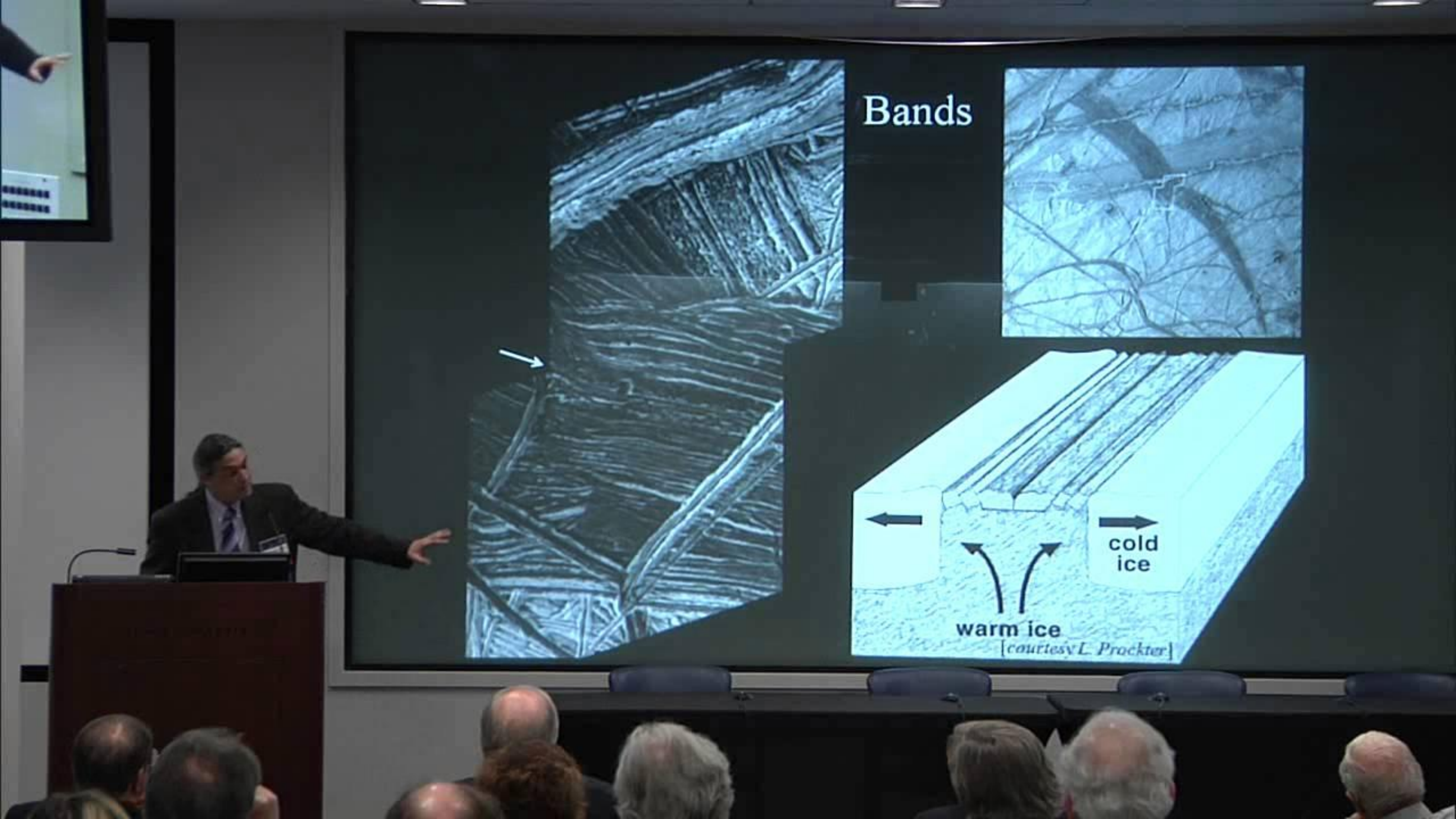
Bands
cold
ice
warm ice
[courtesy L. Prockter]

1
00:00:07,590 --> 00:00:04,710
so our final talk this morning is going

2
00:00:09,589 --> 00:00:07,600
to be by robert popolardo on revealing

3
00:00:12,150 --> 00:00:09,599
europa's ocean

4
00:00:13,990 --> 00:00:12,160
and let me just say that bob is a senior

5
00:00:15,749 --> 00:00:14,000
research science scientist in the

6
00:00:16,710 --> 00:00:15,759
planetary science section the science

7
00:00:18,310 --> 00:00:16,720
division

8
00:00:21,349 --> 00:00:18,320
of the jet propulsion laboratory in

9
00:00:23,670 --> 00:00:21,359
pasadena california that's the other pl

10
00:00:26,150 --> 00:00:23,680
the one on the west coast

11
00:00:28,230 --> 00:00:26,160
his research focuses on processes that

12
00:00:30,710 --> 00:00:28,240
shape the icy satellites the outer solar

13
00:00:32,790 --> 00:00:30,720

system especially europa

14
00:00:34,870 --> 00:00:32,800
and the role of its probable subsurface

15
00:00:37,430 --> 00:00:34,880
ocean he's the europa study scientist

16
00:00:39,910 --> 00:00:37,440
for the development of future europa

17
00:00:51,270 --> 00:00:39,920
mission concepts and a member of the

18
00:00:55,590 --> 00:00:52,950
good morning as

19
00:00:56,830 --> 00:00:55,600
other speakers have

20
00:01:00,790 --> 00:00:56,840
already

21
00:01:01,990 --> 00:01:00,800
mentioned the evidence for a subsurface

22
00:01:04,310 --> 00:01:02,000
ocean

23
00:01:07,109 --> 00:01:04,320
at europa is potentially

24
00:01:09,910 --> 00:01:08,390
europa

25
00:01:13,190 --> 00:01:09,920
has a surface

26
00:01:15,830 --> 00:01:13,200
like no other in the solar system

27
00:01:18,710 --> 00:01:15,840
and its subsurface

28
00:01:19,990 --> 00:01:18,720
arguably offers the greatest likelihood

29
00:01:21,190 --> 00:01:20,000
for life

30
00:01:26,149 --> 00:01:21,200
beyond

31
00:01:30,469 --> 00:01:28,789
uh let's take you back to

32
00:01:31,830 --> 00:01:30,479
400 years ago

33
00:01:34,710 --> 00:01:31,840
when of course

34
00:01:36,550 --> 00:01:34,720
galileo's observations of the galilean

35
00:01:39,590 --> 00:01:36,560
satellites including

36
00:01:41,429 --> 00:01:39,600
europa helped change our sense of place

37
00:01:44,550 --> 00:01:41,439
in the cosmos

38
00:01:45,830 --> 00:01:44,560

there was another center of motion

39
00:01:49,190 --> 00:01:45,840
out there

40
00:01:50,389 --> 00:01:49,200
which argued for copernicus's

41
00:01:53,190 --> 00:01:50,399
idea

42
00:01:54,389 --> 00:01:53,200
and galileo observing over subsequent

43
00:01:57,109 --> 00:01:54,399
knights

44
00:01:58,789 --> 00:01:57,119
saw all four galilean satellites

45
00:02:01,910 --> 00:01:58,799
revolving about

46
00:02:03,590 --> 00:02:01,920
jupiter and using the jpl solar system

47
00:02:05,990 --> 00:02:03,600
simulator we can

48
00:02:08,869 --> 00:02:06,000
reconstruct which ones he saw and on

49
00:02:10,790 --> 00:02:08,879
that first night it looks as though

50
00:02:12,150 --> 00:02:10,800
io and europa

51
00:02:15,510 --> 00:02:12,160
were

52
00:02:21,030 --> 00:02:15,520
grouped together into apparently one

53
00:02:28,070 --> 00:02:25,190
the first spacecraft image of europa

54
00:02:30,869 --> 00:02:28,080
was brought to us by the

55
00:02:32,710 --> 00:02:30,879
imaging photo polarimeter on the pioneer

56
00:02:34,550 --> 00:02:32,720
10 spacecraft

57
00:02:38,150 --> 00:02:34,560
the only image of europa from the

58
00:02:41,350 --> 00:02:38,160
pioneer 10 or 11 spacecraft principally

59
00:02:42,470 --> 00:02:41,360
a magnetometer mission

60
00:02:44,309 --> 00:02:42,480
and

61
00:02:45,990 --> 00:02:44,319
as torrance

62
00:02:47,910 --> 00:02:46,000
reviewed we knew

63
00:02:49,270 --> 00:02:47,920

a little bit about

64
00:02:52,710 --> 00:02:49,280
europe and the other satellites from

65
00:02:54,309 --> 00:02:52,720
telescopic observations we

66
00:02:57,030 --> 00:02:54,319
knew that the surface composition

67
00:02:59,830 --> 00:02:57,040
included water ice based on

68
00:03:01,110 --> 00:02:59,840
spectra we had some idea

69
00:03:03,110 --> 00:03:01,120
of

70
00:03:05,670 --> 00:03:03,120
the density though that information was

71
00:03:07,990 --> 00:03:05,680
improved by pioneer showing that europa

72
00:03:10,149 --> 00:03:08,000
had a density of about three

73
00:03:11,190 --> 00:03:10,159
rocky but less than io a little bit

74
00:03:12,710 --> 00:03:11,200
different

75
00:03:16,149 --> 00:03:12,720
from io

76
00:03:18,630 --> 00:03:16,159
um here's another fun exercise you can

77
00:03:20,149 --> 00:03:18,640
take the new jpl eyes on the solar

78
00:03:22,390 --> 00:03:20,159
system tool

79
00:03:24,390 --> 00:03:22,400
ride along with the pioneer spacecraft

80
00:03:26,869 --> 00:03:24,400
and at the right time at the right on

81
00:03:30,070 --> 00:03:26,879
the right date of december 3rd 1973 look

82
00:03:32,710 --> 00:03:30,080
toward europa and zoom in and see the

83
00:03:34,550 --> 00:03:32,720
view that we had at 200 kilometers per

84
00:03:35,430 --> 00:03:34,560
pixel at the time

85
00:03:36,710 --> 00:03:35,440
of

86
00:03:37,750 --> 00:03:36,720
europa's

87
00:03:39,030 --> 00:03:37,760
surface

88
00:03:41,270 --> 00:03:39,040

and

89
00:03:43,190 --> 00:03:41,280
it seems just like

90
00:03:45,750 --> 00:03:43,200
we're analogous to

91
00:03:47,910 --> 00:03:45,760
galileo who famously recorded

92
00:03:51,190 --> 00:03:47,920
neptune

93
00:03:54,149 --> 00:03:51,200
without knowing it in january 1613

94
00:03:57,350 --> 00:03:54,159
pioneer also spotted neptune

95
00:04:03,670 --> 00:04:01,589
through the 70s as torrance alluded to

96
00:04:05,030 --> 00:04:03,680
there was the thought that there might

97
00:04:07,350 --> 00:04:05,040
be oceans

98
00:04:09,910 --> 00:04:07,360
in some of the large satellites of the

99
00:04:12,550 --> 00:04:09,920
solar system and it was john lewis and

100
00:04:15,910 --> 00:04:12,560
his student guy consummato and

101
00:04:17,349 --> 00:04:15,920
then frazier finale who proposed

102
00:04:19,270 --> 00:04:17,359
from

103
00:04:21,749 --> 00:04:19,280
models of composition

104
00:04:24,550 --> 00:04:21,759
um and radioactive decay that there

105
00:04:26,790 --> 00:04:24,560
might be oceans within these satellites

106
00:04:29,030 --> 00:04:26,800
and then in the late 70s and early 80s

107
00:04:31,350 --> 00:04:29,040
tidal heating

108
00:04:32,629 --> 00:04:31,360
was discussed as a potential way to

109
00:04:34,070 --> 00:04:32,639
maintain

110
00:04:35,350 --> 00:04:34,080
oceans

111
00:04:38,629 --> 00:04:35,360
though

112
00:04:40,710 --> 00:04:38,639
cassin and peel and reynolds

113
00:04:42,870 --> 00:04:40,720

wrote that convection

114
00:04:46,310 --> 00:04:42,880
might kick in and freeze an ocean that

115
00:04:47,430 --> 00:04:46,320
is if an ice shell is thick enough

116
00:04:49,830 --> 00:04:47,440
then

117
00:04:52,310 --> 00:04:49,840
the ice might convect

118
00:04:54,790 --> 00:04:52,320
in a solid state like a lava lamp

119
00:04:55,590 --> 00:04:54,800
and that they thought would freeze up an

120
00:04:59,510 --> 00:04:55,600
ocean

121
00:05:02,070 --> 00:04:59,520
um through this period and actually it

122
00:05:03,670 --> 00:05:02,080
was steve squires uh in a paper with

123
00:05:05,189 --> 00:05:03,680
cast and peeler reynolds who said well

124
00:05:05,990 --> 00:05:05,199
you know there might be enough tidal

125
00:05:08,070 --> 00:05:06,000
heat

126
00:05:09,990 --> 00:05:08,080
uh if we push the parameters a bit to

127
00:05:11,510 --> 00:05:10,000
maintain an ocean within europa

128
00:05:14,150 --> 00:05:11,520
underneath a thin enough shell that it

129
00:05:16,390 --> 00:05:14,160
won't convect that ocean could be there

130
00:05:17,990 --> 00:05:16,400
still today and that was followed up by

131
00:05:20,790 --> 00:05:18,000
ogi congress and stevenson who used a

132
00:05:22,550 --> 00:05:20,800
more sophisticated model in 1989

133
00:05:25,029 --> 00:05:22,560
to say that yes it looked like there

134
00:05:27,430 --> 00:05:25,039
could be sufficient heat to maintain an

135
00:05:29,749 --> 00:05:27,440
ocean beneath a conductive ice shell

136
00:05:32,629 --> 00:05:29,759
using a more sophisticated model

137
00:05:35,270 --> 00:05:32,639
of tidal heating

138
00:05:38,150 --> 00:05:35,280

so that set the stage

139
00:05:40,550 --> 00:05:38,160
so that earlier works at the stage for

140
00:05:41,590 --> 00:05:40,560
voyager

141
00:05:44,710 --> 00:05:41,600
which

142
00:05:47,430 --> 00:05:44,720
saw few large impact craters on the

143
00:05:48,469 --> 00:05:47,440
surface which suggested a very

144
00:05:51,430 --> 00:05:48,479
young

145
00:05:53,909 --> 00:05:51,440
surface surface

146
00:05:56,870 --> 00:05:53,919
or perhaps the larger craters were

147
00:05:58,469 --> 00:05:56,880
relaxing away as mike malen pointed out

148
00:06:00,950 --> 00:05:58,479
uh in

149
00:06:04,150 --> 00:06:00,960
the early 80s along the terminator along

150
00:06:06,629 --> 00:06:04,160
the right-hand edge of that voyager 2

151
00:06:09,670 --> 00:06:06,639
image at the right um

152
00:06:10,870 --> 00:06:09,680
that there is model terrain pits and

153
00:06:13,270 --> 00:06:10,880
domes

154
00:06:15,510 --> 00:06:13,280
along the terminator would those are

155
00:06:16,550 --> 00:06:15,520
those tiny craters and in fact is the

156
00:06:20,950 --> 00:06:16,560
surface

157
00:06:28,550 --> 00:06:24,309
the bright lineated plane suggested

158
00:06:30,790 --> 00:06:28,560
crustal mobility it was shank and safer

159
00:06:33,830 --> 00:06:30,800
back in 1980 who looked

160
00:06:36,070 --> 00:06:33,840
at the voyager images and said you know

161
00:06:37,510 --> 00:06:36,080
there are dark bands that could fit back

162
00:06:40,309 --> 00:06:37,520
together

163
00:06:42,870 --> 00:06:40,319

with the bright pieces moving back into

164
00:06:45,270 --> 00:06:42,880
place like puzzle pieces

165
00:06:47,909 --> 00:06:45,280
but it was nearly a decade before shanks

166
00:06:50,790 --> 00:06:47,919
then controversial idea of crystal

167
00:06:52,629 --> 00:06:50,800
mobility was published right around the

168
00:06:56,070 --> 00:06:52,639
time of dakotas and stevenson said you

169
00:06:57,110 --> 00:06:56,080
know it's possible to maintain an ocean

170
00:07:00,070 --> 00:06:57,120
so

171
00:07:02,469 --> 00:07:00,080
voyager 1 of course had relatively poor

172
00:07:04,870 --> 00:07:02,479
resolution at europa 20 kilometers per

173
00:07:06,309 --> 00:07:04,880
pixel still 10 times better than pioneer

174
00:07:08,870 --> 00:07:06,319
did and

175
00:07:11,270 --> 00:07:08,880
voyager 2 had 10 times better than that

176
00:07:15,909 --> 00:07:11,280
2 kilometers per pixel but it would

177
00:07:18,070 --> 00:07:15,919
uh remain for galileo to really um

178
00:07:18,950 --> 00:07:18,080
greatly increase our knowledge

179
00:07:21,110 --> 00:07:18,960
of

180
00:07:24,629 --> 00:07:21,120
europa through imaging and through other

181
00:07:29,029 --> 00:07:25,909
there were

182
00:07:32,230 --> 00:07:29,039
as torrents alluded to 12 prime mission

183
00:07:35,510 --> 00:07:32,240
close approach flybys by satellites

184
00:07:38,070 --> 00:07:35,520
by galileo and then and three were

185
00:07:40,790 --> 00:07:38,080
usable close europa

186
00:07:43,350 --> 00:07:40,800
flybys

187
00:07:45,270 --> 00:07:43,360
and then there was the galileo europa

188
00:07:47,589 --> 00:07:45,280

mission because

189
00:07:49,749 --> 00:07:47,599
europa was turning out to be so exciting

190
00:07:51,270 --> 00:07:49,759
that an extended mission

191
00:07:53,510 --> 00:07:51,280
would focus

192
00:07:56,710 --> 00:07:53,520
on europa with

193
00:07:58,710 --> 00:07:56,720
eight close approach flybys of europa

194
00:08:01,430 --> 00:07:58,720
excuse me but one of those was gravity

195
00:08:03,589 --> 00:08:01,440
only and two of them ended in

196
00:08:05,510 --> 00:08:03,599
radiation-induced upsets

197
00:08:06,390 --> 00:08:05,520
of the spacecraft

198
00:08:07,510 --> 00:08:06,400
so

199
00:08:10,790 --> 00:08:07,520
um

200
00:08:12,869 --> 00:08:10,800
really with uh five close approach

201
00:08:15,749 --> 00:08:12,879
additional close approach for allies we

202
00:08:20,950 --> 00:08:15,759
were able to learn amazing things

203
00:08:24,950 --> 00:08:23,110
of course it is about

204
00:08:27,270 --> 00:08:24,960
the people i had the pleasure to work

205
00:08:28,790 --> 00:08:27,280
with this motley crew as an affiliate of

206
00:08:31,110 --> 00:08:28,800
the galileo

207
00:08:33,509 --> 00:08:31,120
imaging team mike belton

208
00:08:35,269 --> 00:08:33,519
in front you can recognize let's see

209
00:08:36,790 --> 00:08:35,279
torrential your hat today but there he

210
00:08:40,389 --> 00:08:36,800
is on the

211
00:08:42,550 --> 00:08:40,399
on the right clark chapman in front uh

212
00:08:44,630 --> 00:08:42,560
rick greenberg in the back right

213
00:08:45,829 --> 00:08:44,640

ron greeley

214
00:08:47,750 --> 00:08:45,839
in the back

215
00:08:49,110 --> 00:08:47,760
organizing the crew a bit gym head in

216
00:08:50,790 --> 00:08:49,120
the back

217
00:08:52,630 --> 00:08:50,800
left

218
00:08:58,790 --> 00:08:52,640
we've been having fun on facebook now

219
00:09:03,509 --> 00:09:00,550
um

220
00:09:05,910 --> 00:09:03,519
the first images from galileo of europa

221
00:09:07,990 --> 00:09:05,920
were only slightly better

222
00:09:10,550 --> 00:09:08,000
in geometric resolution than voyager 2

223
00:09:12,949 --> 00:09:10,560
images they're 1.6 kilometers per pixel

224
00:09:14,550 --> 00:09:12,959
but the much better camera a solid state

225
00:09:16,790 --> 00:09:14,560
imager

226
00:09:19,509 --> 00:09:16,800
was able to get much

227
00:09:21,110 --> 00:09:19,519
higher quality images

228
00:09:25,269 --> 00:09:21,120
and hear the surface

229
00:09:28,070 --> 00:09:25,279
shown in false color as compiled by

230
00:09:31,190 --> 00:09:28,080
paul geisler at the time

231
00:09:32,949 --> 00:09:31,200
and what we saw is is the the right hand

232
00:09:35,190 --> 00:09:32,959
side is littered with

233
00:09:37,030 --> 00:09:35,200
some of these pits

234
00:09:38,230 --> 00:09:37,040
that we were getting a feel from from

235
00:09:40,470 --> 00:09:38,240
voyager

236
00:09:42,949 --> 00:09:40,480
and both clark chapman and i looked at

237
00:09:44,550 --> 00:09:42,959
the size distributions of these pits and

238
00:09:46,870 --> 00:09:44,560

said you know they're all kind of the

239
00:09:48,630 --> 00:09:46,880
same size they're all turning out to be

240
00:09:50,630 --> 00:09:48,640
several to 10

241
00:09:52,790 --> 00:09:50,640
a little less than 10 kilometers across

242
00:09:55,509 --> 00:09:52,800
which suggested maybe they're not impact

243
00:09:57,190 --> 00:09:55,519
craters maybe they're endogenic features

244
00:09:59,350 --> 00:09:57,200
related to internal

245
00:10:01,670 --> 00:09:59,360
activity there were these spots

246
00:10:03,670 --> 00:10:01,680
littering the surface the dark spots and

247
00:10:05,590 --> 00:10:03,680
they also seemed to be about the same

248
00:10:07,750 --> 00:10:05,600
size maybe they're

249
00:10:09,910 --> 00:10:07,760
somehow related

250
00:10:11,590 --> 00:10:09,920
is it related to some sort of internal

251
00:10:12,790 --> 00:10:11,600
volcanism or other

252
00:10:13,910 --> 00:10:12,800
activity

253
00:10:16,790 --> 00:10:13,920
um

254
00:10:19,590 --> 00:10:16,800
it we found that the surface was

255
00:10:21,350 --> 00:10:19,600
brightening with age older features

256
00:10:23,750 --> 00:10:21,360
were brighter

257
00:10:25,190 --> 00:10:23,760
the idea of non-synchronous rotation had

258
00:10:28,389 --> 00:10:25,200
come up from

259
00:10:31,990 --> 00:10:28,399
voyager days and based on

260
00:10:33,670 --> 00:10:32,000
this color composite paul geisler argued

261
00:10:35,750 --> 00:10:33,680
for non-synchronous rotation when we

262
00:10:37,750 --> 00:10:35,760
looked at the age of lineaments there

263
00:10:40,389 --> 00:10:37,760

seems to be a rotation of lineaments

264
00:10:43,190 --> 00:10:40,399
through time as well consistent with the

265
00:10:45,509 --> 00:10:43,200
icy shell moving independent from the

266
00:10:48,069 --> 00:10:45,519
interior slightly faster than interior

267
00:10:50,550 --> 00:10:48,079
as if lubricated decoupled from the

268
00:10:53,509 --> 00:10:50,560
interior by a subsurface ocean there

269
00:10:55,509 --> 00:10:53,519
were a series of papers

270
00:10:57,670 --> 00:10:55,519
published based on some of the first

271
00:11:01,190 --> 00:10:57,680
images arguing for crustal

272
00:11:04,470 --> 00:11:01,200
mobility non-synchronous rotation

273
00:11:07,190 --> 00:11:04,480
and this picture from the same sequence

274
00:11:08,470 --> 00:11:07,200
was on the cover of the new york times

275
00:11:10,710 --> 00:11:08,480
arguing for

276
00:11:12,389 --> 00:11:10,720
uh crustal mobility so shank and

277
00:11:14,790 --> 00:11:12,399
mckinnon it seemed

278
00:11:18,550 --> 00:11:14,800
were right the puzzle pieces were

279
00:11:21,670 --> 00:11:20,310
this is europa's surface as it looks

280
00:11:22,630 --> 00:11:21,680
stretched out

281
00:11:25,269 --> 00:11:22,640
into

282
00:11:27,509 --> 00:11:25,279
a global map as we know it today very

283
00:11:28,790 --> 00:11:27,519
few impact craters there's one here this

284
00:11:30,150 --> 00:11:28,800
bright one

285
00:11:32,710 --> 00:11:30,160
pull or

286
00:11:35,110 --> 00:11:32,720
if you're welsh

287
00:11:36,949 --> 00:11:35,120
there are only oh about a dozen or so

288
00:11:39,030 --> 00:11:36,959

that one can recognize and from

289
00:11:40,550 --> 00:11:39,040
observations of impactors in the jovian

290
00:11:42,630 --> 00:11:40,560
system we know one should hit every

291
00:11:44,870 --> 00:11:42,640
three or four million years so you do

292
00:11:47,430 --> 00:11:44,880
the calculation it comes up that

293
00:11:50,310 --> 00:11:47,440
europa's average surface age is about 60

294
00:11:53,350 --> 00:11:50,320
million years europa has been repaved

295
00:11:55,750 --> 00:11:53,360
since dinosaurs roamed the earth we

296
00:11:58,629 --> 00:11:55,760
don't know whether that was in a spurt

297
00:12:01,829 --> 00:11:58,639
50 or 60 million years ago or if it's a

298
00:12:04,629 --> 00:12:01,839
continuous process and is ongoing today

299
00:12:06,949 --> 00:12:04,639
but why would europa die out just 50 or

300
00:12:09,590 --> 00:12:06,959
60 million years ago in fact it's

301
00:12:12,310 --> 00:12:09,600
probably either an ongoing process or

302
00:12:14,389 --> 00:12:12,320
europa may go through cyclical activity

303
00:12:17,350 --> 00:12:14,399
predictions of tidal heating as tied to

304
00:12:19,829 --> 00:12:17,360
io suggests that io is pulling europa

305
00:12:22,310 --> 00:12:19,839
back and forth and increasing its

306
00:12:25,430 --> 00:12:22,320
eccentricity and decreasing it again on

307
00:12:29,030 --> 00:12:25,440
a time scale of 10 to the sixth years or

308
00:12:31,990 --> 00:12:31,190
here's what those ridged planes look

309
00:12:33,990 --> 00:12:32,000
like

310
00:12:36,310 --> 00:12:34,000
close up

311
00:12:38,550 --> 00:12:36,320
those lineaments are ridges not just

312
00:12:40,870 --> 00:12:38,560
single ridges but double ridges

313
00:12:43,670 --> 00:12:40,880

crisscrossing the surface it looks like

314
00:12:45,190 --> 00:12:43,680
generations of ridge upon ridge or sets

315
00:12:46,790 --> 00:12:45,200
of ridges

316
00:12:49,190 --> 00:12:46,800
have created those

317
00:12:50,629 --> 00:12:49,200
ridge planes and then there's that model

318
00:12:53,350 --> 00:12:50,639
terrain

319
00:12:56,470 --> 00:12:53,360
where those pits and spots are uh some

320
00:12:58,230 --> 00:12:56,480
show chaotic chaotic terrain

321
00:13:01,269 --> 00:12:58,240
look looks a little like hamburger and

322
00:13:06,949 --> 00:13:01,279
that ridged plains has just crumbled in

323
00:13:11,110 --> 00:13:09,269
now i'm a geologist and so

324
00:13:13,509 --> 00:13:11,120
we were working to understand whether

325
00:13:16,710 --> 00:13:13,519
the surface geology told us about an

326
00:13:19,750 --> 00:13:16,720
ocean but it was the magnetometer team

327
00:13:21,110 --> 00:13:19,760
if anyone has discovered an ocean

328
00:13:22,710 --> 00:13:21,120
it was them

329
00:13:24,069 --> 00:13:22,720
who

330
00:13:27,190 --> 00:13:24,079
through measurement of an induced

331
00:13:29,430 --> 00:13:27,200
magnetic field at europa found strong

332
00:13:31,430 --> 00:13:29,440
evidence that europa is acting as a

333
00:13:33,350 --> 00:13:31,440
conductor

334
00:13:35,990 --> 00:13:33,360
that jupiter's external field is

335
00:13:37,670 --> 00:13:36,000
inducing a magnetic field in europa and

336
00:13:40,150 --> 00:13:37,680
that's that remains the strongest

337
00:13:41,910 --> 00:13:40,160
evidence for subsurface ocean at europa

338
00:13:45,350 --> 00:13:41,920

today that still exists

339
00:13:47,189 --> 00:13:45,360
today and of course the gravity data

340
00:13:49,350 --> 00:13:47,199
through measurement of the

341
00:13:51,269 --> 00:13:49,360
inference of the moment of inertia tells

342
00:13:53,189 --> 00:13:51,279
us that europa is almost certainly

343
00:13:55,509 --> 00:13:53,199
differentiated with an iron core or

344
00:13:59,110 --> 00:13:55,519
rocky mantle and then an h2o layer

345
00:14:00,550 --> 00:13:59,120
something like 100 kilometers thick

346
00:14:02,550 --> 00:14:00,560
there's a little illustration from

347
00:14:05,269 --> 00:14:02,560
michael carroll of europa

348
00:14:07,350 --> 00:14:05,279
in jupiter's immense

349
00:14:10,230 --> 00:14:07,360
magnetosphere

350
00:14:11,910 --> 00:14:10,240
and an illustration of that induced

351
00:14:14,949 --> 00:14:11,920
magnetic field

352
00:14:17,350 --> 00:14:14,959
at europa recall that europa is bathed

353
00:14:20,230 --> 00:14:17,360
in high energy

354
00:14:22,150 --> 00:14:20,240
plasma charged particles with it with

355
00:14:24,069 --> 00:14:22,160
kilo electron volt and mega electron

356
00:14:27,350 --> 00:14:24,079
ball energies are slamming

357
00:14:29,110 --> 00:14:27,360
into europa uh at all times and while

358
00:14:32,150 --> 00:14:29,120
that is a nasty environment and would

359
00:14:35,030 --> 00:14:32,160
kill a person in 15 or 20 minutes if

360
00:14:36,230 --> 00:14:35,040
exposed to it it is potentially life

361
00:14:38,949 --> 00:14:36,240
nurturing

362
00:14:42,790 --> 00:14:38,959
because when high-energy particles slam

363
00:14:44,629 --> 00:14:42,800

into h2o they make h and they make o

364
00:14:45,590 --> 00:14:44,639
and some of those things recombine and

365
00:14:47,670 --> 00:14:45,600
they recombine with the other

366
00:14:50,629 --> 00:14:47,680
contaminants on the surface

367
00:14:53,350 --> 00:14:50,639
and they make things like peroxides and

368
00:14:54,949 --> 00:14:53,360
formaldehyde and o2

369
00:14:58,870 --> 00:14:54,959
europa doesn't have much of an

370
00:15:01,110 --> 00:14:58,880
atmosphere a picobar 10-12 bars but it

371
00:15:03,670 --> 00:15:01,120
does have essentially an atmosphere

372
00:15:05,829 --> 00:15:03,680
frozen into its surface there's o2

373
00:15:07,590 --> 00:15:05,839
at that surface if

374
00:15:10,310 --> 00:15:07,600
all of europa's

375
00:15:12,470 --> 00:15:10,320
oxidants could be dumped into its

376
00:15:15,509 --> 00:15:12,480
suspected subsurface ocean

377
00:15:17,829 --> 00:15:15,519
then that ocean would be more oxygenated

378
00:15:20,550 --> 00:15:17,839
than is earth's ocean

379
00:15:22,550 --> 00:15:20,560
and that could serve as a fuel for life

380
00:15:24,790 --> 00:15:22,560
we need to understand the processes of

381
00:15:29,670 --> 00:15:24,800
whether that material from the surface

382
00:15:33,269 --> 00:15:31,350
uh here's what the surface looks like a

383
00:15:35,430 --> 00:15:33,279
bit closer up

384
00:15:37,030 --> 00:15:35,440
sorry no scale bar here but again these

385
00:15:38,629 --> 00:15:37,040
these spots are something like seven

386
00:15:41,350 --> 00:15:38,639
kilometers across and bridges are

387
00:15:43,590 --> 00:15:41,360
commonly a couple to five

388
00:15:45,829 --> 00:15:43,600

kilometers across some of them are quite

389
00:15:49,030 --> 00:15:45,839
bizarre seeming to bounce across the

390
00:15:52,870 --> 00:15:51,350
in a cycloidal pattern not something

391
00:15:54,949 --> 00:15:52,880
you're used to seeing

392
00:15:56,870 --> 00:15:54,959
on a planetary body

393
00:16:00,470 --> 00:15:56,880
okay i'm getting a signal to speed it up

394
00:16:03,829 --> 00:16:02,069
the story of europa's ridges is

395
00:16:06,550 --> 00:16:03,839
interesting because

396
00:16:08,150 --> 00:16:06,560
there are many ridge models that have

397
00:16:10,069 --> 00:16:08,160
been proposed and while they're the most

398
00:16:12,389 --> 00:16:10,079
ubiquitous ubiquitous feature on the

399
00:16:15,110 --> 00:16:12,399
surface they're the most controversial

400
00:16:17,430 --> 00:16:15,120
as well is the surface

401
00:16:20,230 --> 00:16:17,440
the ice shell being cut completely

402
00:16:22,949 --> 00:16:20,240
uh through and tidal flexing opening and

403
00:16:25,829 --> 00:16:22,959
closing bridges a model that has been

404
00:16:28,069 --> 00:16:25,839
supported by rick greenberg and

405
00:16:29,910 --> 00:16:28,079
colleagues or are there other models

406
00:16:32,470 --> 00:16:29,920
that might involve solid state ice and

407
00:16:36,310 --> 00:16:32,480
it's almost incidental that the ocean is

408
00:16:37,990 --> 00:16:36,320
below enabling a large scale title uh

409
00:16:39,829 --> 00:16:38,000
flexing

410
00:16:41,509 --> 00:16:39,839
and one model illustrated is right is

411
00:16:42,790 --> 00:16:41,519
the idea of sheer heating that back and

412
00:16:46,069 --> 00:16:42,800
forth motion

413
00:16:49,430 --> 00:16:46,079

created by tidal flexing is what is

414
00:16:51,350 --> 00:16:49,440
heating a plane in the subsurface and

415
00:16:55,430 --> 00:16:51,360
and warming that ice and pushing the

416
00:16:57,749 --> 00:16:55,440
surface up to form a ridge and uh

417
00:16:59,990 --> 00:16:57,759
interesting in the in the

418
00:17:02,230 --> 00:17:00,000
in the sense of the the story of of

419
00:17:04,949 --> 00:17:02,240
galileo and europa exploration this

420
00:17:07,510 --> 00:17:04,959
these models somewhat led to a schism of

421
00:17:09,909 --> 00:17:07,520
is europa's i shall thin or is europa's

422
00:17:12,710 --> 00:17:09,919
i shall thick torrance likes to call it

423
00:17:15,909 --> 00:17:12,720
the pizza debate is it thin crust or

424
00:17:19,750 --> 00:17:15,919
thick crust and um we were working some

425
00:17:22,789 --> 00:17:19,760
of the ridge ideas

426
00:17:24,710 --> 00:17:22,799
and rick greenberg pointed out that

427
00:17:26,390 --> 00:17:24,720
was developing this model and i pointed

428
00:17:27,829 --> 00:17:26,400
out that well this model couldn't work

429
00:17:29,190 --> 00:17:27,839
if the ice shell

430
00:17:31,430 --> 00:17:29,200
because the ice shell had to be less

431
00:17:33,350 --> 00:17:31,440
than about seven kilometers thick to cut

432
00:17:35,350 --> 00:17:33,360
all the way through and the tidal

433
00:17:37,750 --> 00:17:35,360
heating models were suggesting a thicker

434
00:17:39,350 --> 00:17:37,760
ice shell and his response was then the

435
00:17:41,270 --> 00:17:39,360
eye shell must be thin

436
00:17:43,669 --> 00:17:41,280
and so he ran with that

437
00:17:45,430 --> 00:17:43,679
rather than questioning uh the model

438
00:17:48,150 --> 00:17:45,440

itself

439
00:17:49,830 --> 00:17:48,160
whereas in a thicker shell model

440
00:17:53,510 --> 00:17:49,840
the ice shell can be pierced down to a

441
00:17:56,310 --> 00:17:53,520
ductile layer and pulled apart a top

442
00:17:57,590 --> 00:17:56,320
warm flowing glacial ice

443
00:18:00,230 --> 00:17:57,600
and that's the model illustrated at the

444
00:18:01,590 --> 00:18:00,240
bottom right for bands on europa we were

445
00:18:04,310 --> 00:18:01,600
able to zoom in on some of these

446
00:18:05,909 --> 00:18:04,320
wedge-shaped bands that shank mckinnon

447
00:18:08,870 --> 00:18:05,919
had originally

448
00:18:10,710 --> 00:18:08,880
investigated and and again the puzzle

449
00:18:15,510 --> 00:18:10,720
pieces of each side fit back together

450
00:18:16,870 --> 00:18:15,520
perfectly and the center is striated

451
00:18:19,510 --> 00:18:16,880
analogous to what we see at the

452
00:18:21,590 --> 00:18:19,520
mid-ocean ridges at spreading centers

453
00:18:23,909 --> 00:18:21,600
on the earth and then in a thick thin

454
00:18:28,390 --> 00:18:23,919
debate it was is that a top warm ice or

455
00:18:35,590 --> 00:18:31,110
uh impact craters as xb turtle and betsy

456
00:18:37,990 --> 00:18:35,600
pratt so argued um like quill argue for

457
00:18:39,350 --> 00:18:38,000
an ice shell that's relatively thick at

458
00:18:41,590 --> 00:18:39,360
least eight kilometers thick or you

459
00:18:43,590 --> 00:18:41,600
wouldn't get a nice crater morphology

460
00:18:45,510 --> 00:18:43,600
and later paul shank

461
00:18:47,430 --> 00:18:45,520
wrote on these multi-ring structures

462
00:18:50,070 --> 00:18:47,440
there are only two

463
00:18:51,510 --> 00:18:50,080

and he invoked a model

464
00:18:53,350 --> 00:18:51,520
that had been

465
00:18:56,150 --> 00:18:53,360
developed for ganymede and klisto that

466
00:18:58,789 --> 00:18:56,160
says if we penetrate through the ice

467
00:19:01,350 --> 00:18:58,799
shell to a fluid layer then the crater

468
00:19:03,350 --> 00:19:01,360
fills in this large crater essentially

469
00:19:06,470 --> 00:19:03,360
fills in very rapidly pulling the

470
00:19:08,390 --> 00:19:06,480
brittle ice along inward with it to form

471
00:19:10,470 --> 00:19:08,400
these concentric rings and based on the

472
00:19:12,230 --> 00:19:10,480
scale about 40 kilometers across for the

473
00:19:14,789 --> 00:19:12,240
inferred crater he said well then

474
00:19:19,270 --> 00:19:14,799
they've penetrated to about to to liquid

475
00:19:25,510 --> 00:19:22,230
consistent with the title heating models

476
00:19:27,750 --> 00:19:25,520
um in terms of surface composition

477
00:19:30,150 --> 00:19:27,760
uh there's a question of what this dark

478
00:19:32,390 --> 00:19:30,160
reddish stuff is that we see and based

479
00:19:34,870 --> 00:19:32,400
on infrared uh spectra the leading

480
00:19:36,470 --> 00:19:34,880
candidates are sulfate salts or sulfuric

481
00:19:37,990 --> 00:19:36,480
acid hydrate

482
00:19:40,789 --> 00:19:38,000
and in reality it's probably a

483
00:19:43,750 --> 00:19:40,799
combination of those two so is europa's

484
00:19:46,150 --> 00:19:43,760
ocean like epsom salt or battery acid

485
00:19:48,549 --> 00:19:46,160
the answer is more likely that it's like

486
00:19:51,350 --> 00:19:48,559
epsom salt but that the battery acid is

487
00:19:54,710 --> 00:19:51,360
created at the surface by irradiation of

488
00:19:57,510 --> 00:19:55,590

um

489
00:19:59,909 --> 00:19:57,520
here are some of those freckles

490
00:20:00,870 --> 00:19:59,919
lenticulae is latin

491
00:20:03,190 --> 00:20:00,880
for them

492
00:20:05,669 --> 00:20:03,200
that's that

493
00:20:07,750 --> 00:20:05,679
when we saw them first rang a bell with

494
00:20:10,710 --> 00:20:07,760
me is what i had heard

495
00:20:13,830 --> 00:20:10,720
about that reynolds and cassin model uh

496
00:20:15,750 --> 00:20:13,840
way back when that convection may have

497
00:20:19,590 --> 00:20:15,760
kicked in in the ice shell and perhaps

498
00:20:21,909 --> 00:20:19,600
what we're seeing is the tops of diapers

499
00:20:24,310 --> 00:20:21,919
warm ice blobs that have risen up

500
00:20:25,830 --> 00:20:24,320
through europa's ice shell again

501
00:20:28,549 --> 00:20:25,840
implying that it would be

502
00:20:31,830 --> 00:20:28,559
more than 20 or so kilometers

503
00:20:35,029 --> 00:20:31,840
thick and the bottom is showing um a

504
00:20:39,190 --> 00:20:35,039
model by amy barr of that warm

505
00:20:46,470 --> 00:20:43,830
only about 30 celsius below

506
00:20:48,390 --> 00:20:46,480
below zero in terms of the temperature

507
00:20:49,990 --> 00:20:48,400
warm ice even though the surface is a

508
00:20:50,950 --> 00:20:50,000
100

509
00:20:53,830 --> 00:20:50,960
kelvin

510
00:20:57,029 --> 00:20:53,840
that warm convexing ice would be 240 or

511
00:21:00,230 --> 00:20:57,039
so kelvin an illustration

512
00:21:04,390 --> 00:21:00,240
of the lava lamp like model of europa's

513
00:21:07,350 --> 00:21:05,190

um

514
00:21:09,669 --> 00:21:07,360
some of the most fascinating terrain oh

515
00:21:11,270 --> 00:21:09,679
oh our chairs starting to get up

516
00:21:12,230 --> 00:21:11,280
some of the most fascinating terrain is

517
00:21:14,710 --> 00:21:12,240
this

518
00:21:16,789 --> 00:21:14,720
chaotic terrain and in the thicker thick

519
00:21:18,870 --> 00:21:16,799
model thinner thick model of the issue

520
00:21:21,350 --> 00:21:18,880
was has europa's eye shell melted out

521
00:21:24,310 --> 00:21:21,360
completely or have blobs of warm ice

522
00:21:26,549 --> 00:21:24,320
risen and and moved to the blocks above

523
00:21:27,909 --> 00:21:26,559
like in a mosh pit

524
00:21:29,909 --> 00:21:27,919
and recently

525
00:21:31,990 --> 00:21:29,919
brittany schmidt has suggested an

526
00:21:33,990 --> 00:21:32,000
interesting hybrid model that chaos may

527
00:21:35,990 --> 00:21:34,000
form above a melt zone

528
00:21:38,630 --> 00:21:36,000
in a thick ice shell that essentially

529
00:21:42,310 --> 00:21:38,640
we're looking at at areas that used to

530
00:21:44,549 --> 00:21:42,320
have lakes beneath them the size of

531
00:21:46,549 --> 00:21:44,559
one of the u.s

532
00:21:48,630 --> 00:21:46,559
great lakes and that some of these

533
00:21:49,350 --> 00:21:48,640
regions may still have lakes beneath

534
00:21:51,110 --> 00:21:49,360
them

535
00:21:54,149 --> 00:21:51,120
today

536
00:21:56,149 --> 00:21:54,159
and so the the discussion continues as

537
00:21:58,149 --> 00:21:56,159
to whether we're actually looking at

538
00:22:01,590 --> 00:21:58,159

floating icebergs and here just for you

539
00:22:02,630 --> 00:22:01,600
torrents the titanic is about 270 meters

540
00:22:06,470 --> 00:22:02,640
from

541
00:22:09,909 --> 00:22:09,029
so europa may have

542
00:22:10,830 --> 00:22:09,919
uh

543
00:22:12,870 --> 00:22:10,840
the

544
00:22:14,630 --> 00:22:12,880
ingredients for

545
00:22:17,029 --> 00:22:14,640
life

546
00:22:19,270 --> 00:22:17,039
in terms of water more than two times

547
00:22:21,430 --> 00:22:19,280
all of the earth's oceans in terms of

548
00:22:23,830 --> 00:22:21,440
the essential elements from its

549
00:22:26,630 --> 00:22:23,840
formation and from impacts bringing

550
00:22:30,710 --> 00:22:26,640
carbon and other elements it may have

551
00:22:32,789 --> 00:22:30,720
chemical energy from above oxidants

552
00:22:35,990 --> 00:22:32,799
created at the surface by a radiation

553
00:22:38,630 --> 00:22:36,000
and potentially energy from below if the

554
00:22:40,470 --> 00:22:38,640
mantle is warm if it is tidally heated

555
00:22:42,870 --> 00:22:40,480
then there could be black smoker like

556
00:22:44,470 --> 00:22:42,880
activity pouring reductance into the

557
00:22:45,830 --> 00:22:44,480
base of the ocean

558
00:22:48,230 --> 00:22:45,840
and

559
00:22:49,830 --> 00:22:48,240
it's probably a relatively stable

560
00:22:53,110 --> 00:22:49,840
environment somewhat variable but

561
00:22:55,110 --> 00:22:53,120
simmering for four billion years

562
00:22:57,909 --> 00:22:55,120
so

563
00:23:00,310 --> 00:22:57,919

that leads to basic questions

564
00:23:02,149 --> 00:23:00,320
about the ocean its existence its extent

565
00:23:04,470 --> 00:23:02,159
its salinity

566
00:23:06,149 --> 00:23:04,480
about the ice shell the existence nature

567
00:23:08,870 --> 00:23:06,159
of water within and beneath the nature

568
00:23:10,470 --> 00:23:08,880
of the surface ice ocean exchange

569
00:23:12,710 --> 00:23:10,480
composition the distribution and

570
00:23:13,669 --> 00:23:12,720
chemistry of key compounds the links to

571
00:23:15,510 --> 00:23:13,679
ocean

572
00:23:16,710 --> 00:23:15,520
composition

573
00:23:18,390 --> 00:23:16,720
and the geology what are the

574
00:23:20,630 --> 00:23:18,400
characteristics formation of surface

575
00:23:22,789 --> 00:23:20,640
features including sites of recent or

576
00:23:25,350 --> 00:23:22,799
current activity and these all relate to

577
00:23:26,470 --> 00:23:25,360
that overarching theme of europa's

578
00:23:28,230 --> 00:23:26,480
potential

579
00:23:29,110 --> 00:23:28,240
uh habitability

580
00:23:37,510 --> 00:23:29,120
the

581
00:23:40,390 --> 00:23:37,520
late 1990s could be a talk

582
00:23:43,350 --> 00:23:40,400
in itself but i'll i'll simply say that

583
00:23:46,310 --> 00:23:43,360
the latest uh iteration

584
00:23:47,909 --> 00:23:46,320
is a very feasible one that could cost

585
00:23:50,149 --> 00:23:47,919
about two billion dollars short of

586
00:23:52,470 --> 00:23:50,159
launch vehicle

587
00:23:55,190 --> 00:23:52,480
would address these oceanic shell

588
00:23:57,990 --> 00:23:55,200

composition geology objectives and could

589
00:24:00,390 --> 00:23:58,000
have a reconnaissance camera as well to

590
00:24:02,310 --> 00:24:00,400
set the stage for a future lander it

591
00:24:06,390 --> 00:24:02,320
would do

592
00:24:09,590 --> 00:24:06,400
several dozen close flybys of europa to

593
00:24:11,430 --> 00:24:09,600
understand the nature of

594
00:24:14,310 --> 00:24:11,440
its ocean and understand its

595
00:24:17,029 --> 00:24:14,320
habitability potential habitability

596
00:24:19,590 --> 00:24:17,039
and just to finish

597
00:24:21,830 --> 00:24:19,600
um there

598
00:24:24,310 --> 00:24:21,840
are important fundamental questions

599
00:24:27,110 --> 00:24:24,320
remaining to answer in our solar system

600
00:24:30,630 --> 00:24:27,120
especially with regard to

601
00:24:33,750 --> 00:24:30,640
uh its its potential for life beyond

602
00:24:36,070 --> 00:24:33,760
earth its origins and its uh and its

603
00:24:37,350 --> 00:24:36,080
commonness it was 400 years ago the

604
00:24:42,390 --> 00:24:37,360
galileo

605
00:24:44,630 --> 00:24:42,400
the galilean satellites changed the

606
00:24:46,149 --> 00:24:44,640
human perspective on our place in the

607
00:24:48,149 --> 00:24:46,159
universe and it's fascinating to think

608
00:24:49,190 --> 00:24:48,159
that one of those worlds could in the

609
00:24:50,789 --> 00:24:49,200
future

610
00:24:54,789 --> 00:24:50,799
change it again

611
00:24:58,070 --> 00:24:56,070
thank you bob

612
00:25:00,789 --> 00:24:58,080
it's tough to explore and talk about an

613
00:25:01,830 --> 00:25:00,799

entire world in 20 minutes uh i'll tell

614
00:25:04,630 --> 00:25:01,840
you what why don't we go ahead and

615
00:25:06,710 --> 00:25:04,640
assemble the panel and uh so

616
00:25:08,870 --> 00:25:06,720
let you take a seat torrence and arturo

617
00:25:10,390 --> 00:25:08,880
if you can come on up and

618
00:25:11,990 --> 00:25:10,400
uh

619
00:25:15,430 --> 00:25:12,000
you have a question for bob why don't

620
00:25:17,510 --> 00:25:15,440
you try to get first in line okay but we

621
00:25:19,750 --> 00:25:17,520
we will see ah

622
00:25:22,789 --> 00:25:19,760
please go ahead okay

623
00:25:26,830 --> 00:25:25,830
i don't see speaking oh

624
00:25:28,390 --> 00:25:26,840
it's hard to see

625
00:25:30,390 --> 00:25:28,400
around uh

626
00:25:33,190 --> 00:25:30,400
you mentioned about some kind of the

627
00:25:35,990 --> 00:25:33,200
variations in the mutual position of the

628
00:25:37,909 --> 00:25:36,000
say europa and io

629
00:25:41,190 --> 00:25:37,919
you know and uh

630
00:25:42,470 --> 00:25:41,200
in in addition to the regular change so

631
00:25:44,390 --> 00:25:42,480
are these

632
00:25:45,669 --> 00:25:44,400
deviations

633
00:25:48,710 --> 00:25:45,679
mostly

634
00:25:51,830 --> 00:25:48,720
just produced by the

635
00:25:54,310 --> 00:25:51,840
laplace resonance i mean within laplace

636
00:25:57,990 --> 00:25:54,320
resonance or it's some kind additional

637
00:26:00,310 --> 00:25:58,000
mechanism exist and how deep

638
00:26:03,110 --> 00:26:00,320

such fluctuations are

639
00:26:05,990 --> 00:26:03,120
whether their influence on the death of

640
00:26:07,190 --> 00:26:06,000
the ocean or only on the temperature

641
00:26:09,510 --> 00:26:07,200
yeah yeah

642
00:26:10,549 --> 00:26:09,520
so uh the idea that's been developed is

643
00:26:12,470 --> 00:26:10,559
that

644
00:26:14,310 --> 00:26:12,480
by io

645
00:26:16,549 --> 00:26:14,320
heating up

646
00:26:17,430 --> 00:26:16,559
it could heat to the extent

647
00:26:19,430 --> 00:26:17,440
that

648
00:26:20,950 --> 00:26:19,440
its ability to dissipate heat actually

649
00:26:23,110 --> 00:26:20,960
decreases

650
00:26:25,750 --> 00:26:23,120
and to conserve angular momentum that

651
00:26:28,149 --> 00:26:25,760
will actually end up changing slightly

652
00:26:29,750 --> 00:26:28,159
its orbital eccentricity and it will

653
00:26:33,350 --> 00:26:29,760
drag europa

654
00:26:35,669 --> 00:26:33,360
along as it does so and uh recent models

655
00:26:37,830 --> 00:26:35,679
have suggested europa's ice shell

656
00:26:39,190 --> 00:26:37,840
thickness could fluctuate

657
00:26:41,750 --> 00:26:39,200
from

658
00:26:43,750 --> 00:26:41,760
something like 10 or 15 kilometers up to

659
00:26:46,070 --> 00:26:43,760
something like 30 kilometers

660
00:26:48,630 --> 00:26:46,080
so it's possible europa may have even

661
00:26:51,350 --> 00:26:48,640
experienced a thin shell like history

662
00:26:53,430 --> 00:26:51,360
and a thing thick shell like history and

663
00:26:57,350 --> 00:26:53,440

that that may vary on something like a

664
00:27:01,590 --> 00:26:59,430
about ten to the six years

665
00:27:05,350 --> 00:27:01,600
is in the models but the models can be

666
00:27:05,360 --> 00:27:09,510
yes

667
00:27:13,029 --> 00:27:11,590
thank you john sarkisson from csiro

668
00:27:14,549 --> 00:27:13,039
australia this is a question for

669
00:27:16,230 --> 00:27:14,559
torrence um

670
00:27:18,789 --> 00:27:16,240
we've heard about how the spacecraft get

671
00:27:20,950 --> 00:27:18,799
to the planets and and we're able to

672
00:27:22,070 --> 00:27:20,960
image them and and so on but very little

673
00:27:24,710 --> 00:27:22,080
has been said about how that

674
00:27:26,230 --> 00:27:24,720
information's actually returned times

675
00:27:28,870 --> 00:27:26,240
would you like to say a few words about

676
00:27:31,269 --> 00:27:28,880
the the deep space network um

677
00:27:33,190 --> 00:27:31,279
involvement in in those outer planet um

678
00:27:36,549 --> 00:27:33,200
missions sure communications is

679
00:27:39,190 --> 00:27:36,559
obviously a a a critical element in all

680
00:27:42,149 --> 00:27:39,200
of these things and it often operates

681
00:27:44,070 --> 00:27:42,159
beneath everybody's visibility level

682
00:27:46,149 --> 00:27:44,080
it's just something that happens as a

683
00:27:47,909 --> 00:27:46,159
scientist i just regard that as part of

684
00:27:49,669 --> 00:27:47,919
the magic because i can't figure out how

685
00:27:50,549 --> 00:27:49,679
we get all those bits back from out

686
00:27:52,789 --> 00:27:50,559
there

687
00:27:54,710 --> 00:27:52,799
and i know john that i talked with you

688
00:27:56,470 --> 00:27:54,720

the other day walking over and then i

689
00:27:59,190 --> 00:27:56,480
realized reading your bio that you were

690
00:28:01,430 --> 00:27:59,200
one of the people who were at the parks

691
00:28:04,789 --> 00:28:01,440
facility in australia that helped bail

692
00:28:07,510 --> 00:28:04,799
us out when our communications system

693
00:28:08,470 --> 00:28:07,520
became a little flaky on galileo

694
00:28:11,190 --> 00:28:08,480
and

695
00:28:13,990 --> 00:28:11,200
it's a marvelous story in itself how

696
00:28:15,750 --> 00:28:14,000
these communication systems codes

697
00:28:17,990 --> 00:28:15,760
cooperation amongst the various

698
00:28:19,830 --> 00:28:18,000
institutions and uh and

699
00:28:20,950 --> 00:28:19,840
radio tracking facilities around the

700
00:28:26,389 --> 00:28:20,960
world go

701
00:28:30,710 --> 00:28:27,590
heidi

702
00:28:32,950 --> 00:28:30,720
this is for torrance

703
00:28:35,110 --> 00:28:32,960
we'll hear from chaz tomorrow how most

704
00:28:37,350 --> 00:28:35,120
about the exoplanets and the kepler

705
00:28:40,549 --> 00:28:37,360
spacecraft is showing that

706
00:28:43,590 --> 00:28:40,559
most many thousands of candidates are

707
00:28:46,389 --> 00:28:43,600
uranus and neptune-sized bodies and yet

708
00:28:48,789 --> 00:28:46,399
the only mission that has ever gone to

709
00:28:50,789 --> 00:28:48,799
an ice giant was launched before i even

710
00:28:52,710 --> 00:28:50,799
graduated from high school

711
00:28:54,389 --> 00:28:52,720
and now i got gray hair

712
00:28:56,870 --> 00:28:54,399
and you've already pointed out that

713
00:28:58,870 --> 00:28:56,880

we're looking at a radio dark outer

714
00:29:00,149 --> 00:28:58,880
solar system

715
00:29:01,830 --> 00:29:00,159
now

716
00:29:04,149 --> 00:29:01,840
what's your thoughts

717
00:29:05,590 --> 00:29:04,159
from a historical perspective of how

718
00:29:07,909 --> 00:29:05,600
that got lost

719
00:29:10,549 --> 00:29:07,919
from the jupiter orbiter and the cassini

720
00:29:12,470 --> 00:29:10,559
saturn orbiter and why did it get lost

721
00:29:14,630 --> 00:29:12,480
that we don't have

722
00:29:16,710 --> 00:29:14,640
an outer outer solar outer planet

723
00:29:18,470 --> 00:29:16,720
orbiter what happened and

724
00:29:20,389 --> 00:29:18,480
what's the lesson learned so we can fix

725
00:29:23,750 --> 00:29:20,399
it i think i think the discussions

726
00:29:24,549 --> 00:29:23,760
yesterday uh illustrated how cyclical

727
00:29:26,389 --> 00:29:24,559
the

728
00:29:28,870 --> 00:29:26,399
funding for this entire enterprise is

729
00:29:31,029 --> 00:29:28,880
not just outer planet uh

730
00:29:32,470 --> 00:29:31,039
uh exploration it's it's not something

731
00:29:34,950 --> 00:29:32,480
that's taken for granted at the

732
00:29:37,110 --> 00:29:34,960
political level uh it's something that

733
00:29:39,269 --> 00:29:37,120
we have to continually make the uh

734
00:29:41,190 --> 00:29:39,279
arguments for i would uh

735
00:29:42,149 --> 00:29:41,200
just uh remark from a historical point

736
00:29:45,350 --> 00:29:42,159
of view

737
00:29:47,909 --> 00:29:45,360
we were well served by jumping on top of

738
00:29:50,070 --> 00:29:47,919

the grand tour alignment i mean that for

739
00:29:51,750 --> 00:29:50,080
the outer planet exploration because

740
00:29:53,750 --> 00:29:51,760
that actually got us some data in

741
00:29:55,750 --> 00:29:53,760
remarkably short times it's not going to

742
00:29:57,750 --> 00:29:55,760
happen again for a while unless we get

743
00:29:59,590 --> 00:29:57,760
warp drive

744
00:30:00,870 --> 00:29:59,600
so i think the the

745
00:30:02,230 --> 00:30:00,880
uh

746
00:30:05,190 --> 00:30:02,240
we have not

747
00:30:06,789 --> 00:30:05,200
lost the drive to do these things but

748
00:30:09,350 --> 00:30:06,799
we're still struggling with the

749
00:30:14,870 --> 00:30:09,360
generational nature of how long it takes

750
00:30:17,909 --> 00:30:16,310
thanks janet for testing princeton

751
00:30:19,269 --> 00:30:17,919
university it's such a that was a great

752
00:30:20,389 --> 00:30:19,279
question of course

753
00:30:22,470 --> 00:30:20,399
it's interesting to note that the

754
00:30:23,830 --> 00:30:22,480
generational moment corresponds to when

755
00:30:26,389 --> 00:30:23,840
a lot of attention has been placed on

756
00:30:28,549 --> 00:30:26,399
mars as opposed to how long it takes for

757
00:30:31,029 --> 00:30:28,559
satellites to get the outer system i was

758
00:30:32,710 --> 00:30:31,039
really struck by the presentations which

759
00:30:34,950 --> 00:30:32,720
look like we're talking about planets

760
00:30:36,470 --> 00:30:34,960
and moons and institutions but we're

761
00:30:38,389 --> 00:30:36,480
also really talking about some important

762
00:30:41,190 --> 00:30:38,399
relationships that made

763
00:30:43,350 --> 00:30:41,200

those systems work um and i'm struck by

764
00:30:45,190 --> 00:30:43,360
the number of times we've seen um you

765
00:30:47,350 --> 00:30:45,200
know that the torrance has participated

766
00:30:49,190 --> 00:30:47,360
in several generations of missions or

767
00:30:50,630 --> 00:30:49,200
paul shanks name coming up over and over

768
00:30:53,590 --> 00:30:50,640
again or these strong relationships

769
00:30:55,110 --> 00:30:53,600
between nasa and esa that enabled um

770
00:30:56,549 --> 00:30:55,120
something like cassini huygens to be the

771
00:30:58,470 --> 00:30:56,559
success that it is

772
00:31:00,149 --> 00:30:58,480
and i think i like many people in this

773
00:31:01,750 --> 00:31:00,159
room have been very dismayed or

774
00:31:03,830 --> 00:31:01,760
distressed at the cancellations that

775
00:31:06,470 --> 00:31:03,840
some of the larger scale international

776
00:31:08,950 --> 00:31:06,480
collaborations between nasa and nisa

777
00:31:11,269 --> 00:31:08,960
specifically whether it's exomars or the

778
00:31:13,750 --> 00:31:11,279
potential of a of a joint mission to

779
00:31:15,029 --> 00:31:13,760
your uh to jupiter's moons and i'm

780
00:31:17,430 --> 00:31:15,039
wondering if the three of you could

781
00:31:19,750 --> 00:31:17,440
speak from your experience as to what

782
00:31:21,190 --> 00:31:19,760
are the parameters for success for

783
00:31:23,350 --> 00:31:21,200
building the kinds of strong

784
00:31:25,830 --> 00:31:23,360
relationships whether it's across

785
00:31:28,389 --> 00:31:25,840
institutions or across missions or

786
00:31:31,750 --> 00:31:28,399
across continents that enable these

787
00:31:34,070 --> 00:31:31,760
kinds of missions to go forward

788
00:31:35,830 --> 00:31:34,080

let me just make a preliminary uh

789
00:31:38,149 --> 00:31:35,840
comment on that and then ask my

790
00:31:38,870 --> 00:31:38,159
colleagues is that

791
00:31:44,710 --> 00:31:38,880
i

792
00:31:47,110 --> 00:31:44,720
that

793
00:31:49,269 --> 00:31:47,120
we we got the wrong name on our program

794
00:31:52,310 --> 00:31:49,279
by allowing it to be called unmanned or

795
00:31:55,750 --> 00:31:52,320
robotic it is profoundly human

796
00:31:58,870 --> 00:31:55,760
and the crew of these spacecraft are

797
00:32:01,909 --> 00:31:58,880
right here on earth and in the command

798
00:32:03,830 --> 00:32:01,919
center and now with social media and

799
00:32:05,669 --> 00:32:03,840
other things we can bring the rest of

800
00:32:07,110 --> 00:32:05,679
the population of the world together

801
00:32:09,669 --> 00:32:07,120
with that that's been an evolving

802
00:32:11,590 --> 00:32:09,679
picture and that's true in the science

803
00:32:14,549 --> 00:32:11,600
community but there's a broader context

804
00:32:16,310 --> 00:32:14,559
to it

805
00:32:18,470 --> 00:32:16,320
in um

806
00:32:19,830 --> 00:32:18,480
planning these next missions and looking

807
00:32:22,950 --> 00:32:19,840
toward

808
00:32:25,509 --> 00:32:22,960
future missions uh there was a meeting

809
00:32:27,269 --> 00:32:25,519
several years ago working with

810
00:32:29,269 --> 00:32:27,279
many of the same members of science

811
00:32:31,269 --> 00:32:29,279
definition team been working with for

812
00:32:33,509 --> 00:32:31,279
for many years when came to the

813
00:32:34,789 --> 00:32:33,519

realization it's about the journey

814
00:32:36,870 --> 00:32:34,799
that

815
00:32:39,350 --> 00:32:36,880
we have to be

816
00:32:40,789 --> 00:32:39,360
enjoying ourselves along the way

817
00:32:42,870 --> 00:32:40,799
and working

818
00:32:46,549 --> 00:32:42,880
with

819
00:32:47,669 --> 00:32:46,559
good people to who have that very long

820
00:32:50,789 --> 00:32:47,679
term

821
00:32:52,549 --> 00:32:50,799
vision and i think those who are

822
00:32:55,590 --> 00:32:52,559
are dedicated

823
00:32:57,669 --> 00:32:55,600
to that future exploration

824
00:32:59,669 --> 00:32:57,679
work so well together because they have

825
00:33:00,870 --> 00:32:59,679
that long-term

826
00:33:04,310 --> 00:33:00,880
uh

827
00:33:07,350 --> 00:33:04,320
common goal and um

828
00:33:10,149 --> 00:33:07,360
so i'll stop there

829
00:33:10,950 --> 00:33:10,159
i'm not much to add to what i said but i

830
00:33:13,190 --> 00:33:10,960
think

831
00:33:15,509 --> 00:33:13,200
first of all you you have to consider

832
00:33:17,590 --> 00:33:15,519
that space science is not

833
00:33:21,669 --> 00:33:17,600
a scientific discipline

834
00:33:27,269 --> 00:33:24,950
complex a a set of very different

835
00:33:29,830 --> 00:33:27,279
scientific disciplines and so there are

836
00:33:32,789 --> 00:33:29,840
always competition and cooperation

837
00:33:34,070 --> 00:33:32,799
aspects with player role in this in this

838
00:33:35,990 --> 00:33:34,080

field

839
00:33:38,230 --> 00:33:36,000
secondly

840
00:33:41,350 --> 00:33:38,240
even given the scientific disciplines

841
00:33:42,549 --> 00:33:41,360
that we call space science space science

842
00:33:45,350 --> 00:33:42,559
is not

843
00:33:47,269 --> 00:33:45,360
only science they need technological

844
00:33:49,909 --> 00:33:47,279
means rockets

845
00:33:52,310 --> 00:33:49,919
spacecraft

846
00:33:55,350 --> 00:33:52,320
communication networks political

847
00:33:58,070 --> 00:33:55,360
decisions huge amounts of money so it's

848
00:34:01,110 --> 00:33:58,080
not only science and

849
00:34:05,029 --> 00:34:01,120
not even is not science is not even the

850
00:34:06,950 --> 00:34:05,039
most important driving force behind

851
00:34:08,389 --> 00:34:06,960
space science

852
00:34:10,470 --> 00:34:08,399
third

853
00:34:13,270 --> 00:34:10,480
the most challenging and important

854
00:34:15,589 --> 00:34:13,280
scientific mission in space have to be

855
00:34:18,069 --> 00:34:15,599
done in collaboration

856
00:34:19,270 --> 00:34:18,079
big collaborations more collaborations

857
00:34:22,069 --> 00:34:19,280
just having

858
00:34:25,109 --> 00:34:22,079
a launcher is a collaboration

859
00:34:26,230 --> 00:34:25,119
having the deep space network for esa is

860
00:34:28,629 --> 00:34:26,240
essential

861
00:34:31,030 --> 00:34:28,639
if you want to go into the outer system

862
00:34:32,950 --> 00:34:31,040
outer solar system you need an ftg

863
00:34:35,990 --> 00:34:32,960

generation you cannot have this in

864
00:34:38,629 --> 00:34:36,000
europe so that demands in any case some

865
00:34:40,069 --> 00:34:38,639
kind of collaboration and all of this

866
00:34:42,470 --> 00:34:40,079
implies

867
00:34:46,230 --> 00:34:42,480
scientific

868
00:34:49,990 --> 00:34:46,240
personal relationships but also complex

869
00:34:52,069 --> 00:34:50,000
political and economical negotiations so

870
00:34:55,430 --> 00:34:52,079
the situation is always always very

871
00:34:58,630 --> 00:34:55,440
fluid the difference in the budget

872
00:35:00,150 --> 00:34:58,640
system in europe and in nasa has been

873
00:35:03,349 --> 00:35:00,160
the major

874
00:35:04,870 --> 00:35:03,359
stumbling blocks in in some in many in

875
00:35:07,829 --> 00:35:04,880
several cases

876
00:35:09,190 --> 00:35:07,839
and was a source of uh

877
00:35:14,710 --> 00:35:09,200
not

878
00:35:18,630 --> 00:35:15,430
that

879
00:35:20,390 --> 00:35:18,640
professor russo pointed out the

880
00:35:23,270 --> 00:35:20,400
the tensions and the relationships

881
00:35:25,270 --> 00:35:23,280
between issa and nasa particularly

882
00:35:28,390 --> 00:35:25,280
what amazed me was that the

883
00:35:30,550 --> 00:35:28,400
relationships survived

884
00:35:32,630 --> 00:35:30,560
i wasn't certain when we started talking

885
00:35:34,550 --> 00:35:32,640
on cassini whether my european

886
00:35:36,870 --> 00:35:34,560
colleagues would even talk to us after

887
00:35:40,230 --> 00:35:36,880
what the united states had done with

888
00:35:42,710 --> 00:35:40,240

respect to the ulysses program

889
00:35:44,630 --> 00:35:42,720
and it was personal relationships that

890
00:35:46,630 --> 00:35:44,640
allowed people to say hey you know

891
00:35:48,550 --> 00:35:46,640
there's a bigger picture here we have to

892
00:35:52,310 --> 00:35:48,560
work together on this we're not going to

893
00:35:52,320 --> 00:35:56,710
let's take one final question

894
00:36:01,589 --> 00:35:58,950
let me pick up on that theme actually

895
00:36:02,950 --> 00:36:01,599
because that's my question ask the

896
00:36:05,109 --> 00:36:02,960
striking difference between what

897
00:36:06,950 --> 00:36:05,119
professor russo described and what bob

898
00:36:08,870 --> 00:36:06,960
has recently experienced in the

899
00:36:10,870 --> 00:36:08,880
construction of an international program

900
00:36:13,349 --> 00:36:10,880
for outer planet exploration

901
00:36:14,470 --> 00:36:13,359
it seems now as a result we're in a

902
00:36:16,630 --> 00:36:14,480
phase where

903
00:36:17,750 --> 00:36:16,640
u.s and europe are going

904
00:36:19,349 --> 00:36:17,760
apart

905
00:36:21,510 --> 00:36:19,359
uh and planning their programs

906
00:36:23,910 --> 00:36:21,520
independently not just the outer planets

907
00:36:25,349 --> 00:36:23,920
but at mars too it seems as we heard

908
00:36:27,510 --> 00:36:25,359
earlier

909
00:36:29,910 --> 00:36:27,520
what's the impact of the current

910
00:36:34,069 --> 00:36:29,920
situation on this with respect to the

911
00:36:34,079 --> 00:36:37,710
let's start with

912
00:36:44,069 --> 00:36:42,069
the europa ganymede

913
00:36:45,349 --> 00:36:44,079

uh discussion and maybe others can pick

914
00:36:46,310 --> 00:36:45,359
up but

915
00:36:49,510 --> 00:36:46,320
uh

916
00:36:51,829 --> 00:36:49,520
we've certainly so when

917
00:36:54,950 --> 00:36:51,839
so we were working together as one

918
00:36:57,109 --> 00:36:54,960
wonderful group when the u.s said

919
00:37:00,150 --> 00:36:57,119
okay we're not doing europa and europe

920
00:37:03,270 --> 00:37:00,160
said well we are doing this ganymede

921
00:37:04,390 --> 00:37:03,280
mission which has become juice

922
00:37:06,069 --> 00:37:04,400
and

923
00:37:07,430 --> 00:37:06,079
again the personal relationships

924
00:37:10,230 --> 00:37:07,440
continue

925
00:37:12,069 --> 00:37:10,240
we certainly want to

926
00:37:14,470 --> 00:37:12,079
work together with our colleagues in

927
00:37:17,109 --> 00:37:14,480
europe to explore the jupiter system

928
00:37:20,390 --> 00:37:17,119
there will be u.s participation

929
00:37:22,950 --> 00:37:20,400
in the juice mission

930
00:37:25,190 --> 00:37:22,960
and we're doing all we can on our side

931
00:37:27,990 --> 00:37:25,200
to try to

932
00:37:30,069 --> 00:37:28,000
keep alive that vision and resurrect

933
00:37:31,829 --> 00:37:30,079
uh our europa mission

934
00:37:35,109 --> 00:37:31,839
for the exploration of europa and the

935
00:37:36,470 --> 00:37:35,119
jupiter system including ganymede

936
00:37:38,390 --> 00:37:36,480
as a whole

937
00:37:40,710 --> 00:37:38,400
but um

938
00:37:41,670 --> 00:37:40,720

without the u.s participation we will

939
00:37:45,270 --> 00:37:41,680
have

940
00:37:48,870 --> 00:37:45,280
hints of what

941
00:37:51,109 --> 00:37:48,880
europa is like but we won't have answers

942
00:37:53,270 --> 00:37:51,119
and my fear

943
00:37:55,270 --> 00:37:53,280
is that 50 years from now when we do

944
00:37:56,710 --> 00:37:55,280
explore europa and we get a lander to

945
00:37:58,390 --> 00:37:56,720
the surface and we

946
00:38:00,630 --> 00:37:58,400
sample that stuff

947
00:38:02,710 --> 00:38:00,640
my fear is we'll say why didn't we do

948
00:38:06,150 --> 00:38:02,720
this 50 years ago

949
00:38:07,670 --> 00:38:06,160
because it's it could be that important

950
00:38:13,270 --> 00:38:07,680
all right let's thank our panel once

951
00:38:19,910 --> 00:38:15,349
and you may blame the moderator for

952
00:38:23,670 --> 00:38:21,750
no no quite the contrary thank you ralph

953
00:38:25,670 --> 00:38:23,680
we did a fine job and and thanks to the

954
00:38:27,030 --> 00:38:25,680
panel for such a stimulating discussion

955
00:38:29,430 --> 00:38:27,040
couple quick announcements before we

956
00:38:31,670 --> 00:38:29,440
break uh if you haven't already done so

957
00:38:33,910 --> 00:38:31,680
please uh take the opportunity to avail

958
00:38:35,750 --> 00:38:33,920
yourself of the oral history recording

959
00:38:37,270 --> 00:38:35,760
crew they're not down at this end uh

960
00:38:39,829 --> 00:38:37,280
today they're down at this end when you

961
00:38:41,670 --> 00:38:39,839
go out it'll be to your left

962
00:38:44,150 --> 00:38:41,680
we've got a lot of experience and talent

963
00:38:46,230 --> 00:38:44,160

in this room and let's let's share that

964
00:38:47,349 --> 00:38:46,240
as much as we can with the public and

965
00:38:48,790 --> 00:38:47,359
with the

966
00:38:51,109 --> 00:38:48,800
next generation

967
00:38:52,950 --> 00:38:51,119
uh we will be reconvening at one o'clock

968
00:38:55,349 --> 00:38:52,960
so keep an eye on the clock seven

969
00:38:57,589 --> 00:38:55,359
minutes uh won't hurt us but we do need

970
00:39:00,390 --> 00:38:57,599
to be back at one and lastly please

971
00:39:02,710 --> 00:39:00,400
remember the admission uh to take a

972
00:39:04,390 --> 00:39:02,720
buddy to lunch again the advantage of

973
00:39:06,790 --> 00:39:04,400
having us all here physically in one

974
00:39:09,109 --> 00:39:06,800
place is the interpersonal interaction

975
00:39:10,950 --> 00:39:09,119
interaction and lunch time's a a great