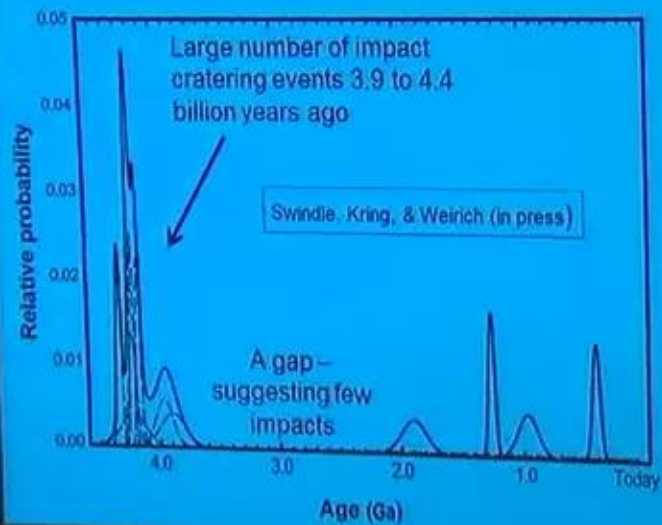


AGES OF IMPACT EVENTS ON AN LL-CHONDRITE PLANETESIMAL

LL chondrite impact age distribution



1  
00:00:08,030 --> 00:00:04,390  
good evening welcome to the lunar and

2  
00:00:10,629 --> 00:00:08,040  
planetary institute as we continue our

3  
00:00:13,669 --> 00:00:10,639  
2013-2014 cosmic exploration speaker

4  
00:00:16,470 --> 00:00:13,679  
series uh the universe is out to get us

5  
00:00:17,430 --> 00:00:16,480  
in what we can or can't do about it our

6  
00:00:18,870 --> 00:00:17,440  
first

7  
00:00:21,269 --> 00:00:18,880  
presentation a few months ago was about

8  
00:00:23,429 --> 00:00:21,279  
the sun and what it throws at us

9  
00:00:25,109 --> 00:00:23,439  
which is bad usually and tonight we're

10  
00:00:27,589 --> 00:00:25,119  
going to be talking about asteroid

11  
00:00:29,349 --> 00:00:27,599  
impacts on the earth and it's a little

12  
00:00:30,630 --> 00:00:29,359  
bit uh fortuitous we actually were

13  
00:00:32,709 --> 00:00:30,640

supposed to have this talk a few weeks

14

00:00:34,389 --> 00:00:32,719

ago and we rescheduled it to this week

15

00:00:36,870 --> 00:00:34,399

and it happened to coincide with a

16

00:00:38,549 --> 00:00:36,880

really cool event that uh dr mackel will

17

00:00:39,430 --> 00:00:38,559

tell you a little bit about here in a

18

00:00:41,430 --> 00:00:39,440

bit

19

00:00:43,430 --> 00:00:41,440

uh our next presentation will be march

20

00:00:45,270 --> 00:00:43,440

6th so we're taking a few months off so

21

00:00:47,190 --> 00:00:45,280

don't forget march 6. we have flyers out

22

00:00:49,990 --> 00:00:47,200

front for it the topic will be on

23

00:00:52,549 --> 00:00:50,000

gamma-ray bursts and supernova

24

00:00:54,229 --> 00:00:52,559

and also note our april presentation was

25

00:00:57,590 --> 00:00:54,239

originally the 17th we have also

26

00:00:59,270 --> 00:00:57,600

rescheduled that for april 24th

27

00:01:01,349 --> 00:00:59,280

so please note that

28

00:01:02,869 --> 00:01:01,359

we have our email list sign up sheet out

29

00:01:04,869 --> 00:01:02,879

front as always we also have some

30

00:01:06,550 --> 00:01:04,879

goodies on the table by the on the other

31

00:01:08,149 --> 00:01:06,560

side of the front door for you to pick

32

00:01:09,429 --> 00:01:08,159

up and take home

33

00:01:11,510 --> 00:01:09,439

teachers if you're with us with your

34

00:01:13,109 --> 00:01:11,520

professional development certificates at

35

00:01:15,350 --> 00:01:13,119

the receptionist desk pick up one of

36

00:01:17,190 --> 00:01:15,360

those before you leave and last time we

37

00:01:18,710 --> 00:01:17,200

asked you to fill an evaluation so if

38

00:01:20,870 --> 00:01:18,720

you could do that again even if you did

39

00:01:22,469 --> 00:01:20,880

do it a few months ago we'll be walking

40

00:01:23,990 --> 00:01:22,479

around with an ipad again if you want to

41

00:01:25,749 --> 00:01:24,000

do it that way we have paper surveys at

42

00:01:27,429 --> 00:01:25,759

the front door and we can also give you

43

00:01:29,109 --> 00:01:27,439

a slip with a url you can take home

44

00:01:31,190 --> 00:01:29,119

without if you want to

45

00:01:32,630 --> 00:01:31,200

when you when you get home

46

00:01:35,030 --> 00:01:32,640

and don't forget our reception

47

00:01:36,710 --> 00:01:35,040

afterwards of course

48

00:01:38,550 --> 00:01:36,720

and we have a shuttle i don't know if

49

00:01:41,030 --> 00:01:38,560

anybody here need to take the shuttle

50

00:01:42,710 --> 00:01:41,040

tonight but if you did they will leave

51  
00:01:44,950 --> 00:01:42,720  
here for the last time to go back to the

52  
00:01:46,630 --> 00:01:44,960  
church at 9 30. so make sure you're on

53  
00:01:47,830 --> 00:01:46,640  
the 9 30 bus

54  
00:01:49,910 --> 00:01:47,840  
so to speak

55  
00:01:52,310 --> 00:01:49,920  
if you need to

56  
00:01:54,550 --> 00:01:52,320  
all right so to tell us more about

57  
00:01:56,230 --> 00:01:54,560  
tonight's speaker i'm going to ask dr

58  
00:01:58,310 --> 00:01:56,240  
stephen mackwell to come up and do that

59  
00:02:01,270 --> 00:01:58,320  
dr mackwell is the director of the lunar

60  
00:02:04,709 --> 00:02:03,109  
thanks andy um

61  
00:02:06,389 --> 00:02:04,719  
welcome it's a great pleasure to have

62  
00:02:08,710 --> 00:02:06,399  
you here tonight

63  
00:02:10,309 --> 00:02:08,720

as andy mentioned we have uh an event

64

00:02:14,790 --> 00:02:10,319  
going on uh in the building at the

65

00:02:16,710 --> 00:02:14,800  
moment um it's a nasa sponsored event um

66

00:02:19,110 --> 00:02:16,720  
that's here was

67

00:02:20,949 --> 00:02:19,120  
from started up last night it's gone

68

00:02:22,869 --> 00:02:20,959  
going today and then tomorrow morning

69

00:02:24,949 --> 00:02:22,879  
it's a continuation of a meeting that we

70

00:02:27,830 --> 00:02:24,959  
started

71

00:02:29,030 --> 00:02:27,840  
the 30th of september an auspicious day

72

00:02:31,750 --> 00:02:29,040  
we started the meeting was supposed to

73

00:02:33,350 --> 00:02:31,760  
go for three days it lasted for one then

74

00:02:36,949 --> 00:02:33,360  
the government shutdown

75

00:02:38,869 --> 00:02:36,959  
so 51 days later we started it up again

76

00:02:40,550 --> 00:02:38,879

um and um

77

00:02:42,070 --> 00:02:40,560

as andy mentioned it's kind of a

78

00:02:44,470 --> 00:02:42,080

something of a coincidence because the

79

00:02:47,750 --> 00:02:44,480

meeting is all about nasa's plans for an

80

00:02:49,750 --> 00:02:47,760

asteroid retrieval mission and so

81

00:02:52,550 --> 00:02:49,760

it's rather interesting and um

82

00:02:54,309 --> 00:02:52,560

coincidence in a way that uh and that we

83

00:02:57,190 --> 00:02:54,319

have david king scheduled to speak

84

00:03:00,550 --> 00:02:57,200

tonight on the recent chugibinsk um

85

00:03:02,470 --> 00:03:00,560

airburst in russia so

86

00:03:05,350 --> 00:03:02,480

uh it's my great pleasure to introduce

87

00:03:06,710 --> 00:03:05,360

david kring tonight david is a senior

88

00:03:08,550 --> 00:03:06,720

staff scientist at the lunar and

89

00:03:10,149 --> 00:03:08,560

planetary institute here

90

00:03:11,589 --> 00:03:10,159

one of my scientists great pleasure to

91

00:03:13,509 --> 00:03:11,599

have him around

92

00:03:15,670 --> 00:03:13,519

david did his bachelor's degree at

93

00:03:17,030 --> 00:03:15,680

indiana university

94

00:03:18,949 --> 00:03:17,040

in geology

95

00:03:21,350 --> 00:03:18,959

moved from there uh did his phd at

96

00:03:23,350 --> 00:03:21,360

harvard university

97

00:03:24,789 --> 00:03:23,360

from there oh i should mention that

98

00:03:27,910 --> 00:03:24,799

while he was doing his undergraduate

99

00:03:30,869 --> 00:03:27,920

work he was an intern here at the lpi in

100

00:03:33,350 --> 00:03:30,879

1983 so he has a long history with the

101  
00:03:36,869 --> 00:03:33,360

lpi

102  
00:03:38,309 --> 00:03:36,879

after he finished his phd he moved to

103  
00:03:39,830 --> 00:03:38,319

the

104  
00:03:41,430 --> 00:03:39,840

division of

105  
00:03:43,270 --> 00:03:41,440

the lunar and planetary laboratory at

106  
00:03:44,630 --> 00:03:43,280

the university of arizona and the

107  
00:03:46,470 --> 00:03:44,640

department of geosciences at the

108  
00:03:48,309 --> 00:03:46,480

university of arizona

109  
00:03:50,949 --> 00:03:48,319

where he kind of moved up in the wrongs

110  
00:03:52,789 --> 00:03:50,959

to become an associate professor

111  
00:03:54,869 --> 00:03:52,799

and managed

112  
00:04:03,509 --> 00:03:54,879

the

113  
00:04:05,270 --> 00:04:03,519

lunar planetary institute first as a

114

00:04:07,830 --> 00:04:05,280

visiting scientist and then said he

115

00:04:10,470 --> 00:04:07,840

liked us so much he stayed um and is now

116

00:04:13,270 --> 00:04:10,480

one of my senior scientists david um has

117

00:04:15,190 --> 00:04:13,280

a number of accomplishments um i could

118

00:04:17,110 --> 00:04:15,200

go through his long long list of things

119

00:04:19,110 --> 00:04:17,120

that he's done and the the commitments

120

00:04:21,430 --> 00:04:19,120

that he's made to the planetary science

121

00:04:23,189 --> 00:04:21,440

community over the years um

122

00:04:25,189 --> 00:04:23,199

but i'll just mention the awards that

123

00:04:26,950 --> 00:04:25,199

he's received he's a fellow of the

124

00:04:29,990 --> 00:04:26,960

meteoritical society a fellow of the

125

00:04:32,150 --> 00:04:30,000

geological society of america um he just

126  
00:04:34,070 --> 00:04:32,160  
recently received the rongrelio

127  
00:04:35,749 --> 00:04:34,080  
award for distinguished services that is

128  
00:04:36,950 --> 00:04:35,759  
given out by the geological society of

129  
00:04:39,510 --> 00:04:36,960  
america

130  
00:04:41,830 --> 00:04:39,520  
and he has a an asteroid named after

131  
00:04:45,030 --> 00:04:41,840  
himself

132  
00:04:48,390 --> 00:04:45,040  
which is quite fortuitous um david is an

133  
00:04:49,909 --> 00:04:48,400  
expert on on impact processes and most

134  
00:04:52,070 --> 00:04:49,919  
much of the time he's been here he's

135  
00:04:54,629 --> 00:04:52,080  
been the director of the

136  
00:04:58,550 --> 00:04:54,639  
center for uh lunar science and

137  
00:05:01,350 --> 00:04:58,560  
exploration um here uh running a group

138  
00:05:02,390 --> 00:05:01,360

of people working on on impact processes

139

00:05:03,830 --> 00:05:02,400

on the moon

140

00:05:05,990 --> 00:05:03,840

um

141

00:05:07,749 --> 00:05:06,000

but his background is much broader than

142

00:05:09,110 --> 00:05:07,759

that and we're going to hear some of his

143

00:05:10,310 --> 00:05:09,120

breath tonight when he's talking about

144

00:05:12,070 --> 00:05:10,320

asteroids of course that's the other

145

00:05:13,990 --> 00:05:12,080

part of the impact process not just

146

00:05:16,230 --> 00:05:14,000

what's hit but what's hitting it

147

00:05:17,909 --> 00:05:16,240

so without further ado i will pass the

148

00:05:21,189 --> 00:05:17,919

microphone to david who's going to talk

149

00:05:22,629 --> 00:05:21,199

about the 2013 chalyburn scare burst and

150

00:05:30,070 --> 00:05:22,639

the hazards of near-earth asteroid

151  
00:05:33,270 --> 00:05:31,909  
thank you very much uh let's go ahead

152  
00:05:35,270 --> 00:05:33,280  
and dig in

153  
00:05:36,830 --> 00:05:35,280  
i want to start with the news friday

154  
00:05:40,070 --> 00:05:36,840  
february 15

155  
00:05:42,230 --> 00:05:40,080  
2013. for those of us in north america

156  
00:05:44,150 --> 00:05:42,240  
you may have been waking up turning on

157  
00:05:45,990 --> 00:05:44,160  
the radio and getting the first first

158  
00:05:48,070 --> 00:05:46,000  
news it may have been over lunch when

159  
00:05:49,990 --> 00:05:48,080  
colleagues around the coffee pot said

160  
00:05:51,350 --> 00:05:50,000  
did you hear where it may have been in

161  
00:05:52,710 --> 00:05:51,360  
the evening when you got home and you

162  
00:05:55,430 --> 00:05:52,720  
turned on the evening news but the

163  
00:05:58,070 --> 00:05:55,440

headline was small asteroid penetrates

164

00:06:00,870 --> 00:05:58,080

earth atmosphere or with some news

165

00:06:02,950 --> 00:06:00,880

organizations a little bit more dramatic

166

00:06:05,029 --> 00:06:02,960

terminology

167

00:06:08,230 --> 00:06:05,039

when this impact occurred

168

00:06:09,749 --> 00:06:08,240

the sun was illuminating the eastern

169

00:06:12,150 --> 00:06:09,759

pacific ocean

170

00:06:15,350 --> 00:06:12,160

dawn was beginning to sweep westward

171

00:06:16,309 --> 00:06:15,360

across asia as this asteroid made its

172

00:06:18,390 --> 00:06:16,319

way

173

00:06:20,390 --> 00:06:18,400

towards the earth

174

00:06:21,350 --> 00:06:20,400

and impacted uh in the early morning

175

00:06:23,830 --> 00:06:21,360

hours

176

00:06:25,990 --> 00:06:23,840

coming from the direction of the sun so

177

00:06:29,029 --> 00:06:26,000

it was completely unseen

178

00:06:31,029 --> 00:06:29,039

unexpected and um as you will see in a

179

00:06:33,029 --> 00:06:31,039

few minutes it startled a great number

180

00:06:34,710 --> 00:06:33,039

of people in russia

181

00:06:37,110 --> 00:06:34,720

okay to illustrate

182

00:06:38,870 --> 00:06:37,120

this trajectory towards the earth i'm

183

00:06:40,390 --> 00:06:38,880

going to use a video that some of my

184

00:06:43,189 --> 00:06:40,400

colleagues in the czech republic and the

185

00:06:45,270 --> 00:06:43,199

university of western ontario produced

186

00:06:46,790 --> 00:06:45,280

so imagine yourself as a space cowboy

187

00:06:48,150 --> 00:06:46,800

sitting on top of this asteroid and

188

00:06:50,870 --> 00:06:48,160

you're going to write it all the way to

189

00:06:52,950 --> 00:06:50,880

the earth i am going to

190

00:06:57,029 --> 00:06:52,960

stop it though before you

191

00:06:57,039 --> 00:07:00,550

they've asked me not to

192

00:07:06,469 --> 00:07:02,550

so here we are approaching the earth

193

00:07:08,390 --> 00:07:06,479

we're 48 41 minutes out so we're

194

00:07:11,189 --> 00:07:08,400

approaching the earth very quick uh

195

00:07:12,070 --> 00:07:11,199

we're now about 15 minutes out screaming

196

00:07:13,270 --> 00:07:12,080

over

197

00:07:16,070 --> 00:07:13,280

asia

198

00:07:19,270 --> 00:07:16,080

just about to hit and you can see the

199

00:07:21,670 --> 00:07:19,280

impact site just ahead of us on the limb

200

00:07:23,510 --> 00:07:21,680

of the earth

201  
00:07:25,510 --> 00:07:23,520  
okay it went screaming into the

202  
00:07:27,510 --> 00:07:25,520  
stratosphere

203  
00:07:30,710 --> 00:07:27,520  
generating

204  
00:07:32,870 --> 00:07:30,720  
twin vortices tails behind the object as

205  
00:07:35,749 --> 00:07:32,880  
it was depositing a tremendous amount of

206  
00:07:37,909 --> 00:07:35,759  
kinetic energy in the atmosphere and

207  
00:07:39,430 --> 00:07:37,919  
there was a series of high energy

208  
00:07:40,870 --> 00:07:39,440  
detonations

209  
00:07:43,029 --> 00:07:40,880  
closer to the ground

210  
00:07:46,150 --> 00:07:43,039  
that generated shock waves which really

211  
00:07:50,070 --> 00:07:46,160  
are the culprit behind the damage that

212  
00:07:50,869 --> 00:07:50,080  
so startled the people in russia

213  
00:07:57,029 --> 00:07:50,879

the

214

00:08:00,469 --> 00:07:57,039

inward

215

00:08:03,350 --> 00:08:00,479

uh here we see smoke or dust rising

216

00:08:05,110 --> 00:08:03,360

where a factory wall collapsed inward

217

00:08:07,430 --> 00:08:05,120

and outward

218

00:08:09,909 --> 00:08:07,440

here is the aftermath of that collapsed

219

00:08:11,990 --> 00:08:09,919

wall from a similar perspective and

220

00:08:13,990 --> 00:08:12,000

here's you can see the debris of the

221

00:08:16,710 --> 00:08:14,000

wall that collapsed onto the sidewalk

222

00:08:18,950 --> 00:08:16,720

unfortunately nobody was caught on very

223

00:08:21,189 --> 00:08:18,960

beneath that debris

224

00:08:24,830 --> 00:08:21,199

a lot of people were injured but for the

225

00:08:26,710 --> 00:08:24,840

most part thankfully they were minor

226

00:08:28,469 --> 00:08:26,720

injuries now

227

00:08:30,869 --> 00:08:28,479

i was showing you a perspective from the

228

00:08:33,750 --> 00:08:30,879

outside i have to say in these types of

229

00:08:36,310 --> 00:08:33,760

events you are not assured safety

230

00:08:39,350 --> 00:08:36,320

on the interior so i'm going to show you

231

00:08:40,790 --> 00:08:39,360

a couple of security films

232

00:08:42,389 --> 00:08:40,800

that

233

00:08:44,870 --> 00:08:42,399

captured

234

00:08:48,310 --> 00:08:44,880

i have to defer to nasa tv i was asked

235

00:08:55,030 --> 00:08:51,110

okay yeah i was asked not to i'm sorry

236

00:08:56,710 --> 00:08:55,040

um so so here is a video um

237

00:08:59,269 --> 00:08:56,720

uh uh and i want to start it and you'll

238

00:09:02,550 --> 00:08:59,279

see a series of security videos that

239

00:09:05,269 --> 00:09:02,560

illustrate uh what people at work

240

00:09:07,110 --> 00:09:05,279

just minding their own business uh saw

241

00:09:22,470 --> 00:09:07,120

whoops it didn't start quite right let

242

00:09:26,550 --> 00:09:24,389

they quite clearly realized that there

243

00:09:30,310 --> 00:09:26,560

was something bad going on outside and

244

00:09:30,320 --> 00:09:35,190

okay now we're going to see a warehouse

245

00:09:44,949 --> 00:09:37,110

that's a shock wave and an air blast

246

00:09:48,310 --> 00:09:46,550

and i like the fact that this gentleman

247

00:09:51,829 --> 00:09:48,320

went over to his colleague and picked

248

00:09:53,750 --> 00:09:51,839

her up and left very well done

249

00:09:56,630 --> 00:09:53,760

okay so

250

00:09:58,070 --> 00:09:56,640

so this obviously was a big event um but

251  
00:10:00,870 --> 00:09:58,080  
there's a couple of things i want to say

252  
00:10:03,030 --> 00:10:00,880  
about them these stuff is falling onto

253  
00:10:05,190 --> 00:10:03,040  
the earth all the time

254  
00:10:07,030 --> 00:10:05,200  
and if we step outside on a clear night

255  
00:10:08,310 --> 00:10:07,040  
you can often times see meteors crossing

256  
00:10:09,430 --> 00:10:08,320  
the sky these little dust sized

257  
00:10:11,670 --> 00:10:09,440  
particles

258  
00:10:13,910 --> 00:10:11,680  
so the process of material hitting the

259  
00:10:15,990 --> 00:10:13,920  
earth is not unique it's not rare it

260  
00:10:17,829 --> 00:10:16,000  
happens all the time fortunately most of

261  
00:10:20,310 --> 00:10:17,839  
the debris hitting the earth

262  
00:10:21,990 --> 00:10:20,320  
is small in size this is a little

263  
00:10:23,910 --> 00:10:22,000

diagram that illustrates the

264

00:10:25,829 --> 00:10:23,920

consequences of different types of

265

00:10:27,269 --> 00:10:25,839

material here are the meteors that you

266

00:10:29,110 --> 00:10:27,279

see burning up in the upper most

267

00:10:31,430 --> 00:10:29,120

atmosphere when they are small dust

268

00:10:33,030 --> 00:10:31,440

sized particles larger objects can

269

00:10:35,350 --> 00:10:33,040

penetrate deeper

270

00:10:37,750 --> 00:10:35,360

to the surface of the earth sometimes

271

00:10:40,470 --> 00:10:37,760

they completely catastrophically

272

00:10:42,550 --> 00:10:40,480

fragment so you cannot

273

00:10:44,389 --> 00:10:42,560

find any remnants of the object but

274

00:10:46,470 --> 00:10:44,399

sometimes they'll reach the lower

275

00:10:47,990 --> 00:10:46,480

atmosphere completely decelerate and

276

00:10:49,269 --> 00:10:48,000

then fall to the earth as a single

277

00:10:51,430 --> 00:10:49,279

meteorite

278

00:10:53,910 --> 00:10:51,440

the more the bigger objects will

279

00:10:57,110 --> 00:10:53,920

generate lots of smoky trails this is

280

00:10:59,350 --> 00:10:57,120

something akin to what chelyabinsk did

281

00:11:01,350 --> 00:10:59,360

can have one or more multiple

282

00:11:03,829 --> 00:11:01,360

fragmentation or have fragmentation

283

00:11:05,750 --> 00:11:03,839

events and shower the ground with a

284

00:11:08,470 --> 00:11:05,760

series of objects

285

00:11:11,030 --> 00:11:08,480

the largest or strongest objects can

286

00:11:13,430 --> 00:11:11,040

penetrate the entire atmosphere hit the

287

00:11:15,350 --> 00:11:13,440

surface and produce a hypervelocity

288

00:11:18,470 --> 00:11:15,360

impact crater so

289

00:11:21,990 --> 00:11:18,480

message one is this is a common process

290

00:11:23,509 --> 00:11:22,000

message two is thankfully we are

291

00:11:25,269 --> 00:11:23,519

surrounded by an atmosphere the

292

00:11:27,670 --> 00:11:25,279

atmosphere is a very important shield

293

00:11:29,350 --> 00:11:27,680

for those of us on earth

294

00:11:31,269 --> 00:11:29,360

as you may recall for those of you are a

295

00:11:32,870 --> 00:11:31,279

little bit older when the astronauts

296

00:11:34,870 --> 00:11:32,880

were walking on the lunar surface they

297

00:11:36,550 --> 00:11:34,880

were walking on on a planetary surface

298

00:11:38,389 --> 00:11:36,560

without an atmosphere and even these

299

00:11:40,389 --> 00:11:38,399

little micrometeoritic objects were

300

00:11:42,710 --> 00:11:40,399

plowing into the surface creating

301  
00:11:44,630 --> 00:11:42,720  
micrometeoritic impact

302  
00:11:46,630 --> 00:11:44,640  
craters that were so energetic they were

303  
00:11:50,150 --> 00:11:46,640  
actually melting parts of the lunar

304  
00:11:52,150 --> 00:11:50,160  
surface continuously okay so thankfully

305  
00:11:54,710 --> 00:11:52,160  
we have a atmosphere that protects us

306  
00:11:57,190 --> 00:11:54,720  
from objects like chelyabinsk otherwise

307  
00:11:59,509 --> 00:11:57,200  
it would have hit the ground and created

308  
00:12:01,110 --> 00:11:59,519  
some more damage okay

309  
00:12:03,269 --> 00:12:01,120  
meteors are something that you can also

310  
00:12:04,870 --> 00:12:03,279  
see from space i love this picture this

311  
00:12:06,550 --> 00:12:04,880  
is captured by some of our colleagues

312  
00:12:07,509 --> 00:12:06,560  
across the street at the johnson space

313  
00:12:09,350 --> 00:12:07,519

center

314

00:12:11,030 --> 00:12:09,360

when they were on orbit on the

315

00:12:13,190 --> 00:12:11,040

international space station you can see

316

00:12:16,069 --> 00:12:13,200

this little perseid meteor streaking

317

00:12:18,069 --> 00:12:16,079

into the upper atmosphere and i would

318

00:12:20,389 --> 00:12:18,079

love to know if somebody saw this very

319

00:12:21,829 --> 00:12:20,399

same year on the ground don't know but

320

00:12:23,030 --> 00:12:21,839

it would be fascinating for it to have

321

00:12:24,870 --> 00:12:23,040

been witnessed

322

00:12:25,990 --> 00:12:24,880

coming and going

323

00:12:28,310 --> 00:12:26,000

okay

324

00:12:30,710 --> 00:12:28,320

not all

325

00:12:33,670 --> 00:12:30,720

fragmentation events also come with

326

00:12:35,269 --> 00:12:33,680

shock shock waves and damaging shock

327

00:12:36,069 --> 00:12:35,279

waves and air blasts

328

00:12:37,910 --> 00:12:36,079

so

329

00:12:40,629 --> 00:12:37,920

this is an example these are a few

330

00:12:44,230 --> 00:12:40,639

stones from the portales valley valley

331

00:12:46,870 --> 00:12:44,240

uh event of 1998 in this case several

332

00:12:48,389 --> 00:12:46,880

dozen stones reached the surface of the

333

00:12:50,389 --> 00:12:48,399

earth after

334

00:12:53,110 --> 00:12:50,399

witnesses reported hearing multiple

335

00:12:55,590 --> 00:12:53,120

detonations and seen smoke trails but in

336

00:12:57,910 --> 00:12:55,600

this case the object was smaller the

337

00:13:00,230 --> 00:12:57,920

detonations occurred a little bit higher

338

00:13:01,910 --> 00:13:00,240

and there was no significant damage on

339

00:13:04,150 --> 00:13:01,920

the ground other than

340

00:13:06,389 --> 00:13:04,160

going through the wall of a barn and

341

00:13:07,990 --> 00:13:06,399

digging a few holes in the field and

342

00:13:08,870 --> 00:13:08,000

roads

343

00:13:10,629 --> 00:13:08,880

okay

344

00:13:13,590 --> 00:13:10,639

so now let's drill in a little bit more

345

00:13:14,949 --> 00:13:13,600

about the chelyabinsk properties itself

346

00:13:17,990 --> 00:13:14,959

first of all the diameter of the

347

00:13:19,670 --> 00:13:18,000

asteroid is about 20 meters 66 feet for

348

00:13:20,790 --> 00:13:19,680

those of you who are used to english

349

00:13:22,949 --> 00:13:20,800

units

350

00:13:25,430 --> 00:13:22,959

the asteroid hit the earth with a

351  
00:13:28,069 --> 00:13:25,440  
velocity of about 19 kilometers per

352  
00:13:29,350 --> 00:13:28,079  
second that's about 41 000 miles per

353  
00:13:31,829 --> 00:13:29,360  
hour

354  
00:13:35,509 --> 00:13:31,839  
most of the kinetic energy was deposited

355  
00:13:38,629 --> 00:13:35,519  
an altitude of 35 to 25 kilometers above

356  
00:13:41,189 --> 00:13:38,639  
the surface and the explosive energy of

357  
00:13:43,590 --> 00:13:41,199  
that event was approximately

358  
00:13:45,269 --> 00:13:43,600  
or equal to approximately 500 kilotons

359  
00:13:46,150 --> 00:13:45,279  
of tnt

360  
00:13:49,269 --> 00:13:46,160  
which is

361  
00:13:50,870 --> 00:13:49,279  
just fairly substantial number uh the

362  
00:13:53,110 --> 00:13:50,880  
energy of the bombs that destroyed

363  
00:13:55,910 --> 00:13:53,120

hiroshima and nagasaki and world war ii

364

00:13:58,629 --> 00:13:55,920

were about 15 kilotons so this was a big

365

00:14:00,710 --> 00:13:58,639

event again fortunately occurred at a

366

00:14:02,470 --> 00:14:00,720

fairly high altitude

367

00:14:04,310 --> 00:14:02,480

this event is roughly an order of

368

00:14:07,750 --> 00:14:04,320

magnitude more energetic than the

369

00:14:09,189 --> 00:14:07,760

seacoast alien event of 1947 that also

370

00:14:11,590 --> 00:14:09,199

occurred in russia

371

00:14:13,350 --> 00:14:11,600

it's roughly an order of magnitude less

372

00:14:15,189 --> 00:14:13,360

energetic than the tunguska event of

373

00:14:17,990 --> 00:14:15,199

1908

374

00:14:18,949 --> 00:14:18,000

which occurred in siberia

375

00:14:21,189 --> 00:14:18,959

so

376

00:14:23,670 --> 00:14:21,199

russia obviously is a big continental

377

00:14:25,350 --> 00:14:23,680

mass and sees an unusually large amount

378

00:14:27,750 --> 00:14:25,360

of these events because of that surface

379

00:14:29,910 --> 00:14:27,760

area now i want to actually it's

380

00:14:31,829 --> 00:14:29,920

important to say that the estimates of

381

00:14:33,110 --> 00:14:31,839

these past events that cico delane and

382

00:14:35,269 --> 00:14:33,120

negusca

383

00:14:36,949 --> 00:14:35,279

are our best guesses

384

00:14:38,550 --> 00:14:36,959

um even

385

00:14:40,629 --> 00:14:38,560

gusting is a historical event the

386

00:14:43,590 --> 00:14:40,639

records are quite clear on it but there

387

00:14:44,389 --> 00:14:43,600

weren't arrays of devices out there to

388

00:14:46,310 --> 00:14:44,399

measure

389

00:14:49,990 --> 00:14:46,320

the event it was in fact only

390

00:14:52,790 --> 00:14:50,000

investigated years later and so

391

00:14:55,110 --> 00:14:52,800

when we try to evaluate the hazards of

392

00:14:57,829 --> 00:14:55,120

futures impacts it's important to

393

00:15:01,350 --> 00:14:57,839

understand that our database is really

394

00:15:03,350 --> 00:15:01,360

small okay and that really underscores

395

00:15:04,550 --> 00:15:03,360

the importance of the cellular dense

396

00:15:06,389 --> 00:15:04,560

impact of them

397

00:15:08,629 --> 00:15:06,399

it was terrible that people were hurt

398

00:15:10,230 --> 00:15:08,639

but for the first time we have a really

399

00:15:12,870 --> 00:15:10,240

good data point

400

00:15:16,870 --> 00:15:12,880

that relates the type of damage with the

401  
00:15:19,110 --> 00:15:16,880  
energy of the impact event okay now when

402  
00:15:21,189 --> 00:15:19,120  
this occurred on february 15th there was

403  
00:15:22,389 --> 00:15:21,199  
of course a lot of discussion as to what

404  
00:15:24,310 --> 00:15:22,399  
hit

405  
00:15:26,150 --> 00:15:24,320  
what entered the earth's atmosphere i've

406  
00:15:27,829 --> 00:15:26,160  
been telling you it's an asteroid and of

407  
00:15:29,670 --> 00:15:27,839  
course we now know it's an asteroid but

408  
00:15:32,310 --> 00:15:29,680  
what were the clues that led us to that

409  
00:15:35,350 --> 00:15:32,320  
conclusion some of these clues emerged

410  
00:15:36,470 --> 00:15:35,360  
really quickly uh so what i'm showing

411  
00:15:38,550 --> 00:15:36,480  
here

412  
00:15:41,110 --> 00:15:38,560  
are the is the evidence from the impact

413  
00:15:43,990 --> 00:15:41,120

velocity and i am plotting

414

00:15:47,030 --> 00:15:44,000

on the y-axis the impact flux as a

415

00:15:49,110 --> 00:15:47,040

consequence of the impact velocity down

416

00:15:51,350 --> 00:15:49,120

here it's in terms of kilometers per

417

00:15:52,550 --> 00:15:51,360

second up here it's in terms of miles

418

00:15:54,710 --> 00:15:52,560

per second

419

00:15:56,310 --> 00:15:54,720

most of the impactors and this is the

420

00:15:59,430 --> 00:15:56,320

follow the gold line most of the

421

00:16:01,749 --> 00:15:59,440

impactors uh that hit the earth

422

00:16:03,910 --> 00:16:01,759

are asteroids and they have an average

423

00:16:05,430 --> 00:16:03,920

impact velocity of 18 kilometers per

424

00:16:09,269 --> 00:16:05,440

second

425

00:16:11,670 --> 00:16:09,279

the earth is also hit by some

426

00:16:13,910 --> 00:16:11,680

short period comets they hit with

427

00:16:15,910 --> 00:16:13,920

velocities from about 30 to 35

428

00:16:17,749 --> 00:16:15,920

kilometers per second and then there's

429

00:16:19,509 --> 00:16:17,759

even a smaller number of long period

430

00:16:22,069 --> 00:16:19,519

comets that occasionally hit the earth

431

00:16:23,670 --> 00:16:22,079

with velocities of 50 to about 55

432

00:16:25,030 --> 00:16:23,680

kilometers per second

433

00:16:26,949 --> 00:16:25,040

on average

434

00:16:29,829 --> 00:16:26,959

the chelyabinsk object that hit the

435

00:16:32,150 --> 00:16:29,839

earth on 15 february 2013 had an

436

00:16:34,790 --> 00:16:32,160

estimated velocity of 19 kilometers per

437

00:16:36,629 --> 00:16:34,800

second which is this red line right here

438

00:16:38,629 --> 00:16:36,639

which suggests that the object was in

439

00:16:40,230 --> 00:16:38,639

fact an asteroid so that was our first

440

00:16:42,389 --> 00:16:40,240

clue

441

00:16:45,269 --> 00:16:42,399

now there was a lot of video with this

442

00:16:47,829 --> 00:16:45,279

object crossing the sky and scientists

443

00:16:50,389 --> 00:16:47,839

in fact people in the public together

444

00:16:51,990 --> 00:16:50,399

on lots of continents began piecing

445

00:16:53,829 --> 00:16:52,000

together the trajectory of that object

446

00:16:55,430 --> 00:16:53,839

through the sky and then they worked

447

00:16:57,350 --> 00:16:55,440

that backward out into space and

448

00:17:00,150 --> 00:16:57,360

calculated a trajectory

449

00:17:02,389 --> 00:17:00,160

or an orbit excuse me out in space and i

450

00:17:04,309 --> 00:17:02,399

show that result here on this diagram

451  
00:17:06,549 --> 00:17:04,319  
this is the sun the orbit of mercury the

452  
00:17:09,029 --> 00:17:06,559  
orbit of venus the orbit of earth orbit

453  
00:17:10,150 --> 00:17:09,039  
of mars and the particular orbit i'm

454  
00:17:11,829 --> 00:17:10,160  
showing you is the one that was

455  
00:17:13,990 --> 00:17:11,839  
determined by paul chotis at the jet

456  
00:17:16,470 --> 00:17:14,000  
propulsion laboratory and you can see

457  
00:17:18,069 --> 00:17:16,480  
that the orbit of chely events before it

458  
00:17:20,710 --> 00:17:18,079  
hit the earth

459  
00:17:22,630 --> 00:17:20,720  
emerged from the asteroid belt okay so

460  
00:17:24,309 --> 00:17:22,640  
this is clue number two which is

461  
00:17:27,110 --> 00:17:24,319  
suggestive of an

462  
00:17:28,549 --> 00:17:27,120  
origin as an asteroid

463  
00:17:30,789 --> 00:17:28,559

finally

464

00:17:33,430 --> 00:17:30,799

not too long after the event occurred

465

00:17:35,270 --> 00:17:33,440

people started reporting stones and and

466

00:17:37,270 --> 00:17:35,280

pebbles and so on and so forth that had

467

00:17:39,909 --> 00:17:37,280

actually reached the surface and began

468

00:17:43,110 --> 00:17:39,919

collecting them so let me show you uh

469

00:17:44,710 --> 00:17:43,120

actually an example of a russian citizen

470

00:17:47,029 --> 00:17:44,720

this is not a scientist but simply a

471

00:17:53,669 --> 00:17:47,039

russian citizen who's very curious about

472

00:17:57,029 --> 00:17:55,270

he's going to drill in he's going to

473

00:17:59,110 --> 00:17:57,039

show you a little spot in the snow

474

00:18:01,430 --> 00:17:59,120

there's that little hole okay

475

00:18:04,070 --> 00:18:01,440

something's pierced the snow he's going

476

00:18:06,070 --> 00:18:04,080

to excavate around that hole

477

00:18:10,950 --> 00:18:06,080

and he's going to uncover

478

00:18:16,630 --> 00:18:13,990

and scrape it away now as it turns out

479

00:18:19,590 --> 00:18:16,640

as these objects pierce the snow they

480

00:18:20,950 --> 00:18:19,600

formed a tube and that tube became icy

481

00:18:23,750 --> 00:18:20,960

and they formed these little objects

482

00:18:25,430 --> 00:18:23,760

that the russians call ice carrots

483

00:18:27,190 --> 00:18:25,440

and at the bottom of the ice carrots you

484

00:18:28,870 --> 00:18:27,200

see these little stones isn't that

485

00:18:29,669 --> 00:18:28,880

wonderful okay

486

00:18:34,789 --> 00:18:29,679

so

487

00:18:36,870 --> 00:18:34,799

we can take away all uncertainty uh and

488

00:18:39,190 --> 00:18:36,880

in fact analyses very quickly revealed

489

00:18:40,870 --> 00:18:39,200

that these uh are related to a type of

490

00:18:42,630 --> 00:18:40,880

meteorites that we call ordinary

491

00:18:43,830 --> 00:18:42,640

copyrights that we know for a lot of

492

00:18:45,909 --> 00:18:43,840

other reasons

493

00:18:47,270 --> 00:18:45,919

come from the asteroid belt and i'll say

494

00:18:50,390 --> 00:18:47,280

something more about

495

00:18:52,710 --> 00:18:50,400

those meteorites in a few minutes now as

496

00:18:55,270 --> 00:18:52,720

i said a few minutes ago this is a 20

497

00:18:57,350 --> 00:18:55,280

meter diameter object it's fairly

498

00:18:59,190 --> 00:18:57,360

substantial composed of ordinary

499

00:19:01,510 --> 00:18:59,200

chondrite material

500

00:19:03,510 --> 00:19:01,520

previously the largest documented

501  
00:19:04,789 --> 00:19:03,520  
explosive fragmentation of an ordinary

502  
00:19:06,870 --> 00:19:04,799  
chondritic asteroid occurred in

503  
00:19:09,270 --> 00:19:06,880  
northwestern arizona

504  
00:19:10,950 --> 00:19:09,280  
seen here in this red circle in an area

505  
00:19:13,270 --> 00:19:10,960  
called gold basin

506  
00:19:15,029 --> 00:19:13,280  
that event involved an 8 meter diameter

507  
00:19:16,070 --> 00:19:15,039  
asteroid so something substantially

508  
00:19:18,390 --> 00:19:16,080  
smaller

509  
00:19:21,669 --> 00:19:18,400  
with a kinetic energy equivalent of 5 to

510  
00:19:23,990 --> 00:19:21,679  
50 kilotons of tnt so something that was

511  
00:19:26,310 --> 00:19:24,000  
significantly by a factor of ten to one

512  
00:19:28,630 --> 00:19:26,320  
hundred smarter than the cellular

513  
00:19:30,310 --> 00:19:28,640

event nonetheless uh it showered the

514

00:19:32,950 --> 00:19:30,320

surface with several thousand relics of

515

00:19:34,710 --> 00:19:32,960

the asteroid which we collected over a

516

00:19:36,710 --> 00:19:34,720

period of years

517

00:19:38,470 --> 00:19:36,720

and i want to point out that this is

518

00:19:39,909 --> 00:19:38,480

actually an event that occurred quite a

519

00:19:41,669 --> 00:19:39,919

long time ago

520

00:19:43,510 --> 00:19:41,679

so we are extracting clues from the

521

00:19:44,390 --> 00:19:43,520

geological record of these types of

522

00:19:46,710 --> 00:19:44,400

events

523

00:19:48,950 --> 00:19:46,720

over significant portions of geologic

524

00:19:50,789 --> 00:19:48,960

time now

525

00:19:52,390 --> 00:19:50,799

chelyabinsk was dramatic because it did

526

00:19:54,549 --> 00:19:52,400

get low enough in the atmosphere it

527

00:19:56,390 --> 00:19:54,559

contained a lot of kinetic energy and

528

00:19:58,789 --> 00:19:56,400

there was the explosion that generated

529

00:19:59,990 --> 00:19:58,799

the shock waves and air blasts now it's

530

00:20:02,630 --> 00:20:00,000

important to understand that there are

531

00:20:04,870 --> 00:20:02,640

actually two sources of the shock waves

532

00:20:06,390 --> 00:20:04,880

in the air blast the first one has to do

533

00:20:07,830 --> 00:20:06,400

with the ballistic bite of that object

534

00:20:10,230 --> 00:20:07,840

through the atmosphere and that's what

535

00:20:11,750 --> 00:20:10,240

this first bullet actually addresses

536

00:20:13,350 --> 00:20:11,760

shock waves are produced by objects

537

00:20:15,430 --> 00:20:13,360

moving faster than the speed of sound

538

00:20:17,430 --> 00:20:15,440

i.e mach 1

539

00:20:19,430 --> 00:20:17,440

impacting near-earth asteroids penetrate

540

00:20:22,390 --> 00:20:19,440

the atmosphere with a speed equal to or

541

00:20:24,630 --> 00:20:22,400

in excess of 11.2 kilometers per second

542

00:20:27,110 --> 00:20:24,640

that's more than 25 000 miles per hour

543

00:20:29,430 --> 00:20:27,120

or greater than mach 35

544

00:20:31,350 --> 00:20:29,440

which produces a ballistic shock wave

545

00:20:35,510 --> 00:20:31,360

the chelyabinsk near earth asteroid was

546

00:20:37,590 --> 00:20:35,520

moving at mach 60 to 61.

547

00:20:39,270 --> 00:20:37,600

now a second

548

00:20:41,430 --> 00:20:39,280

shock wave is produced by the

549

00:20:43,510 --> 00:20:41,440

catastrophic explosion

550

00:20:46,470 --> 00:20:43,520

okay so that's just like a bomb going

551  
00:20:48,950 --> 00:20:46,480  
off anywhere that produces a radiating

552  
00:20:51,430 --> 00:20:48,960  
shock wave that can reach the surface of

553  
00:20:52,630 --> 00:20:51,440  
the earth if it occurs above the surface

554  
00:20:54,630 --> 00:20:52,640  
of the earth

555  
00:20:56,870 --> 00:20:54,640  
and those shock waves are accompanied by

556  
00:20:58,950 --> 00:20:56,880  
high velocity air blaster high velocity

557  
00:21:01,270 --> 00:20:58,960  
winds similar effects were measured

558  
00:21:04,070 --> 00:21:01,280  
around nuclear explosion test lights

559  
00:21:05,830 --> 00:21:04,080  
this is an example of trees around a

560  
00:21:08,070 --> 00:21:05,840  
united states test

561  
00:21:10,230 --> 00:21:08,080  
during the cold war and you can see that

562  
00:21:12,070 --> 00:21:10,240  
the shock wave and the air blast

563  
00:21:13,430 --> 00:21:12,080

actually is picking up a lot of dust

564

00:21:15,909 --> 00:21:13,440

blowing it and

565

00:21:17,909 --> 00:21:15,919

blending over trees now the tunduska

566

00:21:20,310 --> 00:21:17,919

impact event which i've mentioned

567

00:21:23,990 --> 00:21:20,320

once and we'll refer to again the event

568

00:21:25,830 --> 00:21:24,000

of 1908 was so energetic that when it uh

569

00:21:28,230 --> 00:21:25,840

the shockwave and airblast encountered

570

00:21:31,430 --> 00:21:28,240

the forest in siberia it snapped those

571

00:21:34,310 --> 00:21:31,440

trees over like toothpicks over a region

572

00:21:36,470 --> 00:21:34,320

without two thousand square kilometers

573

00:21:39,190 --> 00:21:36,480

okay now

574

00:21:41,029 --> 00:21:39,200

this is a diagram that illustrates uh

575

00:21:44,470 --> 00:21:41,039

the consequence of the shock wave as it

576

00:21:46,470 --> 00:21:44,480

radiates from the point of origin

577

00:21:48,789 --> 00:21:46,480

so this is increasing pressure over

578

00:21:51,669 --> 00:21:48,799

pressure and as a function of distance

579

00:21:53,590 --> 00:21:51,679

from that origin and not surprisingly

580

00:21:56,630 --> 00:21:53,600

the shock wave is more intense the

581

00:21:58,630 --> 00:21:56,640

closer you are to the impact and as time

582

00:22:01,830 --> 00:21:58,640

progresses and the odd the shock wave

583

00:22:02,870 --> 00:22:01,840

passes over a larger and larger area of

584

00:22:04,710 --> 00:22:02,880

the earth

585

00:22:07,029 --> 00:22:04,720

the energy or the magnitude of that

586

00:22:08,070 --> 00:22:07,039

shock wave decreases

587

00:22:11,110 --> 00:22:08,080

now

588

00:22:14,310 --> 00:22:11,120

let's talk about what shock waves and

589

00:22:16,789 --> 00:22:14,320

air blasts have done at some other known

590

00:22:19,190 --> 00:22:16,799

geologic events

591

00:22:21,510 --> 00:22:19,200

the best preserve and i think the most

592

00:22:23,350 --> 00:22:21,520

dramatic near-earth asteroid impact site

593

00:22:25,190 --> 00:22:23,360

is behringer or meteor crater in

594

00:22:26,950 --> 00:22:25,200

northern arizona if you've not been

595

00:22:29,190 --> 00:22:26,960

there you need to go there okay it's

596

00:22:31,029 --> 00:22:29,200

just down the road from the grand canyon

597

00:22:33,830 --> 00:22:31,039

so when you go to the grand canyon make

598

00:22:37,270 --> 00:22:33,840

a stop this is the crater it's 1.2

599

00:22:38,950 --> 00:22:37,280

kilometers in diameter okay uh the the

600

00:22:40,950 --> 00:22:38,960

guides there like to point out that if

601  
00:22:42,470 --> 00:22:40,960  
you had stood the washington monument on

602  
00:22:44,710 --> 00:22:42,480  
the floor of the crater

603  
00:22:46,310 --> 00:22:44,720  
the tip of the monument would just reach

604  
00:22:47,430 --> 00:22:46,320  
the rim

605  
00:22:48,710 --> 00:22:47,440  
and

606  
00:22:49,909 --> 00:22:48,720  
this was a

607  
00:22:51,990 --> 00:22:49,919  
larger

608  
00:22:54,390 --> 00:22:52,000  
impact event the object obviously

609  
00:22:56,549 --> 00:22:54,400  
reached the ground but as i'll discuss a

610  
00:22:58,470 --> 00:22:56,559  
little bit later the object wasn't that

611  
00:22:59,830 --> 00:22:58,480  
much bigger than the chelyabinsk one so

612  
00:23:01,430 --> 00:22:59,840  
that's actually important to keep in

613  
00:23:04,230 --> 00:23:01,440

mind when you're trying to think about

614

00:23:06,470 --> 00:23:04,240

the evaluate the hazard disease types of

615

00:23:07,909 --> 00:23:06,480

objects okay so let's talk about what

616

00:23:10,470 --> 00:23:07,919

meteor crate what happened at meteor

617

00:23:11,909 --> 00:23:10,480

crater this is a satellite view it isn't

618

00:23:13,430 --> 00:23:11,919

actually it's a space shuttle view this

619

00:23:16,390 --> 00:23:13,440

is from columbia

620

00:23:18,149 --> 00:23:16,400

uh and here is the 1.2 kilometer crater

621

00:23:21,430 --> 00:23:18,159

right here in the center of the bullseye

622

00:23:23,350 --> 00:23:21,440

okay now uh in small events like this

623

00:23:25,990 --> 00:23:23,360

one it's hard to imagine this is a small

624

00:23:28,789 --> 00:23:26,000

event but in the scheme of things it is

625

00:23:30,630 --> 00:23:28,799

a fireball shockwave and air blast are

626

00:23:33,510 --> 00:23:30,640

the major environmental effects this is

627

00:23:36,470 --> 00:23:33,520

not the size of the vent that produces

628

00:23:38,149 --> 00:23:36,480

global climatic changes mass extinctions

629

00:23:40,070 --> 00:23:38,159

or anything of that sort

630

00:23:42,070 --> 00:23:40,080

nonetheless the blast effect was

631

00:23:44,710 --> 00:23:42,080

immediately lethal for human sized

632

00:23:48,149 --> 00:23:44,720

animals within the inner six kilometer

633

00:23:50,470 --> 00:23:48,159

diameter circle that circle right there

634

00:23:52,789 --> 00:23:50,480

severe lung damage

635

00:23:54,549 --> 00:23:52,799

uh would occur within the next 10 to 12

636

00:23:57,029 --> 00:23:54,559

kilometer diameter circle due to

637

00:23:59,350 --> 00:23:57,039

pressure pulse alone and animals would

638

00:24:02,390 --> 00:23:59,360

be severely injured and unlikely to

639

00:24:05,350 --> 00:24:02,400

survive with that within that region

640

00:24:08,470 --> 00:24:05,360

now winds and would have exceeded 15

641

00:24:10,470 --> 00:24:08,480

kilometers 1500 excuse me 1500

642

00:24:11,510 --> 00:24:10,480

kilometers per hour within the inner

643

00:24:14,310 --> 00:24:11,520

circle

644

00:24:16,950 --> 00:24:14,320

and still exceed 100 kilometers per hour

645

00:24:19,110 --> 00:24:16,960

at radial distances of 25 kilometers

646

00:24:21,190 --> 00:24:19,120

which is this third circle here the

647

00:24:24,630 --> 00:24:21,200

outermost circle that i portrayed there

648

00:24:26,630 --> 00:24:24,640

at 50 kilometer uh 50 kilometers

649

00:24:28,950 --> 00:24:26,640

represents the outer limit of severe to

650

00:24:31,669 --> 00:24:28,960

moderate damage trees and any human

651  
00:24:32,390 --> 00:24:31,679  
structures of comparable strength to

652  
00:24:34,149 --> 00:24:32,400  
trees

653  
00:24:36,390 --> 00:24:34,159  
and i say that because at this point at

654  
00:24:38,230 --> 00:24:36,400  
the time of this impact event 50 000

655  
00:24:40,149 --> 00:24:38,240  
years ago there weren't humans in the

656  
00:24:43,510 --> 00:24:40,159  
vicinity and there certainly weren't any

657  
00:24:45,269 --> 00:24:43,520  
houses or anything of that sort

658  
00:24:46,950 --> 00:24:45,279  
in contrast to what you'll sometimes

659  
00:24:47,990 --> 00:24:46,960  
hear visitors say

660  
00:24:49,269 --> 00:24:48,000  
on the rim of the crater it's

661  
00:24:53,029 --> 00:24:49,279  
fascinating

662  
00:24:55,110 --> 00:24:53,039  
okay now this being 50 000 years ago

663  
00:24:58,070 --> 00:24:55,120

the landscape was different in fact the

664

00:24:59,430 --> 00:24:58,080

climate was different we had cool cooler

665

00:25:01,350 --> 00:24:59,440

and and wetter conditions we are

666

00:25:03,590 --> 00:25:01,360

actually were in the ice age

667

00:25:05,750 --> 00:25:03,600

uh the animals that would have adorned

668

00:25:08,630 --> 00:25:05,760

the landscape are mammoths and mastodons

669

00:25:11,750 --> 00:25:08,640

giant grounds sloths and bears beating

670

00:25:12,549 --> 00:25:11,760

and browsing and hunting okay

671

00:25:14,390 --> 00:25:12,559

uh

672

00:25:16,549 --> 00:25:14,400

you'll see that red circle

673

00:25:18,549 --> 00:25:16,559

that represents uh where the fireball

674

00:25:20,870 --> 00:25:18,559

would have scorched plants to animals up

675

00:25:23,990 --> 00:25:20,880

to a distance of 10 kilometers

676  
00:25:26,789 --> 00:25:24,000  
the yellow zone represents where large

677  
00:25:29,269 --> 00:25:26,799  
animals were killed or wounded by a

678  
00:25:31,750 --> 00:25:29,279  
pressure pulse and an air blast i mean

679  
00:25:33,990 --> 00:25:31,760  
for example imagine this

680  
00:25:35,430 --> 00:25:34,000  
pressure pulse and an air blast hit

681  
00:25:38,070 --> 00:25:35,440  
going over the landscape picking up

682  
00:25:40,149 --> 00:25:38,080  
sticks and stones and basically creating

683  
00:25:41,590 --> 00:25:40,159  
the fuselage or a shotgun blast that

684  
00:25:42,390 --> 00:25:41,600  
would have impaled

685  
00:25:45,190 --> 00:25:42,400  
organ

686  
00:25:47,510 --> 00:25:45,200  
animals living across the surface so

687  
00:25:50,390 --> 00:25:47,520  
even animals that were wounded and not

688  
00:25:52,950 --> 00:25:50,400

killed directly may have had a hard time

689

00:25:54,470 --> 00:25:52,960

surviving afterwards hurricane force

690

00:25:56,310 --> 00:25:54,480

winds would have then extended up to a

691

00:25:58,390 --> 00:25:56,320

distances of 30 kilometers in all

692

00:26:01,909 --> 00:25:58,400

directions which is represented

693

00:26:04,310 --> 00:26:01,919

by that blue circle okay

694

00:26:07,029 --> 00:26:04,320

now as i said that occurred 50 000 years

695

00:26:09,269 --> 00:26:07,039

ago there were no humans in the region

696

00:26:12,870 --> 00:26:09,279

but it's important to note that if such

697

00:26:15,350 --> 00:26:12,880

an event were to occur today it has

698

00:26:18,070 --> 00:26:15,360

the capability of completely decimating

699

00:26:20,549 --> 00:26:18,080

a population of a modern uh

700

00:26:22,390 --> 00:26:20,559

city like kansas city so here is a

701  
00:26:24,070 --> 00:26:22,400  
outline of the metropolitan area of

702  
00:26:25,510 --> 00:26:24,080  
kansas city

703  
00:26:27,430 --> 00:26:25,520  
that is the

704  
00:26:28,390 --> 00:26:27,440  
circle represents

705  
00:26:30,950 --> 00:26:28,400  
the

706  
00:26:33,029 --> 00:26:30,960  
zone of severe to moderate damage

707  
00:26:34,950 --> 00:26:33,039  
anything in that zone would essentially

708  
00:26:37,269 --> 00:26:34,960  
be annihilated

709  
00:26:39,909 --> 00:26:37,279  
okay

710  
00:26:42,470 --> 00:26:39,919  
larger impact events affect larger

711  
00:26:43,909 --> 00:26:42,480  
regions this is a picture of eastern

712  
00:26:45,669 --> 00:26:43,919  
canada

713  
00:26:47,669 --> 00:26:45,679

in the center of the bullseye is a

714

00:26:51,510 --> 00:26:47,679

crater called Manical Wagon it's about

715

00:26:53,990 --> 00:26:51,520

100 kilometers in diameter

716

00:26:56,789 --> 00:26:54,000

and the white circle represents

717

00:26:58,470 --> 00:26:56,799

the region over which

718

00:27:01,590 --> 00:26:58,480

buildings and structures if they were to

719

00:27:04,149 --> 00:27:01,600

occur there would have been destroyed

720

00:27:06,789 --> 00:27:04,159

so as you can see it's a rather large

721

00:27:09,350 --> 00:27:06,799

area over a diameter of about 1100

722

00:27:11,350 --> 00:27:09,360

kilometers fortunately I've said this

723

00:27:14,310 --> 00:27:11,360

once before and I'll say it again

724

00:27:17,909 --> 00:27:14,320

larger impact events occur far less

725

00:27:20,149 --> 00:27:17,919

frequently than small ones which is good

726

00:27:22,149 --> 00:27:20,159

and really good when you start to step

727

00:27:24,549 --> 00:27:22,159

up to chick sleep size impact events

728

00:27:26,549 --> 00:27:24,559

which are dinosaur killing impact events

729

00:27:28,549 --> 00:27:26,559

mass extinction style impact events

730

00:27:31,669 --> 00:27:28,559

unfortunately for us these occur on

731

00:27:32,549 --> 00:27:31,679

average only once per 100 million years

732

00:27:34,389 --> 00:27:32,559

okay

733

00:27:37,350 --> 00:27:34,399

in this case

734

00:27:39,269 --> 00:27:37,360

um a severe air blast represented by the

735

00:27:40,950 --> 00:27:39,279

red zone flattened would have flattened

736

00:27:42,870 --> 00:27:40,960

any force out to a distance of about

737

00:27:44,950 --> 00:27:42,880

1500 kilometers

738

00:27:47,029 --> 00:27:44,960

gale to hurricane force winds would have

739

00:27:49,430 --> 00:27:47,039

extended over the entire southern part

740

00:27:53,029 --> 00:27:49,440

of the north american continent as

741

00:27:55,350 --> 00:27:53,039

outlined by that yellow circle

742

00:27:58,549 --> 00:27:55,360

in this case these are actually minor

743

00:27:59,510 --> 00:27:58,559

consequences of the impact event in this

744

00:28:01,669 --> 00:27:59,520

case

745

00:28:02,789 --> 00:28:01,679

the impact event was so large that had

746

00:28:05,350 --> 00:28:02,799

global

747

00:28:07,110 --> 00:28:05,360

effects that extinguished most life on

748

00:28:09,590 --> 00:28:07,120

earth at that time

749

00:28:11,350 --> 00:28:09,600

65 million years ago okay

750

00:28:12,870 --> 00:28:11,360

so this is a little chart to kind of

751

00:28:14,710 --> 00:28:12,880

illustrate what i've just said in the

752

00:28:18,870 --> 00:28:14,720

last slides

753

00:28:21,430 --> 00:28:18,880

the area affected uh by the blast

754

00:28:23,110 --> 00:28:21,440

uh increases as the impact energy

755

00:28:24,950 --> 00:28:23,120

increases and so you see several things

756

00:28:28,070 --> 00:28:24,960

here plotted there's behringer meteor

757

00:28:30,070 --> 00:28:28,080

crater uh there's uh the reese crater in

758

00:28:31,590 --> 00:28:30,080

germany there's wagon which i showed you

759

00:28:34,149 --> 00:28:31,600

in canada and here's the chick-fil-a

760

00:28:35,350 --> 00:28:34,159

impact event in mexico that affected the

761

00:28:38,230 --> 00:28:35,360

entire world

762

00:28:41,269 --> 00:28:38,240

shelia bentz you can see is at the

763

00:28:45,350 --> 00:28:41,279

extreme small end of the types of events

764

00:28:47,430 --> 00:28:45,360

that produce air blast okay

765

00:28:49,510 --> 00:28:47,440

so at some level you look at this chart

766

00:28:51,830 --> 00:28:49,520

and say okay they're not bad

767

00:28:53,990 --> 00:28:51,840

inconsequential at some level

768

00:28:55,830 --> 00:28:54,000

but it's important to also realize that

769

00:28:58,389 --> 00:28:55,840

as the world's population grows and

770

00:29:00,310 --> 00:28:58,399

occupies a larger fraction of earth's

771

00:29:02,470 --> 00:29:00,320

surface events like chely events will

772

00:29:05,350 --> 00:29:02,480

potentially affect more people so that

773

00:29:06,470 --> 00:29:05,360

isn't something i think to keep in mind

774

00:29:07,590 --> 00:29:06,480

okay

775

00:29:09,269 --> 00:29:07,600

now

776

00:29:12,149 --> 00:29:09,279

you don't just have to look at the

777

00:29:15,350 --> 00:29:12,159

geologic past

778

00:29:19,430 --> 00:29:17,909

see examples of these type of events

779

00:29:20,870 --> 00:29:19,440

on this is the modification of the

780

00:29:22,789 --> 00:29:20,880

diagram i showed you earlier i've

781

00:29:24,470 --> 00:29:22,799

actually now put on here the

782

00:29:25,830 --> 00:29:24,480

trajectories of several relatively

783

00:29:27,750 --> 00:29:25,840

recent events

784

00:29:30,070 --> 00:29:27,760

here's chelyabinsk itself coming in

785

00:29:32,789 --> 00:29:30,080

rather shallowly detonating here with a

786

00:29:36,149 --> 00:29:32,799

fat blast of 500 kilotons

787

00:29:38,310 --> 00:29:36,159

just the year before in 2012

788

00:29:40,070 --> 00:29:38,320

the sutter's mill meteoroid detonated

789

00:29:41,350 --> 00:29:40,080

over california how many people remember

790

00:29:44,310 --> 00:29:41,360

hearing about that

791

00:29:47,750 --> 00:29:44,320

okay that had the uh energy of about

792

00:29:50,470 --> 00:29:47,760

four kilotons and then in 2008 we had

793

00:29:53,190 --> 00:29:50,480

another asteroid come whizzing in this

794

00:29:54,950 --> 00:29:53,200

one actually was detected before it hit

795

00:29:56,870 --> 00:29:54,960

and so there were prediction predictions

796

00:29:59,510 --> 00:29:56,880

as to where it would burst and in fact

797

00:30:02,710 --> 00:29:59,520

it did burst with a one kiloton blast uh

798

00:30:05,590 --> 00:30:02,720

over northern sudan okay

799

00:30:07,750 --> 00:30:05,600

so these events are something that occur

800

00:30:09,590 --> 00:30:07,760

on a relatively frequent time scale okay

801  
00:30:11,269 --> 00:30:09,600  
now let's let's look at the asteroid

802  
00:30:13,430 --> 00:30:11,279  
itself okay we have all these meteoritic

803  
00:30:15,350 --> 00:30:13,440  
fragments of it here is a picture just

804  
00:30:16,630 --> 00:30:15,360  
rotated of one of these fragments it's a

805  
00:30:19,909 --> 00:30:16,640  
beautiful rock

806  
00:30:23,029 --> 00:30:19,919  
um you can see that it is it's a breccia

807  
00:30:25,830 --> 00:30:23,039  
what i mean by a brecht it it is a rock

808  
00:30:27,190 --> 00:30:25,840  
that is composed of broken fragments of

809  
00:30:29,190 --> 00:30:27,200  
older rocks

810  
00:30:32,230 --> 00:30:29,200  
and they are cross-cut by these dark

811  
00:30:35,110 --> 00:30:32,240  
black veins these veins are material of

812  
00:30:37,909 --> 00:30:35,120  
shock-melted uh portions of the asteroid

813  
00:30:40,230 --> 00:30:37,919

that were created in an impact event on

814

00:30:43,590 --> 00:30:40,240

the asteroid long before it encountered

815

00:30:46,470 --> 00:30:43,600

the earth okay this retriation process

816

00:30:47,750 --> 00:30:46,480

uh probably is responsible for reducing

817

00:30:50,310 --> 00:30:47,760

the structural integrity of the

818

00:30:52,310 --> 00:30:50,320

meteoroid and made it more susceptible

819

00:30:54,710 --> 00:30:52,320

for catastrophic fragmentation in the

820

00:30:57,190 --> 00:30:54,720

earth's atmosphere and this is something

821

00:30:59,750 --> 00:30:57,200

that's been argued on the basis of other

822

00:31:02,470 --> 00:30:59,760

uh meteoritic materials that have fallen

823

00:31:03,190 --> 00:31:02,480

to the earth now scientists love to take

824

00:31:05,669 --> 00:31:03,200

these

825

00:31:08,149 --> 00:31:05,679

thin slices through rocks and this is an

826  
00:31:09,269 --> 00:31:08,159  
example of that through the chelyabinsk

827  
00:31:10,870 --> 00:31:09,279  
meteorite

828  
00:31:13,029 --> 00:31:10,880  
and then we put it on a microscope and

829  
00:31:14,630 --> 00:31:13,039  
this allows us to see the microscopic

830  
00:31:16,630 --> 00:31:14,640  
texture of the interior and the

831  
00:31:18,710 --> 00:31:16,640  
meteoritis in the audience are going to

832  
00:31:20,070 --> 00:31:18,720  
be drawn immediately to these circular

833  
00:31:21,830 --> 00:31:20,080  
objects that are scattered here and

834  
00:31:24,789 --> 00:31:21,840  
there throughout the object

835  
00:31:27,990 --> 00:31:24,799  
these are conduits these represent

836  
00:31:30,149 --> 00:31:28,000  
molten droplets of rock fiery rain that

837  
00:31:33,029 --> 00:31:30,159  
once existed in the solar nebula this

838  
00:31:35,509 --> 00:31:33,039

disk of dust and gas that used to

839

00:31:39,190 --> 00:31:35,519

circulate around the sun long before

840

00:31:41,669 --> 00:31:39,200

planets accreted okay

841

00:31:43,990 --> 00:31:41,679

these chondrules are eventually accreted

842

00:31:45,909 --> 00:31:44,000

to form small planetesimals and those in

843

00:31:48,549 --> 00:31:45,919

turn eventually accreted to form the

844

00:31:50,789 --> 00:31:48,559

larger planets like earth

845

00:31:52,950 --> 00:31:50,799

that material after accreted into some a

846

00:31:54,710 --> 00:31:52,960

small planetary body was then affected

847

00:31:57,350 --> 00:31:54,720

by an impact event and it created these

848

00:31:59,269 --> 00:31:57,360

dark black channels of impact melt

849

00:32:02,230 --> 00:31:59,279

that cross cut the sample

850

00:32:04,789 --> 00:32:02,240

other parts of this meteoroid

851  
00:32:07,029 --> 00:32:04,799  
are completely black okay none of those

852  
00:32:08,950 --> 00:32:07,039  
white fragments survive

853  
00:32:11,350 --> 00:32:08,960  
and those black regions are visible in

854  
00:32:13,029 --> 00:32:11,360  
both the microscopic thin section and

855  
00:32:14,630 --> 00:32:13,039  
actually in whole specimens this is a

856  
00:32:16,470 --> 00:32:14,640  
centimeter cubed

857  
00:32:18,549 --> 00:32:16,480  
and this material has been severely

858  
00:32:20,470 --> 00:32:18,559  
shock damaged and melted by a

859  
00:32:23,029 --> 00:32:20,480  
pre-existing impact event on the

860  
00:32:25,909 --> 00:32:23,039  
asteroid before it actually encountered

861  
00:32:27,590 --> 00:32:25,919  
the earth okay now

862  
00:32:30,310 --> 00:32:27,600  
this is a picture to kind of illustrate

863  
00:32:32,870 --> 00:32:30,320

the processes that this meteorite or the

864

00:32:34,070 --> 00:32:32,880

meat the parent body suffered before it

865

00:32:36,070 --> 00:32:34,080

encountered the earth it came from the

866

00:32:37,590 --> 00:32:36,080

asteroid belt and in the asteroid belt

867

00:32:39,509 --> 00:32:37,600

the asteroids are bumping into each

868

00:32:41,350 --> 00:32:39,519

other and any picture of the asteroid

869

00:32:43,590 --> 00:32:41,360

that you see returned by nasa spacecraft

870

00:32:46,070 --> 00:32:43,600

or other agency spacecraft then you will

871

00:32:48,710 --> 00:32:46,080

inevitably see a surface that has been

872

00:32:50,870 --> 00:32:48,720

pockmarked or affected by collisional

873

00:32:52,230 --> 00:32:50,880

processes here in fact you can see an

874

00:32:54,149 --> 00:32:52,240

impact uh

875

00:32:55,430 --> 00:32:54,159

illustrated uh

876

00:32:57,190 --> 00:32:55,440

and and

877

00:32:58,870 --> 00:32:57,200

going on and i i should say i want to

878

00:33:01,430 --> 00:32:58,880

thank dan durda who is actually the

879

00:33:03,350 --> 00:33:01,440

artist that uh reconstructed these some

880

00:33:05,190 --> 00:33:03,360

of these impact events are so

881

00:33:07,909 --> 00:33:05,200

catastrophic the object might actually

882

00:33:10,389 --> 00:33:07,919

pull apart and reassemble uh forming uh

883

00:33:12,230 --> 00:33:10,399

rubble piles now

884

00:33:13,190 --> 00:33:12,240

this is a picture of the asteroid belt

885

00:33:15,110 --> 00:33:13,200

okay

886

00:33:16,950 --> 00:33:15,120

we have the earth and the moon here's

887

00:33:19,590 --> 00:33:16,960

mars here's jupiter and the asteroid

888

00:33:22,070 --> 00:33:19,600

belt is lined between mars and jupiter

889

00:33:24,710 --> 00:33:22,080

uh asteroids can survive for billions of

890

00:33:25,830 --> 00:33:24,720

years in the asteroid belt up to 4.5

891

00:33:27,909 --> 00:33:25,840

billion years

892

00:33:30,789 --> 00:33:27,919

every once in a while those asteroids

893

00:33:32,789 --> 00:33:30,799

can migrate or will migrate into these

894

00:33:35,909 --> 00:33:32,799

channels you can see there's these gulfs

895

00:33:38,789 --> 00:33:35,919

these gaps they're called kirkwood gaps

896

00:33:40,470 --> 00:33:38,799

where asteroids when they reach those

897

00:33:43,909 --> 00:33:40,480

positions in the asteroid belt are

898

00:33:45,750 --> 00:33:43,919

affected gravitationally by jupiter

899

00:33:47,750 --> 00:33:45,760

and the orbits are perturbed so instead

900

00:33:49,830 --> 00:33:47,760

of having a nice circular orbit around

901  
00:33:52,389 --> 00:33:49,840  
the sun they're perturbed into an

902  
00:33:54,149 --> 00:33:52,399  
elliptical orbit that crosses

903  
00:33:56,789 --> 00:33:54,159  
the orbits of the inner solar system

904  
00:33:59,190 --> 00:33:56,799  
planets like mars earth venus mercury

905  
00:34:01,909 --> 00:33:59,200  
and once they cross those orbits they

906  
00:34:03,590 --> 00:34:01,919  
can collide with the planets so that

907  
00:34:05,830 --> 00:34:03,600  
happened to chelyabinsk at some point in

908  
00:34:07,269 --> 00:34:05,840  
time and put it on a collision course

909  
00:34:09,270 --> 00:34:07,279  
with earth

910  
00:34:11,030 --> 00:34:09,280  
okay now

911  
00:34:14,230 --> 00:34:11,040  
we actually know quite a lot about the

912  
00:34:16,550 --> 00:34:14,240  
asteroids uh and near-earth asteroids

913  
00:34:18,629 --> 00:34:16,560

to be more precise we have fifty

914

00:34:20,869 --> 00:34:18,639

thousand samples an era of asteroids in

915

00:34:23,669 --> 00:34:20,879

our collections every meteorite's near

916

00:34:26,230 --> 00:34:23,679

an asteroid okay so we know something

917

00:34:27,829 --> 00:34:26,240

about uh those those objects and how

918

00:34:29,349 --> 00:34:27,839

they were processed or evolved in the

919

00:34:31,669 --> 00:34:29,359

asteroid belt we know something about

920

00:34:33,510 --> 00:34:31,679

how those objects evolve once they get

921

00:34:36,149 --> 00:34:33,520

into earth crossing orbits and we know

922

00:34:37,829 --> 00:34:36,159

something about uh

923

00:34:40,069 --> 00:34:37,839

the collisional processes when they

924

00:34:42,230 --> 00:34:40,079

actually do encounter the earth now most

925

00:34:43,669 --> 00:34:42,240

of those samples most of those 50 000

926  
00:34:44,790 --> 00:34:43,679  
samples are what we call ordinary

927  
00:34:47,190 --> 00:34:44,800  
chondrites

928  
00:34:49,349 --> 00:34:47,200  
that's the type of material chelyabinsk

929  
00:34:51,270 --> 00:34:49,359  
is composed of okay now there's three

930  
00:34:52,869 --> 00:34:51,280  
types of ordinary chondrites there is

931  
00:34:54,230 --> 00:34:52,879  
something called type h

932  
00:34:56,230 --> 00:34:54,240  
and i'm not going to worry too much

933  
00:34:57,589 --> 00:34:56,240  
about the distinctions between these

934  
00:34:59,910 --> 00:34:57,599  
just understand that there are some

935  
00:35:02,069 --> 00:34:59,920  
compositional differences that suggest

936  
00:35:03,510 --> 00:35:02,079  
they came from three different parent

937  
00:35:05,589 --> 00:35:03,520  
bodies okay

938  
00:35:07,510 --> 00:35:05,599

so there's a type h ordinary chondroitin

939

00:35:09,829 --> 00:35:07,520

type I ordinary chondrites and the type

940

00:35:12,310 --> 00:35:09,839

II ordinary chondrites

941

00:35:14,069 --> 00:35:12,320

and our analyses and analyses by teams

942

00:35:16,790 --> 00:35:14,079

around the world have found that

943

00:35:20,630 --> 00:35:16,800

t'chelyabinsk object is derived from the

944

00:35:23,109 --> 00:35:20,640

II parent body we have almost 6 000

945

00:35:24,710 --> 00:35:23,119

other samples from that parent body so

946

00:35:27,430 --> 00:35:24,720

we can actually piece together a pretty

947

00:35:29,030 --> 00:35:27,440

good story about what that

948

00:35:31,349 --> 00:35:29,040

object experienced and hearing it back

949

00:35:33,349 --> 00:35:31,359

is it's one of one of those six thousand

950

00:35:35,030 --> 00:35:33,359

samples this is the perigold uh

951  
00:35:37,990 --> 00:35:35,040  
meteorite and i love this one because

952  
00:35:39,910 --> 00:35:38,000  
first of all it's a it's a large mass

953  
00:35:41,750 --> 00:35:39,920  
if you have gone to the

954  
00:35:43,750 --> 00:35:41,760  
natural history museum the smithsonian

955  
00:35:45,190 --> 00:35:43,760  
in washington dc and gone to the meteor

956  
00:35:47,270 --> 00:35:45,200  
exhibit you've seen it you may not

957  
00:35:49,670 --> 00:35:47,280  
remember it but you've seen it

958  
00:35:51,829 --> 00:35:49,680  
and you can see here we have relic

959  
00:35:54,069 --> 00:35:51,839  
fragments of the asteroid that were

960  
00:35:56,470 --> 00:35:54,079  
caught up in an impact cratering event

961  
00:35:58,950 --> 00:35:56,480  
on this parent asteroid and it like

962  
00:36:01,430 --> 00:35:58,960  
chelyabinsk is cross-cut with these dark

963  
00:36:04,550 --> 00:36:01,440

impact melted shock veins so in many

964

00:36:06,630 --> 00:36:04,560

ways perigold has a lot of similarities

965

00:36:08,790 --> 00:36:06,640

to chelyabinsk okay

966

00:36:11,349 --> 00:36:08,800

because we have that collection of

967

00:36:13,910 --> 00:36:11,359

meteorites from the same parent body as

968

00:36:15,990 --> 00:36:13,920

chelyabinsk we can begin to piece

969

00:36:17,990 --> 00:36:16,000

together the collisional history of that

970

00:36:19,349 --> 00:36:18,000

parent body and this is something that

971

00:36:21,750 --> 00:36:19,359

i've been doing with tim swindle at the

972

00:36:22,950 --> 00:36:21,760

university of arizona and a student that

973

00:36:25,349 --> 00:36:22,960

tim had

974

00:36:27,589 --> 00:36:25,359

we've been analyzed every single impact

975

00:36:29,589 --> 00:36:27,599

melted ordinary chondrite or II ordinary

976

00:36:32,950 --> 00:36:29,599

chondrite we can get our hands on and

977

00:36:35,109 --> 00:36:32,960

what we found is a large number of them

978

00:36:38,870 --> 00:36:35,119

were involved in impact cratering events

979

00:36:41,270 --> 00:36:38,880

3.9 to 4.4 billion years ago okay

980

00:36:43,430 --> 00:36:41,280

then there's a large gap

981

00:36:45,589 --> 00:36:43,440

in our age distribution which suggests

982

00:36:47,670 --> 00:36:45,599

there were few impacts on that parent

983

00:36:49,750 --> 00:36:47,680

body for a period of about two billion

984

00:36:51,910 --> 00:36:49,760

years and then over the last two billion

985

00:36:53,750 --> 00:36:51,920

years there have been scattered impact

986

00:36:55,430 --> 00:36:53,760

events affecting the surface of that

987

00:36:56,950 --> 00:36:55,440

object one of those probably is

988

00:36:59,190 --> 00:36:56,960

responsible for jet is owning what

989

00:37:01,270 --> 00:36:59,200

became chelyabinsk okay

990

00:37:03,829 --> 00:37:01,280

now more recently we can begin to

991

00:37:05,430 --> 00:37:03,839

analyze chelyabinsk itself okay and so

992

00:37:06,950 --> 00:37:05,440

here are some data that's just appeared

993

00:37:08,630 --> 00:37:06,960

in the literature

994

00:37:11,430 --> 00:37:08,640

our russian colleagues

995

00:37:13,510 --> 00:37:11,440

have determined the age of that black

996

00:37:16,349 --> 00:37:13,520

shock melted veins running through the

997

00:37:19,030 --> 00:37:16,359

sample or produced an impact event

998

00:37:21,270 --> 00:37:19,040

4.452 billion years ago just before the

999

00:37:23,510 --> 00:37:21,280

pulse that tim swindle and i

1000

00:37:26,230 --> 00:37:23,520

seen in other samples

1001  
00:37:29,190 --> 00:37:26,240  
one or more other less damaging impact

1002  
00:37:30,950 --> 00:37:29,200  
events may have affected the object or

1003  
00:37:33,109 --> 00:37:30,960  
the chelyabinsk material

1004  
00:37:35,190 --> 00:37:33,119  
more recently and there was a final

1005  
00:37:36,630 --> 00:37:35,200  
impact in space that occurred about 1.2

1006  
00:37:38,790 --> 00:37:36,640  
billion years ago

1007  
00:37:41,349 --> 00:37:38,800  
that kunin shizumi and colleagues at

1008  
00:37:43,829 --> 00:37:41,359  
berkeley detected uh and this event

1009  
00:37:45,349 --> 00:37:43,839  
exposed what became the surface of chely

1010  
00:37:47,510 --> 00:37:45,359  
events to space

1011  
00:37:50,390 --> 00:37:47,520  
that is the event that liberated the

1012  
00:37:52,310 --> 00:37:50,400  
object that we now know as chelly events

1013  
00:37:55,670 --> 00:37:52,320

okay so let's now step through the

1014

00:37:58,230 --> 00:37:55,680

history of this object we begin

1015

00:37:59,910 --> 00:37:58,240

nearly 4.56 billion years ago with

1016

00:38:01,910 --> 00:37:59,920

formation of molten droplet chondrules

1017

00:38:03,589 --> 00:38:01,920

in the slower nebula and all of that

1018

00:38:06,710 --> 00:38:03,599

occurred within the first four million

1019

00:38:09,030 --> 00:38:06,720

years of solar system history okay

1020

00:38:12,069 --> 00:38:09,040

those chondrules and other dust particles

1021

00:38:14,310 --> 00:38:12,079

accreted to form a parent body the II

1022

00:38:16,310 --> 00:38:14,320

chondrite parent body

1023

00:38:18,310 --> 00:38:16,320

and that material was thermally

1024

00:38:20,470 --> 00:38:18,320

metamorphosed over a period of about 10

1025

00:38:22,069 --> 00:38:20,480

million years now based on the thermal

1026

00:38:24,230 --> 00:38:22,079

metamorphic textures that we actually

1027

00:38:25,510 --> 00:38:24,240

see in the chelyabinsk meteorites we can

1028

00:38:27,270 --> 00:38:25,520

determine that the cellular grains

1029

00:38:29,750 --> 00:38:27,280

material used to be buried several

1030

00:38:30,790 --> 00:38:29,760

kilometers beneath the surface

1031

00:38:35,510 --> 00:38:30,800

okay

1032

00:38:40,470 --> 00:38:37,430

on the surface

1033

00:38:42,470 --> 00:38:40,480

about 115 million years ago and we know

1034

00:38:44,829 --> 00:38:42,480

that because of the analyses of the

1035

00:38:48,630 --> 00:38:44,839

shock blackened veins that cross cut the

1036

00:38:50,710 --> 00:38:48,640

sample analyses of other II chondrites

1037

00:38:52,630 --> 00:38:50,720

that are associated with trojans

1038

00:38:55,109 --> 00:38:52,640

indicated that that parent body was then

1039

00:38:57,990 --> 00:38:55,119

hit severely by a large number of impact

1040

00:38:59,670 --> 00:38:58,000

events between about 4.3 and 3.8 billion

1041

00:39:01,349 --> 00:38:59,680

years ago

1042

00:39:02,790 --> 00:39:01,359

one or two impacts appear to have

1043

00:39:04,470 --> 00:39:02,800

slightly affected the chelyabinsk

1044

00:39:05,510 --> 00:39:04,480

material during the last 500 million

1045

00:39:07,349 --> 00:39:05,520

years

1046

00:39:09,990 --> 00:39:07,359

the meteoroid encountered a

1047

00:39:12,150 --> 00:39:10,000

gravitational resonance with jupiter

1048

00:39:14,069 --> 00:39:12,160

its orbit was modified and it became a

1049

00:39:15,910 --> 00:39:14,079

near-earth asteroid at that point and

1050

00:39:18,870 --> 00:39:15,920

the surface of the trojan benz meteoroid

1051  
00:39:20,790 --> 00:39:18,880  
is exposed to cosmic radiation about 1.2

1052  
00:39:23,030 --> 00:39:20,800  
years ago suggesting a collisional or

1053  
00:39:25,670 --> 00:39:23,040  
fragmentation event and then of course

1054  
00:39:28,390 --> 00:39:25,680  
in 2013 earlier this year

1055  
00:39:30,150 --> 00:39:28,400  
it had its final collision with planet

1056  
00:39:32,310 --> 00:39:30,160  
earth okay

1057  
00:39:35,510 --> 00:39:32,320  
that's fascinating our colleagues in

1058  
00:39:38,470 --> 00:39:35,520  
japan have actually visited a fragment

1059  
00:39:40,470 --> 00:39:38,480  
of the same I chondrite parent body it's

1060  
00:39:42,310 --> 00:39:40,480  
called asteroid itacawa

1061  
00:39:44,710 --> 00:39:42,320  
they sent the spacecraft hayabusa out

1062  
00:39:46,550 --> 00:39:44,720  
there they explored the asteroid they

1063  
00:39:48,069 --> 00:39:46,560

touched down they collected a little bit

1064

00:39:50,870 --> 00:39:48,079

of that material and they returned it to

1065

00:39:53,270 --> 00:39:50,880

earth and so we can analyze it we know

1066

00:39:55,109 --> 00:39:53,280

it is composed of ll-chondrite material

1067

00:39:57,430 --> 00:39:55,119

so here's the asteroid for scale it's

1068

00:39:59,670 --> 00:39:57,440

540 meters across

1069

00:40:01,430 --> 00:39:59,680

for comparison there's the orion crew

1070

00:40:03,750 --> 00:40:01,440

vehicle that's going to carry uh

1071

00:40:06,470 --> 00:40:03,760

astronauts uh beyond low earth orbit the

1072

00:40:08,390 --> 00:40:06,480

moon asteroids and and potentially mars

1073

00:40:11,190 --> 00:40:08,400

uh and here's the current uh

1074

00:40:12,950 --> 00:40:11,200

international space station uh for scale

1075

00:40:16,470 --> 00:40:12,960

as well this is another view of the

1076

00:40:19,829 --> 00:40:16,480

asteroid it is a rocky body uh here for

1077

00:40:22,150 --> 00:40:19,839

scale is a boulder on the surface of

1078

00:40:25,270 --> 00:40:22,160

irokawa that is 20 meters in size that

1079

00:40:26,550 --> 00:40:25,280

is the size of the chelyabinsk meteoroid

1080

00:40:28,550 --> 00:40:26,560

what's a little bit frightening about

1081

00:40:31,430 --> 00:40:28,560

that is you suddenly realize

1082

00:40:33,990 --> 00:40:31,440

there are a lot of potential chelyabinsk

1083

00:40:35,510 --> 00:40:34,000

boulders out there

1084

00:40:40,550 --> 00:40:35,520

okay

1085

00:40:42,950 --> 00:40:40,560

that indicates that irakawa actually is

1086

00:40:44,710 --> 00:40:42,960

part of the inner asteroid belt uh

1087

00:40:46,950 --> 00:40:44,720

chelyabinsk is also part of the inner

1088

00:40:48,870 --> 00:40:46,960

asteroid belt although its orbit carried

1089

00:40:50,790 --> 00:40:48,880

it a little bit farther into the

1090

00:40:53,430 --> 00:40:50,800

asteroid belt

1091

00:40:55,990 --> 00:40:53,440

now here's a comparison of scale

1092

00:40:58,390 --> 00:40:56,000

i want to begin with a picture

1093

00:40:59,750 --> 00:40:58,400

of what the I chondrite parent body

1094

00:41:02,309 --> 00:40:59,760

looked like it was roughly 100

1095

00:41:05,109 --> 00:41:02,319

kilometers in diameter okay

1096

00:41:07,430 --> 00:41:05,119

for comparison there's asteroid in ocawa

1097

00:41:09,109 --> 00:41:07,440

and actually i've had to enlarge it by a

1098

00:41:10,390 --> 00:41:09,119

factor of eight simply so you could see

1099

00:41:12,390 --> 00:41:10,400

it

1100

00:41:14,550 --> 00:41:12,400

okay chili events you simply can't see

1101

00:41:15,750 --> 00:41:14,560

it's at 20 meters and this again drives

1102

00:41:17,190 --> 00:41:15,760

on the point that i mentioned just a

1103

00:41:20,390 --> 00:41:17,200

moment ago

1104

00:41:22,870 --> 00:41:20,400

this object has been fragmented it's

1105

00:41:25,510 --> 00:41:22,880

been scattered across space

1106

00:41:26,950 --> 00:41:25,520

producing a lot more itakawas and

1107

00:41:29,030 --> 00:41:26,960

chelyabinsk some of which could

1108

00:41:31,109 --> 00:41:29,040

potentially hurt earth in the future

1109

00:41:33,109 --> 00:41:31,119

okay now i want to say a couple of other

1110

00:41:34,390 --> 00:41:33,119

things quickly my mind is over there

1111

00:41:35,510 --> 00:41:34,400

telling me you're starting to run out of

1112

00:41:37,030 --> 00:41:35,520

time

1113

00:41:38,790 --> 00:41:37,040

so but these are these are important

1114

00:41:41,190 --> 00:41:38,800

things to understand if you're trying to

1115

00:41:43,270 --> 00:41:41,200

understand the hazards of future impact

1116

00:41:45,270 --> 00:41:43,280

events the first thing i need to explain

1117

00:41:47,109 --> 00:41:45,280

is i made this point before that the

1118

00:41:49,270 --> 00:41:47,119

object that produced ferringer or meteor

1119

00:41:50,150 --> 00:41:49,280

crater in arizona is

1120

00:41:51,829 --> 00:41:50,160

very

1121

00:41:54,870 --> 00:41:51,839

roughly the size of the chelyabinsk

1122

00:41:57,349 --> 00:41:54,880

object okay now a lot of newspapers and

1123

00:41:58,950 --> 00:41:57,359

and pundits and whatnot said oh

1124

00:42:00,309 --> 00:41:58,960

julia bence was half the size of some of

1125

00:42:02,309 --> 00:42:00,319

these other events that were explosive

1126  
00:42:04,309 --> 00:42:02,319  
okay so let's actually explore what that

1127  
00:42:06,069 --> 00:42:04,319  
means half the size are twice the size

1128  
00:42:09,190 --> 00:42:06,079  
so here's here's a picture a stony

1129  
00:42:11,670 --> 00:42:09,200  
asteroid 20 meters in diameter okay

1130  
00:42:12,630 --> 00:42:11,680  
here is an object two times larger

1131  
00:42:15,990 --> 00:42:12,640  
okay

1132  
00:42:18,710 --> 00:42:16,000  
40 meters in diameter

1133  
00:42:20,069 --> 00:42:18,720  
although it is two times larger in

1134  
00:42:22,069 --> 00:42:20,079  
diameter

1135  
00:42:24,309 --> 00:42:22,079  
it has eight times the volume and eight

1136  
00:42:27,030 --> 00:42:24,319  
times the mass if the density is the

1137  
00:42:28,309 --> 00:42:27,040  
same okay so is it two times or eight

1138  
00:42:31,510 --> 00:42:28,319

times bigger

1139

00:42:33,910 --> 00:42:31,520

okay now let's put another twist on that

1140

00:42:36,630 --> 00:42:33,920

those are stony asteroids what happens

1141

00:42:39,670 --> 00:42:36,640

if we're looking at an iron asteroid

1142

00:42:41,589 --> 00:42:39,680

an iron asteroid also two times larger

1143

00:42:43,589 --> 00:42:41,599

has a higher density it might have a

1144

00:42:45,750 --> 00:42:43,599

density of seven grams per cubic

1145

00:42:49,829 --> 00:42:45,760

centimeter as opposed to two grams per

1146

00:42:52,069 --> 00:42:49,839

cubic centimeter so it is twice as large

1147

00:42:55,190 --> 00:42:52,079

with eight times the volume but it has

1148

00:42:57,750 --> 00:42:55,200

28 times the mass okay

1149

00:43:00,069 --> 00:42:57,760

now kinetic energy that is the explosive

1150

00:43:02,470 --> 00:43:00,079

nature of these types of impact events

1151  
00:43:04,710 --> 00:43:02,480  
is one half mv squared one half mass

1152  
00:43:08,309 --> 00:43:04,720  
times velocity square okay so

1153  
00:43:11,349 --> 00:43:08,319  
chelyabinsk is a 500 kiloton blast

1154  
00:43:13,589 --> 00:43:11,359  
an object with 28 times the mass has 28

1155  
00:43:16,150 --> 00:43:13,599  
times kinetic energy and would produce a

1156  
00:43:17,990 --> 00:43:16,160  
14 megaton blast that's about what

1157  
00:43:20,630 --> 00:43:18,000  
produced media crater in northern

1158  
00:43:22,390 --> 00:43:20,640  
arizona so something two times larger

1159  
00:43:26,150 --> 00:43:22,400  
can actually be

1160  
00:43:28,710 --> 00:43:26,160  
quite a bit more destructive now

1161  
00:43:31,670 --> 00:43:28,720  
during the worst um

1162  
00:43:34,150 --> 00:43:31,680  
our community and others at nasa and

1163  
00:43:35,829 --> 00:43:34,160

fema and the organizers of the planetary

1164

00:43:37,910 --> 00:43:35,839

defense conference says what if

1165

00:43:39,829 --> 00:43:37,920

something like this were to truly

1166

00:43:41,910 --> 00:43:39,839

threaten the earth in the future so we

1167

00:43:44,630 --> 00:43:41,920

ran an exercise earlier this year in

1168

00:43:47,589 --> 00:43:44,640

april david morrison i think was there

1169

00:43:49,750 --> 00:43:47,599

uh it's a fascinating exercise everybody

1170

00:43:52,069 --> 00:43:49,760

in the community was divided up into a

1171

00:43:54,150 --> 00:43:52,079

series of teams astronomers trying to

1172

00:43:57,030 --> 00:43:54,160

detect the orbit and and so on and so

1173

00:43:58,390 --> 00:43:57,040

forth uh trying to characterize an

1174

00:43:59,190 --> 00:43:58,400

asteroid that might be threatening the

1175

00:44:00,630 --> 00:43:59,200

earth

1176

00:44:02,150 --> 00:44:00,640

a group that looked at mitigation

1177

00:44:04,230 --> 00:44:02,160

techniques to try to get this thing away

1178

00:44:05,589 --> 00:44:04,240

from the earth before it hit there was a

1179

00:44:07,430 --> 00:44:05,599

team that tried to predict what the

1180

00:44:08,390 --> 00:44:07,440

impact events would be that was the team

1181

00:44:09,829 --> 00:44:08,400

that i led

1182

00:44:10,710 --> 00:44:09,839

and you can see that there are several

1183

00:44:12,470 --> 00:44:10,720

other

1184

00:44:13,349 --> 00:44:12,480

governmental

1185

00:44:16,470 --> 00:44:13,359

press

1186

00:44:19,670 --> 00:44:16,480

space agency and public teams that were

1187

00:44:20,790 --> 00:44:19,680

put in a room and tried to work out

1188

00:44:25,990 --> 00:44:20,800

what

1189

00:44:28,870 --> 00:44:26,000

if something was detected okay so in

1190

00:44:31,990 --> 00:44:28,880

this exercise a threat was detected

1191

00:44:36,390 --> 00:44:32,000

there was a hypothetical asteroid 2013

1192

00:44:38,309 --> 00:44:36,400

pdce discovered on april 16 2013

1193

00:44:40,790 --> 00:44:38,319

it appeared to be a threatening object

1194

00:44:44,550 --> 00:44:40,800

200 to 300 meters in diameter the

1195

00:44:48,309 --> 00:44:44,560

initial probability of impact was .08

1196

00:44:51,430 --> 00:44:48,319

percent in 2028 that is about 15 years

1197

00:44:53,670 --> 00:44:51,440

after discovery if it were to impact the

1198

00:44:55,349 --> 00:44:53,680

velocity was estimated to be 12.4

1199

00:45:00,309 --> 00:44:55,359

kilometers per second with an energy

1200

00:45:01,109 --> 00:45:00,319

equivalent of about 300 megatons of tnt

1201

00:45:03,750 --> 00:45:01,119

note

1202

00:45:06,470 --> 00:45:03,760

if the object passed through what

1203

00:45:09,750 --> 00:45:06,480

astronomers call a keyhole

1204

00:45:11,990 --> 00:45:09,760

the certainty of impact would have risen

1205

00:45:15,430 --> 00:45:12,000

rather dramatically and that event if it

1206

00:45:16,150 --> 00:45:15,440

were to occur would occur in 2023 okay

1207

00:45:18,069 --> 00:45:16,160

so

1208

00:45:19,589 --> 00:45:18,079

in this simulation

1209

00:45:21,190 --> 00:45:19,599

we're trying to track the orbit we're

1210

00:45:22,550 --> 00:45:21,200

trying to better characterize the object

1211

00:45:25,190 --> 00:45:22,560

we're trying to predict what it happens

1212

00:45:27,349 --> 00:45:25,200

and uh as of 2019

1213

00:45:29,430 --> 00:45:27,359

the possible impact points

1214

00:45:30,790 --> 00:45:29,440

calculated impact points lie along

1215

00:45:32,550 --> 00:45:30,800

what's called a risk corridor which you

1216

00:45:34,550 --> 00:45:32,560

can see in a red line crossing across

1217

00:45:36,390 --> 00:45:34,560

the globe the possible impact sites

1218

00:45:39,829 --> 00:45:36,400

include southeast asia the coastal

1219

00:45:42,710 --> 00:45:39,839

waters of china korea and japan siberia

1220

00:45:45,589 --> 00:45:42,720

and the arctic ocean as orbit is better

1221

00:45:48,630 --> 00:45:45,599

defined in 2019 the probability of

1222

00:45:51,030 --> 00:45:48,640

impact has risen to 28 percent now that

1223

00:45:52,950 --> 00:45:51,040

risk order goes around the world

1224

00:45:55,750 --> 00:45:52,960

and passes directly over london and

1225

00:45:57,109 --> 00:45:55,760

paris to rather populist points on the

1226

00:45:59,270 --> 00:45:57,119

earth before passing over the

1227

00:46:02,230 --> 00:45:59,280

mediterranean sea and northern africa

1228

00:46:04,950 --> 00:46:02,240

calculations of impact effect and all

1229

00:46:06,950 --> 00:46:04,960

those different terrains had to be made

1230

00:46:09,670 --> 00:46:06,960

to better inform emergency management in

1231

00:46:11,910 --> 00:46:09,680

the countries along that corridor some

1232

00:46:13,910 --> 00:46:11,920

people were panicking in the room other

1233

00:46:14,950 --> 00:46:13,920

people were taking advantage of the

1234

00:46:16,790 --> 00:46:14,960

panic

1235

00:46:20,230 --> 00:46:16,800

interesting

1236

00:46:21,670 --> 00:46:20,240

okay also as of 2019 several missions

1237

00:46:24,069 --> 00:46:21,680

had been launched to deflect the

1238

00:46:26,470 --> 00:46:24,079

asteroid and they had all failed

1239

00:46:28,550 --> 00:46:26,480

tensions and the exercise started to go

1240

00:46:30,470 --> 00:46:28,560

up there was urgent discussions of

1241

00:46:32,870 --> 00:46:30,480

nuclear weapons and last-ditch attempt

1242

00:46:33,910 --> 00:46:32,880

to destroy the asteroid interestingly

1243

00:46:35,510 --> 00:46:33,920

enough

1244

00:46:37,510 --> 00:46:35,520

some of the

1245

00:46:41,510 --> 00:46:37,520

countries represented in fact some of

1246

00:46:43,270 --> 00:46:41,520

the countries in the target zone

1247

00:46:44,790 --> 00:46:43,280

did not want to use nuclear weapons

1248

00:46:47,030 --> 00:46:44,800

because they were so philosophically

1249

00:46:50,230 --> 00:46:47,040

opposed

1250

00:46:53,109 --> 00:46:50,240

the crisis grows in 2022 the probability

1251  
00:46:54,950 --> 00:46:53,119  
of impact is now 100

1252  
00:46:56,870 --> 00:46:54,960  
so the question is simply a matter of

1253  
00:46:58,710 --> 00:46:56,880  
where it will occur as the orbit is

1254  
00:47:00,309 --> 00:46:58,720  
increasingly refined the risk corridor

1255  
00:47:01,190 --> 00:47:00,319  
shrinks

1256  
00:47:03,190 --> 00:47:01,200  
to

1257  
00:47:04,950 --> 00:47:03,200  
europe and northern africa the impact

1258  
00:47:08,710 --> 00:47:04,960  
will occur in the united kingdom france

1259  
00:47:10,309 --> 00:47:08,720  
the mediterranean sea or northern africa

1260  
00:47:12,150 --> 00:47:10,319  
and then these questions arise do you

1261  
00:47:14,790 --> 00:47:12,160  
evacuate people are nuclear power

1262  
00:47:16,870 --> 00:47:14,800  
stations shut down et cetera et cetera

1263  
00:47:20,950 --> 00:47:16,880

okay

1264

00:47:23,109 --> 00:47:20,960

then impact occurred at 7 00 700 on 21

1265

00:47:24,390 --> 00:47:23,119

november 2029

1266

00:47:25,750 --> 00:47:24,400

at the impact

1267

00:47:27,829 --> 00:47:25,760

fortunately occurred in the

1268

00:47:29,670 --> 00:47:27,839

mediterranean sea nonetheless shockwaves

1269

00:47:32,069 --> 00:47:29,680

roll over the surface of southern france

1270

00:47:34,390 --> 00:47:32,079

tsunamis follow crashing onto shorelines

1271

00:47:36,549 --> 00:47:34,400

around the entire mediterranean region

1272

00:47:40,309 --> 00:47:36,559

etc there's in general tremendous

1273

00:47:42,230 --> 00:47:40,319

devastation and it is not a good day

1274

00:47:44,309 --> 00:47:42,240

we actually learned a lot in that

1275

00:47:47,990 --> 00:47:44,319

exercise and we all walked away with a

1276

00:47:50,230 --> 00:47:48,000

lot of tasks to do including those with

1277

00:47:51,510 --> 00:47:50,240

nasa and fema okay

1278

00:47:53,349 --> 00:47:51,520

now

1279

00:47:57,990 --> 00:47:53,359

it's important a final

1280

00:48:00,069 --> 00:47:58,000

close by uh looking at yes i know

1281

00:48:02,069 --> 00:48:00,079

running out of time

1282

00:48:04,150 --> 00:48:02,079

look at uh

1283

00:48:06,790 --> 00:48:04,160

the probability of these impact events

1284

00:48:08,870 --> 00:48:06,800

and how to prepare them in a blue line

1285

00:48:11,670 --> 00:48:08,880

here what i'm plotting here that i

1286

00:48:14,549 --> 00:48:11,680

actually should say al harris plotted

1287

00:48:17,349 --> 00:48:14,559

and is in an nrc document called

1288

00:48:19,910 --> 00:48:17,359

defending planet earth is the impact

1289

00:48:21,990 --> 00:48:19,920

interval of objects of different sizes

1290

00:48:23,910 --> 00:48:22,000

okay and as we've said before smaller

1291

00:48:24,950 --> 00:48:23,920

objects hit more frequently than bigger

1292

00:48:26,790 --> 00:48:24,960

objects

1293

00:48:29,270 --> 00:48:26,800

this blue line represents the event that

1294

00:48:31,030 --> 00:48:29,280

we just simulated or i showed you in

1295

00:48:33,430 --> 00:48:31,040

that simulation at the planetary defense

1296

00:48:35,109 --> 00:48:33,440

conference this red line represents

1297

00:48:37,349 --> 00:48:35,119

chelyabinsk can you see that a chili

1298

00:48:39,510 --> 00:48:37,359

event size event occurs on average once

1299

00:48:42,390 --> 00:48:39,520

per 10 to 100 years okay and i've said

1300

00:48:44,790 --> 00:48:42,400

that several times on average okay that

1301  
00:48:46,870 --> 00:48:44,800  
is the average cadence but until we've

1302  
00:48:48,950 --> 00:48:46,880  
detected all objects any of these

1303  
00:48:50,390 --> 00:48:48,960  
objects including a mass extinction

1304  
00:48:52,790 --> 00:48:50,400  
hypoth

1305  
00:48:56,230 --> 00:48:52,800  
event could occur tomorrow okay so it's

1306  
00:48:58,710 --> 00:48:56,240  
something important to keep in mind okay

1307  
00:49:00,390 --> 00:48:58,720  
so how do we move forward

1308  
00:49:02,309 --> 00:49:00,400  
to move forward i want to actually draw

1309  
00:49:04,630 --> 00:49:02,319  
your attention to this diagram which is

1310  
00:49:07,349 --> 00:49:04,640  
similar you'll see that same curve

1311  
00:49:10,390 --> 00:49:07,359  
i've put the impact interval in years

1312  
00:49:12,470 --> 00:49:10,400  
from this axis to this axis and now over

1313  
00:49:13,750 --> 00:49:12,480

here are the number of objects

1314

00:49:15,030 --> 00:49:13,760

explicitly

1315

00:49:16,470 --> 00:49:15,040

indicated

1316

00:49:18,710 --> 00:49:16,480

and there's this red curve that al

1317

00:49:19,430 --> 00:49:18,720

harris has put on this diagram that is

1318

00:49:21,430 --> 00:49:19,440

the

1319

00:49:23,750 --> 00:49:21,440

curve illustrating what has been

1320

00:49:25,670 --> 00:49:23,760

discovered at least as of 2009 and you

1321

00:49:26,549 --> 00:49:25,680

can see that there is a big gap

1322

00:49:28,950 --> 00:49:26,559

okay

1323

00:49:30,710 --> 00:49:28,960

so what do we need to do to address

1324

00:49:32,470 --> 00:49:30,720

future hazards the first thing that i

1325

00:49:34,470 --> 00:49:32,480

think we need to do is we need to have

1326  
00:49:36,710 --> 00:49:34,480  
an environmental assessment of events

1327  
00:49:38,710 --> 00:49:36,720  
that occurred in the geologic past

1328  
00:49:40,309 --> 00:49:38,720  
so that we have a foundation to estimate

1329  
00:49:42,230 --> 00:49:40,319  
future events those events should

1330  
00:49:43,990 --> 00:49:42,240  
include all cratering events and those

1331  
00:49:46,470 --> 00:49:44,000  
air bursts that produce meteoritic and

1332  
00:49:50,069 --> 00:49:46,480  
or geologic relics like meteor crater

1333  
00:49:52,069 --> 00:49:50,079  
impacted into northern arizona okay

1334  
00:49:54,069 --> 00:49:52,079  
simultaneously we need to have survey

1335  
00:49:55,910 --> 00:49:54,079  
programs that are designed to identify

1336  
00:49:58,710 --> 00:49:55,920  
potentially threatening objects and here

1337  
00:50:01,109 --> 00:49:58,720  
i'm pointing to this big detection gap

1338  
00:50:04,150 --> 00:50:01,119

we don't have a very good understanding

1339

00:50:06,150 --> 00:50:04,160

of the objects of that size domain and

1340

00:50:08,630 --> 00:50:06,160

here's a little factoid of the 20

1341

00:50:11,990 --> 00:50:08,640

million objects the size of chelyabinsk

1342

00:50:13,750 --> 00:50:12,000

only 500 have been detected so far

1343

00:50:15,349 --> 00:50:13,760

finally mitigation concepts should be

1344

00:50:17,190 --> 00:50:15,359

developed that can be implemented to

1345

00:50:19,589 --> 00:50:17,200

reduce or completely resolve the hazard

1346

00:50:21,829 --> 00:50:19,599

near earth object any near-earth object

1347

00:50:24,230 --> 00:50:21,839

may pose for earth and it's important to

1348

00:50:26,470 --> 00:50:24,240

understand that the earlier we detect an

1349

00:50:28,710 --> 00:50:26,480

object that may hit the earth the easier

1350

00:50:29,829 --> 00:50:28,720

it will be to prevent the impact

1351

00:50:40,950 --> 00:50:29,839

okay

1352

00:50:44,470 --> 00:50:42,710

and then if you folks want to just come

1353

00:50:46,870 --> 00:50:44,480

to one of those two microphones

1354

00:50:49,190 --> 00:50:46,880

you'll hear it in there okay

1355

00:50:50,630 --> 00:50:49,200

so we're gonna just real quick to

1356

00:50:52,150 --> 00:50:50,640

mention we'll we'll take two questions

1357

00:50:53,670 --> 00:50:52,160

in here and then go to our overflow and

1358

00:50:55,109 --> 00:50:53,680

see if they have any and please wait if

1359

00:50:57,109 --> 00:50:55,119

we bring the mic to you so we make sure

1360

00:50:59,670 --> 00:50:57,119

it gets picked up on the cameras

1361

00:51:02,390 --> 00:50:59,680

just a separate question the composition

1362

00:51:08,150 --> 00:51:02,400

the composition of the contract

1363

00:51:12,470 --> 00:51:09,990

okay so yeah so let me repeat the

1364

00:51:13,829 --> 00:51:12,480

question the question is uh what can we

1365

00:51:16,309 --> 00:51:13,839

say about the composition of the

1366

00:51:18,069 --> 00:51:16,319

chondrite or the the impacting object

1367

00:51:20,710 --> 00:51:18,079

how is it compared to the earth okay the

1368

00:51:22,870 --> 00:51:20,720

first order chondritic meteorites

1369

00:51:24,069 --> 00:51:22,880

although they have subtle variations in

1370

00:51:26,150 --> 00:51:24,079

chemistry

1371

00:51:28,950 --> 00:51:26,160

have the composition of the sun minus

1372

00:51:31,349 --> 00:51:28,960

the gases hydrogen and helium okay and

1373

00:51:32,790 --> 00:51:31,359

the first order all of the planets earth

1374

00:51:35,270 --> 00:51:32,800

included accreted from that same

1375

00:51:38,150 --> 00:51:35,280

contradictive debris so

1376

00:51:39,990 --> 00:51:38,160

uh they have a lot of similarities that

1377

00:51:42,870 --> 00:51:40,000

is chelyabins has a lot of similarities

1378

00:51:44,549 --> 00:51:42,880

to both the sun and the earth now i

1379

00:51:46,790 --> 00:51:44,559

don't want to imply with that very

1380

00:51:49,109 --> 00:51:46,800

simple answer that the planets all have

1381

00:51:51,030 --> 00:51:49,119

the same composition and that's actually

1382

00:51:53,190 --> 00:51:51,040

interesting when we do compare the

1383

00:51:55,589 --> 00:51:53,200

composition of the earth mars venus and

1384

00:51:57,670 --> 00:51:55,599

so on they should have

1385

00:51:59,589 --> 00:51:57,680

started out accreting the same material

1386

00:52:01,670 --> 00:51:59,599

and have the same composition and when

1387

00:52:03,750 --> 00:52:01,680

we find they don't like earth and mars

1388

00:52:05,750 --> 00:52:03,760

are a little bit distinct that's a clue

1389

00:52:07,589 --> 00:52:05,760

that something else interesting is going

1390

00:52:09,030 --> 00:52:07,599

on and that's what the planetary science

1391

00:52:13,270 --> 00:52:09,040

community is spending a lot of time

1392

00:52:13,280 --> 00:52:16,829

does anyone here have a

1393

00:52:20,950 --> 00:52:19,349

question david can you can you comment

1394

00:52:22,710 --> 00:52:20,960

on the fact that the chelyabinsk

1395

00:52:24,710 --> 00:52:22,720

meteorite came in

1396

00:52:26,069 --> 00:52:24,720

at a very shallow angle and could just

1397

00:52:28,630 --> 00:52:26,079

have well come in

1398

00:52:29,829 --> 00:52:28,640

vertically over a city in terms of how

1399

00:52:32,150 --> 00:52:29,839

the

1400

00:52:34,390 --> 00:52:32,160

damage to a city within it coming

1401

00:52:36,630 --> 00:52:34,400

straight down yeah

1402

00:52:39,030 --> 00:52:36,640

i showed that plot of the chelyabinsk

1403

00:52:40,870 --> 00:52:39,040

trajectory and several other

1404

00:52:42,470 --> 00:52:40,880

recent

1405

00:52:43,910 --> 00:52:42,480

bolite events in the earth's atmosphere

1406

00:52:44,710 --> 00:52:43,920

and you saw it had a relatively shallow

1407

00:52:48,309 --> 00:52:44,720

angle

1408

00:52:50,710 --> 00:52:48,319

if the object had come in steeper it

1409

00:52:53,109 --> 00:52:50,720

would have deposited more of that energy

1410

00:52:55,349 --> 00:52:53,119

at the earth's surface based on computer

1411

00:52:59,349 --> 00:52:55,359

simulations many of those are done by

1412

00:53:01,589 --> 00:52:59,359

mark boslow in new mexico at los alamos

1413

00:53:03,670 --> 00:53:01,599

and therefore it could have been more

1414

00:53:06,309 --> 00:53:03,680

destructive yeah so the impact

1415

00:53:09,349 --> 00:53:06,319

trajectory actually has a bearing on the

1416

00:53:10,950 --> 00:53:09,359

consequences of the impact event

1417

00:53:13,030 --> 00:53:10,960

do we have any questions in the overflow

1418

00:53:21,109 --> 00:53:13,040

room not at this time

1419

00:53:26,710 --> 00:53:23,349

when you when you said that 20 million

1420

00:53:28,950 --> 00:53:26,720

uh chubby bee and size objects is that

1421

00:53:30,950 --> 00:53:28,960

all among all asteroids are among near

1422

00:53:40,309 --> 00:53:30,960

earth asteroids

1423

00:53:44,950 --> 00:53:42,390

the early photos of the damage showed

1424

00:53:47,510 --> 00:53:44,960

factory walls being knocked down

1425

00:53:49,270 --> 00:53:47,520

as a simple fix

1426  
00:53:52,790 --> 00:53:49,280  
could building codes

1427  
00:53:54,829 --> 00:53:52,800  
be improved and help reduce the damage

1428  
00:53:57,990 --> 00:53:54,839  
yes and i would say that

1429  
00:54:00,470 --> 00:53:58,000  
buildings in earthquake zones

1430  
00:54:03,030 --> 00:54:00,480  
would fare better from this type of

1431  
00:54:04,230 --> 00:54:03,040  
impact event than in areas that don't

1432  
00:54:05,829 --> 00:54:04,240  
have

1433  
00:54:08,230 --> 00:54:05,839  
those enhanced

1434  
00:54:09,270 --> 00:54:08,240  
construction

1435  
00:54:13,030 --> 00:54:09,280  
techniques

1436  
00:54:13,040 --> 00:54:17,589  
yes

1437  
00:54:20,950 --> 00:54:19,190  
how did you figure out the history of

1438  
00:54:22,630 --> 00:54:20,960

this thing by just by just looking at

1439

00:54:24,309 --> 00:54:22,640

those grooves and things on there that

1440

00:54:26,710 --> 00:54:24,319

was amazing that you figured out that

1441

00:54:28,309 --> 00:54:26,720

much detail how did you do that

1442

00:54:30,230 --> 00:54:28,319

well

1443

00:54:32,630 --> 00:54:30,240

that's what cosmo chemists do that's

1444

00:54:34,150 --> 00:54:32,640

what the meteoritical community does

1445

00:54:35,750 --> 00:54:34,160

um i mean

1446

00:54:37,349 --> 00:54:35,760

and and i know that's kind of a glib

1447

00:54:40,789 --> 00:54:37,359

answer but literally that's what we've

1448

00:54:42,069 --> 00:54:40,799

been doing for over 100 years

1449

00:54:50,829 --> 00:54:42,079

the

1450

00:54:53,589 --> 00:54:50,839

that allows us to identify which

1451  
00:54:56,150 --> 00:54:53,599  
meteorites can be grouped together which

1452  
00:54:58,870 --> 00:54:56,160  
meteorites came from the same parent

1453  
00:55:01,270 --> 00:54:58,880  
body in the asteroid belt and in fact

1454  
00:55:03,670 --> 00:55:01,280  
based on the collection of meteorites

1455  
00:55:06,230 --> 00:55:03,680  
that we have it appears that there were

1456  
00:55:08,710 --> 00:55:06,240  
in excess of 100 small planets that

1457  
00:55:09,750 --> 00:55:08,720  
survive between the orbits of mars and

1458  
00:55:11,510 --> 00:55:09,760  
jupiter

1459  
00:55:13,589 --> 00:55:11,520  
and there's some ideas as to why they

1460  
00:55:15,430 --> 00:55:13,599  
didn't accrete to mars

1461  
00:55:17,270 --> 00:55:15,440  
or some of the other planets and in fact

1462  
00:55:19,190 --> 00:55:17,280  
it may have everything to do with the

1463  
00:55:21,670 --> 00:55:19,200

gravitational influence of jupiter which

1464

00:55:23,270 --> 00:55:21,680

didn't allow that that to occur but it's

1465

00:55:25,430 --> 00:55:23,280

based on the mineralogy and the

1466

00:55:28,309 --> 00:55:25,440

chemistry of these objects now

1467

00:55:30,549 --> 00:55:28,319

the other part of the story that i told

1468

00:55:31,349 --> 00:55:30,559

you had something to do

1469

00:55:33,510 --> 00:55:31,359

with

1470

00:55:36,150 --> 00:55:33,520

how deep it was buried

1471

00:55:38,470 --> 00:55:36,160

we can determine that because the the

1472

00:55:41,109 --> 00:55:38,480

deeper the object was buried the hotter

1473

00:55:43,910 --> 00:55:41,119

it got and the slower it cooled

1474

00:55:45,430 --> 00:55:43,920

so that can be equated to a depth

1475

00:55:47,670 --> 00:55:45,440

and then we

1476  
00:55:49,829 --> 00:55:47,680  
outlined some of the collisional history

1477  
00:55:52,630 --> 00:55:49,839  
of the object and we're able to

1478  
00:55:56,069 --> 00:55:52,640  
determine that because if there is a

1479  
00:55:59,109 --> 00:55:56,079  
impact event with sufficient energy

1480  
00:56:00,150 --> 00:55:59,119  
it will reset the radiometric clocks in

1481  
00:56:02,390 --> 00:56:00,160  
the rock

1482  
00:56:04,710 --> 00:56:02,400  
and so we can determine the age

1483  
00:56:09,349 --> 00:56:04,720  
of the new impact rock and then put that

1484  
00:56:11,829 --> 00:56:10,630  
okay go ahead

1485  
00:56:17,109 --> 00:56:11,839  
we do have a

1486  
00:56:22,069 --> 00:56:19,750  
yeah i was interested in the um

1487  
00:56:24,870 --> 00:56:22,079  
basically the frequency

1488  
00:56:27,670 --> 00:56:24,880

that objects actually survive

1489

00:56:28,549 --> 00:56:27,680

to impact the surface of the earth

1490

00:56:30,950 --> 00:56:28,559

so

1491

00:56:33,750 --> 00:56:30,960

say in the last 100 years

1492

00:56:35,589 --> 00:56:33,760

what would be an average value for the

1493

00:56:37,910 --> 00:56:35,599

number of impacts and whether or not

1494

00:56:39,829 --> 00:56:37,920

that's changed

1495

00:56:42,230 --> 00:56:39,839

substantially over

1496

00:56:43,270 --> 00:56:42,240

you know the past that we know of

1497

00:56:45,510 --> 00:56:43,280

okay

1498

00:56:48,710 --> 00:56:45,520

um well it

1499

00:56:50,789 --> 00:56:48,720

again the smaller impacting objects

1500

00:56:51,670 --> 00:56:50,799

occur far more frequently than the small

1501  
00:56:53,829 --> 00:56:51,680  
one

1502  
00:56:56,150 --> 00:56:53,839  
and in fact small meteorite producing

1503  
00:56:58,390 --> 00:56:56,160  
impact events are pretty darn common

1504  
00:57:00,230 --> 00:56:58,400  
i've not done this calculation for texas

1505  
00:57:02,549 --> 00:57:00,240  
and now that i live here i should

1506  
00:57:04,150 --> 00:57:02,559  
but in venera arizona where i spent most

1507  
00:57:06,069 --> 00:57:04,160  
of my life

1508  
00:57:08,789 --> 00:57:06,079  
the answer was two to three fist-sized

1509  
00:57:09,910 --> 00:57:08,799  
meteorites fell in arizona every year

1510  
00:57:12,870 --> 00:57:09,920  
okay

1511  
00:57:15,910 --> 00:57:12,880  
now larger objects the size of

1512  
00:57:17,750 --> 00:57:15,920  
chelyabinsk um they seem to be hitting

1513  
00:57:20,470 --> 00:57:17,760

the atmosphere somewhere between 10 and

1514

00:57:22,710 --> 00:57:20,480

100 years and i have to say we can't be

1515

00:57:24,789 --> 00:57:22,720

more precise for a couple of reasons one

1516

00:57:27,430 --> 00:57:24,799

we don't have a lot of data

1517

00:57:29,349 --> 00:57:27,440

and two that actually can vary quite a

1518

00:57:31,190 --> 00:57:29,359

lot even if we did have a lot of data in

1519

00:57:33,270 --> 00:57:31,200

fact i was discussing this very same

1520

00:57:35,109 --> 00:57:33,280

issue with david morrison one of our

1521

00:57:37,270 --> 00:57:35,119

country's most esteemed astronomers just

1522

00:57:39,510 --> 00:57:37,280

before the talk uh some of our

1523

00:57:40,870 --> 00:57:39,520

colleagues will say it's a firm 20 20 to

1524

00:57:43,190 --> 00:57:40,880

30 years

1525

00:57:44,789 --> 00:57:43,200

some of us think it's more like 50 67

1526

00:57:46,230 --> 00:57:44,799

years but it could be a little bit

1527

00:57:47,589 --> 00:57:46,240

longer so there's there is some

1528

00:57:49,030 --> 00:57:47,599

uncertainty

1529

00:57:51,109 --> 00:57:49,040

to the answer that i can give you to

1530

00:57:53,910 --> 00:57:51,119

that question now the other part of that

1531

00:57:56,470 --> 00:57:53,920

question is how often these things

1532

00:57:58,230 --> 00:57:56,480

either cause damage or reach the ground

1533

00:57:59,510 --> 00:57:58,240

and there it's very important to

1534

00:58:01,670 --> 00:57:59,520

understand

1535

00:58:04,390 --> 00:58:01,680

that the size of the object and the

1536

00:58:05,990 --> 00:58:04,400

strength of the object is very important

1537

00:58:08,950 --> 00:58:06,000

when we're talking about these small

1538

00:58:11,030 --> 00:58:08,960

objects okay when we when we talk about

1539

00:58:13,109 --> 00:58:11,040

something that is mountainous in size

1540

00:58:14,870 --> 00:58:13,119

like like the 10 kilometer object that

1541

00:58:17,430 --> 00:58:14,880

produced the chick's loop crater that

1542

00:58:18,789 --> 00:58:17,440

wiped out dinosaurs okay that object was

1543

00:58:21,190 --> 00:58:18,799

so big

1544

00:58:24,150 --> 00:58:21,200

it would it didn't see the atmosphere it

1545

00:58:26,069 --> 00:58:24,160

just went it's so massive okay but

1546

00:58:27,589 --> 00:58:26,079

smaller objects

1547

00:58:30,230 --> 00:58:27,599

that are

1548

00:58:31,990 --> 00:58:30,240

both small and weak can catastrophically

1549

00:58:34,390 --> 00:58:32,000

fragment

1550

00:58:36,470 --> 00:58:34,400

stones stony asteroids are much weaker

1551  
00:58:38,870 --> 00:58:36,480  
than iron asteroids and so they tend to

1552  
00:58:41,430 --> 00:58:38,880  
fragment in the atmosphere more often

1553  
00:58:44,349 --> 00:58:41,440  
and in fact if you look at the earth's

1554  
00:58:47,109 --> 00:58:44,359  
smallest craters they are almost

1555  
00:58:49,109 --> 00:58:47,119  
exclusively produced by iron asteroids

1556  
00:58:51,349 --> 00:58:49,119  
and that is because the small iron

1557  
00:58:53,910 --> 00:58:51,359  
asteroids can reach the surface while

1558  
00:58:57,829 --> 00:58:53,920  
the smaller stony asteroids are unable

1559  
00:59:01,750 --> 00:58:57,839  
to and so they burst in the atmosphere

1560  
00:59:05,990 --> 00:59:03,349  
not at this time thank you hey we'll

1561  
00:59:09,349 --> 00:59:06,000  
take two more in here

1562  
00:59:13,109 --> 00:59:09,359  
um i heard that uh the uh i don't know

1563  
00:59:16,950 --> 00:59:15,510

military have been monitoring

1564

00:59:18,390 --> 00:59:16,960

things coming through the atmosphere and

1565

00:59:20,950 --> 00:59:18,400

they have

1566

00:59:23,349 --> 00:59:20,960

data that they were discussing

1567

00:59:24,789 --> 00:59:23,359

releasing to astronomers to help provide

1568

00:59:27,829 --> 00:59:24,799

more data do you know anything about

1569

00:59:29,750 --> 00:59:27,839

that yes uh the us government uh we

1570

00:59:32,150 --> 00:59:29,760

refer to that as simply us government

1571

00:59:34,069 --> 00:59:32,160

sensors we don't talk too much about the

1572

00:59:35,430 --> 00:59:34,079

way in which they do this

1573

00:59:37,430 --> 00:59:35,440

i mean obviously those of us in the

1574

00:59:40,230 --> 00:59:37,440

business understand that but the us

1575

00:59:42,789 --> 00:59:40,240

government was very forthcoming uh they

1576  
00:59:45,270 --> 00:59:42,799  
turned over that data and the estimate

1577  
00:59:47,270 --> 00:59:45,280  
of 500 kilotons explosive energy is

1578  
00:59:48,390 --> 00:59:47,280  
consistent with the us government sensor

1579  
00:59:49,109 --> 00:59:48,400  
data

1580  
00:59:51,109 --> 00:59:49,119  
now

1581  
00:59:53,349 --> 00:59:51,119  
the energy can be

1582  
00:59:54,549 --> 00:59:53,359  
estimated by several other techniques

1583  
00:59:56,789 --> 00:59:54,559  
one of which

1584  
00:59:57,990 --> 00:59:56,799  
interestingly enough is a seismic

1585  
01:00:00,549 --> 00:59:58,000  
technique

1586  
01:00:03,829 --> 01:00:00,559  
that the world deployed as a

1587  
01:00:06,710 --> 01:00:03,839  
counter-measure to nuclear weapons tests

1588  
01:00:09,349 --> 01:00:06,720

okay so this is deployed nationally

1589

01:00:10,870 --> 01:00:09,359

so that if a country does

1590

01:00:12,630 --> 01:00:10,880

detonate against

1591

01:00:15,190 --> 01:00:12,640

trees and agreements a nuclear weapon

1592

01:00:17,430 --> 01:00:15,200

that will be detected and so that

1593

01:00:31,990 --> 01:00:17,440

system was also employed in determining

1594

01:00:38,069 --> 01:00:35,109

most of the meteorites or asteroids that

1595

01:00:40,829 --> 01:00:38,079

become meteorites it impact the earth

1596

01:00:45,030 --> 01:00:44,150

lectures gave the asteroid belt as the

1597

01:00:47,270 --> 01:00:45,040

main

1598

01:00:51,190 --> 01:00:47,280

source of these come these

1599

01:00:53,829 --> 01:00:51,200

meteorites that we have

1600

01:00:56,630 --> 01:00:53,839

then we hear i hear about

1601  
01:00:59,470 --> 01:00:56,640  
meteorites from mars that are found in

1602  
01:01:01,109 --> 01:00:59,480  
antarctica are of a different com

1603  
01:01:02,230 --> 01:01:01,119  
comprehension

1604  
01:01:03,430 --> 01:01:02,240  
how does

1605  
01:01:05,589 --> 01:01:03,440  
mars

1606  
01:01:08,470 --> 01:01:05,599  
when when did those meteorites come from

1607  
01:01:10,230 --> 01:01:08,480  
mars and how do we know the difference

1608  
01:01:11,829 --> 01:01:10,240  
between those and the ones from the

1609  
01:01:13,349 --> 01:01:11,839  
asteroid belt yeah that's a great

1610  
01:01:15,430 --> 01:01:13,359  
question

1611  
01:01:17,270 --> 01:01:15,440  
meteorites from mars and for that matter

1612  
01:01:19,109 --> 01:01:17,280  
meteorites from the moon fascinate

1613  
01:01:20,710 --> 01:01:19,119

people in meteorated community because

1614

01:01:23,750 --> 01:01:20,720

they are in some sense free sample

1615

01:01:25,990 --> 01:01:23,760

return missions okay and what

1616

01:01:28,549 --> 01:01:26,000

what has happened in those cases is

1617

01:01:30,789 --> 01:01:28,559

asteroids have hit the surface of mars

1618

01:01:33,349 --> 01:01:30,799

and hit the surface of the moon and some

1619

01:01:35,109 --> 01:01:33,359

of the material that's ejected in those

1620

01:01:37,990 --> 01:01:35,119

events that in the crater forming

1621

01:01:39,430 --> 01:01:38,000

process actually leave with velocities

1622

01:01:41,910 --> 01:01:39,440

that allow them to escape those

1623

01:01:43,829 --> 01:01:41,920

planetary gravities okay then they get

1624

01:01:45,270 --> 01:01:43,839

into space and some of that debris it's

1625

01:01:46,789 --> 01:01:45,280

a small proportion that some of that

1626

01:01:48,549 --> 01:01:46,799

debris will collide with the other

1627

01:01:50,150 --> 01:01:48,559

planets like the earth

1628

01:01:51,589 --> 01:01:50,160

and so we do have a wonderful collection

1629

01:01:53,109 --> 01:01:51,599

of samples from mars and we have a

1630

01:01:54,630 --> 01:01:53,119

wonderful collection of samples from the

1631

01:01:55,349 --> 01:01:54,640

moon now

1632

01:01:56,950 --> 01:01:55,359

the

1633

01:01:59,589 --> 01:01:56,960

meteorites

1634

01:02:01,990 --> 01:01:59,599

that we understand today came from the

1635

01:02:04,309 --> 01:02:02,000

moon were not actually discovered or

1636

01:02:06,150 --> 01:02:04,319

recognized as being from the moon until

1637

01:02:07,270 --> 01:02:06,160

about a decade after the apollo program

1638

01:02:10,390 --> 01:02:07,280

shut down

1639

01:02:11,990 --> 01:02:10,400

but we in that case had all of these

1640

01:02:13,910 --> 01:02:12,000

wonderful samples that the astronauts

1641

01:02:15,430 --> 01:02:13,920

had collected brought down to earth we

1642

01:02:16,789 --> 01:02:15,440

identified their very distinctive

1643

01:02:18,230 --> 01:02:16,799

chemistry and then when we saw a

1644

01:02:19,990 --> 01:02:18,240

meteorite with the very same chemistry

1645

01:02:22,630 --> 01:02:20,000

we said aha we know where those come

1646

01:02:25,029 --> 01:02:22,640

from now the ones on mars

1647

01:02:26,870 --> 01:02:25,039

that was a little trickier puzzle

1648

01:02:29,349 --> 01:02:26,880

because of course we've not yet sent a

1649

01:02:30,390 --> 01:02:29,359

crew nor even a robotic sample return

1650

01:02:32,230 --> 01:02:30,400

mission

1651  
01:02:34,870 --> 01:02:32,240  
to to mars

1652  
01:02:38,230 --> 01:02:34,880  
but in that case um

1653  
01:02:41,430 --> 01:02:38,240  
the atmosphere of mars had been measured

1654  
01:02:43,910 --> 01:02:41,440  
by landers like fighting okay

1655  
01:02:46,710 --> 01:02:43,920  
and then we got these samples back on

1656  
01:02:48,549 --> 01:02:46,720  
earth and some very smart people some of

1657  
01:02:49,589 --> 01:02:48,559  
them right here at the johnson space

1658  
01:02:52,069 --> 01:02:49,599  
center

1659  
01:02:54,789 --> 01:02:52,079  
analyze some shock melted material

1660  
01:02:56,549 --> 01:02:54,799  
within those meteorites and found that

1661  
01:02:58,309 --> 01:02:56,559  
some of the atmosphere on their host

1662  
01:03:00,390 --> 01:02:58,319  
planet was trapped

1663  
01:03:02,470 --> 01:03:00,400

and the composition of that trap gas

1664

01:03:04,069 --> 01:03:02,480

turned out to be absolutely identical to

1665

01:03:05,430 --> 01:03:04,079

what was being measured on the surface

1666

01:03:07,589 --> 01:03:05,440

of mars

1667

01:03:09,190 --> 01:03:07,599

so that has now been bolstered by a lot

1668

01:03:11,109 --> 01:03:09,200

of other evidence but we're really

1669

01:03:13,430 --> 01:03:11,119

confident that we have a really handsome

1670

01:03:15,670 --> 01:03:13,440

collection of samples from mars

1671

01:03:18,950 --> 01:03:15,680

i have to say as interesting as those

1672

01:03:22,630 --> 01:03:18,960

are those is a very tiny proportion

1673

01:03:23,589 --> 01:03:22,640

of the meteorites that fall on earth

1674

01:03:24,950 --> 01:03:23,599

all right well let's take our speaker

1675

01:03:26,789 --> 01:03:24,960

one more time

1676

01:03:27,829 --> 01:03:26,799

and if you have another question

1677

01:03:37,829 --> 01:03:27,839

see if you can catch them now in the