PRAIA FITS Header Extraction Task

Version 3.0.4

- User Guide -

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First V3 release (version 3.0.0): 11 January 2019

Last V3 release (version 3.0.4): 11 January 2023

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1 Introduction

This document presents the functionalities of the PRAIA FITS header extraction task, release version 3.0.4. In any publication that made use of the PRAIA FITS header extraction task, please insert the sentence "This work made use of the PRAIA package." in the Acknowledgements. Please also cite in your publication the following article which briefly refers to this auxiliary PRAIA task: Assafin (2023).

PRAIA stands for "Package for the Reduction of Astronomical Images Automatically". It is a standalone package fully developed in FORTRAN with no graphic interfaces. It is composed of multiple independent tasks. Each task is characterized by its source/executable code and its input text file (ASCII format) with editable input parameters. The tasks can be run in scripts for the astrometry and photometry of observations in (standard or not) Flexible Image Transport System (FITS, Wells et al. 1991) format. PRAIA allows full control by the user to manipulate input and output data with his/her own preferred external statistical, plotting and visualization tools. The tasks of the PRAIA package are publicly available at https://ov.ufrj.br/en/PRAIA/.

An important auxiliary task of the package, used mostly in astrometric works with PRAIA, is the PRAIA FITS header extraction task - hereafter PHE. It extracts all useful astrometric and photometric information from FITS headers and outputs it on file. The file content can be later edited or corrected, specially when important or necessary fields are missing, like the central coordinates of the Field-of-View (FOV). PHE is very useful for storing observation information that can be later used and manipulated by other programs or packages. It serves as a practical auxiliary tool for generating the input file with FOV information for the PRAIA astrometry task (Assafin, 2023).

An important notice: PHE does not extract headers from FITS data cubes. The task assumes that each input FITS file regards to a single FITS image.

2 FITS Header Extraction with PRAIA

The current version 3 (first released in 2019) underwent major improvements in all aspects with respect to the previous versions, including the possibility of registering time instants from FITS headers with absent or incomplete time information. It is the latest and current PHE version in use.

The most fundamental FOV information contained in FITS headers are its sizes, the central coordinates and time data that allows for the knowledge of the mid-instant of the exposure. All this information is needed for FOV astrometry. Time information is essential for photometry work. Other useful information for registration purposes are the filter used in the observation and the target designation.

PHE extracts all this information from the FITS headers of a list of images and outputs it on file. In particular, PHE now allows for registering time data input by the user. This feature is very useful when the FITS headers have absent, incomplete or incorrect time information.

Although image headers should conform to the rules of FITS format, PHE is prepared to deal with a variety of non-standard FITS headers nicely.

3 Creating the Executable Code and Running the Task

Currently the task executable runs only under MacBook and debian-based Linux operation systems. It was thoroughly tested with Ubuntu distributions 16.04–22.04. The task codes consist of 2 files:

- PRAIA_FITS_header_extraction_3_0_04.f: the FORTRAN source code
- PRAIA_FITS_header_extraction_3_0_04.dat: the input data file

To create the executable task file PRAIA_FITS_header_extraction_3_0_04, execute the following command in the prompt line:

gfortran -O3 PRAIA_FITS_header_extraction_3_0_04.f -o PRAIA_FITS_header_extraction_3_0_04

Here, gfortran is the native FORTRAN compiler. To run the task, as in the usual style of PRAIA tasks, simply execute the following command in the prompt line:

```
PRAIA_FITS_header_extraction_3_0_04 < PRAIA_FITS_header_extraction_3_0_04.dat
```

Some information is output on the screen. To store it on file (e.g. on `screen_output.txt`), execute the following command in the prompt line:

```
PRAIA_FITS_header_extraction_3_0_04 < PRAIA_FITS_header_extraction_3_0_04.dat > screen
_output.txt
```

The name of input data file ("`PRAIA_FITS_header_extraction_3_0_04.dat`" in the example) can be freely modified by the user. However, it is recommended that the user keeps track of the released versions being used, as the entries of the input data file may vary from version to version. Avoid using mixed versions of executables and input data files, as crashing or wrong outputs may result.

As is the case with many other `PRAIA` tasks, by construction, there are many ways of building automatic scripts with `PHE`. We leave it to the creative/experienced user the building of such scripts.

4 Configuring the PRAIA FITS Header Extraction Task

`PHE` extracts FOV information from a list of input FITS images. It preserves the original FITS header contents, with the possible exception of time data depending on the user setup. The configuration of the task is made by furnishing input/output file names and setting parameters and keywords in the task's input data file.

The input data file (say, `PRAIA_FITS_header_extraction_3_0_04.dat`) is a simple ASCII text file. `PHE` executes each block of lines separated with "****" symbols. Each block must regard to a set of input images with the same FITS header structure dealt with the respective `PHE` parameters and keywords. Thus, if wished, one may extract FITS header information from several independent sets of distinct observations in one task run.

It is up to the user to create and edit the input data file. Usually, the user will edit a previously existing file, or make a copy and edit the new input data file. As typical in many other `PRAIA` tasks, the input data file content has some formatting. The entries are followed by comments, separated by a "|" character which delimits the valid fields for the input values. Usually the valid space of the entry fields consists of 50 column spaces or characters, but there are exceptions. No entry line can be removed. The order of each entry in the input data file must not be changed. The layout (position) of the separating "|" character, for each entry, must also not be changed. Otherwise, unpredictable execution errors or wrong output results may occur. In Fig. 1 we display a typical filled in block of an input data file for task version 3.0.4.

After the valid blocks (the ones separated by "****" symbols in sequence), there can be other backup blocks or notes from `PRAIA` and/or any annotations made by the user. In the following sub-sections, we give the meaning of each block entry displayed in Fig. 1 regarding to the input data file of `PHE` version 3.0.4.

4.1 Maximum allowed numbers

There are no limits for the number of blocks, number of input images in the blocks, or image sizes for executing `PHE`.

4.2 List of input FITS images

On line 1 of the block in the `PHE` input data file, we furnish the list of FITS images to be processed. It must be created and furnished by the user. Notice that `PHE` only accepts images in FITS format. The input filenames may or may not contain ".fits" or ".FITS" extensions.

Usually the user will run the task at the same directory where the input FITS images are. If not, the input list file must contain valid paths for the input images from the directory where the task is being run.

4.3 Output file with FOV extracted information

On line 2 of the block, we give the name of the only file output by `PHE`. The output file with FOV extracted FITS header information is created at the same directory where the task is run. The format of

```
list                                          | input list of fits images for header extraction
input_Chariklo                                | output file with extracted information
|---------------------------------------------|   *** Science information ***
OBJECT  |-------------------------------------| FITS header keyword: Target name
FILTER  |-------------------------------------| FITS header keyword: Filter designation
|---------------------------------------------|   *** Dimensions ***
01|-----------------------------------------| PRAIA stamp axes key: (x,y) axes dimensions: (1) Two keywords setup; (2) One keyword setup
|---------------------------------------------|   *** Two keywords setup ***
NAXIS1  |-------------------------------------| FITS header keyword : dimension of axis 1 (x)
NAXIS2  |-------------------------------------| FITS header keyword : dimension of axis 2 (y)
|---------------------------------------------|   *** One keyword setup ***
WINSEC1 |-------------------------------------| FITS header keyword : dimension of axes (1,2) = (x,y) together (windows-like section keyword)
|---------------------------------------------|   *** (RA, Dec) coordinates ***
06|-----------------------------------------| PRAIA stamp WCS key: Right Ascension
04|-----------------------------------------| PRAIA stamp WCS key: Declination
|---------------------------------------------|   *** (RA, Dec) given in one WCS keyword for each ccordinate ***
RA      |-------------------------------------| FITS header WCS keyword: Right Ascension (PRAIA RA  stamp key 1 to 5 only)
DEC     |-------------------------------------| FITS header WCS keyword: Declination     (PRAIA Dec stamp key 1 to 3 only)
|---------------------------------------------|   *** (RA, Dec) given in tangent plane WCS keywords ***
01|-----------------------------------------| PRAIA key: WCS tangent plane convention: (1) FITS Standard; (2) Old (AIPS); (3) SAO polynomials   (RA key 6, Dec key 4 only)
01|-----------------------------------------| PRAIA key: WCS tangent plane RA---TAN coordinate units: 01 = DEG; 02 = RAD; 03 = HOUR                      (RA  key 6 only)
01|-----------------------------------------| PRAIA key: WCS tangent plane DEC--TAN coordinate units: 01 = DEG; 02 = RAD;                               (Dec key 4 only)
|---------------------------------------------|   *** (RA, Dec) in tangent plane format with SAO polynomials ***
13|-----------------------------------------| PRAIA key: SAO polynomial in x (RA) : number of available coefficients in x            (RA key 6, Dec key 4, WCS key 4 only)
13|-----------------------------------------| PRAIA key: SAO polynomial in y (Dec): number of available coefficients in y            (RA key 6, Dec key 4, WCS key 4 only)
02|-----------------------------------------| PRAIA key: SAO polynomial in x (RA) : coordinate units: 01 = DEG; 02 = RAD; 03 = HOUR  (RA key 6, Dec key 4, WCS key 4 only)
02|-----------------------------------------| PRAIA key: SAO polynomial in y (Dec): coordinate units: 01 = DEG; 02 = RAD             (RA key 6, Dec key 4, WCS key 4 only)
AMDX    |-------------------------------------| PRAIA keyword: SAO polynomial in x (RA): root of coefficient keyword string           (RA key 6, Dec key 4, WCS key 4 only)
AMDY    |-------------------------------------| PRAIA keyword: SAO polynomial in y (Dec): root of coefficient keyword string          (RA key 6, Dec key 4, WCS key 4 only)
|---------------------------------------------|   *** Time ***
-2|-----------------------------------------| PRAIA stamp time key
|---------------------------------------------|   *** Time extracted from FITS header ***
JD      |-------------------------------------| FITS header keyword: Start instant of exposure, Julian Date
MJD-BEG |-------------------------------------| FITS header keyword: Start instant of exposure, Modified Julian Date
DATE-OBS|-------------------------------------| FITS header keyword: Start Gregorian date of exposure (with or without hh mm ss.sss start instant), UTC
TM-START|-------------------------------------| FITS header keyword: Start instant of exposure (hh mm ss.sss or variations), UTC
TIME-END|-------------------------------------| FITS header keyword: End   instant of exposure (hh mm ss.sss or variations), UTC
TIME    |-------------------------------------| FITS header keyword: Start and End exposure instants (hh mm ss.sss or variations), UTC
XPOSURE |-------------------------------------| FITS header keyword: Exposure time (FITS header units)
1.0                                           | PRAIA exposure factor F: converts FITS header exposure time units to seconds: exp(s) = F * exp(header)
0.0                                           | PRAIA FITS header exposure time correction (seconds) (put zero if no correction needed)
|---------------------------------------------|   *** Time input by the User ***
59870.52504981574                             | Start time of 1rst image in the input list: Julian Date (PRAIA stamp time key = -1) or Modified Julian Date (time key = -2)
2022                                          | Year    of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
10                                            | Month   of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
18                                            | Day     of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
12                                            | Hours   of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
36                                            | Minutes of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
04.3041                                       | Seconds of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
0.3                                           | Exposure time (seconds) (PRAIA stamp time keys -1, -2 or -3)
0.3                                           | Cycle time (s) (time interval between consecutive exposure start times; PRAIA stamp time keys -1, -2 or -3)
|---------------------------------------------|   *** Time instant offsets (valid for all PRAIA stamp time keys) ***
0000.0                                        | PRAIA time instant offset (Julian years)
00.0                                          | PRAIA time instant offset (Julian months of 30.5 days)
00.0                                          | PRAIA time instant offset (days)
00.0                                          | PRAIA time instant offset (hours)
00.0                                          | PRAIA time instant offset (minutes)
00.000                                        | PRAIA time instant offset (seconds)
**********************************************************************************************************************************************************************
```

Figure 1: A sample of the input data file of `PHE` for version 3.0.4.

this output file is given in Section XXXXXXX.

4.4 Science Information

4.4.1 Target name

On line 4, we indicate the keyword for retrieving the target name from the FITS header. Usually, it is the "OBJECT" keyword.

4.4.2 Filter designation

On line 5, we indicate the keyword for retrieving the used filter designation from the FITS header. Usually, it is the "FILTER" keyword.

4.5 Dimensions

4.5.1 FITS extended headers

There is a FITS keyword present in standard FITS headers that indicates if the FITS header is extended, i.e. if more than one FITS header is present in the FITS image file. Usually this keyword reads "EXTEND" (the standard in FITS format). If "EXTEND" is set "F" (false), the FITS file should not have header extensions, and vice-versa if it is set "T" (true).

However, it is not uncommon to find non-standard FITS files with extended FITS headers and "EXTEND" = "F", and vice-versa. Therefore, `PHE` always looks for extended headers and their content, regardless of the presence or not of correctly configured or not extension header keywords. If a given FITS keyword is present in more than one place or header, only the last content is stored.

4.5.2 Image dimensions

On lines 7 to 12, we indicate the FITS keywords present in the FITS image headers that setup the FOV sizes of the images.

There are two ways for defining FOV sizes with FITS. One way is to furnish sizes in one line, the other uses two lines. In both cases, we must follow strict FITS format rules.

On line 7, we set the `PHE` stamp key for axes dimensions, indicating which of the two possible ways is to be used. Option "1" - the most commonly used one by far - is the "two lines rule". Option "2" indicates the "one line rule".

On lines 9 and 10, we indicate the two keywords for the "two lines rule", respectively for the x and y axes. These two keywords are usually "NAXIS1" and "NAXIS2" with x and y associated to axes "1" and "2" respectively.

On line 12, we indicate the keyword for the "one line rule". In this case, x and y axes dimensions are furnished together in one keyword (usually "WINSEC") in the form [N1_1:N1_2,N2_1:N2_2], so that Equation 1 holds.

$$\begin{aligned} NAXIS1 &= N1_2 - N1_1 + 1 \\ NAXIS2 &= N2_2 - N2_1 + 1 \end{aligned} \tag{1}$$

Regardless of the dimension rule effectively in use, all these lines must be present in the block. Of course, according to the rule, the corresponding active keywords must be correctly furnished, otherwise unpredictable results may occur.

4.6 Right ascension and Declination of the FOV center

From lines 14 to 28, we setup `PHE` to retrieve the (α, δ) centre of the FOV given in the FITS headers.

The (α, δ) centre is extracted as it is, without any attempt to convert or correct coordinates. It is up to the user to know the reference system and epoch of the registered coordinates.

Sometimes, the header explicitly indicates the reference system with words like "FK4", "FK5" or "ICRS", and the epoch as "B1950.0" or "J2000.0". Sometimes only the word "B1950.0" is given, which usually indicates coordinates given in the old FK4 system at epoch B1950.0. Sometimes only the word "J2000.0" or "J2000" is present, meaning that the coordinates are at epoch J2000.0, but leaving an ambiguity as it may refer to the old FK5 system or the current standard ICRS system. Even so, as both systems share roughly the same equator and equinox at the 100 mas level, this ambiguity is of no practical importance and poses no problem, since the FOV center does not need to be defined - and is actually not usually known - at this accuracy and precision level.

The extraction setup of the right ascension comes together with that of declination and vice-versa. The user must pay attention not to make inconsistent setups for the extraction of (α, δ) coordinates.

On lines 14 and 15, we furnish `PHE` stamp keys for right ascension and declination. They indicate in practice which Word Coordinate System (WCS) FITS keywords the task must search for in the FITS headers. These two stamp keys define the format which `PHE` uses to retrieve the (α, δ) values. Right ascension and declination valid stamp key values are as follows:

Right Ascension (line 14):

- 01 - RA given in sexagesimal format: hh mm ss.sss (hours)
- 02 - RA given in sexagesimal format: dg mm ss.sss (degrees)
- 03 - RA given in hours and decimal fraction: hh.hhhhh
- 04 - RA given in degrees and decimal fraction: dg.dgdgdg
- 05 - RA given in radians: rad.radradrad
- 06 - RA obtained from tangent plane projection (RA—TAN), see WCS convention key/keywords

Declination (line 15):

- 01 - Dec in sexagesimal format: dg mm ss.sss (degrees)

- 02 - Dec in degrees and decimal fraction: dg.dgdgdg
- 03 - Dec in radians: rad.radradrad
- 04 - Dec obtained from tangent plane projection (DEC—TAN), see WCS convention key/keywords

4.6.1 Right ascension and Declination in one FITS keyword each

On lines 17 and 18, we indicate FITS header WCS keywords for the direct extraction of right ascension and declination values respectively. These keywords are only active and valid for `PHE` stamp keys 01 to 05 for right ascension, and 01 to 03 for declination, i.e. for (α, δ) values not given in tangent plane WCS format. Usually these two WCS keywords are expressed as "RA" and "DEC", being easily recognized in the FITS headers.

4.6.2 Right ascension and Declination in WCS tangent plane format

The (α, δ) can be indirectly furnished in a number of FITS header tangent plane formats. We setup this on lines 14 and 15 by using `PHE` stamp keys 6 (right ascension) and/or 4 (declination).

On line 20, we indicate which WCS tangent plane convention `PHE` must use:

- 1 - FITS Standard
- 2 - Old (AIPS)
- 3 - SAO polynomials

On lines 21 and 22, we furnish the units in which the tangent plane coordinate values to be retrieved are expressed:

- line 21 - WCS tangent plane RA—TAN coordinate units: 01 = degrees; 02 = radians; 03 = hours
- line 22 - WCS tangent plane DEC–TAN coordinate units: 01 = degrees; 02 = radians

`PHE` works with three valid WCS tangent plane formats: FITS standard, old AIPS and SAO polynomials. The user recognizes the format being used by the characteristic FITS keywords in the FITS headers associated for each one of them. Common to all formats are the keywords "CRPIX1", "CRPIX2", "CRVAL1" and "CRVAL2" connecting the reference pixel with a (α, δ) origin. A generalized form resembling the Complete First Degree Polynomial model in tangent plane astrometric reductions is expressed by adding four keywords. They are the "CD1_1", "CD1_2", "CD2_1" and "CD2_2" in the FITS conventional standard format, and "CDELT1", "CDELT2", "CROTA1" and "CROTA2" in the old AIPS format. When pairs of such keywords have equal values (with one of the pairs with opposite signs), we have the more simple yet more common representation of scale and rotation angle in the tangent plane.

4.6.3 Right ascension and Declination in WCS tangent plane format with SAO polynomials

In SAO polynomial convention, more precise and accurate (α, δ) values are retrieved since the FOV distortions are mapped in the tangent plane with bi-variate polynomials $PX = PX(x, y)$ and $PY = PY(x, y)$, expressed as in Equation 2.

$$PX = \sum_{j+i=1}^{2} a_{ji}\ x^j y^i$$
$$PY = \sum_{j+i=1}^{2} b_{ji}\ x^j y^i \tag{2}$$

(Notice that for $j + i = 0$ we already use "CRPIX1" and "CRPIX2" values). The setup using WCS tangent plane SAO polynomial convention format is as follows:

From lines 23 to 28, we setup `PHE` for WCS tangent plane format with SAO polynomials.

- line 23 – SAO polynomial in x (RA) : Number of available coefficients in X
- line 24 – SAO polynomial in y (Dec): Number of available coefficients in Y
- line 25 – SAO polynomial in x (RA) coordinate units: 01 = degrees; 02 = radians; 03 = hours
- line 26 – SAO polynomial in y (Dec) coordinate units: 01 = degrees; 02 = radians
- line 27 – SAO polynomial in x (RA) : root name of coefficient keyword string
- line 28 – SAO polynomial in y (Dec): root name of coefficient keyword string

The keys and keywords from lines 20 to 28 are only active and valid if `PHE` was set to retrieve (α, δ)s using the WCS tangent plane convention with `PHE` stamp keys 6 and/or 4 at lines 14 and 15. The keys and keywords from lines 23 to 28 are only active and valid if `PHE` was set to retrieve (α, δ)s using the WCS tangent plane convention with SAO polynomials, set with option "3" in line 20.

4.7 Time

`PHE` assumes that time is given in UTC (Universal Time Coordinated), and makes no attempts to convert it from or to local or Greenwich time.

From lines 31 to 58, we setup `PHE` to get time information in order to compute the mid-instants of the images. There are 3 parts devoted to time setup: a) time extracted from the FITS header; b) time input by the user; c) time offsets.

On line 31, we furnish the PRAIA stamp time key that defines how `PHE` obtains the mid-instants. The options are shown below.

Negative PRAIA stamp time keys mean time input by the user:

- -3 – Time input by the user, with reference instant in Gregorian Date
- -2 – Time input by the user, with reference instant in Modified Julian Date (MJD)
- -1 – Time input by the user, with reference instant in Julian Date (JD)

Positive PRAIA stamp time keys mean time retrieved from the FITS header:

- $+1$ – Start date and time furnished together in one line/keyword: yr mo day (day mo yr) and hh mm ss.sss (usually at "DATE-OBS" keyword).
- $+2$ – Start date and time in separate lines/keywords: yr mo day (day mo yr) usually furnished in "DATE-OBS" keyword.

  – If the exposure time is given, only the UTC start time (usually hh mm ss.sss) is needed, and given in a separate keyword (usually "UT" or "TIME-BEG" keywords).

  – If the exposure time is not given, then the UTC start and end exposure times must be furnished. They can be evoked by separate keywords (usually "UT"/"TIME-BEG" and "TIME-END" keys), or evoked by the same keyword (user-defined, usually "TIME"), usually in the hh mm ss.sss format.

  – The start and end times may be also furnished in hh mm.mmm or even in sss.sss format.
- $+3$ – Start time in Julian Date (JD): the date is computed from the JD (usually furnished by the "JD" keyword); the exposure time must be also furnished.
- $+4$ – Start time in Modified Julian Date (MJD): the date is computed from the MJD (usually furnished by the "MJD" keyword); the exposure time must be also furnished.

4.7.1 Time extracted from FITS headers

From lines 33 to 41, we setup `PHE` to extract the necessary time information to compute mid-instants. Only a subset of the information is used in accord to the furnished PRAIA stamp time key.

- line 33 – Keyword for start instant of exposure, Julian Date
- line 34 – Keyword for start instant of exposure, Modified Julian Date
- line 35 – Keyword for start Gregorian date of exposure (with or without hh mm ss.sss start instant)
- line 36 – Keyword for start instant of exposure (hh mm ss.sss or variations)
- line 37 – Keyword for end instant of exposure (hh mm ss.sss or variations)
- line 38 – Keyword for start and End exposure instants (hh mm ss.sss or variations)
- line 39 – Keyword for exposure time (no time unit is assumed for exposure time)
- line 40 – Exposure factor F to convert FITS header exposure time units to seconds: exp(seconds) = F * exp(header time units)
- line 41 – FITS header exposure time correction (`ETC`) (seconds) (put zero if no correction needed)

Here, the time setup must be such that it allows `PHE` to find the starting instant and exposure time of the image. This information suffices to get the mid-instants. Regardless of the existence or not of exposure data, mid-instants can also be computed if starting and ending exposure instants are available, which also allows for recovering exposure times, which should match exposure data eventually furnished directly in the header.

Many or even all of these keywords may be present in the FITS header. It is up to the user to know which sets (set) result(s) in the correct mid-instants, and setup `PHE` accordingly.

Sometimes exposures are not given in seconds (FITS standard). On line 40, the user sets up a factor which brings header exposure values to second units (use 1.0 if it is already in seconds). It is mandatory to convert header exposure times to seconds, as `PHE` internally works with exposure times in this unity.

Sometimes the exposure time values in the header are incorrect. Or exposure times are simply absent in the header. `PHE` offers the possibility to correct this by allowing the user to set an exposure time correction `ETC` (seconds) on line 41. If exposure times are present in the header, the stamped values are added by `ETC`. And if no exposure times are furnished in the header, `PHE` assumes `ETC` as the exposure time of observations. If no `ETC` correction is needed, put zero on line 41, otherwise the `ETC` value will be always taken into account.

4.7.2 Time input by the User

From lines 43 to 51, the user directly furnishes `PHE` with the necessary time information to compute the mid-instants.

- line 43 – Start time of 1rst image in the input list: Julian Date (PRAIA stamp time key = -1) or Modified Julian Date (time key = -2)
- line 44 – Year of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
- line 45 – Month of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
- line 46 – Day of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
- line 47 – Hours of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
- line 48 – Minutes of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
- line 49 – Seconds of starting time of 1rst image in the input list (PRAIA stamp time key = -3 only)
- line 50 – Exposure time (seconds) (PRAIA stamp time keys -1, -2 or -3)
- line 51 – Cycle time (s) (time interval between consecutive exposure start times; PRAIA stamp time keys -1, -2 or -3)

This PHE feature is useful when the FITS header has insufficient time information, or even no information at all. PHE assumes that the images are ordered in chronological order in the input file list. Entries from lines 43 to 49 regard to the start exposure time of the first image in the list. The value furnished on line 43 is interpreted as JD or MJD in accord to the furnished PRAIA stamp time key. If this key is "-3", the start exposure time of the first image in the input list is in Gregorian Date format, furnished from lines 44 to 49. The mid-instants of each image i are computed with the start time and the use of the exposure and cycle times as in Equation 3.

$$Mid-instant(JD) = Start\ instant(JD) \quad + \quad \frac{(i-1)*cycle(s) + \frac{exptime(s)}{2}}{86400s} \tag{3}$$

4.7.3 Time offsets

From lines 53 to 58, we set PHE to apply a constant time offset to the computed mid-instants of all images, regardless of the method used (time extracted from FITS header or input by the user).

- line 53 – Time instant offset (Julian years)
- line 54 – Time instant offset (Julian months of 30.5 days)
- line 55 – Time instant offset (days)
- line 56 – Time instant offset (hours)
- line 57 – Time instant offset (minutes)
- line 58 – Time instant offset (seconds)

This PHE feature is useful to correct clock issues during the acquisition of observations, or to convert local times to UTC.

This ends the input block of PHE with the characteristic "*******" symbols.

5 PRAIA FITS header extraction output

The only output by PHE is a file containing all extracted FOV information from the FITS headers of each image. Each line in the file corresponds to a FITS image, following the same order of the input image list. For each FITS image (line in the output file), the FORTRAN-like content and format reads:

- iah,iam,sa,isig,idg,idm,ds,iuth,iutm,sut,iutano, iutmes,iutdia,djm,dj,iexps,ichfil,infits,ichobj,nx,ny
- format(1x,i2.2,1x,i2.2,1x,f7.4,1x,a1,i2.2,1x,i2.2,1x,f6.3,2x,i2.2, 1x,i2.2,1x,f5.2,1x,i4.4,1x,i2.2,1x,i2.2, f16.8,1x,f16.8,2x,i4.4,2x, a20,2x,a50,1x,a20,2(1x,i5.5))
- iah,iam,sa – FOV right ascension of observation (h, m, s)
- isig,idg,idm,ds – FOV declination of observation (^{o}, ', ") .:. (isig is the sign)
- iuth,iutm,sut – (h, m, s) mid-instant of observation at observation date
- iutano,iutmes,iutdia – (year, month, day) date of observation
- djm,dj – Modified Julian Date and Julian Date of observation
- iexps – Exposure time (seconds)
- ichfil – Filter
- infits – FITS file name
- ichobj – Target designation
- nx,ny – (x, y) FOV dimensions (pixels)

If science information (target name, filter) are not available in the FITS headers, they will appear as blank fields. If (α, δ) information are missing or could not have been found, "99" code values appear in the corresponding fields.

It is up to the user to edit and correct the output information of the FOVs, particularly when important content is missing or wrong, such as (α, δ) centre coordinates. The `PRAIA` FOV edit task of the `PRAIA` package allows for the automatic correction (edition) of `PHE` output file contents, such as the target name and filter info. It also corrects all time information, allowing for the edition of the year time stamp, exposure time and application of time offsets. The task also performs corrections in the FOV coordinates, such as the multiplication or division of right ascensions by $\cos\delta$, precession to J2000 and replacement by the ephemeris of Solar System bodies at the mid-instants of the observations. This task is particularly useful in the case of old Solar System observations, when such issues more often than we would like occur.

`PHE` output files (as they are formatted) serve as FOV input information for the `PRAIA` astrometry task (Assafin, 2023). In this case, at least the FOV central coordinates (even if wrong by about several arc minutes) and the mid-instants of observations must be present. Also, ideally (though not mandatorily) the FOV centre coordinates should be ICRS, topocentric, astrometric, and times should be in UTC.

6 Running PHE: an Example

In the `Example_input_files_FITS_header_extraction.zip` file that comes with `PHE` distribution, one has:

- `PRAIA_FITS_header_extraction_3_0_04.dat` - `PHE` input data file
- `TritaoELseq10_05.01.29_0001.fits` - Sample FITS image file
- `list` - Input file with list of images (in this case, the only image in the example)

The sample FOV is a 60s exposure of 6'x6', 2048 x 2048 pixels sizes taken in 2017 far from the meridian with the OPD/LNA 1.6m telescope (IAU code 874) with objects ranging from 10.5 to 21 G magnitudes. It has few stars, some very faint, some very bright with CCD leaking features. The observation was made during a campaign to observe Neptune and Triton, visible in the field (see Assafin 2023).

After running `PHE` with the command line:

`PRAIA_FITS_header_extraction_3_0_04` < `PRAIA_FITS_header_extraction_3_0_04.dat`

one should generate the same output file furnished in the `Example_output_files_FITS_header_extraction.zip` that also comes with `PHE` distribution:

- `FOV_Triton_1` - Output file with FOV information data

References

Assafin M., 2023, Astrometry with PRAIA, Planetary and Space Science (submitted)

Wells, D. C., Greisen, E. W., Harten, R. H., 1981, A&AS, 44, 363