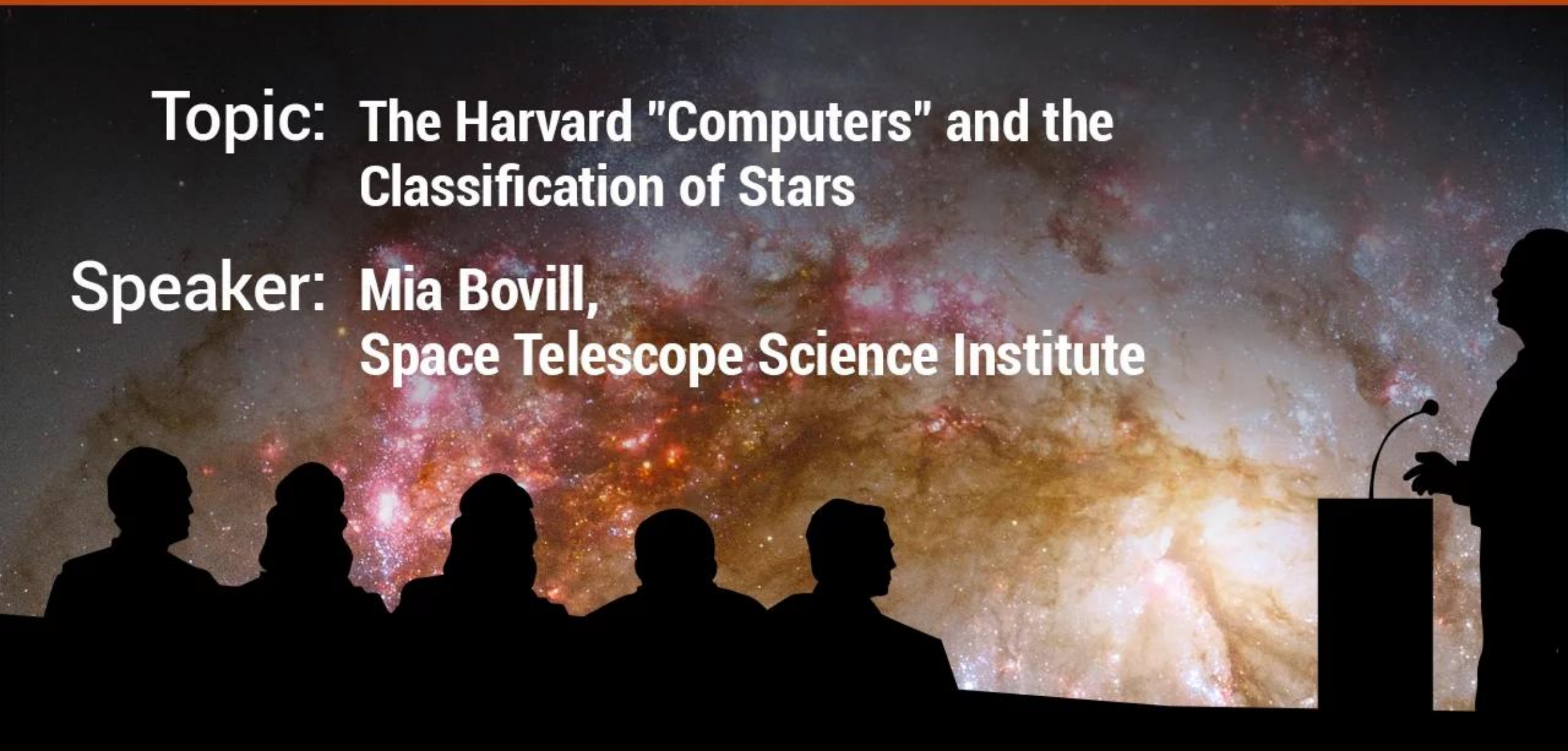
Public Lecture Series



Topic: The Harvard "Computers" and the Classification of Stars

Speaker: Mia Bovill,
Space Telescope Science Institute

1
00:00:04,700 --> 00:00:02,270
then we have our beautiful beautiful

2
00:00:07,519 --> 00:00:04,710
pictures tonight special requests by our

3
00:00:11,270 --> 00:00:07,529
speaker that you have the core of the

4
00:00:13,520 --> 00:00:11,280
globular cluster Omega Centauri okay and

5
00:00:16,460 --> 00:00:13,530
all these beautiful red and blue stars

6
00:00:19,130 --> 00:00:16,470
which are actually ultraviolet and

7
00:00:20,900 --> 00:00:19,140
infrared as well as visible light it

8
00:00:24,920 --> 00:00:20,910
covers the full spectrum with Wide Field

9
00:00:27,740 --> 00:00:24,930
Camera 3 it's beautiful more details

10
00:00:29,150 --> 00:00:27,750
available on the back and I hope our

11
00:00:31,429 --> 00:00:29,160
speaker will actually talk about that a

12
00:00:35,150 --> 00:00:31,439
little bit tonight who is our speaker

13
00:00:36,200 --> 00:00:35,160

our speaker is MIA boville she is going

14
00:00:38,540 --> 00:00:36,210
to talk to you about the Harvard

15
00:00:40,670 --> 00:00:38,550
computers and the classification of

16
00:00:43,369 --> 00:00:40,680
stars of course this was work done a

17
00:00:46,880 --> 00:00:43,379
century ago so computers is in quotes

18
00:00:48,590 --> 00:00:46,890
and you'll understand that in a bit next

19
00:00:51,350 --> 00:00:48,600
month I've been having trouble getting

20
00:00:54,290 --> 00:00:51,360
people to commit to June usually July is

21
00:00:56,240 --> 00:00:54,300
my problem okay but I've had people try

22
00:00:57,020 --> 00:00:56,250
so it's still to be announced but I'm

23
00:00:58,400 --> 00:00:57,030
working on it

24
00:01:00,709 --> 00:00:58,410
trust me I'm working I'll find

25
00:01:04,250 --> 00:01:00,719
somebody's arm to twist for next June

26
00:01:06,410 --> 00:01:04,260
June 6th July is actually been moved

27
00:01:08,630 --> 00:01:06,420
early because we have amber Straughn

28
00:01:11,030 --> 00:01:08,640
from Goddard Space Flight Center here

29
00:01:13,910 --> 00:01:11,040
and she will be talking on dark energy

30
00:01:16,640 --> 00:01:13,920
and new worlds the science that is we

31
00:01:19,240 --> 00:01:16,650
hope to accomplish with NASA's W first

32
00:01:22,130 --> 00:01:19,250
mission that will hopefully launch

33
00:01:23,899 --> 00:01:22,140
sometime next decade

34
00:01:25,730 --> 00:01:23,909
there will be no lecture in July because

35
00:01:27,760 --> 00:01:25,740
we're taking Amber's lecture and

36
00:01:31,160 --> 00:01:27,770
counting that as our July lecture in

37
00:01:33,590 --> 00:01:31,170
August I have a really cool talk for you

38
00:01:35,929 --> 00:01:33,600

the view for Mission Operations that's

39
00:01:38,149 --> 00:01:35,939
not the title I just made that up this

40
00:01:41,120 --> 00:01:38,159
afternoon she hasn't given me a title

41
00:01:43,670 --> 00:01:41,130
but Courtney McManus who has worked on

42
00:01:45,889 --> 00:01:43,680
Mission Operations for the International

43
00:01:48,530 --> 00:01:45,899
Space Station and we're talking we have

44
00:01:50,569 --> 00:01:48,540
the missions opera operations here for

45
00:01:53,060 --> 00:01:50,579
JD OST here in the building so we tell

46
00:01:57,969 --> 00:01:53,070
you all sorts of cool stuff from Mission

47
00:02:00,410 --> 00:01:57,979
Operations standpoint August 1st 2017

48
00:02:03,350 --> 00:02:00,420
can't remember all that you can go to

49
00:02:06,260 --> 00:02:03,360
our website on Hubble site and by the

50
00:02:07,580 --> 00:02:06,270
way Hubble site has been designed has

51
00:02:09,919 --> 00:02:07,590
been changing I don't know how many of

52
00:02:11,690 --> 00:02:09,929
you go to our Hubble site website but

53
00:02:13,070 --> 00:02:11,700
we've been changing it and modernizing

54
00:02:15,970 --> 00:02:13,080
it all the content is

55
00:02:18,560 --> 00:02:15,980
still there okay you can still find us

56
00:02:19,820 --> 00:02:18,570
finding this bed page is probably the

57
00:02:22,310 --> 00:02:19,830
easiest if you go to your favorite

58
00:02:24,890 --> 00:02:22,320
search engine type in Hubbell public

59
00:02:27,610 --> 00:02:24,900
talks you'll find this web page on the

60
00:02:30,980 --> 00:02:27,620
web page we have our links to our live

61
00:02:34,340 --> 00:02:30,990
webcasting links to the archive all the

62
00:02:37,250 --> 00:02:34,350
way back to 2005 in the stsci webcasting

63
00:02:39,920 --> 00:02:37,260

archives as well as a way to sign up for

64
00:02:42,350 --> 00:02:39,930
our email list to get our couple

65
00:02:46,190 --> 00:02:42,360
reminders a month about the talks that

66
00:02:47,840 --> 00:02:46,200
are coming the announcements again sign

67
00:02:48,470 --> 00:02:47,850
up at the website but if you want to do

68
00:02:51,949 --> 00:02:48,480
it the hard way

69
00:02:53,540 --> 00:02:51,959
you can go to mail lists STScI edu the

70
00:02:56,510 --> 00:02:53,550
mail list is called public lecture

71
00:02:59,510 --> 00:02:56,520
announce if you would like to ask us

72
00:03:04,190 --> 00:02:59,520
questions send us comments you can send

73
00:03:05,600 --> 00:03:04,200
email to public lecture at stsci edu for

74
00:03:09,650 --> 00:03:05,610
those of you who like social media

75
00:03:12,550 --> 00:03:09,660
hubble has several ways of communicating

76
00:03:14,930 --> 00:03:12,560
Facebook Twitter feeds Google Plus and

77
00:03:17,479 --> 00:03:14,940
Pinterest out there for those of you who

78
00:03:18,680 --> 00:03:17,489
use those social media myself I have a

79
00:03:21,440 --> 00:03:18,690
blog on Hubbell site

80
00:03:23,750 --> 00:03:21,450
I have Facebook Google+ and Twitter that

81
00:03:25,220 --> 00:03:23,760
I occasionally do but unlike the

82
00:03:29,420 --> 00:03:25,230
president I have better things to do

83
00:03:31,790 --> 00:03:29,430
with my time uh-huh so I have a tendency

84
00:03:35,000 --> 00:03:31,800
to do my science rather than spend too

85
00:03:37,550 --> 00:03:35,010
much time on Twitter okay

86
00:03:40,729 --> 00:03:37,560
Observatory tonight yes the weather is

87
00:03:42,680 --> 00:03:40,739
permitting I talked with Irene E and she

88
00:03:44,810 --> 00:03:42,690

should be here about nine o'clock or so

89
00:03:46,610 --> 00:03:44,820
to take a group across the street to

90
00:03:48,890 --> 00:03:46,620
look through the telescope across the

91
00:03:51,350 --> 00:03:48,900
street so at the end of the lecture if I

92
00:03:52,820 --> 00:03:51,360
forget somebody remind me you'll meet

93
00:03:56,360 --> 00:03:52,830
down here with Irene II and she'll take

94
00:04:00,110 --> 00:03:56,370
you across the street alright and now

95
00:04:06,890 --> 00:04:00,120
okay my section news from the universe

96
00:04:11,470 --> 00:04:06,900
for May 2017 our top story tonight by

97
00:04:13,550 --> 00:04:11,480
Jupiter it's quite a beautiful planet

98
00:04:15,680 --> 00:04:13,560
Thomas can we take the lights down a bit

99
00:04:21,970 --> 00:04:15,690
there's a little bit of spillage onto

100
00:04:29,510 --> 00:04:24,770
okay that's good thank you all right

101
00:04:32,180 --> 00:04:29,520
so every once a year a Jupiter gets into

102
00:04:34,910 --> 00:04:32,190
up what's called opposition okay where

103
00:04:37,610 --> 00:04:34,920
the Sun and Jupiter on the are on the

104
00:04:40,220 --> 00:04:37,620
opposite sides of Earth well this is the

105
00:04:41,900 --> 00:04:40,230
point in Jupiter's orbit when it is

106
00:04:43,730 --> 00:04:41,910
closest to Earth because you can see

107
00:04:45,830 --> 00:04:43,740
that if it were located anywhere else

108
00:04:48,140 --> 00:04:45,840
around its circle around its orbital

109
00:04:52,580 --> 00:04:48,150
circle it would be further from Earth so

110
00:04:54,290 --> 00:04:52,590
the best viewing its closest point is at

111
00:04:57,470 --> 00:04:54,300
opposition also it's its best viewing

112
00:05:00,200 --> 00:04:57,480
because it's up exactly opposite the Sun

113
00:05:02,150 --> 00:05:00,210

so it's not not not up at sunset not up

114
00:05:05,000 --> 00:05:02,160
at sunrise where you have interference

115
00:05:06,350 --> 00:05:05,010
of that and you can see it now Hubble

116
00:05:08,450 --> 00:05:06,360
doesn't have to worry about that too

117
00:05:10,730 --> 00:05:08,460
much because Hubble can doesn't have to

118
00:05:12,140 --> 00:05:10,740
puffles up and up in space and it

119
00:05:14,180 --> 00:05:12,150
doesn't have to worry about you know

120
00:05:15,560 --> 00:05:14,190
daytime versus nighttime because you

121
00:05:19,190 --> 00:05:15,570
know it doesn't have the atmosphere to

122
00:05:21,500 --> 00:05:19,200
look through however we often take

123
00:05:23,540 --> 00:05:21,510
pictures of the planets when they are

124
00:05:26,360 --> 00:05:23,550
opposition and you might think to

125
00:05:28,460 --> 00:05:26,370
yourself well we've had missions that go

126
00:05:30,170 --> 00:05:28,470
to the planets what can Hubble offer and

127
00:05:33,530 --> 00:05:30,180
I sometimes look at these these

128
00:05:34,250 --> 00:05:33,540
presley's as we do and go okay but you

129
00:05:45,470 --> 00:05:34,260
know what

130
00:05:51,260 --> 00:05:45,480
whoops hmm well let me replug ah you

131
00:06:01,069 --> 00:05:51,270
know what this is an observation we have

132
00:06:13,889 --> 00:06:08,789
there we go okay there we go now we got

133
00:06:17,459 --> 00:06:13,899
it we're back great um but you know what

134
00:06:19,499 --> 00:06:17,469
sometimes we just get it right so this

135
00:06:23,359 --> 00:06:19,509
is our picture of Jupiter and opposition

136
00:06:28,439 --> 00:06:26,549
isn't that cool I mean I remember when

137
00:06:31,379 --> 00:06:28,449
we had to have the Voyager missions to

138
00:06:33,329 --> 00:06:31,389

go across go across interplanetary space

139
00:06:35,850 --> 00:06:33,339
to get something that look this gorgeous

140
00:06:39,329 --> 00:06:35,860
I just love all of the hydrodynamic

141
00:06:41,579 --> 00:06:39,339
effects okay I'm I'm a sucker for all

142
00:06:43,859 --> 00:06:41,589
the hydrodynamic effects of the vortices

143
00:06:45,959 --> 00:06:43,869
and the swirls in Jupiter's atmosphere

144
00:06:48,959 --> 00:06:45,969
plus you'll notice we've got not only

145
00:06:51,179 --> 00:06:48,969
the Great Red Spot but also we have what

146
00:06:53,729 --> 00:06:51,189
we colloquially call Red Spot jr.

147
00:06:57,449 --> 00:06:53,739
officially called oval ba

148
00:07:01,499 --> 00:06:57,459
I much prefer Red Spot jr. and red oval

149
00:07:05,369 --> 00:07:01,509
ba formed in the year 2000 okay we had

150
00:07:07,919 --> 00:07:05,379
never seen a second red spot until it

151
00:07:09,689 --> 00:07:07,929
actually well it formed as a white white

152
00:07:12,179 --> 00:07:09,699
spot and then turned red a few years

153
00:07:15,749 --> 00:07:12,189
later but it has now been around for

154
00:07:18,359 --> 00:07:15,759
almost 15 15 20 years okay so we're

155
00:07:21,719 --> 00:07:18,369
seeing a second Red Spot on Jupiter and

156
00:07:23,569 --> 00:07:21,729
it appears to be long-lived but I just

157
00:07:26,969 --> 00:07:23,579
thought this was a really wonderful

158
00:07:28,979 --> 00:07:26,979
beautiful image of Jupiter our second

159
00:07:33,089 --> 00:07:28,989
story tonight is also from the solar

160
00:07:34,350 --> 00:07:33,099
system Europa's Old Faithful alright so

161
00:07:36,509 --> 00:07:34,360
first of all let's make sure everyone

162
00:07:38,749 --> 00:07:36,519
remembers what Old Faithful is Old

163
00:07:42,269 --> 00:07:38,759

Faithful is the geyser in Yellowstone

164
00:07:45,659 --> 00:07:42,279
National Park that erupts approximately

165
00:07:47,279 --> 00:07:45,669
every 90 minutes is that right is that

166
00:07:47,489 --> 00:07:47,289
about 90 minutes or is it longer than

167
00:07:50,549 --> 00:07:47,499
that

168
00:07:52,350 --> 00:07:50,559
yes Caryn's wait Shane yes which is

169
00:07:54,089 --> 00:07:52,360
actually incidentally about the same

170
00:07:56,399 --> 00:07:54,099
time it takes orbit Hubble to orbit

171
00:07:59,699 --> 00:07:56,409
around Earth so every time Hubble passes

172
00:08:02,609 --> 00:07:59,709
over Old Faithful erupts right not quite

173
00:08:06,359 --> 00:08:02,619
and so this is a geyser from Hot Springs

174
00:08:08,729 --> 00:08:06,369
okay and so the idea is that the water

175
00:08:11,850 --> 00:08:08,739
spews up a hundred feet in the air or so

176
00:08:13,570 --> 00:08:11,860
right well if you remember if you were

177
00:08:15,820 --> 00:08:13,580
here last year

178
00:08:18,610 --> 00:08:15,830
I told you about seeing a plume on

179
00:08:21,640 --> 00:08:18,620
Europa that spews out a little bit

180
00:08:23,170 --> 00:08:21,650
further than a hundred feet all right so

181
00:08:26,529 --> 00:08:23,180
you got to understand this image okay

182
00:08:28,659 --> 00:08:26,539
first of all the plume is in white which

183
00:08:30,429 --> 00:08:28,669
is really pulled out of the data it's

184
00:08:34,750 --> 00:08:30,439
really hard to see this it's actually

185
00:08:37,269 --> 00:08:34,760
seen in shadow against the surface of

186
00:08:40,329 --> 00:08:37,279
Jupiter so Europa is passing in front of

187
00:08:42,100 --> 00:08:40,339
of Jupiter and we're seeing that plume

188
00:08:44,230 --> 00:08:42,110

in shadow it's been reversed here so

189
00:08:46,389 --> 00:08:44,240
that you can see it as white and then

190
00:08:48,519 --> 00:08:46,399
the picture of Europa here is not from

191
00:08:50,530 --> 00:08:48,529
Hubble this is actually from the Galileo

192
00:08:52,120 --> 00:08:50,540
mission all right as remember I said we

193
00:08:53,829 --> 00:08:52,130
get missions that have been there they

194
00:08:55,840 --> 00:08:53,839
got better pictures so to give you an

195
00:08:58,960 --> 00:08:55,850
idea of what we're seeing we've taken

196
00:09:00,250 --> 00:08:58,970
the Hubble data stretched it in contrast

197
00:09:02,620 --> 00:09:00,260
so you can see the plume because it's

198
00:09:05,139 --> 00:09:02,630
really tiny there and then thrown the

199
00:09:08,350 --> 00:09:05,149
Galileo image on top of it okay this is

200
00:09:11,170 --> 00:09:08,360
what I told you about last year well we

201
00:09:17,259 --> 00:09:11,180
looked again to try and see if this was

202
00:09:19,900 --> 00:09:17,269
a recurring event and yes it is we are

203
00:09:22,329 --> 00:09:19,910
see another plume now we don't see it

204
00:09:24,220 --> 00:09:22,339
every time we look for it okay we have

205
00:09:26,920 --> 00:09:24,230
done this observation of multiple times

206
00:09:29,470 --> 00:09:26,930
sometimes we see it sometimes we don't

207
00:09:31,420 --> 00:09:29,480
which gave me the sort of instance of

208
00:09:33,759 --> 00:09:31,430
Old Faithful that it sometimes erupts

209
00:09:36,430 --> 00:09:33,769
and sometimes does it what does this

210
00:09:39,220 --> 00:09:36,440
mean well the surface of Europa if you

211
00:09:42,220 --> 00:09:39,230
look at it in detail resembles cracked

212
00:09:44,439 --> 00:09:42,230
ice rafts on in the Arctic this is

213
00:09:46,900 --> 00:09:44,449

actually the surface of Europa and you

214
00:09:50,410 --> 00:09:46,910
can see all the ices when all the cracks

215
00:09:53,829 --> 00:09:50,420
in it okay all right and when we're

216
00:09:56,170 --> 00:09:53,839
because we're able to time when it when

217
00:09:59,500 --> 00:09:56,180
we saw this plume and where it was on on

218
00:10:01,060 --> 00:09:59,510
on the moon were able to narrow down to

219
00:10:05,110 --> 00:10:01,070
where we thought the plume was coming

220
00:10:08,470 --> 00:10:05,120
from to these cracks here on Europa all

221
00:10:11,139 --> 00:10:08,480
right and the idea was to say all right

222
00:10:14,800 --> 00:10:11,149
why would these cracks be emitting a

223
00:10:17,110 --> 00:10:14,810
water vapor well turns out that a

224
00:10:20,290 --> 00:10:17,120
temperature measure of the surface of

225
00:10:23,439 --> 00:10:20,300
Europa shows that that area is 3 degrees

226
00:10:26,019 --> 00:10:23,449
warmer than the rest now you have to

227
00:10:27,370 --> 00:10:26,029
recognize three degrees warmer is going

228
00:10:30,550 --> 00:10:27,380
from 92 Kelvin

229
00:10:32,110 --> 00:10:30,560
295 Kelvin and this is an absolute scale

230
00:10:34,630 --> 00:10:32,120
so this is minus a couple hundred

231
00:10:36,850 --> 00:10:34,640
degrees Fahrenheit okay so when I say

232
00:10:39,010 --> 00:10:36,860
warmer I really should be saying three

233
00:10:43,600 --> 00:10:39,020
degrees less totally absolutely frigid

234
00:10:46,600 --> 00:10:43,610
okay but it is actually warmer so the

235
00:10:48,220 --> 00:10:46,610
idea behind all this all right

236
00:10:50,050 --> 00:10:48,230
the idea behind our understanding of

237
00:10:53,110 --> 00:10:50,060
Europa is we have understood that

238
00:10:56,860 --> 00:10:53,120

underneath it's icy surface there is

239
00:10:59,800 --> 00:10:56,870
probably a liquid water layer now

240
00:11:01,930 --> 00:10:59,810
originally we thought that that icy sea

241
00:11:04,120 --> 00:11:01,940
crust was about a hundred kilometers

242
00:11:04,720 --> 00:11:04,130
thick and if you wanted to sample the

243
00:11:06,220 --> 00:11:04,730
water

244
00:11:08,140 --> 00:11:06,230
you'd have to drill down through a

245
00:11:10,990 --> 00:11:08,150
hundred kilometers which is not a very

246
00:11:14,080 --> 00:11:11,000
easy task however if we're seeing these

247
00:11:16,810 --> 00:11:14,090
plumes and we're seeing them with more

248
00:11:18,640 --> 00:11:16,820
than once it may indicate that there are

249
00:11:21,130 --> 00:11:18,650
pockets of water maybe not the ocean

250
00:11:22,780 --> 00:11:21,140
underneath a layer but maybe there are

251
00:11:26,470 --> 00:11:22,790
pockets of water they're just a few

252
00:11:27,850 --> 00:11:26,480
kilometers down in the ice if you

253
00:11:31,420 --> 00:11:27,860
remember what we learned about Pluto

254
00:11:33,190 --> 00:11:31,430
last year cryo tectonics is really much

255
00:11:35,710 --> 00:11:33,200
more important in the outer solar system

256
00:11:37,510 --> 00:11:35,720
than we'd really understood so we

257
00:11:40,980 --> 00:11:37,520
learned that also about europa that they

258
00:11:44,590 --> 00:11:40,990
Isis move and Kraken and and the

259
00:11:47,320 --> 00:11:44,600
dynamics of ices is a lot more than we

260
00:11:49,210 --> 00:11:47,330
had previously suspected and in perhaps

261
00:11:53,230 --> 00:11:49,220
there are pockets of water that are one

262
00:11:55,270 --> 00:11:53,240
to few kilometers down then that raises

263
00:11:58,000 --> 00:11:55,280

the prospect for being able to go there

264
00:12:00,730 --> 00:11:58,010
drill down to it or melt down to it and

265
00:12:03,880 --> 00:12:00,740
be able to sample it now why would we

266
00:12:05,980 --> 00:12:03,890
care about water well because there are

267
00:12:08,290 --> 00:12:05,990
three things required for life in the

268
00:12:12,010 --> 00:12:08,300
universe that as we know it one is

269
00:12:14,500 --> 00:12:12,020
carbon carbon is everywhere two is a

270
00:12:18,910 --> 00:12:14,510
source of heat we got sources of energy

271
00:12:21,220 --> 00:12:18,920
all over the place and three is water so

272
00:12:24,910 --> 00:12:21,230
our search for life in the universe is

273
00:12:27,000 --> 00:12:24,920
often just boil down to a search for

274
00:12:29,560 --> 00:12:27,010
water where ever liquid water can exist

275
00:12:32,260 --> 00:12:29,570
perhaps life can exist and we have seen

276
00:12:35,020 --> 00:12:32,270
life in all sorts of extreme places here

277
00:12:38,140 --> 00:12:35,030
on earth so Europa is one of our

278
00:12:40,650 --> 00:12:38,150
strongest candidates for possibly having

279
00:12:42,540 --> 00:12:40,660
life elsewhere in the solar system

280
00:12:44,249 --> 00:12:42,550
and the observations from Hubble have

281
00:12:46,829 --> 00:12:44,259
done yet another small part in

282
00:12:49,199 --> 00:12:46,839
convincing us that hey this is a really

283
00:12:52,170 --> 00:12:49,209
cool system we ought to continue to

284
00:12:56,519 --> 00:12:52,180
investigate it and yes it's become one

285
00:13:00,230 --> 00:12:56,529
of our main points of study for trying

286
00:13:04,379 --> 00:13:00,240
to understand our in our solar system

287
00:13:07,139 --> 00:13:04,389
all right third story tonight our 27th

288
00:13:10,499 --> 00:13:07,149

anniversary perspectives on spiral

289
00:13:12,960 --> 00:13:10,509
galaxies the 27th anniversary is of this

290
00:13:15,720 --> 00:13:12,970
event the launch and deployment of the

291
00:13:17,550 --> 00:13:15,730
Hubble Space Telescope it has been 27

292
00:13:19,410 --> 00:13:17,560
years isn't that great

293
00:13:22,710 --> 00:13:19,420
all right we've been up there for 27

294
00:13:26,100 --> 00:13:22,720
years doing science and so every year

295
00:13:27,809 --> 00:13:26,110
they ask us to do a really cool of image

296
00:13:30,090 --> 00:13:27,819
for the 20th for the anniversary and

297
00:13:32,100 --> 00:13:30,100
it's I gotta say one of the gentlemen

298
00:13:34,110 --> 00:13:32,110
who helps choose these images is in the

299
00:13:36,329 --> 00:13:34,120
audience right now and he can confirm

300
00:13:38,100 --> 00:13:36,339
that it's really really hard to keep

301
00:13:41,490 --> 00:13:38,110
outdoing themselves themselves every

302
00:13:44,100 --> 00:13:41,500
year so this year we chose some spiral

303
00:13:46,769 --> 00:13:44,110
galaxies okay and these spiral galaxies

304
00:13:51,389 --> 00:13:46,779
are in the Virgo cluster so we're going

305
00:13:54,240 --> 00:13:51,399
to zoom in from a wide field view I'm

306
00:13:58,319 --> 00:13:54,250
going to go keep going down and going

307
00:14:03,090 --> 00:13:58,329
down and zooming in until we come into

308
00:14:10,550 --> 00:14:03,100
these two spiral galaxies NGC 4302 and

309
00:14:12,840 --> 00:14:10,560
NGC 42.9 t8 such wonderful names and

310
00:14:15,090 --> 00:14:12,850
those are the two spiral galaxies we

311
00:14:17,819 --> 00:14:15,100
chose for the Hubble 27th anniversary

312
00:14:20,670 --> 00:14:17,829
image now if you notice at the end of

313
00:14:22,949 --> 00:14:20,680

that movie it zoomed in in visible light

314
00:14:24,929 --> 00:14:22,959
and then switch to infrared so let me

315
00:14:28,259 --> 00:14:24,939
show you those in detail here is the

316
00:14:31,439 --> 00:14:28,269
Hubble image using visible light and

317
00:14:34,620 --> 00:14:31,449
this is the infrared view all right

318
00:14:37,280 --> 00:14:34,630
using the the NIR and Freud capabilities

319
00:14:41,840 --> 00:14:37,290
of Hubble so visible light infrared

320
00:14:44,639 --> 00:14:41,850
light and you can see that you can the

321
00:14:46,410 --> 00:14:44,649
difference in how we view the galaxies

322
00:14:48,749 --> 00:14:46,420
changes according to the wavelength in

323
00:14:50,670 --> 00:14:48,759
which we view them well we also wanted

324
00:14:53,759 --> 00:14:50,680
to give you another perspective on them

325
00:14:55,229 --> 00:14:53,769
so we created this visualization to

326
00:15:24,910 --> 00:14:55,239
help you understand the shape of these

327
00:15:29,600 --> 00:15:28,280
and so by rotating those galaxies in 3d

328
00:15:31,370 --> 00:15:29,610
by the ways those are just computer

329
00:15:33,410 --> 00:15:31,380
models of the galaxies we don't know the

330
00:15:36,189 --> 00:15:33,420
exact details matter of fact the

331
00:15:40,220 --> 00:15:36,199
galaxies on the left NGC 4302

332
00:15:42,500 --> 00:15:40,230
the model that we used is a model based

333
00:15:44,960 --> 00:15:42,510
on the galaxy m51 the Whirlpool Galaxy

334
00:15:47,389 --> 00:15:44,970
because we're seeing that galaxy edge-on

335
00:15:48,769 --> 00:15:47,399
we really can't tell the truth read a

336
00:15:51,199 --> 00:15:48,779
dimensional structure so we had to use

337
00:15:54,590 --> 00:15:51,209
as I like to say a stunt-double galaxy

338
00:15:57,009 --> 00:15:54,600

for it but that gives you a mental model

339
00:15:59,360 --> 00:15:57,019
of what you're seeing in this image and

340
00:16:02,240 --> 00:15:59,370
when I show you another image which is

341
00:16:04,280 --> 00:16:02,250
also in the Virgo cluster I show you

342
00:16:07,100 --> 00:16:04,290
this image of all these various spiral

343
00:16:09,050 --> 00:16:07,110
galaxies you now have the mental model

344
00:16:10,790 --> 00:16:09,060
in your head to interpret this and say

345
00:16:13,939 --> 00:16:10,800
okay these are all pretty much those

346
00:16:17,240 --> 00:16:13,949
same disc shaped galaxies but seen at

347
00:16:20,030 --> 00:16:17,250
different angles so in doing this you

348
00:16:21,829 --> 00:16:20,040
gain a mental model of how spiral

349
00:16:24,800 --> 00:16:21,839
galaxies look and you can see them in

350
00:16:29,809 --> 00:16:24,810
perspective you can translate images

351
00:16:34,069 --> 00:16:29,819
such as this alright and now it's time

352
00:16:36,139 --> 00:16:34,079
for our featured speaker Mia Bobo Mia is

353
00:16:39,290 --> 00:16:36,149
been here at the Space Telescope Science

354
00:16:41,509 --> 00:16:39,300
Institute for only a year and a half she

355
00:16:42,769 --> 00:16:41,519
gave a wonderful talk last year and I'm

356
00:16:45,730 --> 00:16:42,779
really looking forward to her talk this

357
00:16:49,430 --> 00:16:45,740
year she got her bachelor's and her

358
00:16:52,430 --> 00:16:49,440
master's that bachelors and her PhD from

359
00:16:54,110 --> 00:16:52,440
the University of Maryland physics she

360
00:16:56,980 --> 00:16:54,120
spent a year at the University of Texas

361
00:16:59,809 --> 00:16:56,990
at Austin before spending three years

362
00:17:01,490 --> 00:16:59,819
down in Chile at some unpronounceable

363
00:17:03,379 --> 00:17:01,500

Institute in Santiago

364
00:17:06,049 --> 00:17:03,389
she said she'd pronounced it for you she

365
00:17:08,510 --> 00:17:06,059
wouldn't make me try to pronounce it she

366
00:17:11,299 --> 00:17:08,520
came here and her shoes does her

367
00:17:13,480 --> 00:17:11,309
research on dwarf galaxies as she likes

368
00:17:16,460 --> 00:17:13,490
to say the smallest of the small

369
00:17:18,470 --> 00:17:16,470
galaxies generally those in the nearby

370
00:17:20,780 --> 00:17:18,480
neighborhood nearby universe are those

371
00:17:22,250 --> 00:17:20,790
in the very distant universe she doesn't

372
00:17:25,220 --> 00:17:22,260
care about the 10 or 11 billion

373
00:17:27,530 --> 00:17:25,230
light-years in between she also would

374
00:17:29,840 --> 00:17:27,540
like to note that for tonight she's

375
00:17:32,150 --> 00:17:29,850
doing a talk on the women from Harvard

376
00:17:33,470 --> 00:17:32,160
and when she was an undergraduate she

377
00:17:36,649 --> 00:17:33,480
did a research experience for

378
00:17:38,169 --> 00:17:36,659
undergraduates at Harvard working on of

379
00:17:40,149 --> 00:17:38,179
all things star

380
00:17:42,500 --> 00:17:40,159
Meishan so ladies and gentlemen our

381
00:17:51,070 --> 00:17:42,510
speaker tonight mia boville

382
00:17:57,830 --> 00:17:54,700
can you hear me okay

383
00:18:00,710 --> 00:17:57,840
and it's instituto de astrophysical

384
00:18:06,400 --> 00:18:00,720
Pontificia Universidad católica de Chile

385
00:18:10,640 --> 00:18:08,720
when astronomers talk about the Harvard

386
00:18:14,000 --> 00:18:10,650
computers we actually don't put quotes

387
00:18:16,039 --> 00:18:14,010
around them um this is this is an image

388
00:18:20,210 --> 00:18:16,049

of the Harvard computers it is a group

389
00:18:22,789 --> 00:18:20,220
of women it is a group of women that

390
00:18:26,060 --> 00:18:22,799
worked at the Harvard Observatory over

391
00:18:29,600 --> 00:18:26,070
the course of about 40 years they

392
00:18:32,030 --> 00:18:29,610
generally stayed for 10 20 30 years and

393
00:18:34,580 --> 00:18:32,040
up until the 1920s this was the only

394
00:18:37,340 --> 00:18:34,590
place where you could be a woman and a

395
00:18:39,080 --> 00:18:37,350
professional astronomer other than some

396
00:18:44,510 --> 00:18:39,090
of the women's colleges like Vassar

397
00:18:46,720 --> 00:18:44,520
which has had Mariah Mitchell but what

398
00:18:49,460 --> 00:18:46,730
did they do that was so incredible and

399
00:18:50,930 --> 00:18:49,470
before I get into that the scientific

400
00:18:53,060 --> 00:18:50,940
parts of this story and their

401
00:18:54,710 --> 00:18:53,070
contributions to astronomy are so

402
00:18:58,280 --> 00:18:54,720
fundamental that you learn about them in

403
00:18:59,480 --> 00:18:58,290
your very very first year in fact you

404
00:19:03,710 --> 00:18:59,490
learn about them an introduction to

405
00:19:05,930 --> 00:19:03,720
astronomy for poets but the human side

406
00:19:07,669 --> 00:19:05,940
of this story and many of the quotes

407
00:19:09,320 --> 00:19:07,679
that I'm pretty much all the quotes that

408
00:19:10,940 --> 00:19:09,330
I'm going to be using come from this

409
00:19:14,419 --> 00:19:10,950
wonderful book that just came out called

410
00:19:16,760 --> 00:19:14,429
the glass universe um this is the same

411
00:19:18,350 --> 00:19:16,770
author that wrote Galileo's daughter and

412
00:19:20,810 --> 00:19:18,360
longitude and if you're interested in

413
00:19:22,610 --> 00:19:20,820

hearing more about this story as well as

414
00:19:23,960 --> 00:19:22,620
many of the players that I'm not going

415
00:19:28,000 --> 00:19:23,970
to have time to talk about tonight I

416
00:19:35,150 --> 00:19:31,310
so if any of you you cannot see this

417
00:19:36,560 --> 00:19:35,160
from Baltimore many for many of you who

418
00:19:39,260 --> 00:19:36,570
have ever had the wonderful opportunity

419
00:19:42,860 --> 00:19:39,270
of being in an extremely dark sky you

420
00:19:44,210 --> 00:19:42,870
have this lovely view of the disk of the

421
00:19:48,620 --> 00:19:44,220
Milky Way galaxy

422
00:19:49,850 --> 00:19:48,630
and when you take that into three

423
00:19:51,590 --> 00:19:49,860
dimensions I'm afraid that my

424
00:19:53,840 --> 00:19:51,600
visualization is not as good as the one

425
00:19:58,180 --> 00:19:53,850
you just saw I went for the cartoon

426
00:20:01,080 --> 00:19:58,190
version you have this is that thin disc

427
00:20:05,960 --> 00:20:01,090
that you saw in the animation

428
00:20:12,480 --> 00:20:05,970
in the center of most spirals is a bulge

429
00:20:16,580 --> 00:20:12,490
surrounded by a halo of stars I can tell

430
00:20:19,649 --> 00:20:16,590
you that in this disk are open clusters

431
00:20:22,259 --> 00:20:19,659
these blue objects here these are

432
00:20:24,739 --> 00:20:22,269
regions that are either still forming or

433
00:20:27,989 --> 00:20:24,749
mow very very recently formed stars in

434
00:20:30,860 --> 00:20:27,999
the outskirts of the galaxy are globular

435
00:20:33,539 --> 00:20:30,870
clusters these are old systems they're

436
00:20:35,519 --> 00:20:33,549
1012 billion years old so roughly

437
00:20:42,450 --> 00:20:35,529
approaching the time that I'm interested

438
00:20:45,359 --> 00:20:42,460

in however but how do we know this we

439
00:20:47,549 --> 00:20:45,369
look at we can observe clusters like the

440
00:20:49,289 --> 00:20:47,559
Pleiades which I'm sure if you ask very

441
00:20:51,389 --> 00:20:49,299
nicely and it's up they'll be willing to

442
00:20:53,430 --> 00:20:51,399
show you tonight you can see this by eye

443
00:20:57,480 --> 00:20:53,440
the seven brightest stars are visible by

444
00:21:02,009 --> 00:20:57,490
eye in the constellation of Taurus even

445
00:21:04,200 --> 00:21:02,019
from Baltimore this is about 25 mm this

446
00:21:09,749 --> 00:21:04,210
is an open cluster that is about 25

447
00:21:13,230 --> 00:21:09,759
million years old and you can see some

448
00:21:16,049 --> 00:21:13,240
of the gas here that's still surrounding

449
00:21:20,340 --> 00:21:16,059
the stars so this oh this is very very

450
00:21:22,980 --> 00:21:20,350
recently formed stars this is omega

451
00:21:25,259 --> 00:21:22,990
centauri this is zoomed out quite a bit

452
00:21:28,980 --> 00:21:25,269
from the Hubble image that was handed

453
00:21:31,799 --> 00:21:28,990
out this is a globular cluster it's one

454
00:21:34,049 --> 00:21:31,809
of the younger globular cluster some of

455
00:21:38,580 --> 00:21:34,059
them are billions of years older than

456
00:21:41,399 --> 00:21:38,590
Omega Centauri and so here is a question

457
00:21:45,180 --> 00:21:41,409
how do you find out the age of a star

458
00:21:46,950 --> 00:21:45,190
you can't ask it it would not only be

459
00:21:51,749 --> 00:21:46,960
rude but I don't think you would get an

460
00:21:53,759 --> 00:21:51,759
answer and the answer to that is you use

461
00:21:55,289 --> 00:21:53,769
one of the most powerful diagrams in

462
00:22:00,539 --> 00:21:55,299
astronomy which are color-magnitude

463
00:22:03,029 --> 00:22:00,549

diagram or HR diagrams this is the

464
00:22:06,330 --> 00:22:03,039
Hubble image that you all have there's a

465
00:22:08,279 --> 00:22:06,340
reason that I asked for it and this is

466
00:22:12,899 --> 00:22:08,289
an animation we're going to take the

467
00:22:14,840 --> 00:22:12,909
stars of Omega Sun we're going to zoom

468
00:22:17,640 --> 00:22:14,850
in a little bit

469
00:22:20,270 --> 00:22:17,650
this is the very core of the cluster so

470
00:22:23,250 --> 00:22:20,280
that is an incredibly dense star field

471
00:22:26,400 --> 00:22:23,260
those stars are then going to be sorted

472
00:22:30,420 --> 00:22:26,410
the bluest and hottest stars are going

473
00:22:32,520 --> 00:22:30,430
to move to the left and the coolest and

474
00:22:36,350 --> 00:22:32,530
Retta stars are going to move to the

475
00:22:39,480 --> 00:22:36,360
right you're now going to sort them by

476
00:22:41,730 --> 00:22:39,490
absolute brightness or luminosity the

477
00:22:47,580 --> 00:22:41,740
brightest stars to the top the faintest

478
00:22:50,190 --> 00:22:47,590
to the bottom this is the HR diagram it

479
00:22:51,900 --> 00:22:50,200
is one of the most powerful plots in

480
00:22:54,120 --> 00:22:51,910
astronomy in fact I would tell my

481
00:22:56,820 --> 00:22:54,130
astronomy for poet students you

482
00:22:59,600 --> 00:22:56,830
understand this you're going to pass the

483
00:23:03,690 --> 00:22:59,610
stellar evolution section of the class I

484
00:23:08,430 --> 00:23:03,700
called it their cheat sheet along here

485
00:23:11,040 --> 00:23:08,440
is the main sequence our Sun would sit

486
00:23:14,490 --> 00:23:11,050
about here if it was in omega Sun all

487
00:23:18,300 --> 00:23:14,500
the stars and it's now I have a better

488
00:23:21,060 --> 00:23:18,310

one coming up did you notice that it

489
00:23:23,990 --> 00:23:21,070
turned off the main sequence didn't

490
00:23:28,680 --> 00:23:24,000
continue all the way up it turned off

491
00:23:31,080 --> 00:23:28,690
that is how you determine age this is a

492
00:23:33,360 --> 00:23:31,090
more cartoon version for excellent

493
00:23:36,870 --> 00:23:33,370
explanatory purposes here you have the

494
00:23:40,830 --> 00:23:36,880
main sequence all the stars here are

495
00:23:43,590 --> 00:23:40,840
burning hydrogen in their core and the

496
00:23:45,540 --> 00:23:43,600
more massive you are the hotter you are

497
00:23:50,430 --> 00:23:45,550
you can think of these guys as Hummers

498
00:23:52,410 --> 00:23:50,440
and these guys as Priuses you're also

499
00:23:54,960 --> 00:23:52,420
these are going to be brighter they are

500
00:24:00,000 --> 00:23:54,970
hotter and they also burn out a lot

501
00:24:02,850 --> 00:24:00,010
faster so if the main sequence turns off

502
00:24:05,970 --> 00:24:02,860
here your cluster is about 10 million

503
00:24:08,190 --> 00:24:05,980
years old if when you plot up your main

504
00:24:11,700 --> 00:24:08,200
sequence it turns off here it's a

505
00:24:13,650 --> 00:24:11,710
billion years old once the star turns

506
00:24:15,750 --> 00:24:13,660
off the main sequence it moves up

507
00:24:18,780 --> 00:24:15,760
through the Giants or into the super

508
00:24:22,590 --> 00:24:18,790
Giants and eventually evolves down our

509
00:24:24,900 --> 00:24:22,600
Sun will become a white dwarf objects

510
00:24:26,580 --> 00:24:24,910
that are a little more massive kind of

511
00:24:27,690 --> 00:24:26,590
hang out here for a bit they can't quite

512
00:24:32,669 --> 00:24:27,700
decide where they're going to sit

513
00:24:36,149 --> 00:24:32,679

and then they blow up in supernovae this

514
00:24:38,899 --> 00:24:36,159
is on the y-axis the vertical axis we

515
00:24:40,830 --> 00:24:38,909
have luminosity or absolute brightness

516
00:24:42,480 --> 00:24:40,840
you're going to hear me use those two

517
00:24:46,649 --> 00:24:42,490
terms interchangeably they mean the same

518
00:24:51,690 --> 00:24:46,659
thing and what this entire talk is about

519
00:24:54,330 --> 00:24:51,700
is this x-axis it's in color from red to

520
00:24:56,899 --> 00:24:54,340
blue it's also in something we call the

521
00:25:00,320 --> 00:24:56,909
spectral sequence and we also

522
00:25:03,330 --> 00:25:00,330
temperature increases to the left and

523
00:25:08,629 --> 00:25:03,340
how the fact that I am able to tell you

524
00:25:14,820 --> 00:25:11,039
so we need to go back a little bit

525
00:25:17,850 --> 00:25:14,830
before 1880 this is the refractor at

526
00:25:19,500 --> 00:25:17,860
Harvard these are not reflectors modern

527
00:25:22,259 --> 00:25:19,510
telescopes or reflectors you have a

528
00:25:23,759 --> 00:25:22,269
mirror at the base of the telescope the

529
00:25:25,740 --> 00:25:23,769
telescope's that were used to produce

530
00:25:28,700 --> 00:25:25,750
these observations are refractors they

531
00:25:31,409 --> 00:25:28,710
have a lens at the top of the long tube

532
00:25:33,799 --> 00:25:31,419
they're much larger for the same sized

533
00:25:37,799 --> 00:25:33,809
telescope it's why we stopped using them

534
00:25:39,149 --> 00:25:37,809
at the time in the 1870s and 1880s

535
00:25:40,740 --> 00:25:39,159
there's this newfangled thing called

536
00:25:42,779 --> 00:25:40,750
photography I don't know if any of you

537
00:25:44,430 --> 00:25:42,789
have ever done this for the younger

538
00:25:46,440 --> 00:25:44,440

people in the room there was a time when

539
00:25:48,000 --> 00:25:46,450
you took a picture with a camera and it

540
00:25:52,470 --> 00:25:48,010
was on film and you had to get it

541
00:25:53,519 --> 00:25:52,480
developed it you didn't just take it

542
00:25:57,419 --> 00:25:53,529
with your phone and put it on Facebook

543
00:26:01,320 --> 00:25:57,429
or Twitter or snapchat or whatever the

544
00:26:03,990 --> 00:26:01,330
hell did newest thing is they took

545
00:26:06,060 --> 00:26:04,000
images not on film but on photographic

546
00:26:08,399 --> 00:26:06,070
plates this is a digitalization a part

547
00:26:12,299 --> 00:26:08,409
of the Palomar Sky Survey this is an

548
00:26:16,139 --> 00:26:12,309
actual physical glass plate some of

549
00:26:21,389 --> 00:26:16,149
these could be about that big so they

550
00:26:23,070 --> 00:26:21,399
were heavy they broke and just not the

551
00:26:27,899 --> 00:26:23,080
best option but this was all we had

552
00:26:31,500 --> 00:26:27,909
until about 30 years ago and each of

553
00:26:33,570 --> 00:26:31,510
these points is a star in general the

554
00:26:36,299 --> 00:26:33,580
big the bigger the star the bigger the

555
00:26:37,370 --> 00:26:36,309
black here this is a brighter star than

556
00:26:39,690 --> 00:26:37,380
that

557
00:26:42,539 --> 00:26:39,700
so you can tell the magnitude of the

558
00:26:45,269 --> 00:26:42,549
star and if you take this image in red

559
00:26:46,889 --> 00:26:45,279
and red and green and blue filters you

560
00:26:48,779 --> 00:26:46,899
can also tell the color of the star

561
00:26:54,330 --> 00:26:48,789
which is how the HR diagram was

562
00:26:58,200 --> 00:26:54,340
originally plotted but we want more

563
00:27:00,840 --> 00:26:58,210

information welcome to astronomy this is

564
00:27:02,340 --> 00:27:00,850
Henry Draper and his wife Anna Draper he

565
00:27:08,009 --> 00:27:02,350
was a medical doctor who had an

566
00:27:11,009 --> 00:27:08,019
astronomy habit she had the money and he

567
00:27:14,070 --> 00:27:11,019
developed a method for taking that

568
00:27:18,810 --> 00:27:14,080
spectra for taking this plate and he

569
00:27:20,700 --> 00:27:18,820
stuck a prism in front of it so actually

570
00:27:22,049 --> 00:27:20,710
this is one of this is the best graphic

571
00:27:24,330 --> 00:27:22,059
I could find on the internet for this

572
00:27:26,820 --> 00:27:24,340
I'm not actually kidding you have your

573
00:27:28,799 --> 00:27:26,830
light from a distant star you pass that

574
00:27:32,970 --> 00:27:28,809
light through a prism and it breaks it

575
00:27:35,039 --> 00:27:32,980
into its components and when you break

576
00:27:37,169 --> 00:27:35,049
that light into the component you get a

577
00:27:41,340 --> 00:27:37,179
lot more information than just the color

578
00:27:45,090 --> 00:27:41,350
of the star this is the spectrum of the

579
00:27:49,830 --> 00:27:45,100
Sun so you look at the Sun you see a

580
00:27:53,700 --> 00:27:49,840
yellow star we call it a g-type star all

581
00:27:57,720 --> 00:27:53,710
of these black lines are absorption

582
00:28:00,269 --> 00:27:57,730
lines and each element has a unique set

583
00:28:03,629 --> 00:28:00,279
of absorption lines they think of them

584
00:28:04,889 --> 00:28:03,639
as fingerprints you can identify a human

585
00:28:09,180 --> 00:28:04,899
with their fingerprints you can identify

586
00:28:13,590 --> 00:28:09,190
an element or a molecule by its spectrum

587
00:28:16,889 --> 00:28:13,600
the simplest of these is hydrogen so up

588
00:28:21,869 --> 00:28:16,899

here is wavelength in angstroms that's

589
00:28:25,619 --> 00:28:21,879
about that's 1/10 that's 1 does the

590
00:28:27,539 --> 00:28:25,629
second 1/10 to the so each of these

591
00:28:31,249 --> 00:28:27,549
numbers multiplied by 10 to the 10 so 10

592
00:28:36,320 --> 00:28:31,259
additional zeros will get you on meters

593
00:28:39,749 --> 00:28:36,330
so this is one in 10 to the 10 meters

594
00:28:42,659 --> 00:28:39,759
very very tiny scales H alpha H beta H

595
00:28:43,950 --> 00:28:42,669
gamma and H Delta H alpha is actually

596
00:28:47,039 --> 00:28:43,960
one of the most important lines in

597
00:28:48,570 --> 00:28:47,049
astrophysics the more complicated the

598
00:28:49,760 --> 00:28:48,580
element is you move out the periodic

599
00:28:55,400 --> 00:28:49,770
table the more complicated

600
00:28:58,940 --> 00:28:55,410
at spectra now the plates Draper took

601
00:29:01,310 --> 00:28:58,950
didn't look like that this is on one of

602
00:29:06,470 --> 00:29:01,320
the Draper plates at the location of

603
00:29:08,120 --> 00:29:06,480
each star you see a spectra in the

604
00:29:10,220 --> 00:29:08,130
initial set of plates each of these was

605
00:29:12,200 --> 00:29:10,230
one inch across so if you hold your

606
00:29:14,500 --> 00:29:12,210
fingers at about an inch that's how wide

607
00:29:15,650 --> 00:29:14,510
each of these things was on the glass

608
00:29:21,110 --> 00:29:15,660
breakable

609
00:29:24,740 --> 00:29:21,120
plate unfortunately reasonably quickly

610
00:29:29,660 --> 00:29:24,750
after discovering this method Henry

611
00:29:31,730 --> 00:29:29,670
Draper died as was typical of I think

612
00:29:34,490 --> 00:29:31,740
the entire 19th century he caught it

613
00:29:38,720 --> 00:29:34,500

chill and had a dinner party and went to

614
00:29:40,220 --> 00:29:38,730
bed and never got up and Anna Draper was

615
00:29:42,170 --> 00:29:40,230
so devastated by her husband's death

616
00:29:46,670 --> 00:29:42,180
that she wanted a memorial to him so she

617
00:29:48,860 --> 00:29:46,680
talked to Edward Pickering and endowed

618
00:29:51,020 --> 00:29:48,870
the Harvard Observatory with money to

619
00:29:52,880 --> 00:29:51,030
finish her husband's work and build a

620
00:29:58,810 --> 00:29:52,890
Henry Draper catalog of the stars

621
00:30:04,310 --> 00:30:01,250
Edward Pickering did something that the

622
00:30:06,680 --> 00:30:04,320
time even Anna Draper wasn't expecting

623
00:30:09,040 --> 00:30:06,690
he felt that women would be well suited

624
00:30:11,540 --> 00:30:09,050
to the repetitive and drudgery of

625
00:30:14,060 --> 00:30:11,550
looking through thousands and thousands

626
00:30:16,760 --> 00:30:14,070
of glass plates with spectra that order

627
00:30:20,300 --> 00:30:16,770
inch wide now years later of course you

628
00:30:22,940 --> 00:30:20,310
tend to sugarcoat this and you talk and

629
00:30:24,290 --> 00:30:22,950
he talks about the criticism is often

630
00:30:26,090 --> 00:30:24,300
made by the opponents of higher

631
00:30:28,160 --> 00:30:26,100
education of women that while they are

632
00:30:31,180 --> 00:30:28,170
capable of following others as far as

633
00:30:34,010 --> 00:30:31,190
men can they originate almost nothing so

634
00:30:37,300 --> 00:30:34,020
that human knowledge is not advanced by

635
00:30:40,370 --> 00:30:37,310
their work keep in mind this is 1880

636
00:30:42,770 --> 00:30:40,380
this approach would be well answered if

637
00:30:45,410 --> 00:30:42,780
we could point to a long series of such

638
00:30:48,020 --> 00:30:45,420

observations as are detailed below made

639
00:30:49,730 --> 00:30:48,030
by women observers this is the first

640
00:30:52,160 --> 00:30:49,740
this is one of the first times in

641
00:30:54,230 --> 00:30:52,170
history that women are making

642
00:30:57,760 --> 00:30:54,240
contributions and Pickering acknowledged

643
00:31:00,220 --> 00:30:57,770
the Harvard computers in their work

644
00:31:02,230 --> 00:31:00,230
the first of the Harvard computers was

645
00:31:04,419 --> 00:31:02,240
Wilhelmina Fleming she was a Scottish

646
00:31:06,520 --> 00:31:04,429
immigrant who moved to the United States

647
00:31:10,960 --> 00:31:06,530
got pregnant and her husband promptly

648
00:31:13,950 --> 00:31:10,970
left her so she got a job as the maid at

649
00:31:17,290 --> 00:31:13,960
the observatory residence at Harvard and

650
00:31:19,060 --> 00:31:17,300
Pickering knew her he was the director

651
00:31:22,210 --> 00:31:19,070
of the Harvard observatory at that point

652
00:31:24,580 --> 00:31:22,220
he recognized that she was a little too

653
00:31:26,169 --> 00:31:24,590
intelligent to be a maid she didn't have

654
00:31:29,440 --> 00:31:26,179
a college degree but she was educated

655
00:31:34,299 --> 00:31:29,450
and he hired her as a Harvard computer

656
00:31:35,890 --> 00:31:34,309
in 18m as a computer in 1879 I'd like to

657
00:31:38,560 --> 00:31:35,900
point out the other reason to use women

658
00:31:44,890 --> 00:31:38,570
they're paid less I didn't know if

659
00:31:47,169 --> 00:31:44,900
you've heard about that um she promptly

660
00:31:49,330 --> 00:31:47,179
leaves a year later to give birth to her

661
00:31:51,940 --> 00:31:49,340
son in Scotland and then leaves him with

662
00:31:56,410 --> 00:31:51,950
her mother and her aunt and returns to

663
00:31:57,850 --> 00:31:56,420

Boston without him in 1881 I think he

664
00:31:59,320 --> 00:31:57,860
invent he eventually makes it to the

665
00:32:05,020 --> 00:31:59,330
United States but it's like ten years

666
00:32:06,850 --> 00:32:05,030
later and her task was to classify these

667
00:32:09,669 --> 00:32:06,860
spectra so if you remember this is what

668
00:32:15,220 --> 00:32:09,679
she's looking at through a magnifying

669
00:32:19,090 --> 00:32:15,230
glass and she noticed that here is good

670
00:32:21,430 --> 00:32:19,100
old hydrogen good old hydrogen alpha she

671
00:32:23,200 --> 00:32:21,440
noticed that some stars had stronger

672
00:32:25,900 --> 00:32:23,210
hydrogen lines than others and so she

673
00:32:28,030 --> 00:32:25,910
classified them by the strength of their

674
00:32:32,500 --> 00:32:28,040
hydrogen lines the strongest hydrogen

675
00:32:36,549 --> 00:32:32,510
line she gave called a stars the next B

676
00:32:39,730 --> 00:32:36,559
C D you can see where I'm going all the

677
00:32:42,310 --> 00:32:39,740
way down the alphabet and you'll note

678
00:32:47,669 --> 00:32:42,320
that this is not an alphabetical order

679
00:32:53,169 --> 00:32:51,310
she also discovered variable stars she

680
00:32:55,510 --> 00:32:53,179
found one of the first Nova because

681
00:32:58,120 --> 00:32:55,520
they're looking at a set of plates that

682
00:32:59,169 --> 00:32:58,130
no one's ever had before and in general

683
00:33:01,419 --> 00:32:59,179
in astronomy when you have a

684
00:33:05,500 --> 00:33:01,429
technological advance and insane amounts

685
00:33:07,840 --> 00:33:05,510
of telescope time discoveries happen but

686
00:33:09,200 --> 00:33:07,850
later in her career and for the last

687
00:33:11,299 --> 00:33:09,210
about

688
00:33:14,630 --> 00:33:11,309

10 10 to 15 years that she was at the

689
00:33:19,010 --> 00:33:14,640
observatory her primary duty was to

690
00:33:20,389 --> 00:33:19,020
curate these glass plates these are

691
00:33:21,980 --> 00:33:20,399
irreplaceable you don't have

692
00:33:23,360 --> 00:33:21,990
digitalization you don't have a digit

693
00:33:25,810 --> 00:33:23,370
you don't have a phone you can take out

694
00:33:28,279 --> 00:33:25,820
and take a picture in case you mess up

695
00:33:31,120 --> 00:33:28,289
if something happens to these glass

696
00:33:33,740 --> 00:33:31,130
plates the information is lost forever

697
00:33:36,500 --> 00:33:33,750
she was also responsible with editing

698
00:33:39,889 --> 00:33:36,510
and preparing the drape Henry Draper

699
00:33:47,480 --> 00:33:39,899
memorial catalog for publication there

700
00:33:50,389 --> 00:33:47,490
are 90 volumes of this so she also was

701
00:33:57,639 --> 00:33:50,399
the effective head of the Harvard

702
00:34:00,019 --> 00:33:57,649
computers their leader as you will but

703
00:34:02,560 --> 00:34:00,029
unfortunately I love astronomy everyone

704
00:34:05,060 --> 00:34:02,570
loves astronomy I need to pay rent and

705
00:34:06,769 --> 00:34:05,070
pick and this is a wonderful quote

706
00:34:08,869 --> 00:34:06,779
Pickering seems to think that no work is

707
00:34:10,700 --> 00:34:08,879
too much or too hard for me no matter

708
00:34:13,070 --> 00:34:10,710
what the responsibilities or how long

709
00:34:15,649 --> 00:34:13,080
the hours but let me raise the question

710
00:34:17,839 --> 00:34:15,659
of salary and I am immediately told that

711
00:34:21,800 --> 00:34:17,849
I receive an excellent salary as women

712
00:34:23,450 --> 00:34:21,810
salaries go because of course if you're

713
00:34:27,230 --> 00:34:23,460

a woman your husband's actually making

714
00:34:29,599 --> 00:34:27,240
the money and in general the Harvard

715
00:34:31,399 --> 00:34:29,609
computers were unable to live completely

716
00:34:34,490 --> 00:34:31,409
independently many of them lived in

717
00:34:37,000 --> 00:34:34,500
boarding houses or rented out rooms in

718
00:34:39,079 --> 00:34:37,010
their own homes to make ends meet

719
00:34:44,389 --> 00:34:39,089
because remember they could be paid less

720
00:34:46,520 --> 00:34:44,399
than a man for cheap antonio mari was

721
00:34:48,139 --> 00:34:46,530
actually the first harvard computer she

722
00:34:49,609 --> 00:34:48,149
was related to Draper and she was the

723
00:34:52,790 --> 00:34:49,619
first Harvard computer to actually have

724
00:34:54,320 --> 00:34:52,800
an astronomy degree and that degree was

725
00:34:58,700 --> 00:34:54,330
from Vassar which is where Mariah

726
00:35:00,380 --> 00:34:58,710
mitchell worked and remember what I said

727
00:35:02,390 --> 00:35:00,390
about technological advancement well

728
00:35:04,849 --> 00:35:02,400
instead of having the specter be an inch

729
00:35:08,030 --> 00:35:04,859
wide the plates that Mari got to work on

730
00:35:12,500 --> 00:35:08,040
they were 4 inches wide and they were

731
00:35:18,109 --> 00:35:12,510
far far more detailed and you would

732
00:35:20,960 --> 00:35:18,119
think detail is good detail is generally

733
00:35:21,550 --> 00:35:20,970
good but complicated and she noticed

734
00:35:23,140 --> 00:35:21,560
that in

735
00:35:29,650 --> 00:35:23,150
addition to the lines having different

736
00:35:32,080 --> 00:35:29,660
strengths so having different having two

737
00:35:35,230 --> 00:35:32,090
different depths some of them also had

738
00:35:37,060 --> 00:35:35,240

different widths two stars that seem to

739
00:35:38,740 --> 00:35:37,070
have the same strengths of hydrogen lion

740
00:35:40,120 --> 00:35:38,750
would have different widths of hydrogen

741
00:35:42,610 --> 00:35:40,130
lines and she worked to try to

742
00:35:44,710 --> 00:35:42,620
incorporate this into a new

743
00:35:46,810 --> 00:35:44,720
classification scheme so she threw out

744
00:35:49,240 --> 00:35:46,820
what Wilhelmina Fleming had done with

745
00:35:53,980 --> 00:35:49,250
the alphabet and came up with a numbered

746
00:35:58,110 --> 00:35:53,990
scheme and this worked but it was

747
00:36:01,540 --> 00:35:58,120
actually a little ahead of her time and

748
00:36:03,760 --> 00:36:01,550
so now we get to the three main players

749
00:36:08,170 --> 00:36:03,770
in this little drama there on my shirt

750
00:36:10,240 --> 00:36:08,180
if you need reference Henry Henrietta

751
00:36:12,850 --> 00:36:10,250
Swan Leavitt and Annie jump cannon

752
00:36:15,970 --> 00:36:12,860
arrived at the same time as unpaid

753
00:36:18,730 --> 00:36:15,980
interns for a year both of them then

754
00:36:20,380 --> 00:36:18,740
left and were only able to return when

755
00:36:25,600 --> 00:36:20,390
another one of the computers got married

756
00:36:27,520 --> 00:36:25,610
she had a degree from Radcliffe which no

757
00:36:32,140 --> 00:36:27,530
longer exists because Harvard now lets

758
00:36:38,080 --> 00:36:32,150
women in and she was also deaf not her

759
00:36:40,960 --> 00:36:38,090
entire life but in adulthood and she was

760
00:36:42,760 --> 00:36:40,970
given the task of monitoring variable

761
00:36:44,710 --> 00:36:42,770
stars so you can imagine you've got all

762
00:36:46,300 --> 00:36:44,720
these photographic plates and you're

763
00:36:48,970 --> 00:36:46,310

going to see certain stars vary a little

764
00:36:50,950 --> 00:36:48,980
bit in brightness so you're literally

765
00:36:53,590 --> 00:36:50,960
looking at this plate and then this

766
00:36:57,310 --> 00:36:53,600
image from two days later and two days

767
00:36:59,380 --> 00:36:57,320
after that and she came up with a novel

768
00:37:02,590 --> 00:36:59,390
method that allowed her to look at one

769
00:37:04,150 --> 00:37:02,600
plate on top of the other using a

770
00:37:06,220 --> 00:37:04,160
negative image of one and putting the

771
00:37:11,650 --> 00:37:06,230
positive image of the other on top of it

772
00:37:14,290 --> 00:37:11,660
and down the line she found she was

773
00:37:16,330 --> 00:37:14,300
looking at a set of variables in the LMC

774
00:37:18,850 --> 00:37:16,340
here's a very pretty image it did not

775
00:37:20,440 --> 00:37:18,860
look like that on the plates and she

776
00:37:24,310 --> 00:37:20,450
found a class of variables that were

777
00:37:25,900 --> 00:37:24,320
already known called Cepheid x' and the

778
00:37:28,510 --> 00:37:25,910
characteristic of a Cepheid as it rises

779
00:37:31,030 --> 00:37:28,520
very very quickly in brightness and then

780
00:37:34,710 --> 00:37:31,040
falls off slowly and then rises quickly

781
00:37:37,770 --> 00:37:34,720
again and falls off slowly

782
00:37:39,690 --> 00:37:37,780
and because all of these Sophia's were

783
00:37:40,950 --> 00:37:39,700
in the Large Magellanic Cloud she knew

784
00:37:44,430 --> 00:37:40,960
that they were at about the same

785
00:37:46,620 --> 00:37:44,440
distance from Earth and so if one of

786
00:37:49,500 --> 00:37:46,630
those Cepheid appeared to be brighter

787
00:37:55,620 --> 00:37:49,510
than another it actually was brighter

788
00:37:59,040 --> 00:37:55,630

than another and she plotted this as you

789
00:38:01,320 --> 00:37:59,050
do in astronomy you plot things and she

790
00:38:05,460 --> 00:38:01,330
found that the longer the period of the

791
00:38:09,089 --> 00:38:05,470
Cepheid the brighter the brighter the

792
00:38:11,370 --> 00:38:09,099
Cepheid actually was and you can see

793
00:38:13,830 --> 00:38:11,380
this here the brighter Cepheid with its

794
00:38:16,620 --> 00:38:13,840
longer period and the fainter Cepheid

795
00:38:18,990 --> 00:38:16,630
with the shorter period this was

796
00:38:21,570 --> 00:38:19,000
immediately recognized for what it was

797
00:38:23,640 --> 00:38:21,580
this is called a standard candle this

798
00:38:25,470 --> 00:38:23,650
means you can look at a Cepheid you can

799
00:38:28,349 --> 00:38:25,480
measure its period and you know how

800
00:38:30,330 --> 00:38:28,359
bright it is and if you know how bright

801
00:38:32,880 --> 00:38:30,340
it actually is and you know how bright

802
00:38:37,620 --> 00:38:32,890
it appears to be you know how far away

803
00:38:39,750 --> 00:38:37,630
it is this was used within a year of her

804
00:38:42,240 --> 00:38:39,760
discovery to find that the LMC and the

805
00:38:44,520 --> 00:38:42,250
SMC were just a bit further away than

806
00:38:51,060 --> 00:38:44,530
they thought they were and in actuality

807
00:38:54,030 --> 00:38:51,070
they're even further than that this is

808
00:38:54,800 --> 00:38:54,040
her and Henrietta Leavitt and Annie jump

809
00:39:01,859 --> 00:38:54,810
cannon

810
00:39:04,260 --> 00:39:01,869
um about some time in the teens in front

811
00:39:06,240 --> 00:39:04,270
of the Harvard Observatory they came in

812
00:39:08,730 --> 00:39:06,250
together as interns Annie jump cannon

813
00:39:13,440 --> 00:39:08,740

arrived because there literally somebody

814
00:39:16,290 --> 00:39:13,450
got married so she was hired she

815
00:39:18,630 --> 00:39:16,300
graduated Velvet Orion of Wellesley in a

816
00:39:20,190 --> 00:39:18,640
degree in physics and astronomy after a

817
00:39:22,829 --> 00:39:20,200
brief stint at Harvard she lived with

818
00:39:24,839 --> 00:39:22,839
her parents for 10 years during that

819
00:39:29,880 --> 00:39:24,849
time she contracted scarlet fever and

820
00:39:31,589 --> 00:39:29,890
lost most of her hearing - after ten

821
00:39:34,800 --> 00:39:31,599
years someone got married she was able

822
00:39:36,960 --> 00:39:34,810
to come on as a Harvard computer to give

823
00:39:39,089 --> 00:39:36,970
you a comparison a student of her

824
00:39:41,280 --> 00:39:39,099
caliber or Henrietta Levites caliber or

825
00:39:42,810 --> 00:39:41,290
Antonio Marez caliber today would be off

826
00:39:44,880 --> 00:39:42,820
to one of the greatest best grad

827
00:39:46,380 --> 00:39:44,890
programs in the world they would not be

828
00:39:47,540 --> 00:39:46,390
living with their parents for ten years

829
00:39:51,200 --> 00:39:47,550
hoping that a position

830
00:39:53,630 --> 00:39:51,210
waddup this is her at her graduation

831
00:40:00,740 --> 00:39:53,640
from Wellesley looking through a very

832
00:40:03,440 --> 00:40:00,750
very small refractor and what she did

833
00:40:06,890 --> 00:40:03,450
was organize reorganize what Wilhelmina

834
00:40:10,490 --> 00:40:06,900
Fleming did accounting for what Mari had

835
00:40:13,880 --> 00:40:10,500
noticed in the spectra Mari had noticed

836
00:40:16,250 --> 00:40:13,890
that certain stars like Oh stars had

837
00:40:19,130 --> 00:40:16,260
extremely strong helium lines which

838
00:40:23,180 --> 00:40:19,140

other stars like M stars with very faint

839
00:40:24,560 --> 00:40:23,190
hydron hydrogen lines did not and so

840
00:40:28,760 --> 00:40:24,570
Annie jump cannon did a little bit of

841
00:40:31,700 --> 00:40:28,770
reorganization and some editing she

842
00:40:34,850 --> 00:40:31,710
moved the oh stars to the top of the

843
00:40:38,510 --> 00:40:34,860
sequence because if you're producing

844
00:40:41,720 --> 00:40:38,520
helium lines than your heart she moved

845
00:40:45,190 --> 00:40:41,730
the B stars next to the O and then

846
00:40:48,140 --> 00:40:45,200
edited the rest of the sequence down

847
00:40:50,270 --> 00:40:48,150
this is the sequence we still use to

848
00:40:55,550 --> 00:40:50,280
this day it's a little difficult to

849
00:40:59,600 --> 00:40:55,560
remember so we use Oh be a fine guy kiss

850
00:41:05,810 --> 00:40:59,610
me or Oh be a fine girl kissed me

851
00:41:08,390 --> 00:41:05,820
depending on your preference and so now

852
00:41:10,820 --> 00:41:08,400
this x-axis in addition to being color

853
00:41:16,220 --> 00:41:10,830
from red to blue is now the spectral

854
00:41:17,860 --> 00:41:16,230
sequence of OB AF g/km and by the way if

855
00:41:25,520 --> 00:41:17,870
you ever see this on a license plate

856
00:41:28,130 --> 00:41:25,530
astronomer in addition Annie jump cannon

857
00:41:30,080 --> 00:41:28,140
was the first of the Harvard computers

858
00:41:34,760 --> 00:41:30,090
to actually be allowed to shockingly

859
00:41:37,850 --> 00:41:34,770
observe these telescopes are extremely

860
00:41:39,800 --> 00:41:37,860
big this is her in Peru at the outpost

861
00:41:43,640 --> 00:41:39,810
in Peru they hadn't discovered Chile yet

862
00:41:47,240 --> 00:41:43,650
I don't think and maneuvering the bottom

863
00:41:51,230 --> 00:41:47,250

of the giant refractor there these

864
00:41:53,300 --> 00:41:51,240
telescopes are extremely long extremely

865
00:41:54,620 --> 00:41:53,310
heavy and nothing's motorized today you

866
00:41:56,770 --> 00:41:54,630
sit in a control room

867
00:41:58,660 --> 00:41:56,780
you tell the

868
00:42:00,160 --> 00:41:58,670
you tell your telescope operator I want

869
00:42:01,690 --> 00:42:00,170
to go point at that and then the

870
00:42:02,920 --> 00:42:01,700
telescope operator punches some stuff

871
00:42:06,640 --> 00:42:02,930
into your computer and the telescope

872
00:42:07,990 --> 00:42:06,650
magically moves there's no magic at this

873
00:42:10,510 --> 00:42:08,000
point you had to physically move the

874
00:42:12,100 --> 00:42:10,520
telescope and this de mate and this work

875
00:42:14,650 --> 00:42:12,110
was deemed to be too physically

876
00:42:16,840 --> 00:42:14,660
demanding for the poor weak defenseless

877
00:42:21,160 --> 00:42:16,850
women I'm I don't know where they got

878
00:42:23,080 --> 00:42:21,170
that idea so she also did she was the

879
00:42:27,850 --> 00:42:23,090
first of them but not the last to

880
00:42:31,630 --> 00:42:27,860
actually do up make observations and she

881
00:42:34,630 --> 00:42:31,640
became the world expert in this and in

882
00:42:38,130 --> 00:42:34,640
1920 summer of 1912 she went to Europe

883
00:42:42,100 --> 00:42:38,140
and attended conferences and spoke and

884
00:42:43,690 --> 00:42:42,110
at a meeting that was the precursor to

885
00:42:46,510 --> 00:42:43,700
the modern International Astronomical

886
00:42:47,740 --> 00:42:46,520
Union she said was very surprised to

887
00:42:49,270 --> 00:42:47,750
find that she was put in the committee

888
00:42:50,800 --> 00:42:49,280

of the classification of stellar spectra

889
00:42:54,340 --> 00:42:50,810
and I'm thinking she's being a little

890
00:42:56,560 --> 00:42:54,350
sarcastic here um and she talks about

891
00:42:59,980 --> 00:42:56,570
sitting at a long table and being the

892
00:43:02,140 --> 00:42:59,990
only woman in the room and since I have

893
00:43:03,270 --> 00:43:02,150
done almost all the world's work in this

894
00:43:05,920 --> 00:43:03,280
one branch

895
00:43:08,080 --> 00:43:05,930
she was the classification of stellar

896
00:43:12,430 --> 00:43:08,090
spectra at this point it was necessary

897
00:43:14,430 --> 00:43:12,440
for me to do most of the talking I wish

898
00:43:20,710 --> 00:43:14,440
I could tell you that this has changed

899
00:43:23,620 --> 00:43:20,720
it's better it is better I'm usually not

900
00:43:27,430 --> 00:43:23,630
the only woman in the room there's

901
00:43:28,810 --> 00:43:27,440
usually two others maybe um but I have

902
00:43:35,680 --> 00:43:28,820
definitely been in meetings where this

903
00:43:37,620 --> 00:43:35,690
was the case in 1919 about seven years

904
00:43:42,160 --> 00:43:37,630
after that

905
00:43:43,990 --> 00:43:42,170
Edward Pickering died his replacement at

906
00:43:46,090 --> 00:43:44,000
the Harvard Observatory was a man named

907
00:43:47,890 --> 00:43:46,100
Harlow Shapley who was better known in

908
00:43:49,420 --> 00:43:47,900
astronomy history circles as being

909
00:43:53,260 --> 00:43:49,430
completely wrong about the scale of the

910
00:43:55,240 --> 00:43:53,270
Milky Way galaxy in fact he was on the

911
00:43:57,730 --> 00:43:55,250
one that made the measurements of the

912
00:44:00,250 --> 00:43:57,740
distance to the LMC using Henrietta

913
00:44:03,610 --> 00:44:00,260

Leavitt Cepheid using Henry Leavitt

914
00:44:05,330 --> 00:44:03,620
Cepheid relation like Edward Pickering

915
00:44:08,990 --> 00:44:05,340
before him

916
00:44:11,180 --> 00:44:09,000
supported the Harvard computers and ejup

917
00:44:13,160 --> 00:44:11,190
Canon Antonio Mari were authors on their

918
00:44:14,990 --> 00:44:13,170
publications so was Henriette leave it

919
00:44:17,210 --> 00:44:15,000
in fact if you cite the periods of the

920
00:44:21,290 --> 00:44:17,220
the Cepheid period-luminosity relation

921
00:44:22,910 --> 00:44:21,300
you cite leave it however he also did

922
00:44:30,250 --> 00:44:22,920
refer to the work they did in terms of

923
00:44:41,180 --> 00:44:36,590
the final player in this I guess you

924
00:44:43,550 --> 00:44:41,190
would say drama is a woman named Cecilia

925
00:44:44,900 --> 00:44:43,560
Payne is a woman named Cecilia Payne and

926
00:44:47,270 --> 00:44:44,910
you will have to bear with me I'm about

927
00:44:50,690 --> 00:44:47,280
to give you a very fast introduction to

928
00:44:53,300 --> 00:44:50,700
quantum chemistry she got she was from

929
00:44:55,220 --> 00:44:53,310
England and she read physics and

930
00:44:58,130 --> 00:44:55,230
astronomy at Cambridge but she doesn't

931
00:45:00,790 --> 00:44:58,140
have a degree from there because in 1923

932
00:45:03,500 --> 00:45:00,800
Cambridge did not grant degrees to women

933
00:45:05,150 --> 00:45:03,510
when she asked about what the

934
00:45:08,750 --> 00:45:05,160
opportunities were for doing astronomy

935
00:45:14,200 --> 00:45:08,760
in England she was told you can be an

936
00:45:16,220 --> 00:45:14,210
amateur while teaching Shapley had come

937
00:45:18,350 --> 00:45:16,230
he was now the director of the Harvard

938
00:45:20,570 --> 00:45:18,360

Observatory had come to Cambridge and

939
00:45:24,170 --> 00:45:20,580
given a talk so she knew about the

940
00:45:26,390 --> 00:45:24,180
Harvard computers she cobbled and as all

941
00:45:28,550 --> 00:45:26,400
scientists to do to this day she cobbled

942
00:45:30,310 --> 00:45:28,560
together funding and moved over the

943
00:45:33,110 --> 00:45:30,320
Atlantic Ocean

944
00:45:39,950 --> 00:45:33,120
having done an international move with

945
00:45:44,360 --> 00:45:39,960
Skype I cannot even imagine it when she

946
00:45:46,550 --> 00:45:44,370
arrived at her at Harvard in Cambridge

947
00:45:50,900 --> 00:45:46,560
Massachusetts because you know why mess

948
00:45:52,640 --> 00:45:50,910
with a name she followed instructions

949
00:45:54,430 --> 00:45:52,650
she had followed advice that she had

950
00:45:57,680 --> 00:45:54,440
been given to set out to make

951
00:46:00,140 --> 00:45:57,690
quantitative the qualitative information

952
00:46:03,470 --> 00:46:00,150
that was inherent in the Henry Draper

953
00:46:06,260 --> 00:46:03,480
system so up until this point they've

954
00:46:09,230 --> 00:46:06,270
said the hydrogen lines are stronger in

955
00:46:12,710 --> 00:46:09,240
these stars and they tend to be bluer

956
00:46:15,320 --> 00:46:12,720
than these other stars but there was no

957
00:46:16,990 --> 00:46:15,330
numbers associated with it you couldn't

958
00:46:22,359 --> 00:46:17,000
say that an ocean

959
00:46:24,849 --> 00:46:22,369
had this temperature because the ability

960
00:46:27,370 --> 00:46:24,859
to do that depended on knowledge of a

961
00:46:29,320 --> 00:46:27,380
science that at this point was only just

962
00:46:30,849 --> 00:46:29,330
getting started called quantum mechanics

963
00:46:33,640 --> 00:46:30,859

you had to understand the structure of

964
00:46:36,670 --> 00:46:33,650
an atom and how electrons moved in that

965
00:46:40,210 --> 00:46:36,680
atom and cecilia payne was perfectly

966
00:46:43,570 --> 00:46:40,220
positioned to do this she had been in

967
00:46:45,730 --> 00:46:43,580
europe so she knew about neil the Bohr

968
00:46:49,089 --> 00:46:45,740
model of the atom I did warn you we were

969
00:46:51,220 --> 00:46:49,099
going to do quantum chemistry this is a

970
00:46:53,080 --> 00:46:51,230
very cartoonish model of an atom you

971
00:46:55,450 --> 00:46:53,090
have the nucleus here with the protons

972
00:46:57,760 --> 00:46:55,460
and neutrons and different levels for

973
00:47:02,050 --> 00:46:57,770
the electrons represented here by this

974
00:47:04,210 --> 00:47:02,060
lovely blue circle as electrons move up

975
00:47:08,650 --> 00:47:04,220
and down so if an electron moves down a

976
00:47:11,140 --> 00:47:08,660
level it emits a photon it emits light

977
00:47:13,120 --> 00:47:11,150
and it emits light in a very specific

978
00:47:18,220 --> 00:47:13,130
wavelength this is actually how you get

979
00:47:21,339 --> 00:47:18,230
the lines and a spectra and there are a

980
00:47:24,370 --> 00:47:21,349
series of and with that very basic model

981
00:47:28,720 --> 00:47:24,380
and if that and if for that electron to

982
00:47:31,210 --> 00:47:28,730
jump up to a higher level it needs to

983
00:47:36,450 --> 00:47:31,220
absorb light and it needs to absorb

984
00:47:39,070 --> 00:47:36,460
light at a very very specific wavelength

985
00:47:41,320 --> 00:47:39,080
so the transitions you saw the lines of

986
00:47:43,720 --> 00:47:41,330
the hydrogen spectrum are the movements

987
00:47:48,760 --> 00:47:43,730
of electrons up and down the levels of

988
00:47:55,720 --> 00:47:48,770

the hydrogen atom and with that

989
00:47:58,180 --> 00:47:55,730
knowledge Saha here developed a set of

990
00:48:00,910 --> 00:47:58,190
equations using quantum mechanics that

991
00:48:02,500 --> 00:48:00,920
could tell you if you know the atom that

992
00:48:05,410 --> 00:48:02,510
you're looking at which you know for the

993
00:48:07,359 --> 00:48:05,420
fingerprints of the spectra you can

994
00:48:14,560 --> 00:48:07,369
determine what the temperature of the

995
00:48:15,130 --> 00:48:14,570
gas is is everybody with me okay just

996
00:48:17,920 --> 00:48:15,140
checking

997
00:48:19,839 --> 00:48:17,930
I don't normally try to throw quantum

998
00:48:23,200 --> 00:48:19,849
chemistry and quantum mechanics at a

999
00:48:24,970 --> 00:48:23,210
public talk now she did this

1000
00:48:26,140 --> 00:48:24,980
now she shows it comes to Harvard and

1001
00:48:28,450 --> 00:48:26,150
they happen to have the largest

1002
00:48:29,700 --> 00:48:28,460
repository of spectra in the world on

1003
00:48:32,370 --> 00:48:29,710
these glass plates

1004
00:48:34,710 --> 00:48:32,380
so she can look so she sets about

1005
00:48:37,470 --> 00:48:34,720
measuring the details of the spectra and

1006
00:48:40,050 --> 00:48:37,480
applying Savas equations to determine

1007
00:48:45,870 --> 00:48:40,060
what the quantitative temperatures of

1008
00:48:47,700 --> 00:48:45,880
these stars are this in just this next

1009
00:48:49,500 --> 00:48:47,710
slide is not to scare you but to give

1010
00:48:51,330 --> 00:48:49,510
you a sense of what she did she did this

1011
00:48:53,910 --> 00:48:51,340
20 years before the first computer would

1012
00:49:02,700 --> 00:48:53,920
be built and these are the Saha

1013
00:49:05,730 --> 00:49:02,710

equations yes she did all of this by

1014
00:49:10,040 --> 00:49:05,740
hand looking at multiple elements in

1015
00:49:15,810 --> 00:49:10,050
multiple plates across multiple spectra

1016
00:49:20,760 --> 00:49:15,820
and that added the temperature axis of

1017
00:49:24,090 --> 00:49:20,770
this plot that tells us that an O star

1018
00:49:26,160 --> 00:49:24,100
is 30,000 degrees Kelvin I would say

1019
00:49:27,510 --> 00:49:26,170
that I would put that into more normal

1020
00:49:29,670 --> 00:49:27,520
units but I think when you're up at

1021
00:49:32,520 --> 00:49:29,680
30,000 I don't think the temperature

1022
00:49:37,740 --> 00:49:32,530
scale stops mattering you know that our

1023
00:49:39,660 --> 00:49:37,750
Sun is about 5 or 6,000 Kelvin and so

1024
00:49:41,610 --> 00:49:39,670
now we can say the temperature increased

1025
00:49:43,860 --> 00:49:41,620
not only just the temperature increases

1026
00:49:49,140 --> 00:49:43,870
but exactly what the temperatures of

1027
00:49:51,090 --> 00:49:49,150
those stars are this is why o stars had

1028
00:49:52,680 --> 00:49:51,100
no hydrogen lines they're so hot that

1029
00:49:58,680 --> 00:49:52,690
the hydrogen is completely stripped of

1030
00:50:00,930 --> 00:49:58,690
its electrons and as you start to cool

1031
00:50:05,370 --> 00:50:00,940
down just a little bit you start seeing

1032
00:50:06,810 --> 00:50:05,380
hydrogen lines again now this alone

1033
00:50:08,460 --> 00:50:06,820
would have put her into the history

1034
00:50:09,750 --> 00:50:08,470
books but she wasn't done I'd like to

1035
00:50:14,070 --> 00:50:09,760
remind you she's still the grad student

1036
00:50:15,960 --> 00:50:14,080
at this point friend those of you that

1037
00:50:17,310 --> 00:50:15,970
are having flashbacks to chemistry I

1038
00:50:20,160 --> 00:50:17,320

promise I'll get rid of the periodic

1039
00:50:23,190 --> 00:50:20,170
table in a minute she could also use

1040
00:50:28,650 --> 00:50:23,200
those same equations to determine what

1041
00:50:30,270 --> 00:50:28,660
the universe was made out of now think

1042
00:50:32,430 --> 00:50:30,280
for a minute you're living a hundred

1043
00:50:35,820 --> 00:50:32,440
years ago you look up and you assume

1044
00:50:38,610 --> 00:50:35,830
that that is like this you're going to

1045
00:50:41,580 --> 00:50:38,620
see a lot of iron a lot of carbon a lot

1046
00:50:43,320 --> 00:50:41,590
of oxygen there will be hydrogen and

1047
00:50:47,250 --> 00:50:43,330
there may be a little bit of healing

1048
00:50:49,380 --> 00:50:47,260
but you're not expecting the periodic

1049
00:50:51,180 --> 00:50:49,390
table quote-unquote of the universe to

1050
00:50:55,440 --> 00:50:51,190
look that much different than what you

1051
00:50:58,590 --> 00:50:55,450
see here on earth and so Cecilia Payne

1052
00:51:03,710 --> 00:50:58,600
looked through the Harvard plates she

1053
00:51:06,000 --> 00:51:03,720
did the calculations again by hand and

1054
00:51:07,310 --> 00:51:06,010
she found that it looks a little

1055
00:51:10,080 --> 00:51:07,320
different

1056
00:51:12,210 --> 00:51:10,090
for every one that ever hated chemistry

1057
00:51:14,220 --> 00:51:12,220
you should have been an astronomer we

1058
00:51:20,490 --> 00:51:14,230
have hydrogen we have helium and

1059
00:51:24,450 --> 00:51:20,500
everything else as a metal but more

1060
00:51:28,740 --> 00:51:24,460
importantly hydrogen makes up 75% of the

1061
00:51:32,160 --> 00:51:28,750
universe about 25% of the universe is

1062
00:51:37,880 --> 00:51:32,170
helium everything else is a trace

1063
00:51:41,850 --> 00:51:37,890

element formed in the core of a star in

1064
00:51:44,130 --> 00:51:41,860
1925 this was outrageous this was insane

1065
00:51:48,330 --> 00:51:44,140
this went against all of the prevailing

1066
00:51:50,730 --> 00:51:48,340
wisdom and you're a grad student your

1067
00:51:53,340 --> 00:51:50,740
jr. and you're a woman you're the first

1068
00:51:58,020 --> 00:51:53,350
woman to ever study for a PhD at Harvard

1069
00:52:01,640 --> 00:51:58,030
and one of the first in the world to

1070
00:52:04,110 --> 00:52:01,650
ever study for a PhD and you're and

1071
00:52:07,800 --> 00:52:04,120
Shapley decides you know what we need to

1072
00:52:09,600 --> 00:52:07,810
check with someone more senior who knows

1073
00:52:12,630 --> 00:52:09,610
about this stuff this is Henry Norris

1074
00:52:16,410 --> 00:52:12,640
Russell he is the R of the HR diagram

1075
00:52:19,020 --> 00:52:16,420
and they sent her him Cecilia Payne's

1076
00:52:21,000 --> 00:52:19,030
thesis and he wrote back to her that it

1077
00:52:22,500 --> 00:52:21,010
is clearly impossible that hydrogen

1078
00:52:28,430 --> 00:52:22,510
should be a million times more abundant

1079
00:52:31,080 --> 00:52:28,440
than metals note he hates chemistry and

1080
00:52:33,270 --> 00:52:31,090
he convinced her to temper her

1081
00:52:38,300 --> 00:52:33,280
conclusions in the paper to say this is

1082
00:52:40,800 --> 00:52:38,310
probably wrong it's a measurement error

1083
00:52:43,430 --> 00:52:40,810
several years later he published the

1084
00:52:46,440 --> 00:52:43,440
exact same result and barely cited her

1085
00:52:48,630 --> 00:52:46,450
the good news is most men in this talk

1086
00:52:50,910 --> 00:52:48,640
are generally awesome for their time

1087
00:52:56,630 --> 00:52:50,920
this guy is a complete I'm not going to

1088
00:53:02,700 --> 00:53:00,089

however Cecilia Payne's thesis on

1089
00:53:04,020 --> 00:53:02,710
stellar atmospheres a contribution to

1090
00:53:06,299 --> 00:53:04,030
the observational study of high

1091
00:53:08,790 --> 00:53:06,309
temperatures in reversing layers of

1092
00:53:13,609 --> 00:53:08,800
stars has been called the most brilliant

1093
00:53:16,890 --> 00:53:13,619
PhD thesis ever written in astronomy it

1094
00:53:20,520 --> 00:53:16,900
is in credit it would be incredibly

1095
00:53:21,890 --> 00:53:20,530
impressive work today let alone 100

1096
00:53:28,680 --> 00:53:21,900
years ago

1097
00:53:30,390 --> 00:53:28,690
and at this point the story of the

1098
00:53:33,740 --> 00:53:30,400
Harvard computers is an active group

1099
00:53:35,760 --> 00:53:33,750
somewhat ends this is a transition point

1100
00:53:38,520 --> 00:53:35,770
transitioning from the women being

1101
00:53:41,190 --> 00:53:38,530
Harvard computers to the women being

1102
00:53:47,940 --> 00:53:41,200
scientists and considered scientists in

1103
00:53:50,490 --> 00:53:47,950
and of their own right the people that I

1104
00:53:53,760 --> 00:53:50,500
talked about in this talk are only full

1105
00:53:55,290 --> 00:53:53,770
are only five of dozens of women that

1106
00:54:00,150 --> 00:53:55,300
worked at the Harvard Observatory from

1107
00:54:04,410 --> 00:54:00,160
1880 to the 1920s I'm not even sure a

1108
00:54:07,559 --> 00:54:04,420
complete list even exists by the time

1109
00:54:09,720 --> 00:54:07,569
the Harvard arca archive was complete

1110
00:54:12,059 --> 00:54:09,730
there were half a million glass plates

1111
00:54:15,569 --> 00:54:12,069
in the collection each plate containing

1112
00:54:17,549 --> 00:54:15,579
countless spectra and they classified

1113
00:54:20,789 --> 00:54:17,559

and characterized the stars on all of

1114
00:54:22,559 --> 00:54:20,799
these plates an Egypt Canon who took

1115
00:54:25,049 --> 00:54:22,569
over for will I mean Wilhelmina Fleming

1116
00:54:28,319 --> 00:54:25,059
after her death someone came in and said

1117
00:54:30,180 --> 00:54:28,329
I want swn dramedy I figured that's in

1118
00:54:32,370 --> 00:54:30,190
the constellation of Andromeda but she

1119
00:54:36,870 --> 00:54:32,380
rattled off the five digit plate number

1120
00:54:41,789 --> 00:54:36,880
and sure enough the requested star was

1121
00:54:44,490 --> 00:54:41,799
on that plate the work this is a picture

1122
00:54:48,120 --> 00:54:44,500
Cecilia Payne is in the middle and Annie

1123
00:54:50,730 --> 00:54:48,130
jump cannon is behind her this work

1124
00:54:52,410 --> 00:54:50,740
their work is the backbone of stellar at

1125
00:54:55,049 --> 00:54:52,420
modern stellar astrophysics without

1126
00:54:58,120 --> 00:54:55,059
these women we don't have modern stellar

1127
00:55:03,349 --> 00:55:01,670
well Amina Fleming died in 1911 she was

1128
00:55:06,799 --> 00:55:03,359
the first of them she was also one of

1129
00:55:09,980 --> 00:55:06,809
the oldest remember most of many of her

1130
00:55:12,140 --> 00:55:09,990
contributions were cataloging and making

1131
00:55:14,030 --> 00:55:12,150
sure that the plates were organized and

1132
00:55:16,069 --> 00:55:14,040
so that someone could actually find what

1133
00:55:17,569 --> 00:55:16,079
they were looking for and even in

1134
00:55:19,940 --> 00:55:17,579
astronomy her contributions have been

1135
00:55:21,530 --> 00:55:19,950
largely forgotten I actually didn't know

1136
00:55:25,910 --> 00:55:21,540
her name until I started researching

1137
00:55:27,980 --> 00:55:25,920
this talk on her tombstone under her

1138
00:55:31,040 --> 00:55:27,990

name and the dates of her birth and

1139
00:55:34,700 --> 00:55:31,050
death she simply had written astronomer

1140
00:55:36,620 --> 00:55:34,710
and remember she is the only person that

1141
00:55:40,970 --> 00:55:36,630
I've highlighted here that did not have

1142
00:55:43,940 --> 00:55:40,980
a degree in astronomy any jump cannon

1143
00:55:46,819 --> 00:55:43,950
died in 1941 this is a picture of her

1144
00:55:49,370 --> 00:55:46,829
looking at one of the glass plates they

1145
00:55:53,740 --> 00:55:49,380
would mark in pencil next to each of the

1146
00:55:56,359 --> 00:55:53,750
stars were preliminary classifications

1147
00:56:01,250 --> 00:55:56,369
possible variables that could then be

1148
00:56:03,289 --> 00:56:01,260
wiped away afterwards during her

1149
00:56:05,270 --> 00:56:03,299
lifetime she would classify hundreds of

1150
00:56:07,039 --> 00:56:05,280
thousands of stars she could look at one

1151
00:56:13,339 --> 00:56:07,049
of those spectra on the glass plate and

1152
00:56:16,670 --> 00:56:13,349
say that that's a b2 as casually as you

1153
00:56:23,390 --> 00:56:16,680
decide whether as you look at anything

1154
00:56:25,940 --> 00:56:23,400
that's a b2 that's a G that's a M the O

1155
00:56:28,160 --> 00:56:25,950
be a FG km spectral classification

1156
00:56:29,630 --> 00:56:28,170
sequence that she developed was adopted

1157
00:56:34,630 --> 00:56:29,640
by the International Astronomical Union

1158
00:56:36,799 --> 00:56:34,640
in 1922 and it is still in use today and

1159
00:56:41,559 --> 00:56:36,809
if anyone can come up with a better

1160
00:56:48,289 --> 00:56:46,010
she received a prize from she received a

1161
00:56:50,240 --> 00:56:48,299
prize for her work from a group that

1162
00:56:53,329 --> 00:56:50,250
supported women in research and in

1163
00:56:56,450 --> 00:56:53,339

academia of $1,000 and using this money

1164
00:57:00,260 --> 00:56:56,460
she endowed a prize in her name the

1165
00:57:02,270 --> 00:57:00,270
Annie jump cannon prize for decades this

1166
00:57:05,809 --> 00:57:02,280
was given only once in a while to a

1167
00:57:08,740 --> 00:57:05,819
deserving woman it is now given annually

1168
00:57:12,070 --> 00:57:08,750
to an exemplary early career woman at AU

1169
00:57:13,840 --> 00:57:12,080
nighted states institution which I take

1170
00:57:18,940 --> 00:57:13,850
to mean that there's no more of us than

1171
00:57:20,320 --> 00:57:18,950
there used to be antonio mari would work

1172
00:57:22,810 --> 00:57:20,330
intermittently at the Harvard

1173
00:57:24,580 --> 00:57:22,820
Observatory for decades one of the

1174
00:57:26,770 --> 00:57:24,590
reasons is was intermittent is that she

1175
00:57:29,800 --> 00:57:26,780
couldn't make enough money as a computer

1176
00:57:32,590 --> 00:57:29,810
to actually live so she was often doing

1177
00:57:35,290 --> 00:57:32,600
teaching jobs in addition to her work at

1178
00:57:40,710 --> 00:57:35,300
the observatory and would burn out would

1179
00:57:43,570 --> 00:57:40,720
leave for a while and would come back in

1180
00:57:46,150 --> 00:57:43,580
1944 she became the second recipient of

1181
00:57:50,980 --> 00:57:46,160
the Annie jump cannon prize and passed

1182
00:57:54,400 --> 00:57:50,990
away in 1952 that complex vector

1183
00:57:56,920 --> 00:57:54,410
classification sequence the fact that

1184
00:57:58,480 --> 00:57:56,930
the spectral lines of difference of the

1185
00:58:00,220 --> 00:57:58,490
differ of some of the different stars

1186
00:58:03,840 --> 00:58:00,230
looked different even though their

1187
00:58:06,730 --> 00:58:03,850
strengths were the same is now how we

1188
00:58:11,080 --> 00:58:06,740

determine our differentiate between

1189
00:58:13,030 --> 00:58:11,090
types of stars so how many people have

1190
00:58:18,910 --> 00:58:13,040
seen Betelgeuse the bloody shoulder of

1191
00:58:21,780 --> 00:58:18,920
Orion it's really bright right how many

1192
00:58:25,140 --> 00:58:21,790
of you have heard of Proxima Centauri

1193
00:58:27,730 --> 00:58:25,150
yeah it's been near a start of the Sun

1194
00:58:30,280 --> 00:58:27,740
Betelgeuse but you can't see it from

1195
00:58:34,000 --> 00:58:30,290
earth with the naked eye it is so dim

1196
00:58:37,660 --> 00:58:34,010
that even at 4.1 light-years it is too

1197
00:58:39,190 --> 00:58:37,670
faint but for comparison Alpha Centauri

1198
00:58:43,510 --> 00:58:39,200
is one of the brightest stars on the

1199
00:58:45,990 --> 00:58:43,520
southern sky Proxima Centauri and

1200
00:58:49,840 --> 00:58:46,000
Betelgeuse are the same spectral class

1201
00:58:52,360 --> 00:58:49,850
the difference is in the shape of their

1202
00:58:55,600 --> 00:58:52,370
lines Betelgeuse is a giant star has a

1203
00:58:58,540 --> 00:58:55,610
much broader line Proxima Centauri has a

1204
00:59:01,660 --> 00:58:58,550
much narrower line and mari's

1205
00:59:03,820 --> 00:59:01,670
classification scheme is how we

1206
00:59:07,160 --> 00:59:03,830
differentiate between those types of

1207
00:59:12,630 --> 00:59:11,010
in 1934 Cecilia Payne gevalt skin

1208
00:59:14,940 --> 00:59:12,640
received the first Annie jump cannon

1209
00:59:17,490 --> 00:59:14,950
prize the only recipient to receive it

1210
00:59:20,250 --> 00:59:17,500
directly from Annie jump cannon her

1211
00:59:24,569 --> 00:59:20,260
prize was $50 and a small handcrafted

1212
00:59:27,000 --> 00:59:24,579
medallion of a spiral galaxy she is also

1213
00:59:29,069 --> 00:59:27,010

the other than Wilhelmina Fleming and

1214
00:59:30,809 --> 00:59:29,079
her short-lived early marriage she is

1215
00:59:35,099 --> 00:59:30,819
the only person who I've highlighted

1216
00:59:36,960 --> 00:59:35,109
here that was married she went on to

1217
00:59:38,789 --> 00:59:36,970
become the first female faculty member

1218
00:59:41,450 --> 00:59:38,799
of the Harvard Astronomy Department this

1219
00:59:44,250 --> 00:59:41,460
took until nineteen of the 1950's and

1220
00:59:50,279 --> 00:59:44,260
she became its first female department

1221
00:59:56,490 --> 00:59:50,289
chair and then there is Henrietta

1222
00:59:58,500 --> 00:59:56,500
Leavitt she died of cancer in 1921 five

1223
01:00:02,339 --> 00:59:58,510
years later a man you might have heard

1224
01:00:06,809 --> 01:00:02,349
of Edwin Hubble used the pea found

1225
01:00:11,039 --> 01:00:06,819
Cepheid in Andromeda and he used that

1226
01:00:12,930 --> 01:00:11,049
period-luminosity relation that standard

1227
01:00:15,089 --> 01:00:12,940
candle that Henrietta leave it gave

1228
01:00:17,819 --> 01:00:15,099
astronomy to determine the distance to

1229
01:00:20,849 --> 01:00:17,829
the Andromeda nebula what was then known

1230
01:00:22,859 --> 01:00:20,859
as the Andromeda nebula at that point

1231
01:00:25,470 --> 01:00:22,869
there was a massive debate in the field

1232
01:00:27,630 --> 01:00:25,480
about whether or not objects like

1233
01:00:31,079 --> 01:00:27,640
Andromeda were internal to our own Milky

1234
01:00:34,589 --> 01:00:31,089
Way or galaxies external to our Milky

1235
01:00:38,220 --> 01:00:34,599
Way something that we just know now as a

1236
01:00:40,109 --> 01:00:38,230
fact of the field was under debate the

1237
01:00:42,029 --> 01:00:40,119
distance that he derived from the

1238
01:00:44,160 --> 01:00:42,039

Andromeda sophia's proved beyond a

1239
01:00:48,029 --> 01:00:44,170
shadow of a doubt that Andromeda wasn't

1240
01:00:50,400 --> 01:00:48,039
a nebula it was a it was an external

1241
01:00:56,220 --> 01:00:50,410
galaxy that we now know to be 2.5

1242
01:00:58,710 --> 01:00:56,230
million light-years from our own today

1243
01:01:00,870 --> 01:00:58,720
the Cepheid formed part of what

1244
01:01:05,809 --> 01:01:00,880
astronomers refer to as the distance

1245
01:01:08,370 --> 01:01:05,819
ladder starting down here with parallax

1246
01:01:13,859 --> 01:01:08,380
so if you want an example of parallax

1247
01:01:18,310 --> 01:01:13,869
stick one finger out cover one eye

1248
01:01:21,730 --> 01:01:18,320
cover the other eye quickly and then

1249
01:01:26,920 --> 01:01:21,740
move your finger in and do it again your

1250
01:01:32,410 --> 01:01:26,930
finger moves does your finger move when

1251
01:01:34,170 --> 01:01:32,420
does it move more closer parallax does

1252
01:01:37,420 --> 01:01:34,180
the same thing does the same for stars

1253
01:01:39,430 --> 01:01:37,430
but it only works for stars even today

1254
01:01:41,500 --> 01:01:39,440
four stars relatively close to the earth

1255
01:01:44,050 --> 01:01:41,510
we can't even go outside of our

1256
01:01:48,580 --> 01:01:44,060
immediate neighborhood around the Sun

1257
01:01:51,220 --> 01:01:48,590
let alone outside of the galaxy up here

1258
01:01:53,560 --> 01:01:51,230
we have cosmic distant scales measuring

1259
01:01:55,359 --> 01:01:53,570
things that are millions or billions of

1260
01:01:59,890 --> 01:01:55,369
light-years away and we still need to

1261
01:02:05,140 --> 01:01:59,900
know their distances and in between are

1262
01:02:07,390 --> 01:02:05,150
the Cepheid we use parallax for those

1263
01:02:10,359 --> 01:02:07,400

nearby sophia's for which we know

1264
01:02:11,950 --> 01:02:10,369
parallax we have their parallax's we can

1265
01:02:14,770 --> 01:02:11,960
get their distance with parallax and

1266
01:02:17,740 --> 01:02:14,780
that calibrates henriette leave its

1267
01:02:20,830 --> 01:02:17,750
relation the Cepheid x' in turn

1268
01:02:23,740 --> 01:02:20,840
calibrate the even more distant distant

1269
01:02:26,410 --> 01:02:23,750
scales when you hear about the

1270
01:02:29,170 --> 01:02:26,420
acceleration of the universe or which a

1271
01:02:33,310 --> 01:02:29,180
nobel prize was awarded dependent on the

1272
01:02:35,620 --> 01:02:33,320
period-luminosity relation whenever you

1273
01:02:37,480 --> 01:02:35,630
hear an astronomer tell you how far away

1274
01:02:42,880 --> 01:02:37,490
something is at the edge of the universe

1275
01:02:46,870 --> 01:02:42,890
or even only 5 billion light-years away

1276
01:02:54,130 --> 01:02:46,880
it is dependent on this step in the

1277
01:02:55,680 --> 01:02:54,140
distance ladder on the centennial of her

1278
01:02:58,990 --> 01:02:55,690
discovery of the period-luminosity

1279
01:03:01,420 --> 01:02:59,000
relation a symposium was held at Harvard

1280
01:03:06,070 --> 01:03:01,430
this is something we do in astronomy we

1281
01:03:08,920 --> 01:03:06,080
have symposia and at that symposia it

1282
01:03:11,349 --> 01:03:08,930
was recommended that from there on out

1283
01:03:14,080 --> 01:03:11,359
the Cepheid period-luminosity relation

1284
01:03:17,620 --> 01:03:14,090
which is how I learned it and how most

1285
01:03:22,870 --> 01:03:17,630
astronomers learned it be referred to as

1286
01:03:25,339 --> 01:03:22,880
the Leavitt law the next year the

1287
01:03:30,259 --> 01:03:25,349
American Astronomical Society

1288
01:03:32,599 --> 01:03:30,269

agreed and well you were asking me

1289
01:03:36,969 --> 01:03:32,609
questions I have a little present for

1290
01:03:44,560 --> 01:03:36,979
you from the mm from the women from the

1291
01:04:03,260 --> 01:03:58,060
[Applause]

1292
01:04:06,730 --> 01:04:03,270
questions yes up prior to the

1293
01:04:09,680 --> 01:04:06,740
termination of the standard candle

1294
01:04:10,760 --> 01:04:09,690
parameter step on bevels what's there a

1295
01:04:15,980 --> 01:04:10,770
even Ossipee

1296
01:04:17,870 --> 01:04:15,990
standard prior to that yeah not charcoal

1297
01:04:19,820 --> 01:04:17,880
and earlier the shampoo vanassa ders you

1298
01:04:22,400 --> 01:04:19,830
called the absolute brightness what's

1299
01:04:25,130 --> 01:04:22,410
that smell different that was she could

1300
01:04:27,200 --> 01:04:25,140
do it because she knew the initial group

1301
01:04:31,070 --> 01:04:27,210
but it was done for were all at the same

1302
01:04:32,960 --> 01:04:31,080
distance they were all in the LMC she

1303
01:04:35,270 --> 01:04:32,970
didn't know the distance at the LMC but

1304
01:04:37,280 --> 01:04:35,280
she knew that if one was brighter than

1305
01:04:42,370 --> 01:04:37,290
the other it was actually that much

1306
01:04:45,140 --> 01:04:42,380
brighter than the other so if you take

1307
01:04:48,140 --> 01:04:45,150
so you have this variable of distance

1308
01:04:49,370 --> 01:04:48,150
and if something is much closer to you

1309
01:04:51,830 --> 01:04:49,380
if you have two things that are the same

1310
01:04:54,460 --> 01:04:51,840
brightness and one is closer to the

1311
01:04:56,990 --> 01:04:54,470
other the closer one will appear right

1312
01:04:58,700 --> 01:04:57,000
but if those two objects are taken to

1313
01:05:00,200 --> 01:04:58,710

about the same distance they will appear

1314
01:05:02,089 --> 01:05:00,210
they will appear to have the same

1315
01:05:06,650 --> 01:05:02,099
brightness and they will in fact have

1316
01:05:08,510 --> 01:05:06,660
the same rights if you have one object

1317
01:05:11,329 --> 01:05:08,520
that's much brighter and is further away

1318
01:05:13,130 --> 01:05:11,339
and one object which is fainter and

1319
01:05:14,810 --> 01:05:13,140
closer they may appear to be the same

1320
01:05:18,079 --> 01:05:14,820
brightness but in actuality the more

1321
01:05:20,030 --> 01:05:18,089
distant one is brighter in he would have

1322
01:05:23,359 --> 01:05:20,040
take those two same two objects and move

1323
01:05:25,370 --> 01:05:23,369
them to the same distance the one that

1324
01:05:27,349 --> 01:05:25,380
is brighter will appear to be brighter

1325
01:05:29,510 --> 01:05:27,359
than the fainter object and that was

1326
01:05:32,030 --> 01:05:29,520
what allowed her to have to build the

1327
01:05:33,560 --> 01:05:32,040
period-luminosity relation is that she

1328
01:05:35,089 --> 01:05:33,570
didn't know how far away they actually

1329
01:05:36,680 --> 01:05:35,099
were but she knew they were all out of

1330
01:05:40,640 --> 01:05:36,690
the same distance because they were all

1331
01:05:44,260 --> 01:05:40,650
in the large magellanic cloud does that

1332
01:05:52,520 --> 01:05:48,620
other vessels here yeah I was wondering

1333
01:05:54,950 --> 01:05:52,530
I did the UM was there work instrumental

1334
01:05:56,780 --> 01:05:54,960
connecting with it Einstein that there

1335
01:05:58,849 --> 01:05:56,790
was nuclear fusion and the core of stars

1336
01:06:04,940 --> 01:05:58,859
you have hydrogen going to helium which

1337
01:06:10,680 --> 01:06:08,610
his profession was her work instrumental

1338
01:06:13,670 --> 01:06:10,690

with determining that hydrogen was in

1339
01:06:15,720 --> 01:06:13,680
the core of stars and the answer is no

1340
01:06:17,280 --> 01:06:15,730
Cecilia Payne work dealt with the

1341
01:06:19,140 --> 01:06:17,290
atmospheres of stars the very upper

1342
01:06:21,600 --> 01:06:19,150
level that week the photosphere that we

1343
01:06:23,070 --> 01:06:21,610
can actually observe the physics of what

1344
01:06:30,420 --> 01:06:23,080
actually happened inside the core of

1345
01:06:35,040 --> 01:06:30,430
stars was done by other people when Evan

1346
01:06:38,670 --> 01:06:35,050
Hubble was looking for the second

1347
01:06:41,250 --> 01:06:38,680
variable in Andromeda to find out

1348
01:06:43,590 --> 01:06:41,260
whether it was she had million light

1349
01:06:47,340 --> 01:06:43,600
years away they were just part of our

1350
01:06:50,900 --> 01:06:47,350
galaxy we start looking at all these

1351
01:06:55,170 --> 01:06:50,910
stars with the telescopes they've had

1352
01:07:00,330 --> 01:06:55,180
how do you know precisely what started

1353
01:07:03,560 --> 01:07:00,340
looking at when you got do it lady for

1354
01:07:10,550 --> 01:07:03,570
doing under the thousands of stars you

1355
01:07:16,260 --> 01:07:14,070
the question is how do you go about

1356
01:07:19,680 --> 01:07:16,270
looking for seppius and Andromeda on

1357
01:07:22,710 --> 01:07:19,690
photographic plates and this face were

1358
01:07:25,560 --> 01:07:22,720
actually relatively high resolution you

1359
01:07:29,040 --> 01:07:25,570
can see a lot of individual stars on

1360
01:07:32,160 --> 01:07:29,050
those plates especially analysis as

1361
01:07:33,300 --> 01:07:32,170
close to us as a barometer is you would

1362
01:07:36,720 --> 01:07:33,310
then take an extremely powerful

1363
01:07:38,880 --> 01:07:36,730

magnifying glass and what looks like a

1364
01:07:43,080 --> 01:07:38,890
cloud of stars would actually resolve

1365
01:07:44,820 --> 01:07:43,090
out into individual what's a light you

1366
01:07:46,560 --> 01:07:44,830
also would not point the telescope at

1367
01:07:49,260 --> 01:07:46,570
the very center of Andromeda you would

1368
01:07:51,270 --> 01:07:49,270
look sort of slightly out from the

1369
01:07:53,130 --> 01:07:51,280
center where the stellar the starts

1370
01:07:54,480 --> 01:07:53,140
weren't quite as dense and it is still

1371
01:08:02,280 --> 01:07:54,490
the technique that astronomers use to

1372
01:08:04,470 --> 01:08:02,290
this day in your beautiful image there

1373
01:08:07,860 --> 01:08:04,480
are a lot of blue stars for a very old

1374
01:08:11,490 --> 01:08:07,870
cluster you explained that the HR

1375
01:08:13,650 --> 01:08:11,500
diagram is an evolutionary diagram can

1376
01:08:14,150 --> 01:08:13,660
you explain the blue stars the blue

1377
01:08:22,490 --> 01:08:14,160
stars

1378
01:08:23,990 --> 01:08:22,500
they evolve into the giant phase and

1379
01:08:27,559 --> 01:08:24,000
then they go through sort of an

1380
01:08:29,390 --> 01:08:27,569
oscillation when they go from the red

1381
01:08:33,620 --> 01:08:29,400
part of the diagram over towards the

1382
01:08:35,030 --> 01:08:33,630
blue and then back and they're not when

1383
01:08:36,559 --> 01:08:35,040
they move backwards the blue they're not

1384
01:08:38,539 --> 01:08:36,569
burning hydrogen they're actually

1385
01:08:40,760 --> 01:08:38,549
burning helium and then eventually

1386
01:08:44,689 --> 01:08:40,770
carbon and oxygen for the most massive

1387
01:08:46,579 --> 01:08:44,699
stars and every time they have to burn

1388
01:08:49,610 --> 01:08:46,589

heavier another element so when they

1389
01:08:51,680 --> 01:08:49,620
they evolve up to the red giant they get

1390
01:08:55,280 --> 01:08:51,690
hot enough to burn helium they move over

1391
01:08:58,130 --> 01:08:55,290
and then when they run out of helium

1392
01:09:00,499 --> 01:08:58,140
they go back and they just back and

1393
01:09:03,800 --> 01:09:00,509
forth until they run out of fuel to burn

1394
01:09:04,910 --> 01:09:03,810
at which point they for those stars

1395
01:09:07,459 --> 01:09:04,920
they're going to explode in a supernova

1396
01:09:09,620 --> 01:09:07,469
I would also note in the image that we

1397
01:09:12,320 --> 01:09:09,630
came out today the blue here actually

1398
01:09:14,780 --> 01:09:12,330
represents ultraviolet light this this

1399
01:09:18,559 --> 01:09:14,790
image was taken with ultraviolet visible

1400
01:09:20,300 --> 01:09:18,569
and infrared detectors on like white

1401
01:09:22,430 --> 01:09:20,310
field camera 3 so the colors are

1402
01:09:25,729 --> 01:09:22,440
stretched beyond the visible light and

1403
01:09:29,689 --> 01:09:25,739
is in this image k visually Omega said

1404
01:09:37,030 --> 01:09:29,699
looks yellowish when you actually come

1405
01:09:41,689 --> 01:09:37,040
back love you I'm innocent

1406
01:09:43,610 --> 01:09:41,699
alright this is a curiosity Omega said

1407
01:09:49,329 --> 01:09:43,620
can be seen from Baltimore

1408
01:10:01,189 --> 01:09:51,919
it's about three degrees above the prize

1409
01:10:03,050 --> 01:10:01,199
yes you can see it that's tough in

1410
01:10:04,430 --> 01:10:03,060
astronomy you're not observe a mega

1411
01:10:05,960 --> 01:10:04,440
in the southern time from the northern

1412
01:10:10,700 --> 01:10:05,970
hemisphere the telescope operator would

1413
01:10:14,210 --> 01:10:10,710

kick you out of the room yes if you

1414
01:10:16,130 --> 01:10:14,220
could name a Space Telescope after one

1415
01:10:18,260 --> 01:10:16,140
of these women who would it be

1416
01:10:20,270 --> 01:10:18,270
why so the question is if you can name a

1417
01:10:33,770 --> 01:10:20,280
Space Telescope after one of these women

1418
01:10:36,950 --> 01:10:33,780
which ones it will be one of those three

1419
01:10:39,230 --> 01:10:36,960
I think it would depend on what the

1420
01:10:41,120 --> 01:10:39,240
mission of that telescope was if it was

1421
01:10:42,710 --> 01:10:41,130
a telescope to push the distance ladder

1422
01:10:45,320 --> 01:10:42,720
then you name it for Henrietta leave it

1423
01:10:48,230 --> 01:10:45,330
if it's a telescope its primary mission

1424
01:10:51,140 --> 01:10:48,240
is going to be to go after stars Annie

1425
01:10:56,000 --> 01:10:51,150
jump cannon if you're probing

1426
01:10:57,080 --> 01:10:56,010
fundamental physics hey so it I think it

1427
01:10:58,820 --> 01:10:57,090
would depend but I think it's high time

1428
01:11:07,150 --> 01:10:58,830
we named telescope after one of these

1429
01:11:12,320 --> 01:11:07,160
people other questions we have honey

1430
01:11:20,420 --> 01:11:12,330
you for me please the junk absorption

1431
01:11:23,560 --> 01:11:20,430
lines each is if each element has had

1432
01:11:27,980 --> 01:11:23,570
the bone the books and patterns or

1433
01:11:31,160 --> 01:11:27,990
something else each element has an

1434
01:11:32,240 --> 01:11:31,170
absorption pattern we usually talk about

1435
01:11:32,960 --> 01:11:32,250
them the way that you think about

1436
01:11:36,800 --> 01:11:32,970
fingerprints

1437
01:11:38,750 --> 01:11:36,810
these the specific sort of swirls within

1438
01:11:40,970 --> 01:11:38,760

your finger may be repeated in another

1439
01:11:43,850 --> 01:11:40,980
person but the combination of those

1440
01:11:46,580 --> 01:11:43,860
patterns on all ten of your fingers is

1441
01:11:51,800 --> 01:11:46,590
unique to you and the same thing is true

1442
01:11:54,290 --> 01:11:51,810
of the different elements the there may

1443
01:11:57,860 --> 01:11:54,300
be a line very close to hydrogen alpha

1444
01:11:59,750 --> 01:11:57,870
in for another element but the pattern

1445
01:12:01,820 --> 01:11:59,760
of hydrogen alpha hydrogen mega and

1446
01:12:07,580 --> 01:12:01,830
hydrogen gamma and hydrogen no that is

1447
01:12:09,800 --> 01:12:07,590
unique to hydrogen and you look for

1448
01:12:12,500 --> 01:12:09,810
those patterns rather than the

1449
01:12:16,820 --> 01:12:12,510
individual ones all right in the last

1450
01:12:18,740 --> 01:12:16,830
questions I see that greenie is here so

1451
01:12:20,660 --> 01:12:18,750
everyone say Haier mini she is our

1452
01:12:22,910 --> 01:12:20,670
telescope operator the Maryland space

1453
01:12:24,440 --> 01:12:22,920
grant observatory and if you would like

1454
01:12:26,240 --> 01:12:24,450
to go look through the telescope she

1455
01:12:29,180 --> 01:12:26,250
will take you are you going to come down

1456
01:12:31,190 --> 01:12:29,190
here so that if people are going to be

1457
01:12:32,480 --> 01:12:31,200
leading from over there so if you would

1458
01:12:34,160 --> 01:12:32,490
like to go across the street and meet

1459
01:12:37,370 --> 01:12:34,170
with Iranian she'll take you across the

1460
01:12:39,170 --> 01:12:37,380
street next month is to be announced but

1461
01:12:41,780 --> 01:12:39,180
I will have a speaker for you on June

1462
01:12:44,300 --> 01:12:41,790
6th and let us give a very warm thank

1463
01:12:57,160 --> 01:12:44,310

you to me Abobo