The U.S. Rosetta Project at Its first Science Target: Asteroid (2867) Steins, 2008

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Abstract—On September 5, 2008, the International Rosetta Mission encountered its first formal science target of the mission, asteroid (2867) Steins. We report preliminary results from the U.S. experiments. NASA's contribution to the Rosetta mission consists of an ultraviolet (UV) spectrometer, a microwave spectrometer, a plasma instrument, and a portion of the electronics package for a mass spectrometer. The UV spectrometer (Alice) was used to obtain the first far-ultraviolet (FUV) spectrum of an asteroid. A ten-minute integration, surrounding the time of closest approach, averaging over a variety of geometries, showed very good signal from 850 Å to 2000 Å in the FUV. The microwave instrument (MIRO) obtained a high signal to noise measurement at both observing frequencies, enabling key thermal parameters to be derived. The plasma instrument (IES) obtained a brief measurement of the solar wind, and the Double Focusing Mass Spectrometer (DFMS) of the ROSINA instrument obtained a signal just at closest approach. Laboratory work with analogue materials was begun.[1,2]

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[2] IEEEAC paper #1250, Version 4, Updated Jan, 4 2010

1. INTRODUCTION – A GENERAL DESCRIPTION OF THE PROJECT

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 payload of the International Rosetta Mission. In other contributions to the mission, NASA provides key back-up navigation and tracking support for ESA by way of its Deep Space Network (DSN.) In addition, NASA supports an interdisciplinary scientist (IDS) and Co-Investigators (CO-Is) on non-U.S. payload instruments: the Optical Spectroscopic and Infrared Remote Imaging System (OSIRIS); the Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS), and Radio Science. Details of the instruments and of NASA's role can be found in the instrument description papers [1,2,3].

Rosetta, an ESA cornerstone mission, is currently on an extended cruise, utilizing multiple Earth/Mars gravity assists, destined to rendezvous with and 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 a lander (named 'Philae') will be deployed. 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, implications with regard to the origin of the solar system, and asteroid targets *en route*.

The mission was successfully launched on March 2, 2004. Thereafter followed an extended period—eight months—for spacecraft commissioning which included observations of comet LINEAR. Subsequently, on March, 2005 went through its first gravity assist at Earth, and in July 2005, the mission provided support for the Deep Impact observations of comet Tempel-1. In 2007, Rosetta flew by Mars for a gravity assist, and conducted observations of the Martian upper atmosphere, solar wind interaction [4], as well as extended observations in support of the New Horizons Jupiter encounter, of the Jovian magnetotail and Io torus. Reports on these periods of the mission have been provided by ESA to the IAF [5,6], and at previous IEEE conferences [7,8,9].

2. PRE-ENCOUNTER OBSERVATIONS OF ASTEROID STEINS

The exploration of asteroids is one of the mission science objectives. Designated asteroid targets include the "E"-type and the "M" type (metal-rich) asteroid (2876) Steins and asteroid (21) Lutetia, respectively [10]. In asteroid taxonomy, "E" refers to enstatite, a type of silicate that is formed in an iron poor environment and at high temperature. It is a sub-class of the 'S' type that refers to its silicaceous nature. Figure 1 gives the approximate location of asteroids of various classes as a function of heliocentric distance and the inclination of their orbit.

Initial characterization of the nature of asteroid Steins is derived from ground-based observations of the asteroid using astronomical measuring techniques [11, 12]. A summary of these characteristics is listed in Table 1**.** In a series of observations, as reported previously [9], carried out from April 2004 to December, 2006, the U.S. IDS for comets, Dr. P. Weissman obtained both light-curve and color data on the target with his suite of observations [13,14,15]. The spectrum revealed the deep absorption feature found in some E-type asteroids at or near 0.5 microns. Weissman corroborates the conclusions of others who are studying this target [16,17,18].

The principle feature of the Steins reflectance spectrum is an absorption band at 0.5 microns, a feature that it has in common with other E-type asteroids. In other respects, while the visible spectra of other E-types are relatively 'grey,' for Steins, the spectrum is characterized by a significantly 'redder' slope. The band at 0.5 microns is also found in the mineral oldhamite (CaS) that is the sulfide component of the aubrite meteorites, and for that reason the E-type asteroids are likened to aubrite meteorites [11].

An interesting sidebar: aubrite meteorites are thought to be remnants of a protoplanet that formed in the early solar system and survived as bodies smaller than 100km in diameter. This protoplanet was differentiated as evidenced by the absence of chondrules in the meteorite remnants (hence they are known as 'achondrite' meteorites) and remarkably, a very small amount of iron in their bulk chemistry (<2%). The oxygen isotope ratio of aubrites (an

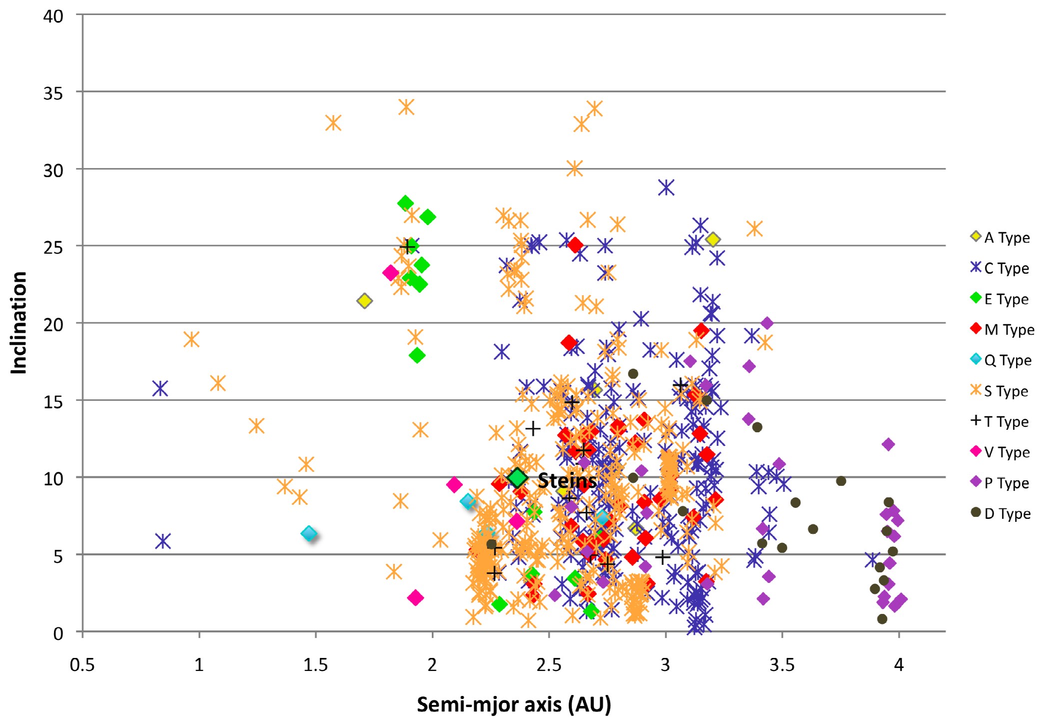

Figure 1. In this figure asteroids of a given taxonomy and distribution are shown with inclination angle plotted against the heliocentric distance. Taxonomic categories are given on the right. Asteroid (2867) Steins is shown in the middle at approximately 10-deg inclination, and at approximately 2.4 AU.

indicator of the nebular reservoir in which it formed) is similar to that of Earth, indicating that the region in which aubrites formed was relatively close to that from which the Earth and Moon formed [19].

To piece together the process of solar system formation, an understanding must be gained of the range of both chemical and physical properties that exist. It is possible that Steins may be among the most highly differentiated bodies in the solar system, one that lost all of its iron. It must have done so very early in solar system formation.

Table 1. Asteroid Steins' properties measured from the ground.

Physical Body
- Radius: 2.18 km
- Albedo: 27-45%
- Spectral Characteristics: spectrally 'red'
- Mineral content: 0.5-micron absorption band similar to that found in the mineral Oldhamite (CaS); small amount of iron
- Taxonomic type: E(II)

Rotational Dynamics
- Period (retrograde): 6 hrs
- Semi-major axis: 2.36 AU
- Revolution around the Sun: 3.63 yrs
- Inclination: 9.9 degrees

History
- Discovery: 1969 by N. Chernykh at Nauchnyj, Crimea, for Karlis Steins, former director of Latvian University Astronomical Observatory.

Knowledge of Steins acquired from the Rosetta flyby will provide us with information about a body that formed in a highly reducing chemical environment (low in iron) and one that is predicted to have distinctive optical properties. Along with the other remote sensing instruments on the payload, spectral regions from 800 Å to 1.56 mm will be covered providing unprecedented close-up information on the physical and chemical properties of this asteroid. Of interest, of course, is if the pre flyby interpretation of Steins is supported by the data acquired by the Rosetta encounter, and ultimately, if the story of the history and evolution of Steins contributes to our understanding of the region of the proto-solar system known as the 'frost line' (in which high temperatures gave way to freezing temperatures and rocky bodies gave way to ice-dominated bodies.)

3. The Steins Encounter of 2008

Most of the instruments of the Rosetta payload are located on one side of the spacecraft, thus enabling a nadir pointed attitude to, in principle, obtain all required science measurements. For this encounter, in order for the instruments to be oriented toward the asteroid target, two maneuvering activities were employed; first a "flip" to point the instruments toward the asteroid, and then a specially defined spacecraft mode for autonomous asteroid-flyby-tracking to keep them pointed at the asteroid throughout the closest approach period. Fly-by took place on the sun facing side of the asteroid. The ESA Rosetta Project reports phase-angle coverage for this period started at –17˚ and ended at 140˚; lowest phase angle (0.27˚) taking place 117 seconds before closest approach (CA); and CA altitude of 802 km [20]. Figure 2 provides a schematic of the encounter with periods of off-Earth pointing indicated and Table 2 gives the timeline of observations from instrument "on" to "off" for this encounter. In actuality, the asteroid was not as bright as expected by the navigation cameras, leading to considerable "jitter" in the autonomous pointing, such that the asteroid moved in and out of instruments' field of view. The flight team provided a pointing reconstruction file; however it was made available to the instrument teams too late for a large percentage of the ensuing data analysis to be included in this paper.

Alice FUV and EUV Observations of Steins

Principal scientific objectives of the Alice team at this time were to sample the environment for the presence of an exosphere, and obtain the first far-ultraviolet spectrum of an asteroid. Results have been submitted to a special issue of Planetary and Space Science

Principle observations consisted of a ten-minute integration surrounding the time of closest approach, averaging over a variety of geometries, and showed very good signal from 850 Å to 2000 Å. These data provided the first spectrum of an E-type asteroid below the atmospheric cutoff, the first ultraviolet spectrum of a small asteroid, and a spectrum extending to shorter wavelengths than has been observed for any other asteroid. In addition, Alice obtained the total FUV count rate integrated with 1-second resolution during the encounter to determine the average variation of reflected UV flux with phase angle. Finally, Alice conducted a deep search of the environment for any exosphere, though low exospheric signal levels were anticipated. The most abundant exospheric species' expected at Steins, based upon the only existing model [21], are hydrogen and oxygen, which have emission lines that lie in the ALICE bandpass.

Figure 3 shows a simulated Alice view of the approach geometry during the time Alice was to conduct the exosphere search. At this point the asteroid, at an almost constant -38˚ phase angle, filled only a tiny fraction of the slit. Throughout the exosphere search Steins remained

Table 2. Timeline for U.S. Instrument Operations

<u>Alice Start-up and Calibration 1 Sept–3 Sept</u>	
Decontamination (25 hrs)	1 Sept. 09:00–2 Sept. 10:00
Dark Calibration	2 Sept. 11:00–14:00
Star Calibration (gamma-Gruis)	2 Sept. 20:00–23:30
Star Calibration (Vega)	3 Sept. 11:50–12:00
<u>ROSINA DFMS Start-up 2–4 Sept</u>	
Outgassing (a)	2 Sept 17:30
Outgassing (b)	4 Sept 09:00
Outgassing (c)	4 Sept 18:00
<u>IES Start-up 5 Sept</u>	
On,	08:29:47
<u>Alice Pre-CA Activities 4 Sept–5 Sept</u>	
Exosphere Search (part 1)	4 Sept. 09:45–5 Sept.04:45
Exosphere Search (part 2)	5 Sept. 08:45–12:45
<u>ROSINA Pre-CA Activities 5 Sept</u>	
DFMS Spectra	08:00
DFMS Spectra	16:50
<u>MIRO Start-up 5 Sept</u>	
On,	13:09:36
Spacecraft roll	18:01–18:17
<u>MIRO Pre-CA Activities 5 Sept</u>	
Asteroid Mode	18:30:20–18:47:20
<u>Steins CA 5 Sept</u>	<u>18:38:20.07</u>
<u>MIRO Post-CA Activities 5–6 Sept</u>	
Recess observations	5 Sept. 23:49–00:49
Dark Sky	6 Sept. 4:35–04:43
<u>ROSINA Pre-CA Activities 6 Sept</u>	
DFMS Spectra	6 Sept. 18:00
<u>Alice Post-CA Activities 6–8 Sept</u>	
CA sky background cal (6 hrs)	6 Sept. 16:45
Exosphere sky background (6 hrs)	7 Sept. 00:45
Decontamination (25 hrs)	7 Sept. 06:45
MIRO off	6 Sept 04:45
IES off	7 Sept 05:00
Alice off	8 Sept 07:50
ROSINA DFMS off	10 Sept 06:20

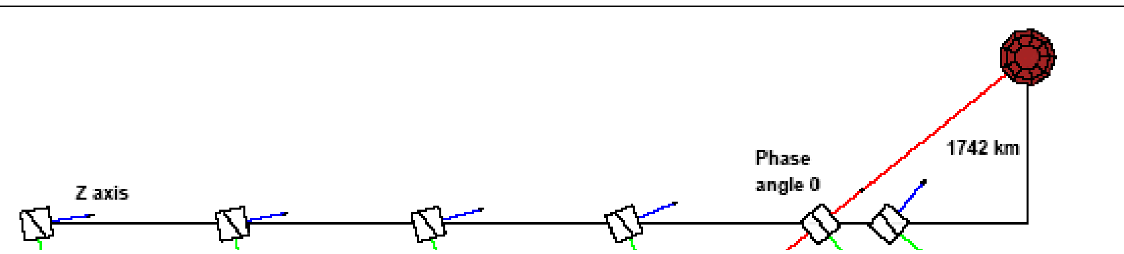

Figure 2. The required trajectory called for a spacecraft "flip" to a position. The attitude change took place 40 minutes prior to closest approach.

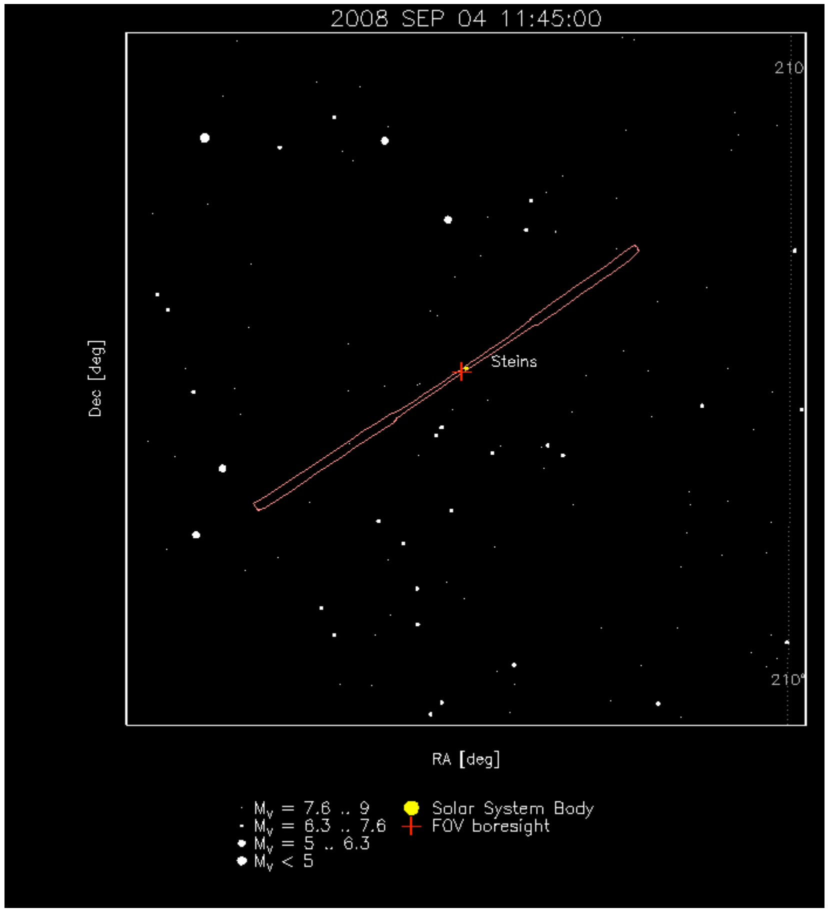

Figure 3. A simulated view of asteroid Steins (yellow) as seen through the Alice slit (red) on approach. At this point the asteroid, at a -38° phase angle, filled only a tiny fraction of the slit. Throughout the exosphere search Steins remained unresolved spatially.

unresolved spatially. The light from Steins itself, even at closest approach, fell entirely within two rows of the detector. Steins was always placed in the narrow portion of the slit but during the closest approach encounter observation the asteroid was wider than the entrance slit.

Two stellar calibrations were conducted, one at gamma-Gruis, and another at Vega. The effective area derived from the gamma-Gruis observation was virtually identical to that seen in PC6, which in turn is a few percent higher than that in PC8. No evidence of any degradation was seen as a result of running the final decontamination of PC8 with the aperture door closed. The stellar calibration at Vega proved to be more variable between that of PC6 (09/2007) and that of ESB2 (11/2007), with those of Steins (09/2008) and PC8 (07/2008) fall between those two extremes. No obvious correlation with time or temperature exists in these four samples. Pointing for the Vega observations seems to have been stable. Over most of the wavelength range, at Steins the effective area derived from Vega is about 7% lower than the effective area derived from gamma-Gruis, one day earlier.

IES Plasma Observations in the solar wind at Steins

IES operation during the flyby was nominal although no indication of the presence of the asteroid was found. Figure 4 is an energy-time spectrogram of IES data covering one hour roughly centered on Steins close approach. The upper panel shows raw counts as function of energy, a more or less typical solar wind spectrum, with the highest counts at low energy. The lower panel shows a similar plot for ions. The spectra are featureless with the exception of a single, red pixel at about 18:40 (CA is logged as 18:38:20.07, where IES time resolution is several minutes). That single pixel represents solar wind protons, as the spacecraft executed a rapid flip, briefly rotating the IES field of view toward the incoming solar wind. The middle panel shows the orientation of the Rosetta +Z axis with respect to the sun during this maneuver. This little bit of data is enough to estimate the solar wind velocity, ~480 km/s, consistent with solar wind observations by other spacecraft at the same time. As of the writing of this paper, it is not yet known if sufficient information exists to calculate related density and temperature – such information is obtained from the 'moments' of the plasma distribution function, quantities that require as close to 4π steradians of spatial coverage as possible. Nevertheless, this information provides some solar

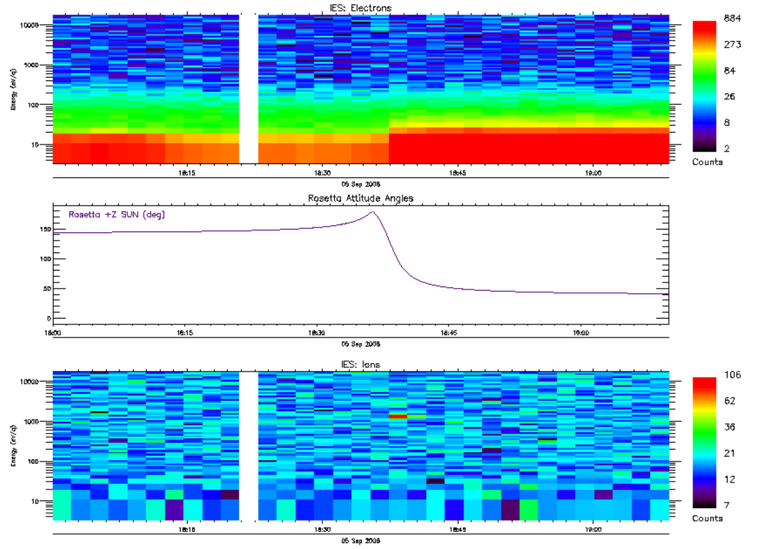

Figure 4. A subset of the IES timeline from shortly after the 'flip' through CA to the end of asteroid fly-by mode. The bottom panel shows the acquired data in the asteroid environment, with electrons in the top portion of the panel, ions in the bottom portion, and spacecraft angle to the sun in the middle panel. Time increases from left to right in this panel, and a color scale of the intensities of counts in each energy bin is provided on the right hand side. The sole moment in which the spacecraft is oriented such that IES is pointed into the solar wind happens fortuitously at CA.

environment context for measurements by the other Rosetta instruments.

The measurement demonstrates that with the proper spacecraft orientation IES can make meaningful measurements, even with a single pixel, of the solar wind environment at the time of flyby, and if close enough, can observe distortions by the target body. The team has great hopes for the 2010 Lutetia flyby.

MIRO at Steins

The instrument obtains spectra in the microwave region of millimeter wavelengths (190 GHz, ~1.6 mm) and sub-millimeter wavelengths (562 GHz, ~0.5 mm). The millimeter and sub-millimeter radiometers are both configured with a broadband continuum detector for the determination of the brightness temperature of the target. The sub-millimeter receiver is a very high-resolution spectrometer for observations of eight given molecular transitions, including that of water [2]. The MIRO instrument is configured to have six modes of operation, including a hibernation mode, and a special asteroid mode. Single and dual receiver continuum modes allow the surface temperature of the targets to be measured. Various combinations of continuum and spectroscopic modes are available. An asteroid mode was defined to focus solely on the water line when the instrument was in a spectroscopic mode.

As indicated in Table 2, the MIRO instrument executed its power on and off commands, all mode changes and operations according to schedule and plans, obtaining data with a high signal to noise response. Engineering and scientific telemetry were downloaded and transferred to JPL successfully. As listed in Table 2, the instrument was powered on for ~10 hours, approximately centered on CA. Instrument 'on' occurred at 13:09 followed by a five- hour period of warming. Warm and cold load calibrations were carried out every 30 minutes (or less) throughout the flyby. The instrument was operated in three modes: a) spectroscopic-dual continuum mode, b) dual continuum mode, and c) asteroid mode.

Steins' signal was seen in both continuum channels, however the responses were of short duration (minutes), because the spacecraft pointing through the MIRO field of view was only intermittent on the asteroid. Figure 5 shows the MIRO instrument boresight positions in relationship to the position of Steins near CA. Green and red circles superimposed on Steins near CA are the half-power beam widths (HPBW) of the MIRO instrument at 190 GHz and 562 GHz respectively. Angular diameters of the HPBWs are 23.8 ± 1.5 (millimeter) and 7.5 ± 0.25 (sub-millimeter) arc min. The asteroid image is that of the OSIRIS (PI - H. U. Keller) wide-angle camera taken near closest approach with the position of the MIRO field of view indicated, showing the part of the asteroid that is in the MIRO field of view [22]. As a result of the pointing, phase coverage was severely limited.

Figure 6 shows sub-millimeter results (squares), and the millimeter results (dots). The shape and width of the spectra were not as expected due to the large amount of dark sky in the beam. A significant amount of work was required, including use of a projected-area shape model of Steins, provided by the OSIRIS team, to find the true pointing of

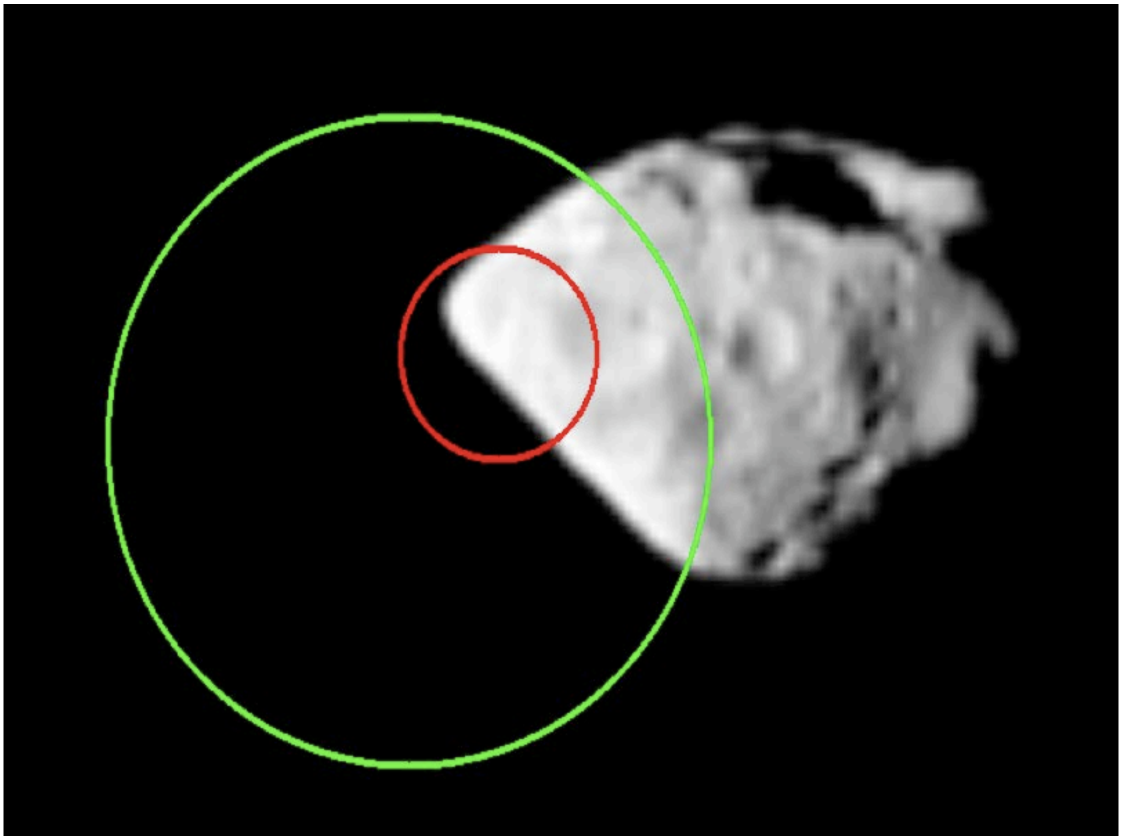

Figure 5. This figure shows the MIRO instrument boresight positions in relationship to the position of Steins near CA. Green and red circles superimposed on Steins near CA are the half-power beam widths of the MIRO instrument at 190 GHz and 562 GHz respectively. The image of Steins was recorded by the OSIRIS wide-angle camera (WAC) on Rosetta (PI - H. U. Keller) near CA. The phase angle is ~-55º. (Image Credit: ESA ©2008 MPS for OSIRIS Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA).

the instrument during this time and to extract the true signal of the target body.

MIRO has the capacity to provide the measurements from which a number of thermal parameters may be derived, such as emissivity, thermal inertia, brightness temperature, as well as some compositional data. Properties of the regolith may be further derived from these thermal parameters. MIRO compared the (dual frequency) continuum data with thermal models of Steins. Using the IR surface temperature maps provided by VIRTIS, the team derived a subsurface temperature gradient, and the loss tangent of the regolith material, from which was derived the dielectric constant, the thermal inertia, and the emissivity. Results have been submitted to a special issue of Planetary and Space Science, including an inference as to the nature of the regolith itself, whether a powdery material or rocky, that contribute in a significant way towards understanding the origin and wild evolution of this unusual body.

ROSINA DFMS at Steins

The Dual Focus Mass Spectrometer (DFMS) was switched on Sept. 2, 0600h in an outgassing mode. In this mode the ion source was heated to 300°C. On Sept. 4, 1800h, as listed in Table 2, the DFMS performed a calibration mode and afterwards started to measure in the asteroid mode. This mode consists of repeated measurements focused on mass 15.5 amu/e, in low resolution mode. In this mode mass, 15 and mass 16 both fall onto the detector and can be measured simultaneously. Figure 7 shows signal detected at 15.05, 15.99, and 16.035, respectively, which correspond to molecules CH_3, O, and CH_4. The oxygen peak measured by DFMS was much more pronounced during the closest approach than during normal background measurements. However, the spacecraft flip also produced a high oxygen peak. The quantity of these molecules that can be attributed either to spacecraft outgassing, or to the Steins exosphere remains to be modeled using the Rosetta spacecraft model.

4. ROSETTA USE OF THE DSN AT STEINS

The Rosetta Project utilizes the capabilities of NASA's Deep Space Network to augment those of the ESA network. The DSN provides nominal X-Band uplink and downlink support as well as S-band support for spacecraft safe mode. Support includes coherent 2-way Doppler and ranging for navigation, commanding, and telemetry acquisition at all Rosetta data rates. Rosetta utilizes the DSN 34-meter and

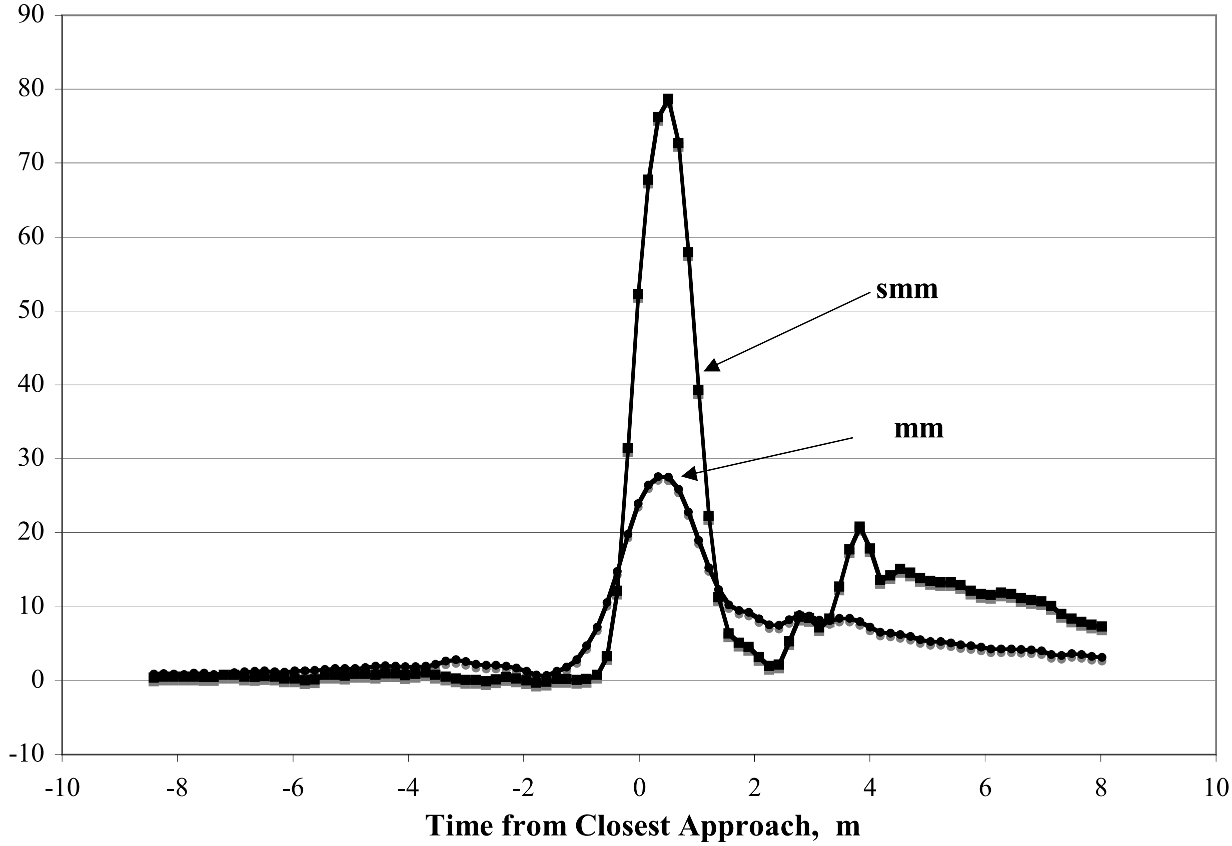

Figure 6. The MIRO Steins signal at the sub-millimeter band (squares), and the millimeter band (dots). The amplitude and width of the signal was not as expected, due to the large amount of dark sky captured in the beam.

70-meter antennas. The DSN also provides support for Radio Science experiments.

For the Steins flyby, the DSN scheduled and supported tracking passes, utilizing navigation, command, and telemetry capabilities.

During a pre-encounter review of DSN support plans, two passes were identified as special—a pre-closest approach command uplink, and a post-closest approach telemetry downlink. Even though these were in very time constrained portions of the Steins sequence, the ESA flight team chose not to request that these passes be designated "critical"—the rationale being that there were backup/replay options available in case of a problem. In actuality, the post closest approach telemetry pass was the one that contained a sizable portion of the data from the ORISIS camera (and other instruments) to be used for presentation at a scheduled press conference the next day.

At 18:30 UTC on September 5, DSS-14, NASA's 70-meter deep space antenna located at Goldstone, California, was declared red and was unable to conduct a tracking pass for this important telemetry downlink. The problem was caused by a coolant leak in the antenna. The pass was not declared critical for the mission.

The ESA flight team, by email, queried the U.S Rosetta team on the possibility of a replacement for DSS-14. The U.S. Rosetta team determined that DSS-15, a 34-meter antenna also at Goldstone, in use by the Mars Express mission and then by the Voyager mission, might be converted for Rosetta on short notice. A request by ESA to reallocate the MEX pass to Rosetta was not successful. A discussion between the U.S. Rosetta manager and the Voyager manager resulted in an agreement to reallocate the Voyager pass to Rosetta. This reallocation was put in place in real-time through the DSN's Operations Chief and by cell-phone with the Rosetta flight manager. DSS-15 acquired Rosetta about 30 minutes later than the time originally scheduled for the red DSS-14. The U.S. Rosetta project takes away the lesson to properly characterize the priority for intended passes.

5. ISAS AND PAYLOAD CHECK-OUT #8

Payload Check-out #8 (PC8) was conducted from July 5, 2008 to Aug 1, 2008, and is more properly designated an 'active' checkout. In addition to the nominal baseline calibration activities that are largely run autonomously, PC8 included a re-run of the Interference Campaign that was originally run in the Commissioning Phase [7]. The objectives of the Interference Campaign were to check for mechanical, electromagnetic or other types of interference between payload instruments, and between the payload, Lander and/or spacecraft sub-systems. An interference test consisted of relevant instruments being suitably configured to emissive modes (operational modes that are a likely source of interference), and susceptible modes (operational modes when an instrument is most likely to experience interference from its environment and/or during scientific measurement.)

The U.S. Rosetta Project keeps a record of mission incidents, surprises, and anomalies, collectively known as ISAs. This record is kept somewhat in parallel with ESA's Anomaly Report (AR) system (the AR system and ISA system are not identical), largely to ensure for historical reasons that NASA documents U.S. Rosetta issues within its own system. Two incidents on U.S. Rosetta instruments are noteworthy during this period.

Alice Upset and Safing

During PC8 Alice experienced an upset (power reset) sometime between 21:33:49 and 21:34:04 on July 19 (day 201). Instrument operation continued, but as a precaution, a subsequent door performance sequence was eliminated. The specific cause of the reset has not been determined, however the Alice team continues to study the ground telemetry from this anomaly, and will perform ground software tests as well as retesting at PC10.

Alice experienced a safe mode event at 15:44:25 on July 26 (Day 208). This occurred during a closed door decontamination activity in which heaters were not turned off at the safe mode entry. The team has determined that the cause was due to an interface issue with pressure trend data provided by the ROSINA instrument. The Alice team has decided to make it standard practice to internally disable Alice's monitoring of ROSINA pressure-trend data whenever Alice is turned on. (NOTE: this disables monitoring of the pressure-trend data only; Alice will continue to monitor separately the instantaneous pressure data). Further, the Alice team will update the flight software to turn off heaters when safe mode is entered.

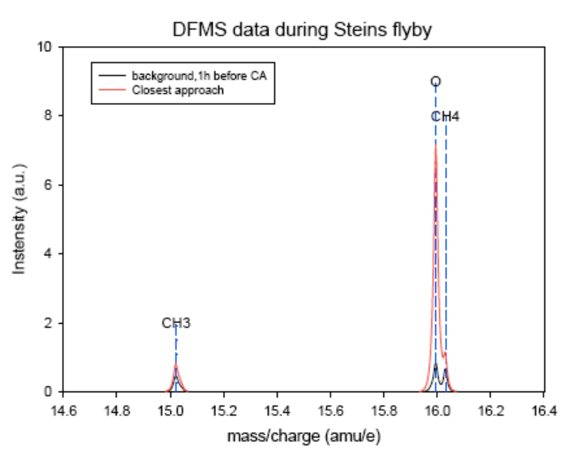

Figure 7. DFMS mass spectrum before and during the Steins flyby.

As a result of lessons from PC8, the Alice team recommended adding several commands to the Steins sequences to ensure that these events would not result in loss of asteroid data acquisition. They were successfully implemented by RSOC.

DFMS low temperature reached:

On Sept. 5, 0600h during the Asteroid Steins encounter, the DFMS was switched to standby due to a planned trajectory correction maneuver. By the end of this stand-by mode a subset of the DFMS known as the LEDA detector (Large Electron Detector Array) reached a temperature of –30°C and DFMS was switched off by the detector power unit (DPU). All subsequent commands from the timeline targeted at DFMS failed because DFMS was off. ESOC manually switched on the non-operating heaters at 10:48 UTC. An attempt to switch on DFMS again failed at 13:07. A second attempt was successful at 15:05. After that DFMS stayed on and resumed measurements with the next command of the timeline at 15:45 h. The non-operating heaters were left on. DFMS was switched to standby again on 0500 h, Sept. 6 for another TCM and resumed measurements again 1 h later. This sensor error was attributed to several factors including a software instability that has subsequently been corrected.

6. Laboratory Work with Asteroid Analogs

In preparation for analysis work with the asteroid, Prof. Marcello Fulchignoni, the Rosetta interdisciplinary scientist (IDS) for asteroids from the Observatoire de Paris, together with Dr. Lucy McFadden of the University of Maryland, Dr. Luigi Colangeli, of the National Institute of Astrophysics in Naples, Italy, Anny-Chantal Levasseur-Regourd and Edith Hadamcik from the Université Pierre et Marie Curie of Paris, Ludmilla Kolokolova of the University of Maryland and V. Psarev Astronomical Institute of Kharkov, Ukraine, have worked together to coordinate laboratory analysis around the world. Three laboratories currently working to examine meteorite samples that might serve as appropriate analogs of asteroid Steins, including a new facility at Southwest Research Institute (SwRI) in San Antonio, known as the Southwest Ultraviolet Reflectometer Chamber (SwURC). (The SwURC is being built primarily to examine lunar samples in the ultraviolet).

Aubrite samples

In February of 2008, Dr. McFadden requested of NASA's Johnson Space Center's Astromaterials Lab, samples of Antarctic meteorites ALH78113 and ALH84007, both of the aubrite class. Five gram chips of aubrite meteorites (ALH78113,82 and ALH 84007,108) with nearly iron-free pyroxene (enstatite) and small amounts of Ni-Fe and sulfides with some iron oxide halos, were received for mineral and chemical analysis and use with light scattering measurements. The chip of ALH78113,82 was spectrally imaged at the Keck/NASA RELAB and INAF, Rome. The sample was then crushed and separated into two sizes, between 125–250 μm and below 125 μm. FEM-SEM images show the sample as well as some small altered grains.

The powders are being distributed to the various laboratories that constitute the consortium for this study. Enstatites and other terrestrial minerals accumulated by the Kharkiv facility, provide an opportunity for comparison with the aubrites and their individual mineral components. Out of the collection they have selected an enstatite that looks very much like the aubrites obtained from the Johnson Space Center. They have measured the powders of this enstatite of different size distributions to get a tentative model of the opposition peak that may have been obtained at the Steins' measurements.

Simulations of the regolith properties, measurements

A program of measurements with PROGRA[2] (PRopriétés Optiques des GRains Astronomiques et Atmosphériques, a facility sponsored by the Centre Nationale d'Etudes Spatiales (CNES) the French Space Agency) is being developed, with experiments in the lab on layers and during parabolic flights campaigns. The latter, to take place between 8 October and 7 November 2009, are to provide reduced gravity conditions close to the gravity field on a ≈5-km-sized body. Single grains of the aubrite will be measured.

Of special interest, both for the aubrite-E-type asteroids link and for the presence of regolith on Steins, will be the determination of the minimum in polarization, the inversion angle and of the spectral gradient for the positive branch of the polarimetric phase curves. The program would be enhanced with consideration of other materials to account for deviations in the signal that might not be due to the presence of an aubrite.

7. Coordinated International Modeling Efforts

Several investigators in the U.S. Rosetta Project participated in modeling efforts sponsored by the International Space Science Institute (ISSI). One such team, the "Composition of Comets, led by Professor Hans Balsiger, of the ROSINA instrument, completed its work in 2007 [23].

Another collaboration, the ISSI Comet Modeling Team, received an additional two-year funding increment to continue work in which the goals include modeling the emission of gas and dust in a comet's coma, the comet solar wind interaction, cometary ion chemistry, and cometary high-energy processes. Professor Tamas Gombosi, a U.S. investigator from the University of Michigan, also of the ROSINA instrument, is the leader. The full team contains representatives from both remote sensing and *in situ* Rosetta experiments.

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 supertherrmal electron model and a charged dust model.

The first release of the comet simulation tool was made available for beta-testing in January of 2008, and version 2.0 was released in January of 2009. Documentation on this tool can be found online [24]. Preliminary results of this collaboration were presented at the 2005 meeting of the Division of Planetary Sciences (DPS) [25], at the Planetary Eurospace conference, 2008 [26], and a full paper has been produced for Planetary and Space Science [27]. This comet simulation was adopted in the summer of 2009 as a tool for Rosetta prime mission preparations, and the team will be re-constituted into an official working group of the mission in the coming year.

8. Summary of the U.S. Rosetta Project at Steins

Rosetta flew by the main-belt, E-type asteroid (2867) Steins on 5 Sept. 2008 obtaining, for its first science target, a suite of measurements. Alice obtained the first far-ultraviolet spectrum of an asteroid, with very good signal from 850 Å to 2000 Å. These data provide the first spectrum of an E-type asteroid below the atmospheric cutoff, the first ultraviolet spectrum of a small asteroid, and a spectrum extending to shorter wavelengths than has been observed for any other asteroid. Likewise, MIRO returned the first microwave measurements of an asteroid target. Results from both these instruments have been submitted to a special issue of Planetary and Space Science. The DFMS detector measured a signal not only at 15 masses but also at 16 masses that has been determined to be CH_3, O, and CH_4 respectively, though of dubious origin (likely origin may be the spacecraft itself). And the IES instrument obtained a signal from the solar wind at closest approach.

In the coming year, laboratory studies will be initiated at the newly established SwURC in San Antonio with the aubrite sample that has been obtained to identify appropriate meteorite analogs for the Steins signatures. Additional materials will be measured to explore the suite of spectral features observed on the asteroid. Interpretive work will continue using these critical measurements as a foundation to understand the character and origin of this interesting object. In other work the comet environment modeling group at ISSI will concentrate on incorporating more complete parameters for the thermo-physical nucleus component of the environment model, and better interfacing tools (a graphical user interface, or GUI) for the user community. Through the year, the project will also gear up for the next science encounter, that with Asteroid (21) Lutetia on July 10, 2010.

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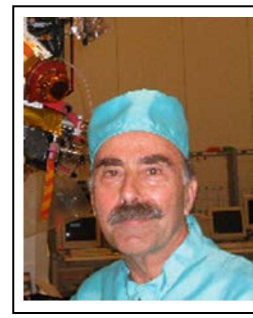
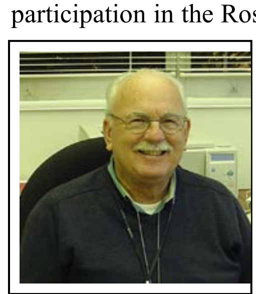
BIOGRAPHY



Dr. Claudia Alexander is currently a Research Scientist at the Jet Propulsion Laboratory, where she serves as both Project Manager and Project Scientist of the U.S. Rosetta Project. She has also served as Project Manager of the historic Galileo Mission to Jupiter in the final 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 in Geophysics from the University of California at Berkeley in 1983, and a Masters Degree in Geophysics and Space Physics from the University of California at Los Angeles in 1985.

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

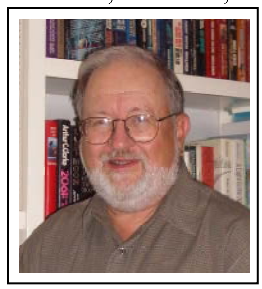


170 papers in scientific journals and conference proceedings.

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.

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 Master's Degree and Ph.D. in Physics from Lehigh University, Bethlehem, Pennsylvania. In his career at JPL he was responsible (as Co-Investigator) for prototype design and laboratory calibration of the ion mass spectrometer flown past comets Halley and Grigg-Skjellerup on the Giotto spacecraft, and has been actively involved in the analysis of data from these encounters, particularly regarding cometary coma composition and the dynamics of the interaction of the solar wind with the coma.

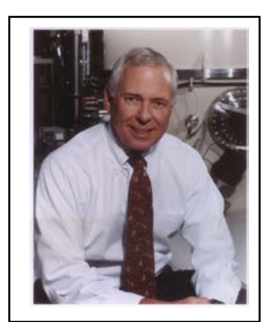
Dr. Joel Parker's research involves photometric and spectroscopic multi-wavelength studies in planetary and stellar astrophysics using ground- and space-based, instruments. He is the Operations Scientist and Project Manager and acting Principle Investigator for the Alice UV spectrometer on the Rosetta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



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

Mr. Donald Sweetnam has been a member of the professional staff at the Jet Propulsion Laboratory for over 30 years. He has conducted scientific investigations into the physical properties and atmospheres of Mercury, Venus, Mars, Jupiter, Io, Saturn, Titan, Uranus, Neptune, and Triton. He has conducted these experiments using NASA Pioneer 10 & 11, Mariner 9, Mariner 10, Viking 1& 2, and Voyager 1 & 2 Spacecraft. Mr. Sweetnam is currently manager of the Genesis Project, a mission to measure the composition of the Sun, which has successfully collected samples of the Solar Wind and returned them to Earth. He is also deputy manager of the U.S. Rosetta Project, a joint mission with ESA, to rendezvous with comet 67P/Churyumov-Gerasimenko.

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. Mary's 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.

Mr. Prachet (Pat) Mokashi is a Senior Research Engineer at Southwest Research Institute in San Antonio, TX. He has been involved with space science instrument development, operations and data analysis since 2002. He is the operations lead for the Cassini Plasma Spectrometer (CAPS) on Cassini and the Ion and Electron Sensor (IES) on Rosetta as well as a science planning lead for the Juno mission. He plans and coordinates instrument activities with flight software engineers, instrument scientists and the mission operations teams. Additionally, he is involved in analyzing plasma science data and generation of mission and instrument science support data.