ESA Rosetta Spacecraft Mission to Comet Churyumov-Gerasimenko - The Orbiter

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KISS Workshop -
In Situ Science and Instrumentation for Primitive Bodies

April 30-May 3, 2012

Pasadena, CA

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Rosetta Mission References

- Schulz, R., Alexander, C., Boehnhardt, H., Glassmeier, K.-H., Editors, *Rosetta – ESA's Mission to the Origin of the Solar System*, Springer, ISBN 978-0-387-77517-3, DOI: 10.1007/978-0-387-77518-0, 2009.
- Space Science Reviews, 128, 2007.

Outline of Talk

- ESA Rosetta Mission Overview
- Orbiter Instruments (Andy Morse to cover Philae lander)
  - Overview
  - Remote sensing
  - Insitu
- Conclusions

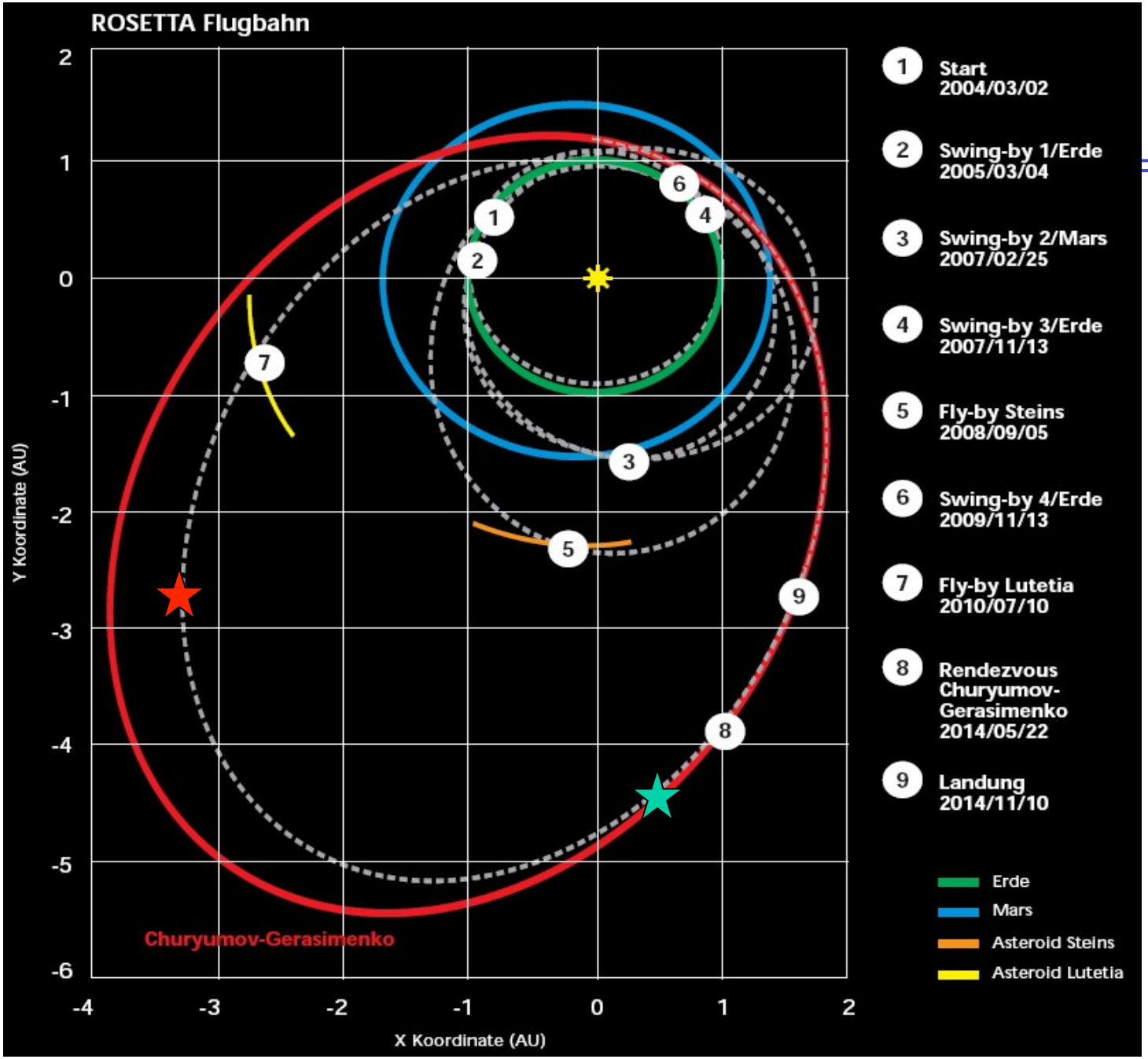
Rosetta Mission Overview

- THIRD CORNERSTONE MISSION OF ESA
- LAUNCHED 4 March 2004 WITH ARIANE 5 (DELAYED IGNITION)
- LAUNCHED FROM KOUROU, FRENCH GUIANA
- FOUR PLANETARY (EMEE) GRAVITY ASSISTS
- LILT TECHNOLOGY SOLAR PANELS (64 m^2 – 32 m tip-to-tip)
- LONG PERIOD OF HIBERNATION (Mar 2011- Jan 2014)
- 2.2-meter STEERABLE HIGH GAIN ANTENNA
- TWO ASTEROID FLYBYS (STEINS 07 & LUTETIA 10)
  - Steins (800 km @ 8.6 km/s) Lutetia (3170 km @ 15 km/s)
- RENDEZVOUS WITH COMET CHURYUMOV-GERASIMENKO
  - Period 6.45 yr; Perihelion 1.289 AU; Aphelion 5.68 AU; 2 km radius
- ELEVEN SCIENTIFIC INSTRUMENTS ON ORBITER
- TEN LANDER INVESTIGATIONS
- NEAR COMET OPERATIONS ~ 17 MONTHS

Rosetta Mission Science Objectives

- Global Characterizationof Nucleus, Surface Morphology and Composition, Dynamic Properties
- Chemical, Mineralogical, and Isotopic Composition of Volatiles and Refractories in Cometary Nucleus
- Physical Properties and Interrelation of Volatiles and Refractories in Cometary Nucleus
- Study of Development of Cometary Activity and the Processes in Surface Layer of Nucleus and in the Inner Coma
- Origin of Comets, Relationship between Cometary-Interstellar Material, Origin of Solar System
- Global Characteristics of Asteroids, Dynamic Properties, Surface Morphology and Composition

Gravity Assist Route to C-G

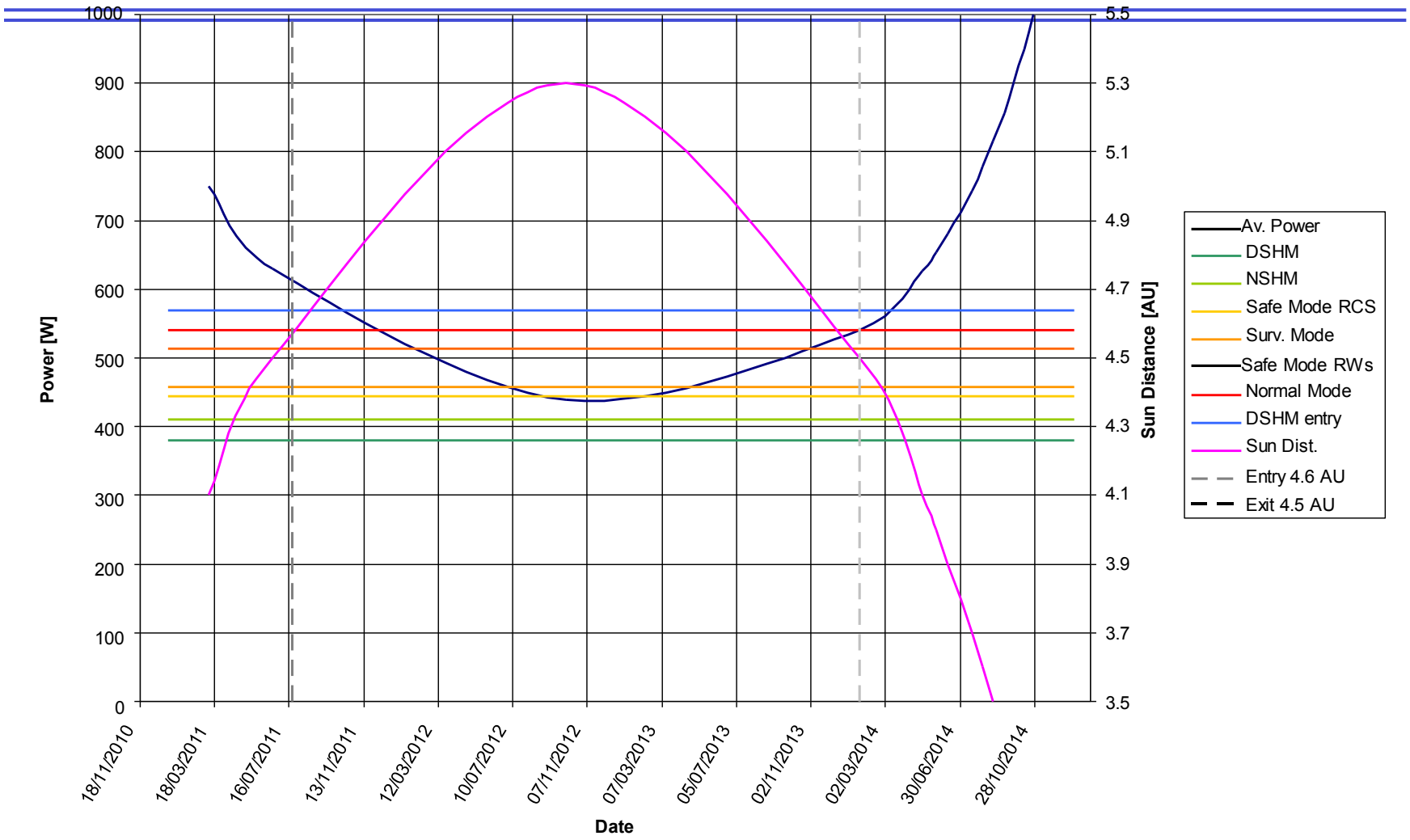


Hibernation Entry

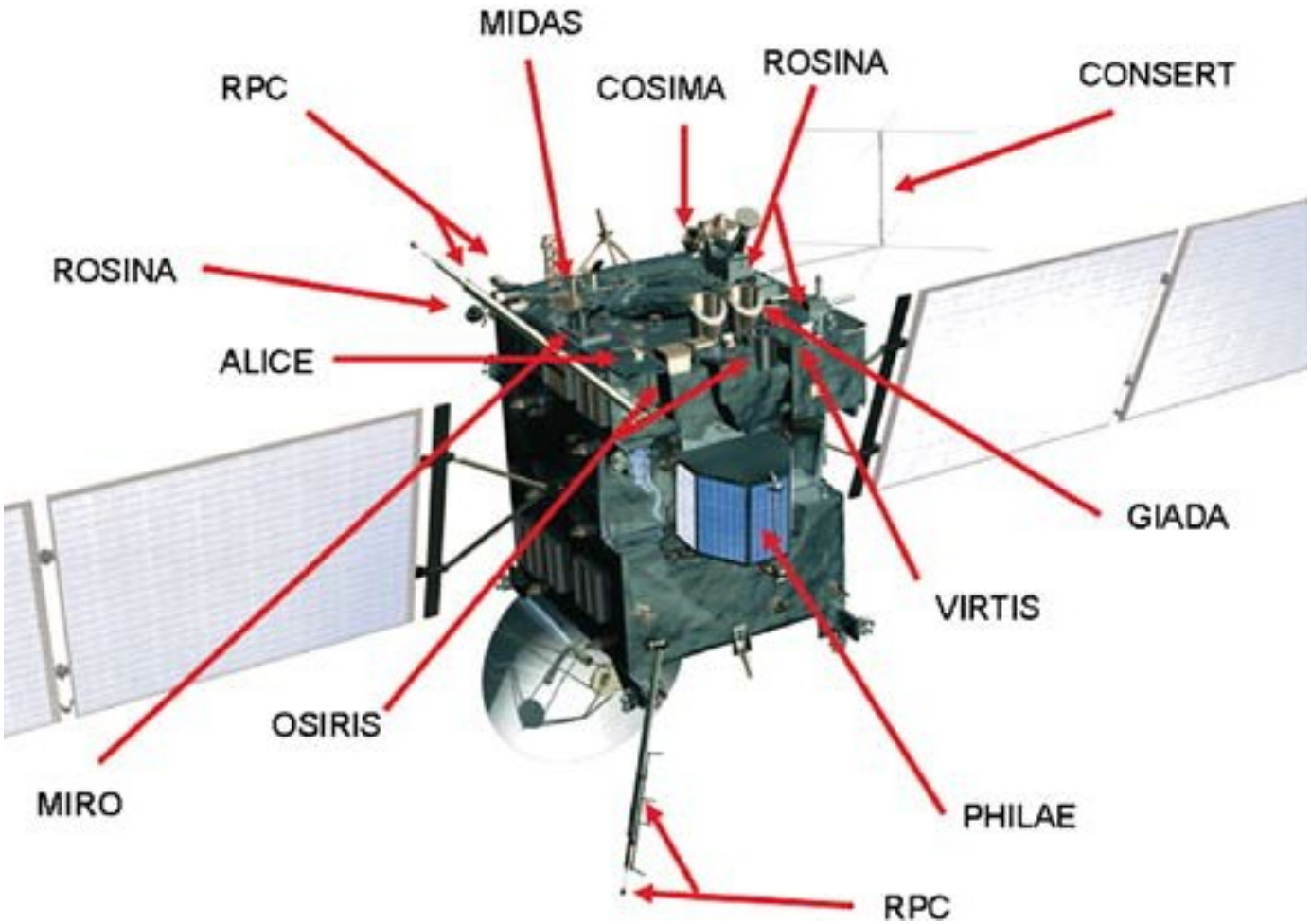
Hibernation Exit

Extended Solar Panels
(64 m^2 – 32 m tip-to-tip – 10 panels)

Power Status – DSH Entry/Exit Dates



Rosetta Spacecraft and Science Payload



Glassmeir et al. (2009), Rosetta, Springer. pp 1,20.

Rosetta Orbiter Scientific Payload (alphabetical)

1) ALICE - Ultraviolet Imaging Spectrometer (Stern/Parker)
2) CONSERT- Comet Nucleus Sounding (Kofman)
3) COSIMA- Cometary Secondary Ion Mass Analyser (Kissel/Hilchenbach)
4) GIADA- Grain Impact Analyser and Dust Accumulator (Colangeli/)
5) MIDAS - Micro-Imaging Analysis System (Riedler)
6) MIRO -Microwave Instrument for the Rosetta Orbiter (Gulkis)
7) OSIRIS- Rosetta Orbiter Imaging System (Keller, Sierks)
8) ROSINA- Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (Balsinger, Altwegg)
9) RPC- Rosetta Plasma Consortium(*6 principal scientist*)
10) RSI -Radio Science Investigation (Patzold)
11) VIRTIS - Visible and Infrared Mapping Spectrometer (Coradini, Capaccioni)

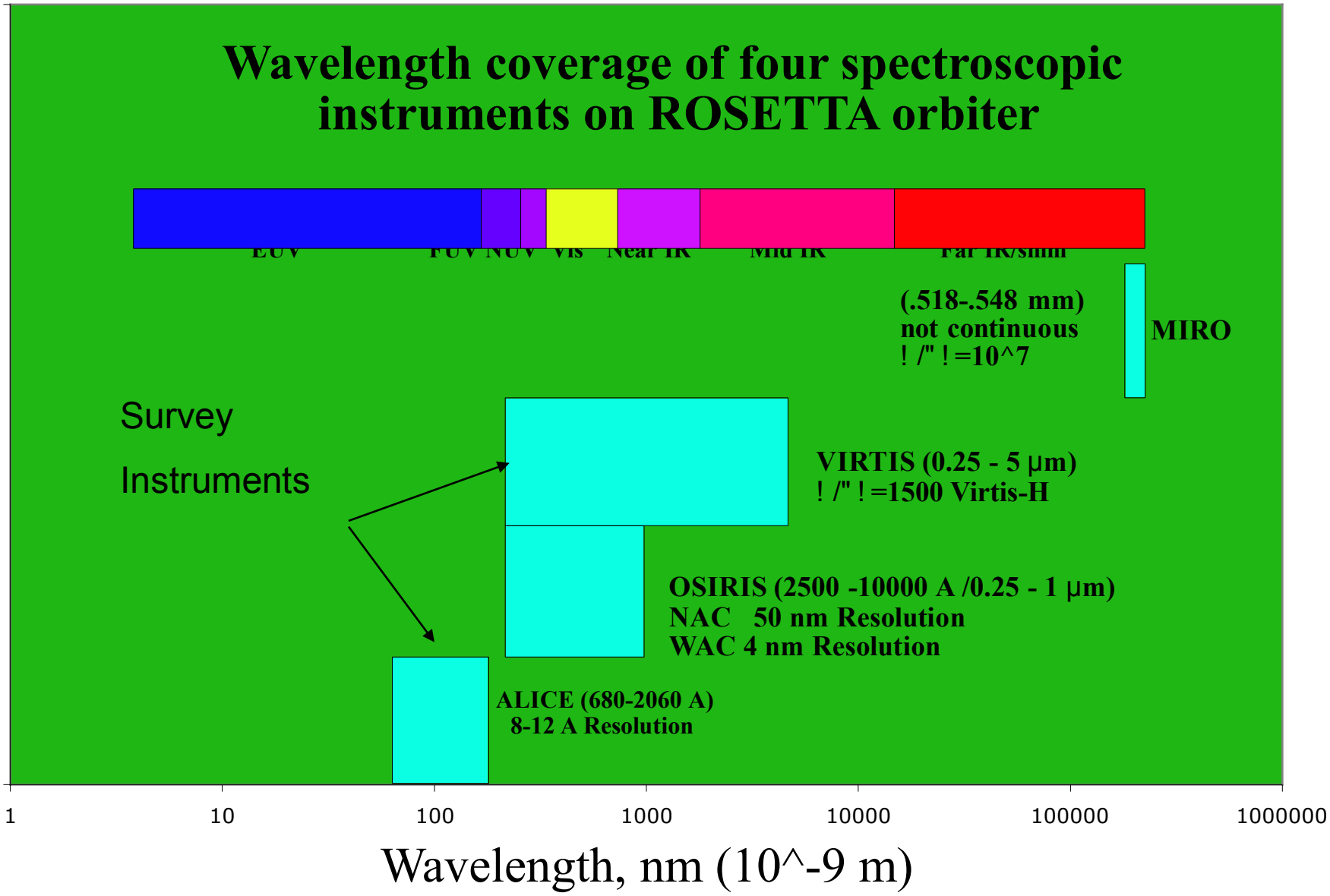
ROSETTA ORBITER PAYLOAD

INSTRUMENT	Mass(kg)	Power(W)	Range
ALICE	2.35	2.94	700-2050 Å
CONSERT	3	3	86-94 MHZ
COSIMA	19.8	20.4	1-3500 amu
GIADA	6.25	20.6	
MIDAS	8.2	8.3-13.4	
MIRO	20.32	18.2-68.8	1.3 & 0.5 mm
OSIRIS	35	<34>	250-1000 nm
ROSINA	36	53	
RPC	7.45	12.1	
RSI			
SREM	2.5	2.6	
VIRTIS	23-30?	<38.2)	

Remote Sounding Instruments

Remote Sensing Instruments

NAME	BAND	RESOLUTION
ALICE	680-2060 Å	8-12 Å
MIRO	1.6 mm; 0.5 mm	C ; C λ/dλ = 10^7
OSIRIS (NAC)	270-990 nm	FUV, NUV, Blue, Green, Orange,Red, Ortho, NIR, Fe2O3, IR
OSIRIS (WAC)	245-640 nm	UV245, CS,UV295, OH, UV325, NH, uv375, CN, green, NH2, Na, Vis, O I, R
VIRTIS – M (VISIBLE)	220.1-1046.0 nm	λ/dλ = 100-380 /Rad cooled
VIRTIS – M (IR)	952.8-5059.2 nm	λ/dλ = 70 -360 / Rad cooled
VIRTIS - H	2000-5000 nm	λ/dλ = 1300–3000 /Rad cooled
CONSERT	90 MHZ	
RSI	2.3 & 8.4 GHz	Coherent 2 way Xup/X&Sdn

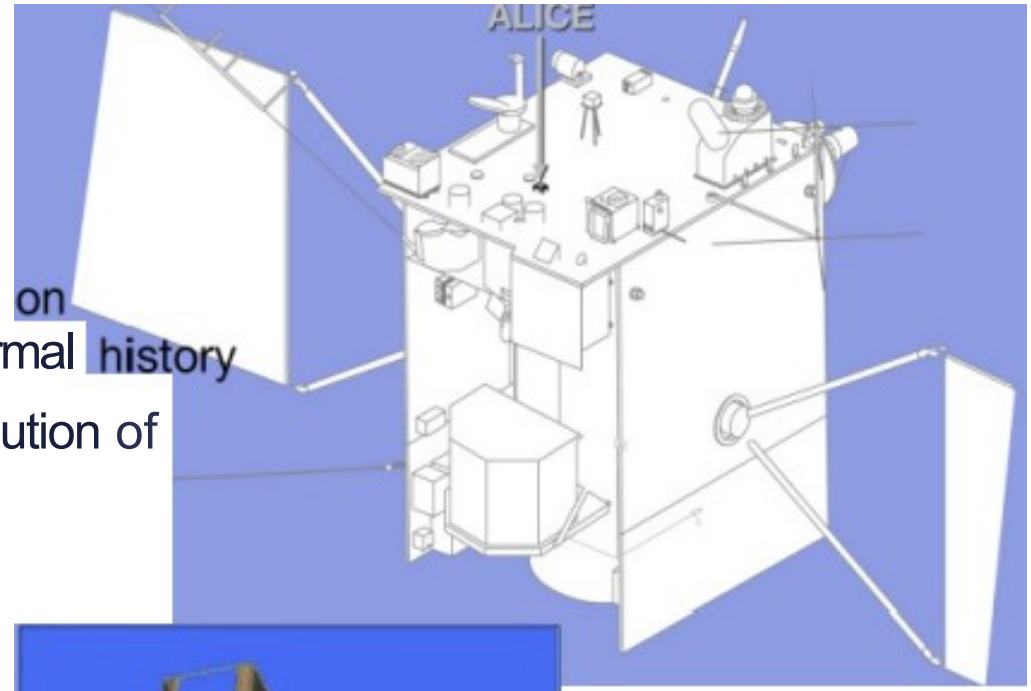

Wavelength coverage of four spectroscopic instruments on ROSETTA orbiter
EUV
FUV
NUV
Vis
Near IR
Mid IR
Far IR/submm
(.518-.548 mm)
not continuous
! /" ! =10^7
MIRO
Survey
Instruments
VIRTIS (0.25 - 5 µm)
! /" ! =1500 Virtis-H
OSIRIS (2500 -10000 A /0.25 - 1 µm)
NAC 50 nm Resolution
WAC 4 nm Resolution
ALICE (680-2060 A)
8-12 A Resolution
1
10
100
1000
10000
100000
1000000
Wavelength, nm (10^-9 m)

ALICE

PI: A. Stem (SWRI, USA)

UV-Spectrometer

- Determine volatalized noble gas content of nucleus - information on the formation temperature and thermal history
- Production rates and spatial distribution of H20, CO, C02
- Atomic budget measurements of C, H, 0, N, S - elemental com position of volatiles on nucleus
- Study onset of activity
- Spectral mapping of nucleus
- Photometric properties and ice/ ice/rock ratio of small grains
- Time variability of 0 +, N+, S+, C+ emissions in coma and ion tail



Co-InvestigatOtS
USA
France

MIRO Instrument Overview

STRUCTURAL THERMAL MODEL

Telescope

30 cm diameter

Boresight along z-axis of s/c

Receivers (two)

Two bands

190 GHz (1.6 mm)

563 GHz(0.5 mm)

Continuum - both bands

Spectroscopic (563 GHz only)

Single linear polarization(crossed)

Flip-mirror calibration(warm-cold-sky)

Half Power Beam Widths

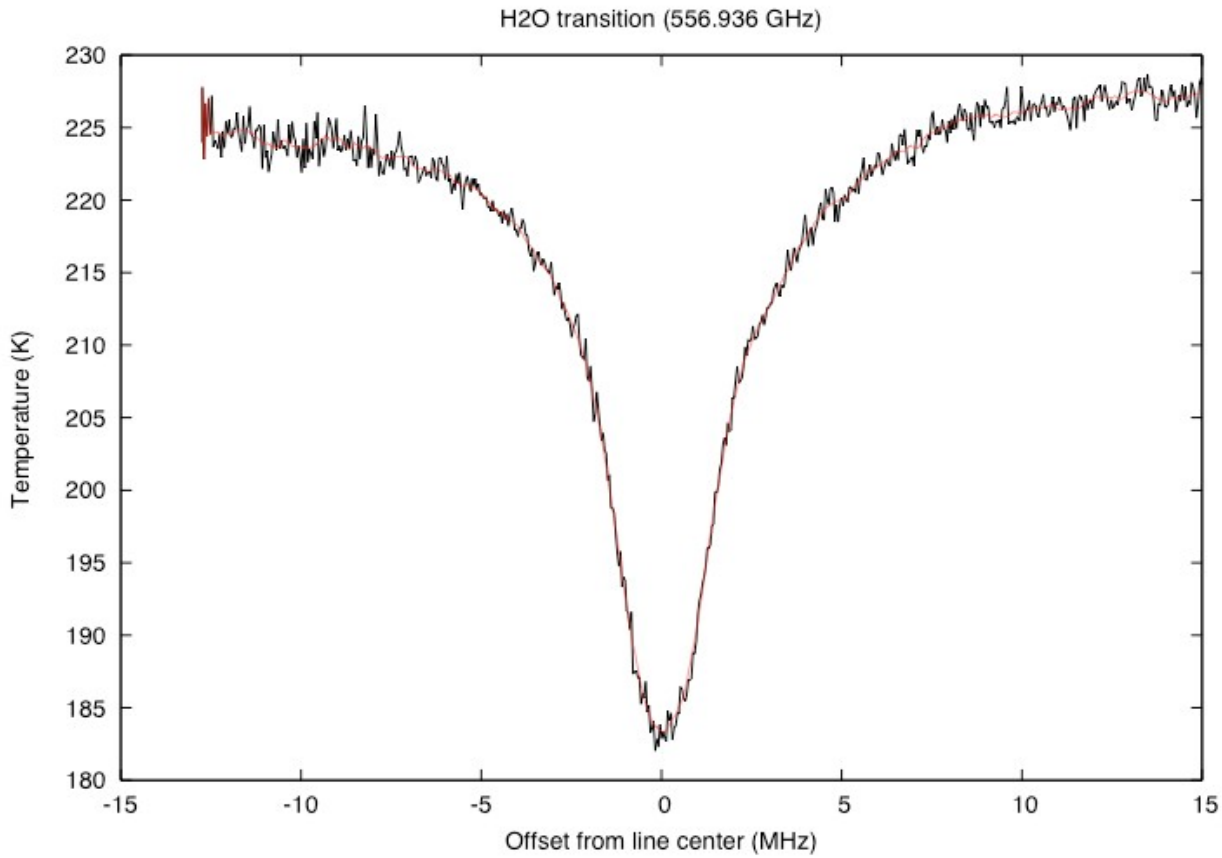
Submillimeter HPBW- 7.5 arc min

Millimeter HPBW- 23.8 arc min

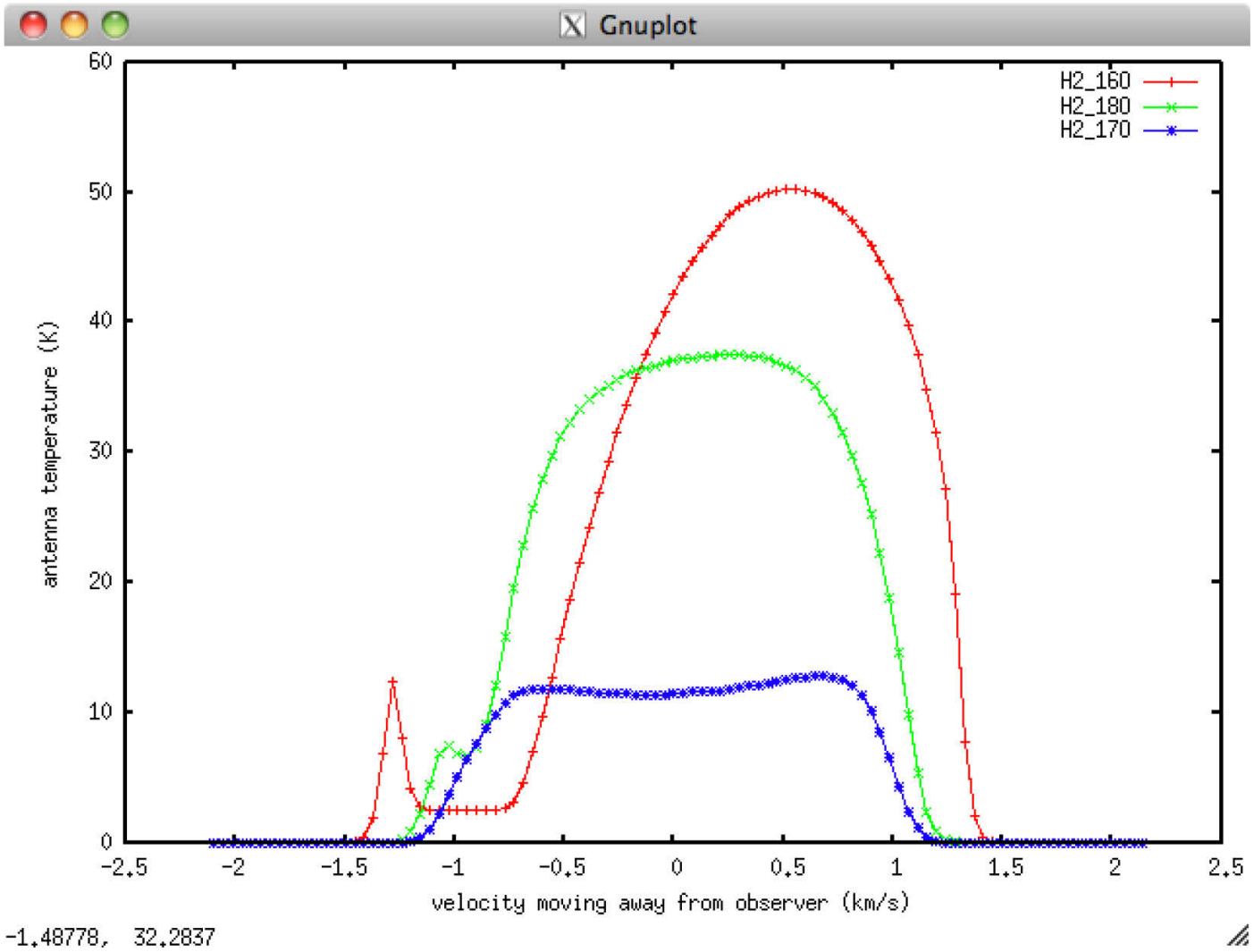
MIRO SPECTRAL LINES

SPECIES		FREQUENCY(Mhz)	TRANSITIONS
WATER	$H_2{}^{16}O$	556936.002	1(1,0)-1(0,1)
	$H_2{}^{17}O$	552020.96	1(1,0)-1(0,1)
	$H_2{}^{18}O$	547676.44	1(1,0)-1(0,1)
CARBON MONOXIDE	CO	576267.9305	J(5-4)
AMMONIA	NH_3	572498.3748	J(1-0)
METHANOL	CH_3OH	553146.296	8 1-7 0 (72.33 cm^{-1})
	CH_3OH	568566.054	3 2 - 2 1 (27.29 cm^{-1})
	CH_3OH	579151.005	12 1 - 11 1(129.19 cm^{-1})

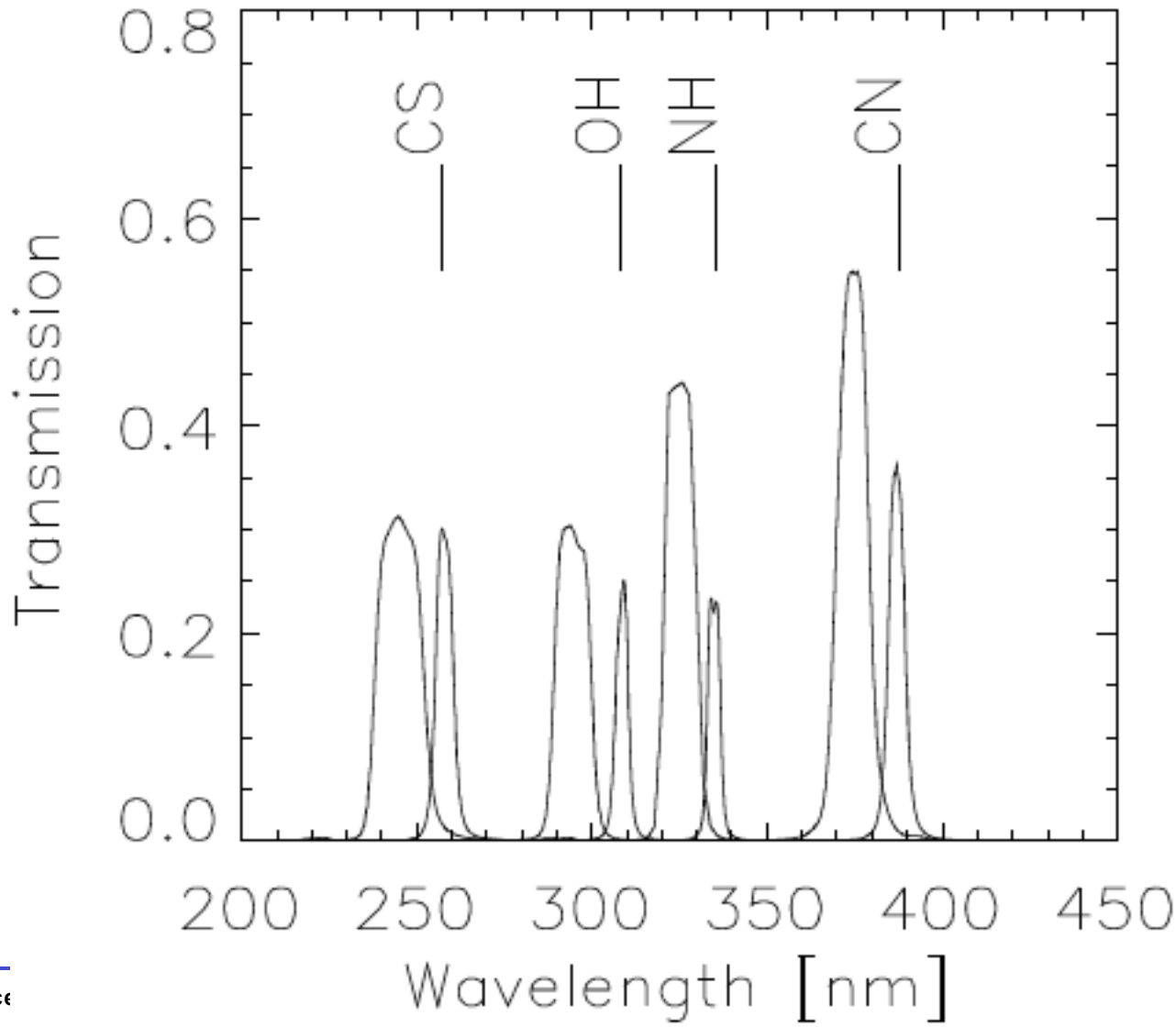
Water Line in Earth's Atmosphere ESB2



H2O Spectrum at 1.3 AU with Q=1E28 mol/s
d1=100 km, d2=7.5km (computed by S. Lee)



OSIRIS WIDE ANGLE CAMERA UV FILTERS



Fundamental Bands of Potential Comet Molecules with VIRTIS

σ (cm^{-1})	λ (μm)	Band	g-factor (s^{-1})	Molecule	σ (cm^{-1})	λ (μm)	Band	g factor (s^{-1})	Molecule
2062.2	4.849	ν_3	2.5×10^{-3}	OCS	3017.0	3.315	ν_4	5.5×10^{-4}	CH_3D
2077.0	4.815	ν_3	2.0×10^{-5}	HC_3N	3019.5	3.312	ν_3	4.0×10^{-4}	CH_4
2138.0	4.677	ν_3	2.3×10^{-5}	CH_3CCH	3047.9	3.281	ν_{12}	2.0×10^{-4}	C_6H_6
2143.2	4.666	1–0	2.6×10^{-4}	CO	3105.3	3.220	ν_9	1.4×10^{-4}	CH_2CH_2
2157.8	4.634	ν_3	2.2×10^{-5}	C_2N_2	3212.9	3.112	ν_1	6.2×10^{-4}	H_2O+
2200.0	4.545	ν_2	2.2×10^{-5}	CH_3D	3259.0	3.068	ν_3	2.4×10^{-3}	H_2O+
2272.0	4.401	ν_2	1.1×10^{-4}	HC_3N	3294.8	3.035	ν_3	1.7×10^{-4}	CHCH
2289.9	4.367	ν_3	1.0×10^{-2}	OC_3O	3311.5	3.020	ν_3	3.5×10^{-4}	HCN
2349.1	4.257	ν_3	2.6×10^{-3}	CO_2	3327.0	3.006	ν_1	8.6×10^{-4}	HC_3N
2727.0	3.667	ν_1	6.5×10^{-5}	HDO	3333.7	3.000	ν_4	1.5×10^{-4}	HCCCCH
2782.5	3.594	ν_1	3.9×10^{-4}	H_2CO	3335.1	2.998	ν_1	2.5×10^{-4}	CH_3CCH
2843.3	3.517	ν_5	4.6×10^{-4}	H_2CO	3337.0	2.997	ν_1	3.4×10^{-5}	NH_3
2844.0	3.516	ν_3	1.5×10^{-4}	CH_3OH	3444.0	2.904	ν_3	2.0×10^{-5}	NH_3
2901.0	3.447	ν_3	4.7×10^{-4}	CH_3CH_2OH	3519.4	2.841	ν_3	5.8×10^{-3}	H_3O+
2941.0	3.400	ν_2	1.0×10^{-4}	CH_3CCH	3568.0	2.803	1–0	6.0×10^{-5}	OH
2942.0	3.399	ν_2	1.9×10^{-4}	HCOOH	3569.0	2.802	ν_1	3.6×10^{-4}	HCOOH
2945.0	3.396	ν_1	3.3×10^{-5}	CH_3D	3607.0	2.772	ν_1	1.0×10^{-4}	H_2O_2
2954.0	3.385	ν_1	1.5×10^{-5}	CH_3CN	3608.0	2.772	ν_5	6.0×10^{-4}	H_2O_2
2970.0	3.367	ν_9	3.5×10^{-4}	CH_3OH	3657.0	2.734	ν_1	1.8×10^{-5}	H_2O
2971.0	3.366	ν_2	3.9×10^{-4}	CH_3CH_2OH	3660.0	2.732	ν_1	1.0×10^{-4}	CH_3CH_2OH
2980.9	3.355	ν_6	8.5×10^{-5}	CH_3CCH	3681.0	2.717	ν_1	1.3×10^{-4}	CH_3OH
2988.6	3.346	ν_{11}	7.3×10^{-5}	CH_2CH_2	3707.0	2.698	ν_3	1.9×10^{-4}	HDO
2999.0	3.334	ν_2	1.9×10^{-4}	CH_3OH	3755.9	2.662	ν_3	2.6×10^{-4}	H_2O

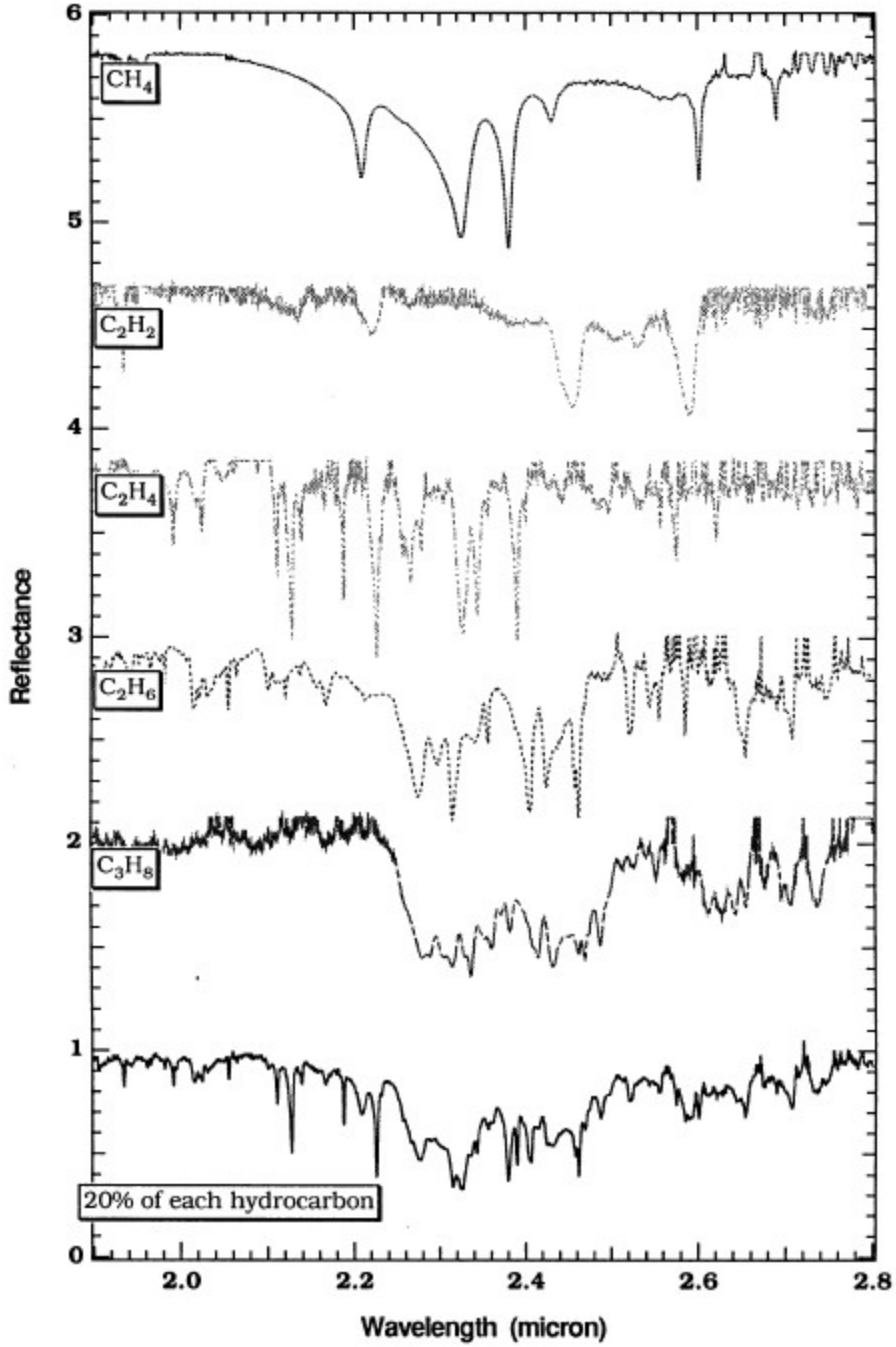
VIRTIS

Theoretical reflectance spectra of solid hydrocarbons

(CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_8)
and their mixture at a spectral resolution of 1500

Identification is possible with VIRTIS-H

Source -Fabrizio Capaccioni



Partial listing of coma gases detectable with Rosetta instruments (1/2)

Type	Species	ALICE	MIRO	OSIRIS	VIRTIS	ROSINA
Atomic	C	■				■
	H	■				■
	O	■				■
	N	■				■
	S	■				■
Noble	He	■				■
	Ne	■				■
	Ar	■				■
	Kr	■				■
Parent	H2O	■	■		■	■
	CO	■	■		■	■
	CO2	■			■	■
	NH3		■		■	■
	CH3OH		■		■	■
	H2CO				■	■
	CH4				■	■
	HCN				■	■
	H2S				■	■
	N2	■				■

Partial listing of coma gases detectable with Rosetta instruments (2/2)

Type	Species	ALICE	MIRO	OSIRIS	VIRTIS	ROSINA
Ions	O+					
	N+					
	S+					
	C+					
	CH+					
	CO+					
	H2O+					
	N2+					
Isotopic	H2 17O					
	H2 18O					
	HDO					
	13CO					
Radicals	CH					
	OH					
	NH					
	CN					
	CS					
	NH2					
	Na					
	O I					

INSITU INSTRUMENTS

Insitu Instruments

NAME	BAND	RESOLUTION
ROSINA	680-2060 Å	8-12 Å
COSIMA	1.6 mm; 0.5 mm	C ; C λ/dλ = 10^7
MIDAS	270-990 nm	FUV, NUV, Blue, Green, Orange,Red, Ortho, NIR, Fe2O3, IR
GIADA	245-640 nm	UV245, CS,UV295, OH, UV325, NH, uv375, CN, green, NH2, Na, Vis, O I, R
RPC	220.1-1046.0 nm	λ/dλ = 100-380
	952.8-5059.2 nm	λ/dλ = 70 -360
	2000-5000 nm	λ/dλ = 1300 - 3000
	90 MHZ	

Rosina Instrument Package

- DFMS – Double focusing magnetic mass spectrometer
  - Mass range 1 – 150 amu
  - Mass resolution 3000 at 1% peak height
  - Optimized for high mass resolution and large dynamic range
  - Example: separate CO from N2
- RTOF – Reflection-type time of flight mass spectrometer
  - Mass range 1 – 300 amu
  - Mass resolution >500 at 1% peak height
  - Optimized for high sensitivity over broad mass range
  - Example: Measure ions and molecules in mass range 1 – 300 amu
- COPS – 2 pressure gauges based on ionization gauge principle
  - Nude gauge measures total neutral particle density
  - Ram gauge measures ram pressure

ROSINA

PI: H. Balsiger (Univ. Bern/Switzerland)

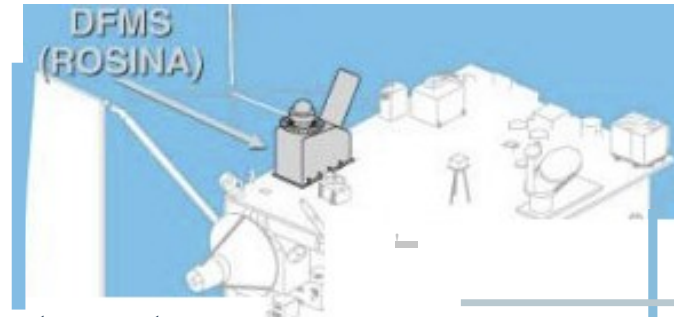
Rosetta Orbiter Spectrometer for Ion and Neutral Analysis

Two sensors:

DFMS: double focusing magnetic mass spectrometer

RTOF: reflectron type time of flight mass spectrometer

- Elemental, isotopic, molecular composition of cometary atmosphere and ionosphere
- Bulk velocities of neutral and ionized components
- Homogeneous and inhomogeneous reactions of neutrals and ions in dusty cometary atmosphere and ionosphere
- Investigate possible asteroid outgassing

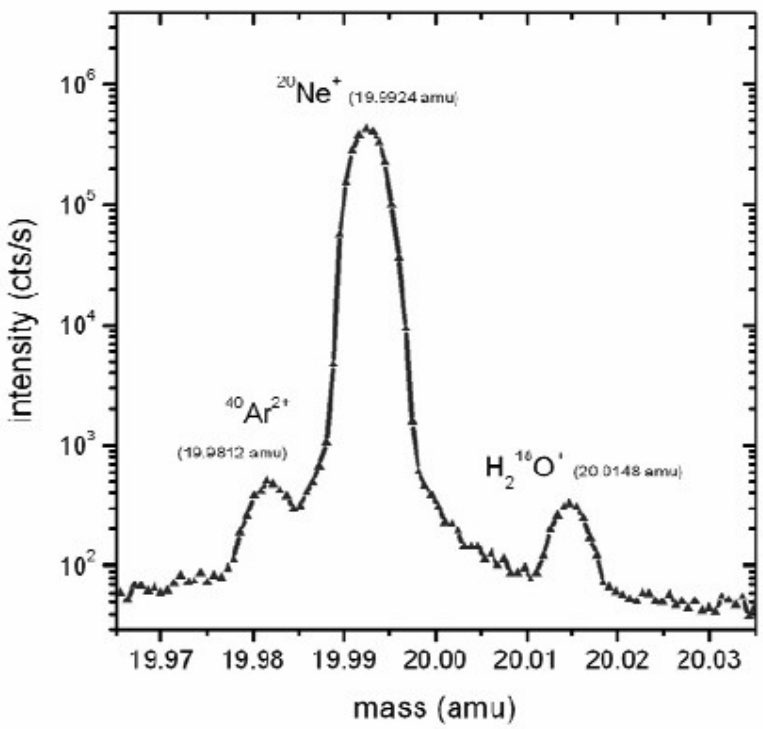


DFMS

Co-Investigators

Switzerland
France
Belgium
USA
Germany

ROSINA: Need for high mass resolution



^{40}Ar++ ^{20}Ne+ $H_2{}^{18}O$+

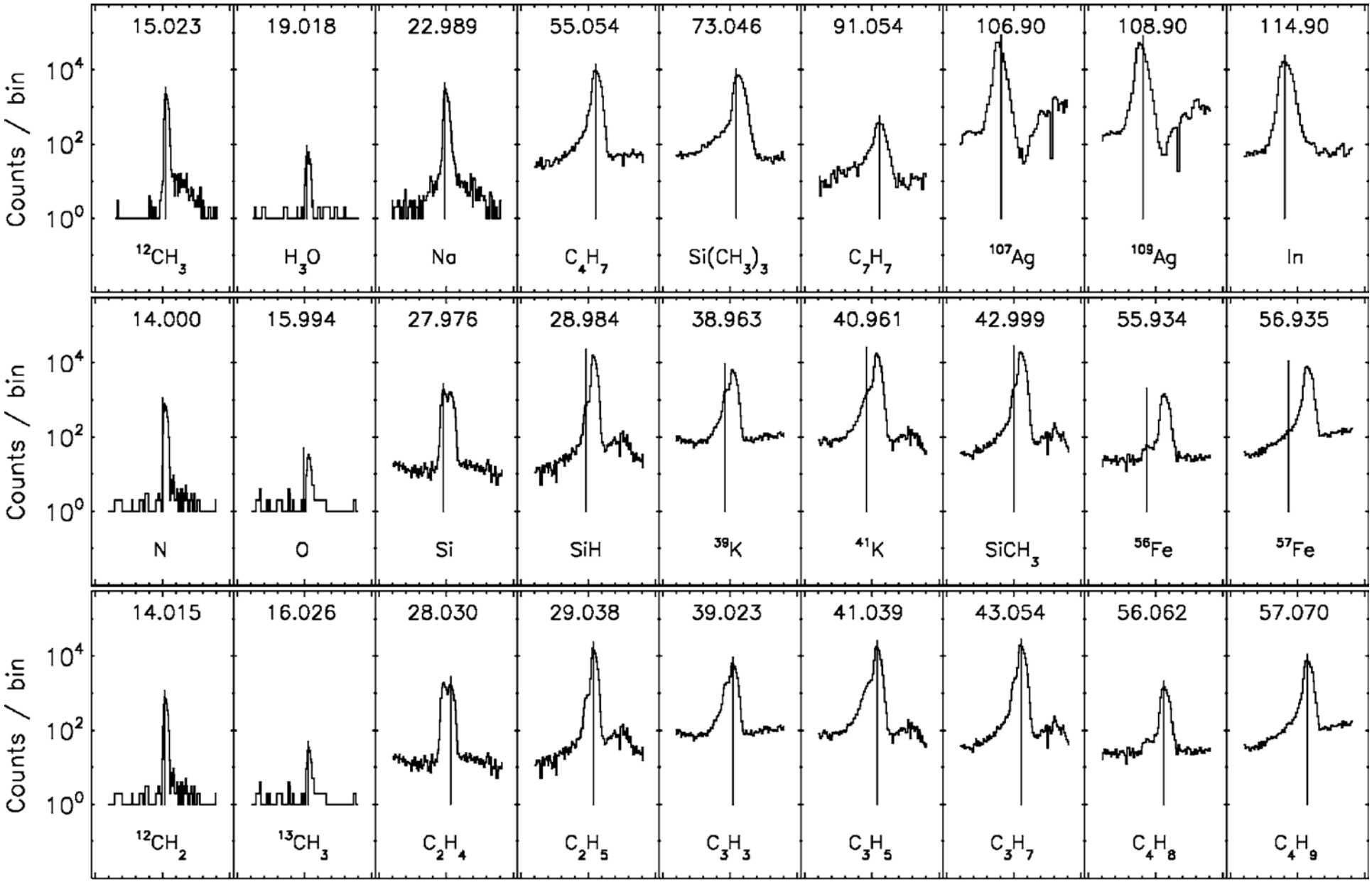
- **CO^+ from $N_2{}^+$**
  - **27.9949 vs 28.0061**
  - **m/dm = 2492**
- **$^{13}C^+$ from $^{12}CH^+$**
  - **13.0033 vs 13.0078**
  - **m/dm = 2890**
- **^{20}Ne+ from ^{40}Ar++**
  - **m/dm = 1785**

Balsiger et al., 2006.

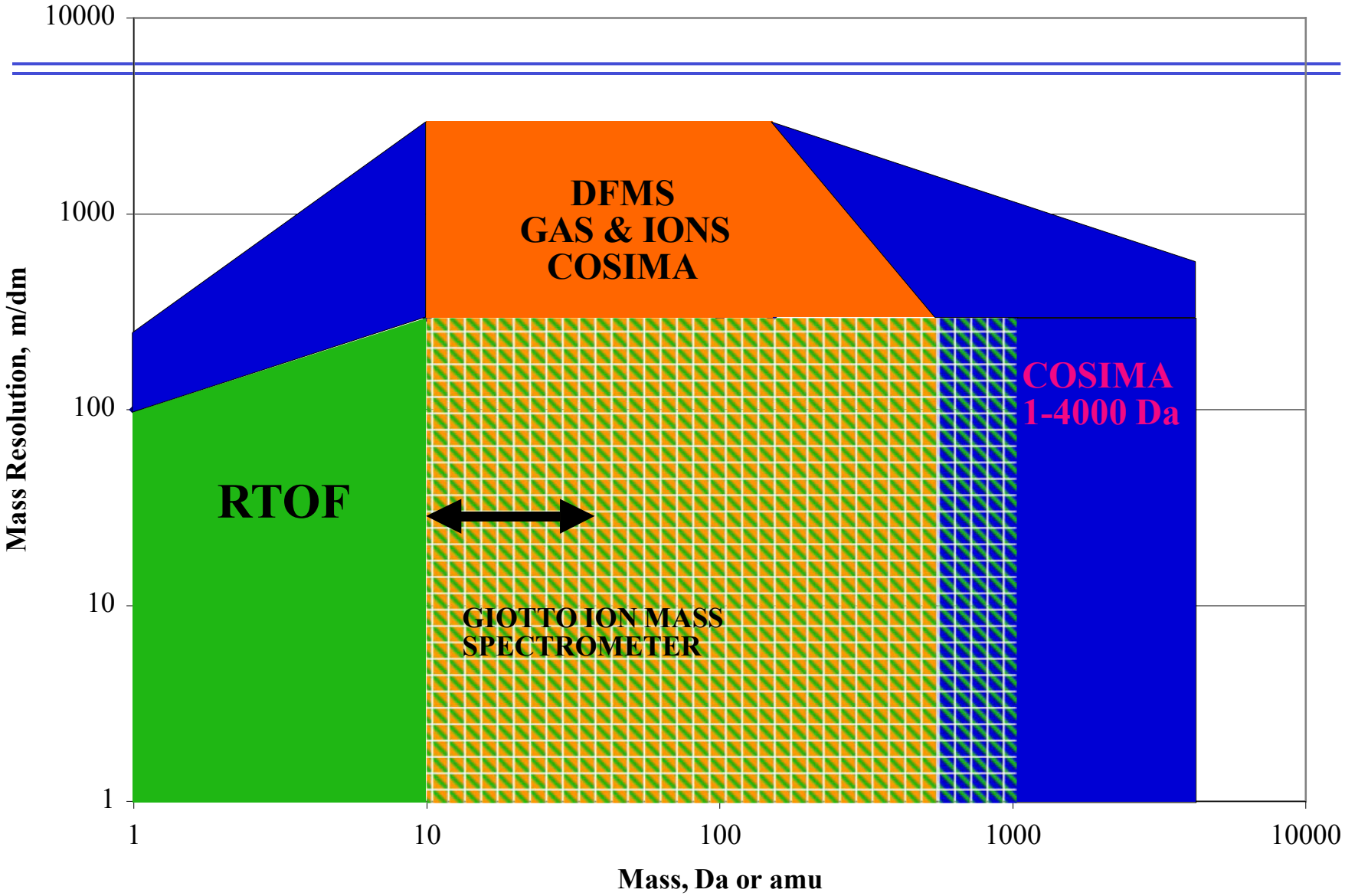
COSIMA: Cometary Secondary Ion Mass Analyzer
Time of Flight secondary ion mass spectrometer

- Cometary Secondary Ion Mass Analyser
  - –Atomic Mass Range = 1 – 3500 amu
  - –Mass resolution – m/delta m (@100 amu) > 2000 at 50% peak width
- Cometary Dust is collected on targets (Au or Ag evaporate in Argon)
- Particles are located using microscopic camera
- Pulsed Indium (^{115}In) ion beam (8 keV) partially ionises dust grain
- Secondary ions (pos or neg) are accelerated in electric field
- Time of flight analyser measures ion masses
- Search for
  - Elemental composition of particles
  - Isotopic composition in solid particles (H, C, Mg, Ca, Ti)
  - Molecular composition of inorganics and organics
  - Variations with heliocentric distance

First COSIMA Inflight + Seconday Ion Measurements



COSIMA AND ROSINA MASS SPECTROMETERS

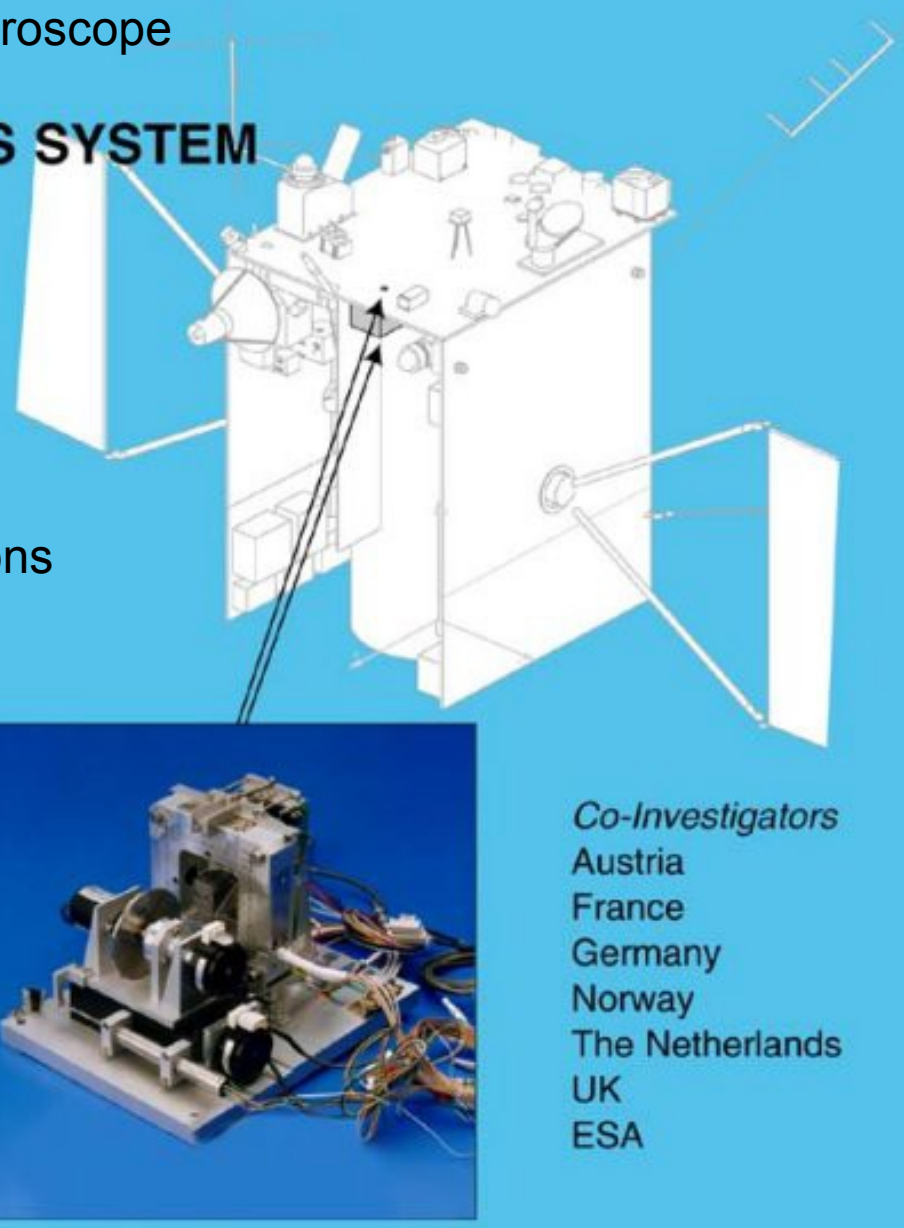


Atomic Force Microscope

MIDAS
MICRO-IMAGING DUST ANALYSIS SYSTEM

PI: W. Riedler (SRI, Graz, Austria)

- Images of single particles (spatial resolution 4 nm)
- Statistical evaluations on sizes, volumes and shapes
- Size distribution from ~ 4 nm to a few μm .004 microns
- Shape, volume, topographic structure of individual particles
- Spatial and temporal variations of particle flux
- Characterization of dust environment of the asteroids
- Imaging and statistical analysis of impact craters caused by interplanetary dust particles



Co-Investigators
Austria
France
Germany
Norway
The Netherlands
UK
ESA

GIADA (Grain Impact Analyser and Dust Accumulator)

- Measures the number, mass, momentum and velocity distribution of dust grains coming from the nucleus and from other directions.
- GIADA will be able to monitor grain fluxes coming from different directions simultaneously
- How it works

Optical system detects transit of individual grains

Mass/size of single particles: > 15 μm

Piezoelectric(PZT) impact sensor monitors momentum released on alum plate

6.5 E-10 to 4.0 E-4 kg m /s velocities < 300 m/s

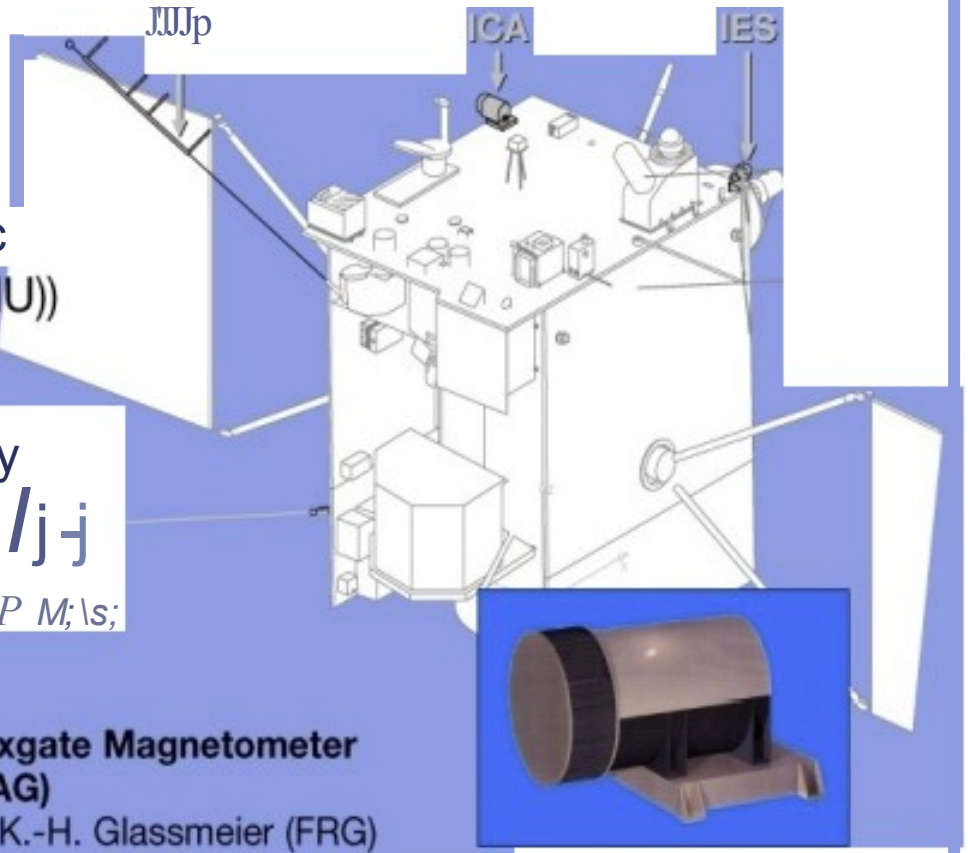
Microbalance system (MBS) measures cumulative dust deposition in 5 directions

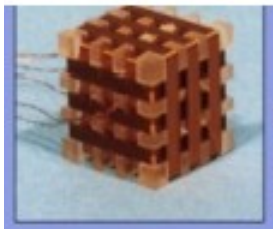
Cumulative mass sensitivity 1.0 E-10 g micron/submicron particles

ROSETTA ORBITER PLASMA CONSORTIUM (RPC)

(5 Sensors &joint instrument control, spatc craft interface, power management unit (PIU))

- Physical properties of the nucleus
- Inner coma structure, dynamics, aeronomy
- Development of cometary activity
- Solar-wind interaction
- Formation and evolution of plasma tail
- Solar-wind asteroid interaction



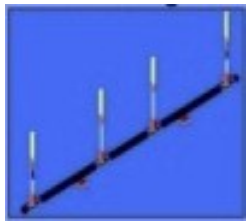


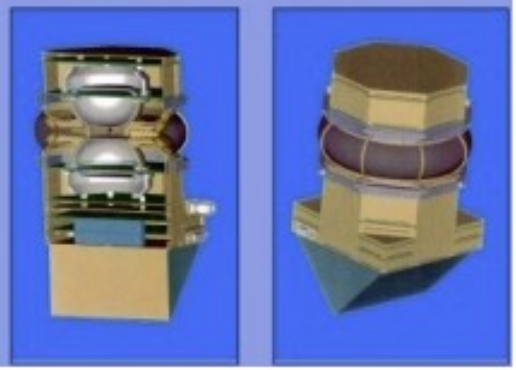
Fluxgate Magnetometer (MAG)
PI: K.-H. Glassmeier (FRG)

Ion Composition Analyser (ICA)
PI: R. Lundin (S)

Langmuir Probe (LAP)
PI: R. BostrOm (S)

Mutual mpedance Probe (MIP)
PI: J.G. (F)





Ion Electron Sensor (IES)
PI: J.L Burch (USA)

Co-Investigators
France
Sweden
UK
USA
Hungary
Germany

RPC-Ion Composition Analyser (ICA)

- Measures ion mass composition in Solar Wind and cometary ion escape
- Mass Range from 1 to 10^6 amu
- Molecular ion
  - H_2O^+ , CO^+ , CO_2^+ , CH^+ , CH_4^+ , H_2^+ , O_2^+ , N_2^+ , …..
- Atomic ions
  - H^+ , O^+ , C^+ , N^+ , …
- Mass resolution is low -
  - Difficult to separate
    - $H2O^+$ from O^+
    - CH^+ , C^+ , and N^+
- Detect big molecules and charged dust. H^+ and $H2^+$ and dusty plasma observed near Phobos using ASPERA

Full Orbit Tomography (FOT)

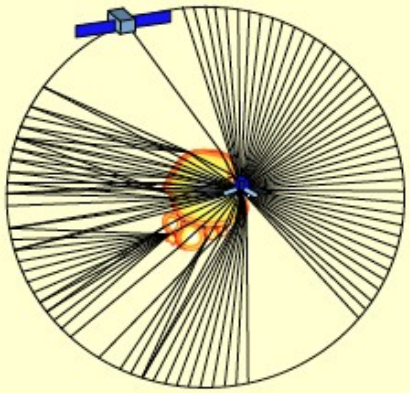
TOMOGRAPHY

Simulation SW

- Lander Landed
- Orbitography
- Nucleus shape model and rotation
- Hypothetic internal structure.

Operational software

- "consert orbit" selection
- Consert setting
  - ⇒ First version with limited performances
  - ⇒ Optimizations TBD



Radio Sounder at 90 MHz

C . O . N . S . E . R . T

A Herique

CONSERT SIMULATIONS OF SHAPE

S
H
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P
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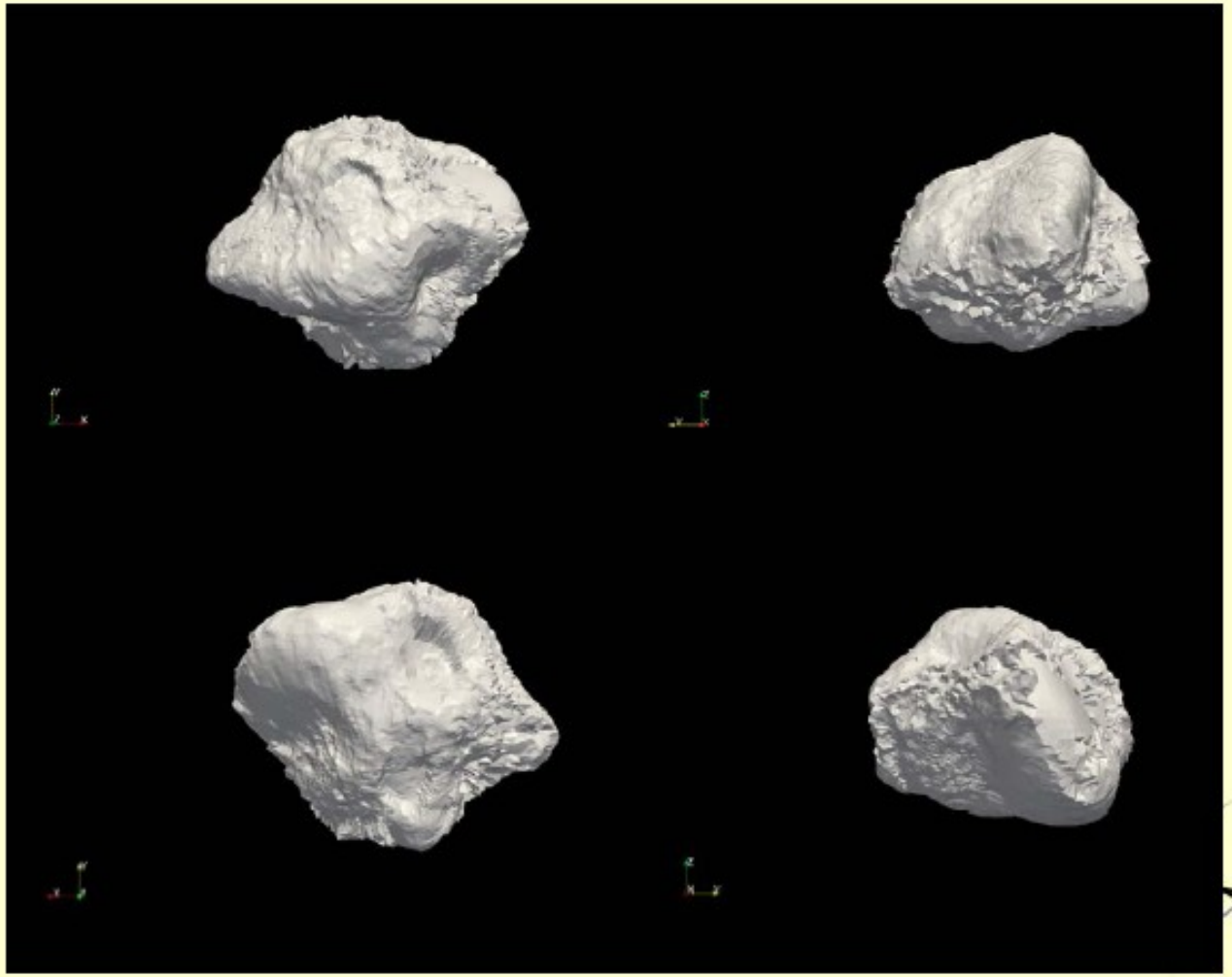
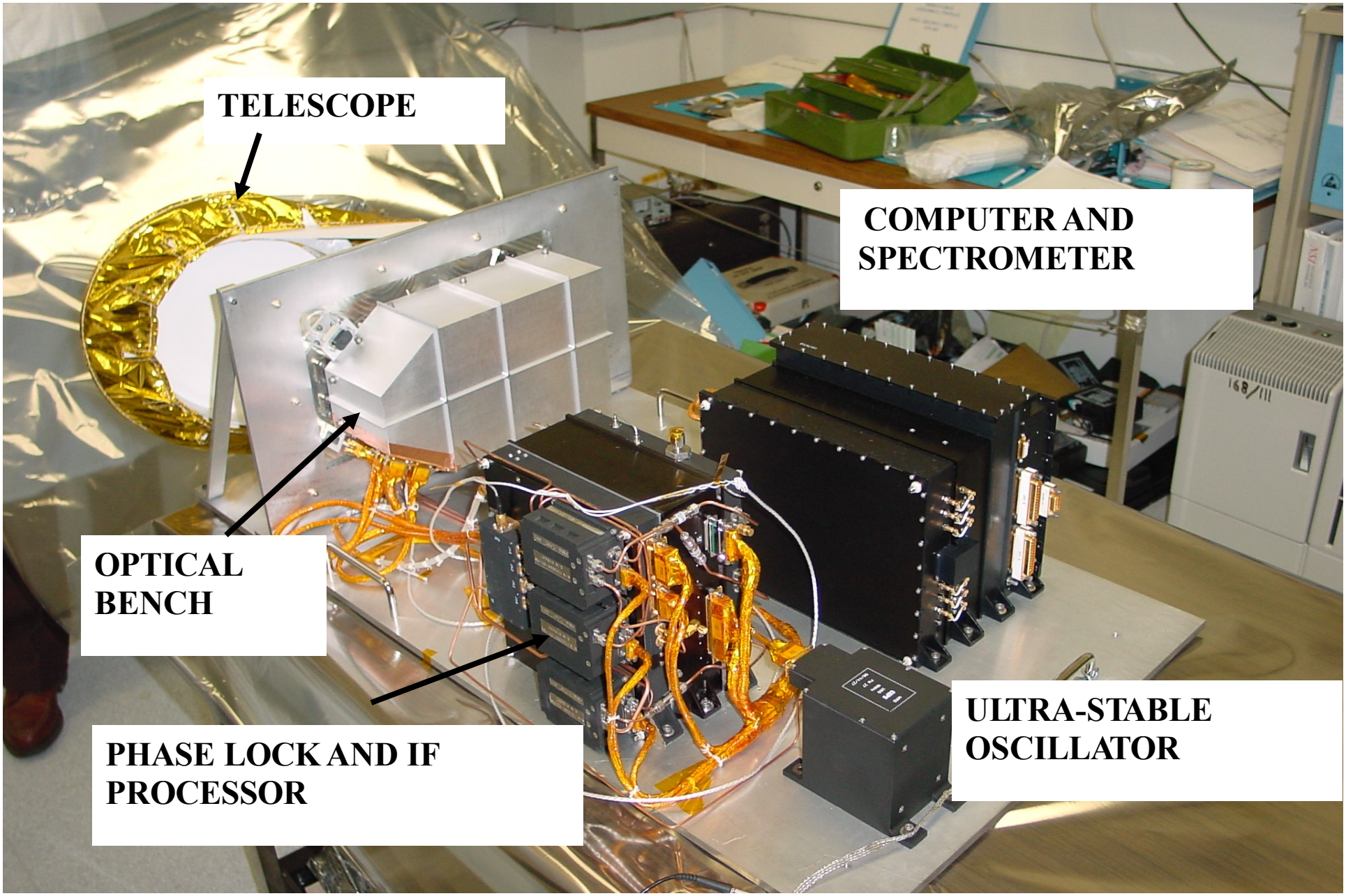
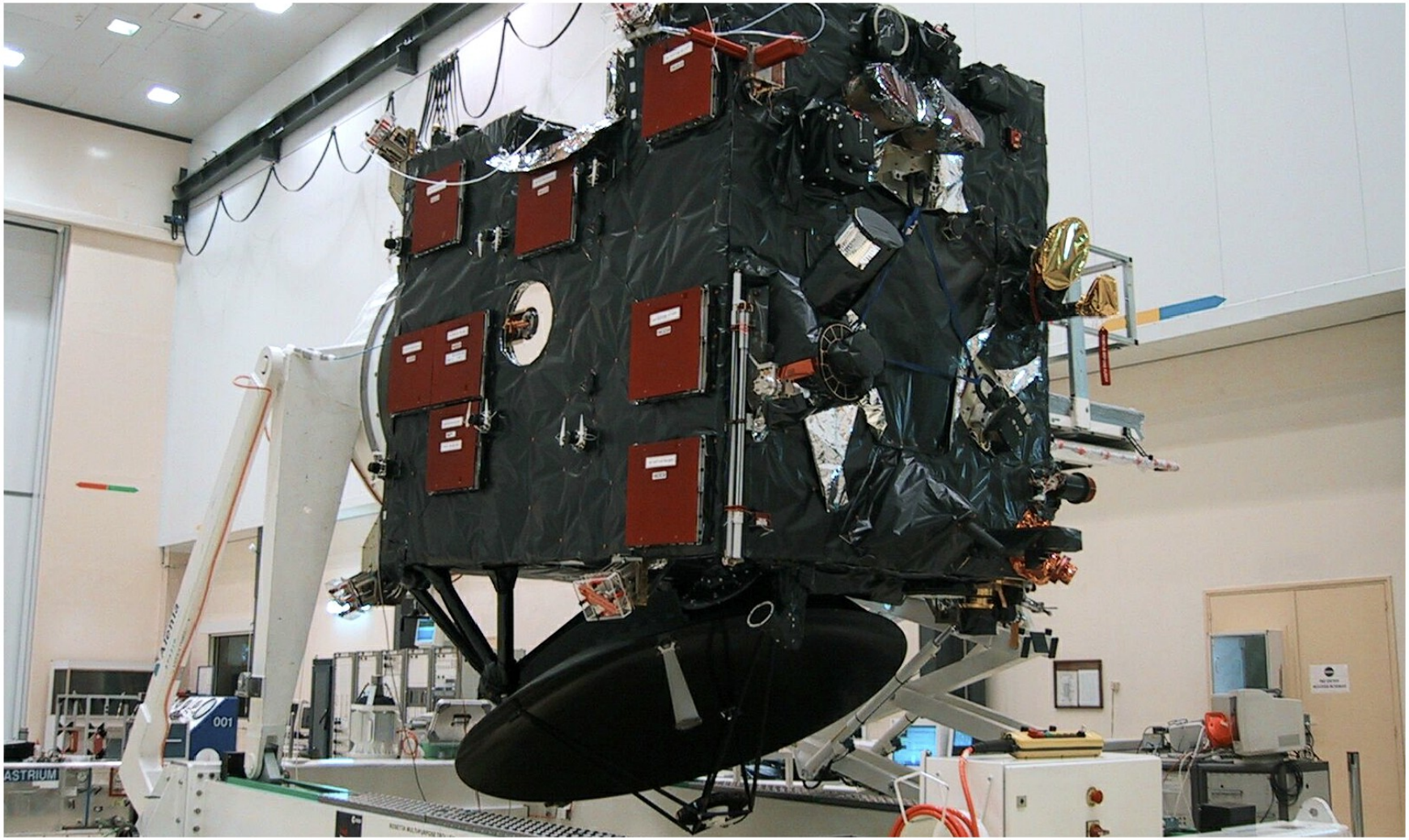


Conclusions

- Trajectory and orbit of Rosetta will provide an opportunity to observe a comet up close and for a range of heliocentric distances (relationship of surface topography to outgassing)
- Orbitter instrumentation provides wide wavelength and mass range coverage for observing the coma gas and dust - including parent molecules, noble gases, atomic species, ions, heavy (organic) molecules and various isotopic abundances
- Overlap in instrumentation provides independent measurements to aid in the analysis and interpretation of data
- Surface temperature and transition boundary region between the nucleus and coma should be well observed
- Issue of discrete vs extended sources of coma gas should be solved
- Issue of homogeneity vs heterogeneity in nucleus should be solved
- Word of caution - Every comet is unique! In extrapolating observations of C-G to conditions in the solar nebula, problem will be to identify generic comet traits from unique Churyumov-Gerashimenko properties

MIRO FLIGHT INSTRUMENT

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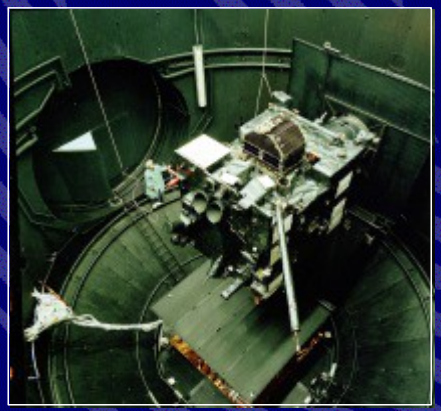
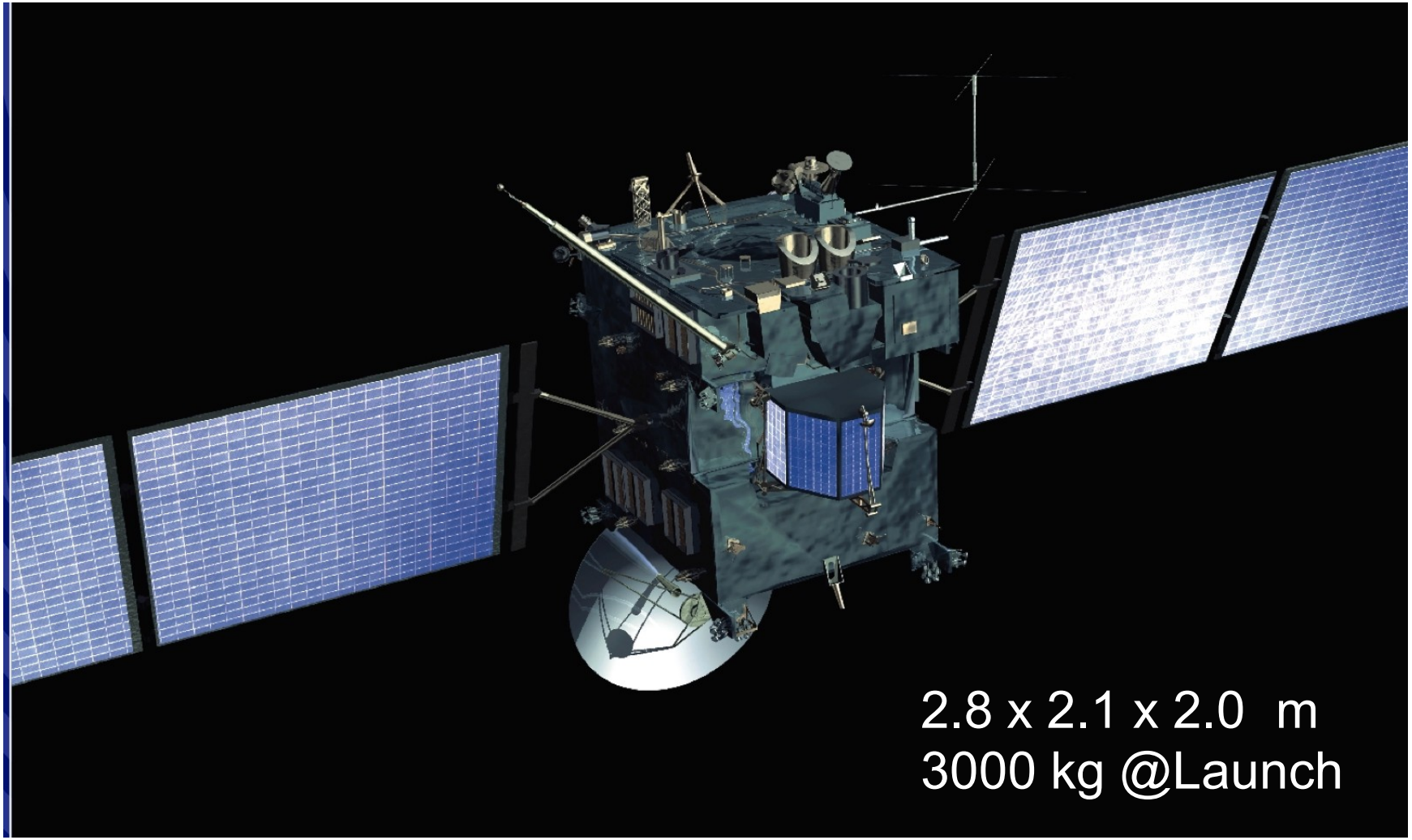
ASTRIUM

Vital statistics

The Spacecraft, Vital statistics



Size:	
main structure	2.8x2.1x2.0 metres
diameter of solar arrays	32 metres
Launch mass - total:	3000 kg (approx.)
- propellant	1670 kg (approx.)
- science payload	165 kg
- Lander	100 kg
Solar array output	850 W at 3.4 AU, 395 W at 5.25 AU
Propulsion subsystem	24 bi-propellant 10N thrusters
Operational mission	12 years

esa

Rosetta Spacecraft