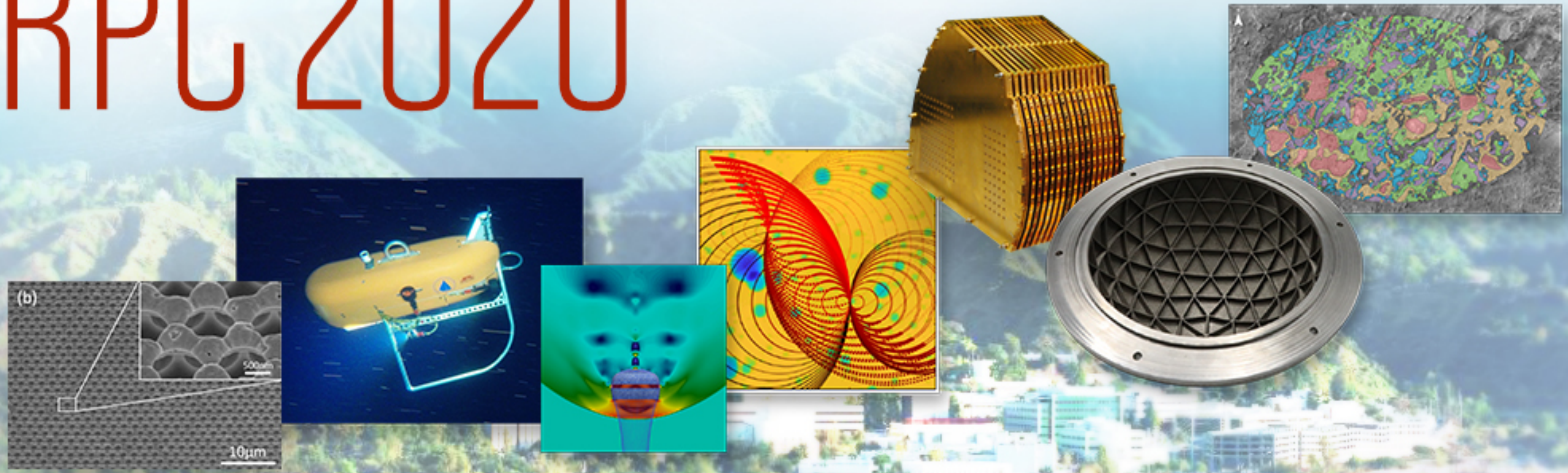
RPC 2020



Virtual Research Presentation Conference

Rotating Synthetic Aperture (RSA) Field Demonstration Camera

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Introduction

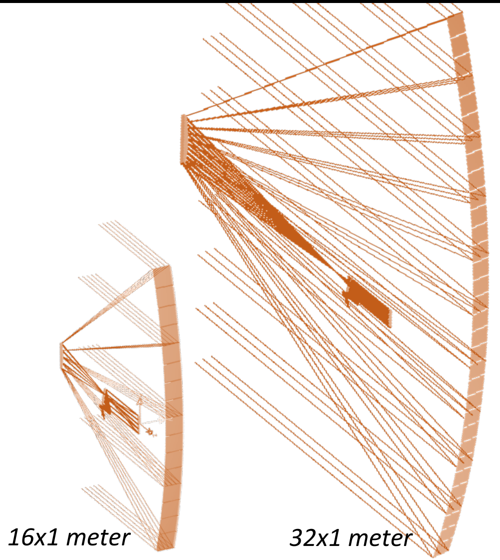
The culmination of our best technologies and engineering practices will soon yield the James Webb Space Telescope. To extend far beyond its 6.5 meter primary mirror to much larger apertures, we must take truly transformational approaches to observational systems.

The rotating synthetic aperture (RSA) telescope architecture maximizes its angular resolution on the sky by arranging its collecting area into a strip. This provides the highest possible instantaneous resolution but is very directional. The full spectrum of a science target is observed by collecting images as the system rotates. After a half-rotation, these measurements are processed into conventional science products, containing information out to the best diffraction-limit but now in all directions.

In our study, we modified a modern commercial camera to employ a 10:1 strip aperture. Advancing our previous work with multi-frame super-resolution algorithms, we processed raw data collections from the camera into high-resolution image products, successfully demonstrating aperture synthesis.

The RSA principal demonstrated here can lead to a variety of future mission concepts that achieve unexpectedly high performance with vastly lower system mass, cost and complexity when compared to conventional approaches.

Example RSA Concepts for Direct Exoplanet Spectroscopy[1]



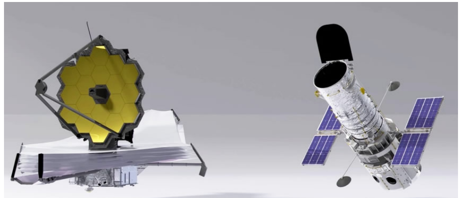


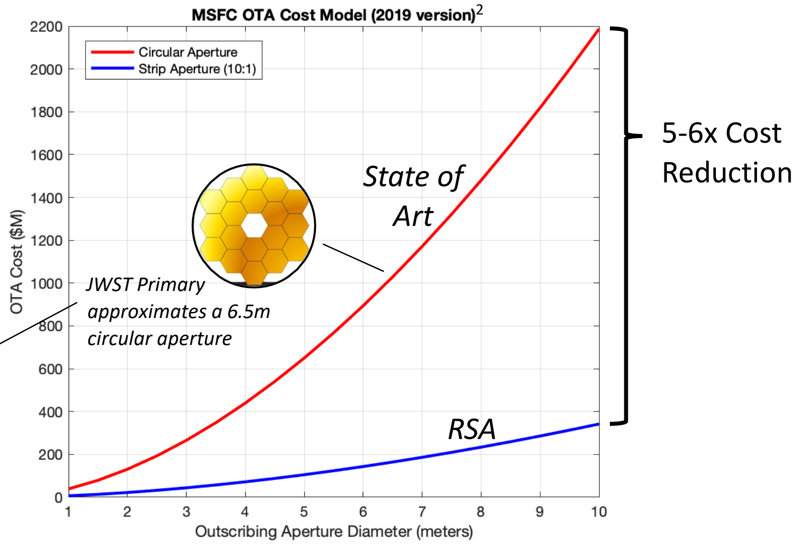
Image Source: www.jwst.nasa.gov

JWST and HST shown for Approximate Scale

Problem Description

Moving Beyond the SOA for Large Space Telescopes

- Science progression demands ever larger apertures while maintaining viable and affordable concepts.
- Current approaches are constrained by the principal that the individual measurements comprising a science observation must themselves be images.
- This drives large apertures, such as JWST, to approximate circular support



The Path to Low-Cost High Performance Systems

- The RSA approach enables incoherent large aperture synthesis while minimizing hardware requirements
- This effort demonstrates the core principal of RSA imaging on small scale traceable hardware and processing
- The modeling, calibration and processing methods validated through this effort carry forward into larger concepts, enabling them to proceed with confidence

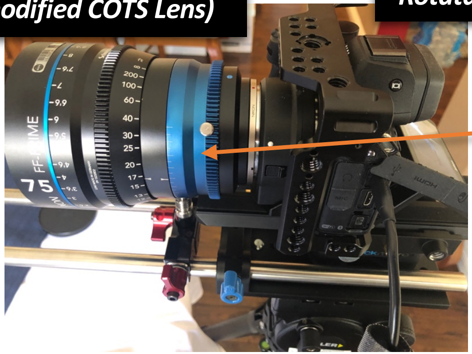
NASA & JPL Benefit

- Lowers cost and risk for large aperture missions that demand high angular resolution
- Enables higher performance for small aperture concepts
- Opens new design space for optimized instruments and observation concepts
  - (e.g.) The ExoSpinAp Concept for Direct Exoplanet Spectroscopy[1]

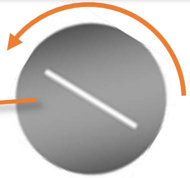
Approach to Proof of Concept

- 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)

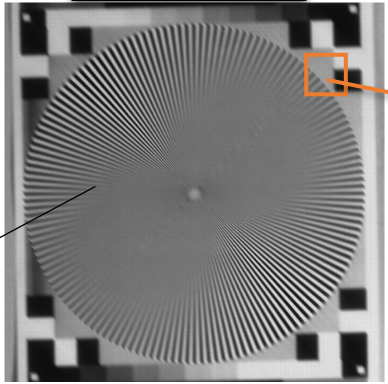


Rotatable Strip Aperture

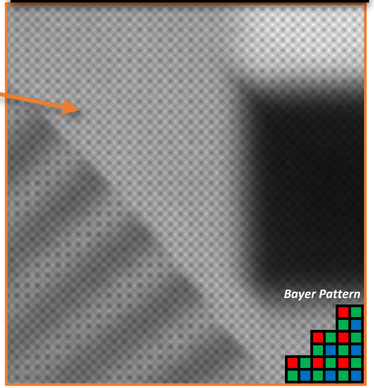


Fixed 10:1 Slit Replaces Traditional Iris

Example of a Raw Image Frame



Zoom-In showing Bayer Pattern on FPA (color filter per pixel)



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

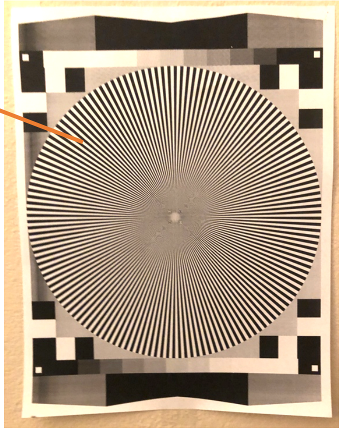
Data Collection Example

- **Setup**: RSA camera imaged focused on radial bar target at a range of 5 meters.
- **Collection:** Acquired 18 images at every 10° of aperture rotation, covering a total of 180 degrees
- **Post- Processing**: Prepared models of the system PSF for each color band at every rotation angle. Processed ensemble with our modified version multiframe PMAP.

Resolution Target and Point Sources

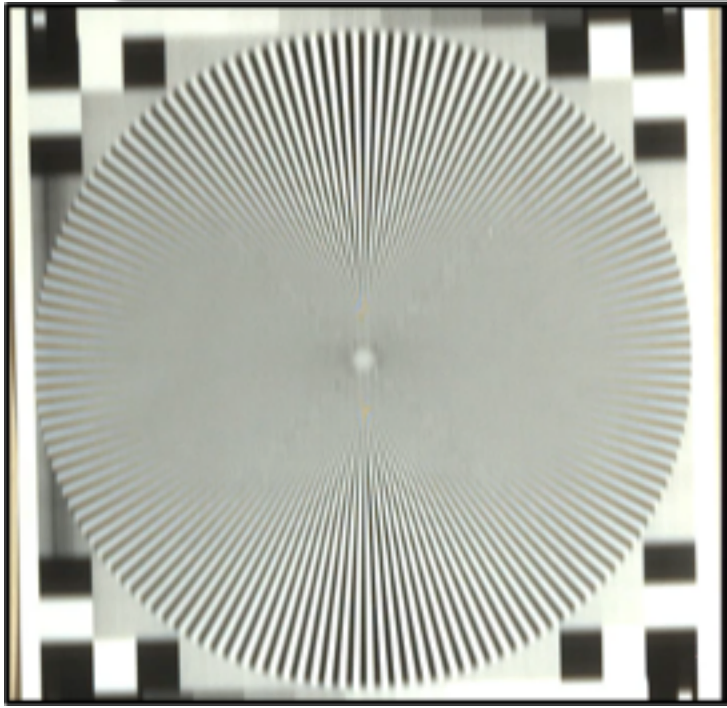
RSA Camera

Oriented Diffraction from Aperture Pose

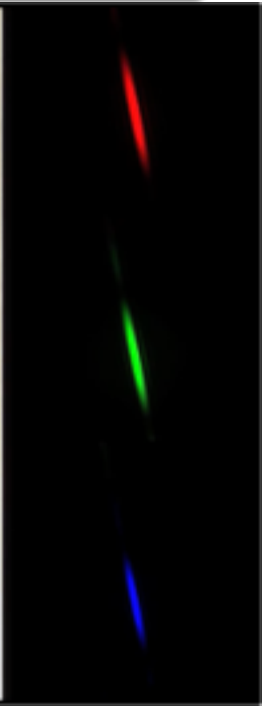


Closeup iPhone picture of target

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)

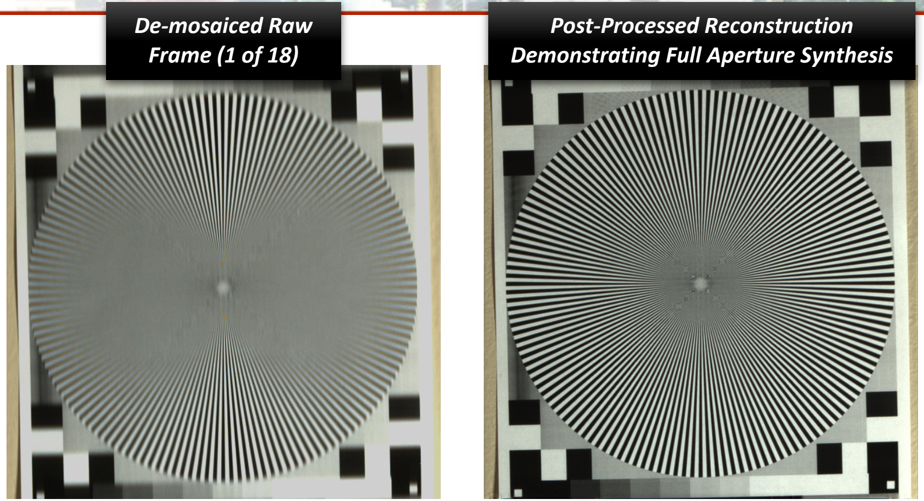


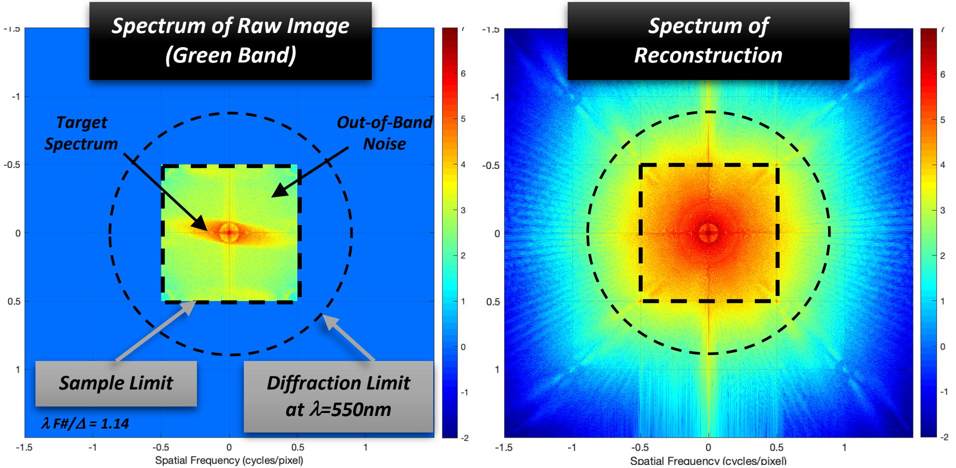
Color PSF Models for Post-Processing

Results

- 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.

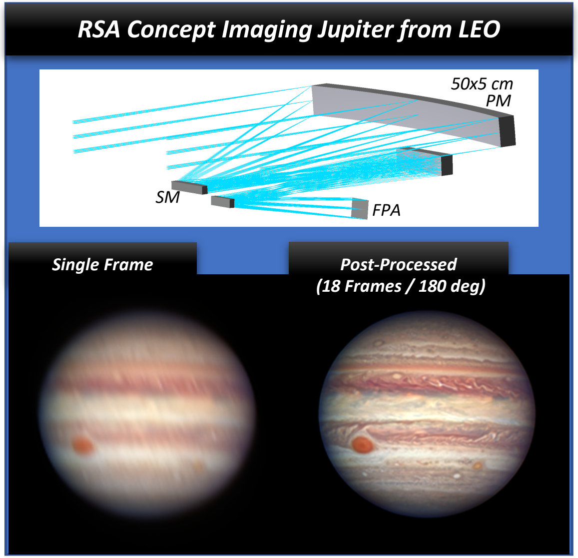
This is a successful experimental demonstration of incoherent aperture synthesis using a rotating strip aperture camera





Next Steps

- In the coming year, we will conduct more extensive field tests and formalize the native and post-processed resolution performance of our RSA Field Camera.
- We will continue to work with our program management and the science community to develop innovative mission concepts that may bring this architecture into practice.



Publications and References

1. J. J. Green, S. Bradford, T. Gautier, E. Sidick and G. Vasisht, “Architecture for space-based exoplanet spectroscopy in the mid-infrared,” Proc. SPIE, vol 10698, (Austin 2018).
2. P. Stahl and M. Allison, “Optical Telescope Assembly Cost Estimating Model,” Space Astro. Landscape, 2019.
3. J. J. Green and B. R. Hunt, “Super-Resolution in a Synthetic Aperture Imaging System,” IEEE ICIP, 1997.
4. D. G. Sheppard, B. R. Hunt, and M. W. Marcellin, “Iterative multiframe super-resolution algorithms for atmospheric turbulence-degraded imagery,” *Journal Optical Soc. Amer.*, vol. 15, pp.978-92, April 1998.