Mass spectrometry in the history of the solar system exploration

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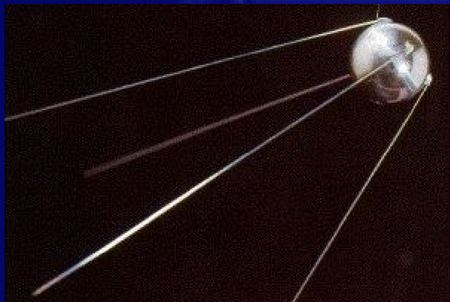
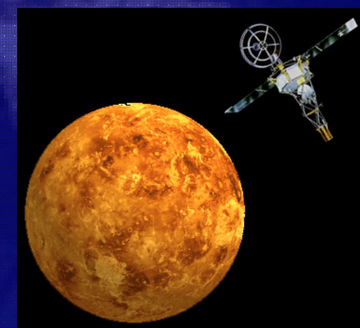
Space exploration at a glance



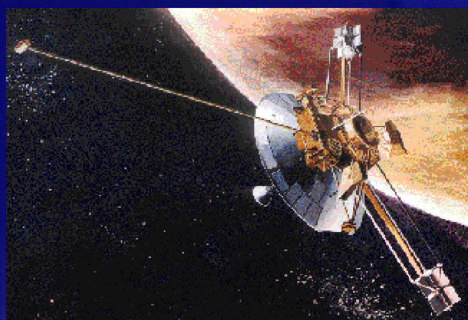
1957 : first artifical satellites (Spoutnik 1 & 2)

1961 : first human in space (Gagarine)



1962 : first interplanetary probe success (Mariner 2, Venus)

1969 : first human on the moon (Armstrong)

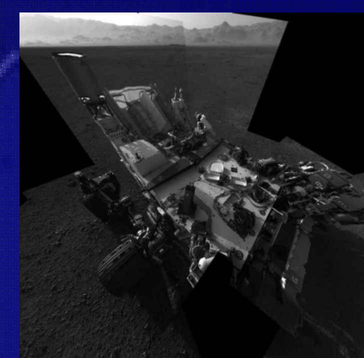


1972 : first probe launched to the outer solar system (Pioneer 10)

1976 : first MS on another planet

1986 : first long term space station in Earth orbit (MIR)

1995 : first orbital probe of the outer solar system (Galileo, Jupiter)

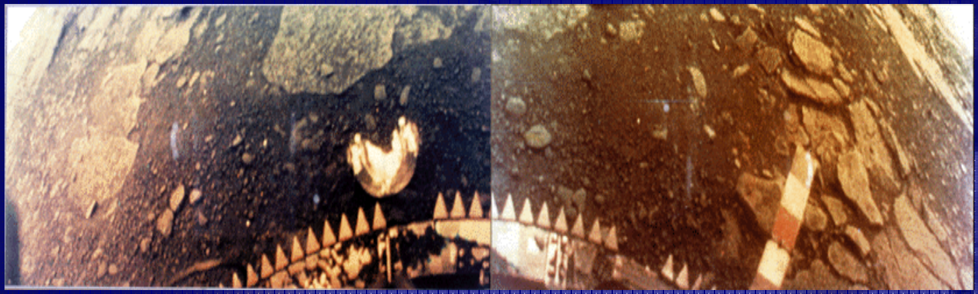


2012 : first one ton rover outside the Earth system

Why sending space probes to explore other worlds ?

Remote sensing by spectroscopy is the primary tool for exploring the solar system **BUT**

1. Limited to observable environments

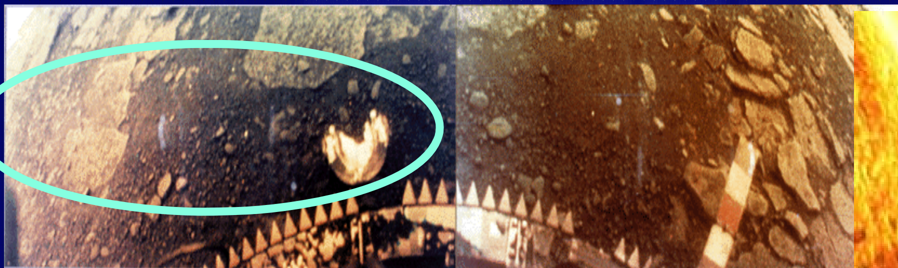


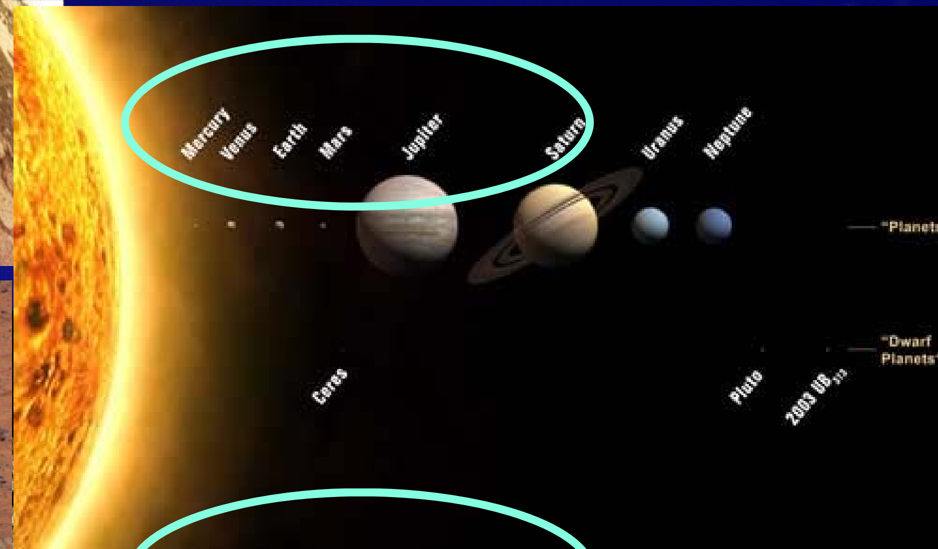
Venus surface as seen by Venera probes

Salts revealed by the Mars Exploration Rovers

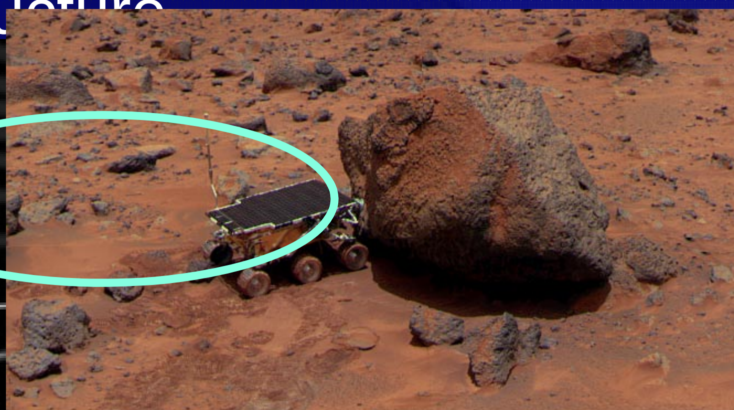
2. Not suited to measure everything
   - Magnetic fields
   - Noble gases
   - …

Main goals of in situ exploration





Structure



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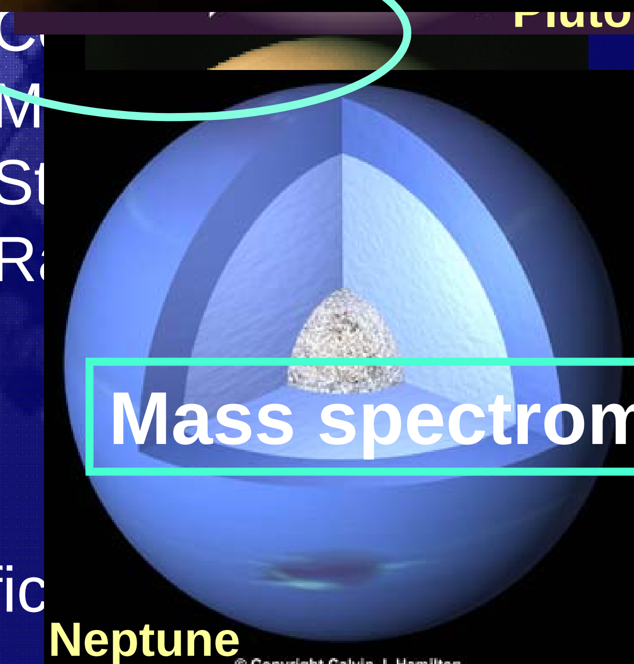
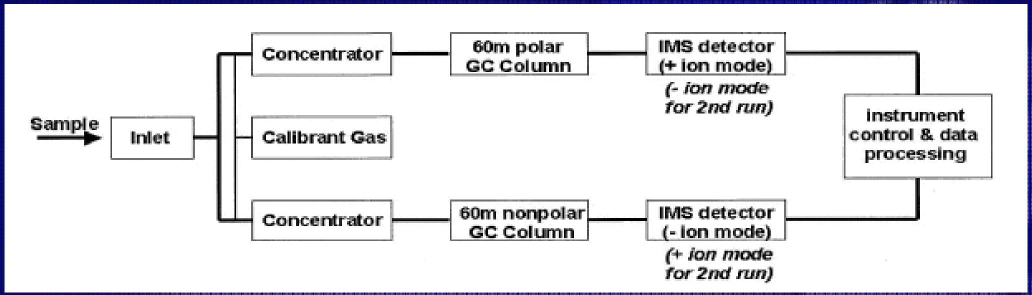


Mass spectrometry

Mass spectrometry in space : what for ?

Two applications :

1. Air monitoring (VOCs) in inhabited spacecrafts and stations (Apollo, MIR, ISS)



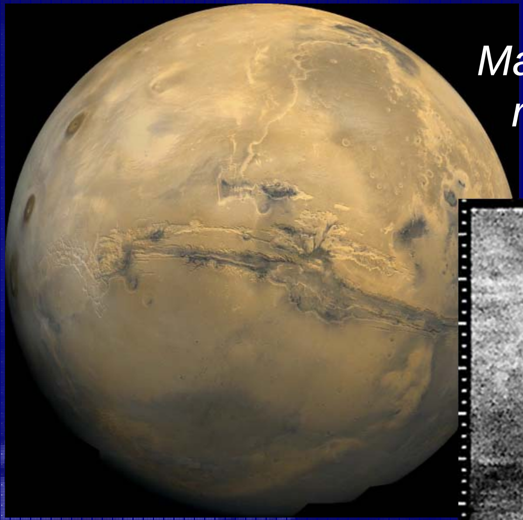
Principle scheme and picture of the VOA system used in the US shuttle to monitor the ambiant air

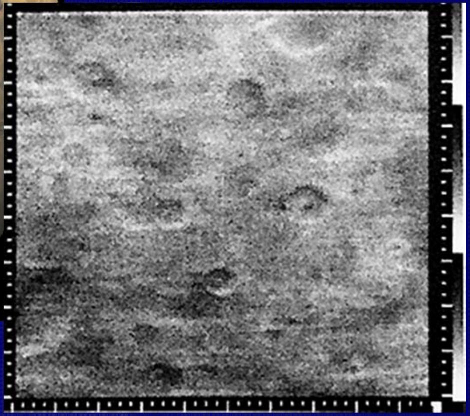
2. Exploration of solar system environments : chemical composition (detect and count various neutrals and ions)

Challenges for in situ mass spectrometry

Property	Space	Laboratory
Weight	~kg	10-100 kg
Power	~10-50 W	100-1000 W
Size	<50 cm	1-10 m
Robustness	10g @ 100 Hz	1g
	Thermal cycling	Isothermal conditions
	Space radiation	
Data volume	~100 Mo max.	No limitation
Contamination	You carry what is on/in the spacecraft	Cleaning/Sterilization
Sampling	Aaaarghhh !	“Easy”

The Viking mission to Mars (1976) : first safe landing on another planet





Mars & 1st picture of its surface returned by Mariner 9 probe

<u>Interest of Mars :</u>

1. Not too far from Earth
2. Telluric planet
3. Believed to host life

Picture of a Viking lander replica with C. Sagan

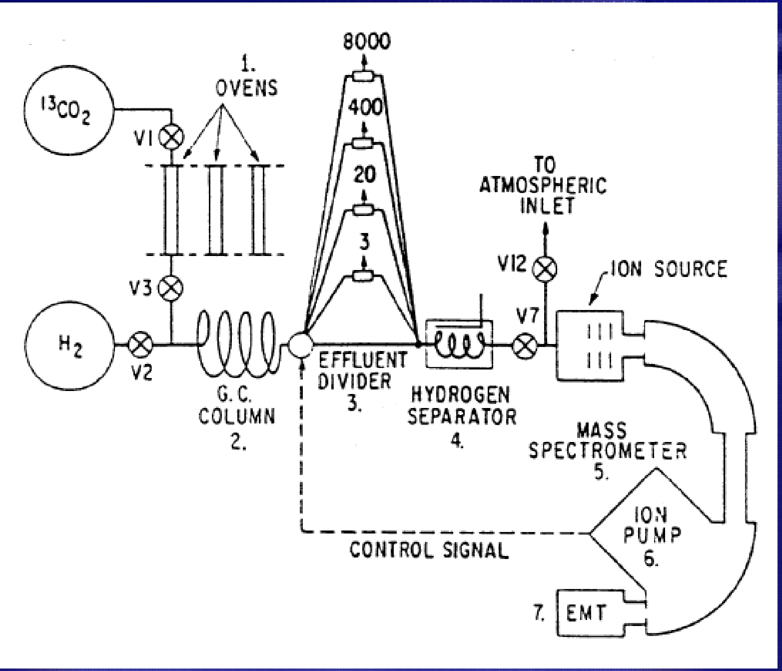
<u>Viking probe & objectives :</u>

1. Lander (~700 kg)
2. Atmosphere and surface composition
3. Search for life

The Viking mission to Mars (1976) : first (GC-)MS in an alien world to seek the first aliens

The GC-MS experiment : all in one !

1. Atmosphere analysis (direct MS)
2. Soil analysis (GC-MS)
3. Label Realeased experiment analysis (GC-MS)



GC-MS experiment scheme

(Biemann et al., 1976)

MS main specifications :

Nature :	Double sector (E/B)
Mass :	~22 kg
Volume :	~20 cm^3
Power :	140 W
m/z range :	12-250
Sensitivity :	ppbv-ppmv (soil)

The Viking mission to Mars (1976) : good atmospheric measurement...

First complete atmospheric composition:

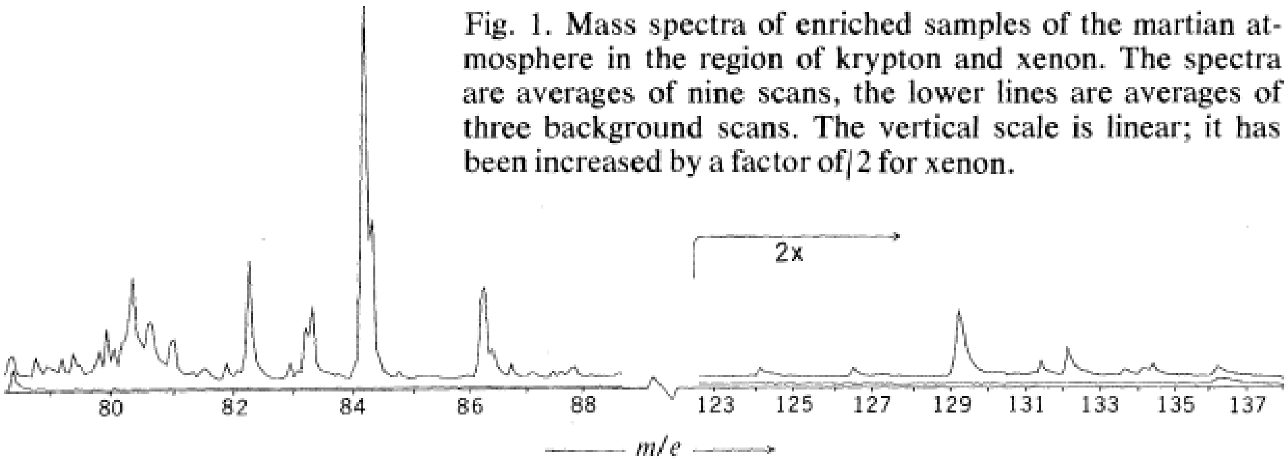


Fig. 1. Mass spectra of enriched samples of the martian atmosphere in the region of krypton and xenon. The spectra are averages of nine scans, the lower lines are averages of three background scans. The vertical scale is linear; it has been increased by a factor of 2 for xenon.

TABLE 1. Composition of the Lower Atmosphere

Gas	Proportion
Carbon dioxide (CO_2)	95.32%
Nitrogen (N_2)*	2.7%
Argon (Ar)*	1.6%
Oxygen (O_2)	0.13%
Carbon monoxide (CO)	0.07%
Water vapor (H_2O)	0.03%†
Neon (Ne)*	2.5 ppm
Krypton (Kr)*	0.3 ppm
Xenon (Xe)	0.08 ppm
Ozone (O_3)	0.03 ppm†

* Discovered by Viking experiments.
† Variable.

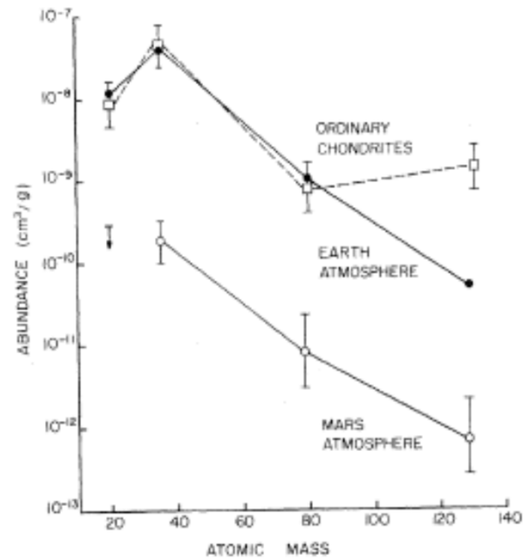


TABLE 2. Isotope Ratios in Atmospheric Gases

Ratio	Earth	Mars
$^{12}C/^{13}C$	89	90
$^{16}O/^{18}O$	499	500
$^{14}N/^{15}N$	277	165
$^{40}Ar/^{36}Ar$	292	3000
$^{129}Xe/^{132}Xe$	0.97	2.5

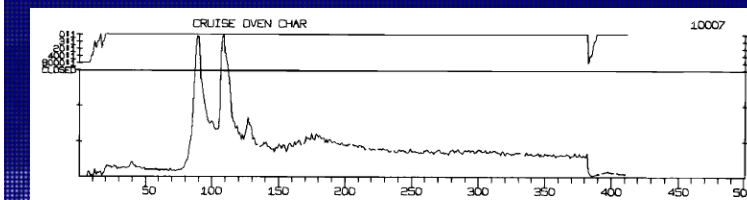
Uncertainties in the Mars values are presently ±10% except for Ar and Xe (see text).

(Owen et al., 1978 & 1980)

The Viking mission to Mars (1976) :
…but no alien (?)

No organic detected=no life (but…) :

Material	Quantity (temperatures in degrees Celsius)
I. Inorganic	
Carbon dioxide	Some in all experiments (quantitation not yet available)
Water	Sample 1: at 200°, much less than 0.1%
	at 500°, 0.1 to 1.0%
	Sample 2: at 350°, 0.1 to 1.0%
	at 500°, somewhat less than at 350°
II. Organic	None detected (see Table 3 for detection limits)
III. Terrestrial contaminants	
Methyl chloride	~ 15 ppb
Fluoroethers	1 to 50 ppb



GC-MS dry run in flight (blank)

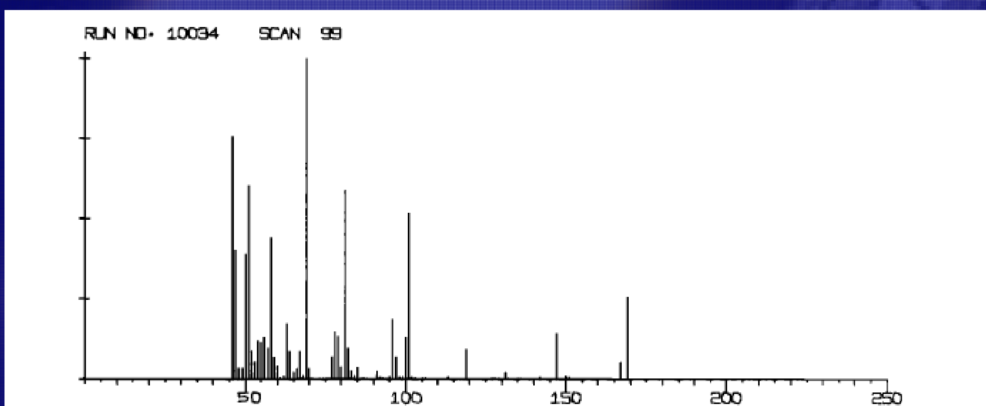


Fig. 5. Typical mass spectrum of the freon-E contaminants. Peaks in the region below m/e 46 have been deleted to avoid distortion of the plot due to contributions of H_2O and CO_2.

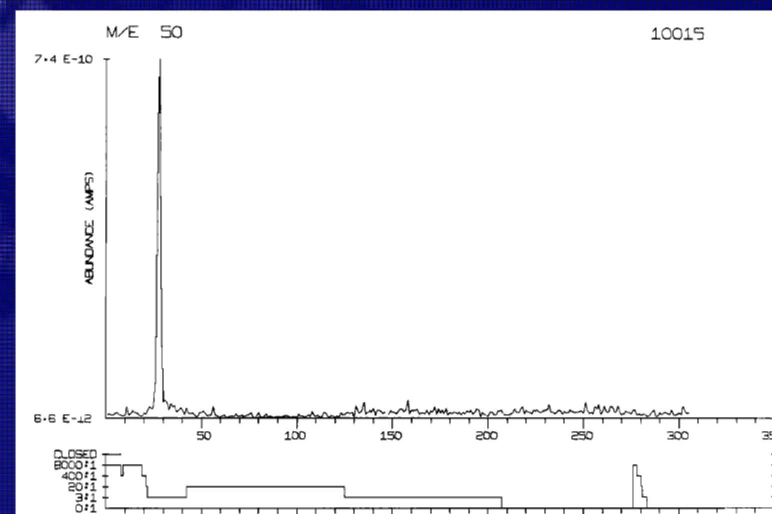
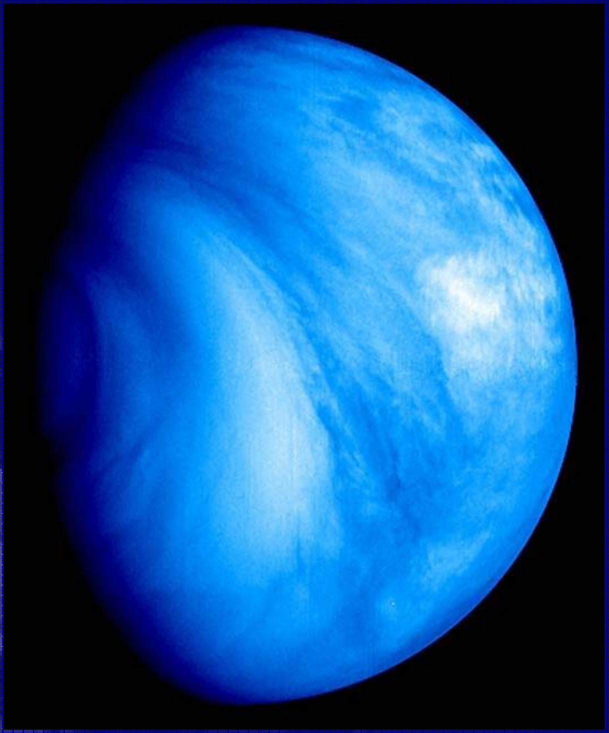


Fig. 4. Mass chromatogram of m/e 50 from the 200° experiment of the first VL-1 sample. In this figure and in Figures 6 and 9 the effluent divider status is plotted underneath the graph (the horizontal line indicates the 1:8000 level, and the step function represents the effluent divider status).

(Biemann et al., 1980)

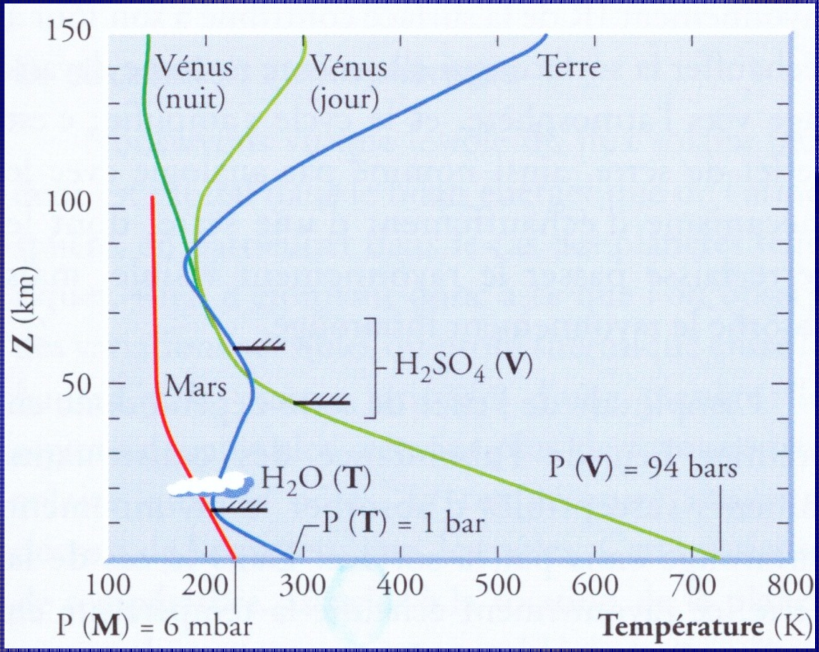
Everybody goes to Venus !



Picture of Venus from the venus express probe

Interest of Venus :

1. Not too far from Earth
2. Telluric planet
3. Very dense atmosphere



Challenges :

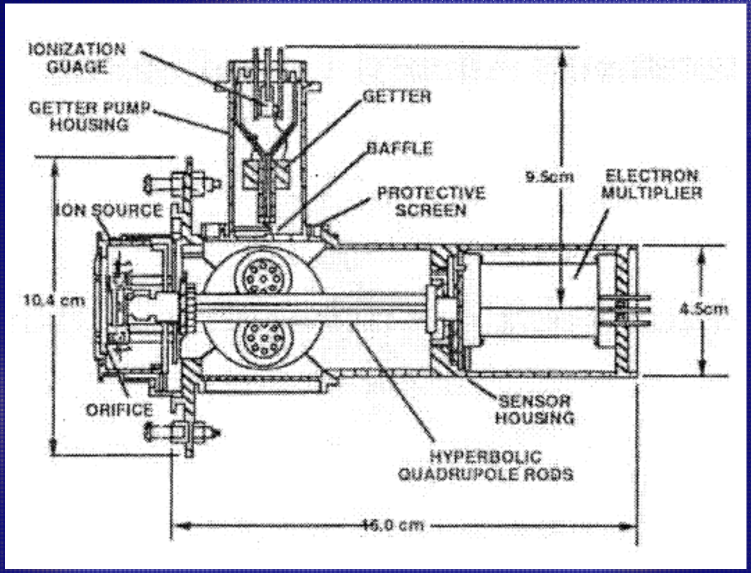
1. Temperature
2. Pressure

The Pioneer-Venus mission to Venus (1978) : Atmosphere of Venus properties

Pioneer-Venus :
5 atmospheric probes,
2 onboarding a MS

Artisit view of Pioneer-Venus

1. Upper atmospheric probe MS



Scheme of the MS of the upper atmosphere probe (NIemann et al., 1980)

MS main specifications :

Nature :	Quadrupole
Mass :	~4 kg
Volume :	~20 cm^3
Power :	12 W
m/z range :	1-46
Sensitivity :	N/A

The Pioneer-Venus mission to Venus (1978) : Atmosphere of Venus properties

First composition of the thermosphere

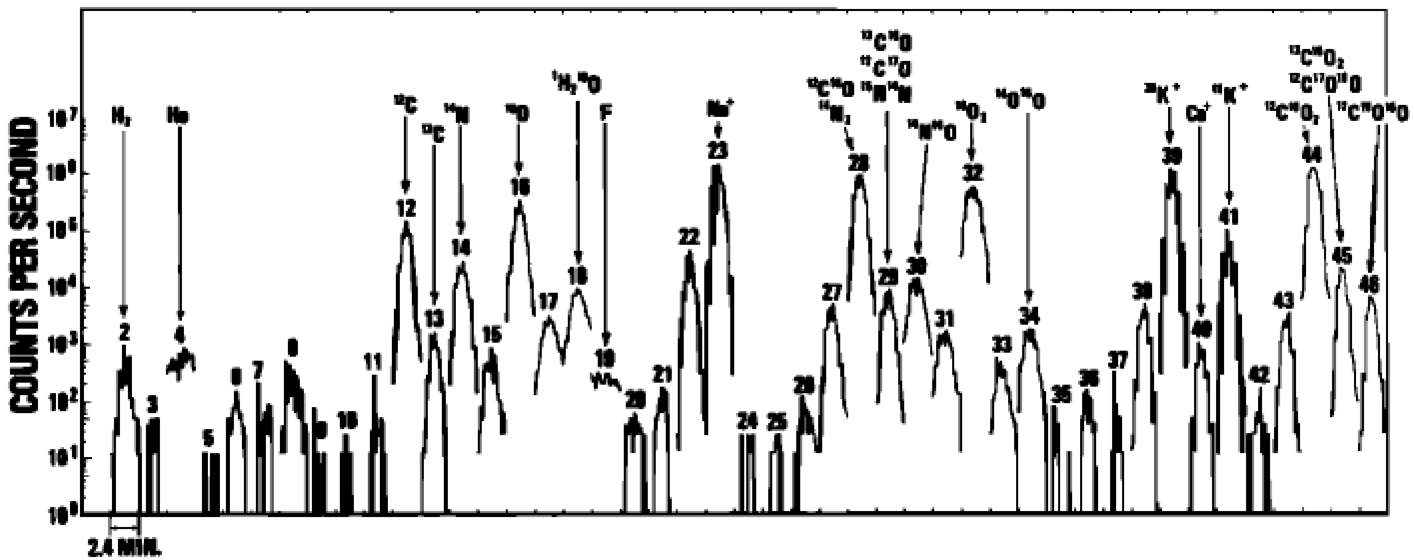
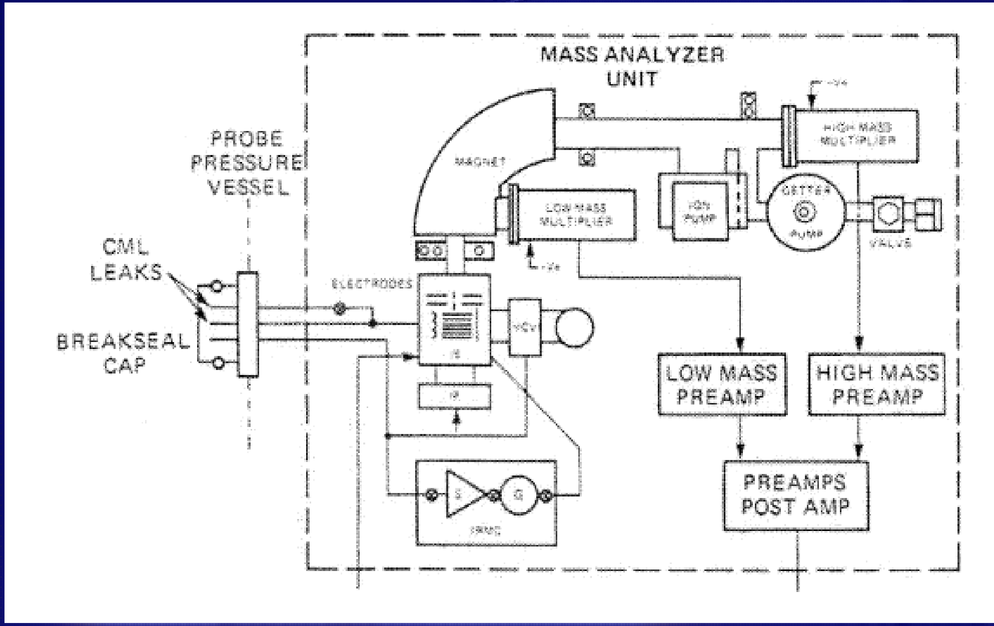


Fig. 3. Summary of the pulse counts measured at ±1.2 min about periapsis for orbit 85 when the instrument was in the unit mass peak stepping mode. Starting on the left of each 2.4-min time interval marked on the abscissa the altitude is 161 km on the ingoing leg. After passing through periapsis altitude at 141 km the interval ends at 160-km altitude on the outgoing leg. The mass numbers are shown above each trace and some constituents are noted. Doubly charged ions, e.g., CO_2^{++} or Ca^{++}, appear in the mass 22 and 20 trace. Na^+, $^{39}K^+$, $^{41}K^+$, and Ca^+ are contaminants sputtered off the ion repeller grid by the CO_2 flux.

(NIemann et al., 1980)

The Pioneer-Venus mission to Venus (1978) : Atmosphere of Venus properties

2. Lower atmospheric probe MS



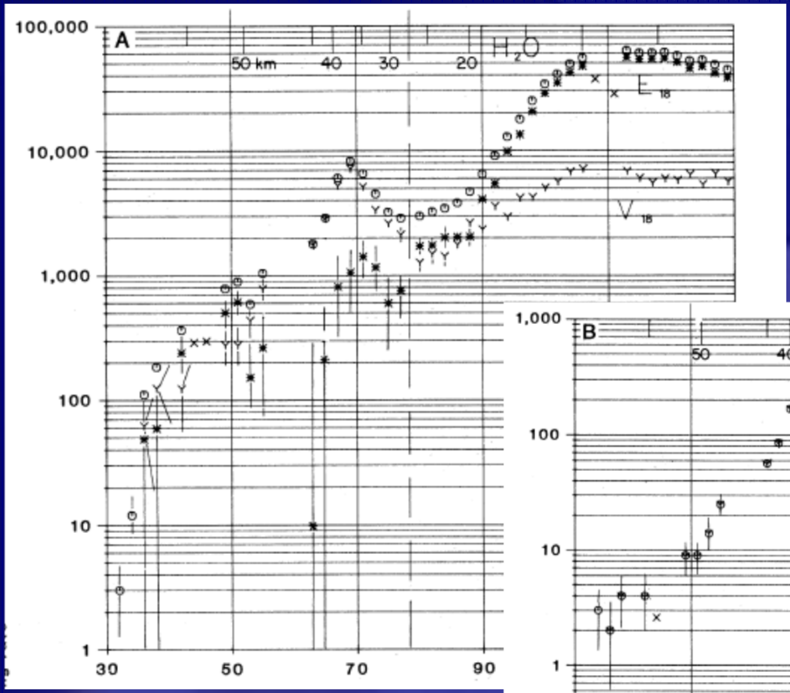
Scheme of the MS of the lower atmosphere probe
(NIemann et al., 1980)

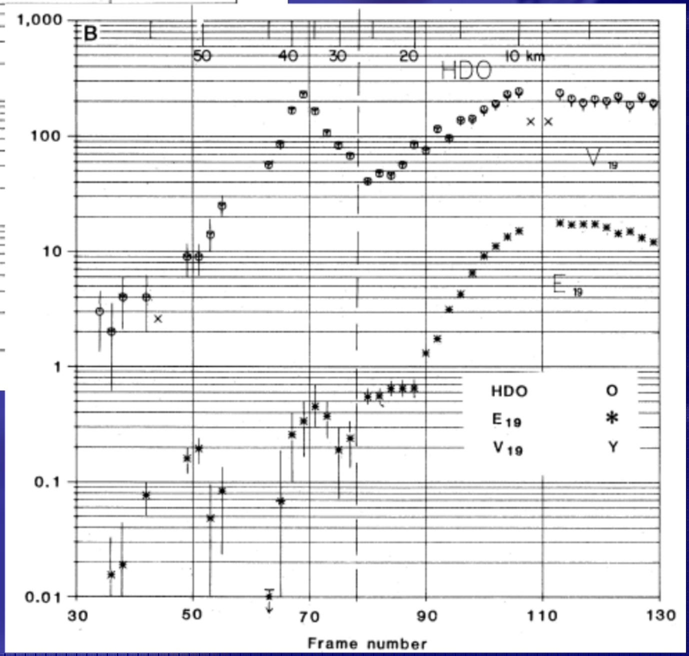
MS main specifications :

Nature :	Sector (B)
Mass :	~12 kg
Volume :	~N/A
Power :	14 W
m/z range :	1-208
Sensitivity :	ppmv

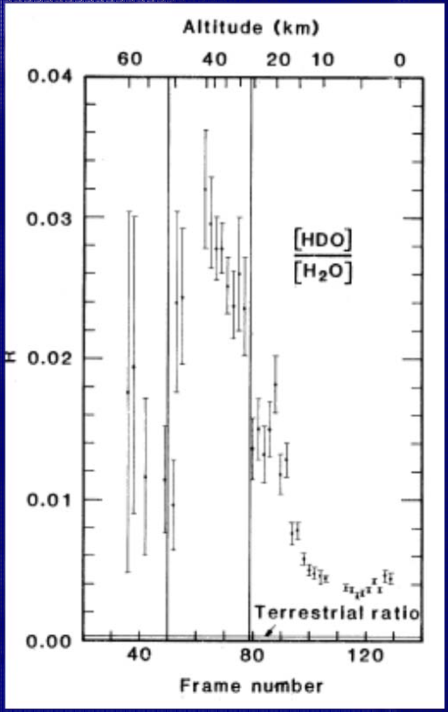
The Pioneer-Venus mission to Venus (1978) : Atmosphere of Venus properties

Venus was wet in the past (and a large amount of water is now in the atmosphere)





Measurement of the amount of H_2O and HDO during the descent



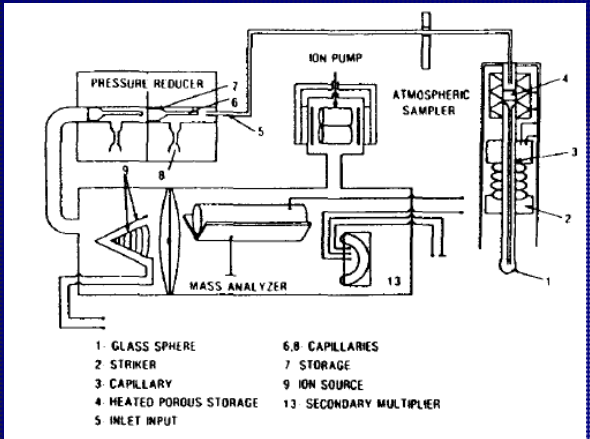
HDO/H_2O ratio

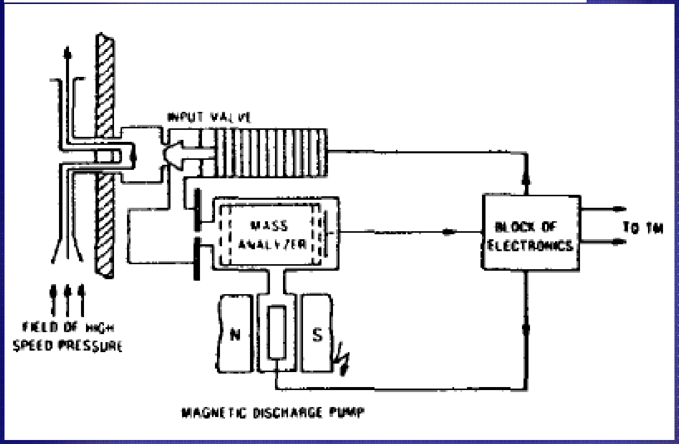
(NIemann et al., 1982)

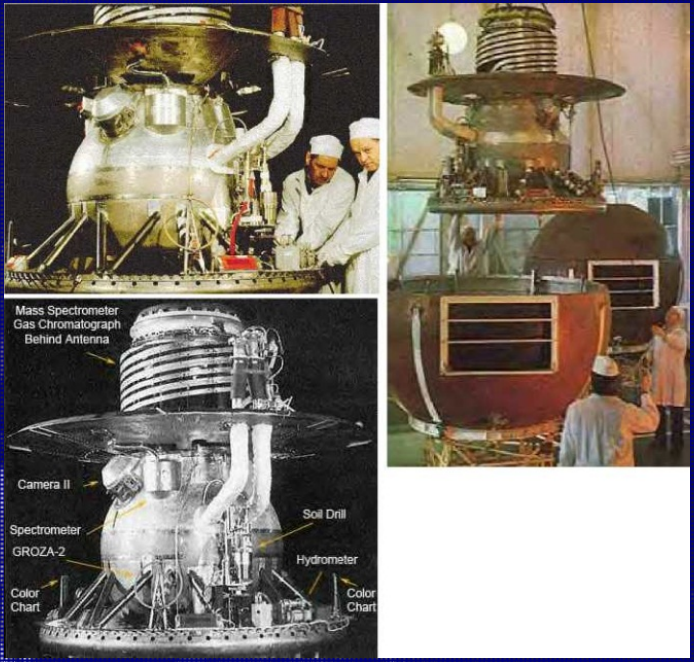
The Venera missions (1975-1978)

Venera :For each mission,
1 orbiter and 1 lander

Mass spectrometer onboard the landers







Picture of the Venera lander

MS main specifications :

Nature : Monopole or Bennett RF
Mass : ~9.5 kg
Volume : ~N/A
Power : 17 W
m/z range : 11-105
Sensitivity : ~ ppmv

Schemes of the MS of the Venera 9 & 10 probes (up), and Venera 11 & 12 (down) *(Istomin et al., 1979 & 1980)*

The Venera missions (1975-1978)

First complete atmospheric composition (with GC analysis):

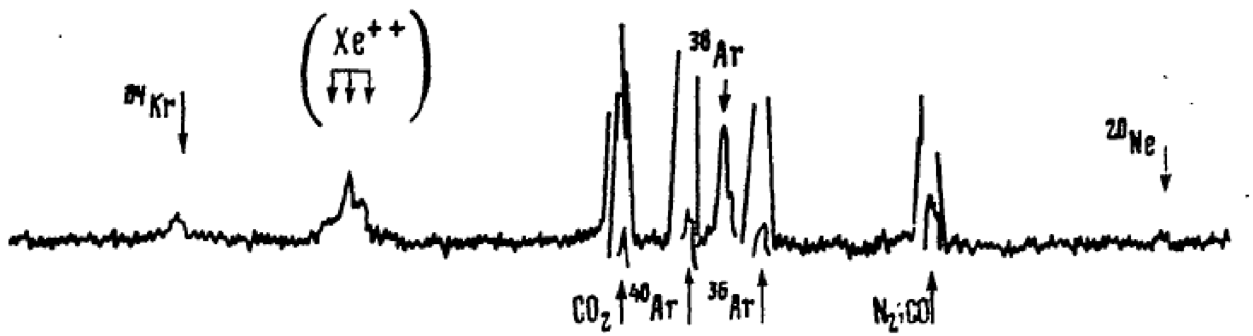


FIG. 3. A mass spectrum fragment in the 20-105 amu range, obtained by Venera 11 in the high-sensitivity mode used for inert-gas analysis. Mass peaks for neon-20 and krypton-84 appear at the sensitivity limit.

Species	Concentration ratio
CO2	95.5%
N2	4.5%
Ar	150 ppm
Ne	10 ppm
Kr	0.5 ppm

(Istomin et al., 1980)

First cometary exploration (1986) : first step of EU in space exploration

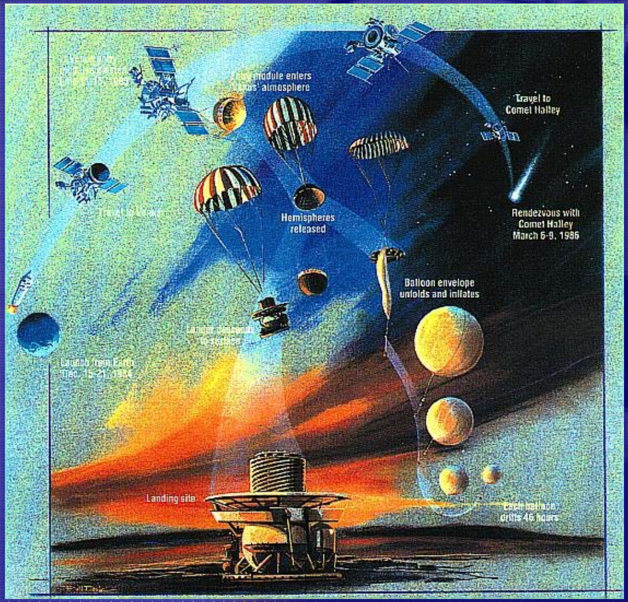
Comet Halley nucleus

Comet P/Hale-Bopp

Interest of comets :

1. Solar system/ISM link
2. Early history of the solar system
3. Origins of atmosphere/life

ESA Giotto probe



VEGA program

Two space missions devoted to study the Halley comet :

1. Giotto ESA probe
2. Vega russian probe

First cometary exploration (1986) : first step of EU in space exploration

2 MS for the analysis of the neutral (NMS/DFMS) and ionized (IMS/Sector (B)) cometary atmosphere (not detailed here) onboard Giotto

MS for dust composition analysis onboard Giotto (PIA) and Vega (PUMA)Interest of comets :

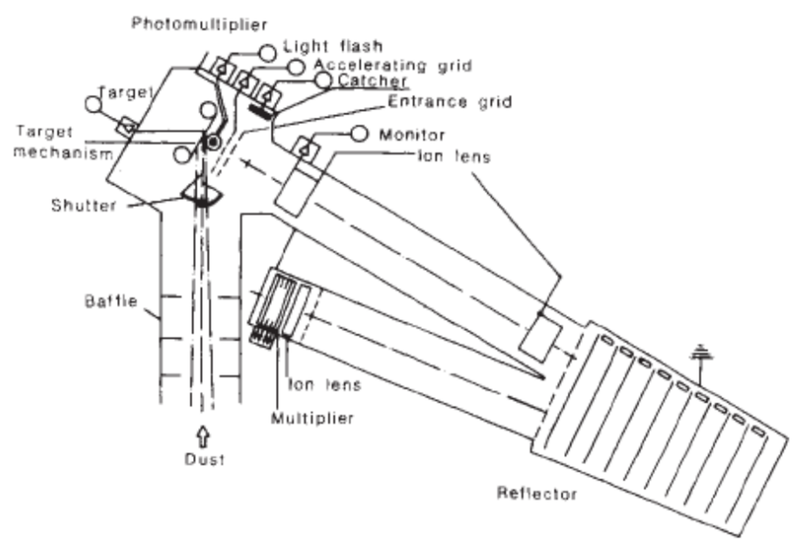


Fig. 1 The time-of-flight mass spectrometer analysing the ions released during the impact of dust particles.

Scheme of the PUMA MS

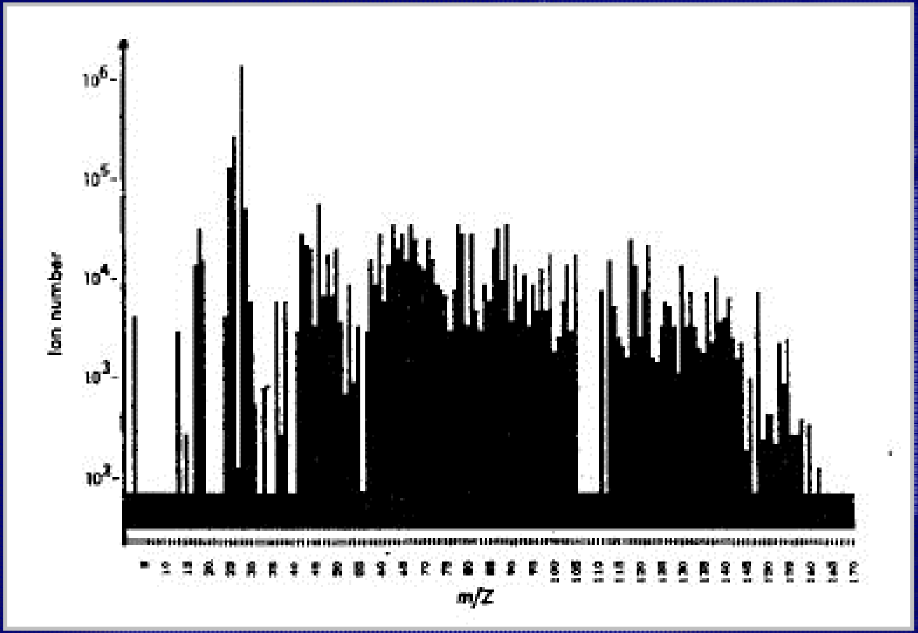
MS main specifications :

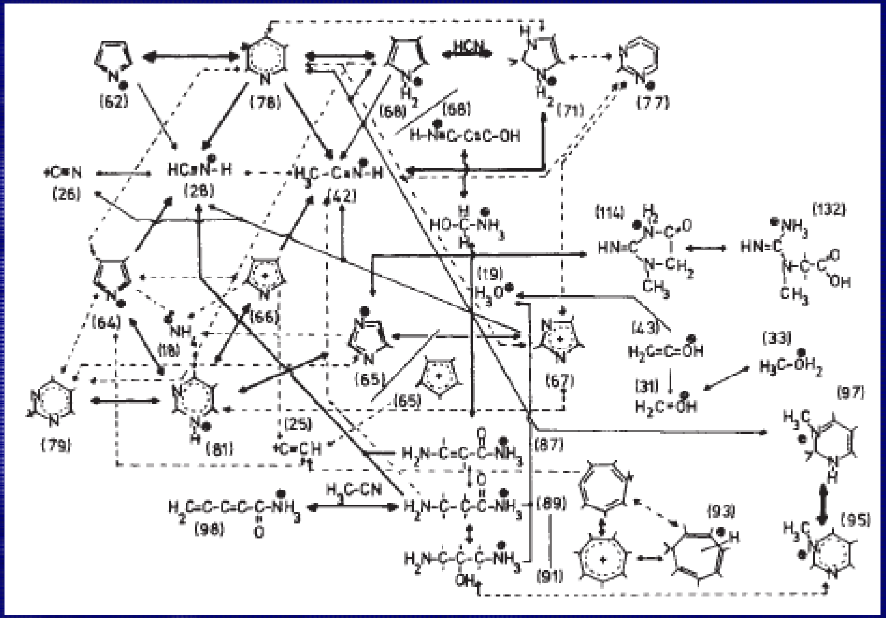
Nature :	Time of Flight (TOF)
Mass :	~9.5 kg
Volume :	~N/A
Power :	17 W
m/z range :	11-105
Sensitivity :	~ ppmv

(Kissel et al., 1986)

First cometary exploration (1986) : first step of EU in space exploration

Comets are really rich in organic materials !



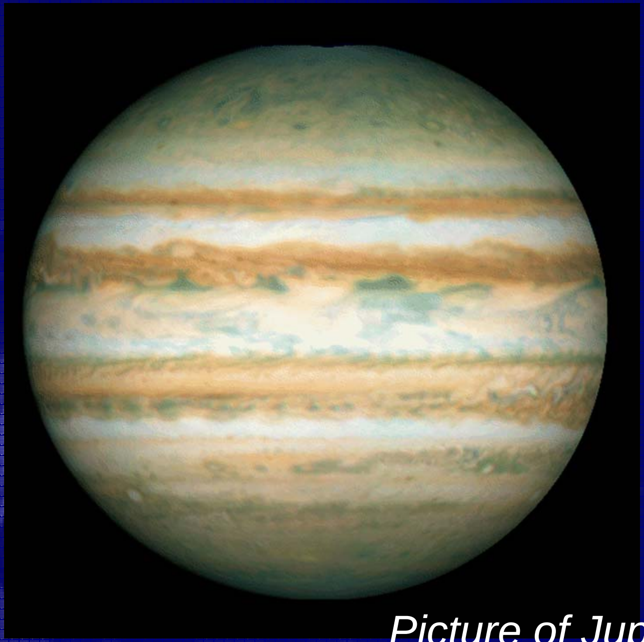


Mass spectrum recorded by PUMA-1 MS in-situ in the coma of comet P/Halley

Presence of complex solid organic compounds in the grains
BUT identification remains speculative

(Kissel et al., 1986)

Exploration of the Jupiter system with the Galileo mission (1995)



Picture of Jupiter

Interest of Jupiter :

1. Biggest gaseous giant
2. Solar system origin
3. System of satellites
4. Similarity with exoplanets

Artist view of the Galileo probe descent

Galileo probe & objectives :

1. Atmospheric probe (340 kg)
2. Composition of the upper atmosphere
3. Dynamics

Exploration of the Jupiter system with the Galileo mission (1995)

The GPMS experiment for the atmospheric composition analysis

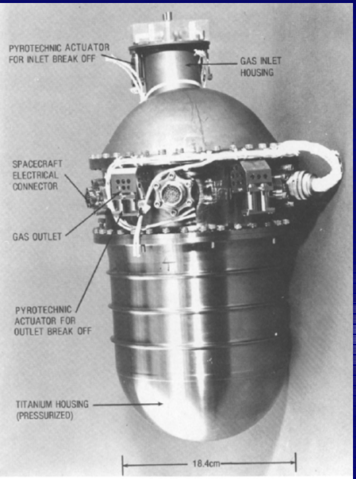
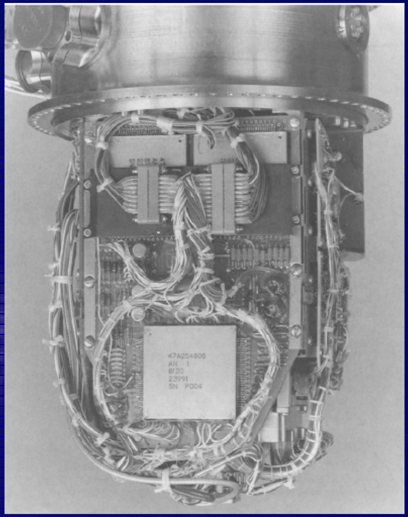
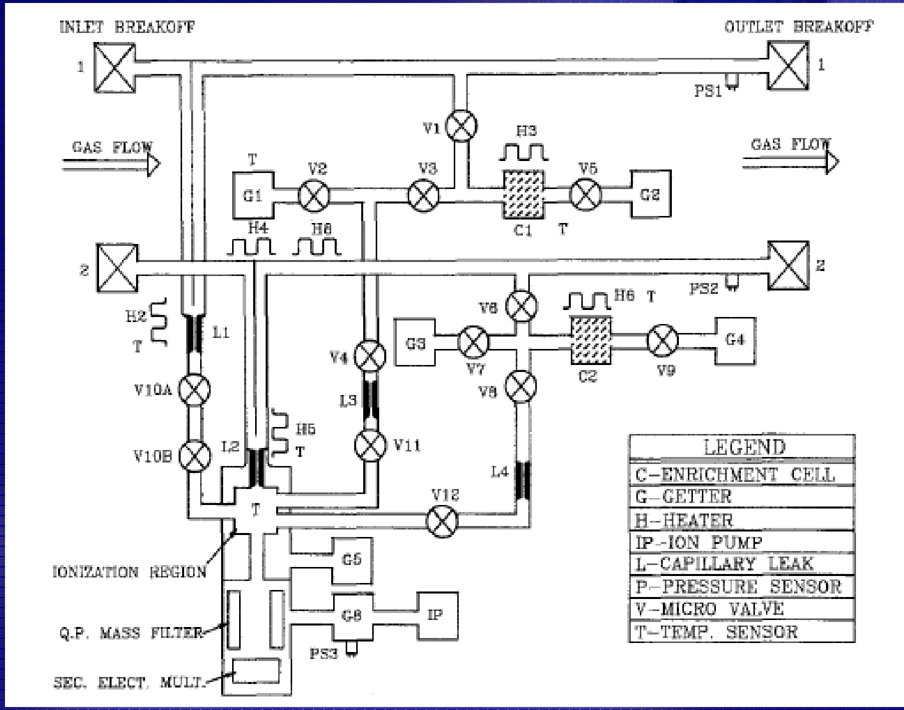


Fig. 8. Fully assembled Galileo Probe Mass Spectrometer.



Pictures of GPMS



Scheme of the GPMS

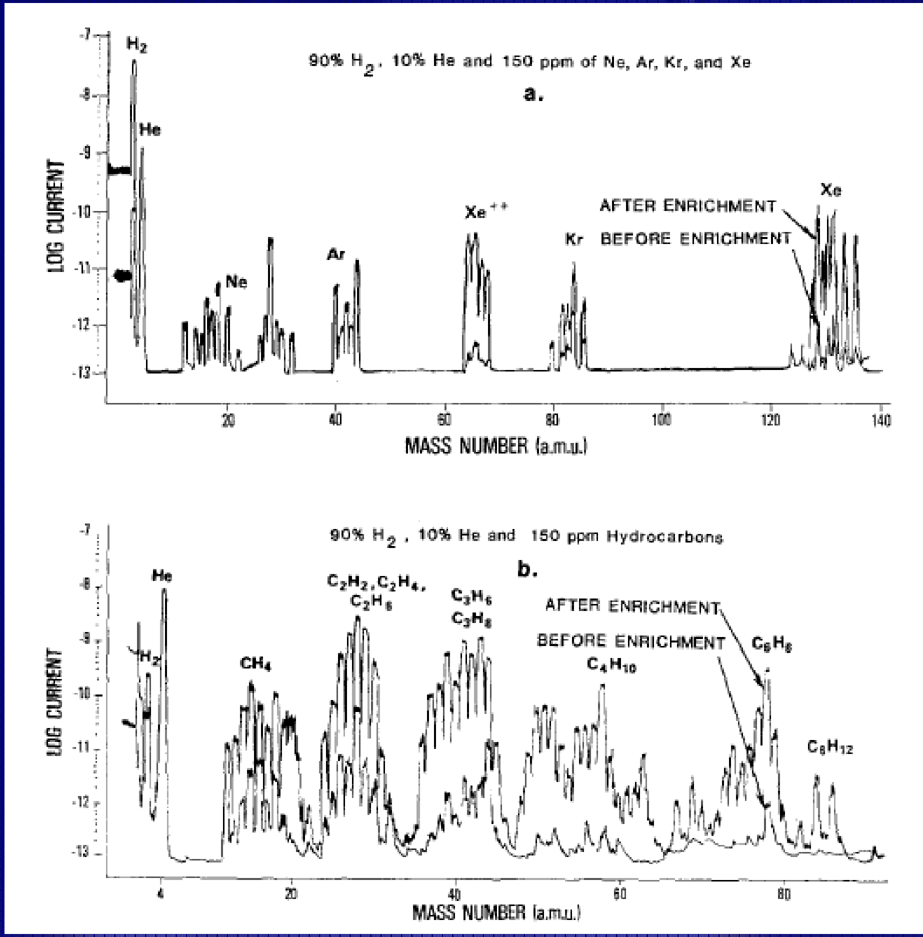
MS main specifications :

Nature :	Quadrupole
Mass :	~12 kg
Volume :	~ 3000 cm^3
Power :	26 W
m/z range :	2-150
Sensitivity :	N/A

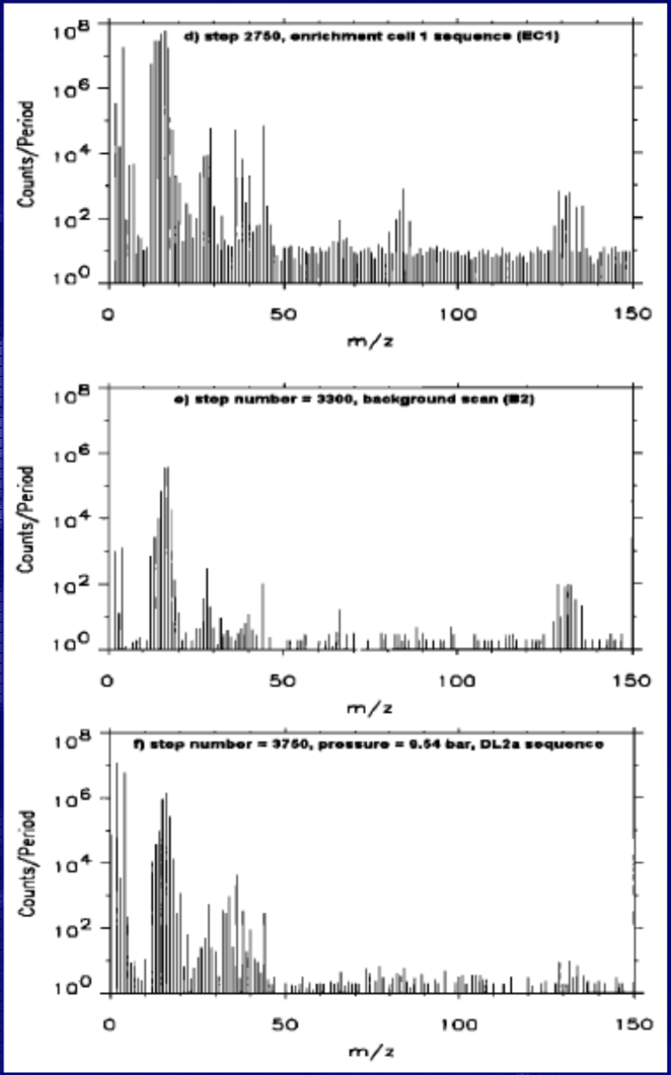
(Niemann et al., 1992)

Exploration of the Jupiter system with the Galileo mission (1995)

A view of the composition of the upper atmosphere



Calibration data before and after enrichement



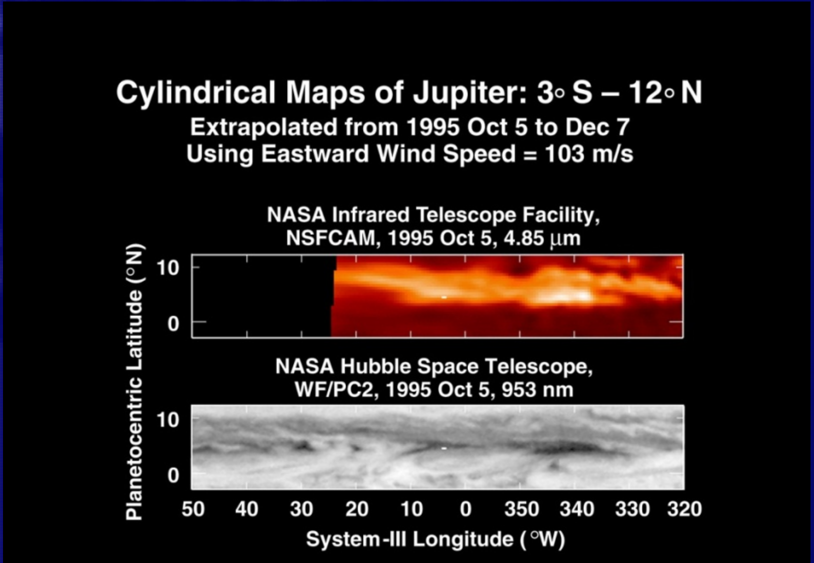
Measurements during the descent

(Niemann et al., 1998)

Exploration of the Jupiter system with the Galileo mission (1995)

Table 1. Measured Mixing Ratios or Isotope Ratios

Species or Ratio	Mixing Ratio f or Isotope Ratio	Mole Fraction q	Ratio to Solar
^{4}He	0.157 ± 0.030	0.136 ± 0.026	0.8
$^{3}He/^{4}He$	$(1.66 \pm 0.05) \times 10^{-4}$		
D/H	$(2.6 \pm 0.7) \times 10^{-5}$		
^{20}Ne	$\leq 3 \times 10^{-5}$	$\leq 2.6 \times 10^{-5}$	≤ 0.13
^{36}Ar	$\leq 10.5 \times 10^{-6}$	$\leq 9.06 \times 10^{-6}$	≤ 1.7
^{84}Kr	$\leq 3.7 \times 10^{-9}$	$\leq 3.2 \times 10^{-9}$	≤ 5
^{132}Xe	$\leq 4.5 \times 10^{-9}$	$\leq 3.8 \times 10^{-10}$	≤ 5
H_2O			
3.6 bars	$\leq 8 \times 10^{-7}$	$\leq 6.9 \times 10^{-7}$	$\leq 4.1 \times 10^{-4}$
12 bars	$\leq (5.6 \pm 2.5) \times 10^{-5}$	$\leq (4.8 \pm 2.1) \times 10^{-5}$	≤ 0.033
19 bars	$\leq (6 \pm 3) \times 10^{-4}$	$\leq (5.2 \pm 2.6) \times 10^{-4}$	≤ 0.35
CH_4	$(2.10 \pm 0.4) \times 10^{-3}$	$(1.81 \pm 0.34) \times 10^{-3}$	2.9
$^{13}C/^{12}C$	0.0108 ± 0.0005		
NH_3 (>15 bars)	$\leq 2.3 \times 10^{-3}$	$\leq 2 \times 10^{-3}$	≤ 10
H_2S			
3.6 bars	$< 10^{-6}$	$< 8.6 \times 10^{-7}$	< 0.03
8.7 bars	7×10^{-6}	6.1×10^{-6}	0.23
>16 bars	$(7.7 \pm 0.5) \times 10^{-5}$	6.7×10^{-5}	2.5
PH_3 (>16 bar)	$\leq 6 \times 10^{-6}$	$\leq 5.2 \times 10^{-6}$	≤ 8
Cl	detected		



(Niemann et al., 1998)

But measurement not representative of the main atmospheric component

Exploration of the Saturn system with the Cassini-Huygens mission (2005)

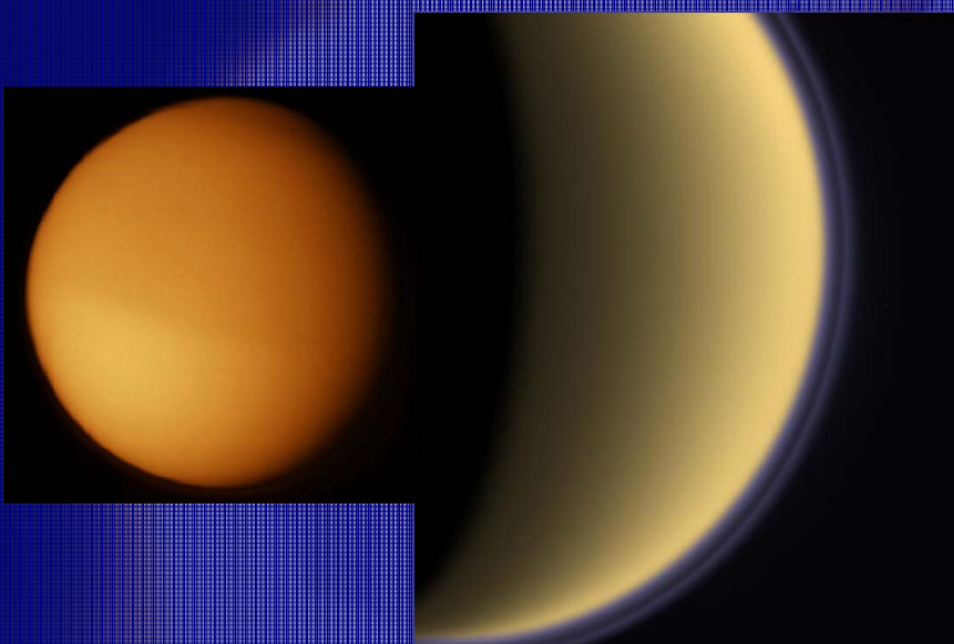
<u>Interest of Saturn :</u>

1. Biggest gaseous giant
2. Solar system origin
3. System of satellites
4. System of rings
5. Similarity with exoplanets

A view of the Saturn system

<u>Interest of Titan :</u>

1. Dense atmosphere
2. Organic chemistry
3. Liquid areas at the surface



Titan as seen by the Voyager and Cassini probes

Exploration of the Saturn system with the Cassini-Huygens mission (2005)

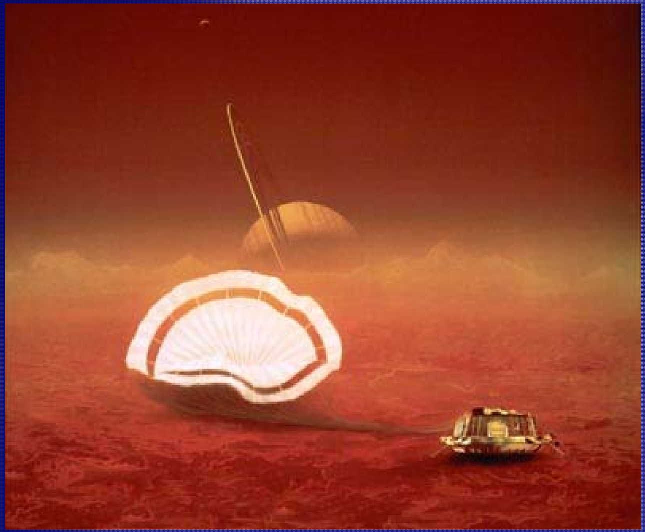
Cassini Saturn probe :

1. Orbital probe
2. Saturn system exploration
3. Titan fly-bys
4. Saturn environment characterisation

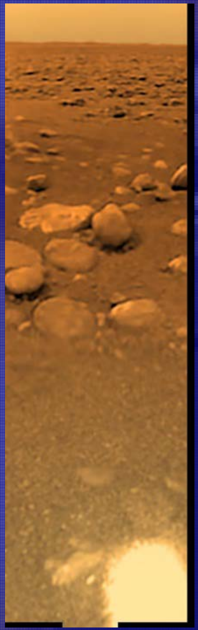
The Cassini spacecraft in a vacuum chamber

Huygens Titan probe :

1. Atmospheric probe
2. Atmospheric properties
3. Surface characterisation



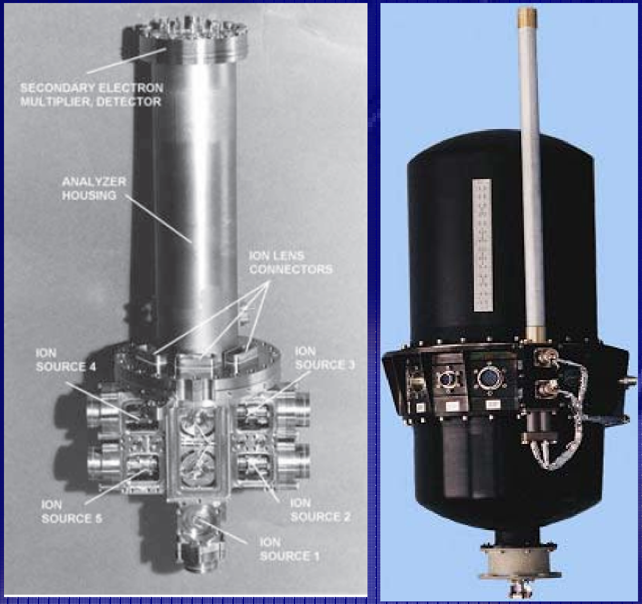
Artist view of the Huygens landing



Picture of the Titan's surface by the Huygens probe

The Cassini-Huygens mission (2005)
Unveiling Titan

The GCMS experiment onboard the Huygens probe :

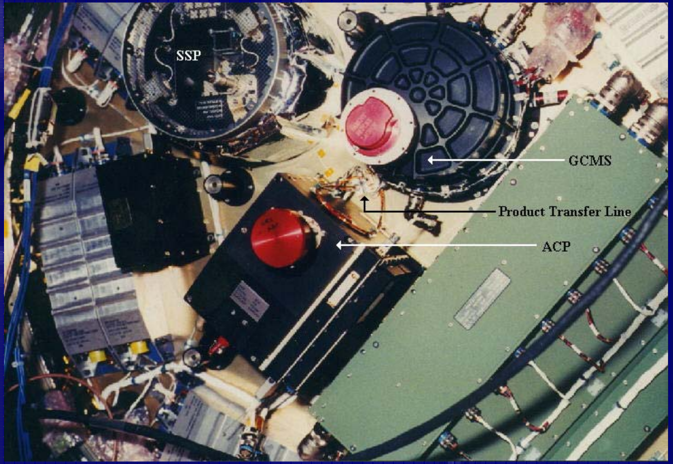


The GCMS experiment and its quadrupolar filter

MS main specifications :

Nature :	Quadrupole
Mass :	~17 kg
Volume :	~20 cm ∅×47 cm H
Power :	41 W
m/z range :	2-141
Sensitivity :	~10 ppbv

Couple with the Aerosol Collector and Pyrolyzer experiment for the analysis of the aerosols composition

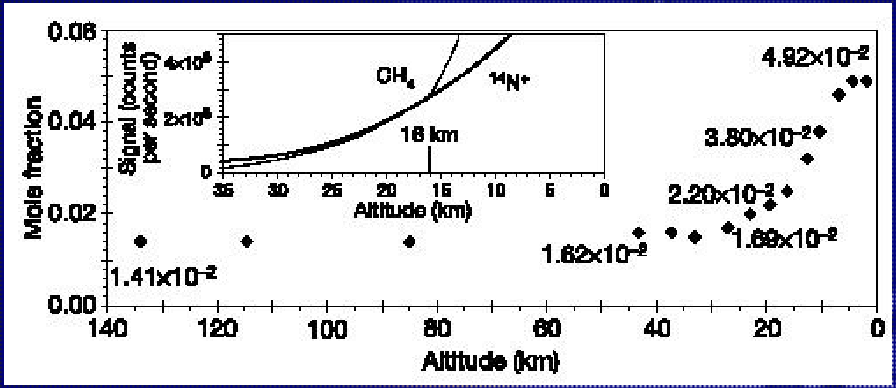


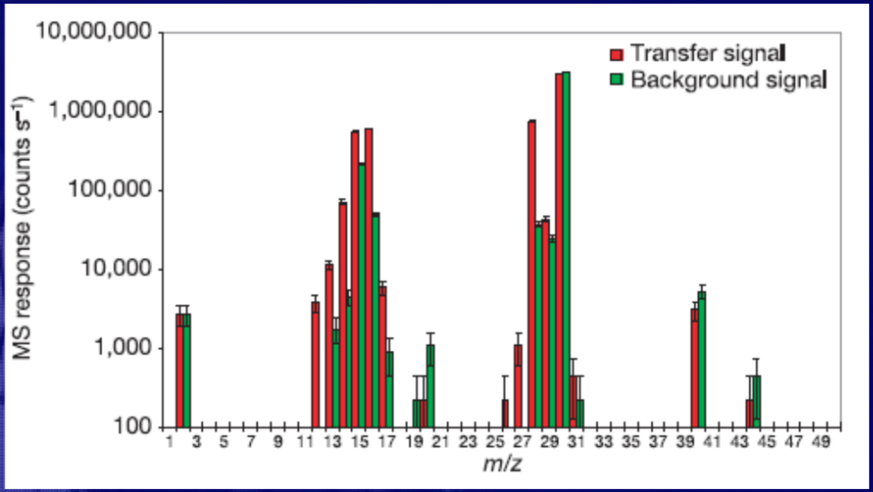
The GCMS experiment coupled with the ACP experiment in the Huygens probe

(Niemann et al., 1998)

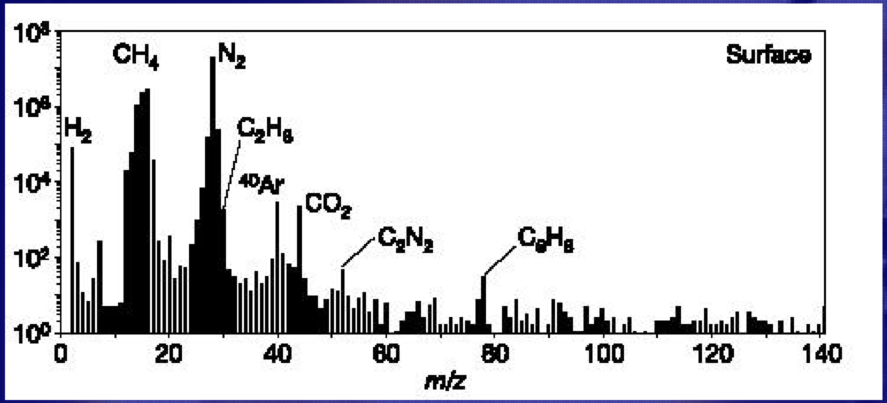
The Cassini-Huygens mission (2005)
Unveiling Titan

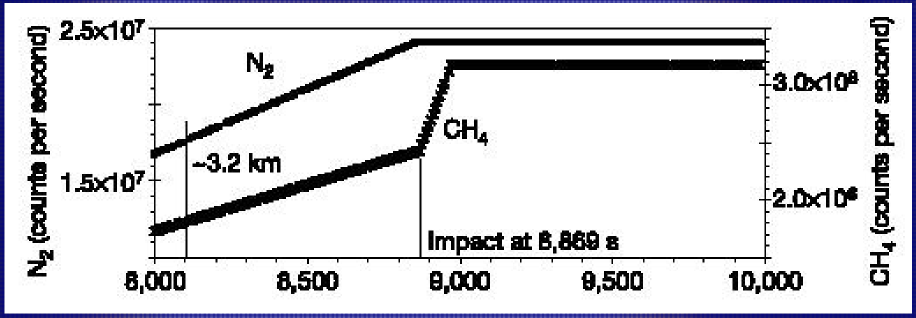
A new idea of the Huygens atmosphere and surface :

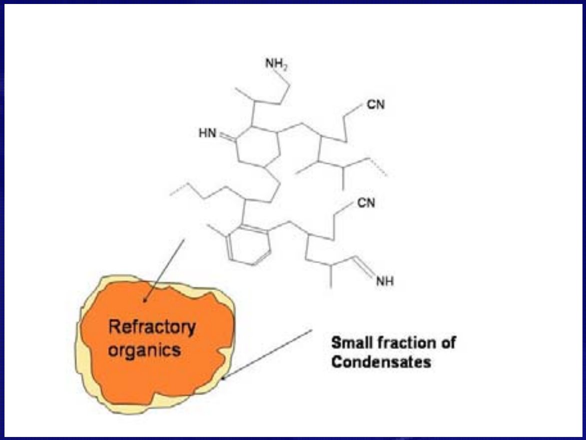




Aerosols pyrolysates (from ACP) analysis



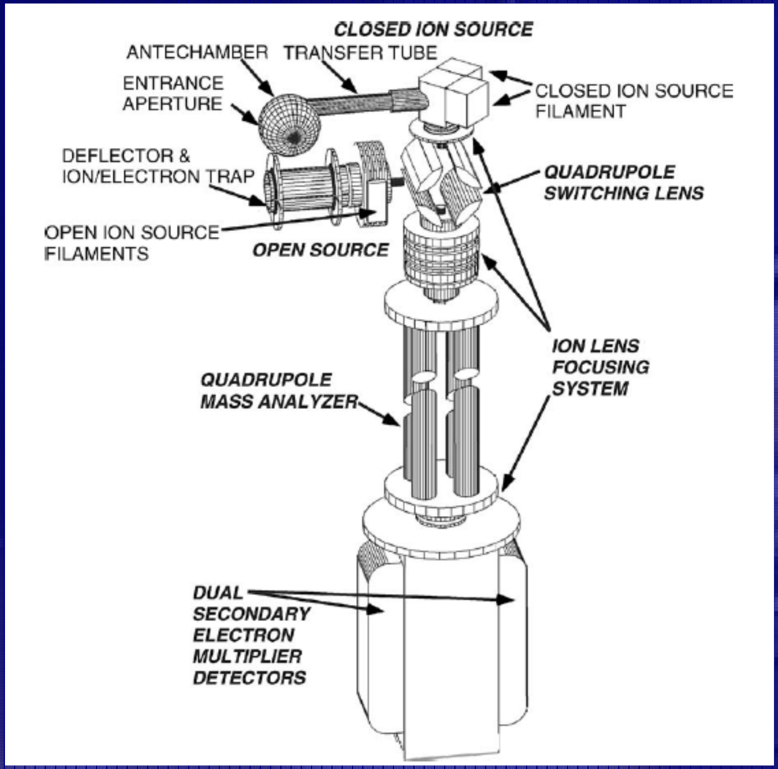




(Niemann et al., 2005; Israel et al., 2005)

The Cassini-Huygens mission (2005) : What is there in the Saturn suburbs ?

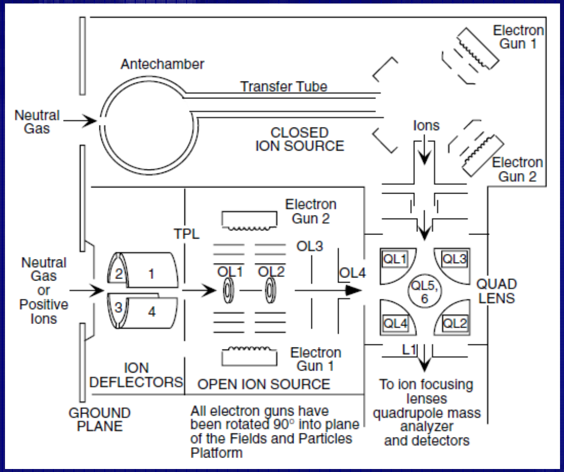
The INMS experiment onboard the Cassini probe :



INMS experiment schemes

MS main specifications :

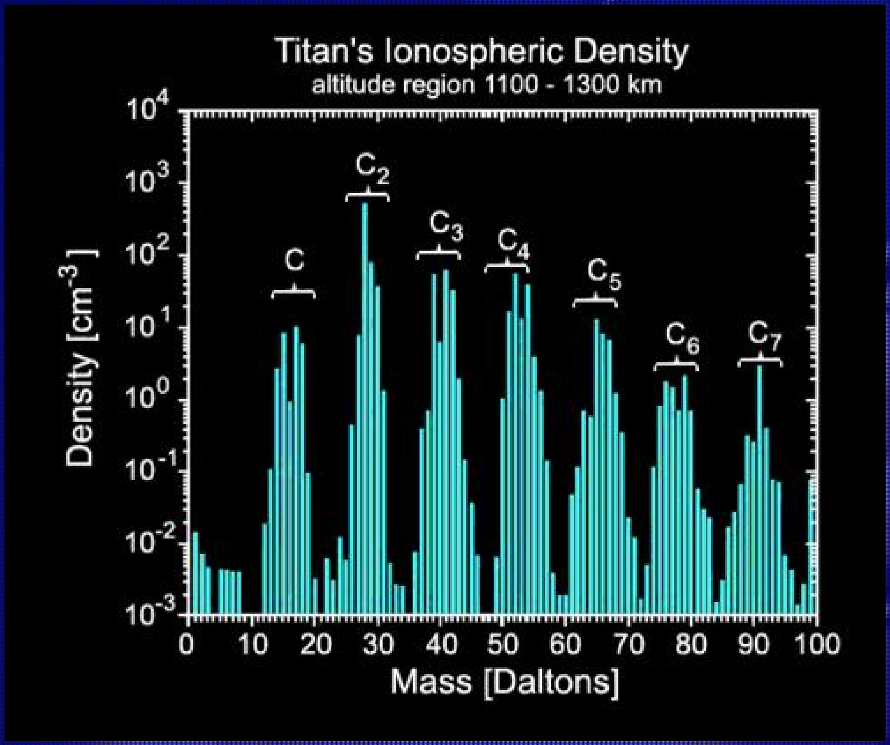
Nature :	Quadrupole
Mass :	~11 kg
Volume :	~30 L
Power :	23 W
m/z range :	1-99
Sensitivity :	N/A



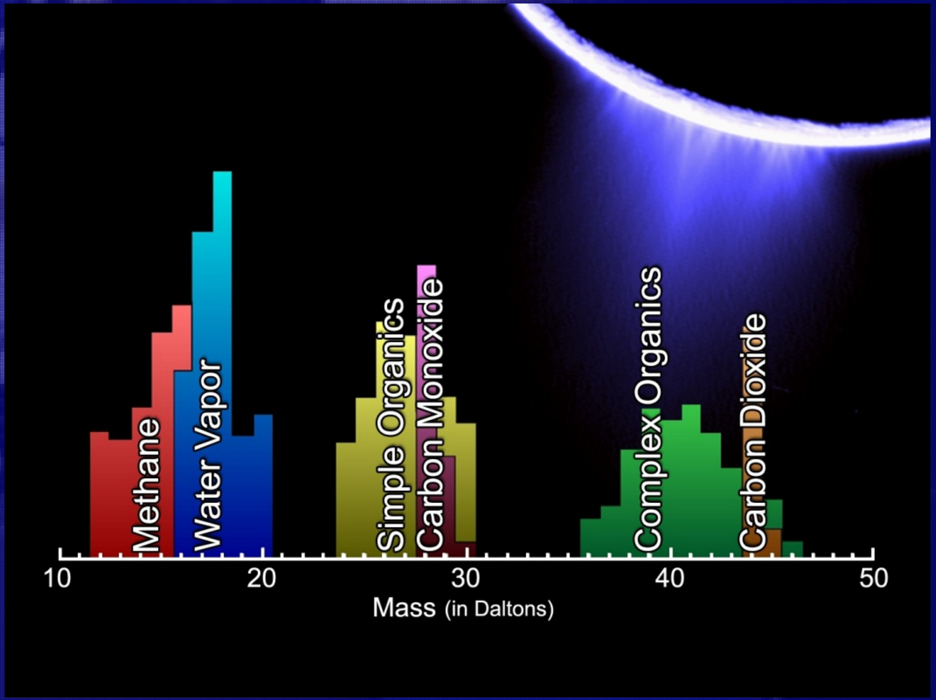
(Waite et al., 1998)

The Cassini-Huygens mission (2005)
What is there in the Saturn suburbs ?

My system is rich !



INMS analysis done in the Titan upper atmosphere



INMS analysis done in the Enceladus plumes

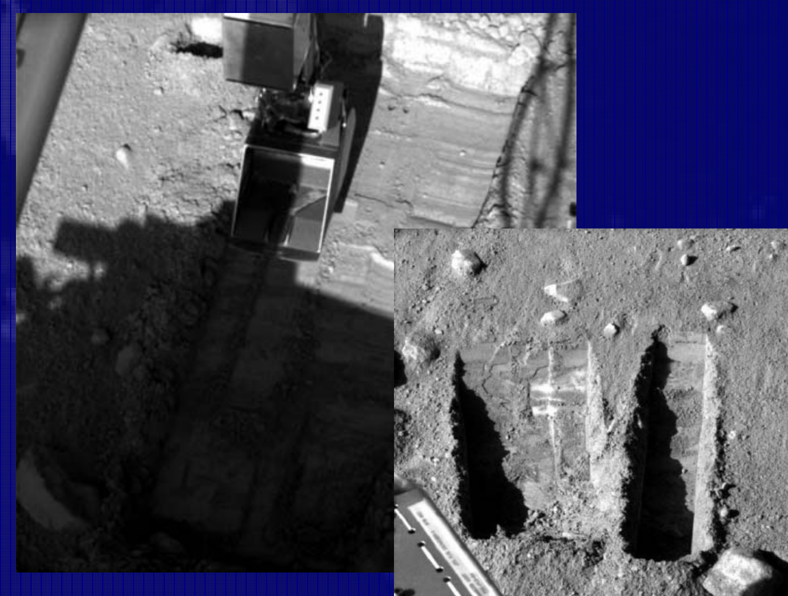
(Waite et al., 2005)

Return to Mars : The Phoenix Mars polar probe and the search for water and minerals (2007)

Phoenix probe & objectives :

1. Lander ()
2. Water at the pole
3. Mineralogy
4. Environment

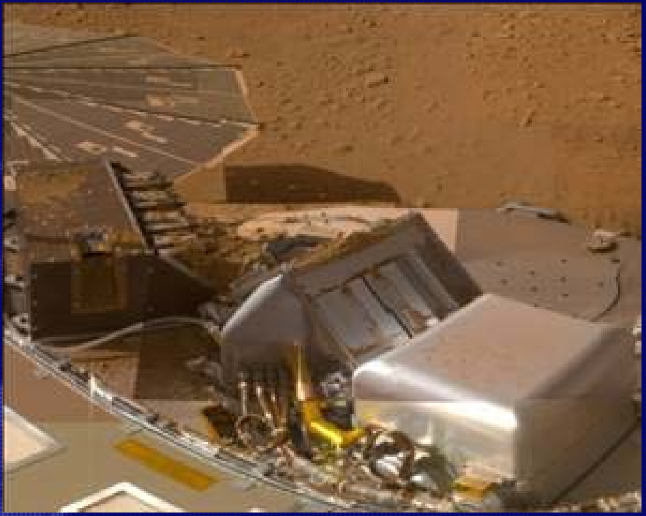
Artist view of Phoenix



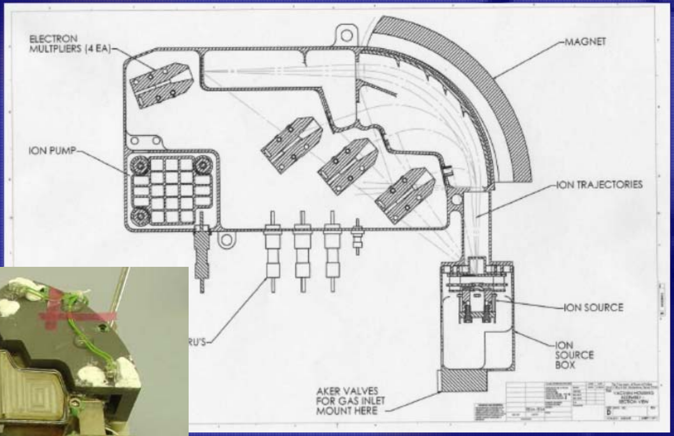
Pictures of Phoenix on Mars

The Phoenix mission and the search for water and mineralogy

<u>The TEGA experiment to analyse the atmosphere and the content of the soil (calorimeter+evolved gas analyzer)</u>



Picture of TEGA on Phoenix



Picture and scheme of the TEGA mass spectrometer

<u>MS main specifications :</u>

Nature :	Sector (B)
Mass :	~6 kg
Volume :	~20 cm^3
Power :	13 W
m/z range :	1-140
Sensitivity :	10-100 ppbv

The Phoenix mission and the search for water and mineralogy

TEGA found CO_2 in the atmosphere and limestone in the soil

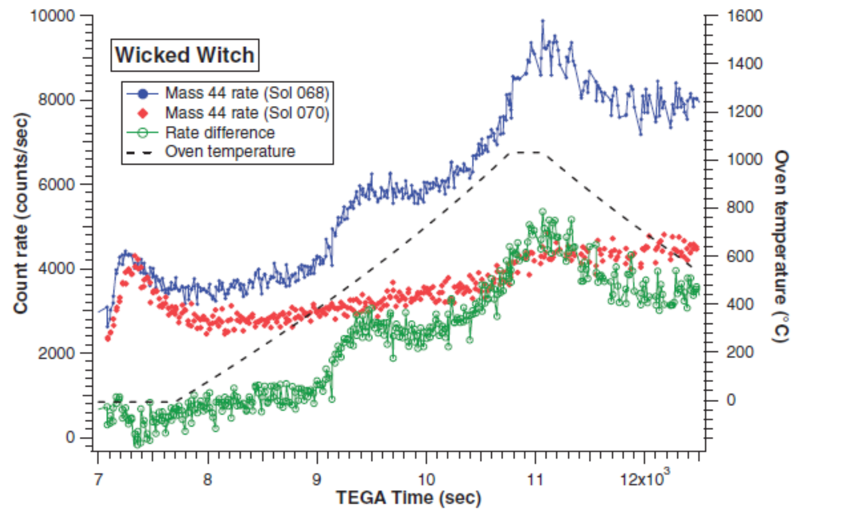
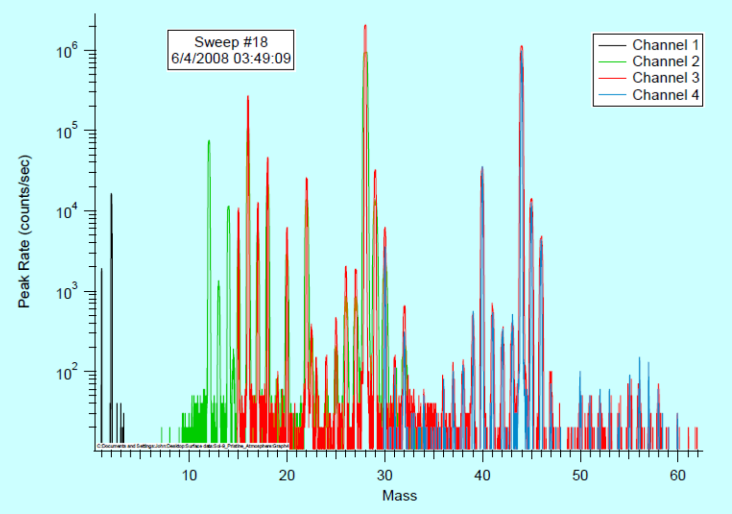


Fig. 2. Plot of Mass 44 (CO_2) count rate and temperature versus run time. The first peak is atmospheric CO_2 that diffuses into the oven and plumbing overnight; the second may be due to carbonates with a low decomposition temperature (e.g., $FeCO_3$ or $MgCO_3$). The high temperature peak is due to decomposition of $CaCO_3$.

Detection of carbonates by following the CO_2 outgassing during the pyrolysis (Boynton et al., 2009)



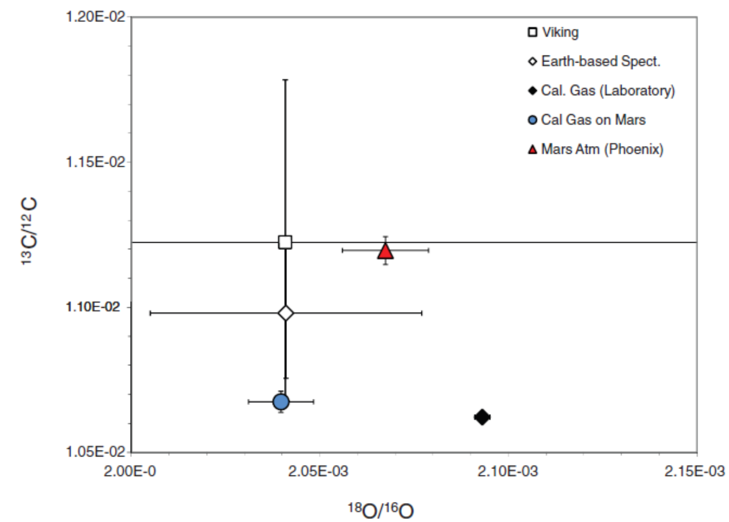


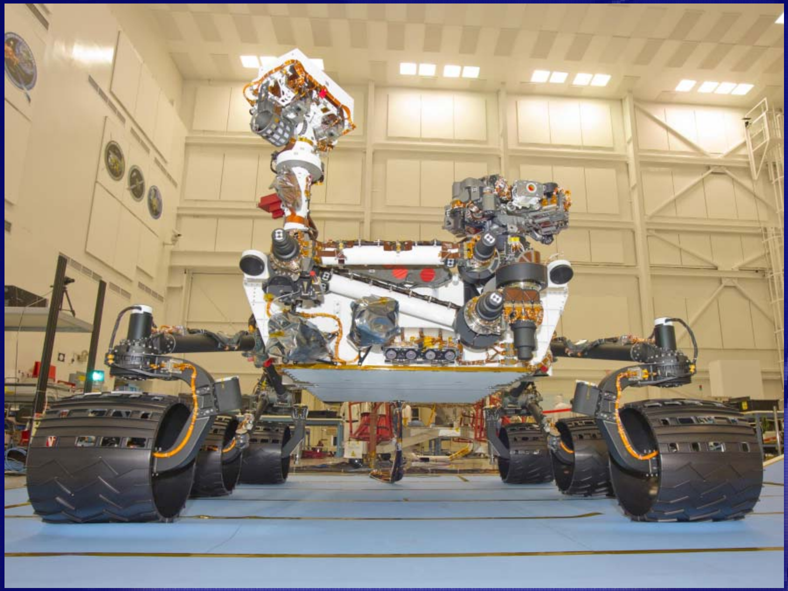
Fig. 2. Corrected and calibrated results of martian atmospheric CO_2 measurement plotted next to results from Viking lander (*28*, *29*), Earth-based spectroscopy (*2*), and measurements of calibration gas on Earth and Mars. The result for calibration gas on Mars is the uncalibrated value to show the magnitude of the calibration correction. Error bars on TEGA measurements are 2σ SE.

A new measurement of the CO_2 isotopic ratios in the atmosphere

(Niles et al., 2010)

Assessing the Mars habitability with the Mars Science Laboratory mission (2012 NOW !!)

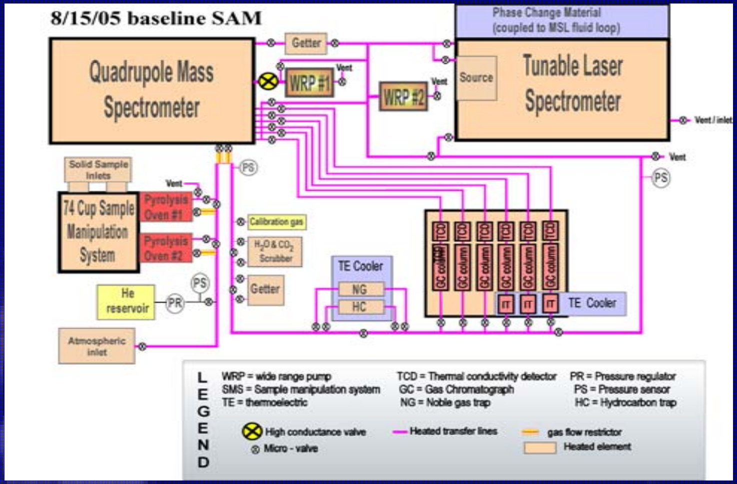
Curiosity : a monster rover in an ancient wet crater



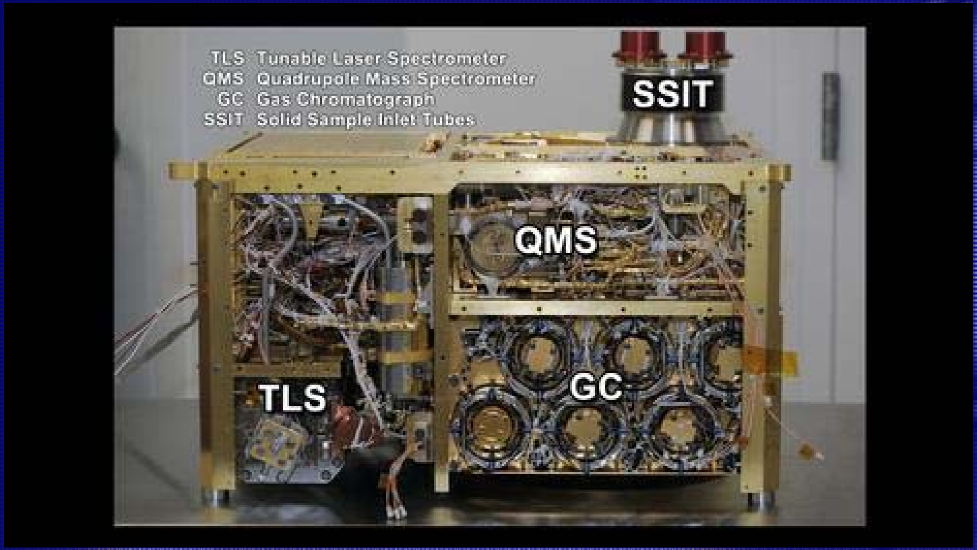
The Mars Science Laboratory mission (2012 NOW !!)

The Sample Analysis at Mars (SAM) experiment or the Curiosity “swiss knife” :

1. Atmosphere (CH_4)
2. Mineralogy (EGA)
3. Organics in the soil

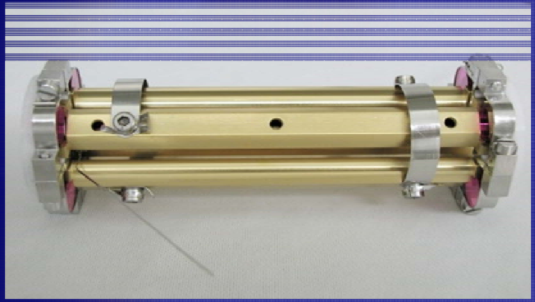


Principle scheme of SAM *(Mahaffy et al., in press)*



SAM main specifications :

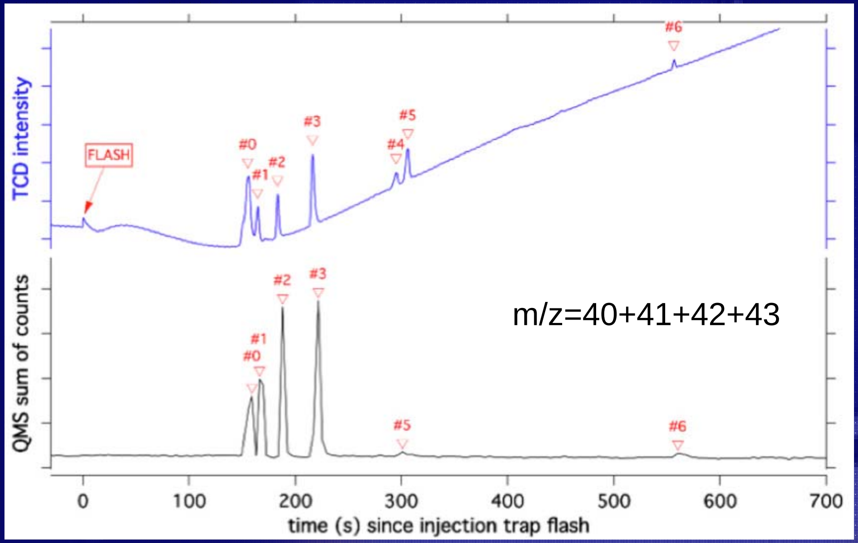
Nature :	Quadrupole
Mass :	~30 kg
Volume :	~45 L
Power :	50 W
m/z range :	2-450
Sensitivity :	1 ppbv

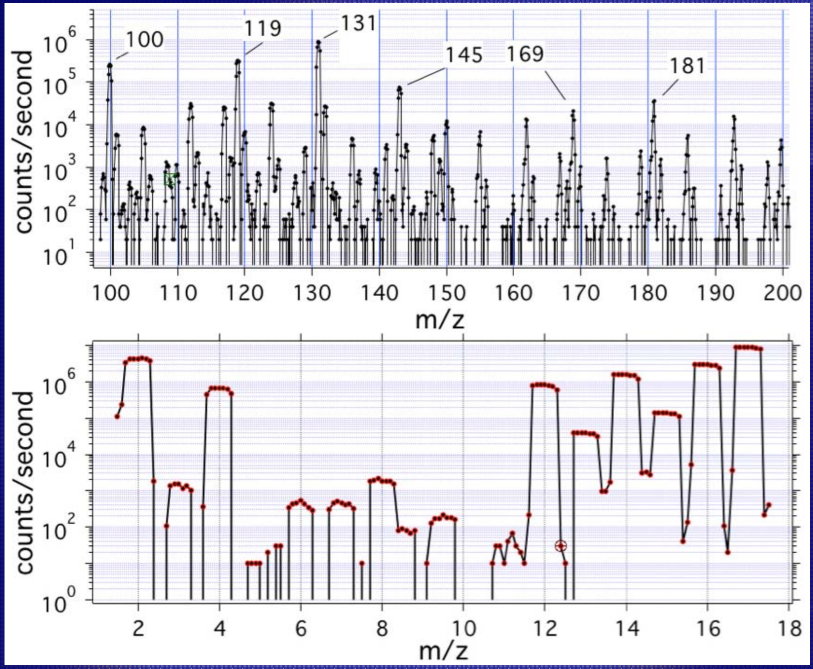


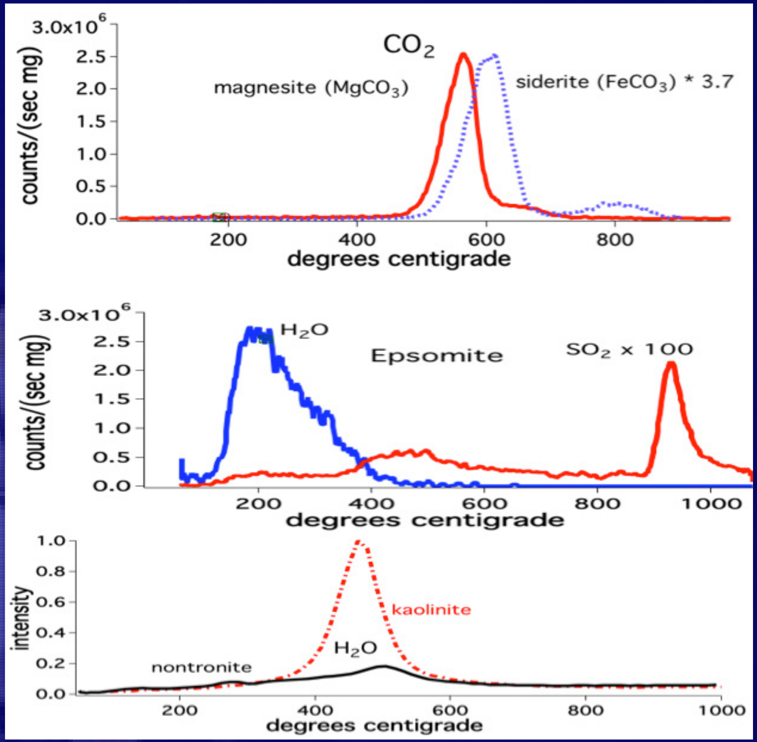
Pictures of SAM and the quadrupolar filter

The Mars Science Laboratory mission (2012 NOW !!)

How SAM will assess the Mars habitability ?





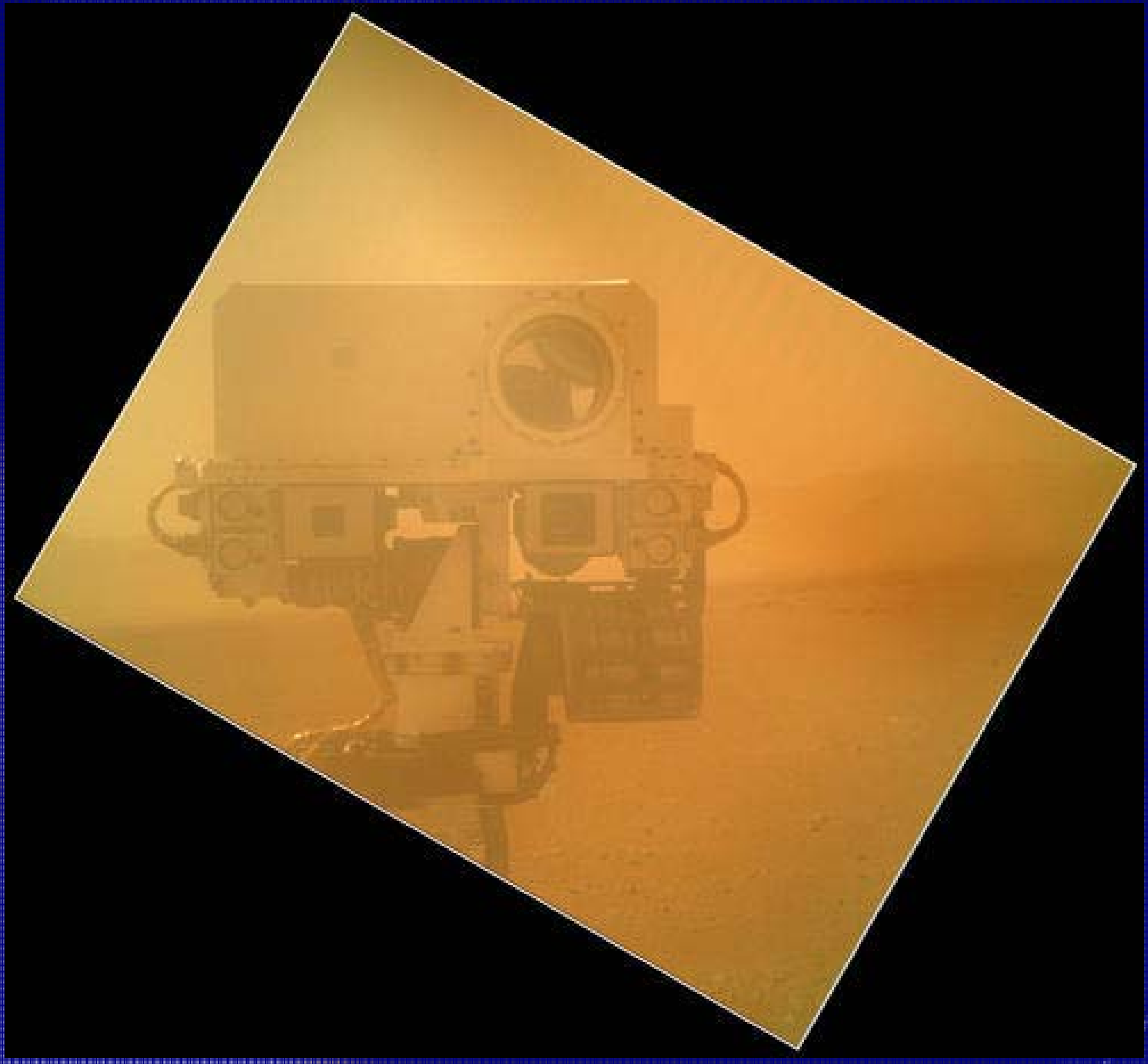


Mineralogical measurements *(Mahaffy et al., in press)*

Look for organics in the atmosphere and in the soil

(Mahaffy et al., in press)

AND TOMORROW ?



The Rosetta mission to a comet (2014): Tomorrow is today !

<u>Objectives :</u>

1. Properties of a cometary nucleus
2. Evolution of the cometary environment with time

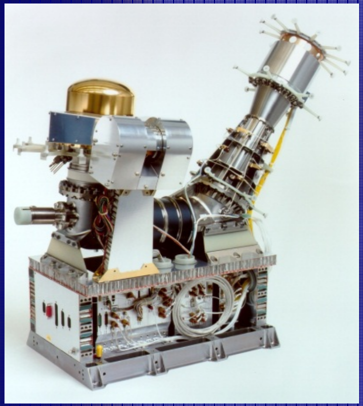
Mass spectrometry in Rosetta

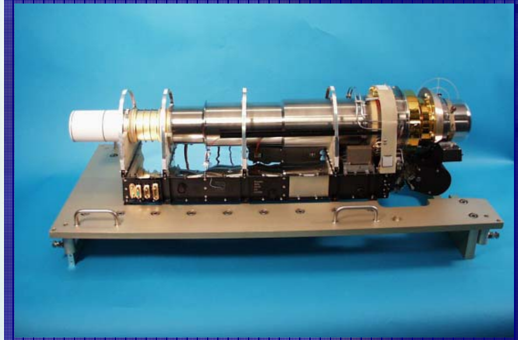
4 experiments based on mass spectrometry

2 in the orbiter

COSIMA : composition of dust grains in the coma

ROSINA : composition of neutral and ion species in the coma

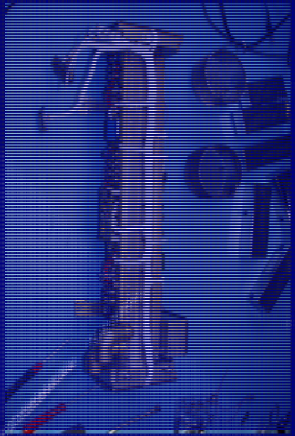




2 in Philae

MODULUS : isotopic composition of the nucleus solid material

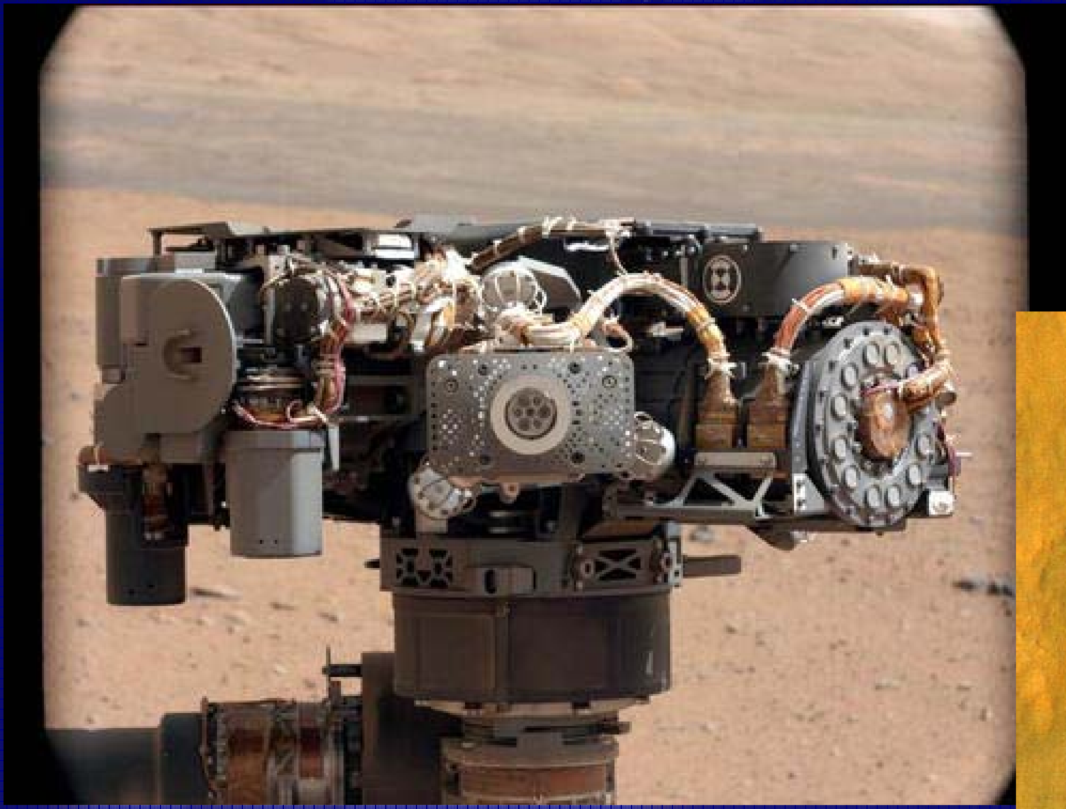
COSAC : molecular composition of the nucleus solid material

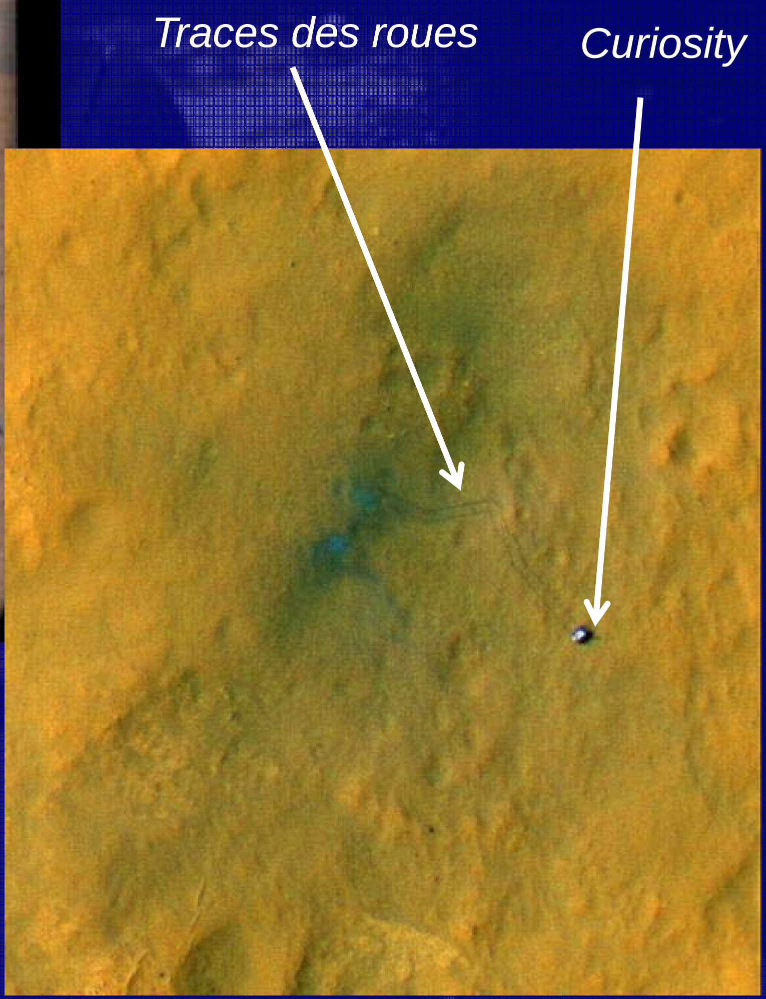


Mass spectrometry in Rosetta

MS name	Sample nature	MS Type	Mass (kg) Size (mm)	Power (W)	m/z range	Resolution
COSIMA	Grains in the coma	TOF		20	1-1300	2000 / 50%
ROSINA	Gas in the coma	DFMS	16.2 630×630×260	19	12-150	3000 / 1%
		TOF	14.7 1140×380×240	24	1-350	>500 / 1%
COSAC	Nucleus surface material	TOF	1.5 460×80×80	15	1-1500	350 / 50%
PTOLEMY	Nucleus surface material	IT	0.5 80×100×55	10	12-150	

AND THE DAYS AFTER ?





How can we improve MS for space exploration ?

1. MS resolution :

Very high resolution to help the species identification

↳ Orbitrap or FTICR in space ?

Orbitrap core

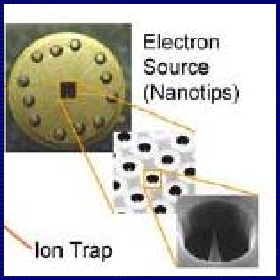
2. Improve the vacuum :

More efficient pumping systems (HRMS, hyphenated techniques…)

3. Ionisation sources :

Less resources (mass, power) consuming sources

↳ nanotips ion sources… ?

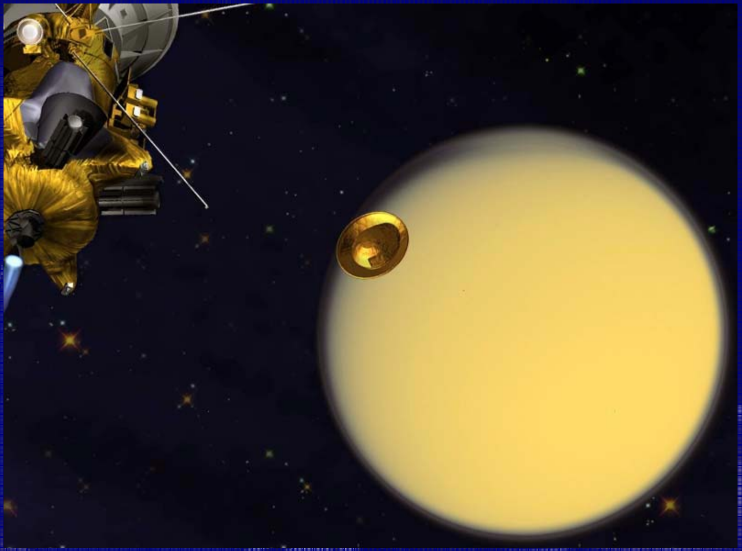


Ion source of the Ptolemy experiment

4. Sensitivity :

Improve the sensitivity

↳ Integration processes, detectors… ?



THANK YOU


ФЕДЕРАЛЬНОЕ КОСМИЧЕСКОЕ АГЕНТСТВО
ФГУП "НПО им. С.А. Лавочкина"
РОССИЙСКАЯ АКАДЕМИЯ НАУК
ИКИ РАН
ИКИ
МЕЖДУНАРОДНЫЙ ПРОЕКТ
«ФОБОС-ГРУНТ»


BACKUP

ROSINA

Rosetta Orbiter Spectrometer for Ion and Neutral Analysis

Principal Investigator : H. Balsiger, Univ. Bern, Sw.

Objectives : determine, the elemental, isotopic and molecular composition of the coma

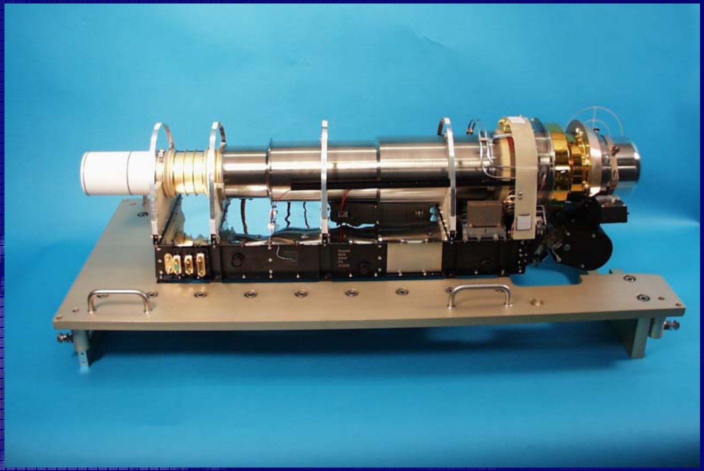
Samples : neutral and ionized gases present in the coma

Method : Double Focusing Mass Spectrometer (DFMS) and Time of Flight (TOF)

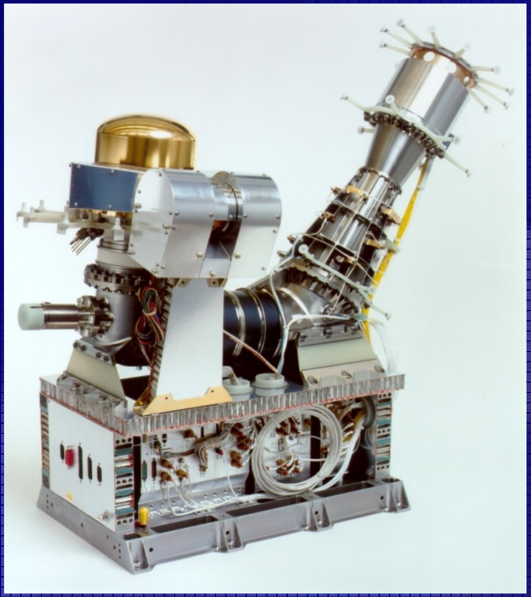
Location : in the Rosetta orbiter

ROSINA
General description

3 instruments in 1 experiment : DFMS (double focusing magnetic mass spectrometer), RTOF (reflectron TOF), COPS (pressure sensor)

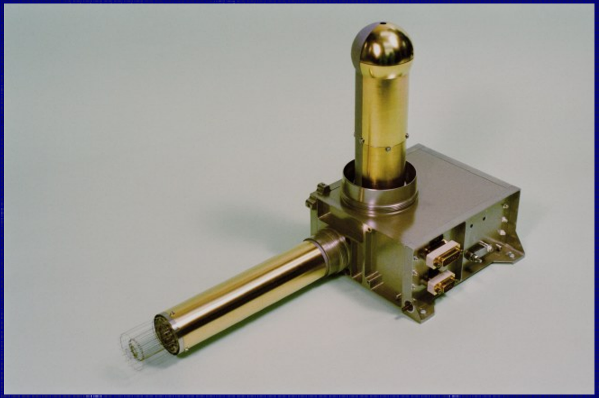


RTOF



DFMS

COPS

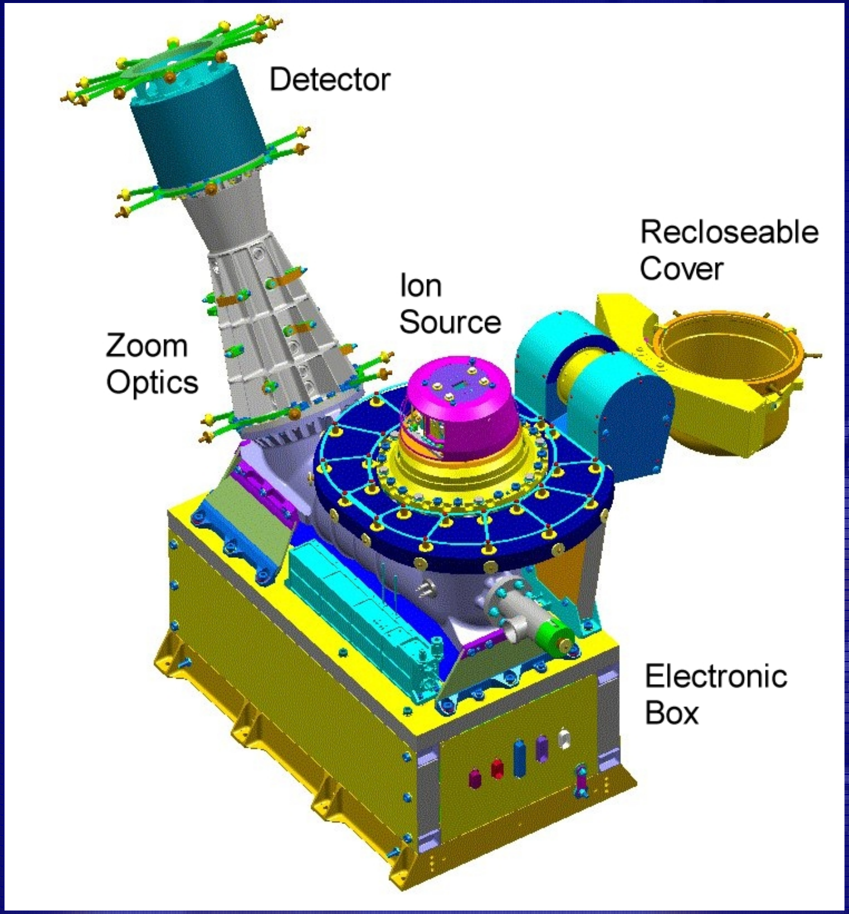


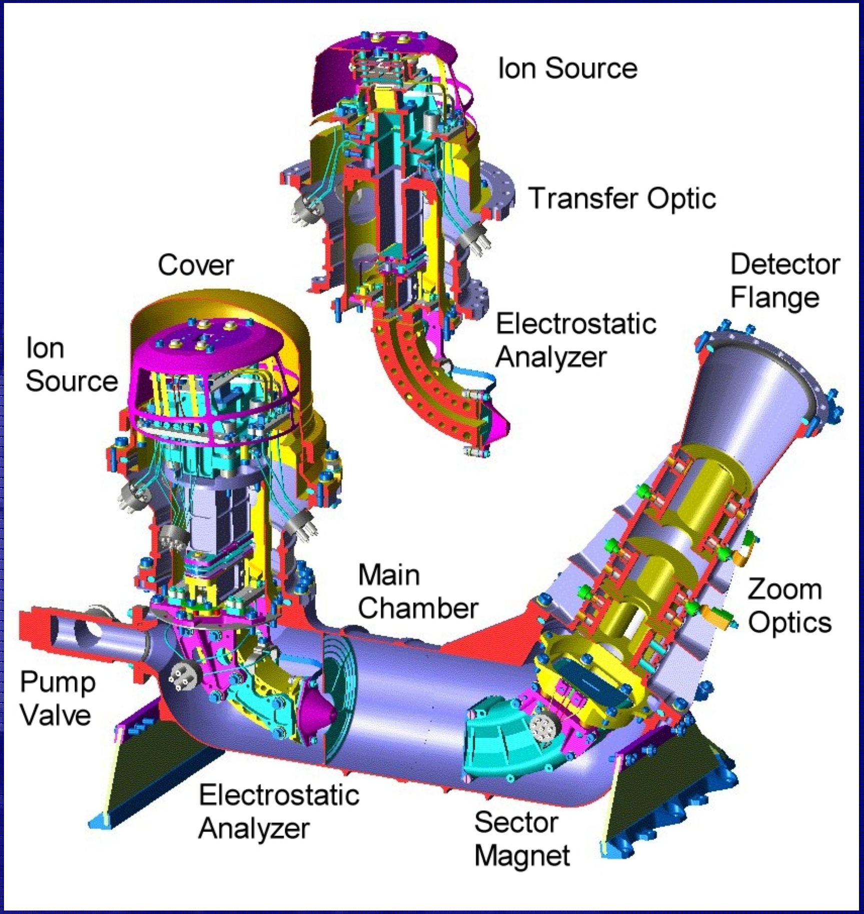
Instrument characteristics :

Mass=34.8 kg

Mean power consumption : 49 W

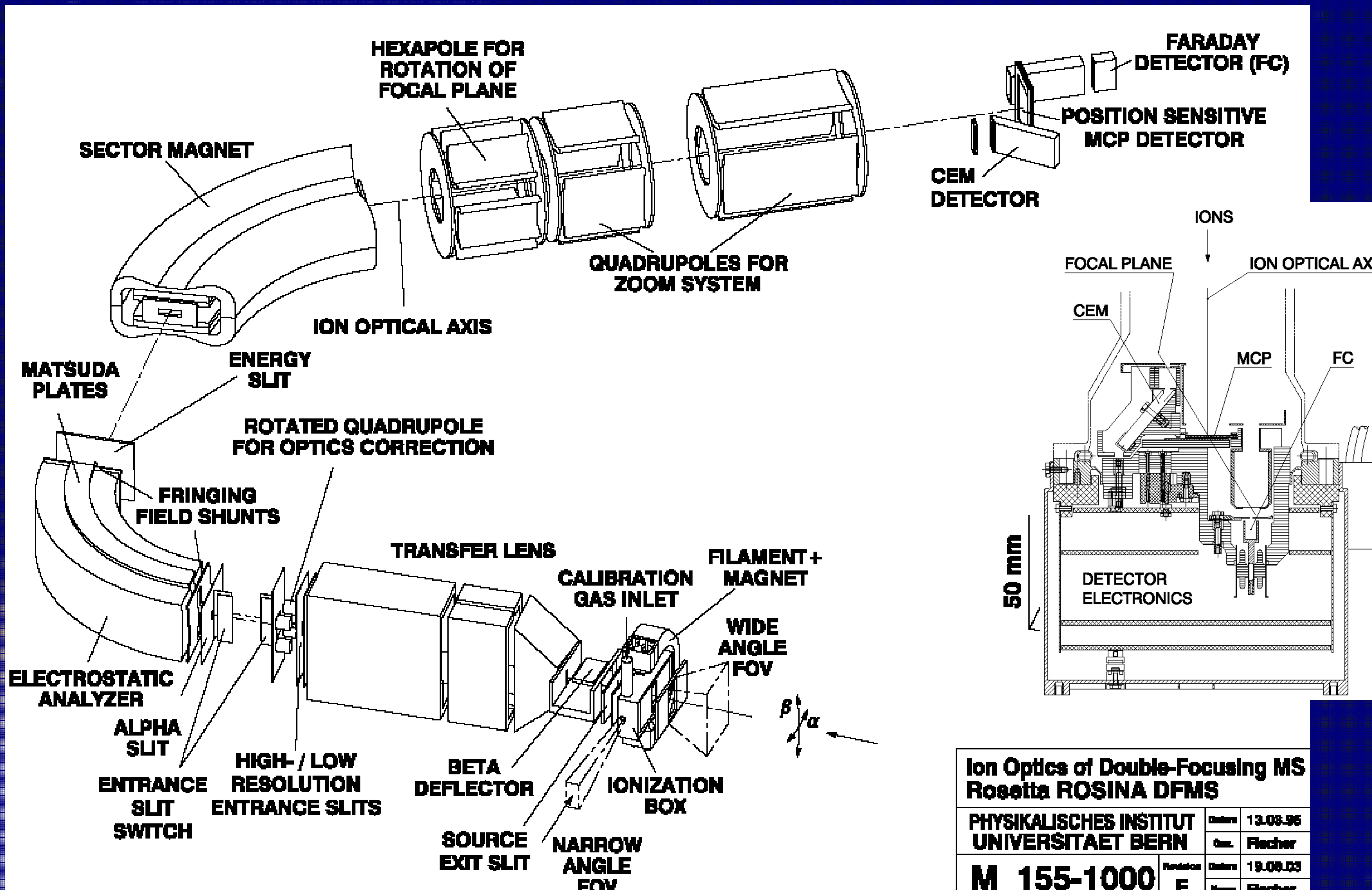
ROSINA Mass spectrometers
DFMS





- Mattauch-Herzog design
- Ions and neutral gas analyzer (2 modes)
- Ion source=e- provided by thermal effect and generated with filaments (E(e-)=10-90 eV)

ROSINA Mass spectrometers DFMS



ROSINA Mass spectrometers DFMS

Mass spectrometers characteristics :

Type : DFMS

Dimensions : 630×630×260 mm/Mass : 16.2 kg

Range : 12-150 Da

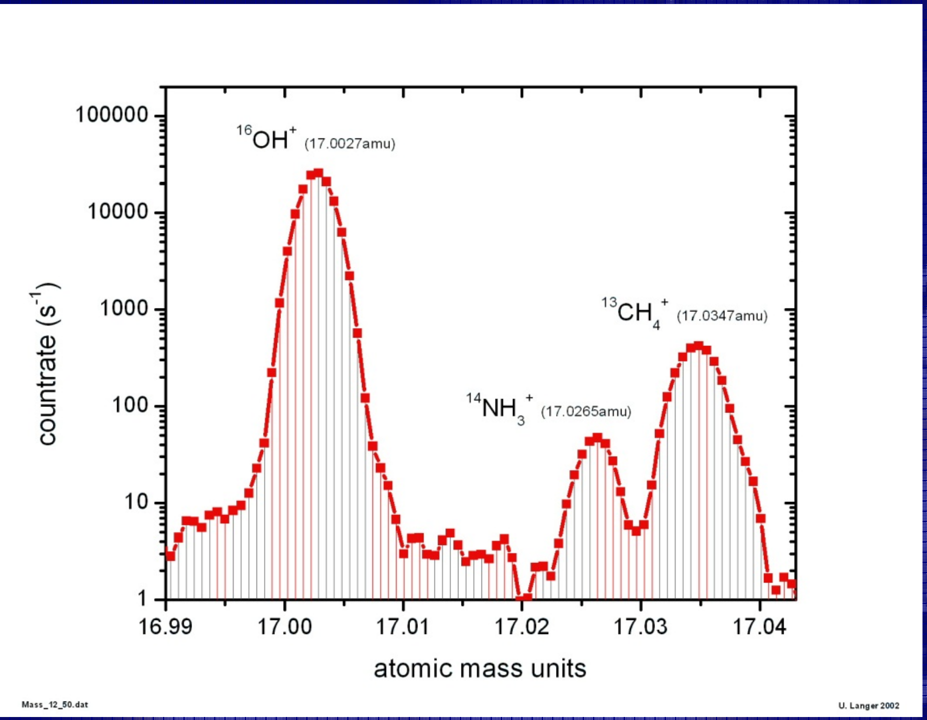
Resolution : m/Δm=3000 @ 1%

Power consumption : 19 W

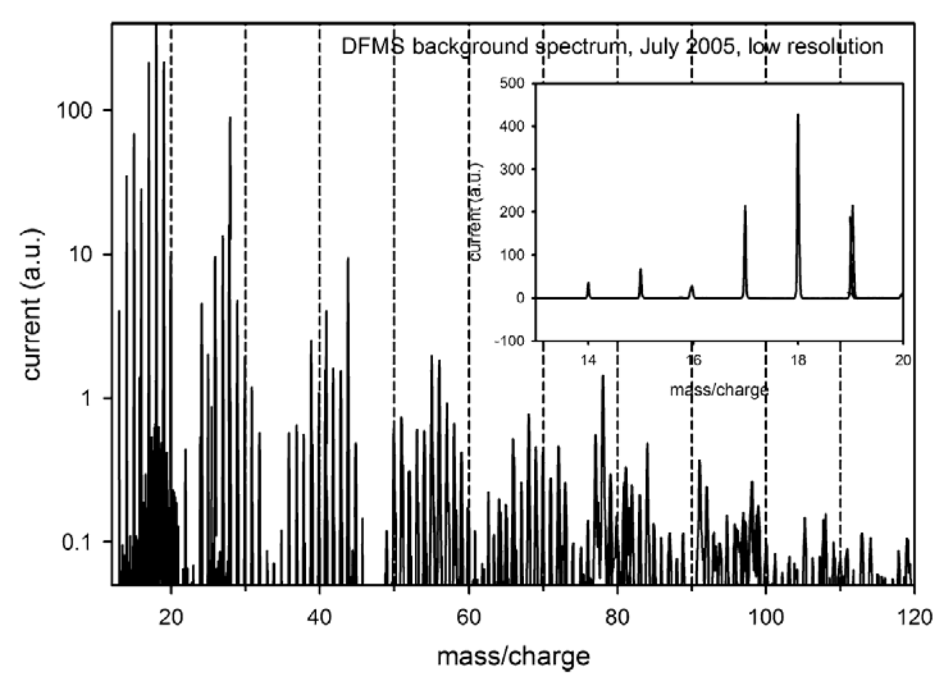
Source=e- provided by thermal effect and generated with filaments (E(e-)=10-90 eV)

Detector=Microchannel plates (MCPs)+Channel Electron Multiplier (CEM)+Faraday Cup (FC)

ROSINA Mass spectrometers
DFMS

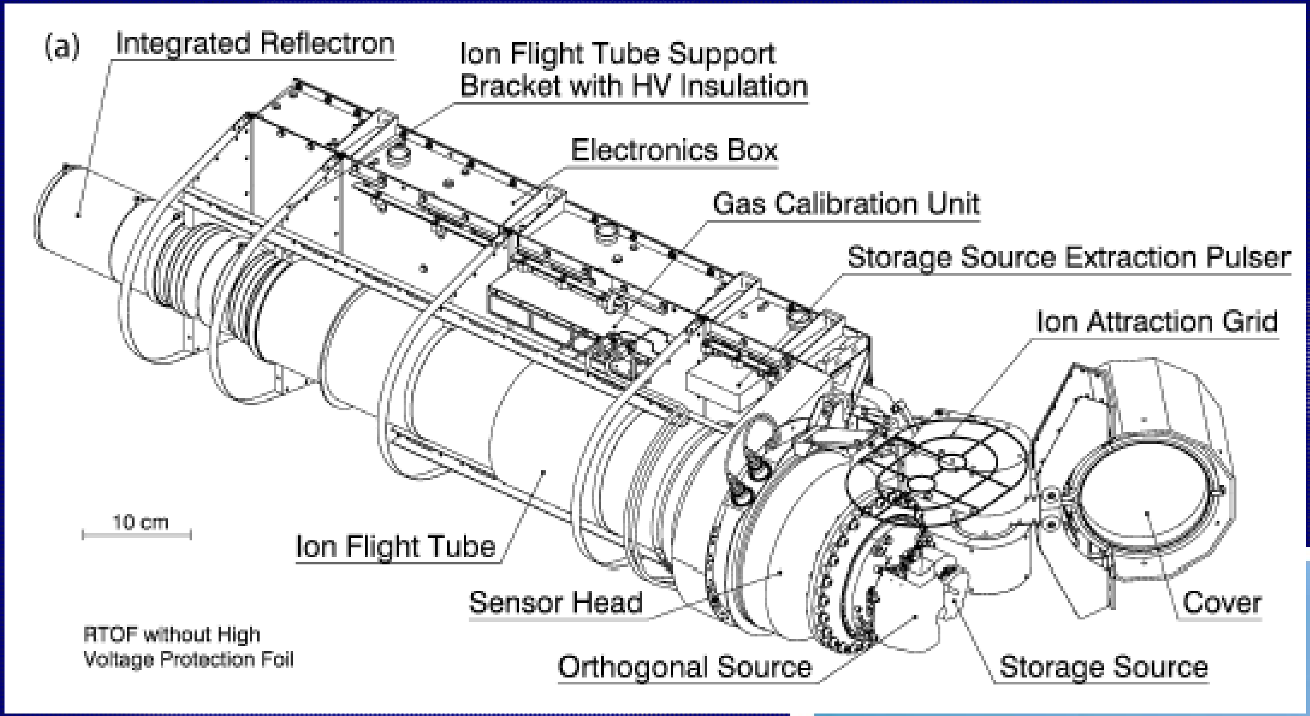


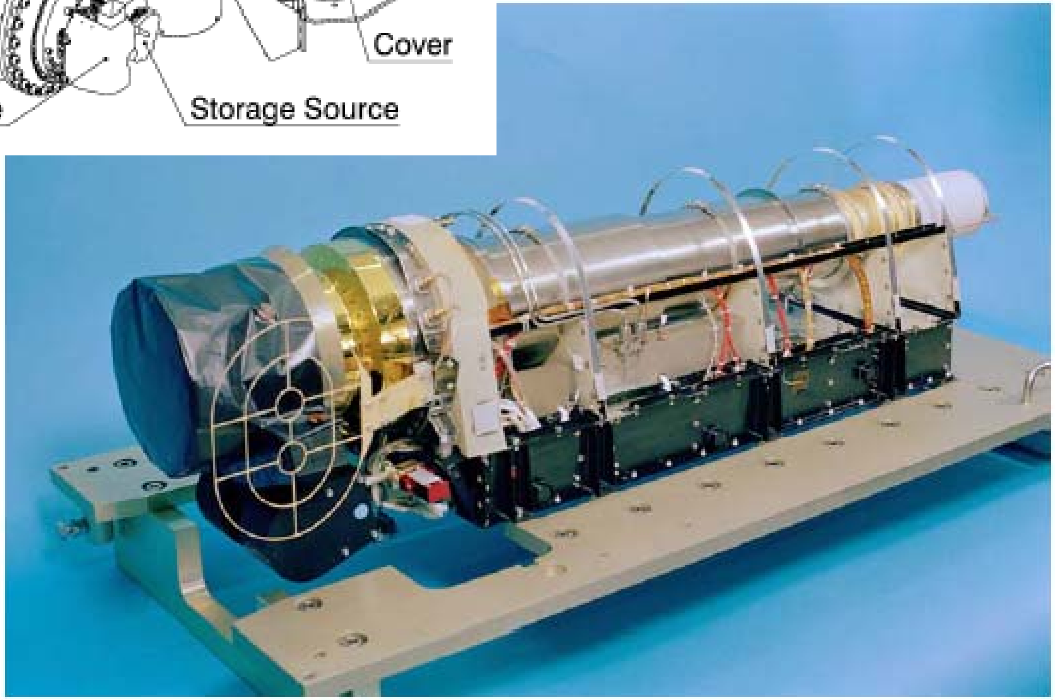
Example of HR mass spectrum recorded with DFMS at the lab



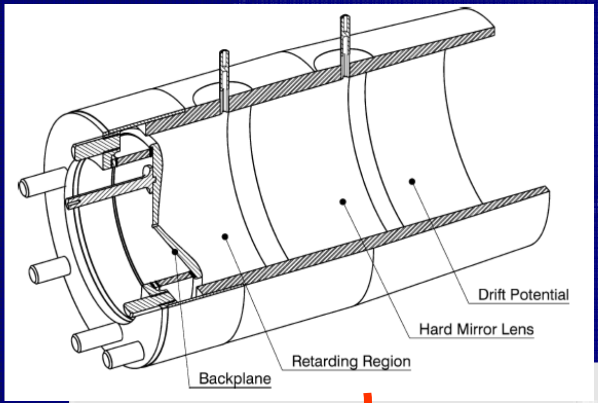
Example of LR mass spectrum recorded in flight with DFMS

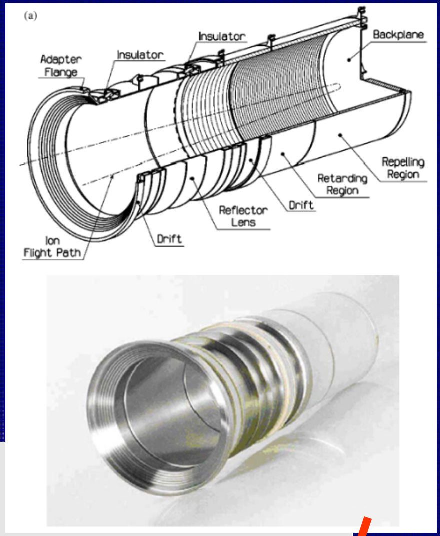
ROSINA Mass spectrometers
RTOF

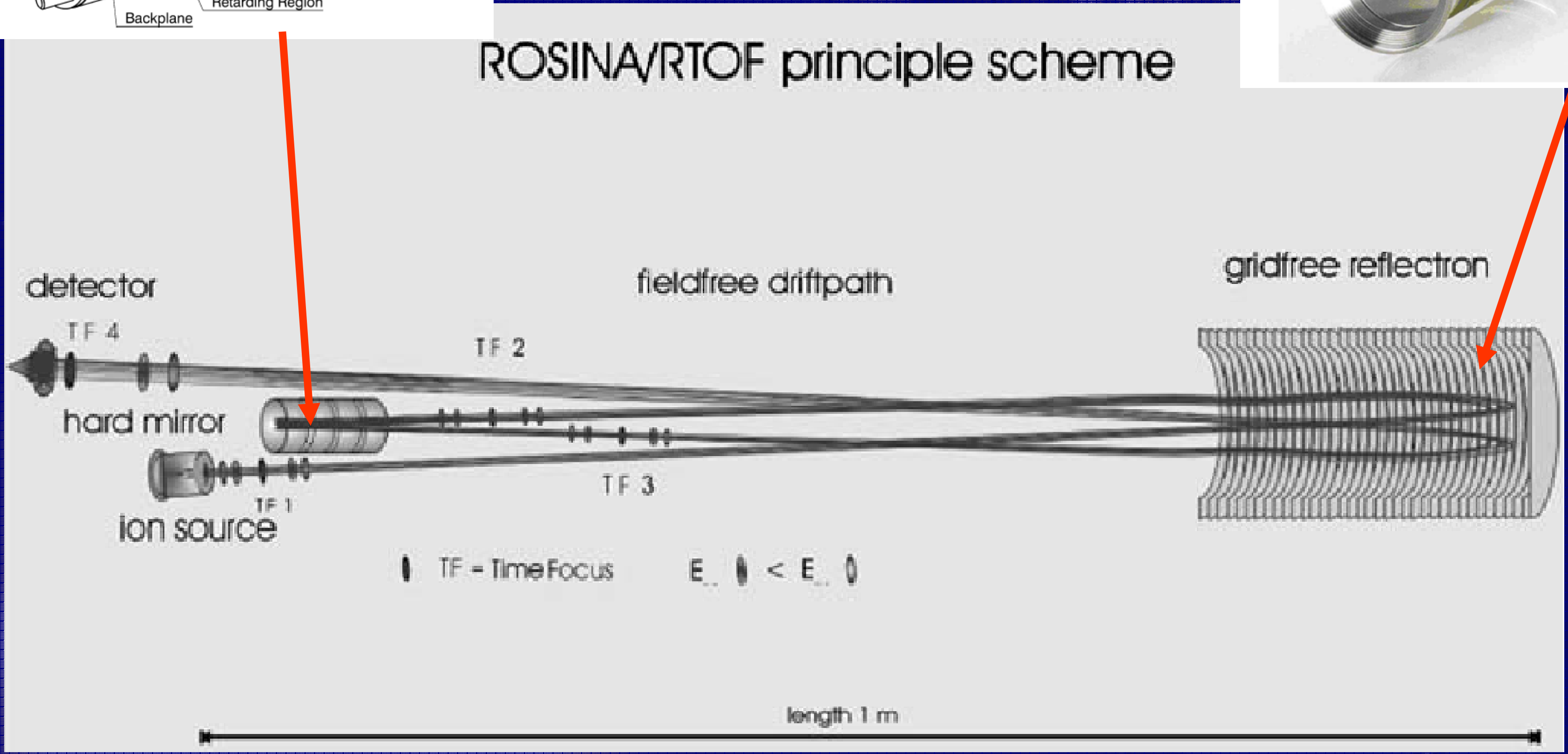




ROSINA Mass spectrometers RTOF







ROSINA Mass spectrometers
RTOF

Mass spectrometers characteristics :

Type : Reflectron Time of Flight (RTOF)

Dimensions : 1140×380×240 mm/Mass : 14.7 kg

Range : 1->350 Da

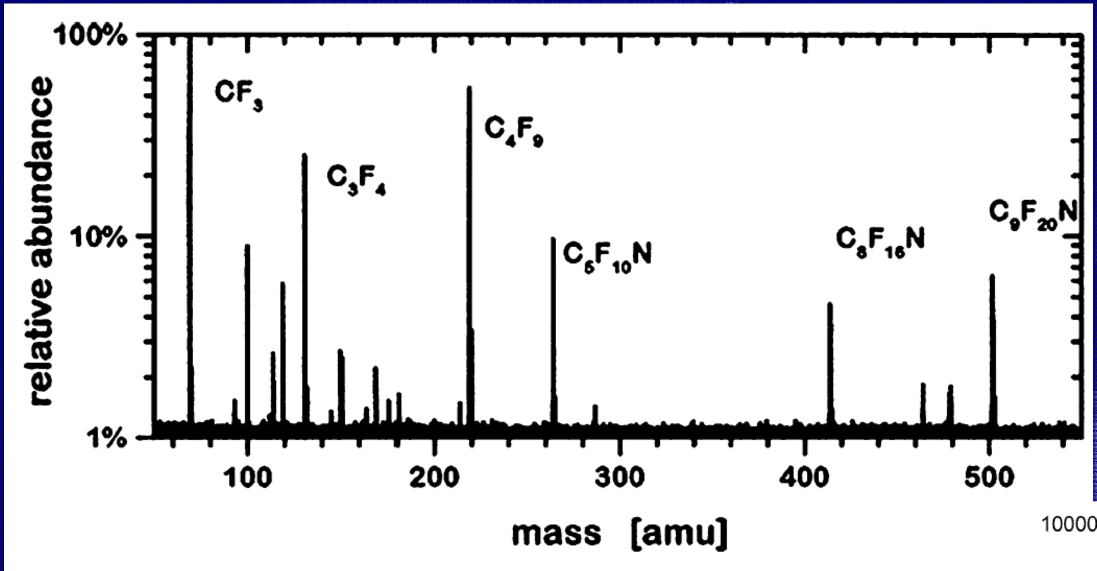
Resolution : m/Δm>500 @ 1%

Power consumption : 24 W

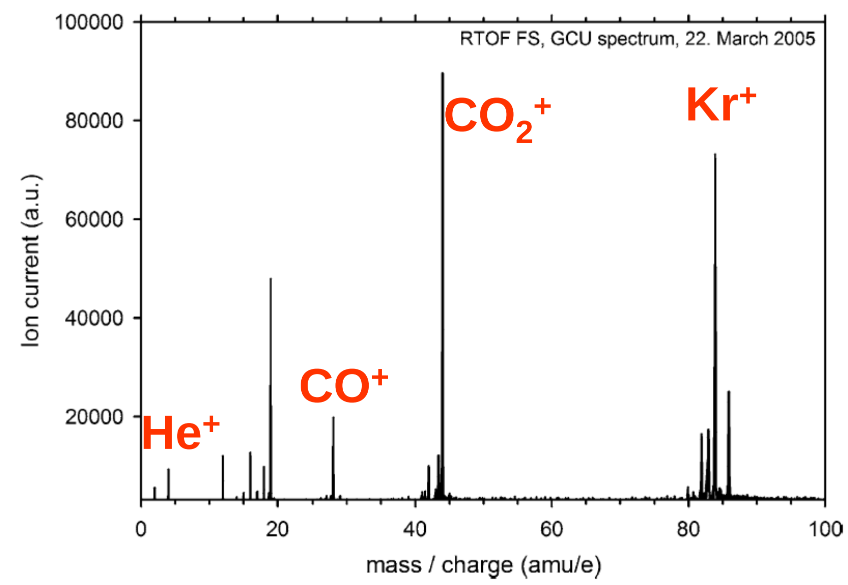
Source=e- from a heated filament of 70 eV energy or more

Detecor=Microchannel plates (MCPs)

ROSINA Mass spectrometers RTOF

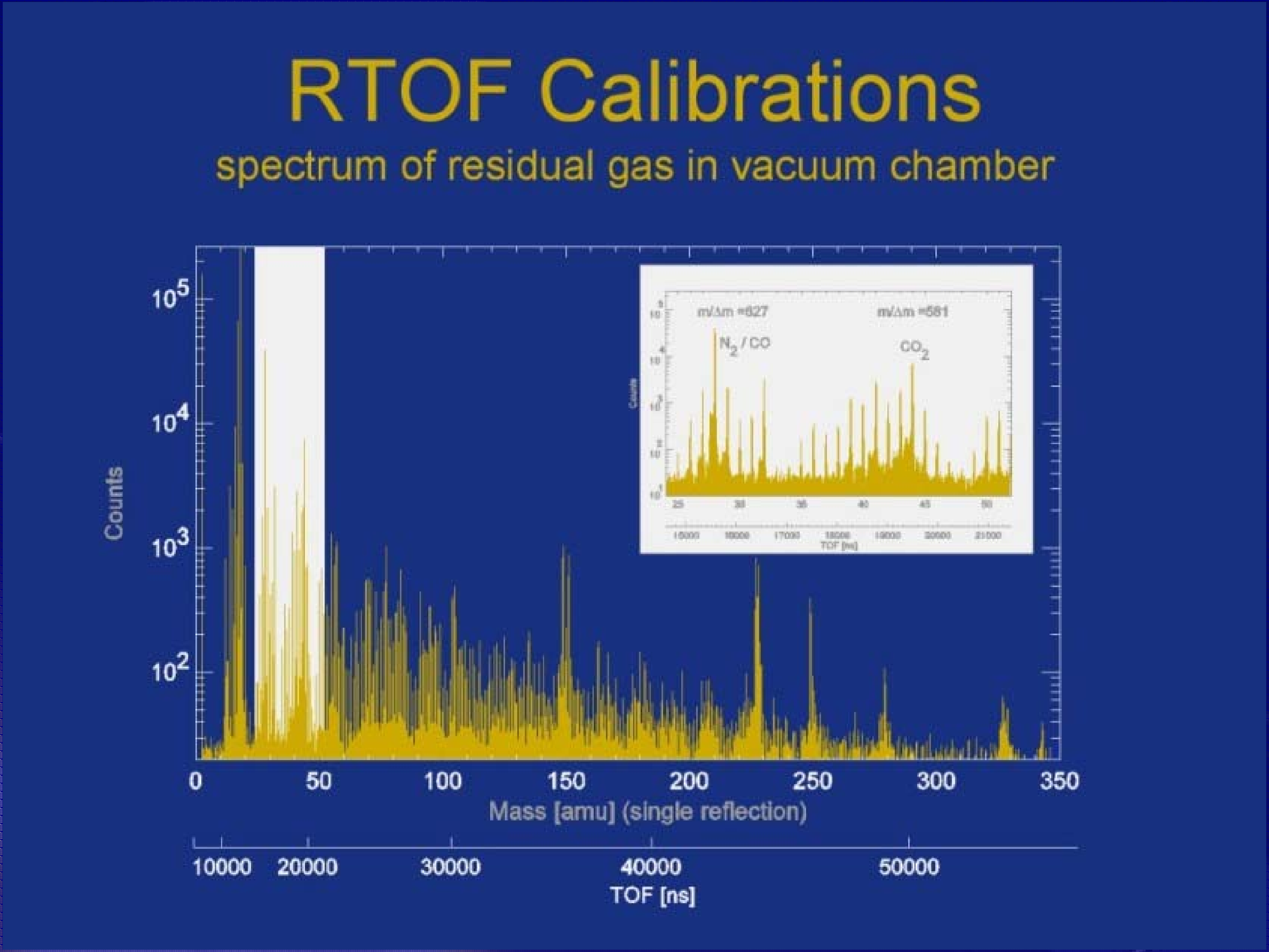


Example of mass spectrum recorded with $(CF_3(CF_2)_3)_3N$ at the lab



Example of mass spectrum recorded in flight with the calibration gas

ROSINA Mass spectrometers RTOF



Example of HR mass spectrum recorded in lab

COSIMA

COmetary Secondary Ion Mass Analyzer

Principal Investigator : **M. Hilchenbach, MPS, Ger.**

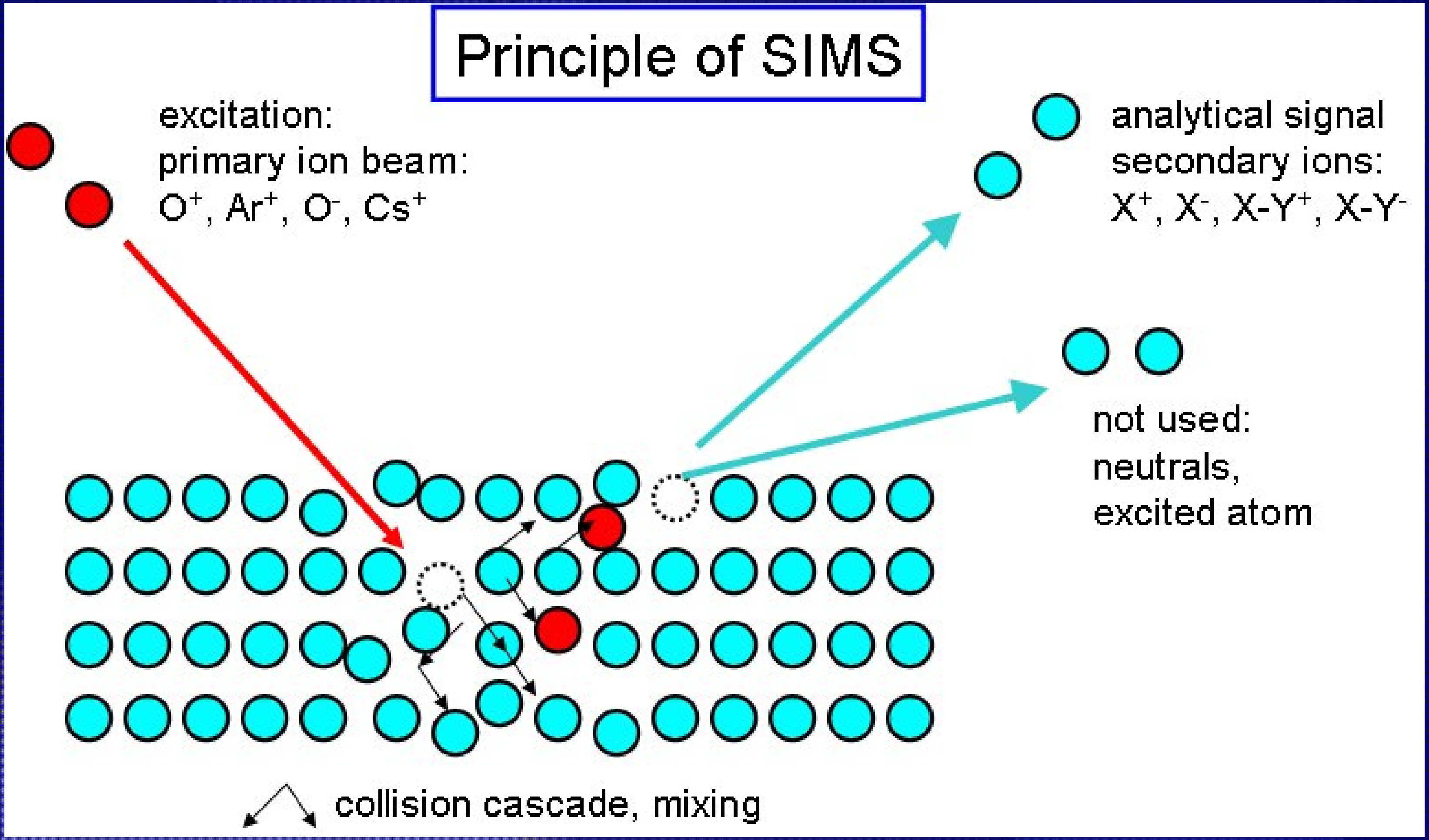
Objectives : **collect and analyze the chemical composition of cometary dust grains of the coma (focus on chemical classes and functional groups)**

Samples : **solid grains collected in the coma**

Method : **Secondary Ion Mass Spectrometry (SIMS)**

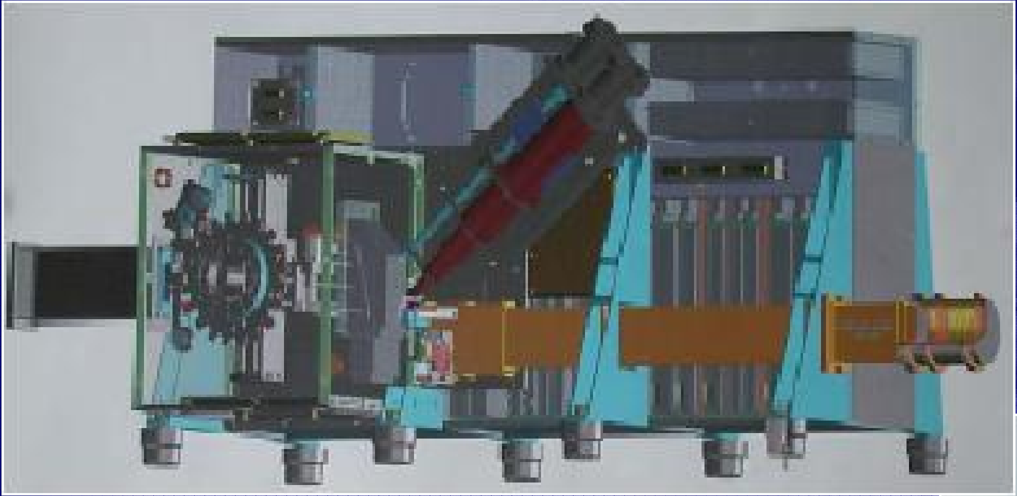
Location : **in the Rosetta orbiter**

COSIMA
Principle of SIMS

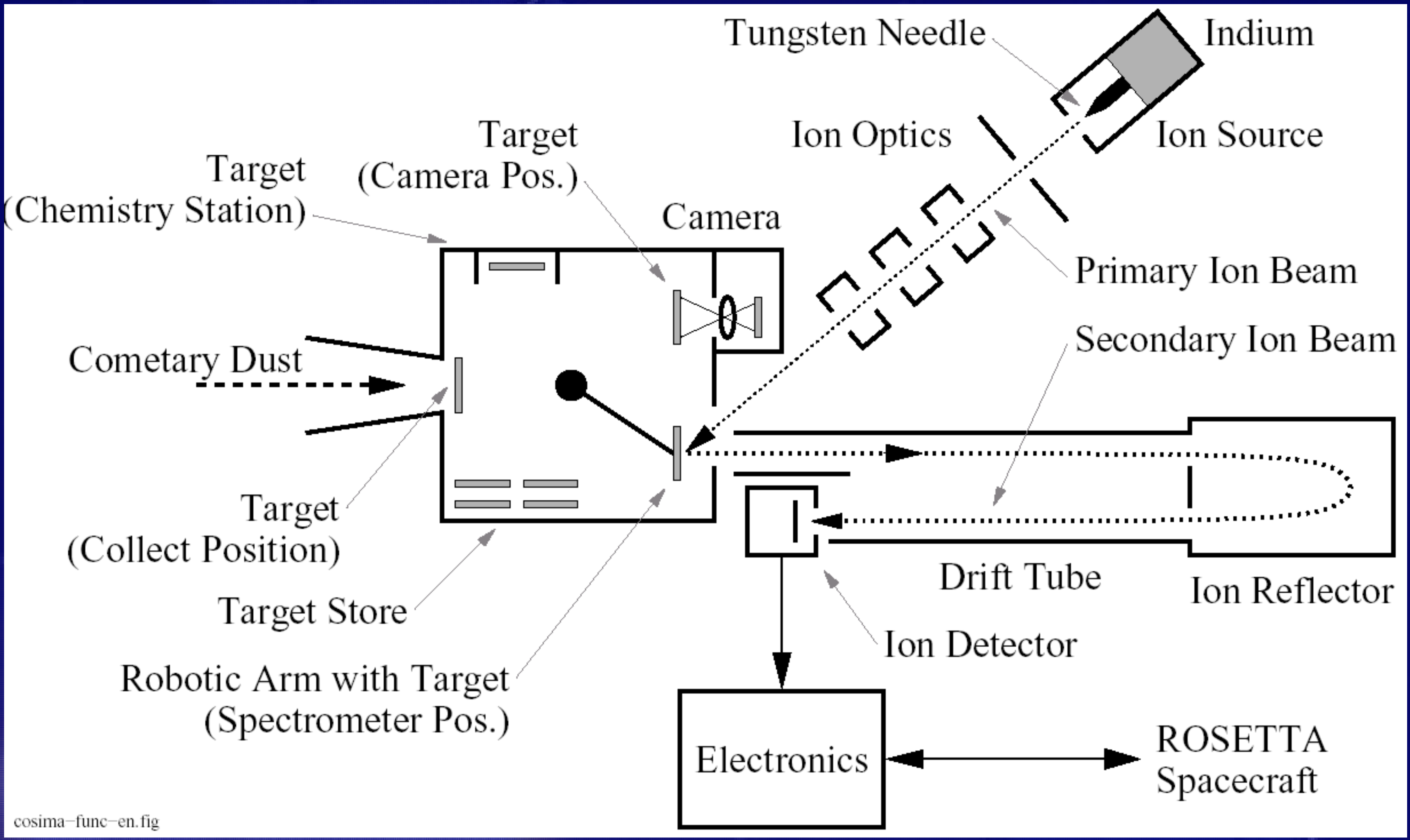


COSIMA
General description

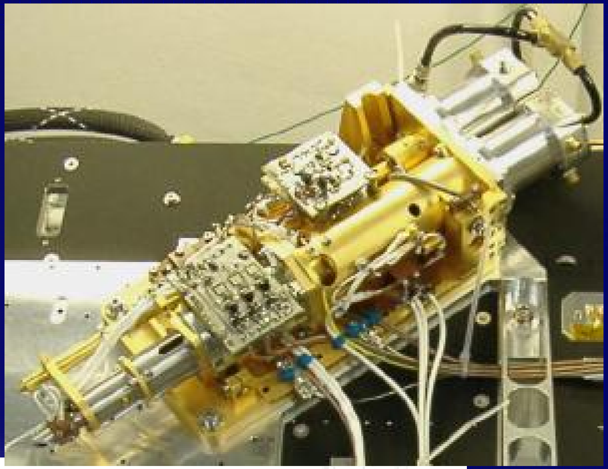
4 main parts : a dust collector, a microscope, an ion source, a mass spectrometer



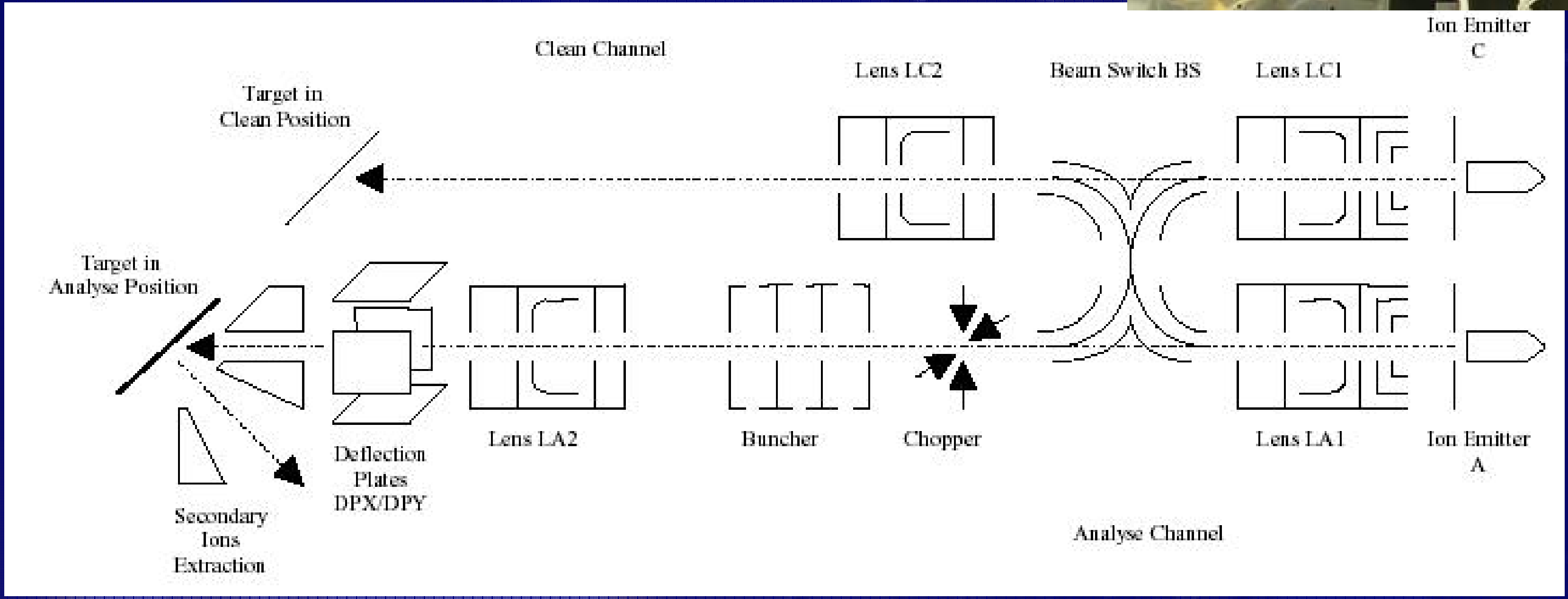
COSIMA
Operations



COSIMA
Ion source



Primary Ions Beam Source



- 1 source for analysis and 1 for cleaning (sputtering)
- PIBS : ions $^{115}In^{+}$; 1000 ions per pulse; spots diameter<20 µm; E=8 keV
- Between 10% and 0.1% of the desorbed material ionized;

COSIMA

Mass spectrometer

Instrument characteristics :

Mass=19.1 kg

Dimensions : 394×973×378 mm

Mean power consumption : 20.6 W

Mass spectrometer characteristics :

Type : Time of Flight (TOF)

Dimensions : ?/Mass : ?

Range : 1-1300 Da

Resolution : $m/\Delta m$=2000 @ 50% for 100 Da

Source=Primary ion source emitting ions $^{115}In^{+}$ (E=8 keV)

Detector=Microsphere Plate (MSP) ion detector

COSAC

Cometary Sampling and Composition

Principal Investigator : F. Goesmann, MPS, Ger.

Objectives : characterize the nature and the amount of volatile species present in the cometary nucleus, and of heavier organics (refractory ones) including their chirality properties

Samples : solid materials collected at the nucleus surface (& gas)

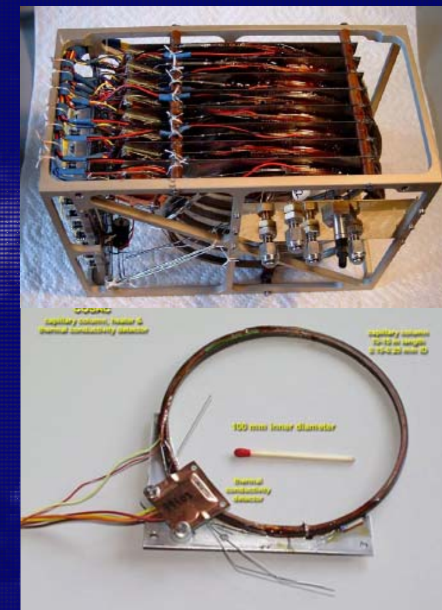
Method : Gas chromatography-time of flight MS (GC-TOFMS)

Location : in the Philae lander

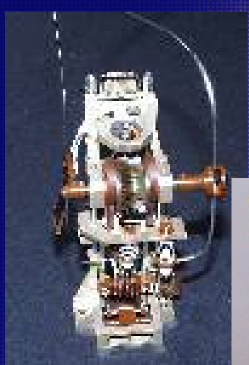
COSAC
General description

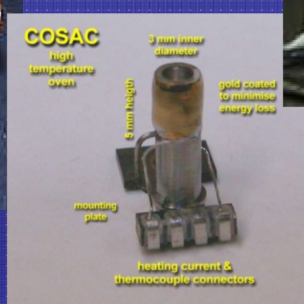
3 main parts : sampling and gas distribution and processing system, gas chromatograph, TOFMS

Gas tanks (He)



GC





Oven and tapping station

TOFMS

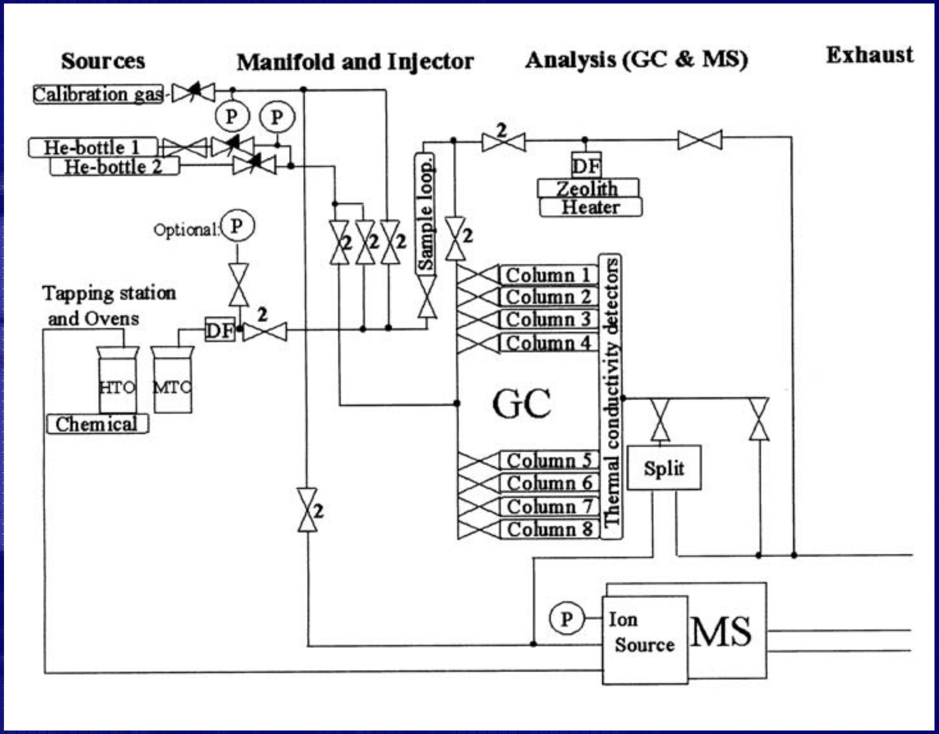
COSAC
Operations

Sampling :

- Step pyrolysis of solids (up to 600°C)
- Derivatisation (DMF-DMA)
- Gas (direct or via Carbosieve)

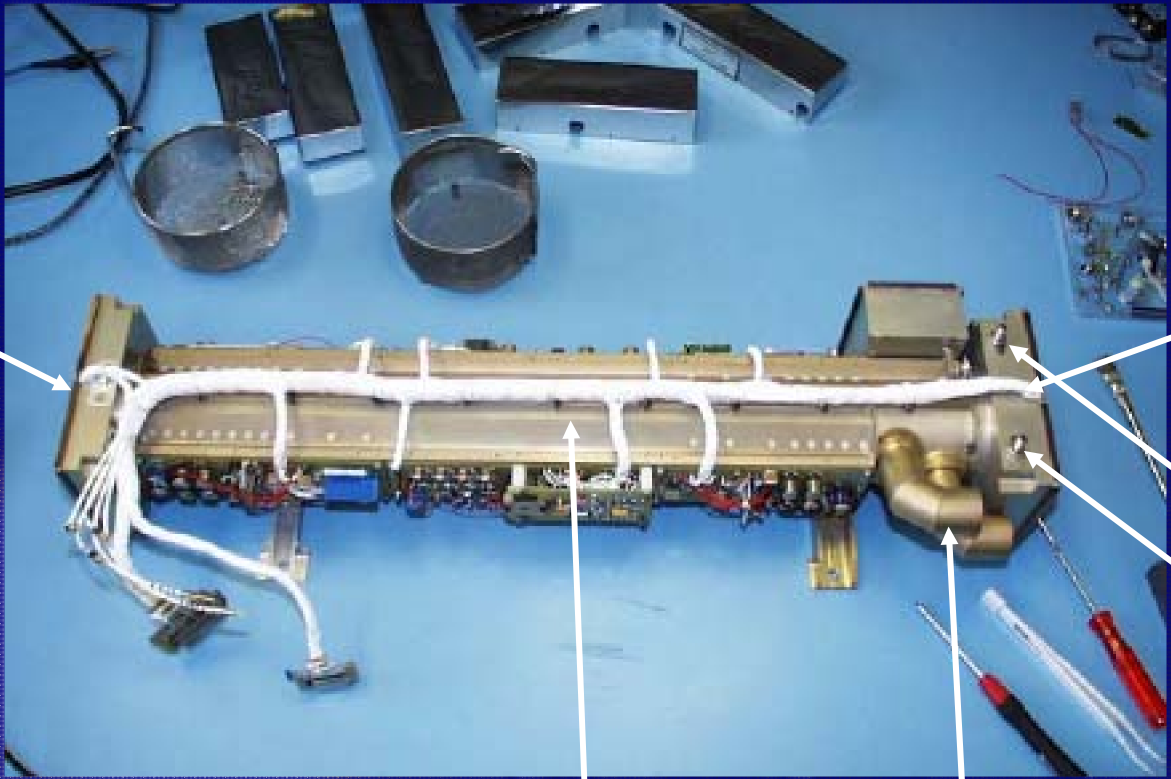
Analysis :

- Direct MS
- GC-MS (3 chanels for enantiomeric characterization, 5 chanels for general molecular characterization (from light inorganics to heavy organics))



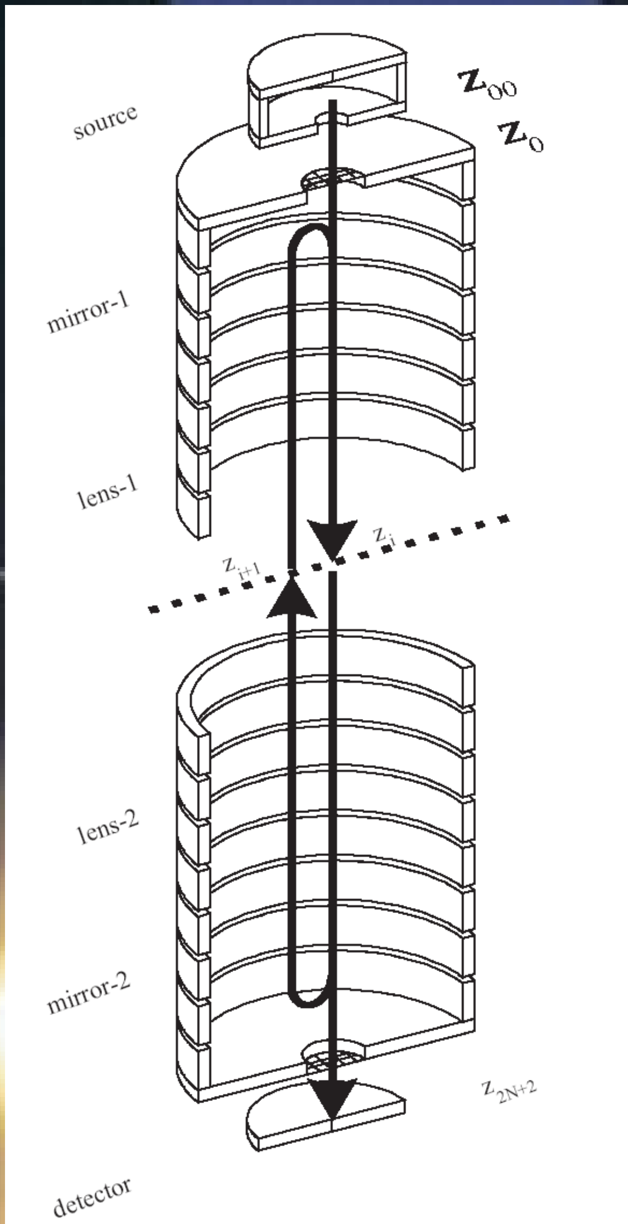
Scheme of COSAC

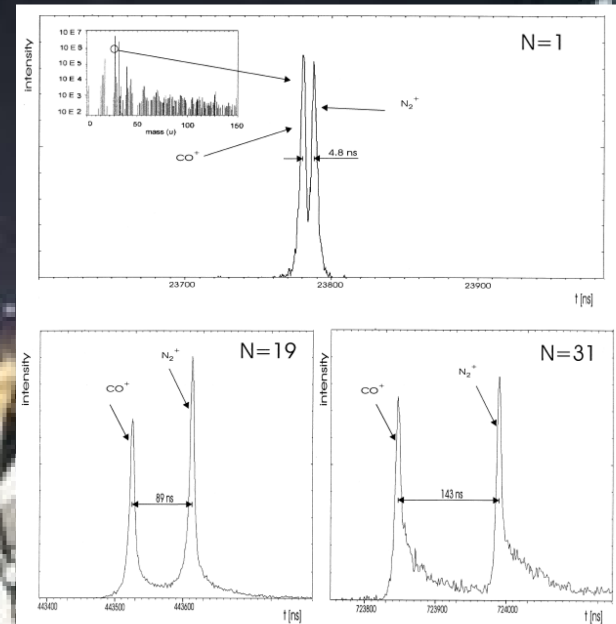
COSAC
Mass spectrometer

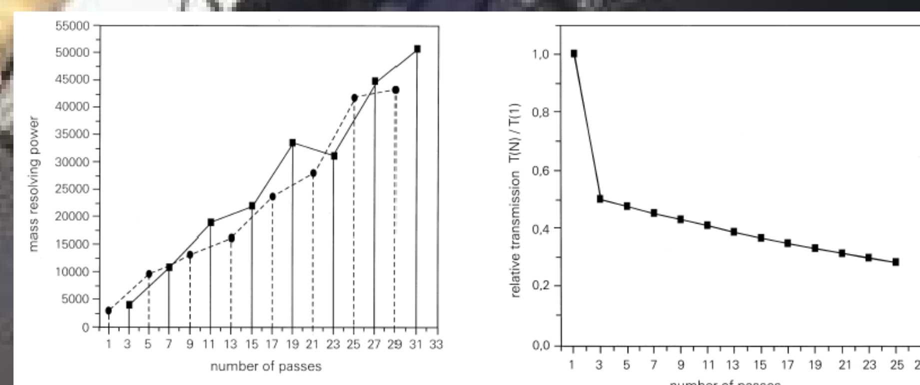


Ion source=e- provided by thermal effect and generated with filaments (E(e-)=70 eV)

COSAC
Mass spectrometer







Typical performances for a 1.2 m long MS

Principle of the multi-reflexion TOF

COSAC
Mass spectrometer

Instrument characteristics :

Mass=4.5 kg

Dimensions : 500×450×250 mm

Max. power consumption : 15 W

Mass spectrometer characteristics :

Type : Time of Flight (TOF)

Dimensions : 460×80×80 mm/Mass : 1.5 kg

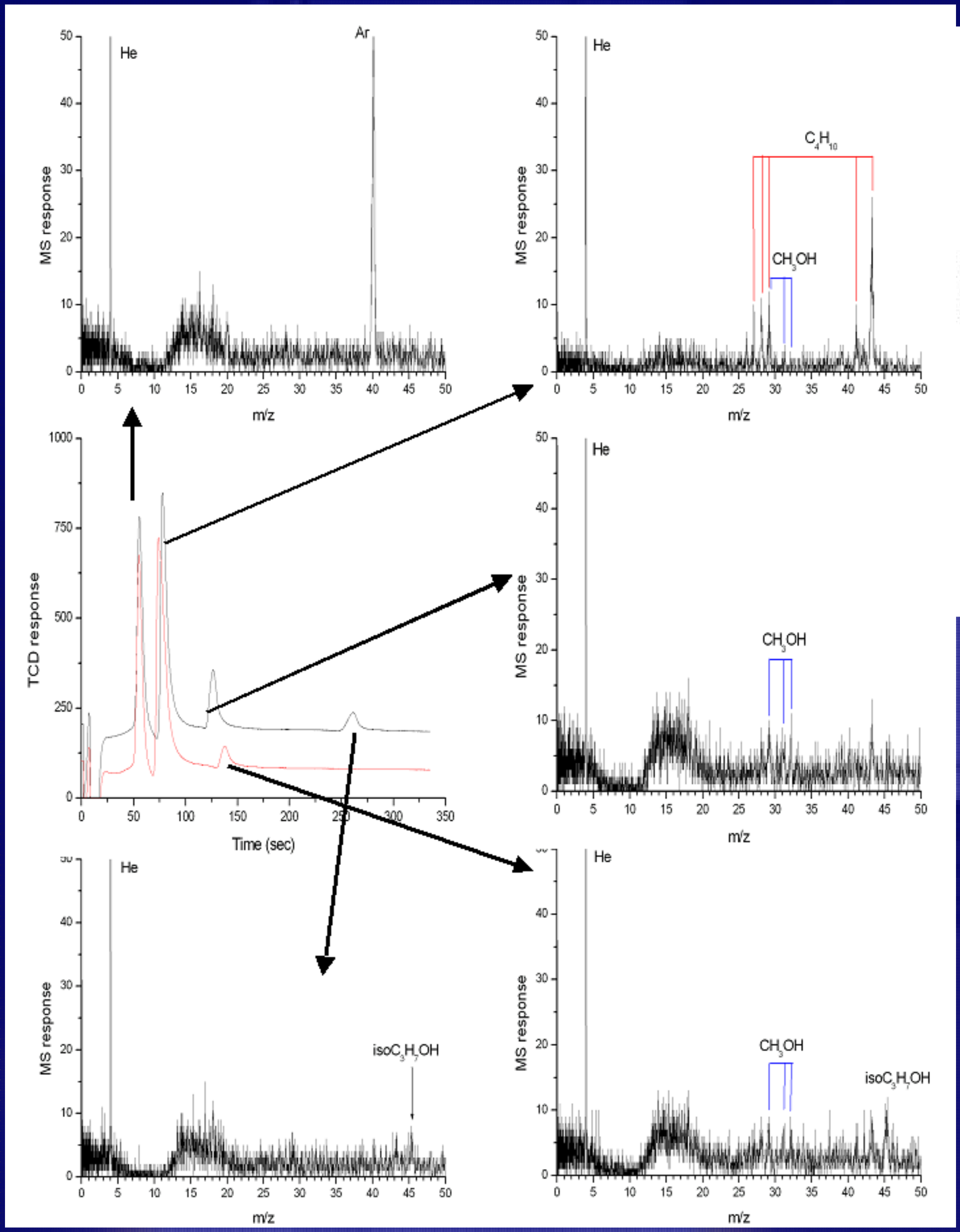
Range : 1-1500 Da

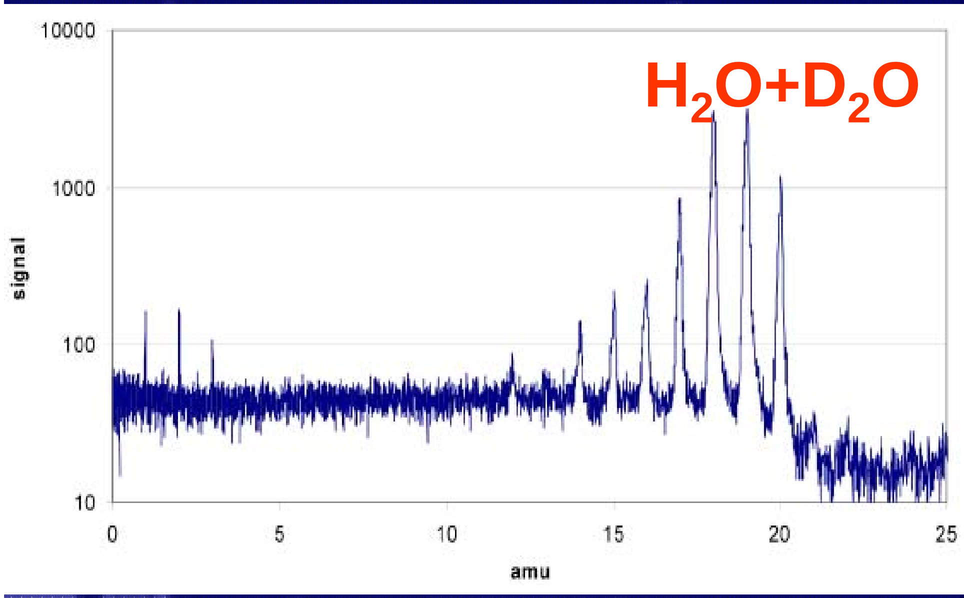
Resolution : m/Δm=350 @ 50% for 70 Da (single path mode L=350 mm); V=1500 V

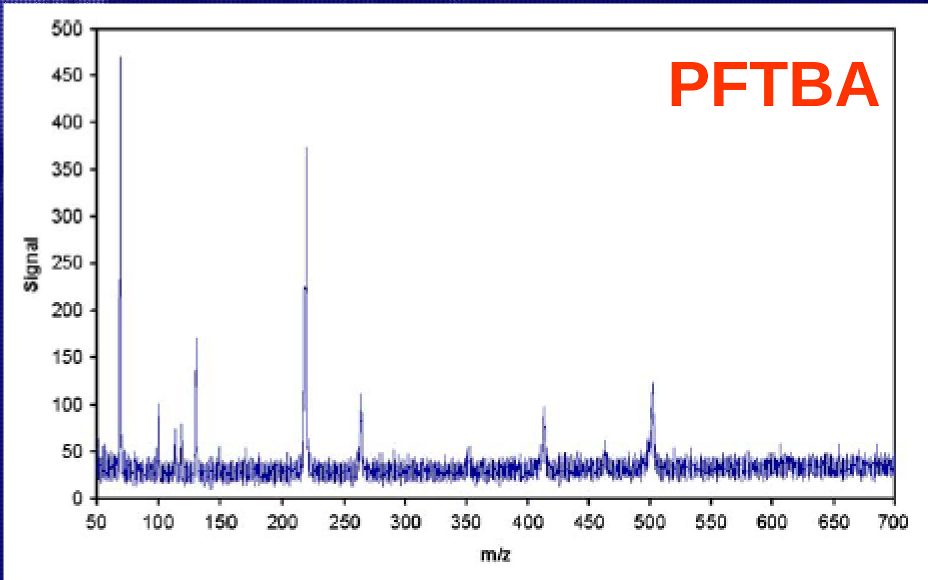
Source=e- from a heated filament of 70 eV energy

Detecor=Microchannel plates (MCPs)

COSAC : experimental results in lab







MODULUS

Methods Of Determining and Understanding Light elements from Unequivocal Stable isotope compositions

Principal Investigator : I.P. Wright, Open Univ., UK

Objectives : characterize the nature and the isotopic (C, N, O, H) compositions of all materials present at the surface of the cometary nucleus

Samples : solid materials collected at the nucleus surface (& gas)

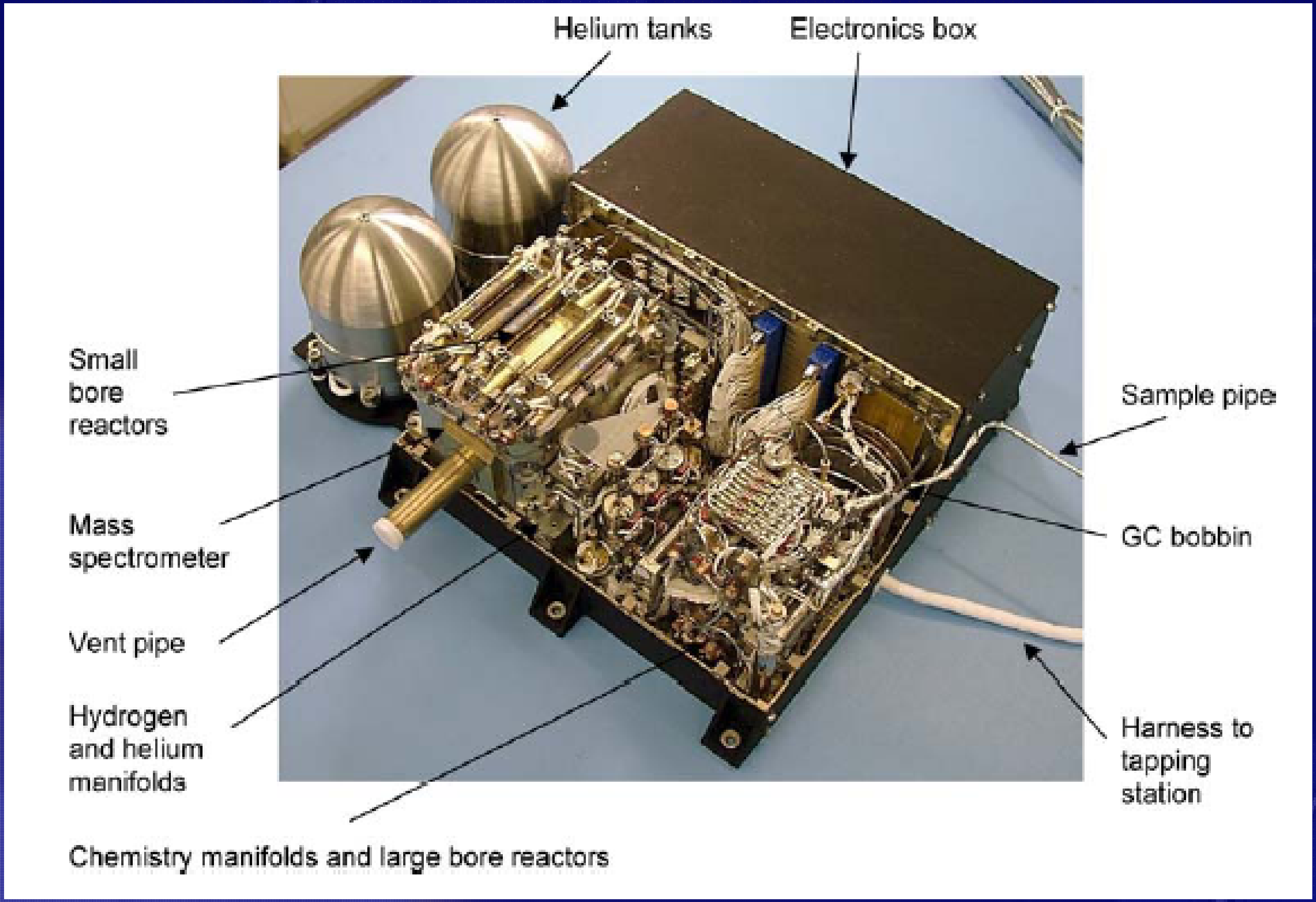
Method : Gas chromatography-ion trap MS (GC-ITMS)

Location : in the Philae lander

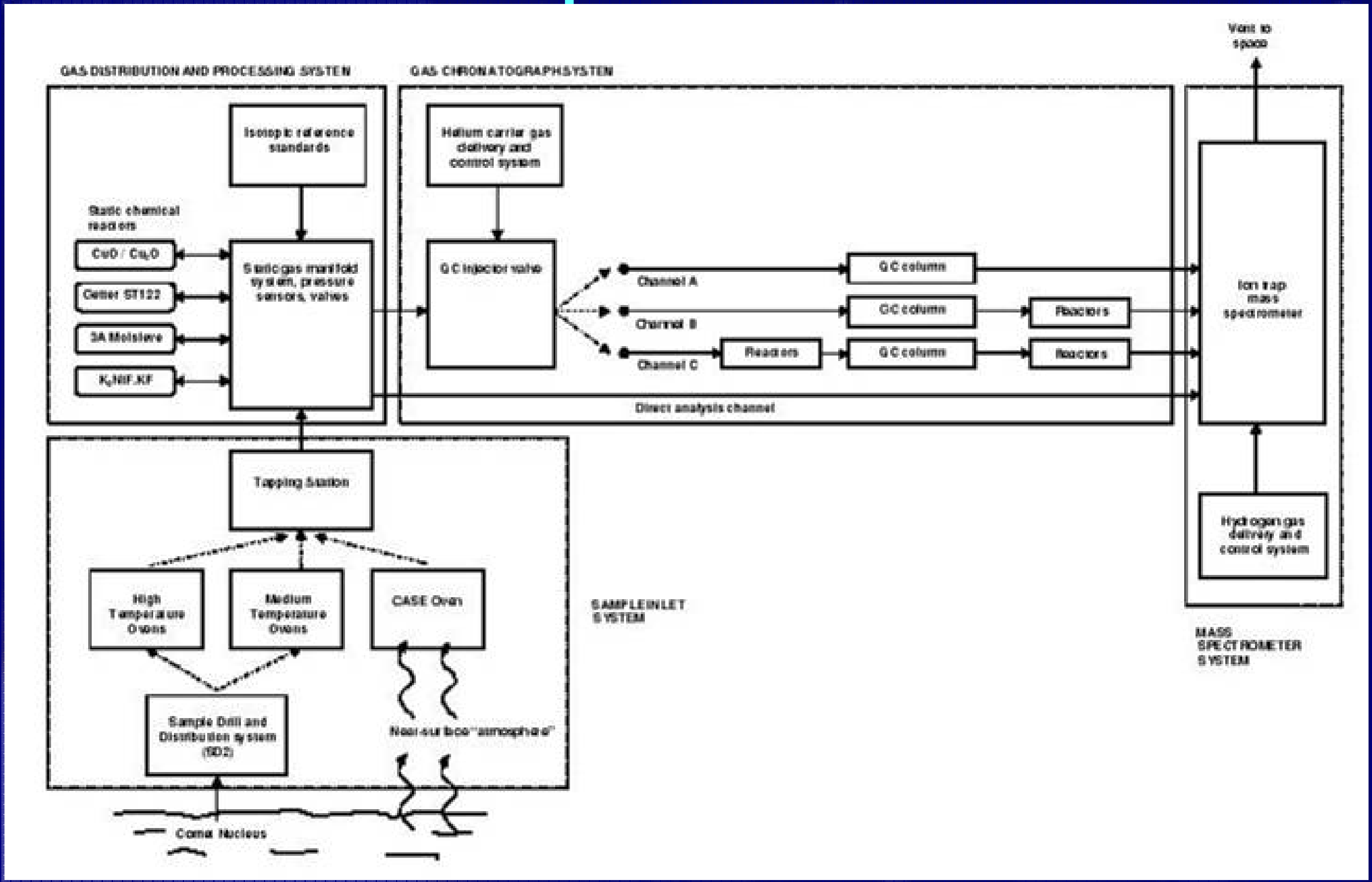
MODULUS
General description

4 main parts : a sampling system, a gas distribution and processing system, a gas chromatograph, ITMS

+Ar (100 ppm)



MODULUS
Operations



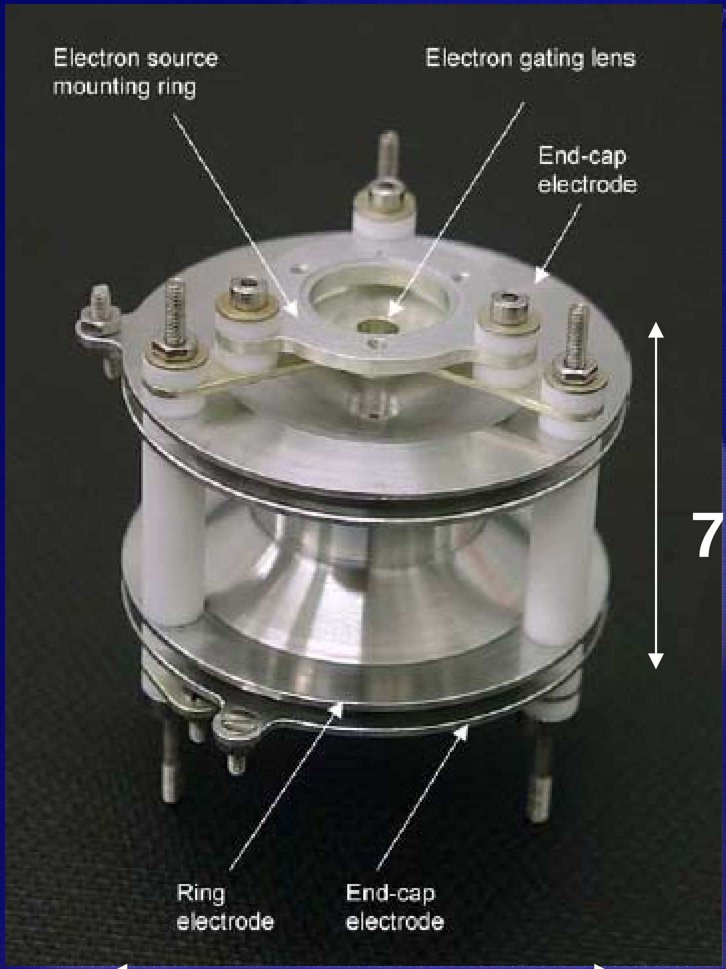
Sampling :

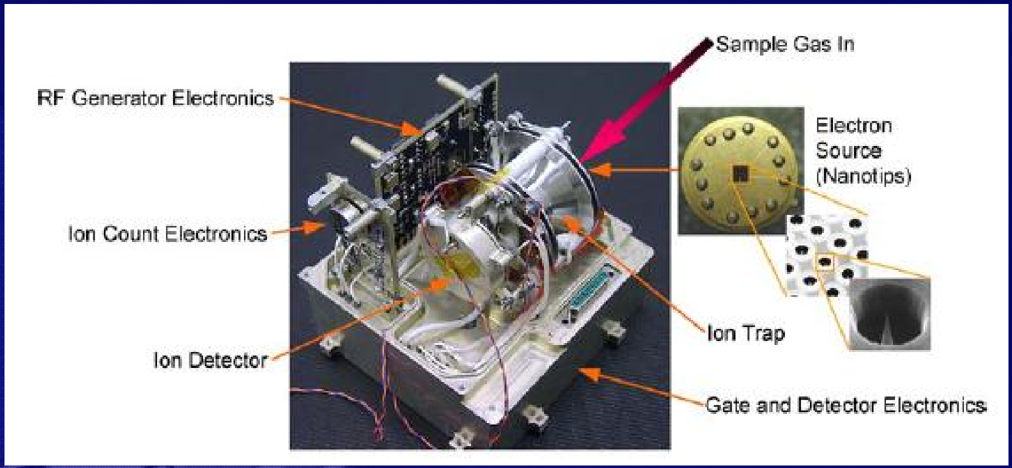
- Step pyrolysis (up 800°C)
- Combusiton with O_2
- Fluorination of silicates (release of O_2)

Analysis :

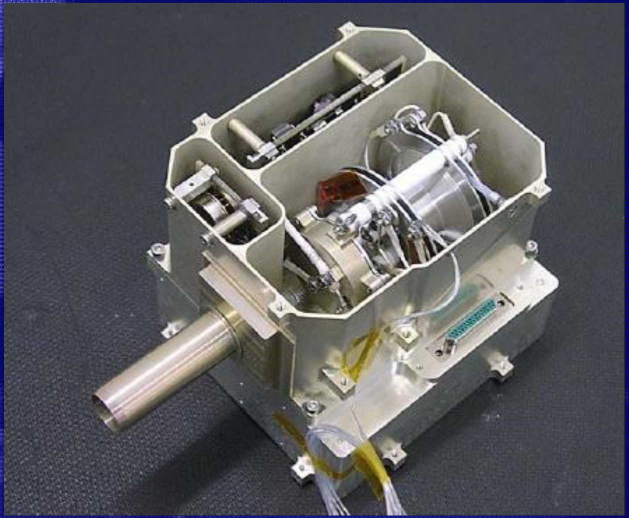
- Direct MS
- GC-MS (1 channel for the general composition, 1 channel for CO_2, CO, CH_4 & N_2 with converion of CH_4 and CO into CO_2, 1 channel for H_2O with a conversion into H_2 and CO)

MODULUS
Mass spectrometer





70 mm



60 mm

Species detected for isotopic measurements :
N_2^+, O_2^+, CO_2H^+, ArH^+

MODULUS

Mass spectrometer

Instrument characteristics :

Mass=4.5 kg

Dimensions : 250×330×110 mm

Mean power consumption : 10 W

Mass spectrometer characteristics :

Type : Ion Trap (IT)

Dimensions : 80×100×55 mm/Mass : 500 g (75 g for IT)

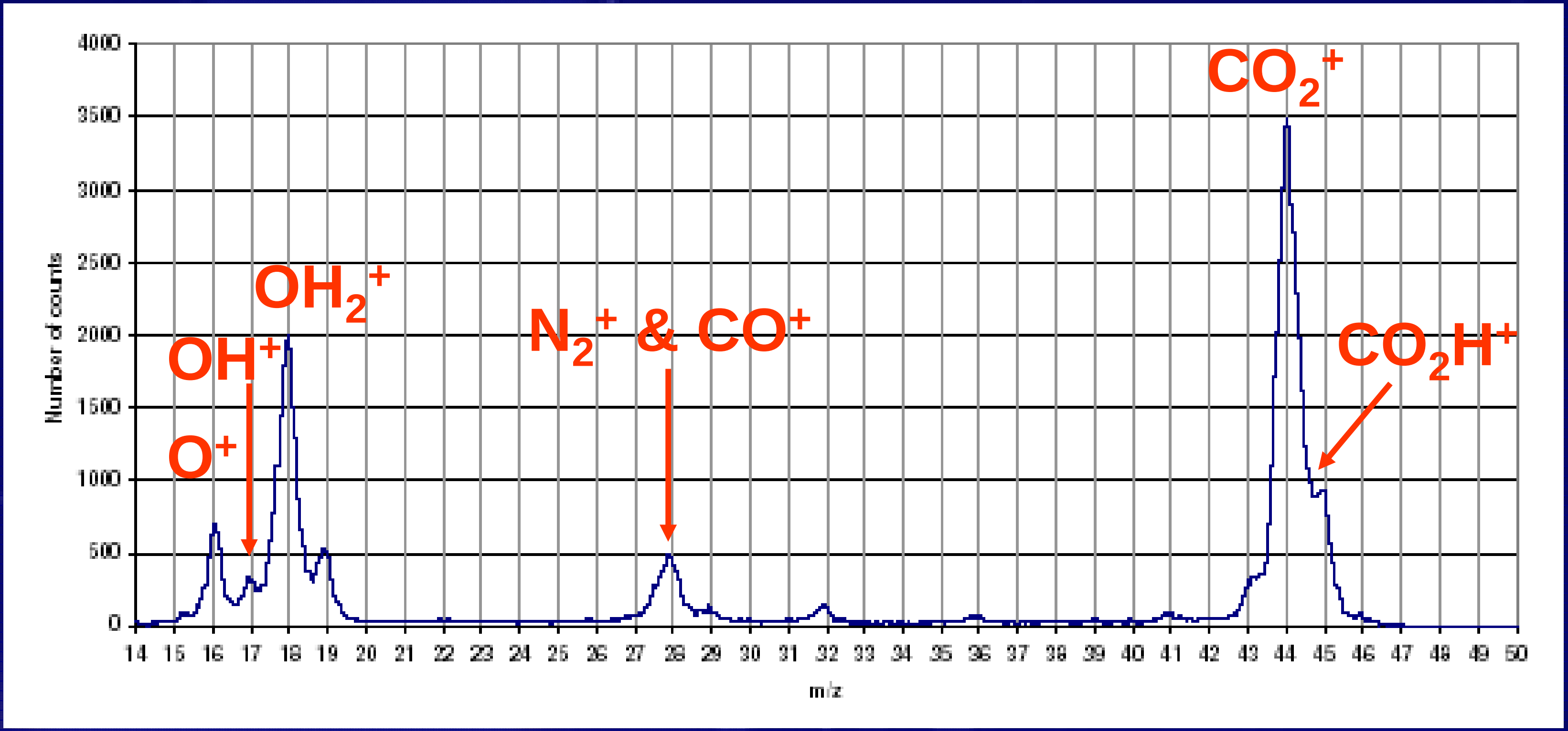
Range : 12-150 Da

Resolution : m/Δm=?/V=25 to 300 V/RF=0.6 MHz

Source=e- provided by field effect generated with arrays of nanotips

Detectro=Spiral electron multiplier (built by MPS, Ger.)

MODULUS
Mass spectrometer



Example of mass spectrum recorded with MODULUS at lab (injection of 20 nmol of CO_2)

MASS SPECTROMETRY IN ROSETTA
Synthesis

MS	Sample	Type	Mass (kg) Size (mm)	Range (Da)	Resolution
COSIMA	Grains in the coma	TOF		1-1300	2000 / 50%
ROSINA	Gas in the coma	DFMS TOF	16.2 630×630×260 14.7 1140×380×240	12-150 1-350	3000 / 1% >500 / 1%
COSAC	Nucleus surface material	TOF	1.5 460×80×80	1-1500	350 / 50%
PTOLEMY	Nucleus surface material	IT	0.5 80×100×55	12-150	

Exploration of the Saturn system with the Cassini-Huygens mission (2005)

Nominal mass	Possible ion at this isobaric mass	Nominal mass	Possible ion at this isobaric mass
1	H^+	26	$C_2H_2^+$
2	H_2^+, D^+	27	HCN^+
3	HD^+, $^3He^+$	28	N_2^+, CO^+, $C_2H_4^+$
4	He^+	29	$^{13}CO^+$, $C^{17}O^+$, $^{15}NN^+$
5		30	NO^+
6		31	
7	Li^+	32	O_2^+, SO_2^{++}
8		33	
9		34	H_2S^+, $O^{14}O^+$
10		35	
11		36	$^{36}Ar^+$, HCl^+
12	C^+	37	
13	$^{13}C^+$	38	$^{38}Ar^+$, $^{37}HCl^+$
14	N^+, N_2^{++}	39	K^+
15		40	Ar^+, Ca^+
16	O^+, O_2^{++}, CH_4^+	41	$^{41}K^+$
17	OH^+, NH_3^+	42	Kr^{++}
18	H_2O^+	43	
19	HDO^+, F^+	44	CO_2^+, N_2O^+
20	Ne^+, HF^+	45	$^{13}CO_2^+$, $^{13}C^{17}OO^+$
21		46	NO_2^+, $C^{18}OO^+$
22	CO_2^{++}, $^{22}Ne^+$	47	
23	Na^+	48	
24		49	$H_2SO_4^{++}$
25		50	

MS main specifications :

Nature : Quadrupole

Mass : ~4 kg

Volume : ~20 cm^3

Power : 12 W

m/z range : 1-46

Resolution :

Sensitivity : N/A

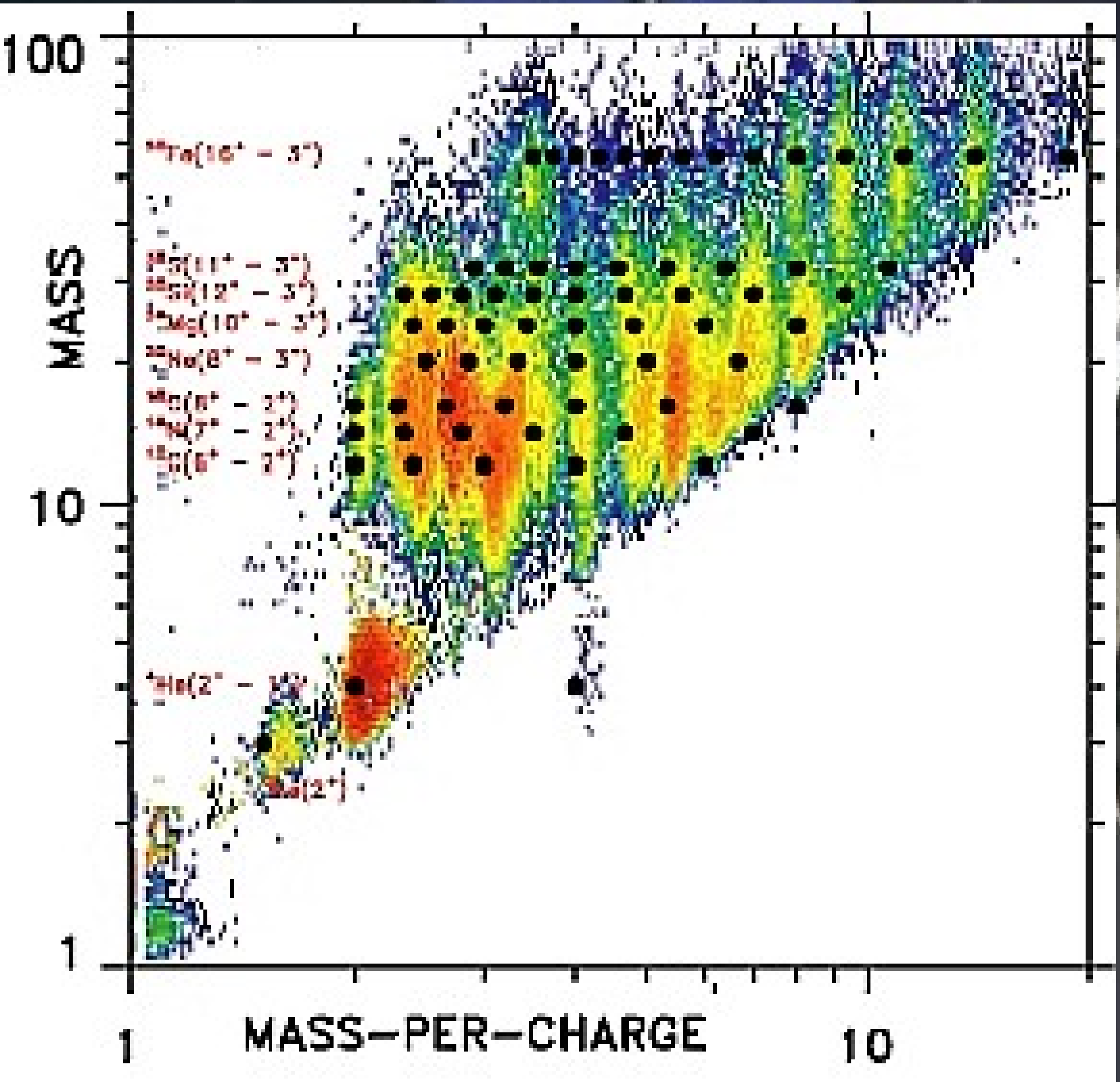
SW/Plasma MS Timeline

Mass Spectrometer	Year, Mission	Resolution
Ion Traps	1959 Luna 1	< 2
Faraday Cup	1961 Explorer 10	~2
Electrostatic E/Q	1962 Mariner 2	~3
Wien Filter	1983 ISEE-3	~5
Magnetic Sector	71 Apollo*, 86 Giotto*	>40, >10
Linear TOF	1984 Ampte	~15
Isochronous TOF	1996 Wind	~100
Reflectron TOF	2004 Rosetta*	>3000
Helical TOF	20??	>1000

Why Bother with Composition?

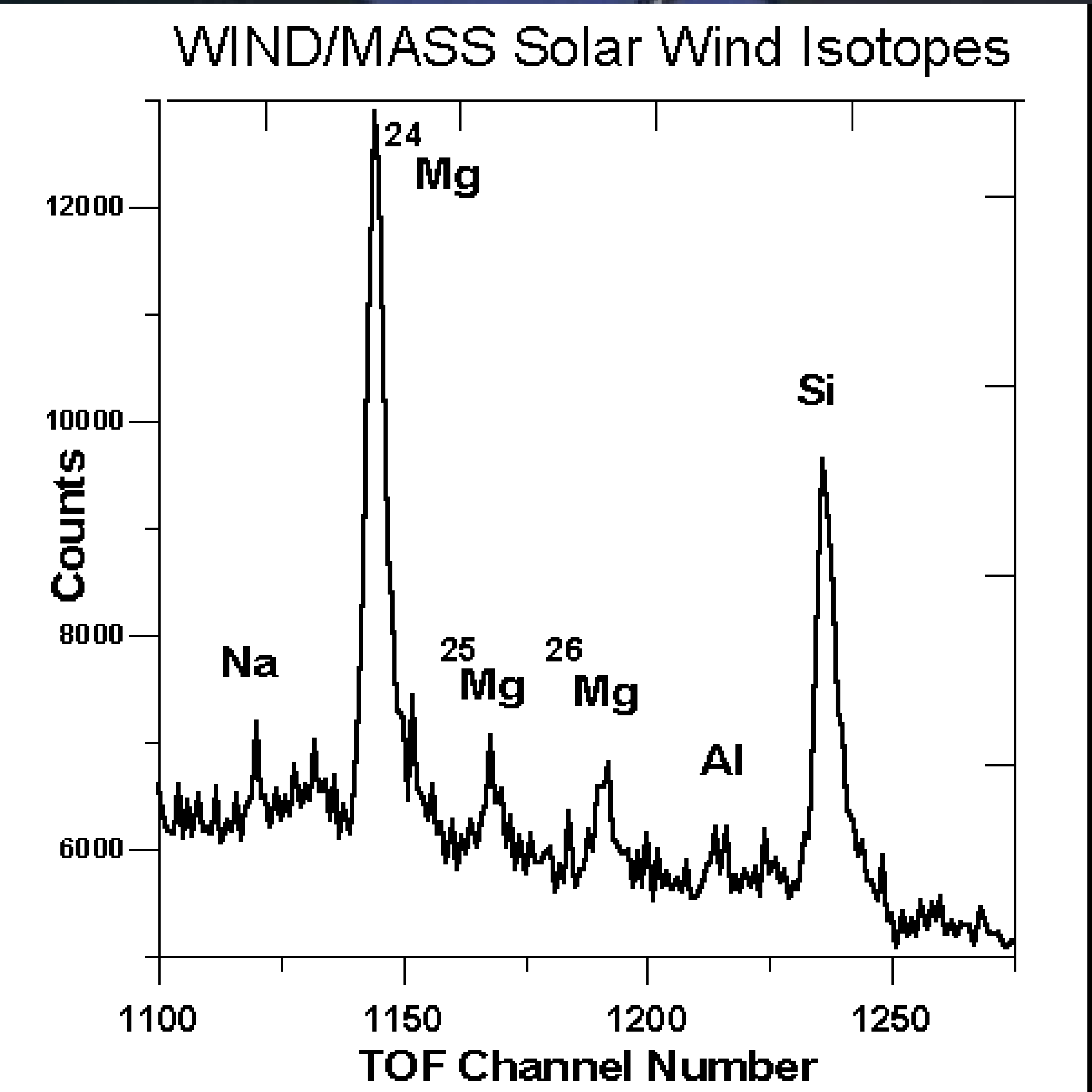
- "Minor effects of minor ions" said a colleague
- The Plasma Ecosystem
  - Origins: tracers
    - Fast/slow solar wind, ionosphere/SW m'spheric
  - Acceleration: both as tracer and trigger
    - O+ changes reconnection rate;
  - Transport: both tracer and differentiator
    - SEP composition reveals E/q acceleration
  - Death: ENA visualizations (IMAGE)
    - He from SW, O from Earth

SW Elemental Composition



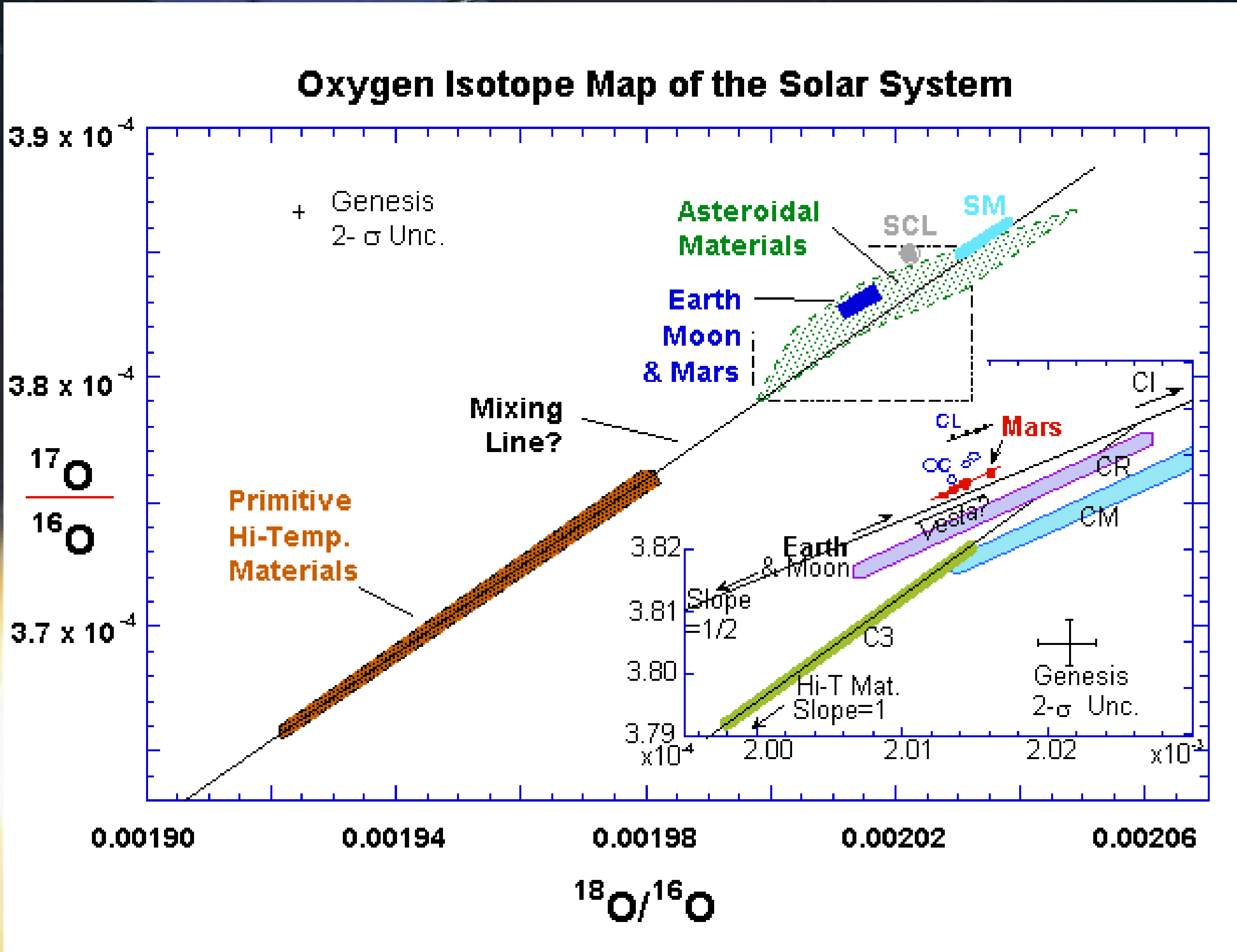
- Mass can separate degenerate M/Q species
- Charge states give coronal temperatures at different altitudes.
- Differentiate Fast/Slow SW
- Ascertain SW origins

SW Isotopic Composition

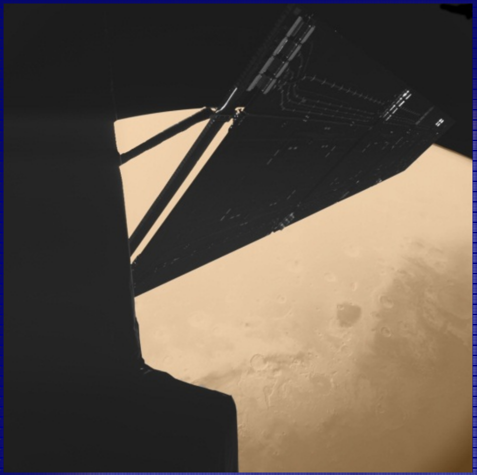


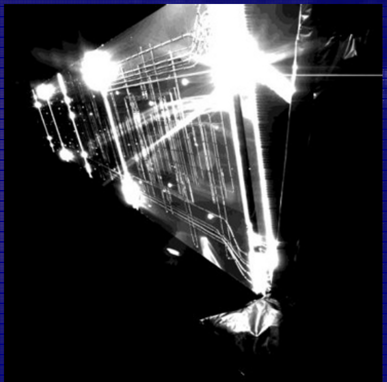
- Isotopes can reveal unique acceleration in SW: 3He, 15N.
- Triple Mg isotopes permit studies of mass fractionation of Solar interior.
- Origins of proto-solar nebulae, age of the sun.

Origins of Solar System



The Rosetta mission
Timeline





03/2004 Launch

03/2005 Earth flyby

02/2007 Mars flyby

11/2007 Earth flyby

09/2008 21Lutetia fly-by

11/2009 Earth flyby

07/2010 2867Steins flyby

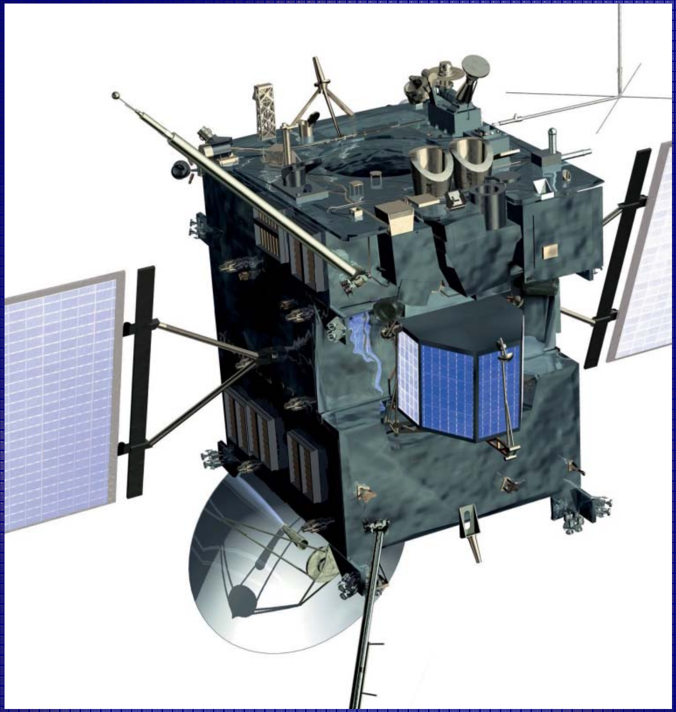
Mid 2014 Rendez-vous
with comet P67CG

11/2014 Philae release

06/2015 Perihelion passage

12/2015 End of the mission

The Rosetta mission
The orbiter



11 instruments :

ALICE
VIRTIS } UV, vis & IR spectroscopy

OSIRIS vis, near IR&UV camera

CONSERT Sounding of the interior of the nucleus

COSIMA
ROSINA } Mass spectrometry

MIRO Microwave instrument

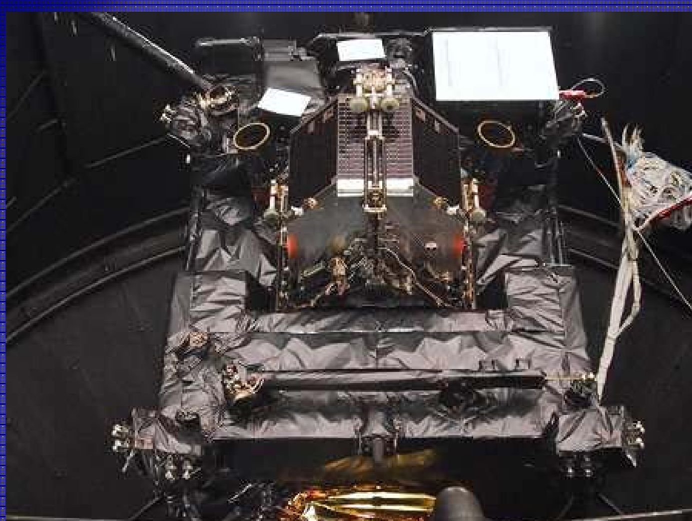
GIADA Instrument for dynamic and morphology of dust grains

MIDAS AFM for dust grains observations

RPC Plasma measurements

RSI Radio science (spacecraft)

The Rosetta mission
Philae : the lander



<u>9 instruments :</u>

COSAC GCMS for molecules

MODULUS-Ptolemy MS for isotopes

CONSERT sounding of the interior of the nucleus

APXS APX spectrometer

MUPUS penetrator

ROMAP magnetometer and plasma monitor

SESAME electric properties of the surface

CIVA visible and IR micro cameras

ROLIS camera

Choice of techniques appropriate to space mass spectrometry

	Mass Range	Mass Resolution FWHM	Sensitivity	Duty Cycle	Complexity (sensor+ electronics)	Technology Readiness	Example
Quadrupole	<150	~150	High	Low	Low	High	Cassini/ Huygens
Magnetic	<150	~2500	Medium	Low	High	High	Rosetta/ DFMS
TOF	>>100	~2500	High	High	Medium	High	Rosetta/ RTOF
Ion trap	>100	>100	High?	Low	Medium	High	Rosetta lander
MBTOF	>>100	>10,000	High	High	High	Medium	SwRI MBTOF