

QACITS

Observer's manual

Version: 1.2 - 2017.03.03

E. Huby

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 (called `psf`) and its associated sky image (called `skp`). Both are needed to calibrate the QACITS estimator. A sky image associated with the science/optimization images is also taken (called `sky`).
- **Optimization sequence:** to center the star and close the loop on QACITS with acquisition settings allowing faster acquisitions (reduced integration time and coadd 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 input and parameter values are defined in Section 3. The QACITS calling sequences are described in Section 4.

The analytical derivation of the model used to compute the QACITS estimators can be found in [Huby et al. 2015](#). The principle is also summarized and the operation at Keck/NIRC2 is described in [Huby et al. 2016](#) (SPIE). On-sky performance characterization is reported in [Huby et al. 2017](#).

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.pro` routine. To open the file, type:

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

The string variable `nirc_account` at *line 116* 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 of the function `run_qacits_nirc2`

| Name | Typical value | Type | Description |
|------------------------|---------------|------------|--|
| <code>n_sci</code> | 10 | [required] | Number of acquisitions requested for the science sequence. Note: can be set to 0 if no science frames are required. |
| <code>tint_sci</code> | 0.5 | [required] | Integration time for the science acquisitions. Note: can be set to 0 to set the minimal possible integration time. |
| <code>coad_sci</code> | 50 | [required] | Number of coadd for the science acquisitions. |
| <code>data_dir</code> | | [required] | Path name of the directory where the data are saved (string). |
| <code>tint_opti</code> | | [optional] | Integration time for the optimization acquisitions. |
| <code>coad_opti</code> | | [optional] | Number of coadd for the optimization acquisitions. |
| <code>subc_opti</code> | | [optional] | Width of the image during optimization (typically 1024, 512, 256 or 128). |
| <code>/no_calib</code> | | [optional] | Skip the calibration sequence. |
| <code>/no_opti</code> | | [optional] | Skip the optimization sequence. |
| <code>/faint</code> | | [optional] | Faint target mode (optimization settings set to science acquisition settings). Typically used when $Lmag \geq 8$. |

3.2 Other parameters defined in `qacits_nirc2_params.pro`

The following parameters can be given different values depending on the spectral band (defined thanks to different case statements). To open the file in the `gedit` text editor, use the IDL `spawn` command (see Sect. 2 for the command syntax)

| Name | Default Value | | Unit | Description |
|-----------------------------|---------------|--------|------|--|
| | L band | M band | | |
| <code>tint_psf</code> | 0 | 0 | sec | Off-axis PSF integration time. Note: Integration time of 0 will force the lower integration time possible, e.g., 0.005s in the case <code>subc=128</code> . |
| <code>coad_psf</code> | 100 | 100 | | Off-axis PSF number of coadd. |
| <code>subc_psf</code> | 128 | 64 | pix | Width of the image for the off-axis PSF (typically 1024, 512, 256, 128 or 64). |
| <code>faint_tint_psf</code> | 0.02 | 0.01 | sec | Integration time for the off-axis PSF in the <code>/faint</code> mode. |
| <code>tint_opti</code> | 0.2 | 0.1 | sec | Integration time for the optimization acquisitions. |
| <code>coad_opti</code> | 10 | 10 | | Number of coadd for the optimization acquisitions. |
| <code>subc_opti</code> | 512 | 512 | pix | Width of the image during optimization (typically 1024, 512, 256 or 128). |
| <code>subc_sci</code> | 1024 | 1024 | pix | Width of the science frames. |

Note: Whenever a value is changed in the parameter file, the observer must *save the file* and *reset the IDL compiler* (IDL> `.res` command) to take the changes into account.

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 is usually not required nor recommended, except for extra science acquisition sequences. Science acquisition sequences can be launched using specific keywords to skip the calibration and optimization steps in the standard 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 image must be roughly centered onto the vortex at the beginning of the sequence (within approximately $1 \lambda/D$: the image should be shaped like a donut... or at least like a croissant!) If not, the sequence will probably fail.

The acquisition settings for the optimization sequence have default values (see §3.2), 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
```

The user can also manually specify that the observations are carried out in M band by using the `/mband` keyword:

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

Additionally, there is a `/faint` keyword that can be used for faint targets ($L_{\text{mag}} \gtrsim 8$).

```
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 value of 0.02 s / 0.01 s (depending on the spectral band, see §3.2).
- 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 and coadd number are not appropriate even for the optimization sequence. Therefore the acquisition settings are directly set to the science settings, such that the acquisitions can potentially be used as science frames.
- note that if the optional keywords `tint_opti`, `coad_opti` and/or `subc_opti` are given as inputs of the function, then they will be used instead (science settings won't be used).

If necessary, 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 be reset to 0 after being read (no need to manually reset it).

4.2 Calibration sequence *only*

The calibration sequence can be run separately using:

```
IDL> run_qacits_nirc2, 0, tint_sci, coad_sci, data_dir=data_dir,  
/no_opti
```

Setting `n_sci=0` and `/no_opti` will skip the science and optimization sequences.

Note that `tint_sci` and `coad_sci` should be provided in order to take the appropriate sky image.

Note that the star image should be roughly centered onto the vortex at the beginning of the sequence (within approximately $1 \lambda/D$: the image should be shaped like a donut/croissant).

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.

4.3 Optimization sequence *only*

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

```
IDL> run_qacits_nirc2, 0, tint_sci, coad_sci, data_dir=data_dir,  
/no_calib
```

Setting `n_sci=0` and `/no_calib` will skip the science and calibration sequences.

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

The optimization sequence is acquired with default values (see §3.2), which can be changed using the `tint_opti`, `coad_opti` and `subc_opti` keywords, or the `/faint` keyword. Note that `tint_sci` and `coad_sci` should be provided in case of `/faint` mode.

Note that a calibration sequence should be run prior to running the optimization, since the off-axis PSF and sky images are needed. If these files do not exist for this target, the optimization will not be run and the user will be asked to run a calibration sequence.

4.4 Science acquisition sequence *only*

The science acquisition sequence can be run by skipping both calibration and optimization:

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

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 named “log” in 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) in λ/D
- the estimated `tiptilt` in `y` (if relevant) in λ/D
- the estimation of the null depth (if relevant)

The acquisition types are:

`sci` : Science image.

`sky` : Sky image for the science images (also used for the optimization sequence with a scaling factor).

`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 double display windows will appear at the top of the screen (windows in the background in Fig. 1). The *left* part of these windows show the off-axis PSF and a circular pattern corresponding to the light emitted by the center of the vortex mask. The *right* part of each display window corresponds to the residuals of the subtraction of the fitted Gaussian profile on each of these patterns. If either of the left part of these windows 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*: sky-subtracted sub-image used to compute the QACITS estimators. The pixel values inside the inner circle (radius of $2 \lambda/D$) are multiplied by a factor 1.3 to highlight this region.
- *middle*: tip-tilt estimators. There are 2 different estimators: the blue / red vectors correspond to the estimator based on the inner / outer part of the image, respectively. The green dot at the end of one of these vectors indicates the estimator currently used by QACITS – the red one by default.
- *right*: all estimations of tip-tilt computed during the current sequence. The latest one is drawn as a white plus symbol, while previous iterations appear in shades of green. The blue / red squares show the previous inner / outer estimates.
- *bottom right*: rough estimation of the null depth (ratio of the flux integrated in the central disk of radius $2 \lambda/D$ of the coronagraphic image and off-axis PSF). The null depth is sensitive to observing conditions, and its value should be comprised between ~ 8 and ~ 25 .

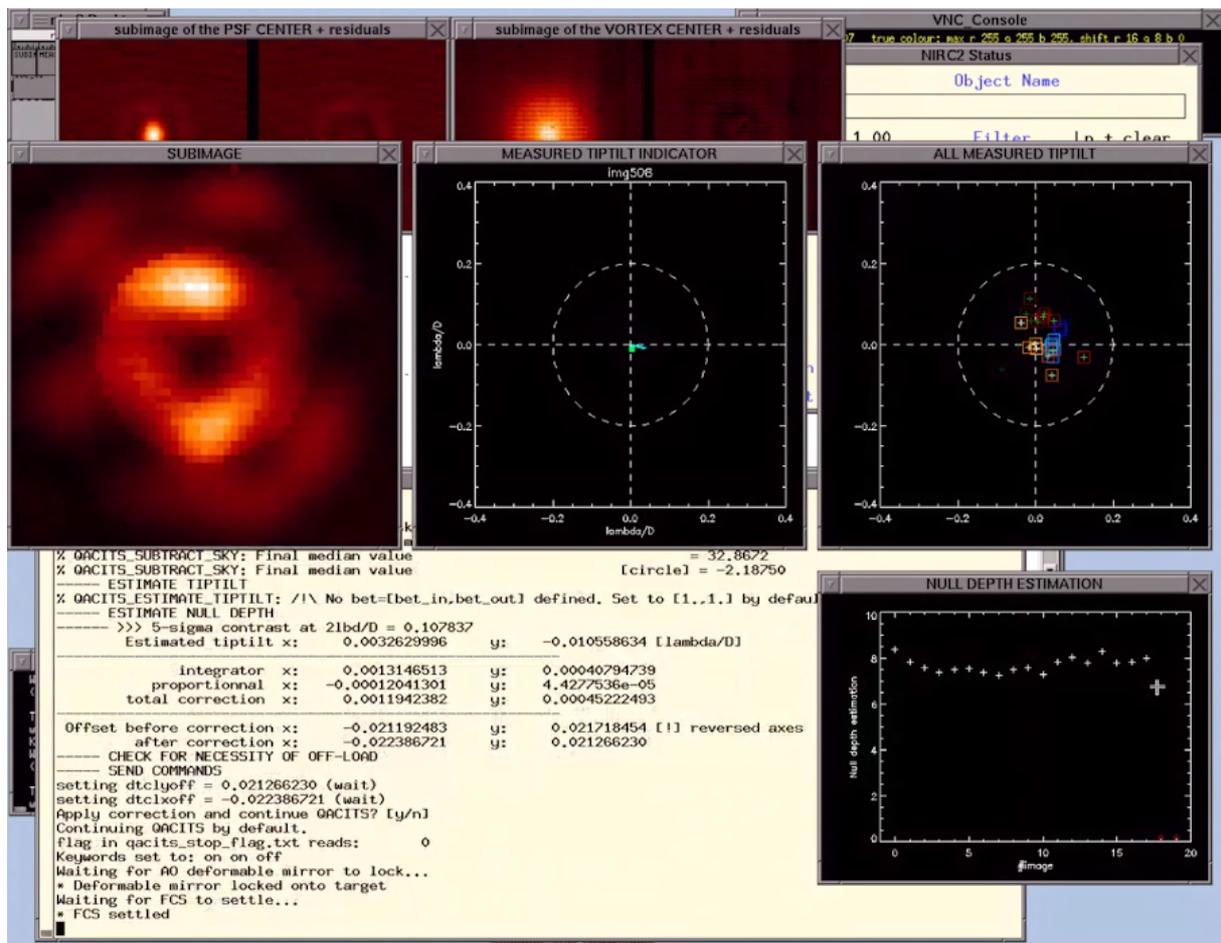


Figure 1 : Typical display windows appearing when running the QACITS loop.

7 Other tips

Bright targets

If the observed target is very bright ($L_{\text{mag}} < 4$), 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 set to a smaller width. Currently, this parameter can be tuned in the `qacits_nirc2_params.pro` routine. To open the file, type:

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

At line 129 or 135 (for L or M band, respectively), the variable `subc_psf` can be changed to a lower value, typically 128 or 64. 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 References

- [Post-coronagraphic tip-tilt sensing for vortex phase masks: The QACITS technique](#)
Huby E., Baudoz P., Mawet D. & Absil O.
A&A, Vol. 584, id. A74
- [The QACITS pointing sensor: from theory to on-sky operation on Keck/NIRC2](#)
Huby E., Absil O., Mawet D., Baudoz P., Femenia Castellà B., Bottom M., Ngo H., & Serabyn E.
Proc. SPIE 990920 (2016)
- [On-sky performance of the QACITS pointing control technique with the Keck/NIRC2 vortex coronagraph](#)
Huby E., Bottom M, Femenia B., Ngo H., Mawet D., Serabyn E. & Absil O.
A&A, in press