National Aeronautics and Space Administration

Rotating Synthetic Aperture (RSA) Field Demonstration Camera

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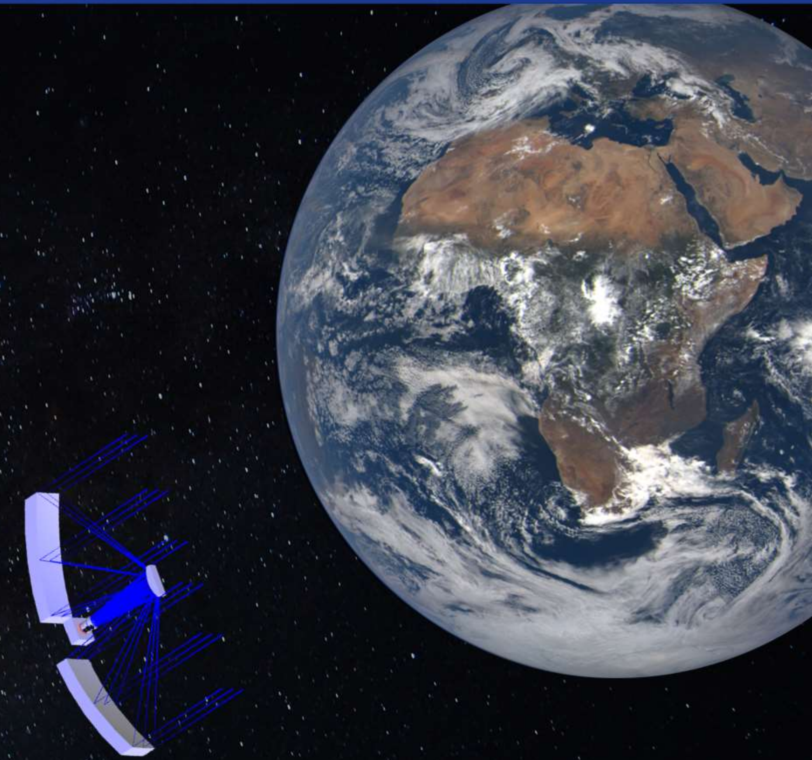
Program: FY21 R&TD Topics **Strategic Focus Area: Advanced Optics Systems and Telescopes**

Objectives and Summary

- This effort implemented, demonstrated and characterized the imaging performance of rotating synthetic aperture imaging (RSA).
- Using a modified commercial camera with a narrow strip-aperture at its pupil imaging, we collected images with rotational diversity against a variety of targets.
- Using resolution and edge targets we demonstrated and quantified the post-processed resolution achievement, documenting the incoherent aperture synthesis in the resulting products.
- We validated our imaging system models that traced with these measurements.
- By exercising these models, we gained additional insights to unique sampling optimization opportunities for future concepts that permit very large fields of view for any given focal plane size while preserving full-aperture resolution.



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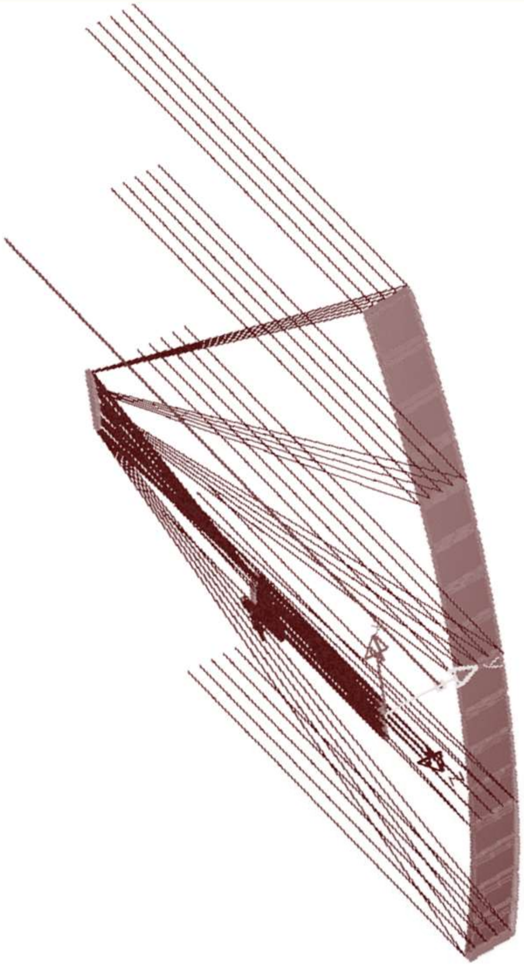
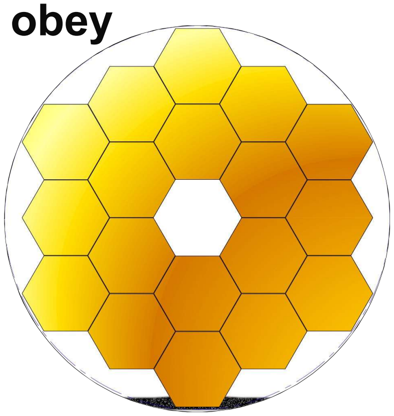
Clearance Number:
RPC/JPL Task Number: R20106

Rotating Synthetic Aperture Imaging



16-meter Telescope Example

We want to break unspoken principal that all telescopes designs obey



JWST Primary approximates a 6.5m circular aperture

The RSA approach arranges the aperture collecting area to maximize resolution in a direction.

Observations are made as the system rotates

After a half-rotation, these measurements are processed into conventional science products,

They contain all the information out to the best diffraction-limit in all directions.

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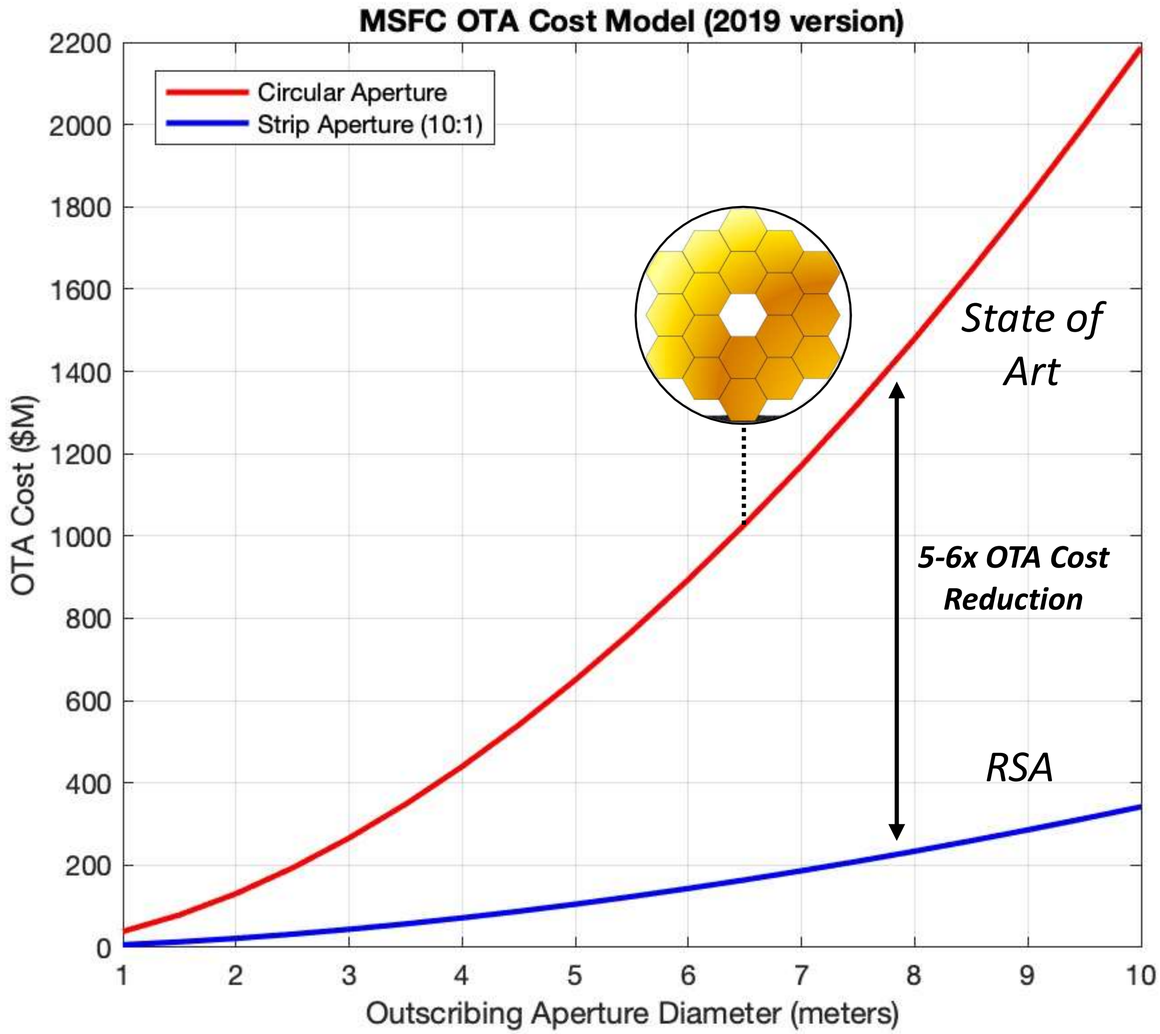
Core Advantages for RSA Concepts

Lowers cost and risk for large aperture missions that demand high resolution

Enables higher performance for small aperture concepts

Opens new design space for optimized instruments and observation concepts



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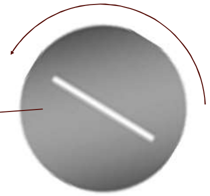
Approach to Proof of Concept

- Implemented RSA Field Camera using modified a COTS lens
- Calibrated camera to estimate as-built parameters (effective pupil size, support and alignment)
- Implemented end-to-end image chain model capturing
  - Lens and aperture parameters (pupil support, focal-length, F/#)
  - FPA Bayer Filter sampling and spectral QE
  - Noise Processes from Scene and Detector
- Extended the Multi-frame Poisson Maximum *a-Posteriori* (PMAP) Algorithm[3,4]
  - Incorporates the Bayer Filter FPA sampling into its data consistency calculations to produce joint estimates of the color channels from the entire group of frames
  - Beyond this application, this version of PMAP can benefit other NASA efforts such MARS 2020 which hosts many cameras with Bayer Filter FPAs.
- Imaged resolution targets and evaluated post-processed reconstructions, demonstrating incoherent aperture synthesis

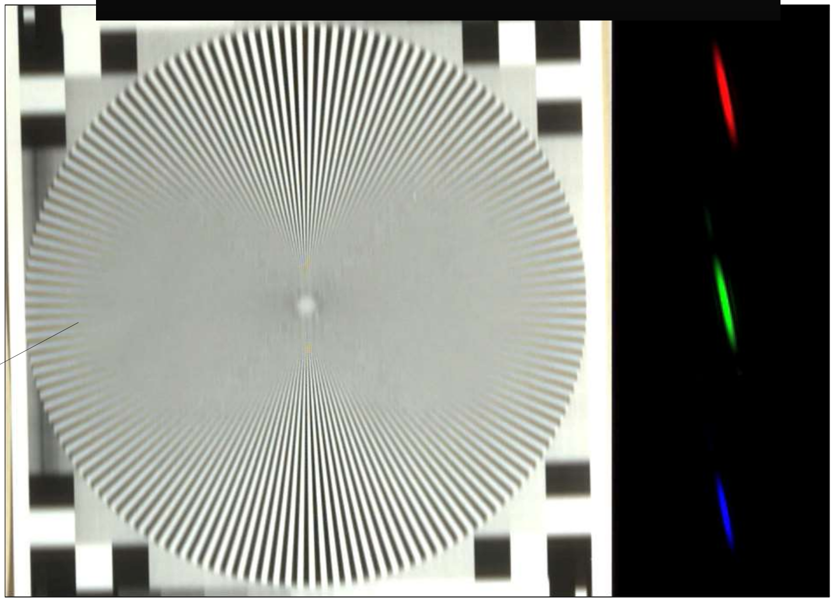
RSA Field Demo Camera (with modified COTS Lens)

Rotatable Strip Aperture



Fixed 10:1 Slit Replaces Traditional Iris

Example of Imaging a Resolution Target as the Camera Aperture Rotates (left) and Related PSF Models (right)



Raw Color Frames from RSA Camera (De-mosaiced but not post-processed)

Color PSF Models for Post-Processing

The orientation of the resolution response to this radial bar target depends upon aperture rotation angle

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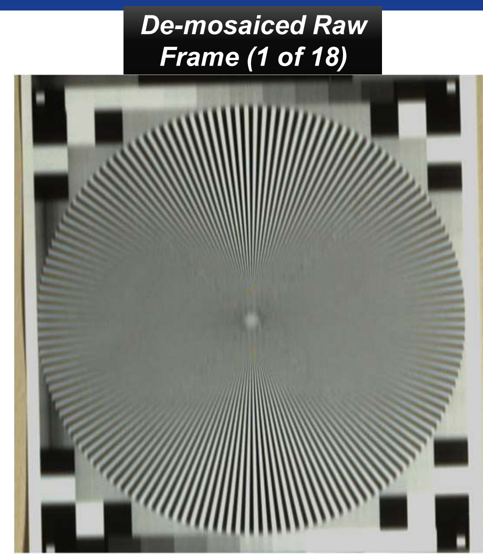
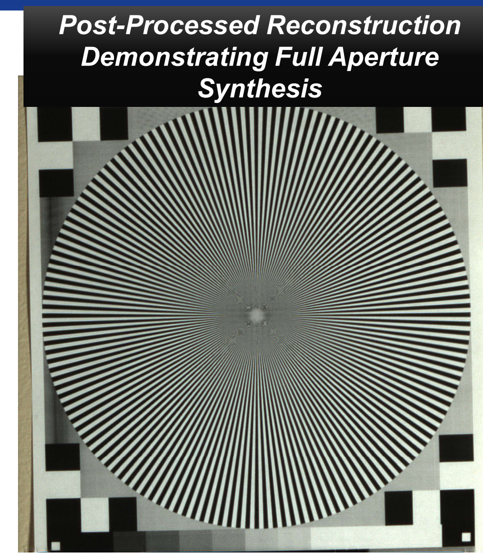
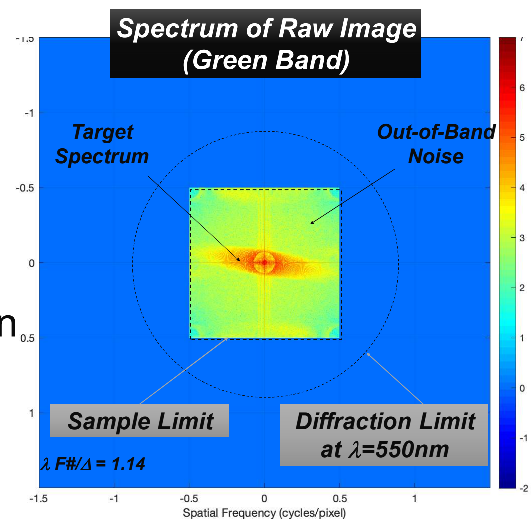
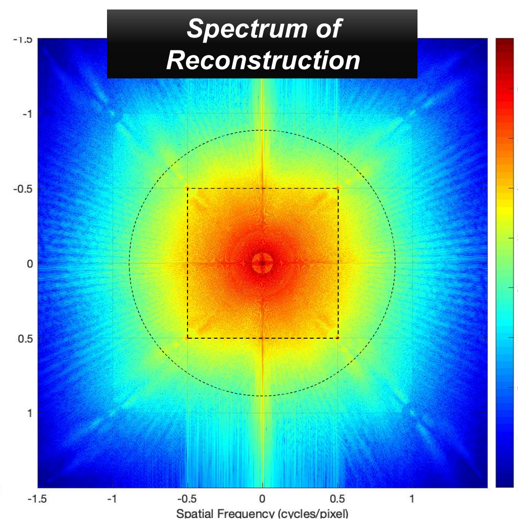
RSA Resolution Synthesis Demonstration

- The top figures show a single RSA camera frame and the multi-frame reconstruction we achieved using our modified version of PMAP.
- We used all 18 frames (at every 10° aperture rotation) to reconstruct the target at 3x the original sampling.
- The post-processed reconstruction clearly shows that all directions of resolution are recovered, synthesizing the equivalent of a filled circular pupil
- The spectral analysis in the figures below reveals that the processing
  - **Restores** the target spectrum within the sample limit
  - **De-aliases** undersampled content, placing it back at appropriate higher frequencies
  - **Super-Resolves** the target, recovering information from beyond the equivalent filled-aperture diffraction-limit.









This is a successful experimental demonstration of incoherent aperture synthesis using a rotating strip aperture camera

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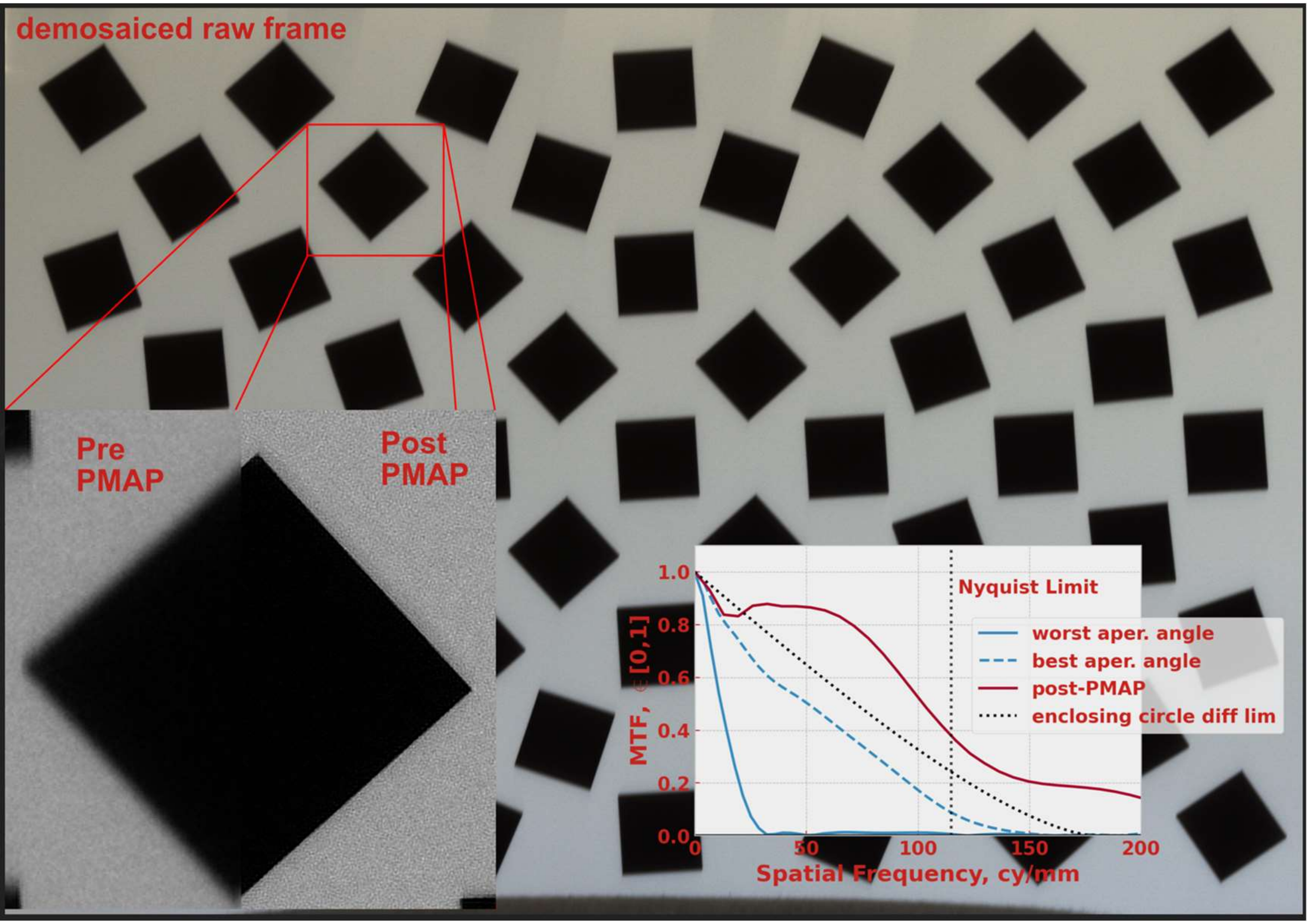
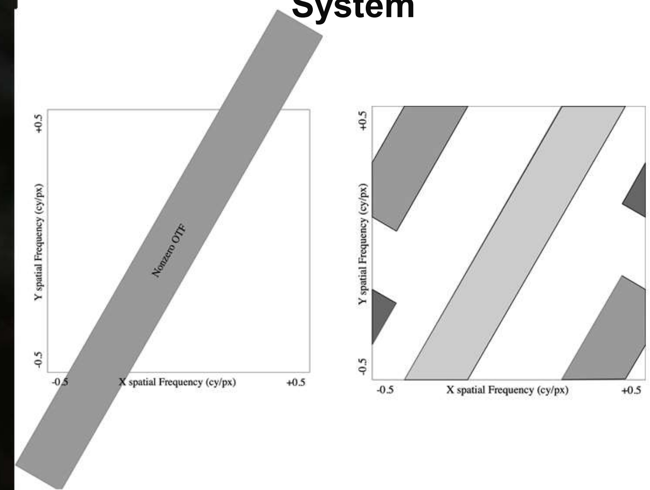
RSA MTF Assessment

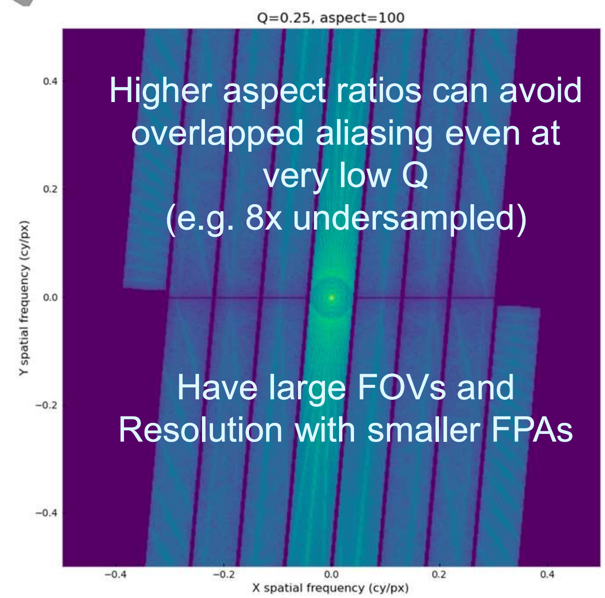


- In the background, the raw (demosaiced) image of a resolution edge-target is shown.
- The inset image on the bottom left compares a unprocessed frame to the post-processed reconstruction of the edge target.
- From these edges, we estimate the MTF of the system with and without processing demonstrating the full-resolution capability of the RSA Field Demonstration Camera.

Key Finding: Unique Optimization for Sampling in RSA Systems

Aliasing in Strip-Aperture Imaging System





The sampling in RSA systems can be optimized to avoid loss of information by aliasing enabling simultaneously large fields of view while preserving maximum image resolution

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Significance and NASA Benefits

RSA is the path to Affordable Large Space Telescopes

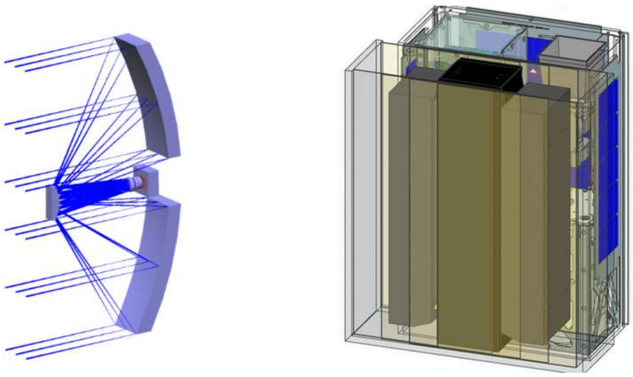
New Design Space for Revolutionary Instruments and Missions

<u>This R&TD provides</u>
- Direct demonstration of the fundamental imaging callability
- Insight to future system optimizations
- High-performance PMAP processing applicable to any deconvolution problem
- Traceable modeling and simulation tools

Apart from this R&TD Effort, we developed several JPL and NASA mission concepts that take advantage of the RSA architecture

ExoSpinAp - Mid-Infrared Exo-Earth Spectroscopy Mission
QUAKES-R - Quantifying Uncertainty and Kinematics in Earth Systems
Occam's Razor – Cubesat demonstration mission for RSA architecture

JPL NEXT Concept:
Occam's Razor



60cm Telescope fits in <u>half</u> of a 12U Cubesat

Publications and References

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3. J. J. Green and B. R. Hunt, "Super-Resolution in a Synthetic Aperture Imaging System," IEEE ICIP, 1997.
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