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Spacecraft outgassing: Rosetta results

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Table of content

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> ROSINA

> Spacecraft outgassing
  - Permanent background and source of contamination
  - The Braycote problem
  - Transient outgassing

> Implications and ROSINA ion measurements

ROSINA:
Rosetta Orbiter Spectrometer for Ion and Neutral Analysis

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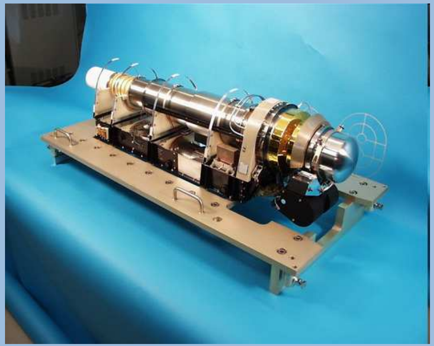
COPS:

•Measures the total neutral particle density and the ram pressure (the cometary gas flux)
•Measures the total pressure down to densities of 10^4 cm^{-3} in 10s
•Resources: 1.6 kg, mean power 3 W



RTOF:

•Covers mass range from 1 to >300 amu/e
•Mass resolution $m/\Delta m$ >1000 (at 50% peak height)
•Detects neutral particle densities of 10^4 cm^{-3} within 10-1000s for a complete spectrum
•Resources: 14.7 kg, mean power 24 W

DFMS:

•Covers mass range from 12 to 150 amu/e
•Mass resolution $m/\Delta m$ ~3000 (at 1% peak height)
•Detects neutral particle densities of 1 cm^{-3} within 20 s for one massline
•Complete mass spectrum ~20 min
•Resources: 16.2 kg, mean power 19 W

Permanent outgassing of the spacecraft

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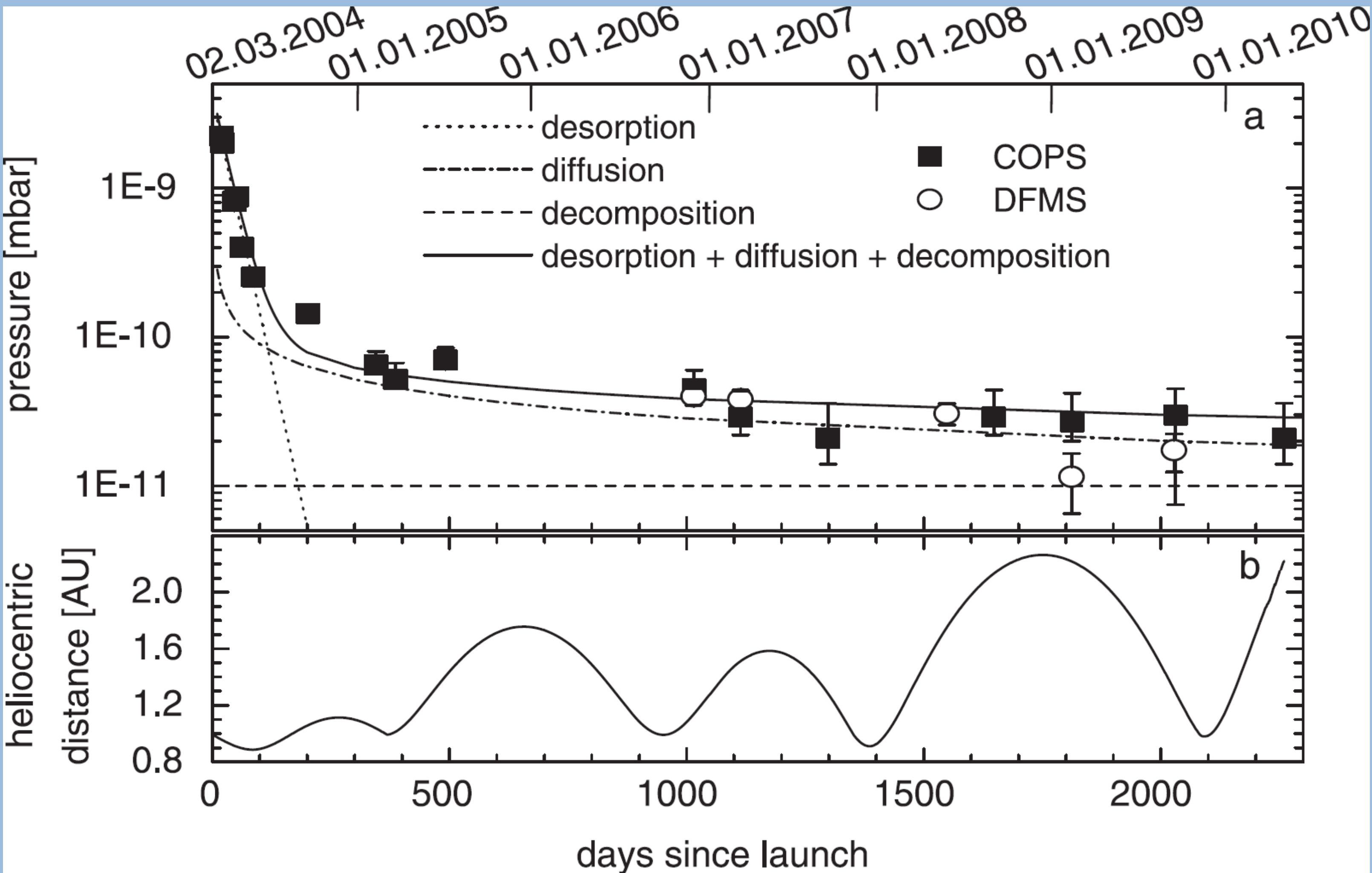


„Outgassing“ mechanisms

(Ref.: Trible A.C., Fundamentals of contamination control, 2000)

Mainly water

Desorption: $$p \propto e^{-\frac{E_a}{RT}} \cdot e^{-\frac{t}{t_d}}$$

with E_a = 4-40 kJ/mole
(1/e temperature range of 500-5000 K) and t_d = 30 days

Diffusion: $$p \propto e^{-\frac{E_a}{RT}} \cdot \frac{1}{\sqrt{t}}$$

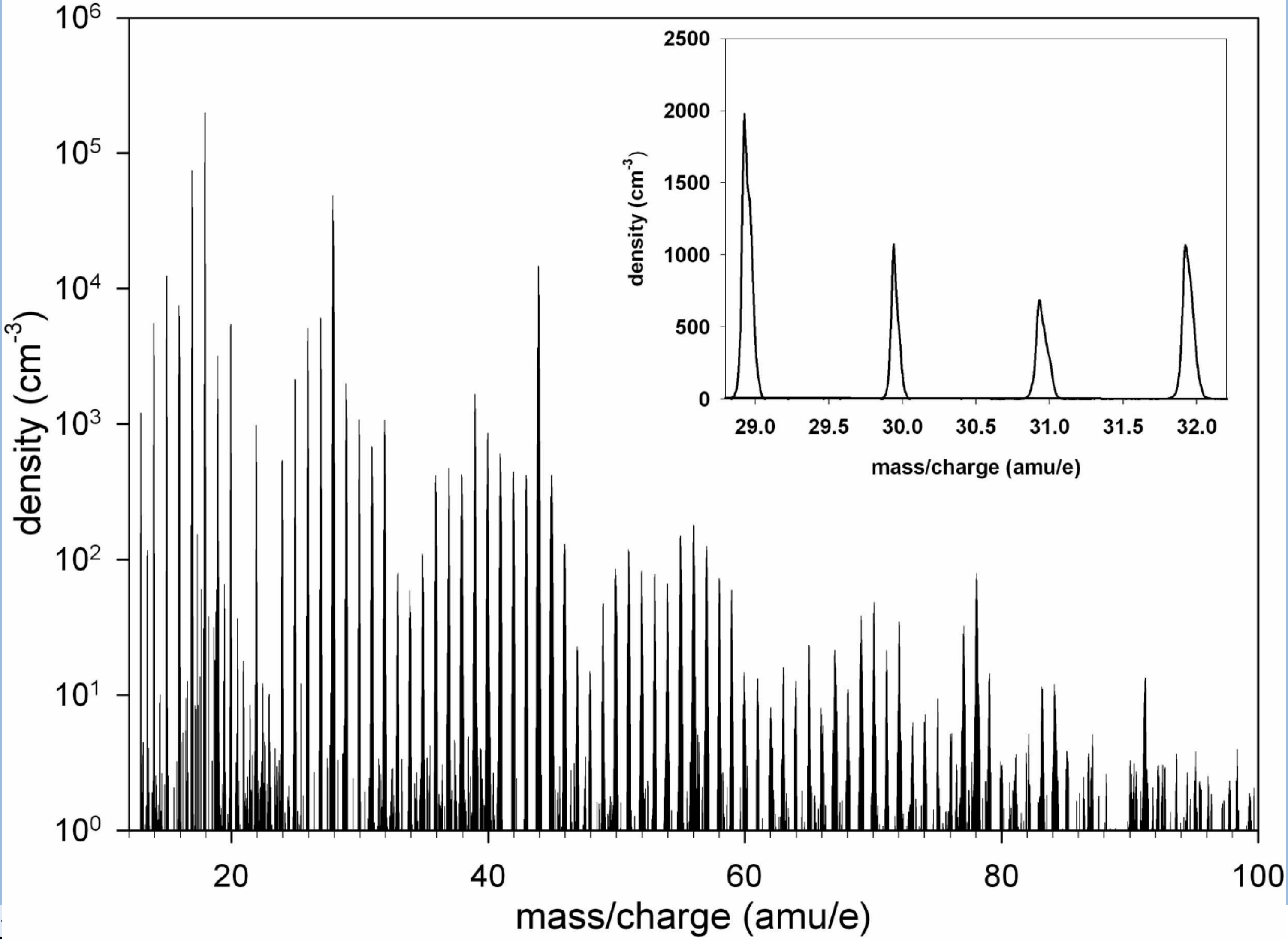
with E_a = 20-60 kJ/mole
(1/e temperature range of 2500-7500 K)

Decomposition: $$p \propto e^{-\frac{E_a}{RT}}$$

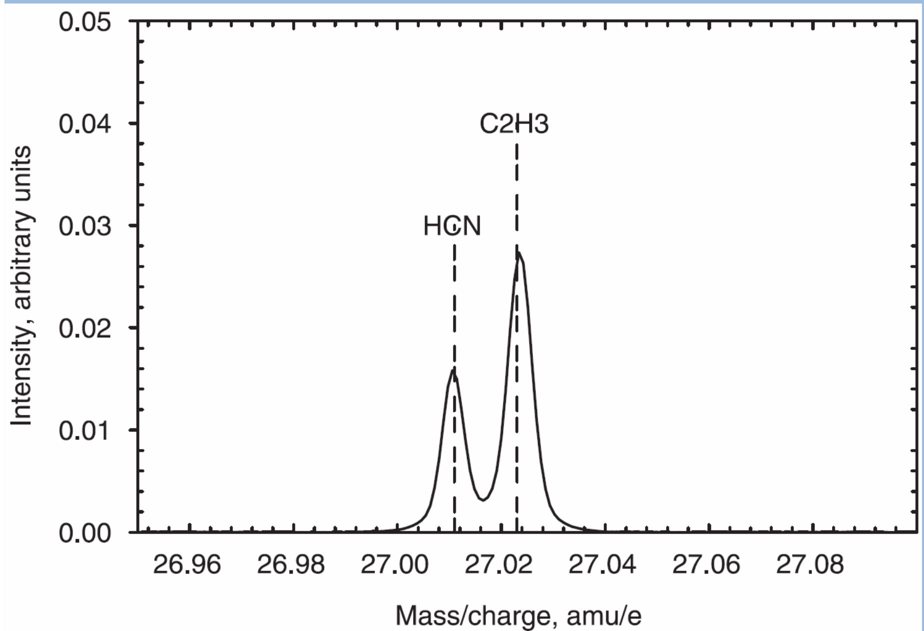
with E_a = 80-320 kJ/mole
(1/e temperature range of 10’000-40’000 K)

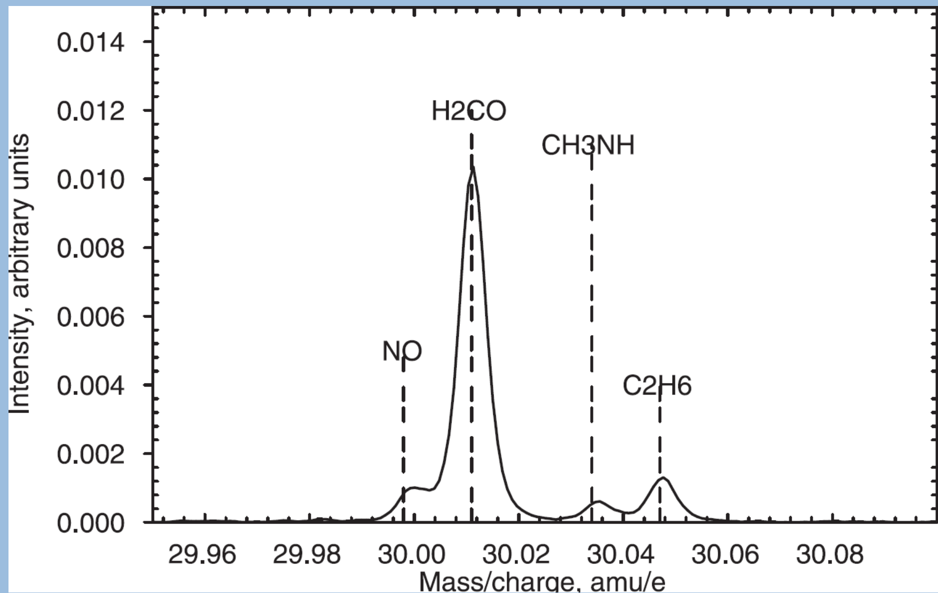
- polyurethane (structure, conformal coatings, and adhesives),
- epoxies (structure, potting, conformal coatings)
- polyamines (structure)
- polyimides (structure)
- fluorocarbons (structure and tapes)
- Solvents
- Polycarbonates (structure)

DFMS low resolution mass spectrum
14. March 2010, 1.7 AU, 200µA, 20s per massline



DFMS high resolution mass spectrum





High resolution mass spectra (m/Δm >9000 at 50% peak height) allow identification of various species and fragments.

Detected species and fragments in the vincinity of Rosetta:

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Hydrocarbons			**PAH**	**C-O**		**C-N**	**N-O**	**N-H**	**Fluorine**
CH	C_4	C_5H_{10}	C_6H	CO	$C_2H_2O_2$	CN	NO	N	F
CH_2	C_4H	C_5H_{11}	C_6H_2	CO_2	$C_2H_3O_2$	CHN	CNO	NH	HF
CH_3	C_4H_2	C_5H_{12}	C_6H_3	HCO	$C_2H_4O_2$	CH_2N	HCNO	NH_2	CF
CH_4	C_4H_3		C_6H_4	CH_2O		CH_3N	H_6CNO	NH_3	
	C_4H_4		C_6H_5	CH_3O	C_4H_4O	CH_3NH	NO_2	N_2	**Sulfur**
C_2	C_4H_5		C_6H_6	CH_4O	C_4H_5O	CH_3NH_2	HNO_2		S
C_2H	C_4H_6			CH_5O	C_4H_6O	CH_3N_2H	H_4NO_2	**Oxygen**	N_2S
C_2H_2	C_4H_7		C_7H_3		C_4H_7O	$CH_3N_2H_2$	H_2N_2O	O	SO_2
C_2H_3	C_4H_8		C_7H_4	C_2O	C_4H_8O	$CH_3N_2H_3$		OH	
C_2H_4	C_4H_9		C_7H_5	C_2HO			$CHNO_2$	H_2O	**Chlorine**
C_2H_5	C_4H_{10}		C_7H_6	C_2H_2O		C_2H_2N	CH_3NO_2	DHO	^{35}Cl
C_2H_6			C_7H_7	C_2H_3O		C_2H_3N	CH_4NO_2	$H_2{}^{18}O$	^{37}Cl
	C_5		C_7H_8	C_2H_4O		C_2H_4N	C_2H_6NO	O_2	$H^{35}Cl$
C_3	C_5H			C_2H_5O			C_2N_2O		$H^{37}Cl$
C_3H	C_5H_2		C_8H_{10}			C_5H_4N	C_2HN_2O		CCl
C_3H_2	C_5H_3			C_3H_2O		C_5H_5N	$C_2H_2N_2O$		CCl_2
C_3H_3	C_5H_4		C_9H_{12}	C_3H_3O		C_5H_6N	$C_2H_3N_2O$		
C_3H_4	C_5H_5			C_3H_4O		C_5H_7N	$C_2H_5N_2O$		
C_3H_5	C_5H_6			C_3H_5O		C_5H_8N	$C_2H_6N_2O$		
C_3H_6	C_5H_7			C_3H_6O			$C_2H_7N_2O$		
C_3H_7	C_5H_8			C_3H_7O		$C_4H_4N_2$	$C_2H_8N_2O$		
C_3H_8	C_5H_9								

Parent molecules comets

Source of contamination

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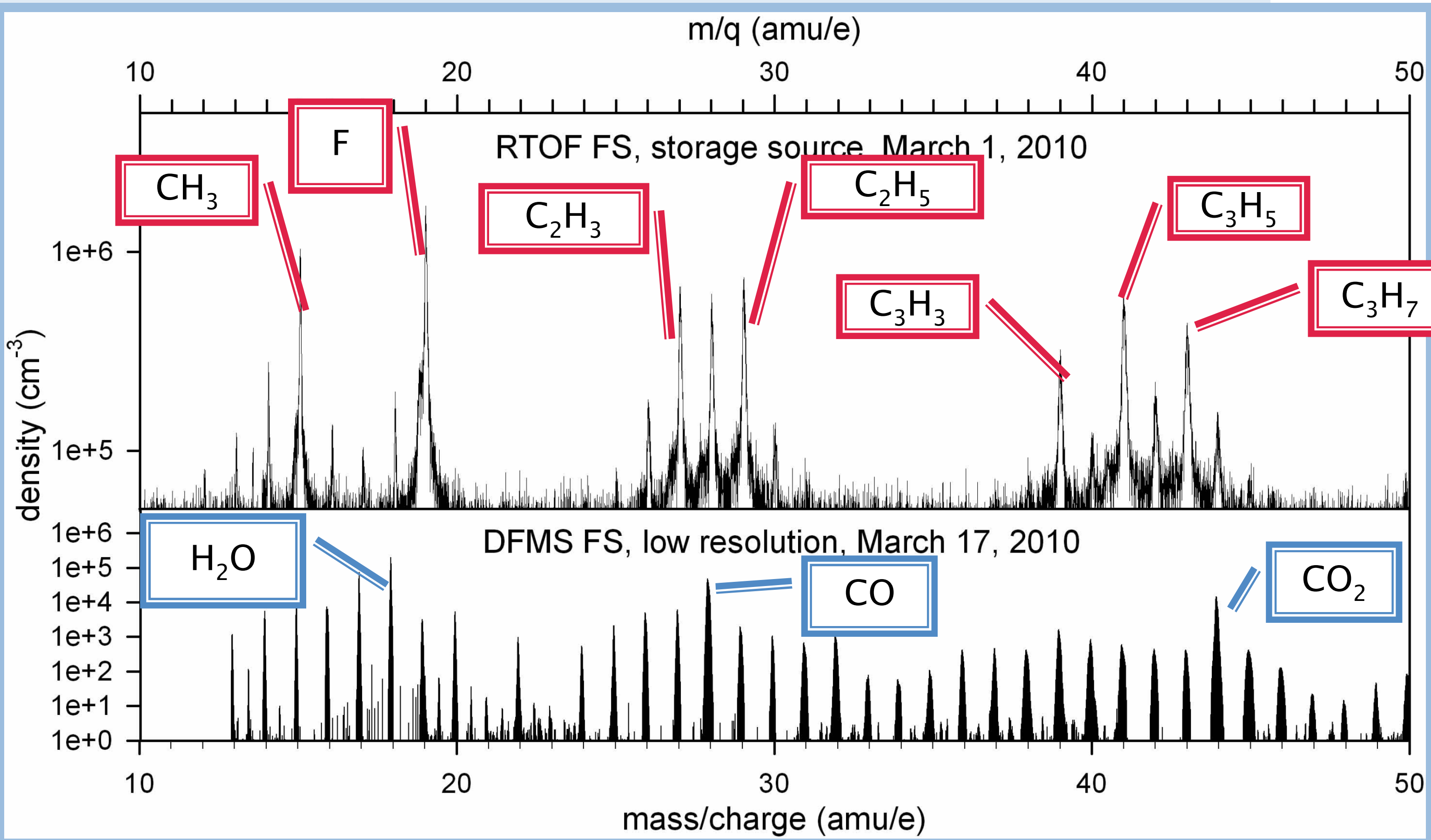
Dry mass of Rosetta: 1200 kg
1/3 non-metallic: 400 kg
TML (1% in 24h @125 °C): 4 kg
(1% in 1000d @0°C)
(TML = total mass loss)

Water layers (SC box and solar panels only):
12 layers of MLI, 30 m^2 => 720 m^2 surface area
100 m^2 honeycomb structure => 5000 m^2 surface area
on aluminum: 10^{21} mol/m^2 (Chen et al., 2001)

=> 180 g water

FACT: Any spacecraft looses 1-10 kg during its mission!

Comparison RTOF and DFMS mass spectrum: The Braycote Problem



RTOF: Fluorine + aliphatic hydrocarbons

DFMS: Water, CO, CO_2

Chandra X-ray Advanced CCD Imaging Spectrometer ACIS

H. Marshall et al., 2003

Facts:

- Launch 1999
- Contamination of ACIS: 370 nm “Fluffium” after three years
- Composition of Fluffium: >80% Carbon, 7% Oxygen, 7% Fluorine
- No C=C bonds
- Aliphatic hydrocarbons (C-C)

Radiation damaged fluorocarbons from lubricants (vacuum grease: Braycote, Krytox)

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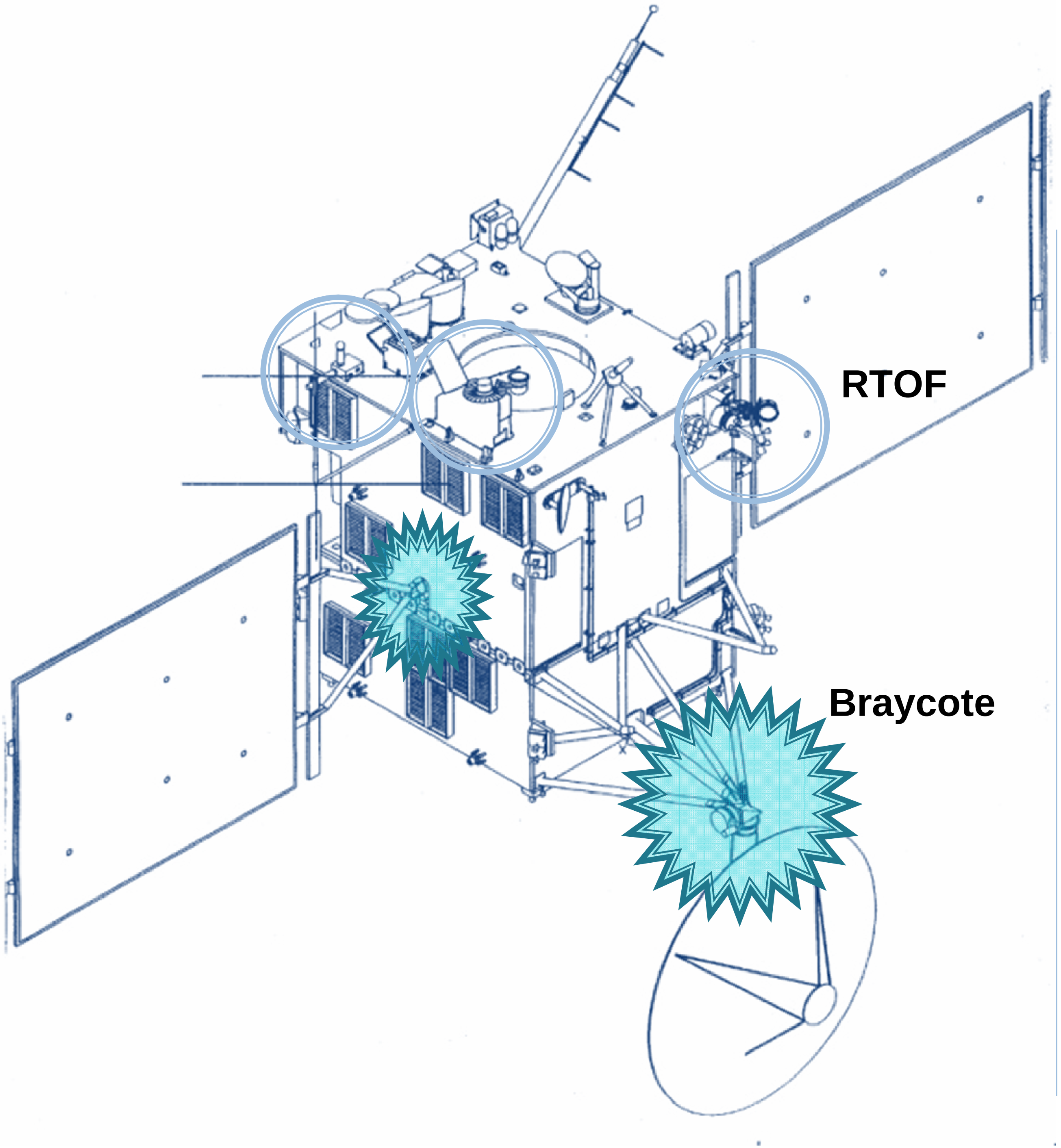
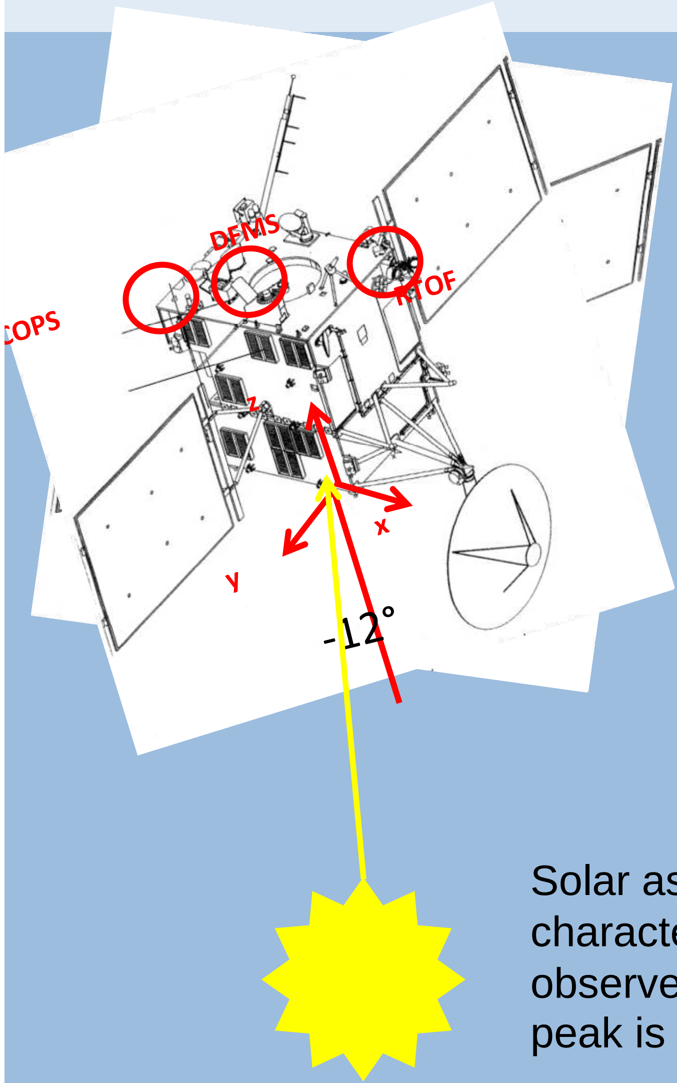
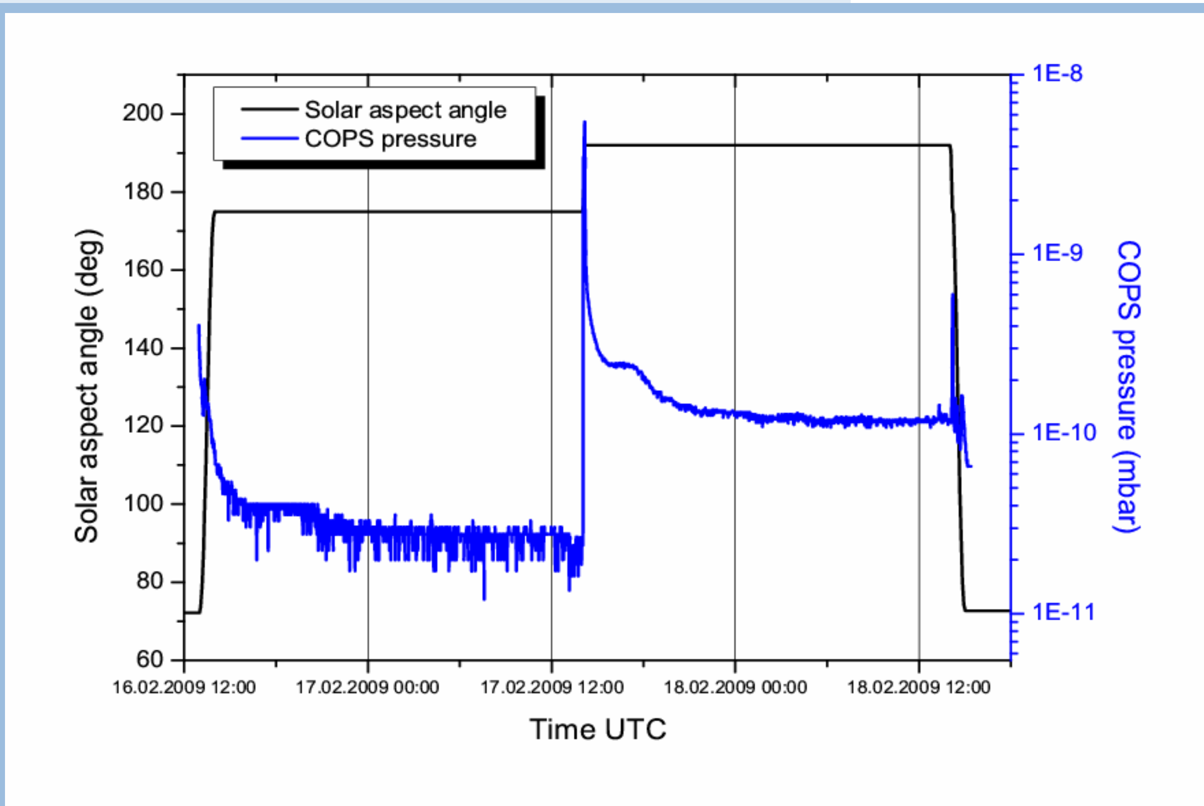


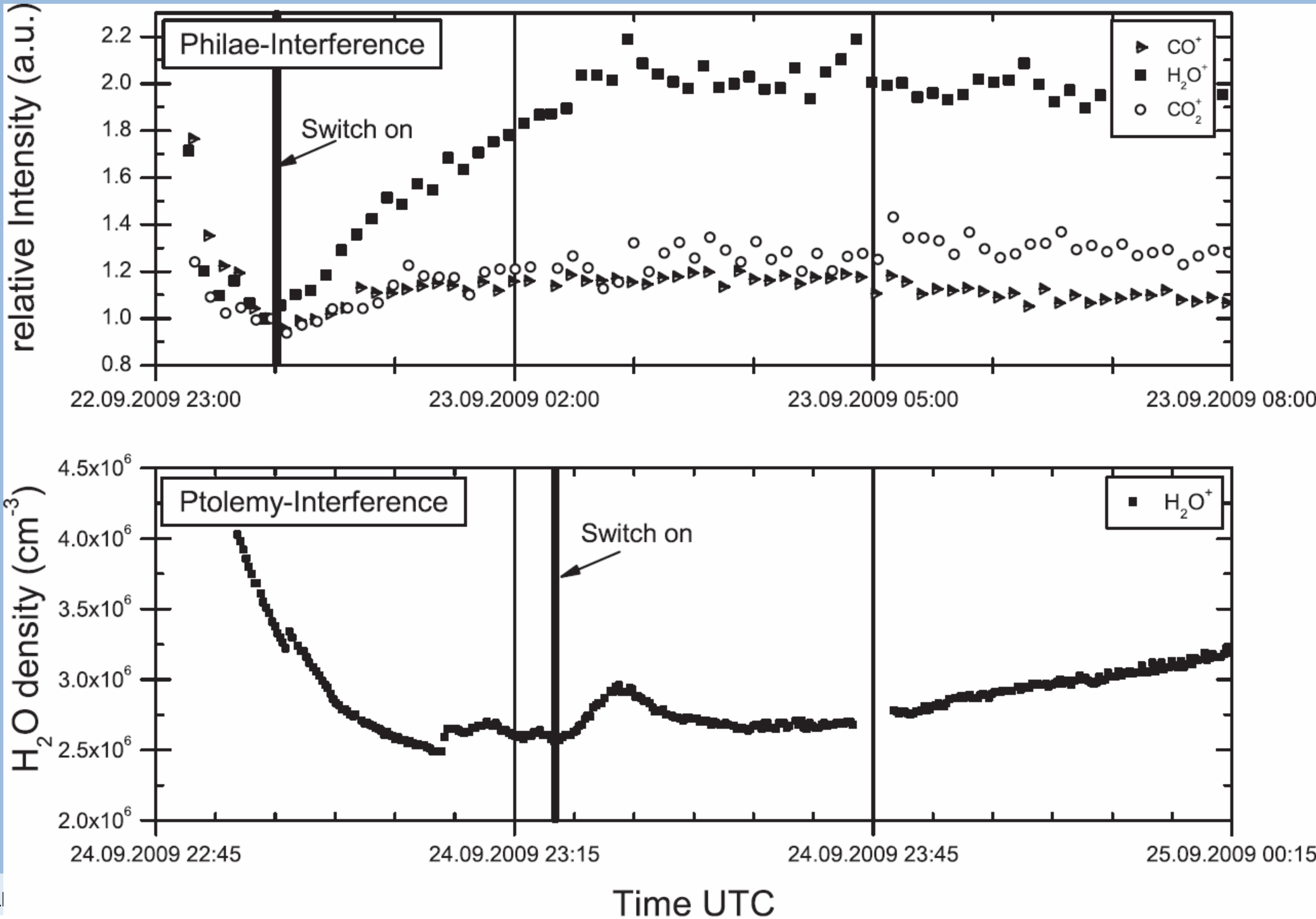
Transient outgassing due to change of orientation



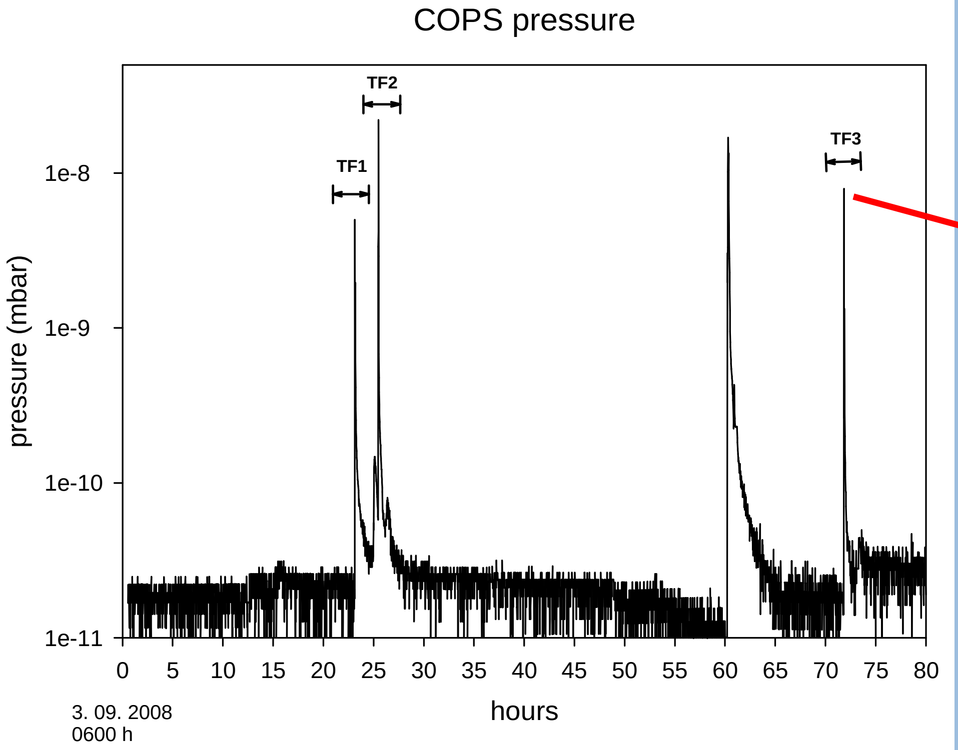


Solar aspect angle and COPS nude gauge pressure during the thermal characterization test of Rosetta in February 2009. The first peak observed by COPS is due to internal outgassing, but an overlapping peak is visible when SAA was approximately 90°.

Transient outgassing due to payload/subsystem activity

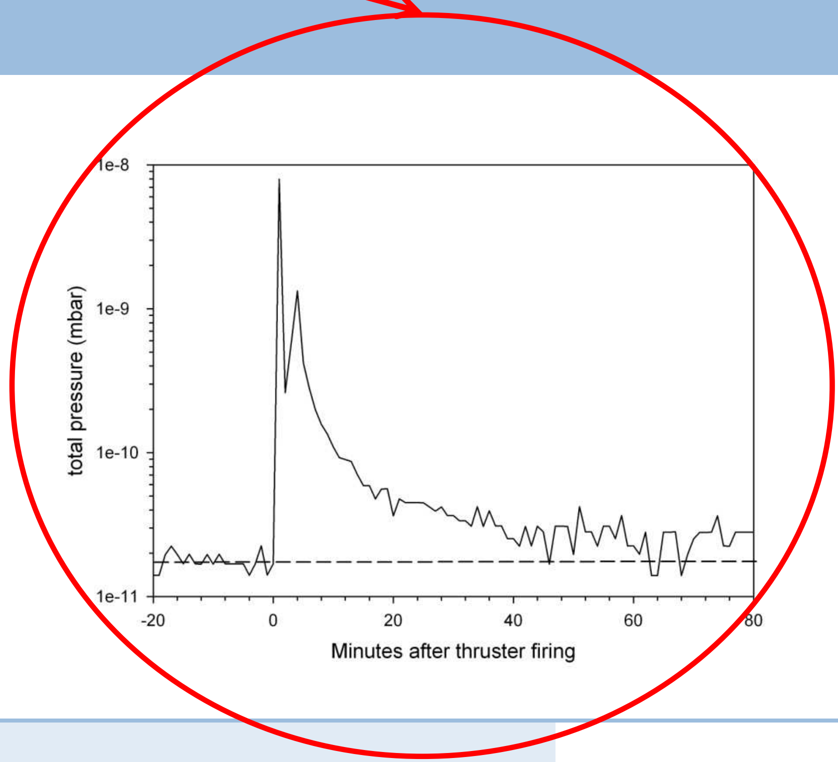


Transient outgassing due to thruster firings



Thruster firing TF

Peak without label is due to the S/C flip



Implications and ROSINA ion measurements

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Neutral particles:

Spacecraft outgassing limits investigations of tenous atmospheres by in situ mass spectrometry (see. Schläppi et al. 2010, JGR, Vol 115)

Ions/Plasma:

Plasma densities resulting from outgassing are probably small, in particular after more than 6 years in space. However, early in a mission or during transient outgassing peaks, the effect might not be negligible.

ROSINA DFMS ion measurements were attempted on two occasions during PC 12 (May 2010), however, no clear detection of external ions was possible.

(Uncertainties of s/c charging and sensor optimization is ongoing → quantification is difficult at the moment)

Backup Slides

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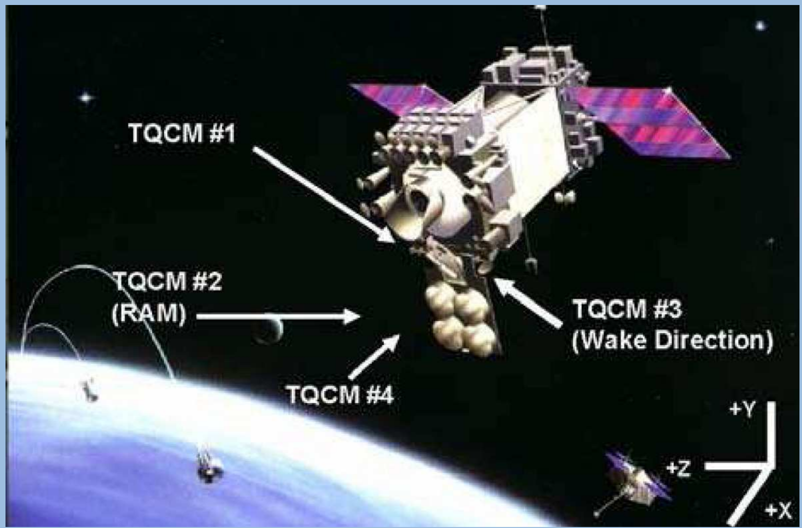
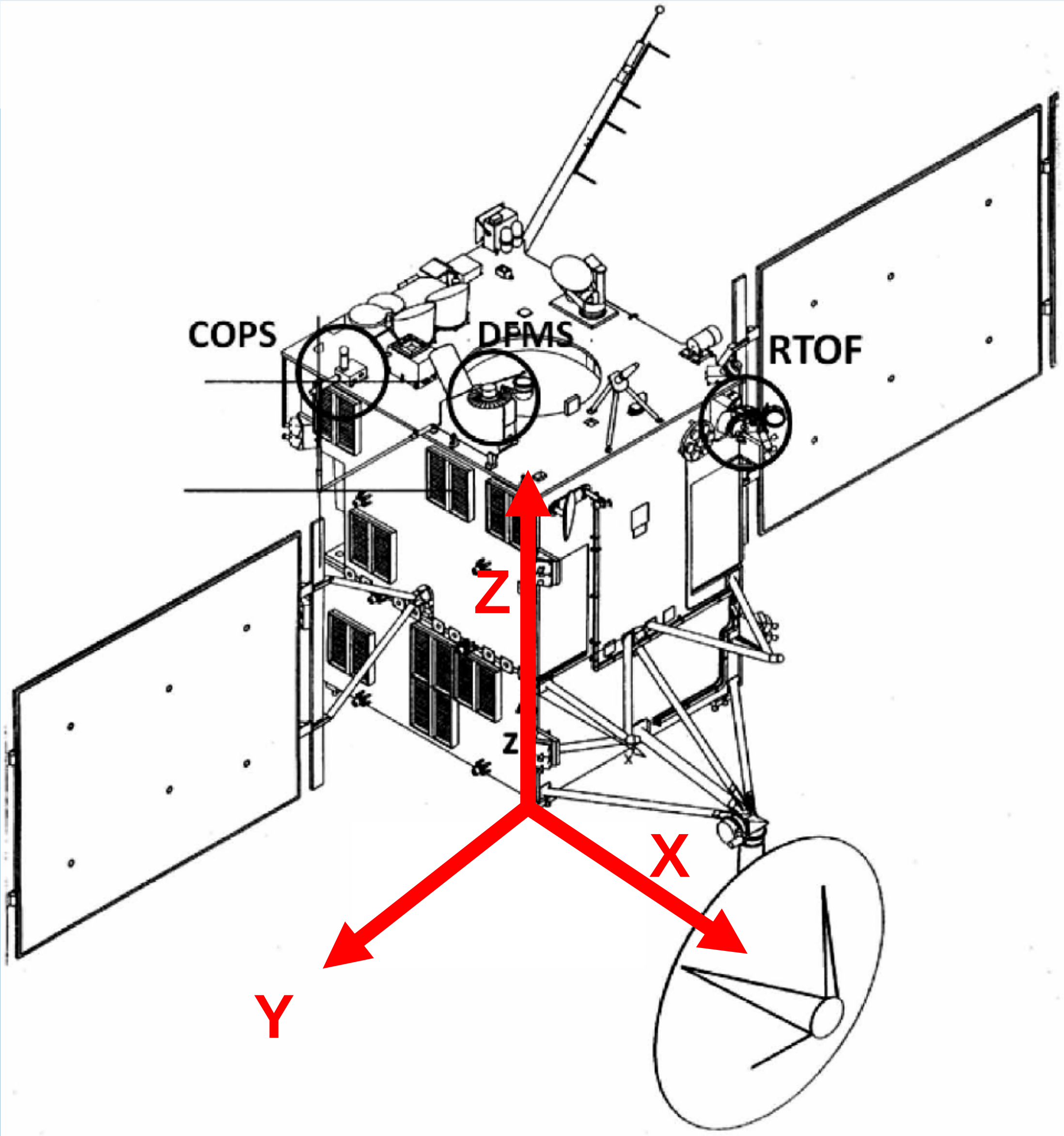
- Optical surfaces axquire a layer of contaminants which can degrade instrument performance:
  - Solar EUV Monitor (CELIAS, SOHO): Degradation consistent with deposition of 15 nm carbon (nonvolatile) over 1300 d (McMullin et al., 2002)
  - Extreme UV Imaging Telescope (SOHO): 40 Å/month “ice” layer (Defise et al., 1997)
  - Deterioration of camera systems on: Stardust (Bhaskaran et al., 2004), Cassini-Huygens (Haemmerle et al., 2006), Chandra X-Ray Observatory (Plucinsky et al., 2003), …
- Midcourse Space Experiment (MSX, 900 km orbit from Earth):
  - Quarz Crystal Microbalances (Mass deposition rate by measuring the change in frequency of a quartz crystal resonator)
  - Total pressure sensor (TPS) and Neutral MS: Significant outgassing even after 7 years in space, cointaining mainly water with pressure peaks during slews and payload activity (Uy et al., 2003).



Rosetta coordinate system



Implications: ROSINA at the comet

Model assumptions:

Comet-Rosetta distance: 30 km

Gas velocity: 300 m/s

Background at 3 AU and 1.7 AU similar

Model	H_2O driven	CO_2 driven	Perihelion
heliocentric distance	3AU	3AU	1.3AU
Production rates			
$H_2O(s^{-1})$	5.0E+25	1.0E+26	1.0E+28
$CO_2(s^{-1})$	2.5E+24	5.0E+24	5.0E+26
$CO(s^{-1})$	5.0E+24	1.0E+27	1.0E+27
$CH_4(s^{-1})$	2.5E+23	5.0E+23	5.0E+25
$HCN(s^{-1})$	5.0E+22	1.0E+23	1.0E+25

Implications: ROSINA at the comet

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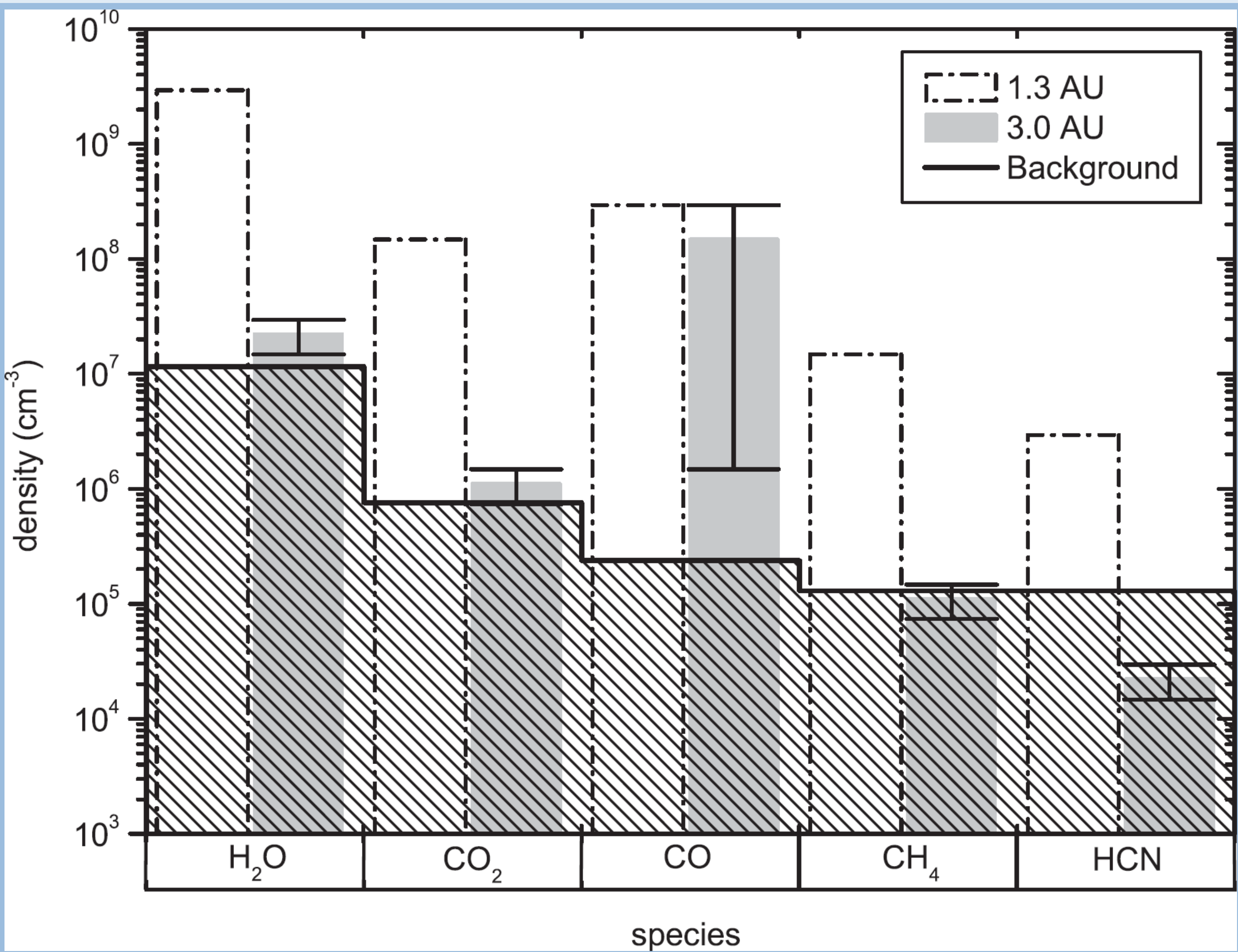

Major species (H_2O, CO, CO_2) are expected to be identified even at large heliocentric distance (3AU).

Minor species (e.g. CH_4, HCN) will require specific measurement methods (comparable to Lutetia-flyby).

At perihelion (<1.3 AU) no interference is expected.

Investigation of tenous atmospheres and exospheres of moons, asteroids and weak comets by mass spectrometers are limited by spacecraft outgassing, not by instrument sensitivity!