High Contrast Imaging with NICMOS - II: Coronagrapihc Polarimetry

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Abstract

The spectral element set in Camera 2 of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) aboard *HST* available for coronagraphic imaging includes 10% (Δλ/λ) bandpass polarizers with a central wavelength of 2.0 μm. Using these capabilities in concert, we have now commissioned and calibrated a coronagraphic imaging polarimetry mode. Here we discuss the capabilities of this mode, illustrated by science observations of the protoplanetary disks around the T-Tauri stars GM Aur and TW Hya that we previously imaged non-polarimetrically at 1.1 and 1.6 μm with NICMOS PSF-subtracted coronagraphy. We also discuss the use of NICMOS coronagraphic polarimetry for observing a variety of targets with *HST*, and the importance of incorporating polarizing optics into future space-based coronagraphic facilities.

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Cycle 12 Enabling Observations

GO 9768 (PI: Hines) was designed to ascertain the viability of coronagraphic polarimetry with NICMOS to probe high contrast regimes that are difficult or impossible from the ground. The program did not explore all possible parameter spaces; in particular, acquiring sufficiently deep images of standard stars to investigate fully instrumental performance beyond radii > 2″ was not possible due to programmatic constraints. None the less, our previous non-coronagraphic (Hines, Schmidt & Schneider 2000, PASP, 112, 983) and subsequent coronagraphic imaging polarimetry (e.g. Fig 5), demonstrate stable and high fidelity performance at larger radii.

In GO 9768, polarization standard stars and TW Hya (posessing a known, face-on circumstellar disk) were each observed at two epochs sufficiently spaced in time to permit large differential rolls of the spacecraft (i.e., field orientations w.r.t. the *HST* optics and NICMOS polarizers). At each epoch, imaging was carried out at two field orientations differing by 29.9° using the then-available two-roll per orbit scheduling paradigm.The intra-visit repeats for the standard stars were designed to check for both repeatability (image stability) and possible image persistence (none of consequence was found).

All coronagraphic polarimetry images were instrumentally calibrated in an APL-based analog to the STSDAS CALNICA task using on-orbit derived calibration reference files. Following the creation of count-rate images individual bad pixels were replaced by 2D weighted Gaussian interpolation (r=5 weighing radius) of good neighbors, and "horizontal striping" associated with heavily exposed targets was characterized and removed by median-collapse subtraction. Conversion to Stokes parameters followed the prescription in Hines et al. (2000).

We chose to observe the same polarized star CHA-DC-F7 (Whittet et al. 1992) and unpolarized (null) star BD +32° 3739 (Schmidt, Elston & Lupie 1992) that were used in Cycle 7, 7N & 11 (CAL 7692, 7958: Axon PI), in Cycle 11 (CAL 9644: Hines PI), and Cycle 13 (CAL 9693: Schneider PI).

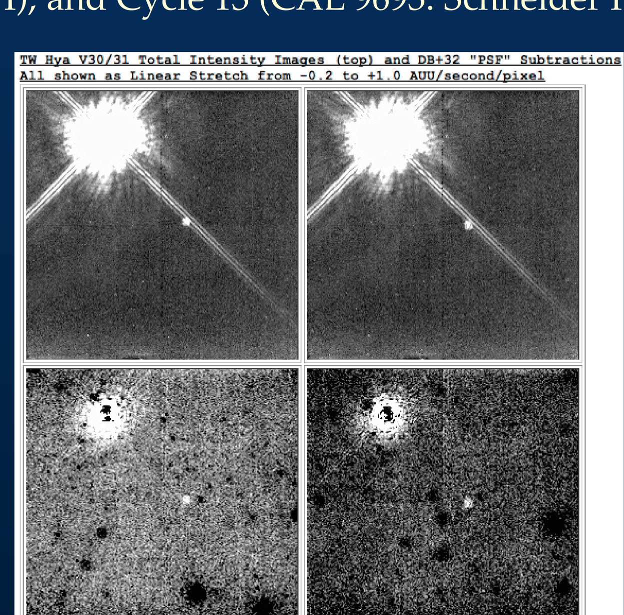

Figure 1: Top - NICMOS coronagraphic polarimetrically derived total intensity images of TW Hya at two epochs. Bottom - PSF subtraction using flux-normalized images of BD+32° 3837, revealing light scattered by circumstellar dust. Dark spots are caused by stars in the field of BD+32° 2837 [0.076" per pixel; spatial resolution at 2.0μm ~ 0.2″; FOV 19.2″x19.2″].

Coronagraphic Polarimetry Results

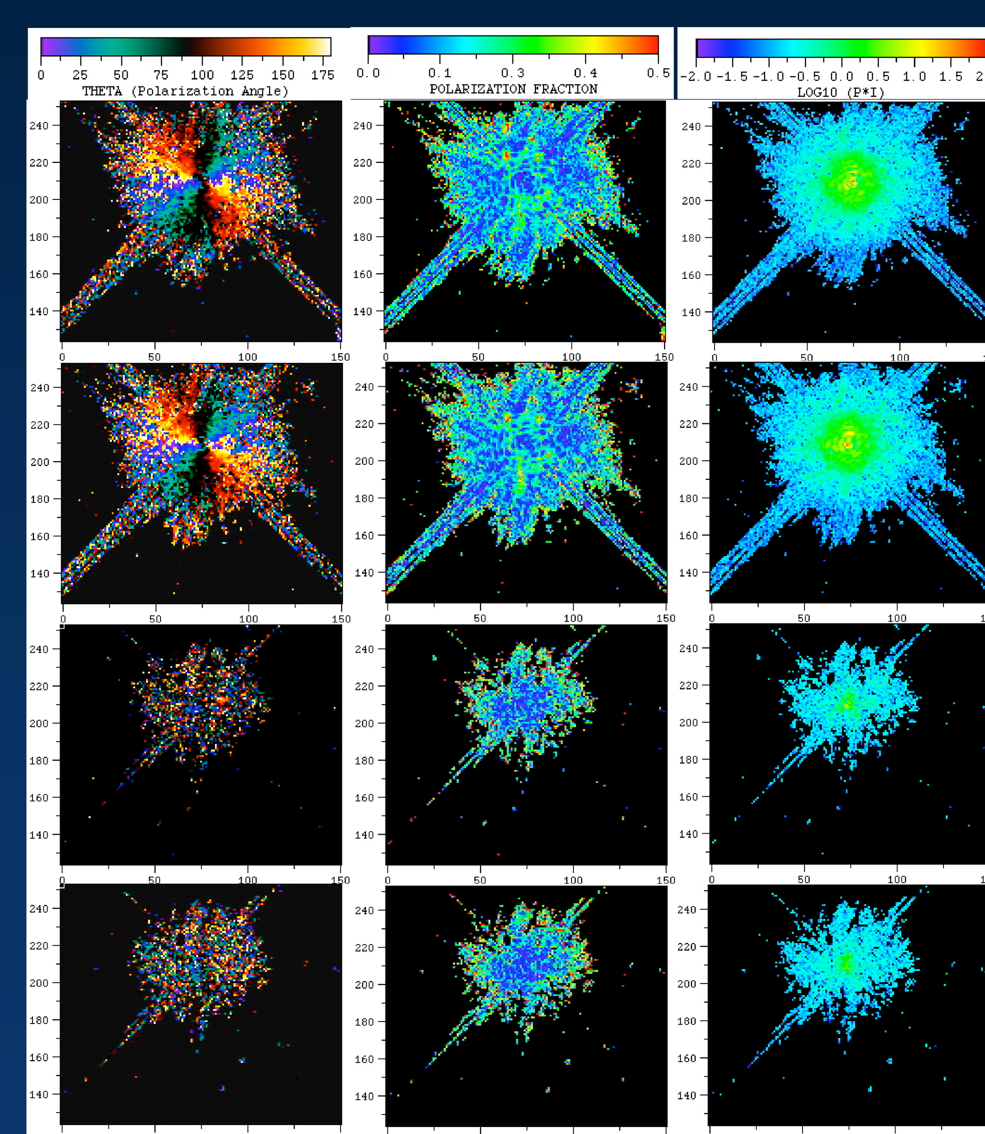

Figure 2: NICMOS coronagraphic polarimetry observations of TW Hya (top 2 panels) and the unpolarized standard star (bottom 2 panels) at two epochs. The centro-symmetric position angle pattern for TW Hya is expected for polarized (scattered) light in this face-on disk. The instrumental polarization induced by the coronagraph is low (≤ 5% at 6 pixels = 0.46″) and the system is stable both in time and with telescope roll angle (ORIENTATION).

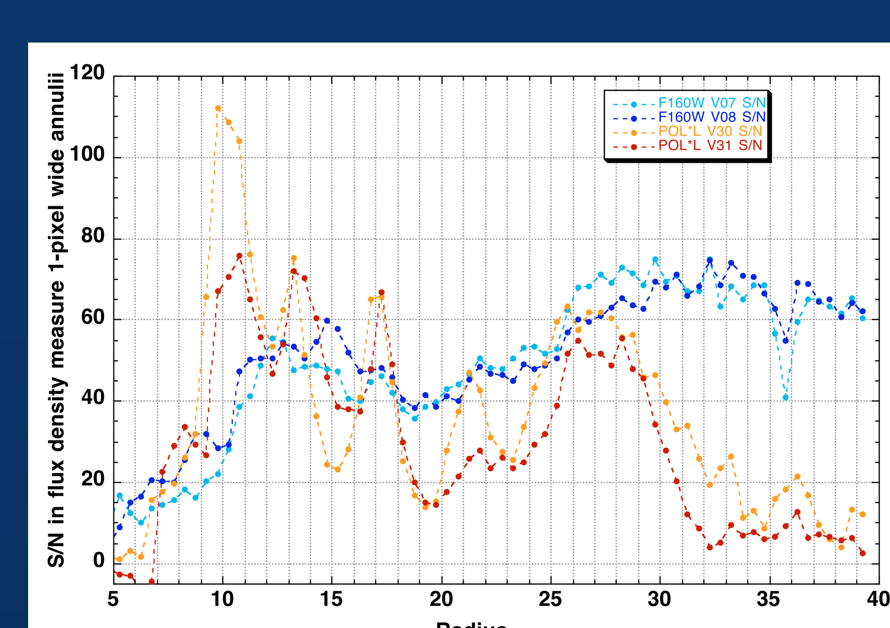

Figure 3: Coronagraphic signal-to-noise for F160W (unpolarized H-band) and 2.0μm (total flux coronagraphic polarimetry) observations of TW Hya with NICMOS. The results suggest an advantage for coronagraphic imaging polarimetry within ~15-20 pixels in these short integration times and for an unpolarized object near or embedded in diffuse polarized emission. The apparent decline in S/N at r > ~ 27 pixels results from the depth of the exposure limited by time available for this observation and should not be attributed to a loss of polarimetric sensitivity.

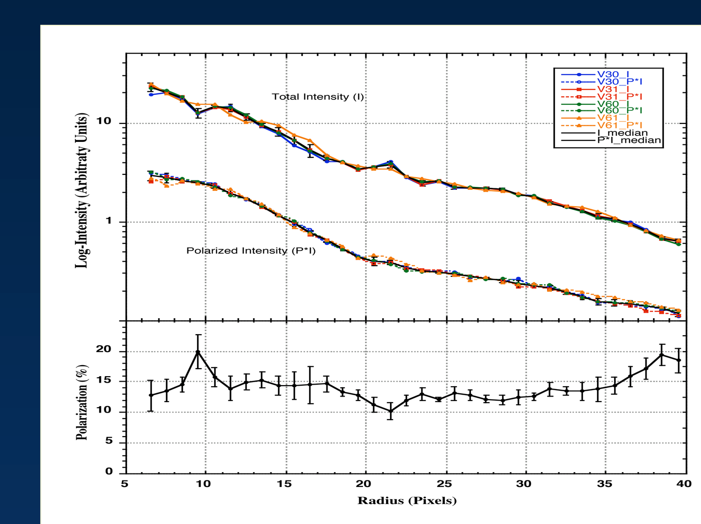

Figure 4: System Stability. Median radial profiles of the total intensity (I) and the polarized intensity (P*I) for TW Hya (top). Both rolls and both epochs (4 total measurements) and the median of the four profiles are shown. The percentage polarization (P*I/I) is shown in the bottom panel. The data probe 0.5″-3″ radii. In each error bars represent 1σ uncertainties in the measured median values at each annulus .

It really works!

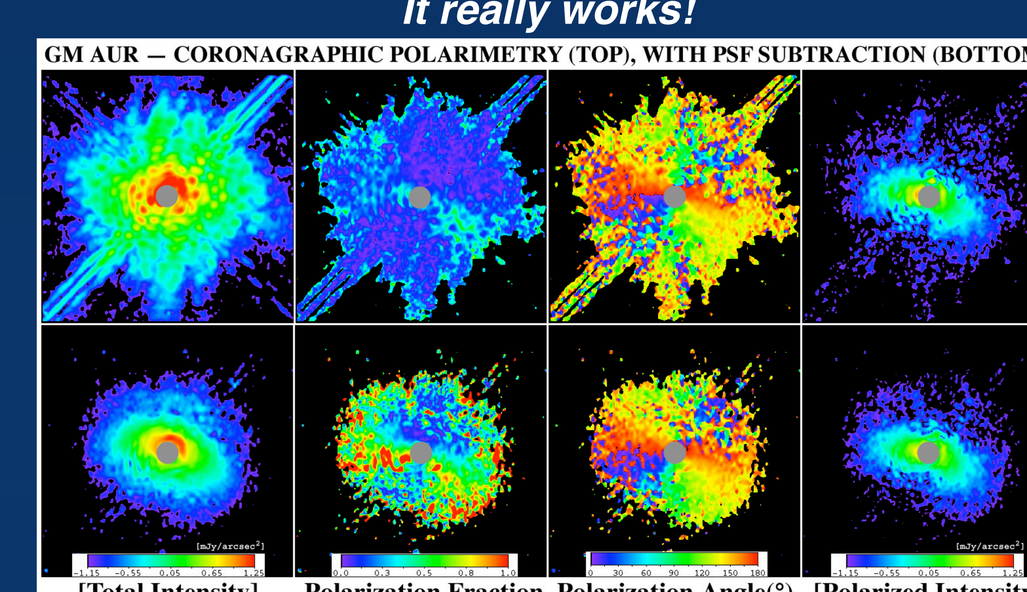

Figure 5: Coronagraphic polarimetry of GM Aur comparing polarimetry results without (top) and with (bottom) matched PSF-subtraction. Without subtraction of an unpolarized PSF-star, the polarization fraction of the GM Aur disk is diluted by residual instrumentally diffracted and scattered light from the coronagraphicaly occulted (unpolarized) central star. The efficacy of the technique is born out by the essentially identical position angle and polarized intensity images in the right two columns. PSF subtraction enables decoupling the polarization fraction and total intensity (2 μm flux density) with accurate measurements of both (overcoming one of the primary difficulties encountered in ground-based AO polarimetry). These observations are from GO 10852 (PI: Schneider).

Results for TW Hya & GM Aur

Figures 2, 4 & 5 demonstrate the ability of NICMOS coronagraphic polarimetry to obtain high contrast images in polarized light. Our *polarized intensity* profile of TW Hya (Fig. 4) is consistent with ground-based AO polarimetry (Apai et al. 2004 A&A, 415, 671; Potter et al. 2007, in prep). However, the stability of NICMOS enables measurement of the *polarization fraction* in the disk. PSF-subtraction (Fig. 5) minimizes dilution of the polarization by the unpolarized central illuminating star, and thus provides more accurate determination of the intrinsic polarization fraction imparted by the scattering medium. This in turn enables more precise models of the scattering geometry to be constructed.

Conclusions

Based upon our analyses and recommendations, STScI offered NICMOS coronagraphic polarimetry as a mode available to observers, and several programs are successfully executing (see Schneider & Hines, this meeting). The same operational constraints and observing strategies that apply to direct coronagraphic imaging apply to this mode as well. In particular, pointing control with two fine guidance sensors is necessary, even more so than at shorter wavelengths because of the relative size of the occulting hole (1.7 λ/d at 2.0μm). In addition, we generally recommend two spacecraft orientations to (a) discriminate against rotationally invariant optical artifacts (b) better sample the PSF, and (c) allow interpolation over bad pixels. We strongly urge GOs to observe an unpolarized standard star of similar H-K color, and at sufficient depth to obtain similar S/N in each polarizer to that obtained for their primary target. NICMOS coronagraphic imaging polarimetry enables detailed measurement of the polarization properties of faint emission near (single) bright point-sources, including YSOs, debris disks, and quasars. The addition of polarizing optics to future coronagraphic missions, such as TPF-C, could provide this capability for much larger contrast ratios than NICMOS, and opens the exciting possibility of detecting polarization of light scattered off extra-solar planets.

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