A Rotating Synthetic Aperture (RSA) Space Telescope for Future UV/Opt/IR Astronomical Missions

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1. Introduction and overview

Observatory aperture size is a key performance-driving parameter for current high-priority astrophysics missions. Large apertures provide high resolution and large light-gathering power; key observatory parameters for the imaging and spectroscopy of faint, distant celestial objects. The limitations of current technologies drive the launch and development costs of large filled-aperture space telescopes. This is due to mass, complexity, launch vehicle fairing volume and the high cost of traditional deployed adaptive optics designs. With filled-aperture designs, the "next big thing" in astrophysics may wait a long time as space telescope and launch vehicle technologies mature. This whitepaper explores an alternate architecture based on current technologies that would provide the resolution of a ~20 m aperture while retaining the mass, cost, and photon throughput of an 8 to 9 m aperture.

Over the last two decades the U.S. government, Northrop Grumman, and Raytheon have invested substantially in a revolutionary non-traditional space telescope architecture that can be deployed today. Elements of Raytheon's "SpinAp" architecture are disclosed in several patents. The architecture is based upon a Rotating Synthetic Aperture (RSA) that synthesizes very large circular apertures at a fraction of the complexity, mass and cost. The 10m SpinAp optic, or even larger spin aperture, can address current astrophysics priorities with today's mature, demonstrated technologies and a single launch to orbit (Figure 1). Assuming mirror mass fraction is proportional to fill factor, for a given aperture, the required mirror mass can be reduced by up to 75% by utilizing the RSA architecture instead of a filled aperture. Reduced mass translates to reduced cost for the optical telescope assembly, spacecraft accommodation, and launch vehicle. Reduced mass also enables scientific missions that would otherwise require many years of technological development or multiple launches. A conceptual RSA Observatory reference design and comparative performance parameters for Hubble, JWST and 12 m filled designs are shown in Figure 2.

Figure 1. "The Universe in High-Definition" can be obtained today using a Rotating Synthetic Aperture (RSA) space telescope

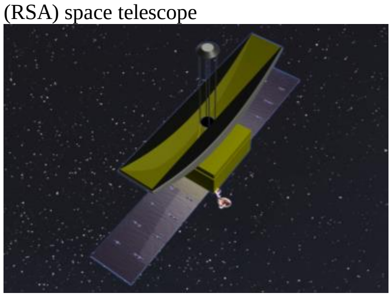


Figure 2. Space Telescope Sensitivity and Resolution Comparison

Telescope Parameter	Hubble Space Telescope	James Webb Space Telescope	12 m Filled Circular Aperture	16-20m RSA (18m x 3m)
Diameter	2.4 m	6.5 m	12 m	16-20 m
Collecting Area	4.5 m^2	25 m^2	113 m^2	50-64 m^2
Angular Resolution[a] (500 nm)	0.05"	0.02"	0.011"	.0063 -.0079" [b]
Angular Resolution[a]: NIR (2 μm)	0.2"	0.08"	0.042"	.031-.025" [b]

[a] Diffraction-limited angular resolution for a filled circular aperture of the given diameter
[b] Linear synthesis processing results in an angular resolution equivalent to a filled circular aperture. Nonlinear processing of SpinAp data will provide 20% better resolution than an equivalent filled circular data set processed with the same algorithms.

We propose that studies of future large normal incidence astrophysics missions (the Far-IR Surveyor, Habitable-Exoplanet Imaging Mission, and the UV/Optical/IR Surveyor) explore using the RSA as their core architecture.

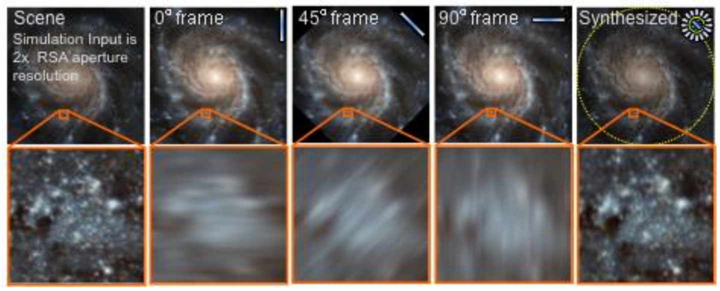
2. Key Science Questions

The key science questions addressed by the RSA architecture are those of any large (> 8 m) filled aperture telescopes. RSA offers a different way to build and use the telescope. It offers the collecting area of an 8 to 9 meter telescope with the resolution (after data processing) of a telescope twice that size.

3. Technical Capabilities

How a Rotating Synthetic Aperture Works Using a 20 meter, 8:1 aspect ratio, RSA as an example that balances aperture (16% fill factor) and resolution (6.3 milliarcsec at 500 nm, this design would provide the resolution of a 20 m aperture while retaining the mass, cost, and light-gathering power of an 8m aperture. Figure 3 simulates a notional imaging sequence for this example design. The HST-derived input scene at left is 2x the resolution of the 8:1 RSA high resolution cutoff. As the telescope rotates it acquires imagery with a two dimensional detector array. The individual frames depicted in Figure 3 all have the same field of view. Each frame measures the spatial frequency information associated with the rectangular aperture. At the completion of an 180^o rotation, with appropriate angular sampling by the individual frames, all spatial frequencies associated with a filled aperture measurement of the scene have been measured, yielding the rightmost frame in Figure 3. This processing chain has been fully demonstrated and has the ability to obtain further resolution enhancement with optimal nonlinear processing.

Figure 3. A synthesized RSA observation of M101 (HST image). In the simulation the 20 m RSA acquired 80 frames over a 180 degree rotation. Synthesis processing results in the image at right.



RSA Architectures and Integration Times Integration times for RSA are increased relative to a filled circular system with the same effective diameter. The RSA design provides an integration time penalty inversely proportional to the *square* of the fill factor, versus the *cube* for dilute and sparse apertures, greatly improving mission capability. RSA is a very flexible architecture: the total integration time, frame integration time and image resolution can be balanced using the mirror aspect ratio to achieve the desired mission science performance. Figure 4 provides key performance parameters for three RSA aspect ratios.

Figure 4. RSA Parameters for a Range of Aspect Ratios

Rotating Synthetic Aperture Parameters					12 m Aperture Comparison		Diameter of filled aperture with equivalent light gathering capability (m)
Aspect Ratio	**Mirror Length (m)**	**Mirror Width (m)**	**Mirror Area (m^2)**	**Vis (500 nm) Angular Res. (milli-arcsec)**	**RSA Fill Factor**	**RSA Integration Time factor**	
4:1	16	4	64	7.86	56.6%	3.12	9.03
6:1	18	3	54	6.99	47.7%	4.39	8.29
8:1	20	2.5	50	6.29	44.2%	5.12	7.98

4. Relevance to the Four Mission Concepts

The RSA architecture is relevant to any normal incidence system including the Far-IR Surveyor, Habitable-Exoplanet Imaging Mission, and the UV/Optical/IR Surveyor.

5. New Technologies

Much of the core technology needed to enable RSA has already been developed by industry and other government agencies. Multiple trade studies are needed to assess the value of RSA for astrophysics but the new technologies needed for RSA are only those that convert the current RSA concept into an astrophysical observatory:

- Development of starlight suppression systems (starshade and/or coronagraph) to enable imaging of exoplanets
  - Starshade starlight suppression systems suitable for RSA sized telescopes: architectures capable of deploying ~60 m starshades, formation flying sensors/algorithms for maintaining alignment to the starshade.
  - Innovative coronagraph architectures: designs that can accommodate the RSA point spread function and are insensitive to telescope system vibration with innovative WFSC systems optimized for coronagraphy.
- Thermal, vibrational, and pointing control technologies to satisfy astrophysics mission requirements.
- Detector technologies that optimize astrophysics mission performance for the rectangular RSA primary mirror and can achieve the low noise performance necessary to image faint objects.

6. Large Mission Needed?

The RSA architecture is best applied to a large mission and will provide a more affordable path to building the next great observatory. The RSA approach can provide an affordable ~9 meter telescope with “super-resolution” to address the highest priority science goals.