



ROSETTA ORBITER SPECTROMETER FOR ION AND NEUTRAL ANALYSIS–ROSINA

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ABSTRACT

The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) will answer outstanding questions concerning the main objectives of the mission. To accomplish the very demanding objectives, ROSINA will have unprecedented capabilities, including: very wide mass range from 1 amu to >300 amu; very high mass resolution (ability to resolve CO from N₂ and ¹³C from ¹²CH); very wide dynamic range and high sensitivity; the ability to determine cometary gas and ion flow velocities and temperatures.

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INTRODUCTION

The international Rosetta comet rendezvous mission represents an extraordinary opportunity to perform a detailed investigation of a primitive object in our solar system. As part of the core payload for this mission, the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) proposed here will answer outstanding questions concerning the main objectives of the mission. The primary measurement objective of the spectrometer 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 ions and the homogenous and inhomogenous reactions of gas and ions in the dusty cometary atmosphere and ionosphere.

In determining the composition of the atmospheres and ionospheres of comets, the following **prime scientific objectives**, also defined by the Rosetta Science Definition Team will be achieved:

- **To determine the global molecular, elemental, and isotopic composition and the physical, chemical and morphological character of the cometary nucleus.**
- **To determine the processes by which the dusty cometary atmosphere and ionosphere are formed**

and to characterize their dynamics as a function of time, heliocentric and cometocentric position.

- **To investigate the origin of comets**, the relationship between cometary and interstellar material and the implications for the origin of the solar system.
- **To investigate possible asteroid outgassing** and establish what possible relationship exists between comets and asteroids.

To accomplish these very demanding objectives, ROSINA will have unprecedented capabilities, including:

- 1) very wide mass range from 1 amu (Hydrogen) to >300 amu (organic molecules).
- 2) very high mass resolution (ability to resolve CO from N₂ and ¹³C from ¹²CH).
- 3) very wide dynamic range and high sensitivity to accommodate very large differences in ion and neutral gas concentrations and large changes in the ion and gas flux as the comet approaches its perihelion.
- 4) the ability to determine the outflowing cometary gas (and possibly ion) flow velocities and temperatures.

Correlated studies with optical observations, with, for example, the dust instruments, the magnetometer and the surface science package further augment the scientific return of the ROSINA instrument. The necessity for the unusual high capabilities of this experiment stems from the fact that it is **one of the key instruments** which is able **to give meaningful data during the whole mission** and thus by monitoring and characterizing the different phases of comet activity from apogee through perigee will lead to a full understanding of cometary behavior. No single instrument could have the capabilities required to accomplish the science objectives of the gas and ion mass spectrometer. These three sensors are: the Double Focusing Mass Spectrometer (DFMS), the Reflectron Time of Flight (RTOF), and the Neutral and Ion Dynamics Monitor (NIDM).

INSTRUMENT REQUIREMENTS AT APPROACH

Table 1 lists the science objectives and the instrument requirements necessary to achieve them. The necessary performance of ROSINA is summarized in table 2 and the comparison of operating ranges of the two mass analyzers is given in fig. 1. The requirements listed in Table 1 are unprecedented in space mass spectrometry. So far, no single instrument is able to fulfill all of these requirements. We have therefore adopted a three sensor approach: each sensor is optimized for part of the scientific objectives while at the same time complementing the other sensors. In view of the very long mission duration they also provide the **necessary redundancy**.

Sensor I (DFMS) is a double focusing magnetic mass spectrometer with a mass range 1- 100 amu and a mass resolution of 3000 at 1% peak height. This sensor is optimized for very high mass resolution and large dynamic range.

Sensor II (RTOF) is a reflectron type time of flight mass spectrometer with a mass range 1->300 amu and a high sensitivity. The mass resolution is better than 500 at 1% peak height. This sensor is optimized for high sensitivity over a very broad mass range.

Sensor III (NIDM) consists of three pressure gauges providing velocity and temperature measurements of the cometary gas. Also included is a sensor providing ion dynamics measurements as an option.

Table 1. Science objectives and measurement requirements for ROSINA

<i>Scientific Objectives</i>	<i>Associated critical measurements</i>	<i>Measurement requirements</i>
Determine elemental abundances in the gas	Separate CO from N ₂	Mass resolution >2500 at 1% of peak height at mass 28 amu
Determine molecular composition of volatiles	Measure and separate heavy hydrocarbons (neutrals and ions) up to mass 300 amu	Mass range 1-300 amu with a resolution of >300 at 1% Sensitivity >10 ⁻³ A/Torr
Determine isotopic composition of volatiles	Separate ¹² CH and ¹³ C. Measure HDO, DCN and other deuterated neutrals and ions	Mass resolution >3000 at 1% peak height, relative accuracy 1%, absolute accuracy 10%.
Study the development of the cometary activity	Measure the composition (water and minor constituents) between 3.5 AU (gas production rate 10 ²⁴ s ⁻¹) and perihelion (10 ²⁹ s ⁻¹)	Mass range 1-300 amu, dynamic range 10 ⁸
Study the coma chemistry and test existing models	Measure ions and molecules in the mass range 1-300 amu and their velocity and temperature	Mass range for ions and neutrals 1->300 amu, dynamic range 10 ⁸ , sensitivity >10 ⁻³ A/Torr
Study the gas dynamics and the interaction with the dust	Measurement of the bulk velocity and temperature of the gas	Bulk velocity corresponding to E≈0.02 eV ± 10 %, temperature = 0.01 eV ±20%
Characterization of the nucleus	Characterization of outbursts and jets of limited angular extent	2° Narrow field of view, time resolution ≈1 minute
Characterization of asteroids	Detect asteroid exosphere or determine upper limit	Extreme sensitivity for H ₂ O, CO, and CO ₂

Table 2: ROSINA Performance

Component	Mass Range [amu]	Mass Resolution m/Δm (at 1%)	Sensitivity Gas [A/Torr] (1)	Ion (2)	Dynamic Range (3)	Pressure range (Torr) (4)	FOV	Highest time resolution for full spectrum
DFMS(5)	12-100	3000	10 ⁻⁵	10 ⁴	10 ¹⁰	10 ⁻⁵ - 10 ⁻¹⁵	20°x 20° 2°x 2° (6)	120 s
RTOF	1->300	>500	10 ⁻³	10 ³	10 ⁶ /10 ⁸	10 ⁻⁶ - 10 ⁻¹⁷	10°x 40°	4 s / 5 min.
NIDM	Temperature 50-500 K		3x10 ⁻²		10 ⁶	Mach number 0.5-4		10 min (7)

(1) 1x10⁻³ A/Torr corresponds to 0.2 counts/s if density is 1 cm⁻³. Emission current of the ion source at 100 μA, can be increased (up to a factor 5) or decreased.

(2) Counts per second for cometary ion density of 1 cm⁻³.

(3) Ratio of highest to lowest peak in one measurement cycle

(4) Total measurement range

(5) High resolution mode (for details see section 3)

(6) Narrow field of view entrance

(7) 1 spacecraft revolution

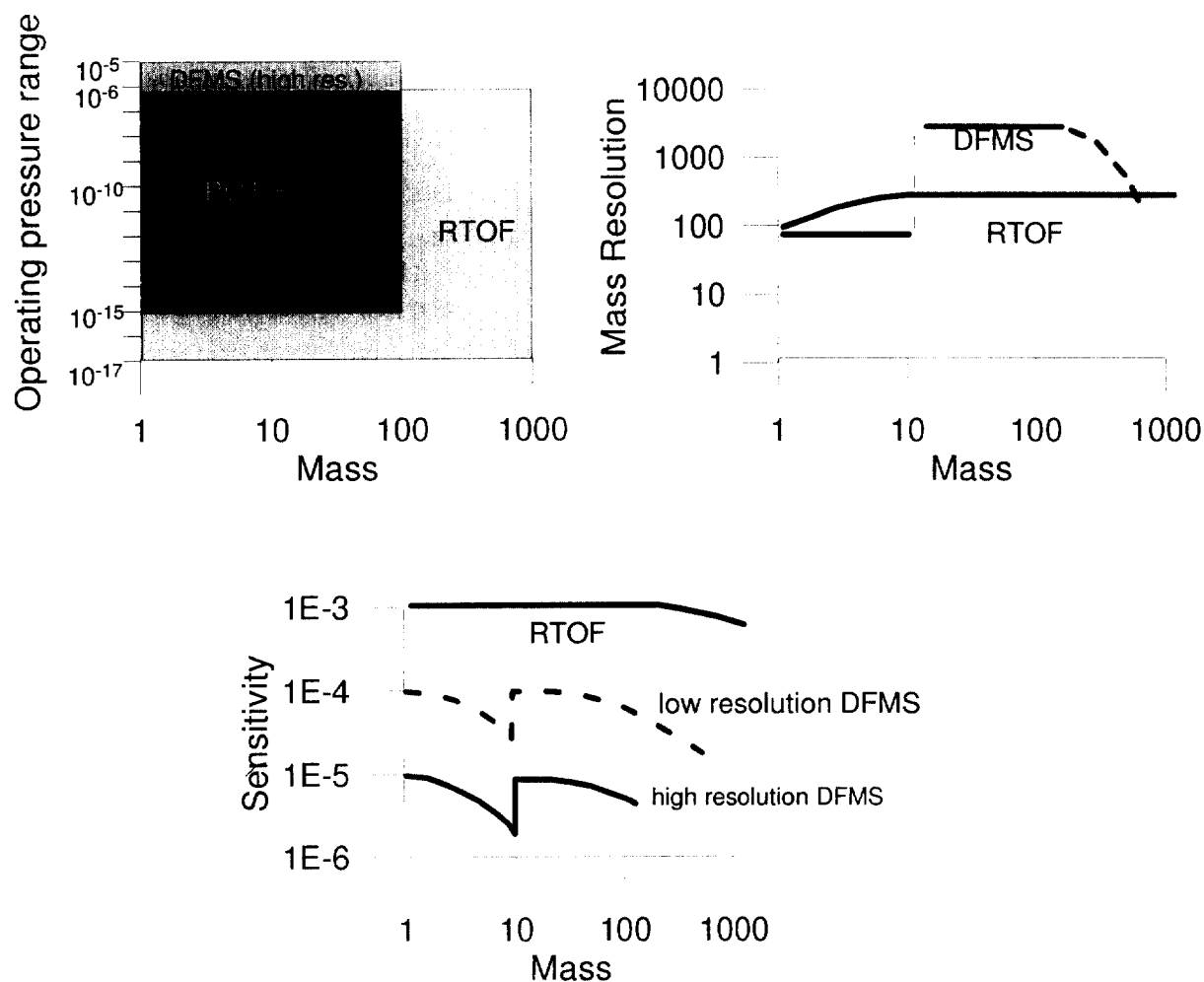


Fig. 1. Comparison of operating ranges of the two mass analyzer sensors. Ionizing electron current is $100 \mu\text{A}$

INSTRUMENT DESCRIPTION

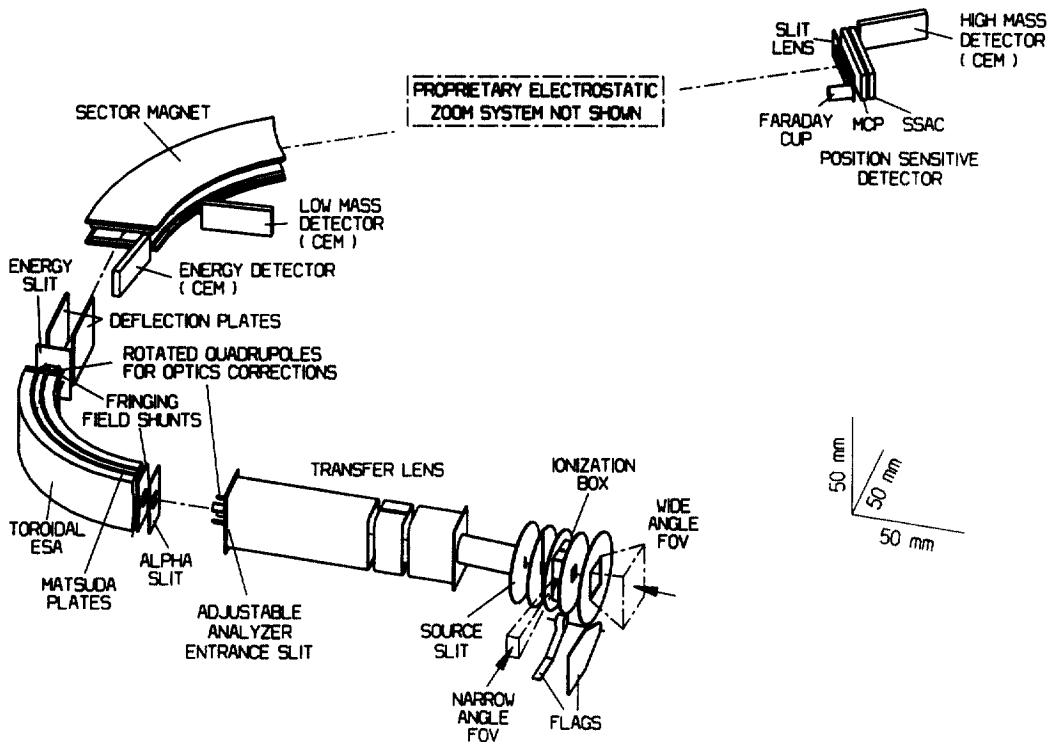
Double Focusing Mass Spectrometer

The double focusing mass spectrometer is a state of the art high resolution mass spectrometer (resolution $m/\Delta m > 3000$ at 1% peak height) with a high dynamic range and a good sensitivity. It is based on well proven design concepts which were optimized for mass resolution and dynamic range using modern methods for calculating ion optical properties.

The DFMS has two basic operation modes: a gas mode for analyzing cometary gases and an ion mode for measuring cometary ions. Switching between the gas and ion modes requires changing only a few potentials in the ion source and suppression of the electron emission that is used to ionize the gas. All

other operations are identical for the two modes.

Figure 2 gives an overview of the DFMS. The three main parts are the ion source, the analyzer and the detectors. The instrument is housed in a vacuum-tight enclosure and will be thoroughly degassed by baking and launched under vacuum. The ion source region will be opened during the cruise phase to the comet by removing the protective cap. At the same time the analyzer section vent, pointing at free space, away from the comet and the ion source will also be opened.



2. Three dimensional view of the main elements of the DFMS

Reflectron Time of Flight

The reflectron time of flight (RTOF) spectrometer was designed to complement the DFMS by extending the mass range and increasing the sensitivity of the full instrument package. TOF instruments have the inherent advantage that the entire mass spectra are recorded at once, without the need of scanning the masses through slits. With a storage ion source – a source that stores the continuously produced ions until their extraction into the TOF section – with high transmission in the TOF section and with a sensitive detector, it is possible to record a very large fraction (>60%) of all ions produced. These factors contribute to the overwhelming sensitivity of TOF instruments. Another reason to use TOF instruments in space science is their simple mechanical design (their performance depends on fast electronics rather than on mechanical tolerances) and easy operation. A RTOF-type instrument was successfully flown on the Giotto mission to measure atoms and molecules ejected from a surface during impact of fast cometary dust particles. The ROSINA RTOF will include two similar and independent source-detector systems, one

for cometary ions and one for cometary neutrals, using the same reflector (Fig. 3). This configuration guarantees high reliability by almost complete redundancy.

A Time of Flight spectrometer operates by simultaneous extraction of all ions from the ionization region into a drift space such that ions of a given m/q are time-focused at the first time focus plane (TF) at the beginning of the drift section. Hereby the temporal spread of such an ion packet is bunched from about 800 ns at the exit of the ionization region to about 3 ns (mass = 28 amu). Those very short m/q ion bunches are then imaged onto the detector by the isochronous drift section. Because different m/q bunches drift with different velocities, the drift length determines the separation of the bunches. The reflector incorporates the isochrony in the drift section.

Mass resolution is determined by the drift time and the temporal spread of the ion packets. Unlike other types of spectrometers, TOF spectrometers have no limit to the mass range. In practice the mass range is limited by the electronics, e.g., by the size of the signal accumulation memories.

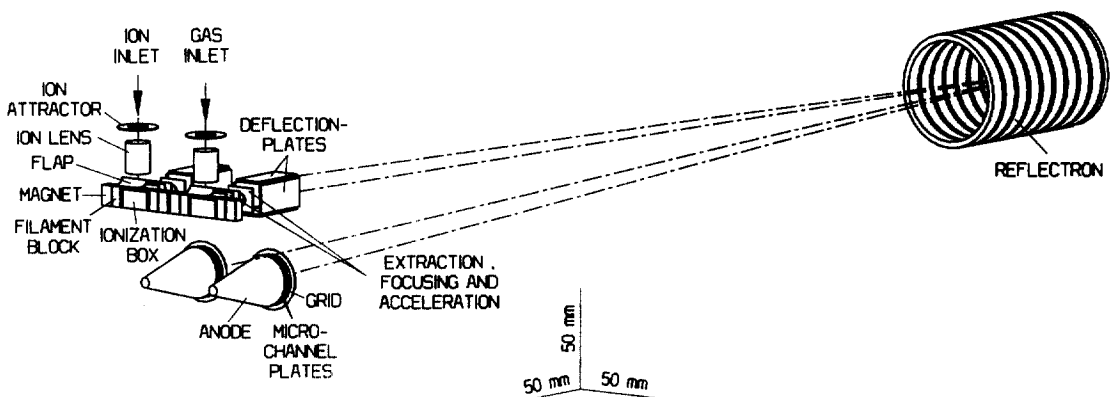


Figure 3. Schematic view of the main elements of the RTOF sensor.

The RTOF consists of four main components: the ion sources, the ion optics, the reflector, and the detectors. Two different channels are used in this spectrometer: one which ionizes the gas in an ion source and stores the ions, and one that pulses the incoming cometary ions onto the TOF path. The two sources are mechanically very similar, with one source optimized for the gas mode and one source optimized for the ion mode. Ions pass through the ion optics section and enter the drift section where they are reflected with an electric field in the ion reflector and return to two separate detectors. Thus, there are two independent mass spectrometers in a single structure.

Neutral (and Ion) Dynamics Monitor

In the ROSETTA study report (SCI (93)7), a second objective was pointed out for investigation of the cometary atmosphere, namely the study of coma dynamics which can be achieved by measuring bulk velocities, temperatures and excess energies of neutral and ions. We stress that these measurements are essential to understand the very dynamical nature of cometary phenomena and their spatial and temporal

evolutions; they are also necessary to quantitatively evaluate the mass spectrometer measurements. We, therefore, propose a sensor for neutral measurements, because they will also provide the essential knowledge of the gas density, with the option of including an ion instrument. This latter requires a uniformly grounded s/c surface, a highly desirable feature also for the mass spectrometers when they operate in their ion mode. We describe in the following a version where neutral and ion sensors are integrated into a single instrument, which saves a significant amount of mass and power.

This instrument will provide observations relevant to the dynamics of the cometary gas (and ions) and their temporal or spatial variations. The results will also be used to support the detailed analysis of the mass spectrometer data by taking into account the flow conditions. Gas Mach number and temperature will be measured (together with the ion angular and energy distributions from which, in case of simple drifting Maxwellian plasmas, a straightforward calculation gives access to the ion bulk velocity and temperature). Sensors for the gas are totally independent from the ion analyzer. However, in this version including the optional ion-mode, they have been integrated in the ion analyzer structure, thus providing a complete and compact packet shown schematically in Fig. 4.

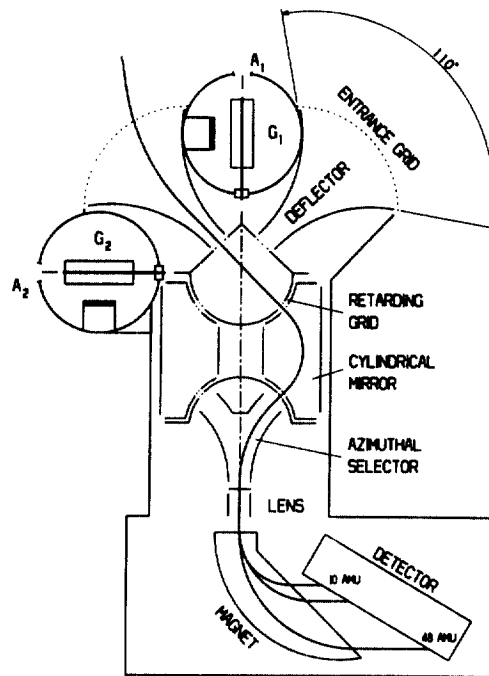


Figure 4. Schematic representation of the equilibrium chambers of the gas velocity and temperature probe.

SCIENTIFIC CLOSURE

Table 3 shows the data products from the ROSINA investigation and the corresponding scientific objectives that will be addressed using these data products. In addition to the specific science objectives

of ROSINA listed in the table, the data products will provide key information for additional science objectives of other Rosetta orbiter and lander instruments. Collaboration between the ROSINA investigation and other orbiter and lander investigations will greatly enhance the scientific results in several key areas including: dust-gas interaction, gas-plasma interaction, causes of cometary activity, and compositional differences within the nucleus.

Table 3. ROSINA sensors, data products and science objectives.

Sensor	Data Product	Science Objective
DFMS/ RTOF	- High Resolution and High Sensitivity Mass Spectra	Composition of the Nucleus
		Origins of Comets
		Origins of organic material in comets
	- Heliocentric/temporal dependence	Onset of cometary activity, composition changes in the coma
	- Cometocentric dependence	Coma chemistry, gas-dust interaction
	- Detailed mapping of active and quiescent regions	Causes of cometary activity, compositional differences within the nucleus
NIDM	Neutral (and possibly ion) Pressures, Velocities, Temperatures	Coma gas-dust dynamics

A complete understanding of the dust-gas interaction will require collaboration between ROSINA and the dust investigation. The comet produces approximately equal concentrations of gas and dust (Balsiger et al., 1988) and there is a strong indication that this combination is responsible for extended sources such as CO in comet Halley (e.g., Eberhardt et al., 1987). Extended observations of the comet by both ROSINA and the dust experiment will be exploited in a search for other extended gas sources and a complete characterization of the known extended sources and their origin within the dusty atmosphere.

Similarly, an understanding of the gas-plasma interaction will require collaboration between ROSINA and the plasma experiment. Basic quantities such as the gas production rate of the comet obtained from ROSINA will be important elements in the understanding of the plasma observations. Likewise, the plasma flow velocity, the electron temperature and the magnetic field will be important quantities for determining and checking the location of the contact surface near the comet when it is close to the sun. Low energy ion flow inside the contact surface is significantly affected by the presence of this barrier and its location will be important in interpreting the ROSINA ion observations.

A complete understanding of the causes of cometary activity and compositional differences within the nucleus will require collaboration between ROSINA and several orbiter and lander investigations. One important aspect to be investigated is the composition of volatiles measured by ROSINA and the composition of non-volatiles surface components measured by the landers. A cross-check of the relative composition of these two cometary components is required to completely account for cometary composition and to understand how (or if) the cometary coma differs from the evacuated material in the mantle. This combination of orbiter and lander composition measurements will be key in resolving the question of the ultimate fate of comets in the solar system.

Causes of cometary activity and compositional differences within the nucleus will also be investigated through a collaboration between ROSINA and other orbiter investigations. One important collaboration will be the coordinated mapping of cometary active regions with ROSINA, the camera investigations and

the dust investigation. Possible compositional differences of the active regions will be measured directly with the narrow field of view part of the ROSINA DFMS. In coordination with camera and dust observations, these regions will be localized and identified. Possible compositional differences of each of these regions will be investigated periodically during the mission to determine if gas from these regions change with increasing cometary activity.

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