Baches Spectrograph Calibration and Reduction with MIBAS - Midas Iraf Baader Astronomy Suite

v1.0

Contents

1 Overview

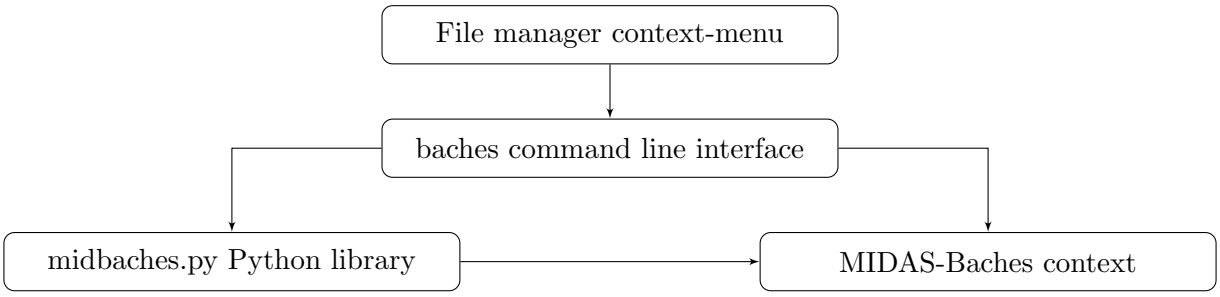
This document gives a brief overview of the calibration and reduction of data taken with the BACHES spectrograph. MIBAS is a virtual machine comprising a plethora of astronomical software building on the ESO Scisoft package. Dedicated data reduction pipelines for the BACHES Spectrograph based on the MIDAS-Echelle context are available in MIBAS.

MIBAS offers different levels of abstraction.

File manager context: The most common tasks for quick calibration and data reduction are available from the file manager context-menu. Internally the baches CLI is called.

Command line interface: The `baches` command offers the full parameter flexibility and additional tools from the terminal. It calls functions from the midbaches.py Python library

midbaches.py Python package: The midbaches.py python library interfaces and enhances the midas functions.



File Manager Context

The most common tasks for quick calibration and data reduction are available from the file manager context-menu. (Re-Calibration using a frame from a reference-lamp and basic reduction of an object frame can be done with two mouse clicks.) This includes:

- Start an interactive initial calibration.
- Start a fully automatic re-calibration.
- Save and load calibration sessions.
- Reduction of object frames with a selection of commonly used parameters.

You can also define your own custom file manager context-menu actions. In thunar (file manager): Edit → Configure custom actions.

CLI

The high level CLI program `baches` calls the python `midbaches.py` and `midas` functions and adds further convenience functions, e.g. user interactive spectrum normalization using adaptive splines. In order to get a quick overview over its functionality enter

```
$ baches --help
Usage: baches [OPTIONS] COMMAND [ARGS]...

  BACHES Utilites is a programm with helpfull tools for data reduction of
  Spectra obtained using the BACHES Spectrograph
```

```
Options:
  --version  Show the version and exit.
  --help     Show this message and exit.

Commands:
  cali   Interactive wavelength calibration using a...
  clean  Removes temporary MIDAS files in current...
  corr   Cross-Correlation of Spectrum 1 with Spectrum...
  crop   Crops a spectrum to given wavelength range if...
  load   Loads a set of calibration files.
  norm   Interactive spectrum normalization using...
  pipe   Reduce Object Frames.
  plot   Plot spectra to file.
  reca   BACHES Re-Calibration.
  reso   Calculate the Resolving Power of up to 1000...
  save   Saves a set of calibration files.
```

in a terminal. Additional help for individual commands is displayed by

```
$ baches <command> --help
```

midbaches.py python library

In order to enable BACHES users to adapt the reduction pipelines to their needs, a Python-Module (`midbaches.py`), containing all relevant tasks, is provided. It uses the `PyMidas` API to MIDAS. It shall also serve as an example for users who want to use MIDAS routines from within python. Other Midas and Iraf functions can be used in conjunction via their Python APIs PyMidas and PyRaf.
The function documentation can be found in `/home/user/Documents/PyMidas/midbaches_doc.html`.
The module resides in `/home/user/.baches/midbaches.py`

2 Initial Calibration

The initial calibration is usually done once for the instrumental setup, or if the spectrum is shifted, the camera is rotated etc. That is to say, if the pixel shift between the frame used for the initial calibration and subsequent calibration frames exceeds several pixel. In order to carry out the wavelength calibration, two frames are to be taken.

- The *Flat* frame, taken from a continuous halogen lamp mapping the full extend of the spectrographs dispersion orders. It is further denoted *ordref*-file in a context where it is used to define the location and extent of the dispersion orders.
- The *Lamp* frame, taken from a suitable reference lamp. It is further assumed that the recommended Thorium-Argon hallow cathode lamp is used, however given a reference line table is provided, other calibration lamps could also be used.

Example

In `/home/user/WORK/Exercise_Files/` example spectra taken with the KAF-1603ME and KAF-8300M sensors are provided. The folder `/home/user/WORK/Exercise_Files/ST-8300M/` comprises three files:

```
lamp_thar80.fits
ordref_ff20.fits
sun360s.fits
```

Please note that in order to use the file-manager context functions, it is mandatory for the file names for lamp and flat frames to resemble the patterns `lamp*.fits` or `lamp*.fit` and `ordref*.fits` or `ordref*.fit`

File manager context-menu

To carry out the initial calibration of the instrument setup, select the *lamp* and *ordref* file (hold shift). Then right-click on either one of them and select:

```
baches cali <lamp*.fits> <ordref*.fits> --session baches
```

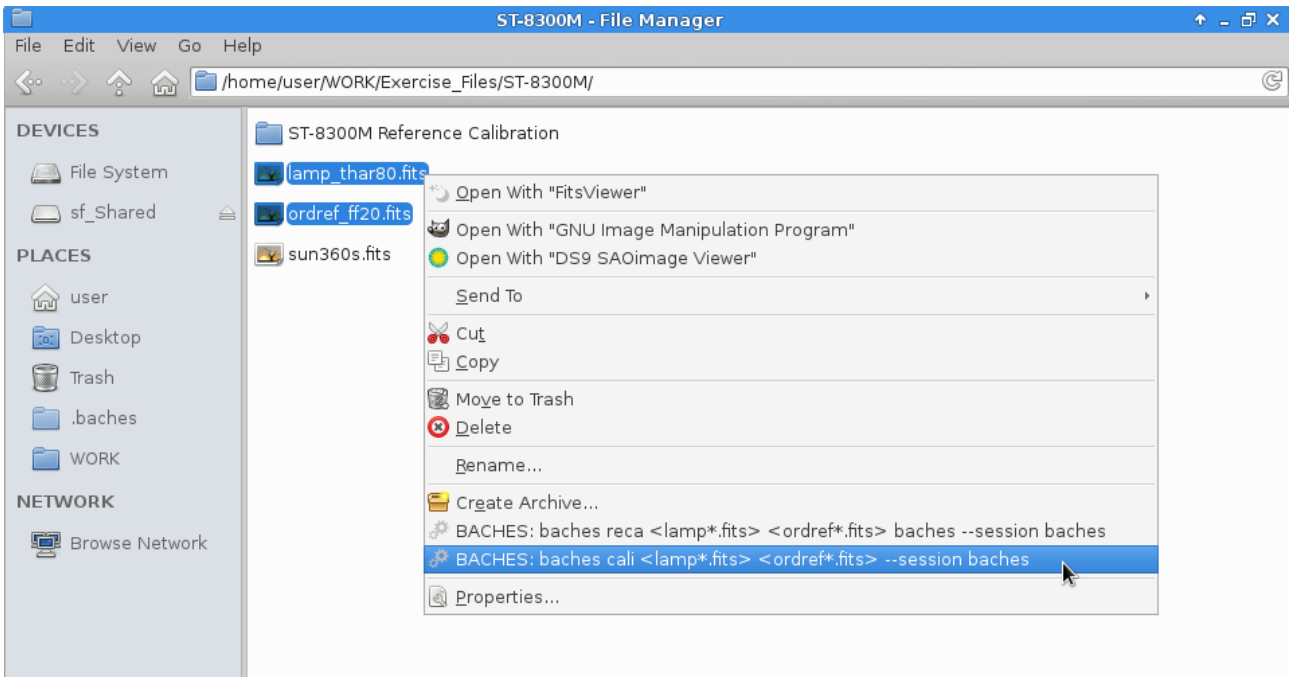


Figure 1: File-manager context menu.

CLI

or open a terminal in the current folder (right-click -¿ open terminal here) and execute the following equivalent command:

```
$ baches cali lamp_thar80.fits ordref_ff20.fits --session baches
```

The default settings are displayed:

```
PARAMETERS FOR THIS CALIBRATION:
================================
ID  Parameter                                 Value

1:  Flat field file name                      ordref_ff20.fits
2:  Calibration lamp file name                lamp_thar80.fits
3:  Reference session name                    baches
4:  Number of orders to be detected (0=auto)  0025
5:  Polynomial degree for wl. solution        0004
6:  Line detection threshold (initial, final) 0400, 0010
7:  Wl. calib. RMS tolerances (initial, final) 1.00000E+00, 1.50000E-02
8:  Slit extraction width                     2.00000E+01
9:  Wavelength calibration method             1D
0:  Calibration reference table               thar.fit

Continue [y] or modify a parameter [ID]? (y)
```

Explanation of the parameters:

1. **Flat field file name**: The name of the file used for the order location detection

2. **Calibration lamp file name**: The name of the file used for the detection of emission lines used for the wavelength calibration.

3. **Reference session name**: The name which is used to save the calibration results. When the file-manager context is to be used for re-calibration and reduction, leave the default reference session name *baches*. The calibration will be saved in two files:

   ```
   <session>ORDE.fits
   <session>bachesLINE.fits
   ```

4. **Number of orders to be detected**: The calibration algorithm will perform a non-interactive search for the N brightest dispersion orders.

5. **Polynomial degree for wl. solution**: The wavelength calibration will fit a dispersion solution with degree N to the detected emission lines within the given tolerance.

6. **Line detection threshold (initial, final)**: The dispersion orders are searched for emission lines above the given threshold. In a first pass, a relatively high threshold is used in order to detect only the brightest lines. The subsequent wavelength calibration is more robust starting with fewer lines. After a first identification and approximation of the wavelength solutions, a low threshold is used to detect as many lines as possible and the wavelength solution is fitted again.

7. **Wl. calib. RMS tolerance (initial, final)**: Initial RMS tolerance [pixel] is used to identify many emission lines while not rejecting too many in order find an approximated wavelength solution in the first pass with fewer lines detected with the initial threshold. The final RMS threshold [pixel] determines which lines are kept and rejected for the final wavelength solution.

8. **Slit extraction width**: Width [pixel] of the slit for the extraction (averaging) of the dispersion orders. Depends on the camera/binning.

9. **Wavelength calibration method**:
   1D: Find wavelength solution for each dispersion order.
   2D: Find global wavelength solution.

10. **Calibration reference table**: The reference table to be used for the identification of lines. Default is `thar.fit` If you want to use a different table, copy the `.fits` file in the current directory were the calibration is carried out and change the parameter accordingly.

By entering the ID number, the parameters can be changed prior to proceeding with the calibration. The default values are however reasonably robust for most cases.

Order Identification

Continue with the dispersion order identification by entering *y* and press *Enter*:
Select the y-range of the frame to be considered. In case of overlapping orders in the far blue and red as present on the bigger KAF-8300 sensor, it is best to crop these regions in advance or exclude them from the detection by specifying the y-range.

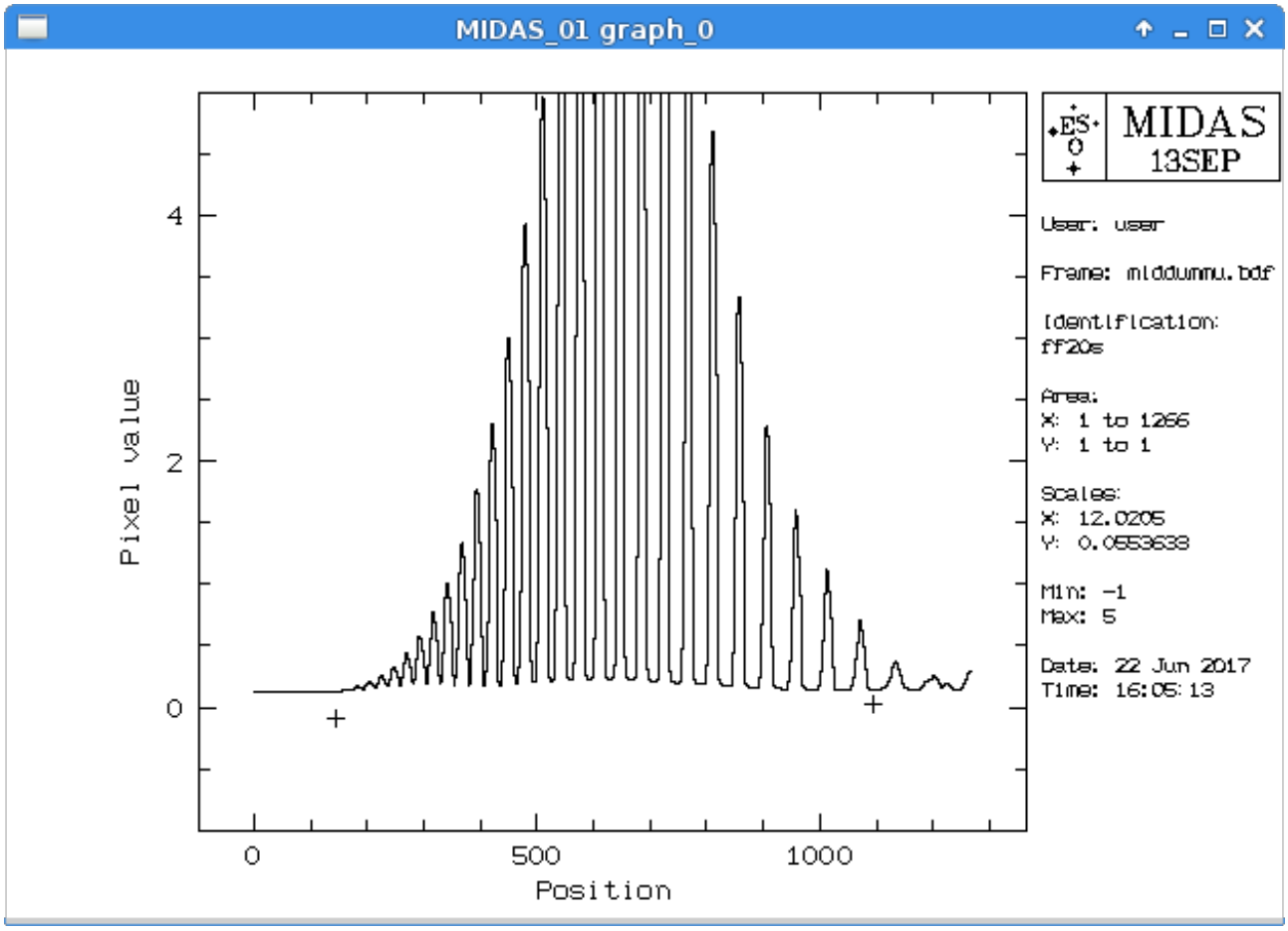


Figure 2: Y-range selection. Define the y-range by two left-clicks.

The automatic order identification is carried out and the found orders are displayed:

```
*************************     OPTIONS     ***********************************

1:   Continue with line identification.
2:   Manually select y-range.
3:   Enter new number of order to be searched for.
4:   Start all over.
5:   Exit.
*******************************************************************************
```

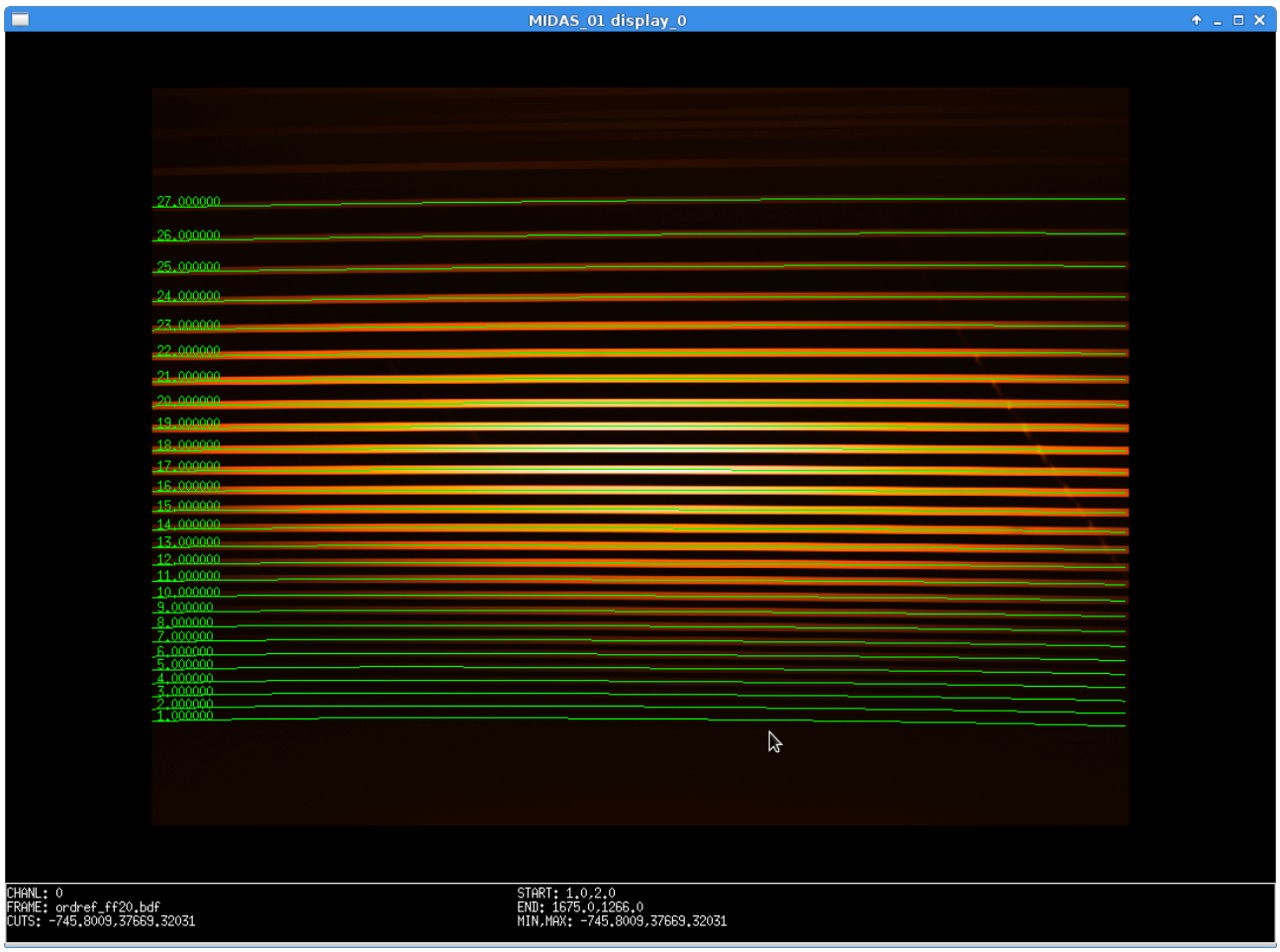


Figure 3: Dispersion order identification

Emission Line identification

Continue with the emission line search. The number of detected lines is dependent on the initial line detection threshold. A value of 400-1000 initially detected lines has proven to be adequate. You can change the threshold and rerun the search by choosing option **2**.

```
*************************      OPTIONS     ***********************************

1:   Continue with wavelength calibration
2:   Change Threshold and repeat line identification
3:   Start all over
4:   Exit
*******************************************************************************
```

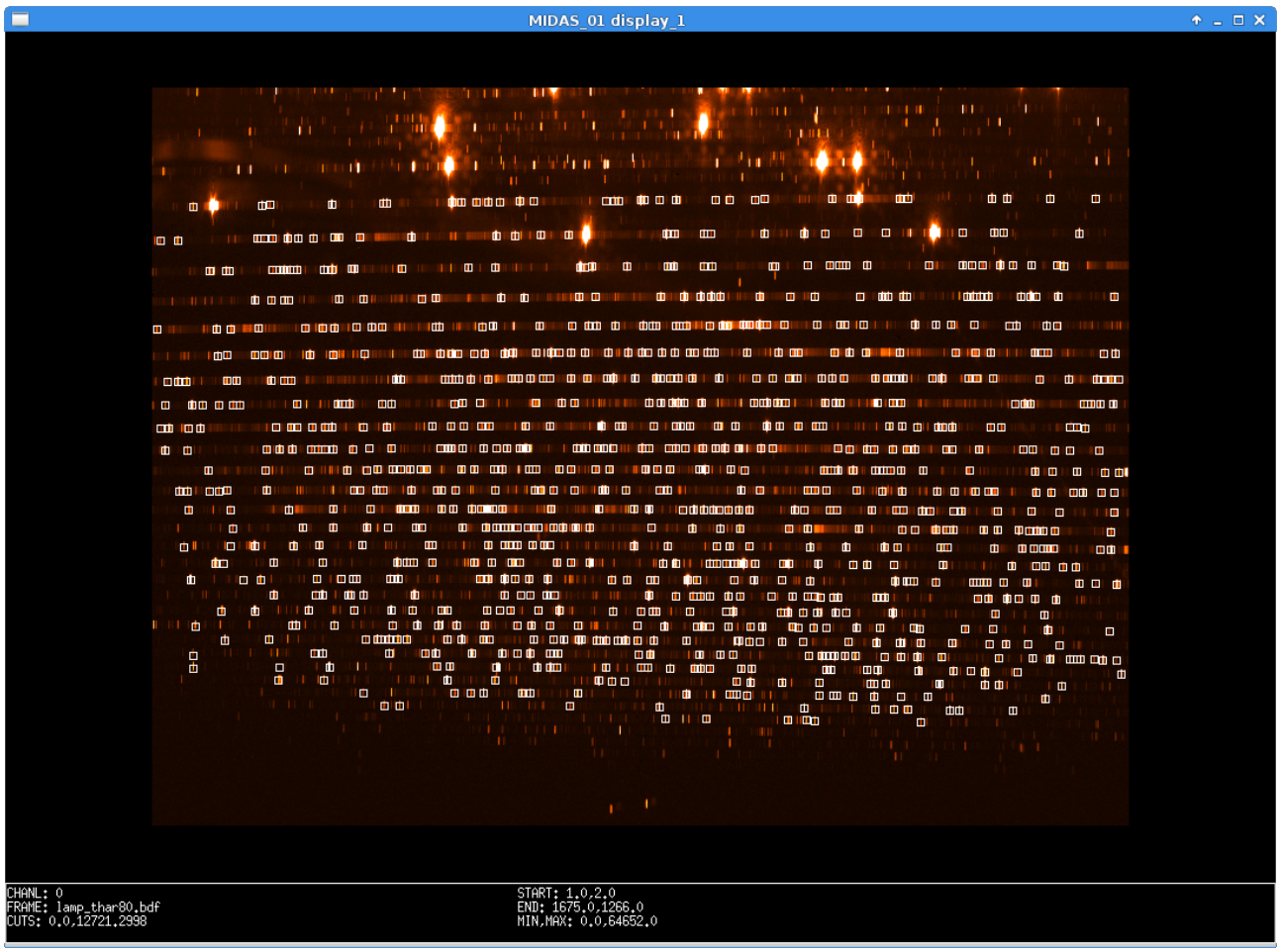


Figure 4: Emission line detection

Line-pair selection

Now select 2 pairs of lines repeated in adjacent orders. The lines at 6662.268Å and 4609.600Å are recommended.
Use *ALT+TAB* to focus on the display an select the 2 pairs on lines from left-to-right, top-to-bottom. The height and width of the selection cursor can be modified using the arrow keys. Once the four lines have been selected, finish with a right-click in the active display.

Now enter the absolute order number of the first selected line. For line 6662.268Å it is 33.

```
Enter absolute order number of first pointed line (square mark) : 33
Sequence no. 0001, Order no. 0033. Enter wavelength : 6662.268
Sequence no. 0003, Order no. 0048. Enter wavelength : 4609.600
```

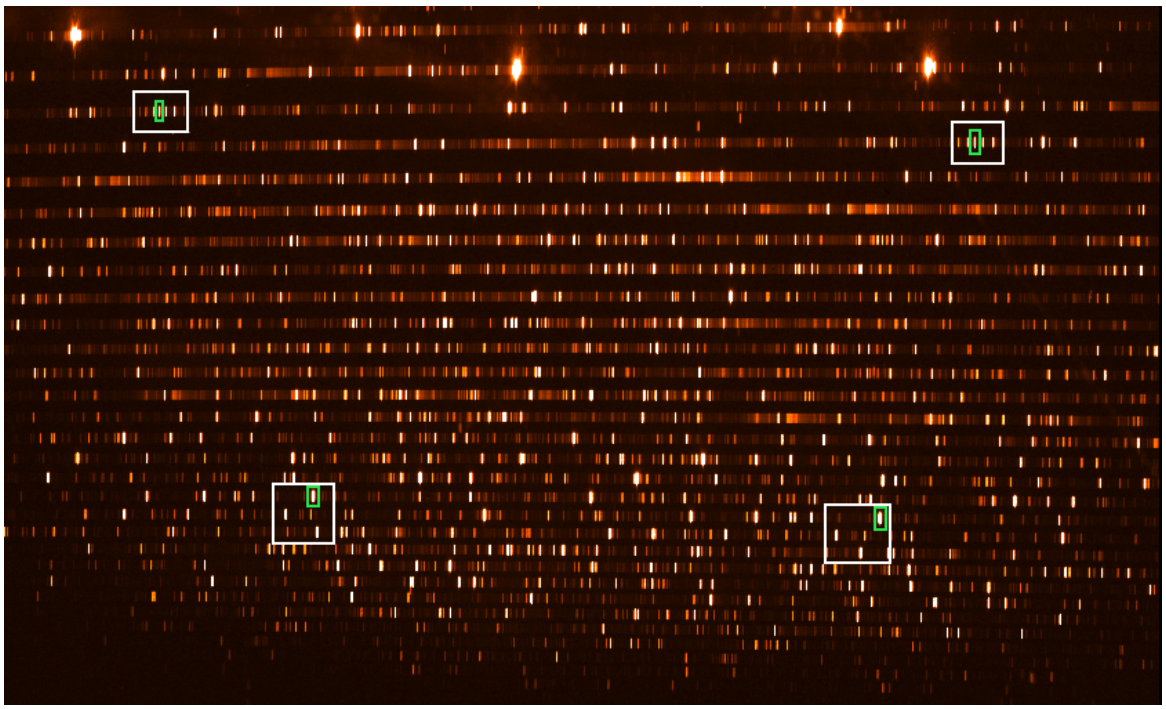


Figure 5: Line pair selection

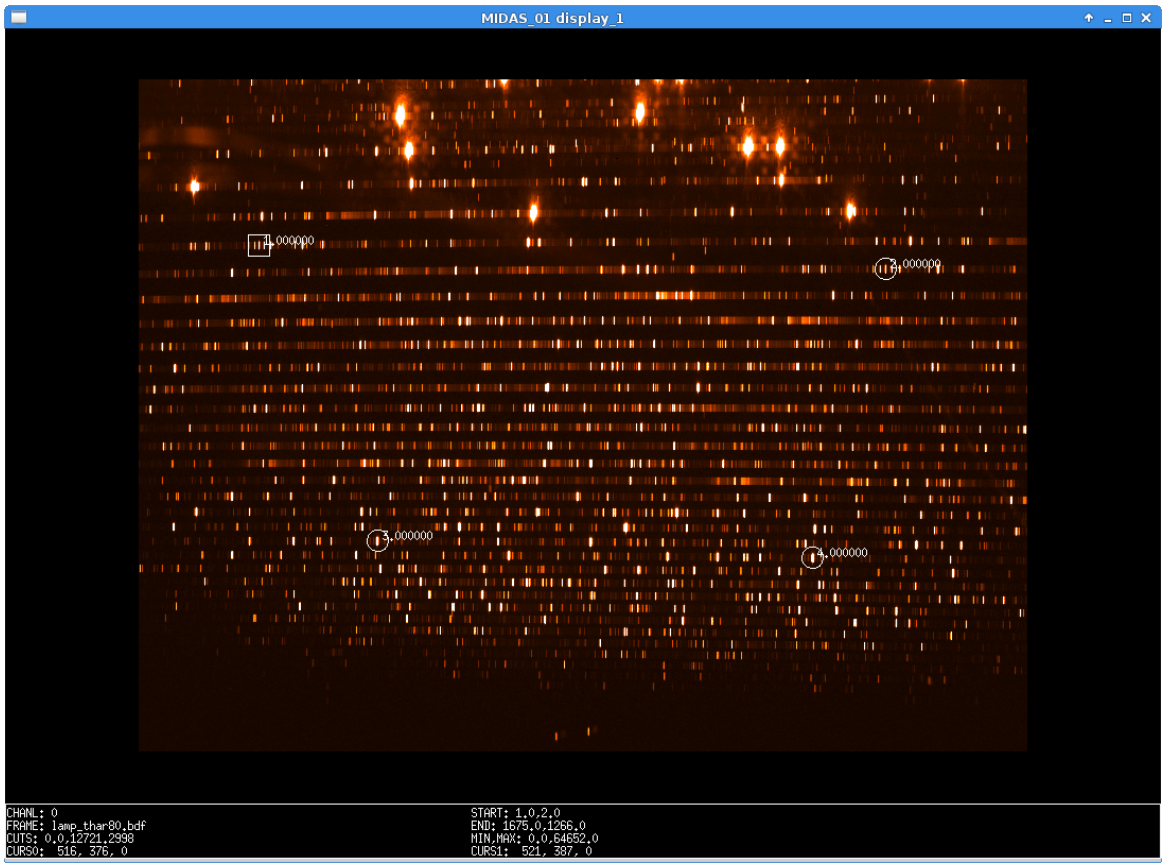


Figure 6: Reference line pairs selected.

Wavelength Calibration

Continue to start the wavelength calibration. A table with information about each order is presented. A good calibration features a low MEAN RMS [Å] with a high number of lines used. This step is

determined by the values of the Final threshold for line detection and the final RMS threshold. In order to improve a calibration, first lower the final line detection threshold [2] in order to increase the number of lines included in the dispersion relation fit. Then lower the RMS tolerance [pixel] in order to tune the mean RMS.

```
COMPUTE DISPERSION COEFFICIENTS
 ------------------------------
 INPUT TABLE : line.tbl
 POLYNOMIAL DEGREE :   4
 SEQ.NO  SPECTRAL  NO.LINES  WL START    WL END  STD. DEV.
          ORDER                                ANGSTROEM
 ------  --------  --------  --------    ------  ---------
      1        57        14   3834.15   3999.52    0.00090
      2        56        21   3902.91   4070.95    0.00094
      3        55        17   3973.71   4144.95    0.00069
      4        54        20   4047.22   4221.69    0.00095
      5        53        19   4123.41   4301.30    0.00085
      6        52        21   4202.62   4383.97    0.00078
      7        51        24   4284.92   4469.87    0.00103
      8        50        22   4370.52   4559.23    0.00097
      9        49        18   4459.62   4652.22    0.00100
     10        48        21   4552.43   4749.07    0.00098
     11        47        25   4649.20   4850.03    0.00087
     12        46        23   4750.19   4955.39    0.00100
     13        45        19   4855.67   5065.45    0.00095
     14        44        19   4965.91   5180.43    0.00106
     15        43        23   5081.32   5300.80    0.00095
     16        42        20   5202.22   5426.89    0.00100
     17        41        18   5329.00   5559.14    0.00098
     18        40        22   5462.14   5698.00    0.00090
     19        39        21   5602.10   5843.95    0.00096
     20        38        25   5749.42   5997.58    0.00094
     21        37        17   5904.69   6159.52    0.00074
     22        36        19   6068.54   6330.44    0.00091
     23        35        17   6241.83   6511.13    0.00103
     24        34        15   6425.22   6702.43    0.00081
     25        33        14   6619.80   6905.40    0.00063
     26        32        16   6826.47   7120.93    0.00087
     27        31        18   7046.46   7350.41    0.00083
 ------------------------------------------------------------
                                          MEAN RMS:   0.00091
** TOTAL NUMBER OF LINES :    528 **
```

```
*************************      OPTIONS     *********************************

1:   Calculate Resolving Power R for lamp_thar80.fits.

Change parameter and repeat calibration:
2:   Final threshold for line detection              0010
3:   Final RMS Tolerance                             1.50000E-02
4:   Polynomial Degree of wavelength Solution        0004
5:   Calibration Method 1D or 2D                     1D
         (1D: Wavelength solution per order
          2D: Global wavelength solution)

6:   Start all over.
7:   Exit.
*******************************************************************************
```

Resolving Power

By entering option 1, the spectrograph's resolving power is calculated for up to 1000 suited ThAr lines (therefore this option is only meaningful if using a ThAr calibration lamp) and plotted. It is also saved in .eps format (`lamp_thar80_wrmRP.eps`) and `ascii` format (`lamp_thar80_wrmRP.txt`). The ascii file can be used to determine the RP of obtained calibration lines closest to wavelengths of interest (e.g. the lines bracketing $H\alpha$).

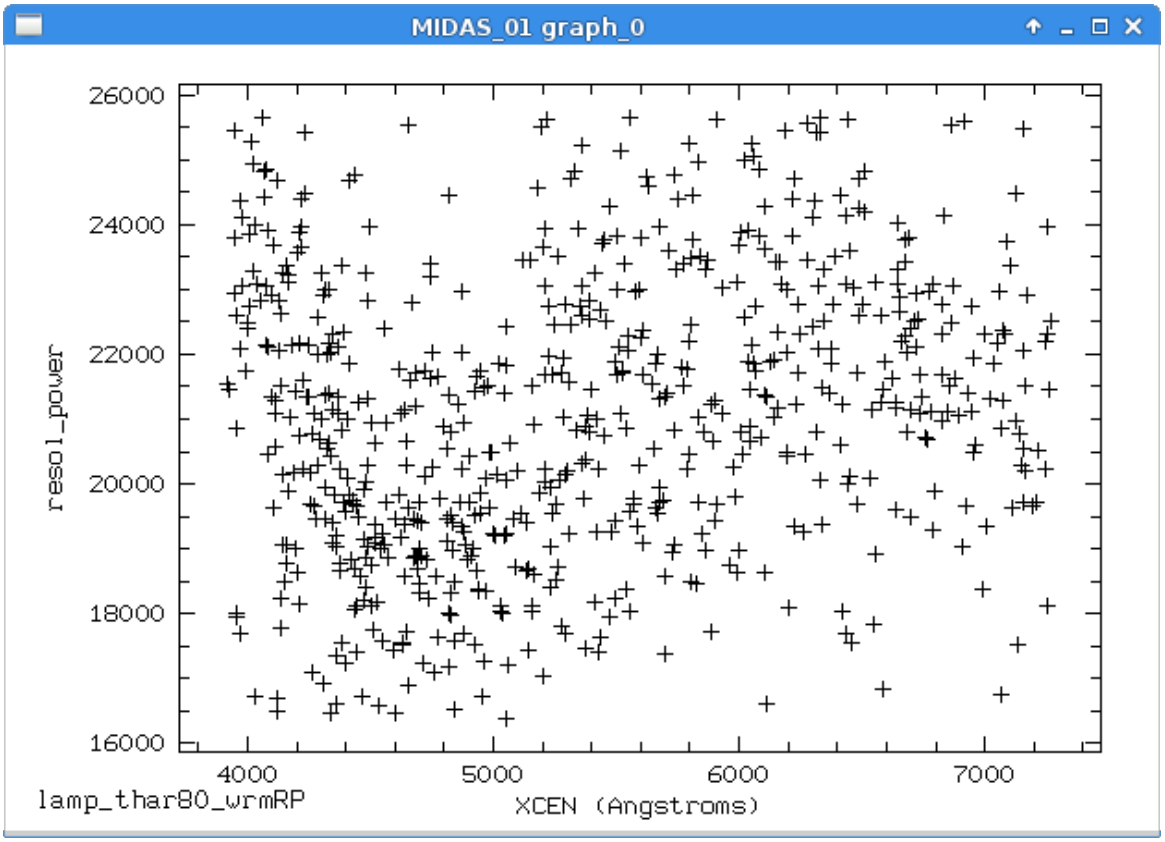


Figure 7: Resolving Power plot.

Results

Exit with option 7. The folder now contains these files:

```
baches_Calib.txt  lamp_thar80_wr.fits    ordref_ff20.fits
bachesLINE.fits   lamp_thar80_wrm.fits   sun360s.fits
bachesORDE.fits   lamp_thar80_wrmRP.eps
lamp_thar80.fits  lamp_thar80_wrmRP.txt
```

- Calibration files:
  The calibration details are stored in the `ascii` file `baches_Calib.txt` The order and line definition used for later automatic re-calibration are stored in `bachesLINE.fits` and `bachesORDE.fits`. The calculated resolving power RP is stored in the `ascii` file `lamp_thar80_wrmRP.txt` and `postscript` file `lamp_thar80_wrmRP.eps`.

- Spectra:
  If you choose to calculate the resolving power, the lamp frame is reduced and the file `lamp_thar80_wr.fits`, containing the spectra of the individual dispersion orders as well as the merged spectrum `lamp_thar80_wrm.fits` are output.

3 Save and load calibration sessions

The wavelength calibration details are stored in the two files `bachesLINE.fits` and `bachesORDE.fits`. They can be saved conveniently for later use.

File manager context-menu

The file manager context-menu offers option for saving and loading the calibration files.

Save a calibration session

If you have done an initial or re-calibration and the two files `bachesLINE.fits` and `bachesORDE.fits` are present in the current directory, the calibration can be saved by right-clicking in the folder and selection of *Save calibration*

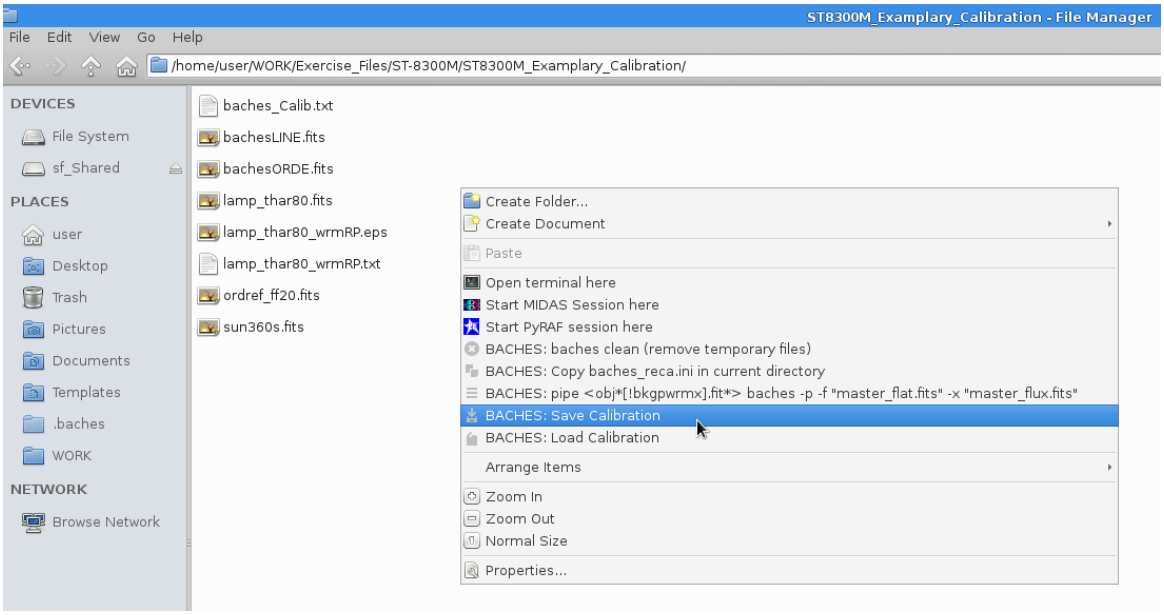


Figure 8: File manager context-menu: Save calibration session.

Now enter a name for this calibration session. The files `bachesLINE.fits` and `bachesORDE.fits` (and `baches_reca.ini` if available) are copied into to directory `/home/user/.baches/Calibrations/NAME/`

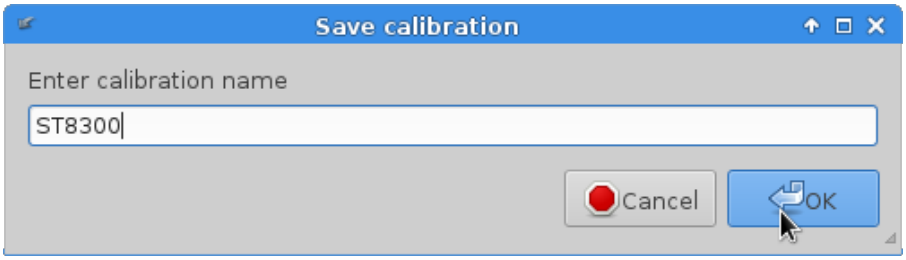


Figure 9: Enter a name for the calibration session to be saved.

Load a calibration session

In order to load a previously saved calibration session, right-click into a folder and select *Load calibration*.

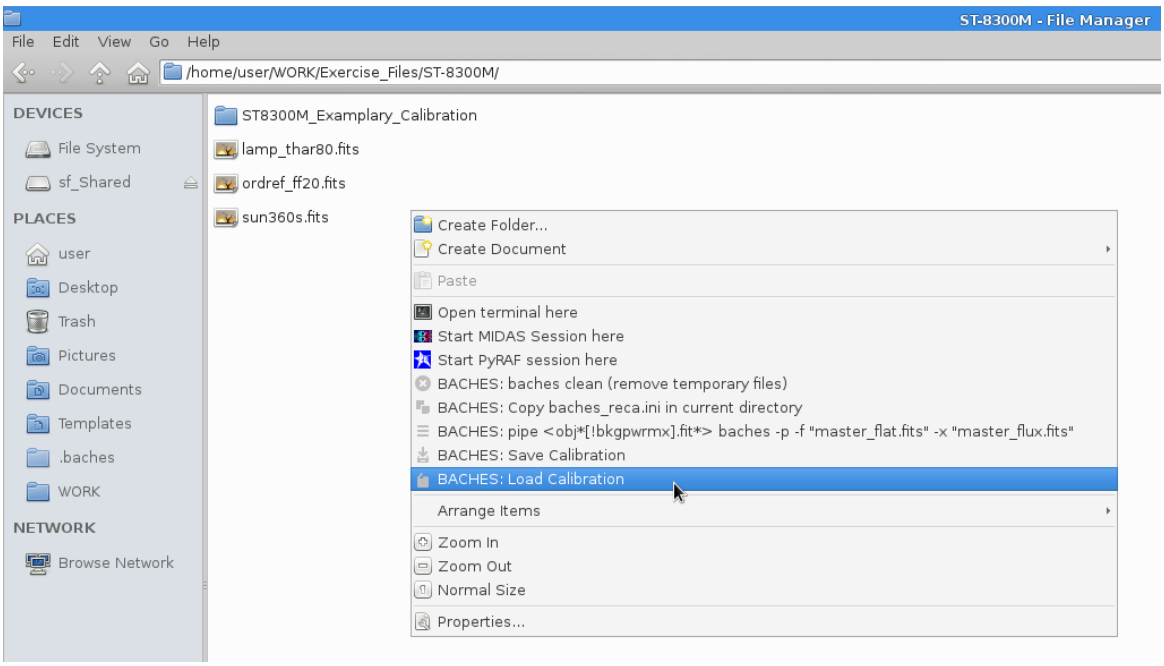


Figure 10: File manager context-menu: Load calibration session

The available calibration session are displayed. Select the calibration to be loaded into the current directory. The files `bachesLINE.fits` and `bachesORDE.fits` (and `baches_reca.ini` if present) are copied into the current directory.

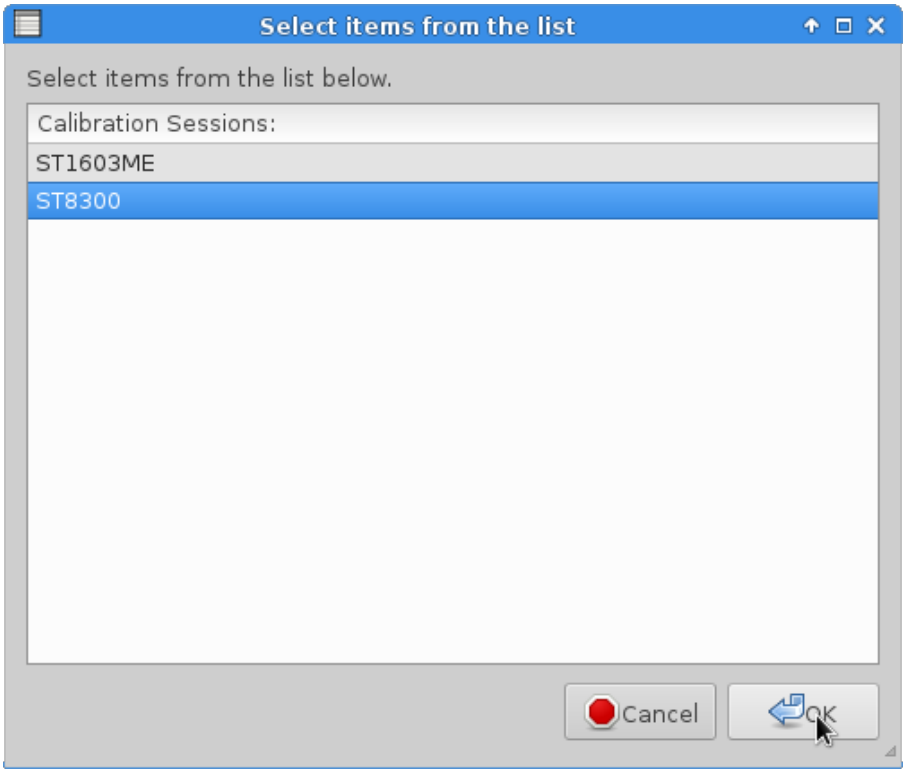


Figure 11: File manager context-menu: Select calibration session to be loaded

You can delete a previously saved calibration session by removing the appropriate folder from `/home/.baches/Calibrations/`.

CLI

Saving and loading is also available from the command line interface.

Save a calibration session

In order to save a calibration from the current directory enter:

```
$ baches save -n NAME
```

The files `bachesLINE.fits` and `bachesORDE.fits` (and `baches_reca.ini` if present in the current folder) will be stored in the folder `\home\user\.baches\Calibrations\NAME`.

Load a calibration session

Respectively the command

```
$ baches load -n NAME
```

will copy the files `bachesORDE.fits` (and `baches_reca.ini` if present in `\home\user\.baches\Calibrations\NAME` to the current folder).

If no –name parameter is specified, the available calibration session will be listed and you will be asked to name one.

4 Reduction

Filemanager context-menu

Once the calibration is completed, science frames in the same directory as `bachesLINE.fits` and `bachesORDE.fits` can be quickly reduced by right-clicking on them and selecting

```
BACHES: baches pipe <frame.fits> --plot
```

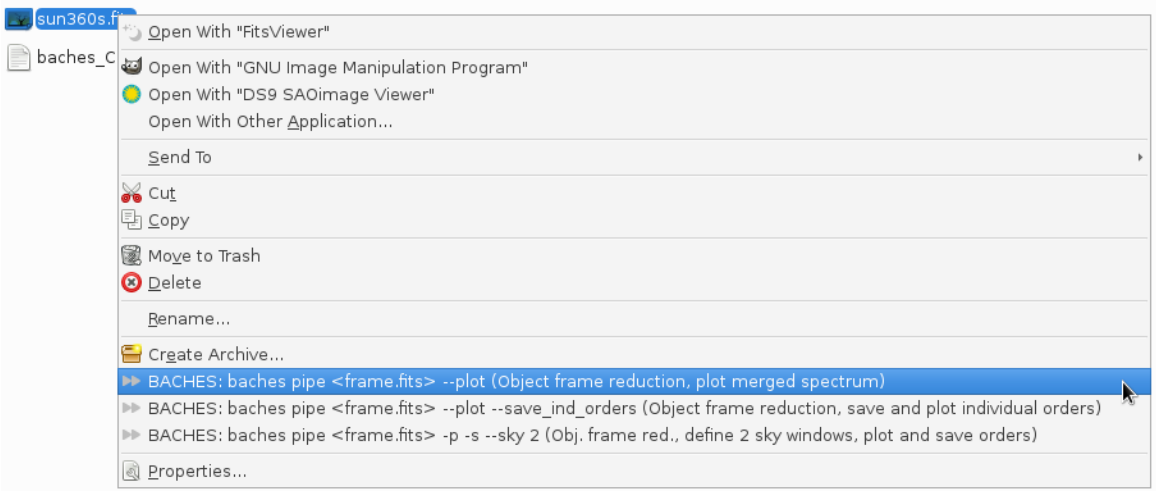


Figure 12: Fiemanager context-menu: Science frame reduction pipeline.

The selected frame will be wavelength calibrated and the file containing all individual order (`*_wr.fits`) and the merged spectrum (`*_wrm.fits`) are output. Optionally the dispersion orders can be saved as individual `.fits` files and plotted as `.png` files in the sub directory `./plots`.

CLI

More options are available from the command line interface. Enter

```
$ baches pipe --help
```

to display the baches pipe help:

```
Usage: baches pipe [OPTIONS] FRAME REFERENCE_SESSION

  Reduce Object Frames. Reduces science frames based on reference
  calibration. Converts images from pixel to wavelength scale

  Example: pipe Sun_15.fits baches -s -p --sky 2 --flux SunRef.fits --flat
  master_flat.fits

  Reduce the object frame "Sun_15.fits" saving (in ./orders/) and plotting
  (in ./plots/) all individual dispersion orders. Interactive selection of
  two sky windows. Object frame is divided by "master_flat.fits" in 2D pixel
  space. Merged spectrum is divided by "SunRef.fits" in wavelength space.

Options:
  -s, --save_ind_orders  Save orders individually as .fits files in subfolder
                         "./orders".
  -f, --flat PATH        Flat (2D) filepath. Divided by if found.
  -x, --flux PATH        Flux (1D) filepath. Divided by if found.
  -p, --plot             Plot spectra as .png in subfolder "./plots".
  -y, --sky [0|1|2]      Number of Sky windows to be subtracted. (Default = 0)
  -b, --background       Subtract Background.
  -l, --slit FLOAT       Slit length in pixel.
  -o, --offset FLOAT     Slit length in pixel.
  --help                 Show this message and exit.
```

5 Automatic Re-Calibration

The calibration is stored in the two files `bachesLINE.fits` and `bachesORDE.fits`. If one wishes to re-calibrate the instrument (ideally in between each science frame if drifts due to temperature changes etc. are expected) the two calibration files as well as the new reference lamp frame (`lamp*.fits`) and the flat field (`ordref*.fits`) need to be present in the same directory. If only small shifts in dispersion direction are expected, it is not mandatory to obtain a new flat field.

File manager context-menu

Select newly obtained reference frames (e.g. `lamp_thar80_2.fits` and `ordref_ff20.fits`) and right-click on either of them in order to select the automatic re-calibration option from the file manager context menu.

```
BACHES: baches reca lamp*.fits ordref*.fits baches --session baches
```

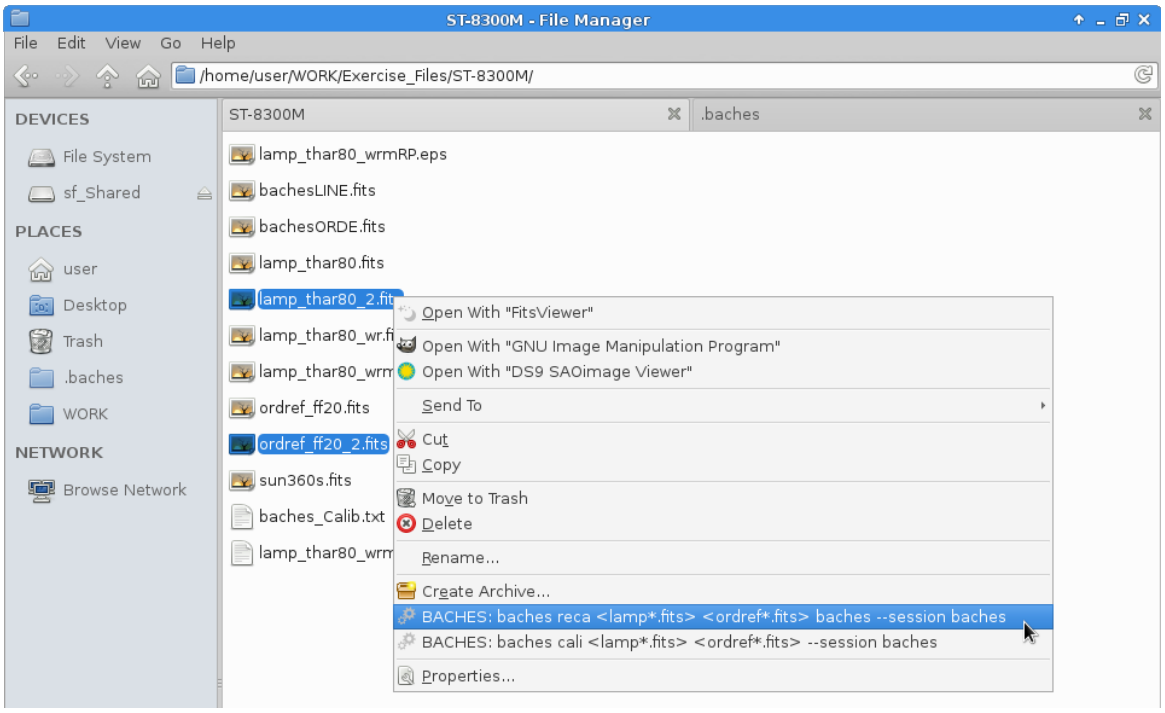


Figure 13: File manager context-menu: Re-Calibration.

The re-calibration uses the parameters specified in the configuration file `./baches_reca.ini`. If the file is not found, the default file in `/home/user/.baches/baches_reca.ini` is copied in the current directory and used. Change this file to your desired default settings. If you want to run the re-calibration with different settings you can copy it in the current directory by right-clicking in the folder and selecting

```
BACHES: Copy baches_reca.ini in the current directory.
```

Change the settings and run the re-calibration.

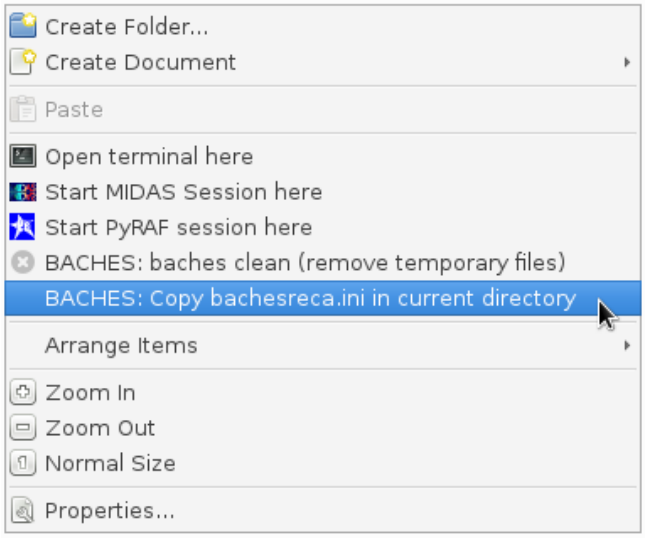


Figure 14: File manager context-menu: Copy baches_reca.ini in current directory.

Please note that the re-calibration run from the file manager context-menu will use the reference calibration session name *baches*, looking for `bachesLINE.fits` and `bachesORDE.fits`. These two calibration files will be overwritten!
This is done to enable a quick re-calibration and reduction of multiple calibration and science frames with a few clicks. The workflow is:

- Copy the reference calibration files `bachesLINE.fits` and `bachesORDE.fits` into the directory containing your calibration and science frames or use. (Assuming the file pattern: `ordref_*.fits`, `lamp_*.fits` and `science_*.fits`)
- Select `lamp_01.fits` and `ordref_01.fits` → Run Re-Calibration.
- Select `science_01.fits` → Run Pipeline.
- Select `lamp_02.fits` and `ordref_02.fits` → Run Re-Calibration.
- Select `science_02.fits` → Run Pipeline.
- ...

CLI

More sophisticated options are available from the command line. The interface is meant to be used by custom reduction pipelines. Enter

```
$ baches reca --help
```

to display the "baches reca" help:

```
Usage: baches reca [OPTIONS] LAMP_FILE ORDREF_FILE [REFERENCE_SESSION]

  BACHES Re-Calibration. Does a re-calibration of a lamp frame using a
  previous reference session. The files "<session>LINE.fits"
  "<session>ORDE.fits" generated by a previous calibration of the same
  instrumental setup have to be placed in the current directory.

  Example: reca tharef02.fits ff02.fits tharef01 --session tharef02 --poly 4
  --tol 0.5 0.01 --thresh 500 10

  Recalibrates the lamp frame "tharef02.fits" using "tharef01" as reference
  session. (The files "thref01LINE.fits" and "tharef01ORDE.fits" have to be
  placed in the current folder, using a wavelength solution of polynom order
  4 with initial RMS tolerance 0.5 [px] and final RMS tolerance 0.01 [px].
  Initial threshold is 500 and final threshold is 10 [counts]. Detailed
  description of the parameters is available in the documentation.)

Options:
  --config TEXT                   Config file path.
  -s, --session TEXT              Calibration Session name.
  -p, --poly INTEGER              WLC Polynom order.
  -l, --tol <FLOAT FLOAT>...      Initial & final RMS Tolerance.
  -t, --thresh <FLOAT FLOAT>...   Initial & final line detection Threshold.
  -c, --cat PATH                  Reference line catalogue.
  --help                          Show this message and exit.
```

The recommended workflow is:

- `$ baches reca lamp_01.fits ordref_01.fits baches  -s lamp_01 -c baches_reca.ini`

  Re-Calibration using the reference calibration session *baches* (`bachesLINE.fits` and `bachesORDE.fits`). Saves the re-calibration under the session name *lamp_01*.

- `$ baches reca lamp_02.fits ordref_02.fits lamp_01  -s lamp_02 -c baches_reca.ini`

  Re-Calibration using the reference calibration session *lamp_01* (`lamp_01LINE.fits` and `lamp_01ORDE.fits`). Saves the under the session name *lamp_02*.

- ...

Now the science frame reduction can be carried out using the desired reference calibration session.

```
$ baches pipe lamp_02.fits lamp_01 -p -s -b --sky 1 --flux response.fits
```

Results

Detailed information about the automatic re-calibration is saved in the `ascii` file `<lamp>ReCalib.txt`. The resolving power is calculated and saved in `<lamp>_wrmRP.txt` and `<lamp>wrmRP.eps`. The calibration files are saved as `<session>LINE.fits` and `<session>ORDE.fits`.

```
CALIBRATION RESULTS:
 -------------------------------
 INPUT TABLE : line.tbl
 POLYNOMIAL DEGREE :   4
 SEQ.NO  SPECTRAL  NO.LINES  WL START    WL END  STD. DEV.
          ORDER                                ANGSTROEM
 ------  --------  --------  --------    ------  ---------
      1        55        12   3973.74   4144.97    0.00075
      2        54        14   4047.23   4221.69    0.00056
      3        53        17   4123.41   4301.30    0.00061
      4        52        17   4202.62   4383.97    0.00073
      5        51        19   4284.91   4469.87    0.00073
      6        50        19   4370.52   4559.23    0.00072
      7        49        16   4459.62   4652.21    0.00078
      8        48        14   4552.42   4749.06    0.00045
      9        47        22   4649.20   4850.03    0.00072
     10        46        20   4750.19   4955.39    0.00052
     11        45        16   4855.67   5065.46    0 .00065
     12        44        15   4965.91   5180.43    0.00072
     13        43        21   5081.31   5300.80    0.00075
     14        42        18   5202.21   5426.89    0.00065
     15        41        16   5329.01   5559.14    0.00056
     16        40        17   5462.14   5698.00    0.00051
     17        39        16   5602.10   5843.95    0.00049
     18        38        21   5749.42   5997.58    0.00062
     19        37        16   5904.69   6159.52    0.00067
     20        36        17   6068.54   6330.44    0.00072
     21        35        13   6241.83   6511.14    0.00045
     22        34        13   6425.22   6702.43    0.00048
     23        33        13   6619.77   6905.34    0.00048
     24        32        14   6826.47   7120.92    0.00078
     25        31        16   7046.46   7350.41    0.00062
 ------------------------------------------------------------
                                        MEAN RMS:   0.00063

Final RMS Tolerance: 0.01
Total number of lines used in WLC: 412

SETTINGS:
---------
Session Name                 : baches
Reference Session used       : baches
Reference Lamp frame         : lamp_thar80.fits
Order Reference Flat frame   : ordref_ff20.fits
Line detection Thresholds:
   Initial Threshold         : 300.0
   Final Threshold           : 8.0
WLC Polynom Order            : 4
WLC Option                   : 1D
RMS Tolerances:
   Initial RMS Tolerance     : 0.75
   Final RMS Tolerance       : 0.01
```