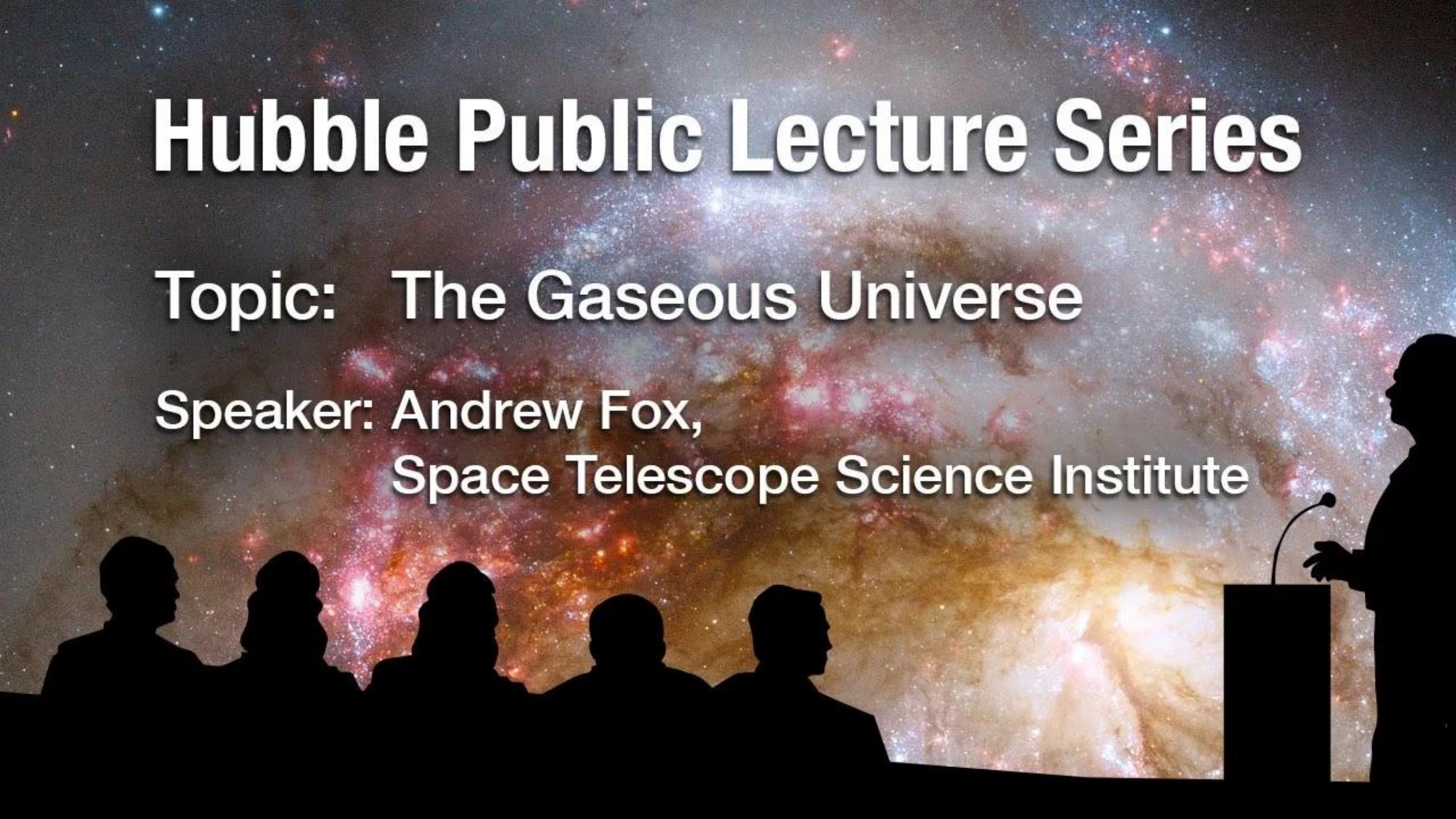
Hubble Public Lecture Series
Topic: The Gaseous Universe
Speaker: Andrew Fox,
Space Telescope Science Institute

1
00:00:12,620 --> 00:00:11,000
okay seeing as how it's right about

2
00:00:15,700 --> 00:00:12,630
eight o'clock and I think we're all set

3
00:00:20,150 --> 00:00:15,710
ready to go the broadcast everything so

4
00:00:24,859 --> 00:00:20,160
good evening welcome to the hubble space

5
00:00:27,859 --> 00:00:24,869
telescope public lecture series can you

6
00:00:32,720 --> 00:00:30,679
my name is volt lavae I'm filling in as

7
00:00:37,010 --> 00:00:32,730
you may have realized I'm not Frank

8
00:00:38,840 --> 00:00:37,020
summers unusual host tonight there's a

9
00:00:41,959 --> 00:00:38,850
big meeting this astronomy meeting going

10
00:00:43,940 --> 00:00:41,969
on this week in Boston American

11
00:00:47,240 --> 00:00:43,950
Astronomical Society so a lot of people

12
00:00:48,740 --> 00:00:47,250
from here or up there and Frank asked me

13
00:00:50,660 --> 00:00:48,750

to fill in sand some one of the few

14
00:00:55,779 --> 00:00:50,670
remaining people here at the Institute

15
00:00:58,250 --> 00:00:55,789
this week so anyway we'll get started as

16
00:01:00,319 --> 00:00:58,260
usual

17
00:01:02,959 --> 00:01:00,329
I'll introduce the speaker in a few

18
00:01:07,370 --> 00:01:02,969
moments have some introductory material

19
00:01:10,750 --> 00:01:07,380
here first of all the next couple of

20
00:01:15,410 --> 00:01:10,760
lectures as you can see July will have

21
00:01:20,770 --> 00:01:15,420
Andrea Vanzetti from right here talking

22
00:01:26,420 --> 00:01:23,990
will have Jennifer Locke's also from the

23
00:01:28,100 --> 00:01:26,430
Institute talking about the frontier

24
00:01:32,149 --> 00:01:28,110
fields which is an exciting new project

25
00:01:45,340 --> 00:01:32,159
just getting started with a sneak peek

26
00:01:51,800 --> 00:01:48,319
trying to be meaning going on this week

27
00:01:53,840 --> 00:01:51,810
in Boston you can sign up for email

28
00:01:57,350 --> 00:01:53,850
notifications for this lecture and for

29
00:01:59,300 --> 00:01:57,360
some other topics if you send a note to

30
00:02:02,450 --> 00:01:59,310
that to the email address you see up

31
00:02:04,480 --> 00:02:02,460
there we promise we won't spam you but

32
00:02:07,540 --> 00:02:04,490
we will send yous

33
00:02:11,140 --> 00:02:07,550
interesting stuff related to these sorts

34
00:02:13,390 --> 00:02:11,150
of these sorts of events and

35
00:02:14,980 --> 00:02:13,400
unfortunately I've been told that the

36
00:02:15,580 --> 00:02:14,990
weather may be kind of iffy later on

37
00:02:19,000 --> 00:02:15,590
tonight

38
00:02:20,560 --> 00:02:19,010

so whereas usually the observatory

39
00:02:23,190 --> 00:02:20,570
across the street at Johns Hopkins at

40
00:02:25,720 --> 00:02:23,200
the Maryland Space Grant Observatory

41
00:02:28,240 --> 00:02:25,730
they usually open up for observing after

42
00:02:30,390 --> 00:02:28,250
the talk tonight they decided not to

43
00:02:33,100 --> 00:02:30,400
open up because there's chance of some

44
00:02:35,430 --> 00:02:33,110
stormy weather in the area so I'm sorry

45
00:02:43,080 --> 00:02:40,000
and just Frank wanted me to just give a

46
00:02:45,640 --> 00:02:43,090
couple of news notes from recent

47
00:02:48,670 --> 00:02:45,650
exciting events from the world of

48
00:02:54,130 --> 00:02:48,680
astronomy one of the more exciting

49
00:03:00,060 --> 00:02:54,140
things we've done lately it's not about

50
00:03:04,510 --> 00:03:00,070
the kids reading the spot here refers to

51
00:03:05,920 --> 00:03:04,520
the Great Red Spot on Jupiter Jupiter of

52
00:03:07,630 --> 00:03:05,930
course is one of the planets in our

53
00:03:09,729 --> 00:03:07,640
solar system it's the largest planet in

54
00:03:11,590 --> 00:03:09,739
our solar system

55
00:03:16,120 --> 00:03:11,600
and it has this feature on it called the

56
00:03:18,310 --> 00:03:16,130
Great Red Spot this this image is from

57
00:03:22,870 --> 00:03:18,320
the Voyager spacecraft which flew by

58
00:03:24,789 --> 00:03:22,880
Jupiter back way back in 1979 and took

59
00:03:27,479 --> 00:03:24,799
this fabulous image of the Great Red

60
00:03:30,670 --> 00:03:27,489
Spot and a lot of other stuff going on

61
00:03:34,300 --> 00:03:30,680
so for for a little bit of context

62
00:03:35,770 --> 00:03:34,310
here's an image of the earth to scale

63
00:03:37,960 --> 00:03:35,780

with the Great Red Spot and that might

64
00:03:41,080 --> 00:03:37,970
give you some idea of how great this

65
00:03:43,180 --> 00:03:41,090
Great Red Spot is the name is kind of a

66
00:03:46,600 --> 00:03:43,190
fanciful name Great Red Spot well it's

67
00:03:48,400 --> 00:03:46,610
great because it's large as you can see

68
00:03:50,800 --> 00:03:48,410
it's larger than the earth

69
00:03:53,470 --> 00:03:50,810
where's Jupiter is much larger in the

70
00:03:55,180 --> 00:03:53,480
earth it's about 11 times diameter of

71
00:03:57,729 --> 00:03:55,190
the earth so about a thousand earths

72
00:04:00,370 --> 00:03:57,739
could fit inside Jupiter if you could

73
00:04:03,069 --> 00:04:00,380
fit things inside of junior Jupiter of

74
00:04:05,199 --> 00:04:03,079
course is almost all gas and hey that's

75
00:04:06,280 --> 00:04:05,209
a great topic for the night our speaker

76
00:04:09,340 --> 00:04:06,290
will be talking about gas in the

77
00:04:10,690 --> 00:04:09,350
universe but Jupiter is a gaseous planet

78
00:04:14,050 --> 00:04:10,700
so it's almost tired

79
00:04:16,479 --> 00:04:14,060
what you see in the atmosphere is all

80
00:04:18,400 --> 00:04:16,489
and the spirit features clouds weather

81
00:04:21,210 --> 00:04:18,410
just like we have on America this is a

82
00:04:23,770 --> 00:04:21,220
very violent storm that's been raging in

83
00:04:26,580 --> 00:04:23,780
Jupiter's atmosphere for a long time in

84
00:04:29,320 --> 00:04:26,590
fact it's been observed as far back as

85
00:04:30,730 --> 00:04:29,330
three or four hundred years ago this is

86
00:04:37,540 --> 00:04:30,740
a drawing by the famous astronomer

87
00:04:40,720 --> 00:04:37,550
Cassini done in 1677 and it made that

88
00:04:42,430 --> 00:04:40,730

black spot on there is probably the

89
00:04:47,460 --> 00:04:42,440
great red spot so we think it's been

90
00:04:51,210 --> 00:04:47,470
around at least that long more recently

91
00:04:54,370 --> 00:04:51,220
of course people have been observing it

92
00:04:56,140 --> 00:04:54,380
Jupiter a lot and in particularly the

93
00:04:59,830 --> 00:04:56,150
red spots been pretty continuously

94
00:05:01,930 --> 00:04:59,840
monitored for about 150 years during

95
00:05:08,620 --> 00:05:01,940
most that time it remained pretty much

96
00:05:10,000 --> 00:05:08,630
the same very recently in about 2012 a

97
00:05:13,780 --> 00:05:10,010
lot of amateur astronomers that were

98
00:05:16,600 --> 00:05:13,790
observing Jupiter noticed that the red

99
00:05:18,580 --> 00:05:16,610
spot seems to be getting smaller and

100
00:05:22,210 --> 00:05:18,590
actually it's been observed to be

101
00:05:24,460 --> 00:05:22,220
shrinking gradually over the last quite

102
00:05:27,430 --> 00:05:24,470
a while but recently that that shrinkage

103
00:05:29,140 --> 00:05:27,440
has seemed accelerated and it's

104
00:05:30,969 --> 00:05:29,150
shrinking and it's also changing its

105
00:05:33,820 --> 00:05:30,979
shape so the shrinkage is mostly along

106
00:05:35,680 --> 00:05:33,830
the long dimension there so it's

107
00:05:37,960 --> 00:05:35,690
becoming rounder as you can see in this

108
00:05:40,659 --> 00:05:37,970
series of images these are very recent

109
00:05:42,760 --> 00:05:40,669
images from Hubble the whole disk of

110
00:05:46,510 --> 00:05:42,770
Jupiter with the beautiful red spot

111
00:05:50,469 --> 00:05:46,520
taken in April 21st and then these other

112
00:05:55,150 --> 00:05:50,479
images are other images that Hubble took

113
00:05:56,740 --> 00:05:55,160

from 1995 2000 and 2009 and you can

114
00:05:59,440 --> 00:05:56,750
pretty clearly see that the spot is

115
00:06:02,860 --> 00:05:59,450
indeed getting smaller now the question

116
00:06:04,570 --> 00:06:02,870
of course is why is it doing this and

117
00:06:07,690 --> 00:06:04,580
unfortunately the answer is nobody

118
00:06:12,620 --> 00:06:07,700
really knows most of the experts don't

119
00:06:15,300 --> 00:06:12,630
really have an explanation any Simon who

120
00:06:17,940 --> 00:06:15,310
astronomer who was leading the Hubble

121
00:06:20,190 --> 00:06:17,950
observations has speculated that it may

122
00:06:24,390 --> 00:06:20,200
have something to do with the very

123
00:06:26,550 --> 00:06:24,400
turbulent material around here and

124
00:06:29,610 --> 00:06:26,560
little Eddie's may be interacting with

125
00:06:32,250 --> 00:06:29,620
edges of the red spot and causing some

126
00:06:33,810 --> 00:06:32,260
strange stuff to go on but he's really

127
00:06:36,780 --> 00:06:33,820
sure so this is a kind of an interesting

128
00:06:39,090 --> 00:06:36,790
area where people are still doing very

129
00:06:41,310 --> 00:06:39,100
actively trying to figure out what's

130
00:06:43,920 --> 00:06:41,320
going on you know in a place like this

131
00:06:46,080 --> 00:06:43,930
it's very close to us I mean Jupiter in

132
00:06:48,030 --> 00:06:46,090
the cosmic sense is is just in our

133
00:06:48,960 --> 00:06:48,040
backyard so it's kind of interesting

134
00:06:51,030 --> 00:06:48,970
that we don't know everything there is

135
00:06:53,400 --> 00:06:51,040
to know about Jupiter and the weather on

136
00:06:56,610 --> 00:06:53,410
Jupiter yet so that was a kind of

137
00:07:00,000 --> 00:06:56,620
interesting thing that came up not too

138
00:07:03,630 --> 00:07:00,010

long ago so without further ado further

139
00:07:08,159 --> 00:07:03,640
ado I'd like to introduce our talk

140
00:07:09,980 --> 00:07:08,169
tonight so gaseous states a matter play

141
00:07:12,420 --> 00:07:09,990
a prominent role throughout the universe

142
00:07:14,640 --> 00:07:12,430
I'm not to mention in our everyday lives

143
00:07:17,490 --> 00:07:14,650
we breathe the air around the sphere all

144
00:07:19,530 --> 00:07:17,500
the time it's a gas from the atmospheres

145
00:07:21,500 --> 00:07:19,540
of planets and stars the vast expanses

146
00:07:23,820 --> 00:07:21,510
of interstellar and intergalactic space

147
00:07:25,650 --> 00:07:23,830
gas clouds are also critical to the

148
00:07:29,280 --> 00:07:25,660
formation and development of stars and

149
00:07:32,219 --> 00:07:29,290
the life cycle of galaxies tonight dr.

150
00:07:34,260 --> 00:07:32,229
Andrew Fox will describe observations of

151
00:07:36,780 --> 00:07:34,270
light emitted by in these various

152
00:07:38,790 --> 00:07:36,790
environments which is our only source of

153
00:07:45,480 --> 00:07:38,800
information for most of our knowledge of

154
00:07:47,550 --> 00:07:45,490
the universe dr. Andrew Fox is on the

155
00:07:49,890 --> 00:07:47,560
staff here at Space Telescope Science

156
00:07:52,070 --> 00:07:49,900
Institute he received his PhD from the

157
00:07:55,680 --> 00:07:52,080
University of Wisconsin at Madison in

158
00:07:58,730 --> 00:07:55,690
2005 before joining STS C eyes and eat

159
00:08:02,040 --> 00:07:58,740
as a European Space Agency astronomer in

160
00:08:05,880 --> 00:08:02,050
2011 he held postdoctoral fellowships in

161
00:08:09,270 --> 00:08:05,890
Paris Santiago and Cambridge UK

162
00:08:10,920 --> 00:08:09,280
Cambridge I assume he's interested in

163
00:08:12,990 --> 00:08:10,930

the mechanics by which galaxies feed

164
00:08:16,080 --> 00:08:13,000
their star formation in particular in

165
00:08:27,980 --> 00:08:16,090
the Milky Way our own galaxy where these

166
00:08:33,300 --> 00:08:30,960
okay thank you salt and it's a pleasure

167
00:08:35,670 --> 00:08:33,310
to be here and I see so many people out

168
00:08:38,089 --> 00:08:35,680
there in the audience this is going to

169
00:08:40,890 --> 00:08:38,099
be a talk about the gaseous universe and

170
00:08:43,140 --> 00:08:40,900
the idea here is to do a tour of

171
00:08:45,330 --> 00:08:43,150
different places that we can observe

172
00:08:47,520 --> 00:08:45,340
with our telescopes and to show to you

173
00:08:49,800 --> 00:08:47,530
the gaseous matter the same kinds of gas

174
00:08:51,780 --> 00:08:49,810
that we can observe in the lab and in

175
00:08:54,020 --> 00:08:51,790
the atmosphere of the earth are also

176
00:08:58,050 --> 00:08:54,030
seen in other places in the universe and

177
00:09:01,080 --> 00:08:58,060
the knowledge that we have of gases here

178
00:09:03,210 --> 00:09:01,090
on planet Earth is vital for us to

179
00:09:05,940 --> 00:09:03,220
understand the gases that we observe in

180
00:09:08,010 --> 00:09:05,950
many many different places in astronomy

181
00:09:10,890 --> 00:09:08,020
so I want to start with some very basic

182
00:09:12,660 --> 00:09:10,900
ideas about what gas is when you think

183
00:09:16,230 --> 00:09:12,670
of gas you might think of the natural

184
00:09:18,000 --> 00:09:16,240
gas that comes out of your stove top you

185
00:09:20,580 --> 00:09:18,010
might think about how expensive it is to

186
00:09:21,960 --> 00:09:20,590
fill up your car at the pump but of

187
00:09:24,150 --> 00:09:21,970
course this kind of gas that's short for

188
00:09:27,350 --> 00:09:24,160

gasoline and that's a liquid that's not

189
00:09:30,900 --> 00:09:27,360
really the gas that we mean in the

190
00:09:33,930 --> 00:09:30,910
scientific sense of the word so as you

191
00:09:34,980 --> 00:09:33,940
may remember there are several basic

192
00:09:36,780 --> 00:09:34,990
states of matter

193
00:09:39,780 --> 00:09:36,790
we're often taught that there are three

194
00:09:41,220 --> 00:09:39,790
solids liquids and gases in fact

195
00:09:43,200 --> 00:09:41,230
nowadays it's more common you'll see

196
00:09:46,230 --> 00:09:43,210
people talk about four phases of matter

197
00:09:48,380 --> 00:09:46,240
with plasma which is an ionized form of

198
00:09:51,990 --> 00:09:48,390
gas where the atoms have been split into

199
00:09:54,840 --> 00:09:52,000
nuclei and electrons now plasma is

200
00:09:58,110 --> 00:09:54,850
treated as a separate category so as you

201
00:10:00,660 --> 00:09:58,120
go from from solids to across to plasma

202
00:10:02,610 --> 00:10:00,670
in this in this representation the idea

203
00:10:05,510 --> 00:10:02,620
with solids is you have a material that

204
00:10:08,460 --> 00:10:05,520
has a fixed volume in and fixed shape a

205
00:10:10,500 --> 00:10:08,470
liquid has a fixed volume but its shape

206
00:10:13,080 --> 00:10:10,510
will change depending on what container

207
00:10:14,940 --> 00:10:13,090
it's in whereas a gas has no fixed

208
00:10:17,550 --> 00:10:14,950
volume or no fixed shape it will just

209
00:10:20,370 --> 00:10:17,560
fill whatever container that it's in now

210
00:10:22,260 --> 00:10:20,380
when it comes to gases in astronomy we

211
00:10:24,120 --> 00:10:22,270
have some pretty big containers and the

212
00:10:25,740 --> 00:10:24,130
Milky Way the halo of the Milky Way the

213
00:10:28,890 --> 00:10:25,750

space between galaxies these are

214
00:10:30,420 --> 00:10:28,900
enormous volumes so gases fill enormous

215
00:10:31,410 --> 00:10:30,430
volumes of space and that's something

216
00:10:34,040 --> 00:10:31,420
I'm going to be coming back to

217
00:10:37,050 --> 00:10:34,050
throughout this talk

218
00:10:38,670 --> 00:10:37,060
matter changes between these phases by

219
00:10:40,110 --> 00:10:38,680
the addition of heat so something gets

220
00:10:41,759 --> 00:10:40,120
hotter and hotter you'll go from solid

221
00:10:43,829 --> 00:10:41,769
to liquid to gas and eventually to

222
00:10:45,869 --> 00:10:43,839
plasma and plasma is where you've

223
00:10:47,790 --> 00:10:45,879
injected so much heat into the matter

224
00:10:50,730 --> 00:10:47,800
that the the electrons are no longer

225
00:10:52,139 --> 00:10:50,740
bound to the nuclei of those atoms and

226
00:11:00,019 --> 00:10:52,149
we're going to come across plasma in

227
00:11:03,540 --> 00:11:00,029
many places in this talk so one of the

228
00:11:05,340 --> 00:11:03,550
reasons that gases is worth studying as

229
00:11:07,650 --> 00:11:05,350
we see in many different places it's

230
00:11:11,460 --> 00:11:07,660
also very well understood from the point

231
00:11:15,030 --> 00:11:11,470
of view of physics we understand how and

232
00:11:17,040 --> 00:11:15,040
why gas emits radiation and how and why

233
00:11:19,410 --> 00:11:17,050
gas absorbs radiation we can study these

234
00:11:21,749 --> 00:11:19,420
things in the lab and so we can see the

235
00:11:25,079 --> 00:11:21,759
same processes happening in astronomy

236
00:11:26,610 --> 00:11:25,089
and it's not just a science that you can

237
00:11:28,800 --> 00:11:26,620
do at visible wavelengths that your eye

238
00:11:30,990 --> 00:11:28,810

can see you can study gases all across

239
00:11:34,230 --> 00:11:31,000
the spectrum using x-rays and using

240
00:11:35,639 --> 00:11:34,240
radio waves and microwaves and many

241
00:11:38,879 --> 00:11:35,649
different wavelengths that are a part of

242
00:11:40,379 --> 00:11:38,889
the toolkit of modern astronomy you

243
00:11:43,530 --> 00:11:40,389
might wonder why do I have in a picture

244
00:11:47,850 --> 00:11:43,540
of a neon sign up here so a neon sign is

245
00:11:51,210 --> 00:11:47,860
a good example of a case where a certain

246
00:11:53,579 --> 00:11:51,220
type of atom a neon atom is excited by

247
00:11:56,869 --> 00:11:53,589
an injecting energy into it and it emits

248
00:11:59,100 --> 00:11:56,879
radiation at a very particular

249
00:12:01,499 --> 00:11:59,110
wavelength or frequency and that's the

250
00:12:03,960 --> 00:12:01,509
wavelength corresponding to red light so

251
00:12:07,439 --> 00:12:03,970
the parallel with astronomy here is that

252
00:12:10,170 --> 00:12:07,449
we can use the colors of light emitted

253
00:12:12,179 --> 00:12:10,180
from different places in the universe to

254
00:12:14,879 --> 00:12:12,189
identify which chemical elements are

255
00:12:16,920 --> 00:12:14,889
present just like the red of a neon sign

256
00:12:21,110 --> 00:12:16,930
tells you something about what chemical

257
00:12:23,340 --> 00:12:21,120
elements are present inside it one other

258
00:12:26,040 --> 00:12:23,350
saying you might have heard of this

259
00:12:28,559 --> 00:12:26,050
nature abhors a vacuum this is first

260
00:12:31,650 --> 00:12:28,569
attributed to Aristotle the philosopher

261
00:12:33,480 --> 00:12:31,660
the basic idea that people have when

262
00:12:36,720 --> 00:12:33,490
they apply this is the reason that you

263
00:12:39,059 --> 00:12:36,730

won't find a complete vacuum in physics

264
00:12:40,619 --> 00:12:39,069
is that if you had a region of space

265
00:12:43,259 --> 00:12:40,629
that didn't have any atoms or molecules

266
00:12:45,010 --> 00:12:43,269
in it then whatever was next to it would

267
00:12:46,750 --> 00:12:45,020
just simply diffuse over and

268
00:12:48,790 --> 00:12:46,760
those particles would spread into it and

269
00:12:52,630 --> 00:12:48,800
fill that region and that physical

270
00:12:55,780 --> 00:12:52,640
principle is basically very valid to

271
00:12:56,890 --> 00:12:55,790
astronomy just as it is here on earth so

272
00:13:00,880 --> 00:12:56,900
let's start in the Earth's atmosphere

273
00:13:06,130 --> 00:13:00,890
this is a great place where we we know

274
00:13:07,570 --> 00:13:06,140
about gas most of the molecules in the

275
00:13:09,130 --> 00:13:07,580
Earth's atmosphere are either nitrogen

276
00:13:11,560 --> 00:13:09,140
or oxygen there's a little bit of argon

277
00:13:13,240 --> 00:13:11,570
carbon dioxide air the atmosphere is

278
00:13:16,840 --> 00:13:13,250
actually pretty thin it's only about a

279
00:13:19,270 --> 00:13:16,850
hundred kilometers thick depending on

280
00:13:20,830 --> 00:13:19,280
exactly how you define it but just for

281
00:13:22,990 --> 00:13:20,840
comparison the radius of the earth is

282
00:13:25,300 --> 00:13:23,000
about six thousand kilometers you just

283
00:13:27,310 --> 00:13:25,310
have this thin 100 kilometer layer of

284
00:13:29,620 --> 00:13:27,320
gas on the surface of it of course

285
00:13:31,630 --> 00:13:29,630
that's vital for life on Earth our

286
00:13:33,490 --> 00:13:31,640
oxygen we breathe is in that atmosphere

287
00:13:35,080 --> 00:13:33,500
there's a tiny amount of ozone that's

288
00:13:37,090 --> 00:13:35,090

the oh three at the end of that list

289
00:13:39,250 --> 00:13:37,100
that ozone is also very important for us

290
00:13:42,730 --> 00:13:39,260
because it blocks some of the harmful UV

291
00:13:46,510 --> 00:13:42,740
radiation from the Sun so the atmosphere

292
00:13:48,940 --> 00:13:46,520
is a critical part of a of a planet like

293
00:13:51,760 --> 00:13:48,950
our own now salt already showed you

294
00:13:54,430 --> 00:13:51,770
what's been happening recently in the

295
00:13:58,750 --> 00:13:54,440
atmosphere of Jupiter this gas giant

296
00:14:02,080 --> 00:13:58,760
planet in our own solar system this is a

297
00:14:03,880 --> 00:14:02,090
planet like Saturn and Uranus and

298
00:14:06,490 --> 00:14:03,890
Neptune that has no solid surface it's

299
00:14:09,690 --> 00:14:06,500
pure gas at least all the way down to

300
00:14:14,320 --> 00:14:12,310
the composition of the atmosphere of

301
00:14:17,230 --> 00:14:14,330
Jupiter there is different from the

302
00:14:19,570 --> 00:14:17,240
atmosphere of the of the earth here most

303
00:14:21,070 --> 00:14:19,580
of their atoms that are the particles

304
00:14:23,080 --> 00:14:21,080
that exist are hydrogen and helium

305
00:14:26,500 --> 00:14:23,090
there's little bits of methane and

306
00:14:28,240 --> 00:14:26,510
ammonia and these the different

307
00:14:30,580 --> 00:14:28,250
compositions of the elements in the

308
00:14:31,960 --> 00:14:30,590
different planets actually go help to

309
00:14:36,130 --> 00:14:31,970
explain the different colors for example

310
00:14:39,430 --> 00:14:36,140
of Neptune and Saturn versus Jupiter but

311
00:14:40,960 --> 00:14:39,440
this is the same series of pictures

312
00:14:42,070 --> 00:14:40,970
showing you the shrinking great red spot

313
00:14:44,950 --> 00:14:42,080

which has left a lot of people

314
00:14:47,580 --> 00:14:44,960
scratching their heads recently well

315
00:14:51,430 --> 00:14:47,590
let's go outside the solar system to

316
00:14:53,680 --> 00:14:51,440
another planet that was observed with

317
00:14:56,380 --> 00:14:53,690
the Hubble Space Telescope and this is

318
00:14:58,870 --> 00:14:56,390
the planet called HD 209 four five eight

319
00:15:03,520 --> 00:14:58,880
B if you're really interested

320
00:15:05,410 --> 00:15:03,530
that means it's the 209458 star in the

321
00:15:07,480 --> 00:15:05,420
catalog of Henry Draper his initials

322
00:15:09,730 --> 00:15:07,490
were HD and he was a famous astronomer

323
00:15:11,260 --> 00:15:09,740
who catalogued this enormous list of

324
00:15:12,790 --> 00:15:11,270
stars so that people could come and

325
00:15:18,280 --> 00:15:12,800
identify them and find where they are in

326
00:15:20,230 --> 00:15:18,290
the sky so this is a star that happens

327
00:15:22,360 --> 00:15:20,240
to have a planet going around it and

328
00:15:23,920 --> 00:15:22,370
when that planet moves in front of the

329
00:15:26,200 --> 00:15:23,930
face of the star which is called a

330
00:15:28,600 --> 00:15:26,210
transit two very interesting things

331
00:15:31,300 --> 00:15:28,610
happen first of all you block some of

332
00:15:33,970 --> 00:15:31,310
the light from the star so that the

333
00:15:38,200 --> 00:15:33,980
brightness of that Stars radiation goes

334
00:15:41,170 --> 00:15:38,210
down and secondly because that planet

335
00:15:42,910 --> 00:15:41,180
has an atmosphere you not only block the

336
00:15:46,600 --> 00:15:42,920
light from the star you also absorb very

337
00:15:49,480 --> 00:15:46,610
specific wavelengths of light and that

338
00:15:51,490 --> 00:15:49,490

tells you about what chemicals exist in

339
00:15:53,110 --> 00:15:51,500
the atmosphere of that planet and it

340
00:15:55,270 --> 00:15:53,120
turns out that when they studied the the

341
00:15:57,100 --> 00:15:55,280
light that had passed through the

342
00:16:00,280 --> 00:15:57,110
atmosphere of that planet they found the

343
00:16:02,560 --> 00:16:00,290
signature of hydrogen gas that was in

344
00:16:06,130 --> 00:16:02,570
the atmosphere of that planet this was

345
00:16:07,630 --> 00:16:06,140
the first planetary atmosphere outside

346
00:16:10,120 --> 00:16:07,640
our solar system

347
00:16:11,800 --> 00:16:10,130
we call that an exoplanet atmosphere

348
00:16:13,780 --> 00:16:11,810
discovered by the Hubble Space Telescope

349
00:16:15,520 --> 00:16:13,790
this is an artist's impression no one

350
00:16:17,080 --> 00:16:15,530
has is able to take a you know

351
00:16:20,650 --> 00:16:17,090
high-resolution image of what it looks

352
00:16:22,990 --> 00:16:20,660
like but it's using a technique called

353
00:16:24,640 --> 00:16:23,000
spectroscopy where you take the light

354
00:16:25,750 --> 00:16:24,650
from from a star and you split it up

355
00:16:27,220 --> 00:16:25,760
into different colors and then you

356
00:16:28,840 --> 00:16:27,230
analyze how much light there is are

357
00:16:30,880 --> 00:16:28,850
different colors that's how you can do

358
00:16:35,430 --> 00:16:30,890
this and you can figure out what is the

359
00:16:38,710 --> 00:16:35,440
actual composition of the the atmosphere

360
00:16:41,190 --> 00:16:38,720
now as I've already said I mean gas is

361
00:16:43,360 --> 00:16:41,200
everywhere in astronomy one place that's

362
00:16:47,140 --> 00:16:43,370
often thought about when people talk

363
00:16:51,820 --> 00:16:47,150

about gaseous clouds is in so-called

364
00:16:53,170 --> 00:16:51,830
nebulae nebulae are very attractive

365
00:16:55,300 --> 00:16:53,180
objects there are a lot of images that

366
00:16:56,620 --> 00:16:55,310
have been taken for example with the

367
00:16:58,930 --> 00:16:56,630
Hubble telescope of these types of

368
00:17:00,940 --> 00:16:58,940
objects and they're basically big clouds

369
00:17:03,880 --> 00:17:00,950
of gas that exists between the stars and

370
00:17:06,040 --> 00:17:03,890
galaxies and these clouds are the places

371
00:17:08,170 --> 00:17:06,050
where new stars are formed and there are

372
00:17:09,570 --> 00:17:08,180
also places where stars release their

373
00:17:11,790 --> 00:17:09,580
elements when the stars get

374
00:17:13,740 --> 00:17:11,800
the end of their lifetime so on the left

375
00:17:17,010 --> 00:17:13,750
here this is a famous nebula called the

376
00:17:18,960 --> 00:17:17,020
butterfly nebula that's actually a type

377
00:17:20,430 --> 00:17:18,970
of nebula a planetary nebula which is

378
00:17:22,920 --> 00:17:20,440
what happens to where star at the end of

379
00:17:24,630 --> 00:17:22,930
its life on the right this is a very

380
00:17:26,370 --> 00:17:24,640
famous image from the Hubble telescope

381
00:17:28,860 --> 00:17:26,380
called the mystic mountain

382
00:17:30,600 --> 00:17:28,870
this is a star-forming nebula where we

383
00:17:33,300 --> 00:17:30,610
can see new stars being formed out of

384
00:17:35,130 --> 00:17:33,310
that gas this was released on the 20th

385
00:17:37,650 --> 00:17:35,140
anniversary of the of the Hubble Space

386
00:17:39,450 --> 00:17:37,660
Telescope but there's a very close link

387
00:17:41,580 --> 00:17:39,460
between the gas and the stars that form

388
00:17:42,900 --> 00:17:41,590

out of out of out of it and that I'm

389
00:17:47,760 --> 00:17:42,910
going to come back to throughout

390
00:17:50,850 --> 00:17:47,770
throughout this now sometimes you hear

391
00:17:54,720 --> 00:17:50,860
people say that galaxies are basically

392
00:17:57,570 --> 00:17:54,730
made of stars and gas well the thing is

393
00:18:00,120 --> 00:17:57,580
is that stars themselves are gaseous

394
00:18:02,190 --> 00:18:00,130
objects what what is a star will the

395
00:18:04,980 --> 00:18:02,200
star is to a very good approximation a

396
00:18:07,740 --> 00:18:04,990
spherical ball of plasma which is an

397
00:18:09,480 --> 00:18:07,750
ionized gas that's held together because

398
00:18:12,150 --> 00:18:09,490
gravity is pulling it in towards the

399
00:18:13,980 --> 00:18:12,160
center and gas pressure the pressure of

400
00:18:18,630 --> 00:18:13,990
all the particles in the gas is holding

401
00:18:20,730 --> 00:18:18,640
it up so stars are in some ways similar

402
00:18:22,320 --> 00:18:20,740
to the gas that's in nebulae in between

403
00:18:23,460 --> 00:18:22,330
stars it's still gas that's there it

404
00:18:27,650 --> 00:18:23,470
just happens to have a very different

405
00:18:30,570 --> 00:18:27,660
temperature and a very different density

406
00:18:32,730 --> 00:18:30,580
so in addition to all the stars that we

407
00:18:34,320 --> 00:18:32,740
have in a galaxy in the Milky Way there

408
00:18:36,840 --> 00:18:34,330
are something like a hundred billion or

409
00:18:39,210 --> 00:18:36,850
so there's a lot of gas that exists

410
00:18:40,770 --> 00:18:39,220
between the stars and I'm not just

411
00:18:42,750 --> 00:18:40,780
talking about the nebulae that I showed

412
00:18:45,900 --> 00:18:42,760
you already I'm talking about a very

413
00:18:47,520 --> 00:18:45,910

widespread diffuse layer of gas that

414
00:18:50,010 --> 00:18:47,530
exists everywhere in the disk of our

415
00:18:52,560 --> 00:18:50,020
galaxy in the plane of our galaxy and

416
00:18:55,790 --> 00:18:52,570
the reason we know there is gas there is

417
00:18:59,700 --> 00:18:55,800
from observations at radio wavelengths

418
00:19:03,390 --> 00:18:59,710
so this is a map of the entire sky taken

419
00:19:04,890 --> 00:19:03,400
at a wavelength of 21 centimeters so if

420
00:19:06,420 --> 00:19:04,900
you have a radio telescope and you look

421
00:19:08,790 --> 00:19:06,430
at a wavelength of 21 centimeters you

422
00:19:11,310 --> 00:19:08,800
make an all-sky map this is what you

423
00:19:13,740 --> 00:19:11,320
find you have you find this narrow strip

424
00:19:15,920 --> 00:19:13,750
of a mission right along the center of

425
00:19:18,810 --> 00:19:15,930
the map there and then it's much fainter

426
00:19:21,180 --> 00:19:18,820
above and below and that's telling you

427
00:19:23,520 --> 00:19:21,190
that everywhere throughout the galaxy

428
00:19:26,270 --> 00:19:23,530
between stars there is a gap

429
00:19:28,980 --> 00:19:26,280
a neutral hydrogen gas and that gas is

430
00:19:31,800 --> 00:19:28,990
emitting these radio waves that we can

431
00:19:35,520 --> 00:19:31,810
we can use to measure how extended that

432
00:19:37,380 --> 00:19:35,530
gas is so now I want to show you a

433
00:19:39,330 --> 00:19:37,390
couple of numbers just to give you a

434
00:19:41,490 --> 00:19:39,340
feel of how these different places

435
00:19:45,480 --> 00:19:41,500
compare when we stack them against each

436
00:19:47,610 --> 00:19:45,490
other now if you want to describe a gas

437
00:19:50,250 --> 00:19:47,620
if there are two numbers the dent the

438
00:19:51,990 --> 00:19:50,260

density and the temperature that tell

439
00:19:53,370 --> 00:19:52,000
you a lot about what's happening the

440
00:19:55,140 --> 00:19:53,380
temperature of course is how hot

441
00:19:57,170 --> 00:19:55,150
something is and the density is a

442
00:20:00,390 --> 00:19:57,180
measure of how many particles you have

443
00:20:02,730 --> 00:20:00,400
per unit volume so we often do that per

444
00:20:04,770 --> 00:20:02,740
cubic centimeter okay how many particles

445
00:20:07,380 --> 00:20:04,780
do you have in each cubic centimeter of

446
00:20:10,410 --> 00:20:07,390
space now if you start in the atmosphere

447
00:20:12,900 --> 00:20:10,420
of the earth just take a point at sea

448
00:20:16,230 --> 00:20:12,910
level typical temperature of course it

449
00:20:17,880 --> 00:20:16,240
varies but on average if it's say 62

450
00:20:20,460 --> 00:20:17,890
degrees Fahrenheit that corresponds to

451
00:20:24,600 --> 00:20:20,470
290 Kelvin which is the temperature

452
00:20:29,490 --> 00:20:24,610
scale we use in astronomy if you look at

453
00:20:31,200 --> 00:20:29,500
the density of one the density of air in

454
00:20:33,480 --> 00:20:31,210
the Earth's atmosphere okay you find

455
00:20:36,210 --> 00:20:33,490
that one cubic centimeter of air

456
00:20:38,220 --> 00:20:36,220
contains something like five times 10 to

457
00:20:41,580 --> 00:20:38,230
the 19 particles mostly nitrogen

458
00:20:43,920 --> 00:20:41,590
molecules that's 50 billion billion

459
00:20:46,140 --> 00:20:43,930
particles all right and one cubic

460
00:20:48,300 --> 00:20:46,150
centimeter is about the volume under the

461
00:20:49,860 --> 00:20:48,310
tip of your thumb so it's amazing to

462
00:20:51,540 --> 00:20:49,870
think even though air it seems like it

463
00:20:54,090 --> 00:20:51,550

doesn't really have much in it that

464
00:20:55,710 --> 00:20:54,100
region of the air which has the same

465
00:20:58,730 --> 00:20:55,720
volume as the tip of your thumb it

466
00:21:03,480 --> 00:20:58,740
contains about 50 billion billion

467
00:21:05,630 --> 00:21:03,490
particles what happens if you go to the

468
00:21:11,610 --> 00:21:05,640
surface of the Sun that's much hotter

469
00:21:14,310 --> 00:21:11,620
almost 6,000 degrees Kelvin and it turns

470
00:21:16,830 --> 00:21:14,320
out the density there it's only known

471
00:21:19,950 --> 00:21:16,840
kind of approximately but it's several

472
00:21:22,050 --> 00:21:19,960
orders of magnitude several times lower

473
00:21:23,550 --> 00:21:22,060
than it is in the Earth's atmosphere but

474
00:21:26,270 --> 00:21:23,560
if you were to go to the core of the Sun

475
00:21:29,610 --> 00:21:26,280
where energy is being produced by

476
00:21:32,880 --> 00:21:29,620
nuclear fusion reactions the temperature

477
00:21:35,820 --> 00:21:32,890
is an enormous 15 million degrees and a

478
00:21:37,320 --> 00:21:35,830
density is as high as 10 of the 26 now

479
00:21:39,480 --> 00:21:37,330
these are all gases or

480
00:21:41,430 --> 00:21:39,490
asthma's but you can just see the huge

481
00:21:44,790 --> 00:21:41,440
variety you get between the different

482
00:21:47,130 --> 00:21:44,800
places we can add a couple more lines to

483
00:21:49,260 --> 00:21:47,140
this table if we go to interstellar

484
00:21:51,870 --> 00:21:49,270
space I showed you that radio emission

485
00:21:53,640 --> 00:21:51,880
from the interstellar space there the

486
00:21:57,150 --> 00:21:53,650
temperature is pretty warm it's about

487
00:22:01,110 --> 00:21:57,160
10,000 Kelvin but the average density is

488
00:22:03,150 --> 00:22:01,120

about one you have one particle per

489
00:22:06,690 --> 00:22:03,160
cubic centimeter of interstellar space

490
00:22:08,430 --> 00:22:06,700
on average in our galaxy so then what's

491
00:22:11,250 --> 00:22:08,440
the difference between a gas in a star

492
00:22:18,030 --> 00:22:11,260
and the gas in interstellar space is

493
00:22:21,240 --> 00:22:18,040
it's 26 orders of magnitude so it's it's

494
00:22:23,270 --> 00:22:21,250
you know one with 26 zeros after it

495
00:22:26,820 --> 00:22:23,280
now if you go to the intergalactic space

496
00:22:29,430 --> 00:22:26,830
between galaxies the densities are

497
00:22:30,810 --> 00:22:29,440
several orders of magnitude lower still

498
00:22:32,970 --> 00:22:30,820
even though the temperature is about the

499
00:22:34,560 --> 00:22:32,980
same so we see this enormous range in

500
00:22:37,310 --> 00:22:34,570
what the density of gases is in

501
00:22:42,080 --> 00:22:37,320
different places of the universe okay

502
00:22:46,980 --> 00:22:42,090
the next thing I want to talk about is

503
00:22:50,310 --> 00:22:46,990
our own Milky Way this is a picture of

504
00:22:54,210 --> 00:22:50,320
the center of the Milky Way those of you

505
00:22:56,880 --> 00:22:54,220
who are amateur astronomers will know

506
00:22:58,230 --> 00:22:56,890
this is in Sagittarius what you're

507
00:23:01,170 --> 00:22:58,240
seeing when you look at the center of

508
00:23:03,270 --> 00:23:01,180
the Milky Way is all the stars that are

509
00:23:05,310 --> 00:23:03,280
unresolved we can hardly separate them

510
00:23:07,470 --> 00:23:05,320
they form this white glow in the

511
00:23:10,710 --> 00:23:07,480
background and then on top of that you

512
00:23:12,330 --> 00:23:10,720
have the dust lanes the brown clouds

513
00:23:18,180 --> 00:23:12,340

that block the light from the stars

514
00:23:19,770 --> 00:23:18,190
behind it turns out that beyond the

515
00:23:21,150 --> 00:23:19,780
Milky Way there's so many three galaxies

516
00:23:21,980 --> 00:23:21,160
that you can actually observe with the

517
00:23:25,320 --> 00:23:21,990
naked eye

518
00:23:28,050 --> 00:23:25,330
two of them are the so called Magellanic

519
00:23:29,850 --> 00:23:28,060
Clouds the Large Magellanic Cloud which

520
00:23:32,790 --> 00:23:29,860
is in the top right of this image and

521
00:23:35,460 --> 00:23:32,800
the small Magellanic Cloud that is down

522
00:23:37,200 --> 00:23:35,470
here and this is an optical view so this

523
00:23:39,750 --> 00:23:37,210
is the what you see if you look at the

524
00:23:43,560 --> 00:23:39,760
Magellanic Clouds with the visible light

525
00:23:46,230 --> 00:23:43,570
okay now the Magellanic Clouds were

526
00:23:50,220 --> 00:23:46,240
named after the famous explorer

527
00:23:51,470 --> 00:23:50,230
Ferdinand Magellan who is well known for

528
00:23:53,520 --> 00:23:51,480
leading the first

529
00:23:54,659 --> 00:23:53,530
circumnavigation of the earth in fact in

530
00:23:57,419 --> 00:23:54,669
a few years we're going to come up on

531
00:23:59,370 --> 00:23:57,429
the 500th anniversary of that journey

532
00:24:02,880 --> 00:23:59,380
around the earth he didn't make it all

533
00:24:04,409 --> 00:24:02,890
the way around he actually died in the

534
00:24:06,539 --> 00:24:04,419
Philippines before he got back to Europe

535
00:24:10,470 --> 00:24:06,549
but then the rest of his crew continued

536
00:24:12,360 --> 00:24:10,480
the tour and brought his ship back back

537
00:24:16,560 --> 00:24:12,370
home but the Magellanic Clouds were

538
00:24:17,340 --> 00:24:16,570

named after him and the name is stark

539
00:24:20,220 --> 00:24:17,350
ever since

540
00:24:22,830 --> 00:24:20,230
now compared to the Milky Way these

541
00:24:24,600 --> 00:24:22,840
clouds are pretty small

542
00:24:26,549 --> 00:24:24,610
I mentioned the Milky Way has about a

543
00:24:27,810 --> 00:24:26,559
hundred billion stars the Large

544
00:24:30,270 --> 00:24:27,820
Magellanic Cloud has something like

545
00:24:32,430 --> 00:24:30,280
three billion and the small Magellanic

546
00:24:34,380 --> 00:24:32,440
Cloud has 300 million in terms of

547
00:24:37,049 --> 00:24:34,390
distances may be familiar with

548
00:24:38,669 --> 00:24:37,059
lightyears how how many years have taken

549
00:24:41,070 --> 00:24:38,679
the light to travel to us from those

550
00:24:43,020 --> 00:24:41,080
galaxies you're talking about a hundred

551
00:24:44,490 --> 00:24:43,030
and sixty thousand or so for the Large

552
00:24:46,649 --> 00:24:44,500
Magellanic Cloud almost two hundred

553
00:24:49,470 --> 00:24:46,659
thousand for the small Magellanic Cloud

554
00:24:51,090 --> 00:24:49,480
those numbers look huge but in terms of

555
00:24:52,380 --> 00:24:51,100
how far away most galaxies are these are

556
00:24:57,299 --> 00:24:52,390
really close by these are in our

557
00:24:59,730 --> 00:24:57,309
backyard now what happens if you look at

558
00:25:01,560 --> 00:24:59,740
these objects with different wavelengths

559
00:25:03,149 --> 00:25:01,570
so let's say we take a radio telescope

560
00:25:05,460 --> 00:25:03,159
this is actually an array of radio

561
00:25:08,190 --> 00:25:05,470
telescopes I'm down in Australia

562
00:25:10,260 --> 00:25:08,200
Australia telescope compact array if you

563
00:25:12,029 --> 00:25:10,270

look at the Magellanic Clouds with

564
00:25:14,430 --> 00:25:12,039
something like that you're going to see

565
00:25:16,380 --> 00:25:14,440
a very different picture this is an idea

566
00:25:18,930 --> 00:25:16,390
of what the gas in the Magellanic Cloud

567
00:25:22,409 --> 00:25:18,940
the Large Magellanic Cloud the LMC looks

568
00:25:24,510 --> 00:25:22,419
like in radio emission you can see all

569
00:25:27,659 --> 00:25:24,520
this very detailed structure all these

570
00:25:30,060 --> 00:25:27,669
clumps all these gaps in the gas and the

571
00:25:33,480 --> 00:25:30,070
this is the brightest parts where there

572
00:25:34,799 --> 00:25:33,490
are the highest concentrations of gas

573
00:25:38,010 --> 00:25:34,809
that's where you're going to get new

574
00:25:39,750 --> 00:25:38,020
stars forming now there's another thing

575
00:25:42,630 --> 00:25:39,760
you can do which is you can say well

576
00:25:45,720 --> 00:25:42,640
let's put the radio emission on the same

577
00:25:47,190 --> 00:25:45,730
scale as this map so instead of using

578
00:25:48,930 --> 00:25:47,200
optical light I'm just going to put the

579
00:25:51,000 --> 00:25:48,940
exact same region of the sky and show

580
00:25:54,350 --> 00:25:51,010
what does the radio light look like when

581
00:25:57,450 --> 00:25:54,360
you do that this is what it looks like

582
00:26:00,029 --> 00:25:57,460
the really neat thing here is that the

583
00:26:02,730 --> 00:26:00,039
the gas that you see in the radio

584
00:26:04,530 --> 00:26:02,740
emission actually covers much more space

585
00:26:05,820 --> 00:26:04,540
than the stars do

586
00:26:08,220 --> 00:26:05,830
right so if I go back to the star as

587
00:26:10,590 --> 00:26:08,230
quickly they're much more confined the

588
00:26:13,260 --> 00:26:10,600

gas is more extended and there's even a

589
00:26:16,290 --> 00:26:13,270
bridge of gas between the two Magellanic

590
00:26:18,240 --> 00:26:16,300
Clouds they're connected so there's a

591
00:26:19,230 --> 00:26:18,250
common envelope of material between them

592
00:26:20,970 --> 00:26:19,240
and you wouldn't have known anything

593
00:26:25,530 --> 00:26:20,980
about that if you hadn't been able to

594
00:26:28,140 --> 00:26:25,540
look at radio wavelengths that's called

595
00:26:30,390 --> 00:26:28,150
the Magellanic bridge now not only is

596
00:26:32,550 --> 00:26:30,400
there this envelope between the clouds

597
00:26:35,580 --> 00:26:32,560
it turns out that there's a huge stream

598
00:26:37,410 --> 00:26:35,590
of gas behind the Magellanic Clouds as

599
00:26:39,300 --> 00:26:37,420
they orbit the Milky Way because these

600
00:26:41,940 --> 00:26:39,310
two galaxies are falling around the

601
00:26:43,650 --> 00:26:41,950
Milky Way they're in there they're in

602
00:26:46,020 --> 00:26:43,660
the gravitational field of our own Milky

603
00:26:48,420 --> 00:26:46,030
Way galaxy and as they come in towards

604
00:26:50,640 --> 00:26:48,430
the Milky Way they're producing a huge

605
00:26:54,270 --> 00:26:50,650
stream of gas which is called the

606
00:26:57,720 --> 00:26:54,280
Magellanic stream now this is another

607
00:26:59,430 --> 00:26:57,730
all-sky map where you've got the the

608
00:27:01,920 --> 00:26:59,440
disk of the Milky Way along the center

609
00:27:03,600 --> 00:27:01,930
so along the equator the white glow that

610
00:27:06,510 --> 00:27:03,610
you can see there is the Starlight from

611
00:27:08,670 --> 00:27:06,520
our own galaxy this is where the

612
00:27:10,680 --> 00:27:08,680
Magellanic Clouds are over here the SMC

613
00:27:13,170 --> 00:27:10,690

and the LMC for the small and a large

614
00:27:15,990 --> 00:27:13,180
and what we see in radio light is this

615
00:27:17,910 --> 00:27:16,000
enormous tail of material that comes all

616
00:27:19,530 --> 00:27:17,920
the way down through the South Pole and

617
00:27:22,500 --> 00:27:19,540
up to the other side of the galaxy and

618
00:27:25,410 --> 00:27:22,510
it also continues up in front of the of

619
00:27:27,780 --> 00:27:25,420
the clouds now just to give you an idea

620
00:27:29,550 --> 00:27:27,790
of how big that is I can put the

621
00:27:32,700 --> 00:27:29,560
continents of the earth on the same

622
00:27:34,410 --> 00:27:32,710
scale because we measure longitude and

623
00:27:37,680 --> 00:27:34,420
latitude to measure where things are on

624
00:27:39,270 --> 00:27:37,690
a map on the surface of our planet in

625
00:27:41,010 --> 00:27:39,280
astronomy we do the same thing for the

626
00:27:45,000 --> 00:27:41,020
galaxy we have Galactic longitude and

627
00:27:47,160 --> 00:27:45,010
Galactic latitude why am I doing this

628
00:27:50,160 --> 00:27:47,170
I'm just showing you how there is an

629
00:27:54,930 --> 00:27:50,170
enormous stream of gas that covers about

630
00:27:56,820 --> 00:27:54,940
half of the of the entire sky you can

631
00:27:58,050 --> 00:27:56,830
see if you compare it to where the

632
00:28:00,120 --> 00:27:58,060
contents are you've got the Magellanic

633
00:28:02,180 --> 00:28:00,130
Clouds down there in the Indian Ocean

634
00:28:04,680 --> 00:28:02,190
somewhere and this dream comes through

635
00:28:06,510 --> 00:28:04,690
and talked to her and all the way up the

636
00:28:08,150 --> 00:28:06,520
coast of South America it's it's

637
00:28:10,890 --> 00:28:08,160
enormous

638
00:28:13,140 --> 00:28:10,900

if you were to look outside of our

639
00:28:15,120 --> 00:28:13,150
galaxy and look back towards us

640
00:28:16,710 --> 00:28:15,130
you might see something like this you've

641
00:28:18,280 --> 00:28:16,720
got the two Magellanic Clouds shown

642
00:28:21,080 --> 00:28:18,290
there that

643
00:28:23,450 --> 00:28:21,090
losing huge amounts of gas and this

644
00:28:26,630 --> 00:28:23,460
Magellanic stream is just extending

645
00:28:28,820 --> 00:28:26,640
behind them as I said they're responding

646
00:28:30,110 --> 00:28:28,830
to the gravity of the Milky Way what's

647
00:28:32,210 --> 00:28:30,120
going to happen to all this gases

648
00:28:33,560 --> 00:28:32,220
eventually it will be able to accumulate

649
00:28:35,150 --> 00:28:33,570
and fall onto the Milky Way

650
00:28:37,130 --> 00:28:35,160
so the Milky Way is the big winner in

651
00:28:39,200 --> 00:28:37,140
all of this these two little dwarf

652
00:28:41,060 --> 00:28:39,210
galaxies are being stripped of the gas

653
00:28:42,920 --> 00:28:41,070
that they have and that gas is going to

654
00:28:46,420 --> 00:28:42,930
end up coming into our own galaxy where

655
00:28:49,550 --> 00:28:46,430
it may eventually be able to form stars

656
00:28:51,590 --> 00:28:49,560
let's move out a little bit further I

657
00:28:53,150 --> 00:28:51,600
mentioned there are only three objects

658
00:28:55,250 --> 00:28:53,160
you can see with the naked eye outside

659
00:28:57,650 --> 00:28:55,260
the Milky Way and two of them with

660
00:29:00,980 --> 00:28:57,660
Magellanic Clouds the third is Andromeda

661
00:29:02,810 --> 00:29:00,990
at the great Andromeda galaxy I'm

662
00:29:04,880 --> 00:29:02,820
showing the full moon there for scale

663
00:29:07,550 --> 00:29:04,890

the full moon is about half a degree

664
00:29:10,400 --> 00:29:07,560
across you can see that this thing is

665
00:29:12,110 --> 00:29:10,410
this galaxy is is is huge several

666
00:29:13,520 --> 00:29:12,120
degrees although with the naked eye you

667
00:29:15,800 --> 00:29:13,530
won't see anything like that this

668
00:29:19,040 --> 00:29:15,810
obviously needs a big telescope to bring

669
00:29:20,540 --> 00:29:19,050
out the structure but this is a now

670
00:29:26,030 --> 00:29:20,550
known to be at a distance of about two

671
00:29:30,250 --> 00:29:26,040
and a half million light-years now the

672
00:29:32,660 --> 00:29:30,260
person who really was the first to

673
00:29:38,570 --> 00:29:32,670
understand how distant the Andromeda

674
00:29:40,160 --> 00:29:38,580
galaxy was or is was Edwin Hubble then

675
00:29:43,130 --> 00:29:40,170
the man who our hubble space telescope

676
00:29:45,350 --> 00:29:43,140
is named after and he was able to make

677
00:29:47,990 --> 00:29:45,360
the first distance estimate to the

678
00:29:49,370 --> 00:29:48,000
Andromeda galaxy and he did that using a

679
00:29:51,080 --> 00:29:49,380
telescope called the hooker telescope

680
00:29:53,750 --> 00:29:51,090
there were 100 inch hooker telescope

681
00:29:55,930 --> 00:29:53,760
which is in California and it's

682
00:29:57,590 --> 00:29:55,940
interesting that this is a 2.5 meter

683
00:29:59,720 --> 00:29:57,600
telescope the Hubble Space Telescope

684
00:30:02,680 --> 00:29:59,730
named after him is 2.4 meters it's

685
00:30:06,950 --> 00:30:02,690
actually pretty close but he was able to

686
00:30:10,310 --> 00:30:06,960
measure the distance to Andromeda and

687
00:30:12,380 --> 00:30:10,320
that settled a really big debate that

688
00:30:15,680 --> 00:30:12,390

was going on in the 1920s it was called

689
00:30:18,890 --> 00:30:15,690
a great debate because back then people

690
00:30:20,390 --> 00:30:18,900
had observed nebulae as they called them

691
00:30:22,580 --> 00:30:20,400
like this but they didn't know was that

692
00:30:25,490 --> 00:30:22,590
something in our own galaxy or was that

693
00:30:29,480 --> 00:30:25,500
outside the Milky Way was it it's in was

694
00:30:31,130 --> 00:30:29,490
it an entirely separate object

695
00:30:33,080 --> 00:30:31,140
and Hubble was the one who actually

696
00:30:34,820 --> 00:30:33,090
settled that because when he measured a

697
00:30:36,860 --> 00:30:34,830
distance to Andromeda and he did that

698
00:30:39,169 --> 00:30:36,870
using a certain type of star called a

699
00:30:41,090 --> 00:30:39,179
Cepheid variable star by measuring how

700
00:30:43,850 --> 00:30:41,100
quickly there was pulsated he was able

701
00:30:46,639 --> 00:30:43,860
to measure the distance to the galaxy he

702
00:30:49,279 --> 00:30:46,649
found that the distance Wars about nine

703
00:30:50,899 --> 00:30:49,289
hundred thousand light-years that was

704
00:30:53,180 --> 00:30:50,909
the number that he published on the

705
00:30:54,980 --> 00:30:53,190
distance to this galaxy well nine

706
00:30:57,590 --> 00:30:54,990
hundred thousand light-years is way

707
00:30:59,180 --> 00:30:57,600
bigger than our own galaxy so he

708
00:31:01,519 --> 00:30:59,190
realized that this couldn't fit inside

709
00:31:04,279 --> 00:31:01,529
the Milky Way this had to be more

710
00:31:05,870 --> 00:31:04,289
distant than that so we couldn't think

711
00:31:07,130 --> 00:31:05,880
of the Milky Way as the center of the

712
00:31:09,200 --> 00:31:07,140
universe it showed that there are other

713
00:31:11,149 --> 00:31:09,210

galaxies out there it turns out that and

714
00:31:12,529 --> 00:31:11,159
rahmanir is actually more massive and

715
00:31:14,269 --> 00:31:12,539
bigger than the Milky Way so this was

716
00:31:17,990 --> 00:31:14,279
very important for putting our galaxy in

717
00:31:20,210 --> 00:31:18,000
context just one last point we now know

718
00:31:22,940 --> 00:31:20,220
that the the value of the distance the

719
00:31:25,190 --> 00:31:22,950
Milky to Andromeda excuse me is about

720
00:31:27,260 --> 00:31:25,200
two and a half million light-years so

721
00:31:29,630 --> 00:31:27,270
it's a factor of two or three higher

722
00:31:31,399 --> 00:31:29,640
than the number that he had to do with

723
00:31:33,529 --> 00:31:31,409
different calibrations for the way he

724
00:31:34,940 --> 00:31:33,539
was measuring distance but the main

725
00:31:36,440 --> 00:31:34,950
point is that he found that this was

726
00:31:40,840 --> 00:31:36,450
certainly far enough away to be outside

727
00:31:43,460 --> 00:31:40,850
the Milky Way now we can see that

728
00:31:46,220 --> 00:31:43,470
between Andromeda which is on the top

729
00:31:50,419 --> 00:31:46,230
right there and its neighbor which is

730
00:31:51,919 --> 00:31:50,429
called m33 there is a bridge of material

731
00:31:53,840 --> 00:31:51,929
just like there was a bridge of material

732
00:31:56,090 --> 00:31:53,850
between the Magellanic Clouds and this

733
00:31:59,690 --> 00:31:56,100
was discovered quite recently in radio

734
00:32:02,180 --> 00:31:59,700
emission exactly where that gas comes

735
00:32:04,399 --> 00:32:02,190
from isn't completely known it may be

736
00:32:06,560 --> 00:32:04,409
falling onto the galaxy and on to

737
00:32:11,810 --> 00:32:06,570
Andromeda for the first time allowing it

738
00:32:14,210 --> 00:32:11,820

to to form new stars so I want to come

739
00:32:17,799 --> 00:32:14,220
back to this idea about gas in astronomy

740
00:32:20,990 --> 00:32:17,809
as fuel for new stars for star formation

741
00:32:24,470 --> 00:32:21,000
because just as you'll put gas in your

742
00:32:27,019 --> 00:32:24,480
car and you'll get motion out of it you

743
00:32:28,820 --> 00:32:27,029
can put gas in the form of interstellar

744
00:32:30,470 --> 00:32:28,830
gas into a galaxy and you'll form new

745
00:32:35,769 --> 00:32:30,480
stars okay that's the idea I have about

746
00:32:38,149 --> 00:32:35,779
fueling and galaxies from from gas now

747
00:32:40,789 --> 00:32:38,159
there are cycles that go on within

748
00:32:41,180 --> 00:32:40,799
galaxies where new stars form out of

749
00:32:43,880 --> 00:32:41,190
into

750
00:32:46,610 --> 00:32:43,890
Stella gasps and once they get to the

751
00:32:49,070 --> 00:32:46,620
end of their life they can return the

752
00:32:50,840 --> 00:32:49,080
gas back into the space around them

753
00:32:52,520 --> 00:32:50,850
but the gas that's been cycled through

754
00:32:54,200 --> 00:32:52,530
stars is different than the gas that

755
00:32:56,750 --> 00:32:54,210
they formed out of and the main

756
00:32:58,850 --> 00:32:56,760
difference is that the the composition

757
00:33:01,190 --> 00:32:58,860
the chemical elements that make up that

758
00:33:05,050 --> 00:33:01,200
gas have have changed because the Stars

759
00:33:07,790 --> 00:33:05,060
have produced new elements all the

760
00:33:10,070 --> 00:33:07,800
chemical elements that we that we study

761
00:33:12,950 --> 00:33:10,080
and we put in a periodic table that a

762
00:33:16,190 --> 00:33:12,960
chemist would show you are ultimately

763
00:33:19,700 --> 00:33:16,200

synthesized in the cores of the central

764
00:33:22,550 --> 00:33:19,710
cores of stars now astronomers like to

765
00:33:26,060 --> 00:33:22,560
make simplifications and sometimes

766
00:33:28,210 --> 00:33:26,070
you'll see an astronomer turn a periodic

767
00:33:32,360 --> 00:33:28,220
table into something like this

768
00:33:34,010 --> 00:33:32,370
everything from lithium up which is the

769
00:33:36,350 --> 00:33:34,020
third element up in the periodic table

770
00:33:39,080 --> 00:33:36,360
they'll just refer to as metals or heavy

771
00:33:40,670 --> 00:33:39,090
elements so you've got hydrogen the

772
00:33:41,930 --> 00:33:40,680
first element you've got helium the

773
00:33:43,820 --> 00:33:41,940
second element those are the two at the

774
00:33:46,370 --> 00:33:43,830
top and then everything else is referred

775
00:33:48,530 --> 00:33:46,380
to as metals now you might say why how

776
00:33:51,650 --> 00:33:48,540
on earth can you do that the reason is

777
00:33:54,350 --> 00:33:51,660
that hydrogen and helium are thought to

778
00:33:56,600 --> 00:33:54,360
be produced very early on in the

779
00:33:59,480 --> 00:33:56,610
universe right after the Big Bang all

780
00:34:02,510 --> 00:33:59,490
the hydrogen and helium atoms were

781
00:34:06,050 --> 00:34:02,520
synthesized at that time but everything

782
00:34:08,660 --> 00:34:06,060
else that's called metals here is mostly

783
00:34:10,190 --> 00:34:08,670
produced I say everything but some of

784
00:34:11,960 --> 00:34:10,200
the lithium and Bourne might have been

785
00:34:13,340 --> 00:34:11,970
produced earlier on but to a to a very

786
00:34:15,020 --> 00:34:13,350
good approximation all the other

787
00:34:18,680 --> 00:34:15,030
elements come from this the course of

788
00:34:21,500 --> 00:34:18,690

massive stars and this is studied by

789
00:34:24,710 --> 00:34:21,510
people who look at stellar evolution the

790
00:34:27,500 --> 00:34:24,720
way that stars changed as time goes on

791
00:34:29,240 --> 00:34:27,510
and they run out of fuel and this is a

792
00:34:31,460 --> 00:34:29,250
picture showing you a slice through what

793
00:34:34,240 --> 00:34:31,470
a massive star will look like at the end

794
00:34:37,130 --> 00:34:34,250
of its life you have these different

795
00:34:39,230 --> 00:34:37,140
rings of material or shells of material

796
00:34:41,390 --> 00:34:39,240
that have a different chemical

797
00:34:43,730 --> 00:34:41,400
composition and when I say a massive

798
00:34:47,150 --> 00:34:43,740
star this is the starlet's about ten

799
00:34:48,770 --> 00:34:47,160
times more massive than the Sun and it's

800
00:34:50,330 --> 00:34:48,780
gone through various stages where it's

801
00:34:53,859 --> 00:34:50,340
burned through different types of fuel

802
00:34:56,020 --> 00:34:53,869
so to start out where the star will burn

803
00:34:58,599 --> 00:34:56,030
our son right now is burning hydrogen

804
00:35:00,700 --> 00:34:58,609
fuel when the hydrogen runs out they

805
00:35:02,500 --> 00:35:00,710
will move on to helium and if the star

806
00:35:04,210 --> 00:35:02,510
is massive enough it will move on to a

807
00:35:05,710 --> 00:35:04,220
whole series of different elements until

808
00:35:07,780 --> 00:35:05,720
you end up with something like this and

809
00:35:09,339 --> 00:35:07,790
this is where the chemical elements are

810
00:35:12,190 --> 00:35:09,349
thought to be produced in the cores of

811
00:35:14,050 --> 00:35:12,200
these stars when a star gets to the end

812
00:35:17,650 --> 00:35:14,060
of its life and all the iron in the core

813
00:35:20,620 --> 00:35:17,660

has been processed you can get a

814
00:35:22,390 --> 00:35:20,630
supernova that's where the star explodes

815
00:35:25,440 --> 00:35:22,400
and releases a lot of these elements out

816
00:35:29,260 --> 00:35:25,450
into interstellar space and eventually

817
00:35:32,020 --> 00:35:29,270
across the galaxy where planets can form

818
00:35:33,460 --> 00:35:32,030
and new stars can form and so on now

819
00:35:35,380 --> 00:35:33,470
that's not the only type of supernova

820
00:35:37,540 --> 00:35:35,390
this is this is what you would call a

821
00:35:39,700 --> 00:35:37,550
core collapse supernova from a very

822
00:35:42,099 --> 00:35:39,710
individual massive star there's another

823
00:35:45,040 --> 00:35:42,109
type of supernova which is called a type

824
00:35:47,500 --> 00:35:45,050
1a supernova this happens when you have

825
00:35:49,810 --> 00:35:47,510
a binary system here you've got a white

826
00:35:51,430 --> 00:35:49,820
dwarf star it's a very dense star on one

827
00:35:54,880 --> 00:35:51,440
side and it's and it's pulling material

828
00:35:57,790 --> 00:35:54,890
off a companion so if it pulls enough

829
00:36:00,849 --> 00:35:57,800
material across onto the white dwarf you

830
00:36:03,220 --> 00:36:00,859
can get an explosion that will be

831
00:36:04,900 --> 00:36:03,230
visible for to very large distances

832
00:36:07,020 --> 00:36:04,910
because it's very bright and you can

833
00:36:10,210 --> 00:36:07,030
also produce elements such as iron

834
00:36:12,670 --> 00:36:10,220
through this channel as well so

835
00:36:14,829 --> 00:36:12,680
supernovae will produce elements but if

836
00:36:17,760 --> 00:36:14,839
you want to get these elements out into

837
00:36:20,320 --> 00:36:17,770
the regions between galaxies you need a

838
00:36:22,599 --> 00:36:20,330

process that can do that can do that for

839
00:36:25,060 --> 00:36:22,609
you and there is something called a

840
00:36:27,160 --> 00:36:25,070
galactic wind that will take material

841
00:36:31,599 --> 00:36:27,170
that has been produced in the disk of a

842
00:36:34,089 --> 00:36:31,609
galaxy and can throw it out into the

843
00:36:36,880 --> 00:36:34,099
intergalactic space this is a very

844
00:36:40,120 --> 00:36:36,890
famous picture of a nearby starburst

845
00:36:41,680 --> 00:36:40,130
galaxy called natt the starburst galaxy

846
00:36:43,930 --> 00:36:41,690
is one that's forming stars much more

847
00:36:46,210 --> 00:36:43,940
rapidly than a galaxy like the Milky Way

848
00:36:48,670 --> 00:36:46,220
is so there's lots of new star formation

849
00:36:50,710 --> 00:36:48,680
going on all the time and you can see

850
00:36:53,650 --> 00:36:50,720
from the central region of this galaxy

851
00:36:56,859 --> 00:36:53,660
you have these huge conical outflows

852
00:37:00,040 --> 00:36:56,869
that are getting out into space driven

853
00:37:01,750 --> 00:37:00,050
by it's debated about how much of that

854
00:37:03,670 --> 00:37:01,760
is driven by supernovae and how much of

855
00:37:05,680 --> 00:37:03,680
that is actually driven by a

856
00:37:06,820 --> 00:37:05,690
supermassive black hole that's in the

857
00:37:09,250 --> 00:37:06,830
middle of the galaxy that

858
00:37:12,400 --> 00:37:09,260
also putting energy into its environment

859
00:37:17,800 --> 00:37:12,410
and throwing out material out of the

860
00:37:19,990 --> 00:37:17,810
galaxy so in the last part of my talk I

861
00:37:21,910 --> 00:37:20,000
want to move to the more distant

862
00:37:24,370 --> 00:37:21,920
universe I've talked about nearby

863
00:37:26,880 --> 00:37:24,380

galaxies mostly up to now how can we

864
00:37:28,900 --> 00:37:26,890
detect gas very far away

865
00:37:30,520 --> 00:37:28,910
particularly where radio telescopes

866
00:37:31,510 --> 00:37:30,530
aren't going to work anymore because the

867
00:37:34,360 --> 00:37:31,520
emission is too faint

868
00:37:36,310 --> 00:37:34,370
well one technique that people spend a

869
00:37:38,950 --> 00:37:36,320
lot of time doing here at the Space

870
00:37:41,140 --> 00:37:38,960
Telescope Institute for example is a

871
00:37:43,660 --> 00:37:41,150
technique called quasar absorption line

872
00:37:45,370 --> 00:37:43,670
spectra skippy now that sounds pretty

873
00:37:47,110 --> 00:37:45,380
complicated but in fact what you're

874
00:37:50,590 --> 00:37:47,120
doing here is it's quite straightforward

875
00:37:53,580 --> 00:37:50,600
you're taking a very bright source of

876
00:37:56,470 --> 00:37:53,590
light think of it like a lighthouse and

877
00:37:58,510 --> 00:37:56,480
you're seeing what happens to that light

878
00:38:00,760 --> 00:37:58,520
when you split it up into all the

879
00:38:02,500 --> 00:38:00,770
different colors of the of the spectrum

880
00:38:04,720 --> 00:38:02,510
all the different colors of the rainbow

881
00:38:06,850 --> 00:38:04,730
if you like so here's an example where

882
00:38:08,560 --> 00:38:06,860
you're looking in a quasar and your line

883
00:38:10,110 --> 00:38:08,570
of sight from your telescope happens to

884
00:38:12,730 --> 00:38:10,120
pass through three different clouds

885
00:38:17,440 --> 00:38:12,740
between us and the quasar in the

886
00:38:20,140 --> 00:38:17,450
background now each of those clouds is a

887
00:38:22,360 --> 00:38:20,150
gas and we know that gas can absorb

888
00:38:24,520 --> 00:38:22,370

light at very particular wavelengths so

889
00:38:27,250 --> 00:38:24,530
each of these clouds leaves a certain

890
00:38:30,040 --> 00:38:27,260
signature in a spectrum of that quasar

891
00:38:32,020 --> 00:38:30,050
so the first cloud can leave you a line

892
00:38:35,080 --> 00:38:32,030
in the spectrum here which is called

893
00:38:36,670 --> 00:38:35,090
will label a the second cloud will leave

894
00:38:38,500 --> 00:38:36,680
a line of this position and the third

895
00:38:39,760 --> 00:38:38,510
cloud will leave a line there so what

896
00:38:43,000 --> 00:38:39,770
you're actually left with when you

897
00:38:45,010 --> 00:38:43,010
observe this is a series of lines that

898
00:38:46,720 --> 00:38:45,020
contain information about what's the

899
00:38:52,150 --> 00:38:46,730
chemical composition of each of these

900
00:38:55,120 --> 00:38:52,160
clouds so this is the technique that

901
00:38:57,760 --> 00:38:55,130
people use to study the halos of

902
00:38:59,740 --> 00:38:57,770
galaxies out to very very high distances

903
00:39:01,720 --> 00:38:59,750
because it turns out that when we see

904
00:39:04,090 --> 00:39:01,730
these gas clouds in front of the quasar

905
00:39:06,820 --> 00:39:04,100
what we're often seeing is the very

906
00:39:09,850 --> 00:39:06,830
extended halos of individual galaxies

907
00:39:11,860 --> 00:39:09,860
the galaxies have these very faint but

908
00:39:13,390 --> 00:39:11,870
large halos that give you this

909
00:39:15,460 --> 00:39:13,400
absorption signal even though you can't

910
00:39:17,350 --> 00:39:15,470
see the stars there and so you can't see

911
00:39:19,510 --> 00:39:17,360
them shining at you you have to detect

912
00:39:23,410 --> 00:39:19,520
them through these other methods

913
00:39:25,910 --> 00:39:23,420

now what if you go to even bigger scales

914
00:39:28,640 --> 00:39:25,920
there is a term called the cosmic web

915
00:39:30,770 --> 00:39:28,650
which describes what on really large

916
00:39:32,930 --> 00:39:30,780
scales astronomers think that the

917
00:39:34,880 --> 00:39:32,940
universe looks like this image is

918
00:39:37,820 --> 00:39:34,890
actually a computer simulation of what

919
00:39:41,540 --> 00:39:37,830
the gas in the universe looks like in a

920
00:39:44,360 --> 00:39:41,550
box where each side of that box is 30

921
00:39:47,540 --> 00:39:44,370
million light years in size okay so this

922
00:39:50,180 --> 00:39:47,550
is an enormous volume of space and you

923
00:39:52,700 --> 00:39:50,190
can see this filamentary structure right

924
00:39:55,490 --> 00:39:52,710
the green is the gas in the universe and

925
00:39:59,480 --> 00:39:55,500
in the in the center of all these

926
00:40:01,130 --> 00:39:59,490
filaments you get the what you might

927
00:40:02,510 --> 00:40:01,140
call the nodes of the cosmic web those

928
00:40:05,330 --> 00:40:02,520
are where the galaxies form and the

929
00:40:06,890 --> 00:40:05,340
clusters of galaxies form but this is a

930
00:40:08,090 --> 00:40:06,900
prediction of what the gas in the

931
00:40:10,430 --> 00:40:08,100
universe would look like on that large

932
00:40:13,430 --> 00:40:10,440
scale so how can we test the prediction

933
00:40:16,160 --> 00:40:13,440
and go out and look for it we can do the

934
00:40:18,530 --> 00:40:16,170
quasar absorption line experiment and we

935
00:40:21,800 --> 00:40:18,540
can see if we can detect that gas in

936
00:40:23,240 --> 00:40:21,810
absorption and this is how you would do

937
00:40:25,580 --> 00:40:23,250
it you would look for something called

938
00:40:27,380 --> 00:40:25,590

the lyman-alpha forest and the

939
00:40:28,910 --> 00:40:27,390
lyman-alpha forest is saying okay if I

940
00:40:31,370 --> 00:40:28,920
take us a sight line that passes through

941
00:40:34,100 --> 00:40:31,380
all these green clouds I should get lots

942
00:40:37,100 --> 00:40:34,110
and lots of features in my spectrum each

943
00:40:41,750 --> 00:40:37,110
one corresponding to one of the features

944
00:40:43,520 --> 00:40:41,760
of the forest of the gas and that's

945
00:40:45,890 --> 00:40:43,530
exactly what we see when we look at very

946
00:40:47,810 --> 00:40:45,900
very distant quasars we take the light

947
00:40:50,930 --> 00:40:47,820
from the quasar and we plot it as

948
00:40:52,730 --> 00:40:50,940
brightness against wavelength now if you

949
00:40:54,230 --> 00:40:52,740
look at a nearby quasar what you'll get

950
00:40:57,140 --> 00:40:54,240
when you look at a spectrum is something

951
00:41:00,410 --> 00:40:57,150
like this there aren't that many dips

952
00:41:02,510 --> 00:41:00,420
and features in the spectrum if you go

953
00:41:05,600 --> 00:41:02,520
to a distant quasar much further away

954
00:41:08,540 --> 00:41:05,610
you see this huge forest of lines there

955
00:41:10,970 --> 00:41:08,550
is just a very large number of dips in

956
00:41:13,340 --> 00:41:10,980
the spectrum and each of those

957
00:41:16,220 --> 00:41:13,350
corresponds to one of the the filaments

958
00:41:17,720 --> 00:41:16,230
of gas in the lyman-alpha forest so by

959
00:41:19,850 --> 00:41:17,730
Counting how many of those that there

960
00:41:21,710 --> 00:41:19,860
are measuring their properties we can

961
00:41:27,050 --> 00:41:21,720
actually learn something observationally

962
00:41:32,030 --> 00:41:27,060
about that gas what about if we go back

963
00:41:36,770 --> 00:41:34,640

the first time that a gas is thought to

964
00:41:39,730 --> 00:41:36,780
have formed in the universe is when the

965
00:41:45,400 --> 00:41:39,740
universe was about 380,000 years old and

966
00:41:48,920 --> 00:41:45,410
this is a time called recombination

967
00:41:52,010 --> 00:41:48,930
before this this is 380,000 years after

968
00:41:53,930 --> 00:41:52,020
the Big Bang the universe was very hot

969
00:41:58,220 --> 00:41:53,940
they were so hot that the material

970
00:41:59,990 --> 00:41:58,230
existed as plasma that is to say the

971
00:42:02,150 --> 00:42:00,000
electrons which are in green here were

972
00:42:04,430 --> 00:42:02,160
not bound to the nuclei which are in red

973
00:42:07,310 --> 00:42:04,440
it was too hot the gas just couldn't

974
00:42:09,380 --> 00:42:07,320
stay bound so it was a plasma but the

975
00:42:11,990 --> 00:42:09,390
universe was expanding and as it

976
00:42:13,850 --> 00:42:12,000
expanded it was cooling down and

977
00:42:18,500 --> 00:42:13,860
eventually it cooled down to a point

978
00:42:20,750 --> 00:42:18,510
where neutral atoms were able to form so

979
00:42:25,130 --> 00:42:20,760
instead of having this plasma you had a

980
00:42:27,260 --> 00:42:25,140
gas you went from a situation where the

981
00:42:28,690 --> 00:42:27,270
universe was opaque and light couldn't

982
00:42:31,760 --> 00:42:28,700
travel through it to where you had a

983
00:42:35,200 --> 00:42:31,770
transparent gas which light could pass

984
00:42:38,030 --> 00:42:35,210
through and that's called recombination

985
00:42:40,250 --> 00:42:38,040
now how do we know that again I want to

986
00:42:44,660 --> 00:42:40,260
come back to the evidence we have in for

987
00:42:46,630 --> 00:42:44,670
each of these physical ideas the answer

988
00:42:50,270 --> 00:42:46,640

is we can see the light that was emitted

989
00:42:52,010 --> 00:42:50,280
from that epoch of recombination and we

990
00:42:56,060 --> 00:42:52,020
see it in the form of the Cosmic

991
00:42:58,400 --> 00:42:56,070
Microwave Background this is what the

992
00:43:03,170 --> 00:42:58,410
night sky looks like if you look at it

993
00:43:05,480 --> 00:43:03,180
in microwaves this radiation came from

994
00:43:08,390 --> 00:43:05,490
that epoch about 380,000 years after the

995
00:43:11,150 --> 00:43:08,400
Big Bang when the first gas formed when

996
00:43:13,310 --> 00:43:11,160
the plasma recombined to form a neutral

997
00:43:14,810 --> 00:43:13,320
gas and it's you'll see it referred to

998
00:43:17,360 --> 00:43:14,820
as the oldest form of light in the

999
00:43:21,190 --> 00:43:17,370
universe now what happened after that

1000
00:43:23,530 --> 00:43:21,200
well the universe didn't stay neutral

1001
00:43:25,790 --> 00:43:23,540
forever

1002
00:43:27,290 --> 00:43:25,800
right after recombination the first

1003
00:43:29,630 --> 00:43:27,300
thing that happened was the period

1004
00:43:31,070 --> 00:43:29,640
called the dark ages we don't know much

1005
00:43:32,840 --> 00:43:31,080
about the universe in the dark ages

1006
00:43:36,950 --> 00:43:32,850
because there weren't many sources of

1007
00:43:39,590 --> 00:43:36,960
light but at one point after that the

1008
00:43:42,290 --> 00:43:39,600
first galaxies and the first quasars

1009
00:43:44,270 --> 00:43:42,300
began to switch on and quasars are the

1010
00:43:45,489 --> 00:43:44,280
cores of the galaxies where a lot of

1011
00:43:48,200 --> 00:43:45,499
radiation is emitted

1012
00:43:51,140 --> 00:43:48,210
now when those galaxies and quasars

1013
00:43:54,229 --> 00:43:51,150

switch on they start to shine into

1014
00:43:57,620 --> 00:43:54,239
bubbles of space around them they around

1015
00:43:59,509 --> 00:43:57,630
them and so you're producing these

1016
00:44:02,089 --> 00:43:59,519
bubbles of gas and eventually as time

1017
00:44:04,190 --> 00:44:02,099
passes further than that the bubbles

1018
00:44:07,249 --> 00:44:04,200
start to overlap and you reach a point

1019
00:44:09,200 --> 00:44:07,259
where all of the space between galaxies

1020
00:44:11,529 --> 00:44:09,210
all the intergalactic space is ionized

1021
00:44:14,390 --> 00:44:11,539
so this whole process is called

1022
00:44:16,400 --> 00:44:14,400
reorganization so the universe you know

1023
00:44:17,839 --> 00:44:16,410
started out ionized very early on and

1024
00:44:19,700 --> 00:44:17,849
then it became neutral and then when the

1025
00:44:22,460 --> 00:44:19,710
galaxy switched on and became ionized

1026
00:44:25,970 --> 00:44:22,470
together so you have this trend going

1027
00:44:30,799 --> 00:44:25,980
from neutral to ionized as cosmic time

1028
00:44:33,979 --> 00:44:30,809
has has progressed so just before I

1029
00:44:35,930 --> 00:44:33,989
finished before we finish up here I

1030
00:44:38,029 --> 00:44:35,940
wanted to mention that and one other

1031
00:44:40,430 --> 00:44:38,039
reason that we're interested in gases is

1032
00:44:42,680 --> 00:44:40,440
that most atoms in the universe are in

1033
00:44:44,450 --> 00:44:42,690
gases compared to all these different

1034
00:44:46,880 --> 00:44:44,460
forms of astronomical matter I've shown

1035
00:44:49,569 --> 00:44:46,890
you solids and liquids really account

1036
00:44:51,829 --> 00:44:49,579
for a very small fraction of all the

1037
00:44:54,440 --> 00:44:51,839
regular matter that exists in the

1038
00:44:57,289 --> 00:44:54,450

universe so with that I'm going to end

1039
00:44:59,569 --> 00:44:57,299
and I'm going to put up this picture of

1040
00:45:02,690 --> 00:44:59,579
the so called monkey head nebula that

1041
00:45:04,249 --> 00:45:02,700
was released earlier this year and ask

1042
00:45:18,070 --> 00:45:04,259
you if you have any questions so thanks

1043
00:45:34,130 --> 00:45:32,600
yes yes that's right so in a stellar gas

1044
00:45:36,590 --> 00:45:34,140
can be heated to high temperatures

1045
00:45:42,130 --> 00:45:36,600
around 10,000 Kelvin or so and it's

1046
00:45:46,880 --> 00:45:45,350
ultraviolet radiation ultraviolet

1047
00:45:49,700 --> 00:45:46,890
photons that come off stars that can

1048
00:45:51,530 --> 00:45:49,710
heat the gas that's present in

1049
00:45:53,060 --> 00:45:51,540
interstellar space and the temperature

1050
00:45:55,130 --> 00:45:53,070
that it has is set by a balance between

1051
00:45:58,340 --> 00:45:55,140
how much heating you have and how much

1052
00:46:00,050 --> 00:45:58,350
cooling you have now saying that there

1053
00:46:02,360 --> 00:46:00,060
are regions of interstellar space that

1054
00:46:04,310 --> 00:46:02,370
are cooler so they're nebulae that new

1055
00:46:07,430 --> 00:46:04,320
stars form out of a much colder than

1056
00:46:09,980 --> 00:46:07,440
that you need cold gas to be able to to

1057
00:46:12,620 --> 00:46:09,990
shrink down and what we call a molecular

1058
00:46:15,740 --> 00:46:12,630
cloud and eventually form a star but

1059
00:46:17,240 --> 00:46:15,750
most of the volume of the space in in

1060
00:46:19,250 --> 00:46:17,250
between stars is filled with this

1061
00:46:25,019 --> 00:46:19,260
diffuse material that has a temperature

1062
00:46:51,509 --> 00:46:50,399
Yeah right one oh yeah for intergalactic

1063
00:47:02,939 --> 00:46:51,519

that's right

1064
00:47:04,499 --> 00:47:02,949
yes so the reason you can talk about

1065
00:47:06,809 --> 00:47:04,509
temperature is you can measure the

1066
00:47:09,809 --> 00:47:06,819
temperature of an astronomical gas even

1067
00:47:11,370 --> 00:47:09,819
if the density is extremely low and we

1068
00:47:15,059 --> 00:47:11,380
have ways of measuring the temperature

1069
00:47:16,799 --> 00:47:15,069
by looking at the width of absorption

1070
00:47:18,870 --> 00:47:16,809
lines that come from these spectroscopy

1071
00:47:20,549 --> 00:47:18,880
experiments so if you look at one of

1072
00:47:23,759 --> 00:47:20,559
these lines like these hydrogen lines

1073
00:47:25,499 --> 00:47:23,769
and you look at how broad it is that

1074
00:47:28,439 --> 00:47:25,509
tells you what the temperature of the

1075
00:47:30,390 --> 00:47:28,449
gas is the hotter the the gas the the

1076
00:47:33,089 --> 00:47:30,400
broader the line that you'll see in your

1077
00:47:35,519 --> 00:47:33,099
spectrum is if a cloud is very cool you

1078
00:47:38,189 --> 00:47:35,529
get a very narrow component because

1079
00:47:40,649 --> 00:47:38,199
there isn't much motion of the atoms

1080
00:47:43,949 --> 00:47:40,659
that are giving you the absorption so we

1081
00:47:45,359 --> 00:47:43,959
make measurements that actually tell you

1082
00:47:47,009 --> 00:47:45,369
what that temperature is is a

1083
00:48:03,749 --> 00:47:47,019
measurement rather than some sort of

1084
00:48:06,390 --> 00:48:03,759
estimate well right so I see what you're

1085
00:48:08,370 --> 00:48:06,400
saying but you only have one per per

1086
00:48:10,229 --> 00:48:08,380
cubic meter or so but remember in a

1087
00:48:12,899 --> 00:48:10,239
Galactic space has a lot of cubic meters

1088
00:48:16,199 --> 00:48:12,909

so we can study a cloud that might have

1089
00:48:17,609 --> 00:48:16,209
a size of you know 10,000 light years or

1090
00:48:18,029 --> 00:48:17,619
something or a hundred thousand light

1091
00:48:19,949 --> 00:48:18,039
years

1092
00:48:22,019 --> 00:48:19,959
if you cut if you turn that into cubic

1093
00:48:24,029 --> 00:48:22,029
meters it's a big number so even though

1094
00:48:26,489 --> 00:48:24,039
there's not many per cubic meter we have

1095
00:48:27,929 --> 00:48:26,499
enough of them overall that we can still

1096
00:48:31,530 --> 00:48:27,939
get an estimate of what that temperature

1097
00:49:13,390 --> 00:48:47,590
sure yes right right that's another way

1098
00:49:16,870 --> 00:49:13,400
putting but but the densities are very

1099
00:49:20,140 --> 00:49:16,880
much lower than what we are used to here

1100
00:49:22,930 --> 00:49:20,150
in the there the Earth's atmosphere as a

1101
00:49:26,490 --> 00:49:22,940
local gas so the amount of heat you have

1102
00:49:40,990 --> 00:49:26,500
per cubic centimeter may be much lower

1103
00:49:43,120 --> 00:49:41,000
but that's okay but see okay

1104
00:49:45,400 --> 00:49:43,130
so temperature is not the same thing as

1105
00:49:48,400 --> 00:49:45,410
heat temperature is the degree of

1106
00:49:49,540 --> 00:49:48,410
hotness which is different from heat

1107
00:49:52,270 --> 00:49:49,550
because heat is to do with how much

1108
00:49:54,750 --> 00:49:52,280
energy you have in a given volume right

1109
00:50:10,140 --> 00:49:54,760
I think that's what you're gonna hear

1110
00:50:15,849 --> 00:50:12,999
that's a that's a very good question

1111
00:50:18,459 --> 00:50:15,859
the I can't tell you from an

1112
00:50:20,259 --> 00:50:18,469
observational point of view how much

1113
00:50:21,789 --> 00:50:20,269

dark matter is in that box what the

1114
00:50:23,679 --> 00:50:21,799
theorists can tell you the the people

1115
00:50:25,359 --> 00:50:23,689
who make the simulations is that in

1116
00:50:27,219 --> 00:50:25,369
their simulations the gas and the Dark

1117
00:50:29,709 --> 00:50:27,229
Matter sort of follows they follow each

1118
00:50:32,079 --> 00:50:29,719
other so this is a picture of what the

1119
00:50:33,579 --> 00:50:32,089
gas looks like you'll find similar

1120
00:50:35,679 --> 00:50:33,589
pictures of what the Dark Matter looks

1121
00:50:38,890 --> 00:50:35,689
like but because it's so hard to observe

1122
00:50:40,809 --> 00:50:38,900
we can't tell you very easily whether

1123
00:50:43,390 --> 00:50:40,819
that Dark Matter really does follow that

1124
00:50:45,929 --> 00:50:43,400
prediction so that's why I focused on

1125
00:50:55,630 --> 00:50:45,939
the gases that we can see the gas right

1126
00:51:00,789 --> 00:50:58,479
yes so the interstellar medium has has

1127
00:51:02,620 --> 00:51:00,799
regions that are neutral on a neutral

1128
00:51:05,829 --> 00:51:02,630
gas but it also has regions that are

1129
00:51:07,599 --> 00:51:05,839
ionized the the stuff you're seeing in

1130
00:51:10,479 --> 00:51:07,609
the hydrogen emission is neutral the

1131
00:51:13,179 --> 00:51:10,489
radio emitting gas that we see in the 21

1132
00:51:15,189 --> 00:51:13,189
centimeter a tracer the 21 centimeter

1133
00:51:17,140 --> 00:51:15,199
line that's neutral gas but there are

1134
00:51:34,779 --> 00:51:17,150
other regions of interstellar space that

1135
00:51:36,609 --> 00:51:34,789
are seeing plasma transitions too well

1136
00:51:39,969 --> 00:51:36,619
most of let me just be very clear most

1137
00:51:41,559 --> 00:51:39,979
of the normal matter which means I'm not

1138
00:51:44,199 --> 00:51:41,569

talking about dark matter or dark energy

1139
00:51:48,749 --> 00:51:44,209
which are two separate subjects but most

1140
00:51:52,509 --> 00:51:48,759
of the the matter that consists of atoms

1141
00:51:54,999 --> 00:51:52,519
the most of that would be would be in

1142
00:51:56,769 --> 00:51:55,009
plasma but the I don't have numbers for

1143
00:51:58,449 --> 00:51:56,779
the exact breakdown between gas and

1144
00:52:00,339 --> 00:51:58,459
plasma but the point I was making is

1145
00:52:02,019 --> 00:52:00,349
that the solids and the liquids are much

1146
00:52:13,800 --> 00:52:02,029
smaller in comparison to the gas in the

1147
00:52:17,340 --> 00:52:16,380
right that's right so I might have been

1148
00:52:19,080 --> 00:52:17,350
a little unclear about that see

1149
00:52:20,010 --> 00:52:19,090
sometimes people talk about plasma as a

1150
00:52:21,720 --> 00:52:20,020
type of gas

1151
00:52:24,240 --> 00:52:21,730
they'll call a plasma is an ionized gas

1152
00:52:26,790 --> 00:52:24,250
but now it's more common that you'll

1153
00:52:28,350 --> 00:52:26,800
hear just plasma and gas treated as two

1154
00:52:29,580 --> 00:52:28,360
separate states of matter I mean

1155
00:52:31,830 --> 00:52:29,590
historically there were only three

1156
00:52:34,950 --> 00:52:31,840
states of matter so plasma was kind of

1157
00:52:53,640 --> 00:52:34,960
tucked in with the gas yeah question

1158
00:52:57,720 --> 00:52:53,650
back there extreme was about look like

1159
00:53:07,010 --> 00:52:57,730
the extreme was about a conference of

1160
00:53:09,920 --> 00:53:07,020
the earth are you suggesting that no so

1161
00:53:14,130 --> 00:53:09,930
what what I'm doing is showing how much

1162
00:53:17,910 --> 00:53:14,140
how much space do they take up on on the

1163
00:53:21,480 --> 00:53:17,920

surface of a globe or on a map angly in

1164
00:53:24,030 --> 00:53:21,490
terms of angle right so so you can look

1165
00:53:25,860 --> 00:53:24,040
at what the what the surface of the

1166
00:53:27,750 --> 00:53:25,870
earth looks like on a projection like

1167
00:53:29,190 --> 00:53:27,760
this which shows you the continents we

1168
00:53:31,470 --> 00:53:29,200
can do the same thing in astronomy when

1169
00:53:33,600 --> 00:53:31,480
we study the galaxy and at new and many

1170
00:53:35,700 --> 00:53:33,610
different people do that when they look

1171
00:53:38,010 --> 00:53:35,710
at radio waves and microwaves is they

1172
00:53:41,100 --> 00:53:38,020
put things on this galactic coordinate

1173
00:53:43,800 --> 00:53:41,110
system so the the comparison I was just

1174
00:53:47,010 --> 00:53:43,810
simply making was if you had it you know

1175
00:53:49,320 --> 00:53:47,020
if you had a gas cloud that covered the

1176
00:53:51,810 --> 00:53:49,330
same fraction of the Earth's sky as this

1177
00:53:53,580 --> 00:53:51,820
thing does of the galaxy you know it

1178
00:53:57,260 --> 00:53:53,590
would come all the way down from this

1179
00:53:59,850 --> 00:53:57,270
continent across South Pole and up their

1180
00:54:12,890 --> 00:53:59,860
perspective yeah thanks and the yellow

1181
00:54:17,940 --> 00:54:12,900
shirt yeah huge marble with striation

1182
00:54:20,030 --> 00:54:17,950
colors of the colors so Jupiter has its

1183
00:54:22,800 --> 00:54:20,040
own weather patterns so it has

1184
00:54:24,900 --> 00:54:22,810
atmospheric circulation it's

1185
00:54:26,700 --> 00:54:24,910
rotating this energy that's associated

1186
00:54:28,290 --> 00:54:26,710
with the planet moving around it's been

1187
00:54:31,590 --> 00:54:28,300
accessed once every day it could be

1188
00:54:34,830 --> 00:54:31,600

Jupiter day and those weather patterns

1189
00:54:37,890 --> 00:54:34,840
give you these bands that you can see in

1190
00:54:41,190 --> 00:54:37,900
the in the colors of the Jupiter's

1191
00:54:42,840 --> 00:54:41,200
atmosphere so I mean even though it

1192
00:54:44,430 --> 00:54:42,850
doesn't have the solid surface the way

1193
00:54:45,870 --> 00:54:44,440
the planet Earth does it can still have

1194
00:54:59,580 --> 00:54:45,880
weather and that's what you're seeing

1195
00:55:01,050 --> 00:54:59,590
when you see those it's it's similar to

1196
00:55:02,790 --> 00:55:01,060
a star in the sense that it's a

1197
00:55:06,000 --> 00:55:02,800
spherical ball of gas the difference is

1198
00:55:17,210 --> 00:55:06,010
it's not producing its own energy in its

1199
00:55:19,800 --> 00:55:17,220
core it's opaque yes well there are

1200
00:55:22,590 --> 00:55:19,810
objects called brown dwarfs which are

1201
00:55:25,020 --> 00:55:22,600
failed stars they're stars that don't

1202
00:55:28,590 --> 00:55:25,030
have enough mass to ever get hot enough

1203
00:55:31,620 --> 00:55:28,600
in their cores to start burning hydrogen

1204
00:55:34,230 --> 00:55:31,630
and producing energy by a nuclear fusion

1205
00:55:35,970 --> 00:55:34,240
but Jupiter is is compared to the mass

1206
00:55:46,950 --> 00:55:35,980
of the Sun Jupiter is much much smaller

1207
00:55:48,720 --> 00:55:46,960
it's much less massive so yeah they have

1208
00:55:50,790 --> 00:55:48,730
right and they've described Jupiter as

1209
00:55:52,230 --> 00:55:50,800
the vacuum cleaner of the the solar

1210
00:55:54,420 --> 00:55:52,240
system because it's more massive than

1211
00:55:55,950 --> 00:55:54,430
the other planets and it sucks out

1212
00:56:04,270 --> 00:55:55,960
passings rocks

1213
00:56:11,089 --> 00:56:07,339

yes I so I haven't mentioned

1214
00:56:13,400 --> 00:56:11,099
interstellar dust dust is basically

1215
00:56:15,290 --> 00:56:13,410
small particles so when an astronomer

1216
00:56:16,580 --> 00:56:15,300
says dust you're not talking about atoms

1217
00:56:19,550 --> 00:56:16,590
or molecules you're talking about

1218
00:56:21,530 --> 00:56:19,560
microscopic dust grains that can have

1219
00:56:23,750 --> 00:56:21,540
different organic molecules in them they

1220
00:56:25,990 --> 00:56:23,760
can have silicon molecules and they

1221
00:56:28,609 --> 00:56:26,000
contain a very small amount of the mass

1222
00:56:31,220 --> 00:56:28,619
compared to the gas but they're still

1223
00:56:32,930 --> 00:56:31,230
important is the dust does things like

1224
00:56:34,849 --> 00:56:32,940
change the color of the star light

1225
00:56:36,710 --> 00:56:34,859
that's passing through it so it's an

1226
00:56:38,030 --> 00:56:36,720
important part of the space between the

1227
00:56:49,910 --> 00:56:38,040
stars even though it doesn't have much

1228
00:57:25,210 --> 00:56:49,920
of the category of well it would be

1229
00:57:41,589 --> 00:57:29,000
in the same reactor gravity we can

1230
00:57:50,180 --> 00:57:46,180
have you here as in heavier than iron so

1231
00:57:53,450 --> 00:57:50,190
there are other processes they called

1232
00:57:55,910 --> 00:57:53,460
nuclear synthesis and in stars where you

1233
00:57:59,240 --> 00:57:55,920
take you take a neutron and you keep

1234
00:58:01,130 --> 00:57:59,250
adding a neutron to each each atomic

1235
00:58:02,720 --> 00:58:01,140
nuclei so you go from iron to the

1236
00:58:05,930 --> 00:58:02,730
element which is 1 above iron and you

1237
00:58:07,730 --> 00:58:05,940
can build up heavier elements that way

1238
00:58:10,400 --> 00:58:07,740

it's called the this something called

1239
00:58:12,530 --> 00:58:10,410
our process for the rapid process where

1240
00:58:14,270 --> 00:58:12,540
you're building up elements one by one

1241
00:58:16,070 --> 00:58:14,280
starting from an iron atom and adding a

1242
00:58:18,570 --> 00:58:16,080
neutron each time

1243
00:58:21,210 --> 00:58:18,580
but again these are processes that are

1244
00:58:23,160 --> 00:58:21,220
thought to happen in the course of stars

1245
00:58:25,020 --> 00:58:23,170
where you need very high temperatures

1246
00:58:26,490 --> 00:58:25,030
and you need high densities so you

1247
00:58:30,000 --> 00:58:26,500
wouldn't ever see something like that in

1248
00:58:40,830 --> 00:58:30,010
the interstellar regions it has to be in

1249
00:58:42,540 --> 00:58:40,840
the course of stars yes the the type 1a

1250
00:58:45,450 --> 00:58:42,550
supernova in the binaries they can also

1251
00:58:48,800 --> 00:58:45,460
synthesize new elements yeah that's

1252
00:59:09,800 --> 00:58:48,810
right yeah yes

1253
00:59:14,310 --> 00:59:12,180
that's that's an excellent question and

1254
00:59:16,440 --> 00:59:14,320
the answer is the same as gravity so

1255
00:59:18,420 --> 00:59:16,450
what keeps this the gas in the Sun

1256
00:59:20,370 --> 00:59:18,430
confined is the gravity of the Sun is

1257
00:59:23,160 --> 00:59:20,380
the mass of the Sun pulling everything

1258
00:59:26,550 --> 00:59:23,170
together and what keeps the gas in the

1259
00:59:29,160 --> 00:59:26,560
disk of the Milky Way in that thin layer

1260
00:59:33,060 --> 00:59:29,170
is gravity because everything is falling

1261
00:59:47,750 --> 00:59:33,070
down towards the central plane of the of

1262
01:00:02,849 --> 00:59:55,910
gravitation explain the rate of rotation

1263
01:00:05,400 --> 01:00:02,859

that's right yeah discrepancy I'm not

1264
01:00:07,230 --> 01:00:05,410
sure if you look at the the height of

1265
01:00:12,270 --> 01:00:07,240
the radio emission from the Milky Way

1266
01:00:14,250 --> 01:00:12,280
whether you can explain that from normal

1267
01:00:16,050 --> 01:00:14,260
matter and the gravitational effect of

1268
01:00:17,849 --> 01:00:16,060
normal matter alone or whether you need

1269
01:00:18,960 --> 01:00:17,859
dark matter I'm not sure it might be

1270
01:00:20,460 --> 01:00:18,970
that you can do it with normal matter

1271
01:00:23,280 --> 01:00:20,470
because it's close to the plane of the

1272
01:00:24,960 --> 01:00:23,290
galaxy the dark matter seems to be more

1273
01:00:27,030 --> 01:00:24,970
extended it goes out towards the outer

1274
01:00:27,410 --> 01:00:27,040
regions so you need to be out there to

1275
01:00:29,059 --> 01:00:27,420
see the

1276
01:00:54,650 --> 01:00:29,069
I saw that but I'm not I'm not

1277
01:00:57,020 --> 01:00:54,660
absolutely sure okay well atmospheres of

1278
01:00:59,809 --> 01:00:57,030
planets certainly do change that's it

1279
01:01:01,910 --> 01:00:59,819
we know that's happened we can see that

1280
01:01:03,440 --> 01:01:01,920
the atmosphere of Mars used to be very

1281
01:01:05,530 --> 01:01:03,450
different than it is now but the

1282
01:01:09,950 --> 01:01:05,540
evidence for water on Mars and different

1283
01:01:11,870 --> 01:01:09,960
you know different forms so atmospheres

1284
01:01:13,760 --> 01:01:11,880
can change but they can't but they tend

1285
01:01:18,579 --> 01:01:13,770
to change on on very long timescales

1286
01:01:20,450 --> 01:01:18,589
compared to human timescales right so

1287
01:01:34,640 --> 01:01:20,460
probably not something we have to worry

1288
01:01:36,470 --> 01:01:34,650

about that's it yes yes well when I say

1289
01:01:39,589 --> 01:01:36,480
hydrogen burning I mean the way that a

1290
01:01:44,059 --> 01:01:39,599
star like the Sun produces energy is it

1291
01:01:46,520 --> 01:01:44,069
takes hydrogen nuclei protons and it

1292
01:01:48,770 --> 01:01:46,530
fuses them together combines them and

1293
01:01:51,500 --> 01:01:48,780
when you do that you make helium right

1294
01:01:56,180 --> 01:01:51,510
so yes so it doesn't involve oxygen

1295
01:01:59,950 --> 01:01:56,190
it's just hydrogen and yeah now there is

1296
01:02:02,960 --> 01:01:59,960
now there are other there are other

1297
01:02:05,299 --> 01:02:02,970
nuclear reaction pathways that do

1298
01:02:07,130 --> 01:02:05,309
involve oxygen the the one that I just

1299
01:02:09,770 --> 01:02:07,140
talked about is called the proton-proton

1300
01:02:11,349 --> 01:02:09,780
chain that is based on hydrogen there

1301
01:02:14,539 --> 01:02:11,359
are other ones that do involve oxygen

1302
01:02:16,309 --> 01:02:14,549
but the it depends on how mass of the

1303
01:02:22,190 --> 01:02:16,319
star is as to which of these pathways

1304
01:02:29,400 --> 01:02:24,779
yes it would be yeah this fusion

1305
01:02:32,160 --> 01:02:29,410
reactions yeah yeah yeah in the

1306
01:02:35,700 --> 01:02:32,170
announcement yesterday the discovery I

1307
01:02:42,089 --> 01:02:35,710
think it's called kepler-10c the mega

1308
01:02:45,109 --> 01:02:42,099
planet the company store at least in the

1309
01:02:51,029 --> 01:02:45,119
post this morning described the Sun a

1310
01:02:52,859 --> 01:02:51,039
yellow dwarf if the Sun is a yellow

1311
01:02:54,930 --> 01:02:52,869
dwarf I mean obviously there's some

1312
01:02:58,380 --> 01:02:54,940
order of magnitude here what would be

1313
01:03:01,109 --> 01:02:58,390

the next larger magnitudes of other

1314
01:03:04,049 --> 01:03:01,119
stars obviously as an implication that

1315
01:03:09,170 --> 01:03:04,059
there are larger stars or Suns yeah our

1316
01:03:13,470 --> 01:03:09,180
Sun so how would you describe them as

1317
01:03:15,870 --> 01:03:13,480
well I mean I guess you can call this a

1318
01:03:18,890 --> 01:03:15,880
star like the Sun a yellow dwarf because

1319
01:03:21,210 --> 01:03:18,900
I mean the the color of the Sun that the

1320
01:03:23,970 --> 01:03:21,220
the wavelength where it emits most of

1321
01:03:27,450 --> 01:03:23,980
its light is is yellow right as you go

1322
01:03:28,890 --> 01:03:27,460
to more massive stars they become hotter

1323
01:03:31,170 --> 01:03:28,900
and when something gets hotter the

1324
01:03:34,769 --> 01:03:31,180
colors change so you head up a scale

1325
01:03:36,569 --> 01:03:34,779
where you go towards bluer stars so if

1326
01:03:38,370 --> 01:03:36,579
and then if you go down to the other way

1327
01:03:40,230 --> 01:03:38,380
you go down to less massive stars than

1328
01:03:42,150 --> 01:03:40,240
the Sun you go down to so-called red

1329
01:03:44,039 --> 01:03:42,160
dwarfs because they're cooler and they

1330
01:03:45,870 --> 01:03:44,049
emit red radiation instead of yellow

1331
01:03:47,609 --> 01:03:45,880
radiation so if you hear a red dwarf

1332
01:03:49,650 --> 01:03:47,619
it's smaller than the Sun if you hear a

1333
01:03:53,759 --> 01:03:49,660
brown dwarf those are the fail stars we

1334
01:03:55,920 --> 01:03:53,769
mentioned before that are too low in

1335
01:04:07,200 --> 01:03:55,930
mass to ever get any nuclear reactions

1336
01:04:10,230 --> 01:04:07,210
going at all well if they form a

1337
01:04:12,180 --> 01:04:10,240
spherical object that you can see people

1338
01:04:14,400 --> 01:04:12,190

will call it a star and the dwarf is the

1339
01:04:17,009 --> 01:04:14,410
smallest type of star if it doesn't form

1340
01:04:25,650 --> 01:04:17,019
a star then it wouldn't be called one so

1341
01:04:30,630 --> 01:04:29,039
that that neutrons will be added to

1342
01:04:38,670 --> 01:04:30,640
actual formation of the different

1343
01:04:40,740 --> 01:04:38,680
elements yes

1344
01:04:43,799 --> 01:04:40,750
so that's a very good point you you add

1345
01:04:45,720 --> 01:04:43,809
a neutron and then depending on what the

1346
01:04:48,450 --> 01:04:45,730
half-life of the newly synthesized

1347
01:04:51,029 --> 01:04:48,460
nuclei is it can data decay to a

1348
01:04:54,000 --> 01:04:51,039
different nuclei and then if that one

1349
01:04:56,130 --> 01:04:54,010
adds a neutron you can you can start a

1350
01:04:58,230 --> 01:04:56,140
new pathway going up from there so

1351
01:05:00,539 --> 01:04:58,240
you're right the the beta decay where an

1352
01:05:01,859 --> 01:05:00,549
electron is released is a very important

1353
01:05:26,279 --> 01:05:01,869
part of that too it's not just the

1354
01:05:30,109 --> 01:05:26,289
addition of nuclear yes I I can try to

1355
01:05:32,430 --> 01:05:30,119
so that's that's a big subject so they

1356
01:05:36,029 --> 01:05:32,440
there's this experiment at the South

1357
01:05:40,470 --> 01:05:36,039
Pole called the bicep experiment where

1358
01:05:42,660 --> 01:05:40,480
they looked for polarization of the

1359
01:05:44,010 --> 01:05:42,670
microwave background I talked about the

1360
01:05:46,950 --> 01:05:44,020
microwave background quickly in this

1361
01:05:48,720 --> 01:05:46,960
talk they found that for the further for

1362
01:05:52,260 --> 01:05:48,730
the first time a particular type of

1363
01:05:55,620 --> 01:05:52,270

polarization signal in that microwave

1364
01:05:59,160 --> 01:05:55,630
radiation and that polarization signal

1365
01:06:01,470 --> 01:05:59,170
is exactly what you expect if you're

1366
01:06:03,089 --> 01:06:01,480
seeing the signature of what's called

1367
01:06:04,230 --> 01:06:03,099
inflation inflation is something that

1368
01:06:06,029 --> 01:06:04,240
happen very soon after the Big Bang

1369
01:06:08,430 --> 01:06:06,039
where the universe went from being very

1370
01:06:10,620 --> 01:06:08,440
small to very big and it left a certain

1371
01:06:12,809 --> 01:06:10,630
signal in the microwave background which

1372
01:06:15,900 --> 01:06:12,819
they're claiming they detected now since

1373
01:06:17,640 --> 01:06:15,910
that announcement there are people that

1374
01:06:20,220 --> 01:06:17,650
have claimed that the signal they're

1375
01:06:22,589 --> 01:06:20,230
seeing maybe some somewhat contaminated

1376
01:06:25,230 --> 01:06:22,599
by dust particles in our in the

1377
01:06:28,950 --> 01:06:25,240
foreground and in the Milky Way I think

1378
01:06:32,760 --> 01:06:28,960
that question is not a hundred percent

1379
01:06:34,920 --> 01:06:32,770
resolved people on the bicep2 team may

1380
01:06:35,940 --> 01:06:34,930
still claim that their results are valid

1381
01:06:41,030 --> 01:06:35,950
whether or not

1382
01:06:43,710 --> 01:06:41,040
there is dust there or not but I think

1383
01:06:45,510 --> 01:06:43,720
we're waiting for the latest dust maps

1384
01:06:47,520 --> 01:06:45,520
to come out where people have looked at

1385
01:06:50,790 --> 01:06:47,530
these four grounds and could very

1386
01:06:52,710 --> 01:06:50,800
carefully map how they change with

1387
01:06:54,900 --> 01:06:52,720
position and then after those there's

1388
01:07:03,589 --> 01:06:54,910

updated dust maps come out then see if

1389
01:07:11,400 --> 01:07:09,630
yes so dust grains can they can change

1390
01:07:12,810 --> 01:07:11,410
the color or starlight passing through

1391
01:07:14,250 --> 01:07:12,820
them or any form of light passing

1392
01:07:16,530 --> 01:07:14,260
through them and they can change the

1393
01:07:18,390 --> 01:07:16,540
polarization of light passing through

1394
01:07:59,940 --> 01:07:18,400
them too so they are something that had

1395
01:08:01,950 --> 01:07:59,950
to be understood right so when they do

1396
01:08:04,500 --> 01:08:01,960
polarization measurements they have to

1397
01:08:08,520 --> 01:08:04,510
use more than one frequency because if

1398
01:08:11,460 --> 01:08:08,530
you have more than one then you can you

1399
01:08:27,260 --> 01:08:11,470
you can figure out what the actual the

1400
01:08:27,270 --> 01:08:30,950
okay

1401
01:08:30,960 --> 01:08:38,960
yeah going to the experiments

1402
01:08:47,180 --> 01:08:42,270
spectrum are you looking at the gas

1403
01:08:54,059 --> 01:08:47,190
through teasing out the redshift effects

1404
01:08:59,940 --> 01:08:54,069
yes you're getting the closer gas and

1405
01:09:02,849 --> 01:08:59,950
the further gas that's exactly right and

1406
01:09:06,170 --> 01:09:02,859
I didn't go into detail on that just for

1407
01:09:10,740 --> 01:09:06,180
reasons of time but if I put this quasar

1408
01:09:13,680 --> 01:09:10,750
absorption line slide up again let's

1409
01:09:16,559 --> 01:09:13,690
assume that this light this line that's

1410
01:09:17,940 --> 01:09:16,569
being absorbed is the hydrogen line then

1411
01:09:19,770 --> 01:09:17,950
the only difference between these three

1412
01:09:22,440 --> 01:09:19,780
clouds is how far star they moving away

1413
01:09:23,940 --> 01:09:22,450

from you so this one is the most distant

1414
01:09:26,280 --> 01:09:23,950
that means it's going to have the

1415
01:09:28,829 --> 01:09:26,290
highest redshift so the lion appears

1416
01:09:31,320 --> 01:09:28,839
closest to the red and then this cloud

1417
01:09:32,789 --> 01:09:31,330
is less distant it gives you a line that

1418
01:09:34,710 --> 01:09:32,799
is here in the yellow part of the

1419
01:09:36,630 --> 01:09:34,720
spectrum whereas the cloud that is

1420
01:09:37,920 --> 01:09:36,640
closest to the earth and gives you a

1421
01:09:47,099 --> 01:09:37,930
line that is in the blue part of the

1422
01:09:49,320 --> 01:09:47,109
spectrum mostly but they do have metals

1423
01:09:51,630 --> 01:09:49,330
in them too modem say metals in the

1424
01:09:53,400 --> 01:09:51,640
sense of heavier elements now this is a

1425
01:09:55,950 --> 01:09:53,410
simplification in that I'm just showing

1426
01:09:58,200 --> 01:09:55,960
one line hydrogen has more than one line

1427
01:09:59,820 --> 01:09:58,210
has whole series of lines but having

1428
01:10:03,150 --> 01:09:59,830
that pattern of lines helps you to

1429
01:10:05,820 --> 01:10:03,160
identify which red shift something comes

1430
01:10:08,700 --> 01:10:05,830
from so you have many you have many

1431
01:10:10,530 --> 01:10:08,710
different fingerprints that you use to

1432
01:10:12,360 --> 01:10:10,540
identify the chemical elements and how

1433
01:10:14,010 --> 01:10:12,370
far the clouds are moving away from you

1434
01:10:16,470 --> 01:10:14,020
so this is a simplification where I've

1435
01:10:18,600 --> 01:10:16,480
got one element and one line real clouds

1436
01:10:22,080 --> 01:10:18,610
have lots of elements with lots of lines

1437
01:10:31,020 --> 01:10:22,090
giving you complicated spectra that you

1438
01:10:33,240 --> 01:10:31,030

need well if you look at one of these

1439
01:10:36,810 --> 01:10:33,250
this is a lyman-alpha forest spectrum

1440
01:10:38,970 --> 01:10:36,820
probably something like 5050 lines there

1441
01:10:40,530 --> 01:10:38,980
and that's just in this and this is only

1442
01:10:42,840 --> 01:10:40,540
a small portion of the spectrum that I'm

1443
01:10:44,940 --> 01:10:42,850
showing in the here in the rest frame

1444
01:10:47,010 --> 01:10:44,950
ultraviolet so you dependence on the way

1445
01:10:49,080 --> 01:10:47,020
you're looking there's huge numbers of

1446
01:10:50,910 --> 01:10:49,090
lines you can look at in the infrared in