National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

Micro-thruster Based ACS Architecture Enabling Spacecraft Ultra-fine Pointing Control

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Strategic Focus Area: GNC and Mission Design

Objectives:

- Establish JPL capability in the design, modeling, and optimization of micro-thruster spacecraft precision pointing, an enabling technology that could support the demanding stability requirements of next gen telescopes such as Habitable Worlds Observatory (HWO)
- Examine "thrusters-only" ACS that eliminates reaction wheels (and their induced disturbances) in favor of RCS thrusters for maneuvering and micro-thrusters for pointing
- Expand on Habitable Exoplanet Observatory (HabEx) micro-thruster research to provide initial treatment of micro-thruster ACS for HWO example design

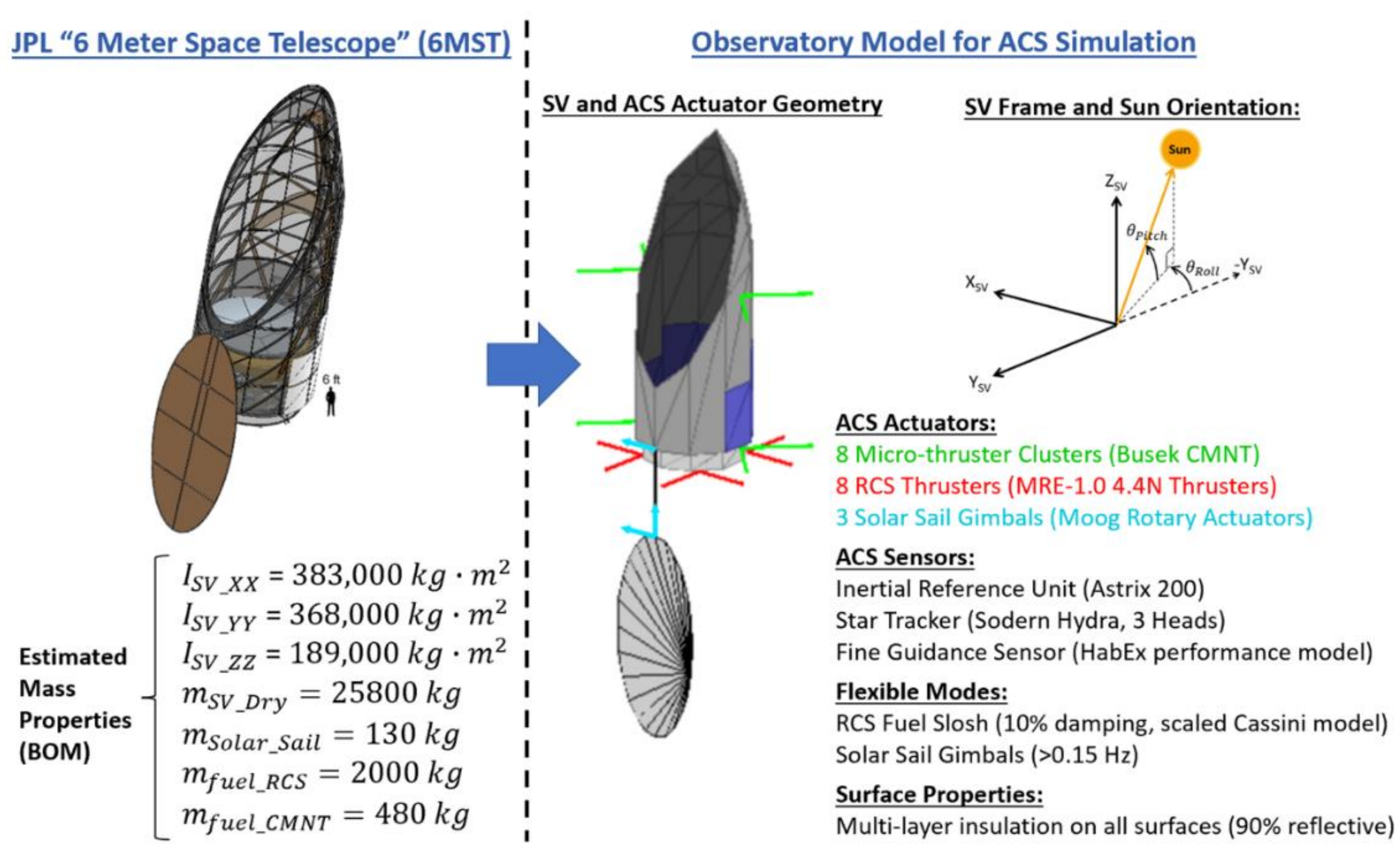
Background:

- Astro2020 goal to conduct imagery and spectroscopy of exo-Earths dictates stringent HWO pointing stability requirement. Starlight suppression with high-contrast coronagraphy drives HWO to order-of-magnitude stability improvement over state-of-the-art wheel-based ACS
- HabEx baselined Busek Colloid Micro-Newton Thruster (CMNT), an electrospray micro-thruster flight-demonstrated on LISA Pathfinder (LPF) in 2016. Electrospray micro-thrusters apply high electric potential to conductive charged liquid at the end of a hollow needle emitter to accelerate charged droplets and generate thrust
- After Astro2020 recommended a 6-meter HWO, JPL developed scaled-up "6 Meter Space Telescope" (6MST) reference design based on HabEx. R&TD examines the CMNT paired with the 6MST to develop a time and fuel-efficient ACS architecture

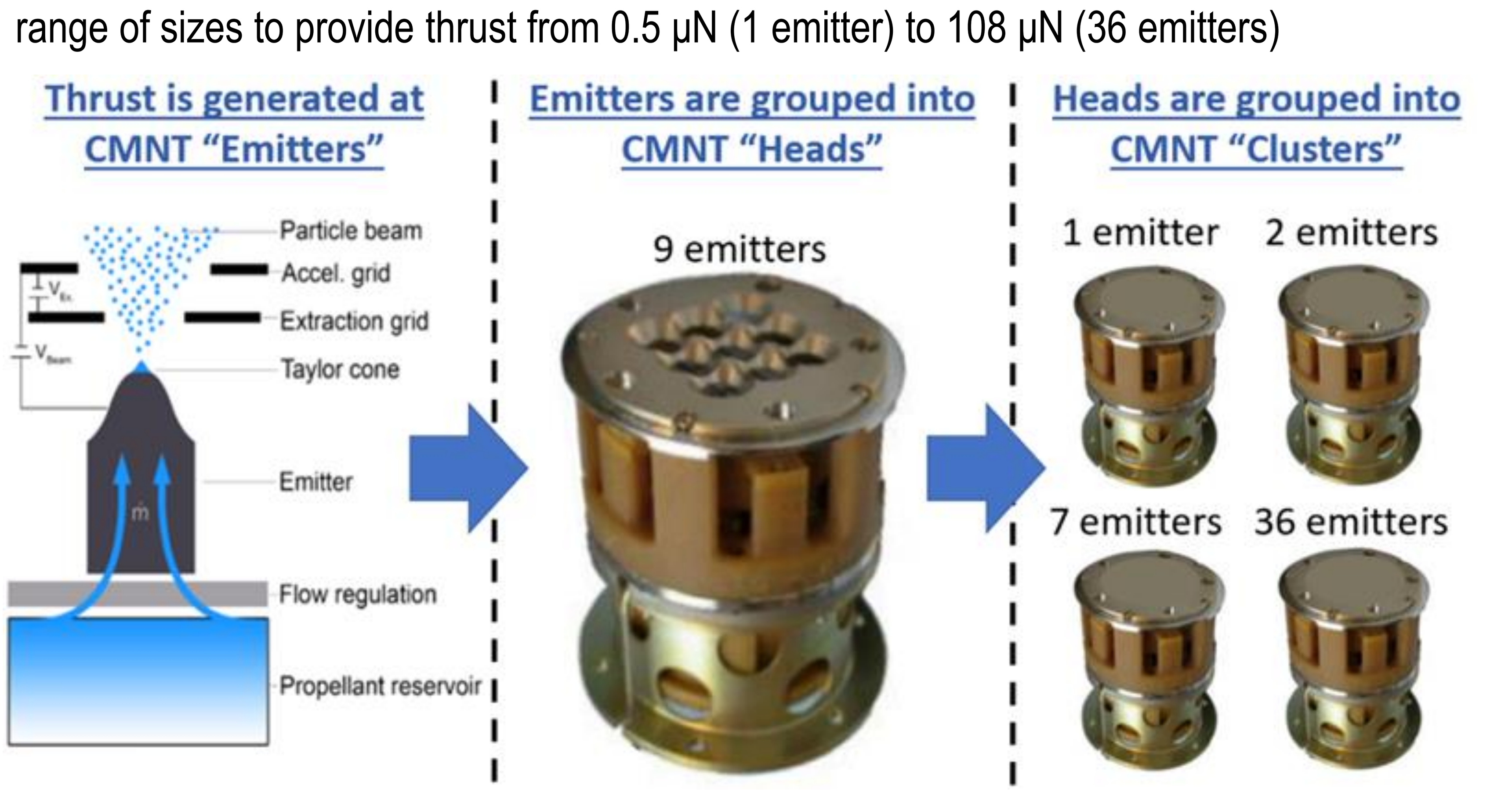
Approach and Results:

Milestone 1: Define 6-meter observatory reference model relevant to HWO

- Observatory model was constructed using JPL's 6MST design for HWO. Conservative solar torque is computed from 6MST geometry assuming reflective multi-layer insulation on all surfaces. Solar torque during science is minimized using the aperture cover as an articulated "solar sail."



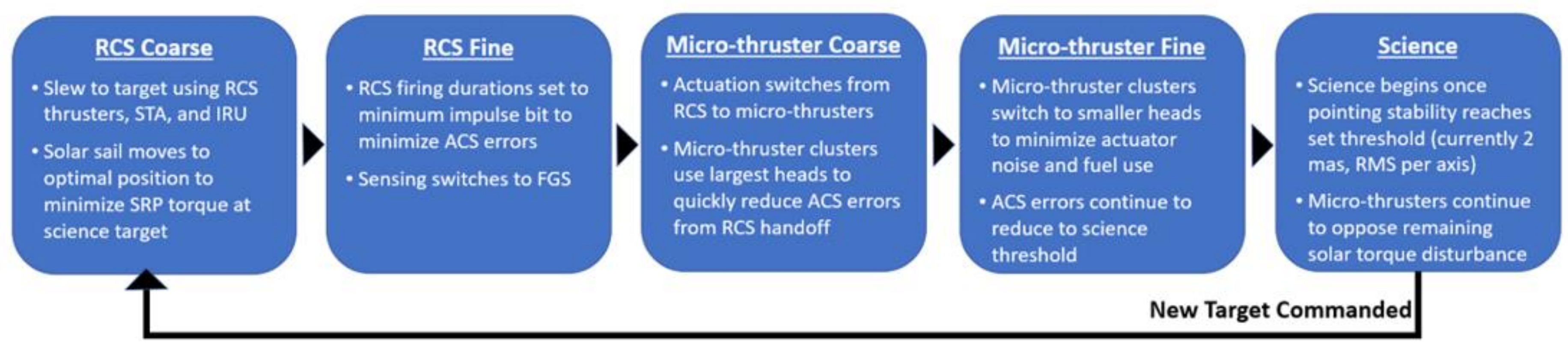
- R&TD analysis uses realistic micro-thruster sizing. LISA Pathfinder demonstrated CMNT thrust range of 0.5 to 3 μN per emitter. Higher emitter thrust limits micro-thruster lifetime, so maximum thrust is increased by grouping emitters into thruster "heads"
- Head size is limited by propellant flow and power electronics capacity. R&TD assumes 36 emitters based on heritage, but 82 emitters are possible with additional power electronics
- Heads are grouped into "clusters" to receive thrust commands. R&TD uses four heads with range of sizes to provide thrust from 0.5 μN (1 emitter) to 108 μN (36 emitters)



Milestone 2: Develop thrusters-only ACS architecture and simulation capability

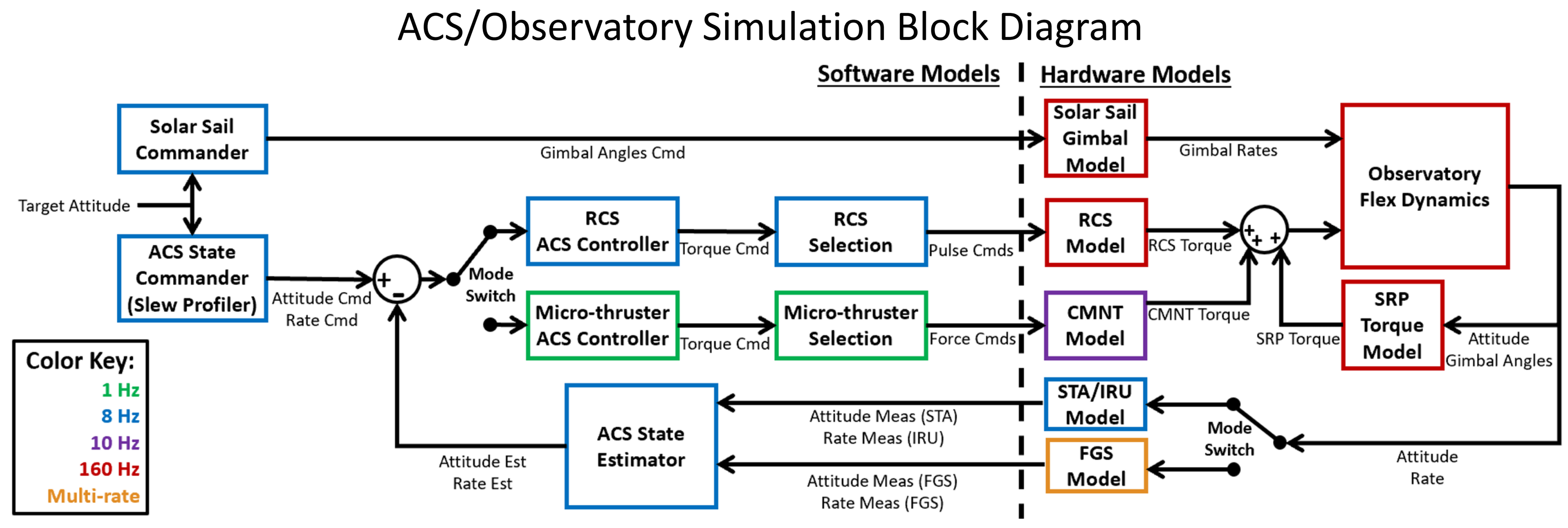
- Thrusters-only ACS follows same operational approach as HabEx. When a target is commanded, ACS transitions through modes in "Slew to Science" Roadmap. Momentum unloading is not required, and a phased array antenna provides downlink during observations

ACS Operational Modes – The "Slew to Science" Roadmap



- High-fidelity ACS/Observatory simulation has been developed in MATLAB to evaluate the thrusters-only ACS. The sim builds on initial work of JPL's HabEx micro-thruster study. R&TD added RCS and solar sail control to evaluate end-to-end "Slew to Science" functionality

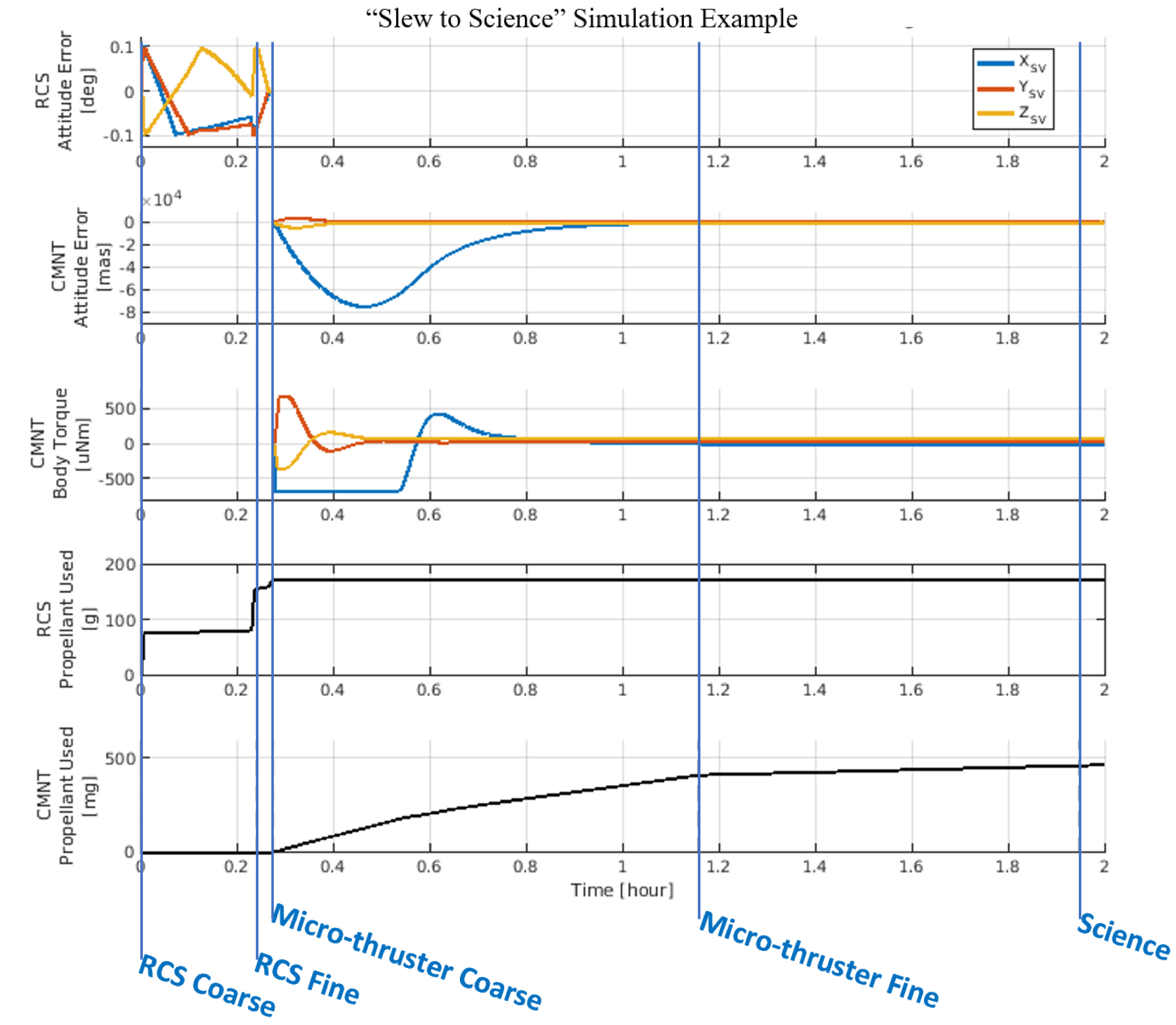
ACS/Observatory Simulation Block Diagram



Milestone 3: Evaluate preliminary performance of thrusters-only ACS architecture

- ACS performance is evaluated statistically over a large set of observations. "Slew to Science" sequences are simulated while tabulating various ACS metrics, including time spent in each ACS mode, thruster fuel use, and unintended delta-V
- Simulation results are shown for a single observation. After slewing, RCS to micro-thruster handoff occurs at 0.3 hours, and science is reached at 2 hours. Time to science is driven by the balance between handoff angular rate and maximum micro-thruster torque

"Slew to Science" Simulation Example



- Average performance metrics "per new target" and "per observation time" will be used to evaluate thrusters-only ACS over mission lifetime for various CONOPS. (See R&TD Annual Report for example Monte Carlo Simulation results)

Significance/Benefits to JPL and NASA:

- R&TD leverages JPL's expertise in electrospray micro-thrusters to establish Lab as technical leader in micro-thruster spacecraft precision pointing. R&TD work presented at "Towards Starlight Suppression for HWO Workshop" on 9/8/2023 to inform HWO community of on-going micro-thruster research at JPL. (Publication A)
- NASA created the Science, Technology, Architecture Review Team (START) and Technical Assessment Group (TAG) on 9/6/2023 to guide technology maturation activities for HWO. R&TD is well timed for JPL to support ACS architectural trades that will soon occur.

Publications:

[A] C. Haag et al., "Micro-thruster ACS Architecture for Precision Pointing of 6-meter exo-Earth Imaging Space Telescope," *Towards Starlight Suppression for the Habitable Worlds Observatory Workshop*, Pasadena, CA, August 8-10, 2023.

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References:

[1] J. Ziemer et al., "In-Flight Verification and Validation of Colloid Microthruster Performance," *2018 Joint Propulsion Conference*, 2018

[2] C. Dennehy et al., "Application of Micro-Thruster Technology for Space Observatory Pointing Stability," NESC-RP-18-01375, Dec. 2020

[3] T. Flinois et al., "Microthruster-based Control for Precision Pointing of Next Generation Space Telescopes," *44th Annual AAS Guidance, Navigation & Control Conference*, Breckenridge, CO, AAS Paper 22-151, Feb. 2022

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