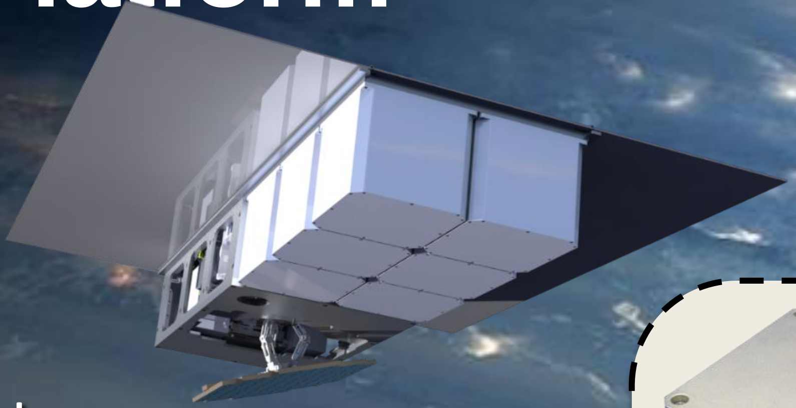
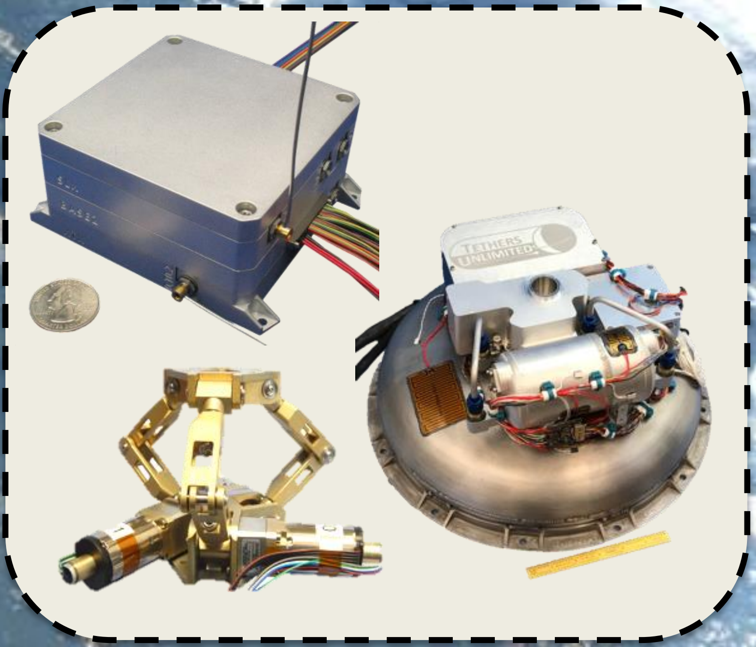
High-Performance SmallSat Components and the HyperBus Modular Payload Platform



Dr. Rob Hoyt, CEO
*Dr. Dan Reuster, VP Strategy
Greg Jimmerson, Chief Concept Dev.

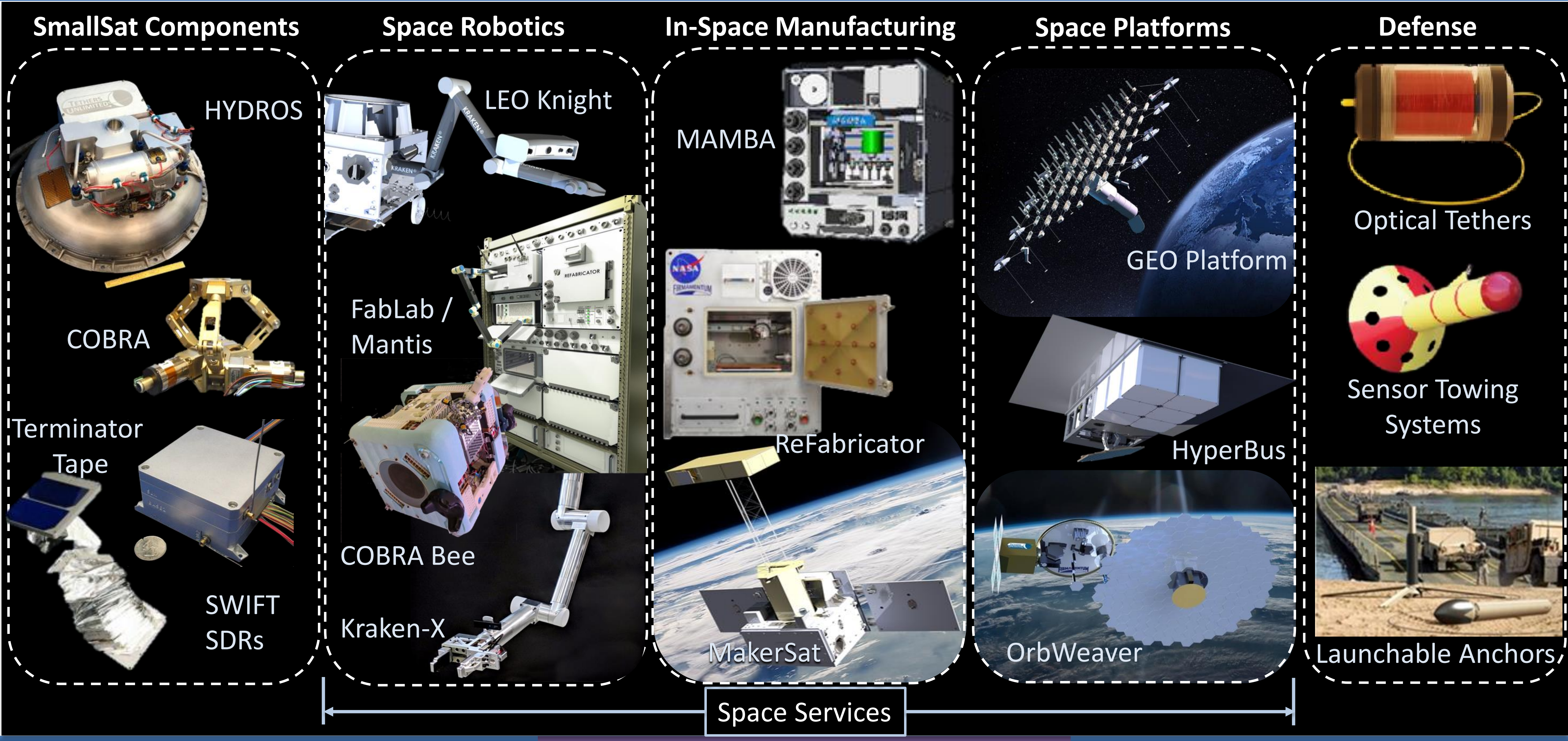
Tethers Unlimited

425.486.0100x111 hoyt@tethers.com



* presenting

TUI’s Five Divisions



Tethers Unlimited, Inc.

Market 1

High-Performance, SmallSat Components

Establish space hardware expertise, processes, revenue, and credibility

Market 2

Satellite Services / Hosted Payloads

TUI Next-Gen Spacecraft – HyperBus (an Ethernet Port in Space)

Market 3

Robotic Servicing: LEO Knight

Fueling / Servicing, Orbital Assembly, Building / Tending Space Infrastructure

Growth Stage
LRIP => Full Production

Development Stage
Preparing Initial Flight Demos

Mission Concept Stage
Laboratory Demos

TUI Next-Gen Spacecraft – HyperBus

HyperBus OV-1 (an Ethernet Port in Space)

HyperBus 12U Platform & Support Modules

ISS Deployment

Orbit Agility™

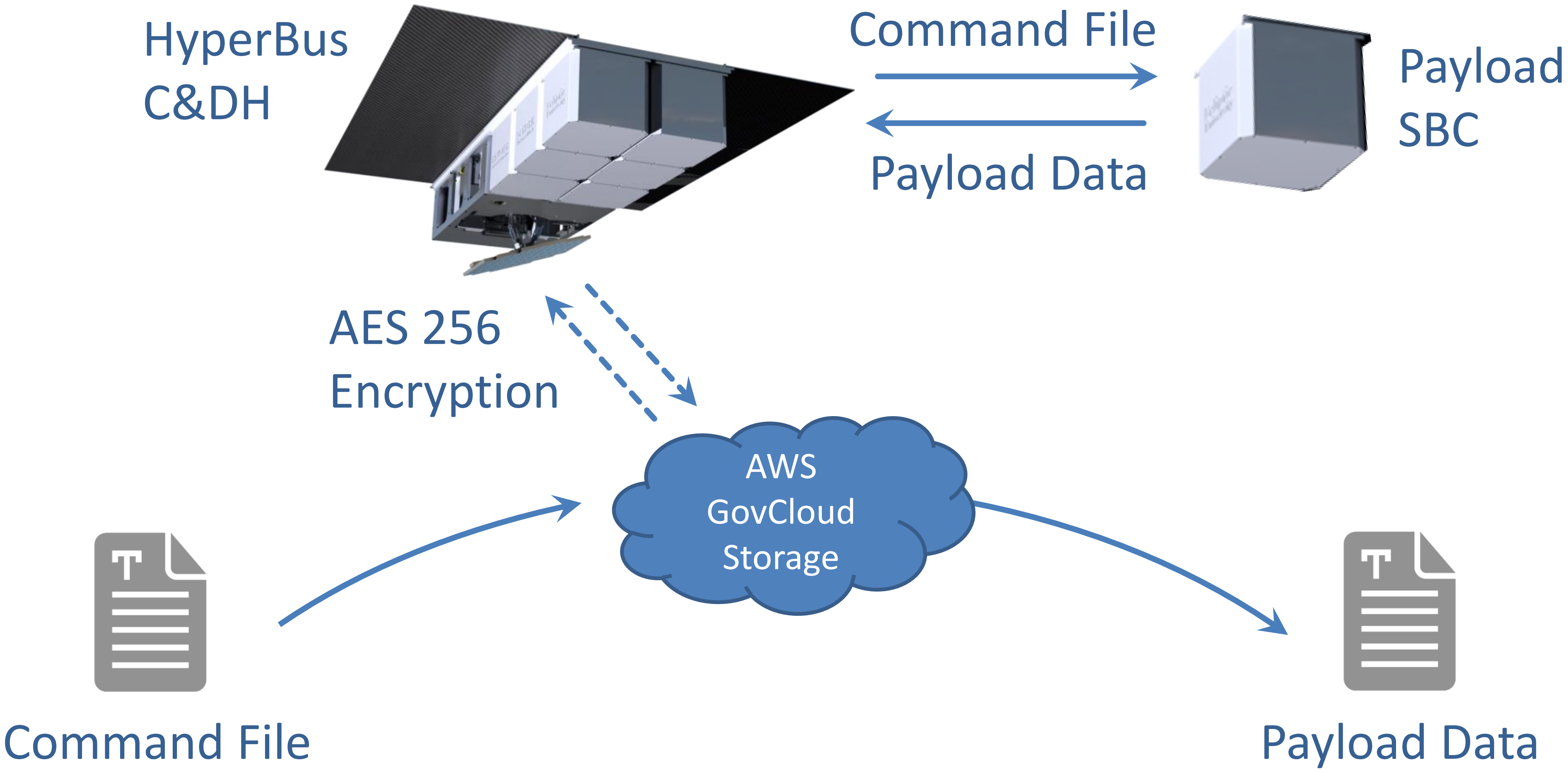
NanoRacks
12U Doublewide Deployer

Advantages for Payload Customer:

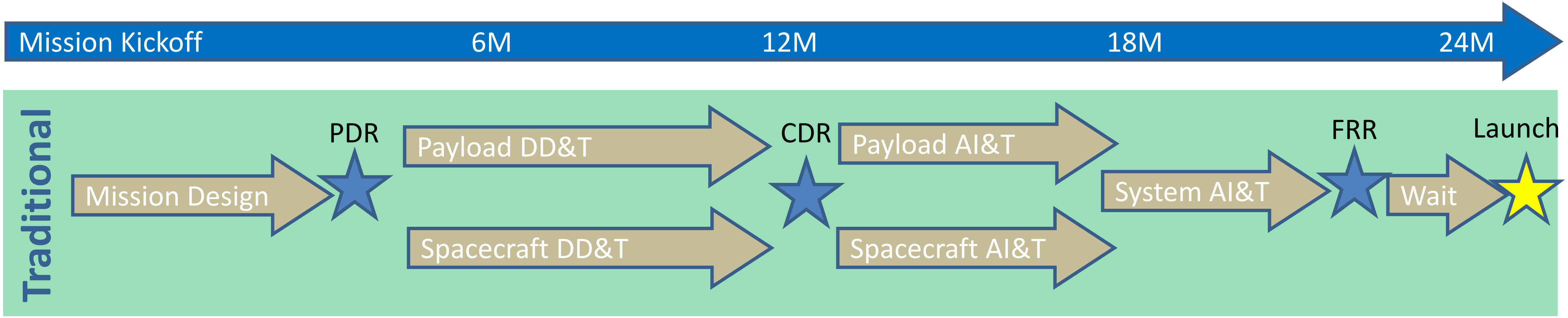
- No Spacecraft Development
- Eliminate Payload I&T Costs
- Minimize Time-to-Launch
- Ops and Data via the Cloud
- Regular Launch Cadence

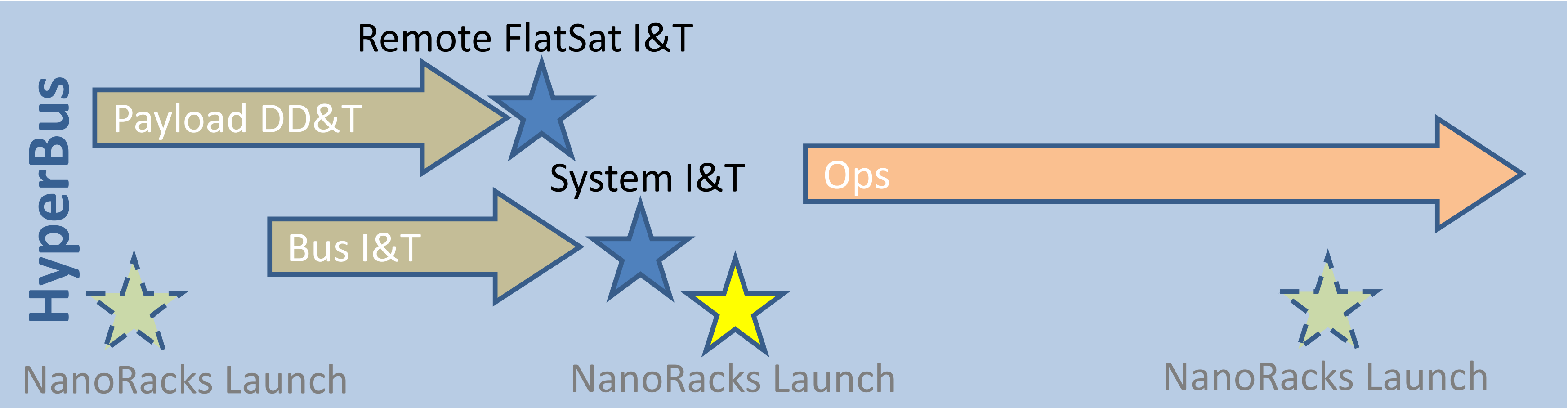
High Bandwidth Data Up/Down

HyperBus Payload Operations Experience



HyperBus Timeline vs. Traditional Approach





Steady Launch Cadence, Modular Bus, & Simple, Remote I&T Enable 6-Month Technology Test Cycle

Parallel development path and remote Integration & Test significantly reduce time-to-flight

HyperBus MPP Modular Assembly

Solar Arrays (108W)

Batteries and Wire Harness

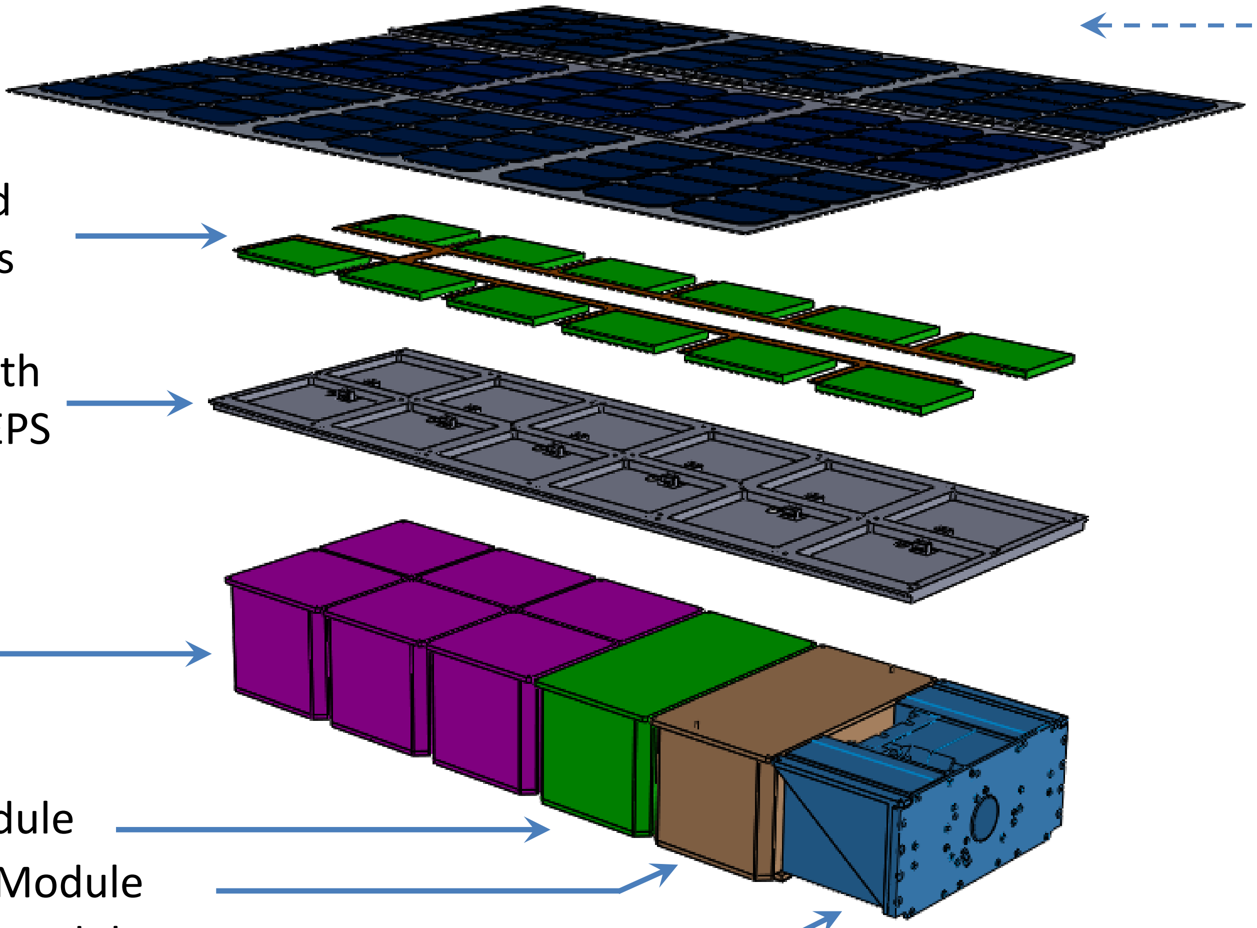
Baseplate with pockets for EPS components

Hosted Payload Volumes

2U Base Module

2U Big Data Module

2U Mobility Module



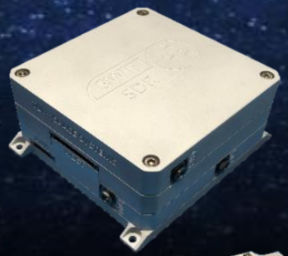
IKEA-like Assembly

5-minute Payload Integration: “Just 4 bolts and a plug”

Readily-Configurable Mission Modules and Payload Accommodations

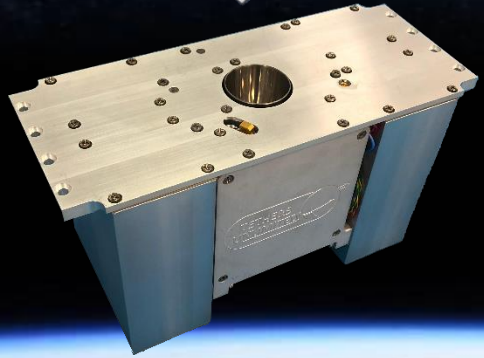
HyperBus 12U Hosted Payload Service

10-Minute Payload Integration | Orbit Agility™ & Persistence | Big Data Delivery



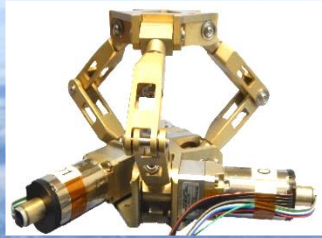
SWIFT® Radios

AFSCN Compatible
TT&C and MDL
TRL-9



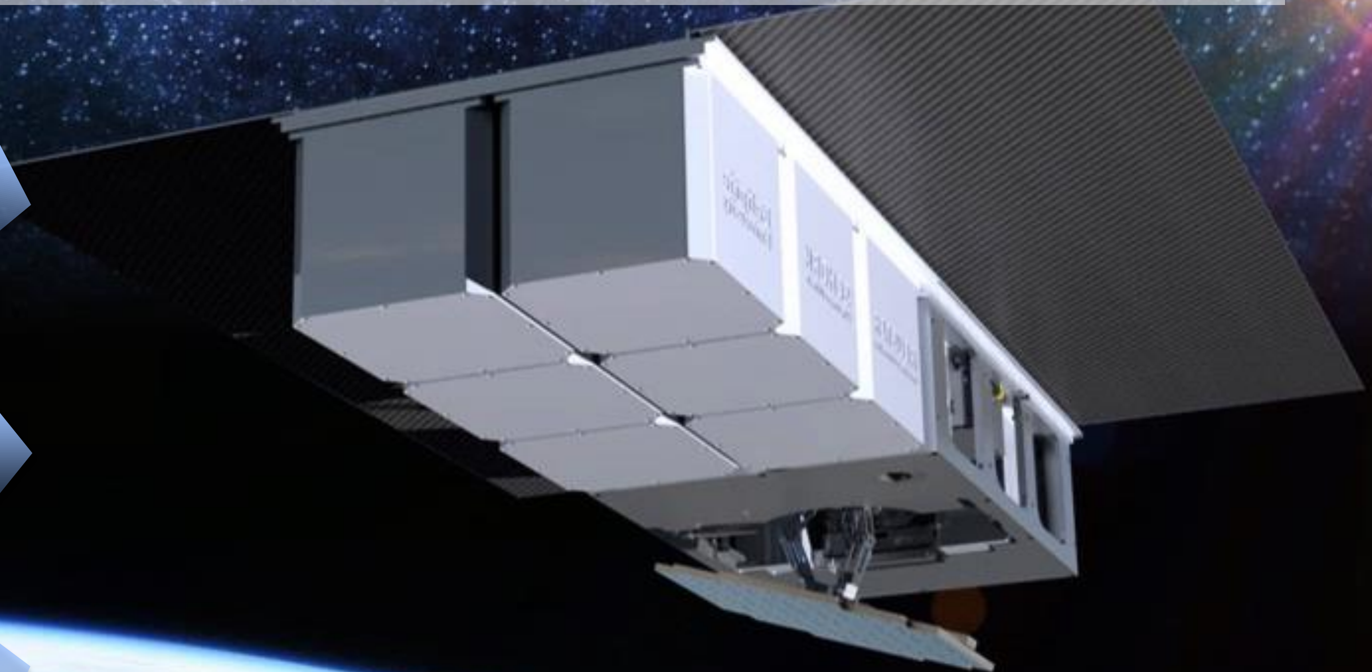
HYDROS™-C

>100 m/s delta-V
TRL-7



COBRA™ Gimbal

Precise steering of communications link
TRL-7



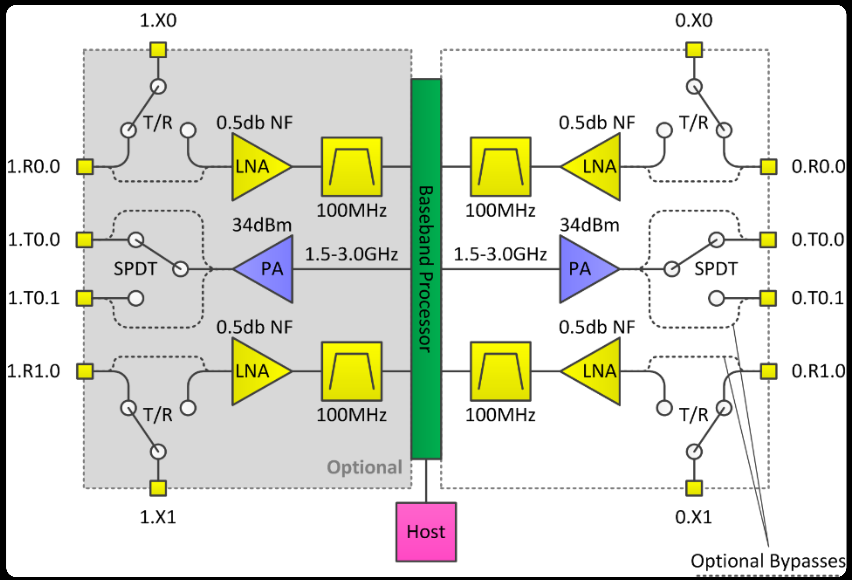
HyperBus 12U Modular Platform

HyperBus integrates TUI's high-TRL, high-performance components to enable mobility, security, and big data capabilities.

SWIFT®-SLX

Flexible High-Performance L- and S-Band Communications

	Qty	Freq. Range	Bandwidth	Power
Tx	2	1.5-2.5 GHz	≈40 max. MHz Inst.	33 dBm /ea
Rx	4	1.0-4.0 GHz	≈100 MHz Tuning ≈7 MHz Inst.	0.75 dB NF



Typical Use	Band	Frequency Range
Uplink	L-band Uplink	1755 to 1850 MHz
Uplink / Downlink	Mobile Satellite	1930 to 2025 MHz
Uplink	USB S-band	2025 to 2110 MHz
Downlink	USB S-band	2200 to 2300 MHz
Uplink / Downlink	ISM S-band	2400 to 2483 MHz

Capabilities

- ≈2W max. S-band Tx w/ ≈40 MHz max. bandwidth
- 1.7-2.7 GHz Tx frequency coverage
- Independent receivers w/ ≈7 MHz typ. bandwidth
- 1.5-3.5 GHz Rx frequency coverage in ≈100 MHz chunks
- ≈0.75 dB typ. receiver noise figure
- Arbitrary waveform/modulation/coding
- Typical LEO max.: 5 Mbps up/20 Mbps down
- 100% re-programmable w/ fail-safe boot modes
- Optional diplexer for full-duplex L-/S-band ops

Network Compatibility

Optional AFSCN-specific firmware interoperable with all non-deprecated modes in ICD-0502E. In addition to AM/FSK, direct carrier PSK uplinks are supported giving the SWIFT-SLX the ability to interoperate with both traditional and newer commercial ground stations.

- NASA's NEN, TDRS (SN), DSN
- Verified w/ RT Logic T400XR, Cortex T70, and Amergint satTRAC
- Simultaneous SGLS and USB uplink reception
- Interface compatible with KI-55 and GNOME Type-1 encryption module
- Onboard commercial-grade AES-256/GCM "full-rate" encryption available, including compatibility with GRYPHON personalities of KIV-7MS

Specifications

- > 3 year LEO mission design life
- 86 x 86 x 25-35mm (0.25U) (excl. diplexer)
- ≈300 grams (excluding diplexer)
- 6-36V unregulated DC
- Pre-qualified to NASA GEVS shock/vibe
- Pre-qualified to -40 to +60°C
- Scalable power consumption
    - 3.0W active standby
    - 6.5W single receive
    - 12W transmit only
    - 15W transmit and single receive

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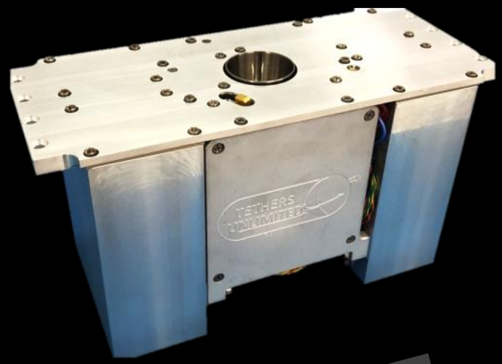
HYDROS™

$H_2O = \Delta V$

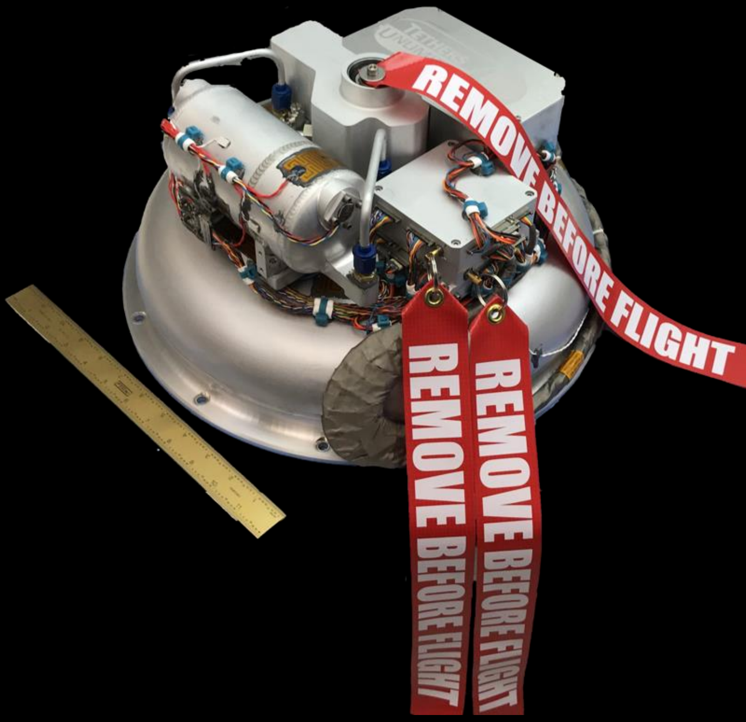
High-Performance Water Based Propulsion for Small Satellites

- Non-Explosive
- Non-Toxic
- High Thrust Efficiency
- High Specific Impulse
- Flight Qualified
- Onboard Crypto Available



First Flight Q4 2019

HYDROS-C	Specifications	HYDROS-M
> 310 s	**Specific Impulse**	> 310 s
> 1.2 N	**Thrust**	> 1.2 N
2.2 mN	**Max Effective Continuous Thrust**	6.8 mN
0.13 mN/W	**Thrust Efficiency**	0.16 mN/W
> 1.75 Ns	**Impulse per Thrust Event**	>1.75 Ns
1,230	**Total # Thrust Events**	10,300
> 2,151	**Total Impulse Delivered**	> 18,000
0.74 kg	**Water Capacity**	6.2 kg
1.87 kg	**Dry Mass**	6.4 kg
2.61 kg	**Wet Mass**	12.6 kg
825 s	**Time to Refill Gas Plenums**	269 s
190 x 190 x 92 mm	**Size**	Ø 381 x 191 mm
5-25 W	**Power**	7-40 W
3 years LEO	**Lifetime**	3 years LEO
Deck or Rail Mount Options	**Mounting**	Within 15” separation ring
RS-422, Ethernet	**Command Interface**	RS-422, Ethernet
TRL 6+	**Qualification Level**	TRL 6+



- SBIR
- Tipping Point
- Ph-III Sales

Next-Gen HYDROS-R will be On-Orbit Re-fuelable

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SWIFT®-XTS

High-Performance X-Band Transmitter and S-Band Transceiver

Capabilities

- >100 Mbps real X-band downlink rates
- >10 Mbps real S-band downlink rates
- >1 Mbps real S-Band uplink rates on up to two independent simultaneous channels
- >6 dB continuously adjustable X-band Tx power w/o losing efficiency
- MIMO antenna connectivity for attitude diversity and ADCS error recovery
- Integrated framing w/ deep store-and-forward buffers, automatic frame sizing and padding
- Full-rate AES-256/GCM crypto offload w/ multiple key indexing, including KIV-7MS GRYPHON compatibility
- Runtime configurable link parameters
  - BPSK/[O]QPSK/8PSK (8PSK Tx Only)
  - LDPC/Reed-Solomon/Convolutional
  - Continuously adjustable symbol rates
- Flexible high-speed digital interface options, including separate command and data ports:
  - RS-422/LVDS: Multiple pairs async. or sync. up to 50 Mbps each
  - SpaceWire: Dual up 100 Mbps each
  - Ethernet: 10/100/1000 Mbit w/ integrated PHY and magnetics

Specifications

Metric	X-band Tx[1]	S-Band Rx (2)
Power/Sensitivity	1-7W RF Output	0.75 dB NF typ.
Gain Control Range	-30 to +6 dB	>90 dB AGC
Dynamic Range	>60 dBc SFDR	>66 dBc SFDR
Bandwidth	>70 MHz	7 MHz/ea typ.
Frequency	7000-8500 MHz	1500-3500 MHz
Base Input Power	3.0W	3.0W
Additional PA Power	+24-42W	1x Rx: +3.5W 2x Rx: +5.0W
Size & Mass	86 x 86 x 50mm , 500g	
Shock/Vibe	Pre-qualified to NASA GEVS levels	
Temperature	Pre-qualified to -40 to +60°C	

[1]See SLX data sheet for S-Band Transmitter specs

Flight Heritage

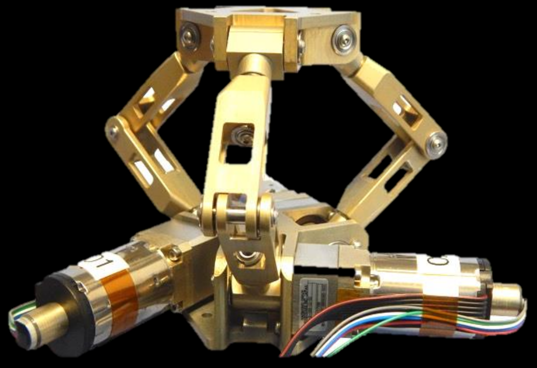
www.tethers.com

High-Performance 3DOF Pointing & Positioning for Small Satellites

TETHERS UNLIMITED

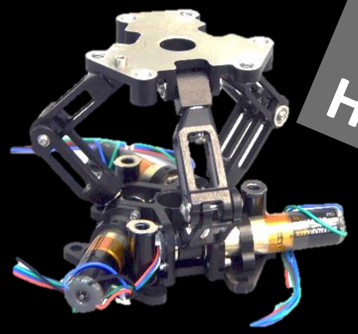
COBRA™ GIMBAL

COBRA™ COMMANDER



Why Fly COBRA?

- Low SWaP-C
- High Precision
- High Payload Capacity
- Hemispherical Workspace
- Continuous Pointing
- Flight Qualified



Flight Heritage

COBRA-UHPX	Specifications	COBRA-HPX
22 mm BLDC Motor	Actuator	12 mm Stepper Motor
100:1 Harmonic Drive	Gearhead	377:1 Zero Backlash Spur
12-bit Magnetic Encoder	Sensor	12-bit Absolute Mag. Encoder
(491 g w/ launch locks)	Mass	184 g (276 g w/ launch locks)
165 mm diameter	Stowed Footprint	113 mm diameter
40 mm (excl. launch locks)	Stowed Height	29.2 mm (excl. launch locks)
85.5 mm (excl. launch locks)	Deployed Height	73.5 mm (excl. launch locks)
Full Hemisphere	Pointing Workspace	Full Hemisphere
≤ ± 237 arc-sec (0.066˚)	Closed-Loop Repeatability	≤ ± 234 arc-sec (0.065˚)
≤ 3 arc-sec (0.00083˚)	Closed-Loop Resolution	≤ 276 arc-sec (0.077˚)
Up to 180˚/s	Slew Rates	Up to 30˚/s
Load dependent	Power Consumption	2.4 W
None	Thru Hole Diameter	10.5 mm
500 g in 1G	Payload Capacity	1200 g in zero-G
-40° C to +85° C	Non-Operating Temperature	-40° C to +85° C
-35° C to +70° C	Operating Temperature	-35° C to +70° C
1X, FD04 Frangibolt (Qual Pending)	Launch Lock Option	3X, FC2 Frangibolts (Qualified)

SWIFT®-KTX & High Gain Pointing Antenna

High-Performance Software-Defined K/Ka-Band Transmitter

Capabilities

SWIFT-KTX provides small satellites with a high-throughput downlink in K-band. When paired with the next generation SWIFT baseband processor and sufficient link margin, real data rates of 500 Mbps or more are achievable using high order modulation (>3 bits/Hz) and Turbo/LDPC encoding. Each radio includes two 2W PAs that directly drive two switchable WR-42 waveguide interfaces for left/right antenna polarization agility. A third ≈10 dBm waveguide output is available before the PAs for driving TWTAs and integrated K-band ESAs.

- >500 MHz real modulation bandwidth
- Two discrete designs covering approximately:
  - 18-23 GHz
  - 23-28 GHz
- ≈33 dBm saturated output power w/ ≈20 dB adjustable range
- Three switchable WR-42 waveguide outputs (two w/ HPAs)

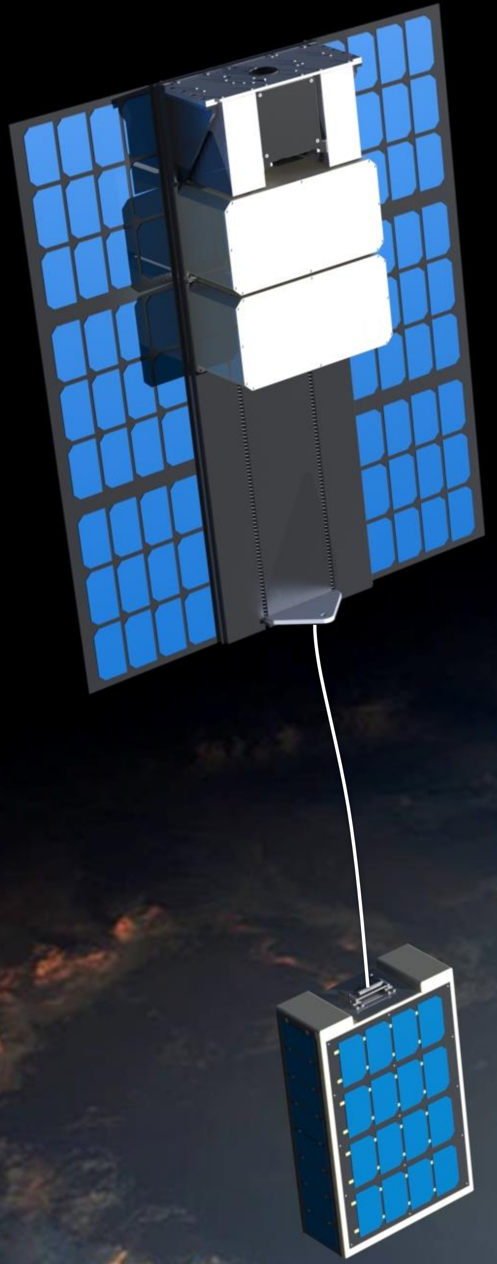
Specifications

- >3 year LEO mission design life
- Size: 86 x 86 x 40mm
- Mass: < 500 grams
- Power: 6-36V unregulated DC
  - Integrated latch-up/fault detection & protection
- Power consumption:
  - Current gen 50 MHz baseband processor: ≈3W
  - Next gen 500 MHz baseband processor: ≈15W
  - K/Ka-band module power consumption for 33 dBm output: ≈16W
- High-speed interface options:
  - 1Gbit Ethernet
  - 200 Mbps SpaceWire (LVDS)
  - 200 Mbps sync. HDLC over LVDS
  - 10+Gbps SERDES (next generation baseband processor only)
- Flexible mounting options

Network Compatibility

- Verified w/ MMR/QMR and ViaSat VHR modems
- TDRS compatibility verification pending

US ARMY SMDC Sponsored – awaiting flight test



Example Scientific Payload

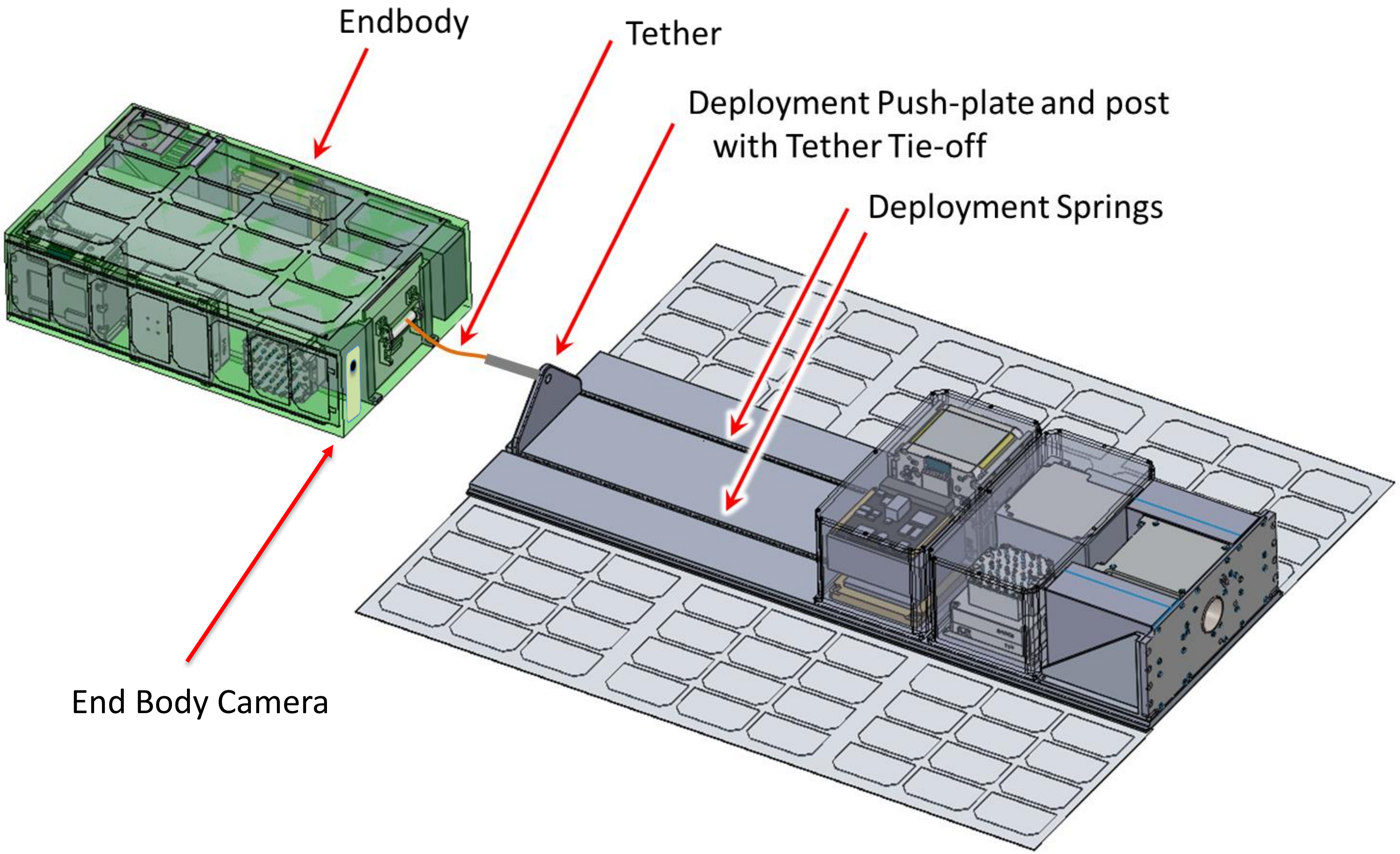
TUI’s HyperBus for TeD^3

(HyperCAST)

HyperCAST (TeD^3) Technology Demonstrator

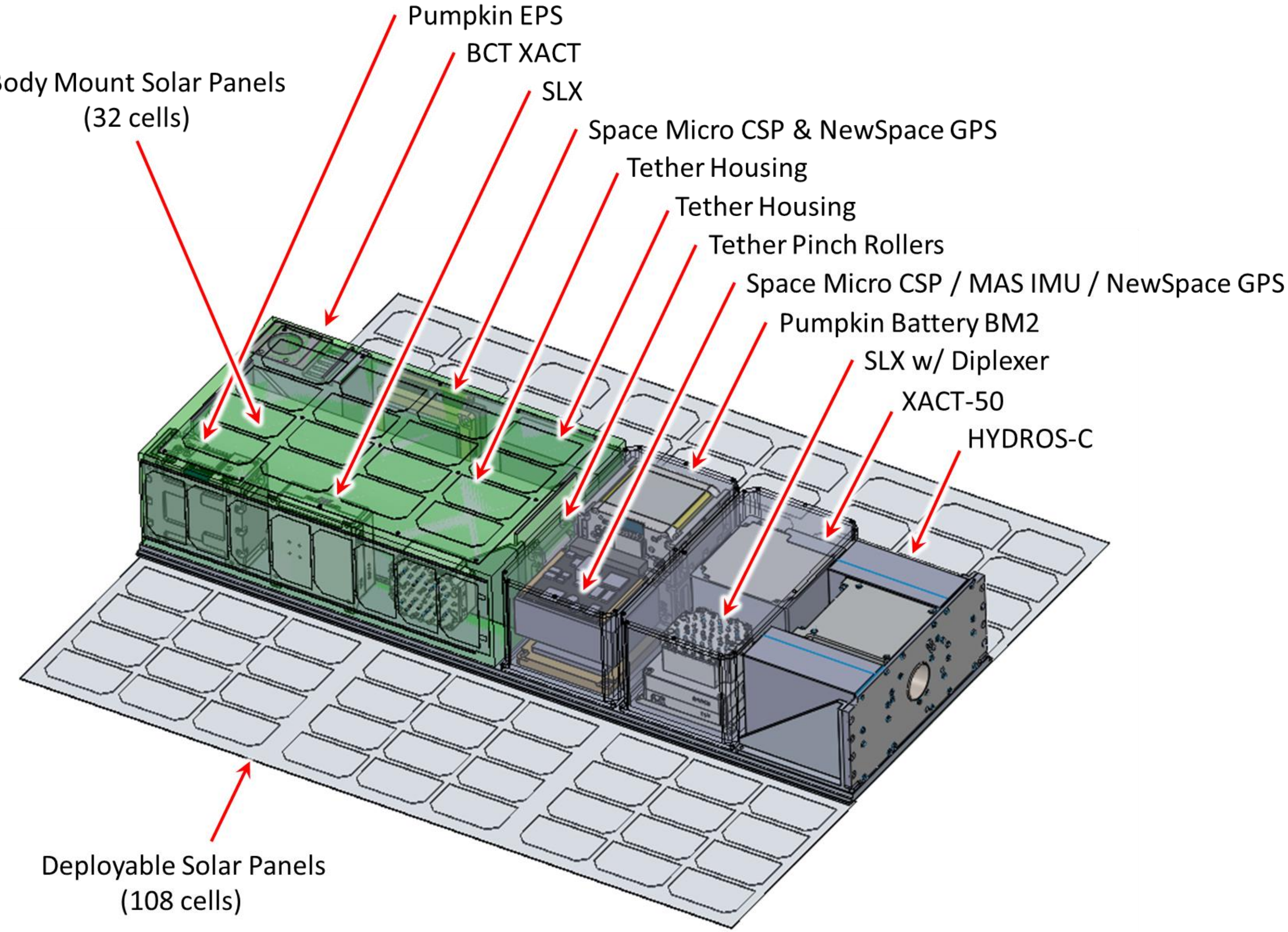
Tether Dynamics Deployer & Demonstrator (TeD^3)

- Demonstrate tether deployment method to be used on Lunar T-REx
- Obtain system dynamics data to validate tether simulation models
- Demonstrate ability to control two tethered spacecraft



HyperCAST (TeD^3) Mission Concept

- Two 6U spacecraft connected by a tether in LEO
- One spacecraft contains a tether deployment system that is representative of a system to be used on Lunar T-Rex
- The two spacecraft enter LEO on an ISS/rideshare opportunity and are in a joined configuration via a release mechanism
- The spacecraft separate and the tether deployment operation is demonstrated
- Both spacecraft have instrumentation that provide data on the dynamics of the deployment operation
- Spacecraft demonstrate stability in the tethered configuration



HyperCAST (TeD^3) Driving Requirements

- Mission cost of < $20M ✓
- Deploy tether using a combination of initial end-off spool free ✓ deployment followed by a slow, controlled deployment via pinch rollers ✓
- LEO lifetime < 25 years ✓
- Conform to ISS deployment requirements ✓
- Satellites to be a 6U form factor ✓
- Capture visual confirmation of the tether deployment ✓
- Obtain metrology data to characterize system dynamics ✓
- Class 3 EEE parts to be used for tether system *
- Minimum mission life of 3 months ✓

* To be addressed in secondary briefing

HyperCAST (TeD^3) ConOps

1. HyperBus carrying the CAST payload (HyperCAST) deploys from the ISS via the NanoRack double wide deployer.
2. HyperCAST drifts to a safe distance from the ISS
3. TUI performs health and checkout activities and reports spacecraft status to NASA
4. NASA reviews the spacecraft check out certifies that HyperCAST propulsion is safe to operate
5. NASA provides the activation code for HYDROS
   a. Limited delta V to ensure no re-contact w/ ISS
   b. Limited action time
   c. Limited power consumption
   d. Watch dog counter
6. HyperCAST navigates down to tether deployment orbit (estimated 300km)
7. NASA provides the activation code for tether deployment
   a. Deployment limited to time window and orbital bounding box
8. One-shot spring deployment of 5km of tether
   a. First 1km is free running (impulse)
   b. Remaining 4km is pinch roller controlled
   c. 1-day deployment (22+ hours)
9. Download deployment data
   a. Using RBC or other commercial ground station
10. Analyze deployment data
11. Monitor tether dynamics
    a. 30 days
    b. Test Tether-Compatible ADCS Methods
12. Final HYDROS fire
    a. Final tether dynamic study
13. Final data download
14. Deorbit in less than 2 years
15. Total mission life 45-days

HyperCAST (TeD^3) MEL and SWaP

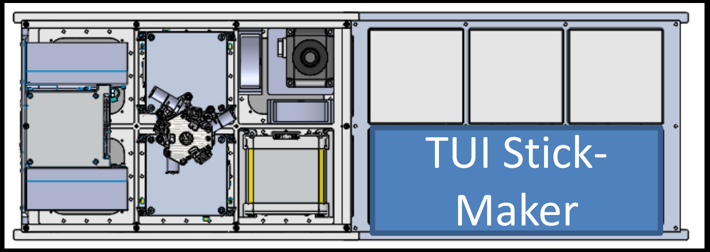
Sub System	Component	Mass (kg)	Power Draw (W)	Power Supplied (W)	Notes/Assumptions
Main Body	TUI HyperBus EPS System	3.4	0	54	108 cells, assume no LiPo batteries in baseplate
	TUI HYDROS-C	3	15	0	Mass incl. brackets, water. Power 5-25 W
	TUI SLX w/ Diplexer	0.6	10	0	single transmit and receive. 15W peak power
	Blue Canyon XACT-50	1.23		0	12V, but what is average power?
	Pumpkin Battery BM2	0.7	1	160	data sheet power < 1W
	Space Micro CSP	0.08	2.8	0	2.8 is max power draw
	Micro Aerospace IMU03	0.15	1.3	0	
	NewSpace GPS Receiver	0.11	1	0	excluding active antenna
	Module housings (x2)	2	0	0	Currently 1.4 kg each, could be optimized to under 1kg
	TOTAL	11.27	31.1	54	
End Body	TUI Pinch Rollers	0.09	4.8	0	
	TUI Tether and Canister	2	0	0	
	TUI SLX w/ Diplexer	0.6	10	0	single transmit and receive. 15W peak power
	Blue Canyon XACT	0.91		0	Small version of XACT-50
	Pumpkin Battery BM2	0.7	1	160	data sheet power < 1W
	Space Micro CSP	0.08	2.85	0	
	Micro Aerospace IMU03	0.15	1.3	0	
	NewSpace GPS Receiver	0.11	1	0	
	Body Mount Solar Panels	0.3	0	12	24 cells (16 on top face, 4 on each side)
	Endbody housing	2	0	0	Currently 2.3, but could optimize to under 2kg
	Camera	0.2	0.2		
	TOTAL	7.14	21.15	12	
TOTAL SATELLITE MASS and POWER		18.41			NanoRacks Double Wide Deployer max payload = 18kg

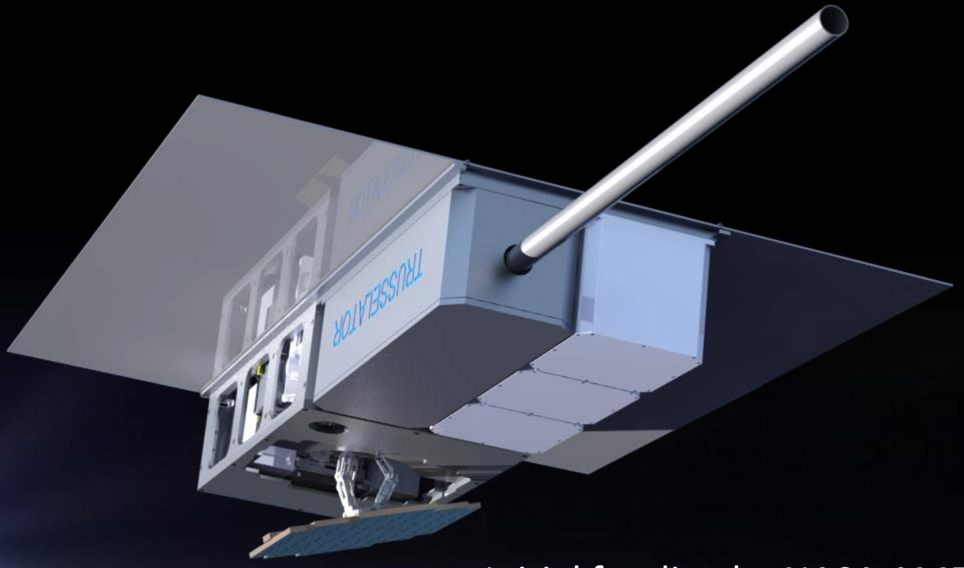
Mass Budget to be refined

Additional HyperBus Payloads / Missions

TUI Stick-Maker

- TUI Sat-3 Subsystems
- TUI Trusselator Demo
- 3U Payload Volume



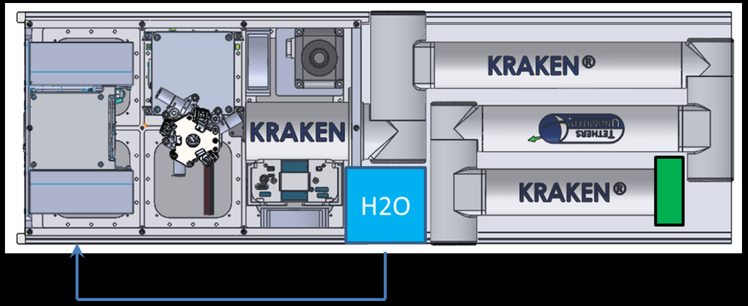


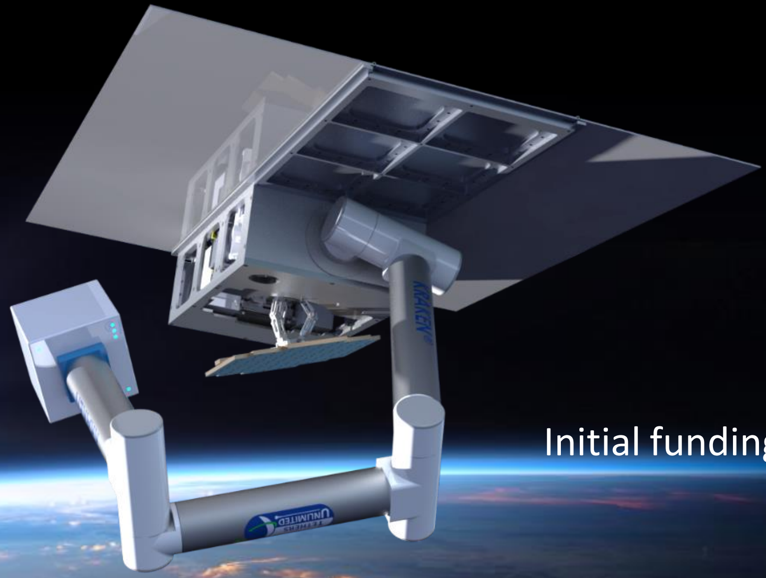
Initial funding by NASA AMES SBIR

Mission being transferred to Restore-L program under NASA's Tipping Point Program

TUI Robotic Refueling

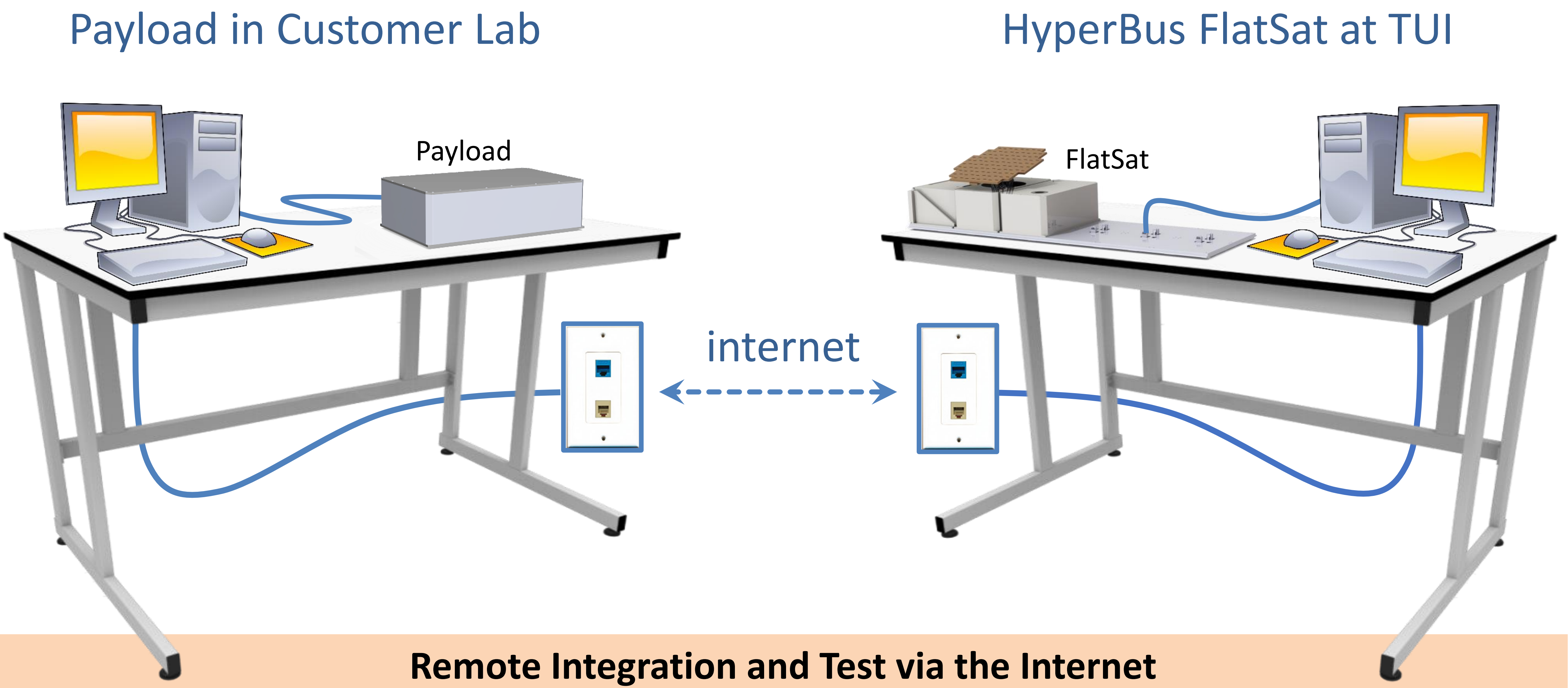
- TUI Sat-3 Sub-Systems
- KRAKEN-X Robotic Arm + Dactylus End-Effector
- HYDROS Refueling Port Demo





Initial funding by Air Force SBIRs

Science Payloads Wanted!



Remote Integration and Test via the Internet

Tethers Unlimited, Inc.

Market 4

SmallSat Servicing

Soft Capture, Hard Capture,
Interfaces & Grounding

Market 5

Fuel Depots / Re-fueling Services

Water Base Space Economy

Market 6

On Orbit Assembly / Robotic Tending

Persistent GEO and LEO Platforms

Research and Development Stage
Initial Laboratory Demonstrations