# Technical Considerations for Telescope Architectures and Aperture Size

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GSFC

**Presented to the LUVOIR STDT**

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# Objectives

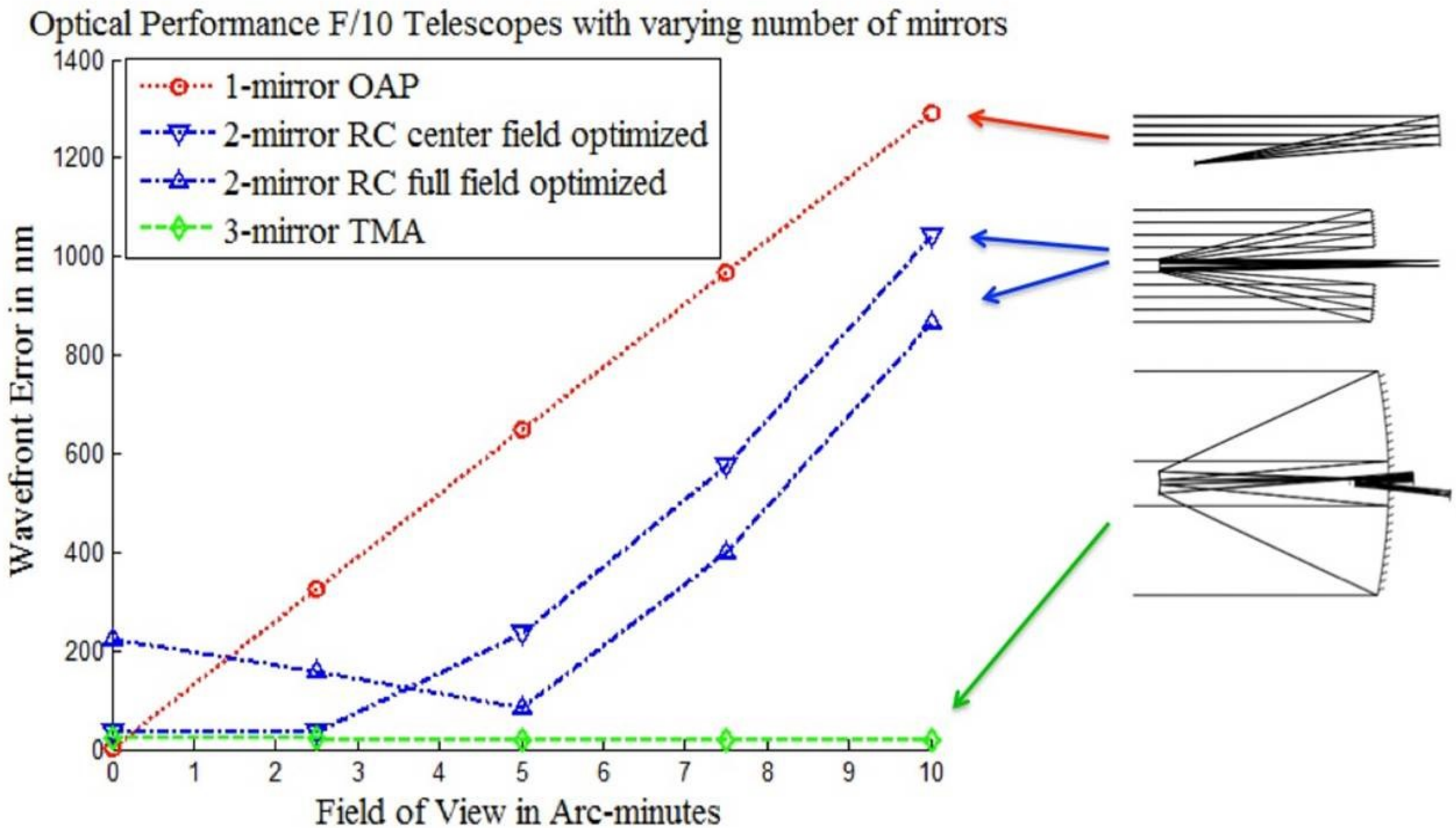
- Review a few *illustrative* telescope designs
  - Three-mirror anastigmat (TMA) vs. Ritchey-Chretien (RC)
  - Discuss strengths & weakness of each

- On-axis vs. off-axis designs

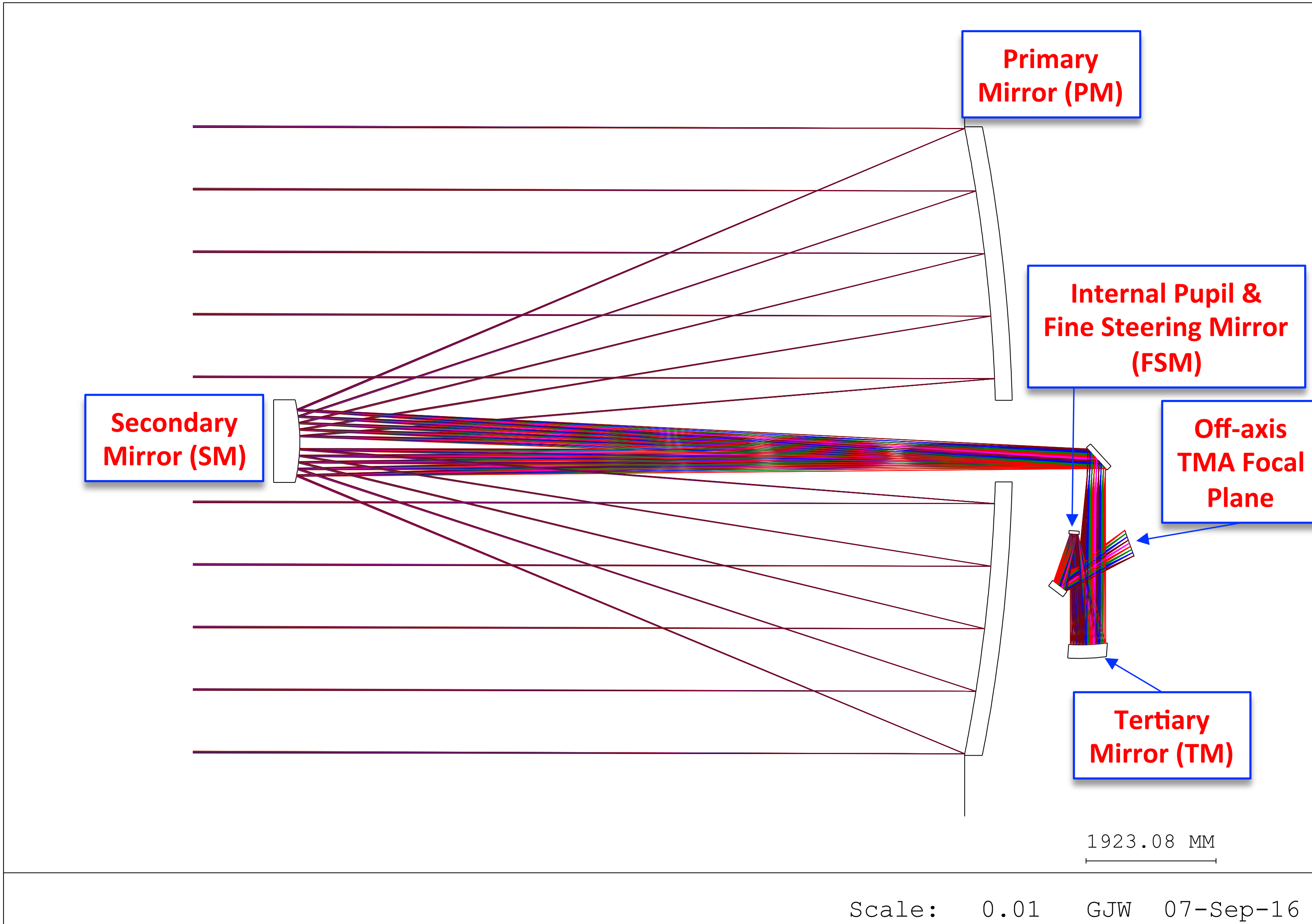
- Relate design considerations to LUVOIR priorities
  - Instrument accommodations
  - Packaging for launch vehicle
  - Test facility accommodations
  - Aperture scaling relationships

# Basic Idea

## More mirrors = Better image quality over wider field



# Three-mirror Anastigmat - Single Focal Plane (TMA-SF)



# TMA-SF Advantages

- Three mirrors simultaneously correct spherical, coma, and astigmatism aberrations
  - Enables diffraction-limited performance over very wide fields-of-view (> 8 x 8 arcmin)
- Access to an internal pupil allows for additional correction:
  - Pointing control with a fine-steering mirror (FSM)
  - Active control with a deformable mirror (DM)
- Heritage: JWST

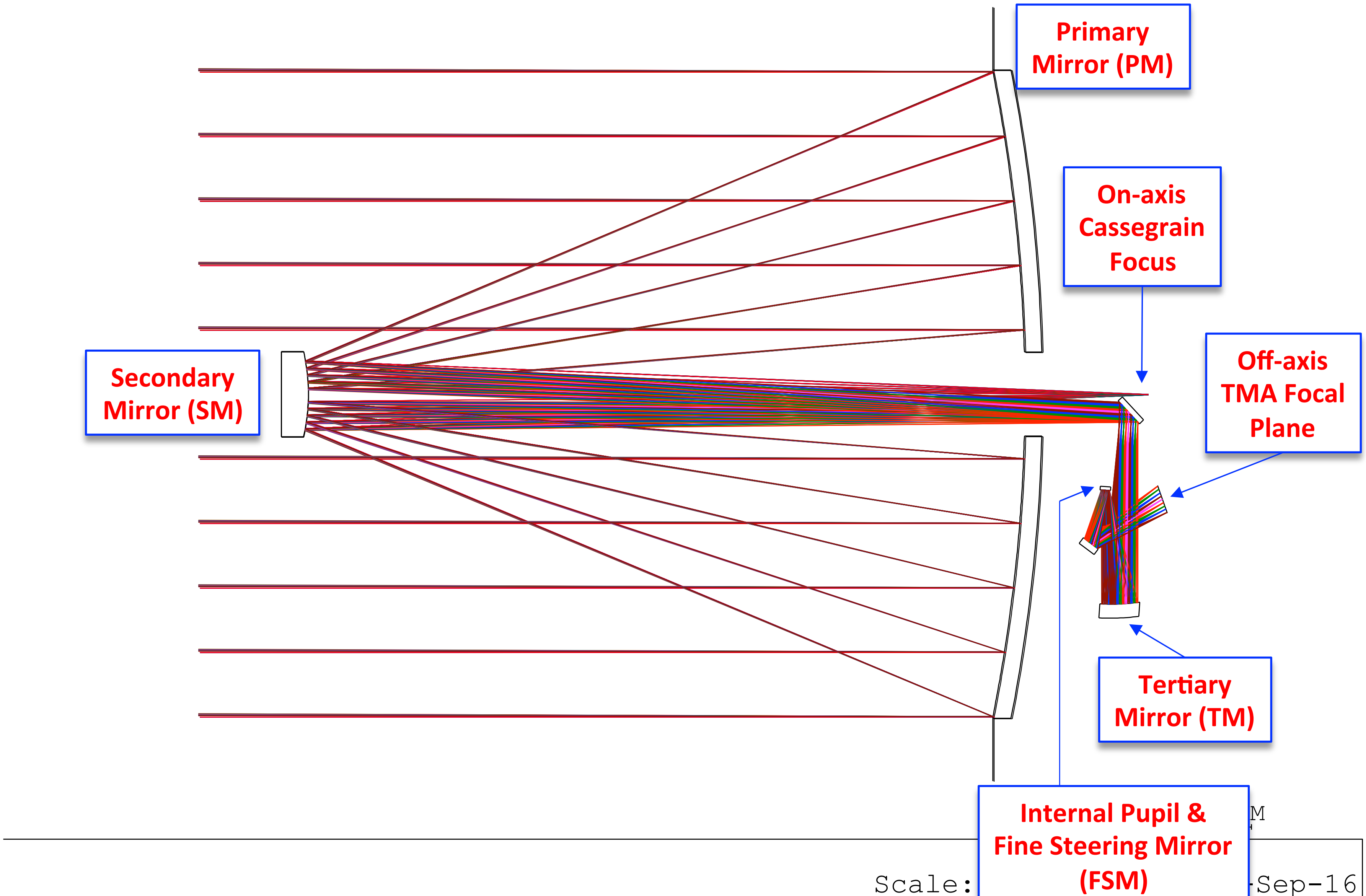
# TMA-SF Disadvantages

- At least four reflections before entering instruments
  - More are likely in order to fold beam for packaging
  - Lower throughput for sensitive instruments (UV & coronagraph)

- Complex aft-optical system (AOS)
  - Complicates system alignment
  - Could present difficulty for instrument packaging behind telescope

- JWST experience indicates stray-light can be difficult to baffle

# Three-mirror Anastigmat - Dual Focal Plane (TMA-DF)



# TMA-DF Advantages

- Narrow FOV on-axis Cassegrain focus
  - Only 2 reflections for high-throughput (UV & coronagraph) instruments

- Wide FOV off-axis TMA focus
  - Well-corrected wide-FOV instruments
  - Silver coating on TM, FSM, etc. for optimized Vis/NIR performance

- Access to an internal pupil in TMA chain allows for additional aberration correction (but only in TMA focal plane):
  - Pointing control with a fine-steering mirror (FSM)
  - Fixed pupil plate corrector
  - Active control with a deformable mirror (DM)

- Heritage: WFIRST

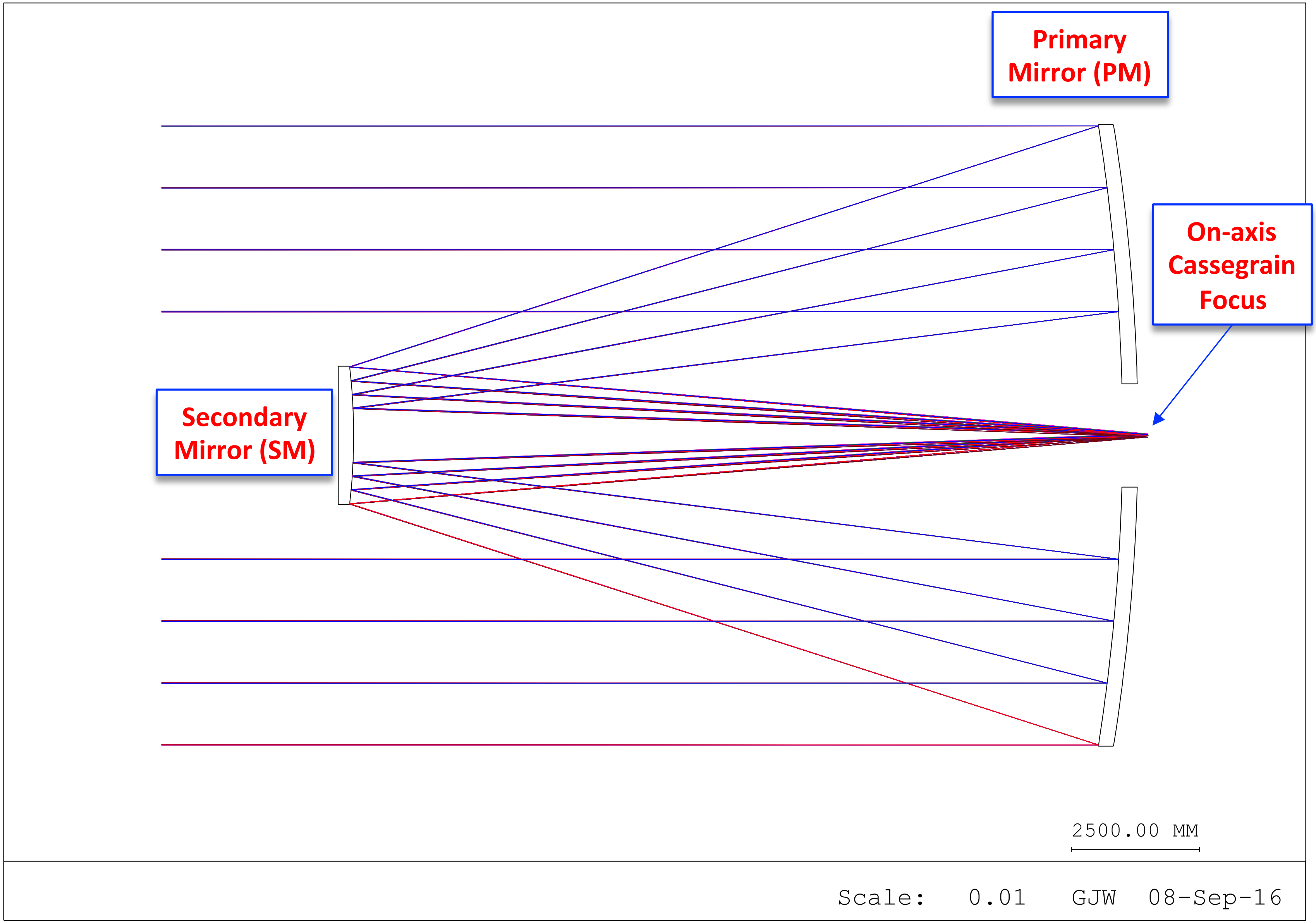
# TMA-DF Disadvantages

- Must balance aberrations between both focal planes
  - Requires a pupil corrector plate to recover image quality at TMA focus

- More difficult packaging configuration since both focal planes need to be accessible
  - May require more fold mirrors, reducing throughput in the TMA focus

- The Cassegrain focus is *very* narrow field-of-view
  - Arcseconds instead of arcminutes

# Ritchey-Chretien (RC)



# RC Advantages

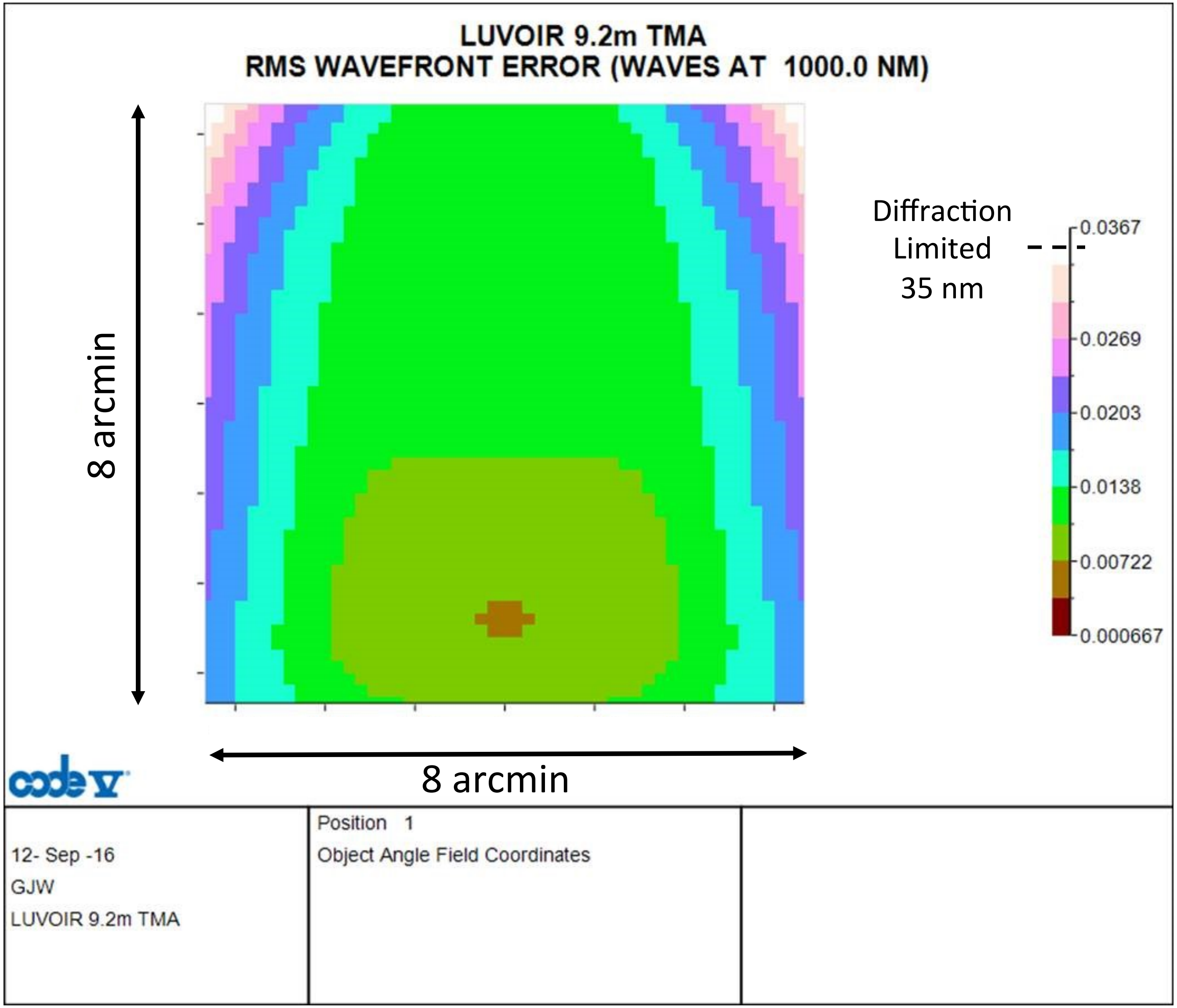
- Single, high-throughput focal plane
  - Possible for every instrument to only see two bounces (though some fold mirrors will likely be necessary)
- Simplified optical train means less complicated alignment and testing
- Heritage: HST

# RC Disadvantages

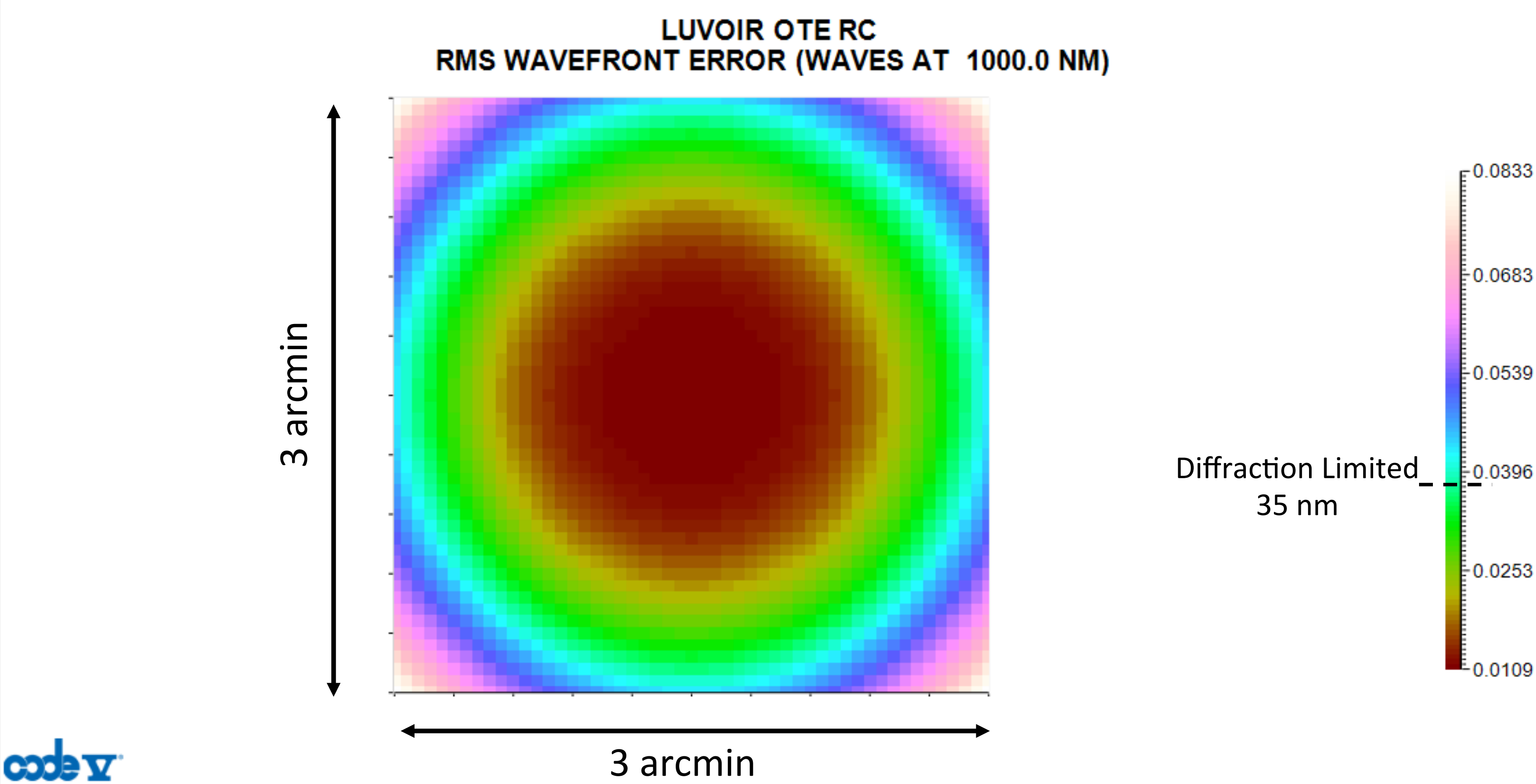
- Narrower overall field-of-view than TMA designs
  - ~3 x 3 arcmin diffraction-limited
  - Instruments outside of this field will need internal corrective optics
  - A curved focal plane can help improve the image quality, but may require some creativity in instrument packaging and design

- No access to internal pupil for a fine-steering mirror
  - Puts all pointing requirements on the spacecraft / disturbance isolation system
  - Or need to include individual fine-steering mirrors inside instruments that need it

# Field-of-View Map: 9.2 m TMA



# Field-of-View Map: 12 m RC

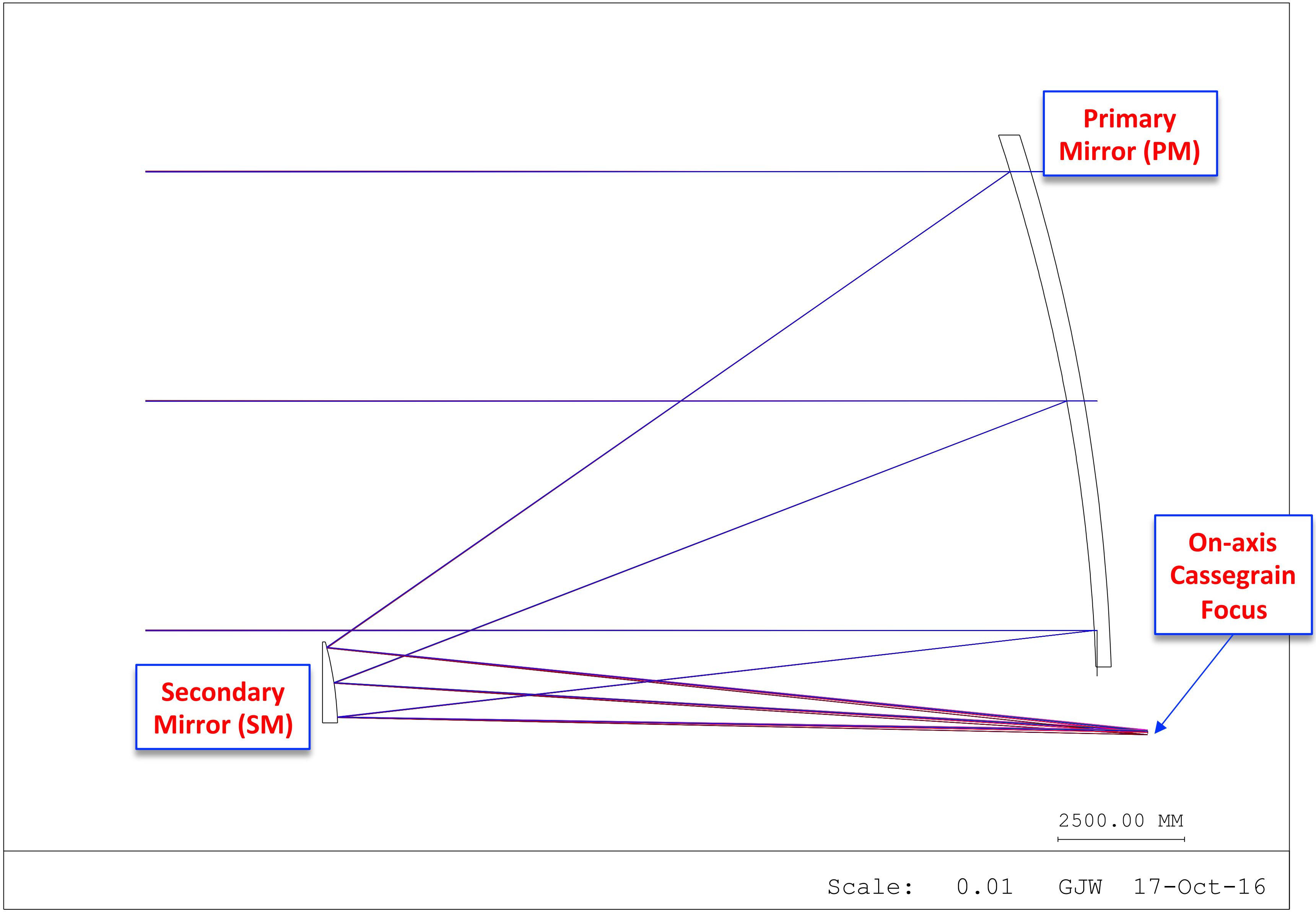



| | | |
|---|---|---|
| 08- Sep -16<br>GJW<br>LUVOIR OTE RC | Position 1<br>Object Angle Field Coordinates | |

# On-axis vs. Off-axis

- All of these designs were presented as nominally on-axis
- Any of them could be made to be unobscured off-axis
- Off-axis advantages:
  - No-obscuration improves overall throughput and possibly coronagraph ease-of-design / performance
- Off-axis disadvantages:
  - Higher angles-of-incidence at PM & SM → Larger polarization effects?
  - Generally increases aberration → Smaller well-corrected FOV
  - PM-to-SM distance increases → Impacts stability & packaging
  - Unclear how an off-axis segmented design could be packaged to fit inside of a fairing

# Off-Axis Ritchey-Chretien (RC)



# Instrument Accommodations

- Each of the LUVOIR instruments may have a preference for one or more of these designs

- The following slides address each instrument separately and discuss the trades associated with each of the telescope designs

- Once all of the instrument performance specifications are in hand, the engineering team will design the telescope to optimize performance over all of the instruments

# Vis/ NIR Coronagraph

- Only requires a small FOV (~arcsecs)
  - Could go in any focal plane of any design

- Cassegrain focus of the TMA-DF, and RC design are attractive for:
  - High throughput due to reduced number of reflections
  - Better wavefront stability with fewer optics in the path

- TMA focus is attractive for:
  - Access to a fine-steering mirror for better pointing control

# *LUMOS* (UV Multi-object Spectrograph)

- TMA-SF design is least desirable
  - Lots of reflections reduce throughput, BUT
  - Allows for wide FOV, with stable pointing behind a FSM

- TMA-DF Cassegrain focus
  - Improves throughput with only two reflections, BUT
  - Extremely limited FOV, pointing must be provided by spacecraft

- Ritchey-Chretien is best overall
  - High throughput with only two bounces
  - Achievable ~3x3 arcmin FOV

- Need to understand pointing stability requirements to determine if there is a need for a FSM

# *HDI* – Vis / NIR Wide-field Imager

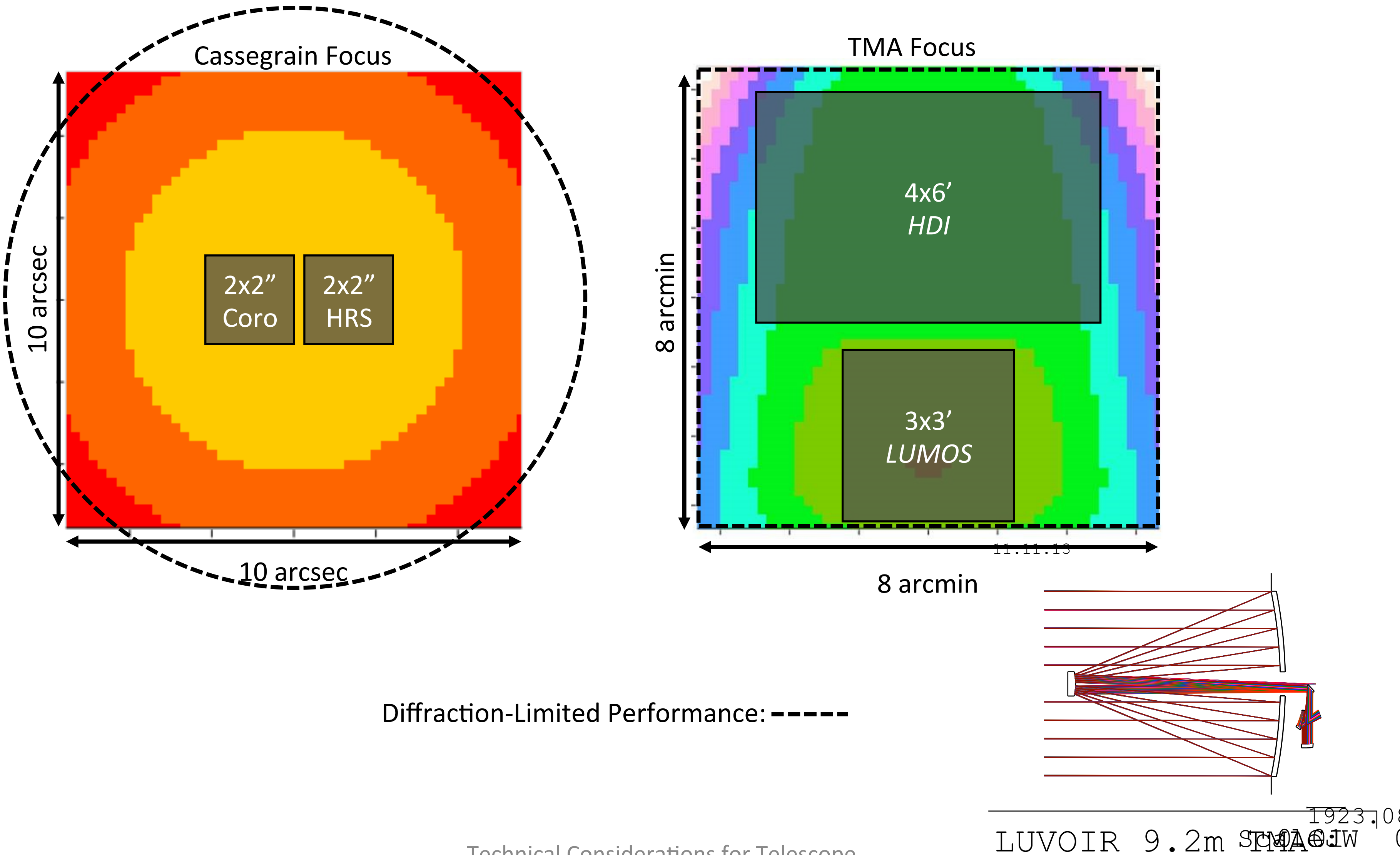
- Obviously wants to be at either of the TMA focal planes for wide field-of-view
- Would need internal corrective optics to work with the limited field-of-view of the Ritchey-Chretien
    - Needs additional study to determine what's achievable
- Need to understand pointing requirements of astrometry mode to determine if an FSM is necessary

# Vis / NIR Multi-resolution Spectrograph

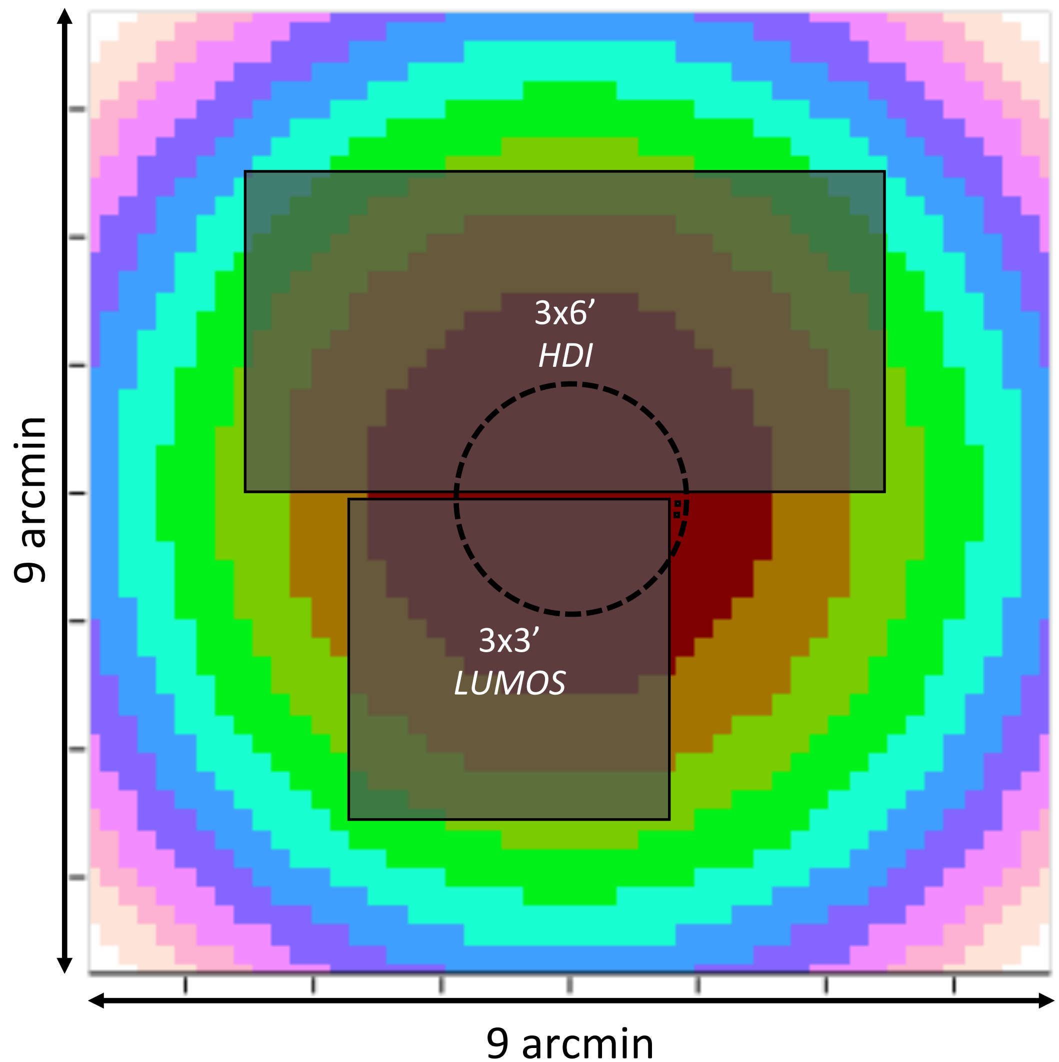
- Narrow field-of-view?
  - Could go in any focal plane of any design

- Need to understand requirements for radial velocity measurements to understand requirements on telescope

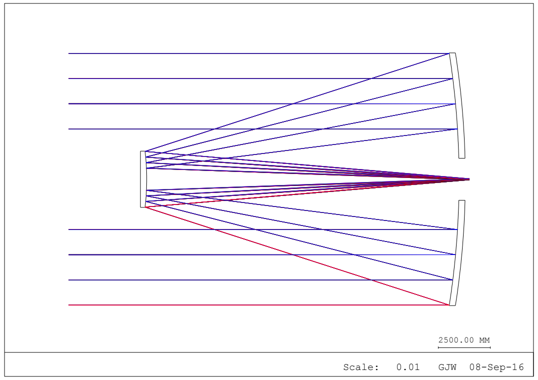
# Example TMA-DF Focal Plane Layout



# Example RC Focal Plane Layout (1)




Diffraction-Limited Performance: -----



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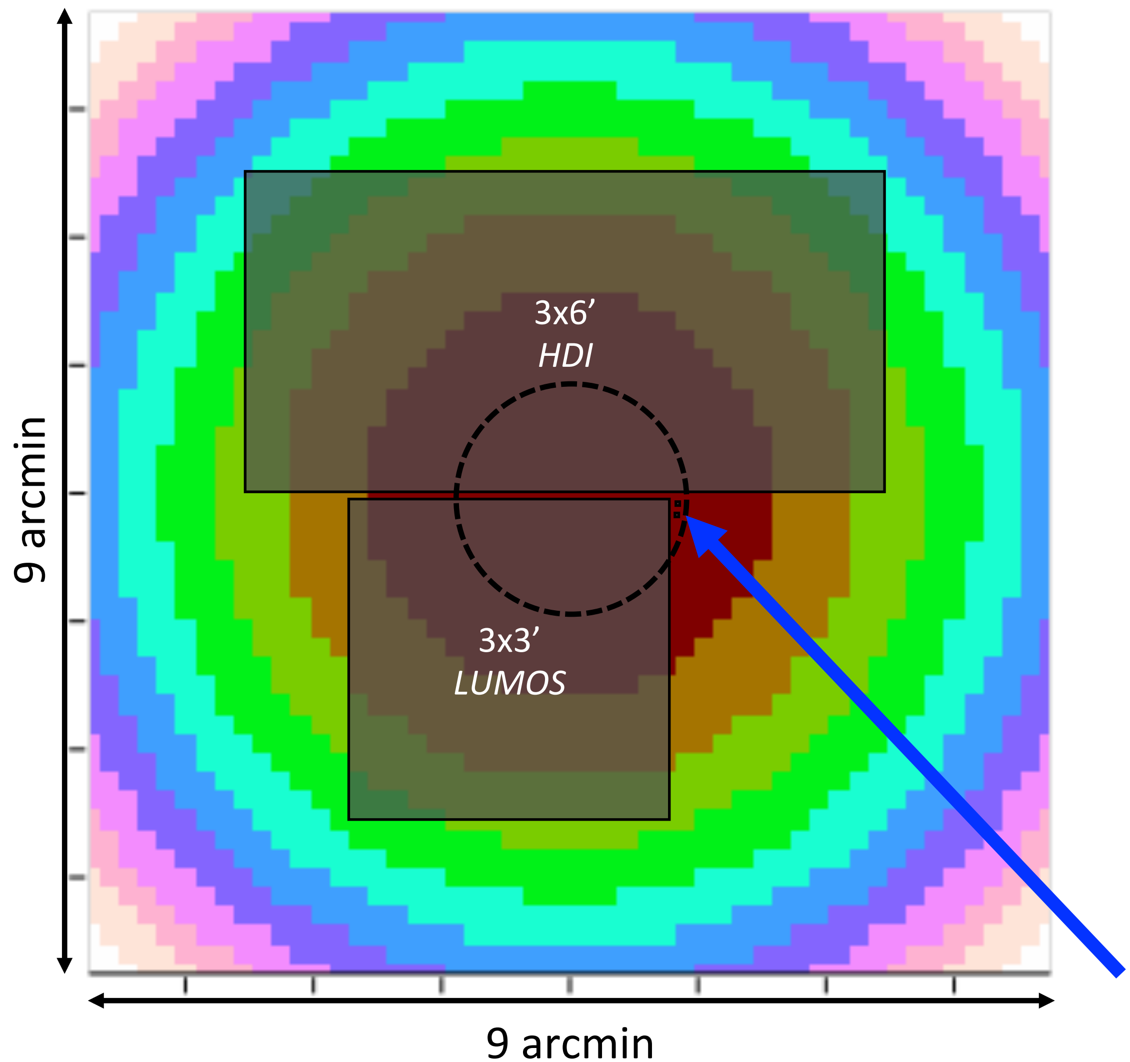
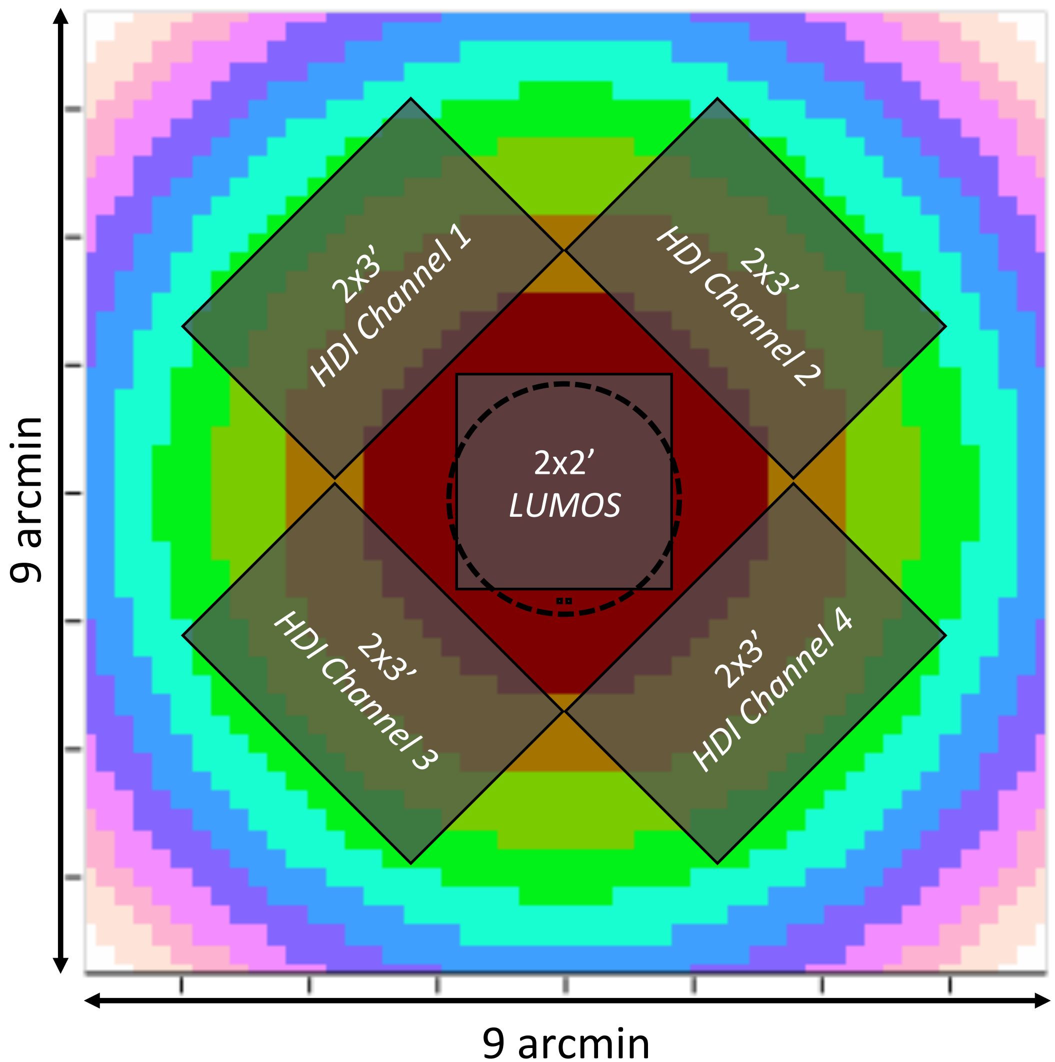



Diffraction-Limited Performance: -----

2x2” Coronagraph and 2x2” HRS fields

# Example RC Focal Plane Layout (2)

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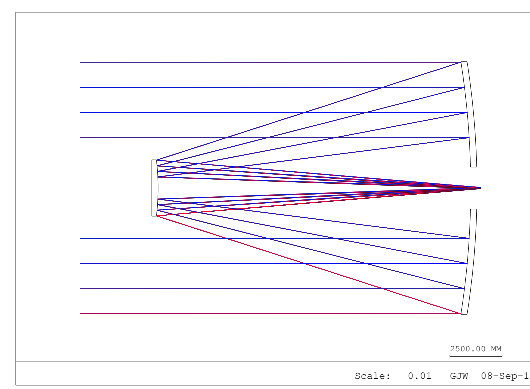

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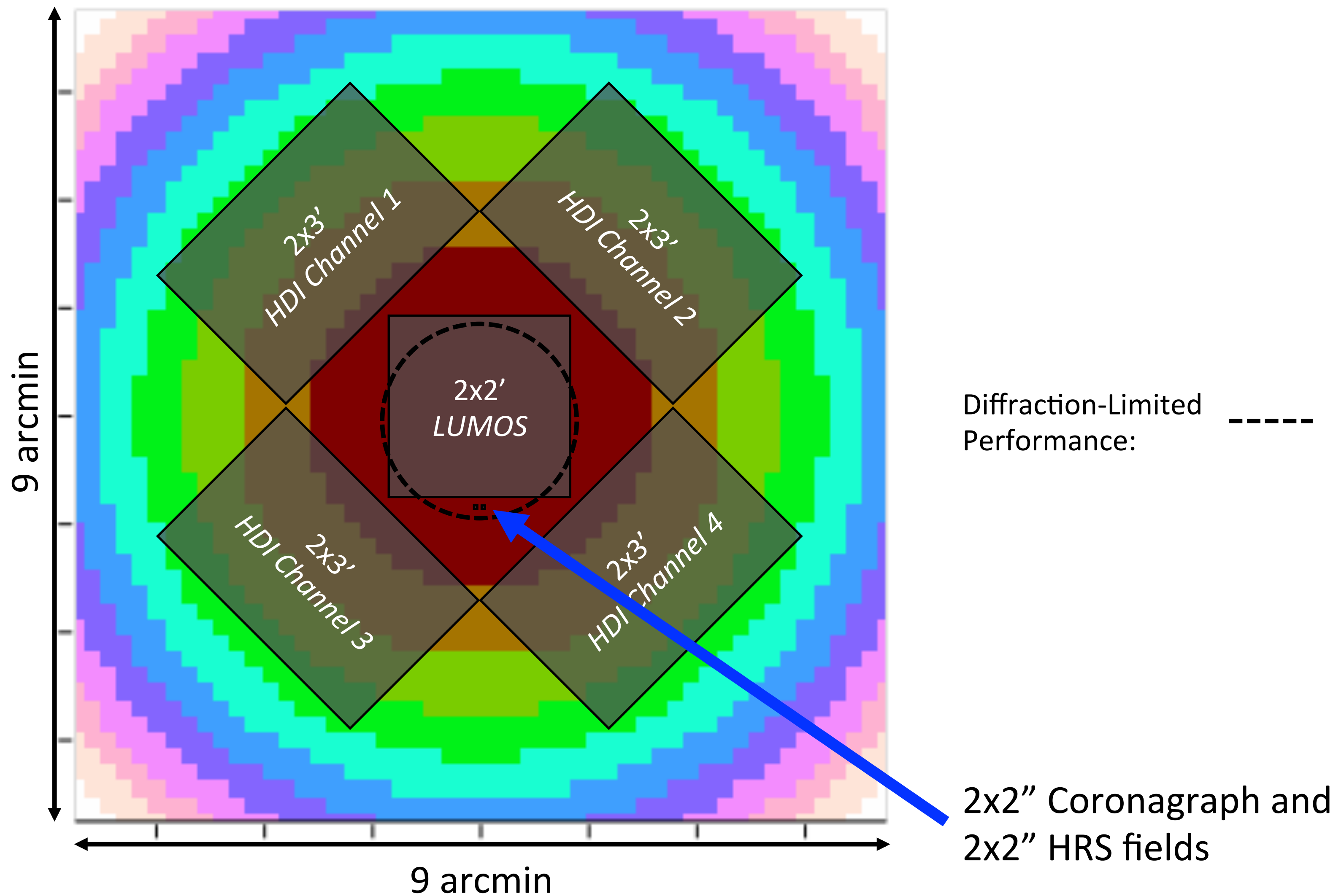

# Summary Stoplight Chart

| **Capability:** | **TMA-SF** | **TMA-DF** | **RC** |
|---|---|---|---|
| Presence of High-Throughput Channel | | | |
| Wide Field-of-View Capability | | | |
| Cassegrain Focus Field-of-View | | | |
| Alignment Complexity | | | |
| Instrument Packaging Complexity | | | |
| Availability of Fine-Steering Mirror | | | |
| Angle-of-Incidence Impact on Polarization | | | |

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| Angle-of-Incidence Impact on Polarization | | | |
| Optical / NIR Coronagraph | | | |
| *LUMOS* | | | |
| *HDI* | | | |
| Optical / NIR Spectrograph | | | |

# LUVOIR Launch Vehicle Accommodations

- Assume LUVOIR will initially accommodate four or more instruments

- Concepts that use an SLS with 8.4-m or 10-m diameter fairings are consistent with this assumption
  - SLS concepts will be constrained by cost before mass to orbit or fairing volume constrains the number of instruments
  - Other launch vehicles (Space X, Blue Origin) worth keeping an eye on

- Concepts that use a launch vehicle with a 5 m dia. fairing (like Delta IV Heavy) are more challenging
  - Instrument studies can probe for risks and methods of mitigation

# LUVOIR Launch Vehicle Accommodation

Telescope Aperture Diameter (m): **6.5** **9.2** **12** **16** **20**

**Launch Vehicle:**

**SLS Block 2B**
50 k kg to L2 orbit
10 m fairing

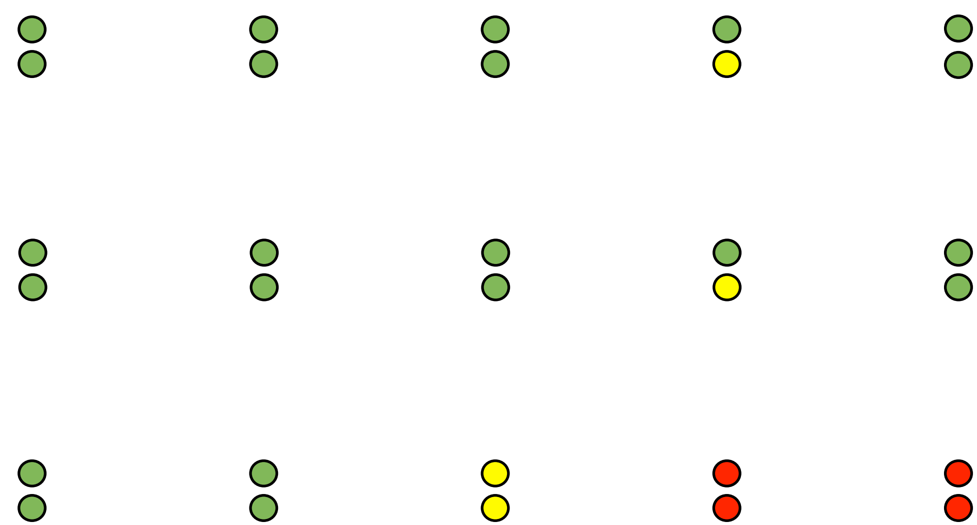
Mass Margin **M**
Volume Margin **V**

**SLS Block 1B**
38 k kg to L2 orbit
8.4 m fairing

**M**
**V**

**Delta IV Heavy**
10 k kg to L2 orbit
5 m fairing

**M**
**V**



Feasible   Not Feasible   Needs Validation

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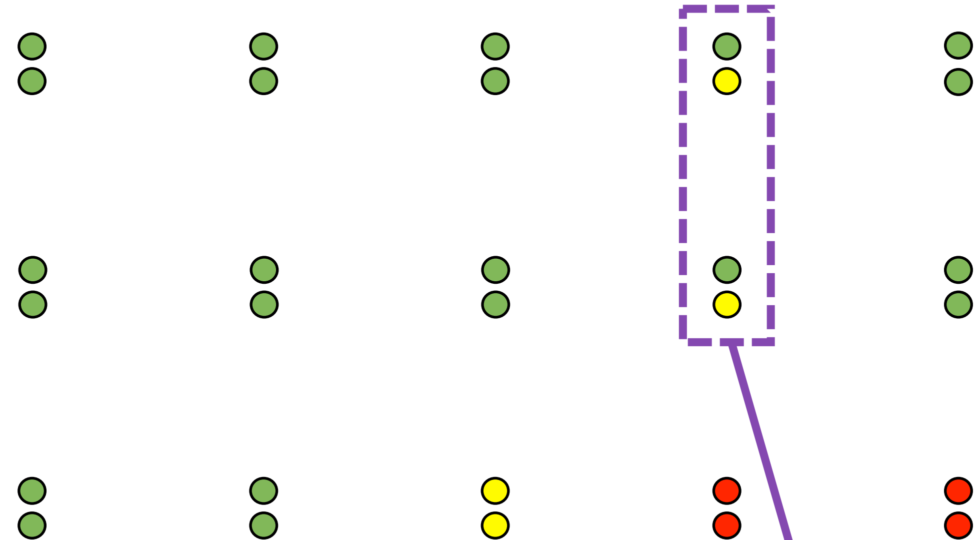

To achieve necessary stiffness requires a thick backplane that consumes volume.

Feasible Not Feasible Needs Validati

# LUVOIR Test Facility (JSC) Accommodation

- $LN_2$ is likely required for thermal balance tests
  - Helium shroud not needed
- Assuming a room temperature telescope:
  - Some tests performed in vacuum with autocollimating flats
  - Some tests, like center of curvature conducted in ambient environment in a cleanroom
  - Both tests leverage JWST experience
- Secondary Mirror will likely need to be deployed or installed inside the chamber
- Need ~2-meter clearance around edge for access, cables, etc.
- Demonstrate thermal stability with subscale testing (e.g. single wing of mirrors)
- Dynamics demonstrated in cleanroom and through model validations

# LUVOIR Test Facility (JSC) Accommodation

| Telescope Aperture Diameter (m): | | | 6.5 | 9.2 | 12 | 16 | 20 |
|---|---|---|---|---|---|---|---|
| **Facility Sizes:** | | | | | | | |
| **Vacuum Vessel** | | | | | | | |
| Diameter (19 m) | Diameter Margin | **D** | 🟢 | 🟢 | 🟢 | 🟡 | 🔴 |
| Height (36 m) | Height Margin | **H** | 🟢 | 🟢 | 🟢 | 🟢 | 🔴 |
| **$LN_2$ Shroud** | | | | | | | |
| Diameter (16 m) | | **D** | 🟢 | 🟢 | 🟢 | 🔴 | 🔴 |
| Height (28 m) | | **H** | 🟢 | 🟢 | 🟢 | 🟢 | 🔴 |
| **Helium Shroud** | | | | | | | |
| Diameter (13 m) | | **D** | 🟢 | 🟢 | 🔴 | 🔴 | 🔴 |
| Height (20 m) | | **H** | 🟢 | 🟢 | 🟡 | 🔴 | 🔴 |

Feasible 🟢 Not Feasible 🔴 Needs Validation 🟡

# Additional Aperture-driven Values*:

| D (meters) | Area ($m^2$) | Number of Segments | Heater Power (W) | Mirror Mass (kg) | Backplane Mass (kg) | Backplane Thickness (m) | Total PM Mass (kg) |
|---|---|---|---|---|---|---|---|
| 6.5 | 33.2 | 18 | 627 | 829 | 1327 | 0.33 | 2156 |
| 9.2 | 66.4 | 36 | 1257 | 1661 | 2658 | 0.66 | 4319 |
| 12 | 113.0 | 61 | 2139 | 2826 | 4522 | 1.12 | 7348 |
| 16 | 201.0 | 109 | 5024 | 5024 | 8038 | 1.98 | 13062 |

*Back of the envelope calculations. Assumes 293 K operating temperature and slightly-better-than-JWST areal density.

# Remaining Telescope Architecture Decisions:

| | |
|---|---|
| Aperture size(s) | Your vote today! |
| Observatory temperature | Red cutoff vs. acceptable cost and risk |
| Telescope optical design | Instrument FOVs<br>Instrument pointing requirements<br>Instrument image quality requirements |
| On- vs. Off-axis | Outcome of polarization studies<br>Investigating deployment/packaging options<br>Impact on exoplanet yield |