

NICMOS Mode-1 Coronagraphic Acquisition

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ABSTRACT

This report describes the acquisition of bright targets for NICMOS coronagraphic observations. A variation of the Reuse Target Offset (RTO) capability was used to position a target into the coronagraphic hole. A total of 30 NICMOS Mode-1 Acquisitions have been performed with 7 failures. Three failures resulted from Phase II errors and four failures resulted from guide star problems. A failure was declared when the target was not positioned into the coronagraphic hole for the science observations.

1. Introduction

Bright targets will saturate the NICMOS Camera 2 detector resulting in possible failure of the on-board software (Mode-2 Acquisition) to successfully acquire and position a target into the coronagraphic hole. Any target that will saturate the detector in the shortest possible Mode-2 ACQ ACCUM exposure, 0.203 seconds, should be considered a bright target. This sets a limiting target magnitude of H (1.60 μm) ~ 3.0 for on-board acquisition with the F187N filter. Any target brighter than this value should be acquired by a variation of the Reuse Target Offset (RTO) capability.

A hole in the Camera 2 Field Divider Assembly (FDA) mirror face, combined with a cold mask, provides coronagraphic imaging capability in Camera 2 (NIC2). In the standard RTO acquisition, a target is imaged in a region of NIC2 which is away from the coronagraphic hole, lamp-on (flat field) and lamp-off (background) observations are obtained, and these images are sent to the ground in real time. OSS and PODPS Unified System (OPUS) staff performs centroiding of the target and coronagraphic hole, and calculates offset slews to move the hole over the target. OPUS staff then provide the offsets to Goddard Space Flight Center (GSFC) staff for uplink to the spacecraft in advance of the coronagraphic observations. Because orbits are allocated in integral units, one orbit is needed to perform this procedure. The science is done in a non-consecutive orbit, recom-

mended to be 3-5 orbits after the decision orbit. An in-depth description can be found in NICMOS ISR-97-031.

2. Movement of the Coronagraphic Hole

The NICMOS dewar anomaly has caused the coronagraphic hole to migrate to different locations on the detector. The position of the hole on the detector has been observed to move as much as ~ 0.25 pixel in three orbits. During the interval April-December 1998, the hole moved about 1 pixel. However, the hole “jitters” back and forth along an X-Y diagonal by as much as ± 0.5 pixel. The movement of the hole causes a problem for coronagraphic observations. Repeat positioning of targets in the coronagraphic hole to a fraction of a pixel is necessary for PSF subtraction. This requires locating the position of the hole for each RTO acquisition.

3. RTO Acquisitions

The list of the NICMOS visits requiring a RTO acquisition is presented in Table 1. For emphasis, the visual and infrared H ($1.6 \mu\text{m}$) magnitudes are included in the table. The majority of targets were bright A stars and the F187N filter was used for flux reduction for all but one target. One PI used the F190N filter for the acquisition images based on a ground-based spectrum of the target. Failed observations are marked with an “asterisk”. A failure was declared when a problem during the acquisition visit or during the following science visit resulted in the target not being positioned in the coronagraphic hole for the science observations. Failures resulted due to Phase II errors, positional errors (incorrect RA, DEC, or proper motion), and guide star problems.

Many observers specified MULTIACCUM observations for the decision observations with a few specifying either ACCUM or BRIGHTOBJ mode observations. MULTIACCUM mode observations are processed on the ground during OPUS pipeline processing, while ACCUM mode observations are zeroth-read subtracted on-board the spacecraft using 16-bit arithmetic. On-board processing of ACCUM mode observations may result in clipping/wrapping of the data. BRIGHTOBJ mode observations require using a synthetic dark for calibration. See the NICMOS Instrument Handbook for more details about observing modes.

It is worth pointing out that coronagraphic observations are obtained at a different focus than the nominal Camera 2 focus. The Pupil Alignment Mechanism/mirror (PAM) is moved to achieve best focus at the position of the coronagraphic hole. The PAM coronagraphic settings are 3075 steps, x-tilt=9, and y-tilt=14, while the nominal Camera 2 PAM settings are 627 steps, x-tilt=5, and y-tilt=10 (PAM movement = 909.5 steps/mm). The commanded coronagraphic focus in PAM space is FOCUS = 3.38 mm.

Table 1. Cycle 7 NICMOS Reuse Target Offset ACQs (Mode-1).

Date (UT)	Prog. ID	Visit	Filter	Target	sp.type	m_v	H (1.6 μm)
22-Jul-98	7835	16	F187N	HD102647	A3V	2.14	1.94
09-Aug-98	7835	04*	F187N	HD38678	A2Vann	3.60	3.32
15-Aug-98	7835	18	F187N	HD128167	F2V	4.46	3.53
17-Aug-98	7835	07	F187N	HD10700	G8V	3.50	1.78
17-Aug-98	7233	38	F187N	HD216956	A3V	1.16	0.96
17-Aug-98	7233	39	F187N	HD216956	A3V	1.16	0.96
18-Aug-98	7835	11	F187N	HD27290	F4III	4.20	3.49
29-Aug-98	7835	09	F187N	HD18978	A4V	4.10	3.74
10-Sep-98	7441	40	F187N	HD61421	F5IV-V	0.38	-0.60
14-Sep-98	7441	21*	F187N	HD187642	A7V	0.77	-
14-Sep-98	7441	30*	F187N	HD10700	G8V	3.49	1.78
16-Sep-98	7835	02	F187N	HD3906	A5V	3.80	3.49
17-Sep-98	7441	31*	F187N	HD10700	G8V	3.49	1.78
21-Sep-98	7248	03	F187N	HD39060	A5V	3.80	3.49
24-Sep-98	7828	01	F190N	HD222800	M7IIIvar	8.5+/-2.5	-0.25
24-Sep-98	7233	16	F187N	HD17206	F5/6	4.46	3.35
24-Sep-98	7233	17*	F187N	HD17206	F5/6	4.46	3.35
26-Sep-98	7233	01	F187N	HD22049	K2V	3.72	1.60
26-Sep-98	7233	02	F187N	HD22049	K2V	3.72	1.60
08-Oct-98	7233	26*	F187N	HD172167	A0	0.033	0.03
08-Oct-98	7233	27*	F187N	HD172167	A0	0.033	0.03
14-Oct-98	7441	20	F187N	HD187642	A7V	0.77	-
20-Oct-98	7441	10	F187N	HD48915	A1V	-1.43	-1.32
21-Oct-98	7441	41	F187N	HD61421	F5IV-V	0.38	-0.60
22-Oct-98	7441	11	F187N	HD48915	A1V	-1.43	-1.32
05-Nov-98	7828	03*	F190N	HD222800	M7IIIvar	8.5+/-2.5	-0.25
10-Nov-98	7233	70	F187N	HD172167	A0	0.033	0.03
10-Nov-98	7233	71	F187N	HD172167	A0	0.033	0.03
15-Nov-98	7835	20	F187N	HD39060	A5V	3.80	3.49
17-Dec-98	7828	53	F190N	HD222800	M7IIIvar	8.5+/-2.5	-0.25

4. Centroiding Within the Decision Observations

OPUS staff calibrate each individual RTO image off line using existing reference files or specially created reference files. A synthetic dark was used to calibrate the BRIGHT-OBJ mode observations. The background and lamp images were each co-added for MULTIACCUM mode observations, while the ACCUM mode exposures were combined by throwing out the higher count pixel between two images. The resulting background was subtracted from the resulting lamp flat image and the location of the hole determined.

For centroiding the coronagraphic hole and the target, OPUS staff used an IRAF SPL language code that was translated into Fortran and then compiled and linked into an executable which included all of the OPUS IRAF tasks. This task is called **centroid** and is only available in OPUS. It should not be confused with the IRAF task **centroid** found in the STSDAS package of routines.

The OPUS **centroid** task will compute the weighted centroid of a specified region, either a rectangular or circular region, or a torus. The centroid is an average of the location in the specified region where each pixel is weighted according to its intensity (counts/sec). The x's and y's are averaged separately to determine the centroid position.

The OPUS **centroid** task allows the user to specify regions to exclude from the centroid measurement when using the torus region option. This option was used for centroiding the saturated ACCUM and MULTIACCUM images of a target. For BRIGHT-OBJ mode observations, a synthetic dark was used for calibration and all of the pixels were used for the centroid determination.

The OPUS X,Y and V2,V3 positions for the target star as determined by the target location activities can be found attached to the "Additional Comments:" section of the Procedural Data Quality (PDQ) file for the association containing the target exposures. If only one decision observation of the target was obtained, then the OPUS information will be found in the PDQ file for that exposure. The target location is reported in the following fields of the PDQ file; these values are from the Sigma Boo observations.

Selected target V2 coordinate = -325.3150 arcsec

Selected target V3 coordinate = 325.4444 arcsec

Selected target SI x coordinate = 72.6680

Selected target SI y coordinate = 211.3550

Since the OPUS **centroid** task works well for locating either the target or the hole, the field reporting the coordinates for the hole in the PDQ file are labeled as a "target" position. A variation of the procedure outlined in NICMOS ISR-98-012 Section 6 is used to determine the location of the coronagraphic hole. The hole location will usually be found

in the PDQ file for the association containing the background exposures. For example, the hole was found to be at pixel location (73.373, 212.390) for the Sigma Boo observations.

The STScI STSDAS group has written a new task **cdq** which performs similarly to the OPUS task **centroid**. This task is based on the IRAF task **imcentroid** with the addition of excluding from the centroid determination bad pixels that are flagged in the DQ array. The new task **cdq** works best for images of symmetric point sources. This task is currently located in the STScI testnic package of routines for testing, but is expected to be released in a future version of STSDAS. A cautionary note: the **cdq** task will yield marginal results for non-symmetric images of point sources.

For example, the MULTIACCUM observation of Sigma Boo (n4xj18ucq) has the DQ bit set (value=2048) for those pixels with counts above the expected counts in the zeroth-read. This indicates there were counts above the bias level in the zeroth-read due to the brightness of the target. The task **cdq** using all the set DQ bits returns a X,Y position larger in Y by 2.359 pixels than determined by OPUS. Ignoring the zeroth-read DQ flagged pixels set by **calnica**, the task determines an X,Y position much closer to the OPUS value with a difference in the y-coordinate of 0.156 pixels. The different measured positions of the target are presented in Table 2.

Table 2. Comparison between OPUS and **cdq** task determined centroids for a MULTI-ACCUM observation of Sigma Boo.

OPUS (X,Y)	CDQ (X,Y)	Comments
162.666, 110.621	162.808, 112.980	use all DQ bits (excludes all flagged pixels)
	162.694, 110.465	zread bit = no (use zread flagged pixels)

The zeroth-read DQ bit is set to alert the observer that there were counts from a source above the expected count level in the zeroth-read (exposure time = 0.175 seconds), not unexpected for bright targets. In short exposures, the affected pixels may not saturate and set the saturation DQ bit. In which case, they would be good pixels and should be used to determine the centroid. Setting the zread bit=no for the **cdq** task ensures all pixels are used for determining the centroid. The small differences between the OPUS and **cdq** task centroids are most probably due to the coding of the two tasks. The following lines are captured IRAF screen messages while using the **cdq** task.

```

> epar cdq
PACKAGE = testnic
TASK = cdq

input = n4xj18ucq_cal.fits[sci,1][153:173,100:120] >Science image
dqf = n4xj18ucq_cal.fits[dq,1][153:173,100:120] >Data Quality File
xcent = 11 >Guess for centroid X position
ycent = 11 >Guess for centroid Y position
(dqpar = ) >Data Quality bits (pset)
(niter = 10) >Number of iterations
(odqf = n4xj18ucq_cal_cdq01) >Output Data Quality File
(backgro= 1.) >Background level
(version= 10Sep98) >Date of installation
(mode = al)
:go

# X Y Total Used
10.694 (0.015) 11.465 (0.015) 441 441
10.694 (0.015) 11.465 (0.015) 441 441
10.694 (0.015) 11.465 (0.015) 441 441
10.694 (0.015) 11.465 (0.015) 441 441
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10.694 (0.015) 11.465 (0.015) 441 441
10.694 (0.015) 11.465 (0.015) 441 441
10.694 (0.015) 11.465 (0.015) 441 441

> = 152 + 10.694
162.694

> = 99 + 11.465
110.465

```

5. Flat Fielding and Locating the Target In the Coronagraphic Hole

One of the coronagraphic calibration problems is “proper” calibration of images near the edge of the hole due to motion of the hole itself. The problem arises from the fact that the OPUS flat field reference files are not contemporary with the coronagraphic images. The coronagraphic hole has moved about 0.1 to 0.2 pixels per month, and there is a short term movement along a pixel diagonal (back-and-forth) with a random jitter of a few tenths of a pixel imposed on this motion.

There are three approaches to solving this flat fielding problem: patched flats, unpatched flats, or contemporary flats. OPUS pipeline reference files are “patched” with re-normalized data from a ground-based vacuum test flat field reference file. This essentially removes the hole profile from the reference flat field. The unpatched reference files are available from the Archive. A patched-flat of this nature does not compensate for the “roll-off” of response from $r = 7$ pixels to the edge of the hole ($\sim r=4$) arising from the reduced throughput of the hole edge. Contemporary flats can be created from the two F160W lamp flat images (and backgrounds) obtained to locate the hole. The hole does not

shift by any significant amount between the paired sets of flats. The lamp flats should have been exposed to $\sim 10,000$ ADU above bias ($S/N \sim 100$).

For illustration only, the F165M coronagraphic image of Sigma Boo is presented in Figure 1. These 8x expanded views of the coronagraphic image were flat fielded using the OPUS patched flat, the unpatched flat, and a contemporary flat created from the F160W filter observations (background and lamp images) used to determine the location of the hole. The F160W filter contemporary flat is a close match to the F165M bandpass, but not ideal.

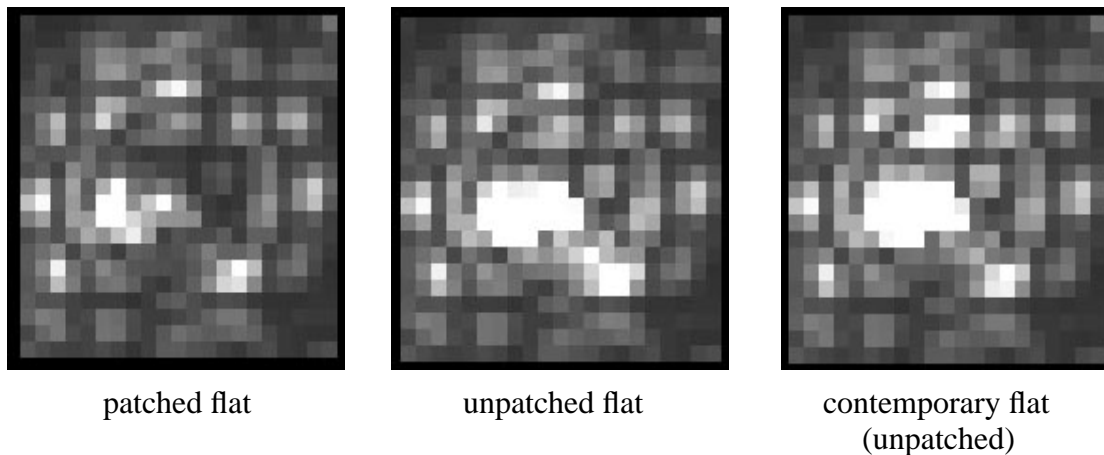


Figure 1: F165M filter coronagraphic image of Sigma Boo calibrated with a patched flat (left), unpatched flat (middle), and for illustration a F160W unpatched contemporary flat (right). Each image is a 21x21 pixel area centered on the hole. The bright pixels are scattered light.

The light pattern about the coronagraphic hole is not symmetric due to glint (See Figure 1.), and will vary depending upon the location of the target in the hole. Calibrating with a contemporary flat which has the coronagraphic hole pattern at the correct location restores the flux level and re-establishes the light pattern about the hole at the time of the observation. This approach does not restore all the information that was lost near the hole. For the majority of coronagraphic observers, the recommended OPUS high S/N patched flat is the best reference file to use for calibration.

Centroiding a target in the coronagraphic hole is problematic. Several methods have been investigated with little or marginal success. These include diffraction spike tracing to determine the line crossing point; measuring the shift between an image of a target close to the hole and in the coronagraphic hole, excluding the region about the hole in the cross-correlation between the two PSFs; and setting the DQ bits to 32 in the hole region and using the task `cdq`. The diffraction spikes are not perpendicular to each other at large distances from the core of the PSF. Cross correlation works best if the target is identical in

both images and the same filter was used for the image of the target outside the hole. The task **cdq** yields good results for symmetric PSF images and is not reliable for non-symmetric PSFs. No technique using IRAF/STSDAS tools for centroiding a target in the hole yields reasonable results.

The NICMOS Instrument Definition Team (IDT) has developed IDL tools that can be used to centroid a target in the hole. They report success in determining the position of a target in the hole by matching diffraction speckles (beads) with a Tiny Tim model PSF. The original position of the model PSF combined with the shift to match the target PSF diffraction speckles (beads) yields the position of the target. Information about the IDL tools can be found on the NICMOS IDT information web page (<http://nicmos.as.arizona.edu/>).

6. Guide Star Pairs

Three of the RTO acquisition failures were due to a change in the FGS guide star pair between the decision and science observations. The respective targets were either positioned away from the coronagraphic hole or on the edge of the hole for the science observations. In both cases, severe saturation (and wrapping for ACCUM observations) of pixel values occurred, limiting the usefulness of the data for the intended purposes. HST Observation Problem Reports (HOPRs) were submitted for repeats and two of the three visits were approved for repeats by the Telescope Time Review Board (TTRB).

This problem was solved when the fix for Operations Problem Report (OPR) 36218, "Members of a SAVE/REUSE TARGET OFFSET link should use the same gs pair", was installed in SOGS with SPSS 42.0 on July 27, 1998. This situation should not happen in the future. However, if the guide star pairs are not verified to make sure the same pair are used for the decision and science observations, there is nothing that can be done to save the observations once the spacecraft load is completed.

It is recommended that future NICMOS coronagraphic observers using the Reuse Target Offset capability specify same guide star pair in the visit level comment sections for linked visits of the Phase II template. Here is an example:

```
Visit_Number: 02
Visit_Requirements:
    SCHED 30%
    ORIENT 255D TO 255D
On_Hold_Comments:
    Visit_Comments: Exposure 13 is the C2 acquisition image for a Mode-1
acquisition in Visit 3. H = 3.4 mag. Visits 02 & 03 should be linked
together. Same guide star pair as visit 03.

Visit_Number: 03
Visit_Requirements:
    PCS MODE FINE
    ORIENT 255D TO 255D
    AFTER 02 BY 3 Orbits TO 5 Orbits
On_Hold_Comments:
```

Visit_Comments: Same guide star pair as visit 02

7. Guide Star Spoilers and non-existent Stars

Two of the RTO acquisition failures were due to a spoiler star and a non-existent guide star (GS). Program 7828 observed a target twice with visit pairs 1 & 2 and 3 & 4. The target visit 03 was not at the expected position in the Camera 2 field of view (FOV) for the decision observations. It was closer to the hole than it was for the previous visit 01 acquisition images. The target was not behind the coronagraphic hole for the following visit 04 coronagraphic observations, but offset from the hole by about 1.8 arcseconds. Information from the engineering telemetry reported in the observation logs (OMS products) indicated that the guide star separation changed significantly between obssets N52M03 and N52M04. The predicted separation was 1075.920 arcseconds, but the actual separations were 1077.896 and 1076.062 arcseconds respectively. The second is only 0.142 arcsec larger than expected, but the first is 1.976 arcsec larger. It appears a spoiler star was acquired for obsset N52M03, causing the target to be positioned at the wrong location in the FOV.

There was an FGS failure to acquire both guide stars for 7233 visit 17 decision observation and the following visit 19 science observations. The secondary guide star was not found in either visit and the spacecraft dropped to gyro guiding. Inspection of GSSS plate scans, quick V plates and the astrometric plates for the secondary guide star showed no star at the expected position. The secondary guide star was actually a defect or ghost on the original photographic plate which was probably mis-classified as a viable guide star.

8. Offsetting after an RTO Acquisition

A few coronagraphic observers offset the target from the hole either for scientific reasons or due to thermal background. The thermal background from the HST OTA is detectable with NICMOS at long wavelengths. Observers are advised to obtain background measurements when observing in one of the thermally impacted filters, wavelengths longer than $\sim 1.7 \mu\text{m}$, as described in NICMOS ISR-98-010, May 18, 1998.

Observers usually chop away from their respective targets either with POS TARGs or with a recommended dither-chop pattern. The problem coronagraphic observers encounter is how to specify a chop in the Phase II template without losing the initial pointing of the telescope to position a target into the hole. The Special Requirement command "SAME POS AS ###" can not be used with dither patterns.

The solution is to specify fully the pointing. The pointing should be identical to the first observation in a coronagraphic visit and avoid the use of the Special Requirement command "SAME POS AS ###". For example, the 7828 visit 52 exposure line 70 specifies observations with the F190N filter. The PI wants to chop away to measure the background. He has fully specified the pointing in the Phase II as displayed below.

Exposure_Number: 70

```

Target_Name: R-AQR
Config: NIC2
Opmode: MULTIACCUM
Aperture: NIC2-CORON
Sp_Element: F190N
Wavelength:
Optional_Parameters: SAMP-SEQ=STEP16,NSAMP=10,
                    PATTERN=ONE-CHOP,CHOP-SIZE=20,
                    NUM-POS=2,PATTERN-ORIENT=90
Number_of_Iterations: 1
Time_Per_Exposure: DEF
Special_Requirements:
                    USE OFFSET OFF03
                    POS TARG 6.374,-6.472
Comments: This is the seventh coronagraphic observation.
          Take a 64 S background before finishing the
          observation.

```

9. Persistence in NICMOS

Persistence is the excess dark current observed immediately after the detectors have been saturated with bright light. NICMOS observations use South Atlantic Anomaly (SAA) contour 23, a footprint on the earth where charged particles have their heaviest impact on the instrument. Observations are scheduled outside the SAA contour. However, if the NICMOS observations are scheduled within 30 minutes of exiting the SAA contour, the data will most probably exhibit a higher background level than normal resulting from insufficient autoflush time to remove all of the residual charge. Persistence is discussed in NICMOS ISR-022, ISR-023, ISR-024, ISR-032, and ISR-98-001.

Coronagraphic observations scheduled over more than one visibility period will most probably be impacted by an SAA passage and be affected by charged particle induced persistence. To avoid breaking exposures across visibility periods, it is recommended that coronagraphic observers use the Phase II exposure level Special Requirement "SEQ <exp. list> NON-INT". For the following example, exposure lines 15-22 are to be scheduled within the same visibility window without interruptions such as Earth occultations or SAA passages.

```

Exposure_Number: 15
Target_Name: EPSILON-ERIDANI
Config: NIC2
Opmode: ACCUM
Aperture: NIC2-CORON
Sp_Element: BLANK
Wavelength:
Optional_Parameters: NREAD = 25
Number_of_Iterations: 1
Time_Per_Exposure: 14.28 S
Special_Requirements: USE OFFSET OFF01
                    POS TARG 6.374, -6.472
                    SEQ 15-22 NON-INT
Comments: "Throw away" exposure to reduce image persistence.

```

10. Summary/Conclusions and Recommendations

In this ISR we report the success and failures for NICMOS Mode-1 coronagraphic acquisitions of bright targets, mostly A stars for which the shortest MULTIACCUM or ACCUM exposure times would result in a saturated image. There were two major causes of failures, failure to acquire guide stars and PI error (i.e. Phase II error). The acquisition strategy as outlined in NICMOS ISR-97-031 and performed by OPUS staff worked quite well with one qualifier, the guide star pair must be the same for the decision and science observations.

Bright targets will saturate the Camera 2 detector in the shortest ACCUM and MULTIACCUM exposures, but not for BRIGHTOBJ mode exposures. The central pixels in the ACCUM and MULTIACCUM images of bright targets will not be usable for centroiding. OPUS staff will be required to select inner (excluded) and outer regions for centroiding targets with these images. These extra regions will introduce errors in the centroid positions as the affected pixels are not usually symmetrically distributed about the center of the PSF. For BRIGHTOBJ mode, each pixel is individually read out. The clocking is very fast allowing for extremely short exposure times, on the order of milliseconds (multiple of 0.001024 seconds). Even with short exposure times, the overhead to read out the entire detector array may take as long as 15 minutes (exposure time ~ 54 milliseconds). However, the central pixels for a BRIGHTOBJ mode observation would be usable for centroiding, thus out-weighting the time needed to complete the BRIGHTOBJ mode exposure. If there are no viable scientific reasons to fill the remaining decision orbit with science observations, then it is recommended that the coronagraphic observer consider specifying BRIGHTOBJ mode exposures for the acquisition image(s).

“Proper” calibration of coronagraphic images is a problem that can be resolved with lamp and background observations obtained close in time to the coronagraphic observations. These contemporary calibration observations could be scheduled in the time remaining in the first orbit and would increase the scientific return of the science data. Calibration observations are normally obtained as part of the STScI calibration program and GOs are not usually allowed to request calibration data. However, the coronagraphic programs are allowed to obtain lamp and background observations to be used to locate the coronagraphic hole which should be extended to include calibrations for specific filters to support the data reductions. Again, if there are no viable scientific reasons to fill the remaining decision orbit with science observations, then it is recommended that lamp and background observations be obtained to support the coronagraphic science observations.

The NICMOS Mode-1 acquisition procedure is labor intensive and requires the “Reuse Target Offset” capability. In addition, orbits need to be linked and sufficient time scheduled between the decision and science orbits to allow the decision observations to be sent to the ground (requiring a TDRSS down link), to provide OPUS staff with sufficient time to determine telescope offsets to position a target into the coronagraphic hole, and

sufficient time to uplink the offsets to the telescope. One solution/improvement for coronagraphic observations of bright targets would be to rework the NICMOS Mode-2 coronagraphic ACQ FSW using a BRIGHTOBJ mode observation for the acquisition image. Possibly, after a more in-depth review, three BRIGHTOBJ mode exposure times could be specified to acquire targets with H (1.6 μm) between -1.3 and +3.6.