Spacecraft and Payload Data Handling

F. Delhaise[1], A. Ercolani[1], J. Zender[2], M. Barthelemy[2], R. Trautner[2] & C. Arviset[3]

[1]*Ground Systems Engineering Department, European Space Operations Centre, ESA, Darmstadt, Germany*
Email: Fabienne.Delhaise@esa.int
[2]*Research and Scientific Support Department, European Space Research and Technology Centre, ESA, Noordwijk, The Netherlands*
[3]*Research and Scientific Support Department, European Space Astronomy Centre, ESA, Madrid, Spain*

The success of a scientific mission is determined by the quality of the scientific results. The prompt delivery of instrument and ancillary raw data to the instrument teams and the delivery of reduced and calibrated data to the scientific community are therefore key elements in the mission design. This paper describes the data flow from the Venus Express spacecraft through the ground segment via the instrument teams to the final scientific archive. Several software tools and standards are used to support the data dissemination. The functionality of the individual tools is explained, the interfaces to the individual groups are discussed and examples of the graphical user interfaces are shown.

1. Introduction

A large number of teams and individuals are involved in the data processing of the byte packages from the spacecraft into scientifically useful, reviewed datasets distributed to the scientific community. The teams have different responsibilities but they all aim to deliver a correct and complete set of information. The information required by the teams is manifold and covers, for example:

— spacecraft and instrument documentation;
— ancillary data such as spacecraft event information and instrument mounting alignments;
— spacecraft orbit and attitude information;
— environmental information;
— spacecraft anomalies;
— instrument housekeeping and scientific data;
— instrument calibration information;
— science operations planning information.

The ground segment includes the reception of the spacecraft data, delivery to the Mission Operations Team at the European Space Operations Centre (ESOC) in Darmstadt (D) and the provision of all spacecraft and instrument data to the instrument teams. ESOC provides corrected data to the scientific investigators; errors arising in the transmission from the spacecraft to the ground station are removed.

Each instrument team retrieves relevant spacecraft and ancillary data and their instrument data from the Data Distribution System (DDS) at ESOC. The data distribution, analysis and validation depend on the internal organisation of each instrument team, the data volume and the type of housekeeping and scientific data. The data paths are different for most the teams; they are described individually in the instrument articles in this volume. The instrument teams

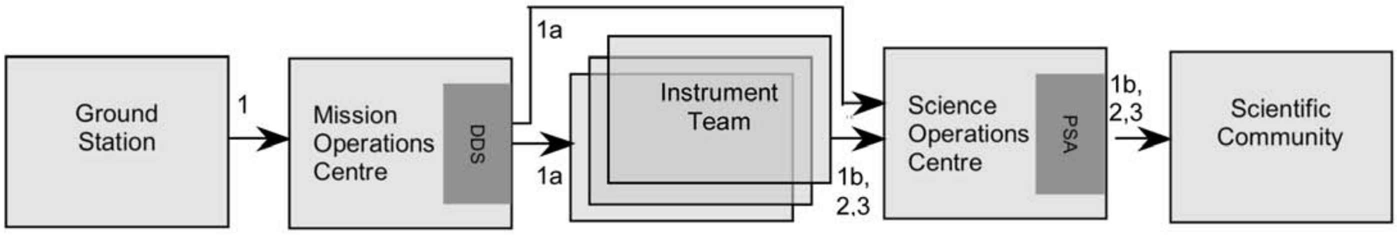

Fig. 1. The data flow from the ground station in Cebreros (E) to the scientific community. The numbers on top of the arrows indicate the data processings. Iterations that might occur in the data flow are not indicated.

reformat their raw and calibrated data into a user-friendlier format following the Planetary Data System (PDS) standard. Also, the ancillary data originating from the Venus Express Mission Operations Centre (VMOC) is formatted following the PDS standard by the archive team of the Venus Express Science Operations Centre (VSOC). The archive team within the VSOC receives datasets that are self-descriptive and complete, and after a first syntactical check these datasets are ingested into the Planetary Science Archive (PSA) repository. Scientists, engineers and interested public can access this repository for the datasets or individual data products.

Figure 1 illustrates the data flow from the ground station to the scientific community. The darker shaded boxes within the VMOC and VSOC represent software applications that are available on the Internet, in the DDS case for the experimenter teams, and the PSA for the whole scientific community. The numbers on top of the arrows indicate the data processing of the data products, as defined by:

— Level-0: raw telemetry data as received at the ground receiving station or ground support equipment; created by spacecraft;
— Level-1: Level-0 data that have been cleaned and merged, time ordered and in frame format; created by the Network Controller and Telemetry Receiver System;
— Level-1a: Level-1 data that have been separated by instrument, as requested by the DDS;
— Level-1b: Level-1a data that have been sorted by instrument data types and instrument modes. Data are in scientifically useful format, such as images or spectra. These data are still uncalibrated. Created by instrument team;
— Level-2: Level-1b with calibration and corrections applied to yield scientific units; created by instrument team;
— Level-3: higher level data products developed for specific scientific investigations; created by instrument team, interdisciplinary scientists or other teams.

This paper provides an overview of the data flow from Level-1 to Level-3. The processing of Level-2 and -3 are instrument-dependent, so further information is provided in the individual instrument papers in this volume. Section 2 gives an overview of the data processing of Level-1 and the DDS that allows the experiment teams to download data of Level 1a on request. Section 3 discusses the science archive process and the PDS standard. Section 4 covers the dissemination of the scientific data to the scientific community.

2. The Ground Segment

2.1 Overview

The control concept for Venus Express was inherited from the Rosetta and Mars Express missions, based on a single control centre in conjunction with the ESA deep space antennas in New Norcia near Perth (Western Australia) and Cebreros

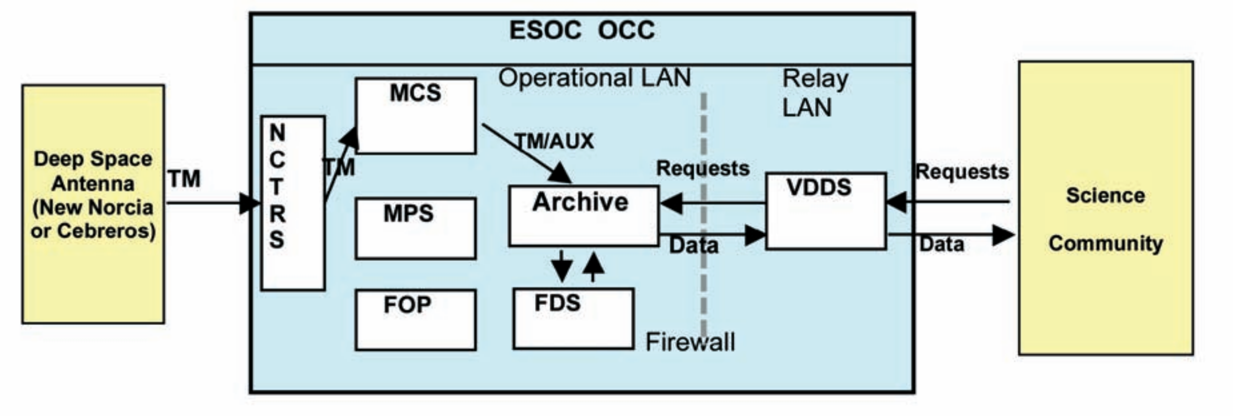

Fig. 2. The Venus Express Operations Control Centre. Acronyms are explained in the text.

(E). The baseline operations philosophy is to acquire the maximum of science data around Venus.

The definition, design and implementation of the ground segments of ESA's planetary missions are the responsibility of ESOC. The Data Processing Systems are part of the ESOC Operations Control Centre (OCC), which is the central facility responsible for operating the spacecraft. As Rosetta and Mars Express share near-identical Data Management System and onboard software, it was decided to develop most of the components jointly for their data systems in order to minimise costs and development time. The Venus Express data systems are a delta development from the existing system.

The major components of the data processing systems are described below and in Fig. 2:

— the Venus Express Mission Control System (VMCS) supports the exchange of telemetry and telecommand data between the OCC and the spacecraft via dedicated communications lines and interfaces with the ground stations. It is based on the ESOC SCOS-2000 infrastructure, and processes housekeeping data in real-time for spacecraft control. This includes command verification and out-of-limit detection. It timestamps the telemetry data by converting the onboard time to UTC with an accuracy of better than 2 ms. Housekeeping telemetry, including the parameters and event messages, are processed by the MCS using calibration curves to convert them into engineering and/or functional parameter values needed to monitor the status of the spacecraft platform and payload and to recover from anomalies, if any. It also provides a command system to control the spacecraft. During nominal operations, commands are calibrated, pre-transmission validated and transmitted to the ground station(s) for uplinking in real-time. A complete history of all commands requested, transmitted and verified is maintained by the OCC. The VMCS is also used to manage the operational database and maintain the onboard software. The Telemetry Data Retrieval System (TDRS) provides a data retrieval interface to extract telemetry parameter values, accessible for authorised users on Intranet and Internet (TDRS Operator User Manual, 2000).

— the Venus Express Data Disposition System (VDDS) is based on the Generic Data Disposition System (GDDS). It allows remote access by the scientific community for the near-real-time and/or offline inspection of mission data. This system also provides facilities for the regular daily production of Raw Data Media for the permanent archiving of raw telemetry and auxiliary data. It is also used to store instrument telemetry data on DVDs, which are sent to VSOC.

— the Mission Planning System (MPS) is an offline system that provides tools for the advance planning of the mission operations based on inputs from the Principal Investigators (PIs), VSOC and the operations staff at ESOC. The final output is in the form of machine-readable schedules for commanding the spacecraft and the two ground stations. In contrast to the other data system components, the MPS is mission-specific.

— the offline Flight Operations Procedure (FOP) System is used by the Mission Operations Team to prepare spacecraft operations procedures and command sequences, which can then be imported into the operational database.

2.2 Collection of telemetry

The VMCS interfaces with the ground station receive and transmit telemetry and telecommand in a controlled and error-free manner. A no-break data link connection is always established when the ground station is in real-time contact with the spacecraft.

The MCS receives the telemetry from the ground stations via a generic infrastructure system called the Network Controller and Telemetry Receiver System (NCTRS). The ground station has already performed some basic checks and timestamped it with the Earth Reception Time. The NCTRS then passes the housekeeping and science telemetry to the appropriate MCS for more specific processing and archiving. It also gathers all the telecommands from the MCS and forwards them to the ground stations.

The NCTRS is also used for acquiring and locally storing tracking data such as antenna angles, range and Doppler measurements made at the ground station. These are then made available to the Flight Dynamics System (FDS) via the File Transfer System (FTS) and to the authorised PIs via the DDS.

The files generated in the OCC, such as antenna pointing information and station schedule files are transferred via the NCTRS to the ground station.

2.3 Dissemination of raw data

The VOCC offers housekeeping and science telemetry and auxiliary data in near-real-time and offline mode to the PIs. Following receipt or generation at the OCC, the data can be accessed from a remote computer on a call-up basis.

Mission products include all payload science data, all platform and payload housekeeping data and auxiliary data, such as telecommand history, station visibility, spacecraft orbital position, attitude and orbit. Housekeeping and science telemetry data (real-time and playback) are extracted and stored as raw data chronologically ordered and sorted by spacecraft and payload. They include quality data and additional timing data to enable the PI to correlate the data with respect to UTC. Science, housekeeping and consolidated auxiliary data are stored on DVDs at regular intervals; one copy is mailed to VSOC at ESTEC and one is kept at the VMOC at ESOC. The DVDs are formatted using the Standard Formatted Data Unit concept as recommended by the Consultative Committee for Space Data Systems (CCSDS). This standard allows the science community to find and retrieve data and their description with no previous knowledge of the file structure being used within the DVD.

Finally, the OCC will archive all Venus Express Level-1 data of all payloads for a period of 10 years from the end of the mission. Archived data include all raw telemetry and auxiliary data.

The VMCS is on the operational LAN and is accessed by operations staff at ESOC (i.e. no remote access). The external access of mission data is via the VDDS and TDRS. They allow secure connection between the external world (especially the PIs) and the ESOC protected operational LAN.

The telemetry packets and auxiliary files can be retrieved via the DDS, while the telemetry parameters can be retrieved via the TDRS. Detailed information on interfaces and conventions used can be found in the Data Delivery Interface Document (2002).

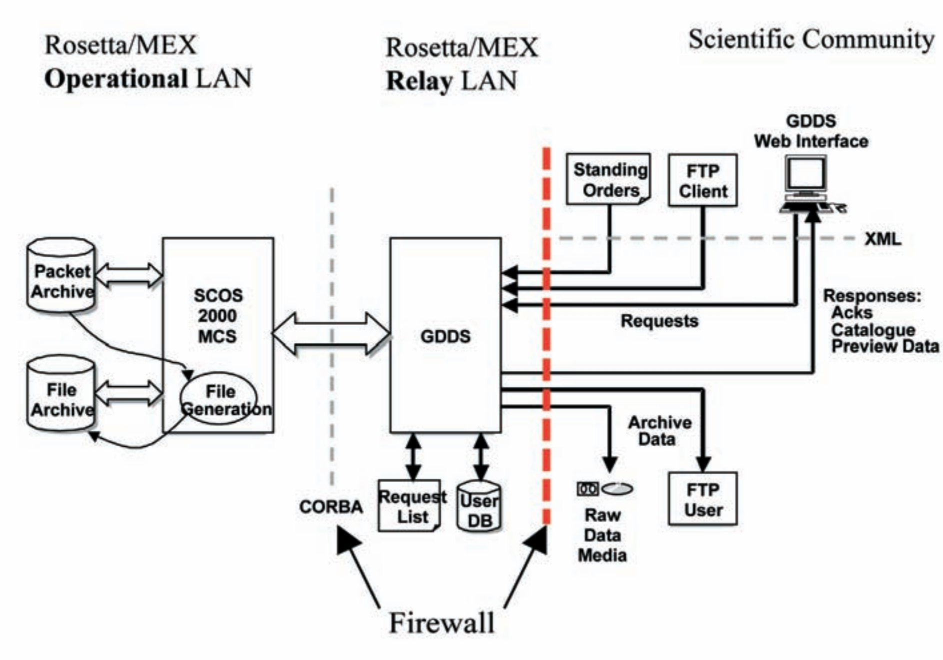

Fig. 3. The architecture of the Generic Data Disposition System. DB: database; LAN: local area network; MEX: Mars Express; other acronyms are explained in the text.

The two sections below describe the functionality of these two subsystems in greater detail.

2.3.1 Dissemination of the mission raw data via the DDS

The DDS is based on the Generic Data Disposition System (GDDS; GDDS Operator User Manual, 2002). It enables PIs and other external users to submit requests for data to be extracted from the mission archives supported by the SCOS-2000 spacecraft control system kernel. These requests are expressed in an XML-based format. An overview of GDDS is given in Fig. 3.

The VMCS, based on SCOS-2000, maintains a mission archive of two main elements: a packet archive, containing historical telemetry, telecommand and derived data; and a file archive, which typically contains flight dynamics and planning data. A file generation process within SCOS-2000 can also be invoked to generate file-based summary data from packet data, such as a Command History report.

Requests for data to be extracted from the mission archive may originate in three ways: scheduled ‘standing orders’; submission via a web-based interface; request files sent using FTP. All requests comprise a list of items to be retrieved, and are expressed in a recursive query language defined in XML, which is used internally within the system, and also exposed to the user on the FTP interface. This allows multiple filters to be applied to the data being retrieved. The requested data can be from three sources: telemetry data; auxiliary data; catalogue data.

These requests are managed by a central DDS server, which interfaces with the VMCS to initiate archive retrievals via a Common Object Request Broker Architecture (CORBA)-based interface. Archive retrievals performed on the VMCS interface are relatively low level, and several individual retrievals may be performed to satisfy a single request. The GDDS server maintains a request list, and collates the retrieved data for a single delivery in response to each request.

Requests must be identified as originating from a previously authorised external user. VDDS maintains a database of these authorised users, together with address information for the delivery of retrieved data. Three methods of archive data delivery are supported: online via web-based interface; FTP; DVDs, available only at the VMOC and VSOC following a pre-agreed recording and

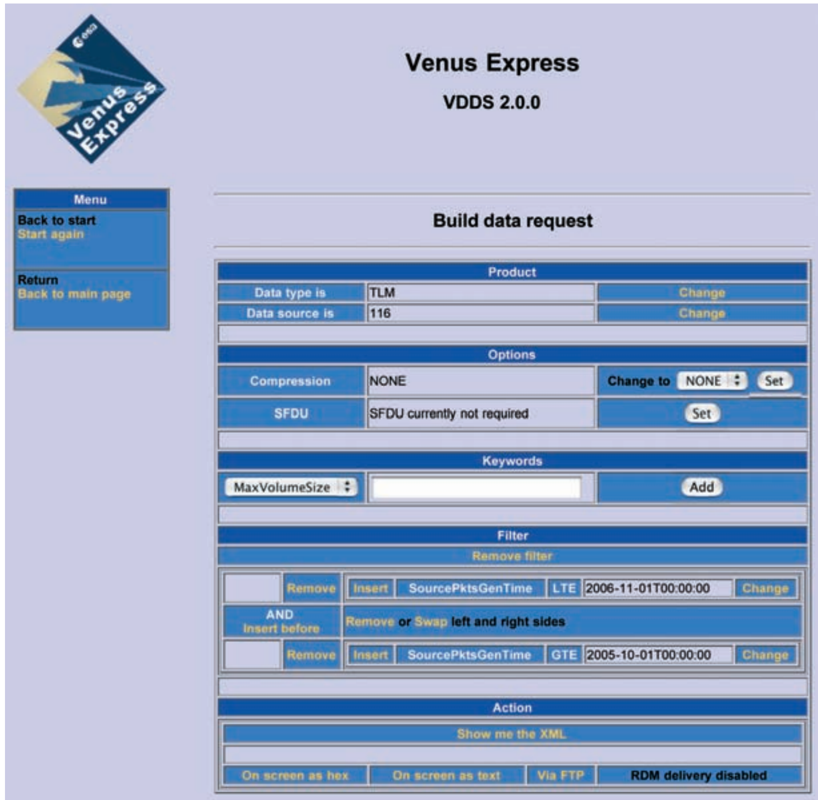

Fig. 4. Sample screen from the DDS web interface.

distribution scheme.

The DDS web-based user interface is designed to allow previously authorised users to view the catalogue of data held in the mission archive, and to generate and submit retrieval requests, for delivery using FTP or http. Fig. 4 shows the user interface for building a data request.

All responses from the VDDS server to the web-based interface are also transferred as XML files. This includes request acknowledgements, catalogue data and online data retrievals. Online data retrieval is available only in response to a request originating from the web-based interface, and is designed for previewing of small amounts of data only. This enables a user to verify that it is the required data, before requesting a full FTP transfer. The data themselves are embedded as a byte stream in the XML response.

2.3.2 Dissemination of the raw data via the TDRS

TDRS is a SCOS-2000 External Interface supporting the retrieval of telemetry data from the History File Archive. Its functionality covers the retrieval of the telemetry packets containing the desired parameters and then the extraction of the parameters from the packets. Calibration of the raw values and evaluation of their validity and out-of-limit status are also offered as an option in the retrieval specification. The service supports only extraction of data out of fixed-length packets and not out of variable-length packets.

The retrieved data are made available in a spreadsheet for analysis and displays by external tools. The files contain a raw value and timestamp for each occurrence of the parameters requested in the retrieval. In the case of Complete Retrieval, the spreadsheets files contain information about the validity and out-of-limit status of each parameter value.

TDRS is available to authorised users on the Intranet and Internet. The user interfaces TDRS via a standard web browser and emails.

3. Scientific Processing and Data Archiving

3.1 Overview

After the success of the Giotto flyby of comets Halley and Grigg-Skjellerup, Rosetta, Mars Express, Huygens, SMART-1 and Venus Express followed as ESA's planetary missions. All the data from the International Halley Watch campaign (including the Giotto data) were archived using the PDS standard driven by NASA. PDS is the *de facto* standard for most the US planetary missions, so it was decided early on in mission development to use it for Rosetta, Mars Express, Huygens, SMART-1 and Venus Express.

To ensure maximum commonality, ESA introduced the single Planetary Science Archive (PSA) for all of its planetary missions (ESA's Planetary Missions Science Data Archive, 2002). Several access methods to engineering, housekeeping and scientific data are available for the scientific community. Information can be queried and retrieved after the proprietary period of the data has ended. All services are Internet-based.

The initial requirements, system tests and further development is driven by the PSA Science Advisory Group, a mission-independent group representing a range of instrument categories and scientific disciplines from the European scientific community.

3.2 The Planetary Data System standard

The PDS standard is a set of guidelines published in the PDS Data Standards Reference (2006). The guidelines cover the archive process and details of predefined data types, an object description language, a data dictionary, rules on labelling data products, catalogue templates and the organisation of logical or physical volumes. As a general rule, each data product must be labelled. A data product is a label linked to a data file. The label is either attached to the data file itself or detached in a separate file (a label file). Documents are classified as products and a label is required. Each self-contained unity, called a dataset, must contain a default set of documentation in ASCII format, referred to as catalogue files. Fig. 5 sketches the parts of the standard, indicating the hierarchical structure.

The glue of all the data products is the standard grammar, the object description language (ODL). The ODL requires that all meta-data be given as a *keyword* = *value* pair.

```
INSTRUMENT_HOST_NAME    = "VENUS EXPRESS"
```

is, for example, a valid description of the spacecraft name. The keywords on

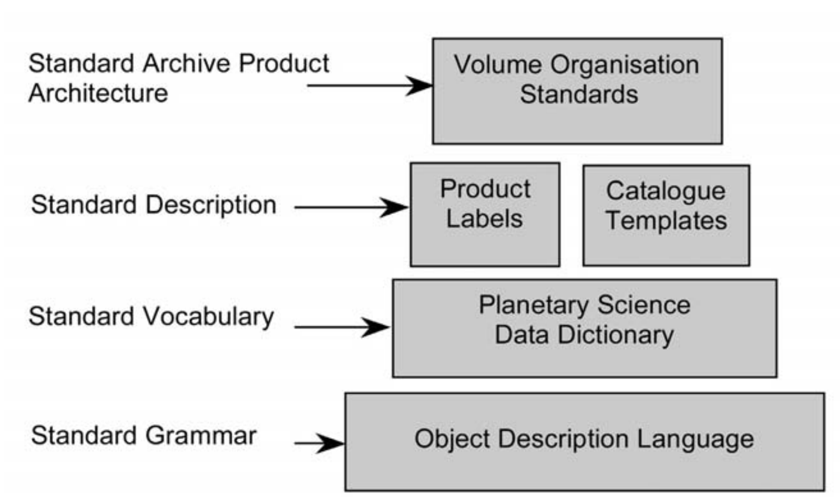

Fig. 5. Hierarchy of the Planetary Data System standard.

the left side of the pair must be defined in the Planetary Science Data Dictionary (PSDD, 1992). A lookup for the keyword *instrument_host_name* results in:

```
NAME = INSTRUMENT_HOST_NAME
 STATUS_TYPE             = APPROVED
 GENERAL_DATA_TYPE   = CHARACTER
 UNIT_ID                   = NONE
 STANDARD_VALUE_TYPE = STATIC
 MAXIMUM_LENGTH        = 60
 DESCRIPTION = "
   The instrument_host_name element provides the full name of
   the host on which an instrument is based. This host can be
   either a spacecraft or an earth base. Thus, the
   instrument_host_name element can contain values which are
   either spacecraft_name values or earth_base_name values."
 STANDARD_VALUE_SET = {
   "ROSETTA",
   "ROSETTA LANDER",
   "MARS EXPRESS",
   "BEAGLE 2",
   "VENUS EXPRESS",
   "SMART 1",
   "2001 MARS ODYSSEY",
   "24-COLOR SURVEY",
   "AMES MARS GENERAL CIRCULATION MODEL",
   "ARECIBO OBSERVATORY",
   "CLEMENTINE 1",
   ....
 }
```

The basic element of the archive is, of course, the data products. The standard has a small number of predefined, simple, data types for these products, but allows the definition of user-defined structures or combined structures. Keeping in mind that the long-term preservation of the data is one of the major goals, the reduced number of available data types is seen as an advantage, because it increases the simplicity of the data in the long-term. Data producers are forced to design easy data types and data structures, which simplifies the access to the data products. To name just a few of these data types: matrix, image, spectrum, qube, table and histogram.

The standard description requires a label for each data product. This label contains *keyword* = *value* pairs that describe the data type, structure and any another meta-information necessary to access the data and to interpret it. The block on the opposite page (top) gives an example of a data product label from the VMC camera on Venus Express.

Further, the standard requires a set of catalogue files. A catalogue file is a label file that contains textual information in ASCII format for at least:

— dataset description (dataset catalogue file);
— spacecraft description (instrument_host catalogue file);
— instrument description (instrument catalogue file);
— mission description (mission catalogue file);
— referenced literature, reports, etc (reference catalogue);
— team information (personnel catalogue file);
— dataset collection description (dataset collection catalogue file, optional);
— Venus information (target catalogue file, optional).

Additionally, the standard is based on a well-defined directory structure. As an example, all catalogue files need to be accessible from a directory named *CATALOG*. The top-level directory must contain a file named *VOLDESC.CAT* that describes the whole archive volume. The block on the page opposite (lower) gives an example of a typical *VOLDESC.CAT* file.

Documentation is found below the directory named *DOC* and software can be archived below the *SOFTWARE* directory. Software products might include visualisation, analysis or calibration routines.

The standard aims further to overcome operating system dependencies and direct the archive designers towards human readability. The provision of browse

```
PDS_VERSION_ID              =   PDS3

/* FILE DATA ELEMENTS */
RECORD_TYPE                 =   FIXED_LENGTH
RECORD_BYTES                =   1024
FILE_RECORDS                =   528
LABEL_RECORDS               =    9

/* POINTERS TO DATA OBJECTS */
^IMAGE_HEADER               =   10
^IMAGE                      =   17

/* PRODUCER IDENTIFICATION */
PRODUCT_CREATION_TIME  =   2006-11-13T13:00:49.000Z
PRODUCER_FULL_NAME          =   "THOMAS ROATSCH"
PRODUCER_ID                 =   DLR
PRODUCER_INSTITUTION_NAME    = "
     DEUTSCHES ZENTRUM FUER LUFT- UND RAUMFAHRT"

/* DATA DESCRIPTION AND IDENTIFICATION */
DATA_SET_ID                 =   "VEX-V-VMC-3-RDR-V1.0"
DATA_SET_NAME               =   "VENUS EXPRESS VENUS VMC 3 V1.0"
DETECTOR_ID                 =   "VEX_VMC_NIR-1"
FILE_NAME                   =   "V0025_0001_N12.IMG"
INSTRUMENT_HOST_ID          =    VEX
INSTRUMENT_HOST_NAME   =   "VENUS EXPRESS"
INSTRUMENT_ID               =   VMC
INSTRUMENT_NAME             =   "VENUS MONITORING CAMERA"
INSTRUMENT_TYPE             =   "FRAMING CAMERA"
^INSTRUMENT_DESC            =   "INSTRUMENT_DESC.TXT"
MISSION_ID                  =   VEX
MISSION_NAME                =   "VENUS EXPRESS"
MISSION_PHASE_NAME          =   PHASE_0
PROCESSING_LEVEL_ID         =   2
PRODUCT_ID                  =   "V0025_0001_N12.IMG"
PRODUCT_TYPE                =   RDR
RELEASE_ID                  =   0001
REVISION_ID                 =   0000

/* TIME RELATED INFORMATION */
SPACECRAFT_CLOCK_START_COUNT  = "1/0038065841.63876"
SPACECRAFT_CLOCK_STOP_COUNT   = "1/0038065841.64341"
IMAGE_TIME                  =   2006-05-15T13:50:42.000Z
START_TIME                  =   2006-05-15T13:50:41.996Z
STOP_TIME                   =   2006-05-15T13:50:42.004Z


/* ORBITAL INFORMATION */
ASCENDING_NODE_LONGITUDE        = 107.3
ORBIT_NUMBER                    =    25
ORBITAL_ECCENTRICITY            =    0.84
ORBITAL_INCLINATION             =    89.94
ORBITAL_SEMIMAJOR_AXIS          =    39468.3
PERIAPSIS_ALTITUDE              =    269.17
PERIAPSIS_ARGUMENT_ANGLE        = 101.25
PERIAPSIS_TIME                  =    2006-05-16T01:34:46.000Z
MAXIMUM_RESOLUTION              =    46022 <m/pixel>
FOOTPRINT_POINT_LATITUDE        = (-9.23546,-10.931,-12.4457, ... )
FOOTPRINT_POINT_LONGITUDE       = (256.241,256.854,258.48,260,... )
SPACECRAFT_ORIENTATION          = (-0.943457,0.329288,-0.0381811)
^SPACECRAFT_ORIENTATION_DESC =
                        "SPACECRAFT_ORIENTATION_DESC.TXT"
SPACECRAFT_POINTING_MODE         = "NULL"
```

```
/* TARGET IDENTIFICATION */
TARGET_TYPE                 =   PLANET
TARGET_NAME                 =   VENUS
RIGHT_ASCENSION             =   -1e+32
DECLINATION                 =   -1e+32
SPACECRAFT_SOLAR_DISTANCE  = 1.0894e+08

/* SCIENCE OPERATIONS INFORMATION */
VEX:SCIENCE_CASE_ID             =    -2147483647
VEX:SCIENCE_CASE_ID_DESC    = "SCIENCE_CASE_ID_DESC.TXT"
OBSERVATION_TYPE                =    "NULL"
^OBSERVATION_TYPE_DESC          =    "OBSERVATION_TYPE_DESC.TXT"

/* INSTRUMENT INFORMATION */
EXPOSURE_DURATION           =   7.1 <ms>
INST_CMPRS_NAME             =   NONE
INST_CMPRS_RATIO            =   1.0
INST_CMPRS_QUALITY          =   0
MACROPIXEL_SIZE             =   1
LINE_FIRST_PIXEL            =   1
SAMPLE_FIRST_PIXEL          =   1
DETECTOR_TEMPERATURE =   3.4 <degC>

/* RADIOMETRIC DATA INFORMATION */
RADIANCE_OFFSET                 = 0.0 <W*m**-3*sr**-1>
RADIANCE_SCALING_FACTOR    = 158779.0 <W*m**-3*sr**-1>


/* DATA OBJECT DEFINITIONS */
OBJECT                      =   IMAGE
 INTERCHANGE_FORMAT         =   BINARY
 LINES                      =   512
 LINE_SAMPLES               =   512
 SAMPLE_TYPE                =   MSB_INTEGER
 SAMPLE_BITS                =   16
 BANDS                      =   1
 BAND_STORAGE_TYPE          =   BAND_SEQUENTIAL
 MAXIMUM                    =   1495
 MEAN                       =   72.5544
 MINIMUM                    =   0
 STANDARD_DEVIATION         =   243.243
END_OBJECT                  =   IMAGE


/* IMAGE HEADER DATA ELEMENTS */
OBJECT                      =   IMAGE_HEADER
 HEADER_TYPE                =   VICAR2
 INTERCHANGE_FORMAT         =   ASCII
 BYTES                      =   7168
 ^DESCRIPTION               =   "VICAR2.TXT"
END_OBJECT                  =   IMAGE_HEADER
END
```

```
PDS_VERSION_ID              =   PDS3
LABEL_REVISION_NOTE         =   "2006-12-01, TR"
RECORD_TYPE                 =   FIXED_LENGTH
RECORD_BYTES                =   80
RELEASE_ID                  =   0001
REVISION_ID                 =   0000

OBJECT                      =   VOLUME

 VOLUME_SERIES_NAME         =   "MISSION TO VENUS"
 VOLUME_SET_NAME            =   "N/A"
 VOLUME_SET_ID              =   "DE_DLR_PF_VEXVMC-0001"
 VOLUMES                    =   "UNK"
 VOLUME_ID                  =   "DE_DLR_PF_VEXVMC-0001"
 VOLUME_VERSION_ID          =   "VERSION 1"
 VOLUME_NAME                =   "VEX VMC RDR ARCHIVES"
 MEDIUM_TYPE                =   "ELECTRONIC"
 VOLUME_FORMAT              =   "N/A"
 PUBLICATION_DATE           =   2007-01-25
 DATA_SET_ID                =   "VEX-V-VMC-3-RDR-V1.0"
 DESCRIPTION                =   "Venus Express VMC data"

 OBJECT                     =   DATA_PRODUCER
  INSTITUTION_NAME          =   "DLR"
  FACILITY_NAME             =   "Institut fuer Planetenforschung"
  FULL_NAME                 =   "Deutsches Zentrum fuer Luft und Raumfahrt
   (DLR), Institut fuer Planetenforschung"
  DISCIPLINE_NAME           =   "N/A"
  ADDRESS_TEXT              =   "Rutherfordstrasse 2, 12489 Berlin, Germany"
 END_OBJECT                 =   DATA_PRODUCER

 OBJECT                             =   CATALOG
  ^MISSION_CATALOG                  =   "MISSION.CAT"
  ^INSTRUMENT_HOST_CATALOG          =   "INSTHOST.CAT"
  ^INSTRUMENT_CATALOG               =   "INST.CAT"
  ^REFERENCE_CATALOG                =   "REF.    CAT"
  ^DATA_SET_RELEASE_CATALOG         =   "RELEASE.CAT"
  ^SOFTWARE_CATALOG                 =   "SOFT.CAT"
  ^PERSONNEL_CATALOG                =   "PERSON.CAT"
  ^DATA_SET_CATALOG                 =   "DATASET.CAT"
 END_OBJECT                         =   CATALOG

END_OBJECT                          =   VOLUME

END
```

information is optional, but the Venus Express teams define and create browse thumbnails for their data products. These thumbnails enable interested end-users to get information of the measurement, data quality and geometrical conditions of the data product.

3.3 The scientific archive process

The archive process started with the agreement of the Archive Generation, Validation and Transfer Plan (2004), also called the Archive Plan, in agreement with ESA's rules on data (Venus Express Science Requirements Document, 2004; ESA Council, 1989). The Archive Plan gives the scope of the scientific data archive for the overall mission, summarises the mission, the instruments and the groups involved in the archiving efforts. It identifies the responsibilities of the different groups and names the instrument contact staff for archiving.

Venus Express is a PI-type mission. This implies the PI is responsible for the scientific archive design and preparation. The Archive Plan contains a first draft of the data types. The expected data volume is captured in annexes and the most important paragraphs of the applicable documents are cited. The Archive Plan was prepared by the ESA archive team, agreed on and issued a year before launch.

The ESA archive team acts as a consultant for the experimenters and supports them in all aspects of archive preparation. Each experimenter team defines its archive design in the Experimenter to Archive Interface Control Document (EAICD). This contains all the details on the archive and directory structure, the data types and the used label keywords. It was issued before launch and updated during the mission as required.

Regular Data Archive Working Group (DAWG) meetings and teleconferences discuss issues of common interest and update everyone on design and implementation.

The scientific archive of Venus Express will be of the order of 10^9 bytes for the nominal mission phase.

Electronic data-handling is the goal for data ingestion from instrument teams into the PSA and from there to the scientific community. To reduce the overhead of PDS standard syntax validation and dataset transmission, ESA offers to all instrument teams a software tool to support the validation of:

— PDS standard syntax;
— used keywords (required, optional against the PSA dictionary);
— keyword values (against the PSA dictionary);
— time information (cross-checks between catalogue files and data product labels);
— reference information (cross-checks between catalogue files and PSA database).

The tool further supports:

— the handling of incremental deliveries and the correction of delivered data products;
— the packing of data into deliverable units (tar, zip);
— the transmission of the deliverable units to the PSA;
— the generation of the main index file.

Besides the spacecraft data prepared at ESOC and the instrument scientific data, the PSA contains geometrical, positional, illumination and mission phase information. The DAWG discusses these issues and tries to achieve maximum commonality in the usage of these keywords between the instrument teams.

Continuous data delivery from the instrument teams to the archive team would require a tremendous technical and data validation effort by all involved parties, so a delivery schedule is followed based on longer time periods: the archive phases. There are three different archive phases: data collection; archive preparation; and archive validation.

During the data-collection phase, the instrument teams receive their data from the DDS, distribute them among the Co-Investigators and other team members and perform the data analysis and team internal validation. For Venus Express, this phase is 3 months. All the data from one collection phase is processed into PDS-compliant datasets during the next 6 months; this is the archive-preparation phase. After an automatic pre-validation, the instrument team ingests its datasets electronically into the PSA database. The ESA archive team runs software validation tools to check for syntax errors and the completeness of the delivered datasets. The ESA archive team manually checks the completeness of the delivered documentation and calibration information. For the first and last deliveries of a mission, a Peer Review by external scientists and engineers are called in to conduct an independent scientific review on the completeness and correctness of the delivered datasets. The data will become available to the scientific community after successful Peer Review for the first delivery in May 2007. At 3-month intervals, the data of the next data-collection phase is made available after an internal validation and check.

4. The Auxiliary Data Conversion system

To support the science analysis and data archiving efforts of the instrument teams, the VSOC converts auxiliary data originating from the Flight Dynamics Team at ESOC into SPICE (Spacecraft, Planet, Instrument, C-matrix, Events) kernels. These are a set of data formats representing spacecraft ephemeris, planetary, instrument, C-matrix (attitude) and event information. They are supported by a powerful library that was created and is maintained by the Navigation and Ancillary Information Facility (NAIF) at the Jet Propulsion Laboratory, Pasadena, California (USA). NAIF is a Discipline Node of the PDS.

Most of the kernels can be processed and validated automatically:

- conversion of orbit files into SPKs (Spacecraft Planet Kernels), and their validation;
- conversion of attitude files into C kernels, and their validation;
- conversion of time correlation packages into SCLKs (Spacecraft Clock Kernels), and their validation;
- creation of orbit numbering files (ORBNUM) from SPKs;

whereas others must be created manually:

- instrument kernels are produced by the NAIF team and VSOC in coordination with the instrument teams;
- frame kernels are produced by the NAIF team and VSOC.

The Auxiliary Data Conversion System (ADCS) is a collection of Perl scripts requesting the latest orbit, attitude and time correlation information from the ESOC DDS system several times a day. Whenever new source information is provided, the conversion is done automatically and validated against a set of constraints. With successful validation, the new kernels produced are copied to the VSOC FTP server and an email notification message is send to a distribution list. The interested instrument team can either request that the data are mirrored to their system or request the kernels themselves via the FTP protocol from the VSOC server. An identical copy of the VSOC FTP server is maintained at the NAIF FTP server.

5. Science Quicklook

To allow members of the planning team at VSOC to validate the execution of the instrument commanding and to judge quickly the quality of the science planning and execution, all instrument telemetry packets are downloaded onto a VSOC computer and processed into a Level-1b data product. This processing step is executed typically once per day for each instrument. A processed data file contains either the science or the housekeeping data of one instrument in PDS-compatible format. The usage of these Level-1b data products is solely to identify processing problems within the Level-1b data processing itself and to allow the visualisation of the data by the VSOC staff.

The Level-1b processor used is a general-purpose software tool that can be tailored to the telemetry packet structure of each instrument. The definition of the resulting PDS labels and PDS conform data structures is done via template files.

A general-purpose visualisation software named QBTool is used to fulfil the quicklook needs. QBTool is a basic visualisation package with two main user windows, the Browse Window and the Visualisation Window. The Browse Window allows the directory browsing of a PDS-compatible dataset, the filtering on file names, keyword label contents or user-defined functions and a quick run through a whole dataset.

The Visualisation Window can list the data product label and the data structure, and visualise the data content.

6. Online Archive Services

The Planetary Science Archive offers several services to the scientific community, including querying, locating, retrieval and notification services for Venus Express (*www.rssd.esa.int/psa*). The PSA database and query architecture is based on and a reuse of the existing ISO and XMM-Newton archive architecture. The Science Archive Development Team of ESA's Research & Scientific Support Department is responsible for the design and implementation of the PSA online services.

Scientific, auxiliary and engineering data can be located via three different services. First, all data from Venus Express are accessible via the known FTP protocol, offering direct data access via file and directory browsing. Second, a parameter-based query client offers query capabilities for mission, spacecraft and instrument-related parameters. Within the list of hits resulting from a query, users can directly download the data or collect data of interest in a delivery basket for later download. Finally, a graphical tool based on a Magellan map allows users to query against a region of interest. Results are overlayed as footprints on the map and corresponding data can be order again directly or via a delivery basket.

7. Conclusion

The data flow and data integrity from the spacecraft to the payload team and to the scientific community are well defined. All the tools and services from the OCC to the PSA online services are operational, stable and in continuous use. The first scientific data from Venus Express were distributed in May 2007; the PSA will provide continuous support to scientists worldwide.

References

— (2002). *Venus Express, MEX, Rosetta Data Delivery Interface Document*, RO-ESC-IF-5003, June 2002.

— (2002). *Generic Data Disposition System Operator User Manual*, DTOS-INFR-UM-1001, Issue1.1, March 2002.

— (2000). *Telemetry Data Retrieval System Operator User Manual*, s2k-mcs-sum-2280-tos-gci, Issue 2.0, 17 July 2000.

— (2004). *Venus Express, Science Requirements Document*, VEX-RSSD-SP-002, March 2004.

— (1989). *ESA Council, Rules Concerning Information and Data*, ESA/C(89)95, rev 1, 21 December 1989.
— (1992). *Planetary Science Data Dictionary Document*, JPL D-7116, Rev C, November 1992.
— (2006). *Planetary Data System Data Standards Reference*, Version 3.7, JPL D-7669, Part 2, February 2006.
— (2002). *ESA's Planetary Missions Science Data Archive, User Requirement Document*, SOP-RSSD-RS-006, June 2002.
— (2002). *PSA User Requirement Document*, SOP-RSSD-RS-006, Issue 1, 17 April 2002.
— (2004). *Venus Express Data Generation, Validation and Transfer Plan*, VEX-RSSD-PL-001, Issue 1.1, 7 June 2004.

Acknowledgements
The authors want to acknowledge all the people who have been involved in the PSA, in particular: J. Dowson, J. Hernandez, I. Barbieri, I. Ortiz, P. Osuna, J. Salgado, V. Venet, E. Parrilla, D. Heather, J. Diaz del Rio, J. Luis Vazquez, (all ESA); and the team members of the NAIF team: N. Bachman, B. Semenov, E. Wright, L. Elson and C. Acton.