mu Command Manual for MuSCAT2

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1. Introduction

Several new scripts have been added and old ones improved since the last version (v1803127) to simplify MuSCAT2 commands. The original commands are preserved and aliases are added. To print a summary of command aliases and their brief description, run **'print_help'** anywhere in alex2 and shine2. The list of aliases is also tabulated in the Appendix.

```
[muscat2@alex2] $ print_help
```

```
[muscat2@shine2] $ print_help
```

While most of the original scripts have to be executed in a specific directory (e.g., ~/observe, ~/auto_guide, and ~/lc_monitor) with "./" before the script names, **the alias commands can be executed in any directories without "./"and file extension (.pl or .pl)**. The alias commands will automatically navigate you to the proper directory before executing the actual command. So you don't need to worry about where you are as long as you are in a proper machine (alex2 or shine2).

Most (both original and alias) scripts show their usage when they are executed without any arguments. So you don't need to remember much; type "print_help", find the proper command, and just run it!

When you have any problems, first of all you should refer to 'Problems and Solutions during the Observations' in the wiki pages! (http://www.iac.es/proyecto/muscat/users/login)

2. Preparing Observation

2.1 Login to tokio

Tokio is usually used as a terminal PC. The login name is "muscat", and the password is "Musc4t90"

2.2 Preparing alex2

1) Open a terminal.

2) ssh log in to alex2. The username is "**muscat2**" and the password is "**hd104985b**".

3) Move to "observe" directory.

4) Run "**./setup_alex2.sh**" (**ALIAS: setup_alex2**). This command resets the CCD powers, open four xterm terminals running a camera server script ("**./run_camera_server.pl**"; **ALIAS: camera_server**) in each terminal for each CCD, and initialize the instrument rotator. The camera server scripts running on the upper left, upper right, bottom left, and bottom right terminals correspond to CCD0 (g-band), CCD1 (r-band), CCD2 (i-band) and CCD3 (z-band), respectively.

Sometimes the camera_server command fails to recognize some CCD cameras.
(The error message *"Picam_OpenCamera() failed. Exiting"* appears in the server terminals.)
In that case, please reboot the camera powers by the following procedure (you may need to do this several times:

1. terminate the camera servers by **"end_server all"**
2. reboot the camera powers by **"recet_CCDs"**
3. restart the camera servers by **"camera_server all"**

Please start camera scripts and power on cameras by **“start_cam_all”**

```
[muscat2@tokio] $ ssh -X muscat2@alex2
[muscat2@alex2] $ cd observe/
[muscat2@alex2 observe] $ ./setup_alex2.sh

Using aliases:
[muscat2@tokio] $ ssh_alex2
[muscat2@alex2] $ setup_alex2
```

5) Check the temperatures of CCDs shown in the output of camera_server.pl. The current temperature is shown as “current temperature=[temperature x 100]”. When they get cold enough, their temperatures should be -70 ℃, which can be seen as "**current temperature=-7000**". Note that the CCD temperatures can also be checked by the command “**temp_check**”, which, however, must not be executed while any CCD camera is exposing.

6) The camera server script can be terminated by “**./end_server.pl** [ccd#]” (**ALIAS: end_server**), where [ccd#] can be 0, 1, 2, 3, or “all”. With “all”, all four servers are terminated at once. When you want to restart the camera servers, use “**./run_camera_server.pl**” (**ALIAS: camera_server**).

7) All the camera server script and camera power can be terminated by “**end_cam_server_all.pl**” (**ALIAS: end_cam_all**), and started by “**start_cam_server_all.pl**” (**ALIAS: start_cam_all**).

Please turn off the cameras by **“end_cam_all”** at the end of every night.

2.3 Preparing shine2

1) Open another terminal.

2) Log in to shine2 by ssh; the username and the password are same as alex2.

3) Move to "observe" directory.

4) Type “**./setup_shine2.sh**” (**ALIAS: setup_shine2**). This command opens one ds9 window, one xgterm with starting IRAF, one xterm for auto guiding (light yellow background), and four xterms (light blue background) with running movie command (with 1 sec exposure) in each terminal for each CCD. Please check if the test images properly appear on the four frames of the ds9 display (see Section 3.1 for the details of the movie command).

```
[muscat2@tokio] $ ssh -X muscat2@shine2
[muscat2@shine2] $ cd observe/
[muscat2@shine2 observe] $ ./setup_shine2.sh

Using aliases:
[muscat2@tokio] $ ssh_shine2
[muscat2@shine2 observe] $ setup_shine2
```

3. Observation Commands

Hereafter, all commands except for the rotator commands have to be executed from shine2.

3.1 Taking test images

1) When you want to take test images, use either of the following "movie" commands, "**./run_MuSCAT_mov.pl**" (**ALIAS: mov**) or "**./run_MuSCAT_mov_sync.pl**" (**ALIAS: mov_sync**). The movie data are not archived but deleted during the next exposure.

The former command is to expose each CCD independently (but you can even send exposure commands to multiple CCDs at once), and the latter command is to expose all four CCDs synchronously, i.e., the **next exposure will start after all four CCDs finish their exposures**.

"run_MuSCAT_mov.pl" and "run_MuSCAT_mov_sync.pl" are just wrapper scripts of the more primitive commands of "./MuCAT_mov.pl" and "./MuCAT_mov_sync.pl", respectively. The wrapper scripts launch the primitive commands in specific terminals (screens): "./MuCAT_mov.pl" for CCD0, 1, 2, and 3 are launched in the upper right, upper left, lower left, and lower right screens, respectively. "./MuCAT_mov_sync.pl" is launched in the upper left screen. Note that **"run_MuSCAT_mov.pl" and "run_MuSCAT_mov_sync.pl" can be executed from any terminals.**

The following example is to take 5 movie images with CCD0 and CCD1 with the exposure times of 3 sec and 5 sec, respectively.

```
[muscat2@shine2 observe]$ ./run_MuSCAT_mov.pl  --exp0=3  --exp1=5 --nexp=5

Using alias:
[muscat2@shine2 observe]$ mov  --exp0=3  --exp1=5 --nexp=5
```

If you want to take dark images, add "--dark" in the arguments.
Note that the order of the arguments can be set arbitrarily.

Note that the exposure time can be set as short as 0.01 s, however, too short exposure time (<0.5 sec) should be avoided because the shutter speed is limited (8 ms), which makes the image non-uniform.

movie commands & parameters

./run_MuSCAT_mov.pl

```
# basic parameters #
--exp[0/1/2/3]=[exposure time (s)](default=1)
        Set the exposure time in second for the specific CCD. At least one (but not necessarily
four) --exp[ccd#] parameter is required.

--nexp=[number of exposures](default=1000)
        Set the number of exposures.

--dark
        Specify if you want to take images with the shutter closed.

# advanced parameters #
--read=[high/low](default=high)
        The option of the readout mode. Images are read out at the rate of 2MHz (readout time of
10s) and 100kHz (readout time of 1s) with “high” and “low”, respectively. The readout noises are
12 e- rms and 4 e- rms in the high and low modes, respectively.
```

./run_MuSCAT_mov_sync.pl

```
# basic parameters #

The following parameters are applied for all CCDs.
--exp=[exposure time for all CCDs (s)] (default=1)
--nexp=[number of exposures](default=1000)
--dark (if you want to keep the shutter closed)

The following parameters can be set for each CCD independently.
--exp[0/1/2/3]=[exp. time (s) for the specific CCD]  (default=none, override --exp)
```

2) The obtained images are displayed in the ds9 window like Fig. 1. These images are updated once new images are taken. All the images are oriented such that north is up and east is to the left.

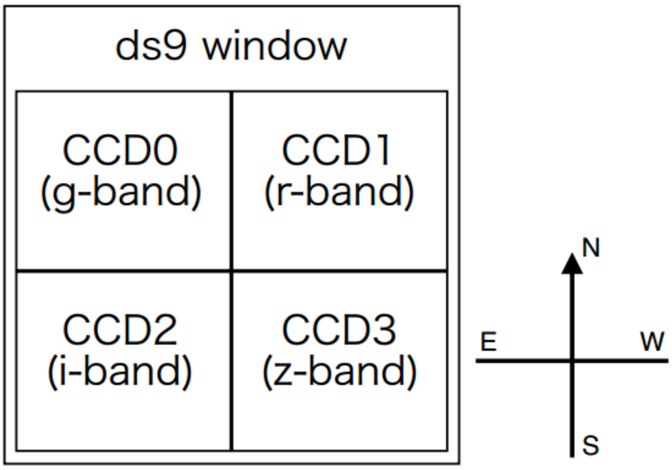


Figure 1: The layout of the four CCD images on the ds9 window.
The orientation of the images is shown in bottom right.

3) To check the PSF of stars, use the IRAF command "**imexam**" in the IRAF console. By putting a circle cursor on a stellar image in the ds9 window and typing “**r**”, you can check the radial profile of the stellar PSF. Set the exposure time of each CCD so that the peak count of the brightest star is around 30,000 ADU or less (the peak count should not exceed 50,000 ADU to keep the linearity).

```
ecl > sam    (then type “r” on a star in the ds9 window)
```

When you mistakenly delete IRAF terminal, use "./**setup_iraf.sh**"(**ALIAS: setup_iraf**) to open IRAF terminal.

4) When you want to stop taking images in the middle, run “./**stop_obs.pl**” (**ALIAS: stop_obs**) command. If you try to stop exposures of any single CCD, specify **0, 1, 2, or 3** in the argument. The parameter "**all**" makes all CCDs stop. Use "**sync**" (not “all”) when "./MuSCAT_mov_sync.pl" is running.

```
[muscat2@shine2 observe]$ ./stop_obs.pl [0/1/2/3/all/sync]

use alias:
[muscat2@shine2 ]$ stop_obs [0/1/2/3/all/sync]
```

5) When you want to move the telescope to adjust the center of the field of view, you can use the **./tel_offset.py** (**ALIAS: offset**) where offsets (relative to current position) in RA and DEC in arcsec are given as arguments:

```
[muscat2@shine2 observe]$ ./tel_offset.py [offset_ra (arcsec)] [offset_dec (arcsec)]
```

```
use alias:
[muscat2@shine2 ]$ offset [offset_ra (arcsec)] [offset_dec (arcsec)]
```

3.2 Rotating MuSCAT2

The position angle can be changed from alex2 by rotating the instrument rotator.

1) The current position angle can be checked by “**CassR_status.py**” (**ALIAS: stat_rot**). The value is shown as "Posi=[value] (deg)". The origin (North is up and East to the left) has the position angle of zero. The positive value is from North to East (when angle is +90 deg, the y axis directs to East.)

```
[muscat2@alex2 observe]$ CassR_status.py
```

2) The instrument rotator can be rotated by using **CassR_move.py** (**ALIAS: rotate**). Note that the allowable position angle is between -45 deg and +45 deg (from the origin).

```
[muscat2@alex2 observe]$ CassR_move.py [angle relative to the origin (deg)]
```

3) If you want to stop the rotator while it is rotating, **type “s” in the terminal where “./CassR_move.py” is running.**

4) **!! Remember to return the position angle to zero at the end of each night. !!**
It may cause a serious problem (i.e., damage on the instrument) if alex2 loses the correct position (e.g., alex2 is shut down) while the rotator is rotated from the origin. This could happen if you forget to return the position angle to the origin.

3.3 Taking science images

1) When you want to take images and store them as scientific data, use the commands of either "**./run_MuSCAT_obj.pl** (**ALIAS: obj**)" or "**./run_MuSCAT_obj_sync.pl**(**ALIAS: obj_sync**)" in the similar way as the movie commands (see Section 3.1). Parameters are the same as the movie commands, except for an additional parameter of "--obj", which specifies the object name that will be recorded in the FITS header. 185-005862

If you want to take 100 images of WASP-33 exposed 30 seconds by CCD0, for example, type the following command.

```
[muscat2@shine2 observe]$ ./run_MuSCAT_obj.pl  --exp0=30  --nexp=100  --obj=WASP-33

Using alias:
[muscat2@shine2 ]$ obj   --exp0=30    --nexp=100    --obj=WASP-33
```

object commands & parameters

./run_MuSCAT_obj.pl

```
# basic parameters #
--exp[0/1/2/3]=[exposure time (s) for the specific CCD](default=1)
--nexp=[number of exposures](default=1)
--obj=[object name]
        Specify an object name, which will be recorded in FITS header.

# advanced parameters #
--read=[readout mode (“high” or “low”)](default=high)
```

./run_MuSCAT_obj_sync.pl

```
# basic parameters #
--exp=[exposure time for all CCDs (s)] (default=1)
--nexp=[number of exposures](default=1)
--obj=[object name]
        Specify an object name, which will be recorded in FITS headers.

# advanced parameters #
--exp[0/1/2/3]=[exp. time for the specific CCD (s)] (default=none, override --exp)
--read[0/1/2/3]=[high/low for the specific CCD] (default=high)
```

See also “movie commands & parameters” in Section 3.1.

2) When you want to stop taking images in the middle, command "**./stop_obs.pl**" (**ALIAS: stop_obs**) in the same way as for "MuSCAT_mov.pl".

3) The obtained images are stored in FITS format as "MCT2[0/1/2/3]_[yymmdd][xxxx].fits" under @shine2:/data/[yymmdd]/. [0/1/2/3] corresponds to CCD number. yy, mm, and dd indicate the last two digit of the year, month, and day of the observing night (UTC - 12 hours), respectively.

Note on exposure time: in general, the desired exposure time would be between 10 and 30 sec, which maximizes the observation efficiency while avoiding accumulation of systematic noises (e.g., cosmic-ray hits, satellite crossing, guiding error, etc.). For bright targets, shorter exposure times may be required to avoid saturation even with defocusing. However, exposure times shorter than 2 sec with 4 channels may overload the control PCs and should be avoided. **The exposure time for guiding channel should be 15 sec or less**, even in the case of faint targets (see also 4.2 The tracking correction function).

4) The obtained images do not automatically appear on the ds9 display. The latest images can be displayed manually by the “**disp_ds9.pl**” (**ALIAS: disp_ds9**) command, which can be executed anywhere in shine2. You can also open past, arbitrary images using the “**disp_ds9_past.pl**” (**ALIAS: disp_ds9_past**) command, which requires date, ccd number, and frame ID in the arguments.

```
To open the latest images:
 [muscat2@shine2]$ disp_ds9
```

```
To open an arbitrary image:
[muscat2@shine2]$ disp_ds9_past --date=[YYMMDD] --ccd=[0/1/2/3] --id=[frame ID (last 4 digit)]

Ex:
[muscat2@shine2]$ disp_ds9_past  --date=181211  --ccd=1  --id=1234
```

Note that dark and flat images are automatically displayed on ds9 once new images are taken.

3.4 Taking dark images

1) When you want to take dark images, use the commands of "**./run_MuSCAT_dark.pl**" (**ALIAS: dark**) or "**./run_MuSCAT_dark_sync.pl**" (**ALIAS: dark_sync**), in the similar way as the "mov" and "obj" commands (see Section 3.1 and 3.3). These commands do not require the parameters of "--obj" and "--dark" but automatically set. The object name in the FITS file will be "DARK".
If you take 5 dark images exposed 30 seconds by CCD0, then type the following command.

```
 [muscat2@shine2 observe]$ ./run_MuSCAT_dark.pl --exp0=30 --nexp=5

use alias:
 [muscat2@shine2 ]$ dark --exp0=30 --nexp=5
```

See also "movie commands and parameters" in Section 3.1.

2) When you want to take dark images of ALL object's exptimes you took today, use the command, "**python ./dark_today.py**" (**ALIAS: dark_today**). This command require "--date" and "--nexp". This command use "dark" command inside this script, so the object name in the FITS file will be "DARK" as same as "dark" command.
"dark_today" doesn't take dark for domeflat. Exptime of domeflat is taken in "flatdark" command. (see Section 3.5)
You can also use this command to take dark for the object you input, by adding optional argument, "--obj".
If you take 5 dark images of ALL exptimes on Feb. 5, 2019 in ALL bands, then type the following command.

```
 [muscat2@shine2 observe]$ python ./dark_today.py --nexp=5 --date=190205

use alias:
 [muscat2@shine2 ]$ dark_today --nexp=5 --date=190205
```

If you take 5 dark images for TOI123 on Feb. 5, 2019, then type the following command.

```
 [muscat2@shine2 observe]$ python ./dark_today.py --nexp=5 --date=190205 --obj=TOI123

use alias:
 [muscat2@shine2 ]$ dark_today --nexp=5 --date=190205 --obj=TOI123
```

Example.

If you observed on Feb. 5, 2019, exptimes are below.

ccd0 = [8.0, 7.0, 5.0, 1.0] (sec)
ccd1 = [8.0, 5.0, 5.0, 2.0] (sec)
ccd2 = [10.0, 7.0, 5.0, 3.0] (sec)

5.0 (sec) is duplicated in ccd1, but this command takes all dark WITHOUT duplication. When you execute “dark_today --nexp=5 --date190205”, this command automatically execute below commands in this order. Exptime of each band are sorted.

```
“dark --nexp=5 --exp0=8.0 --exp1=8.0 --exp2=10.0”
“dark --nexp=5 --exp0=7.0 --exp1=5.0 --exp2=7.0”
“dark --nexp=5 --exp0=5.0 --exp1=2.0 --exp2=5.0”
“dark --nexp=5 --exp0=1.0 --exp2=3.0”
```

dark_today commands & parameters

python ./dark_today.py

parameter to see help is **“-h”**

# basic parameters(required) #
--date=[date(yymmdd)]

# advanced parameters (optional) #
--nexp=[number of exposures](default=5)
--obj=[object name]

--show_exptime

To ONLY check exptimes. Exptimes are shown in the terminal. DOESN’T take dark images.

note:
This script doesn’t work when obs_ccd*.run files exist in ~/observe directory.
This script can work, if the number of CCDs change for some reason.

3.5 Taking es images

1) Before you take flat images, first make sure the dome slit is closed and the telescope points to the flat position (zenith).

2) Turn on the switches [1] & [2], and twist the switch [3] & [4] so that these lights become the faintest. Then, turn on the switch [5] and twist [6] so that two marks align (keep the switch [7] off).

3) When you take flat images, use the command "**./flatdark.pl**" (**ALIAS: flatdark**). This command first takes one test image with 5 sec exposure time to check the average count in each CCD. Then it sets the optimal exposure time for each CCD so that the average count will be around 30,000 ADU. As a safety feature, the user will be asked whether to continue or not after taking the test image. If you type “y”, then 50 flat frames and 5 dark frames with the optimal exposure times will be automatically taken. Please do not execute this command in the “blue-background” terminals.

```
[muscat2@shine2 ]$ flatdark
```

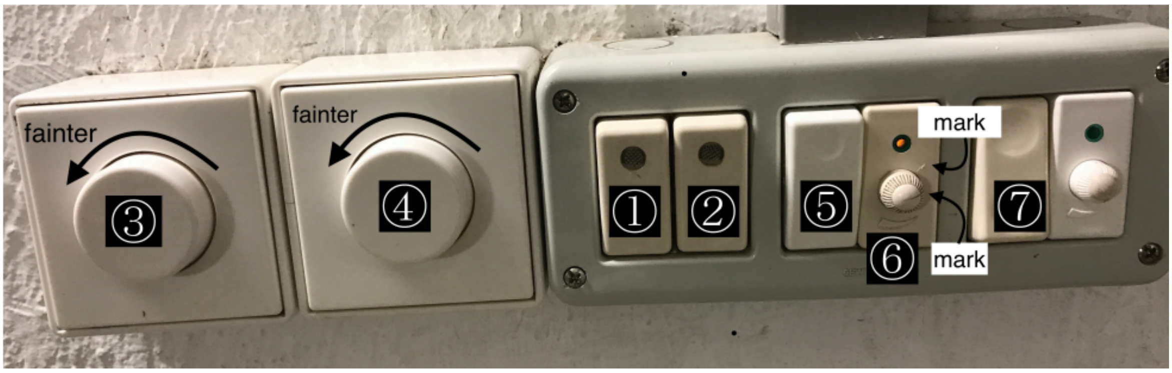


Figure 2: The dome light switches on the TCS dome.

3.6 End of observation

When you finish the whole observation, stop camera servers of all CCDs using **./end_server.pl** (**ALIAS: end_server**).

```
[muscat2@alex2 observe]$ ./end_server.pl [0/1/2/3/all]

use alias:
[muscat2@alex2 ]$ end_server [0/1/2/3/all]
```

3.7 End of observing run

At the end of the observing run, exit all terminals logging in shine2 and all but one terminals logging in alex2. Then, from the last terminal, type "**shutdown_alex2.sh**" (**ALIAS: shutdown_alex2**) from the " /observe" directory in alex2, which will rotate the instrument to a finish position and then shut down alex2.

```
[muscat2@alex2 observe]$ ./shutdown_alex2.sh
```

4 Self auto-guiding

Because of the error of telescope tracking, the sky position of the center of field of view gradually shifts during a long-period observation. This can be avoided by using the "ag” command, which corrects the tracking error by analyzing the images obtained by MuSCAT2 itself on the fly.

4.1 Basic usage

1) Run “**./run_auto_guide.pl**” (**ALIAS: ag**) in the ~/auto_guide directory (in the terminal with white background where you also run observations).
This script passes the entity command “./auto_guide_new.pl” to a terminal that has a background color of light yellow.

```
[muscat2@shine2 auto_guide]$ ./run_auto_guide.pl

Using alias:
[muscat2@shine2] ag
```

parameters of "./run_auto_guide.pl"

```
## Required
--ccd=[0/1/2/3]
        Select one of the CCDs to be used for guiding.
        It is recommended to use CCD1 (r-band) to minimize the effect of differential refraction.

--refid=[the last 4 digits of the reference frame ID]
        Specify the serial number of the frame ID to be used as a reference. For example, specify
“25” when the frame ID is "MCT21_1602090025" (leading zeros in the last 4 digits can be
omitted).
```

--obj=[object name]

Specify the object name, which must be the same one that was given to the command "./MuSCAT_obj.pl"

## Optional

--track=[0/1/2] (default=1)

0: open tracking with self guiding (no tracking correction)
1: tracking correction is activated after initial learning phase
2: tracking correction is immediately activated with the previous parameter values

(see Section 4.2 for the details of this function)

--osci (this option requires no value)

This option switches on the “reducing DEC oscillation” mode, which

- changes the guiding frequency from once in 60 sec to once in 120 sec,
- reduces the guiding signal to DEC by a factor of 2 (which slightly reduces the oscillation amplitude), and
- skips guiding to DEC if d(DEC) is within +/-2 pixels.

--skip=[number of skip images] (default=int(60/(exptime+4)))

This parameter determines the frequency of guiding. When you specify the skip value of N, the guiding signal will send to the telescope once in (N+1) exposures. By default, this value is automatically set to int(60/(exptime+4)) so that the guiding frequency will be ~1/60 s or lower. Basically **you don’t need to set this parameter.**

--date=[date(yymmdd)]

(if you use a reference image taken on a different night)

## Advanced

--cc=[flag for cross correlation algorithm (on/off)] (default=on)

When this flag is on (default), the cross correlation algorithm is used to calculate the stellar positional offsets; otherwise, centroid shift of the brightest stars is calculated (the number of stars, aperture radius, and detection threshold can be specified by --nstars, --rad, and --th, respectively).

Usually the cross correlation algorithm should work better.

Please use --cc=off if a saturated star is inside the field. Otherwise ag sometimes fails.

## Followings are valid only if --cc=off

--nstars=[number of stars(>=1)] (default=3)
--rad=[aperture radius (pixels)] (default=20)
--th=[threshold for detection of stars] (default=10)

5) When you finish auto-guiding, command "**stop_auto_guide.pl**" (**ALIAS: stop_ag**). It is recommended to **turn off the auto-guiding command during cloudy weather** to avoid miss-guiding.

Note: **the ag command does not correct a tracking error larger than 30 pixels** to prevent wrong correction. Once stellar position is moved by more than 30 pixels compared to a reference image for some reason, first you need to return the stellar position to the original (reference) position manually by using “offset” command so that the positional shift is less than 30 pixels.

```
[muscat2@shine2 auto_guide]$ ./stop_auto_guide.pl
```

4.2 The tracking correction function

The TCS telescope has a problem on tracking such that the RA motion oscillates with the period of ~169 sec and the semi-amplitude of up to ~10 pixels (4 arcsec), probably arising from systematic errors in the RA gears of the telescope. This periodic error is not corrected by the ag command with the default setting (--track=1).

This periodic tracking error can be corrected (suppressed) with a sinusoidal function by specifying the --track parameter with the value of 1 or 2.

The equation of the correction function is given by

$$dV = A*\sin(B*x + C) + D,$$

where dV is the velocity offset in hour angle (arcsec), x is hour angle provided by the encoder in radian, and A, B, C, and D are coefficients. Basically all these coefficients more or less depend on the telescope position, and cannot be predicted with a sufficient precision beforehand. Therefore they need to be determined for each observation from time to time.

The updated tracking velocity V_new is calculated as

$$V\_new = V\_sidereal + F*dV,$$

where V_siderial is the sidereal speed at (equivalent to) which the RA motor rotates without any correction and F is a scale factor that is normally fixed at -1.

The function of each tracking-correction mode (1 and 2) is described below.

--track=0

No periodic correction is applied, and only the self-guiding function is activated.

--track=1 (default)

With this mode, **the first 5 minutes is used for initial learning, and no tracking correction is applied during this period.** After this learning phase, initial correction values of **A, C, and D** are determined by fitting the stellar positions in the RA direction (corrected to unguided values) acquired during this period and are recorded in the telescope control PC. The period parameter of B is fixed at a value that corresponds to the average oscillation period of 169.26 sec. Subsequently the correction function is activated.

After the activation of the correction, the stellar positional shifts in RA are evaluated **every 6 minutes**, and the values of **B, C, and D** are updated if the standard deviation of the shifts in the past 6 minutes deviates **more than 1 pixel.** To make a fit easier to converge, the amplitude A is fixed at the value determined in the initial fitting. Note that the amplitude is almost constant over time for a given declination, and is not necessary to be precisely adjusted. On the other hand, the residual stellar position is very sensitive to a small change of B and C (period and phase), and letting them free is essential to stabilize the stellar position for long term.

--track=2

With this mode, **the initial learning phase is skipped**. The tracking correction function is immediately activated with the previous parameter values of A, B, C, and D. Note that these parameter values are kept in the telescope control PC even after the xcommand is terminated. **This mode is useful when you want to resume ag after a short break due to e.g. cloud passing.**

In both modes, the tracking correction function is deactivated when ag is terminated (i.e., “stop_ag” is executed), while the parameter values of A, B, C, and D are kept in the telescope control PC.

Note: **please set the exposure time for the guiding CCD at 15 sec or less** so that the sampling rate is high enough to properly model the 169-sec-period tracking error.

5 Quick-look Light-curve Monitor (m)

You can check quick-look light curves in real-time by using the following tool.

5.1 Step-by-step set-up of LCM

1) Open a new terminal and log in shine2.

2) Move to "**lc_monitor**" directory.
cdm-
3) Run "**./make_rerence.pl**" (**ALIAS: make_ref**). This command first resets the parameter files (calling "./reset_params.pl all") of the light curve figures (see Section 5.2 of this section). Then it makes a reference image, detects stars, and assign ID numbers to the stars **in order of brightness**. You need to do this only once, specifying one of the four CCDs. Any CCD can be used as a reference. (You may want to use CCD3 in the case that the target is an M dwarf; the target may be too faint to be detected in the bluer bands.)

```
[muscat2@shine2] $ cd lc_monitor/
[muscat2@shine2 lc_monitor] $ ./make_reference.pl
```

parameters of "make_reference.pl"

# Required #
--ccd=[0/1/2/3]
    Select one of the four CCDs to be used for reference.

--refid=[the last 4 digits of the reference frame ID]
    Specify the serial number of the reference frame ID. For example, type 25 when the frame ID is "MCT21_1602090025".

--obj=[object name]
    Type the same object name as the one that was given to the command "./run_MuSCAT_obj.pl".

# Optional #
--date=[yymmdd]
    Use this parameter if you want to use a reference image on a different night.
--rad=[aperture radius (pixels)] (default=20)
    The aperture radius for aperture photometry can be set.
--th=[threshold for detection of stars] (default=10)
    Adjust this parameter if the number of detected stars are too few or too many.

4) Run "**./show_star_IDs.py**" (**ALIAS: show_star_IDs**). This command will show the reference image along with the ID numbers beside the stars as shown below (Figure 3).
Note that this command will also update the reference image shown on the web page (http://161.72.192.46/lc_monitor/).

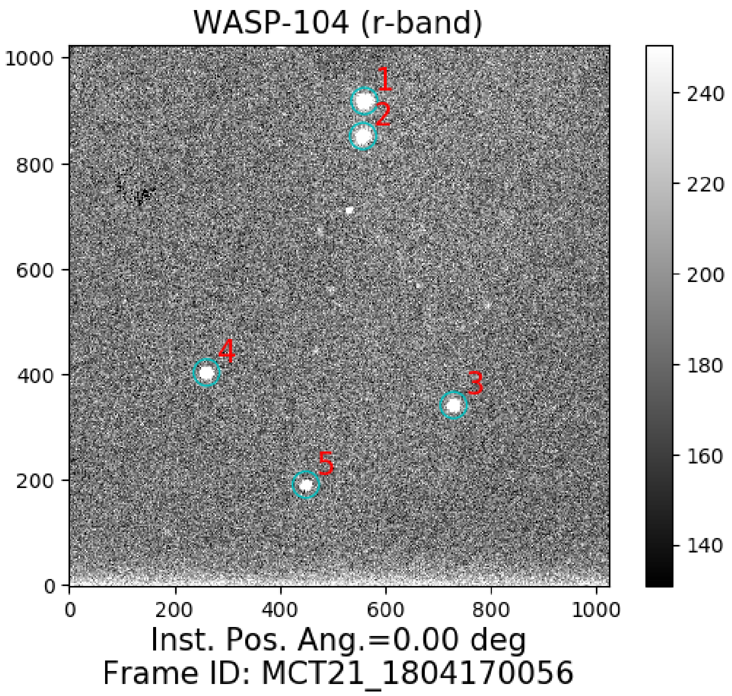


Figure 3: Output of ./make_ref.pl showing the reference image with assigned IDs from bright to faint.

```
[muscat2@shine2] $ cd lc_monitor/
[muscat2@shine2 lc_monitor] $ ./show_star_IDs.py [obs. date (YYMMDD)]  [object name]

Use alias:
[muscat2@shine2 ] $ show_star_IDs 181216 GJ3069

Ex:
[muscat2@shine2 lc_monitor] $ show_star_IDs 181216 GJ3069
```

5) Check the ID numbers of the target star and comparison stars on the reference image.
6) Set the target ID, comparison ID(s), and monitor ID by using "**./set_param.pl**" (**ALIAS: set_param**). The required argument is only CCD number (0/1/2/3 or "all") **without the "--ccd=" syntax**. Then the script will ask you the values of the above parameters interactively. The monitor ID is the ID of the star whose peak count and raw flux are plotted in the figure. It is recommended to set this value to the ID of the brightest star among the target and all comparison stars.
If you specify "all" in the argument, then this script sets the parameters for all CCDs at once, to the same values. To set the other parameters of the figures, see Section 5.2.

7) Run "**./run_lc_monitor.pl**" (**ALIAS: lcm**) in one of the shine2 terminals.
This is a wrapper script of "lc_monitor.pl". When you specify one of the four CCDs in the argument with the parameter "--ccd", it opens a new terminal (light red background) using screen, and run

“./lc_monitor.pl” for the specified CCD. When you specify “all” to the “--ccd” parameter, the script opens 4 terminals and runs “./lc_monitor.pl” in each terminal for each CCD at once. A particular terminal is used for a particular CCD; the upper left, upper right, lower left, and lower right terminals are used for CCD0, 1, 2, and 3, respectively.
See below for the other required arguments.

```
[muscat2@shine2 lc_monitor]$ ./set_param.pl [0, 1, 2, 3 or “all”]
[muscat2@shine2 lc_monitor]$ ./run_lc_monitor.pl

Alias:
[muscat2@shine2]$ set_param [0, 1, 2, or “all”]
[muscat2@shine2]$ lcm

Ex.:
[muscat2@shine2]$ set_param all
[muscat2@shine2]$ lcm --ccd=all --obj=K2-100 --rad=20
```

parameters of "run_lc_monitor.pl" (lcm)

--ccd=[0/1/2/3/all]

Select one of the CCDs, or “all”.

--obj=[object name]

Provide the same object name as the one that was given to the command "./MuSCAT_obj.pl".

--rad=[aperture radius (pixels)] (default=20)

Set the aperture radius for aperture photometry. This value should be large enough so that most of the stellar fluxes are included inside the aperture. The “r” (radial profile) command of IRAF/imexam is useful to determine this value.

## advanced options ##
--nstars=[number of stars to be analyzed]

Set the number of stars to be measured.The top [nstars] brightest stars on the reference image will be measured. This number must be equal to or larger than the ID of the faintest stars among the target and comparison stars.It is not allowed to set the number larger than the number of stars detected in the reference image.

In addition, this number must not exceed the number of stars detected in the reference image.
As a default, nstars will be automatically set at the following value:
min((largest ID among target and comparisons)+5, (number of stars detected on the reference image))

--redo

With this option, all reduction and photometry will be done for all frames.

--ap_type=[“centroid” or “mapping”] (default=”mapping”)
(ex., --ap_type=centroid)
This option selects the algorithm to calculate the image shift and stellar centroids for photometry.

centroid: Image shift is derived by taking the mean of dx or dy of individual stars. Photometry is done at the stellar centroids on the individual images. **This algorithm is recommended if the number of identified stars is three or less**.

mapping: Image shift is estimated by calculating the matrix of coordinate transformation relative to the reference image using a number of stars. Photometry is done at the transformed positions of the stellar centroids on the reference image. **This algorithm is recommended if the number of identified stars is more than three.**

The output light-curve figures created by “./lc_monitor.pl”, as well as the reference image that indicates the stellar IDs, can be seen from your local browser through the following link: http://161.72.192.46/lc_monitor/. This page only renders the latest figures created and is viewable within IAC network.

In the above page, four light-curve figures are shown for four CCDs, each showing the un-detrended normalized light curve (top panel), stellar positional shifts in X and Y (second panel), stellar FWHM value and peak count (third panel), and raw flux and airmass values (bottom panel). See Figure 4 for example.
Each figure is also saved in .png and .ps formats in "png" and “ps” directories, respectively.

7) To stop this script, type "**./stop_lc_monitor.pl**" (**ALIAS: stop_lcm**).

```
[muscat2@shine2 lc_monitor]$ ./stop_lc_monitor.pl [ccd#(0/1/2/3) or “all”]
```

Note1: If you stop “lc_monitor.pl” once and restart it with different values of “--rad” or “--nstars”, then the photometry will be done for all images (not only the latest ones), which may take long time depending on the number of images. This is not the case when you change the values in the parameter files (see the next Section), which will affect only the figures.

Note2: If you change the reference ID using “make_ref” while running “lcm”, you need to once stop lcm (using “stop_lcm”) and rerun “lcm” command again so that the old photometry will be updated using the new reference frame.

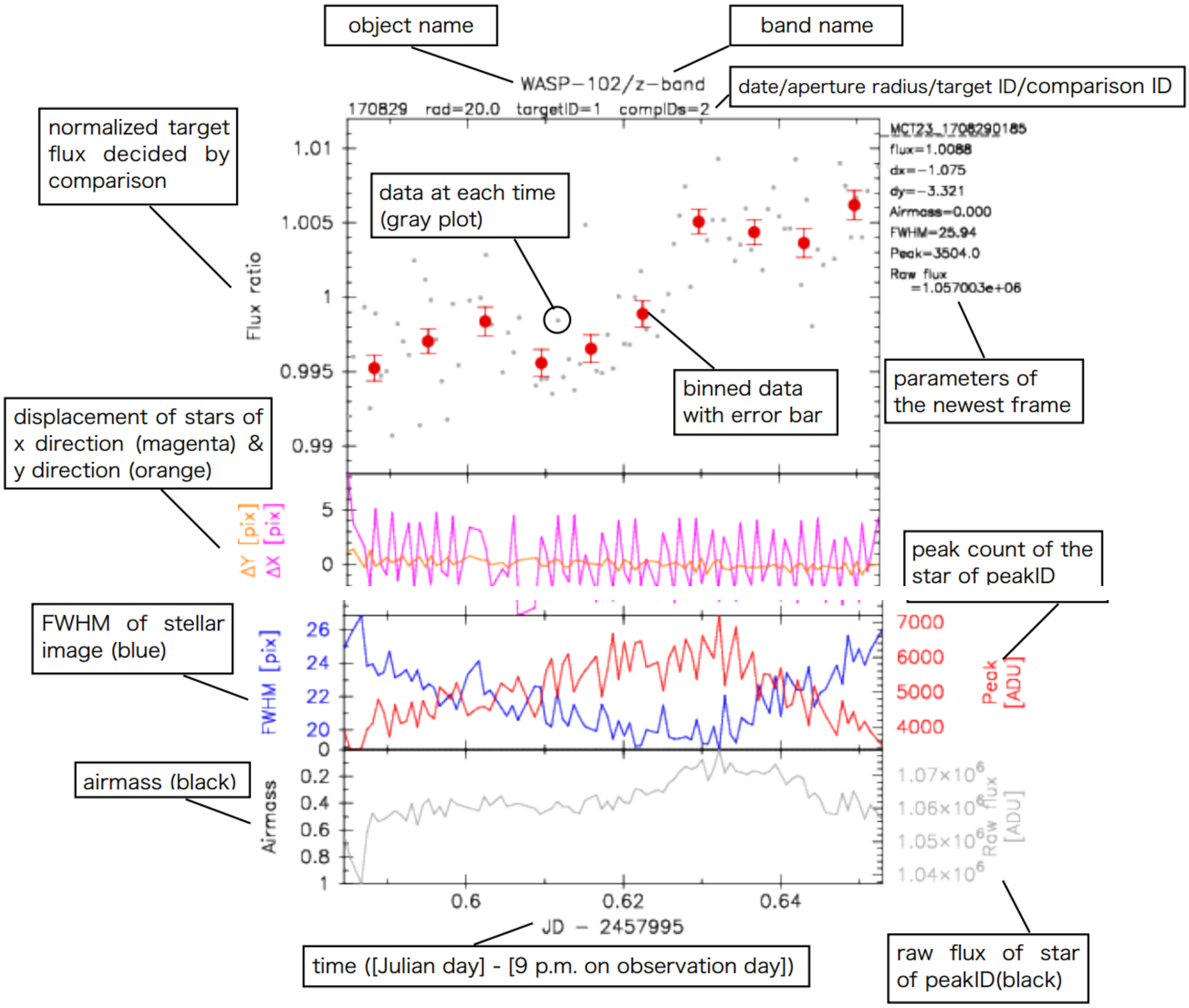


Figure 4: Example of the quick-look light curve for z-band. The band of each light curve can be recognized by the color of the binned data points; g, r, i, and z-band data are shown in blue, green, orange, and red, respectively.

5.2 Setting Parameters of the Figures

The IDs of the target star (targetID), comparison star(s) (compIDs), and monitoring star (monitorID) can be set by using “**./set_param.pl**”, as explained in the previous section.

To set the other parameters related to the light curve figures, edit the parameter files "**param/lc_monitor_[0/1/2/3].par**" by any of your favorite editors (ex. vi, emacs etc). After saving the changes, the plots will be updated once new data have been analyzed.

```
[muscat2@shine2 lc_monitor]$ vi param/lc_monitor_[0/1/2/3].par
```

parameters of "param/lc_monitor_[0/1/2/3].par"

# Essential parameters #
targetID
The ID number of the target star.
compIDs
The ID number(s) of comparison star(s). Insert spaces between numbers if you use more than one comparison stars.
monitorID
The ID number of the star whose peak count and raw flux are shown in the plot.

# Optional parameters #
binsize (default=600)
The binning size of the light curve in seconds.

scale (default=1)
The parameter to fine-tune the scale of the light curve. The light curve divided by this value is plotted.

# Parameters for plot ranges #
auto_range_[flux/dxdy/peak/fwhm/rawflux]
Method of setting the range of y axis for the respective panels. "1" is for automatic setting, "0" is for manual setting.

auto_range_jd_min
Method of setting the minimum range of x axis for all panels. "1" is for automatic setting, "0" is for manual setting.

auto_range_jd_max
Method of setting the maximum range of x axis for all panels. "1" is for automatic setting, "0" is for manual setting.

cut_sigma_[flux/dxdy/peak/fwhm/raw flux]
Threshold for the outlier of each panel in standard deviation. Values exceeding (set value)(standard deviation) are omitted from the plot.

[max/min]_[flux/dxdy/peak/fwhm/raw flux]
The maximum/minimum of y axis for the respective panels. This parameter is effective only when auto range_* is "0".

[max/min]_jd
The maximum/minimum of x axis [JD-int(JD of the first data point)]. This parameter is effective only when "auto_range_jd" is "0".

5.3 Auto defocus

1) Open a new terminal and log in shine2.
2) Execute **auto_defocus** at the terminal.
3) When you stop **auto_defocus,** execute **stop_auto_defocus** at the terminal.

This command is automatically defocusing to avoid saturating the monitorID's star, when the peak counts in any bands are over threshold.
This command works, when lcm is working. When you stop this command, please execute **stop_auto_defocus.**

Warning:
If this command cannot find lcm files at first, it waits new lcm files will come for 10 min. After 10 min passed, it automatically stops.
When you change monitorIDs during observation, this command doesn't follow new monitorIDs.
Don't use focus command during auto_defocus working. Please stop command, once.
It might cause confliction.

```
[muscat2@shine2 observe]$ python ./auto_defocus/auto_defocus.py --obj=TOI0XXXX.01

Alias:
[muscat2@shine2]$ auto_defocus --obj=TOI0XXXX.01

Ex.:
[muscat2@shine2]$ auto_defocus --obj=TOI0XXXX.01  --rad=20 --direction="+" --delta_focus=10
```

parameters of "auto_defocus"

# Essential parameters #
obj
Object you are observing

# Optional parameters #
rad (default=20)
Radius you are using in lcm

peak_th (default=52000)
Threshold of peak count. If the monitorID is over this value, this command will defocus.

delta_focus (default=10)
new focus value = current focus value (+/-) **delta_focus** value.

direction (default="+")

```
        Direction toawrd defocus (ex. : --direction=+) if --direction= +, change 73000 to 73010, if
--direction= -, change 73000 to 72990.',default="+"

ap_type (default="apphot_mapping")
        photometry type. same as -ap_type in lcm
```

6 Tips

1) You can reboot the power of the CCD cameras by the following command:

```
from anywhere in shine2 and alex2
$ reboot_CCDs
```

You can check the status of the power of CCD cameras by

```
from anywhere in shine2
$ power_control_CCDs.pl --status
```

2) For monitoring targets, you should align the current field of view to match the reference image FOV (i.e. the same target taken previously). If you observe the target for the first time, you can create a reference image to be saved in the reference directory by using **./register_ref_image.pl** (**ALIAS: regist_ref**). For example, if you would register a reference for GJ3470 taken in r-band on Feb 12, 2018 whose frame id ends in 1872. Please note that you have to make the reference image only once.

```
[muscat2@shine2 observe] $ ./register_ref_image.pl
                                [object_name] [ccd#(0/1/2/3)] [date(yymmdd)] [refid(4 digits or less)]
[muscat2@shine2 observe] $ ./register_ref_image.pl GJ3470 1 180212 1872
```

The reference image can then be shown using **./show_ref_img.py (ALIAS: show_ref).**

```
[muscat2@shine2 observe] $ ./show_ref_img.py [objname]
```

As in Fig. 5, the filter used, position angle, and frame id are also shown for convenience. You can then visually align the current FOV (being run by mov command). Finer adjustments are done using field_align.pl as explained below. **Note that the PI of the monitoring target should prepare or at least specify the reference image in advance.**

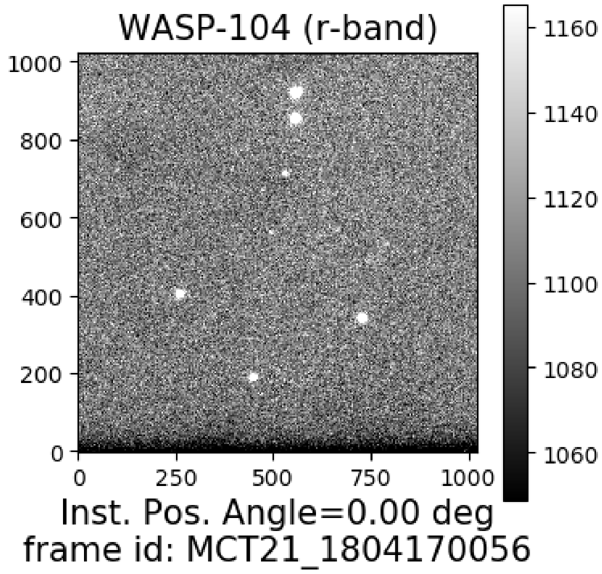


Figure 5: The reference image used to visually compare the current FOV position. ./show_ref_img.py shows the image generated after registering ./regist_ref.pl.

3) If the difference of the current FOV and reference image positions is roughly within 1 arcmin, more precise alignment can be done using **./field_align.pl** (**ALIAS: align**) automatically.

```
[muscat2@shine2 observe] $ ./field_align.pl [object_name]
```

4) Focus can change on a nightly basis and during the observation. To find the foci in different positions, **./find_focus.pl** (**ALIAS: find_focus**) can be used. The script will take nsteps exposures centered at initial position f0. For each exposure, the fwhm of detected stars is measured and saved in a temporary file. Finally, a plot showing the focus as a function of measured fwhm will pop out with a simple quadratic fit. The best focus is determined by interpolating the minimum of this function as shown below.

```
[muscat2@shine2 observe] $ ./find_focus.pl
        --f0= initial position in micron
        --exp= exposure [default=5]
        --nstep= number of steps [default=7]
```

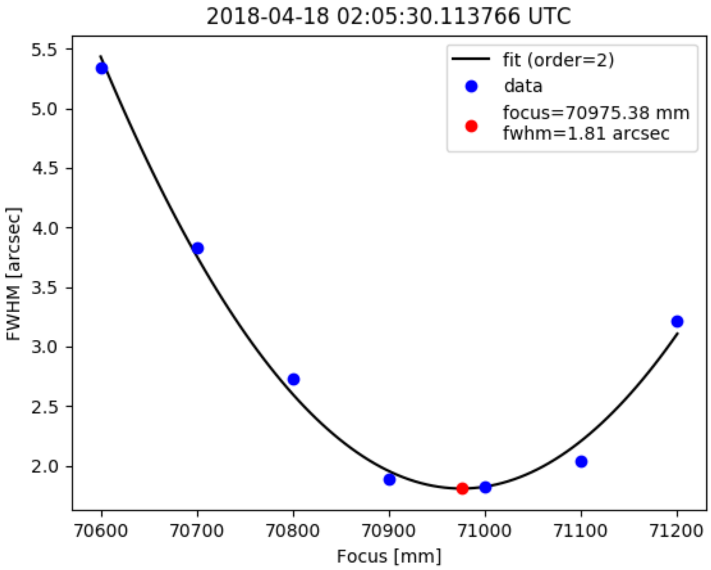


Figure 6: Output of ./find_focus.pl showing the fwhm [in microns] of detected stars within the specified range of focus positions by computing the minimum of a quadratic function fitted to the measured fwhm.

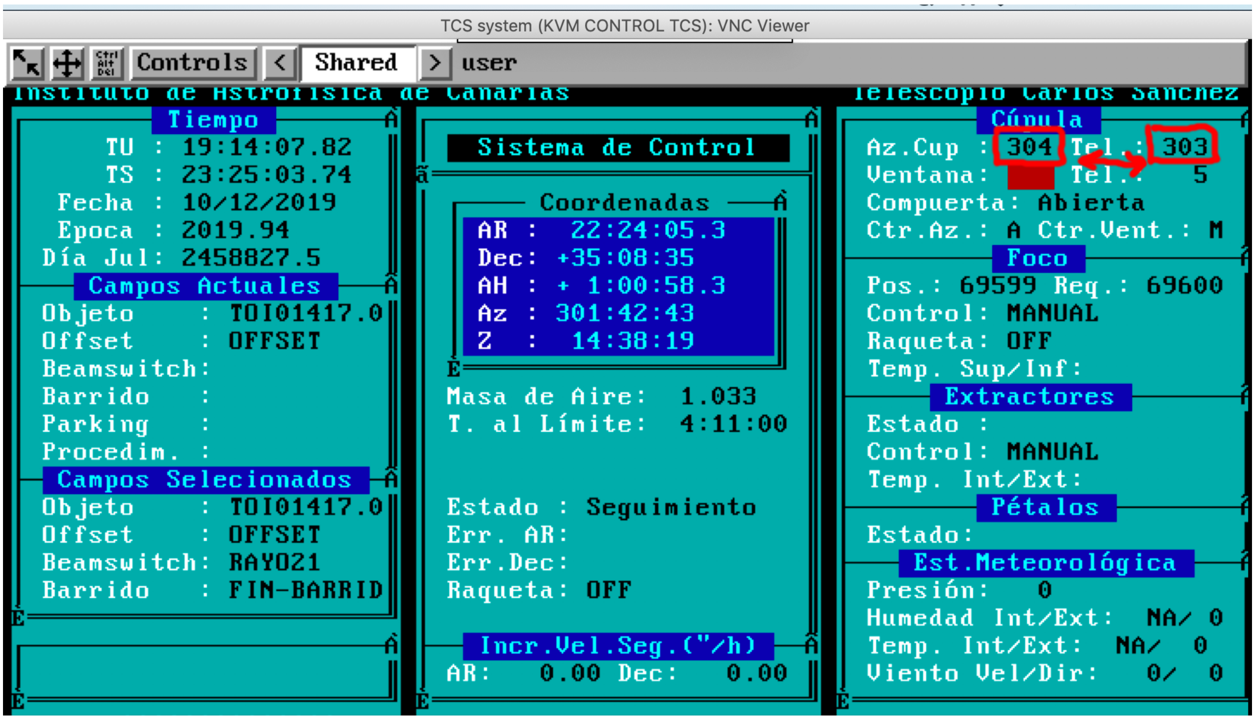
For monitoring targets, taking note of the offset from the best focus (i.e. defocus position) is usually needed. For example, if the previous observation was defocused by 200 micron, it is ideal to set the current observation to same defocus value. The current best focus can be obtained using ./find_focus.pl. Then using **focus.py** (**ALIAS: focus**), 200 micron can be added to the best focus to set the final defocused position. The current focus value is shown when you execute the focus command without any arguments.

```
[muscat2@shine2 ] $ focus.py [position (micron)]

To show the current focus value:
[muscat2@shine2 ] $ focus.py

Use alias:
[muscat2@shine2] $ focus [position (micron)]
[muscat2@shine2] $ focus
```

5) Vignetting due to dome not tracking with telescope

As a reminder, you have to check that in the TCS-Control System PC in the upper right corner of the screen the numbers "Az. Cup" and "Tel" **must be the same within 4 degrees**, if this is not the case (i.e., more than 4 degrees of difference) is highly likely that the dome is not working and we'll have vignetting; so you have to contact the Telescope Operator ASAP to fix this.

Note "Ctr. Az" [control azimuth] should mark A (automatic) and not M (manual) otherwise the dome will not be following the telescope.



```
Instituto de Astrofisica de Canarias                          Telescopio Carlos Sanchez

Tiempo                            Sistema de Control            Cúpula
     TU  : 19:14:07.82                                          Az.Cup : 304 Tel.: 303
     TS  : 23:25:03.74                Coordenadas               Ventana:     Tel.:    5
  Fecha  : 10/12/2019          AR : 22:24:05.3                  Compuerta: Abierta
  Epoca  : 2019.94             Dec: +35:08:35                   Ctr.Az.: A Ctr.Vent.: M
 Día Jul: 2458827.5            AH : + 1:00:58.3                 Foco
Campos Actuales                Az : 301:42:43                   Pos.: 69599 Req.: 69600
 Objeto     : TOI01417.0       Z  :  14:38:19                   Control: MANUAL
 Offset     : OFFSET                                            Raqueta: OFF
 Beamswitch:                  Masa de Aire:   1.033             Temp. Sup/Inf:
 Barrido    :                 T. al Límite:   4:11:00           Extractores
 Parking    :                                                   Estado :
 Procedim.  :                                                   Control: MANUAL
Campos Selecionados                                             Temp. Int/Ext:
 Objeto     : TOI01417.0      Estado : Seguimiento              Pétalos
 Offset     : OFFSET          Err. AR:                          Estado:
 Beamswitch: RAY021           Err.Dec:                          Est.Meteorológica
 Barrido    : FIN-BARRID      Raqueta: OFF                      Presión:    0
                                                                Humedad Int/Ext:   NA/  0
                              Incr.Vel.Seg.("/h)                Temp. Int/Ext:   NA/  0
                              AR:    0.00 Dec:    0.00          Viento Vel/Dir:    0/  0
```

7. Caution

1. Dome behavior

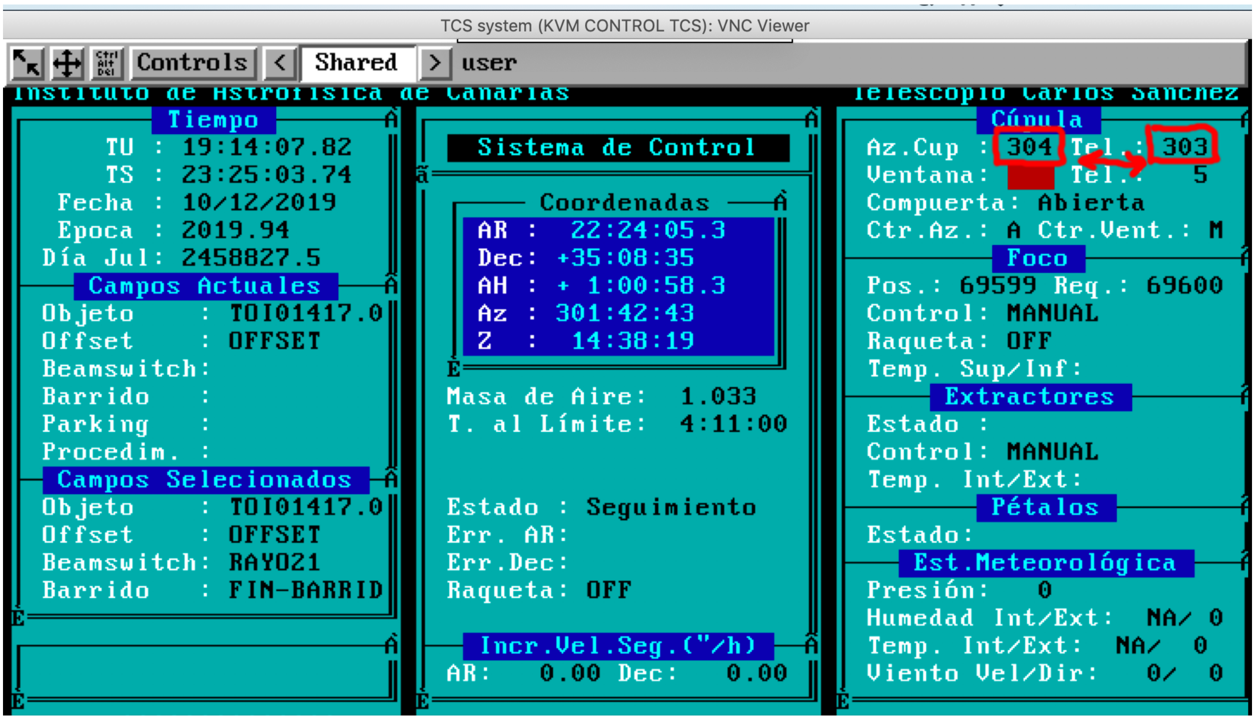
From Felipe's E-mail

Hi MuSCAT2 people,

I noticed that during past weeks there were a lot of problems with TCS dome and several observations were affected by vignetting. As a reminder, you have to check that in the **TCS-Control System PC in the upper right corner of the screen the numbers "Az. Cup" and "Tel" must be the same within 5 degrees**, if this is not the case (i.e., more than 5 degrees of difference) is highly likely that the dome is not working and we'll have vignetting; so you have to contact the Telescope Operator ASAP to fix this. Using my wonderful photoshop skills I've included a screenshot pointing in red where you have to keep an eye for vignetting in TCS Control System.

Cheers,

Felipe Murgas.



```
Instituto de Astrofisica de Canarias

Tiempo
     TU  : 19:14:07.82
     TS  : 23:25:03.74
  Fecha  : 10/12/2019
  Epoca  : 2019.94
 Día Jul: 2458827.5
Campos Actuales
 Objeto       : TOI01417.0
 Offset       : OFFSET
 Beamswitch:
 Barrido      :
 Parking      :
 Procedim.    :
Campos Selecionados
 Objeto       : TOI01417.0
 Offset       : OFFSET
 Beamswitch: RAYO21
 Barrido      : FIN-BARRID

Sistema de Control
Coordenadas
 AR  :  22:24:05.3
 Dec: +35:08:35
 AH  : + 1:00:58.3
 Az  : 301:42:43
 Z   :  14:38:19
Masa de Aire:   1.033
T. al Límite:   4:11:00

Estado : Seguimiento
Err. AR:
Err.Dec:
Raqueta: OFF
Incr.Vel.Seg.("/h)
AR:    0.00 Dec:    0.00

Telescopio Carlos Sanchez
Cúpula
 Az.Cup : 304 Tel.: 303
 Ventana:      Tel.:    5
 Compuerta: Abierta
 Ctr.Az.: A Ctr.Vent.: M
Foco
 Pos.: 69599 Req.: 69600
 Control: MANUAL
 Raqueta: OFF
 Temp. Sup/Inf:
Extractores
 Estado :
 Control: MANUAL
 Temp. Int/Ext:
Pétalos
 Estado:
Est.Meteorológica
 Presión:    0
 Humedad Int/Ext:   NA/ 0
 Temp. Int/Ext:   NA/   0
 Viento Vel/Dir:    0/   0
```

2. Limit of the observation

Target must be in the
Dec < 65 deg.
Altitude > 30 deg.

Appendix

Commands in shine2

```
[muscat2@shine2 ~]$ print_help
```

	ALIAS	SCRIPT	DESCRIPTION
0	setup_shine2	./setup_shine2.sh	set_ds9, open iraf, open 4 screens, & take 1 test exp.
1	set_ds9	./set_ds9.sh	set ds9 display
2	mov	./run_MuSCAT_mov.pl	test exposures in 1 ccd
3	mov_sync	./run_MuSCAT_mov_sync.pl	test exposures in 4 ccds
4	obj	./run_MuSCAT_obj.pl	science exposures in 1 ccd
5	obj_sync	./run_MuSCAT_obj_sync.pl	science exposures in 4 ccds
6	dark	./run_MuSCAT_dark.pl	dark/bias in 1 ccd
7	dark_sync	./run_MuSCAT_dark_sync.pl	dark/bias in 4 ccds
8	stop_obs	./stop_obs.pl	stop movie/science exposures
9	flatdark	./flatdark.pl	take both flat and dark
10	offset	./tel_offset.py	move telescope position
11	focus	./focus.py	change focus
12	find_focus	./find_focus.pl	find best focus

```
13  regist_ref        ./register_ref_img.pl        register reference image
14  show_ref          ./show_ref_img.py            show reference image
15  align             ./field_align.pl             align current FOV to ref image
16  reset_CCDs        ./reset_CCDs.pl              reset CCD state
17  ag                ./auto_guide_new.pl          run auto-guider
18  stop_ag           ./stop_auto_guide.pl         stop auto-guider script
19  make_ref          ./make_reference.pl          make ref image for lc monitor
20  show_star_ID      ./show_star_ID.py            show star IDs
21  reset_param       ./reset_param.pl             reset lc monitor param to default
22  set_param         ./set_param.pl               set parameters for lc monitor
23  lcm               ./run_lc_monitor.pl          run lc monitor
24  stop_lcm          ./stop_lc_monitor.pl         stop lc monitor script
```

Commands in alex2

```
[muscat2@alex2 ~]$ print_help

   ALIAS              SCRIPT                       DESCRIPTION
0  setup_alex2        ./setup_alex2.sh             reset CCD powers, launch camera servers, and i...
1  camera_server      ./run_camera_server.pl       run camera server
2  attach_cam         ./attach_screen_cam.pl       attach screens for camera server
3  detach_cam         ./detach_screen_cam.pl       detach screens for camera server
4  reset_CCDs         ./reset_CCDs.pl              reset CCD powers
5  rotate             ./CassR_move_abs.py          rotate the instrument rotator
6  stat_rot           ./CassR_stat.py              show status of the rotator
```

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Taku Nishiumi

_ MuSCAT2 Observation Cookbook

This is a simple To-Do List of MuSCAT2 observation. For details, please read Command Manual. When you have any problems, first of all you should refer Problems and Solutions.

---

1. Before Observation

a. Check scheduler to decide targets, and check target if there are any suggestions about observation (ex. exposure time, stellar position) from P.I.

b. Useful tools
IAC weather status
UTC Time

2. Setup

a. Ask ToT to open the dome & mirror cover

b. If there is no alex2 and shine2 on Tokio PC, setup both (2.1~2.3)

c. Execute setup_alex2 (2.2.4) and check if the temperature of CCDs ~ -70℃

3. Pointing at a Target

a. Telescope ➪ Point&Track ➪ User Object List ➪ Choose target ➪ Go to

b. If the target is not on the list, Add Object & Save

c. Take test image with mov / mov_sync (3.1)

d. To shift the stellar position, execute offset (3.1.5)

e. For multi-epoch target, show_ref (6.2) to see registered image and align (6.3) with it

f. CAUTION! Check "T. al limite" in TCS control system: not below 0:40:00

4. Observation

a. obj / obj_sync (3.3) ➪ acg (4.1)

b. make_ref ➪ show_star_IDs ➪ set_param ➪ lcm (5.1)

c. Check quick look curve web page .4)

d. stop_ag (4.1) ➪ stop_obs all / sync

e. To change the focus, focus (6.4nc (3.1) ➪ stop_lcm (5.1)

5. Taking FLAT & dark (You can do this part also before/during the observation)

a. Telescope ➪ Stop, then, Telescope ➪ Park ➪ Zenith

b. Ask ToT to close the dome & turn on the lights in dome(3.5)

c. flatdark(3.5)

d. dark_today(3.4)

6. Finishing

a. Ask ToT to close the mirror cover & turn off the lights

b. end_cam_all (3.6)

c. If there is no observation with MuSCAT2 next day, exit from all but one terminals logging in alex2 and execute shutdown_alex2 (3.7)

7. After Observation

a. Write ‘End of night report’ to muscat2@iac.es

b. Update Observations list

8. Troubleshooting

a. When it seems that some CCDs are offline, execute reset_CCDs

b. When camera doesn't work properly(Message: server_ccd was still running), execute ./remove_server_run.pl [ccd# (0/1/2/3/all)]

c. When ds9 suddenly disappear or stop processing, execute

d. 9

e. When it is displayed "lock file found!" in shine2's terminal using offset command, execute setup_shine2.

f. For other problems, check Problems and Solutions or recent end of night reports.

Command in shine2, Command in alex2, Button in FOVIA, section number in command manual