OSIRIS

Optical, Spectroscopic, and Infrared Remote Imaging System

OSIRIS Science User Guide

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1 / -	11-09-2017	Marc Hofmann	3, 4, 10-end	Updated table 1 and 2, updated definitions and descriptions, reworked section about calibration with new tags.
1 / a	08-02-2018	Jakob Deller	1 – 11	Revised the table containing mission periods. Added LTP to mission period descriptions. Minor spelling corrections and further explanations
			Sections 5.8.1, 5.8.7, 5.9.1, 5.9.2	Description of TAG_DUST, TAG_DUST_ PHASE_FUNCTION, TAG_GAS, TAG_GAS_MONITORING science use cases
			Section 5.6	Added reference document RD4 for filter transmission curves
2 / -	21-08-2018	Jakob Deller	Section 1	Added more general introduction, document structure description and a brief introduction into the data delivered by OSIRIS to make this document suitable as entry point into the OSIRIS data archive.
			All	Clarified that the keywords linked to scientific usage are provided only for images after hibernation, e.g. after 2014.

2 / a	29-10-2018	Jakob Deller	All	Added reference documents RD8 RD9, RD10, and RD11.
			All	Moved all headings from "Rosetta and OSIRIS science planning after hibernation", now Section 5, one level down.
			Section 2.2.2	Explained equivalence between level 4 and level 5 image layer. Added details about what files are to be expected at each calibration level.
			Section 2.2.4	Added Section "Image data quality"
			Section 4	Added Section "Rosetta and OSIRIS science planning before hibernation"
			Sections 2.1, 5.9	Added a warning to the gas science part about the filter transmission for narrow band filters and a reference to RD10
			Section 2.6	Added FAQ
2 / b	3-6-2019	C. Tubiana		Updated Table 1 to include CODMAC level 4E/F. Updated Sec. 2.2.2. Updated Sec. 2.6.
2 / c	30 Sep 2019	C. Tubiana	Section 2.6	Added entry to FAQ concerning information about image processing history in image header.
			All	Consistent use of stray light through the document
			Section 6	Added section and Table 7 which contains list of empty datasets
			Sec. 2.2.2	Corrected logic for image calibration
2 / d	5 Nov 2019	C. Tubiana	Sec. 2.6	Added entry to FAQ to explain the difference between standard and enlarged frames
2 / e	10 July 2020	C. Güttler	Sect. 2	Explained OSIRIS Level 4S (CODMAC L5) product

3 / -	20 Dec 2021	J. Deller	Sect. 2.4	Description of changes to the data in the LEGACY dataset
			Sect. 2.2.4	Fixed description of QUALITY_MAP_IMAGE
			Sect. 2.5	Added paragraph about ACTIVITY.TAB data
			Sect. 4	Added phase definitions used in ROSETTA:MISSION_PHASE
			Sect. 6	Updated list of empty datasets.
3 / a	10 May 2022	C. Güttler	Sec. 2.6	- typo: enhanced to enlarged (RID-JL-03) - Explanation on ACTIVITY.TAB in data products

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1 General aspects

1.1 Scope

This document gives a first overview of the data archive containing the images acquired by OSIRIS, the scientific camera system onboard the Rosetta spacecraft, and provided to the public.

For a very quick start, a FAQ section is offered in Section 2.6.

The dataset structure, the archived data products and the documentation provided is briefly explained to provide potential users an overview on what to expect when exploring the OSIRIS image data.

Additionally, it explains the reasoning behind the acquisition of the images, to provide the rationale applied during the science planning phase, and to support the user to find images related to a specific science use case.

1.2 Document structure

This document gives a very short introduction into the structure of the data provided by OSIRIS on the PSA archive (Section 2), and a detailed description of the image header entries related to scientific interpretation (Section 3). Sections 4 to 5.6 introduce the science planning strategy and the terminology used. Section 5.7 and the following sections describe the meaning of all values in the header keyword RATIONALE_DESCRIPTION.

1.3 Reference Documents

No.	Document name	Document number (FILE_NAME)
RD1	Software Interface Specification for OSIRIS Science Products (SIS)	RO-RIS-MPAE-ID-023 (OSIRIS_SIS_V??)
RD2	OSIRIS calibration pipeline OsiCalliope	RO-RIS-MPAE-MA-007 (OSIRIS_CAL_PIPELINE_V??)
RD3	Shutter parameters for exposure time calculation	RO-RIS-MPAE-TN-073 (EXPOSURETIME_COR_V??)
RD4	NAC and WAC FM optical bandpass filter transmission	RO-RIS-MPAE-TN-091 (FILTER_CURVES_V??)
RD5	Rosetta-OSIRIS To Planetary Science Archive Interface Control Document	RO-RIS-MPAE-ID-015 (OSIRIS_EAICD_V??)
RD6	OSIRIS – The Scientific Camera System Onboard Rosetta.	Keller et al. 2007 (KELLER_ET_AL_2007_V01)
RD7	Planetary Data System Standards Reference	JPL D-7669, Part 2, Version 3.8
RD8	OSIRIS Georeferenced Data Products	RO-RIS-MPAE-TN-089 (GEO_PRODUCTS_V??)
RD9	Scientific assessment of the quality of OSIRIS images	Tubiana et al. 2015 (TUBIANA_ET_AL_2015_V01)

RD10	NAC and WAC Optical Band-pass Filter Transmissions	RO-RIS-MPAE-TN-091 (FILTER_CURVES_V??)
RD11	Determination of the absolute calibration coefficients to radiometrically calibrate OSIRIS images	RO-RIS-MPAE-TN-074 (RADIOMETRIC_CALIB_V??)
RD12	In-field Stray-Light determination for NAC and WAC	RO-RIS-MPAE-TN-093 IN-FIELD-STRLIGHT_V??.PDF
RD13	OSIRIS camera distortion and boresight correction	RO-RIS-MPAE-TN-081 GEOMETRIC_DIST_COR_V??
RD14	ROSETTA Mission Calendar	RO-ESC-PL-5026 3/0
RD15	OSIRIS pointing position relative to other boresights on Rosetta	RO-RIS-MPAE-TN-051 BORESIGHT_V??.PDF
RD16	Acquisition and processing of flat field images for OSIRIS calibration	RO-RIS-MPAE-TN-075 FLATFIELDING_V??.PDF

Documents with given FILE_NAME are delivered to the Planetary Science Archive (PSA) as part of each dataset.

2 The OSIRIS data

2.1 The OSIRIS Instrument

OSIRIS, the Optical, Spectroscopic, and Infrared Remote Imaging System is the scientific camera system on board Rosetta. It comprises a Narrow Angle Camera (NAC) and a Wide Angle Camera (WAC) with a field of view (FOV) of about 2°x2° and 12°x12°, respectively.

Both cameras use a 16 bit 2048 x 2048 pixel backside illuminated CCD detector with a UV optimized anti-reflection coating. The CCDs are equipped with lateral anti-blooming that allows overexposure of the nucleus without creating saturation artifacts, enabling the study of details in the faint coma structures next to the illuminated limb.

The NAC is equipped with 11 filters covering a wavelength range from 250 nm to 1000 nm, while the WAC has 14 filters covering a range from 240 nm to 720 nm. The transmission of the narrow band filters is by design dependent on the incident angle of the optical beam, which has to be taken into account when especially when working on scientific analyses of the gas coma (see RD10 for details).

The NAC and WAC have been designed as a complementary pair that addresses, on the one hand, the study of the nucleus surface, and, on the other hand, the investigation of the dynamics of the sublimation processes. The NAC, with its high spatial resolution, was used to detect the nucleus of 67P/Churyumov-Gerasimenko from a distance of millions of kilometers, and it is now used to study the morphology and mineralogy of the surface and details of the dust ejection process. The WAC has a lower spatial resolution and, accordingly, a much wider field of view. This allows observations of the 3D flow-field of dust and gas even if the spacecraft is near the nucleus and provides a synoptic view of the nucleus for context of the NAC and other instruments onboard Rosetta. To summarize, the WAC provides long-term monitoring of the entire nucleus and its surrounding, while the NAC studies the surface details.

For a detailed description of the instrument see Keller et al. (2007) [RD6].

2.2 OSIRIS data provided

OSIRIS has provided the full extent of images acquired during the Rosetta mission to the PSA archive. The data structure, naming schemes, and data products are described in detail in the 'Rosetta-OSIRIS to Planetary Science Archive Interface Control Document' [RD5]. In the following, a short summary of this document is provided to give users an easy start when working with the data.

2.2.1 Datasets

The OSIRIS data are organized in the archive into datasets. Each dataset contains all data files belonging to a single camera (OSINAC/OSIWAC), mission period and data product. The dataset name is given by the DATA_SET_ID, defined in RD5. The DATA_SET_ID contains, among other information, the camera, the CODMAC level, the mission period, and, in the cases specified in Table 1, the data product. For example, the uncalibrated data files of the very last mission period MTP035 for the WAC can be found in the dataset:

RO-C-OSIWAC-2-EXT3-67PCHURYUMOV-M35-V1.0,

and the georeferenced images of the same camera and period in the dataset:

RO-C-OSIWAC-5-EXT3-67P-M35-GEO-V1.0.

2.2.2 Data products

The OSIRIS data are provided in various data products, from raw data to georeferenced data, supporting the needs of different science analysis. The provided data products are:

CODMAC level (OSIRIS level)	**Data product description**	**Keyword in DATA_SET_ID**
2 (1)	PDS compliant data files with calibrated header and **uncalibrated** image data.	
3 (2)	PDS compliant data files with calibrated header and **radiometric calibrated** image data.	
4 (3)	PDS compliant data files with calibrated header and **radiometric calibrated** & **geometric distortion and boresight corrected** (resampled) image data, in **radiance** units.	
4 (3B)	PDS compliant data files with calibrated header and **radiometric calibrated & geometric distortion and boresight corrected** (resampled) image data, in **reflectance** units.	REFLECT
4 (3C)	PDS compliant data files with calibrated header and **solar stray-light corrected**, **radiometric calibrated** & **geometric distortion and boresight corrected** (resampled) image data, in **radiance** units.	STRLIGHT
4 (3D)	PDS compliant data files with calibrated header and **solar stray-light corrected**, **radiometric calibrated** & **geometric distortion and boresight corrected** (resampled) image data, in **reflectance** units.	STR-REFL
4 (3E)	PDS compliant data files with calibrated header and **solar stray-light corrected**, **in-field stray-light corrected, radiometric calibrated** & **geometric distortion and boresight corrected** (resampled) image data, in **radiance** units.	INFLDSTR
4 (3F)	PDS compliant data files with calibrated header and **solar stray-light corrected**, **in-field stray-light corrected, radiometric calibrated** & **geometric distortion and boresight corrected** (resampled) image data, in **reflectance** units.	INF-REFL
5 (4)	PDS compliant .IMG files with 9 layers: one calibrated image data layer equivalent to the corresponding CODMAC level 4 (OSIRIS level 3) data and 8 **georeferencing** layers. The geometry is derived from shape modelling by-products. These data are described in detail in RD8.	GEO

5 (4S)	PDS compliant .IMG files with 9 layers: one calibrated image data layer equivalent to the corresponding CODMAC level 4 (OSIRIS level 3) data and 8 **georeferencing** layers. The geometry is derived from the SPICE toolkit. These data are described in detail in RD8.	GEOSPICE

Table 1 Description of data products

Not all images can be processed into all higher data products. A detailed description of whether calibration steps can be applied to the image and higher levels are generated and stored is provided in the description of the OSIRIS calibration pipeline [RD2, Sec. 2]. A few examples are listed below:

- Images flagged as TARGET_TYPE = CALIBRATION are stored only in CODMAC Level 2 (OSIRIS Level 1).
- Images with shutter errors cannot be exposure time corrected and therefore are only available in CODMAC Level 2 (OSIRIS Level 1).
- Only images of reflecting objects can be generated in reflectance units (CODMAC Level 4 REFLECT / STR-REFL / INF-REFL, OSIRIS Level 3B/3D/3F, respectively).
- In-field stray-light corrected images (CODMAC Level 4 INFLDSTR / INF-REFL, OSIRIS Level 3E/3F) are generated for all full frame images, with the exception of images with TARGET_TYPE = CALIBRATION, if ghost images [RD12] are available.
- Only the images of 67P/Churyumov-Gerasimenko that have been used for the generation of (thus are co-registered on) the shape models could be georeferenced and produced as CODMAC Level 5 (OSIRIS Level 4), see also [RD8].
- OSIRIS Level 4S (CODMAC L5) are generate for images with TARGET_NAME = 67P/Churyumov-Gerasimenko and the comet nucleus is in the field of view.

Please note that OSIRIS datasets are only delivered if they contain image data. A complete list of empty – and therefore not delivered – datasets is provided in Sec. 6.

2.2.3 *Image data formats*

The data are provided in the following formats:

File extension	**Folder**	**Product**
.IMG	\DATA\IMG	PDS compliant image data files with attached label.
.FIT	\DATA\FIT	Data files compliant with FITS Standard Version 3.0, and detached label in PDS format. Please note that no files in FITs format are provided for CODMAC level 5 products.
.JPG	\BROWSE	Image data converted into JPEG format for easy browsing. The JPEG images are in the Rosetta standard orientation, and have the same resolution as the original image data.

Table 2 OSIRIS image data formats provided

2.2.4 Image data quality

The quality of OSIRIS image data is documented at the following places:

- Each image data file in PDS format of OSIRIS level 2 and 3 (CODMAC L3/4) contains an object SIGMA_MAP_IMAGE. In this object, the noise level is stored on a per-pixel basis. This object is described in the OsiCalliope image processing pipeline document [RD2].
- Each image data file in PDS format of OSIRIS level 2 and 3 (CODMAC L3/4) contains an object QUALITY_MAP_IMAGE. This object is an 8 bit map describing for each pixel known errors. If exactly the last bit is set to 1 and all other to 0 (2x0000 0001), the pixel is valid for all science cases. Otherwise the usability for each science case should be assessed individually. It is described in detail in the OsiCalliope image processing pipeline document [RD2].
- The image header keyword DATA_QUALITY_ID in the image label describes if all or part of the image data is affected by an error. It encodes a 16 bit map in a string, describing the kind of error. If all bits are 0, the whole image contains valid data. Otherwise, the image should be used only after assessment if it is usable for a specific science case. The keyword is described in the label of each image by the DATA_QUALITY_DESC keyword, as well as in the SIS [RD1].
- The image header keyword ROSETTA:SHUTTER_FOUND_IN_ERROR_FLAG in combination with ROSETTA:ERROR_TYPE_ID signals if the shutter operation resulted in an error. Shutter operation errors can result in unknown exposure times, therefore making it impossible to convert the image data to physical units. This can happen when either the locking or the unlocking of the first blade fail, resulting in an ERROR_TYPE_ID of either 'LOCKING_ERROR_A' or 'UNLOCKING_ERROR_C'. The other errors, 'MEMORY_ERROR_B' and 'SHE_RESET_ERROR_D' do not result in unknown exposure times, therefore these image fully qualify for all possible science cases. The shutter errors are explained in more detail in the 'Shutter parameters for exposure time calculation' document [RD3].

2.2.5 Documentation

Each dataset contains, in addition to the image data files, all the documents describing the data, the calibration steps applied and the calibration database used to generate the calibrated data:

Folder	**Content**
CALIB/	Contains the calibration database used by the OSIRIS calibration pipeline software OsiCalliope [RD2] to generate the calibrated data.
DOCUMENT/EAICD	Contains the 'Rosetta-OSIRIS to Planetary Science Archive Interface Control Document' (EAICD, [RD5]), a detailed description of the dataset provided and its structure.
DOCUMENT/SIS	Contains the Software Interface Specification for OSIRIS Science Products (SIS, [RD1]). This contains a description of the OSIRIS data format and a definition of all keywords used.
DOCUMENT/CALIB	Contains one document that describes the calibration process performed by OsiCalliope (OSIRIS_CAL_PIPELINE_V<version>.PDF, [RD2]) and several

	documents that describe the calibration database used by OsiCalliope to create calibrated data products. Also contains the description of the filter curves that should be taken into account especially when working on the gas environment of the comet.
DOCUMENT/ SCIENCE_USER_GUIDE	Contains this document.
DOCUMENT/ OSIRIS_SSR	Contains the Keller et al. (2007) paper describing the OSIRIS cameras in detail.
EXTRAS/SOFTWARE	Contains an IDL (Interactive Data Language) software library for reading and manipulating PDS images.
CATALOG/	Contains the catalogue files required by the PDS standard.

2.4 Legacy Dataset

The final re-delivery of all datasets in 2022 – the "legacy dataset" – includes major updates and improvements to the calibration pipeline. Datasets of this release can be identified by the PUBLICATION_DATE, either in the CATINFO.TXT file or in the header of individual images, which should be produced in the year 2022.

The main improvements of the 2022 legacy datasets compared to earlier versions are:

- The header and HISTORY of OSIRIS Level 1 (CODMAC L2) images was reviewed with changes to several entries. The documentation [RD1] includes improved explanations and the previously undocumented HISTORY.
- For WAC images in the BALLISTIC_STACKED shutter operation mode, the start and end times were refined, and an additional keyword STACKING_ACTIVATIONS was added that provides the measured relative time of each shutter activation [RD3].
- The OSIRIS boresight was measured over the full mission using star observation compared to star catalogues. This resulted in a new set of SPICE kernels for the average pointing [RD15] and an image by image shift in OSIRIS Level 3 (CODMAC L4) images based on spacecraft deck temperature (well represented by OSIRIS ADC temperature) and band-pass filter position [RD13]. With these two combined, all OSIRIS Level 3 (CODMAC L4) align to the identical and best known boresight, which is provided in SPICE kernels.
- The SIGMA_MAP of images in OSIRIS Level 2 (CODMAC L3) and higher was expanded. It previously included shot noise and readout noise and now includes errors from all calibration steps (e.g., flatfield, absolute calibration factor, etc.). A complete list of all error components and their values is provided in [RD2].
- The laboratory flatfield images acquired with the flight models before instrument delivery were long suspected to suffer from imperfect illumination conditions. Artefacts in those images that could be clearly associated to the facility were corrected and these improved flatfields are used for image calibration [RD16].
- It was recognised that the laboratory flatfield images of the WAC suffer from a combination of (a) the spectral difference between the integrating sphere light source (halogen or xenon) and the Sun and (b) a field dependent filter transmission band pass. This requires a spectral correction, which was introduced as a spectral flatfielding step in the calibration pipeline [RD16].

- NAC filter combinations 31 and 81 were used for a small number of scientific observations but were previously uncalibrated due to a lack of absolute calibration factors and flatfield images. These were calculated [RD11] and approximated [RD16], such that they can now be calibrated.
- The absolute calibration factors (radiometric calibration) were previously computed based on single observations per filter, mostly from May 2014. An improved method to derive these factors was developed and applied to the whole mission. Transmission of optical elements that are required for these factors were reviewed and in parts re-measured on spare components. The new absolute calibration factors are based on averages of star measurements (per filter) over the whole mission and an enhanced instrument knowledge [RD11].
- For images where the target object does not overlap with the image centre pixel, the IMAGE_POI_PIXEL in the IMAGE_POI now provides the CCD pixel location of the target centre, based on SPICE. This helps in particular to find unresolved scientific targets in the image. It is calculated for levels OSIRIS Level 2 2 (CODMAC L3) and higher if a shape model with pole solution is available for the target.
- OSIRIS Level 2 (CODMAC L3) images are distorted, which implies that the focal length and the iFoV are a function of the pixel location. This can be a problem when performing aperture photometry in this processing level as described in further detail in RD13. The pixel-size value (square iFoV) per pixel is provided as an image file per camera, allowing to apply the required correction for these cases. Distortion corrected images (OSIRIS Level 3, CODMAC L4 and higher) are not affected.
- The distortion-correction coefficients for the WAC were updated, improving the distortion correction to sub-pixel precision [RD13]. The distortion correction for the NAC was re-analysed and confirmed to be excellent.
- Enlarged-frame images (“EF” in the filename) were introduced for OSIRIS Level 3 (CODMAC L4) and higher. With an image-size extension of 128 pixels in all directions, these contain image data that was outside the previous frame on two sides due to the distortion displacement by the camera optics [RD2].
- An improved resampling algorithm for OSIRIS Level 3 (CODMAC L4) and higher was developed, which is optimised for off-axis mirror systems. This method improves the photometric accuracy, particularly for image regions with large intensity gradients [RD13].
- OSIRIS Level 4 (CODMAC L5) data products were corrected, dropping images with inaccurate pointing (described in errata of previous datasets) and matching the image size for geometry layers that were previously not identical to the image layers.
- As the image layers of OSIRIS Level 4 (CODMAC L5) images are shifted between filters and as a function of the S/C deck temperature to match the common boresight (see above), also the geometry layers are shifted by the same value [RD8RD13].
- A new product, OSIRIS Level 4S (CODMAC L5) was introduced [RD8]. The data format is identical to OSIRIS Level 4 (CODMAC L5) but geometry is based on SPICE. This results in twice the number of available geo-referenced images in this level compared to OSIRIS Level 4 (CODMAC L5).
- Packet losses in transmission to ground led to overpainted images by lack of information of the individual start of image. Those images could now be recovered and separated, revealing a number of new (partial) images from the mission.
- The WAC was operated in shutter test mode with ballistic exposure after the loss of shutter locking functionality in autumn 2015. Shutter pulse data in this mode was transmitted

partially in the first lines of image raw data. These lines are now listed in the header and marked in the QUALITY_MAP_IMAGE such that they are not used for scientific analysis.

2.5 Working with OSIRIS images

The first step in working with OSIRIS images is selecting the right dataset for your needs. The JPEG files in the ./BROWSE folder give an easy way to visually identify images showing the type of content the user is interested in, e.g. the limb of the comet, boulders, or images showing the full comet.

For a more systematic search of images fitting the needs of the user, it is recommended to process the information stored in the header. While the header of data file can be accessed and read by any text editor, the usage of automated processing is recommended. Part of the data delivered is an IDL (Interactive Data Language) software library for reading and manipulating PDS images, 'FWPDSLIB'. The routines are able to handle the various layers that may be contained in the image files.

A summary index file containing information about timing, geometry and scientific intended purpose for each image is provided per level on https://www.cosmos.esa.int/web/psa/rosetta (OSIRIS ACTIVITY tables, L<level>[<sublevel>]_ACTIVITY.TAB). The files are also delivered with each OSIRIS dataset in the subdirectory DOCUMENT\ACTIVITY_TABLES.

The quality of the image data can be assessed on a per-image level as well on per pixel-level as described in Section 2.2.4.

In a different programming environment, there are libraries for handling FITs data in all major languages available. For python, the FITs handler as part of 'astropy.io'[1] is recommended, in MatLab the 'fitsread'[2] routine is part of the standard set of routines. Please be aware, that the attached header of the FITs files provides only a limited set of the keywords describing the data. Also only the 'IMAGE' object of the .IMG format files is contained in the FITs files, additional data objects as for example present in the CODMAC level 5 georeferenced files are not present in the FITs data.

The usage of the PDS conformant .IMG format is recommended, as only these images contain the quality map data for error estimation. Unfortunately, the PDS small bodies node[3] provides only data readers in other languages than IDL for the new PDS4 format, not the PDS3 used in the Rosetta mission. The stand-alone tool 'NasaView'[4] can be used to display all PDS3 files, but for automatic processing no library is provided.

For python, the 'planetaryimage'[5] package is developed by volunteers. It works well in parsing PDS compliant image data files, but again does not parse additional data objects.

For MatLab, apparently no PDS file parser is available.

Developing your own parser is not all that complicated. The data file structure and definition of header keywords can be found in the SIS [RD1]. The definition of the PDS3 standard[6] is given by the Planetary Data System Standards Reference [RD7].

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[1] http://docs.astropy.org/en/stable/io/fits/
[2] https://de.mathworks.com/help/matlab/ref/fitsread.html
[3] https://pdssbn.astro.umd.edu/tools/tools_readPDS.shtml
[4] https://pds.nasa.gov/tools/about/pds3-tools/nasa-view.shtml
[5] https://pypi.org/project/planetaryimage/
[6] https://pds.jpl.nasa.gov/datastandards/pds3/standards/

2.6 Frequently Asked Questions (FAQ)

This section contains a list of questions that were repeatedly asked from scientists working with OSIRIS imaging data, inside and outside the team. The answers can and should always be found in the OSIRIS documentation but since it is long and complex, we provide here a first hint on where to search. This does by no means replace the full documentation.

Q: What is the correct orientation of images and browse products?

A: As a default orientation we recommend to use the "standard Rosetta orientation", which is defined and explained in the SIS document [RD1]. In this orientation, images are flipped in the correct way and are rotated such that the solar panels are in the horizontal direction with $+Y_{S/C}$ to the right. For reference, all image browse products (.JPG files) are oriented in this way. Most tools used in the Rosetta community, in particular image simulators, display products in the same orientation.

Q: Why is there no higher level dataset for a certain observation phase, e.g. MTP022 WAC?

A: OSIRIS datasets are only delivered if they contain image data.

Images have to meet certain criteria in order to be calibrated and therefore be available in levels higher than L2. Further details can be found in OSIRIS_CAL_PIPELINE_V<version>.PDF [RD2]. For example, in MTP022 WAC images were acquired only for engineering purposes, and therefore all higher level datasets would be empty and are not created.

A complete list of empty – and therefore non-delivered – datasets, compiled at the time of writing, can be found in Table 7.

Q: Why is the number of images different between different processing levels?

A: The answer can be found in the main calibration pipeline document [RD2]. As a brief explanation, images purposed for calibration and maintenance as well as images with instrument malfunction are not provided in higher levels, since the calibration would not be trustworthy. Images in reflectance units cannot be generated for luminescent objects like stars. Geo referenced images are only provided for a subset of images, where sufficient geometric information was available for generating these [RD8].

Q: Why are there no science planning details for data before 2014?

A: The science planning scheme reflected in the keywords RATIONALE_DESC, OPERATIONAL_ACTIVITY, and ACTIVITY_NAME was introduced only in preparation of the comet rendezvous and therefore starts with post-hibernation in 2014. General details about the science planning prior to this can be found in Section 4.

Q: Why is the time in the image filenames different to the START_TIME in the headers?

A: As explained in the SIS document [RD1], the best known starting time of the image exposure is the START_TIME provided in the image header. The time from the image filename is the uncorrected spacecraft clock and should only be used as a proxy since it is typically one to two minutes off.

Q: How can I assess the quality of an image?

A: It is recommended to use OSIRIS Level 2 (CODMAC L3) images or higher, which are calibrated levels excluding images which have technical issues and unusual instrument settings that cannot be calibrated. The DATA_QUALITY_ID keyword in the image header (see [RD1]) should contain only zero entries, otherwise there is an issue with the image that should be checked for and taken into account (also see DATA_QUALITY_DESC). On top of that, the user should use the quality and sigma maps (extra layers included in every image of OSIRIS level 2 and 3 at all sublevels (CODMAC L3 and L4)), described in the SIS document and in more detail in the main calibration pipeline document [RD2], as outlined in Section 2.2.4. The paper by Tubiana et al. (2015, A&A) [RD9] also gives a good overview on the scientific quality of OSIRIS images.

Q: Which processing level should I use?

A: For images of planetary objects, it is recommended to use solar stray-light corrected, radiometric calibrated & geometric distortion corrected (resampled) image data, in radiance (OSIRIS Level 3C, CODMAC L4, STRLIGHT) or reflectance (OSIRIS Level 3D, CODMAC L4, STR-REFL) units. For images of 67P/Churyumov-Gerasimenko (TARGET_NAME = 67P/Churyumov-Gerasimenko 1) OSIRIS Level 3E or 3F (CODMAC L4, INFLDSTR or L4, INF-REFL) are recommended. Those images are additionally in-field stray-light corrected. If the resampling is a problem, OSIRIS Level 2 (CODMAC L3) data can be used. An overview of all levels is provided above in this section.

Q: Where can I find information about the image processing history? What is the difference between two images in different dataset versions?

A: The image processing history (i.e. the calibration steps that are applied to the image) is stored in the HISTORY section of the image header. The keywords are described in [RD1]. The steps applied to the image are recorder together with the calibration database files and parameters that were used. Further details about the processing can be found in OSIRIS_CAL_PIPELINE_V<version>.PDF [RD2].

Q: **Why do different versions of the same dataset contain different number of images?**

A: There can be many reasons for this, as improvements in the calibration pipeline and/or a change of the assigned TARGET_TYPE of the images, which controls if an image is generated in higher levels. Further details can be found in OSIRIS_CAL_PIPELINE_V<version>.PDF [RD2].

Q: Which is the difference between *ID4n* and *EF4n* images?

A: The distortion correction algorithm stretches the images non-isotropically. Therefore, a certain number of pixels is mapped to positions that are beyond the original image size.

In the standard OSIRIS Level 3 (CODMAC L4) images (*ID4n*) the size of the image is identical to the one of the lower processing levels. This implies that the pixels that fall outside the original area are cropped.

To retain the full image information, OSIRIS Level 3 (CODMAC L4) images are also stored as enlarged frames (*EF4n*). The size of the enlarged frames is extended compared to the original images by 128/b pixels on each side, where b is the binning. Enlarged frame images with 1x1 binning have a size of 2304 x 2304 pixels.

Q: What is the difference between OSIRIS Level 4 and 4S (CODMAC 5)?

A: See [RD8] for a description of the data generation for both products. The image layer is identical. The difference for the geometry layers is (a) a different computation of the observation geometry and (b) a different tool to generate these layers. While the geometry for OSIRIS level 4 (CODMAC L5) is computed from a shape model by product called SUM file, the OSIRIS level 4S (CODMAC L5) product relies on the SPICE toolkit. The set of OSIRIS level 4S (CODMAC L5) images is complete for all images from the comet phase with comet 67P in the field of view, and are also provided as enlarged frames (see above). OSIRIS level 4 (CODMAC L5) images are not provided as enlarged frames.

3 The scientific rationale of OSIRIS image planning

The following chapters provide a link between the science planning and the science use cases that were intended to be feasible with the acquired data. This document thus describes the **intention** the science planners had while implementing a certain observation. The intentions behind any given observation do not exclude the images from being used for different scientific purposes. In turn, due to uncertainties during the planning process and the execution (e.g. uncertainty in spacecraft pointing), the images are sometimes not suitable for the purpose they were acquired.

3.1 Image Header entries related to scientific interpretation

All keywords related to the scientific interpretation are in the ROSETTA namespace, e.g. RATIONALE_DESC is called ROSETTA:RATIONALE_DESC in the image header. All these keywords are supplied only for images taken after hibernation exit on 2014-01-17.

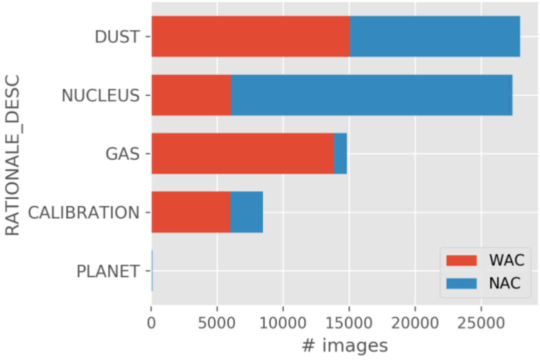
3.1.1 Keyword: RATIONALE_DESC

The keyword RATIONALE_DESC creates a link between any given data product and the general scientific purpose it was acquired for. The list of keywords are valid for all Rosetta remote sensing instruments in refer to the research fields

- nucleus science (NUCLEUS),
- dust science (DUST),
- gas science (GAS),
- combinations thereof and (e. g. DUST_GAS)
- calibration (CALIBRATION).
- planet (PLANET)

These keywords give a first indication of the usability of the data product for a certain scientific field.

The number of images per value of this keyword can be found in Figure 1.



plot_numbers_by_keywords.py: v1.3, File IndexWPC_pds_level1_tagValues.csv (v1.7, latest=True, unmodified); File IndexWPC_pds_level1.csv (v1.4, latest=True, unmodified)

Figure 1 Number of images per value of the RATIONALE_DESC keyword

3.1.2 Keyword: OPERATIONAL_ACTIVITY

The keyword OPERATIONAL_ACTIVITY is in its purpose similar to the RATIONALE_DESC. Contrary to the latter, each instrument has its own set of values for this keyword, giving a more precise indication of the scientific usability of the data product.

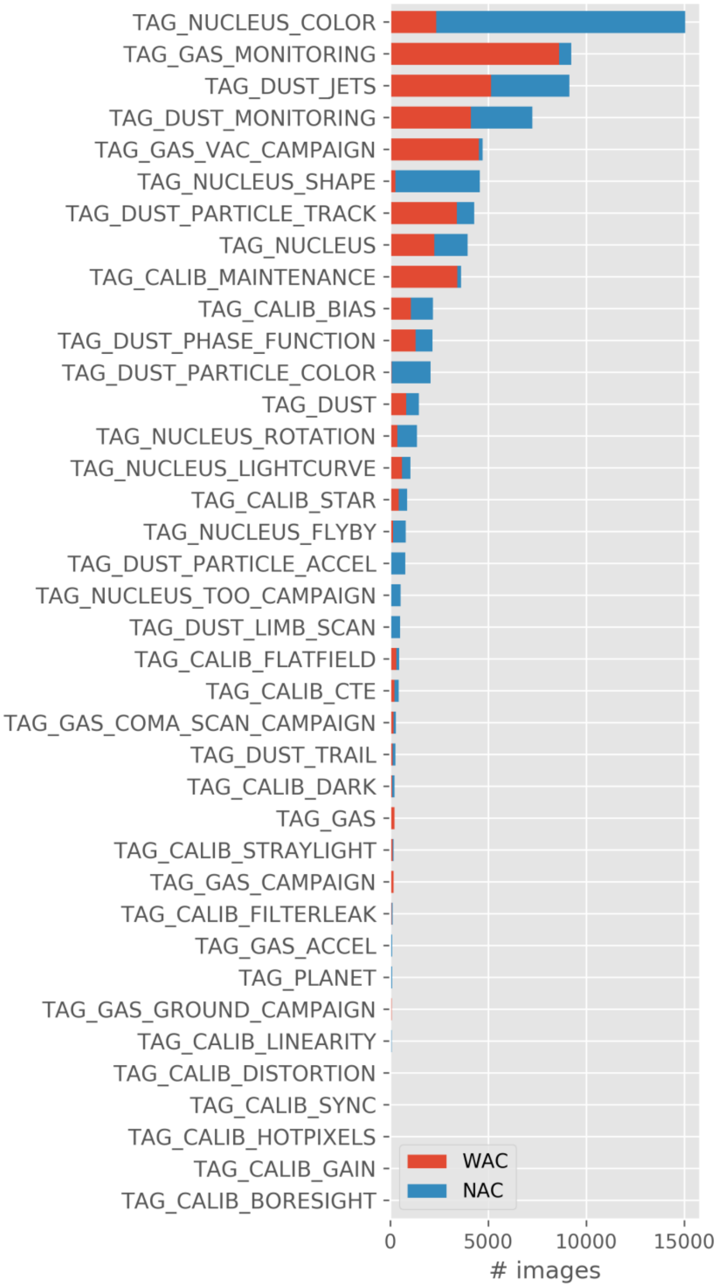
The OSIRIS specific keywords are listed and explained in Chapters 5.7 – 5.11.

Each chapter contains the description for TAGs of the corresponding RATIONALE_DESC.

The TAGs have the following naming convention and are to be seen as instrument specific augmentation for the RATIONALE_DESC.

TAG_[RATIONALE_DESC]_[SPECIFIC-OBSERVATION-TYPE]

Figure 2 shows the number of images in the comet phase acquired by the OSIRIS camera system per value of the OPERATIONAL_ACTIVITY keyword



plot_numbers_by_keywords.py: v1.3, File IndexWPC_pds_level1_tagValues.csv (v1.7, latest=True, unmodified); File IndexWPC_pds_level1.csv (v1.4, latest=True, unmodified)

Figure 2 Number of OSIRIS images per value of the OPERATIONAL_ACTIVITY keyword

3.1.3 Keyword: ACTIVITY_NAME

The activity name, which was used during planning and execution, will be found in the image header under the keyword ACTIVITY_NAME. An activity encompasses a set observations acquired in imaging stations (see Sec. 5.1) during which the image acquisition parameters, e.g. filters, exposure times (per filter and exposure type, see Chapter 5.4) or commanded compression, were generally kept constant.

The activity name is usually (but not always!) following a specific scheme. This is illustrated in Figure 3.

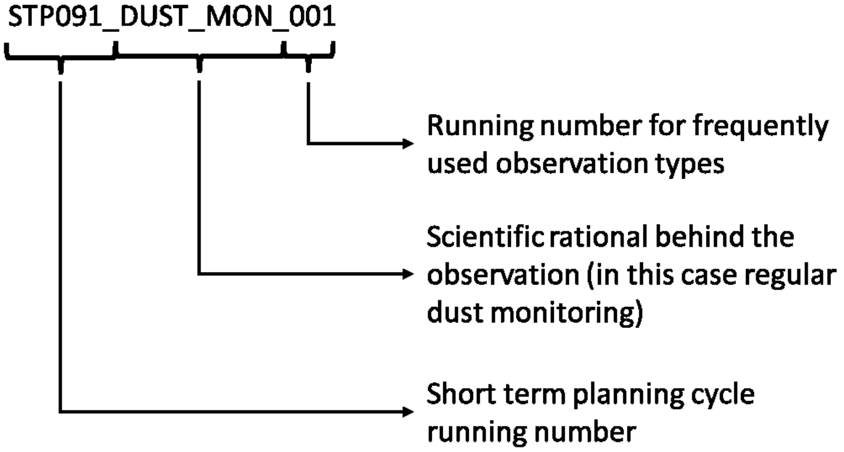


Figure 3 Example for activity naming scheme

The STP number is a time indicator in the mission (see Sec. 5.1 for details).

In the beginning of the mission, activity names were less systematic, resulting in activities with largely different activity names but similar scientific purposes and implementation.

3.2 Other header entries relevant to scientific usability

The OSIRIS image header contains copious amounts of information related to the scientific usability of the data. The user is encouraged to inspect the header of the images before using the data for scientific purposes. Especially entries referring to the shutter operation and possible shutter failures can indicate issues that forfeit the data for scientific use.

A detailed description on the OSIRIS data products, including the header, can be found in the OSIRIS Experiment Data Record and Software Interface Specification (EDR/SIS)[7], attached to all OSIRIS data releases.

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[7] Reference Document RD1.

4 Rosetta and OSIRIS science planning before hibernation

The science planning scheme reflected in the keyword ACTIVITY_NAME and leading to the content described in the keywords RATIONALE_DESC and OPERATIONAL_ACTIVITY was introduced during the preparation for comet rendezvous operation and used only after hibernation exit on 2014-01-17.

These keywords are therefore left empty ("N/A") for the pre-comet mission phase. During these phases, science operations was driven by

- Special events as swing-by maneuvers or close fly-bys
- Special observing opportunities of small bodies in the solar system
- Support imagery for Rosetta or other missions as Deep Impact
- Calibration of the OSIRIS instrument and maintenance of the software

Especially the fly-by sequences at asteroids Steins and Lutetia have been planned to optimize the limited resources in pointing and total amount of data to be fitted into the system memory during these high-speed fly-bys. In general, planning ensured to

- Cover the full phase angle range possible by the fly-by geometry
- Cover as many color filter combinations as possible
- Robustness of sequence against technical and navigational errors, leveraging the redundancy of both cameras

The scientific strategy applied to the Steins fly-by at a Rosetta campaign level is described in detail in Accomazo et al. 2010 (Planetary and Space Science, 58 (9), pp. 1058-1065).

The ROSETTA:MISSION_PHASE before hibernation is derived from the Rosetta Mission Calendar [RD14] phase definitions.

Table 3 Start times (START date at 00:00) and end times (END date at 23:59) for mission phases before hibernation used to provide the ROSETTA:MISSION_PHASE = (LTP, MTP, PHASE) keyword. LTP and MTP are used here as abbreviations and do not directly correspond to these terms used during comet phase. If SOURCE is given as 'ROSETTA', all names and times are specified in the Rosetta Mission Calendar [RD14]. If SOURCE is 'OSIRIS planning', PHASE specifies the main target observed in that timespan. For single-day events such as fly-bys, DATE is given.

PHASE	MTP	LTP	START	END	DATE	SOURCE
LEOP	LEOP	COMMISSIONING	2004-03-02	2004-03-04		ROSETTA
CVP1	CVP1	COMMISSIONING	2004-03-05	2004-04-29		ROSETTA
C/2002 T7	CVP1	COMMISSIONING	2004-04-30	2004-05-01		OSIRIS planning
DSM1	CVP1	COMMISSIONING	2004-05-11	2004-05-11	2004-05-11	ROSETTA
DSM1 Touch-up	CVP1	COMMISSIONING	2004-05-16	2004-05-16	2004-05-16	ROSETTA
CVP1	CVP1	COMMISSIONING	2004-06-03	2004-06-06		OSIRIS planning
Cruise 1	CR1	CRUISE	2004-06-07	2004-09-05	2004-06-07	ROSETTA
DSM1	CVP2	COMMISSIONING	2004-09-06	2004-09-23	2004-05-11	OSIRIS planning

PHASE	MTP	LTP	START	END	DATE	SOURCE
Venus	CVP2	COMMISSIONING	2004-09-24	2004-09-24		OSIRIS planning
Earth 1	CVP2	COMMISSIONING	2004-09-25	2004-09-25	2004-09-25	OSIRIS planning
CVP2	CVP2	COMMISSIONING	2004-09-26	2004-09-27		OSIRIS planning
Saturn 1	CVP2	COMMISSIONING	2004-09-28	2004-09-28	2004-09-28	OSIRIS planning
CVP2	CVP2	COMMISSIONING	2004-09-29	2004-09-30		OSIRIS planning
C/Machholz	EAR1	EARTH	2005-01-20	2005-01-20	2005-01-20	OSIRIS planning
Earth Swing-by 1	EAR1	EARTH	2005-03-04	2005-03-04	2005-03-04	ROSETTA
P/L Checkout 0	EAR1	EARTH	2005-03-28	2005-04-01		ROSETTA
Cruise 2	CR2	CRUISE	2005-06-14	2005-06-27		OSIRIS planning
DeepImpact	CR2	CRUISE	2005-06-28	2005-07-14		OSIRIS planning
P/L Checkout 1	CR2	CRUISE	2005-09-30	2005-10-04		ROSETTA
P/L Checkout 2	CR2	CRUISE	2006-03-03	2006-03-07		ROSETTA
P/L Checkout 2	CR2	CRUISE	2006-03-08	2006-03-10		OSIRIS planning
Steins 1	CR2	CRUISE	2006-03-11	2006-03-11		OSIRIS planning
P/L Checkout 2	CR2	CRUISE	2006-03-12	2006-03-12		OSIRIS planning
P/L Checkout 3	MARS	MARS	2006-08-25	2006-08-30		ROSETTA
DSM2	MARS	MARS	2006-09-29	2006-09-29	2006-09-29	ROSETTA
P/L Checkout 4	MARS	MARS	2006-11-27	2006-12-21		ROSETTA
Lutetia 1	MARS	MARS	2007-01-02	2007-01-03		OSIRIS planning
Mars 1	MARS	MARS	2007-02-23	2007-02-24		OSIRIS planning
Mars Swing-by	MARS	MARS	2007-02-25	2007-02-25	2007-02-25	ROSETTA
Mars 1	MARS	MARS	2007-02-26	2007-02-26		OSIRIS planning
Jupiter 1	MARS	MARS	2007-02-28	2007-02-28	2007-02-28	OSIRIS planning
Cruise 2	CR2	CRUISE	2007-03-01	2006-07-28		ROSETTA
DSM3	MARS	MARS	2007-04-29	2007-04-29	2007-04-29	ROSETTA

PHASE	MTP	LTP	START	END	DATE	SOURCE
P/L Checkout 5	MARS	MARS	2007-05-18	2007-05-22		ROSETTA
Jupiter 2	EAR2	EARTH	2007-09-13	2007-09-14		OSIRIS planning
P/L Checkout 6	EAR2	EARTH	2007-09-16	2007-10-16		ROSETTA
Earth 2	EAR2	EARTH	2007-11-11	2007-11-12		OSIRIS planning
Earth Swing-by 2	EAR2	EARTH	2007-11-13	2007-11-13	2007-11-13	ROSETTA
Earth 2	EAR2	EARTH	2007-11-14	2007-11-16		OSIRIS planning
P/L Checkout 7	EAR2	EARTH	2008-01-04	2008-01-08		ROSETTA
P/L Checkout 7	EAR2	EARTH	2008-02-13	2008-03-19		OSIRIS planning
P/L Checkout 8	CR4A	CRUISE	2008-07-10	2008-08-01		ROSETTA
Jupiter 3	CR4A	CRUISE	2008-07-26	2008-07-26	2008-07-26	OSIRIS planning
Steins 2	AST1	STEINS	2008-08-04	2008-09-04		OSIRIS planning
Steins Fly-by	AST1	STEINS	2008-09-05	2008-09-05	2008-09-05	ROSETTA
Steins 3	AST1	STEINS	2008-09-06	2008-10-04		OSIRIS planning
P/L Checkout 9	CR4B	CRUISE	2009-01-30	2009-02-03		ROSETTA
P/L Checkout 9	CR4B	CRUISE	2009-03-09	2009-03-11		OSIRIS planning
DSM4	CR4B	CRUISE	2009-03-19	2009-03-19	2009-03-19	ROSETTA
P/L Checkout 10	EAR3	EARTH	2009-09-18	2009-09-20		OSIRIS planning
P/L Checkout 10	EAR3	EARTH	2009-09-21	2009-10-04		ROSETTA
P/L Checkout 10	EAR3	EARTH	2009-10-21	2009-10-21		OSIRIS planning
Earth 3	EAR3	EARTH	2009-11-08	2009-11-12		OSIRIS planning
Earth Swing-by 3	EAR3	EARTH	2009-11-13	2009-11-13	2009-11-13	ROSETTA
Earth 3	EAR3	EARTH	2009-11-14	2009-11-18		OSIRIS planning
Saturn 2	EAR3	EARTH	2009-11-21	2009-11-21	2009-11-21	OSIRIS planning
CR5	CR5	CRUISE	2010-02-09	2010-02-10		OSIRIS planning

PHASE	MTP	LTP	START	END	DATE	SOURCE
354P/LINEAR 58	CR5	CRUISE	2010-03-16	2010-03-16	2010-03-16	OSIRIS planning
P/L Checkout 12	CR5	CRUISE	2010-04-22	2010-05-14		ROSETTA
Vesta	CR5	CRUISE	2010-05-01	2010-05-01	2010-05-01	OSIRIS planning
Lutetia 2	AST2	LUTETIA	2010-06-07	2010-07-09		OSIRIS planning
Lutetia Fly-by	AST2	LUTETIA	2010-07-10	2010-07-10	2010-07-10	ROSETTA
Lutetia 2	AST2	LUTETIA	2010-07-12	2010-07-12		OSIRIS planning
P/L Checkout 13	RVM1	CRUISE	2010-12-01	2010-12-08		ROSETTA
RVM 1	RVM1	CRUISE	2011-01-23	2011-01-23	2011-01-23	OSIRIS planning
67P	RVM1	CRUISE	2011-03-24	2011-03-26		OSIRIS planning

5 Rosetta and OSIRIS science planning after hibernation

5.1 Terminology

The Rosetta active mission planning was done predominantly in two planning cycles, MTP and STP. The longest planning cycle, LTP, was used mostly in the high-level science planning.

LTP: The Rosetta **L**ong-**T**erm **P**lanning-cycle is a planning interval comprising on typically 4 MTPs (see below) covering a timespan of roughly three months. The duration and number of MTPs is not fixed but was adapted to mission planning needs. LTP based planning covered the type of trajectory flown, excursions and distance to the nucleus as well as science priority between instruments. There were a total of 10 LTPs during the comet phase.

MTP: The Rosetta **M**id-**T**erm **P**lanning-cycle is a planning interval comprising typically 4 STPs (see below), covering a timespan of roughly four weeks. The duration and number of STPs is not fixed but was adapted to mission planning needs. MTP based planning covered among others data volume allocation, spacecraft pointing, and organization of multi-instrument campaigns. There were 35 MTPs in the comet phase.

STP: The Rosetta **S**hort-**T**erm **P**lanning-cycle is a planning unit corresponding to approximately one week. Over the course of the mission, 130 STPs were completed grouped together in 35 MTPs. STP based planning covered the detailed implementation of observations in the framework of the agreements from the MTP planning. For each STP one commanding file (called ITLS) was submitted to ESA to be executed on the spacecraft. As a consequence of this, any activity (see below) that is repeated within one STP will, in general, have the same implementation (e. g. number of images or used filters). Activities from different STPs aiming for the same scientific goal (i.e. having similar activity names and the same OPERATIONAL_ACTIVITY keyword) can have different implementations. This change can be related to a novel approach to tackling a scientific question.

Activity: An activity is an OSIRIS planning unit of variable duration, associated with one dataset (e. g. the group of images acquired during this activity). Images are grouped together via the activity name and are associated with one STP and MTP. Activities can be interleaved resulting in datasets with images of similar acquisition times. Within one activity image acquisition parameters (e. g. filter choice, cadence, and exposure time) remain constant. This means an imaging station (see below) can be repeated multiple times but will be executed in an identical way.

Imaging station: An imaging station is an OSIRIS planning unit consisting of image acquisitions with defined parameters, which can be repeated several times within one activity. An example of this would be a set of images with different filters with EXP_NUCLEUS exposure time (see Ch. 5.4). This implementation can be repeated as necessary within a mapping activity to achieve a global color map.

5.2 Mission phases after hibernation

MISSION_PHASE	**LTP**	**MTP**	**STP**	**START_TIME**	**END_TIME**
PRELANDING COMMISSIONING	LTP001	MTP001	STP001	2014-01-20T10:00:00	2014-04-05T23:59:59
		MTP002	STP002	2014-04-06T00:00:00	2014-05-07T12:47:59
PRELANDING		MTP003	STP003, STP004	2014-05-07T12:48:00	2014-06-04T10:49:59
		MTP004	STP005, STP006	2014-06-04T10:50:00	2014-07-02T08:34:59
		MTP005	STP007, STP008, STP009, STP010	2014-07-02T08:35:00	2014-08-01T09:59:59
		MTP006	STP011, STP012, STP013, STP014, STP015	2014-08-01T10:00:00	2014-09-02T09:59:59
	LTP002	MTP007	STP016, STP017, STP018	2014-09-02T10:00:00	2014-09-23T09:59:59
		MTP008	STP019, STP020, STP021, STP022, STP023	2014-09-23T10:00:00	2014-10-24T09:59:59
	LTP003	MTP009	STP025, STP026, STP027, STP028, STP029	2014-10-24T10:00:00	2014-11-21T23:24:59
COMET ESCORT 1		MTP010	STP030, STP031, STP032, STP033, STP034	2014-11-21T23:25:00	2014-12-19T23:24:59
	LTP004	MTP011	STP035, STP036, STP037, STP038	2014-12-19T23:25:00	2015-01-13T23:24:59
		MTP012	STP039, STP040, STP041, STP042	2015-01-13T23:25:00	2015-02-10T23:24:59
	LTP005	MTP013	STP043, STP044,	2015-02-10T23:25:00	2015-03-10T23:24:59

			STP045, STP046		
COMET ESCORT 2		MTP014	STP047, STP048, STP049	2015-03-10T23:25:00	2015-04-08T11:24:59
		MTP015	STP051, STP052, STP053, STP054	2015-04-08T11:25:00	2015-05-05T23:24:59
		MTP016	STP055, STP056, STP057, STP058	2015-05-05T23:25:00	2015-06-02T23:24:59
		MTP017	STP059, STP060, STP061, STP062	2015-06-02T23:25:00	2015-06-30T23:24:59
COMET ESCORT 3		MTP018	STP063, STP064, STP065, STP066	2015-06-30T23:25:00	2015-07-28T23:24:59
	LTP006	MTP019	STP067, STP068, STP069, STP070	2015-07-28T23:25:00	2015-08-25T23:24:59
		MTP020	STP071, STP072, STP073, STP074	2015-08-25T23:25:00	2015-09-22T23:24:59
		MTP021	STP075, STP076, STP077, STP078	2015-09-22T23:25:00	2015-10-20T23:24:59
COMET ESCORT 4	LTP007	MTP022	STP079, STP080, STP081, STP082	2015-10-20T23:25:00	2015-11-17T23:24:59
		MTP023	STP083, STP084, STP085, STP086	2015-11-17T23:25:00	2015-12-15T23:24:59
		MTP024	STP087, STP088, STP089, STP090	2015-12-15T23:25:00	2016-01-12T23:24:59
ROSETTA EXTENSION 1	LTP008	MTP025	STP091, STP092,	2016-01-12T23:25:00	2016-02-09T23:24:59

			STP093, STP094		
		MTP026	STP095, STP096, STP097, STP098	2016-02-09T23:25:00	2016-03-08T23:24:59
		MTP027	STP099, STP100, STP101, STP102	2016-03-08T23:25:00	2016-04-05T23:24:59
ROSETTA EXTENSION 2	LTP009	MTP028	STP103, STP104, STP105, STP106	2016-04-05T23:25:00	2016-05-03T23:24:59
		MTP029	STP107, STP108, STP109, STP110	2016-05-03T23:25:00	2016-05-31T23:24:59
		MTP030	STP111, STP112, STP113, STP114	2016-05-31T23:25:00	2016-06-28T23:24:59
ROSETTA EXTENSION 3		MTP031	STP115, STP116, STP117, STP118	2016-06-28T23:25:00	2016-07-26T23:24:59
		MTP032	STP119, STP120	2016-07-26T23:25:00	2016-08-09T23:24:59
	LTP010	MTP033	STP121, STP122, STP123, STP124	2016-08-09T23:25:00	2016-09-02T06:39:59
		MTP034	STP125, STP126, STP127, STP128	2016-09-02T06:40:00	2016-09-26T06:39:59
		MTP035	STP129, STP130	2016-09-26T06:40:00	2016-10-01T00:00:00

Table 4 - Table of mission phases with coverd LTPs, MTPs, STPs and duration.

Source files: OsirisNow/OsirisNow.xlsx v1.58, OsirisNow/mission-phases-uptoMTP030.txt v1.1

5.3 Trajectory and special events

DESCRIPTION	START_TIME	END_TIME
Northern hemisphere mapping	2014-09-10T11.09.54.442	2014-09-23T17.09.48.466
10 km orbits	2014-10-14T18.51.03.550	2014-10-28T15.30.40.738
Philae delivery and landing	2014-11-12T08.35.00.000	2014-11-12T17.32.00.000
Close fly-by with zero-phase angle crossing	2015-02-14T02.37.52.595	2015-02-14T20.03.03.350
Far fly-by with zero-phase angle crossing	2015-02-21T12.52.47.752	2015-02-23T09.54.49.283
Close fly-by	2015-03-28T06.31.49.463	2015-03-28T16.19.04.125
Tail excursion	2015-09-23T09.36.36.727	2015-10-07T17.18.54.775
Southern hemisphere mapping	2016-01-23T15.03.35.693	2016-01-30T19.03.23.815
Night side excursion	2016-03-24T23.03.17.543	2016-04-08T16.58.52.685
Close fly-by with zero-phase angle crossing	2016-04-09T07.22.32.347	2016-04-11T07.20.16.976
Northern hemisphere re-mapping	2016-06-05T11.13.10.854	2016-06-18T22.23.50.986
End of mission ellipses	2016-08-10T01.57.34.800	2016-09-23T11.41.55.760
Rosetta final descent and end of mission	2016-09-30T01.20.24.619	2016-09-30T10.37.40.457

Table 5 - Time line of special observation events. Times refer to the timestamp in the filename of the first and last image of each period, respectively.

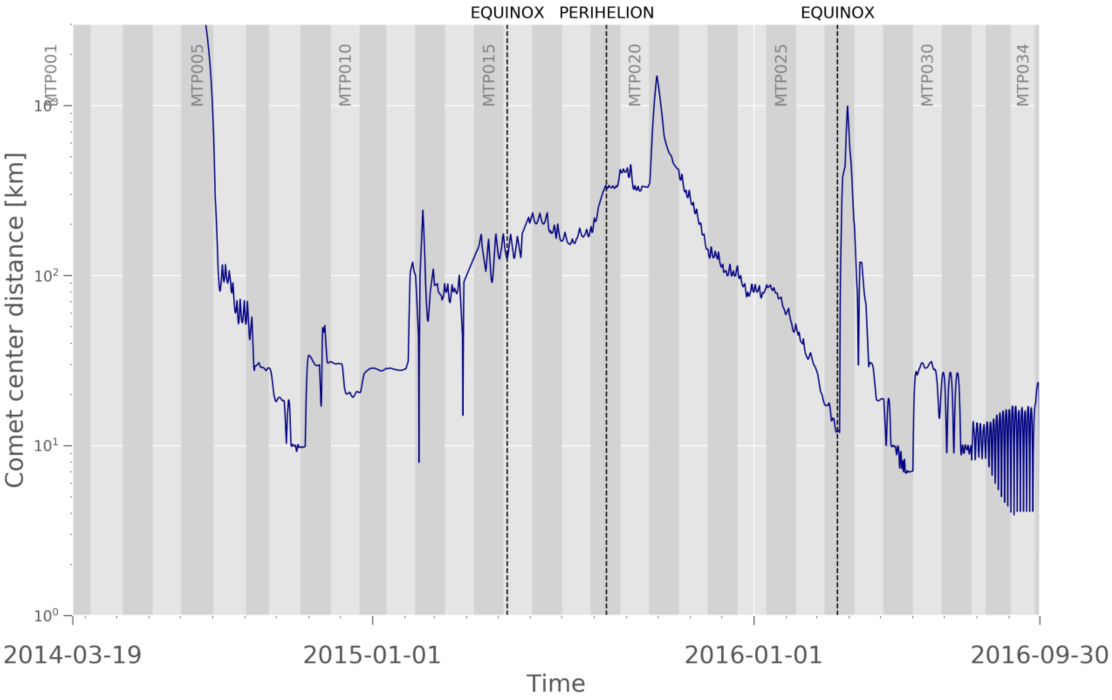

Figure 4 Rosetta's distance to the comet center as a function of time

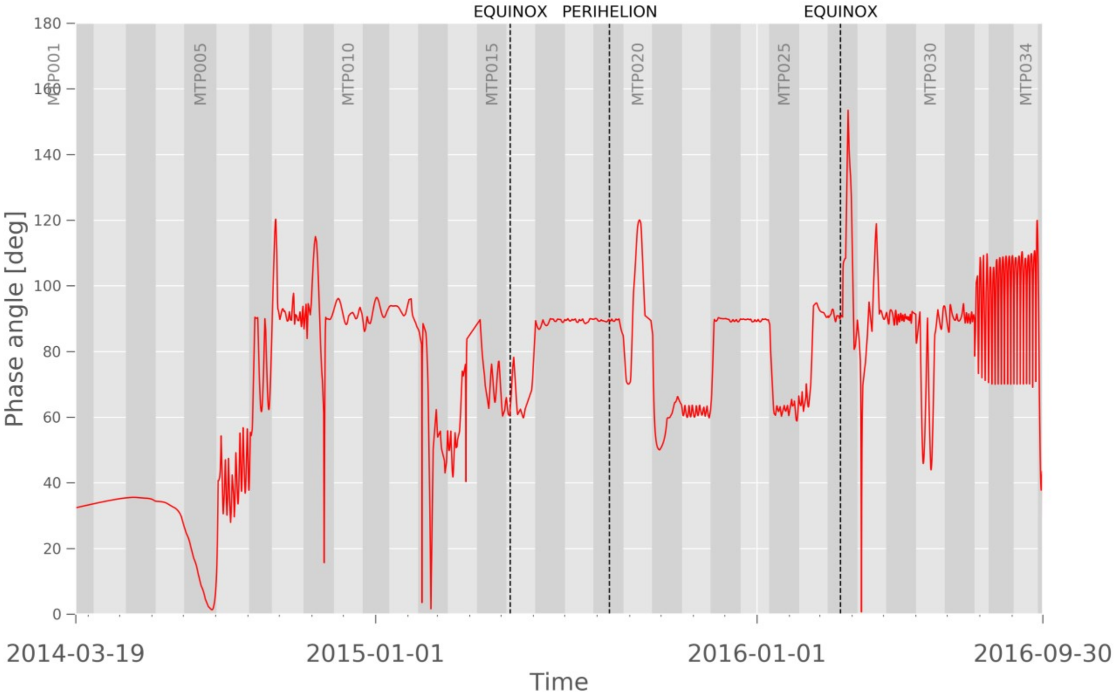

Figure 5 The phase angle (Sun-67P-Rosetta) as a function of time

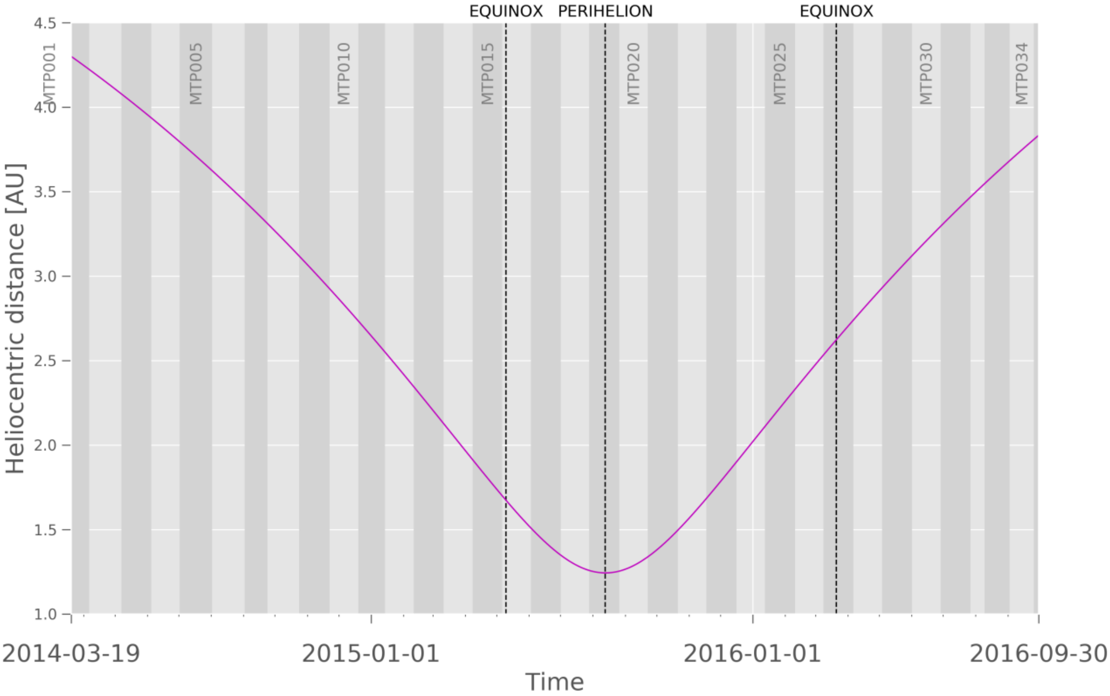

Figure 6 67P/CGs heliocentric distance as a function of time

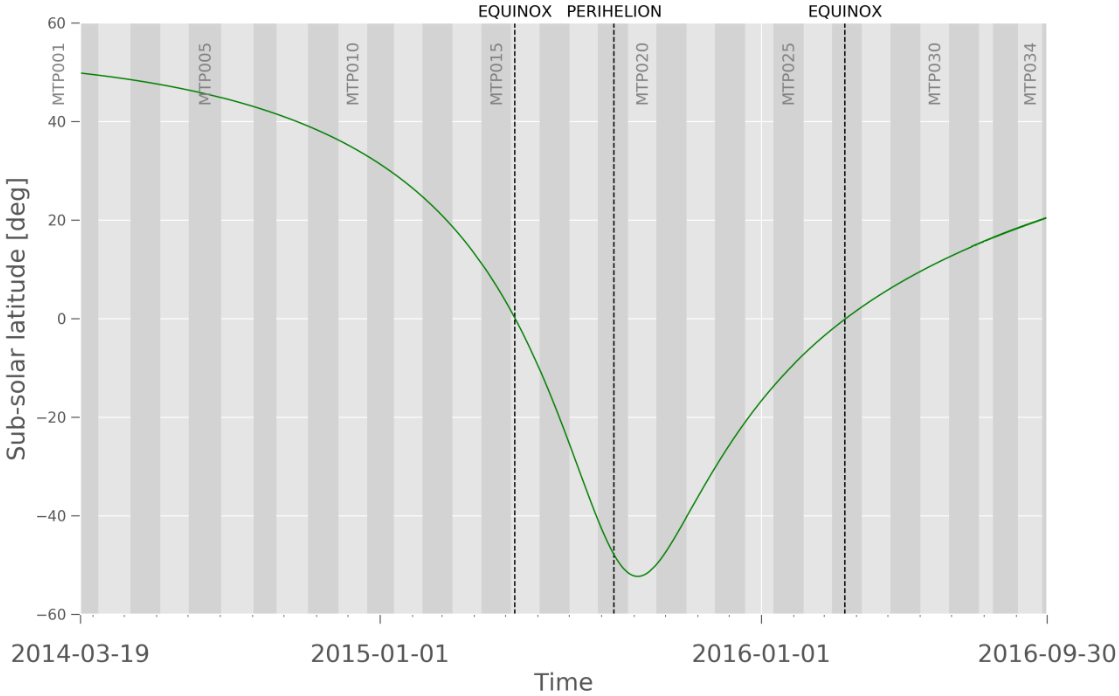

Figure 7 Rosetta's sub-solar latitude on the surface of 67P/CG as a function of time

5.4 Description of exposure types

During the course of the mission, the heliocentric distance of comet 67P/CG, as well as the phase angle of the planned observations varied significantly, and with it the absolute brightness of the cometary surface and the coma. Therefore, the exposure times to result in the same CCD signal level had to be adjusted constantly. During planning, a set of "exposure types" were used, that were converted into exposure times using a model of the comets surface properties. This exposure type is not stored in the header of the images, and is not to be confused with the keyword EXPOSURE_CORRECTION_TYPE in the history section of the header.

EXP_NUCLEUS: This exposure type is designed to result in images that have optimal signal on the illuminated comet surface, i. e. high overall signal without saturating bright areas. Based on a physical reflectance model and taking into account the parameters of the camera (like transmission curves of the filters, quantum efficiency of the CCD etc.) this calculation gives the exposure time needed to reach a user defined signal level (usually 10,000 DN[8]) for a given heliocentric distance and phase angle. In later activities, the exposure times are shortened when the observation took place very close to the nucleus, to avoid smearing of the images due to spacecraft movements and nucleus rotation, resulting in a smaller expected signal level. To ensure minimal strain on the mechanical parts of the shutter in case of shutter errors, the exposure time is limited to 80 ms and above. This can lead to a deviations from the above mentioned targeted signal level in cases where the optimal exposure time is slightly below 80 ms but is then manually increased to the minimum value to meet the safety standards.

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[8] DN stands for "digital number", a unit to measure the signal in an image pixel after analog-to-digital conversion. The OSIRIS camera has a dynamic range of up to 16 bit resulting in measurable DN values between 0 and 65536 with non-linearity and saturation effects becoming measurable above 45000 DN.

EXP_COMA_SHORT: This exposure type is designed to result in images that have optimal signal when observing the dust coma around the nucleus. This was achieved be multiplying the corresponding EXP_NUCLEUS exposure time with an adequate factor (between 12.5 and 25).

EXP_COMA_LONG: This exposure type is designed to result in images that have optimal signal when observing the gas coma around the nucleus. The exposure times are calculated such that the signal from the unresolved dust coma (which is always larger than the signal from the gas) will not saturate the CCD taking into account the parameters of the camera (like transmission curves of the filters, quantum efficiency of the CCD etc.).

WAC_BALLISTIC: After the failure of the WAC shutter to lock blade 1 in the open position, an alternative operation mode for the WAC shutter was devised. To expose the CCD, blade 1 is fired with an initial velocity that results in zero velocity shortly before reaching the locking position and subsequent ballistic fallback of blade 1 without interaction with the locking mechanism and without activations of blade 2. This results in an uneven illumination of the CCD with a fixed exposure time. The lower part of the image, in the standard Rosetta orientation, is exposed longer than the upper part, ranging from ~300 ms at the bottom to ~30 ms at the top having ~90 ms at the center line. The uneven exposure is corrected during calibration[9], resulting in different signal-to-noise ratios across the image. The type of shutter operation results in images that are well illuminated when aiming at the nucleus (compare to 80 ms minimum exposure time for EXP_NUCLEUS) but makes deeper exposure harder to achieve (see WAC_BALLISTIC_STACKING for details).

WAC_BALLISTIC_STACKING: After the WAC shutter failure and subsequent introduction of the WAC_BALLISTIC exposure type, on-chip stacking was chosen as the way to still achieve deep-exposure images. The CCD is exposed several times in ballistic mode before it is read out. This operation mode can be used to achieve images with several seconds of effective exposure time. A caveat is the longer execution time compared to a deep exposure with nominal shutter operations. This leads to an increased number of artefacts created by the penetration of cosmic rays on the CCD as well as a larger influence of nucleus rotation on the physical field of view.

DUAL_BALLISTIC: For the final descent, safety constraints for the WAC shutter operation were lifted to reach an exposure time of 15 ms, necessary to acquire unsaturated images during the descent. For this, the shutter blade 2 was fired 15 ms after shutter blade 1, resulting in both of them forming a slit of constant width, travelling across the CCD, that exposed any part of the CCD for 15 ms. The shutter parameters of the blades were chosen such that at the end of their respective flights, they would collide gently. Blade 1 and 2 would then travel back into the home position in a closed formation, to prevent further illumination of the CCD.

5.5 Compression strategy

During planning of the images, lossless compression was commanded as often as possible. In cases where the data volume available for downlink was limited or a higher number of images was favored over pristine quality, lossy compression of the images was used.

The compression algorithms resulting in best performance for lossy/lossless compression were called TAP/LIFT, respectively. In addition to this compression, a square root filter (SQRT) could be applied to the image before compression to further reduce the image size. The square root filter

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[9] Details on the calibration and shutter operation can be found in the OSIRIS calibration pipeline OsiCalliope documentation (RD2) and Shutter parameters for exposure time calculation documentation (RD3) attached to all OSIRIS data releases

calculates the square root for every pixel before transmission, reducing the number of bits necessary to store the information.

While these types of compression conserve the flux, they can introduce compression artifacts to the images. Whenever possible, lossless compression was commanded (compression ratio of 1:1 to 1.5:1 without SQRT). When lossy compression was needed, the most frequently used ratios were 3:1 with SQRT, 6:1 with and without SQRT.

Certain observation types prohibit the use of the square root filter because of the resulting artifacts (e. g. steps in originally smooth gradients, jumps in color ratios). Among these activities are color observations and observations of the unresolved dust coma.

Details on the compression can be found in the image header in the GROUP SR_COMPRESSION. The values have the format of a list, each entry of the list corresponding to a segment of the image. The number of image segments depends on the total size of the image (a full frame image consist of 16 segments in a 4x4 raster). The starting positions of the segments on the CCD (SEGMENT_X, SEGMENT_Y) and their sizes (SEGMENT_H, SEGMENT_W) as well as an indicator for data loss (LOST_PACKETS) are given in the same header group.

1. COMPRESSION_RATIO gives the achieved compression ratio (floating point number)
2. LOSSLESS_FLAG indicates if an image segment was compressed losslessly (TRUE/FALSE)
3. ENCODING names the compression algorithm
4. SQRT_FILTER_FLAG indicates the use of the square root filter (TRUE/FALSE)

More information about header entries can be found in RD1.

5.6 Pointing and image acquisition terminology

The terminology used to describe the pointing and image acquisition in the following chapters distinguishes between several archetypes.

Pointing direction: A pointing direction describes the viewing direction (e. g. as angular offset from nadir pointing) realized during an observation. This viewing direction remains constant during the acquisition of an imaging station (no spacecraft slew during image acquisition to avoid smearing).

Imaging station: An imaging station refers to a set of images with specific properties like filter choice, cadence or exposure time that can be repeated unchanged several times in its entirety within one activity. The pointing can optionally be changed between imaging stations.

Broad-band vs. narrow-band filter: Both cameras have two filter wheels with eight positions each. The filters used by the OSIRIS camera can be classified as broad-band or narrow-band (line) filter. While narrow-band filters are designed to transmit only light of a specific wavelength (within a few to a few tens of nanometers), broad-band filters have a wider bandpass.

WAC filters: The WAC has a set of 14 broad- and narrow-band filters, while one filter wheel position is empty for each wheel. Among the WAC filters there are two broad-band filters (Red and Green), the rest are narrow-band filters, some of which are tuned to strong emission lines of the most abundant gas species in the coma (CS, OH, NH, CN, NH2, Na, OI). When the WAC is used, one of the filter wheels is in the empty position while the other wheel is rotated to the filter desired for the observation. If both filter wheels are in the empty position (F11) the light arrives at the CCD unfiltered, focused through the optical characteristics of the camera setup resulting in a very narrow focus at ~15 m distance from the camera. The transmission curves of the filters can be found in RD4.

NAC filters: The NAC has a set of 11 broad-band filters, four focusing plates and a neutral density filter. Each broad-band filter needs to be used in tandem with a focusing plate or the neutral density filter. The spectral properties are governed by the broad-band filters (e. g. Orange). The neutral density filter can be used to reduce the signal. The focusing plates are used to control the focus of the camera: far focus plates (FFP; available for UV, visible light and IR) for objects at distances larger than ~2500 m from the camera, the near focus plate (NFP; available for visible light) at smaller distances. When referring to filters in the visible in the following chapters, the filter number will indicate the use of the far focus plate (e. g. F22 for FFP-Vis_Orange). If operationally necessary, the far focus plate was substituted by the neutral density filter (F82, Neutral density_Orange) or the near focus plate (F32, NFP-Vis_Orange), e. g. during nucleus observations at low phase angles the neutral density filters was used when the surface brightness results in inoperably low exposure times for the FFP-Vis_Orange combination. In cases like this, where this change does not affect scientific intent and usability of the images, the (potential) use of NFP or neutral density filter will not be explicitly mentioned. The transmission curves of the filters can be found in RD4.

5.7 Nucleus Science

5.7.1 TAG_NUCLEUS

General imaging of the nucleus surface.

5.7.1.1 Sequence Characteristics

- Field of view/pointing: FoV contains nucleus
- Camera(s): NAC, [WAC]
- Cadence: No constraints
- Duration: Ranging from minutes to hours
- Filter(s): NAC Orange (F22[10]) as standard reference filter (see also Table 6)
- Exposure time(s): EXP_NUCLEUS
- Special characteristics: None
- Optional: WAC context images

5.7.1.2 Description of Science Case

TAG_NUCLEUS images are used to analyze the morphology and structure the comet's surface on varying spatial scales and as a function of time.

Images are therefore acquired only when the surface is resolved. Furthermore, the NAC Orange (F22) standard reference filter is used to facilitate an easier comparison between individual observations and to create a homogeneous dataset.

Combining measurements with different observation geometries allows an analysis of surface scattering properties, e. g. phase curve and opposition effect.

5.7.2 TAG_NUCLEUS_COLOR

Color imaging of the nucleus surface.

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[10] See Ch. 5.6 (NAC filters) for a discussion on the different implementations of color filters in the NAC

5.7.2.1 Sequence Characteristics

- Field of view/pointing: FoV contains nucleus
- Camera(s): NAC, [WAC]
- Cadence:
  - No constraints on cadence between filter sets
  - Individual filters acquired as close in time as possible
- Duration: Ranging from minutes to hours
- Filter(s):
  - NAC:
    - At least three filters
    - For filter priorities refer to Table 6
    - Containing Orange (F22) as standard reference filter
  - Discontinuous use of filters
    - Filter priorities defined in Table 6 are not rigorously valid throughout the mission, especially during early activities
- Exposure time(s): EXP_NUCLEUS
- Special characteristics: None
- Optional: WAC context images

Most sequences are designed using the following filter priorities:

Filter name		**Far-UV**	**Near-UV**	**Orange**	**Green**	**Blue**	**Hydra**	**Red**	**Near-IR**	**Ortho**	**Fe203**	**IR**
		15	**16**	**22**	**23**	**24**	**27**	**28**	**41**	**51**	**61**	**71**
Number of Filters to use	1			X								
	3			X		X			X			
	5		X	X	X	X			X			
	6		X	X	X	X			X			X
	7		X	X	X	X	X		X			X
	9		X	X	X	X	X	X	X		X	X
	10		X	X	X	X	X	X	X	X	X	X
	11	X	X	X	X	X	X	X	X	X	X	X

Table 6 Filter selection per number of filters used in observation

Every TAG_NUCLEUS_COLOR activity also meets the criteria for a TAG_NUCLEUS activity and can be used for those scientific purposes.

Sequences tagged as TAG_NUCLEUS_COLOR may, on rare occasions, contain less than three filters. This can be caused by data loss or acquisition of part of the images in low priority queues that were not downloaded (due to restrictions in available data volume).

5.7.2.2 Description of Science Case

TAG_COLOR images are used to analyze the surface of the comet in terms of spectral properties.

Information on spectral features is available from any TAG_COLOR observation. Depending on the number of filters used for an observation, more details in the spectrum can be retrieved, e.g. spectral slope (at least 2 filters) and color composites (at least 3 filters). From these, properties of the surface material can be deduced, e.g. ice content, mineralogy.

Combining measurements with different observation geometries allows an analysis of surface scattering properties and wavelength dependencies in the phase curve and opposition effect.

The observations are designed to aim for maximum surface coverage with as many filters as possible to allow for global characterization of the comet. Additionally, follow-up sequences were scheduled for regions of interest, e.g. with color features detected early in the mission or frost fronts at retreating shadows.

The surface coverage of the individual filters varies and full coverage is not given for all filters in all phases of the mission.

5.7.3 TAG_NUCLEUS_TOO_CAMPAIGN

Concerted observation of nucleus landmarks with more than one remote sensing instrument operating simultaneously.

5.7.3.1 Sequence Characteristics

- Field of view/pointing: FoV contains selected landmark (surface site specifically selected for individual observation)
- Camera(s): NAC, [WAC]
- Cadence: No constraints
- Duration: Ranging from minutes to hours
- Filter(s): NAC Orange (F22)
- Exposure time(s): EXP_NUCLEUS
- Special characteristics:
    - Landmark is resolved
    - Observation done in concert with VIRITS, MIRO and optionally also ALICE
- Optional:
    - Additional NAC color filters
    - WAC context images
    - 2x2 rasters to compensate for pointing uncertainty

5.7.3.2 Description of Science Case

TAG_NUCLEUS_TOO_CAMPAIGN observations are used to create a large suit of data on a specific landmark (Target of Opportunity, ToO) on the comet's surface. To this end, any ToO observation is carried out with OSIRIS, VIRTIS, MIRO and optionally ALICE.

OSIRIS observations consist of at least one NAC image in the orange filter (F22) to allow for analysis of brightness variegations, surface morphology and changes thereof compared to earlier OSIRIS observations and to give a visual reference for the other instruments.

Additionally, images in other color filters may be acquired to give spectral information about the observed landmark (see TAG_NUCLEUS_COLOR for potential path of interpreting OSIRIS color sequences).

WAC context images may be acquired to get a context of the larger environment of the landmark, e.g. when the spacecraft was very close to the surface at the time of the observation.

These concerted observations were conducted between 2016-06-19 and 2016-08-06 when the spacecraft was mostly at a distance below 20 km to achieve high spatial resolution.

Every TAG_NUCLEUS_TOO_CAMPAIGN activity also meets the criteria for a TAG_NUCLEUS activity. Sequences using more than one NAC color filters additionally satisfy the conditions for a TAG_NUCLEUS_COLOR observation and can be used for those scientific purposes.

5.7.4 TAG_NUCLEUS_ROTATION

Observation designed to reconstruct nucleus rotation properties.

5.7.4.1 Sequence Characteristics

- Field of view/pointing: FoV contains nucleus
- Camera(s): NAC
- Cadence: ranging from 20 (optimal) to 30 minutes
- Duration: At least one full comet rotation
- Filter(s): NAC Orange (F22)
- Exposure time(s): EXP_NUCLEUS
- Special characteristics: Surface is resolved (Nucleus covers an area of at least 10x10 pixels)
- Optional:
  - WAC context images
  - Additional NAC color filters (only in early implementations)

5.7.4.2 Description of Science Case

TAG_NUCLEUS_ROTATION observations are used to measure the comet's rotational elements. This is done by tracking surface features through one full comet rotation.

To easily facilitate this tracking, a cadence of one image every 20 minutes, corresponding to ~10° of nucleus rotation, is desired. Individual images might not be acquired due to operational constraints like navigational slots, temporarily suspending nominal science observations.

This activity is repeated regularly throughout the mission to track the temporal evolution of the comet's rotational state.

Every TAG_NUCLEUS_ROTATION activity also meets the criteria for a TAG_NUCLEUS activity and can be used for those scientific purposes.

5.7.5 TAG_NUCLEUS_SHAPE

Observation designed to reconstruct the nucleus' shape.

5.7.5.1 Sequence Characteristics

- Field of view/pointing: FoV contains nucleus
- Camera(s): NAC, [WAC]
- Cadence: No constraints
- Duration: Ranging from days up to two weeks
- Filter(s): NAC Orange (F22)
- Exposure time(s): EXP_NUCLEUS
- Special characteristics:
  - Surface is resolved (Nucleus covers an area of at least 10x10 pixels)
  - Observation designed for maximum coverage of the illuminated surface
- Optional:

  - Additional NAC color filters
  - WAC context images

5.7.5.2 Description of Science Case

TAG_NUCLEUS_SHAPE observations are designed to allow for a 3D shape reconstruction of the visible portion of the nucleus at a given point in time.

Therefore the images are acquired in a way to maximize the coverage of the illuminated surface while limiting the total observation duration to avoid ambiguities in the shape reconstruction due to surface changes happening within the observation duration.

Every TAG_NUCLEUS_SHAPE activity also meets the criteria for a TAG_NUCLEUS activity. Sequences using more than one NAC color filters additionally satisfy the conditions for a TAG_NUCLEUS_COLOR observation and can be used for those scientific purposes.

5.7.6 TAG_NUCLEUS_FLYBY

Imaging of the nucleus during flybys.

5.7.6.1 Sequence Characteristics

- Field of view/pointing: FoV contains nucleus, mostly nadir pointing
- Camera(s): NAC, [WAC]
- Cadence: Variable cadence to obtain good spatial and phase angle coverage
- Duration: Several hours around closest approach
- Filter(s): NAC Orange (F22)
- Exposure time(s): EXP_NUCLEUS
- Special characteristics:
  - Special observation geometries possible:
    - Zero phase crossing
    - High phase angle
    - Very short to very large distance in short time
- Optional:
  - Additional NAC color filters
  - WAC context images

5.7.6.2 Description of Science Case

TAG_NUCLEUS_FLYBY observations realize a large phase angle coverage in a short time, including a zero phase angle crossing when possible, combined with high spatial resolution at the smallest phase angles.

Every TAG_NUCLEUS_FLYBY activity also meets the criteria for a TAG_NUCLEUS activity. Sequences using more than one NAC color filters additionally satisfy the conditions for a TAG_NUCLEUS_COLOR observation and can be used for those scientific purposes.

During flyby geometries other remote sensing instruments were generally on and acquiring data in parallel to OSIRIS.

5.7.7 TAG_NUCLEUS_LIGHTCURVE

Observation designed to measure the comet’s rotational light curve.

5.7.7.1 Sequence Characteristics

- Field of view/pointing: FoV contains nucleus
- Camera(s): [NAC], WAC
- Cadence: ranging from 20 (optimal) to 40 minutes
- Duration: At least one full comet rotation
- Filter(s): Broadband filters to allow for maximum signal at a given integration time
- Exposure time(s): Fixed 600 s, to limit the amount of cosmics in the image
- Special characteristics:
  - Surface is unresolved or poorly resolved (Nucleus covers an area of less than 10x10 pixels)
  - Observation were carried out during approach only
- Optional: Additional NAC color filters

5.7.7.2 Description of Science Case

TAG_NUCLEUS_LIGHTCURVE observations are designed to measure the brightness of the (unresolved or poorly resolved) nucleus over a full comet rotation to measure its light curve.

The light curve can be used to measure the nucleus' rotation state, rotation period and direction of the spin axis. Additionally, these observations can be used to constrain its three-dimensional shape.

Given more than one observation, the temporal evolution of above quantities can also be studied.

5.8 Dust Science

5.8.1 TAG_DUST

General observation of the dust coma.

5.8.1.1 Sequence Characteristics

- Field of view/pointing: FoV contains coma
- Camera(s): NAC, WAC
- Cadence: No constraints
- Duration: No constraints
- Filter(s): At least 1 dust continuum filter
- Exposure time(s): EXP_NUCLEUS, EXP_COMA_SHORT
- Special characteristics: None
- Optional: Reference images with EXP_NUCLEUS

5.8.1.2 Description of Science Case

TAG_DUST is an aggregator for observations that generally target the dust coma, both individual particles as well as the overall background coma around the nucleus without following the specific pointing and image acquisition strategies detailed in the following sections (e. g. not covering a full nucleus rotation or not containing certain filters).

These observations can be used, especially in addition to other more specific dust science images, to monitor the long-term evolution of dust activity, search for tracks of individual particles, and if the limb is in the FOV locate the source location of jet features.

5.8.2 TAG_DUST_MONITORING

Monitoring of the overall dust coma.

5.8.2.1 Sequence Characteristics

- Field of view/pointing:
    - FoV contains coma and (a fraction of the) nucleus
    - The nucleus should not cover more than 1/3 of the frame
        - When observing at close distance, typically the lower third of the frame is covered by the nucleus
        - When observing at large distances, the full comet is smaller than one third of the frame width
- Camera(s): NAC, WAC
- Cadence: ≲ 1 hour
- Duration:
    - Aimed to be at least one full comet rotation
    - Valuable information can still be recovered from observations lasting half a comet rotation and longer
- Filter(s): At least 1 dust continuum filter
- Exposure time(s): EXP_COMA_SHORT
- Special characteristics: None
- Optional: Reference images with EXP_NUCLEUS

5.8.2.2 Description of Science Case

TAG_DUST_MONITORING observations are designed to measure the intensity of the overall dust coma with the purpose to analyze its diurnal and seasonal brightness variations and structure.

5.8.3 TAG_DUST_COMA_SCAN_CAMPAIGN

Observation of dust coma with large variety of geometries during one activity concerted with other remote sensing instruments.

5.8.3.1 Sequence Characteristics

- Field of view/pointing:
    - FoV contains coma
    - Observations with changing pointing direction
        - Implementation of pointing pattern not constant from activity to activity
        - At least one activity observed the full coma (360°) in the plane perpendicular to the sun-comet-direction.
        - May cover a wide variation of pointing direction
- Camera(s): NAC, WAC
- Cadence: One imaging station per pointing direction
- Duration: 4 to 8 hours
- Filter(s):
    - Depending on the observation time per station, the following filters or a subset thereof were used
        - NAC: Near-UV (F16), Hydra (F27), Blue (24), Green (23), Orange (22), Near-IR (F41)
        - WAC: Vis-610 (F18), O1 (F17), NH2 (F15), CN (F14), UV-375 (F13)

- Exposure time(s):
    - EXP_COMA_LONG
    - One WAC Vis-610 (F18) with EXP_COMA_SHORT
- Special characteristics: Images were binned 8x8 to reduce the execution time of the observations
- Optional:
    - In some instances, in addition to images acquired to analyze the overall dust coma signal, TAG_DUST_PARTICLE_TRACK or TAG_DUST_PARTICLE_COLOR type sequence were commanded at each pointing direction

5.8.3.2 Description of Science Case

TAG_DUST_COMA_SCAN_CAMPAIGN observations are designed to analyze the brightness of the coma at varying comet off-pointing. These observations are conducted together with other remote sensing instruments.

The pointing direction is varied immensely throughout the different activities to acquire data on the global coma structure, its color and level of anisotropy.

5.8.4 TAG_DUST_PARTICLE_TRACK

Tracking of individual particles in the dust coma.

5.8.4.1 Sequence Characteristics

- Field of view/pointing:
    - Coma without nucleus
    - Variable off-pointing within one activity possible
- Camera(s): NAC, WAC
- Cadence: Repeated imaging on time scales comparable to the particle movement in the field of view
- Duration: No constraints
- Filter(s): Varying filter combinations used
- Exposure time(s): Wide range of exposure times commanded to observe particles of different apparent brightness and velocity
- Special characteristics: See below

Variants of TAG_DUST_PARTICLE_TRACK sequences:

a) Sets of subsequent images with varying exposure time
    - NAC or WAC
    - 2-3 exposure times
b) Use of color filters (see also Sec. 5.8.5)
c) Use of NAC FFP-Vis[11] and NAC NFP-Vis, mostly commanded with additional color filters (see also Sec. 5.8.5)
d) Simultaneous use of WAC and NAC
e) Use of WAC Empty-Empty (F11)

These variants (and sometimes combinations thereof) were commanded during different times of the mission with decreasing frequency of use from a) to e).

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[11] See Sec. 5.6 (NAC filters) for details on the focusing plates

Early implementations (up to STP050) are not always compliant with the strict definitions given above but follow the same general principles.

5.8.4.2 Description of Science Case

TAG_DUST_PARTICLE_TRACK sequences are used to analyze statistical properties of the motion of dust particles around the Rosetta spacecraft. Depending on the detailed implementation of the observation, the dust properties (in particular distance and size) that can be derived can differ.

All implementations allow determining number density, velocity and acceleration in up to three dimensions.

Determining the distance of particles (and together with that the reflectance) to the camera can be done by

1. Parallax – Parallax determination can be done through the simultaneous use of WAC and NAC or by observing at different times utilizing the spacecraft motion and assuming a radial trajectory of the particles. Both methods work only for particles that are close enough to the camera to exhibit a visible parallax.
2. Defocusing – For particles that are close enough to the camera to display blurring, the distance can by determined using the known optical properties of the camera.
3. Limb observation – For observations that have the limb of the comet in the field of view, the distance to selected particles will be approximately the same as the distance to the limb (which in turn can be calculated using SPICE information).

5.8.5 TAG_DUST_PARTICLE_COLOR

Color imaging of individual particles in the dust coma.

5.8.5.1 Sequence Characteristics

- Field of view/pointing:
    - Coma without nucleus
    - Variable off-pointing within one activity possible
- Camera(s): NAC, WAC
- Cadence: Repeated imaging on time scales comparable to the particle movement in the field of view
- Duration: No constraints
- Filter(s): NAC: Near-IR (F41), Orange (F22), Blue (F24)
- Exposure time(s):
    - Different exposure time were commanded
        - EXP_COMA_SHORT (early implementation)
        - Fixed 12.5 s for all NAC filters
- Special characteristics: None
- Optional:
    - Additional NAC Orange with NFP-Vis (F32) image
    - Additional WAC Green (F21) image with exposure time similar to or longer than the execution time of full the NAC observation

5.8.5.2 Description of Science Case

TAG_DUST_PARTICLE_COLOR sequences are used to analyze the spectral properties of the dust particles around the Rosetta spacecraft.

When WAC and NAC were operated simultaneously, the WAC exposure time surpassed execution time of the NAC observations to allow a reconstruction of the particle motion, simplify tracking and give a photometric reference.

Every TAG_DUST_PARTICLE_COLOR activity also meets the criteria for one of the TAG_DUST_PARTICLE_TRACK variants and can be used for those scientific purposes.

5.8.6 TAG_DUST_PARTICLE_ACCEL

Observation of individual particles in the acceleration region.

5.8.6.1 Sequence Characteristics

- Field of view/pointing:
  - Limb or close to the limb
  - Typically sub-solar limb close to frame edge
- Camera(s): NAC
- Cadence:
  - Two different implementations
    - Image doublets
      - Varying cadence for image doublets, ranging from 0 to 40 s between doublets
    - Short series of fixed long-exposure images
      - Cadence ranging from 13 to 24 s
- Duration: No constraints
- Filter(s): NAC Orange (F22)
- Exposure time(s):
  - Image doublets with two different exposure times
    - Short exposure (EXP_NUCLEUS or fixed 240 ms)
    - Long exposure (EXP_COMA_SHORT or fixed 3 s)
  - Series of fixed long-exposure images
    - 9 s exposure time
- Special characteristics:
  - Commanded at small comet distances
- Optional: None

5.8.6.2 Description of Science Case

TAG_DUST_PARTICLE_ACCEL sequences are used to analyze the motion of particles in the acceleration region, i.e. close to the nucleus surface.

Two different exposure times and the total activity duration on the order of ten minutes are used to image fast and slow moving particles and analyze their dynamical behavior.

5.8.7 TAG_DUST_PHASE_FUNCTION

Observation to measure the dust coma phase function.

5.8.7.1 Sequence Characteristics

- Field of view/pointing:
    - Coma without nucleus
    - Geometry:
        - Observation of dust coma at varying phase angles with nucleus outside the field of view
            - Range of phase angles typically between 20° and 160°
            - Phase angles close to 0° not realized because of stray-light effects
            - Phase angles close to 180° only realized at heliocentric distances above 2.21 AU due to thermal constraints
        - The observing plane is defined as the plane spanned by the sun, the spacecraft and the nucleus, the phase angle between the sun and the spacecraft viewing direction lies within this plane
        - Not all activities have all pointing directions
- Camera(s): NAC, WAC
- Cadence: one imaging sequence per observing geometry
- Duration: between 4 and 8 hours
- Filter(s):
    - At least two and up to three filters per camera
        - Filters used in every observation:
            - NAC: Orange (F22), Blue (F24)
            - WAC: Green (F21)
        - Intermittently used additional filters:
            - NAC: Red (F28)
            - WAC: UV375 (F13), Vis-610 (F18), Red (F12)
- Exposure time(s):
    - Exposure times optimized for dust signal far from the nucleus
        - EXP_COMA_LONG for the NAC in general and for the WAC prior to shutter failure
        - After WAC shutter failure, stacking was used with a varying number of exposures per stack depending on filter and heliocentric distance
- Special characteristics:
    - Images were binned 4x4 to reduce the execution time of the observations
- Optional: None

5.8.7.2 Description of Science Case

TAG_DUST_ PHASE_FUNCTION sequences are used to analyze the brightness of the dust coma as a function of phase angle and wavelength.

The phase function of the diffuse dust coma is an important parameter to study the physical properties of the individual scattering particles that cannot be resolved. Using appropriate models, this allows inferring the size distribution, surface roughness, porosity and shape of the particles.

If more than 2 filters have been used, the observation can also be applied to determine the spectral reflectance behavior. This information helps to determine the model parameters related to the composition of the particles.

5.8.8 TAG_DUST_LIMB_SCAN

Scan across the full illuminated limb of the comet at high resolution.

5.8.8.1 Sequence Characteristics

- Field of view/pointing:
  - Limb
  - Observations were done at changing positions on the limb to cover to full illuminated limb
- Camera(s): NAC, WAC
- Cadence: One imaging station per pointing direction
- Duration: No constraints
- Filter(s):
  - NAC
    - NUCLEUS: Orange (F22), Blue (F24)
    - COMA_SHORT: Orange (F22), Green (F23), Blue (F24)
  - WAC
    - COMA_SHORT: Vis-610 (F18)
- Exposure time(s): Acquire image sets with EXP_NUCLEUS and EXP_COMA_SHORT
- Special characteristics:
  - WAC context image(s)
  - Raster at high resolution
- Optional: None

5.8.8.2 Description of Science Case

TAG_DUST_ LIMB_SCAN sequences are used to scan the full illuminated limb of the comet at high resolution to get comparable data about diurnal activity variations across the comet.

5.8.9 TAG_DUST_JETS

Limb observation with the specific objective to detect and trace jets.

5.8.9.1 Sequence Characteristics

- Field of view/pointing:
  - Limb
  - Occasional special geometries:
    - Imaging from above pole
    - Imaging the anti-solar limb of the comet
- Camera(s): NAC, WAC
- Cadence: Imaging on time scales comparable to the anticipated time scales of dust variability
- Duration: typically 1 to 2 hours
- Filter(s):
  - Imaging done predominantly with NAC Orange (F22)
  - WAC filters used intermittently:
    - Red (F12), O1 (F17), Vis-610 (F18)
- Exposure time(s): exposure times used vary in the different variants
- Special characteristics: None

- Optional:
    - Additional NAC color filters
    - WAC context images with EXP_NUCLEUS

Variants of TAG_DUST_JETS sequences:

a) Image doublets with short and long exposure time at varying cadence
    - 10 to 30 min between doublets
    - Short exposure time either EXP_NUCLEUS or fixed 240 ms
    - Long exposure time either EXP_COMA_SHORT or fixed 3 s

b) Single filter imaging with high cadence and short duration
    - Predominantly done with the WAC
    - Exposure time EXP_COMA_SHORT

c) Around perihelion the conditions were not always strictly met in terms of cadence and/or duration (both of them usually longer to monitor jet activity levels and outbursts)

5.8.9.2 Description of Science Case

TAG_ DUST_JETS sequences are used to analyze the structure, evolution and sources of cometary jet features. To catch the spatial characteristics as well as the source points of the jets, a limb pointing (at close comet center distances) or nadir pointing (at large comet center distances) is used.

Since jets are varying immensely in their brightness, imaging with different exposure depth is important to catch both bright and faint jets. The fainter jets can be detected using EXP_COMA_SHORT exposure times, which in turn saturates the nucleus, preventing reconstruction of the jet source point. Imaging sequences using the EXP_NUCLEUS exposure type allow detection of brighter jets and serve as reference images for source point detection on the surface.

The temporal evolution of the jet happens on several time scales and thus needs to be addressed with several different imaging cadences. Short term variations, like onset of activity, require short imaging cadences between images. Variations attributed to the comet's rotation need to be monitored using with total activity durations of up to a full comet rotation period.

5.8.10 TAG_DUST_TRAIL

Observation of the dust trail.

5.8.10.1 Sequence Characteristics

- Field of view/pointing: Trail and forward trail
- Camera(s): NAC, WAC
- Cadence: No constraints
- Duration: No constraints
- Filter(s):
    - Varying combinations of the following filters:
        - NAC: Orange (F22), Blue (F24)
        - WAC: Red (F12)
- Exposure time(s):
    - Manually selected exposure times optimized for expected signal of the trail
        - Commanded exposure times vary between 80 seconds and 10 minutes

    - 10 minutes is the maximum exposure time for one image to avoid over-contamination with cosmic rays
- Special characteristics: None
- Optional: None

5.8.10.2 Description of Science Case

TAG_DUST_TRAIL sequences were designed to detect and measure the brightness of the dust trail. The expected brightness from modelling and ground-based observations was used to calculate the exposure times necessary for detection.

The pointing implementation at the time of planning was not guaranteed to be successful.

5.9 Gas Science

Most sequences aimed to measure the gas environment of the comet make use of narrow band filters, especially the WAC narrow band filters. Inherent to the design of narrow band filters in combination with the of-axis design of the camera is a strong line dependency of the throughput of the filters. When working with these data, please make sure to read the “NAC and WAC Optical Band-pass Filter Transmissions” document [RD10].

5.9.1 TAG_GAS

General observation of the gas coma.

5.9.1.1 Sequence Characteristics

- Field of view/pointing: FoV contains coma
- Camera(s): NAC, WAC
- Cadence: No constraints
- Duration: No constraints
- Filter(s): At least 1 dust continuum and 1 gas filter
- Exposure time(s): EXP_COMA_LONG
- Special characteristics: None
- Optional: Reference images with EXP_NUCLEUS

5.9.1.2 Description of Science Case

TAG_GAS is an aggregator for observations that generally target the gas coma around the nucleus without following the specific pointing and image acquisition strategies detailed in the following sections (e. g. not covering a full nucleus rotation or not containing certain filters).

Different gas species can be detected with WAC gas filters centered at the wavelength of a specific emission line. These images are always accompanied with at least one image taken with a continuum filter to allow for the subtraction of the dust continuum signal before analysis of the gas signal.

The aim is to determine the coma structure and production rates for different gas species, the parent and/or daughter species.

5.9.2 TAG_GAS_MONITORING

Monitoring of the gas coma.

5.9.2.1 Sequence Characteristics

- Field of view/pointing:
    - FoV contains coma
        - Nadir pointing at large comet-spacecraft distances
        - Limb pointing at small comet-spacecraft distances
- Camera(s): NAC, WAC
- Cadence: $\lesssim$ 1 hour
- Duration:
    - Aimed to be at least one full comet rotation
    - Valuable information can still be recovered from observations lasting half a comet rotation and longer
- Filter(s):
    - WAC:
        - At least 1 dust continuum and 1 gas filter
    - NAC:
        - Fixed filters: Hydra (F27), Fe2O3 (F61), Near-IR (F41), Near-UV (F16)
- Exposure time(s):
    - At least one image with exposure time optimized for gas signal
        - EXP_COMA_LONG for the NAC in general and for the WAC prior to shutter failure
        - After WAC shutter failure, stacking was used with a varying number of exposures per stack depending on filter and heliocentric distance
- Special characteristics: Images were binned 4x4 to reduce the execution time of the observations
- Optional: surface reference image(s) with EXP_NUCLEUS

5.9.2.2 Description of Science Case

TAG_GAS_MONITORING is used to monitor the long-term behavior of the coma structure and production rates for different gas species. If possible, full nucleus rotations have been acquired to allow the analysis of both diurnal as well as long-term evolution of the gas activity.

After the failure of the WAC shutter and subsequent creation of the ballistic mode (refer to RD3), all sequences aiming at observing the gas had to be redesigned. Since single exposures acquired in ballistic mode (SHUTTER_OPERATION_MODE = ‘BALLISTIC’) resulted in too low CCD signal levels to do gas studies, images needed to be acquired using on-board stacking to reach the necessary signal levels (SHUTTER_OPERATION_MODE = ‘BALLISTIC_STACKED’).

Stacking led to increased execution times for the gas sequences compared to normal shutter operation. This made the analysis more difficult due to increased influence of nucleus rotation and higher levels of cosmics. As a consequence of this, gas observations could only be executed using the OI and Vis-610 filters, as other filters would result in prohibitively large stacking numbers required. A maximum stacking of 100 images has been used.

Additionally, the stacking observations were conducted from January 2016, when the comet was already outbound with decreasing activity level, resulting in potential detection of gas signal only in the strongest emission lines.

5.9.3 TAG_GAS_ACCEL

Observation of gas in the acceleration region.

5.9.3.1 Sequence Characteristics

- Field of view/pointing:
    - Limb
    - Typically sub-solar limb close to frame edge
- Camera(s): NAC, WAC
- Cadence: No constraints
- Duration: No constraints
- Filter(s):
    - WAC:
        - At least 1 dust continuum and 1 gas filter
    - NAC:
        - Fixed filters: Hydra (F27), Fe2O3 (F61), Near-IR (F41), Near-UV (F16)
- Exposure time(s):
    - At least one image with exposure time optimized for gas signal
        - EXP_COMA_LONG for the NAC in general and for the WAC prior to shutter failure
        - After WAC shutter failure, stacking was used with a varying number of exposures per stack depending on filter and heliocentric distance
- Special characteristics:
    - Commanded at small comet distances
- Optional: None

5.9.3.2 Description of Science Case

TAG_GAS_ACCEL sequences are used to study the gas field in the acceleration region, i.e. close to the comet's limb.

These observations were done in parallel to the TAG_DUST_PARTICLE_ACCEL observation to connect the gas field to the dust motion (gas/dust dynamics).

5.9.4 TAG_GAS_VAC_CAMPAIGN

Concerted observation of volatile activity in the gas coma.

5.9.4.1 Sequence Characteristics

- Field of view/pointing:
    - FoV contains coma
    - Limb pointing
- Camera(s): NAC, WAC
- Cadence: 1 hour
- Duration: From several hours to one full comet rotation
- Filter(s):
    - Before WAC shutter failure, WAC only (filters in square brackets not always commanded)
        - Gas filters with COMA_LONG
            - OH (F61), O1 (F17), NH2 (F15), NH (F81), CN (F14), [Na (F16)]
        - Dust continuum filters with COMA_LONG
            - UV-375(F13), Vis-610 (F18)
        - Surface reference images

            - UV-375(F13), [O1 (F17)]
    - Filter implementation after WAC shutter failure, NAC and WAC:
        - WAC part of observation (not always commanded)
            - Two stacks: O1 (F17), Vis-610 (F18)
        - NAC part of observation
            - Fixed filters: Hydra (F27), Fe2O3 (F61), Near-IR (F41), Near-UV (F16)
- Exposure time(s):
    - EXP_COMA_LONG
    - EXP_NUCLEUS for surface reference images
- Special characteristics: Observation done in concert with at least one other remote sensing instrument
- Optional: None

5.9.4.2 Description of Science Case

TAG_ GAS_VAC_CAMPAIGN observations are used to determine the activity of volatiles leaving the comet's surface. To this end, during VAC observations other remote sensing instruments acquired data in parallel to OSIRIS.

5.9.5 TAG_GAS_COMA_SCAN_CAMPAIGN

Concerted scanning observation of the gas coma.

5.9.5.1 Sequence Characteristics

- Field of view/pointing:
    - FoV contains coma
    - Varying comet off-pointings scanning through the coma
- Camera(s): NAC, WAC
- Cadence: One observation per pointing direction
- Duration: No constraints
- Filter(s):
    - NAC:
        - Near-UV (F16), Hydra (F27), Blue (F24), Green (F23), Orange (F22), Near-IR (F41)
    - WAC:
        - COMA_LONG: Vis-610 (F18), O1 (F17), NH2 (F15), CN (F14), UV-375 (F13)
        - COMA_SHORT: Vis-610 (F18)
- Exposure time(s):
    - EXP_COMA_LONG
    - EXP_COMA_SHORT for dust continuum signal
- Special characteristics:
    - Images were binned 8x8 to reduce the execution time of the observations
    - Observation done in concert with at least one other remote sensing instrument
- Optional: None

5.9.5.2 Description of Science Case

TAG_GAS_COMA_SCAN sequences are used to analyze the gas coma around the comet at varying comet off-pointings. During these activities other remote sensing instruments acquired data in parallel to OSIRIS.

5.9.6 TAG_GAS_CAMPAIGN

Concerted observation of the gas coma.

5.9.6.1 Sequence Characteristics

- Field of view/pointing:
    - FoV contains coma
    - Varying comet off-pointings
- Camera(s): WAC
- Cadence: 10s between gas images
- Duration: No constraints
- Filter(s):
    - Vis-610 (F18), O1 (F17) [both exposure types], Na (F16), NH2 (F15), CN (F14), UV-375 (F13) [both exposure types], CS (F41), OH (F61), NH (F81)
- Exposure time(s):
    - EXP_COMA_LONG
    - EXP_NUCLEUS for surface reference
- Special characteristics:
    - Images were binned 4x4 to reduce the execution time of the observations
    - Observation done in concert with at least one other remote sensing instrument
- Optional: None

5.9.6.2 Description of Science Case

TAG_GAS_CAMPAIGN sequences are observations of the gas coma around the comet at varying comet off-pointings without strict pointing pattern or duration. During these activities other remote sensing instruments acquired data in parallel to OSIRIS.

5.9.7 TAG_GAS_GROUND_CAMPAIGN

Observation of the gas coma concerted with ground based observations.

5.9.7.1 Sequence Characteristics

- Field of view/pointing:
    - Coma
    - Nadir pointing done at large comet center distance
- Camera(s): WAC
- Cadence: 7 minutes in between filters
- Duration: one full comet rotation
- Filter(s):
    - Filter pairs (gas + dust continuum) per observation
        - CN (F14) + UV-375(F13)
        - O1 (F17) + Vis-610 (F18)

- Exposure time(s): Fixed 600 seconds for all filters, to limit the amount of cosmics in the image
- Special characteristics: Nadir pointing from great comet center distance
- Optional: None

5.9.7.2 Description of Science Case

TAG_GAS_GROUND_CAMPAIGN observations are aimed at detecting two major gas species, O1 and CN, at large comet distance during the approach phase of the mission.

Simultaneously to the OSIRIS observations, ground based telescopes were observing the comet to detect the same gas species for comparison.

5.10 Non-comet observations

5.10.1 TAG_PLANET

Observation of planetary bodies in the solar system.

5.10.1.1 Sequence Characteristics

- Specialized filter choice varying for different targets
- Manually set exposure times varying for different targets

5.10.1.2 Description of Science Case

TAG_PLANET observations are aimed at planetary bodies in our solar system.

5.11 Non-Science Activities

5.11.1 TAG_CALIB_BIAS

TAG_CALIB_BIAS observations are done regularly to measure and monitor the bias level of the OSIRIS CCDs.

The activities are structured as follows:

- Image acquisition with special BIAS mode
- Repetition cadence: On average bi-weekly

5.11.2 TAG_CALIB_BORESIGHT

TAG_CALIB_BORESIGHT observations are done to cross-calibrate the boresight direction of the OSIRIS cameras with those of other remote sensing instruments.

5.11.3 TAG_CALIB_CTE

TAG_CALIB_CTE observations are done to measure and monitor the charge transfer efficiency of the CCD chips.

5.11.4 TAG_CALIB_DARK

TAG_CALIB_DARK observations are done regularly to measure and monitor the dark current of the OSIRIS CCDs.

The activities are structured as follows:

- Image acquisition with special DARK mode

- Repetition cadence: On average once per month

5.11.5 TAG_CALIB_DISTORTION

TAG_CALIB_BIAS observations are done to measure and monitor the optical distortion of the image. Due to thermal expansion and/or wear the distortion characteristics of the camera systems change over time and need to be monitored.

5.11.6 TAG_CALIB_FILTERLEAK

TAG_CALIB_FILTERLEAK observations are done to characterize the amount of light outside of the bandpass reaching the CCD through pinholes in some of the narrow-band filters.

5.11.7 TAG_CALIB_FLATFIELD

TAG_CALIB_FLATFIELD observations are done to measure and monitor the evolution of flatfields of the CCD in flight to improve calibration, if necessary.

5.11.8 TAG_CALIB_GAIN

TAG_CALIB_GAIN observations are done to measure the conversion rate from number of electrons in a CCD pixel to DN after analog to digital conversion.

5.11.9 TAG_CALIB_HOTPIXELS

TAG_CALIB_HOTPIXELS observations are done to find, characterize and monitor individual pixels and areas on the CCD that provide invalid DN values.

5.11.10 TAG_CALIB_LINEARITY

TAG_CALIB_LINEARITY observations are done to characterize the linearity of the measured brightness of an object on the CCD with exposure time.

5.11.11 TAG_CALIB_MAINTENANCE

TAG_CALIB_MAINTENANCE observations are done to test, monitor and/or improve the functionality of the camera and/or of its component(s). These observations are carried out in such a way that the target in front of the cameras is irrelevant.

5.11.12 TAG_CALIB_STAR

TAG_CALIB_STAR observations are done regularly to measure the brightness of the targeted star. These measurements are then used during the flux calibration of OSIRIS images or for cross-calibration between several instruments.

Target stars for flux calibration are 16 Cygni (16Cyg) and Vega. Target stars for cross-calibration are Zeta Cassiopeiae (ZetaCas) and Zeta Ophiuchi (ZetaOph).

The activities are structured as follows:

- Use all filters of both cameras when possible
    - some filters require too short exposure times to not saturate the CCD and cannot be used with certain stars
- Pointing at star
- Fixed exposure times
- Repetition cadence: On average bi-monthly

5.11.13 TAG_CALIB_STRAYLIGHT

TAG_CALIB_STRAYLIGHT observations are done to characterize the amount of stray light accumulated on the CCD during an observation. This stray light can be out-of-field (solar stray light) or in-field (ghosts on the images created by reflections on optical parts like filters and CCD coatings).

5.11.14 TAG_CALIB_SYNC

TAG_CALIB_SYNC observations are done to characterize the magnitude of the coherent noise as a function of the so-called sync value, which indicates the synchronization of the internal clock of the power converter.

6 List of empty datasets

Table 7 contains a list of empty – and therefore not delivered – datasets, up to date at the time of the document writing.

Table 7 List of empty datasets

Mission Phase	Camera	CODMAC Level	Sublevel	Explanation
M01	NAC	5		Does not contain images used for shape model generation
M01	WAC	5		Does not contain images used for shape model generation
M02	NAC	5		Does not contain images used for shape model generation
M02	WAC	4(E)	INFLDSTR	Ghost images not generated
M02	WAC	4(F)	INF-REFL	Ghost images not generated
M02	WAC	5		Does not contain images used for shape model generation
M03	NAC	5		Does not contain images used for shape model generation
M03	WAC	5		Does not contain images used for shape model generation
M04	NAC	5		Does not contain images used for shape model generation
M04	WAC	4(E)	INFLDSTR	Ghost images not generated
M04	WAC	4(F)	INF-REFL	Ghost images not generated
M04	WAC	5		Does not contain images used for shape model generation
M05	WAC	5		Does not contain images used for shape model generation
M22	WAC	3		Only calibration images acquired
M22	WAC	4		Only calibration images acquired
M22	WAC	4(B)	REFLECT	Only calibration images acquired
M22	WAC	4(C)	STRLIGHT	Only calibration images acquired
M22	WAC	4(D)	STR-REFL	Only calibration images acquired
M22	WAC	4(E)	INFLDSTR	Only calibration images acquired
M22	WAC	4(F)	INF-REFL	Only calibration images acquired
M22	WAC	5		Only calibration images acquired
AST1	NAC	4(E)	INFLDSTR	Not applicable for AST1
AST1	NAC	4F	INF-REFL	Not applicable for AST1
AST1	NAC	5		Not applicable for AST1
AST1	WAC	4(E)	INFLDSTR	Not applicable for AST1
AST1	WAC	4(F)	INF-REFL	Not applicable for AST1
AST1	WAC	5		Not applicable for AST1
AST2	NAC	4(E)	INFLDSTR	Not applicable for AST2
AST2	NAC	4(F)	INF-REFL	Not applicable for AST2

AST2	NAC	5		Not applicable for AST2
AST2	WAC	4(E)	INFLDSTR	Not applicable for AST2
AST2	WAC	4(F)	INF-REFL	Not applicable for AST2
AST2	WAC	5		Not applicable for AST2
CR1	NAC	3		Only calibration images acquired
CR1	NAC	4		Only calibration images acquired
CR1	NAC	4(B)	REFLECT	Only calibration images acquired
CR1	NAC	4(C)	STRLIGHT	Only calibration images acquired
CR1	NAC	4(D)	STR-REFL	Only calibration images acquired
CR1	NAC	4(E)	INFLDSTR	Not applicable for CR1
CR1	NAC	4(F)	INF-REFL	Not applicable for CR1
CR1	NAC	5		Not applicable for CR1
CR1	WAC	3		Only calibration images acquired
CR1	WAC	4		Only calibration images acquired
CR1	WAC	4(B)	REFLECT	Only calibration images acquired
CR1	WAC	4(C)	STRLIGHT	Only calibration images acquired
CR1	WAC	4(D)	STR-REFL	Only calibration images acquired
CR1	WAC	4(E)	INFLDSTR	Not applicable for CR1
CR1	WAC	4(F)	INF-REFL	Not applicable for CR1
CR1	WAC	5		Not applicable for CR1
CR2	NAC	4(E)	INFLDSTR	Not applicable for CR2
CR2	NAC	4(F)	INF-REFL	Not applicable for CR2
CR2	NAC	5	GEO	Not applicable for CR2
CR2	NAC	5(S)	GEOSPICE	Not applicable for CR2
CR2	WAC	4(E)	INFLDSTR	Not applicable for CR2
CR2	WAC	4(F)	INF-REFL	Not applicable for CR2
CR2	WAC	5	GEO	Not applicable for CR2
CR2	WAC	5(S)	GEOSPICE	Not applicable for CR2
CR4A	NAC	4(E)	INFLDSTR	Not applicable for CR4A
CR4A	NAC	4(F)	INF-REFL	Not applicable for CR4A
CR4A	NAC	5		Not applicable for CR4A
CR4A	WAC	4(E)	INFLDSTR	Not applicable for CR4A
CR4A	WAC	4(F)	INF-REFL	Not applicable for CR4A
CR4A	WAC	5		Not applicable for CR4A
CR4B	NAC	3		Only calibration images acquired
CR4B	NAC	4		Only calibration images acquired
CR4B	NAC	4(B)	REFLECT	Only calibration images acquired
CR4B	NAC	4(C)	STRLIGHT	Only calibration images acquired
CR4B	NAC	4(D)	STR-REFL	Only calibration images acquired
CR4B	NAC	4(E)	INFLDSTR	Not applicable for CR4B
CR4B	NAC	4(F)	INF-REFL	Not applicable for CR4B
CR4B	NAC	5		Not applicable for CR4B
CR4B	WAC	3		Only calibration images acquired

CR4B	WAC	4		Only calibration images acquired
CR4B	WAC	4(B)	REFLECT	Only calibration images acquired
CR4B	WAC	4(C)	STRLIGHT	Only calibration images acquired
CR4B	WAC	4(D)	STR-REFL	Only calibration images acquired
CR4B	WAC	4(E)	INFLDSTR	Not applicable for CR4B
CR4B	WAC	4(F)	INF-REFL	Not applicable for CR4B
CR4B	WAC	5		Not applicable for CR4B
CR5	NAC	4(E)	INFLDSTR	Not applicable for CR5
CR5	NAC	4(F)	INF-REFL	Not applicable for CR5
CR5	NAC	5		Not applicable for CR5
CR5	WAC	4(E)	INFLDSTR	Not applicable for CR5
CR5	WAC	4(F)	INF-REFL	Not applicable for CR5
CR5	WAC	5		Not applicable for CR5
CVP1	NAC	4(E)	INFLDSTR	Not applicable for CVP1
CVP1	NAC	4(F)	INF-REFL	Not applicable for CVP1
CVP1	NAC	5		Not applicable for CVP1
CVP1	WAC	4(E)	INFLDSTR	Not applicable for CVP1
CVP1	WAC	4(F)	INF-REFL	Not applicable for CVP1
CVP1	WAC	5		Not applicable for CVP1
CVP2	NAC	4(E)	INFLDSTR	Not applicable for CVP2
CVP2	NAC	4(F)	INF-REFL	Not applicable for CVP2
CVP2	NAC	5		Not applicable for CVP2
CVP2	WAC	4(E)	INFLDSTR	Not applicable for CVP2
CVP2	WAC	4(F)	INF-REFL	Not applicable for CVP2
CVP2	WAC	5		Not applicable for CVP2
EAR1	NAC	4(E)	INFLDSTR	Not applicable for EAR1
EAR1	NAC	4(F)	INF-REFL	Not applicable for EAR1
EAR1	NAC	5		Not applicable for EAR1
EAR1	WAC	4(E)	INFLDSTR	Not applicable for EAR1
EAR1	WAC	4(F)	INF-REFL	Not applicable for EAR1
EAR1	WAC	5		Not applicable for EAR1
EAR2	NAC	4(E)	INFLDSTR	Not applicable for EAR2
EAR2	NAC	4(F)	INF-REFL	Not applicable for EAR2
EAR2	NAC	5		Not applicable for EAR2
EAR2	WAC	4(E)	INFLDSTR	Not applicable for EAR2
EAR2	WAC	4(F)	INF-REFL	Not applicable for EAR2
EAR2	WAC	5		Not applicable for EAR2
EAR3	NAC	4(E)	INFLDSTR	Not applicable for EAR3
EAR3	NAC	4(F)	INF-REFL	Not applicable for EAR3
EAR3	NAC	5		Not applicable for EAR3
EAR3	WAC	4(E)	INFLDSTR	Not applicable for EAR3
EAR3	WAC	4(F)	INF-REFL	Not applicable for EAR3
EAR3	WAC	5		Not applicable for EAR3

MARS	NAC	4(E)	INFLDSTR	Not applicable for MARS
MARS	NAC	4(F)	INF-REFL	Not applicable for MARS
MARS	NAC	5		Not applicable for MARS
MARS	WAC	4(E)	INFLDSTR	Not applicable for MARS
MARS	WAC	4(F)	INF-REFL	Not applicable for MARS
MARS	WAC	5		Not applicable for MARS
RVM1	NAC	4(E)	INFLDSTR	Not applicable for RVM1
RVM1	NAC	4(F)	INF-REFL	Not applicable for RVM1
RVM1	NAC	5		Not applicable for RVM1
RVM1	WAC	4(E)	INFLDSTR	Not applicable for RVM1
RVM1	WAC	4(F)	INF-REFL	Not applicable for RVM1
RVM1	WAC	5		Not applicable for RVM1