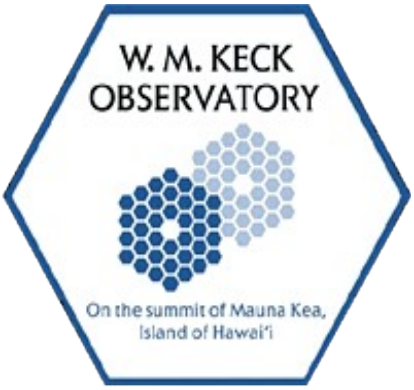

How to run QACITS for the Vortex Coronograph at NIRC2 on Keck II

A Quick User Manual

Keck Adaptive Optics Note 1105

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1.0	10/27/2015	Initial	E. Huby
1.1	03/10/2016	Extended version with screen shots during actual operation. New vortex logo.	E. Huby

QACITS
Observer's manual
Version: 1.1 - 2016.03.13
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1 Introduction

The complete QACITS procedure consists of 3 steps that can be run separately or all in a row:

- **Calibration sequence:** to acquire an off-axis PSF image and its associated sky image (needed to calibrate the QACITS estimator), and also a sky image associated with the science/optimization images.
- **Optimization sequence:** to center the star and close the loop on QACITS with acquisition settings allowing faster acquisitions (reduced integration time and coad number, as well as sub-framed images). The optimization sequence stops as soon as the tip-tilt estimations are stable (by default, there should be 2 consecutive estimations smaller than 0.1 lambda/D, but these criteria can be tuned by the observer). If this criterion is not met during the optimization sequence, it will stop after 10 iterations by default.
- **Science acquisition sequence:** to run QACITS in closed loop while acquiring data with the desired acquisition settings.

The procedure needed to get started is described in Section 2 and the typical inputs are defined in Section 3. The QACITS calling sequences are described in Section 4.

Details about the QACITS estimator can be found in Huby et al. 2015.

2 Getting started

Open an IDL terminal (right click and in the IDL menu, click on IDL 8.1).

In the IDL console, go to the qacits directory:

```
IDL> cd, 'qacits/'
```

The user account used during the observations must be specified in the `qacits_nirc2_params.i` routine (line 92): the string variable `nirc_account` must be set to the correct account name (typically '`nircX`').

The observer should make sure that a folder named log is present in the qacits folder. It will be used to save the log file of the night generated by the QACITS routines (see Section 5).

3 Variables and keywords definition

Several variables and keywords are used in the call to QACITS. They are described in the following sections.

3.1 Typical inputs

`n_sci` : [required] Number of acquisitions requested for the science sequence.
`tint_sci` : [required] Integration time for the science acquisitions.
`coad_sci` : [required] Number of coadd for the science acquisitions.
`data_dir` : [required] Path name of the directory where the data are saved (string).
`tint_opti` : [optional] Integration time for the optimization acquisitions.
`coad_opti` : [optional] Number of coadd for the optimization acquisitions.
`subc_opti` : [optional] Width of the image during optimization (typically 1024, 512, 256 or 128).
`/no_calib` : [optional] Skip the calibration sequence.
`/no_opti` : [optional] Skip the optimization sequence.
`/faint` : [optional] Faint target mode (optimization settings set to science acquisition settings).

3.2 Other parameters

`tint_psf` : Off-axis PSF integration time
`coad_psf` : Off-axis PSF number of coadd.
`subc_psf` : Width of the image for the off-axis PSF (typically 1024, 512, 256 or 128).
`faint_tint_psf` : Integration time for the off-axis PSF in the /faint mode.

3.3 Default values

`tint_opti` : 0.2s
`coad_opti` : 10
`subc_opti` : 512
`tint_psf` : 0 (will force the lower integration time possible, e.g. 0.005 in case subc=128)
`coad_psf` : 100
`subc_psf` : 128
`faint_tint_psf` : 0.2

4 IDL calling sequences

QACITS is usually used to perform the calibration, centering optimization and science acquisition all at once (see §4.1). However, every step can be run separately if needed, but this it usually not required nor recommended, except for extra science acquisition sequences. Science acquisition sequences can be launched either using specific keywords to skip the calibration and optimization steps in the standard calling sequence (see §4.1) or by using the dedicated calling sequence (see §4.4).

4.1 Standard sequence: calibration + optimization + science

```
IDL> run_qacits_nirc2, n_sci, tint_sci, coad_sci, data_dir=data_dir
```

By default, the calibration sequence (sky+psf+skp) and hence the optimization sequence will be performed. The star must be roughly centered onto the vortex at the beginning of the sequence (if not, the sequence will fail and could mess with the offsets sent to the tip-tilt mirror).

If you want to skip both calibration and optimization steps, you can use the `/no_calib` and/or `/no_opti` keywords (it is then equivalent to running a science sequence alone as described in §4.4):

```
IDL> run_qacits_nirc2, n_sci, tint_sci, coad_sci, data_dir=data_dir,
/no_calib, /no_opti
```

The acquisition settings for the optimization sequence have default values (see §3.3), but they can be set to custom values by using the optional keywords:

```
IDL> run_qacits_nirc2, n_sci, tint_sci, coad_sci, data_dir=data_dir,
tint_opti=tint_opti, coad_opti=coad_opti, subc_opti=subc_opti
```

There is also a `/faint` keyword that can be used for faint targets (Lmag $\lesssim$ 8).

```
IDL> run_qacits_nirc2, n_sci, tint_sci, coad_sci, data_dir=data_dir,
/faint
```

In the `/faint` mode:

- the integration time for the off-axis PSF is set to a default 0.2 s value (see §3.3).
- the acquisition settings for the optimization sequence are set to the same as for the science sequence. Indeed, in case of faint targets, low integration time ans coad number are not appropriate even for the optimization sequence. Therefore the acquisition settings are set to the science settings, such that the acquisitions can potentially be used as science.

The optimization and science loops can be stopped in two ways:

- before the completion of each iteration by typing the letter n when the following message is prompted (for less than 1 sec!):

```
Apply correction and continue QACITS? [y/n]>
```

- In case the prompt does not work, a flag set to 1 in the qacits_stop_flag.txt file will stop the loop. If stopped that way, the flag will automatically reset to 0 after being read.

4.2 Calibration sequence

The calibration sequence can be run separately using:

```
IDL> run_qacits_calib, tint_sci, coad_sci, data_dir=data_dir
```

Note that the star should be roughly centered onto the vortex at the beginning of the sequence.

4.3 Optimization sequence

The optimization sequence for finely centering the star onto the vortex mask can be run by calling:

```
IDL> run_qacits_opti, tint_sci, coad_sci, data_dir=data_dir
```

For a maximized efficiency, the star should be roughly centered onto the vortex center (the image should exhibit a donut shape).

Note that tint_sci and coad_sci should be provided in case you want to use the /faint mode.

There are additional optional keywords that you can use:

```
IDL> run_qacits_opti, tint_sci, coad_sci, data_dir=data_dir,
tint_opti=tint_opti, coad_opti=coad_opti, /do_calib
```

The optimization sequence is acquired with default values (see §3.3), which can be changed using the tint_opti, coad_opti and subc_opti keywords, or the /faint keyword.

The keyword /do_calib will force the calibration sequence to be called. If /do_calib is not set and if calibration files already exist for this target, they will be used and the calibration sequence will be automatically skipped. If they do not exist, the calibration sequence will be run automatically.

A calibration sequence should better be performed again if observations on a target are longer than 1h, to refresh the sky image and off-axis PSF.

4.4 Science acquisition sequence

The science acquisition sequence can be run using the dedicated calling sequence:

```
IDL> run_qacits_sci, n_sci, tint_sci, coad_sci, data_dir=data_dir
```

5 Log file

A log file is automatically generated when acquisitions are taken by the QACITS routines (the acquisitions taken using the goi command in the nirc2 terminal are not logged). This file is named as [UT-date]_nirc2_qacits.log and can be found in the folder log of the QACITS folder. The different columns, delimited by semi-colon are:

- the acquisition number of the file
- the UT time
- the name of the object
- the acquisition type (sci/opt/skp/psf/sky)
- the integration time
- the number of coadds
- the dtclxoffset status (if relevant)
- the dtclyoffset status (if relevant)
- the estimated tiptilt in x (if relevant)
- the estimated tiptilt in y (if relevant)
- the estimation of the null depth (if relevant)

The acquisition types are:

`sci` : Science image.
`sky` : Sky image for the science images (also rescaled and used for the optimization sequence).
`psf` : Off-axis PSF image.
`skp` : Sky image for the off-axis PSF.
`opt` : Image taken during the optimization sequence.

Typical lines look like the following:

```
 num ; time ; object ; acq type ; int time ; coadds ; offx ; offy ; ttx ; tty ; null
...
31 ; 06:35:42 ; HR 8799 ; skp ; 0.0180000 ; 100.000 ; 0.0000000 ; 0.0000000 ; nc ; nc ; 0

32 ; 06:36:10 ; HR 8799 ; psf ; 0.0180000 ; 100.000 ; 0.0000000 ; 0.0000000 ; nc ; nc ; 0

33 ; 06:37:21 ; HR 8799 ; sky ; 0.181000 ; 100.000 ; 0.0000000 ; 0.0000000 ; nc ; nc ; 0

34 ; 06:39:58 ; HR 8799 ; opt ; 0.200000 ; 10.0000 ; 0.0000000 ; 0.0000000 ; 0.0623256 ;
0.187051 ; 4.96083

35 ; 06:40:28 ; HR 8799 ; opt ; 0.200000 ; 10.0000 ; -0.0098141832 ; -0.0038910112 ; 0.0649361 ;
0.270143 ; 5.85587

36 ; 06:40:50 ; HR 8799 ; opt ; 0.200000 ; 10.0000 ; -0.023988070 ; -0.0079449946 ; 0.00857234 ;
0.101631 ; 6.94394

37 ; 06:41:12 ; HR 8799 ; opt ; 0.200000 ; 10.0000 ; -0.029320449 ; -0.0079449946 ; 0.00640033 ;
-0.0137577 ; 6.35239

38 ; 06:43:06 ; HR 8799 ; sci ; 0.500000 ; 50.0000 ; -0.029200000 ; -0.0051000000 ; 0.0352203 ;
0.0612146 ; 10.232

39 ; 06:44:06 ; HR 8799 ; sci ; 0.500000 ; 50.0000 ; -0.032411815 ; -0.0072988174 ; 0.0245785 ;
0.0518716 ; 9.98156
```

There is also a log file generated to save the QACITS parameters for engineering purposes (it is named [UT-date]_qacits_params.txt and is located in the same log folder.)

6 Display windows

At the beginning of a sequence, two small display windows will appear at the top of the screen showing the off-axis PSF and a circular pattern corresponding to the light emitted by the center of the vortex mask. If either of this window looks empty or weird, the sequence will most probably crash, and you will need to recenter the star on the vortex manually before starting the sequence again.

During the QACITS loop (optimization or science), several windows will appear and be refreshed at every iteration (see Fig. 1):

- left: the sub-image (sky subtracted) used by the QACITS estimator. The inner circle (radius of 2 lambda/D) of the image is highlighted by 30%.
- middle: the current estimation of tiptilt (there are 2 different estimators: the blue vector corresponds to the estimator based on the inner part of the image, while the red one corresponds to the estimator based on the outer part of the image. The green dashed vector is the one that is currently used by QACITS – by the default the red one only).
- right: all estimations of tip-tilt. The current one is drawn in white, while previous iterations appear in shades of green.
- bottom right: rough estimation of the null depth (ratio of the flux integrated over the central disk (radius of 2 lambda/D) of the coronagraphic image and off-axis PSF).

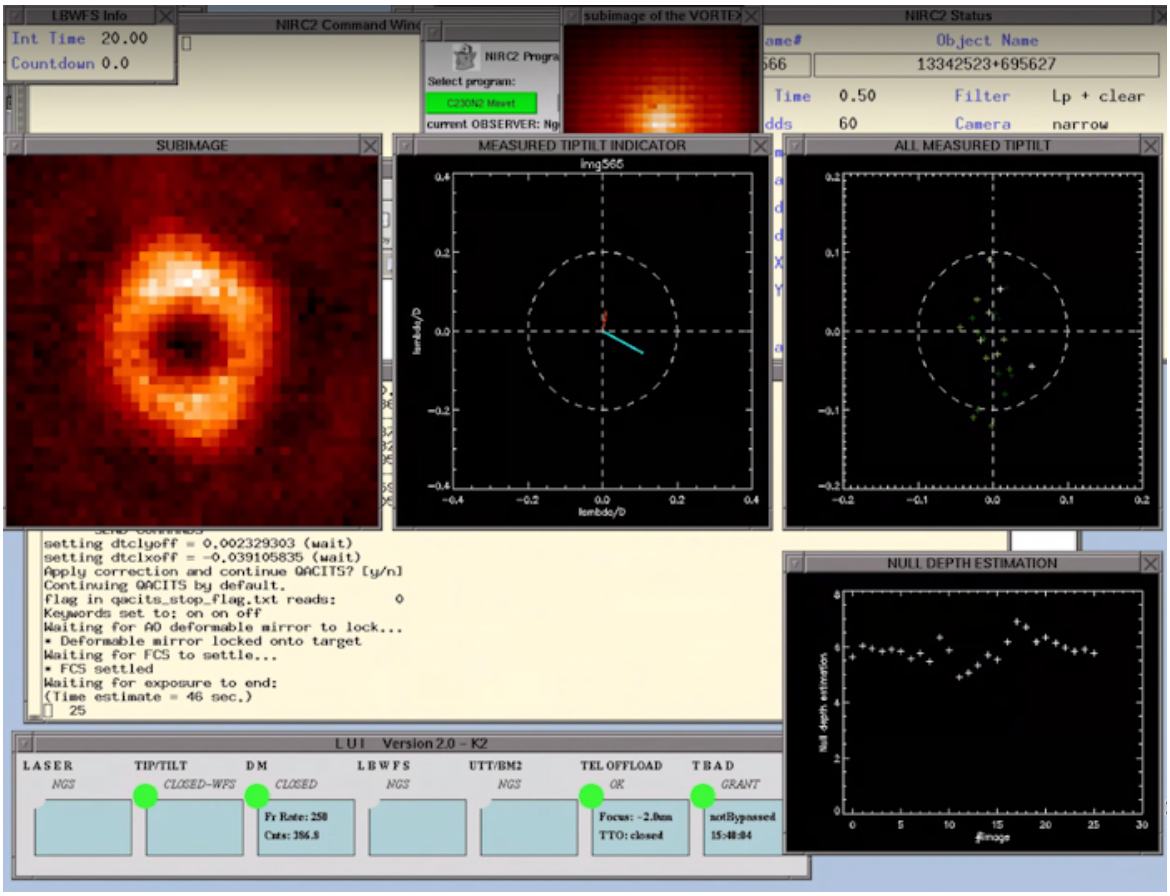

Figure 1: Typical display windows appearing when running the QACITS loop.

7 Other tips

Bright targets

If the observed target is very bright (Lmag < 4), the off-axis PSF might be saturated. In this case, the integration time for the off-axis PSF can be reduced if the size of the sub-frame is made smaller. Currently, this parameter can be tuned in the qacits_nirc2_params.pro routine. To open the file:

```
IDL> spawn, 'gedit qacits_nirc2_params.pro &'
```

At line 99, the variable subc_psf can be changed to a lower value (default: 256), typically 128. Save the file, reset the IDL compiler (IDL>.res command) and run the QACITS routine again.

The optimization is not converging

In case the optimization sequence does not converge and oscillates:

- first, check that the off-axis PSF is not saturated (this has the effect of artificially increasing the gain of the correction loop).
- the instability could be due to an imperfect off-load procedure of the `dtcloffsets`. In this case, we recommend:
  - stopping the loop
  - off-loading the dtcloffsets by typing in the nirc2 terminal:

    ```
    modify -s ao dtclxoff=0 dtclyoff=0
    ```

  - manually recenter the star using px, py or pxy commands, or the mov command in the nirc2 terminal.
  - run the optimization sequence again.

8 Reference

Huby E., Baudoz P., Mawet D. & Absil O., A&A, Vol. 584, id. A74, 12pp.