1
00:00:05,510 --> 00:00:04,150
hi i'm trent perato public affairs

2
00:00:07,110 --> 00:00:05,520
officer for nasa science mission

3
00:00:08,470 --> 00:00:07,120
directorate in washington i'd like to

4
00:00:10,549 --> 00:00:08,480
welcome you to today's news conference

5
00:00:13,030 --> 00:00:10,559
to discuss the results of nasa's gravity

6
00:00:14,549 --> 00:00:13,040
probe b mission let me start by

7
00:00:15,669 --> 00:00:14,559
introducing our five distinguished

8
00:00:16,870 --> 00:00:15,679
panelists joining us for today's

9
00:00:17,750 --> 00:00:16,880
conversation

10
00:00:19,029 --> 00:00:17,760
first

11
00:00:21,029 --> 00:00:19,039
bill danshi

12
00:00:23,349 --> 00:00:21,039
senior astrophysicist and program

13
00:00:25,029 --> 00:00:23,359

scientist at nasa headquarters

14
00:00:26,950 --> 00:00:25,039
francis everett

15
00:00:29,990 --> 00:00:26,960
principal investigator for the gravity

16
00:00:31,509 --> 00:00:30,000
probe b mission at stanford university

17
00:00:33,670 --> 00:00:31,519
rex jevidin

18
00:00:35,270 --> 00:00:33,680
president of teledyne brown engineering

19
00:00:37,670 --> 00:00:35,280
incorporated

20
00:00:39,670 --> 00:00:37,680
colleen hartman senior advisor at nasa

21
00:00:42,150 --> 00:00:39,680
headquarters and research professor at

22
00:00:44,310 --> 00:00:42,160
george washington university

23
00:00:47,510 --> 00:00:44,320
and clifford will professor of physics

24
00:00:49,350 --> 00:00:47,520
at washington university in st louis

25
00:00:51,670 --> 00:00:49,360
for those joining us online you can find

26
00:00:55,670 --> 00:00:51,680
out more information about gravity pro b

27
00:00:59,750 --> 00:00:56,869
and with that let me turn over the

28
00:01:01,430 --> 00:00:59,760
discussion to bill okay today we are

29
00:01:04,310 --> 00:01:01,440
here to announce the results of the

30
00:01:06,789 --> 00:01:04,320
gravity probe b or gpb mission

31
00:01:08,710 --> 00:01:06,799
let me first start by recognizing one of

32
00:01:09,750 --> 00:01:08,720
our distinguished guests in the audience

33
00:01:11,510 --> 00:01:09,760
today

34
00:01:14,469 --> 00:01:11,520
we're pleased to have

35
00:01:17,030 --> 00:01:14,479
his highness dr prince turkey assad vice

36
00:01:19,270 --> 00:01:17,040
president of the king abdulaziz city for

37
00:01:22,070 --> 00:01:19,280
science and technology

38
00:01:24,070 --> 00:01:22,080

gpb is one of only a very few

39
00:01:25,749 --> 00:01:24,080
astrophysics missions dedicated to

40
00:01:27,830 --> 00:01:25,759
fundamental physics

41
00:01:30,789 --> 00:01:27,840
the goal of gravity probe b is to

42
00:01:33,510 --> 00:01:30,799
precisely test two consequences of

43
00:01:35,429 --> 00:01:33,520
einstein's general theory of relativity

44
00:01:36,469 --> 00:01:35,439
the first one is called the geodetic

45
00:01:38,390 --> 00:01:36,479
effect

46
00:01:40,550 --> 00:01:38,400
which is the amount by which space-time

47
00:01:41,510 --> 00:01:40,560
is warped because of the mass of the

48
00:01:43,350 --> 00:01:41,520
earth

49
00:01:45,350 --> 00:01:43,360
the second is called the frame dragging

50
00:01:47,990 --> 00:01:45,360
effect which is the amount by which

51
00:01:50,069 --> 00:01:48,000
space-time is dragged around or twisted

52
00:01:52,789 --> 00:01:50,079
because of the earth's rotation the

53
00:01:55,190 --> 00:01:52,799
latter effect was predicted by joseph

54
00:01:58,550 --> 00:01:55,200
lands and hans thering of austria in

55
00:02:01,749 --> 00:01:58,560
1918 only two years after the initial

56
00:02:04,630 --> 00:02:01,759
paper general relativity was published

57
00:02:06,630 --> 00:02:04,640
the gravity pro b mission measures the

58
00:02:10,070 --> 00:02:06,640
these effects by observing the motion or

59
00:02:12,710 --> 00:02:10,080
precession of the axis of four

60
00:02:14,630 --> 00:02:12,720
gyroscopes these are very precisely made

61
00:02:16,550 --> 00:02:14,640
spheres of fuse quartz that were coated

62
00:02:18,309 --> 00:02:16,560
with niobium so that they are

63
00:02:19,910 --> 00:02:18,319

superconducting when cooled to liquid

64
00:02:21,670 --> 00:02:19,920
helium temperatures

65
00:02:25,430 --> 00:02:21,680
when the gyroscopes spin up to about

66
00:02:27,510 --> 00:02:25,440
5000 rpm they produce a magnetic field

67
00:02:30,070 --> 00:02:27,520
aligned with a spin axis

68
00:02:31,670 --> 00:02:30,080
a super superconducting effect known as

69
00:02:33,670 --> 00:02:31,680
the london moment

70
00:02:35,190 --> 00:02:33,680
this precision is measured

71
00:02:37,670 --> 00:02:35,200
this precession is measured very

72
00:02:39,030 --> 00:02:37,680
precisely by comparison to a fixed

73
00:02:41,750 --> 00:02:39,040
reference star

74
00:02:43,190 --> 00:02:41,760
so that gpb satellite that the satellite

75
00:02:44,070 --> 00:02:43,200
points to during the course of its

76
00:02:46,869 --> 00:02:44,080
mission

77
00:02:48,949 --> 00:02:46,879
the gravity pro b is an extremely well

78
00:02:51,030 --> 00:02:48,959
designed experiment

79
00:02:52,550 --> 00:02:51,040
with many checks and cross checks so

80
00:02:55,110 --> 00:02:52,560
that the measurements and their errors

81
00:02:56,869 --> 00:02:55,120
are well understood and reliable

82
00:02:59,030 --> 00:02:56,879
gravity probe b is designed so that

83
00:03:01,670 --> 00:02:59,040
these two effects are separated the

84
00:03:03,910 --> 00:03:01,680
precession in the north south direction

85
00:03:06,390 --> 00:03:03,920
is caused by the geodetic effect and the

86
00:03:08,710 --> 00:03:06,400
precession in the east-west direction is

87
00:03:10,790 --> 00:03:08,720
caused by the frame dragging effect

88
00:03:13,589 --> 00:03:10,800

gravity probe b is the second nasa

89
00:03:15,910 --> 00:03:13,599
experiment to test general relativity

90
00:03:19,030 --> 00:03:15,920
the first one gravity probe a

91
00:03:20,790 --> 00:03:19,040
was flown in 1976 and was led by dr

92
00:03:23,030 --> 00:03:20,800
robert fasso the smithsonian

93
00:03:24,390 --> 00:03:23,040
astrophysical observatory at harvard

94
00:03:26,470 --> 00:03:24,400
university

95
00:03:29,430 --> 00:03:26,480
gravity probe a compared the elapsed

96
00:03:31,350 --> 00:03:29,440
time on three hydrogen major clocks two

97
00:03:33,910 --> 00:03:31,360
were fixed on the earth and one was

98
00:03:36,309 --> 00:03:33,920
flown in space for about two hours

99
00:03:38,550 --> 00:03:36,319
confirming that a clock on the earth

100
00:03:40,949 --> 00:03:38,560
runs slower than a clock at the altitude

101
00:03:43,030 --> 00:03:40,959
of the spacecraft which is a consequence

102
00:03:45,509 --> 00:03:43,040
of the equivalence principle

103
00:03:47,430 --> 00:03:45,519
this measurement was extremely precise

104
00:03:49,750 --> 00:03:47,440
verifying the equivalence principle to

105
00:03:51,750 --> 00:03:49,760
about 70 parts per million

106
00:03:54,630 --> 00:03:51,760
gravity probe b represents one of the

107
00:03:56,229 --> 00:03:54,640
longest running projects in nasa history

108
00:03:59,350 --> 00:03:56,239
with nasa involvement starting in the

109
00:04:00,949 --> 00:03:59,360
fall of 1963 when nancy roman who's in

110
00:04:02,550 --> 00:04:00,959
the audience there

111
00:04:04,390 --> 00:04:02,560
provided initial funding for the

112
00:04:05,589 --> 00:04:04,400
development of a relativity gyroscope

113
00:04:07,030 --> 00:04:05,599

experiment

114
00:04:11,190 --> 00:04:07,040
francis everett who has been the

115
00:04:12,470 --> 00:04:11,200
principal investigator of gpb since 1981

116
00:04:15,589 --> 00:04:12,480
started with the project as a

117
00:04:17,670 --> 00:04:15,599
postdoctoral researcher in 1962

118
00:04:19,670 --> 00:04:17,680
at that time he assisted professors

119
00:04:21,030 --> 00:04:19,680
william fairbank robert cannon and

120
00:04:23,430 --> 00:04:21,040
leonard schiff

121
00:04:25,670 --> 00:04:23,440
with the proposal to nasa

122
00:04:27,830 --> 00:04:25,680
dr brad parkinson played a key role as a

123
00:04:30,870 --> 00:04:27,840
co-pi and project manager starting in a

124
00:04:33,590 --> 00:04:30,880
1984 as did doctors daniel de bray and

125
00:04:35,830 --> 00:04:33,600
john turner who were also co-pi's on

126
00:04:38,230 --> 00:04:35,840
this mission over the years stanford

127
00:04:41,189 --> 00:04:38,240
had many excellent project managers

128
00:04:43,909 --> 00:04:41,199
including bob farnsworth sasha bookman

129
00:04:45,590 --> 00:04:43,919
ron singley gaylord greene bill bensey

130
00:04:49,270 --> 00:04:45,600
and barry mulfelder

131
00:04:50,790 --> 00:04:49,280
dr matt kaiser is gpb's chief scientist

132
00:04:52,070 --> 00:04:50,800
two of our panelists

133
00:04:54,870 --> 00:04:52,080
played important roles during the

134
00:04:57,670 --> 00:04:54,880
development of gpb dr colleen hartman

135
00:05:00,710 --> 00:04:57,680
was the program manager for gpb at nasa

136
00:05:03,029 --> 00:05:00,720
headquarters and mr rex jevadin oversaw

137
00:05:04,870 --> 00:05:03,039
the development of the gpb

138
00:05:05,830 --> 00:05:04,880

spacecraft at the marshall space flight

139
00:05:08,070 --> 00:05:05,840
center

140
00:05:10,870 --> 00:05:08,080
after rex left the project management

141
00:05:14,070 --> 00:05:10,880
role at marshall mr tony lyons was the

142
00:05:15,990 --> 00:05:14,080
project manager and dr jeff kajak was

143
00:05:17,990 --> 00:05:16,000
the project scientist

144
00:05:20,070 --> 00:05:18,000
gravity pro b has touched many lives

145
00:05:22,710 --> 00:05:20,080
during the course of its evolution it

146
00:05:24,469 --> 00:05:22,720
started as a theoretical concept then it

147
00:05:27,430 --> 00:05:24,479
became a laboratory technology

148
00:05:28,950 --> 00:05:27,440
demonstration after that it transitioned

149
00:05:31,510 --> 00:05:28,960
to a flight mission

150
00:05:33,830 --> 00:05:31,520
then to an operating mission and finally

151
00:05:36,070 --> 00:05:33,840
to an extremely difficult phase of data

152
00:05:38,950 --> 00:05:36,080
analysis after the flight

153
00:05:40,950 --> 00:05:38,960
during each phase the gravity pro-b team

154
00:05:42,950 --> 00:05:40,960
rose to the challenges that it faced and

155
00:05:45,110 --> 00:05:42,960
it overcame all of them

156
00:05:46,950 --> 00:05:45,120
we now turn to professor francis everett

157
00:05:48,469 --> 00:05:46,960
who will discuss the mission in more

158
00:05:50,469 --> 00:05:48,479
detail and the results that have been

159
00:05:52,469 --> 00:05:50,479
achieved francis

160
00:05:54,550 --> 00:05:52,479
you know the scariest moment in the

161
00:05:56,790 --> 00:05:54,560
physicist's life

162
00:06:00,309 --> 00:05:56,800
is when he sees

163
00:06:02,629 --> 00:06:00,319

the apparatus going up into the sky

164
00:06:06,390 --> 00:06:02,639
and knows that the closest he will ever

165
00:06:07,990 --> 00:06:06,400
see it be to it again is 400 miles

166
00:06:09,270 --> 00:06:08,000
and then he starts thinking of all the

167
00:06:11,270 --> 00:06:09,280
things that he ought to have done

168
00:06:14,070 --> 00:06:11,280
differently

169
00:06:16,950 --> 00:06:14,080
and that experience came to me

170
00:06:21,270 --> 00:06:16,960
on 9 57 a.m

171
00:06:25,749 --> 00:06:21,280
plus 24 seconds and a bit more on april

172
00:06:28,710 --> 00:06:26,790
so

173
00:06:33,670 --> 00:06:28,720
what is gravity probably can we have the

174
00:06:37,909 --> 00:06:36,150
picture a gyroscope moving in orbit

175
00:06:38,790 --> 00:06:37,919
around the earth

176
00:06:40,710 --> 00:06:38,800
and

177
00:06:42,790 --> 00:06:40,720
let's ask what happens

178
00:06:44,070 --> 00:06:42,800
if we live in universe you newton's

179
00:06:45,029 --> 00:06:44,080
universe

180
00:06:47,110 --> 00:06:45,039
where

181
00:06:49,670 --> 00:06:47,120
space and time are absolute and you read

182
00:06:51,670 --> 00:06:49,680
an absolutely perfect gyroscope a purely

183
00:06:55,189 --> 00:06:51,680
imaginary perfect gyroscope and you

184
00:06:55,990 --> 00:06:55,199
point it at a remote point in space

185
00:06:57,589 --> 00:06:56,000
uh

186
00:06:59,270 --> 00:06:57,599
nothing will happen it will go on

187
00:07:00,150 --> 00:06:59,280
pointing in the same direction for all

188
00:07:03,029 --> 00:07:00,160

time

189
00:07:06,230 --> 00:07:03,039
but einstein's universe is different

190
00:07:09,990 --> 00:07:06,240
in einstein's universe

191
00:07:12,469 --> 00:07:10,000
space and time are warped by gravity

192
00:07:14,390 --> 00:07:12,479
and so we end up by

193
00:07:16,230 --> 00:07:14,400
handing these two effects already

194
00:07:18,469 --> 00:07:16,240
mentioned the geodetic effect in the

195
00:07:20,629 --> 00:07:18,479
plane of the orbit

196
00:07:24,070 --> 00:07:20,639
and what happens is

197
00:07:25,670 --> 00:07:24,080
the earth distorts the space around it

198
00:07:27,830 --> 00:07:25,680
very slightly

199
00:07:29,670 --> 00:07:27,840
by its gravity

200
00:07:31,830 --> 00:07:29,680
if you're in empty space you'll have a

201
00:07:34,309 --> 00:07:31,840
perfect two pi times the radius around

202
00:07:36,150 --> 00:07:34,319
the earth is a tiny bit less

203
00:07:38,870 --> 00:07:36,160
now you remember the circumference of

204
00:07:41,430 --> 00:07:38,880
the earth is 25 000 miles so you ask the

205
00:07:44,469 --> 00:07:41,440
question how much less

206
00:07:45,749 --> 00:07:44,479
from the distortion due to the earth

207
00:07:50,390 --> 00:07:45,759
and it's

208
00:07:53,749 --> 00:07:50,400
1.1 inches in 25 000 miles

209
00:07:55,749 --> 00:07:53,759
so it's a rather modest distortion

210
00:07:57,830 --> 00:07:55,759
and that's the first of the two effects

211
00:08:01,350 --> 00:07:57,840
that gravity probe b has measured

212
00:08:06,150 --> 00:08:03,430
the measurement on the gyroscope the

213
00:08:08,550 --> 00:08:06,160

effect on the gyroscope is an angular

214
00:08:11,270 --> 00:08:08,560
change of the gyroscope of

215
00:08:12,869 --> 00:08:11,280
66

216
00:08:15,430 --> 00:08:12,879
six hundred and six

217
00:08:16,950 --> 00:08:15,440
milli arc seconds at this 401 mile

218
00:08:17,830 --> 00:08:16,960
altitude

219
00:08:23,189 --> 00:08:17,840
and

220
00:08:25,189 --> 00:08:23,199
one year

221
00:08:27,670 --> 00:08:25,199
second effect is that as the earth

222
00:08:29,990 --> 00:08:27,680
rotates it drags space and time around

223
00:08:32,949 --> 00:08:30,000
with it and picture this

224
00:08:34,469 --> 00:08:32,959
imagine the earth immersed in honey

225
00:08:36,709 --> 00:08:34,479
then you can imagine the honey would be

226
00:08:38,230 --> 00:08:36,719
dragged around with it and

227
00:08:39,670 --> 00:08:38,240
your pointer in the honey would be

228
00:08:41,670 --> 00:08:39,680
dragged around and that's what happens

229
00:08:45,509 --> 00:08:41,680
to a gyroscope so the earth actually

230
00:08:50,310 --> 00:08:45,519
drags space and time around with it

231
00:08:51,990 --> 00:08:50,320
fine so what is a milliarc second

232
00:08:54,230 --> 00:08:52,000
a milliamp second is the width of a

233
00:08:56,070 --> 00:08:54,240
human hair seen at a distance of 10

234
00:08:59,829 --> 00:08:56,080
miles

235
00:09:02,710 --> 00:08:59,839
it really is a rather small angle

236
00:09:05,430 --> 00:09:02,720
and this is the accuracy which gravity

237
00:09:07,750 --> 00:09:05,440
probe b had to achieve

238
00:09:11,350 --> 00:09:07,760

now it's nice to go back to listen to

239
00:09:14,230 --> 00:09:11,360
something that einstein said in 1953 in

240
00:09:16,389 --> 00:09:14,240
his book the meaning of relativity so

241
00:09:18,070 --> 00:09:16,399
i'm going to read this to you

242
00:09:20,389 --> 00:09:18,080
these effects and he's referring

243
00:09:22,710 --> 00:09:20,399
actually the frame dragging effect

244
00:09:25,509 --> 00:09:22,720
which are to be expected in accordance

245
00:09:28,230 --> 00:09:25,519
with ernst marx's ideas

246
00:09:29,829 --> 00:09:28,240
are actually present according to our

247
00:09:33,030 --> 00:09:29,839
theory

248
00:09:34,949 --> 00:09:33,040
although their magnitude is so small

249
00:09:39,430 --> 00:09:34,959
that confirmation of them by laboratory

250
00:09:42,949 --> 00:09:41,110
nice quotation

251
00:09:44,630 --> 00:09:42,959
but thanks to nasa

252
00:09:47,190 --> 00:09:44,640
we've done more than think about them

253
00:09:52,710 --> 00:09:47,200
we've actually measured them

254
00:09:56,550 --> 00:09:54,310
so what you see here is the final

255
00:09:59,350 --> 00:09:56,560
results and the drawing on the left

256
00:10:01,430 --> 00:09:59,360
shows the change in direction of the

257
00:10:03,350 --> 00:10:01,440
spin over the course of a year for the

258
00:10:04,949 --> 00:10:03,360
geodetic effect

259
00:10:06,870 --> 00:10:04,959
in newton's universe it would be a

260
00:10:09,590 --> 00:10:06,880
straight line along the top but you see

261
00:10:11,590 --> 00:10:09,600
for the four gyroscopes you get the

262
00:10:13,670 --> 00:10:11,600
change the same change

263
00:10:15,509 --> 00:10:13,680

the much smaller frame dragging effect

264
00:10:17,190 --> 00:10:15,519
you also see a similar change on the

265
00:10:19,590 --> 00:10:17,200
right hand kind and when you look below

266
00:10:24,590 --> 00:10:19,600
we have the numbers the geodetic effect

267
00:10:27,910 --> 00:10:24,600
the predicted relativity effect is 606

268
00:10:29,430 --> 00:10:27,920
606.1 of these milliarc seconds and the

269
00:10:32,310 --> 00:10:29,440
measured result is

270
00:10:34,310 --> 00:10:32,320
about a quarter of a little over a

271
00:10:37,030 --> 00:10:34,320
quarter of a percent of that

272
00:10:39,509 --> 00:10:37,040
the frame dragging we've measured to a

273
00:10:41,750 --> 00:10:39,519
little better than 20 percent

274
00:10:43,190 --> 00:10:41,760
so that's the results of the experiment

275
00:10:45,350 --> 00:10:43,200
and we'll come back and say more about

276
00:10:46,790 --> 00:10:45,360
them later

277
00:10:48,389 --> 00:10:46,800
so you stand back at this point and

278
00:10:50,630 --> 00:10:48,399
you'll say well why bother about

279
00:10:52,550 --> 00:10:50,640
checking testing einstein i mean these

280
00:10:54,870 --> 00:10:52,560
theories were developed a long time ago

281
00:10:56,790 --> 00:10:54,880
haven't they all been established

282
00:10:59,030 --> 00:10:56,800
we need to understand that einstein

283
00:11:01,990 --> 00:10:59,040
developed two different theories of

284
00:11:04,150 --> 00:11:02,000
relativity 1905

285
00:11:06,150 --> 00:11:04,160
your special theory of relativity deals

286
00:11:08,630 --> 00:11:06,160
with objects that are moving at very

287
00:11:11,910 --> 00:11:08,640
high speeds close to the speed of light

288
00:11:14,069 --> 00:11:11,920

this is extremely well tested you can

289
00:11:15,750 --> 00:11:14,079
ponder about philosophical significance

290
00:11:16,949 --> 00:11:15,760
but as far as the equations and the

291
00:11:20,949 --> 00:11:16,959
numbers

292
00:11:25,030 --> 00:11:23,509
general relativity as we usually call it

293
00:11:26,790 --> 00:11:25,040
maybe you should call it einstein's

294
00:11:29,829 --> 00:11:26,800
theory of gravity

295
00:11:33,430 --> 00:11:29,839
which came 11 years later took einstein

296
00:11:36,790 --> 00:11:33,440
11 years to develop this theory

297
00:11:40,790 --> 00:11:36,800
it's the theory of gravity as we've seen

298
00:11:43,030 --> 00:11:40,800
and this is much less than well tested

299
00:11:45,269 --> 00:11:43,040
the experiments have really been few and

300
00:11:47,670 --> 00:11:45,279
far between that are quantitative

301
00:11:49,910 --> 00:11:47,680
experiments so we know of effects and

302
00:11:52,069 --> 00:11:49,920
can see qualitatively that they may be

303
00:11:55,110 --> 00:11:52,079
correct

304
00:11:57,509 --> 00:11:55,120
the problem is the annoying thing is

305
00:11:59,030 --> 00:11:57,519
newton was much too successful in his

306
00:12:01,190 --> 00:11:59,040
theory of gravity

307
00:12:03,350 --> 00:12:01,200
you can call that annoying or if you

308
00:12:04,949 --> 00:12:03,360
were an experimentally person-minded

309
00:12:06,629 --> 00:12:04,959
person you could say it's exciting

310
00:12:08,550 --> 00:12:06,639
because it now gives us something to do

311
00:12:11,590 --> 00:12:08,560
that's going to be a challenge

312
00:12:14,310 --> 00:12:11,600
whichever way but whatever you take on

313
00:12:17,110 --> 00:12:14,320

that point of view einstein's theory is

314
00:12:18,790 --> 00:12:17,120
tremendously deep because it's basis of

315
00:12:20,470 --> 00:12:18,800
our understanding of the large-scale

316
00:12:21,430 --> 00:12:20,480
structure of the universe

317
00:12:28,069 --> 00:12:21,440
and

318
00:12:31,829 --> 00:12:28,079
black holes gamma-ray bursts jets from

319
00:12:36,230 --> 00:12:33,670
so we've managed to test two of the most

320
00:12:39,350 --> 00:12:36,240
profound effects of general relativity

321
00:12:41,590 --> 00:12:39,360
and do so in a new way

322
00:12:45,750 --> 00:12:41,600
now the heart of this experiment was the

323
00:12:50,870 --> 00:12:48,150
that's interesting we only see one and a

324
00:12:56,389 --> 00:12:50,880
half of this picture but that's fine

325
00:13:01,509 --> 00:12:59,350
seven undergraduate students

326
00:13:05,509 --> 00:13:01,519
which shows the

327
00:13:08,389 --> 00:13:05,519
out of roundness of this gyro rotor

328
00:13:10,150 --> 00:13:08,399
the you see it's in mountains and oceans

329
00:13:13,030 --> 00:13:10,160
the highest mountain if you blew this up

330
00:13:14,310 --> 00:13:13,040
to the size of the earth would be 10

331
00:13:15,910 --> 00:13:14,320
feet

332
00:13:17,670 --> 00:13:15,920
the other part of this picture that i

333
00:13:20,230 --> 00:13:17,680
had intended to show you seems to have

334
00:13:22,230 --> 00:13:20,240
got lost was a picture of the gyroscope

335
00:13:24,230 --> 00:13:22,240
housing itself may diffuse courts

336
00:13:26,310 --> 00:13:24,240
possibly to rex jebedian we'll show you

337
00:13:28,550 --> 00:13:26,320
something but actually we have it right

338
00:13:30,550 --> 00:13:28,560

here in real life

339
00:13:33,509 --> 00:13:30,560
so here is the sphere the size of a ping

340
00:13:36,310 --> 00:13:33,519
pong ball going in the courts housing we

341
00:13:40,870 --> 00:13:36,320
electrically suspend it we spin it up by

342
00:13:42,710 --> 00:13:40,880
means of gas get it spinning to 5000 rpm

343
00:13:45,750 --> 00:13:42,720
pump out the gas to an extremely high

344
00:13:47,590 --> 00:13:45,760
vacuum and there we've got a gyroscope

345
00:13:49,350 --> 00:13:47,600
which brings us to the question of how

346
00:13:51,189 --> 00:13:49,360
do you measure the direction of spin of

347
00:13:55,030 --> 00:13:51,199
a perfectly round perfectly uniform

348
00:13:59,590 --> 00:13:57,350
and this is where superconductivity the

349
00:14:01,670 --> 00:13:59,600
phenomenon discovered exactly a hundred

350
00:14:04,230 --> 00:14:01,680
years ago this year

351
00:14:06,310 --> 00:14:04,240
leads to its what was discovered is that

352
00:14:08,069 --> 00:14:06,320
when certain materials are cool to very

353
00:14:08,949 --> 00:14:08,079
low temperatures

354
00:14:11,030 --> 00:14:08,959
they

355
00:14:12,389 --> 00:14:11,040
completely lose their electrical

356
00:14:13,829 --> 00:14:12,399
resistance

357
00:14:16,389 --> 00:14:13,839
but they have another property that when

358
00:14:19,030 --> 00:14:16,399
you spin them they develop a magnetic

359
00:14:21,750 --> 00:14:19,040
moment a magnetic pointer in them lined

360
00:14:23,590 --> 00:14:21,760
with a spin axis spin them twice as fast

361
00:14:25,110 --> 00:14:23,600
as it gets twice as big stop spinning

362
00:14:26,629 --> 00:14:25,120
and it disappears spin them in the

363
00:14:28,069 --> 00:14:26,639

opposite direction it points in the

364
00:14:29,670 --> 00:14:28,079
other direction

365
00:14:30,790 --> 00:14:29,680
be that as it may

366
00:14:32,949 --> 00:14:30,800
this

367
00:14:35,189 --> 00:14:32,959
with the aid of some very interesting

368
00:14:37,430 --> 00:14:35,199
devices called superconducting quantum

369
00:14:40,230 --> 00:14:37,440
interference devices

370
00:14:41,030 --> 00:14:40,240
all connected into here

371
00:14:44,150 --> 00:14:41,040
uh

372
00:14:46,389 --> 00:14:44,160
gave us a readout which was able to read

373
00:14:50,710 --> 00:14:46,399
one thousandth of an arc second change

374
00:14:53,110 --> 00:14:50,720
in spin direction in 10 hours of time

375
00:14:55,509 --> 00:14:53,120
amazingly sensitive

376
00:14:58,550 --> 00:14:55,519
and in fact the truth is the secret of

377
00:15:01,350 --> 00:14:58,560
this experimentation is causes

378
00:15:03,750 --> 00:15:01,360
two different technologies space

379
00:15:06,790 --> 00:15:03,760
and low temperature physics technology

380
00:15:09,030 --> 00:15:06,800
oh now you see the gyroscope there good

381
00:15:14,949 --> 00:15:09,040
well let's go on over to the next slide

382
00:15:20,550 --> 00:15:18,430
and there on the left you see a

383
00:15:23,269 --> 00:15:20,560
600 gallon

384
00:15:26,710 --> 00:15:23,279
thermos bottle

385
00:15:28,230 --> 00:15:26,720
600 gallon 2400 liters developed by

386
00:15:30,230 --> 00:15:28,240
lockheed martin

387
00:15:31,590 --> 00:15:30,240
in close collaboration with us at

388
00:15:34,150 --> 00:15:31,600

stanford

389
00:15:39,430 --> 00:15:34,160
which managed to stay cold when it was

390
00:15:41,829 --> 00:15:39,440
up in orbit for 17 months and nine days

391
00:15:43,749 --> 00:15:41,839
um lockheed got a little bit of an award

392
00:15:45,990 --> 00:15:43,759
for this because they had only promised

393
00:15:48,949 --> 00:15:46,000
16 and a half months and they beat it by

394
00:15:52,470 --> 00:15:48,959
23 days and it actually turned out those

395
00:15:55,829 --> 00:15:52,480
23 days were very useful

396
00:15:59,590 --> 00:15:57,749
not only does this make this readout

397
00:16:01,110 --> 00:15:59,600
possible it did a whole number of other

398
00:16:03,430 --> 00:16:01,120
things in making this experiment

399
00:16:04,790 --> 00:16:03,440
shielding the gyroscope making a system

400
00:16:07,670 --> 00:16:04,800
mechanically stable it was the

401
00:16:09,110 --> 00:16:07,680
combination of the two the spot counted

402
00:16:11,189 --> 00:16:09,120
and on the right

403
00:16:13,030 --> 00:16:11,199
you start you see with a build wall the

404
00:16:14,710 --> 00:16:13,040
size of a ping pong ball and you end up

405
00:16:17,030 --> 00:16:14,720
with a spacecraft that

406
00:16:19,670 --> 00:16:17,040
stands 24 feet high

407
00:16:20,629 --> 00:16:19,680
but with four of them in it

408
00:16:22,870 --> 00:16:20,639
so

409
00:16:24,069 --> 00:16:22,880
how did this develop we heard about the

410
00:16:26,870 --> 00:16:24,079
funding that

411
00:16:28,790 --> 00:16:26,880
was initiated by nancy roman and was

412
00:16:30,870 --> 00:16:28,800
developed for us in the laboratory in a

413
00:16:33,350 --> 00:16:30,880

certain point after time

414
00:16:34,550 --> 00:16:33,360
you go through a major review process

415
00:16:37,189 --> 00:16:34,560
and

416
00:16:38,230 --> 00:16:37,199
now we're ready to go to space no we're

417
00:16:40,389 --> 00:16:38,240
not

418
00:16:43,670 --> 00:16:40,399
it's at this point you make the huge

419
00:16:45,990 --> 00:16:43,680
transition from laboratory experience to

420
00:16:48,790 --> 00:16:46,000
a flight program

421
00:16:50,550 --> 00:16:48,800
and the key figure in accomplishing this

422
00:16:53,030 --> 00:16:50,560
he's very sorry he wasn't able to be

423
00:16:55,990 --> 00:16:53,040
with us today as bradford parkinson he's

424
00:16:57,910 --> 00:16:56,000
got an unavoidable other commitment

425
00:17:01,749 --> 00:16:57,920
but

426
00:17:03,509 --> 00:17:01,759
he had done his phd on what related to

427
00:17:05,990 --> 00:17:03,519
gravity probe be

428
00:17:07,750 --> 00:17:06,000
he then became an air force officer he

429
00:17:09,829 --> 00:17:07,760
was an air force officer became the air

430
00:17:12,230 --> 00:17:09,839
force colonel responsible for the

431
00:17:13,750 --> 00:17:12,240
development and flight of the first four

432
00:17:14,870 --> 00:17:13,760
gps

433
00:17:17,909 --> 00:17:14,880
satellites

434
00:17:20,710 --> 00:17:17,919
we used to like to tease brad that he's

435
00:17:22,150 --> 00:17:20,720
just changed one letter gps to gpb but

436
00:17:23,909 --> 00:17:22,160
whatever

437
00:17:26,230 --> 00:17:23,919
anyway

438
00:17:27,990 --> 00:17:26,240

one learned an enormous amount from brad

439
00:17:30,310 --> 00:17:28,000
and one of the most interesting remarks

440
00:17:31,669 --> 00:17:30,320
he made one month after he joined us was

441
00:17:35,590 --> 00:17:31,679
look this

442
00:17:37,909 --> 00:17:35,600
what we're doing here is a cross between

443
00:17:40,390 --> 00:17:37,919
an academic program

444
00:17:41,750 --> 00:17:40,400
and a silicon valley startup

445
00:17:44,950 --> 00:17:41,760
and you've got to have both those

446
00:17:46,710 --> 00:17:44,960
mindsets to pull this off

447
00:17:49,029 --> 00:17:46,720
after all you're doing it in university

448
00:17:50,870 --> 00:17:49,039
and it better be a university program

449
00:17:52,630 --> 00:17:50,880
but you've got to be serious working

450
00:17:54,630 --> 00:17:52,640
with industry and everything about how

451
00:17:57,029 --> 00:17:54,640
that gets done

452
00:17:58,390 --> 00:17:57,039
and that was the challenge and the

453
00:18:00,789 --> 00:17:58,400
opportunity

454
00:18:03,909 --> 00:18:00,799
in total this program has seen a hundred

455
00:18:05,990 --> 00:18:03,919
students winning phds

456
00:18:07,830 --> 00:18:06,000
86 at stanford

457
00:18:09,190 --> 00:18:07,840
five at the university of alabama

458
00:18:11,270 --> 00:18:09,200
huntsville

459
00:18:13,350 --> 00:18:11,280
three at the university of aberdeen in

460
00:18:15,110 --> 00:18:13,360
scotland and others at other

461
00:18:16,590 --> 00:18:15,120
universities

462
00:18:19,190 --> 00:18:16,600
also been

463
00:18:20,630 --> 00:18:19,200

353 undergraduates who worked at i

464
00:18:23,750 --> 00:18:20,640
mentioned the work of the mapping that

465
00:18:25,669 --> 00:18:23,760
was done by seven undergraduates

466
00:18:27,190 --> 00:18:25,679
and we've had some very interesting high

467
00:18:29,029 --> 00:18:27,200
school working

468
00:18:30,310 --> 00:18:29,039
students working with us

469
00:18:32,390 --> 00:18:30,320
and i'm glad to say we got

470
00:18:34,150 --> 00:18:32,400
representatives of all three groups with

471
00:18:35,590 --> 00:18:34,160
us here today

472
00:18:38,070 --> 00:18:35,600
some of them are just a little bit older

473
00:18:39,669 --> 00:18:38,080
than they once were but that's all right

474
00:18:41,669 --> 00:18:39,679
you know

475
00:18:43,750 --> 00:18:41,679
now

476
00:18:45,909 --> 00:18:43,760
an old established principle in

477
00:18:47,669 --> 00:18:45,919
experimental physics

478
00:18:50,950 --> 00:18:47,679
supposing you're worried about a certain

479
00:18:54,070 --> 00:18:50,960
error and you're not sure how bad it is

480
00:18:56,870 --> 00:18:54,080
what you do is you deliberately increase

481
00:18:59,590 --> 00:18:56,880
it in some calibrated way so that you

482
00:19:02,310 --> 00:18:59,600
can determine how bad it is or how good

483
00:19:05,750 --> 00:19:02,320
it is whether you're fine or not and we

484
00:19:08,630 --> 00:19:05,760
had in our last 46 days

485
00:19:11,909 --> 00:19:08,640
23 of them given us free by lockheed

486
00:19:15,750 --> 00:19:11,919
we had this calibration phase where we

487
00:19:18,470 --> 00:19:15,760
deliberately did various enhancements

488
00:19:21,190 --> 00:19:18,480

and we discovered one serious effect of

489
00:19:24,390 --> 00:19:21,200
misalignment talk a factor of 100 busier

490
00:19:27,510 --> 00:19:24,400
than we had expected it to be and this

491
00:19:29,830 --> 00:19:27,520
led us to a five-year detective story we

492
00:19:32,470 --> 00:19:29,840
actually discovered three different

493
00:19:34,710 --> 00:19:32,480
consequences of this the one we found

494
00:19:36,870 --> 00:19:34,720
and then two others later

495
00:19:39,110 --> 00:19:36,880
and but we managed to catch the three

496
00:19:41,270 --> 00:19:39,120
criminals and lock them up and that's

497
00:19:44,230 --> 00:19:41,280
how we got the results and it's a heroic

498
00:19:45,110 --> 00:19:44,240
effort by the team i would say

499
00:19:46,549 --> 00:19:45,120
so

500
00:19:49,110 --> 00:19:46,559
in this

501
00:19:51,990 --> 00:19:49,120
completing the data analysis was a large

502
00:19:54,549 --> 00:19:52,000
herd grind we owe enormous thanks to

503
00:19:56,150 --> 00:19:54,559
richard fairbank with matching funds

504
00:19:59,830 --> 00:19:56,160
from nasa

505
00:20:03,590 --> 00:19:59,840
part of it to vance and arlene kaufman

506
00:20:06,390 --> 00:20:03,600
and to the saudi arabian institute kext

507
00:20:08,950 --> 00:20:06,400
not only for a certain amount of support

508
00:20:11,110 --> 00:20:08,960
but also from some superb brains whom

509
00:20:14,710 --> 00:20:11,120
they brought to work with us at stanford

510
00:20:16,870 --> 00:20:14,720
for outstanding analysts

511
00:20:18,549 --> 00:20:16,880
now gravity probe b is not only a new

512
00:20:21,430 --> 00:20:18,559
experiment it's a new

513
00:20:23,830 --> 00:20:21,440

kind of experiment and i don't want to

514
00:20:25,750 --> 00:20:23,840
over or underestimate that

515
00:20:28,070 --> 00:20:25,760
you see it's a controlled physics

516
00:20:31,350 --> 00:20:28,080
experiment based on exact measurements

517
00:20:33,909 --> 00:20:31,360
on orbiting gyroscopes and

518
00:20:36,630 --> 00:20:33,919
many other several other important tests

519
00:20:38,390 --> 00:20:36,640
have been more astrophysical tests

520
00:20:41,350 --> 00:20:38,400
not ranking one against the other but

521
00:20:43,350 --> 00:20:41,360
the great beauty of it is that we have

522
00:20:44,870 --> 00:20:43,360
complementary tests of general

523
00:20:45,990 --> 00:20:44,880
relativity

524
00:20:48,230 --> 00:20:46,000
and so

525
00:20:49,830 --> 00:20:48,240
it was a big challenge and i don't think

526
00:20:51,750 --> 00:20:49,840
we could have ever done it if it hadn't

527
00:20:54,230 --> 00:20:51,760
been for the great collaboration we had

528
00:20:57,270 --> 00:20:54,240
between nasa marshall center

529
00:20:58,230 --> 00:20:57,280
lockheed martin and stanford university

530
00:21:01,029 --> 00:20:58,240
and

531
00:21:03,510 --> 00:21:01,039
that's wonderful have done that

532
00:21:05,990 --> 00:21:03,520
so we completed this landmark experiment

533
00:21:06,870 --> 00:21:06,000
testing einstein's universe

534
00:21:09,669 --> 00:21:06,880
and

535
00:21:11,830 --> 00:21:09,679
einstein survives

536
00:21:14,830 --> 00:21:11,840
so now rex jebedian will say something

537
00:21:16,390 --> 00:21:14,840
about the technologies thank you

538
00:21:18,390 --> 00:21:16,400

francis

539
00:21:20,549 --> 00:21:18,400
gravity probe v while conceptually

540
00:21:23,190 --> 00:21:20,559
simple is a technologically

541
00:21:25,270 --> 00:21:23,200
extremely complex experiment in fact the

542
00:21:26,870 --> 00:21:25,280
the idea came about three four decades

543
00:21:28,310 --> 00:21:26,880
before the technology was available to

544
00:21:30,390 --> 00:21:28,320
test the idea and that's the reason for

545
00:21:33,110 --> 00:21:30,400
the five decades history on it

546
00:21:34,549 --> 00:21:33,120
a french francis mentioned 13 novel

547
00:21:36,470 --> 00:21:34,559
technologies that were created for

548
00:21:38,070 --> 00:21:36,480
gravity probe b i'm going to mention

549
00:21:39,590 --> 00:21:38,080
about a half a dozen of them here but

550
00:21:41,669 --> 00:21:39,600
i'll say that

551
00:21:43,590 --> 00:21:41,679
that special technology breakthroughs

552
00:21:45,190 --> 00:21:43,600
were required in every significant part

553
00:21:46,710 --> 00:21:45,200
of the experiment including the science

554
00:21:48,230 --> 00:21:46,720
instrument itself

555
00:21:49,830 --> 00:21:48,240
the science payload and also the

556
00:21:51,270 --> 00:21:49,840
spacecraft

557
00:21:55,430 --> 00:21:51,280
if you would please bring up the slide

558
00:21:59,990 --> 00:21:57,750
francis has already talked about this

559
00:22:01,750 --> 00:22:00,000
this exquisite quartz ball here if i

560
00:22:03,430 --> 00:22:01,760
could borrow your prop francis i'll give

561
00:22:04,710 --> 00:22:03,440
it back i promise

562
00:22:06,549 --> 00:22:04,720
these are thought to be the roundest

563
00:22:07,830 --> 00:22:06,559

objects ever manufactured in fact you

564
00:22:09,990 --> 00:22:07,840
can look in the guinness book of world

565
00:22:11,830 --> 00:22:10,000
records and find that it's in there

566
00:22:13,510 --> 00:22:11,840
the diametric variation across this

567
00:22:15,990 --> 00:22:13,520
sphere is about two tenths of a

568
00:22:18,070 --> 00:22:16,000
millionth of an inch so it's incredibly

569
00:22:20,149 --> 00:22:18,080
round uh an amazing achievement it's

570
00:22:22,230 --> 00:22:20,159
also very very homogeneous you have the

571
00:22:24,870 --> 00:22:22,240
center of mass needs to to match the

572
00:22:27,270 --> 00:22:24,880
center of geometry of this to avoid any

573
00:22:28,230 --> 00:22:27,280
uh non-newtonia to avoid any newtonian

574
00:22:29,510 --> 00:22:28,240
torques

575
00:22:31,190 --> 00:22:29,520
uh the

576
00:22:33,669 --> 00:22:31,200
equipment that was used to manufacture

577
00:22:35,110 --> 00:22:33,679
those balls this lapping machine was

578
00:22:36,950 --> 00:22:35,120
actually invented at the marshall space

579
00:22:39,190 --> 00:22:36,960
flight center and later refined at

580
00:22:40,870 --> 00:22:39,200
stanford university

581
00:22:42,310 --> 00:22:40,880
and by the way sasha buchmann who's

582
00:22:44,390 --> 00:22:42,320
sitting in the audience here today was

583
00:22:46,470 --> 00:22:44,400
involved ran the gyroscope development

584
00:22:48,310 --> 00:22:46,480
for a good number of years

585
00:22:50,710 --> 00:22:48,320
the gyroscope suspension system was

586
00:22:52,549 --> 00:22:50,720
another trick this

587
00:22:54,549 --> 00:22:52,559
system not only suspends and controls

588
00:22:56,230 --> 00:22:54,559

the gyros at the beginning of the

589
00:22:58,149 --> 00:22:56,240
experiment it also provides very

590
00:23:00,630 --> 00:22:58,159
accurate position information that's

591
00:23:02,310 --> 00:23:00,640
used to feed back into the spacecraft to

592
00:23:03,510 --> 00:23:02,320
enable the drag-free operation of the

593
00:23:05,590 --> 00:23:03,520
spacecraft i'm going to talk a little

594
00:23:06,549 --> 00:23:05,600
more about drag-free in just a minute

595
00:23:08,070 --> 00:23:06,559
and

596
00:23:09,510 --> 00:23:08,080
rob brumley bill bensley are in the

597
00:23:11,350 --> 00:23:09,520
audience today they were both involved

598
00:23:12,470 --> 00:23:11,360
in aspects of that gyro suspension and

599
00:23:15,029 --> 00:23:12,480
spin-up

600
00:23:16,710 --> 00:23:15,039
uh the gyro readout system that francis

601
00:23:19,190 --> 00:23:16,720
mentioned earlier which uses these super

602
00:23:21,669 --> 00:23:19,200
conducting quantum interference devices

603
00:23:24,310 --> 00:23:21,679
to read this london moment from the from

604
00:23:26,149 --> 00:23:24,320
the spinning superconductor uh this is

605
00:23:28,149 --> 00:23:26,159
this is an amazing uh set of

606
00:23:30,070 --> 00:23:28,159
technologies i always think of the

607
00:23:31,990 --> 00:23:30,080
london moment as god's gift to gravity

608
00:23:34,310 --> 00:23:32,000
probe be i mean how do you measure the

609
00:23:36,230 --> 00:23:34,320
direction of this of the spin axis of

610
00:23:38,070 --> 00:23:36,240
this gyroscope without disturbing it and

611
00:23:40,070 --> 00:23:38,080
we get that through the london moment

612
00:23:42,070 --> 00:23:40,080
barry mulfelder who's in the audience

613
00:23:43,430 --> 00:23:42,080

today by the way was involved in in the

614
00:23:45,669 --> 00:23:43,440
squid development

615
00:23:47,909 --> 00:23:45,679
uh one of the photographs that you see

616
00:23:49,990 --> 00:23:47,919
there this you can see the photograph of

617
00:23:51,350 --> 00:23:50,000
the telescope lab technicians holding

618
00:23:53,669 --> 00:23:51,360
that telescope it's about eight inches

619
00:23:55,350 --> 00:23:53,679
in diameter that's a beautiful

620
00:23:57,830 --> 00:23:55,360
breathtakingly beautiful in my opinion

621
00:23:59,909 --> 00:23:57,840
solid glass telescope it functions as a

622
00:24:01,909 --> 00:23:59,919
star tracker in this experiment

623
00:24:03,669 --> 00:24:01,919
and it's the certainly the most precise

624
00:24:04,630 --> 00:24:03,679
star tracker ever conceived and never

625
00:24:06,789 --> 00:24:04,640
developed

626
00:24:08,950 --> 00:24:06,799
a typical star tractor looks at a truck

627
00:24:10,549 --> 00:24:08,960
tracker looks at a field of stars and

628
00:24:12,710 --> 00:24:10,559
uses that to help the spacecraft to

629
00:24:14,630 --> 00:24:12,720
navigate this particular one

630
00:24:16,789 --> 00:24:14,640
literally splits the star into four

631
00:24:18,630 --> 00:24:16,799
quadrants to provide very precise

632
00:24:20,310 --> 00:24:18,640
pointing all the way through the entire

633
00:24:21,830 --> 00:24:20,320
experiment

634
00:24:23,669 --> 00:24:21,840
the science payload

635
00:24:26,149 --> 00:24:23,679
has its own set of amazing technologies

636
00:24:27,830 --> 00:24:26,159
this you saw the you saw the photograph

637
00:24:30,149 --> 00:24:27,840
of the dewar earlier on this giant

638
00:24:32,149 --> 00:24:30,159

thermos bottle 600 gallon

639
00:24:34,070 --> 00:24:32,159
thermos bottle kept the the the

640
00:24:37,430 --> 00:24:34,080
experiment at near absolute zero for

641
00:24:39,510 --> 00:24:37,440
about 18 months that's about 460 degrees

642
00:24:41,190 --> 00:24:39,520
60 degrees below zero fahrenheit by the

643
00:24:44,070 --> 00:24:41,200
way

644
00:24:46,390 --> 00:24:44,080
and it was filled with superfluid helium

645
00:24:48,149 --> 00:24:46,400
inside that doer is a special technology

646
00:24:50,470 --> 00:24:48,159
that was invented on gravity probe b

647
00:24:52,390 --> 00:24:50,480
called the porous plug and that porous

648
00:24:54,789 --> 00:24:52,400
plug what it does is it controls the

649
00:24:56,390 --> 00:24:54,799
interface between the vapor and the

650
00:24:59,190 --> 00:24:56,400
liquid side of that experiment in other

651
00:25:00,789 --> 00:24:59,200
words it allows the helium to boil off

652
00:25:03,430 --> 00:25:00,799
as it warms up but it keeps that

653
00:25:05,269 --> 00:25:03,440
superfluid inside the container super

654
00:25:07,510 --> 00:25:05,279
fluids want to crawl out of there want

655
00:25:09,669 --> 00:25:07,520
to crawl out of their container and so

656
00:25:11,750 --> 00:25:09,679
managing that interface is a trick and

657
00:25:13,190 --> 00:25:11,760
it took special special technology

658
00:25:14,789 --> 00:25:13,200
breakthrough and a special material to

659
00:25:17,110 --> 00:25:14,799
do that

660
00:25:18,870 --> 00:25:17,120
that there's a there's a payload feature

661
00:25:21,750 --> 00:25:18,880
called the probe it's about a ten foot

662
00:25:23,510 --> 00:25:21,760
long uh structure that's used that goes

663
00:25:25,909 --> 00:25:23,520

down into the probe and interfaces the

664
00:25:27,430 --> 00:25:25,919
science instrument to the doer

665
00:25:30,070 --> 00:25:27,440
one of the interesting techniques that

666
00:25:31,830 --> 00:25:30,080
we used uh was to try the

667
00:25:33,750 --> 00:25:31,840
let me back up and say gravity probe b

668
00:25:35,430 --> 00:25:33,760
has to be very magnetically pure it

669
00:25:37,029 --> 00:25:35,440
can't be under the influence of magnetic

670
00:25:39,269 --> 00:25:37,039
fields or it'll mess up the

671
00:25:41,110 --> 00:25:39,279
superconducting readings and so the

672
00:25:42,470 --> 00:25:41,120
probe has to block the earth's magnetic

673
00:25:44,630 --> 00:25:42,480
field but it also

674
00:25:46,470 --> 00:25:44,640
we also had to to work on cleaning out

675
00:25:48,390 --> 00:25:46,480
any stray magnetics that would be inside

676
00:25:50,390 --> 00:25:48,400
the experiment inside the probe and that

677
00:25:51,990 --> 00:25:50,400
was done with this ingenious technique

678
00:25:53,990 --> 00:25:52,000
called flux flushing that involved

679
00:25:55,990 --> 00:25:54,000
cycling the temperature trapping

680
00:25:58,230 --> 00:25:56,000
literally trapping the magnetic flux

681
00:26:00,310 --> 00:25:58,240
inside of a paper thin lead bag and then

682
00:26:02,870 --> 00:26:00,320
pulling layers of that lead bag out of

683
00:26:04,070 --> 00:26:02,880
the out of the probe which enabled us to

684
00:26:05,029 --> 00:26:04,080
to literally

685
00:26:07,269 --> 00:26:05,039
literally

686
00:26:09,590 --> 00:26:07,279
lift the magnetic contamination out of

687
00:26:12,149 --> 00:26:09,600
the probe john mester is here today john

688
00:26:13,909 --> 00:26:12,159

was the magnetics guru back in the day

689
00:26:15,750 --> 00:26:13,919
later went on to larger responsibilities

690
00:26:18,789 --> 00:26:15,760
but his incredible technology and an

691
00:26:20,549 --> 00:26:18,799
incredible technique in that case

692
00:26:23,269 --> 00:26:20,559
the spacecraft i already mentioned was a

693
00:26:25,990 --> 00:26:23,279
remarkable technological marvel the

694
00:26:28,070 --> 00:26:26,000
gyros have to fly basically undisturbed

695
00:26:29,990 --> 00:26:28,080
non-newtonian torques

696
00:26:31,909 --> 00:26:30,000
which means that you basically

697
00:26:34,149 --> 00:26:31,919
have to put the spacecraft into what

698
00:26:35,750 --> 00:26:34,159
simulate what is a drag-free orbit in

699
00:26:37,830 --> 00:26:35,760
other words it needs to be in free fall

700
00:26:39,990 --> 00:26:37,840
as it moves about the earth

701
00:26:41,830 --> 00:26:40,000
any spacecraft at any altitude is going

702
00:26:44,630 --> 00:26:41,840
to experience some amount of atmospheric

703
00:26:46,310 --> 00:26:44,640
drag even at 400 miles there's a very

704
00:26:47,110 --> 00:26:46,320
sort of a tenuous atmosphere you might

705
00:26:48,470 --> 00:26:47,120
say

706
00:26:50,390 --> 00:26:48,480
and because of that you have to

707
00:26:52,789 --> 00:26:50,400
compensate for that drag in order to

708
00:26:53,909 --> 00:26:52,799
keep a drag-free type of of motion to

709
00:26:55,830 --> 00:26:53,919
the spacecraft and the way we

710
00:26:59,190 --> 00:26:55,840
accomplished that was to use the helium

711
00:27:01,110 --> 00:26:59,200
boil off that helium that was boiled off

712
00:27:02,390 --> 00:27:01,120
was used to power some tiny micro

713
00:27:04,950 --> 00:27:02,400

thrusters

714
00:27:06,549 --> 00:27:04,960
uh and and they and they and they

715
00:27:09,110 --> 00:27:06,559
control the spacecraft

716
00:27:11,750 --> 00:27:09,120
attitude and translation with forces

717
00:27:13,350 --> 00:27:11,760
that approximate that of a human breath

718
00:27:15,430 --> 00:27:13,360
so you have this spacecraft just

719
00:27:18,070 --> 00:27:15,440
floating through space and this puff

720
00:27:20,149 --> 00:27:18,080
puff puff going on at about a tenth of

721
00:27:22,950 --> 00:27:20,159
your breath actually let me just

722
00:27:25,269 --> 00:27:22,960
interrupt for a moment we are very happy

723
00:27:28,310 --> 00:27:25,279
to have george pew with us who's the

724
00:27:30,230 --> 00:27:28,320
inventor of the concept of drag free

725
00:27:32,549 --> 00:27:30,240
technology and we should acknowledge him

726
00:27:34,630 --> 00:27:32,559
for that

727
00:27:36,310 --> 00:27:34,640
thank you francis um

728
00:27:37,510 --> 00:27:36,320
so when you look at technology and i

729
00:27:39,990 --> 00:27:37,520
haven't described all of these

730
00:27:42,310 --> 00:27:40,000
technologies on gravity pro b but you

731
00:27:43,669 --> 00:27:42,320
think of technology as the application

732
00:27:46,070 --> 00:27:43,679
of science to some particularly

733
00:27:48,070 --> 00:27:46,080
difficult problem uh but in the case of

734
00:27:49,990 --> 00:27:48,080
gravity probe b there was an incredible

735
00:27:52,070 --> 00:27:50,000
sort of symbiosis between science and

736
00:27:54,070 --> 00:27:52,080
technology the technology enabled the

737
00:27:55,750 --> 00:27:54,080
science the technology that was invented

738
00:27:57,909 --> 00:27:55,760

led to new science

739
00:28:00,070 --> 00:27:57,919
for example this porous plug technology

740
00:28:02,070 --> 00:28:00,080
that i've mentioned already discussed

741
00:28:03,990 --> 00:28:02,080
already was the enabling technology or

742
00:28:06,310 --> 00:28:04,000
an enabling technology for the cosmic

743
00:28:07,909 --> 00:28:06,320
background explorer which accurately

744
00:28:09,350 --> 00:28:07,919
determined the universe's radiation

745
00:28:11,750 --> 00:28:09,360
background and that's an underpinning

746
00:28:13,750 --> 00:28:11,760
for for the big bang theory of course

747
00:28:16,630 --> 00:28:13,760
and its determination led to a nobel

748
00:28:18,789 --> 00:28:16,640
prize for nasa's dr john mather and his

749
00:28:20,789 --> 00:28:18,799
colleague george smoot

750
00:28:23,110 --> 00:28:20,799
and technology development within gpb

751
00:28:25,750 --> 00:28:23,120
led to numerous science breakthroughs dr

752
00:28:28,710 --> 00:28:25,760
everett's thesis advisor was the famous

753
00:28:31,590 --> 00:28:28,720
physicist in nobel laureate pms blackett

754
00:28:33,430 --> 00:28:31,600
and he once said to francis i think

755
00:28:36,389 --> 00:28:33,440
if you can't think of what physics to do

756
00:28:38,149 --> 00:28:36,399
next then invent some new technology

757
00:28:39,830 --> 00:28:38,159
you will find you will find some new

758
00:28:41,430 --> 00:28:39,840
physics and indeed that was the case on

759
00:28:42,710 --> 00:28:41,440
gravity pro-b

760
00:28:44,710 --> 00:28:42,720
i will have to tell you that as the

761
00:28:47,350 --> 00:28:44,720
former program manager of gravity probe

762
00:28:49,110 --> 00:28:47,360
b i was often called upon to defend the

763
00:28:50,630 --> 00:28:49,120

use of public funds for something as

764
00:28:52,870 --> 00:28:50,640
esoteric as

765
00:28:54,950 --> 00:28:52,880
as a measure of as a measurement of

766
00:28:57,350 --> 00:28:54,960
einstein's relativity

767
00:28:58,950 --> 00:28:57,360
and i think the case for its defense is

768
00:29:00,310 --> 00:28:58,960
pretty compelling and pretty easy i

769
00:29:01,909 --> 00:29:00,320
would always say look

770
00:29:03,990 --> 00:29:01,919
even if you if you're not interested in

771
00:29:05,430 --> 00:29:04,000
the science result even if you if you're

772
00:29:08,710 --> 00:29:05,440
not

773
00:29:11,029 --> 00:29:08,720
educational result this hundred phds and

774
00:29:12,710 --> 00:29:11,039
so on then you at least ought to believe

775
00:29:14,470 --> 00:29:12,720
that the technologies that were invented

776
00:29:16,789 --> 00:29:14,480
in the course of gravity probe's

777
00:29:19,110 --> 00:29:16,799
development will pay dividends economic

778
00:29:21,110 --> 00:29:19,120
and scientific dividends for for decades

779
00:29:23,350 --> 00:29:21,120
to come enormous dividends

780
00:29:25,990 --> 00:29:23,360
but but even above the level of a

781
00:29:27,510 --> 00:29:26,000
practical or economic argument about it

782
00:29:29,269 --> 00:29:27,520
i would say that when you take on

783
00:29:30,710 --> 00:29:29,279
something as challenging as gravity

784
00:29:32,710 --> 00:29:30,720
probe b was

785
00:29:34,710 --> 00:29:32,720
and you're facing very long odds when it

786
00:29:36,149 --> 00:29:34,720
comes to the technology very long odds

787
00:29:39,029 --> 00:29:36,159
when it comes to even succeeding

788
00:29:41,190 --> 00:29:39,039

programmatically and you accomplish it

789
00:29:43,190 --> 00:29:41,200
then i think it's a reminder of of the

790
00:29:45,110 --> 00:29:43,200
sort of greatness that humans can get to

791
00:29:47,350 --> 00:29:45,120
when they put their hearts and minds on

792
00:29:48,789 --> 00:29:47,360
on an objective like this and so i think

793
00:29:53,350 --> 00:29:48,799
gpb

794
00:29:55,669 --> 00:29:53,360
technology but it's also about a triumph

795
00:29:57,350 --> 00:29:55,679
of the human spirit in the end

796
00:29:59,750 --> 00:29:57,360
uh with that i'd like to turn it over to

797
00:30:01,029 --> 00:29:59,760
my to my good friend and colleague dr

798
00:30:03,990 --> 00:30:01,039
colleen hartman to talk about the

799
00:30:05,830 --> 00:30:04,000
history of gpb

800
00:30:08,389 --> 00:30:05,840
five decades after it was first

801
00:30:11,830 --> 00:30:08,399
conceived today we're celebrating the

802
00:30:14,149 --> 00:30:11,840
results of the gravity pro-b experiment

803
00:30:16,870 --> 00:30:14,159
testing einstein's most compelling

804
00:30:19,110 --> 00:30:16,880
contribution to humankind is not just

805
00:30:21,510 --> 00:30:19,120
the technological marvel although rex

806
00:30:23,830 --> 00:30:21,520
makes a rather good case for that it's

807
00:30:26,389 --> 00:30:23,840
also an engineering and management case

808
00:30:28,230 --> 00:30:26,399
study that's worth a closer look so my

809
00:30:29,750 --> 00:30:28,240
job is to give you a brief history of

810
00:30:32,389 --> 00:30:29,760
gpb

811
00:30:35,190 --> 00:30:32,399
a half century ago two men had the same

812
00:30:36,950 --> 00:30:35,200
idea to use rotating gyroscopes to test

813
00:30:39,909 --> 00:30:36,960

general relativity

814
00:30:43,110 --> 00:30:39,919
and dr george pugh who is with us today

815
00:30:45,750 --> 00:30:43,120
had the idea of using a gyroscope in

816
00:30:48,710 --> 00:30:45,760
space in low earth orbit pointing at a

817
00:30:50,870 --> 00:30:48,720
guide star in a completely drag-free

818
00:30:52,950 --> 00:30:50,880
environment so no other forces would

819
00:30:55,430 --> 00:30:52,960
impinge upon it so basically you have a

820
00:30:57,909 --> 00:30:55,440
rotating top that you look at its

821
00:31:01,190 --> 00:30:57,919
precession or how much it wobbles

822
00:31:03,110 --> 00:31:01,200
he published his results in 1959

823
00:31:05,350 --> 00:31:03,120
and he was working for the institute for

824
00:31:08,149 --> 00:31:05,360
defense analysis and he was an mit

825
00:31:11,509 --> 00:31:08,159
professor so this idea was published in

826
00:31:13,990 --> 00:31:11,519
a dod publication

827
00:31:16,070 --> 00:31:14,000
he also recognized in this publication

828
00:31:18,310 --> 00:31:16,080
the application that drag free

829
00:31:21,269 --> 00:31:18,320
technology could have for us including

830
00:31:23,669 --> 00:31:21,279
in areas of autonomy geodesy

831
00:31:25,909 --> 00:31:23,679
satellite navigation and modeling the

832
00:31:27,509 --> 00:31:25,919
earth and other planets

833
00:31:30,789 --> 00:31:27,519
meanwhile

834
00:31:34,310 --> 00:31:30,799
leonard shift had the very same idea and

835
00:31:37,190 --> 00:31:34,320
he published his idea in 1960 in

836
00:31:40,389 --> 00:31:37,200
physical review letters the very same

837
00:31:43,190 --> 00:31:40,399
place where 51 years later today we're

838
00:31:44,870 --> 00:31:43,200

announcing the test results of gpb that

839
00:31:48,630 --> 00:31:44,880
francis and his colleagues are

840
00:31:52,470 --> 00:31:50,230
so

841
00:31:54,389 --> 00:31:52,480
the two men learned of each other and

842
00:31:57,190 --> 00:31:54,399
they did something rather quaint in old

843
00:31:59,190 --> 00:31:57,200
fashion if you forgive me dr few they

844
00:32:00,630 --> 00:31:59,200
wrote letters to each other

845
00:32:02,230 --> 00:32:00,640
and eventually they exchanged

846
00:32:04,789 --> 00:32:02,240
manuscripts

847
00:32:07,269 --> 00:32:04,799
so now we go up to about 1963 couple

848
00:32:09,909 --> 00:32:07,279
years later nasa begins funding stanford

849
00:32:13,110 --> 00:32:09,919
to think about this idea and that low

850
00:32:15,190 --> 00:32:13,120
level of funding goes on for two decades

851
00:32:17,590 --> 00:32:15,200
to give you a passage of time during

852
00:32:19,990 --> 00:32:17,600
that two decades nasa launches men to

853
00:32:21,909 --> 00:32:20,000
that puts men on the moon uh launches a

854
00:32:23,750 --> 00:32:21,919
probe to mercury launches the voyagers

855
00:32:25,110 --> 00:32:23,760
to do an outer planet's grand tour and

856
00:32:27,350 --> 00:32:25,120
beyond

857
00:32:29,110 --> 00:32:27,360
conceives of builds and launches the

858
00:32:31,190 --> 00:32:29,120
shuttle and begins to build the

859
00:32:34,870 --> 00:32:31,200
international space station

860
00:32:37,590 --> 00:32:34,880
then in about 1984 nasa actually funds

861
00:32:41,190 --> 00:32:37,600
stanford to begin building the gpb

862
00:32:44,310 --> 00:32:41,200
experiment and now it's a real project

863
00:32:46,710 --> 00:32:44,320

at about this time stanford subcontracts

864
00:32:49,029 --> 00:32:46,720
to the lockheed martin corporation for

865
00:32:50,710 --> 00:32:49,039
their aerospace expertise and the

866
00:32:52,630 --> 00:32:50,720
marshall space flight center comes on

867
00:32:53,990 --> 00:32:52,640
board to add their engineering expertise

868
00:32:56,789 --> 00:32:54,000
to the team

869
00:32:58,710 --> 00:32:56,799
the idea here is to make a shuttle test

870
00:33:01,269 --> 00:32:58,720
flight of some of the most important

871
00:33:03,430 --> 00:33:01,279
components of gpb for a shuttle

872
00:33:05,669 --> 00:33:03,440
acceleration environment to be followed

873
00:33:07,110 --> 00:33:05,679
two years later by a shuttle flight of

874
00:33:10,310 --> 00:33:07,120
the free flyer

875
00:33:13,269 --> 00:33:10,320
the 1986 challenger disaster changes all

876
00:33:15,590 --> 00:33:13,279
of that the plans are scrapped and now

877
00:33:17,269 --> 00:33:15,600
gpb will go directly to flight on a

878
00:33:19,909 --> 00:33:17,279
delta ii

879
00:33:22,630 --> 00:33:19,919
so in rather quick succession here

880
00:33:24,950 --> 00:33:22,640
lockheed martin produces the the this

881
00:33:26,710 --> 00:33:24,960
giant thermos bottle the dewar the probe

882
00:33:29,350 --> 00:33:26,720
the satellite they're delivered to

883
00:33:32,230 --> 00:33:29,360
stanford university the experiment this

884
00:33:33,990 --> 00:33:32,240
amazing uh four ping pong balls if you

885
00:33:36,070 --> 00:33:34,000
will coated with niobium that can be

886
00:33:38,230 --> 00:33:36,080
levitated or integrated in it it's

887
00:33:40,149 --> 00:33:38,240
tested it's shipped to vandenberg air

888
00:33:42,870 --> 00:33:40,159

force base where it meets that one

889
00:33:47,029 --> 00:33:42,880
second launch window in on april 20th

890
00:33:50,470 --> 00:33:47,039
2004 and has the regret of the pi then

891
00:33:53,350 --> 00:33:50,480
looking at it going away from him

892
00:33:56,149 --> 00:33:53,360
after several more years of data

893
00:33:58,950 --> 00:33:56,159
analysis and excruciat data collection

894
00:34:00,549 --> 00:33:58,960
and excruciating data analysis that

895
00:34:04,149 --> 00:34:00,559
brings us to

896
00:34:06,549 --> 00:34:04,159
the celebration and the event today

897
00:34:09,669 --> 00:34:06,559
the last decade has seen the development

898
00:34:11,909 --> 00:34:09,679
of exquisitely sensitive instruments new

899
00:34:14,069 --> 00:34:11,919
instruments that are able to probe our

900
00:34:15,669 --> 00:34:14,079
universe and we have received surprise

901
00:34:18,869 --> 00:34:15,679
after surprise

902
00:34:21,109 --> 00:34:18,879
when carefully tested some laws that we

903
00:34:24,149 --> 00:34:21,119
considered sacrosanct some laws of

904
00:34:25,829 --> 00:34:24,159
physics have been found deficit

905
00:34:28,149 --> 00:34:25,839
so the weakness of the gravitational

906
00:34:30,389 --> 00:34:28,159
force means that general relativity has

907
00:34:31,669 --> 00:34:30,399
not been as thoroughly tested as some

908
00:34:32,470 --> 00:34:31,679
other theories

909
00:34:34,389 --> 00:34:32,480
of

910
00:34:37,750 --> 00:34:34,399
fundamental physics

911
00:34:39,270 --> 00:34:37,760
and that's why this test result is so

912
00:34:40,869 --> 00:34:39,280
important

913
00:34:42,470 --> 00:34:40,879

now even given that

914
00:34:44,629 --> 00:34:42,480
i would say to me the most important

915
00:34:46,389 --> 00:34:44,639
thing about gpb are the people who

916
00:34:48,629 --> 00:34:46,399
touched it and whom it touched

917
00:34:51,349 --> 00:34:48,639
especially the students

918
00:34:53,750 --> 00:34:51,359
and it really is a who's who of america

919
00:34:55,349 --> 00:34:53,760
so i'm just going to name two sally ride

920
00:34:57,990 --> 00:34:55,359
worked on gpb

921
00:35:00,710 --> 00:34:58,000
and eric cornell was an undergraduate

922
00:35:03,430 --> 00:35:00,720
student on gpv he did a senior honors

923
00:35:05,829 --> 00:35:03,440
thesis on it and apparently he was so

924
00:35:09,030 --> 00:35:05,839
inspired he continued in the path of

925
00:35:11,190 --> 00:35:09,040
physics to one day recreate an

926
00:35:14,069 --> 00:35:11,200
einsteinian prediction of a state of

927
00:35:17,190 --> 00:35:14,079
matter of jose einstein condensate for

928
00:35:19,030 --> 00:35:17,200
which he won the nobel prize

929
00:35:21,430 --> 00:35:19,040
so let's return now to the thoughts of

930
00:35:23,990 --> 00:35:21,440
the most famous patent clerk in the

931
00:35:29,109 --> 00:35:26,230
i think he would be very proud of the

932
00:35:31,270 --> 00:35:29,119
tenacity of this group of researchers

933
00:35:33,589 --> 00:35:31,280
and i also think that he said something

934
00:35:36,710 --> 00:35:33,599
of himself that applies to the

935
00:35:39,270 --> 00:35:36,720
researchers scientists engineers

936
00:35:42,069 --> 00:35:39,280
technicians and support staff at

937
00:35:44,390 --> 00:35:42,079
stanford at lockheed martin at the

938
00:35:46,310 --> 00:35:44,400

marshall space flight center and to my

939
00:35:47,990 --> 00:35:46,320
colleagues and friends of gpb here at

940
00:35:49,910 --> 00:35:48,000
nasa headquarters

941
00:35:52,390 --> 00:35:49,920
einstein said

942
00:35:55,349 --> 00:35:52,400
it's not that i'm so smart

943
00:35:57,589 --> 00:35:55,359
it's just that i stay with a problem

944
00:36:00,470 --> 00:35:57,599
longer

945
00:36:01,349 --> 00:36:00,480
so now i'd like to introduce dr clifford

946
00:36:04,630 --> 00:36:01,359
will

947
00:36:07,750 --> 00:36:04,640
who is a physics professor at washington

948
00:36:11,270 --> 00:36:07,760
university at st louis and also the head

949
00:36:13,670 --> 00:36:11,280
of our external review board for gpb

950
00:36:15,589 --> 00:36:13,680
thank you

951
00:36:18,470 --> 00:36:15,599
i first want to describe the role of the

952
00:36:21,270 --> 00:36:18,480
science advisory committee for gpb

953
00:36:22,310 --> 00:36:21,280
the sac was formed in 1998 at nasa's

954
00:36:24,630 --> 00:36:22,320
request

955
00:36:26,710 --> 00:36:24,640
to help ensure that the final scientific

956
00:36:28,390 --> 00:36:26,720
result of the experiment would be of the

957
00:36:30,310 --> 00:36:28,400
highest quality

958
00:36:33,030 --> 00:36:30,320
the sac consisted of six eminent

959
00:36:34,790 --> 00:36:33,040
scientists including one nobel laureate

960
00:36:37,270 --> 00:36:34,800
plus me as chair

961
00:36:39,430 --> 00:36:37,280
all independent of gpb and each an

962
00:36:41,670 --> 00:36:39,440
expert in a specific area relevant to

963
00:36:44,230 --> 00:36:41,680

the mission from low temperature physics

964
00:36:45,109 --> 00:36:44,240
to data analysis to general relativity

965
00:36:46,710 --> 00:36:45,119
theory

966
00:36:49,030 --> 00:36:46,720
two members of the sac are in the

967
00:36:51,990 --> 00:36:49,040
audience today

968
00:36:54,710 --> 00:36:52,000
over a period of 13 years and 20 sac

969
00:36:56,790 --> 00:36:54,720
meetings each lasting one to two days

970
00:36:59,589 --> 00:36:56,800
we reviewed the progress of the mission

971
00:37:02,630 --> 00:36:59,599
we criticized we suggested alternative

972
00:37:04,550 --> 00:37:02,640
approaches and we vetted

973
00:37:07,270 --> 00:37:04,560
we critically reviewed drafts of the

974
00:37:08,950 --> 00:37:07,280
just accepted physical review letter

975
00:37:11,190 --> 00:37:08,960
twice

976
00:37:13,510 --> 00:37:11,200
our charge was to ensure that whatever

977
00:37:15,030 --> 00:37:13,520
result emerged from the experiment it

978
00:37:17,030 --> 00:37:15,040
would be credible to the scientific

979
00:37:20,470 --> 00:37:17,040
community and that the way it was

980
00:37:22,630 --> 00:37:20,480
obtained would be clear and transparent

981
00:37:25,430 --> 00:37:22,640
in the unanimous opinion of the sac the

982
00:37:28,390 --> 00:37:25,440
gpb team attained this goal

983
00:37:29,990 --> 00:37:28,400
indeed in our opinion the effort of the

984
00:37:32,310 --> 00:37:30,000
team in obtaining the result you have

985
00:37:34,069 --> 00:37:32,320
heard today has been nothing short of

986
00:37:35,589 --> 00:37:34,079
heroic

987
00:37:38,470 --> 00:37:35,599
faced with the discovery during the

988
00:37:40,790 --> 00:37:38,480

final months of post-mission tests

989
00:37:43,430 --> 00:37:40,800
that anomalous motions of the gyroscopes

990
00:37:45,270 --> 00:37:43,440
were being induced by stray patches of

991
00:37:47,670 --> 00:37:45,280
electric fields on the surfaces of the

992
00:37:49,109 --> 00:37:47,680
rotors and on the interior surfaces of

993
00:37:51,190 --> 00:37:49,119
their housings

994
00:37:53,109 --> 00:37:51,200
they found truly ingenious and

995
00:37:55,829 --> 00:37:53,119
innovative ways to pool all the

996
00:37:57,910 --> 00:37:55,839
available data in order to understand

997
00:37:59,750 --> 00:37:57,920
and map out these anomalies

998
00:38:00,790 --> 00:37:59,760
they did this so well

999
00:38:03,190 --> 00:38:00,800
that

1000
00:38:04,870 --> 00:38:03,200
they could still measure the tiny frame

1001
00:38:07,589 --> 00:38:04,880
dragging procession

1002
00:38:09,670 --> 00:38:07,599
this detective story as francis puts it

1003
00:38:12,790 --> 00:38:09,680
is an excellent example of how

1004
00:38:14,870 --> 00:38:12,800
physicists solve hard problems

1005
00:38:17,510 --> 00:38:14,880
solving this problem is in part why it

1006
00:38:19,589 --> 00:38:17,520
took over five years of data analysis

1007
00:38:22,470 --> 00:38:19,599
from the end of the mission to reach the

1008
00:38:24,710 --> 00:38:22,480
announcement today

1009
00:38:26,470 --> 00:38:24,720
i would like to remind everybody of the

1010
00:38:28,390 --> 00:38:26,480
importance of testing fundamental

1011
00:38:30,069 --> 00:38:28,400
theories of nature

1012
00:38:32,630 --> 00:38:30,079
even though it is popular lower that

1013
00:38:34,470 --> 00:38:32,640

einstein was right i even wrote a book

1014
00:38:36,870 --> 00:38:34,480
on the subject

1015
00:38:38,310 --> 00:38:36,880
no such book is ever completely closed

1016
00:38:40,630 --> 00:38:38,320
in science

1017
00:38:42,950 --> 00:38:40,640
as we have seen with the 1998 discovery

1018
00:38:44,630 --> 00:38:42,960
of the acceleration of the universe

1019
00:38:45,270 --> 00:38:44,640
measuring an effect

1020
00:38:47,829 --> 00:38:45,280
in

1021
00:38:49,990 --> 00:38:47,839
contrary to established dogma can open

1022
00:38:53,829 --> 00:38:50,000
the door to a whole new world of

1023
00:38:55,750 --> 00:38:53,839
understanding as well as of mystery

1024
00:38:57,750 --> 00:38:55,760
the pressure procession of a gyroscope

1025
00:38:59,910 --> 00:38:57,760
in the gravitational field of a rotating

1026
00:39:01,270 --> 00:38:59,920
body has never been measured before

1027
00:39:03,030 --> 00:39:01,280
today

1028
00:39:06,390 --> 00:39:03,040
while the result in this case does

1029
00:39:08,230 --> 00:39:06,400
support einstein it didn't have to

1030
00:39:10,470 --> 00:39:08,240
physicists will never cease testing

1031
00:39:12,950 --> 00:39:10,480
their basic theories whether in order to

1032
00:39:15,430 --> 00:39:12,960
confirm them better or in order to

1033
00:39:16,630 --> 00:39:15,440
reveal new physics beyond those standard

1034
00:39:18,950 --> 00:39:16,640
theories

1035
00:39:20,950 --> 00:39:18,960
in some realms the only place to do this

1036
00:39:24,710 --> 00:39:20,960
to carry out such experiments is in

1037
00:39:26,950 --> 00:39:24,720
space this was the case with gpb

1038
00:39:29,270 --> 00:39:26,960

another central aspect of the scientific

1039
00:39:30,710 --> 00:39:29,280
method is the publication of the results

1040
00:39:32,470 --> 00:39:30,720
of the research

1041
00:39:33,990 --> 00:39:32,480
the physical review letter that has just

1042
00:39:36,790 --> 00:39:34,000
been accepted

1043
00:39:38,790 --> 00:39:36,800
gives the merest outline of gpb and how

1044
00:39:41,670 --> 00:39:38,800
the result was obtained

1045
00:39:44,069 --> 00:39:41,680
gpb will truly be completed only when

1046
00:39:46,310 --> 00:39:44,079
the full details of the experiment are

1047
00:39:48,950 --> 00:39:46,320
published in the open peer-reviewed

1048
00:39:52,230 --> 00:39:50,310
measuring the frame-bragging effect

1049
00:39:54,790 --> 00:39:52,240
caused by the earth's rotation also has

1050
00:39:56,710 --> 00:39:54,800
implications beyond our planet

1051
00:39:59,190 --> 00:39:56,720
the incredible outpouring of energy from

1052
00:40:01,750 --> 00:39:59,200
quasars along narrow jets of matter that

1053
00:40:04,230 --> 00:40:01,760
stream at nearly the speed of light

1054
00:40:06,309 --> 00:40:04,240
is most likely driven by the same frame

1055
00:40:07,589 --> 00:40:06,319
dragging phenomenon about which you have

1056
00:40:09,990 --> 00:40:07,599
heard today

1057
00:40:12,950 --> 00:40:10,000
in the case of quasars the central body

1058
00:40:14,710 --> 00:40:12,960
is a rapidly rotating black hole

1059
00:40:17,030 --> 00:40:14,720
in my own current field of research

1060
00:40:19,990 --> 00:40:17,040
gravitational wave astronomy

1061
00:40:23,109 --> 00:40:20,000
the final in spiral and merger of two

1062
00:40:25,750 --> 00:40:23,119
spinning black holes involved truly wild

1063
00:40:28,550 --> 00:40:25,760

gyrations of the body spin axes

1064
00:40:31,190 --> 00:40:28,560
uh and of the orbit again driven by the

1065
00:40:33,109 --> 00:40:31,200
same frame dragging phenomenon

1066
00:40:35,349 --> 00:40:33,119
and these motions are encoded in the

1067
00:40:37,510 --> 00:40:35,359
gravitational wave signals that we hope

1068
00:40:39,190 --> 00:40:37,520
will be detected soon by laser

1069
00:40:41,349 --> 00:40:39,200
interferometer interferometric

1070
00:40:44,150 --> 00:40:41,359
observatories on the ground and in the

1071
00:40:46,150 --> 00:40:44,160
future by a similar observatory in space

1072
00:40:48,309 --> 00:40:46,160
so there is a strong link between

1073
00:40:50,470 --> 00:40:48,319
gravity pro-b and some of the most

1074
00:40:51,670 --> 00:40:50,480
energetic and cataclysmic events in the

1075
00:40:53,910 --> 00:40:51,680
universe

1076
00:40:57,190 --> 00:40:53,920
thank you

1077
00:40:58,470 --> 00:40:57,200
um i'd like to go ahead and move on to

1078
00:41:00,069 --> 00:40:58,480
the question and answer session if i

1079
00:41:01,349 --> 00:41:00,079
could uh just reminder for those in the

1080
00:41:02,470 --> 00:41:01,359
audience we do have a microphone coming

1081
00:41:04,550 --> 00:41:02,480
around so

1082
00:41:05,910 --> 00:41:04,560
so just wait for that and please

1083
00:41:07,829 --> 00:41:05,920
identify yourself and give your

1084
00:41:09,109 --> 00:41:07,839
affiliation uh for those that are

1085
00:41:10,550 --> 00:41:09,119
joining by phone you can signal the

1086
00:41:12,390 --> 00:41:10,560
operator that you have a question by

1087
00:41:13,829 --> 00:41:12,400
pushing the star one keys

1088
00:41:15,750 --> 00:41:13,839

um and so let me just check with the

1089
00:41:18,870 --> 00:41:15,760
audience and see if there's any

1090
00:41:23,750 --> 00:41:20,950
yes please spring

1091
00:41:26,069 --> 00:41:23,760
frank with aviation week i wonder if

1092
00:41:29,109 --> 00:41:26,079
someone could give a little bit more

1093
00:41:30,950 --> 00:41:29,119
elaboration on how the um

1094
00:41:32,069 --> 00:41:30,960
the noise was was worked out of the

1095
00:41:33,430 --> 00:41:32,079
equation

1096
00:41:35,030 --> 00:41:33,440
and um

1097
00:41:37,270 --> 00:41:35,040
some idea of the the degree of

1098
00:41:41,910 --> 00:41:37,280
confidence that it was done successfully

1099
00:41:47,190 --> 00:41:44,470
so i should say on that

1100
00:41:49,270 --> 00:41:47,200
franciscan

1101
00:41:51,349 --> 00:41:49,280
um

1102
00:41:53,030 --> 00:41:51,359
first of all

1103
00:41:55,829 --> 00:41:53,040
we discovered

1104
00:41:58,309 --> 00:41:55,839
two things one during the science

1105
00:42:00,950 --> 00:41:58,319
mission itself gathering the science

1106
00:42:03,829 --> 00:42:00,960
data and second during this calibration

1107
00:42:05,430 --> 00:42:03,839
phase

1108
00:42:07,589 --> 00:42:05,440
during the science

1109
00:42:10,390 --> 00:42:07,599
gathering we discovered

1110
00:42:11,430 --> 00:42:10,400
that the gyroscope was gradually

1111
00:42:14,870 --> 00:42:11,440
changing

1112
00:42:16,950 --> 00:42:14,880
its direction not of spin

1113
00:42:18,309 --> 00:42:16,960

but of its body with relation to the

1114
00:42:20,710 --> 00:42:18,319
spin axis

1115
00:42:22,550 --> 00:42:20,720
it's like a football spinning initially

1116
00:42:26,309 --> 00:42:22,560
about the wrong axis and then gradually

1117
00:42:30,470 --> 00:42:28,470
so we discovered that

1118
00:42:33,190 --> 00:42:30,480
then we discovered that there was a

1119
00:42:35,270 --> 00:42:33,200
disturbing effect from pointing off

1120
00:42:38,230 --> 00:42:35,280
by

1121
00:42:40,230 --> 00:42:38,240
which you point it off to other stars

1122
00:42:42,230 --> 00:42:40,240
and we were able to calibrate this as we

1123
00:42:45,190 --> 00:42:42,240
point it off to another star

1124
00:42:47,349 --> 00:42:45,200
and get a reasonably good number

1125
00:42:48,630 --> 00:42:47,359
the very interesting thing on that one

1126
00:42:50,950 --> 00:42:48,640
that came out

1127
00:42:53,190 --> 00:42:50,960
was we could check the number in two

1128
00:42:55,430 --> 00:42:53,200
different ways during the data analysis

1129
00:42:57,190 --> 00:42:55,440
now three sets of measurements of this

1130
00:42:59,349 --> 00:42:57,200
misalignment talk

1131
00:43:01,910 --> 00:42:59,359
one from the calibration and two from

1132
00:43:04,870 --> 00:43:01,920
the other tests within the data analysis

1133
00:43:08,390 --> 00:43:04,880
breasts all agreed very well

1134
00:43:11,589 --> 00:43:08,400
to the accuracy needed in the experiment

1135
00:43:13,990 --> 00:43:11,599
the strangest of all of the effects

1136
00:43:16,390 --> 00:43:14,000
rejoices in the name of the roll poll

1137
00:43:19,349 --> 00:43:16,400
hold resonance talk

1138
00:43:21,430 --> 00:43:19,359

and here is the phenomenon you observe

1139
00:43:23,510 --> 00:43:21,440
we have a spacecraft which rolls to

1140
00:43:25,270 --> 00:43:23,520
averaging things

1141
00:43:29,109 --> 00:43:25,280
and we

1142
00:43:30,790 --> 00:43:29,119
have a gyroscope that's spinning

1143
00:43:32,710 --> 00:43:30,800
and as it spins it goes through a

1144
00:43:34,710 --> 00:43:32,720
certain kind of motion which is called

1145
00:43:36,069 --> 00:43:34,720
pole holding this is relation to the

1146
00:43:39,030 --> 00:43:36,079
motion

1147
00:43:42,069 --> 00:43:39,040
the earth's poles it's an analogous

1148
00:43:43,510 --> 00:43:42,079
and he was sort of watching four

1149
00:43:45,109 --> 00:43:43,520
gyroscopes

1150
00:43:46,950 --> 00:43:45,119
a certain point

1151
00:43:49,349 --> 00:43:46,960
very strange thing happened

1152
00:43:51,670 --> 00:43:49,359
over a course of a day maybe one of the

1153
00:43:53,589 --> 00:43:51,680
gyroscopes moved off to a new position

1154
00:43:55,670 --> 00:43:53,599
and then settled down

1155
00:43:57,750 --> 00:43:55,680
very surprising

1156
00:43:59,349 --> 00:43:57,760
and then another

1157
00:44:01,030 --> 00:43:59,359
you'd go on for a while and then one of

1158
00:44:03,349 --> 00:44:01,040
the other gyros would do something

1159
00:44:05,430 --> 00:44:03,359
similar not in the same magnitude

1160
00:44:07,510 --> 00:44:05,440
necessarily not in the same direction

1161
00:44:08,870 --> 00:44:07,520
but the same phenomenon obviously was

1162
00:44:11,190 --> 00:44:08,880
happening

1163
00:44:13,349 --> 00:44:11,200

um jeff cajo jack at marshall center was

1164
00:44:15,510 --> 00:44:13,359
a key person in uh reaching an

1165
00:44:17,270 --> 00:44:15,520
understanding of this and what he showed

1166
00:44:20,790 --> 00:44:17,280
was happening is

1167
00:44:23,349 --> 00:44:20,800
the slowly changing pure load period at

1168
00:44:25,910 --> 00:44:23,359
certain point reaches a resonance with

1169
00:44:28,069 --> 00:44:25,920
the rotation of the spacecraft

1170
00:44:30,670 --> 00:44:28,079
by the resonance

1171
00:44:33,750 --> 00:44:30,680
it's a resonance with something like the

1172
00:44:36,230 --> 00:44:33,760
123rd harmonic or something which no

1173
00:44:38,230 --> 00:44:36,240
normal physicist ever would believe that

1174
00:44:41,990 --> 00:44:38,240
you get effects like that

1175
00:44:43,750 --> 00:44:42,000
but we were able to vary it verified and

1176
00:44:47,109 --> 00:44:43,760
finally

1177
00:44:49,670 --> 00:44:47,119
i like sometimes to say that gpb is a

1178
00:44:51,510 --> 00:44:49,680
confirmation also newtonian mechanics

1179
00:44:53,030 --> 00:44:51,520
because we had complete newtonian

1180
00:44:55,430 --> 00:44:53,040
explanations

1181
00:44:57,109 --> 00:44:55,440
of these effects and the numbers came

1182
00:44:59,589 --> 00:44:57,119
out right i don't know whether that

1183
00:45:02,309 --> 00:44:59,599
helps i mean i'm not really giving

1184
00:45:04,150 --> 00:45:02,319
five years of data analysis in two

1185
00:45:06,069 --> 00:45:04,160
minutes but that's the feeling do you

1186
00:45:07,750 --> 00:45:06,079
want to add something on that cliff

1187
00:45:09,670 --> 00:45:07,760
well i think another thing that uh was

1188
00:45:11,270 --> 00:45:09,680

important was and this is the kind of

1189
00:45:13,270 --> 00:45:11,280
thing that experimental physicists do

1190
00:45:14,390 --> 00:45:13,280
they take lots of data on a particular

1191
00:45:16,150 --> 00:45:14,400
experiment

1192
00:45:17,589 --> 00:45:16,160
only a small fraction of which may be

1193
00:45:18,470 --> 00:45:17,599
directly relevant to what they want to

1194
00:45:21,109 --> 00:45:18,480
measure

1195
00:45:23,190 --> 00:45:21,119
but in this case there was data taken

1196
00:45:25,510 --> 00:45:23,200
having to do with the

1197
00:45:28,550 --> 00:45:25,520
very small additional magnetic fields

1198
00:45:30,309 --> 00:45:28,560
that these rotors obtained

1199
00:45:31,990 --> 00:45:30,319
and it and that data was in some sense

1200
00:45:34,069 --> 00:45:32,000
housekeeping data or junk data that

1201
00:45:36,710 --> 00:45:34,079
wasn't super relevant to the main

1202
00:45:39,270 --> 00:45:36,720
mission but at the end of the day this

1203
00:45:40,069 --> 00:45:39,280
exploiting this data was really critical

1204
00:45:45,589 --> 00:45:40,079
to

1205
00:45:47,270 --> 00:45:45,599
in such detail that they could track the

1206
00:45:51,030 --> 00:45:47,280
orientation of the spacecraft or

1207
00:45:55,589 --> 00:45:53,030
with a tolerance of a very small angle

1208
00:45:57,430 --> 00:45:55,599
over the billions of cycles

1209
00:45:58,390 --> 00:45:57,440
during which each rotor

1210
00:46:00,710 --> 00:45:58,400
spun

1211
00:46:03,349 --> 00:46:00,720
during the mission so this additional

1212
00:46:05,510 --> 00:46:03,359
data that was there they managed to

1213
00:46:08,230 --> 00:46:05,520

exploit in a really uh

1214
00:46:09,670 --> 00:46:08,240
innovative way to thereby build a model

1215
00:46:12,870 --> 00:46:09,680
that allowed them to take care of these

1216
00:46:16,870 --> 00:46:14,230
thank you very much i believe we have a

1217
00:46:19,030 --> 00:46:16,880
caller on the phone so if we could go to

1218
00:46:21,750 --> 00:46:19,040
adrian cho at science

1219
00:46:23,270 --> 00:46:21,760
go ahead adrian

1220
00:46:26,470 --> 00:46:23,280
um hi this is

1221
00:46:28,950 --> 00:46:26,480
uh hi uh as adrian cho science magazine

1222
00:46:31,990 --> 00:46:28,960
this is a question for uh professor will

1223
00:46:34,630 --> 00:46:32,000
um i'm wondering uh how the gravity

1224
00:46:37,829 --> 00:46:34,640
probe the result compares to previous

1225
00:46:39,910 --> 00:46:37,839
results there was a result in 2004

1226
00:46:42,390 --> 00:46:39,920
an analysis of the legios

1227
00:46:44,470 --> 00:46:42,400
satellites that reported a 10

1228
00:46:46,550 --> 00:46:44,480
precision measurement of frame dragging

1229
00:46:49,270 --> 00:46:46,560
so i'm wondering how this measurement

1230
00:46:51,750 --> 00:46:49,280
compares to that measurement

1231
00:46:53,349 --> 00:46:51,760
right so these uh so this experiment

1232
00:46:54,950 --> 00:46:53,359
he's referring to is a

1233
00:46:57,270 --> 00:46:54,960
measurement of the procession of the

1234
00:46:58,630 --> 00:46:57,280
orbital plane of satellites that are

1235
00:47:00,790 --> 00:46:58,640
orbiting around the earth that are

1236
00:47:02,230 --> 00:47:00,800
tracked extremely precisely by with

1237
00:47:03,910 --> 00:47:02,240
laser tracking

1238
00:47:05,030 --> 00:47:03,920

the phenomenon here is the same it's the

1239
00:47:06,390 --> 00:47:05,040
dragging

1240
00:47:08,069 --> 00:47:06,400
of the

1241
00:47:10,069 --> 00:47:08,079
of spacetime due to the rotating earth

1242
00:47:11,349 --> 00:47:10,079
which causes the orbital plane to also

1243
00:47:13,750 --> 00:47:11,359
drag around

1244
00:47:16,309 --> 00:47:13,760
so i regard these two experiments as

1245
00:47:18,630 --> 00:47:16,319
rather different ways to attack the same

1246
00:47:21,030 --> 00:47:18,640
phenomenon uh you're measuring how an

1247
00:47:22,309 --> 00:47:21,040
orbit varies gpv is measuring how a

1248
00:47:24,549 --> 00:47:22,319
gyroscope

1249
00:47:26,470 --> 00:47:24,559
changes each uh involves some

1250
00:47:27,829 --> 00:47:26,480
complicated data analysis with other

1251
00:47:30,390 --> 00:47:27,839
sources of error that have to be

1252
00:47:33,670 --> 00:47:30,400
understood and modeled to get the final

1253
00:47:35,990 --> 00:47:33,680
result so there are really two ways of

1254
00:47:38,470 --> 00:47:36,000
of attacking the same underlying

1255
00:47:39,750 --> 00:47:38,480
phenomenon

1256
00:47:43,829 --> 00:47:39,760
you just pause and see if there are any

1257
00:47:43,839 --> 00:47:49,349
yes sir well the microphone to you

1258
00:47:52,470 --> 00:47:51,109
joseph taylor professor physics

1259
00:47:55,349 --> 00:47:52,480
princeton university

1260
00:47:58,630 --> 00:47:55,359
for cliff or francis i'm just curious to

1261
00:48:02,150 --> 00:47:58,640
know that whether the patch effect uh

1262
00:48:03,109 --> 00:48:02,160
difficulty uh in the end uh dominates

1263
00:48:06,950 --> 00:48:03,119

the 20

1264
00:48:08,870 --> 00:48:06,960
uncertainty on the frame dragging

1265
00:48:15,829 --> 00:48:08,880
yes

1266
00:48:15,839 --> 00:48:20,150
any further questions

1267
00:48:20,160 --> 00:48:22,870
good frank

1268
00:48:27,349 --> 00:48:25,349
it's frank mooring again uh for rex

1269
00:48:28,470 --> 00:48:27,359
given could you

1270
00:48:30,790 --> 00:48:28,480
um

1271
00:48:32,950 --> 00:48:30,800
hypothesize some of the

1272
00:48:34,870 --> 00:48:32,960
less or elaborate some of the lessons

1273
00:48:36,950 --> 00:48:34,880
that may have been learned in developing

1274
00:48:38,549 --> 00:48:36,960
this this spacecraft

1275
00:48:40,630 --> 00:48:38,559
that could be applied to future

1276
00:48:42,710 --> 00:48:40,640
spacecrafts particularly in the context

1277
00:48:44,150 --> 00:48:42,720
of that quote that you gave about

1278
00:48:45,990 --> 00:48:44,160
inventing

1279
00:48:52,150 --> 00:48:46,000
technology to

1280
00:48:55,190 --> 00:48:53,750
well one of the one of the interesting

1281
00:48:57,109 --> 00:48:55,200
things about the spacecraft that i sort

1282
00:48:58,710 --> 00:48:57,119
of touched on here was

1283
00:49:00,790 --> 00:48:58,720
the interaction of the payload with the

1284
00:49:02,950 --> 00:49:00,800
spacecraft i mean normally we have a

1285
00:49:04,630 --> 00:49:02,960
spacecraft bus that has some sort of

1286
00:49:05,990 --> 00:49:04,640
generic spacecraft functions and you put

1287
00:49:07,510 --> 00:49:06,000
an instrument on there

1288
00:49:08,790 --> 00:49:07,520

and do things with it

1289
00:49:10,150 --> 00:49:08,800
and there's some amount of of

1290
00:49:11,270 --> 00:49:10,160
interaction through data systems and

1291
00:49:13,030 --> 00:49:11,280
such but what was really interesting

1292
00:49:14,470 --> 00:49:13,040
about this one is that the instrument

1293
00:49:16,950 --> 00:49:14,480
itself was kind of the heart of the

1294
00:49:18,950 --> 00:49:16,960
control system for the spacecraft the

1295
00:49:20,150 --> 00:49:18,960
gyroscopes providing direct feedback

1296
00:49:25,349 --> 00:49:20,160
into the

1297
00:49:27,349 --> 00:49:25,359
and positioning information and so forth

1298
00:49:28,870 --> 00:49:27,359
and telescope of course being not only

1299
00:49:31,109 --> 00:49:28,880
part of the science instrument but also

1300
00:49:33,430 --> 00:49:31,119
a guide star so i think this

1301
00:49:35,349 --> 00:49:33,440
i think this um this kind of strong

1302
00:49:36,870 --> 00:49:35,359
interaction between payload and

1303
00:49:40,630 --> 00:49:36,880
spacecraft is pretty interesting and

1304
00:49:41,990 --> 00:49:40,640
might apply to future missions

1305
00:49:43,750 --> 00:49:42,000
well the things that i talked about the

1306
00:49:45,829 --> 00:49:43,760
the tying of the control system between

1307
00:49:48,710 --> 00:49:45,839
the spacecraft and the payload and using

1308
00:49:50,150 --> 00:49:48,720
an instrument for a for a

1309
00:49:51,190 --> 00:49:50,160
you know a navigation and control

1310
00:49:52,710 --> 00:49:51,200
function

1311
00:49:54,710 --> 00:49:52,720
instead of doing that independently on

1312
00:49:56,630 --> 00:49:54,720
the spacecraft i mean it's a very unique

1313
00:49:58,309 --> 00:49:56,640

case and so i don't think it's generally

1314
00:50:02,630 --> 00:49:58,319
applicable but there are some

1315
00:50:06,390 --> 00:50:04,390
okay and with that we're going to go

1316
00:50:07,990 --> 00:50:06,400
ahead and in today's event i just want

1317
00:50:09,829 --> 00:50:08,000
to thank the panelists for their time

1318
00:50:11,430 --> 00:50:09,839
today and thank the audience for joining

1319
00:50:12,390 --> 00:50:11,440
us as always you can find out more

1320
00:50:14,630 --> 00:50:12,400
information

1321
00:50:17,270 --> 00:50:14,640
about nasa missions and connect with us