer modes, less complexity
- Small satellite programmatic & operational aspects
  - management
  - operations
  - debris mitigation

Why consider smallsat-unique testing stds?

- ANSWER: OMIT COUPLED LOADS ANALYSIS
- Greatly simplifies secondary payload incorporation
  - For big boosters, booster/satellite coupled loads analyses not required below ≈ 50 kg
  - For smaller boosters, mass threshold can be << 50 kg
- Launch provider ultimately responsible for deciding what they can and cannot ignore

Standards for responsible deployment and flight

- International Standards Organization (ISO) has codified most IADC guidelines
  - ISO 24113: Overarching debris mitigation
  - ISO 27852: 25 year LEO orbit lifetime



- Small satellite-relevant:
  - ISO 17770: CubeSats
  - ISO 22644: Orbit Data Messages (ODMs)
  - ISO 16164: Disposal of LEO-crossing spacecraft
  - ISO 19683: Qualification & testing of lean satellites (DRAFT)
  - ISO TR 18146: Design for debris mitigation (handbook)
  - Proposing new Launch Data Message (CCSDS & ISO)

Debris mitigation: DRAFT SoF language

- ISO now considering size-agnostic, normative ISO Safety-of-Flight (SoF) language:
  - REQ1: *All satellites operating in either the GEO protected region or the LEO protected region (in operating altitudes with natural orbital lifetimes > 25 years) shall be designed to have the necessary means onboard to actively manage collision risk during its early orbit, operational and deorbit phases of flight.*
  - REQ2: *Spacecraft operators shall assess the risk of collision regularly using a suitable combination of operator and space surveillance positional and quality (i.e. covariance) data and shall conduct collision avoidance manoeuvres as necessary to reduce collision risk.*
  - Note: *If the available operator and space surveillance data supports realistic collision probability assessment (in either "true" or the more conservative "maximum" or "meridian-based" collision probability methodologies), these shall be preferred as the basis for risk assessment over non-probabilistic assessment strategies.*

Sundberg's spacecraft size-agnostic approach

- Some feel small satellites & CubeSats should be controlled more tightly; but is this fair to CubeSats?
- Instead, Sundberg proposed a size-agnostic "5 inclination-independent volumes" approach
  - A – Long Life – apogee > 1000 km – active removal w/in 25 yrs
  - B – Medium Life – apogee > 430 km – active removal w/in 5 yrs
  - C – Habitable, 350 – 430 km – no permanent resident except human manned or occupied – transients must be controlled
  - D – Short Life – 200-350 km – beacon but passive removal
  - E – Apogee below 200 km – "go for it"
- While in principle a good idea, perhaps incompatible w/CubeSat capabilities & intended missions

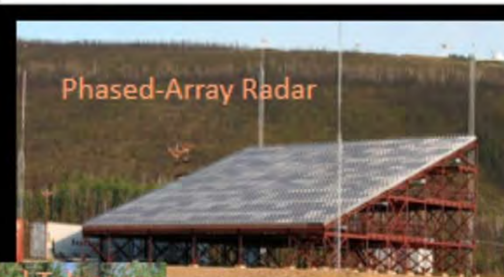
*Sundberg, E., "Debris Mitigation and the Curious Case of CubeSats," CODER Workshop, 19 Nov 2014

Role of commercial S/C design & operations sector

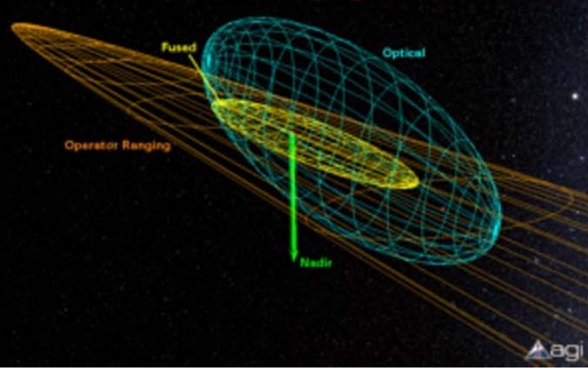
- Debris environment, mitigation and removal research
- Exchange data, foster mutual understanding
  - Space Data Association (data sharing w/in legal framework)
- Nurture space debris awareness and education
- Collaborate w/gov't to establish norms, best practices
  - JSpOC (SSA Data Sharing Agreements)
  - Launch data & deployment scenario sharing
  - Take a more active role in orbit design & selection
  - Devise smarter en masse deployment strategies such as individually-addressable deployments & thrusting during deploy for a well-ordered "string-of-pearls" constellation
  - Develop debris mitigation and operations standards

Private sector role in CubeSats and debris mitigation

- JSpOC SSA Data Sharing Agreement (free service)
- Identical CubeSats pose track misassociation & crosstag issues for non-cooperative radar and optical tracking
  - Degrades orbit solution
- Viable commercial alternatives exist for tracking & SoF
  - Space Data Association (data sharing for SoF & RFI mitigation)
  - AGI's Commercial Space Operations Center (ComSpOC) is the first commercial multi-phenomenology SSA service; merges state-of-art processing w/data fusion, good sensors
- RF techniques & data fusion best-addresses these



Fusion of operator ranging & optical obs



ComSpOC Commercial Space Operations Center

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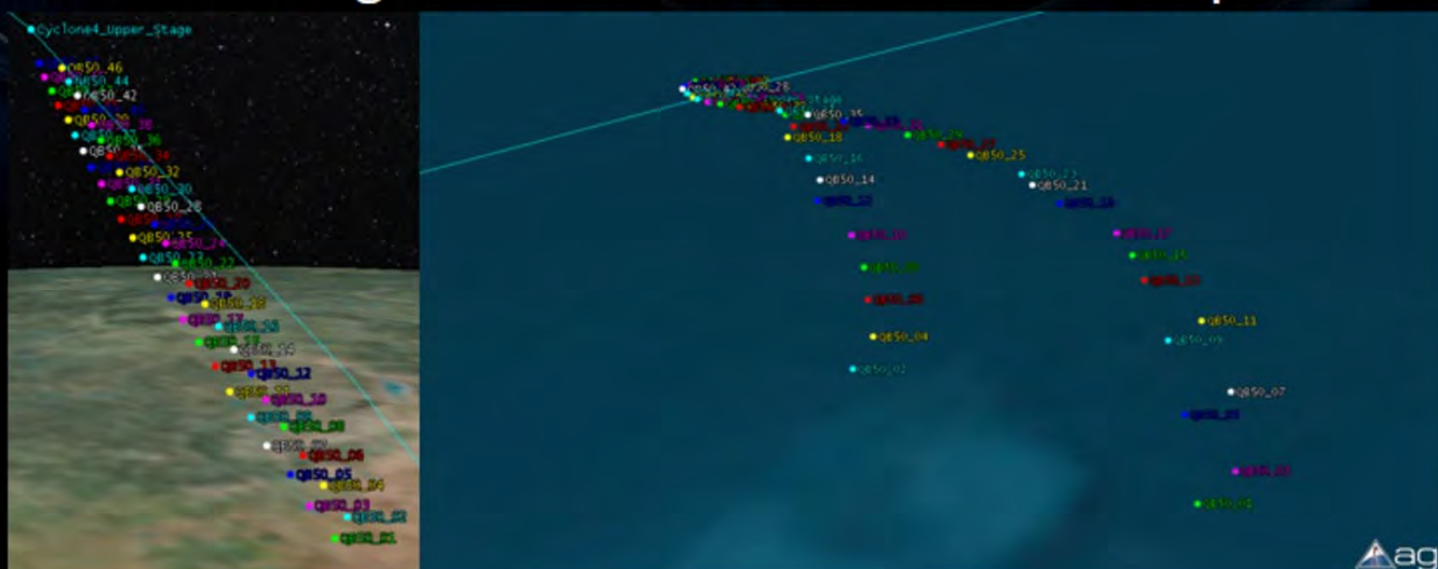
Better en masse large constellation deployment

- Thrusting during deployment yields predictable spread
  - Aids CubeSat operators by reducing collision & RFI risk
  - Allows SSA organizations to best aid CubeSat operators



Policy lessons drawn from other domains

- Economics as it pertains to Safety-of-Flight (SoF)
- Radio-Controlled (RC) airplanes, helicopters
- Cell phones

The changing economics of flight safety

- High mission cost and mission assurance used to drive the need for safety of flight (SoF)
  - But no longer justifies SoF for cheap missions & many S/C
- Ultimately, operators can simply fold if liabilities exceed assets
  - *e.g.,* "space tourist" companies may consider not taking insurance
- Operators must now find other flight safety motivators:
  - Ensure health and viability of space operations
  - Maintain our space presence
  - Ensure we can meet current and future mission needs
  - Minimize liability for wrong-doing
  - Preserve the space environment for future generations

RC Planes

- Originally, very little regulation on RC airplanes, etc.
- Now, RC increasingly capable and prevalent
- So are CubeSats
- Now have new RC flight rules and constraints
- May be entering into similar era for CubeSats

Cell phone mass adoption

- Parallels between CubeSats and cell phone development
  - Initially, cell phones were sparse and unregulated
  - Cell phones weren't on our regulatory radar screen
  - With cell phone proliferation came safety-based regulations:
    - No transmissions during critical aircraft phases-of-flight
    - Studies of effects of radiation and RF energy
    - Only hands-free phone calls in many states
    - No texting while driving
- Proliferation of CubeSats has exposed space operations gaps & shortcomings across the space industry that may need to be similarly addressed

Thank you and Questions …

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