Unique Visible Light Coronagraphy with the HST/STIS Coronagraphic Aperture

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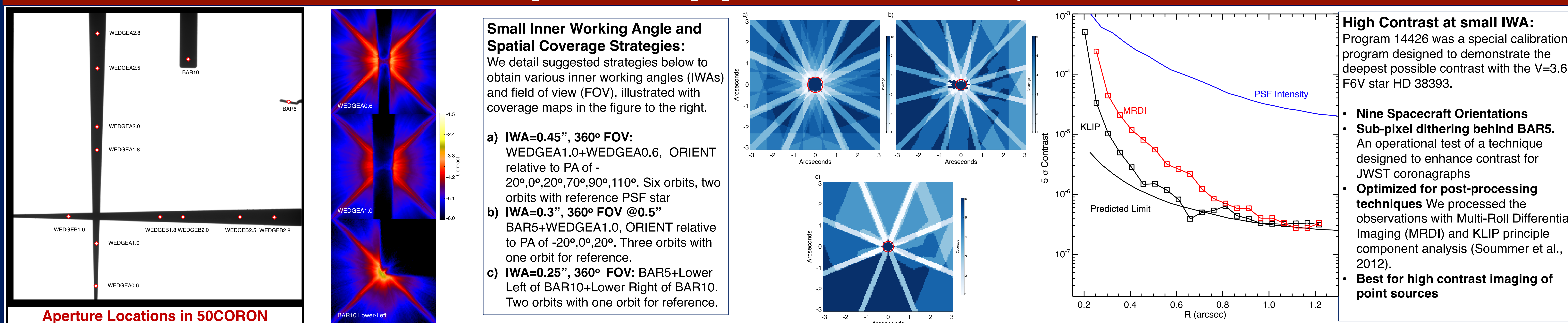
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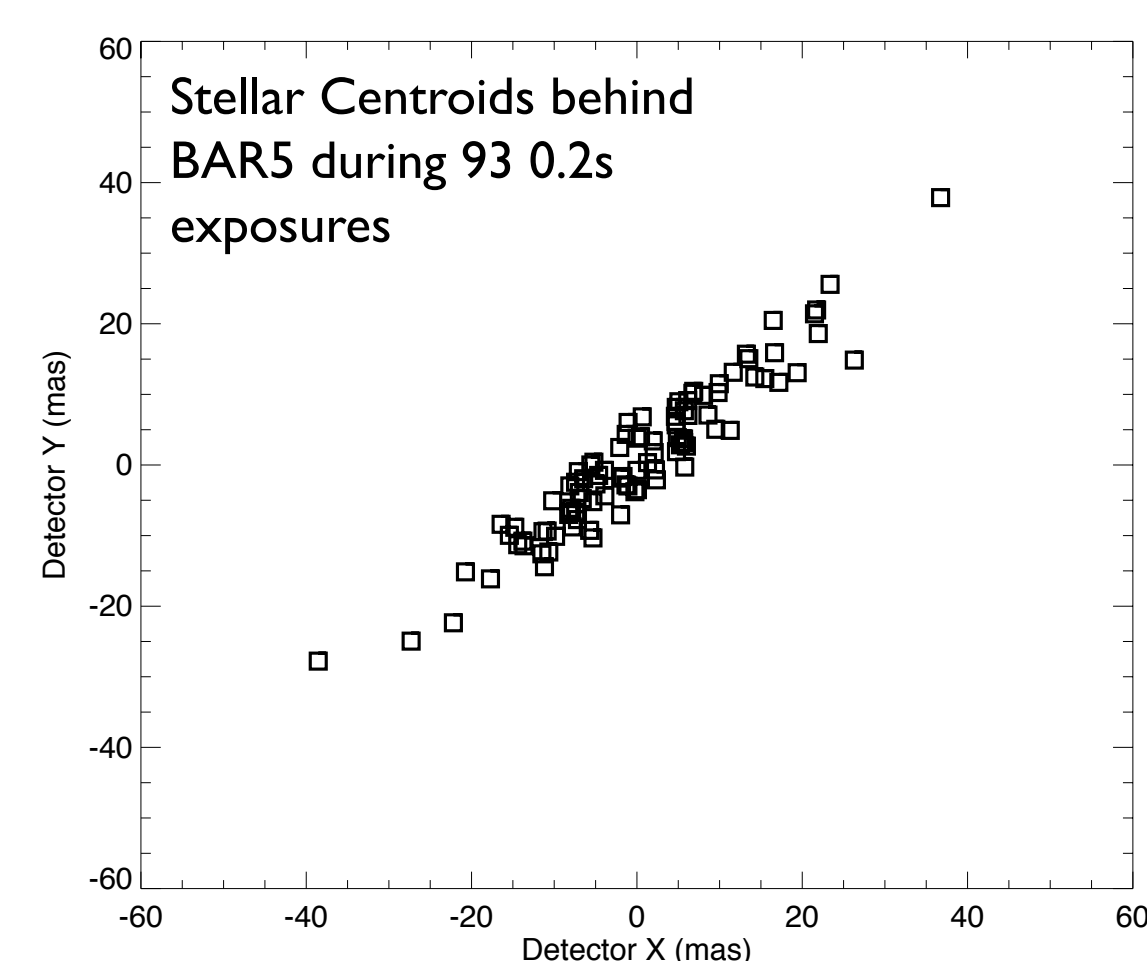@JohnDebes
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Abstract

The Hubble Space Telescope (HST)/Space Telescope Imaging Spectrograph (STIS) contains the only currently operating coronagraph in space that is not trained on the Sun. In an era of extreme-adaptive-optics-fed coronagraphs, and with the possibility of future space-based coronagraphs, we re-evaluate high contrast capabilities of the STIS coronagraphic aperture 50CORON. This coronagraphic aperture consists of a series of occulting wedges and bars, including the recently commissioned BAR5 occulter. We discuss the latest procedures in obtaining high contrast imaging of circumstellar disks and faint point sources with STIS. For the first time, we develop a noise model for the coronagraph, including systematic noise due to speckles, which can be used to predict the performance of future coronagraphic observations. Further, we present results from a recent calibration program that demonstrates better than 10^{-6} point-source contrast at 0.6", ranging to 3×10^{-5} point-source contrast at 0.25". These results are obtained by a combination of sub-pixel dithers, multiple spacecraft orientations, and post-processing techniques. Some of these same techniques will be employed by future space-based coronagraphic missions. We also report the impact of HST's increased jitter from April to October of 2018 on coronagraphic observations.

## 1. High Contrast Imaging with STIS—The 50CORON Aperture

Aperture Locations in 50CORON

Small Inner Working Angle and Spatial Coverage Strategies:
We detail suggested strategies below to obtain various inner working angles (IWAs) and field of view (FOV), illustrated with coverage maps in the figure to the right.

a) **IWA=0.45", 360° FOV:** WEDGEA1.0+WEDGEA0.6, ORIENT relative to PA of -20°,0°,20°,70°,90°,110°. Six orbits, two orbits with reference PSF star.
b) **IWA=0.3", 360° FOV @0.5"** BAR5+WEDGEA1.0, ORIENT relative to PA of -20°,0°,20°. Three orbits with one orbit for reference.
c) **IWA=0.25", 360° FOV:** BAR5+Lower Left of BAR10+Lower Right of BAR10. Two orbits with one orbit for reference.

High Contrast at small IWA:
Program 14426 was a special calibration program designed to demonstrate the deepest possible contrast with the V=3.6 F6V star HD 38393.

- **Nine Spacecraft Orientations**
- **Sub-pixel dithering behind BAR5.** An operational test of a technique designed to enhance contrast for JWST coronagraphs
- **Optimized for post-processing techniques** We processed the observations with Multi-Roll Differential Imaging (MRDI) and KLIP principle component analysis (Soummer et al., 2012).
- **Best for high contrast imaging of point sources**

2. Spacecraft Jitter and Contrast

Stellar Centroids behind BAR5 during 93 0.2s exposures

Spacecraft Jitter degrades Contrast: From 21-April-2018 to 5-October-2018 the combination of gyros 2,4, and 6 resulted in ~15mas of jitter, which increased RMS noise near BAR5 by a factor of ~2 interior to 0.4". The new gyro combination has a jitter rms of ~7mas and contrast is nominal.
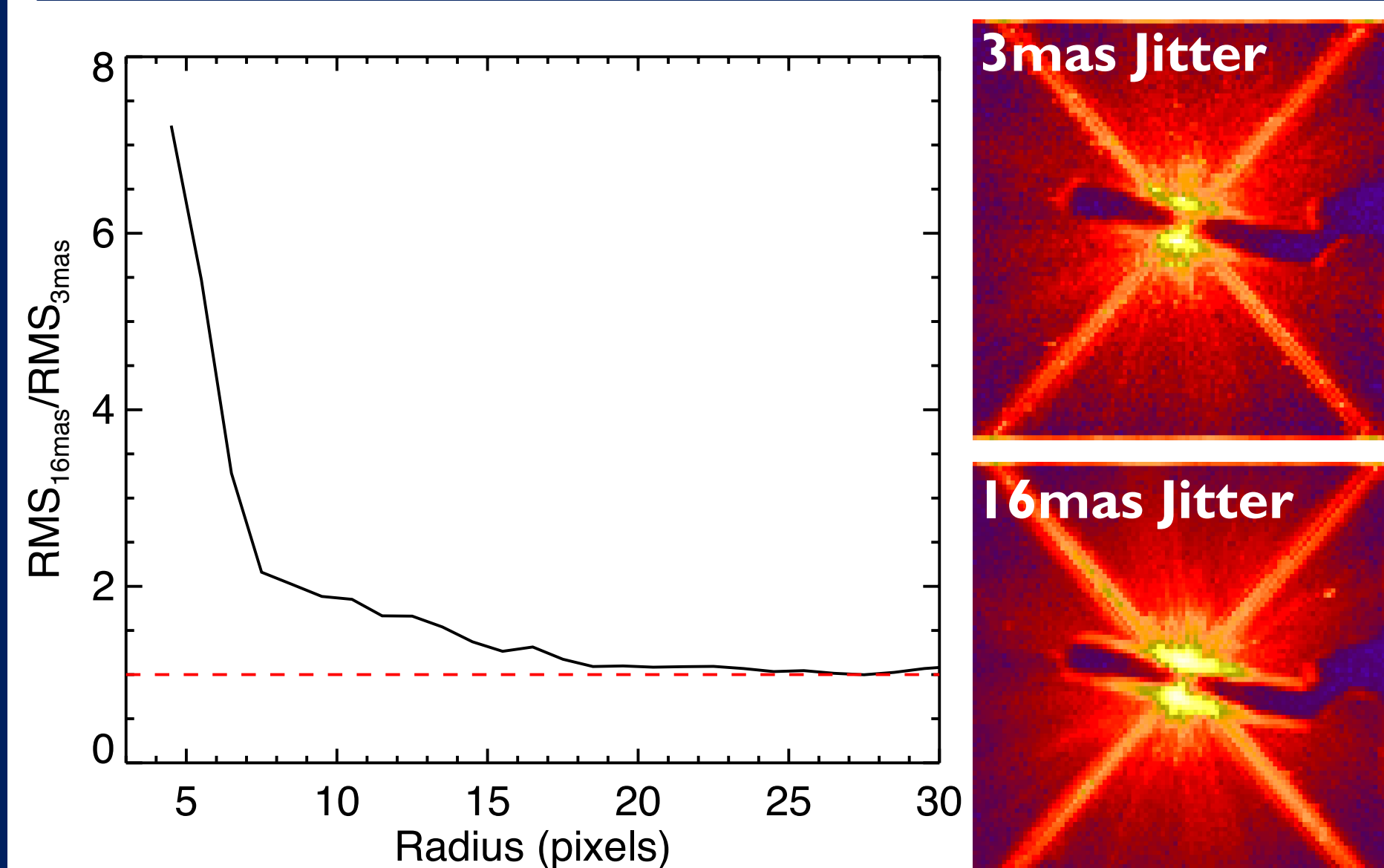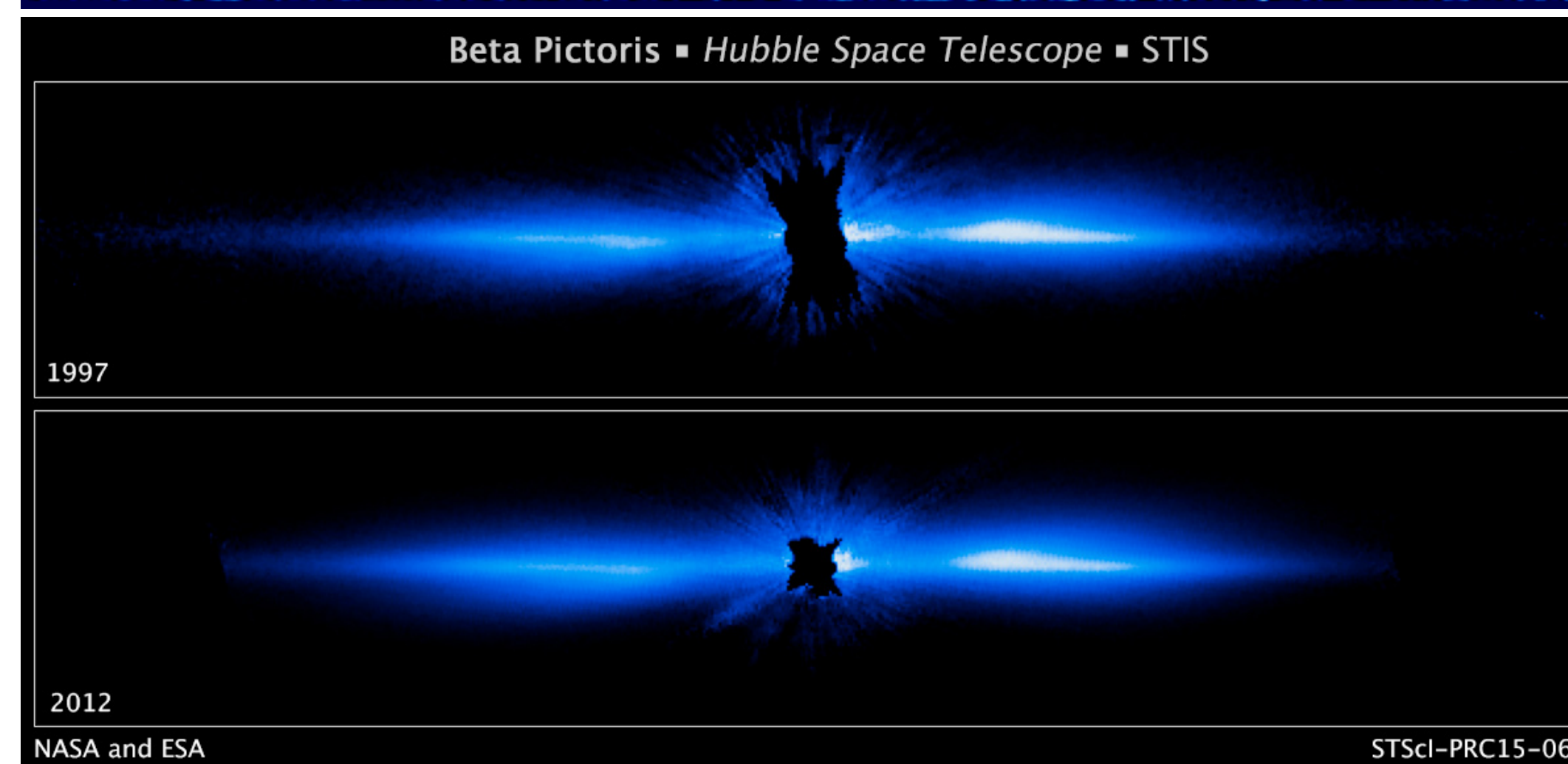

3. Unique Science with STIS Coronagraphy
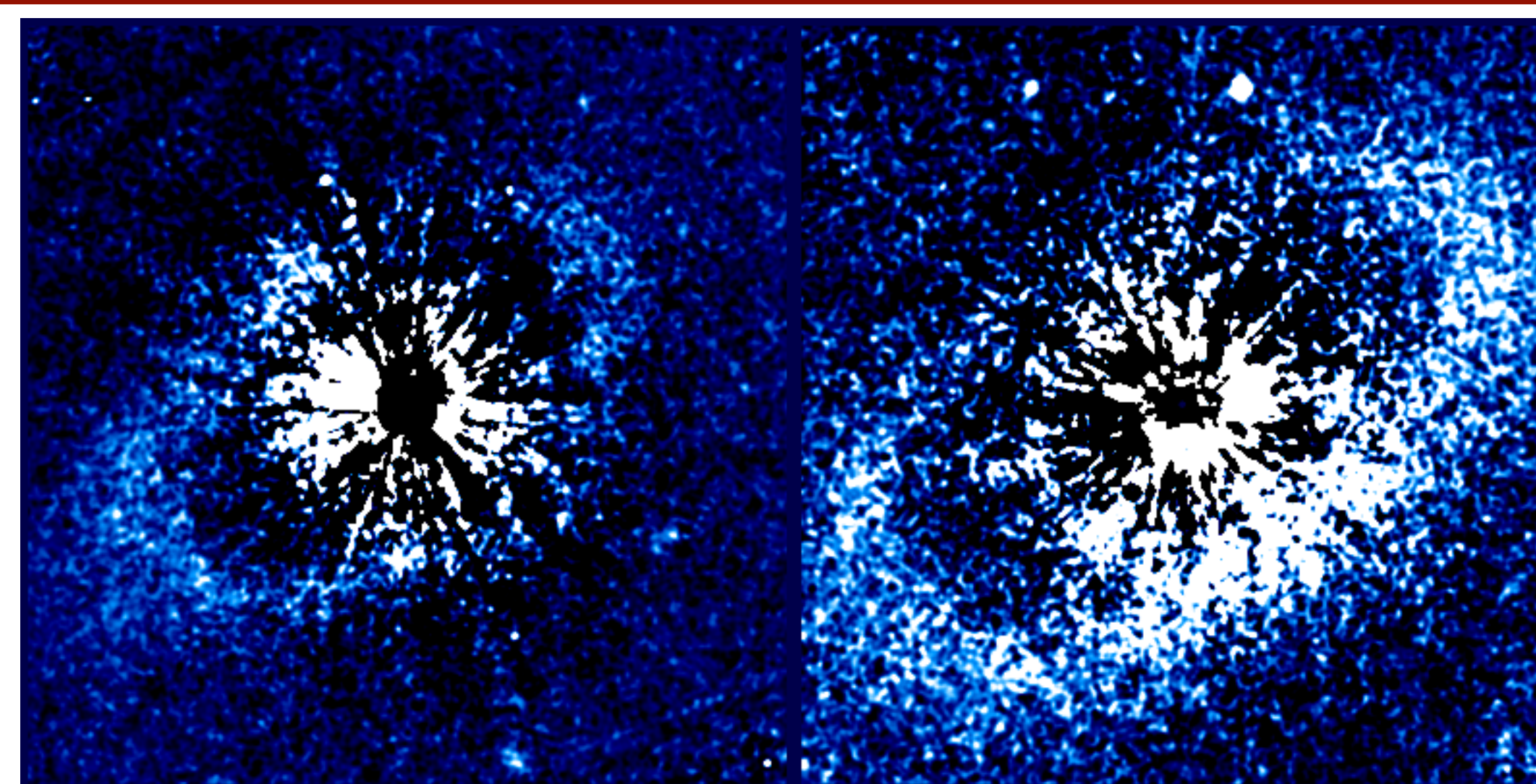
Deep Sensitivity
The left figure shows HD 207129 (left) and HD 202628 (right). Both disks have peak surface brightness of >24 mag arcsec^{-2} in the V band (Schneider et al., 2016)

Beta Pictoris • Hubble Space Telescope • STIS
1997
2012
NASA and ESA   STScI-PRC15-06a

Extreme Repeatability
The top figure shows a STIS image of β Pictoris taken in 1997, while the bottom figure shows the same disk taken 15 years later. The photometry and structures in the disk were the same down to a limit of ~3% (Apai et al., 2015).

Large FOV
The full 50CORON aperture is 52"x52" allowing large structures like the Fomalhaut disk (semi-major axis =17.2") to be imaged (Kalas et al., 2013)

References: Apai et al. 2015 ApJ 800, 136; Kalas et al. 2013 ApJ 775, 56; Schneider et al. 2016 AJ 152, 64

4. A Coronagraphic Noise Model for STIS

PSF Wing Shot Noise and Speckles dictate Contrast with STIS:
For the first time we have determined the primary sources of noise for coronagraphic observations with STIS

- **Detector noise is dominated by read noise:** Read noise is higher for GAIN=4 than GAIN=1, but GAIN=4 allows for more total photons to be collected, boosting efficiency
- **Speckles behave differently from those in AO systems:** The top figure to the right shows the residual noise above that expected from the PSF wings. The speckle noise behaves as a power law and scales with the flux of the star and the exposure time used.
- **We have empirically tested our noise model:** Program 14426 data was well suited for creating a test against our predicted noise model. The lower panel on the right shows the comparison between measured RMS for a given 0.2s exposure and predictions.