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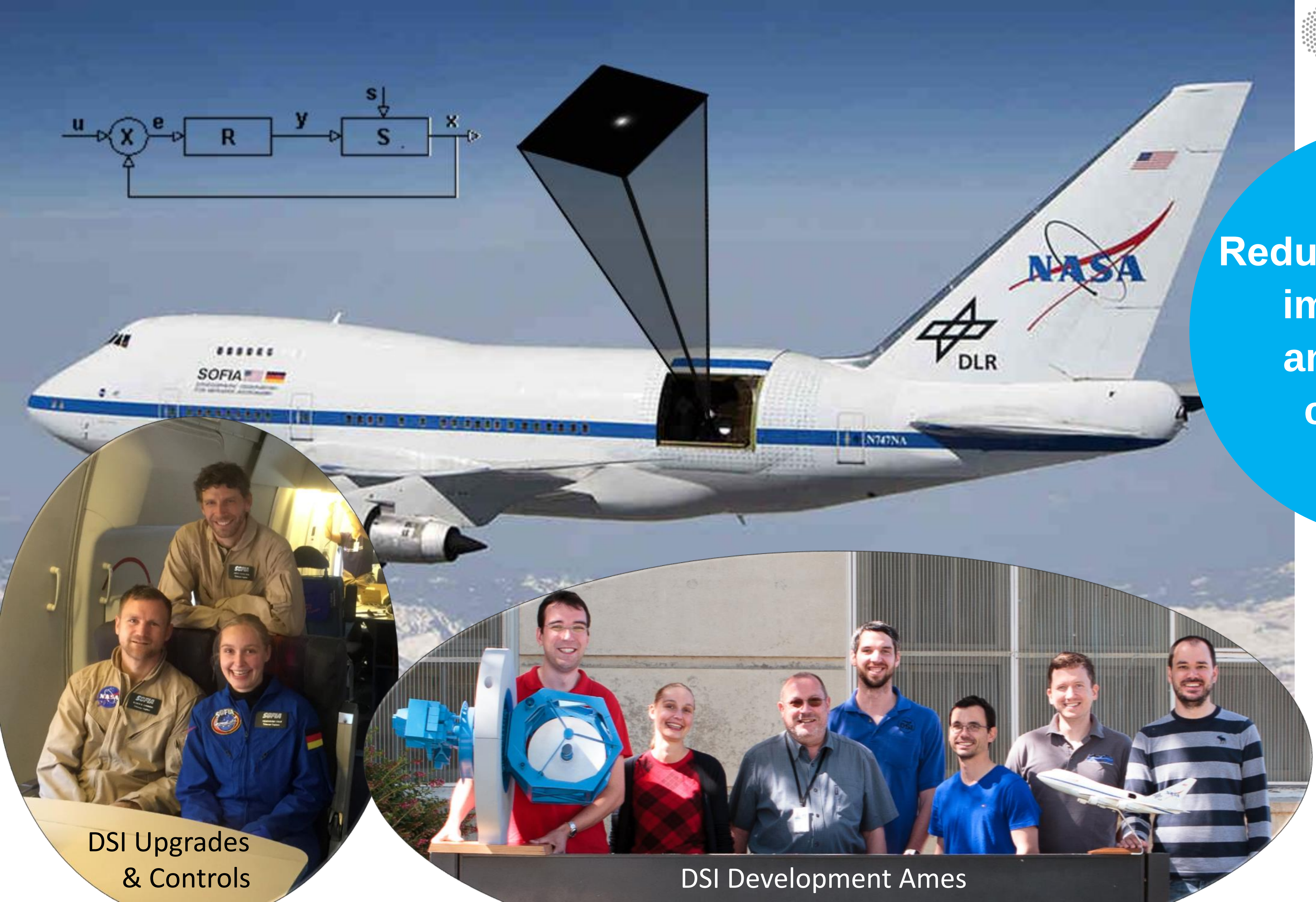
Reducing SOFIA's image jitter: an ongoing challenge

Friederike Graf



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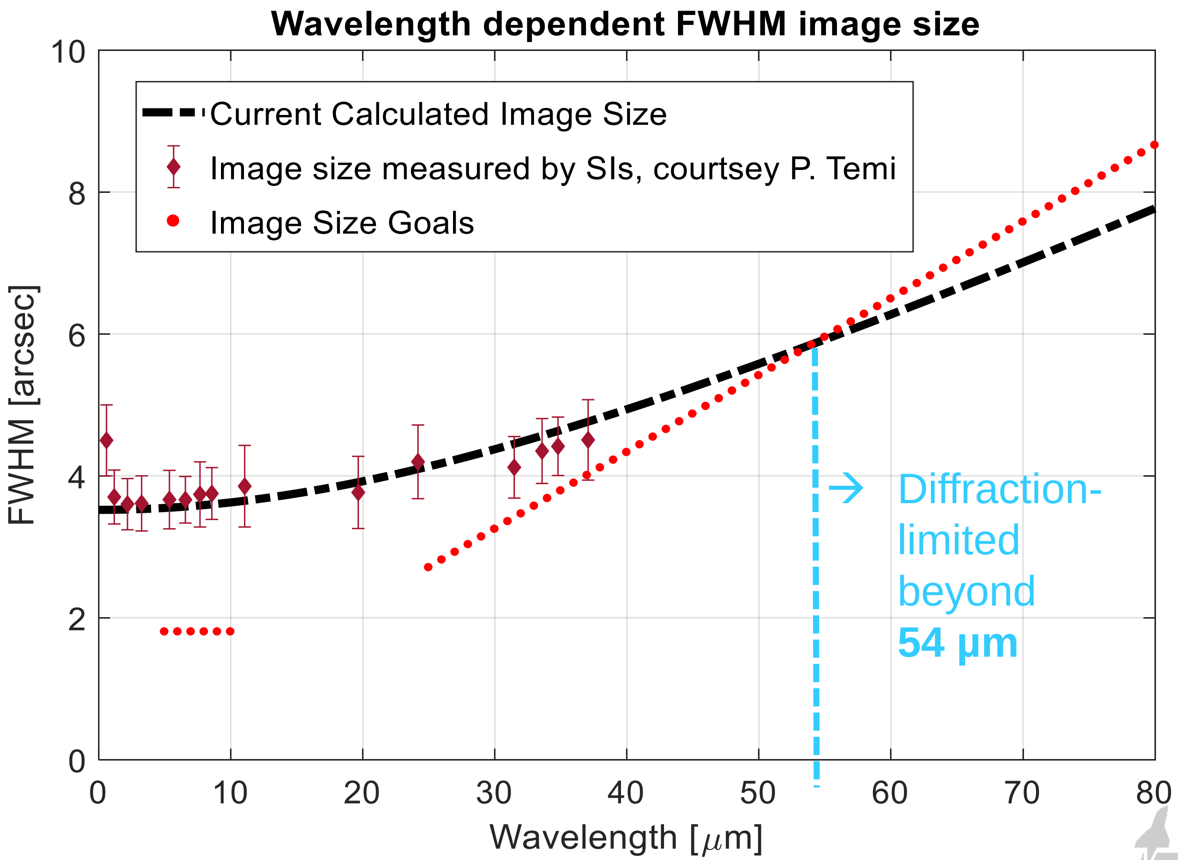
SOFIA Image Size Goals

1) 5 - 10 µm: 50% encircled energy ≤ 1.8 arcsec at an observing altitude of at least 41,000 feet under light turbulence (or better) flight conditions

2) 25 µm : diffraction limited imaging, where diffraction-limited is defined by satisfying a Strehl ratio of at least 80%

→ EXES, FORCAST (FLIPO and FPI+) would benefit from smaller image size

→ EXES and HIRMES could save integration time (EXES up to a factor of 4 and HIRMES 10-20%) if image size is decreased



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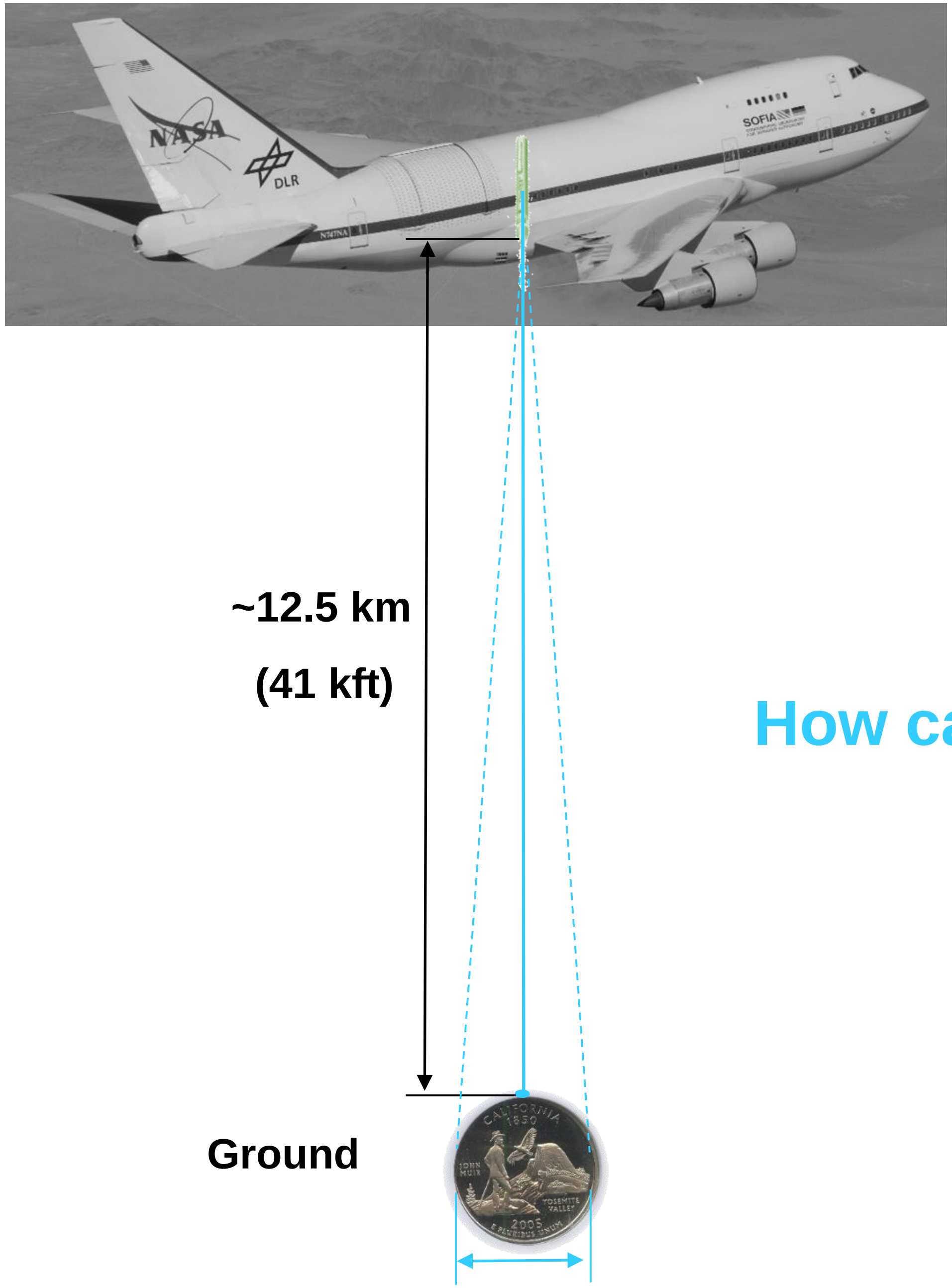
The pointing challenge



Goal Image Size only possible if:

Image Jitter ≤ 0.4 arcsec rms at focal plane

How can we achieve that?

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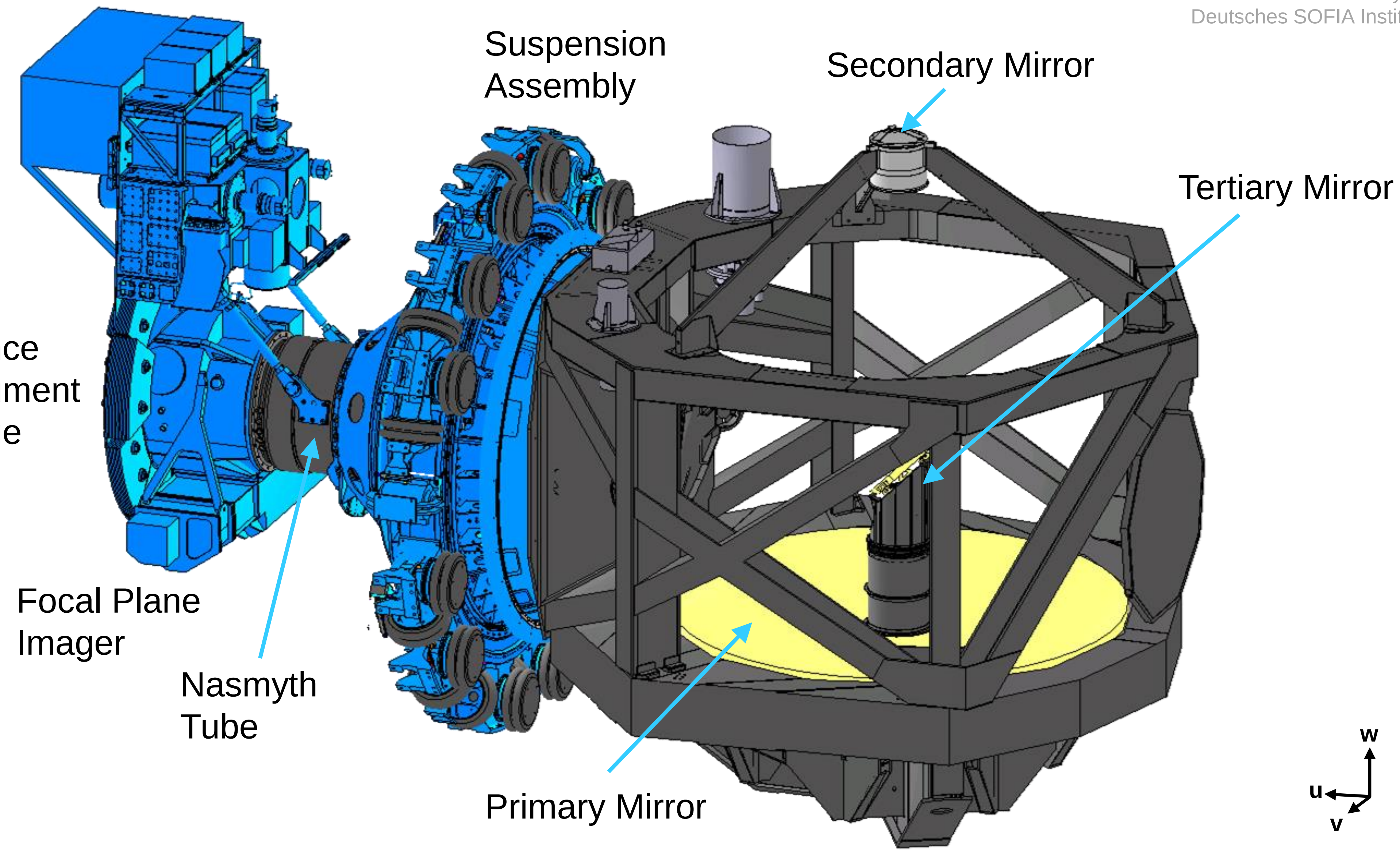
Telescope Assembly (TA)

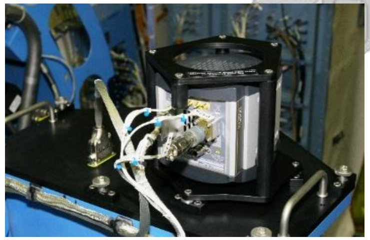


Cabin T ~ + 20°C

Cavity T ~ - 40°C

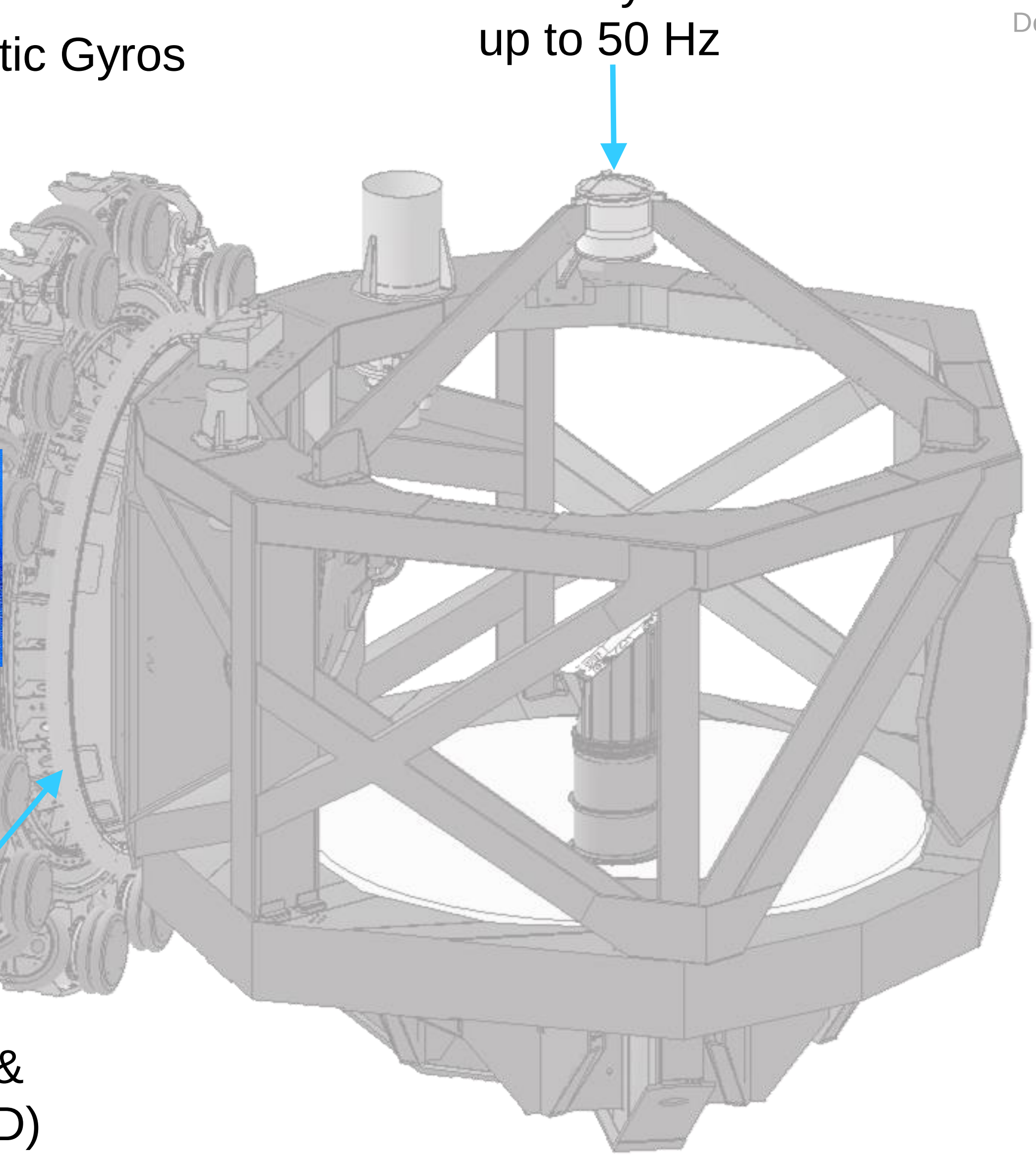
Sensors & Actuators

Accelerometers



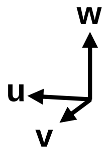
Focal Plane Imager

Fiber Optic Gyros



Secondary Mirror
up to 50 Hz

Fine Drive (FD) &
Coarse Drive (CD)
~3-6 Hz



SOFIA's Control System

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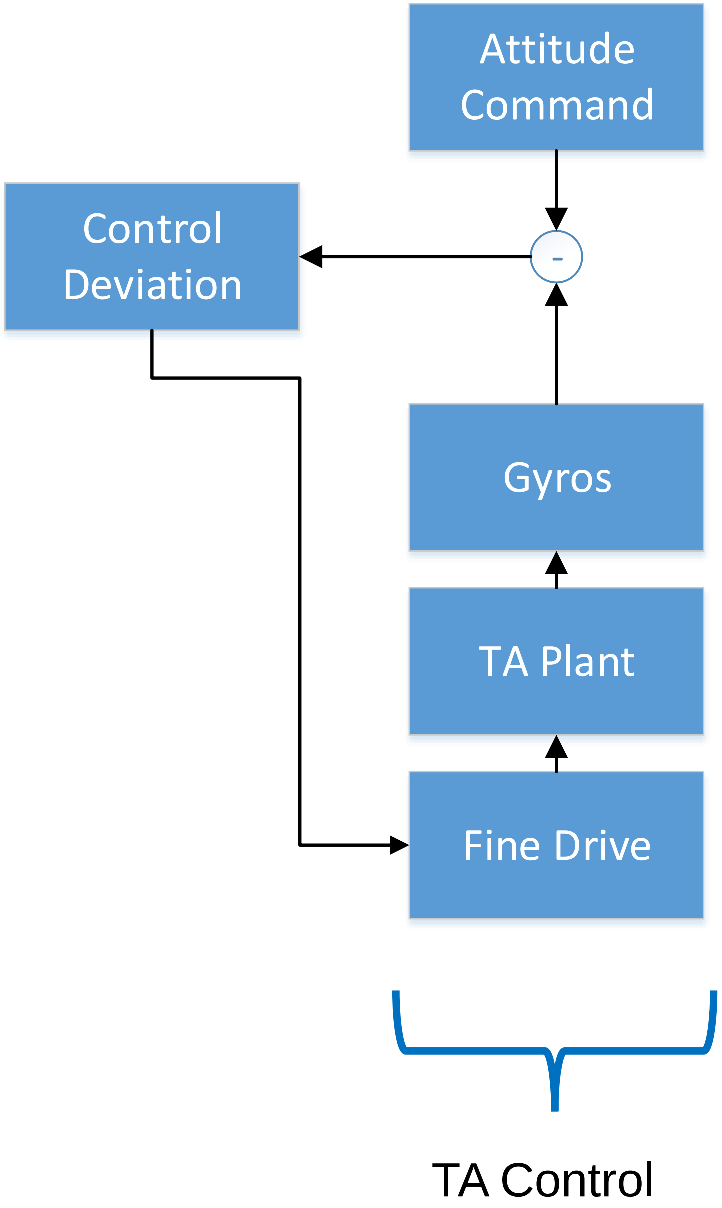

Cascaded control of LOS, XEL, EL

SOFIA's Control System

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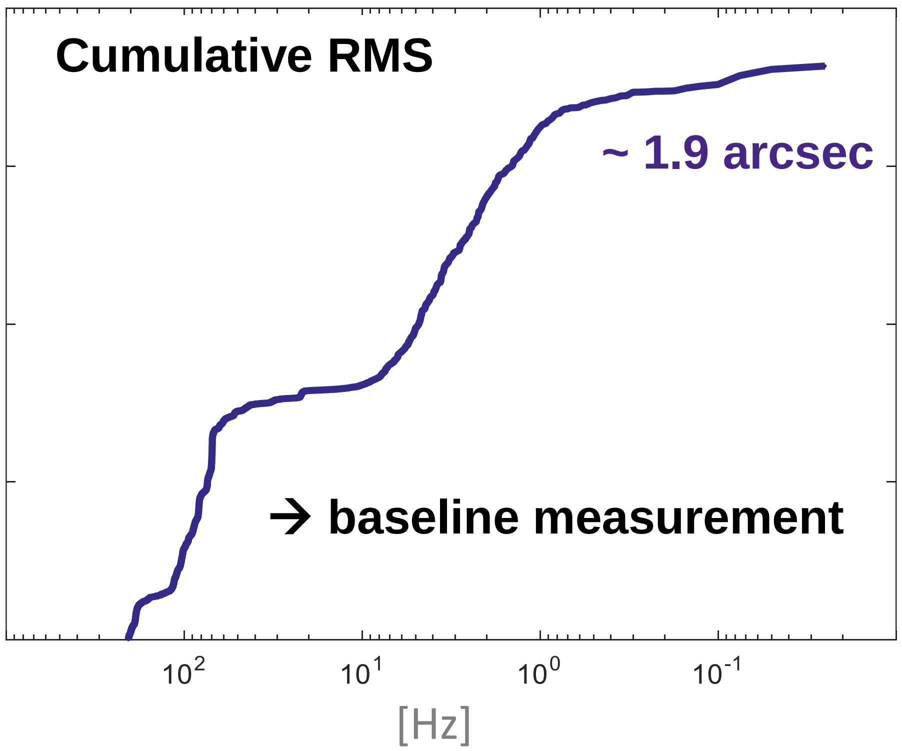
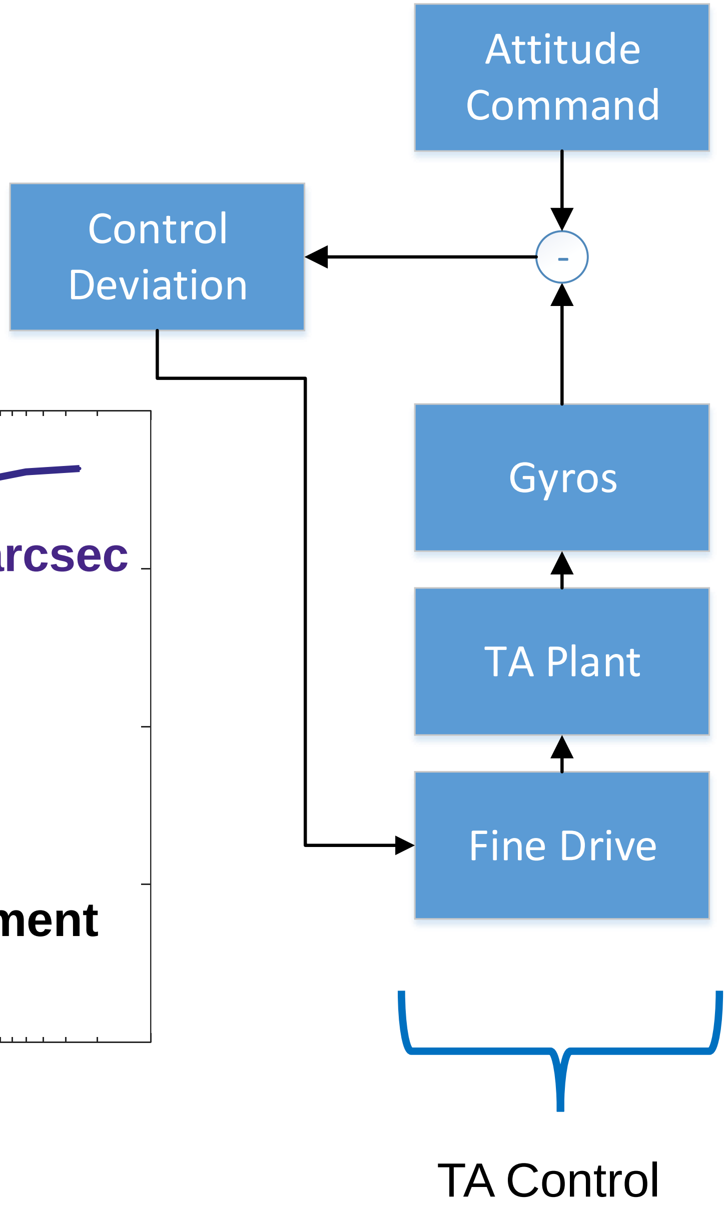
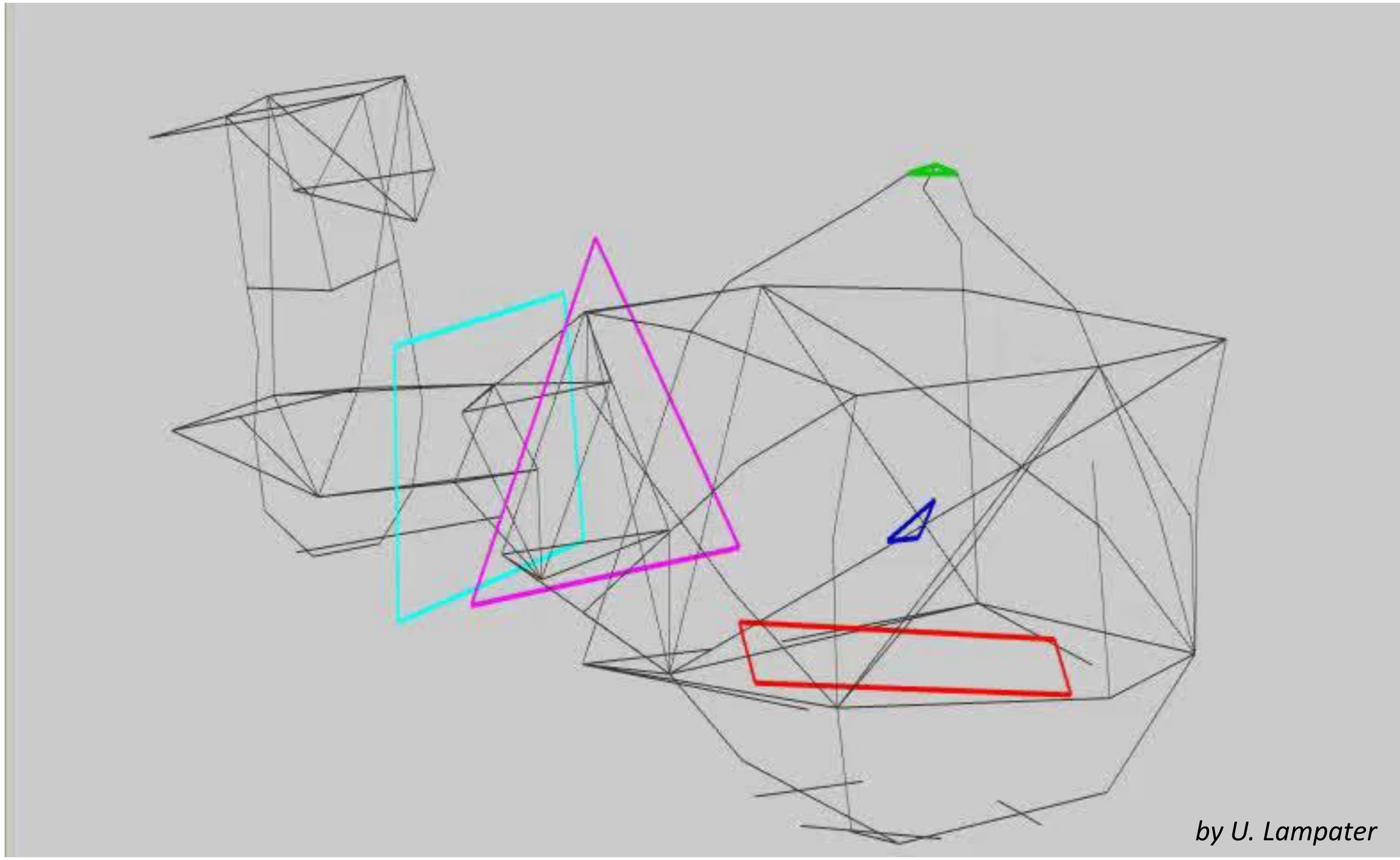




Cascaded control of LOS, XEL, EL

Why FBC?

→ **Flexible body deformation** occurs, especially Nasmyth tube bending, **due to inertial forces (gravity, turbulence etc.)**



FBC:

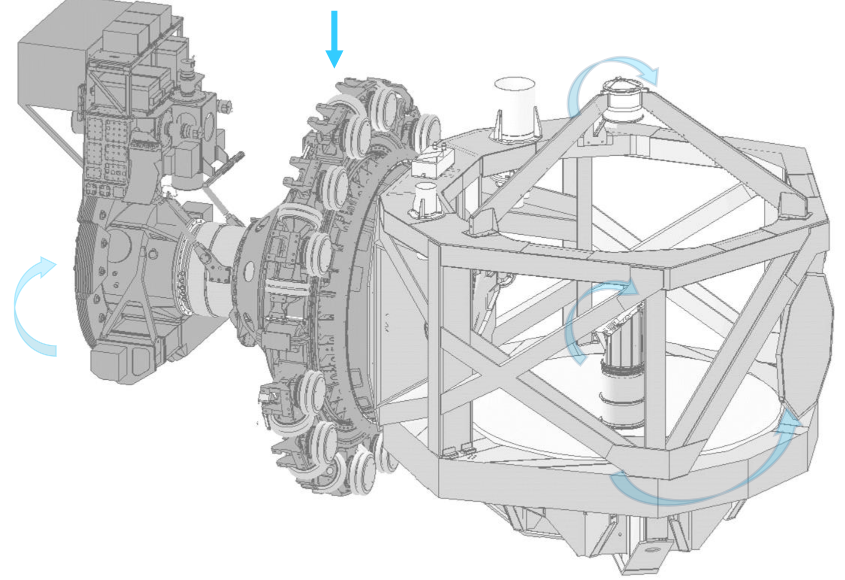
Flexible Body

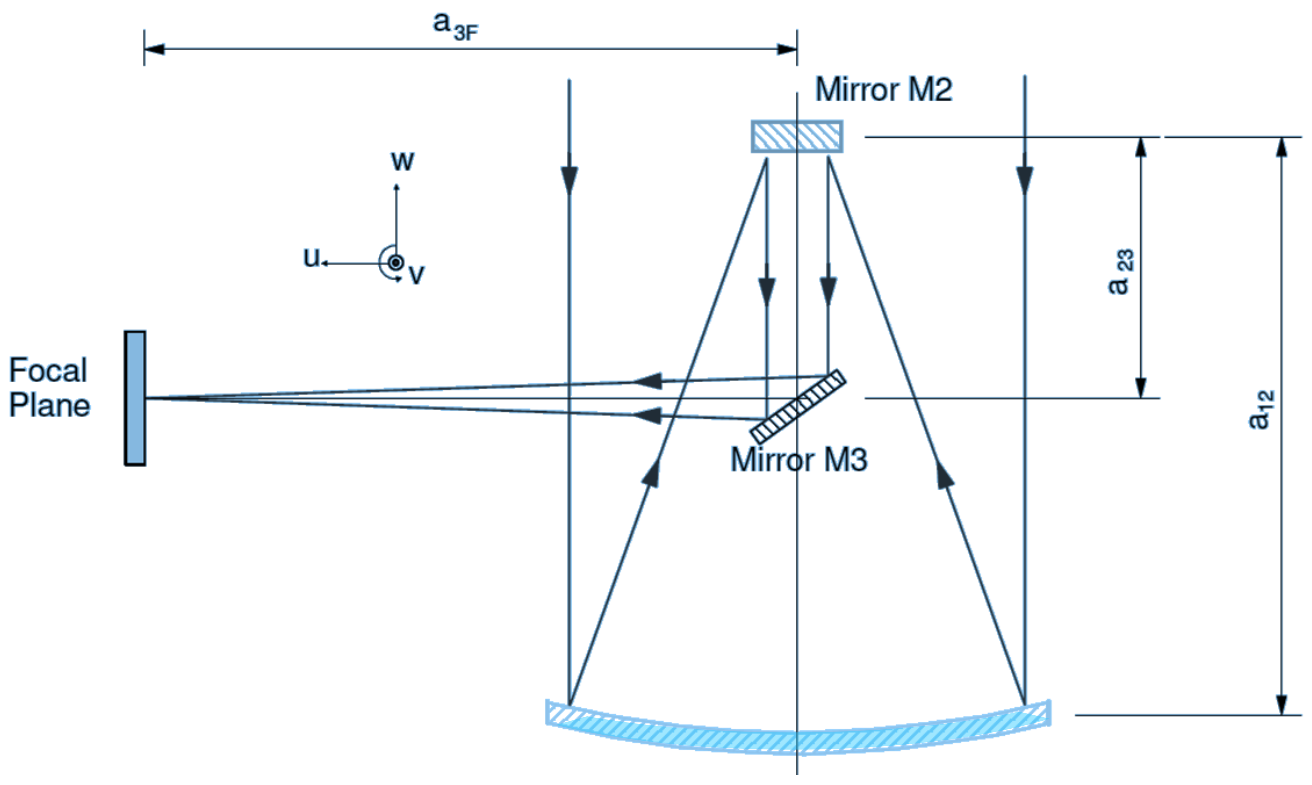
Compensation

FBC: FEM & Ray Tracing

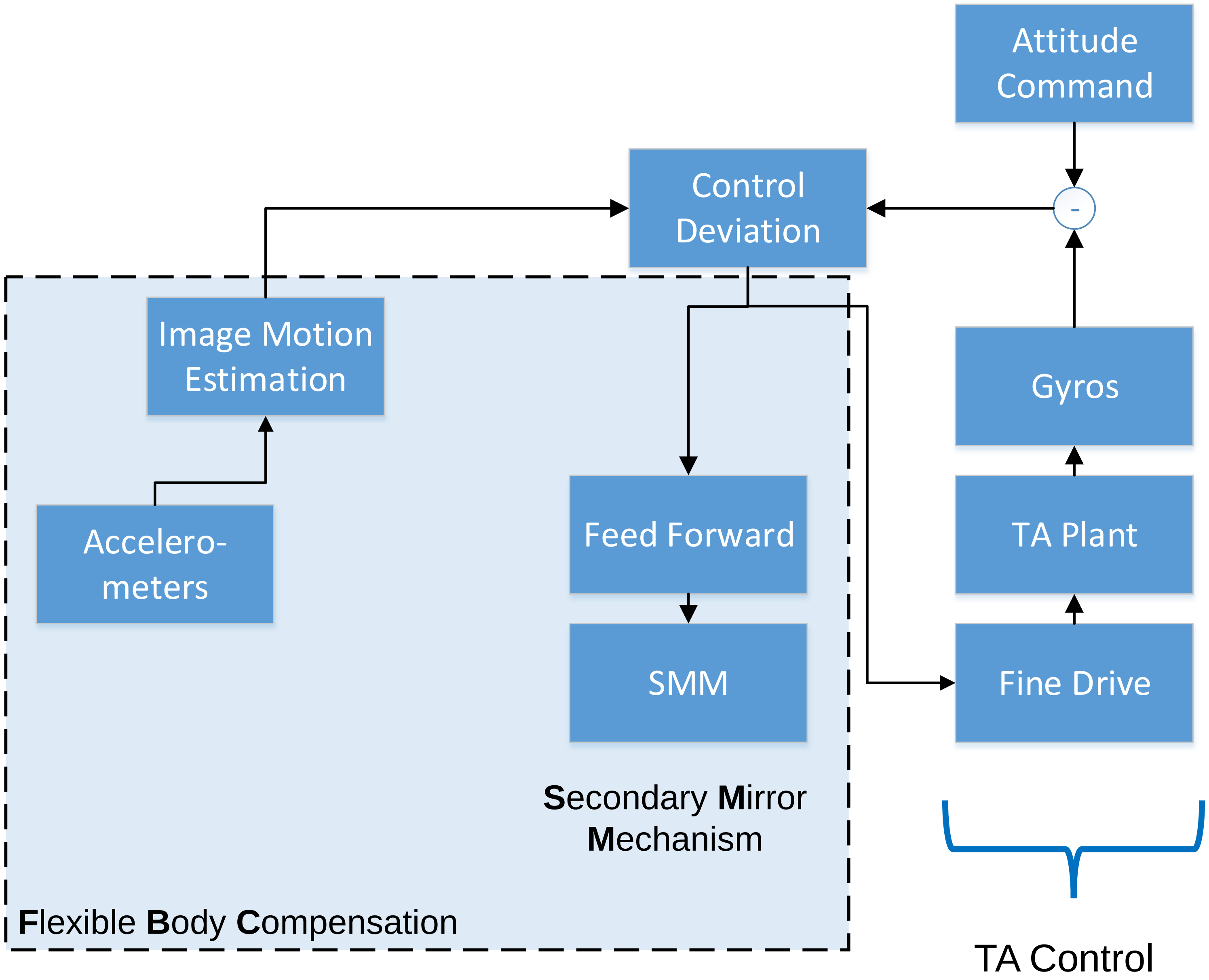
FBC Matrix: Acceleration → φ_{EL} φ_{XEL} → Image Motion Estimation

1g load-case



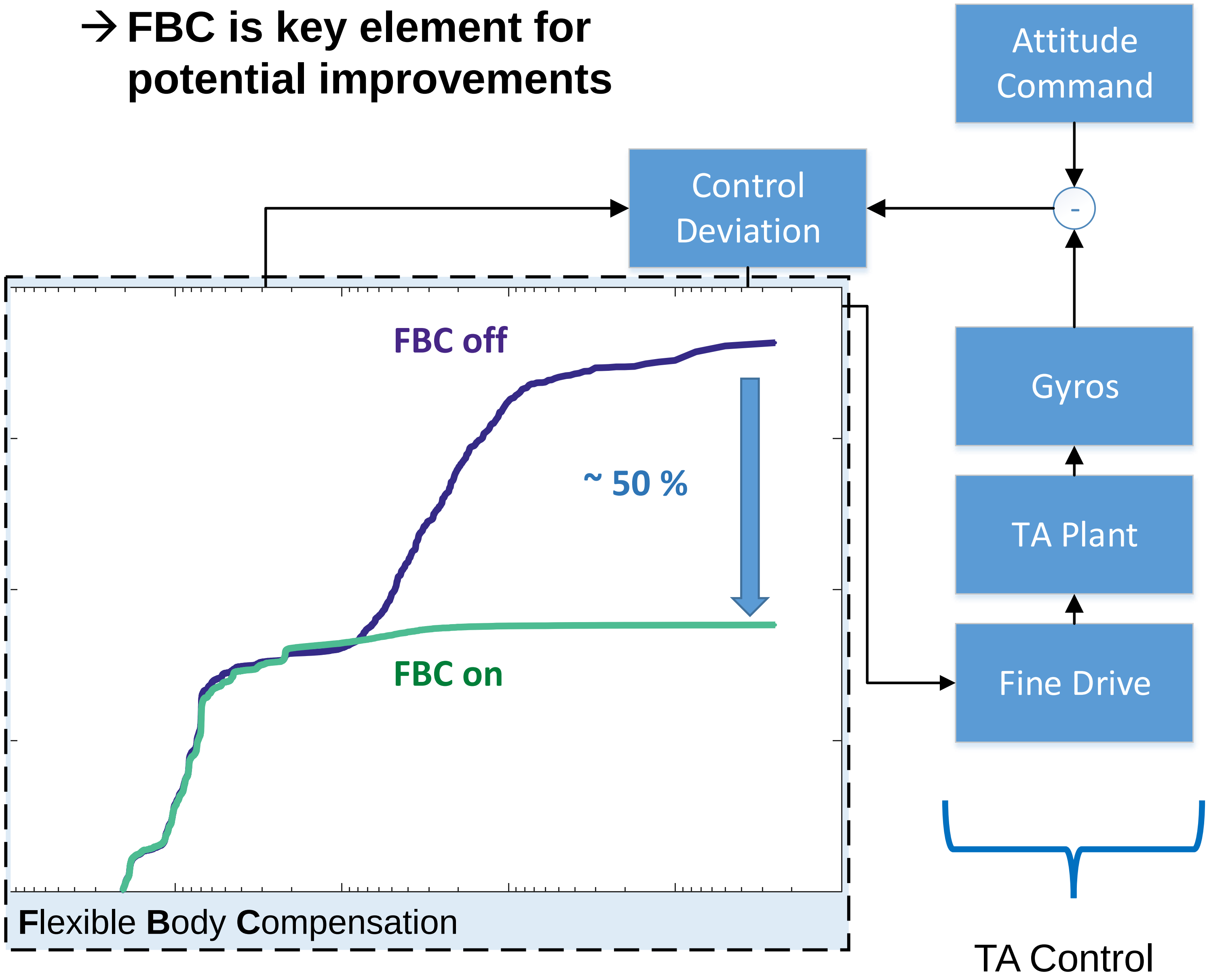


The FBC System

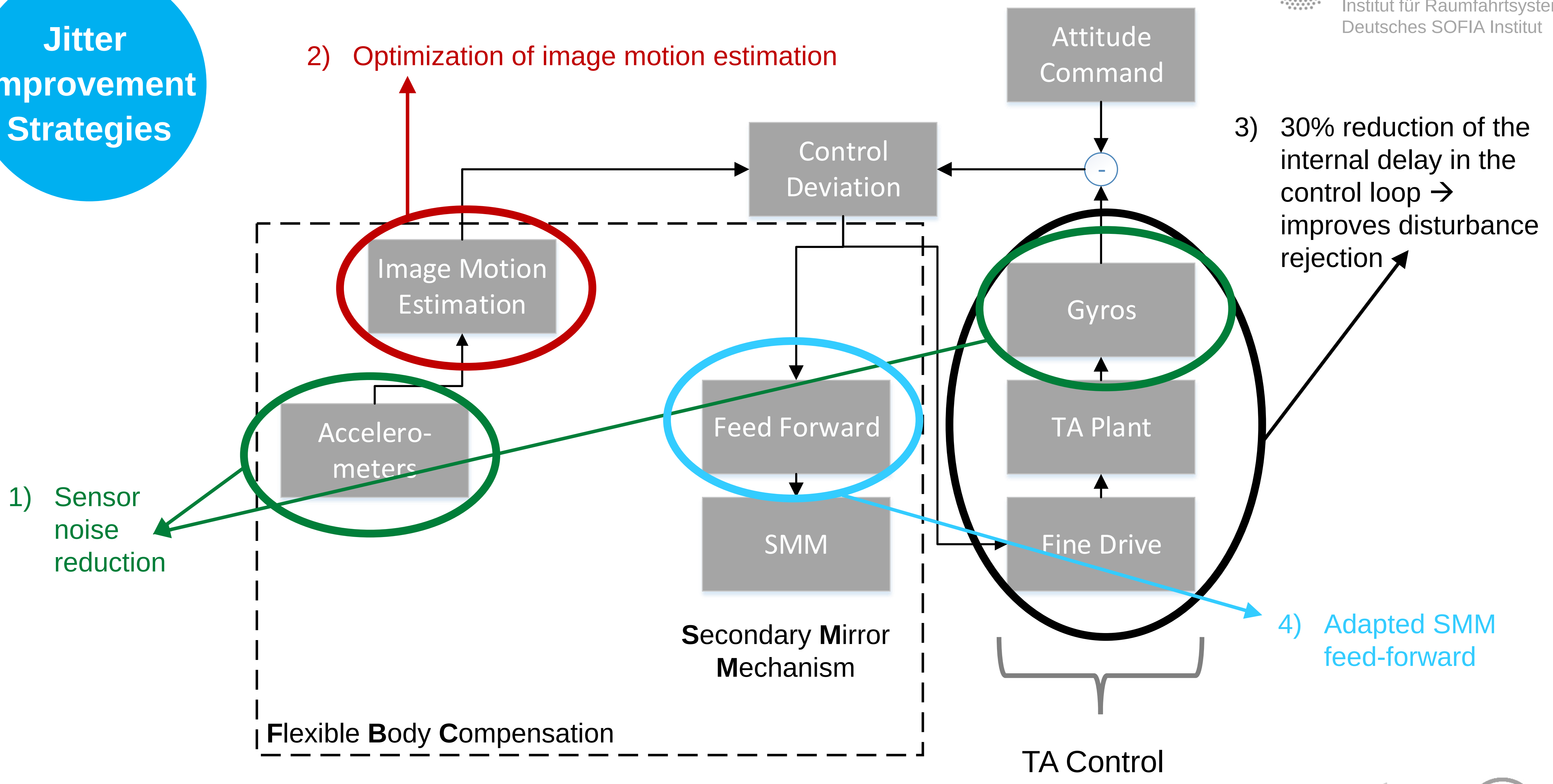


The FBC System

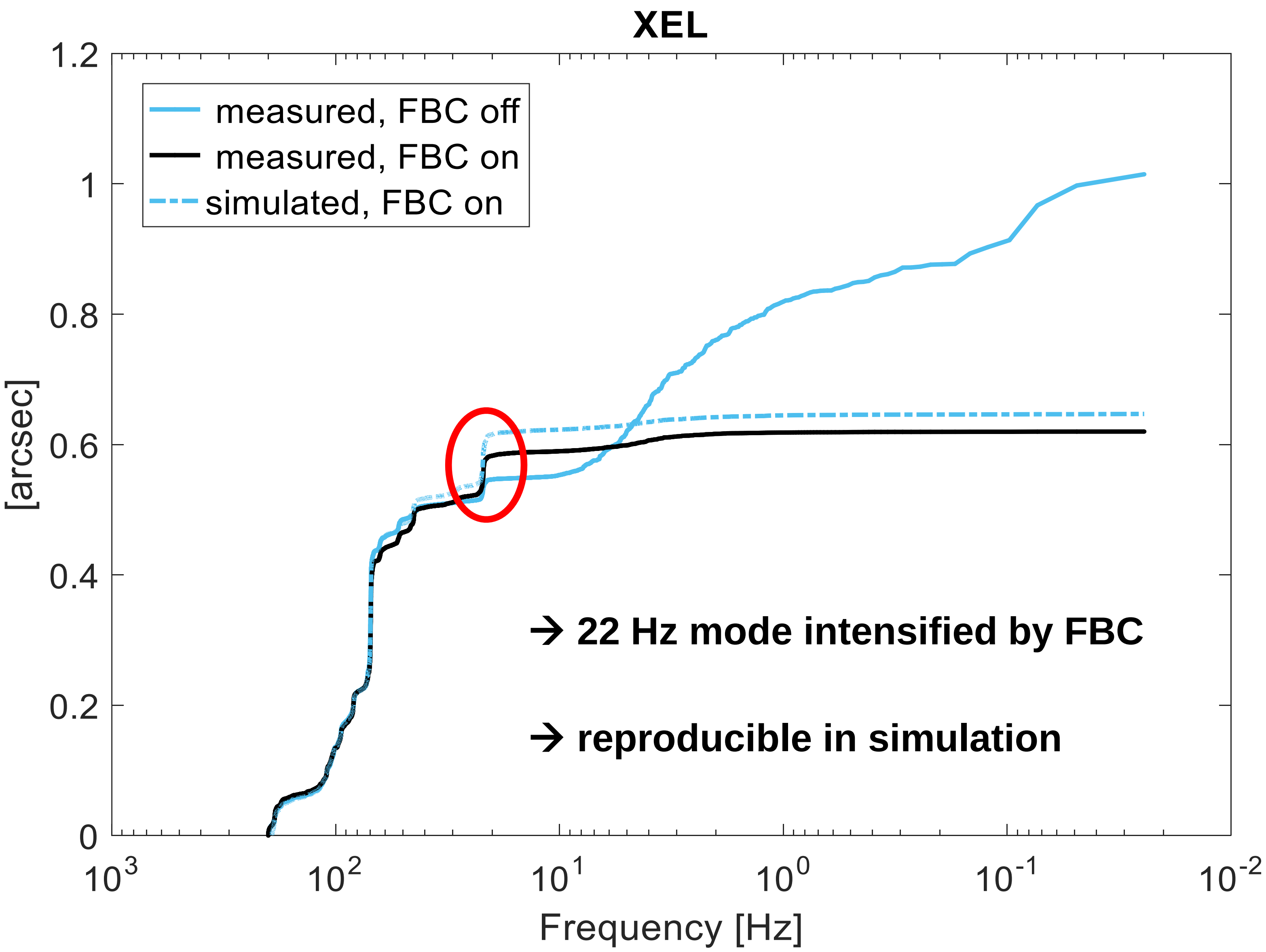
→ **FBC is key element for potential improvements**



Jitter Improvement Strategies



Motivation for 4) adapt SMM FF

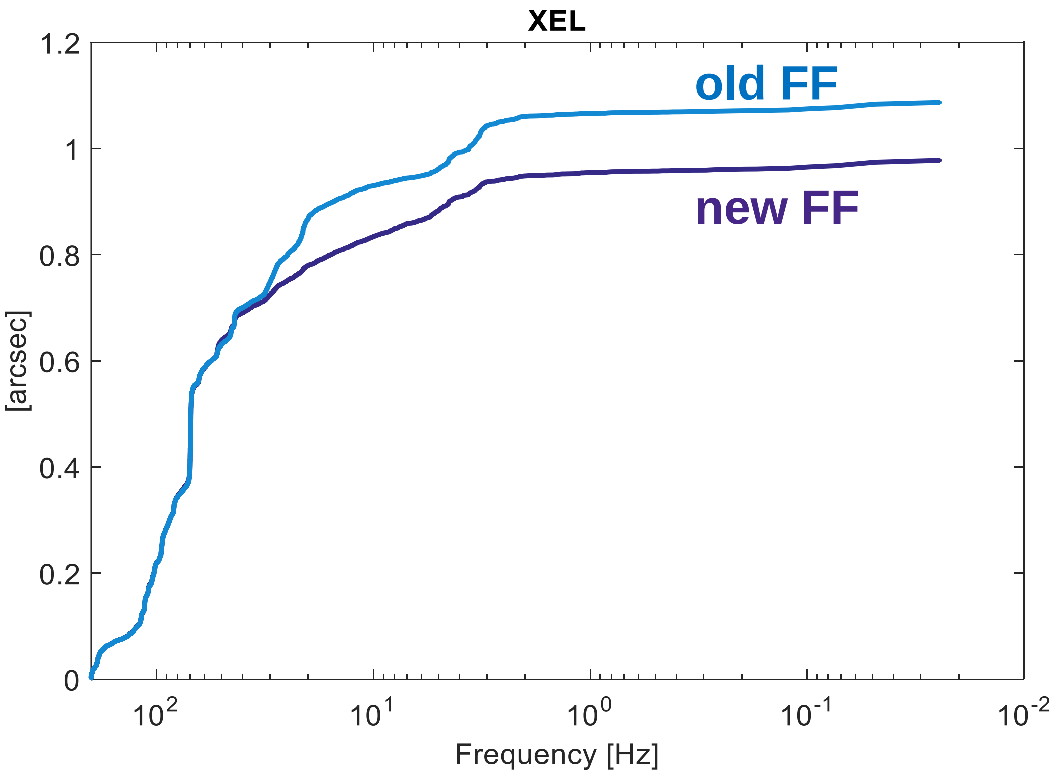


→ **22 Hz mode intensified by FBC**

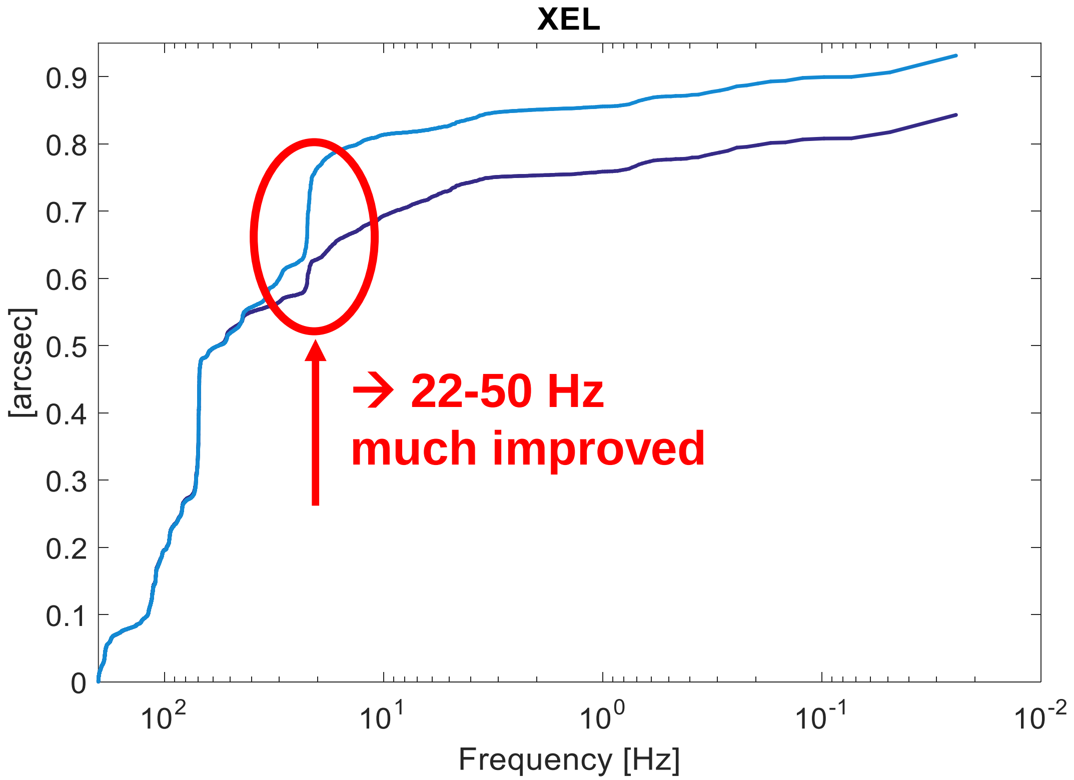
→ **reproducible in simulation**

Simulation Results in XEL

Baseline data from flight 271:



Baseline data from flight 331:



→ 11-13% Improvement in XEL

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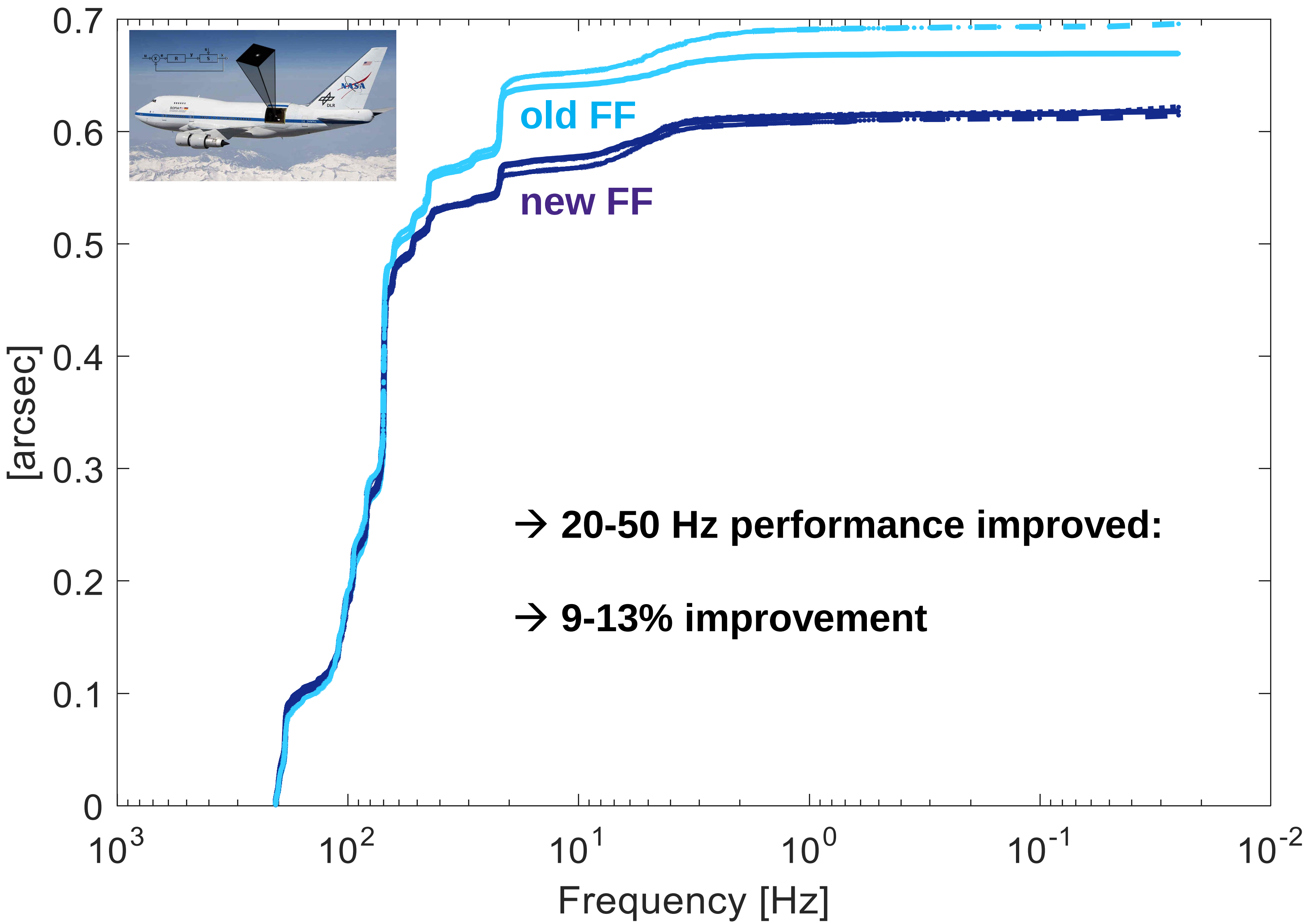
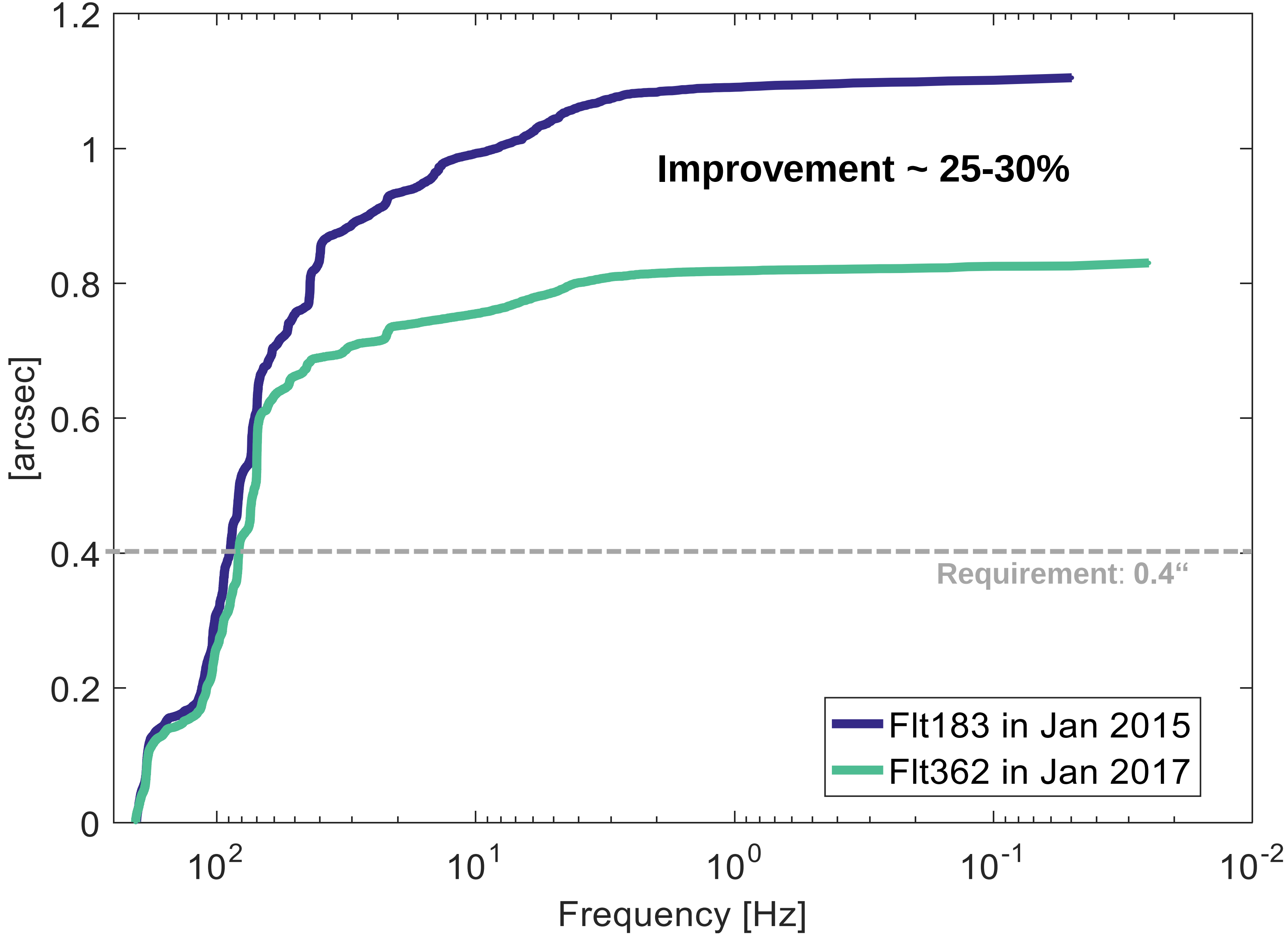
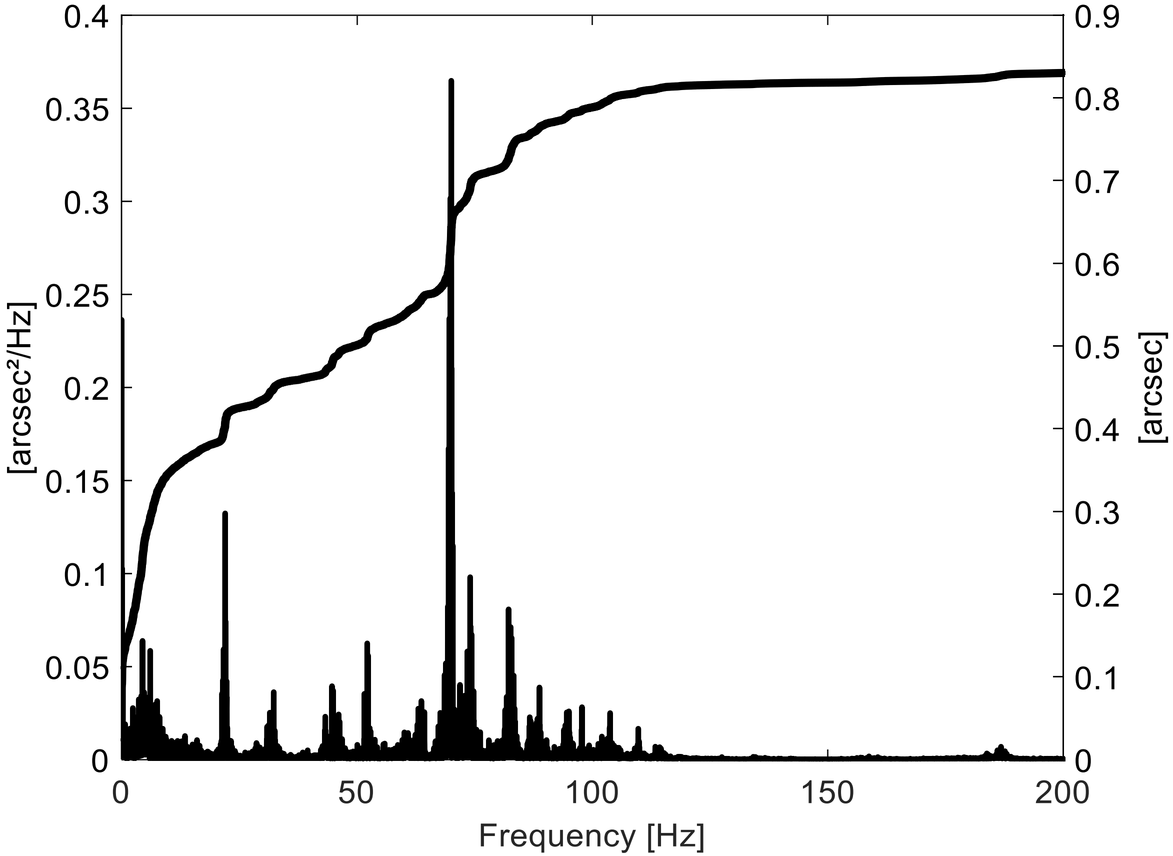
XEL Jitter flight results



Overall Improvement



Future Tasks/ Plans



- Reactivation of optical path sensors and flight data acquisition (started in Nov 2017)
- Use optical path sensors for higher flexible mode estimation
- Improve Fine Drive disturbance rejection
- Implement fancy compensation ring in TCM
- Reactivate Active Mass Dampers
- (Image Motion Compensation)
- (Active Flexures)

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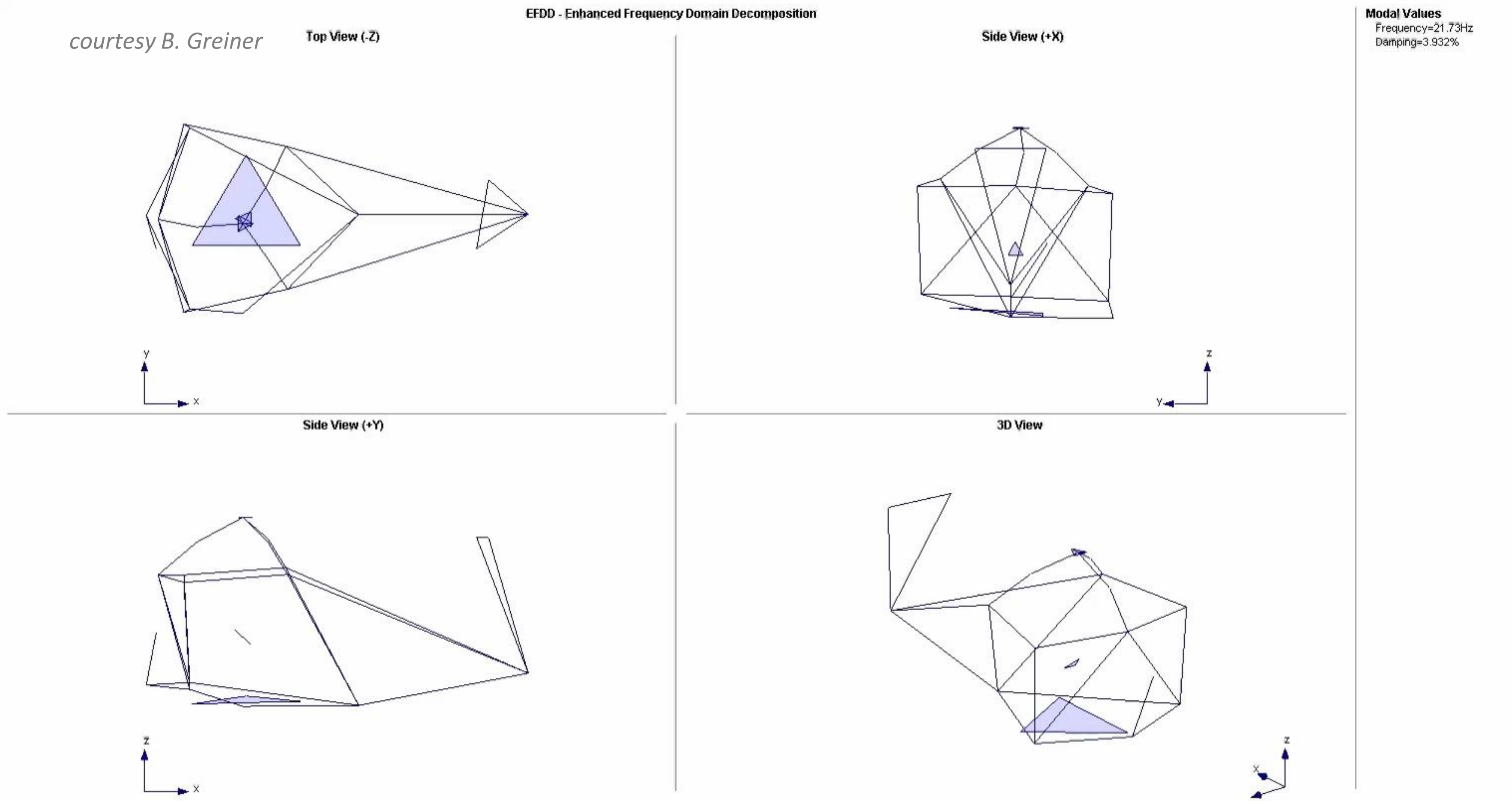
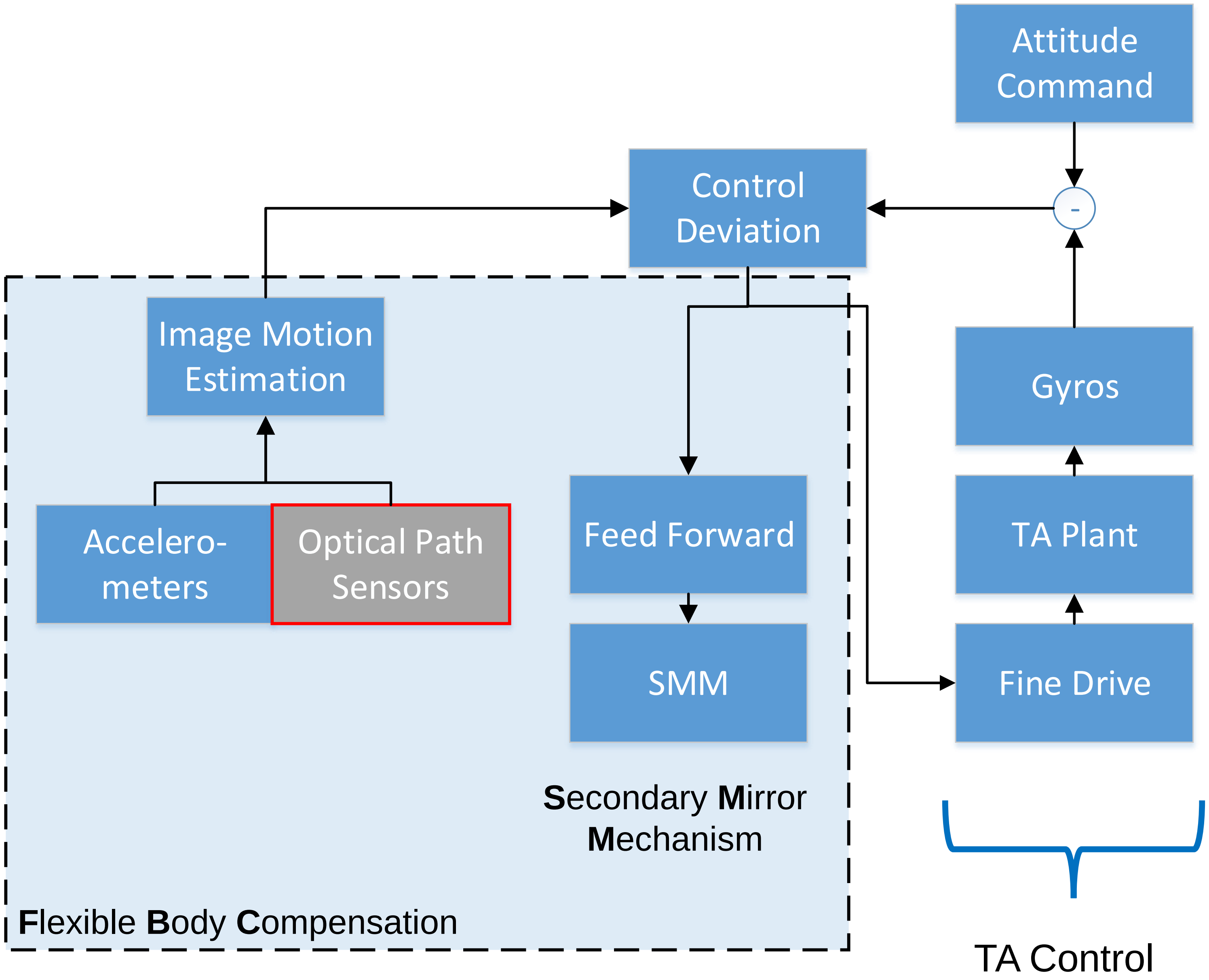
Why more sensors?

courtesy B. Greiner



Not enough sensor data → We need **accelerometers along optical path!**

Optical Path Sensors (OPS)



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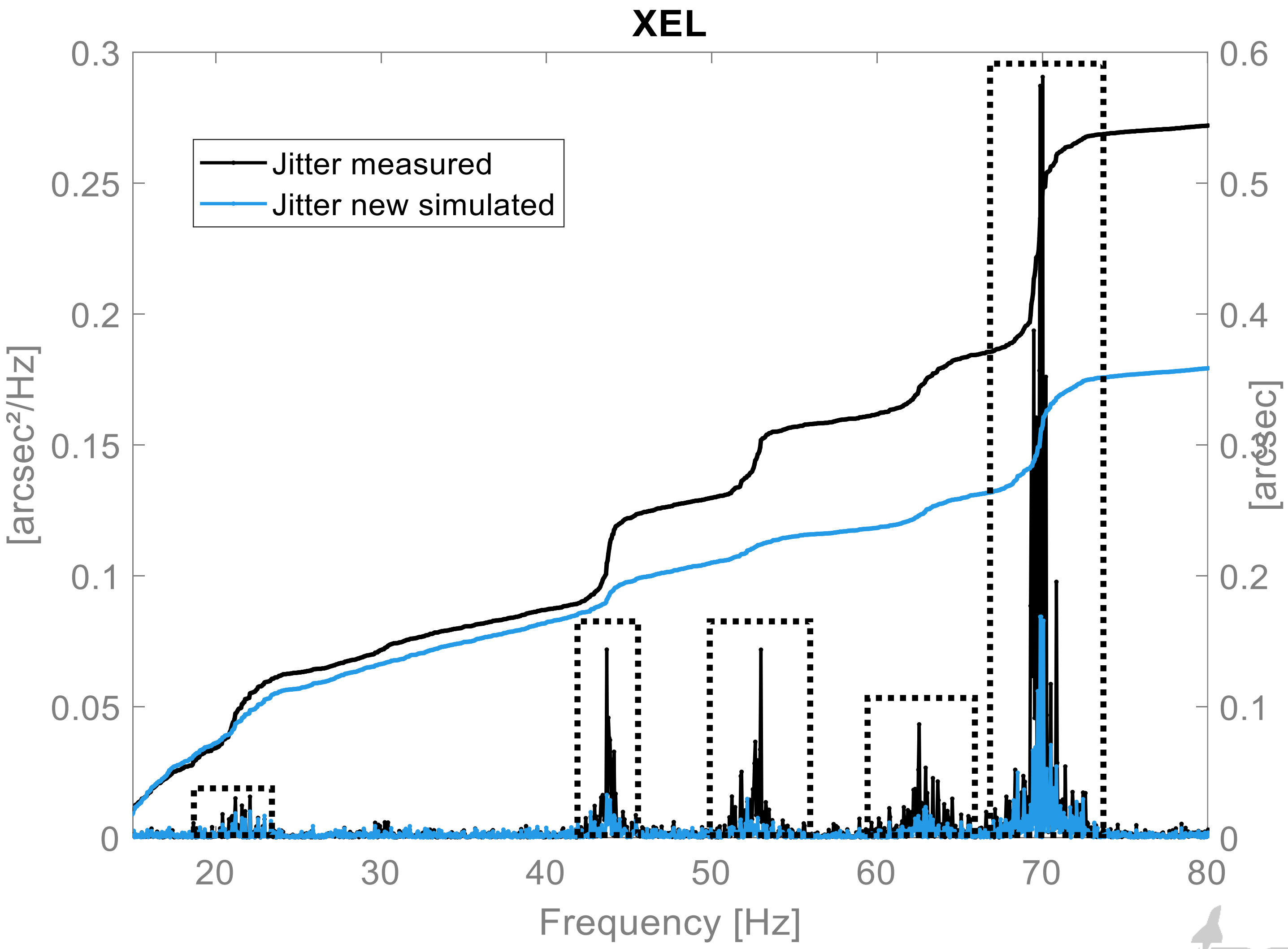
Potential with OPS

One set of old (~2011) sensor data available for first analysis and simulation:

→ New data will be collected early 2018 for further analysis

→ Relevant, well-known frequencies are represented

→ In order to actually remove these modes we need a higher TCM bandwidth



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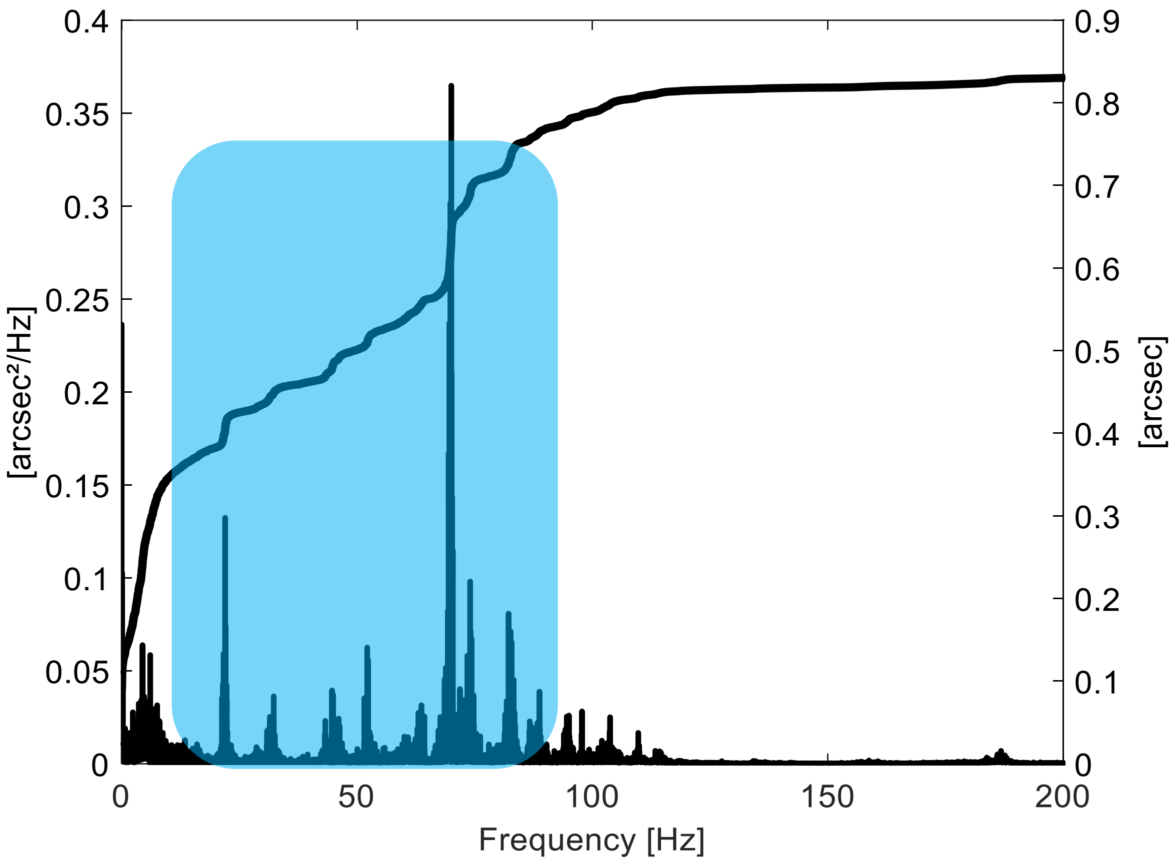

1. OPS and new FBC increase knowledge about image motion

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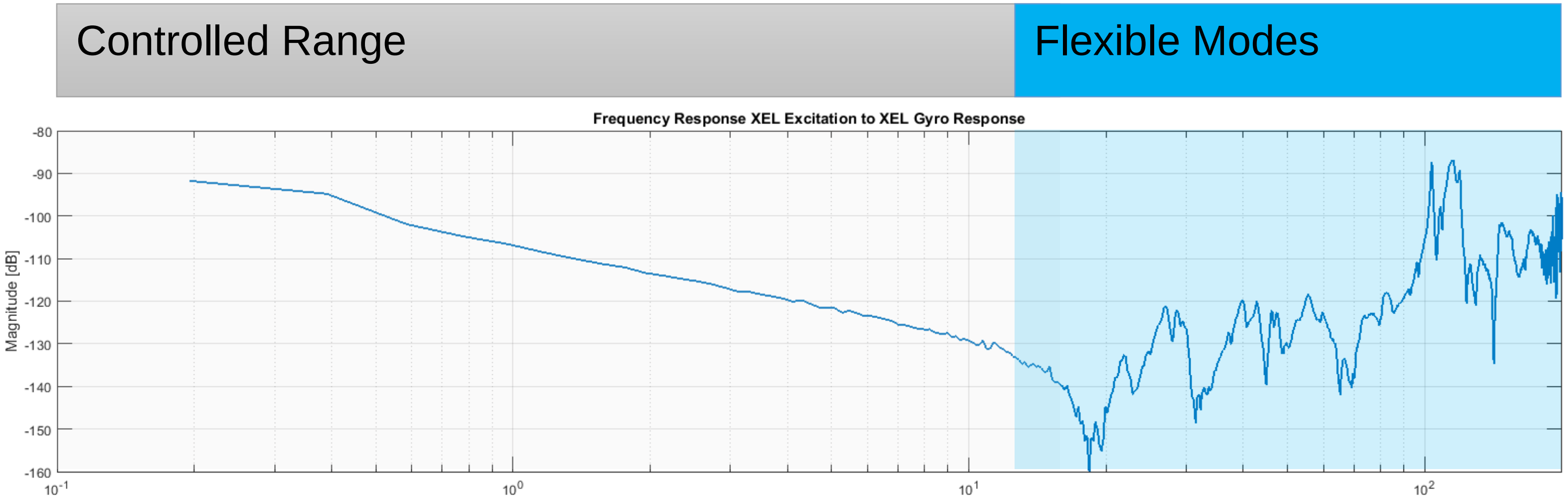
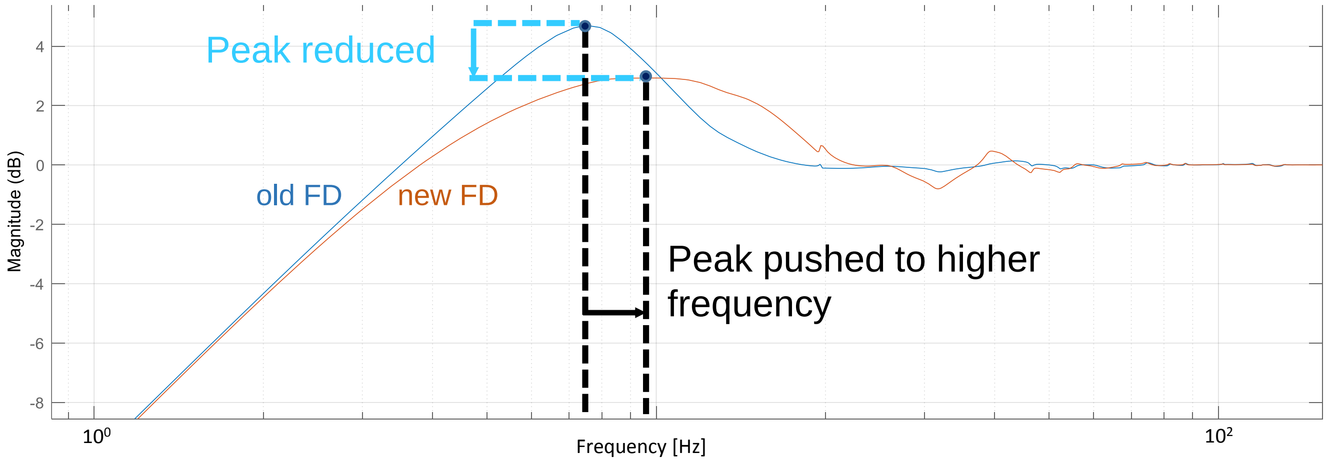
Improve Fine Drive Disturbance Rejection



Idea:
Improve FD disturbance rejection in rigid-body range and reduce impact of flexible modes on FD feedback

Expectations:
→FD bandwidth can be increased
→FD is able to better compensate below 10 Hz
→Stress on SMM can be reduced (focus on flexible mode compensation)

Simulated Disturbance Rejection:



Jitter Improvement Plan

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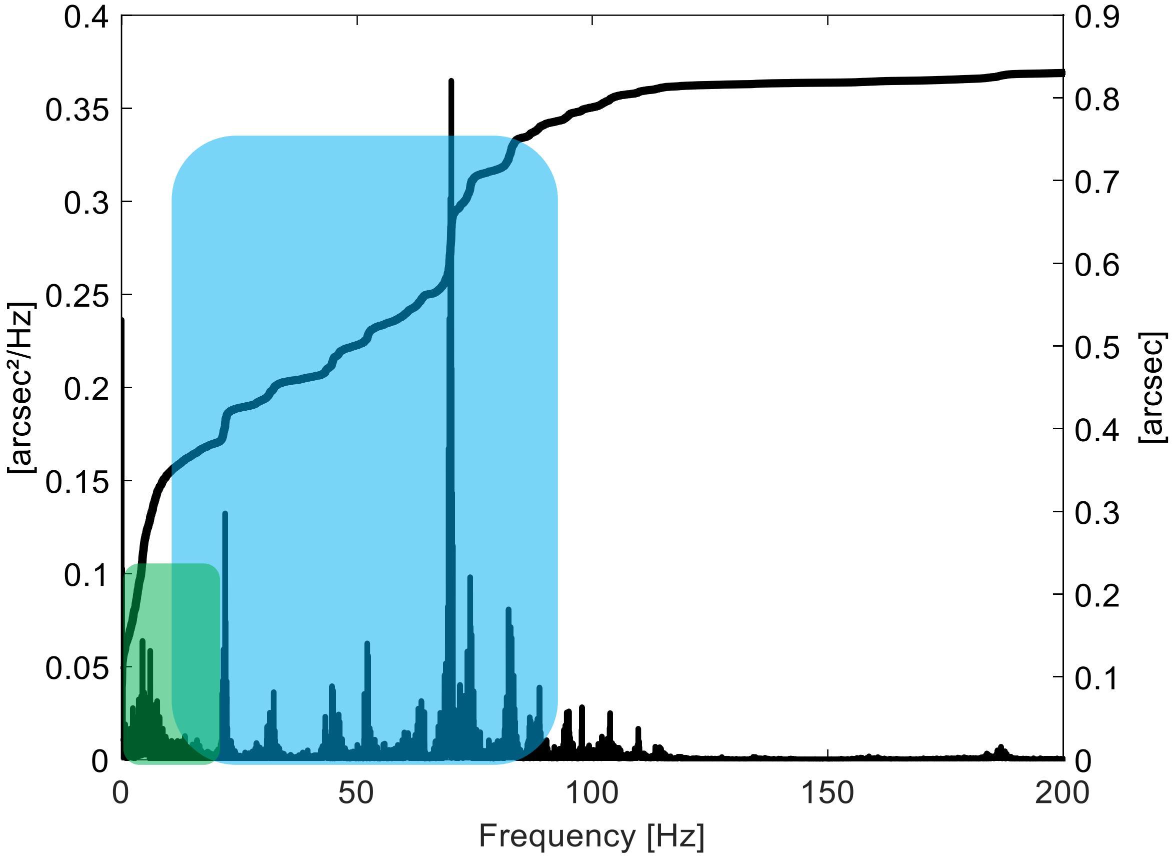

1. OPS and new FBC increase knowledge about image motion

2. FD Observer increases FD bandwidth
→ better VIS mode suppression

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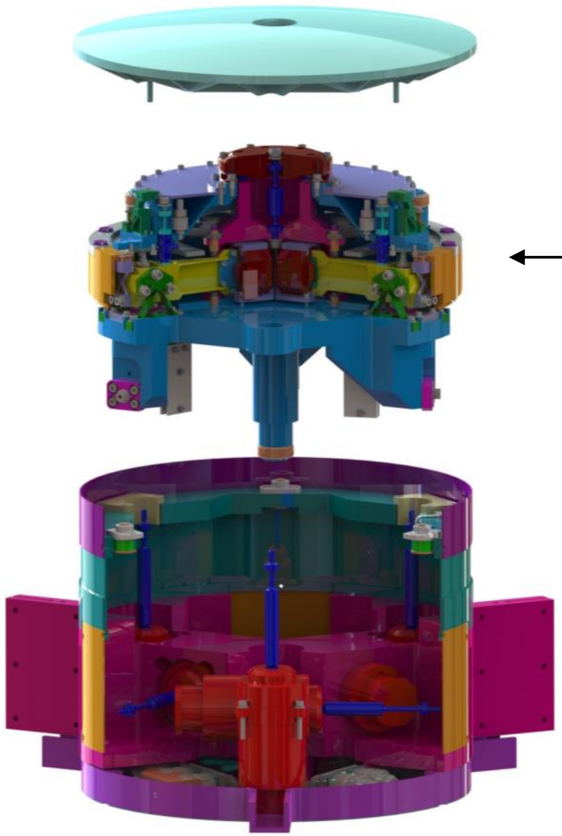
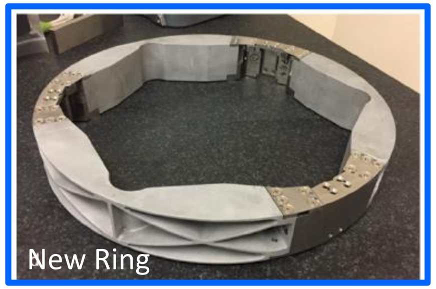
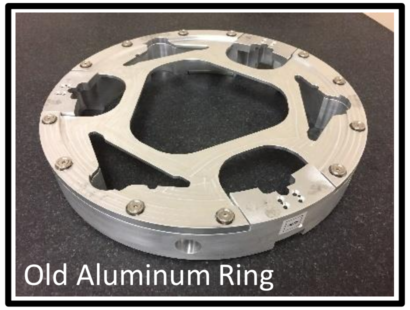
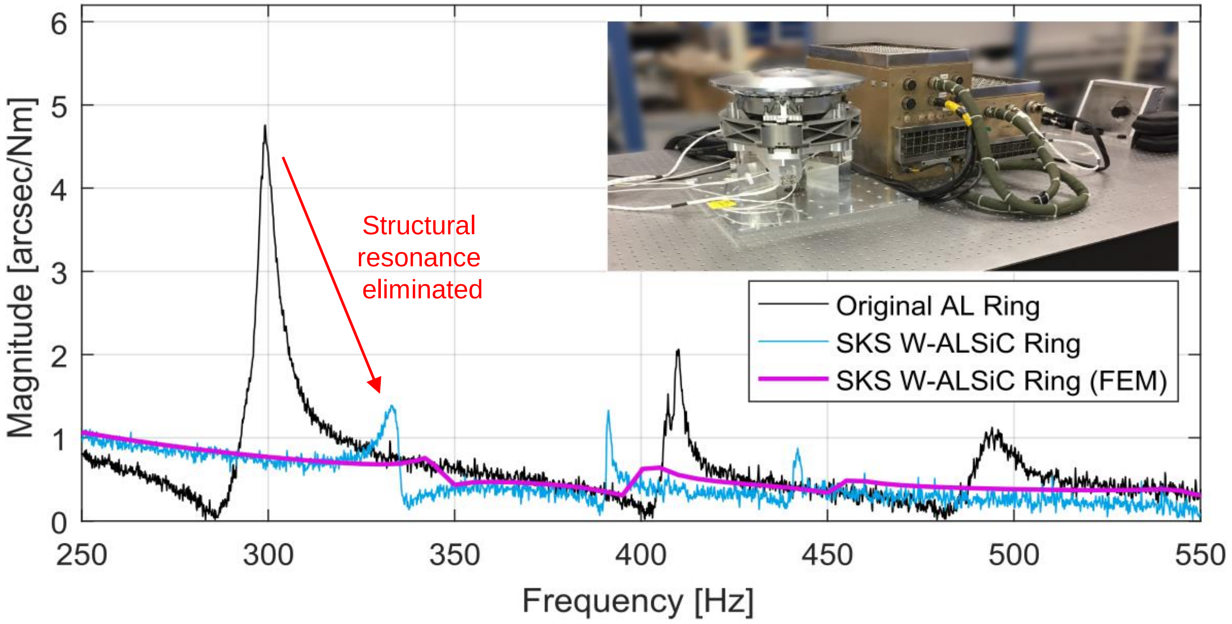
Improved TCM

- New compensation ring concentrates mass at the suspension points and is made of stiffer materials (Tungsten / AlSiC)
- The new ring takes strain energy out of the unwanted resonance modes (300Hz and 425Hz)









- Closed-Loop bandwidth is improved by 80% providing a faster chop transition (10ms -> 7ms*) and a faster steering capability for flexible body compensation and disturbance rejection
- Prototype is manufactured and tested, flight unit is expected to be available Summer 2018

*for small chop throws, large chop throws are limited by the amplifier

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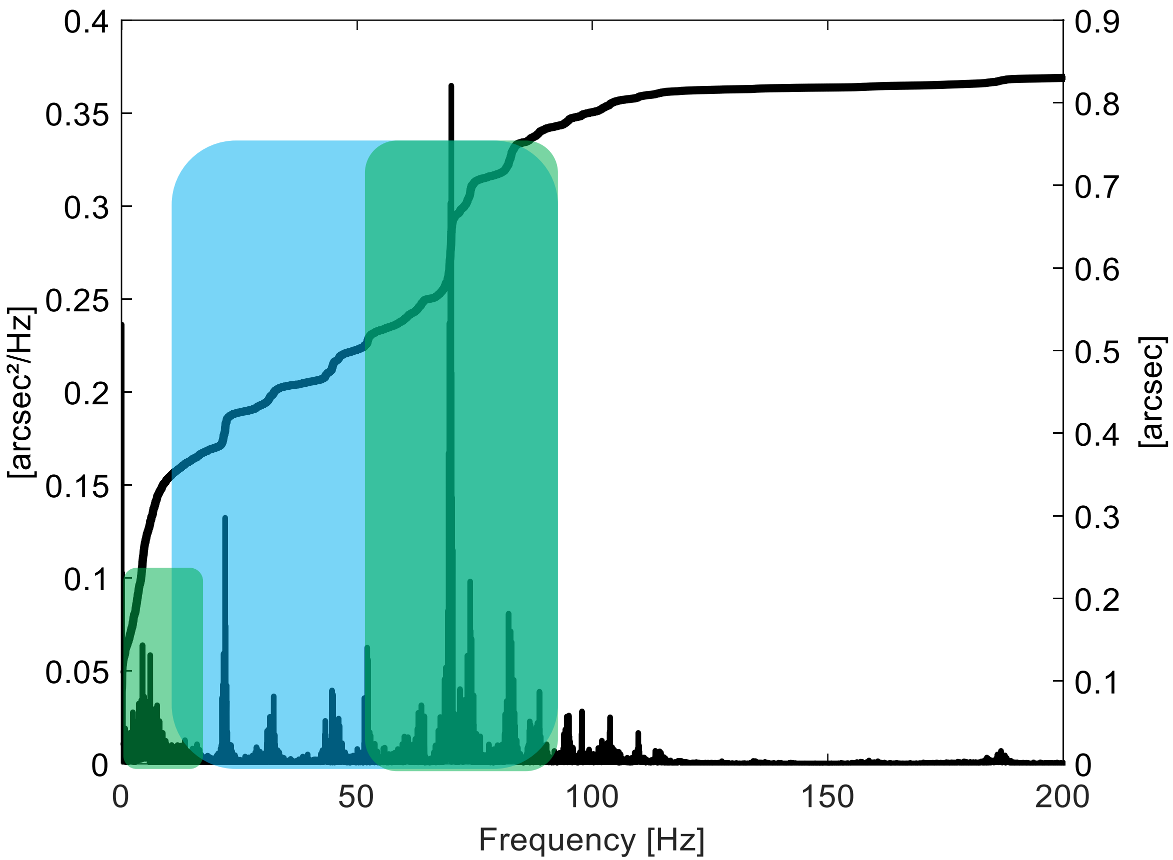
Jitter Improvement Plan



1. OPS and new FBC increase knowledge about image motion

2. FD Observer increases FD bandwidth
→ better VIS mode suppression

3. New TCM damps 300 Hz mode → bandwidth ~80-90 Hz

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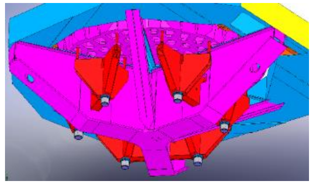
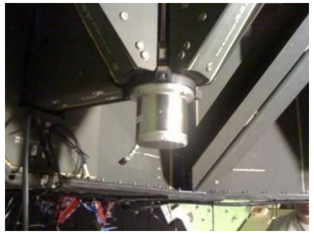
Active Mass Dampers

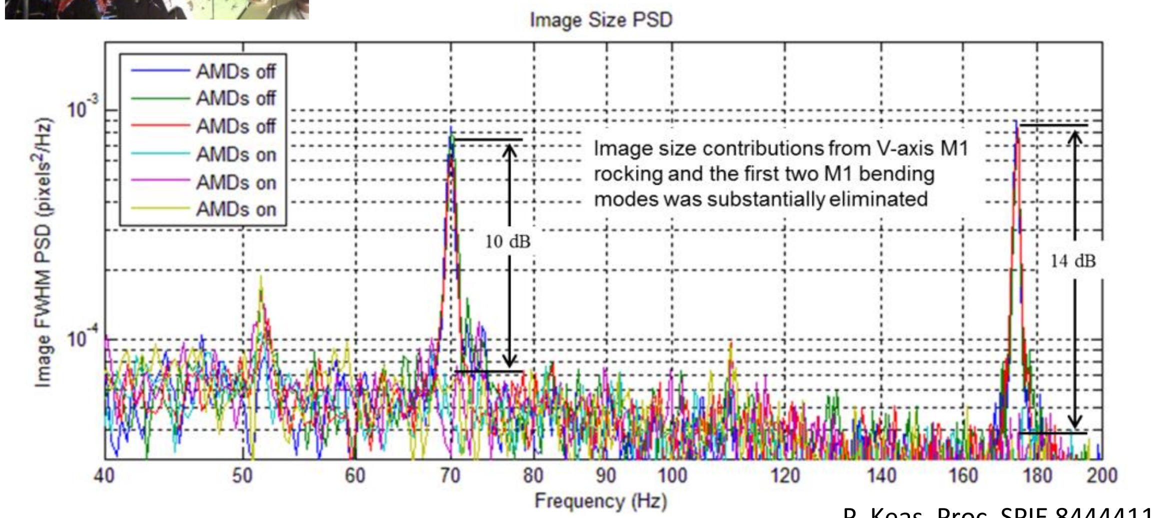
currently reactivated by NASA

2018 →



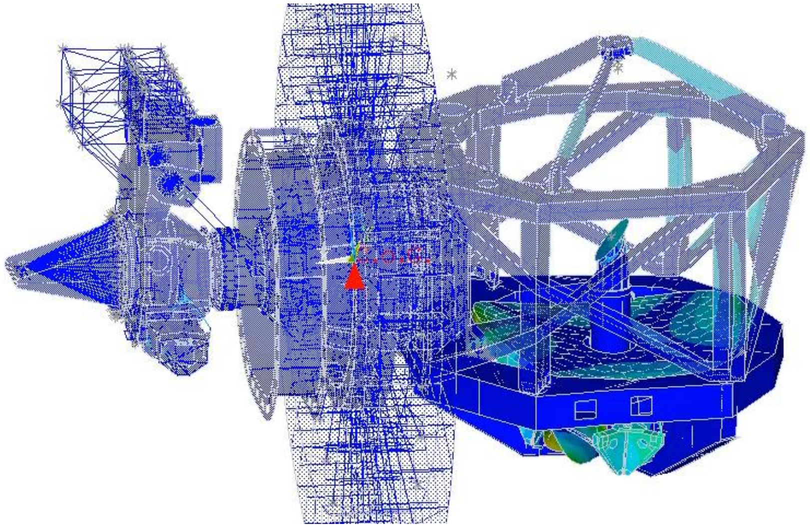


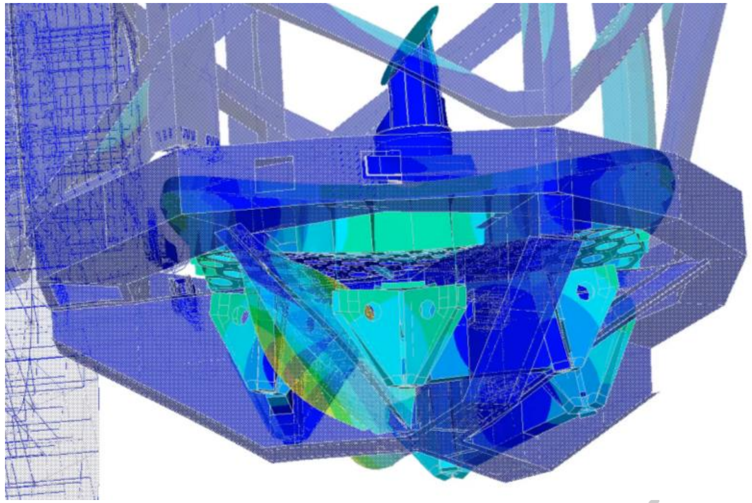
- Six actively controlled reaction masses (reaction force 10lbf) for vibration damping
- Mounted on Whiffle Tree support structure of Primary Mirror
- Test flights during SCAI in December 2011 with limited power show significant improvement on image jitter and size.
    - System was optimized to target Primary Mirror rocking modes at 70 Hz and bending at 173 Hz
    - Adressing bending could improve on higher order optical aberrations (Astigmatism)



P. Keas, Proc. SPIE 8444411-12

Mode Shape of 173 Hz Mode as calculated by FEM Analysis (unscaled!)

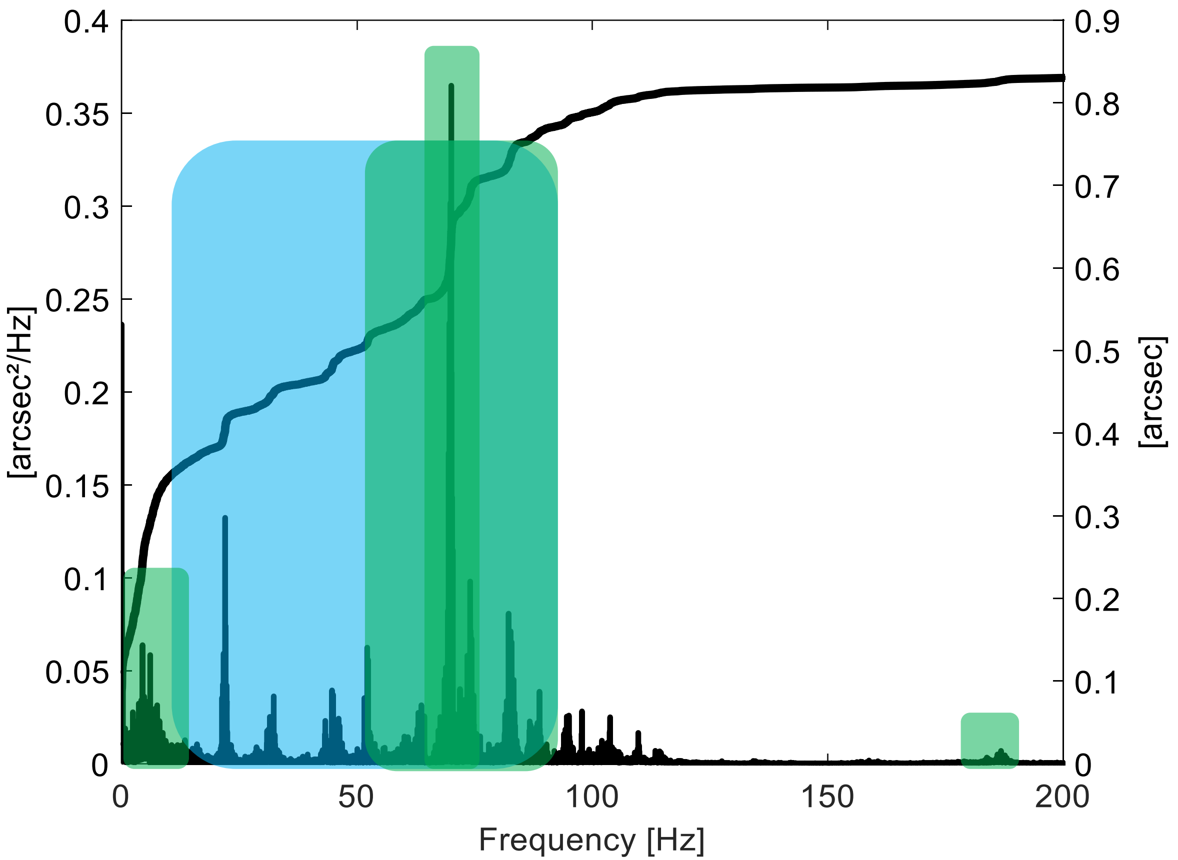




Jitter Improvement Plan




…



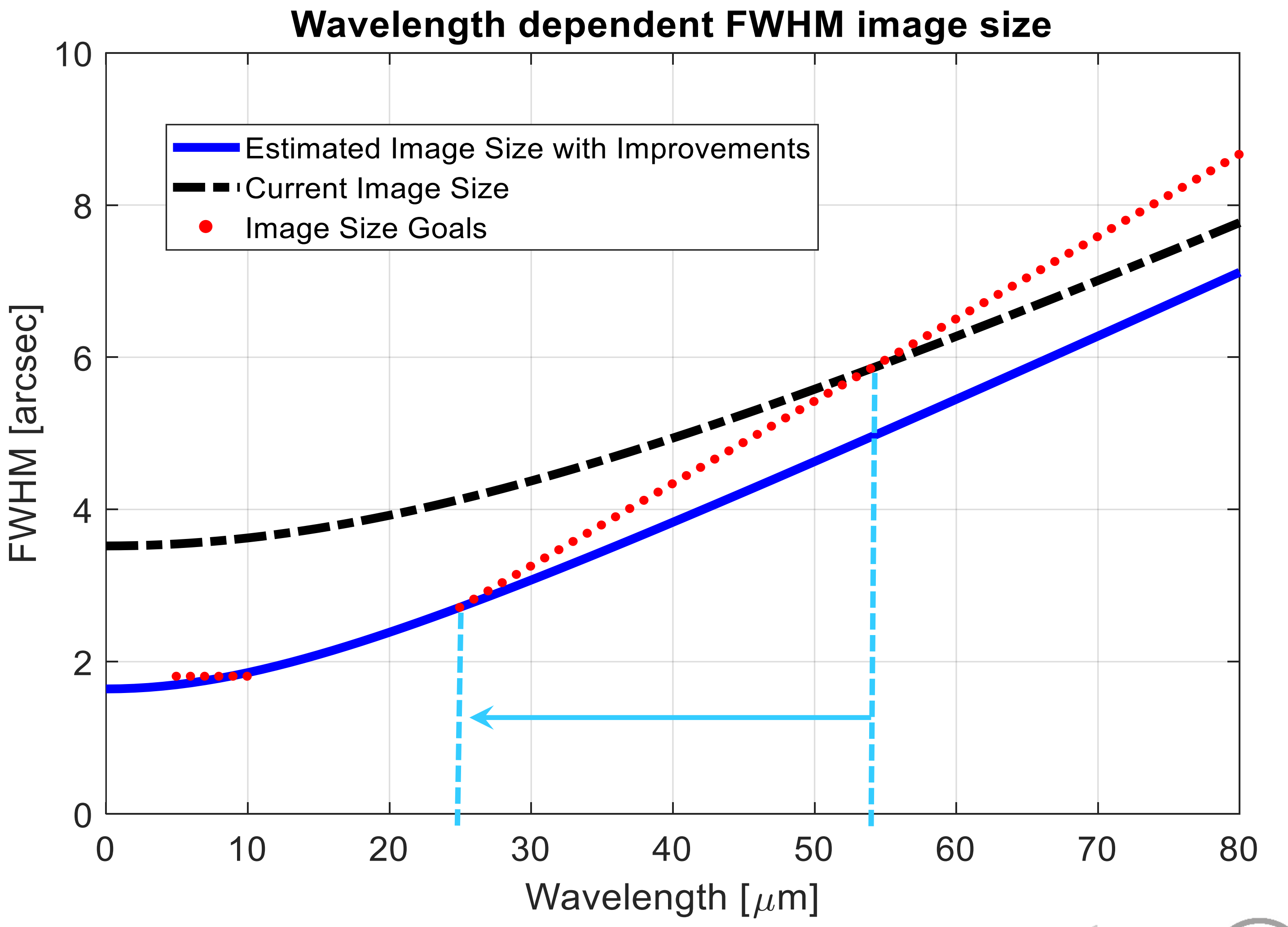
1. OPS and new FBC increase knowledge about image motion (~2019-2020)
2. FD Observer increases FD bandwidth
   → better VIS mode suppression (~2018)
3. New TCM damps 300 Hz mode → bandwidth ~80-90 Hz (~2018)
4. AMDs take out PM modes (~2018)

+ defocus decrease leads to…

Possible Image Size

→ Diffraction-limited beyond 25 microns:

- EXES could save integration time of factor 2-4
- EXES can get close to their originally planned resolution of ~ R = 100.000
- HIRMES starts at 25 microns and saves 10-20% of integration time
- …



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Enrico Pfueller
Michael Lachenmann
Juergen Wolf
Mission Ops
Students
…

Thank you!
Questions?