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Planetary Missions Division

Venus Express

Science Activity Plan for
Extended Mission
SAP-E-3, Part 2
MTPs 66-75

VEX-SCIOPS-PL-031

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	ASPERA		
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1. INTRODUCTION

1.1 Introduction

Venus Express (VEX) is ESA's first mission to Venus. It has a payload consisting of seven scientific instruments, ASPERA, PFS, SPICAV/SOIR, VeRa and VIRTIS, with heritage from Mars Express (MEX) and Rosetta, and MAG and VMC, which are new instruments. The spacecraft was inserted in orbit on April 11, 2006 and since June 2006 performs routine science observations. The Nominal Mission ended on October 2, 2007. However the mission extension till the end of 2012 was approved (third extension). The VEX Science Operations Centre (VSOC) has the task to coordinate the scientific operations of the VEX mission.

1.2 Scope of the document

The Science Activity Plan for Venus Express Third Extended Mission (SAP-E-3) describes in a structured way the scientific activities to be carried out throughout the third extended mission (September 2010 – December 2012). To create more manageable SAP documents, the SAP is subdivided in 3 parts, as follow

SAP number	PART	MTP	Period	SAP document
SAP#3	Part 1	57-65	Sep'10-Apr'11	VEX-SCIOPS-PL-030
	Part 2	66-75	May'11-Feb'12	VEX-SCIOPS-PL-031
	Part 3	76-85	Feb'12'-Dec'12	VEX-SCIOPS-PL-032

This document describes the SAP-E-3 Part 2 (MTP#66-75 May 2011 – February 2012). It follows the objectives set out in the Science Requirements Document (AD6), and is enhanced with specific information applicable to each phase of the mission, as provided by VSOC and the Science Working Team during meetings and in written correspondence. It also includes the requests, per MTPs (Medium Term Planning cycle of 28 days), from each individual instrument team for the observations required to fulfil the different objectives for the respective phases. SAP-E-3 Part 2 contains preliminary MTP timelines (sequences of science cases) agreed by the VEX Science Team. The timelines will be later used as starting point for detailed discussion of each MTP planning. This document will for quite a period be a living document due to its iterative nature. In this respect the document can be considered as a combination of the long term plan and the medium term plan as outlined in the VSOC development plan. Once this document has been established and agreed, it will be used as an input for the detailed short-term plan.

1.3 General observation strategy for Extended Mission

The Venus Express Extended Mission has the following strategic objectives:

- Improve and complete spatial and temporal observational coverage;
- Study in detail the phenomena discovered in the Nominal Mission;
- Take advantage of the new operation modes (case#2 “pendulum”, spot pointing etc)
- Perform pericentre lowering down to the altitude that still allows usual operations without entering aerobraking mode (~170-270 km);
- Perform necessary studies and tests preparing the spacecraft for future aerobraking campaign.

1.4 Applicable Documents

1.4.1 Higher-level documents

AD2: Venus Express Mission Definition Report, ESA-SCI(2001)6, SCI(2001) October 2001

AD3: VEX-RSSD-PL-005_D_2_SAP_implementation_plan

AD4: VEX-RSSD-TN-001_1_b_VEX_Science_Cases

AD5: VEX-RSSD-SP-001_2_0_VSOC_Design_Specification_and_Requirements

AD6: VEX-RSSD-SP-002_1_1_VEX_Science_Requirements_Document

AD7: VEX-RSSD-LI-004_2_0_VEX_science_themes

AD8: VEX-T.ASTR.-TCN-00665_3/0_Science_Cases_Definition_and_Study_Assumptions

AD9: VEX-T.ASTR-TCN-00932_3/0_Synthesis_of_Science_Cases_Analysis, May 29, 2006.

AD10: VEX-T.ASTR-UM-01098_1/1_ Flight User Manual

AD11: VEX-RSSD-TN-0003_1/0_Thermal constraints and science planning

AD12:VEX-RSSD-TN-0006_1/1_Proposal for the post-FAR thermal analysis of the science cases

AD13: Venus Express science cases thermal analyses report, Draft, December 2005.

1.4.2 Documents on the same level

TBD

1.4.3 Lower-level documents

TBD

1.5 Reference Documents

TBD

1.6 Abbreviations

Note: A complete list of all experiment abbreviations and mission phases is given in RD1.

S/C	Spacecraft
CVP	Commissioning and Verification Phase
FoV	Field of View

1.7 Definitions

2. SCIENCE OPERATIONS PLANNING

2.1 Overview

Ten types of orbital science operations (called "science cases") were designed and studied early in the mission planning. They are now used as building blocks to design the Science Activity Plan. In order to check the experiment inputs and to merge them into a consolidated timeline, the VSOC uses a planning concept and two computer based planning tools: MAPPS and EPS. The concept and the tools are described below.

2.2 Science Cases

Science Cases are typical scientific orbital operations to be used as building blocks in the SAP development. The following ten science cases were designed in the early phase of mission planning (AD4, AD8).

Case #1: Pericentre observations (spacecraft sizing case)

Case #2: Off-pericentre observations

Case #3: Apocentre VIRTIS mosaic

Case #4: VeRa bistatic sounding

Case #5: SPICAV stellar occultation

Case #6: SPICAV solar occultation

Case #7: Limb observations

Case #8: VeRa radio occultation

Case #9: VeRa solar corona studies

Case #10: VeRa gravity anomaly studies

The Astrium study of the science cases (AD9) proved their feasibility with some constraints related to the thermal aspects and having seasonal implications.

2.3 SAP planning concept

In order to develop the Science Activity Plan a step-wise approach will be used. A detailed description of the steps are given in the SAP implementation plan (AD3). Current SAP (section

2.3.4) does not impose any limitations on number of cases as soon as the operational constraints (thermal, power, pointing etc) are not violated.

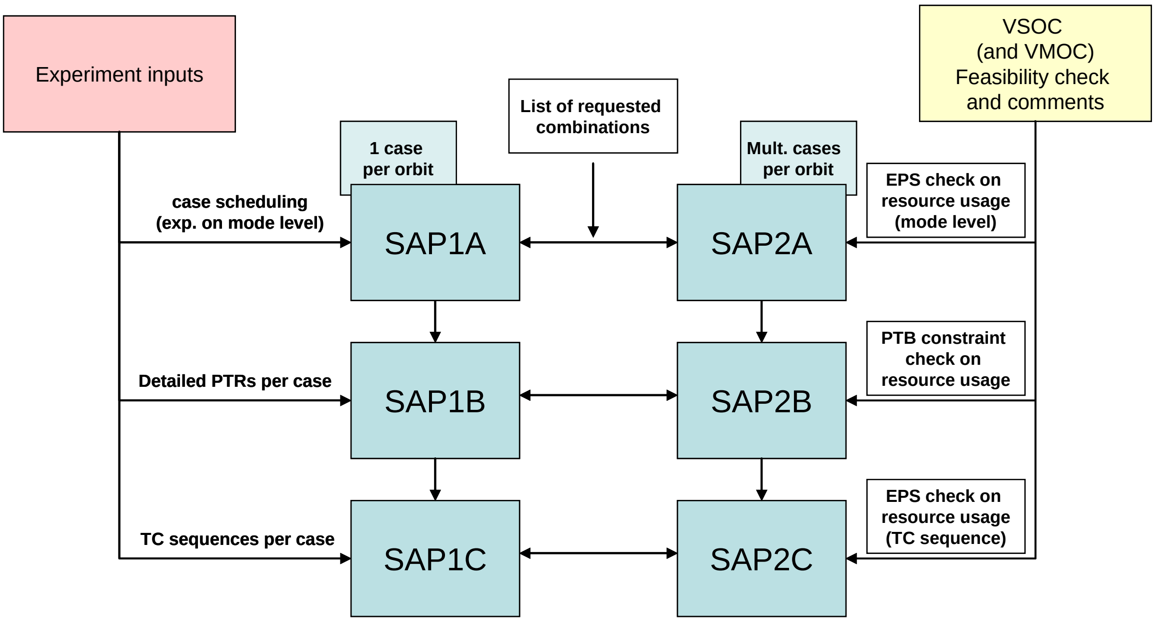


Figure 2.1 *SAP overview diagram*

2.4 MAPPS

MAPPS is a software package that will be used to analyze and plan the mapping of Venus. For Venus Express the EPS (see below) will be integrated within MAPPS. As a result MAPPS will also be able to make the necessary resource validation and conflict checking.

2.5 EPS

The Experiment Planning Software (EPS) is being used in the production of the Science Activity Plan. The particular functions of EPS used for this task are:

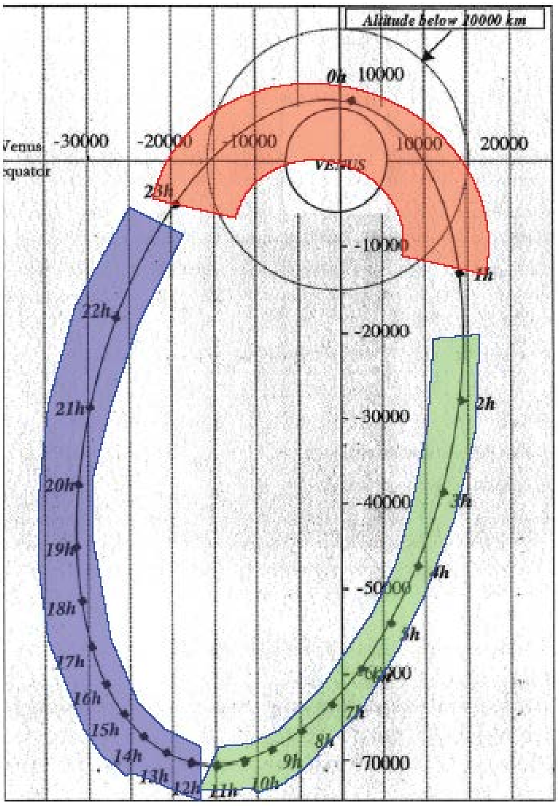
- Model and operate experiments on mode level (Experiment Description File, EDF)
- Consistency checks between the instrument timelines (ITL) on mode level
- Consistency check between the sequences and commands contained within the VMIB.
- Consistency checks between the instrument timelines (ITL) and the VMIB.

- ITL verification on mode level, EPS execution is prevented if ITL actions/transitions not consistent with mode.
- Modelling the resource allocation over the operational timeline.
- Output POR files for ingestion into VMOC MCS.

The use of EPS in planning is discussed in more detail in throughout this document. For more information on the capabilities of EPS refer to the user manual [AD xx].

2.6 Venus Express orbit and visibility of the ground stations

The Venus Express was inserted in a polar orbit with a period of 24 hours. The pericentre altitude was maintained between 250 km and 350 km during the first 8 months of the Extended Mission. In July-August, 2008 the pericenter was lowered to the corridor 170-270 km to allow plasma observations in this altitude range. This pericentre lowering does not require any changes in observations strategy or special spacecraft operations. The apocenter altitude is kept at about 66,000 km. In September 2009 the pericentre latitude reached the Northern pole.



The Venus Express orbit is divided in three parts (figure 2.2): two of them allocated for observations and the third one for telecommunications with the ground station.

***Figure 2.2** The Venus Express orbit and orbital phases: red- pericentre observations, blue off-pericentre observations in ascending branch, green – telecommunications with Cebreros.*

Communication with Earth takes place in each orbit after the pericentre passage, i.e. in the descending part of the orbit. The orbit period is tuned such that the communication window always falls in daytime at the primary ground station Cebreros. Figure 2.3 shows visibility of the

Cebreros station from the satellite. The lower of the upper two lines shows the end of telecommunication slot. Its duration does not exceed 10 hours even in case visibility of the planet is longer. The periods when the telecommunication phase ends early enough provide favorable conditions for the Case#3 apocentric mosaic since the observations can be carried out around pericentre.

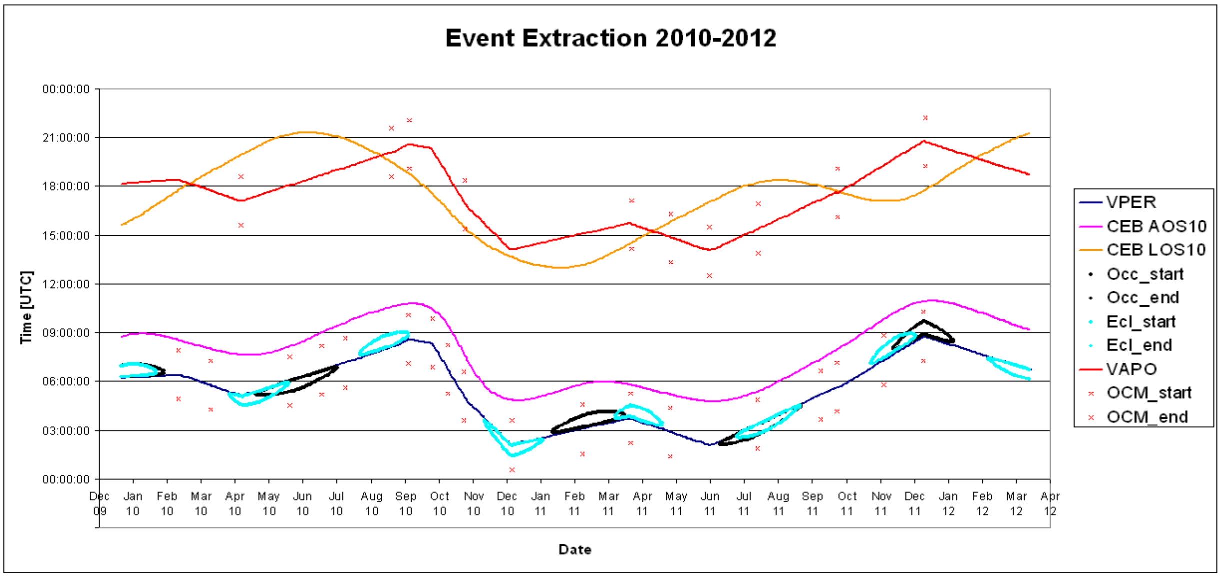


__Figure 2.3__ Visibility of the Cebreros ground station from the satellite.

The ground station at New Norcia, Australia, will be visible around pericentre and will be used for the radio science experiments. The DSN support to the VeRa bi-static radar, solar corona, and some radio occultations as well as the support for the data downlink in the periods of low data rate is agreed between ESA and NASA.

3. THE SAP-E-3 PART-2 PROPER

This section gives an overview of the Science Activity Plan for Extended Mission as a whole (chapter 3.1). It is followed by descriptions of payload activity during the period covering MTP#66-75 (May 2011 – February 2012). Depending on environmental conditions (occultation, illumination conditions etc.), the science will focus on different mission objectives.

3.1 Science Activity Plan overview

3.1.1 Coverage

The SAP-E-3 Part 2 (SAP for 3rd extension) will cover in detail the period from May 2011 till February 2012, or MTP range from #66 till #75.

3.1.2 Mission Objectives

The Venus Express mission aim is a global investigation of the Venus atmosphere, plasma environment and some important aspects of the surface. The detailed Science Objectives of the Venus Express mission are described in AD6.

3.1.3 Main principles of the SAP development

The SAP development was based on the following principles:

1. Complete and uniform coverage of the science themes;
2. Balance between distant and close-up views of the planet;
3. Balance between the observations of the Northern and Southern hemisphere;
4. Synergy between experiments in covering science objectives;
5. Use of multiple science cases in each orbit taking into account mission constraints (thermal, pointing, data volume etc);
6. Even distribution of pericentic science cases with priority given to the solar and Earth radio occultation experiments in specific seasons of the mission;
7. Maximum compliance with the current flight rules.

3.1.4 *Extended Mission overview*

Extended mission overview is given in the Annexe 1.

3.1.5 *Instruments objectives and Request Summary*

3.1.5.1 *Introduction*

In this section the individual objectives for each instrument are summarised and their over all operational requests are listed.

3.1.5.2 *ASPERA*

ASPERA shall be ON during the entire mission thus permanently collecting data. Strategically the ASPERA activity will consist of two parts: survey observations in the beginning of the mission and more specific, more detailed observations performed on selected part of orbit later in the mission. Data is collected at different rates depending on the selected mode.

3.1.5.3 *MAG*

MAG shall be ON during the entire mission and would permanently collect data. Data is collected at different rates depending on the selected mode.

3.1.5.4 *PFS*

PFS experiment was not operational during the nominal mission despite of several attempts to unblock the scanning mechanism.

3.1.5.5 *SPICAV*

Environment dependent. The main goal of the SPICAV experiment is to sound the Venus atmosphere in solar and stellar occultation geometry with sufficient latitude and local time coverage. In these cases SPICAV will define the spacecraft pointing profile. SPICAV stellar occultation that require +Z axis pointing to a star at the limb will be combined with the observations of other +Z looking instruments. In case of stellar occultation observations of dark limb are preferable.

Environment independent. (1). Nadir observations by SPICAV will be performed together with other +Z looking experiments. (2). SPICAV will observe the Venus hydrogen corona. For this purpose in apocentre the s/c will perform a 90 degrees slew from nadir pointing and back.

3.1.5.6 VeRA

The VeRa experiment will perform 4 kinds of *"environment dependent"* observations.

(1) Earth occultation with as good as possible latitude and local time coverage of Venus. Attitude profile in this experiment is the most demanding for the spacecraft AOCS system. It will be provided by the VeRa PI for each radio-occultation individually and will define the pointing for the other experiments. It would be highly desirable to select the orientation of the spacecraft +Z axis during radio occultation so that the +Z looking instruments could simultaneously see the planet.

(2). Bi-static sounding of surface targets. These observations are abandoned since autumn 2007 due to power loss in the S-band.

(3). Solar Corona observations. These observations are abandoned since autumn 2007 due to power loss in the S-band.

(4). Gravity anomaly. This investigation consists of precise tracking of the spacecraft while it passes over global geological formations on Venus solid body. It will be carried out twice during the nominal mission.

The VeRa experiment is mainly performed using the ESA New Norcia station. Support from the DSN antennae for the VeRa experiments as well as for the data downlink is agreed between ESA and NASA.

3.1.5.7 VIRTIS

Environment independent. VIRTIS goal is to provide spectral mapping of Venus with moderate spectral resolution and high spectral resolution observations preferably imbedded in the spectral maps. The off-pericentre and apocentre observations will be organized in special VIRTIS campaigns. They will consist of similar sessions performed on several (about 5) consecutive orbits and would allow continuous temporal coverage of atmospheric dynamical phenomena. In these periods VIRTIS will define VEX operations (e.g. pointing). VIRTIS specific pointing request concerns the apocentric observations in which the experiment will take twelve images organised in a raster of 3x3 images of the whole Venus disc. That would require 12 spacecraft re-pointings by an angle of < 5 deg. These mosaics campaign will be performed in specific seasons of the mission when the telecoms with Cebreros station end relatively early (figure 2.4)

Environment dependent. VIRTIS will provide spectral mapping of specific surface targets in order to search for traces of volcanic activity, provide thermal mapping of geologically interesting regions. This type of activity is possible on the night side only.

3.1.5.8 VMC

Environment independent. The task of VMC is to perform wide-angle imaging of Venus in 4 narrow spectral channels. VMC has no specific pointing requirements.

Environment dependent. VMC will provide imaging of specific surface targets in order to provide thermal maps of geologically interesting regions. This type of activity is possible when the spacecraft is in eclipse.

3.2 MTP #66

3.2.1 MTP in brief

MTP #66 covers the period from May 1 till May 28, 2011 and orbits #1836 -1863. This MTP includes neither Earth occultation nor eclipse season. Illumination conditions are similar to those in MTP #58. The MTP is hot. The data rate is low. Local time at ascending node changes from 15h to 18h. The last 7 orbits belong to the Drag Campaign #5. Pericentre altitude is shown in Annex #2. Figures 3.1 and 3.2 show observations timeline and planet coverage by orbital tracks.

3.2.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 15-18 h (similar to MTP#58)
- Hot season
- Drag campaign #5: orbits 1858-1863 with DSN (see Annex #2 for pericentre altitude)
- Downlink is low

3.2.3 Specific observations and MTP#66 timeline

Table 3.1 summarizes specific observation requests from the experiments.

Table 3.1 *Specific observation requests in MTP #66*

	Apocentre & ascending arc		Pericentre pass	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	SPICAV-SPICAM observations in the beginning of MTP.		1. Nadir obs along terminator at the end of MTP – SO_2 chemistry. 2.Day side tangential limb in the second half of MTP.	1. Stellar occultations 2.Day side tangential limb in the second half of MTP.
VeRa				
VEXADE			Drag Campaign #5 #1858-1863 (DSN) [3)]	
VIRTIS	Day latitude track Full mosaic		VIR-H meridional [2)] Day spectroscopy	VIR-H meridional [2)] Night limb tracking

	Terminator orbit campaign [1]			
VMC	Day side monitoring Terminator orbit campaign [1]	Case #2 with off-set to day side	Latitude day tracking (evening) Day limb tracking Surface out of eclipse	Latitude day tracking (morning) Surface out of eclipse
ASPERA				
MAG				

Notes to the table:

1) Terminator orbit campaign: as long as possible imaging of the Southern polar region with minimized duration of CEB pass in several orbits around the terminator orbit (end of MTP#66). In each particular orbit the observations are performed from +3h till -3h.

2) VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Repeated twice per MTP in orbits 1837 and 1850.

3) The first part of the Drag Campaign #5 is scheduled for orbits #1858-1863. The spacecraft will be tracked from -2h till +2 h by 70m DSN station.

The proposed timeline consists of alternation of four types of orbits:

- Type #1: cases 2-1-P-1 (VIR-H meridional cross section in orbits #1837 and 1850)
- Type #2: cases 2-1-P-7
- Type #3: cases 2-1-P-5
- Type #4: cases 3-2-P (terminator orbit campaign including VIRTIS full mosaic in the last 3 orbits of the MTP). This period coincides with the drag campaign #5.

The pointing for cases #5 and #7 after pericenter is likely hot. It should be combined with hot case 2 by alternating between normal and shifted pendulum.

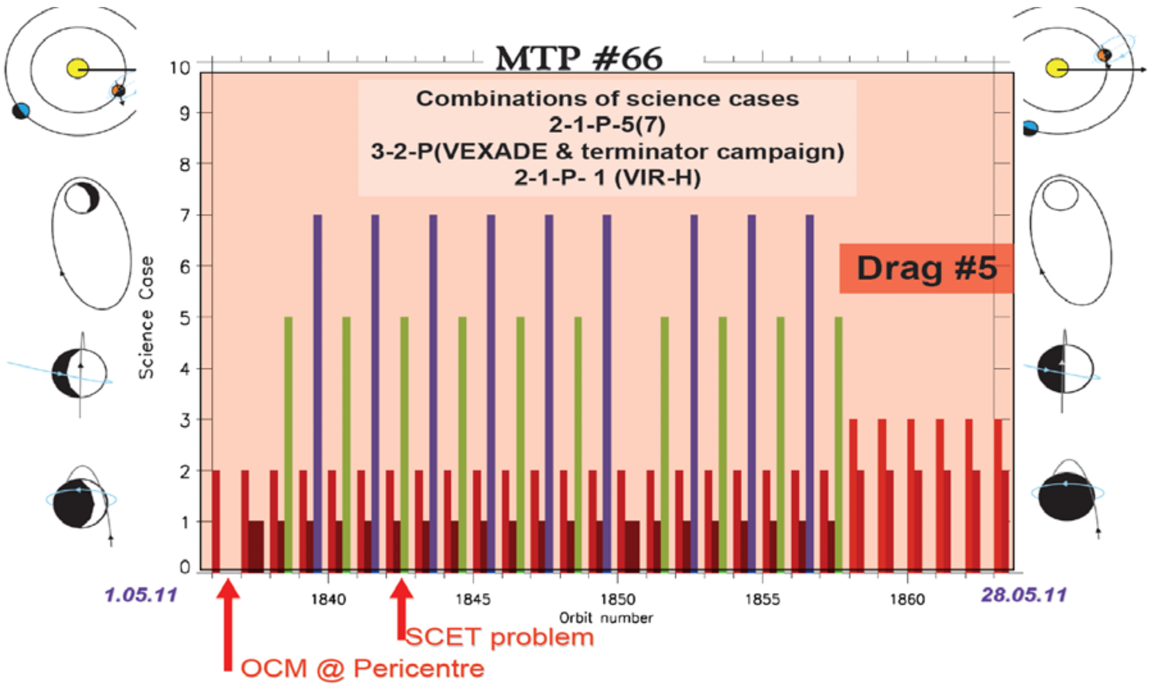


Figure 3.1 *MTP#66 timeline.*

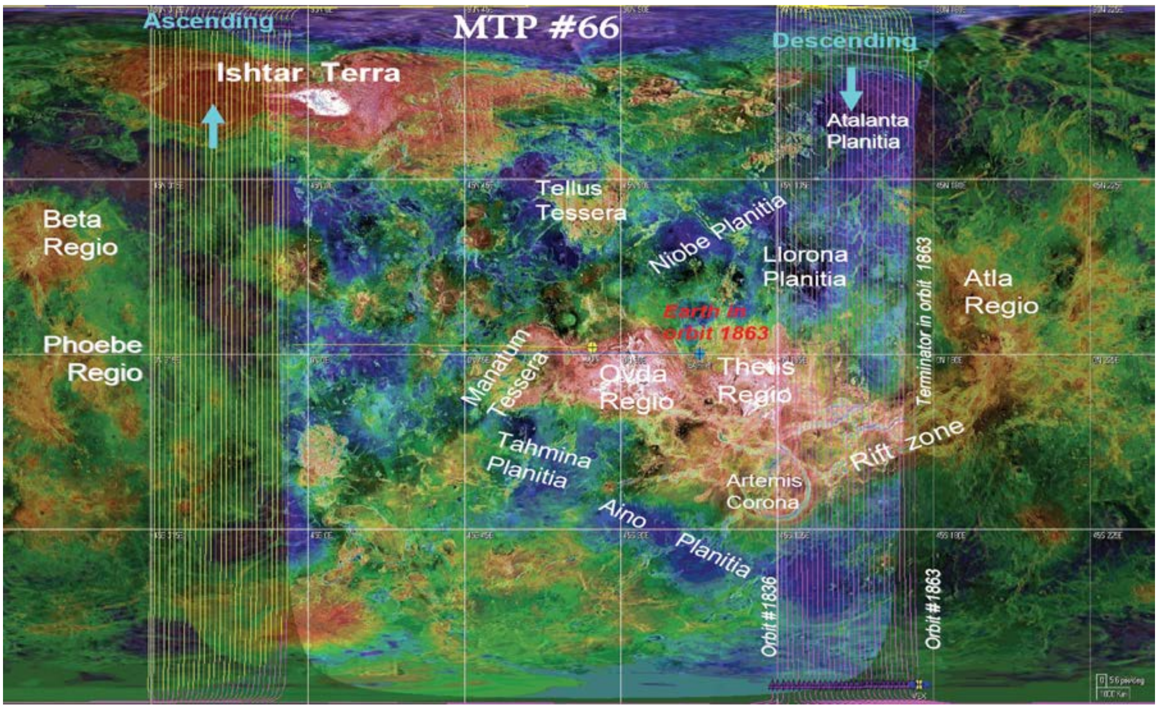


Figure 3.2 *Planet coverage by orbital tracks in MTP#66. Position of terminator, Earth and Sun correspond to the last orbit of MTP.*

3.3 MTP #67

3.3.1 MTP in brief

MTP #67 covers the period from May 29 till June 25, 2011 and includes orbits #1864-1891. Local time at ascending node changes from 18h to 21h that makes illumination conditions similar to those in MTP #59. The MTP is cold. The MTP begins with 6 orbits of Drag Campaign #5 (#1864-1869) by NNO station with pericentre as low as 165 km. In these orbits the pericenter arc (from -2h to +2h) will be devoted to the spacecraft tracking and no observations in this period will be allowed. Right after the drag campaign #5 the pericentre altitude will be raised to 290 km.

The second part of the MTP starting with orbit 1880 contains the beginning of the Earth occultation season #11 with occultation occurring before pericentre. For the first time in the mission “asymmetric” Earth occultation strategy will be implemented. Geometry of the Venus Express orbit is such that latitude of ingress occultation in the Southern hemisphere changes with orbit much faster than for egress occultations in the North. So some of egress occultations can be skipped without significant degradation of the latitude coverage. This would allow other experiments to make observations in pericentre. Annex 4 gives the local time and latitude coverage in solar occultation experiment. The data rate is low. Low downlink can create problems in terminator orbit campaign when CEB passes will be shortened or skipped.

Figures 3.4 and 3.5 show observations timeline and planet coverage by orbital tracks.

3.3.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 18-21 h (similar to MTP #59)
- Drag Campaign #5 in orbits #1864-1869 with pericentre altitude of 165 km
- Earth occ season #11 starting from orbit #1880
- Cold season
- Downlink is low to very low.

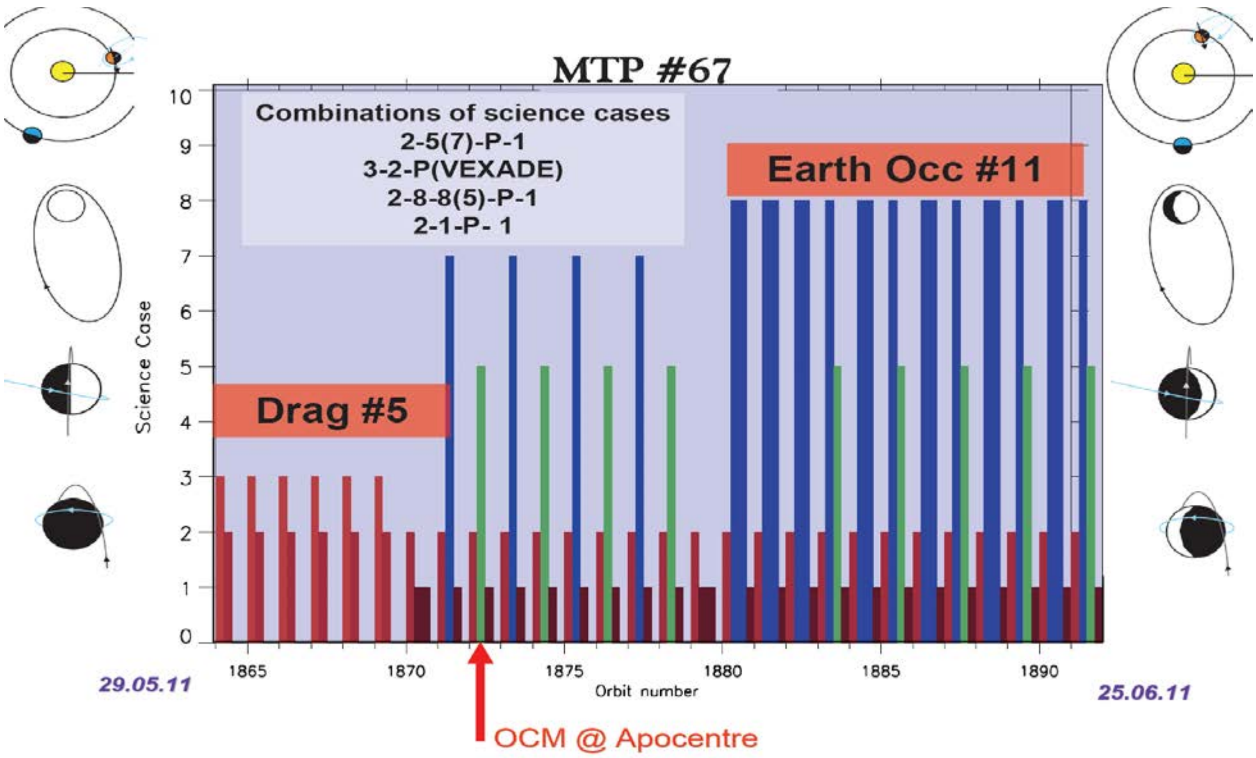


Figure 3.4 *MTP#67 timeline.*

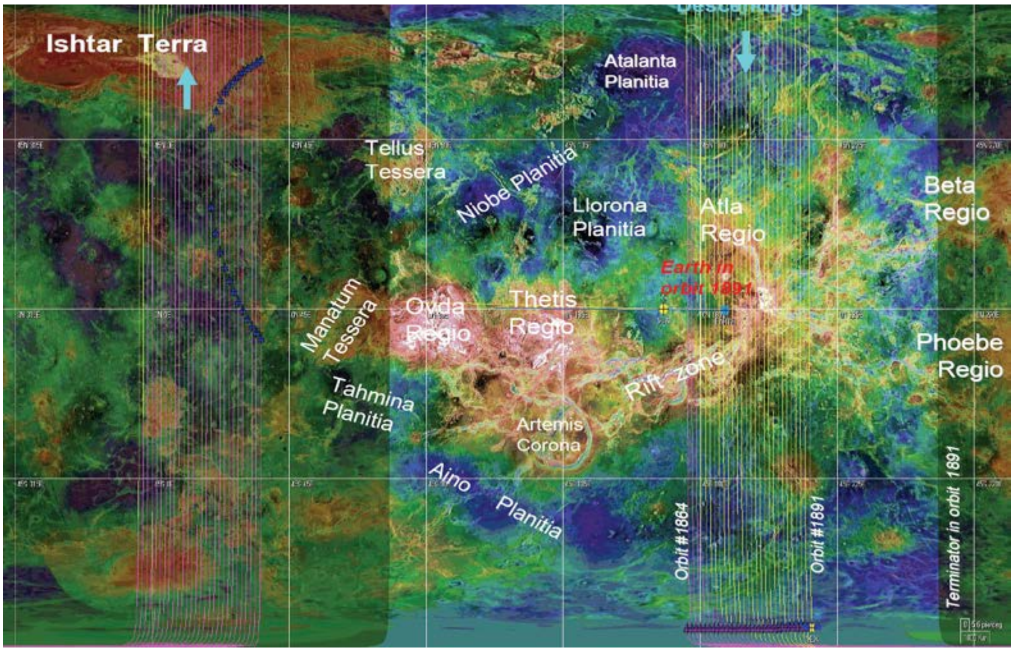


Figure 3.5 *Planet coverage by orbital tracks in MTP#67. Position of terminator, Earth and Sun correspond to the last orbit of MTP.*

3.3.3 Specific observations and MTP#67 timeline

Table 3.2 summarizes specific observation requests from the experiments.

Table 3.2 *Specific observation requests in MTP #67*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	SOIR calibration [1]	Stellar occs	In the beginning of MTP nadir obs along terminator at the end of MTP – SO_2 chemistry.	1. Aeronomic emissions[2] 2.Day-side nadir after pericenter in the second half of MTP
VeRa				
VEXADE		Drag campaign #5 [5]		
VIRTIS	Day side campaign Tracking along terminator 2 full mosaics Night side obs		VIR-H meridional [3]	VIR-H meridional [3] Night limb tracking
VMC	Case#2 Terminator orbit campaign [4]	Case #2 with off-set to day side	Latitude day tracking (evening) Surface out of eclipse	Day latitude tracking (morning) Day limb
ASPERA				
MAG				

Notes to the table:

[1] SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

[2] Aeronomic day side emissions: Day limb in specific orientation with Sun on +X. Request shall be agreed by VSOC and VIRTIS.

[3] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Repeated twice per MTP usually with a step of 14 orbits. However, in MTP#67 the first meridional cross-section is shifted to orbit #1870 due to Drag Campaign.

[4] Terminator orbit campaign (case #3): as long as possible imaging of the Southern polar region with minimized duration of CEB pass in several orbits around the terminator orbit (beginning of

MTP#67). In each particular orbit the observations are performed from +3h till -3h. Can be combined with VIRTIS tracking along terminator. In the particular case of MTP#67 there can be a potential conflict with too low downlink since terminator campaign requires shortening or cancelling Cebreros passes.

5) Drag Campaign #4 in orbits #1864-1869: Spacecraft tracking from -2h till +2 h will be provided by NNO station.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 2-1-P-1 (VIR-H meridional cross section in orbits #1870 and 1879). The first orbit is moved to 1870 because of drag campaign in the beginning of the MTP.
- Type #2: cases 3-2-P (terminator orbit campaign including VIRTIS full mosaic in the first 6 orbits of the MTP). These orbits coincide with Drag campaign #5.
- Type #3: cases 2-5-P-1 or 2-7-P-1
- Type #4: cases 2-8-8-P-1

Note that case #3 in terminator orbit campaigns is different from the earlier defined case #3 as VIRTIS mosaic. In this case it looks more like extended case #2. Conditions for implementation of cases #5 and #7 on the night-side before pericenter in the first 10 orbits of MTP are not favourable because of proximity of bright limb. Also night-side nadir observations before pericenter during entire MTP are not favourable because of proximity of bright limb. In the second half of the MTP cases #5 and #7 are very interesting but pointing is likely hot and should be combined with other hot pointing.

3.4 MTP #68

3.4.1 MTP in brief

MTP #68 covers the period from June 26 till July 23, 2011 and orbits #1892-1919. The MTP includes both Earth occultation season #11 till orbit #1907 and eclipse season #18 that starts in orbit 1895. Both occultation occur before pericentre. Annex 4 gives local time and latitude coverage in solar occultation experiment. The last orbit with radio-occultation will be #1907. After that the experiment will not be performed due to perturbations from the solar corona. Since in this MTP Venus, Earth and Sun will be approximately on one line, radio and solar occultations will sound approximately the same regions on Venus. This creates a rare opportunity of co-located sounding by both experiments.

The MTP is characterised by very low data rate due to proximity to superior conjunction. Local time at ascending node changes from 21h to 24h that makes illumination conditions similar to those of MTP#60. Night surface observations in eclipse at ascending branch cover eastern part of Aphrodite Terra (Manatum Tessera) and Tellus tessera. Figures 3.7 and 3.8 show observations timeline and planet coverage by orbital tracks in MTP# 68.

3.4.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 21-24 h (similar to MTP#60)
- Eclipse season #18 starts in orbit 1895
- Radio occultations till orbit #1907
- Rare opportunity for co-located sounding by VeRa and SOIR
- Surface targets: Ovda Regio, Manatum and Tellus tessera.
- Cold period
- Downlink is very low

3.4.3 Specific observations and MTP#68 timeline

Table 3.3 summarizes specific observation requests from the experiments.

Table 3.3 *Specific observation requests in MTP #68*

	Apocentre & ascending arc		Pericentre pass	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV/ SOIR	1.SOIR calibration [1)] 2. SPICAV-SPICAM observations	Stellar occs	1. Solar occs 2. Zodiacal light	1. Exospheric limb [3)] 2. Polarization calibration
VeRa			OCC season #11 till orbit 1907	
VEXADE				
VIRTIS	Day latitude track		VIR-H meridional [2)] VIR-H limb scans [4)] VIR-M spectra VIR-M night limb (every 5-th orbit)	VIR-H meridional [2)] VIR-M day spectra VIR-M night limb (every 5-th orbit)
VMC	Days side monitoring		Surface in eclipse Limb in eclipse	Day latitude tracking till +2h (delayed CEB pass) Phase function Day limb
ASPERA				
MAG				

Notes to the table:

[1)] SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

[2)] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Repeated twice per MTP in orbits #1892 and #1906.

[3)] In-plane exospheric limb observations after pericenter, to be combined with ingress case 6 in every 4-5 orbit.

[4)] VIRTIS-H limb scans using 1). inertial pointing or 2). slow slew with star tracker data for aposteriori attitude reconstruction or 3). “limb track” mode for several attitudes in sequence.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 2-1-P-1 (VIR-H meridional cross section in orbits #1892 and 1906)
- Type #2: cases 2-6-6-P-1 or 2-6-6-P-7 (first 6 orbits of eclipse season when eclipses occur in low latitudes and eclipse is short)

  Type #3: cases 2-6-5-6-P-1 or 2-6-1-6-P-1 (when eclipse moves to high latitudes and its duration is >15 min)
- Type #4 (VeRa orbits): cases 2-8-8-P-1

Notes to the proposed timeline.

1. Case #1 after Pericentre shall be extended till about +2h to allow day side observations at good illumination conditions. This causes delay of CEB pass that reduces already very low downlink volume.
2. Limb track is not favourable in the second part of MTP because of OCM.
3. Case 5 is very interesting during entire MTP. It should be alternated with case 6 in the end of MTP when the latitude at egress from eclipse does not vary rapidly anymore.
4. Case 5 on the ascending branch should be combined with case 2 in each 2-d orbit.
5. In-plane exospheric limb observations after pericenter should be combined with ingress case 6 in every 4-5 orbits.
6. Cross Polarization calibration for SPICAV, means high exposure on –Z (see MTP 17 and 53) at the end of MTP.
7. Opportunity for Zodiacal Light Observation during Eclipse (see MTP 53) at the end of MTP

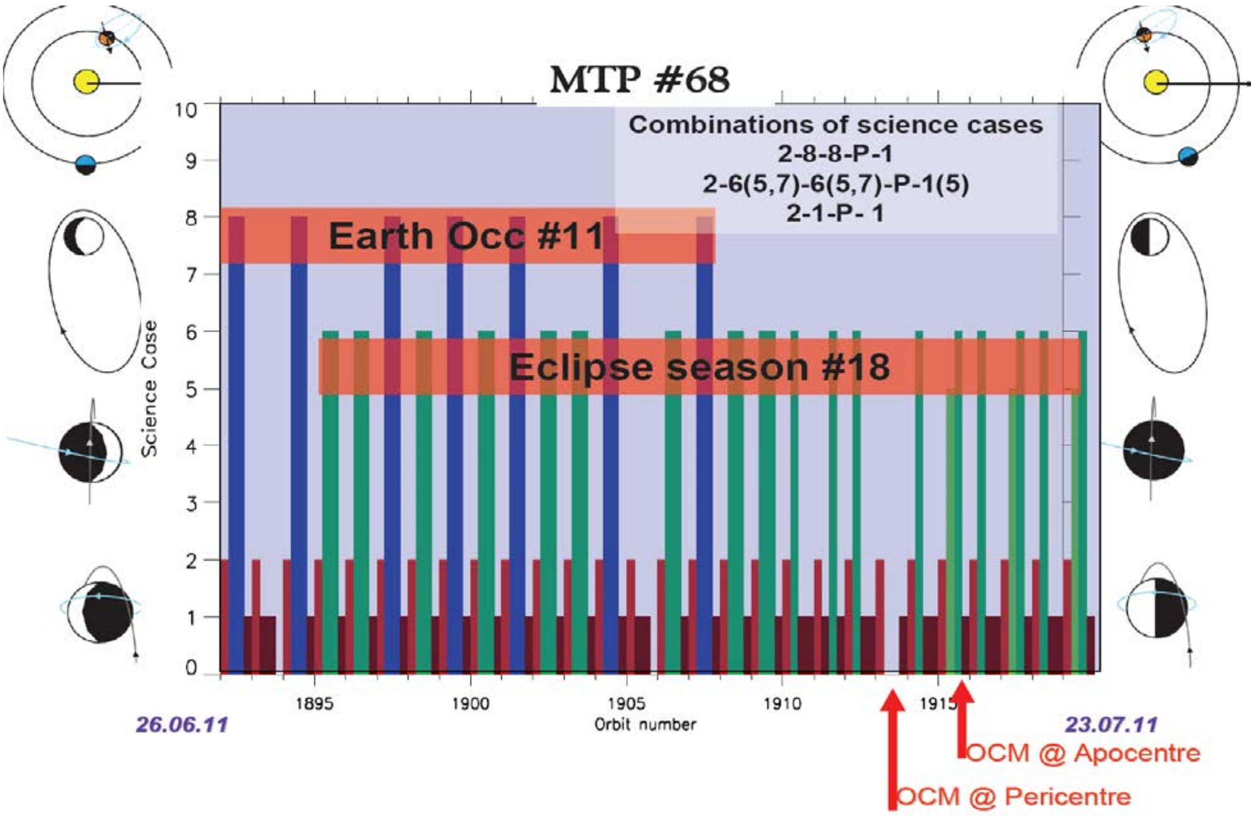


Figure 3.7 *MTP#68 timeline.*

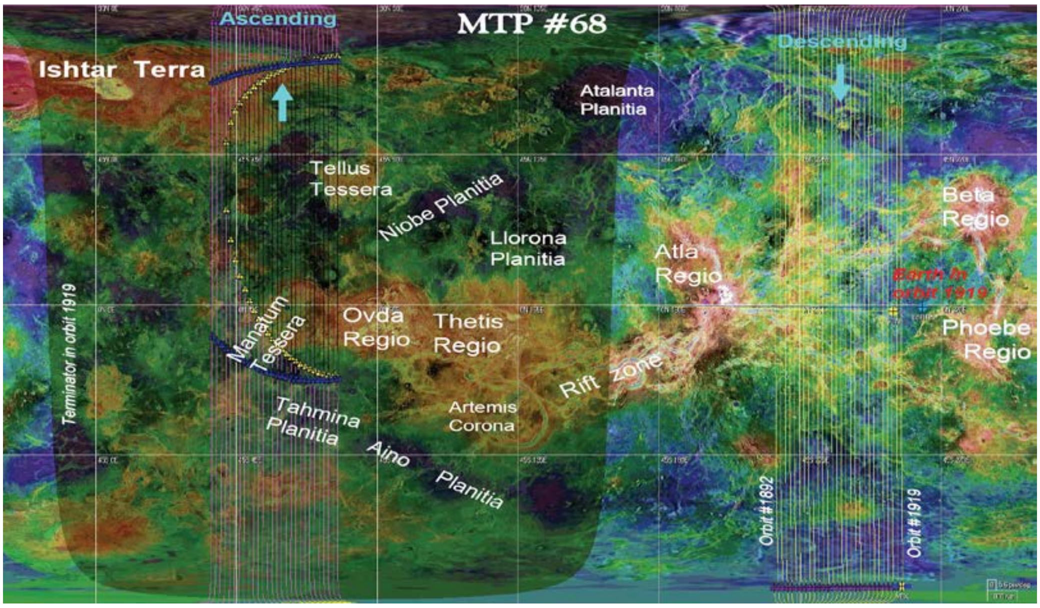


Figure 3.8 *Planet coverage by orbital tracks in MTP#68. Position of terminator, Earth and Sun correspond to the last orbit of MTP.*

3.5 MTP #69

3.5.1 MTP in brief

MTP #69 covers the period from July 24 till August 20, 2011 and includes orbits #1920-1947. The MTP contains both eclipse season #18 and Earth occultation season #11. However, due to proximity to solar conjunction and perturbations from the solar corona, the radio-occultation experiment will not be carried out in this MTP. Annex 4 gives the local time and latitude coverage in the solar occultation experiment. Starting with orbit #1933 there will be no science observations due to superior conjunction outage. The MTP is cold and has very low data rate. Local time at ascending node changes from 0h to 3h, thus illumination conditions are similar to those in MTP#61 and on the descending arc will be ideal to study the day side. It is preferred to extend observations till about +2:00 by delaying CEB pass. Night surface observations in eclipse at ascending branch cover Ovda Regio, Niobe Planitia and Tellus tessera. Figures 3.10 and 3.11 show observations timeline and surface coverage in MTP#69.

3.5.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 0-3 h (similar to MTP#61)
- Cold season
- Eclipse season #18
- Earth occultation season #11, but no VeRa experiment
- Surface targets: Thesis Regio, Niobe Planitia, Tellus tessera.
- Very low data rate

3.5.3 Specific observations and MTP#69 timeline

Table 3.4 summarizes specific observation requests from the experiments.

Table 3.4 *Specific observation requests in MTP #69*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	1. SOIR calibration[1)] 2. SPICAV-SPICAM observations	Stellar occs	1. Solar occs 2. NO emission mapping in nadir (every 2-d orbit) 3. Zodiacal light observations in the beginning (as in MTP 53)	1. Exospheric limb [3)] every 4-5 orbits 2.Polarization calibration
VeRa			Earth occultation season #11	
VEXADE				
VIRTIS	Day latitude track		VIR-H meridional [2)] VIR-H limb scans [4)] VIR-M spectra	VIR-H meridional [2)] VIR-M day spectra
VMC			Surface in eclipse Limb in eclipse	Day latitude tracking till +2h (delayed CEB pass) Phase function Day limb
ASPERA				
MAG				

Notes to the table:

[1)] SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

[2)] VIRTIS-H meridional cross-section in orbits 1920 and 1933: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Repeated twice per MTP: in orbits 1920 and 1933.

[3)] In-plane exospheric limb observations after pericenter, to be combined with ingress case 6 in every 4-5 orbit.

[4)] VIRTIS-H limb scans using 1). inertial pointing or 2). slow slew with star tracker data for aposteriori attitude reconstruction or 3). "limb track" mode for several attitudes in sequence.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 2-1-P-1 (VIR-H meridional cross section in orbits #1920 and 1933)
- Type #2: cases 2-5-6-P-1 or 2-1-6-P-1
- Type #4 (limb orbits): cases 2-6-7-P-7

Type #5: cases 2-1-P-7 or 2-5-P-7 (in quadrature when hot observations are not allowed)

Notes to the proposed timeline.

1. Case #1 after pericentre shall be extended till +2h that causes delay of CEB pass.
2. Exospheric limb to be combined with ingress case #6.

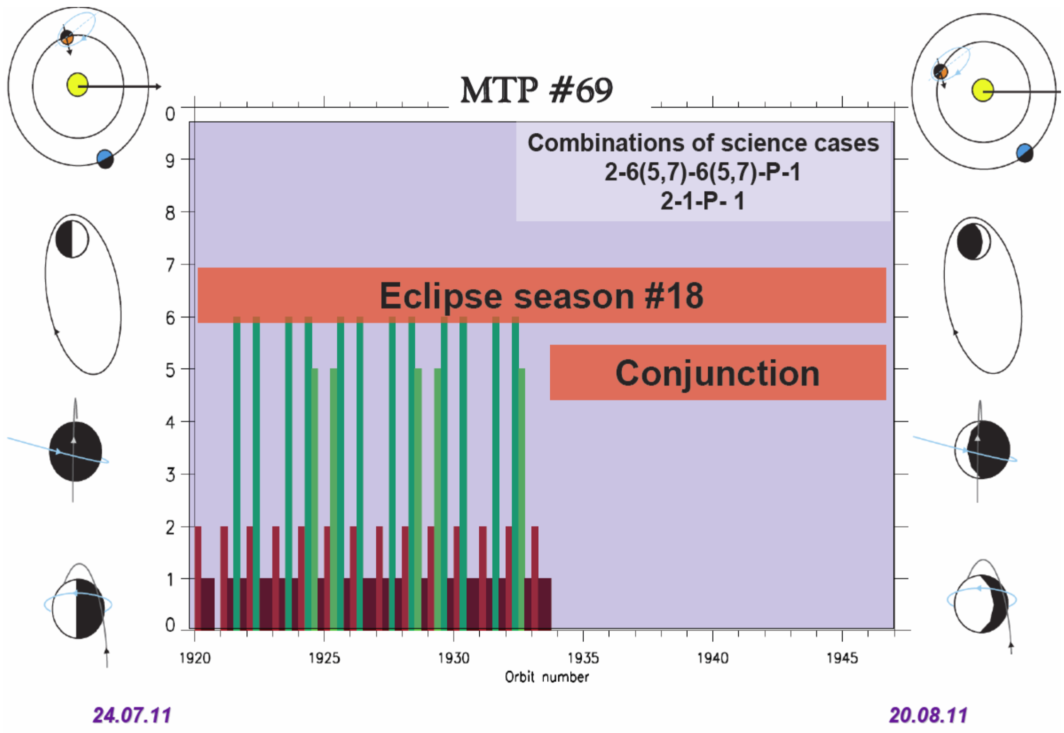


Figure 3.10 *MTP#69 timeline.*

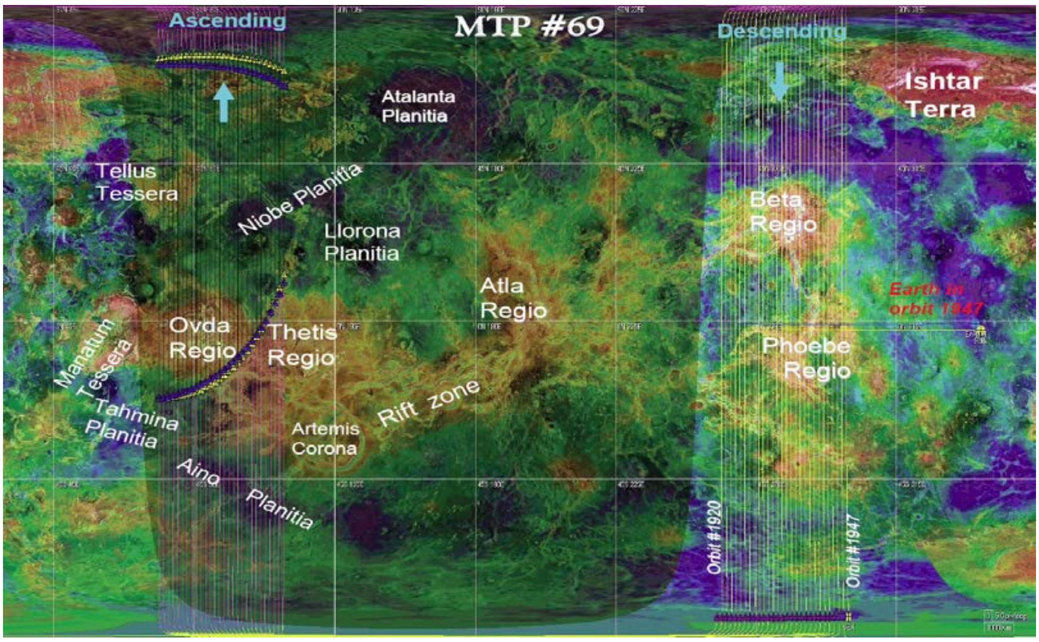


Figure 3.11 *Planet coverage by orbital tracks in MTP#69. Positions of terminator, Earth and Sun correspond to the last orbit of MTP.*

3.6 MTP #70

3.6.1 MTP in brief

MTP #70 covers the period from August 21 till September 17, 2011 and orbits #1948-1975. Science operations will be resumed after the superior conjunction outage in orbit #1954. The MTP is cold. Local time at ascending note changes from 3h to 6h that make illumination conditions similar to MTP #62. Data rate is very low. Figures 3.13 and 3.14 show observations timeline and planet coverage by orbital tracks.

3.6.2 Environmental conditions

- Observations resume in orbit #1954
- Drag campaign #6 in orbits 1971-1975
- Local Time at Ascending Node (LTAN): 3h-6h (similarity to MTP 62)
- Cold season
- Very low data rate

3.6.3 Specific observations and MTP#70 timeline

Table 3.5 summarizes specific observation requests from the experiments.

***Table 3.5** Specific observation requests in MTP #70*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	SOIR calibration [1)] SPICAV-SPICAM observations	Stellar occs	SO_2 obs nadir at terminator in the end of MTP	SO_2 obs nadir at terminator in the end of MTP
VeRa				
VEXADE			Drag #6 campaign in orbits #1971-1975	
VIRTIS	Day latitude track		VIR-H meridional [2)] VIR-H limb scans [3)]	VIR-H meridional [2)] VIR-M day spectra
VMC	Day side monitoring Terminator orbit campaign in the end of MTP [4)]		Morning sector	Day latitude tracking Evening sector
ASPERA				

MAG				

Notes to the table:

1) SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

2) VIRTIS-H meridional cross-section in orbits 1955 and 1970: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Repeated twice per MTP: at the 1-st and 15-th orbits.

3) VIRTIS-H limb scans using 1). inertial pointing or 2). slow slew with star tracker data for aposteriori attitude reconstruction or 3). “limb track” mode for several attitudes in sequence.

4) Terminator orbit campaign: as long as possible imaging of the Southern polar region with minimized duration of CEB pass in several orbits around the terminator orbit. In each particular orbit the observations are performed from +3h till -3h. The observation is cold.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 2-1(5, 7)-P-1(7) (including VIRTIS-H in orbits 1955 and 1970)
- Type #2: cases 3-2-P (Terminator orbit campaign +VEXADE in pericentre)

Notes to the proposed timeline.

1. Case #3 in terminator orbit campaign is different from the earlier defined case #3 as VIRTIS mosaic. Here it looks more like extended case #2.

2. Cases 5 and 7 before pericenter are likely hot and should be combined with other hot cases.

3. Cases 5 and 7 before pericenter in last 10 orbits of MTP are not favourable because of proximity of bright limb.

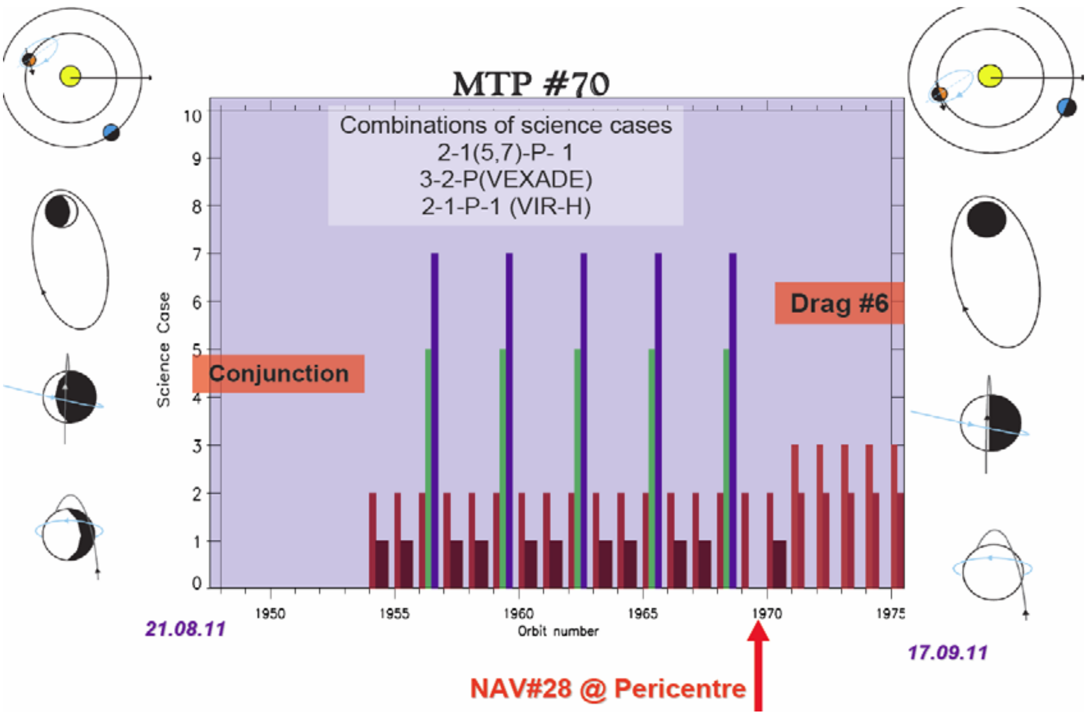


Figure 3.13 *MTP#70 timeline.*

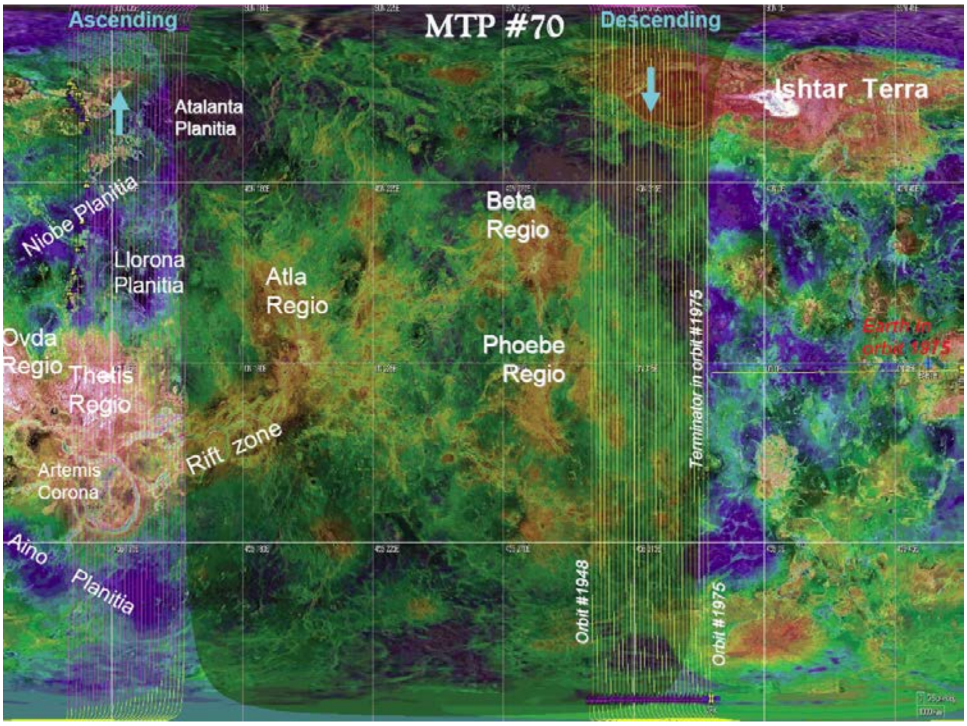


Figure 3.14 *Planet coverage by orbital tracks in MTP#70. Positions of terminator, Earth and Sun correspond to the last orbit of the MTP.*

3.7 MTP #71

3.7.1 MTP in brief

MTP #71 covers the period from 18.09 till 15.10.2011 and orbits #1976-2003. The MTP has no peculiarities except for that it begins with seven orbits of Drag campaign #6 (1976-1982). The MTP is hot and has low data rate. Local time at ascending note changes from 6h to 9h that makes illumination conditions similar to MTP#63. Figures 3.16 and 3.17 show observations timeline and planet coverage by orbital tracks.

3.7.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 6 - 9 h (similarity to MTP #63)
- Hot MTP
- Continuation of the Drag Campaign #6 in the beginning of the MTP (1976-1982)
- Terminator orbit campaign in the beginning of the MTP combined with drag campaign
- Downlink is low

3.7.3 Specific observations and MTP#71 timeline

Table 3.15 summarizes specific observation requests from the experiments.

Table 3.15 *Specific observation requests in MTP #71*

	Apocentre & ascending arc		Pericentre pass	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	SOIR calibration [1)] SPICAV-SPICAM [5)]	Stellar occs	SO_2 obs in nadir at terminator in the beginning of MTP	
VeRa				
VEXADE			Drag campaign #7 in orbits 1976-1982	
VIRTIS	Day latitude track Night obs Terminator orbit		VIR-H meridional [2)] VIR-H limb scans [3)]	VIR-H meridional [2)] VIR-M day spectra

	campaign in the beginning of MTP [4]			
VMC	Case#2 Terminator orbit campaign in the beginning of MTP [4]		Morning sector Day latitude tracking	Evening sector
ASPERA				
MAG				

Notes to the table:

[1] SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

[2] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Executed in orbits 1984 and 1994.

[3] VIRTIS-H limb scans using 1). inertial pointing or 2). slow slew with star tracker data for aposteriori attitude reconstruction or 3). “limb track” mode for several attitudes in sequence.

[4] Terminator orbit campaign: as long as possible imaging of the Southern polar region with minimized duration of CEB pass in several orbits around the terminator orbit. In each particular orbit the observations are performed from +3h till -3h. The observation is cold.

[5] Joint SPICAV-SPICAM observations of hydrogen distribution in solar corona. Perform in every 5-th orbit. Can be embedded in case#2.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 3-2-P (drag campaign #7 and terminator campaign)
- Type#2: cases 2-1-P-1
- Type#3: cases 2-7-P-5

Notes to the proposed timeline.

1. Case #3 in terminator orbit campaign is different from the earlier defined case #3 as VIRTIS mosaic. In this case it looks more like extended case #2.
2. Limb track is not favourable during the first half of MTP because of OCM
3. Cases #5 and #7 (night-side, after pericenter) in first 10 orbits of MTP not favourable because of proximity of bright limb.

4. Cases #5 and #7 in the second half of MTP should be combined with hot case #2 (possibility to alternate between normal and shifted pendulum)
5. Night-side nadir after pericentre during entire MTP is not favourable because of proximity of bright limb.

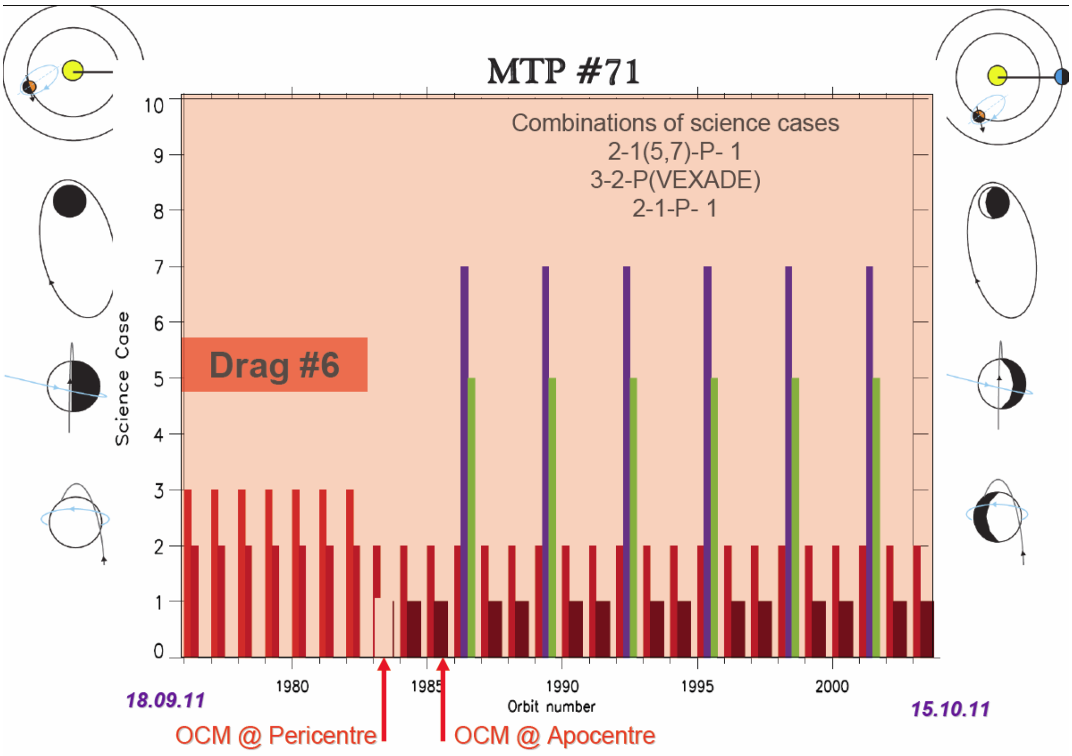


Figure 3.16 *MTP#71 timeline.*

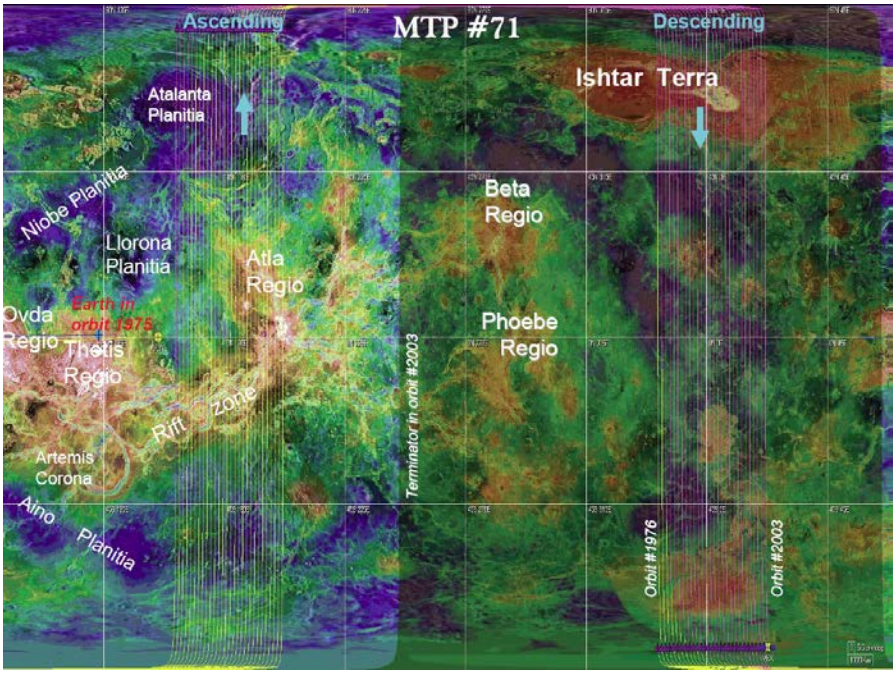


Figure 3.17 *Planet coverage by orbital tracks in MTP#71. Positions of terminator, Earth and Sun correspond to the last orbit of the MTP.*

3.8 MTP #72

3.8.1 MTP in brief

MTP #72 covers the period 16.10 till 12.11.2011 and orbits #2004-2031. Eclipse season #19 starts in orbit 2013 with eclipses occurring after pericenter. The MTP is hot. Local time at ascending note changes from 9h to 12h that makes illumination conditions similar to MTP#64. Figures 3.19 and 3.20 show observations timeline and planet coverage by orbital tracks. Night surface observations in eclipse in descending branch cover Manatum Tessera and low lands North from it. Tahmina Planitia can be observed by pointing the s/c slightly forward at egress.

3.8.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 9-12 h (similarity to MTP #64)
- Solar occultation season #19 starts in orbit 2013
- Surface targets: Manatum Tessera, Tahmina Planitia

- Hot period
- Downlink from moderate to low

3.8.3 Specific observations and MTP#72 timeline

Table 3.16 summarizes specific observation requests from the experiments.

Table 3.16 *Specific observation requests in MTP #72*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	1.SOIR calibration [1] 2. Cross polarisation calibration 3. SPICAV-SPICAM[4]	Stellar occs		1. Solar occs 2. Zodiacal light obs at the end of MTP
VeRa				
VEXADE				
VIRTIS	Day latitude track Night obs		VIR-H meridional [2] VIR-H limb scans [3] VIR-M day spectra	VIR-H meridional [2]
VMC	Day side monitoring		Day latitude tracking Phase function Mosaic	Surface obs
ASPERA				
MAG				

Notes:

[1] SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

[2] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Performed in orbits 2005 and 2019.

[3] VIRTIS-H limb scans using 1). inertial pointing or 2). slow slew with star tracker data for aposteriori attitude reconstruction or 3). "limb track" mode for several attitudes in sequence.

[4] Joint SPICAV-SPICAM observations of hydrogen distribution in solar corona. Perform in every 5-th orbit. Can be embedded in case#2.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 2-6(1,7)-6(5,7)-P-1
- Type #2 : cases 2-7-P-5
- Type#3: cases 2-1-P-1 (VIRTIS-H)

Notes to the proposed timeline.

1. In ascending branch the pendulum version of case#2 shall be used.
2. Limb track not favourable in first half of MTP because of OCM
3. Case 5 preferably every orbit near beginning of MTP (night, after pericenter)
4. Case 5 on the descending branch, every ~2-d orbit, to be combined with case 2
5. In-plane exospheric limb observations before pericenter, to be combined with ingress case 6 -> every 4-5 orbits

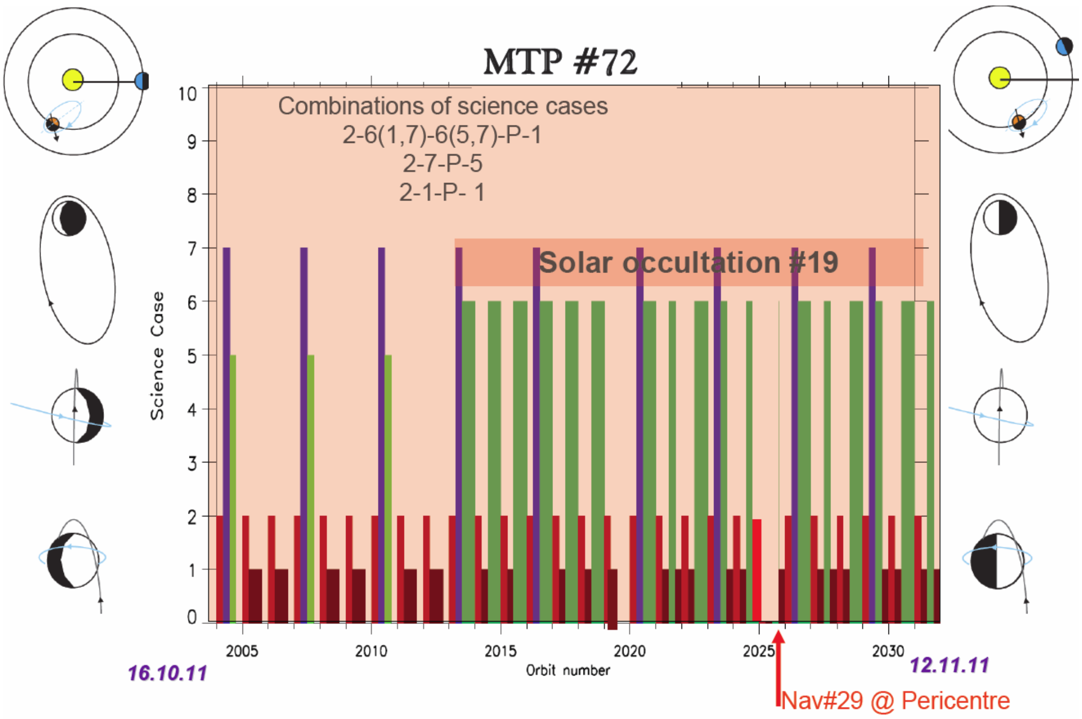


Figure 3.19 *MTP#72 timeline.*

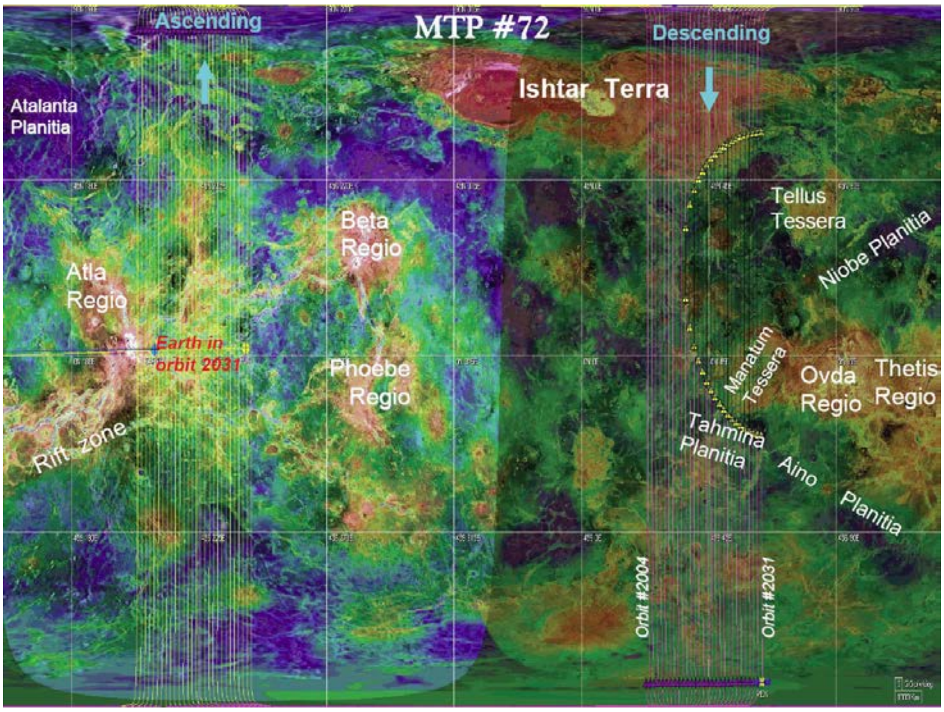


Figure 3.20 *Planet coverage by orbital tracks in MTP#72. Positions of terminator, Earth and Sun correspond to the last orbit of the MTP.*

3.9 MTP #73

3.9.1 MTP in brief

MTP #73 covers the period from 13.11 till 10.12.2011 and orbits #2032-2059. Eclipse season #19 continues till orbit 2053 with solar occultation after pericentre. Earth occultation season #12 begins in orbit #2034 with occultation occurring also after pericentre. The MTP is hot. The data rate is moderate. Local time at ascending node changes from 12h to 15h that makes illumination conditions similar to those of MTP#65. Night surface observations in eclipse in descending branch cover Tellus Tessera, Niobe Planitia and Ovda Regio. Figures 3.22 and 3.23 show observations timeline and planet coverage by orbital tracks.

3.9.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 12-15 h (similarity to MTP #65)
- Eclipse season #19 till orbit #2053 (after pericentre)

- Earth occultation season #12 begins in orbit #2034 (after pericentre)
- Surface targets: Tellus Tessera, Niobe Planitia and Ovda Regio
- Hot period
- Downlink is moderate

3.9.3 *Specific observations and MTP#73 timeline*

Table 3.17 summarizes specific observation requests from the experiments.

Table 3.17 *Specific observation requests in MTP #73*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV/ SOIR			1. In plane exospheric limb 2. Polarization calibration [1)]	1. Solar occs 2. Zodiacal light in the beginning of MTP
VeRa				Radio occs
VEXADE				
VIRTIS	Day latitude track Night surface		VIR-H meridional [3)] Phase function	VIR-H meridional [3)] Night limb tracking
VMC	Day side monitoring		Latitude tracking Phase function Day limb tracking	Surface Night limb tracking
ASPERA				
MAG				

Notes to the table:

[1)] SPICAV polarization calibration – observations of Venus close to equator in anti-solar direction. It can be combined with VMC phase function sequence or VIRTIS-H meridional cross- section.

[2)] Joint SPICAV-SPICAM observations of hydrogen distribution in solar corona in every 5-th orbit. Can be embedded in case#2.

[3)] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Implemented in orbits 2032 and 2045.

The proposed timeline includes four types of orbits and their modifications:

- Type #1: cases 1-P-1 (VIR-H meridional cross section)
- Type #2: cases 2-1-P-6(5,7,1)-6
- Type #3: cases 2-1-P-8-8

Notes to the proposed timeline.

1. In ascending branch the pendulum version of case#2 shall be used.
2. Case 5 on the descending branch in every ~2 orbits, to be combined with hot case 2 (alternate normal and short pendulum).
3. In-plane exospheric limb observations before pericenter, to be combined with egress case 6 -> every 4-5 orbits

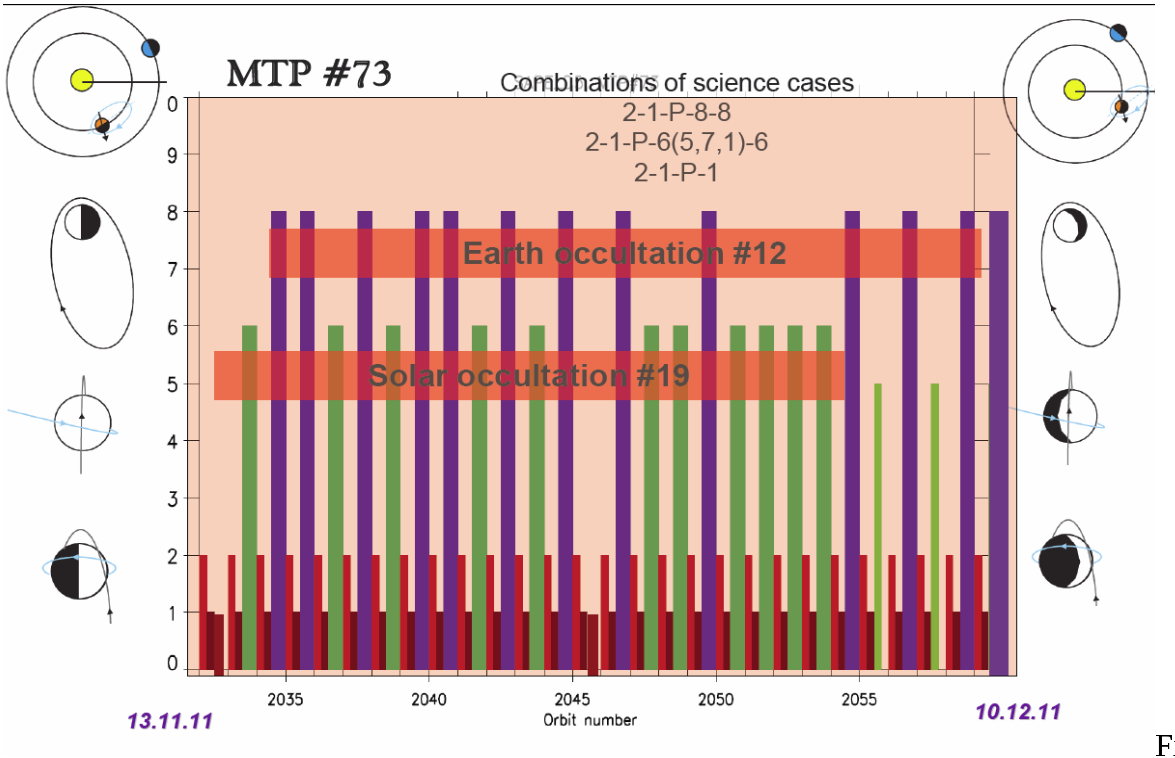


Figure 3.22 ***MTP#73 timeline.***

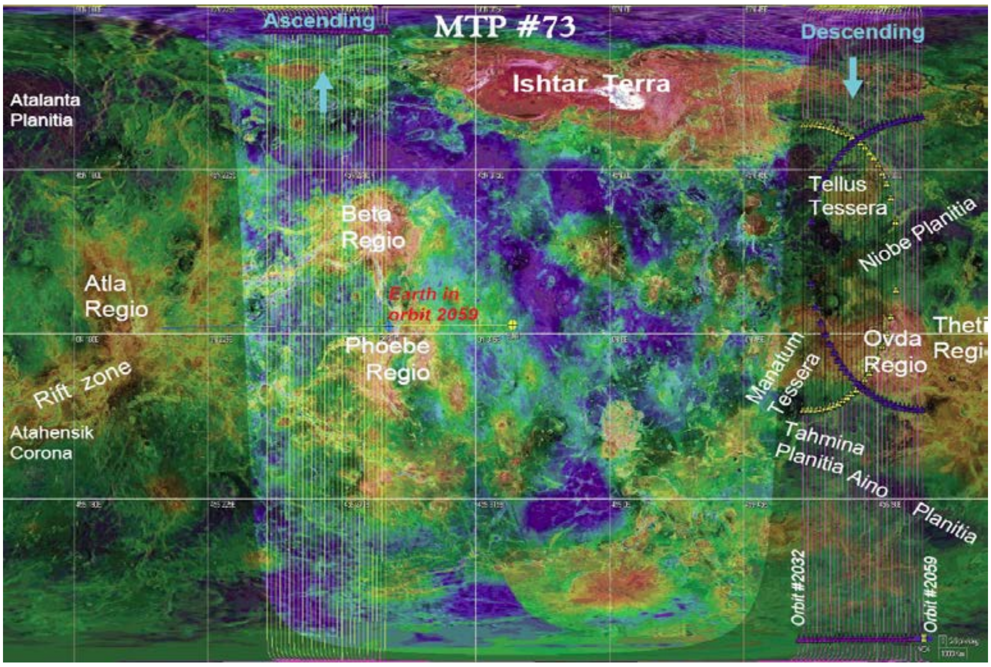


Figure 3.23 *Planet coverage by orbital tracks in MTP#73. Positions of terminator, Earth and Sun correspond to the last orbit of the MTP.*

3.10 MTP #74

3.10.1 MTP in brief

MTP #74 covers the period from 11.12.2011 till 7.01.2012 and orbits #2060-2087. This MTP includes the second part of the Earth occultation season #12. Since occultation occur after pericentre, i.e. ingress occultation at high Northern latitudes and egress in the Southern hemisphere, "asymmetric" occultation scheme is not possible and in each orbit allocated for radio-science both ingress and egress occultation will be performed. The MTP is hot. The data rate is moderate. Local time at ascending node changes from 15h to 18h. Illumination conditions are similar to those in MTP #66. Figures 3.25 and 3.26 show observations timeline and planet coverage by orbital tracks.

3.10.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 15-18 h (similar to MTP#66)

- Second part of the Earth occultation season #12
- Hot season
- Downlink is moderate

3.10.3 Specific observations and MTP#66 timeline

Table 3.18 summarizes specific observation requests from the experiments.

Table 3.18 *Specific observation requests in MTP #66*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV			1. Day tangential limb in the 2-d half of MTP	1. Stellar occs 2. Day tangential limb in the 2-d half of MTP
VeRa				Radio occs
VEXADE				
VIRTIS	Day latitude track Full mosaic Terminator orbit campaign [1)]		VIR-H meridional [2)] Day spectroscopy	VIR-H meridional [2)] Night limb tracking
VMC	Day side monitoring Terminator orbit campaign [1)]	Case #2 with off-set to day side	Latitude day tracking (evening) Day limb tracking Surface out of eclipse	Latitude day tracking (morning) Surface out of eclipse
ASPERA				
MAG				

Notes to the table:

[1)] Terminator orbit campaign: as long as possible imaging of the Southern polar region with minimized duration of CEB pass in several orbits around the terminator orbit (end of MTP#66). In each particular orbit the observations are performed from +3h till -3h.

[2)] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Implemented in orbits 2061 and 2076.

The proposed timeline consists of alternation of four types of orbits:

- Type #1: cases 2-1-P-1 (VIR-H meridional cross section in orbits #2061 and 2076)

- Type #2: cases 2-1-P-8-8
- Type #3: cases 2-1-P-5

Notes to the proposed timeline.

1. Pointing for cases 5 and 7 after pericenter is likely hot. It should be combined with hot case 2 (alternation between normal and shifted pendulum).

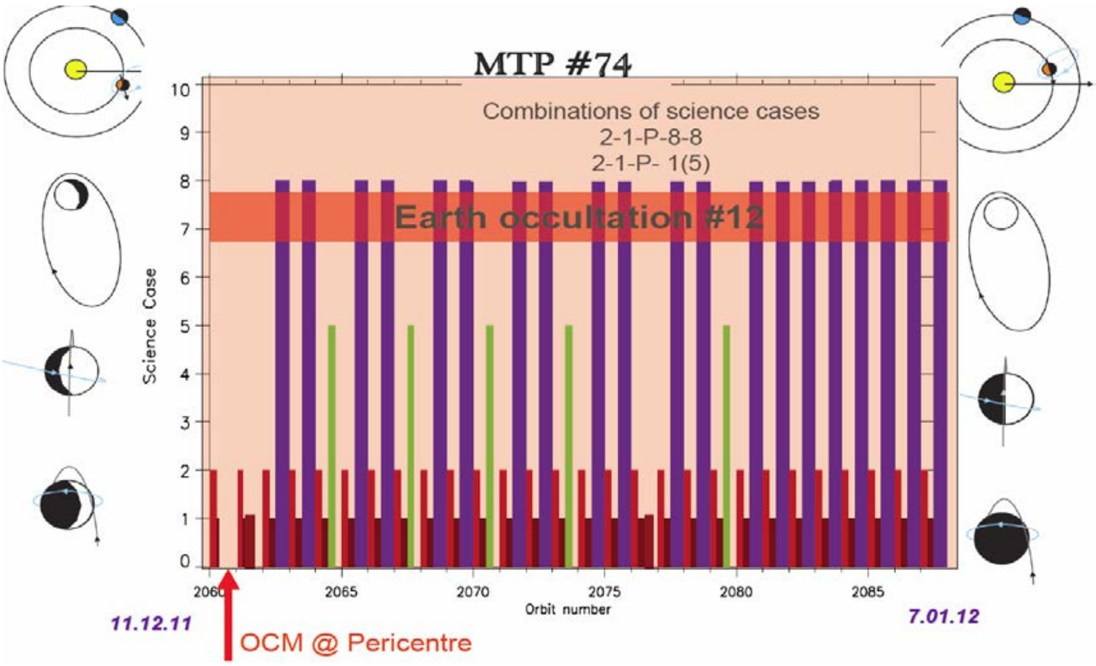


Figure 3.25 *MTP#74 timeline.*

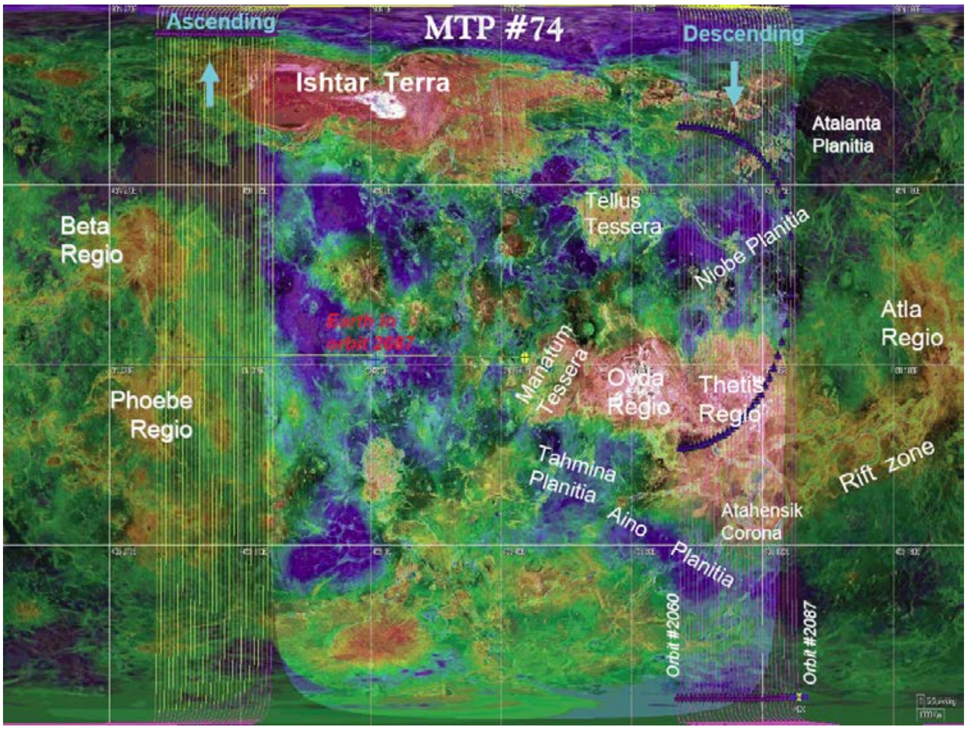


Figure 3.26 *Planet coverage by orbital tracks in MTP#74. Positions of terminator, Earth and Sun correspond to the last orbit of the MTP.*

3.11 MTP #75

3.11.1 MTP in brief

MTP #75 covers the period from 8.01.2012 till 4.02.2012 and includes orbits #2088-2115. The MTP is cold except for several orbits in the beginning. The MTP begins with 12 orbits of Drag Campaign #7 (#2088-2099) by NNO and DSN stations that can be combined with terminator orbit campaign. The pericentre will be as low as 165 km (see Annex #2). In these orbits the pericenter arc (from -2h to +2h) will be devoted to the spacecraft tracking and no observations in pericentre will be allowed.

The data rate is moderate to high. Local time at ascending node changes from 18h to 21h. Illumination conditions are similar to those in MTP#67. Figures 3.28 and 3.29 show observations timeline and planet coverage by orbital tracks.

3.11.2 Environmental conditions

- Local Time at Ascending Node (LTAN): 18-21 h (similar to MTP #67)
- Cold season
- Downlink is moderate to high
- Drag Campaign #7 in orbits #2088-2099 by NNO and DSN with pericentre altitude of 165 km

3.11.3 Specific observations and MTP#75 timeline

Table 3.19 summarizes specific observation requests from the experiments.

Table 3.19 *Specific observation requests in MTP #75*

	Apocentre & ascending arc		**Pericentre pass**	
Experiment	**< -3h**	**-3h….-1h**	**-1h…Per**	**Per… +1h**
SPICAV	SOIR calibration [1)]	Stellar occs	Nadir at terminator	1. Day side in the 2-d part of MTP 2. Cases 5 and 7 in the 2-d half of MTP 3. Aeronomic emissions [2)]
VeRa				
VEXADE		Drag campaign #7 [5)]		

VIRTIS	Day side campaign Tracking along terminator in the beginning 2 full mosaics Night side obs		VIR-H meridional [3]	VIR-H meridional [3] Night limb tracking
VMC	Case#2 Terminator orbit campaign [4]	Case #2 with off-set to day side	Latitude day tracking (evening) Surface out of eclipse	Day latitude tracking (morning) Day limb
ASPERA				
MAG				

Notes to the table:

[1] SOIR calibration consisting of 2 miniscans, 1 alignment and 1 thermal performed in any part of orbit outside of eclipse.

[2] Aeronomic day side emissions: Day limb in specific orientation with Sun on +X. Request shall be agreed by VSOC and VIRTIS.

[3] VIRTIS-H meridional cross-section: observations from -2h till +2h in local nadir or slightly off-nadir to cover all latitudes. Implemented in orbits 2101 and 2115

[4] Terminator orbit campaign (case #3): as long as possible imaging of the Southern polar region with minimized duration of CEB pass in several orbits around the terminator orbit (beginning of MTP#67). In each particular orbit the observations are performed from +3h till -3h. Can be combined with VIRTIS tracking along terminator.

[5] Drag Campaign #7 in orbits #2088-209: Spacecraft tracking from -2h till +2 h will be provided by NNO (6 orbits) and DSN (6 orbits) stations.

The proposed timeline consists of alternation of several types of orbits:

- Type #1: cases 2-1-P-1 (VIR-H meridional cross section in orbits #2101 and 2115).
- Type #2: cases 3-2-P (terminator orbit campaign including VIRTIS full mosaic in the first 6 orbits of the MTP). These orbits coincide with Drag campaign #7.
- Type #3: cases 2-1-P-5(7)

Note that case #3 in terminator orbit campaigns is different from the earlier defined case #3 as VIRTIS mosaic. In this case it looks more like extended case #2.

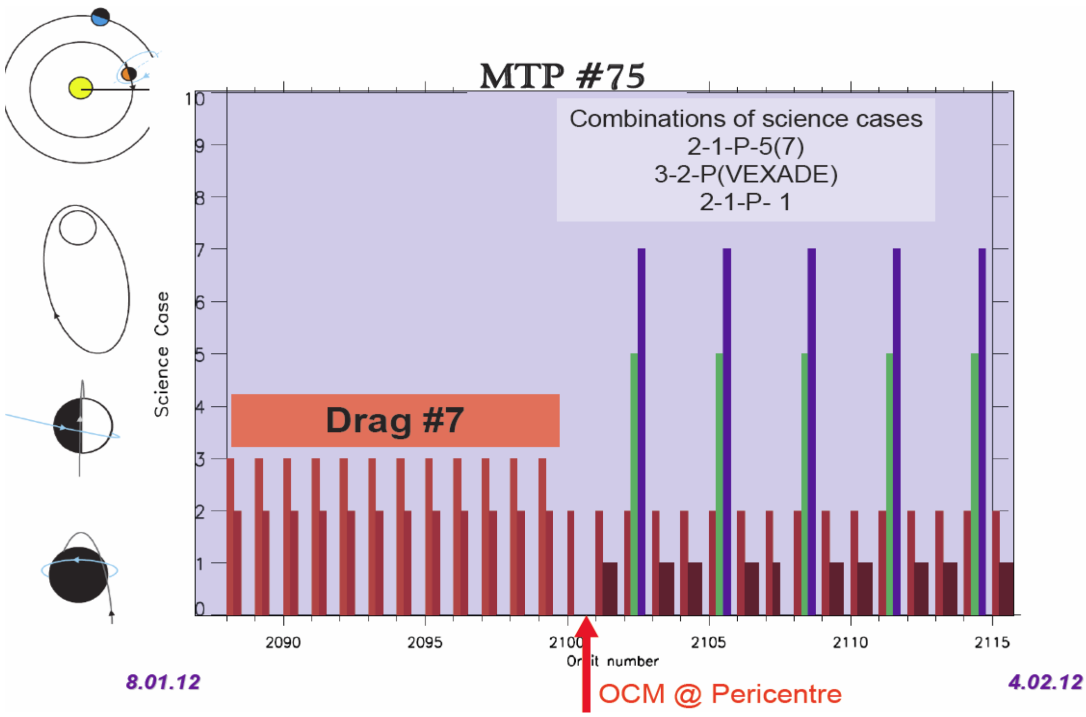


Figure 3.28 *MTP#75 timeline.*

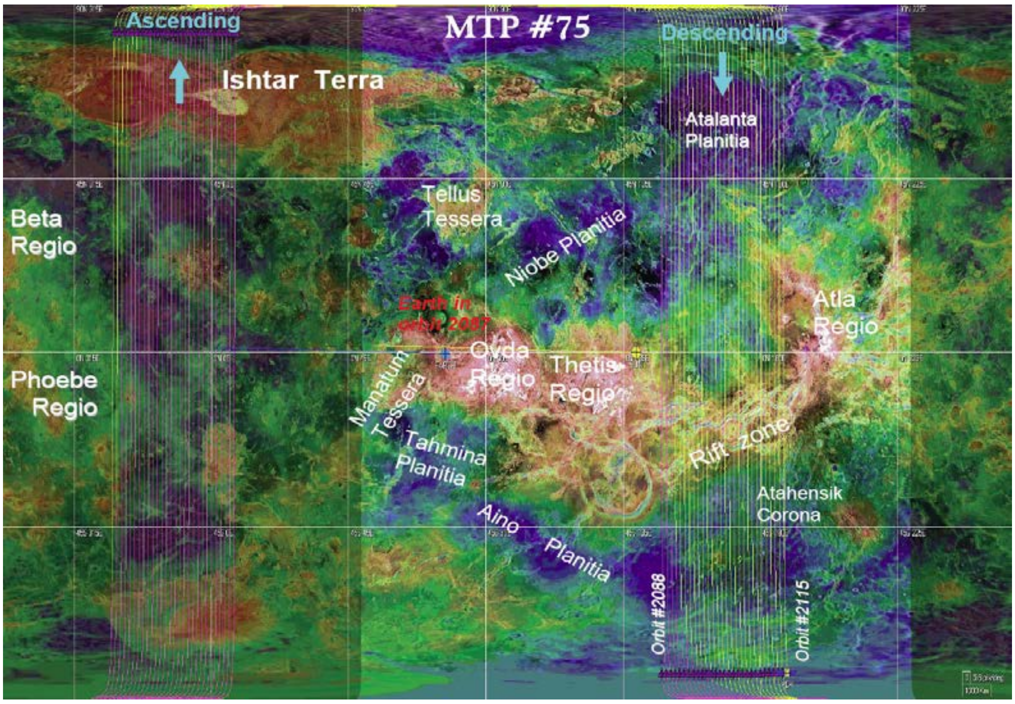


Figure 3.29 *Planet coverage by orbital tracks in MTP#75. Positions of terminator, Earth and Sun correspond to the last orbit of the MTP.*

4. STRATEGY OF COORDINATED OBSERVATIONS WITH THE JAXA AKATSUKI MISSION

In the middle of December 2010 the Akatsuki spacecraft (JAXA, Japan) is expected to arrive at Venus that would create a unique chance to simultaneously study Venus by two orbital spacecraft. In January 2011 (VEX MTP 61-62) after several weeks of in orbit manoeuvring and commissioning Akatsuki will begin science observations. The JAXA spacecraft will deliver a set of remote sensing instruments: five cameras covering spectral range from UV to thermal IR and a radio-occultation experiment. The main goal of the JAXA mission is to study meteorology and cloud dynamics. Both the science objectives and the payload suite of Akatsuki make it very complementary to Venus Express. This section describes general strategy of joint Venus Express/Akatsuki observations. Detailed plan of joint observations will be elaborated in a dedicated document that is currently being developed by VSOC/ESA and the JAXA science operations team.

4.1 Venus Express and Akatsuki orbits

The Akatsuki spacecraft will be inserted in a quasi-equatorial orbit with 30 hours revolution period. This allows the spacecraft to co-rotate with the Venus middle cloud deck (~50 km), thus providing ideal conditions for tracking of cloud motions for about 20 hours. Table 4.1 compares orbital parameters of both spacecraft (Fig. 4.1).

Table 4.1 *Orbital parameters of the Venus Express and Akatsuki spacecraft*

	Venus Express	Akatsuki
Orbit type	Polar	Equatorial
Inclination	~90 deg	~ 172 deg
Pericentre latitude	~90 N	~ 8 S deg
Pericentre distance, km	165-350	400
Apocentre distance, km	66,000	80,000

Period, h	24	30

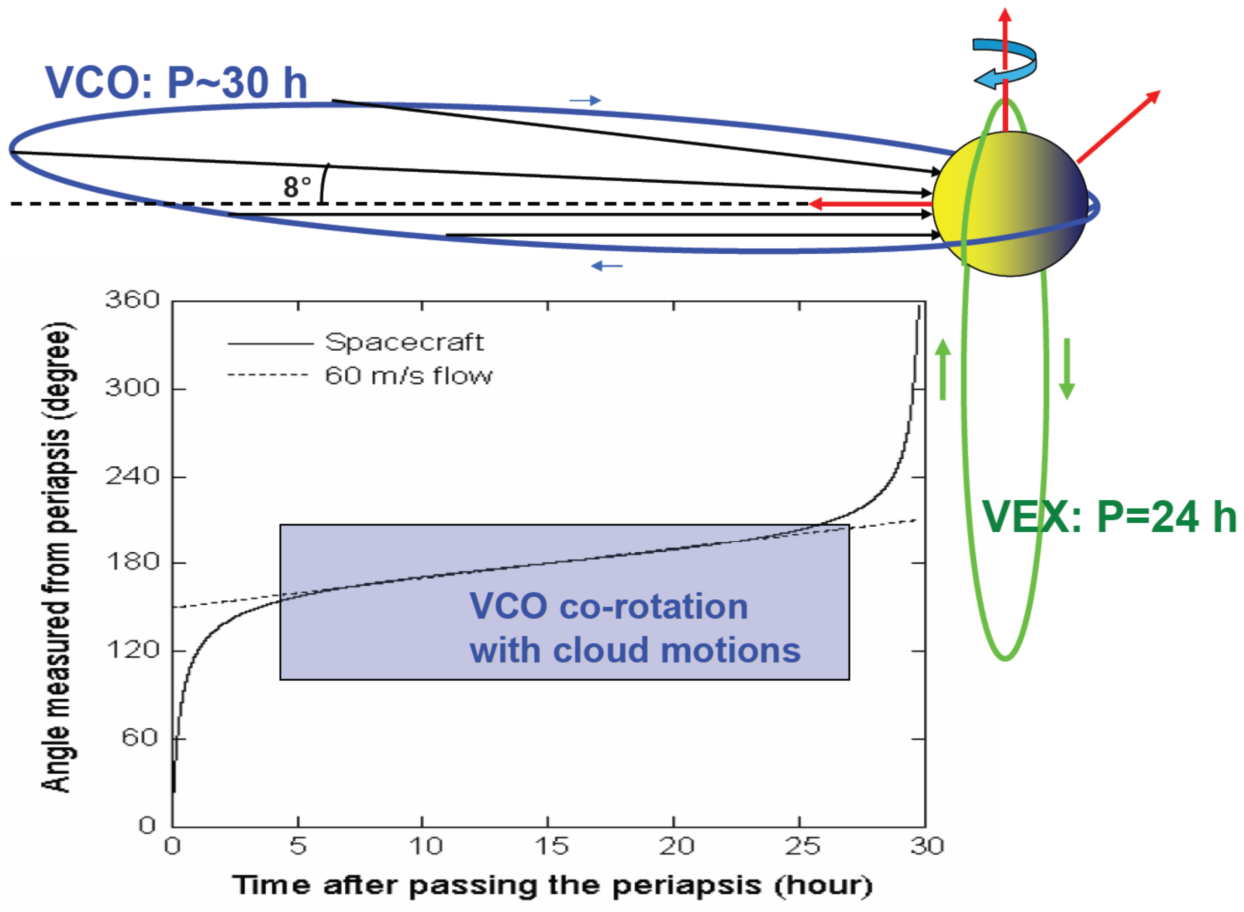


***Figure 4.1** Sketch of the relative positions of the Akatsuki (VCO) and VEX orbits. Inserted plot shows the orbital time range when VCO is in co-rotation with the main cloud deck superrotation.*

Akatsuki will be inserted in Venus orbit in the beginning of December 2010. The orbit parameters will slightly depend on concrete day of VOI. Figure 4.2 shows the sketch of Akatsuki orbit with respect to SUN, Earth, Venus and Venus Express orbit. Note that the major axis of the Akatsuki orbit is almost perpendicular to the VEX orbital plane. After VOI and orbit forming maneuvers the relative position of the VEX and Akatsuki orbits will remain fixed.

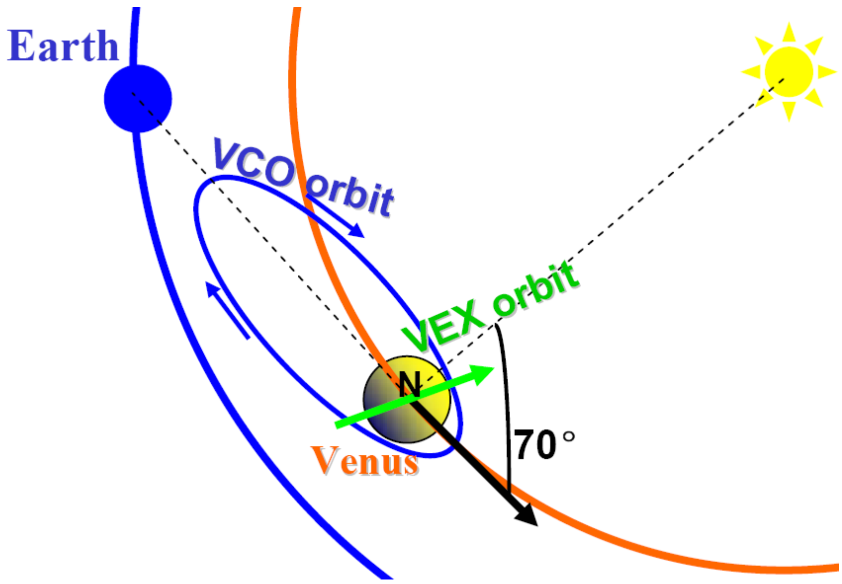


***Figure 4.2** Sketch of the position of the Akatsuki orbit (blue ellipse) relative to Earth, Venus, Sun and the Venus Express orbit (green arrow) for Akatsuki VOI on December 13, 2010.*

Figure 4.3 shows evolution of positions of Venus Express and Akatsuki spacecraft during one day in 4 hours step. Approximate locations of corresponding ground stations are marked in red (Cebreros) and yellow (Usuda) arcs.

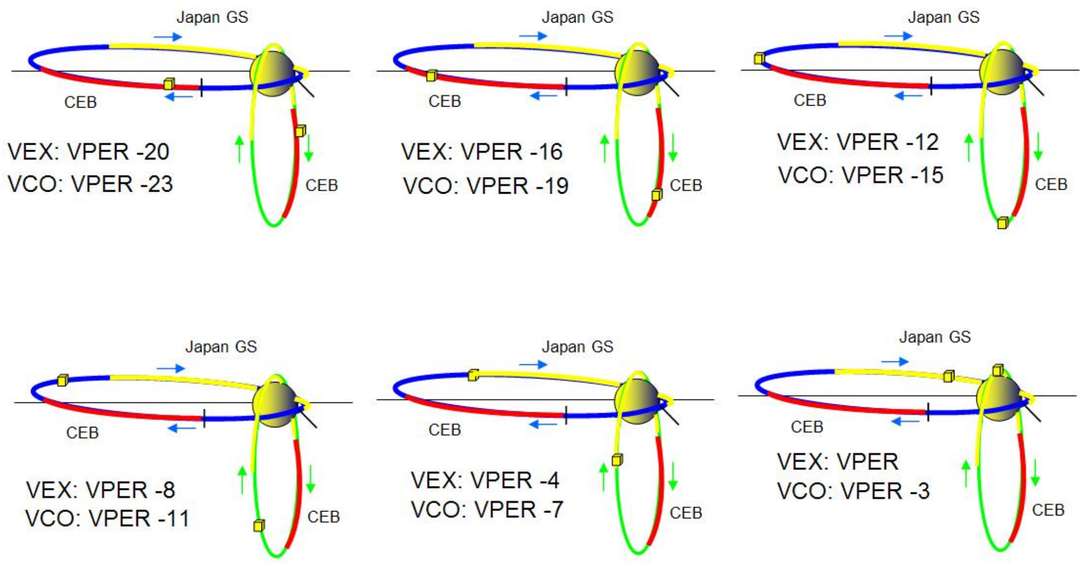


Figure 4.3 *Orbital positions of Venus Express and Akatsuki during one day. Red and yellow arcs show location of telecoms phases for VEX and Akatsuki.*

Figure 4.4 shows relative positions of two spacecraft and their ground stations during 6 days with a one day step. Since the ratio of orbital periods is 4:5 relative positions of spacecraft will have periodicity of 5 days.

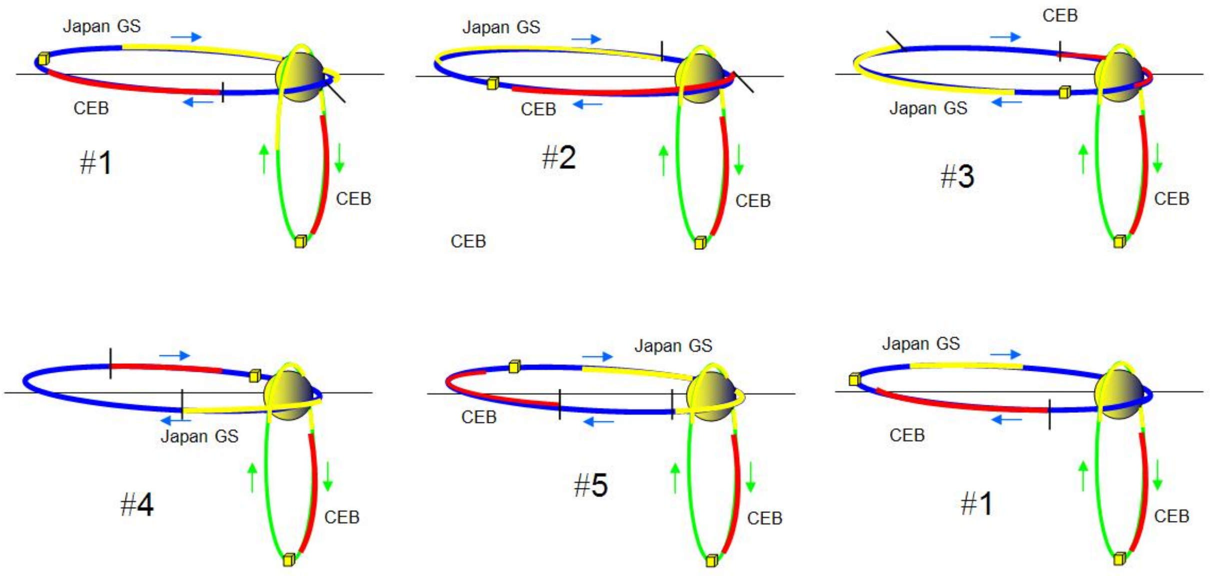


Figure 4.4 *Orbital positions of Venus Express and Akatsuki during six day. Red and yellow arcs show location of telecoms phases for VEX and Akatsuki.*

The above mentioned properties of the Venus Express and Akatsuki orbits have several implications on the strategy of joint observations.

1. Combination of polar and equatorial orbits provide favorable conditions for coordinated observations, especially in what concerns scattering phase function studies and latitudinal coverage. This also results in strong complementarily in radio occultation sounding of low latitudes.
2. The 4:5 ratio of orbital periods results in repeating of observational geometry with a period of 5 days.

3. Downlink to two ground stations separated by 8 hours local time creates certain constrains in simultaneous observations that needs to be carefully taken into account in the planning.

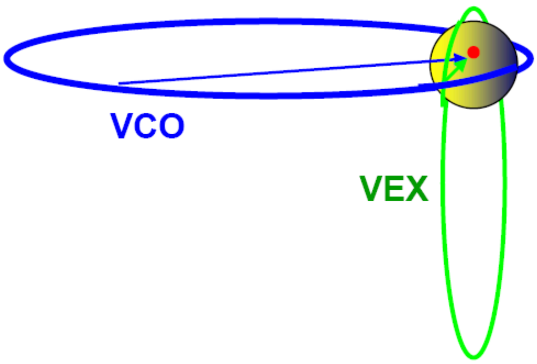
The following section describes major modes of coordinated observations.

4.2 Modes of joint observations

The equatorial orbit of Akatsuki and the polar one of Venus Express as well as their different orbital periods create unique geometry conditions for observing Venus from different angles and tracking cloud features for a long time. Both are very important for the study of cloud properties and atmospheric dynamics. Different orbit inclinations result in different geometries of Earth radio-occultation thus creating a background for complementary sounding of the atmospheric structure. This section provides typical modes of joint observations.

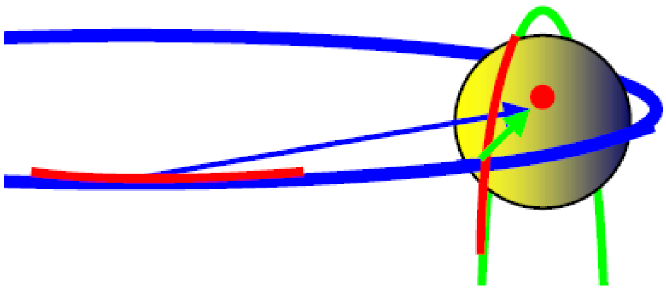
4.2.1 *Simultaneous observations at different spatial resolution (day side)*

These observations are possible when VCO is in the apocenter part of its orbit while VEX is close to the planet, thus resulting in about an order of magnitude difference in spatial resolution. In this case VCO will provide context imaging for Venus Express, which high resolution images can be imbedded in the global cloud patterns observed by VCO (see figure).



4.2.2 *Simultaneous phase function observations (day side)*

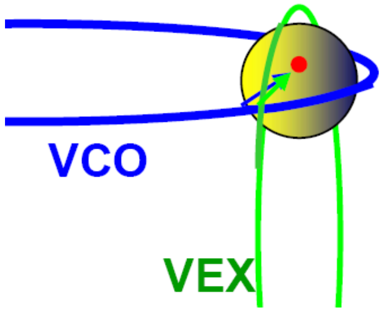
Observations of reflected solar light in the range of phase angles from 0° (backscattering) to ~90° are very informative about the microphysical and optical properties of aerosol particles at the cloud tops. Due to thermal constrains



Venus Express cannot cover this range of phase angles in one orbit. Simultaneous imaging by Akatsuki will help to overcome this limitation. The figure shows that simultaneous observations by two spacecraft moving along red arcs in their orbits will cover the required range of phase angles.

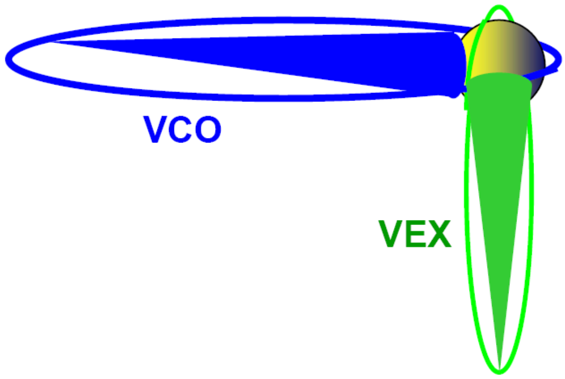
4.2.3 *Cross-calibration of the optical instruments (day side)*

Cross check of the radiometric calibration of the Venus Express and Akatsuki optical instruments is an important task for joint observations. This task requires specific geometry when both spacecraft observe Venus simultaneously from the same direction that ensures similar illumination conditions (see figure).

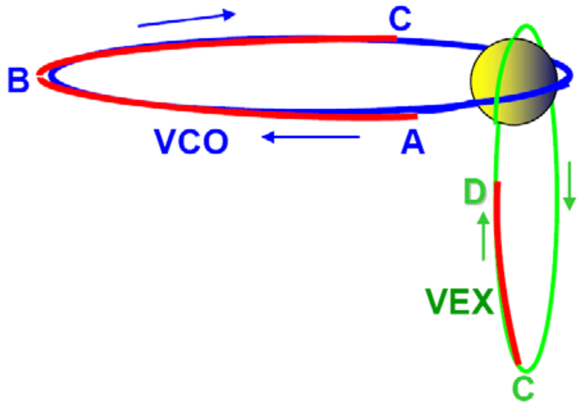


4.2.4 *Simultaneous observations of dynamics and cloud morphology at all latitudes (day side)*

The polar orbit of Venus Express is well suited for observations of cloud morphology and atmospheric dynamics in the middle to high latitudes of the Southern hemisphere. At close approach when VEX sees low latitudes fields of view of the imaging instruments are too narrow and the observations loose spatial coverage. Combination of VEX and Akatsuki observations from around apocentres of both orbits will allow to the planet from South pole to high Northern latitudes. These observations will give an instantaneous snapshot of cloud morphology and dynamics on the most of day side (see figure).



4.2.5 *Continuous monitoring of cloud motions (day side)*



Determination of the wind field from tracking of cloud features is one of the main goals of both missions. In this task keeping a cloud feature in the field of view and tracking its evolution for as long as possible is of great importance. Maximal duration of such observation is ~10 hours for Venus Express and ~20 hours for Akatsuki. Combination of both when, one spacecraft starts tracking of a certain feature and the second one takes over would result in extension of observation time to ~30 hours. The figure shows the sequence that starts with VCO observations for ~20 hours (red arc A-B-C), and when the feature disappears from the VCO field of view (point C) Venus Express takes over and continues observations for another 10 hours until point D.

4.2.6 *Surface observations (night side)*

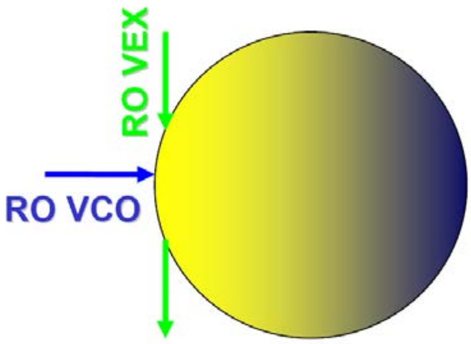
Surface imaging requires correction for variations of cloud opacity. Since the failure of the VIRTIS-M cooler in October 2008, this correction is not possible anymore. With arrival of Akatsuki spacecraft that carries near-IR cameras such correction will become possible again. Simultaneous observations by the JAXA spacecraft will help both VIRTIS and VMC to "de-cloud" the night images.

4.2.7 *Observations of lightning (night side)*

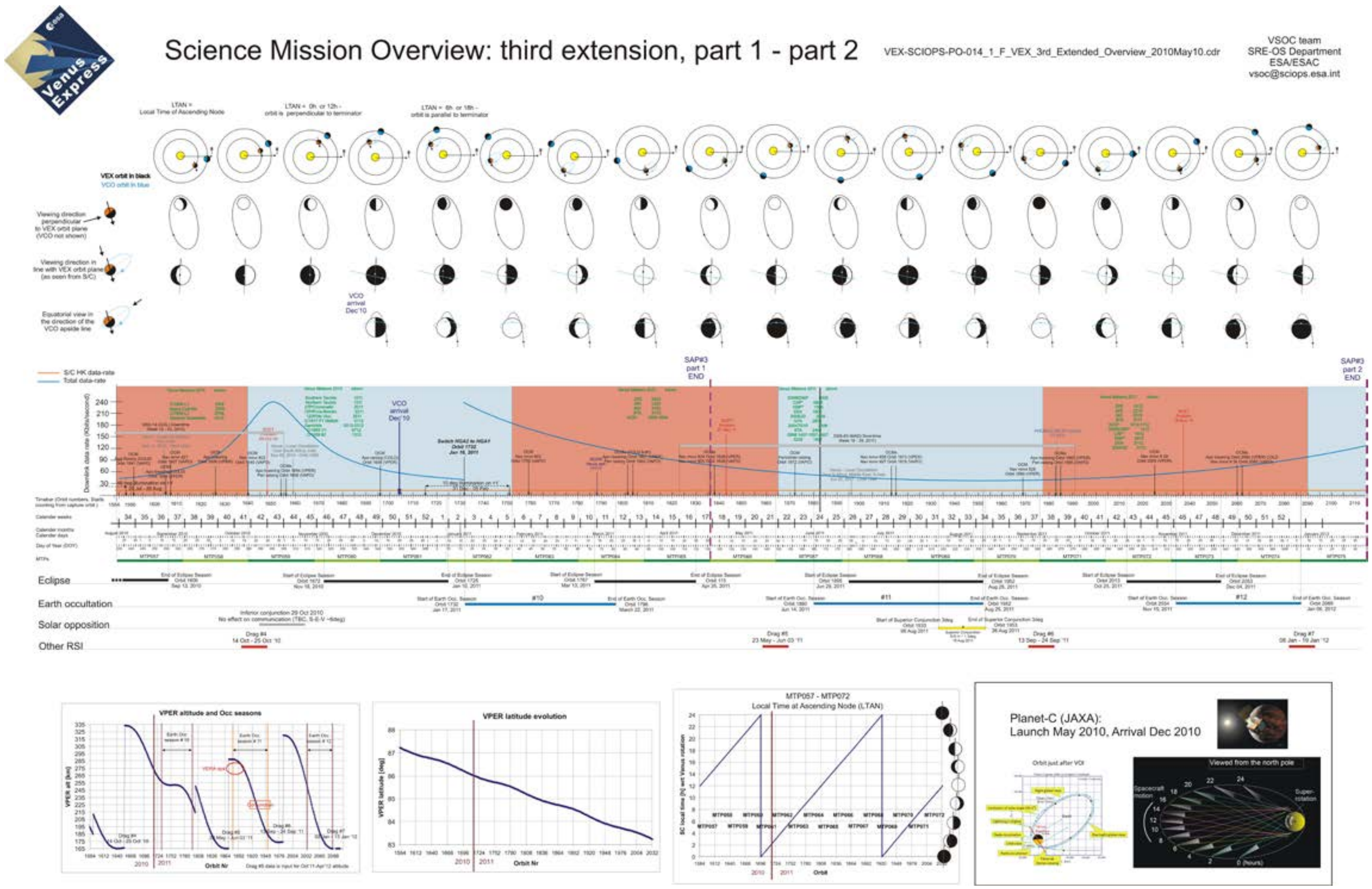
Lightning is regularly observed by Venus Express as whistler waves in the magnetometer records. MAG/VEX searches for lightning at closest approach to Venus in pericentre by switching to the high frequency (128 Hz) mode. However lightning has never been detected by the optical instruments of Venus Express probably because they are not suited for lightning detection. The Akatsuki spacecraft has the LAC camera which designed to detect lightning flashes. Simultaneous observations by both techniques can provide additional evidences for lightning. However, since LAC will observe lightning in tropics, MAG shall also switch to high frequency mode ~30 minutes before or after pericentre.

4.2.8 Coordinated radio-occultation experiments

The polar orbit of Venus Express provides almost complete latitude coverage in radio-occultation experiment. However low latitudes are sounded in grazing geometry that significantly decreases latitude resolution of the experiment. The Akatsuki radio-occultation will have close to nadir entrance of radio beam in the atmosphere that provides much better latitude resolution, thus giving important complement in sounding of Venus tropics. The figure compares geometry of VEX and Akatsuki radio-occultation experiment. Simultaneous and co-located occultation will help to compare both experiments.

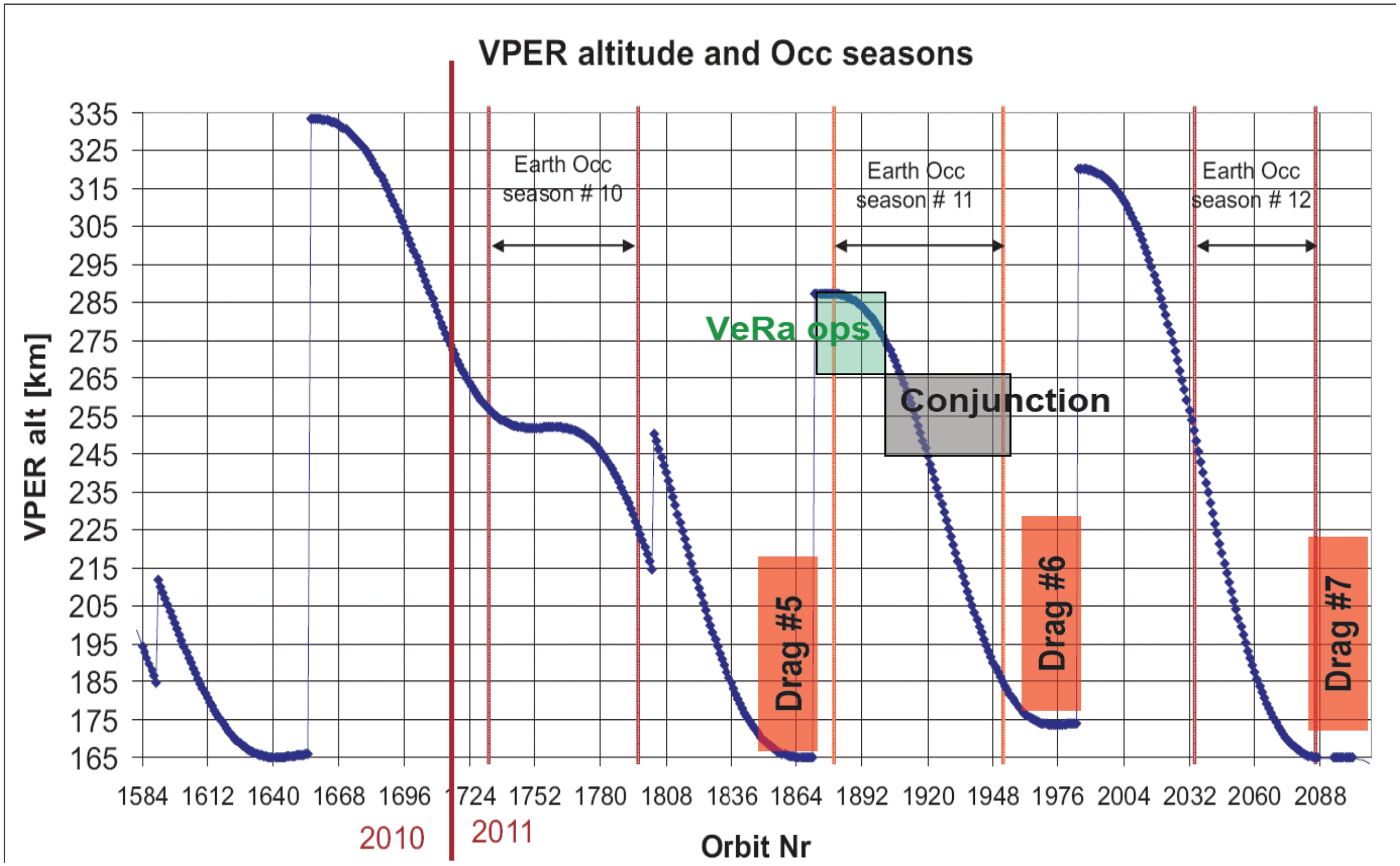


5. ANNEX 1. EXTENDED-3 MISSION OVERVIEW



6. ANNEX 2. PERICENTRE ALTITUDE IN EXTENDED MISSION

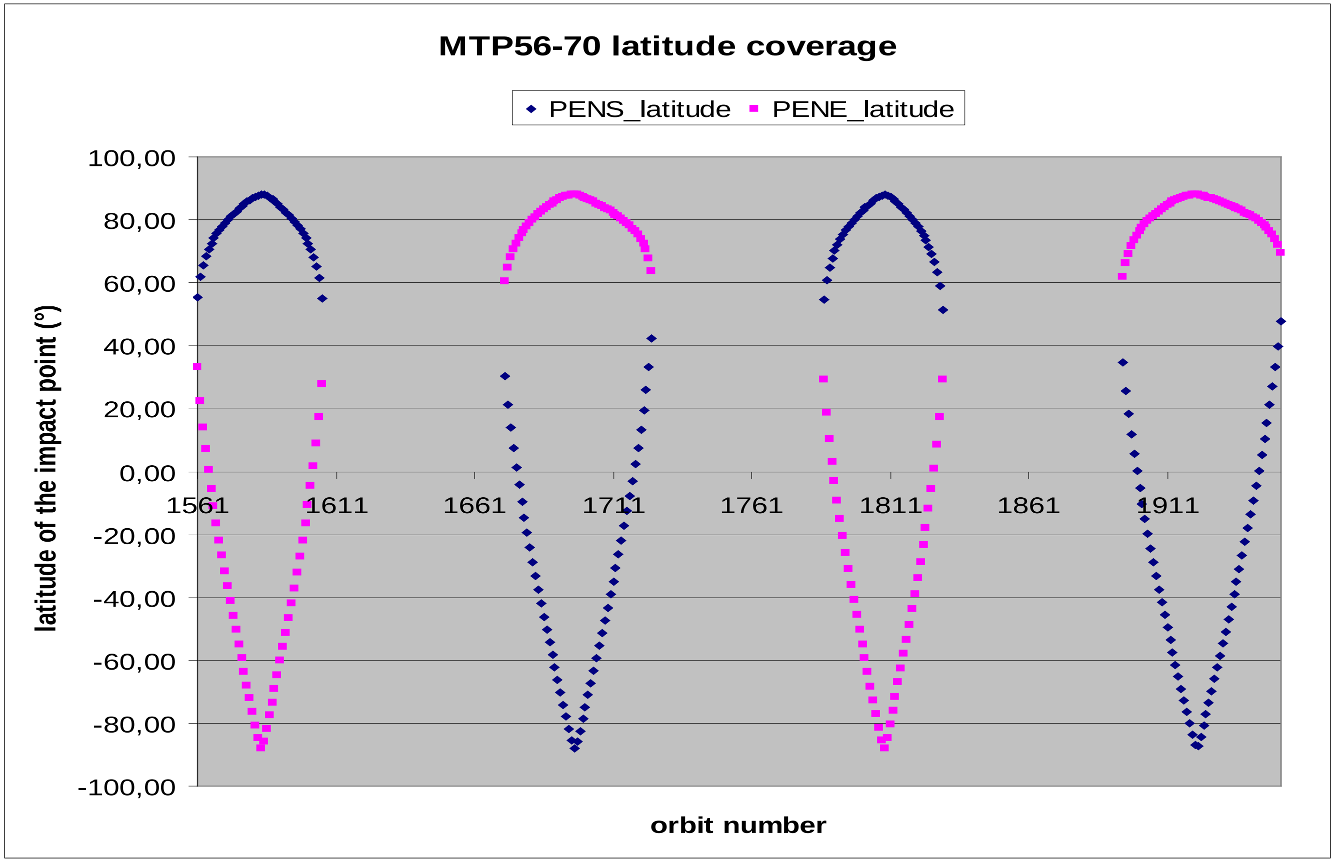
Pericentre altitude



7. ANNEX 3. LIST OF STARS FOR STELLAR OCCULTATION OBSERVATIONS

PTB	Star	RA	DEC	RelTimeSt	RelTimeE	Lat.in	Long.in	LSunIn	day/night	Lat.out	Long.out	LSunOut	day/night	OccDurIn	Dist.In	OTAngle	OccDurOu	Dist.Out	OTAngle	TotOccDu
0	Star02	14,18	60,72																	
1	Star05	24,43	-57,24	-00:15:24	0:06:39	-1,52615	76,51323	2,626595	day	22,72781	-62,6585	134,4168	night	20	6031,593	137,4298	20	2926,255	25,39706	1330
2	Star08	58,53	31,88																	
3	Star09	59,46	40,01																	
4	Star12	78,63	-8,2	-00:04:14	0:19:49	59,20332	84,87461	58,52108	day	-32,9264	-38,4585	112,0243	night	20	2281,488	14,9577	20	7500,586	50,42033	1450
5	Star14	81,28	6,35	-00:02:14	0:24:39	73,92013	79,05021	72,94643	day	-38,9943	-25,3373	100,4806	night	30	1671,059	4,914946	20	9115,084	55,89387	1620
6	Star16	83	-0,3	-00:03:14	0:22:59	67,03779	85,61797	66,31215	day	-41,4765	-32,4052	105,3624	night	30	1905,423	9,954681	10	8578,777	54,2923	1580
7	Star17	83,78	9,93	-00:01:44	0:26:49	77,29326	77,23876	76,31203	day	-44,0114	-21,5792	97,12293	night	40	1559,126	12,96677	20	9793,102	57,68868	1720
8	Star18	83,86	-5,91	-00:04:04	0:21:29	61,22688	88,54272	60,85109	day	-41,3905	-38,6019	109,8713	night	30	2113,063	14,1317	10	8095,281	52,76362	1540
9	Star19	84,05	-1,2	-00:03:24	0:22:59	66,05069	87,02989	65,4361	day	-43,0943	-33,8472	106,0254	night	30	1924,192	10,79526	10	8573,839	54,2463	1590
10	Star20	85,19	-1,94	-00:03:24	0:22:59	65,26197	87,71637	64,71658	day	-44,7144	-35,236	106,5763	night	20	2005,366	10,79526	10	8583,436	54,33569	1590
11	Star21	86,94	-9,67	-00:04:34	0:21:09	57,29751	91,5157	57,44477	day	-44,3804	-45,1392	113,335	night	20	2277,305	16,59827	20	7937,852	51,94641	1550
12	Star25	95,68	-17,96	-00:05:34	0:19:49	49,09939	98,23362	51,35743	day	-46,941	-63,5439	122,8486	night	20	2651,067	21,41675	10	7512,451	50,53084	1530
13	Star28	101,29	-16,72	-00:05:24	0:20:29	50,69713	101,6513	53,8204	day	-50,5652	-72,5089	124,2366	night	20	2547,36	20,62522	10	7748,924	51,4704	1560
14	Star29	104,66	-28,97	-00:07:04	0:17:19	38,80049	104,4555	45,23914	day	-38,7178	-79,7036	136,8199	night	20	3095,736	143,3061	10	6649,52	47,01372	1470
15	Star36	120,9	-40	-00:08:24	0:14:19	29,63647	113,6572	44,89034	day	-22,8603	-92,125	155,8545	night	10	3655,507	143,7496	10	5613,058	42,21509	1370
16	Star41	140,53	-55,01	-00:11:04	0:10:29	15,64025	121,4636	45,94201	day	-0,98847	-93,032	170,3865	night	10	4572,081	142,5674	20	4226,653	34,27959	1300
17	Star44	160,74	-64,39	-00:13:34	0:08:09	4,658614	125,9419	48,70821	day	13,13918	-91,2806	161,9285	night	10	5424,197	139,87	20	3401,374	28,78338	1310
18	Star46	182,09	-50,72	-00:11:54	0:06:29	20,99942	138,0424	62,45686	day	27,94993	-98,2228	150,7571	night	20	4807,523	141,7882	20	2865,369	24,92755	1110
19	Star48	186,65	-63,1	-00:14:54	0:06:19	2,881351	133,6256	56,32148	day	25,90673	-92,5787	151,4038	night	10	5897,068	138,1165	20	2814,149	24,54457	1280
20	Star49	186,65	-63,1	-00:14:54	0:06:19	2,881351	133,6256	56,32148	day	25,90673	-92,5787	151,4038	night	10	5897,068	138,1165	20	2814,149	24,54457	1280
21	Star53	191,93	-59,69	-00:14:44	0:05:49	6,217824	136,7763	59,55759	day	29,98369	-93,8861	147,9248	night	20	5827,177	138,3426	20	2654,043	23,31475	1240
22	Star55	201,3	-11,16																	
23	Star56	204,97	-53,47	-00:14:54	0:04:29	11,59861	143,4431	66,4495	day	40,67981	-94,6861	137,7106	night	20	5903,796	138,1165	30	2147,901	19,15139	1170
24	Star57	206,88	49,31																	
25	Star59	208,88	-47,29	-00:13:54	0:03:29	20,78805	147,4832	71,15649	day	48,10999	-96,6269	130,6286	night	20	5544,446	139,4451	30	1891,641	17,05003	1050
26	Star60	210,96	-60,37	-00:17:14	0:04:29	-1,55653	140,1299	62,88125	day	38,58507	-92,0297	139,2418	night	20	6686,812	134,8496	20	2237,505	19,98597	1310
27	Star62	218,88	-42,16	-00:14:14	0:01:49	25,96898	153,5111	74,414	day	58,79292	-96,78	120,1165	night	30	5651,26	138,9936	40	1543,116	14,07431	970
28	Star65	220,48	-47,39	-00:16:24	0:02:29	13,74902	151,1879	71,13378	day	54,01476	-93,7994	124,7265	night	20	6406,017	136,0191	40	1652,793	15,01162	1140
29	Star70	239,71	-26,11																	
30	Star71	240,08	-22,62																	
31	Star73	241,36	-19,81																	
32	Star74	245,3	-25,59																	
33	Star76	248,97	-28,22	-00:23:54	-00:06:44	17,83872	162,7077	82,40637	day	73,85444	-174,197	93,22955	term	60	8889,839	125,8604	110	2971,777	25,76973	1030
34	Star77	249,29	-10,57																	
35	Star84	263,4	-37,1	-00:36:04	-00:02:04	-33,6313	163,8089	85,16366	day	75,47152	-97,1408	103,4659	night	20	12628,92	113,5194	60	1601,644	14,59286	2040
36	Star86	265,62	-39,03	-00:36:24	-00:01:24	-39,3528	161,7472	84,04897	day	73,61713	-90,8344	105,1381	night	20	12718,15	113,2478	60	1434,464	13,10046	2100
37	Star89	283,82	-26,3	-00:53:44	-00:06:14	-79,3618	170,6336	91,09294	term	85,94663	-96,5174	92,99871	term	20	17419,86	102,3025	50	2807,568	24,52729	2850
38	Star91	306,41	-56,74	-00:29:14	0:02:09	-50,076	83,67022	51,35008	day	53,44445	-73,3506	120,3645	night	20	10586,77	119,8081	30	1562,408	14,22119	1890
	LSun	=	Local	(Zenith)																
		angle	>	90	->	dark	conditions													
		angle	=	90	->	terminator	conditions													
		angle	<	90	->	light	conditions													
		RA	of	Express	orbit	is	102	degrees												
		Stars	in	102	and	282	(102	+		180)	will	get		occulted	easily					
		Stars	in	192	(102	+	90)	and		12	(102	-		90)	will	not	get	occulted	easily	

8. ANNEX 4. LATITUDE COVERAGE IN THE SOIR SOLAR OCCULTATION EXPERIMENT



9. ANNEX 5. TABLE OF THE VERA EXPERIMENTS

Scheduling of the VeRa experiments in the Extended-3 Mission (May 2011 – February 2012).

The VeRa Synoptic Table is taken from the document: VEX-SCIOPS-LI-500_32_VeRa_Synoptic_Table_2010Apr15.xls.

23. May 2011- 03. Jun. 2011	1858-1869	143-154	Drag Campaign #5	1.5		DSN/NNO	6 + 6		
Part 1									
23.05.2011	1858	143		1.5		DSN	1	requested	4hours around pericenter, DSN 70 m
24.05.2011	1859	144				DSN	1	requested	4hours around pericenter, DSN 70 m
25.05.2011	1860	145				DSN	1	requested	4hours around pericenter, DSN 70 m
26.05.2011	1861	146				DSN	1	requested	4hours around pericenter, DSN 70 m
27.05.2011	1862	147				DSN	1	requested	4hours around pericenter, DSN 70 m
28.05.2011	1863	148				DSN	1	requested	4hours around pericenter, DSN 70 m
Part 2									
29.05.2011	1864	149				NNO	1	requested	4hours around pericenter
30.05.2011	1865	150				NNO	1	requested	4hours around pericenter
31.05.2011	1866	151				NNO	1	requested	4hours around pericenter
01.06.2011	1867	152				NNO	1	requested	4hours around pericenter
02.06.2011	1868	153				NNO	1	requested	4hours around pericenter
03.06.2011	1869	154		1.6		NNO	1	requested	4hours around pericenter
14. Jun. 2011- 25. Aug. 2011	1880-1952	165-237	Earth Occultation #11			NNO			Planning Strategy Adapted to Lower Latitude Coverage
						Ingress	Egress		on average request of 6 DSN passes for ULP in each season are possible
14.06.2011	1880	165				NNO	NNO	requested	
15.06.2011	1881	166				NNO	NNO	requested	
16.06.2011	1882	167				NNO	NNO	requested	
17.06.2011	1883	168				NNO		requested	
18.06.2011	1884	169				NNO	NNO	requested	
19.06.2011	1885	170				NNO		requested	
20.06.2011	1886	171				NNO	NNO	requested	
21.06.2011	1887	172				NNO		requested	
22.06.2011	1888	173				NNO	NNO	requested	
23.06.2011	1889	174				NNO		requested	
24.06.2011	1890	175				NNO	NNO	requested	
25.06.2011	1891	176				NNO		requested	
26.06.2011	1892	177				NNO	NNO	requested	
28.06.2011	1894	179				NNO	NNO	requested	
01.07.2011	1897	182				NNO	NNO	requested	
03.07.2011	1899	184				NNO	NNO	requested	
05.07.2011	1901	186				NNO	NNO	requested	
08.07.2011	1904	189				NNO	NNO	requested	
11.07.2011	1907	192				NNO	NNO	requested	Solar Corona 10 deg cone
13. Sep. 2011- 24. Sep. 2011	1971-1982	256-267	Drag Campaign #6	1.7		DSN/NNO	6 + 6		
Part 1									
13.09.2011	1971	256		1.70		DSN	1	requested	4hours around pericenter, DSN 70 m
14.09.2011	1972	257				DSN	1	requested	4hours around pericenter, DSN 70 m
15.09.2011	1973	258				DSN	1	requested	4hours around pericenter, DSN 70 m
16.09.2011	1974	259				DSN	1	requested	4hours around pericenter, DSN 70 m
17.09.2011	1975	260				DSN	1	requested	4hours around pericenter, DSN 70 m
18.09.2011	1976	261				DSN	1	requested	4hours around pericenter, DSN 70 m
Part 2									
19.09.2011	1977	262				NNO	1	requested	4hours around pericenter
20.09.2011	1978	263				NNO	1	requested	4hours around pericenter

21.09.2011	1979	264				NNO	1	requested	4hours around pericenter
22.09.2011	1980	265				NNO	1	requested	4hours around pericenter
23.09.2011	1981	266				NNO	1	requested	4hours around pericenter
24.09.2011	1982	267		1.68		NNO	1	requested	4hours around pericenter
15. Nov. 2011- 6. Jan. 2012	**2034-2086**	**319-006**	**Earth Occultation #12**			**NNO**	**33**		**Planning Strategy Adapted to Lower Latitude Coverage**
15.11.2011	**2034**	**319**				**NNO**	**1**		
16.11.2011	**2035**	**320**				**NNO**	**1**		**request of 6 DSN passes for ULP**
18.11.2011	**2037**	**322**				**NNO**	**1**		
20.11.2011	**2039**	**324**				**NNO**	**1**		
21.11.2011	**2040**	**325**				**NNO**	**1**		
23.11.2011	**2042**	**327**				**NNO**	**1**		
25.11.2011	**2044**	**329**				**NNO**	**1**		
27.11.2011	**2046**	**331**				**NNO**	**1**		
30.11.2011	**2049**	**334**				**NNO**	**1**		
05.12.2011	**2054**	**339**				**NNO**	**1**		
07.12.2011	**2056**	**341**				**NNO**	**1**		
09.12.2011	**2058**	**343**				**NNO**	**1**		
11.12.2011	**2060**	**345**				**NNO**	**1**		OCM at pericenter
13.12.2011	**2062**	**347**				**NNO**	**1**		
14.12.2011	**2063**	**348**				**NNO**	**1**		
16.12.2011	**2065**	**350**				**NNO**	**1**		
17.12.2011	**2066**	**351**				**NNO**	**1**		
19.12.2011	**2068**	**353**				**NNO**	**1**		
20.12.2011	**2069**	**354**				**NNO**	**1**		
22.12.2011	**2071**	**356**				**NNO**	**1**		
23.12.2011	**2072**	**357**				**NNO**	**1**		
25.12.2011	**2074**	**359**				**NNO**	**1**		
26.12.2011	**2075**	**360**				**NNO**	**1**		
28.12.2011	**2077**	**362**				**NNO**	**1**		
29.12.2011	**2078**	**363**				**NNO**	**1**		
31.12.2011	**2080**	**365**				**NNO**	**1**		
01.01.2012	**2081**	**1**				**NNO**	**1**		
02.01.2012	**2082**	**2**				**NNO**	**1**		
03.01.2012	**2083**	**3**				**NNO**	**1**		
04.01.2012	**2084**	**4**				**NNO**	**1**		
05.01.2012	**2085**	**5**				**NNO**	**1**		
06.01.2012	**2086**	**6**				**NNO**	**1**		
07.01.2012	**2087**	**7**				**NNO**	**1**		
02. Jan. 2012 - 13. Jan.2012	**2082-2093**	**002-013**	**Drag Campaign #7**	**1.25**		**NNO/DSN**	**6 + 6**		4hours around pericenter, DSN 70 m
Part 1									
02.01.2012	2082	002		1.28		**DSN**	1	cacelled	The OCC season has not ended / shifted
03.01.2012	2083	003				**DSN**	1	cacelled	The OCC season has not ended / shifted
04.01.2012	2084	004				**DSN**	1	cacelled	The OCC season has not ended / shifted
05.01.2012	2085	005				**DSN**	1	cacelled	The OCC season has not ended / shifted
06.01.2012	2086	006				**DSN**	1	cacelled	The OCC season has not ended / shifted
07.01.2012	2087	007				**DSN**	1	cacelled	The OCC season has not ended / shifted
Part 1									
08.01.2012	2088	008				NNO	1	requested	4hours around pericenter

09.01.2012	2089	009				NNO	1	requested	4hours around pericenter
10.01.2012	2090	010				NNO	1	requested	4hours around pericenter
11.01.2012	2091	011				NNO	1	requested	4hours around pericenter
12.01.2012	2092	012				NNO	1	requested	4hours around pericenter
13.01.2012	2093	013		1.22		NNO	1	requested	4hours around pericenter
Part 2									
14.01.2012	2094	014				**DSN**	1	requested	4hours around pericenter, DSN 70 m
15.01.2012	2095	015				**DSN**	1	requested	4hours around pericenter, DSN 70 m
16.01.2012	2096	016				**DSN**	1	requested	4hours around pericenter, DSN 70 m
17.01.2012	2097	017				**DSN**	1	requested	4hours around pericenter, DSN 70 m
18.01.2012	2098	018				**DSN**	1	requested	4hours around pericenter, DSN 70 m
19.01.2012	2099	019				**DSN**	1	requested	4hours around pericenter, DSN 70 m
July 2012			**Drag Campaign #8 (Aerobraking)**			**DSN**	**6**		4hours around pericenter, DSN 70 m
November 2012			**Drag Campaign #9 (Aerobraking)**			**DSN**	**6**		4hours around pericenter, DSN 70 m

10. ANNEX 6. COVERAGE IN THE VERA OCCULTATION EXPERIMENT

"Asymmetric" radio-occultation