The U.S. Rosetta Project: Eighteen Months in Flight

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Abstract—The International Rosetta Mission, the 3rd cornerstone mission of the European Space Agency (ESA) has been in operations since March 2, 2004. This year, Rosetta conducted observations of comet 9P/Tempel 1 in support of NASA's Deep Impact mission. Observations of this comet target were conducted from a distance of approximately 0.5 AU, and provided for approximately 2 weeks of observation time to complement the 800 seconds of observation time afforded Deep Impact's cameras. In this paper we will update the status of the instruments following the commissioning exercise, an exercise that was only partially complete when a report was prepared for the 2005 IEEE conference. We will present an overview of the 2005 Earth/Moon activities, and the Deep Impact set of observations. The paper will also provide an update of the role of NASA's Deep Space Network in supporting an ESA request for Delta Difference One-Way Ranging to provide improved tracking and navigation capability in preparation for the Mars flyby in 2007.

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[1]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 interdisciplinary scientist and provides investigator support to Co-Investigator's (CO-I's) on non U.S. payload instruments. Details of the instruments and of NASA's role can be found in our previous paper [10], instrument description papers [1,2,3,4,5,6], as well as summary Table 3 of this paper.

The International Rosetta 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. The measurements to be made to achieve this are:

(1) Global characterization of the nucleus, determination of dynamic properties, and surface morphology and composition

(2) Determination of the chemical, mineralogical, and isotopic compositions of volatiles and refractories in a cometary nucleus

(3) Determination of the physical properties and interrelation of volatiles and refractories in a cometary nucleus

(4) Study of the development of cometary activity and the processes in the surface layer of the nucleus and the inner coma (dust/gas interaction)

(5) Global characterization of asteroids, including determination of dynamic properties, surface morphology, and composition

The mission was successfully launched on March 2, 2004. Back-up tracking and navigation support provided to ESA by NASA's Deep Space Network (DSN) involved the so called Space Link Extension (SLE) services interface between the NASA and ESA ground support networks, interleaving two differing cultures of communication and ground station equipment

Table 1. Science Targets observed by the Rosetta Project to date

Target / Instrument	Date
__Venus__	
MIRO	April 1, 2004
__Earth and Moon__	
MIRO	April 24, 2004
Alice and MIRO	March 4, 2005
__Comet LINEAR__	
Alice and MIRO	April 30, 2004
Alice and MIRO	May 14, 2004
__Comet Catalina__	
MAG and LAP	June 26, 2005
__Comet Tempel 1__	
Alice	June 27 – July 14, 2005
MIRO	June 28 – July 14, 2005

Because commissioning was not fully complete as of the writing of the 2005 report, the timeframe covered in that report was the first 6 months of Rosetta's cruise from March 2 through August 2, 2004. In this report we will discuss the final phase of commissioning and summarize the instrument status as of the close of that mission phase. We will report on the Earth Gravity assist, and associated Moon calibrations, discuss the Tempel 1 observations that were coordinated with the Deep Impact mission, and conclude with the science opportunity of the upcoming Mars encounter.

2. Commissioning Wrap-up

Commissioning for ESA missions has always been different from that for NASA missions in that the commissioning/check-out phase nominally takes place over a 90 day period rather than the 30 day period used in a NASA mission. As an added complexity for the Rosetta Project, ESA planned a hiatus in Rosetta spacecraft commissioning for Mars Express orbital operations. ESOC staff were to shift their attention from Rosetta to Mars Express during the summer of 2004. Thus Rosetta commissioning took place in two phases. Phase 1 commenced at launch and continued through mid-June, 2004. Phase 2 commenced in early September and continued through mid-October, 2004.

Following launch a successful series of activities commenced to initiate commissioning of the payload. The Alice detector door was opened, and first light was recorded. MIRO, using its chirp transform spectrometer (CTS) for the first time, obtained the water signal of the Earth, as well as signals from Venus. A sophisticated spacecraft "spiral scan" pointing scheme was worked out and deployed for the first time for the MIRO measurements [10]. IES validated its interface with the power interface unit (PIU) and conducted successful low-voltage operations. The double focusing mass spectrometer conducted successful high-voltage operations.

In the middle of commissioning, comet C/2002 T7 (LINEAR) provided an unexpected target of opportunity.

Aside from instrument turn-on and verification of nominal modes, voltages, and telemetry, Phase 1 objectives of the commissioning exercise for the U.S. Rosetta Project included the following: (1) Verification of the MIRO beam direction, and characterization of the side-lobes of the beam. Beam misalignment is supposed to be minimized by placing the beam nearly parallel at the telescope/optical bench interface. Lateral misalignments are supposed to be minimized by the placing of the telescope mount near the beam axis. (2) Execution of the Alice Performance Aliveness Test (PAT) that provides the instrument sensitivity and alignment information needed for mission science data acquisition and allows for derivation of the instrument effective area curve. (3) Validation of the basic performance of the ROSINA DFMS with high-voltage operations. (4) Validation of the basic performance of IES with low voltage operations. Additional science functionality, check-out, and high voltage operations with IES were delayed to Phase 2 of the commissioning timeframe, as shown in Table 2. This delay provided assurance that the instrument was fully outgassed before high voltage turn-on.

U.S. Rosetta Phase 1 Commissioning

Alice Phase 1 commissioning took place in three stages. On March 26, Alice powered on for the first time and performed the following: verification of the prime and redundant power, C&DH interfaces, aperture door unlatching and then operations (initial opening, plus 12 repeated cycles), microprocessor context save and restore functions, heater performance tests, a broad suite of memory checksums, and testing of detector electronics. The April 15-24 dates contained the bulk of Alice commissioning activities. During this time, Alice opened the detector door, performed ramp-up tests of the high-voltage power supply, executed detector performance tests (dark count and response), executed software performance tests, and obtained a first-light image of the hydrogen background emission.

Table 2. Timeline since Launch for the U.S. Rosetta Project

Launch	March 2, 2004
Commissioning, Part 1, Functional Check	
IES power on	March 19, 2004
Alice power on	March 26, 2004
MIRO power on	March 31, 2004
MIRO Venus calibrations	April 1, 2004
Alice open detector door	April 17, 2004
Alice first light	April 21, 2004
MIRO Earth calibration	April 24, 2004
IES low-voltage operations	May 9, 2004
DFMS HV operations	May 21, 2004
Alice Performance Aliveness Test (PAT)	May 28, 2004
Observations of Comet LINEAR	
Alice and MIRO	April 30, 2004
Alice and MIRO	May 14, 2004
Commissioning, Part 2, Pointing and Interference Campaigns	
IES HV operations	Sept 6-10, 2004
Pointing Campaign #1	Sept 11-17, 2004
Interference Campaign #1	Sept 22-24, 2005
Pointing Campaign #2	Sept 25-28, 2004
Interference Campaign #2	Oct 12-13, 2004
Earth-Moon Observations during Gravity Assist #1	
IES measurements of the outer magnetosphere	March 4-5, 2005
MIRO Earth Calibration	March 4, 2005
Alice Moon Calibration	March 4, 2005
Observations of Comet Tempel 1 coordinated with Deep Impact	
Alice and MIRO	June 27- July 14, 2005

The Performance Aliveness test (PAT), produced the first measurement of the in-flight effective area of ALICE at wavelengths between ~1275-1900 Å. The effective area curve as a function of wavelength was measured and the total in-flight sensitivity of ALICE in the 1275-1900 Å regime was shown to be close to the in-flight expected sensitivity based on earlier ground calibration tests.

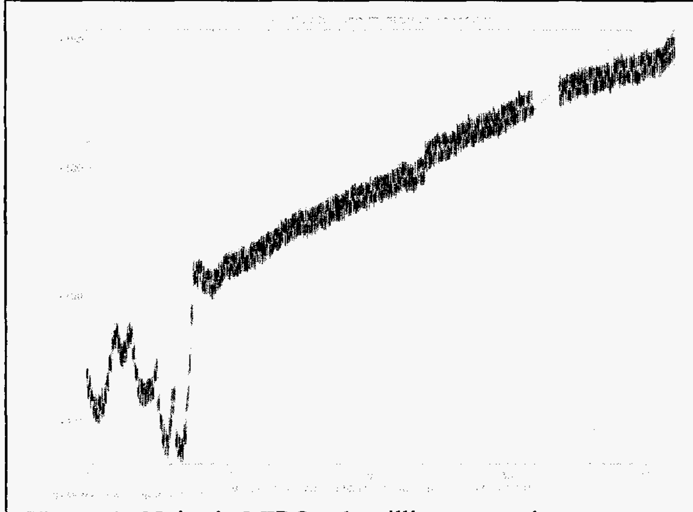

Figure 1 –Noise in MIRO sub-millimeter continuum spectra obtained during the Interference test of Sept., 2004. The figure shows approximately 40 minutes of data from instrument turn-on.

MIRO Phase 1 commissioning was accomplished in two stages. On March 30, MIRO powered on for the first time and performed exercise of all modes and of the calibration mirror. In this phase, engineering data were nominal, including currents, voltages, and temperatures; receiver gains matched laboratory measurements; noise sensitivities met or were slightly better than in the laboratory; and spectroscopic spectra appeared normal. The next day the beam direction was calibrated with spiral scans around Venus. On April 30, goals accomplished included 1) validation of pointing, 2) verifying end-to-end spectroscopic capability by observing the ground state transition of water at 557 GHz in the Earth's upper atmosphere.

IES concluded Phase 1 commissioning with low-voltage check-out on May 9, 2004 while the ROSINA DFMS electronics performance was validated on May 21, producing spectra.

U.S. Rosetta Phase 2 Commissioning

IES successfully operated all of its high voltages during Phase 2 and acquired about 5 hours of solar wind data. The latter show that IES is fully functional.

Tests were conducted to determine whether or not there was mutual interference between the instruments or between the instruments and the spacecraft. Of the U.S. Rosetta instruments, MIRO experienced intermittent interference during these tests, the source of which was not determined. Figure 1 provides an example of the interference, in which offsets in the sub-millimeter signal from a baseline can be seen near the 25 minute mark. The MIRO instrument team is currently trying to understand the test results in terms of interference or possibly self-interference. Because of the very low duty cycle of the interference, these are not expected to impact the instruments performance.

Wrap-Up

A summary of instrument status at the close of commissioning is provided in Table 3. The instruments compare favorably with their predicted performance prior to launch. In some cases the post-launch performance exceeds expectations. Stray light tests with the Alice instrument show the instrument to be less susceptible to stray light than previously expected. The Alice passband is wider than that proposed – Alice proposed 700-2050 Å and in flight it is measured at 660-2060 Å. The spectral resolution improved from 8-12 Å to 11-12 Å. The effective area is smaller than proposed, but not expected to impact Alice science objectives. The ROSINA DFMS electronics package is

Table 3. Specifications of hardware components in the U.S. Rosetta I

Alice	**Measured Flight Performance**
Passband	660-2060 Å
Spectral resolution	11-12 Å extended source
Effective Area	0.05 x 0.02 cm^2
Field of view	0.05° x 2.0° + 0.1° x 4.0°
Offset:	ΔX: 0° ΔY: -0.1°

IES	**Measured Flight Performance**
Energy range	1 eV - 30 keV
Energy resolution	4%
Field of view	2.8 π steradians

MIRO	**Measured Flight Performance**
Passband	190 GHz, ~1.6 mm (millimet wavelengths)
	562 GHz, ~0.5 mm (sub-millimet wavelengths)
Spectral resolution	44 kHz (sub-millimeter)
Spatial resolution	7.5 arc min (millimeter)
	2.5 arc min (sub-millimeter)
Radiometric sensitivity	1 K (continuum)
Offset: MIRO submm beam	ΔX: -0.082° ΔY: --0.0067°
Offset: MIRO smm beam	ΔX: -0.018° ΔY: -0.057°

ROSINA - DFMS	**Measured Flight Performance**
Mass range	12- >130 AMU
Mass resolution	1200-3650 @ 1%
Sensitivity	5 x 10^-6 A/Torr

capable of a resolution of 1%.

3. THE EARTH-MOON FLYBY OF 2005

The first gravity assist at the Earth took place on March 4, 2005, one year after launch. . During this encounter, the Earth occulted the Moon for approximately a half hour. A few hours after Earth closest approach the payload executed a simulation of an asteroid flyby mode as the spacecraft passed the Moon. In addition to these payload operations, MIRO completed a calibration exercise on the Earth's atmosphere during the Moon occultation, Alice completed calibration exercises on the Moon, and IES participated with the Rosetta Plasma Consortium (RPC) to collect *in situ* data on the Earth's plasma environment.

Alice Moon Calibrations

•Three calibration tasks using the Moon were outlined for the Alice Earth-Moon #1 encounter: an absolute solar flux calibration, a scattered light calibration, and a flat fielding calibration. It was at this time that complexity involving conflicting constraints between those of the spacecraft solar panel pointing and those of Alice for observing became evident and the operational complexity of Alice operations became apparent (see section 5). The Alice slit is aligned perpendicular to the solar array rotation axis. The solar array rotation axis must always be perpendicular (or nearly so) to the Sun, so the Alice slit angle is similarly constrained. As the solar elongation angle decreases, the allowable Alice slit positions also diminish. This means that Alice is unable to request specific slit orientations (e.g., tangent to sunlit lunar limb), resulting in unexpected slit orientations for this set of calibration activities. As a result of this complexity, Alice was only able to complete a subset of the expected calibrations and will request additional calibration time at the Earth-Moon encounter #2 in November of 2007.

IES Plasma Observations in the outer magnetosphere

Ion spectra acquired during the Earth encounter is shown in figure 2. The data indicate that it was a quiet solar wind day. ACE data confirm a very low number of alphas. There were two bow shock crossings – timing is shown in figure 2.

4. OBSERVATIONS OF COMET 9/P TEMPEL 1

On July 4, 2005 Rosetta was afforded the opportunity of an astronomically close view, from 0.5 AU of the Deep Impact impactor connecting with the surface of comet 9/P Tempel 1. All four remote sensing instruments of Rosetta: Alice, MIRO, OSIRIS (the camera), and VIRTIS (an infrared instrument) were turned and watching. The set of observations began with calibrations July 27 and 28, then full observational cycles starting July 28. These pre-impact observations served as baseline on the activity of the perihelion phase comet. Post-impact observations were conducted July 4- 14, 2005.

No significant signal was detected in the pre-impact data, by either MIRO or Alice. The lack of signal was in keeping not only with the distance at which the observations were being conducted but also with the findings of other observing platforms both ground based and in flight, indicating that the water production was low [14].

Figure 3 shows the Alice post-impact spectrum acquired of the comet coma. H Lyman α and β were detected at 973 Å

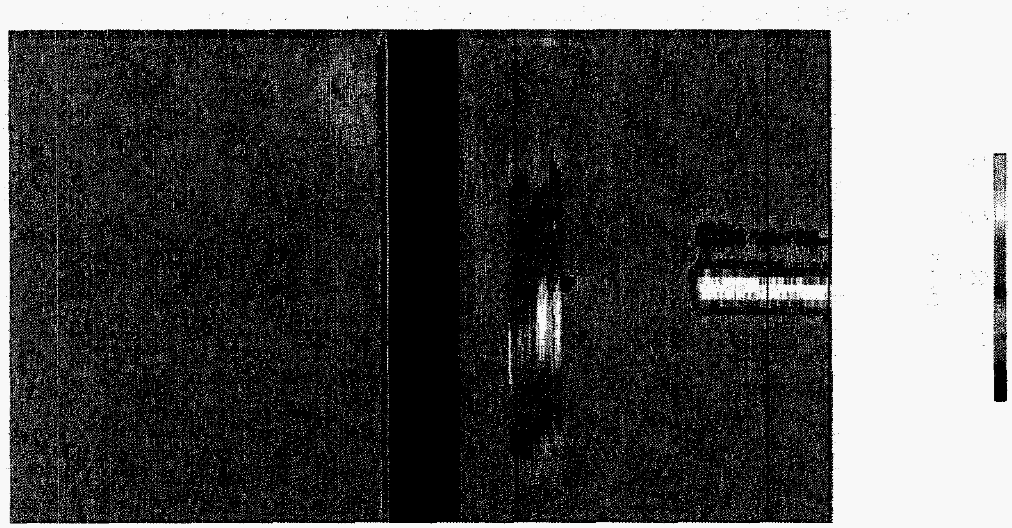

Figure 2 – Acquired IES ion spectra of Earth's magnetosphere taken March 4-5, 2005.

and 1025 Å, respectively; in addition, oxygen at 1304 Å and carbon at 1561 Å and 1657 Å were also detected. Continued study of these data will result in derived gas production rates from this set of observations.

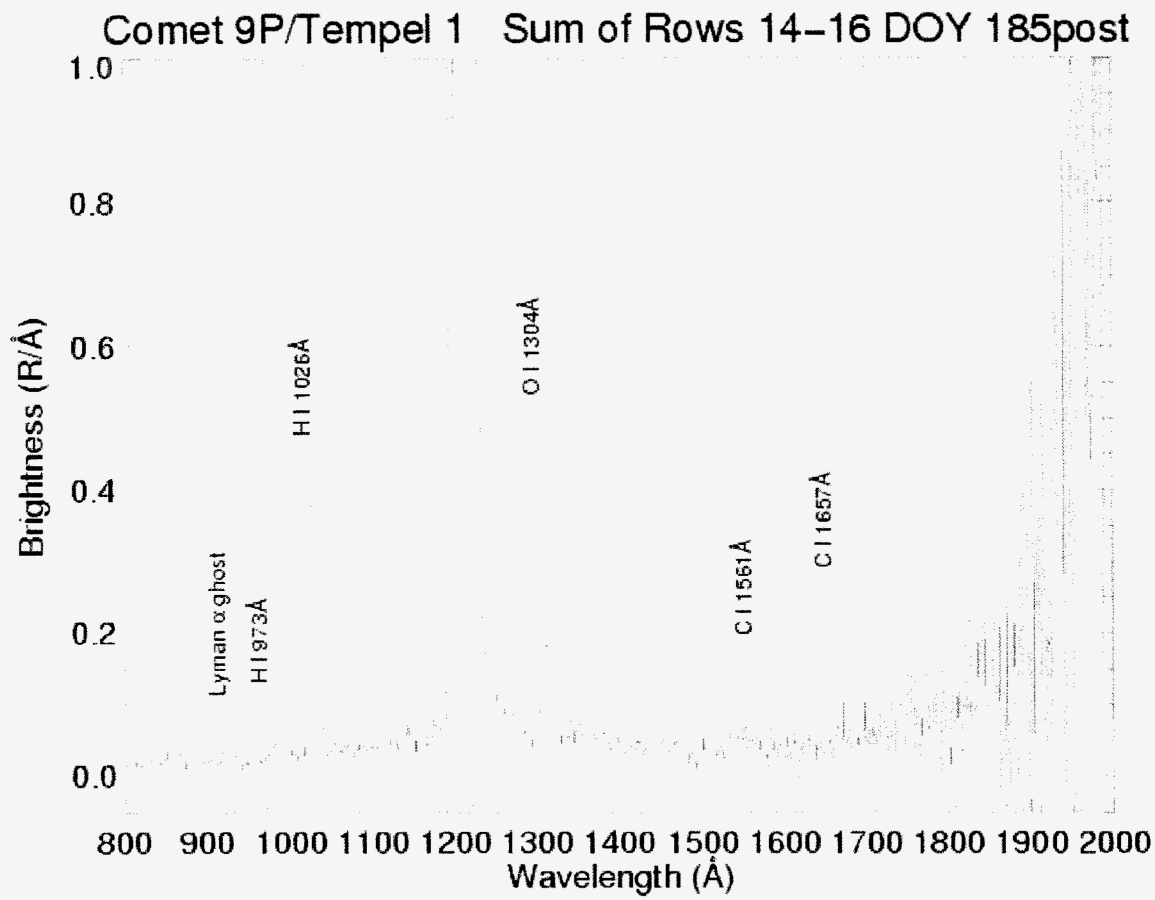

Figure 3 – Acquired Alice spectra of comet Tempel 1 taken July 2005.

Figure 4 shows the ground state rotational transition of water at 556.936 GHz detected by the MIRO instrument in the post-impact phase of the observations. This measurement provides for the first direct water production rate for this target. The signal to noise was too low to detect variability in the water production rate in the post-impact phase, however the Doppler shift of gaseous efflux was measured, giving the direction of expanding gas following the explosion – a critical element in understanding the efficacy of the impact.

5. Incidents, Surprises, and Anomalies (ISAs)

The project keeps a record of mission incidents, surprises, and anomalies. These are known collectively as ISAs. For the second year in a row, very few problems fall into the category of an anomaly. Most of the instrument issues fall under the category of surprises. Such surprises are cataloged nonetheless. In this section we provide a sampling of instrument ISAs.

Alice Slit Orientation — In readying for the Moon calibrations the Alice team discovered that spacecraft pointing constraints precluded motions necessary to obtain the complete sweep of required wavelengths for Alice calibrations. Alice has no moving components, and is dependent upon the spacecraft motions for movement of the viewing slit. However as the solar elongation angle decreases, allowable Alice slit positions for successful science operations also diminish. This constraint, coupled with those spacecraft operational constraints related to the attitude that must be maintained for the solar panels, couple in such a way that the Alice slit orientation cannot be controlled. Following the Moon observations, it is now recognized that Alice operations will be demanding on the spacecraft attitude. This, combined with spacecraft operational power and thermal constraints, translates into a set of complex operational constraints that were not originally anticipated by ESA or NASA. The final impact of these constraints will be known only after the definitive orbital trajectory is defined. However, the large number of operational opportunities expected in the prime mission is an excellent indicator that Alice's primary and secondary instrument objectives will be satisfied.

IES Noisy Channel — 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 will be performed when the opportunity arises to identify the specific channel and quantify the noise.

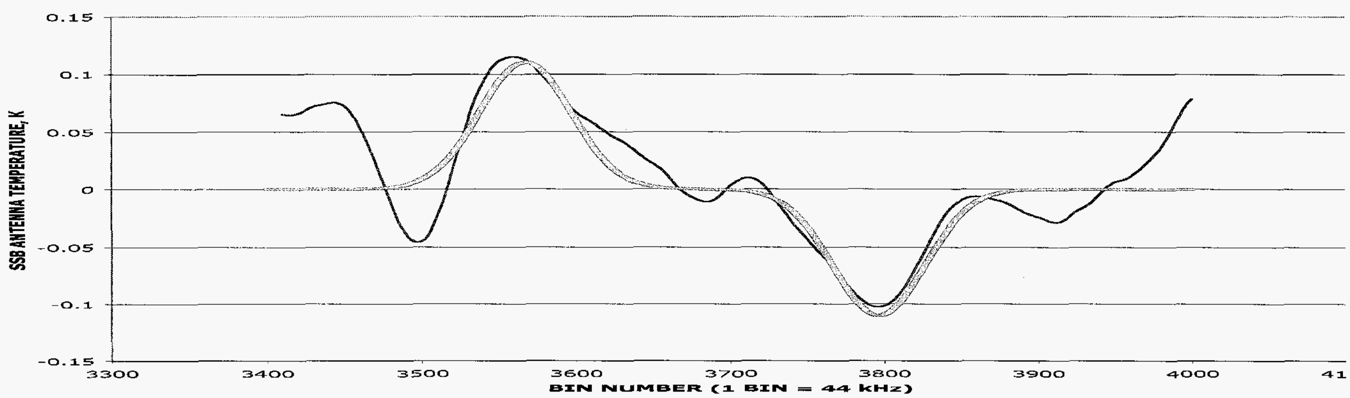

Figure 4 – Acquired MIRO water spectrum of comet Tempel 1 taken in July 2005 is shown in the light blue line. The pink line is the modeled water signal.

MIRO Software Fault — 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 round the clock). Seventeen hours lapsed before the CTS resumed normal operations, and executed all commands stacked in its que. The root cause of this data loss has not been established, however the possibility of an error in the software is currently being investigated.

ROSINA DFMS Temperature — The temperature sensor of the DFMS detector (not the electronics package) is providing readings of an operational temperature currently established to be -18°. Extrapolations of the gradient in temperature with distance predict further drops in the operating temperature to -70° or -80°. The implications of this extreme temperature drop include requirements of power from the spacecraft to operate the detector. The thermal behavior of the detector is not established, however. The extrapolation curve might not be linear slope, or may change to a smaller slope with time. The non-operating temperature limit is -55°. Concerns include mechanical issues of expansion and contraction of materials associated with the entire detector including the electronics package; metal interfacing with ceramics, etc. A thermal model is expected to be performed by the DFMS electronics team to understand the implications of the detector behavior on the electronics.

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 Science Group - PSG). Observing tasks include obtaining photometry of the mission targets for use in deriving precise rotation periods and for generating shape models. Modeling tasks include the comet nucleus, the gas and dust environment, and studies of the nucleus composition and its relationship with interplanetary, interstellar and circumstellar dust.

On August 1-3 and 6-10, 2005, Dr. Weissman conducted observations of Asteroid 2867 Steins from Cerro Tololo. Asteroid Steins, an S-type outlier asteroid, is a Rosetta mission target for 2008. Dr. Weissman obtained both lightcurve and color data on the target with this set of observations, the analysis of which indicate Steins has a rotation period of 6 hours.

7. MODELING EFFORTS

Investigators in the U.S. Rosetta Project participated in a modeling effort sponsored by the International Space Science Institute (ISSI). Ongoing efforts of the ISSI Comet Modeling Team include goals of improving our understanding of the emission of gas and dust in a comet's coma from the nucleus, the comet solar wind interaction, cometary ion chemistry, and cometary high-energy processes. These goals are achieved through the combination of state-of-the-art modeling, and analysis of observations of the cometary environment. The understanding of comets and cometary processes gained from the ongoing modeling studies constitutes important preparatory work for Rosetta mission planning.

The team has linked together a series of 3D models for the nucleus, neutral gas, plasma, and dust. The model suite includes a thermophysical model of the upper layers of the porous nucleus surface, the Knudsen layer at the boundary with the coma, a Direct Simulation Monte Carlo dusty-gas kinetic model for the neutral dust and gas coma, both magnetohydrodynamic and hybrid-kinetic models for the solar wind cometary plasma interaction, a two-stream thermal and superthermal electron model and a charged dust model.

Information from each model is propagated into the others providing a full description of the environment from the surface out to millions of km. The fully 3D coupled model suite has revealed a number of new insights into the cometary environment. For example, the non-spherical nature of dust and gas flow from the nucleus produces a decidedly non-radial flow in the very inner coma. the Preliminary results were presented at the DPS, 2005 [13].

8. PREPARATIONS FOR THE MARS ENCOUNTER INCLUDING DSMS DELTA-DOR OBSERVATIONS

We are eagerly anticipating the Mars encounter of February, 2007. It will be the first time a microwave instrument has been flown to Mars, and the first time measurements in the FUV have been made at Mars since Mariner 7 in the 1960's. As of this writing, a trajectory for the Mars encounter is not available, and formal planning for the Mars encounter has yet to commence. Nevertheless, we anticipate a flyby distance between 200 and 300 km altitude. Such an altitude will allow for measurements that will be critical for modelers of the upper atmosphere in (1) future aerobraking (2) accurate weather prediction, and (3) addressing questions about atmospheric escape mechanisms, particularly questions about the escape of water.

Potential Measurements of Alice at Mars

Mariner 9 last obtained close-up ultraviolet spectra – between the wavelengths of 1100 and 3400 Å, of airglow in the Martian upper atmosphere in 1970. In 2007, Alice will look at the strong emissions of H, O, C, N, Ar, and CO in the upper atmosphere of Mars at ultraviolet wavelengths, and other emissions in the far ultraviolet – wavelengths below 1000 Å at higher resolution that those obtained by the Mariner missions.

Potential Measurements by IES at Mars

IES will be able to measure ion and electron distributions in the ionosphere at a higher energy resolution than previously obtained. Also, since the ionospheric plasma is cold, the flyby speed of Rosetta will allow ion composition determination since the energy/charge measured can be converted to a mass/charge spectrum.

Potential Measurements of MIRO at Mars

There are no instruments with the capabilities of MIRO on any satellite around Mars. Thus MIRO has the potential for providing unique data about Mars. Its two continuum channels will provide surface and sub-surface temperatures. Its high resolution spectrometer has the potential for measuring high altitude water concentration and stratospheric winds [13]. Carbon monoxide and several isotopes of water may also be measured.

Deep Space Mission System (DSMS)

The Rosetta mission requires augmented telecommunications support for tracking (navigation), telemetry and telecommand during defined event phases of the mission which includes the Mars approach and flyby in February 2007. ESA's deep space tracking network, with 35m stations at New Norcia, Australia and Cebreros,Spain provides primary support throughout the mission. NASA's role includes the use of DSN resources for backup, emergency and launch activities. The DSN will also be utilized during the various critical events: planetary gravity assists an asteroid fly-by, and the final comet encounter.

The DSN, with three 70m antennas spaced 120 degrees apart in longitude, provides the capability to acquire the spacecraft downlink signal under conditions that could be below capture threshold for either the ESA 35m stations or the DSN 34m station subnets. These conditions include spacecraft states such as "safe mode" in which the spacecraft either reverts to S-band on a low gain antenna (broader beam width ease in uplink capture), at the medium gain X-band antenna for conditions which might include spacecraft attitude off Earth point for trajectory maneuvers.

The DSN can also provide alternative spacecraft navigation capability. Traditional spacecraft navigation depends on radiometric data to determine range and range rate. The observables include Doppler profile of the downlink signal referenced to the uplink, as well as ranged data based on correlated ranging tones referenced to the ground station. Other components include the ground station location, antenna pointing angles, and highly accurate clocks. This technique provides very accurate range, velocity, and acceleration components, but angular resolution in the plane of the sky requires integration over a number of observations. The navigation problem when approaching, orbiting, or just flying close to a celestial object is that accurate measurements can be time critical. This is particularly true for conditions in which heavy spacecraft activity increases the risks of a safe mode entry. Safe Mode is the generally accepted lowest level of spacecraft activity in which only fundamental health and safety functions are operating. The state allows trouble shooting of the safe mode entry event and eventual recovery to normal operations. The event can also significantly impact the operation team's ability to collect accurate and consistent radiometric data for navigation.

The alternative navigation mode provided by the DSN that compensates for the loss of spacecraft navigation accuracy due to integration time constraints is a technique known as Delta Difference One-Way Range (DDOR). The techniques 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 70m antennas. Quasar sources are typically very weak 10^{-26} Watts/Hertz per square meter of aperture [9]. The technique requires the ability to record and correlate the signals from two Quasars and the spacecraft over a baseline of thousand of kilometers. The spacecraft must be configured so that its downlink can be correlated with itself from the cooperating observing station. The technique provides direct geometric determination of spacecraft angular resolution on the order of 5 nanoradians ($5x10^{-9}$ radians) with a single observation.

In order to achieve the accuracies currently available with the DDOR technique, the spacecraft must be equipment with DDOR tones on board with which optimize the correlation process. However, DDOR can be used with spacecraft not equipped with DDOR tones, by configuration the downlink telemetry to maximize the harmonic content of the downlink signal. Rosetta was designed with the capability at launch to implement the DDOR tones when required. Rosetta will begin testing with DDOR at the end of 2006 in preparation for the Mars flyby. DDOR will be further used at each of the critical asteroid encounters, flybys, and final comet rendezvous.

The complexity of two tracking complexes 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 requires the advanced process of SOE generation using DSN keyword files.

The Use of DSN Keyword Files (DKF's) with Rosetta

As called for in the mission governing documents, NASA supplied telecommunications support in the form of back-up tracking and navigation coverage during the launch activities and through the early operations phase (LEOP). In many respects, Rosetta was a pioneering mission with regard to international collaboration and the use of the DSN and other NASA resources in conjunction with foreign institutions. When the initial commitments were made the complexity of implementing ground support of this kind between two very different agencies was not appreciated. Moreover, the mission was always to be operated under strictest constraints in cost. As the use of DSN assets and calculation of navigation solutions is resource rich, NASA was interested in ensuring that the cost of such support did not become more than the agency could bear. Finally, as with all things technical, time produces advances, simplifications, or at least changes in format that must be accounted for. Adjusting for all of these components were hidden challenges for the U.S. Rosetta project.

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 Keyword Files (DKF's). ESA has found the use of DKF's on Mars Express to be cumbersome and work-intensive. After an initial study in the weeks preceding launch, ESA recommended against the use of DKF's for Rosetta. The mission provides for less interference with other deep space missions (unlike the Mars' case) and long-term mission operations will be sufficiently repetitive that the DSN need not worry about rapid changes in the sequence of events. The issue remains unresolved however because NASA's attempts to automate more the mission scheduling will require all missions to move to the use of DKF's. A brief introduction to the issue follows.

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. DKF's allow for rapid implementation of changes, and allow the DSN facilities greater flexibility in allocation of station resources. The complex process of creating such a file is outlined below.

(1) The process starts with a Navigation solution for Rosetta. ESOC Flight Dynamics (FD) group, the primary navigation group for Rosetta mission, will periodically send JPL Nav team updated predicted trajectories in EPM format. JPL Nav team will convert the files into SPK (or P-file, if necessary) format and delivery it to DSN predict team. DSN predict team will use the SPK files to create DSN view period files to support Multi-mission DSN Allocation and Planning Team (MDAPT)/Mission Planning and Sequencing Team (MPST). View periods define intervals when Rosetta is visible from each Deep Space Station and specify limits for each station transmitter. The MDAPT would then allocate specific stations to support Rosetta.

(2) JPL Navigation team will also create Orbit Propagation and Timing Geometry (OPTG) file and Light Time file using the predicted trajectory provided by ESOC. OPTG file contains orbital elements, orbital event times and cruise event times. The OPTG file is a trajectory representation more suitable for missions orbiting planetary bodies. The light time file contains Earth-centered spacecraft one-way light time. Light time and OPTG files will be mainly used by MPST team.

(3) The Rosetta Ground Segment at ESA will use the DSN allocation files, navigation information, and science requests to prepare sequences and commands for ROS. A portion of this commanding will concern the status of the Rosetta telecom system. These commands must be communicated to MPST for use in generating the DKF. Rather than providing MPST with a strip of actual commands from the telecom system, Rosetta controllers will only send a 'telecom key file' (not the DKF) that represents the telecom system as it pertains to the DSN. *It is assumed that Rosetta will always have the appropriate antenna pointed at Earth during the portion of the pass allocated to Rosetta.* This assumption is required because the SEQGEN models implemented for Rosetta do not represent the attitude control subsystem, only the telecom subsystem. The JPL Ground Data System (GDS) team will be responsible for importing the key file, reformatting it, and renaming it.

(4) Once the DSN allocation is finalized, DSN predict team will use the SPK file to create DSN antenna predict files (antenna pointing and frequency predicts) and deliver them to DSN stations before each scheduled pass.

The process described above is designed for easy manual execution, if necessary, since tasks will be mostly scripted. It is expected that for early orbital operations, manual execution will be the normal method used to build DKFs. Since so much of the process is scripted and since MPST is not planning on staffing Central European Standard Time prime shifts, it is expected that the generation of DKFs during orbital operations will be automated.

Software would be employed to facilitate the generation of these files. The Automated Sequence Processor (ASP) is a tool that allows command files and DSN predicts to be generated without manual intervention on the part of the MPST. The GDS transfer script at JPL would periodically (every 5 minutes) check the key file directory for a file and make rapid transfer of the file to the appropriate server. Generation and distribution of the products will then occur automatically per standard ASP scripting.

A key problem with this process for ESA is its complexity and time-consuming nature. A key advantage for NASA is the way it provides for greater automation, easy update, and ease of integrating multiple stations.

9. Summary of the U.S. Rosetta Project's First Eighteen Months in Flight

Instruments in the U.S. Rosetta Project have completed all commissioning activities and are operating nominally. Quite a bit of science data has already been returned from the mission. Observations of comet LINEAR were taken even before the spacecraft commissioning was completed. Observations of the Earth-Moon system have been made, as well as observations of the recently discovered comet Catalina. A very successful joint campaign was conducted with the NASA Deep Impact mission for the study of comet Tempel 1. Investigators eagerly anticipate the Mars encounter in 2007. With all this successful data return, the spacecraft seems very ready for prime mission operations at comet Churyumov-Gerasimenko.

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The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

BIOGRAPHY

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Dr. S. Alan Stern currently serves as the Executive Director of the Space Science and Engineering Division

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Dr. Raymond Goldstein is currently a Staff Scientist at the Southwest Research Institute. While there he has been involved in analysis of Cassini/CAPS and DS-1/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 Masters and Ph.D. degree 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. James L. Burch is Vice-President of the Space Science and Engineering Division at Southwest Research Institute in San Antonio, TX. He received his B.S. in Physics in 1964 from St. Marys University

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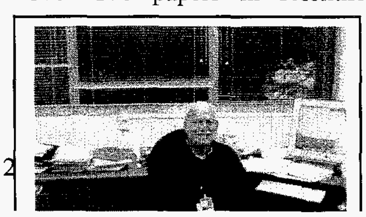
Dr. Stephen Fuselier is presently Manager of the Space Physics Department at Lockheed Martin Advanced Technology Center (approximately 40 scientists and engineers). He previously served as Group Leader for the Space Plasmas. He has served as Co-I on Imager for Magnetopause to Aurora Global Exploration (IMAGE), and Co-I on the Rosetta ion and neutral mass spectrometer and the Simple Plasma Experiment for the RoLand lander. He serves as the Lead US Co-I on the Rosetta orbiter spectrometer for ion and neutral analysis (ROSINA), developing instrumentation for a rendezvous with a comet. He assisted in the calibration of the GIOTTO ion mass spectrometer and analyzed data from the GIOTTO encounter with comets Halley and Grigg-Skjellerup. He has been responsible for analysis of space plasma data from the ISEE, ICE, AMPTE/CCE, POLAR and IMAGE spacecraft, CRRES chemical releases, and AEPI artificial aurora experiment. He was Project Manager for the LMMS participation in the Imager for Magnetopause to Aurora Global Exploration (IMAGE) mission and the LMMS participation in the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) experiment. He has published over 170 papers in scientific journals and conference proceedings.



Dr. Samuel Gulkis has over 35 years of research experience in radio and submillimeter astronomy, specializing in studies of Jovian magnetospheric physics, the major planet atmospheres, and experimental cosmology. He has served as Co-Investigator on two NASA space experiments (COBE and Voyager), and is currently the Principal Investigator of the MIRO-ROSETTA experiment, currently under development by the European Space Agency. He has served on numerous NASA Advisory Committees on Planetary and Space Astronomy, and has served on the Icarus Board of Editors. He received two NASA Exceptional Scientific Achievement Awards, one for work on Outer Planet Models, the other for work on Observational Cosmology. He was appointed Senior Research Scientist at JPL in 1981. Dr. Gulkis has managed planetary atmospheres, space physics, planetary and life detection and astrophysics research groups in the Earth and Space Sciences Division, and served as the Program Scientist for Solar System Exploration in the Space and Earth Science Program Directorate.

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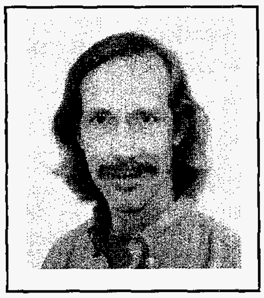

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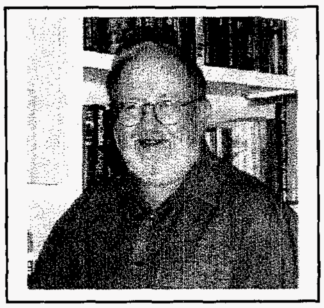

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Dr. Paolo Ferri Is the Rosetta Spacecraft Operations Manager at the European Space operations Centre in

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