TRW Space & Electronics Group

Nulling Interferometers

James Larkin, UCLA

NI Systems Seek High Resolution at Minimum Optics Size

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- Benefits of small optics offset by system complexity and technology risk
- Need to rotate baseline adds to complexity in design and operations
- Formation flying implementation adds further system complexity and thermal control issues

Wide Variety of Interferometer Approaches Possible

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- TRW Team examined a range of potential configurations for basic performance parameters
- We performed detailed studies of the OASES concept
  - Linear 1-3-3-1 chosen as representative
- Both monolithic and formation flying implementations examined
- Performance and error investigations used to assess technical risk areas

Terrestrial Planet Finder

Two Implementation Architectures Selected for Interferometer

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- Nulling Interferometer
  - Wavelength
    - •Visible
    - •Infrared
  - Array Configuration
    - •OASES 1-3-3-1
    - •OASES 1-2-2-1
    - •OASES 1-4-6-4-1
    - •Angel Cross
    - •Generalized Angel Cross
    - •Laurance
    - •Mariotti
  - Flight System Configuration
    - •Monolith
    - •Formation Flying

Both Monolith and Formation Flyers are examined

Monolith Nulling Interferometer Key Features

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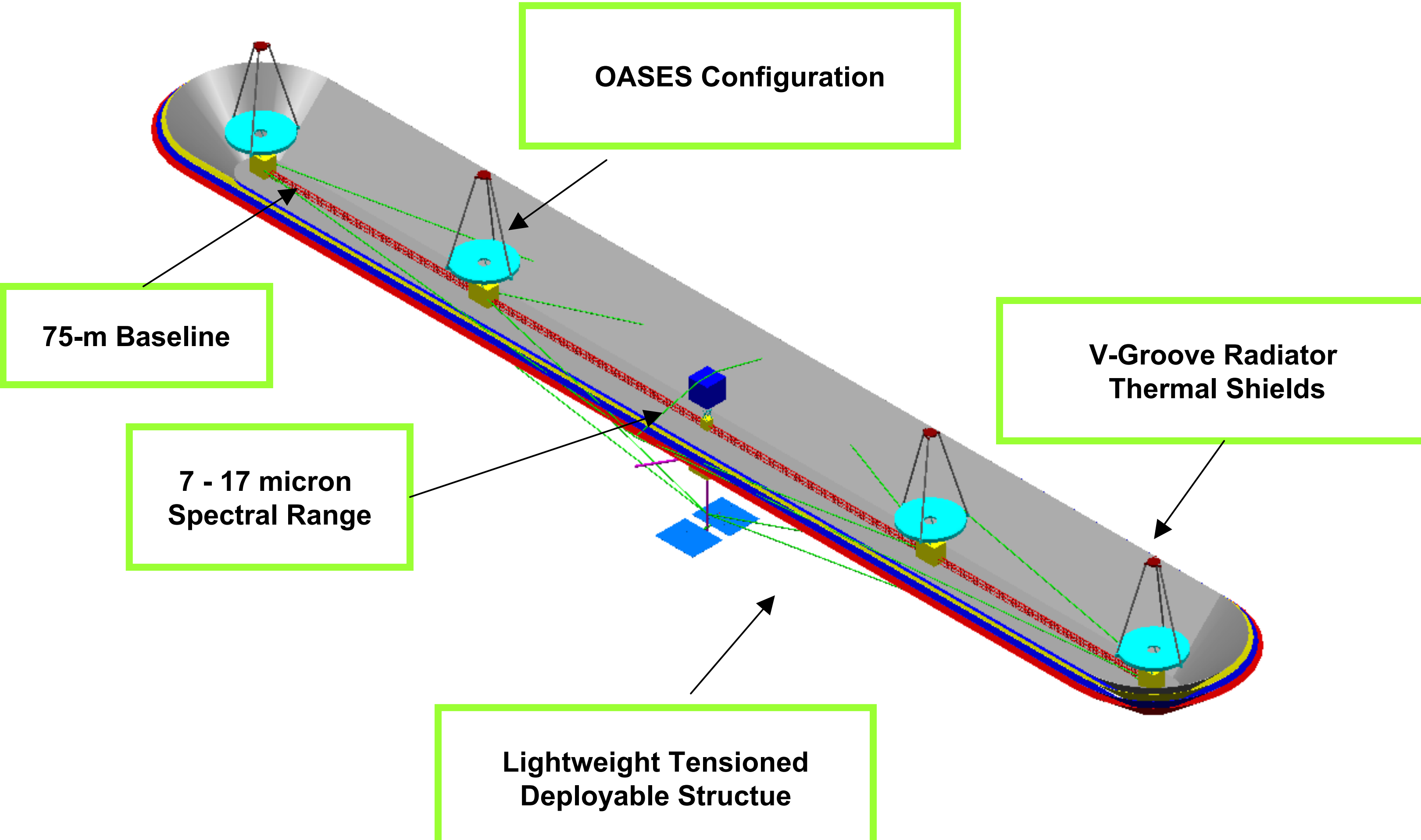

Formation Flying Nulling Interferometer Key Features

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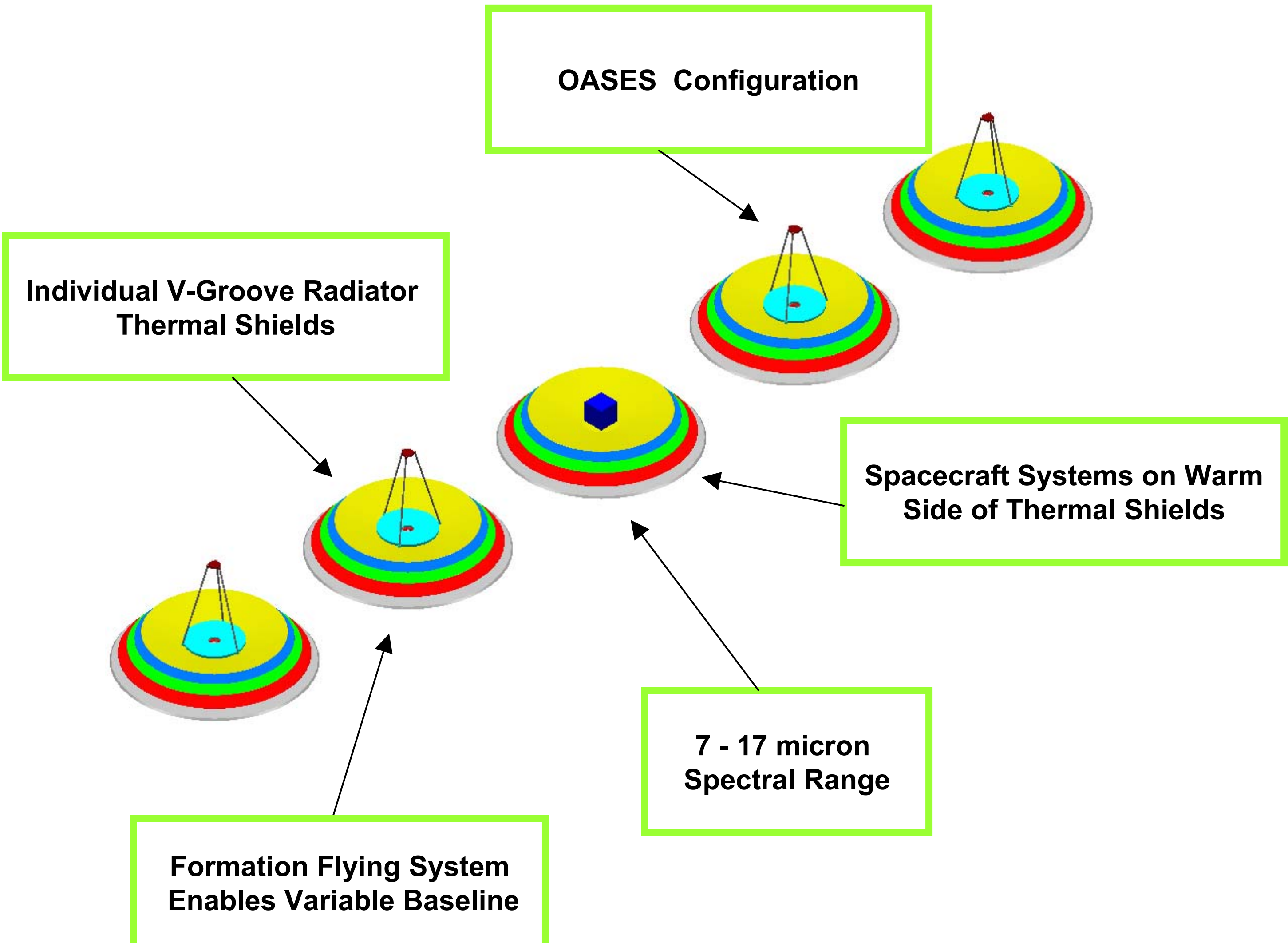

Two Models Developed to Investigate Interferometers

- Performance model
  - Developed by C. Bennett at LLNL
  - Computes integration times based on system parameters
- System simulation
  - Developed by J. Larkin at UCLA
  - Models operations and includes Monte Carlo error approach, transmission pattern, and scene
- Models developed together to ensure consistency

One-Dimensional and Two-Dimensional Arrays Considered

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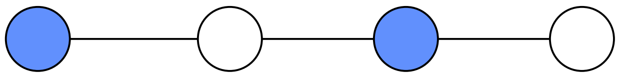
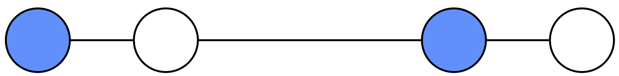
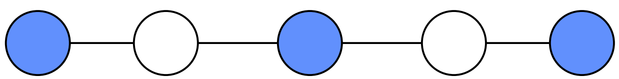
OASES 1-3-3-1



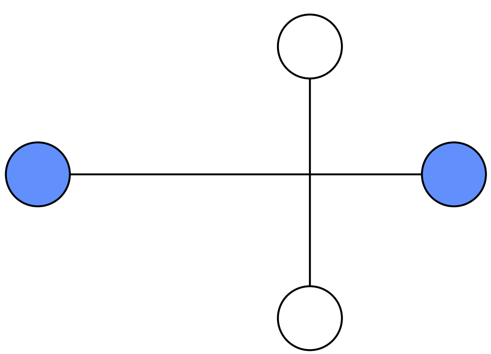
OASES 1-2-2-1



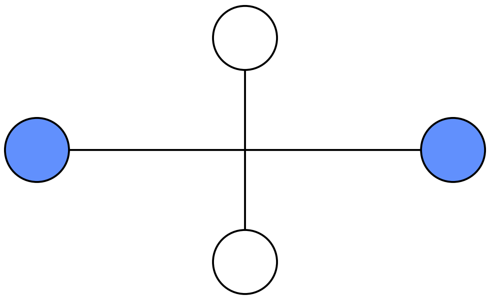
OASES 1-4-6-4-1



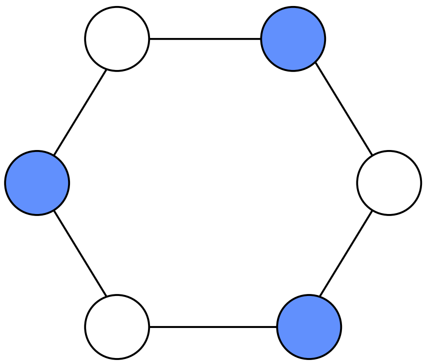
Generalized Angel Cross



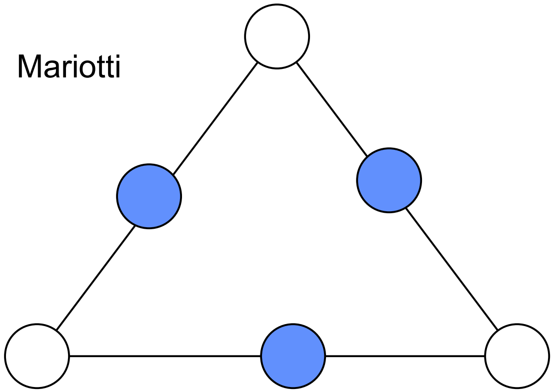
Angel Cross



Laurance



Mariotti



We Chose a Representative Array to Select Configuration

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- Detailed examination of all possible interferometer arrays would be too time consuming
- Selected array that gives good nulling performance for further study
  - Looking for deep and wide null with minimum number of collecting apertures

Comparison of Stellar Leakage Performance

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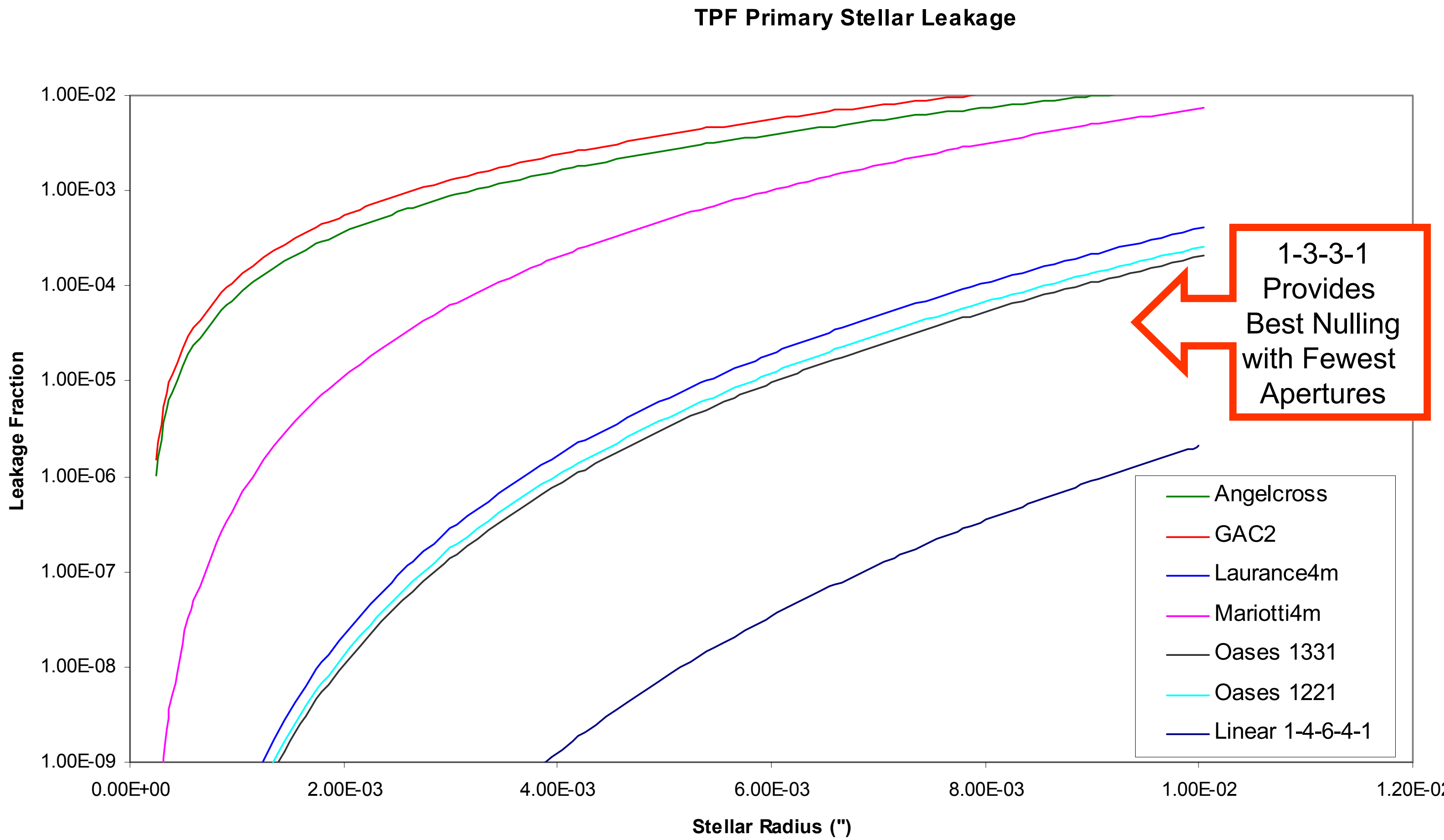
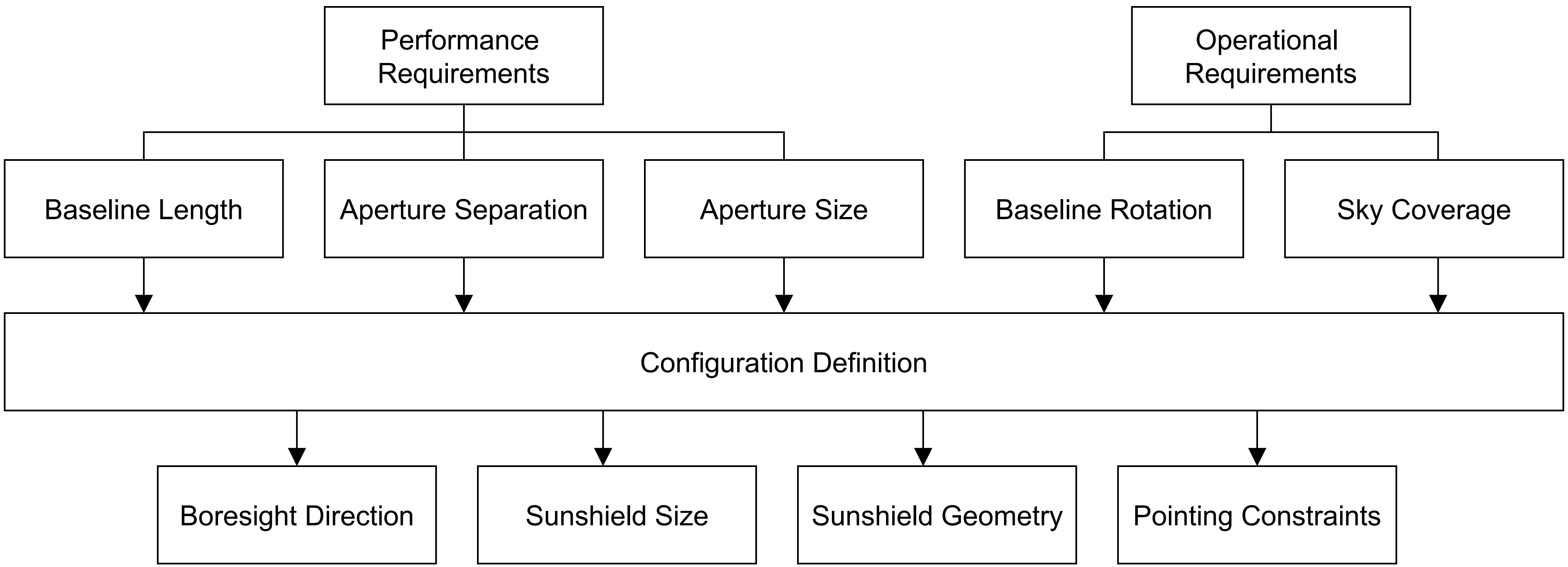


TRW Examined Impacts of Mission Requirements on System



Total Sky Coverage Difficult Due to Sunshade Constraints

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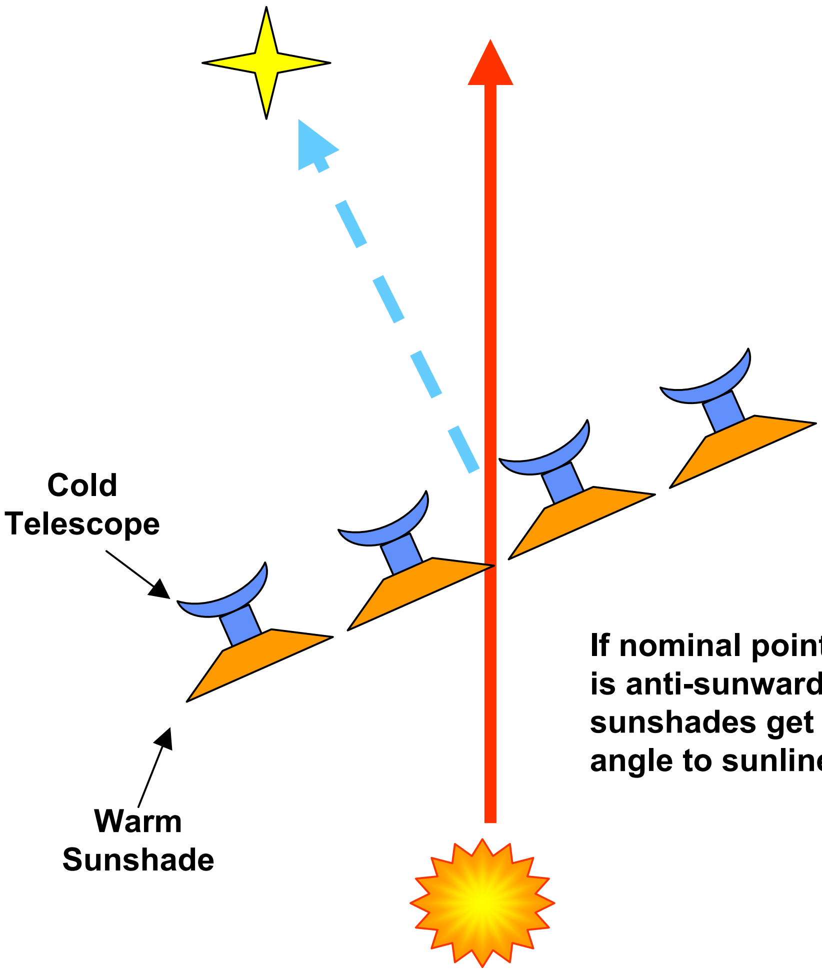
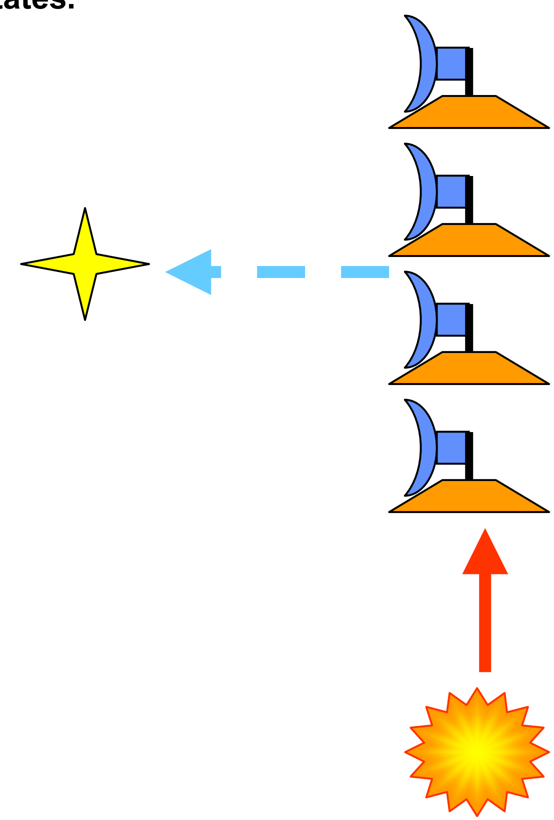


If nominal pointing direction is anti-sunward, the sunshades get too large as angle to sunline increases.

If nominal pointing direction is perpendicular to the sunline, the cold telescopes can see the warm sides of the sunshades when the array rotates.



Impact of Maximizing Sky Coverage on Monolithic Interferometer

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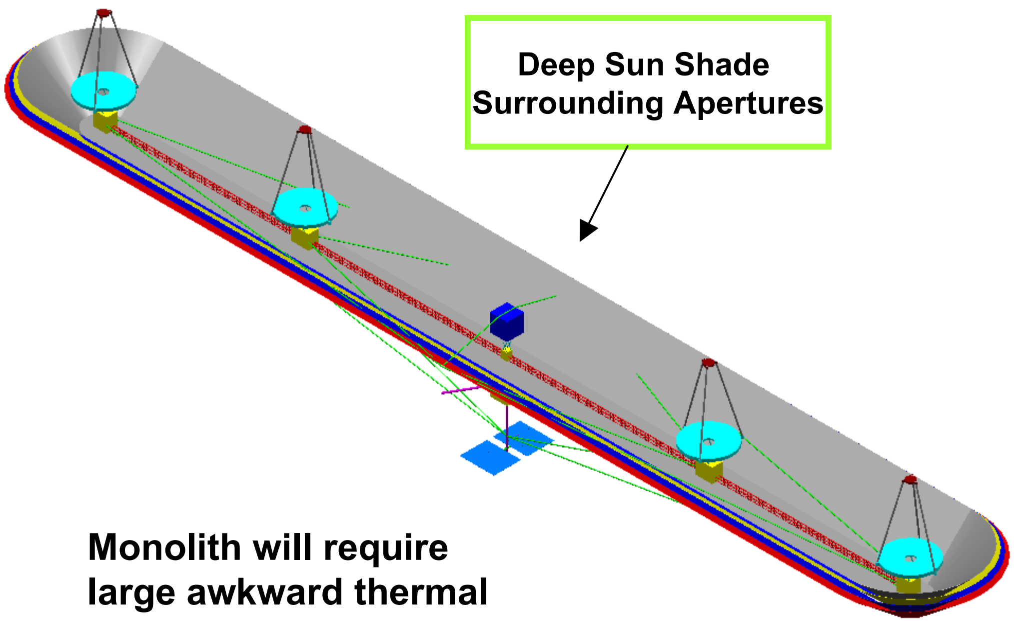

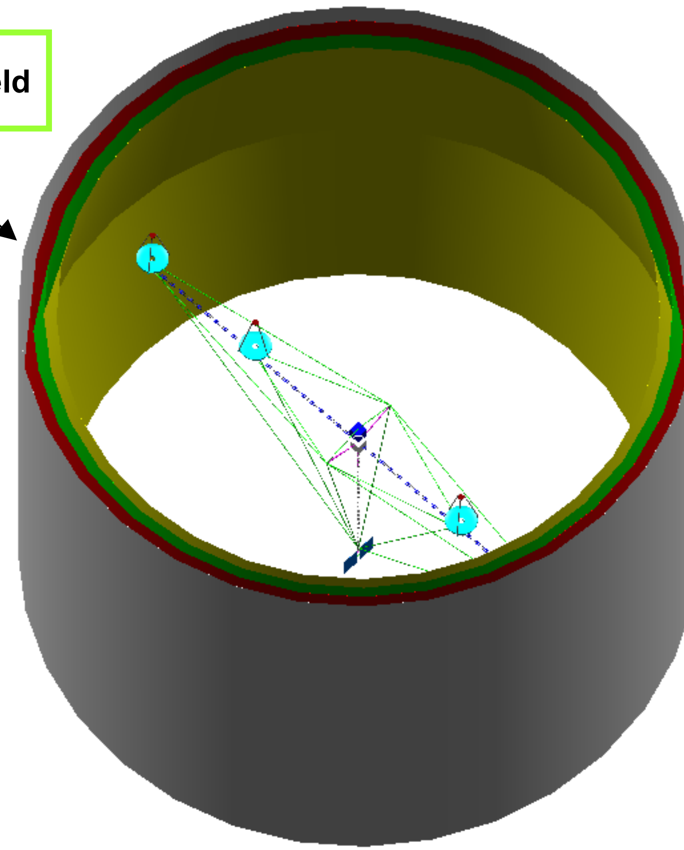

Monolith will require large awkward thermal shields to get sky coverage near poles of ecliptic

Impact of Maximizing Sky Coverage on Formation Flying Interferometer

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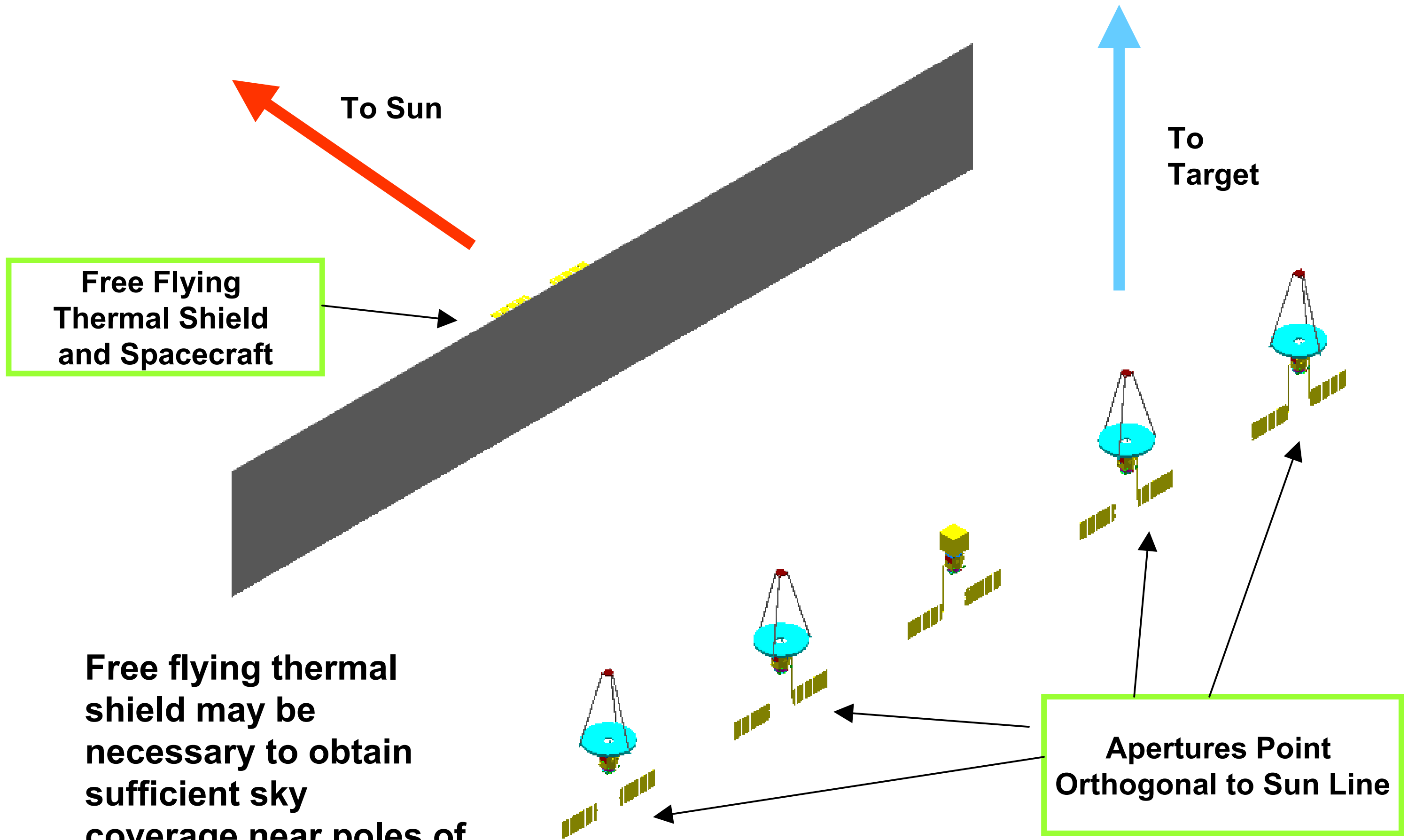

Free flying thermal shield may be necessary to obtain sufficient sky coverage near poles of ecliptic

Thermal Design of Formation Flyer Must Consider Impacts of Neighbors

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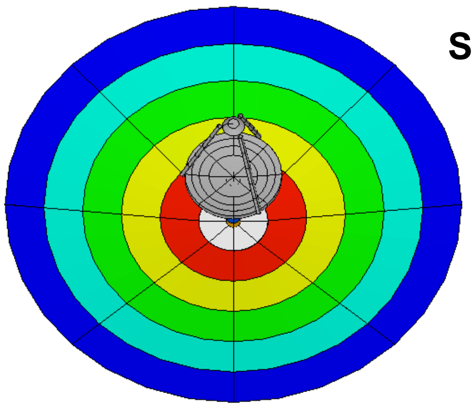
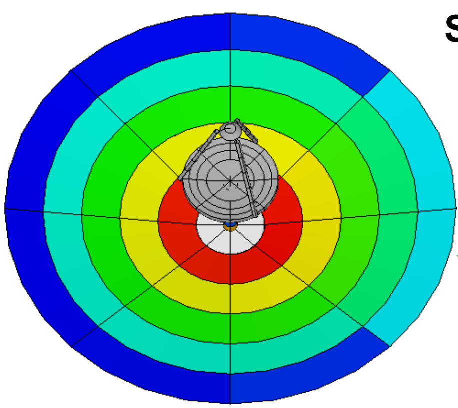
Single Spacecraft



Two Spacecraft
Separated by 20 m



Warming Due to Neighbor

- Thermal interaction between spacecraft is a moderate effect when satellites in formation are closely spaced
- Thermal modeling technique developed and demonstrated for parametric analysis of shield design and satellite spacing
- Conical sunshield is viable concept for maintaining optics temperatures near 30°K for solar off-point angles up to 50°-70°
- Further analysis required to optimize shield design relative to solar off-pointing and formation spacing requirements

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Summary of Thermal Design Issues

- Sky coverage goals directly impact the overall configuration of thermal shields
- Need to rotate the array further complicates thermal design
- Addressing thermal impacts of neighboring spacecraft in the formation flying implementation poses moderate design risks

Scene Modeling Assesses Imaging Performance

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- Nulling interferometer requires discrete sampling of the u-v plane
  - Performance more complex than with straightforward imager
- Model constructed to simulate actual operations
  - System errors such as pointing and alignment
  - Modulation effects of exo-solar systems with multiple stars

Errors Terms Added Into Performance Model

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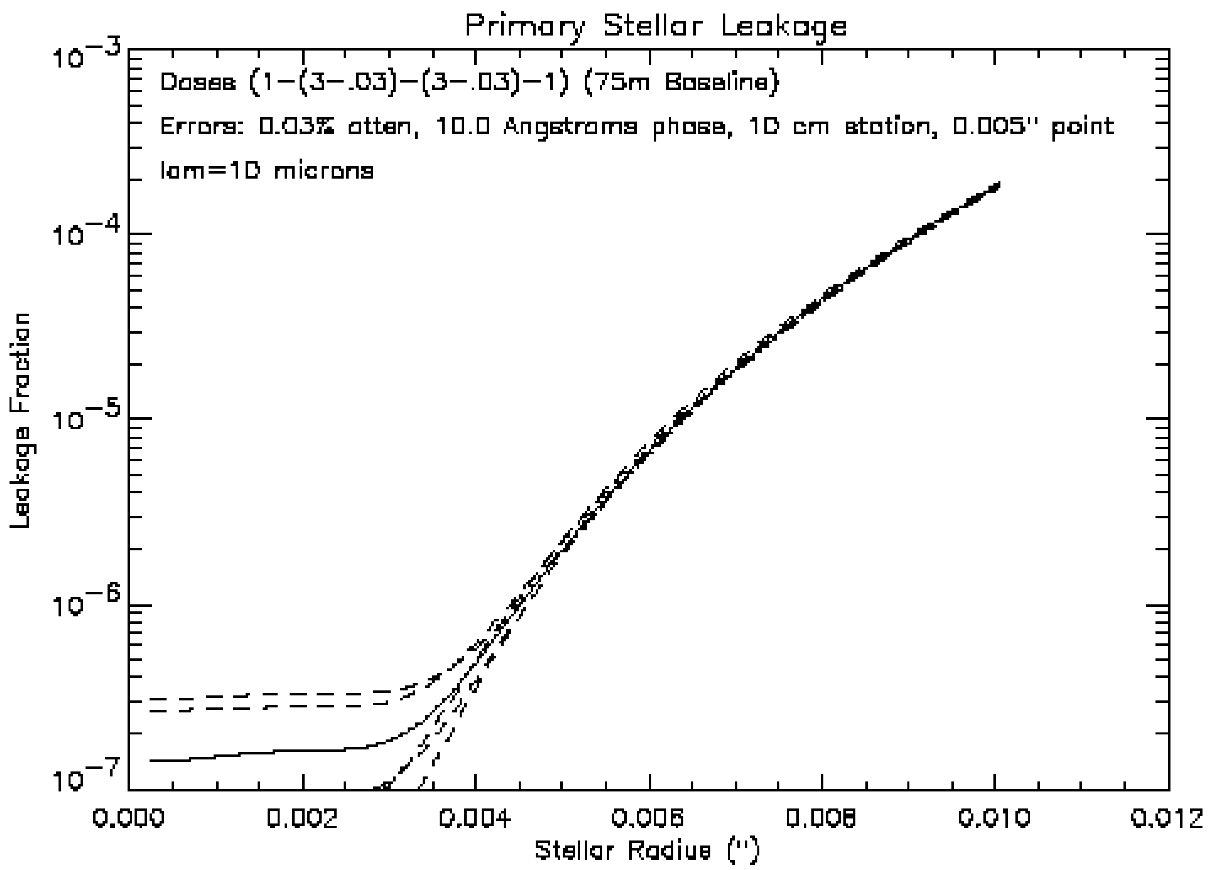
- Attenuation errors: 0.03%
- Phase errors: 1 nanometer
- Station keeping errors: 10 cm
- Pointing errors: 5 milliarcseconds

Model Assesses Impact of Error Terms on Stellar Leakage



Solar System at 10 pc

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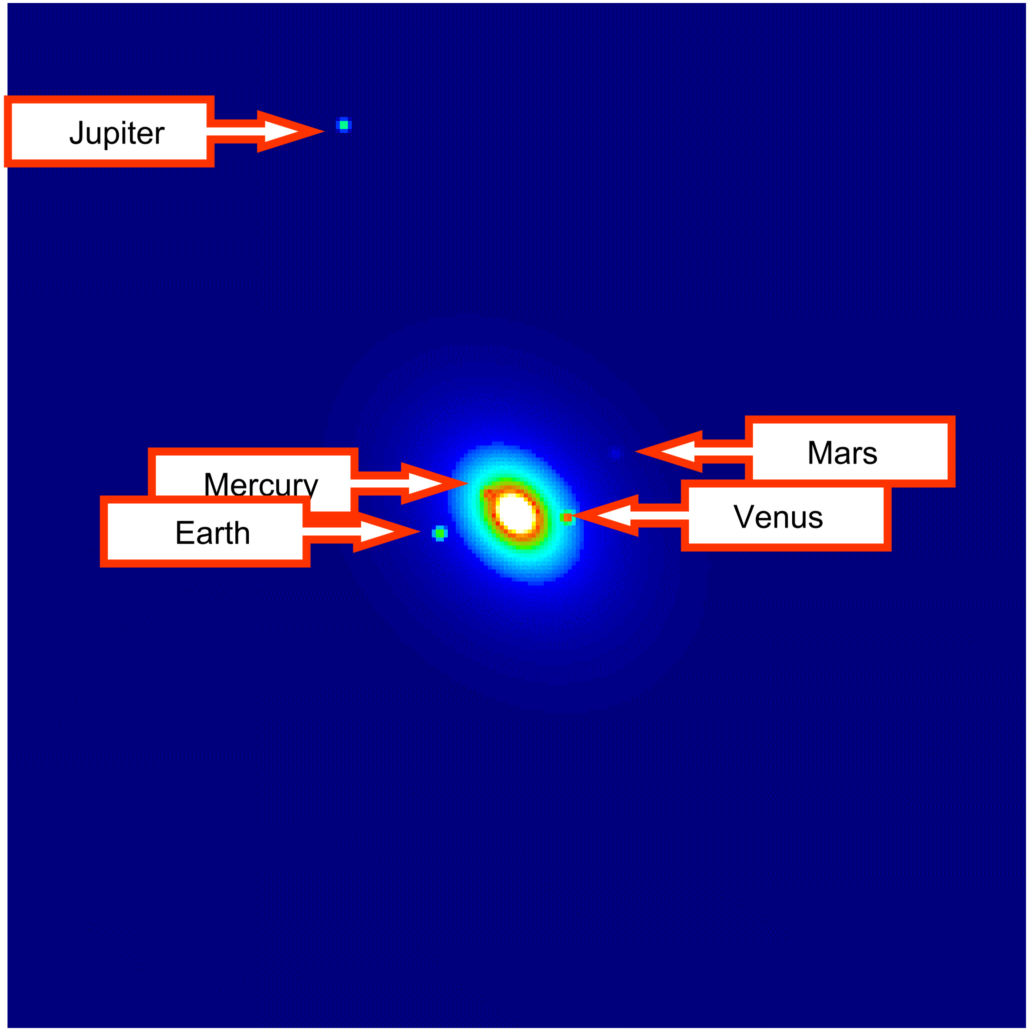

Convolution of Airy Disk and Transmission Pattern

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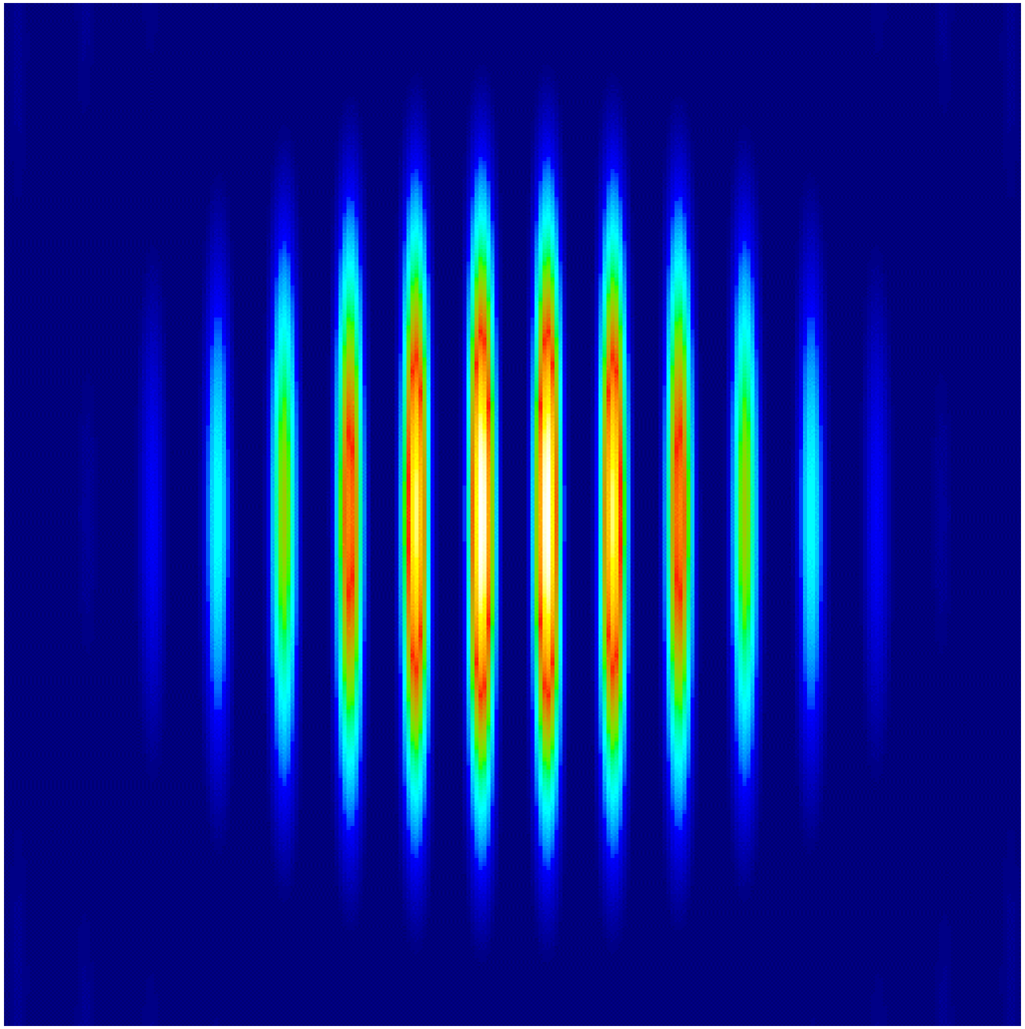

Exo-Solar System Scene Convolved With Transmission Pattern

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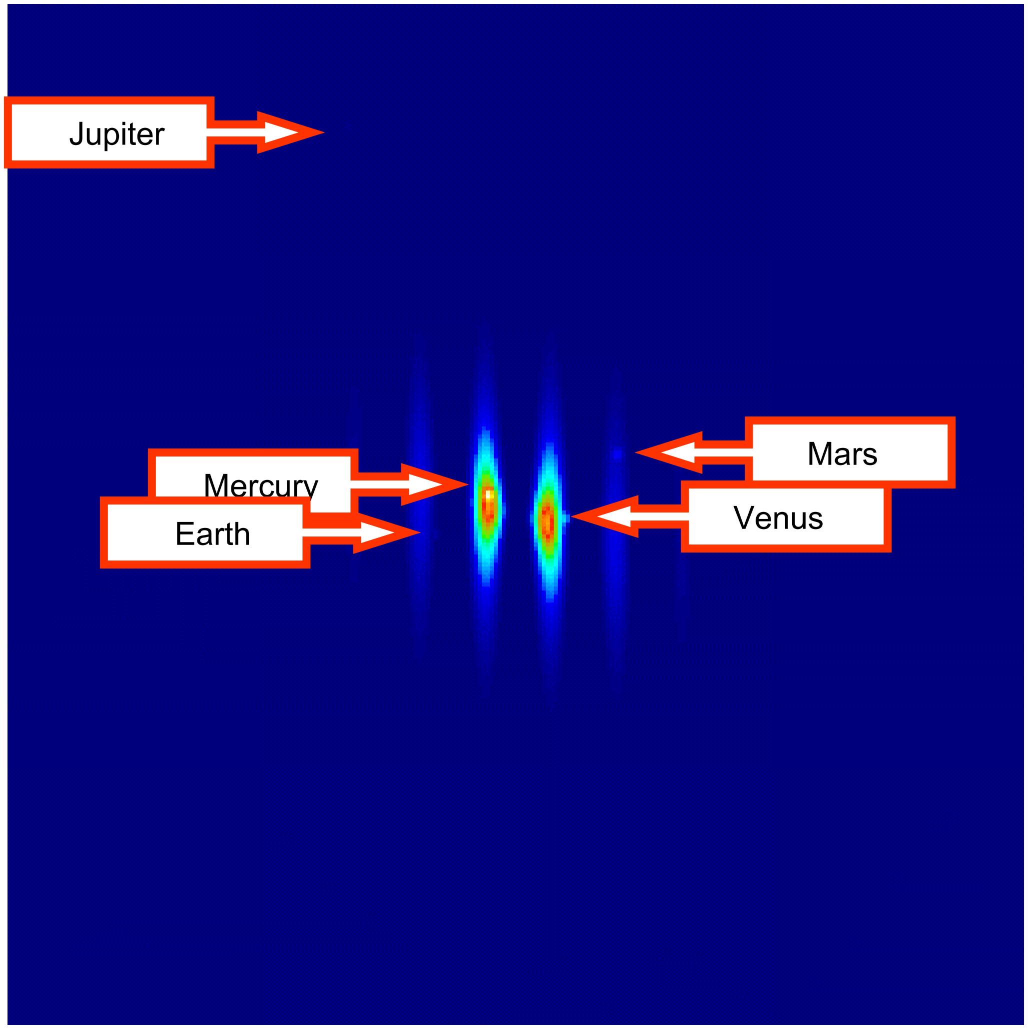

Signal Modulation for Rotating OASES 1-3-3-1

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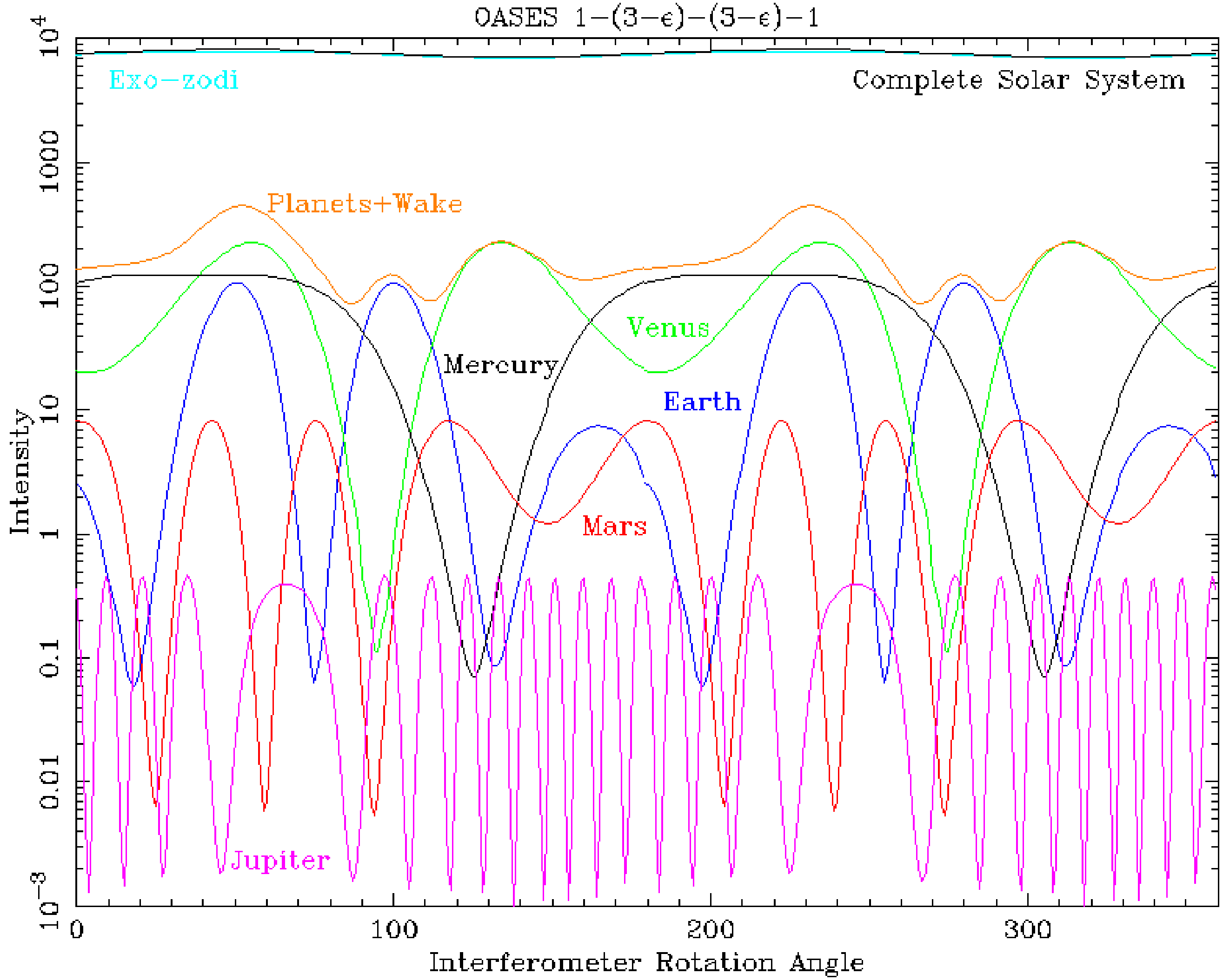

Nodding of Interferometer Effective in Removing Exo-Zodi

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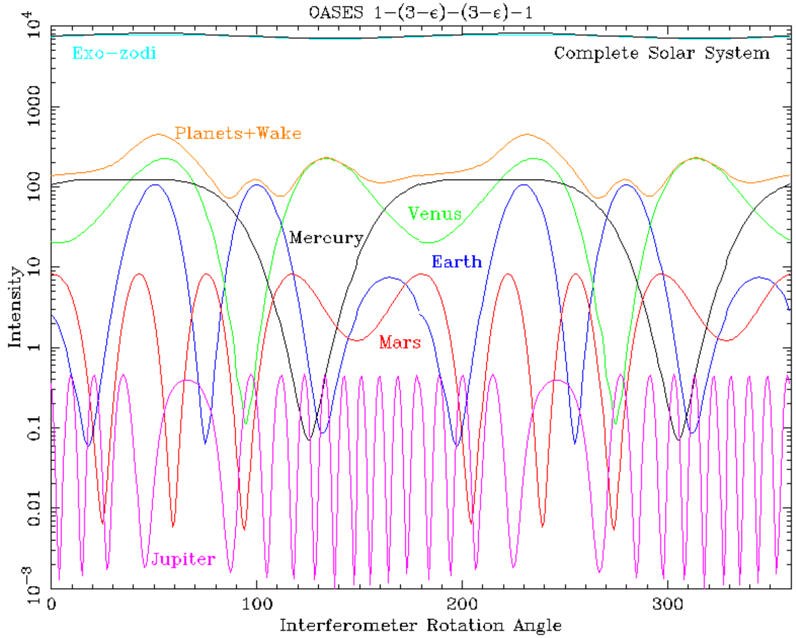
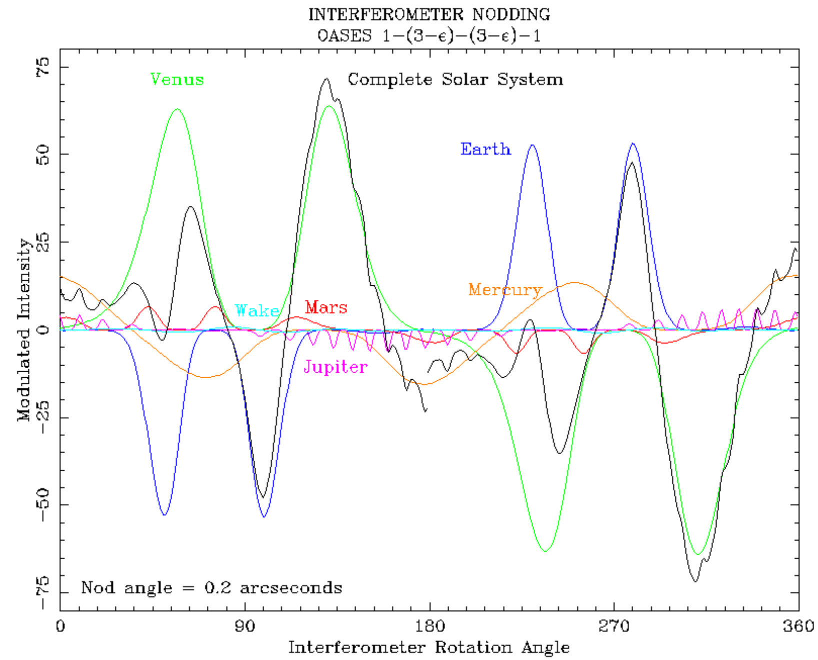


Intensity modulation without nodding



Intensity modulation with nodding

Functional Block Diagram of Nulling Interferometer

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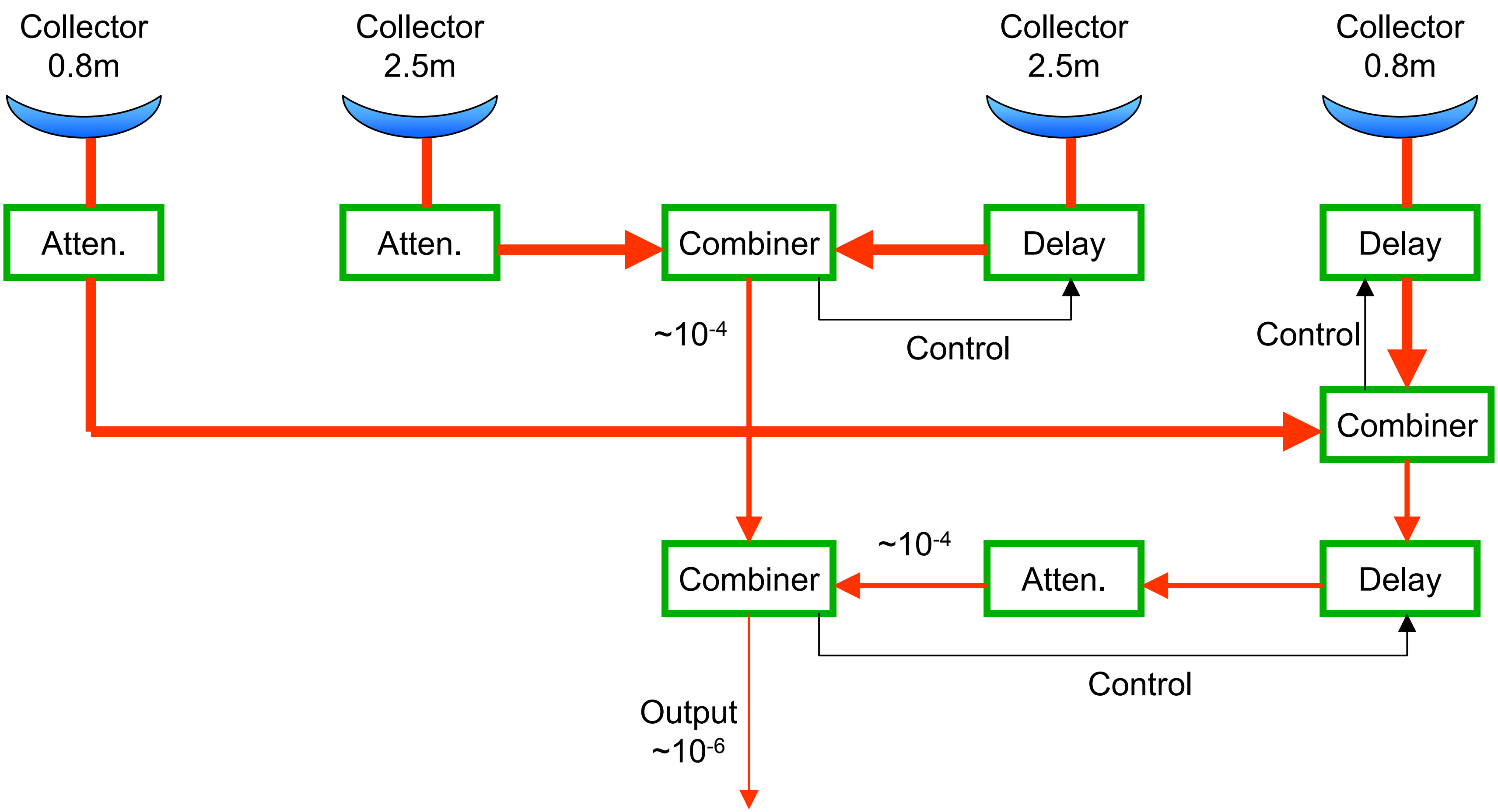

Error Budget for Nulling Interferometer

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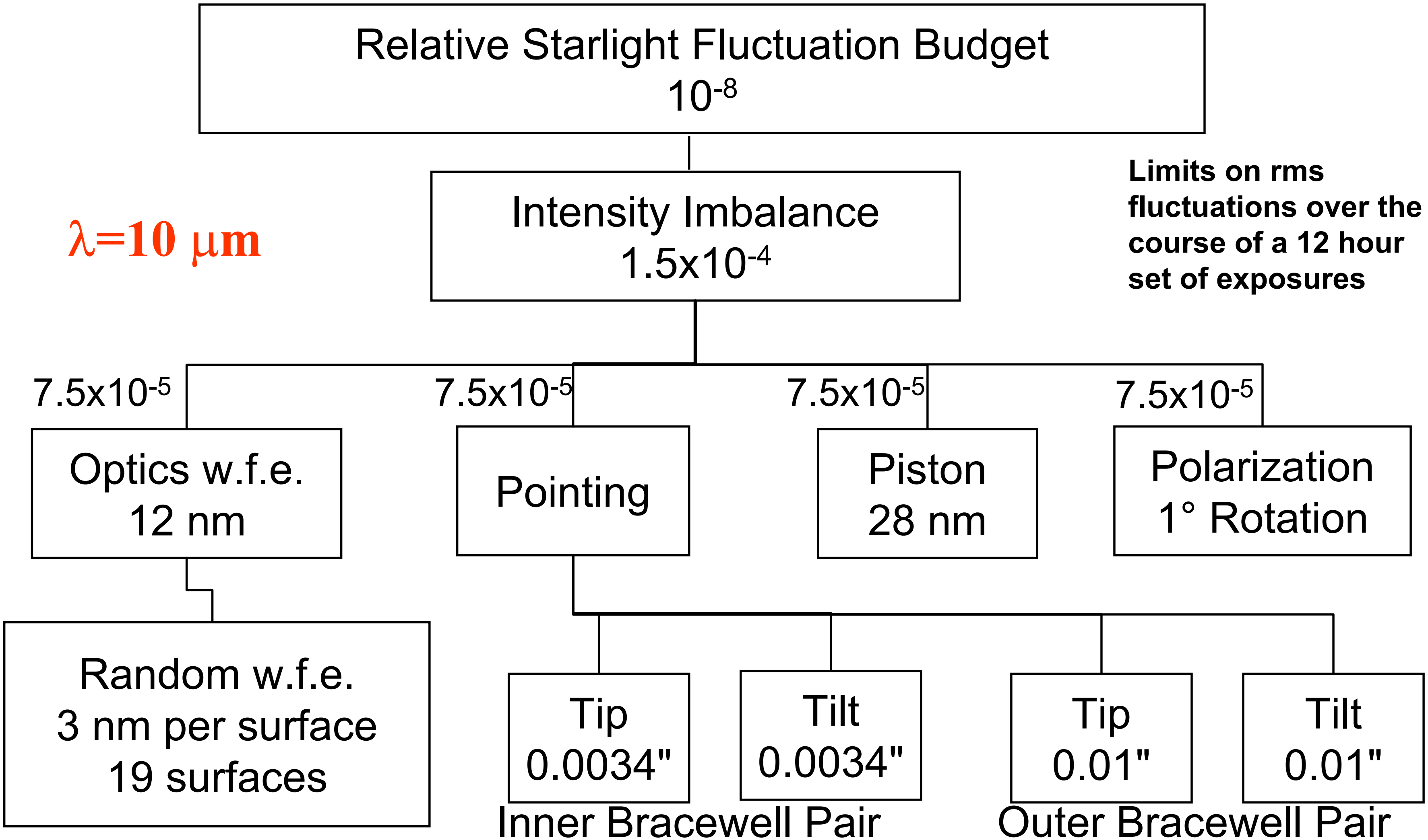

$\lambda = 10\ \mu m$

Limits on rms fluctuations over the course of a 12 hour set of exposures

Preliminary Analyses Show Challenging Requirements

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- Nulling interferometer is a far more complex design than a straightforward imaging system
- Achieving required starlight nulling performance requires tight wave front error control and pointing
- Detailed explanation of error terms contained in additional charts

Formation Flying Adds Design and Operational Complexity

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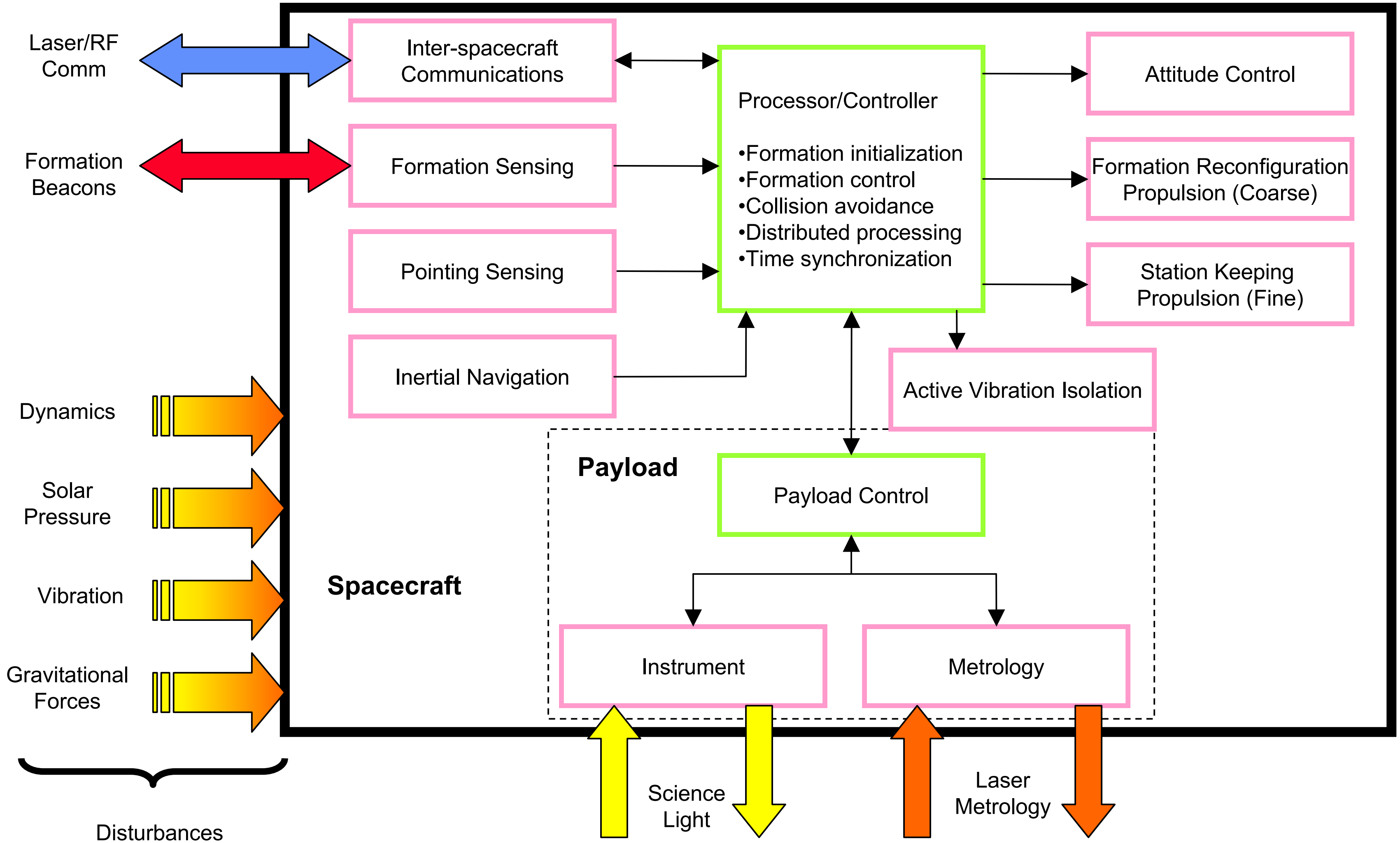

Nulling Interferometers Significant Risk Areas

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- SIM technologies need to be rescaled and made to work at cryogenic temperatures
  - Tighter pointing and WFE requirements
- Use of single mode wave guides hinders optical efficiency
- Need to rotate adds complexity to the flight system and operations
- Thermal control of formation flying system is a moderate risk due to impacts of neighbors
- Complexity of testing a formation flying system with the interferometer adds risk
  - Multiple, complex, layered control loops

Additional Charts

- Parameters for arrays studied
- Array transmission patterns
- TPF simulator model
- Examination of error sources
- Monolith tensioned structure concept
- Thermal shield design
- Interferometer block diagram and error budget
- Nodding Modulation