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Satellite Operations and Infrastructure

NEOSSat FITS Image User's Guide

FITS Processor Version 4.00

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Canada

Approvals

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Revision History

Rev.	Description	Initials	Date
Draft	Initial Release based on FITS Processor 2.06 (beta)	VA	12 Oct 2018
2.07	Updates for FITS Processor 2.07	SH	07 Dec 2018
2.08	Updates for FITS Processor 2.08, including: • Added AVG_VEL field in meta-data • Fixed OVERSCAN field in meta-data for all cases • Added section of image cleaning conventions	VA / RK	01 Aug 2019
3.00	Updates for FITS Processor 3.00, including: • WCS header fields: WCSNAME, WCSAXES, CRPIX, CTYPE, CUNIT, CDELT, CRVAL, CROTA2, CDx_y • New header fields: FILTER, WAVELENG, BANDPASS, LEN_SAVE • Optional user-based fields: PROJECT, PROP_ID, PI_NAME, TITLE	VA / MH / JFC	17 April 2020
4.00	Initial Integration with FITS Image Processing Pipeline • Python-cleaned "_cord.fits" and "_cor.fits" images • New header fields (all images): GEO_LAT, GEO_LONG, NBSATPIX • New header section (calibrated images): CAL_INFO, with new header fields: ARCHIVE, CAL_LVL, PRODUCT, OBS_ID, OBSTYPE, RELEASE, SW_REF, DARKTMIN, DARKTMAX, DARKTMED, DARKMODE and DARK_### • ".fits.gz" RAW and Cleaned file compression	AF / LK / VA	22 Feb 2021

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1 SCOPE

1.1 Purpose and Scope

This document presents a user's guide to the NEOSSat FITS Images.

1.2 Document Overview

First, some reference document and basic version information is provided.

Then, an overview of the NEOSSat CCD and image coordinates is provided.

Finally, the detailed format of the NEOSSat FITS image file is provided. Details of the primary header (i.e., the 'FITS header') are specified, as well as binary extensions that contain unprocessed raw telemetry data, embedded in every FITS image file. These binary extensions could be read with programs such as Matlab.

2 DOCUMENTS

2.1 Applicable Documents

None

2.2 Reference Documents

Table 1: Reference Documents

RD No.	Document Number	Document Title	Rev. No.	Date
RD-1.	fits_standard30aa.pdf	Definition of the Flexible Image Transport System (FITS), FITS Working Group. Available from http://fits.gsfc.nasa.gov/fits_standard.html	3.0	10 July, 2008

3 VERSION INFORMATION

3.1 Current Version Identification

- This document applies to version 4.00 of NEOSSat FITS Production Software.

Future updates in the NEOSSat FITS production software could add/remove/change header information or otherwise affect performance. The header tag CONV_VER indicates which version of the FITS Converter ground segment software was used to create the FITS image. Tags ROE_SW and S921_SW indicate flight software versions used to create the FITS image.

4 IMAGE SPECIFICATIONS, AND SCIENCE CCD FRAME

The following illustrations provides the basic specifications of NEOSSat image coordinates, either from Science ROE or Star Tracker ROE. Depending on onboard settings, an image may be a subset of these coordinates, or even may be composed of a mosaic of multiple smaller sub-images.

Note that in some case (e.g. binned image) the coordinates may be transformed.

Note also that depending on the direction of the readout (opamp setting), it is possible to have images which coordinates will go outside these boundaries, mainly for diagnostic purposes since extra pixels values will not correspond to an actual CCD pixel but rather be "overscan" data.

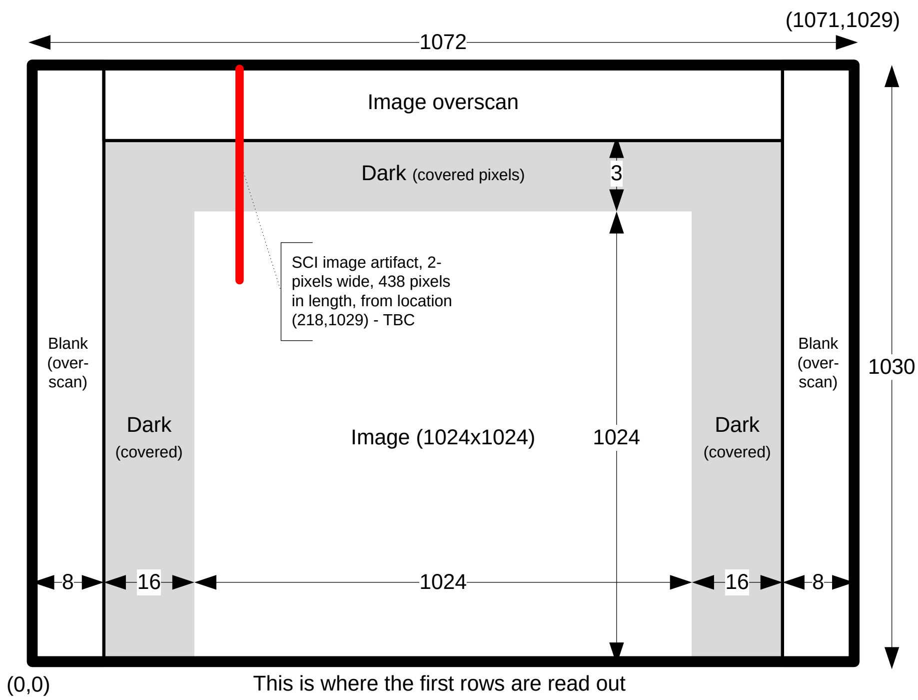
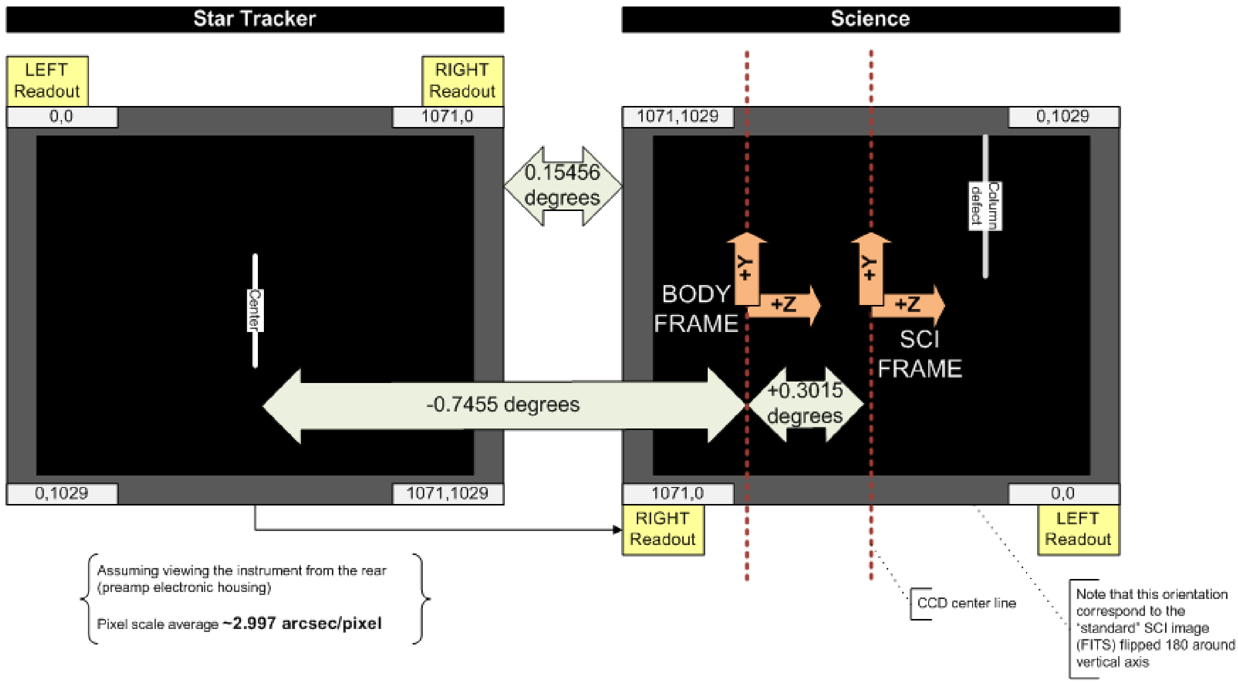


Figure 1: Explanation of the satellite image coordinates

The field of view within the 1024 x 1024 area 'seeing' space, is 0.86 degrees. Therefore, each pixel correspond approximately to 3 arc-seconds.

The Science CCD frame is defined with its origin at the center of the 1024x1024 CCD area 'seeing space'. It is aligned in X and Y with the body frame, and offsetted by 0.3015 degrees along +Z.


Star Tracker
Science
LEFT Readout
RIGHT Readout
0,0
1071,0
0,1029
1071,1029
Center
0.15456 degrees
-0.7455 degrees
1071,1029
0,1029
1071,0
0,0
RIGHT Readout
LEFT Readout
Column defect
+Y
+Z
BODY FRAME
SCI FRAME
+0.3015 degrees
Assuming viewing the instrument from the rear (preamp electronic housing)
Pixel scale average ~2.997 arcsec/pixel
CCD center line
Note that this orientation correspond to the "standard" SCI image (FITS) flipped 180 around vertical axis

5 FITS FORMAT

5.1 General

The application generates Multi-Extension FITS (MEF), which means it consists of the primary header and data unit (HDU), plus extensions containing raw meta-data. The purpose of the extensions is to allow access to raw, un-processed and complete data if necessary (e.g. for verification of data displayed in the primary header, or to get more resolution than what would be displayed in the primary header).

Enough header blocks (2880 bytes each) are created to contain all image meta-data, and the primary data array contains the image pixels (16-bit for each pixel), padded at the end with zeros if necessary so that 2880-bytes data-block boundaries are respected.

Each record strictly follows FITS standard, :

1. Keyword name is uppercase and fits in first 8 bytes (bytes 1 to 8) (and is padded with spaces to be 8 bytes long). *Note that in some case we use leading zeros for indices, which is specifically forbidden in the FITS standard (e.g. CCDCLK01 instead of CCDCLK1)*.
2. When a value follows, next two bytes (bytes 9 and 10) are "= " (equal sign plus a space);
3. Remaining bytes (11 to 80) contains the value in ASCII text and a comment preceeded by "/".

5.2 Primary Header Keyword Records Summary

Keyword Record	Unit	Description
SIMPLE	String	Set to True ("T"), must be first record for standard FITS
BITPIX	bits	Bits per pixel for image data. Set to 16 in our case
NAXIS	Axis	Number of axis in the represented image. Our image is a 2-D CCD plane, so this value is set to 2
NAXIS1	Pixels	Size of image – Xaxis, in units of pixels. Note that in our case, depending on the read list, an "image" may be a mosaic of several sub-images from an exposure. NAXIS1 and NAXIS2 provide the outside boundary of a composite image containing all sub-images
NAXIS2	Pixels	Size of image – Yaxis, in units of pixels. See NAXIS1 for more details
BSCALE	Factor	Data scaling. Set to '1'
BZERO	Adu	zero def of pixel (for unsigned short). Set to 32768
IMAGE		**Placeholder for image specification header**
BIASSEC	Pixel range	Overscan area, in image coordinates [colStart:colEnd,rowSt,rowEnd]
TRIMSEC	Pixel range	Science area, in image coordinates [colStart:colEnd,rowSt,rowEnd]
DATASEC	Pixel range	Science area, in image coordinates [colStart:colEnd,rowSt,rowEnd]
CCDSEC	Pixel range	Science data coordinates in CCD system [colStart:colEnd,rowSt,rowEnd]. Per image coordinate conventions, indices start at 1, not zero.
CORNER1X	Column	Image coordinates **in CCD system**, lower left corner column. Indices starts at zero, and may be negative to include overscan. See section "Image Coordinates" for more details

CORNER1Y	Row	Image coord **in CCD system**, Lower Left Corner row
CORNER2X	Column	Image coord **in CCD system**, Upper Right Corner column
CORNER2Y	Row	Image coord **in CCD system**, Upper Right Corner row
OPAMP	String	Read out chain used: Left, right, both. Note that if this image is composed of sub-images, individual sub-images could have different OPAMP settings. Individual OPAMP settings are not provided in the FITS header.
GAIN	String	Estimated CCD amplifier gain in electrons per analog unit. When OPAMP String equals "both", two comma-separate values are specified (GAIN_LEFT, GAIN_RIGHT).
RDNOISE	String	Estimated CCD readout noise in electrons. When OPAMP String equals "both", two comma-separate values are specified (RDNOISE_LEFT, RDNOISE_RIGHT). If binning is in effect, multiply the RDNOISE by the binning factor, as binning is implemented on the CCD as a hardware summation of the contributing pixels, (charge from group of pixel cells dumped into the accumulators for the row/column).
FILTER	String	Filters in the beam. Fixed to 'CLEAR' for NEOSSat
WAVELENG	Angstrom	Central wavelength of the filter (in Angstrom). Value is estimated and could be refined based on calibration.
BANDPASS	String	Approximate bandpass of the filter (Angstrom,Angstrom). Value is estimated and could be refined based on calibration.
XBINNING	Pixels	Number of grouped CCD pixels, on the X-axis (binning, X)
YBINNING	Pixels	Number of grouped CCD pixels, on the Y-axis (binnin, Y)
COMPR_AL	String	Identification of the algorithm used for compressing image data (by the spacecraft), or "Uncompress" if compression was not used.
COMP_SET	Integer	Compression settings, as reported by the spacecraft. For now, only value '1' is expected, as there is only one possible setting. If image is not compressed, this record will specify "N/A".
N_SUBIMG	Counter	Number of sub-images composing this image. Note that if there is only one main image, this record will be set to zero. If there are sub-images, there will be at least two of them, so this record possible values are 0, then 2 to the maximum number of sub-images. Coordinates of every sub-images are given in subsequent fields, with first sub-image identified as sub-image zero. Note that the maximum number of sub-images is 10.
RGN*nnn*X1	Column	Sub-image *nnn* (starting at zero) , x position of bottom left corner in CCD coordinate system.
RGN*nnn*Y1	Row	Sub-image *nnn* (starting at zero) , y position of bottom left corner in CCD coordinate system.
RGN*nnn*X2	Column	Sub-image *nnn* (starting at zero) , x position of top right corner in CCD coordinate system.
RGN*nnn*Y2	Row	Sub-image *nnn* (starting at zero) , y position of top right corner in CCD coordinate system.
OVERSCAN	Flag	Indicates whether this image contains overscan pixel values (lying outside of the CCD area, therefore not corresponding to actual CCD pixels). Possible values are zero (for NO) and non-zero (for OVERSCAN DATA present). Note that the standard overscan columns on the edge of the CCD chip are not counted as 'overscan' per se.
CREATOR	String	Origin of FITS file. Fixed to "NEOSSat".
TELESCOP	String	Identification of the telescope used to take the image. Fixed to "NEOSSat".

SHUTTER	String	Shutter status (OPEN or CLOSED). The reported status number is given, followed by a description string (e.g. '**0 (open)**'). Dark frame images for NEOSSat are specified by the shutter being closed.
SHUT_AGE	Seconds	Specifies the time elapsed since the SHUTTER state is in effect. Note that a negative number represents time in the past (which will normally be the case).
DETECTOR	String	Identification of the detector being used (Science or Star Tracker) to generate this image.
TIMING		**Placeholder for timing specification header**
TIMESYS	String	Time scale specification (set to 'UTC')
EXPOSURE	Seconds	Actual Length of exposure
AEXPTIME	Seconds	Actual length of exposure. This record is identical to EXPOSURE, and was added because needed by MPS using this particular keyword.
REXPTIME	Seconds	Requested length of exposure. Populated based on user tasking.
DATE-OBS	Date & Time	Date of observation (start of exposure). Format is YYYY-MM-DD**T**HH:MM:SS.sss.
TIME-OBS	Date & Time	Time of observation (start of exposure). Format is YY-MM-DD**T**HH:MM:SS.sss.
JD-OBS	JD	Date of observation (start of exposure). Expressed in Julian Date (continuous count of days since noon Universal Time on Jan 1st, 4713 BCE on the Julian calendar).
R_EXP_S	Date & Time	Requested exposure start time. Format is YY-MM-DD**T**HH:MM:SS.sss. Note that the actual exposure start time may differ from the commanded one.
A_EXP_S	Date & Time	Actual exposure start time. Format is YYYY-MM-DD**T**HH:MM:SS.sss. This is a duplicate of record DATE-OBS, required by MPS.
LEN_FLU	Seconds	Length of the CCD FLUSH operation in the process of taking this image.
LEN_TRAN	Seconds	Length of the frame transfer operation in the process of taking this image.
LEN_READ	Seconds	Length of the frame transfer and readout operations in the process of taking this image.
LEN_PROC	Seconds	Length of post-processing operations in the process of taking this image.
LENDELAY	Seconds	Length of the delay between exposure command execution and the first operation (CCD FLUSH) involved in taking this image.
LEN_SAVE	Seconds	Length of image saving to Flash operation (populated post-OPS-11)
POINTING		**Placeholder for pointing specification header**
EQUINOX	Year	Equatorial coordinates. Fixed to 2000.0 (for J2000)
MODE	String	Spacecraft Attitude Control System (ACS) pointing state. The number (as specified in the spacecraft ACS state diagram) is given, followed by a string identifying the mode. The key imaging modes for NEOSSat are: 16-FINE_POINT : indicates NEOSSat is stabilized relative to fixed stars 14-FINE_SLEW : indicates NEOSSat is slewing to track a moving object. The slew rate can be determined using RA_VEL, DEC_VEL, ROL_VEL. Dark frame images (taken with the shutter closed) typically cannot be taken in these modes and so mode should be ignored on those cases.

		Non-dark images that are in neither FINE_POINT nor FINE_SLEW are typically not useful for science purposes.
MODETIME	Seconds	Time elapsed since the spacecraft entered the specified MODE. This number, expressed in seconds, will always be negative as it represents time in the past.
CMD	Radians	Commanded spacecraft pointing, celestial coordinates, in Science CCD frame. Format = 'RA=x.xxx DEC=x.xxx ROLL=x.xxx'
CMDRA	hrs,min,sec	Commanded Right Acension (RA), in Science CCD frame. Format is 'hh mm ss.s' where hh=hours, mm=minutes and ss.s=decimal seconds
CMDDEC	deg,min,sec	Commanded Declination (DEC) , in Science CCD frame. Format is 'dd mm ss.s' where dd=degrees, mm=minutes and ss.s=decimal seconds
CMDROL	Degrees	Commanded Roll, in degrees, in Science CCD frame.
CMDQ0	n/a	Commanded quaternion qp[0]. Represents QB, or "i" in the "scalar,i,j,k" notation.
CMDQ1	n/a	Commanded quaternion qp[1]. Represents QC, or "j".
CMDQ2	n/a	Commanded quaternion qp[2]. Represents QD, or "k".
CMDQ3	n/a	Commanded quaternion qp[3]. Represents QA, or "scalar".
OBJCTRA	hrs,min,sec	Actual Right Ascension (RA) at start of exposure, in Science CCD frame. Format is 'hh mm ss.s' where hh=hours, mm=minutes and ss.s=decimal seconds.
OBJCTDEC	deg,min,sec	Actual Declination (DEC) at start of exposure, in Science CCD frame. Format is 'dd mm ss.s' where dd=degrees, mm=minutes and ss.s=decimal seconds.
OBJCTROL	degrees	Actual Roll at start of exposure, in Science CCD frame, provided in degrees.
RA	hrs:min:sec	Actual Right Ascension (RA). Same as OBJCTRA using 'hh:mm:ss.s' format, where hh=hours, mm=minutes and ss.s=decimal seconds.
DEC	deg:min:sec	Actual Declination (DEC). Same as OBJCTDEC using 'dd:mm:ss.s' format, where dd=degrees, mm=minutes and ss.s=decimal seconds.
ELA_MIN	degrees	Minimum Earth limb angle attained while exposing, from an axis perpendicular to the image plane.
ELA_MAX	degrees	Maximum Earth limb angle attained while exposing, from an axis perpendicular to the image plane.
ELA_ANG	degrees	Angle to Earth Limb while exposing. **NOTE that at this moment we populate this record with ELA_MIN value. It is TBC if this is adequate**.
SUN_MIN	degrees	Minimum Sun angle attained while exposing, from an axis perpendicular to the image plane.
SUN_MAX	degrees	Maximum Sun angle attained while exposing, from an axis perpendicular to the image plane.
HIST_NB	count	Number of ACS history points (i.e. number of samples of pointing data recorded and provided while exposing) that follows this field. Note that whenever Star Tracker is operating (e.g. in fine pointing modes), the ACS history will contain data exclusively computed from Star Tracker solutions, and provided at the same rate as Star Tracker images (typically between 0.5 and 1Hz). When Star Tracker is not operating, estimated EKF data at full rate (5Hz) is provided.
DELT_*nnn*	seconds	Time difference between this pointing data sample (identified by a sequence number *nnn* starting at 000) and the start of exposure. The first sample can be before the actual exposure start, represented by a negative number here. This is part of the *ACS history*.

DEV_*nnn*	arc-sec	A sample of the spacecraft pointing wander while exposing. Expressed in rotations around X/Y/Z body frame axis, relative to the first attitude data point (therefore DEV_000 will always be "0 0 0"). . This is part of the *ACS history*.
VEL_*nnn*	rad/sec	A sample of the spacecraft estimated velocity. Expressed around X/Y/Z body frame axis at instantaneous time. This is part of the *ACS history*.
AVG_VEL	arcsec/s	Average angular slew velocity in the body frame
RA_VEL	hours/s	Signed angular slew velocity in Right Ascension (RA) at midpoint of the exposure.
DEC_VEL	degrees/s	Signed angular slew velocity in Declination at midpoint of the exposure.
ROL_VEL	degrees/s	Signed angular slew velocity in Roll at midpoint of the exposure.
ENVIRO		**Placeholder for environment data header**
TEMP_CCD	kelvins	Temperature of CCD. If the CCD temperature history is available, the temperature will be the average of all temperature samples taken while exposing (+/- 1 second). If the CCD temperature history is not available, this value is set from the temperature sample sent by the imager after readout (which will be several seconds after exposure, more than 30 seconds for a full image).
CCD-TEMP	Celsius	Temperature of CCD in Celsius. Derived from the value of TEMP_CCD, using formula CCD-TEMP = TEMP_CCD – 273.15.
CCDT_NB	Count	Number of samples included in the CCD temperature history, that follows this field.
CCDT_*nnn*	Various	Provides data related to a specific sample of the CCD temperature history, in addition to the state of the transmitters. Format = '**S.SSS KKK.K TX- TX+**' where **S.SSS** = Number of seconds between this sample and start of exposure (negative if prior exposure). **KKK.K** = Temperature of the CCD in Kelvins. **TX-** = "ON" if minus_Y transmitter module is powered ON, "OFF" if powered OFF, "N/A" if status is unknown. **TX+** = Same as TX-. NOTE THAT a module being powered ON does not necessarily mean that data transmission is underway. Example: '71.302 230.5 OFF OFF' means that this sample was taken 71.302 seconds after start of exposure, the CCD was at 230.5K, and both transmitters were OFF. Note that when this CCD temperature history is available, all temperature with a number of seconds from exposure between -1 and +(exposure time+1) are retained and averaged to produce the TEMP_CCD value.
TEMP_ROE	kelvins	Temperature of the imager (Read-Out Electronics or ROE) after image exposure and readout.
TEMP_AMP	kelvins	Temperature of the pre-amplifier electronics after image exposure and readout.
TEMP_PLD	kelvins	Temperature of the imager (ROE) Programmable Logic Device circuit (FPGA) after image exposure and readout.
P28V	volts	+28V supply sensor reading.
P24V	volts	+24V supply sensor reading.
P12V	volts	+12V supply sensor reading.
N12V	volts	-12V supply sensor reading.
P10V	volts	+10V supply sensor reading.
N10V	volts	-10V supply sensor reading.

P5V	volts	+5V supply sensor reading.
N5V	volts	-5V supply sensor reading.
P5VD	volts	+5V differential supply sensor reading.
P3V3D	volts	+3.3V supply sensor reading.
VTG	volts	TG voltage reading.
CCDBIAS0	volts	Voltage for CCD clocking line - IMG_L_BIAS
CCDBIAS1	volts	Voltage for CCD clocking line - IMG_R_BIAS
CCDBIAS2	volts	Voltage for CCD clocking line - ODR
CCDBIAS3	volts	Voltage for CCD clocking line - ODL
CCDBIAS4	volts	Voltage for CCD clocking line - RDR
CCDBIAS5	volts	Voltage for CCD clocking line - RDL
CCDBIAS6	volts	Voltage for CCD clocking line - OG
CCDBIAS7	volts	Voltage for CCD clocking line – ABG
CCDCLK00	volts	Voltage for CCD clocking line - IPC-
CCDCLK01	volts	Voltage for CCD clocking line - IPC+
CCDCLK02	volts	Voltage for CCD clocking line - RG-
CCDCLK03	volts	Voltage for CCD clocking line - RG+
CCDCLK04	volts	Voltage for CCD clocking line - S- R1L/R2L/R3L
CCDCLK05	volts	Voltage for CCD clocking line - S+ R1R/R2R/R3R
CCDCLK06	volts	Voltage for CCD clocking line - DG-
CCDCLK07	volts	Voltage for CCD clocking line - DG+
CCDCLK08	volts	Voltage for CCD clocking line - TG-
CCDCLK09	Volts	Voltage for CCD clocking line - TG+
CCDCLK10	Volts	Voltage for CCD clocking line - P1- ST1-/IM1-
CCDCLK11	Volts	Voltage for CCD clocking line - P1+ ST1+/IM1+
CCDCLK12	Volts	Voltage for CCD clocking line - P2- ST2-/IM2-
CCDCLK13	Volts	Voltage for CCD clocking line - P2+ ST2+/IM2+
CCDCLK14	Volts	Voltage for CCD clocking line - P3- ST3-/IM3-
CCDCLK15	Volts	Voltage for CCD clocking line - P3+ ST3+/IM3+
MPS		**Placeholder for the MPS section header**
OBJECT	String	Prime object name (specified by the user)
OBSERVER	String	HEOSS || NESS || ASTRO (specified by the user)
INTENT	String	Intent of the object (CALIBRATION || SCIENCE)
INSTRUME	String	Instrument used (NEOSSAT_Science || NEOSSAT_StarTracker)
TARGTYPE	String	Target type (OBJECT || FIELD). May be specified by user or estimated by processing software based on keywords.
PROJECT	String	Project name. Only populated if specified by user.
PROP_ID	String	Proposal ID. Only populated if specified by user.
PI_NAME	String	Principal Investigator (PI) name. Only populated if specified by user.
TITLE	String	Title. Only populated if specified by user.
MOVING	String	Flag, whether target is moving or not (T|| F). May be specified by user or estimated by processing software based on keywords.
M1	Tbd	Future Use
M2	String	State Vector Solution Status, specifying the source of the state vector data (from GPS telemetry or .navsol). Currently one of three Status': FINE_TLM_T, FINE_NAVSOL_T, NO_SOLUTION_T, where 'T' represents the largest timestep, in seconds, between GPS data points used for interpolation of solution. (T < 5 indicate nominal GPS data availability; state vector solution interpolated using FINE_TLM should be more precise than using FINE_NAVSOL as it considers both position and velocity measurements, while NAVSOL is position only; interpolation over periods of NO_SOLUTION induces larger errors).

GEO_LAT	degrees	The Geocentric latitude of NEOSSat at mid-exposure
GEO_LONG	degrees	The Geocentric longitude of NEOSSat at mid-exposure
EPOS1_1	km	ECEF Position at Exp start, X-component
EPOS1_2	km	ECEF Position at Exp start, Y-Component
EPOS1_3	km	ECEF Position at Exp start, Z-Component
EPOS2_1	km	ECEF Position at Exp middle, X-component
EPOS2_2	km	ECEF Position at Exp middle, Y-component
EPOS2_3	km	ECEF Position at Exp middle, Z-component
EPOS3_1	km	ECEF Position at Exp end, X-component
EPOS3_2	km	ECEF Position at Exp end, Y-component
EPOS3_3	km	ECEF Position at Exp end, Z-component
JPOS1_1	km	J2000 Position at Exp start, X-component
JPOS1_2	km	J2000 Position at Exp start, Y-component
JPOS1_3	km	J2000 Position at Exp start, Y-component
JVEL1_1	km/s	J2000 Velocity at Exp start, X-component
JVEL1_2	km/s	J2000 Velocity at Exp start, Y-component
JVEL1_3	km/s	J2000 Velocity at Exp start, Z-component
JPOS2_1	km	J2000 Position at Exp middle, X-component
JPOS2_2	km	J2000 Position at Exp middle, Y-component
JPOS2_3	km	J2000 Position at Exp middle, Z-component
JVEL2_1	km/s	J2000 Velocity at Exp middle, X-component
JVEL2_2	km/s	J2000 Velocity at Exp middle, Y-component
JVEL2_3	km/s	J2000 Velocity at Exp middle, Z-component
JPOS3_1	km	J2000 Position at Exp end, X-component
JPOS3_2	km	J2000 Position at Exp end, Y-component
JPOS3_3	km	J2000 Position at Exp end, Z-component
JVEL3_1	km/s	J2000 Velocity at Exp end, X-component
JVEL3_2	km/s	J2000 Velocity at Exp end, Y-component
JVEL3_3	km/s	J2000 Velocity at Exp end, Z-component
EVEL3_1	km/s	ECEF Velocity at Exp end, X-component
EVEL3_2	km/s	ECEF Velocity at Exp end, Y-component
EVEL3_3	km/s	ECEF Velocity at Exp end, Z-component
EVEL2_1	km/s	ECEF Velocity at Exp middle, X-component
EVEL2_2	km/s	ECEF Velocity at Exp middle, Y-component
EVEL2_3	km/s	ECEF Velocity at Exp middle, Z-component
EVEL1_1	km/s	ECEF Velocity at Exp start, X-component
EVEL1_2	km/s	ECEF Velocity at Exp start, Y-component
EVEL1_3	km/s	ECEF Velocity at Exp start, Z-component
WCS		**Placeholder for the World Coordinate System section header**
WCSNAME	String	WCS coordinate system. Fixed to 'celestial'
WCSAXES	Integer	Number of axes in WCS. Fixed to '2'
CRPIX1	Pixel coord.	Reference pixel, X-coordinate, in Image system
CRPIX2	Pixel coord.	Reference pixel, Y-coordinate, in Image system
CRTYPE1	String	Type of world coordinate system X-Axis. Fixed to 'RA---TAN'
CRTYPE2	String	Type of world coordinate system Y-Axis. Fixed to 'DEC--TAN'
CUNIT1	String	Coordinate system units, X-Axis. Fixed at 'degrees'
CUNIT2	String	Coordinate system units, Y-Axis. Fixed at 'degrees'
CDELT1	degrees/pixel	Pixel size, X-Axis. Based on 2.997 arcsecond/pixel, unbinned
CDELT2	degrees/pixel	Pixel size, Y-Axis. Based on 2.997 arcsecond/pixel, unbinned
CRVAL1	degrees	Right Ascension of reference pixel, based on spacecraft ACS estimates
CRVAL2	degrees	Declination of reference pixel, based on spacecraft ACS estimates
CROTA2	degrees	Rotation angle between axes

CD1_1	degrees/pixel	WCS CD matrix: RA deg/pixel in X
CD1_2	degrees/pixel	WCS CD matrix: RA deg/pixel in Y
CD2_1	degrees/pixel	WCS CD matrix: DEC deg/pixel in X
CD2_2	degrees/pixel	WCS CD matrix: DEC deg/pixel in Y
DIAG		**Placeholder for diagnostic section header**
ROE_SW	String	Identification of the imager (Read-Out Electronics or "ROE") software version running at the time the image was taken.
S921_SW	String	Identification of the C&DH flight software version running at the time the image was taken.
CONV_SW	String	Name of the FITS conversion software used to convert raw science data into this FITS image (FITS Processor name)
CONV_VER	String	Version identifier of the FITS conversion software used to convert raw science data into this FITS image (FITS Processor version).
TMFILE*n*	String	*n*=0..00. Provides name of source telemetry file. As data for an image can be contained in multiple telemetry files (usually no more than 2 consecutive files), the name of each one is given here (e.g. 'TMFILE0='NEOS_20141852225H.VC1', 'TMFILE1='NEOS_20141852355H.VC1')
RUNID	Date & Time	Timestamp of the FITS processing run ('YYYY-MM-DDThh:mm:ss')
META_TLM	String	Indicates if image telemetry meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled: • TEMP_AMP, TEMP_CCD, TEMP_ROE • P28V, P24V… TG_sense
META_TIM	String	Indicates if image timing meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled: • EXPOSURE, AEXPTIME • LENDELAY, LEN_FLU, LEN_TRAN, LEN_READ, LEN_PROC • R_EXP_S, A_EXP_S • TIME_OBS, DATE_OBS, JD_OBS
META_ACS	String	Indicates if ACS history meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled: • HIST_NB • MODE • CMD • CMDRA, CMDDEC, CMDROL • CMDQ0 to CMDQ3 • MINEARTH, MAXEARTH • MINSUN, MAXSUN • OBJRA, OBJDEC, OBJROL • SHUTTER • Wander data
META_CCD	String	Indicates if CCD history meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled: • CCDT_NB • CCD history data (including TX state)

		Note also that if META_CCD is MISSING, the value of field TEMP_CCD will be that of TEMP_CCD returned by META_TLM, which is a sample taken several seconds after exposure (less accurate), instead of being calculated from an average of CCD temperature history during exposure.
META_VLT	String	Indicates if voltages meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled: • CCDBIAS0..7 • CCDCLK0..15 • CCDBIAS0_IMG_L_BIAS_RAW • … • CCDCLK15_P3P_ST3P_IM3P_RAW
META_FSW	String	Indicates if SW Versions meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled: • S921_SW • ROE_SW
META_RDL	String	Indicates if image read list meta-data packet was accompanying this image. Possible values are "OK" or "MISSING". If missing, some records in the header won't be filled or will be filled with default values not necessarily corresponding to actual image specifications: • NAXIS1, NAXIS2 • OPAMP • GAIN • XBINNING, YBINNING • NYSCAN • CORNER1_X, CORNER2_X, CORNER1_Y, CORNER2_Y and the decoding software will not be able to determine the specification of the image (i.e. size, coordinates, sub-rasters…) so there is a high probability that the image displayed with be incoherent.
IMGSTATE	String	An indication if the data received from the spacecrafted and decoded is complete for this image. Possible values are **'NOT_VERIFIED'**, **'INCOMPLETE'**, **'COMPLETE'** and **'HAS_ZEROS'**, where: **NOT_VERIFIED** = The FITS processor was not able to determine the state of the image (not a nominal case). **INCOMPLETE** = Not all expected pixel values for this image were extracted from telemetry. There will be missing data within the image. **COMPLETE** = All expected data have been read and used to create the image. There are no pixel value that have been seen at value zero. **HAS_ZEROS** = All expected data have been read, however some pixel have zero values, which is not a nominal case for images taken with the spacecraft.
IMG_PERC	0-100%	Percentage of completion of the image (i.e. number of pixels read from telemetry vs total number of pixels needed to complete the image). A value of less than 100% means that some pixel values were 'lost' in the delivery process from space or decoding. Note that this percentage does not include image meta-data.

NB_0_PIX	Nb pixels	Number of pixels that have exactly the value 0 (or black pixel). Note that a value different than zero indicates a non-nominal situation, except for specific test images taken on the flatsat.
NBSATPIX	Nb pixels	Number of pixels at full-scale value (saturated, i.e., 66535) in original raw U16 image.
FRM_SEQ	String	Indicates whether raw telemetry transfer frame sequence (Virtual Channel Counter), while dumping this image, was continuous or not. Possible values are "**OK**" or "***n*** **ANOMALIES**" where ***n*** gives the number of "holes" in the sequence. These anomalies would be signatures for downlink problems. If anomalies, we can expect that some pixel data will be missing (see IMGSTATE and IMG_PERC). The application will not detected missing frame at the beginning or at the end of the image.
PKT_SEQ	String	Indicates whether raw telemetry packet sequence counter, while dumping this image from the spacecraft, was continuous or not. Possible values are "**OK**" or "***n*** **ANOMALIES**" where ***n*** gives the number of "holes" in the sequence. These anomalies would be signatures for downlink problems. If anomalies, we can expect that some pixel data will be missing (see IMGSTATE and IMG_PERC). The application will not detected missing frame at the beginning or at the end of the image.
CAL_INFO		**Placeholder for the calibration section header**
ARCHIVE	String	Data archive source of image: • 'NEOSSat'
CAL_LVL	String	Indicates whether working file has been calibrated by the cleaner software. Possible values are 'CALIBRATED' if it has gone through the cleaner or 'RAW_STANDARD' if it has not.
PRODUCT	String	Information regarding the type of final product the image is. Possible values: • 'raw ' • 'cor ' • 'cord ' • 'clean '
OBS_ID	String	Observation ID of image taken. Formatted in 'NEOS_SCI_YYYYDoyHHMMSS'
OBSTYPE	String	The image observation type. Distinguishes between a value of 'DARK' or 'OBJECT'.
RELEASE	String	The time and date the image was released by our operational pipeline. Formatting of 'YYYY-MM-DD***T***HH:MM:SS.'.
SW_REF	String	Data processing software reference link. Only in Python-cleaned data.
DARKTMIN	kelvins	The minimum CCD temperature of the dark frames in the master dark. Only present in "_cord.fits" files.
DARKTMAX	kelvins	The maximum CCD temperature of the dark frames in the master dark. Only present in "_cord.fits" files.
DARKTMED	kelvins	The median CCD temperature of the dark frames in the master dark.. Only present in "_cord.fits" files.
DARKMODE	String	The scaling method used to combine darks and scale lights to darks, either "logspace", "zscale", "range" or "npbin. Only present in "_cord.fits" files.
DARK_###	String	List of darks used to produce "_cord.fits" file. Only present in "_cord.fits" files. This header contains every dark utilized in the dark subtraction process to build the master dark. A value collection example:

		• DARK_001='NEOS_SCI_YYYYDoyHHMMSS' • DARK_002='NEOS_SCI_YYYYDoyHHMMSS' • DARK_003='NEOS_SCI_YYYYDoyHHMMSS' • DARK_004='NEOS_SCI_YYYYDoyHHMMSS'
EXTEND		**Set at value "T" to specify extension HDU exists**
END	N/A	Specifies the end of the primary header

5.3 Padding

FITS files are composed of blocks of fixed length, which need to be padded if data specific to each block do not fill it completely.

The primary header block is padded with spaces character (' '), while the pixel values block and the binary tables with 0x00 bytes.

5.4 Extension Header Keyword Records Summary

Each Neossat Science FITS file created by the FITS processor, in addition to the primary header and pixel values, includes binary extensions containing raw meta-data, as sent by the spacecraft. Data contained in binary extensions can be extracted and consulted/processed with Matlab, for example. An example of Matlab usage to consult binary extension data is provided in appendix to this document.

Five binary tables have been added to the Fits file, for saving raw values from the spacecraft telemetry for later use:

1. Raw image voltages (content of telemetry packet 1304/1314);
2. ACS history raw values received from the spacecraft (packet 1306/1316);
3. CCD history (including transmitters status) (packet 1309/1319);
4. Read List raw values received from the spacecraft (packet 1303/1313); and
5. ROE telemetry (packet 1305/1315).

The next sub-sections will describe each binary table header and provide a typical example of the data that it can contain.

5.4.1 Raw Voltages Binary Table Summary

This binary table have raw byte values from the TM 1304/1314 Image Voltages.

The first column of the binary table is a 12 characters description and the second column is the corresponding raw values (a 16-bit unsigned integer/short).

Table 2 : Raw Voltages Binary Table Header

Keyword Record	Value	Description/Comments
'XTENSION'	'BINTABLE'	' Raw DAC Binary Table '
'BITPIX'	8	' Manditory for BINTABLE '
'NAXIS'	2	' Manditory for BINTABLE '
'NAXIS1'	14	' Bytes per row '
'NAXIS2'	24	' Rows in table '
'PCOUNT'	0	' Manditory for BINTABLE '
'GCOUNT'	1	' Manditory for BINTABLE '
'TFIELDS'	2	' Fields per row '
'EXTNAME'	'Raw Value'	' Extension name '
'TFORM1'	'12A'	' 12 characters '
'TTYPE1'	'item name'	' Item name '
'TDISP1'	'A12'	' Suggested column display '
'TFORM2'	'1I'	' 16-bit integer '
'TZERO2'	32768	' 16-bit unsigned integer '
'TUNIT2'	'adu'	' 16-bit unsigned integer '
'TTYPE2'	'Raw_Value'	' Raw values '
'TDISP2'	'I5'	' Suggested column display '
'END'	n/a	n/a

Table 3 : Raw Voltages Binary Table Example

Description	Value
'CCDBIAS0 '	1556
'CCDBIAS1 '	1556
'CCDBIAS2 '	3712
'CCDBIAS3 '	3712
'CCDBIAS4 '	2458
'CCDBIAS5 '	2458
'CCDBIAS6 '	2627
'CCDBIAS7 '	2627
'CCDCLK00 '	0
'CCDCLK01 '	1311
'CCDCLK02 '	3448
'CCDCLK03 '	3119
'CCDCLK04 '	3119
'CCDCLK05 '	328
'CCDCLK06 '	3448
'CCDCLK07 '	328
'CCDCLK08 '	0
'CCDCLK09 '	983
'CCDCLK10 '	3448
'CCDCLK11 '	1311
'CCDCLK12 '	3448
'CCDCLK13 '	1311
'CCDCLK14 '	3448
'CCDCLK15 '	1311

5.4.2 Raw Telemetry Binary Table Summary

This binary table have raw byte values from the TM 1307/1317 Image Telemetry packet.

The first column of the binary table is a 12 characters description and the second column is the corresponding raw values (a 16-bit unsigned integer/short).

Table 4 : Raw Telemetry Binary Table Header

Keyword Record	Value	Description/Comments
'XTENSION'	'BINTABLE'	' Raw DAC Binary Table '
'BITPIX'	8	' Manditory for BINTABLE '
'NAXIS'	2	' Manditory for BINTABLE '
'NAXIS1'	14	' Bytes per row '

'NAXIS2'	15	' Rows in table '
'PCOUNT'	0	' Manditory for BINTABLE '
'GCOUNT'	1	' Manditory for BINTABLE '
'TFIELDS'	2	' Fields per row '
'EXTNAME'	'Raw Value'	' Extension name '
'TFORM1'	'12A'	' 12 characters '
'TTYPE1'	'item name'	' Item name '
'TDISP1'	'A12'	' Suggested column display '
'TFORM2'	'1I'	' 16-bit integer '
'TZERO2'	32768	' 16-bit unsigned integer '
'TUNIT2'	'adu'	' 16-bit unsigned integer '
'TTYPE2'	'Raw_Value'	' Raw values '
'TDISP2'	'I5'	' Suggested column display '
'END'	n/a	n/a

Table 5 : Raw Telemetry Binary Table Example

Description	Value
'v28 '	2334
'v24 '	1759
'v12 '	2627
'vm12 '	1826
'v10 '	2326
'vm10 '	1741
'v5 '	3066
'vm5 '	748
'v5d '	3066
'v33d '	2049
'tBoard '	1857
'tPreamp '	354
'tCcd '	1113
'tPld '	2
'vTg '	720

5.4.3 ACS History Binary Table Summary

This binary table have all the raw records from the ACS history. Note that the number of row in the binary table can changed depending on the number of ACS history record that has been saved.

Table 6 : ACS history Binary Table Header

Keyword Record	Value	Description/Comments
'XTENSION'	'BINTABLE'	' ACS History Binary Table '
'BITPIX'	8	' Manditory for BINTABLE '
'NAXIS'	2	' Manditory for BINTABLE '
'NAXIS1'	61	' Bytes per row '
'NAXIS2'	**VARIABLE**	' Rows in table '
'PCOUNT'	0	' Manditory for BINTABLE '
'GCOUNT'	1	' Manditory for BINTABLE '
'TFIELDS'	10	' Fields per row '
'EXTNAME'	'ACS History'	' Extension name '
'TFORM1'	'1E'	' 32-bit floating point '
'TTYPE1'	'Elapsed'	' Time from exposure start '
'TUNIT1'	's'	' Time value units '
'TDISP1'	'F8.3'	' Suggested column display '
'TFORM2'	'19A'	' 19 characters '
'TTYPE2'	'ACS_State'	' Attitude control state '
'TDISP2'	'A19'	' Suggested column display '
'TFORM3'	'10A'	' 10 characters '
'TTYPE3'	'Shutter_State'	' Shutter state '
'TDISP3'	'A10'	' Suggested column display '
'TFORM4'	'1E'	' 32-bit floating point '
'TTYPE4'	'qEst[0]'	' Estimated q0 '
'TUNIT4'	's'	' Value units '
'TDISP4'	'F8.3'	' Suggested column display '
'TFORM5'	'1E'	' 32-bit floating point '
'TTYPE5'	'qEst[1]'	' Estimated q1 '
'TUNIT5'	's'	' Value units '
'TDISP5'	'F8.3'	' Suggested column display '
'TFORM6'	'1E'	' 32-bit floating point '

'TTYPE6'	'qEst[2]'	' Estimated q2 '
'TUNIT6'	's'	' Value units '
'TDISP6'	'F8.3'	' Suggested column display '
'TFORM7'	'1E'	' 32-bit floating point '
'TTYPE7'	'qEst[3]'	' Estimated q3 '
'TUNIT7'	's'	' Value units '
'TDISP7'	'F8.3'	' Suggested column display '
'TFORM8'	'1E'	' 32-bit floating point '
'TTYPE8'	'wEst[0]'	' Estimated w0 '
'TUNIT8'	's'	' Value units '
'TDISP8'	'F8.3'	' Suggested column display '
'TFORM9'	'1E'	' 32-bit floating point '
'TTYPE9'	'wEst[1]'	' Estimated w1 '
'TUNIT9'	's'	' Value units '
'TDISP9'	'F8.3'	' Suggested column display '
'TFORM10'	'1E'	' 32-bit floating point '
'TTYPE10'	'wEst[2]'	' Estimated w2 '
'TUNIT10'	's'	' Value units '
'TDISP10'	'F8.3'	' Suggested column display '
'END'	n/a	n/a

Table 7 : ACS History Binary Table Example

Time from exposure start'	Attitude control state	Shutter state	qEst[0]	qEst[1]	qEst[2]	qEst[3]	wEst[0]	wEst[1]	wEst[2]
-0.152875006	'COARSE_POINT '	'OPEN '	0.573366463	0.818273008	0.023468034	0.033607192	0.000115008	0.000465731	0.000106655
0.047125001	'COARSE_POINT '	'OPEN '	0.57337749	0.81826669	0.023462078	0.033576157	0.000114463	0.000467226	0.000103885
0.247125	'COARSE_POINT '	'OPEN '	0.573388696	0.818260312	0.023455996	0.033545066	0.000113867	0.000468616	0.000101162

5.4.4 CCD & Transmitters History Binary Table Summary

This binary table have raw byte values from the TM 1309/1319 Image Telemetry packet.

The first column of the binary table represents the number of seconds since start of exposure, expressed as floating point value (4 bytes). Then, the temperature sensor reading is provided (16-bit unsigned integer, with offset of 32768, a standard for FITS data). Finally, the status of the transmitters are provided, 1 byte each (0=OFF, 1=ON).

Table 8 : CCD History Binary Table Header

Keyword Record	Value	Description/Comments
'XTENSION'	'BINTABLE'	' Raw DAC Binary Table '
'BITPIX'	8	' Manditory for BINTABLE '
'NAXIS'	2	' Manditory for BINTABLE '
'NAXIS1'	14	' Bytes per row '
'NAXIS2'	15	' Rows in table '
'PCOUNT'	0	' Manditory for BINTABLE '
'GCOUNT'	1	' Manditory for BINTABLE '
'TFIELDS'	2	' Fields per row '
'EXTNAME'	'CCD_History'	' Extension name '
'TFORM1'	'1E'	' 32-bit floating point '
'TTYPE1'	'Elapsed'	' Time from exposure start '
'TUNIT1'	's'	' Time value unit '
'TDISP1'	'F8.3'	' Suggested column display '
'TFORM2'	'1I'	' 16-bit integer '
'TZERO2'	32768	' 16-bit unsigned integer '
'TUNIT2'	'adu'	' 16-bit unsigned integer '
'TTYPE2'	'Raw_Temp'	' Raw temperature sensor '
'TDISP2'	'I5'	' Suggested column display '
'TFORM3'	'1B'	' Unsigned byte '
'TTYPE3'	'TX_MY'	' Minus Y transmitter status '
'TUNIT3'	'flag'	' 0=OFF, 1=ON '
'TDISP3'	'I1'	' Suggested column display '
'TFORM4'	'1B'	' Unsigned byte '
'TTYPE4'	'TX_PY'	' Plus Y transmitter status '
'TUNIT4'	'flag'	' 0=OFF, 1=ON '
'TDISP4'	'I1'	' Suggested column display '
'END'	n/a	n/a

Table 9 : CCD History Binary Table Example

Elapsed	Raw_Temp	TX_MY	TX_PY
-0.502	232.1	0	0
0.502	232.0	0	0
1.502	232.3	0	0
2.502	232.2	0	0
…			

5.4.5 Read List Binary Table Summary

The table have all the Read List values used to make the Fits Image. Note that the first row of each column represent, respectively, the raw number of element in the Read List, the OP Amp Code and the Gain. After these values, it represent each field of the RD List (A,B,C). The number of row in the binary table depends on the number of RD List entry.

Table 10 : Read List Binary Table Header

Keyword Record	Value	Description/Comments
'XTENSION'	'BINTABLE'	' RDList Binary Table '
'BITPIX'	8	' Manditory for BINTABLE '
'NAXIS'	2	' Manditory for BINTABLE '
'NAXIS1'	6	' Bytes per row '
'NAXIS2'	**Variable**	' Rows in table '
'PCOUNT'	0	' Manditory for BINTABLE '
'GCOUNT'	1	' Manditory for BINTABLE '
'TFIELDS'	3	' Fields per row '
'EXTNAME'	'Image RDList'	' Extension name '
'TFORM1'	'1I'	' 16-bit integer '
'TZERO1'	32768	' 16-bit unsigned integer '
'TTYPE1'	'A'	number of item then 'A''
'TFORM2'	'1I'	' 16-bit integer '
'TZERO2'	32768	' 16-bit unsigned integer '
'TTYPE2'	'B'	opamp then 'B' '
'TFORM3'	'1I'	' 16-bit integer '
'TZERO3'	32768	' 16-bit unsigned integer '
'TTYPE3'	'C'	''gain then C '''
'END'	n/a	n/a

Table 11 : Read List Binary Table Example

RDList 'A or rawNumberOfElement'	RDList 'B or OP Amp code'	RDList 'C' or GAIN
15 (*)	**2 (*)**	**0 (*)**
0	1030	1
0	1072	2
0	0	0

(*) Note: The first row of the RDList binary table represent respectively the rawNumberOfElement, OpAMP Code and the Gain.

6 NEOSSAT FITS IMAGE NAMING CONVENTIONS

6.1 Raw Images

The raw science data downlinked from the spacecraft in the form of CCSDS packet streams is assembled into FITS image products. The most basic image product is the raw, unprocessed image (level 1). These images can be identified when the filenames following this convention:

- NEOS_<detector>_<timestamp>.fits

  where <detector> is either "SCI" (for Science CCD) or "ST" (for Star Tracker CCD) and where <timestamp> follows the convention "YYYYDDDhhmmss" corresponding to the start of exposure in Coordinated Universal Time (UTC).

Examples of NEOSSat raw image filenames would be:

- NEOS_SCI_2019173171040.fits → an image taken using NEOSSat's Science CCD with exposure starting at 2019-173 at 17:10:40 UTC. (Day of year 2019-173 corresponding to June 22, 2019)

6.2 Cleaned Images

Raw images contain noise that can be cleaned with appropriate software. Traditionally, image processing had been the responsibility of the user of the data. However, over time, some cleaning routines have been developed and integrated into the operational pipeline. In addition, newer more powerful routines have been developed and have been run manually to produce cleaned images. Thus, a variety of cleaned images are also available from NEOSSat. Cleaned images are Level 2 products.

6.2.1 Java-cleaned images: "_clean.fits"

A first version of cleaning software was developed in-house and integrated within the Java FITS processor. This produces files with the "_clean.fits" extension, (leaving the root part of the filename unchanged). The only correction applied in the "_clean.fits" is the overscan correction.

This image cleaning software is unable to perform the overscan correction in the presence of the discontinuity between the overscan region and the image region. Thus, as of FITSv2.07, this image file is only produced when there is no discontinuity between the overscan region and the image region. Care should be taken when using "_clean.fits" images processed by a FITS Processor older than 2.07, as the "_clean.fits" could be noisier than the raw image for images containing a subraster leading to a discontinuity between the overscan region and the image region. Nevertheless, for full-frame images with overscan, the image quality for the "_clean.fits" images is signicantly better than the raw images.

6.2.2 Python-cleaned images: "_cord.fits" and "_cor.fits"

A new version of the NEOSSat image cleaning software was developed by Jason Rowe at Bishop's University, which addresses the discontinuity issue with the Java cleaning and also applies additional corrections. Applying these corrections, NEOSSat images are suitable for photometric applications.

The following corrections can be performed with the Python cleaning routines.

- Clipping (removing the overscan region, post-correction, based on TRIMSEC metadata)
- Overscan correction (when an overscan region is present)
- Dark subtraction (when dark frames are available of the same raster size and exposure length)

As of v4.00, this cleaning software is integrated into the CSA FITS production pipeline, resulting in processed files with either "_cor.fits" or "_cord.fits" extension (leaving the root part of the filename unchanged). In this naming convention, "c" stands for clipping, "or" for overscan correction, and "d" for dark substraction. The "_cor.fits" files have clipping and overscan correction, but no dark subtraction, while the "_cord.fits" files have all three corrections applied. The "_cor.fits" files can be produced immediately for every RAW file, including darks, while the "_cord.fits" files are produced for light exposures only, once there are a suitable number of usuable darks of the same exposure length and raster settings. Depending on the sequencing of darks and timing of downlink, the "_cord.fits" files might be delayed relative to corresponding raw and "_cor.fits" file. Dark-corrected "_cord.fits" files may also be regenerated following initial production if additional darks becomes available in a future downlink and a mix of older and newer dark frames may be used to correct a given light frame image, depending on the best matches available. For a "_cord.fits" file to generated (or re-generated), the following conditions must be true, (specified in a pipeline configuration file):

- The exposure is a "light" exposure (shutter open)
- There are at least 10 darks available that meet the following conditions:
    - Same exposure duration as the light (within 10 milliseconds)
    - Same raster size as the light
    - Taken within 10 days of the light (configurable)
    - Taken outside of the South Atlantic Anomaly (SAA) (configurable Lat/Long dimensions)
    - Temperature of the dark frame is "close" to that of the light frame, (as described below)

Going into more detail on the temperature proximity condition, to ensure highest quality image correction, all collected darks are partitioned into dark bins/buckets defined by raster size, exposure length and also CCD Temperature in degrees kelvin. The temperature width of these intervals may vary depending on the availability of dark frames within a given temperature range. When the dark subtraction process is performed, the algorithm will select the dark bin/bucket with the closest matching temperature to the light being corrected. As such, the pipeline software attempts to maximize the performance of the image cleaning / dark subtraction functionality, and minimize over-correction or under-correction. These algorithms would explain why different dark frames may be used – and some dark frames may be excluded – when cleaning a given light frame image and producing the "_cord.fits" output. Details on the dark frames used (and their temperature characterstics) are provided in the DARK* meta-data header fields.

Figure 2 below shows side-by-side comparisons of raw, "_corr.fits", and "_cord.fits" files for image "NEOS_SCI_2021043141700.fits", target - exoplanet TOI 1823.01.

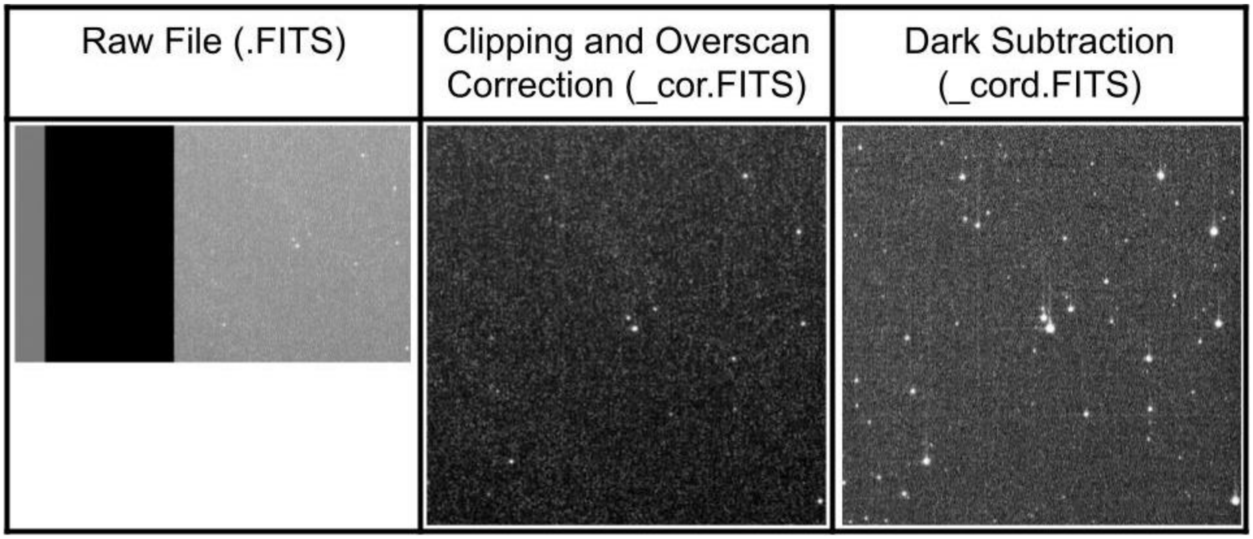


Figure 2: FITS Cleaner Process Example (exoplanet raster)

7 NEOSSAT FITS IMAGE FILE COMPRESSION

Raw and Python-cleaned images may appear in a compressed format. Utilizing "gzip", the lossless data compression algorithm *DEFLATE* with a compression ratio of 1 to 9 is applied to the aforementioned files, striking a good balance between storage efficiency, system compatibility, and extraction time. Many FITS image processing packages can handle " .fits.gz", but if not, files can be returned to "fits" format simply using Linux "gunzip" or similar tools on other operating systems.

As referenced in **Section *6***, all expected naming conventions still apply, but each file instance is stored in a ".fits.gz" archive. With compression enabled, a full data set looks as follows:

- ***NEOS_SCI_2020296000254.fits.gz***
- ***NEOS_SCI_2020296000254_cor.fits.gz***
- ***NEOS_SCI_2020296000254_cord.fits.gz***

In this example set, each individual FITS image approached a size reduction of approximately 50%.