

1
00:00:00,000 --> 00:00:09,750
upcast and pulling it to youtube so give

2
00:00:02,759 --> 00:00:12,349
grant a hand alright let me start the

3
00:00:09,750 --> 00:00:12,349
real talk

4
00:00:13,369 --> 00:00:30,918
I'm sure this working as you came in if

5
00:00:28,879 --> 00:00:33,799
you saw these on the table we have our

6
00:00:30,919 --> 00:00:36,558
lithographs tonight's lithograph is of

7
00:00:33,799 --> 00:00:38,780
30 Doradus a turbulent star-forming

8
00:00:36,558 --> 00:00:41,030
region which really should be called the

9
00:00:38,780 --> 00:00:42,530
tarantula nebula because 30 Doradus is

10
00:00:41,030 --> 00:00:44,960
just basically the star cluster at the

11
00:00:42,530 --> 00:00:47,359
heart of it it was originally it was so

12
00:00:44,960 --> 00:00:48,500
bright it was thought to be a star but

13
00:00:47,359 --> 00:00:50,448
it's now a said known to be a star

14
00:00:48,500 --> 00:00:52,909
cluster and actually it's a part of a

15
00:00:50,448 --> 00:00:55,039
big nebula called the tarantula nebula

16
00:00:52,909 --> 00:00:57,890
if you'd like to learn more about it

17
00:00:55,039 --> 00:01:00,439
it's on the back and it talks about star

18
00:00:57,890 --> 00:01:01,820
formation but you don't have to read you

19
00:01:00,439 --> 00:01:04,370
can listen to will tonight because he's

20
00:01:01,820 --> 00:01:06,109
gonna tell you everything you wanted to

21
00:01:04,370 --> 00:01:10,070
know about star formation because our

22
00:01:06,109 --> 00:01:12,409
talk tonight is star formation in Orion

23
00:01:10,069 --> 00:01:16,129
one of my favorite places in the

24
00:01:12,409 --> 00:01:18,530
universe next month we will have the

25
00:01:16,129 --> 00:01:21,649
Milky Way's bulge from a hypothesized

26
00:01:18,530 --> 00:01:24,079
blob to a remarkably detailed picture I

27
00:01:21,650 --> 00:01:26,750
actually wanted to call this the blob

28
00:01:24,079 --> 00:01:30,259
that ate the Milky Way but David didn't

29

00:01:26,750 --> 00:01:33,109
seem to like that title in August

30
00:01:30,260 --> 00:01:36,500
ashes to ashes dust to dust the fate of

31
00:01:33,109 --> 00:01:40,700
stars like the Sun death of stars in

32
00:01:36,500 --> 00:01:43,640
August and in September more death and

33
00:01:40,700 --> 00:01:46,250
destruction 100 ways to die in the

34
00:01:43,640 --> 00:01:51,680
universe I really don't know what that

35
00:01:46,250 --> 00:01:53,870
talk is about but if you would like to

36
00:01:51,680 --> 00:01:56,780
find out more about to keep remind

37
00:01:53,870 --> 00:01:58,700
yourself of these talks we have our web

38
00:01:56,780 --> 00:02:00,650
page you take go to your favorite search

39
00:01:58,700 --> 00:02:02,719
engine and type o hubble public talks

40
00:02:00,650 --> 00:02:04,790
you'll find this page we have our list

41
00:02:02,719 --> 00:02:07,719
of the upcoming lectures we have the

42
00:02:04,790 --> 00:02:10,610
links to the live webcasting both on our

43
00:02:07,719 --> 00:02:13,340

STScI webcasting site as well as on

44

00:02:10,610 --> 00:02:18,470

youtube we have the archives all the way

45

00:02:13,340 --> 00:02:21,319

back to 2005 from STFC i so you can get

46

00:02:18,469 --> 00:02:23,509

your fill of astronomy should you wake

47

00:02:21,318 --> 00:02:25,369

up at 3 in the morning go I really need

48

00:02:23,509 --> 00:02:28,429

some astronomy right now

49

00:02:25,370 --> 00:02:32,340

you can also sign up for our email list

50

00:02:28,430 --> 00:02:33,990

here let's see the announcements if you

51

00:02:32,340 --> 00:02:35,670

sign up to the website we'll just send

52

00:02:33,990 --> 00:02:37,770

you a really only send you like one or

53

00:02:35,669 --> 00:02:39,629

two emails a month selling reminding you

54

00:02:37,770 --> 00:02:41,130

of the upcoming lectures and telling you

55

00:02:39,629 --> 00:02:43,409

where you can find the webcast when it

56

00:02:41,129 --> 00:02:45,509

is posted if you have comments or

57

00:02:43,409 --> 00:02:51,030

questions you can send them to us at

58
00:02:45,509 --> 00:02:52,979
public lecture at STScI edu social media

59
00:02:51,030 --> 00:02:54,870
should you want to follow us on these

60
00:02:52,979 --> 00:02:56,340
various things we have facebook we have

61
00:02:54,870 --> 00:02:59,099
twitter we have YouTube we have

62
00:02:56,340 --> 00:03:03,479
Instagram and we have two or three on

63
00:02:59,099 --> 00:03:06,419
each of those channels for your social

64
00:03:03,479 --> 00:03:08,399
media pleasure myself I'm on Facebook

65
00:03:06,419 --> 00:03:12,389
Google+ and Twitter but I'm not very

66
00:03:08,400 --> 00:03:15,750
active so don't expect daily tweets from

67
00:03:12,389 --> 00:03:17,939
me Observatory I got the email from

68
00:03:15,750 --> 00:03:19,979
ireenie and she said it's just cloudy

69
00:03:17,939 --> 00:03:22,530
all evening so we will not have the

70
00:03:19,979 --> 00:03:24,719
observatory open after the lecture but

71
00:03:22,530 --> 00:03:27,960
as we remind you every month they do

72
00:03:24,719 --> 00:03:31,590
have open houses on Friday evenings you

73
00:03:27,960 --> 00:03:33,030
go to MD dot space grant org you find

74
00:03:31,590 --> 00:03:35,099
their Observatory page and this

75
00:03:33,030 --> 00:03:38,009
Observatory status box over here on the

76
00:03:35,099 --> 00:03:39,269
right will tell you what whether or not

77
00:03:38,009 --> 00:03:41,159
they're gonna be open basically you

78
00:03:39,270 --> 00:03:42,659
check it Friday at around 5:00 or 6:00

79
00:03:41,159 --> 00:03:44,310
and they'll tell you whether they're

80
00:03:42,659 --> 00:03:48,030
gonna be open sort of like the email I

81
00:03:44,310 --> 00:03:50,670
get every time we have to lecture okay

82
00:03:48,030 --> 00:03:53,360
and now our news from the universe for

83
00:03:50,669 --> 00:03:59,639
June 2018

84
00:03:53,360 --> 00:04:02,790
our first story a galaxy tug of war well

85
00:03:59,639 --> 00:04:04,949
let's start with our galaxy okay so this

86

00:04:02,789 --> 00:04:07,319
is an all-sky view of our Milky Way

87
00:04:04,949 --> 00:04:08,969
galaxy and you can see right across the

88
00:04:07,319 --> 00:04:11,849
center here is the plane of our Milky

89
00:04:08,969 --> 00:04:14,129
Way galaxy it's a disc shaped galaxy and

90
00:04:11,849 --> 00:04:18,480
we're inside that disc so we see it as

91
00:04:14,129 --> 00:04:21,060
this long straight structure heading all

92
00:04:18,480 --> 00:04:23,009
the way across the sky but there are

93
00:04:21,060 --> 00:04:25,199
other galaxies in this image all right

94
00:04:23,009 --> 00:04:28,289
you may not know them as galaxies but

95
00:04:25,199 --> 00:04:31,289
you have this spot down here this spot

96
00:04:28,290 --> 00:04:35,800
down here they are nearby galaxies this

97
00:04:31,290 --> 00:04:38,470
one is called the Large Magellanic Cloud

98
00:04:35,800 --> 00:04:41,470
yeah they're called Magellanic because

99
00:04:38,470 --> 00:04:44,590
they were discovered by Magellan on his

100
00:04:41,470 --> 00:04:46,180

trip around the world actually they

101

00:04:44,589 --> 00:04:47,649

can't say that Magellan discovered them

102

00:04:46,180 --> 00:04:49,360

because it was just he was the first

103

00:04:47,649 --> 00:04:52,120

Europe he brought back the news of these

104

00:04:49,360 --> 00:04:53,830

objects to Europe of course anybody can

105

00:04:52,120 --> 00:04:56,620

see them they just look up if you're in

106

00:04:53,829 --> 00:04:58,930

the southern hemisphere unfortunately we

107

00:04:56,620 --> 00:05:00,069

can't see them here from Baltimore but

108

00:04:58,930 --> 00:05:02,500

if you do get down in the southern

109

00:05:00,069 --> 00:05:04,870

hemisphere you must look up get find a

110

00:05:02,500 --> 00:05:07,449

dark spot and it's just beautiful to see

111

00:05:04,870 --> 00:05:09,250

these these clouds up there in the sky

112

00:05:07,449 --> 00:05:10,598

so that's the large magellanic cloud and

113

00:05:09,250 --> 00:05:14,529

if there's a large magellanic cloud

114

00:05:10,598 --> 00:05:16,598

there's also a small magellanic cloud

115
00:05:14,529 --> 00:05:20,829
yes this is the small Magellanic Cloud

116
00:05:16,598 --> 00:05:23,259
now these two clouds are not clouds they

117
00:05:20,829 --> 00:05:25,209
look kind of cloudy when viewed with the

118
00:05:23,259 --> 00:05:27,819
human eye but as you can see from these

119
00:05:25,209 --> 00:05:30,250
images they're composed of millions of

120
00:05:27,819 --> 00:05:33,158
stars they are actually satellite

121
00:05:30,250 --> 00:05:36,009
galaxies of the Milky Way the LMC and

122
00:05:33,158 --> 00:05:37,959
the SMC are two satellite galaxies

123
00:05:36,009 --> 00:05:40,778
they're actually orbiting around the

124
00:05:37,959 --> 00:05:43,180
Milky Way how do we know that they are

125
00:05:40,778 --> 00:05:44,860
orbiting well we can measure their

126
00:05:43,180 --> 00:05:47,889
dynamics and everything but it's

127
00:05:44,860 --> 00:05:50,650
actually kind of easy when you look at

128
00:05:47,889 --> 00:05:54,250
them in radio light because in radio

129
00:05:50,649 --> 00:05:56,528
light you see this sorry I changed the

130
00:05:54,250 --> 00:05:58,778
Milky Way from a longitude latitude

131
00:05:56,528 --> 00:06:02,098
projection to what this is an eighth off

132
00:05:58,778 --> 00:06:04,839
all sky projection but here are the

133
00:06:02,098 --> 00:06:07,028
large and small Magellanic Clouds and

134
00:06:04,839 --> 00:06:09,968
you see this radio light coming along

135
00:06:07,028 --> 00:06:12,218
here okay and you see all this junk up

136
00:06:09,968 --> 00:06:14,379
here also associated with Magellanic

137
00:06:12,218 --> 00:06:16,718
Clouds okay so let me put on some some

138
00:06:14,379 --> 00:06:19,330
graphics we've got the LMC and the SMC

139
00:06:16,718 --> 00:06:24,009
and then this is called the Magellanic

140
00:06:19,329 --> 00:06:27,430
stream okay and this is understood to be

141
00:06:24,009 --> 00:06:30,038
material that has been pulled out of the

142
00:06:27,430 --> 00:06:31,900
large and small Magellanic Clouds due to

143

00:06:30,038 --> 00:06:34,538
this sort of tug-of-war as they're

144
00:06:31,899 --> 00:06:37,388
orbiting around gravity pulls on these

145
00:06:34,538 --> 00:06:39,550
galaxies and if you've got the Milky Way

146
00:06:37,389 --> 00:06:41,468
which is a large galaxy and you've got

147
00:06:39,550 --> 00:06:43,210
the LMC and the SMC which are small

148
00:06:41,468 --> 00:06:47,500
galaxies and they're in a tug-of-war

149
00:06:43,209 --> 00:06:49,638
who's gonna win yeah you can see here

150
00:06:47,500 --> 00:06:51,918
the out of the Milky Way galaxy

151
00:06:49,639 --> 00:06:55,098
is gonna win and you get this big title

152
00:06:51,918 --> 00:06:56,779
tail of material that we previously used

153
00:06:55,098 --> 00:06:58,430
Hubble observations to understand that

154
00:06:56,779 --> 00:07:00,978
they kept this material actually

155
00:06:58,430 --> 00:07:04,278
contains material from both the SMC and

156
00:07:00,978 --> 00:07:07,399
the LMC now that's sort of what we call

157
00:07:04,278 --> 00:07:09,528

the trailing arm of a title interaction

158

00:07:07,399 --> 00:07:11,748

stuff that's pulled out okay but stuff

159

00:07:09,528 --> 00:07:13,278

also pulls out on the near side due to

160

00:07:11,749 --> 00:07:15,289

the gravitational interactions these

161

00:07:13,278 --> 00:07:17,689

tidal interactions and this is the

162

00:07:15,288 --> 00:07:20,149

leading arm of it and that stuff is

163

00:07:17,689 --> 00:07:23,090

actually falling into and interacting

164

00:07:20,149 --> 00:07:25,250

with the Milky Way and we do not know

165

00:07:23,089 --> 00:07:29,560

where that leading arm material comes

166

00:07:25,250 --> 00:07:32,028

from and if you just look at it sort of

167

00:07:29,560 --> 00:07:34,519

geometrically right it's closer to the

168

00:07:32,028 --> 00:07:38,740

LMC and you say oh maybe that stuff is

169

00:07:34,519 --> 00:07:42,859

from the LMC dynamically you can't tell

170

00:07:38,740 --> 00:07:45,468

however you can tell if you use spectra

171

00:07:42,860 --> 00:07:48,620

all right so what we did is we found

172
00:07:45,468 --> 00:07:51,228
three quasars these are very distant

173
00:07:48,620 --> 00:07:53,209
very bright objects and their light is

174
00:07:51,228 --> 00:07:56,269
actually shining through this material

175
00:07:53,209 --> 00:07:59,180
and so we can look in the spectrum of

176
00:07:56,269 --> 00:08:02,149
the quasar to see what type of material

177
00:07:59,180 --> 00:08:05,538
is in this leading arm so here are the

178
00:08:02,149 --> 00:08:08,388
spectra all right quasar a quasar being

179
00:08:05,538 --> 00:08:10,459
quasar C and these are just uh you know

180
00:08:08,389 --> 00:08:11,978
graphic artist versions of them to show

181
00:08:10,459 --> 00:08:15,399
the hydrogen and the oxygen

182
00:08:11,978 --> 00:08:18,860
concentration in these various spectra

183
00:08:15,399 --> 00:08:21,139
so what we're looking at is what is the

184
00:08:18,860 --> 00:08:24,528
relative abundance of hydrogen and

185
00:08:21,139 --> 00:08:26,569
oxygen in this material and does it

186
00:08:24,528 --> 00:08:29,329
match the hydrogen oxygen abundance in

187
00:08:26,569 --> 00:08:33,879
the LMC or the SMC or is it a little bit

188
00:08:29,329 --> 00:08:38,149
of both the answer is it's from the SMC

189
00:08:33,879 --> 00:08:40,158
so the conclusion is that the LMC is

190
00:08:38,149 --> 00:08:42,769
pulling more material out of the SMC

191
00:08:40,158 --> 00:08:44,870
that is then falling in to form this

192
00:08:42,769 --> 00:08:46,459
leading arm at least these three signs

193
00:08:44,870 --> 00:08:49,009
that actually I think there were seven

194
00:08:46,458 --> 00:08:53,208
lines of sight through the leading arm

195
00:08:49,009 --> 00:08:57,009
and the oxygen to hydrogen ratio matches

196
00:08:53,208 --> 00:08:59,119
that of the SMC and not that of the LMC

197
00:08:57,009 --> 00:09:00,649
indicating that when you go with a large

198
00:08:59,120 --> 00:09:02,860
magellanic cloud versus the small

199
00:09:00,649 --> 00:09:05,200
magellanic cloud in a tug-of-war

200

00:09:02,860 --> 00:09:07,930
who's gonna win the Large Magellanic

201
00:09:05,200 --> 00:09:10,120
Cloud seems to win and that material is

202
00:09:07,929 --> 00:09:11,500
as can be traced back to the SMC and

203
00:09:10,120 --> 00:09:14,470
this is the first time we've been able

204
00:09:11,500 --> 00:09:16,450
to get the full understanding of this

205
00:09:14,470 --> 00:09:18,460
full Magellanic stream of these dwarf

206
00:09:16,450 --> 00:09:20,500
galaxies and they're losing you know

207
00:09:18,460 --> 00:09:22,139
just a small bit of the material as they

208
00:09:20,500 --> 00:09:29,440
orbit around the Milky Way

209
00:09:22,139 --> 00:09:32,259
yes question I don't know what has to be

210
00:09:29,440 --> 00:09:34,060
hundreds of millions of years could be

211
00:09:32,259 --> 00:09:37,720
as much as 500 million years do you know

212
00:09:34,059 --> 00:09:39,879
will yeah he he would guess the same

213
00:09:37,720 --> 00:09:41,700
amount so uh a few hundred million years

214
00:09:39,879 --> 00:09:44,409

maybe five hundred million years because

215

00:09:41,700 --> 00:09:46,840

our Sun orbiting within the Milky Way is

216

00:09:44,409 --> 00:09:48,850

200 250 million years and that of that

217

00:09:46,840 --> 00:09:51,129

timeframe so these are already way

218

00:09:48,850 --> 00:09:56,050

outside so I got to give it probably

219

00:09:51,129 --> 00:09:58,090

about 500 million okay yes they're there

220

00:09:56,049 --> 00:10:00,219

they're not in the plane they are if the

221

00:09:58,090 --> 00:10:01,870

plane is here they're down here and

222

00:10:00,220 --> 00:10:05,290

they're coming and we're not exactly

223

00:10:01,870 --> 00:10:07,389

sure they're of their exact orbit you

224

00:10:05,289 --> 00:10:09,789

can sort of trace and get a get a feel

225

00:10:07,389 --> 00:10:12,789

for it from the dynamics of that but

226

00:10:09,789 --> 00:10:14,529

it's it's it's still there's still

227

00:10:12,789 --> 00:10:37,719

significant uncertainty in the exact

228

00:10:14,529 --> 00:10:40,629

orbits of them okay yes okay so you're

229
00:10:37,720 --> 00:10:43,000
asking alright how far out into the

230
00:10:40,629 --> 00:10:45,549
Milky Way can we see with the human eye

231
00:10:43,000 --> 00:10:46,740
you're seeing just a small region of the

232
00:10:45,549 --> 00:10:48,849
Milky Way

233
00:10:46,740 --> 00:10:50,169
you didn't mean there's certain things

234
00:10:48,850 --> 00:10:52,750
that you can see that are really far

235
00:10:50,169 --> 00:10:55,329
away but most of all the stars you can

236
00:10:52,750 --> 00:10:57,340
see with the the human eye are about the

237
00:10:55,330 --> 00:10:59,560
size of a sausage on a 16 inch pizza

238
00:10:57,340 --> 00:11:01,540
okay that's the volume that you can see

239
00:10:59,559 --> 00:11:02,829
and maybe if you include all the other

240
00:11:01,539 --> 00:11:06,039
stuff you can see it gets out to the

241
00:11:02,830 --> 00:11:08,500
size about pepperoni on a pizza but you

242
00:11:06,039 --> 00:11:08,889
really can't see much much further than

243
00:11:08,500 --> 00:11:12,279
that

244
00:11:08,889 --> 00:11:13,330
okay questions about the the news story

245
00:11:12,279 --> 00:11:14,889
because I don't want to eat into wills

246
00:11:13,330 --> 00:11:17,440
time yeah

247
00:11:14,889 --> 00:11:19,720
in the arm is that dust or is it are

248
00:11:17,440 --> 00:11:21,730
there stars in there yes the the the

249
00:11:19,720 --> 00:11:23,230
with it within the spiral galaxy we have

250
00:11:21,730 --> 00:11:27,759
a lot of dust and we have a lot of stars

251
00:11:23,230 --> 00:11:30,009
the spiral arms contain both oh these

252
00:11:27,759 --> 00:11:33,850
are the these Magellanic streams no this

253
00:11:30,009 --> 00:11:36,610
is just I assume its hydrogen gas that

254
00:11:33,850 --> 00:11:38,590
you would decked in the radio there will

255
00:11:36,610 --> 00:11:40,899
be you know there will be some stars in

256
00:11:38,590 --> 00:11:42,430
this but it's not place where stars

257

00:11:40,899 --> 00:11:44,069
would be made because it's very diffused

258
00:11:42,429 --> 00:11:49,659
material okay

259
00:11:44,070 --> 00:11:52,420
second-story exoplanet helium alright so

260
00:11:49,659 --> 00:11:54,579
uh we all took him how many of you took

261
00:11:52,419 --> 00:11:55,899
chemistry or will take chemistry for the

262
00:11:54,580 --> 00:11:57,370
for the young kids in the audience right

263
00:11:55,899 --> 00:11:59,110
put your hands up you're gonna take

264
00:11:57,370 --> 00:12:00,730
chemistry right he's Peter you're gonna

265
00:11:59,110 --> 00:12:03,759
make sure she takes chemistry okay good

266
00:12:00,730 --> 00:12:05,680
alright if you took chemistry you

267
00:12:03,759 --> 00:12:07,600
remember the periodic table of the

268
00:12:05,679 --> 00:12:11,739
elements and maybe you remember with

269
00:12:07,600 --> 00:12:14,139
dread but it's a really cool diagram

270
00:12:11,740 --> 00:12:17,139
okay it really puts things in lots of

271
00:12:14,139 --> 00:12:20,230

order but there's a ton of elements out

272

00:12:17,139 --> 00:12:22,870
there okay there's a lot of really

273

00:12:20,230 --> 00:12:25,180
interesting stuff out there but for the

274

00:12:22,870 --> 00:12:28,409
universe we can simplify it we really

275

00:12:25,179 --> 00:12:30,789
only have to look it up here and up here

276

00:12:28,409 --> 00:12:35,559
because when we look at the content of

277

00:12:30,789 --> 00:12:38,259
the universe it's 75% hydrogen 23%

278

00:12:35,559 --> 00:12:41,349
helium and 2% other and that's by mass

279

00:12:38,259 --> 00:12:42,939
okay so it's mostly hydrogen helium and

280

00:12:41,350 --> 00:12:45,430
yeah there's all that other stuff okay

281

00:12:42,940 --> 00:12:47,830
which is why we astronomers talk about

282

00:12:45,429 --> 00:12:50,979
hydrogen helium and then heavy elements

283

00:12:47,830 --> 00:12:53,139
okay so when we look at that you know we

284

00:12:50,980 --> 00:12:55,539
can see hydrogen if we look at our Sun

285

00:12:53,139 --> 00:12:58,000
the composition of our Sun well that's

286
00:12:55,539 --> 00:13:00,879
pretty much the same hydrogen helium

287
00:12:58,000 --> 00:13:02,409
yeah and all this other stuff okay all

288
00:13:00,879 --> 00:13:05,439
the stuff that you really think of you

289
00:13:02,409 --> 00:13:08,230
know yeah that's just that's in the

290
00:13:05,440 --> 00:13:11,260
noise and even when you look at the

291
00:13:08,230 --> 00:13:13,480
giant planets Jupiter Saturn Uranus and

292
00:13:11,259 --> 00:13:15,220
Neptune this is a table you can see now

293
00:13:13,480 --> 00:13:17,379
this is not by mass this is by number

294
00:13:15,220 --> 00:13:20,290
eighty six and thirteen eighty eight

295
00:13:17,379 --> 00:13:24,039
eighty two eighty nineteen fifty most of

296
00:13:20,289 --> 00:13:25,929
all the stuff is hydrogen and helium all

297
00:13:24,039 --> 00:13:27,328
right so that's setting you up to

298
00:13:25,929 --> 00:13:29,548
understand that that this

299
00:13:27,328 --> 00:13:33,958
is really expected to be everywhere in

300
00:13:29,548 --> 00:13:37,289
the universe so we have found 3000

301
00:13:33,958 --> 00:13:40,198
extrasolar planets out there and a lot

302
00:13:37,289 --> 00:13:42,808
of these extrasolar planets we are able

303
00:13:40,198 --> 00:13:45,298
to we detect them by the transit method

304
00:13:42,808 --> 00:13:47,730
where the planet passes in front of its

305
00:13:45,298 --> 00:13:50,458
star and for certain ones that are

306
00:13:47,730 --> 00:13:52,528
nearby when that planet passes in front

307
00:13:50,458 --> 00:13:54,778
of a star and it's close enough to that

308
00:13:52,528 --> 00:13:57,208
star some of the light of the star goes

309
00:13:54,778 --> 00:13:59,548
through the atmosphere of that planet

310
00:13:57,208 --> 00:14:02,278
and if we take a picture when it's in

311
00:13:59,548 --> 00:14:04,919
front and when it's not in front and we

312
00:14:02,278 --> 00:14:08,220
subtract the two we get the spectrum of

313
00:14:04,919 --> 00:14:10,889
the atmosphere of the planet we can

314

00:14:08,220 --> 00:14:13,499
examine the atmospheres of other planets

315
00:14:10,889 --> 00:14:17,459
and so for example here is an example

316
00:14:13,499 --> 00:14:20,009
spectrum of planet called wasp 39b

317
00:14:17,458 --> 00:14:22,498
and these features here are associated

318
00:14:20,009 --> 00:14:24,539
with water molecules and these are

319
00:14:22,499 --> 00:14:27,178
associated with carbon dioxide and this

320
00:14:24,539 --> 00:14:30,269
is potassium and this is sodium and we

321
00:14:27,178 --> 00:14:33,678
have seen methane and we seen ammonia we

322
00:14:30,269 --> 00:14:38,909
have seen all sorts of species out there

323
00:14:33,678 --> 00:14:40,558
we've never seen helium which if given

324
00:14:38,909 --> 00:14:42,778
the intro that I did for this is kind of

325
00:14:40,558 --> 00:14:45,539
strange because you would expect there's

326
00:14:42,778 --> 00:14:51,899
a lot of helium out there and we have

327
00:14:45,539 --> 00:14:55,889
never seen it until obviously last 107

328
00:14:51,899 --> 00:14:58,350

be ok this is an artist illustration of

329

00:14:55,889 --> 00:15:01,438

it well it's actually you know this is

330

00:14:58,350 --> 00:15:04,860

not wasp 107 this is the Sun acting as a

331

00:15:01,438 --> 00:15:08,248

stunt double for wasp 107 and this would

332

00:15:04,860 --> 00:15:10,438

be wasps 107 be drawn in this and you

333

00:15:08,249 --> 00:15:15,269

can see it's got this very extended

334

00:15:10,438 --> 00:15:18,948

extended in wasp 107 be using infrared

335

00:15:15,269 --> 00:15:21,940

spectra we were finally able to detect

336

00:15:18,948 --> 00:15:24,189

helium

337

00:15:21,940 --> 00:15:26,850

in in in in the atmosphere of a planet

338

00:15:24,190 --> 00:15:29,860

and you might say well why did it take

339

00:15:26,850 --> 00:15:31,629

this special well first of all previous

340

00:15:29,860 --> 00:15:35,769

observations had been using visible

341

00:15:31,629 --> 00:15:39,669

light and ultraviolet light and they did

342

00:15:35,769 --> 00:15:42,789

not find the the helium and it turns out

343
00:15:39,669 --> 00:15:44,439
that you know the interesting lines that

344
00:15:42,789 --> 00:15:49,120
you want are can be found in the

345
00:15:44,440 --> 00:15:52,120
infrared but also lost 107 B is one of

346
00:15:49,120 --> 00:15:55,389
the lowest density giant planets we've

347
00:15:52,120 --> 00:15:59,350
ever discovered okay it is the same size

348
00:15:55,389 --> 00:16:02,559
as Jupiter but it's only 12% the mass of

349
00:15:59,350 --> 00:16:04,778
Jupiter that's really low density and

350
00:16:02,559 --> 00:16:07,449
these giant planets aren't very high

351
00:16:04,778 --> 00:16:09,269
density to begin with okay and they say

352
00:16:07,450 --> 00:16:12,520
that Saturn would float in a bathtub

353
00:16:09,269 --> 00:16:15,100
which is kind of funky but anyways it's

354
00:16:12,519 --> 00:16:17,710
lower density than water alright this is

355
00:16:15,100 --> 00:16:20,259
really really low density which means

356
00:16:17,710 --> 00:16:23,080
its atmosphere must be it's really

357
00:16:20,259 --> 00:16:26,049
really extended and must extend tens of

358
00:16:23,080 --> 00:16:28,778
thousands of kilometers out into space

359
00:16:26,049 --> 00:16:31,689
and it's because it's such a low density

360
00:16:28,778 --> 00:16:34,059
planet it has this really extended

361
00:16:31,690 --> 00:16:36,360
atmosphere it's in close to its star and

362
00:16:34,059 --> 00:16:39,278
they did the observations in infrared

363
00:16:36,360 --> 00:16:41,980
that they finally been able to discover

364
00:16:39,278 --> 00:16:43,778
helium in other planet atmospheres we

365
00:16:41,980 --> 00:16:45,940
always knew it inspected it would be

366
00:16:43,778 --> 00:16:48,159
there but it's really kind of nice to

367
00:16:45,940 --> 00:16:50,410
find what to expect and not be missing

368
00:16:48,159 --> 00:16:52,299
one of the the two primary elements in

369
00:16:50,409 --> 00:16:55,569
the universe in extrasolar planet

370
00:16:52,299 --> 00:16:57,609
atmospheres all right and so that's our

371

00:16:55,570 --> 00:16:59,500
news summary for tonight any other

372
00:16:57,610 --> 00:17:07,660
questions on the two stories I presented

373
00:16:59,500 --> 00:17:08,980
to here yes so the question of why we

374
00:17:07,660 --> 00:17:10,689
didn't find it in all the other planets

375
00:17:08,980 --> 00:17:12,849
is because this is an extended

376
00:17:10,689 --> 00:17:15,910
atmosphere without the extended

377
00:17:12,849 --> 00:17:17,349
atmosphere the helium layers aren't

378
00:17:15,910 --> 00:17:19,269
weren't exposed okay

379
00:17:17,349 --> 00:17:21,208
Alice that's the current understanding

380
00:17:19,269 --> 00:17:23,889
we'll have to detect it in a few more

381
00:17:21,209 --> 00:17:25,990
planets and a whole asshole to get a

382
00:17:23,890 --> 00:17:28,059
statistical sense of when we can see

383
00:17:25,990 --> 00:17:30,579
helium and when we can't but now we know

384
00:17:28,058 --> 00:17:32,869
how to find it we will look at the other

385
00:17:30,579 --> 00:17:35,809

ones and see if we can get a

386

00:17:32,869 --> 00:17:37,639

enough to make a statistical argument as

387

00:17:35,809 --> 00:17:39,919

to exactly why we're not seeing in any

388

00:17:37,640 --> 00:17:44,800

other and any of the others okay all

389

00:17:39,920 --> 00:17:44,800

right thank you all right so our

390

00:17:47,230 --> 00:17:52,370

featured speaker tonight is dr. wil

391

00:17:50,390 --> 00:17:54,710

Fisher from here at the Space Telescope

392

00:17:52,369 --> 00:17:56,509

Science Institute he got his

393

00:17:54,710 --> 00:17:59,900

undergraduate degree at the University

394

00:17:56,509 --> 00:18:05,420

of Toledo then went on to do a postdoc

395

00:17:59,900 --> 00:18:09,320

was it Goddard first or Toledo for the

396

00:18:05,420 --> 00:18:11,930

post Oh Toledo for a postdoc and then to

397

00:18:09,319 --> 00:18:13,789

Goddard for that and then he came what

398

00:18:11,930 --> 00:18:16,400

did you come right here from Goddard yes

399

00:18:13,789 --> 00:18:19,579

okay so he came to us from Goddard only

400
00:18:16,400 --> 00:18:22,250
a year year-and-a-half ago and his work

401
00:18:19,579 --> 00:18:26,089
is as a support scientist for the cosmic

402
00:18:22,250 --> 00:18:29,029
origins spectrograph and when he is not

403
00:18:26,089 --> 00:18:31,669
doing his astronomy he is a father of an

404
00:18:29,029 --> 00:18:33,529
11 year old girl who has gotten

405
00:18:31,670 --> 00:18:35,960
interested in astronomy he tells me but

406
00:18:33,529 --> 00:18:38,750
from a special perspective she likes to

407
00:18:35,960 --> 00:18:41,569
explore the art of astronomy astronomy

408
00:18:38,750 --> 00:18:43,880
and art so he's leading his daughter

409
00:18:41,569 --> 00:18:47,119
into not just a stem career but a steam

410
00:18:43,880 --> 00:18:49,580
career science technology arts and

411
00:18:47,119 --> 00:18:59,959
mathematics so ladies and gentlemen dr.

412
00:18:49,579 --> 00:19:00,289
will Fisher well thanks for coming

413
00:18:59,960 --> 00:19:03,380
everyone

414
00:19:00,289 --> 00:19:07,639
to start here I'm showing you a picture

415
00:19:03,380 --> 00:19:11,750
of Orion from Mayer's famous atlas of

416
00:19:07,640 --> 00:19:13,700
1603 and he's looking at an image of

417
00:19:11,750 --> 00:19:16,880
Orion from the infrared astronomy

418
00:19:13,700 --> 00:19:19,309
satellite which orbited in the 1980s and

419
00:19:16,880 --> 00:19:20,930
you might imagine that Orion is a little

420
00:19:19,309 --> 00:19:23,839
bit puzzled to learn what he's really

421
00:19:20,930 --> 00:19:26,390
made up of I'm gonna be telling you all

422
00:19:23,839 --> 00:19:28,669
about Star formation in Orion and how we

423
00:19:26,390 --> 00:19:30,710
learn about this with a lot of different

424
00:19:28,670 --> 00:19:34,430
space telescopes and a few that aren't

425
00:19:30,710 --> 00:19:36,710
quite in space so one of the reasons

426
00:19:34,430 --> 00:19:38,960
that were interested in how stars form

427
00:19:36,710 --> 00:19:40,549
is all of these thousands of exoplanets

428

00:19:38,960 --> 00:19:43,250
that have been discovered over the last

429
00:19:40,549 --> 00:19:45,298
20 to 25 years this is an artist's

430
00:19:43,250 --> 00:19:49,079
rendition of some of those at

431
00:19:45,298 --> 00:19:52,970
so planets and they exists in a wide

432
00:19:49,079 --> 00:19:55,439
variety of densities and compositions

433
00:19:52,970 --> 00:19:58,079
they orbit at some pretty surprising

434
00:19:55,440 --> 00:20:00,119
distances from their stars and to

435
00:19:58,079 --> 00:20:01,769
understand how all this comes to exist

436
00:20:00,118 --> 00:20:04,618
we have to know how the parent stars

437
00:20:01,769 --> 00:20:06,239
form so this has given new importance to

438
00:20:04,618 --> 00:20:11,928
studies of star formation in the past

439
00:20:06,239 --> 00:20:13,798
few decades but star formation began

440
00:20:11,929 --> 00:20:16,409
quite some time ago

441
00:20:13,798 --> 00:20:18,450
I think of 1852 is the beginning of star

442
00:20:16,409 --> 00:20:20,429

formation studies this is when this

443

00:20:18,450 --> 00:20:22,950

astronomer pictured here John Russell

444

00:20:20,429 --> 00:20:24,720

hind discovered a nebula that we now

445

00:20:22,950 --> 00:20:27,840

known as Hines nebula and there is a

446

00:20:24,720 --> 00:20:31,350

star in that nebula called t-tauri if

447

00:20:27,839 --> 00:20:33,209

you see a star where its name begins

448

00:20:31,349 --> 00:20:36,839

with one or two capital letters that

449

00:20:33,210 --> 00:20:38,579

means it's a variable star T Tauri as a

450

00:20:36,839 --> 00:20:41,519

variable star changed in brightness

451

00:20:38,579 --> 00:20:44,069

somewhat irregularly over periods of

452

00:20:41,519 --> 00:20:46,048

days to weeks but the interesting thing

453

00:20:44,069 --> 00:20:48,388

about this discovery is that the nebula

454

00:20:46,048 --> 00:20:51,418

also varied in brightness along with the

455

00:20:48,388 --> 00:20:53,368

star so that's a sign that the star and

456

00:20:51,419 --> 00:20:56,940

the nebula are physically connected the

457
00:20:53,368 --> 00:20:58,199
star is embedded in the nebula people

458
00:20:56,940 --> 00:21:01,679
didn't know what to make of this at

459
00:20:58,200 --> 00:21:03,899
first but as time went on more of these

460
00:21:01,679 --> 00:21:06,570
T Tauri like stars were discovered and

461
00:21:03,898 --> 00:21:10,319
then finally in an important paper in

462
00:21:06,569 --> 00:21:14,308
1945 the astronomer Alfred Joy laid out

463
00:21:10,319 --> 00:21:17,278
the class of T Tauri stars often a class

464
00:21:14,308 --> 00:21:19,230
of objects in the sky is named after the

465
00:21:17,278 --> 00:21:20,909
first one to be discovered and this is

466
00:21:19,230 --> 00:21:22,889
an important step in putting a science

467
00:21:20,909 --> 00:21:24,539
together to go from a single object to

468
00:21:22,888 --> 00:21:26,788
understanding that there's a collection

469
00:21:24,538 --> 00:21:29,669
of objects that all have similar

470
00:21:26,788 --> 00:21:31,888
observational properties this is a light

471
00:21:29,669 --> 00:21:34,739
curve of an example of a T Tauri star

472
00:21:31,888 --> 00:21:37,648
and when you plot a light curve high

473
00:21:34,739 --> 00:21:40,048
points are bright and low points are dim

474
00:21:37,648 --> 00:21:41,878
and you plot those against time so you

475
00:21:40,048 --> 00:21:44,069
can see over the course of about a month

476
00:21:41,878 --> 00:21:46,738
you have these irregular variations in a

477
00:21:44,069 --> 00:21:49,288
T Tauri star and the change in

478
00:21:46,739 --> 00:21:52,528
brightness here corresponds to about a

479
00:21:49,288 --> 00:21:57,240
factor of 10 or a little bit less than

480
00:21:52,528 --> 00:21:58,529
10 and he recognized that there were 11

481
00:21:57,240 --> 00:22:00,390
known stars that had

482
00:21:58,529 --> 00:22:02,490
herbs like this and they were all in

483
00:22:00,390 --> 00:22:05,910
nebulous regions of the sky in these

484
00:22:02,490 --> 00:22:08,670
clouds so these must all have something

485

00:22:05,910 --> 00:22:10,130
to do with each other and people started

486
00:22:08,670 --> 00:22:12,300
to try to make some sense of this

487
00:22:10,130 --> 00:22:15,030
scientific understanding began to

488
00:22:12,299 --> 00:22:17,549
develop and this is Cecilia Payne de

489
00:22:15,029 --> 00:22:20,670
pasión she is my daughter's scientific

490
00:22:17,549 --> 00:22:22,349
hero I guess you could say she was the

491
00:22:20,670 --> 00:22:23,640
one who discovered what stars are made

492
00:22:22,349 --> 00:22:26,009
of that they're mostly hydrogen and

493
00:22:23,640 --> 00:22:27,180
helium nobody believed her for a few

494
00:22:26,009 --> 00:22:29,160
years because this was such a radical

495
00:22:27,180 --> 00:22:32,070
idea but eventually people came to

496
00:22:29,160 --> 00:22:33,600
realize that she was right after some of

497
00:22:32,069 --> 00:22:35,789
her most important discovery she began

498
00:22:33,599 --> 00:22:39,149
to write about science and astronomy for

499
00:22:35,789 --> 00:22:40,920

public audiences here in 1952 she said

500

00:22:39,150 --> 00:22:43,710

perhaps the nebula is in some way

501

00:22:40,920 --> 00:22:45,690

responsible for their very existence so

502

00:22:43,710 --> 00:22:48,509

people were beginning to figure out that

503

00:22:45,690 --> 00:22:50,250

maybe stars formed from nebulae and this

504

00:22:48,509 --> 00:22:52,379

is one of the earliest photographs of

505

00:22:50,250 --> 00:22:54,390

the Orion Nebula so you can see there

506

00:22:52,380 --> 00:22:58,440

are several stars that are potentially

507

00:22:54,390 --> 00:23:00,900

embedded in that nebula it all came

508

00:22:58,440 --> 00:23:03,210

together when two astronomers were able

509

00:23:00,900 --> 00:23:06,030

to make sense of it all so on the left

510

00:23:03,210 --> 00:23:07,890

here is Victor and Barsboomian he was an

511

00:23:06,029 --> 00:23:09,359

armenian astronomer which meant that at

512

00:23:07,890 --> 00:23:09,810

the time he was working in the soviet

513

00:23:09,359 --> 00:23:12,329

union

514
00:23:09,809 --> 00:23:13,889
so people outside of the soviet union

515
00:23:12,329 --> 00:23:15,710
had a pretty limited understanding of

516
00:23:13,890 --> 00:23:18,690
the science that was going on there and

517
00:23:15,710 --> 00:23:21,299
then independently george herbert who

518
00:23:18,690 --> 00:23:25,259
was on the faculty at the university of

519
00:23:21,299 --> 00:23:29,069
hawaii both argued that t-tauri stars

520
00:23:25,259 --> 00:23:31,200
must be young they are clustered here's

521
00:23:29,069 --> 00:23:35,700
a cluster of many many t-tauri stars

522
00:23:31,200 --> 00:23:37,049
it's a Hubble image of NGC 3603 and not

523
00:23:35,700 --> 00:23:39,440
only are they clustered but they're

524
00:23:37,049 --> 00:23:41,879
embedded in these clouds of gas and dust

525
00:23:39,440 --> 00:23:43,740
so these are signs that these are young

526
00:23:41,880 --> 00:23:47,630
stars that they have formed from the

527
00:23:43,740 --> 00:23:50,339
nebula itself and this was

528
00:23:47,630 --> 00:23:52,890
philosophically an important advance in

529
00:23:50,339 --> 00:23:55,470
the thinking of astronomers for

530
00:23:52,890 --> 00:23:57,509
millennia people had imagined that the

531
00:23:55,470 --> 00:23:59,970
universe had all come together and was

532
00:23:57,509 --> 00:24:02,430
formed sometime in the distant past and

533
00:23:59,970 --> 00:24:04,559
humanity showed up and it was our job to

534
00:24:02,430 --> 00:24:07,830
figure out what was already there but

535
00:24:04,559 --> 00:24:10,200
this was one of the first signs that the

536
00:24:07,829 --> 00:24:10,609
cosmos was still in the act of forming

537
00:24:10,200 --> 00:24:13,490
its

538
00:24:10,609 --> 00:24:16,250
that new objects and new potential

539
00:24:13,490 --> 00:24:18,370
places were continuing to form out of

540
00:24:16,250 --> 00:24:23,329
the original materials of the universe

541
00:24:18,369 --> 00:24:25,308
so we are in an evolving universe today

542

00:24:23,329 --> 00:24:28,009
we know of thousands of young stars in

543
00:24:25,308 --> 00:24:30,319
various star forming regions here's the

544
00:24:28,009 --> 00:24:33,048
Orion Nebula and then these are some

545
00:24:30,319 --> 00:24:34,939
other star forming regions in our galaxy

546
00:24:33,048 --> 00:24:43,339
where you can see these young stars

547
00:24:34,940 --> 00:24:45,470
forming from gas and dust clouds now

548
00:24:43,339 --> 00:24:49,428
this is our conceptual picture of how

549
00:24:45,470 --> 00:24:51,380
these stars form you have these huge

550
00:24:49,429 --> 00:24:54,548
clouds of gas and dust that can give

551
00:24:51,380 --> 00:24:58,130
birth to thousands of solar systems and

552
00:24:54,548 --> 00:24:59,960
in small regions of those clouds you

553
00:24:58,130 --> 00:25:02,540
might have just enough material that the

554
00:24:59,960 --> 00:25:04,539
gravity of that material is powerful

555
00:25:02,539 --> 00:25:07,940
enough to cause it to start collapsing

556
00:25:04,539 --> 00:25:10,579

so early on you have a dusty envelope

557

00:25:07,940 --> 00:25:13,390

that's collapsing and becoming more and

558

00:25:10,579 --> 00:25:17,480

more dense and hotter at its center

559

00:25:13,390 --> 00:25:20,320

after about 150,000 years most of that

560

00:25:17,480 --> 00:25:22,730

envelope has formed into a central star

561

00:25:20,319 --> 00:25:25,759

but the material doesn't just fall

562

00:25:22,730 --> 00:25:27,529

directly onto the star these cores are

563

00:25:25,759 --> 00:25:29,569

spinning very slowly and anything that

564

00:25:27,529 --> 00:25:32,690

spins as it falls in word instead of

565

00:25:29,569 --> 00:25:36,259

forming just a central sphere it's gonna

566

00:25:32,690 --> 00:25:40,039

first form a disk so this disk forms and

567

00:25:36,259 --> 00:25:41,569

it progresses to feed onto the star so

568

00:25:40,039 --> 00:25:44,269

for a few hundred thousand years you

569

00:25:41,569 --> 00:25:46,250

have a star with a disk kind of a

570

00:25:44,269 --> 00:25:48,139

remnant remnant envelope still falling

571
00:25:46,250 --> 00:25:49,789
onto the disk and then some fraction of

572
00:25:48,140 --> 00:25:53,179
that material gets ejected from the

573
00:25:49,789 --> 00:25:55,700
poles of the stars carving out a cavity

574
00:25:53,179 --> 00:25:57,860
in the envelope and sometimes you can

575
00:25:55,700 --> 00:26:01,160
see some pretty dramatic outflows gas

576
00:25:57,859 --> 00:26:03,289
being launched from the star after about

577
00:26:01,160 --> 00:26:04,820
five hundred thousand years the envelope

578
00:26:03,289 --> 00:26:07,069
is gone and you're left with a disk

579
00:26:04,819 --> 00:26:09,349
orbiting the star and that disk may be

580
00:26:07,069 --> 00:26:11,629
forming planets that's a really hot

581
00:26:09,349 --> 00:26:13,250
topic of research right now how early in

582
00:26:11,630 --> 00:26:15,620
the formation of a star do you see

583
00:26:13,250 --> 00:26:17,298
planets and the signs are starting to

584
00:26:15,619 --> 00:26:19,879
point to planets forming almost as soon

585
00:26:17,298 --> 00:26:22,099
as the star does there's a lot of debate

586
00:26:19,880 --> 00:26:23,389
if you see gaps in a disc does that

587
00:26:22,099 --> 00:26:25,428
necessarily mean there's

588
00:26:23,388 --> 00:26:28,668
planet there or could some other process

589
00:26:25,429 --> 00:26:30,019
be giving the signposts of planets after

590
00:26:28,669 --> 00:26:32,059
about two million years

591
00:26:30,019 --> 00:26:34,519
plus or minus a million years it varies

592
00:26:32,058 --> 00:26:36,819
a lot from system to system that disk is

593
00:26:34,519 --> 00:26:39,348
gone and you're left with planets

594
00:26:36,819 --> 00:26:41,868
orbiting the star and this is a very

595
00:26:39,348 --> 00:26:47,358
stable situation in many cases it lasts

596
00:26:41,868 --> 00:26:49,819
for billions of years now where are

597
00:26:47,358 --> 00:26:51,558
stars forming in our galaxy this is an

598
00:26:49,819 --> 00:26:53,088
artist's rendition of the Milky Way by

599

00:26:51,558 --> 00:26:56,808
Robert heard at the Spitzer Science

600
00:26:53,088 --> 00:26:58,759
Center and you can see the sort of dense

601
00:26:56,808 --> 00:27:01,848
central bulge of our galaxy and the

602
00:26:58,759 --> 00:27:04,278
spiral arms the stars are forming in the

603
00:27:01,848 --> 00:27:06,348
coldest parts of the galaxy you can see

604
00:27:04,278 --> 00:27:08,989
these little brown clouds here these are

605
00:27:06,348 --> 00:27:10,759
cold molecular clouds they're so cold

606
00:27:08,989 --> 00:27:12,919
that the gas forms in the moist

607
00:27:10,759 --> 00:27:16,519
remains in a molecular State instead of

608
00:27:12,919 --> 00:27:18,229
an atomic form so they're cold and dense

609
00:27:16,519 --> 00:27:19,608
and they start collapsing like I was

610
00:27:18,229 --> 00:27:24,229
showing you in the previous slide to

611
00:27:19,608 --> 00:27:26,208
form these new stars to really study

612
00:27:24,229 --> 00:27:28,700
where the stars are though we have to

613
00:27:26,209 --> 00:27:31,429

use more than just the light that meets

614

00:27:28,700 --> 00:27:34,098

our eyes so a star formation is really a

615

00:27:31,429 --> 00:27:36,200

challenge for multi-wavelength astronomy

616

00:27:34,098 --> 00:27:39,078

where we're using not just visible light

617

00:27:36,200 --> 00:27:41,659

but ultraviolet light infrared light

618

00:27:39,078 --> 00:27:43,898

radio waves all these different

619

00:27:41,659 --> 00:27:46,609

wavelengths of light that can reach us

620

00:27:43,898 --> 00:27:49,699

the best way to map the large-scale

621

00:27:46,608 --> 00:27:52,009

distribution of gas to form stars is by

622

00:27:49,700 --> 00:27:54,259

doing radio astronomy this is the five

623

00:27:52,009 --> 00:27:56,389

College Radio Astronomy Observatory it

624

00:27:54,259 --> 00:27:58,759

no longer exists but it was on a

625

00:27:56,388 --> 00:28:00,769

peninsula in western Massachusetts that

626

00:27:58,759 --> 00:28:01,669

extends into the Quabbin Reservoir it

627

00:28:00,769 --> 00:28:03,950

reached the end of its scientific

628
00:28:01,669 --> 00:28:05,719
lifetime and this is kind of a natural

629
00:28:03,950 --> 00:28:07,609
preserve so the agreement was they had

630
00:28:05,719 --> 00:28:09,558
to disassemble the radio telescope after

631
00:28:07,608 --> 00:28:12,468
they were done doing science with it but

632
00:28:09,558 --> 00:28:14,838
this is an image it made of carbon

633
00:28:12,469 --> 00:28:17,570
monoxide gas in the torah' star-forming

634
00:28:14,838 --> 00:28:20,269
region carbon monoxide is far from the

635
00:28:17,569 --> 00:28:22,548
most common component of these molecular

636
00:28:20,269 --> 00:28:24,798
clouds it's mostly hydrogen molecular

637
00:28:22,548 --> 00:28:26,778
hydrogen but carbon monoxide is really

638
00:28:24,798 --> 00:28:28,489
easy to detect so we're going to map a

639
00:28:26,778 --> 00:28:31,338
star-forming region that's that's a good

640
00:28:28,489 --> 00:28:33,440
way to go and you can see in this image

641
00:28:31,338 --> 00:28:37,339
this filamentary structure these long

642
00:28:33,440 --> 00:28:40,039
sort of trails of gas that's

643
00:28:37,339 --> 00:28:42,470
to a radio telescope and these trails

644
00:28:40,039 --> 00:28:44,480
are where you call or they're called

645
00:28:42,470 --> 00:28:46,640
filaments and these are the dense

646
00:28:44,480 --> 00:28:51,650
regions that are likely to form stars in

647
00:28:46,640 --> 00:28:53,180
fact are forming stars and torez I'm

648
00:28:51,650 --> 00:28:55,810
going to be telling you mostly about

649
00:28:53,180 --> 00:28:58,160
what you can do with infrared astronomy

650
00:28:55,809 --> 00:29:01,069
there's an inner multi-wavelength study

651
00:28:58,160 --> 00:29:02,990
of star formation this is Barnard dark

652
00:29:01,069 --> 00:29:05,089
cloud 68 and you can tell why it's

653
00:29:02,990 --> 00:29:07,910
called a dark cloud it's it's a cloud

654
00:29:05,089 --> 00:29:10,490
and it's dark you can see how this is a

655
00:29:07,910 --> 00:29:14,060
very dense star field but around the

656

00:29:10,490 --> 00:29:16,910
cloud you see some reddened stars around

657
00:29:14,059 --> 00:29:19,759
its edges and the center almost nothing

658
00:29:16,910 --> 00:29:22,910
pops out this is a visible light image

659
00:29:19,759 --> 00:29:26,329
if we look in the infrared it's a very

660
00:29:22,910 --> 00:29:29,630
different situation this is an infrared

661
00:29:26,329 --> 00:29:32,210
image and suddenly we see hundreds of

662
00:29:29,630 --> 00:29:34,490
stars poking through the cloud the

663
00:29:32,210 --> 00:29:38,210
advantage to infrared light is that it

664
00:29:34,490 --> 00:29:40,190
lets us see through the dust the

665
00:29:38,210 --> 00:29:42,500
infrared light escapes more easily

666
00:29:40,190 --> 00:29:44,980
through this dust and it's also

667
00:29:42,500 --> 00:29:47,299
sensitive to objects that aren't hot

668
00:29:44,980 --> 00:29:48,769
astronomers tend to play fast and loose

669
00:29:47,299 --> 00:29:50,269
with their temperature words we'll talk

670
00:29:48,769 --> 00:29:53,420

about cool things that are actually

671

00:29:50,269 --> 00:29:55,190

hundreds of degrees but this infrared

672

00:29:53,420 --> 00:29:58,220

light is really sensitive to things that

673

00:29:55,190 --> 00:29:59,690

aren't as hot as stars yet they

674

00:29:58,220 --> 00:30:01,700

eventually will be but they're there

675

00:29:59,690 --> 00:30:03,200

from a few hundred to a few thousand

676

00:30:01,700 --> 00:30:08,509

degrees that's where the infrared is

677

00:30:03,200 --> 00:30:11,090

really most useful here's a Ryan in

678

00:30:08,509 --> 00:30:14,000

visible light the famous constellation

679

00:30:11,089 --> 00:30:16,099

the three stars in the belt Betelgeuse

680

00:30:14,000 --> 00:30:19,039

is a red supergiant and the shoulder of

681

00:30:16,099 --> 00:30:21,379

Orion Rigel is a blue supergiant down

682

00:30:19,039 --> 00:30:23,480

here it is me and you have a sword

683

00:30:21,380 --> 00:30:27,500

hanging from the belt the Orion Nebula

684

00:30:23,480 --> 00:30:31,130

is this faint fuzzy patch here and so

685
00:30:27,500 --> 00:30:34,190
visible light detects stars that here's

686
00:30:31,130 --> 00:30:37,400
Orion in the infrared the picture I

687
00:30:34,190 --> 00:30:39,200
showed you at the beginning you don't

688
00:30:37,400 --> 00:30:40,759
really see many stars in this one

689
00:30:39,200 --> 00:30:43,009
Betelgeuse because it's such a bright

690
00:30:40,759 --> 00:30:47,150
red star still pops out in the infrared

691
00:30:43,009 --> 00:30:50,970
image but Rigel and the belt stars are

692
00:30:47,150 --> 00:30:52,769
totally absent and you see these bright

693
00:30:50,970 --> 00:30:55,079
regions where the stars are forming the

694
00:30:52,769 --> 00:30:57,150
Orion Nebula is now the brightest thing

695
00:30:55,079 --> 00:30:59,639
in the image and you can see that in

696
00:30:57,150 --> 00:31:01,710
Orion you have these bright star-forming

697
00:30:59,640 --> 00:31:02,880
regions extending kind of all up and

698
00:31:01,710 --> 00:31:06,150
down the southern half of the

699
00:31:02,880 --> 00:31:07,770
constellation so the infrared is really

700
00:31:06,150 --> 00:31:14,280
the key to telling us where the stars

701
00:31:07,769 --> 00:31:15,298
are forming and why is a Ryan so

702
00:31:14,279 --> 00:31:18,029
important from a star-forming

703
00:31:15,298 --> 00:31:20,879
perspective we have thousands of young

704
00:31:18,029 --> 00:31:22,558
stars in the Orion Nebula alone but it's

705
00:31:20,880 --> 00:31:26,730
really just the centerpiece of this huge

706
00:31:22,558 --> 00:31:29,819
star forming complex if you were to draw

707
00:31:26,730 --> 00:31:32,038
a circle around our solar system that

708
00:31:29,819 --> 00:31:34,470
was about fifteen hundred light years in

709
00:31:32,038 --> 00:31:37,069
radius encompassing many of the nearby

710
00:31:34,470 --> 00:31:39,538
stars that we are all familiar to us

711
00:31:37,069 --> 00:31:43,649
Orion contains more than half of the

712
00:31:39,538 --> 00:31:45,929
young forming stars in that region it's

713

00:31:43,650 --> 00:31:48,059
the nearest place where the most massive

714
00:31:45,929 --> 00:31:50,159
stars are forming so you really see the

715
00:31:48,058 --> 00:31:53,308
full spectrum of stellar masses forming

716
00:31:50,159 --> 00:31:55,260
an Orion and we can also probe a lot of

717
00:31:53,308 --> 00:31:58,470
different star forming environments in

718
00:31:55,259 --> 00:32:01,140
Orion on the left is one of these

719
00:31:58,470 --> 00:32:02,909
Barnard dark clouds this is not an Orion

720
00:32:01,140 --> 00:32:05,669
but it's just an example of isolated

721
00:32:02,909 --> 00:32:09,539
star forming you have this really dense

722
00:32:05,669 --> 00:32:11,850
field of advanced more more aged older

723
00:32:09,538 --> 00:32:14,640
stars and then this dark cloud that

724
00:32:11,849 --> 00:32:19,980
contains maybe one or a few forming

725
00:32:14,640 --> 00:32:23,549
stars here is part of Orion OMC 2 3 is

726
00:32:19,980 --> 00:32:25,470
the Orion molecular cloud 2/3 it's just

727
00:32:23,548 --> 00:32:27,269

a part of the Orion molecular clouds and

728

00:32:25,470 --> 00:32:30,329

this is an example of clustered star

729

00:32:27,269 --> 00:32:33,569

formation you can see these dark dusty

730

00:32:30,329 --> 00:32:35,730

filaments with young stars all along

731

00:32:33,569 --> 00:32:37,918

them so in Orion we can really get a

732

00:32:35,730 --> 00:32:42,480

sense for how stars interact with one

733

00:32:37,919 --> 00:32:44,850

another as they form there are even

734

00:32:42,480 --> 00:32:47,519

different environments within Orion this

735

00:32:44,849 --> 00:32:49,408

is a map of coal dust in Orion going

736

00:32:47,519 --> 00:32:52,619

from the Orion Nebula far to the south

737

00:32:49,409 --> 00:32:54,809

and then these are in sets where we zoom

738

00:32:52,619 --> 00:32:57,319

in on a couple of these regions and look

739

00:32:54,808 --> 00:33:00,450

at how stars are distributed in them

740

00:32:57,319 --> 00:33:02,460

this is a very densely populated star

741

00:33:00,450 --> 00:33:04,419

forming region within Orion that you

742
00:33:02,460 --> 00:33:06,159
might think of as a city all

743
00:33:04,419 --> 00:33:08,379
these circles mark the locations of

744
00:33:06,159 --> 00:33:10,299
young stars what we call protostars

745
00:33:08,378 --> 00:33:12,158
and the size of the circle tells you how

746
00:33:10,298 --> 00:33:15,278
luminous it is how bright it is how much

747
00:33:12,159 --> 00:33:18,159
light it's giving off so in this part of

748
00:33:15,278 --> 00:33:21,009
Orion you have very dense clusters of

749
00:33:18,159 --> 00:33:23,350
stars that are quite luminous and all

750
00:33:21,009 --> 00:33:24,700
interacting with one another farther to

751
00:33:23,349 --> 00:33:26,980
the south we have what you might think

752
00:33:24,700 --> 00:33:29,649
of as the suburbs where there are fewer

753
00:33:26,980 --> 00:33:31,960
stars there's fewer back there's less

754
00:33:29,648 --> 00:33:34,988
background emission from the from local

755
00:33:31,960 --> 00:33:36,970
gas and dust the stars are less luminous

756
00:33:34,989 --> 00:33:39,369
and there's a little bit less going on

757
00:33:36,970 --> 00:33:41,710
there so it really is sort of an

758
00:33:39,368 --> 00:33:48,189
experimental lab to see how stars form

759
00:33:41,710 --> 00:33:49,329
in different environments so I'm going

760
00:33:48,190 --> 00:33:51,519
to tell you about how we've used

761
00:33:49,329 --> 00:33:54,069
different space telescopes to understand

762
00:33:51,519 --> 00:33:57,128
star formation in Orion and it begins

763
00:33:54,069 --> 00:33:59,439
with the spitzer space telescope this is

764
00:33:57,128 --> 00:34:02,079
a point eight five meter telescope not

765
00:33:59,440 --> 00:34:05,019
huge compared to a few of the ones we'll

766
00:34:02,079 --> 00:34:08,168
be discussing it launched in 2003 and

767
00:34:05,019 --> 00:34:09,760
these infrared space telescopes they

768
00:34:08,168 --> 00:34:12,009
have to be cooled to be most effective

769
00:34:09,760 --> 00:34:13,809
they're about the same temperature as

770

00:34:12,010 --> 00:34:15,730
the objects they're trying to detect so

771
00:34:13,809 --> 00:34:18,548
if you don't cool them they're going to

772
00:34:15,730 --> 00:34:20,260
detect themselves to put it simply so

773
00:34:18,548 --> 00:34:21,969
you have to cool them down and you do

774
00:34:20,260 --> 00:34:23,889
that by putting some kind of substance

775
00:34:21,969 --> 00:34:27,009
aboard some kind of cryogen to keep it

776
00:34:23,889 --> 00:34:28,990
cold cryogen loses its effectiveness

777
00:34:27,010 --> 00:34:32,069
after a while so spitzer launched in

778
00:34:28,989 --> 00:34:34,719
2003 but it ran out of cryogen in 2009

779
00:34:32,068 --> 00:34:36,250
it's still effective at some level it

780
00:34:34,719 --> 00:34:40,178
has limited capabilities and it's

781
00:34:36,250 --> 00:34:42,068
continuing to send back data and it's in

782
00:34:40,179 --> 00:34:43,869
an earth trailing orbit this is

783
00:34:42,068 --> 00:34:47,739
approximately where it was when I put

784
00:34:43,869 --> 00:34:49,269

the slide together it's about the same

785

00:34:47,739 --> 00:34:51,039

distance from the Sun as Earth but just

786

00:34:49,269 --> 00:34:53,230

a little farther out so it orbits a

787

00:34:51,039 --> 00:34:55,239

little bit more slowly and it loses

788

00:34:53,230 --> 00:34:56,588

ground on earth as each year goes by so

789

00:34:55,239 --> 00:34:58,179

that's another thing that's limiting its

790

00:34:56,588 --> 00:34:59,529

capabilities is it's farther from Earth

791

00:34:58,179 --> 00:35:01,539

it becomes more difficult to communicate

792

00:34:59,530 --> 00:35:04,420

with it but it's been a very productive

793

00:35:01,539 --> 00:35:09,009

Space Telescope so far and we used it to

794

00:35:04,420 --> 00:35:12,130

survey Oh Ryan this is a Spitzer map of

795

00:35:09,010 --> 00:35:14,319

part of the Orion Molecular clouds you

796

00:35:12,130 --> 00:35:17,740

can see all of this bright gaseous

797

00:35:14,318 --> 00:35:20,469

material dark dusty lanes

798

00:35:17,739 --> 00:35:22,809

and young stars that are forming this

799
00:35:20,469 --> 00:35:24,879
schematic gives you a sense for why and

800
00:35:22,809 --> 00:35:29,679
infrared telescope is good at detecting

801
00:35:24,880 --> 00:35:32,320
young stars a plain old star it's light

802
00:35:29,679 --> 00:35:34,000
output peaks at wavelengths that we can

803
00:35:32,320 --> 00:35:36,789
detect with our eye is it visible or

804
00:35:34,000 --> 00:35:38,800
optical wavelengths and then it's light

805
00:35:36,789 --> 00:35:40,360
distribution falls off pretty rapidly as

806
00:35:38,800 --> 00:35:43,750
you go into the infrared the longer

807
00:35:40,360 --> 00:35:46,090
wavelengths but if you have a disc of

808
00:35:43,750 --> 00:35:49,269
relatively cool dust around the star

809
00:35:46,090 --> 00:35:52,329
that's bright in the infrared so instead

810
00:35:49,269 --> 00:35:54,130
of your basic star the spectrum of the

811
00:35:52,329 --> 00:35:55,900
star it's energy distribution falls off

812
00:35:54,130 --> 00:35:58,869
a lot more slowly through the infrared

813
00:35:55,900 --> 00:36:01,900
and thus infrared Space Telescope's are

814
00:35:58,869 --> 00:36:04,059
really good at picking these out so we

815
00:36:01,900 --> 00:36:05,200
can see the real-life equivalents of

816
00:36:04,059 --> 00:36:07,509
these cartoons I showed you earlier

817
00:36:05,199 --> 00:36:09,368
where you have the very young protostars

818
00:36:07,510 --> 00:36:12,010
where there's an envelope falling onto a

819
00:36:09,369 --> 00:36:14,289
disc and then the slightly more advanced

820
00:36:12,010 --> 00:36:19,840
young stars where much most of the

821
00:36:14,289 --> 00:36:22,779
envelope has been cleared away once we

822
00:36:19,840 --> 00:36:24,840
identified all these young stars with

823
00:36:22,780 --> 00:36:28,510
Spitzer we continued with Herschel

824
00:36:24,840 --> 00:36:30,490
Herschel was primarily funded by the

825
00:36:28,510 --> 00:36:34,180
European Space Agency but it also had

826
00:36:30,489 --> 00:36:36,339
contributions from NASA it's a big one

827

00:36:34,179 --> 00:36:38,139
three and a half meters in diameter its

828
00:36:36,340 --> 00:36:40,420
primary mirror and it operated in the

829
00:36:38,139 --> 00:36:42,219
far infrared so Spitzer was sort of mid

830
00:36:40,420 --> 00:36:46,180
infrared Herschel is even longer

831
00:36:42,219 --> 00:36:49,329
wavelengths it launched in 2009 ran out

832
00:36:46,179 --> 00:36:51,819
of cryogen in 2013 and all of Herschel's

833
00:36:49,329 --> 00:36:54,159
instruments required higher cryogen to

834
00:36:51,820 --> 00:36:56,890
operate so it's no longer you know

835
00:36:54,159 --> 00:37:00,250
producing images for us it is at a

836
00:36:56,889 --> 00:37:04,000
special point in space called L2 the

837
00:37:00,250 --> 00:37:05,739
second lagrangian point at L2 the

838
00:37:04,000 --> 00:37:07,900
Earth's gravity and the sun's gravity

839
00:37:05,739 --> 00:37:10,029
balance out so you get a stable orbit

840
00:37:07,900 --> 00:37:13,869
even though you're kind of far away from

841
00:37:10,030 --> 00:37:16,330

Earth in fact the L2 point is four times

842

00:37:13,869 --> 00:37:19,420

farther away than the moon it's really

843

00:37:16,329 --> 00:37:21,549

out there so unlike a telescope at low

844

00:37:19,420 --> 00:37:23,250

Earth orbit you can't go out to L2 and

845

00:37:21,550 --> 00:37:26,230

fix things at least not yet

846

00:37:23,250 --> 00:37:28,630

so after Herschel's life cycle was over

847

00:37:26,230 --> 00:37:30,250

that was the end of its science but L2

848

00:37:28,630 --> 00:37:31,630

is a great place to put a foreign for a

849

00:37:30,250 --> 00:37:34,929

telescope it's a stable

850

00:37:31,630 --> 00:37:36,280

orbit and things are also cold there so

851

00:37:34,929 --> 00:37:38,619

you really get a great view of the

852

00:37:36,280 --> 00:37:40,090

infrared sky from L2 and it's not the

853

00:37:38,619 --> 00:37:41,859

only telescope that's currently there

854

00:37:40,090 --> 00:37:46,630

are not additional ones you're going to

855

00:37:41,860 --> 00:37:48,490

join it how mention that later on the

856
00:37:46,630 --> 00:37:50,860
advantage to Herschel is that we could

857
00:37:48,489 --> 00:37:53,439
follow up on these protostars that

858
00:37:50,860 --> 00:37:55,809
Spitzer had identified we conducted hops

859
00:37:53,440 --> 00:37:57,730
that's the Herschel Orion protostar

860
00:37:55,809 --> 00:37:59,500
Survey these are some members of the

861
00:37:57,730 --> 00:38:02,619
hops team one of our meetings in Granada

862
00:37:59,500 --> 00:38:05,139
Spain a few years ago with Spitzer we

863
00:38:02,619 --> 00:38:06,639
found more than 500 of these protostars

864
00:38:05,139 --> 00:38:08,170
these are young stars with the dusty

865
00:38:06,639 --> 00:38:11,230
envelopes that are just beginning to

866
00:38:08,170 --> 00:38:13,630
form and then we follow it up on more

867
00:38:11,230 --> 00:38:16,269
than 300 of them with Herschel so this

868
00:38:13,630 --> 00:38:20,140
map the dark shading tells you where the

869
00:38:16,269 --> 00:38:22,480
where that dust is in Orion all up and

870
00:38:20,139 --> 00:38:24,849
down the Orion molecular clouds the

871
00:38:22,480 --> 00:38:27,309
Orion Nebula is here and then these

872
00:38:24,849 --> 00:38:29,650
circles mark the locations of protostars

873
00:38:27,309 --> 00:38:31,150
that we followed up with Herschel all

874
00:38:29,650 --> 00:38:32,950
these little thumbnails here are

875
00:38:31,150 --> 00:38:35,309
actually Spitzer images they give you a

876
00:38:32,949 --> 00:38:38,079
sense for the environment whether it's

877
00:38:35,309 --> 00:38:40,719
crowded with bright backgrounds or maybe

878
00:38:38,079 --> 00:38:43,360
somewhat less crowded with with a dim

879
00:38:40,719 --> 00:38:47,079
background going from the city out to

880
00:38:43,360 --> 00:38:50,200
the suburbs so we did all this follow up

881
00:38:47,079 --> 00:38:52,480
with Herschel and this really gives you

882
00:38:50,199 --> 00:38:55,000
a sense comparing Spitzer data on the

883
00:38:52,480 --> 00:38:56,409
left to the combination of Spitzer and

884

00:38:55,000 --> 00:38:58,349
Herschel on the right this shows you

885
00:38:56,409 --> 00:39:01,299
what you can do with the far infrared

886
00:38:58,349 --> 00:39:03,880
Spitzer the dustiest regions in the

887
00:39:01,300 --> 00:39:05,560
cloud are dark they're cold they're not

888
00:39:03,880 --> 00:39:07,539
really emitting very much at the mid wid

889
00:39:05,559 --> 00:39:09,789
mid infrared wavelengths that Spitzer

890
00:39:07,539 --> 00:39:11,800
detects so you have these dark dust

891
00:39:09,789 --> 00:39:13,929
lanes and then you can tell where the

892
00:39:11,800 --> 00:39:16,240
stars are but they're really deeply

893
00:39:13,929 --> 00:39:17,849
embedded young ones you can't learn very

894
00:39:16,239 --> 00:39:21,189
much about them because they're faint

895
00:39:17,849 --> 00:39:22,900
here the blue is from Spitzer but then

896
00:39:21,190 --> 00:39:25,119
the red and yellow we're bringing in the

897
00:39:22,900 --> 00:39:27,070
Herschel data so there are two things to

898
00:39:25,119 --> 00:39:29,259

notice here first of all some of these

899

00:39:27,070 --> 00:39:31,000

faint protostars in the spitzer image

900

00:39:29,260 --> 00:39:32,980

are now some of the brightest ones in

901

00:39:31,000 --> 00:39:35,199

Herschel there are two here there's one

902

00:39:32,980 --> 00:39:37,119

up here these really bright Herschel

903

00:39:35,199 --> 00:39:38,829

protostars those are the really young

904

00:39:37,119 --> 00:39:41,469

ones those are the ones we can study to

905

00:39:38,829 --> 00:39:43,299

learn exactly what's going on as gas and

906

00:39:41,469 --> 00:39:45,419

dust begins to condense from the

907

00:39:43,300 --> 00:39:48,460

molecular cloud to forms

908

00:39:45,420 --> 00:39:51,550

the other thing to notice here is that

909

00:39:48,460 --> 00:39:54,460

the dark dust lanes are now glowing at

910

00:39:51,550 --> 00:39:56,560

the longest far infrared wavelengths you

911

00:39:54,460 --> 00:39:58,750

can really see where the dust is and see

912

00:39:56,559 --> 00:40:01,000

how intense and how much dust there is

913
00:39:58,750 --> 00:40:02,409
by how brightly it's glowing so this

914
00:40:01,000 --> 00:40:04,059
really allows us to understand

915
00:40:02,409 --> 00:40:06,219
everything that's going on in a

916
00:40:04,059 --> 00:40:08,019
star-forming region when we combine the

917
00:40:06,219 --> 00:40:12,250
mid infrared and the far for headlight

918
00:40:08,019 --> 00:40:14,219
from Herschel I'm going to tell you

919
00:40:12,250 --> 00:40:17,170
about one of our first hops results

920
00:40:14,219 --> 00:40:19,869
we're going to go back in time from the

921
00:40:17,170 --> 00:40:22,000
Herschel Space Telescope to Herschel the

922
00:40:19,869 --> 00:40:23,619
astronomers William Herschel and

923
00:40:22,000 --> 00:40:27,570
Caroline Herschel they're shown in this

924
00:40:23,619 --> 00:40:30,549
painting here they were some of the best

925
00:40:27,570 --> 00:40:34,480
astronomers of their time working in the

926
00:40:30,550 --> 00:40:36,670
18th century and William Herschel was

927
00:40:34,480 --> 00:40:40,179
conducting a survey with his telescope

928
00:40:36,670 --> 00:40:43,450
of the Milky Way and he discovered dark

929
00:40:40,179 --> 00:40:45,159
patches and he said he spoke German but

930
00:40:43,449 --> 00:40:46,899
what he said was truly there is a hole

931
00:40:45,159 --> 00:40:49,719
in the sky here when he saw these dark

932
00:40:46,900 --> 00:40:51,190
patches this is one of the dark patches

933
00:40:49,719 --> 00:40:54,219
that he talked about this is what we

934
00:40:51,190 --> 00:40:56,650
today call NGC 1999

935
00:40:54,219 --> 00:40:58,779
this is our first Herschel image we

936
00:40:56,650 --> 00:41:01,269
bring in some Kitt Peak data that's in

937
00:40:58,780 --> 00:41:03,790
blue for context that's a that's optical

938
00:41:01,269 --> 00:41:06,070
possibly near infrared imaging we see

939
00:41:03,789 --> 00:41:07,989
some of our Herschel protostars here and

940
00:41:06,070 --> 00:41:12,400
then this is a Hubble close-up of this

941

00:41:07,989 --> 00:41:16,409
NGC 1999 region it's one of these holes

942
00:41:12,400 --> 00:41:16,410
in the sky that William Herschel noticed

943
00:41:16,679 --> 00:41:22,269
it turned out that Herschel's holes in

944
00:41:20,050 --> 00:41:24,010
the sky are mostly these dark dust

945
00:41:22,269 --> 00:41:28,329
clouds like we were talking about before

946
00:41:24,010 --> 00:41:30,160
this is NGC 1999 this is Barnard 68 that

947
00:41:28,329 --> 00:41:33,429
I showed you before where the dark cloud

948
00:41:30,159 --> 00:41:35,199
is it's not a hole it's a dark dusty

949
00:41:33,429 --> 00:41:40,119
cloud and when you look in the infrared

950
00:41:35,199 --> 00:41:43,599
you see lots of stars here but in this

951
00:41:40,119 --> 00:41:45,639
particular case NGC 1999 it's a little

952
00:41:43,599 --> 00:41:46,869
bit different this is the Hubble image I

953
00:41:45,639 --> 00:41:50,650
showed you but then when you look at

954
00:41:46,869 --> 00:41:53,079
Herschel images in the far infrared the

955
00:41:50,650 --> 00:41:54,730

hole in the sky is still a hole if there

956

00:41:53,079 --> 00:41:57,579

were dust here it would start to glow in

957

00:41:54,730 --> 00:41:58,849

the far infrared when we go even further

958

00:41:57,579 --> 00:42:03,319

out into the infer

959

00:41:58,849 --> 00:42:06,019

it's still dark so there's no dust there

960

00:42:03,320 --> 00:42:08,450

it would glow and here in this very deep

961

00:42:06,019 --> 00:42:12,739

near infrared image we see a star

962

00:42:08,449 --> 00:42:15,349

through this hole in the nebula that's

963

00:42:12,739 --> 00:42:18,379

not particularly red so we're actually

964

00:42:15,349 --> 00:42:21,139

seeing through empty space here this one

965

00:42:18,380 --> 00:42:22,730

really is a hole in the sky so it was

966

00:42:21,139 --> 00:42:24,349

kind of a kind of a neat discovery we

967

00:42:22,730 --> 00:42:26,840

made Herschel the astronomer said

968

00:42:24,349 --> 00:42:29,839

something in 1774 truly there was a hole

969

00:42:26,840 --> 00:42:31,640

in the sky here 236 years later the

970
00:42:29,840 --> 00:42:37,130
telescope named after him confirmed that

971
00:42:31,639 --> 00:42:39,429
he was right about this one and this was

972
00:42:37,130 --> 00:42:42,349
the beginning of our of our hops project

973
00:42:39,429 --> 00:42:44,989
another really key discovery with hops

974
00:42:42,349 --> 00:42:49,219
is that there were proto stars in Orion

975
00:42:44,989 --> 00:42:51,259
that Spitzer missed they were too faint

976
00:42:49,219 --> 00:42:53,509
in the Spitzer images for people to

977
00:42:51,260 --> 00:42:55,700
realize that they were protostars so

978
00:42:53,510 --> 00:42:57,410
this is these are some thumbnails of two

979
00:42:55,699 --> 00:43:00,439
of these protostars the top row our

980
00:42:57,409 --> 00:43:02,869
Spitzer images this is kind of the near

981
00:43:00,440 --> 00:43:04,519
to mid infrared wavelengths that are a

982
00:43:02,869 --> 00:43:06,650
little bit longer than our eyes can

983
00:43:04,519 --> 00:43:08,599
detect and here in these two circles you

984
00:43:06,650 --> 00:43:11,809
see a faint object here and a brighter

985
00:43:08,599 --> 00:43:13,489
object here if you go out to some of the

986
00:43:11,809 --> 00:43:16,519
longest wavelengths that Spitzer was

987
00:43:13,489 --> 00:43:19,519
able to effectively work at in Orion you

988
00:43:16,519 --> 00:43:22,509
see nothing in this top circle and just

989
00:43:19,519 --> 00:43:24,800
a very faint blob in this bottom circle

990
00:43:22,510 --> 00:43:26,480
we weren't sure what these were just

991
00:43:24,800 --> 00:43:29,240
based on this information alone they

992
00:43:26,480 --> 00:43:31,730
were classified as galaxies to the

993
00:43:29,239 --> 00:43:33,049
extent they were classified at all but

994
00:43:31,730 --> 00:43:35,480
when we looked at them with Herschel

995
00:43:33,050 --> 00:43:37,519
they really jumped out all of a sudden

996
00:43:35,480 --> 00:43:40,460
they're the brightest point sources in

997
00:43:37,519 --> 00:43:42,679
this field down here at the bottom we've

998

00:43:40,460 --> 00:43:44,389
gone out to submillimetre wavelengths

999
00:43:42,679 --> 00:43:46,399
this is almost in the radio at this

1000
00:43:44,389 --> 00:43:49,429
point where we're detecting very cold

1001
00:43:46,400 --> 00:43:52,369
dust and they remain bright there so

1002
00:43:49,429 --> 00:43:54,589
this is a sign that Herschel was able to

1003
00:43:52,369 --> 00:43:56,989
detect protostars that spits our mist

1004
00:43:54,590 --> 00:43:58,910
and because there's you have to look at

1005
00:43:56,989 --> 00:44:00,439
such long wavelengths to see them that

1006
00:43:58,909 --> 00:44:01,969
means they're among the coldest proto

1007
00:44:00,440 --> 00:44:05,269
stars in Orion and therefore the

1008
00:44:01,969 --> 00:44:07,429
youngest our estimates are that they may

1009
00:44:05,269 --> 00:44:09,800
have formerly 25,000 years and I say

1010
00:44:07,429 --> 00:44:11,419
only that seems like a long time if you

1011
00:44:09,800 --> 00:44:12,048
remember back I told you it takes on

1012
00:44:11,420 --> 00:44:13,849

average to

1013

00:44:12,048 --> 00:44:15,380

million years for a starter for twenty

1014

00:44:13,849 --> 00:44:16,068

five thousand years is a tiny fraction

1015

00:44:15,380 --> 00:44:18,170

of that

1016

00:44:16,068 --> 00:44:20,329

so Herschel really allowed us to

1017

00:44:18,170 --> 00:44:22,039

complete the census of protostars in

1018

00:44:20,329 --> 00:44:27,019

Orion and really see what was going on

1019

00:44:22,039 --> 00:44:30,140

in the very youngest systems this is a

1020

00:44:27,018 --> 00:44:32,659

larger scale image of spit of these new

1021

00:44:30,139 --> 00:44:34,400

protostars Spitzer is on the right and

1022

00:44:32,659 --> 00:44:36,170

again in these four circles these are

1023

00:44:34,400 --> 00:44:37,548

the two I showed you before there are a

1024

00:44:36,170 --> 00:44:39,920

couple more down here to the south

1025

00:44:37,548 --> 00:44:41,420

there's almost nothing in Spitzer but

1026

00:44:39,920 --> 00:44:44,209

when you bring in the Herschel far

1027
00:44:41,420 --> 00:44:47,389
infrared data and the apex submillimetre

1028
00:44:44,208 --> 00:44:49,399
data they're very bright so we can

1029
00:44:47,389 --> 00:44:50,958
really understand all of the secrets

1030
00:44:49,400 --> 00:44:56,809
that are ayan has to offer but you only

1031
00:44:50,958 --> 00:44:59,478
do the longest wavelengths now that the

1032
00:44:56,809 --> 00:45:01,459
Herschel project has been we've had all

1033
00:44:59,478 --> 00:45:03,828
of our Herschel data for a few years and

1034
00:45:01,458 --> 00:45:05,478
most of the science has come out there

1035
00:45:03,829 --> 00:45:06,559
are still a few papers lingering along

1036
00:45:05,478 --> 00:45:09,078
that we're trying to get into the

1037
00:45:06,559 --> 00:45:10,880
literature but we've turned to detailed

1038
00:45:09,079 --> 00:45:14,298
follow-up of some of these protostars

1039
00:45:10,880 --> 00:45:16,009
with Hubble for instance with Hubble

1040
00:45:14,298 --> 00:45:17,989
once we know the proto stars are there

1041
00:45:16,009 --> 00:45:20,028
we can zoom in on them and get very

1042
00:45:17,989 --> 00:45:23,139
high-resolution images compared to what

1043
00:45:20,028 --> 00:45:25,338
we can get with Spitzer or with Herschel

1044
00:45:23,139 --> 00:45:28,518
now Hubble has a lot of different

1045
00:45:25,338 --> 00:45:30,259
instruments I work on the cosmic origins

1046
00:45:28,518 --> 00:45:32,419
spectrograph which is optimized for the

1047
00:45:30,259 --> 00:45:35,208
ultraviolet but for science we tend to

1048
00:45:32,420 --> 00:45:37,278
use for prints the science of star

1049
00:45:35,208 --> 00:45:38,808
formation at least the sort of work that

1050
00:45:37,278 --> 00:45:41,539
we do we tend to use the near infrared

1051
00:45:38,809 --> 00:45:42,640
cameras on Hubble there's Nick Moss

1052
00:45:41,539 --> 00:45:45,890
which was an earlier generation

1053
00:45:42,639 --> 00:45:48,858
instrument and then with c3 is why Field

1054
00:45:45,889 --> 00:45:50,478
Camera 3 which as you can see gives us a

1055

00:45:48,858 --> 00:45:51,978
wide field of view and we can see

1056
00:45:50,478 --> 00:45:56,328
high-resolution images of many

1057
00:45:51,978 --> 00:45:58,308
protostars at once so here we can see

1058
00:45:56,329 --> 00:46:00,528
some edge on protostars where we're

1059
00:45:58,309 --> 00:46:02,298
looking through a dusty disc and we can

1060
00:46:00,528 --> 00:46:05,119
see some of the outflow cavities

1061
00:46:02,298 --> 00:46:07,219
here we see some point like protostars

1062
00:46:05,119 --> 00:46:08,900
or maybe we're looking more pull on and

1063
00:46:07,219 --> 00:46:11,479
just seeing the light from the central

1064
00:46:08,900 --> 00:46:13,579
regions of the system and we can see all

1065
00:46:11,478 --> 00:46:15,288
sorts of details about exactly how gas

1066
00:46:13,579 --> 00:46:19,500
and dust are distributed around these

1067
00:46:15,289 --> 00:46:21,060
stars and

1068
00:46:19,500 --> 00:46:22,710
is just a demonstration of what you can

1069
00:46:21,059 --> 00:46:25,199

really do with the high resolution of

1070

00:46:22,710 --> 00:46:26,610

Hubble in the 1980s if you looked in

1071

00:46:25,199 --> 00:46:29,489

review papers you would see these

1072

00:46:26,610 --> 00:46:31,890

cartoons showing how stars and disks and

1073

00:46:29,489 --> 00:46:35,399

maybe outflow cavities worked well when

1074

00:46:31,889 --> 00:46:37,980

we did our Hubble imaging we found you

1075

00:46:35,400 --> 00:46:39,960

know Hubble or we found cart it was

1076

00:46:37,980 --> 00:46:42,780

almost like those cartoons have become

1077

00:46:39,960 --> 00:46:45,539

reality here in this image of a star

1078

00:46:42,780 --> 00:46:47,690

called hops 136 we can see everything

1079

00:46:45,539 --> 00:46:53,000

that people predicted in these cartoons

1080

00:46:47,690 --> 00:46:55,800

20-30 years ago we see these dark lanes

1081

00:46:53,000 --> 00:46:58,679

which is the sort of circumstellar disk

1082

00:46:55,800 --> 00:47:00,720

seen in projection we see these bright

1083

00:46:58,679 --> 00:47:05,099

nebulae from the upper layers of the

1084
00:47:00,719 --> 00:47:07,230
disk the disk casts a shadow here we can

1085
00:47:05,099 --> 00:47:09,119
see light being scattered off the inner

1086
00:47:07,230 --> 00:47:11,400
edges of the envelope and then the

1087
00:47:09,119 --> 00:47:14,099
outflow cavities so it's all there

1088
00:47:11,400 --> 00:47:17,970
just as the theorists of the 1980s we're

1089
00:47:14,099 --> 00:47:19,230
predicting one of the things we can do

1090
00:47:17,969 --> 00:47:22,859
with these Hubble images is study

1091
00:47:19,230 --> 00:47:27,119
multiple systems so protostars rarely

1092
00:47:22,860 --> 00:47:29,340
form as single stars they tend to form

1093
00:47:27,119 --> 00:47:30,809
in double systems or triple systems

1094
00:47:29,340 --> 00:47:33,360
sometimes you even have quadruple

1095
00:47:30,809 --> 00:47:36,210
systems something about the way stars

1096
00:47:33,360 --> 00:47:39,090
form tends to form leads them to form in

1097
00:47:36,210 --> 00:47:40,710
pairs or even greater systems and here

1098
00:47:39,090 --> 00:47:43,500
are some examples of these here's a

1099
00:47:40,710 --> 00:47:45,389
binary system where the top one is one

1100
00:47:43,500 --> 00:47:47,250
of these edge-on discs where you can see

1101
00:47:45,389 --> 00:47:49,199
this dark lane and then submit below see

1102
00:47:47,250 --> 00:47:51,510
on either side of it and then the

1103
00:47:49,199 --> 00:47:53,609
southern member of the pair is seen more

1104
00:47:51,510 --> 00:47:56,040
pull on so the light from the central

1105
00:47:53,610 --> 00:48:00,150
regions is escaping it's just a point of

1106
00:47:56,039 --> 00:48:02,009
light here's a triple system a double

1107
00:48:00,150 --> 00:48:04,200
system where this more distant one might

1108
00:48:02,010 --> 00:48:06,750
be related and here's a very close

1109
00:48:04,199 --> 00:48:08,669
double what's interesting about these

1110
00:48:06,750 --> 00:48:10,769
young stars they form in these little

1111
00:48:08,670 --> 00:48:13,260
clusters of two or three or more stars

1112

00:48:10,769 --> 00:48:15,269
but then if you go look at main sequence

1113
00:48:13,260 --> 00:48:17,490
stars more evolved ones you don't see

1114
00:48:15,269 --> 00:48:19,199
nearly as many pairs you still see a lot

1115
00:48:17,489 --> 00:48:20,849
of them but not quite as many so

1116
00:48:19,199 --> 00:48:22,739
something about the way these stars are

1117
00:48:20,849 --> 00:48:24,599
interacting through their gravity the

1118
00:48:22,739 --> 00:48:26,939
third member of a system might get flung

1119
00:48:24,599 --> 00:48:29,069
out so you're left with just a binary

1120
00:48:26,940 --> 00:48:30,869
system where there used to be three it's

1121
00:48:29,070 --> 00:48:32,670
possible that the Sun may even have

1122
00:48:30,869 --> 00:48:32,909
formed in one of these small collections

1123
00:48:32,670 --> 00:48:36,889
of

1124
00:48:32,909 --> 00:48:36,889
stars that was disrupted by gravity

1125
00:48:37,190 --> 00:48:40,650
another exciting thing we can do with

1126
00:48:39,269 --> 00:48:43,199

these Hubble images is to study the

1127

00:48:40,650 --> 00:48:44,880

cavities and the outflows here you can

1128

00:48:43,199 --> 00:48:46,439

see all sorts of different morphologies

1129

00:48:44,880 --> 00:48:47,250

it's pretty surprising they're not at

1130

00:48:46,440 --> 00:48:50,670

all alike

1131

00:48:47,250 --> 00:48:52,920

you have examples up here of bipolar

1132

00:48:50,670 --> 00:48:54,900

systems where you have this dark lane

1133

00:48:52,920 --> 00:48:58,559

and then the two nebulae on either side

1134

00:48:54,900 --> 00:49:00,750

that are pretty symmetrical here you see

1135

00:48:58,559 --> 00:49:03,420

this huge system that's a little bit of

1136

00:49:00,750 --> 00:49:07,559

a symmetrical here's kind of a smaller

1137

00:49:03,420 --> 00:49:09,090

more tightly contained one this one one

1138

00:49:07,559 --> 00:49:11,880

side of the nebula is much brighter than

1139

00:49:09,090 --> 00:49:13,530

the other down here you have all sorts

1140

00:49:11,880 --> 00:49:15,570

of structure like there have been maybe

1141
00:49:13,530 --> 00:49:18,450
multiple outbursts from this system in

1142
00:49:15,570 --> 00:49:20,519
the past this bizarre ring-like

1143
00:49:18,449 --> 00:49:23,960
structure here's a very wide angle

1144
00:49:20,519 --> 00:49:26,400
outflow there's lots going on here and

1145
00:49:23,960 --> 00:49:28,619
we think that one of the important

1146
00:49:26,400 --> 00:49:30,420
things these cavities do is these cos

1147
00:49:28,619 --> 00:49:32,309
star formation to slow down and

1148
00:49:30,420 --> 00:49:34,320
eventually stop in a star forming region

1149
00:49:32,309 --> 00:49:36,329
the outflow is being launched from the

1150
00:49:34,320 --> 00:49:38,039
star disrupt the cloud and eventually

1151
00:49:36,329 --> 00:49:40,139
there's not enough dense material to

1152
00:49:38,039 --> 00:49:44,119
continue forming stars so we think this

1153
00:49:40,139 --> 00:49:44,119
is a clue to how star formation ends

1154
00:49:44,539 --> 00:49:50,159
Alma is another facility this one on the

1155
00:49:47,309 --> 00:49:53,130
ground Alma is the Atacama Large

1156
00:49:50,159 --> 00:49:54,690
millimeter array where millimetre refers

1157
00:49:53,130 --> 00:49:58,230
to the wavelengths of the light that

1158
00:49:54,690 --> 00:50:00,630
we're studying and as an array it's

1159
00:49:58,230 --> 00:50:03,630
actually a collection of sort of medium

1160
00:50:00,630 --> 00:50:05,610
sized radio telescopes they're not quite

1161
00:50:03,630 --> 00:50:08,190
radio telescopes but they're there they

1162
00:50:05,610 --> 00:50:10,559
work like them and by using an array of

1163
00:50:08,190 --> 00:50:12,000
telescopes you can get some of the

1164
00:50:10,559 --> 00:50:14,070
benefits of having a single large

1165
00:50:12,000 --> 00:50:15,960
telescope but you can kind of

1166
00:50:14,070 --> 00:50:18,269
reconfigure the different dishes to

1167
00:50:15,960 --> 00:50:22,079
study physical structures at different

1168
00:50:18,269 --> 00:50:23,909
scales Alma is on the ground but it's

1169

00:50:22,079 --> 00:50:26,210
kind of almost in the sky because it's

1170
00:50:23,909 --> 00:50:29,730
sixteen thousand feet above sea level

1171
00:50:26,210 --> 00:50:32,820
one of the highest flat places on the

1172
00:50:29,730 --> 00:50:35,039
Earth's surface up there the air is

1173
00:50:32,820 --> 00:50:39,269
exceedingly dry it really doesn't rain

1174
00:50:35,039 --> 00:50:44,159
there ever and exceedingly thin so it's

1175
00:50:39,269 --> 00:50:46,380
almost as though you're in space these

1176
00:50:44,159 --> 00:50:49,679
are images of

1177
00:50:46,380 --> 00:50:51,390
protoplanetary disks in Orion so we're looking

1178
00:50:49,679 --> 00:50:55,019
through the envelope and imaging the

1179
00:50:51,389 --> 00:50:57,420
disks themselves and the important thing

1180
00:50:55,019 --> 00:50:59,219
here is for comparison if something just

1181
00:50:57,420 --> 00:51:01,200
like Neptune were orbiting one of these

1182
00:50:59,219 --> 00:51:05,789
stars at the same distance from its star

1183
00:51:01,199 --> 00:51:07,799

as neptune is you would be able to you

1184

00:51:05,789 --> 00:51:09,029

know resolve the orbit of neptune so

1185

00:51:07,800 --> 00:51:11,460

we're really getting to the point where

1186

00:51:09,030 --> 00:51:13,620

we can witness not just stars but the

1187

00:51:11,460 --> 00:51:15,809

Syst solar systems the systems of proto

1188

00:51:13,619 --> 00:51:17,609

planets themselves in the act of

1189

00:51:15,809 --> 00:51:19,619

formation this is really cutting-edge

1190

00:51:17,610 --> 00:51:21,360

science and Alma's continuing to get

1191

00:51:19,619 --> 00:51:23,519

more powerful and more able to resolve

1192

00:51:21,360 --> 00:51:25,079

these fine structures so there are lots

1193

00:51:23,519 --> 00:51:27,480

of debates going on right now about

1194

00:51:25,079 --> 00:51:29,250

which stars have planets and which ones

1195

00:51:27,480 --> 00:51:33,389

or maybe just beginning to form planets

1196

00:51:29,250 --> 00:51:34,980

I want to talk a little bit about the

1197

00:51:33,389 --> 00:51:39,059

science that I'm doing in particular

1198
00:51:34,980 --> 00:51:40,800
with star formation in Orion so I'm

1199
00:51:39,059 --> 00:51:41,849
interested in out bursting protostars

1200
00:51:40,800 --> 00:51:45,360
and I'll show you what I mean by that

1201
00:51:41,849 --> 00:51:47,489
this is a wide field image of Orion

1202
00:51:45,360 --> 00:51:49,050
starting the Orion Nebula is off the top

1203
00:51:47,489 --> 00:51:50,939
of the page and then this is this kind

1204
00:51:49,050 --> 00:51:53,130
of suburban region of Orion that I was

1205
00:51:50,940 --> 00:51:54,450
telling you about the circle toward the

1206
00:51:53,130 --> 00:51:57,660
bottom of the image marks the location

1207
00:51:54,449 --> 00:51:59,129
of hops 2:23 it's fairly isolated it's

1208
00:51:57,659 --> 00:52:01,920
part of this little group of three young

1209
00:51:59,130 --> 00:52:06,140
stars this is a near infrared image of

1210
00:52:01,920 --> 00:52:09,420
hops 2:23 and friends in the late 90s

1211
00:52:06,139 --> 00:52:11,369
ops 223 pretty faint compared to the

1212
00:52:09,420 --> 00:52:14,940
other two objects in the field well we

1213
00:52:11,369 --> 00:52:17,639
came and looked again in 2011 it was

1214
00:52:14,940 --> 00:52:20,340
suddenly much brighter now the brightest

1215
00:52:17,639 --> 00:52:22,679
object in the field so something

1216
00:52:20,340 --> 00:52:24,990
happened here that may tell us about how

1217
00:52:22,679 --> 00:52:28,289
stars form this is a Hubble image of

1218
00:52:24,989 --> 00:52:31,079
hops 223 and friends this is hops 223

1219
00:52:28,289 --> 00:52:33,150
this is hops 221 down here the numbers

1220
00:52:31,079 --> 00:52:35,099
are not quite randomly assigned they

1221
00:52:33,150 --> 00:52:36,450
don't they don't mean a whole lot but

1222
00:52:35,099 --> 00:52:38,639
this is just a little collection of

1223
00:52:36,449 --> 00:52:42,960
stars and hops 223 is undergoing one of

1224
00:52:38,639 --> 00:52:45,420
these outbursts we think that the reason

1225
00:52:42,960 --> 00:52:47,730
these get so much brighter is because

1226

00:52:45,420 --> 00:52:49,980
they suddenly begin this episode of

1227
00:52:47,730 --> 00:52:51,840
rapid mass accretion there may be

1228
00:52:49,980 --> 00:52:53,699
gradually accreting material from there

1229
00:52:51,840 --> 00:52:54,930
circumstellar disks over a period of

1230
00:52:53,699 --> 00:52:57,269
thousands of years and then suddenly

1231
00:52:54,929 --> 00:52:59,129
something happens to cause material to

1232
00:52:57,269 --> 00:53:01,800
pour on it pour unto the star

1233
00:52:59,130 --> 00:53:02,910
more rapidly these are light curves if

1234
00:53:01,800 --> 00:53:04,350
you remember way back near the beginning

1235
00:53:02,909 --> 00:53:06,690
of the talk I showed you a light curve

1236
00:53:04,349 --> 00:53:09,420
of a typical young star these are light

1237
00:53:06,690 --> 00:53:12,539
curves of three famous outbursts this

1238
00:53:09,420 --> 00:53:16,019
one here was a pretty normal star in

1239
00:53:12,539 --> 00:53:18,179
about 1935 but then suddenly just in a

1240
00:53:16,019 --> 00:53:20,969

span of months it became more than 100

1241
00:53:18,179 --> 00:53:24,059
times brighter shot way up here and ever

1242
00:53:20,969 --> 00:53:26,219
since then for decades it's been slowly

1243
00:53:24,059 --> 00:53:27,630
trailing off in brightness but it's

1244
00:53:26,219 --> 00:53:29,969
still much brighter than it ever was

1245
00:53:27,630 --> 00:53:32,940
before hand and there are a couple of

1246
00:53:29,969 --> 00:53:34,649
other objects that were detected back in

1247
00:53:32,940 --> 00:53:36,150
the twentieth century to do this and

1248
00:53:34,650 --> 00:53:39,990
we've started finding more and more of

1249
00:53:36,150 --> 00:53:41,940
them more recently so these outbursts

1250
00:53:39,989 --> 00:53:44,219
may actually be essential for the

1251
00:53:41,940 --> 00:53:45,929
formation of a star we think it's

1252
00:53:44,219 --> 00:53:48,029
possible that most of a star's mass

1253
00:53:45,929 --> 00:53:49,769
might be assembled in a series of a few

1254
00:53:48,030 --> 00:53:51,360
dozens of these outbursts over the two

1255
00:53:49,769 --> 00:53:53,309
million years star formation period

1256
00:53:51,360 --> 00:53:57,599
rather than as a slow and gradual

1257
00:53:53,309 --> 00:53:59,070
process a lot of theorists have put

1258
00:53:57,599 --> 00:54:01,139
together simulations of how these

1259
00:53:59,070 --> 00:54:03,450
outbursts work so a little bit about the

1260
00:54:01,139 --> 00:54:06,420
physics of star formation this is a

1261
00:54:03,449 --> 00:54:09,210
scenario so in this image the star is

1262
00:54:06,420 --> 00:54:12,900
here at the center in yellow of the

1263
00:54:09,210 --> 00:54:15,990
system this is all disc material so the

1264
00:54:12,900 --> 00:54:18,630
Stars disk is gradually drifting inward

1265
00:54:15,989 --> 00:54:20,069
trying to accrete onto the star but the

1266
00:54:18,630 --> 00:54:21,840
star has got a magnetic field it's just

1267
00:54:20,070 --> 00:54:23,070
like a bar magnet it's got a North Pole

1268
00:54:21,840 --> 00:54:25,769
and a South Pole in a magnetic field

1269
00:54:23,070 --> 00:54:27,570
that magnetic field keeps the disk from

1270
00:54:25,769 --> 00:54:30,059
coming in all the way so then the

1271
00:54:27,570 --> 00:54:31,950
material instead flows along these field

1272
00:54:30,059 --> 00:54:32,730
lines and crashes into the star at high

1273
00:54:31,949 --> 00:54:35,519
latitudes

1274
00:54:32,730 --> 00:54:37,139
we call this magnetospheric accretion

1275
00:54:35,519 --> 00:54:40,139
it's the accretion of gas through the

1276
00:54:37,139 --> 00:54:42,750
star's magnetosphere but when an

1277
00:54:40,139 --> 00:54:44,849
outburst begins there's maybe some blob

1278
00:54:42,750 --> 00:54:46,170
in the disk that's debt much denser than

1279
00:54:44,849 --> 00:54:48,329
the rest of the disk and when that

1280
00:54:46,170 --> 00:54:50,909
accretes it brings a lot more pressure

1281
00:54:48,329 --> 00:54:52,409
with it so the disc plows into the

1282
00:54:50,909 --> 00:54:54,210
surface of the star right at its equator

1283

00:54:52,409 --> 00:54:56,819
it completely overwhelms the star's

1284
00:54:54,210 --> 00:54:59,639
magnetic field and some of that material

1285
00:54:56,820 --> 00:55:02,039
gets shot off along the poles to form

1286
00:54:59,639 --> 00:55:04,049
these outflows so it's an entirely

1287
00:55:02,039 --> 00:55:06,210
different scenario for these stars

1288
00:55:04,050 --> 00:55:08,610
getting built up and this seems to

1289
00:55:06,210 --> 00:55:11,970
persist for maybe hundreds of years all

1290
00:55:08,610 --> 00:55:12,880
of these out bursting stars we've never

1291
00:55:11,969 --> 00:55:14,619
seen one

1292
00:55:12,880 --> 00:55:19,619
the major outburst turn off completely

1293
00:55:14,619 --> 00:55:19,619
so it's unclear how long these persist I

1294
00:55:20,369 --> 00:55:25,569
used one more space telescope called

1295
00:55:23,079 --> 00:55:26,980
wise this is the wide-field Infrared

1296
00:55:25,570 --> 00:55:28,930
Survey Explorer and it's one of the

1297
00:55:26,980 --> 00:55:30,849

smallest ones probably the smallest one

1298

00:55:28,929 --> 00:55:32,769

we've discussed so far it's kind of a

1299

00:55:30,849 --> 00:55:35,409

small but mighty Space Telescope though

1300

00:55:32,769 --> 00:55:37,449

it was launched in 2009 and it did a

1301

00:55:35,409 --> 00:55:39,730

survey of the entire sky it was very

1302

00:55:37,449 --> 00:55:42,669

flexible it did an all-sky survey in

1303

00:55:39,730 --> 00:55:44,650

2010 and it's continuing to orbit the

1304

00:55:42,670 --> 00:55:46,659

Earth performing a search for near-earth

1305

00:55:44,650 --> 00:55:49,599

asteroids which is pretty important if

1306

00:55:46,659 --> 00:55:51,579

you think about it this is an image of

1307

00:55:49,599 --> 00:55:54,190

the Milky Way from the wise telescope

1308

00:55:51,579 --> 00:55:57,489

and we actually used it to search for

1309

00:55:54,190 --> 00:56:00,639

more outbursts Spitzer made a map of a

1310

00:55:57,489 --> 00:56:02,709

Ryan in 2004 wise came around in 2010

1311

00:56:00,639 --> 00:56:05,049

and did the same thing and we could do a

1312
00:56:02,710 --> 00:56:06,970
computer-based comparison of the two

1313
00:56:05,050 --> 00:56:11,170
maps to look for stars that got much

1314
00:56:06,969 --> 00:56:13,379
brighter in the intervening time we have

1315
00:56:11,170 --> 00:56:16,750
one really great find of an outburst

1316
00:56:13,380 --> 00:56:18,579
when I was a postdoc at Toledo Emily

1317
00:56:16,750 --> 00:56:20,949
shown here was working with me on her

1318
00:56:18,579 --> 00:56:24,909
senior thesis and discovered Hopps 383

1319
00:56:20,949 --> 00:56:28,029
an out bursting proto star in Orion this

1320
00:56:24,909 --> 00:56:30,250
is a fairly large image of part of Orion

1321
00:56:28,030 --> 00:56:32,080
with the nebula here hops 383 is just to

1322
00:56:30,250 --> 00:56:33,610
the north of it along one of these dark

1323
00:56:32,079 --> 00:56:37,210
filaments that I've been talking about

1324
00:56:33,610 --> 00:56:40,269
from time to time these are the Spitzer

1325
00:56:37,210 --> 00:56:41,679
images of hops 383 where you can barely

1326
00:56:40,269 --> 00:56:44,679
see it at the shortest spitzer

1327
00:56:41,679 --> 00:56:46,239
wavelengths pokes out a little bit here

1328
00:56:44,679 --> 00:56:48,519
and then at the longest spitzer

1329
00:56:46,239 --> 00:56:49,750
wavelengths it's it's faint nothing you

1330
00:56:48,519 --> 00:56:50,880
would have imagined was a protostar

1331
00:56:49,750 --> 00:56:53,559
maybe some kind of background

1332
00:56:50,880 --> 00:56:56,320
contamination or something but here it

1333
00:56:53,559 --> 00:56:58,630
is in wise look how bright it is the

1334
00:56:56,320 --> 00:57:00,190
longest why of wise wavelengths this was

1335
00:56:58,630 --> 00:57:01,869
an unambiguous sign that something

1336
00:57:00,190 --> 00:57:04,539
happened in this object something made

1337
00:57:01,869 --> 00:57:09,400
it get a factor of a few dozen brighter

1338
00:57:04,539 --> 00:57:11,500
between 2004 and 2010 this is actually

1339
00:57:09,400 --> 00:57:14,800
the youngest known out bursting

1340

00:57:11,500 --> 00:57:17,019
protostar it's barely visible at the

1341
00:57:14,800 --> 00:57:19,300
shortest wave wavelengths even now and

1342
00:57:17,019 --> 00:57:21,159
it's extremely bright as you go farther

1343
00:57:19,300 --> 00:57:22,710
and farther out into the infrared that

1344
00:57:21,159 --> 00:57:26,349
means it's young and deeply embedded

1345
00:57:22,710 --> 00:57:27,250
it's maybe a hundred thousand years old

1346
00:57:26,349 --> 00:57:28,900
give

1347
00:57:27,250 --> 00:57:31,780
it's hard to date these things precisely

1348
00:57:28,900 --> 00:57:33,340
but it's it's young so even in their

1349
00:57:31,780 --> 00:57:35,110
earliest stages these stars undergo

1350
00:57:33,340 --> 00:57:37,480
these outbursts which is evidence that

1351
00:57:35,110 --> 00:57:39,789
this is a really important aspect of

1352
00:57:37,480 --> 00:57:42,849
star formation this was enough to

1353
00:57:39,789 --> 00:57:44,559
generate a press release here's an image

1354
00:57:42,849 --> 00:57:46,839

from our press really showing that

1355

00:57:44,559 --> 00:57:48,250
before pictures here in the after

1356

00:57:46,840 --> 00:57:51,190
pictures in the bottom row

1357

00:57:48,250 --> 00:57:54,550
these are near infrared images from Kitt

1358

00:57:51,190 --> 00:57:57,159
Peak and what we found so we have over

1359

00:57:54,550 --> 00:57:59,800
300 protostars here two of them began

1360

00:57:57,159 --> 00:58:02,769
outbursts in a period of a few years

1361

00:57:59,800 --> 00:58:04,480
between 2004 and 2010 there's hops 2:23

1362

00:58:02,769 --> 00:58:08,800
that i started off talking about and

1363

00:58:04,480 --> 00:58:10,869
hops 383 shown here that's kind of small

1364

00:58:08,800 --> 00:58:13,240
number of Statistics but it's an

1365

00:58:10,869 --> 00:58:14,679
indication that any given protostar may

1366

00:58:13,239 --> 00:58:16,569
have an outburst like this once every

1367

00:58:14,679 --> 00:58:18,669
thousand years that's where that number

1368

00:58:16,570 --> 00:58:21,490
comes from the protostar might do this

1369
00:58:18,670 --> 00:58:25,380
50 times over its formation period so

1370
00:58:21,489 --> 00:58:27,219
these protostars are active young stars

1371
00:58:25,380 --> 00:58:31,110
engaging in some pretty dramatic

1372
00:58:27,219 --> 00:58:31,109
fluctuations and they're brightnesses

1373
00:58:31,650 --> 00:58:36,340
the lasts are just about the last

1374
00:58:34,650 --> 00:58:38,440
observatory I'm going to tell you about

1375
00:58:36,340 --> 00:58:40,240
is Sophia this is not technically a

1376
00:58:38,440 --> 00:58:42,159
space-based observatories it comes

1377
00:58:40,239 --> 00:58:44,679
pretty close this is the stratospheric

1378
00:58:42,159 --> 00:58:46,359
Observatory for infrared astronomy it's

1379
00:58:44,679 --> 00:58:49,569
actually a passenger plane that has been

1380
00:58:46,360 --> 00:58:51,730
turned into a telescope if you see this

1381
00:58:49,570 --> 00:58:54,130
large rectangular opening in the back of

1382
00:58:51,730 --> 00:58:56,170
the plane this plane takes off every

1383
00:58:54,130 --> 00:58:59,349
night from Palmdale California in the

1384
00:58:56,170 --> 00:59:01,059
desert near Los Angeles sometimes it can

1385
00:58:59,349 --> 00:59:03,309
observe the southern sky by taking off

1386
00:59:01,059 --> 00:59:05,739
from New Zealand and after it reaches

1387
00:59:03,309 --> 00:59:07,329
cruising altitude this door opens up in

1388
00:59:05,739 --> 00:59:09,489
the back of the plane to let the

1389
00:59:07,329 --> 00:59:13,000
telescope peer out into the mid infrared

1390
00:59:09,489 --> 00:59:15,219
sky the cool thing about Sofia is that

1391
00:59:13,000 --> 00:59:18,250
astronomers who get time to use Sofia

1392
00:59:15,219 --> 00:59:20,859
are able to fly on it so you can kind of

1393
00:59:18,250 --> 00:59:23,500
see the whole flight operations crew in

1394
00:59:20,860 --> 00:59:26,289
action this is a view from inside of the

1395
00:59:23,500 --> 00:59:30,639
observatory where instead of tightly

1396
00:59:26,289 --> 00:59:35,019
packed rows of Economy seats you see all

1397

00:59:30,639 --> 00:59:36,529
of these scientific workstations all so

1398
00:59:35,019 --> 00:59:38,480
tightly packed

1399
00:59:36,530 --> 00:59:40,820
there's a flight commander that sort of

1400
00:59:38,480 --> 00:59:42,289
makes sure the pilots and the scientists

1401
00:59:40,820 --> 00:59:43,340
understand what each other is trying to

1402
00:59:42,289 --> 00:59:45,739
do and make sure everything goes

1403
00:59:43,340 --> 00:59:47,990
smoothly you have instrument scientists

1404
00:59:45,739 --> 00:59:50,209
on board and then the astronomers who

1405
00:59:47,989 --> 00:59:52,549
got time are just kind of there trying

1406
00:59:50,210 --> 00:59:54,349
not to cause too many problems and

1407
00:59:52,550 --> 00:59:55,580
trying not to interfere with the process

1408
00:59:54,349 --> 00:59:57,949
too much we're just learning how it all

1409
00:59:55,579 --> 00:59:59,779
works in the back of this image we're

1410
00:59:57,949 --> 01:00:01,489
actually seeing the right side of the

1411
00:59:59,780 --> 01:00:04,790

telescope the telescopes peering out of

1412

01:00:01,489 --> 01:00:06,289

the plane this way and this is you know

1413

01:00:04,789 --> 01:00:08,000

just the side of the telescope and the

1414

01:00:06,289 --> 01:00:11,900

instruments get attached they're that

1415

01:00:08,000 --> 01:00:13,489

detect and record the light and Sofia

1416

01:00:11,900 --> 01:00:15,340

flies pretty high many of its

1417

01:00:13,489 --> 01:00:18,139

observations are conducted from 35

1418

01:00:15,340 --> 01:00:20,450

37,000 feet but to go out to the longest

1419

01:00:18,139 --> 01:00:22,819

wavelengths it goes up above 40,000 feet

1420

01:00:20,449 --> 01:00:25,279

where the air is you know as thin as you

1421

01:00:22,820 --> 01:00:27,620

can get access to and as dry as you can

1422

01:00:25,280 --> 01:00:29,870

get access to so it leads to some fairly

1423

01:00:27,619 --> 01:00:32,299

sensitive infrared studies it's not

1424

01:00:29,869 --> 01:00:36,679

quite as sensitive as a Spitzer or

1425

01:00:32,300 --> 01:00:38,300

Herschel but it lands every morning so

1426
01:00:36,679 --> 01:00:54,679
you can go and fix things and improve

1427
01:00:38,300 --> 01:00:58,850
things yeah question the telescope is

1428
01:00:54,679 --> 01:01:00,710
yeah is isolated in that sense and it's

1429
01:00:58,849 --> 01:01:02,150
kind of interesting to watch it when

1430
01:01:00,710 --> 01:01:04,039
you're flying because it looks like the

1431
01:01:02,150 --> 01:01:05,809
telescope is rotating but it's actually

1432
01:01:04,039 --> 01:01:08,980
the plane sort of moving around and the

1433
01:01:05,809 --> 01:01:19,940
telescope is engineered to remain steady

1434
01:01:08,980 --> 01:01:22,369
yeah right it's I don't understand the

1435
01:01:19,940 --> 01:01:24,769
details precisely but it's it's sort of

1436
01:01:22,369 --> 01:01:27,619
it's it's isolated in such a way that it

1437
01:01:24,769 --> 01:01:31,329
can move freely or rather you know stay

1438
01:01:27,619 --> 01:01:31,329
put while the plane vibrates

1439
01:01:33,019 --> 01:01:38,659
so this is our image and image of hops

1440
01:01:36,380 --> 01:01:40,550
383 with Sophia it's this faint fuzzy

1441
01:01:38,659 --> 01:01:43,460
blob in the center of this circle here

1442
01:01:40,550 --> 01:01:45,170
so with Sophia we're just barely able to

1443
01:01:43,460 --> 01:01:48,139
detect something deeply as embedded as

1444
01:01:45,170 --> 01:01:49,820
hops 383 but we can detect it well

1445
01:01:48,139 --> 01:01:53,118
enough to know that it's still in out

1446
01:01:49,820 --> 01:01:55,700
burst mode in 2016 10 years after the

1447
01:01:53,119 --> 01:01:58,309
outburst began and this is currently the

1448
01:01:55,699 --> 01:02:01,789
best way we have of monitoring outbursts

1449
01:01:58,309 --> 01:02:03,769
in the infrared coming along a few years

1450
01:02:01,789 --> 01:02:05,900
down the road Road though is James Webb

1451
01:02:03,769 --> 01:02:08,150
and from the perspective of somebody who

1452
01:02:05,900 --> 01:02:09,530
studies star formation Webb has two

1453
01:02:08,150 --> 01:02:12,590
advantages it's going to have the

1454

01:02:09,530 --> 01:02:15,350
detailed high-resolution view of Hubble

1455
01:02:12,590 --> 01:02:18,320
but also the infrared capabilities of

1456
01:02:15,349 --> 01:02:20,150
Spitzer so by combining those two we can

1457
01:02:18,320 --> 01:02:22,970
really begin to look at the most deeply

1458
01:02:20,150 --> 01:02:25,130
embedded protostars study how often they

1459
01:02:22,969 --> 01:02:26,750
have outbursts and start to learn

1460
01:02:25,130 --> 01:02:28,789
something about the precise physical

1461
01:02:26,750 --> 01:02:31,519
conditions that exist in the innermost

1462
01:02:28,789 --> 01:02:33,199
regions of those young stars this is

1463
01:02:31,519 --> 01:02:35,420
just some text from one of the JWST

1464
01:02:33,199 --> 01:02:37,099
science themes to show that star

1465
01:02:35,420 --> 01:02:41,470
formation is supposed to be one of the

1466
01:02:37,099 --> 01:02:41,469
hot topics the Webb's going to address

1467
01:02:41,739 --> 01:02:46,519
so just to wrap things up here this is a

1468
01:02:44,480 --> 01:02:49,639

whole gallery of all the different

1469

01:02:46,519 --> 01:02:51,590

telescopes from the ground with Alma to

1470

01:02:49,639 --> 01:02:53,750

the stratosphere with Sofia to space

1471

01:02:51,590 --> 01:02:55,760

with all of these guys and they're

1472

01:02:53,750 --> 01:02:59,000

really beginning to reveal the secrets

1473

01:02:55,760 --> 01:03:01,520

of star formation in Orion and this is

1474

01:02:59,000 --> 01:03:03,530

how we learn how our Sun formed all of

1475

01:03:01,519 --> 01:03:06,469

these young stars in the Orion molecular

1476

01:03:03,530 --> 01:03:08,210

clouds their average mass is a little

1477

01:03:06,469 --> 01:03:11,089

bit less than that of the Sun but we

1478

01:03:08,210 --> 01:03:14,059

expect many of them to form planets and

1479

01:03:11,090 --> 01:03:15,800

go through the cycle of sorts just like

1480

01:03:14,059 --> 01:03:17,570

our Sun does so this is really our best

1481

01:03:15,800 --> 01:03:20,060

way to figure out how the Sun and

1482

01:03:17,570 --> 01:03:22,490

planets all formed five billion years

1483
01:03:20,059 --> 01:03:25,599
ago thank you

1484
01:03:22,489 --> 01:03:25,599
[Applause]

1485
01:03:33,139 --> 01:03:46,139
yeah question well so you're referring

1486
01:03:44,579 --> 01:03:48,900
to when nuclear fusion begins in the

1487
01:03:46,139 --> 01:03:50,519
corn it becomes a true star it's a

1488
01:03:48,900 --> 01:03:52,170
little bit difficult to see that in the

1489
01:03:50,519 --> 01:03:55,139
act of happening just because it's such

1490
01:03:52,170 --> 01:03:59,070
a slow long process for what's happening

1491
01:03:55,139 --> 01:04:00,900
in the core to propagate outward we see

1492
01:03:59,070 --> 01:04:06,660
lots of stars that are kind of on both

1493
01:04:00,900 --> 01:04:11,720
sides of that boundary those let's go

1494
01:04:06,659 --> 01:04:17,629
into the back Oh research do you have

1495
01:04:11,719 --> 01:04:17,629
how many stars actually develop planets

1496
01:04:20,480 --> 01:04:27,150
so the question was we have an idea of

1497
01:04:24,570 --> 01:04:30,510
how many stars create planets from this

1498
01:04:27,150 --> 01:04:32,700
work from this work and from other work

1499
01:04:30,510 --> 01:04:34,890
it looks like nearly all of them do I

1500
01:04:32,699 --> 01:04:37,319
mean everywhere we look stars have

1501
01:04:34,889 --> 01:04:39,509
planets there's all sorts of evidence

1502
01:04:37,320 --> 01:04:42,150
coming from these Alma images of young

1503
01:04:39,510 --> 01:04:43,980
stars that there is no such thing as a

1504
01:04:42,150 --> 01:04:45,329
perfect disc they're all distorted in

1505
01:04:43,980 --> 01:04:47,190
some way that might be due to planets

1506
01:04:45,329 --> 01:04:48,509
it's kind of an open question still but

1507
01:04:47,190 --> 01:04:49,920
it looks like planets are a pretty

1508
01:04:48,510 --> 01:04:53,460
standard outcome with the star formation

1509
01:04:49,920 --> 01:04:55,920
process I mean when you showed the the

1510
01:04:53,460 --> 01:04:57,869
the disks from Alma I mean almost

1511

01:04:55,920 --> 01:05:00,090
finding a tremendous number of these

1512
01:04:57,869 --> 01:05:02,219
disks around photo stars right right

1513
01:05:00,090 --> 01:05:03,720
it's got its it's it to me is the one

1514
01:05:02,219 --> 01:05:06,989
that has the greatest resolution for

1515
01:05:03,719 --> 01:05:08,969
seeing all these disks mm-hmm yeah are

1516
01:05:06,989 --> 01:05:10,709
our disks in Orion this is kind of a

1517
01:05:08,969 --> 01:05:12,869
snapshot survey but people who go look

1518
01:05:10,710 --> 01:05:14,460
and find detail at any given disk see a

1519
01:05:12,869 --> 01:05:30,599
lot more structure that I show you here

1520
01:05:14,460 --> 01:05:33,630
even yes the accretion process so what

1521
01:05:30,599 --> 01:05:38,819
is the minimum for fusion for minimum

1522
01:05:33,630 --> 01:05:40,890
density or the threshold are you talking

1523
01:05:38,820 --> 01:05:42,700
density are you talking amount of

1524
01:05:40,889 --> 01:05:45,489
material

1525
01:05:42,699 --> 01:05:48,009

all right so was it take first for a

1526

01:05:45,489 --> 01:05:49,839

clump of gas to collapse down and become

1527

01:05:48,010 --> 01:05:51,190

a star what's it what's were the

1528

01:05:49,840 --> 01:05:52,990

thresholds it has to cross

1529

01:05:51,190 --> 01:05:56,289

we often talk in terms of a mass

1530

01:05:52,989 --> 01:06:01,929

accretion rate and the unit's we use are

1531

01:05:56,289 --> 01:06:04,570

solar masses per year so a typical

1532

01:06:01,929 --> 01:06:06,279

t-tauri stars might accrete at 10 to the

1533

01:06:04,570 --> 01:06:08,260

minus 8 solar masses per year that

1534

01:06:06,280 --> 01:06:09,820

really means about one moon's worth of

1535

01:06:08,260 --> 01:06:12,910

material is falling under the star every

1536

01:06:09,820 --> 01:06:15,190

year that's not very much very early in

1537

01:06:12,909 --> 01:06:17,429

the star formation phase the accretion

1538

01:06:15,190 --> 01:06:28,599

rates are maybe ten thousand times that

1539

01:06:17,429 --> 01:06:30,069

so ten to the minus four all right so

1540
01:06:28,599 --> 01:06:32,380
the question the minimum amount of

1541
01:06:30,070 --> 01:06:37,960
matter necessary for fusion for the

1542
01:06:32,380 --> 01:06:40,329
fusion so the least massive stars that

1543
01:06:37,960 --> 01:06:42,280
are fusing hydrogen in their centers are

1544
01:06:40,329 --> 01:06:51,059
a little less than a tenth of a solar

1545
01:06:42,280 --> 01:06:51,060
mass other questions yeah over here

1546
01:06:51,300 --> 01:07:00,640
points or they have to get pretty

1547
01:06:54,880 --> 01:07:02,230
crowded several so Herschel's already

1548
01:07:00,639 --> 01:07:04,299
out of the I2 we're gonna send a web out

1549
01:07:02,230 --> 01:07:05,099
to I2 man is it gonna get crowded out

1550
01:07:04,300 --> 01:07:08,260
there

1551
01:07:05,099 --> 01:07:10,029
yeah the Planck Space Telescope is

1552
01:07:08,260 --> 01:07:12,220
another one that's out there they're not

1553
01:07:10,030 --> 01:07:15,310
all like precisely at one point they're

1554
01:07:12,219 --> 01:07:18,519
all in various orbits around I2 so maybe

1555
01:07:15,309 --> 01:07:20,409
crowded in a sense but not that crowded

1556
01:07:18,519 --> 01:07:21,579
yeah I don't think that's I don't think

1557
01:07:20,409 --> 01:07:23,230
it's a concern that any of them would

1558
01:07:21,579 --> 01:07:25,779
collide geosynchronous orbit around

1559
01:07:23,230 --> 01:07:38,800
Earth is much much much much much more

1560
01:07:25,780 --> 01:07:42,550
crowded okay do stars have an axis and

1561
01:07:38,800 --> 01:07:45,280
magnetic holes and if so why oh well

1562
01:07:42,550 --> 01:07:47,650
yeah they are magnetic it's because the

1563
01:07:45,280 --> 01:07:50,580
gas in these stars is so hot that the

1564
01:07:47,650 --> 01:07:53,470
atoms dissociate into charged particles

1565
01:07:50,579 --> 01:07:56,210
so you have ions protons and electrons

1566
01:07:53,469 --> 01:07:58,250
and the elect

1567
01:07:56,210 --> 01:08:02,269
charge also generates a magnetic field

1568

01:07:58,250 --> 01:08:04,489
and in the least the less massive stars

1569
01:08:02,269 --> 01:08:05,690
you have these convection currents so

1570
01:08:04,489 --> 01:08:07,159
you get a current going with these

1571
01:08:05,690 --> 01:08:13,400
charged particles and that gives you a

1572
01:08:07,159 --> 01:08:15,319
magnetic field yes kind of the opposite

1573
01:08:13,400 --> 01:08:16,609
of the first question I know the things

1574
01:08:15,320 --> 01:08:20,239
start to heat up when they collapse

1575
01:08:16,609 --> 01:08:26,180
gravitationally at what point we start

1576
01:08:20,238 --> 01:08:28,278
are we able to start alright so you has

1577
01:08:26,180 --> 01:08:30,170
to collapse and get darkened when does

1578
01:08:28,279 --> 01:08:31,730
it win where do we able to actually see

1579
01:08:30,170 --> 01:08:37,239
the stars that were your question yeah

1580
01:08:31,729 --> 01:08:40,579
when did when it's with the Herschel

1581
01:08:37,238 --> 01:08:44,689
telescope we were detecting stars that

1582
01:08:40,579 --> 01:08:47,238

had temperatures of maybe 40 to 50

1583

01:08:44,689 --> 01:08:51,139
degrees above absolute zero 40 to 50

1584

01:08:47,238 --> 01:08:53,599
Kelvin so we're getting cold not quite

1585

01:08:51,140 --> 01:09:09,950
as cold as like interstellar space but

1586

01:08:53,600 --> 01:09:12,650
cool so to see them in visible light

1587

01:09:09,949 --> 01:09:14,238
wavelengths what has to happen do we

1588

01:09:12,649 --> 01:09:16,909
and the fusion has to be turned on of

1589

01:09:14,238 --> 01:09:19,399
course so these T Tauri stars that I was

1590

01:09:16,909 --> 01:09:21,619
talking about or what we call optically

1591

01:09:19,399 --> 01:09:24,829
revealed they show up in visible light

1592

01:09:21,619 --> 01:09:28,699
images they're not yet fusing but the

1593

01:09:24,829 --> 01:09:30,559
energy of contraction as the star gets

1594

01:09:28,699 --> 01:09:32,449
smaller from its initial state to

1595

01:09:30,560 --> 01:09:36,109
eventually become dense enough to fuse

1596

01:09:32,449 --> 01:09:39,289
that in itself releases plenty of energy

1597
01:09:36,109 --> 01:09:42,140
and once all that cloud is gone it gets

1598
01:09:39,289 --> 01:09:44,180
radiated as visible light so even even

1599
01:09:42,140 --> 01:09:47,150
before hydrogen fuses you can see

1600
01:09:44,180 --> 01:09:48,920
optical light from these and a lot of

1601
01:09:47,149 --> 01:09:51,019
that's geometric of course too because

1602
01:09:48,920 --> 01:09:53,000
if they're deeply embedded within the

1603
01:09:51,020 --> 01:09:54,890
molecular cloud you're not going to see

1604
01:09:53,000 --> 01:09:57,560
them whereas Orion is like a blister

1605
01:09:54,890 --> 01:09:59,539
nebula so if we're able to see there's a

1606
01:09:57,560 --> 01:10:02,890
relatively clear right there site and

1607
01:09:59,539 --> 01:10:02,890
visible at least mm-hmm

1608
01:10:19,779 --> 01:10:30,710
so what's the day how big are these

1609
01:10:22,369 --> 01:10:32,479
Lagrangian points the area yeah I'm not

1610
01:10:30,710 --> 01:10:39,050
sure what exactly the radius of the

1611
01:10:32,479 --> 01:10:40,459
orbit around the I2 point is it's it's

1612
01:10:39,050 --> 01:10:42,050
large enough that their telescopes are

1613
01:10:40,460 --> 01:10:46,579
not colliding within one another but I'm

1614
01:10:42,050 --> 01:10:47,779
not sure I'm not sure numerically the

1615
01:10:46,579 --> 01:10:50,390
Webb Space Telescope's

1616
01:10:47,779 --> 01:10:52,880
library market is really quite large I

1617
01:10:50,390 --> 01:10:56,420
mean it's several Earth radii in in

1618
01:10:52,880 --> 01:11:00,949
diameter at least I don't know I also

1619
01:10:56,420 --> 01:11:03,920
don't know an actual number yeah well

1620
01:11:00,949 --> 01:11:05,779
it's just it's a nice big library more

1621
01:11:03,920 --> 01:11:11,420
of it around the around the veil to

1622
01:11:05,779 --> 01:11:15,710
point any idea the length of life of a

1623
01:11:11,420 --> 01:11:19,239
star-forming region so what is the how

1624
01:11:15,710 --> 01:11:21,980
long does a star-forming region last

1625

01:11:19,239 --> 01:11:24,500
that's a little hard to tell we we have

1626
01:11:21,979 --> 01:11:26,419
some sense for how long the individual

1627
01:11:24,500 --> 01:11:28,189
stars last but you might get successive

1628
01:11:26,420 --> 01:11:30,920
waves of star formation before the gas

1629
01:11:28,189 --> 01:11:33,259
is fully exhausted so you maybe will

1630
01:11:30,920 --> 01:11:34,399
have a you know if the average time it

1631
01:11:33,260 --> 01:11:36,110
takes to form a star as two million

1632
01:11:34,399 --> 01:11:40,179
years maybe the star forming region

1633
01:11:36,109 --> 01:11:43,399
itself could last for a few times that

1634
01:11:40,180 --> 01:11:45,170
small interestingly compared to like

1635
01:11:43,399 --> 01:11:46,670
geologic timescales like when the

1636
01:11:45,170 --> 01:11:48,550
dinosaurs roamed the earth there is

1637
01:11:46,670 --> 01:11:50,779
probably no Orion Nebula yet to speak of

1638
01:11:48,550 --> 01:11:56,539
just for a little bit of comparison

1639
01:11:50,779 --> 01:11:58,819

there yes when you look at us the Orion

1640

01:11:56,539 --> 01:12:03,819

Nebula through a small telescope you see

1641

01:11:58,819 --> 01:12:06,460

these four stars trapezium arrangement

1642

01:12:03,819 --> 01:12:09,079

how did they relate to your talk tonight

1643

01:12:06,460 --> 01:12:10,789

alright so how do the trapezium stars at

1644

01:12:09,079 --> 01:12:13,279

the core of Orion relate to what you're

1645

01:12:10,789 --> 01:12:15,500

talking about today those are the most

1646

01:12:13,279 --> 01:12:16,729

massive stars in Orion and those are

1647

01:12:15,500 --> 01:12:18,619

part of what makes it such an

1648

01:12:16,729 --> 01:12:20,750

interesting star forming region that's

1649

01:12:18,619 --> 01:12:22,609

the closest star forming

1650

01:12:20,750 --> 01:12:27,800

and where you have stars that massive

1651

01:12:22,609 --> 01:12:31,219

and the winds the outflows energetic

1652

01:12:27,800 --> 01:12:33,619

outflows from these stars tend to shape

1653

01:12:31,220 --> 01:12:35,810

the entire dynamics and evolution of the

1654
01:12:33,619 --> 01:12:37,550
immediate Orion Nebula region there are

1655
01:12:35,810 --> 01:12:39,289
largely responsible for a lot of the

1656
01:12:37,550 --> 01:12:42,320
bright emission you see from the nebula

1657
01:12:39,289 --> 01:12:45,769
they may play a role in sort of blasting

1658
01:12:42,319 --> 01:12:47,509
discs away from the lower mass stars in

1659
01:12:45,770 --> 01:12:50,390
my talk I didn't touch on that too much

1660
01:12:47,510 --> 01:12:52,100
because they were so bright to Spitzer

1661
01:12:50,390 --> 01:12:54,740
that Spitzer actually couldn't image

1662
01:12:52,100 --> 01:12:56,690
them so we necessarily focused on kind

1663
01:12:54,739 --> 01:12:59,059
of a more outlying areas of Orion but

1664
01:12:56,689 --> 01:13:00,500
they're really responsible for just a

1665
01:12:59,060 --> 01:13:03,410
lot of what goes on in that central

1666
01:13:00,500 --> 01:13:05,689
region you know I'm learning a lot about

1667
01:13:03,409 --> 01:13:08,869
Orion as we did the visualizations of

1668
01:13:05,689 --> 01:13:11,539
the Orion Nebula and to see that giant

1669
01:13:08,869 --> 01:13:13,819
river of gas in behind it and recognize

1670
01:13:11,539 --> 01:13:15,769
that Terry yes this may be the city but

1671
01:13:13,819 --> 01:13:20,299
there is a tremendous number of suburbs

1672
01:13:15,770 --> 01:13:23,780
within the OMC out there that there's a

1673
01:13:20,300 --> 01:13:25,820
rich picture of star formation within

1674
01:13:23,779 --> 01:13:38,559
Orion is so much more than we think of

1675
01:13:25,819 --> 01:13:40,699
when we just think of the Orion Nebula I

1676
01:13:38,560 --> 01:13:42,740
may have missed it but what was the

1677
01:13:40,699 --> 01:13:44,329
mechanism for brightness changes that

1678
01:13:42,739 --> 01:13:45,769
quickly all right so what's the

1679
01:13:44,329 --> 01:13:47,569
mechanism for the quick brightness

1680
01:13:45,770 --> 01:13:51,680
changes within the t-tauri stars plot

1681
01:13:47,569 --> 01:13:53,299
you showed so if you remember that sort

1682

01:13:51,680 --> 01:13:55,970
of schematic I showed of how material

1683
01:13:53,300 --> 01:13:59,750
falls under the star exactly that's all

1684
01:13:55,970 --> 01:14:02,270
happening over about one tenth of the

1685
01:13:59,750 --> 01:14:05,119
earth-sun distance so a fairly small

1686
01:14:02,270 --> 01:14:07,600
region and just changes in the density

1687
01:14:05,119 --> 01:14:10,309
of the accreting material due to

1688
01:14:07,600 --> 01:14:12,680
pre-existing irregularities in the disk

1689
01:14:10,310 --> 01:14:14,480
structure can cause those brightness

1690
01:14:12,680 --> 01:14:16,760
variations the accretion rate sort of

1691
01:14:14,479 --> 01:14:20,239
goes up and down and that leads to

1692
01:14:16,760 --> 01:14:29,570
changes in the brightness other

1693
01:14:20,239 --> 01:14:31,309
questions yeah so what caused those

1694
01:14:29,569 --> 01:14:33,698
holes if that's really if Herschel

1695
01:14:31,310 --> 01:14:37,389
really is finding a hole

1696
01:14:33,698 --> 01:14:38,978

how did it get there that is probably

1697

01:14:37,389 --> 01:14:41,708

due to those outflows that I've been

1698

01:14:38,979 --> 01:14:44,139

talking about that some all of these

1699

01:14:41,708 --> 01:14:47,319

stars they accrete matter but then some

1700

01:14:44,139 --> 01:14:49,510

fraction of that is pushed off along the

1701

01:14:47,319 --> 01:14:51,670

poles of the star with some force and

1702

01:14:49,510 --> 01:14:53,440

that could actually blow holes in the

1703

01:14:51,670 --> 01:14:55,269

nebula if you have a few of them that

1704

01:14:53,439 --> 01:14:57,819

with the chance alignment so they're all

1705

01:14:55,269 --> 01:15:03,099

sort of collaborating on opening up a

1706

01:14:57,819 --> 01:15:05,288

hole in the nebula all right we got like

1707

01:15:03,099 --> 01:15:05,889

two more one here and one there and one

1708

01:15:05,288 --> 01:15:17,349

back there

1709

01:15:05,889 --> 01:15:18,969

that's three men all right so why do we

1710

01:15:17,349 --> 01:15:21,400

see this filament or river of gas

1711
01:15:18,969 --> 01:15:23,380
through Orion it seems like it's

1712
01:15:21,399 --> 01:15:24,848
probably magnetic fields that are

1713
01:15:23,380 --> 01:15:26,889
responsible for the filaments you've got

1714
01:15:24,849 --> 01:15:29,260
these large-scale magnetic fields kind

1715
01:15:26,889 --> 01:15:34,029
of threading the galaxies due to the

1716
01:15:29,260 --> 01:15:35,769
motion of hot gas and any gas that's

1717
01:15:34,029 --> 01:15:38,109
even a little bit ionized tends to

1718
01:15:35,769 --> 01:15:39,489
follow along those field lines so that

1719
01:15:38,109 --> 01:15:42,880
leads to these kind of stretched out

1720
01:15:39,488 --> 01:15:54,368
filamentary structures okay we had one

1721
01:15:42,880 --> 01:15:56,349
way in the back when a cloud of gas that

1722
01:15:54,368 --> 01:15:57,578
presented to a binary star with that

1723
01:15:56,349 --> 01:16:00,729
form gravity waves

1724
01:15:57,578 --> 01:16:04,208
all right so gravity waves detected from

1725
01:16:00,729 --> 01:16:06,010
two black holes merging together the

1726
01:16:04,208 --> 01:16:08,319
creation of these binary stars would

1727
01:16:06,010 --> 01:16:11,789
that also create binary gravitational

1728
01:16:08,319 --> 01:16:15,130
waves that summarize a question right

1729
01:16:11,788 --> 01:16:17,109
these are much lower energy events than

1730
01:16:15,130 --> 01:16:19,389
the creation than the collision of

1731
01:16:17,109 --> 01:16:21,189
binary black holes so there really

1732
01:16:19,389 --> 01:16:24,099
wouldn't be any appreciable gravity

1733
01:16:21,189 --> 01:16:27,939
waves from this it's more just this this

1734
01:16:24,099 --> 01:16:30,099
the clouds kind of quietly relatively

1735
01:16:27,939 --> 01:16:33,879
quietly collapsing into two stars on

1736
01:16:30,099 --> 01:16:40,349
their own okay who had the last question

1737
01:16:33,880 --> 01:16:40,349
their p jeab stars together

1738
01:16:46,500 --> 01:16:58,260
the clustered beginner custard together

1739

01:16:55,489 --> 01:17:00,059
childhood under the impression we look

1740
01:16:58,260 --> 01:17:02,130
at a constellation up there what you

1741
01:17:00,060 --> 01:17:03,480
really see is a flat field and it'll

1742
01:17:02,130 --> 01:17:04,970
start one start moving here the other

1743
01:17:03,479 --> 01:17:07,979
maybe way to tell I'm not over there

1744
01:17:04,970 --> 01:17:11,400
when they just look like they're aligned

1745
01:17:07,979 --> 01:17:13,500
in a pattern you've seen of it right

1746
01:17:11,399 --> 01:17:18,809
there angular separation

1747
01:17:13,500 --> 01:17:22,260
visibly that's not true then or other

1748
01:17:18,810 --> 01:17:25,500
constellations those same stars kind of

1749
01:17:22,260 --> 01:17:27,510
grouped together okay so yeah the

1750
01:17:25,500 --> 01:17:29,640
question it is I when we look at

1751
01:17:27,510 --> 01:17:32,909
constellations in the night sky the

1752
01:17:29,640 --> 01:17:35,100
Stars the the full Orion constellation

1753
01:17:32,909 --> 01:17:38,489

like Betelgeuse and Rigel there are

1754

01:17:35,100 --> 01:17:41,700

totally different distances but so how

1755

01:17:38,489 --> 01:17:43,050

does that up does how does that

1756

01:17:41,699 --> 01:17:45,300

translate to some of this stuff we're

1757

01:17:43,050 --> 01:17:47,039

here working looking at here yeah so in

1758

01:17:45,300 --> 01:17:48,750

general if you pick some random

1759

01:17:47,039 --> 01:17:50,699

constellation out of the sky the stars

1760

01:17:48,750 --> 01:17:52,050

of that constellation have no physical

1761

01:17:50,699 --> 01:17:54,479

relationship to one another

1762

01:17:52,050 --> 01:17:55,800

Orion's kind of an exception is

1763

01:17:54,479 --> 01:17:58,619

everything I've been talking about here

1764

01:17:55,800 --> 01:18:01,079

this is a single well two really clouds

1765

01:17:58,619 --> 01:18:03,750

of molecular gas they're forming stars

1766

01:18:01,079 --> 01:18:05,909

that are in close proximity so all of

1767

01:18:03,750 --> 01:18:07,770

the young stars in Orion are physically

1768
01:18:05,909 --> 01:18:10,199
associated it's kind of an exception to

1769
01:18:07,770 --> 01:18:12,390
the usual rule about constellations well

1770
01:18:10,199 --> 01:18:14,149
also on the angular separation on the

1771
01:18:12,390 --> 01:18:17,100
sky of the stars of the constellation

1772
01:18:14,149 --> 01:18:19,289
are much much much much larger these are

1773
01:18:17,100 --> 01:18:21,990
all very close they're all basically in

1774
01:18:19,289 --> 01:18:27,390
Orion hanging down from Orion's belt in

1775
01:18:21,989 --> 01:18:30,719
this area down what you're talking about

1776
01:18:27,390 --> 01:18:32,850
the Magellanic Clouds no I'm not talking

1777
01:18:30,720 --> 01:18:36,409
about the Magellanic Clouds the Orion

1778
01:18:32,850 --> 01:18:39,660
the the star formation in Orion is all

1779
01:18:36,409 --> 01:18:42,180
in the area around the Orion Nebula down

1780
01:18:39,659 --> 01:18:45,109
from the below the belt you're hitting a

1781
01:18:42,180 --> 01:18:45,110
Ryan below the belt here

1782
01:18:46,800 --> 01:18:51,579
all right Hartman do you have one last

1783
01:18:49,448 --> 01:18:54,308
thing interesting I think I remember

1784
01:18:51,578 --> 01:18:57,189
right output of the three famous stars

1785
01:18:54,309 --> 01:19:00,070
in Orion's belt I'll attack although hi

1786
01:18:57,189 --> 01:19:04,238
millou taka 2,000 light-years away and

1787
01:19:00,069 --> 01:19:06,399
the end stars are like five hundred I

1788
01:19:04,238 --> 01:19:08,049
actually I guess oh he's talking about

1789
01:19:06,399 --> 01:19:10,868
that stars in the Bell being a totally

1790
01:19:08,050 --> 01:19:14,019
different distances yes I did a constant

1791
01:19:10,868 --> 01:19:17,109
I did a visualization of the main stars

1792
01:19:14,019 --> 01:19:18,940
of Orion in 3d and spin it around if you

1793
01:19:17,109 --> 01:19:22,448
look on youtube you can find it the

1794
01:19:18,939 --> 01:19:25,779
Orion constellation in 3d and it's one

1795
01:19:22,448 --> 01:19:27,578
of our more popular ones for educational

1796

01:19:25,779 --> 01:19:29,259
purposes because it takes a Ryan you see

1797
01:19:27,578 --> 01:19:31,090
it as it does and then you spin it

1798
01:19:29,260 --> 01:19:32,769
sideways and it looks more like a

1799
01:19:31,090 --> 01:19:37,179
stealth bomber than it does look like a

1800
01:19:32,769 --> 01:19:41,079
hundred all right let let's see next

1801
01:19:37,179 --> 01:19:43,828
month is it's June so July I forget what

1802
01:19:41,078 --> 01:19:46,569
our time oh the Milky Way bulge the blob

1803
01:19:43,828 --> 01:19:49,779
from from blob - remarkably detailed

1804
01:19:46,569 --> 01:19:52,179
picture that will be our July talk hope

1805
01:19:49,779 --> 01:19:53,489
to see you all there and let's give will

1806
01:19:52,179 --> 01:20:04,470
another big

1807
01:19:53,489 --> 01:20:08,969
[Applause]

1808
01:20:04,470 --> 01:20:08,970
yeah thank you for organizing