pyIRSF user's manual

the English version

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Edition History

2015-07-30	updated for pyIRSF-2.0 The cover and the edition history were added. The description of recom.param was updated. New parameters norot and commethod were added. sirius.py tune and sirpol.py tune were added. '5.6 Some important remarks on obslog' and 6.6 were added
2015-06-05	The first edition for pyIRSF-2.0b

1. Introduction

The pyIRSF package is constructed for the data redcution of the rawdata obtained with IRSF + SIRIUS / SIRPOL : dark subtraction, flat field correction, sky-bias subtraction, image registration and recombination. There are also some scripts for rough photometry and photomretric and astrometric (WCS) calibrations based on the 2MASS catalog.

1.1 requirments

OS   Linux/UNIX including MacOSX

IRAF and PyRAF
The latest version of IRAF and PyRAF are recommended.

Python 2.7

C compiler

CFITSIO
The rawdata of SIRIUS/SIRPOL are compressed with the fpack program of CFITSIO. The CFITSIO library is necessary to read the compressed data. No need to uncompress the compressed rawdata before you run the pipeline.

matplotlib (optional)

1.2 How to install

1. Download the latest version of pyIRSF-XXX.tar.gz from
http://sourceforge.net/projects/irsfsoftware/
where XXX is a version (e.g., pyIRSF-2.0).

2. Unpack pyIRSF-XXX.tar.gz and you will find a directory, pyIRSF-XXX.

3. Execute make in the directory.
If you installed the CFITSIO library in directories other than /usr/local/lib and /usr/local/include, edit the lines for LDFLAG and CFLAG in the Makefile.

4. If you use Ubuntu, modify the Makefile as following.
(before) COPTS = -O2
(after) COPTS = -O2 -Wl,--no-as-needed

5. Add the pyIRSF-XXX directory to your PATH in the .bashrc or something.

1.3 The rawdata files the SIRIUS standard directory structure

The name of SIRIUS raw data file is labeled
jyymmdd_nnnn.fits, hyymmdd_nnnn.fits, and kyymmdd_nnnn.fits
for the j, h, and k band, respectively. I describe them as [j|h|k]yymmdd_nnnn.fits all at once in this document. Obviously, yymmdd is the date and nnnn is the file number of the day.
Each of the raw data file is usually compressed with the fpack program of CFITSIO and has an extension of .fz or .ic.

The raw data files observed on yymmdd are contained in a directory yymmdd/rawdata (e.g., 140306/rawdata). I call this as the SIRIUS standard directory structure.
The pyIRSF pipeline softwares assume this standard structure.

Besides that, the pyIRSF pipeline softwares assumes the followings.
1. There are not the other files than the SIRIUS rawdata files in the rawdata directory.
2. The extension is unified to one of .fits or .fits.fz or .fits.ic in a rawdata directory. However, a contamination of less than 10% of the other extensions will be just ignored.

2. Contents of pyIRSF

sirius.py the pipeline software for SIRIUS

sirpol.py the pipeline software for SIRPOL

mklog.py to create an obslog file from a set of raw data of a day

mktwflatlist.py to select pairs of rawdata frames with adequate background levels and to create a list of files from which flatfield images are created

twflatcom.py to create flatfield images from the list created with mktwflatlist.py

corrflat.py to correct the non-uniform component of twilight illumination to the flat fieldimages created with twflatcom.py

imgrecom.py to register and combine frames which are already corrected for dark and sky biases and flatfield with sirius.py. to combine frames that sirius.py failed combining or frames from different nights.

polrecom.py sirpol version of imgrecom.py

sirphot.py to carry out rough aperture photometry

sirwcs2.py to carry out rough aperture photometry and rough photometric calibration by comparing the 2MASS catalog and to transform (x, y) coordinate to (RA, DEC) coordinates for each star. WCS is also embedded to the FITS files.

3. flatfield images

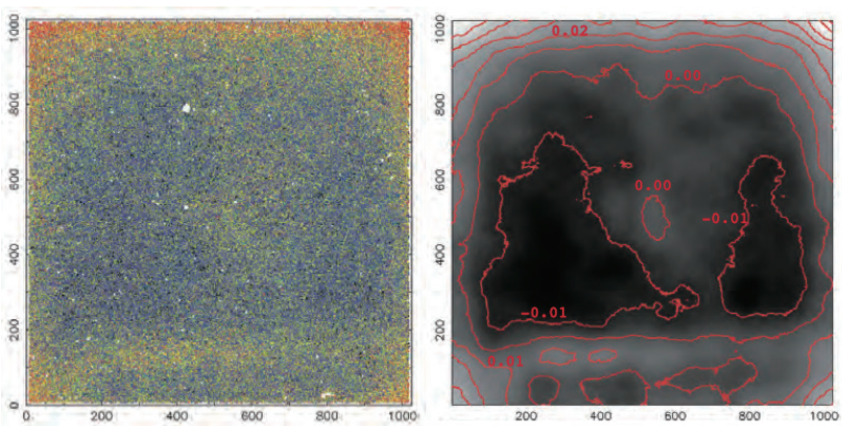
Flatfield images (multiplicative gain corrections) are derived from the measurements of the rapidly dimming or brightening twilight sky by charting the relative change in intensity seen in every pixel in response to the changing illumination level. The resulting pixel-by-pixel responsivity images are normalized to have a median of unity. Finally, a flatfield image is created by taking a median of a number of the normalized images, in order to achieve a higher S/N and to remove bad signals accidentaly caputured in some frames.

3.1 Master flatfield images

There are built-in flatfield images in the pyIRSF package. I refere them as the master flatfield images. These are used for the flatfield correction in the pipeline process when a user has not prepared their flatfield images for the date. The master flatfield images were made from twilight sky frames from 53 nights between 2000 April 25 and 2004 April 22 and a correction using a comparison of the SIRIUS point source photometry with the 2MASS catalog.

When flatfield images are created, it is assumed that a distribution of pixel intensity difference between a brighter and a fainter twilight sky is equivalent with a pixel intensity distribution yielded by an observation of an uniform illumination. However, it is not the case for SIRIUS, probably, due to stray light inside the camera. The amplitude of the non-uniformity can reach 5 percent or more near the edge of the arrays. (When a demanded photometric accuracy is about 0.05 mag, it is enough uniform though.) This has been estimated by comparing the dependency on the array position of magnitude difference of several hundreds of thousand point sources between the SIRIUS and 2MASS measurements. It is necessary to correct this component from flatfield frames to attain a better photometric precision.

A "canonical" flatfield image for each band was made from twilight sky frames from the 53 nights. Then frames from 79 nights between 2000 April 25 and 2004 April 22 were dark-subtracted, flatfield corrected with the canonical flatfield images, and sky-bias subtracted. Magnitudes of the point sources are measured with the aperture photometry in each frame. The magnitude zero point was obtained by a regression of comparison with the 2MASS point sources in the same field for each frame. Magnitude differences between the SIRIUS and 2MASS measurements were obtained for all the point sources. The left of the following figure denotes the map of the



Left : Each dot denotes a magnitude difference, Δm, between the SIRIUS and 2MASS measurements at the array position. Red, orange, yellow, green, blue, purple, grey, and black are assigned for $\Delta m>0.06$, $0.06>\Delta m>0.04$, $0.04>\Delta m>0.02$, $0.02>\Delta m>0.00$, $0.00>\Delta m>-0.02$, $-0.02>\Delta m>-0.04$, $-0.04>\Delta m>-0.06$, $-0.06>\Delta m$, respectively.

right : A median smoothed map of the left one. The interval of contours is 0.01 mag.

magnitude difference for the H band. Each dot represents the magnitude difference for a star found at the array position. This indicates a clear pattern of the magnitude difference and the array position. Similar results are obtained for the J and K band as well. Presumably, the arrays are not illuminated uniformly but there is a contamination probably due to scattered light within the camera. I consider that this pattern represents the deviation from the true flatfield correction that would be obtained from the uniform illumination and this pattern can be used to correct the "canonical" flatfield images. A correction image is made by taking a median in an apeture with a radius of 40 pixels for each pixel for each band, which is shown in the right. The canonical flatfield images are multiplied by the correction images to produce the master flatfield images. The accuracy of the master flatfield images is estimated to be less than 2-3 percent.

See xxxx for the details.

3.2 To create your flatfield images

If you think the master flatfield images are not appropriate to your data reduction, you can make your own flatfield images with **mktwflist.py**, **twfcom.py**, and **corrflat.py** in pyIRSF.

I recommend you to use as many data as possible, like 10 nights. It yields a higher S/N for the flatfield images and bad frames suffering from cloud on the sky or condensation on the window of SIRIUS can be removed statistically. The flatfield characteristic for SIRIUS is confirmed not to change more than 1% at least in several months.

How to put file and directories

Make a working directory at the same level as the date directories.

```
$ mkdir wrk
$ ls
$ 030211/  030214/  030219/ wrk/
```

Each of the date directores has a directory "rawdata" in accordance with the SIRIUS standard directory structure. The "rawdata" directories have FITS files icluding rawdata. The FITS files may be uncompressed ones, or cfitsio's fpack-compressed files with extension of "fits.fz", or cfitsio's imcopy-compressed files with extension of "fits.ic". You do not need to uncompress compressed files.

Then, move into the working directory and create a list to specify dates from which twilight sky data are available. Just write dates line by line as shown in the following example.

```
$ more dlist
030211
030214
030219
```

You do not need to be too careful. Directories without twilight sky data are just ignored. The mktwflist.py program examines the FITS header of every FITS file in the specified directories. A FITS file having "OBJECT= twflat" is considered to be twilight flat data frame.

Basic processes

(1) Execute mktwflist.py in the working directory first, as shown in the following example.

```
$ mktwflist.py dlist
```

A list specifying the date directories is given as the first argument.

If there is no twilight sky data at a specified date, a message like

```
No flat frames taken on 030211
```

is shown. At the end of the process, messages like the following will be displayed.

```
a total of 62 pairs are selected for j
a total of 59 pairs are selected for h
a total of 47 pairs are selected for k
Done
```

As the results, [jlhlk]flatlist.0, [jlhlk]flatlist, [jlhlk]backround.txt, mktwflist.param, will be created.

(2) Execute twflatcom.py

```
$ twflatcom.py flat0302
```

You name the resultant flatfield frame by giving (a part of) it at the first argument. In the above example, [jlhlk]flat0302.fits will be created.

The differential image created from a pair listed in each line of jflatlist, hflatlist, and kflatlist will be normalized by the median of the pixel values, and all the normalized images are median-combined into a flatfield frame.

Keyword NCOMBIME in the header of the flatfield frames denotes the number of differential images used for combination.

If you are suspicous about the correction process, you may skip this step and use the flatfield images calculated in the standard manner with twflatcom.py.

(3) Run corrflat.py

```
$ corrflat.py flat0302 nflat0302
```

Give the common part, excluding the extension, of the file names which are made by twflatcom.py as the first argument, and the name of the final 'corrected' flatfield frames as the second argument. In this example, [jlhlk]nflat0302.fits will be created from [jlhlk]flat0302.fits.

This program corrects the flatfield images obtained with twflatcom.py by removing the contaminating component due to the non-uniform illumination. It is assumed that the non-uniform component has not changed since the master flatfied frames were constructed.

The following calculation is carried out in corrflat.py.

```
nflat(x, y) = iflat(x, y) / cflat(x, y) * mflat(x, y)
```

Here, nflat(x, y), iflat(x, y), cflat(x,y) and mflat(x, y) are the pixel value distribution of the resultant corrected flatfield, the flatfield obtained by twfcom.py, the canonical flatfield from which the master flatfield was generated, and the master flatfield, respectively.

It is not confirmed yet if the correction process is legitimate for SIRPOL and observations with the narrow band filters. Use it with a caution.

Optional processes, a warning message, and the other outputs

(1) optional argumemts for mktwflist.py

`-noexgap`

not to exclude pairs of which differential image has the central gap more than 1%. See the details in 3.3.

`-skydiff=[float]` (example : *mktwflist.py dlist -skydiff=1000*)

A pair of brighter and fainter twilight sky frames is selected so that the difference of the background level is more than 2000 ADUs by default. You can change the threshold ADU with this argument.

`-maxgood=[float]` (example : *mktwflist.py dlist -maxgood=6500*)

Frames with the median of the pixel values less than 6000 ADUs are adopted to make flatfield images by default. You can change the threshold with this argument.

`-keyword=[string]` (example: *mktwflist.py dlist -keyword=NB14twflat*)

Frames with FITS keyword of 'twflat' are selected to make flatfield images by default. you can change the keyword here.

`-band=[string]` (example: *mktwflist.py dlist -band=j mktwflist.py dlist -band=h, k*)

Text files necessary for the following processes are created for all the JHK bands by default. You can specify an band or two bands here.

To see how to use the options, execute

```
$ mktwflist.py
```

without arguments. A quick list will be displayed.

(2) A warning message while mktwflist.py is running

The background level monotonically increases in the morning and decreases in the evening while observing twilight sky frames when there is no cloud on the sky. When it does not, some of the frames may have observed cloud in the field.

A message like

```
background level unstable at 030313 0010
```

appears on the terminal, when the background does not change monotonically in the J band. The warning is also recorded in jbackground.txt with an asterisk, * , at the end of the lines for unstable frames. The background level is affected also by OH and thermal emissions for the H and K bands. Therefore, it does not always indicates the presence of cloud when the background doesn't change monotonically in the H and K bands. So, the masseges are not displayed on the terminal but recoreded in [hlk]background.txt.

This warning messege is recorded in mktwfwarning.txt as well.

If there is not warning during the process, mktwflist.py doe not create mktwfwarning.txt.

(3) Output files from mktwflist.py

[jlhlk]flatlist are the input files to twfcom.py and **[jlhlk]flatlist.0** are log files.

The following is an example of jflatlist.

```
$ more jflatlist
030129 0025 0036 3310.0 1254.0
030129 0026 0040 3001.0 928.0
030129 0027 0044 2724.0 720.0
030129 0914 0909 4712.0 2468.0
030129 0913 0907 4157.0 1912.0
030129 0912 0905 3651.0 1465.0
...
```

The first line denotes that the J band frames 0025 and 0036 on 030129, of which medians of pixel values are 3310.0 and 1254.0, respectively, were selected as a pair to make a differential image.

[jlhlk]flatlist.0 are similar, but they also include pairs of which differential image has the central gap more than 1%. [jlhlk]flatlist are made by excluding such pairs from [jlhlk]flatlist.0. When you add **-noexgap** as an option, mktwflist.py does not carry out the exclusion process and does not create [jlhlk]flatlist.0.

mktwflist.param

Parameters used in mktwflist.py are recorded in it.

[jlhlk]background.txt

The median of pixel values are recorded for all the frames.

(4) options for twfcom.py

-band=[string] (example : *twfcom.py flat0302 -band=j* *twfcom.py flat0302 -band=h,k*)

Flatfield images are created for all the JHK bands by default. You can specify an band or two bands here.

If you want to remove some pairs of frames, edit [jlhlk]flatlist before executing twfcom.py.

Delete the lines or add # at the beginning of the line.

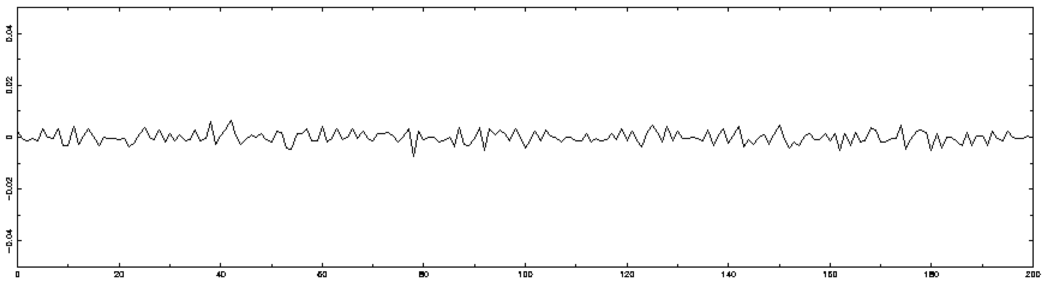
3.3 Excluding differential images with a central vertical gap

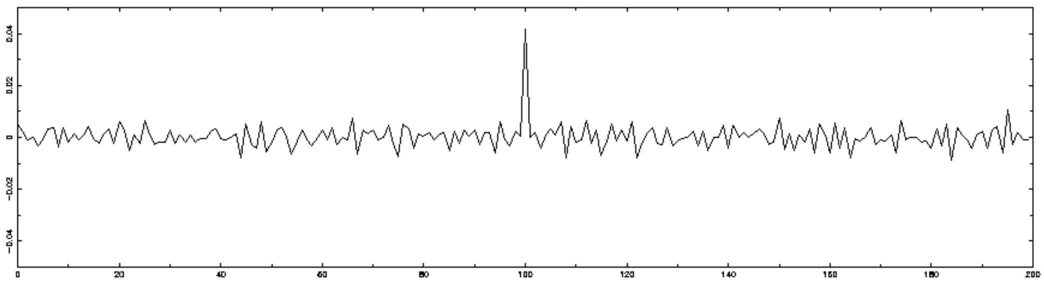
The HAWAII array has a characteristc of reset anomally which results in a central gap of pixel values between the 511st and 512nd columns in rawdata frames. When this pattern is stable, there is no gap found in a dufferential image. However, it becomes unstable sometimes and yields a differential image with the central vertical gap.

The algorithm to find the gap is the followings.

1. For a normalized differential image, the program calculate a pixel value difference between adjacent pixels in the x direction, dI(i, j) = I(i+1, j) - I(i, j), for j from 1 to 1024 and for i from 413 to 612.
2. The median through the y direction, M(i), is calculated for every i in the range.
3. The madian and standard deviation, sigma, of M(i) are calculated. The median is around 0.
4. If M(511) is less than 0.01 or less than 3 sigma, there is no gap recognised in this differential image.

The following figures are examples of M(i). The horizontal axis denotes i and the vertical M(i).





The upper shows no sign of the central gap, while the lower shows a clear sign of the central gap about 4 %.

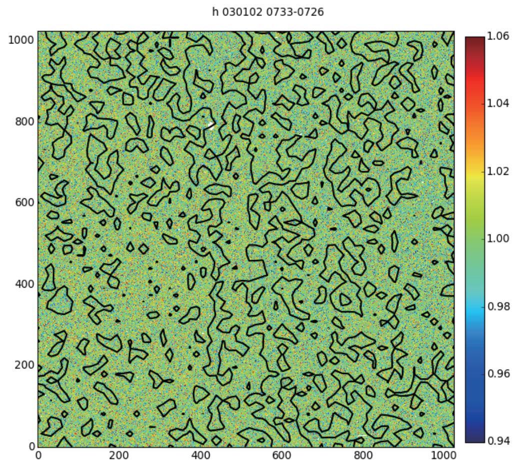
3.4 Eye inspection -- twflatview.py

An optional task "twflatview.py" helps you to remove bad-behaved pairs with eye inspection.
It sequentially displays differential images divided by the final median flat frame, which tells you how each differential image deviates from the final one. (You need the matplotlib module for python to use this.)

Input a list obtained by mktwflist.py and the flatfield image into twflatview.py .

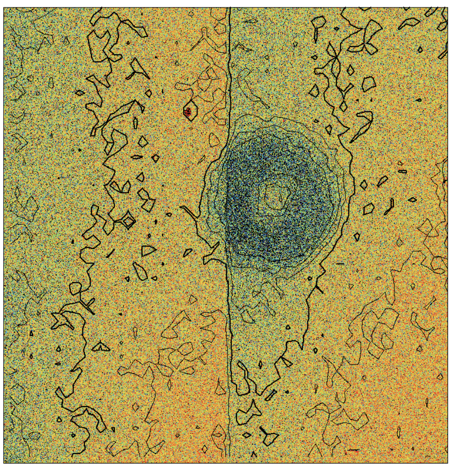
```
$ twflatview.py hflatlist hflat0302.fits
```

Then, you see a figure of the differential image divided by the final median flat frame for the first pair. An example is the below.



You will see the figures sequantialy by typing the return key. The pair ID appears at the top. The contour denotes the level smoothed by 16x16 pixel median. The thick contour denotes the level of 1.00, while thin contours denote the other levels with the step of 0.01(=1%). Normally, you will see only the thick contour as in the above example.

The following figure show clear deviated patterns with levels 2% or more. If you wish to remove such pairs from flat frame combination, delete or comment out the corresponding lines in [jlhlk] flatlist, then run twflatcom.py again.



4. Making an obslog file with mklog.py

The mklog.py program reads the keywords in the header of FITS files in the rawdata directory and creates an obslog file which is a table of frame number, object name, exposure time, dithering offset in RA and Dec directions, date, time, RA, Dec, and airmass.

mklog.py is executed in a working directory created at the same level as the rawdata directory of a date and creates an obslog file in the same directory. See section 5 and 6 for actual usages of mklog.py.

There are some options for mklog.py.

mklog.py -twflat -object=[string] -itime=[float] -help

-twflat : to make an obslog file without lines with object names starting with 'twflat'

-object=[string] : to make an obslog file with lines with object names starting with the string, case insensitive, and lines for dark frames with the same exposure time as the specified object frames.

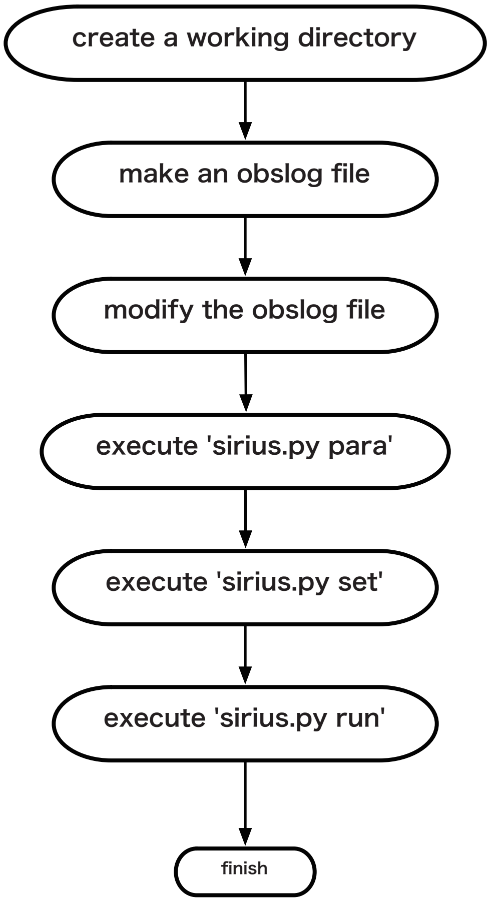
-itime=[float] : to make an obslog file with lines with an exposure time equals to the value.

-help : to display the usages and examples.

5. SIRIUS data reduction

5.1 The simplest case

The flow of data reduction is like the following in the simplest case.



Here is an example.

When you reduce only 'omegaCen' in the data of 2001-1-2.

```
$ pwd
/data/010102
$ ls
rawdata/
```

There is 'rawdata' directory in '010102' directory in accordance with the SIRIUS standard directory structure. The first thing to do is

(1) to make a working directory at the same level as the rawdata directory.

The name of the working directory can be anything. ('wrk' in this example.)

mklog.py -object=omegaCen is much easier here, actually. The detail is found in section 4

All commands are carried out at shell command lines. IRAF is used just as a library. PyRAF is an interface to connect IRAF and python.

(2) to make an obslog file by executing 'mklog.py' in the working directory.

This is carrried out at a shell command line instead of IRAF nor PyRAF.

```
$ ls
rawdata/  wrk/
$ cd wrk
$ mklog.py
$ ls
obslog
```

'obslog' is a text file, which contains frame number, object name, exposure time, dithering offset values, and etc. for each frame. mklog.py reads the header of rawdata FITS files to make this.

At this moment, we want to reduce only omegaCen, therefore, we need

(3) to modify the obslog file

with a text editor to remove unnecessary lines.

This night, 'omegaCen' and 'omegaCensky', a sky bias field for omegaCen, were observed with an exposure time of 5 seconds for frames 0450-0458 and 0459-0467, respectively.

A set of 5 second dark frames were obtained for frames 0057-0067, which are necessary to process the above set of 'omegaCen'.

The 'obslog' file will be like the below.

```
FRAME¯OBJECT ITIME RA_OFF DEC_OFF¯DATE_UTC TIME_UTC DATE_LT TIME_LT JD EPOCH RA DEC AIRM
0057 DARK 5. 0 0
0058 DARK 5. 0 0
0059 DARK 5. 0 0
0060 DARK 5. 0 0
0061 DARK 5. 0 0
0062 DARK 5. 0 0
0063 DARK 5. 0 0
0064 DARK 5. 0 0
0065 DARK 5. 0 0
0066 DARK 5. 0 0
0450 omegaCen 5. 0.0 0.0 2001/01/03 01:46:04.5 2001/01/03 03:46:04.5 51912.0 2000 13:26:
0451 omegaCen 5. 14.6 3.9 2001/01/03 01:46:40.3 2001/01/03 03:46:40.3 51912.0 2000 13:26
0452 omegaCen 5. 7.5 13.1 2001/01/03 01:47:15.1 2001/01/03 03:47:15.1 51912.0 2000 13:26
0453 omegaCen 5. -3.9 14.6 2001/01/03 01:47:51.8 2001/01/03 03:47:51.8 51912.0 2000 13:2
0454 omegaCen 5. -13.1 7.5 2001/01/03 01:48:26.5 2001/01/03 03:48:26.5 51912.0 2000 13:2
0455 omegaCen 5. -14.6 3.9 2001/01/03 01:49:02.8 2001/01/03 03:49:02.8 51912.0 2000 13:2
0456 omegaCen 5. -7.5 -13.1 2001/01/03 01:49:39.4 2001/01/03 03:49:39.4 51912.0 2000 13:
0457 omegaCen 5. 3.9 -14.6 2001/01/03 01:50:13.7 2001/01/03 03:50:13.7 51912.0 2000 13:2
0458 omegaCen 5. 13.1 -7.5 2001/01/03 01:50:49.5 2001/01/03 03:50:49.5 51912.0 2000 13:2
0459 omegaCensky 5. 0.0 0.0 2001/01/03 01:52:51.4 2001/01/03 03:52:51.4 51912.0 2000 13:
0460 omegaCensky 5. 19.4 5.2 2001/01/03 01:53:26.0 2001/01/03 03:53:26.0 51912.0 2000 13
0461 omegaCensky 5. 10.0 17.4 2001/01/03 01:54:01.7 2001/01/03 03:54:01.7 51912.0 2000 1
0462 omegaCensky 5. -5.2 19.4 2001/01/03 01:54:37.3 2001/01/03 03:54:37.3 51912.0 2000 1
0463 omegaCensky 5. -17.4 10.0 2001/01/03 01:55:13.1 2001/01/03 03:55:13.1 51912.0 2000
0464 omegaCensky 5. -19.4 5.2 2001/01/03 01:55:48.9 2001/01/03 03:55:48.9 51912.0 2000 1
0465 omegaCensky 5. -10.0 -17.4 2001/01/03 01:56:24.8 2001/01/03 03:56:24.8 51912.0 2000
0466 omegaCensky 5. 5.2 -19.4 2001/01/03 01:57:00.5 2001/01/03 03:57:00.5 51912.0 2000 1
0467 omegaCensky 5. 17.4 -10.0 2001/01/03 01:57:36.3 2001/01/03 03:57:36.3 51912.0 2000
```

Note that a set of a target, 0450-0458 in this example, must be a neighbor of a set of a sky bias. If the object name ends with 'sky', regardless of the lower or upper cases, the set is recognised to be a set of a sky bias for the adjacent target set(s).

Now

(4) Execute 'sirius.py para'

in the working directory.

```
$ sirius.py para
yymmdd is 010102
the mastar flat frames are deployed
```

A message to confirm the date appears. What is the second message? Flat correction frames were not prepared this time. sirius.py noticed that and declared to use the master flat frames for the flat correction in the reduction.

Do the master flat frames work properly? They work at least for data of this period. I will discuss it later.

```
$ ls
hmflat.fits@   jmflat.fits@   kmflat.fits@  obslog obslog~
recom.param  sirius.param
```

[jlhlk]mflat.fits@ are symbolic links to the master flat frames in the pyIRSF package.

If you want use your own flatfield images, put them in the working directory before executing 'sirius.py para'

recom.param and sirius.param are files to adjust parameters for the pipeline. No need to edit them this time.

(5) Execute 'sirius.py set'

in the working directory.

```
$ sirius.py set
```

This will create necessary files for the following process.

(6) Execute 'sirius.py run'

in the working directory.

```
$ sirius.py run
```

This will start the pipeline process.

Messages will appear on the terminal.

```
average dark frames ...  have been created
dark subtraction and flat division ...  done
making sky bias frames and bad pixel masks ...  ... done
masking ...  done
sky subtraction ...  done

*****************
o1.omegaCen
*****************
j-band
yymmdd.fnum  fwhm ellip snum  median stddev
010102.0450   3.8  0.39  141    82.1   31.3
010102.0451   3.5  0.28  106    80.9   30.7
010102.0452   3.6  0.23  171    77.5   30.5
010102.0453   3.3  0.28  117    78.8   30.8
010102.0454   3.9  0.24  150    81.0   31.6
010102.0455   3.4  0.24  119    83.5   31.2
010102.0456   3.9  0.23  150    84.3   31.9
010102.0457   3.6  0.28  156    84.9   31.5
010102.0458   3.9  0.25  148    82.2   31.1

daofind detection threshold : 171.4 sigma
snum is the number of stars detected
max : 171, min : 106, median : 148.0

registration ...
yymmdd.fnum good  matched   dmag xrms yrms   rot    dx    dy
010102.0450    1        0   0.00 0.00 0.00  0.00   0.0   0.0
010102.0451    1      101  -0.03 0.14 0.17 -0.00   0.5   0.8
010102.0452    1      130  -0.01 0.18 0.20  0.00   1.0   1.0
010102.0453    1      107  -0.02 0.15 0.18  0.00   1.6  -0.2
010102.0454    1      125   0.01 0.14 0.19  0.00   0.5  -1.2
010102.0455    1      107  -0.02 0.13 0.17  0.01   0.1  -1.3
010102.0456    1      128   0.00 0.15 0.19 -0.00  -1.4  -0.5
010102.0457    1      126  -0.01 0.22 0.18 -0.01  -1.0   0.8
010102.0458    1      131   0.01 0.14 0.18 -0.00  -0.2   1.7
* * * * * * * * 100% done
combining done
```

... skip ...

```
010102.0453    1      111   0.02 0.15 0.17  0.01   1.5  -0.3
010102.0454    1      110   0.04 0.14 0.14 -0.00   0.7  -1.1
010102.0455    1      113  -0.01 0.15 0.13  0.01   0.2  -1.0
010102.0456    1      116   0.03 0.21 0.14  0.00  -0.9   0.3
010102.0457    1      112   0.03 0.17 0.15 -0.00  -0.5   0.9
010102.0458    1       84   0.02 0.09 0.18  0.00   0.1   1.2
* * * * * * * * 100% done
combining done

done

cleaning the working directory ...
done
```

(7) View the results.

After the pipeline process, the working directory is like the following.

```
010102.ffiles/  jmflat.fits@  log/          obslog   recom.param
hmflat.fits@    kmflat.fits@  o1.omegaCen/  obslog~  sirius.param
```

The combined images are in **o1.omegaCen** directory.

```
homegaCen.fits  jomegaCen.fits  komegaCen.fits
hquality.txt    jquality.txt    kquality.txt
```

[jlhlk]omegaCen.fits are averagedly combined images of frames after dark subtraction, flat correction, sky bias subtraction, and image registration.

Let's take a look at one of the combined frames with ds9.

```
$ ds9 jomegaCen.fits
```

Select File > Display Headers to see the FITS header.

NAXIS1 and NAXIS2 are larger than 1024, because of dithering. Lines for OBJECT to HUMIDITY, including UT/LT and airmass, are for the first frame of the set.

The last 4 lines include the output from the pipeline.

NCOMBINE : the number of frames combined

COMMETHO : the combine method used for iraf.imcombine, although this is fixed to 'average'.

COMAREA : A square area all the frames would have been combined, if all 1024 x 1024 pixels were alive.

REJECT : the reject method used for iraf.imcombine

Another image is included in this FITS file.

```
$ ds9 jomegaCen.fits[1]
```

The pixel value denotes the number of frames with which the average was calculated after rejection of bad pixels.

Notice that the magnitude zero point is different among the areas with different number of this value when it is not a photometric night.

Besides the FITS files, text files are also stored in this resultant directory.

[jlhlk]quality.txt record the average of fwhm, ellipticity of stars and the median and standard deviation of background level and etc. for each individual frames before combination which were displayed on the terminal during the pipeline process.

jquality.txt obtained for this example is shown below.

yymmdd.fnum	fwhm	ellip	snum	median	stddev	good	matched	dmag	xrms	yrms	rot	dx	dy
010102.0450	3.8	0.39	141	82.1	31.3	1	0	0.00	0.00	0.00	0.00	0.0	0.0
010102.0451	3.5	0.28	106	80.9	30.7	1	101	-0.03	0.14	0.17	-0.00	0.5	0.8
010102.0452	3.6	0.23	171	77.5	30.5	1	130	-0.01	0.18	0.20	0.00	1.0	1.0
010102.0453	3.3	0.28	117	78.8	30.8	1	107	-0.02	0.15	0.18	0.00	1.6	-0.2
010102.0454	3.9	0.24	150	81.0	31.6	1	125	0.01	0.14	0.19	0.00	0.5	-1.2
010102.0455	3.4	0.24	119	83.5	31.2	1	107	-0.02	0.13	0.17	0.01	0.1	-1.3
010102.0456	3.9	0.23	150	84.3	31.9	1	128	0.00	0.15	0.19	-0.00	-1.4	-0.5
010102.0457	3.6	0.28	156	84.9	31.5	1	126	-0.01	0.22	0.18	-0.01	-1.0	0.8
010102.0458	3.9	0.25	148	82.2	31.1	1	131	0.01	0.14	0.18	-0.00	-0.2	1.7

fwhm, ellip : the average of fwhm and ellipticity of the detected stars on the frame. fwhm and ellipticity are measured with the psfmeasure program of IRAF.

snum : the number of stars detected. The detection threshold of the daofind program of IRAF is fixed through a set, which is determined so that the number of stars does not exceed 150 on the first frame.

median, stddev : the median and standard deviation of the background.

good : If all the conditions specified in recom.param, e.g., the number of matched stars and the fwhm value, are satisfied, it is set to be 1. If it is 1, the frame is included in the final combined image. If it is 0, the frame is rejected.

matched : The number of stars matched between each frame and the first frame.

dmag : the difference of magnitude zero point between each frame and the first frame. This is estimated by calculating the median of the magnitude difference of matched stars: magnitude (the first frame) - magnitude(each frame).

xrms, yrms : the residuals of the coordinate transformation fit between each frame and the first frame by the geomap program of IRAF. these are measured in pixels.

rot : the rotation degree relative to the first frame

dx, dy : deviation of the actual relative shift to the first frame from the dithering offset values. These are measured in pixels.

yymmdd.ffiles, 010102.ffiles in this example, directory will be created in the working directory after the pipeline process. There are dark subtracted, flat corrected and sky bias subtracted frames in the directory. They are named as [jlhlk]fnnnn.fits, here nnnn is a 4-digit number. They are ready for image registration and combination.
These frames are stored so that you are able to check the quality of each frames, or to redo the image registration and combination with different parameters, or to carry out image registration and combination of frames from different nights.

log directory will be found in the working directory, too. There are **[jlhlk]skybg.list** in the directory. The medain of the background is recorded for each sky bias frame in these files.

5.2 To process multiple targets

Let's see an example of processing data of four different fields; NGC2024, NGC2024B, NGC2024C, and NGC2024D on 2001-01-03. The flow is the same as the previous example.

(1) to make a working directory at the same level as the rawdata directory

mklog.py -object=NGC2024 is much easier here, as well.

(2) to make an obslog file by executing 'mklog.py' in the working directory

(3) to modify the obslog file

NGC2024, NGC2024sky, NGC2024B, NGC2024C, NGC2024Csky, and NGC2024 were observed with an exposure time of 30 second for frames 0364 - 0418 in a row. A set of 30 second dark frames were obtained for frames 0031-0040. Remove the rest from the obslog file.

```
FRAME OBJECT ITIME RA_OFF DEC_OFF DATE_UTC TIME_UTC
0031 DARK 30. 0 0
0032 DARK 30. 0 0
0033 DARK 30. 0 0
0034 DARK 30. 0 0
0035 DARK 30. 0 0
0036 DARK 30. 0 0
0037 DARK 30. 0 0
0038 DARK 30. 0 0
0039 DARK 30. 0 0
0040 DARK 30. 0 0
0364 NGC2024 30. 0.0 0.0 2001/01/04 00:22:07.0 2001
0365 NGC2024 30. 14.6 3.9 2001/01/04 00:23:04.9 200
0366 NGC2024 30. 7.5 13.1 2001/01/04 00:24:01.4 200
0367 NGC2024 30. -3.9 14.6 2001/01/04 00:24:57.6 20
0368 NGC2024 30. -13.1 7.5 2001/01/04 00:25:53.7 20
0369 NGC2024 30. -14.6 3.9 2001/01/04 00:26:50.6 20
0370 NGC2024 30. -7.5 -13.1 2001/01/04 00:27:48.3 2
0371 NGC2024 30. 3.9 -14.6 2001/01/04 00:28:44.8 20
0372 NGC2024 30. 13.1 -7.5 2001/01/04 00:29:41.1 20
0374 NGC2024sky 30. 0.0 0.0 2001/01/04 00:36:09.9 2
0375 NGC2024sky 30. 19.4 5.2 2001/01/04 00:37:06.1
0376 NGC2024sky 30. 10.0 17.4 2001/01/04 00:38:02.7
0377 NGC2024sky 30. -5.2 19.4 2001/01/04 00:38:59.1
0378 NGC2024sky 30. -17.4 10.0 2001/01/04 00:39:56.
0379 NGC2024sky 30. -19.4 5.2 2001/01/04 00:40:53.2
0380 NGC2024sky 30. -10.0 -17.4 2001/01/04 00:41:49
0381 NGC2024sky 30. 5.2 -19.4 2001/01/04 00:42:46.0
0382 NGC2024sky 30. 17.4 -10.0 2001/01/04 00:43:42.
0383 NGC2024B 30. 0.0 0.0 2001/01/04 00:49:31.6 200
0384 NGC2024B 30. 14.6 3.9 2001/01/04 00:50:27.8 20
0385 NGC2024B 30. 7.5 13.1 2001/01/04 00:51:24.3 20
0386 NGC2024B 30. -3.9 14.6 2001/01/04 00:52:20.6 2
```

```
0387 NGC2024B 30. -13.1 7.5 2001/01/04 00:53:18.0 20
0388 NGC2024B 30. -14.6 3.9 2001/01/04 00:54:14.7 20
0389 NGC2024B 30. -7.5 -13.1 2001/01/04 00:55:11.1 2
0390 NGC2024B 30. 3.9 -14.6 2001/01/04 00:56:07.7 20
0391 NGC2024B 30. 13.1 -7.5 2001/01/04 00:57:04.3 20
0392 NGC2024C 30. 0.0 0.0 2001/01/04 01:01:45.9 2001
0393 NGC2024C 30. 14.6 3.9 2001/01/04 01:02:42.1 200
0394 NGC2024C 30. 7.5 13.1 2001/01/04 01:03:39.6 200
0395 NGC2024C 30. -3.9 14.6 2001/01/04 01:04:36.6 20
0396 NGC2024C 30. -13.1 7.5 2001/01/04 01:05:33.0 20
0397 NGC2024C 30. -14.6 3.9 2001/01/04 01:06:29.3 20
0398 NGC2024C 30. -7.5 -13.1 2001/01/04 01:07:25.9 2
0399 NGC2024C 30. 3.9 -14.6 2001/01/04 01:08:22.2 20
0400 NGC2024C 30. 13.1 -7.5 2001/01/04 01:09:19.0 20
0401 NGC2024Csky 30. 0.0 0.0 2001/01/04 01:13:31.3 2
0402 NGC2024Csky 30. 14.6 3.9 2001/01/04 01:14:27.8
0403 NGC2024Csky 30. 7.5 13.1 2001/01/04 01:15:24.3
0404 NGC2024Csky 30. -3.9 14.6 2001/01/04 01:16:20.7
0405 NGC2024Csky 30. -13.1 7.5 2001/01/04 01:17:17.1
0406 NGC2024Csky 30. -14.6 3.9 2001/01/04 01:18:14.2
0407 NGC2024Csky 30. -7.5 -13.1 2001/01/04 01:19:10.
0408 NGC2024Csky 30. 3.9 -14.6 2001/01/04 01:20:07.1
0409 NGC2024Csky 30. 13.1 -7.5 2001/01/04 01:21:03.1
0410 NGC2024D 30. 0.0 0.0 2001/01/04 01:24:10.9 2001
0411 NGC2024D 30. 14.6 3.9 2001/01/04 01:25:06.3 200
0412 NGC2024D 30. 7.5 13.1 2001/01/04 01:26:02.3 200
0413 NGC2024D 30. -3.9 14.6 2001/01/04 01:26:59.3 20
0414 NGC2024D 30. -13.1 7.5 2001/01/04 01:27:55.2 20
0415 NGC2024D 30. -14.6 3.9 2001/01/04 01:28:51.7 20
0416 NGC2024D 30. -7.5 -13.1 2001/01/04 01:29:48.0 2
0417 NGC2024D 30. 3.9 -14.6 2001/01/04 01:30:45.1 20
0418 NGC2024D 30. 13.1 -7.5 2001/01/04 01:31:41.6 20
```

Sets of frames were observed in an order of target, sky-bias, target, target, sky-bias, target. Note that a set of a target must be a neighbor of a set of a sky bias, otherwise sirius.py set yields an error message and you can't proceed further.

(4) Execute 'sirius.py para'

(5) Execute 'sirius.py set'

(6) Execute 'sirius.py run'

(7) View the results.

The working directory will be like below.

```
010103.ffiles/  jmflat.fits@  log/          o2.NGC2024B/  o4.NGC2024D/  recom.param
hmflat.fits@    kmflat.fits@  o1.NGC2024/   o3.NGC2024C/  obslog        sirius.param
```

o[integer].[target name] directory will be created for each target, in which resultant files are stored. o[integer] is an index to dinstinguish the target sets. The index is used so that one can register and combine frames from different sets of the same target name separately.

5.3 To process a target observed with multiple sets

One often observes a target with many sets to increase a total integration time. These frames are need to be registered and combined into one frame per band.

A field of CenA was observed with four sets on 2001-01-02.

(1) Make a working directory at the same level as the rawdata directory

(2) Make an obslog file by executing 'mklog.py' in the working directory

(3) Modify the obslog file

```
0067 DARK 30. 0 0
0068 DARK 30. 0 0
0069 DARK 30. 0 0
0070 DARK 30. 0 0
0071 DARK 30. 0 0
0072 DARK 30. 0 0
0073 DARK 30. 0 0
0074 DARK 30. 0 0
0075 DARK 30. 0 0
0076 DARK 30. 0 0
0468 CenA1 30. 0.0 0.0 2001/01/03 02:01:21.0 2001
0469 CenA1 30. 14.6 3.9 2001/01/03 02:02:22.6 200
0470 CenA1 30. 7.5 13.1 2001/01/03 02:03:23.4 200
0471 CenA1 30. -3.9 14.6 2001/01/03 02:04:23.7 20
0472 CenA1 30. -13.1 7.5 2001/01/03 02:05:24.0 20
0473 CenA1 30. -14.6 3.9 2001/01/03 02:06:24.6 20
0474 CenA1 30. -7.5 -13.1 2001/01/03 02:07:27.4 2
0475 CenA1 30. 3.9 -14.6 2001/01/03 02:08:34.0 20
0476 CenA1 30. 13.1 -7.5 2001/01/03 02:09:36.2 20
0477 CenA1sky 30. 0.0 0.0 2001/01/03 02:11:14.0 2
0478 CenA1sky 30. 19.4 5.2 2001/01/03 02:12:13.8
0479 CenA1sky 30. 10.0 17.4 2001/01/03 02:13:14.1
0480 CenA1sky 30. -5.2 19.4 2001/01/03 02:14:14.5
0481 CenA1sky 30. -17.4 10.0 2001/01/03 02:15:14.
0482 CenA1sky 30. -19.4 5.2 2001/01/03 02:16:16.4
0483 CenA1sky 30. -10.0 -17.4 2001/01/03 02:17:15
0484 CenA1sky 30. 5.2 -19.4 2001/01/03 02:18:16.3
0485 CenA1sky 30. 17.4 -10.0 2001/01/03 02:19:16.
0486 CenA2 30. 0.0 0.0 2001/01/03 02:21:01.7 2001
0487 CenA2 30. 14.6 3.9 2001/01/03 02:22:01.7 200
0488 CenA2 30. 7.5 13.1 2001/01/03 02:23:04.5 200
0489 CenA2 30. -3.9 14.6 2001/01/03 02:24:05.0 20
```

```
0490 CenA2 30. -13.1 7.5 2001/01/03 02:25:05.5
0491 CenA2 30. -14.6 3.9 2001/01/03 02:26:06.0
0492 CenA2 30. -7.5 -13.1 2001/01/03 02:27:06.
0493 CenA2 30. 3.9 -14.6 2001/01/03 02:28:06.8
0494 CenA2 30. 13.1 -7.5 2001/01/03 02:29:07.5
0495 CenA2sky 30. 0.0 0.0 2001/01/03 02:31:42.
0496 CenA2sky 30. 19.4 5.2 2001/01/03 02:32:42
0497 CenA2sky 30. 10.0 17.4 2001/01/03 02:33:4
0498 CenA2sky 30. -5.2 19.4 2001/01/03 02:34:4
0499 CenA2sky 30. -17.4 10.0 2001/01/03 02:35:
0500 CenA2sky 30. -19.4 5.2 2001/01/03 02:36:4
0501 CenA2sky 30. -10.0 -17.4 2001/01/03 02:37
0502 CenA2sky 30. 5.2 -19.4 2001/01/03 02:38:4
0503 CenA2sky 30. 17.4 -10.0 2001/01/03 02:39:
0504 CenA3 30. 0.0 0.0 2001/01/03 02:41:23.0 2
0505 CenA3 30. 14.6 3.9 2001/01/03 02:42:24.1
0506 CenA3 30. 7.5 13.1 2001/01/03 02:43:24.8
0507 CenA3 30. -3.9 14.6 2001/01/03 02:44:25.5
0508 CenA3 30. -13.1 7.5 2001/01/03 02:45:26.2
0509 CenA3 30. -14.6 3.9 2001/01/03 02:46:27.1
0510 CenA3 30. -7.5 -13.1 2001/01/03 02:47:29.
0511 CenA3 30. 3.9 -14.6 2001/01/03 02:48:30.6
0512 CenA3 30. 13.1 -7.5 2001/01/03 02:49:32.2
0513 CenA3sky 30. 0.0 0.0 2001/01/03 02:51:38.
0514 CenA3sky 30. 19.4 5.2 2001/01/03 02:52:39
0515 CenA3sky 30. 10.0 17.4 2001/01/03 02:53:4
0516 CenA3sky 30. -5.2 19.4 2001/01/03 02:54:4
0517 CenA3sky 30. -17.4 10.0 2001/01/03 02:55:
0518 CenA3sky 30. -19.4 5.2 2001/01/03 02:56:4
0519 CenA3sky 30. -10.0 -17.4 2001/01/03 02:57
0520 CenA3sky 30. 5.2 -19.4 2001/01/03 02:58:4
0521 CenA3sky 30. 17.4 -10.0 2001/01/03 02:59:
```

(4) Execute 'sirius.py para'

(5) Execute 'sirius.py set'

(6) Execute 'sirius.py run'

(7) View the results.

The working directory is like below.

```
010102.ffiles/  jmflat.fits@  log/        obslog   recom.param
hmflat.fits@    kmflat.fits@  o1.CenA1/   obslog~  sirius.param
```

There is only one resultant directory with a target name, o1.CenA1, in the working directory, because the same field is observed for all CenA1, CenA2, and CenA3. pyIRSF automatically recognises if the same field is observed for different sets based on RA, DEC, RA_OFF, and DEC_OFF in the FITS header of each frame. RA_OFF and DEC_OFF are the offset from the dithering center. If the dithering centers are within 10 arcsec, pyIRSF recognises them to be the same field. Observed sets with the same field and exposure time are registered and combined into a sigle image per band. The target name of the first set will be used in o[integer].[target name].

You can change this default value, 10 arcsec, in recom.param.

You can also combine each set separately by changing a parameter in recom.param, even if they have the same field and exposure time.

5.4 Pairing of a target and a sky-bias set

pyIRSF makes a pair of a target set and a sky-bias set based on the obslog file. The median sky from the sky-bias set is subtracted from each frame in the target set.
I explain the rules of the pairing.

a set of dithering observation

A set of dithering observation is defined as
a set of sequentially observed frames
1. with the same field (having the same dithering center within 10 arcsec)
2. with the same exposure time
3. with the same object name in the FITS header
4. among which the starting times of exposure are within 10 minutes for any seqential two frames
5. such that a frame with (RA_OFF, DEC_OFF) = (0, 0) is always at the first frame of a set.
6. in which no frame has the same (RA_OFF, DEC_OFF) as the others. If a frame having the same (RA_OFF, DEC_OFF) as one of the previous frames appears in a set that satisfies the above criteria, then the frame is the first frame of another new set.

The criterion 1 and 4 are changeable in recom.param.
The criterion 4 is adopted in order not to use sky-bias frames of which sky condition can be different from that for the target frames.
The criterion 5 is adopted because sets of observation can be repeated with an identical object name.
The criterion 6 is adopted so that the end of a set can be detected when the next set does not start with (RA_OFF, DEC_OFF) = (0, 0). A set of frames does not start with (RA_OFF, DEC_OFF) = (0, 0) when the first frame with (RA_OFF, DEC_OFF) = (0, 0) failed.

types of sets of observation

A set has a special meaning when its target name ends with one of the followings: **sky, self, map, std, cset, sset**. I call them as a sky set, a self set, a map set, ... A sky set is a set of sky bias observation and I will explain the others below. A set other than that is a set for pure target observation, which I call an on-target set. The pairing rule depends on the type of sets.

on-target set
If a neighboring set is a sky set, the medain image of frames of the sky set is used for the sky-bias subtraction for the on-target set. If the both neighbors are sky sets, the medain image of frames from the both sets will be the sky-bias image.
The name of object for the neighboring sky set does not need to include the name of the on-target set.
If there is no sky set neighboring to an on-target set, no sky bias frame can be created for the on-taget set. Hence, the pipeline process cannot be carried out for the set.

If there is no sky set for any of on-target sets in the obslog file, **'sirius.py set'** yields an error message of 'No sky for xxx'. **'sirius.py run**' cannot be executed while you recieve this error message.
You need to modify the obslog file to add map or self after the object name so that the target set is adequately paired with a sky bias set, or to delete the lines of the on-taget set if there is no adequate sky set to be paired.

self set
The sky bias image is made from the set of itself. It is so called self sky.

map set
The sky bias image is made from the neighboring sets and the set of itself.

std set
This object name was used for standard stars. The sky bias image is made from the set of itself as well as the self set.

cset, sset
These are used for the magellanic cloud survey observations. No explanation at the moment.

objectskylist

'sirius.py set' yields a text file 'objectskylist' in which results of the pairing of target and sky bias sets are written.
An example of the objectskylist for CenA in 3.3 is shown below.

```
0468-0476 CenA1 0477-0485 sky1
0486-0494 CenA2 0477-0485:0495-0503 sky2
0504-0512 CenA3 0495-0503:0513-0521 sky3
```

The first line denotes that a sky bias image for frames 0468-0476 in a set 'CenA1' is made from frames 0477-0485. The second line denotes that a sky bias image for frames 0486-0494 is made from frames 0477-485 and 0495-0503. objectskylist is read in **'sirius.py run'** process to make sky bias images and sky bias subtraction.

to change the pairing of target and sky bias

You can change the pairing of target and sky bias by modifying the 'objectskylist' file. It is denoted that a sky bias image for a set 'CenA3' is made from frames 0495-0503 and 0513-0521 in the 'objectskylist' above. If you want to use only a set of frames 0495-0503 to make the sky bias image, modify the 'objectskylist' file as following.
':0513-0521' was removed from the third line. Then execute

```
0468-0476 CenA1 0477-0485 sky1
0486-0494 CenA2 0477-0485:0495-0503 sky2
0504-0512 CenA3 0495-0503 sky3
```

sirius.py skyset
Then all the files related to sky-bias process will be updated.
Then, execute **'sirius.py run'** .

5.5 Rules for the image registration and how to change it

By default, all frames from the sets with the same dithering center and exposure time in the obslog file are to be combined to one image for each band by **`'sirius.py run'`** process. It does not matter if the object names are not the same. Besides that, by default, frames with object name ending with 'sky' or 'std' are not combined. I describe how to change these rules.

By modifying dithsetlist

The **`'sirius.py set'`** process makes a text file 'dithsetlist' denoting how to combine frames based on the dithering center, exposure time, and object name.

Here is an example of the obslog file from 2001-01-02.

```
0382 p9109std 20. 0.0 0.0 2001/01/03 00:09:
0383 p9109std 20. 120.0 120.0 2001/01/03 00
0384 p9109std 20. -120.0 120.0 2001/01/03 0
0385 p9109std 20. -120.0 -120.0 2001/01/03
0386 p9109std 20. 120.0 -120.0 2001/01/03 0
0450 omegaCen 5. 0.0 0.0 2001/01/03 01:46:0
0451 omegaCen 5. 14.6 3.9 2001/01/03 01:46:
0452 omegaCen 5. 7.5 13.1 2001/01/03 01:47:
0453 omegaCen 5. -3.9 14.6 2001/01/03 01:47
0454 omegaCen 5. -13.1 7.5 2001/01/03 01:48
0455 omegaCen 5. -14.6 3.9 2001/01/03 01:49
0456 omegaCen 5. -7.5 -13.1 2001/01/03 01:4
0457 omegaCen 5. 3.9 -14.6 2001/01/03 01:50
0458 omegaCen 5. 13.1 -7.5 2001/01/03 01:50
0459 omegaCensky 5. 0.0 0.0 2001/01/03 01:5
0460 omegaCensky 5. 19.4 5.2 2001/01/03 01:
0461 omegaCensky 5. 10.0 17.4 2001/01/03 01
0462 omegaCensky 5. -5.2 19.4 2001/01/03 01
0463 omegaCensky 5. -17.4 10.0 2001/01/03 0
0464 omegaCensky 5. -19.4 5.2 2001/01/03 01
0465 omegaCensky 5. -10.0 -17.4 2001/01/03
0466 omegaCensky 5. 5.2 -19.4 2001/01/03 01
0467 omegaCensky 5. 17.4 -10.0 2001/01/03 0
0468 CenA1 30. 0.0 0.0 2001/01/03 02:01:21.
0469 CenA1 30. 14.6 3.9 2001/01/03 02:02:22
0470 CenA1 30. 7.5 13.1 2001/01/03 02:03:23
0471 CenA1 30. -3.9 14.6 2001/01/03 02:04:2
0472 CenA1 30. -13.1 7.5 2001/01/03 02:05:2
0473 CenA1 30. -14.6 3.9 2001/01/03 02:06:2
0474 CenA1 30. -7.5 -13.1 2001/01/03 02:07:
0475 CenA1 30. 3.9 -14.6 2001/01/03 02:08:3
0476 CenA1 30. 13.1 -7.5 2001/01/03 02:09:3
0477 CenA1sky 30. 0.0 0.0 2001/01/03 02:11:
0478 CenA1sky 30. 19.4 5.2 2001/01/03 02:12
0479 CenA1sky 30. 10.0 17.4 2001/01/03 02:1
0480 CenA1sky 30. -5.2 19.4 2001/01/03 02:1
0481 CenA1sky 30. -17.4 10.0 2001/01/03 02:
0482 CenA1sky 30. -19.4 5.2 2001/01/03 02:1
0483 CenA1sky 30. -10.0 -17.4 2001/01/03 02
0484 CenA1sky 30. 5.2 -19.4 2001/01/03 02:1
0485 CenA1sky 30. 17.4 -10.0 2001/01/03 02:
```

```
0486 CenA2 30. 0.0 0.0 2001/01/03 02:21:01.
0487 CenA2 30. 14.6 3.9 2001/01/03 02:22:01
0488 CenA2 30. 7.5 13.1 2001/01/03 02:23:04
0489 CenA2 30. -3.9 14.6 2001/01/03 02:24:0
0490 CenA2 30. -13.1 7.5 2001/01/03 02:25:0
0491 CenA2 30. -14.6 3.9 2001/01/03 02:26:0
0492 CenA2 30. -7.5 -13.1 2001/01/03 02:27:
0493 CenA2 30. 3.9 -14.6 2001/01/03 02:28:0
0494 CenA2 30. 13.1 -7.5 2001/01/03 02:29:0
0495 CenA2sky 30. 0.0 0.0 2001/01/03 02:31:
0496 CenA2sky 30. 19.4 5.2 2001/01/03 02:32
0497 CenA2sky 30. 10.0 17.4 2001/01/03 02:3
0498 CenA2sky 30. -5.2 19.4 2001/01/03 02:3
0499 CenA2sky 30. -17.4 10.0 2001/01/03 02:
0500 CenA2sky 30. -19.4 5.2 2001/01/03 02:3
0501 CenA2sky 30. -10.0 -17.4 2001/01/03 02
0502 CenA2sky 30. 5.2 -19.4 2001/01/03 02:3
0503 CenA2sky 30. 17.4 -10.0 2001/01/03 02:
0504 CenA3 30. 0.0 0.0 2001/01/03 02:41:23.
0505 CenA3 30. 14.6 3.9 2001/01/03 02:42:24
0506 CenA3 30. 7.5 13.1 2001/01/03 02:43:24
0507 CenA3 30. -3.9 14.6 2001/01/03 02:44:2
0508 CenA3 30. -13.1 7.5 2001/01/03 02:45:2
0509 CenA3 30. -14.6 3.9 2001/01/03 02:46:2
0510 CenA3 30. -7.5 -13.1 2001/01/03 02:47:
0511 CenA3 30. 3.9 -14.6 2001/01/03 02:48:3
0512 CenA3 30. 13.1 -7.5 2001/01/03 02:49:3
0513 CenA3sky 30. 0.0 0.0 2001/01/03 02:51:
0514 CenA3sky 30. 19.4 5.2 2001/01/03 02:52
0515 CenA3sky 30. 10.0 17.4 2001/01/03 02:5
0516 CenA3sky 30. -5.2 19.4 2001/01/03 02:5
0517 CenA3sky 30. -17.4 10.0 2001/01/03 02:
0518 CenA3sky 30. -19.4 5.2 2001/01/03 02:5
0519 CenA3sky 30. -10.0 -17.4 2001/01/03 02
0520 CenA3sky 30. 5.2 -19.4 2001/01/03 02:5
0521 CenA3sky 30. 17.4 -10.0 2001/01/03 02:
```

The lines for dark were omitted.

The obslog file includes sets of a standard star, omegaCen, CenA1-A3 and theoir sky bias fields. The same field was observed for CenA1, A2, and A3.

'sirius.py set' yields a dithsetlist file as below.

```
0 1 p9109std 20 0382 0386
1 2 omegaCen 5 0450 0458
0 3 omegaCensky 5 0459 0467
1 4 CenA1 30 0468 0476
1 4 CenA2 30 0486 0494
1 4 CenA3 30 0504 0512
0 5 CenA1sky 30 0477 0485
0 6 CenA2sky 30 0495 0503
0 7 CenA3sky 30 0513 0521
```

The first column denotes if the set is combined, 1, or not, 0. As described above, frames with object name ending with 'sky' or 'std' are not combined by default.

The second column denotes an ID such that target sets with the same exposure time and field are given the same ID. Because CenA1, CenA2, and CenA3 have the same exposure time and field, ID of 4 is given to them. Object name, exposure time, and starting and ending frame numbers are given in the column 3, 4, 5, 6, respectively.

If you execute '**sirius.py run**' with this dithsetlist file, o1.omegaCen and o2.CenA1 directories will be created in which combine FITS images of [jlhlk]omegaCen.fits and [jlhlk] CenA1.fits are created, respectively.

Now, let's modify the dithsetlist like following.

```
0 1 p9109std 20 0382 0386
1 2 omegaCen 5 0450 0458
1 3 omegaCensky 5 0459 0467
1 4 CenA1 30 0468 0476
1 4 CenA2 30 0486 0494
2 4 CenA3 30 0504 0512
0 5 CenA1sky 30 0477 0485
0 6 CenA2sky 30 0495 0503
0 7 CenA3sky 30 0513 0521
```

The first column for the third line, omegaCensky, was changed to 1, in order to combine the frames. And that for the sixth line, CenA3, was changed to 2, in order to combine the frames separately from those for CenA1 and CenA2.

After editing the dithsetlist file, execute '**sirius.py comset**' .

Then, text files related to registration and recombination are updated.

Then, execute '**sirius.py run**'.

The working directory will be like the following after the process.

```
010102.ffiles/  kmflat.fits@     o2.omegaCen/  obslog      sirius.param
hmflat.fits@    log/             o3.CenA1/     obslog~
jmflat.fits@    o1.omegaCensky/  o4.CenA3/     recom.param
```

If you want to combine each of CenA1, CenA2, and CenA3 separately, change the first column to 2 for their lines.

By modifying sirius.param

You can change the default rules by modifying the sirius.param file before executing '**sirius.py set**'.

Frames for the sky bias sets will be sky-bias-subtracted, registered and combine by changing from 0 to 1 in

`comsky 0   # combine sky frames? 0:no 1:yes`

Target sets with the same exposure time and field are **not** combined into one image per band, if you change from 1 to 0 in

`allcom 1   # combine all the sets with the same field and itime? 0:no 1:yes`

The other parameters in sirius.param will be explained later.

If you change an object name in the dithsetlist file, the corresponding name for the resultant directory and FITS files will be changed accordingly. For example, if you change from CenA1 to CenA in the dithsetlist and proceed the processes, you will obtain o2.CenA directory and [jlhlk] CenA.fits in the directory.

5.6 Some important remarks on obslog

One of the most important points I described so far is that how you edit object names and how you combine sets of observations determine the pipeline process. (It can be modified later by editing objectskylist and dithsetlist, though.)

Followings are some important remarks on how to describe the obslog file. (These include some repetition of what I described before.)

1. The lines are in the ascending order of the frame number.

2. No duplicated lines in the obslog file.

3. An on-target set must have at least one neighboring sky set.

If you have observed a sequence of sets like, target1 - target2 - target3 - sky, please execute the pipeline separately for target1, target2 and target3 while making separate obslog files like

target1 - sky

target2 - sky

target3 - sky .

You may need to set *dtime* with a larger value in sirius.param for target1 and target2, because they were observed much earlier than the sky set was observed. If you receive an error message like 'No sky for target1' , please set dtime so that it includes the starting time of the first frame of target1 set and that of the sky set. See 5.8 more for dtime and sirius.param.

4. The object name for the neighboring sky set does not need to include the name of the on-target set.

The object name can even be just 'sky' for sky sets. The object name does not matter. If as long as a sky set is the neighbor of an on-tagret set and the exposure time per frame is the same and the starting time of the first frame for both the sky and the on-target sets are within an interval of *dtime,* they are considered as a pair of target and sky.

5. By default, all frames from the sets with the same dithering center and exposure time are combined to one image for each band. It does not matter if the object names are not the same.

'with the same dithering center' technically means 'if the dithering centers are within *fldrad* arcsec'. The value of fldrad is defined in sirius.param.

If you want to combine frames separately for each set, please set allcom in sirius.param to 0.

5.7 Preparation of flat correction images

The master flat images are used in the examples so far. The master flat images are, at least, vaild for data from 2000 till 2004 and likely safe within 1% for dat till 2008.
You can also make your flat correction images with mktwflist.py, twfcom.py and corrflat.py programs in pyIRSF. See the details for the section 5.

Put your flat correction images at the working directory before **'sirius.py para'**.
'sirius.py para' recognises FITS files in the working directory as the flat correction files.

5.8 Tuning the pipeline process (1) ~ by editting sirius.param

You can tune the pipeline process by editting sirius.param file created by **'sirius.py para'**.
You need to finish editting it before **'sirius.py set'**.
The following is the sirius.param file with the default value for each parameter. Keyword and value for each parameter are in the first and second columns followed by comments.

```
band jhk    # [j|h|k|jhk]
stop 0   # to stop pipeline after 1:dark+flat 2:sky-subtraction
crremove 0   # cosmic ray removal 0:no 1:min-max method
linear 0   # linearity correction 0:no 1:yes
darkopt 0   # use prepared dark frames? 0:no 1:yes
fix 0   # target frames fixed while observation? 0:no 1:yes
comsky 0   # combine sky frames? 0:no 1:yes
allcom 1   # combine all the sets with the same object name? 0:no 1:yes
dtime 10   # in minutes.
fldrad 10  # in arcsec
cfitsio 1   # use cfitsio library? 0:no 1:yes
keepd 0   # keep dark.fits files? 0:no 1:yes
keeps 0   # keep sky.fits files? 0:no 1:yes
keepm 0   # keep mask.fits files? 0:no 1:yes
```

band : The pipeline processes all the JHK bands by default. You can specify one or two bands to be processed in the lower cases; e.g, j, hk.

stop : The pipeline completes the whole process when this value is 0. When this is 1, the pipeline quits just after the dark subtraction and flat correction processes. When this is 2, the pipeline quits just after the sky bias subtration process.

crremove : No cosmic ray removal is done by default. When this value is 1, the min-max rejection is applied for the imcombine of IRAF when combining the final images.

linear : No linearity correction is done by default. When this value is 1, the linearity correction is applied to the raw data.

darkopt : When necessary sets of dark frames were not observed for a night, you need to prepare averagedly combined FITS files for dark subtraction, e.g., [j|h|k]dark30.fits, made from dark frames of another night. Copy the FITS files to the working directory after **'sirius.py para'**. Then change the value for darkopt to 1.

fix : Change this value to 1, when you reduce data observed without dithering, e.g., transits of exo-planet.

comsky : By default, this value is set to be 0 and sky bias subtraction and registration and recombination are not carried out for frames of sky bias sets. Change this to 1, when you want to reduce the sky bias sets as well. The self sky is applied to the sky subtration.

allcom : By default, target sets with the same exposure time and field are combined into one image per band. If you change this to 0, frames for each set are combined separately.

dtime : This valus is set to be 10 minutes by default. If the interval of the start of exposure between a pair of seqentially obtained frames is longer than this, they will be separated to different sets. Besides, if the interval between the start of exposure of the last frame of a target set and that of the first frame of a sky bias set is longer than this value, they will not be paired for the sky bias subtraction.

fldrad : The pipeline recognises that the same field is observed for two sets, when the dithering center coordinates are within this limit. This valus is set to be 10 arcseconds by default.

cfitsio : Set this value to 0, when you don't have the cfitsio library installed in your computer and have uncompressed FITS files in the rawdata directory. You don't need to uncompress FITS files in the rawdata directory, if you have cfitsio installed.

keepd : Average combined dark images for dark subtraction are removed after the pipeline process by default. If you set this to be 1, they will remain.

keeps : Sky bias images for sky bias subtraction are removed after the pipeline process by default. If you set this to be 1, they will remain.

keepm : Bad pixel mask images are removed after the pipeline process by default. If you set this to be 1, they will remain.

5.9 Tuning the pipeline process (2) ~ by editting recom.param

The recom.param file created by 'sirius.py para' contains parameters for image registration and recombination. You need to finish editting it before 'sirius.py run'.

```
search 20     # search radius
minsep 9      # minimum separation
reject 0      # reject in imcombine [0:sigclip|1:minmax]
ifwhm 3.5     # initial guess of fwhm for daofind
lstarnum 3    # lower limit for the number of matched stars in a field
ufwhm 10      # upper limit for fwhm
uellip 1      # upper limit for ellipticity
urms 0.5      # upper limit for matching rms
mlim 0.1      # upper limit for magnitude error
theta 0       # fov's up position angle in degrees measured unti-clockwise from the north
count 1       # pixel count image [0:no|1:yes]
norot 0       # prohibit rotation while matching? [0:no|1:yes]
commethod 0   # imcombine method [0:average|1:median]
```

search : The pipeline uses the xyxymatch program of IRAF to match stars among two frames. The pipeline tries first the tolarance algorithm in xyxymatch and sets the tolarance parameter to be 5 pixels. The initial guess of shift values in the x and y directions are estimated from RA_ OFF and DEC_OFF values. This works in most cases, especially when processing a single set. However, when you observe multiple sets of a field for a target, telescope pointing gradually deviates from the initial one and RA_OFF and DEC_OFF become unreliable. Consequetly, the macthing can fail with that algorithm and the parameter in such cases. The value set here is applied to the tolarance value when the matching failed. However, the tolarance value can be adjusted to a smaller value than the search value when the average stellar number density is high, because a large tolarance value can lead to a faulse matching. When the tolerance algorithm failed in the matching, the triangle algorithm will be applied. The algorithm of tuning the tolerance parameter will be described somewhere else.

minsep : The separation parameter in the xyxymatch program of IRAF.

reject : The reject parameter in the imcombine program of IRAF. When cosmic rays affect your combined images, try the minmax algorithm by setting this value to be 1.

ifwhm : an initial guess of fwhm for the daofind program in IRAF. The default value is 3.5 pixels. When the seeing size is larger than 6 pixels, set an appropriate value here.

lstarnum : Frames with the number of matched stars less than this value will be not be combined.

ufwhm : Frames with the average FWHM of the stars larger then this value will not be combined.

uellip : Frames with the average ellipticity of the stars larger then this value will not be combined.

urms : If either of xrms or yrms is larger than this value, the frame will not be combined.

mlim : Stars with magnitude errors larger than this value will not be used for the frame registration.

theta : If the Y direction of the image does not match to the north, the image registrtion fails. Give a degree measured counter clockwise from the north.

count : If you set this value to 0, an extended image will not be included in which the pixel value denotes the number of frames with which the average was calculated after rejection of bad pixels.

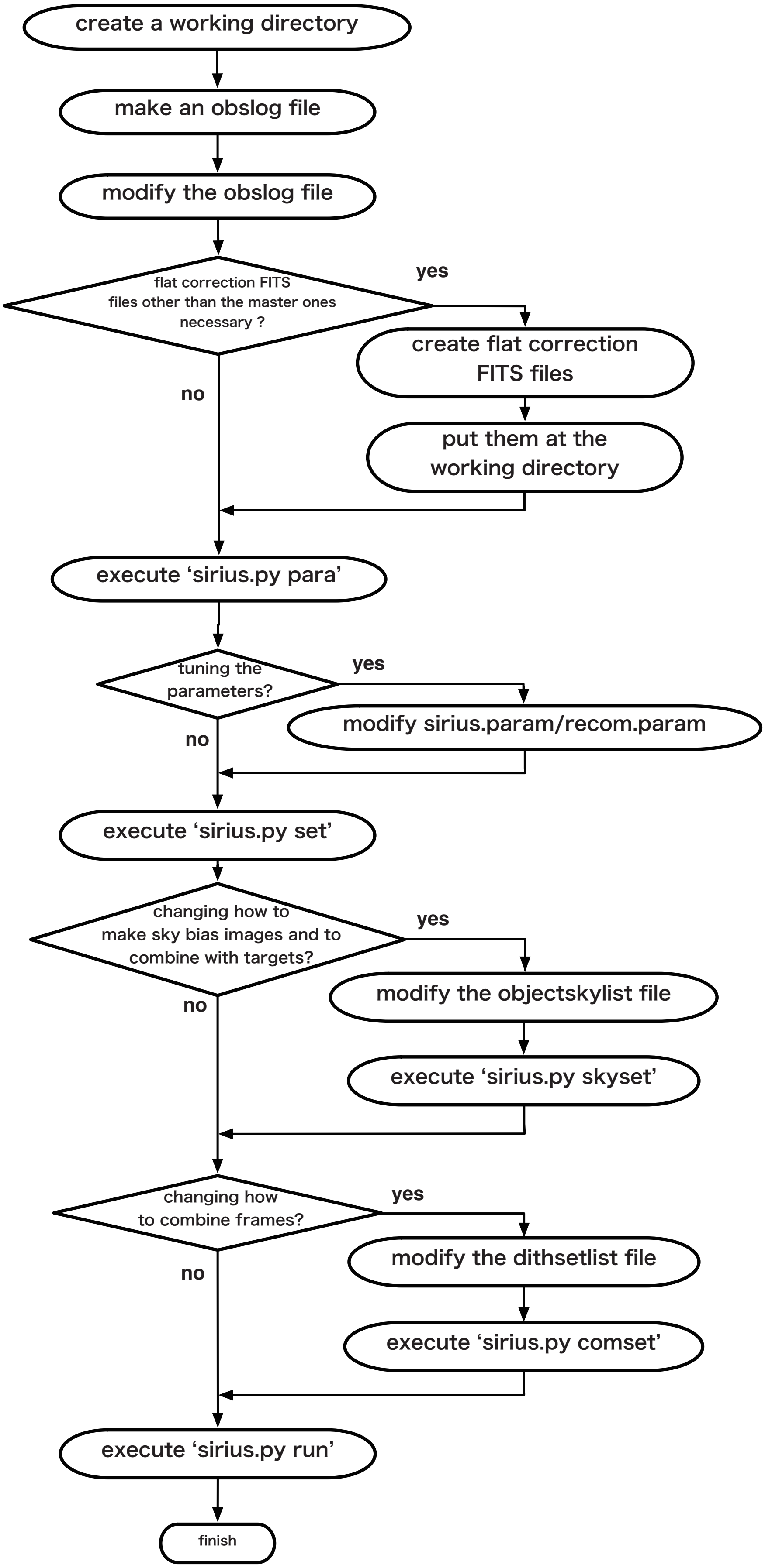
norot : The default value is 0. Rotation is taken into account when image registration registration. If you set this value to 1, rotation is not taken into account and only shift transformation in the x- and y- directions is calculated.

commethod : The defalt value is 0 and dithered images are combined with the average method of iraf.imcombine. 1 for the median method.

5.10 Tuning the pipeline process (3) ~ sirius.py tune

You can adjust the parameters in sirius.param and recom.param from the comand line.
After **`sirius.py para`**, execute
`sirius.py tune` `-`*`parameter=xxx`* .
e.g., sirius.py tune -allcom=0
You can adjust *any* parameters in sirius.param and recom.param, while you can adjust only the parameter band with sirius.py para, e.g., sirius.py para -band=j.

5.11 Summary of the flow



5.12 to execute only registration and recombination ~ imgrecom.py

You can redo the image registration and recombination processes by using **imgrecom.py** and frames stored in yymmdd.ffiles directories, when you retry them with different parameters after failure or you register and recombine frames of a feild observed in different nights.

Case 1 : to process frames from a night ~ the simplest case

In this example, there is a directory, 010102.ffiles, in a directory. There are FITS files after the dark subtraction, flat correction and sky-bias subtraction processes only for a target, omegaCen, of a field,i.e. the same dithering center, and an exposure time. The content of the 010102.ffiles directory is shown below.

```
hf0450.fits  hf0454.fits  hf0458.fits  jf0453.fits  jf0457.fits  kf0452.fits  kf0456.fits
hf0451.fits  hf0455.fits  jf0450.fits  jf0454.fits  jf0458.fits  kf0453.fits  kf0457.fits
hf0452.fits  hf0456.fits  jf0451.fits  jf0455.fits  kf0450.fits  kf0454.fits  kf0458.fits
hf0453.fits  hf0457.fits  jf0452.fits  jf0456.fits  kf0451.fits  kf0455.fits
```

(1) Make a working directory

at the same directory as the yymmdd.ffiles directory.

```
$ ls
010102.ffiles/   wrk/
```

The name of the working directory can be anything.

(2) execute 'imgrecom.py para'

in the working directory and sirius.param and recom.param will be created. If necessary, edit the parameters in these files. sirius.param is shorter than that created by 'sirius.py para', because some of the parameters are not necessary for registration and recombination.

```
band jhk     # [j|h|k|jhk] default jhk
crremove 0   # cosmic ray removal 0:no 1:min-max method
dtime 10   # in minutes.
fldrad 10  # in arcsec
```

(3) execute 'imgrecom.py set'

in the working directory to make a text file, imgrecom.list.

```
1 010102.ffiles 0450 0.0 0.0 1 omegaCen 5.0
1 010102.ffiles 0451 14.6 3.9 1 omegaCen 5.0
1 010102.ffiles 0452 7.5 13.1 1 omegaCen 5.0
1 010102.ffiles 0453 -3.9 14.6 1 omegaCen 5.0
1 010102.ffiles 0454 -13.1 7.5 1 omegaCen 5.0
1 010102.ffiles 0455 -14.6 3.9 1 omegaCen 5.0
1 010102.ffiles 0456 -7.5 -13.1 1 omegaCen 5.0
1 010102.ffiles 0457 3.9 -14.6 1 omegaCen 5.0
1 010102.ffiles 0458 13.1 -7.5 1 omegaCen 5.0
```

The columns denotes field index, yymmdd.ffiles, frame number, ra_off, dec_off, set number, object name, and exposure time. In this example, number in the first column is 1 for all the lines, which indicates that these frames have the same field and exposure time. If you delete lines in this file, the corresponing frame will not be combined.

(4) execute 'imgrecom.py run'

in the working directory. Similar messages as 'sirius.py run' appears on the terminal . This creates combined FITS files and [jlhlk]quality.txt in the working directory.

```
homegaCen.fits  imgrecom.list   jquality.txt    kquality.txt  sirius.param
hquality.txt    jomegaCen.fits  komegaCen.fits  recom.param
```

Case2 : to process frames from a night ~ when yymmdd.ffiles contains multiple targes

imgrecom.py can process one field of a target at a time. However, it often happens that frames for multple targets are included in a yymmdd.ffile directory. It is tedious to remove unnecessary frames from a yymmdd.ffile directory. But you don't have to do that. You can specify a field to combine with a command option of imgrecom.py.

In this example, there are frames for omegaCen and CenA in 010102.ffiles.

(1) Make a working directory

(2) execute 'imgrecom.py para' in the working directory

(3) execute 'imgrecom.py set'

yields a message this time.

```
$ imgrecom.py set
multiple fields are mixed in imgrecom.list.
```

The content of imgrecom.list is shown below.

The field index at the first column includes not only 1 but also 2 and 3 , which indicates that there

```
1 010102.ffiles 0450 0.0 0.0 1 omegaCen 5.0
1 010102.ffiles 0451 14.6 3.9 1 omegaCen 5.0
1 010102.ffiles 0452 7.5 13.1 1 omegaCen 5.0
1 010102.ffiles 0453 -3.9 14.6 1 omegaCen 5.0
1 010102.ffiles 0454 -13.1 7.5 1 omegaCen 5.0
1 010102.ffiles 0455 -14.6 3.9 1 omegaCen 5.0
1 010102.ffiles 0456 -7.5 -13.1 1 omegaCen 5.0
1 010102.ffiles 0457 3.9 -14.6 1 omegaCen 5.0
1 010102.ffiles 0458 13.1 -7.5 1 omegaCen 5.0
2 010102.ffiles 0459 0.0 0.0 2 omegaCensky 5.0
2 010102.ffiles 0460 19.4 5.2 2 omegaCensky 5.
2 010102.ffiles 0461 10.0 17.4 2 omegaCensky 5
2 010102.ffiles 0462 -5.2 19.4 2 omegaCensky 5
2 010102.ffiles 0463 -17.4 10.0 2 omegaCensky
2 010102.ffiles 0464 -19.4 5.2 2 omegaCensky 5
2 010102.ffiles 0465 -10.0 -17.4 2 omegaCensky
2 010102.ffiles 0466 5.2 -19.4 2 omegaCensky 5
2 010102.ffiles 0467 17.4 -10.0 2 omegaCensky
3 010102.ffiles 0468 0.0 0.0 3 CenA1 30.0
3 010102.ffiles 0469 14.6 3.9 3 CenA1 30.0
3 010102.ffiles 0470 7.5 13.1 3 CenA1 30.0
3 010102.ffiles 0471 -3.9 14.6 3 CenA1 30.0
3 010102.ffiles 0472 -13.1 7.5 3 CenA1 30.0
```

```
3 010102.ffiles 0473 -14.6 3.9 3 CenA1 30.0
3 010102.ffiles 0474 -7.5 -13.1 3 CenA1 30.0
3 010102.ffiles 0475 3.9 -14.6 3 CenA1 30.0
3 010102.ffiles 0476 13.1 -7.5 3 CenA1 30.0
3 010102.ffiles 0486 0.0 0.0 4 CenA2 30.0
3 010102.ffiles 0487 14.6 3.9 4 CenA2 30.0
3 010102.ffiles 0488 7.5 13.1 4 CenA2 30.0
3 010102.ffiles 0489 -3.9 14.6 4 CenA2 30.0
3 010102.ffiles 0490 -13.1 7.5 4 CenA2 30.0
3 010102.ffiles 0491 -14.6 3.9 4 CenA2 30.0
3 010102.ffiles 0492 -7.5 -13.1 4 CenA2 30.0
3 010102.ffiles 0493 3.9 -14.6 4 CenA2 30.0
3 010102.ffiles 0494 13.1 -7.5 4 CenA2 30.0
3 010102.ffiles 0504 0.0 0.0 5 CenA3 30.0
3 010102.ffiles 0505 14.6 3.9 5 CenA3 30.0
3 010102.ffiles 0506 7.5 13.1 5 CenA3 30.0
3 010102.ffiles 0507 -3.9 14.6 5 CenA3 30.0
3 010102.ffiles 0508 -13.1 7.5 5 CenA3 30.0
3 010102.ffiles 0509 -14.6 3.9 5 CenA3 30.0
3 010102.ffiles 0510 -7.5 -13.1 5 CenA3 30.0
3 010102.ffiles 0511 3.9 -14.6 5 CenA3 30.0
3 010102.ffiles 0512 13.1 -7.5 5 CenA3 30.0
```

are frames for three fields.

(4) execute 'imgrecom.py run [field index]'

You can specify a field to regoster and combine by adding a field index at the end of the command. In this example, if you want to register and combine omegaCen, execute

```
$ imgrecom.py run 1
```

Then lines with the field index of 1 are extracted from the list and their frames are processed.

Alternatively, you can remove the lines for the other fields than that you want to register and combine from imgrecom.list by your hand, then execute just 'imgrecom.py run'.

Case 3 : to process frames from multiple nights

Here is an example to combine frames for a field of 30Dor from 050701 and 050703. They have been processed with sirius.py and there are 050701.ffiles and 050703.ffiles somewhere.

(1) Make a working directory

(2) Create a symbolic link of each yymmdd.ffiles to the working directory

(or copy yymmdd.ffiles to the working directory)

(3) Make another working directory at the same directory as yymmdd.ffiles

```
$ ls
050701.ffiles@    050703.ffiles@     mywrk/
```

(4) execute 'imgrecom.py para' in the working directory at the same level as yymmdd.ffiles, 'mywrk' this example .

(5) execute 'imgrecom.py set' in the same directory

An imgrecom.list file will be created.

```
1 050701.ffiles 2137 0.0 0.0 1 30Dorn2 5.0
1 050701.ffiles 2138 19.4 5.2 1 30Dorn2 5.0
1 050701.ffiles 2139 11.4 16.4 1 30Dorn2 5.0
1 050701.ffiles 2140 -0.2 19.8 1 30Dorn2 5.0
1 050701.ffiles 2141 -14.2 14.2 1 30Dorn2 5.0
1 050701.ffiles 2142 -19.8 0.2 1 30Dorn2 5.0
1 050701.ffiles 2143 -16.4 -11.4 1 30Dorn2 5.0
1 050701.ffiles 2144 -5.2 -19.4 1 30Dorn2 5.0
1 050701.ffiles 2145 8.4 -18.2 1 30Dorn2 5.0
1 050701.ffiles 2146 18.2 -8.4 1 30Dorn2 5.0
2 050701.ffiles 2157 0.0 0.0 2 30Dorn3 30.0
2 050701.ffiles 2158 19.4 5.2 2 30Dorn3 30.0
2 050701.ffiles 2159 11.4 16.4 2 30Dorn3 30.0
2 050701.ffiles 2160 -0.2 19.8 2 30Dorn3 30.0
2 050701.ffiles 2161 -14.2 14.2 2 30Dorn3 30.0
2 050701.ffiles 2162 -19.8 0.2 2 30Dorn3 30.0
2 050701.ffiles 2163 -16.4 -11.4 2 30Dorn3 30.0
2 050701.ffiles 2164 -5.2 -19.4 2 30Dorn3 30.0
2 050701.ffiles 2165 8.4 -18.2 2 30Dorn3 30.0
2 050701.ffiles 2166 18.2 -8.4 2 30Dorn3 30.0
```

```
1 050703.ffiles 1714 0.0 0.0 3 30Dorn1 5.0
1 050703.ffiles 1715 19.4 5.2 3 30Dorn1 5.0
1 050703.ffiles 1716 11.4 16.4 3 30Dorn1 5.0
1 050703.ffiles 1717 -0.2 19.8 3 30Dorn1 5.0
1 050703.ffiles 1718 -14.2 14.2 3 30Dorn1 5.0
1 050703.ffiles 1719 -19.8 0.2 3 30Dorn1 5.0
1 050703.ffiles 1720 -16.4 -11.4 3 30Dorn1 5.0
1 050703.ffiles 1721 -5.2 -19.4 3 30Dorn1 5.0
1 050703.ffiles 1722 8.4 -18.2 3 30Dorn1 5.0
1 050703.ffiles 1723 18.2 -8.4 3 30Dorn1 5.0
1 050703.ffiles 1734 0.0 0.0 4 30Dorn2 5.0
1 050703.ffiles 1735 19.4 5.2 4 30Dorn2 5.0
1 050703.ffiles 1736 11.4 16.4 4 30Dorn2 5.0
1 050703.ffiles 1737 -0.2 19.8 4 30Dorn2 5.0
1 050703.ffiles 1738 -14.2 14.2 4 30Dorn2 5.0
1 050703.ffiles 1739 -19.8 0.2 4 30Dorn2 5.0
1 050703.ffiles 1740 -16.4 -11.4 4 30Dorn2 5.0
1 050703.ffiles 1741 -5.2 -19.4 4 30Dorn2 5.0
1 050703.ffiles 1742 8.4 -18.2 4 30Dorn2 5.0
1 050703.ffiles 1743 18.2 -8.4 4 30Dorn2 5.0
```

There are frames with a exposure time of 30 second in 050701.ffiles in this example, which are distinguished from frames with 5 second exposure time and a field index of 2 is assigned.

Even if there are frames with the same frame number, frames from different nights are distinguished and you don't need to alter the file name by your hand.

(6) execute 'imgrecom.py run [field index]'

To combine frames for 30 dor with 5 second exposure time, execute

```
$ imgrecom.py run 1
```

When there is only one number in the field index column, you can omit the option for the field index in the command.

[other options]

imgrecom.py set -object=[string] -itime=[float]

-object=[string] : This option selects frames whose object name starting with the string to make imgrecom.list. This is case insensitive. *example : imgrecom.py set -object=M42*

-itime=[float] : This option selects frames whose exposure time equals to the value to make imgrecom.list. *example : imgrecom.py set -itime=5*

imgrecom.py para -band=[j|h|k]

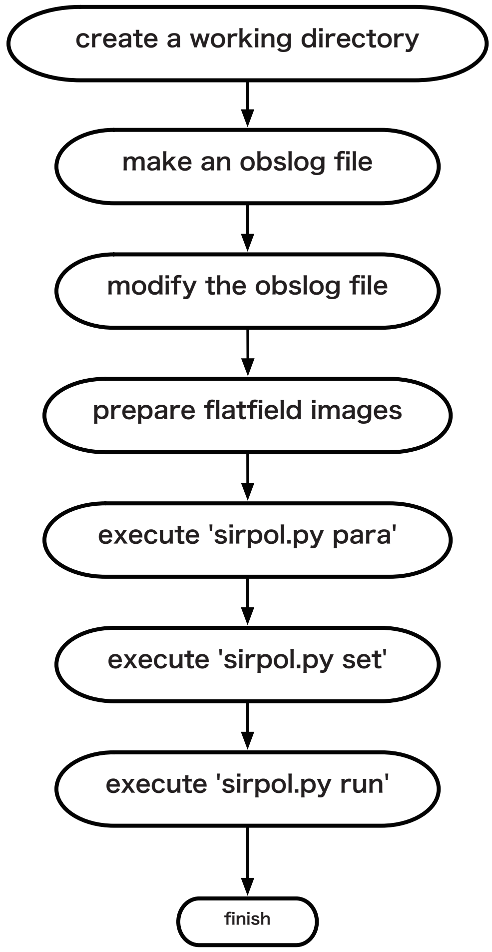
You can specify a band to process. Alternatively, you can edit the first line in sirius.param after executing 'imgrecom.py para' without the option.

6. SIRPOL data reduction

6.1 The simplest case

The flow of data reduction is like the following in the simplest case.

Many parts in this section are common with the section 5 for SIRIUS. This redundancy is not eliminated so that SIRPOL users don't have to read the section 5. However, repeating the sections 5.4, 5.5, 5.6 and 5.8 is too redundant. Read these sections when necessary.



Master flatfield images for SIRPOL are not built-in in the pyIRSF package. If you execute 'sirpol.py para' without any flatfield FITS files in the working directory, the master flatfield images for SIRIUS will be linked to the working directory. These are not supposed to be used for the SIRPOL data reductions, because the polarizer and the wave plates also affect the multiplicative gain correction. However, the SIRPOL pipeline does not prevent the master flatfield images and using the master flatfield images are an easy choice for quick look reductions.

Here is an example to reduce a linear polarimetry observation of M42 on 051226.

```
$ pwd
/data/051226/
$ ls
rawdata/
```

There is 'rawdata' directory in '051226' directory in accordance with the SIRIUS standard directory structure. The first thing to do is

(1) to make a working directory at the same level as the rawdata directory.

The name of the working directory can be anything. ('wrk' in this example.)

(2) to make an obslog file by executing 'mklog.py' in the working directory.

All commands are carried out at shell command lines. IRAF is used just as a library. PyRAF is an interface to connect IRAF and python.

This is carrried out at a shell command line instead of IRAF nor PyRAF.

```
$ ls
rawdata/  wrk/
$ cd wrk
$ mklog.py
$ ls
obslog
```

'obslog' is a text file, which contains frame number, object name, exposure time, dithering offset values, and etc. for each frame. mklog.py reads the header of rawdata FITS files to make this.

At this moment, we want to reduce only M42 therefore, we need

mklog.py -object=M42_n1 does this automatically. See the detailes in section 4.

(3) to modify the obslog file

with a text editor to remove unnecessary lines.

This night, 'M42_n1' and 'M42_n1sky', a sky bias field for M42_n1, were observed with an exposure time of 10 seconds for frames 0291-0330 and 0331-0370, respectively.

A set of 10 second dark frames were obtained for frames 1491-1500, which are necessary to process the above set of 'M42_n1'.

The 'obslog' file will be like the below.

```
FRAME OBJECT ITIME RA_OFF DEC_OFF DATE_UTC T
0291 M42_n1 10. 0.0 0.0 2005-12-26 19:55:46.
0292 M42_n1 10. 0.0 0.0 2005-12-26 19:56:01.
0293 M42_n1 10. 0.0 0.0 2005-12-26 19:56:17.
0294 M42_n1 10. 0.0 0.0 2005-12-26 19:56:32.
0295 M42_n1 10. 14.6 3.9 2005-12-26 19:56:51
0296 M42_n1 10. 14.6 3.9 2005-12-26 19:57:06
0297 M42_n1 10. 14.6 3.9 2005-12-26 19:57:22
0298 M42_n1 10. 14.6 3.9 2005-12-26 19:57:37
0299 M42_n1 10. 8.6 12.3 2005-12-26 19:57:56
0300 M42_n1 10. 8.6 12.3 2005-12-26 19:58:11
0301 M42_n1 10. 8.6 12.3 2005-12-26 19:58:27
0302 M42_n1 10. 8.6 12.3 2005-12-26 19:58:42
0303 M42_n1 10. -0.1 14.8 2005-12-26 19:59:0
0304 M42_n1 10. -0.1 14.8 2005-12-26 19:59:1
0305 M42_n1 10. -0.1 14.8 2005-12-26 19:59:3
0306 M42_n1 10. -0.1 14.8 2005-12-26 19:59:4
0307 M42_n1 10. -10.7 10.7 2005-12-26 20:00:
0308 M42_n1 10. -10.7 10.7 2005-12-26 20:00:
0309 M42_n1 10. -10.7 10.7 2005-12-26 20:00:
0310 M42_n1 10. -10.7 10.7 2005-12-26 20:00:
0311 M42_n1 10. -14.8 0.1 2005-12-26 20:01:1
0312 M42_n1 10. -14.8 0.1 2005-12-26 20:01:2
0313 M42_n1 10. -14.8 0.1 2005-12-26 20:01:4
0314 M42_n1 10. -14.8 0.1 2005-12-26 20:01:5
0315 M42_n1 10. -12.3 -8.6 2005-12-26 20:02:
0316 M42_n1 10. -12.3 -8.6 2005-12-26 20:02:
0317 M42_n1 10. -12.3 -8.6 2005-12-26 20:02:
0318 M42_n1 10. -12.3 -8.6 2005-12-26 20:03:
0319 M42_n1 10. -3.9 -14.6 2005-12-26 20:03:
0320 M42_n1 10. -3.9 -14.6 2005-12-26 20:03:
0321 M42_n1 10. -3.9 -14.6 2005-12-26 20:03:
0322 M42_n1 10. -3.9 -14.6 2005-12-26 20:04:
0323 M42_n1 10. 6.3 -13.7 2005-12-26 20:04:2
0324 M42_n1 10. 6.3 -13.7 2005-12-26 20:04:4
0325 M42_n1 10. 6.3 -13.7 2005-12-26 20:04:5
0326 M42_n1 10. 6.3 -13.7 2005-12-26 20:05:1
0327 M42_n1 10. 13.7 -6.3 2005-12-26 20:05:3
0328 M42_n1 10. 13.7 -6.3 2005-12-26 20:05:4
0329 M42_n1 10. 13.7 -6.3 2005-12-26 20:06:0
0330 M42_n1 10. 13.7 -6.3 2005-12-26 20:06:1
0331 M42_n1sky 10. 0.0 0.0 2005-12-26 20:13:
0332 M42_n1sky 10. 0.0 0.0 2005-12-26 20:13:
0333 M42_n1sky 10. 0.0 0.0 2005-12-26 20:13:
0334 M42_n1sky 10. 0.0 0.0 2005-12-26 20:14:
0335 M42_n1sky 10. 29.1 7.8 2005-12-26 20:14
```

```
0336 M42_n1sky 10. 29.1 7.8 2005-12-26 20:14
0337 M42_n1sky 10. 29.1 7.8 2005-12-26 20:14
0338 M42_n1sky 10. 29.1 7.8 2005-12-26 20:15
0339 M42_n1sky 10. 17.1 24.6 2005-12-26 20:1
0340 M42_n1sky 10. 17.1 24.6 2005-12-26 20:1
0341 M42_n1sky 10. 17.1 24.6 2005-12-26 20:1
0342 M42_n1sky 10. 17.1 24.6 2005-12-26 20:1
0343 M42_n1sky 10. -0.3 29.7 2005-12-26 20:1
0344 M42_n1sky 10. -0.3 29.7 2005-12-26 20:1
0345 M42_n1sky 10. -0.3 29.7 2005-12-26 20:1
0346 M42_n1sky 10. -0.3 29.7 2005-12-26 20:1
0347 M42_n1sky 10. -21.3 21.3 2005-12-26 20:
0348 M42_n1sky 10. -21.3 21.3 2005-12-26 20:
0349 M42_n1sky 10. -21.3 21.3 2005-12-26 20:
0350 M42_n1sky 10. -21.3 21.3 2005-12-26 20:
0351 M42_n1sky 10. -29.7 0.3 2005-12-26 20:1
0352 M42_n1sky 10. -29.7 0.3 2005-12-26 20:1
0353 M42_n1sky 10. -29.7 0.3 2005-12-26 20:1
0354 M42_n1sky 10. -29.7 0.3 2005-12-26 20:1
0355 M42_n1sky 10. -24.6 -17.1 2005-12-26 20
0356 M42_n1sky 10. -24.6 -17.1 2005-12-26 20
0357 M42_n1sky 10. -24.6 -17.1 2005-12-26 20
0358 M42_n1sky 10. -24.6 -17.1 2005-12-26 20
0359 M42_n1sky 10. -7.8 -29.1 2005-12-26 20:
0360 M42_n1sky 10. -7.8 -29.1 2005-12-26 20:
0361 M42_n1sky 10. -7.8 -29.1 2005-12-26 20:
0362 M42_n1sky 10. -7.8 -29.1 2005-12-26 20:
0363 M42_n1sky 10. 12.6 -27.3 2005-12-26 20:
0364 M42_n1sky 10. 12.6 -27.3 2005-12-26 20:
0365 M42_n1sky 10. 12.6 -27.3 2005-12-26 20:
0366 M42_n1sky 10. 12.6 -27.3 2005-12-26 20:
0367 M42_n1sky 10. 27.3 -12.6 2005-12-26 20:
0368 M42_n1sky 10. 27.3 -12.6 2005-12-26 20:
0369 M42_n1sky 10. 27.3 -12.6 2005-12-26 20:
0370 M42_n1sky 10. 27.3 -12.6 2005-12-26 20:
1491 DARK 10. 0 0
1492 DARK 10. 0 0
1493 DARK 10. 0 0
1494 DARK 10. 0 0
1495 DARK 10. 0 0
1496 DARK 10. 0 0
1497 DARK 10. 0 0
1498 DARK 10. 0 0
1499 DARK 10. 0 0
1500 DARK 10. 0 0
```

Note that a set of a target, 0291-0330 in this example, must be a neighbor of a set of a sky bias. If the object name ends with 'sky', regardless of the lower or upper cases, the set is recognised to be a set of a sky bias for the adjacent target set(s). The same rule as SIRIUS is adopted for SIRPOL. See the details for section 5.4.

(4) Prepare flatfield images and put them in the working directory.

Flatfield images for SIRPOL are available for some periods at the SIRPOL team web page:

http://esppro.mtk.nao.ac.jp/SIRPOL/calibration.html

In this example, I download [jlhlk]twfJan06.fits from the link and put them in the working directory.

Alternatively, you can make your own flatfield images from twilight sky data observed with SIRPOL using mktwflist.py and twfcom.py. See the details for section 3.2.

(5) Execute 'sirpol.py para' in the working directory.

```
$ ls
htwfJan06.fits  jtwfJan06.fits  ktwfJan06.fits  obslog
$ sirpol.py para
yymmdd is 051226
user-parepared flat frames have been detected.
twfname is twfJan06
$ls
htwfJan06.fits  ktwfJan06.fits  recom.param
jtwfJan06.fits  obslog          sirpol.param
```

FITS frames in the working directory were recognised as flatfield images. If there are FITS files in the working directory and their names starts with j, h, and k and they have a common part in the file names other than the first letter and the extension, sirpol.para recognises them as flatfield images. The common part is displayed as 'twfname is ... '.

recom.param and sirius.param are files to adjust parameters for the pipeline. No need to edit them this time.

(6) Execute 'sirpol.py set' in the working directory.

```
$ sirpol.py set
```

This will create necessary files for the following process.

(7) Execute 'sirpol.py run' in the working directory.

This will start the pipeline process. Messages will appear on the terminal.

```
dark frames ...  have been created
dark subtraction and flat division ...  done
making sky bias frames and bad pixel masks ...  done.
masking ...  done
sky subtraction ...  done

*****************
o1.M42_n1
*****************
j-band
yymmdd.fnum  fwhm ellip snum  median stddev
051226.0291   3.5  0.29  138    92.9   31.0
051226.0292   3.6  0.21  125    79.0   33.0
051226.0293   3.2  0.21  117    79.7   32.6
051226.0294   3.4  0.24   88    76.8   33.1
```

... skip ...

```
051226.0325    1       94  -0.02 0.13 0.12 -0.00   0.3   0.3
051226.0326    1      102  -0.02 0.12 0.09  0.00  -0.1   0.4
051226.0327    1       75   0.02 0.17 0.14  0.00  -0.3  -0.4
051226.0328    1       73   0.02 0.16 0.16  0.00  -0.3   0.1
051226.0329    1       84   0.02 0.14 0.15  0.00  -0.4  -0.3
051226.0330    1       81  -0.00 0.11 0.13  0.00  -0.5  -0.7
10% 20% 30% 40% 50% 60% 70% 80% 90% 100% done
making i,q,u,v images for each cycle  q  u  i  done
combining i q u a00 a22 a45 a67 done

done

done
```

(8) View the results.

After the pipeline process, the working directory is like the following.

```
051226.ffiles/  jtwfJan06.fits  log/        obslog   recom.param
htwfJan06.fits  ktwfJan06.fits  o1.M42_n1/  obslog~  sirpol.param
```

The combined images are in o1.M42_n1 directory.

```
ha00M42_n1.fits  hquality.txt     jiM42_n1.fits    ka45M42_n1.fits
ha22M42_n1.fits  huM42_n1.fits    jqM42_n1.fits    ka67M42_n1.fits
ha45M42_n1.fits  ja00M42_n1.fits  jquality.txt     kiM42_n1.fits
ha67M42_n1.fits  ja22M42_n1.fits  juM42_n1.fits    kqM42_n1.fits
hiM42_n1.fits    ja45M42_n1.fits  ka00M42_n1.fits  kquality.txt
hqM42_n1.fits    ja67M42_n1.fits  ka22M42_n1.fits  kuM42_n1.fits
```

They are averagedly combined images of frames after dark subtraction, flat correction, sky bias subtraction, and image registration for

[jlhlk]i[object].fits : Stokes parameter I

[jlhlk]q[object].fits : Stokes parameter Q

[jlhlk]u[object].fits : Stokes parameter U

[jlhlk]a00[object].fits : wave plate angle of 0 degree

[jlhlk]a22[object].fits : wave plate angle of 22.5 degree

[jlhlk]a45[object].fits : wave plate angle of 45 degree

[jlhlk]a67[object].fits : wave plate angle of 67.5 degree

The combined I, Q, U images are not made from the combined 0, 22.5, 45, 67.5 degree images. Differential images of i = [i(0) + i(45) + i(22.5) + i(67.5)] /2, q = i(0) - i(45) and u = i(22.5) - i(67.5) are made for each cycle of wave plate rotation. The i, q and u images are averagedly combined to make the final I, Q, and U images. Subtraction within each cycle mitigates the affects of atmospheric variation on photometry and yields a better subtraction of sky-bias.

Let's take a look at one of the combined frames with ds9.

```
$  ds9 jiM42_n1.fits
```

Select File > Display Headers to see the FITS header.

NAXIS1 and NAXIS2 are larger than 1024, because of dithering. Lines for OBJECT to HUMIDITY, including UT/LT and airmass, are for the first frame of the set.

The last 4 lines include the output from the pipeline.

NCOMBINE : the number of frames combined

COMMETHO : the combine method used for iraf.imcombine, although this is fixed to 'average'.

COMAREA : A square area all the frames would have been combined, if all 1024 x 1024 pixels were alive.

REJECT : the reject method used for iraf.imcombine

Another image is included in this FITS file.

```
$  ds9 jiM42_n1.fits[1]
```

The pixel value denotes the number of frames with which the average was calculated after rejection of bad pixels.

Notice that the magnitude zero point is different among the areas with different number of this value when it is not a photometric night.

Besides the FITS files, text files are also stored in this resultant directory.

[jlhlk]quality.txt record the average of fwhm, ellipticity of stars and the median and standard deviation of background level and etc. for each individual frames before combination which were displayed on the terminal during the pipeline process.

fwhm, ellip : the average of fwhm and ellipticity of the detected stars on the frame. fwhm and ellipticity are measured with the psfmeasure program of IRAF.

snum : the number of stars detected. The detection threshold of the daofind program of IRAF is

fixed through a set, which is determined so that the number of stars does not exceed 150 on the first frame.
median, stddev : the median and standard deviation of the background.
good : If all the conditions specified in recom.param, e.g., the number of matched stars and the fwhm value, are satisfied, it is set to be 1. If it is 1, the frame is included in the final combined image. If it is 0, the frame is rejected.
matched : The number of stars matched between each frame and the first frame.
dmag : the difference of magnitude zero point between each frame and the first frame. This is estimated by calculating the median of the magnitude difference of matched stars: magnitude (the first frame) - magnitude(each frame).
xrms, yrms : the residuals of the coordinate transformation fit between each frame and the first frame by the geomap program of IRAF. these are measured in pixels.
rot : the rotation degree relative to the first frame
dx, dy : deviation of the actual relative shift to the first frame from the dithering offset values. These are measured in pixels.

yymmdd.ffiles, 051226.ffiles in this example, directory will be created in the working directory after the pipeline process. There are dark subtracted, flat corrected and sky bias subtracted frames in the directory. They are named as [jlhlk]fnnnn.fits, here nnnn is a 4-digit number. They are ready for image registration and combination.
These frames are stored so that you are able to check the quality of each frames, or to redo the image registration and combination with different parameters, or to carry out image registration and combination of frames from different nights.

log directory will be found in the working directory, too. There are **[jlhlk]skybg.list** in the directory. The medain of the background is recorded for each sky bias frame in these files.

6.2 To process multiple targets

Let's see an example of processing data of two targets; 30Dor_n1 and M1_1 on 2005-12-28. The flow is the same as the previous example.

(1) Make a working directory at the same level as the rawdata directory.

(2) Make an obslog file by executing 'mklog.py' in the working directory.

(3) Modify the obslog file.

Delete lines other than those for 0121-0200, 30Dor_n1 and its sky bias field, 0201-0280, M1 and its sky bias field, and 0983-0992, 20 second dark frames.

```
FRAME OBJECT ITIME RA_OFF DEC_OFF DATE_UT
0121 30Dor_n1 20. 0.0 0.0 2005-12-28 20:3
0122 30Dor_n1 20. 0.0 0.0 2005-12-28 20:3
0123 30Dor_n1 20. 0.0 0.0 2005-12-28 20:3
0124 30Dor_n1 20. 0.0 0.0 2005-12-28 20:3
0125 30Dor_n1 20. 14.6 3.9 2005-12-28 20:
0126 30Dor_n1 20. 14.6 3.9 2005-12-28 20:
0127 30Dor_n1 20. 14.6 3.9 2005-12-28 20:
0128 30Dor_n1 20. 14.6 3.9 2005-12-28 20:
0129 30Dor_n1 20. 8.6 12.3 2005-12-28 20:
0130 30Dor_n1 20. 8.6 12.3 2005-12-28 20:
0131 30Dor_n1 20. 8.6 12.3 2005-12-28 20:
0132 30Dor_n1 20. 8.6 12.3 2005-12-28 20:
0133 30Dor_n1 20. -0.1 14.8 2005-12-28 20
0134 30Dor_n1 20. -0.1 14.8 2005-12-28 20
0135 30Dor_n1 20. -0.1 14.8 2005-12-28 20
0136 30Dor_n1 20. -0.1 14.8 2005-12-28 20
0137 30Dor_n1 20. -10.7 10.7 2005-12-28 2
0138 30Dor_n1 20. -10.7 10.7 2005-12-28 2
0139 30Dor_n1 20. -10.7 10.7 2005-12-28 2
0140 30Dor_n1 20. -10.7 10.7 2005-12-28 2
0141 30Dor_n1 20. -14.8 0.1 2005-12-28 20
0142 30Dor_n1 20. -14.8 0.1 2005-12-28 20
0143 30Dor_n1 20. -14.8 0.1 2005-12-28 20
0144 30Dor_n1 20. -14.8 0.1 2005-12-28 20
0145 30Dor_n1 20. -12.3 -8.6 2005-12-28 2
0146 30Dor_n1 20. -12.3 -8.6 2005-12-28 2
0147 30Dor_n1 20. -12.3 -8.6 2005-12-28 2
0148 30Dor_n1 20. -12.3 -8.6 2005-12-28 2
0149 30Dor_n1 20. -3.9 -14.6 2005-12-28 2
0150 30Dor_n1 20. -3.9 -14.6 2005-12-28 2
0151 30Dor_n1 20. -3.9 -14.6 2005-12-28 2
0152 30Dor_n1 20. -3.9 -14.6 2005-12-28 2
0153 30Dor_n1 20. 6.3 -13.7 2005-12-28 20
0154 30Dor_n1 20. 6.3 -13.7 2005-12-28 20
0155 30Dor_n1 20. 6.3 -13.7 2005-12-28 20
0156 30Dor_n1 20. 6.3 -13.7 2005-12-28 20
0157 30Dor_n1 20. 13.7 -6.3 2005-12-28 20
0158 30Dor_n1 20. 13.7 -6.3 2005-12-28 20
0159 30Dor_n1 20. 13.7 -6.3 2005-12-28 20
0160 30Dor_n1 20. 13.7 -6.3 2005-12-28 20
0161 30Dor_n1sky 20. 0.0 0.0 2005-12-28 2
0162 30Dor_n1sky 20. 0.0 0.0 2005-12-28 2
0163 30Dor_n1sky 20. 0.0 0.0 2005-12-28 2
0164 30Dor_n1sky 20. 0.0 0.0 2005-12-28 2
0165 30Dor_n1sky 20. 29.1 7.8 2005-12-28
0166 30Dor_n1sky 20. 29.1 7.8 2005-12-28
0167 30Dor_n1sky 20. 29.1 7.8 2005-12-28
0168 30Dor_n1sky 20. 29.1 7.8 2005-12-28
0169 30Dor_n1sky 20. 17.1 24.6 2005-12-28
0170 30Dor_n1sky 20. 17.1 24.6 2005-12-28
0171 30Dor_n1sky 20. 17.1 24.6 2005-12-28
```

... skipping here ...

... skipping here ...

```
0237 M1_1 20. 13.7 -6.3 2005-12-28 21:47:0
0238 M1_1 20. 13.7 -6.3 2005-12-28 21:47:3
0239 M1_1 20. 13.7 -6.3 2005-12-28 21:47:5
0240 M1_1 20. 13.7 -6.3 2005-12-28 21:48:2
0241 M1_1sky 20. 0.0 0.0 2005-12-28 21:49:
0242 M1_1sky 20. 0.0 0.0 2005-12-28 21:49:
0243 M1_1sky 20. 0.0 0.0 2005-12-28 21:49:
0244 M1_1sky 20. 0.0 0.0 2005-12-28 21:50:
0245 M1_1sky 20. 29.1 7.8 2005-12-28 21:50
0246 M1_1sky 20. 29.1 7.8 2005-12-28 21:51
0247 M1_1sky 20. 29.1 7.8 2005-12-28 21:51
0248 M1_1sky 20. 29.1 7.8 2005-12-28 21:52
0249 M1_1sky 20. 17.1 24.6 2005-12-28 21:5
0250 M1_1sky 20. 17.1 24.6 2005-12-28 21:5
0251 M1_1sky 20. 17.1 24.6 2005-12-28 21:5
0252 M1_1sky 20. 17.1 24.6 2005-12-28 21:5
0253 M1_1sky 20. -0.3 29.7 2005-12-28 21:5
0254 M1_1sky 20. -0.3 29.7 2005-12-28 21:5
0255 M1_1sky 20. -0.3 29.7 2005-12-28 21:5
0256 M1_1sky 20. -0.3 29.7 2005-12-28 21:5
0257 M1_1sky 20. -21.3 21.3 2005-12-28 21:
0258 M1_1sky 20. -21.3 21.3 2005-12-28 21:
0259 M1_1sky 20. -21.3 21.3 2005-12-28 21:
0260 M1_1sky 20. -21.3 21.3 2005-12-28 21:
0261 M1_1sky 20. -29.7 0.3 2005-12-28 21:5
0262 M1_1sky 20. -29.7 0.3 2005-12-28 21:5
0263 M1_1sky 20. -29.7 0.3 2005-12-28 21:5
0264 M1_1sky 20. -29.7 0.3 2005-12-28 21:5
0265 M1_1sky 20. -24.6 -17.1 2005-12-28 21
0266 M1_1sky 20. -24.6 -17.1 2005-12-28 22
0267 M1_1sky 20. -24.6 -17.1 2005-12-28 22
0268 M1_1sky 20. -24.6 -17.1 2005-12-28 22
0269 M1_1sky 20. -7.8 -29.1 2005-12-28 22:
0270 M1_1sky 20. -7.8 -29.1 2005-12-28 22:
0271 M1_1sky 20. -7.8 -29.1 2005-12-28 22:
0272 M1_1sky 20. -7.8 -29.1 2005-12-28 22:
0273 M1_1sky 20. 12.6 -27.3 2005-12-28 22:
0274 M1_1sky 20. 12.6 -27.3 2005-12-28 22:
0275 M1_1sky 20. 12.6 -27.3 2005-12-28 22:
0276 M1_1sky 20. 12.6 -27.3 2005-12-28 22:
0277 M1_1sky 20. 27.3 -12.6 2005-12-28 22:
0278 M1_1sky 20. 27.3 -12.6 2005-12-28 22:
0279 M1_1sky 20. 27.3 -12.6 2005-12-28 22:
0280 M1_1sky 20. 27.3 -12.6 2005-12-28 22:
0983 DARK 20. 0 0
0984 DARK 20. 0 0
0985 DARK 20. 0 0
0986 DARK 20. 0 0
0987 DARK 20. 0 0
0988 DARK 20. 0 0
0989 DARK 20. 0 0
0990 DARK 20. 0 0
0991 DARK 20. 0 0
0992 DARK 20. 0 0
```

Sets of frames were observed in an order of target, sky-bias, target, target, sky-bias. Note that a set of frames for a target must be a neighbor of a set of frames for a sky bias, otherwise **`sirpol.py set`** yields an error message and you can't proceed further.

(4) Prepare flatfield images and put them in the working directory.

(5) Execute 'sirpol.py para'

(6) Execute 'sirpol.py set'

(7) Execute 'sirpol.py run'

(8) View the results.

The working directory will be like below.

o[integer].[target name] directory will be created for each target, in which resultant files are

```
051228.ffiles/    ktwfLP06Jun.fits  o2.M1_1/   recom/
htwfLP06Jun.fits  log/              obslog     recom.param
jtwfLP06Jun.fits  o1.30Dor_n1/      obslog~    sirpol.param
```

stored. o[integer] is an index to dinstinguish the target sets. The index is used so that one can register and combine frames from different sets of the same target name separately.

6.3 To process a target observed with multiple sets

One often observes a target with many sets to increase a total integration time. These frames are need to be registered and combined into one frame per band.

Here is an example that a field of M42 was observed with four sets on 2005-12-26.

(1) Make a working directory at the same level as the rawdata directory

(2) Make an obslog file by executing 'mklog.py' in the working directory

(3) Modify the obslog file

```
FRAME OBJECT ITIME RA_OFF DEC_OFF DATE_
0291 M42_n1 10. 0.0 0.0 2005-12-26 19:5
0292 M42_n1 10. 0.0 0.0 2005-12-26 19:5
0293 M42_n1 10. 0.0 0.0 2005-12-26 19:5
0294 M42_n1 10. 0.0 0.0 2005-12-26 19:5
0295 M42_n1 10. 14.6 3.9 2005-12-26 19:
0296 M42_n1 10. 14.6 3.9 2005-12-26 19:
0297 M42_n1 10. 14.6 3.9 2005-12-26 19:
0298 M42_n1 10. 14.6 3.9 2005-12-26 19:
0299 M42_n1 10. 8.6 12.3 2005-12-26 19:
0300 M42_n1 10. 8.6 12.3 2005-12-26 19:
0301 M42_n1 10. 8.6 12.3 2005-12-26 19:
0302 M42_n1 10. 8.6 12.3 2005-12-26 19:
0303 M42_n1 10. -0.1 14.8 2005-12-26 19
0304 M42_n1 10. -0.1 14.8 2005-12-26 19
0305 M42_n1 10. -0.1 14.8 2005-12-26 19
0306 M42_n1 10. -0.1 14.8 2005-12-26 19
0307 M42_n1 10. -10.7 10.7 2005-12-26 2
0308 M42_n1 10. -10.7 10.7 2005-12-26 2
0309 M42_n1 10. -10.7 10.7 2005-12-26 2
0310 M42_n1 10. -10.7 10.7 2005-12-26 2
0311 M42_n1 10. -14.8 0.1 2005-12-26 20
0312 M42_n1 10. -14.8 0.1 2005-12-26 20
0313 M42_n1 10. -14.8 0.1 2005-12-26 20
0314 M42_n1 10. -14.8 0.1 2005-12-26 20
0315 M42_n1 10. -12.3 -8.6 2005-12-26 2
0316 M42_n1 10. -12.3 -8.6 2005-12-26 2
0317 M42_n1 10. -12.3 -8.6 2005-12-26 2
0318 M42_n1 10. -12.3 -8.6 2005-12-26 2
0319 M42_n1 10. -3.9 -14.6 2005-12-26 2
0320 M42_n1 10. -3.9 -14.6 2005-12-26 2
0321 M42_n1 10. -3.9 -14.6 2005-12-26 2
0322 M42_n1 10. -3.9 -14.6 2005-12-26 2
0323 M42_n1 10. 6.3 -13.7 2005-12-26 20
0324 M42_n1 10. 6.3 -13.7 2005-12-26 20
0325 M42_n1 10. 6.3 -13.7 2005-12-26 20
0326 M42_n1 10. 6.3 -13.7 2005-12-26 20
0327 M42_n1 10. 13.7 -6.3 2005-12-26 20
0328 M42_n1 10. 13.7 -6.3 2005-12-26 20
0329 M42_n1 10. 13.7 -6.3 2005-12-26 20
0330 M42_n1 10. 13.7 -6.3 2005-12-26 20
0331 M42_n1sky 10. 0.0 0.0 2005-12-26 2
0332 M42_n1sky 10. 0.0 0.0 2005-12-26 2
0333 M42_n1sky 10. 0.0 0.0 2005-12-26 2
0334 M42_n1sky 10. 0.0 0.0 2005-12-26 2
0335 M42_n1sky 10. 29.1 7.8 2005-12-26
0336 M42_n1sky 10. 29.1 7.8 2005-12-26
0337 M42_n1sky 10. 29.1 7.8 2005-12-26
0338 M42_n1sky 10. 29.1 7.8 2005-12-26
0339 M42_n1sky 10. 17.1 24.6 2005-12-26
0340 M42_n1sky 10. 17.1 24.6 2005-12-26
0341 M42_n1sky 10. 17.1 24.6 2005-12-26
0342 M42_n1sky 10. 17.1 24.6 2005-12-26
0343 M42_n1sky 10. -0.3 29.7 2005-12-26
```

... skipping here ...

```
0486 M42_n3sky 10. 12.6 -27.3 2005-12-2
0487 M42_n3sky 10. 27.3 -12.6 2005-12-2
0488 M42_n3sky 10. 27.3 -12.6 2005-12-2
0489 M42_n3sky 10. 27.3 -12.6 2005-12-2
0490 M42_n3sky 10. 27.3 -12.6 2005-12-2
0491 M42_n4 10. 0.0 0.0 2005-12-26 21:0
0492 M42_n4 10. 0.0 0.0 2005-12-26 21:0
0493 M42_n4 10. 0.0 0.0 2005-12-26 21:0
0494 M42_n4 10. 0.0 0.0 2005-12-26 21:0
0495 M42_n4 10. 14.6 3.9 2005-12-26 21:
0496 M42_n4 10. 14.6 3.9 2005-12-26 21:
0497 M42_n4 10. 14.6 3.9 2005-12-26 21:
0498 M42_n4 10. 14.6 3.9 2005-12-26 21:
0499 M42_n4 10. 8.6 12.3 2005-12-26 21:
0500 M42_n4 10. 8.6 12.3 2005-12-26 21:
0501 M42_n4 10. 8.6 12.3 2005-12-26 21:
0502 M42_n4 10. 8.6 12.3 2005-12-26 21:
0503 M42_n4 10. -0.1 14.8 2005-12-26 21
0504 M42_n4 10. -0.1 14.8 2005-12-26 21
0505 M42_n4 10. -0.1 14.8 2005-12-26 21
0506 M42_n4 10. -0.1 14.8 2005-12-26 21
0507 M42_n4 10. -10.7 10.7 2005-12-26 2
0508 M42_n4 10. -10.7 10.7 2005-12-26 2
0509 M42_n4 10. -10.7 10.7 2005-12-26 2
0510 M42_n4 10. -10.7 10.7 2005-12-26 2
0511 M42_n4 10. -14.8 0.1 2005-12-26 21
0512 M42_n4 10. -14.8 0.1 2005-12-26 21
0513 M42_n4 10. -14.8 0.1 2005-12-26 21
0514 M42_n4 10. -14.8 0.1 2005-12-26 21
0515 M42_n4 10. -12.3 -8.6 2005-12-26 2
0516 M42_n4 10. -12.3 -8.6 2005-12-26 2
0517 M42_n4 10. -12.3 -8.6 2005-12-26 2
0518 M42_n4 10. -12.3 -8.6 2005-12-26 2
0519 M42_n4 10. -3.9 -14.6 2005-12-26 2
0520 M42_n4 10. -3.9 -14.6 2005-12-26 2
0521 M42_n4 10. -3.9 -14.6 2005-12-26 2
0522 M42_n4 10. -3.9 -14.6 2005-12-26 2
0523 M42_n4 10. 6.3 -13.7 2005-12-26 21
0524 M42_n4 10. 6.3 -13.7 2005-12-26 21
0525 M42_n4 10. 6.3 -13.7 2005-12-26 21
0526 M42_n4 10. 6.3 -13.7 2005-12-26 21
0527 M42_n4 10. 13.7 -6.3 2005-12-26 21
0528 M42_n4 10. 13.7 -6.3 2005-12-26 21
0529 M42_n4 10. 13.7 -6.3 2005-12-26 21
0530 M42_n4 10. 13.7 -6.3 2005-12-26 21
0531 M42_n5 10. 0.0 0.0 2005-12-26 21:1
0532 M42_n5 10. 0.0 0.0 2005-12-26 21:1
0533 M42_n5 10. 0.0 0.0 2005-12-26 21:1
0534 M42_n5 10. 0.0 0.0 2005-12-26 21:1
0535 M42_n5 10. 14.6 3.9 2005-12-26 21:
0536 M42_n5 10. 14.6 3.9 2005-12-26 21:
0537 M42_n5 10. 14.6 3.9 2005-12-26 21:
0538 M42_n5 10. 14.6 3.9 2005-12-26 21:
```

... skipping here ...

```
0807 M42_n9 10. 13.7 -6.3 2005-12-26 22:3
0808 M42_n9 10. 13.7 -6.3 2005-12-26 22:3
0809 M42_n9 10. 13.7 -6.3 2005-12-26 22:3
0810 M42_n9 10. 13.7 -6.3 2005-12-26 22:3
0811 M42_n9sky 10. 0.0 0.0 2005-12-26 22:
0812 M42_n9sky 10. 0.0 0.0 2005-12-26 22:
0813 M42_n9sky 10. 0.0 0.0 2005-12-26 22:
0814 M42_n9sky 10. 0.0 0.0 2005-12-26 22:
0815 M42_n9sky 10. 29.1 7.8 2005-12-26 22
0816 M42_n9sky 10. 29.1 7.8 2005-12-26 22
0817 M42_n9sky 10. 29.1 7.8 2005-12-26 22
0818 M42_n9sky 10. 29.1 7.8 2005-12-26 22
0819 M42_n9sky 10. 17.1 24.6 2005-12-26 2
0820 M42_n9sky 10. 17.1 24.6 2005-12-26 2
0821 M42_n9sky 10. 17.1 24.6 2005-12-26 2
0822 M42_n9sky 10. 17.1 24.6 2005-12-26 2
0823 M42_n9sky 10. -0.3 29.7 2005-12-26 2
0824 M42_n9sky 10. -0.3 29.7 2005-12-26 2
0825 M42_n9sky 10. -0.3 29.7 2005-12-26 2
0826 M42_n9sky 10. -0.3 29.7 2005-12-26 2
0827 M42_n9sky 10. -21.3 21.3 2005-12-26
0828 M42_n9sky 10. -21.3 21.3 2005-12-26
0829 M42_n9sky 10. -21.3 21.3 2005-12-26
0830 M42_n9sky 10. -21.3 21.3 2005-12-26
0831 M42_n9sky 10. -29.7 0.3 2005-12-26 2
0832 M42_n9sky 10. -29.7 0.3 2005-12-26 2
0833 M42_n9sky 10. -29.7 0.3 2005-12-26 2
0834 M42_n9sky 10. -29.7 0.3 2005-12-26 2
0835 M42_n9sky 10. -24.6 -17.1 2005-12-26
0836 M42_n9sky 10. -24.6 -17.1 2005-12-26
0837 M42_n9sky 10. -24.6 -17.1 2005-12-26
0838 M42_n9sky 10. -24.6 -17.1 2005-12-26
0839 M42_n9sky 10. -7.8 -29.1 2005-12-26
0840 M42_n9sky 10. -7.8 -29.1 2005-12-26
0841 M42_n9sky 10. -7.8 -29.1 2005-12-26
0842 M42_n9sky 10. -7.8 -29.1 2005-12-26
0843 M42_n9sky 10. 12.6 -27.3 2005-12-26
0844 M42_n9sky 10. 12.6 -27.3 2005-12-26
0845 M42_n9sky 10. 12.6 -27.3 2005-12-26
0846 M42_n9sky 10. 12.6 -27.3 2005-12-26
0847 M42_n9sky 10. 27.3 -12.6 2005-12-26
0848 M42_n9sky 10. 27.3 -12.6 2005-12-26
0849 M42_n9sky 10. 27.3 -12.6 2005-12-26
0850 M42_n9sky 10. 27.3 -12.6 2005-12-26
1491 DARK 10. 0 0
1492 DARK 10. 0 0
1493 DARK 10. 0 0
1494 DARK 10. 0 0
1495 DARK 10. 0 0
1496 DARK 10. 0 0
1497 DARK 10. 0 0
1498 DARK 10. 0 0
1499 DARK 10. 0 0
1500 DARK 10. 0 0
```

... skipping here ...

... skipping here ...

(4) Prepare flatfield images and put them in the working directory.

(5) Execute 'sirpol.py para'

(6) Execute 'sirpol.py set'

(7) Execute 'sirpol.py run'

(8) View the results.

```
051226.ffiles/  jtwfJan06.fits  log/         obslog   recom.param
htwfJan06.fits  ktwfJan06.fits  o1.M42_n1/   obslog~  sirpol.param
```

There is only one resultant directory with a target name, o1.M42_n1, in the working directory, because the same field is observed for all M42_n1 ~ n9. pyIRSF automatically recognises if the same field is observed for different sets based on RA, DEC, RA_OFF, and DEC_OFF in the FITS header of each frame. RA_OFF and DEC_OFF are the offset from the dithering center. If the dithering centers are within 10 arcsec, pyIRSF recognises them to be the same field. Observed sets with the same field and exposure time are registered and combined into a sigle image per band. The target name of the first set will be used in o[integer].[target name].

6.4 Pairing of a target and a sky-bias set

pyIRSF makes a pair of a target set and a sky-bias set based on the obslog file. The median sky from the sky-bias set is subtracted from each frame in the target set.
The rules of the pairing is the same for SIRIUS and SIRPOL. Please refer the section 5.4 about the rule and replace **`sirius.py`** with **`sirpol.py`** when using SIRPOL data.

6.5 Rules for the image registration and how to change it

By default, all frames from the sets with the same dithering center and exposure time in the obslog file are to be combined to one image for each band by **`'sirpol.py run'`** process. It does not matter if the object names are not the same. Besides that, by default, frames with object name ending with 'sky' or 'std' are not combined.
Again, the rules for the image registration is the same for SIRIUS and SIRPOL. Please refer the section 5.5 about the rule and replace **`sirius.py`** with **`sirpol.py`** when using SIRPOL data.

6.6 Some important remarks on obslog

One of the most important points I described so far is that how you edit object names and how you combine sets of observations determine the pipeline process. (It can be modified later by editing objectskylist and dithsetlist, though.)

Some important remarks on how to describe the obslog file is described in 5.6.

6.6 Tuning the pipeline process (1) ~ by editting sirpol.param

Many parameters are common with sirius.param. polmode and fiim~f135im are uniue in sirpol.param.

You can tune the pipeline process by editting sirius.param file created by **'sirpol.py para'**. You need to finish editting it before **'sirpol.py set'**.

The following is the sirpol.param file with the default value for each parameter. Keyword and value for each parameter are in the first and second columns followed by comments.

```
band jhk   # [j|h|k|all]
stop 0   # to stop pipeline after 1:dark+flat 2:sky-subtraction
crremove 0   # cosmic ray removal 0:no 1::min-max
linear 0   # linearity correction 0:no 1:yes
darkopt 0   # use prepared dark frames? 0:no 1:yes
fix 0   # target frames fixed while observation? 0:no 1:yes
comsky 0   # combine sky frames? 0:no 1:yes
allcom 1   # combine all the sets with the same field and itime? 0:no 1:yes
polmode 1 # 1:LP, 2:CP2, 3:CP4
dtime 10   # in minutes.
fldrad 10  # in arcsec
cfitsio 1   # use cfitsio library? 0:no 1:yes
fiim 1 # make I image? 0:no 1:yes
fqim 1 # make Q image? 0:no 1:yes
fuim 1 # make U image? 0:no 1:yes
fvim 1 # make V image? 0:no 1:yes
f00im 1 # make 0deg image? 0:no 1:yes
f22im 1 # make 22.5deg image? 0:no 1:yes
f45im 1 # make 45deg image? 0:no 1:yes
f67im 1 # make 67.5deg image? 0:no 1:yes
f90im 1 # make 90deg image? 0:no 1:yes
f135im 1 # make 135deg image? 0:no 1:yes
keepd 0   # keep dark.fits files? 0:no 1:yes
keeps 0   # keep sky.fits files? 0:no 1:yes
keepm 0   # keep mask.fits files? 0:no 1:yes
```

band : The pipeline processes all the JHK bands by default. You can specify one or two bands to be processed in the lower cases; e.g, j, hk.

stop : The pipeline completes the whole process when this value is 0. When this is 1, the pipeline quits just after the dark subtraction and flat correction processes. When this is 2, the pipeline quits just after the sky bias subtration process.

crremove : No cosmic ray removal is done by default. When this value is 1, the min-max rejection is applied for the imcombine of IRAF when combining the final images.

linear : No linearity correction is done by default. When this value is 1, the linearity correction is applied to the raw data.

darkopt : When necessary sets of dark frames were not observed for a night, you need to prepare averagedly combined FITS files for dark subtraction, e.g., [j|h|k]dark30.fits, made from dark frames of another night. Copy the FITS files to the working directory after **'sirpol.py para'**. Then change the value for darkopt to 1.

fix : Change this value to 1, when you reduce data observed without dithering, e.g., transits of exo-planet.

comsky : By default, this value is set to be 0 and sky bias subtraction and registration and recombination are not carried out for frames of sky bias sets. Change this to 1, when you want to reduce the sky bias sets as well. The self sky is applied to the sky subtration.

allcom : By default, target sets with the same exposure time and field are combined into one image per band. If you change this to 0, frames for each set are combined separately.

polmode : Select 1 for the linear polarimetry, 2 for the two points circulatr polarimetry, 3 for the four points polarimetry

dtime : This valus is set to be 10 minutes by default. If the interval of the start of exposure between a pair of seqentially obtained frames is longer than this, they will be separated to different sets. Besides, if the interval between the start of exposure of the last frame of a target set and that of the first frame of a sky bias set is longer than this value, they will not be paired for the sky bias subtraction.

fldrad : The pipeline recognises that the same field is observed for two sets, when the dithering center coordinates are within this limit. This valus is set to be 10 arcseconds by default.

cfitsio : Set this value to 0, when you don't have the cfitsio library installed in your computer and have uncompressed FITS files in the rawdata directory. You don't need to uncompress FITS files in the rawdata directory, if you have cfitsio installed.

fiim : Creating the combined I image ? 0 for No, 1 for Yes.
fqim : Creating the combined Q image ? 0 for No, 1 for Yes.
fuim : Creating the combined U image ? 0 for No, 1 for Yes.
fvim : Creating the combined V image ? 0 for No, 1 for Yes.
fpim : Creating the combined PI image ? 0 for No, 1 for Yes.
f00im : Creating the combined 0 degree image ? 0 for No, 1 for Yes.
f22im : Creating the combined 22.5 degree image ? 0 for No, 1 for Yes.
f45im : Creating the combined 45 degree image ? 0 for No, 1 for Yes.
f67im : Creating the combined 67.5 degree image ? 0 for No, 1 for Yes.
f90im : Creating the combined 90 degree image ? 0 for No, 1 for Yes.
f135im : Creating the combined 135 degree image ? 0 for No, 1 for Yes.

If your polarimetry mode is not relevant to the specified images, it will be just ignored. For example, if you set fvim == 1 or f90im == 1 or f135im == 1 when your polarimetry mode is the linear polarimetry, they are just ignored.

keepd : Average combined dark images for dark subtraction are removed after the pipeline process by default. If you set this to be 1, they will remain.

keeps : Sky bias images for sky bias subtraction are removed after the pipeline process by default. If you set this to be 1, they will remain.

keepm : Bad pixel mask images are removed after the pipeline process by default. If you set this to be 1, they will remain.

6.7 Tuning the pipeline process (2) ~ by editting recom.param

The recom.param file created by '**`sirpol.py para`**' contains parameters for image registration and recombination. You need to finish editting it before '**`sirpol.py run`**'.
Please refer the section 5.8 about how to set the parameters.

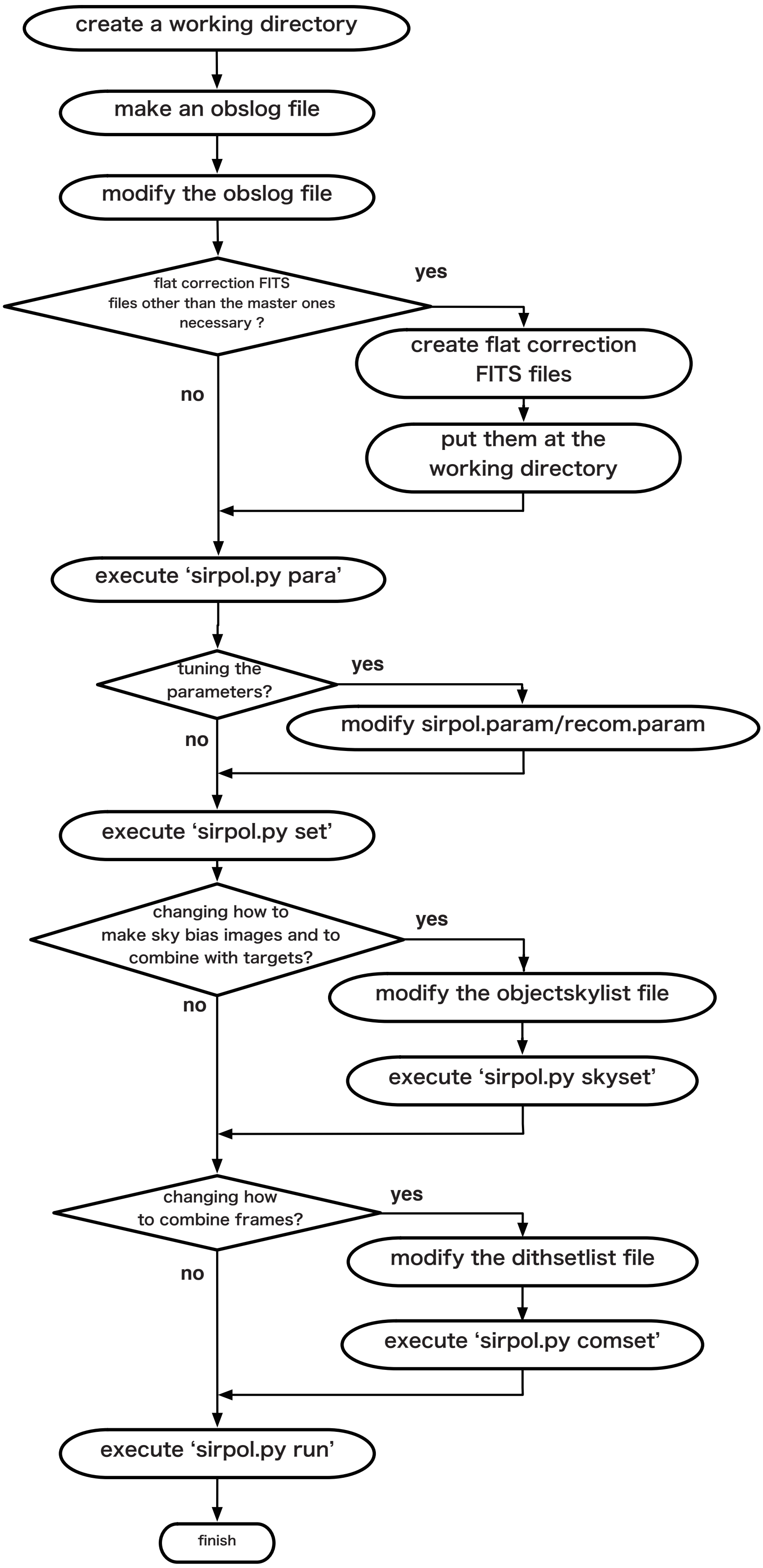
6.8 Tuning the pipeline process (3) ~ sirpol.py tune

You can adjust the parameters in sirpol.param and recom.param from the comand line.
After sirpol.py para, execute
`sirpol.py tune -`*`parameter=xxx`* .
e.g., sirpol.py tune -allcom=0
You can adjust any parameters in sirpol.param and recom.param, while you can adjust only the parameter band with sirpol.py para, e.g., sirpol.py para -band=j.

6.9 to execute only registration and recombination ~ polrecom.py

You can redo the image registration and recombination processes by using **polrecom.py** and frames stored in yymmdd.ffiles directories, when you retry them with different parameters after failure or you register and recombine frames of a feild observed in different nights. How to use **polrecom.py** is the same as **imgrecom.py** except that you need to replace imgrecom.py with polrecom.py, imgrecom.list with polrecom.list, and sirius.py with sirpol.py in section 5.10.

6.9 Summary of the flow



7. Quick look photometry and wcs

7.1 sirphot.py

This carries out apeture photometry for combined FITS images created with pyIRSF programs. This is a combination of daofind, apphot, and psfmeasure programs of IRAF. This is just a rough photometry. Careful inspection of point source selection or technics like aperture correction are not applied. Magnitude is not calibrated. Just a fixed typical zero magnitude value is applied for each band's magnitude caliculation.

usage : sirphot.py [filename] -fwhm=[float] -thresh=[float] -aprad=[float]

```
$ sirphot.py jM42_n1.fits
```

This yields a text file jsirphot.txt containing x, y coordinates, magnitude and its error from iraf. apphot, fwhm and ellipcitiy from iraf.psfmeasure for each point sources.

```
757.9 10.6 12.222 0.006 4.120 0.32
321.4 23.3 12.288 0.006 3.698 0.44
328.8 23.4 12.931 0.012 INDEF INDEF
220.8 29.5 15.151 0.064 3.518 0.32
129.8 46.4 14.793 0.037 3.652 0.22
344.8 50.8 11.802 0.003 INDEF INDEF
401.1 51.5 13.270 0.021 3.592 0.32
338.3 54.0 11.157 0.002 3.512 0.38
366.6 56.9 15.599 0.108 3.108 0.30
524.5 57.3 13.782 0.024 3.346 0.52
974.6 56.8 14.314 0.023 3.744 0.14
950.4 61.8 13.615 0.012 3.800 0.13
281.7 67.3 15.174 0.060 INDEF INDEF
240.6 71.0 14.330 0.034 3.358 0.18
271.7 72.3 12.195 0.004 3.452 0.13
494.3 72.6 12.785 0.007 3.484 0.02
365.3 73.9 13.341 0.016 3.572 0.22
416.9 74.5 14.949 0.108 INDEF INDEF
315.5 75.6 12.869 0.006 3.534 0.06
461.3 90.2 14.034 0.037 INDEF INDEF
362.5 96.4 14.194 0.039 INDEF INDEF
```

This does not process the three band's images at once. You need to repeat this for each band.

Options :

-ifwhm=[float] : This is the initial guess of stellar fwhm used in daofind. The default value is 3 pixels. When the size of fwhm is larger than 6, you may want to specify a rough value here.

-thresh=[float] : This value is used for iraf.daofind.datapars.threshold. The default value is 10.

-aprad=[float] : An aperture radius in pixels put into iraf.apphot.photpars.apertures. The default values is the resultant fwhm obtained with iraf,psfmeasure.

INDEF is found for fwhm and ellipticity, column 5 and 6, for some lines. This happens when the central coordinates obtained with iraf.psfmeasure is shifted from that obtained with iraf.apphot by more than the fwhm value of the field, which implies the fwhm was not measured correctly for the star and possibly it is not a star.

7.2 sirwcs2.py

The former version sirwcs.py used the OPM program for catalog matching. But this version uses iraf.ccxymatch. Also, some algorithms have been improved.

This program carries out aperture photometry, by using sirphot.py, and compares the results with the 2MASS catalog to transform the (x, y) coordinates to (RA, Dec) coordinates, and to calibrate the J, H, Ks magnitudes roughly, and to put the wcs information into the combined image FITS files.

This is also a quick look analisys. Be careful when you use this result for your paper.

usage : sirwcs2.py filename.fits -jhk -fwhm=[float] -thresh=[float] -aprad=[float] -noget2mass

To use this, the computer needs to be connected to the internet.

```
$  sirwcs2.py  jM42_n1.fits
```

This will yeild [jlhlk]sirphotwcs.txt in the same directory.

```
5:35:24.64 -5:19:09.5 12.588 0.006 757.9 10.6
5:35:11.38 -5:19:12.2 12.654 0.006 321.4 23.3
5:35:11.61 -5:19:12.3 13.297 0.012 328.8 23.4
5:35:08.33 -5:19:14.3 15.517 0.064 220.8 29.5
5:35:05.56 -5:19:21.3 15.159 0.037 129.8 46.4
5:35:12.08 -5:19:24.8 12.168 0.003 344.8 50.8
5:35:13.79 -5:19:25.5 13.636 0.021 401.1 51.5
5:35:11.88 -5:19:26.2 11.523 0.002 338.3 54.0
5:35:12.74 -5:19:27.7 15.965 0.108 366.6 56.9
5:35:17.53 -5:19:29.0 14.148 0.024 524.5 57.3
5:35:31.20 -5:19:32.0 14.680 0.023 974.6 56.8
5:35:30.46 -5:19:34.1 13.982 0.012 950.4 61.8
5:35:10.16 -5:19:31.8 15.540 0.060 281.7 67.3
5:35:08.91 -5:19:33.2 14.697 0.034 240.6 71.0
5:35:09.85 -5:19:34.0 12.561 0.004 271.7 72.3
5:35:16.61 -5:19:35.7 13.151 0.007 494.3 72.6
```

The columns denote RA, Dec, magnitude and its error, and (x, y) coordinates.
A part of the 2MASS catalog corresponding to the field will be downloaded and be compared to the photometry result by sirphot.py. Then RA and DEC will be calculated for each point sources and the median of the magnitude diffrence of matched stars will be calculated to calibrate the magnitude of all the stars listed.

Also, the FITS file will have wcs information in the header.

Options :
-fwhm=[float], -thresh=[float] , and -aprad=[float] are the same for sirphot.py.
-jhk : to process all the three bands at once. For example,
$ sirwcs2.py jM42_n1.fits -jhk

-noget2mass : If you have already downloaded the 2MASS catalog for the field, 2mass.out, you may want to use this option not to download it again. This is helpful when you redo the matching with changing parameters like -fwhm or -thresh.