Alternate Architectures for Future Astronomy Missions

THE VALUE OF PERFORMANCE.

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Presentation to COPAG

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and
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Northrop Grumman Aerospace Systems

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History of Large Observatories and Implications for the Future

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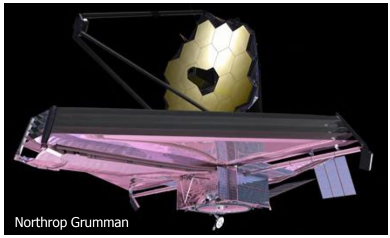
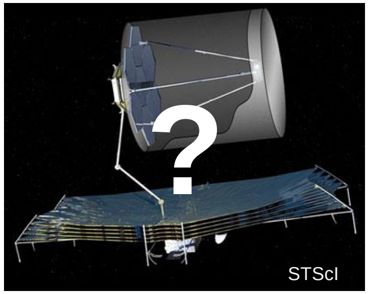
- Both Hubble and Webb space telescopes were threatened with cancellation for cost and schedule growth at various times in their development (as were virtually all flagship missions)
  - Rising NASA budgets mitigated this issue prior to mid-2000's
  - In our current era we have flat/declining budgets but large apertures are still needed to do forefront science
    - Cost growth generates a negative image of large space telescopes
    - Continued cost growth may end future large aperture space telescopes
  - The total cost is certainly a problem, but the annual cost generates the most immediate threat
    - As the annual cost becomes a large fraction of the astrophysics budget it delays all other developments and termination of the "monster" program begins to appeal to the community



- Future outlook
  - NASA budget will likely continue to be flat, at best
  - Cost curve "breaks" and international collaborations will help reduce or distribute costs but are unlikely to reduce total/annual costs by > 50%
  - Large space telescopes will still cost more than the budget allows



- ***Then how do we build the next big observatory (after WFIRST)?***

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Alternate Large Space Telescope Architecture Studies

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- In 2014 NGAS undertook an internal study to explore alternate ways to build future telescopes
  - Work on various large space telescope concepts had been done by various groups (NG and others) over the past decade
  - With the onset of a “flat” NASA budget a substantial amount of discussion occurred on ways to “break the cost curve” and build a more affordable telescope
  - Technology advances in mirrors, wavefront control, deployable structures, mechanical and thermal disturbance control, and many other areas allowed for exploration of new approaches to building space telescopes
  - The time was ripe for a new and integrated look at large space telescopes

The Evolvable Space Telescope Study was begun…

- In 2015 we broadened this study to also look at a Rotating Synthetic Aperture
  - This is a rotating rectangular aperture concept in which the US Government has invested a large amount of funding for non-astrophysics application
- Today I will present a very, very brief overview of both concepts
  - Work is continuing in 2015 on both architectures

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Evolvable Space Telescope

Evolvable Space Telescope (EST)

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A major system architecture change is needed to make large space telescopes buildable

- Begin small and grow in stages to achieve a > 14 meter segmented telescope
  1. **Stage 1**: First, build, launch, and conduct high value science with a fully functional medium size "bow-tie" two segment (3-4 meters segments) telescope complete with instruments.
  2. **Stage 2**: Some years later augment a mirror, instrument, and service package to join with and enhance the Stage 1 telescope to a larger (8 – 12 meter) aperture for increased collecting area and resolution and enhanced instruments. Support subsystems can also be improved.
  3. **Stage 3**: Augment the existing Stage 2 telescope with more mirror segments, achieving a 14 – 20 meter aperture with new, enhanced, instruments and additional support systems.
  4. **Stage 4+**: Sustain and enhance the now existing Space Observatory as needed and possible to enable a multi-decade useful lifetime.
- This approach alleviates the peak cost per year issue and overly long development cycles where no science is obtained
  - The augmentation schedule is dictated by budget realities, science needs, and technology advances.
  - Science data is obtained continuously beginning with Stage 1 commissioning with only HST-like servicing gaps in the science return

An Evolvable Space Telescope Requires a Different Culture Change

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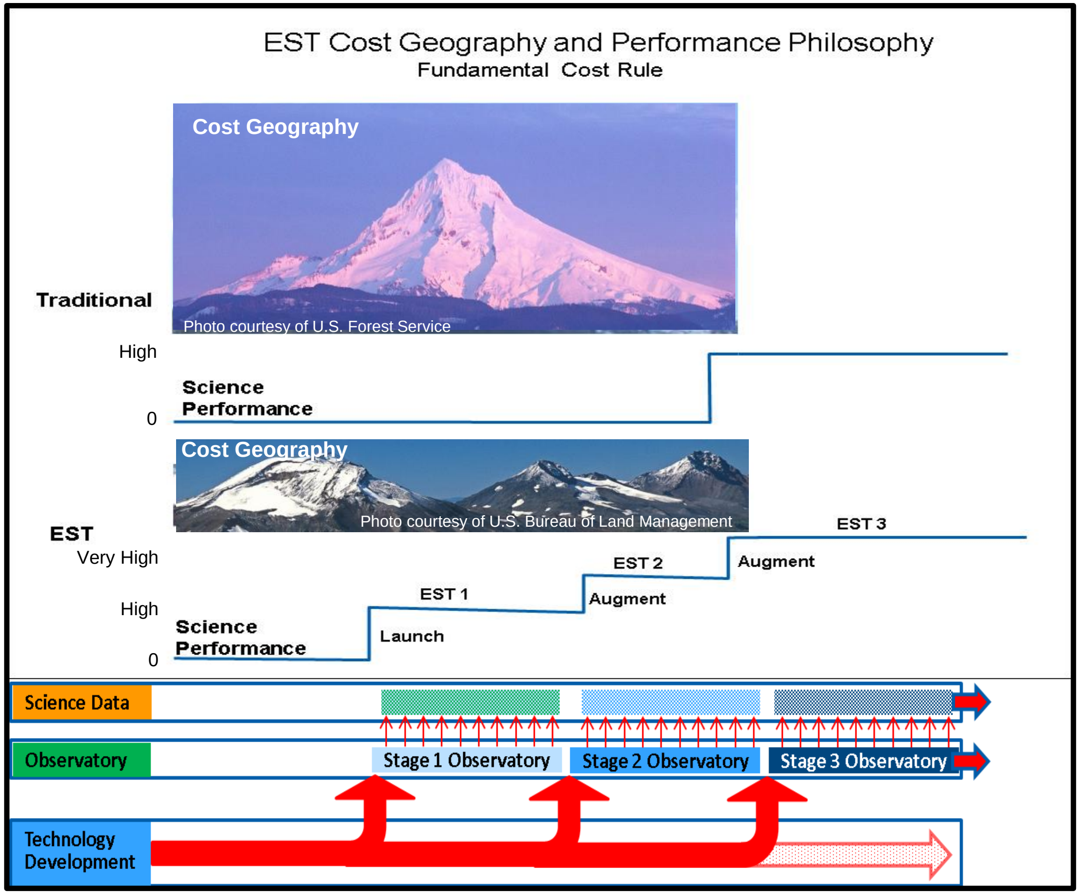
- Commit to a longer term program to modulate the large cost/year fluctuations
  - Schedule is dictated by budget realities (can accelerate or decelerate), new science needs, and technology advances.
- Grow the performance in space over time
  - Launch early with a telescope capable of first rank science
  - Design for aperture, resolution, science scope to evolve with time
  - Improve/advance instruments with on-orbit replacement



- Benefits:
  - Much earlier science return
  - On-orbit replacement of instruments and support hardware to adapt to evolving science and technology
  - Better overall science due to “newer” instruments

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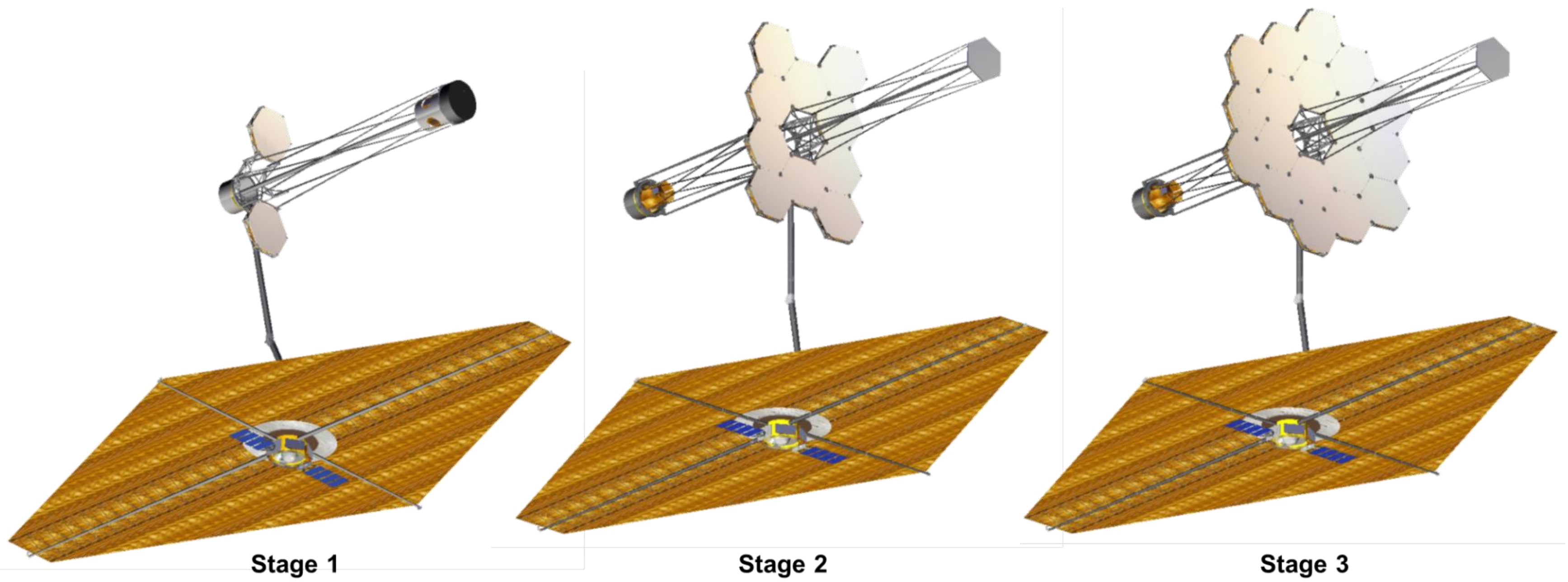
Visualization of All Three EST Stages



Evolvable Space Telescope Observatory Stages

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EST Specific Measures of Merit:
Evolvability, Adaptability, and Serviceability

- Evolvability driven principally by evolving science goals and technology
  - Science goals that advance and adapt in the light of enhanced knowledge
  - Adapt to newly developed technological capabilities for science measurement
  - Evolve system capability through adding, modifying, or eliminating subsystems
  - Need to maintain technology roadmap for both incremental and dramatic advances
- Adaptability (science and technology are the core – evolvability)
  - Budgetary (need to respond flexibly and rapidly to increments and decrements – and to find greater efficiencies)
  - Incorporate standard systems, internal and external to EST, wherever possible (e.g., docking)
  - Responsive to changes in programmatic and political environments, both positive and negative
    - Able to incorporate new collaborators
- Serviceability: designed for maintenance, repair, and upgrading
  - Serviceability also provides a common basis for assembly on orbit:
    - Minimize complex deployments
    - Reduce failure modes

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Top Level Requirements

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- To achieve the suggested science goals for a beyond JWST/WFIRST era we developed a set of preliminary top level requirements for the observatory system:

Parameter	Requirement	Goal	Notes
Telescope Aperture	> 10 m	> 16 m	> ATLAST concept
Stage 1	Bow-tie	4 x 12 m	Two hexagonal segments
Stage 2	Filled Aperture	12 m	Twelve hexagonal segments
Stage 3	Filled Aperture	20 m	Eighteen hexagonal segments
Wavelength	100-2400 nm	90-8000 nm	UVOIR, MIR under evaluation
Field of View	5 to 8 arcmin	30 arcmin	Wide field VNIR imaging
Diffraction Limit	500 nm	250 nm	Enhanced UV/Optical resolution
Primary Segment Size	2.4 m	3.93 m	flat to flat
Primary Mirror Temp	< 200 K	150 K	Minimize heater power
Design Lifetime	15 years	>30 years	On-orbit assembly and servicing

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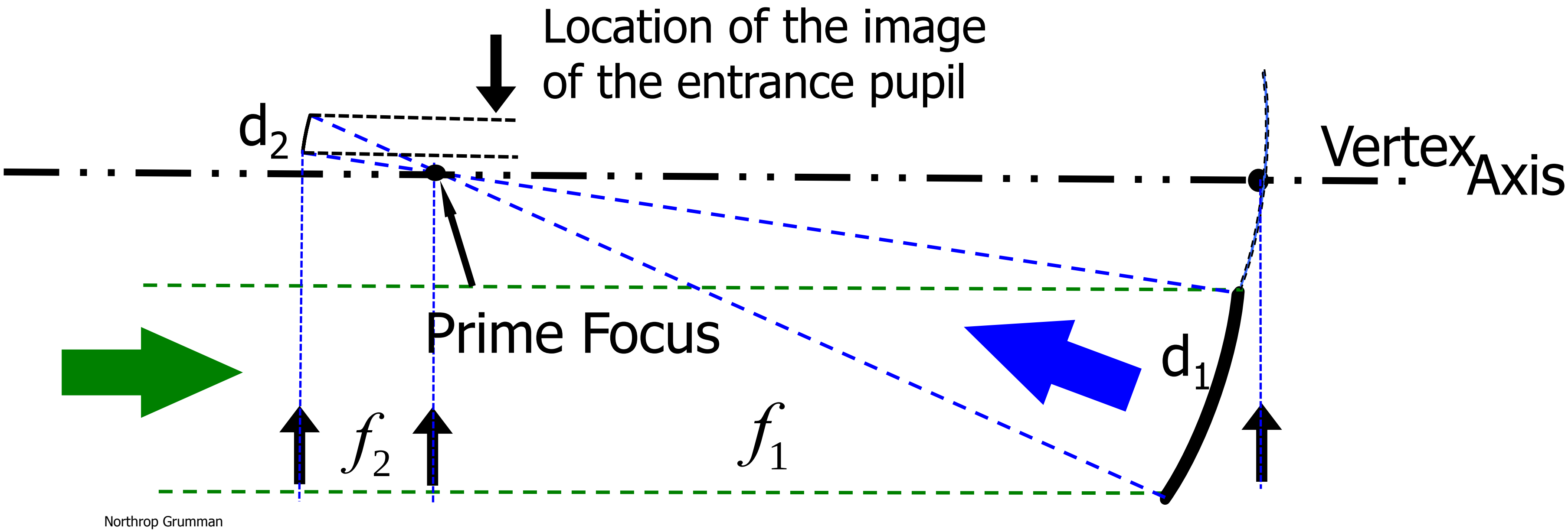
Prime focus layout for one segment



- One reflection to the prime focus instrument (1st Coronagraph Mask and/or UV spectrograph entrance slit)
  - Excellent UV performance, maximum transmittance
  - Scattered light control maximum (coronagraphy)
- Two reflections to the primary A/O
  - Minimum instrumental polarization & thermal surfaces to radiate
- Primary topic of study in 2015

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Rotating Synthetic Aperture

Rotating Synthetic Aperture (RSA) Architecture

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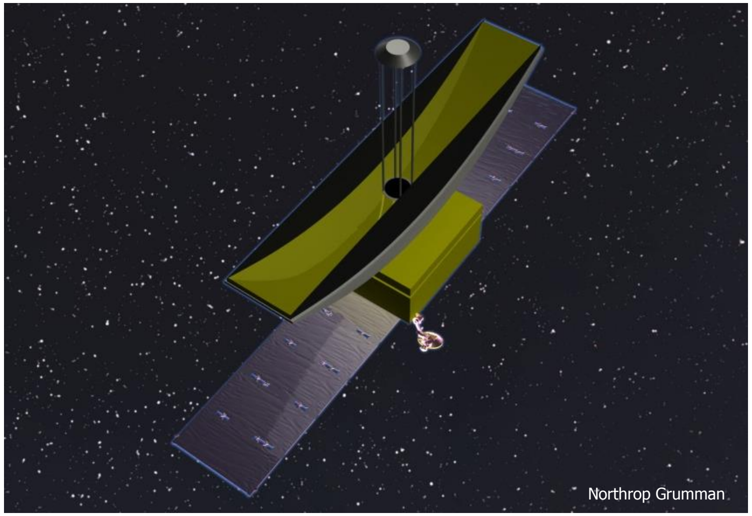
- The U.S. Government has invested nearly a third of a billion dollars in the development of RSA technologies that can be leveraged to yield the highest performing, lowest cost, large aperture astrophysics mission.

- A range of options enables the architect to balance key parameters such as
  - Light gathering area
  - Angular resolution
  - Integration times

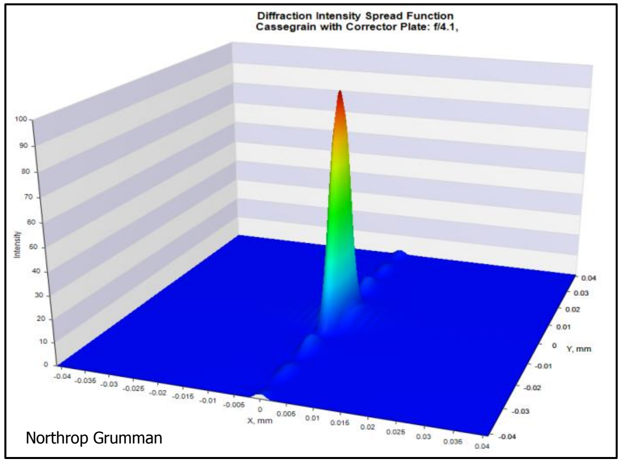


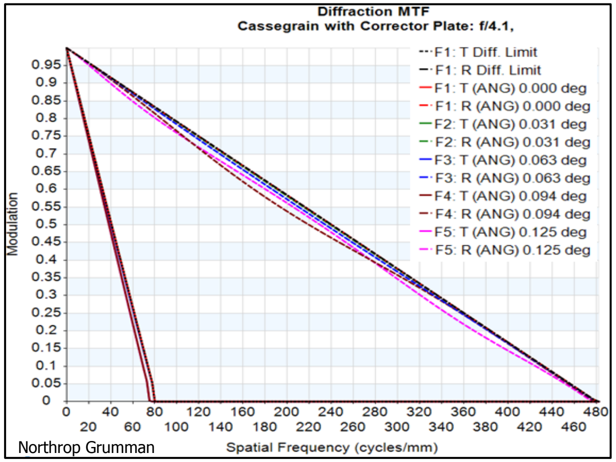
A 10m RSA hosted on a JWST-adapted Bus

Rotating Synthetic Aperture Parameters					12m Aperture Comparison		Diameter of filled aperture with equivalent light gathering capability (m)
Aspect Ratio	length (m)	width (m)	mirror area (m^2)	Vis. (500nm) Ang. Res. (arcsec)	RSA Fill Factor	RSA Integration Time factor	
4:1	16	4	64	0.00786	56.6%	3.12	9.03
6:1	18	3	54	0.00699	47.7%	4.39	8.29
8:1	20	2.5	50	0.00629	44.2%	5.12	7.98

How a Rotating Synthetic Optical Aperture Works

- The Point Spread Function (PSF) produces resolutions that differ by the aspect ratio of the aperture. PSF stability over longer integration times is critical to the objective astrophysics missions
- PSF stability may be accomplished with large format mirrors made from low coefficient of thermal expansion (CTE) materials such as beryllium, ultra-low expansion (ULE) glass or ZERODUR® and mounted on a Glass Fiber-Reinforced Polymer (GFRP) backplane for added stability
- PSF Noise may be minimized by matching detector and synthetic aperture aspect ratios, thus improving Signal to Noise Ratio (SNR)
- The Modulation Transfer Function (MTF) degrades from near ideal on axis to lower resolution as the field angle in the MTF figure increases





RSA PSF and MTF functions, evaluated at the focus of the parabolic primary mirror for a Cassegrain f/4.1 optic

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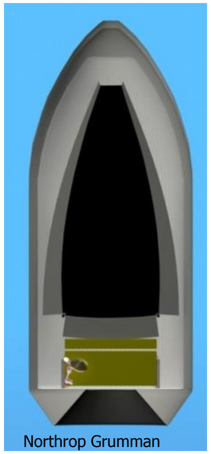
RSA Single Launch to L2 Orbit

- An 18m 6:1 aspect ratio RSA optic weighs about 22% of an 18m filled aperture optic. This mass reduction translates to cost savings on both the observatory and launch vehicle.
- Synthetic apertures up to 20m may be stowed within 5m fairings with two hinged folds between 3 mirror segments
- A 9000 kg RSA observatory can be launched to L2 Orbit on any one of three current or planned U.S. launch vehicles

	Mass (kg)	Power (W)
Slit Aperture Optical Telescope Element (18m)	**3764**	**54**
(Scaled from JWST 70 kg/m^2, 1 W/m^2 CBE ratios)		
Integrated Science Instrument Element	**1263**	**268**
(from JWST CBE)		
Spacecraft Element (from JWST CBE)	**2462**	**898**
Electrical Power Subsystem	163	87
Attitude Control Subsystem	124	216
Comm Subsystem	20	183
C&DH Subsystem	39	175
Propulsion Subsystem (wet)	325	74
Structure Subsystem	651	
Thermal Control Subsystem	100	138
Harnesses Subsystem	268	
Sunshield Subsystem	668	25
LV Adapter	104	
Slit Aperture Observatory Totals	**7489**	**1220**
20% Margin + contingency	1498	244
Slit Aperture Observatory CBE	**8987**	**1464**

18m RSA Mass and Power scaled from JWST current estimates



18m RSA Observatory stowed in a 5m fairing

Launch Vehicle	PL Mass to L2 (kg)
Delta IV Heavy	10,170
Falcon 9 Heavy	15,500
Block 1 SLS	22,000

Current and planned US Launch Vehicles (with Injection C3 = -0.7 km^2/sec^2)

Rotating Synthetic Apertures – Next Steps

The RSA team is seeking partners to extend the application of SpinAp technologies to astrophysics, refine the RSA architecture and explore system/science trades to develop the next generation of spectacular space observatories. We plan to address the following trades and analyses at a minimum:

- Collection Area vs. Resolution – Define the optimal range to address top priority astrophysics science goals
- Aperture Aspect Ratio – Quantify the impact of asymmetric PSF on image quality, exoplanet detection (coronagraph/starshade), exozodiacal light suppression, etc.
- Detector Assessment – square vs rectangular (to match aperture aspect ratio), noise requirements, dark current, etc.
- Spin vs. Multi-orientation – Optimize operations for top priority astrophysics science goals
- Science Accommodation Requirements – Stability (thermal and vibrational), Stray light rejection, Optical telescope design (f-number, wavelength range/coatings, etc.)

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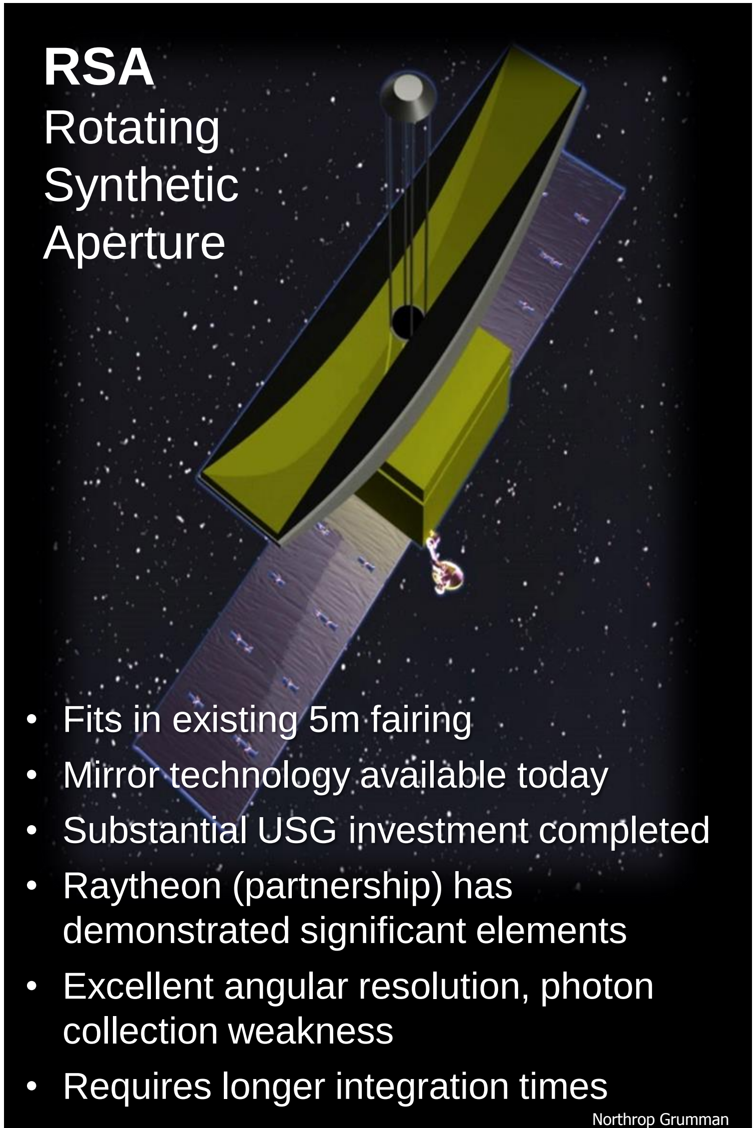
Work in 2015 Has Produced Two Possible Revisions of the EST Stage 1 Architecture



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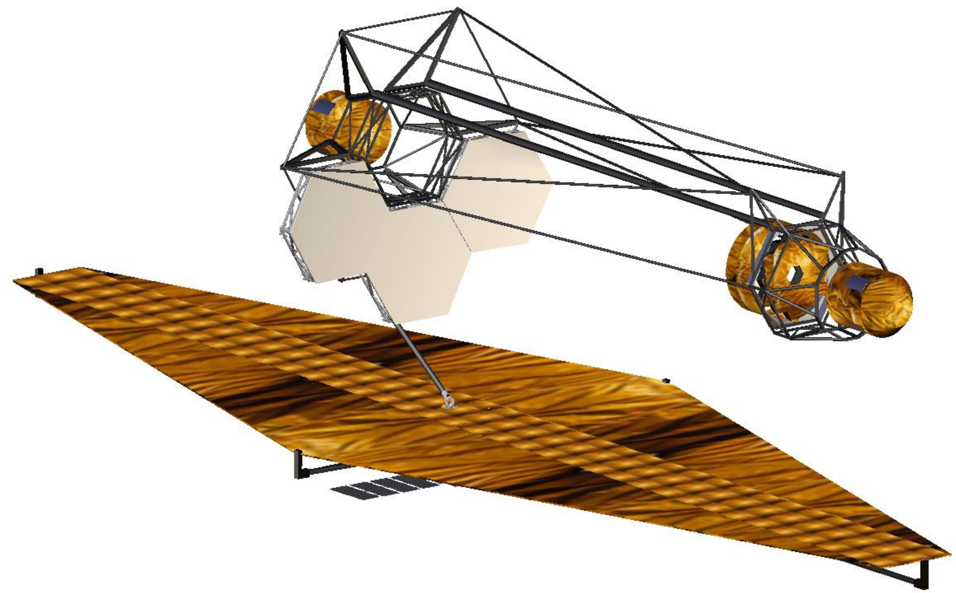
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- Revised EST Stage 1:
  - 3 Primary Mirror Segment Telescope:
    - Offset Secondary Tower – So No FOV Obscuration
  - Both Prime and Cassegrain Focus
    - Movable Secondary Mirror System enables switching between foci

Summary and Plan Forward

- We have developed an Evolvable Space telescope (EST) architecture by which we can build very large (>12 meter) space observatories in an era of flat budgets
  - Begin small and grow in stages to achieve a > 12 meter segmented telescope that is capable of doing the needed science
  - The augmentation schedule to build up from the initial system is dictated by budget realities, science needs, and technology advances
  - Science data is obtained continuously from initial system commissioning with only HST-like servicing gaps in the science return

– We are exploring adapting the Rotating Synthetic Aperture (RSA) concept that was developed by other government agencies for astronomical application:
  - Offers an opportunity for a lower cost, lower risk architecture
  - Excellent angular resolution, but requires longer integration times
  - Plans are in place to simulate astronomical imaging with the system to verify applicability
  - Starlight suppression systems (coronagraphs, nullers, and starshades) for RSA are being studied

- The EST and RSA studies are continuing in 2015. We are inviting interested parties to contact us to help us refine these two concepts and help determine how we will build the next great astronomical space observatory

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