TRW Space & Electronics Group

Very Large Sparse Aperture Concept

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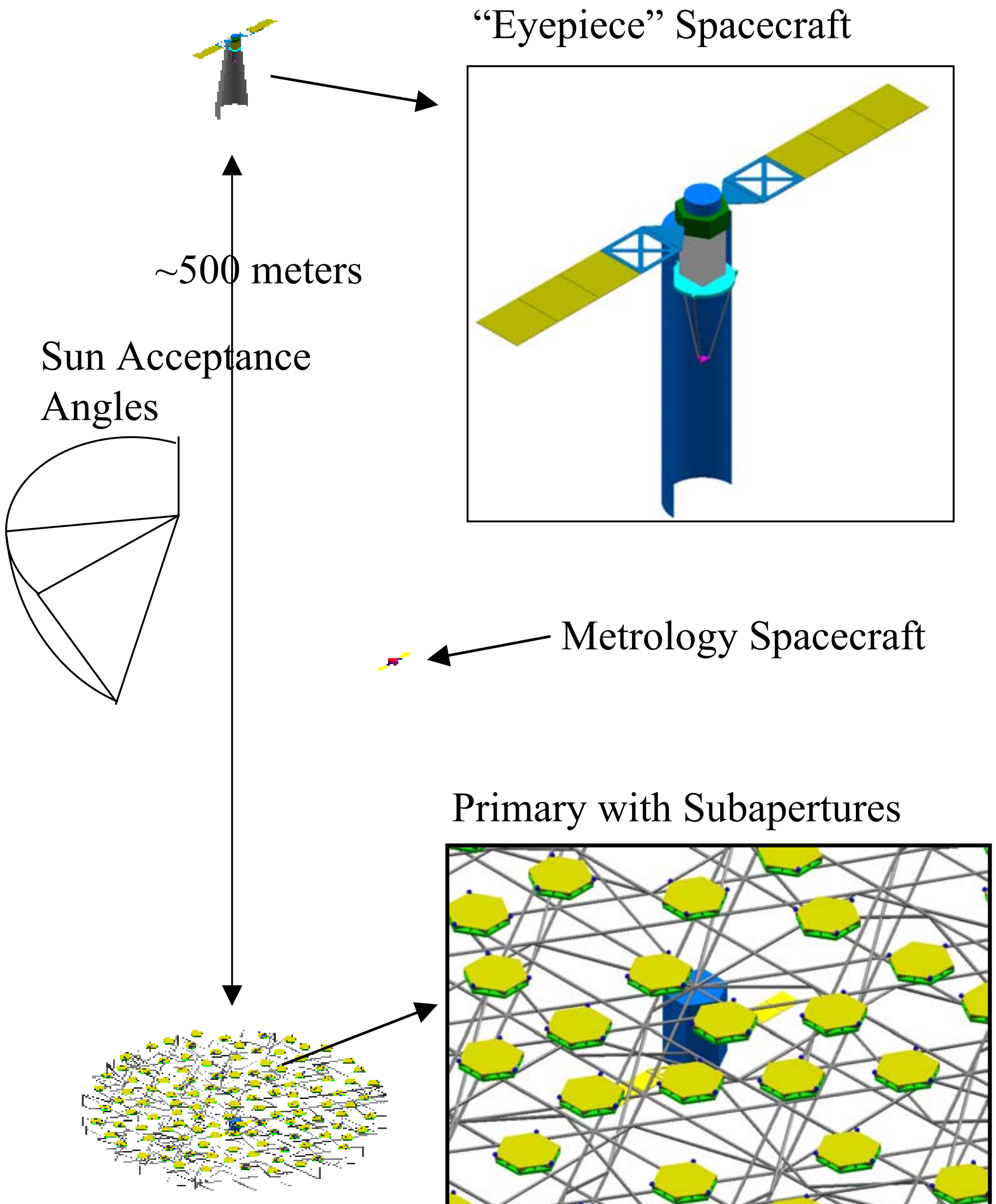
Sparse Aperture Concept Description

TRW



- Eyepiece spacecraft is self contained assembly housing secondary, additional optics, simple occulting spot and focal plane
- Sugar scoop baffle provides sunlight rejection and optics cooling

- Metrology spacecraft provides laser metrology between secondary spacecraft and the primary

- Primary is a lightweight monolithic truss supporting subapertures
- One satellite performs formation flying and actuators position of individual mirror elements

Concept Description

~120 4 meter subapertures sparsely filled (5-20%) 100 meter class giant telescope

- Operation on IR
- Excellent resolution
- Large collecting area

Primary mirror:

~100m monolithic structure

- Spherical mirrors with radius of curvature control
  - Simulates elements of a large parabola
  - Passively cooled mirrors (~100K) allows operation into LWIR
- Primary spacecraft formation flies to sub-centimeter accuracy

Instrument spacecraft directly images the exo-solar system

- 3 meter secondary, with territory and quaternary
- Simple occulting spot reduces starlight intensity
- ‘Snow-scoop’ thermal baffling

Navigation spacecraft measures and directs spacecraft and optics into position

- 3 color laser metrology measures optical elements to nanometer accuracy
- Directs spacecraft and optical elements into alignment

Sparse Aperture Trade Space Considered

Orbits
- Earth
- Drift-Away
- L2

Wavelengths
- Visible
- 1-5 µm
- 5-20 µm

Primary Size
- 50m
- 150m
- 500m
- 1000m

Number of Subapertures
- ~50
- ~100
- ~300

Primary Geometry
- Free Flying
- Monolithic Structure

Subaperture Diameter
- ~2m
- ~4m
- ~5+m

Subaperture Figure
- Spherical - fixed
- Spherical - adjustable Rc
- Spherical - dual-axis adjusted Rc
- Off-axis paraboloid

Optical Configuration
- Prime focus
- 3 mirror
- 4 mirror
- 5 mirror

Legend

🟥 **Rejected**

⬛ **Baseline**

Trade Space Considerations

- Orbit
  - Earth orbit: Not appropriate for tight Formation Flying (FF)
  - Drift-away: Good for FF; not suitable for multiple launches; cannot be replenished
  - L2: Satisfactory for FF; easy replenishment

- Wavelengths
  - Visible: Imposes tight constraints on pointing/alignment accuracy
  - 1-5 µm: Doable pointing requirements; poor performance
  - 5-20 µm: Good performance, easier pointing/alignment requirements

Trade Space Considerations (Cont'd)

- Primary size
  - 50m: Good resolution at ~1µm
  - 150m: Acceptable resolution at ~10µm
  - 500m: Good resolution at 10µm (however, poor fill factor)
  - 1000m: Poor fill factor

- Primary structure
  - Free Flying: Allows flexibility in aperture size/spacing; significant operation complexity; significant cost for multiple spacecraft
  - Monolithic Structure: Very large size requires on-orbit assembly; aperture not adjustable; low thrust upper stage to L2

- Number of sub-apertures
  - ~50: Results in a very sparse array
  - ~100: Results in a reasonable fill factor
  - ~300: Too expensive

Trade Space Considerations (Cont’d)

Subaperture diameter

- ~2m: Relatively inexpensive, but wastes LV volume
- ~4m: Largest size fitting in typical LV
- ~5+m: Requires a deployable design; added cost, complexity

Subaperture figure

- Spherical-fixed: Inexpensive to fabricate; results in large aberrations
- Spherical-adjustable R_c: Permits first order correction to match local figure of parabola; allows subaperature placement anywhere in primary; simple mechanism
- Spherical-dual axis adjustable R_c: Permits second order matching of local parabola figure; more complicated
- Off-axis parablola: Expensive to fabricate and each unique to one radius of the primary

Trade Space Considerations (Cont'd)

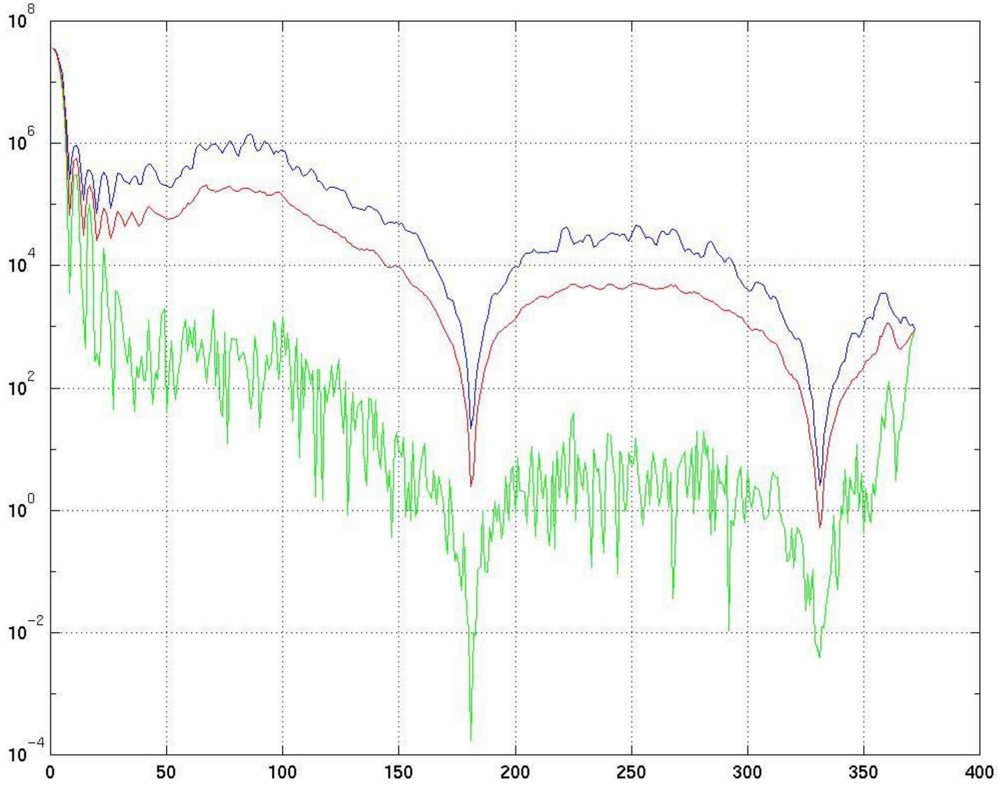
- Optical configurations
  - Prime Focus
    - Poor fit to pixel size and PSF sampling unless system is quite long (f/30)
    - No field or Lyot stops
  - 3-mirror telescope:
    - Poor satellite/optical architecture unless a large convex secondary is used
    - Usually no field or Lyot stops
    - Poor fit to pixel size and PSF sampling
  - 4-mirror telescope:
    - Practical mechanical architecture with fewest mirrors
    - Concave secondary
    - Field and Lyot stops
    - Easy matching to pixel size and PSF sampling
  - 6-mirror telescope:
    - 3-mirror objective with 3-mirror off-axis reimaging anastigmatic
    - Concave secondary
    - Accessible intermediate field and Lyot stops for aberration correction and scattered-light control

System Sizing for Science

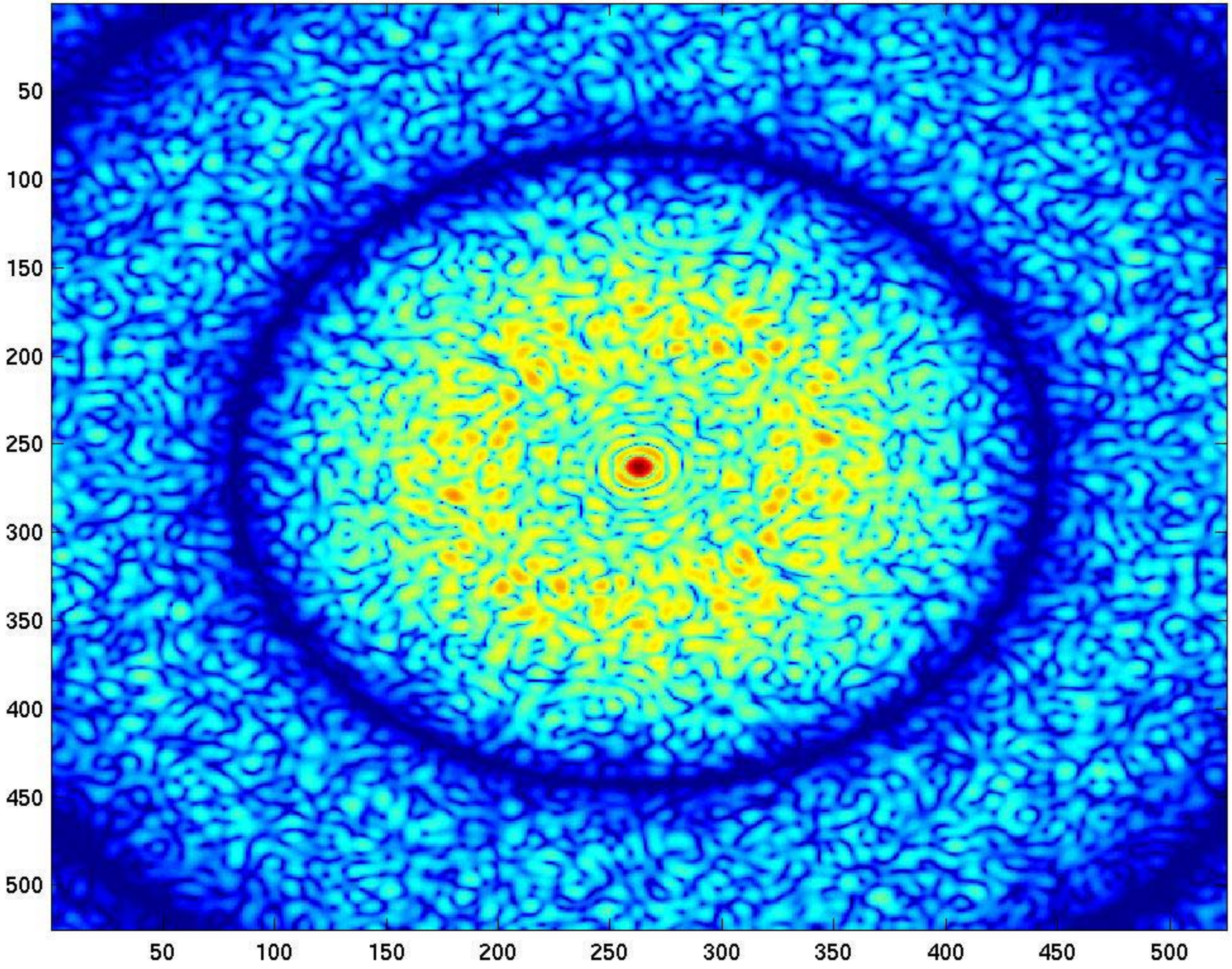
Science Driver	System Sizing for Science	Engineering Constraints
• Good imaging performance	• Fill factor for good imaging – >20% desired – <5% is poor	• < 50% for collision avoidance
	• Random positioning of sub-apertures to reduce structure/aliasing in PSF	–
	• Many subapertures	• ~ 100-150 subapertures; cost constrained
• Resolution to separate planet from star	• Planet-finding region substantially far from central spike (~10x)	–
	– 1 µm >30m primary	• Collision concern at <50m for FF option
	– 10 µm >300m primary	• Poor fill factor at >150m

Numerical Integration Produces Sparse Aperture PSF

- Diffraction integral over complex aperture function adds subaperture Airy spots in phase with appropriate subaperture spacing
- 100 m primary mirror
- 120 x 4 m subapertures (19% fill factor)



Sparse PSF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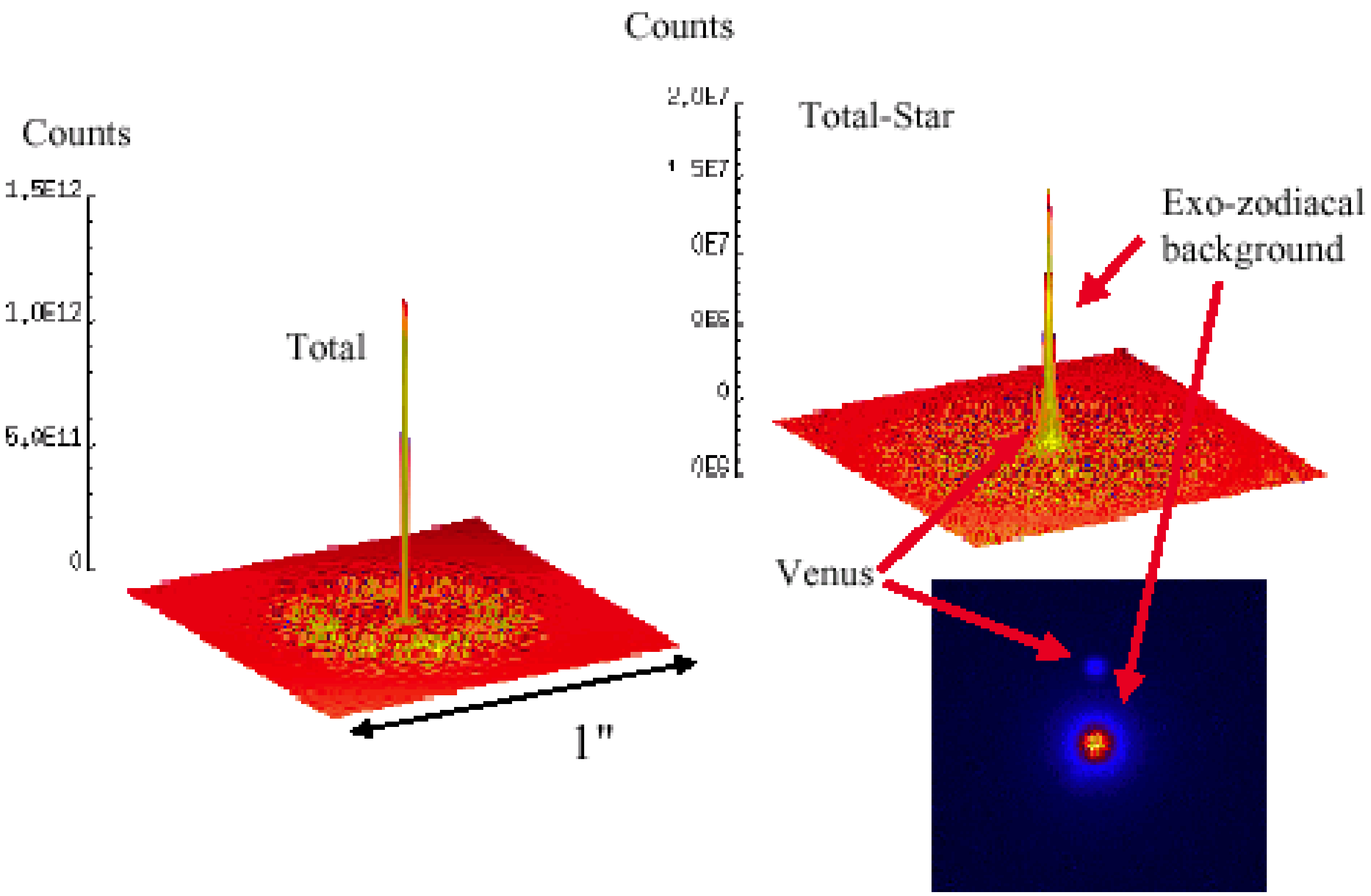
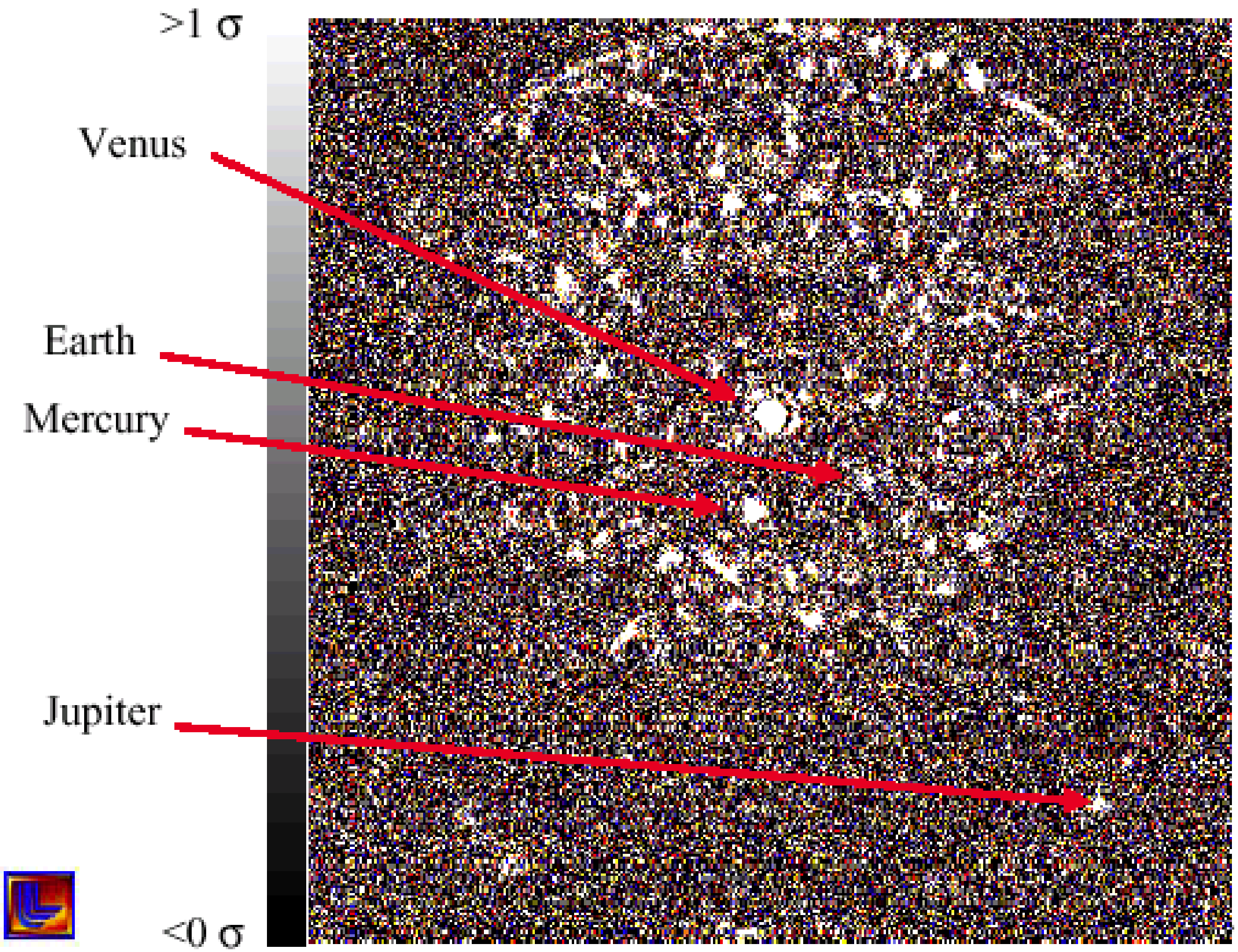
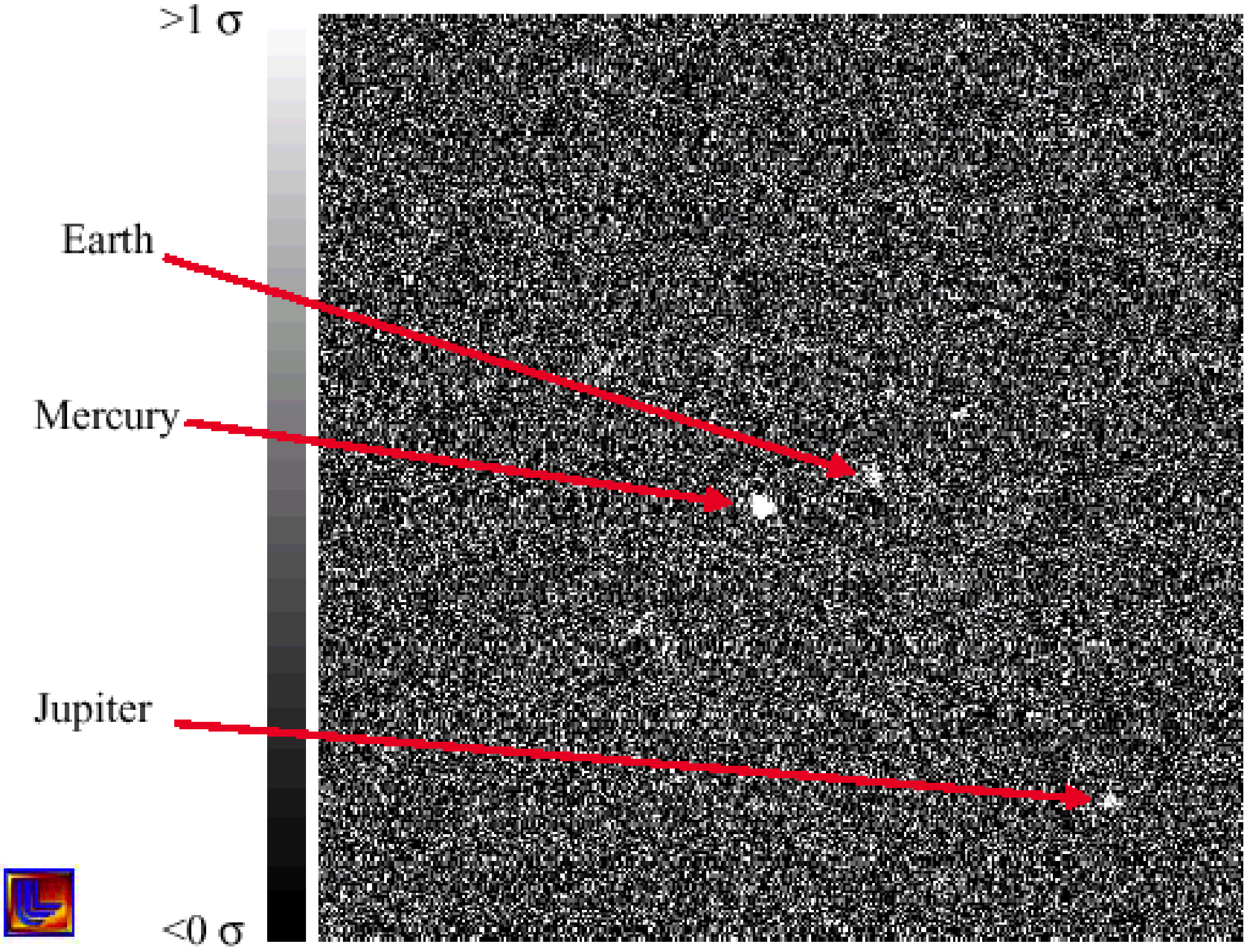
Simulated Sparse Aperture Scene



Scene With Venus



Scene Without Venus



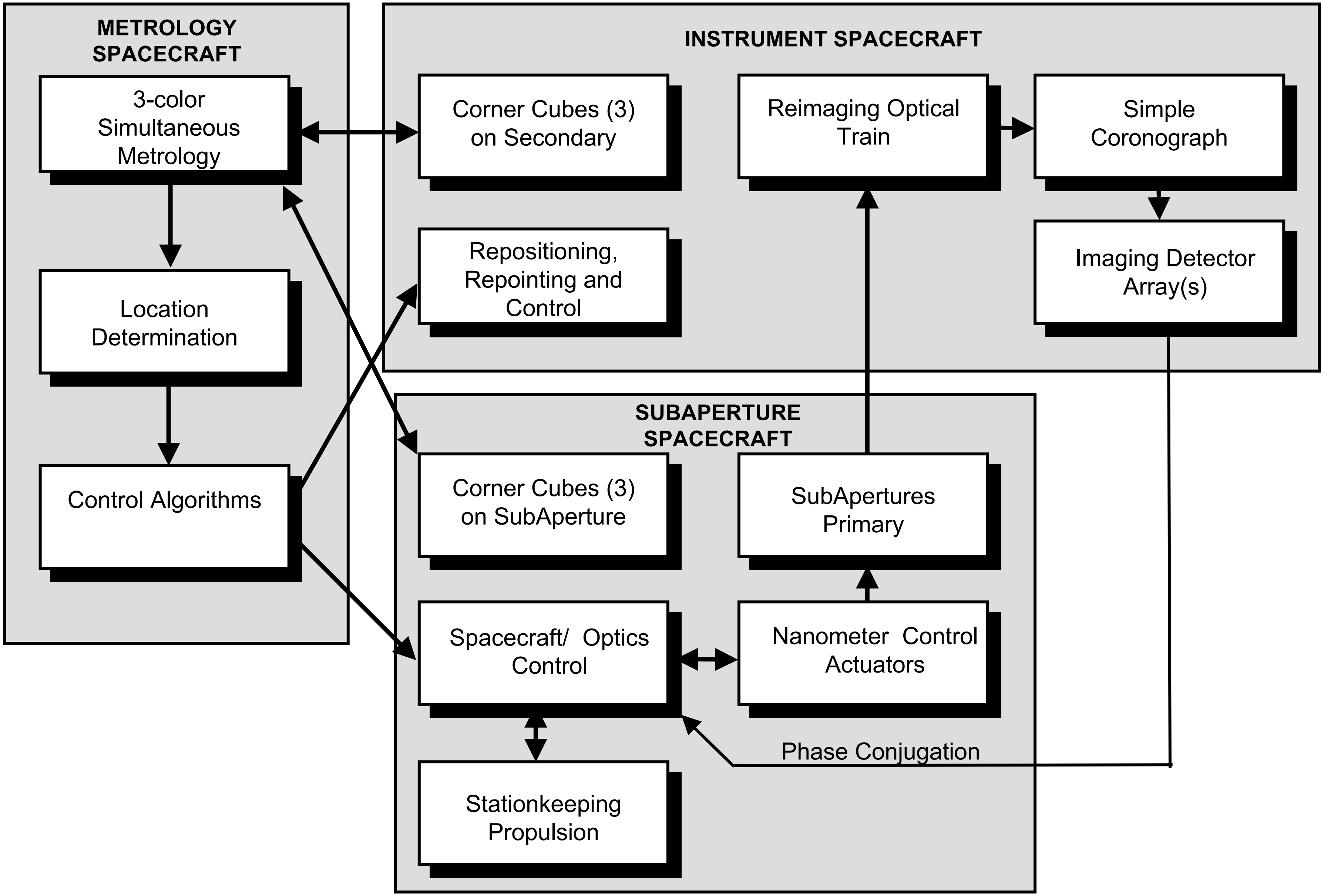
Sparse Aperture Detection/ Characterization Times

- Sun at 10 pc, Earth 100 marcsec from Sun; albedo = 0.38; 50% phase
- 100 m f5 primary; 120 4 m subapertures randomly distributed
- 120K Mirror temperature
- SNR = 5

	Time (hours)				
R ($\lambda/\Delta\lambda$)	0.8 um	1.0 um	1.5 um	8 um	15 um
2	1396	1333	1609	-	-
3	2066	2000	2469	2.3*	0.4
10	-	-	-	7.1	1.2
30	-	-	-	21.2	3.6
100	-	-	-	70.5	12.1
300	-	-	-	211.5	36.2
1000	-	-	-	704.9	120.7

* Charlie Bennett’s model calculates 0.6-2.5 hours depending on assumptions (see backup charts)

Sparse Aperture Functional Block Diagram



Key Engineering Parameters

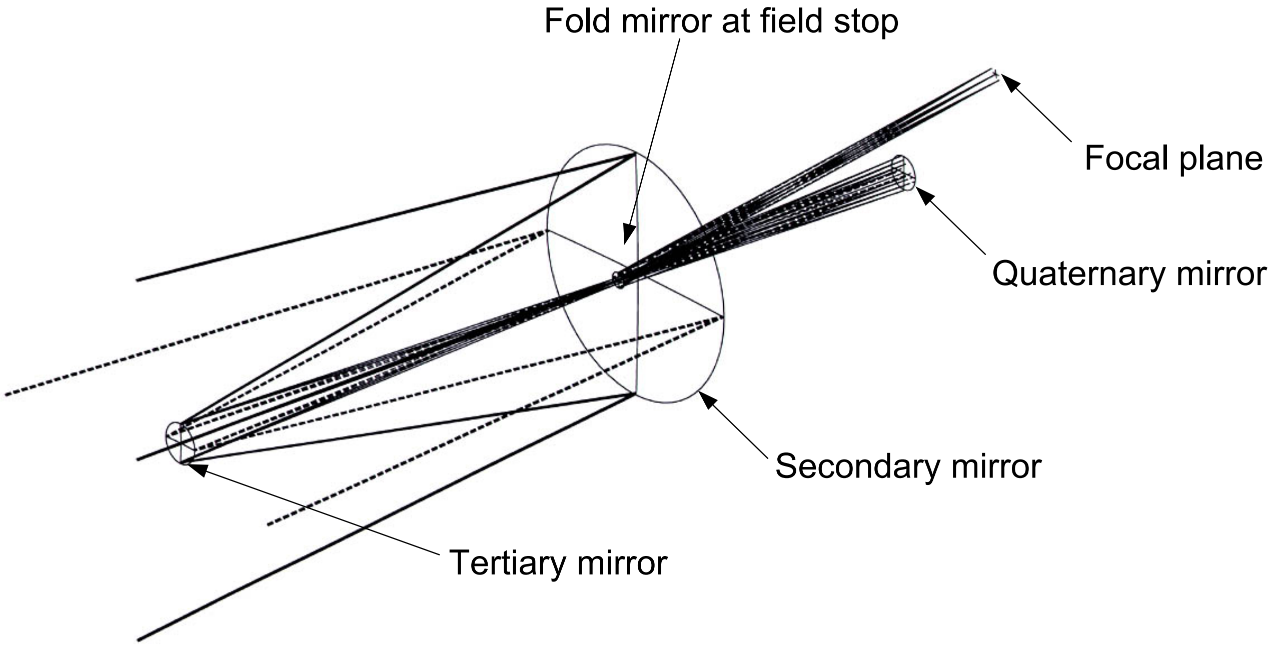
Engineering Parameter	Rationale
Formation Flying subaperture option	Allows primary reconfiguration to different diameters, subaperture arrangements
Monolithic structure supporting option	On-orbit construction required and launch subaperture into final orbit
4m collecting subapertures	Fits in existing LV fairings
120 subapertures	Provides good PSF
Spherical mirrors	Inexpensive to make
25 nm rms subaperture piston position accuracy	Can closely match appropriate parabola
16 nm rms subaperture tilt about center	Tilt less than half the primary Airy radius
1nm metrology accuracy	Relieves alignment requirements
f5 primary	Easily achieved via passive cooling
~100K mirror temperatures	Enables operation into MWIR (<10 µm)
~1cm spacecraft Formation Flying (FF) accuracy	Capability to be verified by ST-3
1cm - 1 nm actuators	Bridges FF and optical control capabilities

Preliminary Optical Prescription of Instrument

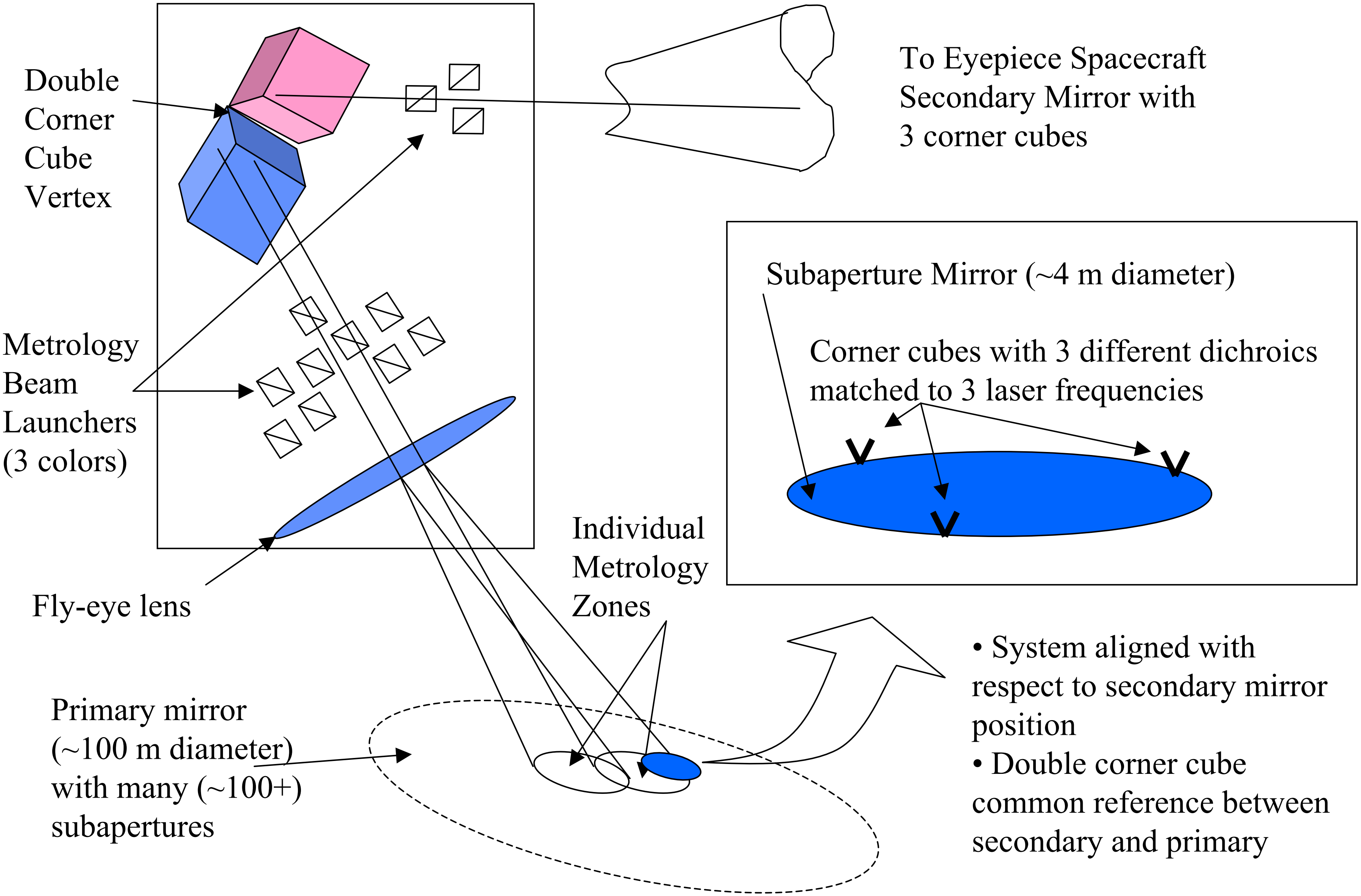
Optic	Diameter	Curvature Radii	Shape	Figure
Sparse Primary	< 125 m	1250 m	Concave	Parabola
Secondary	3.0155 m	22.0 m	Concave	Hyperboloid
Tertiary	0.423 m	2.11 m	Convex	Hyperboloid
Quaternary	0.300 m	4.70 m	Concave	Prolate Ellipsoid

FPA Characteristics: (5 arcsec FOV)

– 3726 x 3726 pixels, 40 μm (149 x 149 mm array)



Strawman Metrology System



Double Corner Cube Vertex

To Eyepiece Spacecraft Secondary Mirror with 3 corner cubes

Metrology Beam Launchers (3 colors)

Subaperture Mirror (~4 m diameter)

Corner cubes with 3 different dichroics matched to 3 laser frequencies

Fly-eye lens

Individual Metrology Zones

Primary mirror (~100 m diameter) with many (~100+) subapertures

- System aligned with respect to secondary mirror position
- Double corner cube common reference between secondary and primary

Technology Status

Key Enabling Technology	Technology Status
Nanometer resolution metrology	Existing technology developed on SIM program
Nanometer metrology providing absolute distances over meter class zones	TBD
Simultaneous multi-color metrology	New development
Nanometer control over ~cm stroke	NGST actuators and SIM delay lines meet these requirements
100 m sparsely filled primary	Similar to Space Station dimensions; on-orbit construction may be common by TPF timeframe
Formation Flying Technology to <1 cm accuracy	In development on ST-3
4 meter variable curvature spherical mirrors, lightweight, inexpensive	AMSD and Kodak technology shows this is feasible
Passive thermal cooling of optics	Existing SIRTF technology; NGST developing similar technology

Tall Tent Poles

- Multicolor metrology capable of nanometer resolution and absolute distance measurements over 100s meters
  - SIM has developed nanometer resolution metrology
  - Development of multicolor capability and absolute measurement is challenging
- Precision control of hundreds of optical elements to nanometers