LUVOIR – Lockheed Martin Cooperative Agreement Progress Report

Larry Dewell, Alison Nordt
Lockheed Martin Space, Advanced Technology Center
Palo Alto, California

Key Contributors:
Kiarash Tajdaran, Shawn Wood

5/11/2018

Cooperative Agreement Technical Objectives

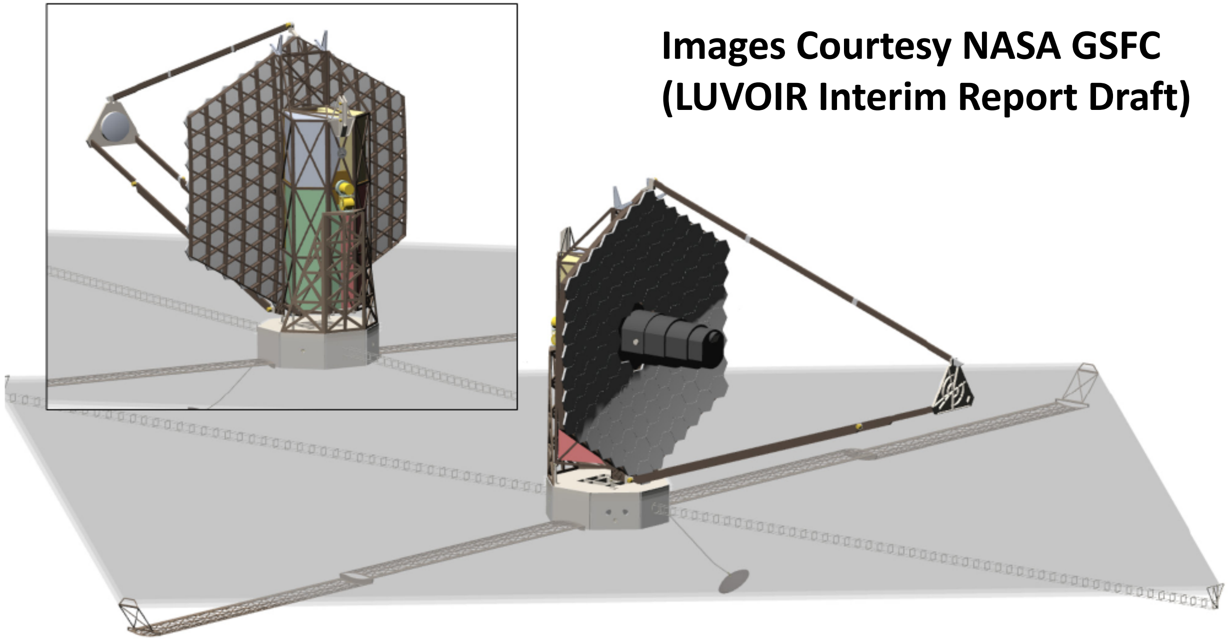
- **Task 1: System-level architecture and performance predication of a non-contact vibration isolation system**
  - Assessment of architecture support for observatory line-of-sight agility requirements
  - Integrated control/structure/optics modeling of a reference LUVOIR architecture with a non-contact interface, and frequency-domain prediction of LOS stability performance in the presence of spacecraft disturbances
  - Documents and engineering details to support non-contact isolation system integration into architecture baseline (Master Equipment List, system-level block diagrams, performance models, contribution to Conops)

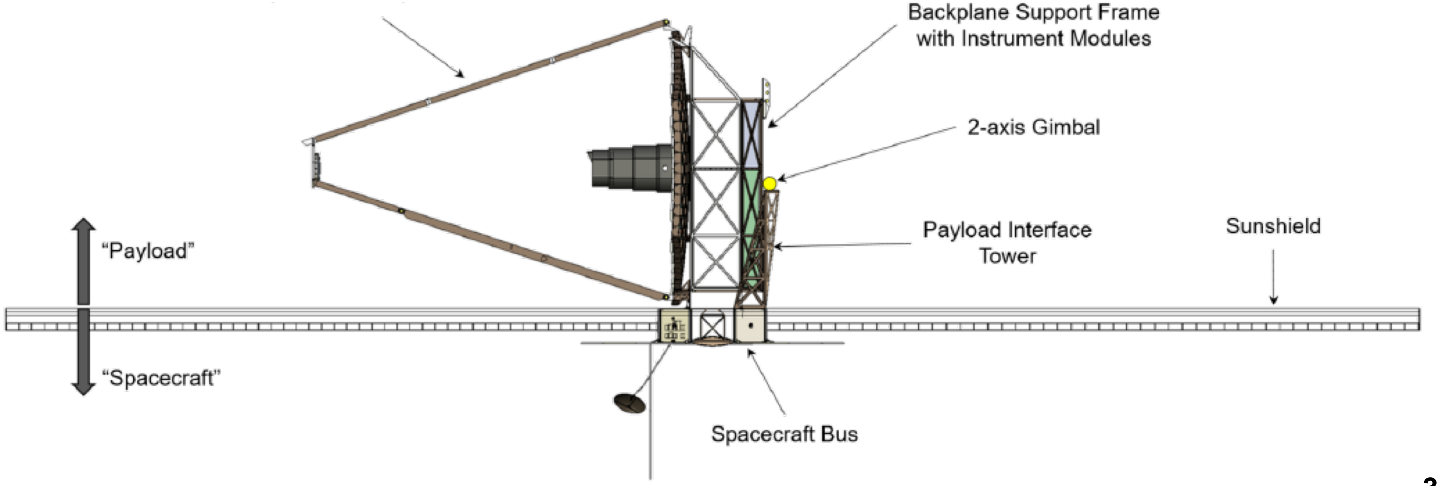
- **Task 2: Instrument-Level AI&T Planning support**
  - Develop I&T plans and schedules for the LUVOIR Instruments:
    - Extreme Coronagraph for Living Planetary Systems (ECLIPS)
    - LUVOIR Ultraviolet Multi-Object Spectrograph (LUMOS)
  - Outline instrument-level activities up to delivery to "OTIS" integration
    - OTIS = Optical Telescope Element + Instruments

Key System-Level Requirements Relevant to Telescope LOS Pointing and Isolation – LUVOIR Architecture A

Specification	Req. Value
Dynamic wavefront error stability	Driven by coronagraph high-contrast requirements: ≤ 40 pm (TBR) RMS WFE over ~10 minutes
Telescope pointing stability (@ OTE focal plane)	< 0.3 mas 1σ over an observation
Object tracking	≤ 60 mas/sec, object space
Slew rate	Repoint anywhere in anti-sun hemisphere in 45 minutes (Goal: 30 minutes)

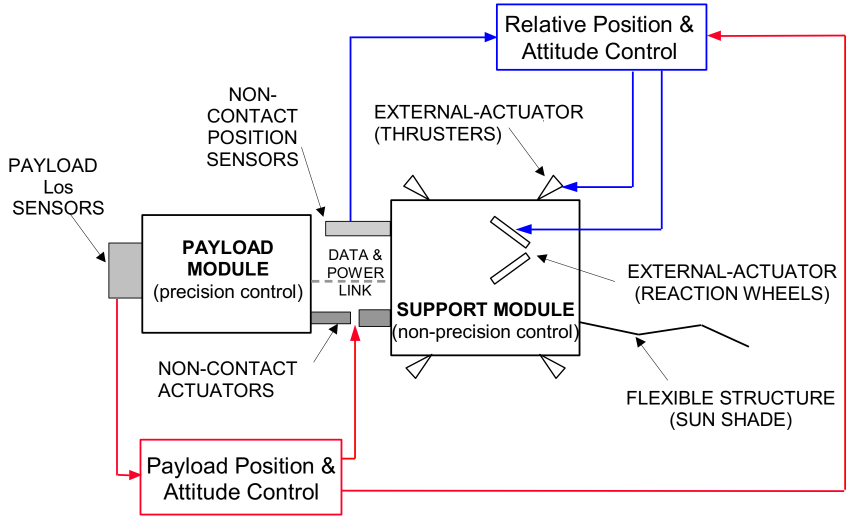
Images Courtesy NASA GSFC (LUVOIR Interim Report Draft)

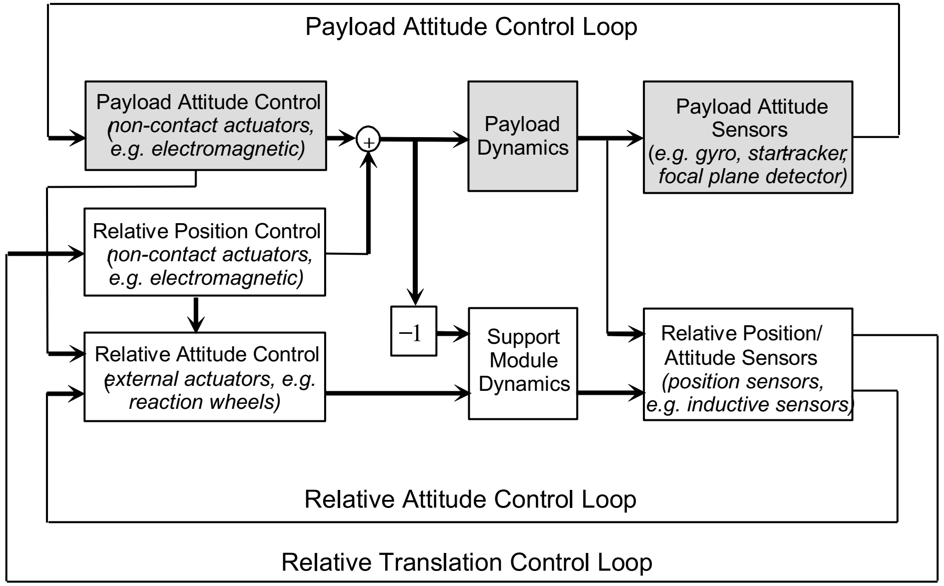




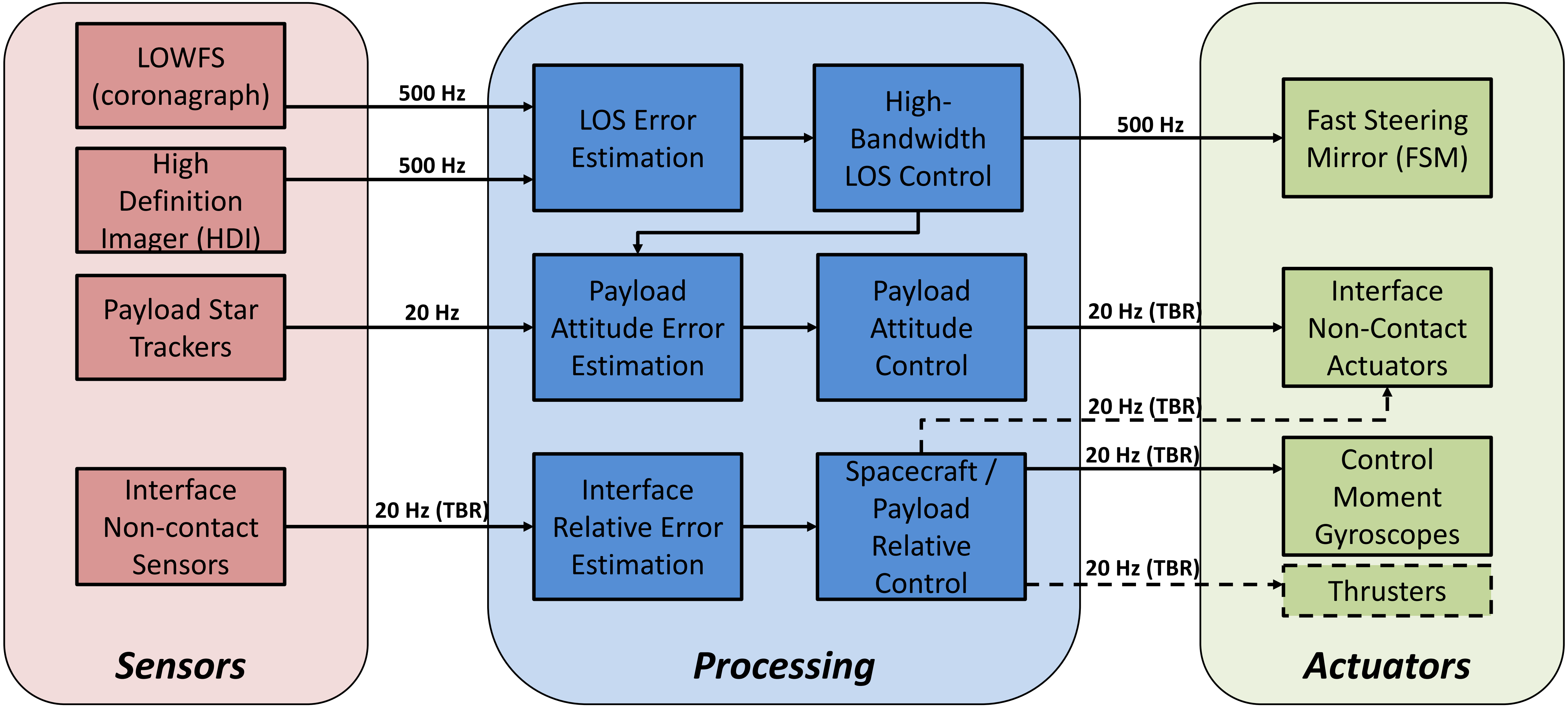
Overview of a Canonical Non-Contact Pointing and Vibration Isolation System

- **Non-contact vibration isolation technologies, like Lockheed Martin's Disturbance Free Payload (DFP), is an entirely novel concept for isolation of a sensitive science payload from the supporting spacecraft mechanisms**
  - ***A DFP-configured spacecraft is actually two spacecraft flying in close formation***
- **The payload controls the telescope Line-of-Sight by pushing against the spacecraft inertia using a set of six non-contact Lorentz force actuators**
- **The spacecraft controls its inertial attitude such that interface stroke and gap are maintained**
  - **Requirements for spacecraft attitude control are no more stringent than those for conventional spacecraft, and do not derive from payload pointing requirements**
- **Payload Line-of-Sight isolation from Spacecraft disturbances is broadband, even down to low frequency, and is not affected by interface sensor measurement noise**

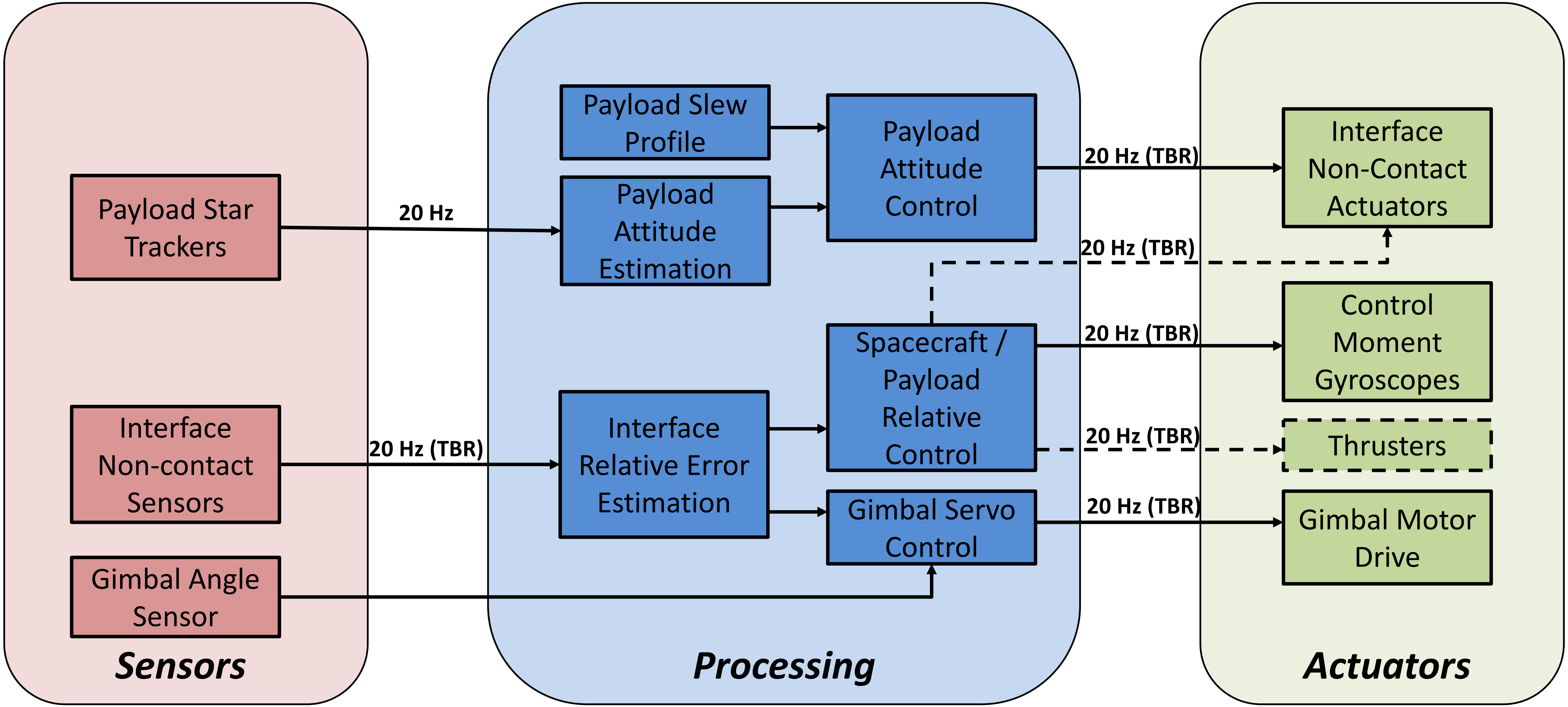




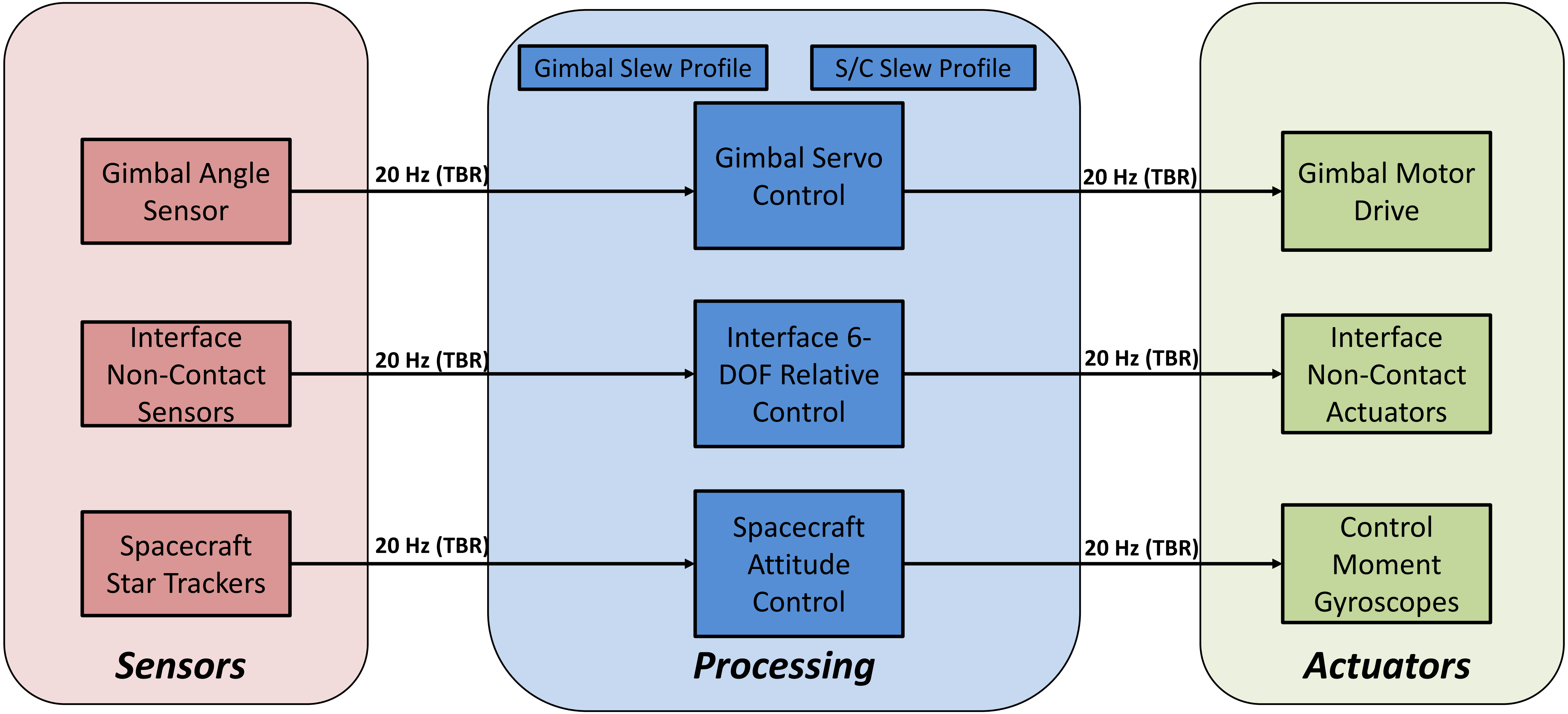
Principal Signal Architecture: Steady-State Observatory Observation



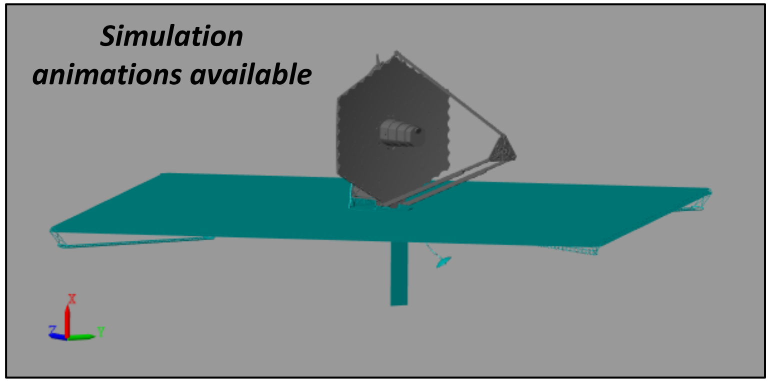
Principal Signal Architecture: Observatory Repointing and Slewing



Alternate Signal Architecture: Observatory Repointing and Slewing

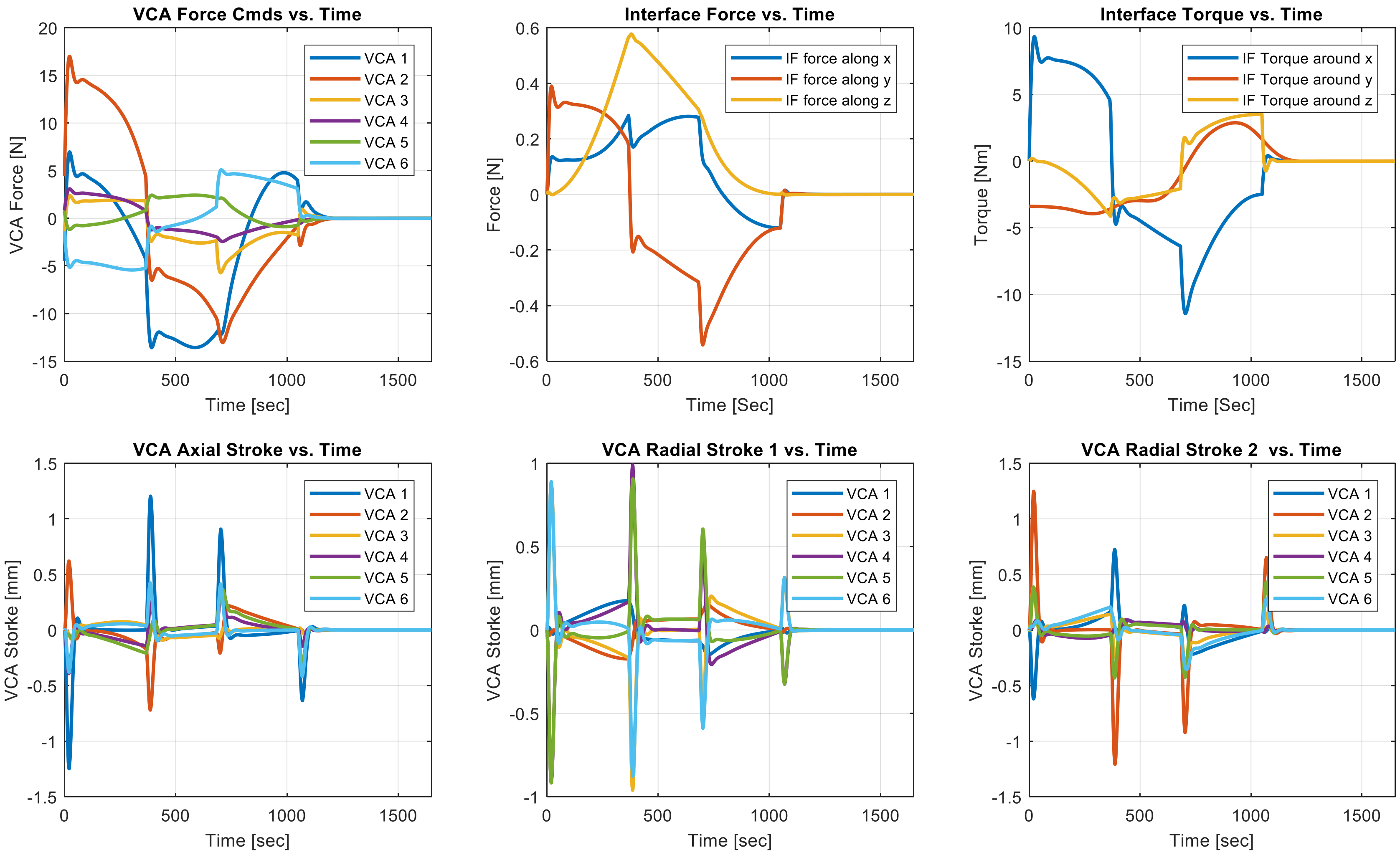


Nonlinear, Rigid-Body Simulation Results: LUVOIR repositioning with a non-contact interface



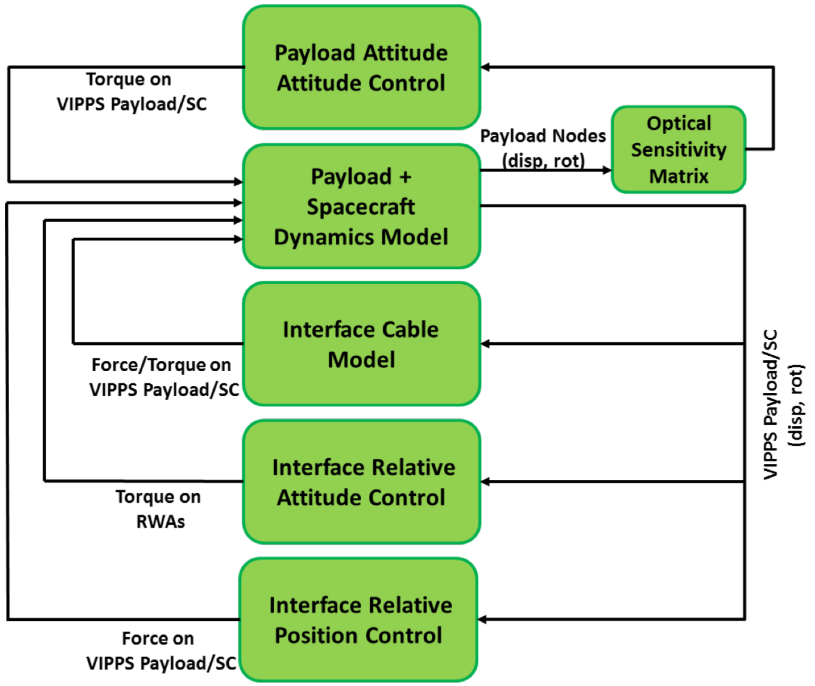
	Initial Angular Condition	Final Angular Condition
Spacecraft	0^o around sun pointing axis (x axis)	180^o around sun pointing axis (x axis)
Gimbal	90^o	0^o

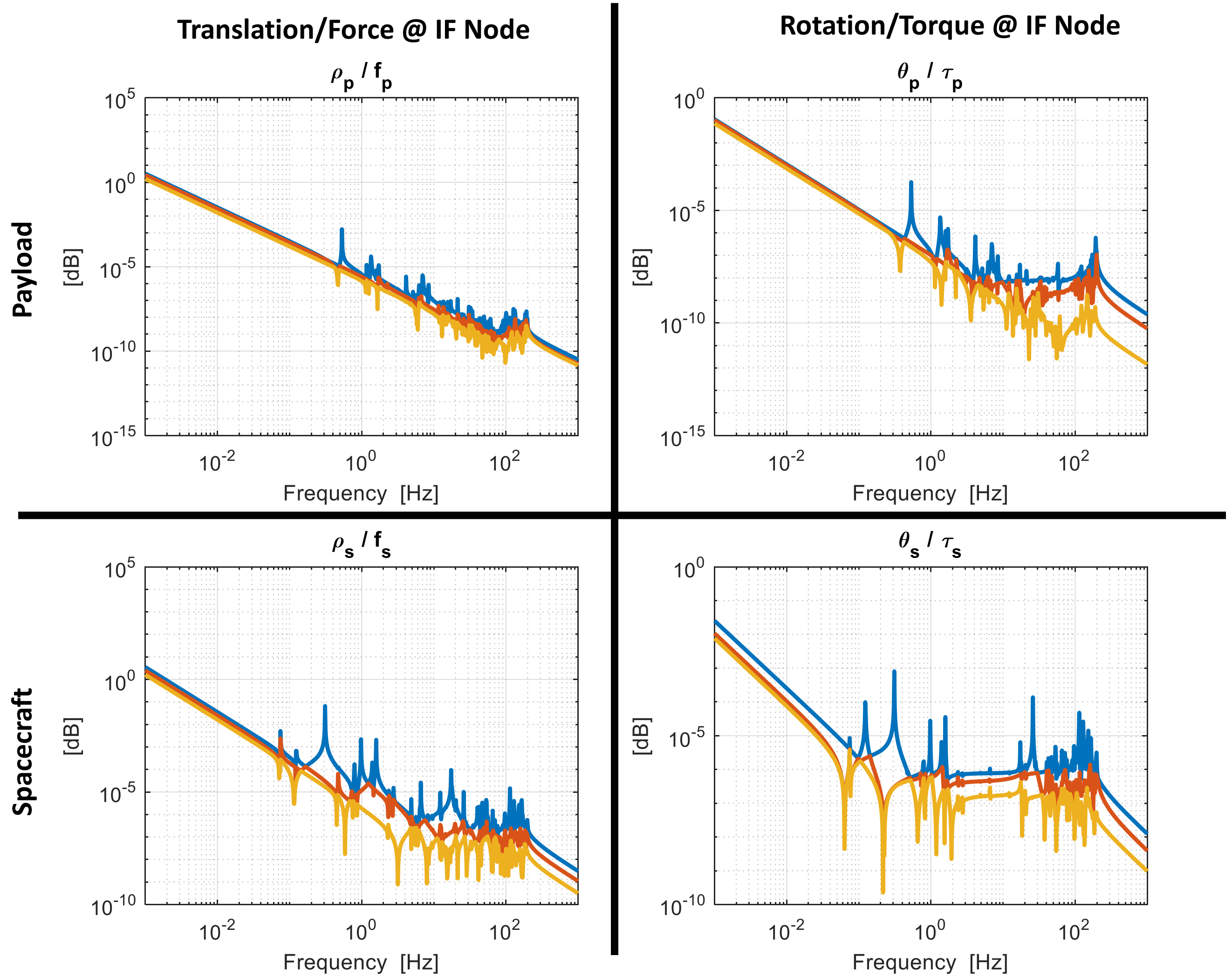
- **Lockheed Martin's 10 mm VCA design can achieve the peak force and gap/stroke demands:**
  - **Max. VCA Force: 16.9 N**
  - **Max. Axial Gap: 1.24 mm**
  - **Max. Radial Gap: 1.24 mm**
  - **Max. Current: 3.08 A (per actuator)**
  - **Max. Power: 31.9 W (per actuator)**



Nonlinear dynamics simulations of multiple repositioning profiles shows that the non-contact interface can be maintained within gap and NCA force limits

Integrated Structure/Controls/Optics Modeling: an Early LUVOIR Architecture A Finite Element Model



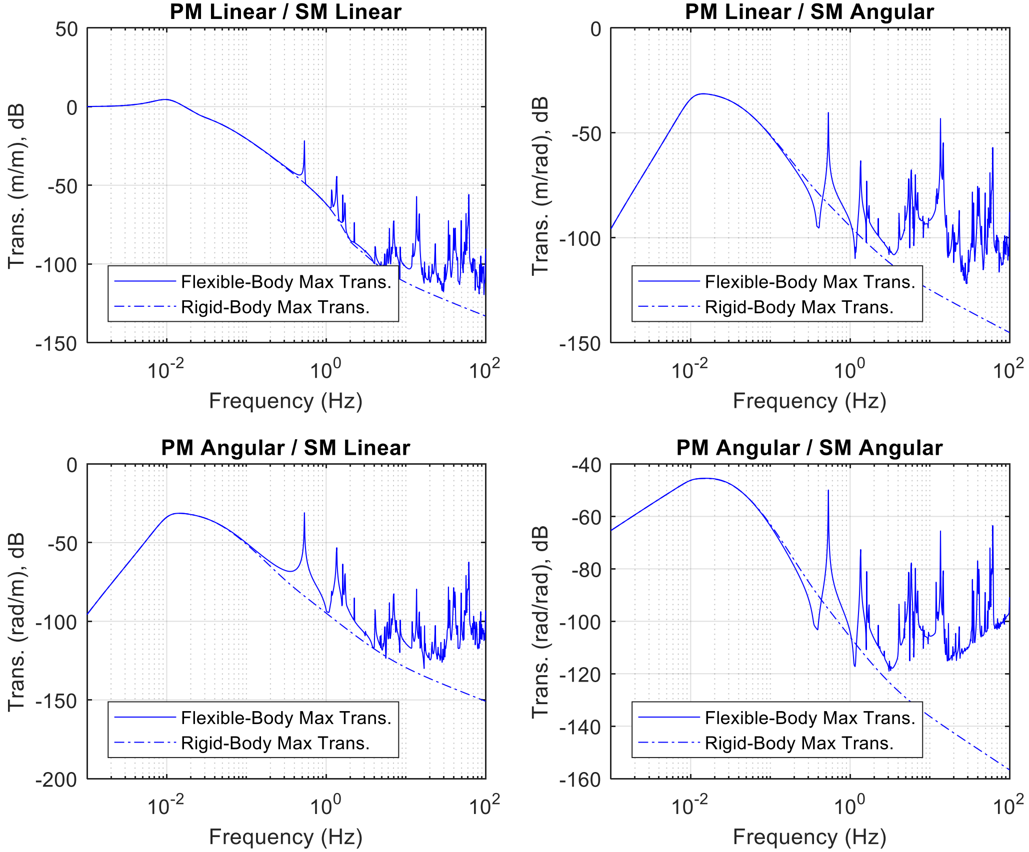


- **Structural dynamics model was extracted from a single FEM with two disconnected spacecraft and payload bodies**
- **Number of modes: 4373**
- **Model restrictions: monolithic PM, only LOS output from linear optical sensitivities (no WFE output)**

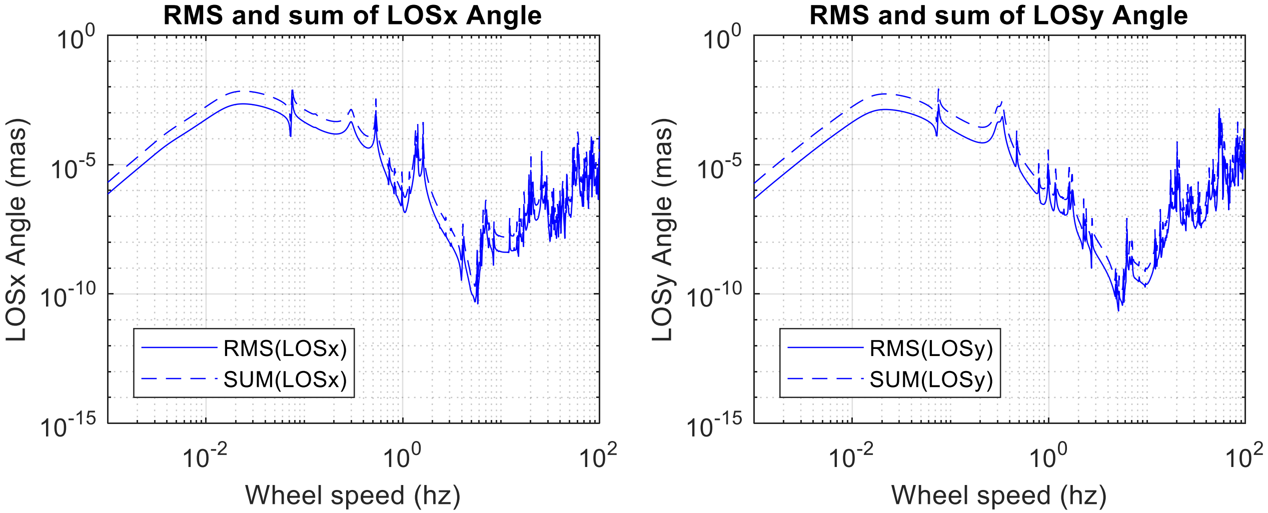
Early efforts of integrated controls/structure/optics modeling has yielded insights into LUVOIR dynamics and sharpened the process of further model integration activities

Example closed-loop frequency-response results: steady-state science observation

- Spacecraft/payload interface transmissibility obtained
- Structural resonances in spacecraft or payload can have a significant effect on transmissibility
- Transmissibility is not a direct measure of system optical stability



- Initial simplified analysis of LOS error amplitude over a range of possible CMG rotor speeds:
  - assuming static and dynamic imbalance of the CMGs
  - Total LOS output was computed under two assumptions: (a) all 4 CMG imbalances are in phase (sum); (b) all 4 CMG imbalances have random phase (RMS)
- Forward work: consider CMG disturbance harmonics and contribution over all CMG gimbal angles



I&T Concept Planning for Estimating

LUVOIR

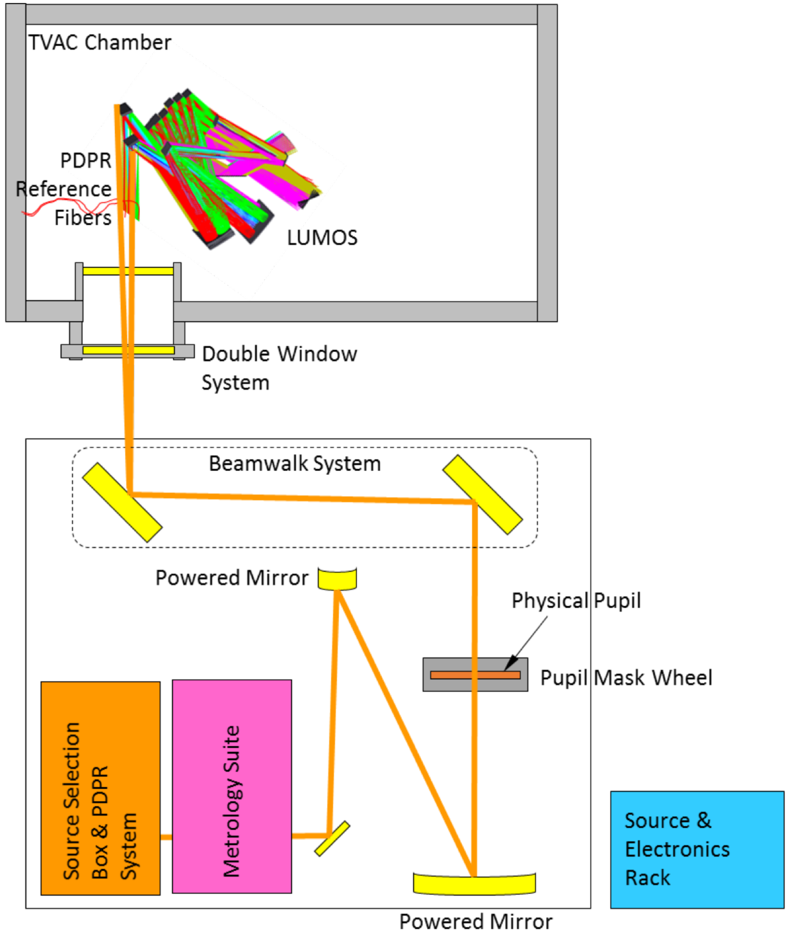
Assembly & Alignment Build LUMOS/ECLIPSE Align with est. offsets for operational T&P → **LPT** Baseline Ambient → **TVAC (+CPT)** Full Tvac Test with Alignment Verification, with Performance CPT → **LPT** Post Ambient → **Assessment**

Establish sequence and timelines

- Establish nominal integration flow to assemble and perform baseline test at temperature and pressure efficiently. Validate predicts.
- Establish assembly sequences to reference, course align and fine align optical train. Design in reference fiducials for alignment efficiencies.
- Plan for surrogates, with capability for component remove/replace within spatial alignment.
- Once comprehensive baseline is established, execute environmental test program, using Limited Performance Tests throughout to track health, alignment and trending data.

Transport SV Test Facilities → **LPT** Ambient → **Vibration Testing** Sinusoidal & Random Environments → **LPT** Ambient → **EMI/EMC Testing** Anechoic Facility →

→ **LPT** Ambient → **Mass Properties** & Static Envelope → **Potential TVAC2 (+CPT)** Full Tvac Test with Alignment Verification, with Performance CPT → **Assessment** → **Transport**



LUMOS and ECLIPS Test

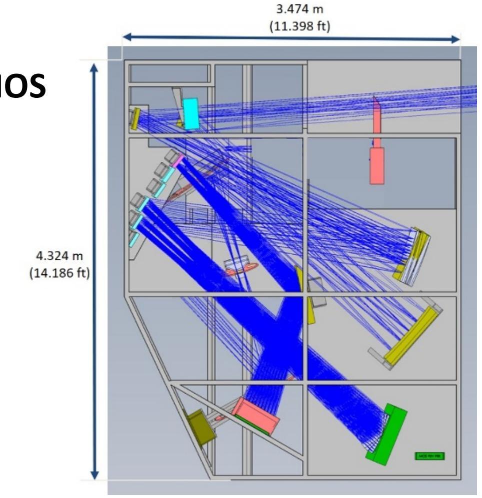
I&T Facilities Considerations for planning

Facilities

Establish facilities required to Handle, Integrate, Test and Deliver two Large Optical Payload Assemblies. Desire to have best co-location to minimize transport and handling risk.

- LUMOS – Approximately 3.5 m (11.4 ft) x 4.3 m (14.2 ft)
- ECLIPS – Approximately 1.5 m (5 ft) x 2 m (6 ft)

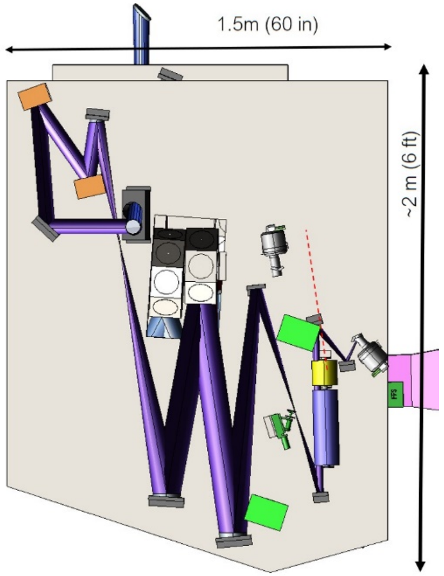
LUMOS



Integration Space Considerations

- Sufficient clean rooms with optical bench space capable of supporting sizes indicated
- Adjacent space to support optical test bed for alignments, optical train buildup and phase retrieval
- Handling/Crane Considerations, Logistical support considerations (precision clean, optics stores, etc)

ECLIPSE



Environmental Test Considerations

- TVac: Chamber large enough to accommodate LN shrouds, Helium Cyro Shrouds and Payloads.
- TVac: Chamber incorporates large enough optical window and adjacent floor space for external optical test bed sources, compound motion beam walking and other potential optical metrology.
- EMI: Anechoic Chamber large enough to accommodate, appropriate noise floor and cleanliness level.
- Vibe: Shaker system to meet size/mass and modal requirements of each system

System-Level Segmented Telescope Design

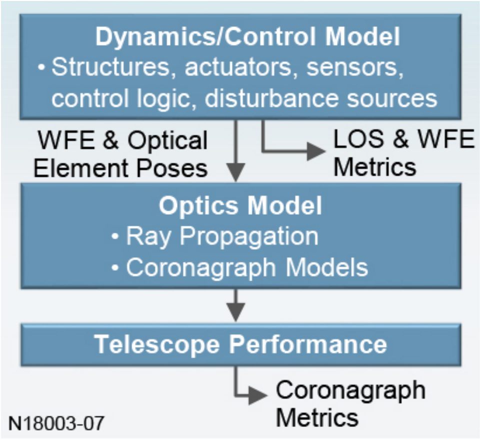
PI: Larry D. Dewell/Lockheed Martin

Objectives and Key Challenges:

- Address the system-level design challenges of large, UV/IR space telescopes to achieving picometer-level wavefront stability to support coronography-based science
- Develop new testbeds to anchor picometer-class integrated models
- Inform NASA technology development plans to support large telescope missions in the 2020 Decadal Survey

Significance of Work:

- Establish, through analysis and anchoring testbeds, engineering confidence in the feasibility of picometer stability for large telescopes



Segmented Telescope Modeling, Anchored by Test

Approach:

- Develop integrated telescope models to predict quasi-static and dynamic wavefront error performance from STDT initial models
- Anchor models and mature technology through testing under internal R&D funding

Key Collaborators:

- Ray Bell and Alison Nordt – Lockheed Martin Advanced Technology Center
- Jay Daniel – Coherent Inc.
- Jeffrey Klingzahn – Harris Corp.
- Bari Southard – United Technologies Aerospace Systems (UTAS)

Current Funded Period of Performance:

- April 2018 – April 2019

Recent Accomplishments:

✓ Notification of award: March 16, 2018
✓ Kickoff meeting: April 17, 2018

Next Milestones:

- Baseline architecture performance complete, and mid-term review: September 2018
- Technology development plan: December 2018
- Final report: April 2019

Application:

- Large Ultraviolet / Optical / Infrared (LUVOIR) Surveyor, Habitable Exoplanet Imaging Mission (HabEx), Origins Space Telescope (OST)

Cooperative Agreement Progress Report Summary

- Key Program Points
  - Period of Performance has been extended at no cost to NASA to 7/31/2018
  - Final report will summarize results of integrated modeling exercise, and Instrument AI&T plans

- Key takeaways:
  - Through analysis, modeling and simulation, the CAN activity has shown that a non-contact payload/spacecraft isolation system is feasible for LUVOIR, meets the necessary agility requirements, and suggests excellent pointing and vibration isolation benefits to the architecture
  - The CAN pointing and isolation integrated modeling has provided an early exercise in this integrated modeling approach which will be more further refined and exercised in the System-Level Segmented Telescope Design (SLSTD) follow-on efforts
  - Requirements for LUVOIR Instrument Assembly, Integration and Test (AI&T) have been reviewed, a initial conceptual work flow concept is established, and further planning efforts are underway to support the CAN Final Report