Pushing STIS Coronagraphy Deeper with New Coronagraphic Modes

John Debes, *debes@stsci.edu*, **Andras Gaspar,** *agaspar@as.arizona.edu*, **& Glenn Schneider,** *gschneider@as.arizona.edu*

The process of subtracting off or suppressing the diffracted and scattered light from a star is called "high-contrast" imaging. These techniques allow observers to detect circumstellar material and exoplanets in close proximity to stars. The starlight suppression required can be extreme: the light from exoplanets and dust structures can be as much as a thousandth or less than a billionth the brightness of their host star.

As detailed in a previous *Newsletter* article (Vol. 30 No 01; **https://blogs.stsci.edu/newsletter/2013/04/10/the-unique-coronagraphic-capabilities-of-stis-direct-imaging/**), the Space Telescope Imaging Spectrograph (STIS) possesses unique visible-light coronagraphic modes that keep the instrument at the forefront of exoplanet and debris-disk research. In Cycle 22, a new coronagraphic position is available that will push even closer to nearby bright stars. A damaged but now commissioned, coronagraphic, image-plane occulter in the 50CORON aperture is nicknamed "the bent finger."

The BAR5 aperture

Figure 1 shows a schematic of the 50CORON aperture of STIS, which includes two wedges, a large occulting bar, and the bent finger. Historically, this finger was named BAR5, which denoted the length of the bar, rather than its width. The second, larger occulting bar at the top of the detector is named BAR10, while the two wedges comprise the bulk of positions used for high-contrast imaging. Currently, the narrowest supported position in 50CORON is at WEDGEA0.6, corresponding to a minimum inner working angle of 300 mas.

BAR5 was damaged during the construction of the STIS instrument and thus was never activated as a usable coronagraphic position on the detector—primarily due to concerns that BAR5 might not be stable. After nearly two decades in orbit, BAR5 has not appreciably moved relative to the other occulting masks in the aperture. An outsourced calibration program 12923 (PI: Gaspar) in Cycle 20 was accepted to determine the positional offsets needed to reliably place stars behind the BAR5 mask, and to test its viability for starlight suppression at the smallest inner working angle ever offered by *Hubble*.

Pushing to smaller inner working angles

Program 12923 tested three separate positions on the detector that could allow inner working angles smaller than WEDGEA0.6: the middle of BAR5, and the lower left- and lower right-hand corners of the BAR10 mask. Such moves required a precise knowledge of how the plate scale of the detector and the geometric distortion were defined in the flight software and in the STIS space instrument aperture file.

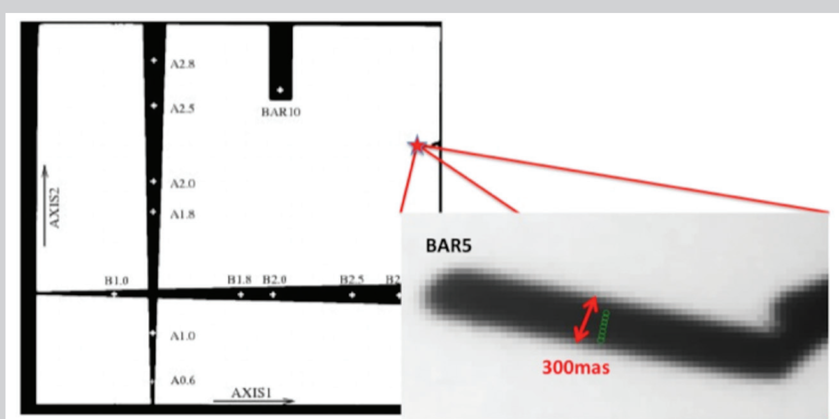

Figure 1: Full STIS 50CORON aperture including two wedges, a wide bar, and a coronagraphic finger that was bent during the assembly of STIS named BAR5. Due to its stability, BAR5 was investigated for a new coronagraphic position on the aperture that decreases the inner working angle to 150 mas, a factor of two smaller than the smallest wedge position, WEDGEA0.6. For a full listing of all supported positions, see (**http://www.stsci.edu/hst/stis/documents/handbooks/currentIHB/c12_special12.html**).

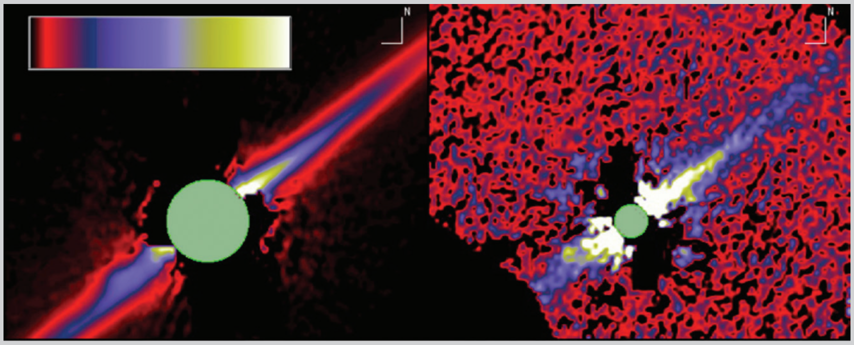

Figure 2: Comparing the AU Microscopii observations obtained in program 12228 (*left*: 12 ksec total integration time, inner working angle = 500 mas), with those obtained in program 12923 (*right*: 23 seconds total integration time, inner working angle = 200 mas). The images are on the same image flux and spatial scale, orientation, and linear display dynamic range: 0 to 15 counts/sec per pixel.

The program was designed to take observations of four stars at the three new aperture locations. Two target stars, known to host debris disks, have very different spectral types and brightnesses: AU Microspii (M1) and β Pictoris (A6). The other two are reference stars for the point-spread function (PSF). Offsets relative to the BAR10 fiducial location placed the stars near the corners of the BAR10 mask and in the center of the BAR5 mask. To optimize contrast, small dithers mapped the edges of the mask at high precision. In addition, the dithers helped to further optimize for small, sub-pixel shifts that occur when the 50CORON focal plane masks are moved into the field of view.

Observations of the stars executed nominally, and initial results at all three positions succeeded in obtaining both raw and PSF-subtracted, high-contrast imaging at apparent separations <300 mas. Figure 2 shows PSF-subtracted images of AU Microscopii from program 12228 (PI: Schneider) obtained at six separate spacecraft orientations, with a combination of the WEDGEA1.0 and WEDGEA0.6 positions compared with the shallower, exploratory observations taken with 12923 at BAR5. The edge-on debris disk of AU Microscopii is recovered to ~200 mas, close to the limit of the BAR5 inner working angle and corresponding to a physical separation of 2 AU at AU Microscopii's distance of 10 pc.

A Visible Legacy for *Webb*

The availability of these new coronagraphic mask locations in the 50CORON aperture will provide a legacy of high-contrast, visible-light imaging for *Webb*. In particular, the 200 mas inner working angle obtained in program 12923 is similar to the offering of NIRCAM's coronagraphic occulting wedges (~4λ/D or 270 mas) at 2.1 microns. STIS's visible-light coronagraphy of circumstellar material and substellar objects will provide the contrast and spatial resolution for a range of targets at a level comparable to future observations with *Webb*, which will allow multi-wavelength studies spanning from the visible to the infrared.