Jet Propulsion Laboratory
California Institute of Technology

Small but Powerful

State of the Art in Small Flight Systems

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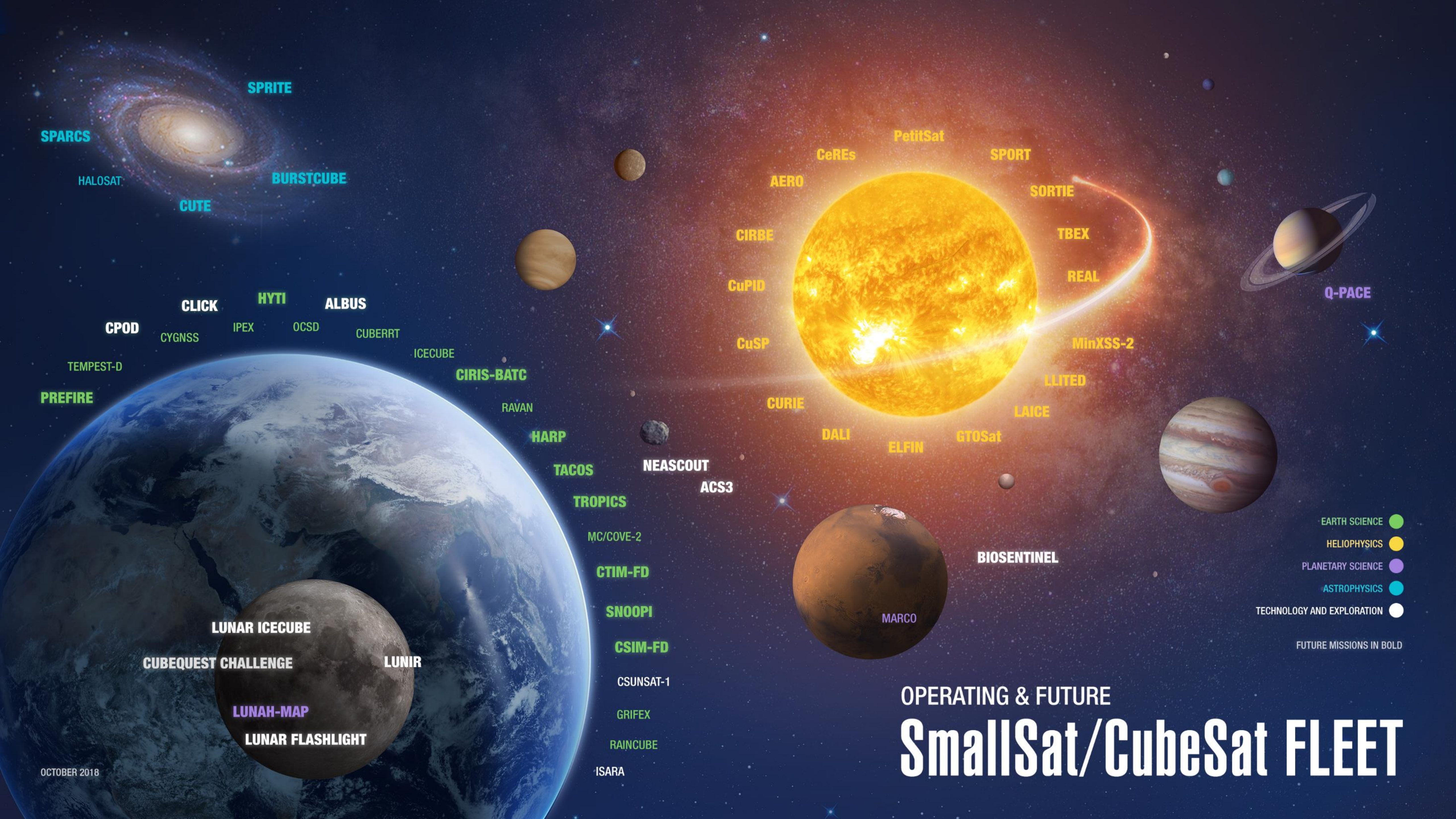
Keck *Exploring Once-in-a-Lifetime Targets* Short Course

10/29/18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TECHNOLOGY AND EXPLORATION
FUTURE MISSIONS IN BOLD
OPERATING & FUTURE
SmallSat/CubeSat FLEET

Outline

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

General Specifications and Resources

Definition of “Small”

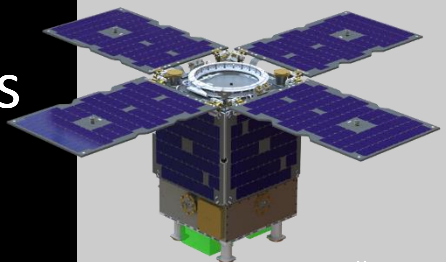
- Shift in launch cost
  - Can launch to LEO or GEO as secondary spacecraft up to 300 kg
  - Constellations fit many spacecraft in a single launch
- Shift in risk tolerance
  - Shorter development times, reduced testing, and commercial or lower-TRL parts
  - Redundancy in numbers for constellations
- 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)

- Form factor constrained by deployer
- 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 envelope
- 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

SPACEFLIGHT

Secondary launch to GEO or Transfer Orbit

- 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
- Com-sat manufacturer 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 commercial kick stage to access 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

Reference 6.1, 6.2

Image courtesy of Spaceflight Inc

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 7.1 through 7.15

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.

References 7.1 through 7.15

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)

References 7.1 through 7.15

Performance Envelopes
Pointing and Propulsion

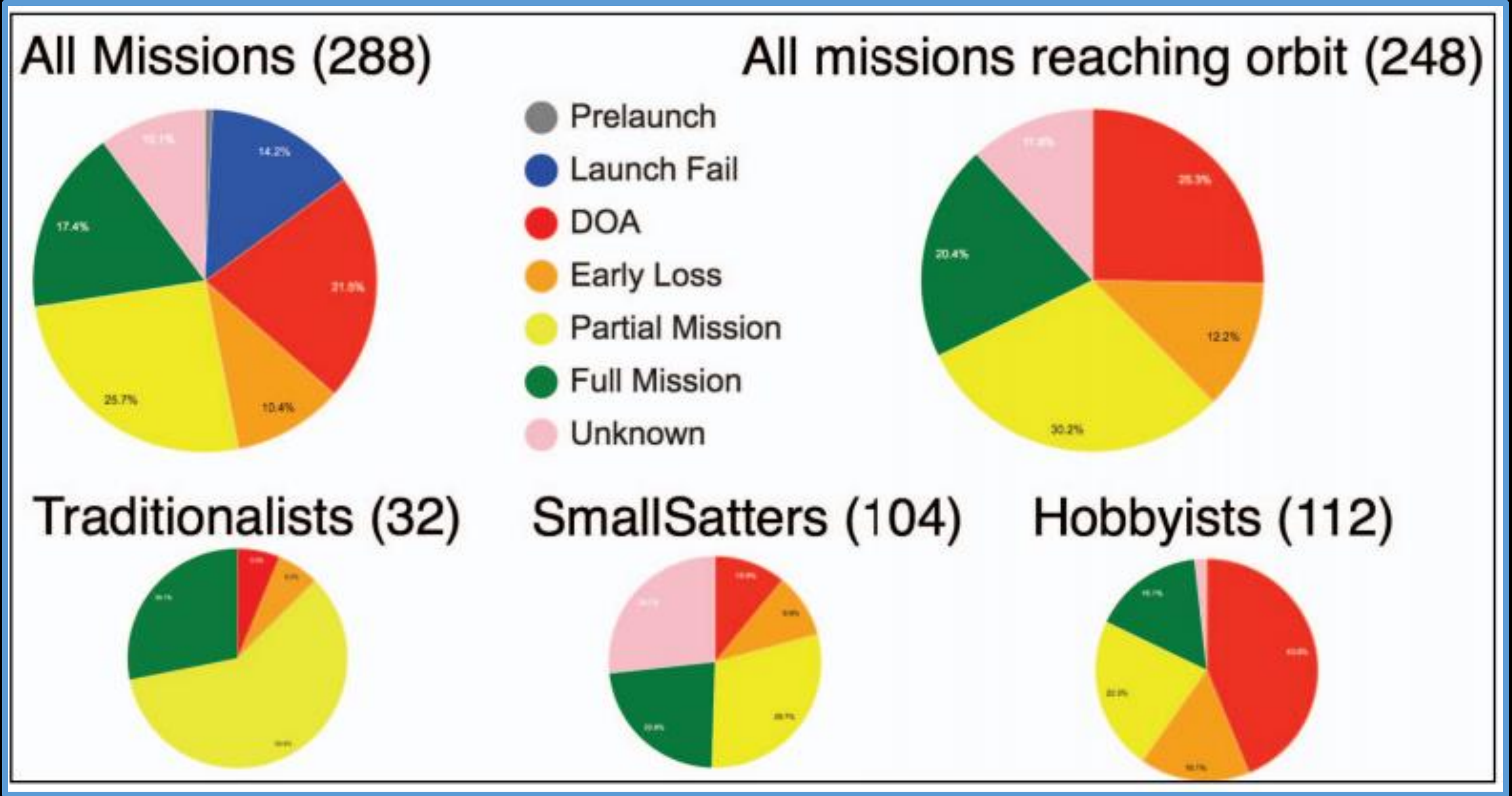
	3U	6U	12U	Mid-ESPA	ESPA
Pointing accuracy	.004^{o}-10^{o} Typical: 1^{o}	.004^{o}-3^{o} Typical: 1^{o}	.004^{o}-.01^{o} Typical: .01^{o}	.004^{o}-.15^{o} Typical: .007^{o}	.004^{o}-.03^{o} Typical: .005^{o}
Delta-V	~ 10 m/s	~ 40 m/s	< 200 m/s	< 1 km/s	> 1 km/s

Again, can always trade payload for capability!

References 7.1 through 7.15

Reliability and Cost

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



Reference 11.1

Subsystem-Specific Capabilities

ACDS, Propulsion, and Telecom

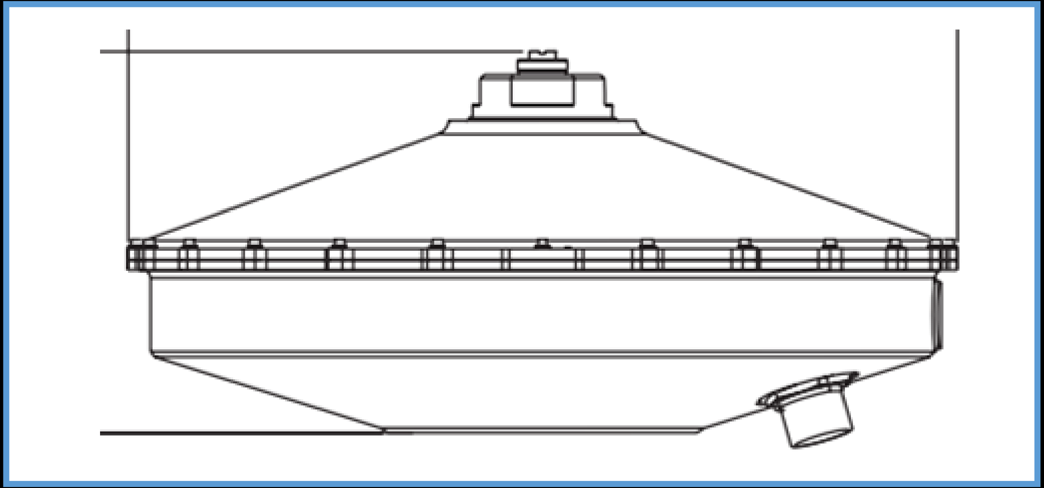
ACDS for SmallSats

Star tracker

Reaction wheel x 3

BCT XACT 0.015 Nms integrated ACDS
Volume: 10 cm x 10 cm x 5 cm (0.5U)
Used on ASTERIA and MarCO

BCT 8 Nms single reaction wheel
Volume 19 cm x 19 cm x 8 cm



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

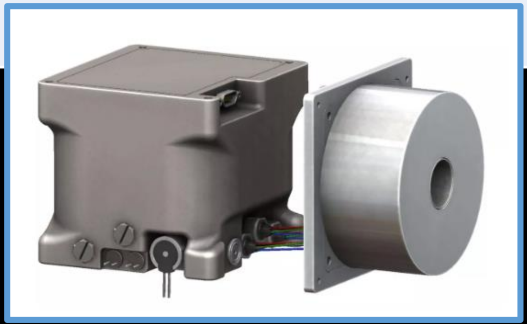
References 13.1, 13.2

Propulsion for SmallSats

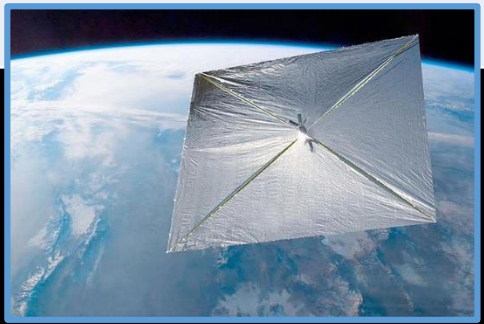
Chemical	Cold Gas	Electric	Solar sails
I_{sp}: 200 s – 250 s Thrust: 0.1 N – 30 N	I_{sp}: 65 s-70 s Thrust: 10 mN – 10 N	I_{sp}: 700 s – 3000 s Thrust: very small	Thrust: ~mN
• Many high-heritage and reliable hydrazine systems used on large missions • Hydrazine is generally a no-go for secondary launches • “Green” propellant options on the horizon	• Compact, simple, and most common option for CubeSats • Low I_{sp} compared to chemical options	• Mature technology for larger systems, but miniaturization in work • Good choice for high ΔV applications and long-term station-keeping	• Demonstrated deployment from CubeSats (NanoSail, LightSail) • Propulsion demonstrations on upcoming missions • Still need propellant for steering

VACCO’s Lunar Flashlight green propulsion system 240 m/s ΔV for 14-kg CubeSat

VACCO’s MaRCO propulsion system 30 m/s ΔV for 6U CubeSat



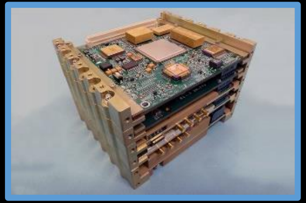
Phase4 Rider plasma system with 160 m/s ΔV for 12-kg CubeSat



LightSail 32 m^2 solar sail

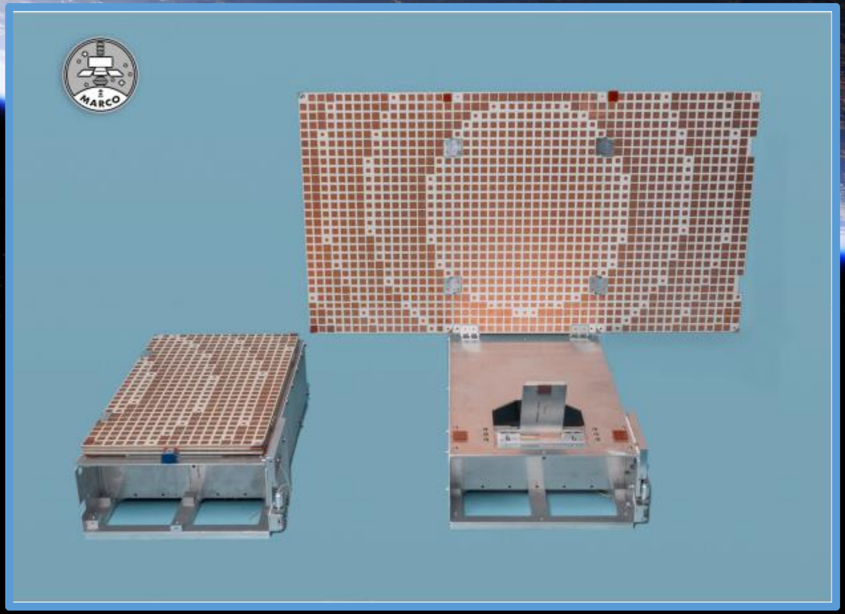
References 14.1 through 14.8

Telecom for SmallSats



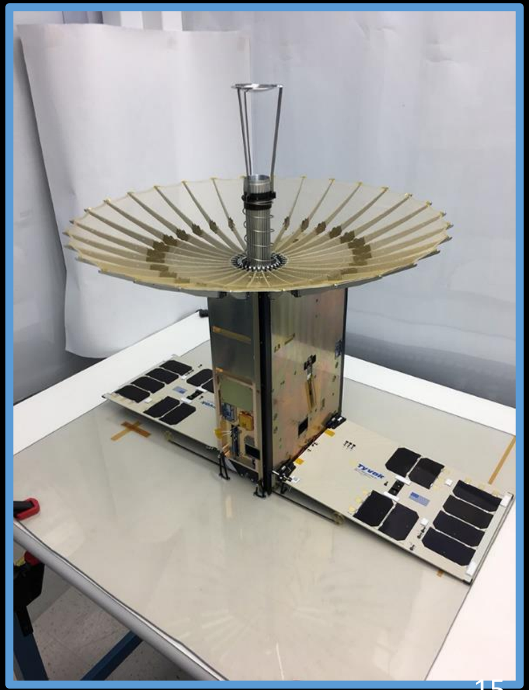
Iris CubeSat X-band DSN-compatible transponder + amplifier
4 W RF output, 35 W DC input, 1.2 kg, 0.5U

Reflectarray antenna on MarCO (6U, X-band, 8 kbps from Mars) and ISARA (3U, Ka-band, 100 Mbps from LEO)



X/Ka-band Small Deep Space Transponder (SDST)
Needs an amplifier, customizable to mission requirements
3.2 kg, 18 cm x 17 cm x 12 cm (~4U)

0.5-m deployable Ka-band HGA on Raincube fit in 1.5U volume



References 15.1 through 15.5

The Current and Near-Future Landscape

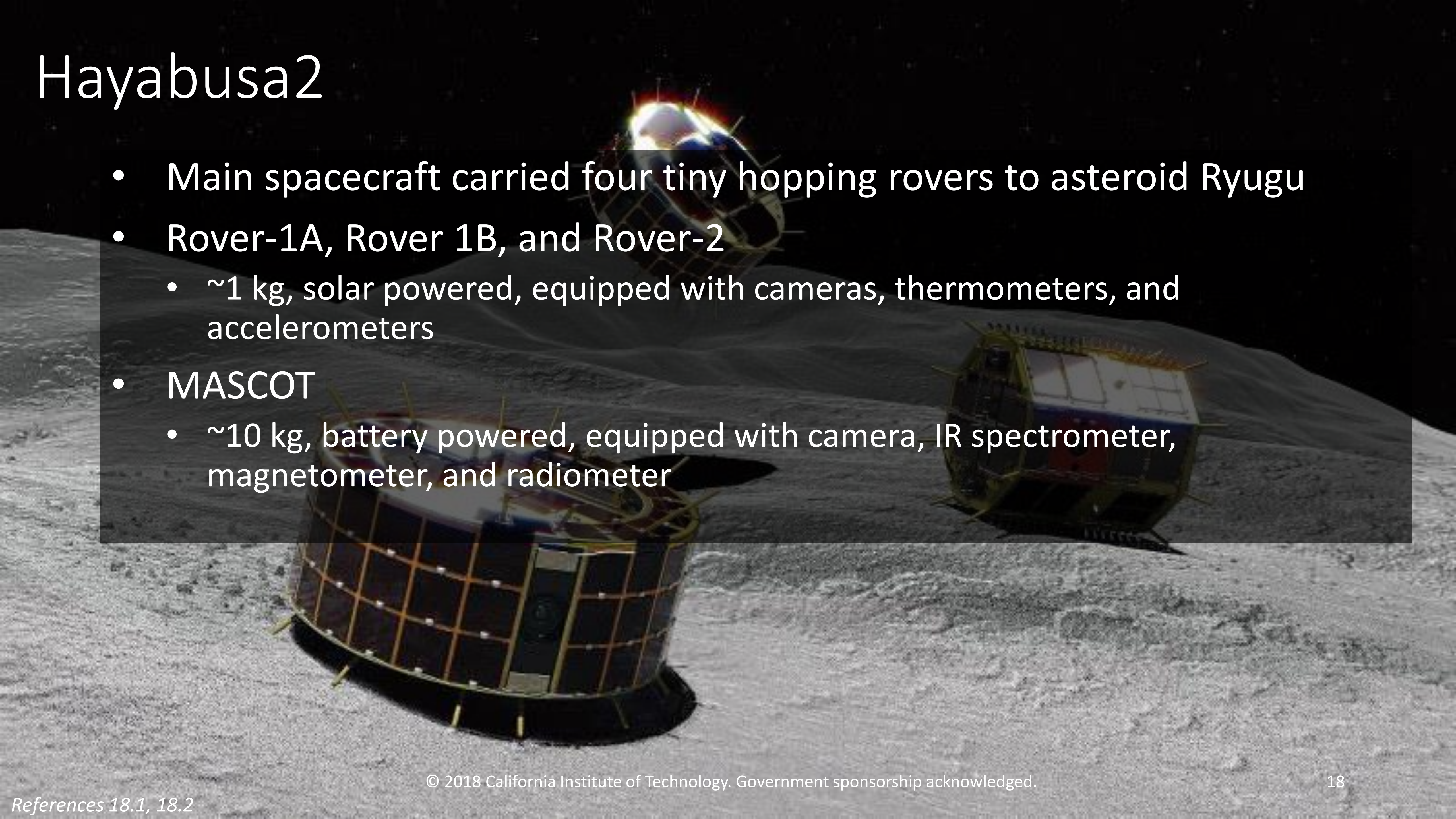
Near-term proposals or launches of SmallSat science missions beyond LEO

Mars Cube One (MarCO)

- Two CubeSats (A and B) launched with the InSight Mars lander
- First interplanetary CubeSats
- 6U form factor with Reflectarray antenna, IRIS radio, ~30 m/s ΔV
- Will monitor InSight’s landing and act as a communications relay

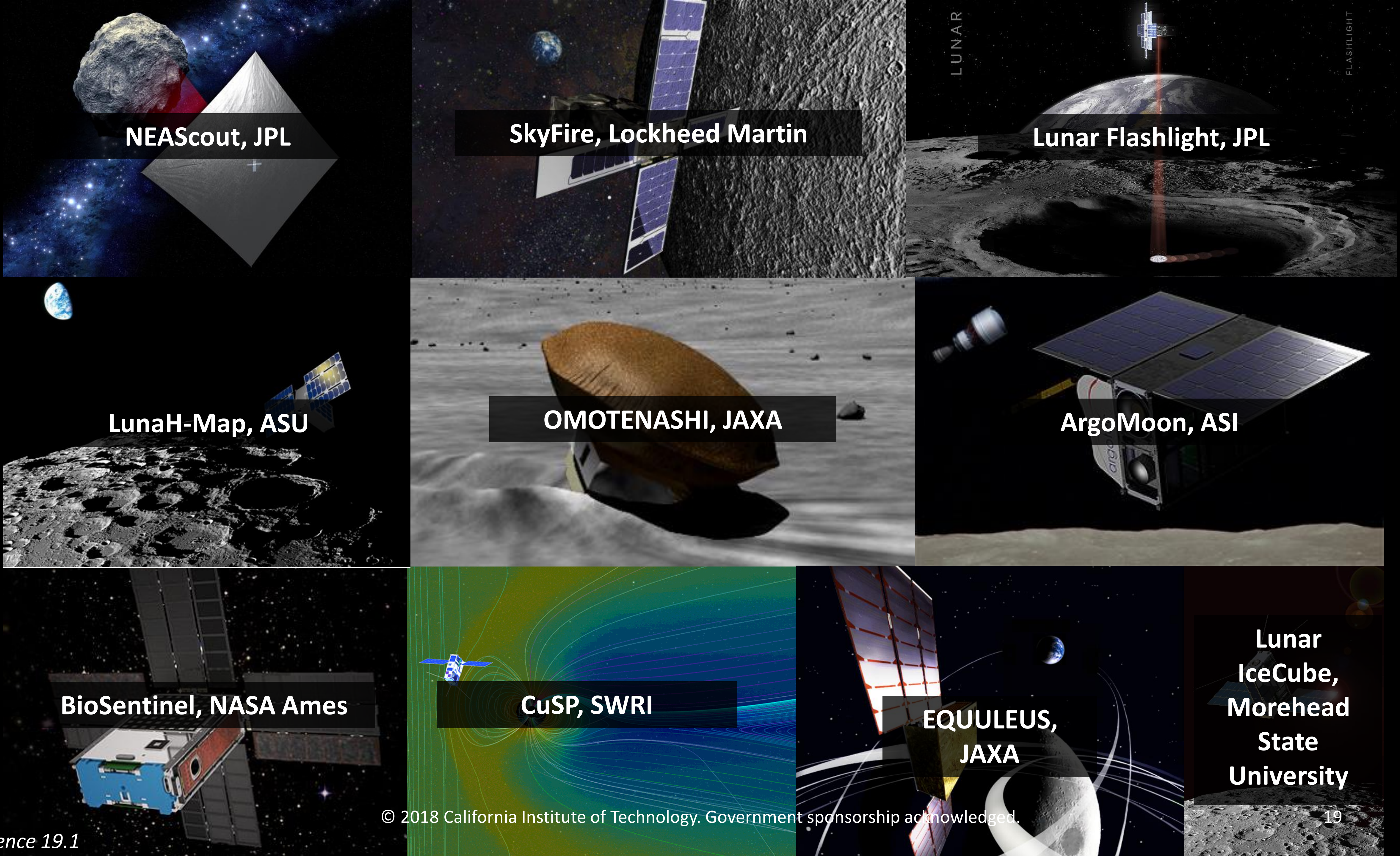
References 17.1, 17.2

Hayabusa2

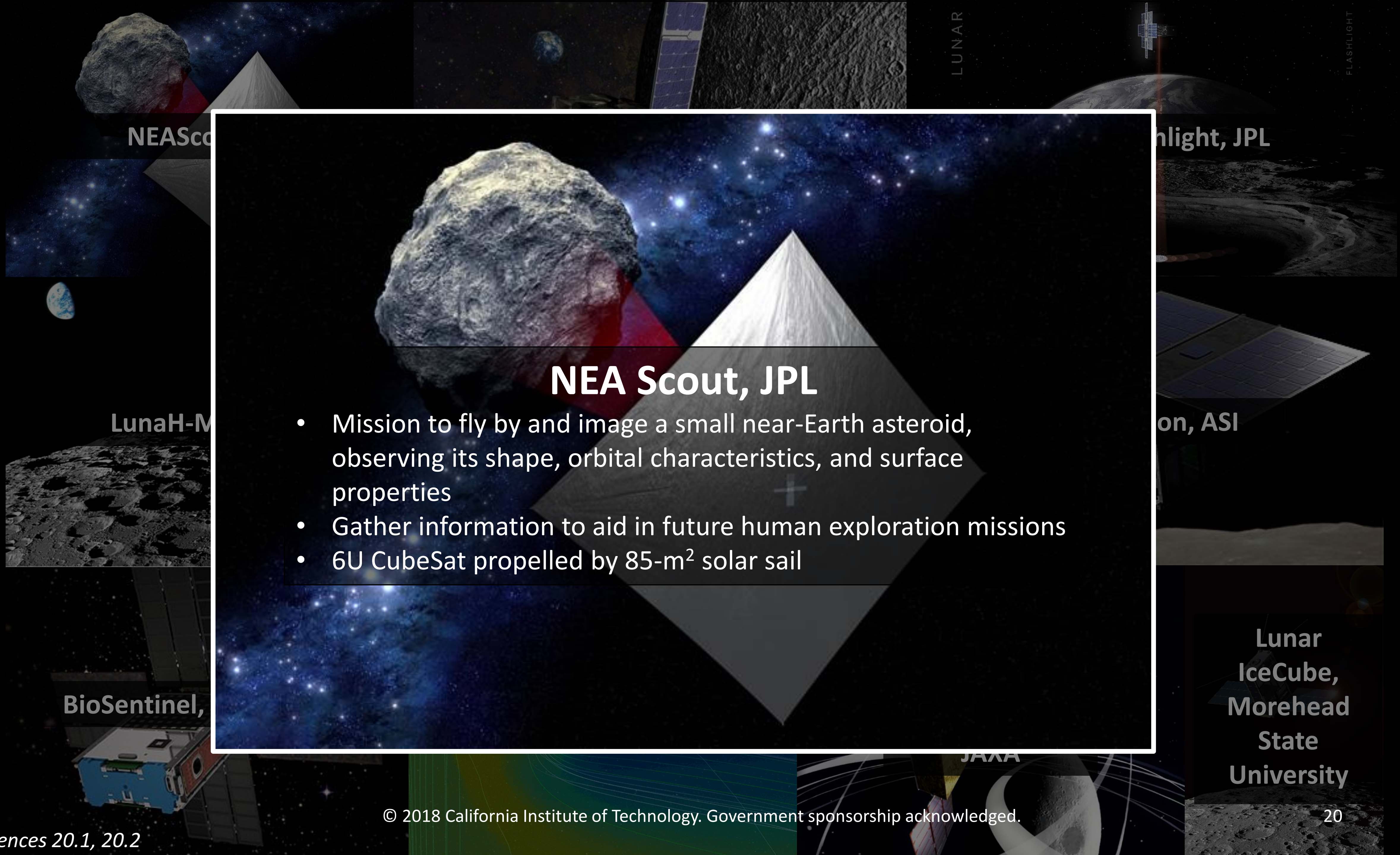


- Main spacecraft carried four tiny hopping rovers to asteroid Ryugu
- Rover-1A, Rover 1B, and Rover-2
  - ~1 kg, solar powered, equipped with cameras, thermometers, and accelerometers
- MASCOT
  - ~10 kg, battery powered, equipped with camera, IR spectrometer, magnetometer, and radiometer

References 18.1, 18.2



Reference 19.1

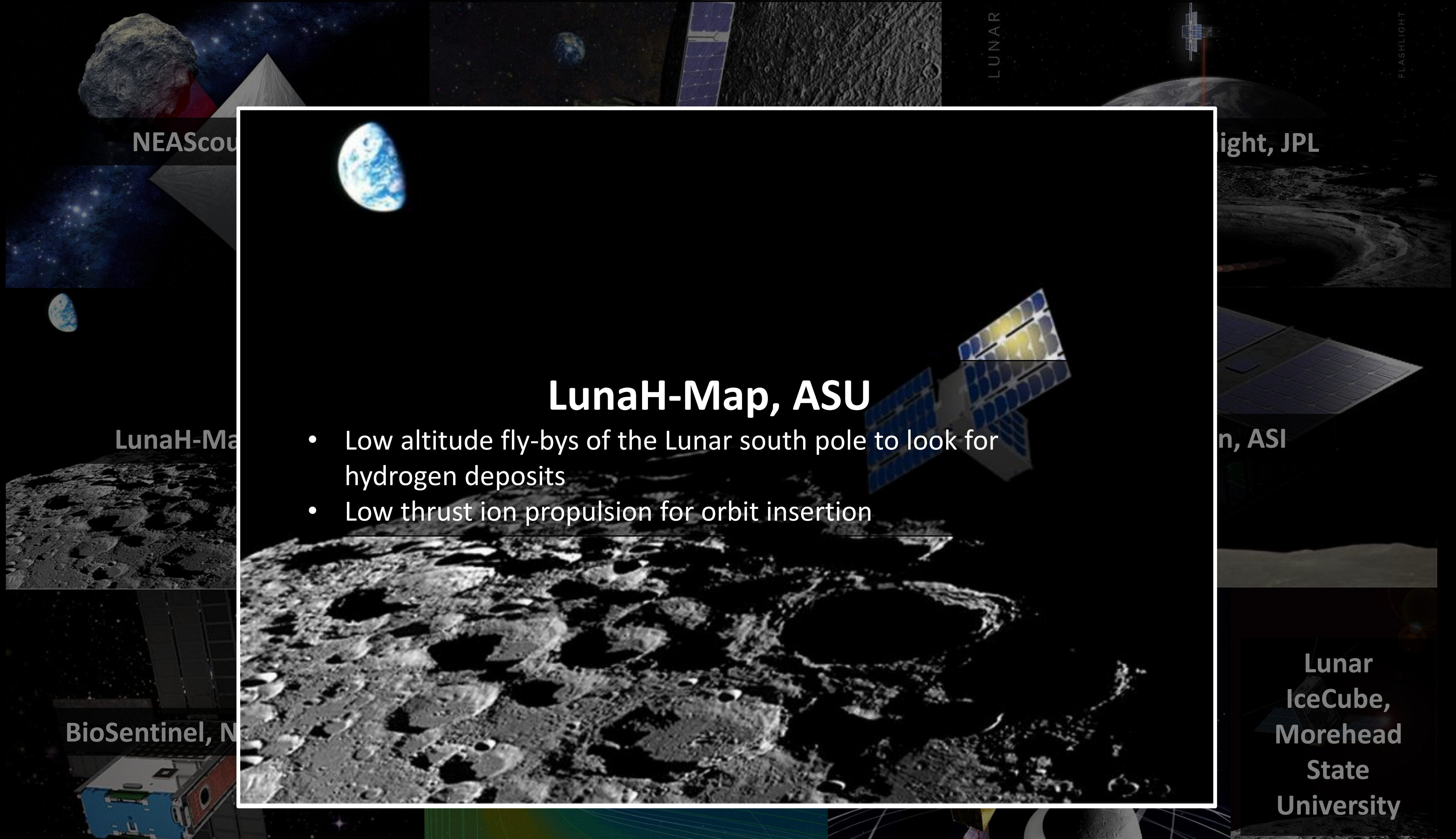


NEA Scout, JPL

- Mission to fly by and image a small near-Earth asteroid, observing its shape, orbital characteristics, and surface properties
- Gather information to aid in future human exploration missions
- 6U CubeSat propelled by 85-m^2 solar sail

References 20.1, 20.2

Reference 21.1

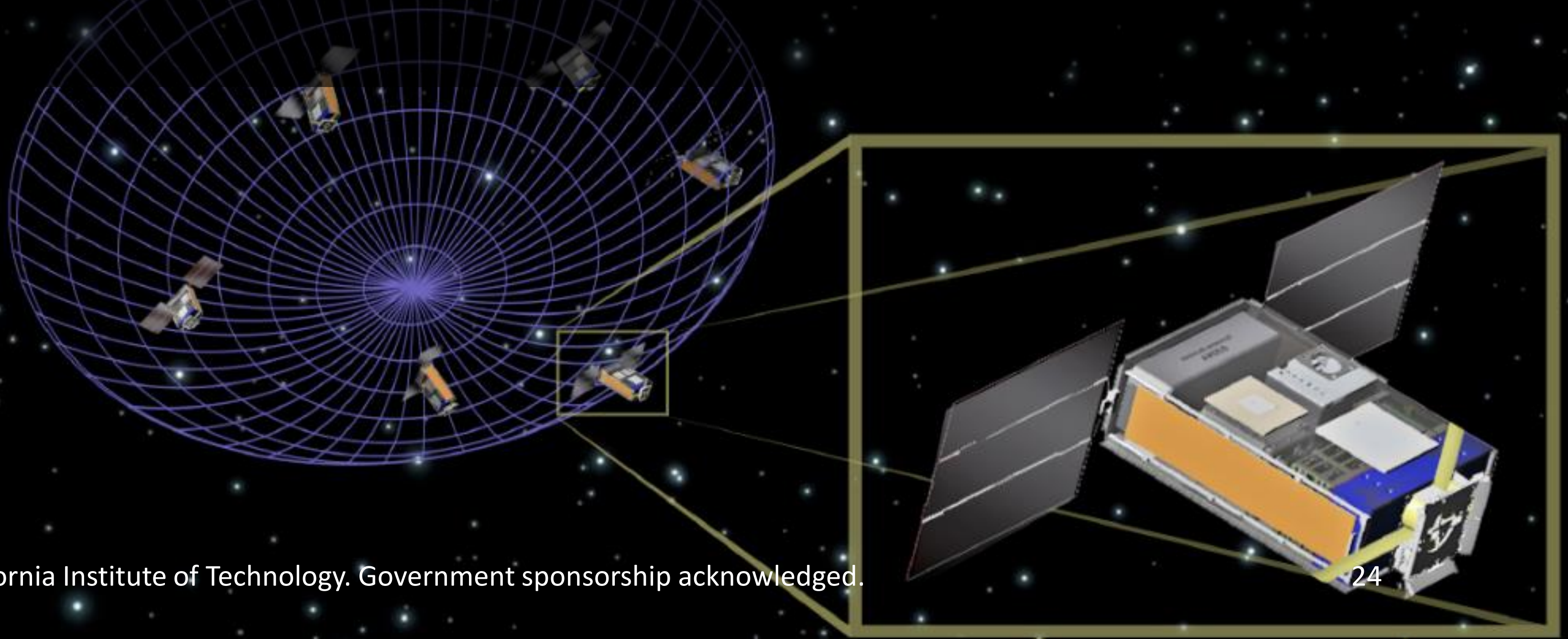


Reference 22.1

Reference 23.1

Sun Radio Interferometer Space Experiment (SunRISE)

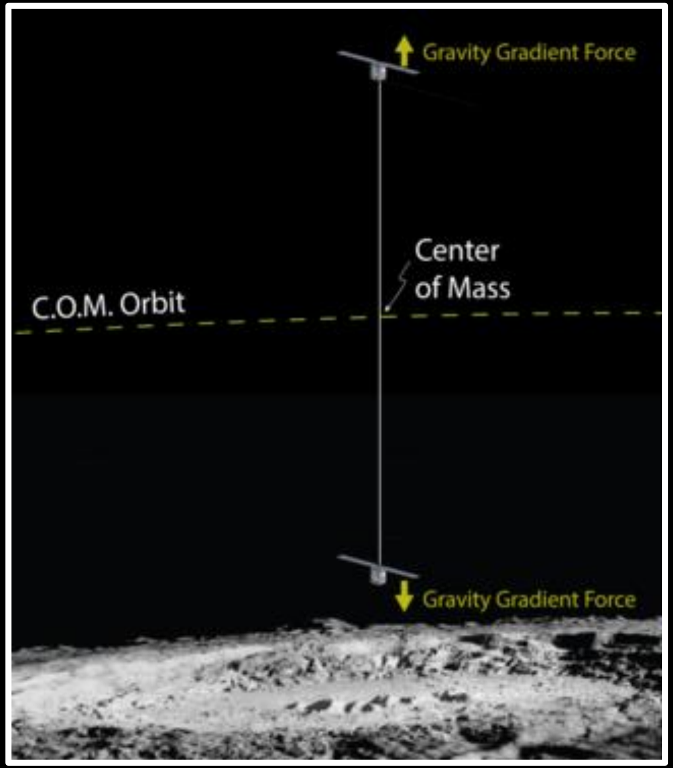
- Proposed to the NASA Small Explorer (SMEX) call
- Constellation of six 6U CubeSats brought to near-GEO with rideshare
- Formation flying to form 10 km synthetic aperture
- Observe solar radio bursts that can't be observed from the ground due to ionic absorption



Reference 24.1

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

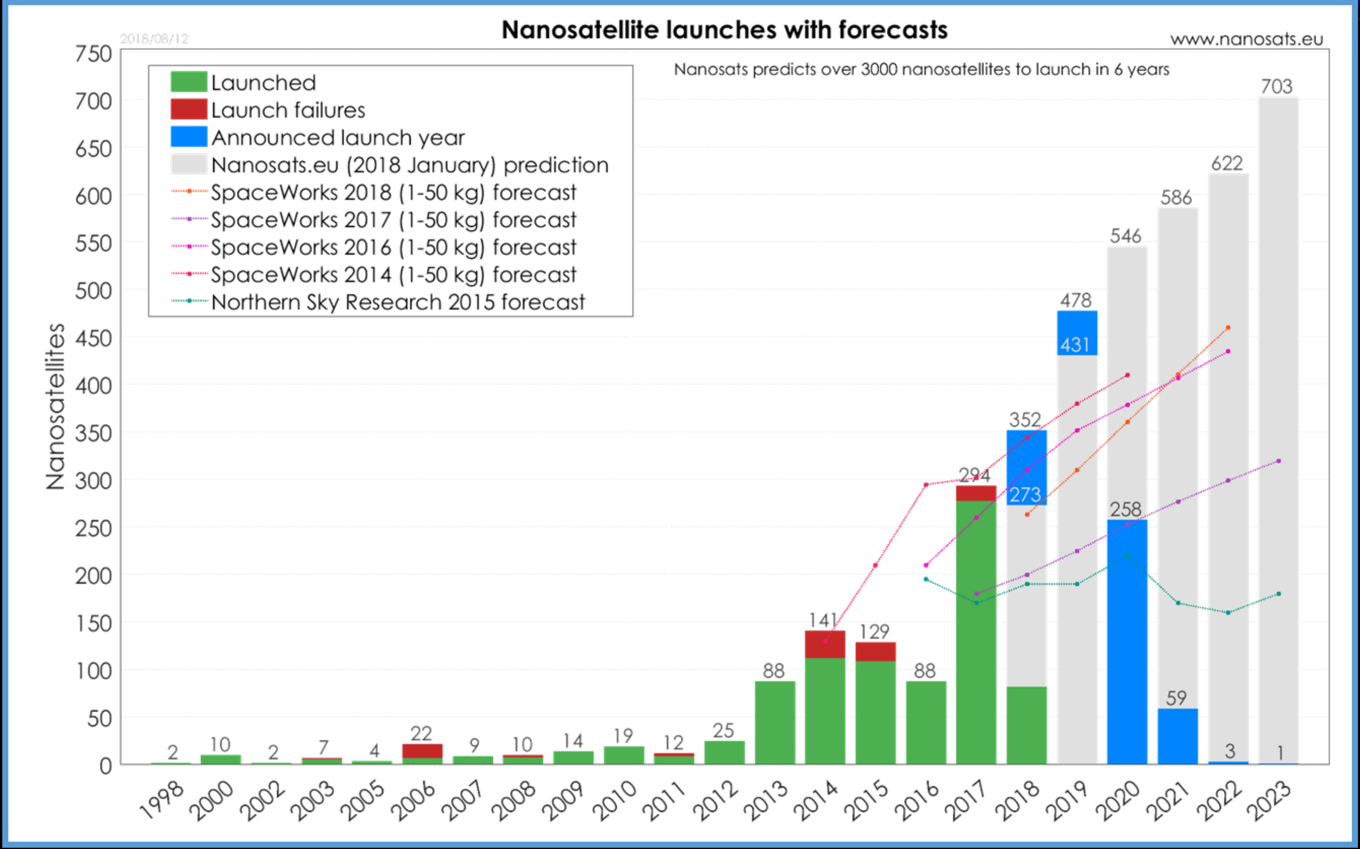


References 25.1 through 25.4

The Far Future Landscape

Projections for the next 15 years

- 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



Reference 27.1

Acknowledgements

- Annie Marinan
- Steve Matousek
- Hayden Burgoyne
- Alan Didion
- David Sternberg
- Chi-Wung Lau
- Thaddeus Voss

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