Search for signs of life by means of ATR spectroscopy (experiment “MATROS”)

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MATROS

Microbiologic
Attenuated
Total
Reflection
Optical
Spectrometer

Space Research Institute
Biology faculty
Soil Science faculty
Institute for Spectroscopy

RAS
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Lomonosov Moscow State University
RAS
Objectives for Astrobiology

• Europa may have an sub-surface ocean and it may be inhabited by Earth-like microbes
• Earth microorganisms in situ are proved to be very stable to radiation, low temperature, high pressure and other unfavorable factors present at Europa. Actually, the limits for cells surviving are not known yet.
• Fast freezing doesn’t destroy bacterial cells, they transit to anabiotic state. Therefore, in frozen outbursts on Europa microorganisms may be present (at about 0.5m depth)
Objectives for methodology

• Possibility of direct express in-situ analysis

• Method’s multifunctionality

• Possibility of hardware operation at Europa surface environment

• Duration of the experiment must fit to spacecraft life time
ATR spectroscopy

• Fits to all above-listed requirements

• Does not request any complicated sample preparation

• Detects directly proteins, DNA/RNA, carbohydrates, lipids and other metabolites

• Does not destroy or damage cell, investigates object “as is”

• Can detect cell presence independently of its physiological state (viable or anabiotic)
Total Reflection occurs, if $\theta > \arcsin \left( \frac{n_{\text{substance}}}{n_{\text{prism}}} \right)$

E.g., for ZnSe ($n_p = 2.4$) and $\theta = 45^\circ$: $n_s < 1.7$

An ATR spectrum is:
- basically, spectrum of absorption
- spectrum of a very thin sample
- the bigger $\lambda$ – the “thicker” sample

Spectral range: 2.5 - 25 $\mu$m
Spectral resolution: 5 - 10 cm$^{-1}$
Sources of bio-bands

Protein

C=O stretch vibration gives main contribution to Amide-1 band
N-H bending vibration gives main contribution to Amide-2 band
Sources of bio-bands

DNA characteristic band originates from vibrations in $O=PO^{-}$ linking group
Sources of bio-bands

Typical IR absorbance positions:
- Protein Amide I: 1690-1600
- Protein Amide II: 1575-1480
- Lipid -CH$_2$: 3100-3000
- Lipid -CH$_2$, -CH$_3$: 3000-2850
- Nucleic Acid -PO$_2$: 1225, 1084
Spectral bands of bio-cells

BLACK - WATER; RED - CANDIDA HUMICOLA

Eucaryote (cell with nucleus)
Spectral bands of bio-cells

BLACK - WATER, BLUE - ARTHROBACTER (PROCARYOTE)
Spectral bands of bio-cells

NATIVE SAMPLE FROM ICE VEIN IN ARCTIC PERMAFROST (20m, 30 th. years)

AMIDE-1

AMIDE-2
Spectral bands of bio-cells

SPORES OF BACILLUS SP. FROM ANTARCTIC PERMAFROST (13m, 170 th.years)

AMIDE-1

AMIDE-2
Bio-molecules or minerals?

Minerals have very different spectra and by a proper mixture one can construct any spectral features. 

So, some *additional information* (except spectral bands position) is needed for sure detection of bio-cells:

- Study at different penetration depths
- Bands deepening due to bacteria propagation
- Dichroic ratio measurements in bio-bands
Study at different penetration depths

Spore Clostridium pectinofermentans

Shallow penetration: no DNA/RNA band
Deep penetration: DNA/RNA band appears

Cell at ATR-prism
Bands deepening due to propagation

BACTERIA GROW AT AGAR.
- BLACK: DAY #1
- BLUE: DAY #5
- RED: DAY #9

"Amide-2" band
Dichroic ratio in bio-bands

\[ R = \frac{A_{\parallel}}{A_{\perp}} \]

In 1978 Korolev with colleagues for the first time implemented ATR measurements of dichroic ratio in bio-bands for investigation of bacterial spores (e.g., Mikrobiologiya. 1978. V.47. P.750). Dichroic ratio in cell membranes varies a lot, distinguishing them from minerals.

Now such measurements became a normal laboratory practice (e.g. D.Marsh. Biophysical J. ,1997 V.72 P.2710)

MATROS will have a polarizer for measurements of dichroic ratio. It will give an additional criterion for proving the biological origin of the bands.
Technical realization

- flat spring
- valve
- CO$_2$ + H$_2$ + H$_2$S
- ATR-prism
- window
- outlet tube of the loading funnel

Dimensions:
- $\varnothing 5$
- 9
- 6
- 7.5
- 20

Sample
# Main parameters

<table>
<thead>
<tr>
<th>Specification / Parameter</th>
<th>Type / Value</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>Spectroscopy technique</td>
<td>Attenuated Total Reflection</td>
<td>By now not used in planetary missions</td>
</tr>
<tr>
<td>Spectral range</td>
<td>2.5 - 25 μm</td>
<td></td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>5 - 10 cm⁻¹</td>
<td>Internal miniature Fourier-spectrometer</td>
</tr>
<tr>
<td>Size</td>
<td>11 x 17 x 13 cm</td>
<td>Internal miniature Fourier-spectrometer</td>
</tr>
<tr>
<td>Mass</td>
<td>2 kg</td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td>6 W</td>
<td>Average, when operating</td>
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<tr>
<td>External assistance</td>
<td>Soil sample delivery</td>
<td>By spacecraft robotic arm, preferably from ~20cm depth</td>
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THANKS FOR ATTENTION!