EARTH-LIFE
SCIENCE
INSTITUTE

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*The building blocks and formation of Earth*

1
00:00:20,080 --> 00:00:16,600
I am Ramon brosser I work here at LC I

2
00:00:22,030 --> 00:00:20,090
study the formation of planets and also

3
00:00:25,090 --> 00:00:22,040
some of their evolution but mostly the

4
00:00:27,100 --> 00:00:25,100
earlier stages because I think that we

5
00:00:29,620 --> 00:00:27,110
can understand a lot of what happened to

6
00:00:31,180 --> 00:00:29,630
the Earth and Mars and Venus and so

7
00:00:33,720 --> 00:00:31,190
forth if we actually understand more

8
00:00:36,380 --> 00:00:33,730
about their information

9
00:00:38,880 --> 00:00:36,390
so today I'm going to walk you

10
00:00:41,430 --> 00:00:38,890
essentially through a little journey

11
00:00:44,220 --> 00:00:41,440
holding your hand as to how the solar

12
00:00:47,880 --> 00:00:44,230
system came to form so very early on

13
00:00:50,760 --> 00:00:47,890

about 4 and 1/2 billion years ago the

14
00:00:53,430 --> 00:00:50,770
Sun formed from a gas of cloud which was

15
00:00:55,940 --> 00:00:53,440
collapsing very slowly I will show you

16
00:01:01,860 --> 00:00:55,950
an animation of that in the next slide

17
00:01:04,770 --> 00:01:01,870
then some of the gas and the solids in

18
00:01:07,469 --> 00:01:04,780
the disk that surrounded the Sun so as

19
00:01:09,420 --> 00:01:07,479
the gas cloud was collapsing you formed

20
00:01:11,160 --> 00:01:09,430
the Sun and it is surrounded by a disc

21
00:01:13,290 --> 00:01:11,170
which is like a spinning pancake

22
00:01:16,530 --> 00:01:13,300
sometimes you know when you go to a

23
00:01:18,540 --> 00:01:16,540
pizza parlor in Italy you see somebody

24
00:01:20,760 --> 00:01:18,550
that holds the pizza on their hand and

25
00:01:22,859 --> 00:01:20,770
they're spinning it like this and you

26
00:01:26,670 --> 00:01:22,869
notice that as he keeps spinning it the

27
00:01:28,469 --> 00:01:26,680
pizza expands right just imagine that

28
00:01:30,210 --> 00:01:28,479
the same thing is happening here with

29
00:01:32,880 --> 00:01:30,220
the Sun so you have the Sun it is

30
00:01:35,520 --> 00:01:32,890
surrounded by a very thin pizza as it

31
00:01:38,550 --> 00:01:35,530
were that is spinning around very slowly

32
00:01:40,260 --> 00:01:38,560
and part of that pizza is expanding

33
00:01:45,059 --> 00:01:40,270
outwards and the inner part is going

34
00:01:49,680 --> 00:01:45,069
closer to the Sun that Pizza around the

35
00:01:51,809 --> 00:01:49,690
Sun is made up of gas and solids some of

36
00:01:54,419 --> 00:01:51,819
these solids will then coagulate to form

37
00:01:56,609 --> 00:01:54,429
the terrestrial planets which will then

38
00:01:59,400 --> 00:01:56,619

happen in this stage and all of this

39
00:02:01,020 --> 00:01:59,410
stuff is being smashed together through

40
00:02:04,020 --> 00:02:01,030
giant impacts such as the one that

41
00:02:08,790 --> 00:02:04,030
formed our Moon and eventually we end up

42
00:02:13,190 --> 00:02:08,800
with a nice set of planets at the end so

43
00:02:15,900 --> 00:02:13,200
here's an animation of a molecular cloud

44
00:02:17,610 --> 00:02:15,910
this is a computer animation this is not

45
00:02:19,470 --> 00:02:17,620
from observation because these things

46
00:02:22,980 --> 00:02:19,480
takes tens of thousands of years and we

47
00:02:26,280 --> 00:02:22,990
only live about 80 years you can see

48
00:02:28,890 --> 00:02:26,290
here that there's this spiral wave here

49
00:02:31,559 --> 00:02:28,900
where you have the gas falling together

50
00:02:34,320 --> 00:02:31,569
and forming the Sun but in because the

51
00:02:37,530 --> 00:02:34,330
gas is rotating it will start to rotate

52
00:02:39,750 --> 00:02:37,540
around the Sun and you get these spiral

53
00:02:42,830 --> 00:02:39,760
like structures that you also see in

54
00:02:45,280 --> 00:02:42,840
spiral galaxies when you look at the sky

55
00:02:48,250 --> 00:02:45,290
now the animation is zoomed

56
00:02:51,280 --> 00:02:48,260
in the central star in our case the Sun

57
00:02:53,500 --> 00:02:51,290
is right here in the beginning and you

58
00:02:55,929 --> 00:02:53,510
see that all of this material is

59
00:02:58,420 --> 00:02:55,939
spiraling spiraling around the Sun and

60
00:03:01,030 --> 00:02:58,430
you get these density waves and so forth

61
00:03:04,390 --> 00:03:01,040
you see clumps of material that are here

62
00:03:06,670 --> 00:03:04,400
and here which ultimately or so we think

63
00:03:10,320 --> 00:03:06,680

will form giant planets such as Jupiter

64
00:03:16,830 --> 00:03:13,770
so we start with the gas with a disc of

65
00:03:19,230 --> 00:03:16,840
gas and solids that surround the very

66
00:03:21,060 --> 00:03:19,240
very early Sun like in the first hundred

67
00:03:24,630 --> 00:03:21,070
thousand to 1 million or two million

68
00:03:27,300 --> 00:03:24,640
years of the solar system we have small

69
00:03:29,340 --> 00:03:27,310
tiny dust grains like the dust that you

70
00:03:31,830 --> 00:03:29,350
get on your shelves and so forth that

71
00:03:34,230 --> 00:03:31,840
you need to wipe off every week that

72
00:03:36,150 --> 00:03:34,240
sort of dust also existed in the solar

73
00:03:40,740 --> 00:03:36,160
system where it's less of a nuisance

74
00:03:43,110 --> 00:03:40,750
than in your home the dust grains then

75
00:03:45,780 --> 00:03:43,120
form together because of gravity you

76
00:03:47,430 --> 00:03:45,790
know gravity attracts right the Sun

77
00:03:49,380 --> 00:03:47,440
holds the planets and so forth together

78
00:03:51,240 --> 00:03:49,390
but gravity is everywhere there's

79
00:03:52,770 --> 00:03:51,250
gravitational attraction between all of

80
00:03:55,410 --> 00:03:52,780
us in this room even though we don't

81
00:03:58,790 --> 00:03:55,420
feel it so the dust grains they form

82
00:04:01,350 --> 00:03:58,800
together and they form pebble sized

83
00:04:03,240 --> 00:04:01,360
objects you know that like like a small

84
00:04:05,360 --> 00:04:03,250
stone that you find on the beach or in

85
00:04:09,060 --> 00:04:05,370
riverbeds or something like that and

86
00:04:11,070 --> 00:04:09,070
these pebbles are drifting into the gas

87
00:04:13,230 --> 00:04:11,080
there they're revolving around the Sun

88
00:04:15,030 --> 00:04:13,240

but there's gas around and you know

89
00:04:17,190 --> 00:04:15,040
sometimes when you're biking and the

90
00:04:17,909 --> 00:04:17,200
wind is in your face it's called a

91
00:04:22,800 --> 00:04:17,919
headwind

92
00:04:26,220 --> 00:04:22,810
the Sun and it slows them down so they

93
00:04:30,270 --> 00:04:26,230
then drift they migrate towards the Sun

94
00:04:32,460 --> 00:04:30,280
the pebbles then stick together to form

95
00:04:34,650 --> 00:04:32,470
larger objects planetesimals essentially

96
00:04:37,590 --> 00:04:34,660
asteroids you know the stuff that we see

97
00:04:39,780 --> 00:04:37,600
around the sky and then these form

98
00:04:42,840 --> 00:04:39,790
together to form small planetary embryos

99
00:04:46,500 --> 00:04:42,850
like moon sized Mar sized mercury sized

100
00:04:48,630 --> 00:04:46,510
planets and eventually then if the gas

101
00:04:50,730 --> 00:04:48,640
is still there and we are lucky we can

102
00:04:54,150 --> 00:04:50,740
get gaseous planets such as Jupiter and

103
00:04:56,070 --> 00:04:54,160
Saturn and if there's no gas in the disk

104
00:04:58,950 --> 00:04:56,080
then we form terrestrial planets like

105
00:05:01,020 --> 00:04:58,960
the earth Mars Venus and so forth which

106
00:05:02,880 --> 00:05:01,030
are mostly rocky with a little bit of

107
00:05:06,360 --> 00:05:02,890
water a little bit of other stuff but

108
00:05:08,880 --> 00:05:06,370
it's mostly rock and metal this is a

109
00:05:10,860 --> 00:05:08,890
very simplified story of how the planets

110
00:05:12,720 --> 00:05:10,870
in the solar system came to be so you

111
00:05:15,510 --> 00:05:12,730
start with very small stuff that grows

112
00:05:17,850 --> 00:05:15,520
progressively larger and you can either

113
00:05:19,350 --> 00:05:17,860

go into gas giant planets or into

114
00:05:21,810 --> 00:05:19,360
terrestrial planets depending on whether

115
00:05:23,460 --> 00:05:21,820
or not there's gas still around and to

116
00:05:24,180 --> 00:05:23,470
give you an idea of the timescale on

117
00:05:27,210 --> 00:05:24,190
which this half

118
00:05:28,890 --> 00:05:27,220
you form moon-sized mars-sized objects

119
00:05:32,490 --> 00:05:28,900
within a hundred thousand years till

120
00:05:34,800 --> 00:05:32,500
about 1 million years and then those

121
00:05:37,080 --> 00:05:34,810
mars-sized objects as I'll show in a

122
00:05:38,850 --> 00:05:37,090
moment will then all smash together to

123
00:05:40,980 --> 00:05:38,860
form planets the size of Earth and Venus

124
00:05:44,070 --> 00:05:40,990
and that takes between ten and a hundred

125
00:05:47,610 --> 00:05:44,080
million years so by about a hundred

126
00:05:49,320 --> 00:05:47,620
million years we're mostly done so these

127
00:05:53,190 --> 00:05:49,330
are the terrestrial planets as we know

128
00:05:56,280 --> 00:05:53,200
them today Venus Earth Mars and so forth

129
00:05:58,020 --> 00:05:56,290
and here's an animation of how the

130
00:05:59,940 --> 00:05:58,030
planets form so you start with a lot of

131
00:06:01,770 --> 00:05:59,950
small stuff that is circling around the

132
00:06:04,470 --> 00:06:01,780
Sun I'm going to speed it up a great

133
00:06:06,030 --> 00:06:04,480
number of times and you can see that I'm

134
00:06:08,430 --> 00:06:06,040
starting to get some waves and I'm

135
00:06:11,190 --> 00:06:08,440
slowly clearing out the region here in

136
00:06:13,710 --> 00:06:11,200
the center where I'm starting to form

137
00:06:17,000 --> 00:06:13,720
planets then in this region stuff

138
00:06:19,620 --> 00:06:17,010

revolves slower so it takes more time to

139
00:06:21,510 --> 00:06:19,630
form planets here you can see that I've

140
00:06:24,420 --> 00:06:21,520
already got a couple of planets here and

141
00:06:28,230 --> 00:06:24,430
then in the outer edges it's takes even

142
00:06:30,510 --> 00:06:28,240
longer so by this time I have enough I

143
00:06:32,610 --> 00:06:30,520
have a little bit of material left so

144
00:06:34,920 --> 00:06:32,620
I'm starting to get these giant impacts

145
00:06:39,000 --> 00:06:34,930
such as what you have for example for

146
00:06:42,900 --> 00:06:39,010
the moon and so forth the giant impacted

147
00:06:45,030 --> 00:06:42,910
form the moon as you can see the number

148
00:06:46,890 --> 00:06:45,040
of ellipses in this animation is

149
00:06:49,830 --> 00:06:46,900
decreasing that is because stuff is

150
00:06:52,530 --> 00:06:49,840
colliding with each other and then forms

151
00:06:54,960 --> 00:06:52,540
larger and larger bodies but also fewer

152
00:06:57,450 --> 00:06:54,970
and fewer of them so I start with a very

153
00:07:00,120 --> 00:06:57,460
large amount of small bodies and then

154
00:07:03,260 --> 00:07:00,130
progressively I get larger bodies of the

155
00:07:06,350 --> 00:07:03,270
size of planets but fewer of them and

156
00:07:08,580 --> 00:07:06,360
towards the very end of the animation I

157
00:07:11,390 --> 00:07:08,590
still have some other stuff flying

158
00:07:14,820 --> 00:07:11,400
around on very strange very highly

159
00:07:17,310 --> 00:07:14,830
elliptical orbits stuff is ejected out

160
00:07:20,340 --> 00:07:17,320
of the solar system some stuff will fall

161
00:07:23,400 --> 00:07:20,350
onto the Sun and ultimately in the top

162
00:07:26,670 --> 00:07:23,410
case I end up with four planets one two

163
00:07:29,190 --> 00:07:26,680

three and another tiny one here and in

164
00:07:31,080 --> 00:07:29,200
this middle case I have also four

165
00:07:33,000 --> 00:07:31,090
planets with this one being on a very

166
00:07:35,640 --> 00:07:33,010
highly eccentric orbit I have a tiny one

167
00:07:37,270 --> 00:07:35,650
there and another two or three here even

168
00:07:39,700 --> 00:07:37,280
though I start with the same

169
00:07:41,200 --> 00:07:39,710
simulation but I just run it on a

170
00:07:42,100 --> 00:07:41,210
different computer I get a different

171
00:07:45,280 --> 00:07:42,110
outcome

172
00:07:48,430 --> 00:07:45,290
so our solar system is unique if I were

173
00:07:50,260 --> 00:07:48,440
to reset the clock back 4.6 billion

174
00:07:52,120 --> 00:07:50,270
years ago and I would run the same

175
00:07:54,850 --> 00:07:52,130
experiment again I would get a different

176
00:07:56,920 --> 00:07:54,860
outcome I will not get four in small

177
00:07:58,570 --> 00:07:56,930
planets in the in in the inner part and

178
00:08:00,970 --> 00:07:58,580
four gas giants at the end I will not

179
00:08:03,430 --> 00:08:00,980
get an earth I will not get a Venus its

180
00:08:05,710 --> 00:08:03,440
unique because every simulation is

181
00:08:09,700 --> 00:08:05,720
different and every system is unique and

182
00:08:11,760 --> 00:08:09,710
different in its own way so if we want

183
00:08:14,260 --> 00:08:11,770
to understand what the earth is made of

184
00:08:16,540 --> 00:08:14,270
right I mean if you take a sample of

185
00:08:18,820 --> 00:08:16,550
rock right how do you know what it's

186
00:08:20,920 --> 00:08:18,830
made of you can analyze it but is it a

187
00:08:24,820 --> 00:08:20,930
good idea of what is very deep inside

188
00:08:26,740 --> 00:08:24,830

the earth I'm not sure that we know but

189
00:08:28,600 --> 00:08:26,750
if I want to unanalyzed what the earth

190
00:08:30,610 --> 00:08:28,610
is made of I have to go very deep in the

191
00:08:32,230 --> 00:08:30,620
earth but I kind of drilled 2,000

192
00:08:37,810 --> 00:08:32,240
kilometers in the earth it's just not

193
00:08:39,909 --> 00:08:37,820
possible we can use a proxy there is

194
00:08:42,550 --> 00:08:39,919
material that is still flying around the

195
00:08:45,400 --> 00:08:42,560
solar system today which is raining on

196
00:08:49,120 --> 00:08:45,410
us every once in a while in meteorites

197
00:08:51,340 --> 00:08:49,130
we have stuff that sometimes falls from

198
00:08:53,740 --> 00:08:51,350
the sky onto the earth in the form of

199
00:08:55,600 --> 00:08:53,750
meteorites and what you can do is you

200
00:08:57,880 --> 00:08:55,610
can classify these meteorites with

201
00:09:00,100 --> 00:08:57,890
something called cosmochemistry where

202
00:09:03,790 --> 00:09:00,110
you analyze their composition you

203
00:09:05,620 --> 00:09:03,800
analyze their structure and self-worth

204
00:09:07,740 --> 00:09:05,630
and then you can classify them into

205
00:09:10,329 --> 00:09:07,750
different groups

206
00:09:12,430 --> 00:09:10,339
these primitive these meteorites are

207
00:09:15,760 --> 00:09:12,440
very old about the age of the solar

208
00:09:18,460 --> 00:09:15,770
system 4.5 4.6 billion years ago and

209
00:09:19,600 --> 00:09:18,470
they're very primitive so they have not

210
00:09:21,670 --> 00:09:19,610
been processed

211
00:09:23,860 --> 00:09:21,680
they basically formed there and they

212
00:09:28,000 --> 00:09:23,870
stayed there flying around the solar

213
00:09:30,730 --> 00:09:28,010

system for the past 4.6 billion years ok

214
00:09:33,550 --> 00:09:30,740
and we want to try to use these

215
00:09:36,970 --> 00:09:33,560
meteorites as an idea to understand what

216
00:09:38,590 --> 00:09:36,980
the earth is made of so the first group

217
00:09:42,400 --> 00:09:38,600
that we know are what is called

218
00:09:44,560 --> 00:09:42,410
enstatite chondrites enstatite chondrite

219
00:09:47,470 --> 00:09:44,570
they're very primitive they're mostly

220
00:09:49,369 --> 00:09:47,480
magnesium silicate so they have

221
00:09:51,169 --> 00:09:49,379
magnesium and silicon and oxygen

222
00:09:53,299 --> 00:09:51,179
in them and that is mostly what they're

223
00:09:56,839 --> 00:09:53,309
made of the Earth's mantle is also made

224
00:10:00,710 --> 00:09:56,849
of a lot of magnesium silicate they are

225
00:10:02,809 --> 00:10:00,720
also very reduced so in other words all

226
00:10:04,429 --> 00:10:02,819
the oxygen is essentially in the

227
00:10:10,779 --> 00:10:04,439
silicate there's no free oxygen

228
00:10:14,289 --> 00:10:10,789
available and they are very very dry in

229
00:10:17,029 --> 00:10:14,299
these meteorites there's almost no water

230
00:10:19,519 --> 00:10:17,039
there's almost no nitrogen there's

231
00:10:24,710 --> 00:10:19,529
almost no carbon and so forth they're

232
00:10:27,919 --> 00:10:24,720
very very dry which means that most

233
00:10:32,839 --> 00:10:27,929
likely these enstatite chondrites formed

234
00:10:35,629 --> 00:10:32,849
very close to the Sun there it is hot so

235
00:10:37,699 --> 00:10:35,639
the volatile material like water which

236
00:10:40,460 --> 00:10:37,709
evaporates at a hundred degrees or so

237
00:10:44,749 --> 00:10:40,470
forth will then be evaporated and you're

238
00:10:49,519 --> 00:10:44,759

only left with very dry rock which is

239
00:10:51,199 --> 00:10:49,529
what these enstatite chondrites are then

240
00:10:52,549 --> 00:10:51,209
we have another group called the

241
00:10:54,649 --> 00:10:52,559
ordinary chondrites

242
00:10:56,809 --> 00:10:54,659
these are called ordinary because they

243
00:11:00,049 --> 00:10:56,819
are the most common meteorite that falls

244
00:11:02,359 --> 00:11:00,059
from the sky the ordinary chondrite are

245
00:11:05,029 --> 00:11:02,369
mostly made of stone so they're not that

246
00:11:07,099 --> 00:11:05,039
hard compressed in magnesium silicate

247
00:11:08,809 --> 00:11:07,109
that you find in the enstatite congratz

248
00:11:11,269 --> 00:11:08,819
but they're more like stone so if you go

249
00:11:13,969 --> 00:11:11,279
to a beach or to a riverbed you pick up

250
00:11:15,710 --> 00:11:13,979
some stones you might get lucky and one

251
00:11:17,299 --> 00:11:15,720
of them is an ordinary chondrite you

252
00:11:19,519 --> 00:11:17,309
just wouldn't know because we don't have

253
00:11:22,189 --> 00:11:19,529
the expertise to be able to distinguish

254
00:11:24,199 --> 00:11:22,199
such rocks they're mostly made of

255
00:11:26,509 --> 00:11:24,209
olivine which is I think isn't is an

256
00:11:28,909 --> 00:11:26,519
iron silicate and so forth and they also

257
00:11:31,669 --> 00:11:28,919
have some metal in it that is oxidized

258
00:11:33,829 --> 00:11:31,679
so they have a higher fraction of oxygen

259
00:11:35,929 --> 00:11:33,839
in them then the enstatite congruous

260
00:11:39,590 --> 00:11:35,939
they have more metal in them as well

261
00:11:41,479 --> 00:11:39,600
and they also have more volatiles these

262
00:11:44,689 --> 00:11:41,489
have a little bit of water in them about

263
00:11:47,569 --> 00:11:44,699

the same amount as the earth house right

264
00:11:52,009 --> 00:11:47,579
so it's about you know one thousandth of

265
00:11:53,389 --> 00:11:52,019
the mass of these objects is water you

266
00:11:55,069 --> 00:11:53,399
just don't know it because it is

267
00:11:56,659 --> 00:11:55,079
embedded in the rock but it's there if

268
00:12:01,489 --> 00:11:56,669
you heat it up you'll find actually that

269
00:12:02,360 --> 00:12:01,499
there's water the third group is called

270
00:12:06,620 --> 00:12:02,370
carbonation

271
00:12:08,540 --> 00:12:06,630
chondrites these are thought to form

272
00:12:11,990 --> 00:12:08,550
very far from the Sun where it's very

273
00:12:14,060 --> 00:12:12,000
cold so they form in an environment

274
00:12:16,940 --> 00:12:14,070
where the temperature is about 50

275
00:12:21,290 --> 00:12:16,950
degrees above absolute zero so it's

276
00:12:23,120 --> 00:12:21,300
about 220 degrees below zero if you were

277
00:12:25,010 --> 00:12:23,130
to be out there in that temperature you

278
00:12:26,900 --> 00:12:25,020
would freeze solid in a few seconds

279
00:12:30,579 --> 00:12:26,910
that's how cold it is it's it's

280
00:12:33,260 --> 00:12:30,589
absolutely devastating for any any life

281
00:12:36,380 --> 00:12:33,270
but they form in there and because they

282
00:12:38,870 --> 00:12:36,390
form so cold they did not lose their

283
00:12:41,120 --> 00:12:38,880
volatiles they keep most of their water

284
00:12:45,620 --> 00:12:41,130
they keep their nitrogen they keep their

285
00:12:47,780 --> 00:12:45,630
carbon hence carbonaceous chondrites and

286
00:12:49,730 --> 00:12:47,790
some of the minerals have been altered

287
00:12:52,490 --> 00:12:49,740
because of water as you know for example

288
00:12:54,079 --> 00:12:52,500

water reacts with everything right you

289
00:12:55,970 --> 00:12:54,089
get milled you and so forth on your

290
00:12:58,550 --> 00:12:55,980
walls because its water reacting with

291
00:13:01,250 --> 00:12:58,560
something if you pour metal and water it

292
00:13:06,710 --> 00:13:01,260
oxidizes in particularly iron water is

293
00:13:09,380 --> 00:13:06,720
reactive water alters the compounds that

294
00:13:11,150 --> 00:13:09,390
exist within the meteorite and we know

295
00:13:12,949 --> 00:13:11,160
that there's water in there because if

296
00:13:15,199 --> 00:13:12,959
you analyze these meteorites you find

297
00:13:17,090 --> 00:13:15,209
water and you find the evidence of water

298
00:13:20,660 --> 00:13:17,100
in the minerals that have been altered

299
00:13:23,930 --> 00:13:20,670
by it so these are the guys that deliver

300
00:13:26,000 --> 00:13:23,940
the water to the Earth's okay these were

301
00:13:27,829 --> 00:13:26,010
the ones that brought us all the rain

302
00:13:31,400 --> 00:13:27,839
that we're getting every day in the

303
00:13:34,280 --> 00:13:31,410
weather right now so let us run a

304
00:13:36,170 --> 00:13:34,290
simulation now of Thresher planet

305
00:13:39,769 --> 00:13:36,180
formation these are the initial

306
00:13:42,019 --> 00:13:39,779
conditions so I have Jupiter here this

307
00:13:42,470 --> 00:13:42,029
is the distance to the Sun on this axis

308
00:13:44,870 --> 00:13:42,480
here

309
00:13:47,720 --> 00:13:44,880
Jupiter is a little about five the earth

310
00:13:49,610 --> 00:13:47,730
is at one right here and this is the

311
00:13:51,800 --> 00:13:49,620
eccentricity of the orbit it measures

312
00:13:53,870 --> 00:13:51,810
how elongated the orbit is so if the

313
00:13:55,400 --> 00:13:53,880

orbit is perfectly circular which I

314
00:13:58,160 --> 00:13:55,410
can't draw but you just have to imagine

315
00:14:00,560 --> 00:13:58,170
it then the eccentricity is zero and if

316
00:14:03,610 --> 00:14:00,570
I have a very elongated ellipse then the

317
00:14:07,280 --> 00:14:03,620
eccentricity is 0.8 or 0.9 or something

318
00:14:10,600 --> 00:14:07,290
okay enstatite chondrites which are the

319
00:14:12,860 --> 00:14:10,610
magnesium silicon rich bone-dry

320
00:14:15,500 --> 00:14:12,870
meteorites form here the ordinary

321
00:14:16,010 --> 00:14:15,510
chondrites which are in between a little

322
00:14:19,100 --> 00:14:16,020
bit of

323
00:14:20,930 --> 00:14:19,110
stone metal form in the middle and the

324
00:14:22,699 --> 00:14:20,940
carbonaceous chondrites which have all

325
00:14:24,590 --> 00:14:22,709
the water and all the carbon and the

326
00:14:27,019 --> 00:14:24,600
nitrogen and so forth in them all the

327
00:14:30,680 --> 00:14:27,029
stuff that life depends on they come

328
00:14:33,440 --> 00:14:30,690
from farther out so Jupiter is going to

329
00:14:35,630 --> 00:14:33,450
perturb all this stuff you see that I'm

330
00:14:38,060 --> 00:14:35,640
starting to form some planets right away

331
00:14:39,800 --> 00:14:38,070
and the growth is from the inside out I

332
00:14:42,650 --> 00:14:39,810
have some planets here but I don't have

333
00:14:44,690 --> 00:14:42,660
planets here yet that is because here it

334
00:14:47,210 --> 00:14:44,700
takes longer for the planets to accrete

335
00:14:49,610 --> 00:14:47,220
than it is here because here I go around

336
00:14:51,680 --> 00:14:49,620
the Sun in about half a year but here it

337
00:14:55,490 --> 00:14:51,690
takes me about three years which is a

338
00:14:58,519 --> 00:14:55,500

factor of six so here I form the planet

339
00:15:00,740 --> 00:14:58,529
six times faster than about here notice

340
00:15:02,840 --> 00:15:00,750
also that the color of these planets is

341
00:15:05,389 --> 00:15:02,850
changing in the beginning they're mostly

342
00:15:08,150 --> 00:15:05,399
red there we go so in the beginning

343
00:15:10,010 --> 00:15:08,160
they're mostly red because they accrete

344
00:15:12,920 --> 00:15:10,020
the stuff from the enstatite congratz

345
00:15:15,079 --> 00:15:12,930
but eventually this stuff the

346
00:15:17,480 --> 00:15:15,089
carbonaceous chondrites and the ordinary

347
00:15:19,250 --> 00:15:17,490
chondrite are being pushed inwards

348
00:15:23,240 --> 00:15:19,260
towards the terrestrial planets by the

349
00:15:25,310 --> 00:15:23,250
action of Jupiter okay so you see this

350
00:15:29,060 --> 00:15:25,320
one is now becoming orange because he is

351
00:15:30,860 --> 00:15:29,070
he is feeding off of material in this

352
00:15:33,590 --> 00:15:30,870
outer disc and these guys are now

353
00:15:36,620 --> 00:15:33,600
becoming green because you know the red

354
00:15:38,030 --> 00:15:36,630
is given some blue material and you end

355
00:15:40,010 --> 00:15:38,040
up then somewhere here in the middle

356
00:15:41,990 --> 00:15:40,020
right I start very dry

357
00:15:43,819 --> 00:15:42,000
I then have some of the blue material

358
00:15:45,620 --> 00:15:43,829
come in and I end up somewhere in the

359
00:15:47,540 --> 00:15:45,630
middle and that is where Earth's water

360
00:15:50,840 --> 00:15:47,550
is coming from I'll play it one more

361
00:15:52,819 --> 00:15:50,850
time so I start here I have local

362
00:15:55,220 --> 00:15:52,829
accretion some of the ordinary chondrite

363
00:15:58,100 --> 00:15:55,230

sand carbonaceous chondrites end up in

364
00:16:00,519 --> 00:15:58,110
the planets in the earth analog which is

365
00:16:03,290 --> 00:16:00,529
sitting roughly in this region here and

366
00:16:05,269 --> 00:16:03,300
because of Jupiter we are actually

367
00:16:07,550 --> 00:16:05,279
getting some of that water so it's only

368
00:16:10,430 --> 00:16:07,560
because of Jupiter if Jupiter was not

369
00:16:12,710 --> 00:16:10,440
there we wouldn't have as much water on

370
00:16:16,819 --> 00:16:12,720
the earths as we do today because there

371
00:16:19,430 --> 00:16:16,829
is no agent that is able to push the

372
00:16:21,440 --> 00:16:19,440
material that is farther away from the

373
00:16:27,230 --> 00:16:21,450
Sun these carbonaceous chondrites onto

374
00:16:29,070 --> 00:16:27,240
the earth okay so ultimately after the

375
00:16:31,950 --> 00:16:29,080
simulation is done

376
00:16:34,500 --> 00:16:31,960
what happens is that I end up mostly

377
00:16:37,410 --> 00:16:34,510
with three planets I know there are four

378
00:16:39,510 --> 00:16:37,420
but in the simulations you get four plus

379
00:16:42,180 --> 00:16:39,520
or minus one so sometimes I get three

380
00:16:46,320 --> 00:16:42,190
sometimes I get four sometimes I get

381
00:16:48,930 --> 00:16:46,330
five sometimes I even get six but on

382
00:16:51,510 --> 00:16:48,940
average we get about four in this case I

383
00:16:53,700 --> 00:16:51,520
get three so I get something that looks

384
00:16:55,260 --> 00:16:53,710
like Venus I get something that looks

385
00:16:56,850 --> 00:16:55,270
like Earth and I get something that

386
00:16:58,740 --> 00:16:56,860
looks a little bit like Mars it's a bit

387
00:16:59,250 --> 00:16:58,750
heavier than Mars but you know that's

388
00:17:01,530 --> 00:16:59,260

fine

389
00:17:03,930 --> 00:17:01,540
in another simulation it would be and I

390
00:17:06,030 --> 00:17:03,940
have some leftover material sitting here

391
00:17:08,660 --> 00:17:06,040
which is essentially not being cleared

392
00:17:12,240 --> 00:17:08,670
out by Jupiter and by the other planets

393
00:17:14,820 --> 00:17:12,250
but what is important is that even

394
00:17:16,829 --> 00:17:14,830
though in this region here very close to

395
00:17:20,340 --> 00:17:16,839
the Sun I started out with the red

396
00:17:22,560 --> 00:17:20,350
material the dry material because of

397
00:17:24,480 --> 00:17:22,570
Jupiter some of the blue material which

398
00:17:26,699 --> 00:17:24,490
was here the carbonaceous chondrites

399
00:17:28,980 --> 00:17:26,709
ended up in the planets and that's why

400
00:17:30,900 --> 00:17:28,990
they have this nice green bluish color

401
00:17:33,960 --> 00:17:30,910
which means that they have accreted some

402
00:17:36,600 --> 00:17:33,970
water and what you can also do is

403
00:17:39,180 --> 00:17:36,610
essentially you can say okay if I now

404
00:17:42,720 --> 00:17:39,190
analyze these planets I can determine

405
00:17:44,760 --> 00:17:42,730
how much material in the planets is from

406
00:17:48,090 --> 00:17:44,770
the enstatite group and the ordinary

407
00:17:50,250 --> 00:17:48,100
group and the carbonaceous group the

408
00:17:53,700 --> 00:17:50,260
last thing I want to discuss is the moon

409
00:17:56,970 --> 00:17:53,710
formation event so the earth has a large

410
00:17:59,400 --> 00:17:56,980
moon the moon is about one-and-a-half

411
00:18:03,270 --> 00:17:59,410
percent of the mass of the Earth is one

412
00:18:05,010 --> 00:18:03,280
over 81 to be precise it's pretty far

413
00:18:08,250 --> 00:18:05,020

from the earth it's about sixty times

414
00:18:11,280 --> 00:18:08,260
the radius of the earth from us so how

415
00:18:12,990 --> 00:18:11,290
did it get there because Mars has two

416
00:18:15,030 --> 00:18:13,000
small satellites but they're very very

417
00:18:16,950 --> 00:18:15,040
small there are only a few kilometers in

418
00:18:18,540 --> 00:18:16,960
size there they're tiny compared to both

419
00:18:21,180 --> 00:18:18,550
the planet and the moon itself but

420
00:18:23,850 --> 00:18:21,190
Earth's moon is very big venus has no

421
00:18:26,220 --> 00:18:23,860
moon either this mercury so how did the

422
00:18:29,630 --> 00:18:26,230
earth get its moon while we think

423
00:18:33,270 --> 00:18:29,640
through a giant impact so what we think

424
00:18:36,690 --> 00:18:33,280
happened was that the earth was sitting

425
00:18:38,940 --> 00:18:36,700
there going around the Sun and an object

426
00:18:41,520 --> 00:18:38,950
the size of Mars roughly the size of

427
00:18:45,740 --> 00:18:41,530
Mars struck the earth

428
00:18:48,660 --> 00:18:45,750
and then because of gravitational

429
00:18:51,870 --> 00:18:48,670
interaction between the material from

430
00:18:54,960 --> 00:18:51,880
the earth and from the impactor that

431
00:18:56,940 --> 00:18:54,970
then formed a disc around the earth here

432
00:18:59,490 --> 00:18:56,950
you have a blob of material which is

433
00:19:01,320 --> 00:18:59,500
spinning around the earth eventually it

434
00:19:03,980 --> 00:19:01,330
has another collision with the earth but

435
00:19:06,870 --> 00:19:03,990
you can see you form this sort of varies

436
00:19:09,660 --> 00:19:06,880
strung-out material that is orbiting the

437
00:19:12,180 --> 00:19:09,670
earth and you have a lot of other stuff

438
00:19:17,100 --> 00:19:12,190

that is just sitting around and spinning

439
00:19:20,100 --> 00:19:17,110
around the earth the idea is this object

440
00:19:22,620 --> 00:19:20,110
it came in it hit the earth and it came

441
00:19:25,380 --> 00:19:22,630
with such force that you basically tore

442
00:19:27,210 --> 00:19:25,390
it apart if you have a rock and you're

443
00:19:29,370 --> 00:19:27,220
trying to tear it apart it's very very

444
00:19:31,560 --> 00:19:29,380
difficult to do that but if you're

445
00:19:33,120 --> 00:19:31,570
somebody like Superman you might be able

446
00:19:37,320 --> 00:19:33,130
to tear it apart if you do it with

447
00:19:40,340 --> 00:19:37,330
enough force okay this thing comes in

448
00:19:43,080 --> 00:19:40,350
incredibly fast you know we're talking

449
00:19:45,870 --> 00:19:43,090
tens of thousands of kilometers per hour

450
00:19:48,990 --> 00:19:45,880
much much faster than any aeroplane is

451
00:19:51,870 --> 00:19:49,000
able to come to go on the earth it hits

452
00:19:53,760 --> 00:19:51,880
the earth at an angle and then it is

453
00:19:56,070 --> 00:19:53,770
kind of torn apart because of the

454
00:19:59,490 --> 00:19:56,080
gravitational forces as you can see here

455
00:20:02,580 --> 00:19:59,500
and you form this blob on both the earth

456
00:20:04,740 --> 00:20:02,590
that increases a lot of material from

457
00:20:07,590 --> 00:20:04,750
there you have material which is then

458
00:20:10,140 --> 00:20:07,600
spinning around the earth and eventually

459
00:20:12,110 --> 00:20:10,150
after a couple of days of that all that

460
00:20:15,920 --> 00:20:12,120
material going around the earth

461
00:20:20,880 --> 00:20:15,930
colliding with itself we form the moon

462
00:20:23,010 --> 00:20:20,890
just one moon and then because of tidal

463
00:20:24,750 --> 00:20:23,020

evolution the moon will be pushed away

464
00:20:26,700 --> 00:20:24,760
from the earth and after four billion

465
00:20:29,580 --> 00:20:26,710
years four and a half billion years that

466
00:20:31,530 --> 00:20:29,590
is where it is today tide tides we're

467
00:20:33,990 --> 00:20:31,540
all familiar with tides if you go to the

468
00:20:36,180 --> 00:20:34,000
beach right you have low and high tide

469
00:20:37,800 --> 00:20:36,190
that's because of the gravitational

470
00:20:39,630 --> 00:20:37,810
attraction of the moon but in of course

471
00:20:42,210 --> 00:20:39,640
when the moon was much closer to the

472
00:20:44,190 --> 00:20:42,220
earth the tides were much stronger so

473
00:20:47,070 --> 00:20:44,200
the tides from the earth push the moon

474
00:20:49,290 --> 00:20:47,080
away that slows down the rotation of the

475
00:20:51,420 --> 00:20:49,300
earth that's why we have a 24-hour day

476
00:20:53,320 --> 00:20:51,430
right now but a few billion years ago it

477
00:20:55,660 --> 00:20:53,330
was like 20 hours or even eight

478
00:20:57,670 --> 00:20:55,670
hours and the moon was closer it's being

479
00:21:01,560 --> 00:20:57,680
pushed away and we end up with the

480
00:21:05,740 --> 00:21:01,570
earth-moon system that we have today so

481
00:21:07,570 --> 00:21:05,750
this is my last slide a summary slide so

482
00:21:11,080 --> 00:21:07,580
earth is composed of a mixture of

483
00:21:13,630 --> 00:21:11,090
meteorite groups right we think that is

484
00:21:15,250 --> 00:21:13,640
what the current analysis of samples

485
00:21:18,400 --> 00:21:15,260
from the earth and meteorite groups

486
00:21:21,640 --> 00:21:18,410
seems to indicate Earth experienced a

487
00:21:23,890 --> 00:21:21,650
very violent and destructive impact

488
00:21:27,790 --> 00:21:23,900

about four and a half billion years ago

489
00:21:29,920 --> 00:21:27,800
which formed the moon also earth

490
00:21:31,660 --> 00:21:29,930
accreted a small amount of water from

491
00:21:32,680 --> 00:21:31,670
carbonaceous chondrites from the outer

492
00:21:36,130 --> 00:21:32,690
solar system

493
00:21:38,620 --> 00:21:36,140
I say a small amount now when I was

494
00:21:40,810 --> 00:21:38,630
living in Taipei before I came here I

495
00:21:43,180 --> 00:21:40,820
never thought that the earth was a dry

496
00:21:46,900 --> 00:21:43,190
planet because it rained almost every

497
00:21:48,910 --> 00:21:46,910
day ok even here in Tokyo this summer

498
00:21:50,860 --> 00:21:48,920
has been incredibly wet I think we've

499
00:21:53,260 --> 00:21:50,870
set a record for the amount of rain and

500
00:21:54,790 --> 00:21:53,270
when my colleagues tell me the earth is

501
00:21:58,000 --> 00:21:54,800
a dry planet I said have you been

502
00:22:00,130 --> 00:21:58,010
outside but it's true because most of

503
00:22:01,840 --> 00:22:00,140
the water is actually on the surface or

504
00:22:05,350 --> 00:22:01,850
at least half of it or something like

505
00:22:08,140 --> 00:22:05,360
that but it's still a very very very

506
00:22:10,060 --> 00:22:08,150
small amount of the total mass of the

507
00:22:14,080 --> 00:22:10,070
earth it just happens to be concentrated

508
00:22:15,910 --> 00:22:14,090
mostly on the surface if you run the

509
00:22:18,040 --> 00:22:15,920
miracle simulations you will find that

510
00:22:20,140 --> 00:22:18,050
the composition of Venus and Mars should

511
00:22:22,360 --> 00:22:20,150
be fairly similar to that of Earth ie

512
00:22:24,070 --> 00:22:22,370
it's made from the same material and you

513
00:22:26,740 --> 00:22:24,080

end up with roughly the same composition

514
00:22:28,390 --> 00:22:26,750
and all planets through forms through

515
00:22:30,730 --> 00:22:28,400
violent collisions as I showed you

516
00:22:32,800 --> 00:22:30,740
halfway through the talk you had all

517
00:22:35,560 --> 00:22:32,810
these these orbits which were spinning

518
00:22:37,690 --> 00:22:35,570
around and eventually stuff was secreted

519
00:22:40,810 --> 00:22:37,700
and you formed larger planets as the

520
00:22:44,010 --> 00:22:40,820
number of bodies decreased so our asura

521
00:22:46,960 --> 00:22:44,020
planets formed violently and rapidly

522
00:22:50,030 --> 00:22:46,970
from a mixture of material that gave us

523
00:22:55,800 --> 00:22:50,040
the earth as we know it today thank you

524
00:23:12,590 --> 00:22:55,810
[Applause]

525
00:23:12,600 --> 00:23:27,280
[Music]