The U.S. Rosetta Project: Mars Gravity Assist

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Abstract—Since launch on March 2, 2004, the International Rosetta Mission has flown by the Earth/Moon system one time and conducted several distant observations of comets, including support for the Deep Impact measurements of comet 9 P/Tempel 1. In 2007, Rosetta flew by Mars for a gravity assist, and conducted observations of the Martian upper atmosphere as well as extended observations, in support of the New Horizons Jupiter encounter, of the Jovian magnetotail and Io torus. In late 2007 Rosetta had its second encounter with the Earth/Moon system. NASA's contribution to the Rosetta mission consists of three hardware experiments, and the portion of the electronics package for a fourth, as well as the participation of an Interdisciplinary Scientist (IDS); backup tracking, telecommunications, and navigation assurance provided by the Deep Space Network (DSN); support for the scientific participation of U.S. investigators on non-U.S. PI-led experiments. Collectively these elements are known as the U.S. Rosetta Project. In this paper we will update the status of the instruments following the both the Mars and Earth/Moon gravity assists. In addition, we will present a summary of the science observations for both Mars and Jupiter. [1 2]

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1. INTRODUCTION

NASA's contribution to the International Rosetta mission is designated the U.S. Rosetta Project. The U.S. Rosetta Project consists in part of 3.5 instruments: Alice (an ultraviolet spectrometer), IES (the Ion and Electron Sensor, a plasma instrument), MIRO (the Microwave Instrument for the Rosetta Orbiter), and a subset of the electronics package for one of a pair of spectrometers on the ROSINA instrument called the Double Focusing Mass Spectrometer (DFMS). These elements comprise the NASA hardware contribution to the International Rosetta Mission payload. In other contributions to the mission, NASA provides key back-up navigation and tracking support for the International Rosetta Mission by way of its Deep Space Network (DSN.) In addition, NASA supports an inter-disciplinary scientist and provides investigator support to Co-Investigators (Co-Is) on non-U.S. payload instruments. Details of the instruments and of NASA's role can be found in Rosetta instrument description papers [1,2,3].

The International Rosetta Mission, an ESA cornerstone mission, is destined to study the nucleus of comet 67P/Churyumov-Gerasimenko and its environment for a period of 17 months starting in August 2014. The near-nucleus phase will begin at a heliocentric distance of about 3.25 AU, after which there will be the deployment of a Lander (designated 'Philae'). The Lander mission will last approximately 2 weeks after which the orbiter will conduct observations from both far and close proximity to the nucleus, leading ultimately to passes in which observations may be conducted from as close as 1 km (3280 feet). The orbiter will escort the comet through perihelion, to a post-perihelion distance of about 2 AU. The prime scientific objectives of the Rosetta mission are to study the origin of comets, the relationship between cometary and interstellar material and its implications with regard to the origin of the Solar System.

[1] 1-4244-1488-1/08/$25.00 ©2008 IEEE
[2] IEEEAC paper #1593, Version 8, Updated Dec. 14, 2007

The mission was successfully launched on March 2, 2004. Thereafter followed an extended period—eight months—for spacecraft commissioning which included observations of comet C/2002 T7 (LINEAR) (while the spacecraft was as yet incompletely commissioned!). Subsequently, the mission provided support for the Deep Impact observations of comet Tempel 1, and went through its first gravity assist at Earth. Reports on these periods of the mission have been provided by ESA to the IAF [4], and at previous IEEE conferences [5,6]. In this report we will discuss Mars encounter of 2007 and a little about the upcoming asteroid Steins encounter in 2008.

2. THE MARS GRAVITY ASSIST OF 2007

The Mars encounter of February 25, 2007, also known as the Mars Swingby (MSB), was eagerly anticipated by the science community. The required trajectory carried the spacecraft into eclipse just after closest approach (CA). To conserve power, the payload unfortunately had to be commanded off for two hours in advance of CA. Figure 1 provides a schematic of the encounter timeline from minus to plus two hours around the CA to Mars, with periods of blackout indicated for the payload. Not withstanding the blackout times indicated on the figure, the project allowed restricted payload operations, with pointing to Mars, in advance of the encounter to allow for selected instrument operations such as the Alice scans. At minus 2 hours the spacecraft executed a change of attitude to line up remote-sensing instrument boresights with Mars. The spacecraft entered into eclipse from CA to +35 minutes. The science component of the encounter took place entirely on the post-CA side of the gravity assist.

The logistics of this pre-encounter situation required that MIRO remain off during the post-encounter science activities. Nevertheless, the Rosetta Plasma Consortium (RPC) had an opportunity to fly down the Martian magnetotail. Observations in the far-ultraviolet (FUV) were made by the Alice instrument for the first time since 1970, allowing for measurements that will be critical for modelers of the upper atmosphere in future aerobraking, accurate weather prediction, and addressing questions about atmospheric escape mechanisms, particularly questions about the escape of water.

Alice FUV and EUV Observations of the Atmosphere

The last time close-up spectra of airglow was obtained in the Martian upper atmosphere at far- to near-ultraviolet wavelengths (between 1100 and 3400 Å), was with the

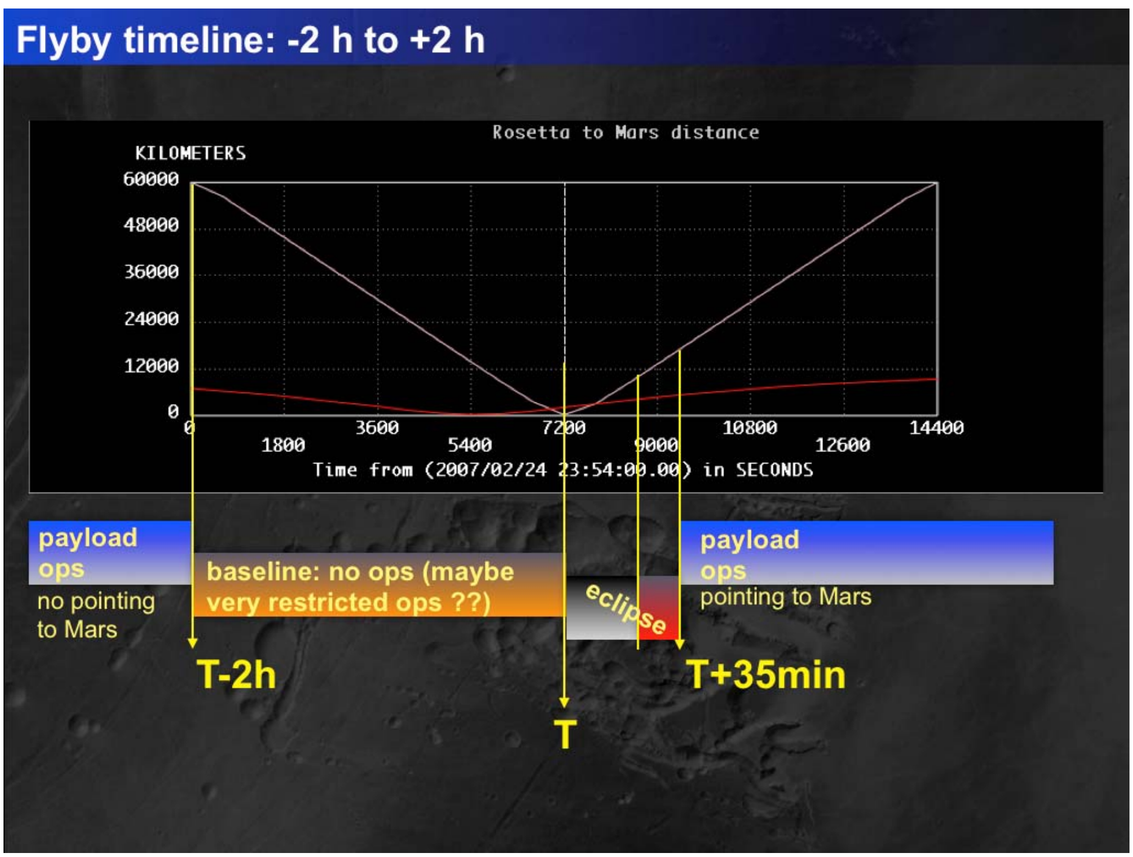

Figure 1. The encounter timeline from minus to plus 2 hours around the closest approach (CA) to Mars. At –2 hours the spacecraft executed a change of attitude to line up remote sensing instrument boresights with Mars. The spacecraft entered into eclipse from CA to +35 minutes. The science component of the encounter took place entirely on the post-CA side of the gravity assist. (Figure courtesy of ESA.)

Mariner 9 mission. In February 2007, Alice measured the strong far-ultraviolet emissions of H, O, C, N, Ar, and CO in the upper atmosphere of Mars from a distance of only 247 km, and obtained the first observations at Mars in the extreme-ultraviolet (EUV, wavelengths below 1000 Å).

The Mars encounter provided the first opportunity for Alice to operate in a simulated cometary environment. The ultraviolet spectrum of a comet in the Alice spectral band is very similar to that of the CO_2-dominated Mars upper atmosphere, consisting mainly of emissions of CO, H, C, and O, as well as the ions of O and C. In the cometary coma these emissions are generally optically thin and are excited by resonance fluorescence of solar radiation, while in the Mars upper atmosphere there are several excitation processes at work, principally photoelectron excitation.

Principal scientific objectives of the Alice team at this time were to study the daytime Mars atmospheric emissions, particularly those below 1200 Å that had not previously been observed *in situ*, and to perform night-side spectral mapping to study the FUV nightglow and search for signatures of aurora. The observing geometry, first viewing the nearly fully illuminated disk, followed by observation of the dark disk with a thin solar illuminated crescent, allows for a sensitive test of recent upper atmosphere photochemical models.

Table 1. Timeline for Alice Operations at Mars

Start-up and Calibration 22 Feb–23 Feb.	
Decontamination (25 hrs)	10:00–11:00
HV ramp-up	11:50–12:00
Vega star scan	12:00–14:00
Pre-CA activities 24 Feb.	
E-W scan across Mars (a)	18:11–18:21
E-W scan across Mars (b)	19:50–20:05
E-W scan across Mars (c)	21:50–22:10
Dayglow aeronomy, Boresight at Mars center	18:25–19:45
Offset pointing to Mars equator	19:20–21:00
Offset pointing to Mars disk	21:00–21:45
Alice off	22:10
Mars CA ... 25 Feb	01:54
Post-CA activities 25–26 Feb.	
Alice on	02:45
Nightglow aeronomy	03:00–03:25
Boresight at Mars center	06:10–14:00
	16:30–08:45
E-W scan across Mars (d)	03:30–04:00
E-W scan across Mars (e)	05:45–06:05
E-W scan across Mars (f)	21:50–22:10
N-S scan across Mars (a)	04:05–04:15
Alice off 28 Feb	07:31

Additionally, the MSB allowed Alice to significantly enhance the instrument characterization, notably the wavelength calibration as a function of position along the slit and the determination of extended source spectral resolution as a function of wavelength. The small solar elongation angles following CA also allowed a serendipitous evaluation of the scattered light properties of the instrument; a more methodical set of observations at a wide range of solar elongations (20–140 deg) was obtained during a subsequent payload checkout in September 2007.

The primary Alice observations were fixed pointings centered on the Martian disk with the slit oriented roughly east–west: the illuminated disk pre-closest approach (pre-CA) and the dark disk post-CA (three separate sequences). In addition, observations were made during scans of the Visible InfraRed Thermal Imaging Spectrometer (VIRTIS) and Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) offset pointings. A list of the observation timing is provided in Table 1.

The slit geometry for the Alice nightglow observations, beginning 25 February 2007 at UT 03:00:00, is shown in Figure 2. At this time the disk spanned five spatial pixels (each spatial pixel is 0.3°). Four exposures, each of 1028 seconds, were obtained. The illuminated crescent migrated

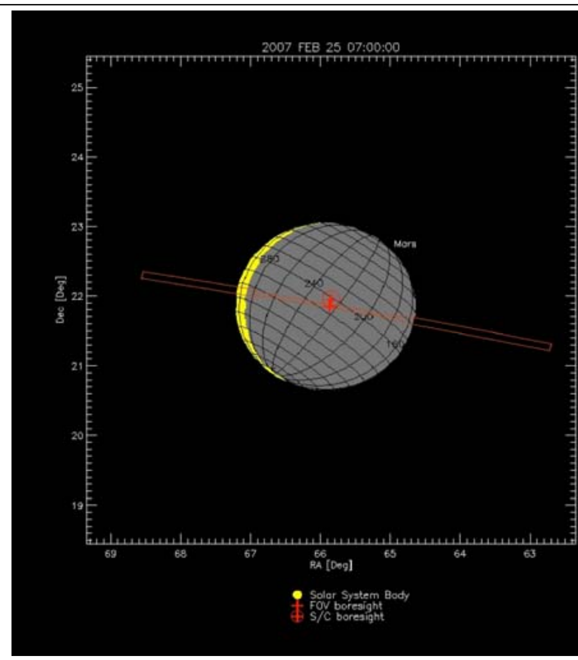

Figure 2. A visualization of the Alice field of view superimposed with the spacecraft view of Mars during the post-encounter phase, when Alice was able to obtain nightglow spectra.

to smaller row numbers within the slit as the spacecraft receded from Mars. Comparison of the dayside disc spectrum (black), with the crescent limb observed on the nightside (red) is shown in Figure 3. Differences between the two spectra are due to optical depth (in oxygen) and differing absorption columns of CO_2 in the two viewing geometries. Figure 4 shows the nightside aeronomy spectra. The region of interest is that below 1200 Å, but the whole region (red is the spectra shown in black, multiplied by a factor of 10) illustrates the rich structure in this spectral band. H I Lyman-α, β, and γ, were detected along with other features that may be due to solar scattered light that manifests itself at long wavelengths. For data comparison with other work, the Alice team uses the Mars full-disk spectrum [7] recorded by the Hopkins Ultraviolet Telescope (HUT) in March 1995 (a full solar cycle earlier).

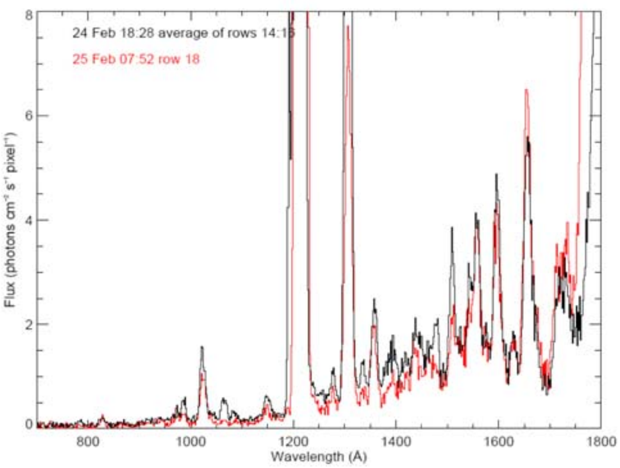

Figure 3. Comparison of dayside disk spectrum (black) with that of the crescent limb (red). Differences between the two are due to optical depth effects (in oxygen) and different absorption columns of CO_2 in the two viewing geometries.

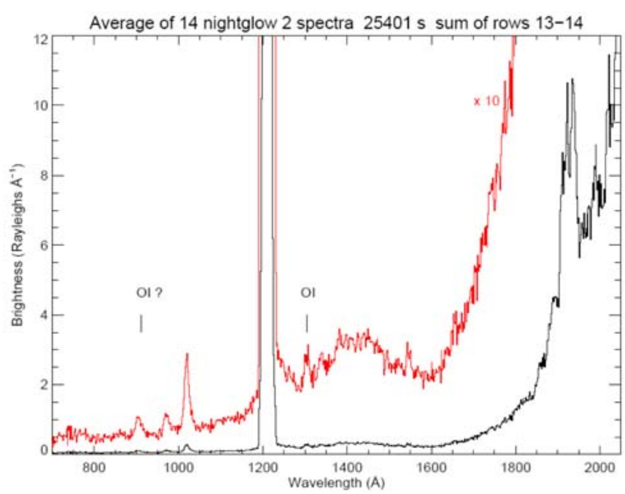

Figure 4 shows the nightside spectra. The region shown in red is that shown in black multiplied by a factor of 10 to illustrate the rich structure in this spectral band.

IES Plasma Observations in the Magnetosphere

IES operated successfully for about 98 hours during the swingby. There were three periods, each about 2 hours long in which the instrument was turned off by previously programmed commands. Two of these were to avoid contamination and possible high-voltage problems during thruster operation for wheel unloads. The third period occurred during the close approach period (early 25 February) when all of the payload was turned off.

Figure 5 (top) shows the timing of IES observations during the flyby, the accompanying spectrogram (Figure 5, bottom) shows the time history of the raw data over the flyby period. Universal time (UTC) is along the horizontal axis and energy along the Y-axis. The number of counts for each bin is indicated by the color bar. Data for electrons are shown above and for ions below. A general comment about the data is that much of the variability seen is a result of spacecraft turning to point various other instruments. Hence the plasma sometimes fell out of the IES field of view or shifted in apparent direction. As far as we are able to determine at present, all of the plasma detected is probably of solar wind origin and very little if any from Mars.

MIRO at Mars

MIRO requires significant warm-up time prior to the commencement of operations. Due to the unfortunate timing of the occultation, with the payload switched off to conserve power twenty minutes prior to closest appproach, MIRO remained off through closest approach and did not obtain science at Mars.

3. ROSETTA USE OF THE DSN AT MARS

Deep Space Network

ESA's deep-space tracking network, with 35-m stations at New Norcia, Australia (DSS-32), and Cebreros, Spain, provides primary support throughout the mission. NASA's role includes the use of Deep Space Network (DSN) resources for backup, emergency, and primary tracking activities. Participation by NASA's DSN in the Mars flyby was predominantly in support of navigation accuracy. Requirements were: provide 34-m pre- and post-flyby support, including telemetry, command, and Doppler/Range data; deliver an orbit data file (ODF) to ESA at prescribed times, support Delta Differenced One-way Ranging (DDOR, discussed below). The DSN was configured to provide Space Link Extension (SLE) command and return services. Pre- and post-flyby DSN tracks were the backup to New Norcia. Closest approach occurred over New Norcia on DOY 056 at approximately 01:58 UTC. DSN ended pre-flyby support on DOY 056, 0100 UTC over Canberra. Rosetta has two known spacecraft transponder anomalies. The transponder receiver does not lock at –117dBm, and the transponder may report a false lock status if the deep-space

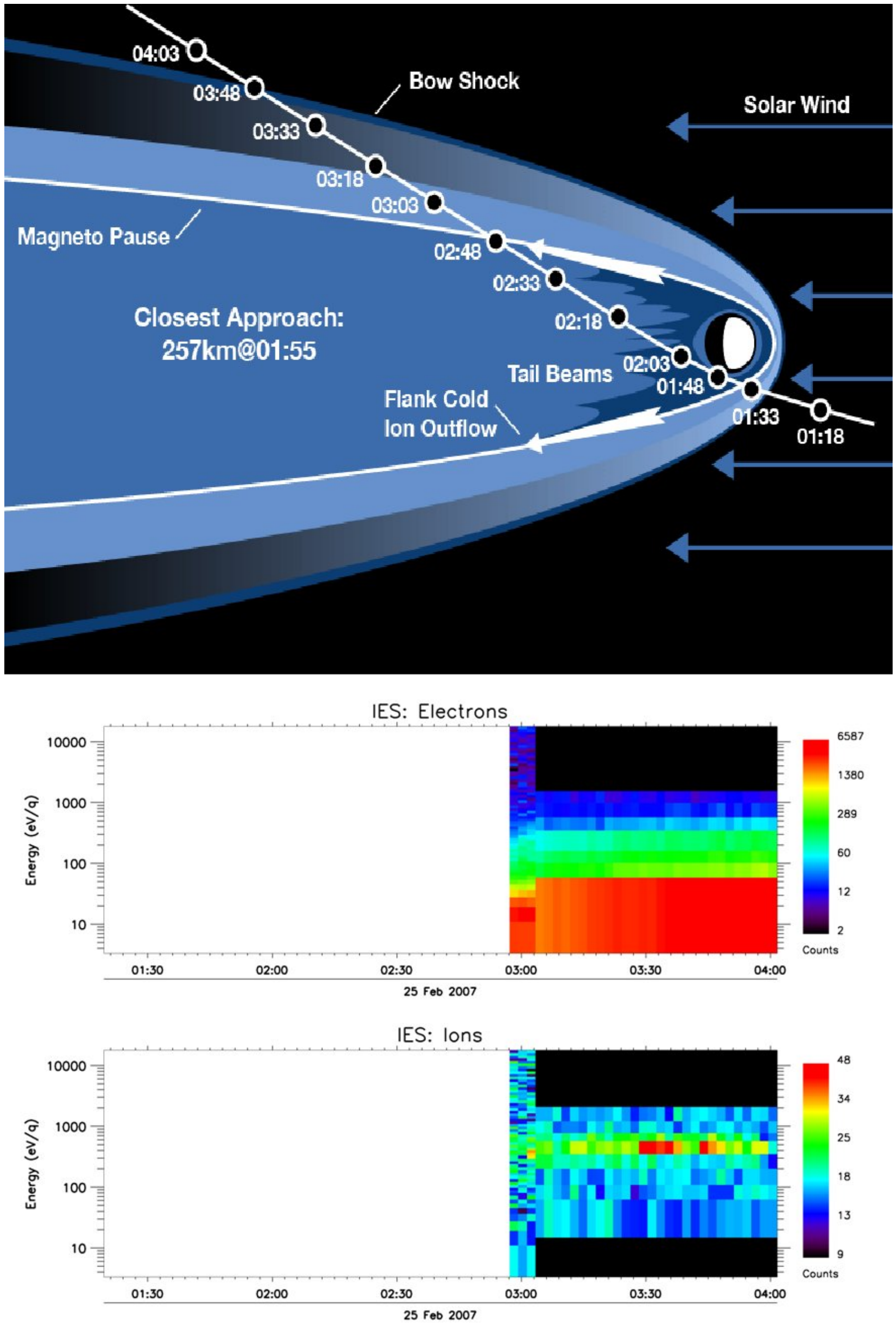

Figure 5 shows a schematic of the Mars encounter (top), with times of prospective RPC measurements, including those of IES, against the expected plasma boundaries and geometry of the Martian magnetosphere. Time increases from right to left. The bottom panel shows the acquired data in the Mars environment, with electrons in the top portion of the panel and ions in the bottom portion. Time increases from left to right in this panel, and a color scale of the intensities of counts in each energy bin is provided on the right hand side.

station (DSS) removes the uplink near the spacecraft best lock frequency. Work-around procedures were documented and no flight anomalies were reported.

Because of the critical nature of the targeting at Mars, the flyby occurred approximately 247 km above the surface, a combination of radiometric tracking as well as a technique known as Delta Differenced One-way Ranging (DDOR) was incorporated into the operational sequences. DDOR is an alternative navigation mode, provided by the DSN, that compensates for the loss of spacecraft navigation accuracy due to integration time constraints. DDOR uses distant celestial objects (quasars) as reference points, the separation of two DSN complexes, and highly accurate clocks to determine the angular resolution of the spacecraft in the plane of the sky. The technique is based on very long baseline interferometry (VLBI) used by radio astronomers for accurate measurements of distant stars. The DSN is particularly suited to this measurement because of signal capturing capability of the 70-m antennas. Nominal radiometric data provide the radial component. Cross-track information comes from numerous tracks and integration of the data set. By contrast, DDOR provides the cross track directly because it is an angular displacement technique that uses the spacecraft, several reference quasars, and two widely separated tracking stations as a baseline. DDOR will be further used at each of the critical asteroid encounters, flybys, and final comet rendezvous.

DDOR tracking tests were conducted in late July 2006, several months before the Mars Flyby, following Rosetta's return to active cruise after the near-Sun hibernation phase. The Mars approach DDOR tracking campaign began October 2006 and ended 22 February 2007. Sixteen DDOR measurements were successfully supported during that time. Twelve additional DDOR took place on 22 February 2007. The ESA station at New Norcia served as the primary tracking station for the encounter, and covered the CA prior to the spacecraft being occulted by the planet. The DSN station in Canberra used the occultation exit track to confirm the trajectory after CA.

ESA was able to take DDOR passes with its stations and compile the data from the DSN DDOR passes, along with the routine radiometric passes to arrive at a precise entry point for the flyby within 12 km of the target at Mars. The end result was a precise flyby that only required a single velocity cleanup post encounter, saving 1.2 kg of fuel that can be used to lengthen the final encounter at the comet in 2014.

The Use of DSN Keyword Files with Rosetta

As described previously, [5,6], the complexity of two tracking stations simultaneously observing the spacecraft, then switching between the spacecraft and the reference quasars requires an observational sequence of events that is not the standard for DSN operations with Rosetta. Since most of the DSN tracking is routine, a set of standard sequence of events (SOE) files are generated for a defined set of known conditions, i.e., spacecraft state and ground configuration. However, the complexity and timing of the DDOR observation generally requires the advanced process of SOE generation using DSN keyword files (DKFs).

Rosetta has been a pioneering mission with regard to international collaboration and the use of the DSN and other NASA resources in conjunction with foreign institutions. To make the integration of ESA requests easier to handle in terms of the DSN lexicon and ease of scheduling with other NASA missions, the DSN first requested Mars Express and then Rosetta to make use of DSN DKFs. ESA has found the use of DKFs on Mars Express to be cumbersome and work-intensive. After an initial study in the weeks preceding launch, ESA recommended against the use of DKFs for Rosetta.

A keyword file is essentially a collection of the parameters needed, with advance knowledge of the necessary modes required, for station operation with a particular pointing configuration. A keyword file may contain multiple telecom configuration blocks. DKFs allow for rapid implementation of changes and allow the DSN facilities greater flexibility in allocation of station resources. A major problem with this process for ESA is its complexity and time-consuming nature. A major advantage for NASA is the way it provides for greater automation, easy update, and ease of integrating multiple stations.

In practice, when the Mars encounter finally arrived, the ground stations implemented their sequence of operations based on DKFs created by JPL's mission planning and sequencing DDOR team, without complex international coordination. The effort to provide consistent and complete tracking support required the use of a technique, within the DSN, to manage station activities. In order to perform DDOR tracks a simplified procedure was initiated, by ensuring that prior to each DDOR tracking session, the state of the spacecraft was fixed and precisely known. The DSN never entered into a DDOR tracking campaign in which it was first acquiring telemetry data or collecting radiometric data. This mode relieved the burden on operations at ESOC. For ESA's part, all that was required was to provide the precise time for the pass with the spacecraft already configured in a predetermined state.

The Use of DSN for the Rosetta Deep-Space Maneuver

The second Rosetta deep-space maneuver (DSM) was conducted over New Norcia on 29 September 2006. The post-DSM trim maneuver took place on 13 November 2006. The DSN provided Level 2 pre- and post-DSM radiometric tracking support for this maneuver. Additionally, Goldstone and Madrid tracking complexes supported weekly tracking passes during this time.

4. JUPITER OBSERVATIONS

Joint Alice Jovian Observations, in situ and from Mars

By fortuitous chance, NASA's New Horizons mission had a gravity assist at Jupiter a few days after the Rosetta Mars gravity assist. The Rosetta Mars encounter took place on February 25, the New Horizon's Jupiter encounter on February 28, 2007. Both the New Horizons and Rosetta payloads include an Alice instrument, designated here as Alice-R (Rosetta), and Alice-NH (New Horizons). Following its gravity assist at Jupiter, the New Horizons spacecraft flew down the long magnetotail of Jupiter for several weeks, and for at least 100 Rj. The long residence time in the magnetotail of Jupiter afforded the opportunity for joint observations with each Alice instrument, the better to cross-correlate the data sets of Jovian ultraviolet emissions from the Io torus and plasma in the magnetotail.

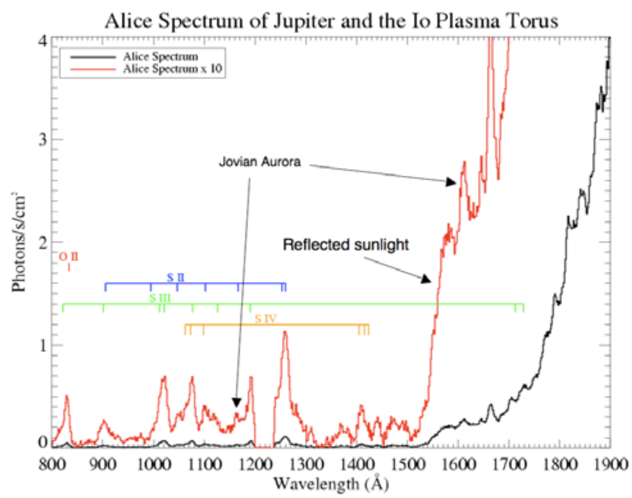

Figure 6. Spectra captured from Rosetta-Alice's observations of the Jupiter system, including the Io plasma torus.

Figure 6 shows the spectra of the Io torus captured by Alice-R during this timeframe.

5. Incidents, Surprises, and Anomalies

The U.S. Rosetta Project keeps a record of mission incidents, surprises, and anomalies, collectively known as ISAs. There were no ISAs as a result of instrument operation in the period covered in this paper. A discussion of progress on some ISAs documented in [7] follows.

IES Noisy Channel: Resolved—Prior to launch, one electron detector channel (of 16) was noisy. This showed again after the first high-voltage turn-on, but the specific identification of the channel was not possible because of telemetry limitations on the data. Subsequently, the noise disappeared, which may have been the result of detector (microchannel plate) outgassing. However, the noise reappeared in the Earth flyby data. Tests revealed channel 11 to be the faulty one and provided an opportunity to quantify the noise.

MIRO Software Fault: Resolved—Midway through its observations of the Deep Impact target of Tempel 1, telemetry from the MIRO instrument abruptly stopped. MIRO was left powered on through a ground segment 'dark' period (downlink from the spacecraft is not received at the ESA ground station around the clock). Seventeen hours lapsed before the Chirp-Transform Spectrometer resumed normal operations and executed all commands stacked in its que. The root cause of this data loss has been established as a coding error in the floating point calculation that resulted in a long-term loop being executed in software until the error timed out. A patch was uplinked on March 5, 2007, to correct the problem

6. Observations of Asteroid Steins

Dr. Paul Weissman is the sole U.S. interdisciplinary scientist for Rosetta. His tasks include modeling and observation of mission targets in support of the science planning work of the Science Working Team (SWT or the ESA analog of what is known on NASA missions as the Project Steering Group, PSG). His tasks include obtaining photometry/spectroscopy of the mission targets for use in the derivation of precise rotation periods, and for the generation of shape models. He has conducted observations through three apparitions of Steins. Table 2 contains the observing times of Dr. Weissman's Steins observations.

Asteroid Steins, a small outlier asteroid, designated a Rosetta mission target in 2004 after the launch delay, was previously believed to be an S-type asteroid. In asteroid taxonomy, "S" refers to an inferred surface mineral content relatively rich in iron; containing olivine, pyroxene, and metals. The meteorite analog of an S-type asteroid includes the stony irons and chondrites (where a chondrite is a mineral that includes chondrules—spherical grains that form as the temperature cools). Dr. Weissman obtained both lightcurve and color data on the target with his suite of observations [8,9]. The lightcurve revealed a deep absorption feature characteristic of E-type asteroids. The taxonomic designation "E" refers to enstatite, a type of silicate that is formed in an iron-poor environment and at high temperature. The closest taxonomic analog for Steins is 64/Angelina, the closest meteorite analog is aubrite, an enstatite achondrite (a mineral without chondrules), with inclusions of a mineral, calcium sulfide (CaS), that exists at high temperature. Thus, the region of origin of this target might be a very early period in Solar System evolution, when the temperatures were high, potentially from a region

Table 2. Asteroid Observations by the IDS to Date

Photometry
•April 14–16, 2004
Table Mountain Observatory, 0.6-m telescope

•August 1–3, 7–11, 2005
Cerro Tololo Inter-American Observatory (half-nights), 0.9-m Smarts telescope

•January 16–17, 2007
Table Mountain Observatory, 0.6-m telescope

•January 23-25, 2007
Steward Observatory, 1.55-m Kuiper telescope

Spectroscopy
•December 19, 2006
Palomar Observatory, 200" Hale telescope

of the asteroid belt where the temperature gradient was expected to be extremely steep. There are only a small number of E-type asteroids recorded, making Steins unusual. Unlike other E-type objects, Steins was revealed to be very red in color, making it even more unique. Steins has a (retrograde) rotation period of 6 hours, and radius of 4.6 km. With these observations, Dr. Weissman corroborates the conclusions of others who are also studying this target.

7. SUMMARY OF THE U.S. ROSETTA PROJECT THROUGH THE MARS GRAVITY ASSIST

Rosetta was in a position to make historic measurements at the Mars gravity assist. A very successful joint campaign was conducted with the NASA New Horizons mission for the study of ultraviolet emissions from the Io torus and deep magnetotail of Jupiter. Investigators look forward now to the encounter in September of 2008 with the enigmatic little asteroid, Steins, possibly the most thermally processed asteroid yet encountered by any spacecraft mission, more processed than Vesta, the asteroid target to be visited by the Dawn mission.

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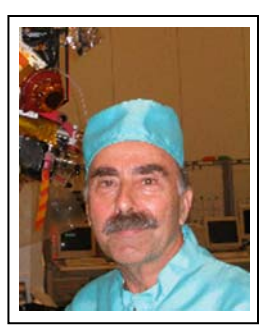
BIOGRAPHY

Dr. Claudia Alexander is currently a Research Scientist at the Jet Propulsion Laboratory, where she serves as both Project Manager and Project Scientist of the U.S. Rosetta Project. She has also served as Project Manager of the historic Galileo Mission to Jupiter in the final days of the mission. Dr. Alexander is an interdisciplinary scientist. She is currently at work on a model of the rarefied atmosphere surrounding Jupiter's moon Ganymede. She completed a Ph.D. in 1993 in Space Plasma Physics at the University of Michigan. Dr. Alexander received a Bachelor's Degree in Geophysics from the University of California at Berkeley in 1983, and a Masters Degree in Space Physics from the University of California at Los Angeles in 1985.



Dr. Raymond Goldstein is currently a Staff Scientist at the Southwest Research Institute. While there, he has been involved in analysis of Cassini/CAssini Plasma Spectrometer (CAPS) and

Deep Space 1 (DS-1)/Plasma Experiment of Planetary Exploration (PEPE) flight data, laboratory calibration of the Rosetta/IES instrument, and as its project manager, and in the design of several flight instruments. Prior to that, he was a Staff Scientist at the Jet Propulsion Laboratory. He received a B.S. degree in Physics from City College of New York, New York, N.Y., and a Master's Degree and Ph.D. in Physics from Lehigh University, Bethlehem, Pennsylvania. In his career at JPL he was responsible (as Co-Investigator) for prototype design and laboratory calibration of the ion mass spectrometer flown past comets Halley and Grigg-Skjellerup on the Giotto spacecraft, and has been actively involved in the analysis of data from these encounters, particularly regarding cometary coma composition and the dynamics of the interaction of the solar wind with the coma.

Dr. Joel Parker was recently named acting Principal Investigator of the Alice instrument on Rosetta. He is the Project Manager for the Alice-New Horizons project, and Science Operations Center manager for the Lyman-Alpha Mapping Period (LAMP) instrument on the Lunar Reconnaissance Orbiter. His research involves photometric and spectroscopic multi-wavelength studies in planetary and stellar astrophysics using ground- and space-based, instruments. His topics of interest include asteroids, comets, Centaurs and Kuiper Belt objects, Pluto, the Moon, vulcanoids, local group galaxies, young stellar groups and their environments, initial mass functions and star-formation rates, interactions of massive stars with the interstellar medium, luminous blue variables, and data reduction and analysis techniques. He received B.A. degrees in Physics and Astronomy at the University of California, Berkeley, in 1986, an M.S. in Astrophysics at the University of Colorado, Boulder, in 1989, and a Ph.D. in Astrophysics at the University of Colorado, Boulder, in 1992.

Dwight Holmes is currently at the Jet Propulsion Laboratory where he serves as the Telecommunications and Mission Systems (TMS) manager for Rosetta. Mr. Holmes is also the current TMS manager for three other NASA/ESA cooperative missions, Integral, Venus Express, and Mars Express. Mr. Holmes has also served as the TMS manager for the launch and early operations of NASA's Genesis and Stardust missions. Early in his career at JPL Mr. Holmes served as the Radio Science support team chief for the Voyager dual mission to the outer planets, and as the Radio Science support team chief in the early mission development phase of the Galileo program. He completed his Master's Degree in Space Science and Applied Physics at Johns Hopkins University in 1978, the same year he began work at JPL. Mr. Holmes received his Bachelor's Degree in Electrical Engineering from Rutgers University, New Brunswick, New Jersey, in 1968. Mr. Holmes is a recent graduate of the Claremont Graduate University executive MBA program and is currently a Ph. D. candidate studying the economics of international collaborative science projects.