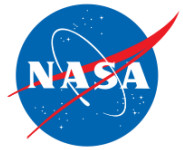

Precision Pointing for the Wide-Field Infrared Survey Telescope (WFIRST)

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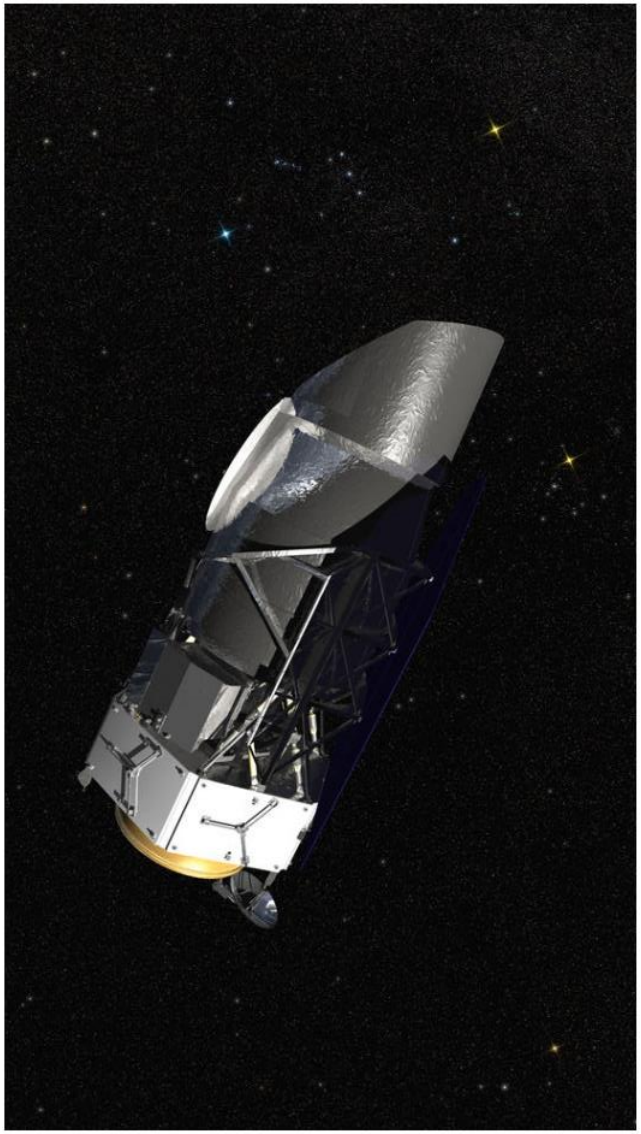
Outline

- Introduction to WFIRST
- Fine Guidance Sensor
- Slew Laws
- Wheel Nullspace Control Law
- GNC Hardware Architecture
- Conclusion

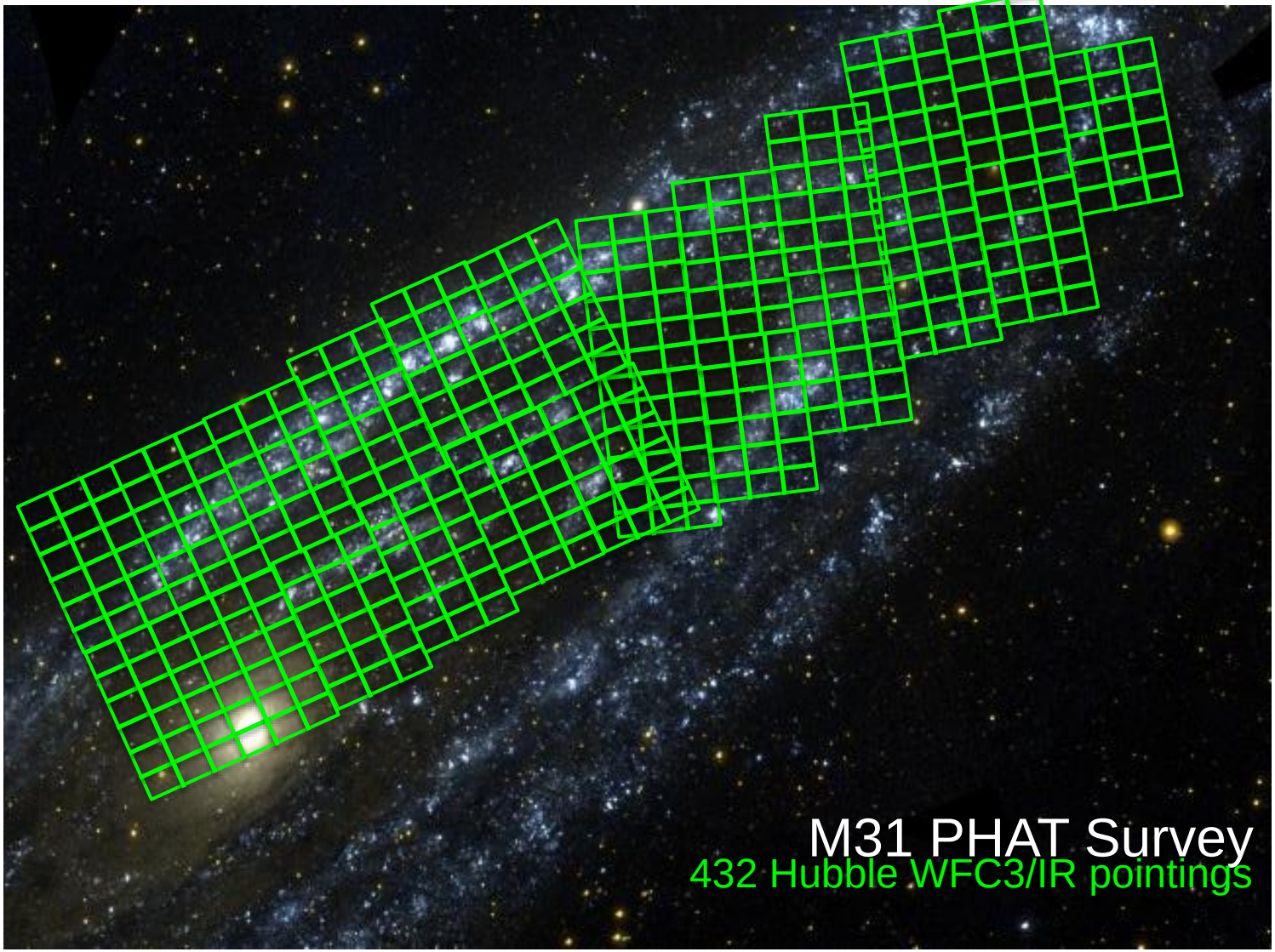
Introduction to WFIRST

- Hubble-class Telescope
  - 2.4-m aperture
  - Jitter: 14 milliarsec RMS
  - Stability: 11.6 milliarcsec RMS over 180 sec exposures
  - Near infrared
    - Detectors ~100 Kelvin
- Science campaigns interleaved over 6-year mission
  - Supernova Survey: Cosmic Expansion
  - High Latitude Survey
    - Baryonic Acoustic Oscillation: Dark Energy
    - Weak Lensing Survey: Dark Matter
  - Microlensing Exoplanet Survey: Census
  - Exoplanet Coronagraphy: Characterization

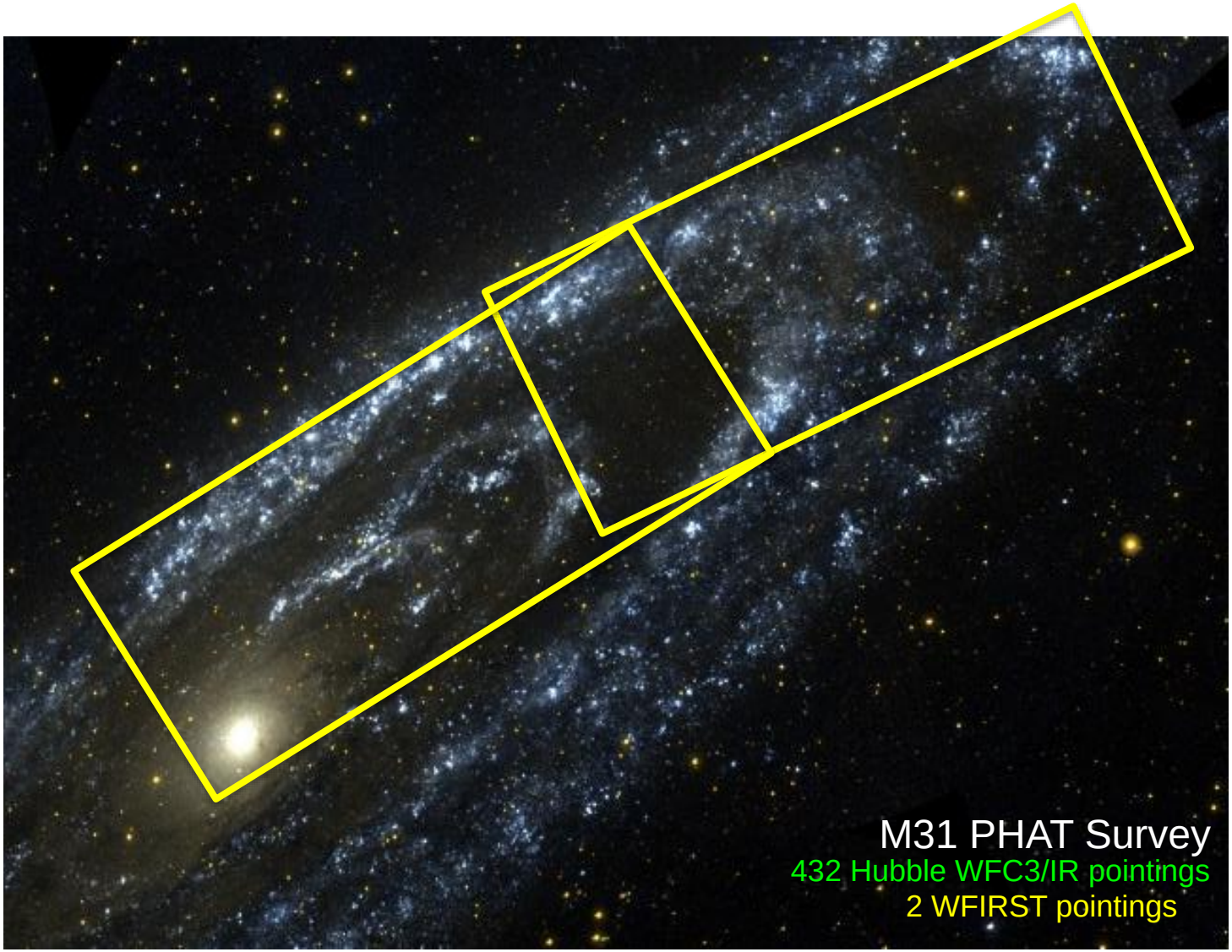


Wide Field

432 Hubble Pointings…



Covered by 2 WFIRST Pointings

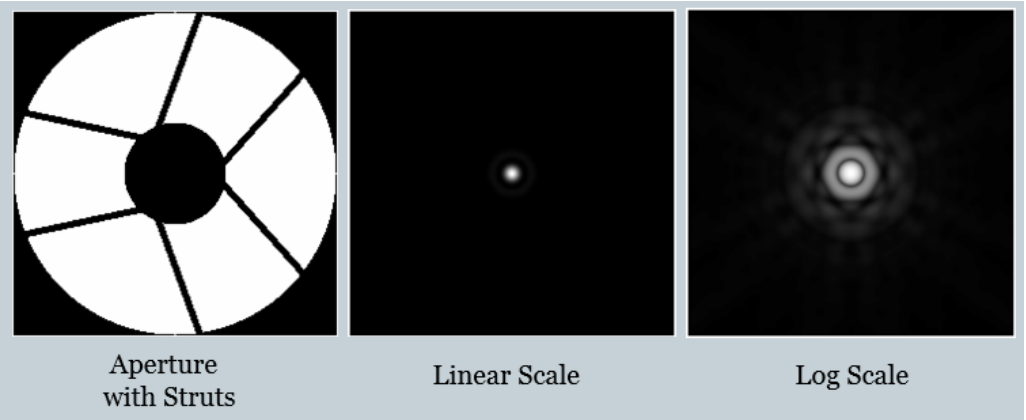


Fine Guidance Sensor

- FGS is integral to Wide Field Instrument
  - One guide window per detector (18)
    - HAWAII-4RG 4Kx4K
  - GW data readout interleaved with science data readout
    - 0.17-sec GW sample time vs. 5-sec science frame
- Six waveband filters for imaging, plus a grism for spectroscopy
  - Filters affect perceived magnitude, PSF of guide stars
  - Grism spreads star image over ~800 pixels in one dimension

FGS Image Tracking

- Track up to 18 stars
  - One per detector
- Magnitude Range H(AB) 14.5 to 17
- Centroid computed using Discrete Fourier Transform (DFT)
  - Fit subwindow readings to sine, cosine
  - Phase angle yields centroid
  - Accurate, robust to noise



FGS Spectrum Tracking

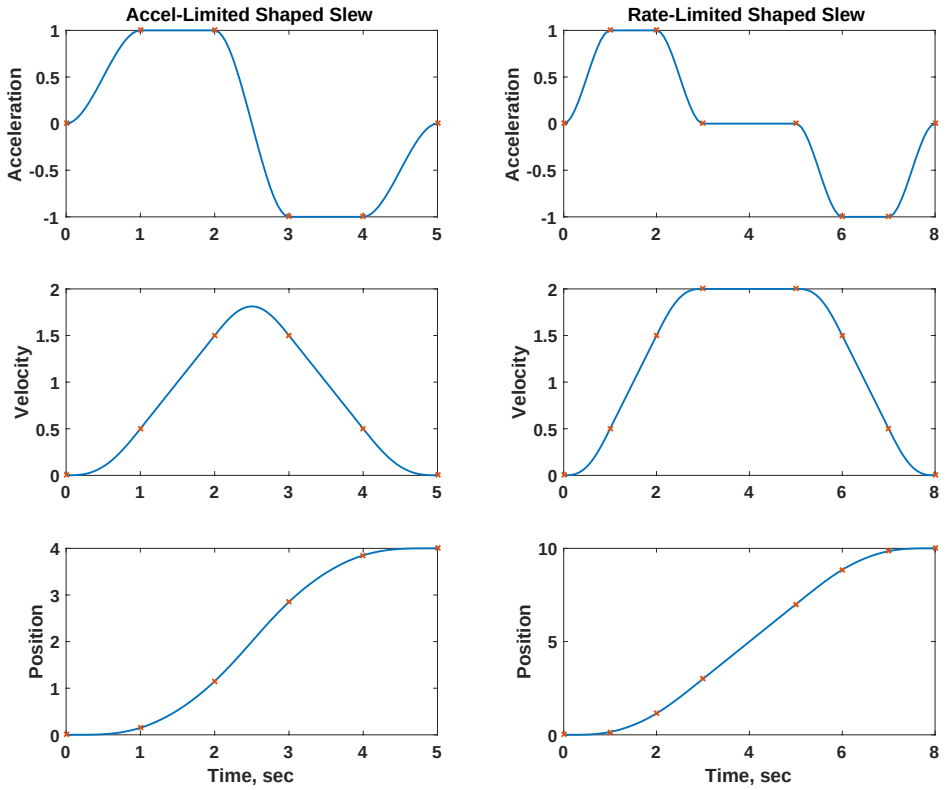
- H(AB) 10 to 12
  - Limited by signal-to-noise
- 3-4 stars tracked
  - Limited by distribution on sky
- Fit pixel measurements to a curve
- 0.25-sec sample time
- Simulations show centroiding to 100 milliarcsec in dispersed direction

FGS Acquisition

- Survey operations require rapid slew and acquisition of FGS at each target
- During slew, attitude determination based on star trackers, gyros
- Handoff from ST-IRU to FGS guidance uses a dedicated Settle mode
  - Acquisition guide windows are larger (64x64 pixels) to envelope expected ST-based attitude errors
  - Each guide window searches for candidate guide stars to match uploaded pattern
  - FGS takes over pointing guidance once enough (~4) stars are tracked
    - All guide windows reduced to tracking size (16x16 pixels)
    - Any guide windows failing to match the pattern restart search using improved offsets
  - Once locked, guide windows move if needed to follow guide stars
    - Allows acquisition in parallel with settling of residual slew motion

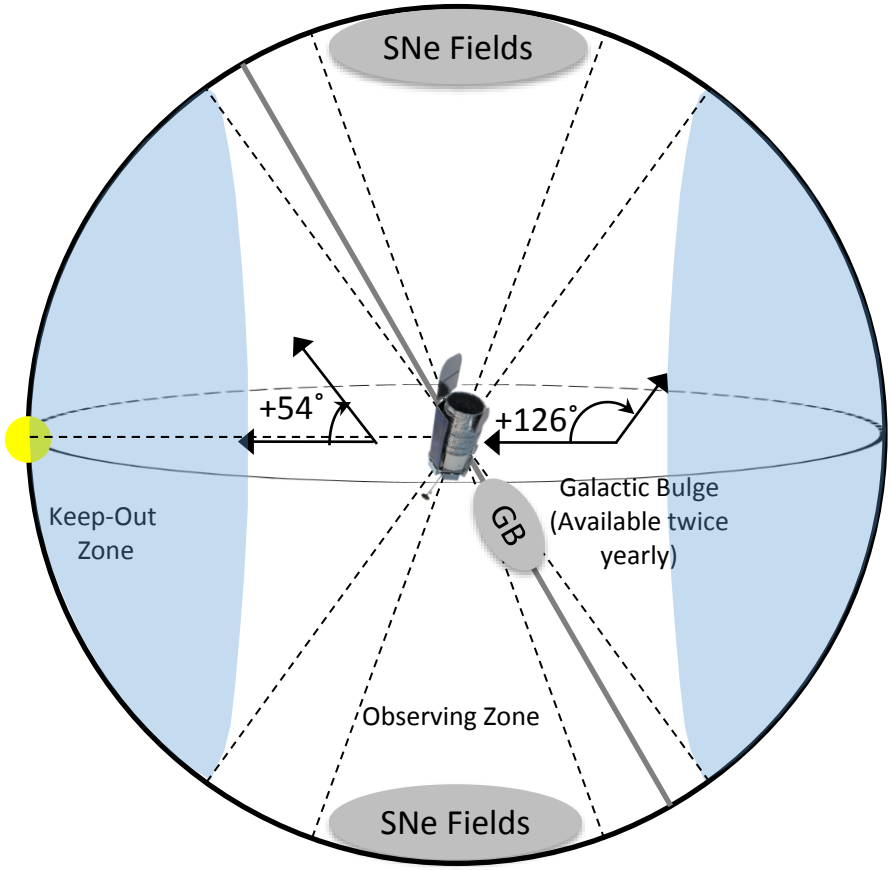
Slew Law: Profile

- Shaped slew profiles are used to minimize excitation of structural modes
  - "Rise time" of 1-2 sec to avoid 1-Hz mode
- Most slews are torque-limited
  - Rate-limited above ~6.5 deg



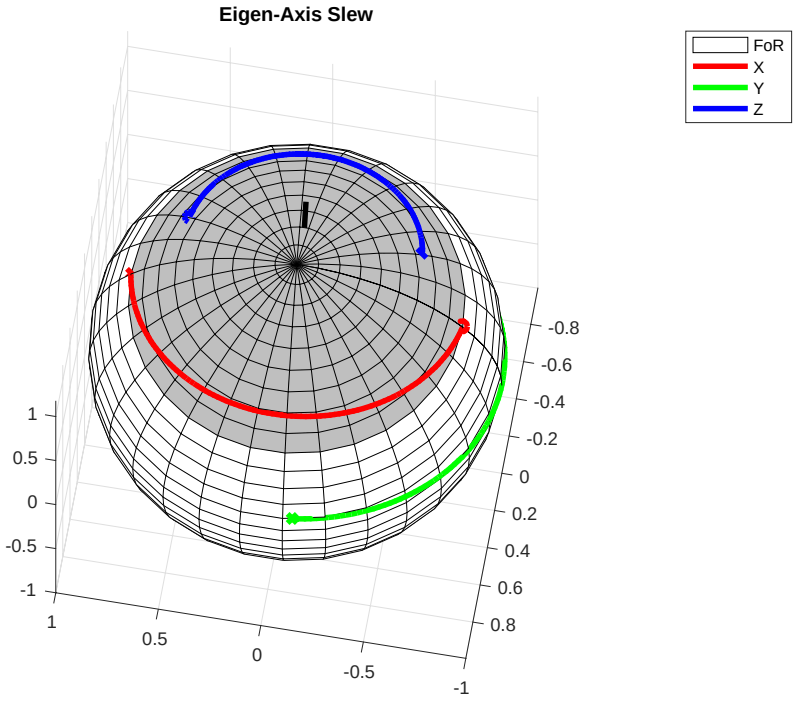
Slew Law: Sun Constraint

- WFIRST has a Field of Regard defined by a Sun Constraint
  - Telescope boresight axis always kept between 54 deg and 126 deg from Sun



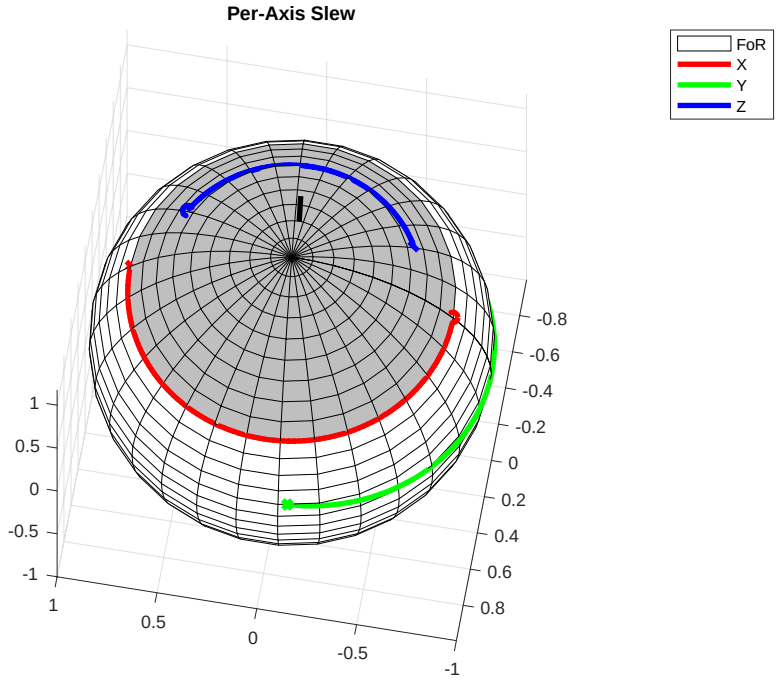
Eigenaxis Slew May Violate Sun Constraint

- Telescope Boresight trace in Red
  - Observatory +X Axis
- Sun is “pole” in this view
- Slew endpoints are within Field of Regard, but +X axis travels through Sun keep-out zone



Per-Axis Slew Stays Within Field of Regard

- Euler Angle Sequence introduced, based on FoR
- Slew is monotonic in each Euler angle
  - If both endpoints are in FoR, then every point along slew is too
- All three ‘single-axis’ slews performed concurrently
  - Two shorter slews scaled in time to match longest slew duration

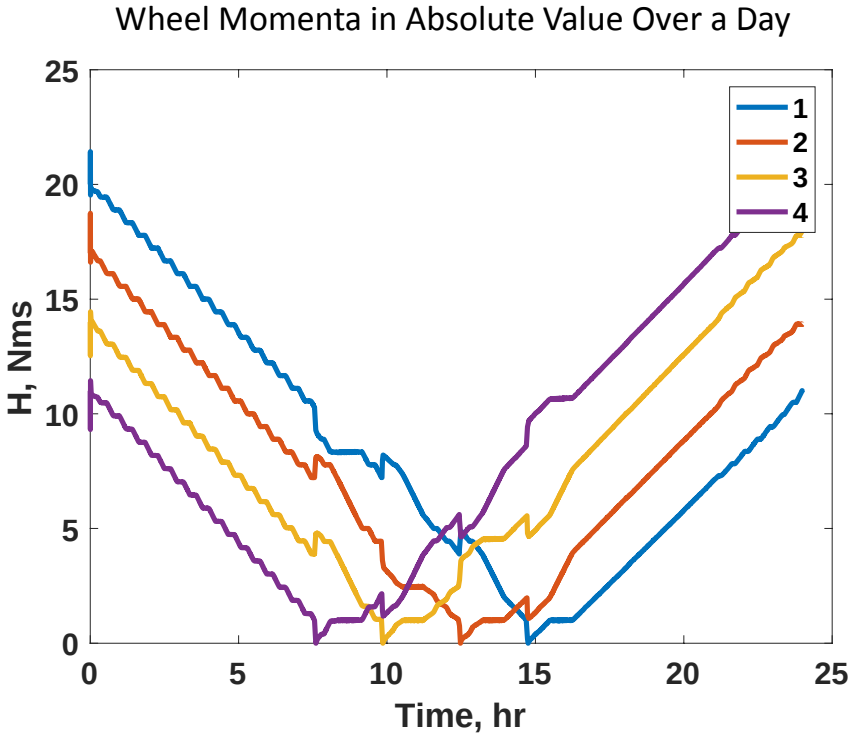


Wheel Nullspace Control

- Four wheels provide three axes of control, plus one null-torque degree of freedom
- This DOF is used for:
  - 1) Balance the work to avoid spinning one wheel up more than its share
    - Conserves torque authority, prolongs interval between momentum unloads
  - 2) Keep wheel speeds separated by 1 Hz
    - Avoids reinforcing undesirable excitation of structural resonances
  - 3) Push each wheel through its zero-speed crossing
    - Minimizes perturbation to pointing stability
- It can't all be done at once with only one DOF, but:
  - Balance, separation are naturally opposed to each other
  - Zero-speed crossings are episodic
  - So a weighted multi-term control law finds a happy medium

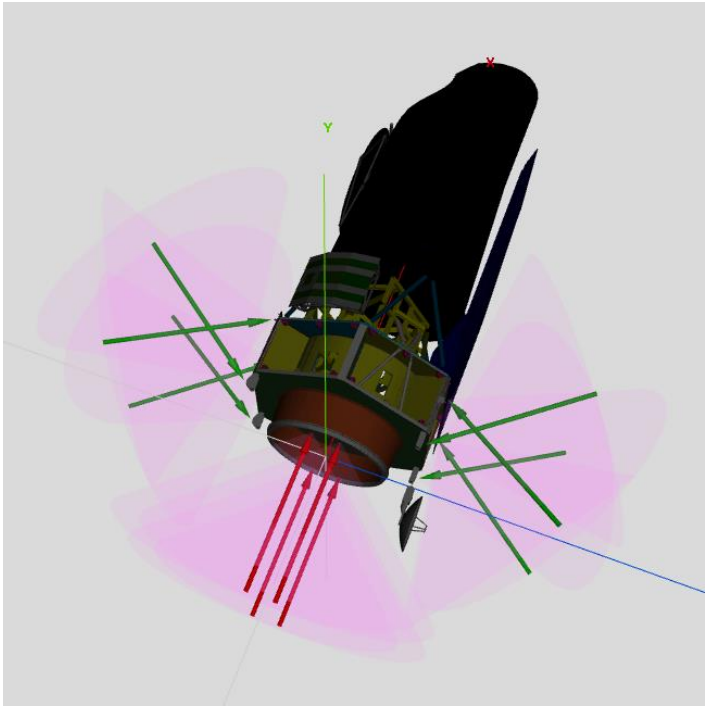
Wheel Momenta

- Initial speed separation must be done by targeted momentum unload
  - Some wheel speed crossings are unavoidable, but not long-term
- Solar radiation pressure causes steady ramp
- As each wheel approaches zero, it is pushed through
  - This perturbs other wheel speeds
  - Zero-crossings spaced so only one wheel is involved at a time



GNC Hardware Architecture

- GNC architecture is single-fault tolerant
- Sensors:
  - Coarse sun sensors (4-pi steradian coverage)
  - Inertial Reference Unit
    - Angle random walk is performance driver for larger slews
  - Star sensors (3)
  - Fine Guidance Sensor (integral with Wide-Field Instrument)
- Actuators
  - Reaction Wheels (now considering 6x)
  - Thrusters
    - 8x 22-N class for insertion, midcourse maneuvers
    - 16x 5-N class for stationkeeping, momentum unload



Thruster Layout showing thrust axes, plume avoidance cones

Conclusion

- WFIRST is a unique combination of precision pointing and agility
  - FGS integral with Wide-Field Instrument
  - Rapid and robust handoff from star tracker-gyro to FGS
  - Avoid structural excitation
    - Shaped slews
    - Wheel nullspace management
- Hardware architecture definition is in work
  - Currently in Phase A, requirements definition
    - Components have not been selected
    - Basic architecture and requirements are outlined
  - Late-breaking: Moving to 6-wheel architecture from 4 wheels
    - Need high torque for microlensing slews