
AB
GRAD
CON23

1
00:00:04,230 --> 00:00:11,470
[Music]

2
00:00:14,930 --> 00:00:14,209
hello as Miguel said

3
00:00:17,150 --> 00:00:14,940
um

4
00:00:20,090 --> 00:00:17,160
my name is Marshall and I'm an NPP

5
00:00:23,029 --> 00:00:20,100
fellow at JPL Caltech and I work with

6
00:00:24,769 --> 00:00:23,039
Morgan cable and Brianna Henderson and I

7
00:00:27,490 --> 00:00:24,779
do most of my experimental work at

8
00:00:31,130 --> 00:00:27,500
Caltech and Paul asimov's lab but

9
00:00:33,530 --> 00:00:31,140
because this is a conference of

10
00:00:36,290 --> 00:00:33,540
literally graduate students and postdocs

11
00:00:38,630 --> 00:00:36,300
I wanted to talk about the planetary

12
00:00:40,910 --> 00:00:38,640
science summer school program which is a

13
00:00:43,970 --> 00:00:40,920

program for graduate students and

14
00:00:45,889 --> 00:00:43,980
postdocs to teach you all how to help

15
00:00:48,170 --> 00:00:45,899
Mission design for planetary missions

16
00:00:49,850 --> 00:00:48,180
actually happens and to learn the

17
00:00:51,170 --> 00:00:49,860
process and so I'm going to be

18
00:00:53,869 --> 00:00:51,180
presenting

19
00:00:56,270 --> 00:00:53,879
the mission that my team and I developed

20
00:00:59,150 --> 00:00:56,280
during the PSS

21
00:01:01,130 --> 00:00:59,160
in which the majority of the framework

22
00:01:04,009 --> 00:01:01,140
for the mission was developed back in

23
00:01:05,990 --> 00:01:04,019
2021 and that we iterated on since then

24
00:01:08,149 --> 00:01:06,000
the astrobiology exploration at

25
00:01:10,850 --> 00:01:08,159
Enceladus or X for short and I'm going

26
00:01:13,010 --> 00:01:10,860
to preface this by saying that this is

27
00:01:16,969 --> 00:01:13,020
an Unholy amount of information to

28
00:01:18,950 --> 00:01:16,979
distill into a dozen slides and so uh I

29
00:01:20,990 --> 00:01:18,960
did my best unfortunately I can't go

30
00:01:22,609 --> 00:01:21,000
into a lot of detail with these slides

31
00:01:24,830 --> 00:01:22,619
but if you have any questions about the

32
00:01:27,109 --> 00:01:24,840
science ask a question if you don't want

33
00:01:29,990 --> 00:01:27,119
to ask a question come find me I'd love

34
00:01:32,149 --> 00:01:30,000
to be stoked to talk about this stuff

35
00:01:33,530 --> 00:01:32,159
Okay so

36
00:01:35,569 --> 00:01:33,540
I'm sure you guys are familiar with

37
00:01:38,210 --> 00:01:35,579
Enceladus at this point

38
00:01:40,550 --> 00:01:38,220

um but that thing is in Solace it's one

39
00:01:42,670 --> 00:01:40,560
of uh Saturn's moons and it's it's

40
00:01:46,310 --> 00:01:42,680
relatively pretty small it's only about

41
00:01:48,710 --> 00:01:46,320
500 uh kilometers in diameter but

42
00:01:50,510 --> 00:01:48,720
there's some super cool stuff going on

43
00:01:53,030 --> 00:01:50,520
even though it's it's this tiny little

44
00:01:55,249 --> 00:01:53,040
thing that stuff coming out of the

45
00:01:58,010 --> 00:01:55,259
bottom of Enceladus

46
00:02:00,170 --> 00:01:58,020
um is a continuous plume that's formed

47
00:02:03,289 --> 00:02:00,180
over the South polar Terrain

48
00:02:05,149 --> 00:02:03,299
and so if we zoom in a little bit closer

49
00:02:06,830 --> 00:02:05,159
these are images from Cassini and though

50
00:02:08,330 --> 00:02:06,840
it's not actually blue like that that's

51
00:02:11,330 --> 00:02:08,340
in false color but that's just to show

52
00:02:13,190 --> 00:02:11,340
you where these um fractures are

53
00:02:14,750 --> 00:02:13,200
and the plume is sourced from those

54
00:02:17,030 --> 00:02:14,760
fractures

55
00:02:19,130 --> 00:02:17,040
um that all combines to form a

56
00:02:21,290 --> 00:02:19,140
continuous plume over the South polar

57
00:02:24,290 --> 00:02:21,300
terrain and we have really strong

58
00:02:27,949 --> 00:02:24,300
evidence from some of the measurements

59
00:02:30,229 --> 00:02:27,959
by Cassini that this plume is directly

60
00:02:32,390 --> 00:02:30,239
sourced from a subsurface Global liquid

61
00:02:34,670 --> 00:02:32,400
water ocean

62
00:02:36,530 --> 00:02:34,680
and so this presents a unique

63
00:02:39,650 --> 00:02:36,540

opportunity we're unique in our solar

64
00:02:43,309 --> 00:02:39,660
system to sample the contents of a

65
00:02:45,050 --> 00:02:43,319
subsurface ocean in situ using uh

66
00:02:46,970 --> 00:02:45,060
multi-flyby or an Orbiter Mission

67
00:02:49,009 --> 00:02:46,980
architecture

68
00:02:52,729 --> 00:02:49,019
and we have some rough compositional

69
00:02:55,430 --> 00:02:52,739
information of the plume uh from Cassini

70
00:02:56,930 --> 00:02:55,440
using the inms or the ion and neutral

71
00:02:58,790 --> 00:02:56,940
Mass spectrometer and the cosmic dust

72
00:03:02,630 --> 00:02:58,800
analyzer and so

73
00:03:05,869 --> 00:03:02,640
um in the plume gas we see water

74
00:03:08,089 --> 00:03:05,879
um small hydrocarbons some simple and

75
00:03:09,530 --> 00:03:08,099
complex Organics and this is a paper

76
00:03:11,990 --> 00:03:09,540
from

77
00:03:15,050 --> 00:03:12,000
the weight at all paper back in 2006

78
00:03:17,089 --> 00:03:15,060
from the inms data but if we look at

79
00:03:19,250 --> 00:03:17,099
plume grains we see that they're

80
00:03:21,170 --> 00:03:19,260
waterized but um we see a lot of

81
00:03:23,390 --> 00:03:21,180
different salts but in addition to that

82
00:03:25,130 --> 00:03:23,400
and I I think a previous talk hit on

83
00:03:26,869 --> 00:03:25,140
this a little bit we see silicon Nano

84
00:03:29,570 --> 00:03:26,879
grains and that's really important

85
00:03:32,030 --> 00:03:29,580
because based on what we know the only

86
00:03:34,309 --> 00:03:32,040
way that these silicon nanoparticles

87
00:03:36,290 --> 00:03:34,319
could be produced within this size range

88
00:03:38,449 --> 00:03:36,300

are high temperature hydrothermal

89
00:03:40,789 --> 00:03:38,459
reactions and that's huge from a

90
00:03:42,250 --> 00:03:40,799
habitability standpoint and in addition

91
00:03:45,589 --> 00:03:42,260
to this

92
00:03:47,930 --> 00:03:45,599
looking at the CDA data that Cosmic dust

93
00:03:50,809 --> 00:03:47,940
analyzer we see evidence not direct

94
00:03:52,850 --> 00:03:50,819
detection because of the the

95
00:03:54,770 --> 00:03:52,860
instrumental capabilities we had at the

96
00:03:57,470 --> 00:03:54,780
time this is like 80s technology

97
00:03:59,930 --> 00:03:57,480
but we see strong evidence for

98
00:04:02,750 --> 00:03:59,940
macromolecular organic compounds

99
00:04:04,910 --> 00:04:02,760
and so there's this complex organic

100
00:04:06,710 --> 00:04:04,920
chemistry going on that we don't really

101
00:04:08,149 --> 00:04:06,720
understand and we don't know what's

102
00:04:10,610 --> 00:04:08,159
going on there but like something's

103
00:04:12,289 --> 00:04:10,620
happening and so we need to figure out

104
00:04:14,809 --> 00:04:12,299
what's up

105
00:04:17,390 --> 00:04:14,819
and so with that being said we have

106
00:04:18,770 --> 00:04:17,400
liquid water we have a geothermal source

107
00:04:20,800 --> 00:04:18,780
of feed via the high temperature

108
00:04:20,930 --> 00:04:20,810
hydrothermal reactions

109
00:04:22,129 --> 00:04:20,940
[Music]

110
00:04:23,749 --> 00:04:22,139
um

111
00:04:25,969 --> 00:04:23,759
essentially all the chemical building

112
00:04:27,770 --> 00:04:25,979
blocks for Life as we know it they're

113
00:04:29,689 --> 00:04:27,780

present

114
00:04:31,969 --> 00:04:29,699
um sulfur hasn't been published yet but

115
00:04:33,230 --> 00:04:31,979
it has been detected in the greens it

116
00:04:35,270 --> 00:04:33,240
should be published in the next year or

117
00:04:39,409 --> 00:04:35,280
so so with all of this

118
00:04:41,570 --> 00:04:39,419
in mind could Enceladus

119
00:04:44,450 --> 00:04:41,580
Harbor life

120
00:04:47,210 --> 00:04:44,460
we thought it would be sick to develop a

121
00:04:49,670 --> 00:04:47,220
mission concept that would be capable of

122
00:04:51,710 --> 00:04:49,680
finding out and so just a brief overview

123
00:04:53,629 --> 00:04:51,720
of our mission architecture it's be it

124
00:04:55,610 --> 00:04:53,639
multiply by Mission but you're orbiting

125
00:04:57,950 --> 00:04:55,620
Saturn and do multiple flybysmen zeldas

126
00:05:00,530 --> 00:04:57,960
and we would require 30 flybys for our

127
00:05:03,050 --> 00:05:00,540
science and would launch in 2033 and

128
00:05:04,670 --> 00:05:03,060
after a nine-year cruise phase and a

129
00:05:07,430 --> 00:05:04,680
one-year pump down phase we would enter

130
00:05:09,590 --> 00:05:07,440
four years of science operations

131
00:05:11,930 --> 00:05:09,600
where we would directly search for

132
00:05:14,629 --> 00:05:11,940
biosignatures through n-situ chemical

133
00:05:17,350 --> 00:05:14,639
compositional analysis of the plume and

134
00:05:19,850 --> 00:05:17,360
contextualize these in-situ measurement

135
00:05:22,010 --> 00:05:19,860
in-situ measurements through a

136
00:05:24,010 --> 00:05:22,020
synergistic combination of geophysical

137
00:05:26,870 --> 00:05:24,020
and geomorphological investigations

138
00:05:29,330 --> 00:05:26,880

aimed at also assessing the habitability

139
00:05:31,070 --> 00:05:29,340
of Enceladus over geologic time

140
00:05:32,990 --> 00:05:31,080
and we would do this using a mass

141
00:05:35,990 --> 00:05:33,000
spectrometer a high resolution camera

142
00:05:37,850 --> 00:05:36,000
and just a high gain antenna so three it

143
00:05:38,990 --> 00:05:37,860
well two and a half instruments because

144
00:05:41,450 --> 00:05:39,000
the antenna you use for radio

145
00:05:43,610 --> 00:05:41,460
communications

146
00:05:44,990 --> 00:05:43,620
and so just briefly to talk about how

147
00:05:46,730 --> 00:05:45,000
before I dive into the science

148
00:05:48,230 --> 00:05:46,740
objectives how these objectives were

149
00:05:49,790 --> 00:05:48,240
formulated

150
00:05:51,650 --> 00:05:49,800
um NASA

151
00:05:54,830 --> 00:05:51,660
doesn't like

152
00:05:56,510 --> 00:05:54,840
as much when people just when they're

153
00:05:57,590 --> 00:05:56,520
developing missions to like take this

154
00:05:59,150 --> 00:05:57,600
instrument okay we have a sick

155
00:06:01,249 --> 00:05:59,160
instrument what kind of science can we

156
00:06:03,529 --> 00:06:01,259
do with it instead

157
00:06:06,050 --> 00:06:03,539
um we were taught and we were informed

158
00:06:09,170 --> 00:06:06,060
that NASA prefers that you first start

159
00:06:12,050 --> 00:06:09,180
by answering or by asking questions like

160
00:06:14,350 --> 00:06:12,060
what do we not know about Enceladus what

161
00:06:16,850 --> 00:06:14,360
do we need to know to ask more questions

162
00:06:19,430 --> 00:06:16,860
and so that's what we started by doing

163
00:06:20,689 --> 00:06:19,440

and if you do that if you start from the

164
00:06:22,249 --> 00:06:20,699
science questions and what you're

165
00:06:24,529 --> 00:06:22,259
interested in and what you want to find

166
00:06:28,550 --> 00:06:24,539
out the rest of it follows pretty

167
00:06:30,290 --> 00:06:28,560
logically and so say we want to find out

168
00:06:32,390 --> 00:06:30,300
this thing okay what do we need to

169
00:06:33,529 --> 00:06:32,400
measure to figure that thing out okay

170
00:06:35,570 --> 00:06:33,539
then you have your measurement

171
00:06:37,309 --> 00:06:35,580
requirements and then at what levels do

172
00:06:39,110 --> 00:06:37,319
we need to measure this there you have

173
00:06:40,490 --> 00:06:39,120
like further established measurement

174
00:06:42,050 --> 00:06:40,500
requirements well how do we make these

175
00:06:43,550 --> 00:06:42,060
measurements and then you select your

176
00:06:45,890 --> 00:06:43,560
instruments and then so on and so forth

177
00:06:47,570 --> 00:06:45,900
and so it just logically flows from it's

178
00:06:50,510 --> 00:06:47,580
called left to right approach

179
00:06:52,610 --> 00:06:50,520
and so I'll talk a little bit about our

180
00:06:54,529 --> 00:06:52,620
science objectives of course the first

181
00:06:57,170 --> 00:06:54,539
which is to determine if the molecular

182
00:06:59,150 --> 00:06:57,180
and isotopic distributions uh within the

183
00:07:02,029 --> 00:06:59,160
plume are a result of biological

184
00:07:03,710 --> 00:07:02,039
activity or abiotic chemical processing

185
00:07:06,590 --> 00:07:03,720
and we would do this just with your

186
00:07:08,809 --> 00:07:06,600
usual suspects amino acids fatty acids

187
00:07:11,990 --> 00:07:08,819
and plume grains and um by assessing

188
00:07:13,790 --> 00:07:12,000

isotopic fractionation in um in the

189
00:07:15,409 --> 00:07:13,800
plume gas and we would do this just

190
00:07:17,210 --> 00:07:15,419
using a mass spectrometer and if you

191
00:07:18,590 --> 00:07:17,220
have any questions about Mass specs or

192
00:07:20,990 --> 00:07:18,600
instrument selection please ask a

193
00:07:22,490 --> 00:07:21,000
question or find me later I'd love to

194
00:07:25,490 --> 00:07:22,500
talk about that

195
00:07:27,469 --> 00:07:25,500
and the second of our objectives is to

196
00:07:29,089 --> 00:07:27,479
determine whether Enceladus is in

197
00:07:31,189 --> 00:07:29,099
thermal equilibrium and is therefore

198
00:07:33,170 --> 00:07:31,199
capable of sustaining an ocean over

199
00:07:34,850 --> 00:07:33,180
geologic time scales and this is

200
00:07:37,010 --> 00:07:34,860
essentially just a heat balance equation

201
00:07:39,409 --> 00:07:37,020
we want to know how much being how much

202
00:07:41,629 --> 00:07:39,419
heat is being input to Enceladus through

203
00:07:43,670 --> 00:07:41,639
tidal dissipation from Saturn and how

204
00:07:47,029 --> 00:07:43,680
much heat is being emitted by Enceladus

205
00:07:48,230 --> 00:07:47,039
through like um conductive heat loss and

206
00:07:50,270 --> 00:07:48,240
you can

207
00:07:51,710 --> 00:07:50,280
actually determine the heat being

208
00:07:55,909 --> 00:07:51,720
generated

209
00:08:00,589 --> 00:07:58,790
looking at tidal dissipation from Saturn

210
00:08:02,450 --> 00:08:00,599
and you can do this using orbital

211
00:08:05,150 --> 00:08:02,460
migration rates so you could look at

212
00:08:07,010 --> 00:08:05,160
where Enceladus is at in its orbital

213
00:08:09,529 --> 00:08:07,020

phase relative to What was seen by

214
00:08:11,710 --> 00:08:09,539
Cassini to see how the orbital migration

215
00:08:14,809 --> 00:08:11,720
happens and

216
00:08:16,969 --> 00:08:14,819
uh from that you could calculate a tidal

217
00:08:19,490 --> 00:08:16,979
dissipation quality factor and you can

218
00:08:21,170 --> 00:08:19,500
determine the heat being emitted by

219
00:08:23,029 --> 00:08:21,180
measuring ice shell thickness which is a

220
00:08:24,290 --> 00:08:23,039
proxy for the heat loss and you can do

221
00:08:26,170 --> 00:08:24,300
that using a gravity science

222
00:08:30,290 --> 00:08:26,180
measurements

223
00:08:32,990 --> 00:08:30,300
the third of our objective objectives

224
00:08:34,610 --> 00:08:33,000
is looking at plume formation mechanisms

225
00:08:36,889 --> 00:08:34,620
to determine whether the plume material

226
00:08:40,029 --> 00:08:36,899
is being delivered to the surface via

227
00:08:42,889 --> 00:08:40,039
open crevice boiling or explosive

228
00:08:45,949 --> 00:08:42,899
cryovolcanic-like eruptions and we

229
00:08:48,290 --> 00:08:45,959
expect there to be differences in the

230
00:08:50,870 --> 00:08:48,300
morphology of the vents at the surface

231
00:08:52,070 --> 00:08:50,880
that are expressed in each scenario and

232
00:08:54,769 --> 00:08:52,080
you could

233
00:08:56,930 --> 00:08:54,779
actually sort of tease out how these

234
00:08:59,570 --> 00:08:56,940
plumes are being formed by high

235
00:09:01,730 --> 00:08:59,580
resolution imaging of the vents so for

236
00:09:03,130 --> 00:09:01,740
an open crevice model we expect there to

237
00:09:06,050 --> 00:09:03,140
be

238
00:09:07,910 --> 00:09:06,060

vent width variations in response to

239
00:09:10,610 --> 00:09:07,920
Tidal forcing throughout enceladus's

240
00:09:12,290 --> 00:09:10,620
orbital phase and for an open crevice

241
00:09:14,150 --> 00:09:12,300
model we expect these vent width

242
00:09:15,590 --> 00:09:14,160
variations to be consistent along the

243
00:09:17,090 --> 00:09:15,600
strike of the vent

244
00:09:19,130 --> 00:09:17,100
and so by taking multiple high

245
00:09:20,990 --> 00:09:19,140
resolution images of a single vent

246
00:09:23,630 --> 00:09:21,000
throughout enceladus's orbital phase and

247
00:09:25,070 --> 00:09:23,640
looking at vent width variations we can

248
00:09:27,350 --> 00:09:25,080
determine if that were the case whereas

249
00:09:30,110 --> 00:09:27,360
for a purely cryovolcanic eruptive model

250
00:09:32,150 --> 00:09:30,120
we expect these vent width variations to

251
00:09:33,590 --> 00:09:32,160
be restricted to the immediate vicinity

252
00:09:35,509 --> 00:09:33,600
of the vent

253
00:09:37,130 --> 00:09:35,519
and so we could sort of tease out the

254
00:09:39,470 --> 00:09:37,140
relative contribution of each of these

255
00:09:41,269 --> 00:09:39,480
models to plume formation

256
00:09:42,650 --> 00:09:41,279
and then our fourth and final science

257
00:09:45,050 --> 00:09:42,660
objective

258
00:09:47,810 --> 00:09:45,060
is to determine if the geologic activity

259
00:09:49,490 --> 00:09:47,820
that uh is modifying the South polar

260
00:09:52,130 --> 00:09:49,500
terrain like we see in all those awesome

261
00:09:55,070 --> 00:09:52,140
images if it's influenced other regions

262
00:09:57,410 --> 00:09:55,080
in the past over geologic time

263
00:09:59,090 --> 00:09:57,420

we would do this by looking at two

264
00:10:01,790 --> 00:09:59,100
things both crater infilling and

265
00:10:04,550 --> 00:10:01,800
elliptical crater orientations because

266
00:10:06,350 --> 00:10:04,560
if you look at the depth diameter ratios

267
00:10:08,750 --> 00:10:06,360
of craters around the South polar

268
00:10:10,610 --> 00:10:08,760
terrain they're pretty shallow compared

269
00:10:12,829 --> 00:10:10,620
to the rest of the the crater population

270
00:10:14,810 --> 00:10:12,839
because of all that plume Fallout that's

271
00:10:16,910 --> 00:10:14,820
infilling the craters and so we see

272
00:10:18,470 --> 00:10:16,920
really shallow craters around there

273
00:10:20,449 --> 00:10:18,480
but if you look at the global crater

274
00:10:22,310 --> 00:10:20,459
population like typically

275
00:10:23,990 --> 00:10:22,320
um they have a pretty well defined depth

276
00:10:26,150 --> 00:10:24,000
diameter ratio and so if we were to look

277
00:10:30,350 --> 00:10:26,160
at survey the global crater population

278
00:10:32,810 --> 00:10:30,360
and find an area around Enceladus where

279
00:10:34,250 --> 00:10:32,820
we see anomalously infilled craters that

280
00:10:36,530 --> 00:10:34,260
could be evidence that there was past

281
00:10:38,870 --> 00:10:36,540
plume activity and another thing that we

282
00:10:41,090 --> 00:10:38,880
would look at uh are elliptical crater

283
00:10:42,889 --> 00:10:41,100
orientations to see if there could have

284
00:10:45,650 --> 00:10:42,899
been any eye shell reorientation in the

285
00:10:47,150 --> 00:10:45,660
past because given a preferential

286
00:10:48,949 --> 00:10:47,160
velocity vector and the impactor

287
00:10:51,590 --> 00:10:48,959
population and a small enough impact

288
00:10:53,990 --> 00:10:51,600

angle below about 15 degrees elliptical

289
00:10:55,430 --> 00:10:54,000
craters are formed and so like given a

290
00:10:58,130 --> 00:10:55,440
preferential velocity Vector we expect

291
00:10:58,850 --> 00:10:58,140
to see mostly East-West

292
00:11:02,030 --> 00:10:58,860
um

293
00:11:04,430 --> 00:11:02,040
uh oriented elliptical craters

294
00:11:08,509 --> 00:11:04,440
and so if we were to survey the crater

295
00:11:10,250 --> 00:11:08,519
population and see a shift in the

296
00:11:12,590 --> 00:11:10,260
orientation of these elliptical craters

297
00:11:14,449 --> 00:11:12,600
that is like relatively consistent we

298
00:11:17,630 --> 00:11:14,459
could infer past eye shell reorientation

299
00:11:24,170 --> 00:11:20,150
and so for the mission trajectory

300
00:11:26,329 --> 00:11:24,180
um briefly we'd use a Venus Earth Earth

301
00:11:30,790 --> 00:11:26,339
Venus Earth Earth Earth Jupiter gravity

302
00:11:32,990 --> 00:11:30,800
assist where we would do we do a a

303
00:11:34,610 --> 00:11:33,000
slingshot around Venus and then a couple

304
00:11:36,230 --> 00:11:34,620
orbits around Earth and then slingshot

305
00:11:37,910 --> 00:11:36,240
out to the Jupiter system and then use

306
00:11:40,790 --> 00:11:37,920
Jupiter's gravity to slingshot out into

307
00:11:43,370 --> 00:11:40,800
the Saturn system but

308
00:11:45,710 --> 00:11:43,380
getting out to Saturn isn't a problem

309
00:11:48,050 --> 00:11:45,720
it's slowing down that's the problem

310
00:11:50,990 --> 00:11:48,060
because you're going like 15 20

311
00:11:52,490 --> 00:11:51,000
kilometers a second and so after Saturn

312
00:11:55,250 --> 00:11:52,500
orbital insertion

313
00:11:57,410 --> 00:11:55,260

we do a one-year pump down phase and

314
00:11:59,870 --> 00:11:57,420
using multiple use multiple flybys of

315
00:12:03,230 --> 00:11:59,880
Titan using Titan's gravity to reduce

316
00:12:05,990 --> 00:12:03,240
the spacecraft velocity and tailor the

317
00:12:08,030 --> 00:12:06,000
inclination and altitude such that we

318
00:12:10,670 --> 00:12:08,040
could Target and sell at us properly for

319
00:12:12,050 --> 00:12:10,680
our flybys and then after that enter a

320
00:12:13,550 --> 00:12:12,060
four-year tour phase where we would

321
00:12:17,449 --> 00:12:13,560
conduct all of our science operations

322
00:12:20,269 --> 00:12:17,459
that would consist of 30 flybys at least

323
00:12:22,430 --> 00:12:20,279
and this is this uh requirement is

324
00:12:25,190 --> 00:12:22,440
driven primarily by our gravity science

325
00:12:26,990 --> 00:12:25,200
measurements that we need to make and

326
00:12:30,769 --> 00:12:27,000
the surface mapping would require a

327
00:12:34,250 --> 00:12:30,779
total of 22 flybys not necessarily 22

328
00:12:37,730 --> 00:12:34,260
flybys total dedicated surface mapping

329
00:12:41,090 --> 00:12:37,740
but the data downlink would require 22

330
00:12:43,069 --> 00:12:41,100
flybys um and so a minimum of five

331
00:12:45,170 --> 00:12:43,079
flybys at low altitudes as well for

332
00:12:47,389 --> 00:12:45,180
event imagery and Institute Bloom

333
00:12:50,269 --> 00:12:47,399
analyzes

334
00:12:52,069 --> 00:12:50,279
so keyword to key takeaway uh installed

335
00:12:54,009 --> 00:12:52,079
is a sick it's super awesome there's a

336
00:12:56,690 --> 00:12:54,019
lot of really cool stuff going on there

337
00:12:58,730 --> 00:12:56,700
and we would

338
00:13:01,069 --> 00:12:58,740

see what's going on there by looking at

339
00:13:04,009 --> 00:13:01,079
plume composition heat balance the

340
00:13:07,670 --> 00:13:04,019
different event formation mechanisms and

341
00:13:09,590 --> 00:13:07,680
what the surface of Enceladus can tell

342
00:13:11,329 --> 00:13:09,600
us about its past

343
00:13:13,389 --> 00:13:11,339
and this is important because in the

344
00:13:16,129 --> 00:13:13,399
most recent decadal survey

345
00:13:19,370 --> 00:13:16,139
they specifically call out a New

346
00:13:21,829 --> 00:13:19,380
Frontiers mission to Enceladus using a

347
00:13:23,389 --> 00:13:21,839
multi-flyby mission architecture and so

348
00:13:25,370 --> 00:13:23,399
there's so many outstanding questions

349
00:13:26,930 --> 00:13:25,380
that we just we just don't know about

350
00:13:30,110 --> 00:13:26,940
what's going on in Enceladus and we need

351
00:13:32,629 --> 00:13:30,120
to go back to figure out what's going on

352
00:13:36,230 --> 00:13:32,639
so as promised a little talk about PSS

353
00:13:38,170 --> 00:13:36,240
this is my team that I worked with and

354
00:13:40,610 --> 00:13:38,180
they're the most

355
00:13:41,870 --> 00:13:40,620
absurdly brilliant group of people that

356
00:13:43,190 --> 00:13:41,880
I've ever had the pleasure of working

357
00:13:44,509 --> 00:13:43,200
with

358
00:13:46,310 --> 00:13:44,519
um they're incredible I'm still friends

359
00:13:48,590 --> 00:13:46,320
with many of them now

360
00:13:50,509 --> 00:13:48,600
um and so I I'd like to talk a little

361
00:13:52,910 --> 00:13:50,519
bit about the PSS

362
00:13:55,129 --> 00:13:52,920
um it's uh it's not really as much of a

363
00:13:57,949 --> 00:13:55,139

summer school as it is a rigorous

364
00:14:01,370 --> 00:13:57,959
Mission design program where they teach

365
00:14:03,050 --> 00:14:01,380
you how to actually formulate a mission

366
00:14:05,090 --> 00:14:03,060
um and the deadlines pass for this year

367
00:14:07,310 --> 00:14:05,100
but it's it's it's competitive you have

368
00:14:09,050 --> 00:14:07,320
to apply for it and they take 18 people

369
00:14:10,910 --> 00:14:09,060
per cohort

370
00:14:12,829 --> 00:14:10,920
um but you get to work with literally

371
00:14:15,050 --> 00:14:12,839
the best in the business

372
00:14:17,449 --> 00:14:15,060
um you're mentored by people that are on

373
00:14:19,430 --> 00:14:17,459
like Europa Clipper Mars sample return

374
00:14:22,730 --> 00:14:19,440
all that kind of stuff and in the last

375
00:14:26,509 --> 00:14:22,740
week you get to work one-on-one and are

376
00:14:30,410 --> 00:14:26,519
mentored by a member of NASA's uh

377
00:14:32,449 --> 00:14:30,420
Advanced project design team uh TMax

378
00:14:34,730 --> 00:14:32,459
they're literally the best at what they

379
00:14:37,190 --> 00:14:34,740
do formulating missions and you've

380
00:14:37,910 --> 00:14:37,200
learned so much and it's incredible

381
00:14:40,310 --> 00:14:37,920
um

382
00:14:42,230 --> 00:14:40,320
if you have any questions please come

383
00:14:43,670 --> 00:14:42,240
find me ask here or if you don't want to

384
00:14:46,490 --> 00:14:43,680
ask a question in front of a bunch of

385
00:14:49,490 --> 00:14:46,500
people come find me talk to me

386
00:14:50,930 --> 00:14:49,500
um I knew when I first like was thinking

387
00:14:52,009 --> 00:14:50,940
about doing it I was like oh my God I

388
00:14:54,050 --> 00:14:52,019

don't know anything about Mission design

389
00:14:55,910 --> 00:14:54,060
how am I going to do this but everybody

390
00:14:57,410 --> 00:14:55,920
else in my court thought the exact same

391
00:14:59,210 --> 00:14:57,420
thing so you don't need to be an expert

392
00:15:01,670 --> 00:14:59,220
in Mission design you just need to be

393
00:15:03,290 --> 00:15:01,680
interested and enthusiastic about doing

394
00:15:05,930 --> 00:15:03,300
this stuff and this is the the most

395
00:15:08,269 --> 00:15:05,940
incredible experience I've had of my

396
00:15:11,150 --> 00:15:08,279
professional career so I would highly

397
00:15:13,730 --> 00:15:11,160
highly recommend this program to anybody

398
00:15:22,910 --> 00:15:13,740
interested in Mission design

399
00:15:22,920 --> 00:15:30,889
any questions

400
00:15:35,329 --> 00:15:34,550
hi Michael I'm from UCSD just up the

401
00:15:37,970 --> 00:15:35,339
hill

402
00:15:41,629 --> 00:15:37,980
um I was wondering

403
00:15:43,069 --> 00:15:41,639
is there like how quickly or is it

404
00:15:47,689 --> 00:15:43,079
plooming like is it gonna run out of

405
00:15:53,750 --> 00:15:49,730
um oh

406
00:15:56,090 --> 00:15:53,760
it's been active for I mean Enceladus is

407
00:15:58,910 --> 00:15:56,100
anywhere between like 100 million and

408
00:16:01,670 --> 00:15:58,920
over one two billion years old

409
00:16:05,090 --> 00:16:01,680
um and it's been like the e-ring around

410
00:16:06,650 --> 00:16:05,100
Saturn is composed mostly of Enceladus

411
00:16:08,870 --> 00:16:06,660
plume materials so we know it's been

412
00:16:11,990 --> 00:16:08,880
around for a very very long time

413
00:16:13,550 --> 00:16:12,000

and we also know that the ocean is is a

414
00:16:15,170 --> 00:16:13,560
quite large

415
00:16:18,410 --> 00:16:15,180
um and makes up a pretty significant

416
00:16:21,829 --> 00:16:18,420
portion of the the mass of the Moon so I

417
00:16:24,110 --> 00:16:21,839
I there's a not any evidence as far as

418
00:16:25,910 --> 00:16:24,120
I'm concerned or as far as I know uh

419
00:16:37,610 --> 00:16:25,920
that it's running out anytime soon and

420
00:16:41,629 --> 00:16:39,350
I'm curious

421
00:16:43,910 --> 00:16:41,639
um does this program kind of have a

422
00:16:45,470 --> 00:16:43,920
component where you assess the costs of

423
00:16:50,949 --> 00:16:45,480
certain missions and sort of optimize

424
00:16:55,670 --> 00:16:53,810
that's the it's like the entire last

425
00:16:58,249 --> 00:16:55,680
week is like the so the New Frontiers

426
00:17:00,470 --> 00:16:58,259
five cost cap is 900 million and it

427
00:17:04,250 --> 00:17:00,480
takes like 700 million to take a piece

428
00:17:06,890 --> 00:17:04,260
of cardboard to Enceladus and so

429
00:17:08,449 --> 00:17:06,900
and so yeah that's a huge part of it and

430
00:17:10,610 --> 00:17:08,459
that's like a huge part of like working

431
00:17:13,189 --> 00:17:10,620
with TMax is to try and do rapid

432
00:17:15,890 --> 00:17:13,199
iterations of your your mission concept

433
00:17:18,230 --> 00:17:15,900
to see what you can do and what trade

434
00:17:21,590 --> 00:17:18,240
space you can explore to fall with under

435
00:17:23,390 --> 00:17:21,600
the cost cap because the problem isn't

436
00:17:25,130 --> 00:17:23,400
like finding all the science to do

437
00:17:27,370 --> 00:17:25,140
because like there's so much science you

438
00:17:31,130 --> 00:17:27,380

can do it's finding

439
00:17:33,950 --> 00:17:31,140
what it's doing the most science for the

440
00:17:37,370 --> 00:17:33,960
least money and so unfortunately that is

441
00:17:38,450 --> 00:17:37,380
a massive part of mission design and

442
00:17:48,289 --> 00:17:38,460
formulation

443
00:17:54,049 --> 00:17:51,230
hi uh Colin Robinson uh very man

444
00:17:55,310 --> 00:17:54,059
University I I was just wondering uh I

445
00:17:58,190 --> 00:17:55,320
know one of the big

446
00:18:00,650 --> 00:17:58,200
hindrances to uh sampling Organics from

447
00:18:03,289 --> 00:18:00,660
blooms and Enceladus is uh destruction

448
00:18:05,570 --> 00:18:03,299
of Organics because in the sampling

449
00:18:06,950 --> 00:18:05,580
processes right because of velocity and

450
00:18:09,110 --> 00:18:06,960
you just

451
00:18:10,669 --> 00:18:09,120
go you know at high speeds through the

452
00:18:12,110 --> 00:18:10,679
bloom with like a cup to pick up all

453
00:18:14,330 --> 00:18:12,120
that stuff lots of Organics are just

454
00:18:16,669 --> 00:18:14,340
gonna be obliterated so what steps were

455
00:18:19,610 --> 00:18:16,679
you guys thinking of taking to eliminate

456
00:18:21,230 --> 00:18:19,620
destruction of Bio signatures

457
00:18:22,190 --> 00:18:21,240
thank you so much for asking that

458
00:18:22,730 --> 00:18:22,200
question

459
00:18:25,070 --> 00:18:22,740
um

460
00:18:26,930 --> 00:18:25,080
I actually that's the research that I'm

461
00:18:30,169 --> 00:18:26,940
doing at Caltech is we're simulating

462
00:18:30,950 --> 00:18:30,179
hyper velocity impacts of eye screens

463
00:18:32,750 --> 00:18:30,960

um

464
00:18:35,750 --> 00:18:32,760
using impact ionization mass

465
00:18:37,430 --> 00:18:35,760
spectrometry and we're the only lab in

466
00:18:39,230 --> 00:18:37,440
the world that can do that at the moment

467
00:18:41,630 --> 00:18:39,240
they can actually simulate a

468
00:18:43,610 --> 00:18:41,640
distribution of I well I don't want to

469
00:18:45,590 --> 00:18:43,620
get i'll nerd out too much come find me

470
00:18:48,130 --> 00:18:45,600
to talk about that after after this if

471
00:18:51,590 --> 00:18:48,140
you want but to answer your question yes

472
00:18:54,710 --> 00:18:51,600
there is a velocity regime where you

473
00:18:56,270 --> 00:18:54,720
have both efficient ionization assuming

474
00:18:58,490 --> 00:18:56,280
you're using an impact ionization Mass

475
00:19:00,110 --> 00:18:58,500
spectrometer for analysis of plume

476
00:19:02,990 --> 00:19:00,120
grains which is pretty necessary at this

477
00:19:05,870 --> 00:19:03,000
stage yes there is a velocity regime

478
00:19:08,330 --> 00:19:05,880
that you have efficient ionization and

479
00:19:10,730 --> 00:19:08,340
molecular survivability for a range of

480
00:19:13,190 --> 00:19:10,740
of compound classes and the

481
00:19:15,470 --> 00:19:13,200
survivability velocity range

482
00:19:18,049 --> 00:19:15,480
um is depends on molecular functionality

483
00:19:19,850 --> 00:19:18,059
but it's somewhere between four and six

484
00:19:22,310 --> 00:19:19,860
kilometers per second it is like the

485
00:19:24,049 --> 00:19:22,320
Goldilocks zone that you wanna that you

486
00:19:26,750 --> 00:19:24,059
want to sample at so yes that's a

487
00:19:28,430 --> 00:19:26,760
fantastic question and that is a problem

488
00:19:30,830 --> 00:19:28,440

that a lot of very smart people are

489
00:19:32,330 --> 00:19:30,840
trying to solve right now in in terms of

490
00:19:34,730 --> 00:19:32,340
that speed four to six kilometers per

491
00:19:36,169 --> 00:19:34,740
second uh is that fast enough to be able

492
00:19:38,930 --> 00:19:36,179
to stay out of the gravitational pull of

493
00:19:40,130 --> 00:19:38,940
Enceladus okay yeah Enceladus does it

494
00:19:42,650 --> 00:19:40,140
there's not very much gravity there

495
00:19:47,990 --> 00:19:42,660
exactly that's tiny yeah thank you no

496
00:19:55,270 --> 00:19:51,529
uh hi I'm over for Veronica from Cornell

497
00:20:01,810 --> 00:19:59,210
but whether it's like a open for

498
00:20:04,789 --> 00:20:01,820
fracture for purposes uh cryova

499
00:20:08,529 --> 00:20:04,799
volcanism is that going to

500
00:20:13,669 --> 00:20:08,539
um impact the types of uh biosis

501
00:20:14,690 --> 00:20:13,679
signatures that uh could be detected

502
00:20:17,810 --> 00:20:14,700
yes

503
00:20:18,529 --> 00:20:17,820
very much so that's a fantastic question

504
00:20:20,450 --> 00:20:18,539
um

505
00:20:23,150 --> 00:20:20,460
in each case

506
00:20:26,810 --> 00:20:23,160
um the mechanism of plume formation

507
00:20:28,130 --> 00:20:26,820
that's under underlying the surface

508
00:20:29,690 --> 00:20:28,140
um

509
00:20:32,990 --> 00:20:29,700
I'm trying to think of the best way to

510
00:20:36,110 --> 00:20:33,000
say it but the way the grains are formed

511
00:20:37,909 --> 00:20:36,120
actually strongly influences the

512
00:20:40,490 --> 00:20:37,919
composition of the grains because you

513
00:20:43,250 --> 00:20:40,500

have homogeneous nucleation where if you

514
00:20:45,529 --> 00:20:43,260
just have like water that just freezes

515
00:20:48,049 --> 00:20:45,539
and is is shot out in the like the open

516
00:20:49,970 --> 00:20:48,059
crevice boiling situation

517
00:20:52,190 --> 00:20:49,980
um where you have uh

518
00:20:54,049 --> 00:20:52,200
a heterogeneous nucleation where you

519
00:20:58,310 --> 00:20:54,059
have well I don't want to get too much

520
00:21:00,770 --> 00:20:58,320
in the weeds but but uh yes um for a an

521
00:21:01,789 --> 00:21:00,780
explosive cryovolcanic scenario like you

522
00:21:05,090 --> 00:21:01,799
mentioned

523
00:21:07,010 --> 00:21:05,100
um we wouldn't see very many

524
00:21:09,529 --> 00:21:07,020
um compositional differences from grain

525
00:21:11,570 --> 00:21:09,539
to grain whereas for the open crevice

526
00:21:14,810 --> 00:21:11,580
boiling scenario due to the different

527
00:21:17,270 --> 00:21:14,820
ice cream nucleation processes that that

528
00:21:19,190 --> 00:21:17,280
can occur you would see very distinct

529
00:21:21,890 --> 00:21:19,200
compositional differences in the grains

530
00:21:23,050 --> 00:21:21,900
and we see that in the CDA data that's

531
00:21:23,690 --> 00:21:23,060
where all those the

532
00:21:25,190 --> 00:21:23,700
[Music]

533
00:21:27,169 --> 00:21:25,200
um

534
00:21:28,370 --> 00:21:27,179
evidence for those Organics that I was

535
00:21:31,190 --> 00:21:28,380
talking about before those complex

536
00:21:34,370 --> 00:21:31,200
Organics that comes from Ice grains that

537
00:21:37,149 --> 00:21:34,380
are composed primarily of an organic

538
00:21:40,850 --> 00:21:37,159

phase that were formed very likely

539
00:21:42,289 --> 00:21:40,860
through open crevice boiling and so

540
00:21:45,590 --> 00:21:42,299
um I guess that's a long answer to

541
00:21:49,250 --> 00:21:45,600
saying yes that it very much matters

542
00:21:53,330 --> 00:21:51,649
okay our lunch delivery is running a

543
00:22:00,370 --> 00:21:53,340
little late so we have time for another

544
00:22:04,310 --> 00:22:02,390
thanks Marshall I've heard this talk

545
00:22:06,289 --> 00:22:04,320
many times you're welcome and every time

546
00:22:07,730 --> 00:22:06,299
and every time it's enjoyable and every

547
00:22:10,610 --> 00:22:07,740
time I feel like I ask the question

548
00:22:12,169 --> 00:22:10,620
about uh what kind of mass spectrometer

549
00:22:15,649 --> 00:22:12,179
are you going to include what kind of

550
00:22:18,169 --> 00:22:15,659
resolution or msms capabilities do you

551
00:22:20,149 --> 00:22:18,179
need to detect bioseignatures get

552
00:22:22,789 --> 00:22:20,159
isotopic information

553
00:22:25,130 --> 00:22:22,799
get through matrices of the salt grains

554
00:22:27,529 --> 00:22:25,140
crystals thank you you gave me an excuse

555
00:22:30,049 --> 00:22:27,539
to talk about that now

556
00:22:33,710 --> 00:22:30,059
um so for for the the

557
00:22:37,549 --> 00:22:33,720
gas the plume gas you need some sort of

558
00:22:39,710 --> 00:22:37,559
like uh qitms or like Mass specs type

559
00:22:41,090 --> 00:22:39,720
instrument that I'm sure you're familiar

560
00:22:44,210 --> 00:22:41,100
with that stuff

561
00:22:46,130 --> 00:22:44,220
um but where you need to be able to like

562
00:22:48,770 --> 00:22:46,140
have a sample Inlet where you take gas

563
00:22:50,210 --> 00:22:48,780

in and then you you determine the the

564
00:22:53,510 --> 00:22:50,220
composition of that and that's really

565
00:22:55,130 --> 00:22:53,520
necessary for uh assessing isotopic

566
00:22:56,390 --> 00:22:55,140
fractionation

567
00:22:59,270 --> 00:22:56,400
um because those typically have very

568
00:23:01,010 --> 00:22:59,280
high mass resolution which you need for

569
00:23:04,669 --> 00:23:01,020
looking at different isotope logs and

570
00:23:07,909 --> 00:23:04,679
things whereas for the plume grains

571
00:23:10,010 --> 00:23:07,919
um a lot of dust detectors don't have

572
00:23:11,750 --> 00:23:10,020
the same mass resolution

573
00:23:13,789 --> 00:23:11,760
um just due to the the way the

574
00:23:16,070 --> 00:23:13,799
instruments are designed and but you

575
00:23:18,830 --> 00:23:16,080
need information about the ice cream

576
00:23:21,169 --> 00:23:18,840
composition because of all the cool

577
00:23:22,909 --> 00:23:21,179
stuff is in the grains and the lower the

578
00:23:25,850 --> 00:23:22,919
bigger the grains are the lower the

579
00:23:28,070 --> 00:23:25,860
velocity the or the lower the altitude

580
00:23:31,070 --> 00:23:28,080
uh the more interesting the grin

581
00:23:34,070 --> 00:23:31,080
composition is and so you need

582
00:23:35,870 --> 00:23:34,080
in theory you could just use one to

583
00:23:37,610 --> 00:23:35,880
answer your question like a mass specs

584
00:23:39,529 --> 00:23:37,620
type instrument

585
00:23:41,210 --> 00:23:39,539
um where when I for those people that

586
00:23:42,770 --> 00:23:41,220
don't know Mass specs is an acronym for

587
00:23:44,049 --> 00:23:42,780
the mass spectrometer for planetary

588
00:23:46,490 --> 00:23:44,059

expert well

589
00:23:47,750 --> 00:23:46,500
enter export yes Mass Spectrum for

590
00:23:49,730 --> 00:23:47,760
Planetary Exploration that's going to be

591
00:23:54,350 --> 00:23:49,740
going on Europa clipper

592
00:23:56,510 --> 00:23:54,360
um but that can do grains but those sort

593
00:23:59,529 --> 00:23:56,520
of instruments have issues with some of

594
00:24:02,510 --> 00:23:59,539
the more refractory Organics and some

595
00:24:04,669 --> 00:24:02,520
inorganic species and so what you really

596
00:24:07,070 --> 00:24:04,679
need to be able to do this given that

597
00:24:09,590 --> 00:24:07,080
you have enough cost margin is you need

598
00:24:10,970 --> 00:24:09,600
a dust detector or a grain like some

599
00:24:12,649 --> 00:24:10,980
sort of impact ionization Mass

600
00:24:15,110 --> 00:24:12,659
spectrometer that can utilize these

601
00:24:16,610 --> 00:24:15,120
hyper velocity impacts as an ionization

602
00:24:19,070 --> 00:24:16,620
source to determine ice grain

603
00:24:20,990 --> 00:24:19,080
composition and also something where you

604
00:24:22,730 --> 00:24:21,000
can assess the composition of the plume

605
00:24:33,770 --> 00:24:22,740
gas as well

606
00:24:33,780 --> 00:24:45,470
missions

607
00:24:51,649 --> 00:24:46,450
um

608
00:24:55,909 --> 00:24:53,630
a couple of slides

609
00:24:58,789 --> 00:24:55,919
um so it's in eccentric orbit the

610
00:25:00,950 --> 00:24:58,799
various intric orbit around Saturn and

611
00:25:02,510 --> 00:25:00,960
so if you look at I don't know can you

612
00:25:05,630 --> 00:25:02,520
see the the curse okay yeah you can

613
00:25:08,149 --> 00:25:05,640

right here see that little Green Dot

614
00:25:10,909 --> 00:25:08,159
um that's where the their every orbit

615
00:25:12,470 --> 00:25:10,919
you do like a small burn where you use a

616
00:25:14,990 --> 00:25:12,480
little bit of fuel to make sure that you

617
00:25:16,909 --> 00:25:15,000
stay uh in the orbit that you need to

618
00:25:18,710 --> 00:25:16,919
actually do these measurements and so

619
00:25:20,750 --> 00:25:18,720
it's not as huge of a deal and doesn't

620
00:25:23,870 --> 00:25:20,760
require like a ton of Delta V or like

621
00:25:25,430 --> 00:25:23,880
change in velocity of the spacecraft

622
00:25:26,870 --> 00:25:25,440
um but no that is something to consider

623
00:25:28,789 --> 00:25:26,880
and though you're you're right and that

624
00:25:30,769 --> 00:25:28,799
is something that we took into account

625
00:25:37,669 --> 00:25:30,779
when doing all these uh the orbital

626
00:25:42,710 --> 00:25:40,430
uh so the that's before we actually

627
00:25:45,110 --> 00:25:42,720
start science operations

628
00:25:47,630 --> 00:25:45,120
um because upon

629
00:25:50,029 --> 00:25:47,640
Saturn orbital insertion

630
00:25:53,090 --> 00:25:50,039
um we're going too fast

631
00:25:55,610 --> 00:25:53,100
um and the the spacecraft the

632
00:25:58,370 --> 00:25:55,620
inclination altitude geometry things

633
00:26:00,710 --> 00:25:58,380
like that aren't suitable to immediately

634
00:26:03,590 --> 00:26:00,720
enter science operations to start doing

635
00:26:06,169 --> 00:26:03,600
targeted Enceladus flybys and so we need

636
00:26:08,750 --> 00:26:06,179
to use Titan's gravity to further slow

637
00:26:10,250 --> 00:26:08,760
down so we can get within that goldilock

638
00:26:12,169 --> 00:26:10,260

zone that we talked about before for

639
00:26:20,910 --> 00:26:12,179
sampling

640
00:26:23,560 --> 00:26:21,250
[Music]