<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roland Thissen</td>
<td>LPG</td>
<td>LISA</td>
</tr>
<tr>
<td>Pascal Puget</td>
<td>LAOG</td>
<td>LISA</td>
</tr>
<tr>
<td>Alexander Makarov</td>
<td>ThermoFisher</td>
<td>CSNSM</td>
</tr>
<tr>
<td>Christelle Briois</td>
<td>LPC2E</td>
<td></td>
</tr>
<tr>
<td>Laurent Thirkell</td>
<td>LPC2E</td>
<td></td>
</tr>
<tr>
<td>Nathalie Carrasco</td>
<td>LATMOS</td>
<td></td>
</tr>
<tr>
<td>Jean Jacques Berthellier</td>
<td>LATMOS</td>
<td></td>
</tr>
<tr>
<td>Cyril Szopa</td>
<td>LATMOS</td>
<td></td>
</tr>
</tbody>
</table>
Cassini (INMS) ionic densities in Titan ionosphere

<table>
<thead>
<tr>
<th>Ion</th>
<th>Mass</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₇NH⁺</td>
<td>99.0109</td>
<td>resolution</td>
</tr>
<tr>
<td>C₈H₃⁺</td>
<td>99.0235</td>
<td>7857</td>
</tr>
<tr>
<td>C₄N₃H₉⁺</td>
<td>99.0797</td>
<td>1761</td>
</tr>
<tr>
<td>C₅N₂H₁₁⁺</td>
<td>99.0923</td>
<td>7857</td>
</tr>
<tr>
<td>C₆NH₁₃⁺</td>
<td>99.1049</td>
<td>7853</td>
</tr>
<tr>
<td>C₇H₁₅⁺</td>
<td>99.1174</td>
<td>7920</td>
</tr>
</tbody>
</table>
Measurement of Xe isotopes??
(B. Marty)
need for H/D inside primitive molecules??
(T. Owen)
Rosetta’s Rosina DFMS 3 000 16 kg

Mass Filter

Figure 12. Part of a high resolution background mass spectrum from space at a total pressure of $4 \times 10^{-11}$ mbar. Integration time was 20 s per mass. The triplets at mass/charge 28 and 29 amu/e can be separated easily.
What if we study Titan with DFMS?
10 000 resolution...
Orbitrap, big box... but very small analyser inside
Orbitrap, new concept for mass spectrometry

- Electrodes shapes

\[ z_{1,2}(r) = \sqrt{\frac{r^2}{2} - \frac{(R_{1,2})^2}{2}} + (R_m)^2 \ln \left[ \frac{R_{1,2}}{r} \right] \]

- Ion frequencies along Z

\[ \omega_z = \sqrt{\frac{q}{m}} k \]

- Ultimate Resolution:
  100 000 at mass 400

Detection by image current + FT

Simultaneous measurement of all ions
Orbitrap, potential

- Ultra high resolution 100,000 at mass 400, adjustable during mission, as it depends only on the integration time
- Very small volume, lightweight: $l = 4$, $\phi = 4$ cm
- Good detection Dynamic 50,000
- Positive or negative Ions as only one potential to invert
- All ions are analysed simultaneously
- No detector, no saturation, ...
- No RF, no moving part
- Ideal for solids or aerosols
- Source by laser or pulsed ions ➔ ILMA
Tremendous effect of signal averaging
(1 spectrum vs average of 400)
Sensitivity: 6 charges

For 1 ion with +20 charges, S/N=3.7 on average (0.76 sec acquisition). It means that Noise-band≈5.5 charges. This fits with noise characteristics of image current preamplifier.
ILMA
Ion Laser Mass Spectrometer

ILMA, a high resolution mass spectrometer for in situ analysis of mineral and organic composition of NEOs

Hervé Cottin and the ILMA team

cottin@lisa.univ-paris12.fr
Cosmic Vision & Marco Polo Science objectives
- Origin of the Solar System
- Origin of life

Astrobiology relevance of the mission if organic compounds are measured

- Need an actual identification of the molecular structure
- Possible with high resolution mass spectrometry

**In situ** measurements of organics are mandatory

Pristine organic material can be highly sensitive to T (as low as 320 K)

**Contamination** must be evaluated
ILMA
Ion Laser Mass Spectrometer

What is ILMA?

A new generation high resolution mass spectrometer, proposed to be part of the MSC or the lander payload.

ILMA is an ion trap Fourier Transform mass spectrometer using SIMS (Secondary Ion Mass Spectrometry) and LDIMS (Laser Desorption Ion Mass Spectrometry)

ILMA is built on an ORBITRAP analyser
Resolution > 100 000!
**Secondary Ions**

**Vacuum**

**Solid**

**Collision cascade**

Region of greatest damage

Region of least damage

---

**SIMS Process**

**Primary Ion**

**Laser Beam**

**Secondary Ion optic**

**Sam**

**Inner electrode**

**Signal**

**FT**

**Spectra**

**Primary Ion Beam System**

**Outer electrode**

---

**TECHNICAL REQUIREMENTS**

**Mass:**

- ~ 3 kg  Laser + Ion gun
- ~ 2 kg  Laser only

**Volume:**

- 15x15x5 cm³

**Electronic unit:**

- 15x10x3 cm³

**Mean power:**

- ~ 9 W

**Mass range:**

- 1-30 / 25-750 amu

**Mass resolution:**

- 10,000 at 50% height
- at 400 amu

**Analyzed area:**

- a few µm² to 1 mm²

---

**Thanks to the high resolution**

**Analysis of Minerals & Organics**

**With amount << 1g !**
Secondary Ions

Vacuum

Solid

Collision cascade

Region of greatest damage

Region of least damage

SIMS Process

Primary Ion

Vacuum

Solid

Collision cascade

Region of greatest damage

Region of least damage

Primary Ion Beam System

Ion trap

Outer electrode

Inner electrode

Sample

Signal → FT → Spectra

Laser Beam

Secondary Ion optic

H = 1,008 g.mol⁻¹
C = 12,000 g.mol⁻¹
Si = 27,977 g.mol⁻¹

Organic : m+δm
Mineral : m-δm

C₂H₄
**ILMA and the origin of the Solar System**

ILMA will characterize *in-situ* the elemental, isotopic and molecular composition of the targeted NEO.

- Measurement of various isotopic ratios ($^{12}$C/$^{13}$C, $^{14}$N/$^{15}$N, $^{16}$O/$^{17-18}$O, $^{28}$Si/$^{29-30}$Si)
- Information on the formation processes, alteration (hydrothermalism), interstellar component...
- Datation is possible: $^{207}$Pb/$^{206}$Pb

**ILMA and the origin of Life**

ILMA will analyze volatile and organic compounds in the NEO.

- The measurement of D/H ratios will give better constraints on the origin of water on Earth.
- D/H and C/H ratios will help link the organic component of the NEO to the different families of organic material present in meteorites.
- Analysis of organic molecules will assess the relevance of NEOs for the origin of life.
Example : analysis at mass 18

<table>
<thead>
<tr>
<th>Point</th>
<th>ions18</th>
<th>masse18</th>
<th>intense18</th>
<th>dif18</th>
<th>resol18</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18O</td>
<td>17.9988</td>
<td>0.000205</td>
<td>0</td>
<td>inf</td>
</tr>
<tr>
<td>1</td>
<td>17OH</td>
<td>18.0072</td>
<td>0.00037995633</td>
<td>0.00844002</td>
<td>2133</td>
</tr>
<tr>
<td>2</td>
<td>16OD</td>
<td>18.009</td>
<td>0.00011472055</td>
<td>0.0017757</td>
<td>10137</td>
</tr>
<tr>
<td>3</td>
<td>16OH2</td>
<td>18.0106</td>
<td>0.99734062</td>
<td>0.00155067</td>
<td>11608</td>
</tr>
<tr>
<td>4</td>
<td>15NH3</td>
<td>18.0236</td>
<td>0.0036787309</td>
<td>0.0130177</td>
<td>1383</td>
</tr>
<tr>
<td>5</td>
<td>NH2D</td>
<td>18.0328</td>
<td>0.00011455046</td>
<td>0.00924301</td>
<td>1947</td>
</tr>
<tr>
<td>6</td>
<td>NH4</td>
<td>18.0344</td>
<td>0.99686189</td>
<td>0.00154877</td>
<td>11622</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example: acid fulvic (humus component, high molecular weight organic)
Example: acid fulvic (humus component, high molecular weight organic)

Lab. measurement with electrospray injection
Example: HCN polymer at mass 234

Processing of the polymer

Lab. measurement with electrospray injection
Co-investigators -
CONCLUSIONS

Collaboration with the inventor of the concept (A. Makarov) and the ThermoFisher company distributing the commercial version (NDA agreement between ThermoFisher company and the participating teams).

Laboratory prototype coupling laser & orbitrap foreseen by Oct. 2009

CNES is supporting ILMA

A team with a strong experience of mass spectrometry (some of the ColIs involved in the COSIMA mass spectrometer onboard ROSETTA)

**ILMA** is a unique opportunity to characterize the context of the sampling. Either on the mother spacecraft or on a lander. For 2 kg.

⇒ Mineral and organic molecular composition

⇒ Isotopic ratios (D/H, C, O, N, Si…)

⇒ Dating

Earth as seen from NEA TOUTATIS, 29/9/2004, 1.5 million km from Earth