User Manual

C.A.T.C.H.

Collection of **A**nalysis **T**ools for **C**oronal **H**oles

Version 1.02

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If you have any problems, questions, ideas or suggestions, please contact the author at: stephan.heinemann@hmail.at

If you use CATCH, please cite Heinemann et al. 2019.

Figure 1: CATCH Logo

System Requirements

- LINUX SSW-IDL (tested under 8.6.)
  - Coyote Library http://www.idlcoyote.com/documents/programs.php
  - SSW Libraries:
    - AIA *ssw-path, /aia* (if needed add this line to your IDL startup file)
    - HMI *ssw-path,/hmi*
    - EIT *ssw-path,/eit*
    - MDI *ssw-path,/mdi*
    - STEREO *ssw-path,/stereo*

Note: *Not all dependencies have been tested, there might be more packages to include.*
Note: *Not compatible with the windows distribution of IDL, not tested for mac-OS.*
Note: *Including the MDI package might produce problems with the IDL plot function*

Setup

- Unzip *catch_XXX.tar.gz*
- Add the path to the unzipped folder to your IDL startup file:
  - *!path=!path + ':' + expand_path('+path_to_catch/', /all_dirs)*
- Add the routine to your IDL startup file:
  - *resolve_routine, 'catch_main', /COMPILE_FULL_FILE*
  - Alternatively compile *catch_main.pro* before running CATCH

Run CATCH

- Call *catch_main* in the sswidl-command line to start the widget.

First Start

- The widget will alert the user that no configuration file was found, and if a new one should be created. To continue, proceed with *YES* and a default configuration file will be created.
- In the MAIN MENU (see Section: The Main Menu) got to the PROPERTIES window accessible through the button of the same name (right bottom corner). There CATCH can be configured (see Section: The Properties Window). Then proceed with SAVE, and CATCH is ready to use.

- Note: *This process may be repeated if the configuration file was deleted.*
- Note: *This process may give an error message concerning the default paths. This can be ignored as the paths should be set manually afterwards anyways.*

File Management

- For each EUV file that is analyzed, a directory will be created named 'YYYYMMDD_HHMMSS_CATCH', into which all files for this project will be saved. E.g., if multiple coronal holes are extracted from one EUV file, all saved files (e.g., Images, …) will be numbered and saved in the same directory.
- Produced files are named: YYYYMMDD_HHMMSS_<properties>_<function>.<extension>

CATCH Output Files

- When saving the coronal hole extraction, the following files are created:
  - Standard
    - Binary FITS file of with the coronal hole boundaries (0-no CH, values gt 0 are CH pixel; see uncertainty calculations for more details))
      - Pixel value = 1: smallest boundary (thr -2DN)
      - Pixel value = 1 or 2: small boundary (thr -1DN)
      - Pixel value = 1,2 or 3: boundary of the chosen thr
      - Pixel value = 1,2,3 or4: large boundary (thr +1DN)
      - Pixel value=1,2,3,4 or 5: largest boundar (thr +2DN)
    - Text file with the coronal hole properties. The format is given within the file.
  - Optional
    - IDL SAVE (.sav) file including all the maps used for the calculations.
    - PNG image (EUV) of the solar disk with the coronal hole boundary overplotted.
    - PNG image (EUV) of a subfield around the area of interest with the coronal hole boundary overplotted.
    - EPS image (EUV) of the solar disk with the coronal hole boundary overplotted.
    - EPS image (EUV) of a subfield around the area of interest with the coronal hole boundary overplotted.

- When saving the magnetic analysis, the following files are created:
  - Standard
    - Text file with the magnetic field properties of the coronal hole. The format is given within the file.
  - Optional
    - IDL SAVE (.sav) file including all the maps used for the calculations.
    - PNG image (magnetogram) of the solar disk with the coronal hole boundary overplotted.
    - PNG (magnetogram) image of a subfield around the area of interest with the coronal hole boundary overplotted.
    - PNG (magnetogram) image of a subfield around the area of interest with the coronal hole boundary overplotted. The flux tubes are also overlayd. Magenta represents the weak flux tubes and cyan the strong flux tubes.
    - EPS image (magnetogram) of the solar disk with the coronal hole boundary overplotted.
    - EPS image (magnetogram) of a subfield around the area of interest with the coronal hole boundary overplotted.

- EPS (magnetogram) image of a subfield around the area of interest with the coronal hole boundary overplotted. The flux tubes are also overlayd. Magenta represents the weak flux tubes and cyan the strong flux tubes.

User supplied full-disk images

- By activating the FREE INPUT option in the PROPERTIES tab, the input procedure changes from a specific, instrument dependent load and processing (e.g., *read_sdo* + *aia_prep*) to a general read fits routine (*mreadfits*). Any other image processing is disabled.
- The format of the user supplied images should be as follows:
  - Standard *.fits* file
  - Header should match an SDO-fits header (see *jsoc.stanford.edu* for more information)
  - Different headers may also work, but this has not been tested and should be used with caution.
- This is an advanced user option and should be only used with care. Use at your own risk.

1. The Main Menu

The MAIN MENU is the primary navigation panel of CATCH. Through it the various tools may be accessed. The options are:

- DOWNLOAD DATA: See Section 3.
- CORONAL HOLE EXTRACTION: See Section 4.
- MAGNETIC FIELD ANALYSIS: See Section 5.
- PROPERTIES: See Section 2.
- EXIT: Exit CATCH.

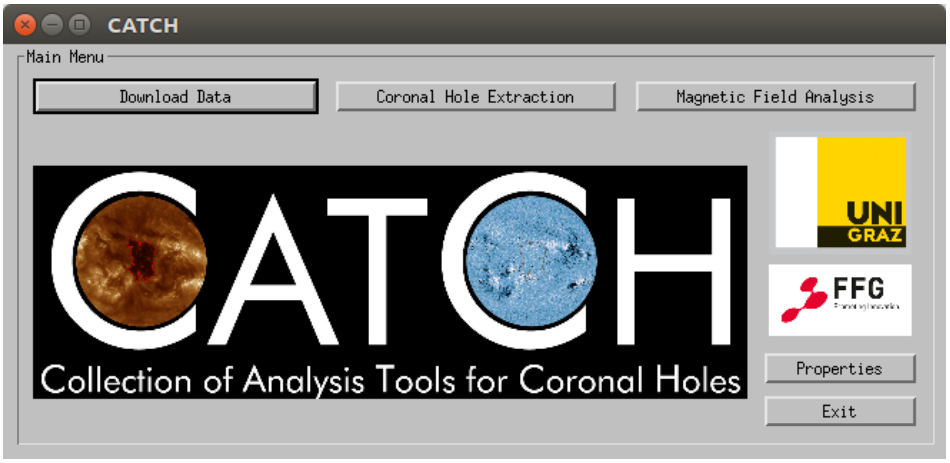


Figure 2: CATCH MAIN MENU

2. Properties Widget

Through the PROPERTIES option, CATCH can be modified. Options included are shown below:

- PLOT OPTIONS:

  Default values for dmin, dmax, gridsize (in Degrees) and contour line thickness may be specified.

- PATHS:

  Default paths for downloading, input and output may be specified here.

- SAVES:

  The output of the SAVE option of the CORONAL HOLE EXTRACTION and MAGNETIC FIELD ANALYSIS can be configured here.

- HANDLING:

  The default values for data input resolution as well as the limb brightening correction may be set here. The uncertainty calculations can be turned on/off here as well. The LOCK PROPERTIES option disables the option that the CATCH configuration may be updated during use. The option to use any full-disk input magnetograms or filtergrams can be enabled here (FREE INPUT). Please use this option on your own responsibility.

- RESET:

  Resets the configuration to the default.

- ABORT:

  Exit the Properties Widget without saving.

- SAVE:

  Save the changes and exit the Properties Widget .

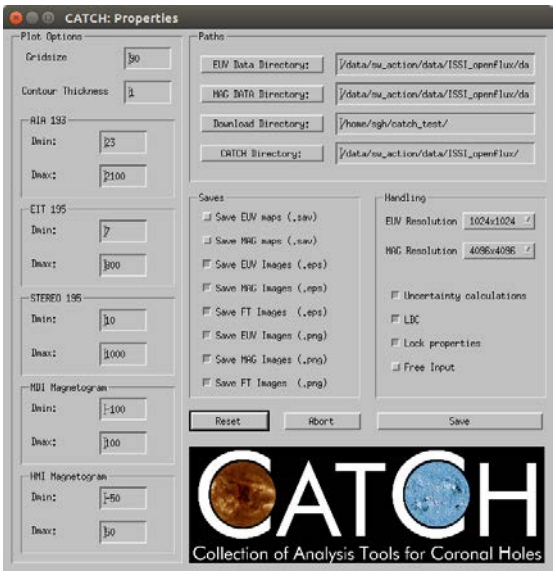


Figure 3: CATCH PROPERTIES

3. Download Data Widget

The DOWNLOAD DATA option is a way to download data for CATCH using the SSWIDL routines *vso_search* and *vso_get*.

Note: *If problems with the download occur, the most probable causes are server problems at the server supplying the data. This seems to happen especially often for SDO data that is downloaded from JSOC. If problems persist, please download the data manually via http://jsoc.stanford.edu/.*

The options of downloading data are limited to usable files for CATCH:

- Filtergrams
  - AIA/SDO 193 Å
  - EIT/SOHO 195 Å
  - EUVI/STEREO 195Å
- Magnetograms
  - HMI/SDO 45s LoS
  - HMI/SDO 720s LoS
  - MDI/SOHO 96m LoS

The options are:

- DOWNLOAD DIRECTORY:
  By clicking the button, you may navigate to the directory in which you want the data downloaded or you may type the path into the text field.

- SOURCE:
  Specify source (SDO/SOHO/STERO-A/STEREO-B).

- DATA PRODUCT:
  Specify product (Filtergram or Magnetogram).
  Note: For STEREO this option is not available as there is only one data product (EUVI 195Å)

- DATE/TIME:
  Specify date and time of the data product desired.

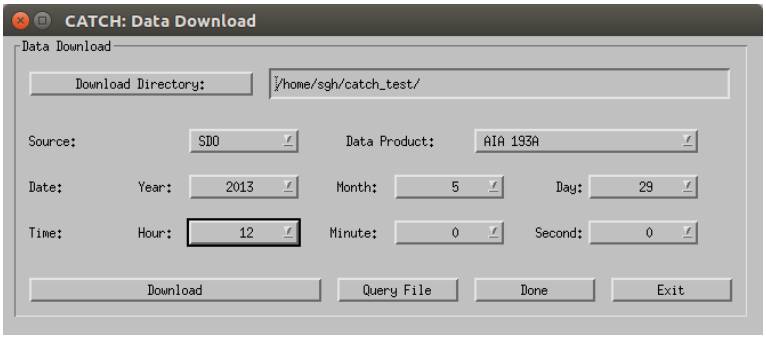
- QUERY FILE:
  Check for the data product closest to the set date, without downloading.

- DOWNLOAD:
  Queries the closest data product to the set date and downloads it.

- DONE:
  Exit the Download Widget.

- EXIT:
  Exit CATCH.

Figure 4: CATCH DATA DOWNLOAD



4. Coronal Hole Extraction

The CORONAL HOLE EXTRACTION option is used to extract coronal holes from EUV (193/195 Å) and to calculate the associated parameters.

The options are:

- FILE MANAGEMENT:
  - OUTPUT/DATA DIRECTORY:
    By clicking the button, you may navigate to the directory or you may type the path into the text field. In the output directory the results will be saved, the data directory specifies where the EUV data is stored.
  - REFRESH:
    Refresh the files list.
  - FILES LIST:
    Select an EUV file (can be a FITS file or a IDL-save file created by CATCH).
  - PSF ON/OFF:
    Apply a point spread function deconvolution to AIA/SDO 193 Å images.

    Note: *For full resolution (4096x4096) it can take some time. This also holds for the first time a PSF deconvolution is applied as the point spread function has to be created (will be saved for future uses in the CATCH directory).*
  - LBC ON/OFF:
    Apply a Limb Brightening Correction (LBC) based on Verbeeck et al. (2014) when loading the data.
  - RESOLUTION:
    Select the pixel resolution for the input file. Files with lower resolution than selected can be scaled up using the SSWIDL function *rebin_map.*
  - LOAD:
    Loads and processes the selected file.
- EXTRACTION PARAMETERS:
  - THRESHOLD:
    Select a threshold for the extraction. It is based on the median intensity of the solar disk (see Rotter et al. 2012; Reiss et al. 2015; Hofmeister et al. 2017 and Heinemann et al., 2018 for more details).
  - MORPH RADIUS:
    Select the radius for the morphological operators (*morph_open* and *morph_close*) to smooth the coronal hole boundary. Set to 1 for no morphological operations.
  - HISTOGRAM:
    Displays the intensity histogram of the solar disk with the currently selected threshold (red vertical line). This is used to find an optimal threshold using the method proposed by Krista & Gallagher, 2009.

- APPLY EXTRACTION:
  Applies the coronal hole extraction based on the selected threshold and morph radius. All found structures are then over-plotted on the EUV image displayed to the right. To analyze a specific coronal hole select it by left-clicking into a structure over-plotted in the image.

- CORONAL HOLE PROPERTIES:
  - MEAN VALUES AND UNCERTAINTY VALUES:
    When selecting a coronal hole in the EUV IMAGE after initiating APPLY EXTRACTION five boundaries of the selected coronal hole are created. One with the selected threshold (in % of the median solar disk intensity) and four with a slightly bigger (+1DN, +2DN) and slightly smaller threshold (-1DN, -2DN). The properties of these five boundaries are calculated and the mean value ($\bar{x}$) is the value displayed (left value). The uncertainty value is the maximum deviation of the individual values from the mean value ($\sigma = maximum(\bar{x} - x_i)$). It represents a measure of the stability of the boundary as explained in Heinemann et al. 2019.
    In principle: At the boundary there is a steep gradient in the intensity which should make the optimal boundary largely independent to small perturbations of the threshold. This can be interpreted as such that the smaller the uncertainty value the better the extraction.

    Note*: The calculated properties do not exactly correspond to the boundary seen in the figures as they represent the mean, calculated from five thresholds around the selected threshold.*
    Note*: The uncertainty calculations can be turned off in the* PROPERTIES *tab.*

  - UNCERTAINTY ESTIMATION USING THE CATEGORY FACTOR:
    The category factor, ζ (displayed in the small box within the CORONAL HOLE PROPERTIES SECTION) shows the stability of the extracted coronal hole boundary according to Heinemann et al. 2019. Using the category factor the boundary stability can be characterized in three categories which is displayed below the category factor as a colored bar.
    - $\zeta < 1$: high stability (green)
    - $1 < \zeta < 2$: medium stability (orange)
    - $\zeta > 2$: low stability (red)

    Note: *It is not possible for every coronal hole to get a high stability boundary.*
    Note: *The categories have been empirically defined from a study of over 700 coronal holes observed by SDO throughout the solar cycle 24.*
    Note*: The category factor might or might not be accurate for SOHO and STEREO data as it has been derived from SDO data and only tested there.*

- EUV IMAGE:
  The loaded data is displayed in the interactive window. A mouse-over shows X and Y position of the cursor (in arcsec) and the intensity of the pixel at the position.
  If APPLY EXTRACTION was initiated, a structure can be selected which is then analyzed. The selected structure will now show a red contour and blue shaded areas (if the uncertainty calculations are enabled). The blue

shaded areas represent the uncertainties of the extracted coronal hole boundary. The red contour is the one extracted by the selected threshold.

- PLOT OPTIONS:

  Opens a tab to adjust the current dmin, dmax, gridsize and contour line thickness. These adjustments may be saved when exiting the widget (through EXIT or DONE) if the LOCK PROPERTIES option in the PROPERTIES is disabled.

- DRAWING TOOL:

  See Section 4.1.

- IN-SITU DATA:

  See Section 4.2.

- IN-SITU PREDICTION:

  See Section 4.3.

- SAVE:

  Save the currently analyzed coronal hole in from of a properties text file and a boundary FITS file. Additional options may be specified in the PROPERTIES. These include saving the maps as a IDL-save file (which can be restored), and full-disk and cut-out images of the coronal hole in form of EPS of PNG files.

  Note: *When saving an analyzed coronal hole, you may override the initially created file (without a number at the end of the file) even if there are multiple numbered files or create a new file numbered in ascending order. Caution is advised when overriding save files.*

- DONE:

  Exit the Coronal Hole Extraction Widget.

- EXIT:

  Exit CATCH..

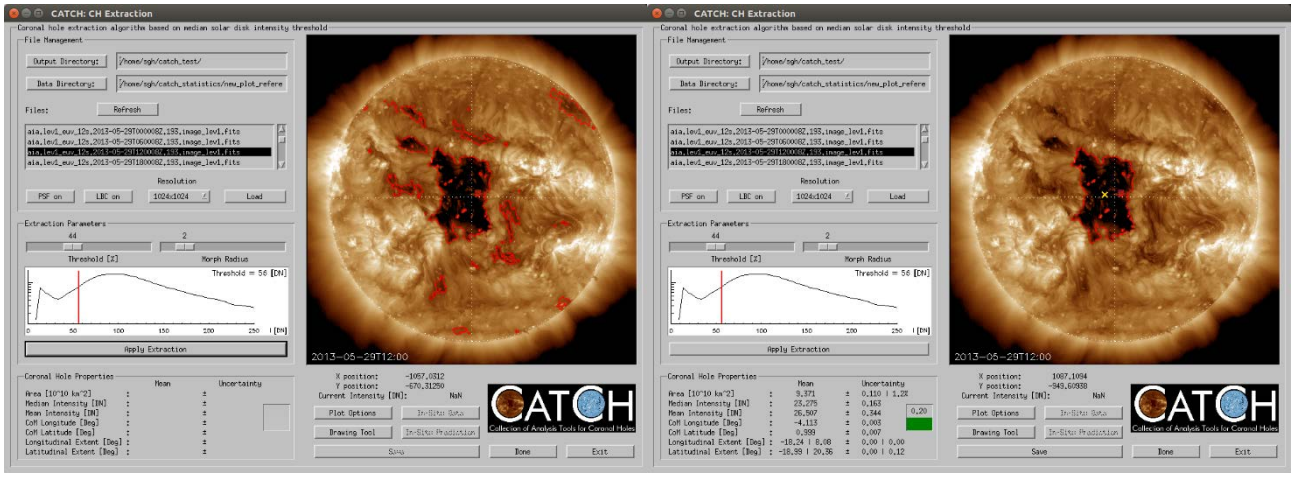


Figure 5: CATCH CORONAL HOLE EXTRACTION after initiating APPLY EXTRACTION (left) and SELECTING the coronal hole under study (right).

4.1 Drawing Tool

The DRAWING TOOL option is used to manually extract coronal holes from EUV (193/195 Å) or to modify a coronal hole boundary extracted with a threshold. This is applied in a 'paint' like fashion. The coronal hole can simply be drawn on the EUV image.

Note: *The wanted area must be filled. Therefore, everything covered by the red overlay will be counted as the area to analyze.*

The options are:

- BRUSH:
  - DRAWING MODE/ERASER MODE:
    Toggle between drawing (red) and erasing (blue).
  - BRUSH SIZE:
    Brush size in pixels.
- SMOOTH:
  - SMOOTH EDGES:
    Apply morphological operators (*morph_open* and *morph_close*) to smooth the coronal hole boundary.
  - MORPH SIZE
    Select the radius for the morphological operators.
- NEW:
  - NEW MASK:
    Remove the current coronal hole mask.
- PLOT OPTIONS:
  - PLOT:
    Opens a tab to adjust the current dmin, dmax and gridsize. These adjustments may be saved when exiting the Coronal Hole Extraction widget (through EXIT or DONE) if the LOCK PROPERTIES option in the PROPERTIES is disabled.
- FINISH:
  - ABORT:
    Close the drawing tool without saving the changes to the coronal hole mask.
  - APPLY:
    Close the drawing tool and apply the changes to the coronal hole mask. Calculate the properties of the new coronal hole.

    Note: *When using a coronal hole mask created with the* DRAWING TOOL *no error values will be calculated as they are linked to the intensity threshold extraction method. The error values will only show NaN.*

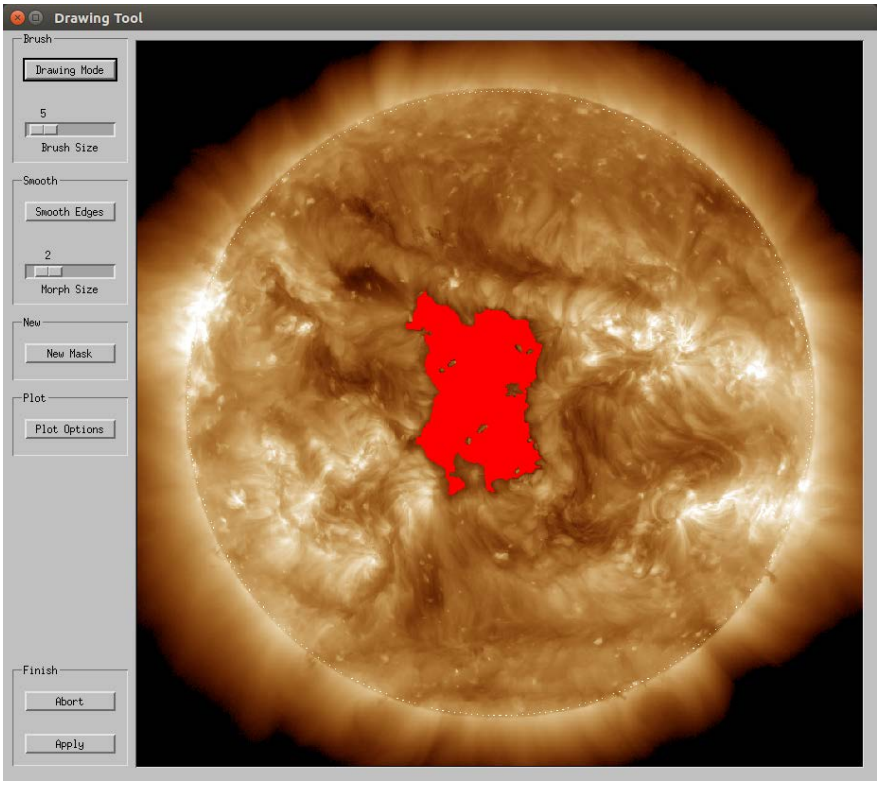


Figure 6: CATCH DRAWING TOOL

4.2 In-Situ Data

The IN-SITU DATA option is used to display the solar wind plasma and magnetic field parameters near the time of the loaded file.

Note: *This option is currently disabled due to problems with the NASA servers for the in-situ data in combination with the SSW database. Will be reintroduced in a future update.*

4.3 In-Situ Prediction

The IN-SITU PREDICTION option is used to calculate and predict the resulting high-speed stream from the extracted coronal hole parameters.

Note: *This option is currently not available as the study for the part is still ongoing.*

5. Magnetic Field Analysis

The MAGNETIC FIELD ANALYSIS option is used to extract and calculate the parameters of the photospheric magnetic field below the coronal hole extracted from EUV before using the CORONAL HOLE EXTRACTION option.

The options are:

- FILE MANAGEMENT:
    - OUTPUT/DATA/CATCH DIRECTORY:
      By clicking the button, you may navigate to the directory or you may type the path into the text field. In the output directory the results will be saved, the data directory specifies where the magnetic field data is stored and the CATCH directory is where the results from the CORONAL HOLE EXTRACTION option were saved.

    - REFRESH:
      Refresh the files list.

    - FILES LISTS:
      Select a magnetic field file in the first file list and an extracted boundary in the second file list. The files must be temporally aligned.

    - RESOLUTION:
      Select the pixel resolution for the input file. Files with lower resolution than selected can be scaled up using the SSWIDL function *rebin_map.*

    - LOAD:
      Loads and processes the selected magnetic field file and the selected coronal hole boundary. Also calculates the general magnetic properties of the photospheric magnetic field underlying the extracted mask.
      General magnetic properties include the mean magnetic field strength (signed and unsigned), magnetic flux (signed and unsigned), flux balance (ratio of signed to unsigned magnetic flux) and the skewness of the magnetic field distribution. See Heinemann et al. 2018b for more details.

- FLUX TUBE ANALYSIS:
  Analyze the magnetic field fine structure in form of flux tube. See Heinemann et al. 2018b for more details.

  Note: *This analysis is computational expensive, especially for the highest resolution. It usually takes several minutes to be completed but it may take up to 20 minutes for one image depending on size, resolution and computational power. There is a loading bar, to track the progress.*

- CORONAL HOLE PROPERTIES:
    - MEAN VALUES AND ERROR VALUES:
      For the magnetic field the same method of calculating the mean and error values is used as in calculating the coronal hole parameters in the CORONAL HOLE EXTRACTION option. For more details see Heinemann et al. 2019.

- MAG IMAGE:

  The loaded data is displayed in the interactive window as a cut-out around the coronal hole. A mouse-over shows X and Y position of the cursor (in arcsec) and the mean magnetic field strength of the pixel at the position. Overlayed on the magnetic field are 3 contours (red, 2x blue). The blue contours represent the smallest and biggest boundaries used for the calculation as explained above. The red contour is the one extracted by the selected threshold.

- PLOT OPTIONS:

  Opens a tab to adjust the current dmin, dmax, gridsize and contour line thickness. These adjustments may be saved when exiting the widget (through EXIT or DONE) if the LOCK PROPERTIES option in the PROPERTIES is disabled.

- SAVE:

  Save the currently analyzed coronal hole in from of a properties text file and a boundary FITS file. Additional options may be specified in the PROPERTIES. These include saving the maps as a IDL-save file (which can be restored), and full-disk and cut-out images of the coronal hole in form of EPS of PNG files.

  Note: *Save files created from numbered input (*_CATCH_binary_mask_<Nr>.fits) are numbered in the same way.*

- DONE:

  Exit the Magnetic Field Analysis Widget.

- EXIT:

  Exit CATCH.

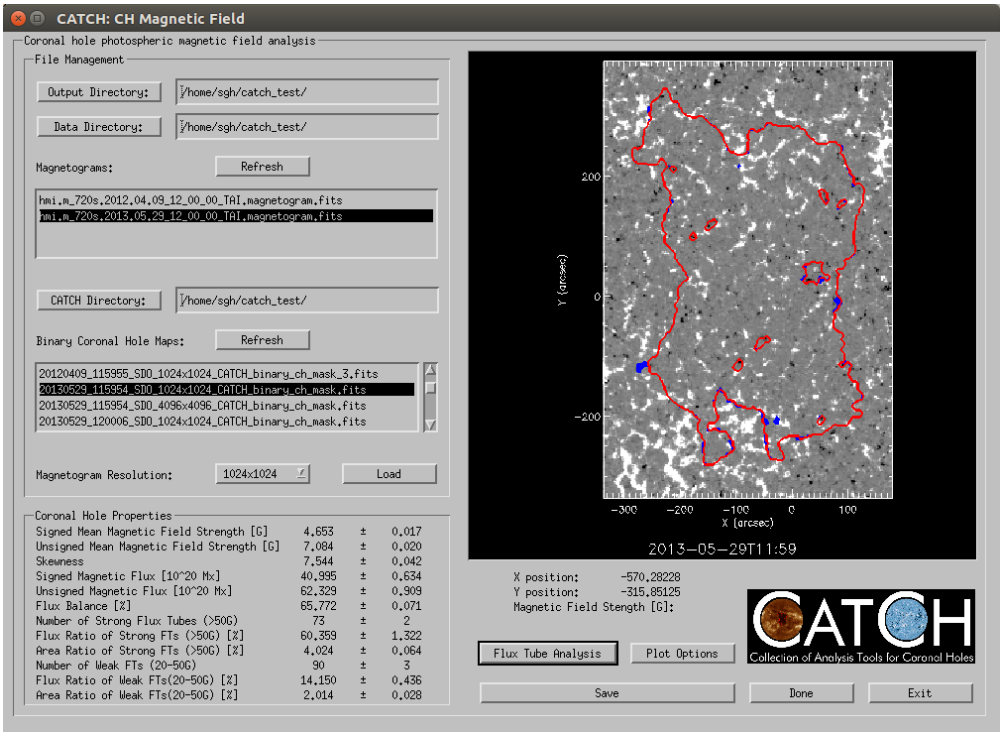


Figure 7: CATCH MAGNETIC FIELD ANALYSIS

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