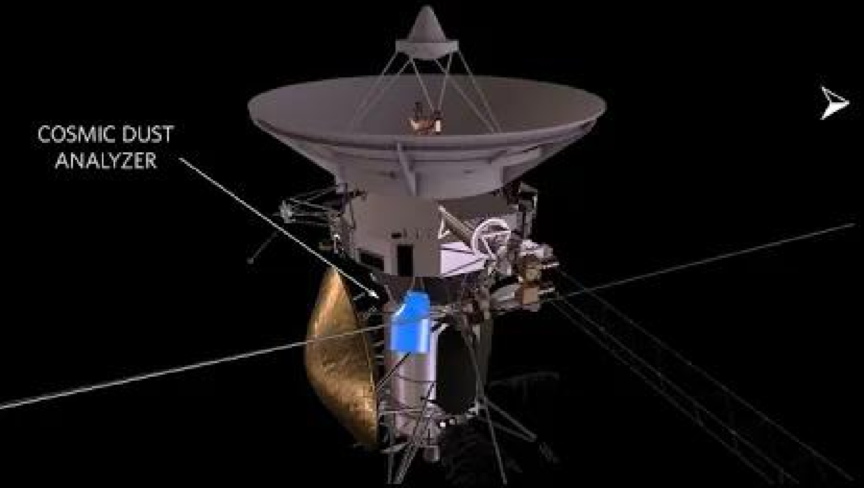
How to analyze ice grains from icy moons?



- compositional analysis by **impact ionization mass spectrometers**
  - high-velocity impacts of ice grains into a metal target
  - time-of-flight mass spectra of the created ions

→ **can indirectly sample the subsurface oceans**

The Cassini spacecraft

Credit: NASA/JPL-Caltech

Surface Dust Analyzer (SUDA)
onboard **Europa Clipper**

Credit: NASA/JPL-Caltech

1
00:00:03,830 --> 00:00:02,550
hello everyone and welcome to my

2
00:00:05,829 --> 00:00:03,840
presentation

3
00:00:08,310 --> 00:00:05,839
about analog experiments for the

4
00:00:12,549 --> 00:00:08,320
detection of bacterial biosignatures

5
00:00:16,390 --> 00:00:14,629
active ocean worlds are some of the most

6
00:00:18,150 --> 00:00:16,400
interesting solar system bodies for

7
00:00:20,790 --> 00:00:18,160
astrobiology

8
00:00:21,990 --> 00:00:20,800
saturn's moon's enceladus and jupiter's

9
00:00:24,070 --> 00:00:22,000
moon europa

10
00:00:25,109 --> 00:00:24,080
are predicted to harbor global liquid

11
00:00:28,950 --> 00:00:25,119
water oceans

12
00:00:31,830 --> 00:00:28,960
beneath the icy crusts in 2005

13
00:00:33,670 --> 00:00:31,840

the cassini spacecraft discovered plumes

14
00:00:35,030 --> 00:00:33,680
originating from the south pole region

15
00:00:38,470 --> 00:00:35,040
of enceladus

16
00:00:42,069 --> 00:00:38,480
from four main surface fissures

17
00:00:44,630 --> 00:00:42,079
called the tiger stripes these plumes

18
00:00:46,069 --> 00:00:44,640
are composed of vapour and water ice and

19
00:00:49,110 --> 00:00:46,079
they eject ice grains

20
00:00:51,670 --> 00:00:49,120
from the subsurface ocean into space

21
00:00:52,950 --> 00:00:51,680
some of these ice grains escape

22
00:00:55,990 --> 00:00:52,960
enceladus gravity

23
00:00:57,910 --> 00:00:56,000
and comprise saturn's diffuse earring

24
00:01:00,150 --> 00:00:57,920
like enceladus europa could be

25
00:01:02,310 --> 00:01:00,160
cryovolcanically active

26
00:01:03,750 --> 00:01:02,320
some recent papers reported evidence of

27
00:01:05,429 --> 00:01:03,760
cream activity

28
00:01:07,750 --> 00:01:05,439
sputtering and micrometeorite

29
00:01:09,830 --> 00:01:07,760
bombardment may also eject icy surface

30
00:01:15,030 --> 00:01:09,840
particles to high altitudes

31
00:01:18,469 --> 00:01:17,749
ice grains ejected from icy moons can be

32
00:01:21,109 --> 00:01:18,479
analyzed

33
00:01:23,270 --> 00:01:21,119
during spacecraft flybys by impact

34
00:01:26,630 --> 00:01:23,280
ionization mass spectrometers

35
00:01:28,630 --> 00:01:26,640
such as the cosmic dust analyzer cda

36
00:01:29,990 --> 00:01:28,640
unbound the onboard the cassini

37
00:01:32,390 --> 00:01:30,000
spacecraft

38
00:01:34,550 --> 00:01:32,400

or such as the surface dust analyzer

39
00:01:36,550 --> 00:01:34,560
suda that will be on board the europa

40
00:01:38,710 --> 00:01:36,560
clipper mission

41
00:01:39,990 --> 00:01:38,720
impact ionization mass spectrometer

42
00:01:42,389 --> 00:01:40,000
record mass spectra

43
00:01:44,389 --> 00:01:42,399
of ions that are generated by high

44
00:01:47,910 --> 00:01:44,399
velocity impact of ice grain

45
00:01:49,429 --> 00:01:47,920
into a metal target this instrument can

46
00:01:51,830 --> 00:01:49,439
determine the composition

47
00:01:53,109 --> 00:01:51,840
of the ice grains and potentially

48
00:01:57,749 --> 00:01:53,119
indirectly sample

49
00:02:01,510 --> 00:02:00,310
in saturn's system data collected by

50
00:02:04,230 --> 00:02:01,520
cassini's cda

51
00:02:05,350 --> 00:02:04,240
instrument show that enceladus ocean is

52
00:02:08,070 --> 00:02:05,360
salt rich

53
00:02:11,110 --> 00:02:08,080
sustains hydrothermal interaction and

54
00:02:13,350 --> 00:02:11,120
contains a variety of organic material

55
00:02:15,510 --> 00:02:13,360
including complex macromolecules and

56
00:02:18,710 --> 00:02:15,520
low-mass volatiles which may as

57
00:02:20,630 --> 00:02:18,720
act as amino acid precursors

58
00:02:21,990 --> 00:02:20,640
these discoveries were supported by

59
00:02:24,550 --> 00:02:22,000
laboratory analog

60
00:02:25,350 --> 00:02:24,560
data using little bit the laser-induced

61
00:02:27,990 --> 00:02:25,360
liquid beam

62
00:02:30,550 --> 00:02:28,000
iron desorption experiment that i will

63
00:02:33,190 --> 00:02:30,560

present in the next slide

64
00:02:35,190 --> 00:02:33,200
on europa the subsurface ocean is also

65
00:02:37,270 --> 00:02:35,200
predicted to be in direct contact with

66
00:02:39,030 --> 00:02:37,280
silicates and possibly with seafloor

67
00:02:40,790 --> 00:02:39,040
magmatic activity

68
00:02:43,270 --> 00:02:40,800
which would enhance the potential

69
00:02:45,750 --> 00:02:43,280
habitability of this moon

70
00:02:47,750 --> 00:02:45,760
the upcoming europa clipper mission will

71
00:02:50,710 --> 00:02:47,760
be able to assemble ice grains

72
00:02:55,190 --> 00:02:50,720
originating from europa's surface or the

73
00:02:58,710 --> 00:02:57,350
interpreting interpreting the data

74
00:03:01,110 --> 00:02:58,720
recorded in space

75
00:03:03,030 --> 00:03:01,120
required calibration via analog

76
00:03:05,750 --> 00:03:03,040
experiment

77
00:03:07,430 --> 00:03:05,760
in space impact ionization works in a

78
00:03:10,390 --> 00:03:07,440
way where the ice grains

79
00:03:12,869 --> 00:03:10,400
impact a metal target at high velocity

80
00:03:15,670 --> 00:03:12,879
this creates ions that are then detected

81
00:03:17,910 --> 00:03:15,680
by a time-of-flight mass spectrometer

82
00:03:19,990 --> 00:03:17,920
you can see here on the left the

83
00:03:20,550 --> 00:03:20,000
resulting mass spectra of water ice

84
00:03:22,630 --> 00:03:20,560
grain

85
00:03:24,309 --> 00:03:22,640
the x-axis shows the mass of the

86
00:03:28,309 --> 00:03:24,319
detected molecules

87
00:03:30,789 --> 00:03:28,319
while the y-axis shows the intensity

88
00:03:33,110 --> 00:03:30,799

in the lab we simulate the hyper

89
00:03:35,430 --> 00:03:33,120
velocity impact of the ice grains

90
00:03:36,949 --> 00:03:35,440
with the laser induced liquid beam iron

91
00:03:40,470 --> 00:03:36,959
disruption experiment

92
00:03:42,869 --> 00:03:40,480
or a little bit here the impact is

93
00:03:44,149 --> 00:03:42,879
ionization process is simulated by

94
00:03:47,190 --> 00:03:44,159
irradiating

95
00:03:50,070 --> 00:03:47,200
a micrometer size liquid water beam

96
00:03:51,990 --> 00:03:50,080
that contains dissolved analytes with an

97
00:03:54,070 --> 00:03:52,000
infrared laser

98
00:03:55,750 --> 00:03:54,080
when the water beam absorbs the laser

99
00:03:58,949 --> 00:03:55,760
energy it is heated up

100
00:04:01,509 --> 00:03:58,959
and it explodes into fragments

101
00:04:02,070 --> 00:04:01,519
the created ions are then accelerated by

102
00:04:54,070 --> 00:04:02,080
a

103
00:04:58,629 --> 00:04:56,950
so here i present the next steps of the

104
00:05:01,029 --> 00:04:58,639
little bit experiments

105
00:05:02,550 --> 00:05:01,039
we measured cell material extracted from

106
00:05:05,189 --> 00:05:02,560
cultured bacteria

107
00:05:07,510 --> 00:05:05,199
to predict their spectral appearances in

108
00:05:11,990 --> 00:05:07,520
impact ionization mass spectra

109
00:05:16,550 --> 00:05:14,469
so we isolated cell material from two

110
00:05:18,870 --> 00:05:16,560
different bacterial species

111
00:05:19,990 --> 00:05:18,880
escarica coli and sphinxopixes

112
00:05:23,270 --> 00:05:20,000
alaskansis

113
00:05:26,150 --> 00:05:23,280

in short e coli and sls cances

114
00:05:26,550 --> 00:05:26,160
e coli is a well-studied model bacterium

115
00:05:30,070 --> 00:05:26,560
while

116
00:05:32,629 --> 00:05:30,080
sls kansas is a marine bacterium that we

117
00:05:33,590 --> 00:05:32,639
that was isolated from alaska called sea

118
00:05:35,909 --> 00:05:33,600
water

119
00:05:36,790 --> 00:05:35,919
it's an oligotroph bacteria so that

120
00:05:39,830 --> 00:05:36,800
means it can

121
00:05:42,710 --> 00:05:39,840
live with low nutrients and is very

122
00:05:45,350 --> 00:05:42,720
small inside it's a very good analog

123
00:05:47,430 --> 00:05:45,360
bacteria to potential life forms on icum

124
00:05:49,670 --> 00:05:47,440
oceans

125
00:05:51,029 --> 00:05:49,680
the material we extracted from this

126
00:05:54,230 --> 00:05:51,039
bacteria includes

127
00:05:57,029 --> 00:05:54,240
genomic dna membrane lipids and the

128
00:05:58,870 --> 00:05:57,039
aqueous space of the lipid extraction

129
00:06:00,550 --> 00:05:58,880
these extract represent potential

130
00:06:02,629 --> 00:06:00,560
biosignatures

131
00:06:05,029 --> 00:06:02,639
and they were also investigated in

132
00:06:07,029 --> 00:06:05,039
sodium chloride rich mattresses

133
00:06:08,469 --> 00:06:07,039
to account for the salty oceans of the

134
00:06:11,350 --> 00:06:08,479
icy moons

135
00:06:17,110 --> 00:06:11,360
we also investigated light cells of the

136
00:06:20,870 --> 00:06:19,749
our results show that by signatures from

137
00:06:24,950 --> 00:06:20,880
the two bacteria

138
00:06:27,749 --> 00:06:24,960

are clearly visible in both ion modes

139
00:06:29,029 --> 00:06:27,759
here you can see as an example an anion

140
00:06:32,390 --> 00:06:29,039
spectrum of dna

141
00:06:35,270 --> 00:06:32,400
extracted from the s-als kansas bacteria

142
00:06:36,469 --> 00:06:35,280
we identified two nucleobases adenine

143
00:06:39,110 --> 00:06:36,479
and guanine

144
00:06:40,309 --> 00:06:39,120
and several nucleobased fragments we

145
00:06:42,550 --> 00:06:40,319
also

146
00:06:44,309 --> 00:06:42,560
identified compounds deriving from the

147
00:06:49,510 --> 00:06:44,319
phosphate deoxyribose

148
00:06:51,749 --> 00:06:49,520
backbone of the dna

149
00:06:53,110 --> 00:06:51,759
we also extracted lipids from the two

150
00:06:55,029 --> 00:06:53,120
bacteria

151
00:06:56,150 --> 00:06:55,039
here you can see the spectra of lipids

152
00:06:59,909 --> 00:06:56,160
extracted from

153
00:07:01,510 --> 00:06:59,919
sls cancers where we clearly identified

154
00:07:08,150 --> 00:07:01,520
many lipid fragments

155
00:07:12,230 --> 00:07:10,629
here you can see this picture of e coli

156
00:07:14,469 --> 00:07:12,240
aqueous phase

157
00:07:15,270 --> 00:07:14,479
so the at the end of the lipid

158
00:07:18,150 --> 00:07:15,280
extraction

159
00:07:18,870 --> 00:07:18,160
we obtain two phases one phase contains

160
00:07:21,189 --> 00:07:18,880
the lipid

161
00:07:24,870 --> 00:07:21,199
and the other phase the aqueous phase

162
00:07:27,589 --> 00:07:24,880
contains all the polar molecules

163
00:07:28,390 --> 00:07:27,599

so here in the aqueous phase spectra on

164
00:07:31,510 --> 00:07:28,400
the right

165
00:07:32,469 --> 00:07:31,520
we identified guanine again and some

166
00:07:35,670 --> 00:07:32,479
nuclear based

167
00:07:37,909 --> 00:07:35,680
fragments and many compounds from the

168
00:07:39,110 --> 00:07:37,919
phosphate deoxyribose backbone of the

169
00:07:44,869 --> 00:07:39,120
dna

170
00:07:47,510 --> 00:07:44,879
and also several amino acids

171
00:07:49,990 --> 00:07:47,520
we compared the speed spectra between

172
00:07:52,390 --> 00:07:50,000
the two bacterial species

173
00:07:54,070 --> 00:07:52,400
fatty acids are especially interesting

174
00:07:56,629 --> 00:07:54,080
because their relative

175
00:07:58,629 --> 00:07:56,639
abundances can serve as a discriminator

176
00:08:00,710 --> 00:07:58,639
for biosignatures

177
00:08:03,029 --> 00:08:00,720
in most organisms fatty acids are

178
00:08:04,550 --> 00:08:03,039
produced by the addition of two carbon

179
00:08:07,749 --> 00:08:04,560
atoms at a time

180
00:08:10,150 --> 00:08:07,759
so this results in an excess of

181
00:08:11,430 --> 00:08:10,160
fatty acids with an even number of

182
00:08:15,270 --> 00:08:11,440
carbon atoms

183
00:08:19,110 --> 00:08:15,280
and also with c16 and c18 dominated

184
00:08:22,070 --> 00:08:19,120
dominating on the contrary in the

185
00:08:24,309 --> 00:08:22,080
abiotic synthetic of carbon chains the

186
00:08:26,390 --> 00:08:24,319
carbon atoms are added one at a time

187
00:08:29,110 --> 00:08:26,400
so there is no difference between even

188
00:08:31,670 --> 00:08:29,120

or odd carbon number

189
00:08:32,790 --> 00:08:31,680
so here as expected for biological

190
00:08:35,269 --> 00:08:32,800
samples

191
00:08:37,509 --> 00:08:35,279
the spectra from both bacteria show a

192
00:08:38,230 --> 00:08:37,519
predominance of even carbon number fatty

193
00:08:45,110 --> 00:08:38,240
acids

194
00:08:48,790 --> 00:08:45,120
we also see that c16 and c18

195
00:08:52,150 --> 00:08:48,800
fatty acids are also c15 for sls cancers

196
00:08:55,269 --> 00:08:52,160
are the most abundant fatty acids

197
00:08:57,910 --> 00:08:55,279
um the we also noticed that the

198
00:09:01,030 --> 00:08:57,920
sls cancers bacteria contains more

199
00:09:03,269 --> 00:09:01,040
unsaturated fatty acids than e coli

200
00:09:05,509 --> 00:09:03,279
and this difference may be due to the

201
00:09:07,750 --> 00:09:05,519
different bacteria species

202
00:09:12,389 --> 00:09:07,760
which have may have different membrane

203
00:09:16,470 --> 00:09:15,430
we investigated whole cells of sls

204
00:09:18,389 --> 00:09:16,480
cancers

205
00:09:19,509 --> 00:09:18,399
so instead of performing a chemical

206
00:09:23,110 --> 00:09:19,519
extraction

207
00:09:25,750 --> 00:09:23,120
we only lysed the cells by sonication

208
00:09:27,990 --> 00:09:25,760
this process makes more sense than a

209
00:09:30,389 --> 00:09:28,000
chemical extraction if we

210
00:09:31,750 --> 00:09:30,399
compare to a potential detection of

211
00:09:34,870 --> 00:09:31,760
these compounds on

212
00:09:37,990 --> 00:09:34,880
emissions such as europa clipper

213
00:09:41,350 --> 00:09:38,000

here you can see um the spectra of

214
00:09:43,829 --> 00:09:41,360
um the lifestyles in the positive mode

215
00:09:45,829 --> 00:09:43,839
and we identified two nuclear bases

216
00:09:49,030 --> 00:09:45,839
adenine and thymine

217
00:09:50,070 --> 00:09:49,040
many nuclear based fragments many amino

218
00:09:53,190 --> 00:09:50,080
acids and some

219
00:09:55,350 --> 00:09:53,200
sugar of the dna backbone

220
00:09:57,990 --> 00:09:55,360
um in the negative mode we also

221
00:09:59,110 --> 00:09:58,000
identified many lipids i didn't show the

222
00:10:01,750 --> 00:09:59,120
spectra here

223
00:10:02,790 --> 00:10:01,760
because of left of time but if you are

224
00:10:09,110 --> 00:10:02,800
interested

225
00:10:15,910 --> 00:10:12,550
finally we also investigated dna

226
00:10:18,470 --> 00:10:15,920
dna in salt rich mattresses so

227
00:10:20,790 --> 00:10:18,480
here on the spectra you can see that we

228
00:10:21,829 --> 00:10:20,800
observed a lower peak for the nuclear

229
00:10:24,949 --> 00:10:21,839
bases and sugar

230
00:10:27,110 --> 00:10:24,959
than in pure water spectra and overall

231
00:10:30,230 --> 00:10:27,120
the spectral sensitivity of the

232
00:10:34,630 --> 00:10:30,240
extracts decreases with the increasing

233
00:10:39,750 --> 00:10:37,910
so for conclusion are results true that

234
00:10:40,790 --> 00:10:39,760
microbial based signatures can be

235
00:10:43,750 --> 00:10:40,800
identified

236
00:10:45,990 --> 00:10:43,760
with impact ionization mass spectrometer

237
00:10:48,949 --> 00:10:46,000
and in particular we observed

238
00:10:51,190 --> 00:10:48,959

nuclear bases the fragments of the

239
00:10:55,910 --> 00:10:51,200
phosphate dioxide ribose

240
00:10:57,829 --> 00:10:55,920
dna backbone many amino acids and lipids

241
00:10:59,990 --> 00:10:57,839
ideally a future applied instrument

242
00:11:03,030 --> 00:11:00,000
should be capable of detecting both

243
00:11:04,069 --> 00:11:03,040
cation and anion to detect the complete

244
00:11:05,990 --> 00:11:04,079
range of the

245
00:11:08,630 --> 00:11:06,000
biosignature that we have so far

246
00:11:10,310 --> 00:11:08,640
investigated

247
00:11:12,550 --> 00:11:10,320
our results complement a spectral

248
00:11:16,150 --> 00:11:12,560
reference library for europa clipper

249
00:11:18,630 --> 00:11:16,160
and other future ocean world missions

250
00:11:19,670 --> 00:11:18,640
and ongoing and future work include the

251
00:11:22,870 --> 00:11:19,680
investigation of

252
00:11:25,990 --> 00:11:22,880
other microbial species phages and

253
00:11:27,670 --> 00:11:26,000
other potential by signature thank you

254
00:11:30,910 --> 00:11:27,680
very much for your attention