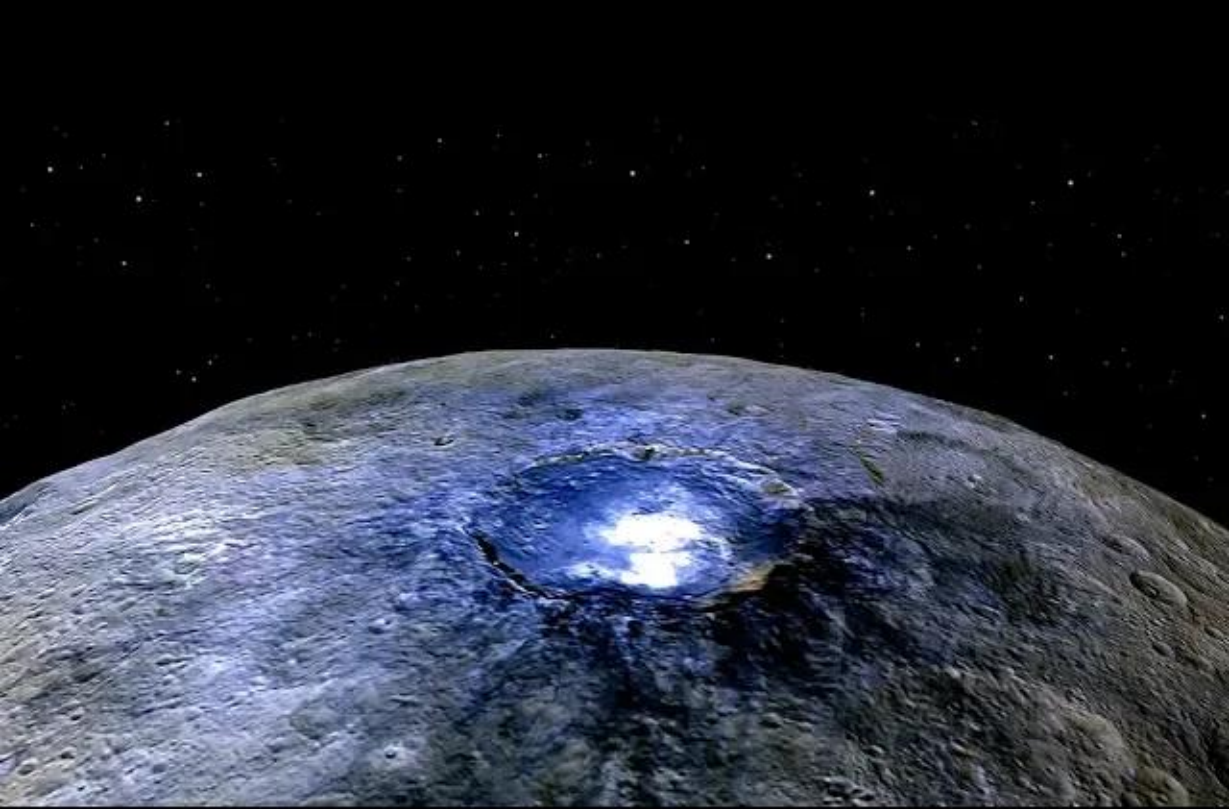

1
00:00:08,810 --> 00:00:04,610
NASA's Jet Propulsion Laboratory

2
00:00:11,240 --> 00:00:08,820
presents the von Karman lecture a series

3
00:00:13,610 --> 00:00:11,250
of talks by scientists and engineers who

4
00:00:16,330 --> 00:00:13,620
are exploring our planet our solar

5
00:00:29,100 --> 00:00:16,340
system and all that lies beyond

6
00:00:33,820 --> 00:00:32,290
good evening i am brian white from the

7
00:00:36,400 --> 00:00:33,830
office of communications in education

8
00:00:40,960 --> 00:00:36,410
and welcome to this evenings von Karman

9
00:00:46,360 --> 00:00:40,970
lecture small world's big science James

10
00:00:52,030 --> 00:00:46,370
Bond Tom Hanks psyche Monty Python and

11
00:00:54,760 --> 00:00:52,040
la petit Prince some of you got it these

12
00:00:57,010 --> 00:00:54,770
are all names of asteroids small worlds

13
00:00:59,680 --> 00:00:57,020

in our solar system now what can

14
00:01:01,870 --> 00:00:59,690
asteroids planetesimals or small worlds

15
00:01:05,170 --> 00:01:01,880
teach us about the origins and evolution

16
00:01:07,930 --> 00:01:05,180
of our solar system these worlds be but

17
00:01:09,940 --> 00:01:07,940
little they be fierce our speaker

18
00:01:12,070 --> 00:01:09,950
tonight a prince is a principal

19
00:01:14,830 --> 00:01:12,080
scientist joined JPL in 1990 after

20
00:01:17,859 --> 00:01:14,840
receiving a PhD in geophysics from

21
00:01:19,060 --> 00:01:17,869
Columbia University in 1989 she assumed

22
00:01:21,130 --> 00:01:19,070
the role of deputy principal

23
00:01:23,440 --> 00:01:21,140
investigator and project scientist of

24
00:01:25,990 --> 00:01:23,450
the dawn discovery mission to Vesta and

25
00:01:28,690 --> 00:01:26,000
Ceres in 2002 and became the missions

26
00:01:30,160 --> 00:01:28,700
principal investigator in 2018

27
00:01:31,899 --> 00:01:30,170
she currently serves as a

28
00:01:34,539 --> 00:01:31,909
co-investigator on the Europa clipper

29
00:01:36,789 --> 00:01:34,549
and Psyche missions in addition to her

30
00:01:39,370 --> 00:01:36,799
flight project work she manages the

31
00:01:41,380 --> 00:01:39,380
small bodies office within the solar

32
00:01:41,890 --> 00:01:41,390
system exploration directorate here at

33
00:01:44,350 --> 00:01:41,900
JPL

34
00:01:45,969 --> 00:01:44,360
she has over 300 publications has

35
00:01:48,250 --> 00:01:45,979
received two exceptional achievement

36
00:01:50,680 --> 00:01:48,260
medals from NASA the Antarctic Service

37
00:01:52,300 --> 00:01:50,690
Medal and is a fellow of the Geological

38
00:01:55,350 --> 00:01:52,310

Society of America now this is my

39
00:01:59,320 --> 00:01:55,360
favorite part about her in 2014

40
00:02:01,810 --> 00:01:59,330
asteroid 107 to 4 was named Carol

41
00:02:05,020 --> 00:02:01,820
Raymond to recognize her work on the

42
00:02:08,710 --> 00:02:05,030
dawn mission please help me welcome dr.

43
00:02:08,720 --> 00:02:12,350
that's right

44
00:02:12,360 --> 00:02:16,420
[Applause]

45
00:02:16,430 --> 00:02:19,649
Thank You Bryan

46
00:02:24,280 --> 00:02:21,759
thank you all for coming

47
00:02:26,500 --> 00:02:24,290
it's amazing how excited people get

48
00:02:28,899 --> 00:02:26,510
about the fact that I have an asteroid

49
00:02:34,539 --> 00:02:28,909
named after me it's like my greatest

50
00:02:36,789 --> 00:02:34,549
achievement and in fact it's it's one of

51
00:02:39,009 --> 00:02:36,799
the great honors of doing this kind of

52
00:02:40,660 --> 00:02:39,019
research because there are a lot of

53
00:02:43,809 --> 00:02:40,670
asteroids out there as as you'll find

54
00:02:49,270 --> 00:02:43,819
out in my talk and they all need names

55
00:02:50,050 --> 00:02:49,280
so so our esteemed colleagues from time

56
00:02:51,699 --> 00:02:50,060
to time

57
00:02:55,929 --> 00:02:51,709
contact the International Astronomical

58
00:02:59,020 --> 00:02:55,939
Union and and nominate people to for

59
00:03:01,959 --> 00:02:59,030
these bodies to be named after so it's

60
00:03:03,970 --> 00:03:01,969
not a distinctive honor it's one that's

61
00:03:07,809 --> 00:03:03,980
shared by many but it's it's a great

62
00:03:09,939 --> 00:03:07,819
honor nonetheless so let's get started I

63
00:03:12,129 --> 00:03:09,949

have a lot of material to go over

64
00:03:14,229 --> 00:03:12,139
tonight and I'm going to try to go

65
00:03:16,300 --> 00:03:14,239
through it rather quickly both to keep

66
00:03:19,300 --> 00:03:16,310
you engaged and to make sure there's

67
00:03:22,830 --> 00:03:19,310
time for questions at the end so what

68
00:03:25,960 --> 00:03:22,840
I'm going to try to do today tonight is

69
00:03:29,309 --> 00:03:25,970
is give you a taste of what small bodies

70
00:03:31,719 --> 00:03:29,319
can tell us about our solar system and

71
00:03:33,309 --> 00:03:31,729
in particular what we've learned from

72
00:03:37,059 --> 00:03:33,319
the dawn mission which recently

73
00:03:39,099 --> 00:03:37,069
concluded its operations and what we may

74
00:03:43,479 --> 00:03:39,109
learn from the psychie mission which is

75
00:03:45,159 --> 00:03:43,489
now in preparation for launch and then

76
00:03:48,969 --> 00:03:45,169
we'll we'll take a little bit of a look

77
00:03:55,210 --> 00:03:48,979
at what's next so starting at the

78
00:03:59,349 --> 00:03:55,220
beginning our star began as a cloud of

79
00:04:01,199 --> 00:03:59,359
gas and dust it was likely formed by a

80
00:04:04,649 --> 00:04:01,209
shockwave from a nearby supernova

81
00:04:08,800 --> 00:04:04,659
explosion compressing the interplanetary

82
00:04:13,259 --> 00:04:08,810
medium into a dense nebula and that

83
00:04:16,449 --> 00:04:13,269
nebula started to to condense into

84
00:04:18,490 --> 00:04:16,459
grains and then the grains were

85
00:04:20,770 --> 00:04:18,500
accreting together sticking together and

86
00:04:23,379 --> 00:04:20,780
then becoming planetesimals and then

87
00:04:27,250 --> 00:04:23,389
from these planets as well as these

88
00:04:29,730 --> 00:04:27,260

these small pieces came eventually the

89
00:04:31,480 --> 00:04:29,740
planets an important thing about the

90
00:04:34,740 --> 00:04:31,490
fact that our

91
00:04:37,629 --> 00:04:34,750
star our solar nebula was born out of a

92
00:04:42,249 --> 00:04:37,639
nearby supernova explosion is that that

93
00:04:44,110 --> 00:04:42,259
supernovae seeded the nebula with

94
00:04:46,089 --> 00:04:44,120
radioactive material short-lived

95
00:04:49,180 --> 00:04:46,099
radioactive material and as that

96
00:04:52,080 --> 00:04:49,190
material decayed it gave off heat and

97
00:04:57,070 --> 00:04:52,090
heat is one of the primary ingredients

98
00:05:00,249 --> 00:04:57,080
to begin processes as anybody who cooks

99
00:05:02,879 --> 00:05:00,259
knows you put your ingredients together

100
00:05:06,240 --> 00:05:02,889
you turn on the heat and things happen

101
00:05:13,230 --> 00:05:06,250
so this is an artist's rendition of that

102
00:05:16,450 --> 00:05:13,240
swirling disk nebula of gas and dust and

103
00:05:19,330 --> 00:05:16,460
the gaps forming where material has been

104
00:05:23,309 --> 00:05:19,340
clumping together into planets has moles

105
00:05:28,240 --> 00:05:23,319
and what were what we are trying to

106
00:05:31,689 --> 00:05:28,250
understand about this process is whether

107
00:05:33,070 --> 00:05:31,699
the outcome in terms of our planets and

108
00:05:35,950 --> 00:05:33,080
the other bodies in our solar system

109
00:05:39,010 --> 00:05:35,960
were largely affected by chemical

110
00:05:42,520 --> 00:05:39,020
variations within that disk did it start

111
00:05:46,600 --> 00:05:42,530
with a lot of you know variations of

112
00:05:48,820 --> 00:05:46,610
material how did the time at which these

113
00:05:52,209 --> 00:05:48,830

things came clumping together and

114
00:05:55,290 --> 00:05:52,219
farming affect the outcome of what they

115
00:05:58,779 --> 00:05:55,300
ended up being and then what processes

116
00:06:01,510 --> 00:05:58,789
post formation mixed all that material

117
00:06:03,670 --> 00:06:01,520
together within our solar system so

118
00:06:06,550 --> 00:06:03,680
we're sort of looking at nature versus

119
00:06:07,990 --> 00:06:06,560
nurture versus where you live or

120
00:06:10,570 --> 00:06:08,000
something like that you know people

121
00:06:15,730 --> 00:06:10,580
people moving around changes the

122
00:06:19,990 --> 00:06:15,740
character of the neighborhood so here's

123
00:06:22,420 --> 00:06:20,000
a nice simple diagram and our solar

124
00:06:24,760 --> 00:06:22,430
nebula was certainly not this simple to

125
00:06:26,850 --> 00:06:24,770
start out with but it reinforces a few

126
00:06:30,459 --> 00:06:26,860
concepts that you'll need to understand

127
00:06:34,480 --> 00:06:30,469
and that's that the solar nebula was not

128
00:06:36,879 --> 00:06:34,490
just a was not just a flat plane of gas

129
00:06:42,010 --> 00:06:36,889
and dust if I could control this thing I

130
00:06:43,990 --> 00:06:42,020
guess so it wasn't just a disk but it

131
00:06:44,730 --> 00:06:44,000
was more of a torus so as you get

132
00:06:47,820 --> 00:06:44,740
further away

133
00:06:51,360 --> 00:06:47,830
from the protosun in the center

134
00:06:53,219 --> 00:06:51,370
the disk expands it's also cooler the

135
00:06:58,920 --> 00:06:53,229
farther away you get from the protosun

136
00:07:00,210 --> 00:06:58,930
and the chemistry that therefore changes

137
00:07:02,670 --> 00:07:00,220
and the chemistry changes for two

138
00:07:05,930 --> 00:07:02,680

reasons one is the temperature and the

139
00:07:08,999 --> 00:07:05,940
second is that you may have sources

140
00:07:11,700 --> 00:07:09,009
bringing material in to the outer edges

141
00:07:14,400 --> 00:07:11,710
of the disks and and also falling in

142
00:07:17,969 --> 00:07:14,410
from the top that may be changing the

143
00:07:23,339 --> 00:07:17,979
chemistry with with distance from the

144
00:07:26,430 --> 00:07:23,349
center so the chemistry is recorded in

145
00:07:28,800 --> 00:07:26,440
these bodies that are forming within the

146
00:07:31,680 --> 00:07:28,810
nebula and so this is these are little

147
00:07:34,050 --> 00:07:31,690
icons to show you that each body carries

148
00:07:36,360 --> 00:07:34,060
a chemical fingerprint of the material

149
00:07:38,850 --> 00:07:36,370
if formed from a tits

150
00:07:44,189 --> 00:07:38,860
it's a particular place in the disk and

151
00:07:47,730 --> 00:07:44,199
then post formation there we know that

152
00:07:50,820 --> 00:07:47,740
things moved around and we'll talk about

153
00:07:55,159 --> 00:07:50,830
that later and so the the motion of the

154
00:08:01,890 --> 00:07:55,169
objects also played a big role in how we

155
00:08:06,180 --> 00:08:01,900
what we ended up with today so let's

156
00:08:08,430 --> 00:08:06,190
take a look at what we know of the main

157
00:08:11,760 --> 00:08:08,440
asteroid belt and eventually you'll see

158
00:08:13,670 --> 00:08:11,770
in this graphic also all of the as the

159
00:08:17,879 --> 00:08:13,680
objects near the earth this so-called

160
00:08:23,010 --> 00:08:17,889
near-earth objects belt and we're going

161
00:08:26,580 --> 00:08:23,020
to see what we knew starting from 1970

162
00:08:28,680 --> 00:08:26,590
there's a cronut in the corner here that

163
00:08:31,550 --> 00:08:28,690

it's also over here and I apologize it's

164
00:08:33,810 --> 00:08:31,560
really hard to see I'm going to be

165
00:08:35,610 --> 00:08:33,820
narrating for you as we go through time

166
00:08:37,889 --> 00:08:35,620
and tell you some of the events that

167
00:08:38,610 --> 00:08:37,899
you'll see occurring so let's get

168
00:08:51,290 --> 00:08:38,620
started here

169
00:08:53,040 --> 00:08:51,300
so 1970 this is what we knew of of the

170
00:08:55,260 --> 00:08:53,050
distribution of asteroids in the main

171
00:08:57,780 --> 00:08:55,270
belt

172
00:08:59,910 --> 00:08:57,790
let me try this way there we go I'm

173
00:09:01,410 --> 00:08:59,920
pointing in the wrong direction and as

174
00:09:05,040 --> 00:09:01,420
you'll see all these blue dots are

175
00:09:06,540 --> 00:09:05,050
individual asteroids and then every once

176
00:09:11,610 --> 00:09:06,550
in a while you'll see a little burst

177
00:09:14,660 --> 00:09:11,620
there's one now that is likely that the

178
00:09:17,280 --> 00:09:14,670
Palomar telescope was looking for

179
00:09:19,560 --> 00:09:17,290
asteroids following Jupiter or leading

180
00:09:21,660 --> 00:09:19,570
Jupiter the so-called Trojans and if the

181
00:09:24,060 --> 00:09:21,670
telescope is trained at a certain part

182
00:09:26,190 --> 00:09:24,070
of the sky at a certain time it's going

183
00:09:28,170 --> 00:09:26,200
to see everything in that direction and

184
00:09:32,340 --> 00:09:28,180
that's why these little bursts of

185
00:09:34,620 --> 00:09:32,350
detections show up in this in this

186
00:09:38,040 --> 00:09:34,630
animation so we're going along now it's

187
00:09:40,620 --> 00:09:38,050
1982 more telescopes are coming online

188
00:09:43,110 --> 00:09:40,630

and you'll start to see a very rapid

189
00:09:49,410 --> 00:09:43,120
increase in the number of of known

190
00:09:51,750 --> 00:09:49,420
objects and in particular there's

191
00:09:54,360 --> 00:09:51,760
there's going to be a lot of bursty

192
00:09:58,350 --> 00:09:54,370
activity going on so again each of these

193
00:10:00,270 --> 00:09:58,360
is a specific survey that was looking

194
00:10:02,880 --> 00:10:00,280
for something probably out in the outer

195
00:10:04,170 --> 00:10:02,890
planet regions and and now you're

196
00:10:06,540 --> 00:10:04,180
starting to see that they're going off

197
00:10:11,430 --> 00:10:06,550
much more regularly and so that's when

198
00:10:14,430 --> 00:10:11,440
these tracking tell us telescope started

199
00:10:17,040 --> 00:10:14,440
to track the objects near the earth from

200
00:10:20,580 --> 00:10:17,050
the near-earth objects through to the

201
00:10:22,440 --> 00:10:20,590
main belt and all of the sudden this

202
00:10:24,360 --> 00:10:22,450
this tourist starts to really fill in

203
00:10:26,850 --> 00:10:24,370
and then you're starting to see that the

204
00:10:29,400 --> 00:10:26,860
the area around the earth is also

205
00:10:32,370 --> 00:10:29,410
becoming much more populated so now

206
00:10:34,820 --> 00:10:32,380
we're at year 2000 and as you can see

207
00:10:38,430 --> 00:10:34,830
things are really starting to take off

208
00:10:40,170 --> 00:10:38,440
we have we have dedicated survey

209
00:10:43,980 --> 00:10:40,180
telescopes in Arizona

210
00:10:47,220 --> 00:10:43,990
in Hawaii they're they're operating all

211
00:10:49,470 --> 00:10:47,230
the time focused on trying to find these

212
00:10:52,140 --> 00:10:49,480
objects and you may have heard about a

213
00:10:54,690 --> 00:10:52,150

congressional mandate to find all of the

214
00:10:57,720 --> 00:10:54,700
objects greater than one kilometer in

215
00:11:01,170 --> 00:10:57,730
diameter with within the near Earth

216
00:11:04,950 --> 00:11:01,180
object population and so that is also

217
00:11:08,250 --> 00:11:04,960
one of the motivations for some of these

218
00:11:11,040 --> 00:11:08,260
surveys that are looking out at

219
00:11:15,030 --> 00:11:11,050
these objects that are in our midst so

220
00:11:19,800 --> 00:11:15,040
if you if you if these objects were

221
00:11:22,340 --> 00:11:19,810
large enough and and shiny enough the

222
00:11:26,070 --> 00:11:22,350
the nice guy would just be you know

223
00:11:29,520 --> 00:11:26,080
completely bright with all of these dots

224
00:11:33,170 --> 00:11:29,530
but just one thing to take away from

225
00:11:35,790 --> 00:11:33,180
this we're and we're almost at the end

226
00:11:41,010 --> 00:11:35,800
when you go home don't worry about these

227
00:11:43,590 --> 00:11:41,020
things hitting us because the fact that

228
00:11:46,890 --> 00:11:43,600
we know where they are and we track them

229
00:11:51,510 --> 00:11:46,900
and we actually do that from JPL JPL

230
00:11:54,090 --> 00:11:51,520
tracks every known object that's that's

231
00:11:58,260 --> 00:11:54,100
in the main in the near-earth asteroid

232
00:12:01,170 --> 00:11:58,270
belt and and will be you know alerting

233
00:12:01,950 --> 00:12:01,180
to the hazard when when anything looks

234
00:12:06,450 --> 00:12:01,960
out of sorts

235
00:12:11,970 --> 00:12:06,460
so so this is just an amazing population

236
00:12:16,220 --> 00:12:11,980
though of objects and each of them is is

237
00:12:19,740 --> 00:12:16,230
a fragment of that original process of

238
00:12:22,500 --> 00:12:19,750

material coalescing that eventually

239
00:12:26,340 --> 00:12:22,510
ended up building the planets of our

240
00:12:31,830 --> 00:12:26,350
solar system the planets the moons etc

241
00:12:34,410 --> 00:12:31,840
and some of it is original material like

242
00:12:37,170 --> 00:12:34,420
the the pieces that came together and

243
00:12:40,350 --> 00:12:37,180
were their own things which we call

244
00:12:42,870 --> 00:12:40,360
planetesimals and then others are just

245
00:12:45,150 --> 00:12:42,880
shattered remnants of those original

246
00:12:47,940 --> 00:12:45,160
objects and we call that collisional

247
00:12:50,670 --> 00:12:47,950
debris so we have still the some of the

248
00:12:53,190 --> 00:12:50,680
original accretionary material you know

249
00:12:56,010 --> 00:12:53,200
objects and and a lot of the material is

250
00:12:57,780 --> 00:12:56,020
small collisional debris or things that

251
00:13:03,260 --> 00:12:57,790
have kind of come back together after

252
00:13:07,590 --> 00:13:03,270
being blown apart now one other thing

253
00:13:10,370 --> 00:13:07,600
that another new model or theory that

254
00:13:12,480 --> 00:13:10,380
has been around for about a decade now

255
00:13:15,800 --> 00:13:12,490
is it's called

256
00:13:20,970 --> 00:13:15,810
is about giant planets scattering

257
00:13:21,790 --> 00:13:20,980
material from in the inner solar system

258
00:13:24,280 --> 00:13:21,800
and out

259
00:13:27,880 --> 00:13:24,290
solar system basically moving material

260
00:13:29,710 --> 00:13:27,890
in and out in a very catastrophic way so

261
00:13:34,210 --> 00:13:29,720
I'm going to show you a little animation

262
00:13:38,350 --> 00:13:34,220
here these four circles are the original

263
00:13:41,920 --> 00:13:38,360

orbits of the giant planets so Jupiter

264
00:13:44,889 --> 00:13:41,930
Saturn Uranus Neptune and in the middle

265
00:13:48,930 --> 00:13:44,899
is the you know still accreting material

266
00:13:52,960 --> 00:13:48,940
of the inner solar system and as these

267
00:13:55,449 --> 00:13:52,970
planets grow their gravitational

268
00:13:57,670 --> 00:13:55,459
perturbations so that they're they're

269
00:13:59,860 --> 00:13:57,680
becoming more massive and therefore

270
00:14:03,000 --> 00:13:59,870
their gravity is becoming more massive

271
00:14:05,350 --> 00:14:03,010
and they can interact with each other in

272
00:14:09,220 --> 00:14:05,360
resonances and a resonance is simply

273
00:14:10,810 --> 00:14:09,230
when you know if you are whipping

274
00:14:13,660 --> 00:14:10,820
something up you know that if you keep

275
00:14:15,190 --> 00:14:13,670
pushing in the same direction that it's

276
00:14:17,170 --> 00:14:15,200
something is going to go faster and

277
00:14:19,210 --> 00:14:17,180
faster right and the same thing for a

278
00:14:21,610 --> 00:14:19,220
planet if applet if two planets interact

279
00:14:24,220 --> 00:14:21,620
in the same manner over and over again

280
00:14:28,449 --> 00:14:24,230
then all of that energy momentum

281
00:14:30,610 --> 00:14:28,459
transfer just keeps accruing to have a

282
00:14:32,290 --> 00:14:30,620
much bigger effect so that's what

283
00:14:34,420 --> 00:14:32,300
happens with as these planets are

284
00:14:35,829 --> 00:14:34,430
growing they start to to move a little

285
00:14:38,319 --> 00:14:35,839
bit in their orbits and then they hit

286
00:14:41,620 --> 00:14:38,329
these residences and all of a sudden you

287
00:14:44,290 --> 00:14:41,630
know everything scatters so that's what

288
00:14:48,400 --> 00:14:44,300

you'll see in this little animation and

289
00:14:50,829 --> 00:14:48,410
then now we're seeing the we're seeing

290
00:14:53,769 --> 00:14:50,839
Jupiter and Saturn come in in the solar

291
00:14:55,540 --> 00:14:53,779
system and then move back out and that's

292
00:14:56,829 --> 00:14:55,550
what's called the grand tack model and

293
00:14:58,840 --> 00:14:56,839
if you're a sailor you'll know why it's

294
00:15:01,000 --> 00:14:58,850
called the grand attack because Jupiter

295
00:15:02,560 --> 00:15:01,010
and Saturn go one way they go in they

296
00:15:05,470 --> 00:15:02,570
turn around because the gas is

297
00:15:07,930 --> 00:15:05,480
dissipated they've basically already

298
00:15:11,500 --> 00:15:07,940
accreted all of the material and now

299
00:15:13,750 --> 00:15:11,510
they're being driven back out and want

300
00:15:16,920 --> 00:15:13,760
to make a point here so I've just

301
00:15:19,210 --> 00:15:16,930
explained to you the this theory of

302
00:15:21,430 --> 00:15:19,220
scattering by giant planet growth and

303
00:15:24,370 --> 00:15:21,440
migration but I also want to make the

304
00:15:27,069 --> 00:15:24,380
point that look at the just how much

305
00:15:29,889 --> 00:15:27,079
material is left after this process

306
00:15:33,160 --> 00:15:29,899
takes place and I just showed you how

307
00:15:35,620 --> 00:15:33,170
much material we know about its it looks

308
00:15:40,150 --> 00:15:35,630
like a lot and it is a lot

309
00:15:42,750 --> 00:15:40,160
but it's about 1/10 or less you know

310
00:15:45,670 --> 00:15:42,760
less than 10% of what we think was in

311
00:15:47,530 --> 00:15:45,680
the inner solar system to begin with

312
00:15:53,350 --> 00:15:47,540
although a lot of that material was

313
00:15:57,460 --> 00:15:53,360

ejected in populating areas outside of

314
00:16:00,660 --> 00:15:57,470
the giant planet region okay so that's

315
00:16:04,420 --> 00:16:00,670
kind of the end of the big picture of

316
00:16:06,550 --> 00:16:04,430
why study of these objects is important

317
00:16:11,470 --> 00:16:06,560
but then I always like to bring it back

318
00:16:14,050 --> 00:16:11,480
to why should any of you care what it

319
00:16:16,540 --> 00:16:14,060
why is this important and it really does

320
00:16:20,220 --> 00:16:16,550
pertain to some big questions like how

321
00:16:22,300 --> 00:16:20,230
unique is our water water rich planet

322
00:16:27,550 --> 00:16:22,310
which unfortunately is getting less

323
00:16:31,060 --> 00:16:27,560
water rich every year but we have you

324
00:16:34,390 --> 00:16:31,070
know earth is in a very odd position

325
00:16:39,420 --> 00:16:34,400
being an ocean planet in the inner solar

326
00:16:43,930 --> 00:16:39,430
system Mars is dry Venus is hot and dry

327
00:16:49,810 --> 00:16:43,940
and Earth is in the Goldilocks zone now

328
00:16:51,520 --> 00:16:49,820
earth formed from the same feedstock or

329
00:16:54,370 --> 00:16:51,530
the same materials as these other

330
00:16:58,090 --> 00:16:54,380
planets it went through a process of

331
00:17:01,810 --> 00:16:58,100
melting farming it's iron core and and

332
00:17:05,230 --> 00:17:01,820
basaltic crust and so we know it was hot

333
00:17:08,140 --> 00:17:05,240
enough to boil off most of its internal

334
00:17:10,750 --> 00:17:08,150
water so the fact that as an ocean today

335
00:17:13,949 --> 00:17:10,760
is a little bit perplexing there's

336
00:17:18,100 --> 00:17:13,959
there's two main reasons for it we think

337
00:17:21,400 --> 00:17:18,110
one is that water was delivered to the

338
00:17:24,309 --> 00:17:21,410

earth after it formed and that water was

339
00:17:27,120 --> 00:17:24,319
likely coming from objects that that

340
00:17:31,120 --> 00:17:27,130
were water rich impacting the earth and

341
00:17:33,160 --> 00:17:31,130
leaving the water behind the Earth's

342
00:17:37,110 --> 00:17:33,170
gravity is high enough that it can

343
00:17:40,240 --> 00:17:37,120
retain those volatiles that were

344
00:17:42,460 --> 00:17:40,250
delivered and then the other important

345
00:17:44,980 --> 00:17:42,470
aspect of the earth is that it has a

346
00:17:47,890 --> 00:17:44,990
protective magnetic field which keeps

347
00:17:51,160 --> 00:17:47,900
the solar wind which is very corrosive

348
00:17:53,110 --> 00:17:51,170
to to light elements like water

349
00:17:56,650 --> 00:17:53,120
it keeps the solar wind from stripping

350
00:17:58,180 --> 00:17:56,660
all of that atmosphere away and ocean

351
00:18:01,540 --> 00:17:58,190
away and that's what happened to Mars

352
00:18:03,790 --> 00:18:01,550
when it lost its magnetic field then the

353
00:18:08,860 --> 00:18:03,800
surface water had had and the atmosphere

354
00:18:10,990 --> 00:18:08,870
it had or highly degraded so I kind of

355
00:18:12,670 --> 00:18:11,000
got ahead of myself but you know we're

356
00:18:14,799 --> 00:18:12,680
really after these questions of where

357
00:18:17,650 --> 00:18:14,809
where exactly did the earth get water

358
00:18:20,770 --> 00:18:17,660
what objects brought the water and then

359
00:18:22,510 --> 00:18:20,780
when and where were conditions for life

360
00:18:25,690 --> 00:18:22,520
met during old early solar system

361
00:18:27,790 --> 00:18:25,700
history because you put two and two

362
00:18:29,650 --> 00:18:27,800
together and I just said there's other

363
00:18:32,320 --> 00:18:29,660

objects that have water that we're

364
00:18:34,720 --> 00:18:32,330
bringing it to the earth and so if they

365
00:18:36,580 --> 00:18:34,730
had water and they had energy sources

366
00:18:39,549 --> 00:18:36,590
then they could potentially have been

367
00:18:42,280 --> 00:18:39,559
little habitats for life themselves so

368
00:18:45,780 --> 00:18:42,290
this is this is all part and parcel of

369
00:18:49,450 --> 00:18:45,790
the big questions in planetary science

370
00:18:55,180 --> 00:18:49,460
okay so one more piece of sort of the

371
00:18:58,390 --> 00:18:55,190
recent modeling and and understanding of

372
00:19:02,260 --> 00:18:58,400
the materials that we have in hand which

373
00:19:06,870 --> 00:19:02,270
are meteorites there's a recent

374
00:19:14,110 --> 00:19:06,880
recognition that our our solar system

375
00:19:16,450 --> 00:19:14,120
formed our the the main defining event

376
00:19:20,970 --> 00:19:16,460
of our solar system's formation was

377
00:19:25,750 --> 00:19:20,980
likely the formation of Jupiter at a

378
00:19:29,080 --> 00:19:25,760
very early time in history so here the

379
00:19:31,060 --> 00:19:29,090
axis on this plot I'm going to get to

380
00:19:34,450 --> 00:19:31,070
this a sec the exes on this plot is in

381
00:19:37,570 --> 00:19:34,460
time after CIA formation and CCAI

382
00:19:39,730 --> 00:19:37,580
formation is calcium aluminum inclusions

383
00:19:42,100 --> 00:19:39,740
which you find in chondrules which are

384
00:19:45,430 --> 00:19:42,110
the very first solar system solids so

385
00:19:46,510 --> 00:19:45,440
let's just take that as time zero you

386
00:19:49,419 --> 00:19:46,520
don't have to understand what they are

387
00:19:51,250 --> 00:19:49,429
and how they form just that when you

388
00:19:53,620 --> 00:19:51,260

find these in Iraq and you date them

389
00:19:56,500 --> 00:19:53,630
they have a specific age that's the age

390
00:19:59,440 --> 00:19:56,510
of the beginning of formation of bodies

391
00:20:00,330 --> 00:19:59,450
in the solar system and what we find is

392
00:20:03,210 --> 00:20:00,340
that

393
00:20:06,450 --> 00:20:03,220
the very first objects because they had

394
00:20:09,300 --> 00:20:06,460
the most aluminum-26 which was

395
00:20:12,690 --> 00:20:09,310
generating a lot of heat those early

396
00:20:20,120 --> 00:20:12,700
forming planetesimals all melted and

397
00:20:22,800 --> 00:20:20,130
formed iron cores so that led to the

398
00:20:26,250 --> 00:20:22,810
when they when these when these objects

399
00:20:29,970 --> 00:20:26,260
were disrupted they were smashed up then

400
00:20:31,860 --> 00:20:29,980
the iron became chunks and eventually

401
00:20:35,040 --> 00:20:31,870
some of those chunks fell to earth as

402
00:20:36,570 --> 00:20:35,050
meteorites and so we have all of these

403
00:20:40,410 --> 00:20:36,580
different classes of meteorites that

404
00:20:43,950 --> 00:20:40,420
have very non original names of you know

405
00:20:47,790 --> 00:20:43,960
one two three ABCD you know things like

406
00:20:51,120 --> 00:20:47,800
that but it's recognized now that these

407
00:20:54,750 --> 00:20:51,130
form two distinct groups and one are

408
00:20:58,860 --> 00:20:54,760
associated with non carbonaceous bodies

409
00:21:02,460 --> 00:20:58,870
so carbonaceous another word that me

410
00:21:05,640 --> 00:21:02,470
that you'll need to understand means is

411
00:21:08,460 --> 00:21:05,650
it stands in four light elements like

412
00:21:10,770 --> 00:21:08,470
carbon hydrogen oxygen nitrogen all of

413
00:21:13,440 --> 00:21:10,780

these so-called volatile elements the

414
00:21:15,630 --> 00:21:13,450
things that are easily lost because

415
00:21:19,260 --> 00:21:15,640
they're light and they're they're

416
00:21:21,810 --> 00:21:19,270
volatile and so we find there's a group

417
00:21:24,600 --> 00:21:21,820
that is associated with non Carbonite

418
00:21:26,760 --> 00:21:24,610
carbonaceous meteorites and a group

419
00:21:29,340 --> 00:21:26,770
that's associated with carbonaceous iron

420
00:21:33,030 --> 00:21:29,350
meteorites and they're very different in

421
00:21:35,160 --> 00:21:33,040
their isotopic ratios of certain

422
00:21:38,550 --> 00:21:35,170
elements this is tungsten and you don't

423
00:21:40,200 --> 00:21:38,560
need to know the details of that just

424
00:21:43,230 --> 00:21:40,210
that there are these two separate groups

425
00:21:47,010 --> 00:21:43,240
so we know that early on in solar system

426
00:21:49,410 --> 00:21:47,020
history the really really first steps we

427
00:21:52,260 --> 00:21:49,420
had some sort of a boundary some sort of

428
00:21:56,760 --> 00:21:52,270
a separation of reservoirs so we call

429
00:21:59,120 --> 00:21:56,770
these these area these regions where

430
00:22:03,750 --> 00:21:59,130
material is coalescing to form

431
00:22:05,610 --> 00:22:03,760
individual bodies a reservoir and so we

432
00:22:08,070 --> 00:22:05,620
have these carbonaceous and non

433
00:22:12,150 --> 00:22:08,080
carbonaceous iron meteorite reservoirs

434
00:22:14,010 --> 00:22:12,160
so at time 0 we can see that we had

435
00:22:16,890 --> 00:22:14,020
mainly these non carbonaceous are

436
00:22:19,770 --> 00:22:16,900
rights and that means formation and a

437
00:22:23,880 --> 00:22:19,780
hotter environment so formation closer

438
00:22:26,310 --> 00:22:23,890

to the protostar the protosun and as

439
00:22:28,980 --> 00:22:26,320
time went on you can see this is time on

440
00:22:33,770 --> 00:22:28,990
the axis here the carbonaceous iron

441
00:22:37,020 --> 00:22:33,780
meteorites formed a little bit later and

442
00:22:39,030 --> 00:22:37,030
the explanation for this and then going

443
00:22:42,390 --> 00:22:39,040
farther up there's also then the the

444
00:22:44,820 --> 00:22:42,400
follow-on bodies the chondrites that are

445
00:22:47,760 --> 00:22:44,830
the not the iron me rights but the

446
00:22:51,390 --> 00:22:47,770
actual stony parts of these bodies and

447
00:22:53,490 --> 00:22:51,400
you see that that by by the time of

448
00:22:55,680 --> 00:22:53,500
three to four million years after ca

449
00:23:00,570 --> 00:22:55,690
eyes there were these two distinct

450
00:23:03,780 --> 00:23:00,580
populations of bodies forming so what we

451
00:23:06,180 --> 00:23:03,790
now understand or the leading hypothesis

452
00:23:08,070 --> 00:23:06,190
is that Jupiter formed up to about 20

453
00:23:11,520 --> 00:23:08,080
Matt earth masses the core of Jupiter

454
00:23:13,830 --> 00:23:11,530
formed at about 1 million year past ca

455
00:23:16,740 --> 00:23:13,840
eyes and then it kept growing its

456
00:23:18,600 --> 00:23:16,750
gaseous envelope until about 4 million

457
00:23:21,270 --> 00:23:18,610
years and separating these two

458
00:23:23,940 --> 00:23:21,280
reservoirs so you might ask ok why is

459
00:23:26,760 --> 00:23:23,950
that important well the water is out

460
00:23:29,790 --> 00:23:26,770
here and the terrestrial planets are

461
00:23:32,520 --> 00:23:29,800
forming in here so it's already telling

462
00:23:33,900 --> 00:23:32,530
you that we've lost

463
00:23:37,410 --> 00:23:33,910

you know we've lost communication

464
00:23:40,140 --> 00:23:37,420
between the very volatile rich material

465
00:23:42,120 --> 00:23:40,150
and and where our planet our terrestrial

466
00:23:43,650 --> 00:23:42,130
planets are forming so we're going to

467
00:23:46,500 --> 00:23:43,660
take a look at the mission results from

468
00:23:49,050 --> 00:23:46,510
Dawn and and find out what we learned

469
00:23:53,310 --> 00:23:49,060
more specifically about some of these

470
00:23:56,790 --> 00:23:53,320
processes that were occurring so Dawn

471
00:24:00,900 --> 00:23:56,800
was a fantastic mission propelled by an

472
00:24:05,760 --> 00:24:00,910
ion engine that went out into the main

473
00:24:08,280 --> 00:24:05,770
belt and visited two asteroids but two

474
00:24:10,550 --> 00:24:08,290
bodies one is the giant asteroid Vesta

475
00:24:15,770 --> 00:24:10,560
and the other is a dwarf planet Ceres

476
00:24:21,330 --> 00:24:15,780
and it's it did this over the course of

477
00:24:24,000 --> 00:24:21,340
an 11-year mission and what broke many

478
00:24:27,299 --> 00:24:24,010
records for longest powered flight and

479
00:24:29,460 --> 00:24:27,309
and certainly first to do any

480
00:24:33,330 --> 00:24:29,470
objects in the main belt much less going

481
00:24:35,279 --> 00:24:33,340
into orbit around to Dawn's targets then

482
00:24:37,080 --> 00:24:35,289
we're invested in series and these are

483
00:24:39,210 --> 00:24:37,090
the two most massive objects in the main

484
00:24:43,320 --> 00:24:39,220
asteroid belt and so I will get right

485
00:24:45,119 --> 00:24:43,330
into telling you about them so this is

486
00:24:48,600 --> 00:24:45,129
this should just be review for you by

487
00:24:51,539 --> 00:24:48,610
now because I've gone through this ad

488
00:24:53,220 --> 00:24:51,549

nauseam but these two bodies are

489
00:24:57,389 --> 00:24:53,230
survivors from the earliest epoch of

490
00:25:00,299 --> 00:24:57,399
solar system history and we were aiming

491
00:25:03,690 --> 00:25:00,309
to investigate the role of size and

492
00:25:05,820 --> 00:25:03,700
accretion time in their differentiation

493
00:25:10,409 --> 00:25:05,830
and interior evolution history

494
00:25:13,409 --> 00:25:10,419
now the word differentiation means there

495
00:25:16,560 --> 00:25:13,419
are different layers so you've got an

496
00:25:18,419 --> 00:25:16,570
iron core a body that's homogeneous will

497
00:25:21,509 --> 00:25:18,429
and when it melts the iron will go to

498
00:25:25,710 --> 00:25:21,519
the center it's heavy it sinks then

499
00:25:28,769 --> 00:25:25,720
you'll get a more dense mantle made of

500
00:25:31,109 --> 00:25:28,779
things like olivine and finally the

501
00:25:34,739 --> 00:25:31,119
lighter basaltic crust and that's kind

502
00:25:37,529 --> 00:25:34,749
of a layer cake classic differentiation

503
00:25:39,840 --> 00:25:37,539
series differentiation

504
00:25:42,690 --> 00:25:39,850
also just means any separation of

505
00:25:45,480 --> 00:25:42,700
materials that were initially you know

506
00:25:47,070 --> 00:25:45,490
intimately mixed and so we'll see in the

507
00:25:49,889 --> 00:25:47,080
case of series differentiation means

508
00:25:54,359 --> 00:25:49,899
something different but we're going to

509
00:25:56,700 --> 00:25:54,369
look at then why two bodies that appear

510
00:25:58,980 --> 00:25:56,710
to be close together or are close

511
00:26:01,350 --> 00:25:58,990
together now and appear to maybe have

512
00:26:06,239 --> 00:26:01,360
formed closely in time turned out so

513
00:26:08,190 --> 00:26:06,249

differently and then also we want to see

514
00:26:11,070 --> 00:26:08,200
the effects of impact processes because

515
00:26:14,970 --> 00:26:11,080
as you recall if stuff is really flying

516
00:26:17,820 --> 00:26:14,980
all around crazily during these dynamic

517
00:26:20,850 --> 00:26:17,830
scattering events that has some

518
00:26:26,009 --> 00:26:20,860
implications for the bodies that get hit

519
00:26:30,029 --> 00:26:26,019
so where our series invest located they

520
00:26:32,730 --> 00:26:30,039
are in the main asteroid belt and Vesta

521
00:26:35,580 --> 00:26:32,740
is if so here we are looking plan view

522
00:26:39,379 --> 00:26:35,590
you know down on the the plane of the

523
00:26:40,800 --> 00:26:39,389
solar system and here we're looking

524
00:26:45,690 --> 00:26:40,810
across

525
00:26:49,800 --> 00:26:45,700
so 1.5 au is the orbit of Mars and then

526
00:26:52,380 --> 00:26:49,810
5 au is the orbit of Jupiter so in the

527
00:26:55,920 --> 00:26:52,390
the main belt there are clumps and each

528
00:26:59,520 --> 00:26:55,930
of these like notches is a residence of

529
00:27:01,590 --> 00:26:59,530
Jupiter's gravity field so again that

530
00:27:04,890 --> 00:27:01,600
that's a place where nothing can live

531
00:27:08,450 --> 00:27:04,900
because it's being moved out of the way

532
00:27:12,090 --> 00:27:08,460
by Jupiter and what happens with Vesta

533
00:27:15,830 --> 00:27:12,100
which is roughly in this area is it it's

534
00:27:18,780 --> 00:27:15,840
so close to to a major residence that

535
00:27:20,760 --> 00:27:18,790
material small small pieces of Vesta

536
00:27:24,510 --> 00:27:20,770
that were excavated from the surface

537
00:27:26,460 --> 00:27:24,520
during impacts are would move into these

538
00:27:29,340 --> 00:27:26,470

residences because of they were light

539
00:27:32,010 --> 00:27:29,350
enough and then that would send the

540
00:27:34,860 --> 00:27:32,020
material on an earth crossing orbit so

541
00:27:38,280 --> 00:27:34,870
there's like a superhighway to send

542
00:27:40,440 --> 00:27:38,290
pieces of Vesta to the earth and as a

543
00:27:43,380 --> 00:27:40,450
consequence we have a lot of pieces of

544
00:27:47,030 --> 00:27:43,390
Vesta meteorites and I brought one of

545
00:27:51,120 --> 00:27:47,040
them with me today so this is a Ukraine

546
00:27:53,790 --> 00:27:51,130
and it's a piece of the crust of Vesta a

547
00:27:55,590 --> 00:27:53,800
Ukraine is like a basalt on the earth

548
00:27:58,890 --> 00:27:55,600
this is a little bit lighter than you

549
00:28:00,570 --> 00:27:58,900
would think about with basalt but on

550
00:28:05,340 --> 00:28:00,580
Vesta that's what it looks like

551
00:28:12,120 --> 00:28:05,350
so that'll play into the story a little

552
00:28:15,480 --> 00:28:12,130
bit later so let's just look at these

553
00:28:17,280 --> 00:28:15,490
two objects in size context because we

554
00:28:18,930 --> 00:28:17,290
hear a lot about emissions going to

555
00:28:21,020 --> 00:28:18,940
asteroids we know that a lot of

556
00:28:23,580 --> 00:28:21,030
spacecraft have visited asteroids and

557
00:28:25,560 --> 00:28:23,590
these are the asteroids that have been

558
00:28:28,110 --> 00:28:25,570
visited by spacecraft and some of them

559
00:28:33,270 --> 00:28:28,120
are so small that you can't see them on

560
00:28:36,390 --> 00:28:33,280
this on this slide and this doesn't have

561
00:28:39,930 --> 00:28:36,400
the most recent two which are been new

562
00:28:43,830 --> 00:28:39,940
and ryugu but they would be they would

563
00:28:46,080 --> 00:28:43,840

be in this size fraction as well so you

564
00:28:48,690 --> 00:28:46,090
know the differences of Vesta is a

565
00:28:51,750 --> 00:28:48,700
planetesimal a protoplanet a small world

566
00:28:53,550 --> 00:28:51,760
as we call it and it's undergone

567
00:28:55,620 --> 00:28:53,560
planetary processes and it

568
00:28:58,950 --> 00:28:55,630
Pearse to be intact from the time it

569
00:29:01,500 --> 00:28:58,960
formed at that various early epoch of

570
00:29:03,540 --> 00:29:01,510
the solar system and as such it

571
00:29:06,030 --> 00:29:03,550
literally is a little time capsule or

572
00:29:08,250 --> 00:29:06,040
fossil and so you know we can

573
00:29:08,910 --> 00:29:08,260
interrogate it and find out what it has

574
00:29:13,860 --> 00:29:08,920
to tell us

575
00:29:16,320 --> 00:29:13,870
and then series on the other hand is is

576
00:29:20,280 --> 00:29:16,330
a full-blown dwarf planet it's a

577
00:29:22,410 --> 00:29:20,290
thousand kilometers in diameter it you

578
00:29:26,340 --> 00:29:22,420
know it's has a gravitationally relaxed

579
00:29:29,840 --> 00:29:26,350
shape meaning it's its own rotation kind

580
00:29:34,740 --> 00:29:29,850
of smooth its shape into a a nice

581
00:29:38,100 --> 00:29:34,750
spheroid so these two guys are are very

582
00:29:41,520 --> 00:29:38,110
special and that's why they were the

583
00:29:43,770 --> 00:29:41,530
targets of our mission and then if we

584
00:29:46,050 --> 00:29:43,780
look at them compared to the moon you

585
00:29:48,240 --> 00:29:46,060
can see that they aren't they really

586
00:29:52,290 --> 00:29:48,250
aren't small objects these are like

587
00:29:56,700 --> 00:29:52,300
really planetary scale bodies and an

588
00:29:59,760 --> 00:29:56,710

important fact ID is that together they

589
00:30:03,600 --> 00:29:59,770
make up 45 percent of the mass of the

590
00:30:05,100 --> 00:30:03,610
entire main asteroid belt so I'll just

591
00:30:08,520 --> 00:30:05,110
keep going back to remember that mass a

592
00:30:12,540 --> 00:30:08,530
doughnut of stuff that you saw these two

593
00:30:17,700 --> 00:30:12,550
are the big swingers they're the they're

594
00:30:19,620 --> 00:30:17,710
the king and the queen okay so

595
00:30:22,710 --> 00:30:19,630
meteorites from Vesta I already told you

596
00:30:28,220 --> 00:30:22,720
that we have a lot of them and as it

597
00:30:32,520 --> 00:30:28,230
turns out Vesta has a extremely specific

598
00:30:36,390 --> 00:30:32,530
reflectance spectrum in visible and IR

599
00:30:39,810 --> 00:30:36,400
light so when the Sun hits Vesta and you

600
00:30:42,330 --> 00:30:39,820
look at it through a telescope then you

601
00:30:44,760 --> 00:30:42,340
see specific absorptions of that solar

602
00:30:47,070 --> 00:30:44,770
spectrum which are related to the

603
00:30:49,470 --> 00:30:47,080
minerals on the surface and there are

604
00:30:51,270 --> 00:30:49,480
these two here at what we call the one

605
00:30:53,730 --> 00:30:51,280
micron band and the two micron band and

606
00:30:59,100 --> 00:30:53,740
all you need to know is that these two

607
00:31:02,310 --> 00:30:59,110
are very diagnostic of Vesta and if you

608
00:31:05,580 --> 00:31:02,320
look at spectra of lots and lots of

609
00:31:06,810 --> 00:31:05,590
other bodies you don't find that kind of

610
00:31:09,270 --> 00:31:06,820
a fingerprint

611
00:31:12,480 --> 00:31:09,280
on others now there there are a couple

612
00:31:16,260 --> 00:31:12,490
way out in the outer belt that have some

613
00:31:19,490 --> 00:31:16,270

similarities to the best in spectrum but

614
00:31:23,000 --> 00:31:19,500
they're not as great a match is this and

615
00:31:25,650 --> 00:31:23,010
here what happened was we had all these

616
00:31:28,170 --> 00:31:25,660
HED meteorites which are the Howard I

617
00:31:29,550 --> 00:31:28,180
you cried ionized series they've been

618
00:31:31,530 --> 00:31:29,560
studied in the lab they'd been

619
00:31:33,810 --> 00:31:31,540
recognized that they belonged together

620
00:31:38,280 --> 00:31:33,820
they were a sequence of quote you know

621
00:31:41,550 --> 00:31:38,290
kind of the mantle which is the the the

622
00:31:43,760 --> 00:31:41,560
die at night the slower cooled more

623
00:31:47,160 --> 00:31:43,770
crystalline materials that cooled

624
00:31:49,290 --> 00:31:47,170
interior to the small planet then you

625
00:31:53,910 --> 00:31:49,300
had the u k-- right much faster quenched

626
00:31:56,190 --> 00:31:53,920
so like a an extrusive lava and then you

627
00:31:59,310 --> 00:31:56,200
had howard ight which is just too broken

628
00:32:01,740 --> 00:31:59,320
up fragments the breccia of impact

629
00:32:04,110 --> 00:32:01,750
processes on the surface so this thing's

630
00:32:05,910 --> 00:32:04,120
been battered over 4.5 billion years and

631
00:32:09,240 --> 00:32:05,920
so it's you know things have ground up

632
00:32:11,940 --> 00:32:09,250
into this melange and that's what a

633
00:32:14,700 --> 00:32:11,950
howard ID is so they were called the heg

634
00:32:16,740 --> 00:32:14,710
series they were studied in the lab here

635
00:32:21,060 --> 00:32:16,750
you see a u k-- right spectrum imagine

636
00:32:24,960 --> 00:32:21,070
spectrum and in the late sixties spurred

637
00:32:27,450 --> 00:32:24,970
by the apollo missions some of my

638
00:32:30,410 --> 00:32:27,460

colleagues Tom McCord and particularly

639
00:32:35,040 --> 00:32:30,420
the first planetary science graduate

640
00:32:37,820 --> 00:32:35,050
from the Caltech Department decided to

641
00:32:40,320 --> 00:32:37,830
look at two trained telescopes on

642
00:32:43,610 --> 00:32:40,330
different objects and try to make

643
00:32:47,310 --> 00:32:43,620
matches to spectra in laboratory

644
00:32:49,830 --> 00:32:47,320
meteorites but specimens and it didn't

645
00:32:52,020 --> 00:32:49,840
take them long to make this match to

646
00:32:54,720 --> 00:32:52,030
Vesta and it was a it was a confident

647
00:32:58,650 --> 00:32:54,730
match there was no question that Vesta

648
00:33:01,350 --> 00:32:58,660
was the parent body of the Aichi DS and

649
00:33:03,930 --> 00:33:01,360
they had a big project set up to keep

650
00:33:08,640 --> 00:33:03,940
doing this and they didn't have any more

651
00:33:11,310 --> 00:33:08,650
success and and that goes to prove the

652
00:33:14,700 --> 00:33:11,320
point that Vesta is a unique object and

653
00:33:19,770 --> 00:33:14,710
that many of the objects in the main

654
00:33:20,580 --> 00:33:19,780
belt are more generically you know more

655
00:33:23,369 --> 00:33:20,590
generic and

656
00:33:25,919 --> 00:33:23,379
and don't have these very specific

657
00:33:28,710 --> 00:33:25,929
characteristics which tell us which

658
00:33:32,249 --> 00:33:28,720
rocks come from them so that made this

659
00:33:35,700 --> 00:33:32,259
an extra-special object okay so I need

660
00:33:37,759 --> 00:33:35,710
to move along here this is just to give

661
00:33:41,610 --> 00:33:37,769
you a comparison of Vesta and Ceres

662
00:33:43,619 --> 00:33:41,620
Vesta is quite dense it's more like the

663
00:33:47,100 --> 00:33:43,629

density of basalt as I've been telling

664
00:33:51,230 --> 00:33:47,110
you it's also this is 530 kilometers in

665
00:33:57,899 --> 00:33:51,240
diameter and it's got 40 kilometer

666
00:34:01,799 --> 00:33:57,909
topography 40 kilometers so just this

667
00:34:03,659 --> 00:34:01,809
this bump at the bottom here which is

668
00:34:06,210 --> 00:34:03,669
inside of a crater that's bigger than

669
00:34:09,180 --> 00:34:06,220
Mount Everest in terms of you know going

670
00:34:13,050 --> 00:34:09,190
from the bottom of the ocean to the top

671
00:34:16,409 --> 00:34:13,060
so this is a very rugged planet Ceres on

672
00:34:19,050 --> 00:34:16,419
the other hand bigger 940 kilometers in

673
00:34:20,909 --> 00:34:19,060
diameter you see the density is much

674
00:34:24,059 --> 00:34:20,919
less because it's retained a lot of its

675
00:34:26,280 --> 00:34:24,069
water and and that's a key to

676
00:34:29,010 --> 00:34:26,290
understanding the different evolution of

677
00:34:30,720 --> 00:34:29,020
these two bodies and it has less relief

678
00:34:32,520 --> 00:34:30,730
but it's still you can still see craters

679
00:34:34,230 --> 00:34:32,530
and you can see it has Highlands and

680
00:34:36,240 --> 00:34:34,240
lowlands and and that was somewhat of a

681
00:34:40,409 --> 00:34:36,250
surprise to us because we did know it

682
00:34:43,559 --> 00:34:40,419
had a lot of water from telescope shape

683
00:34:45,510 --> 00:34:43,569
measurements showing that it had this

684
00:34:47,609 --> 00:34:45,520
kind of relaxed shape but we didn't

685
00:34:50,730 --> 00:34:47,619
expect that the surface was strong

686
00:34:52,770 --> 00:34:50,740
enough to maintain topography we thought

687
00:34:54,899 --> 00:34:52,780
it was much more like ice that would

688
00:34:56,940 --> 00:34:54,909

flow easily and it might look like a

689
00:34:58,500 --> 00:34:56,950
bowling ball that was my my worst

690
00:35:00,359 --> 00:34:58,510
nightmare is that we're gonna get there

691
00:35:01,230 --> 00:35:00,369
and the body was going to look kind of

692
00:35:02,910 --> 00:35:01,240
like a bowling ball

693
00:35:05,550 --> 00:35:02,920
and then we'll just trying to like

694
00:35:07,710 --> 00:35:05,560
figure out from these little like clues

695
00:35:11,430 --> 00:35:07,720
on the surface what was going on that

696
00:35:12,410 --> 00:35:11,440
was not the case okay so what did we

697
00:35:15,630 --> 00:35:12,420
learn

698
00:35:17,670 --> 00:35:15,640
first we we knew that Vesta from the

699
00:35:18,690 --> 00:35:17,680
meteorites we knew it was the HTTP

700
00:35:21,270 --> 00:35:18,700
embody we knew it was fully

701
00:35:23,069 --> 00:35:21,280
differentiated to an iron core and we

702
00:35:24,480 --> 00:35:23,079
knew was a volatile pour and it boiled

703
00:35:28,589 --> 00:35:24,490
off a lot of its water and other

704
00:35:30,930 --> 00:35:28,599
volatiles and what we learned from

705
00:35:34,080 --> 00:35:30,940
looking at the elemental abundances from

706
00:35:35,700 --> 00:35:34,090
looking at the detailed mineralogy and

707
00:35:36,960 --> 00:35:35,710
and using gravity and topography to

708
00:35:39,990 --> 00:35:36,970
understand what was going on in the

709
00:35:42,930 --> 00:35:40,000
center in the interior we understand

710
00:35:47,220 --> 00:35:42,940
that it formed from already volatile

711
00:35:48,930 --> 00:35:47,230
depleted material so that in the nebula

712
00:35:51,150 --> 00:35:48,940
at the time this was forming which was

713
00:35:54,120 --> 00:35:51,160

very very early in the in the like

714
00:35:55,710 --> 00:35:54,130
million year range already the nebula

715
00:35:59,990 --> 00:35:55,720
had lost a lot of its volatile and

716
00:36:03,000 --> 00:36:00,000
that's a key observation and it also

717
00:36:04,410 --> 00:36:03,010
accreted impact delivered volatile rich

718
00:36:07,560 --> 00:36:04,420
material and you're going to see some

719
00:36:10,020 --> 00:36:07,570
evidence of that at Ceres we confirmed

720
00:36:12,210 --> 00:36:10,030
that it is volatile rich it is partially

721
00:36:15,380 --> 00:36:12,220
differentiated it did not form an iron

722
00:36:18,840 --> 00:36:15,390
core and experienced global aqueous

723
00:36:21,090 --> 00:36:18,850
alteration so what that means is you've

724
00:36:23,880 --> 00:36:21,100
heard of hydrothermal vents on the ocean

725
00:36:26,250 --> 00:36:23,890
floor and I think everybody's familiar

726
00:36:29,100 --> 00:36:26,260
with the fact that the hot water will

727
00:36:31,500 --> 00:36:29,110
circulate through cracks in the the sea

728
00:36:34,890 --> 00:36:31,510
floor or cracks and in any kind of rock

729
00:36:36,900 --> 00:36:34,900
that that has hot water going through it

730
00:36:39,780 --> 00:36:36,910
and that hot water reacts with the rocks

731
00:36:42,600 --> 00:36:39,790
and it alters the minerals and that

732
00:36:46,200 --> 00:36:42,610
alteration creates hydrated silicates

733
00:36:50,310 --> 00:36:46,210
which are like clays and it also changes

734
00:36:52,020 --> 00:36:50,320
the chemistry and we found abundant

735
00:36:55,830 --> 00:36:52,030
evidence for this process having

736
00:36:58,820 --> 00:36:55,840
occurred globally over a series we'll

737
00:37:04,890 --> 00:36:58,830
talk about that oops sorry

738
00:37:06,690 --> 00:37:04,900

so what we thought this was are going in

739
00:37:10,320 --> 00:37:06,700
on Ceres we thought these things would

740
00:37:12,840 --> 00:37:10,330
be true but what we learned was really

741
00:37:15,540 --> 00:37:12,850
so much more interesting than that

742
00:37:17,880 --> 00:37:15,550
that's the series is nitrogen rich and

743
00:37:23,810 --> 00:37:17,890
nitrogen is one of those super volatiles

744
00:37:27,540 --> 00:37:23,820
it it goes away with when things heat up

745
00:37:29,250 --> 00:37:27,550
very quickly so it's really stable only

746
00:37:32,700 --> 00:37:29,260
in the outer reaches of the solar system

747
00:37:36,000 --> 00:37:32,710
not where Ceres is now so that is a clue

748
00:37:39,630 --> 00:37:36,010
that series did not form and sit you and

749
00:37:42,630 --> 00:37:39,640
we'll talk about that it's similar but

750
00:37:46,560 --> 00:37:42,640
not a match to an altered carbonaceous

751
00:37:47,910 --> 00:37:46,570
chondrite and really surprisingly has

752
00:38:01,259 --> 00:37:47,920
ongoing grinder

753
00:38:08,190 --> 00:38:01,269
and geologic activity okay sometimes

754
00:38:13,019 --> 00:38:08,200
this gets a little bit flaky okay it

755
00:38:17,400 --> 00:38:13,029
woke up yeah okay so quickly go through

756
00:38:20,039 --> 00:38:17,410
a few of the results and and why they

757
00:38:24,390 --> 00:38:20,049
were important to the overall story so

758
00:38:26,910 --> 00:38:24,400
when as I said we we confirmed the Vesta

759
00:38:32,400 --> 00:38:26,920
was the parent body of the Aedes that

760
00:38:34,799 --> 00:38:32,410
was both satisfying that and hypothesis

761
00:38:37,859 --> 00:38:34,809
had been advanced based on ground-based

762
00:38:40,589 --> 00:38:37,869
data from telescopes based on study of

763
00:38:44,370 --> 00:38:40,599

these rocks we went there and we checked

764
00:38:47,430 --> 00:38:44,380
the box and said it was correct also

765
00:38:50,730 --> 00:38:47,440
though from the meteorites geochemists

766
00:38:54,170 --> 00:38:50,740
had done models that looked at how much

767
00:38:57,240 --> 00:38:54,180
metal was missing from the the basalts

768
00:38:59,640 --> 00:38:57,250
which meant that from from the stuff

769
00:39:01,950 --> 00:38:59,650
that best secreted from the metal had

770
00:39:04,319 --> 00:39:01,960
gone somewhere and from that they could

771
00:39:07,230 --> 00:39:04,329
judge that it had an iron core so they

772
00:39:09,900 --> 00:39:07,240
we didn't have the iron meteorites from

773
00:39:12,359 --> 00:39:09,910
Vesta we had the you know the crust and

774
00:39:14,549 --> 00:39:12,369
we had part of the mantle but we didn't

775
00:39:16,109 --> 00:39:14,559
have the court but you could imply you

776
00:39:18,329 --> 00:39:16,119
can infer that there was a core of a

777
00:39:21,690 --> 00:39:18,339
certain size based on the what was left

778
00:39:24,900 --> 00:39:21,700
in the rocks and what we found from our

779
00:39:27,329 --> 00:39:24,910
gravity measurements is a core of almost

780
00:39:29,940 --> 00:39:27,339
exactly the size inferred from those

781
00:39:36,660 --> 00:39:29,950
models so again that was a another very

782
00:39:38,910 --> 00:39:36,670
satisfying results and I'll just point

783
00:39:42,599 --> 00:39:38,920
out that the the radius of that core so

784
00:39:44,460 --> 00:39:42,609
the radius of Vesta right Otis 530

785
00:39:50,009 --> 00:39:44,470
kilometers in diameter

786
00:39:54,180 --> 00:39:50,019
it's about 330 miles but that's 265

787
00:39:56,099 --> 00:39:54,190
kilometers radius this core is about 110

788
00:39:59,430 --> 00:39:56,109

kilometers in radius so it's a very

789
00:40:01,529 --> 00:39:59,440
substantial fraction of Vesta it's a

790
00:40:04,559 --> 00:40:01,539
large core

791
00:40:07,289 --> 00:40:04,569
now what we didn't expect and really had

792
00:40:09,509 --> 00:40:07,299
a hard time not a hard time explaining

793
00:40:11,939 --> 00:40:09,519
but had a lot of fun trying to figure

794
00:40:14,429 --> 00:40:11,949
out what was going on was that there's a

795
00:40:16,979 --> 00:40:14,439
big splotch of hydrated material on

796
00:40:19,229 --> 00:40:16,989
Vesta so remember I told you it melted

797
00:40:24,379 --> 00:40:19,239
it formed a core it boiled off its

798
00:40:27,089 --> 00:40:24,389
volatile in fact we expected that it was

799
00:40:29,629 --> 00:40:27,099
drier than the moon because at least the

800
00:40:33,749 --> 00:40:29,639
moon has the solar wind bringing protons

801
00:40:35,999 --> 00:40:33,759
you know and implanting some material on

802
00:40:39,569 --> 00:40:36,009
its surface kind of a steady stream of a

803
00:40:42,509 --> 00:40:39,579
low-level hydration but Vestas too far

804
00:40:46,199 --> 00:40:42,519
out for that so when we found this spot

805
00:40:48,839 --> 00:40:46,209
of hydrogen from our gamma ray Neutron

806
00:40:52,679 --> 00:40:48,849
detector that that orange orangey spot

807
00:40:56,489 --> 00:40:52,689
there and we found a band depth

808
00:41:00,599 --> 00:40:56,499
indicative of hydrated minerals from the

809
00:41:03,389 --> 00:41:00,609
IR spectrometer and they coincide there

810
00:41:05,429 --> 00:41:03,399
was no question that we had hydrated

811
00:41:08,969 --> 00:41:05,439
material on the surface of Vesta and

812
00:41:10,559 --> 00:41:08,979
it's at the equator where you would

813
00:41:13,019 --> 00:41:10,569

least expect it because sometimes you

814
00:41:15,059 --> 00:41:13,029
can get hydrated you can get water and

815
00:41:18,389 --> 00:41:15,069
cold traps at poles that don't see

816
00:41:23,359 --> 00:41:18,399
sunlight but that's not the case here so

817
00:41:26,129 --> 00:41:23,369
the conclusion was that this material is

818
00:41:29,129 --> 00:41:26,139
accreted to Vesta the stuff that got

819
00:41:33,779 --> 00:41:29,139
stuck onto Vesta by impacts bringing it

820
00:41:37,529 --> 00:41:33,789
in from elsewhere and we can go back to

821
00:41:39,419 --> 00:41:37,539
the meteorites and ask did do we see any

822
00:41:42,539 --> 00:41:39,429
evidence of that and sure enough there

823
00:41:44,999 --> 00:41:42,549
it is so these dark spots in this Howard

824
00:41:48,089 --> 00:41:45,009
I remember again that's that broken up

825
00:41:51,329 --> 00:41:48,099
melange of all the junk it's the end

826
00:41:54,239 --> 00:41:51,339
product of the impact gardening process

827
00:41:57,239 --> 00:41:54,249
shows you a little class of you know

828
00:41:58,589 --> 00:41:57,249
probably you Krait and and a bunch of

829
00:42:00,719 --> 00:41:58,599
other matrix materials and then these

830
00:42:03,149 --> 00:42:00,729
dark things are class of carbonaceous

831
00:42:04,859 --> 00:42:03,159
chondrite and people saw those in the

832
00:42:07,709 --> 00:42:04,869
Howard ice for they're like yeah there's

833
00:42:09,959 --> 00:42:07,719
some class of carbonaceous chondrite not

834
00:42:12,779 --> 00:42:09,969
unexpected but what we didn't understand

835
00:42:13,609 --> 00:42:12,789
until we saw that map was it's a big

836
00:42:16,130 --> 00:42:13,619
percent

837
00:42:18,559 --> 00:42:16,140
there's a lot of material and if you

838
00:42:22,039 --> 00:42:18,569

look at the the concentration in this

839
00:42:26,329 --> 00:42:22,049
rock and you kind of add it up it makes

840
00:42:30,650 --> 00:42:26,339
sense so it it was our first sort of

841
00:42:34,190 --> 00:42:30,660
smoking gun that there's a significant

842
00:42:36,710 --> 00:42:34,200
delivery of hydrous material to the

843
00:42:45,380 --> 00:42:36,720
inner solar system via the impact

844
00:42:48,680 --> 00:42:45,390
process and that dark material shows up

845
00:42:51,410 --> 00:42:48,690
all across the surface of Vesta so not

846
00:42:55,400 --> 00:42:51,420
just we made the correspondence between

847
00:42:58,759 --> 00:42:55,410
that hydrated patch and a darker

848
00:43:01,069 --> 00:42:58,769
appearance of the surface but if you

849
00:43:05,059 --> 00:43:01,079
look everywhere on Vesta you see a lot

850
00:43:07,880 --> 00:43:05,069
of these dark and bright very you know

851
00:43:10,549 --> 00:43:07,890
dark and bright contrasts and and this

852
00:43:12,410 --> 00:43:10,559
was is just a beautiful example of how

853
00:43:14,269 --> 00:43:12,420
there's some stratigraphy in the surface

854
00:43:16,190 --> 00:43:14,279
there's some layering of this bright and

855
00:43:18,890 --> 00:43:16,200
dark material that's being excavated by

856
00:43:21,289 --> 00:43:18,900
a small crater and and this color map

857
00:43:23,329 --> 00:43:21,299
which is giving you an idea of mineral

858
00:43:25,609 --> 00:43:23,339
variations is also showing you that

859
00:43:28,670 --> 00:43:25,619
there's some some different minerals

860
00:43:32,769 --> 00:43:28,680
involved in this so Vesta turned out to

861
00:43:36,950 --> 00:43:32,779
be super interesting and and and quite

862
00:43:39,140 --> 00:43:36,960
intriguing in its geology and and that

863
00:43:42,049 --> 00:43:39,150

big surprise of the hydrated material

864
00:43:45,049 --> 00:43:42,059
led us to to look more carefully at some

865
00:43:47,719 --> 00:43:45,059
other features so here in a recent March

866
00:43:50,299 --> 00:43:47,729
a crater you can see the the layer of

867
00:43:52,729 --> 00:43:50,309
dark material cropping out here along

868
00:43:56,599 --> 00:43:52,739
the crater wall I think I would close up

869
00:43:59,599 --> 00:43:56,609
here and this native bright Vesta

870
00:44:02,749 --> 00:43:59,609
material sitting on top you can see kind

871
00:44:04,940 --> 00:44:02,759
of falling down and covering that up so

872
00:44:07,459 --> 00:44:04,950
so you know that dark material got laid

873
00:44:10,219 --> 00:44:07,469
down before that other material got laid

874
00:44:12,229 --> 00:44:10,229
on top and you can you can look at these

875
00:44:14,299 --> 00:44:12,239
so called superposition relationships

876
00:44:17,299 --> 00:44:14,309
what you know what came first what went

877
00:44:21,559 --> 00:44:17,309
on top its etc and and work out a

878
00:44:23,539 --> 00:44:21,569
history and we'll take a little tour of

879
00:44:24,950 --> 00:44:23,549
this crater and as we go around I want

880
00:44:26,779 --> 00:44:24,960
to point out a couple of other features

881
00:44:29,380 --> 00:44:26,789
that gave us

882
00:44:33,589 --> 00:44:29,390
a clue about what might be going on

883
00:44:35,929 --> 00:44:33,599
overall and that's that there are

884
00:44:38,569 --> 00:44:35,939
there's some very smooth material that

885
00:44:40,309 --> 00:44:38,579
you can see right here I'm sitting up on

886
00:44:43,279 --> 00:44:40,319
I like a bench on the side of the crater

887
00:44:45,169 --> 00:44:43,289
and then deep within the crater here

888
00:44:48,679 --> 00:44:45,179

we're gonna get a close-up in the next

889
00:44:52,339 --> 00:44:48,689
slide our so-called pits so they're

890
00:44:55,069 --> 00:44:52,349
they're like little indentations but

891
00:44:57,380 --> 00:44:55,079
they're not due to small impact craters

892
00:45:00,859 --> 00:44:57,390
because they don't have rims so they're

893
00:45:03,409 --> 00:45:00,869
just us they're just like a hole and

894
00:45:04,959 --> 00:45:03,419
then you saw the the bright and dark

895
00:45:08,719 --> 00:45:04,969
layers that I showed you previously

896
00:45:11,419 --> 00:45:08,729
cropping along here and you can also see

897
00:45:13,969 --> 00:45:11,429
just a lot of different textures to this

898
00:45:19,669 --> 00:45:13,979
crater and it's not a very circular one

899
00:45:21,439 --> 00:45:19,679
so these wallets will release pits well

900
00:45:23,719 --> 00:45:21,449
we we figured out these are volatile

901
00:45:26,539 --> 00:45:23,729
release pits and they're very analogous

902
00:45:29,329 --> 00:45:26,549
to PT trains on Mars so what we think is

903
00:45:31,489 --> 00:45:29,339
happening here and it's and we we found

904
00:45:34,939 --> 00:45:31,499
them in another small crater where you

905
00:45:38,989 --> 00:45:34,949
can see this kind of bumpy texture in

906
00:45:41,479 --> 00:45:38,999
the bottom of this crater we also found

907
00:45:44,989 --> 00:45:41,489
that associated with those pits the

908
00:45:48,259 --> 00:45:44,999
bumpy texture were these these sinuous

909
00:45:53,839 --> 00:45:48,269
gullies so some of the gullies on on

910
00:45:57,079 --> 00:45:53,849
Vesta have straight straight stree and

911
00:46:00,259 --> 00:45:57,089
that is associated with dry material

912
00:46:02,539 --> 00:46:00,269
flowing downslope but we all know that

913
00:46:05,299 --> 00:46:02,549

when water flows downslope it tends to

914
00:46:07,880 --> 00:46:05,309
meander and things you know merge

915
00:46:10,759 --> 00:46:07,890
together as they go down so called sin

916
00:46:14,809 --> 00:46:10,769
yosity and we find these sinuous gullies

917
00:46:17,679 --> 00:46:14,819
in association with the pits and even

918
00:46:20,779 --> 00:46:17,689
though it's a preposterous conclusion

919
00:46:24,229 --> 00:46:20,789
the best explanation for these gullies

920
00:46:29,269 --> 00:46:24,239
is that the water was flowing for a

921
00:46:32,809 --> 00:46:29,279
short period of time in these craters so

922
00:46:34,459 --> 00:46:32,819
yeah that was like we had to have a lot

923
00:46:38,179 --> 00:46:34,469
of discussions about you know could

924
00:46:39,240 --> 00:46:38,189
could that even be happening so so

925
00:46:41,730 --> 00:46:39,250
here's um

926
00:46:44,940 --> 00:46:41,740
cartoon that I'll end with for Vesta

927
00:46:48,080 --> 00:46:44,950
that kind of summarizes the importance

928
00:46:51,570 --> 00:46:48,090
of you know going to this body and and

929
00:46:55,590 --> 00:46:51,580
investigating it in in some depth and

930
00:46:58,380 --> 00:46:55,600
and really bringing it all home too how

931
00:47:00,330 --> 00:46:58,390
do how were how was what processes and

932
00:47:02,670 --> 00:47:00,340
those were operating the solar system

933
00:47:04,230 --> 00:47:02,680
during his formation and evolution so we

934
00:47:06,450 --> 00:47:04,240
think what happened is that you know

935
00:47:10,100 --> 00:47:06,460
Vesta formed and had this pre-existing

936
00:47:14,820 --> 00:47:10,110
surface and ice rich bodies pelted it

937
00:47:17,120 --> 00:47:14,830
that ice was buried in the subsurface it

938
00:47:19,440 --> 00:47:17,130

may have been liquid and then it froze

939
00:47:24,690 --> 00:47:19,450
and as soon as you put just the

940
00:47:30,720 --> 00:47:24,700
slightest cover of dust on ice it can be

941
00:47:35,310 --> 00:47:30,730
stable over eons so we think that in

942
00:47:39,270 --> 00:47:35,320
this case the the ice was buried and

943
00:47:42,480 --> 00:47:39,280
then a crater occurred later on another

944
00:47:46,380 --> 00:47:42,490
impact occurred it excavated that ice

945
00:47:49,170 --> 00:47:46,390
and melted it it then flowed down the

946
00:47:51,060 --> 00:47:49,180
walls of the crater and melted the

947
00:47:53,060 --> 00:47:51,070
transient reservoir beneath and then

948
00:47:55,620 --> 00:47:53,070
that material

949
00:47:56,880 --> 00:47:55,630
exhaled it swallowed tools and it was

950
00:48:01,800 --> 00:47:56,890
released through these little pits

951
00:48:03,690 --> 00:48:01,810
so we now again have that evidence that

952
00:48:06,530 --> 00:48:03,700
not only did the this false alert

953
00:48:09,090 --> 00:48:06,540
material get delivered to Vesta this dry

954
00:48:11,570 --> 00:48:09,100
differentiated body but it also seems to

955
00:48:14,430 --> 00:48:11,580
have been able to sequester it and

956
00:48:17,040 --> 00:48:14,440
reactivate it through the impact process

957
00:48:20,130 --> 00:48:17,050
to form these little reservoirs and that

958
00:48:24,540 --> 00:48:20,140
was just a hugely interesting and

959
00:48:26,460 --> 00:48:24,550
unexpected result so we will leave Vesto

960
00:48:28,470 --> 00:48:26,470
with this question did C type bodies

961
00:48:35,490 --> 00:48:28,480
deliver water to earth like they

962
00:48:38,730 --> 00:48:35,500
possibly did to Vesta okay well Ceres is

963
00:48:42,300 --> 00:48:38,740

like a sea type body I told you similar

964
00:48:45,570 --> 00:48:42,310
to a CI chondrite it formed from

965
00:48:47,610 --> 00:48:45,580
abundant volatile material and the

966
00:48:49,440 --> 00:48:47,620
presence of ammoniated material I told

967
00:48:51,600 --> 00:48:49,450
you was nitrogen rich the nitrogen is in

968
00:48:52,849 --> 00:48:51,610
the form of ammonia which has reacted

969
00:48:56,509 --> 00:48:52,859
with

970
00:48:59,329 --> 00:48:56,519
he rocks and formed clays which contain

971
00:49:02,239 --> 00:48:59,339
ammonia and we find those pervasively

972
00:49:05,960 --> 00:49:02,249
all over the surface so whatever process

973
00:49:08,660 --> 00:49:05,970
cooked the rock with the ammonia to make

974
00:49:11,839 --> 00:49:08,670
these clays happened everywhere pretty

975
00:49:17,210 --> 00:49:11,849
much the same and we we infer from that

976
00:49:21,410 --> 00:49:17,220
that it was a global subsurface ocean

977
00:49:25,880 --> 00:49:21,420
environment so this global alteration

978
00:49:27,650 --> 00:49:25,890
also the the presence of the water and

979
00:49:29,900 --> 00:49:27,660
the circulation of the water moderated

980
00:49:33,140 --> 00:49:29,910
the internal temperature so the fact

981
00:49:35,839 --> 00:49:33,150
that the water was there and it was the

982
00:49:38,359 --> 00:49:35,849
ice melted the water was circulating and

983
00:49:41,779 --> 00:49:38,369
it was carrying the heat out of the core

984
00:49:44,900 --> 00:49:41,789
so series did not heat up internally

985
00:49:47,479 --> 00:49:44,910
high enough to melt the silicates

986
00:49:51,680 --> 00:49:47,489
and to you know separate the metal from

987
00:49:54,019 --> 00:49:51,690
the other phases so Ceres never got to

988
00:49:56,720 --> 00:49:54,029

the same point of its evolution that

989
00:49:59,150 --> 00:49:56,730
Vesta did forming the iron core and it

990
00:50:01,249 --> 00:49:59,160
was able to retain then its water

991
00:50:05,210 --> 00:50:01,259
fraction because it didn't heat up that

992
00:50:06,799 --> 00:50:05,220
high so that was that's probably the

993
00:50:12,849 --> 00:50:06,809
biggest difference between Vesta and

994
00:50:16,519 --> 00:50:12,859
Ceres and I'll fill in a few details of

995
00:50:19,880 --> 00:50:16,529
why that's important but another major

996
00:50:24,910 --> 00:50:19,890
finding that was very important was that

997
00:50:29,210 --> 00:50:24,920
organics were detected this is inorganic

998
00:50:31,759 --> 00:50:29,220
insoluble organic matter not associated

999
00:50:33,979 --> 00:50:31,769
with biologic activity but organic

1000
00:50:36,710 --> 00:50:33,989
matter all the same it could have been

1001
00:50:39,440 --> 00:50:36,720
inherited from the proto solo and nebula

1002
00:50:42,950 --> 00:50:39,450
it could have been produced with in

1003
00:50:45,589 --> 00:50:42,960
series from from the native materials

1004
00:50:51,380 --> 00:50:45,599
but all we know is it's only in one

1005
00:50:53,299 --> 00:50:51,390
location and in general Ceres is

1006
00:50:55,729 --> 00:50:53,309
representative of a class of large

1007
00:50:58,940 --> 00:50:55,739
volatile enriched bodies that are much

1008
00:51:03,680 --> 00:50:58,950
more similar to the boons of Europa and

1009
00:51:06,380 --> 00:51:03,690
Enceladus the moon of Saturn then then

1010
00:51:08,420 --> 00:51:06,390
it is two other

1011
00:51:12,980 --> 00:51:08,430
asteroids in the main belt so it really

1012
00:51:14,960 --> 00:51:12,990
stands out as its own its own thing it's

1013
00:51:17,150 --> 00:51:14,970

a the only dwarf planet in the inner

1014
00:51:21,529 --> 00:51:17,160
solar system it's the only body that

1015
00:51:23,900 --> 00:51:21,539
looks like itself so it's it's a rock

1016
00:51:30,880 --> 00:51:27,140
it was just just a treasure trove the

1017
00:51:35,059 --> 00:51:30,890
most amazing target to go investigate

1018
00:51:38,210 --> 00:51:35,069
okay so this is in this is kind of the

1019
00:51:42,349 --> 00:51:38,220
the movie version of Ceres evolution so

1020
00:51:45,980 --> 00:51:42,359
we started out with water co2 silicates

1021
00:51:46,940 --> 00:51:45,990
and ammonia hydrates so those are all

1022
00:51:52,069 --> 00:51:46,950
your volatiles

1023
00:51:56,539 --> 00:51:52,079
and any rocks and then you began to cook

1024
00:51:58,789 --> 00:51:56,549
it and now we know because of the amount

1025
00:52:02,529 --> 00:51:58,799
of melting implied by all that

1026
00:52:05,960 --> 00:52:02,539
alteration that series had to have had a

1027
00:52:09,380 --> 00:52:05,970
significant enough amount of aluminum-26

1028
00:52:13,220 --> 00:52:09,390
to to perform that melting or to achieve

1029
00:52:15,759 --> 00:52:13,230
that much melting so that places it only

1030
00:52:18,440 --> 00:52:15,769
maybe if a million or two years

1031
00:52:22,700 --> 00:52:18,450
separated from Vesta in its accretion

1032
00:52:25,730 --> 00:52:22,710
and again when I showed you that initial

1033
00:52:28,279 --> 00:52:25,740
plot of the isotopes and the non

1034
00:52:29,870 --> 00:52:28,289
carbonaceous and the carbonaceous iron

1035
00:52:31,430 --> 00:52:29,880
meteorites you saw that there was those

1036
00:52:35,269 --> 00:52:31,440
two groups and they were separated by

1037
00:52:37,579 --> 00:52:35,279
about that same amount of time so it

1038
00:52:40,640 --> 00:52:37,589

seems like series of Vesta are kind of

1039
00:52:43,249 --> 00:52:40,650
straddling that divide created by

1040
00:52:46,309 --> 00:52:43,259
Jupiter that's implied by that that

1041
00:52:51,349 --> 00:52:46,319
model based on the iron meteorites okay

1042
00:52:54,109 --> 00:52:51,359
so back to Ceres so it heats up the ice

1043
00:52:56,269 --> 00:52:54,119
melts the mud is kind of like a muddy

1044
00:52:59,019 --> 00:52:56,279
slurry starts to convict and then

1045
00:53:02,630 --> 00:52:59,029
eventually the water makes its way

1046
00:53:07,069 --> 00:53:02,640
through the matrix and to form this this

1047
00:53:08,839 --> 00:53:07,079
nice Brian rich layer we call a

1048
00:53:12,049 --> 00:53:08,849
subsurface ocean could have been a

1049
00:53:15,410 --> 00:53:12,059
fairly muddy ocean but it had to have

1050
00:53:17,569 --> 00:53:15,420
been a global a global layer and then we

1051
00:53:19,760 --> 00:53:17,579
would have had an ice ice shell covering

1052
00:53:24,860 --> 00:53:19,770
that and in the center

1053
00:53:29,470 --> 00:53:24,870
is hydrated clay type minerals so that's

1054
00:53:33,140 --> 00:53:29,480
that was the early evolution and then

1055
00:53:35,840 --> 00:53:33,150
what happened is over time the impacts

1056
00:53:38,720 --> 00:53:35,850
will erode this icy shell anytime you

1057
00:53:41,300 --> 00:53:38,730
smash something into icy Isis at Ceres

1058
00:53:44,270 --> 00:53:41,310
it's rather warm compared to say Europa

1059
00:53:47,510 --> 00:53:44,280
or in sulla dis we're in the inner solar

1060
00:53:50,570 --> 00:53:47,520
system it's about 240 K it's a surface

1061
00:53:53,410 --> 00:53:50,580
155 below the surface whereas the

1062
00:53:56,920 --> 00:53:53,420
surface of Europe is about 70 K so

1063
00:54:01,480 --> 00:53:56,930

impacts coming in will sublimate the ice

1064
00:54:06,680 --> 00:54:01,490
excavate the ice and you're left with a

1065
00:54:11,750 --> 00:54:06,690
garden mixed crust that has ice but is

1066
00:54:14,300 --> 00:54:11,760
not pure and then where our own has

1067
00:54:18,140 --> 00:54:14,310
frozen out for the most part but we're

1068
00:54:20,990 --> 00:54:18,150
seeing evidence for at least pockets of

1069
00:54:25,820 --> 00:54:21,000
brine driving geologic activity over

1070
00:54:29,360 --> 00:54:25,830
time and this was the huge surprise at

1071
00:54:32,210 --> 00:54:29,370
Ceres because we really did not expect

1072
00:54:34,640 --> 00:54:32,220
that it had any ongoing geology and

1073
00:54:36,950 --> 00:54:34,650
that's quartz the same case as we found

1074
00:54:39,200 --> 00:54:36,960
with Pluto the New Horizons mission

1075
00:54:42,920 --> 00:54:39,210
thought that you know we're going to see

1076
00:54:46,480 --> 00:54:42,930
Pluto as this is frozen world and it is

1077
00:54:51,290 --> 00:54:46,490
very cold but there is active geology so

1078
00:54:53,060 --> 00:54:51,300
there's ample ok so the resident bright

1079
00:54:55,940 --> 00:54:53,070
separate surface and bulk elements with

1080
00:55:01,190 --> 00:54:55,950
composition differ those are mainly of

1081
00:55:03,620 --> 00:55:01,200
interest to scientists but but they're

1082
00:55:05,150 --> 00:55:03,630
important so you know the the real

1083
00:55:07,610 --> 00:55:05,160
message here though is that these are

1084
00:55:10,310 --> 00:55:07,620
these are all super interesting worlds

1085
00:55:12,590 --> 00:55:10,320
and they're you know we could we could

1086
00:55:14,660 --> 00:55:12,600
do it drive by and just you know take a

1087
00:55:16,460 --> 00:55:14,670
few pictures but going and looking at

1088
00:55:19,940 --> 00:55:16,470

them up close and and really

1089
00:55:23,000 --> 00:55:19,950
understanding them brings a an amazing

1090
00:55:25,520 --> 00:55:23,010
amount of information to bear on testing

1091
00:55:29,630 --> 00:55:25,530
a lot of the existing models and driving

1092
00:55:31,310 --> 00:55:29,640
other models forward so here's just a

1093
00:55:32,930 --> 00:55:31,320
picture to show you then what we figured

1094
00:55:33,650 --> 00:55:32,940
out the interior of Ceres looks like

1095
00:55:38,180 --> 00:55:33,660
it's actually

1096
00:55:41,779 --> 00:55:38,190
not green that's just artistic but we

1097
00:55:44,990 --> 00:55:41,789
have a crust that's this mostly it's

1098
00:55:47,210 --> 00:55:45,000
only about 30% ice it's about maybe 30%

1099
00:55:51,529 --> 00:55:47,220
rock and that it's got a lot of salt and

1100
00:55:53,960 --> 00:55:51,539
in clathrates clathrates are gas

1101
00:55:55,849 --> 00:55:53,970
hydrates so it's a water it's a cage of

1102
00:55:58,940 --> 00:55:55,859
water molecules with a gas molecule in

1103
00:56:00,319 --> 00:55:58,950
the middle it's what causes drilling

1104
00:56:02,390 --> 00:56:00,329
rigs to blow out in the Gulf of Mexico

1105
00:56:05,180 --> 00:56:02,400
when they hit it and they destabilized

1106
00:56:08,720 --> 00:56:05,190
and the gas decides to come to the

1107
00:56:10,730 --> 00:56:08,730
surface really quickly so we found that

1108
00:56:12,559 --> 00:56:10,740
a lot of that there's a lot of that it's

1109
00:56:14,240 --> 00:56:12,569
Ceres it also makes the crust really

1110
00:56:15,079 --> 00:56:14,250
strong which is why we see all those

1111
00:56:18,380 --> 00:56:15,089
craters

1112
00:56:20,799 --> 00:56:18,390
that we weren't expecting so we we now

1113
00:56:25,270 --> 00:56:20,809

know a tremendous amount about how the

1114
00:56:28,370 --> 00:56:25,280
all of the material inside of Ceres was

1115
00:56:31,339 --> 00:56:28,380
interacting that all of the the

1116
00:56:33,829 --> 00:56:31,349
individual elements the the minerals

1117
00:56:35,870 --> 00:56:33,839
that were being formed at what time and

1118
00:56:39,190 --> 00:56:35,880
what we could expect in terms of the

1119
00:56:42,859 --> 00:56:39,200
length of time the subsurface ocean was

1120
00:56:46,279 --> 00:56:42,869
operating and that indicates to us that

1121
00:56:48,289 --> 00:56:46,289
there was a good portion of hundreds of

1122
00:56:50,089 --> 00:56:48,299
millions to maybe a billion years when

1123
00:56:53,420 --> 00:56:50,099
there was a substantial amount of fluid

1124
00:56:54,230 --> 00:56:53,430
in the center of Ceres or in under the

1125
00:56:58,789 --> 00:56:54,240
surface of Ceres

1126
00:57:01,180 --> 00:56:58,799
and that coupled with its the energy

1127
00:57:05,660 --> 00:57:01,190
from the the chemical disequilibrium

1128
00:57:09,529 --> 00:57:05,670
could have provided the ingredients for

1129
00:57:12,680 --> 00:57:09,539
life so series is considered you know

1130
00:57:14,839 --> 00:57:12,690
one of those objects that has had a has

1131
00:57:17,269 --> 00:57:14,849
a potential to have been a habitable

1132
00:57:20,240 --> 00:57:17,279
environment in the past by virtue of it

1133
00:57:22,160 --> 00:57:20,250
being a frozen ocean world and it's

1134
00:57:23,990 --> 00:57:22,170
certainly one that we'll go back to at

1135
00:57:28,870 --> 00:57:24,000
some point in the future and try to

1136
00:57:32,000 --> 00:57:28,880
understand better what that potential is

1137
00:57:36,079 --> 00:57:32,010
okay and that we also know from the

1138
00:57:39,319 --> 00:57:36,089

shape the overall round shape that there

1139
00:57:41,329 --> 00:57:39,329
is this weak layer within beneath the

1140
00:57:44,029 --> 00:57:41,339
crust and we think it's where you know

1141
00:57:46,400 --> 00:57:44,039
where this line is drawn in this

1142
00:57:49,190 --> 00:57:46,410
cross-section it's likely there's a

1143
00:57:51,890 --> 00:57:49,200
thin layer of fluid of briny fluids

1144
00:57:53,690 --> 00:57:51,900
salty fluid this residual from that

1145
00:57:56,799 --> 00:57:53,700
global ocean and it's just it's not

1146
00:58:06,069 --> 00:57:56,809
allowing the the body to hold a shape

1147
00:58:08,180 --> 00:58:06,079
that's not relaxed okay so one of the

1148
00:58:10,760 --> 00:58:08,190
really interesting things I'm sure

1149
00:58:12,529 --> 00:58:10,770
everybody knows about the bright spot

1150
00:58:14,329 --> 00:58:12,539
that we saw when we were coming into

1151
00:58:18,380 --> 00:58:14,339
Ceres and people thought maybe there was

1152
00:58:21,890 --> 00:58:18,390
flashlights and aliens but it's not it's

1153
00:58:24,079 --> 00:58:21,900
sodium carbonate and you can see it from

1154
00:58:26,660 --> 00:58:24,089
space you know if you look at California

1155
00:58:29,200 --> 00:58:26,670
it's like cereals the same material

1156
00:58:34,000 --> 00:58:29,210
sitting on surface hydrothermal Lake

1157
00:58:37,069 --> 00:58:34,010
saline lake similar sodium carbonate and

1158
00:58:38,720 --> 00:58:37,079
ammonium chloride and they're also

1159
00:58:41,870 --> 00:58:38,730
coming out of the plumes of Enceladus

1160
00:58:44,319 --> 00:58:41,880
and these are the three places that we

1161
00:58:49,549 --> 00:58:44,329
know of in our solar system where these

1162
00:58:54,519 --> 00:58:49,559
where these murals exist so this was a

1163
00:58:57,230 --> 00:58:54,529

really important observation because the

1164
00:58:58,609 --> 00:58:57,240
presence of ammonia and the the

1165
00:59:01,640 --> 00:58:58,619
chemistry that created the sodium

1166
00:59:03,289 --> 00:59:01,650
carbonate is indicative of the processes

1167
00:59:06,620 --> 00:59:03,299
that that we were interested in

1168
00:59:09,319 --> 00:59:06,630
understanding in terms of Ceres overall

1169
00:59:11,390 --> 00:59:09,329
evolution and it's habitable potential

1170
00:59:15,529 --> 00:59:11,400
and then just a reminder that we did

1171
00:59:17,690 --> 00:59:15,539
find organics at one point but it's a

1172
00:59:22,910 --> 00:59:17,700
little unclear what prop by what process

1173
00:59:29,539 --> 00:59:22,920
they were created okay so where did

1174
00:59:32,359 --> 00:59:29,549
series form because of the ammonia it

1175
00:59:33,920 --> 00:59:32,369
would place series formation out here in

1176
00:59:37,279 --> 00:59:33,930
what we call the trans-neptunian belt

1177
00:59:39,769 --> 00:59:37,289
that's where ammonia is stable and that

1178
00:59:42,500 --> 00:59:39,779
would require that it was implanted that

1179
00:59:44,779 --> 00:59:42,510
it was scattered by this you know growth

1180
00:59:46,670 --> 00:59:44,789
migration of the giant plants event all

1181
00:59:49,700 --> 00:59:46,680
the way into the main belt and that's a

1182
00:59:53,029 --> 00:59:49,710
little hard to do and also Ceres doesn't

1183
00:59:55,279 --> 00:59:53,039
resemble the other objects that exist

1184
00:59:58,400 --> 00:59:55,289
out here the trans-neptunian objects and

1185
00:59:59,710 --> 00:59:58,410
the Kuiper belt objects so we we don't

1186
01:00:03,790 --> 00:59:59,720
think that's a favorite

1187
01:00:06,040 --> 01:00:03,800
apophysis it could have been that the

1188
01:00:08,710 --> 01:00:06,050

material that contained the ammonia was

1189
01:00:12,370 --> 01:00:08,720
simply drifting in and there was enough

1190
01:00:17,040 --> 01:00:12,380
of it that it series accreted from it in

1191
01:00:20,560 --> 01:00:17,050
place but as I told you before about the

1192
01:00:24,400 --> 01:00:20,570
the opening of this gap by Jupiter

1193
01:00:26,020 --> 01:00:24,410
forming very early really doesn't favor

1194
01:00:28,510 --> 01:00:26,030
that hypothesis because it's going to

1195
01:00:32,470 --> 01:00:28,520
stop all of the material crossing that

1196
01:00:36,010 --> 01:00:32,480
boundary so that implies that series had

1197
01:00:39,370 --> 01:00:36,020
to be had to be you know on the other

1198
01:00:42,010 --> 01:00:39,380
side of the gap to get the volatile rich

1199
01:00:43,570 --> 01:00:42,020
material coming from you know the the

1200
01:00:47,400 --> 01:00:43,580
drag coming from the outer solar system

1201
01:00:49,810 --> 01:00:47,410
in and so we we think the likely

1202
01:00:52,000 --> 01:00:49,820
formation region is the giant planet

1203
01:00:55,210 --> 01:00:52,010
region and then it would have been

1204
01:00:57,970 --> 01:00:55,220
scattered during one of those resonance

1205
01:01:01,089 --> 01:00:57,980
or one of those scattering events into

1206
01:01:03,940 --> 01:01:01,099
this area of the main belt and that as

1207
01:01:05,560 --> 01:01:03,950
I've already explained is is now quite

1208
01:01:12,130 --> 01:01:05,570
consistent with this emerging paradigm

1209
01:01:14,410 --> 01:01:12,140
of cosmochemistry so think about this

1210
01:01:17,500 --> 01:01:14,420
you know it's hypothesis emerged based

1211
01:01:20,290 --> 01:01:17,510
on study of meteorite data and other

1212
01:01:22,420 --> 01:01:20,300
chemical data that was available about

1213
01:01:25,750 --> 01:01:22,430

Jupiter forming very early and opening

1214
01:01:27,700 --> 01:01:25,760
this gap and this mission was providing

1215
01:01:31,980 --> 01:01:27,710
you know sort of the first test of

1216
01:01:35,290 --> 01:01:31,990
whether that made sense and it does so

1217
01:01:39,660 --> 01:01:35,300
science is moving very quickly in

1218
01:01:44,620 --> 01:01:39,670
planetary in the planetary realm okay

1219
01:01:46,750 --> 01:01:44,630
and series with a few highlights of its

1220
01:01:49,300 --> 01:01:46,760
geologic activity this is just to show

1221
01:01:51,190 --> 01:01:49,310
you that if you enhance the colors of

1222
01:01:53,560 --> 01:01:51,200
Ceres you can see that there are places

1223
01:01:55,390 --> 01:01:53,570
which are bluer and younger have

1224
01:01:58,390 --> 01:01:55,400
brighter material and the background is

1225
01:02:00,310 --> 01:01:58,400
kind of this orangey red color so there

1226
01:02:02,770 --> 01:02:00,320
are different geologic provinces and

1227
01:02:06,010 --> 01:02:02,780
what we find is that in the younger

1228
01:02:08,890 --> 01:02:06,020
brighter and bluer areas that you saw in

1229
01:02:11,500 --> 01:02:08,900
that map we see evidence for Bryan

1230
01:02:12,529 --> 01:02:11,510
driven geology this is the famous Hoonah

1231
01:02:14,989 --> 01:02:12,539
Mons

1232
01:02:16,640 --> 01:02:14,999
singular mountain that was created seems

1233
01:02:19,759 --> 01:02:16,650
to have been created very recently it

1234
01:02:21,620 --> 01:02:19,769
just kind of Scrolls up on the surface

1235
01:02:25,279 --> 01:02:21,630
like you're squeezing a tube of

1236
01:02:27,589 --> 01:02:25,289
toothpaste and it's made of the bright

1237
01:02:30,019 --> 01:02:27,599
streaks here are sodium carbonate so

1238
01:02:31,999 --> 01:02:30,029

this is one of the pieces of evidence

1239
01:02:36,079 --> 01:02:32,009
that says there are still subsurface

1240
01:02:38,329 --> 01:02:36,089
brien pockets and they are and that

1241
01:02:41,120 --> 01:02:38,339
brine is being able to make it to the

1242
01:02:44,239 --> 01:02:41,130
surface this is a unique area because

1243
01:02:46,039 --> 01:02:44,249
there's no nearby impact crater and what

1244
01:02:49,249 --> 01:02:46,049
we're finding is that the impacts

1245
01:02:51,769 --> 01:02:49,259
themselves create heat which melts a lot

1246
01:02:53,630 --> 01:02:51,779
of the frozen brides and surface and

1247
01:02:55,009 --> 01:02:53,640
then drives this sort of hydrothermal

1248
01:02:57,859 --> 01:02:55,019
system that brings them to the surface

1249
01:03:00,409 --> 01:02:57,869
but in this case there's no obvious heat

1250
01:03:04,130 --> 01:03:00,419
source so it may be just a slow freezing

1251
01:03:06,650 --> 01:03:04,140
of the subsurface crust which is

1252
01:03:08,779 --> 01:03:06,660
creating volume changes and that is

1253
01:03:11,749 --> 01:03:08,789
enough to you know be squeezing these

1254
01:03:14,630 --> 01:03:11,759
residual fluids to the surface really

1255
01:03:17,419 --> 01:03:14,640
fascinating so we'll take a little tour

1256
01:03:19,759 --> 01:03:17,429
of rocketry reader that's the the famous

1257
01:03:22,309 --> 01:03:19,769
one that hosts the bright spots we took

1258
01:03:24,979 --> 01:03:22,319
a close look at this in our last mission

1259
01:03:28,939 --> 01:03:24,989
phase so here we're seeing things at ten

1260
01:03:31,519 --> 01:03:28,949
meters per pixel that's a really fine

1261
01:03:34,370 --> 01:03:31,529
scale for this kind of exploration and

1262
01:03:36,669 --> 01:03:34,380
you can see a lot of the details of this

1263
01:03:40,239 --> 01:03:36,679

bright deposit with its radial fractures

1264
01:03:43,489 --> 01:03:40,249
sharp boundaries and and just different

1265
01:03:48,019 --> 01:03:43,499
character of the deposits around the

1266
01:03:51,859 --> 01:03:48,029
central pit this is an example of again

1267
01:03:54,919 --> 01:03:51,869
some carbonate coming out on the crater

1268
01:03:58,789 --> 01:03:54,929
wall as it some sort of chunk that's

1269
01:04:01,880 --> 01:03:58,799
stuck in the the the subsurface and it's

1270
01:04:04,370 --> 01:04:01,890
it's poking out we have clearly

1271
01:04:08,269 --> 01:04:04,380
different types of materials some are

1272
01:04:11,359 --> 01:04:08,279
more more competent more like rock like

1273
01:04:15,499 --> 01:04:11,369
or sandstone like and and then we have

1274
01:04:17,390 --> 01:04:15,509
the the fluffy material we saw a lot of

1275
01:04:19,549 --> 01:04:17,400
fractures they seem to be associated

1276
01:04:22,159 --> 01:04:19,559
with the emergence of this bright

1277
01:04:22,910 --> 01:04:22,169
material from the subsurface as you'll

1278
01:04:25,520 --> 01:04:22,920
see in

1279
01:04:27,589 --> 01:04:25,530
in the next video and and this was a

1280
01:04:29,890 --> 01:04:27,599
really interesting feature that came

1281
01:04:32,089 --> 01:04:29,900
into sharp focus with the

1282
01:04:35,140 --> 01:04:32,099
high-resolution data it's a what we

1283
01:04:39,079 --> 01:04:35,150
called a Mesa but it's really a Ledge

1284
01:04:41,150 --> 01:04:39,089
this is a this is a high standing Massif

1285
01:04:42,680 --> 01:04:41,160
and there's kind of a ledge on the side

1286
01:04:44,599 --> 01:04:42,690
of it and it's just coated with this

1287
01:04:48,620 --> 01:04:44,609
bright material and you can see it

1288
01:04:51,640 --> 01:04:48,630

dripping down the down the steep wall

1289
01:04:54,020 --> 01:04:51,650
and so there's another example of

1290
01:04:57,549 --> 01:04:54,030
evidence for the material coming out of

1291
01:05:01,099 --> 01:04:57,559
the subsurface onto the surface and

1292
01:05:04,250 --> 01:05:01,109
encoding things not that it was there

1293
01:05:08,180 --> 01:05:04,260
from the very beginning so a lot of

1294
01:05:11,620 --> 01:05:08,190
evidence for ongoing processes so I'm

1295
01:05:13,880 --> 01:05:11,630
gonna give you a chance to watch this

1296
01:05:16,849 --> 01:05:13,890
movie for a minutes

1297
01:05:22,280 --> 01:05:16,859
it's a flyover of the crater and you can

1298
01:05:24,740 --> 01:05:22,290
see that the the bright deposits seem to

1299
01:05:27,770 --> 01:05:24,750
be associated with fractures in one part

1300
01:05:30,890 --> 01:05:27,780
of the crater and then they're

1301
01:05:32,210 --> 01:05:30,900
clustering around the central pit and

1302
01:05:35,410 --> 01:05:32,220
that's the area we're just looking at

1303
01:05:38,390 --> 01:05:35,420
and here you're seeing how the

1304
01:05:41,299 --> 01:05:38,400
resolution of our data changed as we

1305
01:05:44,000 --> 01:05:41,309
went and got closer to the surface of a

1306
01:05:48,020 --> 01:05:44,010
kind of detail we saw and the impact

1307
01:05:49,910 --> 01:05:48,030
melt lobes and and just the overall

1308
01:05:51,829 --> 01:05:49,920
character of the surface when we we got

1309
01:05:54,200 --> 01:05:51,839
that very high-resolution data and it's

1310
01:05:56,450 --> 01:05:54,210
taught us a tremendous amount about the

1311
01:05:58,819 --> 01:05:56,460
process by which this material was

1312
01:06:01,250 --> 01:05:58,829
coming up to the surface and the and the

1313
01:06:05,120 --> 01:06:01,260

relative youth it's it's a very research

1314
01:06:09,440 --> 01:06:05,130
process so here's that the Thewlis the

1315
01:06:15,620 --> 01:06:09,450
dome in the center and that that other

1316
01:06:17,390 --> 01:06:15,630
region that I mentioned okay so I'm a

1317
01:06:18,680 --> 01:06:17,400
couple of bullets and I'm gonna tell you

1318
01:06:23,359 --> 01:06:18,690
a little bit about the psychie mission

1319
01:06:26,120 --> 01:06:23,369
and thanks for sticking with me so we

1320
01:06:28,460 --> 01:06:26,130
learned the Vesta and Ceres form closely

1321
01:06:30,829 --> 01:06:28,470
in time with similar amounts of

1322
01:06:32,839 --> 01:06:30,839
radioactive radioactive material but

1323
01:06:35,120 --> 01:06:32,849
their paths diverged largely as a result

1324
01:06:36,620 --> 01:06:35,130
of their initial composition volatile

1325
01:06:41,630 --> 01:06:36,630
poorer for Vesta

1326
01:06:42,350 --> 01:06:41,640
for series series incorporated about

1327
01:06:46,100 --> 01:06:42,360
pneumonia

1328
01:06:48,140 --> 01:06:46,110
so indicating that it formed beyond five

1329
01:06:51,140 --> 01:06:48,150
au and migrated to its current

1330
01:06:53,720 --> 01:06:51,150
neighborhood and the ongoing geologic

1331
01:06:56,140 --> 01:06:53,730
activity there suggests that habitable

1332
01:06:58,760 --> 01:06:56,150
environments possibly existed within the

1333
01:07:02,210 --> 01:06:58,770
dwarf planet so both the subsurface

1334
01:07:05,540 --> 01:07:02,220
ocean and and then the ongoing brine

1335
01:07:10,430 --> 01:07:05,550
activity indicate a very active and and

1336
01:07:13,910 --> 01:07:10,440
and wet interior and then I've always

1337
01:07:17,540 --> 01:07:13,920
talked about its affinity to these icy

1338
01:07:20,600 --> 01:07:17,550

moons but it was clearly Ceres is going

1339
01:07:22,130 --> 01:07:20,610
to help us as we get to Europa with the

1340
01:07:23,720 --> 01:07:22,140
Europa clipper mission to better

1341
01:07:25,820 --> 01:07:23,730
understand what's going on there and

1342
01:07:31,460 --> 01:07:25,830
hopefully when we get to Enceladus

1343
01:07:35,690 --> 01:07:31,470
someday okay so now we're back to the

1344
01:07:38,150 --> 01:07:35,700
iron meteorites this one's big this is

1345
01:07:40,730 --> 01:07:38,160
one of my favorite pictures for a couple

1346
01:07:44,750 --> 01:07:40,740
of reasons one is it's a beautiful

1347
01:07:48,500 --> 01:07:44,760
meteorite second is I don't think they

1348
01:07:50,960 --> 01:07:48,510
allow you to sit on them anymore but

1349
01:07:54,430 --> 01:07:50,970
these these two kids are preserved

1350
01:07:57,590 --> 01:07:54,440
forever and posterity in this picture

1351
01:08:01,460 --> 01:07:57,600
okay so we've learned a lot from iron

1352
01:08:05,210 --> 01:08:01,470
meteorites so maybe we should go to an

1353
01:08:07,490 --> 01:08:05,220
object that looks like the iron core of

1354
01:08:08,330 --> 01:08:07,500
one of these bodies and that would be

1355
01:08:11,930 --> 01:08:08,340
the psyche mission

1356
01:08:16,280 --> 01:08:11,940
it's a journey to a metal world it will

1357
01:08:19,760 --> 01:08:16,290
launch in 2022 and arrive to this exotic

1358
01:08:22,970 --> 01:08:19,770
metal world in 2026 this is an artist's

1359
01:08:26,800 --> 01:08:22,980
rendition by Peter Rubin he's he's a

1360
01:08:28,550 --> 01:08:26,810
Hollywood artist and he's damn good and

1361
01:08:30,500 --> 01:08:28,560
listening you know he listens to

1362
01:08:34,370 --> 01:08:30,510
scientists and then he comes up with his

1363
01:08:39,890 --> 01:08:34,380

is lets his imagination tell him what it

1364
01:08:41,030 --> 01:08:39,900
might look like so psyche is I've talked

1365
01:08:42,950 --> 01:08:41,040
about plants as well as being the

1366
01:08:44,330 --> 01:08:42,960
building blocks of planets talked about

1367
01:08:46,970 --> 01:08:44,340
how the dust particles came together

1368
01:08:48,820 --> 01:08:46,980
then we formed these you know large

1369
01:08:50,120 --> 01:08:48,830
plants has moles some of them

1370
01:08:54,800 --> 01:08:50,130
differentiated

1371
01:09:01,550 --> 01:08:54,810
very quickly and some of them didn't

1372
01:09:05,479 --> 01:09:01,560
make it because they got crushed so when

1373
01:09:09,410 --> 01:09:05,489
two by two large bodies collide at high

1374
01:09:13,039 --> 01:09:09,420
speed then it causes basically a total

1375
01:09:16,160 --> 01:09:13,049
disruption and this is called in in the

1376
01:09:19,669 --> 01:09:16,170
parlance a hit-and-run where you can

1377
01:09:22,729 --> 01:09:19,679
strip all of the materials you strip all

1378
01:09:26,059 --> 01:09:22,739
the materials disrupt them all and then

1379
01:09:28,610 --> 01:09:26,069
things can react read but in a

1380
01:09:31,459 --> 01:09:28,620
hit-and-run you're left because of the

1381
01:09:33,620 --> 01:09:31,469
momentum of the the particles with

1382
01:09:35,749 --> 01:09:33,630
separation of the different layers so

1383
01:09:39,649 --> 01:09:35,759
that you don't end up putting the body

1384
01:09:41,720 --> 01:09:39,659
back together so we think that psyche

1385
01:09:44,149 --> 01:09:41,730
may be the naked remnant of a

1386
01:09:47,059 --> 01:09:44,159
planetesimals metal core stripped by

1387
01:09:50,510 --> 01:09:47,069
these collisions and here's another

1388
01:09:53,809 --> 01:09:50,520

illustration to to try to capture the

1389
01:09:56,660 --> 01:09:53,819
violence of that event where you know

1390
01:09:59,600 --> 01:09:56,670
this this may have been psyche and this

1391
01:10:03,790 --> 01:09:59,610
is the the impactor and everything is

1392
01:10:08,660 --> 01:10:03,800
just one molten ball of stuff but then

1393
01:10:14,180 --> 01:10:08,670
it comes back together so if we start

1394
01:10:16,250 --> 01:10:14,190
with the parent body of psyche and I

1395
01:10:18,560 --> 01:10:16,260
should have mentioned before psyche is

1396
01:10:20,660 --> 01:10:18,570
the name of the mission and psyche is

1397
01:10:24,280 --> 01:10:20,670
the name of the object it's sixteen

1398
01:10:27,370 --> 01:10:24,290
psyche so when I say psyche it's both

1399
01:10:29,720 --> 01:10:27,380
but so here we have we have the impactor

1400
01:10:32,540 --> 01:10:29,730
disrupting and then what we're left it

1401
01:10:35,720 --> 01:10:32,550
here with this the core the iron core is

1402
01:10:37,550 --> 01:10:35,730
now reading and it's been stripped of

1403
01:10:40,820 --> 01:10:37,560
the rock it's been stripped of like the

1404
01:10:44,149 --> 01:10:40,830
basalt and the and the mantle and now

1405
01:10:49,060 --> 01:10:44,159
it's going to cool and form this

1406
01:10:52,490 --> 01:10:49,070
metallic body so the question is what

1407
01:10:55,160 --> 01:10:52,500
based on what it's made of it may

1408
01:10:58,189 --> 01:10:55,170
manifest its surface may manifest

1409
01:11:01,129 --> 01:10:58,199
different characteristics and so or

1410
01:11:03,470 --> 01:11:01,139
after is to look at three main

1411
01:11:05,090 --> 01:11:03,480
characteristics of this body and

1412
01:11:10,900 --> 01:11:05,100
try to understand if it really is the

1413
01:11:14,120 --> 01:11:10,910

stripped core of a planetesimal so the

1414
01:11:16,580 --> 01:11:14,130
one of the main ways we do that is by

1415
01:11:21,200 --> 01:11:16,590
looking at for its magnetic field

1416
01:11:23,180 --> 01:11:21,210
because a circulating conductor or a

1417
01:11:26,660 --> 01:11:23,190
moving conductor will create a magnetic

1418
01:11:30,229 --> 01:11:26,670
field and within bodies with molten

1419
01:11:32,000 --> 01:11:30,239
cores the rotation will drive a dynamo

1420
01:11:35,930 --> 01:11:32,010
and that will create a magnetic field

1421
01:11:41,510 --> 01:11:35,940
and so if we see a magnetic field will

1422
01:11:46,010 --> 01:11:41,520
know that this body started to cool at

1423
01:11:48,280 --> 01:11:46,020
the outside and it cooled inward and it

1424
01:11:51,020 --> 01:11:48,290
could possibly after it finish cooling

1425
01:11:52,700 --> 01:11:51,030
have been disrupted again and what we're

1426
01:11:54,680 --> 01:11:52,710
left with is a what's called a remnant

1427
01:11:57,470 --> 01:11:54,690
field a frozen field frozen into the

1428
01:12:04,310 --> 01:11:57,480
rocks so we could see either either of

1429
01:12:10,100 --> 01:12:04,320
these two states if this body formed if

1430
01:12:12,650 --> 01:12:10,110
it cooled from the inside outward then

1431
01:12:14,750 --> 01:12:12,660
it would not have been able to sustain a

1432
01:12:18,010 --> 01:12:14,760
magnetic field and we would expect to

1433
01:12:22,130 --> 01:12:18,020
see nothing so it would be inconclusive

1434
01:12:24,470 --> 01:12:22,140
now if we combine what we we find with

1435
01:12:26,830 --> 01:12:24,480
the magnetic field to what's on the

1436
01:12:30,530 --> 01:12:26,840
surface whether we see any silicates

1437
01:12:36,140 --> 01:12:30,540
especially sulfur on the surface or and

1438
01:12:40,070 --> 01:12:36,150

with the nickel content then we can we

1439
01:12:43,100 --> 01:12:40,080
can find us this specific answer to the

1440
01:12:46,960 --> 01:12:43,110
question of whether it's the core of a

1441
01:12:51,410 --> 01:12:46,970
differentiated planetesimal or perhaps

1442
01:12:54,680 --> 01:12:51,420
the unexpected result that this is not

1443
01:12:56,690 --> 01:12:54,690
have does not have to do with plants has

1444
01:12:59,900 --> 01:12:56,700
no differentiation event but it could

1445
01:13:01,970 --> 01:12:59,910
just be metal that was accreted directly

1446
01:13:06,490 --> 01:13:01,980
from the solar nebula and that would be

1447
01:13:11,150 --> 01:13:06,500
a completely unexpected result but

1448
01:13:13,610 --> 01:13:11,160
perhaps not out of the question so we're

1449
01:13:16,220 --> 01:13:13,620
going to be making these very simple

1450
01:13:17,390 --> 01:13:16,230
measurements looking at what kind of

1451
01:13:19,280 --> 01:13:17,400
minerals are on the surface

1452
01:13:21,430 --> 01:13:19,290
what kind of structures are there are

1453
01:13:23,750 --> 01:13:21,440
there sulfur lava flows on the surface

1454
01:13:26,540 --> 01:13:23,760
what is the nickel content that we can

1455
01:13:28,880 --> 01:13:26,550
measure with the elemental abundance

1456
01:13:30,470 --> 01:13:28,890
from gamma ray Neutron spectrometer and

1457
01:13:34,400 --> 01:13:30,480
then what is the magnetic field

1458
01:13:36,890 --> 01:13:34,410
character and it's just a cartoon to say

1459
01:13:40,040 --> 01:13:36,900
that we because the sulfur fluids are

1460
01:13:42,310 --> 01:13:40,050
will stick around you know they'll stay

1461
01:13:46,520 --> 01:13:42,320
liquid longer than the iron nickel metal

1462
01:13:48,740 --> 01:13:46,530
and as the core freezes they could be

1463
01:13:51,590 --> 01:13:48,750

you know driven out through cracks and

1464
01:13:55,070 --> 01:13:51,600
and create these sulfur volcanoes on the

1465
01:13:57,310 --> 01:13:55,080
surface very interesting and then

1466
01:14:01,460 --> 01:13:57,320
finally this this is a meteorite that

1467
01:14:02,540 --> 01:14:01,470
represents the core mantle boundary of a

1468
01:14:05,000 --> 01:14:02,550
differentiated body

1469
01:14:08,260 --> 01:14:05,010
they're called Pallas i'ts there's many

1470
01:14:12,020 --> 01:14:08,270
in meteorite collection those are

1471
01:14:15,610 --> 01:14:12,030
crystals of olivine in an iron nickel

1472
01:14:18,170 --> 01:14:15,620
matrix and so we might be seeing

1473
01:14:22,250 --> 01:14:18,180
beautiful crystals of olivine you know

1474
01:14:24,650 --> 01:14:22,260
on the surface of Saiki as well but this

1475
01:14:25,940 --> 01:14:24,660
is all just conjecture we really don't

1476
01:14:29,660 --> 01:14:25,950
know and that's why we're going there

1477
01:14:31,400 --> 01:14:29,670
and then finally it's just what what's

1478
01:14:34,670 --> 01:14:31,410
this thing gonna look like we don't know

1479
01:14:38,060 --> 01:14:34,680
what what an impact into a metal object

1480
01:14:40,330 --> 01:14:38,070
would do but in anticipation when we're

1481
01:14:42,770 --> 01:14:40,340
trying to find out by doing some

1482
01:14:45,110 --> 01:14:42,780
experiments with an air gun up at the

1483
01:14:48,890 --> 01:14:45,120
Ames Research Center and in basically

1484
01:14:52,400 --> 01:14:48,900
shooting ingots into into metal and

1485
01:14:56,500 --> 01:14:52,410
here's a the resulting impact crater so

1486
01:15:03,440 --> 01:14:56,510
we might be seeing stuff like that okay

1487
01:15:05,480 --> 01:15:03,450
you made it here's a few takeaways the

1488
01:15:07,790 --> 01:15:05,490

population of small worlds in our solar

1489
01:15:17,560 --> 01:15:07,800
system record its history I hope I've

1490
01:15:24,950 --> 01:15:21,520
the slighted answer doesn't always work

1491
01:15:27,890 --> 01:15:24,960
but I'm gonna try this okay and and

1492
01:15:30,560 --> 01:15:27,900
importantly they they were there to

1493
01:15:32,570 --> 01:15:30,570
record the important processes and

1494
01:15:35,030 --> 01:15:32,580
events that shaped our planetary

1495
01:15:38,209 --> 01:15:35,040
neighborhood both the small and the

1496
01:15:40,310 --> 01:15:38,219
larger bodies they can be used to test

1497
01:15:43,280 --> 01:15:40,320
various hypotheses disk chemistry

1498
01:15:47,600 --> 01:15:43,290
internal evolutionary processes dynamics

1499
01:15:49,070 --> 01:15:47,610
scattering and those processes have

1500
01:15:51,229 --> 01:15:49,080
important implications for a

1501
01:15:53,510 --> 01:15:51,239
distribution of water creation of

1502
01:15:57,080 --> 01:15:53,520
habitable environments so they're

1503
01:15:59,510 --> 01:15:57,090
essentially you know critical with with

1504
01:16:03,709 --> 01:15:59,520
all the other exploration we're doing to

1505
01:16:07,129 --> 01:16:03,719
really develop a full picture of how our

1506
01:16:11,359 --> 01:16:07,139
solar system formed and came to be what

1507
01:16:15,740 --> 01:16:11,369
we have today so in my view small body

1508
01:16:18,680 --> 01:16:15,750
exploration and sample return is the has

1509
01:16:21,830 --> 01:16:18,690
the greatest promise for continued rich

1510
01:16:25,120 --> 01:16:21,840
rewards and understanding our our our

1511
01:16:29,600 --> 01:16:25,130
neighborhood so let's just end with

1512
01:16:32,240 --> 01:16:29,610
what's coming up besides psyche is that

1513
01:16:36,140 --> 01:16:32,250

we're now at the asteroid Bennu many of

1514
01:16:39,410 --> 01:16:36,150
the osiris-rex mission and the Japanese

1515
01:16:41,899 --> 01:16:39,420
Hayabusa to mission is at ryugu they're

1516
01:16:43,790 --> 01:16:41,909
both collecting samples and returning

1517
01:16:46,729 --> 01:16:43,800
samples to the earth so we're going to

1518
01:16:49,180 --> 01:16:46,739
understand what these very small but

1519
01:16:52,310 --> 01:16:49,190
important carbon-rich

1520
01:16:57,169 --> 01:16:52,320
asteroids from our neighborhood can tell

1521
01:16:58,729 --> 01:16:57,179
us about early evolution also spacecraft

1522
01:17:02,570 --> 01:16:58,739
is going out to visit the Jupiter

1523
01:17:04,339 --> 01:17:02,580
Trojans the NASA Lucy mission and the

1524
01:17:07,070 --> 01:17:04,349
Trojans come from all over they were

1525
01:17:09,979 --> 01:17:07,080
captured by Jupiter in these clumps in

1526
01:17:11,959 --> 01:17:09,989
the at the Jupiter Sun Lagrange points

1527
01:17:17,419 --> 01:17:11,969
and so they're a nice collection of

1528
01:17:19,640 --> 01:17:17,429
material to take a look at and then in

1529
01:17:22,640 --> 01:17:19,650
addition we would like to go to other

1530
01:17:25,370 --> 01:17:22,650
early foreign planetesimals to try to

1531
01:17:28,550 --> 01:17:25,380
continue to hone our understanding of

1532
01:17:30,229 --> 01:17:28,560
that early period go visit more comets

1533
01:17:32,359 --> 01:17:30,239
and in

1534
01:17:34,669 --> 01:17:32,369
particular active asteroids which could

1535
01:17:38,089 --> 01:17:34,679
be one of the sources of water to the

1536
01:17:40,609 --> 01:17:38,099
earth and then we're we're on the cusp

1537
01:17:43,879 --> 01:17:40,619
of being able to visit large numbers of

1538
01:17:46,549 --> 01:17:43,889

near-earth objects with capable small

1539
01:17:49,970 --> 01:17:46,559
satellites so that we can really start

1540
01:17:53,120 --> 01:17:49,980
to fill in the statistics of what these

1541
01:17:56,500 --> 01:17:53,130
bodies are like and and you know fill in

1542
01:17:58,790 --> 01:17:56,510
our knowledge about the overall picture

1543
01:18:02,779 --> 01:17:58,800
so with that I hope I've given you a

1544
01:18:05,299 --> 01:18:02,789
good overview there's a few links here

1545
01:18:07,879 --> 01:18:05,309
if you want to learn more and I'd be

1546
01:18:19,620 --> 01:18:07,889
happy to take questions and thank you so

1547
01:18:24,520 --> 01:18:23,140
so folks if you are here on lab and you

1548
01:18:26,140 --> 01:18:24,530
have questions you're gonna step up to

1549
01:18:27,970 --> 01:18:26,150
the microphone we've got some questions

1550
01:18:29,320 --> 01:18:27,980
from our online viewers we've got

1551
01:18:32,459 --> 01:18:29,330
somebody up in the microphone already so

1552
01:18:42,610 --> 01:18:35,160
coolest phone karma lectures of all time

1553
01:18:46,240 --> 01:18:42,620
I had a question about the hydrated

1554
01:18:48,850 --> 01:18:46,250
deposits on Vesta given that the ejecta

1555
01:18:52,060 --> 01:18:48,860
plume kind of occupied a third of the

1556
01:18:54,610 --> 01:18:52,070
body's diameter that would suggest an

1557
01:18:57,040 --> 01:18:54,620
absolutely insane impact wouldn't we

1558
01:18:59,320 --> 01:18:57,050
expect a massive excavation Basin kind

1559
01:19:04,930 --> 01:18:59,330
of like like the south quality can basin

1560
01:19:07,180 --> 01:19:04,940
and and then a related question with the

1561
01:19:08,800 --> 01:19:07,190
the thermal profile of that impact

1562
01:19:10,630 --> 01:19:08,810
wouldn't we expect all the volatile to

1563
01:19:18,070 --> 01:19:10,640

have spoiled off in the impact area and

1564
01:19:21,130 --> 01:19:18,080
just be in the ejecta plume okay so we

1565
01:19:23,560 --> 01:19:21,140
think that all of that dark material

1566
01:19:25,870 --> 01:19:23,570
actually came out of one of the giant

1567
01:19:29,380 --> 01:19:25,880
basins in the south the venom eya Basin

1568
01:19:33,550 --> 01:19:29,390
to be exact and that's a 400 kilometer

1569
01:19:35,830 --> 01:19:33,560
diameter Basin on on you know 530

1570
01:19:39,520 --> 01:19:35,840
kilometer diameter body so it's a big

1571
01:19:41,740 --> 01:19:39,530
basin and it looks like the material was

1572
01:19:46,600 --> 01:19:41,750
kind of like thrown up or the the

1573
01:19:49,930 --> 01:19:46,610
impactor was not was retained but it the

1574
01:19:54,130 --> 01:19:49,940
ejecta was was thrown up to the area

1575
01:19:55,959 --> 01:19:54,140
that we're seeing it now there's a big

1576
01:20:00,130 --> 01:19:55,969
difference in impact velocity in the

1577
01:20:02,260 --> 01:20:00,140
main belt versus say the moon difference

1578
01:20:03,939 --> 01:20:02,270
in gravity and just the speed at which

1579
01:20:08,200 --> 01:20:03,949
the objects are interacting with each

1580
01:20:12,220 --> 01:20:08,210
other so we expect asteroid collisions

1581
01:20:14,560 --> 01:20:12,230
to be in the 5 km/s range only a comet

1582
01:20:17,590 --> 01:20:14,570
would be energetic enough that it could

1583
01:20:20,560 --> 01:20:17,600
vaporize all of the volatiles and also

1584
01:20:23,320 --> 01:20:20,570
else it's really hard to get water out

1585
01:20:25,240 --> 01:20:23,330
of minerals so if it's already locked

1586
01:20:27,940 --> 01:20:25,250
into the minerals then you're gonna have

1587
01:20:30,370 --> 01:20:27,950
to heat it up to say 400 degrees C

1588
01:20:33,490 --> 01:20:30,380

before you drive the water off thank you

1589
01:20:37,300 --> 01:20:33,500
great t-shirt

1590
01:20:39,940 --> 01:20:37,310
how will you uh find psyche when you

1591
01:20:42,250 --> 01:20:39,950
like launch it because it's like it'll

1592
01:20:46,390 --> 01:20:42,260
take like sick like four years to reach

1593
01:20:49,240 --> 01:20:46,400
there how how will you like like find it

1594
01:20:54,720 --> 01:20:49,250
how will we find psyche once we send the

1595
01:20:57,880 --> 01:20:54,730
mission psyche out to psyche yeah so

1596
01:21:01,600 --> 01:20:57,890
it's more like this it's more like when

1597
01:21:06,610 --> 01:21:01,610
we launch we're getting into the car and

1598
01:21:09,820 --> 01:21:06,620
turning it on so the rocket takes us out

1599
01:21:12,970 --> 01:21:09,830
of Earth's gravity well and then we turn

1600
01:21:14,560 --> 01:21:12,980
on the ion engine and the controllers

1601
01:21:17,530 --> 01:21:14,570
here on the ground are constantly

1602
01:21:19,900 --> 01:21:17,540
watching it because it's talking to the

1603
01:21:21,490 --> 01:21:19,910
deep space network the dishes that are

1604
01:21:23,820 --> 01:21:21,500
listening all the time so they're

1605
01:21:27,490 --> 01:21:23,830
talking back and forth and it knows

1606
01:21:29,710 --> 01:21:27,500
that's kind of like GPS you know you can

1607
01:21:34,600 --> 01:21:29,720
always figure out where you are and then

1608
01:21:36,940 --> 01:21:34,610
the the navigators figure out what

1609
01:21:39,040 --> 01:21:36,950
forces are you know pushing kind of like

1610
01:21:40,780 --> 01:21:39,050
a wind pushing a sailboat you know you

1611
01:21:43,420 --> 01:21:40,790
kind of figure out what little forces

1612
01:21:45,100 --> 01:21:43,430
are maybe putting you off the the track

1613
01:21:47,290 --> 01:21:45,110

and you make little adjustments to get

1614
01:21:50,020 --> 01:21:47,300
back on with an ion propulsion mission

1615
01:21:52,330 --> 01:21:50,030
like Don was and psyche is you you're

1616
01:21:54,160 --> 01:21:52,340
driving all the time you're you're

1617
01:21:55,690 --> 01:21:54,170
thrusting all the time and so you're

1618
01:21:59,500 --> 01:21:55,700
you're making all these adjustments so

1619
01:22:01,720 --> 01:21:59,510
it's it's a process of being constantly

1620
01:22:03,340 --> 01:22:01,730
aware and interacting with the

1621
01:22:06,760 --> 01:22:03,350
spacecraft all the way there but how

1622
01:22:10,180 --> 01:22:06,770
will you like like react in time because

1623
01:22:13,630 --> 01:22:10,190
it takes like time so there's a light

1624
01:22:16,270 --> 01:22:13,640
time which for that distance will end up

1625
01:22:18,400 --> 01:22:16,280
being you know it'll grow from almost

1626
01:22:21,670 --> 01:22:18,410
nothing right after launch to on the

1627
01:22:24,250 --> 01:22:21,680
order of 20 to 25 minutes and that means

1628
01:22:26,410 --> 01:22:24,260
you know this when you talk it here is

1629
01:22:32,230 --> 01:22:26,420
it 25 minutes later and and you get a

1630
01:22:34,330 --> 01:22:32,240
response okay before we ask our next one

1631
01:22:37,150 --> 01:22:34,340
in house Zhi Jing asks are there any

1632
01:22:40,810 --> 01:22:37,160
plans to return to series after the dawn

1633
01:22:44,470 --> 01:22:40,820
mission well NASA is quite interested in

1634
01:22:47,200 --> 01:22:44,480
turning to series it has or many of the

1635
01:22:48,850 --> 01:22:47,210
planetary science scientists have

1636
01:22:52,810 --> 01:22:48,860
expressed the interest in going back and

1637
01:22:57,940 --> 01:22:52,820
landing on the surface and either using

1638
01:23:02,350 --> 01:22:57,950

some equipment to try to sample the

1639
01:23:04,420 --> 01:23:02,360
material below the surface or or just

1640
01:23:07,230 --> 01:23:04,430
Rove around and and and do other things

1641
01:23:10,120 --> 01:23:07,240
but there are a lot of studies going on

1642
01:23:13,570 --> 01:23:10,130
so nothing is certain right now but

1643
01:23:17,370 --> 01:23:13,580
there are certainly going to be a set of

1644
01:23:20,380 --> 01:23:17,380
studies that will be conducted and then

1645
01:23:23,680 --> 01:23:20,390
proposals will be written the process

1646
01:23:26,110 --> 01:23:23,690
will you know ching Chunk along and

1647
01:23:29,200 --> 01:23:26,120
maybe sometime in the next decade will

1648
01:23:34,800 --> 01:23:29,210
have another mission to series okay yes

1649
01:23:38,200 --> 01:23:34,810
sir um do you know if there is any

1650
01:23:41,380 --> 01:23:38,210
volcanic activity on any of the planets

1651
01:23:43,660 --> 01:23:41,390
you mentioned here there any volcanic

1652
01:23:48,520 --> 01:23:43,670
activity on any of these objects were

1653
01:23:51,580 --> 01:23:48,530
looking at out there so we expected that

1654
01:23:55,600 --> 01:23:51,590
we would see some volcanic features on

1655
01:23:59,650 --> 01:23:55,610
Vesta because as I told you it was a

1656
01:24:02,770 --> 01:23:59,660
volcanic Li it was born from a volcanic

1657
01:24:04,420 --> 01:24:02,780
process the basalts erupted on the

1658
01:24:07,600 --> 01:24:04,430
surface they covered the surface like

1659
01:24:10,030 --> 01:24:07,610
like the you know the ocean floor is

1660
01:24:12,910 --> 01:24:10,040
created so we thought we'd see you know

1661
01:24:15,280 --> 01:24:12,920
individual volcanoes or something that

1662
01:24:16,930 --> 01:24:15,290
we got identified we found nothing that

1663
01:24:18,220 --> 01:24:16,940

doesn't mean those features weren't

1664
01:24:19,030 --> 01:24:18,230
there it just means they're not there

1665
01:24:20,640 --> 01:24:19,040
anymore

1666
01:24:23,980 --> 01:24:20,650
they've been either covered over with

1667
01:24:26,760 --> 01:24:23,990
right with ejecta from impact so they've

1668
01:24:29,140 --> 01:24:26,770
been the rock has just been pulverized

1669
01:24:31,470 --> 01:24:29,150
but we know that volcanism would have

1670
01:24:35,770 --> 01:24:31,480
happened very early on like the first

1671
01:24:38,860 --> 01:24:35,780
hundred million years of Vestas history

1672
01:24:41,530 --> 01:24:38,870
and so there's a lot of time for any of

1673
01:24:46,090 --> 01:24:41,540
those features to get ground down on

1674
01:24:48,940 --> 01:24:46,100
Ceres what I showed you there that Luna

1675
01:24:52,540 --> 01:24:48,950
Mons is it's been referred to as a

1676
01:24:54,649 --> 01:24:52,550
cryovolcano so cryovolcano is made of a

1677
01:24:58,490 --> 01:24:54,659
magma which is water

1678
01:25:00,530 --> 01:24:58,500
frozen we you know it's kind of a turn

1679
01:25:03,890 --> 01:25:00,540
that's not well defined

1680
01:25:05,240 --> 01:25:03,900
but essentially it means that fluids are

1681
01:25:06,740 --> 01:25:05,250
coming out of the interior and they're

1682
01:25:12,379 --> 01:25:06,750
creating creatures that that are

1683
01:25:15,649 --> 01:25:12,389
constructional in nature psyche I

1684
01:25:18,290 --> 01:25:15,659
mentioned maybe sulfur volcanoes but

1685
01:25:21,680 --> 01:25:18,300
that's just total conjecture we we don't

1686
01:25:23,689 --> 01:25:21,690
know so hopefully we will find something

1687
01:25:25,399 --> 01:25:23,699
really interesting there stay tuned

1688
01:25:27,140 --> 01:25:25,409

great actually we've got time for one

1689
01:25:28,970 --> 01:25:27,150
last question it's coming from from our

1690
01:25:30,620 --> 01:25:28,980
online if you have your in house and you

1691
01:25:32,149 --> 01:25:30,630
got questions feel free to come up

1692
01:25:35,030 --> 01:25:32,159
afterwards you can ask those questions

1693
01:25:37,220 --> 01:25:35,040
but the last one comes from Mozart on

1694
01:25:42,910 --> 01:25:37,230
YouTube and asks how alike are series

1695
01:25:49,970 --> 01:25:42,920
and Pluto Ceres and Pluto so serious

1696
01:25:54,950 --> 01:25:49,980
they are not that similar Pluto is quite

1697
01:26:00,140 --> 01:25:54,960
a bit larger than series and it's so

1698
01:26:02,930 --> 01:26:00,150
much colder that it's its surface is you

1699
01:26:07,430 --> 01:26:02,940
know the surface that we saw with New

1700
01:26:12,129 --> 01:26:07,440
Horizons shows these vast sea of of

1701
01:26:14,570 --> 01:26:12,139
nitrogen ice in Sputnik pleasure and so

1702
01:26:17,899 --> 01:26:14,580
the materials on the surface are

1703
01:26:23,290 --> 01:26:17,909
different I think so other processes are

1704
01:26:26,240 --> 01:26:23,300
different it appears that the Pluto also

1705
01:26:30,910 --> 01:26:26,250
accreted from more probably more

1706
01:26:35,330 --> 01:26:30,920
volatile rich material then series did

1707
01:26:38,990 --> 01:26:35,340
what is similar about the two is the

1708
01:26:41,899 --> 01:26:39,000
fact that as I mentioned before there's

1709
01:26:45,590 --> 01:26:41,909
documented volcanic that's a documented

1710
01:26:48,379 --> 01:26:45,600
geologic activity on Pluto which was

1711
01:26:51,290 --> 01:26:48,389
rather unexpected and on Ceres as well

1712
01:26:54,290 --> 01:26:51,300
so the similarity maybe not so much

1713
01:26:57,590 --> 01:26:54,300

between those two objects as that being

1714
01:26:59,570 --> 01:26:57,600
common amongst a lot of these larger

1715
01:27:02,090 --> 01:26:59,580
bodies throughout the solar system that

1716
01:27:04,640 --> 01:27:02,100
you know the geology just does not sleep

1717
01:27:08,060 --> 01:27:04,650
and and things things just keep

1718
01:27:08,920 --> 01:27:08,070
happening and and and also for Pluto and

1719
01:27:13,010 --> 01:27:08,930
first

1720
01:27:17,090 --> 01:27:13,020
impacts are a really important driver of

1721
01:27:19,850 --> 01:27:17,100
this activity and we know that impacts

1722
01:27:23,150 --> 01:27:19,860
occur on all bodies across the solar

1723
01:27:26,810 --> 01:27:23,160
system so we have a lot of potential

1724
01:27:29,480 --> 01:27:26,820
for these types of interesting features

1725
01:27:31,850 --> 01:27:29,490
and situations on other bodies as well

1726
01:27:33,290 --> 01:27:31,860
very cool well that is all the time we

1727
01:27:34,580 --> 01:27:33,300
have for tonight let's give a bit dr.

1728
01:27:42,020 --> 01:27:34,590
Carol Ram in a big round of applause

1729
01:27:45,080 --> 01:27:42,030
please join us next month September 19th

1730
01:27:46,220 --> 01:27:45,090
and 20th for it broke a story of how he

1731
01:27:48,290 --> 01:27:46,230
fixed it thank you and have a wonderful

1732
01:27:55,820 --> 01:27:48,300
evening everybody