PUBLIC LECTURE SERIES

Star Formation in Orion

Featuring Guest Speaker :

Will Fischer

1
00:00:09,740 --> 00:00:02,750
upcast and pulling it to youtube so give

2
00:00:13,360 --> 00:00:09,750
grant a hand alright let me start the

3
00:00:30,909 --> 00:00:28,870
I'm sure this working as you came in if

4
00:00:33,790 --> 00:00:30,919
you saw these on the table we have our

5
00:00:36,549 --> 00:00:33,800
lithographs tonight's lithograph is of

6
00:00:38,770 --> 00:00:36,559
30 Doradus a turbulent star-forming

7
00:00:41,020 --> 00:00:38,780
region which really should be called the

8
00:00:42,520 --> 00:00:41,030
tarantula nebula because 30 Doradus is

9
00:00:44,950 --> 00:00:42,530
just basically the star cluster at the

10
00:00:47,349 --> 00:00:44,960
heart of it it was originally it was so

11
00:00:48,490 --> 00:00:47,359
bright it was thought to be a star but

12
00:00:50,439 --> 00:00:48,500
it's now a said known to be a star

13
00:00:52,900 --> 00:00:50,449

cluster and actually it's a part of a

14
00:00:55,029 --> 00:00:52,910
big nebula called the tarantula nebula

15
00:00:57,880 --> 00:00:55,039
if you'd like to learn more about it

16
00:01:00,430 --> 00:00:57,890
it's on the back and it talks about star

17
00:01:01,810 --> 00:01:00,440
formation but you don't have to read you

18
00:01:04,360 --> 00:01:01,820
can listen to will tonight because he's

19
00:01:06,100 --> 00:01:04,370
gonna tell you everything you wanted to

20
00:01:10,060 --> 00:01:06,110
know about star formation because our

21
00:01:12,399 --> 00:01:10,070
talk tonight is star formation in Orion

22
00:01:16,120 --> 00:01:12,409
one of my favorite places in the

23
00:01:18,520 --> 00:01:16,130
universe next month we will have the

24
00:01:21,640 --> 00:01:18,530
Milky Way's bulge from a hypothesized

25
00:01:24,070 --> 00:01:21,650
blob to a remarkably detailed picture I

26
00:01:26,740 --> 00:01:24,080
actually wanted to call this the blob

27
00:01:30,250 --> 00:01:26,750
that ate the Milky Way but David didn't

28
00:01:33,100 --> 00:01:30,260
seem to like that title in August

29
00:01:36,490 --> 00:01:33,110
ashes to ashes dust to dust the fate of

30
00:01:40,690 --> 00:01:36,500
stars like the Sun death of stars in

31
00:01:43,630 --> 00:01:40,700
August and in September more death and

32
00:01:46,240 --> 00:01:43,640
destruction 100 ways to die in the

33
00:01:51,670 --> 00:01:46,250
universe I really don't know what that

34
00:01:53,860 --> 00:01:51,680
talk is about but if you would like to

35
00:01:56,770 --> 00:01:53,870
find out more about to keep remind

36
00:01:58,690 --> 00:01:56,780
yourself of these talks we have our web

37
00:02:00,640 --> 00:01:58,700
page you take go to your favorite search

38
00:02:02,710 --> 00:02:00,650

engine and type o hubble public talks

39
00:02:04,780 --> 00:02:02,720
you'll find this page we have our list

40
00:02:07,710 --> 00:02:04,790
of the upcoming lectures we have the

41
00:02:10,600 --> 00:02:07,720
links to the live webcasting both on our

42
00:02:13,330 --> 00:02:10,610
STScI webcasting site as well as on

43
00:02:18,460 --> 00:02:13,340
youtube we have the archives all the way

44
00:02:21,309 --> 00:02:18,470
back to 2005 from STFC i so you can get

45
00:02:23,500 --> 00:02:21,319
your fill of astronomy should you wake

46
00:02:25,360 --> 00:02:23,510
up at 3 in the morning go I really need

47
00:02:28,420 --> 00:02:25,370
some astronomy right now

48
00:02:32,330 --> 00:02:28,430
you can also sign up for our email list

49
00:02:33,980 --> 00:02:32,340
here let's see the announcements if you

50
00:02:35,660 --> 00:02:33,990
sign up to the website we'll just send

51
00:02:37,760 --> 00:02:35,670
you a really only send you like one or

52
00:02:39,620 --> 00:02:37,770
two emails a month selling reminding you

53
00:02:41,120 --> 00:02:39,630
of the upcoming lectures and telling you

54
00:02:43,400 --> 00:02:41,130
where you can find the webcast when it

55
00:02:45,500 --> 00:02:43,410
is posted if you have comments or

56
00:02:51,020 --> 00:02:45,510
questions you can send them to us at

57
00:02:52,970 --> 00:02:51,030
public lecture at STScI edu social media

58
00:02:54,860 --> 00:02:52,980
should you want to follow us on these

59
00:02:56,330 --> 00:02:54,870
various things we have facebook we have

60
00:02:59,090 --> 00:02:56,340
twitter we have YouTube we have

61
00:03:03,470 --> 00:02:59,100
Instagram and we have two or three on

62
00:03:06,410 --> 00:03:03,480
each of those channels for your social

63
00:03:08,390 --> 00:03:06,420

media pleasure myself I'm on Facebook

64
00:03:12,380 --> 00:03:08,400
Google+ and Twitter but I'm not very

65
00:03:15,740 --> 00:03:12,390
active so don't expect daily tweets from

66
00:03:17,930 --> 00:03:15,750
me Observatory I got the email from

67
00:03:19,970 --> 00:03:17,940
ireenie and she said it's just cloudy

68
00:03:22,520 --> 00:03:19,980
all evening so we will not have the

69
00:03:24,710 --> 00:03:22,530
observatory open after the lecture but

70
00:03:27,950 --> 00:03:24,720
as we remind you every month they do

71
00:03:31,580 --> 00:03:27,960
have open houses on Friday evenings you

72
00:03:33,020 --> 00:03:31,590
go to MD dot space grant org you find

73
00:03:35,090 --> 00:03:33,030
their Observatory page and this

74
00:03:38,000 --> 00:03:35,100
Observatory status box over here on the

75
00:03:39,260 --> 00:03:38,010
right will tell you what whether or not

76
00:03:41,150 --> 00:03:39,270
they're gonna be open basically you

77
00:03:42,650 --> 00:03:41,160
check it Friday at around 5:00 or 6:00

78
00:03:44,300 --> 00:03:42,660
and they'll tell you whether they're

79
00:03:48,020 --> 00:03:44,310
gonna be open sort of like the email I

80
00:03:50,660 --> 00:03:48,030
get every time we have to lecture okay

81
00:03:53,350 --> 00:03:50,670
and now our news from the universe for

82
00:03:59,630 --> 00:03:53,360
June 2018

83
00:04:02,780 --> 00:03:59,640
our first story a galaxy tug of war well

84
00:04:04,940 --> 00:04:02,790
let's start with our galaxy okay so this

85
00:04:07,310 --> 00:04:04,950
is an all-sky view of our Milky Way

86
00:04:08,960 --> 00:04:07,320
galaxy and you can see right across the

87
00:04:11,840 --> 00:04:08,970
center here is the plane of our Milky

88
00:04:14,120 --> 00:04:11,850

Way galaxy it's a disc shaped galaxy and

89
00:04:18,470 --> 00:04:14,130
we're inside that disc so we see it as

90
00:04:21,050 --> 00:04:18,480
this long straight structure heading all

91
00:04:23,000 --> 00:04:21,060
the way across the sky but there are

92
00:04:25,190 --> 00:04:23,010
other galaxies in this image all right

93
00:04:28,280 --> 00:04:25,200
you may not know them as galaxies but

94
00:04:31,280 --> 00:04:28,290
you have this spot down here this spot

95
00:04:35,790 --> 00:04:31,290
down here they are nearby galaxies this

96
00:04:38,460 --> 00:04:35,800
one is called the Large Magellanic Cloud

97
00:04:41,460 --> 00:04:38,470
yeah they're called Magellanic because

98
00:04:44,580 --> 00:04:41,470
they were discovered by Magellan on his

99
00:04:46,170 --> 00:04:44,590
trip around the world actually they

100
00:04:47,640 --> 00:04:46,180
can't say that Magellan discovered them

101
00:04:49,350 --> 00:04:47,650
because it was just he was the first

102
00:04:52,110 --> 00:04:49,360
Europe he brought back the news of these

103
00:04:53,820 --> 00:04:52,120
objects to Europe of course anybody can

104
00:04:56,610 --> 00:04:53,830
see them they just look up if you're in

105
00:04:58,920 --> 00:04:56,620
the southern hemisphere unfortunately we

106
00:05:00,059 --> 00:04:58,930
can't see them here from Baltimore but

107
00:05:02,490 --> 00:05:00,069
if you do get down in the southern

108
00:05:04,860 --> 00:05:02,500
hemisphere you must look up get find a

109
00:05:07,439 --> 00:05:04,870
dark spot and it's just beautiful to see

110
00:05:09,240 --> 00:05:07,449
these these clouds up there in the sky

111
00:05:10,589 --> 00:05:09,250
so that's the large magellanic cloud and

112
00:05:14,520 --> 00:05:10,599
if there's a large magellanic cloud

113
00:05:16,589 --> 00:05:14,530

there's also a small magellanic cloud

114
00:05:20,820 --> 00:05:16,599
yes this is the small Magellanic Cloud

115
00:05:23,249 --> 00:05:20,830
now these two clouds are not clouds they

116
00:05:25,200 --> 00:05:23,259
look kind of cloudy when viewed with the

117
00:05:27,809 --> 00:05:25,210
human eye but as you can see from these

118
00:05:30,240 --> 00:05:27,819
images they're composed of millions of

119
00:05:33,149 --> 00:05:30,250
stars they are actually satellite

120
00:05:35,999 --> 00:05:33,159
galaxies of the Milky Way the LMC and

121
00:05:37,950 --> 00:05:36,009
the SMC are two satellite galaxies

122
00:05:40,769 --> 00:05:37,960
they're actually orbiting around the

123
00:05:43,170 --> 00:05:40,779
Milky Way how do we know that they are

124
00:05:44,850 --> 00:05:43,180
orbiting well we can measure their

125
00:05:47,879 --> 00:05:44,860
dynamics and everything but it's

126
00:05:50,640 --> 00:05:47,889
actually kind of easy when you look at

127
00:05:54,240 --> 00:05:50,650
them in radio light because in radio

128
00:05:56,519 --> 00:05:54,250
light you see this sorry I changed the

129
00:05:58,769 --> 00:05:56,529
Milky Way from a longitude latitude

130
00:06:02,089 --> 00:05:58,779
projection to what this is an eighth off

131
00:06:04,830 --> 00:06:02,099
all sky projection but here are the

132
00:06:07,019 --> 00:06:04,840
large and small Magellanic Clouds and

133
00:06:09,959 --> 00:06:07,029
you see this radio light coming along

134
00:06:12,209 --> 00:06:09,969
here okay and you see all this junk up

135
00:06:14,369 --> 00:06:12,219
here also associated with Magellanic

136
00:06:16,709 --> 00:06:14,379
Clouds okay so let me put on some some

137
00:06:19,320 --> 00:06:16,719
graphics we've got the LMC and the SMC

138
00:06:23,999 --> 00:06:19,330

and then this is called the Magellanic

139
00:06:27,420 --> 00:06:24,009
stream okay and this is understood to be

140
00:06:30,029 --> 00:06:27,430
material that has been pulled out of the

141
00:06:31,890 --> 00:06:30,039
large and small Magellanic Clouds due to

142
00:06:34,529 --> 00:06:31,900
this sort of tug-of-war as they're

143
00:06:37,379 --> 00:06:34,539
orbiting around gravity pulls on these

144
00:06:39,540 --> 00:06:37,389
galaxies and if you've got the Milky Way

145
00:06:41,459 --> 00:06:39,550
which is a large galaxy and you've got

146
00:06:43,200 --> 00:06:41,469
the LMC and the SMC which are small

147
00:06:47,490 --> 00:06:43,210
galaxies and they're in a tug-of-war

148
00:06:49,629 --> 00:06:47,500
who's gonna win yeah you can see here

149
00:06:51,909 --> 00:06:49,639
the out of the Milky Way galaxy

150
00:06:55,089 --> 00:06:51,919
is gonna win and you get this big title

151
00:06:56,770 --> 00:06:55,099
tail of material that we previously used

152
00:06:58,420 --> 00:06:56,780
Hubble observations to understand that

153
00:07:00,969 --> 00:06:58,430
they kept this material actually

154
00:07:04,269 --> 00:07:00,979
contains material from both the SMC and

155
00:07:07,390 --> 00:07:04,279
the LMC now that's sort of what we call

156
00:07:09,519 --> 00:07:07,400
the trailing arm of a title interaction

157
00:07:11,739 --> 00:07:09,529
stuff that's pulled out okay but stuff

158
00:07:13,269 --> 00:07:11,749
also pulls out on the near side due to

159
00:07:15,279 --> 00:07:13,279
the gravitational interactions these

160
00:07:17,679 --> 00:07:15,289
tidal interactions and this is the

161
00:07:20,140 --> 00:07:17,689
leading arm of it and that stuff is

162
00:07:23,080 --> 00:07:20,150
actually falling into and interacting

163
00:07:25,240 --> 00:07:23,090

with the Milky Way and we do not know

164
00:07:29,550 --> 00:07:25,250
where that leading arm material comes

165
00:07:32,019 --> 00:07:29,560
from and if you just look at it sort of

166
00:07:34,510 --> 00:07:32,029
geometrically right it's closer to the

167
00:07:38,730 --> 00:07:34,520
LMC and you say oh maybe that stuff is

168
00:07:42,850 --> 00:07:38,740
from the LMC dynamically you can't tell

169
00:07:45,459 --> 00:07:42,860
however you can tell if you use spectra

170
00:07:48,610 --> 00:07:45,469
all right so what we did is we found

171
00:07:51,219 --> 00:07:48,620
three quasars these are very distant

172
00:07:53,200 --> 00:07:51,229
very bright objects and their light is

173
00:07:56,260 --> 00:07:53,210
actually shining through this material

174
00:07:59,170 --> 00:07:56,270
and so we can look in the spectrum of

175
00:08:02,140 --> 00:07:59,180
the quasar to see what type of material

176
00:08:05,529 --> 00:08:02,150
is in this leading arm so here are the

177
00:08:08,379 --> 00:08:05,539
spectra all right quasar a quasar being

178
00:08:10,450 --> 00:08:08,389
quasar C and these are just uh you know

179
00:08:11,969 --> 00:08:10,460
graphic artist versions of them to show

180
00:08:15,389 --> 00:08:11,979
the hydrogen and the oxygen

181
00:08:18,850 --> 00:08:15,399
concentration in these various spectra

182
00:08:21,129 --> 00:08:18,860
so what we're looking at is what is the

183
00:08:24,519 --> 00:08:21,139
relative abundance of hydrogen and

184
00:08:26,559 --> 00:08:24,529
oxygen in this material and does it

185
00:08:29,320 --> 00:08:26,569
match the hydrogen oxygen abundance in

186
00:08:33,870 --> 00:08:29,330
the LMC or the SMC or is it a little bit

187
00:08:38,139 --> 00:08:33,880
of both the answer is it's from the SMC

188
00:08:40,149 --> 00:08:38,149

so the conclusion is that the LMC is

189
00:08:42,759 --> 00:08:40,159
pulling more material out of the SMC

190
00:08:44,860 --> 00:08:42,769
that is then falling in to form this

191
00:08:46,449 --> 00:08:44,870
leading arm at least these three signs

192
00:08:49,000 --> 00:08:46,459
that actually I think there were seven

193
00:08:53,199 --> 00:08:49,010
lines of sight through the leading arm

194
00:08:57,000 --> 00:08:53,209
and the oxygen to hydrogen ratio matches

195
00:08:59,110 --> 00:08:57,010
that of the SMC and not that of the LMC

196
00:09:00,639 --> 00:08:59,120
indicating that when you go with a large

197
00:09:02,850 --> 00:09:00,649
magellanic cloud versus the small

198
00:09:05,190 --> 00:09:02,860
magellanic cloud in a tug-of-war

199
00:09:07,920 --> 00:09:05,200
who's gonna win the Large Magellanic

200
00:09:10,110 --> 00:09:07,930
Cloud seems to win and that material is

201
00:09:11,490 --> 00:09:10,120
as can be traced back to the SMC and

202
00:09:14,460 --> 00:09:11,500
this is the first time we've been able

203
00:09:16,440 --> 00:09:14,470
to get the full understanding of this

204
00:09:18,450 --> 00:09:16,450
full Magellanic stream of these dwarf

205
00:09:20,490 --> 00:09:18,460
galaxies and they're losing you know

206
00:09:22,130 --> 00:09:20,500
just a small bit of the material as they

207
00:09:29,430 --> 00:09:22,140
orbit around the Milky Way

208
00:09:32,250 --> 00:09:29,440
yes question I don't know what has to be

209
00:09:34,050 --> 00:09:32,260
hundreds of millions of years could be

210
00:09:37,710 --> 00:09:34,060
as much as 500 million years do you know

211
00:09:39,870 --> 00:09:37,720
will yeah he he would guess the same

212
00:09:41,690 --> 00:09:39,880
amount so uh a few hundred million years

213
00:09:44,400 --> 00:09:41,700

maybe five hundred million years because

214
00:09:46,830 --> 00:09:44,410
our Sun orbiting within the Milky Way is

215
00:09:48,840 --> 00:09:46,840
200 250 million years and that of that

216
00:09:51,120 --> 00:09:48,850
timeframe so these are already way

217
00:09:56,040 --> 00:09:51,130
outside so I got to give it probably

218
00:09:58,080 --> 00:09:56,050
about 500 million okay yes they're there

219
00:10:00,210 --> 00:09:58,090
they're not in the plane they are if the

220
00:10:01,860 --> 00:10:00,220
plane is here they're down here and

221
00:10:05,280 --> 00:10:01,870
they're coming and we're not exactly

222
00:10:07,380 --> 00:10:05,290
sure they're of their exact orbit you

223
00:10:09,780 --> 00:10:07,390
can sort of trace and get a get a feel

224
00:10:12,780 --> 00:10:09,790
for it from the dynamics of that but

225
00:10:14,520 --> 00:10:12,790
it's it's it's still there's still

226
00:10:37,710 --> 00:10:14,530
significant uncertainty in the exact

227
00:10:40,620 --> 00:10:37,720
orbits of them okay yes okay so you're

228
00:10:42,990 --> 00:10:40,630
asking alright how far out into the

229
00:10:45,540 --> 00:10:43,000
Milky Way can we see with the human eye

230
00:10:46,730 --> 00:10:45,550
you're seeing just a small region of the

231
00:10:48,840 --> 00:10:46,740
Milky Way

232
00:10:50,160 --> 00:10:48,850
you didn't mean there's certain things

233
00:10:52,740 --> 00:10:50,170
that you can see that are really far

234
00:10:55,320 --> 00:10:52,750
away but most of all the stars you can

235
00:10:57,330 --> 00:10:55,330
see with the the human eye are about the

236
00:10:59,550 --> 00:10:57,340
size of a sausage on a 16 inch pizza

237
00:11:01,530 --> 00:10:59,560
okay that's the volume that you can see

238
00:11:02,820 --> 00:11:01,540

and maybe if you include all the other

239
00:11:06,030 --> 00:11:02,830
stuff you can see it gets out to the

240
00:11:08,490 --> 00:11:06,040
size about pepperoni on a pizza but you

241
00:11:08,880 --> 00:11:08,500
really can't see much much further than

242
00:11:12,270 --> 00:11:08,890
that

243
00:11:13,320 --> 00:11:12,280
okay questions about the the news story

244
00:11:14,880 --> 00:11:13,330
because I don't want to eat into wills

245
00:11:17,430 --> 00:11:14,890
time yeah

246
00:11:19,710 --> 00:11:17,440
in the arm is that dust or is it are

247
00:11:21,720 --> 00:11:19,720
there stars in there yes the the the

248
00:11:23,220 --> 00:11:21,730
with it within the spiral galaxy we have

249
00:11:27,750 --> 00:11:23,230
a lot of dust and we have a lot of stars

250
00:11:30,000 --> 00:11:27,760
the spiral arms contain both oh these

251
00:11:33,840 --> 00:11:30,010
are the these Magellanic streams no this

252
00:11:36,600 --> 00:11:33,850
is just I assume its hydrogen gas that

253
00:11:38,580 --> 00:11:36,610
you would decked in the radio there will

254
00:11:40,890 --> 00:11:38,590
be you know there will be some stars in

255
00:11:42,420 --> 00:11:40,900
this but it's not place where stars

256
00:11:44,060 --> 00:11:42,430
would be made because it's very diffused

257
00:11:49,650 --> 00:11:44,070
material okay

258
00:11:52,410 --> 00:11:49,660
second-story exoplanet helium alright so

259
00:11:54,570 --> 00:11:52,420
uh we all took him how many of you took

260
00:11:55,890 --> 00:11:54,580
chemistry or will take chemistry for the

261
00:11:57,360 --> 00:11:55,900
for the young kids in the audience right

262
00:11:59,100 --> 00:11:57,370
put your hands up you're gonna take

263
00:12:00,720 --> 00:11:59,110

chemistry right he's Peter you're gonna

264
00:12:03,750 --> 00:12:00,730
make sure she takes chemistry okay good

265
00:12:05,670 --> 00:12:03,760
alright if you took chemistry you

266
00:12:07,590 --> 00:12:05,680
remember the periodic table of the

267
00:12:11,730 --> 00:12:07,600
elements and maybe you remember with

268
00:12:14,130 --> 00:12:11,740
dread but it's a really cool diagram

269
00:12:17,130 --> 00:12:14,140
okay it really puts things in lots of

270
00:12:20,220 --> 00:12:17,140
order but there's a ton of elements out

271
00:12:22,860 --> 00:12:20,230
there okay there's a lot of really

272
00:12:25,170 --> 00:12:22,870
interesting stuff out there but for the

273
00:12:28,400 --> 00:12:25,180
universe we can simplify it we really

274
00:12:30,780 --> 00:12:28,410
only have to look it up here and up here

275
00:12:35,550 --> 00:12:30,790
because when we look at the content of

276
00:12:38,250 --> 00:12:35,560
the universe it's 75% hydrogen 23%

277
00:12:41,340 --> 00:12:38,260
helium and 2% other and that's by mass

278
00:12:42,930 --> 00:12:41,350
okay so it's mostly hydrogen helium and

279
00:12:45,420 --> 00:12:42,940
yeah there's all that other stuff okay

280
00:12:47,820 --> 00:12:45,430
which is why we astronomers talk about

281
00:12:50,970 --> 00:12:47,830
hydrogen helium and then heavy elements

282
00:12:53,130 --> 00:12:50,980
okay so when we look at that you know we

283
00:12:55,530 --> 00:12:53,140
can see hydrogen if we look at our Sun

284
00:12:57,990 --> 00:12:55,540
the composition of our Sun well that's

285
00:13:00,870 --> 00:12:58,000
pretty much the same hydrogen helium

286
00:13:02,400 --> 00:13:00,880
yeah and all this other stuff okay all

287
00:13:05,430 --> 00:13:02,410
the stuff that you really think of you

288
00:13:08,220 --> 00:13:05,440

know yeah that's just that's in the

289
00:13:11,250 --> 00:13:08,230
noise and even when you look at the

290
00:13:13,470 --> 00:13:11,260
giant planets Jupiter Saturn Uranus and

291
00:13:15,210 --> 00:13:13,480
Neptune this is a table you can see now

292
00:13:17,370 --> 00:13:15,220
this is not by mass this is by number

293
00:13:20,280 --> 00:13:17,380
eighty six and thirteen eighty eight

294
00:13:24,030 --> 00:13:20,290
eighty two eighty nineteen fifty most of

295
00:13:25,920 --> 00:13:24,040
all the stuff is hydrogen and helium all

296
00:13:27,319 --> 00:13:25,930
right so that's setting you up to

297
00:13:29,539 --> 00:13:27,329
understand that that this

298
00:13:33,949 --> 00:13:29,549
is really expected to be everywhere in

299
00:13:37,280 --> 00:13:33,959
the universe so we have found 3000

300
00:13:40,189 --> 00:13:37,290
extrasolar planets out there and a lot

301
00:13:42,799 --> 00:13:40,199
of these extrasolar planets we are able

302
00:13:45,289 --> 00:13:42,809
to we detect them by the transit method

303
00:13:47,720 --> 00:13:45,299
where the planet passes in front of its

304
00:13:50,449 --> 00:13:47,730
star and for certain ones that are

305
00:13:52,519 --> 00:13:50,459
nearby when that planet passes in front

306
00:13:54,769 --> 00:13:52,529
of a star and it's close enough to that

307
00:13:57,199 --> 00:13:54,779
star some of the light of the star goes

308
00:13:59,539 --> 00:13:57,209
through the atmosphere of that planet

309
00:14:02,269 --> 00:13:59,549
and if we take a picture when it's in

310
00:14:04,910 --> 00:14:02,279
front and when it's not in front and we

311
00:14:08,210 --> 00:14:04,920
subtract the two we get the spectrum of

312
00:14:10,879 --> 00:14:08,220
the atmosphere of the planet we can

313
00:14:13,489 --> 00:14:10,889

examine the atmospheres of other planets

314
00:14:17,449 --> 00:14:13,499
and so for example here is an example

315
00:14:19,999 --> 00:14:17,459
spectrum of planet called wasp 39b

316
00:14:22,489 --> 00:14:20,009
and these features here are associated

317
00:14:24,530 --> 00:14:22,499
with water molecules and these are

318
00:14:27,169 --> 00:14:24,540
associated with carbon dioxide and this

319
00:14:30,259 --> 00:14:27,179
is potassium and this is sodium and we

320
00:14:33,669 --> 00:14:30,269
have seen methane and we seen ammonia we

321
00:14:38,900 --> 00:14:33,679
have seen all sorts of species out there

322
00:14:40,549 --> 00:14:38,910
we've never seen helium which if given

323
00:14:42,769 --> 00:14:40,559
the intro that I did for this is kind of

324
00:14:45,530 --> 00:14:42,779
strange because you would expect there's

325
00:14:51,889 --> 00:14:45,540
a lot of helium out there and we have

326
00:14:55,879 --> 00:14:51,899
never seen it until obviously last 107

327
00:14:58,340 --> 00:14:55,889
be ok this is an artist illustration of

328
00:15:01,429 --> 00:14:58,350
it well it's actually you know this is

329
00:15:04,850 --> 00:15:01,439
not wasp 107 this is the Sun acting as a

330
00:15:08,239 --> 00:15:04,860
stunt double for wasp 107 and this would

331
00:15:10,429 --> 00:15:08,249
be wasps 107 be drawn in this and you

332
00:15:15,259 --> 00:15:10,439
can see it's got this very extended

333
00:15:18,939 --> 00:15:15,269
extended in wasp 107 be using infrared

334
00:15:21,930 --> 00:15:18,949
spectra we were finally able to detect

335
00:15:24,180 --> 00:15:21,940
helium

336
00:15:26,840 --> 00:15:24,190
in in in in the atmosphere of a planet

337
00:15:29,850 --> 00:15:26,850
and you might say well why did it take

338
00:15:31,620 --> 00:15:29,860

this special well first of all previous

339
00:15:35,760 --> 00:15:31,630
observations had been using visible

340
00:15:39,660 --> 00:15:35,770
light and ultraviolet light and they did

341
00:15:42,780 --> 00:15:39,670
not find the the helium and it turns out

342
00:15:44,430 --> 00:15:42,790
that you know the interesting lines that

343
00:15:49,110 --> 00:15:44,440
you want are can be found in the

344
00:15:52,110 --> 00:15:49,120
infrared but also lost 107 B is one of

345
00:15:55,380 --> 00:15:52,120
the lowest density giant planets we've

346
00:15:59,340 --> 00:15:55,390
ever discovered okay it is the same size

347
00:16:02,550 --> 00:15:59,350
as Jupiter but it's only 12% the mass of

348
00:16:04,769 --> 00:16:02,560
Jupiter that's really low density and

349
00:16:07,440 --> 00:16:04,779
these giant planets aren't very high

350
00:16:09,260 --> 00:16:07,450
density to begin with okay and they say

351
00:16:12,510 --> 00:16:09,270
that Saturn would float in a bathtub

352
00:16:15,090 --> 00:16:12,520
which is kind of funky but anyways it's

353
00:16:17,700 --> 00:16:15,100
lower density than water alright this is

354
00:16:20,250 --> 00:16:17,710
really really low density which means

355
00:16:23,070 --> 00:16:20,260
its atmosphere must be it's really

356
00:16:26,040 --> 00:16:23,080
really extended and must extend tens of

357
00:16:28,769 --> 00:16:26,050
thousands of kilometers out into space

358
00:16:31,680 --> 00:16:28,779
and it's because it's such a low density

359
00:16:34,050 --> 00:16:31,690
planet it has this really extended

360
00:16:36,350 --> 00:16:34,060
atmosphere it's in close to its star and

361
00:16:39,269 --> 00:16:36,360
they did the observations in infrared

362
00:16:41,970 --> 00:16:39,279
that they finally been able to discover

363
00:16:43,769 --> 00:16:41,980

helium in other planet atmospheres we

364
00:16:45,930 --> 00:16:43,779
always knew it inspected it would be

365
00:16:48,150 --> 00:16:45,940
there but it's really kind of nice to

366
00:16:50,400 --> 00:16:48,160
find what to expect and not be missing

367
00:16:52,290 --> 00:16:50,410
one of the the two primary elements in

368
00:16:55,560 --> 00:16:52,300
the universe in extrasolar planet

369
00:16:57,600 --> 00:16:55,570
atmospheres all right and so that's our

370
00:16:59,490 --> 00:16:57,610
news summary for tonight any other

371
00:17:07,650 --> 00:16:59,500
questions on the two stories I presented

372
00:17:08,970 --> 00:17:07,660
to here yes so the question of why we

373
00:17:10,679 --> 00:17:08,980
didn't find it in all the other planets

374
00:17:12,840 --> 00:17:10,689
is because this is an extended

375
00:17:15,900 --> 00:17:12,850
atmosphere without the extended

376
00:17:17,340 --> 00:17:15,910
atmosphere the helium layers aren't

377
00:17:19,260 --> 00:17:17,350
weren't exposed okay

378
00:17:21,199 --> 00:17:19,270
Alice that's the current understanding

379
00:17:23,880 --> 00:17:21,209
we'll have to detect it in a few more

380
00:17:25,980 --> 00:17:23,890
planets and a whole to get a

381
00:17:28,049 --> 00:17:25,990
statistical sense of when we can see

382
00:17:30,570 --> 00:17:28,059
helium and when we can't but now we know

383
00:17:32,860 --> 00:17:30,580
how to find it we will look at the other

384
00:17:35,800 --> 00:17:32,870
ones and see if we can get a

385
00:17:37,630 --> 00:17:35,810
enough to make a statistical argument as

386
00:17:39,910 --> 00:17:37,640
to exactly why we're not seeing in any

387
00:17:47,220 --> 00:17:39,920
other and any of the others okay all

388
00:17:52,360 --> 00:17:50,380

featured speaker tonight is dr. wil

389
00:17:54,700 --> 00:17:52,370
Fisher from here at the Space Telescope

390
00:17:56,500 --> 00:17:54,710
Science Institute he got his

391
00:17:59,890 --> 00:17:56,510
undergraduate degree at the University

392
00:18:05,410 --> 00:17:59,900
of Toledo then went on to do a postdoc

393
00:18:09,310 --> 00:18:05,420
was it Goddard first or Toledo for the

394
00:18:11,920 --> 00:18:09,320
post Oh Toledo for a postdoc and then to

395
00:18:13,780 --> 00:18:11,930
Goddard for that and then he came what

396
00:18:16,390 --> 00:18:13,790
did you come right here from Goddard yes

397
00:18:19,570 --> 00:18:16,400
okay so he came to us from Goddard only

398
00:18:22,240 --> 00:18:19,580
a year year-and-a-half ago and his work

399
00:18:26,080 --> 00:18:22,250
is as a support scientist for the cosmic

400
00:18:29,020 --> 00:18:26,090
origins spectrograph and when he is not

401
00:18:31,660 --> 00:18:29,030
doing his astronomy he is a father of an

402
00:18:33,520 --> 00:18:31,670
11 year old girl who has gotten

403
00:18:35,950 --> 00:18:33,530
interested in astronomy he tells me but

404
00:18:38,740 --> 00:18:35,960
from a special perspective she likes to

405
00:18:41,560 --> 00:18:38,750
explore the art of astronomy astronomy

406
00:18:43,870 --> 00:18:41,570
and art so he's leading his daughter

407
00:18:47,110 --> 00:18:43,880
into not just a stem career but a steam

408
00:18:49,570 --> 00:18:47,120
career science technology arts and

409
00:18:59,950 --> 00:18:49,580
mathematics so ladies and gentlemen dr.

410
00:19:00,280 --> 00:18:59,960
will Fisher well thanks for coming

411
00:19:03,370 --> 00:19:00,290
everyone

412
00:19:07,630 --> 00:19:03,380
to start here I'm showing you a picture

413
00:19:11,740 --> 00:19:07,640

of Orion from Mayer's famous atlas of

414
00:19:13,690 --> 00:19:11,750
1603 and he's looking at an image of

415
00:19:16,870 --> 00:19:13,700
Orion from the infrared astronomy

416
00:19:19,300 --> 00:19:16,880
satellite which orbited in the 1980s and

417
00:19:20,920 --> 00:19:19,310
you might imagine that Orion is a little

418
00:19:23,830 --> 00:19:20,930
bit puzzled to learn what he's really

419
00:19:26,380 --> 00:19:23,840
made up of I'm gonna be telling you all

420
00:19:28,660 --> 00:19:26,390
about Star formation in Orion and how we

421
00:19:30,700 --> 00:19:28,670
learn about this with a lot of different

422
00:19:34,420 --> 00:19:30,710
space telescopes and a few that aren't

423
00:19:36,700 --> 00:19:34,430
quite in space so one of the reasons

424
00:19:38,950 --> 00:19:36,710
that were interested in how stars form

425
00:19:40,540 --> 00:19:38,960
is all of these thousands of exoplanets

426
00:19:43,240 --> 00:19:40,550
that have been discovered over the last

427
00:19:45,289 --> 00:19:43,250
20 to 25 years this is an artist's

428
00:19:49,070 --> 00:19:45,299
rendition of some of those at

429
00:19:52,960 --> 00:19:49,080
so planets and they exists in a wide

430
00:19:55,430 --> 00:19:52,970
variety of densities and compositions

431
00:19:58,070 --> 00:19:55,440
they orbit at some pretty surprising

432
00:20:00,109 --> 00:19:58,080
distances from their stars and to

433
00:20:01,759 --> 00:20:00,119
understand how all this comes to exist

434
00:20:04,609 --> 00:20:01,769
we have to know how the parent stars

435
00:20:06,229 --> 00:20:04,619
form so this has given new importance to

436
00:20:11,919 --> 00:20:06,239
studies of star formation in the past

437
00:20:13,789 --> 00:20:11,929
few decades but star formation began

438
00:20:16,399 --> 00:20:13,799

quite some time ago

439
00:20:18,440 --> 00:20:16,409
I think of 1852 is the beginning of star

440
00:20:20,419 --> 00:20:18,450
formation studies this is when this

441
00:20:22,940 --> 00:20:20,429
astronomer pictured here John Russell

442
00:20:24,710 --> 00:20:22,950
hind discovered a nebula that we now

443
00:20:27,830 --> 00:20:24,720
known as Hines nebula and there is a

444
00:20:31,340 --> 00:20:27,840
star in that nebula called t-tauri if

445
00:20:33,200 --> 00:20:31,350
you see a star where its name begins

446
00:20:36,830 --> 00:20:33,210
with one or two capital letters that

447
00:20:38,570 --> 00:20:36,840
means it's a variable star T Tauri as a

448
00:20:41,509 --> 00:20:38,580
variable star changed in brightness

449
00:20:44,060 --> 00:20:41,519
somewhat irregularly over periods of

450
00:20:46,039 --> 00:20:44,070
days to weeks but the interesting thing

451
00:20:48,379 --> 00:20:46,049
about this discovery is that the nebula

452
00:20:51,409 --> 00:20:48,389
also varied in brightness along with the

453
00:20:53,359 --> 00:20:51,419
star so that's a sign that the star and

454
00:20:56,930 --> 00:20:53,369
the nebula are physically connected the

455
00:20:58,190 --> 00:20:56,940
star is embedded in the nebula people

456
00:21:01,669 --> 00:20:58,200
didn't know what to make of this at

457
00:21:03,889 --> 00:21:01,679
first but as time went on more of these

458
00:21:06,560 --> 00:21:03,899
T Tauri like stars were discovered and

459
00:21:10,310 --> 00:21:06,570
then finally in an important paper in

460
00:21:14,299 --> 00:21:10,320
1945 the astronomer Alfred joy laid out

461
00:21:17,269 --> 00:21:14,309
the class of T Tauri stars often a class

462
00:21:19,220 --> 00:21:17,279
of objects in the sky is named after the

463
00:21:20,899 --> 00:21:19,230

first one to be discovered and this is

464
00:21:22,879 --> 00:21:20,909
an important step in putting a science

465
00:21:24,529 --> 00:21:22,889
together to go from a single object to

466
00:21:26,779 --> 00:21:24,539
understanding that there's a collection

467
00:21:29,659 --> 00:21:26,789
of objects that all have similar

468
00:21:31,879 --> 00:21:29,669
observational properties this is a light

469
00:21:34,729 --> 00:21:31,889
curve of an example of a T Tauri star

470
00:21:37,639 --> 00:21:34,739
and when you plot a light curve high

471
00:21:40,039 --> 00:21:37,649
points are bright and low points are dim

472
00:21:41,869 --> 00:21:40,049
and you plot those against time so you

473
00:21:44,060 --> 00:21:41,879
can see over the course of about a month

474
00:21:46,729 --> 00:21:44,070
you have these irregular variations in a

475
00:21:49,279 --> 00:21:46,739
T Tauri star and the change in

476
00:21:52,519 --> 00:21:49,289
brightness here corresponds to about a

477
00:21:57,230 --> 00:21:52,529
factor of 10 or a little bit less than

478
00:21:58,520 --> 00:21:57,240
10 and he recognized that there were 11

479
00:22:00,380 --> 00:21:58,530
known stars that had

480
00:22:02,480 --> 00:22:00,390
herbs like this and they were all in

481
00:22:05,900 --> 00:22:02,490
nebulous regions of the sky in these

482
00:22:08,660 --> 00:22:05,910
clouds so these must all have something

483
00:22:10,120 --> 00:22:08,670
to do with each other and people started

484
00:22:12,290 --> 00:22:10,130
to try to make some sense of this

485
00:22:15,020 --> 00:22:12,300
scientific understanding began to

486
00:22:17,540 --> 00:22:15,030
develop and this is Cecilia Payne de

487
00:22:20,660 --> 00:22:17,550
pasión she is my daughter's scientific

488
00:22:22,340 --> 00:22:20,670

hero I guess you could say she was the

489
00:22:23,630 --> 00:22:22,350
one who discovered what stars are made

490
00:22:26,000 --> 00:22:23,640
of that they're mostly hydrogen and

491
00:22:27,170 --> 00:22:26,010
helium nobody believed her for a few

492
00:22:29,150 --> 00:22:27,180
years because this was such a radical

493
00:22:32,060 --> 00:22:29,160
idea but eventually people came to

494
00:22:33,590 --> 00:22:32,070
realize that she was right after some of

495
00:22:35,780 --> 00:22:33,600
her most important discovery she began

496
00:22:39,140 --> 00:22:35,790
to write about science and astronomy for

497
00:22:40,910 --> 00:22:39,150
public audiences here in 1952 she said

498
00:22:43,700 --> 00:22:40,920
perhaps the nebula is in some way

499
00:22:45,680 --> 00:22:43,710
responsible for their very existence so

500
00:22:48,500 --> 00:22:45,690
people were beginning to figure out that

501
00:22:50,240 --> 00:22:48,510
maybe stars formed from nebulae and this

502
00:22:52,370 --> 00:22:50,250
is one of the earliest photographs of

503
00:22:54,380 --> 00:22:52,380
the Orion Nebula so you can see there

504
00:22:58,430 --> 00:22:54,390
are several stars that are potentially

505
00:23:00,890 --> 00:22:58,440
embedded in that nebula it all came

506
00:23:03,200 --> 00:23:00,900
together when two astronomers were able

507
00:23:06,020 --> 00:23:03,210
to make sense of it all so on the left

508
00:23:07,880 --> 00:23:06,030
here is Victor and Barsoomian he was an

509
00:23:09,350 --> 00:23:07,890
armenian astronomer which meant that at

510
00:23:09,800 --> 00:23:09,360
the time he was working in the soviet

511
00:23:13,880 --> 00:23:09,810
union

512
00:23:15,700 --> 00:23:13,890
had a pretty limited understanding of

513
00:23:18,680 --> 00:23:15,710

the science that was going on there and

514
00:23:21,290 --> 00:23:18,690
then independently george herbert who

515
00:23:25,250 --> 00:23:21,300
was on the faculty at the university of

516
00:23:29,060 --> 00:23:25,260
hawaii both argued that t-tauri stars

517
00:23:31,190 --> 00:23:29,070
must be young they are clustered here's

518
00:23:35,690 --> 00:23:31,200
a cluster of many many t-tauri stars

519
00:23:37,040 --> 00:23:35,700
it's a Hubble image of NGC 3603 and not

520
00:23:39,430 --> 00:23:37,050
only are they clustered but they're

521
00:23:41,870 --> 00:23:39,440
embedded in these clouds of gas and dust

522
00:23:43,730 --> 00:23:41,880
so these are signs that these are young

523
00:23:47,620 --> 00:23:43,740
stars that they have formed from the

524
00:23:50,330 --> 00:23:47,630
nebula itself and this was

525
00:23:52,880 --> 00:23:50,340
philosophically an important advance in

526
00:23:55,460 --> 00:23:52,890
the thinking of astronomers for

527
00:23:57,500 --> 00:23:55,470
millennia people had imagined that the

528
00:23:59,960 --> 00:23:57,510
universe had all come together and was

529
00:24:02,420 --> 00:23:59,970
formed sometime in the distant past and

530
00:24:04,550 --> 00:24:02,430
humanity showed up and it was our job to

531
00:24:07,820 --> 00:24:04,560
figure out what was already there but

532
00:24:10,190 --> 00:24:07,830
this was one of the first signs that the

533
00:24:10,600 --> 00:24:10,200
cosmos was still in the act of forming

534
00:24:13,480 --> 00:24:10,610
its

535
00:24:16,240 --> 00:24:13,490
that new objects and new potential

536
00:24:18,360 --> 00:24:16,250
places were continuing to form out of

537
00:24:23,320 --> 00:24:18,370
the original materials of the universe

538
00:24:25,299 --> 00:24:23,330

so we are in an evolving universe today

539
00:24:28,000 --> 00:24:25,309
we know of thousands of young stars in

540
00:24:30,310 --> 00:24:28,010
various star forming regions here's the

541
00:24:33,039 --> 00:24:30,320
Orion Nebula and then these are some

542
00:24:34,930 --> 00:24:33,049
other star forming regions in our galaxy

543
00:24:43,330 --> 00:24:34,940
where you can see these young stars

544
00:24:45,460 --> 00:24:43,340
forming from gas and dust clouds now

545
00:24:49,419 --> 00:24:45,470
this is our conceptual picture of how

546
00:24:51,370 --> 00:24:49,429
these stars form you have these huge

547
00:24:54,539 --> 00:24:51,380
clouds of gas and dust that can give

548
00:24:58,120 --> 00:24:54,549
birth to thousands of solar systems and

549
00:24:59,950 --> 00:24:58,130
in small regions of those clouds you

550
00:25:02,530 --> 00:24:59,960
might have just enough material that the

551
00:25:04,530 --> 00:25:02,540
gravity of that material is powerful

552
00:25:07,930 --> 00:25:04,540
enough to cause it to start collapsing

553
00:25:10,570 --> 00:25:07,940
so early on you have a dusty envelope

554
00:25:13,380 --> 00:25:10,580
that's collapsing and becoming more and

555
00:25:17,470 --> 00:25:13,390
more dense and hotter at its center

556
00:25:20,310 --> 00:25:17,480
after about 150,000 years most of that

557
00:25:22,720 --> 00:25:20,320
envelope has formed into a central star

558
00:25:25,750 --> 00:25:22,730
but the material doesn't just fall

559
00:25:27,520 --> 00:25:25,760
directly onto the star these cores are

560
00:25:29,560 --> 00:25:27,530
spinning very slowly and anything that

561
00:25:32,680 --> 00:25:29,570
spins as it falls in word instead of

562
00:25:36,250 --> 00:25:32,690
forming just a central sphere it's gonna

563
00:25:40,030 --> 00:25:36,260

first form a disk so this disk forms and

564
00:25:41,560 --> 00:25:40,040
it progresses to feed onto the star so

565
00:25:44,260 --> 00:25:41,570
for a few hundred thousand years you

566
00:25:46,240 --> 00:25:44,270
have a star with a disk kind of a

567
00:25:48,130 --> 00:25:46,250
remnant remnant envelope still falling

568
00:25:49,780 --> 00:25:48,140
onto the disk and then some fraction of

569
00:25:53,169 --> 00:25:49,790
that material gets ejected from the

570
00:25:55,690 --> 00:25:53,179
poles of the stars carving out a cavity

571
00:25:57,850 --> 00:25:55,700
in the envelope and sometimes you can

572
00:26:01,150 --> 00:25:57,860
see some pretty dramatic outflows gas

573
00:26:03,280 --> 00:26:01,160
being launched from the star after about

574
00:26:04,810 --> 00:26:03,290
five hundred thousand years the envelope

575
00:26:07,060 --> 00:26:04,820
is gone and you're left with a disk

576
00:26:09,340 --> 00:26:07,070
orbiting the star and that disk may be

577
00:26:11,620 --> 00:26:09,350
forming planets that's a really hot

578
00:26:13,240 --> 00:26:11,630
topic of research right now how early in

579
00:26:15,610 --> 00:26:13,250
the formation of a star do you see

580
00:26:17,289 --> 00:26:15,620
planets and the signs are starting to

581
00:26:19,870 --> 00:26:17,299
point to planets forming almost as soon

582
00:26:22,090 --> 00:26:19,880
as the star does there's a lot of debate

583
00:26:23,379 --> 00:26:22,100
if you see gaps in a disc does that

584
00:26:25,419 --> 00:26:23,389
necessarily mean there's

585
00:26:28,659 --> 00:26:25,429
planet there or could some other process

586
00:26:30,009 --> 00:26:28,669
be giving the signposts of planets after

587
00:26:32,049 --> 00:26:30,019
about two million years

588
00:26:34,509 --> 00:26:32,059

plus or minus a million years it varies

589
00:26:36,810 --> 00:26:34,519
a lot from system to system that disk is

590
00:26:39,339 --> 00:26:36,820
gone and you're left with planets

591
00:26:41,859 --> 00:26:39,349
orbiting the star and this is a very

592
00:26:47,349 --> 00:26:41,869
stable situation in many cases it lasts

593
00:26:49,810 --> 00:26:47,359
for billions of years now where are

594
00:26:51,549 --> 00:26:49,820
stars forming in our galaxy this is an

595
00:26:53,079 --> 00:26:51,559
artist's rendition of the Milky Way by

596
00:26:56,799 --> 00:26:53,089
Robert heard at the Spitzer Science

597
00:26:58,749 --> 00:26:56,809
Center and you can see the sort of dense

598
00:27:01,839 --> 00:26:58,759
central bulge of our galaxy and the

599
00:27:04,269 --> 00:27:01,849
spiral arms the stars are forming in the

600
00:27:06,339 --> 00:27:04,279
coldest parts of the galaxy you can see

601
00:27:08,979 --> 00:27:06,349
these little brown clouds here these are

602
00:27:10,749 --> 00:27:08,989
cold molecular clouds they're so cold

603
00:27:12,909 --> 00:27:10,759
that the gas forms in the moist

604
00:27:16,509 --> 00:27:12,919
remains in a molecular State instead of

605
00:27:18,219 --> 00:27:16,519
an atomic form so they're cold and dense

606
00:27:19,599 --> 00:27:18,229
and they start collapsing like I was

607
00:27:24,219 --> 00:27:19,609
showing you in the previous slide to

608
00:27:26,199 --> 00:27:24,229
form these new stars to really study

609
00:27:28,690 --> 00:27:26,209
where the stars are though we have to

610
00:27:31,419 --> 00:27:28,700
use more than just the light that meets

611
00:27:34,089 --> 00:27:31,429
our eyes so a star formation is really a

612
00:27:36,190 --> 00:27:34,099
challenge for multi-wavelength astronomy

613
00:27:39,069 --> 00:27:36,200

where we're using not just visible light

614
00:27:41,649 --> 00:27:39,079
but ultraviolet light infrared light

615
00:27:43,889 --> 00:27:41,659
radio waves all these different

616
00:27:46,599 --> 00:27:43,899
wavelengths of light that can reach us

617
00:27:49,690 --> 00:27:46,609
the best way to map the large-scale

618
00:27:51,999 --> 00:27:49,700
distribution of gas to form stars is by

619
00:27:54,249 --> 00:27:52,009
doing radio astronomy this is the five

620
00:27:56,379 --> 00:27:54,259
College Radio Astronomy Observatory it

621
00:27:58,749 --> 00:27:56,389
no longer exists but it was on a

622
00:28:00,759 --> 00:27:58,759
peninsula in western Massachusetts that

623
00:28:01,659 --> 00:28:00,769
extends into the Quabbin Reservoir it

624
00:28:03,940 --> 00:28:01,669
reached the end of its scientific

625
00:28:05,709 --> 00:28:03,950
lifetime and this is kind of a natural

626
00:28:07,599 --> 00:28:05,719
preserve so the agreement was they had

627
00:28:09,549 --> 00:28:07,609
to disassemble the radio telescope after

628
00:28:12,459 --> 00:28:09,559
they were done doing science with it but

629
00:28:14,829 --> 00:28:12,469
this is an image it made of carbon

630
00:28:17,560 --> 00:28:14,839
monoxide gas in the torah' star-forming

631
00:28:20,259 --> 00:28:17,570
region carbon monoxide is far from the

632
00:28:22,539 --> 00:28:20,269
most common component of these molecular

633
00:28:24,789 --> 00:28:22,549
clouds it's mostly hydrogen molecular

634
00:28:26,769 --> 00:28:24,799
hydrogen but carbon monoxide is really

635
00:28:28,479 --> 00:28:26,779
easy to detect so we're going to map a

636
00:28:31,329 --> 00:28:28,489
star-forming region that's that's a good

637
00:28:33,430 --> 00:28:31,339
way to go and you can see in this image

638
00:28:37,330 --> 00:28:33,440

this filamentary structure these long

639
00:28:40,030 --> 00:28:37,340
sort of trails of gas that's

640
00:28:42,460 --> 00:28:40,040
to a radio telescope and these trails

641
00:28:44,470 --> 00:28:42,470
are where you call or they're called

642
00:28:46,630 --> 00:28:44,480
filaments and these are the dense

643
00:28:51,640 --> 00:28:46,640
regions that are likely to form stars in

644
00:28:53,170 --> 00:28:51,650
fact are forming stars and torez I'm

645
00:28:55,800 --> 00:28:53,180
going to be telling you mostly about

646
00:28:58,150 --> 00:28:55,810
what you can do with infrared astronomy

647
00:29:01,060 --> 00:28:58,160
there's an inner multi-wavelength study

648
00:29:02,980 --> 00:29:01,070
of star formation this is Barnard dark

649
00:29:05,080 --> 00:29:02,990
cloud 68 and you can tell why it's

650
00:29:07,900 --> 00:29:05,090
called a dark cloud it's it's a cloud

651
00:29:10,480 --> 00:29:07,910
and it's dark you can see how this is a

652
00:29:14,050 --> 00:29:10,490
very dense star field but around the

653
00:29:16,900 --> 00:29:14,060
cloud you see some reddened stars around

654
00:29:19,750 --> 00:29:16,910
its edges and the center almost nothing

655
00:29:22,900 --> 00:29:19,760
pops out this is a visible light image

656
00:29:26,320 --> 00:29:22,910
if we look in the infrared it's a very

657
00:29:29,620 --> 00:29:26,330
different situation this is an infrared

658
00:29:32,200 --> 00:29:29,630
image and suddenly we see hundreds of

659
00:29:34,480 --> 00:29:32,210
stars poking through the cloud the

660
00:29:38,200 --> 00:29:34,490
advantage to infrared light is that it

661
00:29:40,180 --> 00:29:38,210
lets us see through the dust the

662
00:29:42,490 --> 00:29:40,190
infrared light escapes more easily

663
00:29:44,970 --> 00:29:42,500

through this dust and it's also

664
00:29:47,290 --> 00:29:44,980
sensitive to objects that aren't hot

665
00:29:48,760 --> 00:29:47,300
astronomers tend to play fast and loose

666
00:29:50,260 --> 00:29:48,770
with their temperature words we'll talk

667
00:29:53,410 --> 00:29:50,270
about cool things that are actually

668
00:29:55,180 --> 00:29:53,420
hundreds of degrees but this infrared

669
00:29:58,210 --> 00:29:55,190
light is really sensitive to things that

670
00:29:59,680 --> 00:29:58,220
aren't as hot as stars yet they

671
00:30:01,690 --> 00:29:59,690
eventually will be but they're there

672
00:30:03,190 --> 00:30:01,700
from a few hundred to a few thousand

673
00:30:08,500 --> 00:30:03,200
degrees that's where the infrared is

674
00:30:11,080 --> 00:30:08,510
really most useful here's a Ryan in

675
00:30:13,990 --> 00:30:11,090
visible light the famous constellation

676
00:30:16,090 --> 00:30:14,000
the three stars in the belt Betelgeuse

677
00:30:19,030 --> 00:30:16,100
is a red supergiant and the shoulder of

678
00:30:21,370 --> 00:30:19,040
Orion Rigel is a blue supergiant down

679
00:30:23,470 --> 00:30:21,380
here it is me and you have a sword

680
00:30:27,490 --> 00:30:23,480
hanging from the belt the Orion Nebula

681
00:30:31,120 --> 00:30:27,500
is this faint fuzzy patch here and so

682
00:30:34,180 --> 00:30:31,130
visible light detects stars that here's

683
00:30:37,390 --> 00:30:34,190
Orion in the infrared the picture I

684
00:30:39,190 --> 00:30:37,400
showed you at the beginning you don't

685
00:30:40,750 --> 00:30:39,200
really see many stars in this one

686
00:30:43,000 --> 00:30:40,760
Betelgeuse because it's such a bright

687
00:30:47,140 --> 00:30:43,010
red star still pops out in the infrared

688
00:30:50,960 --> 00:30:47,150

image but Rigel and the belt stars are

689
00:30:52,760 --> 00:30:50,970
totally absent and you see these bright

690
00:30:55,070 --> 00:30:52,770
regions where the stars are forming the

691
00:30:57,140 --> 00:30:55,080
Orion Nebula is now the brightest thing

692
00:30:59,630 --> 00:30:57,150
in the image and you can see that in

693
00:31:01,700 --> 00:30:59,640
Orion you have these bright star-forming

694
00:31:02,870 --> 00:31:01,710
regions extending kind of all up and

695
00:31:06,140 --> 00:31:02,880
down the southern half of the

696
00:31:07,760 --> 00:31:06,150
constellation so the infrared is really

697
00:31:14,270 --> 00:31:07,770
the key to telling us where the stars

698
00:31:15,289 --> 00:31:14,280
are forming and why is a Ryan so

699
00:31:18,020 --> 00:31:15,299
important from a star-forming

700
00:31:20,870 --> 00:31:18,030
perspective we have thousands of young

701
00:31:22,549 --> 00:31:20,880
stars in the Orion Nebula alone but it's

702
00:31:26,720 --> 00:31:22,559
really just the centerpiece of this huge

703
00:31:29,810 --> 00:31:26,730
star forming complex if you were to draw

704
00:31:32,029 --> 00:31:29,820
a circle around our solar system that

705
00:31:34,460 --> 00:31:32,039
was about fifteen hundred light years in

706
00:31:37,060 --> 00:31:34,470
radius encompassing many of the nearby

707
00:31:39,529 --> 00:31:37,070
stars that we are all familiar to us

708
00:31:43,640 --> 00:31:39,539
Orion contains more than half of the

709
00:31:45,919 --> 00:31:43,650
young forming stars in that region it's

710
00:31:48,049 --> 00:31:45,929
the nearest place where the most massive

711
00:31:50,149 --> 00:31:48,059
stars are forming so you really see the

712
00:31:53,299 --> 00:31:50,159
full spectrum of stellar masses forming

713
00:31:55,250 --> 00:31:53,309

an Orion and we can also probe a lot of

714
00:31:58,460 --> 00:31:55,260
different star forming environments in

715
00:32:01,130 --> 00:31:58,470
Orion on the left is one of these

716
00:32:02,899 --> 00:32:01,140
Barnard dark clouds this is not an Orion

717
00:32:05,659 --> 00:32:02,909
but it's just an example of isolated

718
00:32:09,529 --> 00:32:05,669
star forming you have this really dense

719
00:32:11,840 --> 00:32:09,539
field of advanced more more aged older

720
00:32:14,630 --> 00:32:11,850
stars and then this dark cloud that

721
00:32:19,970 --> 00:32:14,640
contains maybe one or a few forming

722
00:32:23,539 --> 00:32:19,980
stars here is part of Orion OMC 2 3 is

723
00:32:25,460 --> 00:32:23,549
the Orion molecular cloud 2/3 it's just

724
00:32:27,260 --> 00:32:25,470
a part of the Orion molecular clouds and

725
00:32:30,320 --> 00:32:27,270
this is an example of clustered star

726
00:32:33,560 --> 00:32:30,330
formation you can see these dark dusty

727
00:32:35,720 --> 00:32:33,570
filaments with young stars all along

728
00:32:37,909 --> 00:32:35,730
them so in Orion we can really get a

729
00:32:42,470 --> 00:32:37,919
sense for how stars interact with one

730
00:32:44,840 --> 00:32:42,480
another as they form there are even

731
00:32:47,510 --> 00:32:44,850
different environments within Orion this

732
00:32:49,399 --> 00:32:47,520
is a map of coal dust in Orion going

733
00:32:52,610 --> 00:32:49,409
from the Orion Nebula far to the south

734
00:32:54,799 --> 00:32:52,620
and then these are in sets where we zoom

735
00:32:57,310 --> 00:32:54,809
in on a couple of these regions and look

736
00:33:00,440 --> 00:32:57,320
at how stars are distributed in them

737
00:33:02,450 --> 00:33:00,450
this is a very densely populated star

738
00:33:04,409 --> 00:33:02,460

forming region within Orion that you

739
00:33:06,149 --> 00:33:04,419
might think of as a city all

740
00:33:08,369 --> 00:33:06,159
these circles mark the locations of

741
00:33:10,289 --> 00:33:08,379
young stars what we call protostars

742
00:33:12,149 --> 00:33:10,299
and the size of the circle tells you how

743
00:33:15,269 --> 00:33:12,159
luminous it is how bright it is how much

744
00:33:18,149 --> 00:33:15,279
light it's giving off so in this part of

745
00:33:20,999 --> 00:33:18,159
Orion you have very dense clusters of

746
00:33:23,340 --> 00:33:21,009
stars that are quite luminous and all

747
00:33:24,690 --> 00:33:23,350
interacting with one another farther to

748
00:33:26,970 --> 00:33:24,700
the south we have what you might think

749
00:33:29,639 --> 00:33:26,980
of as the suburbs where there are fewer

750
00:33:31,950 --> 00:33:29,649
stars there's fewer back there's less

751
00:33:34,979 --> 00:33:31,960
background emission from the from local

752
00:33:36,960 --> 00:33:34,989
gas and dust the stars are less luminous

753
00:33:39,359 --> 00:33:36,970
and there's a little bit less going on

754
00:33:41,700 --> 00:33:39,369
there so it really is sort of an

755
00:33:48,180 --> 00:33:41,710
experimental lab to see how stars form

756
00:33:49,320 --> 00:33:48,190
in different environments so I'm going

757
00:33:51,509 --> 00:33:49,330
to tell you about how we've used

758
00:33:54,060 --> 00:33:51,519
different space telescopes to understand

759
00:33:57,119 --> 00:33:54,070
star formation in Orion and it begins

760
00:33:59,430 --> 00:33:57,129
with the spitzer space telescope this is

761
00:34:02,070 --> 00:33:59,440
a point eight five meter telescope not

762
00:34:05,009 --> 00:34:02,080
huge compared to a few of the ones we'll

763
00:34:08,159 --> 00:34:05,019

be discussing it launched in 2003 and

764
00:34:09,750 --> 00:34:08,169
these infrared space telescopes they

765
00:34:12,000 --> 00:34:09,760
have to be cooled to be most effective

766
00:34:13,799 --> 00:34:12,010
they're about the same temperature as

767
00:34:15,720 --> 00:34:13,809
the objects they're trying to detect so

768
00:34:18,539 --> 00:34:15,730
if you don't cool them they're going to

769
00:34:20,250 --> 00:34:18,549
detect themselves to put it simply so

770
00:34:21,960 --> 00:34:20,260
you have to cool them down and you do

771
00:34:23,879 --> 00:34:21,970
that by putting some kind of substance

772
00:34:27,000 --> 00:34:23,889
aboard some kind of cryogen to keep it

773
00:34:28,980 --> 00:34:27,010
cold cryogen loses its effectiveness

774
00:34:32,059 --> 00:34:28,990
after a while so spitzer launched in

775
00:34:34,710 --> 00:34:32,069
2003 but it ran out of cryogen in 2009

776
00:34:36,240 --> 00:34:34,720
it's still effective at some level it

777
00:34:40,169 --> 00:34:36,250
has limited capabilities and it's

778
00:34:42,059 --> 00:34:40,179
continuing to send back data and it's in

779
00:34:43,859 --> 00:34:42,069
an earth trailing orbit this is

780
00:34:47,730 --> 00:34:43,869
approximately where it was when I put

781
00:34:49,260 --> 00:34:47,740
the slide together it's about the same

782
00:34:51,030 --> 00:34:49,270
distance from the Sun as Earth but just

783
00:34:53,220 --> 00:34:51,040
a little farther out so it orbits a

784
00:34:55,230 --> 00:34:53,230
little bit more slowly and it loses

785
00:34:56,579 --> 00:34:55,240
ground on earth as each year goes by so

786
00:34:58,170 --> 00:34:56,589
that's another thing that's limiting its

787
00:34:59,520 --> 00:34:58,180
capabilities is it's farther from Earth

788
00:35:01,530 --> 00:34:59,530

it becomes more difficult to communicate

789
00:35:04,410 --> 00:35:01,540
with it but it's been a very productive

790
00:35:09,000 --> 00:35:04,420
Space Telescope so far and we used it to

791
00:35:12,120 --> 00:35:09,010
survey Oh Ryan this is a Spitzer map of

792
00:35:14,309 --> 00:35:12,130
part of the Orion Molecular clouds you

793
00:35:17,730 --> 00:35:14,319
can see all of this bright gaseous

794
00:35:20,460 --> 00:35:17,740
material dark dusty lanes

795
00:35:22,800 --> 00:35:20,470
and young stars that are forming this

796
00:35:24,870 --> 00:35:22,810
schematic gives you a sense for why and

797
00:35:29,670 --> 00:35:24,880
infrared telescope is good at detecting

798
00:35:32,310 --> 00:35:29,680
young stars a plain old star it's light

799
00:35:33,990 --> 00:35:32,320
output peaks at wavelengths that we can

800
00:35:36,780 --> 00:35:34,000
detect with our eye is it visible or

801
00:35:38,790 --> 00:35:36,790
optical wavelengths and then it's light

802
00:35:40,350 --> 00:35:38,800
distribution falls off pretty rapidly as

803
00:35:43,740 --> 00:35:40,360
you go into the infrared the longer

804
00:35:46,080 --> 00:35:43,750
wavelengths but if you have a disc of

805
00:35:49,260 --> 00:35:46,090
relatively cool dust around the star

806
00:35:52,320 --> 00:35:49,270
that's bright in the infrared so instead

807
00:35:54,120 --> 00:35:52,330
of your basic star the spectrum of the

808
00:35:55,890 --> 00:35:54,130
star it's energy distribution falls off

809
00:35:58,859 --> 00:35:55,900
a lot more slowly through the infrared

810
00:36:01,890 --> 00:35:58,869
and thus infrared Space Telescope's are

811
00:36:04,050 --> 00:36:01,900
really good at picking these out so we

812
00:36:05,190 --> 00:36:04,060
can see the real-life equivalents of

813
00:36:07,500 --> 00:36:05,200

these cartoons I showed you earlier

814
00:36:09,359 --> 00:36:07,510
where you have the very young protostars

815
00:36:12,000 --> 00:36:09,369
where there's an envelope falling onto a

816
00:36:14,280 --> 00:36:12,010
disc and then the slightly more advanced

817
00:36:19,830 --> 00:36:14,290
young stars where much most of the

818
00:36:22,770 --> 00:36:19,840
envelope has been cleared away once we

819
00:36:24,830 --> 00:36:22,780
identified all these young stars with

820
00:36:28,500 --> 00:36:24,840
Spitzer we continued with Herschel

821
00:36:30,480 --> 00:36:28,510
Herschel was primarily funded by the

822
00:36:34,170 --> 00:36:30,490
European Space Agency but it also had

823
00:36:36,330 --> 00:36:34,180
contributions from NASA it's a big one

824
00:36:38,130 --> 00:36:36,340
three and a half meters in diameter its

825
00:36:40,410 --> 00:36:38,140
primary mirror and it operated in the

826
00:36:42,210 --> 00:36:40,420
far infrared so Spitzer was sort of mid

827
00:36:46,170 --> 00:36:42,220
infrared Herschel is even longer

828
00:36:49,320 --> 00:36:46,180
wavelengths it launched in 2009 ran out

829
00:36:51,810 --> 00:36:49,330
of cryogen in 2013 and all of Herschel's

830
00:36:54,150 --> 00:36:51,820
instruments required higher cryogen to

831
00:36:56,880 --> 00:36:54,160
operate so it's no longer you know

832
00:37:00,240 --> 00:36:56,890
producing images for us it is at a

833
00:37:03,990 --> 00:37:00,250
special point in space called l2 the

834
00:37:05,730 --> 00:37:04,000
second lagrangian point at l2 the

835
00:37:07,890 --> 00:37:05,740
Earth's gravity and the sun's gravity

836
00:37:10,020 --> 00:37:07,900
balance out so you get a stable orbit

837
00:37:13,859 --> 00:37:10,030
even though you're kind of far away from

838
00:37:16,320 --> 00:37:13,869

Earth in fact the l2 point is four times

839
00:37:19,410 --> 00:37:16,330
farther away than the moon it's really

840
00:37:21,540 --> 00:37:19,420
out there so unlike a telescope at low

841
00:37:23,240 --> 00:37:21,550
Earth orbit you can't go out to l2 and

842
00:37:26,220 --> 00:37:23,250
fix things at least not yet

843
00:37:28,620 --> 00:37:26,230
so after Herschel's life cycle was over

844
00:37:30,240 --> 00:37:28,630
that was the end of its science but l2

845
00:37:31,620 --> 00:37:30,250
is a great place to put a foreign for a

846
00:37:34,920 --> 00:37:31,630
telescope it's a stable

847
00:37:36,270 --> 00:37:34,930
orbit and things are also cold there so

848
00:37:38,610 --> 00:37:36,280
you really get a great view of the

849
00:37:40,080 --> 00:37:38,620
infrared sky from l2 and it's not the

850
00:37:41,850 --> 00:37:40,090
only telescope that's currently there

851
00:37:46,620 --> 00:37:41,860
are not additional ones you're going to

852
00:37:48,480 --> 00:37:46,630
join it how mention that later on the

853
00:37:50,850 --> 00:37:48,490
advantage to Herschel is that we could

854
00:37:53,430 --> 00:37:50,860
follow up on these protostars that

855
00:37:55,800 --> 00:37:53,440
Spitzer had identified we conducted hops

856
00:37:57,720 --> 00:37:55,810
that's the Herschel Orion protostar

857
00:37:59,490 --> 00:37:57,730
Survey these are some members of the

858
00:38:02,610 --> 00:37:59,500
hops team one of our meetings in Granada

859
00:38:05,130 --> 00:38:02,620
Spain a few years ago with Spitzer we

860
00:38:06,630 --> 00:38:05,140
found more than 500 of these protostars

861
00:38:08,160 --> 00:38:06,640
these are young stars with the dusty

862
00:38:11,220 --> 00:38:08,170
envelopes that are just beginning to

863
00:38:13,620 --> 00:38:11,230

form and then we follow it up on more

864
00:38:16,260 --> 00:38:13,630
than 300 of them with Herschel so this

865
00:38:20,130 --> 00:38:16,270
map the dark shading tells you where the

866
00:38:22,470 --> 00:38:20,140
where that dust is in Orion all up and

867
00:38:24,840 --> 00:38:22,480
down the Orion molecular clouds the

868
00:38:27,300 --> 00:38:24,850
Orion Nebula is here and then these

869
00:38:29,640 --> 00:38:27,310
circles mark the locations of protostars

870
00:38:31,140 --> 00:38:29,650
that we followed up with Herschel all

871
00:38:32,940 --> 00:38:31,150
these little thumbnails here are

872
00:38:35,300 --> 00:38:32,950
actually Spitzer images they give you a

873
00:38:38,070 --> 00:38:35,310
sense for the environment whether it's

874
00:38:40,710 --> 00:38:38,080
crowded with bright backgrounds or maybe

875
00:38:43,350 --> 00:38:40,720
somewhat less crowded with with a dim

876
00:38:47,070 --> 00:38:43,360
background going from the city out to

877
00:38:50,190 --> 00:38:47,080
the suburbs so we did all this follow up

878
00:38:52,470 --> 00:38:50,200
with Herschel and this really gives you

879
00:38:54,990 --> 00:38:52,480
a sense comparing Spitzer data on the

880
00:38:56,400 --> 00:38:55,000
left to the combination of Spitzer and

881
00:38:58,340 --> 00:38:56,410
Herschel on the right this shows you

882
00:39:01,290 --> 00:38:58,350
what you can do with the far infrared

883
00:39:03,870 --> 00:39:01,300
Spitzer the dustiest regions in the

884
00:39:05,550 --> 00:39:03,880
cloud are dark they're cold they're not

885
00:39:07,530 --> 00:39:05,560
really emitting very much at the mid wid

886
00:39:09,780 --> 00:39:07,540
mid infrared wavelengths that Spitzer

887
00:39:11,790 --> 00:39:09,790
detects so you have these dark dust

888
00:39:13,920 --> 00:39:11,800

lanes and then you can tell where the

889
00:39:16,230 --> 00:39:13,930
stars are but they're really deeply

890
00:39:17,840 --> 00:39:16,240
embedded young ones you can't learn very

891
00:39:21,180 --> 00:39:17,850
much about them because they're faint

892
00:39:22,890 --> 00:39:21,190
here the blue is from Spitzer but then

893
00:39:25,110 --> 00:39:22,900
the red and yellow we're bringing in the

894
00:39:27,060 --> 00:39:25,120
Herschel data so there are two things to

895
00:39:29,250 --> 00:39:27,070
notice here first of all some of these

896
00:39:30,990 --> 00:39:29,260
faint protostars in the spitzer image

897
00:39:32,970 --> 00:39:31,000
are now some of the brightest ones in

898
00:39:35,190 --> 00:39:32,980
Herschel there are two here there's one

899
00:39:37,110 --> 00:39:35,200
up here these really bright Herschel

900
00:39:38,820 --> 00:39:37,120
protostars those are the really young

901
00:39:41,460 --> 00:39:38,830
ones those are the ones we can study to

902
00:39:43,290 --> 00:39:41,470
learn exactly what's going on as gas and

903
00:39:45,410 --> 00:39:43,300
dust begins to condense from the

904
00:39:48,450 --> 00:39:45,420
molecular cloud to forms

905
00:39:51,540 --> 00:39:48,460
the other thing to notice here is that

906
00:39:54,450 --> 00:39:51,550
the dark dust lanes are now glowing at

907
00:39:56,550 --> 00:39:54,460
the longest far infrared wavelengths you

908
00:39:58,740 --> 00:39:56,560
can really see where the dust is and see

909
00:40:00,990 --> 00:39:58,750
how intense and how much dust there is

910
00:40:02,400 --> 00:40:01,000
by how brightly it's glowing so this

911
00:40:04,050 --> 00:40:02,410
really allows us to understand

912
00:40:06,210 --> 00:40:04,060
everything that's going on in a

913
00:40:08,010 --> 00:40:06,220

star-forming region when we combine the

914
00:40:12,240 --> 00:40:08,020
mid infrared and the farm for headlight

915
00:40:14,210 --> 00:40:12,250
from Herschel I'm going to tell you

916
00:40:17,160 --> 00:40:14,220
about one of our first hops results

917
00:40:19,860 --> 00:40:17,170
we're going to go back in time from the

918
00:40:21,990 --> 00:40:19,870
Herschel Space Telescope to Herschel the

919
00:40:23,610 --> 00:40:22,000
astronomers William Herschel and

920
00:40:27,560 --> 00:40:23,620
Caroline Herschel they're shown in this

921
00:40:30,540 --> 00:40:27,570
painting here they were some of the best

922
00:40:34,470 --> 00:40:30,550
astronomers of their time working in the

923
00:40:36,660 --> 00:40:34,480
18th century and William Herschel was

924
00:40:40,170 --> 00:40:36,670
conducting a survey with his telescope

925
00:40:43,440 --> 00:40:40,180
of the Milky Way and he discovered dark

926
00:40:45,150 --> 00:40:43,450
patches and he said he spoke German but

927
00:40:46,890 --> 00:40:45,160
what he said was truly there is a hole

928
00:40:49,710 --> 00:40:46,900
in the sky here when he saw these dark

929
00:40:51,180 --> 00:40:49,720
patches this is one of the dark patches

930
00:40:54,210 --> 00:40:51,190
that he talked about this is what we

931
00:40:56,640 --> 00:40:54,220
today call NGC 1999

932
00:40:58,770 --> 00:40:56,650
this is our first Herschel image we

933
00:41:01,260 --> 00:40:58,780
bring in some Kitt Peak data that's in

934
00:41:03,780 --> 00:41:01,270
blue for context that's a that's optical

935
00:41:06,060 --> 00:41:03,790
possibly near infrared imaging we see

936
00:41:07,980 --> 00:41:06,070
some of our Herschel protostars here and

937
00:41:12,390 --> 00:41:07,990
then this is a Hubble close-up of this

938
00:41:16,670 --> 00:41:12,400

NGC 1999 region it's one of these holes

939
00:41:22,260 --> 00:41:20,040
it turned out that Herschel's holes in

940
00:41:24,000 --> 00:41:22,270
the sky are mostly these dark dust

941
00:41:28,320 --> 00:41:24,010
clouds like we were talking about before

942
00:41:30,150 --> 00:41:28,330
this is NGC 1999 this is Barnard 68 that

943
00:41:33,420 --> 00:41:30,160
I showed you before where the dark cloud

944
00:41:35,190 --> 00:41:33,430
is it's not a hole it's a dark dusty

945
00:41:40,110 --> 00:41:35,200
cloud and when you look in the infrared

946
00:41:43,590 --> 00:41:40,120
you see lots of stars here but in this

947
00:41:45,630 --> 00:41:43,600
particular case NGC 1999 it's a little

948
00:41:46,860 --> 00:41:45,640
bit different this is the Hubble image I

949
00:41:50,640 --> 00:41:46,870
showed you but then when you look at

950
00:41:53,070 --> 00:41:50,650
Herschel images in the far infrared the

951
00:41:54,720 --> 00:41:53,080
hole in the sky is still a hole if there

952
00:41:57,570 --> 00:41:54,730
were dust here it would start to glow in

953
00:41:58,840 --> 00:41:57,580
the far infrared when we go even further

954
00:42:03,310 --> 00:41:58,850
out into the infer

955
00:42:06,010 --> 00:42:03,320
it's still dark so there's no dust there

956
00:42:08,440 --> 00:42:06,020
it would glow and here in this very deep

957
00:42:12,730 --> 00:42:08,450
near infrared image we see a star

958
00:42:15,340 --> 00:42:12,740
through this hole in the nebula that's

959
00:42:18,370 --> 00:42:15,350
not particularly red so we're actually

960
00:42:21,130 --> 00:42:18,380
seeing through empty space here this one

961
00:42:22,720 --> 00:42:21,140
really is a hole in the sky so it was

962
00:42:24,340 --> 00:42:22,730
kind of a kind of a neat discovery we

963
00:42:26,830 --> 00:42:24,350

made Herschel the astronomer said

964
00:42:29,830 --> 00:42:26,840
something in 1774 truly there was a hole

965
00:42:31,630 --> 00:42:29,840
in the sky here 236 years later the

966
00:42:37,120 --> 00:42:31,640
telescope named after him confirmed that

967
00:42:39,420 --> 00:42:37,130
he was right about this one and this was

968
00:42:42,340 --> 00:42:39,430
the beginning of our of our hops project

969
00:42:44,980 --> 00:42:42,350
another really key discovery with hops

970
00:42:49,210 --> 00:42:44,990
is that there were proto stars in Orion

971
00:42:51,250 --> 00:42:49,220
that Spitzer missed they were too faint

972
00:42:53,500 --> 00:42:51,260
in the Spitzer images for people to

973
00:42:55,690 --> 00:42:53,510
realize that they were protostars so

974
00:42:57,400 --> 00:42:55,700
this is these are some thumbnails of two

975
00:43:00,430 --> 00:42:57,410
of these protostars the top row our

976
00:43:02,860 --> 00:43:00,440
Spitzer images this is kind of the near

977
00:43:04,510 --> 00:43:02,870
to mid infrared wavelengths that are a

978
00:43:06,640 --> 00:43:04,520
little bit longer than our eyes can

979
00:43:08,590 --> 00:43:06,650
detect and here in these two circles you

980
00:43:11,800 --> 00:43:08,600
see a faint object here and a brighter

981
00:43:13,480 --> 00:43:11,810
object here if you go out to some of the

982
00:43:16,510 --> 00:43:13,490
longest wavelengths that Spitzer was

983
00:43:19,510 --> 00:43:16,520
able to effectively work at in Orion you

984
00:43:22,500 --> 00:43:19,520
see nothing in this top circle and just

985
00:43:24,790 --> 00:43:22,510
a very faint blob in this bottom circle

986
00:43:26,470 --> 00:43:24,800
we weren't sure what these were just

987
00:43:29,230 --> 00:43:26,480
based on this information alone they

988
00:43:31,720 --> 00:43:29,240

were classified as galaxies to the

989
00:43:33,040 --> 00:43:31,730
extent they were classified at all but

990
00:43:35,470 --> 00:43:33,050
when we looked at them with Herschel

991
00:43:37,510 --> 00:43:35,480
they really jumped out all of a sudden

992
00:43:40,450 --> 00:43:37,520
they're the brightest point sources in

993
00:43:42,670 --> 00:43:40,460
this field down here at the bottom we've

994
00:43:44,380 --> 00:43:42,680
gone out to submillimetre wavelengths

995
00:43:46,390 --> 00:43:44,390
this is almost in the radio at this

996
00:43:49,420 --> 00:43:46,400
point where we're detecting very cold

997
00:43:52,360 --> 00:43:49,430
dust and they remain bright there so

998
00:43:54,580 --> 00:43:52,370
this is a sign that Herschel was able to

999
00:43:56,980 --> 00:43:54,590
detect protostars that spits our mist

1000
00:43:58,900 --> 00:43:56,990
and because there's you have to look at

1001
00:44:00,430 --> 00:43:58,910
such long wavelengths to see them that

1002
00:44:01,960 --> 00:44:00,440
means they're among the coldest proto

1003
00:44:05,260 --> 00:44:01,970
stars in Orion and therefore the

1004
00:44:07,420 --> 00:44:05,270
youngest our estimates are that they may

1005
00:44:09,790 --> 00:44:07,430
have formerly 25,000 years and I say

1006
00:44:11,410 --> 00:44:09,800
only that seems like a long time if you

1007
00:44:12,039 --> 00:44:11,420
remember back I told you it takes on

1008
00:44:13,839 --> 00:44:12,049
average to

1009
00:44:15,370 --> 00:44:13,849
million years for a starter for twenty

1010
00:44:16,059 --> 00:44:15,380
five thousand years is a tiny fraction

1011
00:44:18,160 --> 00:44:16,069
of that

1012
00:44:20,319 --> 00:44:18,170
so Herschel really allowed us to

1013
00:44:22,029 --> 00:44:20,329

complete the census of protostars in

1014
00:44:27,009 --> 00:44:22,039
Orion and really see what was going on

1015
00:44:30,130 --> 00:44:27,019
in the very youngest systems this is a

1016
00:44:32,650 --> 00:44:30,140
larger scale image of spit of these new

1017
00:44:34,390 --> 00:44:32,660
protostars Spitzer is on the right and

1018
00:44:36,160 --> 00:44:34,400
again in these four circles these are

1019
00:44:37,539 --> 00:44:36,170
the two I showed you before there are a

1020
00:44:39,910 --> 00:44:37,549
couple more down here to the south

1021
00:44:41,410 --> 00:44:39,920
there's almost nothing in Spitzer but

1022
00:44:44,199 --> 00:44:41,420
when you bring in the Herschel far

1023
00:44:47,380 --> 00:44:44,209
infrared data and the apex submillimetre

1024
00:44:49,390 --> 00:44:47,390
data they're very bright so we can

1025
00:44:50,949 --> 00:44:49,400
really understand all of the secrets

1026
00:44:56,799 --> 00:44:50,959
that are ayan has to offer but you only

1027
00:44:59,469 --> 00:44:56,809
do the longest wavelengths now that the

1028
00:45:01,449 --> 00:44:59,479
Herschel project has been we've had all

1029
00:45:03,819 --> 00:45:01,459
of our Herschel data for a few years and

1030
00:45:05,469 --> 00:45:03,829
most of the science has come out there

1031
00:45:06,549 --> 00:45:05,479
are still a few papers lingering along

1032
00:45:09,069 --> 00:45:06,559
that we're trying to get into the

1033
00:45:10,870 --> 00:45:09,079
literature but we've turned to detailed

1034
00:45:14,289 --> 00:45:10,880
follow-up of some of these protostars

1035
00:45:15,999 --> 00:45:14,299
with Hubble for instance with Hubble

1036
00:45:17,979 --> 00:45:16,009
once we know the proto stars are there

1037
00:45:20,019 --> 00:45:17,989
we can zoom in on them and get very

1038
00:45:23,130 --> 00:45:20,029

high-resolution images compared to what

1039
00:45:25,329 --> 00:45:23,140
we can get with Spitzer or with Herschel

1040
00:45:28,509 --> 00:45:25,339
now Hubble has a lot of different

1041
00:45:30,249 --> 00:45:28,519
instruments I work on the cosmic origins

1042
00:45:32,410 --> 00:45:30,259
spectrograph which is optimized for the

1043
00:45:35,199 --> 00:45:32,420
ultraviolet but for science we tend to

1044
00:45:37,269 --> 00:45:35,209
use for prints the science of star

1045
00:45:38,799 --> 00:45:37,279
formation at least the sort of work that

1046
00:45:41,529 --> 00:45:38,809
we do we tend to use the near infrared

1047
00:45:42,630 --> 00:45:41,539
cameras on Hubble there's Nick Moss

1048
00:45:45,880 --> 00:45:42,640
which was an earlier generation

1049
00:45:48,849 --> 00:45:45,890
instrument and then with c3 is why Field

1050
00:45:50,469 --> 00:45:48,859
Camera 3 which as you can see gives us a

1051
00:45:51,969 --> 00:45:50,479
wide field of view and we can see

1052
00:45:56,319 --> 00:45:51,979
high-resolution images of many

1053
00:45:58,299 --> 00:45:56,329
protostars at once so here we can see

1054
00:46:00,519 --> 00:45:58,309
some edge on protostars where we're

1055
00:46:02,289 --> 00:46:00,529
looking through a dusty disc and we can

1056
00:46:05,109 --> 00:46:02,299
see some of the outflow cavities

1057
00:46:07,209 --> 00:46:05,119
here we see some point like protostars

1058
00:46:08,890 --> 00:46:07,219
or maybe we're looking more pull on and

1059
00:46:11,469 --> 00:46:08,900
just seeing the light from the central

1060
00:46:13,569 --> 00:46:11,479
regions of the system and we can see all

1061
00:46:15,279 --> 00:46:13,579
sorts of details about exactly how gas

1062
00:46:19,490 --> 00:46:15,289
and dust are distributed around these

1063
00:46:21,050 --> 00:46:19,500

stars and

1064
00:46:22,700 --> 00:46:21,060
is just a demonstration of what you can

1065
00:46:25,190 --> 00:46:22,710
really do with the high resolution of

1066
00:46:26,600 --> 00:46:25,200
Hubble in the 1980s if you looked in

1067
00:46:29,480 --> 00:46:26,610
review papers you would see these

1068
00:46:31,880 --> 00:46:29,490
cartoons showing how stars and disks and

1069
00:46:35,390 --> 00:46:31,890
maybe outflow cavities worked well when

1070
00:46:37,970 --> 00:46:35,400
we did our Hubble imaging we found you

1071
00:46:39,950 --> 00:46:37,980
know Hubble or we found cart it was

1072
00:46:42,770 --> 00:46:39,960
almost like those cartoons have become

1073
00:46:45,530 --> 00:46:42,780
reality here in this image of a star

1074
00:46:47,680 --> 00:46:45,540
called hops 136 we can see everything

1075
00:46:52,990 --> 00:46:47,690
that people predicted in these cartoons

1076
00:46:55,790 --> 00:46:53,000
20-30 years ago we see these dark lanes

1077
00:46:58,670 --> 00:46:55,800
which is the sort of circumstellar disk

1078
00:47:00,710 --> 00:46:58,680
seen in projection we see these bright

1079
00:47:05,090 --> 00:47:00,720
nebulae from the upper layers of the

1080
00:47:07,220 --> 00:47:05,100
disk the disk casts a shadow here we can

1081
00:47:09,110 --> 00:47:07,230
see light being scattered off the inner

1082
00:47:11,390 --> 00:47:09,120
edges of the envelope and then the

1083
00:47:14,090 --> 00:47:11,400
outflow cavities so it's all there

1084
00:47:17,960 --> 00:47:14,100
just as the theorists of the 1980s we're

1085
00:47:19,220 --> 00:47:17,970
predicting one of the things we can do

1086
00:47:22,850 --> 00:47:19,230
with these Hubble images is study

1087
00:47:27,110 --> 00:47:22,860
multiple systems so protostars rarely

1088
00:47:29,330 --> 00:47:27,120

form as single stars they tend to form

1089
00:47:30,800 --> 00:47:29,340
in double systems or triple systems

1090
00:47:33,350 --> 00:47:30,810
sometimes you even have quadruple

1091
00:47:36,200 --> 00:47:33,360
systems something about the way stars

1092
00:47:39,080 --> 00:47:36,210
form tends to form leads them to form in

1093
00:47:40,700 --> 00:47:39,090
pairs or even greater systems and here

1094
00:47:43,490 --> 00:47:40,710
are some examples of these here's a

1095
00:47:45,380 --> 00:47:43,500
binary system where the top one is one

1096
00:47:47,240 --> 00:47:45,390
of these edge-on discs where you can see

1097
00:47:49,190 --> 00:47:47,250
this dark lane and then submit below see

1098
00:47:51,500 --> 00:47:49,200
on either side of it and then the

1099
00:47:53,600 --> 00:47:51,510
southern member of the pair is seen more

1100
00:47:56,030 --> 00:47:53,610
pull on so the light from the central

1101
00:48:00,140 --> 00:47:56,040
regions is escaping it's just a point of

1102
00:48:02,000 --> 00:48:00,150
light here's a triple system a double

1103
00:48:04,190 --> 00:48:02,010
system where this more distant one might

1104
00:48:06,740 --> 00:48:04,200
be related and here's a very close

1105
00:48:08,660 --> 00:48:06,750
double what's interesting about these

1106
00:48:10,760 --> 00:48:08,670
young stars they form in these little

1107
00:48:13,250 --> 00:48:10,770
clusters of two or three or more stars

1108
00:48:15,260 --> 00:48:13,260
but then if you go look at main sequence

1109
00:48:17,480 --> 00:48:15,270
stars more evolved ones you don't see

1110
00:48:19,190 --> 00:48:17,490
nearly as many pairs you still see a lot

1111
00:48:20,840 --> 00:48:19,200
of them but not quite as many so

1112
00:48:22,730 --> 00:48:20,850
something about the way these stars are

1113
00:48:24,590 --> 00:48:22,740

interacting through their gravity the

1114
00:48:26,930 --> 00:48:24,600
third member of a system might get flung

1115
00:48:29,060 --> 00:48:26,940
out so you're left with just a binary

1116
00:48:30,860 --> 00:48:29,070
system where there used to be three it's

1117
00:48:32,660 --> 00:48:30,870
possible that the Sun may even have

1118
00:48:32,900 --> 00:48:32,670
formed in one of these small collections

1119
00:48:37,180 --> 00:48:32,910
of

1120
00:48:40,640 --> 00:48:39,260
another exciting thing we can do with

1121
00:48:43,190 --> 00:48:40,650
these Hubble images is to study the

1122
00:48:44,870 --> 00:48:43,200
cavities and the outflows here you can

1123
00:48:46,430 --> 00:48:44,880
see all sorts of different morphologies

1124
00:48:47,240 --> 00:48:46,440
it's pretty surprising they're not at

1125
00:48:50,660 --> 00:48:47,250
all alike

1126
00:48:52,910 --> 00:48:50,670
you have examples up here of bipolar

1127
00:48:54,890 --> 00:48:52,920
systems where you have this dark lane

1128
00:48:58,550 --> 00:48:54,900
and then the two nebulae on either side

1129
00:49:00,740 --> 00:48:58,560
that are pretty symmetrical here you see

1130
00:49:03,410 --> 00:49:00,750
this huge system that's a little bit of

1131
00:49:07,550 --> 00:49:03,420
a symmetrical here's kind of a smaller

1132
00:49:09,080 --> 00:49:07,560
more tightly contained one this one one

1133
00:49:11,870 --> 00:49:09,090
side of the nebula is much brighter than

1134
00:49:13,520 --> 00:49:11,880
the other down here you have all sorts

1135
00:49:15,560 --> 00:49:13,530
of structure like there have been maybe

1136
00:49:18,440 --> 00:49:15,570
multiple outbursts from this system in

1137
00:49:20,510 --> 00:49:18,450
the past this bizarre ring-like

1138
00:49:23,950 --> 00:49:20,520

structure here's a very wide angle

1139
00:49:26,390 --> 00:49:23,960
outflow there's lots going on here and

1140
00:49:28,610 --> 00:49:26,400
we think that one of the important

1141
00:49:30,410 --> 00:49:28,620
things these cavities do is these cos

1142
00:49:32,300 --> 00:49:30,420
star formation to slow down and

1143
00:49:34,310 --> 00:49:32,310
eventually stop in a star forming region

1144
00:49:36,320 --> 00:49:34,320
the outflow is being launched from the

1145
00:49:38,030 --> 00:49:36,330
star disrupt the cloud and eventually

1146
00:49:40,130 --> 00:49:38,040
there's not enough dense material to

1147
00:49:44,530 --> 00:49:40,140
continue forming stars so we think this

1148
00:49:50,150 --> 00:49:47,300
Alma is another facility this one on the

1149
00:49:53,120 --> 00:49:50,160
ground Alma is the Atacama Large

1150
00:49:54,680 --> 00:49:53,130
millimeter array where millimetre refers

1151
00:49:58,220 --> 00:49:54,690
to the wavelengths of the light that

1152
00:50:00,620 --> 00:49:58,230
we're studying and as an array it's

1153
00:50:03,620 --> 00:50:00,630
actually a collection of sort of medium

1154
00:50:05,600 --> 00:50:03,630
sized radio telescopes they're not quite

1155
00:50:08,180 --> 00:50:05,610
radio telescopes but they're there they

1156
00:50:10,550 --> 00:50:08,190
work like them and by using an array of

1157
00:50:11,990 --> 00:50:10,560
telescopes you can get some of the

1158
00:50:14,060 --> 00:50:12,000
benefits of having a single large

1159
00:50:15,950 --> 00:50:14,070
telescope but you can kind of

1160
00:50:18,260 --> 00:50:15,960
reconfigure the different dishes to

1161
00:50:22,070 --> 00:50:18,270
study physical structures at different

1162
00:50:23,900 --> 00:50:22,080
scales Alma is on the ground but it's

1163
00:50:26,200 --> 00:50:23,910

kind of almost in the sky because it's

1164
00:50:29,720 --> 00:50:26,210
sixteen thousand feet above sea level

1165
00:50:32,810 --> 00:50:29,730
one of the highest flat places on the

1166
00:50:35,030 --> 00:50:32,820
Earth's surface up there the air is

1167
00:50:39,260 --> 00:50:35,040
exceedingly dry it really doesn't rain

1168
00:50:44,150 --> 00:50:39,270
there ever and exceedingly thin so it's

1169
00:50:46,370 --> 00:50:44,160
almost as though you're in space these

1170
00:50:49,670 --> 00:50:46,380
are images of

1171
00:50:51,380 --> 00:50:49,680
pterri disks in orion so we're looking

1172
00:50:55,010 --> 00:50:51,390
through the envelope and imaging the

1173
00:50:57,410 --> 00:50:55,020
disks themselves and the important thing

1174
00:50:59,210 --> 00:50:57,420
here is for comparison if something just

1175
00:51:01,190 --> 00:50:59,220
like neptune were orbiting one of these

1176
00:51:05,780 --> 00:51:01,200
stars at the same distance from its star

1177
00:51:07,790 --> 00:51:05,790
as neptune is you would be able to you

1178
00:51:09,020 --> 00:51:07,800
know resolve the orbit of neptune so

1179
00:51:11,450 --> 00:51:09,030
we're really getting to the point where

1180
00:51:13,610 --> 00:51:11,460
we can witness not just stars but the

1181
00:51:15,800 --> 00:51:13,620
Syst solar systems the systems of proto

1182
00:51:17,600 --> 00:51:15,810
planets themselves in the act of

1183
00:51:19,610 --> 00:51:17,610
formation this is really cutting-edge

1184
00:51:21,350 --> 00:51:19,620
science and Alma's continuing to get

1185
00:51:23,510 --> 00:51:21,360
more powerful and more able to resolve

1186
00:51:25,070 --> 00:51:23,520
these fine structures so there are lots

1187
00:51:27,470 --> 00:51:25,080
of debates going on right now about

1188
00:51:29,240 --> 00:51:27,480

which stars have planets and which ones

1189
00:51:33,380 --> 00:51:29,250
or maybe just beginning to form planets

1190
00:51:34,970 --> 00:51:33,390
I want to talk a little bit about the

1191
00:51:39,050 --> 00:51:34,980
science that I'm doing in particular

1192
00:51:40,790 --> 00:51:39,060
with star formation in Orion so I'm

1193
00:51:41,840 --> 00:51:40,800
interested in out bursting protostars

1194
00:51:45,350 --> 00:51:41,850
and I'll show you what I mean by that

1195
00:51:47,480 --> 00:51:45,360
this is a wide field image of Orion

1196
00:51:49,040 --> 00:51:47,490
starting the Orion Nebula is off the top

1197
00:51:50,930 --> 00:51:49,050
of the page and then this is this kind

1198
00:51:53,120 --> 00:51:50,940
of suburban region of Orion that I was

1199
00:51:54,440 --> 00:51:53,130
telling you about the circle toward the

1200
00:51:57,650 --> 00:51:54,450
bottom of the image marks the location

1201
00:51:59,120 --> 00:51:57,660
of hops 2:23 it's fairly isolated it's

1202
00:52:01,910 --> 00:51:59,130
part of this little group of three young

1203
00:52:06,130 --> 00:52:01,920
stars this is a near infrared image of

1204
00:52:09,410 --> 00:52:06,140
hops 2:23 and friends in the late 90s

1205
00:52:11,360 --> 00:52:09,420
ops 223 pretty faint compared to the

1206
00:52:14,930 --> 00:52:11,370
other two objects in the field well we

1207
00:52:17,630 --> 00:52:14,940
came and looked again in 2011 it was

1208
00:52:20,330 --> 00:52:17,640
suddenly much brighter now the brightest

1209
00:52:22,670 --> 00:52:20,340
object in the field so something

1210
00:52:24,980 --> 00:52:22,680
happened here that may tell us about how

1211
00:52:28,280 --> 00:52:24,990
stars form this is a Hubble image of

1212
00:52:31,070 --> 00:52:28,290
hops 223 and friends this is hops 223

1213
00:52:33,140 --> 00:52:31,080

this is hops 221 down here the numbers

1214
00:52:35,090 --> 00:52:33,150
are not quite randomly assigned they

1215
00:52:36,440 --> 00:52:35,100
don't they don't mean a whole lot but

1216
00:52:38,630 --> 00:52:36,450
this is just a little collection of

1217
00:52:42,950 --> 00:52:38,640
stars and hops 223 is undergoing one of

1218
00:52:45,410 --> 00:52:42,960
these outbursts we think that the reason

1219
00:52:47,720 --> 00:52:45,420
these get so much brighter is because

1220
00:52:49,970 --> 00:52:47,730
they suddenly begin this episode of

1221
00:52:51,830 --> 00:52:49,980
rapid mass accretion there may be

1222
00:52:53,690 --> 00:52:51,840
gradually accreting material from there

1223
00:52:54,920 --> 00:52:53,700
circumstellar disks over a period of

1224
00:52:57,260 --> 00:52:54,930
thousands of years and then suddenly

1225
00:52:59,120 --> 00:52:57,270
something happens to cause material to

1226
00:53:01,790 --> 00:52:59,130
pour on it pour unto the star

1227
00:53:02,900 --> 00:53:01,800
more rapidly these are light curves if

1228
00:53:04,340 --> 00:53:02,910
you remember way back near the beginning

1229
00:53:06,680 --> 00:53:04,350
of the talk I showed you a light curve

1230
00:53:09,410 --> 00:53:06,690
of a typical young star these are light

1231
00:53:12,530 --> 00:53:09,420
curves of three famous outbursts this

1232
00:53:16,010 --> 00:53:12,540
one here was a pretty normal star in

1233
00:53:18,170 --> 00:53:16,020
about 1935 but then suddenly just in a

1234
00:53:20,960 --> 00:53:18,180
span of months it became more than 100

1235
00:53:24,050 --> 00:53:20,970
times brighter shot way up here and ever

1236
00:53:26,210 --> 00:53:24,060
since then for decades it's been slowly

1237
00:53:27,620 --> 00:53:26,220
trailing off in brightness but it's

1238
00:53:29,960 --> 00:53:27,630

still much brighter than it ever was

1239
00:53:32,930 --> 00:53:29,970
before hand and there are a couple of

1240
00:53:34,640 --> 00:53:32,940
other objects that were detected back in

1241
00:53:36,140 --> 00:53:34,650
the twentieth century to do this and

1242
00:53:39,980 --> 00:53:36,150
we've started finding more and more of

1243
00:53:41,930 --> 00:53:39,990
them more recently so these outbursts

1244
00:53:44,210 --> 00:53:41,940
may actually be essential for the

1245
00:53:45,920 --> 00:53:44,220
formation of a star we think it's

1246
00:53:48,020 --> 00:53:45,930
possible that most of a star's mass

1247
00:53:49,760 --> 00:53:48,030
might be assembled in a series of a few

1248
00:53:51,350 --> 00:53:49,770
dozens of these outbursts over the two

1249
00:53:53,300 --> 00:53:51,360
million years star formation period

1250
00:53:57,590 --> 00:53:53,310
rather than as a slow and gradual

1251
00:53:59,060 --> 00:53:57,600
process a lot of theorists have put

1252
00:54:01,130 --> 00:53:59,070
together simulations of how these

1253
00:54:03,440 --> 00:54:01,140
outbursts work so a little bit about the

1254
00:54:06,410 --> 00:54:03,450
physics of star formation this is a

1255
00:54:09,200 --> 00:54:06,420
scenario so in this image the star is

1256
00:54:12,890 --> 00:54:09,210
here at the center in yellow of the

1257
00:54:15,980 --> 00:54:12,900
system this is all disc material so the

1258
00:54:18,620 --> 00:54:15,990
Stars disk is gradually drifting inward

1259
00:54:20,060 --> 00:54:18,630
trying to accrete onto the star but the

1260
00:54:21,830 --> 00:54:20,070
star has got a magnetic field it's just

1261
00:54:23,060 --> 00:54:21,840
like a bar magnet it's got a North Pole

1262
00:54:25,760 --> 00:54:23,070
and a South Pole in a magnetic field

1263
00:54:27,560 --> 00:54:25,770

that magnetic field keeps the disk from

1264
00:54:30,050 --> 00:54:27,570
coming in all the way so then the

1265
00:54:31,940 --> 00:54:30,060
material instead flows along these field

1266
00:54:32,720 --> 00:54:31,950
lines and crashes into the star at high

1267
00:54:35,510 --> 00:54:32,730
latitudes

1268
00:54:37,130 --> 00:54:35,520
we call this magnetospheric accretion

1269
00:54:40,130 --> 00:54:37,140
it's the accretion of gas through the

1270
00:54:42,740 --> 00:54:40,140
star's magnetosphere but when an

1271
00:54:44,840 --> 00:54:42,750
outburst begins there's maybe some blob

1272
00:54:46,160 --> 00:54:44,850
in the disk that's debt much denser than

1273
00:54:48,320 --> 00:54:46,170
the rest of the disk and when that

1274
00:54:50,900 --> 00:54:48,330
accretes it brings a lot more pressure

1275
00:54:52,400 --> 00:54:50,910
with it so the disc plows into the

1276
00:54:54,200 --> 00:54:52,410
surface of the star right at its equator

1277
00:54:56,810 --> 00:54:54,210
it completely overwhelms the star's

1278
00:54:59,630 --> 00:54:56,820
magnetic field and some of that material

1279
00:55:02,030 --> 00:54:59,640
gets shot off along the poles to form

1280
00:55:04,040 --> 00:55:02,040
these outflows so it's an entirely

1281
00:55:06,200 --> 00:55:04,050
different scenario for these stars

1282
00:55:08,600 --> 00:55:06,210
getting built up and this seems to

1283
00:55:11,960 --> 00:55:08,610
persist for maybe hundreds of years all

1284
00:55:12,870 --> 00:55:11,970
of these out bursting stars we've never

1285
00:55:14,610 --> 00:55:12,880
seen one

1286
00:55:20,360 --> 00:55:14,620
the major outburst turn off completely

1287
00:55:25,560 --> 00:55:23,070
used one more space telescope called

1288
00:55:26,970 --> 00:55:25,570

wise this is the wide-field Infrared

1289
00:55:28,920 --> 00:55:26,980
Survey Explorer and it's one of the

1290
00:55:30,840 --> 00:55:28,930
smallest ones probably the smallest one

1291
00:55:32,760 --> 00:55:30,850
we've discussed so far it's kind of a

1292
00:55:35,400 --> 00:55:32,770
small but mighty Space Telescope though

1293
00:55:37,440 --> 00:55:35,410
it was launched in 2009 and it did a

1294
00:55:39,720 --> 00:55:37,450
survey of the entire sky it was very

1295
00:55:42,660 --> 00:55:39,730
flexible it did an all-sky survey in

1296
00:55:44,640 --> 00:55:42,670
2010 and it's continuing to orbit the

1297
00:55:46,650 --> 00:55:44,650
Earth performing a search for near-earth

1298
00:55:49,590 --> 00:55:46,660
asteroids which is pretty important if

1299
00:55:51,570 --> 00:55:49,600
you think about it this is an image of

1300
00:55:54,180 --> 00:55:51,580
the Milky Way from the wise telescope

1301
00:55:57,480 --> 00:55:54,190
and we actually used it to search for

1302
00:56:00,630 --> 00:55:57,490
more outbursts Spitzer made a map of a

1303
00:56:02,700 --> 00:56:00,640
Ryan in 2004 wise came around in 2010

1304
00:56:05,040 --> 00:56:02,710
and did the same thing and we could do a

1305
00:56:06,960 --> 00:56:05,050
computer-based comparison of the two

1306
00:56:11,160 --> 00:56:06,970
maps to look for stars that got much

1307
00:56:13,370 --> 00:56:11,170
brighter in the intervening time we have

1308
00:56:16,740 --> 00:56:13,380
one really great find of an outburst

1309
00:56:18,570 --> 00:56:16,750
when I was a postdoc at Toledo Emily

1310
00:56:20,940 --> 00:56:18,580
shown here was working with me on her

1311
00:56:24,900 --> 00:56:20,950
senior thesis and discovered Hopps 383

1312
00:56:28,020 --> 00:56:24,910
an out bursting proto star in Orion this

1313
00:56:30,240 --> 00:56:28,030

is a fairly large image of part of Orion

1314
00:56:32,070 --> 00:56:30,250
with the nebula here hops 383 is just to

1315
00:56:33,600 --> 00:56:32,080
the north of it along one of these dark

1316
00:56:37,200 --> 00:56:33,610
filaments that I've been talking about

1317
00:56:40,260 --> 00:56:37,210
from time to time these are the Spitzer

1318
00:56:41,670 --> 00:56:40,270
images of hops 383 where you can barely

1319
00:56:44,670 --> 00:56:41,680
see it at the shortest spitzer

1320
00:56:46,230 --> 00:56:44,680
wavelengths pokes out a little bit here

1321
00:56:48,510 --> 00:56:46,240
and then at the longest spitzer

1322
00:56:49,740 --> 00:56:48,520
wavelengths it's it's faint nothing you

1323
00:56:50,870 --> 00:56:49,750
would have imagined was a protostar

1324
00:56:53,550 --> 00:56:50,880
maybe some kind of background

1325
00:56:56,310 --> 00:56:53,560
contamination or something but here it

1326
00:56:58,620 --> 00:56:56,320
is in wise look how bright it is the

1327
00:57:00,180 --> 00:56:58,630
longest why of wise wavelengths this was

1328
00:57:01,860 --> 00:57:00,190
an unambiguous sign that something

1329
00:57:04,530 --> 00:57:01,870
happened in this object something made

1330
00:57:09,390 --> 00:57:04,540
it get a factor of a few dozen brighter

1331
00:57:11,490 --> 00:57:09,400
between 2004 and 2010 this is actually

1332
00:57:14,790 --> 00:57:11,500
the youngest known out bursting

1333
00:57:17,010 --> 00:57:14,800
protostar it's barely visible at the

1334
00:57:19,290 --> 00:57:17,020
shortest wise wavelengths even now and

1335
00:57:21,150 --> 00:57:19,300
it's extremely bright as you go farther

1336
00:57:22,700 --> 00:57:21,160
and farther out into the infrared that

1337
00:57:26,340 --> 00:57:22,710
means it's young and deeply embedded

1338
00:57:27,240 --> 00:57:26,350

it's maybe a hundred thousand years old

1339
00:57:28,890 --> 00:57:27,250
give

1340
00:57:31,770 --> 00:57:28,900
it's hard to date these things precisely

1341
00:57:33,330 --> 00:57:31,780
but it's it's young so even in their

1342
00:57:35,100 --> 00:57:33,340
earliest stages these stars undergo

1343
00:57:37,470 --> 00:57:35,110
these outbursts which is evidence that

1344
00:57:39,780 --> 00:57:37,480
this is a really important aspect of

1345
00:57:42,840 --> 00:57:39,790
star formation this was enough to

1346
00:57:44,550 --> 00:57:42,850
generate a press release here's an image

1347
00:57:46,830 --> 00:57:44,560
from our press really showing that

1348
00:57:48,240 --> 00:57:46,840
before pictures here in the after

1349
00:57:51,180 --> 00:57:48,250
pictures in the bottom row

1350
00:57:54,540 --> 00:57:51,190
these are near infrared images from Kitt

1351
00:57:57,150 --> 00:57:54,550
Peak and what we found so we have over

1352
00:57:59,790 --> 00:57:57,160
300 protostars here two of them began

1353
00:58:02,760 --> 00:57:59,800
outbursts in a period of a few years

1354
00:58:04,470 --> 00:58:02,770
between 2004 and 2010 there's hops 2:23

1355
00:58:08,790 --> 00:58:04,480
that i started off talking about and

1356
00:58:10,860 --> 00:58:08,800
hops 383 shown here that's kind of small

1357
00:58:13,230 --> 00:58:10,870
number of Statistics but it's an

1358
00:58:14,670 --> 00:58:13,240
indication that any given protostar may

1359
00:58:16,560 --> 00:58:14,680
have an outburst like this once every

1360
00:58:18,660 --> 00:58:16,570
thousand years that's where that number

1361
00:58:21,480 --> 00:58:18,670
comes from the protostar might do this

1362
00:58:25,370 --> 00:58:21,490
50 times over its formation period so

1363
00:58:27,210 --> 00:58:25,380

these protostars are active young stars

1364
00:58:31,640 --> 00:58:27,220
engaging in some pretty dramatic

1365
00:58:36,330 --> 00:58:34,640
the lasts are just about the last

1366
00:58:38,430 --> 00:58:36,340
observatory I'm going to tell you about

1367
00:58:40,230 --> 00:58:38,440
is Sophia this is not technically a

1368
00:58:42,150 --> 00:58:40,240
space-based observatories it comes

1369
00:58:44,670 --> 00:58:42,160
pretty close this is the stratospheric

1370
00:58:46,350 --> 00:58:44,680
Observatory for infrared astronomy it's

1371
00:58:49,560 --> 00:58:46,360
actually a passenger plane that has been

1372
00:58:51,720 --> 00:58:49,570
turned into a telescope if you see this

1373
00:58:54,120 --> 00:58:51,730
large rectangular opening in the back of

1374
00:58:56,160 --> 00:58:54,130
the plane this plane takes off every

1375
00:58:59,340 --> 00:58:56,170
night from Palmdale California in the

1376
00:59:01,050 --> 00:58:59,350
desert near Los Angeles sometimes it can

1377
00:59:03,300 --> 00:59:01,060
observe the southern sky by taking off

1378
00:59:05,730 --> 00:59:03,310
from New Zealand and after it reaches

1379
00:59:07,320 --> 00:59:05,740
cruising altitude this door opens up in

1380
00:59:09,480 --> 00:59:07,330
the back of the plane to let the

1381
00:59:12,990 --> 00:59:09,490
telescope peer out into the mid infrared

1382
00:59:15,210 --> 00:59:13,000
sky the cool thing about Sofia is that

1383
00:59:18,240 --> 00:59:15,220
astronomers who get time to use Sofia

1384
00:59:20,850 --> 00:59:18,250
are able to fly on it so you can kind of

1385
00:59:23,490 --> 00:59:20,860
see the whole flight operations crew in

1386
00:59:26,280 --> 00:59:23,500
action this is a view from inside of the

1387
00:59:30,630 --> 00:59:26,290
observatory where instead of tightly

1388
00:59:35,010 --> 00:59:30,640

packed rows of Economy seats you see all

1389
00:59:36,520 --> 00:59:35,020
of these scientific workstations all so

1390
00:59:38,470 --> 00:59:36,530
tightly packed

1391
00:59:40,810 --> 00:59:38,480
there's a flight commander that sort of

1392
00:59:42,280 --> 00:59:40,820
makes sure the pilots and the scientists

1393
00:59:43,330 --> 00:59:42,290
understand what each other is trying to

1394
00:59:45,730 --> 00:59:43,340
do and make sure everything goes

1395
00:59:47,980 --> 00:59:45,740
smoothly you have instrument scientists

1396
00:59:50,200 --> 00:59:47,990
on board and then the astronomers who

1397
00:59:52,540 --> 00:59:50,210
got time are just kind of there trying

1398
00:59:54,340 --> 00:59:52,550
not to cause too many problems and

1399
00:59:55,570 --> 00:59:54,350
trying not to interfere with the process

1400
00:59:57,940 --> 00:59:55,580
too much we're just learning how it all

1401
00:59:59,770 --> 00:59:57,950
works in the back of this image we're

1402
01:00:01,480 --> 00:59:59,780
actually seeing the right side of the

1403
01:00:04,780 --> 01:00:01,490
telescope the telescopes peering out of

1404
01:00:06,280 --> 01:00:04,790
the plane this way and this is you know

1405
01:00:07,990 --> 01:00:06,290
just the side of the telescope and the

1406
01:00:11,890 --> 01:00:08,000
instruments get attached they're that

1407
01:00:13,480 --> 01:00:11,900
detect and record the light and Sofia

1408
01:00:15,330 --> 01:00:13,490
flies pretty high many of its

1409
01:00:18,130 --> 01:00:15,340
observations are conducted from 35

1410
01:00:20,440 --> 01:00:18,140
37,000 feet but to go out to the longest

1411
01:00:22,810 --> 01:00:20,450
wavelengths it goes up above 40,000 feet

1412
01:00:25,270 --> 01:00:22,820
where the air is you know as thin as you

1413
01:00:27,610 --> 01:00:25,280

can get access to and as dry as you can

1414
01:00:29,860 --> 01:00:27,620
get access to so it leads to some fairly

1415
01:00:32,290 --> 01:00:29,870
sensitive infrared studies it's not

1416
01:00:36,670 --> 01:00:32,300
quite as sensitive as a Spitzer or

1417
01:00:38,290 --> 01:00:36,680
Herschel but it lands every morning so

1418
01:00:54,670 --> 01:00:38,300
you can go and fix things and improve

1419
01:00:58,840 --> 01:00:54,680
things yeah question the telescope is

1420
01:01:00,700 --> 01:00:58,850
yeah is isolated in that sense and it's

1421
01:01:02,140 --> 01:01:00,710
kind of interesting to watch it when

1422
01:01:04,030 --> 01:01:02,150
you're flying because it looks like the

1423
01:01:05,800 --> 01:01:04,040
telescope is rotating but it's actually

1424
01:01:08,970 --> 01:01:05,810
the plane sort of moving around and the

1425
01:01:19,930 --> 01:01:08,980
telescope is engineered to remain steady

1426
01:01:22,360 --> 01:01:19,940
yeah right it's I don't understand the

1427
01:01:24,760 --> 01:01:22,370
details precisely but it's it's sort of

1428
01:01:27,610 --> 01:01:24,770
it's it's isolated in such a way that it

1429
01:01:33,010 --> 01:01:27,620
can move freely or rather you know stay

1430
01:01:38,650 --> 01:01:36,370
so this is our image and image of hops

1431
01:01:40,540 --> 01:01:38,660
383 with Sophia it's this faint fuzzy

1432
01:01:43,450 --> 01:01:40,550
blob in the center of this circle here

1433
01:01:45,160 --> 01:01:43,460
so with Sophia we're just barely able to

1434
01:01:48,130 --> 01:01:45,170
detect something deeply as embedded as

1435
01:01:49,810 --> 01:01:48,140
hops 383 but we can detect it well

1436
01:01:53,109 --> 01:01:49,820
enough to know that it's still in out

1437
01:01:55,690 --> 01:01:53,119
burst mode in 2016 10 years after the

1438
01:01:58,300 --> 01:01:55,700

outburst began and this is currently the

1439
01:02:01,780 --> 01:01:58,310
best way we have of monitoring outbursts

1440
01:02:03,760 --> 01:02:01,790
in the infrared coming along a few years

1441
01:02:05,890 --> 01:02:03,770
down the road Road though is James Webb

1442
01:02:08,140 --> 01:02:05,900
and from the perspective of somebody who

1443
01:02:09,520 --> 01:02:08,150
studies star formation Webb has two

1444
01:02:12,580 --> 01:02:09,530
advantages it's going to have the

1445
01:02:15,340 --> 01:02:12,590
detailed high-resolution view of Hubble

1446
01:02:18,310 --> 01:02:15,350
but also the infrared capabilities of

1447
01:02:20,140 --> 01:02:18,320
Spitzer so by combining those two we can

1448
01:02:22,960 --> 01:02:20,150
really begin to look at the most deeply

1449
01:02:25,120 --> 01:02:22,970
embedded protostars study how often they

1450
01:02:26,740 --> 01:02:25,130
have outbursts and start to learn

1451
01:02:28,780 --> 01:02:26,750
something about the precise physical

1452
01:02:31,510 --> 01:02:28,790
conditions that exist in the innermost

1453
01:02:33,190 --> 01:02:31,520
regions of those young stars this is

1454
01:02:35,410 --> 01:02:33,200
just some text from one of the JWST

1455
01:02:37,090 --> 01:02:35,420
science themes to show that star

1456
01:02:41,730 --> 01:02:37,100
formation is supposed to be one of the

1457
01:02:46,510 --> 01:02:44,470
so just to wrap things up here this is a

1458
01:02:49,630 --> 01:02:46,520
whole gallery of all the different

1459
01:02:51,580 --> 01:02:49,640
telescopes from the ground with Alma to

1460
01:02:53,740 --> 01:02:51,590
the stratosphere with Sofia to space

1461
01:02:55,750 --> 01:02:53,750
with all of these guys and they're

1462
01:02:58,990 --> 01:02:55,760
really beginning to reveal the secrets

1463
01:03:01,510 --> 01:02:59,000

of star formation in Orion and this is

1464
01:03:03,520 --> 01:03:01,520
how we learn how our Sun formed all of

1465
01:03:06,460 --> 01:03:03,530
these young stars in the Orion molecular

1466
01:03:08,200 --> 01:03:06,470
clouds their average mass is a little

1467
01:03:11,080 --> 01:03:08,210
bit less than that of the Sun but we

1468
01:03:14,050 --> 01:03:11,090
expect many of them to form planets and

1469
01:03:15,790 --> 01:03:14,060
go through the cycle of sorts just like

1470
01:03:17,560 --> 01:03:15,800
our Sun does so this is really our best

1471
01:03:20,050 --> 01:03:17,570
way to figure out how the Sun and

1472
01:03:22,480 --> 01:03:20,060
planets all formed five billion years

1473
01:03:33,130 --> 01:03:22,490
ago thank you

1474
01:03:46,130 --> 01:03:44,570
yeah question well so you're referring

1475
01:03:48,890 --> 01:03:46,140
to when nuclear fusion begins in the

1476
01:03:50,510 --> 01:03:48,900
corn it becomes a true star it's a

1477
01:03:52,160 --> 01:03:50,520
little bit difficult to see that in the

1478
01:03:55,130 --> 01:03:52,170
act of happening just because it's such

1479
01:03:59,060 --> 01:03:55,140
a slow long process for what's happening

1480
01:04:00,890 --> 01:03:59,070
in the core to propagate outward we see

1481
01:04:06,650 --> 01:04:00,900
lots of stars that are kind of on both

1482
01:04:11,710 --> 01:04:06,660
sides of that boundary those let's go

1483
01:04:20,470 --> 01:04:11,720
into the back Oh research do you have

1484
01:04:27,140 --> 01:04:24,560
so the question was we have an idea of

1485
01:04:30,500 --> 01:04:27,150
how many stars create planets from this

1486
01:04:32,690 --> 01:04:30,510
work from this work and from other work

1487
01:04:34,880 --> 01:04:32,700
it looks like nearly all of them do I

1488
01:04:37,310 --> 01:04:34,890

mean everywhere we look stars have

1489
01:04:39,500 --> 01:04:37,320
planets there's all sorts of evidence

1490
01:04:42,140 --> 01:04:39,510
coming from these Alma images of young

1491
01:04:43,970 --> 01:04:42,150
stars that there is no such thing as a

1492
01:04:45,320 --> 01:04:43,980
perfect disc they're all distorted in

1493
01:04:47,180 --> 01:04:45,330
some way that might be due to planets

1494
01:04:48,500 --> 01:04:47,190
it's kind of an open question still but

1495
01:04:49,910 --> 01:04:48,510
it looks like planets are a pretty

1496
01:04:53,450 --> 01:04:49,920
standard outcome with the star formation

1497
01:04:55,910 --> 01:04:53,460
process I mean when you showed the the

1498
01:04:57,860 --> 01:04:55,920
the disks from Alma I mean almost

1499
01:05:00,080 --> 01:04:57,870
finding a tremendous number of these

1500
01:05:02,210 --> 01:05:00,090
disks around photo stars right right

1501
01:05:03,710 --> 01:05:02,220
it's got its it's it to me is the one

1502
01:05:06,980 --> 01:05:03,720
that has the greatest resolution for

1503
01:05:08,960 --> 01:05:06,990
seeing all these disks mm-hmm yeah are

1504
01:05:10,700 --> 01:05:08,970
our disks in Orion this is kind of a

1505
01:05:12,860 --> 01:05:10,710
snapshot survey but people who go look

1506
01:05:14,450 --> 01:05:12,870
and find detail at any given disk see a

1507
01:05:30,590 --> 01:05:14,460
lot more structure that I show you here

1508
01:05:33,620 --> 01:05:30,600
even yes the accretion process so what

1509
01:05:38,810 --> 01:05:33,630
is the minimum for fusion for minimum

1510
01:05:40,880 --> 01:05:38,820
density or the threshold are you talking

1511
01:05:42,690 --> 01:05:40,890
density are you talking amount of

1512
01:05:45,480 --> 01:05:42,700
material

1513
01:05:48,000 --> 01:05:45,490

all right so was it take first for a

1514
01:05:49,830 --> 01:05:48,010
clump of gas to collapse down and become

1515
01:05:51,180 --> 01:05:49,840
a star what's it what's were the

1516
01:05:52,980 --> 01:05:51,190
thresholds it has to cross

1517
01:05:56,280 --> 01:05:52,990
we often talk in terms of a mass

1518
01:06:01,920 --> 01:05:56,290
accretion rate and the unit's we use are

1519
01:06:04,560 --> 01:06:01,930
solar masses per year so a typical

1520
01:06:06,270 --> 01:06:04,570
t-tauri stars might accrete at 10 to the

1521
01:06:08,250 --> 01:06:06,280
minus 8 solar masses per year that

1522
01:06:09,810 --> 01:06:08,260
really means about one moon's worth of

1523
01:06:12,900 --> 01:06:09,820
material is falling under the star every

1524
01:06:15,180 --> 01:06:12,910
year that's not very much very early in

1525
01:06:17,420 --> 01:06:15,190
the star formation phase the accretion

1526
01:06:28,590 --> 01:06:17,430
rates are maybe ten thousand times that

1527
01:06:30,060 --> 01:06:28,600
so ten to the minus four all right so

1528
01:06:32,370 --> 01:06:30,070
the question the minimum amount of

1529
01:06:37,950 --> 01:06:32,380
matter necessary for fusion for the

1530
01:06:40,320 --> 01:06:37,960
fusion so the least massive stars that

1531
01:06:42,270 --> 01:06:40,330
are fusing hydrogen in their centers are

1532
01:06:51,290 --> 01:06:42,280
a little less than a tenth of a solar

1533
01:07:00,630 --> 01:06:54,870
points or they have to get pretty

1534
01:07:02,220 --> 01:07:00,640
crowded several so Herschel's already

1535
01:07:04,290 --> 01:07:02,230
out of the l2 we're gonna send a web out

1536
01:07:05,090 --> 01:07:04,300
to l2 man is it gonna get crowded out

1537
01:07:08,250 --> 01:07:05,100
there

1538
01:07:10,020 --> 01:07:08,260

yeah the Planck Space Telescope is

1539
01:07:12,210 --> 01:07:10,030
another one that's out there they're not

1540
01:07:15,300 --> 01:07:12,220
all like precisely at one point they're

1541
01:07:18,510 --> 01:07:15,310
all in various orbits around l2 so maybe

1542
01:07:20,400 --> 01:07:18,520
crowded in a sense but not that crowded

1543
01:07:21,570 --> 01:07:20,410
yeah I don't think that's I don't think

1544
01:07:23,220 --> 01:07:21,580
it's a concern that any of them would

1545
01:07:25,770 --> 01:07:23,230
collide geosynchronous orbit around

1546
01:07:38,790 --> 01:07:25,780
Earth is much much much much much more

1547
01:07:42,540 --> 01:07:38,800
crowded okay do stars have an axis and

1548
01:07:45,270 --> 01:07:42,550
magnetic holes and if so why oh well

1549
01:07:47,640 --> 01:07:45,280
yeah they are magnetic it's because the

1550
01:07:50,570 --> 01:07:47,650
gas in these stars is so hot that the

1551
01:07:53,460 --> 01:07:50,580
atoms dissociate into charged particles

1552
01:07:56,200 --> 01:07:53,470
so you have ions protons and electrons

1553
01:07:58,240 --> 01:07:56,210
and the elect

1554
01:08:02,260 --> 01:07:58,250
charge also generates a magnetic field

1555
01:08:04,480 --> 01:08:02,270
and in the least the less massive stars

1556
01:08:05,680 --> 01:08:04,490
you have these convection currents so

1557
01:08:07,150 --> 01:08:05,690
you get a current going with these

1558
01:08:13,390 --> 01:08:07,160
charged particles and that gives you a

1559
01:08:15,310 --> 01:08:13,400
magnetic field yes kind of the opposite

1560
01:08:16,599 --> 01:08:15,320
of the first question I know the things

1561
01:08:20,229 --> 01:08:16,609
start to heat up when they collapse

1562
01:08:26,170 --> 01:08:20,239
gravitationally at what point we start

1563
01:08:28,269 --> 01:08:26,180

are we able to start alright so you has

1564
01:08:30,160 --> 01:08:28,279
to collapse and get darkened when does

1565
01:08:31,720 --> 01:08:30,170
it win where do we able to actually see

1566
01:08:37,229 --> 01:08:31,730
the stars that were your question yeah

1567
01:08:40,570 --> 01:08:37,239
when did when it's with the Herschel

1568
01:08:44,680 --> 01:08:40,580
telescope we were detecting stars that

1569
01:08:47,229 --> 01:08:44,690
had temperatures of maybe 40 to 50

1570
01:08:51,130 --> 01:08:47,239
degrees above absolute zero 40 to 50

1571
01:08:53,590 --> 01:08:51,140
Kelvin so we're getting cold not quite

1572
01:09:09,940 --> 01:08:53,600
as cold as like interstellar space but

1573
01:09:12,640 --> 01:09:09,950
cool so to see them in visible light

1574
01:09:14,229 --> 01:09:12,650
wavelengths what has to happen do we

1575
01:09:16,900 --> 01:09:14,239
and the fusion has to be turned on of

1576
01:09:19,390 --> 01:09:16,910
course so these T Tauri stars that I was

1577
01:09:21,610 --> 01:09:19,400
talking about or what we call optically

1578
01:09:24,820 --> 01:09:21,620
revealed they show up in visible light

1579
01:09:28,690 --> 01:09:24,830
images they're not yet fusing but the

1580
01:09:30,550 --> 01:09:28,700
energy of contraction as the star gets

1581
01:09:32,440 --> 01:09:30,560
smaller from its initial state to

1582
01:09:36,099 --> 01:09:32,450
eventually become dense enough to fuse

1583
01:09:39,280 --> 01:09:36,109
that in itself releases plenty of energy

1584
01:09:42,130 --> 01:09:39,290
and once all that cloud is gone it gets

1585
01:09:44,170 --> 01:09:42,140
radiated as visible light so even even

1586
01:09:47,140 --> 01:09:44,180
before hydrogen fuses you can see

1587
01:09:48,910 --> 01:09:47,150
optical light from these and a lot of

1588
01:09:51,010 --> 01:09:48,920

that's geometric of course too because

1589
01:09:52,990 --> 01:09:51,020
if they're deeply embedded within the

1590
01:09:54,880 --> 01:09:53,000
molecular cloud you're not going to see

1591
01:09:57,550 --> 01:09:54,890
them whereas Orion is like a blister

1592
01:09:59,530 --> 01:09:57,560
nebula so if we're able to see there's a

1593
01:10:19,770 --> 01:09:59,540
relatively clear right there site and

1594
01:10:30,700 --> 01:10:22,360
so what's the day how big are these

1595
01:10:32,470 --> 01:10:30,710
Lagrangian points the area yeah I'm not

1596
01:10:39,040 --> 01:10:32,480
sure what exactly the radius of the

1597
01:10:40,450 --> 01:10:39,050
orbit around the l2 point is it's it's

1598
01:10:42,040 --> 01:10:40,460
large enough that their telescopes are

1599
01:10:46,570 --> 01:10:42,050
not colliding within one another but I'm

1600
01:10:47,770 --> 01:10:46,580
not sure I'm not sure numerically the

1601
01:10:50,380 --> 01:10:47,780
Webb Space Telescope's

1602
01:10:52,870 --> 01:10:50,390
library market is really quite large I

1603
01:10:56,410 --> 01:10:52,880
mean it's several Earth radii in in

1604
01:11:00,940 --> 01:10:56,420
diameter at least I don't know I also

1605
01:11:03,910 --> 01:11:00,950
don't know an actual number yeah well

1606
01:11:05,770 --> 01:11:03,920
it's just it's a nice big library more

1607
01:11:11,410 --> 01:11:05,780
of it around the around the veil to

1608
01:11:15,700 --> 01:11:11,420
point any idea the length of life of a

1609
01:11:19,230 --> 01:11:15,710
star-forming region so what is the how

1610
01:11:21,970 --> 01:11:19,240
long does a star-forming region last

1611
01:11:24,490 --> 01:11:21,980
that's a little hard to tell we we have

1612
01:11:26,410 --> 01:11:24,500
some sense for how long the individual

1613
01:11:28,180 --> 01:11:26,420

stars last but you might get successive

1614
01:11:30,910 --> 01:11:28,190
waves of star formation before the gas

1615
01:11:33,250 --> 01:11:30,920
is fully exhausted so you maybe will

1616
01:11:34,390 --> 01:11:33,260
have a you know if the average time it

1617
01:11:36,100 --> 01:11:34,400
takes to form a star as two million

1618
01:11:40,170 --> 01:11:36,110
years maybe the star forming region

1619
01:11:43,390 --> 01:11:40,180
itself could last for a few times that

1620
01:11:45,160 --> 01:11:43,400
small interestingly compared to like

1621
01:11:46,660 --> 01:11:45,170
geologic timescales like when the

1622
01:11:48,540 --> 01:11:46,670
dinosaurs roamed the earth there is

1623
01:11:50,770 --> 01:11:48,550
probably no Orion Nebula yet to speak of

1624
01:11:56,530 --> 01:11:50,780
just for a little bit of comparison

1625
01:11:58,810 --> 01:11:56,540
there yes when you look at us the Orion

1626
01:12:03,810 --> 01:11:58,820
Nebula through a small telescope you see

1627
01:12:06,450 --> 01:12:03,820
these four stars trapezium arrangement

1628
01:12:09,070 --> 01:12:06,460
how did they relate to your talk tonight

1629
01:12:10,780 --> 01:12:09,080
alright so how do the trapezium stars at

1630
01:12:13,270 --> 01:12:10,790
the core of Orion relate to what you're

1631
01:12:15,490 --> 01:12:13,280
talking about today those are the most

1632
01:12:16,720 --> 01:12:15,500
massive stars in Orion and those are

1633
01:12:18,610 --> 01:12:16,730
part of what makes it such an

1634
01:12:20,740 --> 01:12:18,620
interesting star forming region that's

1635
01:12:22,600 --> 01:12:20,750
the closest star forming

1636
01:12:27,790 --> 01:12:22,610
and where you have stars that massive

1637
01:12:31,210 --> 01:12:27,800
and the winds the outflows energetic

1638
01:12:33,610 --> 01:12:31,220

outflows from these stars tend to shape

1639
01:12:35,800 --> 01:12:33,620
the entire dynamics and evolution of the

1640
01:12:37,540 --> 01:12:35,810
immediate Orion Nebula region there are

1641
01:12:39,280 --> 01:12:37,550
largely responsible for a lot of the

1642
01:12:42,310 --> 01:12:39,290
bright emission you see from the nebula

1643
01:12:45,760 --> 01:12:42,320
they may play a role in sort of blasting

1644
01:12:47,500 --> 01:12:45,770
discs away from the lower mass stars in

1645
01:12:50,380 --> 01:12:47,510
my talk I didn't touch on that too much

1646
01:12:52,090 --> 01:12:50,390
because they were so bright to Spitzer

1647
01:12:54,730 --> 01:12:52,100
that Spitzer actually couldn't image

1648
01:12:56,680 --> 01:12:54,740
them so we necessarily focused on kind

1649
01:12:59,050 --> 01:12:56,690
of a more outlying areas of Orion but

1650
01:13:00,490 --> 01:12:59,060
they're really responsible for just a

1651
01:13:03,400 --> 01:13:00,500
lot of what goes on in that central

1652
01:13:05,680 --> 01:13:03,410
region you know I'm learning a lot about

1653
01:13:08,860 --> 01:13:05,690
Orion as we did the visualizations of

1654
01:13:11,530 --> 01:13:08,870
the Orion Nebula and to see that giant

1655
01:13:13,810 --> 01:13:11,540
river of gas in behind it and recognize

1656
01:13:15,760 --> 01:13:13,820
that Terry yes this may be the city but

1657
01:13:20,290 --> 01:13:15,770
there is a tremendous number of suburbs

1658
01:13:23,770 --> 01:13:20,300
within the OMC out there that there's a

1659
01:13:25,810 --> 01:13:23,780
rich picture of star formation within

1660
01:13:38,550 --> 01:13:25,820
Orion is so much more than we think of

1661
01:13:40,690 --> 01:13:38,560
when we just think of the Orion Nebula I

1662
01:13:42,730 --> 01:13:40,700
may have missed it but what was the

1663
01:13:44,320 --> 01:13:42,740

mechanism for brightness changes that

1664
01:13:45,760 --> 01:13:44,330
quickly all right so what's the

1665
01:13:47,560 --> 01:13:45,770
mechanism for the quick brightness

1666
01:13:51,670 --> 01:13:47,570
changes within the t-tauri stars plot

1667
01:13:53,290 --> 01:13:51,680
you showed so if you remember that sort

1668
01:13:55,960 --> 01:13:53,300
of schematic I showed of how material

1669
01:13:59,740 --> 01:13:55,970
falls under the star exactly that's all

1670
01:14:02,260 --> 01:13:59,750
happening over about one tenth of the

1671
01:14:05,110 --> 01:14:02,270
earth-sun distance so a fairly small

1672
01:14:07,590 --> 01:14:05,120
region and just changes in the density

1673
01:14:10,300 --> 01:14:07,600
of the accreting material due to

1674
01:14:12,670 --> 01:14:10,310
pre-existing irregularities in the disk

1675
01:14:14,470 --> 01:14:12,680
structure can cause those brightness

1676
01:14:16,750 --> 01:14:14,480
variations the accretion rate sort of

1677
01:14:20,230 --> 01:14:16,760
goes up and down and that leads to

1678
01:14:29,560 --> 01:14:20,240
changes in the brightness other

1679
01:14:31,300 --> 01:14:29,570
questions yeah so what caused those

1680
01:14:33,689 --> 01:14:31,310
holes if that's really if Herschel

1681
01:14:37,379 --> 01:14:33,699
really is finding a hole

1682
01:14:38,969 --> 01:14:37,389
how did it get there that is probably

1683
01:14:41,699 --> 01:14:38,979
due to those outflows that I've been

1684
01:14:44,129 --> 01:14:41,709
talking about that some all of these

1685
01:14:47,310 --> 01:14:44,139
stars they accrete matter but then some

1686
01:14:49,500 --> 01:14:47,320
fraction of that is pushed off along the

1687
01:14:51,660 --> 01:14:49,510
poles of the star with some force and

1688
01:14:53,430 --> 01:14:51,670

that could actually blow holes in the

1689
01:14:55,259 --> 01:14:53,440
nebula if you have a few of them that

1690
01:14:57,810 --> 01:14:55,269
with the chance alignment so they're all

1691
01:15:03,089 --> 01:14:57,820
sort of collaborating on opening up a

1692
01:15:05,279 --> 01:15:03,099
hole in the nebula all right we got like

1693
01:15:05,879 --> 01:15:05,289
two more one here and one there and one

1694
01:15:17,339 --> 01:15:05,889
back there

1695
01:15:18,959 --> 01:15:17,349
that's three men all right so why do we

1696
01:15:21,390 --> 01:15:18,969
see this filament or river of gas

1697
01:15:23,370 --> 01:15:21,400
through Orion it seems like it's

1698
01:15:24,839 --> 01:15:23,380
probably magnetic fields that are

1699
01:15:26,879 --> 01:15:24,849
responsible for the filaments you've got

1700
01:15:29,250 --> 01:15:26,889
these large-scale magnetic fields kind

1701
01:15:34,020 --> 01:15:29,260
of threading the galaxies due to the

1702
01:15:35,759 --> 01:15:34,030
motion of hot gas and any gas that's

1703
01:15:38,100 --> 01:15:35,769
even a little bit ionized tends to

1704
01:15:39,479 --> 01:15:38,110
follow along those field lines so that

1705
01:15:42,870 --> 01:15:39,489
leads to these kind of stretched out

1706
01:15:54,359 --> 01:15:42,880
filamentary structures okay we had one

1707
01:15:56,339 --> 01:15:54,369
way in the back when a cloud of gas that

1708
01:15:57,569 --> 01:15:56,349
presented to a binary star with that

1709
01:16:00,719 --> 01:15:57,579
form gravity waves

1710
01:16:04,199 --> 01:16:00,729
all right so gravity waves detected from

1711
01:16:06,000 --> 01:16:04,209
two black holes merging together the

1712
01:16:08,310 --> 01:16:06,010
creation of these binary stars would

1713
01:16:11,779 --> 01:16:08,320

that also create binary gravitational

1714
01:16:15,120 --> 01:16:11,789
waves that summarize a question right

1715
01:16:17,100 --> 01:16:15,130
these are much lower energy events than

1716
01:16:19,379 --> 01:16:17,110
the creation than the collision of

1717
01:16:21,180 --> 01:16:19,389
binary black holes so there really

1718
01:16:24,089 --> 01:16:21,190
wouldn't be any appreciable gravity

1719
01:16:27,930 --> 01:16:24,099
waves from this it's more just this this

1720
01:16:30,089 --> 01:16:27,940
the clouds kind of quietly relatively

1721
01:16:33,870 --> 01:16:30,099
quietly collapsing into two stars on

1722
01:16:46,490 --> 01:16:33,880
their own okay who had the last question

1723
01:16:58,250 --> 01:16:55,480
the clustered beginner custard together

1724
01:17:00,050 --> 01:16:58,260
childhood under the impression we look

1725
01:17:02,120 --> 01:17:00,060
at a constellation up there what you

1726
01:17:03,470 --> 01:17:02,130
really see is a flat field and it'll

1727
01:17:04,960 --> 01:17:03,480
start one start moving here the other

1728
01:17:07,970 --> 01:17:04,970
maybe way to tell I'm not over there

1729
01:17:11,390 --> 01:17:07,980
when they just look like they're aligned

1730
01:17:13,490 --> 01:17:11,400
in a pattern you've seen of it right

1731
01:17:18,800 --> 01:17:13,500
there angular separation

1732
01:17:22,250 --> 01:17:18,810
visibly that's not true then or other

1733
01:17:25,490 --> 01:17:22,260
constellations those same stars kind of

1734
01:17:27,500 --> 01:17:25,500
grouped together okay so yeah the

1735
01:17:29,630 --> 01:17:27,510
question it is I when we look at

1736
01:17:32,900 --> 01:17:29,640
constellations in the night sky the

1737
01:17:35,090 --> 01:17:32,910
Stars the the full Orion constellation

1738
01:17:38,480 --> 01:17:35,100

like Betelgeuse and Rigel there are

1739
01:17:41,690 --> 01:17:38,490
totally different distances but so how

1740
01:17:43,040 --> 01:17:41,700
does that up does how does that

1741
01:17:45,290 --> 01:17:43,050
translate to some of this stuff we're

1742
01:17:47,030 --> 01:17:45,300
here working looking at here yeah so in

1743
01:17:48,740 --> 01:17:47,040
general if you pick some random

1744
01:17:50,690 --> 01:17:48,750
constellation out of the sky the stars

1745
01:17:52,040 --> 01:17:50,700
of that constellation have no physical

1746
01:17:54,470 --> 01:17:52,050
relationship to one another

1747
01:17:55,790 --> 01:17:54,480
Orion's kind of an exception is

1748
01:17:58,610 --> 01:17:55,800
everything I've been talking about here

1749
01:18:01,070 --> 01:17:58,620
this is a single well two really clouds

1750
01:18:03,740 --> 01:18:01,080
of molecular gas they're forming stars

1751
01:18:05,900 --> 01:18:03,750
that are in close proximity so all of

1752
01:18:07,760 --> 01:18:05,910
the young stars in Orion are physically

1753
01:18:10,190 --> 01:18:07,770
associated it's kind of an exception to

1754
01:18:12,380 --> 01:18:10,200
the usual rule about constellations well

1755
01:18:14,140 --> 01:18:12,390
also on the angular separation on the

1756
01:18:17,090 --> 01:18:14,150
sky of the stars of the constellation

1757
01:18:19,280 --> 01:18:17,100
are much much much much larger these are

1758
01:18:21,980 --> 01:18:19,290
all very close they're all basically in

1759
01:18:27,380 --> 01:18:21,990
Orion hanging down from Orion's belt in

1760
01:18:30,710 --> 01:18:27,390
this area down what you're talking about

1761
01:18:32,840 --> 01:18:30,720
the Magellanic Clouds no I'm not talking

1762
01:18:36,400 --> 01:18:32,850
about the Magellanic Clouds the Orion

1763
01:18:39,650 --> 01:18:36,410

the the star formation in Orion is all

1764
01:18:42,170 --> 01:18:39,660
in the area around the Orion Nebula down

1765
01:18:46,790 --> 01:18:42,180
from the below the belt you're hitting a

1766
01:18:51,569 --> 01:18:49,439
all right Hartman do you have one last

1767
01:18:54,299 --> 01:18:51,579
thing interesting I think I remember

1768
01:18:57,180 --> 01:18:54,309
right output of the three famous stars

1769
01:19:00,060 --> 01:18:57,190
in Orion's belt I'll attack although hi

1770
01:19:04,229 --> 01:19:00,070
millou taka 2,000 light-years away and

1771
01:19:06,390 --> 01:19:04,239
the end stars are like five hundred I

1772
01:19:08,040 --> 01:19:06,400
actually I guess oh he's talking about

1773
01:19:10,859 --> 01:19:08,050
that stars in the Bell being a totally

1774
01:19:14,009 --> 01:19:10,869
different distances yes I did a constant

1775
01:19:17,100 --> 01:19:14,019
I did a visualization of the main stars

1776
01:19:18,930 --> 01:19:17,110
of Orion in 3d and spin it around if you

1777
01:19:22,439 --> 01:19:18,940
look on youtube you can find it the

1778
01:19:25,770 --> 01:19:22,449
Orion constellation in 3d and it's one

1779
01:19:27,569 --> 01:19:25,780
of our more popular ones for educational

1780
01:19:29,250 --> 01:19:27,579
purposes because it takes a Ryan you see

1781
01:19:31,080 --> 01:19:29,260
it as it does and then you spin it

1782
01:19:32,759 --> 01:19:31,090
sideways and it looks more like a

1783
01:19:37,169 --> 01:19:32,769
stealth bomber than it does look like a

1784
01:19:41,069 --> 01:19:37,179
hundred all right let let's see next

1785
01:19:43,819 --> 01:19:41,079
month is it's June so July I forget what

1786
01:19:46,560 --> 01:19:43,829
our time oh the Milky Way bulge the blob

1787
01:19:49,770 --> 01:19:46,570
from from blob - remarkably detailed

1788
01:19:52,169 --> 01:19:49,780

picture that will be our July talk hope

1789
01:19:53,480 --> 01:19:52,179
to see you all there and let's give will

1790
01:20:04,460 --> 01:19:53,490
another big