OUTLINE FOR SCIENCE SECTION

Proposed new outline with hopefully a better logical order and with science emphasized.

D. Science investigation
  D.1. Science objectives
  D.2. Plasma environment and escape processes
  D.3. Measurement requirements
  D.4. Science implementation
    D.4.a. Data Analysis
    D.4.b. Data Processing and Archiving
    D.4.c. Instrumentation
    D.4.d. Mission concept
    D.4.e. Science Team
  D.5. Science Data and other products
  D.6. Minimum science mission

FIGURES TO BE ADDED

- Do we have a cover? Collage of hybrid model run showing the asymmetric outflow on top of a photograph of venus shouldn't be too hard to throw together.
- ENA images of (right now, most of the simulations are from Mars):
  - Direct solar wind interaction with atmosphere
  - Pick-up ions emphasizing the asymmetry in outflow
  - Backscattered ENAs emphasizing the signature of atmospheric particle precipitation
- Kallio and Janhunen [2002] O+ and O-ENA image from hybrid model.
- **Spectra:** Simulated ENA spectra for Venus illustrating the spectral differences of planetary ENAs and solar wind ENAs. Need to show this to illustrate how well we think we can separate planetary H-ENAs from solar wind ENAs by their spectral signature in NPD. Right now I have Lichtenegger et al.'s [2002] spectra in here, but if we have any results from within the team (or from Kallio) we might want to use that instead. I'm asking Kallio about this as well.
- Simulated spectra of backscattered Oxygen-ENAs from Venus (Luhmann and Kozyra, 1991).
- Relation ENA-escape rate from Barabash et al. [2002] but for Venus.

OPEN ISSUES

1. Scientific closure is needed for the atmospheric escape rate estimation. A good place for this is probably in the Data Analysis subsection. What I mean by this is that we need to describe the plan for estimating the global escape rates by using NPI, NPD, IMA and models.

2. Luhmann and Kozyra: In this version I have thrown in results by Barabash, Holmstrom, Kallio, to show model results for solar wind ENAs, ENA albedo effects, Oxygen ENA escape, and full blown hybrid model. Please forgive my ignorance. What models do you have cooking, or do you anticipate close collaboration with Kallio?

3. All ENA simulations only take into account one single charge exchange interaction. Multiple interaction in the "thick" part of the atmosphere will certainly modify the ENA fluxes we expect and may be important for the energy deposition as well. Ed is working on this right now.

4. We should elaborate more on how we're going to use in-situ measurements in our estimation of global escape rates. The only thing I can think of is to use in-situ passes to restrict the boundary

conditions of the particular model (that will provide us with simulate ENA images) we choose to use. Any ideas?

5. Mention some of the science that the JPL proposal is going to cover, so that we complement each other smoothly.

6. Need to mention extraction of fundamental exospheric parameters and solar wind flow geometry. Roelof, Kallio and Holmstrom had an idea for a technique in the Aspera-3 proposal that we might want to add. Ed, any comments on this?

Science Investigation

[SOME RELEVANT INTRO HERE]

D.1. Science Objectives

[I'm trying to hit the central objectives hard here, so that reviewers know from the start what central question(s) we are going to answer. Also, I'm trying to keep the number of questions to a minimum. I think that the estimation of global escape rates should be strongly emphasized. Easy to understand for a reviewer. Atmospheric heating is baked into that question.]

The central science objective of the entire VEX mission is to find out *how the atmosphere of Venus evolves under the combined effects of escape and interactions with the solid planet*. This can be subdivided into three investigations: (1) Surface and surface interactions; (2) Lower, middle, and upper atmosphere; And (3) plasma environment and escape processes. This proposal aims at investigating the last point of these three, by analyzing data from and providing hardware for the ASPERA-4 experiment. The objectives of the ASPERA-4 experiment are to perform:

1) **Remote measurements of ENAs in order to**
    a) **investigate the interaction between the solar wind and Venusian atmosphere,**
    b) **characterize quantitatively the impact of the plasma process on the atmosphere evolution, and**
    c) **obtain the global plasma and neutral gas distributions in the near-Venus environment.**
2) **in-situ measurements of ions and electrons in order to**
    a) **complement the ENA images (electrons and multiply-charged ions cannot be imaged by ENAs),**
    b) **provide undisturbed solar wind parameters necessary for interpretation of the ENA images.**

The two most important questions of the ASPERA-4 investigation can be summarized as follows:

I. **<u>What is the global atmospheric escape rates of ions and neutrals to space.?</u>**
II. **<u>What is the energy deposition to the atmosphere of precipitating particles from space?</u>**

There are two main reasons why an estimate of the global atmospheric escape rate is needed for Venus: First, it is needed to fulfill the objective of the entire VEX mission. Second, in order to fully understand the different fates of the three sister planets Mars, Earth, and Venus, we need to establish the significance of atmospheric escape to space in the overall atmospheric budget. Understanding the energy deposition of particle precipitation into the atmosphere is a part of understanding the thermal escapes to space as well as atmospheric heat budget [MORE FROM KOZYRA HERE?]

[BELOW ARE A FEW LEFT-OVERS FROM THE PREVIOUS VERSION. WE PROBABLY NEED MORE ON VEX ATMOSPHERE OBJECTIVES HERE AND MENTIONING OF D/H RATIOS THAT WILL BE ADDRESSED BY THE JPL PROPOSAL.]

The Venera and Pioneer Venus orbiters found that the current induced by the solar wind electric field forms a magnetic barrier (induced magnetic field) that deflects most of the solar wind flow around the planet and leads to the formation of the bow shock [Russell and Vaisberg, 1983]. This bow shock compresses the ionosphere on the dayside causing rapid anti-sunward convection and tail rails on the nightside. However, the short lifetime of the Venera-9, and-10 orbiters, and insufficient temporal as well as the absence of mass resolution in the Pioneer Venus plasma instrument did not allow a study of the mass exchange between the solar wind and the upper atmosphere of Venus and energy deposition to the upper atmosphere in sufficient detail. Moreover, studies of the atmospheric escape *via in situ* measurements are inherently limited by spatial coverage of a spacecraft and can be performed only statistically. Only through global imaging techniques such as ENA imaging by ASPERA-4 can instantaneous observations of the global distribution of the escaping plasma be provided [Williams et al., 1992].

While the plasma dynamics in the near-Venus space is governed by the interplanetary magnetic field, the plasma transport in the ionosphere is fully determined by the local magnetic field, originating from a pileup of the interplanetary magnetic field around the planet, and secondary magnetic fields due to local currents in the ionospheric plasma. Through such currents the magnetic field structure around Venus is closely associated with the formation of the main plasma boundaries and domains such as magnetosheath, magnetic barrier, the ionopause, and the magnetotail. In turn the geometry of the structures constrains possible plasma escape channels. Therefore it is obvious that it will be difficult to interpret the *in situ* plasma measurements and associated ionospheric structures below, without the help of magnetic field measurements. The investigation of vertical distribution of species in the exosphere and plasma/magnetic field ENA environment near Venus is very important in order to understand the evolution of terrestrial atmospheres and to understand better the Earth's environment during the epochs of weak magnetic field.

The Analyser of Space Plasmas and Energetic Atoms is the fourth experiment (ASPERA-4) within the ASPERA investigation series. The ASPERA experiment series has improved its instrument complement. The ASPERA-4 is virtually identical to the ASPERA-3 unit flying on the ESA Mars Express Mission (inserted into Mars orbit 25 December 2003). ASPERA-4 studies the solar wind interaction with the planet with the use of a 3D ion mass analyzer, high energy resolution electron spectrometer, and energetic neutral atom imager. This proposal to NASA seeks support for the United States part of the ASPERA-4 experiment team under the Mission of Opportunity category. Included within the United States portion of the ASPERA-4 experiment is support for 1) the electron spectrometer instrumentation, 2) surface preparation of internal instrument components within the neutral particle detector, 3) ASPERA-4 telemetry ground system development and operation, and 5) theoretical, science, and analysis of ASPERA-4 data from the Venus Express mission. The emphasis of this proposal is on the United States portion of the ASPERA-4 experiment. More detailed information on the VEX mission objectives and overall science can be found in the VEX Mission Definition Report [http://www.rssd.esa.int/SB-general/Projects/VenusExpress/VEX_MDR_final.PDF].

The first phase of Venus spacecraft exploration (1962-1985) by the Venera, Pioneer Venus and Vega missions established a basic description of the physical and chemical conditions prevailing in the atmosphere, near-planetary environment, and at the surface of the planet. At the same time, they raised many questions on the physical processes sustaining these conditions, most of which remain as of today, unsolved. Extensive radar mapping by Venera-15,-16 and Magellan orbiters, combined with earlier glimpses from landers, have expanded considerably our knowledge of Venus' geology and geophysics. A similar systematic survey of the atmosphere is now in order. This particularly concerns the atmosphere below the cloud tops, which, with the exception of local measurements from descent probes, has escaped detection from previous Venus orbiters. Many problems of the solar wind interaction, in particular those related to the impact of planetary evolution are still not resolved.

The fundamental mysteries of Venus are related to the global atmospheric circulation, the atmospheric chemical composition and its variations, the surface-atmosphere physical and chemical interactions including volcanism, the physics and chemistry of the cloud layer, the thermal balance and role of trace gases in the greenhouse effect, the origin and evolution of the atmosphere, and the plasma environment and its interaction with the solar wind. Besides, the key issues of the history of Venusian volcanism, the global tectonic structure of Venus, and important characteristics of the planet's surface are still unresolved. Beyond the specific case of Venus, resolving these issues are of crucial importance in a comparative planetology context and notably for understanding the long-term climatic evolution processes on Earth.

The study of escape processes from the upper atmosphere has direct implications for the origin and evolution of the Venus atmosphere. Venus is similar to Earth in size and density, and it is likely that Venus contained initially a similar amount of volatiles. How did the atmosphere of Venus evolve under the combined effects of escape and interaction with the solid planet? Why did the two neighboring planets become so different? At present, there is evidently no water in significant amount on Venus, possibly explained by intense hydrogen escape at early epochs. Similarly, the lack of molecular oxygen in the present Venus atmosphere requires extremely strong escape in the past and/or massive oxidation of surface material. Current understanding of these processes based on relative abundance of noble gases and isotopic ratios is rather poor.

The history of water on the planet is recorded in the value of the D/H ratio. Deuterium is found to be ~150 times more abundant on Venus than on Earth [Donahue et al., 1997]. This enrichment of D/H is explained by preferential escape of H atoms from the upper atmosphere. The present water content and D/H ratio can be interpreted either as the signature of a lost primordial ocean, or a steady state in which water is continuously supplied to the surface by comets or volcanism, or a non-steady regime combining the two sources. The present lifetime of the atmospheric water is highly uncertain but is likely less than 1 million years, so that the primordial ocean is probably not the sole source of the present water. It may however be possible to derive constraints on the primordial water abundance by measuring precisely the atmospheric escape of water (i.e. of H atoms).

The absence of a planetary magnetic field leads to important differences between Venus' and Earth's atmospheric escape and energy deposition processes. The upper atmosphere of Venus is not protected by magnetic field from direct interaction with the solar wind. As a result, a large portion of the exosphere resides in the shocked solar wind flow; the Photo Ionization, charge exchange and electron impact ionization effectively remove ionized exospheric components by the plasma flow. The tailward convection of the plasma mantle, situated between the shocked solar wind flow and the ionosphere, leads to another type of atmospheric loss. The ions gyrating around the magnetic field embedded in plasma may re-enter the atmosphere causing its massive sputtering [Luhmann and Kozyra, 1991]. Finally, erosion of the Venusian ionosphere under varying solar wind conditions provides an additional loss mechanism of atmospheric constituents. The solar wind interacts with the top of the ionosphere to form a complex array of plasma clouds, tail rails, filaments and ionospheric holes on the night side. A substantial amount of material leaves the planet due to these escape mechanisms. Figure 1 illustrates associated electrodynamics processes and plasma domains of the Venus upper ionosphere. It is not known whether this picture, obtained for solar maximum conditions, is valid for solar minimum when the ionospheric structure becomes different (the Venus Express encounter is schedules for solar minimum). The escape mechanisms induced by the solar wind are the dominant ones for the loss of heavy atmospheric gases such as oxygen because the planetary gravitational force inhibits the Jeans (thermal) escape even for non-thermal components.

The Aspera-4 experiment seeks to characterize the plasma environment of Venus and provide global atmospheric escape rates. The rest of this proposal will focus on the objective of the Aspera-4 experiment. Below we will review the current knowledge of solar wind interaction and atmospheric escape processes, describe the measurements needed to make these estimates, and propose a method of analysis to estimate the global escape rates using a combination of global and in-situ measurements hosted by the Aspera-4 experiment.

D.2. Plasma environment and escape processes

BRIEF INTRO ON THE GENERAL PLASMA ENVIRONMENT RELATING TO FIG 1.

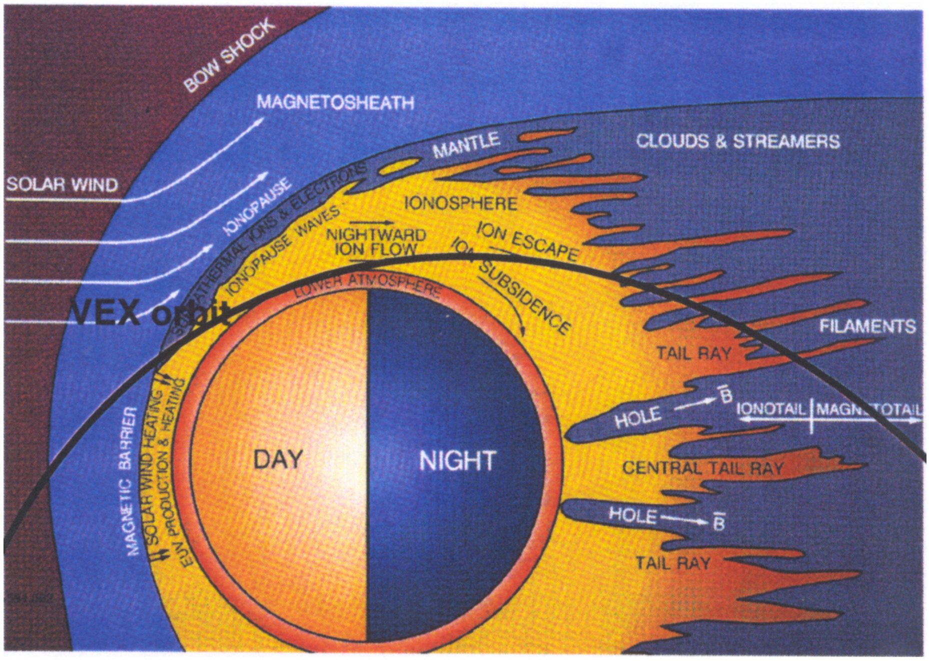


Figure 1. The Near Planet Structure Around Venus. Shown is an artist conception of the structure of the Venus ionosphere induced by the solar wind interactions. The black line shows the Venus Express orbit. ASPERA-4 operations occur through out the solar wind interaction region.

The dominant escape process of a non-magnetized planet is the pick-up process. Solar radiation is the source for ionizing the atmospheric neutrals which forms an ionosphere. A thermal ion from the ionosphere is gradually accelerated by the convective electric field from the solar wind. The pick-up ion can reach an energy greater than the escape energy and thus be lost from the ionospheric and atmospheric system and instead be a part of the solar wind (mass loading). Due to the large gyroradii of the ion the pick-up ion process is expected to be highly asymmetric. Depending on the direction of the solar wind magnetic field (and therefore the direction of the convective electric field) an ion picked up in one hemisphere will be accelerated towards the surface and thus have no room to make even one gyration before it hits the planetary atmosphere again and is lost to the atmosphere. An ion picked up in the opposite hemisphere will more easily be accelerated away from the planet. A presence of such an asymmetry in energetic ion outflow is therefore a clear indicator that a pick-up process is at work.

This process should be effective for H+ through O+ and even molecular ions such as O2+, CO2+, N2+, CO+, and NO+ [Luhmann et al., 1995].

A second escape process is the heating of atmospheric species to energies above the gravitational escape energy. In the case of Mars, the dominating heat source is solar EUV and penetration of solar wind ions. The second most important heat source is precipitating ENAs produced in the solar wind and by charge exchange of pick-up ions. The third source is precipitating pick-up O+ and protons. Although solar radiation and solar wind ion precipitation is the dominating heating process, the second and third source may be important for the long-term evolution of the atmosphere.

[MORE HERE FROM LUHMANN&KOZYRA ON BACKSCATTERED IONS AND PERHAPS THEIR SPECTRUM (Fig 8 in Luhmannand Kozyra, 1991)]

[BELOW IS AN ATTEMPT TO EXPLAIN WHY WE USE ENA IMAGING]
Attempts to estimate the global escape rates from in-situ data and modeling have been made at both Mars and Venus [Lundin and Dubinin, 1992; Mihalov and Barnes 1982; Brace et al., 1987; Moore et al., 1991]. While reasonable estimates can be given with sufficient number of orbits, it is difficult to say whether these are realistic. The morphology of the outflow (and precipitation) is highly dependent on the IMF.

[MORE ON OBSERVATIONALLY ESTIMATED ESCAPE RATES HERE]

A new, promising technique to make global measurements is the detection of ENAs [Kallio et al., 1997; Barabash et al., 2002; Lichtenegger et al., 2002]. While ENA imaging has proven useful to image the Earth’s ring current, plasma sheet and ionospheric outflow, the Aspera-3 experiment on board the MEX mission is the first of its kind to utilize this technique at a non-magnetized planet. The Low-Energy Neutral Atom (LENA) imager on board the IMAGE mission could detect the ENAs produced in the Earth’s magnetosheath from charge exchange between the solar wind flow and the neutral exosphere [Moore et al., 2003; Fok et al., 2003].

There are three main sources of ENAs at non-magnetized planets. The first is the direct interaction of the solar wind ions with the neutral exosphere and upper atmosphere of the planet. ENAs will be produced primarily in the direction of the deflected solar wind flow around the planet and so, ENA flux will be highly dependent on the vantage point. Their energy spectrum will be characteristic of the solar wind ion energy with very little spread. Figure 2 shows a simulated ENA spectrum

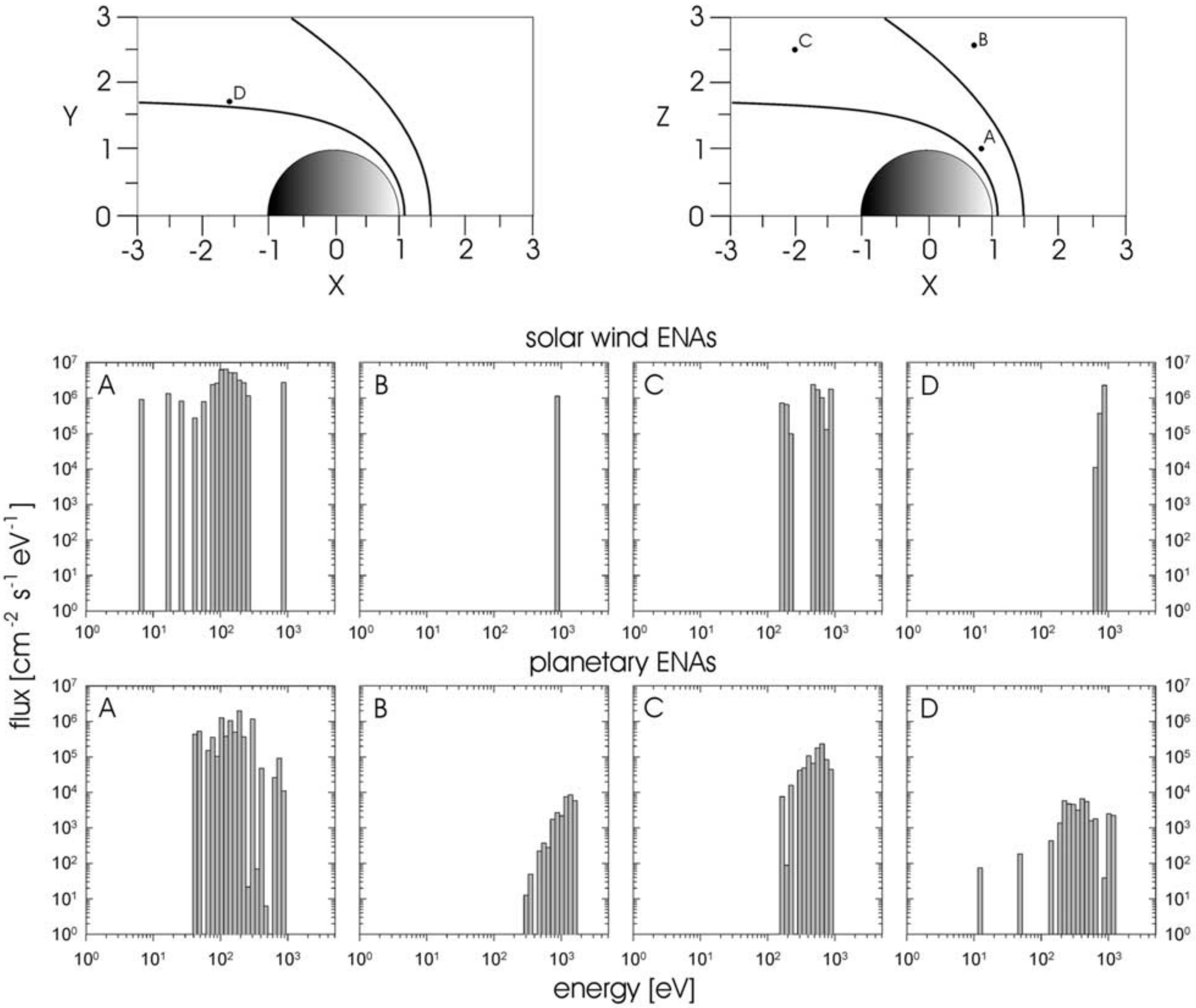


Figure 2: Upper panel: Position in the simulation box where the ENA energy spectra are calculated. Middle and lower panel: Energy spectra of ENAs coming from the solar wind and from the planetary atmosphere, respectively. The bin at ~840 eV includes ENAs born upstream of the bow shock. Taken from Lichtengger et al., [2002].

The second source of ENAs is the charge exchange of pick-up ions with the neutral exosphere and upper atmosphere. Since the pick-up ions constitute the main atmospheric escape, global images of ENAs produced by the pick-up ions will provide the best information on global escape morphology and rates.

The third known source of ENAs is the backscattered ENAs produced by precipitating ENAs into the atmosphere. Both ENAs from the pick-up ion process [Luhmann and Kozyra 1991] as well as ENAs produced by solar wind ions [Kallio and Barabash, 2001] can precipitate into the atmosphere and produce backscattered ENAs.

Figure 3 shows ENA image simulated using only the proton solar wind flow.

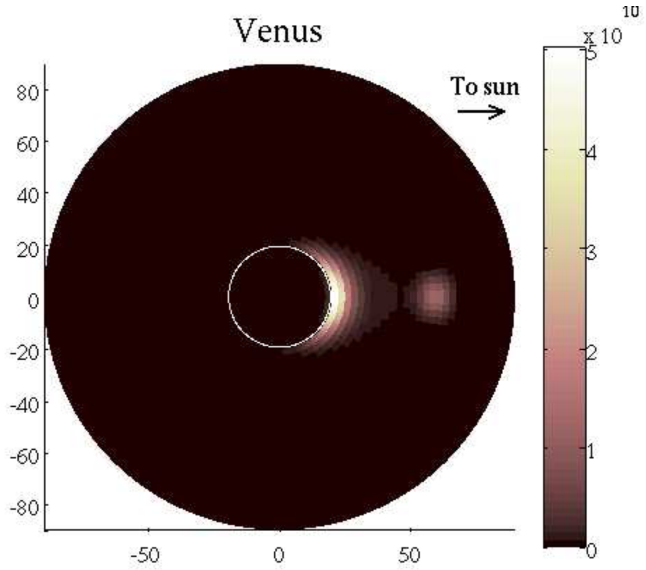


Figure 3: ENA simulation showing only the solar wind proton flow. The solar wind proton flow is based on an MHD model by Biernat et al. [2001]. The observer is located at a distance of 3 RV at a solar zenith angle of 120 deg.

Figure 4 shows ENA simulations of the atmospheric O+ ion escape from two different vantage points at Mars (SHOULD BE UPDATED TO VENUS!). Here, the model by Barabash et al. [2002] was used to compute the global escape rate of O+ ions. The model is based on the semi-empirical stream line model by Kallio [1996], which provides a velocity, magnetic field and density around a non-magnetized planet. Barabash et al. [2002] used the velocity and magnetic field to compute the convective electric field. Assuming an initial thermal ionospheric O+ distribution they could integrate the equation of motion to compute the final distribution of picked-up O+ ions. We can see in Figure X that this model reproduces the essential asymmetric features of the atmospheric escape.

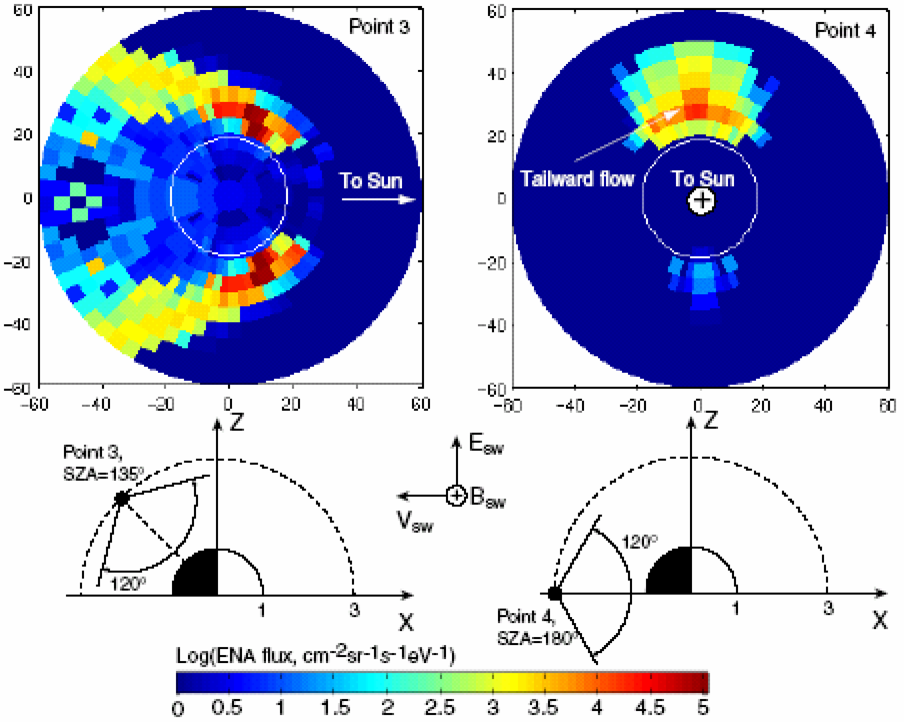


Figure 4: Simulated ENA images of pick-up O+ ions from two different vantage points. Note the asymmetric outflow of O+ in the right image. The model uses a computationally efficient analytic streamline model to compute the acceleration of the O+ pick-up ions. This kind of model will be used to understand the overall features of the solar wind flow and provide preliminary estimate of the global outflow.

Figure 5 shows the effects at Mars of the backscattered ENAs ("ENA albedo").

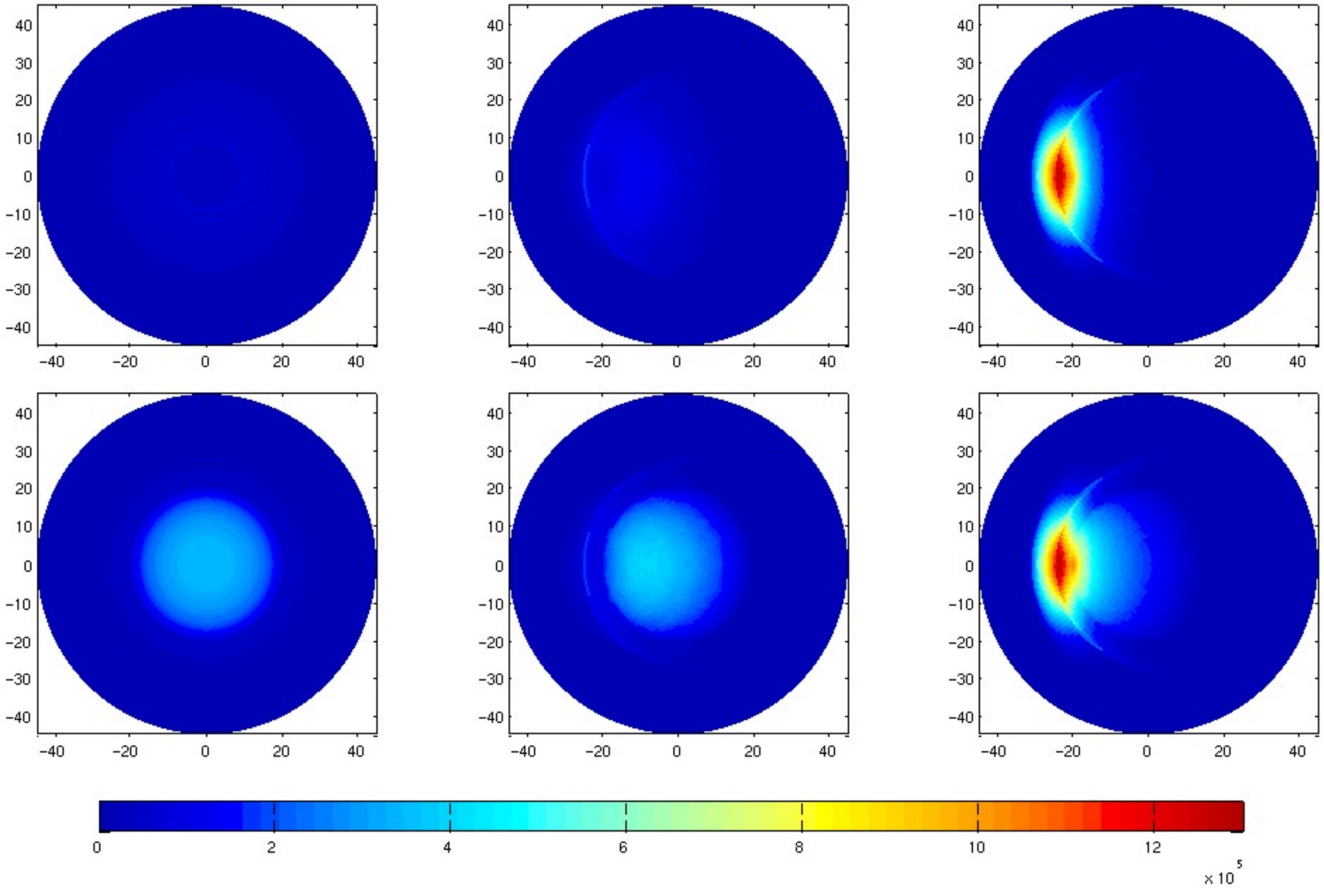


Figure 5: ENA simulation showing the ENA "albedo" at Mars produced by the backscattered precipitating ENAs. Figure taken from Holmstrom et al. [2002]. The top row is images without ENA albedo, while the bottom row includes the effect. From left to right, the angle between the Sun-Mars line and the view position is 0_, 30_, and 60_. The images have a field of view of 90_, at a distance of 3 Rm from the center of Mars, with the Sun to the left. All other view parameters are identical to those in Plate 1. The unit of the intensity is [1/(cm2 sterad s)].

There are more advanced models, that will be used to analyze the observations, such as the quasi-neutral hybrid model developed by Kallio and Janhunen [2002]. Here, electrons are treated as an MHD fluid while ions are traced in the resulting electric and magnetic field. Figure 6 show a results from one run of this model. It clearly shows the asymmetric feature of the O+ distribution due to the solar wind convection electric field and the large gyroradii of the O+ ions. This kind of model is expected to provide much more realistic results at the expense of computation time (several days for one run). Therefore, we anticipate preliminary modeling using the less complex models to obtain the global features of solar wind flow and outflow. Detailed studies would use the more complex hybrid model. We will describe in more detail the proposed analysis scheme below (in Section "Data Analysis").

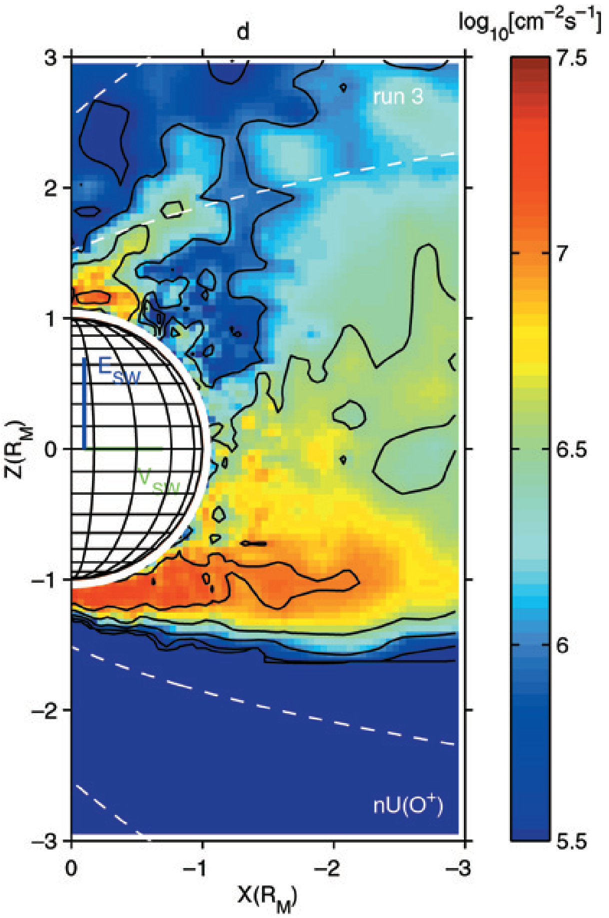


Figure 6: O+ ion flux at Mats (TO BE UPDATED WITH VENUS) from a run of the quasi-neutral hybrid model developed by Kallio and Janhunen [2002]. Note the strong asymmetry north-south asymmetry due to the solar wind convective electric field and the large gyro radii of the O+ ions. This kind of model will be crucial to understand more detailed features of the solar wind interaction and the atmospheric escape.

[ABOUT LOW-ALTITUDE ENA EMISSIONS. MORE NEEDED. ED IS CURRENTLY WORKING ON THIS.]All available models for ENA production assume only a single charge exchange interaction for each ion. ENA measurements at Earth have shown that multiple charge exchange and stripping interactions are needed to model the ENA emissions correctly [Roelof et al., ????]. We anticipate to take into account multiple interactions in the simulation of ENA images as well as in the modeling. The multiple interaction will change the amount of energy deposited in the upper atmosphere.

D.3. Measurement Requirements

In order to estimate the atmospheric escape rates the instruments must be able to separate planetary ENAs from solar wind ENAs. Almost all Oxygen ENAs are planetary in origin, but Hydrogen ENAs could originate from the atmosphere (pick-up ions) or the direct charge exchange between the solar wind protons and the neutral exosphere. According to the simulated spectra in Figure X, solar wind Hydrogen ENAs have a spectrum that peaks around 1 keV, whereas the planetary Hydrogen ENAs display an almost flat continuum down to about 10-100 eV. Table 1 below describes

[The following table is taken directly from the Aspera-3 proposal. The objectives in this traceability matrix should be consistent with what we're saying in the very beginning.]

Table 1. Measurement Requirements

SCIENTIFIC OBJECTIVE	ASSOCIATED MEASUREMENT	MEASUREMENT REQUIREMENTS
Determine the instantaneous global distribution of plasma and neutral gas near the planet	ENAs originated from the shocked solar wind	• Measure the ENA flux in the energy range 10's eV - ~1 keV with 4 pi coverage. • ENA flux > 10^4 (cm^2 sr s keV)$^{-1}$ • Measure the upstream solar wind parameters.
Study the plasma induced atmospheric escape	ENAs originating inside the magnetosphere	• Mass resolved (H, O) ENA measurements in the energy range up to ~10's keV. • ENA flux > 10^3 (cm^2 sr s keV)$^{-1}$
Investigate the modification of the atmosphere through particle precipitation	ENA albedo	• Mass resolved (H, O) ENA measurements down to ~10's eV. • ENA flux > 10^6 (cm^2 sr s keV)$^{-1}$ (at 100 eV).
Investigate the energy deposition from the solar wind to the ionosphere	Precipitating ENAs	• ENA measurements in the ~10 eV - ~1 keV. • ENA flux > 10^4 (cm^2 sr s keV)$^{-1}$
Define the local characteristics of the main plasma regions	Ion and electron measurements of hot plasma	• Ion and electron measurements in the energy range ~1 eV - ~10 keV with 4 pi coverage.

The ASPERA-4 experiment accomplishes measurement of these requirements using a set of four instruments. These instruments are the Neutral Particle Imager (NPI), the Neutral Particle Detector (NPD), the Ion Mass Analyzer (IMA), and the ELectron Spectrometer (ELS). The Neutral Particle Imager provides measurements of the integral ENA flux in the energy range 0.1 - 60 keV with no mass and energy resolution, but comparatively high angular resolution at 4.6°x 11.5°. The Neutral Particle Detector provides measurements of the ENA flux in the energy range 0.1 - 10 keV, resolving velocity and mass (H and O) with a coarse angular resolution. The Ion Mass Analyzer provides ion measurements in the energy range 0.01 - 30 keV/q for the main ion components at 1, 2, 4, 16 amu/q and the group of molecular ions between 20 - 80 amu/q. The instantaneous field of view is 4.6° x 360°. The Electron Spectrometer is a standard top-hat electrostatic analyzer in a very compact design covering the energy range 0.0º 1 - 20 keV with a field of view of 5° x 22.5°. The characteristics of these instruments are given in Table 2.

Table 2. ASPERA-4 Instrument Characteristics

ASPERA-4 Instrument	NPI	NPD	IMA	ELS
Particles to be measured	ENA	ENA	Ions	Electrons
Energy range, keV	0.1-60	0.1-60	0.01-40	0.0º 1-20
Energy resolution, $\Delta E/E$	No	80 %	10 %	8 %
Mass resolution	No	H, O	$M/\Delta M=5$	No
Intrinsic field of view	9° x 344°	9° x 180°	90° x 360°	10° x 360°
Angular resolution (FWHM)	4.6° x 11.5°	5° x 30°	5° x 22.5°	5° x 22.5°
G-factor / pixel, cm^2 sr	2.5 x 10^{-3} (no ϵ)	6.2 x 10^{-3} (no ϵ)	3.5 x 10^{-4} (ϵ included)	6 x 10^{-4} (ϵ included)
Efficiency, epsilon (ϵ), %	1 %	1 – 25 %	N/A	N/A
Time resolution for full 3D	32 sec	32 sec	32 sec	32 sec
Instrument Temporal Resolution	32 msec	32 msec	32 msec	32 msec

ASPERA-4 observations will be performed from an elliptical orbit between 250 km to 10,000 km altitude and of about 90º. Data measurements will be accomplished about the pericenter of the elliptical Venus Express orbit and stored in memory. On the apocenter of the orbit, telemetry will be transmitted to the Earth. ASPERA-4 instrument operations will be performed by IRF. The instruments have various data generation modes and IRF will allocate instrument telemetry within ASPERA-4 telemetry resources and within those of the Venus Express mission. ASPERA-4 data files are anticipated to be at most 500 Mbits/day. Results expected are energy spectra and ENA distributions that indicate locations of high flux density. Analysis of the ASPERA-4 data will reveal regions of particle and ENA flows around the planet. Ion and electron spectrograms are a standard analysis tool used for defining and characterizing plasma flow. Spacecraft orientation is used to understand plasma flow directions and regions, relating them to planet orientation.

Thus, ASPERA-4 addresses the question of determining atmospheric escape and plasma environment by *in situ* measurements of the energetic neutral atoms, ions, electrons. ASPERA-4 addresses the Venus Express goal of determining atmospheric escape and plasma environment by *in situ* measurements of the energetic neutral atoms, ions, electrons, and magnetic field and inference of escape rates.

D.4. Science Implementation

The Analyzer of Space Plasmas and Energetic Atoms has been selected as a part of the ESA Venus Express core payload. The launch date is November, 2005. The ASPERA-4 instrument is a copy of the ASPERA-3 experiment to be flown to Mars on the ESA Mars Express mission with a launch of June 2, 2003. The general scientific objective of the ASPERA-4 experiment, to study the solar wind-atmosphere interaction and to characterize the plasma and neutral gas environment in the near-Venus space through energetic neutral atom (ENA) imaging, are similar to the ESA Mars Express mission. Thus, this opportunity provides a unique opportunity to investigate another non-magnetized planets. It provides the added benefit that both planets (Mars and Venus) will be studied with identical instrumentation.

The ASPERA-4 (and ASPERA-3 shown in Figure 2) instrument comprises four sensors, two ENA imagers, an electron spectrometer, and ion spectrometer. The Neutral Particle Imager (NPI) provides measurements of the integral ENA flux in the energy range 0.1 - 60 keV with no mass and energy resolution, but comparatively high angular resolution at 4.6° x 11.5°. The Neutral Particle Detector (NPD) provides measurements of the ENA flux in the energy range 0.1 - 10 keV, resolving velocity and mass (H and O) with a coarse angular resolution. The Electron Spectrometer (ELS) is a standard top-hat electrostatic analyzer in a very compact design with high energy resolution to achieve good photoelectron measurements. ELS measures electrons in an energy range 0.001 – 20 keV These three sensors are located on a scanning platform to cover ideally the full 4π sphere.

The ASPERA instrument also contains a mass resolving sensor, IMA (Ion Mass Analyzer). IMA provides ion measurements in the energy range 0.01 - 30 keV/q for the main ion components (1, 2, 4, 16 amu/q) and the group of molecular ions (20 - 80 amu/q). The instantaneous field of view is 4.6° x 360°. Electrostatic sweeping performs elevation coverage of + and - 45º with respect to the IMA aperture plane.

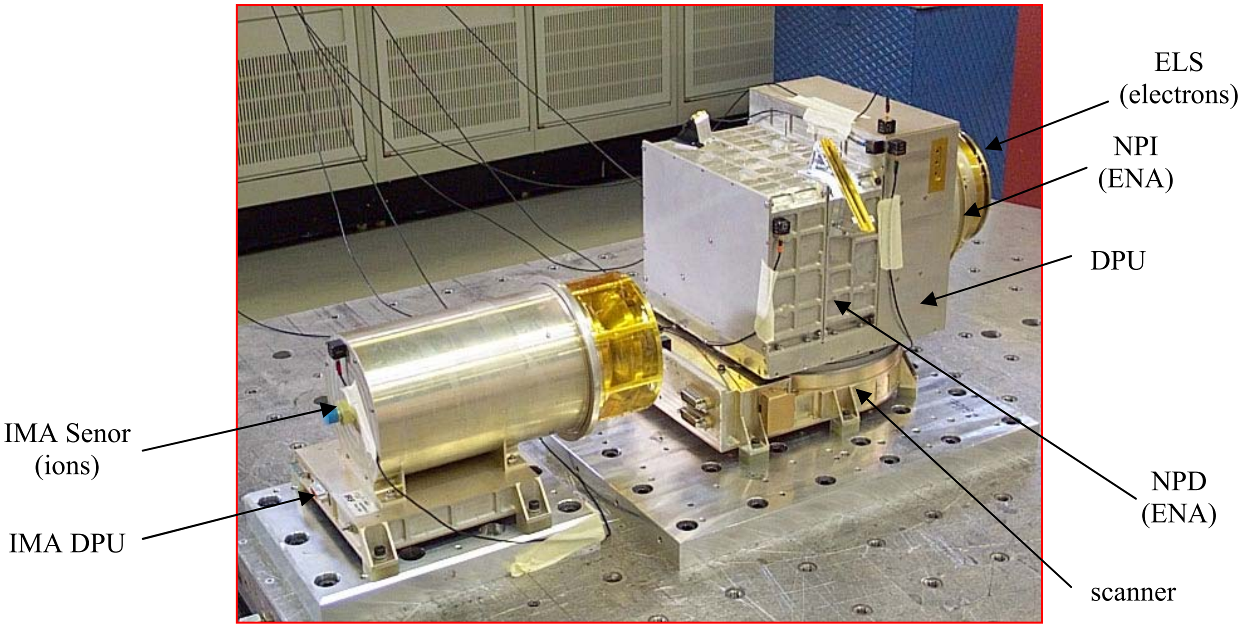


Figure 2. Shown here is the ASPERA-3 experiment undergoing vibration testing. The main unit (right) is mounted on the top of the Mars Express spacecraft and contains the ELS, NPI, and NPD instruments mounted on a scanner. The IMA unit (left) is mounted on the bottom of the spacecraft. The ASPERA-4 experiment on Venus Express spacecraft uses mostly modified Flight Spare units from Mars Express instrumentation and will be flown is the same configuration.

D.4.a. Data Analysis

[This is where the "recipe" of how we're proposing to extract global escape rates should be.]

Data analysis will be the prime responsibility of the Science Team (see below). In order to provide estimates of the global atmospheric escape rates, we need to relate the global ENA fluxes to total ion (and ENA) outflow. This has to be done in close synthesis with models and measurements [Barabash et al., 2002]. The following steps outline how we propose to do this.

1. **Process ENA images:** ENA images need to be assembled and validated from NPI and NPD.
2. **Separate planetary ENAs from solar wind ENAs with the best possible resolution:** Oxygen ENAs can be separated from Hydrogen ENAs by NPD. The resolution of the species-separated images needs to be improved by use of the higher resolution (but no mass or energy resolution) data from NPI. **[DON'T KNOW HOW YET]**
3. **Run realistic models for atmospheric escape with boundary conditions set by in-situ measurements:** Use computationally efficient models of the solar wind flow and ionosphere to model pick-up ion processes and estimate the global escape rates and affects of particle precipitation.

D.4.b. Data Processing and Archiving

Data processing and archiving will be the primary responsibility of SwRI (Dr. Winningham, Dr. Sharber, and Dr. Frahm). ASPERA-4 data from the Venus Express spacecraft will be telemetered through the ESA ESTEC data collection system. This data will be transmitted electronically to the ASPERA-4 PI institution, IRF. IRF will in turn send the telemetry to SwRI. SwRI will process the Venus Express telemetry into files of IDFS format. SwRI will archive this processed data, transmit the processed data to IRF for archival, transmit this data to the remainder of the ASPERA-4 team, and update public web displays with ASPERA-4 data. The goal is to complete all data processing and archiving within 24 hours of when data is delivered to SwRI.

ESA requires a 6 month proprietary data use period. After this time, ASPERA-4 data will be transmitted to the Planetary Data Systems (PDS) node for long-term NASA archival. The PDS system can archive IDFS format data and it will accept data from SwRI electronically. This system of data archival to PDS will be similar to the system of archiving ASPERA-3 data from Mars Express which is currently under construction.

ASPERA-4 data will have mirror archive web site access for the ASPERA-4 CoIs in Europe at IRF and the USA at SwRI. Network speeds between IRF and SwRI are around 4 Mbits/sec and data files are anticipated to be at most 500 Mbits/day. The dual mirror site configuration allows data to be accessed from either system at any time and provides redundancy and a back-up should one archive site encounter difficulties. SwRI will also directly send data files to other ASPERA-4 CoIs as directed by the ASPERA-4 PI.

The IDFS system stores raw data and analysis procedures. Conversions to valid science data occur on the fly. Computer speeds are more than adequate to achieve multiprocessing of large data quantities in short periods of time. It is not uncommon to plot data from a 32-point spectrum (at 1 spectrum per second) for an analysis time period of several hours within a few seconds of clock time.

IDFS is a standard file format. IDFS files can be viewed using the SwRI SDDAS system. SDDAS takes full advantage of the IDFS definitions and executes data calibration on-the-fly. SDDAS will be used to construct a password protected web site which will have public and private areas. The public areas will show displays of uncalibrated data directly from telemetry. Private areas will be access for ASPERA-4 CoIs only. The private areas may be used by the CoIs to examine data details, adjust data calibrations, download data to their home institutions, or generate presentations with the latest calibrated data. This web site for ASPERA-4 Venus Express data will be modeled after the Cluster/PEACE high resolution data system, which can be found at http://cluster2.space.swri.edu/.

After the 6 month proprietary data use period required by ESA, SDDAS will be executed to create stand-alone ASPERA-4 data files to be archived in the PDS system of the USA. When executing SDDAS, the latest calibration factors will be used to generate static data for PDS. Data files are expected to be transmitted to PDS each day after being delayed by 6 months for science evaluation. It is expected that there will be times when the PDS node may have difficulties maintaining the daily transfer cycle, so periodically, PDS is expected to re-request data sets. The normal Venus Express mission end date is November of 2007. Six months are then allotted to achieve the ESA proprietary requirement and then 6 additional months are allotted to fill in data gaps missing by PDS, reprocessing of any data archived at PDS that has had calibration parameters adjusted since archival at PDS and submission of all other data products.

Currently, SDDAS displays a variety of data. IDFS data archival format was developed under the NASA DE, UARS, and TSS and Cluster programs. SDDAS is continually improving and adding more tools to facilitate the ease of analysis and improve the number of analysis tools available. SDDAS is written generically so that any data in IDFS format may take advantage of any tools within SDDAS. Once data is placed within the IDFS format, all SDDAS functions become immediately available. This saves time and cost of re-developing analysis tools for each spacecraft mission.

The IDFS and SDDAS systems are being used as the Mars Express data archiving and analysis system for ASPERA-3. Similar ESA requirements also cause a delay of 6 months is archiving data at PDS. ASPERA-4 data delivery schedule is shown in Table 4:

Table 4. ASPERA-4 Data Delivery

	Launch ↓			**Encounter ↓**																			**End Normal ↓**	
	2006												**2007**											
Task Description	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
ASPERA-4 Data Acquired						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	🟨
ASPERA-4 Data Delivered to NASA PDS node												■	■	■	■	■	■	■	■	■	■	■	■	■

					End Normal Delivery ↓						**End Reprocessing Delivery ↓**												**End Extended Mission ↓**	
	2008												**2009**											
Task Description	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
ASPERA-4 Data Acquired	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
ASPERA-4 Data	■	■	■	■	■	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨

Delivered to NASA PDS node	■	🟨	🟨
ASPERA-4 Data Reprocessed		■	

					End Extended Delivery ↓	2010					End Reprocessing Delivery ↓	
Task Description	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
ASPERA-4 Data Delivered to NASA PDS node	🟨	🟨	🟨	🟨	🟨							
ASPERA-4 Data Reprocessed						🟨	🟨	🟨	🟨	🟨	🟨	

*Preflight calibration data delivered at the end of the mission

Data processing software will be verified using simulated data sets, laboratory calibration data, data from Mars Express where appropriate, and data from instrument level tests of ASPERA-4 on the Venus Express spacecraft. Preliminary analysis, comparison, and validation of data will occur during the orbital transfer phase of Venus Express. Data from the solar wind is fairly constant and mostly predictable. When possible, scaling laws will allow comparison of Venus Express data to identical instrumentation on ASPERA-3 at Mars.

The Venus Thermosphere General Circulation Model (VTGCM) simulates the physics of the Venus CO_2 dominated thermosphere and photochemical ionosphere, and has been documented in detail by Bougher et al. [1988, 1990, 1994; 1997]. It will be used for theoretical studies of the interaction of the Venus atmosphere with the solar wind. Through out the mission, VTGCM theoretical results will be compared with ASPERA-4 data

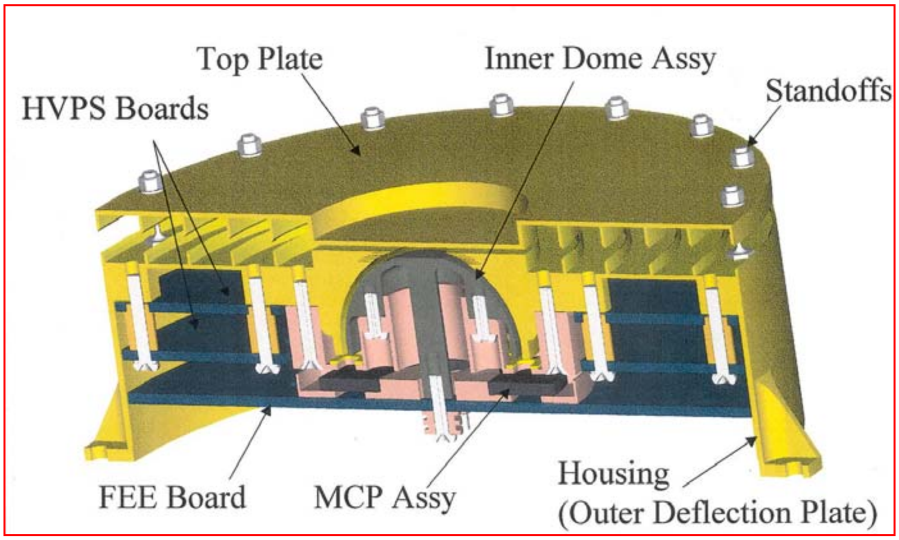
D.4.c. Instrumentation

The Electron Spectrometer (ELS) instrument represents a new generation of ultra-light (300 g), low-power (650 mW), electron sensors flight-proven on Astrid-2 and Munin (see Figure 3). It is formed by one spherical electrostatic analyzer in a top hat configuration with a single collimator system. Particles enter the aperture at any angle in the plane of incidence. Electrons are then deflected into the top hat spectrometer by applying a positive voltage to the inner spherical electron deflection plate. The electrons hit a microchannel plate (MCP) detector after being filtered in energy by the analyzer plates. The plates are stepped in voltage to achieve an energy spectrum.

Electrons with energies up to 20 keV/q will be measured, with a maximum time resolution of one energy sweep (128 values) per four seconds. There are 16 anodes, each defining a 22.5° sector, which provide simultaneous measurement. The ELS energy resolution is 8% and its geometric factor is 5.7×10^{-4} cm^2 sr. ELS was designed to resolve the major photoelectron peaks from Mars measurements (see Figure 4). Identification of these major peaks aids in identification of major atmospheric species which have been ionized. Its capabilities will be an important diagnostic tool used at Venus to identify atmospheric escape.

Figure 3. Internal View of the ASPERA-4 ELS. View of the ELS cut in half to reveal its major internal parts. ELS is a standard top hat sensor constructed with high precision.

SwRI will provide the ELS unit. The ELS Flight Spare from the Mars Express program will be modified and calibrated by MSSL, and become the Flight Unit for Venus Express. SwRI will upgrade, modify, and calibrate the Mars Express ELS engineering unit so that it becomes a space qualified Flight Spare for Venus Express.



The Neutral Particle detector (NPD) instrument consists of two identical detectors, each of which is a pinhole camera (see Figure 5). NPD provides measurements of the ENA flux, resolving velocity and mass (H and O) with a coarse angular resolution. Within each detector near the entrance, charged particles with energies up to 70 keV (electrons and ions) are removed by the deflection system. The deflection system consists of two 90° sectors separated by a 4.5 mm gap. Apart from being ON or OFF, the deflection system can be operated in an alternating mode.

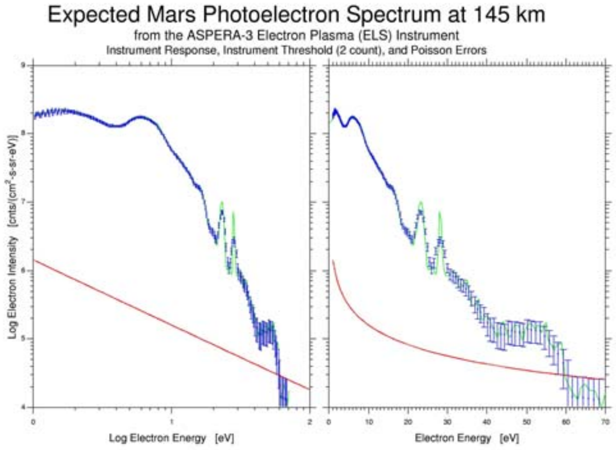


Figure 4. Mars Photoelectron Spectrum Comparison. Presented in this figure is a simulated measurement of ELS to a theoretical Martian electron spectrum (log presentation on the left; semilog presentation on the right). The energy resolution is such that the major photoelectron spectrum peaks can be resolved.

Entering particles not swepted away by the deflection plates are ENA particles. The ENA beam emerging from the 4.5 x 4.5-mm pin-hole hits the START surface under the grazing angle 20° and causes secondary electron emission from the START surface. Using a system of collecting grids, the secondary electrons are transported to one of two MCP assemblies giving the START signal for NPD's time-of-flight (TOF) electronics.

Depending on the azimuth angle, the collection efficiency varies from 80% to 95%. The incident ENAs are reflected from the START surface near-specularly. Since the charge state equilibrium is established during the interaction with the surface, the emerging beam contains both the neutral and ionized (positive and negative) components. To increase the total efficiency, no further separation by the charge is made. As proven by the ion tracing, there is very little disturbance to the reflected atomic ions leaving the START surface with an energy above 80 eV, introduced by the START electron optics. Therefore particles of all charge states - negative, neutral, and positive - will impact the second surface, the STOP surface, and again produce secondary electrons which are detected by one of the three MCP assemblies giving the STOP signal for NPD's TOF electronics.

The TOF over the fixed NPD distance of 8 cm defines the particle velocity. The STOP MCPs also give the azimuthal direction. Since the secondary electron yield emitted from the START surface for the same velocity ENA depends on the ENA mass, the pulse height distribution analysis of the START signals and independent analysis of the STOP signals provide the estimation of ENA mass. Each event is stored in the array START MCP charge x STOP MCP charge x time-of-flight x direction.

The UV suppression in NPD is based on the coincidence of START/STOP signals. To increase the particle reflectivity, we will use very smooth (roughness is of the order of 5 - 10 A) metal surfaces. On the other hand the STOP surface is proposed to be made of graphite (roughness around 100 nm) covered by MgO. This combination has a very high secondary electron yield, low photoelectron yield and high UV absorption. Both proposed surfaces are stable and do not require special maintaining.

The University of Arizona will be responsible for coating the NPD START surfaces. Two separate NPD units are required to produce a complete NPD instrument. There is one unit available as the spare from Mars Express ASPERA-3. IRF will produce a second NPD unit and a flight spare NPD unit the University of Arizona will coat the START surfaces for the 2 units produced by IRF.

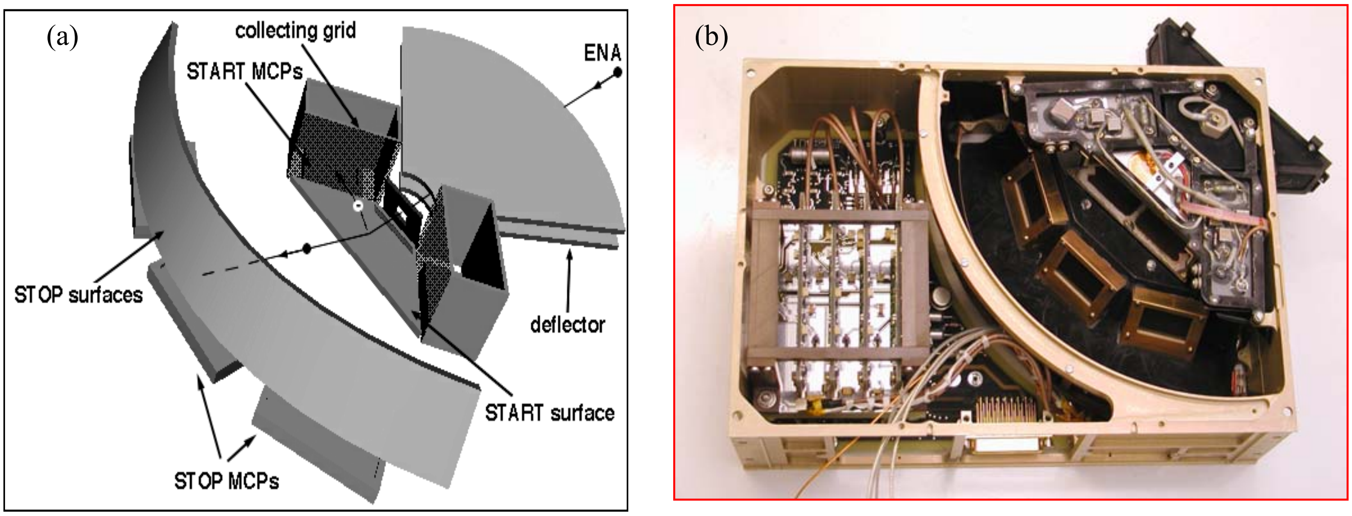


Figure 5. NPD in Theory and Practice. The theoretical design of the NPD is shown in (a). This design was implemented to produce an NPD flight unit shown in (b).

The Neutral Particle Imager (NPI) head is a replica of the NPI-MCP sensor developed for the ASPERA-C experiment on the Mars-96 mission and successfully, flown on the Swedish micro-satellite Astrid-1 launched in 1995 (see Figure 6). NPI provides measurements of the integral ENA flux with no mass and energy resolution, but comparatively high angular resolution. In the NPI the charged particles (electrons and ions) are removed by the electrostatic deflection system which consists of two disks separated by a 3 mm gap. The 5 kV potential sweeps away all charged particles with energies up to 60 keV. The disks also collimate the incoming beam in the elevation angle. Apart from being ON or OFF the deflection system can be operated in an alternating mode. The deflection system also collimates the beam into 32 sectors.

Neutrals passing through the deflection system hit a 32 sided cone target with a grazing (20°) angle of incidence. A MCP stack in the chevron configuration detects the particles leaving the target block with 32 anodes. The signal from the MCP gives the direction of the primary incoming neutral. The MCP operates in ion mode with a negative bias of -2.4 kV and thus detects (a) sputtered ions of the target material, (b) ions resulting from stripping of the primary neutrals, and (c) neutrals reflected from the target surface. In order to improve the angular resolution and collimate the particles leaving the interaction surface, 32 separating walls are attached to the target forming a star-like structure. NPI covers 4pi in one instrument scan and produces an image of the ENA distribution in the form of an azimuth x elevation matrix. To suppress the UV flux the NPI target uses the same coating as in the PIPPI and ASPERA-C experiments, namely, DAG 213, a resin-based graphite dispersion.

The flight spare units of NPI from the Mars Express mission are provided by Instituto de Fisica dello Spazio Interplanetari (IFSI) and IRF, and will be the flight units for Venus Express. IRF will modify the NPI units for the higher radiation environment experienced by the ASPERA-4 at Venus and calibrated by the Institute of Space and Astronautical .Science (ISAS).

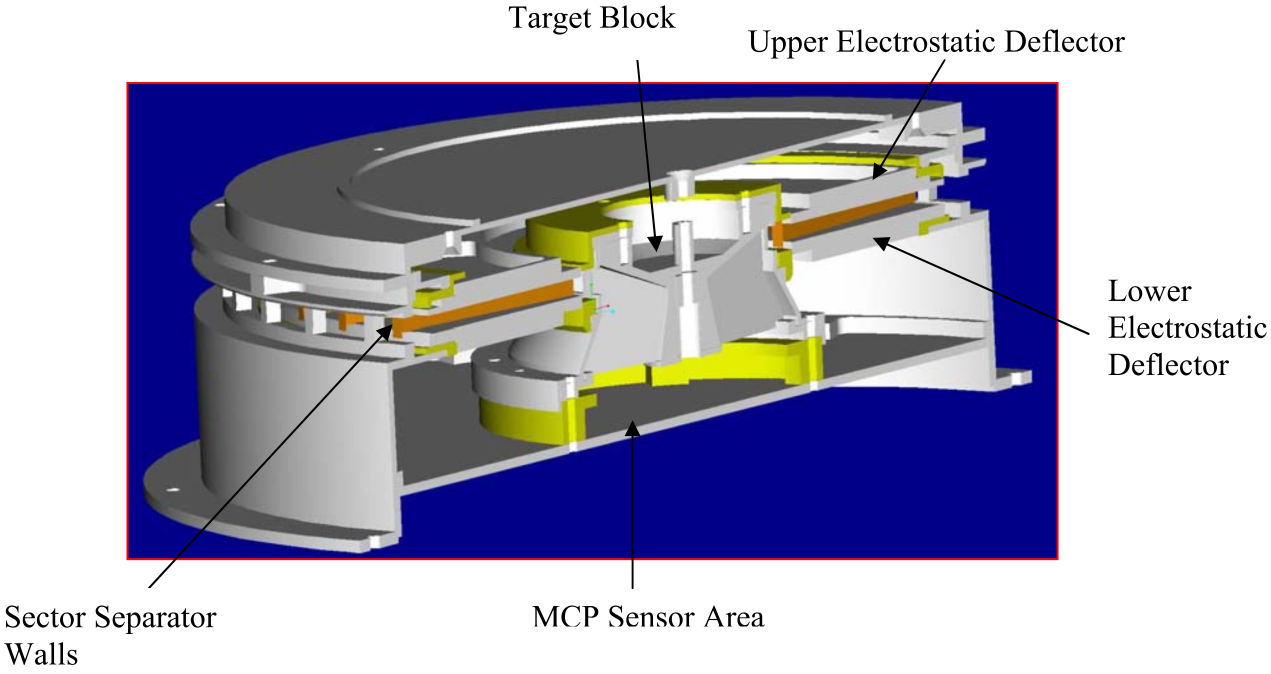


Figure 6. Internal View of the ASPERA-4 NPI. Shown is a cut through the NPI. Major components are identified. The Electrostatic Deflector sweeps away charged particles leaving an input beam of neutral particles.

These three units (ELS, NPD, and NPI) are mounted on a scanner which actuates the instruments so that they can observe a 4pi field of view. This occurs in 32, 64, or 128 seconds depending on the scanner operational mode. The scanner design is part of ASPERA-C and is flight proven to be robust and long life. It contains a doubly redundant electronic and motor system which control a worm screw design. The flight spare scanner from the Mars Express mission will be provided by IRF.

The Ion Mass Analyzer (IMA) is an improved version of the ion mass spectrographs TICS (Freja, 1992), IMIS (part of ASPERA-C, Mars-96, 1996), and IMI (Planet-B, 1998). It is an exact copy of the ICA instrument to be flown on the ESA Rosetta mission. IMA is a mass resolving instrument providing ion measurements in the energy range 0.01 - 30 keV/q for the main ion components (1, 2, 4, 16 amu/q) and the group of molecular ions (20 - 80 amu/q) (See Figure 7).

Particles enter the analyzer through an outer grounded grid. Behind the grid is a deflection system to deflect particles coming from angles lying between 45° and 135° (with respect to the symmetry axis) into an electrostatic analyzer. The electrostatic analyzer filters the ions by selecting those with a certain energy. After passing the electrostatic analyzer the ions are deflected in a cylindrical magnetic field set up by permanent magnets. The cylindrical magnetic field deflects lighter ions more than heavy ions. The direction of deflection is radially outward from the center of the analyzer. The ions finally hit a 10 cm diameter MCP and are detected by an anode system with digital position determination electronics. The anode system consists of 32 concentric rings to measure the radial impact position (representing ion mass) and 16 sector anodes to measure the azimuthal impact position (representing ion entrance angle). The magnet assembly can be biased with respect to the electrostatic analyzer to post-accelerate ions and optimize the mass range and mass resolution.

A specific Data Processing Unit (DPU) for IMA controls IMA data compression and IMA data formats. The IMA DPU works with the main DPU to control the ASPERA telemetry resources. All

ASPERA commands are sent to the main DPU. The main DPU passes IMA related commands on to the IMA DPU.

The flight spare IMA sensor head from the Mars Express mission are provided by IRF. The IMA sensor head will be modified by Centre d'Etude Spatiale des Rayonnements (CESR)/Centre National de Recherche Scientifique (CNRS) and calibrated by CESR/CNRS. IRF will rebuild a new set of IMA DPU electronics for Venus Express.

The ASPERA-4 data processing unit for ASPERA-4 will be constructed from spare DPU components which were available as Mars Express flight spares. Due to the higher radiation environment at Venus, additional hardware upgrades will need to be employed. Additional thermal constraints also need to be included within the DPU. Hardware modifications of the DPU will be performed by the Finnish Meteorological Institute. The Venus Express flight software for the DPU will be reconfigured to be similar to the design of the IMA DPU flight software and will be generated by IRF.

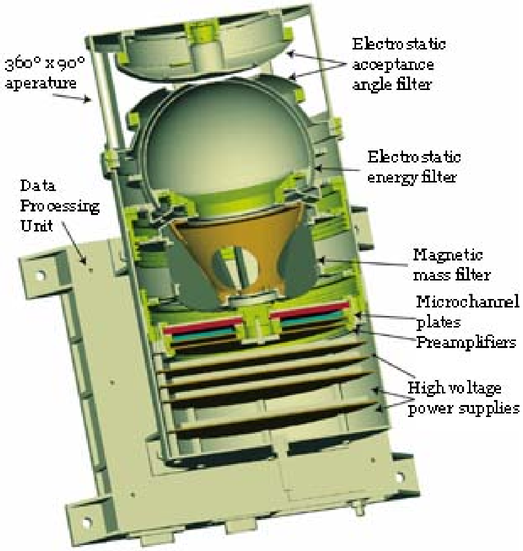


Figure 7. Internal view of the ASPERA-4 IMA. Shown is a slice through the IMA to reveal the internal IMA deflection. The electrical acceptance filter, electrostatic energy filter, and magnetic mass filter are arranged to analyze entering ions.

D.4.d. Mission Concept

The Venus Express mission will be operated by ESA. The reader is referred to the ESA Venus Express Mission Definition Report included in Appendix 9, Part B for mission concept, mission observing strategy, spacecraft performance, and orbital requirements. A brief summary is given here, emphasizing ASPERA-4 operations. The Venus Express mission utilizes the Mars Express designed hardware, spacecraft, and launch vehicle, modified for the investigation occurring at Venus.

The Venus Express mission aims at exploring the Venusian atmosphere, the plasma environment, and the surface geology of Venus from orbit. The selected orbit is quasi-polar with a pericenter at ~250 km and apocenter in the range 30,000-45,000 km with a period of 9.6 to 16 hours. A high-inclination elliptical orbit provides complete latitudinal coverage and gives the best compromise for allowing both high-resolution observations near pericenter and global observations during the apogee part of the orbit, and for *in-situ* measurements of the Venusian environment and its interaction with the solar wind.

The "store and forward" concept of the orbital operations, implemented for the Mars Express mission, fits the Venus Express requirements. The ASPERA-4 experiment will collect the data in the vicinity of pericenter and store them in the mass memory. Data transmission periods will occur during the apocenter part of the orbit. ASPERA-4 will be observing when the orbital altitude becomes less than 10,000 km to obtain data on the solar wind interaction with the planet. All ASPERA-4 instrumentation works together and they are all activated simultaneously.

ASPERA-4 contains low, medium, and high data compression modes for ELS, NPI, NPD, and IMA independently. ELS, NPI, and NPD data compression modes are generally set by ground command and IMA data compression modes are dynamically set to maximize the use of ASPERA-4 telemetry. The ASPERA-4 PI at IRF and other instruments on Venus Express will negotiate with ESA for specific times when ASPERA-4 will operate in each of its data compression modes. Data compression modes are both lossy and lossless, and are used in combination to maximize the amount and accuracy of transmitted ASPERA-4 data.

Due to the heritage and the fact that most of the flight instrumentation has already been designed and built, it is proposed that this investigation start at Phase C/D. In order to start the process of refurbishment of the ELS flight spare unit for ASPERA-4 and the coating of spare NPD START surfaces, SwRI and UA are proposing that their hardware phases be funded as described in sections F on Management and Schedule and G on Cost and Cost Estimating Methodology.

D.4.e. Science Team

This proposal seeks funding to support efforts of the United States Co-Investigators as part of the ASPERA-4 experiment for the ESA Venus Express mission. The Venus Express mission was approved by ESA's Science Programme Committee (SPC) by unanimous approval on November 5, 2002. The full international ASPERA-4 science team (listed in Appendix 9, Part C) was selected to provide the ASPERA-4 science investigation. The ASPERA-4 Principal Investigator is Dr. Stas Barabash of the Swedish Institute of Space Physics (IRF), Kiruna, Sweden. ESA recognizes a Co-Principal Investigator and for the ASPERA-4 experiment, this is Dr. Jean-Andre Sauvaud of CESR/CNRS, France. The ASPERA-4 Experiment Manager is Mr. Herman Andersson, also from the Swedish Institute of Space Physics, Kiruna, Sweden.

For the ASPERA-4 experiment, the United States Co-Investigators are lead by Dr. J. David Winningham of Southwest Research Institute. He will serve as the Principal Investigator for this NASA Mission of Opportunity. All United States ASPERA-4 Co-Investigators are included under this proposal lead, by Dr. Winningham. The United States ASPERA-4 Co-Investigators are Dr. James R. Sharber and Dr. Rudy A. Frahm at Southwest Research Institute, Dr. Charles Curtis, Dr. Ke Chiang (Johnny) Hsieh, and Dr. Bill R. Sandel at the University of Arizona, Dr. Edmond C. Roelof and Dr. Pontus C:son Brandt at the Johns Hopkins University Applied Physics Laboratory, Dr. Janet G. Luhmann at the University of California at Berkley, and Dr. Janet U. Kozyra at the University of

Michigan. For the United States part of the ASPERA-4 experiment, the Project Manager is Ms. Sandee J. Jeffers of Southwest Research Institute.

D.4.f. ***Scientific Personnel***

Dr. J. David Winningham will act as the United States Principal Investigator for all ASPERA-4 related activities and is an Institute Scientist at Southwest Research Institute. Dr. Winningham has been the PI/CoI of plasma instruments for NASA ISIS, DE-2/LAPI, UARS/PEM, TSS-1/ROPE, TSS-1R/ROPE, and Cluster/PEACE. He has been the United States PI for plasma instruments flown on Giotto/JPA, Mars Express/ASPERA-3, Astrid-2/MEDUSA, and Munin/MEDUSA-2. Every program included MO&DA phases and Dr. Winningham has been PI on several data analysis contracts including AFGL, Cluster-I through NASA, and Cluster-II through NASA. Dr. Winningham has been PI on several sounding rocket programs and CoI on numerous satellite and rocket programs.

Dr. Winningham will fulfill the role of Principal Investigator for NASA on this program. He will direct both hardware and software construction at SwRI, direct hardware construction of NPD to UA, and lead the United States science analysis effort on ASPERA-4. Dr. Winningham will communicate and coordinate with ASPERA-4 PI and PM at IRF, communicate and coordinate with CoI's at MSSL, and communicate with all CoI's in the United States. During the coarse of this contract, Dr. Winningham will be responsible to NASA for all reporting: scientific, technical, and budgetary.

Dr. James R. Sharber will be a Co-Investigator at Southwest Research Institute. He has an extensive background in instrument design and flight data analysis from his involvement in numerous NASA sponsored satellite programs. He is a CoI on UARS/PEM, Cluster-II/PEACE, and Mars Express/ASPERA-3 experiments. He has been Principal Investigator for the plasma instruments on the Polar ARCS, PULSAR-II, ARIA 1-4, and Svalbard Cusp campaign rocket investigations. Dr. Sharber recently spent 3 years at NASA Headquarters as Discipline Scientist in the Sun-Earth Connection Division of the Office of Space Science where he managed research SR&T programs of the division and was program scientist for the Polar, Wind, Geotail, Twins, and Cluster missions. Dr. Sharber will be responsible for and direct the EP/O portion of this proposal. He will also participate in analysis of ELS calibration data, data validation, and analysis of ASPERA-4 observations.

Dr. Rudy A. Frahm will be a Co-Investigator and is a Senior Research Scientist at Southwest Research Institute. Dr. Frahm participated in the calibration of the DE-1/HAPI, DE-2/LAPI, DMSP/SSJ4/Block5D, UARS/PEM/MEPS, TSS-1/ROPE/SPES, TSS-1R/ROPE/SPES, and Mars Express/ASPERA-3/ELS spacecraft experiment plasma instruments. Dr. Frahm is a CoI on UARS/PEM and Mars Express/ASPERA-3. He has assisted in and directed the development of some of the UARS/PEM, Cluster-II, and ASPERA-3 ground software data display and analysis system currently in use at SwRI.

Dr. Frahm will be responsible for directing and performing much of the ELS FS calibration at SwRI. He will participate in hardware related activities at MSSL and IRF. Dr. Frahm will conduct the initial analysis of instrument characteristics and reduce the ELS FS laboratory calibration data at SwRI and the ELS FU calibration at MSSL. Dr. Frahm will also be responsible for directing the design of the ASPERA-4 data analysis system, instrument descriptions, design of analysis system for spacecraft telemetry, and he will participate in the science analysis of ASPERA-4 data.

Dr. Charles C. Curtis will be a Co-Investigator and is a Research Associate Professor at the Department of Physics of the University of Arizona. Dr. Curtis is the designer of the FIS and EIS mass spectrometer sensors for the Soviet VEGA probes to Comet Halley. Dr. Curtis has also served as project manager for the development of the EUV Imager for the NASA IMAGE Mission. As a CoI, Dr. Curtis is involved with the NPD sensor on Mars Express/ASPERA-3 and aided in the design of START surfaces.

Dr. Curtis will be responsible for overseeing the hardware and data analysis activities at the University of Arizona. He will be directly involved in NPD design activities and directly interface with IRF. Dr. Curtis will participate in the science analysis of ASPERA-4 data.

Dr. Ke Chiang (Johnny) Hsieh will be a Co-Investigator and is a Professor at the Department of Physics of the University of Arizona. Dr. Hsieh has served as PI for the neutral gas analyzers for the Soviet VEGA mission to Comet Hally and was the original instrument lead of the High Energy Neutral Atom imager for the NASA IMAGE Mission. Dr. Hsieh is a CoI on CELIAS/SOHO, MIMI/Cassini, HENA/IMAGE, and ASPERA-3/Mars Express.

Dr. Hsieh will be responsible for conducting the evaluation and determining the performance of the NPD START surface coatings at the University of Arizona. He will participate in the science analysis of ASPERA-4 data.

Dr. Bill R. Sandel will be a Co-Investigator and is a Senior Research Scientist at the Lunar and Planetary Laboratory of the University of Arizona. Dr. Sandel served as PI for the UV intensifiers in the Auroral Imager for Viking and the EUV Imager on IMAGE. Dr Sandel is a CoI on UVS/Voyager, UVS/EUV/Galileo, and ASPERA-3/Mars Express. He has also developed advanced photon-counting array detectors for eight Shuttle experiments and an EUV-FUV telescope for study of the Jupiter system and stars.

Dr. Sandel will be responsible for performing much of the surface coating for the NPD START surface at the University of Arizona.

Dr. Edmond C. Roelof will be a Co-Investigator and is Principal Professional Staff at Johns Hopkins University Applied Physics Laboratory. Dr. Roelof is a CoI on Pioneer 10/11 Cosmic Ray Energy Spectra experiment, Galileo/EPD, Ulysses/HI-SCALE, Geotail/EPIC, Cassini/INCA, the TWINS and Astrid energetic neutral atom imagers, and Mars Express/ASPERA-3. He is an expert on the theory and analysis of data on energetic charged particles and ENA imaging.

Dr. Roelof, together with Dr. Pontus C. Brandt, will be responsible for the in-depth analysis of the ENA data from NPI and NPD and extraction of physical parameters by the use of models.

Dr. Pontus C. Brandt will be a Co-Investigator and is a Senior Professional Staff at Johns Hopkins University Applied Physics Laboratory. Dr. Brandt analyzed the ENA data from the ENA imager PIPPI (almost identical to the NPI instrument) on board the Astrid-1 spacecraft. Dr. Brandt is currently analyzing the data from the HENA instrument onboard IMAGE.

Dr. Brandt will be responsible for the in-depth analysis of the ENA images from the NPI and NPD instruments as well as extraction of physical parameters from the ENA images by use of models.

Both Dr. Roelof and Dr. Brandt will work closely with Dr. Luhmann, Dr. Kozyra, and the European investigators.

Dr. Janet G. Luhmann will be a Co-Investigator and is a Senior Fellow at the Space Sciences Laboratory of the University of California at Berkeley. Dr. Luhmann is the PI of an in-situ particles and fields experiment on the twin STEREO spacecraft, is a CoI on the ASPERA-3 experiment on Mars Express, and is a member of the ion-neutral mass spectrometer facility instrument team on the Cassini Orbiter mission to Saturn.

Dr. Luhmann together with associate research Stephen Ledvina, will be responsible for providing comparative modeling support for data interpretation in the form of models of the solar wind-Venus interaction. She will collaborate with other ASPERA-4 CoIs on calculations related to the generation of the ENA fluxes that will be imaged with ASPERA-4, and to evaluate the properties of the ENA fluxes incident on the upper atmosphere of Venus. Dr. Luhmann will also participate in the analysis of data on energetic charged particles and ENA imaging.

Dr. Janet U. Kozyra will be a Co-Investigator and is a Senior Research Scientist at the Space Physics Research Laboratory of the University of Michigan. Dr. Kozyra is an Interdisciplinary Scientist in the Thermosphere -Ionosphere - Mesosphere Energetics and Dynamics (TIMED) Mission, a CoI on Polar/TIDE and a CoI on the ASPERA-3 experiment on Mars Express. Dr. Kozyra has a long history in data analysis as PI of an interdisciplinary science investigation on DE and as a guest investigator on the AMPTE/CCE spacecraft. Her specific interest area is neutral atom and ion precipitation, and decay of the Earth's ring current. She is experienced in the theory and modeling of the ionosphere - magnetosphere coupling process.

Dr. Kozyra will be responsible for providing models of the Venusian atmospheric response to precipitating energetic neutrals and ions which originate from the solar wind and interact with Venus. For this effort, Dr. Kozyra will use an ion/neutral transport model and a Coulomb heating model. She will model the evolution of the Venus atmosphere using neutral heating, ionization and production of excited chemistry model results as inputs to a physics-based Venus atmosphere model. The feedback between the two sets of models will also be included in understanding the time-dependent response to solar wind inputs. Dr. Kozyra will also participate in the science analysis of ASPERA-4 data.

D.4.g. Key Technical Personnel

Ms. Sandee J. Jeffers will be the United States Project Manager and is a Group Leader at Southwest Research Institute. Ms. Jeffers is the current PM of the United States effort on ASPERA-3 for Mars Express. She is also directing the UARS/PEM and Cluster-II data archival efforts at SwRI. For this proposal, her duties at SwRI include organizing and overseeing the telemetry ground data analysis system, directing construction of the ELS FS hardware, directing calibration of the ELS FS, international delivery of ELS FS to MSSL or IRF, preparing technical status reports and project level responses when requested by NASA, and directing budgetary reporting to NASA. Ms. Jeffers will interact with IRF and ESTEC on data analysis issues for ASPERA-4 when requested by MSSL or the IRF PI. Ms. Jeffers will interact with and direct storage of ASPERA-4 data into the Planetary Data System node.

Mr. John R. Scherrer is a Group Leader at Southwest Research Institute. Mr. Scherrer has participated in SwRI programs for SwRI projects on UARS, GGS, SEPAC, TSS, Wakeshield, and Comet. He has been the lead mechanical engineer and PM for plasma payloads on Maimik/SPI, Polar Arcs/AREA, AREA/SPS, CENTAUR rocket programs, Astrid-2/MEDUSA, Munin/MEDUSA-2, and Mars Express/ASPERA-3. Mr. Scherrer will be the mechanical lead for the ELS FS on Venus Express.

Ms. Carrie A. Gonzalez is a Senior Research Analyst at Southwest Research Institute. Ms. Gonzalez is the primary author of the science data analysis systems used to analyze DE and Giotto plasma data, the Science Operations Center for TSS-1 and TSS-1R, and the primary author of the data handling routines used in the Mars Express ASPERA-3 data analysis system. Ms. Gonzalez will use her knowledge to generate a data analysis system for ASPERA-4.

Dr. Stephen A. Ledvina is an associate researcher at the University of California at Berkeley. He has performed extensive work on Saturn's interaction with Titan and has worked with Dr. Janet Luhmann on the solar wind interaction with Mars. Dr. Ledvina will work together with Dr. Luhmann on the theory and modeling of the interaction of Venus with the solar wind and will participate in the science analysis of ASPERA-4 data.

Dr. Stephen W. Bougher is a Senior Research Scientist at the University of Michigan's Space Physics Research Laboratory (SPRL). Dr. Bougher has done extensive modeling work by adapting the NCAR Thermospheric General Circulation Model (TGCM) to the Venus, Mars, and Jupiter thermosphere-ionospheres for the interpretation of available upper atmosphere data obtained from spacecraft and groundbased observations. Dr. Bougher served as a Guest Investigator pursuing Venus TGCM analyses of Pioneer Venus Orbiter datasets. Presently, he is a Planet-B (Nozomi) Co-Investigator who will be involved in the overall project and NMS science activity (2004-2005), should Nozomi survive through Mars Orbit Insertion. In addition, Bougher was recently selected to participate on the MRO Accelerometer Facility Team (2002-2007). For this Venus Express investigation, Dr. Bougher will exercise the Venus Thermospheric General Circulation Model (VTGCM) to model the evolution of the Venus atmosphere using neutral heating, ionization and production functions for excited chemical species as inputs from Dr. Kozyra's models.

D.5. Science Data and Other Science Products

Laboratory calibration data will be used to determine the characteristics of the instrument. Individual manipulations in laboratory data will be used to generate descriptions of the instruments and their specifics so that science data returned will be accurate.

SwRI will provide web access to all ASPERA-4 CoIs to analyze and down load data to their home institutions. ASPERA-4 will use the SDDAS system for its science investigation of coordinated studies with ASPERA-4 instrumentation. SDDAS offers a variety of analysis tools. These include sequential spectral plots, time oriented spectrograms, angle oriented spectrograms, correlograms, real time plotting capabilities, source integration methods, plasma moment calculations, 3D visualization and contouring. Since SDDAS is continually improving, the list of analysis tools will grow as needs for additional analysis tools arise. ASPERA-4 CoIs will immediately have all of the SDDAS tools for their use.

SDDAS also has the capability to include special computation formulation (SCF), a procedure description which is unique to the users science data. The procedure interfaces with some SDDAS routines so that results can be presented along with any IDFS data. The SCF contains some definitions but there are cases where the user may have a special analysis code. As long as the user can develop a user defined procedure for performing the calculations, that procedure may be included within a special computation formulation. An example from UARS/PEM data was to use the SCF to combine data from different plasma instruments having different energy and time base ranges, and then using a user defined routine, to determine the amount of ionization occurring at different altitudes in the Earth's atmosphere.

The SDDAS system will allow scientists to interrogate and investigate ASPERA-4 data to uncover the plasma-atmosphere interaction details. SDDAS can be configured to examine ASPERA-4 data to address the question of determining atmospheric escape in a coordinated fashion by examining the ion, electron, and ENA fluxes from the planet, simultaneously.

Data products will be delivered to the NASA Planetary Data System (PDS) Planetary Plasma Interactions node after an ESA requirement of a 6 month proprietary data use period. Data analysis and archiving will be the primary responsibility of SwRI (Dr. Winningham, Dr. Sharber, and Dr. Frahm). ASPERA-4 data from the Venus Express mission will be archived in calibrated flux values at PDS for the particle instruments, data matrix ENA flux values for the NPI data, and data matrix values from the TOF NPD based instrument.

Laboratory calibration data will be used as test sets of the PDS archival system when PDS is configuring to accept ASPERA-4 Venus Express data from SwRI. At the end of the science investigation, all US generated electronic documents in SwRI's document control archive will also be transferred to NASA's PDS. Plans for NASA PDS archive are similar to the arrangements for archiving data from ASPERA-3 on Mars Express.

??????????????????????????????????The Venus Thermosphere General Circulation Model (VTGCM) simulates the physics of the Venus CO_2 dominated thermosphere and photochemical ionosphere, and has been documented in detail by Bougher et al. [1988; 1990; 1994; 1997]. The VTGCM will be used for theoretical studies of the interaction of the Venus atmosphere with the solar wind. Throught the mission, VTGCM theoretical results will be compared with ASPERA-4 data.

Table 3 outlines the VTGCM input parameters, fields, and its computational domain. Also, O_2 visible (400-800 nm), IR (1.27-micron), and NO ultraviolet (198.0 nm) nightglow distributions can be explicitly calculated. Solar cycle variations of Venus upper atmosphere temperatures, neutral and ion densities, and airglow intensities have been monitored using Pioneer Venus Orbiter (PVO) and Magellan measurements taken over a fraction of two 11-year periods [e.g. Kasprzak et al., 1997; Fox and Bougher, 1991]. Many of the features of these observed solar cycle responses are captured by the VTGCM and in two empirical models: VIRA (Venus International Reference Atmosphere) [Keating et al., 1985; 1999] and VTS3 [Hedin et al., 1983]. A combination of collisionally enhanced CO_2 15-micron cooling, wave drag, and standard eddy diffusion formulations are incorporated into the VTGCM. Rayleigh friction was used initially in the VTGCM to mimic wave drag on the mean flow and a superrotating zonal wind was prescribed to simulate the asymmetry of the circulation [Bougher et al., 1988]. In recent years, a gravity wave drag parameterization has been tested in the VTGCM that may replace Rayleigh friction and give rise to the asymmetric flow [Zhang et al., 1996; Bougher et al., 1997] in order to reproduce the observed thermospheric structure.

Table 3. VENUS TGCM Input Parameters, Fields, and Computation Domain

TGCM	Domain -Alt Range -Pres Range Resolution (LatxLon)	Major Species	Minor Species	Ions	Time-Step (secs)	Homopause Kzz (cm2/sec)	Heating Efficiencies (EUV vs. UV)
VTGCM	94-200 km 11-4.6E-7 Pa 33-levels 5x5 degrees	CO$_2$ CO O N$_2$	O$_2$ He NO N(4S) N(2D)	CO$_2$+ O$_2$+ O+ NO+ (PCE)	180	1.0E+7 (at 136 km)	EUV = 20% UV + 22%

Where PCE refers to photochemical equilibrium: DYN refers to vertical diffusion and horizontal advection; Chem signifies neutral-neutral and ion-neutral chemical heating below 200 km; EUV refers to Extreme Ultraviolet heating efficiency; UV refers to Ultraviolet heating efficiency. In addition, 1E-7 is interpreted as 1x10^{-7}.

D.6. Minimum Science Investigation

The minimum acceptable data and science will be determined by ESA

There are a variety of descoping options shown in Table 4. These options have consequences to other ASPERA-4 CoIs and other nations. A list of possible descope options are cited below along with the consequence to the descope option, phasing, schedule and cost savings for the US. In most cases, there is only savings on the US side as the tasks might be picked up by other ESA partners. However most of the ASPERA-4 for Venus Express is identical to ASPERA-3 from Mars Express and the rolls of the personnel involved in almost cases are identical. Therefore, the ASPERA-4 program for Venus Express is expected to be of low risk and the need to execute a descope option is expected to be low as well.

Table 4. Descope Plan

Descope Option	Consequences	Phasing	Schedule Savings	Cost Savings
A) SwRI does not produce an ELS Flight Spare	ELS Spare Unit not available to IRF. If the ELS Flight Unit becomes damaged beyond timely repair by IRF or MSSL, no electron data will be obtained from Venus Express. ASPERA-4 and Mission will be incomplete	At Selection	No ELS FS delivery	SwRI hardware budget
B) SwRI produces but does not calibrate the ELS Flight Spare	If IRF needs to use the spare unit, then electron data from Venus Express will be present, however, its interpretation will be difficult, instrument characteristics will be approximated, and the validity of Venus Express electron data will always be questioned.	In May of 2004	About a month	SwRI calibration budget
C) UA does not coat START surfaces for NPD	IRF will have to deal with an alternative method of producing coated NDP START surfaces. If successful, there will be no consequence to the science mission. If unsuccessful, NPD noise will be significant which could results in a total loss of useful data, and ASPERA-4 and Mission goal of determining atmospheric escape will become restricted without the knowledge	At Selection	No NPD part delivery	$107,000

	of particle mass.			
D) EP/O Elimination	Public information	Any Time	No EP/O	$140,000.
E) Elimination of PDS archiving during last year	No PDS data available after November 2007	Before November 2007	No PDS after activity November 2007	Last year of PDS (ASK SANDEE)