The U.S. Rosetta Project: NASA`s Contribution to the International Rosetta Mission

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Abstract—The International Rosetta Mission was successfully launched on March 2, 2004. NASA's contribution to this mission consists of the following three hardware experiments: Alice (an Ultraviolet Spectrometer), the Ion and Electron Sensor (IES - a plasma instrument), and the Microwave Instrument for the Rosetta Orbiter (MIRO), as well as other components. Collectively these elements are known as the U.S. Rosetta Project. In this paper we present an overview of the U.S. Rosetta Project. We present and summarize the successful launch and early operations phases of the U.S. Rosetta Project. Finally, an unplanned science target appeared in the form of comet C/2002 T7 (LINEAR). Comet Linear was successfully observed by the U.S. Rosetta project on two occasions, April 30 and May 17, 2004, by both Alice and MIRO.12

1. INTRODUCTION

The U.S. Rosetta Project stands on the verge of the transition to Mission Operations. The 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 the electronics package for one of a pair of spectrometers on the ROSINA instrument called the Double Focusing Mass Spectrometer (DFMS). These elements

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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 (Philae). The Lander mission will last approximately 2 weeks after which the orbiter will conduct observations of 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 objective of the Rosetta mission is 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

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. 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. This paper discusses the first phase of commissioning, as well as anomalies and surprises that were discovered.

In the middle of commissioning, an unexpected target of opportunity appeared in the form of comet C/2002 T7 (LINEAR). This paper concludes with a description of how scientific measurements were obtained when the spacecraft was not fully characterized and what they might mean.

Because commissioning was not fully complete as of the writing of this report, the timeframe covered here includes the months leading up to launch and the first 6 months of Rosetta’s cruise from March 2 through August 2, 2004.

2. THE U.S. ROSETTA PROJECT

NASA’s contributions to the International Rosetta mission are the following three U.S. hardware experiments: Alice (an ultraviolet imaging spectrometer), the Ion and Electron Sensor (IES), and the Microwave Instrument for the Rosetta Mission (MIRO). A fourth instrument, ROSINA, the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis, is a European investigation with a U.S. hardware contribution consisting of the electronics package. Specifications of these hardware components are summarized in table 1. Other components of the NASA contribution to the mission include: the participation of an interdisciplinary scientist (IDS); backup tracking, telecommunications, and navigation assurance provided by the DSN; and support for the scientific participation of U.S. investigators on non U.S. experiments.

Alice

The Alice instrument [1, 2, 3] will obtain spectra of the nucleus and the coma in the 700-2050 Å bandpass (ultra-violet and extreme ultra-violet wavelength regions). This investigation will: (1) directly determine the volatilized helium (He), neon (Ne), Argon (Ar), and possibly krypton (Kr), and the nitrogen (N2) content of the nucleus in order to provide information concerning the temperature of formation and the thermal history of the comet since its formation; (2) directly determine the production rates and spatial distributions of the key parent species, water (H2O),...
carbon monoxide (CO), and carbon dioxide (CO$_2$), thereby allowing the nucleus/coma coupling to be observed and interpreted without significant ambiguities; (3) obtain unambiguous atomic budget measurements of carbon, hydrogen, oxygen, nitrogen and sulfur in the coma to derive the elemental composition of the volatile fraction of the nucleus; and (4) study the onset of cometary nuclear activity in ways that Rosetta otherwise cannot. Additional objectives include (5) mapping the cometary nucleus at far-UV wavelengths and characterizing the presence of icy UV absorbers on its surface; (6) studying the photometric properties of small grains in the coma as an aid to understanding the size distribution of cometary grains and how they vary in time; and (7) mapping the time variability of O II, C II, and N II emissions in the coma and ion tail around perihelion in order to connect nuclear activity to changes in tail morphology and structure, and coupling to the solar wind.

**Ion and Electron Sensor (IES)**

The IES [4] is a plasma instrument consisting of two electrostatic analyzers, one each for electrons and ions. In general, IES acquires ion and electron measurements in 256 bins over an azimuth range of 90 degrees and polar angle of 360 degrees (less spacecraft obstructions). Thus IES collects plasma data roughly in 2.8 steradians of space, and samples plasma velocity space. The IES will investigate (1) the solar wind interaction with the cometary nucleus, (2) the processes that govern the composition and structure of the cometary atmosphere, and (3) the interaction between the solar wind and the cometary atmosphere. In addition, the IES will investigate the interaction between the solar wind and one or two main-belt asteroids, with specific objectives related to sputtering and ion implantation, electrical charging of the surface, and wake effects.

**Microwave Instrument for the Rosetta Orbiter (MIRO)**

The instrument [5] will obtain spectra of the nucleus and the coma in the microwave region of millimeter wavelengths (190 GHz, ~1.6 mm) and submillimeter wavelengths (562 GHz, ~0.5 mm). This scientific investigation addresses the nature of the cometary nucleus, outgassing, and development of the coma as strongly interrelated aspects of cometary physics. MIRO will measure the near-surface temperatures of at least one asteroid and the comet 67P/Churyumov-Gerasimenko, thereby allowing estimation of the thermal and electrical properties of these surfaces. In addition, the spectrometer portion of MIRO will allow measurements of water, carbon monoxide, ammonia, and methanol in the gaseous coma of comet 67P/Churyumov-Gerasimenko. These measurements will allow study of the process of icy cometary sublimation (change from the frozen state, ice, to a gas) in time and distance from the sun. The data from MIRO, along with data from other instruments on the orbiter and the comet lander, will give scientists a better idea of how comets formed, what they are made of and how they change with time.

**Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA); electronics package for the Double Focusing Mass Spectrometer (DFMS)**

ROSINA is a state-of-the-art mass spectrometer [6] with two redundant sensors using different technologies for simultaneous and independent mass detection and verification. The ROSINA instrument is capable of making mass detections to 300 AMU (atomic mass units), and of resolving mass to and accuracy of one in three thousand (on the 1 percent level). The primary measurement objective of ROSINA is to determine the elemental, isotopic, and molecular composition of the atmospheres and ionospheres of comets, as well as the temperature and bulk velocity of the gas and the homogeneous and inhomogeneous reactions of gas and ions in the dusty cometary atmosphere and ionosphere. One of the most exciting measurements will be the carbon dating of the nucleus, or the determination of the C$^{12}$/C$^{13}$ ratio and the D/H ratios in organic molecules. ROSINA will also provide gas pressure measurements important for the health and safety of other instruments, notably Alice, which will use ROSINA detections of significant increases in gas flux to close its aperture door.

ROSINA consists of (1) two separate spectrometers, (2) a velocity and temperature sensor and (3) a common data processing unit. The mass spectrometers employ different and complementary measurement techniques. The DFMS uses magnetic analysis to achieve high mass resolution and high dynamic range. The Reflectron Time of Flight (RTOF) spectrometer uses time of flight analysis to achieve high sensitivity over a broad mass range. The velocity and temperature sensor determines the flow velocity and temperature of the cometary gas in the coma. The NASA hardware contribution to ROSINA consists of a big part of the electronics package for the DFMS sensor.

**Deep Space Mission System (DSMS)**

The Rosetta mission requires telecommunications support for navigation, tracking, and telecom (command and telemetry). NASA’s role includes the use of DSN resources for backup and emergency and launch activities. It will also be utilized during the various critical events: planetary gravity assists an asteroid fly-by, and the final comet encounter.

**Interdisciplinary Scientist (IDS)**

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). Modeling tasks include...
comet nucleus modeling, gas and dust environment modeling, and studies of the comet nucleus composition and its relationship with interplanetary, interstellar and circumstellar dust. On April 14-16, 2004, he obtained photometry of asteroid 2867 Steins, one of the Rosetta flyby targets, for use in deriving a precise rotation period for the asteroid and for generating a shape model.

In Table 1, we present specifications of hardware components in the U.S. Rosetta Project. The table includes the following columns: Alice, EIES, MIRO, and ROSINA-DFMS. Each component has its own specifications for passband, spectral resolution, spatial resolution, field of view, and mass/power. The table provides a comprehensive overview of the flight performance of each component.

### Investigator Support on non U.S. experiment teams

NASA identified 8 U.S. Co-I's on ESA-led Rosetta Orbiter experiments for support. Supported investigations are: VIRTIS (Visible and Infrared Thermal Imaging Spectrometer), Radio Science, and OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System). The sole U.S. Co-I on the COSIMA (Cometary Secondary Ion Mass Analyser) experiment passed away on Nov. 21, 2003. Science objectives for these investigations include definition of post-launch instrument calibration parameters and instrument spectral sensitivities.

Interdisciplinary studies include UV chemical data with thermal IR surface maps such that the resident depth of volatiles can be revealed, cross-correlation of noble gas abundances with those measured by a mass spectrometer but without the mass to charge uncertainty, and thermal IR coma maps combined with UV fluorescence data such that fluorescence and collision process that are otherwise model dependent can be studied.

VIRTIS. Support includes contributions towards: full spectro-photometric calibration; establishment and modeling of instrument performance, modeling of target photometric properties, and instrument measurement scenario development.

Radio Science: Long-term support will include a component addressed to gravity science experiments: (1) Accumulate dynamical facts about the target object for the Rosetta mission; (2) Define the dynamical problem; (3) Develop an analytical solution, including rotation to first order, and perform numerical tests of
the first order theory; and (4) study orbits near any identified resonances, and test for stable orbits.

OSIRIS: Current support includes a subset of instrument calibration work, including establishment of the temperature dependence of the gain of the CCD output amplifiers on the wide and narrow angle cameras, and shape determination of the PSF.

3. LAUNCH SUPPORT

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.

The Use of JPL’s DSMS in a Back-up Capacity

Back-up support was initially defined as a rather vague requirement to point a DSN asset at the Rosetta spacecraft should an occasion arise and/or during specific periods surrounding mission-critical events as a secondary tracking mechanism. ESA’s exact requirement was better defined as “hot back-up”, a term and capability that is obsolete in the era of expanding mission sets and limited resources. The DSN antenna would be on point, prepared to support the Rosetta spacecraft but on stand-by, until ESA called for tracking support. Given the number of missions the DSN is requested to support, it could not provide a service that is principally “hot back-up”. Instead, DSN assets, under such requirements are scheduled as prime, because the antenna cannot be used for any other purpose while these requirements are being met. Likewise, navigation support was initially defined to be a review of imprecisely defined ESA solutions. NASA had not initially expected to commit DSN tracking assets for an ESA mission in large blocks of time as “prime” tracking support.

The current definition of back-up support for the Rosetta project is as follows: The Rosetta Project uses the ESA New Norcia station as the principal support station during the Rosetta mission. DSN provides back-up support for specific mission-critical events, such as launch and early orbit, planetary encounters and deep space maneuvers. Within the scheduling regime at JPL the allocated DSN backup stations are scheduled as prime. Rationale: Each DSN station will be on point and ready to provide immediate command capability per ESA requirements.

The DSN will augment the ESA ground support with telemetry and radiometric data for all allocated passes. DSN command support will occur only at the request of the Rosetta operations manager at ESOC. Nominal tracking support remains a principal responsibility of ESA’s New Norcia station. Radiometric data collected from the DSN in back-up mode will be used to augment the ESA prime navigation data types collected from New Norcia, and as such provide critical support for mission navigation. NASA is sufficiently satisfied with this definition that it will become the prototype wording for future mission Memoranda of Understanding (MOUs) where such support is required.

A major component of the agreement to provide cross support for the Rosetta mission that is very import, but separate from the availability of DSN resources, is the interface, which enabled convenient and low cost data transport services. These services have recently been included in technical upgrades to the capability of the DSN and have been key to Rosetta support.

DSMS Cross Support Services for Rosetta

The application of Consultative Committee for Space Data Systems (CCSDS) standards [7] applied to the acquisition and delivery of telemetry data, and for the radiation of telecommands for this mission. Two other missions currently supported by the DSN, along with Rosetta, have made use of the CCSDS standards known as the Space Link Extension (SLE) interface. Essentially, SLE is an additional protocol layer with a common interface such that each participant in the interface might have access to services, which would normally be specific to the user and/or provider organization(s). NASA has been a participant in the development of these standards, which greatly simplify cross support between agencies.

The implementation of SLE used for Rosetta incorporates telecommand capability to a DSN station directly from the ESA mission operations control center. ESA connects to the scheduled DSN station using what is termed a “bind” procedure, which provides authentication and authorization. Once established, ESA has control of when and how commands are radiated to the spacecraft. The circuits used to make the connection are dedicated circuits established specifically for ESA cooperative missions utilizing standard TCP/IP protocols. In this particular case the circuit is shared with Mars Express because of the commonality of services and integrated operations.
On the telemetry side, return services are provided to ESA through an indirect path. Instead of a connection directly to the ground station tracking Rosetta, telemetry data is transported to JPL via internal circuit and protocols to the multi-mission operations center at JPL. ESA connects to dedicated SLE servers within the Advanced Multimission Operations Systems (AMMOS) that then provides the return data services specified by the SLE standard.

Service Management, as a SLE service, has not been implemented and sequence of events planning and scheduling are accomplished in a simplified mode, using manual inputs and nominal sequence of events formats for station operations.

**LEOP**

The interaction between the ESA Science Operation Center (ESOC) and the DSN was highly successful with Rosetta [8], more so than with Mars Express, or INTEGRAL - other ESA missions requiring DSN support that use the same SLE services as Rosetta. This situation is attributable to the fact that Rosetta was launched after both INTEGRAL and Mars Express so that most of the interface issues had been resolved. It would not have been that way except for an Ariane launch failure that preceded the Rosetta launch. Rosetta was originally targeted to comet Wirtanen with a launch date of January 13, 2003. With the postponement of Rosetta’s launch to February 26, 2004, JPL and ESOC had time to resolve a number of outstanding issues, for example, the distribution of service instance files. The service package that defines how SLE is to be used for each defined track, could not be broadcast to all DSN stations simultaneously as is the practice within the DSN with station configuration data. Each service instance is defined for a particular antenna and separate distribution mechanism had to be implemented to ensure delivery. Without the authenticated service instance file in place, ESA could not make the connection to the assigned station. One other outstanding issue was the uncertainty in acquiring the spacecraft. The ESA transponder had at least two known anomalies and close attention had to be paid to the acquisition profile. Originally Rosetta would have launched before Mars Express and would have thoroughly exercised the telecom system in flight. Instead, Mars Express became the in-flight example. Both missions have the exact same transponder.

There were further consequences of the Rosetta launch delay. From NASA’s perspective, the new launch date followed a very high activity period at Mars, which included an armada of spacecraft in orbit and on the surface. A February 26 launch date, although at the tail end of the peak of activity, resulted in significant negotiations for DSN resources to insure the Project that it had the antennas it needed.

Soon after the launch delay began a search for a new target, since a possible delay of a year could not get the spacecraft to the original target in the right phase, comet orbit sunward months before perihelion, without a different launch vehicle. When a new target was selected and trajectory options assessed, it was discovered that the proposed launch date would have the spacecraft launching in the direction of the sun. This would not normally be a major problem, but ESA starts its missions at S-band during the LEOP phase. Solar noise at S-band effects station performance and degrades the signal to noise ratio of the tracking station. ESA planned on using their 15 meter tracking station at the Kourou launch site for most of the LEOP. With performance significantly degraded by solar noise, the station could not be used past the first few days of operation. As the launch window slipped, the apparent angle between the sun and the spacecraft decreased exacerbating the problem. The solution was add an additional DSN station within the mix to cover the gap between the New Norcia station near Perth Australia and the DSN complex near Madrid Spain. Although similarly affected by solar noise at S-band, the aperture was more than double, 34m vs 15m, and provided the margin necessary for quality telemetry performance.

As the launch date approached the date and timing of launch slipped several windows due to high winds at the launch site, and an unusual configuration of Launcher thermal protection detected during a countdown visual inspection. Finally, launch conditions were positive and the spacecraft was launched on March 2, 2004. The ESA station at Kourou acquired the first downlink S-band signal at 09:34:51 UTC. The DSN acquired the downlink with 26m station at Madrid at 09:40:59 UTC for the purpose of initial acquisition and predicts updates. Subsequently the 34-m station, at Madrid was used to acquire telemetry. The LEOP phase was extremely successful with now major anomalies and was officially terminated at 10:05 UTC on March 5. In fact, Rosetta ground support and spacecraft operations went so well within the first months that a total of 22 DSN stations were released from the schedule, available to other users.

**4. COMMISSIONING**

Commissioning for ESA missions has always been different from that for NASA missions in that the commissioning/check-out phase nominally lasts 90 days rather than the 30 days 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 was to take place in two phases. Phase 1 would commence at launch and wind
down in mid-June. Phase 2 would commence in early September and wind down in mid-October.

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) which 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) Validate the basic performance of IES with low voltage operations. Additional science functionality, check-out, and high voltage operations with IES are to be conducted in Phase 2 of the commissioning timeframe, as shown in Table 2.

**U.S. Rosetta Commissioning Schedule**

IES was the first instrument of the U.S. Rosetta project to initiate commissioning activities. With an initial power-up on March 19, 17 days after launch, the entire Rosetta Plasma Consortium validated power to the consortium instruments and the operation of the power interface unit (PIU). Low-voltage operations with IES were then postponed until much later in the commissioning schedule as the spacecraft entered an unexpected thermal regime.

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. The PAT was canceled, a few hours before it was scheduled to begin on the last day, due to spacecraft thermal problems (see page 9, IES Temperature discussion).

The PAT test, rescheduled to a special slot very late in the Phase 1 commissioning, 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 using scans of two IUE-calibrated UV stars (HD 203245 and HD 218045), along with both Kurucz spectral models and IUE-measured flux values at specific wavelengths. With this technique, 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.

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, and 3) verification that the commands for the CTS heater were implemented correctly in the command database in response to the Venus CTS anomaly (next section).
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 as shown in figure 1.

**Unforeseen Complex Pointing Profiles with MIRO**

To map the MIRO beam profile a unique series of spacecraft maneuvers was executed. The beam profile, a size of approximately 7 x 7 arc min, required scans of an area of approximately 1 square degree. MIRO had originally proposed several different scan patterns, including the raster scan with which to obtain a calibration signal from the Earth. The project felt that the spacecraft was not sufficiently well characterized this early in the commissioning timeline to perform either the raster scans or any of the other suggested techniques. The concern was the stopping and starting of the spacecraft at the end of each raster scan. The only option was continuous spiral scans, a unique technique and one applicable only to the MIRO instrument. The technique is illustrated in figure 2 as it applied to the Earth measurement. Input to the navigation team included the spiral pitch (spacing between the scans) and the number of revolutions. The comparison with a standard raster pattern is that scan lines are moved closer together with multiple spirals. Each successive scan improved the spatial density in which the 1 square degree could be scanned and consequently improved the capability to map the response function of the MIRO instrument. Multiple scans improved the signal-to-noise and provided redundancy.

To employ this technique and validate the beam profile, data were taken on Earth on April 24. The starting points mapped out an equilateral triangle with the Earth positioned in the center. The configuration placed the Earth in a different location on each spiral scan. The scans commenced close to the position of the Earth to keep Earth close to the center of the scanned area. Data were taken continuously until three scans were complete. There was no particular rationale for the choice of three scans (it could have been 5 or 1). There was nothing unique about the starting configurations. The Earth signal was detected in each of the three scans, providing redundancy in the process. Steps one through two of the process are outlined below.

**Step 1:** The spacecraft Z axis (nominal boresight direction of the spacecraft) performs a spiral scan on the sky in the vicinity of the earth. The spiral spacing is approximately half the response pattern of the MIRO telescope. The full scan covers approximately 1 square degree. (In practice, three spiral scans were used, each starting at a different position in the sky. It takes about 1 hour to perform one spiral scan, and three hours to complete the measurement.)

Figure 1 – Acquired mass spectra of the ROSINA Double Focusing Mass Spectrometer (DFMS) taken on May 21, 2004.
The projection of the X-Y axis on the sky at each point in time defines a reference frame relative to the nominal pointing direction \(x=y=0\). The MIRO beam is fixed in the X-Y reference frame. As the spiral scan proceeds, the Earth moves around in \(x\)-\(y\) reference frame and serves as a source of emission for the MIRO beam. When the Earth is in the MIRO beam the MIRO radiometer responds with an increased intensity.

Step 2: As the spacecraft Z axis approaches Earth, the MIRO radiometer responds with an increase in intensity. The increase in intensity is mapped onto an X-Y contour map (as shown in the first panel along the bottom of figure 2) with intensity the 3rd dimension (as shown in the peak displayed in the second panel, along the bottom of figure 2). As expected, the map does not reach a maximum at \(x=0\) and \(y=0\) because the MIRO beam is not exactly aligned with the nominal spacecraft boresight. The MIRO beam is approximately 5 arc minutes away from the spacecraft boresight.

Figure 2 presents the 3D representation of the contour map. It shows the shape of MIRO beam as well as the offset from \(x=y=0.0\) (first and second panels from the left along the bottom of figure 2). The noise level of the instrument also shows up clearly in both of these panels.

Incident’s, Surprises, and Anomalies (ISAs)

The project keeps a record of mission incidents, surprises, and anomalies. These are known collectively as ISAs. For this period of performance, very few problems would 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 Pyro — Upon command to open the ALICE detector door (a one time only mission event), the primary pyro circuit failed to fire. Alice halted commissioning to determine the cause of failure. After more than one day, when insufficient telemetry had been obtained to determine the root cause, it was ascertained that the secondary pyro circuit should be fired, and the detector door was successfully opened. The cause was ultimately determined to be a short in the A-side firing lines.

Alice Timing — Alice telemetry exhibited behavior consistent with the drift of its internal clock by -1.8 seconds per hour. Once the problem was confirmed, a software patch uploaded to the instrument fully corrected the
IES Temperature — The IES temperature approached the operating limit (58°C) as the spacecraft trajectory carried it inside 1 AU, and some low-voltage operations were temporarily postponed. The high temperatures were somewhat unexpected but mainly attributable to a poorly calibrated spacecraft thermal model and proximity to the Sun. A higher than expected temperature at the HGA motor was noticed, and the spacecraft was tilted from the nominal angle to shade the motor with the dish. That step resulted in a higher than nominal solar flux on IES, increasing its temperature. The temperature increased further when IES was operated, but it never exceeded the safe limit. Once the problem was confirmed, low-voltage operations were resumed and completed inside the period of Commissioning Phase 1.

MIRO CTS — A potentially significant problem took place with the MIRO chirp transform spectrometer (CTS) after the Venus observations on April 1. The CTS is the primary spectral detector of the instrument. After a scan, the telemetry bus “busy” signal remained engaged, causing the MIRO fault protection software to switch the instrument to engineering telemetry. Diagnostics found inverted parameters for the CTS in the project database. Upon correction of these inverted parameters, and re-command of the CTS to a science from an engineering mode, MIRO has operated flawlessly. Ground assessment continues.

ROSINA DFMS High Voltage — Upon initial command of the power supply to the DFMS, the nominal output of 3 KV for the transfer optics subsystem power supply caused shutdown rather than activation of the circuit. During investigation, when re-set to 2 KV, the circuit operated normally. A new set of voltages were found with the help of the DFMS reference model which allows to run the DFMS transfer optics subsystem at 1 kV while maintaining the performance.

5. OBSERVATIONS OF COMET C/2002 T7 (LINEAR)

A successful LINEAR observation with Rosetta would be among the closest space-based observations of a comet ever conducted; however, with spacecraft commissioning in progress, squeezing in a set of sciences observation was problematic. The Project wanted to use the recently validated boresight pointing of MIRO to drive the pointing requirements for this exercise. On April 30, however, the comet signal was expected to be doppler shifted out of the MIRO range. For this reason, the project scheduled a second opportunity on May 14 when the comet signal was expected to be in MIRO’s range. Other remote sensing instruments riding along with this observation included Alice, OSIRIS, and VIRTIS, but the pointing specifications for these instruments remained to be validated. This meant that on April 30, use of MIRO’s pointing requirements necessarily implied that the comet might not fall into the other instrument’s fields of view, and a MIRO signal might not be obtained because the comet was out of range. On May 14, the second opportunity for an attempted measurement, a signal from all these instruments might be obtained. The problem there was that May 14 fell inside an important spacecraft maneuver window, the first of a limited number of trajectory maneuvers for the spacecraft that keep the spacecraft on course for the prime mission, with a window that spanned May 11-15. The rationale for prohibiting science observations inside a trajectory maneuver window includes the residual effects of the burning of engines, and potential problems with arcing if instrument high voltages are powered on. As it turned out, the trajectory maneuver executed successfully and early, thus a second opportunity presented itself for science observations of the comet.

![Image](image.png)

Figure 4 – Acquired EUV/FUV spectrum of comet Linear taken by ALICE on 30 April 2004.
measurements at a better time for the science instruments involved.

The MIRO Linear data were primarily of interest because they validate the MIRO instrument in close to actual operational conditions. The data from MIRO can be used to determine the water production rate of the comet at one point in its orbit. This is of limited scientific interest by itself, but it provides an excellent illustration of the MIRO capabilities. When combined with measurements made with other ground-based and spacecraft instruments, the MIRO data will help to define how the water production rate varies as the comet moves around the sun. The actual returned MIRO measurement is shown in figure 3. MIRO was able to detect the comet successfully during both opportunities.

ALICE successfully observed comet Linear on both 30 April 2004 and 14 May 2004. Figure 4 shows the acquired spectrum of the comet’s nucleus region taken on 30 April 2004 at a Rosetta spacecraft to comet distance of 16 million kilometers. H Lyman α and β were detected at 1216 Å and 1025 Å, respectively; in addition, oxygen at 1301 Å and carbon at 1561 Å and 1657 Å were also detected. Initial rate estimates for these emissions closely match that expected for this comet at the heliocentric range at the date of these observations (Feldman 2004 – private communication, [9]), and excellent validation of the Alice experiment.

6. SUMMARY OF POST-LAUNCH OPERATIONS

WITH THE U.S. ROSSETTA PROJECT

Instruments in the U.S. Rosetta Project seem very ready for prime mission operations at comet Churyumov-Gerasimenko. The instruments have completed all commissioning activities to date and are operating nominally. Subsequent to the drafting of this report, IES successfully completed its commissioning and demonstrated its capability to measure the solar wind ions and electrons. Two IES channels that were noisy in ground calibrations cleared up significantly with spacecraft outgassing. MIRO and Alice successfully participated in the Interference Campaign, and Alice conducted stray light tests that showed the instrument to be less susceptible to stray light than previously expected.
REFERENCES


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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 US Rosetta Project. She has also served as Project Manager of the historic Galileo Mission to Jupiter in the final last 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 from the University of California at Berkeley in 1983, and a Master's Degree from the University of California at Los Angeles in 1985.

Dr. S. Alan Stern currently serves as the Executive Director of the Space Science and Engineering Division of Southwest Research Institute’s Boulder campus. He is a planetary scientist and astrophysicist with both observational and theoretical interests. His research has focused on studies of the satellites of the outer planets, Pluto, comets, the Oort Cloud and Kuiper Disk, and tenuous planetary atmospheres. Dr. Stern has over 20 years of experience in space remote sensing instrument development, with a strong concentration in ultraviolet and imaging technologies. Dr. Stern is a PI in NASA’s UV sounding rocket program. He has participated as a project scientist and later PI on two Shuttle mid-deck experiments spanning four flights, and a Shuttle-deployable satellite. In 1993, he was PI of the miniaturized HIPPS Pluto breadboard camera/IR spectrometer/UV spectrometer payload. In 1996 he became PI of NASA’s Alice UV spectrometer aboard the Rosetta comet orbiter mission. In 2001 he became PI of NASA’s New Horizons Pluto-Kuiper Belt mission. He has two bachelor’s degrees, two Masters degrees, and a Ph.D. in Astrophysics and Planetary Science from the University of Colorado in 1989.

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. David Slater is a Principal Scientist at Southwest Research Institute where he serves as the Project Scientist for the Rosetta ALICE instrument. Dr. Slater is also serving as a Co-Investigator for the ALICE UV instrument on the NASA New Horizons mission to Pluto/Charon and the Kuiper Belt scheduled for launch in January 2006. His main interests involve the design and development of detectors and remote sensing instruments for space science missions and ground-based astronomy. In addition, he is interested in EUV/FUV spectroscopy of planetary atmospheres and solar physics. Dr. Slater received his Ph.D. in 1991 in Applied Physics at Stanford University. He received his Bachelor’s Degree in Physics at the University of California, Los Angeles in 1979, and a Master’s Degree from the Air Force Institute of Technology in 1980.

Dr. Stephen Fusilier 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. 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 of Texas and his Ph.D. in Space Science from Rice University in 1968. Dr. Burch is a fellow of the American Geophysical Union. He has served as a member of the NASA Space Science and Applications Advisory Committee (1990-1993) and the Space Physics Subcommittee (1991-1994) and has chaired the Sun-Earth Connection Strategic Planning Integration Team (1996-1997). He has also served as president of the Space Physics and Aeronomy Section of the AGU (1996-98) and is a Member of the International Academy of Astronautics. Dr. Burch has served as Editor and Editor-in-Chief of Geophysical Research Letters (1988-1993). He served as chair of the AGU Committee on Public Affairs (2001-2003) and chair of the National Research Council Committee on Solar and Space Physics (2000-2004). He was Principal Investigator for the Dynamics Explorer 1 High-Altitude Plasma Instrument and the ATLAS-1 Space Experiments with Particle Accelerators (SEPAC). Currently, he is principal investigator for the Ion and Electron Sensor for the European Space Agency ROSETTA comet orbiter and for a NASA Medium Class Explorer (MIDEX) mission: Imager for Magnetopause-to-Aurora Global Exploration (IMAGE), launched in March 2000. Dr. Burch was the AGU Van Allen Lecturer and the Rice University Marlar Lecturer, both in 2001.

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.

Dr. Joel Parker’s research involves photometric and spectroscopic multi-wavelength studies in planetary and stellar astrophysics using ground- and space-based, instruments. He is the Operations Scientist and Project Manager for the Alice UV spectrometer on the Rosetta mission, and data processing and archiving lead on both the Alice-Rosetta and Alice-New Horizons projects. His topics of interest include asteroids, comets, Centaurs and Kuiper Belt objects, Pluto, the Moon, volcanoids, local group galaxies, young stellar groups and their environments, initial mass functions and star-formation rates, interactions of massive stars with the ISM, luminous blue variables, and data reduction and analysis techniques. He received a B.A. in Physics and Astronomy at the University of California, Berkeley, in 1986, an M.S. in Astrophysics at the University of Colorado, Boulder, 1989, and a Ph.D. in Astrophysics at the University of Colorado, Boulder, in 1992.

John Scherrer is currently a Senior Program Manager at Southwest Research Institute, where he serves as the Project Manager for the New Horizons Alice ultraviolet imaging spectrometer delivered for spacecraft integration in September 2004. Mr. Scherrer also served as the Project manager of Rosetta Alice during the development phases of that instrument. Mr. Scherrer was the deputy project manager/spaccraft manager for NASA’s first MIDEX mission, IMAGE, launched in March 2000 and the Project Manger of Mars Express ASPERA-3, the NASA Discovery office’s first Mission of Opportunity. Mr. Scherrer received a Bachelor’s degree from Texas A&M University in 1982 and a Masters degree from the University of Texas at San Antonio in 1986.

Dwight Holmes is currently at the Jet Propulsion Laboratory where is serves as the Telecommunications and Mission Services (TMS) manager for Rosetta. Mr. Holmes is also the current TMS manager for two other NASA/ESA cooperative missions, INTEGRAL, 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 team chief for the Voyager dual mission to the outer planets, and as the Radio Science 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.

William C. Gibson is Assistant Vice-President, Space Science and Engineering Division, Southwest Research Institute. He has extensive experience in the management of projects involving the development of scientific instruments and support systems for use on the Space Shuttle, free flying satellites, sounding rockets, and high-altitude research balloons. Mr. Gibson has managed such projects as the SEPAC Interface Unit for Spacelab Mission I, the High Altitude Plasma Instrument for the Dynamics Explorer Satellite, the Fast Ion Mass Spectrometer for the Centaur Rocket Project, and the Balloon-Borne Ultraviolet Stellar Spectrometer. In addition to these projects, he has served as the project manager for the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) Medium-Sized Explorer (MIDEX) mission and is the project manager designee for the Waves Explorer MIDEX mission. His areas of technical specialization include the design of spacecraft data systems, spacecraft telemetry and control systems, and spacecraft heat transfer systems. Mr. Gibson was the architect of the multiprocessor SEPAC On-Line Data Analysis (SODA) real-time telemetry ground station used during STS-9 and the lead-design engineer on the Johnson Space Center Stratospheric Ozone Experiment. Mr. Gibson has served as a member of NASA source selection boards and as chairman of the NASA Confirmation Review Board for the GALEX Small Explorer mission. Mr. Gibson also served as a member of the standing review board for the NASA Advanced Composition Explorer (ACE) mission. He is a member of the NRC Task Group on the Principal Investigator-led Earth Science Mission.
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