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Small but Powerful

State of the Art in Small Flight Systems

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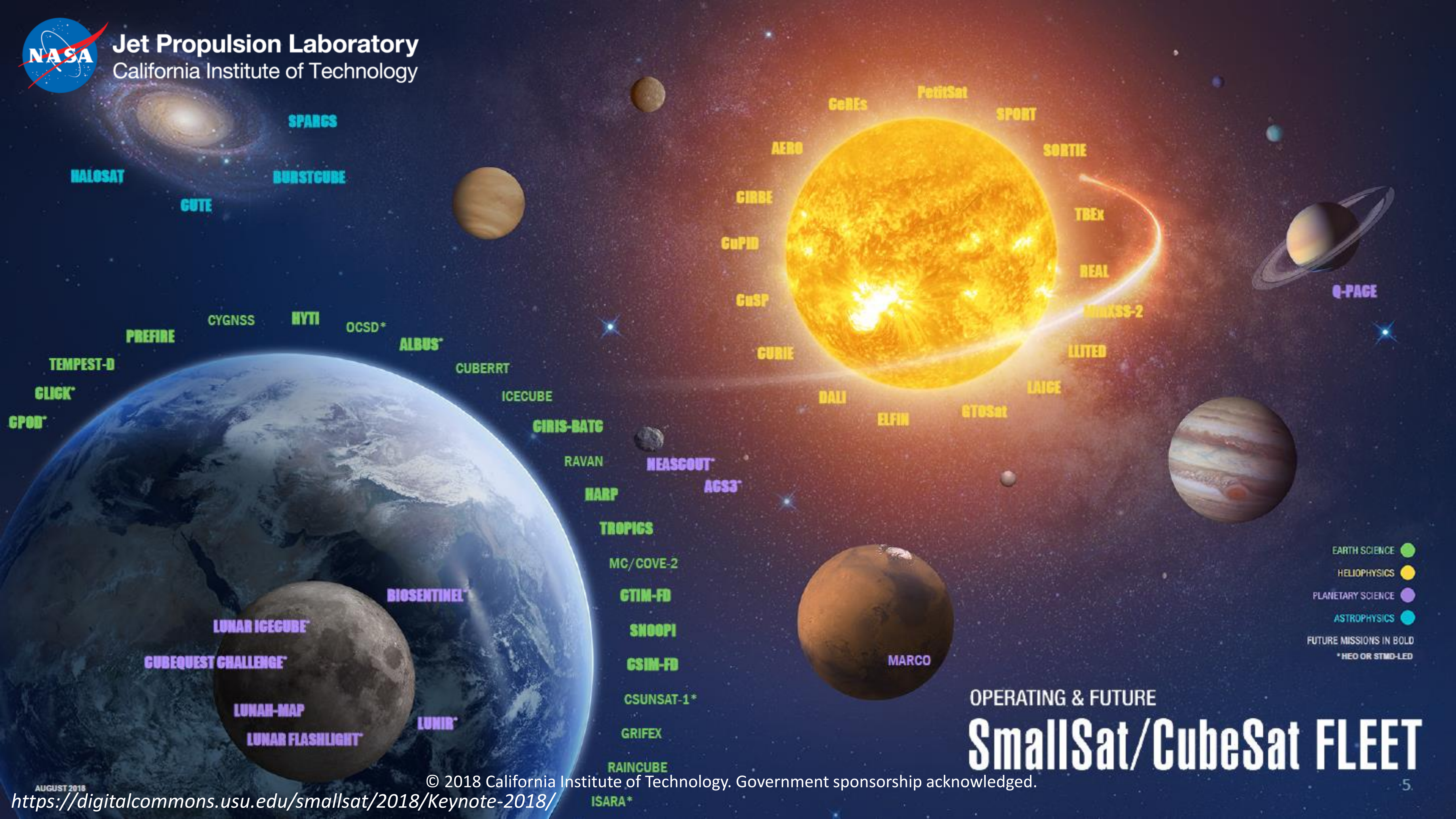
Exploring Once-in-a-Lifetime Targets Short Course

10/29/18



https://digitalcommons.usu.edu/smallsat/2018/Keynote-2018/

Outline

- General specifications and resources
- Subsystem capabilities
- Current and near-future landscape
- Far future landscape

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General Specifications and Resources

Definition of "Small"

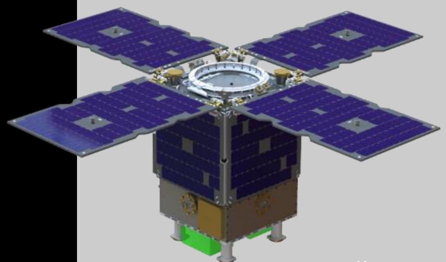
- Shift in launch cost
  - Launch to GTO as secondary spacecraft up to 300 kg
  - Constellations fit many spacecraft in a single launch
- Shift in risk tolerance
  - Shorter development times, reduced testing, and commercial or lower-TRL parts
  - Redundancy in numbers for constellations
- Set cut-off at 180 kg per NASA's Small Spacecraft Technology Program, but mass is really a proxy for other delimiters

Two classes of SmallSats


ISIS

CubeSats (< 20 kg)

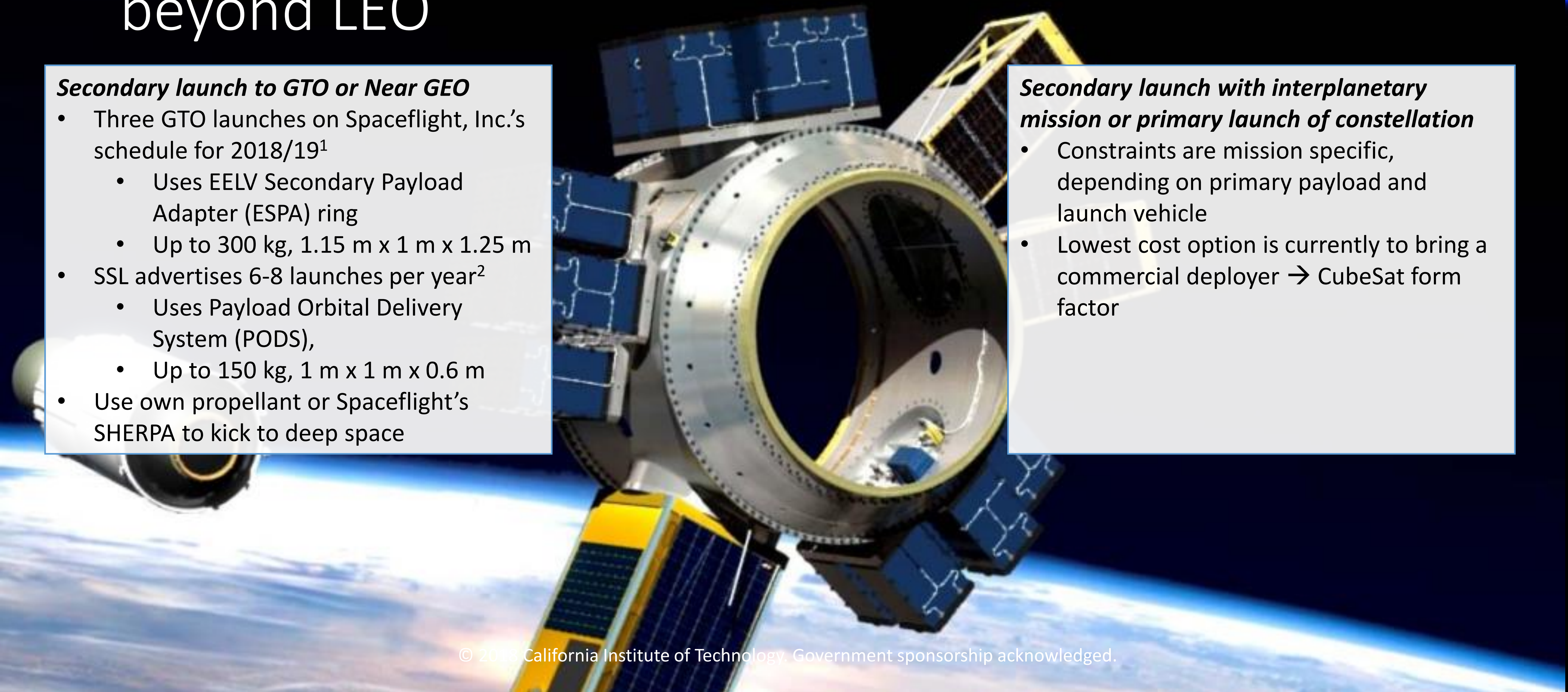
- Constrained to specific form factor
- Typically limited by volume rather than mass
- Plug-and-play commercial parts available
- Traditionally high-risk "unclassified" missions with 3-7 year lifetimes


Surrey Satellite Technology US LLC

Micro/minisats (< 180 kg)

- No set form factor, just volume limit by launch constraints
- Can be limited by either mass or volume
- Can accommodate more traditional space-qualified components with longer lifetimes (if they fit!)

Launch Opportunities beyond LEO



Secondary launch to GTO or Near GEO

- Three GTO launches on Spaceflight, Inc.'s schedule for 2018/19[1]
    - Uses EELV Secondary Payload Adapter (ESPA) ring
    - Up to 300 kg, 1.15 m x 1 m x 1.25 m
- SSL advertises 6-8 launches per year[2]
    - Uses Payload Orbital Delivery System (PODS),
    - Up to 150 kg, 1 m x 1 m x 0.6 m
- Use own propellant or Spaceflight's SHERPA to kick to deep space

Secondary launch with interplanetary mission or primary launch of constellation

- Constraints are mission specific, depending on primary payload and launch vehicle
- Lowest cost option is currently to bring a commercial deployer → CubeSat form factor

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Performance Envelopes

Mass and Volume

	3U	6U	12U	Mid-ESPA	ESPA
Total Mass	3.5-8 kg Typical: 4 kg	12-17 kg Typical: 14 kg	Typical: 25 kg	30-75 kg	150-180 kg
Payload Mass	1-4 kg Typical: 2.5 kg	5-12 kg Typical: 6 kg	11-13 kg Typical: 12 kg	10-45 kg	10-85 kg
Payload Volume	1-2U Typical: 1.5U	2.5-5U Typical: 3U	Typical: 10U	Typical: 64U	Typical: 120U

Payload mass and volume be traded for spacecraft capability…
but you can’t have it all!

References 3-16

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Performance Envelopes

Power

	3U	6U	12U	Mid-ESPA	ESPA
Peak Power at 1 AU	7-56 W Typical: 30 W	42-112 W Typical: 100 W	100-250 W Typical: 150 W	100-250 W Typical: 200 W	400-6000 W Typical: 500 W
Payload LEO Orbit Average	2-12 W Typical: 5 W	5-45 W Typical: 25 W	Typical: 40 W	Typical: 75 W	Typical: 150 W

Wide range depending on whether deployable arrays are used. State-of-the-art in deployable arrays come from MMA's HaWK product line.

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Performance Envelopes

Data

	3U	6U	12U	Mid-ESPA	ESPA
Downlink from LEO	1-100 Mbps Typical: 2 Mbps	1-100 Mbps Typical: 2 Mbps	15-100 Mbps Typical: 50 Mbps	1-160 Mbps Typical: 100 Mbps	50-200 Mbps Typical: 150 Mbps
Data Volume	4-64 GB Typical: 16 GB	4-64 GB Typical: 16 GB	4-64 GB Typical: 16 GB	32-128 GB Typical: 64 GB	32-128 GB Typical: 64 GB
Redun-dancy	No	No	No	Yes	Yes

CubeSat avionics are typically single string and not rad-hard (< 10 krad total dose)

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Performance Envelopes

Pointing and Propulsion

	3U	6U	12U	Mid-ESPA	ESPA
Pointing accuracy	.004°-10° Typical: 1°	.004°-3° Typical: 1°	.004°-.01° Typical: .01°	.004°-.15° Typical: .007°	.004°-.03° Typical: .005°
Delta-V	~ 10 m/s	~ 40 m/s	< 200 m/s	< 1 km/s	> 1 km/s

Again, can always trade payload for capability!

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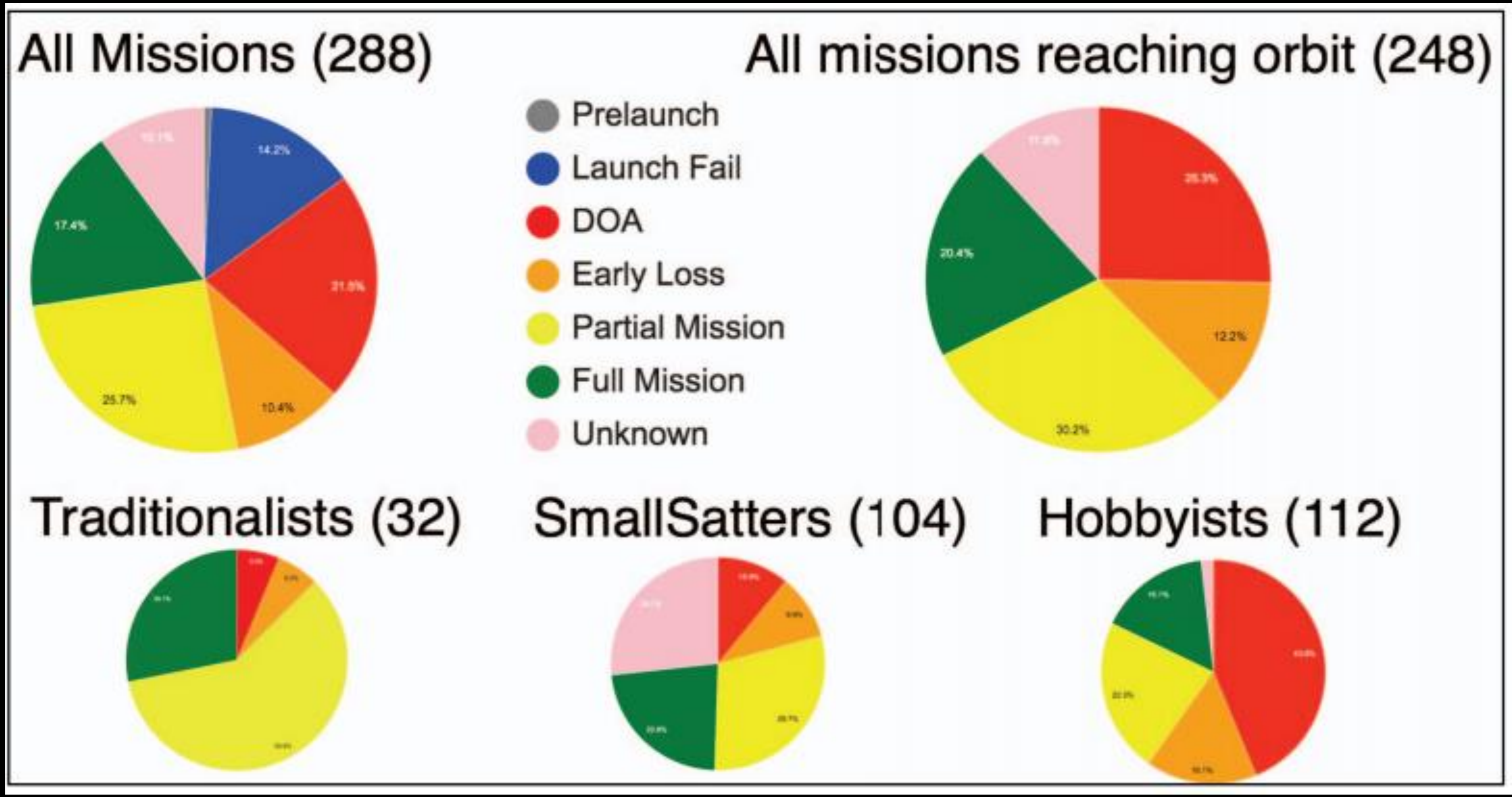
Reliability and Cost

CubeSats can be reliable platforms for science missions – with time and money



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Subsystem-Specific Capabilities

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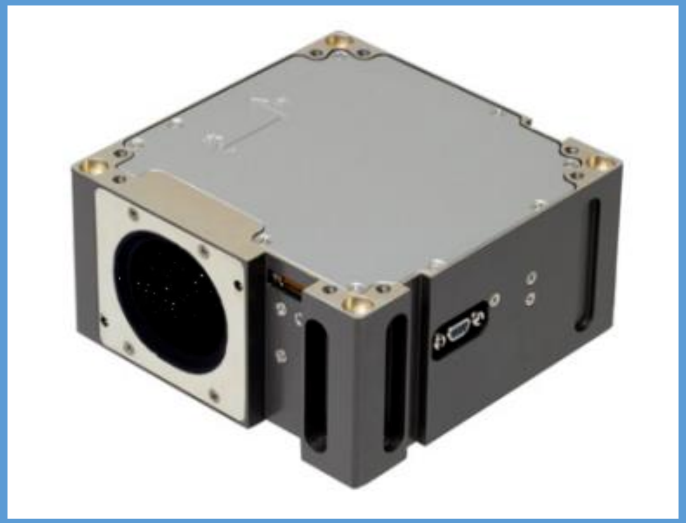
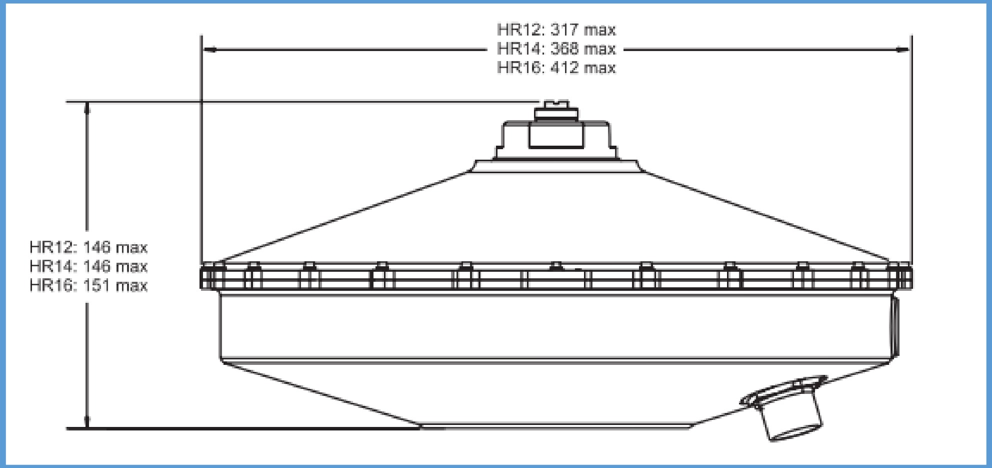
GNC for SmallSats

- For CubeSats, BCT leads the market[18]
  - Have been qualified on a number of science missions, like ASTERIA and MarCO
  - Integrated XACT or XACT-50 for CubeSats up to 12 U, or more flexible with all necessary components
  - Wheels can scale from 0.015 Nms (XACT) to 8 Nms, more suitable for ESPA-class spacecraft
  - Quotes $\pm$.002° pointing accuracy for all their integrated platforms (3U through ESPA)
  - Parts aren't necessarily rad-hard or suitable for long-duration missions
- For larger spacecraft, there's a miniaturization gap
  - Space-qualified, reliable wheels available for > 12 Nms, but are heavy and power hungry[19]



BCT XACT integrated ACDS
Momentum .015 Nms
Volume 0.5U



Honeywell single reaction wheel
Momentum 12 Nms
Volume 30 cm x 30 cm x 15 cm

http://bluecanyontech.com/xact/
ftp://apollo.ssl.berkeley.edu/pub/Pointing_Studies/Hardware/Honeywell%20Reaction%20Wheels.pdf

Propulsion for SmallSats

- Cold gas
  - Compact, simple, and regularly used on CubeSats
  - MarCO (6U) sized for 30 m/s with VACCO cold gas system
  - VACCO also creating cold gas systems for other 6Us with up to 40 m/s
  - Low I_{sp}, best for CubeSats or attitude control
- Electric propulsion
  - Good for high delta-V requirements for SmallSats, but require a lot of power
  - Many commercial systems proposed for CubeSats, few flown
- Chemical propulsion
  - Many high-heritage and reliable small thrusters used on larger systems for ACS could be used for SmallSats
  - However, secondary launches typically restrict the use of hydrazine
- Other
  - 86 m^2 Solar sails on NEAScout

https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4286&context=smallsat
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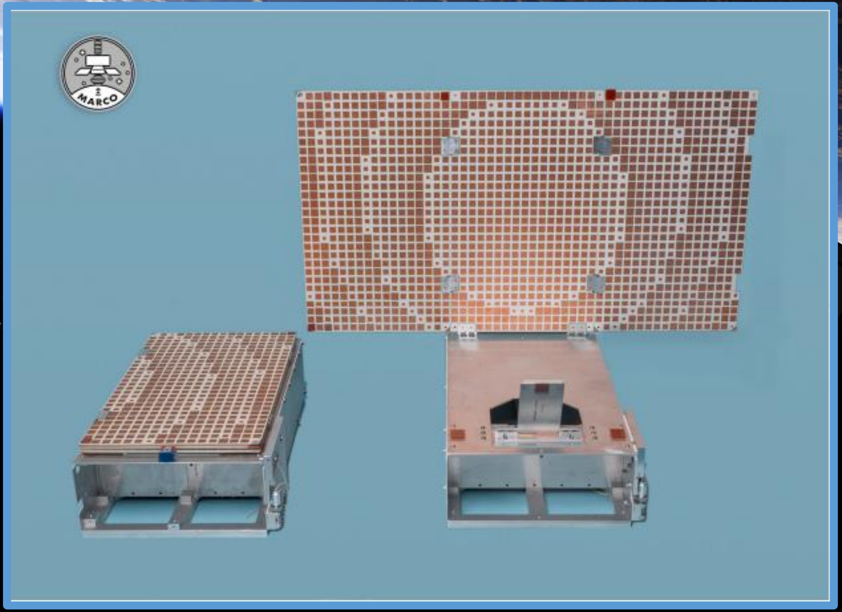
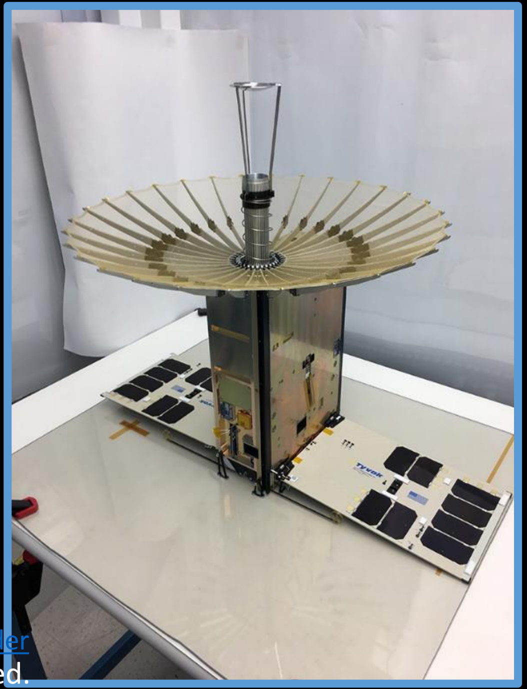
Telecom for SmallSats



- Transponders and amplifiers
  - For CubeSats, lots of commercial solutions for LEO, but X-band IRIS radio is the answer for DSN ranging
    - Combined with amplifier, 4 W RF output, 35 W DC input
    - 1.2 kg, 0.5U
  - For larger missions, X and Ka-band SDST is long-standing industry standard
    - Needs an amplifier, customizable to mission requirements
    - 3.2 kg, 18 cm x 17 cm x 12 cm (~4U)
- High gain antennas
  - Reflectarray antenna on MarCO (6U, X-band, 8 kbps from Mars) and ISARA (3U, Ka-band, 100 Mbps from LEO)
  - 0.5-m deployable Ka-band HGA on Raincube fit in 1.5U volume
- Alternatives
  - Optical comm could achieve many Gbps in the near future



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https://www.jpl.nasa.gov/cubesat/missions/isara.php

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The Current and Near-Future Landscape

Near-term proposals or launches of SmallSat science missions beyond LEO

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MarCO
Mars Cube One

- First interplanetary CubeSats
- 6U form factor with Reflectarray antenna and IRIS radio
- Will monitor InSight's landing and act as a communications relay
- https://www.jpl.nasa.gov/CubeSat/missions/marco.php

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Hayabusa2

- Main spacecraft carried four tiny hopping rovers
- Rover-1A, Rover 1B, and Rover-2
  - ~1 kg, solar powered, equipped with cameras, thermometers, and accelerometers,
- MASCOT
  - ~10 kg, battery powered, equipped with camera, IR spectrometer, magnetometer, and radiometer
- https://en.wikipedia.org/wiki/Hayabusa2

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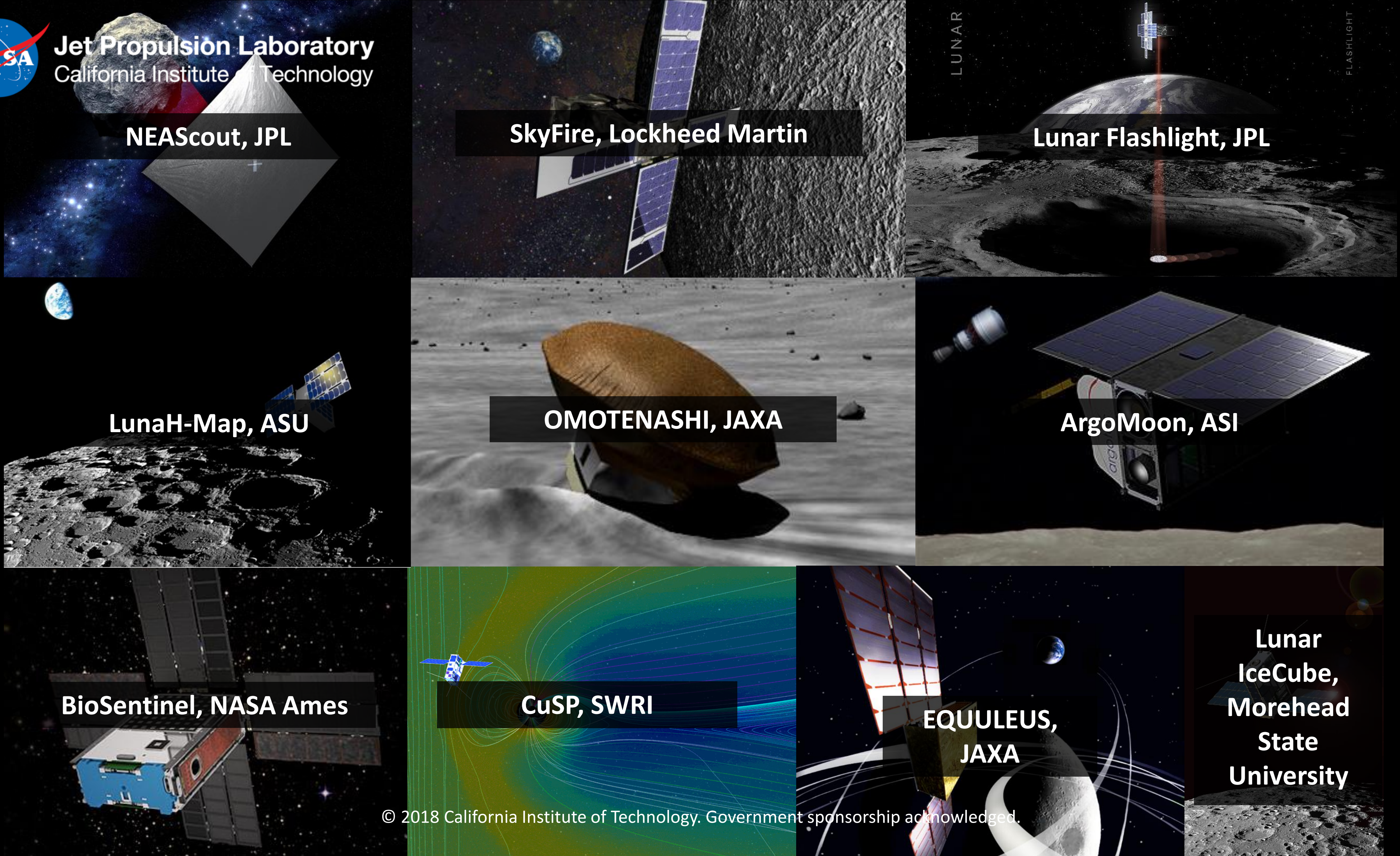
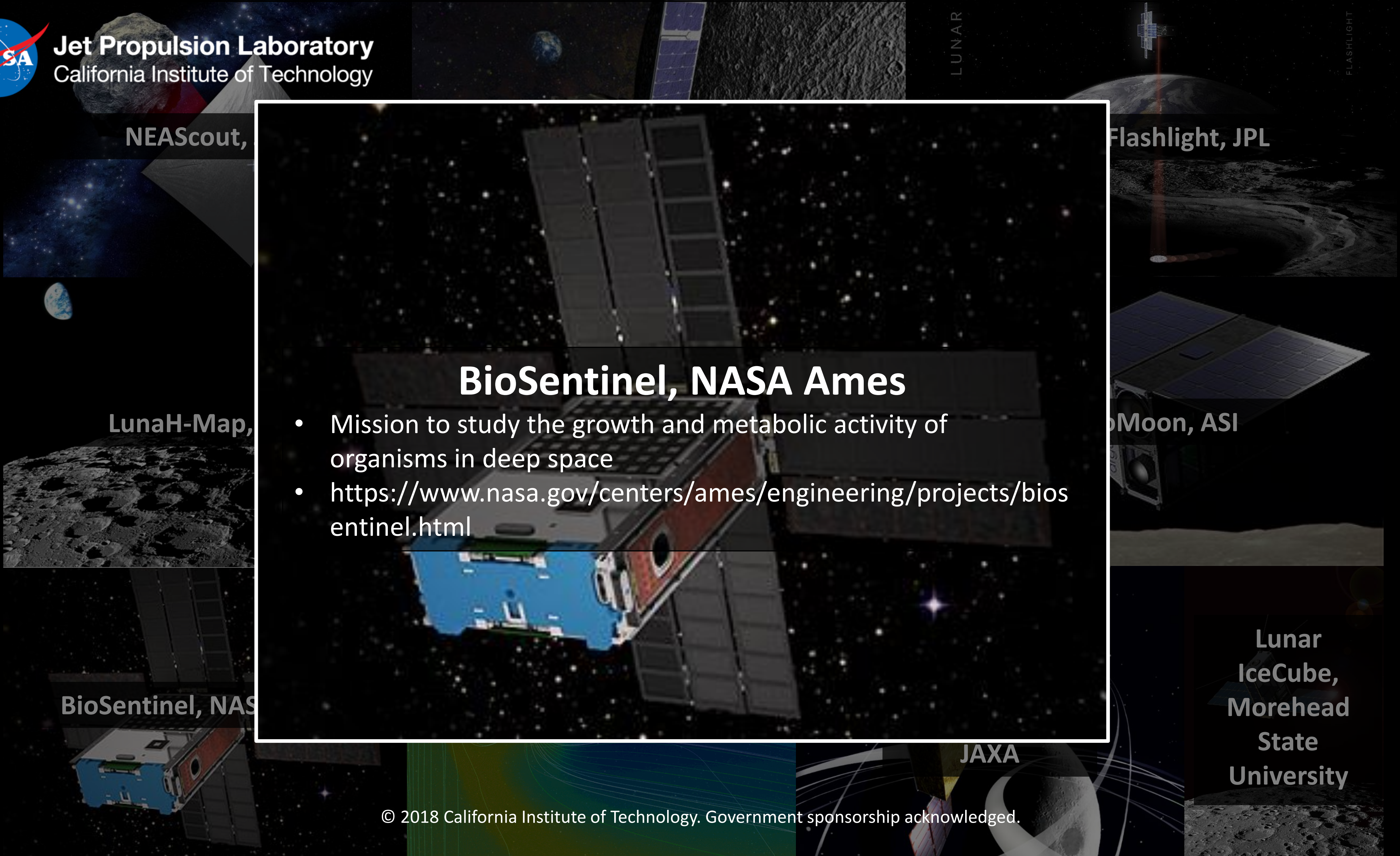


NEA Scout, JPL

- Mission to observe an asteroid and gather information to aid in future human exploration missions
- Propelled by solar sail
- https://www.jpl.nasa.gov/CubeSat/missions/neascout.php

Lunar IceCube, Morehead State University



BioSentinel, NASA Ames

- Mission to study the growth and metabolic activity of organisms in deep space
- https://www.nasa.gov/centers/ames/engineering/projects/biosentinel.html

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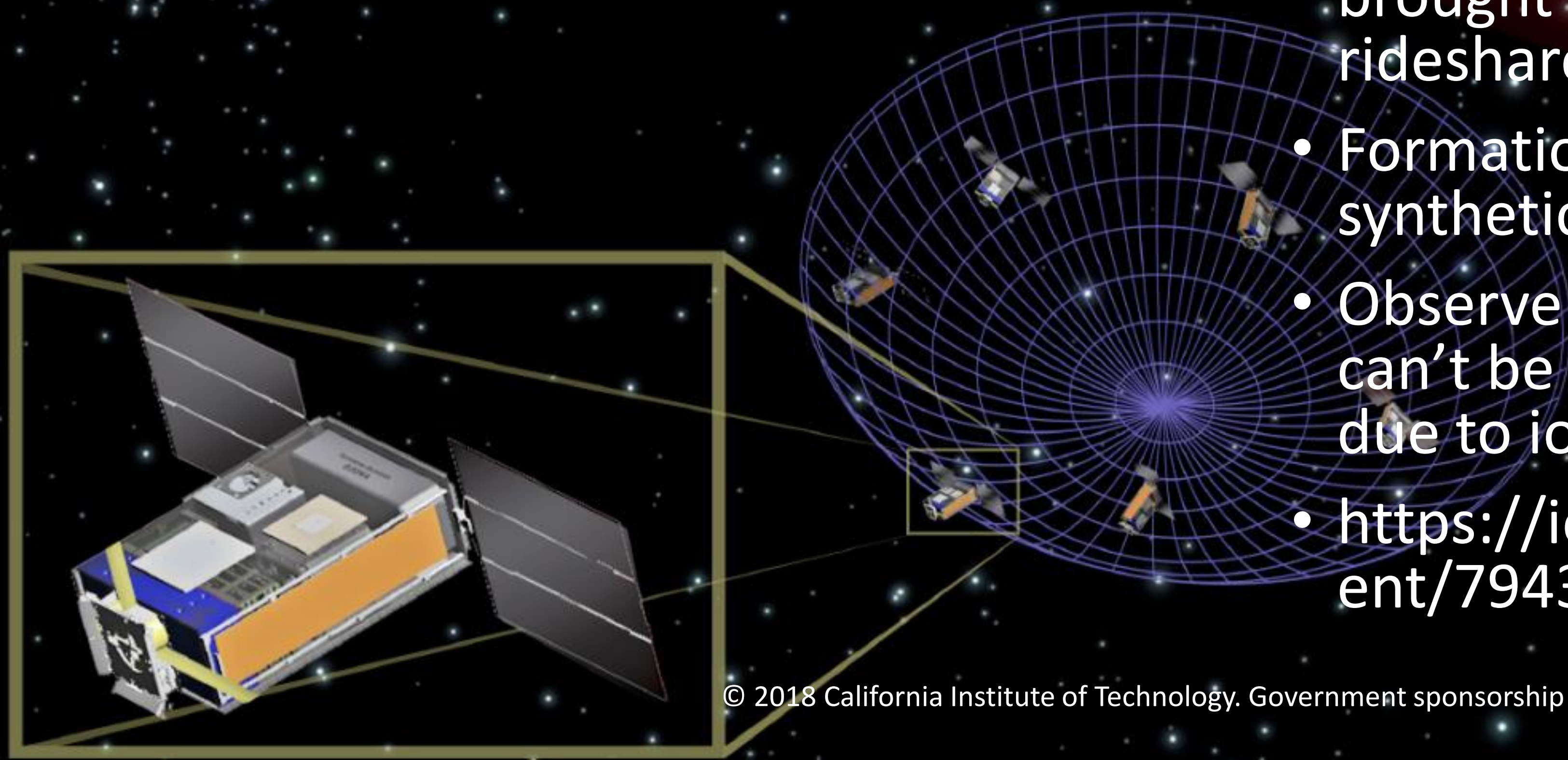
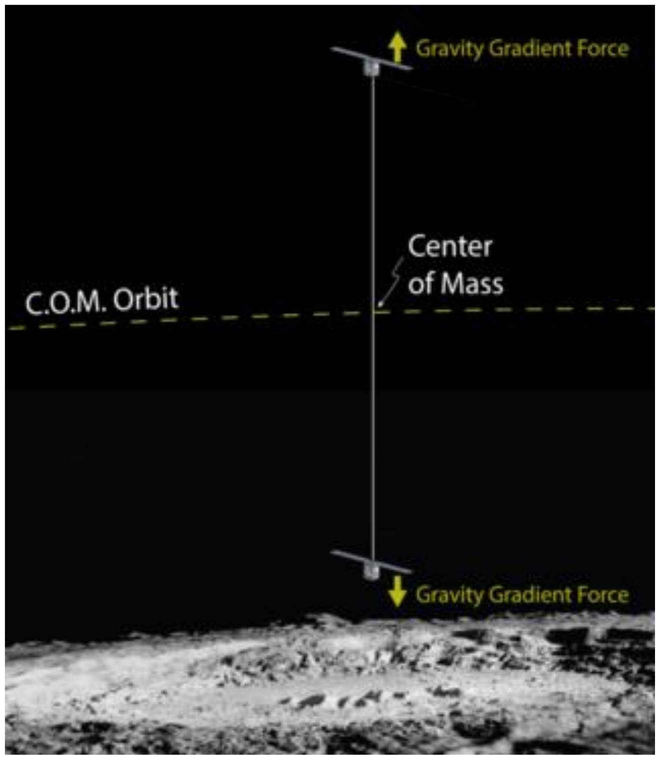
Sun Radio Interferometer Space Experiment (SunRISE)

- Proposed to the NASA Small Explorer (SMEX) call
- Constellation of six 6U CubeSats brought to near-GEO with rideshare
- Formation flying to form 10 km synthetic aperture
- Observe solar radio bursts that can’t be observed from the ground due to ionic absorption
- https://ieeexplore.ieee.org/document/7943789



Planetary Science Deep Space SmallSat Studies (PSDS3)

- 19 studies awarded to develop concepts that explore Venus, the Moon, asteroids, Mars, Jupiter, and Uranus
- Two CubeSat constellations
  - Ross (formerly CAESAR): a dozen 12U CubeSats each targeting a different Near-Earth asteroid
  - Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS): two 12U tethered CubeSats characterize lunar hydrogen cycle from both low and high altitude



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The Far Future Landscape

Projections for the next 15 years

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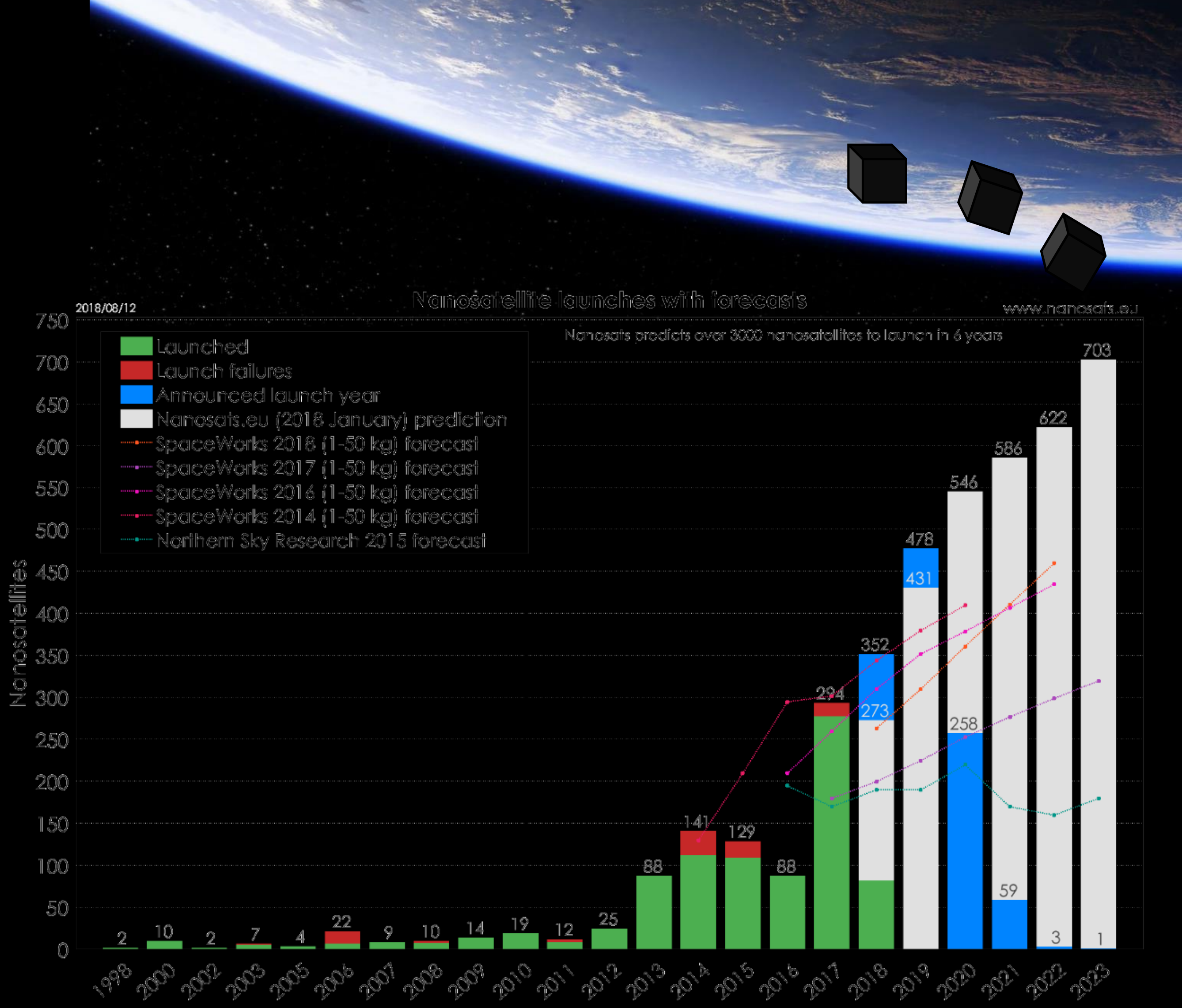
- A look back…
  - CubeSats and SmallSats have come a long way in the last 15 years
  - Launches have been largely commercial or experimental
  - However, great science is being done in LEO and the first steps beyond LEO have been taken
- A look forward!
  - Many science missions beyond LEO just on the horizon
  - Bigger launch vehicles → more room for secondary payloads
  - Stronger partnerships with government and commercial companies
  - Value in distributed networks and constellations will be realized



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Acknowledgements

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- Alan Didion
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- Chi-Wung Lau
- Thaddeus Voss

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