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SIM (Lite)

SIM-Lite Instrument Overview

SIM Science Studies Workshop

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24 September 2008

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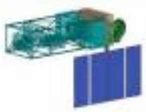
Outline

- Introduction
- Astrometry with SIM-Lite
- SIM-Lite Instrument design
- Fringe detection
- Major error sources

SIM-Lite Mission



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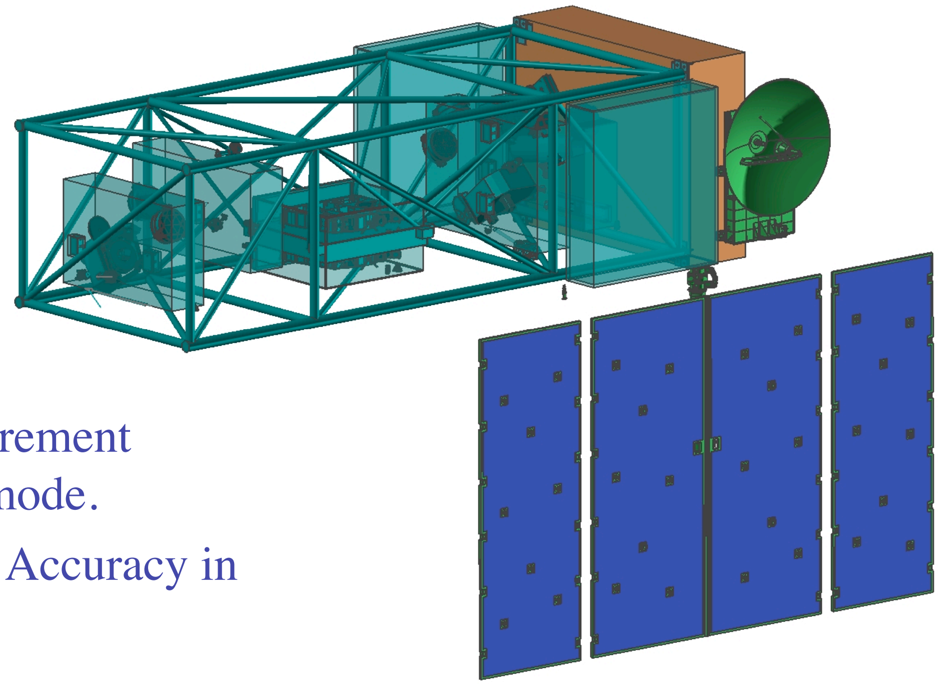
Salient Features

- ***6 meter Science Michelson Stellar Interferometer (MSI)***
- ***4.2meter Guide 1 Interferometer***
- ***30cm Guide 2 Telescope***
- Visible wavelength 450 – 950 nm.
- 1.0 micro-arc-second Single Measurement Accuracy (900s) in Narrow Angle mode.
- 4 micro-arc-second End of Mission Accuracy in Wide Angle mode.
- Mass without contingency 3,750 kg.
- Launch vehicle: Atlas V – 531.
- Earth-trailing solar orbit.
- 5 year mission.



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Astrometry with an stellar interferometer

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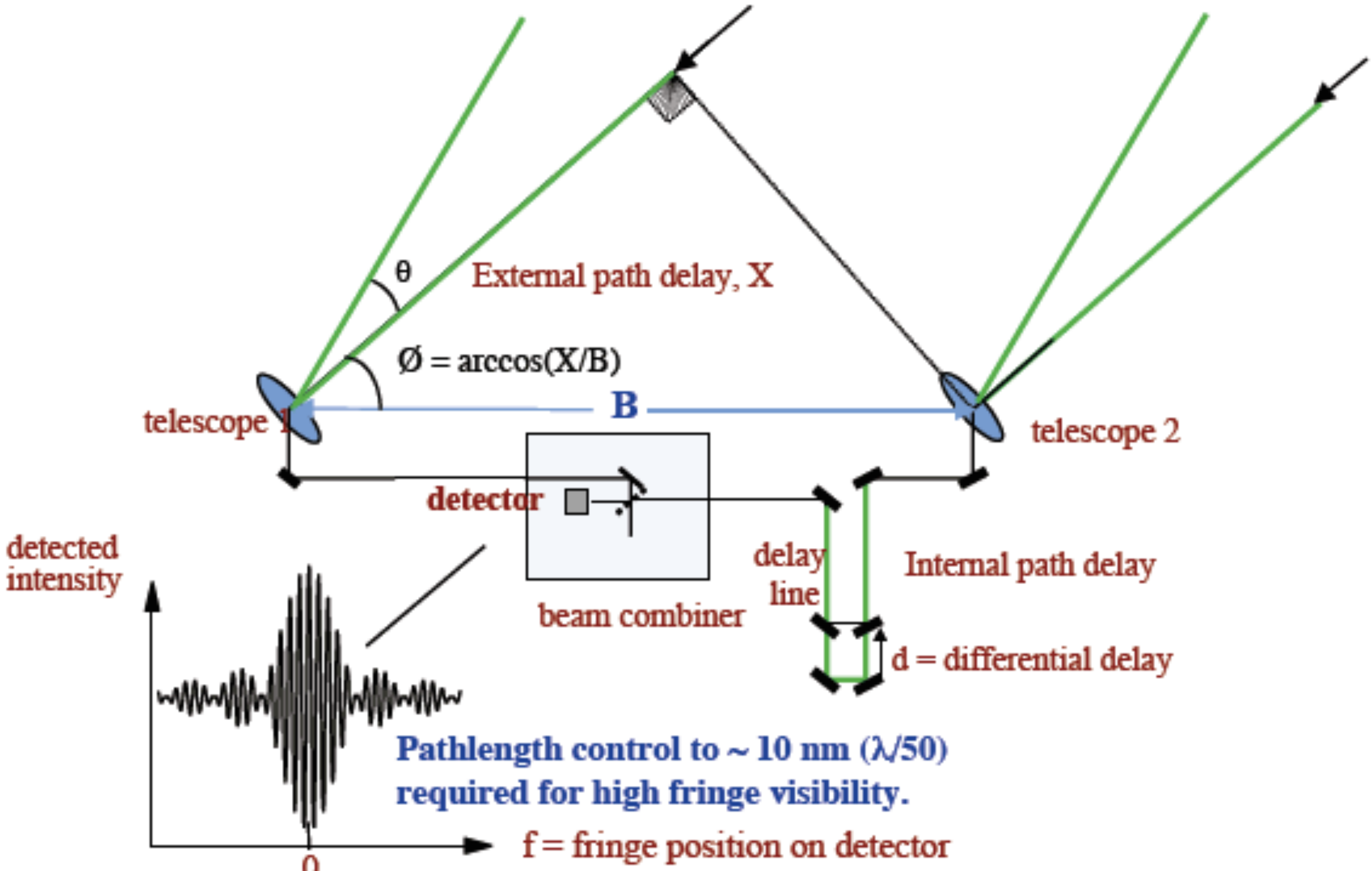
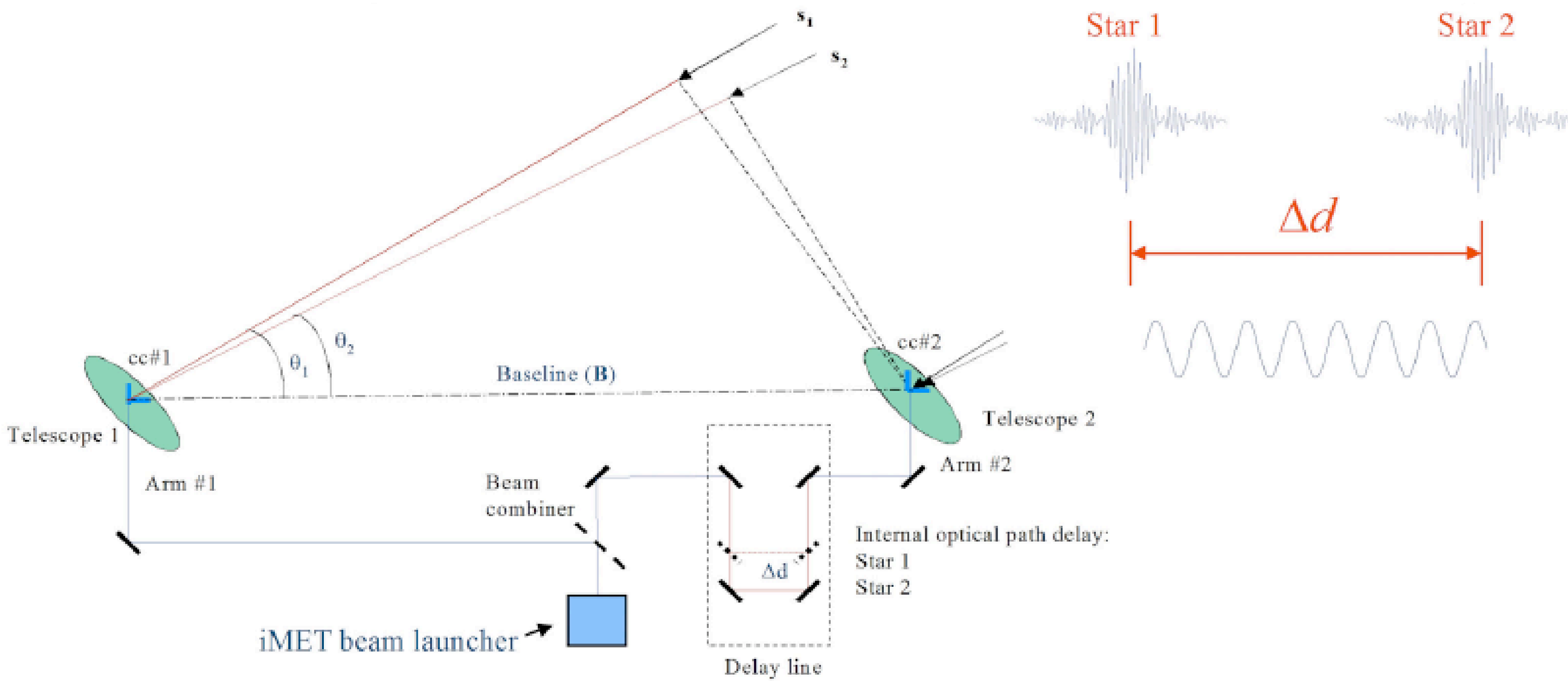


- The peak of the interference pattern occurs at zero OPD to star

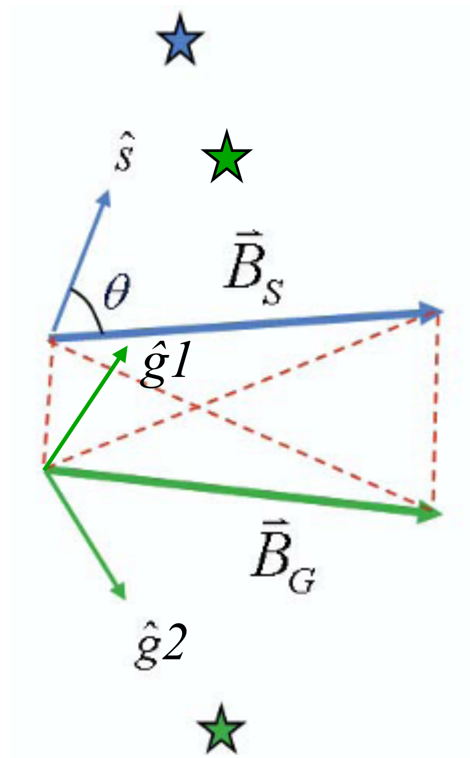
Differential Astrometry

- SIM measures the differential astrometric position between several stars, using the internal metrology system.



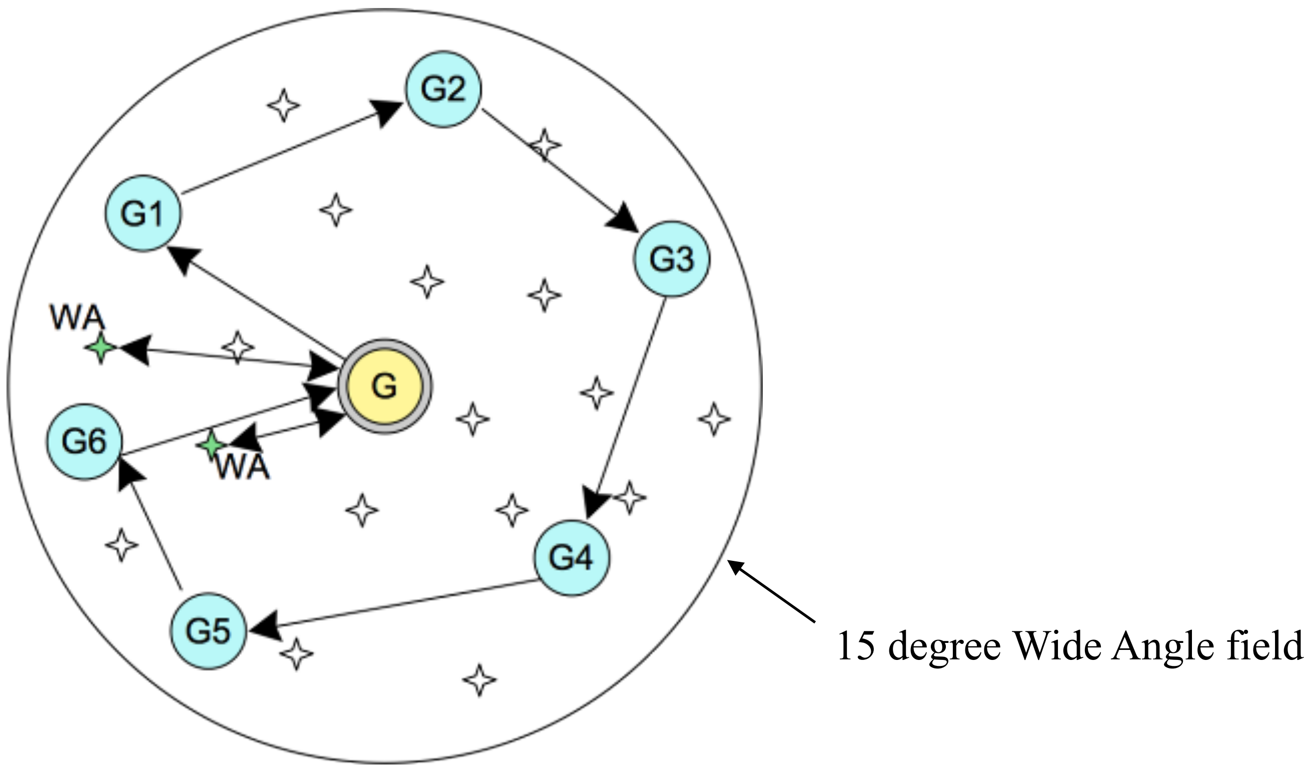
Guide stars

- The Guide 1 interferometer and Guide 2 telescope track two bright stars ($g1$, $g2$) to monitor the change of the Guide baseline (B_G) attitude.
- The external metrology system track the change in the Science baseline (B_S) orientation relative to the Guide baseline. It also tracks the change in the baseline length.



Wide Angle Observation

- The Guide 1 interferometer and Guide 2 telescope stay locked to their respective guide stars, tracking the change of the baseline attitude.
- The Science interferometer observes sequentially the Guide 1 star, the Grid stars and the Wide Angle target stars if any.



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Narrow Angle Observation

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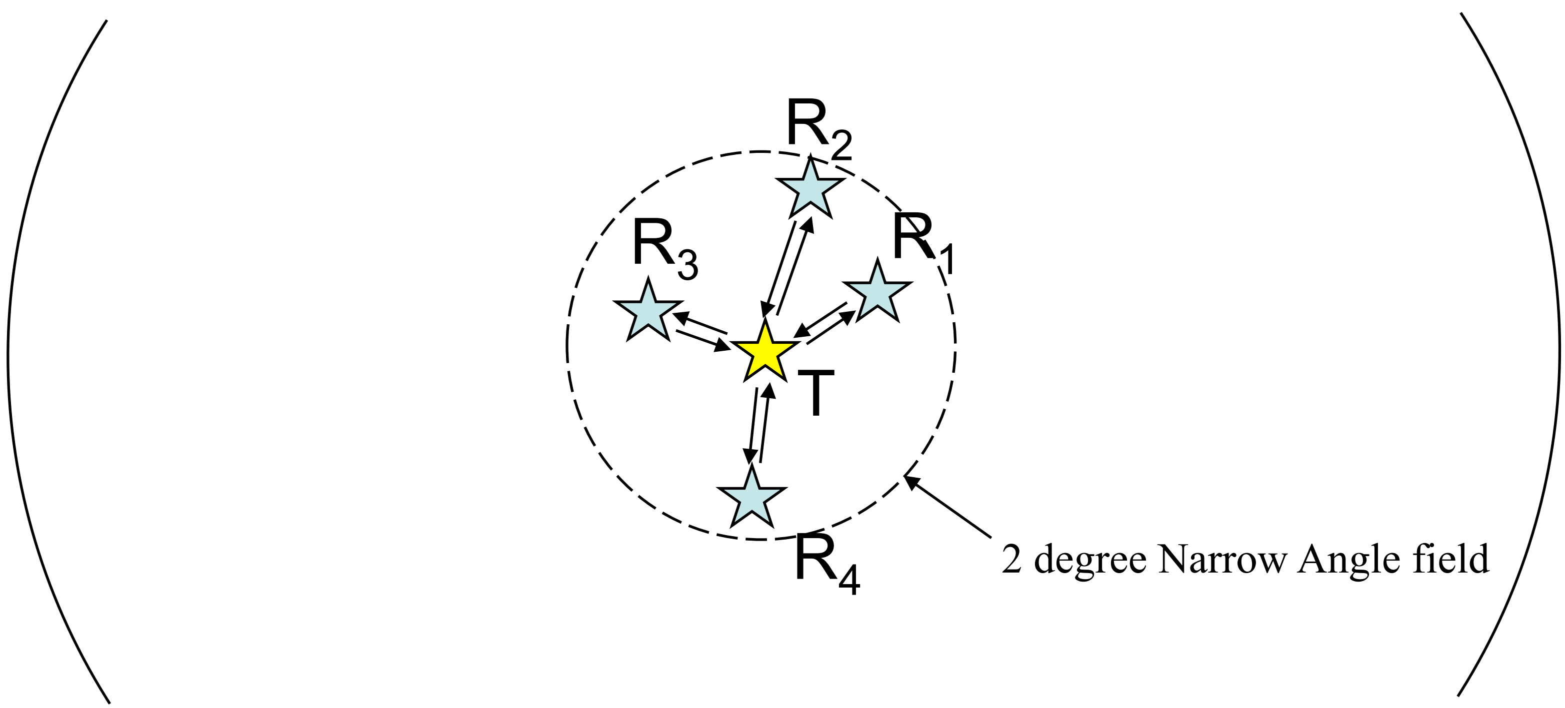
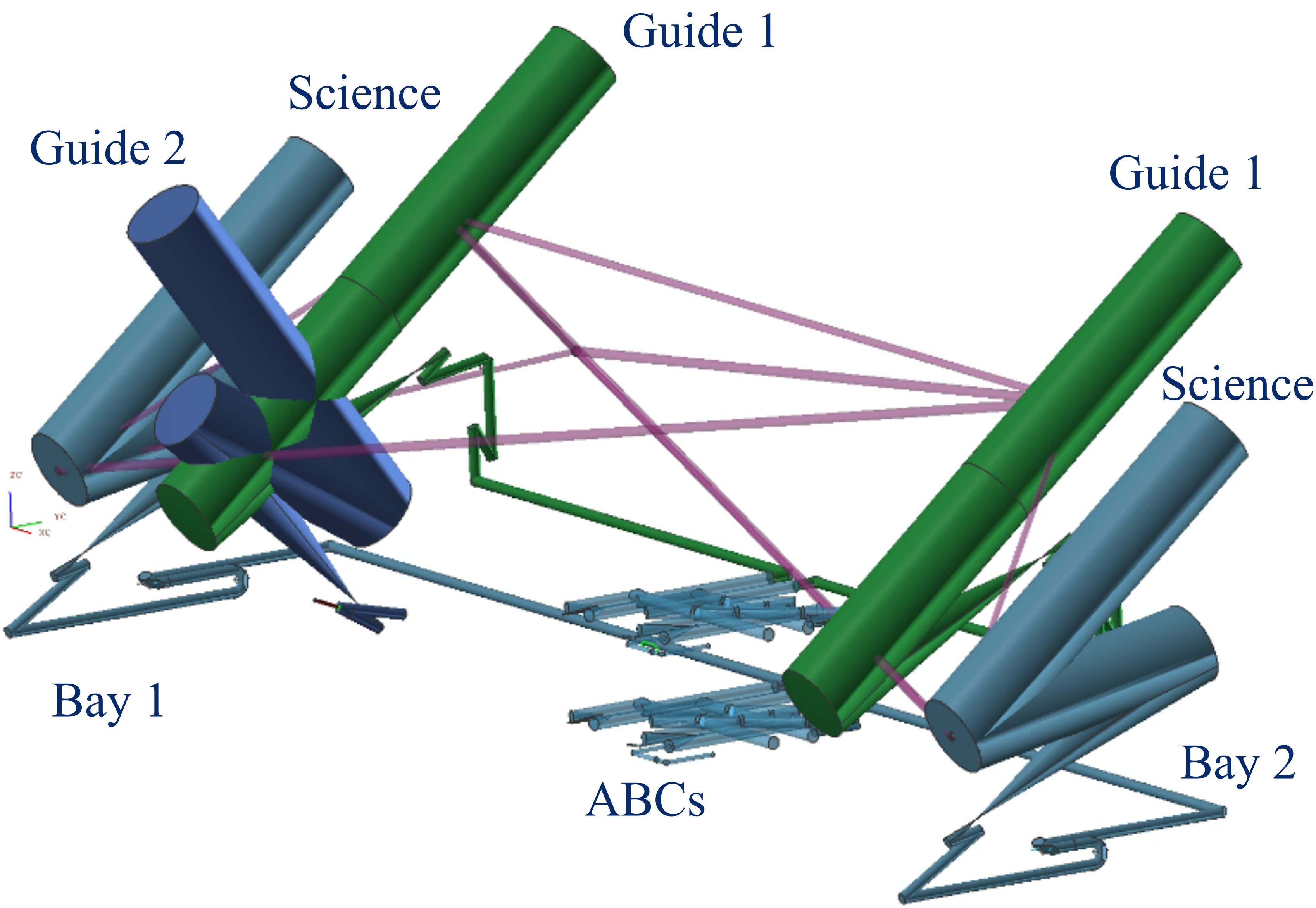
- The Guide 1 interferometer and Guide 2 telescope stay locked to their respective guide stars, tracking the change of the baseline attitude.
- The Science interferometer chops between the Narrow Angle target star (T) and each of the Reference stars (R_1, R_2, R_3, R_4).



Optical Prescription



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Configuration

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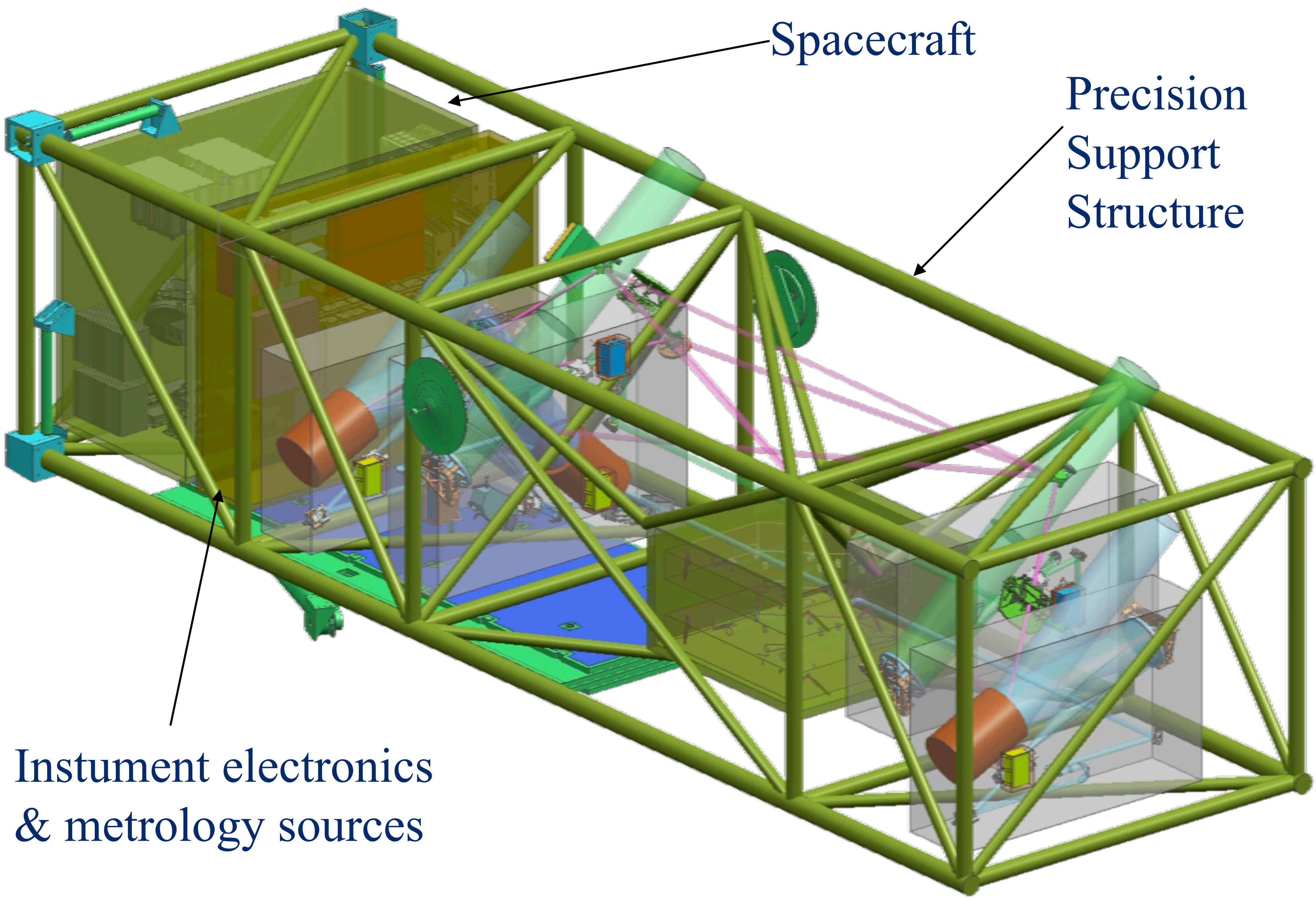

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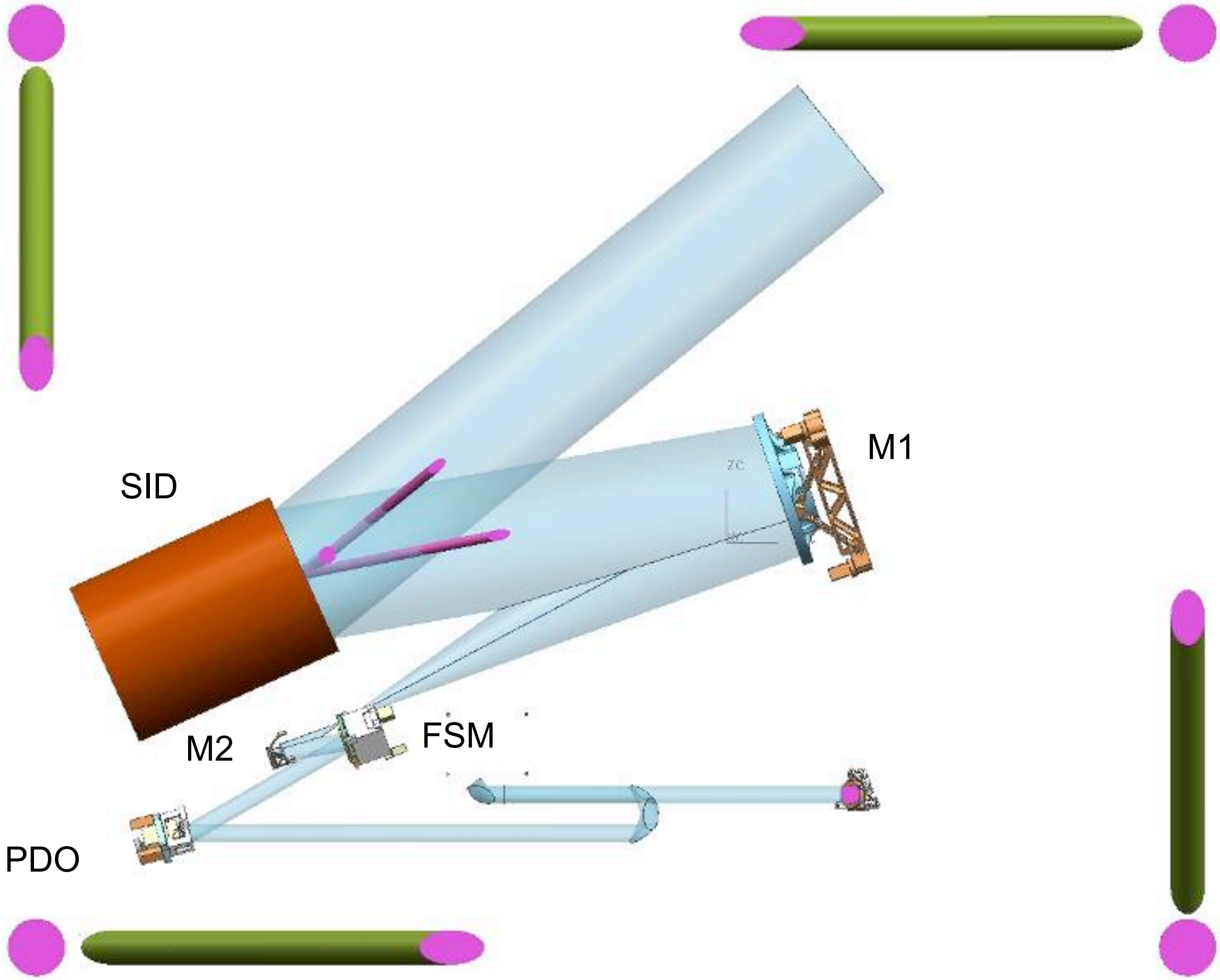
Science Bay 1 (looking from –X)



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Motor-based mechanisms

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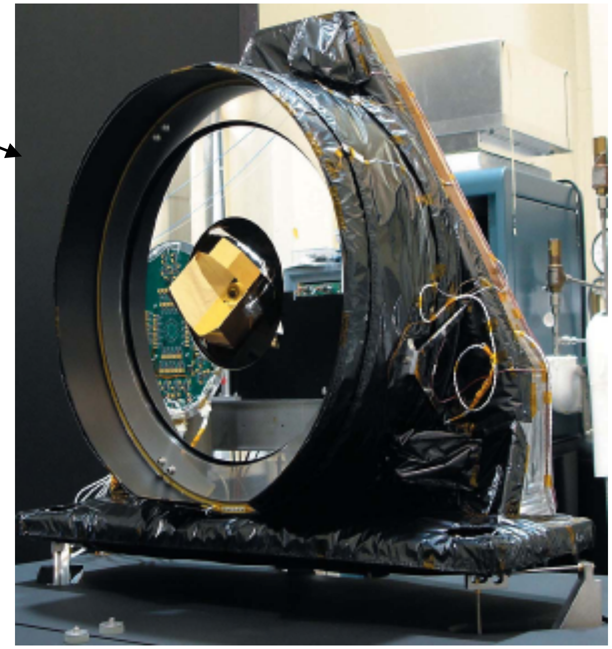
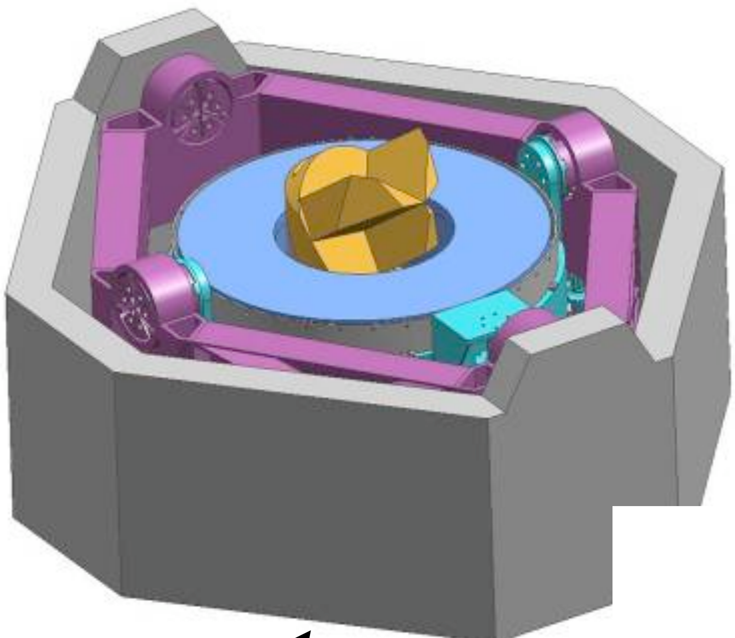
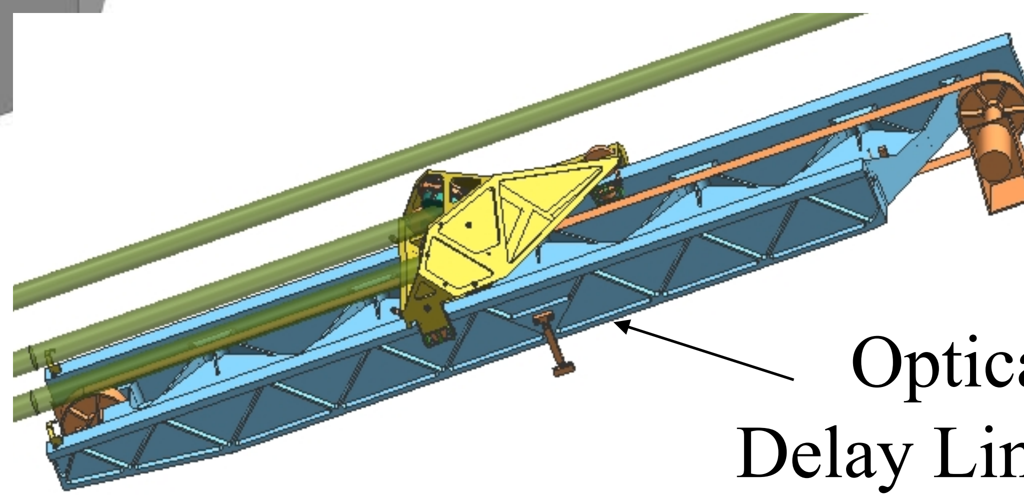
Siderostat optic





Siderostat mechanism



Optical Delay Line

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Guide 1/2 Bay 1 (looking from –X)

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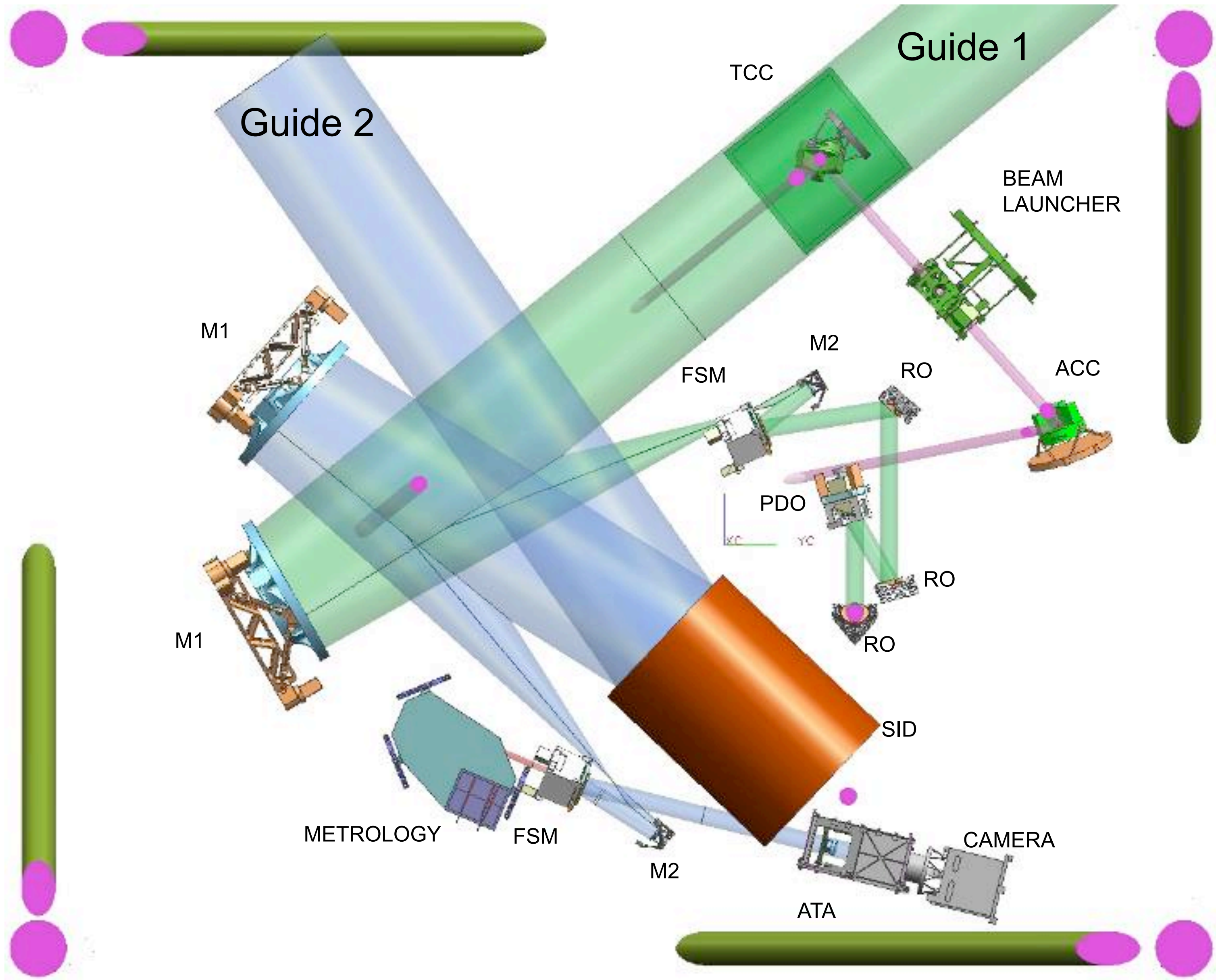
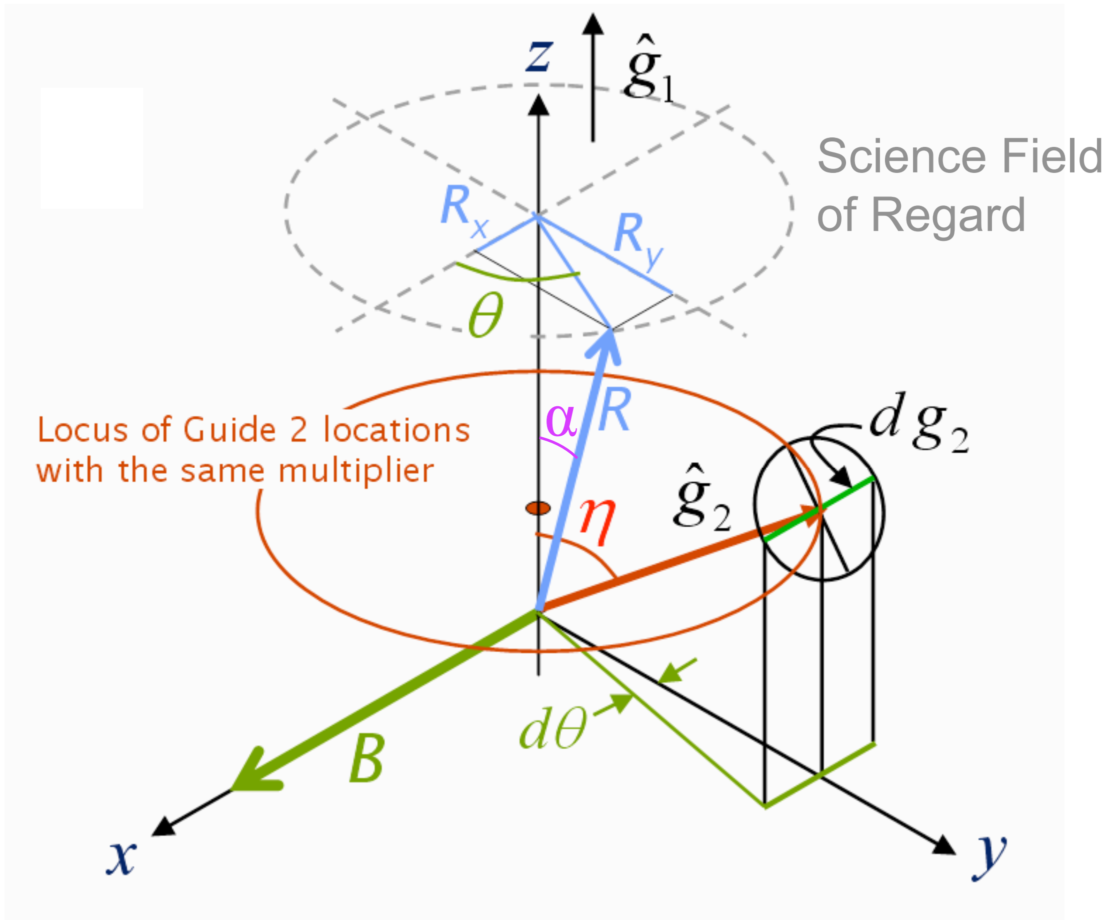


Guide 2 Sensor

- "Guide 2" tracks θ, the rotation of the astrometric baseline around the Guide 1 star.



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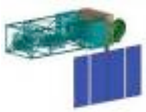
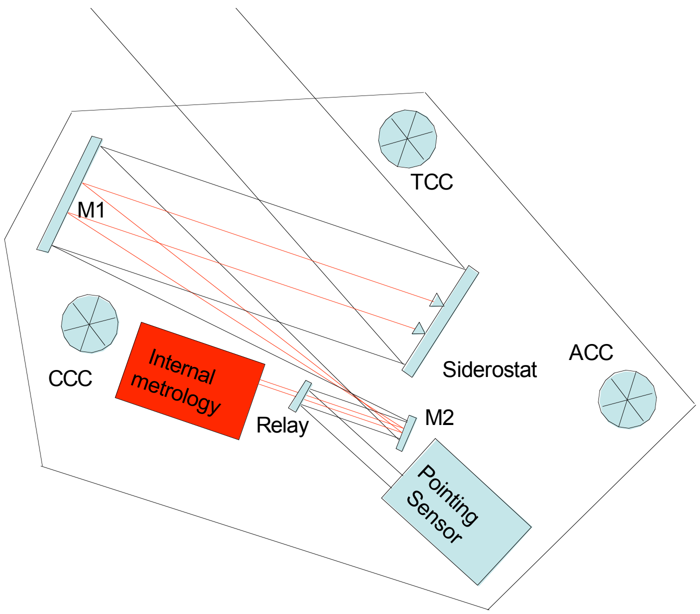
Guide 2 Telescope



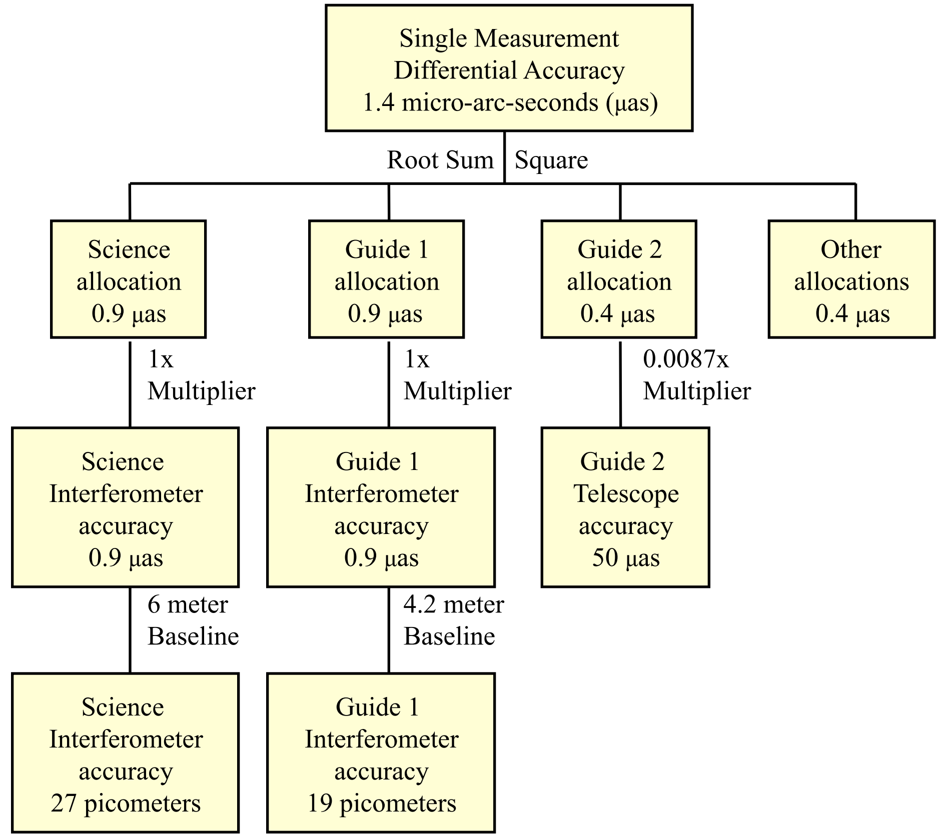
Guide 2 Multiplier:

$$M_{G2} = \frac{1}{2 \cdot \sin \eta} \alpha_{Science}$$

50 micro-arcsec accuracy Star Tracker over 1 arcsec range.

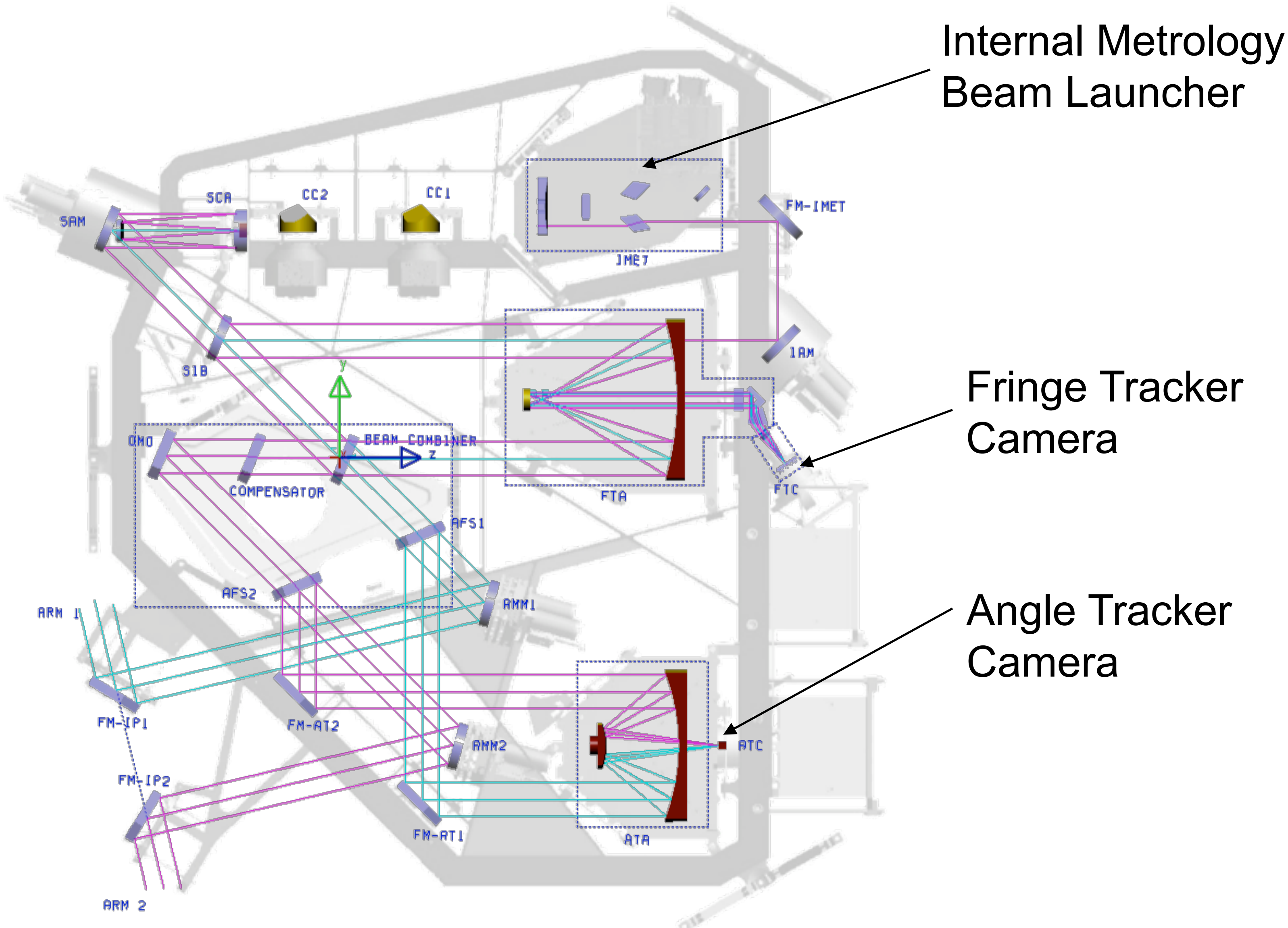


Astrometric Error Budget (Top level)



Astrometric Beam Combiner

SIM (Lite)



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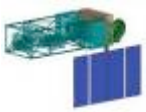
Internal Metrology



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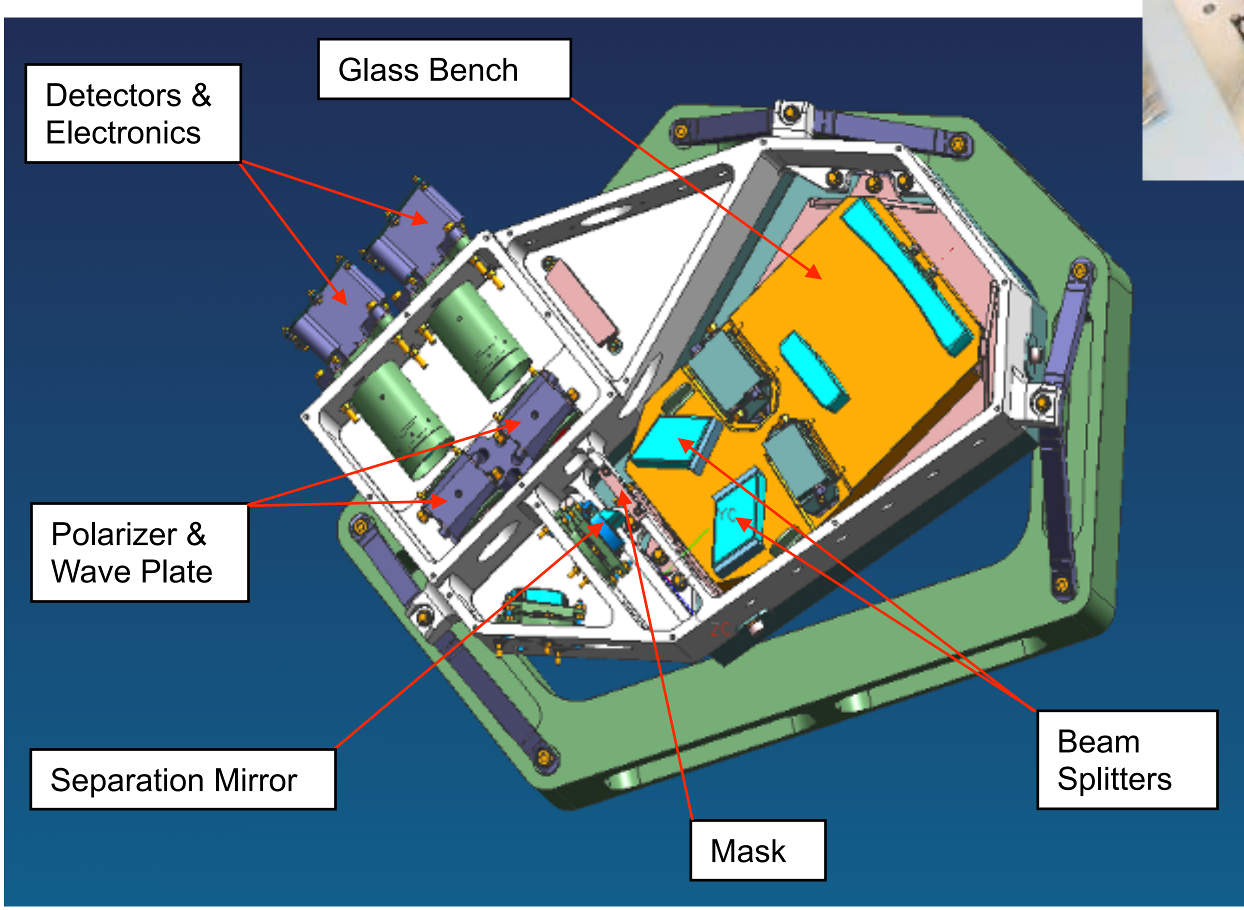
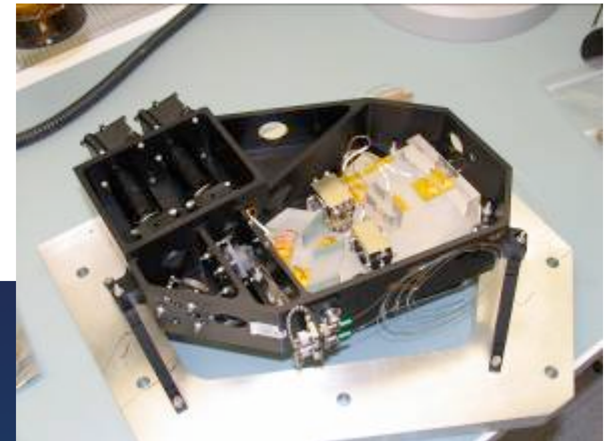
- Heterodyne metrology system
- Internal metrology Beam Launcher





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Camera focal planes

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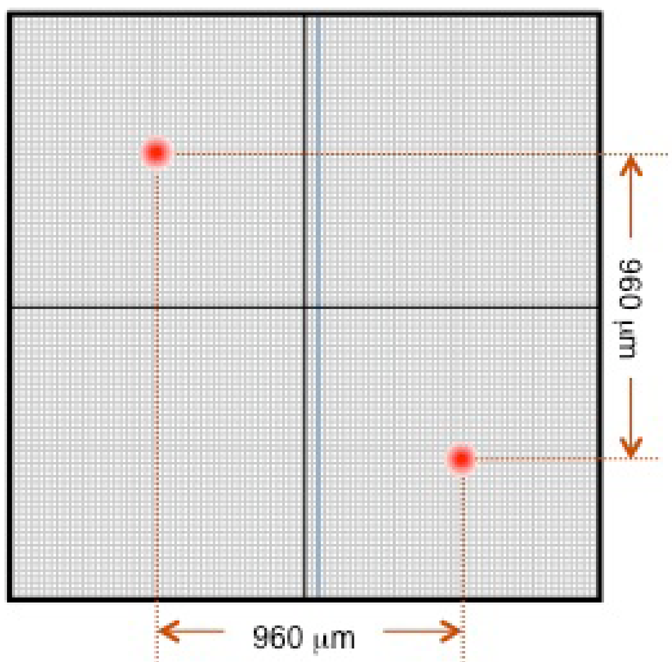
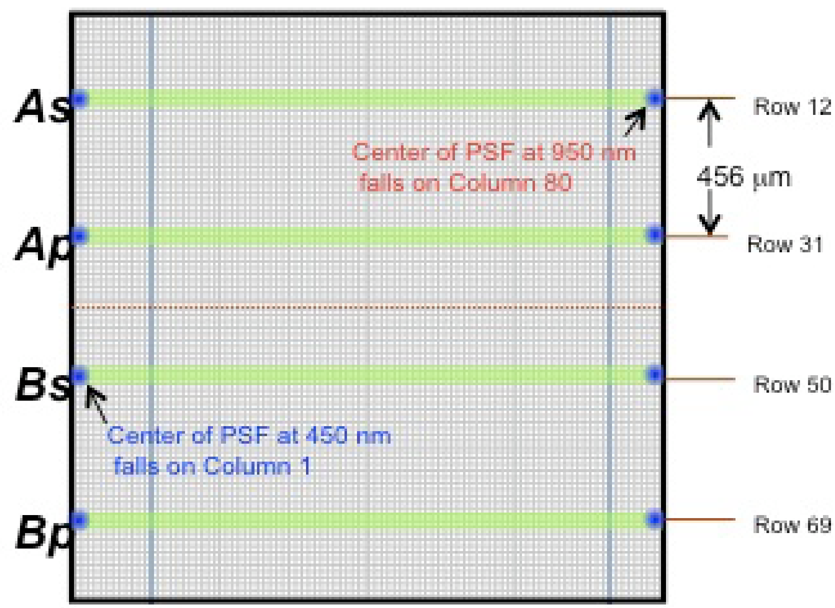
- An image of the star is formed on two quadrants of the star tracker detector, one image per arm of the interferometer.
- Four sets of fringes (two polarization states x two recombination ports) are dispersed on the Fringe Tracker detector.

Angle Tracker

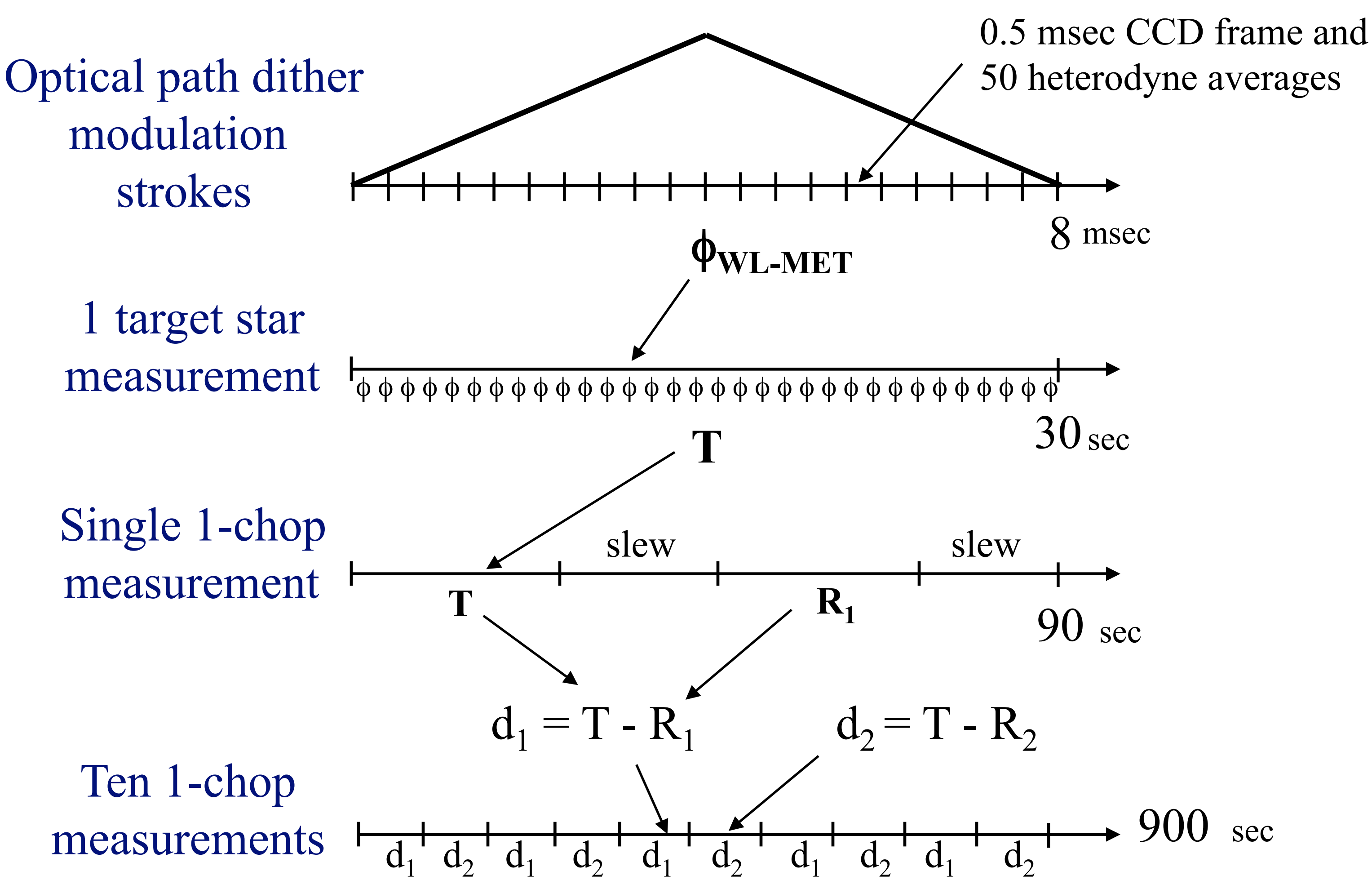


Fringe Tracker



E2V CCD-39 array

SIM's time scales



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White light fringes

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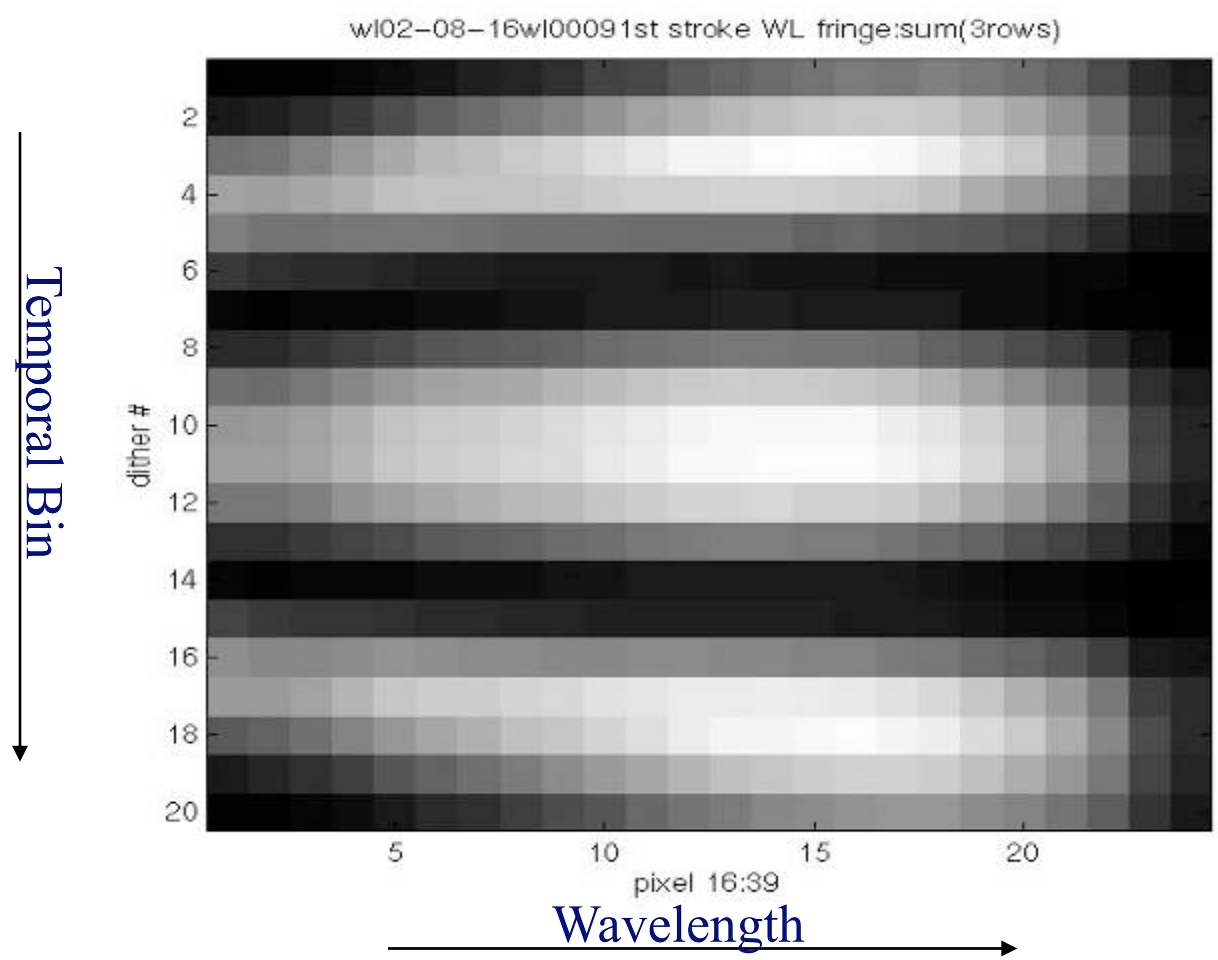
- We displayed only one full dither stroke (20 images), as a function of the spectral channel along the horizontal axis



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Actual fringe and dither positions observed in MAM testbed.

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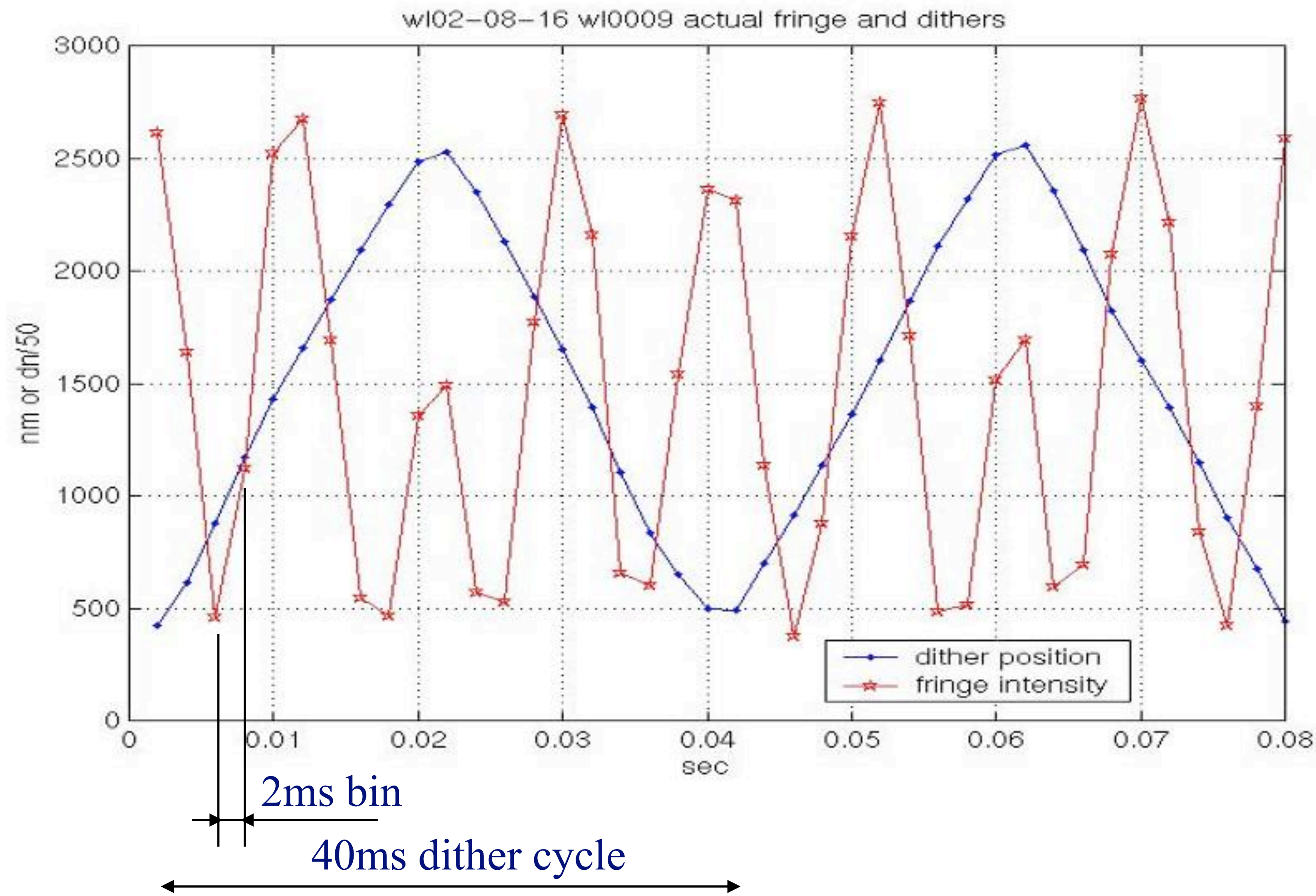
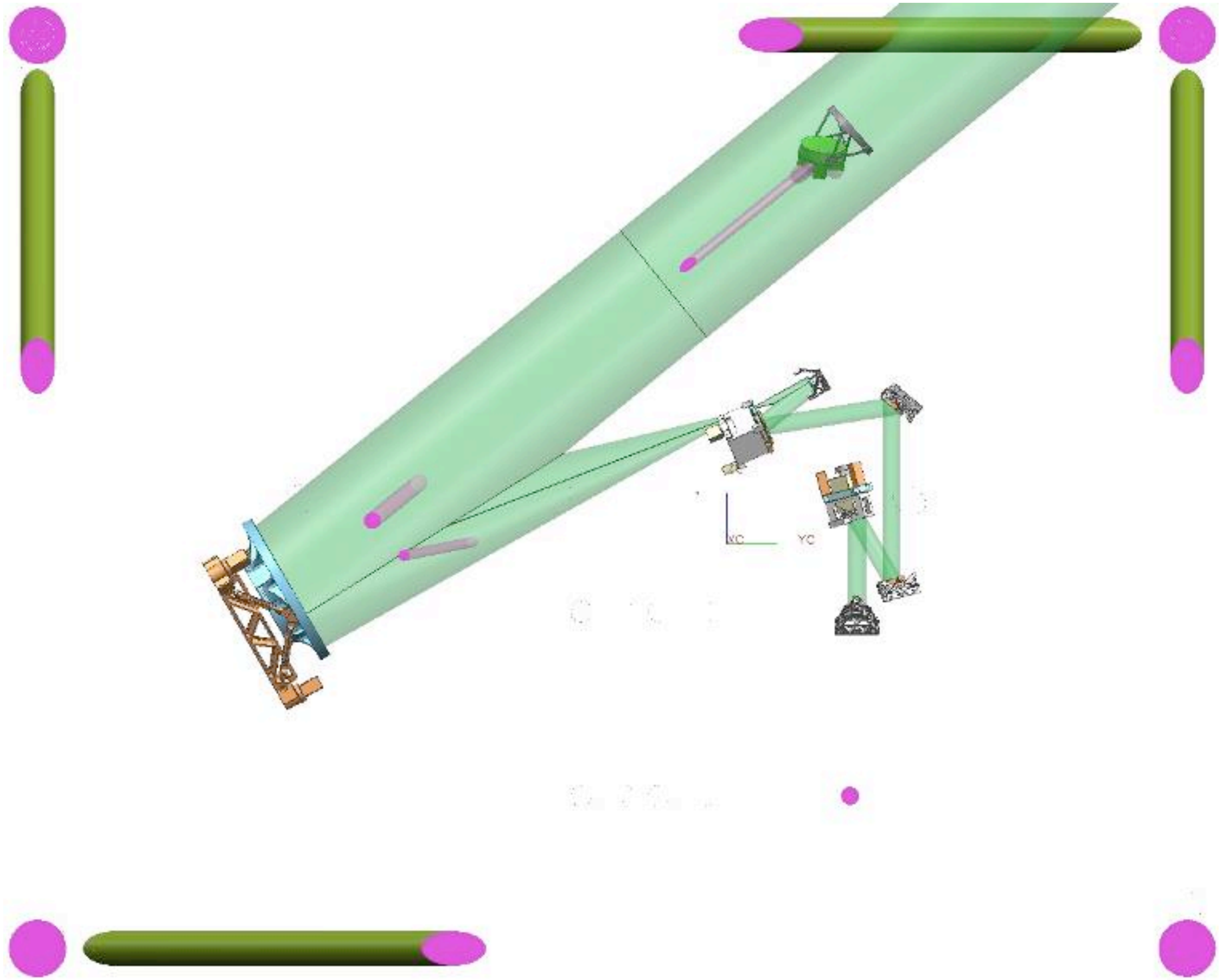


Guide 1 Bay 2 (looking from –X)



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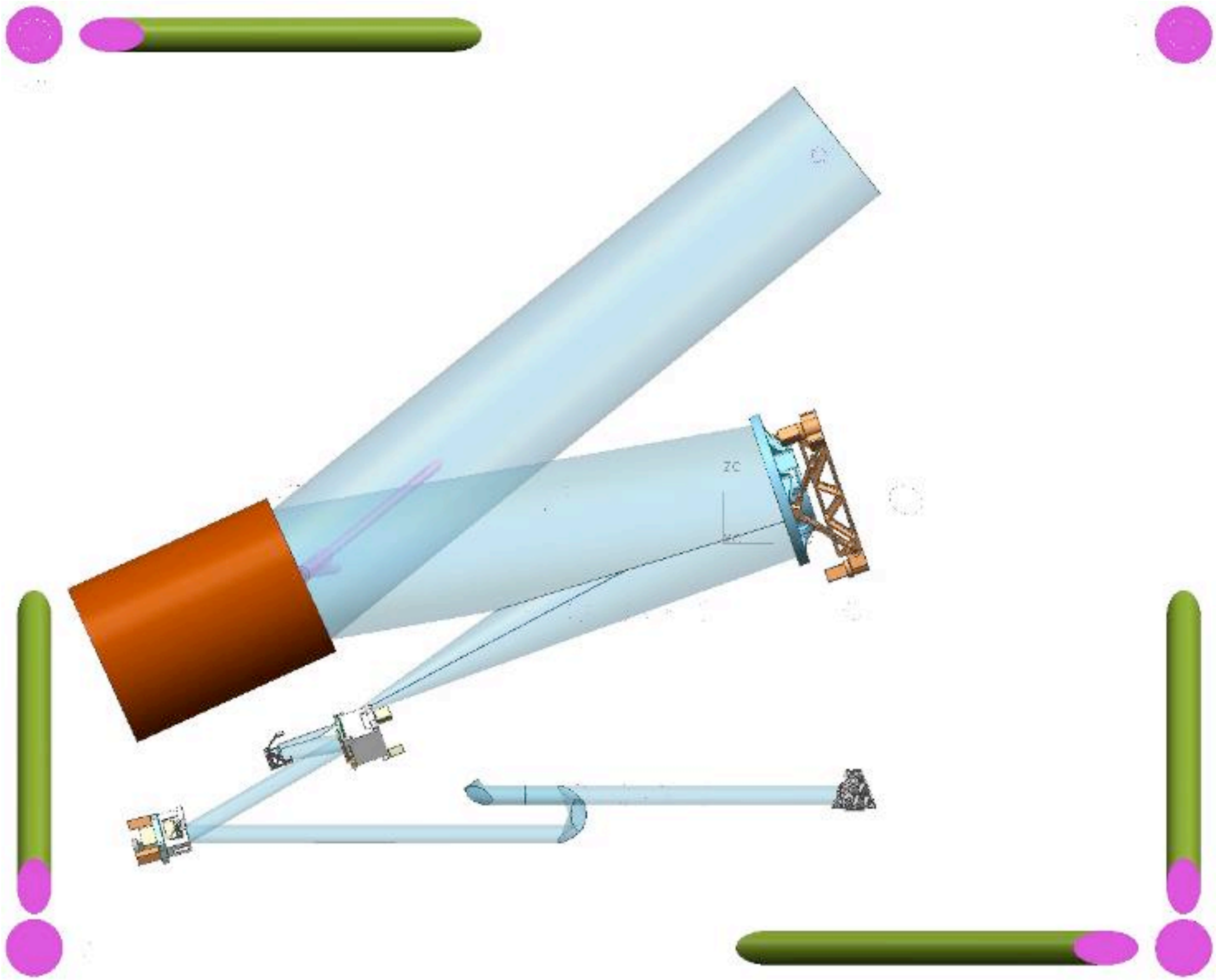
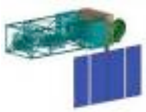
Science Bay 2 (looking from –X)

SIM (Lite)



SIM Basic Definitions and Parameter Values



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Term	Description	Value
Interferometer Baseline (BL)	The distance between two collecting mirrors.	6 m
Single Measurement Accuracy (SMA)	The uncertainty associated with measuring the angle between the baseline vector and target star.	1.0 μas, 1-sigma RMS
One-Dimensional (1D) Measurement Accuracy or Differential Measurement Accuracy (DMA)	During a typical ~1100 s measurement, the angle between the target star and baseline vector is measured to the SMA. Similarly, the angle between the baseline vector and a reference star (or the average of a group of reference stars) is determined to the SMA. Both angles are measured from one interferometer baseline orientation in inertial space. The angle between the target star and the reference is the difference between these two angles with a resulting accuracy given by the root-sum-square (RSS) of these two measurement accuracies.	1.4 μas, 1-sigma RMS
Two-Dimensional (2D) Measurement Accuracy	Two one-dimensional (1D) measurements made with roughly orthogonal interferometer baseline orientations and made relatively close together in time.	2-axis, 1.4 μas on each axis, 1-sigma RMS.
External Delay Uncertainty Noise Floor (EDUNF)	Uncertainty in measuring the difference in external delays resulting from all instrument errors (see the Astrometric Error Budget (AEB)) as validated by testbed measurements.	1 picometer, 1-sigma RMS
Instrument Noise Floor (INF)	Noise floor for measuring the angular distance between two stars, determined from the fringe position uncertainty noise floor and the interferometer baseline (EDUNF/BL*asec/radian).	0.035 μas
N_Obs_Max, or N_lim (2D)	The number of 2D differential measurments that can be made on a single target star that results in net noise reaching the Instrument Noise Floor. Equals (DMA/INF)^2.	1,600
Minimum Detectable Astrometric Signature (MDAS)	Instrument Noise Floor times desired SNR. For 1% false alarm probability (FAP), want SNR=~6. INF*SNR=0.035μas*6= 0.21μas.	0.21 μas
Minimum Detectable Earth-like Planet Mass	This is dependent upon the MDAS, star distance, stellar mass, and the planet's orbit. For a one Solar mass star at 10 pc, the minimum detectable habitable-zone planet mass depends upon where the planet is in the habitable-zone as shown below.	See below
	At the outer edge of habitable zone (1.6 AU)	0.44 Mearth
	Mid habitable zone (1.0 AU)	0.70 Mearth
	At the inner edge of the habitable zone (0.82 AU)	0.85 Mearth

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Instrument Errors

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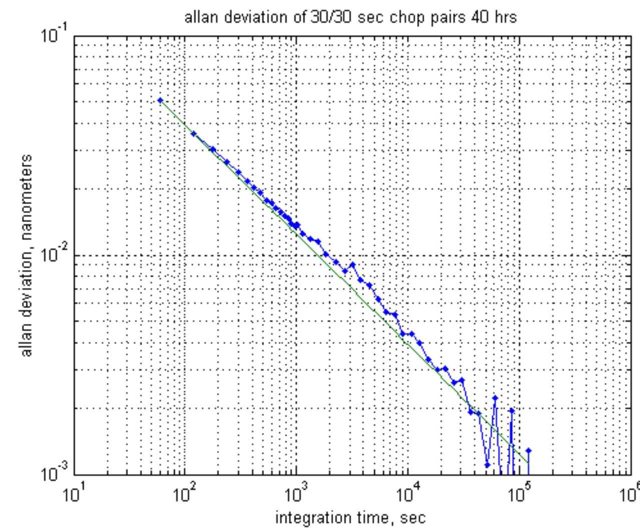
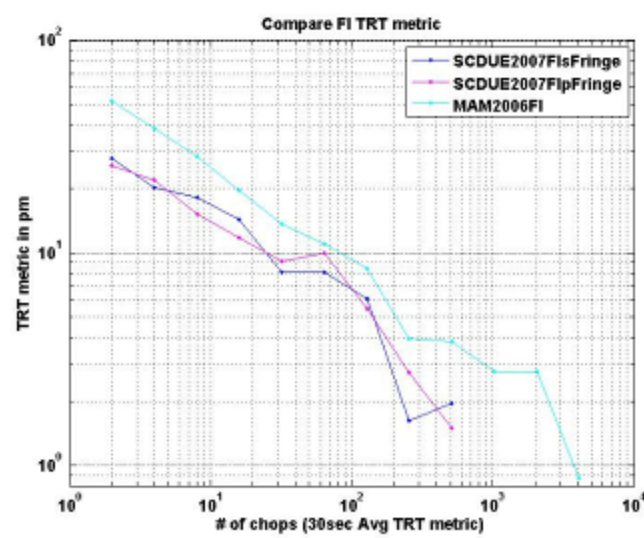
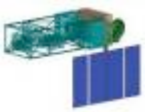
- Random noise and thermal drift
  - Modeling predicts flight performance better than that of ground testbeds.
  - Ground testbed data (MAM & SCDU) show random/thermal noise to be white after chopping and averages to less than 1 pm with no floor based upon longest data sets taken to date.
- Field dependent (e.g., beamwalk)
  - SIM-Lite NA measurements all made within 1° of center of field. Ground testbed data (MAM & Kite) show no significant high order field errors over that range.
- Color dependent
  - Spectral Calibration Development Unit (SCDU) showed how to correct for stellar color dependent errors when chopping.





Summary



SIM (Lite)

- SIM-Lite's technology development program is completed.
  - Perhaps the most heavily externally reviewed technology program ever.
  - Demonstrated better than NRC Goal-level performance capability.
- Subsequent engineering risk reduction has demonstrated flyable hardware for most critical elements (e.g., picometer metrology).
- SIM-Lite science remains as compelling today as it was in 1990.
  - SIM-Lite's combination of dim-star (≤V20) with ultra astrometric precision (1 μas) penetrates where no other mission can.
- The project has worked hard to find more affordable options.
- SIM-Lite is *technically* ready to launch as early as mid-decade. Actual launch date will depend upon funding