The National Academies of
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SPACE STUDIES BOARD

Achieving Science with CubeSats: Thinking Inside the Box

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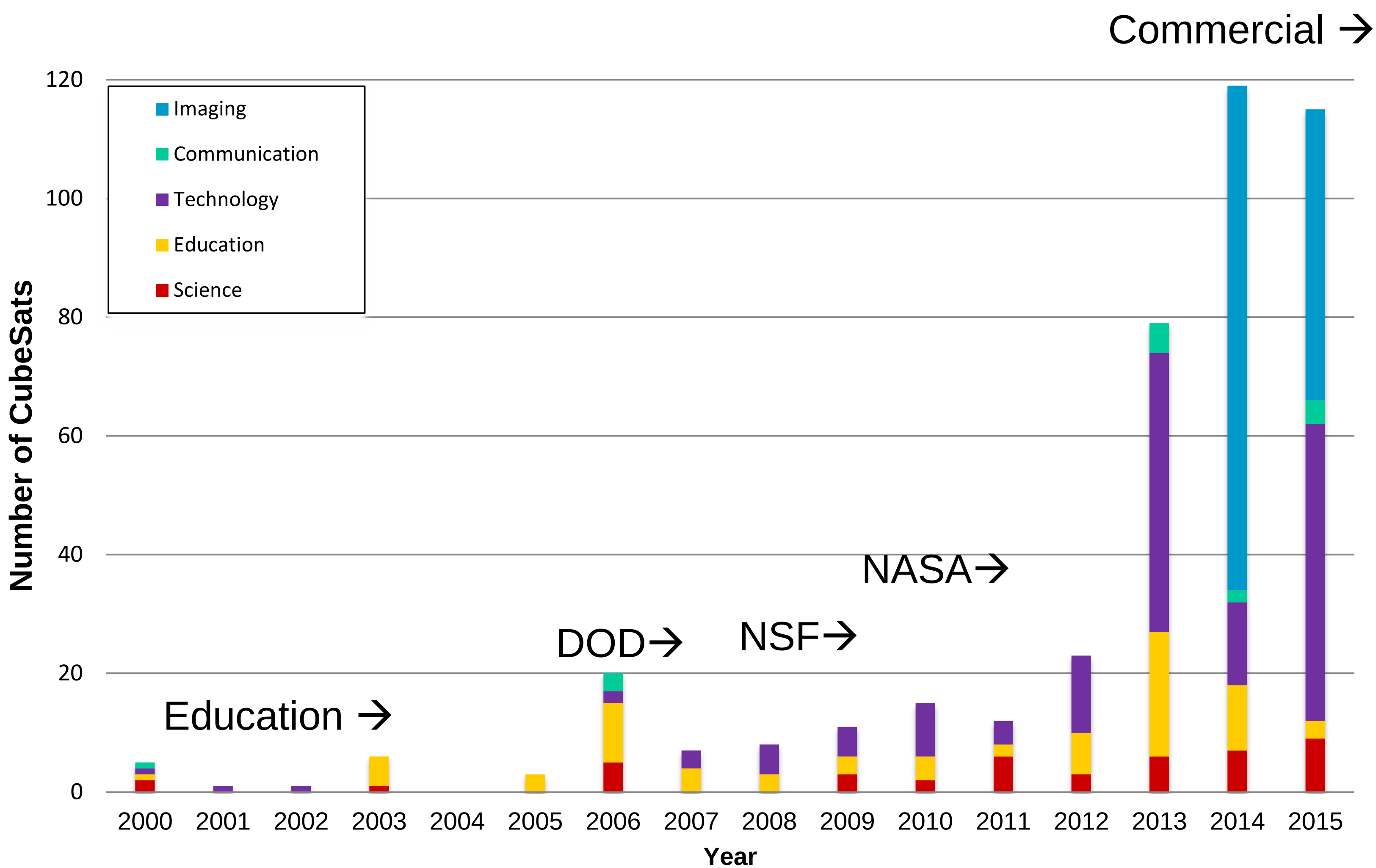
Key Elements of Charge to Committee

- Develop a **summary of status**, capability, availability, and accomplishments in the government, academic, and industrial sectors
- Recommend **potential near-term investments** that could be made to improve the capabilities and usefulness of CubeSats for scientific return and to enable the science communities' use of CubeSats
- Identify a set of **sample priority science goals** that describe near-term science opportunities

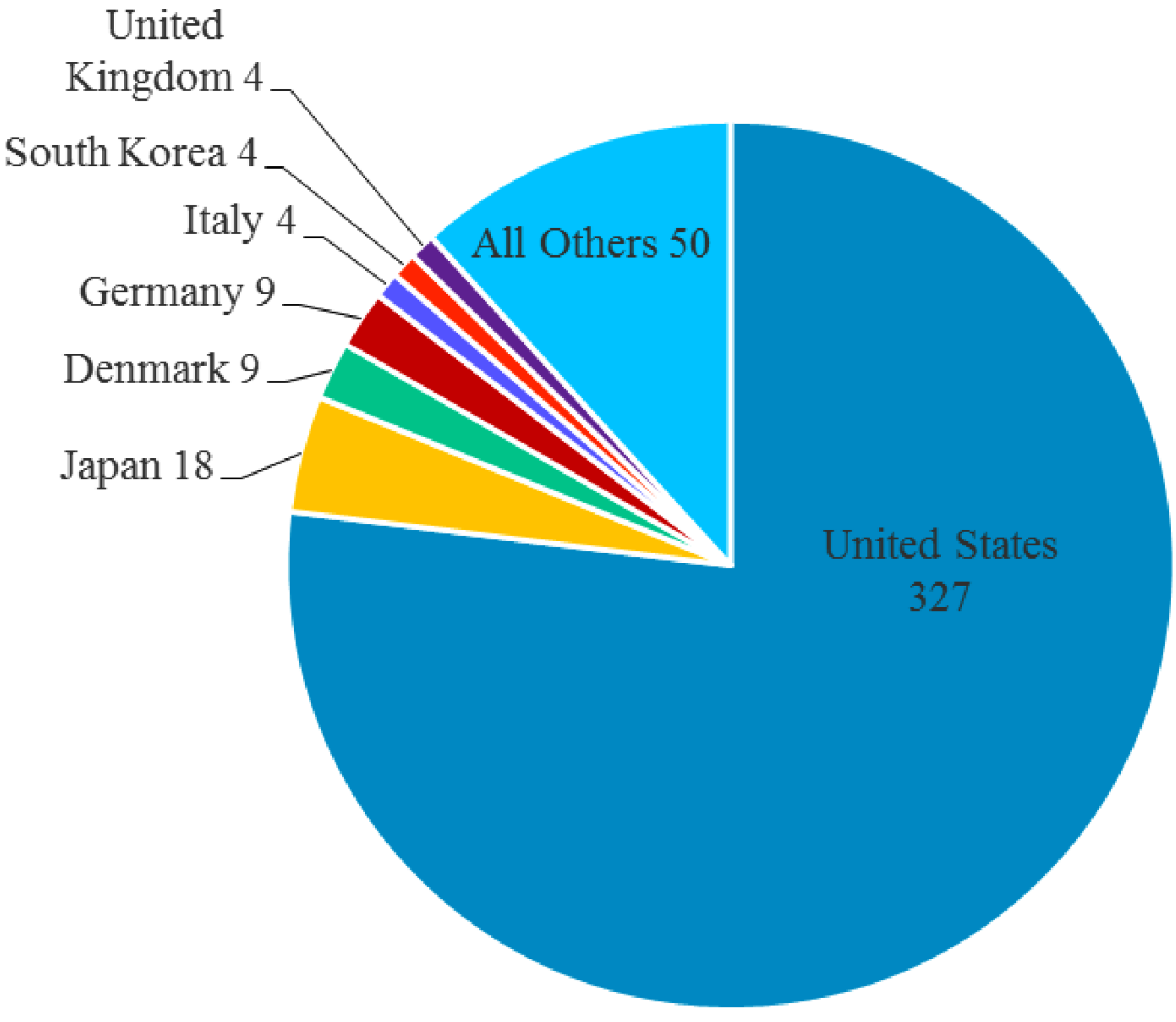
Overview

1. Based on detailed analysis of available data
2. Recognized similarity to disruptive innovation
3. Analysis of science publications: CubeSats can do high priority science
4. Science potential in all science divisions to varying degrees. However, not every application is appropriate for CubeSats.
5. Potential is materialized if a number of conditions are fulfilled
    1. Technology and connections to industry
    2. Policy issues
    3. Programmatic and management issues

US CubeSats Launched – by Mission Type



International Participation



Concept of a Disruptive Innovation

- “Process by which a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up market […].” Clayton Christenson, 1995
- Has been used to describe many shifts in the economy
  - Personal computers (that disrupted the mainframe computer industry)
  - Cellular phones (that disrupted fixed line telephony)
  - Smartphones (that continue disruption of multiple sectors, computers, digital cameras, telephones, and GPS receivers)
- End-state and especially level of disruption is unclear at beginning

CubeSats Share Characteristics of Disruptive Innovations

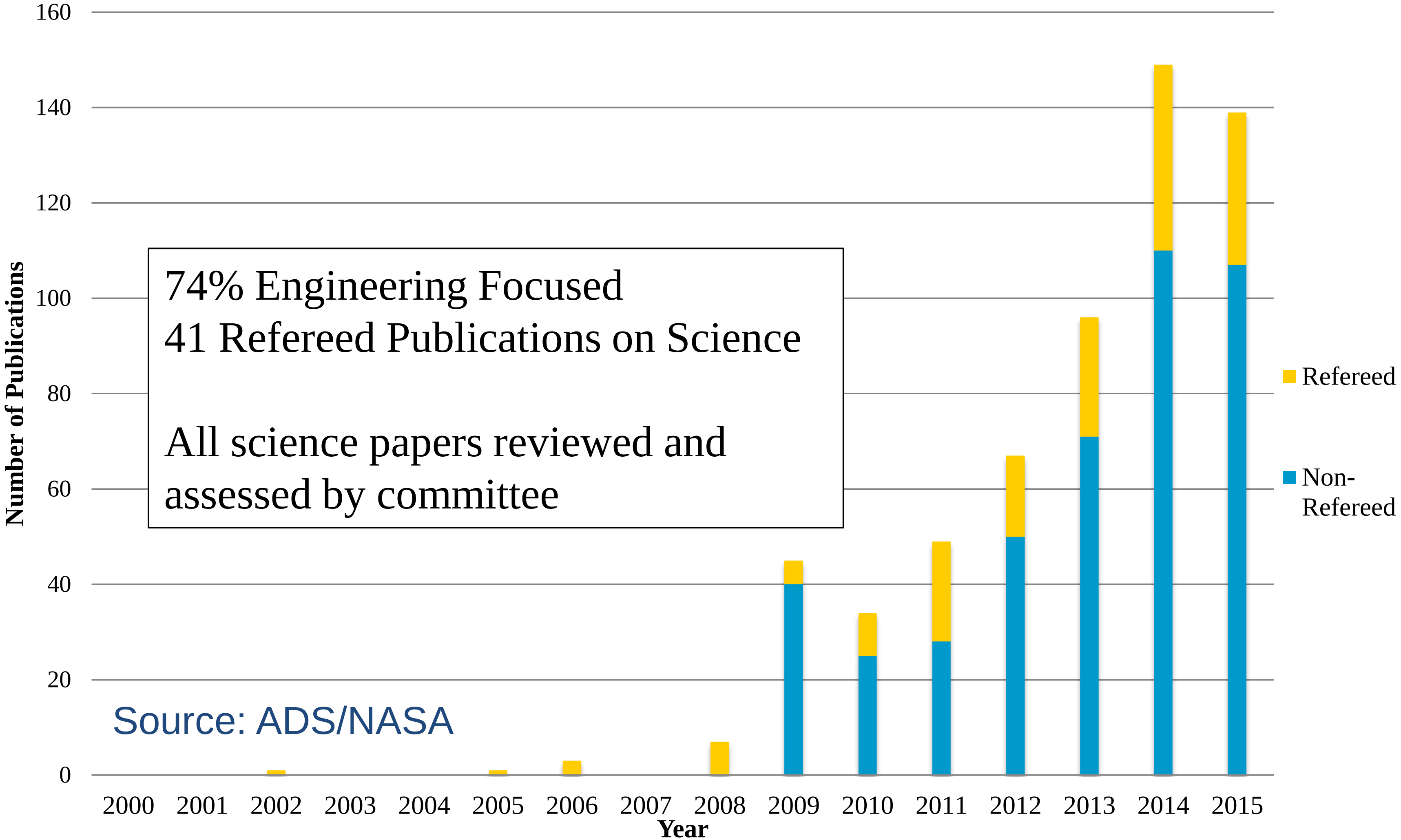
- **Performance**. Early CubeSats were essentially “beepsats”
- **Cost.** Hardware for a basic CubeSat can be purchased for a few tens of thousands of dollars
- **Users**. CubeSats are introducing students and other participants to space technology; introducing the potential for new functionalities such as stop-and-stare and multi-hundred/thousand swarm systems
- **Speed**. CubeSats began as platforms for technology testing, and are being considered for advanced missions such providing real-time relay communication
- **Origin.** Introduced by educators not the stalwarts of aerospace
- **Enabling technology.** Propelled by advances in software, processing power, data storage, camera technology, compression and solar array efficiency
- **Development models**. Adopted by entrepreneurs using fly-test-refly and other lean manufacturing technology and business models

End-state and especially level of disruption CubeSats may create is unclear

What CubeSats Can Enable

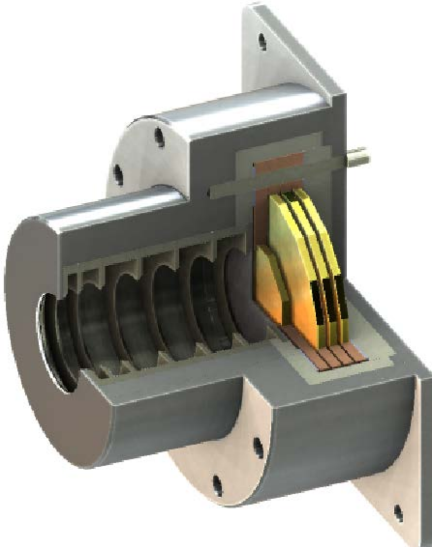
- They are standardized – creation of supply chain
- They are cheaper - conduct of higher risk activities, “fly-learn-refly” paradigm
- Enables new mission types, especially high-risk orbits and secondary lines of sights, as well as targeted science
- Enables creation of entirely new architectures, especially constellations and swarms

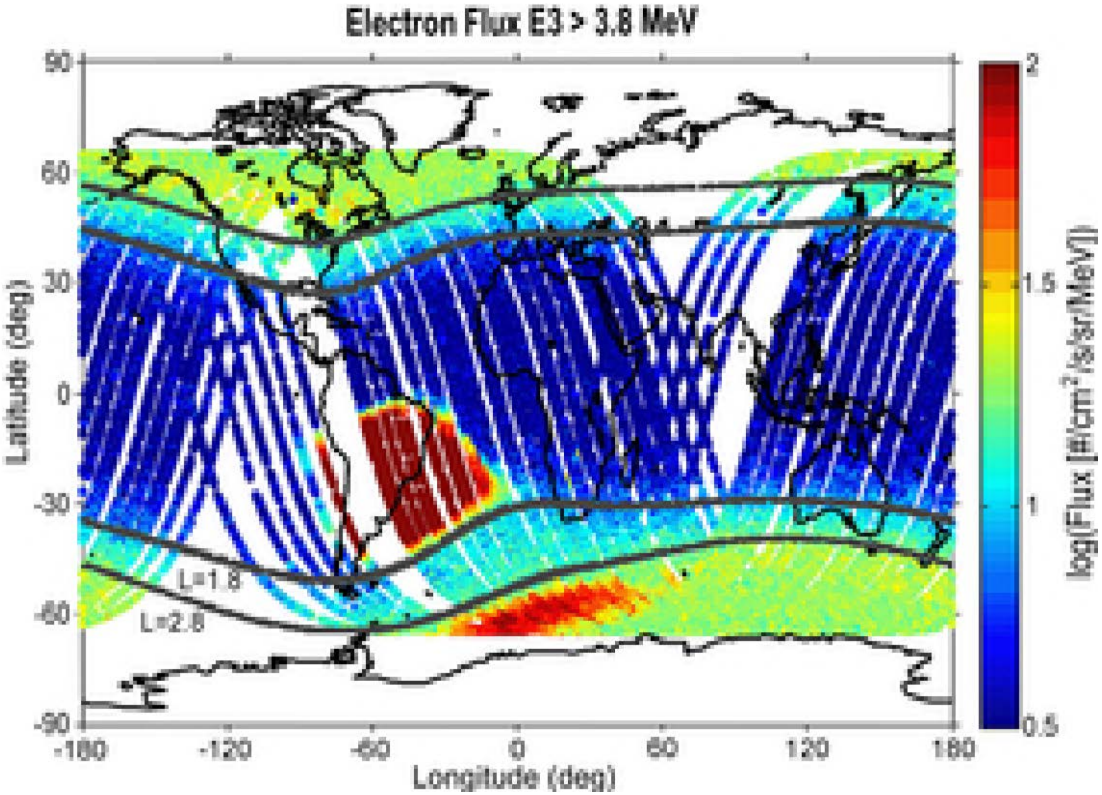
Number of CubeSat Publications



Conclusion: **CubeSats have already produced high-value science, as demonstrated by peer-reviewed publications in high-impact journals. {…}**

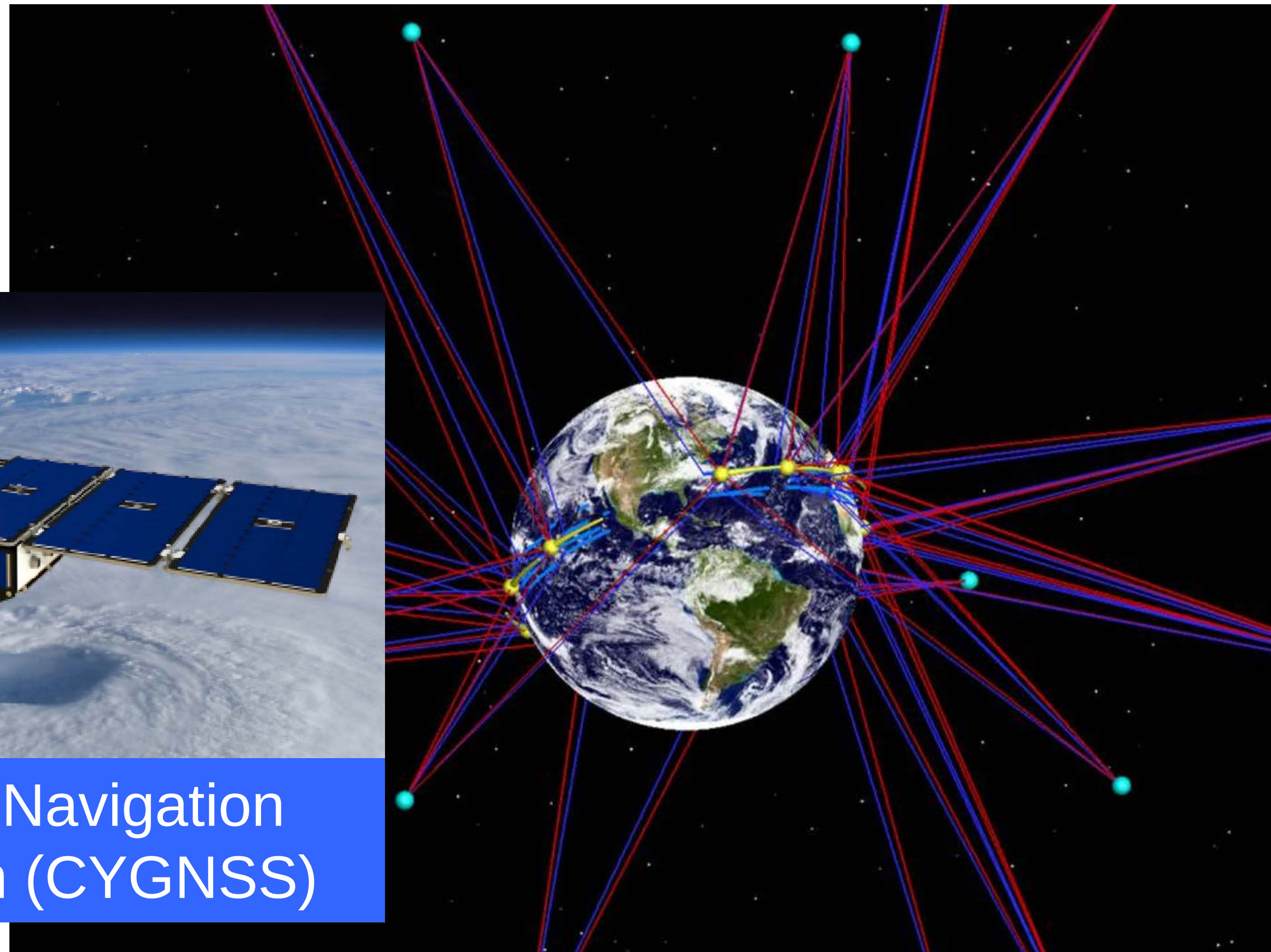
CubeSat Example for High-Risk Orbits, with other Mission

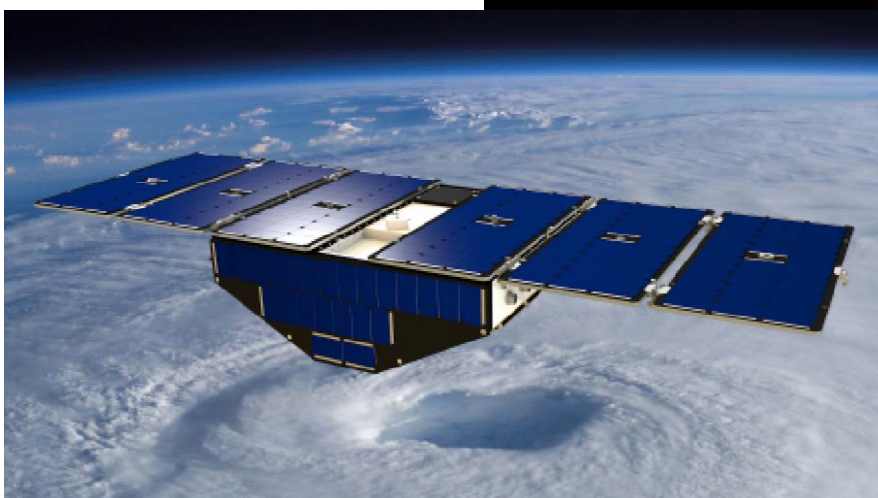




Colorado Student Space Weather Experiment (CSSWE)

Example: Constellations/Swarms

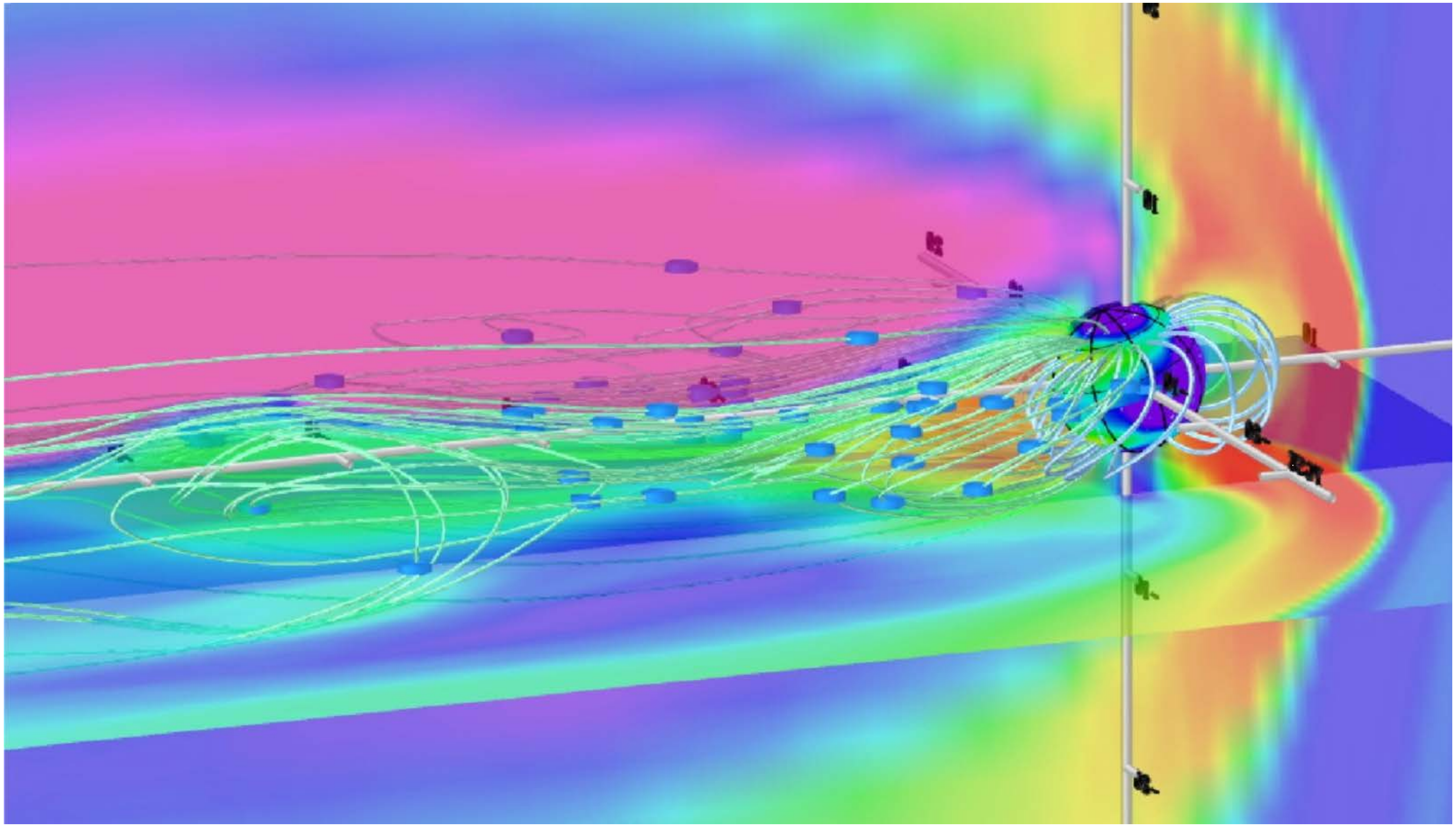




Cyclone Global Navigation Satellite System (CYGNSS)

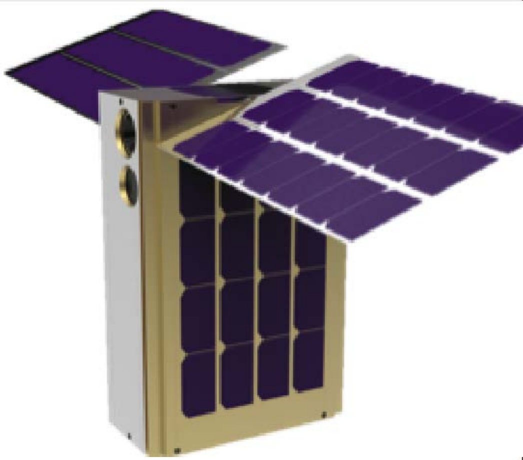
Not a CubeSat, but CubeSat enabled

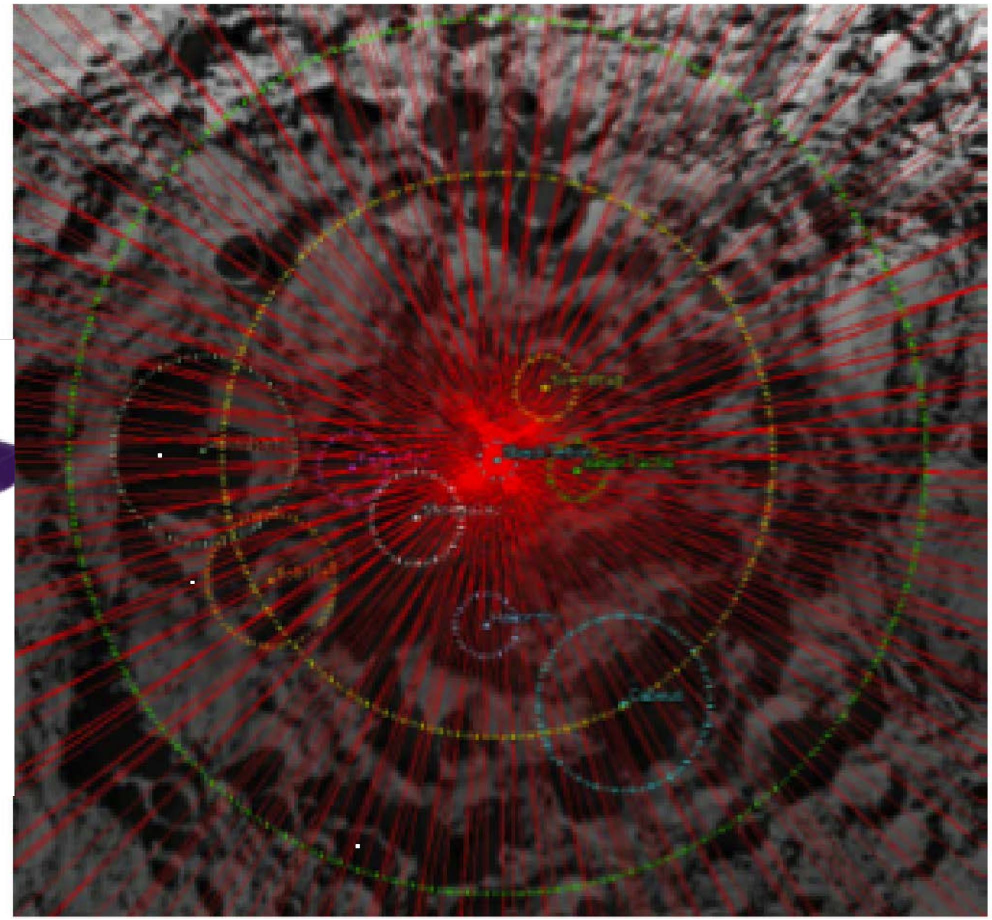
Constellations for Space Weather



"Instrumenting Space" through Distributed Architectures

Example: Targeted Science: 1 Instrument, 1 Question



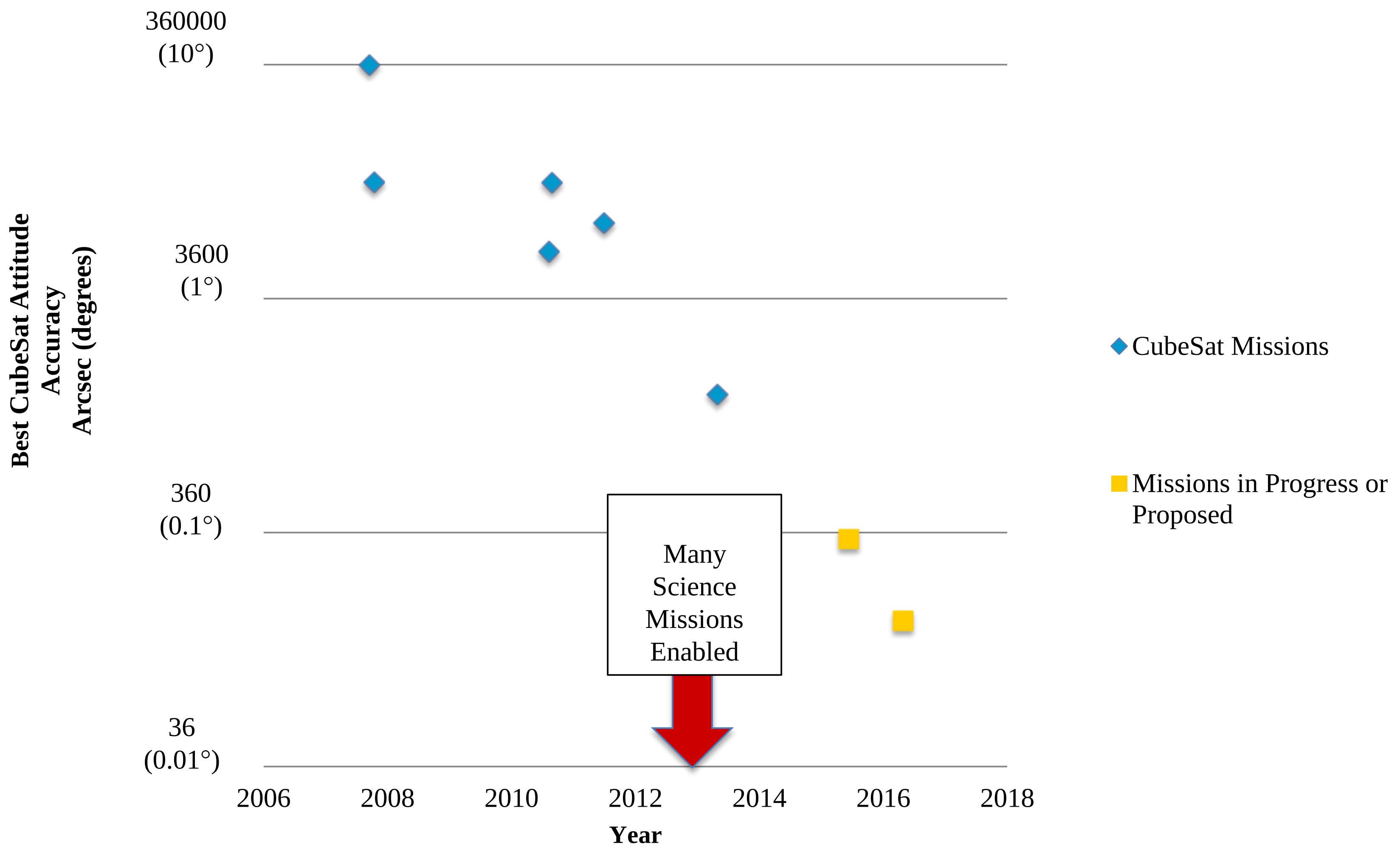


LunaH Map
SIMPLEx Program

Enabling Technology by Science Discipline

Science Discipline	Enabling Technology	Example Application
Solar and Space Physics	**Propulsion**	Constellation deployment and maintenance, formation flight
	Sub-arcsecond attitude control	High resolution solar imaging
	Communications	Missions beyond low Earth orbit
	Miniaturized field and plasma sensors	In-situ measurements of upper atmosphere plasmas
Earth Science	**Propulsion**	Constellations for high-temporal resolution observation and orbit maintenance
	Miniaturized sensors	Stable, repeatable and calibrated datasets
	Communications	High data rate
Planetary Science	**Propulsion**	Orbit insertion
	Communications, Comm Infrastructure	Direct/indirect to Earth communications
	Radiation-tolerant electronics	Enhanced survival in planetary magnetospheres, long duration flight
	Deployables	Enhanced power generation beyond Mars
Astronomy and Astrophysics	**Propulsion**	Constellations for interferometry, distributed apertures
	Sub-arcsecond attitude control	High resolution imaging
	Communications	High data rate
	Deployables	Increase aperture and thermal control
	Miniaturized sensors	UV and X-ray imaging
Physical and Biological	Thermal control	Stable payload environment

Illustrating Speed of Development: Attitude Control



Policy Issues Considered

- Regulatory framework for CubeSats is nearly identical to that of large spacecraft
- Issues particularly affecting or potentially limiting the development of CubeSats as a science tool
  - Orbital debris
  - Communications
  - Launch vehicles
  - Other restrictions affecting the community, such as ITAR, etc.

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Download full report at: goo.gl/osCSQ3
Full presentation: goo.gl/fQXXYp

Questions, Comments?