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DOCUMENT

Comet 67P/Churyumov-Gerasimenko Shape Models EAICD

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1 INTRODUCTION

1.1 Purpose and Scope

The purpose of this EAICD (Experimenter to Archive Interface Control Document) is twofold:

- First it provides users of the Rosetta Shape Model data set with detailed description of the product and a description of how it was generated, including data sources and destinations.
- Secondly, it is the official interface between the instrument teams generating shape models and the archiving authority.

This document covers all shape models generated for comet 67P/Churyumov-Gerasimenko that are archived in the ESA Planetary Science Archive (PSA) and in the NASA Planetary Data System (PDS).

1.2 Archiving Authorities

The PDS standard is used as archiving standard by:

- NASA for U.S. planetary missions, implemented by PDS (Planetary Data System)
- The European Space Agency (ESA) for European Planetary Missions, implemented by the PSA (Planetary Science Archive) of ESA.

1.2.1 ESA's Planetary Science Archive (PSA)

ESA implements an online science archive, the PSA,

- to support and ease data ingestion
- to offer additional services to the scientific user community and science operations teams as e.g.
    - search queries that allow searches across instruments, missions and scientific disciplines
    - several data delivery options as
        - direct download of data products, linked files and data sets
        - ftp download of data products, linked files and data sets

1.3 Contents

This document describes the shape models of comet 67P/Churyumov-Gerasimenko created by different institutions using OSIRIS and NavCam instruments on-board Rosetta mission.

It includes information on how data were processed, formatted, labelled and uniquely identified. The document discusses general naming schemes for data and label files. Standards used to generate the product are also explained. The design of the data set structure and the data products is also given.

1.4 Intended Readership

- Users of the 67P/Churyumov-Gerasimenko shape models.
- The staff of the archiving authority (PSA, PDS) and members of the Rosetta Science Ground Segment.

1.5 Applicable and Reference Documents

Applicable Documents	
AD.1	Planetary Data System Preparation Workbook, February 1, 1995, Version 3.1, JPL, D-7669, Part1
AD.2	Planetary Data System Standards Reference, February 27, 2009, Version 3.8, JPL, D-7669, Part 2

Table 1 Applicable documents

Reference Documents	
RD.1	Rosetta-Osiris to Planetary Science Archive Interface Control Document, Version 3.e, RO-RIS-MPAE-ID-015 (can be found in any OSIRIS data set in the PSA archive).
RD.2	Rosetta-NavCam to Planetary Science Archive Interface Control Document, Version 4.0, O-SGS-IF-0001 (can be found in any NavCam data set in the PSA archive).
RD.3	Reference frames and mapping schemes of comet 67P, Franck Scholten et al. 24th Sept. 2015, Version 2.0 (provided in the data set)
RD.4	OSIRIS – The Scientific Camera System Onboard Rosetta, Keller et al. 2007, Space Science Review
RD.6	Characterizing and navigating small bodies with imaging data, Meteoritics and Planet. Sci. 43, 1049-1061, Gaskell et al., 2008
RD.7	Optical measurements for attitude control and shape reconstruction at the Rosetta flyby of asteroid Lutetia, M. Lauer, S. Kielbassa, R. Pardo, ISSFD2012 paper,Pasadena, California,

	USA, 2012
RD.8	Surface Characterization and optical navigation at the Rosetta flyby of asteroid Lutetia, R. Pardo de Santayana, M. Lauer, P, Munoz, F. Castellini, ISSFD2014 paper, Laurel, Maryland, USA, 2014.
RD.9	Optical measurements for Rosetta navigation near the comet, R. Pardo de Santayana, M. Lauer, ISSFD2015 paper, Munich, Germany, 2015.

Table 2 Reference documents

1.6 Relationships to Other Interface Documents

The shape models in this multi-instrument data set were created using images coming from OSIRIS and NavCam instruments. Each of these two instruments has its own EAICD covering all the flow from acquisition to processing and archiving as images in the PSA archive. See document [RD.1] for OSIRIS and [RD.2] for NavCam which can be found in the PSA online archive. Those documents do not cover the processing of the images to obtain shape model which is covered by this EAICD.

Finally note that this data set follows PDS 3 standard which definition can be found in [AD.2]

1.7 Acronyms

Acronym	Meaning
CAD	Computer Aided Design
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAICD	Experiment to Archive Interface Control Document
ESA	European Space Agency
ESAC	European Space Astronomy Center
ESOC	European Space Operations Centre
LAM	Laboratoire d’Astrophysique de Marseille
MOC	Mission Operations Centre
MSPCD	Multi-Resolution Stereophotoclinometry by Deformation
MTP	Mid Term Plan
NAC	Narrow Angle Camera
NASA	National Aerospace Agency
NavCam	Navigation Camera
OSIRIS	Optical, Spectroscopic, and Infrared Remote Imaging System
PDS	Planetary Data System
PSA	Planetary Science Archive
PSI	Planetary Science Institute
RMOC	Rosetta Mission Operations Centre

ROSINA	Rosetta Orbiter Spectrometer for Ion and Neutral Analysis
RSGS	Rosetta Science Ground Segment
RSSD	Research and Scientific Support Department
SPC	Stereo-Photo-Clinometry
SPG	Stereo-Photogrammetric
VRML	Virtual Reality Modelling Language
VSTP	Very Short Term Plan
WAC	Wide Angle Camera

Table 3 Acronyms list

1.8 Definitions

Data Set: It is used to define a set of products, files and documents compliant with PDS 3 standard. It follows a standardized directory structure and it contains not only the data but also documentation and other files.

1.9 Contact Names and Addresses

This data set contains shape models from different sources compiled by RSGS and PDS.

You can contact RSGS archiving team at:

Rosetta Science Ground Segment
ESAC
P.O. Box, 78 28691 Villanueva de la Cañada
Madrid, Spain

Or at the following e-mail address:
rsgs_arc@sciops.esa.int

The data set has been archived in the PSA archive. You can contact PSA at:

Planetary Science Archive
ESAC
P.O. Box, 78 28691 Villanueva de la Cañada
Madrid, Spain

Or in the following web address:
psa.esac.esa.int

1.10 Shape Model Providers

The shape model data set contains shape models created and provided by the following institutions:

- ESA (European Space Agency). The shape models were created by the Flight Dynamics group of the Rosetta Mission Operations Centre (RMOC) at ESOC in Germany.
- LAM (Laboratoire d'Astrophysique de Marseille) in France. Contact person, Laurent Jorda.
- LAM & PSI. LAM and PSI (Planetary Science Institute, USA). Contact person Laurent Jorda and Robert Gaskell.
- DLR (Deutsches Zentrum für Luft- und Raumfahrt) in Germany. Contact person, Frank Scholten.

The information on how to cite a specific shape model can be found in the CITATION_DESC keyword within the label file (LBL extension) accompanying each shape model file.

1.11 Shape Modelling Techniques

Below it is listed the techniques used to create the shape models. Specific references that provide more information are included in the detailed discussions of the individual models.

- MSPCD: Multi-Resolution StereoPhotoClinometry by Deformation
- SPC: StereoPhotoClinometry
- SPG: StereoPhotoGrammetric

1.12 Shape Model Version

There are various versions (or generations) of the shape model, some of which may not be available in the archive, yet. These may be subdivided into different resolutions (different numbers of vertices/plates) usually produced by smoothing of a higher resolution into a lower one.

These terms tend to refer to the range of dates for which data were used to create the model, and are defined in the SHAPE_DATA_ORGANIZATION.ASC file in the DOCUMENTS directory and in the scientific index in the INDEX directory.

For the shape models generated using OSIRIS images, the versions are called SHAP*x* where the SHAP term comes from "shape" and *x* is a version number. Versions with higher number were created when new images were available and therefore are more accurate. The existing shape models using OSIRIS images are:

- SHAP2: Different generations of the OSIRIS-derived models
- SHAP4: DLR version of the OSIRIS-derived model
- SHAP5: PSI/LAM version of the OSIRIS-derived SPC models
- SHAP7: Not in the archive at the time of writing this document

Shape models generated by ESA using NavCam images are versioned by the Medium Term Plan (MTP). For example, MTP009 indicates that this shape model was generated during the so-called MTP009 time interval during operations using images obtained up to that time. In general shape models with a higher MTP number are more accurate.

1.13 Summary of Providers, Techniques and Versions

The shape models data set compiles shape models coming from different providers using different techniques and instruments and available in different versions. The following table summarizes the relation between providers, techniques and versions.

Provider (institution)	Provider (contact person)	Sensor	Technique	Version (1)
ESA	Maud Barthelemy	NavCam	SPC	MTP009
LAM	Laurent Jorda	OSIRIS	MSPCD	SHAP2
LAM & PSI	Laurent Jorda & Robert Gaskell	OSIRIS	SPC	SHAP2 SHAP5
DLR	Frank Scholten	OSIRIS	SPG	SHAP4s SHAP7

Table 4 1.13 Summary of providers, techniques and versions

(1) More versions of the shape model might be added to the data set in the future without necessarily updating this document. Check the archive for availability of new versions.

2 OVERVIEW OF INSTRUMENT DESIGN, DATA HANDLING PROCESS AND PRODUCT GENERATION

2.1 Scientific and Operational Objectives

2.1.1 Scientific Applications

Shape model is a key higher-level science product that enables a much better scientific interpretation of other data sets observing the same object. Multiple direct scientific applications are foreseen with the use of a shape model, they are tentatively enumerated here:

1. Topographic profile of the surface between different locations
2. Slope angles at a given location of the surface
3. Gravity potential and acceleration at a given location of the surface
4. Local illumination angles (incidence, emission, phase) at a given location of the surface
5. Quantify the erosion of the surface and the changes
6. Identify source regions of cometary activity
7. Provide a view of the shape model and its orientation (using appropriate reference frame) for interpretation of data set

2.1.2 Operational Applications in Flight Dynamics

The ESA NavCam shape model, produced by Flight Dynamics at ESOC, was used in a number of operational applications as mentioned below grouped by subsystem. However it also has scientific interest and it is published for its use outside ESA operations.

2.1.2.1 Attitude Determination

- Landmark tracking: the shape is key for the automatic landmark detection algorithms. These surface feature observations allow precise navigation relative to the comet.
- Limb fitting: during night side excursions when landmark tracking becomes challenging navigation can be achieved by fitting the expected contour of the comet shape with the actual image.

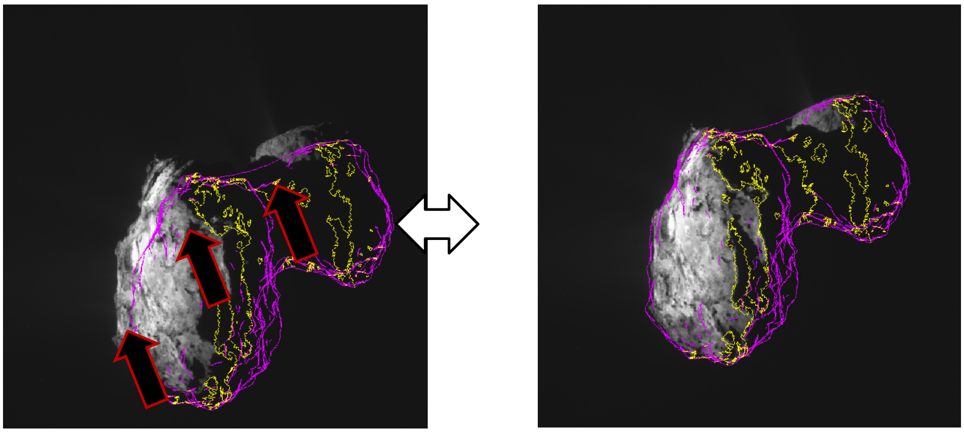

Figure 1 Image simulation: synthetic images are rendered to predict the future pictures appearance to prepare for upcoming mission phases.

2.1.2.2 Orbit Determination

Gravity model: gravity model parameters can be estimated and cross-checked against the output from the orbit determination.

Philae (lander) trajectory reconstruction:

- Few observations of the lander were available after first touchdown. However a couple of Philae shadows were spotted at ESOC. The shadow observations projected onto the shape model helped a lot on the lander trajectory estimation.
- The lander flew during two hours at very low heights over the surface where the gravity is very dependent on the shape of the comet.
- The second bounce of Philae was discovered by intersecting the reconstructed trajectory with the shape model where a collision with a crater rim was certain. The assumption was later confirmed by the instrument readings.

2.1.2.3 Manoeuvre Optimisation

Landing site selection: The different landing site candidates were assessed by flight dynamics. Several operational constraints had to be fulfilled:

- Philae trajectory perpendicular to the local terrain.
- Touch down velocity and time of flight within limits.
- Avoid collisions with other comet parts.

Dispersion from landing target: once the target was selected a Montecarlo analysis was performed to assess the touchdown point dispersion that should be expected.

2.1.2.4 Command Generation

Correlation with ROSINA data: the comet atmosphere (coma) has been modelled and correlated with ROSINA data. The shape of the nucleus plays an important role in the coma drag when navigating a spacecraft in the proximity of a comet.

2.1.2.5 Test and Validation

Assess landmark quality: landmark position estimates are compared with the shape surface.

Ensure landmark observations visibility: landmark observations visibility from Rosetta and Sun illumination are checked against shape model.

2.2 Overview of Instruments Design

The current data set includes shape models generated from images coming from one of these Rosetta instruments:

- OSIRIS: It is composed of two cameras designed specifically for scientific purposes. One is the Wide Angle Camera (WAV) and the other is the Narrow Angle Camera (NAC).
- NavCam: It is a camera designed specifically for navigation purposes.

The following subsections summarize the main specifications of these two instruments.

2.2.1 OSIRIS

The OSIRIS camera system is composed of two telescopes:

- A Wide Angle Camera (WAC) and
- A Narrow Angle Camera (NAC)

You can find a brief description of these two instruments in the next subsections and a deeper discussion in [RD.4].

2.2.1.1 The Narrow Angle Camera (NAC)

The NAC uses an off axis three mirror optical design. The off axis design was selected in order to minimize the straylight reaching the CCD (The NAC has a proven stray light attenuation of better than 1.0e-9). The optical beam is reflected off the three mirrors (M1, M2 and M3) before passing through a double filter wheel, a mechanical shutter mechanism and an anti-radiation plate (ARP) before reaching the CCD (see Figure 2). The detectors are back illuminated back thinned 2048x2048 pixel CCDs.

The NAC has a field of view of 2.20 x 2.22 deg and a resolution on ground from 100 Km of 1.86 m/pixel. It operates in the 250-1000 nm wavelength range. For further technical specifications see the table below.

Figure 2 OSIRIS NAC flight unit (left) and optical path (right)

Optical design	3-mirror off-axis
Angular resolution	18.6 µrad px^{-1}
Focal length	717.4 mm
Mass	13.2 kg
Field of view	2.20 x 2.22°
F-number	8
Spatial scale from 100 km	1.86 m px^{-1}
Typical filter bandpass	40 nm
Wavelength range	250nm - 1000nm
Number of filters	12
Estimated detection threshold	18 mV

Table 5 OSIRIS NAC main parameters

2.2.1.2 The Wide Angle Camera (WAC)

The WAC uses an off axis two mirror optical design. The off axis design was selected in order to minimize the stray light reaching the CCD (The WAC has a proven stray light attenuation of better than 1.0e-8).

The optical beam is reflected off the two mirrors (M1 & M2) before passing through a double filter wheel, a mechanical shutter mechanism and anti-radiation plate (ARP) before reaching the CCD (see Figure 3).

For main technical specifications see Table 6.

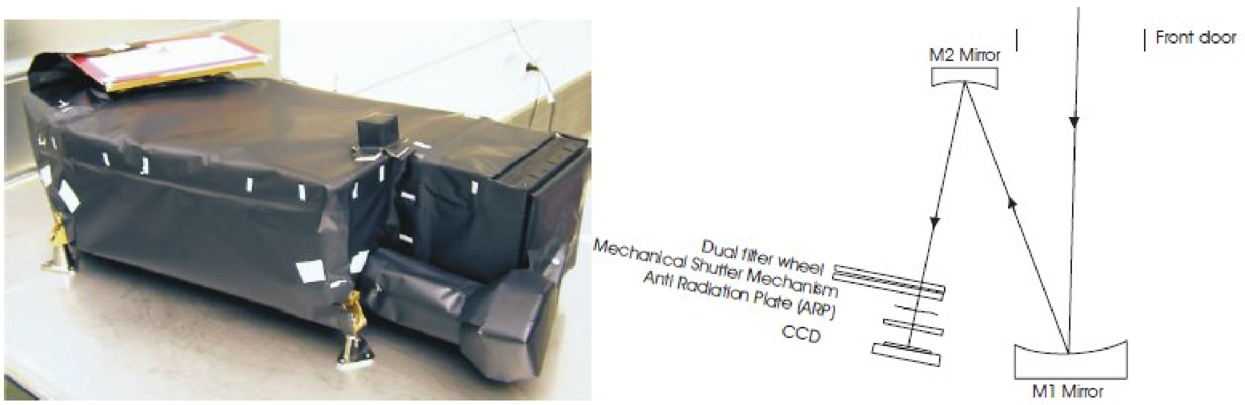

Figure 3 OSIRIS WAC flight unit (left) and optical path (right)

Optical design	2-mirror off-axis
Angular resolution	101 µrad px-1
Focal length	140(sag)/131(tan)
Mass	9.48 kg
Field of view	11.34 x 12.11°
F-number	5.6
Spatial scale from 100 km	10.1 m px-1
Typical filter bandpass	5 nm
Wavelength range	240nm - 720nm
Number of filters	14
Estimated detection threshold	13 mV

Table 6 OSIRIS WAC main parameters

The WAC has a wider field of view than the NAC and lower resolution. Its field of view is 11.34 x 12.11 deg and has a resolution on ground from 100 Km of 10.1 m/pixel. It operates in the 240-720 nm wavelength range.

2.2.2 NavCam

It is a camera designed mainly for navigation purposes. It operates in the visible range, covering a 5 x 5 deg field of view and based on a CCD sensor. Table 7 summarizes its main characteristics. For further details please see document RD.1 which can be found in the PSA.

Parameter	Value	Comment
Mass CAM-OH	6.050 kg	Camera Optical Head
Mass CAM-EU	2.700 kg	Camera Electronic Unit
Mass CAM-BAF	1.408 kg	Camera Baffle
Total Mass	10.158 kg	
Total Power	16.8 W	
Field of View	$5° \times 5°$	
Sensor Type	CCD	CCD47-20 by e2v
Number of Pixels	1024×1024	
Focal Length	152.5 mm	
Pixel Size	13 μm	
Pixel Angular Size	17 arcsec	
Aperture	70 mm 30 mm	Non-Attenuated Modes Attenuated Mode
F/Number	f/2.2 f/5.1	Non-Attenuated Modes Attenuated Mode
Limit Magnitude	$M_v = 11$	Exposure time 5 s, SNR $\geq$ 5
Saturation Magnitude	$M_v = 1.6$ $M_v = 0.8$	Whole spectral range, G2 Class; exposure time = 10ms
Integration Time	10 ms 30 s	Minimum, Maximum
Bias error (1 σ)	0.2 pixels	$M_v = 11$, exposure time = 5 s, De-focused mode
NEA (1 σ)	0.1 pixels	$M_v = 11$, exposure time = 5 s, De-focused mode
Commanded Window Size	20×20 1024×1024	Minimum pixel array Maximum pixel array
CCD Operative Temp. Range	-50°C +50°C	Minimum Maximum
CCD Performance Temp. Range	-25°C 0°C	Minimum Maximum

Table 7 NavCam main specifications

2.3 Data Handling Process

This data set includes shape models generated with different techniques. The technique used for each provider is as follows:

- ESA: The ESA NavCam shape model uses the Stereo-Photoclinometry (SPC) technique over NavCam images.
- LAM: Uses the Multi-Resolution Stereo-Photoclinometry by Deformation (MSPCD) technique over OSIRIS images.
- LAM/PSI: Uses the stereophotoclinometry (SPC) technique over OSIRIS images.
- DLR: Uses the Stereo-Photogrammetric (SPG) technique over OSIRIS images.

The next sections provide the available information on the technique used to produce the models for the different models providers.

2.3.1 ESA NavCam Shape Model

2.3.1.1 Introduction

The ESA NavCam Shape Model is a 3-D digital representation of the surface of the comet obtained by processing the NavCam images. It was produced by the Rosetta Mission Operation Centre (RMOC) in ESOC.

The techniques and algorithms used to process the data and produce the shape model are extensively discussed in the following papers (in chronological order of publication):

1. [RD.7] *Optical measurements for attitude control and shape reconstruction at the Rosetta flyby of asteroid Lutetia* : This paper was published previous to the arrival to the commet and describes the algorithms used to produce the Lutetia asteroid shape model.
2. [RD.8] *Surface Characterization and optical navigation at the Rosetta flyby of asteroid Lutetia* : This document was also published previous to the arrival to the commet. It describes in great detail the algorithms, techniques and software used to obtain the shape models as well as the validation of he results. It uses Lutetia as a test case but the same technique and tools were used later on to obtain the comet shape model. Together with [RD.7] it is the best description on the shape model algorithms.
3. [RD.9] *Optical measurements for Rosetta navigation near the comet*. It describes the technique used to obtain the commet shape model. It is specific for the commet shape model but it is less detailed that the previous two papers.

For the convenience of the reader the technique is briefly summarised in the next subsections. For further details and a more technical explanation see the references above.

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2.3.1.2 Rough Shape from Silhouettes

A rough shape was obtained using the silhouette of the comet as observed on the pictures acquired by Rosetta NavCam. This technique is called silhouette carving.

It consists of starting with a usually rounded bigger shape than the actual body, and then the illuminated limb of the object is used to define the actual shape model. Every part that falls out of the silhouette is then carved out.

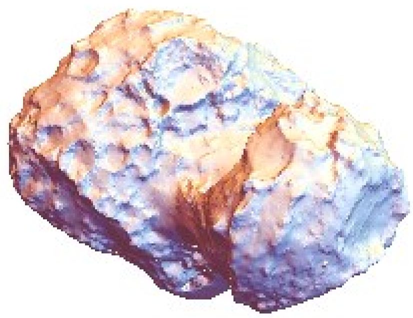
The shape from silhouette is an essential part to determine a good first estimate of the shape model to be used in more advanced techniques.

2.3.1.3 Fine 3D Maplets

In a second step small 3D high-resolution maps (maplets) were created centred on landmarks spread all around the body. The technique employed was stereophotoclinometry that consists of translating the grey levels of the image into slopes assuming or not photometric properties of the surface. For more details see [RD.6].

2.3.1.4 Fine shape model

As a final step the collection of maplets is assembled together into a fine shape model.



2.3.1.5 Model Resolutions

The shape ESA NavCam Shape Models are provided in high and low resolution. The number of facets for each resolution can be found in the label file (LBL extension) accompanying the shape model file.

2.3.1.6 MTP009 Version of the Model

This version of the model has been built using images taken from the 6 of August 2014 to the 2 of November 2014. More precisely the start and end date of the measurements are:

Start: 2014-08-06T12:22:19.000
End: 2014-11-02T11:52:56.000

However most useful information came from Sept-Oct 2014 when Rosetta was close to the comet.

This shape model version does not include the details of the South Pole since Rosetta had not imaged it yet.

2.3.1.7 MTP019 Version of the Model

This version of the model has been built using images taken from the 6 of August 2014 to the 25 of August 2015.

It includes details of the whole comet nucleus including the South Pole.

2.3.2 LAM and LAM/PSI Shape Models

2.3.2.1 Introduction

The shape models presented here were developed by Laurent Jorda et al. (LAM, Marseille, France) and Robert Gaskell (PSI, Tucson, USA) from two different techniques: Stereophotoclinometry (SPC) and Multi-resolution stereophotoclinometry by deformation (MSPCD).

The SPC versions of the data set represent the shape models of the nucleus of comet 67P/Churyumov-Gerasimenko as derived using photoclinometry techniques. Images obtained with the Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) instrument (including both the Narrow Angle Camera and the Wide Angle Camera) were used in constructing these models.

Details about the SPC technique can be found in Gaskell et al., 'Characterizing and navigating small bodies with imaging data', Meteoritics and Planet. Sci. 43, 1049-1061, 2008 [GASKELLETAL2008].

The MSPCD technique has been described in detail by Capanna et al., 'Three-dimensional 3D reconstruction using multiresolution photoclinometry by deformation', The Visual Computer 29, 825-835, 2013 [CAPANNAETAL2013]. Both techniques allowed modeling of the areas of the surface illuminated and visible in the Rosetta images.

Additional information about the nucleus of 67P can be found in Sierks et al., 'On the nucleus structure and activity of comet 67P/Churyumov-Gerasimenko', Science 347, aaa1044, 2014 [SIERKSETAL2014].

2.3.2.2 Model Resolutions

Two different SPC-derived models are included, known as SPC and MSPCD. Each of these models is presented in its highest resolution form, with additional versions degraded in resolution (in steps of ~2). The different resolutions are included to allow calculations to be optimized for a given problem, when the highest resolution is not needed.

Additional information on how the high-resolution shape model was degraded into lower resolution versions can be found in H. Hoppe, 'Progressive meshes', Conference SIGGRAPH 96; 23rd International Conference on Computer Graphics and Interactive Techniques. New Orleans, LA, USA — August 04 - 09, 1996, pp. 99-108. DOI: 10.1145/237170.237216.

2.3.2.3 SHAP2 Version of the Model

General Description

The SHAP2 models represent the first archived versions of the 67P nucleus, and were used for the first series of publications. These models were produced using images obtained up through 3 August 2014. This was before the South Pole had become illuminated, so there are regions on the surface that are not constrained by observations. These unconstrained areas of the surface appear smooth in the models.

OSIRIS obtained body-resolved images during the approach phase to comet 67P/Churyumov-Gerasimenko, before the spacecraft started orbiting the nucleus on August 6, 2014. Four sets of images were used during the model construction. The acquisition dates are as follows:

i. between July 14, 14:24 UTC and July 15, 02:04 UTC,
ii. between July 21, 14:34 UTC and July 22, 00:44 UTC,
iii. on August 1, between 11:49 UTC and 21:24 UTC, and
iv. on August 3, between 11:04 UTC and 21:39 UTC.

The images covered about 75 % of the surface, with a spatial scale up to 4.9 m/pix.

Details about the MSPCD SHAP2 files

CG_MSPCD_SHAP2_006K_CART.WRL - 2894 vertices forming 5784 triang. plates
CG_MSPCD_SHAP2_012K_CART.WRL - 5958 vertices forming 11912 triang. plates
CG_MSPCD_SHAP2_024K_CART.WRL - 12225 vertices forming 24446 triang. plates
CG_MSPCD_SHAP2_048K_CART.WRL - 23780 vertices forming 47556 triang. plates
CG_MSPCD_SHAP2_098K_CART.WRL - 48893 vertices forming 97782 triang. plates
CG_MSPCD_SHAP2_191K_CART.WRL - 95268 vertices forming 190532 triang. plates
CG_MSPCD_SHAP2_391K_CART.WRL - 195743 vertices forming 391482 triang. plates
CG_MSPCD_SHAP2_760K_CART.WRL - 379794 vertices forming 759584 triang. plates
CG_MSPCD_SHAP2_001M_CART.WRL - 655000 vertices forming 1309996 triang. plates

Details about the SPC SHAP2 files

CG_SPC_SHAP2_006K_CART.WRL - 2860 vertices forming 5716 triang. plates
CG_SPC_SHAP2_012K_CART.WRL - 5928 vertices forming 11852 triang. plates
CG_SPC_SHAP2_024K_CART.WRL - 12176 vertices forming 24348 triang. plates
CG_SPC_SHAP2_047K_CART.WRL - 23656 vertices forming 47308 triang. plates
CG_SPC_SHAP2_096K_CART.WRL - 47932 vertices forming 95860 triang. plates
CG_SPC_SHAP2_195K_CART.WRL - 97347 vertices forming 194690 triang. plates
CG_SPC_SHAP2_399K_CART.WRL - 199434 vertices forming 398864 triang. plates
CG_SPC_SHAP2_786K_CART.WRL - 392942 vertices forming 785880 triang. plates

Shap2 MSPCD Characteristics

Table 8 summarizes the characteristics of the Shap2 MSPCD model.

Parameter	Value for the Shap2 MSPCD model
Surface Area	46.2 km^2
Volume	21.4 +/- 3.6 km^3
Mean diameter	3.4 +/- 0.2 km (diameter of sphere of equivalent vol.)
Dimensions along the principal axes of inertia	A: (4.6 +/- 0.1) km B: (2.6 +/- 0.1) km C: (2.2 +/- 0.4) km
Axis orientation	RA: 69.4 +/- 0.2 deg Dec: +64.1 +/- 0.2 deg
Rotation Period	12.4041 +/- 0.0001 hr

Table 8 Shape Model Characteristics for the Shap2 MSPCD model

2.3.2.4 SHAP5 Version of the Model

General Description

The SHAP5 SPC model represents a much more advanced model compared to the SHAP2 models for the following reasons.

a) It is based on a large data set of 16182 OSIRIS/NAC images and 5138 OSIRIS/WAC images acquired between July 11, 2014 and February 16, 2016 (see below).
b) The model covers the whole surface of the nucleus, including the south pole region which was not imaged at the time the SHAP2 models were reconstructed.
c) The model has a global average sampling of about 6 m instead of 20 m for the SHAP2 models.

The model is based on a tiling of the nucleus surface with 12734 "maplets" with a sampling of 1 m and 2161 "maplets" with a resolution of 2.5 m. In the SPC technique, a "maplet" is a 99x99 surface elements digital elevation model.

The 2.5 m "maplets" covers the whole nucleus surface while the 1 m "maplets" covers 97 % of the nucleus surface.

The images used for the reconstruction of the model were acquired during several OSIRIS observational phases, from the initial mapping phases (SHAP2, SHAP4, SHAP4S and SHAP5) in 2014 up to those obtained in Feb 2016.

Table 9 summarizes the parameters used to generate the SHAP5 SPC model.

Parameters	SHAP5 SPC Value
UTC date of first NAC image	2014 JUL 11 09:22:05.118
UTC date of last NAC image	2016 FEB 13 19:09:27.158
UTC date of first WAC image	2014 AUG 05 00:20:43.281
UTC date of last WAC image	2016 FEB 16 22:35:12.636
Number of NAC images	16182
Number of WAC images	5138
Minimum number of images per maplet	7
Maximum number of images per maplet	567
Average number of images per maplet	161
Distance to surface	5.8-287 km (*)
Lowest image resolution	5.4 m/pixel (*)
Highest image resolution	0.11 m/pixel(*)
Average image resolution	1.6 m/pixel(*)

Table 9 Parameters of all images used to reconstruct the SHAP5 SPC model

(*)Data at the centre of the 1 m sampling "maplets".)

Details about the SPC SHAP5 files

CG_SPC_SHAP5_006K_CART.WRL - 2842 vertices forming 5678 triang. plates
CG_SPC_SHAP5_012K_CART.WRL - 5861 vertices forming 11716 triang. plates
CG_SPC_SHAP5_024K_CART.WRL - 12070 vertices forming 24134 triang. plates
CG_SPC_SHAP5_050K_CART.WRL - 24877 vertices forming 49748 triang. plates
CG_SPC_SHAP5_097K_CART.WRL - 48420 vertices forming 96834 triang. plates
CG_SPC_SHAP5_199K_CART.WRL - 99729 vertices forming 199452 triang. plates
CG_SPC_SHAP5_384K_CART.WRL - 191997 vertices forming 383988 triang. plates
CG_SPC_SHAP5_788K_CART.WRL - 393963 vertices forming 787920 triang. plates
CG_SPC_SHAP5_001M_CART.WRL - 597251 vertices forming 1194496 triang. plates
CG_SPC_SHAP5_003M_CART.WRL - 1572866 vertices forming 3145728 triang. plates

Shap5 SPC characteristics

Table 10 summarizes the characteristics of the Shap5 SPC model.

Parameter	Value for the Shap5 SPC model
Surface Area	48.4 km^2
Volume	18.8 +/- 0.3 km^3
Mean diameter	3.48 +/- 0.01 km (diameter of sphere of equivalent vol.)
Dimensions along the principal axes of inertia	A: (4.34 +/- 0.02) km B: (2.60 +/- 0.02) km C: (2.12 +/- 0.06) km
Axis orientation	RA: 69.57 +/- 0.35 deg Dec: +64.01 +/- 0.12 deg
Rotation Period	12.4041 +/- 0.0001 hr (pre-perihelion)

Table 10 **Shape Model Characteristics for the Shap5 SPC model**

2.3.3 DLR Shape Models

This shape models use a different processing technique, the so-called stereo-photogrammetric (SPG).

Information on the shape models created by DLR can be found in L. Jorda et.al. The global shape, density and rotation of Comet 67P/Churyumov-Gerasimenko from preperihelion Rosetta/OSIRIS observations, 2016 and in Preusker, F. Shape model, reference system definition, and cartographic mapping standards for comet 67P/Churyumov-Gerasimenko - Stereo-photogrammetric analysis of Rosetta/OSIRIS image data, 2015.

2.3.3.1 Shap4s Version of the Model

At the time of writing there is one version of the DLR shape model, the so-called SHAP4s version.

2.4 Shape Models File Formats

2.4.1 File Formats

The shape models are presented in one or more of the following formats:

- **PDSSBN (.TAB extension):** ASCII table format adopted by the SBN for general shape models. Described in detail in the PDSSBN_PLATE_SHAPE_DEF.ASC file in the DOCUMENTS directory.
- **VRML (.WRL)**: Same as the PDSSBN format, but includes a VRML wrapper that allows the model to be displayed with freely available software.
- **ROS**: Format adopted by the RMOC for the ESA NavCam shape models.
- **OBJ**: Object format defined by Wavefront Technologies for use in 3D printers, etc.
- **STL**: STereoLithography format native to the stereolithography CAD software created by 3D Systems. Note that this format cannot be easily described in the label, and thus is not included in DATA directory. Instead, it is included in the EXTRAS directory when provided.
- **DBS (.DSK extension)**: Digital Shape Kernel for use with the SPICE toolkits. See http://naif.jpl.nasa.gov/naif/index.html for information on SPICE.

DBS (.DSK) format is the only binary format, all others are ASCII based. Note that all current models are defined by triangular plates produced by connecting Cartesian coordinate vertices, but the presentation of the data differs slightly in the various formats. The data label contains the relevant information needed to read the file except for DSK and STL which must be read with software tools compatible with these formats.

2.4.2 File Formats: Details Specific for ESA NavCam

Further details are given in this section about the format of ESA NavCam shap models. Some of this information might be generic for any shape model with that format but other details are specific to ESA NavCam.

2.4.2.1 ROS Format

The data products are provided by RMOC in ROS format, with .ROS extension. The data is composed of 1 header followed by 2 tables. The header describes the content of the file, giving among other things the number of vertices and of facets.

The first table gives the vertices of the shape model. The vertices are given in an indexed list.

Example:

1 -2.3858335364460230 -0.9475305867992641 -0.3629040077651267

The line above is the first row of the vertices table. The first number gives the index of the vertex and the three last numbers are the coordinates (x,y,z) of the vertex in the Cheops Reference Frame.

The second table gives the facets of the shape model. The facets are triangular.
Example:

1 3 1 500067 500091

The above line shows the first row of the facet table. The first number is the facet index. The second value is the number of vertices in the facet, which is always. The three last numbers give the index of the vertex from the vertex table.

An example of the file is shown in the next table.

```
FILE_TYPE = SHAPE MODEL
CREATION_DATE = 2009-07-20T10:00:00
VERSION_NUMBER = 1
OBJECT_NAME = CHURYUMOV-GERASIMENKO

COMMENT This shape model is a test file

META_START
MODEL_TYPE = POLYHEDRON
NUMBER_OF_VERTICES = 642
NUMBER_OF_FACES = 1280
META_END

1 -1.0424605975740150e-01 8.7074100536646415e-01 1.4088885420812851e+00
2 -1.0424605975740150e-01 -8.7074100536646393e-01 1.4088885420812851e+00
3 -1.0424605975740150e-01 8.7074100536646415e-01 -1.4088885420812851e+00
4 -1.0424605975740150e-01 -8.7074100536646393e-01 -1.4088885420812851e+00
5 1.7189829886014056e+00 5.8544321745811784e-17 1.1268175211617955e+00
...
```

```
1 3 5 163 165
2 3 163 43 164
3 3 164 45 165
4 3 163 164 165
5 3 43 166 168
...
```

Table 11 Example of ROS format for ESA NavCam shape models

The file format is fully described in the corresponding PDS label file (file with the same name and LBL extension).

2.4.2.2 WRL Format

The WRL format is often used by 3D viewers.

The basic content is the same as the ROS format; there is a vertex table followed by a facet table. The text around these tables differs as the file is written in VRML format.

The vertex table is composed of 3 number lines, which are the (x,y,z) coordinates of the vertex in the Cheops Reference Frame. Example:

-2.38583353644460230 -0.94753058679926641 -0.36290400776512667

The facet table is composed of 4 number rows - Example:

176562 706248 706246 -1

The first three numbers are the indices of the 3 vertices in the vertex table, counting from 0 – i.e. the first line of the vertex table is numbered “0”.

The last number indicates the end of the list of vertices in the described face.

There is some surrounding text to give more information for the 3D viewer, such as transparency.

The file format is fully described in the corresponding PDS label file (file with the same name and LBL extension).

2.4.2.3 OBJ Format

The OBJ format is composed of a table of vertices followed by a table of facets. The numbering of the vertices begins at “1” – the first vertex is given in the first line of the file and is number one. When a facet is said to contain vertex number 1, it refers to the first line of the file, where the first vertex is defined.

The file format is fully described in the corresponding PDS label file (file with the same name and LBL extension).

2.4.2.4 STL Format

The STL file is composed of a list of facets. The file is a succession of 7 lines such as the ones below:

```
facet normal 0 0 0
outer loop
vertex -2.385834 -0.947531 -0.362904
vertex -2.386673 -0.953326 -0.360448
vertex -2.389075 -0.950796 -0.358577
endloop
endfacet
```

Each group defines a facet with 3 vertices that are listed per line.

3 ARCHIVE FORMAT AND CONTENT

3.1 Format and Conventions

3.1.1 Data Set ID Formation

The generic data set ID formation in Rosetta mission follows the following rule:

<INST HOST>-<TARGET ID>-<INST>-<CODMAC LEVEL>-<MISSION PHASE ABBREVIATION>-<VERSION>

For the Rosetta shape model data set it is as follows:

RO-C-MULTI-5-67P-SHAPE-Vx.y

Where:

Placeholder	Value	Value meaning
<INST HOST>	RO	Rosetta mission
<TARGET ID>	C	The target is a comet
<INST>	MULTI	Data coming from several instruments (NavCam and OSIRIS)
<CODMAC LEVEL>	5	CODMAC level indicating “Higher level data products developed for specific scientific investigations”
<MISSION PHASE ABBREVIATION>	67P-SHAPE	The data set is a shape model of comet 67P. The shape model is not associated to any specific phase so this field has been reinterpreted.
<VERSION>	Vx.y	Data set version number, e.g. V1.1

Table 12 Data Set ID formation

3.1.1 File Naming Convention

This section explains the naming convention used for the data products (shape model files) in the shape models data set.

3.1.1.1 LAM/PSI/DLR Shape Models (OSIRIS Shape Models)

This naming convention is applicable to the shape models provided by LAM, LAM/PSI and DLR (TBC for DLR).

CG_technique_SHAPx_yyyy_CART.ext

Where:

- CG: Refers to comet name Churyumov Gerasimenko
- technique: Is the processing technique used to generate the model. For example SPC or MSPCD
- SHAPx: Indicates the model version
- yyyy: Indicates the approximate number of facets (triangular plates) in the model.
- CART: Indicates that the coordinates are Cartesian
- ext: Is the file extension indicating the file format

3.1.1.2 ESA NavCam Shape Models

These names come from the naming conventions used for many products created by RMOC. For traceability it has been decided to preserve the original RMOC name.

The ESA NavCam shape model product has the following naming convention:

CSHP_DV_*xxx_yy_resolution_zzzzz.ext*

Where:

- CSHP: Stands for Comet Shape Product
- DV: Corresponds to a planning cycle of type V, i.e. Very Short Term Plan (VSTP).
- xxx: Refers to the VSTP planning cycle during operations.
- yy is an internal MOC version number (version of the planning cycle).
- resolution: "hires" indicates that it is a high resolution version whereas "lores" indicates that is a low resolution version.
- zzzzz is a file version number internal to RMOC (e.g 00085 or 00086). For products with extension (format) different to ROS (original RMOC format) it has been substituted by _ext in order to meet the maximum length requirement imposed by PDS standard.
- ext: It is the extension of the file and is associated to the file format.

The fact that the name is linked to a VSTP planning cycle does not mean that images used to generate the model were acquired during that VSTP. It only means that this file was delivered by RMOC to RSGS with a group of files delivered at that VSTP. For example, the version with value 047 was delivered by RMOC during VSTP 047 that lasted from from 2 to 5 Nov 2014 and was created using all convenient images acquired up to that time.

3.2 Standards Used in Data Product Generation

3.2.1 PDS Standard

The data follows the PDS (Planetary Data System) standard 3.8 [AD.2]. This standard fixes common rules for all data in the ESA and NASA planetary archives. A few key points of this standard are:

- The data are stored in Data Sets. Data Sets are a collection of files arranged in standard folders. The Data Set includes not only the data files but also documentation and metadata.
- The ODL (Object Definition Language) is used to describe the format of the data. Many times this information is in detached files with extension .LBL (label files)

3.2.2 Spatial Reference Frame, Coordinate System and Rotation State

All versions of the shape models were developed with respect to the Cheops reference frame, which is defined and described in the CHEOPS_REF_FRAME_V1.PDF [RD.3] file in the DOCUMENTS directory.

The SHAP5 SPC version of the shape models was reconstructed in a frame rotated by 0.28 deg and translated by (2.8,1.3,17.0) m with respect to the Cheops frame. The transformation between the two frame was determined using a tool called "PC_ALIGN" available in the NASA Ames Stereo Pipeline (ASP). The method is based on the article of Pomerleau et al., 'Comparing ICP Variants on Real-World Data Sets', Autonomous Robots 34(3), 133-148, February 2013.

The rotation state of the nucleus, for dates before early September, is also described in that document. As the nucleus approached the Sun, activity caused its rotation state to change, but documentation of these changes is not available as of the release of this version of the data set.

The spin axis orientation was derived from a stereophotogrammetric analysis of OSIRIS images acquired in between August and early September 2014. The orientation of the models in the J2000 Equatorial frame (EME2000) is described in Scholten, F. et al., 'Reference Frames and Mapping Schemes of Comet 67P/C-G' in the PDF document CHEOPS_REF_FRAME_V1.PDF in the DOCUMENTS directory. The SPC technique led to a spin axis such that the North (positive) pole points to a right ascension of 69.4+/-0.2 deg and a declination of +64.1+/-0.2 deg (J2000), compatible with the more accurate definition given in the above document.

The body's coordinate system was defined with the +Z axis in the direction of the spin axis and the prime meridian (+X axis) is defined such that the center of the large boulder named Cheops is at a longitude +142.35 degrees, following the IAU definition presented in the document CHEOPS_REF_FRAME_V1.PDF. The +Y axis completes the right-hand coordinate system. The body center is not exactly coincident with its center of gravity, but the offset is within the uncertainties derived for the surface positions.

3.3 Data Set Structure

In the data set you will find the following directories:

- DATA
- DOCUMENT
- CATALOG
- EXTRAS
- INDEX

Their content is described in detail in the next subsections. Also at each directory it can be found an INFO.TXT file explaining the files that can be found in the directory.

3.3.1 Data Directory

Data products can be found in the DATA directory. The DATA directory has the following structure:

- **Level 1**, file format family: There is one directory for each file format family. You can find the same data with different formats at each directory. Note that not all formats may be available for some of the shape model types, producers or versions. The directories you can find are the following.
    - **SPICE_DSK**: In this directory you can find the shape models in SPICE format.
    - **TRIPLATE**: In this directory you can find the shape model in several text based formats. The facets of the shape are given in triplets of points.

- **Level 2**, technique_producer: There is one subdirectory for each processing technique and institution producing the shape model. These directories are:
    - **SPC_ESA**: Using the stereophotoclinometry technique and created by ESA
    - **SPC_LAM_PSI**: Using the stereophotoclinometry technique and created by LAM and PSI.
    - **MSPCD_LAM**: Using the Multi-Resolution Stereophotoclinometry by Deformation technique and created by LAM
    - **SPG_DLR**: Using the stereo-photogrammetric technique and created by DLR

- **Level 3**, version: One subdirectory for each version of the shape model. Versions might differ from each other in the precise images used to generate the shape model or in other aspects.

3.3.2 Document Directory

Contains all documentation related to the shape models and this data set. All files are either in PDF or plain ASCII text files. The most up to date information on the content of this file can be found in the DOCINFO.TXT file of this directory.

3.3.3 Extras Directory

Contains extra data or information that is useful but not essential and that does not conform to the PDS standard and therefore cannot be placed in other folders.

In the case of the shape model data set, it contains a directory TRIPLATE/SPC_ESA with the ESA NavCam shape model in the STL format that is a useful format but that does not conform to the PDS standard. The reason that it does not conform to the PDS standard is that its PDS label file (LBL extension file) does not fully define the data file but anyone familiar to the STL format or with the appropriate software will be able to read this files.

3.3.4 Catalog Directory

Contains plain text files containing meta data according to the PDS standard (catalog files). These files are:

- DATASET.CAT: Description of the data set
- INSTHOST.CAT: Description of the Rosetta orbiter spacecraft that host the OSIRIS and NavCam instruments
- MISSION.CAT: Description of the Rosetta mission
- NAVCAM_INST.CAT: Description of the NavCam camera
- OSINAC_INST.CAT: Description of the OSIRIS NAC camera
- OSIWAC_INST.CAT: Description of the OSIRIS WAC camera
- REFERENCE.CAT: References to per reviewed publications applicable to the Rosetta mission
- SFTWARE.CAT: Currently empty for the shape model data set

In addition it contains a DOCINF.TXT document explaining the contents of the directory.

3.3.5 Index Directory

This directory contains the indices for all data products on the volume. The indices contain the list of all files in the data set together with its path and other information.

The files in this directory are:

- INDXINFO.TXT: This file identifies and describes the function of each file in the INDEX subdirectory. This description includes:
  - o A description of the structure and contents of each index table in this subdirectory
  - o Usage notes
- INDEX.TAB: This file contains the volume index in tabular format (i.e., the INDEX_TABLE specific object is used to identify and describe the data stored on an archive volume). Only data product label files (i.e., not the data files) are included in an index table.
- CHECKSUM.TAB: Contains the MD5 checksums for every file (except itself and its label) contained in this volume.
- CITATIONS.TAB: Contains a listing of all CITATION_DESC found within this data set for each data or document product.

All TAB files are accompanied by their PDS label files (LBL extension).

4 GUIDE TO SELECT A SHAPE MODEL

4.1 Guide for SHAP2/SHAP5 OSIRIS Models (LAM and LAM/PSI Providers)

The SHAP2 archive contains two different models of comet 67P/C-G: the SPC model reconstructed with the "stereophotoclinometry" technique, and the MSPCD model build with a new method called "multi-resolution stereophotoclinometry by deformation", which are described more fully in the shap2_model_info.asc document. This file provides some guidance to the users of these models.

The SHAP5 archive only contains the SPC model reconstructed with the "stereophotoclinometry" technique from a much larger set of images than the SHAP2 models. This model has a higher resolution than the SHAP2 models and should be used in priority.

Notes about the two techniques:

- The SPC technique is more robust and much better tested than MSPCD. It has been successfully applied to several small bodies and planets.
- The SPC technique translates gray-level variations in the images into slopes. The algorithm guarantees that it will almost never create artificial topography. MSPCD on the other hand can sometimes create small "ripples", holes or discontinuities in the topography due to the nonlinear inversion algorithm used to generate it.
- Although both techniques use a "smoothness constraint" to regularize the solution (slopes for SPC, heights for MSPCD), the SPC algorithm tends to smooth sharp edges more than MSPCD. This has a real impact on the shape of 67P/C-G since the comet exhibits several features containing such sharp edges: cliffs, large boulders, pits.

Recommendations for users:

The SHAP5 SPC model should be used in priority. If the user's work relies on an accurate description of the slopes along cliffs and/or pits, the MSPCD model may be used in addition, to compare the results obtained with the SPC model.

4.2 Comments Regarding ESA NavCam Models

These models use the stereophotoclinometry (SPC) technique.

This model was created specifically for use in operational applications. It can be used in scientific applications as well, though its strengths and weaknesses in this respect were not specified at the time of the data set ingestion.

END OF DOCUMENT