

1  
00:00:08,330 --> 00:00:12,629  
okay seeing as how it's right about

2  
00:00:11,009 --> 00:00:15,710  
eight o'clock and I think we're all set

3  
00:00:12,630 --> 00:00:20,160  
ready to go the broadcast everything so

4  
00:00:15,710 --> 00:00:24,868  
good evening welcome to the hubble space

5  
00:00:20,160 --> 00:00:27,140  
telescope public lecture series can you

6  
00:00:24,868 --> 00:00:27,140  
hear me

7  
00:00:27,868 --> 00:00:32,729  
my name is volt lavae I'm filling in as

8  
00:00:30,689 --> 00:00:37,020  
you may have realized I'm not Frank

9  
00:00:32,729 --> 00:00:38,849  
summers unusual host tonight there's a

10  
00:00:37,020 --> 00:00:41,969  
big meeting this astronomy meeting going

11  
00:00:38,850 --> 00:00:43,950  
on this week in Boston American

12  
00:00:41,969 --> 00:00:47,250  
Astronomical Society so a lot of people

13  
00:00:43,950 --> 00:00:48,750  
from here or up there and Frank asked me

14  
00:00:47,250 --> 00:00:50,670  
to fill in sand some one of the few

15  
00:00:48,750 --> 00:00:55,789  
remaining people here at the Institute

16  
00:00:50,670 --> 00:00:58,260  
this week so anyway we'll get started as

17  
00:00:55,789 --> 00:01:00,329  
usual

18  
00:00:58,259 --> 00:01:02,968  
I'll introduce the speaker in a few

19  
00:01:00,329 --> 00:01:07,379  
moments have some introductory material

20  
00:01:02,969 --> 00:01:10,760  
here first of all the next couple of

21  
00:01:07,379 --> 00:01:15,419  
lectures as you can see July will have

22  
00:01:10,760 --> 00:01:20,240  
Andrea Vanzetti from right here talking

23  
00:01:15,420 --> 00:01:20,240  
about building new worlds in planetarium

24  
00:01:20,780 --> 00:01:26,430  
will have Jennifer Locke's also from the

25  
00:01:24,000 --> 00:01:28,109  
Institute talking about the frontier

26  
00:01:26,430 --> 00:01:32,159  
fields which is an exciting new project

27  
00:01:28,109 --> 00:01:38,599  
just getting started with a sneak peek

28  
00:01:32,159 --> 00:01:38,600  
at the first ability of the my name is

29

00:01:45,349 --> 00:01:51,809  
trying to be meaning going on this week

30  
00:01:48,328 --> 00:01:53,849  
in Boston you can sign up for email

31  
00:01:51,810 --> 00:01:57,359  
notifications for this lecture and for

32  
00:01:53,849 --> 00:01:59,309  
some other topics if you send a note to

33  
00:01:57,359 --> 00:02:02,459  
that to the email address you see up

34  
00:01:59,310 --> 00:02:04,490  
there we promise we won't spam you but

35  
00:02:02,459 --> 00:02:07,549  
we will send you

36  
00:02:04,489 --> 00:02:11,150  
interesting stuff related to these sorts

37  
00:02:07,549 --> 00:02:13,400  
of these sorts of events and

38  
00:02:11,150 --> 00:02:14,990  
unfortunately I've been told that the

39  
00:02:13,400 --> 00:02:15,590  
weather may be kind of iffy later on

40  
00:02:14,990 --> 00:02:19,010  
tonight

41  
00:02:15,590 --> 00:02:20,569  
so whereas usually the observatory

42  
00:02:19,009 --> 00:02:23,199  
across the street at Johns Hopkins at

43  
00:02:20,569 --> 00:02:25,729

the Maryland Space Grant Observatory

44

00:02:23,199 --> 00:02:28,250

they usually open up for observing after

45

00:02:25,729 --> 00:02:30,399

the talk tonight they decided not to

46

00:02:28,250 --> 00:02:33,110

open up because there's chance of some

47

00:02:30,400 --> 00:02:35,349

stormy weather in the area so I'm sorry

48

00:02:33,110 --> 00:02:35,350

about that

49

00:02:35,439 --> 00:02:43,090

and just Frank wanted me to just give a

50

00:02:40,009 --> 00:02:45,649

couple of news notes from recent

51

00:02:43,090 --> 00:02:48,680

exciting events from the world of

52

00:02:45,650 --> 00:02:54,140

astronomy one of the more exciting

53

00:02:48,680 --> 00:03:00,069

things we've done lately it's not about

54

00:02:54,139 --> 00:03:04,519

the kids reading the spot here refers to

55

00:03:00,069 --> 00:03:05,930

the Great Red Spot on Jupiter Jupiter of

56

00:03:04,520 --> 00:03:07,640

course is one of the planets in our

57

00:03:05,930 --> 00:03:09,739

solar system it's the largest planet in

58  
00:03:07,639 --> 00:03:11,599  
our solar system

59  
00:03:09,739 --> 00:03:16,129  
and it has this feature on it called the

60  
00:03:11,599 --> 00:03:18,319  
Great Red Spot this this image is from

61  
00:03:16,129 --> 00:03:22,879  
the Voyager spacecraft which flew by

62  
00:03:18,319 --> 00:03:24,799  
Jupiter back way back in 1979 and took

63  
00:03:22,879 --> 00:03:27,489  
this fabulous image of the Great Red

64  
00:03:24,799 --> 00:03:30,680  
Spot and a lot of other stuff going on

65  
00:03:27,489 --> 00:03:34,310  
so for for a little bit of context

66  
00:03:30,680 --> 00:03:35,780  
here's an image of the earth to scale

67  
00:03:34,310 --> 00:03:37,969  
with the Great Red Spot and that might

68  
00:03:35,780 --> 00:03:41,090  
give you some idea of how great this

69  
00:03:37,969 --> 00:03:43,189  
Great Red Spot is the name is kind of a

70  
00:03:41,090 --> 00:03:46,610  
fanciful name Great Red Spot well it's

71  
00:03:43,189 --> 00:03:48,409  
great because it's large as you can see

72  
00:03:46,610 --> 00:03:50,810  
it's larger than the earth

73  
00:03:48,409 --> 00:03:53,479  
where's Jupiter is much larger in the

74  
00:03:50,810 --> 00:03:55,189  
earth it's about 11 times diameter of

75  
00:03:53,479 --> 00:03:57,738  
the earth so about a thousand earths

76  
00:03:55,189 --> 00:04:00,379  
could fit inside Jupiter if you could

77  
00:03:57,739 --> 00:04:03,079  
fit things inside of junior Jupiter of

78  
00:04:00,379 --> 00:04:05,209  
course is almost all gas and hey that's

79  
00:04:03,079 --> 00:04:06,290  
a great topic for the night our speaker

80  
00:04:05,209 --> 00:04:09,349  
will be talking about gas in the

81  
00:04:06,289 --> 00:04:10,699  
universe but Jupiter is a gaseous planet

82  
00:04:09,349 --> 00:04:14,060  
so it's almost tired

83  
00:04:10,699 --> 00:04:16,488  
what you see in the atmosphere is all

84  
00:04:14,060 --> 00:04:18,410  
and the spirit features clouds weather

85  
00:04:16,488 --> 00:04:21,219  
just like we have on America this is a

86

00:04:18,410 --> 00:04:23,780  
very violent storm that's been raging in

87  
00:04:21,220 --> 00:04:26,590  
Jupiter's atmosphere for a long time in

88  
00:04:23,779 --> 00:04:29,329  
fact it's been observed as far back as

89  
00:04:26,589 --> 00:04:30,739  
three or four hundred years ago this is

90  
00:04:29,329 --> 00:04:37,550  
a drawing by the famous astronomer

91  
00:04:30,740 --> 00:04:40,730  
Cassini done in 1677 and it made that

92  
00:04:37,550 --> 00:04:42,439  
black spot on there is probably the

93  
00:04:40,730 --> 00:04:47,470  
great red spot so we think it's been

94  
00:04:42,439 --> 00:04:51,219  
around at least that long more recently

95  
00:04:47,470 --> 00:04:54,380  
of course people have been observing it

96  
00:04:51,220 --> 00:04:56,150  
Jupiter a lot and in particularly the

97  
00:04:54,379 --> 00:04:59,839  
red spots been pretty continuously

98  
00:04:56,149 --> 00:05:01,939  
monitored for about 150 years during

99  
00:04:59,839 --> 00:05:08,629  
most that time it remained pretty much

100  
00:05:01,939 --> 00:05:10,009

the same very recently in about 2012 a

101

00:05:08,629 --> 00:05:13,790

lot of amateur astronomers that were

102

00:05:10,009 --> 00:05:16,610

observing Jupiter noticed that the red

103

00:05:13,790 --> 00:05:18,590

spot seems to be getting smaller and

104

00:05:16,610 --> 00:05:22,220

actually it's been observed to be

105

00:05:18,589 --> 00:05:24,469

shrinking gradually over the last quite

106

00:05:22,220 --> 00:05:27,440

a while but recently that that shrinkage

107

00:05:24,470 --> 00:05:29,150

has seemed accelerated and it's

108

00:05:27,439 --> 00:05:30,978

shrinking and it's also changing its

109

00:05:29,149 --> 00:05:33,829

shape so the shrinkage is mostly along

110

00:05:30,978 --> 00:05:35,689

the long dimension there so it's

111

00:05:33,829 --> 00:05:37,969

becoming rounder as you can see in this

112

00:05:35,689 --> 00:05:40,668

series of images these are very recent

113

00:05:37,970 --> 00:05:42,770

images from Hubble the whole disk of

114

00:05:40,668 --> 00:05:46,519

Jupiter with the beautiful red spot

115  
00:05:42,769 --> 00:05:50,478  
taken in April 21st and then these other

116  
00:05:46,519 --> 00:05:55,159  
images are other images that Hubble took

117  
00:05:50,478 --> 00:05:56,750  
from 1995 2000 and 2009 and you can

118  
00:05:55,160 --> 00:05:59,450  
pretty clearly see that the spot is

119  
00:05:56,750 --> 00:06:02,870  
indeed getting smaller now the question

120  
00:05:59,449 --> 00:06:04,579  
of course is why is it doing this and

121  
00:06:02,870 --> 00:06:07,699  
unfortunately the answer is nobody

122  
00:06:04,579 --> 00:06:12,629  
really knows most of the experts don't

123  
00:06:07,699 --> 00:06:15,310  
really have an explanation any Simon who

124  
00:06:12,629 --> 00:06:17,949  
astronomer who was leading the Hubble

125  
00:06:15,310 --> 00:06:20,199  
observations has speculated that it may

126  
00:06:17,949 --> 00:06:24,399  
have something to do with the very

127  
00:06:20,199 --> 00:06:26,560  
turbulent material around here and

128  
00:06:24,399 --> 00:06:29,620  
little Eddie's may be interacting with

129  
00:06:26,560 --> 00:06:32,259  
edges of the red spot and causing some

130  
00:06:29,620 --> 00:06:33,819  
strange stuff to go on but he's really

131  
00:06:32,259 --> 00:06:36,789  
sure so this is a kind of an interesting

132  
00:06:33,819 --> 00:06:39,099  
area where people are still doing very

133  
00:06:36,790 --> 00:06:41,319  
actively trying to figure out what's

134  
00:06:39,100 --> 00:06:43,930  
going on you know in a place like this

135  
00:06:41,319 --> 00:06:46,089  
it's very close to us I mean Jupiter in

136  
00:06:43,930 --> 00:06:48,040  
the cosmic sense is is just in our

137  
00:06:46,089 --> 00:06:48,969  
backyard so it's kind of interesting

138  
00:06:48,040 --> 00:06:51,040  
that we don't know everything there is

139  
00:06:48,970 --> 00:06:53,410  
to know about Jupiter and the weather on

140  
00:06:51,040 --> 00:06:56,620  
Jupiter yet so that was a kind of

141  
00:06:53,410 --> 00:07:00,010  
interesting thing that came up not too

142  
00:06:56,620 --> 00:07:03,639  
long ago so without further ado further

143

00:07:00,009 --> 00:07:08,168  
ado I'd like to introduce our talk

144  
00:07:03,639 --> 00:07:09,990  
tonight so gaseous states a matter play

145  
00:07:08,168 --> 00:07:12,430  
a prominent role throughout the universe

146  
00:07:09,990 --> 00:07:14,650  
I'm not to mention in our everyday lives

147  
00:07:12,430 --> 00:07:17,500  
we breathe the air around the sphere all

148  
00:07:14,649 --> 00:07:19,539  
the time it's a gas from the atmospheres

149  
00:07:17,500 --> 00:07:21,509  
of planets and stars the vast expanses

150  
00:07:19,540 --> 00:07:23,830  
of interstellar and intergalactic space

151  
00:07:21,509 --> 00:07:25,659  
gas clouds are also critical to the

152  
00:07:23,829 --> 00:07:29,289  
formation and development of stars and

153  
00:07:25,660 --> 00:07:32,229  
the life cycle of galaxies tonight dr.

154  
00:07:29,290 --> 00:07:34,270  
Andrew Fox will describe observations of

155  
00:07:32,228 --> 00:07:36,789  
light emitted by in these various

156  
00:07:34,269 --> 00:07:38,799  
environments which is our only source of

157  
00:07:36,790 --> 00:07:45,490

information for most of our knowledge of

158

00:07:38,800 --> 00:07:47,560

the universe dr. Andrew Fox is on the

159

00:07:45,490 --> 00:07:49,900

staff here at Space Telescope Science

160

00:07:47,560 --> 00:07:52,079

Institute he received his PhD from the

161

00:07:49,899 --> 00:07:55,689

University of Wisconsin at Madison in

162

00:07:52,079 --> 00:07:58,740

2005 before joining STS C eyes and eat

163

00:07:55,689 --> 00:08:02,050

as a European Space Agency astronomer in

164

00:07:58,740 --> 00:08:05,889

2011 he held postdoctoral fellowships in

165

00:08:02,050 --> 00:08:09,280

Paris Santiago and Cambridge UK

166

00:08:05,889 --> 00:08:10,930

Cambridge I assume he's interested in

167

00:08:09,279 --> 00:08:13,000

the mechanics by which galaxies feed

168

00:08:10,930 --> 00:08:16,090

their star formation in particular in

169

00:08:13,000 --> 00:08:19,829

the Milky Way our own galaxy where these

170

00:08:16,089 --> 00:08:19,829

processes can be viewed in great detail

171

00:08:27,990 --> 00:08:33,310

okay thank you salt and it's a pleasure

172  
00:08:30,970 --> 00:08:35,680  
to be here and I see so many people out

173  
00:08:33,309 --> 00:08:38,098  
there in the audience this is going to

174  
00:08:35,679 --> 00:08:40,899  
be a talk about the gaseous universe and

175  
00:08:38,099 --> 00:08:43,150  
the idea here is to do a tour of

176  
00:08:40,899 --> 00:08:45,340  
different places that we can observe

177  
00:08:43,149 --> 00:08:47,529  
with our telescopes and to show to you

178  
00:08:45,340 --> 00:08:49,810  
the gaseous matter the same kinds of gas

179  
00:08:47,529 --> 00:08:51,789  
that we can observe in the lab and in

180  
00:08:49,809 --> 00:08:54,029  
the atmosphere of the earth are also

181  
00:08:51,789 --> 00:08:58,059  
seen in other places in the universe and

182  
00:08:54,029 --> 00:09:01,089  
the knowledge that we have of gases here

183  
00:08:58,059 --> 00:09:03,219  
on planet Earth is vital for us to

184  
00:09:01,090 --> 00:09:05,950  
understand the gases that we observe in

185  
00:09:03,220 --> 00:09:08,019  
many many different places in astronomy

186  
00:09:05,950 --> 00:09:10,900  
so I want to start with some very basic

187  
00:09:08,019 --> 00:09:12,669  
ideas about what gas is when you think

188  
00:09:10,899 --> 00:09:16,240  
of gas you might think of the natural

189  
00:09:12,669 --> 00:09:18,009  
gas that comes out of your stove top you

190  
00:09:16,240 --> 00:09:20,590  
might think about how expensive it is to

191  
00:09:18,009 --> 00:09:21,970  
fill up your car at the pump but of

192  
00:09:20,590 --> 00:09:24,160  
course this kind of gas that's short for

193  
00:09:21,970 --> 00:09:27,360  
gasoline and that's a liquid that's not

194  
00:09:24,159 --> 00:09:30,909  
really the gas that we mean in the

195  
00:09:27,360 --> 00:09:33,940  
scientific sense of the word so as you

196  
00:09:30,909 --> 00:09:34,990  
may remember there are several basic

197  
00:09:33,940 --> 00:09:36,790  
states of matter

198  
00:09:34,990 --> 00:09:39,789  
we're often taught that there are three

199  
00:09:36,789 --> 00:09:41,230  
solids liquids and gases in fact

200

00:09:39,789 --> 00:09:43,209  
nowadays it's more common you'll see

201  
00:09:41,230 --> 00:09:46,240  
people talk about four phases of matter

202  
00:09:43,210 --> 00:09:48,389  
with plasma which is an ionized form of

203  
00:09:46,240 --> 00:09:52,000  
gas where the atoms have been split into

204  
00:09:48,389 --> 00:09:54,850  
nuclei and electrons now plasma is

205  
00:09:52,000 --> 00:09:58,120  
treated as a separate category so as you

206  
00:09:54,850 --> 00:10:00,670  
go from from solids to across to plasma

207  
00:09:58,120 --> 00:10:02,620  
in this in this representation the idea

208  
00:10:00,669 --> 00:10:05,519  
with solids is you have a material that

209  
00:10:02,620 --> 00:10:08,470  
has a fixed volume in and fixed shape a

210  
00:10:05,519 --> 00:10:10,509  
liquid has a fixed volume but its shape

211  
00:10:08,470 --> 00:10:13,090  
will change depending on what container

212  
00:10:10,509 --> 00:10:14,950  
it's in whereas a gas has no fixed

213  
00:10:13,090 --> 00:10:17,560  
volume or no fixed shape it will just

214  
00:10:14,950 --> 00:10:20,379

fill whatever container that it's in now

215

00:10:17,559 --> 00:10:22,269

when it comes to gases in astronomy we

216

00:10:20,379 --> 00:10:24,129

have some pretty big containers and the

217

00:10:22,269 --> 00:10:25,750

Milky Way the halo of the Milky Way the

218

00:10:24,129 --> 00:10:28,899

space between galaxies these are

219

00:10:25,750 --> 00:10:30,429

enormous volumes so gases fill enormous

220

00:10:28,899 --> 00:10:31,419

volumes of space and that's something

221

00:10:30,429 --> 00:10:34,049

I'm going to be coming back to

222

00:10:31,419 --> 00:10:37,059

throughout this talk

223

00:10:34,049 --> 00:10:38,679

matter changes between these phases by

224

00:10:37,059 --> 00:10:40,119

the addition of heat so something gets

225

00:10:38,679 --> 00:10:41,769

hotter and hotter you'll go from solid

226

00:10:40,120 --> 00:10:43,839

to liquid to gas and eventually to

227

00:10:41,769 --> 00:10:45,879

plasma and plasma is where you've

228

00:10:43,839 --> 00:10:47,800

injected so much heat into the matter

229

00:10:45,879 --> 00:10:50,740

that the the electrons are no longer

230

00:10:47,799 --> 00:10:52,149

bound to the nuclei of those atoms and

231

00:10:50,740 --> 00:11:00,028

we're going to come across plasma in

232

00:10:52,149 --> 00:11:03,549

many places in this talk so one of the

233

00:11:00,028 --> 00:11:05,350

reasons that gases is worth studying as

234

00:11:03,549 --> 00:11:07,659

we see in many different places it's

235

00:11:05,350 --> 00:11:11,470

also very well understood from the point

236

00:11:07,659 --> 00:11:15,039

of view of physics we understand how and

237

00:11:11,470 --> 00:11:17,050

why gas emits radiation and how and why

238

00:11:15,039 --> 00:11:19,419

gas absorbs radiation we can study these

239

00:11:17,049 --> 00:11:21,758

things in the lab and so we can see the

240

00:11:19,419 --> 00:11:25,088

same processes happening in astronomy

241

00:11:21,759 --> 00:11:26,620

and it's not just a science that you can

242

00:11:25,089 --> 00:11:28,810

do at visible wavelengths that your eye

243  
00:11:26,620 --> 00:11:31,000  
can see you can study gases all across

244  
00:11:28,809 --> 00:11:34,239  
the spectrum using x-rays and using

245  
00:11:31,000 --> 00:11:35,649  
radio waves and microwaves and many

246  
00:11:34,240 --> 00:11:38,889  
different wavelengths that are a part of

247  
00:11:35,649 --> 00:11:40,389  
the toolkit of modern astronomy you

248  
00:11:38,889 --> 00:11:43,539  
might wonder why do I have in a picture

249  
00:11:40,389 --> 00:11:47,860  
of a neon sign up here so a neon sign is

250  
00:11:43,539 --> 00:11:51,219  
a good example of a case where a certain

251  
00:11:47,860 --> 00:11:53,589  
type of atom a neon atom is excited by

252  
00:11:51,220 --> 00:11:56,879  
an injecting energy into it and it emits

253  
00:11:53,589 --> 00:11:59,110  
radiation at a very particular

254  
00:11:56,879 --> 00:12:01,509  
wavelength or frequency and that's the

255  
00:11:59,110 --> 00:12:03,970  
wavelength corresponding to red light so

256  
00:12:01,509 --> 00:12:07,449  
the parallel with astronomy here is that

257

00:12:03,970 --> 00:12:10,180  
we can use the colors of light emitted

258  
00:12:07,448 --> 00:12:12,188  
from different places in the universe to

259  
00:12:10,179 --> 00:12:14,888  
identify which chemical elements are

260  
00:12:12,188 --> 00:12:16,929  
present just like the red of a neon sign

261  
00:12:14,889 --> 00:12:21,120  
tells you something about what chemical

262  
00:12:16,929 --> 00:12:23,349  
elements are present inside it one other

263  
00:12:21,120 --> 00:12:26,049  
saying you might have heard of this

264  
00:12:23,350 --> 00:12:28,569  
nature abhors a vacuum this is first

265  
00:12:26,049 --> 00:12:31,659  
attributed to Aristotle the philosopher

266  
00:12:28,568 --> 00:12:33,490  
the basic idea that people have when

267  
00:12:31,659 --> 00:12:36,730  
they apply this is the reason that you

268  
00:12:33,490 --> 00:12:39,068  
won't find a complete vacuum in physics

269  
00:12:36,730 --> 00:12:40,629  
is that if you had a region of space

270  
00:12:39,068 --> 00:12:43,269  
that didn't have any atoms or molecules

271  
00:12:40,629 --> 00:12:45,019

in it then whatever was next to it would

272

00:12:43,269 --> 00:12:46,759  
just simply diffuse over and

273

00:12:45,019 --> 00:12:48,799  
those particles would spread into it and

274

00:12:46,759 --> 00:12:52,639  
fill that region and that physical

275

00:12:48,799 --> 00:12:55,789  
principle is basically very valid to

276

00:12:52,639 --> 00:12:56,899  
astronomy just as it is here on earth so

277

00:12:55,789 --> 00:13:00,889  
let's start in the Earth's atmosphere

278

00:12:56,899 --> 00:13:06,139  
this is a great place where we we know

279

00:13:00,889 --> 00:13:07,580  
about gas most of the molecules in the

280

00:13:06,139 --> 00:13:09,139  
Earth's atmosphere are either nitrogen

281

00:13:07,580 --> 00:13:11,570  
or oxygen there's a little bit of argon

282

00:13:09,139 --> 00:13:13,250  
carbon dioxide air the atmosphere is

283

00:13:11,570 --> 00:13:16,850  
actually pretty thin it's only about a

284

00:13:13,250 --> 00:13:19,279  
hundred kilometers thick depending on

285

00:13:16,850 --> 00:13:20,840  
exactly how you define it but just for

286  
00:13:19,279 --> 00:13:23,000  
comparison the radius of the earth is

287  
00:13:20,840 --> 00:13:25,310  
about six thousand kilometers you just

288  
00:13:23,000 --> 00:13:27,320  
have this thin 100 kilometer layer of

289  
00:13:25,309 --> 00:13:29,629  
gas on the surface of it of course

290  
00:13:27,320 --> 00:13:31,640  
that's vital for life on Earth our

291  
00:13:29,629 --> 00:13:33,500  
oxygen we breathe is in that atmosphere

292  
00:13:31,639 --> 00:13:35,090  
there's a tiny amount of ozone that's

293  
00:13:33,500 --> 00:13:37,100  
the oh three at the end of that list

294  
00:13:35,090 --> 00:13:39,259  
that ozone is also very important for us

295  
00:13:37,100 --> 00:13:42,740  
because it blocks some of the harmful UV

296  
00:13:39,259 --> 00:13:46,519  
radiation from the Sun so the atmosphere

297  
00:13:42,740 --> 00:13:48,950  
is a critical part of a of a planet like

298  
00:13:46,519 --> 00:13:51,769  
our own now salt already showed you

299  
00:13:48,950 --> 00:13:54,440  
what's been happening recently in the

300  
00:13:51,769 --> 00:13:58,759  
atmosphere of Jupiter this gas giant

301  
00:13:54,440 --> 00:14:02,090  
planet in our own solar system this is a

302  
00:13:58,759 --> 00:14:03,889  
planet like Saturn and Uranus and

303  
00:14:02,090 --> 00:14:06,500  
Neptune that has no solid surface it's

304  
00:14:03,889 --> 00:14:09,370  
pure gas at least all the way down to

305  
00:14:06,500 --> 00:14:09,370  
perhaps its core

306  
00:14:09,700 --> 00:14:14,330  
the composition of the atmosphere of

307  
00:14:12,320 --> 00:14:17,240  
Jupiter there is different from the

308  
00:14:14,330 --> 00:14:19,580  
atmosphere of the of the earth here most

309  
00:14:17,240 --> 00:14:21,080  
of their atoms that are the particles

310  
00:14:19,580 --> 00:14:23,090  
that exist are hydrogen and helium

311  
00:14:21,080 --> 00:14:26,509  
there's little bits of methane and

312  
00:14:23,090 --> 00:14:28,250  
ammonia and these the different

313  
00:14:26,509 --> 00:14:30,590  
compositions of the elements in the

314

00:14:28,250 --> 00:14:31,970  
different planets actually go help to

315  
00:14:30,590 --> 00:14:36,139  
explain the different colors for example

316  
00:14:31,970 --> 00:14:39,440  
of Neptune and Saturn versus Jupiter but

317  
00:14:36,139 --> 00:14:40,970  
this is the same series of pictures

318  
00:14:39,440 --> 00:14:42,080  
showing you the shrinking great red spot

319  
00:14:40,970 --> 00:14:44,960  
which has left a lot of people

320  
00:14:42,080 --> 00:14:47,590  
scratching their heads recently well

321  
00:14:44,960 --> 00:14:51,440  
let's go outside the solar system to

322  
00:14:47,590 --> 00:14:53,690  
another planet that was observed with

323  
00:14:51,440 --> 00:14:56,390  
the Hubble Space Telescope and this is

324  
00:14:53,690 --> 00:14:58,880  
the planet called HD 209 four five eight

325  
00:14:56,389 --> 00:15:03,529  
B if you're really interested

326  
00:14:58,879 --> 00:15:05,419  
that means it's the 209458 star in the

327  
00:15:03,529 --> 00:15:07,490  
catalog of Henry Draper his initials

328  
00:15:05,419 --> 00:15:09,740

were HD and he was a famous astronomer

329

00:15:07,490 --> 00:15:11,269

who catalogued this enormous list of

330

00:15:09,740 --> 00:15:12,799

stars so that people could come and

331

00:15:11,269 --> 00:15:18,289

identify them and find where they are in

332

00:15:12,799 --> 00:15:20,240

the sky so this is a star that happens

333

00:15:18,289 --> 00:15:22,370

to have a planet going around it and

334

00:15:20,240 --> 00:15:23,930

when that planet moves in front of the

335

00:15:22,370 --> 00:15:26,210

face of the star which is called a

336

00:15:23,929 --> 00:15:28,609

transit two very interesting things

337

00:15:26,210 --> 00:15:31,310

happen first of all you block some of

338

00:15:28,610 --> 00:15:33,980

the light from the star so that the

339

00:15:31,309 --> 00:15:38,209

brightness of that Stars radiation goes

340

00:15:33,980 --> 00:15:41,180

down and secondly because that planet

341

00:15:38,210 --> 00:15:42,920

has an atmosphere you not only block the

342

00:15:41,179 --> 00:15:46,609

light from the star you also absorb very

343  
00:15:42,919 --> 00:15:49,490  
specific wavelengths of light and that

344  
00:15:46,610 --> 00:15:51,500  
tells you about what chemicals exist in

345  
00:15:49,490 --> 00:15:53,120  
the atmosphere of that planet and it

346  
00:15:51,500 --> 00:15:55,279  
turns out that when they studied the the

347  
00:15:53,120 --> 00:15:57,110  
light that had passed through the

348  
00:15:55,279 --> 00:16:00,289  
atmosphere of that planet they found the

349  
00:15:57,110 --> 00:16:02,570  
signature of hydrogen gas that was in

350  
00:16:00,289 --> 00:16:06,139  
the atmosphere of that planet this was

351  
00:16:02,570 --> 00:16:07,640  
the first planetary atmosphere outside

352  
00:16:06,139 --> 00:16:10,129  
our solar system

353  
00:16:07,639 --> 00:16:11,809  
we call that an exoplanet atmosphere

354  
00:16:10,129 --> 00:16:13,789  
discovered by the Hubble Space Telescope

355  
00:16:11,809 --> 00:16:15,529  
this is an artist's impression no one

356  
00:16:13,789 --> 00:16:17,089  
has is able to take a you know

357  
00:16:15,529 --> 00:16:20,659  
high-resolution image of what it looks

358  
00:16:17,090 --> 00:16:23,000  
like but it's using a technique called

359  
00:16:20,659 --> 00:16:24,649  
spectroscopy where you take the light

360  
00:16:23,000 --> 00:16:25,759  
from from a star and you split it up

361  
00:16:24,649 --> 00:16:27,230  
into different colors and then you

362  
00:16:25,759 --> 00:16:28,850  
analyze how much light there is are

363  
00:16:27,230 --> 00:16:30,889  
different colors that's how you can do

364  
00:16:28,850 --> 00:16:35,440  
this and you can figure out what is the

365  
00:16:30,889 --> 00:16:38,720  
actual composition of the the atmosphere

366  
00:16:35,440 --> 00:16:41,200  
now as I've already said I mean gas is

367  
00:16:38,720 --> 00:16:43,370  
everywhere in astronomy one place that's

368  
00:16:41,200 --> 00:16:47,150  
often thought about when people talk

369  
00:16:43,370 --> 00:16:51,830  
about gaseous clouds is in so-called

370  
00:16:47,149 --> 00:16:53,179  
nebulae nebulae are very attractive

371

00:16:51,830 --> 00:16:55,310  
objects there are a lot of images that

372  
00:16:53,179 --> 00:16:56,629  
have been taken for example with the

373  
00:16:55,309 --> 00:16:58,939  
Hubble telescope of these types of

374  
00:16:56,629 --> 00:17:00,950  
objects and they're basically big clouds

375  
00:16:58,940 --> 00:17:03,890  
of gas that exists between the stars and

376  
00:17:00,950 --> 00:17:06,049  
galaxies and these clouds are the places

377  
00:17:03,889 --> 00:17:08,180  
where new stars are formed and there are

378  
00:17:06,049 --> 00:17:09,579  
also places where stars release their

379  
00:17:08,180 --> 00:17:11,799  
elements when the stars get

380  
00:17:09,579 --> 00:17:13,750  
the end of their lifetime so on the left

381  
00:17:11,799 --> 00:17:17,019  
here this is a famous nebula called the

382  
00:17:13,750 --> 00:17:18,970  
butterfly nebula that's actually a type

383  
00:17:17,019 --> 00:17:20,440  
of nebula a planetary nebula which is

384  
00:17:18,970 --> 00:17:22,930  
what happens to where star at the end of

385  
00:17:20,440 --> 00:17:24,640

its life on the right this is a very

386

00:17:22,930 --> 00:17:26,380

famous image from the Hubble telescope

387

00:17:24,640 --> 00:17:28,870

called the mystic mountain

388

00:17:26,380 --> 00:17:30,610

this is a star-forming nebula where we

389

00:17:28,869 --> 00:17:33,309

can see new stars being formed out of

390

00:17:30,609 --> 00:17:35,139

that gas this was released on the 20th

391

00:17:33,309 --> 00:17:37,659

anniversary of the of the Hubble Space

392

00:17:35,140 --> 00:17:39,460

Telescope but there's a very close link

393

00:17:37,660 --> 00:17:41,590

between the gas and the stars that form

394

00:17:39,460 --> 00:17:42,910

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

395

00:17:41,589 --> 00:17:47,769

going to come back to throughout

396

00:17:42,910 --> 00:17:50,860

throughout this now sometimes you hear

397

00:17:47,769 --> 00:17:54,730

people say that galaxies are basically

398

00:17:50,859 --> 00:17:57,579

made of stars and gas well the thing is

399

00:17:54,730 --> 00:18:00,130

is that stars themselves are gaseous

400  
00:17:57,579 --> 00:18:02,199  
objects what what is a star will the

401  
00:18:00,130 --> 00:18:04,990  
star is to a very good approximation a

402  
00:18:02,200 --> 00:18:07,750  
spherical ball of plasma which is an

403  
00:18:04,990 --> 00:18:09,490  
ionized gas that's held together because

404  
00:18:07,750 --> 00:18:12,160  
gravity is pulling it in towards the

405  
00:18:09,490 --> 00:18:13,990  
center and gas pressure the pressure of

406  
00:18:12,160 --> 00:18:18,640  
all the particles in the gas is holding

407  
00:18:13,990 --> 00:18:20,740  
it up so stars are in some ways similar

408  
00:18:18,640 --> 00:18:22,330  
to the gas that's in nebulae in between

409  
00:18:20,740 --> 00:18:23,470  
stars it's still gas that's there it

410  
00:18:22,329 --> 00:18:27,659  
just happens to have a very different

411  
00:18:23,470 --> 00:18:30,579  
temperature and a very different density

412  
00:18:27,660 --> 00:18:32,740  
so in addition to all the stars that we

413  
00:18:30,579 --> 00:18:34,329  
have in a galaxy in the Milky Way there

414  
00:18:32,740 --> 00:18:36,849  
are something like a hundred billion or

415  
00:18:34,329 --> 00:18:39,220  
so there's a lot of gas that exists

416  
00:18:36,849 --> 00:18:40,779  
between the stars and I'm not just

417  
00:18:39,220 --> 00:18:42,759  
talking about the nebulae that I showed

418  
00:18:40,779 --> 00:18:45,910  
you already I'm talking about a very

419  
00:18:42,759 --> 00:18:47,529  
widespread diffuse layer of gas that

420  
00:18:45,910 --> 00:18:50,019  
exists everywhere in the disk of our

421  
00:18:47,529 --> 00:18:52,569  
galaxy in the plane of our galaxy and

422  
00:18:50,019 --> 00:18:55,799  
the reason we know there is gas there is

423  
00:18:52,569 --> 00:18:59,710  
from observations at radio wavelengths

424  
00:18:55,799 --> 00:19:03,399  
so this is a map of the entire sky taken

425  
00:18:59,710 --> 00:19:04,900  
at a wavelength of 21 centimeters so if

426  
00:19:03,400 --> 00:19:06,430  
you have a radio telescope and you look

427  
00:19:04,900 --> 00:19:08,800  
at a wavelength of 21 centimeters you

428

00:19:06,430 --> 00:19:11,320  
make an all-sky map this is what you

429  
00:19:08,799 --> 00:19:13,750  
find you have you find this narrow strip

430  
00:19:11,319 --> 00:19:15,929  
of a mission right along the center of

431  
00:19:13,750 --> 00:19:18,819  
the map there and then it's much fainter

432  
00:19:15,930 --> 00:19:21,190  
above and below and that's telling you

433  
00:19:18,819 --> 00:19:23,529  
that everywhere throughout the galaxy

434  
00:19:21,190 --> 00:19:26,279  
between stars there is a gap

435  
00:19:23,529 --> 00:19:28,990  
a neutral hydrogen gas and that gas is

436  
00:19:26,279 --> 00:19:31,809  
emitting these radio waves that we can

437  
00:19:28,990 --> 00:19:35,529  
we can use to measure how extended that

438  
00:19:31,809 --> 00:19:37,389  
gas is so now I want to show you a

439  
00:19:35,529 --> 00:19:39,339  
couple of numbers just to give you a

440  
00:19:37,390 --> 00:19:41,500  
feel of how these different places

441  
00:19:39,339 --> 00:19:45,490  
compare when we stack them against each

442  
00:19:41,500 --> 00:19:47,619

other now if you want to describe a gas

443

00:19:45,490 --> 00:19:50,259

if there are two numbers the dent the

444

00:19:47,619 --> 00:19:52,000

density and the temperature that tell

445

00:19:50,259 --> 00:19:53,379

you a lot about what's happening the

446

00:19:52,000 --> 00:19:55,150

temperature of course is how hot

447

00:19:53,380 --> 00:19:57,180

something is and the density is a

448

00:19:55,150 --> 00:20:00,400

measure of how many particles you have

449

00:19:57,180 --> 00:20:02,740

per unit volume so we often do that per

450

00:20:00,400 --> 00:20:04,780

cubic centimeter okay how many particles

451

00:20:02,740 --> 00:20:07,390

do you have in each cubic centimeter of

452

00:20:04,779 --> 00:20:10,420

space now if you start in the atmosphere

453

00:20:07,390 --> 00:20:12,910

of the earth just take a point at sea

454

00:20:10,420 --> 00:20:16,240

level typical temperature of course it

455

00:20:12,910 --> 00:20:17,890

varies but on average if it's say 62

456

00:20:16,240 --> 00:20:20,470

degrees Fahrenheit that corresponds to

457  
00:20:17,890 --> 00:20:24,610  
290 Kelvin which is the temperature

458  
00:20:20,470 --> 00:20:29,500  
scale we use in astronomy if you look at

459  
00:20:24,609 --> 00:20:31,209  
the density of one the density of air in

460  
00:20:29,500 --> 00:20:33,490  
the Earth's atmosphere okay you find

461  
00:20:31,210 --> 00:20:36,220  
that one cubic centimeter of air

462  
00:20:33,490 --> 00:20:38,230  
contains something like five times 10 to

463  
00:20:36,220 --> 00:20:41,589  
the 19 particles mostly nitrogen

464  
00:20:38,230 --> 00:20:43,930  
molecules that's 50 billion billion

465  
00:20:41,589 --> 00:20:46,149  
particles all right and one cubic

466  
00:20:43,930 --> 00:20:48,310  
centimeter is about the volume under the

467  
00:20:46,150 --> 00:20:49,870  
tip of your thumb so it's amazing to

468  
00:20:48,309 --> 00:20:51,549  
think even though air it seems like it

469  
00:20:49,869 --> 00:20:54,099  
doesn't really have much in it that

470  
00:20:51,549 --> 00:20:55,720  
region of the air which has the same

471  
00:20:54,099 --> 00:20:58,740  
volume as the tip of your thumb it

472  
00:20:55,720 --> 00:21:03,490  
contains about 50 billion billion

473  
00:20:58,740 --> 00:21:05,640  
particles what happens if you go to the

474  
00:21:03,490 --> 00:21:11,620  
surface of the Sun that's much hotter

475  
00:21:05,640 --> 00:21:14,320  
almost 6,000 degrees Kelvin and it turns

476  
00:21:11,619 --> 00:21:16,839  
out the density there it's only known

477  
00:21:14,319 --> 00:21:19,960  
kind of approximately but it's several

478  
00:21:16,839 --> 00:21:22,059  
orders of magnitude several times lower

479  
00:21:19,960 --> 00:21:23,559  
than it is in the Earth's atmosphere but

480  
00:21:22,059 --> 00:21:26,279  
if you were to go to the core of the Sun

481  
00:21:23,559 --> 00:21:29,619  
where energy is being produced by

482  
00:21:26,279 --> 00:21:32,889  
nuclear fusion reactions the temperature

483  
00:21:29,619 --> 00:21:35,829  
is an enormous 15 million degrees and a

484  
00:21:32,890 --> 00:21:37,330  
density is as high as 10 of the 26 now

485

00:21:35,829 --> 00:21:39,490  
these are all gases or

486  
00:21:37,329 --> 00:21:41,439  
asthma's but you can just see the huge

487  
00:21:39,490 --> 00:21:44,799  
variety you get between the different

488  
00:21:41,440 --> 00:21:47,140  
places we can add a couple more lines to

489  
00:21:44,799 --> 00:21:49,269  
this table if we go to interstellar

490  
00:21:47,140 --> 00:21:51,880  
space I showed you that radio emission

491  
00:21:49,269 --> 00:21:53,650  
from the interstellar space there the

492  
00:21:51,880 --> 00:21:57,160  
temperature is pretty warm it's about

493  
00:21:53,650 --> 00:22:01,120  
10,000 Kelvin but the average density is

494  
00:21:57,160 --> 00:22:03,160  
about one you have one particle per

495  
00:22:01,119 --> 00:22:06,699  
cubic centimeter of interstellar space

496  
00:22:03,160 --> 00:22:08,440  
on average in our galaxy so then what's

497  
00:22:06,700 --> 00:22:11,259  
the difference between a gas in a star

498  
00:22:08,440 --> 00:22:18,039  
and the gas in interstellar space is

499  
00:22:11,259 --> 00:22:21,250

it's 26 orders of magnitude so it's it's

500

00:22:18,039 --> 00:22:23,279

you know one with 26 zeros after it

501

00:22:21,250 --> 00:22:26,829

now if you go to the intergalactic space

502

00:22:23,279 --> 00:22:29,440

between galaxies the densities are

503

00:22:26,829 --> 00:22:30,819

several orders of magnitude lower still

504

00:22:29,440 --> 00:22:32,980

even though the temperature is about the

505

00:22:30,819 --> 00:22:34,569

same so we see this enormous range in

506

00:22:32,980 --> 00:22:37,319

what the density of gases is in

507

00:22:34,569 --> 00:22:42,089

different places of the universe okay

508

00:22:37,319 --> 00:22:46,990

the next thing I want to talk about is

509

00:22:42,089 --> 00:22:50,319

our own Milky Way this is a picture of

510

00:22:46,990 --> 00:22:54,220

the center of the Milky Way those of you

511

00:22:50,319 --> 00:22:56,889

who are amateur astronomers will know

512

00:22:54,220 --> 00:22:58,240

this is in Sagittarius what you're

513

00:22:56,890 --> 00:23:01,180

seeing when you look at the center of

514  
00:22:58,240 --> 00:23:03,279  
the Milky Way is all the stars that are

515  
00:23:01,180 --> 00:23:05,320  
unresolved we can hardly separate them

516  
00:23:03,279 --> 00:23:07,480  
they form this white glow in the

517  
00:23:05,319 --> 00:23:10,720  
background and then on top of that you

518  
00:23:07,480 --> 00:23:12,339  
have the dust lanes the brown clouds

519  
00:23:10,720 --> 00:23:18,190  
that block the light from the stars

520  
00:23:12,339 --> 00:23:19,779  
behind it turns out that beyond the

521  
00:23:18,190 --> 00:23:21,160  
Milky Way there's so many three galaxies

522  
00:23:19,779 --> 00:23:21,990  
that you can actually observe with the

523  
00:23:21,160 --> 00:23:25,330  
naked eye

524  
00:23:21,990 --> 00:23:28,059  
two of them are the so called Magellanic

525  
00:23:25,329 --> 00:23:29,859  
Clouds the Large Magellanic Cloud which

526  
00:23:28,059 --> 00:23:32,799  
is in the top right of this image and

527  
00:23:29,859 --> 00:23:35,469  
the small Magellanic Cloud that is down

528  
00:23:32,799 --> 00:23:37,210  
here and this is an optical view so this

529  
00:23:35,470 --> 00:23:39,759  
is the what you see if you look at the

530  
00:23:37,210 --> 00:23:43,569  
Magellanic Clouds with the visible light

531  
00:23:39,759 --> 00:23:46,240  
okay now the Magellanic Clouds were

532  
00:23:43,569 --> 00:23:50,230  
named after the famous explorer

533  
00:23:46,240 --> 00:23:51,480  
Ferdinand Magellan who is well known for

534  
00:23:50,230 --> 00:23:53,529  
leading the first

535  
00:23:51,480 --> 00:23:54,669  
circumnavigation of the earth in fact in

536  
00:23:53,529 --> 00:23:57,428  
a few years we're going to come up on

537  
00:23:54,669 --> 00:23:59,380  
the 500th anniversary of that journey

538  
00:23:57,429 --> 00:24:02,890  
around the earth he didn't make it all

539  
00:23:59,380 --> 00:24:04,419  
the way around he actually died in the

540  
00:24:02,890 --> 00:24:06,549  
Philippines before he got back to Europe

541  
00:24:04,419 --> 00:24:10,480  
but then the rest of his crew continued

542

00:24:06,548 --> 00:24:12,369  
the tour and brought his ship back back

543  
00:24:10,480 --> 00:24:16,569  
home but the Magellanic Clouds were

544  
00:24:12,369 --> 00:24:17,349  
named after him and the name is stark

545  
00:24:16,569 --> 00:24:20,230  
ever since

546  
00:24:17,349 --> 00:24:22,839  
now compared to the Milky Way these

547  
00:24:20,230 --> 00:24:24,610  
clouds are pretty small

548  
00:24:22,839 --> 00:24:26,558  
I mentioned the Milky Way has about a

549  
00:24:24,609 --> 00:24:27,819  
hundred billion stars the Large

550  
00:24:26,558 --> 00:24:30,279  
Magellanic Cloud has something like

551  
00:24:27,819 --> 00:24:32,439  
three billion and the small Magellanic

552  
00:24:30,279 --> 00:24:34,389  
Cloud has 300 million in terms of

553  
00:24:32,440 --> 00:24:37,058  
distances may be familiar with

554  
00:24:34,390 --> 00:24:38,679  
lightyears how how many years have taken

555  
00:24:37,058 --> 00:24:41,079  
the light to travel to us from those

556  
00:24:38,679 --> 00:24:43,030

galaxies you're talking about a hundred

557

00:24:41,079 --> 00:24:44,500

and sixty thousand or so for the Large

558

00:24:43,029 --> 00:24:46,658

Magellanic Cloud almost two hundred

559

00:24:44,500 --> 00:24:49,480

thousand for the small Magellanic Cloud

560

00:24:46,659 --> 00:24:51,100

those numbers look huge but in terms of

561

00:24:49,480 --> 00:24:52,390

how far away most galaxies are these are

562

00:24:51,099 --> 00:24:57,308

really close by these are in our

563

00:24:52,390 --> 00:24:59,740

backyard now what happens if you look at

564

00:24:57,308 --> 00:25:01,569

these objects with different wavelengths

565

00:24:59,740 --> 00:25:03,159

so let's say we take a radio telescope

566

00:25:01,569 --> 00:25:05,470

this is actually an array of radio

567

00:25:03,159 --> 00:25:08,200

telescopes I'm down in Australia

568

00:25:05,470 --> 00:25:10,269

Australia telescope compact array if you

569

00:25:08,200 --> 00:25:12,038

look at the Magellanic Clouds with

570

00:25:10,269 --> 00:25:14,440

something like that you're going to see

571  
00:25:12,038 --> 00:25:16,390  
a very different picture this is an idea

572  
00:25:14,440 --> 00:25:18,940  
of what the gas in the Magellanic Cloud

573  
00:25:16,390 --> 00:25:22,419  
the Large Magellanic Cloud the LMC looks

574  
00:25:18,940 --> 00:25:24,519  
like in radio emission you can see all

575  
00:25:22,419 --> 00:25:27,669  
this very detailed structure all these

576  
00:25:24,519 --> 00:25:30,069  
clumps all these gaps in the gas and the

577  
00:25:27,669 --> 00:25:33,490  
this is the brightest parts where there

578  
00:25:30,069 --> 00:25:34,808  
are the highest concentrations of gas

579  
00:25:33,490 --> 00:25:38,019  
that's where you're going to get new

580  
00:25:34,808 --> 00:25:39,759  
stars forming now there's another thing

581  
00:25:38,019 --> 00:25:42,639  
you can do which is you can say well

582  
00:25:39,759 --> 00:25:45,730  
let's put the radio emission on the same

583  
00:25:42,640 --> 00:25:47,200  
scale as this map so instead of using

584  
00:25:45,730 --> 00:25:48,940  
optical light I'm just going to put the

585  
00:25:47,200 --> 00:25:51,009  
exact same region of the sky and show

586  
00:25:48,940 --> 00:25:54,360  
what does the radio light look like when

587  
00:25:51,009 --> 00:25:57,460  
you do that this is what it looks like

588  
00:25:54,359 --> 00:26:00,038  
the really neat thing here is that the

589  
00:25:57,460 --> 00:26:02,740  
the gas that you see in the radio

590  
00:26:00,038 --> 00:26:04,539  
emission actually covers much more space

591  
00:26:02,740 --> 00:26:05,829  
than the stars do

592  
00:26:04,539 --> 00:26:08,230  
right so if I go back to the star as

593  
00:26:05,829 --> 00:26:10,599  
quickly they're much more confined the

594  
00:26:08,230 --> 00:26:13,269  
gas is more extended and there's even a

595  
00:26:10,599 --> 00:26:16,299  
bridge of gas between the two Magellanic

596  
00:26:13,269 --> 00:26:18,250  
Clouds they're connected so there's a

597  
00:26:16,299 --> 00:26:19,240  
common envelope of material between them

598  
00:26:18,250 --> 00:26:20,980  
and you wouldn't have known anything

599

00:26:19,240 --> 00:26:25,539  
about that if you hadn't been able to

600  
00:26:20,980 --> 00:26:28,150  
look at radio wavelengths that's called

601  
00:26:25,539 --> 00:26:30,399  
the Magellanic bridge now not only is

602  
00:26:28,150 --> 00:26:32,560  
there this envelope between the clouds

603  
00:26:30,400 --> 00:26:35,590  
it turns out that there's a huge stream

604  
00:26:32,559 --> 00:26:37,419  
of gas behind the Magellanic Clouds as

605  
00:26:35,589 --> 00:26:39,309  
they orbit the Milky Way because these

606  
00:26:37,420 --> 00:26:41,950  
two galaxies are falling around the

607  
00:26:39,309 --> 00:26:43,659  
Milky Way they're in there they're in

608  
00:26:41,950 --> 00:26:46,029  
the gravitational field of our own Milky

609  
00:26:43,660 --> 00:26:48,430  
Way galaxy and as they come in towards

610  
00:26:46,029 --> 00:26:50,649  
the Milky Way they're producing a huge

611  
00:26:48,430 --> 00:26:54,279  
stream of gas which is called the

612  
00:26:50,650 --> 00:26:57,730  
Magellanic stream now this is another

613  
00:26:54,279 --> 00:26:59,440

all-sky map where you've got the the

614

00:26:57,730 --> 00:27:01,930

disk of the Milky Way along the center

615

00:26:59,440 --> 00:27:03,610

so along the equator the white glow that

616

00:27:01,930 --> 00:27:06,519

you can see there is the Starlight from

617

00:27:03,609 --> 00:27:08,679

our own galaxy this is where the

618

00:27:06,519 --> 00:27:10,690

Magellanic Clouds are over here the SMC

619

00:27:08,680 --> 00:27:13,180

and the LMC for the small and a large

620

00:27:10,690 --> 00:27:16,000

and what we see in radio light is this

621

00:27:13,180 --> 00:27:17,920

enormous tail of material that comes all

622

00:27:16,000 --> 00:27:19,539

the way down through the South Pole and

623

00:27:17,920 --> 00:27:22,509

up to the other side of the galaxy and

624

00:27:19,539 --> 00:27:25,420

it also continues up in front of the of

625

00:27:22,509 --> 00:27:27,789

the clouds now just to give you an idea

626

00:27:25,420 --> 00:27:29,560

of how big that is I can put the

627

00:27:27,789 --> 00:27:32,710

continents of the earth on the same

628  
00:27:29,559 --> 00:27:34,419  
scale because we measure longitude and

629  
00:27:32,710 --> 00:27:37,690  
latitude to measure where things are on

630  
00:27:34,420 --> 00:27:39,279  
a map on the surface of our planet in

631  
00:27:37,690 --> 00:27:41,019  
astronomy we do the same thing for the

632  
00:27:39,279 --> 00:27:45,009  
galaxy we have Galactic longitude and

633  
00:27:41,019 --> 00:27:47,170  
Galactic latitude why am I doing this

634  
00:27:45,009 --> 00:27:50,170  
I'm just showing you how there is an

635  
00:27:47,170 --> 00:27:54,940  
enormous stream of gas that covers about

636  
00:27:50,170 --> 00:27:56,830  
half of the of the entire sky you can

637  
00:27:54,940 --> 00:27:58,059  
see if you compare it to where the

638  
00:27:56,829 --> 00:28:00,129  
contents are you've got the Magellanic

639  
00:27:58,059 --> 00:28:02,190  
Clouds down there in the Indian Ocean

640  
00:28:00,130 --> 00:28:04,690  
somewhere and this dream comes through

641  
00:28:02,190 --> 00:28:06,519  
and talked to her and all the way up the

642  
00:28:04,690 --> 00:28:08,160  
coast of South America it's it's

643  
00:28:06,519 --> 00:28:10,900  
enormous

644  
00:28:08,160 --> 00:28:13,150  
if you were to look outside of our

645  
00:28:10,900 --> 00:28:15,130  
galaxy and look back towards us

646  
00:28:13,150 --> 00:28:16,720  
you might see something like this you've

647  
00:28:15,130 --> 00:28:18,290  
got the two Magellanic Clouds shown

648  
00:28:16,720 --> 00:28:21,089  
there that

649  
00:28:18,289 --> 00:28:23,460  
losing huge amounts of gas and this

650  
00:28:21,089 --> 00:28:26,639  
Magellanic stream is just extending

651  
00:28:23,460 --> 00:28:28,829  
behind them as I said they're responding

652  
00:28:26,640 --> 00:28:30,120  
to the gravity of the Milky Way what's

653  
00:28:28,829 --> 00:28:32,220  
going to happen to all this gases

654  
00:28:30,119 --> 00:28:33,569  
eventually it will be able to accumulate

655  
00:28:32,220 --> 00:28:35,160  
and fall onto the Milky Way

656

00:28:33,569 --> 00:28:37,139  
so the Milky Way is the big winner in

657  
00:28:35,160 --> 00:28:39,210  
all of this these two little dwarf

658  
00:28:37,140 --> 00:28:41,070  
galaxies are being stripped of the gas

659  
00:28:39,210 --> 00:28:42,930  
that they have and that gas is going to

660  
00:28:41,069 --> 00:28:46,429  
end up coming into our own galaxy where

661  
00:28:42,930 --> 00:28:49,560  
it may eventually be able to form stars

662  
00:28:46,430 --> 00:28:51,600  
let's move out a little bit further I

663  
00:28:49,559 --> 00:28:53,159  
mentioned there are only three objects

664  
00:28:51,599 --> 00:28:55,259  
you can see with the naked eye outside

665  
00:28:53,160 --> 00:28:57,660  
the Milky Way and two of them with

666  
00:28:55,259 --> 00:29:00,990  
Magellanic Clouds the third is Andromeda

667  
00:28:57,660 --> 00:29:02,820  
at the great Andromeda galaxy I'm

668  
00:29:00,990 --> 00:29:04,890  
showing the full moon there for scale

669  
00:29:02,819 --> 00:29:07,559  
the full moon is about half a degree

670  
00:29:04,890 --> 00:29:10,410

across you can see that this thing is

671

00:29:07,559 --> 00:29:12,119

this galaxy is is is huge several

672

00:29:10,410 --> 00:29:13,529

degrees although with the naked eye you

673

00:29:12,119 --> 00:29:15,809

won't see anything like that this

674

00:29:13,529 --> 00:29:19,049

obviously needs a big telescope to bring

675

00:29:15,809 --> 00:29:20,549

out the structure but this is a now

676

00:29:19,049 --> 00:29:26,039

known to be at a distance of about two

677

00:29:20,549 --> 00:29:30,259

and a half million light-years now the

678

00:29:26,039 --> 00:29:32,670

person who really was the first to

679

00:29:30,259 --> 00:29:38,579

understand how distant the Andromeda

680

00:29:32,670 --> 00:29:40,170

galaxy was or is was Edwin Hubble then

681

00:29:38,579 --> 00:29:43,139

the man who our hubble space telescope

682

00:29:40,170 --> 00:29:45,360

is named after and he was able to make

683

00:29:43,140 --> 00:29:48,000

the first distance estimate to the

684

00:29:45,359 --> 00:29:49,379

Andromeda galaxy and he did that using a

685  
00:29:48,000 --> 00:29:51,089  
telescope called the hooker telescope

686  
00:29:49,380 --> 00:29:53,760  
there were 100 inch hooker telescope

687  
00:29:51,089 --> 00:29:55,939  
which is in California and it's

688  
00:29:53,759 --> 00:29:57,599  
interesting that this is a 2.5 meter

689  
00:29:55,940 --> 00:29:59,730  
telescope the Hubble Space Telescope

690  
00:29:57,599 --> 00:30:02,689  
named after him is 2.4 meters it's

691  
00:29:59,730 --> 00:30:06,960  
actually pretty close but he was able to

692  
00:30:02,690 --> 00:30:10,320  
measure the distance to Andromeda and

693  
00:30:06,960 --> 00:30:12,390  
that settled a really big debate that

694  
00:30:10,319 --> 00:30:15,689  
was going on in the 1920s it was called

695  
00:30:12,390 --> 00:30:18,900  
a great debate because back then people

696  
00:30:15,690 --> 00:30:20,400  
had observed nebulae as they called them

697  
00:30:18,900 --> 00:30:22,590  
like this but they didn't know was that

698  
00:30:20,400 --> 00:30:25,500  
something in our own galaxy or was that

699  
00:30:22,589 --> 00:30:29,490  
outside the Milky Way was it it's in was

700  
00:30:25,500 --> 00:30:31,140  
it an entirely separate object

701  
00:30:29,490 --> 00:30:33,089  
and Hubble was the one who actually

702  
00:30:31,140 --> 00:30:34,830  
settled that because when he measured a

703  
00:30:33,089 --> 00:30:36,869  
distance to Andromeda and he did that

704  
00:30:34,829 --> 00:30:39,178  
using a certain type of star called a

705  
00:30:36,869 --> 00:30:41,099  
Cepheid variable star by measuring how

706  
00:30:39,179 --> 00:30:43,860  
quickly there was pulsated he was able

707  
00:30:41,099 --> 00:30:46,648  
to measure the distance to the galaxy he

708  
00:30:43,859 --> 00:30:49,288  
found that the distance Wars about nine

709  
00:30:46,648 --> 00:30:50,908  
hundred thousand light-years that was

710  
00:30:49,288 --> 00:30:53,190  
the number that he published on the

711  
00:30:50,909 --> 00:30:54,990  
distance to this galaxy well nine

712  
00:30:53,190 --> 00:30:57,600  
hundred thousand light-years is way

713

00:30:54,990 --> 00:30:59,190  
bigger than our own galaxy so he

714  
00:30:57,599 --> 00:31:01,528  
realized that this couldn't fit inside

715  
00:30:59,190 --> 00:31:04,288  
the Milky Way this had to be more

716  
00:31:01,528 --> 00:31:05,880  
distant than that so we couldn't think

717  
00:31:04,288 --> 00:31:07,140  
of the Milky Way as the center of the

718  
00:31:05,880 --> 00:31:09,210  
universe it showed that there are other

719  
00:31:07,140 --> 00:31:11,159  
galaxies out there it turns out that and

720  
00:31:09,210 --> 00:31:12,538  
rahmanir is actually more massive and

721  
00:31:11,159 --> 00:31:14,278  
bigger than the Milky Way so this was

722  
00:31:12,538 --> 00:31:18,000  
very important for putting our galaxy in

723  
00:31:14,278 --> 00:31:20,220  
context just one last point we now know

724  
00:31:18,000 --> 00:31:22,950  
that the the value of the distance the

725  
00:31:20,220 --> 00:31:25,200  
Milky to Andromeda excuse me is about

726  
00:31:22,950 --> 00:31:27,269  
two and a half million light-years so

727  
00:31:25,200 --> 00:31:29,640

it's a factor of two or three higher

728

00:31:27,269 --> 00:31:31,408

than the number that he had to do with

729

00:31:29,640 --> 00:31:33,538

different calibrations for the way he

730

00:31:31,409 --> 00:31:34,950

was measuring distance but the main

731

00:31:33,538 --> 00:31:36,450

point is that he found that this was

732

00:31:34,950 --> 00:31:40,850

certainly far enough away to be outside

733

00:31:36,450 --> 00:31:43,470

the Milky Way now we can see that

734

00:31:40,849 --> 00:31:46,230

between Andromeda which is on the top

735

00:31:43,470 --> 00:31:50,429

right there and its neighbor which is

736

00:31:46,230 --> 00:31:51,929

called m33 there is a bridge of material

737

00:31:50,429 --> 00:31:53,850

just like there was a bridge of material

738

00:31:51,929 --> 00:31:56,100

between the Magellanic Clouds and this

739

00:31:53,849 --> 00:31:59,699

was discovered quite recently in radio

740

00:31:56,099 --> 00:32:02,189

emission exactly where that gas comes

741

00:31:59,700 --> 00:32:04,409

from isn't completely known it may be

742  
00:32:02,190 --> 00:32:06,570  
falling onto the galaxy and on to

743  
00:32:04,409 --> 00:32:11,820  
Andromeda for the first time allowing it

744  
00:32:06,569 --> 00:32:14,220  
to to form new stars so I want to come

745  
00:32:11,819 --> 00:32:17,808  
back to this idea about gas in astronomy

746  
00:32:14,220 --> 00:32:21,000  
as fuel for new stars for star formation

747  
00:32:17,808 --> 00:32:24,480  
because just as you'll put gas in your

748  
00:32:21,000 --> 00:32:27,028  
car and you'll get motion out of it you

749  
00:32:24,480 --> 00:32:28,829  
can put gas in the form of interstellar

750  
00:32:27,028 --> 00:32:30,480  
gas into a galaxy and you'll form new

751  
00:32:28,829 --> 00:32:35,778  
stars okay that's the idea I have about

752  
00:32:30,480 --> 00:32:38,159  
fueling and galaxies from from gas now

753  
00:32:35,778 --> 00:32:40,798  
there are cycles that go on within

754  
00:32:38,159 --> 00:32:41,190  
galaxies where new stars form out of

755  
00:32:40,798 --> 00:32:43,889  
into

756  
00:32:41,190 --> 00:32:46,620  
Stella gasps and once they get to the

757  
00:32:43,890 --> 00:32:49,080  
end of their life they can return the

758  
00:32:46,619 --> 00:32:50,849  
gas back into the space around them

759  
00:32:49,079 --> 00:32:52,529  
but the gas that's been cycled through

760  
00:32:50,849 --> 00:32:54,209  
stars is different than the gas that

761  
00:32:52,529 --> 00:32:56,759  
they formed out of and the main

762  
00:32:54,210 --> 00:32:58,860  
difference is that the the composition

763  
00:32:56,759 --> 00:33:01,200  
the chemical elements that make up that

764  
00:32:58,859 --> 00:33:05,059  
gas have have changed because the Stars

765  
00:33:01,200 --> 00:33:07,799  
have produced new elements all the

766  
00:33:05,059 --> 00:33:10,079  
chemical elements that we that we study

767  
00:33:07,799 --> 00:33:12,960  
and we put in a periodic table that a

768  
00:33:10,079 --> 00:33:16,199  
chemist would show you are ultimately

769  
00:33:12,960 --> 00:33:19,710  
synthesized in the cores of the central

770

00:33:16,200 --> 00:33:22,559  
cores of stars now astronomers like to

771  
00:33:19,710 --> 00:33:26,069  
make simplifications and sometimes

772  
00:33:22,559 --> 00:33:28,220  
you'll see an astronomer turn a periodic

773  
00:33:26,069 --> 00:33:32,369  
table into something like this

774  
00:33:28,220 --> 00:33:34,019  
everything from lithium up which is the

775  
00:33:32,369 --> 00:33:36,359  
third element up in the periodic table

776  
00:33:34,019 --> 00:33:39,089  
they'll just refer to as metals or heavy

777  
00:33:36,359 --> 00:33:40,679  
elements so you've got hydrogen the

778  
00:33:39,089 --> 00:33:41,939  
first element you've got helium the

779  
00:33:40,680 --> 00:33:43,830  
second element those are the two at the

780  
00:33:41,940 --> 00:33:46,380  
top and then everything else is referred

781  
00:33:43,829 --> 00:33:48,539  
to as metals now you might say why how

782  
00:33:46,380 --> 00:33:51,660  
on earth can you do that the reason is

783  
00:33:48,539 --> 00:33:54,359  
that hydrogen and helium are thought to

784  
00:33:51,660 --> 00:33:56,610

be produced very early on in the

785

00:33:54,359 --> 00:33:59,490

universe right after the Big Bang all

786

00:33:56,609 --> 00:34:02,519

the hydrogen and helium atoms were

787

00:33:59,490 --> 00:34:06,059

synthesized at that time but everything

788

00:34:02,519 --> 00:34:08,670

else that's called metals here is mostly

789

00:34:06,059 --> 00:34:10,199

produced I say everything but some of

790

00:34:08,670 --> 00:34:11,970

the lithium and Borne might have been

791

00:34:10,199 --> 00:34:13,349

produced earlier on but to a to a very

792

00:34:11,969 --> 00:34:15,029

good approximation all the other

793

00:34:13,349 --> 00:34:18,690

elements come from this the course of

794

00:34:15,030 --> 00:34:21,510

massive stars and this is studied by

795

00:34:18,690 --> 00:34:24,720

people who look at stellar evolution the

796

00:34:21,510 --> 00:34:27,510

way that stars changed as time goes on

797

00:34:24,719 --> 00:34:29,250

and they run out of fuel and this is a

798

00:34:27,510 --> 00:34:31,470

picture showing you a slice through what

799  
00:34:29,250 --> 00:34:34,250  
a massive star will look like at the end

800  
00:34:31,469 --> 00:34:37,139  
of its life you have these different

801  
00:34:34,250 --> 00:34:39,239  
rings of material or shells of material

802  
00:34:37,139 --> 00:34:41,400  
that have a different chemical

803  
00:34:39,239 --> 00:34:43,739  
composition and when I say a massive

804  
00:34:41,400 --> 00:34:47,160  
star this is the starlet's about ten

805  
00:34:43,739 --> 00:34:48,779  
times more massive than the Sun and it's

806  
00:34:47,159 --> 00:34:50,339  
gone through various stages where it's

807  
00:34:48,780 --> 00:34:53,869  
burned through different types of fuel

808  
00:34:50,340 --> 00:34:56,030  
so to start out where the star will burn

809  
00:34:53,869 --> 00:34:58,608  
our son right now is burning hydrogen

810  
00:34:56,030 --> 00:35:00,710  
fuel when the hydrogen runs out they

811  
00:34:58,608 --> 00:35:02,509  
will move on to helium and if the star

812  
00:35:00,710 --> 00:35:04,220  
is massive enough it will move on to a

813  
00:35:02,510 --> 00:35:05,720  
whole series of different elements until

814  
00:35:04,219 --> 00:35:07,789  
you end up with something like this and

815  
00:35:05,719 --> 00:35:09,348  
this is where the chemical elements are

816  
00:35:07,789 --> 00:35:12,199  
thought to be produced in the cores of

817  
00:35:09,349 --> 00:35:14,059  
these stars when a star gets to the end

818  
00:35:12,199 --> 00:35:17,659  
of its life and all the iron in the core

819  
00:35:14,059 --> 00:35:20,630  
has been processed you can get a

820  
00:35:17,659 --> 00:35:22,399  
supernova that's where the star explodes

821  
00:35:20,630 --> 00:35:25,450  
and releases a lot of these elements out

822  
00:35:22,400 --> 00:35:29,269  
into interstellar space and eventually

823  
00:35:25,449 --> 00:35:32,029  
across the galaxy where planets can form

824  
00:35:29,269 --> 00:35:33,469  
and new stars can form and so on now

825  
00:35:32,030 --> 00:35:35,390  
that's not the only type of supernova

826  
00:35:33,469 --> 00:35:37,549  
this is this is what you would call a

827

00:35:35,389 --> 00:35:39,710  
core collapse supernova from a very

828  
00:35:37,550 --> 00:35:42,109  
individual massive star there's another

829  
00:35:39,710 --> 00:35:45,050  
type of supernova which is called a type

830  
00:35:42,108 --> 00:35:47,509  
1a supernova this happens when you have

831  
00:35:45,050 --> 00:35:49,820  
a binary system here you've got a white

832  
00:35:47,510 --> 00:35:51,440  
dwarf star it's a very dense star on one

833  
00:35:49,820 --> 00:35:54,890  
side and it's and it's pulling material

834  
00:35:51,440 --> 00:35:57,800  
off a companion so if it pulls enough

835  
00:35:54,889 --> 00:36:00,858  
material across onto the white dwarf you

836  
00:35:57,800 --> 00:36:03,230  
can get an explosion that will be

837  
00:36:00,858 --> 00:36:04,909  
visible for to very large distances

838  
00:36:03,230 --> 00:36:07,030  
because it's very bright and you can

839  
00:36:04,909 --> 00:36:10,219  
also produce elements such as iron

840  
00:36:07,030 --> 00:36:12,680  
through this channel as well so

841  
00:36:10,219 --> 00:36:14,838

supernovae will produce elements but if

842

00:36:12,679 --> 00:36:17,769

you want to get these elements out into

843

00:36:14,838 --> 00:36:20,329

the regions between galaxies you need a

844

00:36:17,769 --> 00:36:22,608

process that can do that can do that for

845

00:36:20,329 --> 00:36:25,069

you and there is something called a

846

00:36:22,608 --> 00:36:27,170

galactic wind that will take material

847

00:36:25,070 --> 00:36:31,609

that has been produced in the disk of a

848

00:36:27,170 --> 00:36:34,099

galaxy and can throw it out into the

849

00:36:31,608 --> 00:36:36,889

intergalactic space this is a very

850

00:36:34,099 --> 00:36:40,130

famous picture of a nearby starburst

851

00:36:36,889 --> 00:36:41,690

galaxy called natt the starburst galaxy

852

00:36:40,130 --> 00:36:43,940

is one that's forming stars much more

853

00:36:41,690 --> 00:36:46,220

rapidly than a galaxy like the Milky Way

854

00:36:43,940 --> 00:36:48,679

is so there's lots of new star formation

855

00:36:46,219 --> 00:36:50,719

going on all the time and you can see

856  
00:36:48,679 --> 00:36:53,659  
from the central region of this galaxy

857  
00:36:50,719 --> 00:36:56,868  
you have these huge conical outflows

858  
00:36:53,659 --> 00:37:00,049  
that are getting out into space driven

859  
00:36:56,869 --> 00:37:01,760  
by it's debated about how much of that

860  
00:37:00,050 --> 00:37:03,680  
is driven by supernovae and how much of

861  
00:37:01,760 --> 00:37:05,690  
that is actually driven by a

862  
00:37:03,679 --> 00:37:06,829  
supermassive black hole that's in the

863  
00:37:05,690 --> 00:37:09,260  
middle of the galaxy that

864  
00:37:06,829 --> 00:37:12,409  
also putting energy into its environment

865  
00:37:09,260 --> 00:37:17,810  
and throwing out material out of the

866  
00:37:12,409 --> 00:37:20,000  
galaxy so in the last part of my talk I

867  
00:37:17,809 --> 00:37:21,920  
want to move to the more distant

868  
00:37:20,000 --> 00:37:24,380  
universe I've talked about nearby

869  
00:37:21,920 --> 00:37:26,889  
galaxies mostly up to now how can we

870  
00:37:24,380 --> 00:37:28,910  
detect gas very far away

871  
00:37:26,889 --> 00:37:30,529  
particularly where radio telescopes

872  
00:37:28,909 --> 00:37:31,519  
aren't going to work anymore because the

873  
00:37:30,530 --> 00:37:34,370  
emission is too faint

874  
00:37:31,519 --> 00:37:36,320  
well one technique that people spend a

875  
00:37:34,369 --> 00:37:38,960  
lot of time doing here at the Space

876  
00:37:36,320 --> 00:37:41,150  
Telescope Institute for example is a

877  
00:37:38,960 --> 00:37:43,670  
technique called quasar absorption line

878  
00:37:41,150 --> 00:37:45,380  
spectra skippy now that sounds pretty

879  
00:37:43,670 --> 00:37:47,119  
complicated but in fact what you're

880  
00:37:45,380 --> 00:37:50,599  
doing here is it's quite straightforward

881  
00:37:47,119 --> 00:37:53,589  
you're taking a very bright source of

882  
00:37:50,599 --> 00:37:56,480  
light think of it like a lighthouse and

883  
00:37:53,590 --> 00:37:58,519  
you're seeing what happens to that light

884

00:37:56,480 --> 00:38:00,769  
when you split it up into all the

885  
00:37:58,519 --> 00:38:02,509  
different colors of the of the spectrum

886  
00:38:00,769 --> 00:38:04,730  
all the different colors of the rainbow

887  
00:38:02,510 --> 00:38:06,860  
if you like so here's an example where

888  
00:38:04,730 --> 00:38:08,570  
you're looking in a quasar and your line

889  
00:38:06,860 --> 00:38:10,120  
of sight from your telescope happens to

890  
00:38:08,570 --> 00:38:12,740  
pass through three different clouds

891  
00:38:10,119 --> 00:38:17,449  
between us and the quasar in the

892  
00:38:12,739 --> 00:38:20,149  
background now each of those clouds is a

893  
00:38:17,449 --> 00:38:22,369  
gas and we know that gas can absorb

894  
00:38:20,150 --> 00:38:24,530  
light at very particular wavelengths so

895  
00:38:22,369 --> 00:38:27,259  
each of these clouds leaves a certain

896  
00:38:24,530 --> 00:38:30,050  
signature in a spectrum of that quasar

897  
00:38:27,260 --> 00:38:32,030  
so the first cloud can leave you a line

898  
00:38:30,050 --> 00:38:35,090

in the spectrum here which is called

899

00:38:32,030 --> 00:38:36,680

will label a the second cloud will leave

900

00:38:35,090 --> 00:38:38,510

a line of this position and the third

901

00:38:36,679 --> 00:38:39,769

cloud will leave a line there so what

902

00:38:38,510 --> 00:38:43,010

you're actually left with when you

903

00:38:39,769 --> 00:38:45,019

observe this is a series of lines that

904

00:38:43,010 --> 00:38:46,730

contain information about what's the

905

00:38:45,019 --> 00:38:52,159

chemical composition of each of these

906

00:38:46,730 --> 00:38:55,130

clouds so this is the technique that

907

00:38:52,159 --> 00:38:57,769

people use to study the halos of

908

00:38:55,130 --> 00:38:59,750

galaxies out to very very high distances

909

00:38:57,769 --> 00:39:01,730

because it turns out that when we see

910

00:38:59,750 --> 00:39:04,099

these gas clouds in front of the quasar

911

00:39:01,730 --> 00:39:06,829

what we're often seeing is the very

912

00:39:04,099 --> 00:39:09,860

extended halos of individual galaxies

913  
00:39:06,829 --> 00:39:11,869  
the galaxies have these very faint but

914  
00:39:09,860 --> 00:39:13,400  
large halos that give you this

915  
00:39:11,869 --> 00:39:15,469  
absorption signal even though you can't

916  
00:39:13,400 --> 00:39:17,360  
see the stars there and so you can't see

917  
00:39:15,469 --> 00:39:19,519  
them shining at you you have to detect

918  
00:39:17,360 --> 00:39:23,420  
them through these other methods

919  
00:39:19,519 --> 00:39:25,920  
now what if you go to even bigger scales

920  
00:39:23,420 --> 00:39:28,650  
there is a term called the cosmic web

921  
00:39:25,920 --> 00:39:30,780  
which describes what on really large

922  
00:39:28,650 --> 00:39:32,940  
scales astronomers think that the

923  
00:39:30,780 --> 00:39:34,890  
universe looks like this image is

924  
00:39:32,940 --> 00:39:37,829  
actually a computer simulation of what

925  
00:39:34,889 --> 00:39:41,549  
the gas in the universe looks like in a

926  
00:39:37,829 --> 00:39:44,369  
box where each side of that box is 30

927  
00:39:41,550 --> 00:39:47,550  
million light years in size okay so this

928  
00:39:44,369 --> 00:39:50,190  
is an enormous volume of space and you

929  
00:39:47,550 --> 00:39:52,710  
can see this filamentary structure right

930  
00:39:50,190 --> 00:39:55,500  
the green is the gas in the universe and

931  
00:39:52,710 --> 00:39:59,490  
in the in the center of all these

932  
00:39:55,500 --> 00:40:01,139  
filaments you get the what you might

933  
00:39:59,489 --> 00:40:02,519  
call the nodes of the cosmic web those

934  
00:40:01,139 --> 00:40:05,339  
are where the galaxies form and the

935  
00:40:02,519 --> 00:40:06,900  
clusters of galaxies form but this is a

936  
00:40:05,340 --> 00:40:08,100  
prediction of what the gas in the

937  
00:40:06,900 --> 00:40:10,440  
universe would look like on that large

938  
00:40:08,099 --> 00:40:13,440  
scale so how can we test the prediction

939  
00:40:10,440 --> 00:40:16,170  
and go out and look for it we can do the

940  
00:40:13,440 --> 00:40:18,539  
quasar absorption line experiment and we

941

00:40:16,170 --> 00:40:21,809  
can see if we can detect that gas in

942  
00:40:18,539 --> 00:40:23,250  
absorption and this is how you would do

943  
00:40:21,809 --> 00:40:25,590  
it you would look for something called

944  
00:40:23,250 --> 00:40:27,389  
the Lyman-alpha forest and the

945  
00:40:25,590 --> 00:40:28,920  
Lyman-alpha forest is saying okay if I

946  
00:40:27,389 --> 00:40:31,379  
take us a sight line that passes through

947  
00:40:28,920 --> 00:40:34,110  
all these green clouds I should get lots

948  
00:40:31,380 --> 00:40:37,110  
and lots of features in my spectrum each

949  
00:40:34,110 --> 00:40:41,760  
one corresponding to one of the features

950  
00:40:37,110 --> 00:40:43,530  
of the forest of the gas and that's

951  
00:40:41,760 --> 00:40:45,900  
exactly what we see when we look at very

952  
00:40:43,530 --> 00:40:47,820  
very distant quasars we take the light

953  
00:40:45,900 --> 00:40:50,940  
from the quasar and we plot it as

954  
00:40:47,820 --> 00:40:52,740  
brightness against wavelength now if you

955  
00:40:50,940 --> 00:40:54,240

look at a nearby quasar what you'll get

956

00:40:52,739 --> 00:40:57,149

when you look at a spectrum is something

957

00:40:54,239 --> 00:41:00,419

like this there aren't that many dips

958

00:40:57,150 --> 00:41:02,519

and features in the spectrum if you go

959

00:41:00,420 --> 00:41:05,610

to a distant quasar much further away

960

00:41:02,519 --> 00:41:08,550

you see this huge forest of lines there

961

00:41:05,610 --> 00:41:10,980

is just a very large number of dips in

962

00:41:08,550 --> 00:41:13,350

the spectrum and each of those

963

00:41:10,980 --> 00:41:16,230

corresponds to one of the the filaments

964

00:41:13,349 --> 00:41:17,730

of gas in the lyman-alpha forest so by

965

00:41:16,230 --> 00:41:19,860

Counting how many of those that there

966

00:41:17,730 --> 00:41:21,719

are measuring their properties we can

967

00:41:19,860 --> 00:41:27,059

actually learn something observationally

968

00:41:21,719 --> 00:41:31,250

about that gas what about if we go back

969

00:41:27,059 --> 00:41:31,250

even further to the early universe

970  
00:41:32,039 --> 00:41:36,779  
the first time that a gas is thought to

971  
00:41:34,650 --> 00:41:39,740  
have formed in the universe is when the

972  
00:41:36,780 --> 00:41:45,410  
universe was about 380,000 years old and

973  
00:41:39,739 --> 00:41:48,929  
this is a time called recombination

974  
00:41:45,409 --> 00:41:52,019  
before this this is 380,000 years after

975  
00:41:48,929 --> 00:41:53,940  
the Big Bang the universe was very hot

976  
00:41:52,019 --> 00:41:58,230  
they were so hot that the material

977  
00:41:53,940 --> 00:42:00,000  
existed as plasma that is to say the

978  
00:41:58,230 --> 00:42:02,159  
electrons which are in green here were

979  
00:42:00,000 --> 00:42:04,440  
not bound to the nuclei which are in red

980  
00:42:02,159 --> 00:42:07,319  
it was too hot the gas just couldn't

981  
00:42:04,440 --> 00:42:09,389  
stay bound so it was a plasma but the

982  
00:42:07,320 --> 00:42:12,000  
universe was expanding and as it

983  
00:42:09,389 --> 00:42:13,859  
expanded it was cooling down and

984  
00:42:12,000 --> 00:42:18,510  
eventually it cooled down to a point

985  
00:42:13,860 --> 00:42:20,760  
where neutral atoms were able to form so

986  
00:42:18,510 --> 00:42:25,140  
instead of having this plasma you had a

987  
00:42:20,760 --> 00:42:27,270  
gas you went from a situation where the

988  
00:42:25,139 --> 00:42:28,699  
universe was opaque and light couldn't

989  
00:42:27,269 --> 00:42:31,769  
travel through it to where you had a

990  
00:42:28,699 --> 00:42:35,210  
transparent gas which light could pass

991  
00:42:31,769 --> 00:42:38,039  
through and that's called recombination

992  
00:42:35,210 --> 00:42:40,260  
now how do we know that again I want to

993  
00:42:38,039 --> 00:42:44,670  
come back to the evidence we have in for

994  
00:42:40,260 --> 00:42:46,640  
each of these physical ideas the answer

995  
00:42:44,670 --> 00:42:50,280  
is we can see the light that was emitted

996  
00:42:46,639 --> 00:42:52,019  
from that epoch of recombination and we

997  
00:42:50,280 --> 00:42:56,070  
see it in the form of the Cosmic

998

00:42:52,019 --> 00:42:58,409  
Microwave Background this is what the

999  
00:42:56,070 --> 00:43:03,180  
night sky looks like if you look at it

1000  
00:42:58,409 --> 00:43:05,489  
in microwaves this radiation came from

1001  
00:43:03,179 --> 00:43:08,399  
that epoch about 380,000 years after the

1002  
00:43:05,489 --> 00:43:11,159  
Big Bang when the first gas formed when

1003  
00:43:08,400 --> 00:43:13,320  
the plasma recombined to form a neutral

1004  
00:43:11,159 --> 00:43:14,819  
gas and it's you'll see it referred to

1005  
00:43:13,320 --> 00:43:17,370  
as the oldest form of light in the

1006  
00:43:14,820 --> 00:43:21,200  
universe now what happened after that

1007  
00:43:17,369 --> 00:43:23,539  
well the universe didn't stay neutral

1008  
00:43:21,199 --> 00:43:25,799  
forever

1009  
00:43:23,539 --> 00:43:27,300  
right after recombination the first

1010  
00:43:25,800 --> 00:43:29,640  
thing that happened was the period

1011  
00:43:27,300 --> 00:43:31,080  
called the dark ages we don't know much

1012  
00:43:29,639 --> 00:43:32,849

about the universe in the dark ages

1013

00:43:31,079 --> 00:43:36,960

because there weren't many sources of

1014

00:43:32,849 --> 00:43:39,599

light but at one point after that the

1015

00:43:36,960 --> 00:43:42,300

first galaxies and the first quasars

1016

00:43:39,599 --> 00:43:44,279

began to switch on and quasars are the

1017

00:43:42,300 --> 00:43:45,499

cores of the galaxies where a lot of

1018

00:43:44,280 --> 00:43:48,210

radiation is emitted

1019

00:43:45,498 --> 00:43:51,149

now when those galaxies and quasars

1020

00:43:48,210 --> 00:43:54,239

switch on they start to shine into

1021

00:43:51,150 --> 00:43:57,630

bubbles of space around them they around

1022

00:43:54,239 --> 00:43:59,519

them and so you're producing these

1023

00:43:57,630 --> 00:44:02,099

bubbles of gas and eventually as time

1024

00:43:59,518 --> 00:44:04,199

passes further than that the bubbles

1025

00:44:02,099 --> 00:44:07,259

start to overlap and you reach a point

1026

00:44:04,199 --> 00:44:09,210

where all of the space between galaxies

1027  
00:44:07,259 --> 00:44:11,539  
all the intergalactic space is ionized

1028  
00:44:09,210 --> 00:44:14,400  
so this whole process is called

1029  
00:44:11,539 --> 00:44:16,410  
reorganization so the universe you know

1030  
00:44:14,400 --> 00:44:17,849  
started out ionized very early on and

1031  
00:44:16,409 --> 00:44:19,710  
then it became neutral and then when the

1032  
00:44:17,849 --> 00:44:22,470  
galaxy switched on and became ionized

1033  
00:44:19,710 --> 00:44:25,980  
together so you have this trend going

1034  
00:44:22,469 --> 00:44:30,808  
from neutral to ionized as cosmic time

1035  
00:44:25,980 --> 00:44:33,989  
has has progressed so just before I

1036  
00:44:30,809 --> 00:44:35,940  
finished before we finish up here I

1037  
00:44:33,989 --> 00:44:38,039  
wanted to mention that and one other

1038  
00:44:35,940 --> 00:44:40,440  
reason that we're interested in gases is

1039  
00:44:38,039 --> 00:44:42,690  
that most atoms in the universe are in

1040  
00:44:40,440 --> 00:44:44,460  
gases compared to all these different

1041  
00:44:42,690 --> 00:44:46,889  
forms of astronomical matter I've shown

1042  
00:44:44,460 --> 00:44:49,579  
you solids and liquids really account

1043  
00:44:46,889 --> 00:44:51,838  
for a very small fraction of all the

1044  
00:44:49,579 --> 00:44:54,450  
regular matter that exists in the

1045  
00:44:51,838 --> 00:44:57,298  
universe so with that I'm going to end

1046  
00:44:54,449 --> 00:44:59,578  
and I'm going to put up this picture of

1047  
00:44:57,298 --> 00:45:02,699  
the so called monkey head nebula that

1048  
00:44:59,579 --> 00:45:04,259  
was released earlier this year and ask

1049  
00:45:02,699 --> 00:45:06,889  
you if you have any questions so thanks

1050  
00:45:04,259 --> 00:45:06,889  
for your attention

1051  
00:45:18,079 --> 00:45:34,139  
yes yes that's right so in a stellar gas

1052  
00:45:32,610 --> 00:45:36,599  
can be heated to high temperatures

1053  
00:45:34,139 --> 00:45:41,779  
around 10,000 Kelvin or so and it's

1054  
00:45:36,599 --> 00:45:41,779  
mostly heated by starlight so they're

1055

00:45:42,139 --> 00:45:46,889  
ultraviolet radiation ultraviolet

1056  
00:45:45,360 --> 00:45:49,710  
photons that come off stars that can

1057  
00:45:46,889 --> 00:45:51,539  
heat the gas that's present in

1058  
00:45:49,710 --> 00:45:53,070  
interstellar space and the temperature

1059  
00:45:51,539 --> 00:45:55,139  
that it has is set by a balance between

1060  
00:45:53,070 --> 00:45:58,350  
how much heating you have and how much

1061  
00:45:55,139 --> 00:46:00,059  
cooling you have now saying that there

1062  
00:45:58,349 --> 00:46:02,369  
are regions of interstellar space that

1063  
00:46:00,059 --> 00:46:04,320  
are cooler so they're nebulae that new

1064  
00:46:02,369 --> 00:46:07,440  
stars form out of a much colder than

1065  
00:46:04,320 --> 00:46:09,990  
that you need cold gas to be able to to

1066  
00:46:07,440 --> 00:46:12,630  
shrink down and what we call a molecular

1067  
00:46:09,989 --> 00:46:15,750  
cloud and eventually form a star but

1068  
00:46:12,630 --> 00:46:17,250  
most of the volume of the space in in

1069  
00:46:15,750 --> 00:46:19,260

between stars is filled with this

1070

00:46:17,250 --> 00:46:22,940

diffuse material that has a temperature

1071

00:46:19,260 --> 00:46:22,940

around 10000 Kelvin or so

1072

00:46:25,028 --> 00:46:51,518

Yeah right one oh yeah for intergalactic

1073

00:46:50,409 --> 00:47:02,949

that's right

1074

00:46:51,518 --> 00:47:04,508

yes so the reason you can talk about

1075

00:47:02,949 --> 00:47:06,818

temperature is you can measure the

1076

00:47:04,509 --> 00:47:09,818

temperature of an astronomical gas even

1077

00:47:06,818 --> 00:47:11,380

if the density is extremely low and we

1078

00:47:09,818 --> 00:47:15,068

have ways of measuring the temperature

1079

00:47:11,380 --> 00:47:16,809

by looking at the width of absorption

1080

00:47:15,068 --> 00:47:18,880

lines that come from these spectroscopy

1081

00:47:16,809 --> 00:47:20,559

experiments so if you look at one of

1082

00:47:18,880 --> 00:47:23,769

these lines like these hydrogen lines

1083

00:47:20,559 --> 00:47:25,509

and you look at how broad it is that

1084  
00:47:23,768 --> 00:47:28,448  
tells you what the temperature of the

1085  
00:47:25,509 --> 00:47:30,400  
gas is the hotter the the gas the the

1086  
00:47:28,449 --> 00:47:33,099  
broader the line that you'll see in your

1087  
00:47:30,400 --> 00:47:35,528  
spectrum is if a cloud is very cool you

1088  
00:47:33,099 --> 00:47:38,199  
get a very narrow component because

1089  
00:47:35,528 --> 00:47:40,659  
there isn't much motion of the atoms

1090  
00:47:38,199 --> 00:47:43,959  
that are giving you the absorption so we

1091  
00:47:40,659 --> 00:47:45,369  
make measurements that actually tell you

1092  
00:47:43,958 --> 00:47:47,018  
what that temperature is is a

1093  
00:47:45,369 --> 00:48:03,759  
measurement rather than some sort of

1094  
00:47:47,018 --> 00:48:06,399  
estimate well right so I see what you're

1095  
00:48:03,759 --> 00:48:08,380  
saying but you only have one per per

1096  
00:48:06,400 --> 00:48:10,239  
cubic meter or so but remember in a

1097  
00:48:08,380 --> 00:48:12,909  
Galactic space has a lot of cubic meters

1098  
00:48:10,239 --> 00:48:16,208  
so we can study a cloud that might have

1099  
00:48:12,909 --> 00:48:17,619  
a size of you know 10,000 light years or

1100  
00:48:16,208 --> 00:48:18,038  
something or a hundred thousand light

1101  
00:48:17,619 --> 00:48:19,959  
years

1102  
00:48:18,039 --> 00:48:22,028  
if you cut if you turn that into cubic

1103  
00:48:19,958 --> 00:48:24,038  
meters it's a big number so even though

1104  
00:48:22,028 --> 00:48:26,498  
there's not many per cubic meter we have

1105  
00:48:24,039 --> 00:48:27,939  
enough of them overall that we can still

1106  
00:48:26,498 --> 00:48:30,118  
get an estimate of what that temperature

1107  
00:48:27,938 --> 00:48:30,118  
is

1108  
00:48:31,539 --> 00:49:13,400  
sure yes right right that's another way

1109  
00:48:47,599 --> 00:49:16,880  
putting but but the densities are very

1110  
00:49:13,400 --> 00:49:20,150  
much lower than what we are used to here

1111  
00:49:16,880 --> 00:49:22,940  
in the there the Earth's atmosphere as a

1112

00:49:20,150 --> 00:49:26,500  
local gas so the amount of heat you have

1113  
00:49:22,940 --> 00:49:41,000  
per cubic centimeter may be much lower

1114  
00:49:26,500 --> 00:49:43,130  
but that's okay but see okay

1115  
00:49:41,000 --> 00:49:45,409  
so temperature is not the same thing as

1116  
00:49:43,130 --> 00:49:48,410  
heat temperature is the degree of

1117  
00:49:45,409 --> 00:49:49,549  
hotness which is different from heat

1118  
00:49:48,409 --> 00:49:52,279  
because heat is to do with how much

1119  
00:49:49,550 --> 00:49:54,760  
energy you have in a given volume right

1120  
00:49:52,280 --> 00:50:01,600  
I think that's what you're gonna hear

1121  
00:49:54,760 --> 00:50:01,600  
yes yeah

1122  
00:50:10,150 --> 00:50:15,858  
that's a that's a very good question

1123  
00:50:13,009 --> 00:50:18,469  
the I can't tell you from an

1124  
00:50:15,858 --> 00:50:20,268  
observational point of view how much

1125  
00:50:18,469 --> 00:50:21,798  
dark matter is in that box what the

1126  
00:50:20,268 --> 00:50:23,688

theorists can tell you the the people

1127

00:50:21,798 --> 00:50:25,369

who make the simulations is that in

1128

00:50:23,688 --> 00:50:27,228

their simulations the gas and the Dark

1129

00:50:25,369 --> 00:50:29,719

Matter sort of follows they follow each

1130

00:50:27,228 --> 00:50:32,088

other so this is a picture of what the

1131

00:50:29,719 --> 00:50:33,588

gas looks like you'll find similar

1132

00:50:32,088 --> 00:50:35,688

pictures of what the Dark Matter looks

1133

00:50:33,588 --> 00:50:38,900

like but because it's so hard to observe

1134

00:50:35,688 --> 00:50:40,818

we can't tell you very easily whether

1135

00:50:38,900 --> 00:50:43,400

that Dark Matter really does follow that

1136

00:50:40,818 --> 00:50:45,938

prediction so that's why I focused on

1137

00:50:43,400 --> 00:50:48,939

the gases that we can see the gas right

1138

00:50:45,938 --> 00:50:48,938

yes

1139

00:50:55,639 --> 00:51:00,798

yes so the interstellar medium has has

1140

00:50:58,489 --> 00:51:02,630

regions that are neutral on a neutral

1141  
00:51:00,798 --> 00:51:05,838  
gas but it also has regions that are

1142  
00:51:02,630 --> 00:51:07,608  
ionized the the stuff you're seeing in

1143  
00:51:05,838 --> 00:51:10,489  
the hydrogen emission is neutral the

1144  
00:51:07,608 --> 00:51:13,188  
radio emitting gas that we see in the 21

1145  
00:51:10,489 --> 00:51:15,199  
centimeter a tracer the 21 centimeter

1146  
00:51:13,188 --> 00:51:17,149  
line that's neutral gas but there are

1147  
00:51:15,199 --> 00:51:34,789  
other regions of interstellar space that

1148  
00:51:17,150 --> 00:51:36,619  
are seeing plasma transitions too well

1149  
00:51:34,789 --> 00:51:39,979  
most of let me just be very clear most

1150  
00:51:36,619 --> 00:51:41,568  
of the normal matter which means I'm not

1151  
00:51:39,978 --> 00:51:44,208  
talking about dark matter or dark energy

1152  
00:51:41,568 --> 00:51:48,759  
which are two separate subjects but most

1153  
00:51:44,208 --> 00:51:52,518  
of the the matter that consists of atoms

1154  
00:51:48,759 --> 00:51:55,009  
the most of that would be would be in

1155  
00:51:52,518 --> 00:51:56,778  
plasma but the I don't have numbers for

1156  
00:51:55,009 --> 00:51:58,458  
the exact breakdown between gas and

1157  
00:51:56,778 --> 00:52:00,349  
plasma but the point I was making is

1158  
00:51:58,458 --> 00:52:02,028  
that the solids and the liquids are much

1159  
00:52:00,349 --> 00:52:04,209  
smaller in comparison to the gas in the

1160  
00:52:02,028 --> 00:52:04,208  
plasma

1161  
00:52:13,809 --> 00:52:17,349  
right that's right so I might have been

1162  
00:52:16,389 --> 00:52:19,089  
a little unclear about that see

1163  
00:52:17,349 --> 00:52:20,019  
sometimes people talk about plasma as a

1164  
00:52:19,090 --> 00:52:21,730  
type of gas

1165  
00:52:20,019 --> 00:52:24,250  
they'll call a plasma is an ionized gas

1166  
00:52:21,730 --> 00:52:26,800  
but now it's more common that you'll

1167  
00:52:24,250 --> 00:52:28,360  
hear just plasma and gas treated as two

1168  
00:52:26,800 --> 00:52:29,590  
separate states of matter I mean

1169

00:52:28,360 --> 00:52:31,840  
historically there were only three

1170  
00:52:29,590 --> 00:52:34,960  
states of matter so plasma was kind of

1171  
00:52:31,840 --> 00:52:53,650  
tucked in with the gas yeah question

1172  
00:52:34,960 --> 00:52:57,730  
back there extreme was about look like

1173  
00:52:53,650 --> 00:53:07,019  
the extreme was about a conference of

1174  
00:52:57,730 --> 00:53:09,929  
the earth are you suggesting that no so

1175  
00:53:07,019 --> 00:53:14,139  
what what I'm doing is showing how much

1176  
00:53:09,929 --> 00:53:17,919  
how much space do they take up on on the

1177  
00:53:14,139 --> 00:53:21,489  
surface of a globe or on a map angly in

1178  
00:53:17,920 --> 00:53:24,039  
terms of angle right so so you can look

1179  
00:53:21,489 --> 00:53:25,869  
at what the what the surface of the

1180  
00:53:24,039 --> 00:53:27,759  
earth looks like on a projection like

1181  
00:53:25,869 --> 00:53:29,199  
this which shows you the continents we

1182  
00:53:27,760 --> 00:53:31,480  
can do the same thing in astronomy when

1183  
00:53:29,199 --> 00:53:33,609

we study the galaxy and at new and many

1184

00:53:31,480 --> 00:53:35,710

different people do that when they look

1185

00:53:33,610 --> 00:53:38,019

at radio waves and microwaves is they

1186

00:53:35,710 --> 00:53:41,110

put things on this galactic coordinate

1187

00:53:38,019 --> 00:53:43,809

system so the the comparison I was just

1188

00:53:41,110 --> 00:53:47,019

simply making was if you had it you know

1189

00:53:43,809 --> 00:53:49,329

if you had a gas cloud that covered the

1190

00:53:47,019 --> 00:53:51,820

same fraction of the Earth's sky as this

1191

00:53:49,329 --> 00:53:53,590

thing does of the galaxy you know it

1192

00:53:51,820 --> 00:53:57,269

would come all the way down from this

1193

00:53:53,590 --> 00:53:59,860

continent across South Pole and up their

1194

00:53:57,269 --> 00:54:12,900

perspective yeah thanks and the yellow

1195

00:53:59,860 --> 00:54:17,950

shirt yeah huge marble with striation

1196

00:54:12,900 --> 00:54:20,039

colors of the colors so Jupiter has its

1197

00:54:17,949 --> 00:54:22,809

own weather patterns so it has

1198  
00:54:20,039 --> 00:54:24,909  
atmospheric circulation it's

1199  
00:54:22,809 --> 00:54:26,710  
rotating this energy that's associated

1200  
00:54:24,909 --> 00:54:28,299  
with the planet moving around it's been

1201  
00:54:26,710 --> 00:54:31,599  
accessed once every day it could be

1202  
00:54:28,300 --> 00:54:34,840  
Jupiter day and those weather patterns

1203  
00:54:31,599 --> 00:54:37,900  
give you these bands that you can see in

1204  
00:54:34,840 --> 00:54:41,200  
the in the colors of the Jupiter's

1205  
00:54:37,900 --> 00:54:42,849  
atmosphere so I mean even though it

1206  
00:54:41,199 --> 00:54:44,439  
doesn't have the solid surface the way

1207  
00:54:42,849 --> 00:54:45,880  
the planet Earth does it can still have

1208  
00:54:44,440 --> 00:54:59,590  
weather and that's what you're seeing

1209  
00:54:45,880 --> 00:55:01,059  
when you see those it's it's similar to

1210  
00:54:59,590 --> 00:55:02,800  
a star in the sense that it's a

1211  
00:55:01,059 --> 00:55:06,009  
spherical ball of gas the difference is

1212  
00:55:02,800 --> 00:55:17,220  
it's not producing its own energy in its

1213  
00:55:06,010 --> 00:55:19,810  
core it's opaque yes well there are

1214  
00:55:17,219 --> 00:55:22,599  
objects called brown dwarfs which are

1215  
00:55:19,809 --> 00:55:25,029  
failed stars they're stars that don't

1216  
00:55:22,599 --> 00:55:28,599  
have enough mass to ever get hot enough

1217  
00:55:25,030 --> 00:55:31,630  
in their cores to start burning hydrogen

1218  
00:55:28,599 --> 00:55:34,239  
and producing energy by a nuclear fusion

1219  
00:55:31,630 --> 00:55:35,980  
but Jupiter is is compared to the mass

1220  
00:55:34,239 --> 00:55:46,959  
of the Sun Jupiter is much much smaller

1221  
00:55:35,980 --> 00:55:48,730  
it's much less massive so yeah they have

1222  
00:55:46,960 --> 00:55:50,800  
right and they've described Jupiter as

1223  
00:55:48,730 --> 00:55:52,240  
the vacuum cleaner of the the solar

1224  
00:55:50,800 --> 00:55:54,430  
system because it's more massive than

1225  
00:55:52,239 --> 00:55:55,959  
the other planets and it sucks out

1226

00:55:54,429 --> 00:56:00,869  
passings rocks

1227  
00:55:55,960 --> 00:56:00,869  
that's right yeah yeah

1228  
00:56:04,280 --> 00:56:11,099  
yes I so I haven't mentioned

1229  
00:56:07,349 --> 00:56:13,410  
interstellar dust dust is basically

1230  
00:56:11,099 --> 00:56:15,300  
small particles so when an astronomer

1231  
00:56:13,409 --> 00:56:16,589  
says dust you're not talking about atoms

1232  
00:56:15,300 --> 00:56:19,560  
or molecules you're talking about

1233  
00:56:16,590 --> 00:56:21,539  
microscopic dust grains that can have

1234  
00:56:19,559 --> 00:56:23,759  
different organic molecules in them they

1235  
00:56:21,539 --> 00:56:26,000  
can have silicon molecules and they

1236  
00:56:23,760 --> 00:56:28,619  
contain a very small amount of the mass

1237  
00:56:26,000 --> 00:56:31,230  
compared to the gas but they're still

1238  
00:56:28,619 --> 00:56:32,940  
important is the dust does things like

1239  
00:56:31,230 --> 00:56:34,858  
change the color of the star light

1240  
00:56:32,940 --> 00:56:36,720

that's passing through it so it's an

1241  
00:56:34,858 --> 00:56:38,039  
important part of the space between the

1242  
00:56:36,719 --> 00:56:49,919  
stars even though it doesn't have much

1243  
00:56:38,039 --> 00:57:07,759  
of the category of well it would be

1244  
00:56:49,920 --> 00:57:07,760  
neither understand yes I think it is not

1245  
00:57:25,219 --> 00:57:39,019  
in the same reactor gravity we can

1246  
00:57:29,010 --> 00:57:39,020  
detect that it's been up for a while

1247  
00:57:41,599 --> 00:57:50,190  
have you here as in heavier than iron so

1248  
00:57:46,190 --> 00:57:53,460  
there are other processes they called

1249  
00:57:50,190 --> 00:57:55,920  
nuclear synthesis and in stars where you

1250  
00:57:53,460 --> 00:57:59,250  
take you take a neutron and you keep

1251  
00:57:55,920 --> 00:58:01,139  
adding a neutron to each each atomic

1252  
00:57:59,250 --> 00:58:02,730  
nuclei so you go from iron to the

1253  
00:58:01,139 --> 00:58:05,940  
element which is 1 above iron and you

1254  
00:58:02,730 --> 00:58:07,740  
can build up heavier elements that way

1255  
00:58:05,940 --> 00:58:10,409  
it's called the this something called

1256  
00:58:07,739 --> 00:58:12,539  
our process for the rapid process where

1257  
00:58:10,409 --> 00:58:14,279  
you're building up elements one by one

1258  
00:58:12,539 --> 00:58:16,079  
starting from an iron atom and adding a

1259  
00:58:14,280 --> 00:58:18,580  
neutron each time

1260  
00:58:16,079 --> 00:58:21,219  
but again these are processes that are

1261  
00:58:18,579 --> 00:58:23,170  
thought to happen in the course of stars

1262  
00:58:21,219 --> 00:58:25,029  
where you need very high temperatures

1263  
00:58:23,170 --> 00:58:26,500  
and you need high densities so you

1264  
00:58:25,030 --> 00:58:30,010  
wouldn't ever see something like that in

1265  
00:58:26,500 --> 00:58:40,840  
the interstellar regions it has to be in

1266  
00:58:30,010 --> 00:58:42,550  
the course of stars yes the the type 1a

1267  
00:58:40,840 --> 00:58:45,460  
supernova in the binaries they can also

1268  
00:58:42,550 --> 00:58:48,810  
synthesize new elements yeah that's

1269  
00:58:45,460 --> 00:58:52,829  
right yeah yes

1270  
00:58:48,809 --> 00:58:52,829  
and then afterwards they'll come here

1271  
00:59:09,809 --> 00:59:14,320  
that's that's an excellent question and

1272  
00:59:12,190 --> 00:59:16,450  
the answer is the same as gravity so

1273  
00:59:14,320 --> 00:59:18,430  
what keeps this the gas in the Sun

1274  
00:59:16,449 --> 00:59:20,379  
confined is the gravity of the Sun is

1275  
00:59:18,429 --> 00:59:23,169  
the mass of the Sun pulling everything

1276  
00:59:20,380 --> 00:59:26,559  
together and what keeps the gas in the

1277  
00:59:23,170 --> 00:59:29,170  
disk of the Milky Way in that thin layer

1278  
00:59:26,559 --> 00:59:33,070  
is gravity because everything is falling

1279  
00:59:29,170 --> 00:59:37,588  
down towards the central plane of the of

1280  
00:59:33,070 --> 00:59:37,588  
the galaxy do calculations show

1281  
00:59:47,760 --> 01:00:02,859  
gravitation explain the rate of rotation

1282  
00:59:55,920 --> 01:00:05,409  
that's right yeah discrepancy I'm not

1283

01:00:02,858 --> 01:00:07,239  
sure if you look at the the height of

1284  
01:00:05,409 --> 01:00:12,279  
the radio emission from the Milky Way

1285  
01:00:07,239 --> 01:00:14,259  
whether you can explain that from normal

1286  
01:00:12,280 --> 01:00:16,060  
matter and the gravitational effect of

1287  
01:00:14,260 --> 01:00:17,859  
normal matter alone or whether you need

1288  
01:00:16,059 --> 01:00:18,969  
dark matter I'm not sure it might be

1289  
01:00:17,858 --> 01:00:20,469  
that you can do it with normal matter

1290  
01:00:18,969 --> 01:00:23,289  
because it's close to the plane of the

1291  
01:00:20,469 --> 01:00:24,969  
galaxy the dark matter seems to be more

1292  
01:00:23,289 --> 01:00:27,039  
extended it goes out towards the outer

1293  
01:00:24,969 --> 01:00:27,419  
regions so you need to be out there to

1294  
01:00:27,039 --> 01:00:29,068  
see the

1295  
01:00:27,420 --> 01:00:54,659  
I saw that but I'm not I'm not

1296  
01:00:29,068 --> 01:00:57,029  
absolutely sure okay well atmospheres of

1297  
01:00:54,659 --> 01:00:59,818

planets certainly do change that's it

1298

01:00:57,030 --> 01:01:01,920

we know that's happened we can see that

1299

01:00:59,818 --> 01:01:03,449

the atmosphere of Mars used to be very

1300

01:01:01,920 --> 01:01:05,539

different than it is now but the

1301

01:01:03,449 --> 01:01:09,960

evidence for water on Mars and different

1302

01:01:05,539 --> 01:01:11,880

you know different forms so atmospheres

1303

01:01:09,960 --> 01:01:13,769

can change but they can't but they tend

1304

01:01:11,880 --> 01:01:18,588

to change on on very long timescales

1305

01:01:13,769 --> 01:01:20,460

compared to human timescales right so

1306

01:01:18,588 --> 01:01:34,650

probably not something we have to worry

1307

01:01:20,460 --> 01:01:36,480

about that's it yes yes well when I say

1308

01:01:34,650 --> 01:01:39,599

hydrogen burning I mean the way that a

1309

01:01:36,480 --> 01:01:44,068

star like the Sun produces energy is it

1310

01:01:39,599 --> 01:01:46,530

takes hydrogen nuclei protons and it

1311

01:01:44,068 --> 01:01:48,779

fuses them together combines them and

1312  
01:01:46,530 --> 01:01:51,510  
when you do that you make helium right

1313  
01:01:48,780 --> 01:01:56,190  
so yes so it doesn't involve oxygen

1314  
01:01:51,510 --> 01:01:59,960  
it's just hydrogen and yeah now there is

1315  
01:01:56,190 --> 01:02:02,970  
now there are other there are other

1316  
01:01:59,960 --> 01:02:05,309  
nuclear reaction pathways that do

1317  
01:02:02,969 --> 01:02:07,139  
involve oxygen the the one that I just

1318  
01:02:05,309 --> 01:02:09,780  
talked about is called the proton-proton

1319  
01:02:07,139 --> 01:02:11,358  
chain that is based on hydrogen there

1320  
01:02:09,780 --> 01:02:14,548  
are other ones that do involve oxygen

1321  
01:02:11,358 --> 01:02:16,318  
but the it depends on how mass of the

1322  
01:02:14,548 --> 01:02:20,750  
star is as to which of these pathways

1323  
01:02:16,318 --> 01:02:20,750  
--is is the most is the dominant

1324  
01:02:22,199 --> 01:02:29,409  
yes it would be yeah this fusion

1325  
01:02:24,789 --> 01:02:32,170  
reactions yeah yeah yeah in the

1326  
01:02:29,409 --> 01:02:35,710  
announcement yesterday the discovery I

1327  
01:02:32,170 --> 01:02:42,099  
think it's called kepler-10c the mega

1328  
01:02:35,710 --> 01:02:45,119  
planet the company store at least in the

1329  
01:02:42,099 --> 01:02:51,039  
post this morning described the Sun a

1330  
01:02:45,119 --> 01:02:52,869  
yellow dwarf if the Sun is a yellow

1331  
01:02:51,039 --> 01:02:54,940  
dwarf I mean obviously there's some

1332  
01:02:52,869 --> 01:02:58,390  
order of magnitude here what would be

1333  
01:02:54,940 --> 01:03:01,119  
the next larger magnitudes of other

1334  
01:02:58,389 --> 01:03:04,058  
stars obviously as an implication that

1335  
01:03:01,119 --> 01:03:09,180  
there are larger stars or Suns yeah our

1336  
01:03:04,059 --> 01:03:13,480  
Sun so how would you describe them as

1337  
01:03:09,179 --> 01:03:15,879  
well I mean I guess you can call this a

1338  
01:03:13,480 --> 01:03:18,900  
star like the Sun a yellow dwarf because

1339  
01:03:15,880 --> 01:03:21,220  
I mean the the color of the Sun that the

1340

01:03:18,900 --> 01:03:23,980  
the wavelength where it emits most of

1341  
01:03:21,219 --> 01:03:27,459  
its light is yellow right as you go

1342  
01:03:23,980 --> 01:03:28,900  
to more massive stars they become hotter

1343  
01:03:27,460 --> 01:03:31,179  
and when something gets hotter the

1344  
01:03:28,900 --> 01:03:34,778  
colors change so you head up a scale

1345  
01:03:31,179 --> 01:03:36,578  
where you go towards bluer stars so if

1346  
01:03:34,778 --> 01:03:38,380  
and then if you go down to the other way

1347  
01:03:36,579 --> 01:03:40,240  
you go down to less massive stars than

1348  
01:03:38,380 --> 01:03:42,160  
the Sun you go down to so-called red

1349  
01:03:40,239 --> 01:03:44,048  
dwarfs because they're cooler and they

1350  
01:03:42,159 --> 01:03:45,879  
emit red radiation instead of yellow

1351  
01:03:44,048 --> 01:03:47,619  
radiation so if you hear a red dwarf

1352  
01:03:45,880 --> 01:03:49,660  
it's smaller than the Sun if you hear a

1353  
01:03:47,619 --> 01:03:53,769  
brown dwarf those are the fail stars we

1354  
01:03:49,659 --> 01:03:55,929

mentioned before that are too low in

1355

01:03:53,768 --> 01:04:07,209

mass to ever get any nuclear reactions

1356

01:03:55,929 --> 01:04:10,239

going at all well if they form a

1357

01:04:07,210 --> 01:04:12,190

spherical object that you can see people

1358

01:04:10,239 --> 01:04:14,409

will call it a star and the dwarf is the

1359

01:04:12,190 --> 01:04:17,019

smallest type of star if it doesn't form

1360

01:04:14,409 --> 01:04:19,409

a star then it wouldn't be called one so

1361

01:04:17,018 --> 01:04:19,409

yes

1362

01:04:25,659 --> 01:04:30,639

that that neutrons will be added to

1363

01:04:29,048 --> 01:04:38,679

actual formation of the different

1364

01:04:30,639 --> 01:04:40,750

elements yes

1365

01:04:38,679 --> 01:04:43,808

so that's a very good point you you add

1366

01:04:40,750 --> 01:04:45,730

a neutron and then depending on what the

1367

01:04:43,809 --> 01:04:48,460

half-life of the newly synthesized

1368

01:04:45,730 --> 01:04:51,039

nuclei is it can data decay to a

1369  
01:04:48,460 --> 01:04:54,010  
different nuclei and then if that one

1370  
01:04:51,039 --> 01:04:56,140  
adds a neutron you can you can start a

1371  
01:04:54,010 --> 01:04:58,240  
new pathway going up from there so

1372  
01:04:56,139 --> 01:05:00,548  
you're right the the beta decay where an

1373  
01:04:58,239 --> 01:05:01,868  
electron is released is a very important

1374  
01:05:00,548 --> 01:05:26,288  
part of that too it's not just the

1375  
01:05:01,869 --> 01:05:30,119  
addition of nuclear yes I I can try to

1376  
01:05:26,289 --> 01:05:32,440  
so that's that's a big subject so they

1377  
01:05:30,119 --> 01:05:36,039  
there's this experiment at the South

1378  
01:05:32,440 --> 01:05:40,480  
Pole called the bicep experiment where

1379  
01:05:36,039 --> 01:05:42,670  
they looked for polarization of the

1380  
01:05:40,480 --> 01:05:44,019  
microwave background I talked about the

1381  
01:05:42,670 --> 01:05:46,960  
microwave background quickly in this

1382  
01:05:44,019 --> 01:05:48,730  
talk they found that for the further for

1383  
01:05:46,960 --> 01:05:52,269  
the first time a particular type of

1384  
01:05:48,730 --> 01:05:55,630  
polarization signal in that microwave

1385  
01:05:52,269 --> 01:05:59,170  
radiation and that polarization signal

1386  
01:05:55,630 --> 01:06:01,480  
is exactly what you expect if you're

1387  
01:05:59,170 --> 01:06:03,099  
seeing the signature of what's called

1388  
01:06:01,480 --> 01:06:04,240  
inflation inflation is something that

1389  
01:06:03,099 --> 01:06:06,039  
happen very soon after the Big Bang

1390  
01:06:04,239 --> 01:06:08,439  
where the universe went from being very

1391  
01:06:06,039 --> 01:06:10,630  
small to very big and it left a certain

1392  
01:06:08,440 --> 01:06:12,818  
signal in the microwave background which

1393  
01:06:10,630 --> 01:06:15,910  
they're claiming they detected now since

1394  
01:06:12,818 --> 01:06:17,650  
that announcement there are people that

1395  
01:06:15,909 --> 01:06:20,230  
have claimed that the signal they're

1396  
01:06:17,650 --> 01:06:22,599  
seeing maybe some somewhat contaminated

1397

01:06:20,230 --> 01:06:25,240  
by dust particles in our in the

1398  
01:06:22,599 --> 01:06:28,960  
foreground and in the Milky Way I think

1399  
01:06:25,239 --> 01:06:32,769  
that question is not a hundred percent

1400  
01:06:28,960 --> 01:06:34,929  
resolved people on the bicep2 team may

1401  
01:06:32,769 --> 01:06:35,949  
still claim that their results are valid

1402  
01:06:34,929 --> 01:06:41,039  
whether or not

1403  
01:06:35,949 --> 01:06:43,719  
there is dust there or not but I think

1404  
01:06:41,039 --> 01:06:45,519  
we're waiting for the latest dust maps

1405  
01:06:43,719 --> 01:06:47,529  
to come out where people have looked at

1406  
01:06:45,519 --> 01:06:50,800  
these four grounds and could very

1407  
01:06:47,530 --> 01:06:52,720  
carefully map how they change with

1408  
01:06:50,800 --> 01:06:54,910  
position and then after those there's

1409  
01:06:52,719 --> 01:07:00,779  
updated dust maps come out then see if

1410  
01:06:54,909 --> 01:07:00,779  
that the bicep results still stand

1411  
01:07:03,599 --> 01:07:11,410

yes so dust grains can they can change

1412

01:07:09,639 --> 01:07:12,819

the color or starlight passing through

1413

01:07:11,409 --> 01:07:14,259

them or any form of light passing

1414

01:07:12,820 --> 01:07:16,539

through them and they can change the

1415

01:07:14,260 --> 01:07:18,400

polarization of light passing through

1416

01:07:16,539 --> 01:07:59,949

them too so they are something that had

1417

01:07:18,400 --> 01:08:01,960

to be understood right so when they do

1418

01:07:59,949 --> 01:08:04,509

polarization measurements they have to

1419

01:08:01,960 --> 01:08:08,530

use more than one frequency because if

1420

01:08:04,510 --> 01:08:11,470

you have more than one then you can you

1421

01:08:08,530 --> 01:08:15,000

you can figure out what the actual the

1422

01:08:11,469 --> 01:08:15,000

effect is rather than something else

1423

01:08:27,270 --> 01:08:30,270

okay

1424

01:08:30,960 --> 01:08:37,109

yeah going to the experiments

1425

01:08:38,970 --> 01:08:47,190

spectrum are you looking at the gas

1426  
01:08:42,279 --> 01:08:54,068  
through teasing out the redshift effects

1427  
01:08:47,189 --> 01:08:59,949  
yes you're getting the closer gas and

1428  
01:08:54,069 --> 01:09:02,859  
the further gas that's exactly right and

1429  
01:08:59,949 --> 01:09:06,179  
I didn't go into detail on that just for

1430  
01:09:02,859 --> 01:09:10,750  
reasons of time but if I put this quasar

1431  
01:09:06,180 --> 01:09:13,690  
absorption line slide up again let's

1432  
01:09:10,750 --> 01:09:16,569  
assume that this light this line that's

1433  
01:09:13,689 --> 01:09:17,949  
being absorbed is the hydrogen line then

1434  
01:09:16,569 --> 01:09:19,780  
the only difference between these three

1435  
01:09:17,949 --> 01:09:22,449  
clouds is how far star they moving away

1436  
01:09:19,779 --> 01:09:23,949  
from you so this one is the most distant

1437  
01:09:22,449 --> 01:09:26,289  
that means it's going to have the

1438  
01:09:23,949 --> 01:09:28,838  
highest redshift so the lion appears

1439  
01:09:26,289 --> 01:09:31,329  
closest to the red and then this cloud

1440  
01:09:28,838 --> 01:09:32,798  
is less distant it gives you a line that

1441  
01:09:31,329 --> 01:09:34,720  
is here in the yellow part of the

1442  
01:09:32,798 --> 01:09:36,640  
spectrum whereas the cloud that is

1443  
01:09:34,720 --> 01:09:37,930  
closest to the earth and gives you a

1444  
01:09:36,640 --> 01:09:47,109  
line that is in the blue part of the

1445  
01:09:37,930 --> 01:09:49,329  
spectrum mostly but they do have metals

1446  
01:09:47,109 --> 01:09:51,640  
in them too modern say metals in the

1447  
01:09:49,329 --> 01:09:53,409  
sense of heavier elements now this is a

1448  
01:09:51,640 --> 01:09:55,960  
simplification in that I'm just showing

1449  
01:09:53,409 --> 01:09:58,210  
one line hydrogen has more than one line

1450  
01:09:55,960 --> 01:09:59,829  
has whole series of lines but having

1451  
01:09:58,210 --> 01:10:03,159  
that pattern of lines helps you to

1452  
01:09:59,829 --> 01:10:05,829  
identify which red shift something comes

1453  
01:10:03,159 --> 01:10:08,710  
from so you have many you have many

1454

01:10:05,829 --> 01:10:10,539  
different fingerprints that you use to

1455  
01:10:08,710 --> 01:10:12,369  
identify the chemical elements and how

1456  
01:10:10,539 --> 01:10:14,019  
far the clouds are moving away from you

1457  
01:10:12,369 --> 01:10:16,479  
so this is a simplification where I've

1458  
01:10:14,020 --> 01:10:18,610  
got one element and one line real clouds

1459  
01:10:16,479 --> 01:10:22,089  
have lots of elements with lots of lines

1460  
01:10:18,609 --> 01:10:31,029  
giving you complicated spectra that you

1461  
01:10:22,090 --> 01:10:33,250  
need well if you look at one of these

1462  
01:10:31,029 --> 01:10:36,819  
this is a lyman-alpha forest spectrum

1463  
01:10:33,250 --> 01:10:38,979  
probably something like 5050 lines there

1464  
01:10:36,819 --> 01:10:40,539  
and that's just in this and this is only

1465  
01:10:38,979 --> 01:10:42,849  
a small portion of the spectrum that I'm

1466  
01:10:40,539 --> 01:10:44,949  
showing in the here in the rest frame

1467  
01:10:42,850 --> 01:10:47,020  
ultraviolet so you dependence on the way

1468  
01:10:44,949 --> 01:10:49,090

you're looking there's huge numbers of

1469

01:10:47,020 --> 01:10:50,920

lines you can look at in the infrared in

1470

01:10:49,090 --> 01:10:53,310

the optical radio different parts of the

1471

01:10:50,920 --> 01:10:53,310

spectrum