

1
00:00:00,030 --> 00:00:04,710
then we have our beautiful beautiful

2
00:00:02,279 --> 00:00:07,528
pictures tonight special requests by our

3
00:00:04,710 --> 00:00:11,280
speaker that you have the core of the

4
00:00:07,528 --> 00:00:13,530
globular cluster Omega Centauri okay and

5
00:00:11,279 --> 00:00:16,469
all these beautiful red and blue stars

6
00:00:13,529 --> 00:00:19,140
which are actually ultraviolet and

7
00:00:16,469 --> 00:00:20,910
infrared as well as visible light it

8
00:00:19,140 --> 00:00:24,929
covers the full spectrum with Wide Field

9
00:00:20,910 --> 00:00:27,750
Camera 3 it's beautiful more details

10
00:00:24,929 --> 00:00:29,160
available on the back and I hope our

11
00:00:27,750 --> 00:00:31,439
speaker will actually talk about that a

12
00:00:29,160 --> 00:00:35,159
little bit tonight who is our speaker

13
00:00:31,439 --> 00:00:36,210
our speaker is MIA boville she is going

14
00:00:35,159 --> 00:00:38,549
to talk to you about the Harvard

15
00:00:36,210 --> 00:00:40,679
computers and the classification of

16
00:00:38,549 --> 00:00:43,378
stars of course this was work done a

17
00:00:40,679 --> 00:00:46,890
century ago so computers is in quotes

18
00:00:43,378 --> 00:00:48,599
and you'll understand that in a bit next

19
00:00:46,890 --> 00:00:51,359
month I've been having trouble getting

20
00:00:48,600 --> 00:00:54,300
people to commit to June usually July is

21
00:00:51,359 --> 00:00:56,250
my problem okay but I've had people try

22
00:00:54,299 --> 00:00:57,029
so it's still to be announced but I'm

23
00:00:56,250 --> 00:00:58,409
working on it

24
00:00:57,030 --> 00:01:00,719
trust me I'm working I'll find

25
00:00:58,409 --> 00:01:04,259
somebody's arm to twist for next June

26
00:01:00,719 --> 00:01:06,420
June 6th July is actually been moved

27
00:01:04,260 --> 00:01:08,640
early because we have amber Straughn

28
00:01:06,420 --> 00:01:11,040
from Goddard Space Flight Center here

29

00:01:08,640 --> 00:01:13,920
and she will be talking on dark energy

30
00:01:11,040 --> 00:01:16,650
and new worlds the science that is we

31
00:01:13,920 --> 00:01:19,250
hope to accomplish with NASA's W first

32
00:01:16,650 --> 00:01:22,140
mission that will hopefully launch

33
00:01:19,250 --> 00:01:23,909
sometime next decade

34
00:01:22,140 --> 00:01:25,739
there will be no lecture in July because

35
00:01:23,909 --> 00:01:27,770
we're taking Amber's lecture and

36
00:01:25,739 --> 00:01:31,169
counting that as our July lecture in

37
00:01:27,769 --> 00:01:33,599
August I have a really cool talk for you

38
00:01:31,170 --> 00:01:35,939
the view for Mission Operations that's

39
00:01:33,599 --> 00:01:38,158
not the title I just made that up this

40
00:01:35,938 --> 00:01:41,129
afternoon she hasn't given me a title

41
00:01:38,159 --> 00:01:43,680
but Courtney McManus who has worked on

42
00:01:41,129 --> 00:01:45,899
Mission Operations for the International

43
00:01:43,680 --> 00:01:48,540

Space Station and we're talking we have

44

00:01:45,899 --> 00:01:50,579

the missions opera operations here for

45

00:01:48,540 --> 00:01:53,070

JD OST here in the building so we tell

46

00:01:50,578 --> 00:01:57,978

you all sorts of cool stuff from Mission

47

00:01:53,069 --> 00:02:00,419

Operations standpoint August 1st 2017

48

00:01:57,978 --> 00:02:03,359

can't remember all that you can go to

49

00:02:00,420 --> 00:02:06,269

our website on Hubble site and by the

50

00:02:03,359 --> 00:02:07,590

way Hubble site has been designed has

51

00:02:06,269 --> 00:02:09,929

been changing I don't know how many of

52

00:02:07,590 --> 00:02:11,700

you go to our Hubble site website but

53

00:02:09,929 --> 00:02:13,080

we've been changing it and modernizing

54

00:02:11,699 --> 00:02:15,979

it all the content is

55

00:02:13,080 --> 00:02:18,570

still there okay you can still find us

56

00:02:15,979 --> 00:02:19,829

finding this bed page is probably the

57

00:02:18,569 --> 00:02:22,319

easiest if you go to your favorite

58
00:02:19,830 --> 00:02:24,900
search engine type in Hubbell public

59
00:02:22,319 --> 00:02:27,620
talks you'll find this web page on the

60
00:02:24,900 --> 00:02:30,990
web page we have our links to our live

61
00:02:27,620 --> 00:02:34,349
webcasting links to the archive all the

62
00:02:30,990 --> 00:02:37,260
way back to 2005 in the stsci webcasting

63
00:02:34,349 --> 00:02:39,930
archives as well as a way to sign up for

64
00:02:37,259 --> 00:02:42,359
our email list to get our couple

65
00:02:39,930 --> 00:02:46,200
reminders a month about the talks that

66
00:02:42,360 --> 00:02:47,850
are coming the announcements again sign

67
00:02:46,199 --> 00:02:48,479
up at the website but if you want to do

68
00:02:47,849 --> 00:02:51,959
it the hard way

69
00:02:48,479 --> 00:02:53,549
you can go to mail lists STScI edu the

70
00:02:51,959 --> 00:02:56,520
mail list is called public lecture

71
00:02:53,550 --> 00:02:59,520
announce if you would like to ask us

72
00:02:56,520 --> 00:03:04,200
questions send us comments you can send

73
00:02:59,520 --> 00:03:05,610
email to public lecture at stsci edu for

74
00:03:04,199 --> 00:03:09,659
those of you who like social media

75
00:03:05,610 --> 00:03:12,560
hubble has several ways of communicating

76
00:03:09,659 --> 00:03:14,939
Facebook Twitter feeds Google Plus and

77
00:03:12,560 --> 00:03:17,489
Pinterest out there for those of you who

78
00:03:14,939 --> 00:03:18,689
use those social media myself I have a

79
00:03:17,489 --> 00:03:21,450
blog on Hubbell site

80
00:03:18,689 --> 00:03:23,759
I have Facebook Google+ and Twitter that

81
00:03:21,449 --> 00:03:25,229
I occasionally do but unlike the

82
00:03:23,759 --> 00:03:29,429
president I have better things to do

83
00:03:25,229 --> 00:03:31,799
with my time uh-huh so I have a tendency

84
00:03:29,430 --> 00:03:35,010
to do my science rather than spend too

85
00:03:31,800 --> 00:03:37,560
much time on Twitter okay

86

00:03:35,009 --> 00:03:40,739
Observatory tonight yes the weather is

87
00:03:37,560 --> 00:03:42,689
permitting I talked with Irene E and she

88
00:03:40,739 --> 00:03:44,819
should be here about nine o'clock or so

89
00:03:42,689 --> 00:03:46,620
to take a group across the street to

90
00:03:44,819 --> 00:03:48,900
look through the telescope across the

91
00:03:46,620 --> 00:03:51,360
street so at the end of the lecture if I

92
00:03:48,900 --> 00:03:52,830
forget somebody remind me you'll meet

93
00:03:51,360 --> 00:03:56,370
down here with Irene II and she'll take

94
00:03:52,830 --> 00:04:00,120
you across the street alright and now

95
00:03:56,370 --> 00:04:06,900
okay my section news from the universe

96
00:04:00,120 --> 00:04:11,480
for May 2017 our top story tonight by

97
00:04:06,900 --> 00:04:13,560
Jupiter it's quite a beautiful planet

98
00:04:11,479 --> 00:04:15,689
Thomas can we take the lights down a bit

99
00:04:13,560 --> 00:04:19,879
there's a little bit of spillage onto

100
00:04:15,689 --> 00:04:19,879

the onto the screen here

101

00:04:21,980 --> 00:04:29,520

okay that's good thank you all right

102

00:04:24,779 --> 00:04:32,189

so every once a year a Jupiter gets into

103

00:04:29,519 --> 00:04:34,919

up what's called opposition okay where

104

00:04:32,189 --> 00:04:37,620

the Sun and Jupiter on the are on the

105

00:04:34,920 --> 00:04:40,230

opposite sides of Earth well this is the

106

00:04:37,620 --> 00:04:41,910

point in Jupiter's orbit when it is

107

00:04:40,230 --> 00:04:43,740

closest to Earth because you can see

108

00:04:41,910 --> 00:04:45,840

that if it were located anywhere else

109

00:04:43,740 --> 00:04:48,150

around its circle around its orbital

110

00:04:45,839 --> 00:04:52,589

circle it would be further from Earth so

111

00:04:48,149 --> 00:04:54,299

the best viewing its closest point is at

112

00:04:52,589 --> 00:04:57,479

opposition also it's its best viewing

113

00:04:54,300 --> 00:05:00,210

because it's up exactly opposite the Sun

114

00:04:57,480 --> 00:05:02,160

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

115
00:05:00,209 --> 00:05:05,009
at sunrise where you have interference

116
00:05:02,160 --> 00:05:06,360
of that and you can see it now Hubble

117
00:05:05,009 --> 00:05:08,459
doesn't have to worry about that too

118
00:05:06,360 --> 00:05:10,740
much because Hubble can doesn't have to

119
00:05:08,459 --> 00:05:12,149
puffles up and up in space and it

120
00:05:10,740 --> 00:05:14,189
doesn't have to worry about you know

121
00:05:12,149 --> 00:05:15,569
daytime versus nighttime because you

122
00:05:14,189 --> 00:05:19,199
know it doesn't have the atmosphere to

123
00:05:15,569 --> 00:05:21,509
look through however we often take

124
00:05:19,199 --> 00:05:23,550
pictures of the planets when they are

125
00:05:21,509 --> 00:05:26,370
opposition and you might think to

126
00:05:23,550 --> 00:05:28,470
yourself well we've had missions that go

127
00:05:26,370 --> 00:05:30,180
to the planets what can Hubble offer and

128
00:05:28,470 --> 00:05:33,540
I sometimes look at these these

129
00:05:30,180 --> 00:05:34,259
presley's as we do and go okay but you

130
00:05:33,540 --> 00:05:45,480
know what

131
00:05:34,259 --> 00:05:51,269
whoops hmm well let me replugin ah you

132
00:05:45,480 --> 00:05:58,730
know what this is an observation we have

133
00:05:51,269 --> 00:05:58,729
yet to take let me try this again

134
00:06:01,079 --> 00:06:13,899
there we go okay there we go now we got

135
00:06:08,798 --> 00:06:17,468
it we're back great um but you know what

136
00:06:13,899 --> 00:06:19,509
sometimes we just get it right so this

137
00:06:17,468 --> 00:06:23,009
is our picture of Jupiter and opposition

138
00:06:19,509 --> 00:06:23,009
from this year

139
00:06:23,369 --> 00:06:28,449
isn't that cool I mean I remember when

140
00:06:26,559 --> 00:06:31,389
we had to have the Voyager missions to

141
00:06:28,449 --> 00:06:33,338
go across go across interplanetary space

142
00:06:31,389 --> 00:06:35,860
to get something that look this gorgeous

143

00:06:33,338 --> 00:06:39,338
I just love all of the hydrodynamic

144
00:06:35,860 --> 00:06:41,588
effects okay I'm I'm a sucker for all

145
00:06:39,338 --> 00:06:43,868
the hydrodynamic effects of the vortices

146
00:06:41,588 --> 00:06:45,968
and the swirls in Jupiter's atmosphere

147
00:06:43,869 --> 00:06:48,969
plus you'll notice we've got not only

148
00:06:45,968 --> 00:06:51,189
the Great Red Spot but also we have what

149
00:06:48,968 --> 00:06:53,738
we colloquially call Red Spot jr.

150
00:06:51,189 --> 00:06:57,459
officially called oval ba

151
00:06:53,738 --> 00:07:01,508
I much prefer Red Spot jr. and red oval

152
00:06:57,459 --> 00:07:05,379
ba formed in the year 2000 okay we had

153
00:07:01,509 --> 00:07:07,929
never seen a second red spot until it

154
00:07:05,379 --> 00:07:09,699
actually well it formed as a white white

155
00:07:07,928 --> 00:07:12,188
spot and then turned red a few years

156
00:07:09,699 --> 00:07:15,759
later but it has now been around for

157
00:07:12,189 --> 00:07:18,369

almost 15 15 20 years okay so we're

158

00:07:15,759 --> 00:07:21,729

seeing a second Red Spot on Jupiter and

159

00:07:18,369 --> 00:07:23,579

it appears to be long-lived but I just

160

00:07:21,728 --> 00:07:26,978

thought this was a really wonderful

161

00:07:23,579 --> 00:07:28,989

beautiful image of Jupiter our second

162

00:07:26,978 --> 00:07:33,098

story tonight is also from the solar

163

00:07:28,988 --> 00:07:34,359

system Europa's Old Faithful alright so

164

00:07:33,098 --> 00:07:36,519

first of all let's make sure everyone

165

00:07:34,360 --> 00:07:38,759

remembers what Old Faithful is Old

166

00:07:36,519 --> 00:07:42,278

Faithful is the geyser in Yellowstone

167

00:07:38,759 --> 00:07:45,669

National Park that erupts approximately

168

00:07:42,278 --> 00:07:47,288

every 90 minutes is that right is that

169

00:07:45,668 --> 00:07:47,498

about 90 minutes or is it longer than

170

00:07:47,288 --> 00:07:50,558

that

171

00:07:47,499 --> 00:07:52,360

yes Caryn's wait Shane yes which is

172
00:07:50,559 --> 00:07:54,099
actually incidentally about the same

173
00:07:52,360 --> 00:07:56,408
time it takes orbit Hubble to orbit

174
00:07:54,098 --> 00:07:59,709
around Earth so every time Hubble passes

175
00:07:56,408 --> 00:08:02,618
over Old Faithful erupts right not quite

176
00:07:59,709 --> 00:08:06,369
and so this is a geyser from Hot Springs

177
00:08:02,619 --> 00:08:08,739
okay and so the idea is that the water

178
00:08:06,369 --> 00:08:11,860
spews up a hundred feet in the air or so

179
00:08:08,738 --> 00:08:13,579
right well if you remember if you were

180
00:08:11,860 --> 00:08:15,830
here last year

181
00:08:13,579 --> 00:08:18,620
I told you about seeing a plume on

182
00:08:15,829 --> 00:08:21,649
Europa that spews out a little bit

183
00:08:18,620 --> 00:08:23,180
further than a hundred feet all right so

184
00:08:21,649 --> 00:08:26,538
you got to understand this image okay

185
00:08:23,180 --> 00:08:28,668
first of all the plume is in white which

186
00:08:26,538 --> 00:08:30,438
is really pulled out of the data it's

187
00:08:28,668 --> 00:08:34,759
really hard to see this it's actually

188
00:08:30,439 --> 00:08:37,278
seen in shadow against the surface of

189
00:08:34,759 --> 00:08:40,338
Jupiter so Europa is passing in front of

190
00:08:37,278 --> 00:08:42,110
of Jupiter and we're seeing that plume

191
00:08:40,339 --> 00:08:44,240
in shadow it's been reversed here so

192
00:08:42,110 --> 00:08:46,399
that you can see it as white and then

193
00:08:44,240 --> 00:08:48,528
the picture of Europa here is not from

194
00:08:46,399 --> 00:08:50,539
Hubble this is actually from the Galileo

195
00:08:48,528 --> 00:08:52,129
mission all right as remember I said we

196
00:08:50,539 --> 00:08:53,838
get missions that have been there they

197
00:08:52,129 --> 00:08:55,850
got better pictures so to give you an

198
00:08:53,839 --> 00:08:58,970
idea of what we're seeing we've taken

199
00:08:55,850 --> 00:09:00,259
the Hubble data stretched it in contrast

200

00:08:58,970 --> 00:09:02,629
so you can see the plume because it's

201
00:09:00,259 --> 00:09:05,149
really tiny there and then thrown the

202
00:09:02,629 --> 00:09:08,360
Galileo image on top of it okay this is

203
00:09:05,149 --> 00:09:11,179
what I told you about last year well we

204
00:09:08,360 --> 00:09:17,269
looked again to try and see if this was

205
00:09:11,179 --> 00:09:19,909
a recurring event and yes it is we are

206
00:09:17,269 --> 00:09:22,339
see another plume now we don't see it

207
00:09:19,909 --> 00:09:24,230
every time we look for it okay we have

208
00:09:22,339 --> 00:09:26,930
done this observation of multiple times

209
00:09:24,230 --> 00:09:29,480
sometimes we see it sometimes we don't

210
00:09:26,929 --> 00:09:31,429
which gave me the sort of instance of

211
00:09:29,480 --> 00:09:33,769
Old Faithful that it sometimes erupts

212
00:09:31,429 --> 00:09:36,439
and sometimes does it what does this

213
00:09:33,769 --> 00:09:39,230
mean well the surface of Europa if you

214
00:09:36,440 --> 00:09:42,230

look at it in detail resembles cracked

215

00:09:39,230 --> 00:09:44,449
ice rafts on in the Arctic this is

216

00:09:42,230 --> 00:09:46,909
actually the surface of Europa and you

217

00:09:44,448 --> 00:09:50,419
can see all the ices when all the cracks

218

00:09:46,909 --> 00:09:53,838
in it okay all right and when we're

219

00:09:50,419 --> 00:09:56,179
because we're able to time when it when

220

00:09:53,839 --> 00:09:59,510
we saw this plume and where it was on on

221

00:09:56,179 --> 00:10:01,069
on the moon were able to narrow down to

222

00:09:59,509 --> 00:10:05,120
where we thought the plume was coming

223

00:10:01,070 --> 00:10:08,480
from to these cracks here on Europa all

224

00:10:05,120 --> 00:10:11,149
right and the idea was to say all right

225

00:10:08,480 --> 00:10:14,810
why would these cracks be emitting a

226

00:10:11,149 --> 00:10:17,120
water vapor well turns out that a

227

00:10:14,809 --> 00:10:20,299
temperature measure of the surface of

228

00:10:17,120 --> 00:10:23,448
Europa shows that that area is 3 degrees

229
00:10:20,299 --> 00:10:26,028
warmer than the rest now you have to

230
00:10:23,448 --> 00:10:27,379
recognize three degrees warmer is going

231
00:10:26,028 --> 00:10:30,559
from 92 Kelvin

232
00:10:27,379 --> 00:10:32,120
295 Kelvin and this is an absolute scale

233
00:10:30,559 --> 00:10:34,639
so this is minus a couple hundred

234
00:10:32,120 --> 00:10:36,860
degrees Fahrenheit okay so when I say

235
00:10:34,639 --> 00:10:39,019
warmer I really should be saying three

236
00:10:36,860 --> 00:10:43,610
degrees less totally absolutely frigid

237
00:10:39,019 --> 00:10:46,610
okay but it is actually warmer so the

238
00:10:43,610 --> 00:10:48,230
idea behind all this all right

239
00:10:46,610 --> 00:10:50,060
the idea behind our understanding of

240
00:10:48,230 --> 00:10:53,120
Europa is we have understood that

241
00:10:50,059 --> 00:10:56,869
underneath it's icy surface there is

242
00:10:53,120 --> 00:10:59,810
probably a liquid water layer now

243
00:10:56,870 --> 00:11:01,940
originally we thought that that icy sea

244
00:10:59,809 --> 00:11:04,129
crust was about a hundred kilometers

245
00:11:01,940 --> 00:11:04,730
thick and if you wanted to sample the

246
00:11:04,129 --> 00:11:06,230
water

247
00:11:04,730 --> 00:11:08,149
you'd have to drill down through a

248
00:11:06,230 --> 00:11:11,000
hundred kilometers which is not a very

249
00:11:08,149 --> 00:11:14,090
easy task however if we're seeing these

250
00:11:11,000 --> 00:11:16,820
plumes and we're seeing them with more

251
00:11:14,090 --> 00:11:18,649
than once it may indicate that there are

252
00:11:16,820 --> 00:11:21,140
pockets of water maybe not the ocean

253
00:11:18,649 --> 00:11:22,789
underneath a layer but maybe there are

254
00:11:21,139 --> 00:11:26,480
pockets of water they're just a few

255
00:11:22,789 --> 00:11:27,860
kilometers down in the ice if you

256
00:11:26,480 --> 00:11:31,430
remember what we learned about Pluto

257

00:11:27,860 --> 00:11:33,200
last year cryo tectonics is really much

258
00:11:31,429 --> 00:11:35,719
more important in the outer solar system

259
00:11:33,200 --> 00:11:37,520
than we'd really understood so we

260
00:11:35,720 --> 00:11:40,990
learned that also about europa that they

261
00:11:37,519 --> 00:11:44,600
Isis move and Kraken and and the

262
00:11:40,990 --> 00:11:47,330
dynamics of ices is a lot more than we

263
00:11:44,600 --> 00:11:49,220
had previously suspected and in perhaps

264
00:11:47,330 --> 00:11:53,240
there are pockets of water that are one

265
00:11:49,220 --> 00:11:55,279
to few kilometers down then that raises

266
00:11:53,240 --> 00:11:58,009
the prospect for being able to go there

267
00:11:55,279 --> 00:12:00,740
drill down to it or melt down to it and

268
00:11:58,009 --> 00:12:03,889
be able to sample it now why would we

269
00:12:00,740 --> 00:12:05,990
care about water well because there are

270
00:12:03,889 --> 00:12:08,299
three things required for life in the

271
00:12:05,990 --> 00:12:12,019

universe that as we know it one is

272

00:12:08,299 --> 00:12:14,509

carbon carbon is everywhere two is a

273

00:12:12,019 --> 00:12:18,919

source of heat we got sources of energy

274

00:12:14,509 --> 00:12:21,230

all over the place and three is water so

275

00:12:18,919 --> 00:12:24,919

our search for life in the universe is

276

00:12:21,230 --> 00:12:27,009

often just boil down to a search for

277

00:12:24,919 --> 00:12:29,569

water where ever liquid water can exist

278

00:12:27,009 --> 00:12:32,269

perhaps life can exist and we have seen

279

00:12:29,570 --> 00:12:35,030

life in all sorts of extreme places here

280

00:12:32,269 --> 00:12:38,149

on earth so Europa is one of our

281

00:12:35,029 --> 00:12:40,659

strongest candidates for possibly having

282

00:12:38,149 --> 00:12:42,549

life elsewhere in the solar system

283

00:12:40,659 --> 00:12:44,259

and the observations from Hubble have

284

00:12:42,549 --> 00:12:46,838

done yet another small part in

285

00:12:44,259 --> 00:12:49,209

convincing us that hey this is a really

286
00:12:46,839 --> 00:12:52,180
cool system we ought to continue to

287
00:12:49,208 --> 00:12:56,528
investigate it and yes it's become one

288
00:12:52,179 --> 00:13:00,239
of our main points of study for trying

289
00:12:56,528 --> 00:13:04,389
to understand our in our solar system

290
00:13:00,240 --> 00:13:07,149
all right third story tonight our 27th

291
00:13:04,389 --> 00:13:10,509
anniversary perspectives on spiral

292
00:13:07,149 --> 00:13:12,970
galaxies the 27th anniversary is of this

293
00:13:10,509 --> 00:13:15,730
event the launch and deployment of the

294
00:13:12,970 --> 00:13:17,560
Hubble Space Telescope it has been 27

295
00:13:15,730 --> 00:13:19,420
years isn't that great

296
00:13:17,559 --> 00:13:22,719
all right we've been up there for 27

297
00:13:19,419 --> 00:13:26,110
years doing science and so every year

298
00:13:22,720 --> 00:13:27,819
they ask us to do a really cool of image

299
00:13:26,110 --> 00:13:30,100
for the 20th for the anniversary and

300
00:13:27,818 --> 00:13:32,110
it's I gotta say one of the gentlemen

301
00:13:30,100 --> 00:13:34,120
who helps choose these images is in the

302
00:13:32,110 --> 00:13:36,339
audience right now and he can confirm

303
00:13:34,120 --> 00:13:38,110
that it's really really hard to keep

304
00:13:36,339 --> 00:13:41,500
outdoing themselves themselves every

305
00:13:38,110 --> 00:13:44,110
year so this year we chose some spiral

306
00:13:41,500 --> 00:13:46,778
galaxies okay and these spiral galaxies

307
00:13:44,110 --> 00:13:51,399
are in the Virgo cluster so we're going

308
00:13:46,778 --> 00:13:54,250
to zoom in from a wide field view I'm

309
00:13:51,399 --> 00:13:58,328
going to go keep going down and going

310
00:13:54,250 --> 00:14:03,100
down and zooming in until we come into

311
00:13:58,328 --> 00:14:10,559
these two spiral galaxies NGC 4302 and

312
00:14:03,100 --> 00:14:12,850
NGC 42.9 t8 such wonderful names and

313
00:14:10,559 --> 00:14:15,099
those are the two spiral galaxies we

314

00:14:12,850 --> 00:14:17,829
chose for the Hubble 27th anniversary

315
00:14:15,100 --> 00:14:20,680
image now if you notice at the end of

316
00:14:17,828 --> 00:14:22,958
that movie it zoomed in in visible light

317
00:14:20,679 --> 00:14:24,938
and then switch to infrared so let me

318
00:14:22,958 --> 00:14:28,268
show you those in detail here is the

319
00:14:24,938 --> 00:14:31,448
Hubble image using visible light and

320
00:14:28,269 --> 00:14:34,629
this is the infrared view all right

321
00:14:31,448 --> 00:14:37,289
using the the NIR and Freud capabilities

322
00:14:34,629 --> 00:14:41,850
of Hubble so visible light infrared

323
00:14:37,289 --> 00:14:44,649
light and you can see that you can the

324
00:14:41,850 --> 00:14:46,420
difference in how we view the galaxies

325
00:14:44,649 --> 00:14:48,759
changes according to the wavelength in

326
00:14:46,419 --> 00:14:50,679
which we view them well we also wanted

327
00:14:48,759 --> 00:14:53,769
to give you another perspective on them

328
00:14:50,679 --> 00:14:55,238

so we created this visualization to

329
00:14:53,769 --> 00:14:58,110
help you understand the shape of these

330
00:14:55,239 --> 00:14:58,110
spiral galaxies

331
00:15:24,919 --> 00:15:29,610
and so by rotating those galaxies in 3d

332
00:15:28,289 --> 00:15:31,379
by the ways those are just computer

333
00:15:29,610 --> 00:15:33,419
models of the galaxies we don't know the

334
00:15:31,379 --> 00:15:36,198
exact details matter of fact the

335
00:15:33,419 --> 00:15:40,229
galaxies on the left NGC 4302

336
00:15:36,198 --> 00:15:42,509
the model that we used is a model based

337
00:15:40,230 --> 00:15:44,970
on the galaxy m51 the Whirlpool Galaxy

338
00:15:42,509 --> 00:15:47,399
because we're seeing that galaxy edge-on

339
00:15:44,970 --> 00:15:48,778
we really can't tell the truth read a

340
00:15:47,399 --> 00:15:51,208
dimensional structure so we had to use

341
00:15:48,778 --> 00:15:54,600
as I like to say a stunt-double galaxy

342
00:15:51,208 --> 00:15:57,018
for it but that gives you a mental model

343
00:15:54,600 --> 00:15:59,370
of what you're seeing in this image and

344
00:15:57,019 --> 00:16:02,250
when I show you another image which is

345
00:15:59,370 --> 00:16:04,289
also in the Virgo cluster I show you

346
00:16:02,250 --> 00:16:07,110
this image of all these various spiral

347
00:16:04,289 --> 00:16:09,059
galaxies you now have the mental model

348
00:16:07,110 --> 00:16:10,800
in your head to interpret this and say

349
00:16:09,059 --> 00:16:13,948
okay these are all pretty much those

350
00:16:10,799 --> 00:16:17,250
same disc shaped galaxies but seen at

351
00:16:13,948 --> 00:16:20,039
different angles so in doing this you

352
00:16:17,250 --> 00:16:21,839
gain a mental model of how spiral

353
00:16:20,039 --> 00:16:24,809
galaxies look and you can see them in

354
00:16:21,839 --> 00:16:29,819
perspective you can translate images

355
00:16:24,809 --> 00:16:34,078
such as this alright and now it's time

356
00:16:29,818 --> 00:16:36,149
for our featured speaker Mia Bobo Mia is

357
00:16:34,078 --> 00:16:39,299
been here at the Space Telescope Science

358
00:16:36,149 --> 00:16:41,519
Institute for only a year and a half she

359
00:16:39,299 --> 00:16:42,778
gave a wonderful talk last year and I'm

360
00:16:41,519 --> 00:16:45,740
really looking forward to her talk this

361
00:16:42,778 --> 00:16:49,439
year she got her bachelor's and her

362
00:16:45,740 --> 00:16:52,440
master's that bachelors and her PhD from

363
00:16:49,440 --> 00:16:54,120
the University of Maryland physics she

364
00:16:52,440 --> 00:16:56,990
spent a year at the University of Texas

365
00:16:54,120 --> 00:16:59,818
at Austin before spending three years

366
00:16:56,990 --> 00:17:01,500
down in Chile at some unpronounceable

367
00:16:59,818 --> 00:17:03,389
Institute in Santiago

368
00:17:01,500 --> 00:17:06,058
she said she'd pronounced it for you she

369
00:17:03,389 --> 00:17:08,519
wouldn't make me try to pronounce it she

370
00:17:06,058 --> 00:17:11,308
came here and her shoes does her

371

00:17:08,519 --> 00:17:13,490
research on dwarf galaxies as she likes

372
00:17:11,308 --> 00:17:16,470
to say the smallest of the small

373
00:17:13,490 --> 00:17:18,480
galaxies generally those in the nearby

374
00:17:16,470 --> 00:17:20,789
neighborhood nearby universe are those

375
00:17:18,480 --> 00:17:22,259
in the very distant universe she doesn't

376
00:17:20,789 --> 00:17:25,230
care about the 10 or 11 billion

377
00:17:22,259 --> 00:17:27,539
light-years in between she also would

378
00:17:25,230 --> 00:17:29,849
like to note that for tonight she's

379
00:17:27,539 --> 00:17:32,159
doing a talk on the women from Harvard

380
00:17:29,849 --> 00:17:33,480
and when she was an undergraduate she

381
00:17:32,160 --> 00:17:36,659
did a research experience for

382
00:17:33,480 --> 00:17:38,179
undergraduates at Harvard working on of

383
00:17:36,659 --> 00:17:40,159
all things star

384
00:17:38,179 --> 00:17:42,509
Meishan so ladies and gentlemen our

385
00:17:40,159 --> 00:17:50,689

speaker tonight mia boville

386

00:17:42,509 --> 00:17:50,689
[Applause]

387

00:17:51,079 --> 00:17:57,839
can you hear me okay

388

00:17:54,710 --> 00:18:00,720
and it's instituto de astrophysical

389

00:17:57,839 --> 00:18:04,069
Pontificia Universidad católica de Chile

390

00:18:00,720 --> 00:18:04,069
I wasn't going to make him do that again

391

00:18:06,410 --> 00:18:10,650
when astronomers talk about the Harvard

392

00:18:08,730 --> 00:18:14,009
computers we actually don't put quotes

393

00:18:10,650 --> 00:18:16,048
around them um this is this is an image

394

00:18:14,009 --> 00:18:20,220
of the Harvard computers it is a group

395

00:18:16,048 --> 00:18:22,798
of women it is a group of women that

396

00:18:20,220 --> 00:18:26,069
worked at the Harvard Observatory over

397

00:18:22,798 --> 00:18:29,609
the course of about 40 years they

398

00:18:26,069 --> 00:18:32,039
generally stayed for 10 20 30 years and

399

00:18:29,609 --> 00:18:34,589
up until the 1920s this was the only

400
00:18:32,039 --> 00:18:37,349
place where you could be a woman and a

401
00:18:34,589 --> 00:18:39,089
professional astronomer other than some

402
00:18:37,349 --> 00:18:44,519
of the women's colleges like Vassar

403
00:18:39,089 --> 00:18:46,730
which has had Mariah Mitchell but what

404
00:18:44,519 --> 00:18:49,470
did they do that was so incredible and

405
00:18:46,730 --> 00:18:50,940
before I get into that the scientific

406
00:18:49,470 --> 00:18:53,069
parts of this story and their

407
00:18:50,940 --> 00:18:54,720
contributions to astronomy are so

408
00:18:53,069 --> 00:18:58,289
fundamental that you learn about them in

409
00:18:54,720 --> 00:18:59,490
your very very first year in fact you

410
00:18:58,289 --> 00:19:03,720
learn about them an introduction to

411
00:18:59,490 --> 00:19:05,940
astronomy for poets but the human side

412
00:19:03,720 --> 00:19:07,679
of this story and many of the quotes

413
00:19:05,940 --> 00:19:09,330
that I'm pretty much all the quotes that

414
00:19:07,679 --> 00:19:10,950
I'm going to be using come from this

415
00:19:09,329 --> 00:19:14,428
wonderful book that just came out called

416
00:19:10,950 --> 00:19:16,769
the glass universe um this is the same

417
00:19:14,429 --> 00:19:18,360
author that wrote Galileo's daughter and

418
00:19:16,769 --> 00:19:20,819
longitude and if you're interested in

419
00:19:18,359 --> 00:19:22,619
hearing more about this story as well as

420
00:19:20,819 --> 00:19:23,970
many of the players that I'm not going

421
00:19:22,619 --> 00:19:27,619
to have time to talk about tonight I

422
00:19:23,970 --> 00:19:27,620
highly highly recommend that you read it

423
00:19:28,009 --> 00:19:35,160
so if any of you you cannot see this

424
00:19:31,319 --> 00:19:36,569
from Baltimore many for many of you who

425
00:19:35,160 --> 00:19:39,269
have ever had the wonderful opportunity

426
00:19:36,569 --> 00:19:42,869
of being in an extremely dark sky you

427
00:19:39,269 --> 00:19:44,220
have this lovely view of the disk of the

428

00:19:42,869 --> 00:19:48,629
Milky Way galaxy

429
00:19:44,220 --> 00:19:49,860
and when you take that into three

430
00:19:48,630 --> 00:19:51,600
dimensions I'm afraid that my

431
00:19:49,859 --> 00:19:53,849
visualization is not as good as the one

432
00:19:51,599 --> 00:19:58,189
you just saw I went for the cartoon

433
00:19:53,849 --> 00:20:01,089
version you have this is that thin disc

434
00:19:58,190 --> 00:20:05,970
that you saw in the animation

435
00:20:01,089 --> 00:20:12,490
in the center of most spirals is a bulge

436
00:20:05,970 --> 00:20:16,589
surrounded by a halo of stars I can tell

437
00:20:12,490 --> 00:20:19,659
you that in this disk are open clusters

438
00:20:16,589 --> 00:20:22,269
these blue objects here these are

439
00:20:19,659 --> 00:20:24,749
regions that are either still forming or

440
00:20:22,269 --> 00:20:27,999
now very very recently formed stars in

441
00:20:24,749 --> 00:20:30,870
the outskirts of the galaxy are globular

442
00:20:27,999 --> 00:20:33,548

clusters these are old systems they're

443

00:20:30,869 --> 00:20:35,528
1012 billion years old so roughly

444

00:20:33,548 --> 00:20:42,460
approaching the time that I'm interested

445

00:20:35,528 --> 00:20:45,368
in however but how do we know this we

446

00:20:42,460 --> 00:20:47,558
look at we can observe clusters like the

447

00:20:45,368 --> 00:20:49,298
Pleiades which I'm sure if you ask very

448

00:20:47,558 --> 00:20:51,398
nicely and it's up they'll be willing to

449

00:20:49,298 --> 00:20:53,440
show you tonight you can see this by eye

450

00:20:51,398 --> 00:20:57,489
the seven brightest stars are visible by

451

00:20:53,440 --> 00:21:02,019
eye in the constellation of Taurus even

452

00:20:57,490 --> 00:21:04,210
from Baltimore this is about 25 mm this

453

00:21:02,019 --> 00:21:09,759
is an open cluster that is about 25

454

00:21:04,210 --> 00:21:13,240
million years old and you can see some

455

00:21:09,759 --> 00:21:16,058
of the gas here that's still surrounding

456

00:21:13,240 --> 00:21:20,349
the stars so this oh this is very very

457
00:21:16,058 --> 00:21:22,990
recently formed stars this is omega

458
00:21:20,349 --> 00:21:25,269
centauri this is zoomed out quite a bit

459
00:21:22,990 --> 00:21:28,990
from the Hubble image that was handed

460
00:21:25,269 --> 00:21:31,808
out this is a globular cluster it's one

461
00:21:28,990 --> 00:21:34,058
of the younger globular cluster some of

462
00:21:31,808 --> 00:21:38,589
them are billions of years older than

463
00:21:34,058 --> 00:21:41,408
Omega Centauri and so here is a question

464
00:21:38,589 --> 00:21:45,189
how do you find out the age of a star

465
00:21:41,409 --> 00:21:46,960
you can't ask it it would not only be

466
00:21:45,190 --> 00:21:51,759
rude but I don't think you would get an

467
00:21:46,960 --> 00:21:53,769
answer and the answer to that is you use

468
00:21:51,759 --> 00:21:55,298
one of the most powerful diagrams in

469
00:21:53,769 --> 00:22:00,548
astronomy which are color-magnitude

470
00:21:55,298 --> 00:22:03,038
diagram or HR diagrams this is the

471
00:22:00,548 --> 00:22:06,339
Hubble image that you all have there's a

472
00:22:03,038 --> 00:22:08,288
reason that I asked for it and this is

473
00:22:06,339 --> 00:22:12,908
an animation we're going to take the

474
00:22:08,288 --> 00:22:14,849
stars of Omega Sun we're going to zoom

475
00:22:12,909 --> 00:22:17,650
in a little bit

476
00:22:14,849 --> 00:22:20,279
this is the very core of the cluster so

477
00:22:17,650 --> 00:22:23,259
that is an incredibly dense star field

478
00:22:20,279 --> 00:22:26,410
those stars are then going to be sorted

479
00:22:23,259 --> 00:22:30,430
the bluest and hottest stars are going

480
00:22:26,410 --> 00:22:32,529
to move to the left and the coolest and

481
00:22:30,430 --> 00:22:36,360
Red stars are going to move to the

482
00:22:32,529 --> 00:22:39,490
right you're now going to sort them by

483
00:22:36,359 --> 00:22:41,740
absolute brightness or luminosity the

484
00:22:39,490 --> 00:22:47,589
brightest stars to the top the faintest

485

00:22:41,740 --> 00:22:50,200
to the bottom this is the HR diagram it

486
00:22:47,589 --> 00:22:51,909
is one of the most powerful plots in

487
00:22:50,200 --> 00:22:54,130
astronomy in fact I would tell my

488
00:22:51,910 --> 00:22:56,830
astronomy for poet students you

489
00:22:54,130 --> 00:22:59,610
understand this you're going to pass the

490
00:22:56,829 --> 00:23:03,699
stellar evolution section of the class I

491
00:22:59,609 --> 00:23:08,439
called it their cheat sheet along here

492
00:23:03,700 --> 00:23:11,049
is the main sequence our Sun would sit

493
00:23:08,440 --> 00:23:14,500
about here if it was in omega Sun all

494
00:23:11,049 --> 00:23:18,309
the stars and it's now I have a better

495
00:23:14,500 --> 00:23:21,069
one coming up did you notice that it

496
00:23:18,309 --> 00:23:24,000
turned off the main sequence didn't

497
00:23:21,069 --> 00:23:28,689
continue all the way up it turned off

498
00:23:24,000 --> 00:23:31,089
that is how you determine age this is a

499
00:23:28,690 --> 00:23:33,370

more cartoon version for excellent

500

00:23:31,089 --> 00:23:36,879

explanatory purposes here you have the

501

00:23:33,369 --> 00:23:40,839

main sequence all the stars here are

502

00:23:36,880 --> 00:23:43,600

burning hydrogen in their core and the

503

00:23:40,839 --> 00:23:45,549

more massive you are the hotter you are

504

00:23:43,599 --> 00:23:50,439

you can think of these guys as Hummers

505

00:23:45,549 --> 00:23:52,419

and these guys as Priuses you're also

506

00:23:50,440 --> 00:23:54,970

these are going to be brighter they are

507

00:23:52,420 --> 00:24:00,009

hotter and they also burn out a lot

508

00:23:54,970 --> 00:24:02,860

faster so if the main sequence turns off

509

00:24:00,009 --> 00:24:05,980

here your cluster is about 10 million

510

00:24:02,859 --> 00:24:08,199

years old if when you plot up your main

511

00:24:05,980 --> 00:24:11,710

sequence it turns off here it's a

512

00:24:08,200 --> 00:24:13,660

billion years old once the star turns

513

00:24:11,710 --> 00:24:15,759

off the main sequence it moves up

514
00:24:13,660 --> 00:24:18,790
through the Giants or into the super

515
00:24:15,759 --> 00:24:22,599
Giants and eventually evolves down our

516
00:24:18,789 --> 00:24:24,909
Sun will become a white dwarf objects

517
00:24:22,599 --> 00:24:26,589
that are a little more massive kind of

518
00:24:24,910 --> 00:24:27,700
hang out here for a bit they can't quite

519
00:24:26,589 --> 00:24:32,678
decide where they're going to sit

520
00:24:27,700 --> 00:24:36,159
and then they blow up in supernovae this

521
00:24:32,679 --> 00:24:38,909
is on the y-axis the vertical axis we

522
00:24:36,159 --> 00:24:40,840
have luminosity or absolute brightness

523
00:24:38,909 --> 00:24:42,490
you're going to hear me use those two

524
00:24:40,839 --> 00:24:46,658
terms interchangeably they mean the same

525
00:24:42,490 --> 00:24:51,700
thing and what this entire talk is about

526
00:24:46,659 --> 00:24:54,340
is this x-axis it's in color from red to

527
00:24:51,700 --> 00:24:56,909
blue it's also in something we call the

528
00:24:54,339 --> 00:25:00,329
spectral sequence and we also

529
00:24:56,909 --> 00:25:03,340
temperature increases to the left and

530
00:25:00,329 --> 00:25:07,288
how the fact that I am able to tell you

531
00:25:03,339 --> 00:25:07,288
that is because of the Harvard computers

532
00:25:08,638 --> 00:25:14,829
so we need to go back a little bit

533
00:25:11,048 --> 00:25:17,859
before 1880 this is the refractor at

534
00:25:14,829 --> 00:25:19,509
Harvard these are not reflectors modern

535
00:25:17,859 --> 00:25:22,269
telescopes or reflectors you have a

536
00:25:19,509 --> 00:25:23,769
mirror at the base of the telescope the

537
00:25:22,269 --> 00:25:25,750
telescope's that were used to produce

538
00:25:23,769 --> 00:25:28,710
these observations are refractors they

539
00:25:25,750 --> 00:25:31,419
have a lens at the top of the long tube

540
00:25:28,710 --> 00:25:33,808
they're much larger for the same sized

541
00:25:31,419 --> 00:25:37,809
telescope it's why we stopped using them

542

00:25:33,808 --> 00:25:39,158
at the time in the 1870s and 1880s

543
00:25:37,808 --> 00:25:40,750
there's this newfangled thing called

544
00:25:39,159 --> 00:25:42,789
photography I don't know if any of you

545
00:25:40,750 --> 00:25:44,440
have ever done this for the younger

546
00:25:42,788 --> 00:25:46,450
people in the room there was a time when

547
00:25:44,440 --> 00:25:48,009
you took a picture with a camera and it

548
00:25:46,450 --> 00:25:52,480
was on film and you had to get it

549
00:25:48,009 --> 00:25:53,528
developed it you didn't just take it

550
00:25:52,480 --> 00:25:57,429
with your phone and put it on Facebook

551
00:25:53,528 --> 00:26:01,329
or Twitter or snapchat or whatever the

552
00:25:57,429 --> 00:26:04,000
hell did newest thing is they took

553
00:26:01,329 --> 00:26:06,069
images not on film but on photographic

554
00:26:04,000 --> 00:26:08,409
plates this is a digitalization a part

555
00:26:06,069 --> 00:26:12,308
of the Palomar Sky Survey this is an

556
00:26:08,409 --> 00:26:16,149

actual physical glass plate some of

557

00:26:12,308 --> 00:26:21,398

these could be about that big so they

558

00:26:16,148 --> 00:26:23,079

were heavy they broke and just not the

559

00:26:21,398 --> 00:26:27,908

best option but this was all we had

560

00:26:23,079 --> 00:26:31,509

until about 30 years ago and each of

561

00:26:27,909 --> 00:26:33,580

these points is a star in general the

562

00:26:31,509 --> 00:26:36,308

big the bigger the star the bigger the

563

00:26:33,579 --> 00:26:37,379

black here this is a brighter star than

564

00:26:36,308 --> 00:26:39,700

that

565

00:26:37,380 --> 00:26:42,549

so you can tell the magnitude of the

566

00:26:39,700 --> 00:26:45,278

star and if you take this image in red

567

00:26:42,548 --> 00:26:46,898

and red and green and blue filters you

568

00:26:45,278 --> 00:26:48,788

can also tell the color of the star

569

00:26:46,898 --> 00:26:54,339

which is how the HR diagram was

570

00:26:48,788 --> 00:26:58,210

originally plotted but we want more

571
00:26:54,339 --> 00:27:00,849
information welcome to astronomy this is

572
00:26:58,210 --> 00:27:02,350
Henry Draper and his wife Anna Draper he

573
00:27:00,849 --> 00:27:08,019
was a medical doctor who had an

574
00:27:02,349 --> 00:27:11,019
astronomy habit she had the money and he

575
00:27:08,019 --> 00:27:14,079
developed a method for taking that

576
00:27:11,019 --> 00:27:18,819
spectra for taking this plate and he

577
00:27:14,079 --> 00:27:20,710
stuck a prism in front of it so actually

578
00:27:18,819 --> 00:27:22,058
this is one of this is the best graphic

579
00:27:20,710 --> 00:27:24,340
I could find on the internet for this

580
00:27:22,058 --> 00:27:26,829
I'm not actually kidding you have your

581
00:27:24,339 --> 00:27:28,808
light from a distant star you pass that

582
00:27:26,829 --> 00:27:32,980
light through a prism and it breaks it

583
00:27:28,808 --> 00:27:35,048
into its components and when you break

584
00:27:32,980 --> 00:27:37,179
that light into the component you get a

585
00:27:35,048 --> 00:27:41,349
lot more information than just the color

586
00:27:37,179 --> 00:27:45,100
of the star this is the spectrum of the

587
00:27:41,349 --> 00:27:49,839
Sun so you look at the Sun you see a

588
00:27:45,099 --> 00:27:53,709
yellow star we call it a g-type star all

589
00:27:49,839 --> 00:27:57,730
of these black lines are absorption

590
00:27:53,710 --> 00:28:00,278
lines and each element has a unique set

591
00:27:57,730 --> 00:28:03,639
of absorption lines they think of them

592
00:28:00,278 --> 00:28:04,898
as fingerprints you can identify a human

593
00:28:03,638 --> 00:28:09,189
with their fingerprints you can identify

594
00:28:04,898 --> 00:28:13,599
an element or a molecule by its spectrum

595
00:28:09,190 --> 00:28:16,899
the simplest of these is hydrogen so up

596
00:28:13,599 --> 00:28:21,878
here is wavelength in angstroms that's

597
00:28:16,898 --> 00:28:25,628
about that's 1/10 that's 1 does the

598
00:28:21,878 --> 00:28:27,548
second 1/10 to the so each of these

599

00:28:25,628 --> 00:28:31,259
numbers multiplied by 10 to the 10 so 10

600
00:28:27,548 --> 00:28:36,329
additional zeros will get you on meters

601
00:28:31,259 --> 00:28:39,759
so this is one in 10 to the 10 meters

602
00:28:36,329 --> 00:28:42,668
very very tiny scales H alpha H beta H

603
00:28:39,759 --> 00:28:43,960
gamma and H Delta H alpha is actually

604
00:28:42,669 --> 00:28:47,049
one of the most important lines in

605
00:28:43,960 --> 00:28:48,579
astrophysics the more complicated the

606
00:28:47,048 --> 00:28:49,769
element is you move out the periodic

607
00:28:48,579 --> 00:28:55,409
table the more complicated

608
00:28:49,769 --> 00:28:58,950
at spectra now the plates Draper took

609
00:28:55,410 --> 00:29:01,320
didn't look like that this is on one of

610
00:28:58,950 --> 00:29:06,480
the Draper plates at the location of

611
00:29:01,319 --> 00:29:08,129
each star you see a spectra in the

612
00:29:06,480 --> 00:29:10,230
initial set of plates each of these was

613
00:29:08,130 --> 00:29:12,210

one inch across so if you hold your

614

00:29:10,230 --> 00:29:14,509

fingers at about an inch that's how wide

615

00:29:12,210 --> 00:29:15,660

each of these things was on the glass

616

00:29:14,509 --> 00:29:21,119

breakable

617

00:29:15,660 --> 00:29:24,750

plate unfortunately reasonably quickly

618

00:29:21,119 --> 00:29:29,669

after discovering this method Henry

619

00:29:24,750 --> 00:29:31,740

Draper died as was typical of I think

620

00:29:29,670 --> 00:29:34,500

the entire 19th century he caught it

621

00:29:31,740 --> 00:29:38,730

chill and had a dinner party and went to

622

00:29:34,500 --> 00:29:40,230

bed and never got up and Anna Draper was

623

00:29:38,730 --> 00:29:42,180

so devastated by her husband's death

624

00:29:40,230 --> 00:29:46,680

that she wanted a memorial to him so she

625

00:29:42,180 --> 00:29:48,870

talked to Edward Pickering and endowed

626

00:29:46,680 --> 00:29:51,029

the Harvard Observatory with money to

627

00:29:48,869 --> 00:29:52,889

finish her husband's work and build a

628
00:29:51,029 --> 00:29:57,470
Henry Draper catalog of the stars

629
00:29:52,890 --> 00:29:57,470
because remember she had the money and

630
00:29:58,819 --> 00:30:04,319
Edward Pickering did something that the

631
00:30:01,259 --> 00:30:06,690
time even Anna Draper wasn't expecting

632
00:30:04,319 --> 00:30:09,049
he felt that women would be well suited

633
00:30:06,690 --> 00:30:11,549
to the repetitive and drudgery of

634
00:30:09,049 --> 00:30:14,069
looking through thousands and thousands

635
00:30:11,549 --> 00:30:16,769
of glass plates with spectra that order

636
00:30:14,069 --> 00:30:20,309
inch wide now years later of course you

637
00:30:16,769 --> 00:30:22,950
tend to sugarcoat this and you talk and

638
00:30:20,309 --> 00:30:24,299
he talks about the criticism is often

639
00:30:22,950 --> 00:30:26,100
made by the opponents of higher

640
00:30:24,299 --> 00:30:28,169
education of women that while they are

641
00:30:26,099 --> 00:30:31,189
capable of following others as far as

642
00:30:28,170 --> 00:30:34,019
men can they originate almost nothing so

643
00:30:31,190 --> 00:30:37,309
that human knowledge is not advanced by

644
00:30:34,019 --> 00:30:40,379
their work keep in mind this is 1880

645
00:30:37,309 --> 00:30:42,779
this approach would be well answered if

646
00:30:40,380 --> 00:30:45,420
we could point to a long series of such

647
00:30:42,779 --> 00:30:48,029
observations as are detailed below made

648
00:30:45,420 --> 00:30:49,740
by women observers this is the first

649
00:30:48,029 --> 00:30:52,170
this is one of the first times in

650
00:30:49,740 --> 00:30:54,240
history that women are making

651
00:30:52,170 --> 00:30:57,769
contributions and Pickering acknowledged

652
00:30:54,240 --> 00:31:00,230
the Harvard computers in their work

653
00:30:57,769 --> 00:31:02,240
the first of the Harvard computers was

654
00:31:00,230 --> 00:31:04,429
Wilhelmina Fleming she was a Scottish

655
00:31:02,240 --> 00:31:06,529
immigrant who moved to the United States

656

00:31:04,429 --> 00:31:10,970
got pregnant and her husband promptly

657
00:31:06,529 --> 00:31:13,960
left her so she got a job as the maid at

658
00:31:10,970 --> 00:31:17,299
the observatory residence at Harvard and

659
00:31:13,960 --> 00:31:19,069
Pickering knew her he was the director

660
00:31:17,299 --> 00:31:22,220
of the Harvard observatory at that point

661
00:31:19,069 --> 00:31:24,589
he recognized that she was a little too

662
00:31:22,220 --> 00:31:26,179
intelligent to be a maid she didn't have

663
00:31:24,589 --> 00:31:29,449
a college degree but she was educated

664
00:31:26,179 --> 00:31:34,309
and he hired her as a Harvard computer

665
00:31:29,450 --> 00:31:35,900
in 18m as a computer in 1879 I'd like to

666
00:31:34,308 --> 00:31:38,569
point out the other reason to use women

667
00:31:35,900 --> 00:31:44,900
they're paid less I didn't know if

668
00:31:38,569 --> 00:31:47,178
you've heard about that um she promptly

669
00:31:44,900 --> 00:31:49,340
leaves a year later to give birth to her

670
00:31:47,179 --> 00:31:51,950

son in Scotland and then leaves him with

671

00:31:49,339 --> 00:31:56,419

her mother and her aunt and returns to

672

00:31:51,950 --> 00:31:57,860

Boston without him in 1881 I think he

673

00:31:56,420 --> 00:31:59,330

invent he eventually makes it to the

674

00:31:57,859 --> 00:32:05,029

United States but it's like ten years

675

00:31:59,329 --> 00:32:06,859

later and her task was to classify these

676

00:32:05,029 --> 00:32:09,678

spectra so if you remember this is what

677

00:32:06,859 --> 00:32:15,229

she's looking at through a magnifying

678

00:32:09,679 --> 00:32:19,100

glass and she noticed that here is good

679

00:32:15,230 --> 00:32:21,440

old hydrogen good old hydrogen alpha she

680

00:32:19,099 --> 00:32:23,209

noticed that some stars had stronger

681

00:32:21,440 --> 00:32:25,910

hydrogen lines than others and so she

682

00:32:23,210 --> 00:32:28,039

classified them by the strength of their

683

00:32:25,910 --> 00:32:32,509

hydrogen lines the strongest hydrogen

684

00:32:28,039 --> 00:32:36,558

line she gave called a stars the next B

685
00:32:32,509 --> 00:32:39,740
C D you can see where I'm going all the

686
00:32:36,558 --> 00:32:42,319
way down the alphabet and you'll note

687
00:32:39,740 --> 00:32:47,079
that this is not an alphabetical order

688
00:32:42,319 --> 00:32:47,079
and we're going to get to that in a bit

689
00:32:47,679 --> 00:32:53,179
she also discovered variable stars she

690
00:32:51,319 --> 00:32:55,519
found one of the first Nova because

691
00:32:53,179 --> 00:32:58,130
they're looking at a set of plates that

692
00:32:55,519 --> 00:32:59,179
no one's ever had before and in general

693
00:32:58,130 --> 00:33:01,429
in astronomy when you have a

694
00:32:59,179 --> 00:33:05,509
technological advance and insane amounts

695
00:33:01,429 --> 00:33:07,850
of telescope time discoveries happen but

696
00:33:05,509 --> 00:33:09,210
later in her career and for the last

697
00:33:07,849 --> 00:33:11,308
about

698
00:33:09,210 --> 00:33:14,640
10 10 to 15 years that she was at the

699
00:33:11,308 --> 00:33:19,019
observatory her primary duty was to

700
00:33:14,640 --> 00:33:20,399
curate these glass plates these are

701
00:33:19,019 --> 00:33:21,990
irreplaceable you don't have

702
00:33:20,398 --> 00:33:23,369
digitalization you don't have a digit

703
00:33:21,990 --> 00:33:25,819
you don't have a phone you can take out

704
00:33:23,369 --> 00:33:28,288
and take a picture in case you mess up

705
00:33:25,819 --> 00:33:31,129
if something happens to these glass

706
00:33:28,288 --> 00:33:33,750
plates the information is lost forever

707
00:33:31,130 --> 00:33:36,510
she was also responsible with editing

708
00:33:33,750 --> 00:33:39,898
and preparing the drape Henry Draper

709
00:33:36,509 --> 00:33:47,490
memorial catalog for publication there

710
00:33:39,898 --> 00:33:50,398
are 90 volumes of this so she also was

711
00:33:47,490 --> 00:33:57,649
the effective head of the Harvard

712
00:33:50,398 --> 00:34:00,028
computers their leader as you will but

713

00:33:57,648 --> 00:34:02,569
unfortunately I love astronomy everyone

714
00:34:00,028 --> 00:34:05,069
loves astronomy I need to pay rent and

715
00:34:02,569 --> 00:34:06,778
pick and this is a wonderful quote

716
00:34:05,069 --> 00:34:08,878
Pickering seems to think that no work is

717
00:34:06,778 --> 00:34:10,710
too much or too hard for me no matter

718
00:34:08,878 --> 00:34:13,079
what the responsibilities or how long

719
00:34:10,710 --> 00:34:15,659
the hours but let me raise the question

720
00:34:13,079 --> 00:34:17,848
of salary and I am immediately told that

721
00:34:15,659 --> 00:34:21,809
I receive an excellent salary as women

722
00:34:17,849 --> 00:34:23,460
salaries go because of course if you're

723
00:34:21,809 --> 00:34:27,239
a woman your husband's actually making

724
00:34:23,460 --> 00:34:29,608
the money and in general the Harvard

725
00:34:27,239 --> 00:34:31,408
computers were unable to live completely

726
00:34:29,608 --> 00:34:34,500
independently many of them lived in

727
00:34:31,409 --> 00:34:37,010

boarding houses or rented out rooms in

728

00:34:34,500 --> 00:34:39,088

their own homes to make ends meet

729

00:34:37,010 --> 00:34:44,399

because remember they could be paid less

730

00:34:39,088 --> 00:34:46,529

than a man for cheap antonio mari was

731

00:34:44,398 --> 00:34:48,148

actually the first harvard computer she

732

00:34:46,530 --> 00:34:49,619

was related to Draper and she was the

733

00:34:48,148 --> 00:34:52,799

first Harvard computer to actually have

734

00:34:49,619 --> 00:34:54,329

an astronomy degree and that degree was

735

00:34:52,800 --> 00:34:58,710

from Vassar which is where Mariah

736

00:34:54,329 --> 00:35:00,389

mittell worked and remember what I said

737

00:34:58,710 --> 00:35:02,400

about technological advancement well

738

00:35:00,389 --> 00:35:04,858

instead of having the specter be an inch

739

00:35:02,400 --> 00:35:08,039

wide the plates that Mari got to work on

740

00:35:04,858 --> 00:35:12,509

they were 4 inches wide and they were

741

00:35:08,039 --> 00:35:18,119

far far more detailed and you would

742
00:35:12,510 --> 00:35:20,970
think detail is good detail is generally

743
00:35:18,119 --> 00:35:21,559
good but complicated and she noticed

744
00:35:20,969 --> 00:35:23,149
that in

745
00:35:21,559 --> 00:35:29,659
addition to the lines having different

746
00:35:23,150 --> 00:35:32,090
strengths so having different having two

747
00:35:29,659 --> 00:35:35,239
different depths some of them also had

748
00:35:32,090 --> 00:35:37,070
different widths two stars that seem to

749
00:35:35,239 --> 00:35:38,750
have the same strengths of hydrogen lion

750
00:35:37,070 --> 00:35:40,130
would have different widths of hydrogen

751
00:35:38,750 --> 00:35:42,619
lines and she worked to try to

752
00:35:40,130 --> 00:35:44,720
incorporate this into a new

753
00:35:42,619 --> 00:35:46,819
classification scheme so she threw out

754
00:35:44,719 --> 00:35:49,250
what Wilhelmina Fleming had done with

755
00:35:46,820 --> 00:35:53,990
the alphabet and came up with a numbered

756
00:35:49,250 --> 00:35:58,119
scheme and this worked but it was

757
00:35:53,989 --> 00:36:01,549
actually a little ahead of her time and

758
00:35:58,119 --> 00:36:03,769
so now we get to the three main players

759
00:36:01,550 --> 00:36:08,180
in this little drama there on my shirt

760
00:36:03,769 --> 00:36:10,250
if you need reference Henry Henrietta

761
00:36:08,179 --> 00:36:12,859
Swan Leavitt and Annie jump cannon

762
00:36:10,250 --> 00:36:15,980
arrived at the same time as unpaid

763
00:36:12,860 --> 00:36:18,740
interns for a year both of them then

764
00:36:15,980 --> 00:36:20,389
left and were only able to return when

765
00:36:18,739 --> 00:36:25,609
another one of the computers got married

766
00:36:20,389 --> 00:36:27,529
she had a degree from Radcliffe which no

767
00:36:25,610 --> 00:36:32,150
longer exists because Harvard now lets

768
00:36:27,530 --> 00:36:38,090
women in and she was also deaf not her

769
00:36:32,150 --> 00:36:40,970
entire life but in adulthood and she was

770

00:36:38,090 --> 00:36:42,769
given the task of monitoring variable

771
00:36:40,969 --> 00:36:44,719
stars so you can imagine you've got all

772
00:36:42,769 --> 00:36:46,309
these photographic plates and you're

773
00:36:44,719 --> 00:36:48,980
going to see certain stars vary a little

774
00:36:46,309 --> 00:36:50,960
bit in brightness so you're literally

775
00:36:48,980 --> 00:36:53,599
looking at this plate and then this

776
00:36:50,960 --> 00:36:57,320
image from two days later and two days

777
00:36:53,599 --> 00:36:59,389
after that and she came up with a novel

778
00:36:57,320 --> 00:37:02,600
method that allowed her to look at one

779
00:36:59,389 --> 00:37:04,159
plate on top of the other using a

780
00:37:02,599 --> 00:37:06,230
negative image of one and putting the

781
00:37:04,159 --> 00:37:11,659
positive image of the other on top of it

782
00:37:06,230 --> 00:37:14,300
and down the line she found she was

783
00:37:11,659 --> 00:37:16,339
looking at a set of variables in the LMC

784
00:37:14,300 --> 00:37:18,860

here's a very pretty image it did not

785

00:37:16,340 --> 00:37:20,450

look like that on the plates and she

786

00:37:18,860 --> 00:37:24,320

found a class of variables that were

787

00:37:20,449 --> 00:37:25,909

already known called Cepheid x' and the

788

00:37:24,320 --> 00:37:28,519

characteristic of a Cepheid as it rises

789

00:37:25,909 --> 00:37:31,039

very very quickly in brightness and then

790

00:37:28,519 --> 00:37:34,719

falls off slowly and then rises quickly

791

00:37:31,039 --> 00:37:37,779

again and falls off slowly

792

00:37:34,719 --> 00:37:39,699

and because all of these Sophia's were

793

00:37:37,780 --> 00:37:40,960

in the Large Magellanic Cloud she knew

794

00:37:39,699 --> 00:37:44,439

that they were at about the same

795

00:37:40,960 --> 00:37:46,630

distance from Earth and so if one of

796

00:37:44,440 --> 00:37:49,510

those Cepheid appeared to be brighter

797

00:37:46,630 --> 00:37:55,630

than another it actually was brighter

798

00:37:49,510 --> 00:37:59,050

than another and she plotted this as you

799
00:37:55,630 --> 00:38:01,329
do in astronomy you plot things and she

800
00:37:59,050 --> 00:38:05,470
found that the longer the period of the

801
00:38:01,329 --> 00:38:09,098
Cepheid the brighter the brighter the

802
00:38:05,469 --> 00:38:11,379
Cepheid actually was and you can see

803
00:38:09,099 --> 00:38:13,840
this here the brighter Cepheid with its

804
00:38:11,380 --> 00:38:16,630
longer period and the fainter Cepheid

805
00:38:13,840 --> 00:38:19,000
with the shorter period this was

806
00:38:16,630 --> 00:38:21,579
immediately recognized for what it was

807
00:38:19,000 --> 00:38:23,650
this is called a standard candle this

808
00:38:21,579 --> 00:38:25,480
means you can look at a Cepheid you can

809
00:38:23,650 --> 00:38:28,358
measure its period and you know how

810
00:38:25,480 --> 00:38:30,340
bright it is and if you know how bright

811
00:38:28,358 --> 00:38:32,889
it actually is and you know how bright

812
00:38:30,340 --> 00:38:37,630
it appears to be you know how far away

813
00:38:32,889 --> 00:38:39,759
it is this was used within a year of her

814
00:38:37,630 --> 00:38:42,250
discovery to find that the LMC and the

815
00:38:39,760 --> 00:38:44,530
SMC were just a bit further away than

816
00:38:42,250 --> 00:38:51,070
they thought they were and in actuality

817
00:38:44,530 --> 00:38:54,040
they're even further than that this is

818
00:38:51,070 --> 00:38:54,809
her and Henrietta Leavitt and Annie jump

819
00:38:54,039 --> 00:39:01,869
cannon

820
00:38:54,809 --> 00:39:04,269
um about some time in the teens in front

821
00:39:01,869 --> 00:39:06,250
of the Harvard Observatory they came in

822
00:39:04,269 --> 00:39:08,739
together as interns Annie jump cannon

823
00:39:06,250 --> 00:39:13,449
arrived because there literally somebody

824
00:39:08,739 --> 00:39:16,299
got married so she was hired she

825
00:39:13,449 --> 00:39:18,639
graduated Velvet Orion of Wellesley in a

826
00:39:16,300 --> 00:39:20,200
degree in physics and astronomy after a

827

00:39:18,639 --> 00:39:22,838
brief stint at Harvard she lived with

828
00:39:20,199 --> 00:39:24,848
her parents for 10 years during that

829
00:39:22,838 --> 00:39:29,889
time she contracted scarlet fever and

830
00:39:24,849 --> 00:39:31,599
lost most of her hearing - after ten

831
00:39:29,889 --> 00:39:34,809
years someone got married she was able

832
00:39:31,599 --> 00:39:36,970
to come on as a Harvard computer to give

833
00:39:34,809 --> 00:39:39,099
you a comparison a student of her

834
00:39:36,969 --> 00:39:41,289
caliber or Henrietta Levites caliber or

835
00:39:39,099 --> 00:39:42,820
Antonio Marez caliber today would be off

836
00:39:41,289 --> 00:39:44,889
to one of the greatest best grad

837
00:39:42,820 --> 00:39:46,390
programs in the world they would not be

838
00:39:44,889 --> 00:39:47,549
living with their parents for ten years

839
00:39:46,389 --> 00:39:51,210
hoping that a position

840
00:39:47,550 --> 00:39:53,640
waddup this is her at her graduation

841
00:39:51,210 --> 00:40:00,750

from Wellesley looking through a very

842

00:39:53,639 --> 00:40:03,449

very small refractor and what she did

843

00:40:00,750 --> 00:40:06,900

was organize reorganize what Wilhelmina

844

00:40:03,449 --> 00:40:10,500

Fleming did accounting for what Mari had

845

00:40:06,900 --> 00:40:13,889

noticed in the spectra Mari had noticed

846

00:40:10,500 --> 00:40:16,260

that certain stars like Oh stars had

847

00:40:13,889 --> 00:40:19,139

extremely strong helium lines which

848

00:40:16,260 --> 00:40:23,190

other stars like M stars with very faint

849

00:40:19,139 --> 00:40:24,569

hydron hydrogen lines did not and so

850

00:40:23,190 --> 00:40:28,769

Annie jump cannon did a little bit of

851

00:40:24,570 --> 00:40:31,710

reorganization and some editing she

852

00:40:28,769 --> 00:40:34,860

moved the oh stars to the top of the

853

00:40:31,710 --> 00:40:38,519

sequence because if you're producing

854

00:40:34,860 --> 00:40:41,730

helium lines than your heart she moved

855

00:40:38,519 --> 00:40:45,199

the B stars next to the O and then

856
00:40:41,730 --> 00:40:48,150
edited the rest of the sequence down

857
00:40:45,199 --> 00:40:50,279
this is the sequence we still use to

858
00:40:48,150 --> 00:40:55,559
this day it's a little difficult to

859
00:40:50,280 --> 00:40:59,610
remember so we use Oh be a fine guy kiss

860
00:40:55,559 --> 00:41:05,820
me or Oh be a fine girl kissed me

861
00:40:59,610 --> 00:41:08,400
depending on your preference and so now

862
00:41:05,820 --> 00:41:10,830
this x-axis in addition to being color

863
00:41:08,400 --> 00:41:16,230
from red to blue is now the spectral

864
00:41:10,829 --> 00:41:17,869
sequence of OB AF g/km and by the way if

865
00:41:16,230 --> 00:41:25,530
you ever see this on a license plate

866
00:41:17,869 --> 00:41:28,139
astronomer in addition Annie jump cannon

867
00:41:25,530 --> 00:41:30,090
was the first of the Harvard computers

868
00:41:28,139 --> 00:41:34,769
to actually be allowed to shockingly

869
00:41:30,090 --> 00:41:37,860
observe these telescopes are extremely

870
00:41:34,769 --> 00:41:39,809
big this is her in Peru at the outpost

871
00:41:37,860 --> 00:41:43,650
in Peru they hadn't discovered Chile yet

872
00:41:39,809 --> 00:41:47,250
I don't think and maneuvering the bottom

873
00:41:43,650 --> 00:41:51,240
of the giant refractor there these

874
00:41:47,250 --> 00:41:53,309
telescopes are extremely long extremely

875
00:41:51,239 --> 00:41:54,629
heavy and nothing's motorized today you

876
00:41:53,309 --> 00:41:56,779
sit in a control room

877
00:41:54,630 --> 00:41:58,670
you tell the

878
00:41:56,780 --> 00:42:00,170
you tell your telescope operator I want

879
00:41:58,670 --> 00:42:01,700
to go point at that and then the

880
00:42:00,170 --> 00:42:02,930
telescope operator punches some stuff

881
00:42:01,699 --> 00:42:06,649
into your computer and the telescope

882
00:42:02,929 --> 00:42:08,000
magically moves there's no magic at this

883
00:42:06,650 --> 00:42:10,519
point you had to physically move the

884

00:42:08,000 --> 00:42:12,110
telescope and this de mate and this work

885
00:42:10,519 --> 00:42:14,659
was deemed to be too physically

886
00:42:12,110 --> 00:42:16,849
demanding for the poor weak defenseless

887
00:42:14,659 --> 00:42:21,170
women I'm I don't know where they got

888
00:42:16,849 --> 00:42:23,089
that idea so she also did she was the

889
00:42:21,170 --> 00:42:27,860
first of them but not the last to

890
00:42:23,090 --> 00:42:31,640
actually do up make observations and she

891
00:42:27,860 --> 00:42:34,640
became the world expert in this and in

892
00:42:31,639 --> 00:42:38,139
1920 summer of 1912 she went to Europe

893
00:42:34,639 --> 00:42:42,109
and attended conferences and spoke and

894
00:42:38,139 --> 00:42:43,699
at a meeting that was the precursor to

895
00:42:42,110 --> 00:42:46,519
the modern International Astronomical

896
00:42:43,699 --> 00:42:47,750
Union she said was very surprised to

897
00:42:46,519 --> 00:42:49,280
find that she was put in the committee

898
00:42:47,750 --> 00:42:50,809

of the classification of stellar spectra

899

00:42:49,280 --> 00:42:54,350

and I'm thinking she's being a little

900

00:42:50,809 --> 00:42:56,570

sarcastic here um and she talks about

901

00:42:54,349 --> 00:42:59,989

sitting at a long table and being the

902

00:42:56,570 --> 00:43:02,150

only woman in the room and since I have

903

00:42:59,989 --> 00:43:03,279

done almost all the world's work in this

904

00:43:02,150 --> 00:43:05,930

one branch

905

00:43:03,280 --> 00:43:08,090

she was the classification of stellar

906

00:43:05,929 --> 00:43:12,440

spectra at this point it was necessary

907

00:43:08,090 --> 00:43:14,440

for me to do most of the talking I wish

908

00:43:12,440 --> 00:43:20,720

I could tell you that this has changed

909

00:43:14,440 --> 00:43:23,630

it's better it is better I'm usually not

910

00:43:20,719 --> 00:43:27,439

the only woman in the room there's

911

00:43:23,630 --> 00:43:28,820

usually two others maybe um but I have

912

00:43:27,440 --> 00:43:35,690

definitely been in meetings where this

913
00:43:28,820 --> 00:43:37,630
was the case in 1919 about seven years

914
00:43:35,690 --> 00:43:42,170
after that

915
00:43:37,630 --> 00:43:44,000
Edward Pickering died his replacement at

916
00:43:42,170 --> 00:43:46,099
the Harvard Observatory was a man named

917
00:43:44,000 --> 00:43:47,900
Harlow Shapley who was better known in

918
00:43:46,099 --> 00:43:49,429
astronomy history circles as being

919
00:43:47,900 --> 00:43:53,269
completely wrong about the scale of the

920
00:43:49,429 --> 00:43:55,250
Milky Way galaxy in fact he was on the

921
00:43:53,269 --> 00:43:57,739
one that made the measurements of the

922
00:43:55,250 --> 00:44:00,260
distance to the LMC using Henrietta

923
00:43:57,739 --> 00:44:03,619
Leavitt Cepheid using Henry Leavitt

924
00:44:00,260 --> 00:44:05,340
Cepheid relation like Edward Pickering

925
00:44:03,619 --> 00:44:09,000
before him

926
00:44:05,340 --> 00:44:11,190
supported the Harvard computers and ejup

927
00:44:09,000 --> 00:44:13,170
Canon Antonio Mari were authors on their

928
00:44:11,190 --> 00:44:15,000
publications so was Henriette leave it

929
00:44:13,170 --> 00:44:17,220
in fact if you cite the periods of the

930
00:44:15,000 --> 00:44:21,300
the Cepheid period-luminosity relation

931
00:44:17,219 --> 00:44:22,919
you cite leave it however he also did

932
00:44:21,300 --> 00:44:29,390
refer to the work they did in terms of

933
00:44:22,920 --> 00:44:29,389
girl hours so you win some you lose some

934
00:44:30,260 --> 00:44:41,190
the final player in this I guess you

935
00:44:36,599 --> 00:44:43,559
would say drama is a woman named Cecilia

936
00:44:41,190 --> 00:44:44,909
Payne is a woman named Cecilia Payne and

937
00:44:43,559 --> 00:44:47,279
you will have to bear with me I'm about

938
00:44:44,909 --> 00:44:50,699
to give you a very fast introduction to

939
00:44:47,280 --> 00:44:53,310
quantum chemistry she got she was from

940
00:44:50,699 --> 00:44:55,230
England and she read physics and

941

00:44:53,309 --> 00:44:58,139
astronomy at Cambridge but she doesn't

942
00:44:55,230 --> 00:45:00,800
have a degree from there because in 1923

943
00:44:58,139 --> 00:45:03,509
Cambridge did not grant degrees to women

944
00:45:00,800 --> 00:45:05,160
when she asked about what the

945
00:45:03,510 --> 00:45:08,760
opportunities were for doing astronomy

946
00:45:05,159 --> 00:45:14,210
in England she was told you can be an

947
00:45:08,760 --> 00:45:16,230
amateur while teaching Shapley had come

948
00:45:14,210 --> 00:45:18,360
he was now the director of the Harvard

949
00:45:16,230 --> 00:45:20,579
Observatory had come to Cambridge and

950
00:45:18,360 --> 00:45:24,180
given a talk so she knew about the

951
00:45:20,579 --> 00:45:26,400
Harvard computers she cobbled and as all

952
00:45:24,179 --> 00:45:28,559
scientists to do to this day she cobbled

953
00:45:26,400 --> 00:45:30,320
together funding and moved over the

954
00:45:28,559 --> 00:45:33,119
Atlantic Ocean

955
00:45:30,320 --> 00:45:39,960

having done an international move with

956

00:45:33,119 --> 00:45:44,369

Skype I cannot even imagine it when she

957

00:45:39,960 --> 00:45:46,559

arrived at her at Harvard in Cambridge

958

00:45:44,369 --> 00:45:50,909

Massachusetts because you know why mess

959

00:45:46,559 --> 00:45:52,650

with a name she followed instructions

960

00:45:50,909 --> 00:45:54,440

she had followed advice that she had

961

00:45:52,650 --> 00:45:57,690

been given to set out to make

962

00:45:54,440 --> 00:46:00,150

quantitative the qualitative information

963

00:45:57,690 --> 00:46:03,480

that was inherent in the Henry Draper

964

00:46:00,150 --> 00:46:06,269

system so up until this point they've

965

00:46:03,480 --> 00:46:09,240

said the hydrogen lines are stronger in

966

00:46:06,269 --> 00:46:12,719

these stars and they tend to be bluer

967

00:46:09,239 --> 00:46:15,329

than these other stars but there was no

968

00:46:12,719 --> 00:46:17,000

numbers associated with it you couldn't

969

00:46:15,329 --> 00:46:22,369

say that an ocean

970
00:46:17,000 --> 00:46:24,858
had this temperature because the ability

971
00:46:22,369 --> 00:46:27,380
to do that depended on knowledge of a

972
00:46:24,858 --> 00:46:29,329
science that at this point was only just

973
00:46:27,380 --> 00:46:30,858
getting started called quantum mechanics

974
00:46:29,329 --> 00:46:33,650
you had to understand the structure of

975
00:46:30,858 --> 00:46:36,679
an atom and how electrons moved in that

976
00:46:33,650 --> 00:46:40,220
atom and Cecilia Payne was perfectly

977
00:46:36,679 --> 00:46:43,579
positioned to do this she had been in

978
00:46:40,219 --> 00:46:45,739
Europe so she knew about Neil the Bohr

979
00:46:43,579 --> 00:46:49,098
model of the atom I did warn you we were

980
00:46:45,739 --> 00:46:51,229
going to do quantum chemistry this is a

981
00:46:49,099 --> 00:46:53,090
very cartoonish model of an atom you

982
00:46:51,230 --> 00:46:55,460
have the nucleus here with the protons

983
00:46:53,090 --> 00:46:57,769
and neutrons and different levels for

984
00:46:55,460 --> 00:47:02,059
the electrons represented here by this

985
00:46:57,769 --> 00:47:04,219
lovely blue circle as electrons move up

986
00:47:02,059 --> 00:47:08,659
and down so if an electron moves down a

987
00:47:04,219 --> 00:47:11,149
level it emits a photon it emits light

988
00:47:08,659 --> 00:47:13,129
and it emits light in a very specific

989
00:47:11,150 --> 00:47:18,230
wavelength this is actually how you get

990
00:47:13,130 --> 00:47:21,349
the lines and a spectra and there are a

991
00:47:18,230 --> 00:47:24,380
series of and with that very basic model

992
00:47:21,349 --> 00:47:28,730
and if that and if for that electron to

993
00:47:24,380 --> 00:47:31,220
jump up to a higher level it needs to

994
00:47:28,730 --> 00:47:36,460
absorb light and it needs to absorb

995
00:47:31,219 --> 00:47:39,079
light at a very very specific wavelength

996
00:47:36,460 --> 00:47:41,329
so the transitions you saw the lines of

997
00:47:39,079 --> 00:47:43,730
the hydrogen spectrum are the movements

998

00:47:41,329 --> 00:47:48,769
of electrons up and down the levels of

999
00:47:43,730 --> 00:47:55,730
the hydrogen atom and with that

1000
00:47:48,769 --> 00:47:58,190
knowledge Saha here developed a set of

1001
00:47:55,730 --> 00:48:00,920
equations using quantum mechanics that

1002
00:47:58,190 --> 00:48:02,510
could tell you if you know the atom that

1003
00:48:00,920 --> 00:48:05,420
you're looking at which you know for the

1004
00:48:02,510 --> 00:48:07,369
fingerprints of the spectra you can

1005
00:48:05,420 --> 00:48:14,570
determine what the temperature of the

1006
00:48:07,369 --> 00:48:15,140
gas is is everybody with me okay just

1007
00:48:14,570 --> 00:48:17,930
checking

1008
00:48:15,139 --> 00:48:19,848
I don't normally try to throw quantum

1009
00:48:17,929 --> 00:48:23,210
chemistry and quantum mechanics at a

1010
00:48:19,849 --> 00:48:24,980
public talk now she did this

1011
00:48:23,210 --> 00:48:26,150
now she shows it comes to Harvard and

1012
00:48:24,980 --> 00:48:28,460

they happen to have the largest

1013

00:48:26,150 --> 00:48:29,710

repository of spectra in the world on

1014

00:48:28,460 --> 00:48:32,380

these glass plates

1015

00:48:29,710 --> 00:48:34,720

so she can look so she sets about

1016

00:48:32,380 --> 00:48:37,480

measuring the details of the spectra and

1017

00:48:34,719 --> 00:48:40,059

applying Savas equations to determine

1018

00:48:37,480 --> 00:48:45,880

what the quantitative temperatures of

1019

00:48:40,059 --> 00:48:47,710

these stars are this in just this next

1020

00:48:45,880 --> 00:48:49,510

slide is not to scare you but to give

1021

00:48:47,710 --> 00:48:51,340

you a sense of what she did she did this

1022

00:48:49,510 --> 00:48:53,920

20 years before the first computer would

1023

00:48:51,340 --> 00:49:02,710

be built and these are the Saha

1024

00:48:53,920 --> 00:49:05,740

equations yes she did all of this by

1025

00:49:02,710 --> 00:49:10,050

hand looking at multiple elements in

1026

00:49:05,739 --> 00:49:15,819

multiple plates across multiple spectra

1027
00:49:10,050 --> 00:49:20,769
and that added the temperature axis of

1028
00:49:15,820 --> 00:49:24,100
this plot that tells us that an O star

1029
00:49:20,769 --> 00:49:26,170
is 30,000 degrees Kelvin I would say

1030
00:49:24,099 --> 00:49:27,519
that I would put that into more normal

1031
00:49:26,170 --> 00:49:29,680
units but I think when you're up at

1032
00:49:27,519 --> 00:49:32,530
30,000 I don't think the temperature

1033
00:49:29,679 --> 00:49:37,750
scale stops mattering you know that our

1034
00:49:32,530 --> 00:49:39,670
Sun is about 5 or 6,000 Kelvin and so

1035
00:49:37,750 --> 00:49:41,619
now we can say the temperature increased

1036
00:49:39,670 --> 00:49:43,869
not only just the temperature increases

1037
00:49:41,619 --> 00:49:49,150
but exactly what the temperatures of

1038
00:49:43,869 --> 00:49:51,099
those stars are this is why o stars had

1039
00:49:49,150 --> 00:49:52,690
no hydrogen lines they're so hot that

1040
00:49:51,099 --> 00:49:58,690
the hydrogen is completely stripped of

1041
00:49:52,690 --> 00:50:00,940
its electrons and as you start to cool

1042
00:49:58,690 --> 00:50:05,380
down just a little bit you start seeing

1043
00:50:00,940 --> 00:50:06,820
hydrogen lines again now this alone

1044
00:50:05,380 --> 00:50:08,470
would have put her into the history

1045
00:50:06,820 --> 00:50:09,760
books but she wasn't done I'd like to

1046
00:50:08,469 --> 00:50:14,079
remind you she's still the grad student

1047
00:50:09,760 --> 00:50:15,970
at this point friend those of you that

1048
00:50:14,079 --> 00:50:17,319
are having flashbacks to chemistry I

1049
00:50:15,969 --> 00:50:20,169
promise I'll get rid of the periodic

1050
00:50:17,320 --> 00:50:23,200
table in a minute she could also use

1051
00:50:20,170 --> 00:50:28,659
those same equations to determine what

1052
00:50:23,199 --> 00:50:30,279
the universe was made out of now think

1053
00:50:28,659 --> 00:50:32,440
for a minute you're living a hundred

1054
00:50:30,280 --> 00:50:35,830
years ago you look up and you assume

1055

00:50:32,440 --> 00:50:38,619
that that is like this you're going to

1056
00:50:35,829 --> 00:50:41,590
see a lot of iron a lot of carbon a lot

1057
00:50:38,619 --> 00:50:43,329
of oxygen there will be hydrogen and

1058
00:50:41,590 --> 00:50:47,260
there may be a little bit of healing

1059
00:50:43,329 --> 00:50:49,389
but you're not expecting the periodic

1060
00:50:47,260 --> 00:50:51,190
table quote-unquote of the universe to

1061
00:50:49,389 --> 00:50:55,449
look that much different than what you

1062
00:50:51,190 --> 00:50:58,599
see here on earth and so Cecilia Payne

1063
00:50:55,449 --> 00:51:03,719
looked through the Harvard plates she

1064
00:50:58,599 --> 00:51:06,009
did the calculations again by hand and

1065
00:51:03,719 --> 00:51:07,319
she found that it looks a little

1066
00:51:06,010 --> 00:51:10,090
different

1067
00:51:07,320 --> 00:51:12,220
for every one that ever hated chemistry

1068
00:51:10,090 --> 00:51:14,230
you should have been an astronomer we

1069
00:51:12,219 --> 00:51:20,500

have hydrogen we have helium and

1070

00:51:14,230 --> 00:51:24,460

everything else as a metal but more

1071

00:51:20,500 --> 00:51:28,750

importantly hydrogen makes up 75% of the

1072

00:51:24,460 --> 00:51:32,170

universe about 25% of the universe is

1073

00:51:28,750 --> 00:51:37,889

helium everything else is a trace

1074

00:51:32,170 --> 00:51:41,860

element formed in the core of a star in

1075

00:51:37,889 --> 00:51:44,139

1925 this was outrageous this was insane

1076

00:51:41,860 --> 00:51:48,340

this went against all of the prevailing

1077

00:51:44,139 --> 00:51:50,739

wisdom and you're a grad student your

1078

00:51:48,340 --> 00:51:53,350

jr. and you're a woman you're the first

1079

00:51:50,739 --> 00:51:58,029

woman to ever study for a PhD at Harvard

1080

00:51:53,349 --> 00:52:01,650

and one of the first in the world to

1081

00:51:58,030 --> 00:52:04,120

ever study for a PhD and you're and

1082

00:52:01,650 --> 00:52:07,809

Shapley decides you know what we need to

1083

00:52:04,119 --> 00:52:09,609

check with someone more senior who knows

1084
00:52:07,809 --> 00:52:12,639
about this stuff this is Henry Norris

1085
00:52:09,610 --> 00:52:16,420
Russell he is the R of the HR diagram

1086
00:52:12,639 --> 00:52:19,029
and they sent her him Cecilia Payne's

1087
00:52:16,420 --> 00:52:21,010
thesis and he wrote back to her that it

1088
00:52:19,030 --> 00:52:22,510
is clearly impossible that hydrogen

1089
00:52:21,010 --> 00:52:28,440
should be a million times more abundant

1090
00:52:22,510 --> 00:52:31,090
than metals note he hates chemistry and

1091
00:52:28,440 --> 00:52:33,280
he convinced her to temper her

1092
00:52:31,090 --> 00:52:38,309
conclusions in the paper to say this is

1093
00:52:33,280 --> 00:52:40,810
probably wrong it's a measurement error

1094
00:52:38,309 --> 00:52:43,440
several years later he published the

1095
00:52:40,809 --> 00:52:46,449
exact same result and barely cited her

1096
00:52:43,440 --> 00:52:48,639
the good news is most men in this talk

1097
00:52:46,449 --> 00:52:50,919
are generally awesome for their time

1098
00:52:48,639 --> 00:52:53,309
this guy is a complete I'm not going to

1099
00:52:50,920 --> 00:52:53,309
say it publicly

1100
00:52:56,639 --> 00:53:02,710
however Cecilia Payne's thesis on

1101
00:53:00,099 --> 00:53:04,030
stellar atmospheres a contribution to

1102
00:53:02,710 --> 00:53:06,309
the observational study of high

1103
00:53:04,030 --> 00:53:08,800
temperatures in reversing layers of

1104
00:53:06,309 --> 00:53:13,619
stars has been called the most brilliant

1105
00:53:08,800 --> 00:53:16,900
PhD thesis ever written in astronomy it

1106
00:53:13,619 --> 00:53:20,530
is in credit it would be incredibly

1107
00:53:16,900 --> 00:53:21,900
impressive work today let alone 100

1108
00:53:20,530 --> 00:53:28,690
years ago

1109
00:53:21,900 --> 00:53:30,400
and at this point the story of the

1110
00:53:28,690 --> 00:53:33,750
Harvard computers is an active group

1111
00:53:30,400 --> 00:53:35,769
somewhat ends this is a transition point

1112

00:53:33,750 --> 00:53:38,530
transitioning from the women being

1113
00:53:35,769 --> 00:53:41,199
Harvard computers to the women being

1114
00:53:38,530 --> 00:53:47,950
scientists and considered scientists in

1115
00:53:41,199 --> 00:53:50,500
and of their own right the people that I

1116
00:53:47,949 --> 00:53:53,769
talked about in this talk are only full

1117
00:53:50,500 --> 00:53:55,300
are only five of dozens of women that

1118
00:53:53,769 --> 00:54:00,159
worked at the Harvard Observatory from

1119
00:53:55,300 --> 00:54:04,420
1880 to the 1920s I'm not even sure a

1120
00:54:00,159 --> 00:54:07,568
complete list even exists by the time

1121
00:54:04,420 --> 00:54:09,730
the Harvard arca archive was complete

1122
00:54:07,568 --> 00:54:12,068
there were half a million glass plates

1123
00:54:09,730 --> 00:54:15,579
in the collection each plate containing

1124
00:54:12,068 --> 00:54:17,558
countless spectra and they classified

1125
00:54:15,579 --> 00:54:20,798
and characterized the stars on all of

1126
00:54:17,559 --> 00:54:22,569

these plates an Egypt Canon who took

1127

00:54:20,798 --> 00:54:25,059

over for will I mean Wilhelmina Fleming

1128

00:54:22,568 --> 00:54:28,329

after her death someone came in and said

1129

00:54:25,059 --> 00:54:30,190

I want swan dramedy I figured that's in

1130

00:54:28,329 --> 00:54:32,380

the constellation of Andromeda but she

1131

00:54:30,190 --> 00:54:36,880

rattled off the five digit plate number

1132

00:54:32,380 --> 00:54:41,798

and sure enough the requested star was

1133

00:54:36,880 --> 00:54:44,500

on that plate the work this is a picture

1134

00:54:41,798 --> 00:54:48,130

Cecilia Payne is in the middle and Annie

1135

00:54:44,500 --> 00:54:50,739

jump cannon is behind her this work

1136

00:54:48,130 --> 00:54:52,420

their work is the backbone of stellar at

1137

00:54:50,739 --> 00:54:55,058

modern stellar astrophysics without

1138

00:54:52,420 --> 00:54:57,298

these women we don't have modern stellar

1139

00:54:55,059 --> 00:54:57,298

astrophysics

1140

00:54:58,130 --> 00:55:03,358

well Amina Fleming died in 1911 she was

1141
00:55:01,679 --> 00:55:06,808
the first of them she was also one of

1142
00:55:03,358 --> 00:55:09,989
the oldest remember most of many of her

1143
00:55:06,809 --> 00:55:12,150
contributions were cataloging and making

1144
00:55:09,989 --> 00:55:14,039
sure that the plates were organized and

1145
00:55:12,150 --> 00:55:16,079
so that someone could actually find what

1146
00:55:14,039 --> 00:55:17,579
they were looking for and even in

1147
00:55:16,079 --> 00:55:19,950
astronomy her contributions have been

1148
00:55:17,579 --> 00:55:21,539
largely forgotten I actually didn't know

1149
00:55:19,949 --> 00:55:25,919
her name until I started researching

1150
00:55:21,539 --> 00:55:27,989
this talk on her tombstone under her

1151
00:55:25,920 --> 00:55:31,050
name and the dates of her birth and

1152
00:55:27,989 --> 00:55:34,709
death she simply had written astronomer

1153
00:55:31,050 --> 00:55:36,630
and remember she is the only person that

1154
00:55:34,710 --> 00:55:40,980
I've highlighted here that did not have

1155
00:55:36,630 --> 00:55:43,950
a degree in astronomy any jump cannon

1156
00:55:40,980 --> 00:55:46,829
died in 1941 this is a picture of her

1157
00:55:43,949 --> 00:55:49,379
looking at one of the glass plates they

1158
00:55:46,829 --> 00:55:53,750
would mark in pencil next to each of the

1159
00:55:49,380 --> 00:55:56,369
stars were preliminary classifications

1160
00:55:53,750 --> 00:56:01,260
possible variables that could then be

1161
00:55:56,369 --> 00:56:03,298
wiped away afterwards during her

1162
00:56:01,260 --> 00:56:05,280
lifetime she would classify hundreds of

1163
00:56:03,298 --> 00:56:07,048
thousands of stars she could look at one

1164
00:56:05,280 --> 00:56:13,349
of those spectra on the glass plate and

1165
00:56:07,048 --> 00:56:16,679
say that that's a b2 as casually as you

1166
00:56:13,349 --> 00:56:23,400
decide whether as you look at anything

1167
00:56:16,679 --> 00:56:25,949
that's a b2 that's a G that's a M the O

1168
00:56:23,400 --> 00:56:28,170
be a FG km spectral classification

1169

00:56:25,949 --> 00:56:29,639
sequence that she developed was adopted

1170
00:56:28,170 --> 00:56:34,639
by the International Astronomical Union

1171
00:56:29,639 --> 00:56:36,808
in 1922 and it is still in use today and

1172
00:56:34,639 --> 00:56:40,848
if anyone can come up with a better

1173
00:56:36,809 --> 00:56:40,849
mnemonic to remember it I am all yours

1174
00:56:41,568 --> 00:56:48,298
she received a prize from she received a

1175
00:56:46,019 --> 00:56:50,250
prize for her work from a group that

1176
00:56:48,298 --> 00:56:53,338
supported women in research and in

1177
00:56:50,250 --> 00:56:56,460
academia of \$1,000 and using this money

1178
00:56:53,338 --> 00:57:00,269
she endowed a prize in her name the

1179
00:56:56,460 --> 00:57:02,280
Annie jump cannon prize for decades this

1180
00:57:00,269 --> 00:57:05,818
was given only once in a while to a

1181
00:57:02,280 --> 00:57:08,750
deserving woman it is now given annually

1182
00:57:05,818 --> 00:57:12,079
to an exemplary early career woman at AU

1183
00:57:08,750 --> 00:57:13,849

nighted states institution which I take

1184

00:57:12,079 --> 00:57:18,949

to mean that there's no more of us than

1185

00:57:13,849 --> 00:57:20,329

there used to be antonio mari would work

1186

00:57:18,949 --> 00:57:22,819

intermittently at the Harvard

1187

00:57:20,329 --> 00:57:24,590

Observatory for decades one of the

1188

00:57:22,820 --> 00:57:26,780

reasons is was intermittent is that she

1189

00:57:24,590 --> 00:57:29,809

couldn't make enough money as a computer

1190

00:57:26,780 --> 00:57:32,600

to actually live so she was often doing

1191

00:57:29,809 --> 00:57:35,299

teaching jobs in addition to her work at

1192

00:57:32,599 --> 00:57:40,719

the observatory and would burn out would

1193

00:57:35,300 --> 00:57:43,580

leave for a while and would come back in

1194

00:57:40,719 --> 00:57:46,159

1944 she became the second recipient of

1195

00:57:43,579 --> 00:57:50,989

the Annie jump cannon prize and passed

1196

00:57:46,159 --> 00:57:54,409

away in 1952 that complex vector

1197

00:57:50,989 --> 00:57:56,929

classification sequence the fact that

1198
00:57:54,409 --> 00:57:58,489
the spectral lines of difference of the

1199
00:57:56,929 --> 00:58:00,230
differ of some of the different stars

1200
00:57:58,489 --> 00:58:03,849
looked different even though their

1201
00:58:00,230 --> 00:58:06,740
strengths were the same is now how we

1202
00:58:03,849 --> 00:58:11,089
determine our differentiate between

1203
00:58:06,739 --> 00:58:13,039
types of stars so how many people have

1204
00:58:11,090 --> 00:58:18,920
seen Betelgeuse the bloody shoulder of

1205
00:58:13,039 --> 00:58:21,789
Orion it's really bright right how many

1206
00:58:18,920 --> 00:58:25,150
of you have heard of Proxima Centauri

1207
00:58:21,789 --> 00:58:27,739
yeah it's been near a start of the Sun

1208
00:58:25,150 --> 00:58:30,289
Betelgeuse but you can't see it from

1209
00:58:27,739 --> 00:58:34,009
earth with the naked eye it is so dim

1210
00:58:30,289 --> 00:58:37,670
that even at 4.1 light-years it is too

1211
00:58:34,010 --> 00:58:39,200
faint but for comparison Alpha Centauri

1212
00:58:37,670 --> 00:58:43,519
is one of the brightest stars on the

1213
00:58:39,199 --> 00:58:46,000
southern sky Proxima Centauri and

1214
00:58:43,519 --> 00:58:49,849
Betelgeuse are the same spectral class

1215
00:58:46,000 --> 00:58:52,369
the difference is in the shape of their

1216
00:58:49,849 --> 00:58:55,610
lines Betelgeuse is a giant star has a

1217
00:58:52,369 --> 00:58:58,549
much broader line Proxima Centauri has a

1218
00:58:55,610 --> 00:59:01,670
much narrower line and mari's

1219
00:58:58,550 --> 00:59:03,830
classification scheme is how we

1220
00:59:01,670 --> 00:59:06,130
differentiate between those types of

1221
00:59:03,829 --> 00:59:06,130
stars

1222
00:59:07,170 --> 00:59:12,639
in 1934 Cecilia Payne gevalt skin

1223
00:59:11,019 --> 00:59:14,949
received the first Annie jump cannon

1224
00:59:12,639 --> 00:59:17,500
prize the only recipient to receive it

1225
00:59:14,949 --> 00:59:20,259
directly from Annie jump cannon her

1226

00:59:17,500 --> 00:59:24,579
prize was \$50 and a small handcrafted

1227
00:59:20,260 --> 00:59:27,010
medallion of a spiral galaxy she is also

1228
00:59:24,579 --> 00:59:29,079
the other than Wilhelmina Fleming and

1229
00:59:27,010 --> 00:59:30,819
her short-lived early marriage she is

1230
00:59:29,079 --> 00:59:35,109
the only person who I've highlighted

1231
00:59:30,818 --> 00:59:36,969
here that was married she went on to

1232
00:59:35,108 --> 00:59:38,798
become the first female faculty member

1233
00:59:36,969 --> 00:59:41,459
of the Harvard Astronomy Department this

1234
00:59:38,798 --> 00:59:44,259
took until nineteen of the 1950's and

1235
00:59:41,460 --> 00:59:50,289
she became its first female department

1236
00:59:44,260 --> 00:59:56,500
chair and then there is Henrietta

1237
00:59:50,289 --> 00:59:58,510
Leavitt she died of cancer in 1921 five

1238
00:59:56,500 --> 01:00:02,349
years later a man you might have heard

1239
00:59:58,510 --> 01:00:06,819
of Edwin Hubble used the pea found

1240
01:00:02,349 --> 01:00:11,048

Cepheid in Andromeda and he used that

1241
01:00:06,818 --> 01:00:12,940
period-luminosity relation that standard

1242
01:00:11,048 --> 01:00:15,099
candle that Henrietta leave it gave

1243
01:00:12,940 --> 01:00:17,829
astronomy to determine the distance to

1244
01:00:15,099 --> 01:00:20,859
the Andromeda nebula what was then known

1245
01:00:17,829 --> 01:00:22,869
as the Andromeda nebula at that point

1246
01:00:20,858 --> 01:00:25,480
there was a massive debate in the field

1247
01:00:22,869 --> 01:00:27,640
about whether or not objects like

1248
01:00:25,480 --> 01:00:31,088
Andromeda were internal to our own Milky

1249
01:00:27,639 --> 01:00:34,598
Way or galaxies external to our Milky

1250
01:00:31,088 --> 01:00:38,230
Way something that we just know now as a

1251
01:00:34,599 --> 01:00:40,119
fact of the field was under debate the

1252
01:00:38,230 --> 01:00:42,039
distance that he derived from the

1253
01:00:40,119 --> 01:00:44,170
Andromeda sophia's proved beyond a

1254
01:00:42,039 --> 01:00:48,039
shadow of a doubt that Andromeda wasn't

1255
01:00:44,170 --> 01:00:50,409
a nebula it was a it was an external

1256
01:00:48,039 --> 01:00:56,230
galaxy that we now know to be 2.5

1257
01:00:50,409 --> 01:00:58,719
million light-years from our own today

1258
01:00:56,230 --> 01:01:00,880
the Cepheid formed part of what

1259
01:00:58,719 --> 01:01:05,818
astronomers refer to as the distance

1260
01:01:00,880 --> 01:01:08,380
ladder starting down here with parallax

1261
01:01:05,818 --> 01:01:13,869
so if you want an example of parallax

1262
01:01:08,380 --> 01:01:18,320
stick one finger out cover one eye

1263
01:01:13,869 --> 01:01:21,740
cover the other eye quickly and then

1264
01:01:18,320 --> 01:01:26,930
move your finger in and do it again your

1265
01:01:21,739 --> 01:01:32,419
finger moves does your finger move when

1266
01:01:26,929 --> 01:01:34,179
does it move more closer parallax does

1267
01:01:32,420 --> 01:01:37,430
the same thing does the same for stars

1268
01:01:34,179 --> 01:01:39,440
but it only works for stars even today

1269
01:01:37,429 --> 01:01:41,509
four stars relatively close to the earth

1270
01:01:39,440 --> 01:01:44,059
we can't even go outside of our

1271
01:01:41,510 --> 01:01:48,590
immediate neighborhood around the Sun

1272
01:01:44,059 --> 01:01:51,230
let alone outside of the galaxy up here

1273
01:01:48,590 --> 01:01:53,570
we have cosmic distant scales measuring

1274
01:01:51,230 --> 01:01:55,369
things that are millions or billions of

1275
01:01:53,570 --> 01:01:59,900
light-years away and we still need to

1276
01:01:55,369 --> 01:02:05,150
know their distances and in between are

1277
01:01:59,900 --> 01:02:07,400
the Cepheid we use parallax for those

1278
01:02:05,150 --> 01:02:10,369
nearby sophia's for which we know

1279
01:02:07,400 --> 01:02:11,960
parallax we have their parallax's we can

1280
01:02:10,369 --> 01:02:14,780
get their distance with parallax and

1281
01:02:11,960 --> 01:02:17,750
that calibrates henriette leave its

1282
01:02:14,780 --> 01:02:20,840
relation the Cepheid x' in turn

1283

01:02:17,750 --> 01:02:23,750
calibrate the even more distant distant

1284
01:02:20,840 --> 01:02:26,420
scales when you hear about the

1285
01:02:23,750 --> 01:02:29,179
acceleration of the universe or which a

1286
01:02:26,420 --> 01:02:33,320
nobel prize was awarded dependent on the

1287
01:02:29,179 --> 01:02:35,629
period-luminosity relation whenever you

1288
01:02:33,320 --> 01:02:37,490
hear an astronomer tell you how far away

1289
01:02:35,630 --> 01:02:42,890
something is at the edge of the universe

1290
01:02:37,489 --> 01:02:46,879
or even only 5 billion light-years away

1291
01:02:42,889 --> 01:02:54,139
it is dependent on this step in the

1292
01:02:46,880 --> 01:02:55,690
distance ladder on the centennial of her

1293
01:02:54,139 --> 01:02:59,000
discovery of the period-luminosity

1294
01:02:55,690 --> 01:03:01,429
relation a symposium was held at Harvard

1295
01:02:59,000 --> 01:03:06,079
this is something we do in astronomy we

1296
01:03:01,429 --> 01:03:08,929
have symposia and at that symposia it

1297
01:03:06,079 --> 01:03:11,358

was recommended that from there on out

1298

01:03:08,929 --> 01:03:14,089

the Cepheid period-luminosity relation

1299

01:03:11,358 --> 01:03:17,630

which is how I learned it and how most

1300

01:03:14,090 --> 01:03:22,880

astronomers learned it be referred to as

1301

01:03:17,630 --> 01:03:25,349

the Leavitt law the next year the

1302

01:03:22,880 --> 01:03:30,269

American Astronomical Society

1303

01:03:25,349 --> 01:03:32,609

agreed and well you were asking me

1304

01:03:30,268 --> 01:03:36,978

questions I have a little present for

1305

01:03:32,608 --> 01:03:42,498

you from the mm from the women from the

1306

01:03:36,978 --> 01:03:42,498

2017 women of astronomy thank you

1307

01:03:44,570 --> 01:04:03,269

[Applause]

1308

01:03:58,070 --> 01:04:06,740

questions yes up prior to the

1309

01:04:03,269 --> 01:04:09,690

termination of the standard candle

1310

01:04:06,739 --> 01:04:10,769

parameter step on bevels what's there a

1311

01:04:09,690 --> 01:04:15,990

even Ossipee

1312
01:04:10,769 --> 01:04:17,880
standard prior to that yeah not charcoal

1313
01:04:15,989 --> 01:04:19,829
and earlier the shampoo vanassa ders you

1314
01:04:17,880 --> 01:04:22,410
called the absolute brightness what's

1315
01:04:19,829 --> 01:04:25,139
that smell different that was she could

1316
01:04:22,409 --> 01:04:27,210
do it because she knew the initial group

1317
01:04:25,139 --> 01:04:31,079
but it was done for were all at the same

1318
01:04:27,210 --> 01:04:32,970
distance they were all in the LMC she

1319
01:04:31,079 --> 01:04:35,279
didn't know the distance at the LMC but

1320
01:04:32,969 --> 01:04:37,289
she knew that if one was brighter than

1321
01:04:35,280 --> 01:04:42,380
the other it was actually that much

1322
01:04:37,289 --> 01:04:45,150
brighter than the other so if you take

1323
01:04:42,380 --> 01:04:48,150
so you have this variable of distance

1324
01:04:45,150 --> 01:04:49,380
and if something is much closer to you

1325
01:04:48,150 --> 01:04:51,840
if you have two things that are the same

1326
01:04:49,380 --> 01:04:54,470
brightness and one is closer to the

1327
01:04:51,840 --> 01:04:57,000
other the closer one will appear right

1328
01:04:54,469 --> 01:04:58,709
but if those two objects are taken to

1329
01:04:57,000 --> 01:05:00,210
about the same distance they will appear

1330
01:04:58,710 --> 01:05:02,099
they will appear to have the same

1331
01:05:00,210 --> 01:05:06,659
brightness and they will in fact have

1332
01:05:02,099 --> 01:05:08,519
the same rights if you have one object

1333
01:05:06,659 --> 01:05:11,338
that's much brighter and is further away

1334
01:05:08,519 --> 01:05:13,139
and one object which is fainter and

1335
01:05:11,338 --> 01:05:14,820
closer they may appear to be the same

1336
01:05:13,139 --> 01:05:18,088
brightness but in actuality the more

1337
01:05:14,820 --> 01:05:20,039
distant one is brighter in he would have

1338
01:05:18,088 --> 01:05:23,369
take those two same two objects and move

1339
01:05:20,039 --> 01:05:25,380
them to the same distance the one that

1340

01:05:23,369 --> 01:05:27,358
is brighter will appear to be brighter

1341
01:05:25,380 --> 01:05:29,519
than the fainter object and that was

1342
01:05:27,358 --> 01:05:32,039
what allowed her to have to build the

1343
01:05:29,519 --> 01:05:33,570
period-luminosity relation is that she

1344
01:05:32,039 --> 01:05:35,099
didn't know how far away they actually

1345
01:05:33,570 --> 01:05:36,690
were but she knew they were all out of

1346
01:05:35,099 --> 01:05:40,650
the same distance because they were all

1347
01:05:36,690 --> 01:05:42,858
in the large magellanic cloud does that

1348
01:05:40,650 --> 01:05:42,858
make sense

1349
01:05:44,269 --> 01:05:52,530
other vessels here yeah I was wondering

1350
01:05:48,630 --> 01:05:54,960
I did the UM was there work instrumental

1351
01:05:52,530 --> 01:05:56,790
connecting with it Einstein that there

1352
01:05:54,960 --> 01:05:58,858
was nuclear fusion and the core of stars

1353
01:05:56,789 --> 01:06:03,829
you have hydrogen going to helium which

1354
01:05:58,858 --> 01:06:03,829

her are you referring to that's up yeah

1355

01:06:04,949 --> 01:06:10,689

his profession was her work instrumental

1356

01:06:08,619 --> 01:06:13,679

with determining that hydrogen was in

1357

01:06:10,690 --> 01:06:15,730

the core of stars and the answer is no

1358

01:06:13,679 --> 01:06:17,289

Cecilia Payne work dealt with the

1359

01:06:15,730 --> 01:06:19,150

atmospheres of stars the very upper

1360

01:06:17,289 --> 01:06:21,610

level that week the photosphere that we

1361

01:06:19,150 --> 01:06:23,079

can actually observe the physics of what

1362

01:06:21,610 --> 01:06:30,430

actually happened inside the core of

1363

01:06:23,079 --> 01:06:35,049

stars was done by other people when Evan

1364

01:06:30,429 --> 01:06:38,679

Hubble was looking for the second

1365

01:06:35,050 --> 01:06:41,260

variable in Andromeda to find out

1366

01:06:38,679 --> 01:06:43,599

whether it was she had million light

1367

01:06:41,260 --> 01:06:47,350

years away they were just part of our

1368

01:06:43,599 --> 01:06:50,909

galaxy we start looking at all these

1369
01:06:47,349 --> 01:06:55,179
stars with the telescopes they've had

1370
01:06:50,909 --> 01:07:00,339
how do you know precisely what started

1371
01:06:55,179 --> 01:07:03,569
looking at when you got do it lady for

1372
01:07:00,340 --> 01:07:10,530
doing under the thousands of stars you

1373
01:07:03,570 --> 01:07:10,530
look in the outskirts let's go quality

1374
01:07:10,559 --> 01:07:16,269
the question is how do you go about

1375
01:07:14,079 --> 01:07:19,690
looking for seppius and Andromeda on

1376
01:07:16,269 --> 01:07:22,719
photographic plates and this face were

1377
01:07:19,690 --> 01:07:25,570
actually relatively high resolution you

1378
01:07:22,719 --> 01:07:29,049
can see a lot of individual stars on

1379
01:07:25,570 --> 01:07:32,170
those plates especially analysis as

1380
01:07:29,050 --> 01:07:33,310
close to us as a barometer is you would

1381
01:07:32,170 --> 01:07:36,730
then take an extremely powerful

1382
01:07:33,309 --> 01:07:38,889
magnifying glass and what looks like a

1383
01:07:36,730 --> 01:07:43,090
cloud of stars would actually resolve

1384
01:07:38,889 --> 01:07:44,829
out into individual what's a light you

1385
01:07:43,090 --> 01:07:46,570
also would not point the telescope at

1386
01:07:44,829 --> 01:07:49,269
the very center of Andromeda you would

1387
01:07:46,570 --> 01:07:51,280
look sort of slightly out from the

1388
01:07:49,269 --> 01:07:53,139
center where the stellar the starts

1389
01:07:51,280 --> 01:07:54,490
weren't quite as dense and it is still

1390
01:07:53,139 --> 01:08:02,289
the technique that astronomers use to

1391
01:07:54,489 --> 01:08:04,479
this day in your beautiful image there

1392
01:08:02,289 --> 01:08:07,869
are a lot of blue stars for a very old

1393
01:08:04,480 --> 01:08:11,500
cluster you explained that the HR

1394
01:08:07,869 --> 01:08:13,659
diagram is an evolutionary diagram can

1395
01:08:11,500 --> 01:08:14,159
you explain the blue stars the blue

1396
01:08:13,659 --> 01:08:16,250
stars

1397

01:08:14,159 --> 01:08:20,099
whatever called horizontal branch stars

1398
01:08:16,250 --> 01:08:22,500
so some stars evolve on the HR diagram

1399
01:08:20,100 --> 01:08:24,000
they evolve into the giant phase and

1400
01:08:22,500 --> 01:08:27,569
then they go through sort of an

1401
01:08:24,000 --> 01:08:29,399
oscillation when they go from the red

1402
01:08:27,569 --> 01:08:33,630
part of the diagram over towards the

1403
01:08:29,399 --> 01:08:35,039
blue and then back and they're not when

1404
01:08:33,630 --> 01:08:36,569
they move backwards the blue they're not

1405
01:08:35,039 --> 01:08:38,548
burning hydrogen they're actually

1406
01:08:36,569 --> 01:08:40,770
burning helium and then eventually

1407
01:08:38,548 --> 01:08:44,698
carbon and oxygen for the most massive

1408
01:08:40,770 --> 01:08:46,589
stars and every time they have to burn

1409
01:08:44,698 --> 01:08:49,619
heavier another element so when they

1410
01:08:46,588 --> 01:08:51,689
they evolve up to the red giant they get

1411
01:08:49,619 --> 01:08:55,289

hot enough to burn helium they move over

1412

01:08:51,689 --> 01:08:58,139

and then when they run out of helium

1413

01:08:55,289 --> 01:09:00,509

they go back and they just back and

1414

01:08:58,140 --> 01:09:03,810

forth until they run out of fuel to burn

1415

01:09:00,509 --> 01:09:04,920

at which point they for those stars

1416

01:09:03,810 --> 01:09:07,469

they're going to explode in a supernova

1417

01:09:04,920 --> 01:09:09,630

I would also note in the image that we

1418

01:09:07,469 --> 01:09:12,329

came out today the blue here actually

1419

01:09:09,630 --> 01:09:14,789

represents ultraviolet light this this

1420

01:09:12,329 --> 01:09:18,568

image was taken with ultraviolet visible

1421

01:09:14,789 --> 01:09:20,310

and infrared detectors on like white

1422

01:09:18,569 --> 01:09:22,440

field camera 3 so the colors are

1423

01:09:20,310 --> 01:09:25,739

stretched beyond the visible light and

1424

01:09:22,439 --> 01:09:29,698

is in this image k visually Omega said

1425

01:09:25,738 --> 01:09:37,039

looks yellowish when you actually come

1426
01:09:29,698 --> 01:09:41,698
back love you I'm innocent

1427
01:09:37,039 --> 01:09:43,619
alright this is a curiosity Omega said

1428
01:09:41,698 --> 01:09:48,979
can be seen from Baltimore

1429
01:09:43,619 --> 01:09:48,979
no showed up other my house con pictures

1430
01:09:49,338 --> 01:10:01,198
it's about three degrees above the prize

1431
01:09:51,929 --> 01:10:03,060
yes you can see it that's tough in

1432
01:10:01,198 --> 01:10:04,439
astronomy you're not observe a mega

1433
01:10:03,060 --> 01:10:05,970
in the southern time from the northern

1434
01:10:04,439 --> 01:10:10,710
hemisphere the telescope operator would

1435
01:10:05,970 --> 01:10:14,220
kick you out of the room yes if you

1436
01:10:10,710 --> 01:10:16,140
could name a Space Telescope after one

1437
01:10:14,220 --> 01:10:18,270
of these women who would it be

1438
01:10:16,140 --> 01:10:20,280
why so the question is if you can name a

1439
01:10:18,270 --> 01:10:33,780
Space Telescope after one of these women

1440
01:10:20,279 --> 01:10:36,960
which ones it will be one of those three

1441
01:10:33,779 --> 01:10:39,239
I think it would depend on what the

1442
01:10:36,960 --> 01:10:41,130
mission of that telescope was if it was

1443
01:10:39,239 --> 01:10:42,719
a telescope to push the distance ladder

1444
01:10:41,130 --> 01:10:45,329
then you name it for Henrietta leave it

1445
01:10:42,720 --> 01:10:48,240
if it's a telescope its primary mission

1446
01:10:45,329 --> 01:10:51,149
is going to be to go after stars Annie

1447
01:10:48,239 --> 01:10:56,010
jump cannon if you're probing

1448
01:10:51,149 --> 01:10:57,089
fundamental physics hey so it I think it

1449
01:10:56,010 --> 01:10:58,829
would depend but I think it's high time

1450
01:10:57,090 --> 01:11:07,159
we named telescope after one of these

1451
01:10:58,829 --> 01:11:12,329
people other questions we have honey

1452
01:11:07,159 --> 01:11:20,430
you for me please the junk absorption

1453
01:11:12,329 --> 01:11:23,569
lines each is if each element has had

1454

01:11:20,430 --> 01:11:27,990
the bone the books and patterns or

1455
01:11:23,569 --> 01:11:31,170
something else each element has an

1456
01:11:27,989 --> 01:11:32,250
absorption pattern we usually talk about

1457
01:11:31,170 --> 01:11:32,970
them the way that you think about

1458
01:11:32,250 --> 01:11:36,810
fingerprints

1459
01:11:32,970 --> 01:11:38,760
these the specific sort of swirls within

1460
01:11:36,810 --> 01:11:40,980
your finger may be repeated in another

1461
01:11:38,760 --> 01:11:43,860
person but the combination of those

1462
01:11:40,979 --> 01:11:46,589
patterns on all ten of your fingers is

1463
01:11:43,859 --> 01:11:51,809
unique to you and the same thing is true

1464
01:11:46,590 --> 01:11:54,300
of the different elements the there may

1465
01:11:51,810 --> 01:11:57,870
be a line very close to hydrogen alpha

1466
01:11:54,300 --> 01:11:59,760
in for another element but the pattern

1467
01:11:57,869 --> 01:12:01,829
of hydrogen alpha hydrogen mega and

1468
01:11:59,760 --> 01:12:07,590

hydrogen gamma and hydrogen no that is

1469

01:12:01,829 --> 01:12:09,809

unique to hydrogen and you look for

1470

01:12:07,590 --> 01:12:12,510

those patterns rather than the

1471

01:12:09,810 --> 01:12:16,830

individual ones all right in the last

1472

01:12:12,510 --> 01:12:18,750

questions I see that greenie is here so

1473

01:12:16,829 --> 01:12:20,670

everyone say Haier mini she is our

1474

01:12:18,750 --> 01:12:22,920

telescope operator the Maryland space

1475

01:12:20,670 --> 01:12:24,449

grant observatory and if you would like

1476

01:12:22,920 --> 01:12:26,250

to go look through the telescope she

1477

01:12:24,449 --> 01:12:29,189

will take you are you going to come down

1478

01:12:26,250 --> 01:12:31,199

here so that if people are going to be

1479

01:12:29,189 --> 01:12:32,489

leading from over there so if you would

1480

01:12:31,199 --> 01:12:34,170

like to go across the street and meet

1481

01:12:32,489 --> 01:12:37,380

with Iranian she'll take you across the

1482

01:12:34,170 --> 01:12:39,180

street next month is to be announced but

1483
01:12:37,380 --> 01:12:41,789
I will have a speaker for you on June

1484
01:12:39,180 --> 01:12:44,310
6th and let us give a very warm thank

1485
01:12:41,789 --> 01:12:55,420
you to me Abobo

1486
01:12:44,310 --> 01:12:55,420
[Applause]

1487
01:12:57,170 --> 01:13:06,619
the point was that me shone the priest

1488
01:13:03,029 --> 01:13:06,619
off I shown the Christoffel symbols