

Hubble Public Lecture Series

Topic: A Trip Through the
Light Fantastic

Speaker: Frank Summers,
Space Telescope Science Institute



1
00:00:04,249 --> 00:00:02,030
on the way in there's still plenty on

2
00:00:08,390 --> 00:00:04,259
the table over there get them on the way

3
00:00:11,690 --> 00:00:08,400
out our talk tonight a trip through the

4
00:00:13,999 --> 00:00:11,700
light fantastic by Frank summers of

5
00:00:18,050 --> 00:00:14,009
space telescope and I'll introduce him

6
00:00:21,380 --> 00:00:18,060
in just a minute let's say upcoming our

7
00:00:22,970 --> 00:00:21,390
talks I as I said I'm trying to get

8
00:00:25,820 --> 00:00:22,980
somebody from New Horizons to do the

9
00:00:27,859 --> 00:00:25,830
October talk but I haven't haven't had

10
00:00:29,960 --> 00:00:27,869
much success I was on vacation a lot

11
00:00:32,720 --> 00:00:29,970
this month so I am a little bit behind

12
00:00:34,670 --> 00:00:32,730
on things November we have mario livio

13
00:00:36,200 --> 00:00:34,680

and i know I looked in my email today

14

00:00:38,450 --> 00:00:36,210

and he still hadn't given me a talk

15

00:00:40,340 --> 00:00:38,460

title so I have to contact him tomorrow

16

00:00:43,340 --> 00:00:40,350

and say Mario give me a talk for

17

00:00:46,819 --> 00:00:43,350

November and in December Lucy McFadden

18

00:00:49,549 --> 00:00:46,829

from Goddard Space Flight Center one of

19

00:00:51,560 --> 00:00:49,559

the lead people on the dawn mission that

20

00:00:54,650 --> 00:00:51,570

went past Vesta a couple years ago went

21

00:00:57,350 --> 00:00:54,660

to Ceres is currently orbiting series

22

00:00:59,660 --> 00:00:57,360

will give a talk on dawn a journey to

23

00:01:01,700 --> 00:00:59,670

the early solar system in December I'm

24

00:01:04,310 --> 00:01:01,710

extremely excited to have Lucy come up

25

00:01:07,149 --> 00:01:04,320

here in December you want the latest

26

00:01:10,429 --> 00:01:07,159

information you can go to our website

27

00:01:13,310 --> 00:01:10,439

and you can do Hubble site Dargo talks

28

00:01:15,109 --> 00:01:13,320

or if you just put Hubble public lecture

29

00:01:17,030 --> 00:01:15,119

in your favorite search engine this

30

00:01:19,429 --> 00:01:17,040

should be the page that you get which

31

00:01:22,850 --> 00:01:19,439

lists our upcoming lectures and it also

32

00:01:26,149 --> 00:01:22,860

has a link to our wonderful STScI web

33

00:01:28,940 --> 00:01:26,159

casting team archive our web casting

34

00:01:31,760 --> 00:01:28,950

team has been as the archive of them all

35

00:01:34,280 --> 00:01:31,770

the way back to 2005 you've got ten

36

00:01:36,710 --> 00:01:34,290

years of public lecture and goodness to

37

00:01:39,200 --> 00:01:36,720

explore so if you've got a free weekend

38

00:01:43,249 --> 00:01:39,210

or a free few weeks you can watch them

39

00:01:46,700 --> 00:01:43,259

all back to 2005 all right if you would

40

00:01:48,319 --> 00:01:46,710

like announcements you sign up and this

41

00:01:52,160 --> 00:01:48,329

is new because we started this in the

42

00:01:54,469 --> 00:01:52,170

spring nail list that STScl dot edu okay

43

00:01:56,690 --> 00:01:54,479

and you look for public lecture

44

00:01:58,190 --> 00:01:56,700

announced I think there's only one or

45

00:02:00,260 --> 00:01:58,200

two mail lists that are public on that

46

00:02:04,160 --> 00:02:00,270

anyways just provide your email address

47

00:02:06,560 --> 00:02:04,170

and you will not be getting any spam or

48

00:02:09,020 --> 00:02:06,570

if you would like to have us sign you up

49

00:02:12,589 --> 00:02:09,030

for it you can contact us at public

50

00:02:13,220 --> 00:02:12,599

lecture at STScl edu you can sign up the

51
00:02:15,530 --> 00:02:13,230
announcements

52
00:02:17,960 --> 00:02:15,540
or if you have comments or questions you

53
00:02:21,229 --> 00:02:17,970
would like to ask please send them to

54
00:02:23,479 --> 00:02:21,239
that email address we have social media

55
00:02:25,550 --> 00:02:23,489
for those who do it of course we have

56
00:02:26,540 --> 00:02:25,560
facebook we have at two different

57
00:02:29,839 --> 00:02:26,550
Twitter feeds

58
00:02:31,309 --> 00:02:29,849
we have Google+ we have Pinterest for

59
00:02:34,910 --> 00:02:31,319
those who do that I think we probably

60
00:02:36,740 --> 00:02:34,920
even have oh what's the other one

61
00:02:39,530 --> 00:02:36,750
Instagram I don't know if we have that

62
00:02:43,009 --> 00:02:39,540
I'm sorry I only do so much i I do

63
00:02:45,289 --> 00:02:43,019

Facebook and Google+ and Twitter for my

64

00:02:47,780 --> 00:02:45,299

stuff unfortunately not as much as I

65

00:02:49,610 --> 00:02:47,790

should I just have so much stuff to do

66

00:02:52,339 --> 00:02:49,620

it's hard to keep up doing a lot of

67

00:02:53,270 --> 00:02:52,349

social media but I will try and keep up

68

00:02:55,610 --> 00:02:53,280

all right

69

00:02:58,309 --> 00:02:55,620

the observatory tonight the weather is

70

00:03:00,979 --> 00:02:58,319

permitting I got an email saying yes the

71

00:03:02,569 --> 00:03:00,989

observatory is on so after the lecture

72

00:03:04,039 --> 00:03:02,579

if you would like to go across the

73

00:03:06,020 --> 00:03:04,049

street to the Maryland Space Grant

74

00:03:08,120 --> 00:03:06,030

Observatory which looks something like

75

00:03:11,870 --> 00:03:08,130

this up on the physics and astronomy

76

00:03:14,420 --> 00:03:11,880

building across the street the person I

77

00:03:16,460 --> 00:03:14,430

believe it's Duncan is it Duncan he's

78

00:03:18,830 --> 00:03:16,470

not here right now obviously we'll be

79

00:03:20,930 --> 00:03:18,840

here afterwards come down meet here as a

80

00:03:22,610 --> 00:03:20,940

group and walk over across the street as

81

00:03:24,050 --> 00:03:22,620

a group you cannot go over on your own

82

00:03:26,569 --> 00:03:24,060

you have to go over with the group

83

00:03:30,080 --> 00:03:26,579

because he's got to let folks in certain

84

00:03:31,789 --> 00:03:30,090

doors etc okay all right normally I

85

00:03:34,729 --> 00:03:31,799

would be doing news from the universe

86

00:03:37,420 --> 00:03:34,739

for September 2015 but as is my

87

00:03:40,280 --> 00:03:37,430

tradition whenever I give the talk I

88

00:03:41,720 --> 00:03:40,290

don't have enough time to prepare a news

89

00:03:44,150 --> 00:03:41,730

summary it takes a little while to do

90

00:03:47,059 --> 00:03:44,160

that so as I promised I will make sure

91

00:03:49,520 --> 00:03:47,069

you get your full dose of Pluto next

92

00:03:52,550 --> 00:03:49,530

month okay alright we get lots of Pluto

93

00:03:56,360 --> 00:03:52,560

next month now I get to introduce our

94

00:03:58,250 --> 00:03:56,370

featured speaker and when I give the

95

00:04:01,400 --> 00:03:58,260

talk alright how many people are new

96

00:04:02,900 --> 00:04:01,410

here haven't been here before we got

97

00:04:04,099 --> 00:04:02,910

about a dozen alright so let me do my

98

00:04:06,559 --> 00:04:04,109

introduction the rest of you can close

99

00:04:08,210 --> 00:04:06,569

your eyes for a second I'm an astronomer

100

00:04:12,500 --> 00:04:08,220

in the office of public outreach here

101

00:04:14,600 --> 00:04:12,510

I've been here for 14 years I work on

102

00:04:17,449 --> 00:04:14,610

all things Hubble and weather

103

00:04:19,849 --> 00:04:17,459

they press releases or websites or

104

00:04:22,310 --> 00:04:19,859

educational activities or working with

105

00:04:25,270 --> 00:04:22,320

planet area my favorite things to do are

106

00:04:29,000 --> 00:04:25,280

astronomy visualizations right and so I

107

00:04:30,740 --> 00:04:29,010

you know got a history doing I'm an

108

00:04:33,050 --> 00:04:30,750

astronomer but actually I'm a

109

00:04:35,000 --> 00:04:33,060

professional outreach astronomer I have

110

00:04:37,250 --> 00:04:35,010

been doing outreach only for over a

111

00:04:40,220 --> 00:04:37,260

decade I've been about two decades worth

112

00:04:41,300 --> 00:04:40,230

of outreach astronomy so I don't do

113

00:04:44,360 --> 00:04:41,310

research anymore

114

00:04:46,460 --> 00:04:44,370

now but the rest of you when I do these

115

00:04:48,620 --> 00:04:46,470

talks since some of you who've been here

116

00:04:50,659 --> 00:04:48,630

have been here longer than I have coming

117

00:04:52,250 --> 00:04:50,669

for public lecture series I like to show

118

00:04:55,220 --> 00:04:52,260

you something that you didn't you may

119

00:04:58,640 --> 00:04:55,230

not remember about me so our speech

120

00:05:00,590 --> 00:04:58,650

speaker tonight when he was young this

121

00:05:14,600 --> 00:05:00,600

is a picture of the astrophysicist as a

122

00:05:16,940 --> 00:05:14,610

young man this is me in 1983 was it this

123

00:05:19,760 --> 00:05:16,950

is the paso doble costume I was a

124

00:05:21,770 --> 00:05:19,770

competitive ice dancer this photograph

125

00:05:25,010 --> 00:05:21,780

by David Leonardi the photographer of

126

00:05:27,320 --> 00:05:25,020

all the great ice skating stars and my

127

00:05:29,930 --> 00:05:27,330

skating partner sand sandy McGee

128

00:05:33,170 --> 00:05:29,940

Sanderlin McGee I was a competitive ice

129

00:05:36,409 --> 00:05:33,180

dancer for I don't know about a decade

130

00:05:41,570 --> 00:05:36,419

or so and I retired at the ripe old age

131

00:05:44,480 --> 00:05:41,580

of 20 or so I was ranked tenth in the

132

00:05:46,010 --> 00:05:44,490

United States when I retired so I like

133

00:05:47,360 --> 00:05:46,020

to show pictures like this to say hey

134

00:05:49,250 --> 00:05:47,370

you know what you can be an

135

00:05:52,730 --> 00:05:49,260

astrophysicist geek but you can also

136

00:05:55,370 --> 00:05:52,740

have an artistic background okay and so

137

00:05:58,159 --> 00:05:55,380

I was a competitive ice dancer before I

138

00:06:00,260 --> 00:05:58,169

became an astrophysicist the two are not

139

00:06:03,830 --> 00:06:00,270

mutually exclusive you have at least one

140

00:06:11,230 --> 00:06:03,840

example of that all right so let us

141

00:06:17,180 --> 00:06:14,450

all right so tonight's talk is a trip

142

00:06:19,190 --> 00:06:17,190

through the light fantastic and as I

143

00:06:21,290 --> 00:06:19,200

said in my previous intro before this

144

00:06:23,540 --> 00:06:21,300

this is a talk that I have given to

145

00:06:25,370 --> 00:06:23,550

educators I've spiced it up a bit and

146

00:06:26,970 --> 00:06:25,380

changed it around just a little bit in

147

00:06:31,890 --> 00:06:26,980

terms to present it for the public

148

00:06:35,040 --> 00:06:31,900

but it is really it's a fundamental idea

149

00:06:36,450 --> 00:06:35,050

of the electromagnetic spectrum and the

150

00:06:39,120 --> 00:06:36,460

electromagnetic spectrum that underlies

151

00:06:41,430 --> 00:06:39,130

astronomy but also underlies lots of

152

00:06:44,520 --> 00:06:41,440

other sciences because it is used in

153

00:06:47,400 --> 00:06:44,530

physics it is used underlying chemistry

154

00:06:50,340 --> 00:06:47,410

and in biology understanding the idea of

155

00:06:53,370 --> 00:06:50,350

life and when you think about astronomy

156

00:06:56,340 --> 00:06:53,380

you might have that romantic notion that

157

00:06:58,560 --> 00:06:56,350

idea of the astronomer standing at the

158

00:07:00,360 --> 00:06:58,570

telescope looking through his giant

159

00:07:03,300 --> 00:07:00,370

telescope perhaps up on top of a

160

00:07:06,840 --> 00:07:03,310

mountaintop and that's just not how it

161

00:07:10,020 --> 00:07:06,850

is anymore that's how it was 150 years

162

00:07:13,590 --> 00:07:10,030

ago when this engraving was done this is

163

00:07:15,540 --> 00:07:13,600

from night from 1848 this is the

164

00:07:17,850 --> 00:07:15,550

telescope at the Cincinnati observatory

165

00:07:18,830 --> 00:07:17,860

which at the time was the second largest

166

00:07:21,420 --> 00:07:18,840

in the country

167

00:07:24,810 --> 00:07:21,430

Cincinnati second largest telescope in

168

00:07:26,850 --> 00:07:24,820

the country at that time but what do

169

00:07:28,710 --> 00:07:26,860

astronomers look like these days do they

170

00:07:31,260 --> 00:07:28,720

go they go up to the mountaintops yes

171

00:07:34,050 --> 00:07:31,270

but what do they do they sit in front of

172

00:07:36,120 --> 00:07:34,060

banks of computers okay they don't put

173

00:07:38,610 --> 00:07:36,130

their eye up to the telescope it's not

174

00:07:40,260 --> 00:07:38,620

that poetic anymore we have CCD

175

00:07:42,300 --> 00:07:40,270

detectors that do all that for them

176

00:07:44,160 --> 00:07:42,310

everything becomes digital it comes to

177

00:07:45,960 --> 00:07:44,170

the computers and you sit there at the

178

00:07:47,970 --> 00:07:45,970

keyboard with your notes and everything

179

00:07:51,510 --> 00:07:47,980

and very carefully taking taking

180

00:07:54,960 --> 00:07:51,520

advantage of it also astronomers have

181

00:07:58,200 --> 00:07:54,970

used other wavelengths now all right we

182

00:07:59,940 --> 00:07:58,210

do radio observations okay giant radio

183

00:08:02,280 --> 00:07:59,950

dishes and where are you gonna put your

184

00:08:05,130 --> 00:08:02,290

eye on this hmm are you actually gonna

185

00:08:06,600 --> 00:08:05,140

go there well well actually you know the

186

00:08:09,510 --> 00:08:06,610

Jodie Foster character from the movie

187

00:08:11,310 --> 00:08:09,520

contact notwithstanding and that the

188

00:08:14,220 --> 00:08:11,320

idea was that she was actually listening

189

00:08:17,220 --> 00:08:14,230

to the radio signals that were being

190

00:08:17,940 --> 00:08:17,230

detected by these dishes yeah doesn't

191

00:08:20,790 --> 00:08:17,950

happen okay

192

00:08:24,270 --> 00:08:20,800

nice poetic idea for the movie yeah

193

00:08:26,970 --> 00:08:24,280

doesn't happen so when we are looking in

194

00:08:29,130 --> 00:08:26,980

wavelengths that are I can't see of

195

00:08:31,890 --> 00:08:29,140

course we have to be doing detected uh

196

00:08:34,409 --> 00:08:31,900

if you're using detectors to do this and

197

00:08:36,630 --> 00:08:34,419

one of the great advances of 20th

198

00:08:39,630 --> 00:08:36,640

century astronomy was a hundred years

199

00:08:41,060 --> 00:08:39,640

ago all we were doing was looking with

200

00:08:43,610 --> 00:08:41,070

our eyes okay

201
00:08:46,160 --> 00:08:43,620
and we started to take photography in

202
00:08:48,009 --> 00:08:46,170
the late 1800s but we were using visible

203
00:08:51,530 --> 00:08:48,019
light astronomy

204
00:08:54,319 --> 00:08:51,540
until we started to exploit the other

205
00:08:56,720 --> 00:08:54,329
wavelengths radio waves came first but

206
00:08:59,960 --> 00:08:56,730
we now do astronomy across the entire

207
00:09:01,670 --> 00:08:59,970
electromagnetic spectrum and so that

208
00:09:04,670 --> 00:09:01,680
what is what this trip through the light

209
00:09:06,920 --> 00:09:04,680
fantastic is about is to show you the

210
00:09:10,790 --> 00:09:06,930
variety of ways that we look at the

211
00:09:12,319 --> 00:09:10,800
universe and remind you of the different

212
00:09:14,930 --> 00:09:12,329
things that we can see using the

213
00:09:17,600 --> 00:09:14,940

different types of light so let's begin

214

00:09:19,930 --> 00:09:17,610

with visible light visible light is of

215

00:09:24,110 --> 00:09:19,940

course the light that the human eye sees

216

00:09:27,019 --> 00:09:24,120

right and it is also the light that is

217

00:09:30,129 --> 00:09:27,029

given off most by our Sun this of course

218

00:09:32,990 --> 00:09:30,139

is not a coincidence if you want to see

219

00:09:35,569 --> 00:09:33,000

in the light of the Sun well it helps if

220

00:09:37,850 --> 00:09:35,579

your detector is tuned to the

221

00:09:40,970 --> 00:09:37,860

wavelengths to given off by that Sun

222

00:09:44,689 --> 00:09:40,980

here are three blackpot for blackbody

223

00:09:46,819 --> 00:09:44,699

curves of various stars so our Sun is

224

00:09:48,650 --> 00:09:46,829

approximately a 6,000 degree Kelvin star

225

00:09:51,470 --> 00:09:48,660

so it's this curve in here in the middle

226
00:09:54,769 --> 00:09:51,480
and the upper curve at 7,000 degrees

227
00:09:57,050 --> 00:09:54,779
Kelvin is a hotter star the 5000-year

228
00:09:59,569 --> 00:09:57,060
Kelvin is just a little cooler than the

229
00:10:02,600 --> 00:09:59,579
Sun and then the 3,000 degree Kelvin is

230
00:10:05,030 --> 00:10:02,610
a red dwarf much cooler than the Sun all

231
00:10:06,530 --> 00:10:05,040
right and so this is the emission all

232
00:10:10,309 --> 00:10:06,540
right the amount of emission on the

233
00:10:12,949 --> 00:10:10,319
y-axis by wavelength on the x-axis for

234
00:10:15,139 --> 00:10:12,959
various stars and where does the Sun

235
00:10:17,210 --> 00:10:15,149
peak right here in the visible

236
00:10:19,309 --> 00:10:17,220
wavelengths all right the hotter stars

237
00:10:21,079 --> 00:10:19,319
can move toward the ultraviolet the

238
00:10:24,949 --> 00:10:21,089

cooler stars actually have their peaks

239

00:10:28,100 --> 00:10:24,959

out in the infrared so visible light is

240

00:10:30,470 --> 00:10:28,110

where our Sun emits most of its light

241

00:10:33,730 --> 00:10:30,480

and if you know anything about our Sun

242

00:10:39,259 --> 00:10:33,740

you know that we call it a yellow star

243

00:10:42,829 --> 00:10:39,269

however this is wrong okay our Sun may

244

00:10:46,400 --> 00:10:42,839

be called a yellow star but it is not a

245

00:10:48,889 --> 00:10:46,410

yellow star we do not see a yellow star

246

00:10:51,439 --> 00:10:48,899

you have been lied to your entire life

247

00:10:52,820 --> 00:10:51,449

because they draw a blue sky with a

248

00:10:55,040 --> 00:10:52,830

yellow Sun in it okay

249

00:10:57,470 --> 00:10:55,050

that's not what the Sun looks like if

250

00:10:59,600 --> 00:10:57,480

you look at the Sun and you measure its

251
00:11:02,360 --> 00:10:59,610
color as perceived by the human eye

252
00:11:05,120 --> 00:11:02,370
you take that blackbody curve you map it

253
00:11:08,440 --> 00:11:05,130
through the RGB cones of your eye the

254
00:11:12,710 --> 00:11:08,450
color you'll get is something like this

255
00:11:15,800 --> 00:11:12,720
our Sun is mostly white okay it may be

256
00:11:17,540 --> 00:11:15,810
called a yellow star but in its white

257
00:11:19,460 --> 00:11:17,550
light actually you know if you do it

258
00:11:21,920 --> 00:11:19,470
really carefully I I see a little bit of

259
00:11:23,690 --> 00:11:21,930
peach in it okay there's it's mostly

260
00:11:26,000 --> 00:11:23,700
white with a little bit of peach now

261
00:11:28,490 --> 00:11:26,010
this color comes from my monitor to the

262
00:11:30,350 --> 00:11:28,500
projector to the screen etc so there's

263
00:11:33,130 --> 00:11:30,360

no real color fidelity here I can't show

264

00:11:37,220 --> 00:11:33,140

you exactly exact color matching here

265

00:11:39,949 --> 00:11:37,230

but basically the Sun is mostly white

266

00:11:43,670 --> 00:11:39,959

okay now of course white light itself

267

00:11:46,519 --> 00:11:43,680

can be broken down into all the colors

268

00:11:48,410 --> 00:11:46,529

of the rainbow okay that red orange

269

00:11:50,900 --> 00:11:48,420

yellow green blue violet of that rainbow

270

00:11:52,819 --> 00:11:50,910

is really just breaking up the sun's

271

00:11:54,949 --> 00:11:52,829

light into its component wavelengths to

272

00:11:57,980 --> 00:11:54,959

see those various colors

273

00:11:59,569 --> 00:11:57,990

alright so Sun emits white light white

274

00:12:01,970 --> 00:11:59,579

light is actually composed of many

275

00:12:05,079 --> 00:12:01,980

different colors now we see a lot of

276

00:12:08,000 --> 00:12:05,089

things in astronomy using visible light

277

00:12:10,010 --> 00:12:08,010

so we look at the moon and here's a

278

00:12:13,010 --> 00:12:10,020

gorgeous picture of the full moon out

279

00:12:16,490 --> 00:12:13,020

over the ocean but the moon doesn't emit

280

00:12:19,310 --> 00:12:16,500

light okay the moon only reflects the

281

00:12:20,930 --> 00:12:19,320

light of the Sun okay it's important to

282

00:12:23,420 --> 00:12:20,940

recognize that the Sun emits the light

283

00:12:27,319 --> 00:12:23,430

but the moon only sees by reflected

284

00:12:29,269 --> 00:12:27,329

light Jupiter also invisible light we

285

00:12:31,639 --> 00:12:29,279

don't actually see it we it does not

286

00:12:33,829 --> 00:12:31,649

emit visible light but it reflects the

287

00:12:35,829 --> 00:12:33,839

light of the Sun Jupiter as I'll show

288

00:12:39,199 --> 00:12:35,839

you a little bit later actually does

289

00:12:41,329 --> 00:12:39,209

emit some infrared light it actually is

290

00:12:43,819 --> 00:12:41,339

glowing in infrared but it is not

291

00:12:46,660 --> 00:12:43,829

glowing in visible light it is just

292

00:12:50,060 --> 00:12:46,670

reflecting the light of the Sun

293

00:12:52,040 --> 00:12:50,070

asteroids they're not glowing they're

294

00:12:53,800 --> 00:12:52,050

just reflecting the light of Sun what

295

00:12:56,300 --> 00:12:53,810

about comets

296

00:12:58,220 --> 00:12:56,310

comets are really cool they look like

297

00:12:59,660 --> 00:12:58,230

they're actually glowing like they're

298

00:13:02,870 --> 00:12:59,670

actually emitting light but again

299

00:13:04,519 --> 00:13:02,880

they're also just reflecting light okay

300

00:13:06,600 --> 00:13:04,529

so most of the things we see in the

301

00:13:10,139 --> 00:13:06,610

solar system are just reflecting

302

00:13:12,960 --> 00:13:10,149

the light of the Sun the Sun is our is

303

00:13:14,869 --> 00:13:12,970

our source of visible light if we look

304

00:13:16,619 --> 00:13:14,879

at other stars are they emitting light

305

00:13:18,269 --> 00:13:16,629

yes of course

306

00:13:21,949 --> 00:13:18,279

right but I like to show the Pleiades

307

00:13:25,590 --> 00:13:21,959

because all this blue gas around here

308

00:13:27,929 --> 00:13:25,600

it's called a reflection nebula that gas

309

00:13:29,489 --> 00:13:27,939

is not glowing because it's hot it's

310

00:13:32,069 --> 00:13:29,499

glowing because it's reflecting the

311

00:13:34,169 --> 00:13:32,079

light of the stars around it

312

00:13:36,449 --> 00:13:34,179

the plea DS are relatively young star

313

00:13:38,129 --> 00:13:36,459

cluster the gas from which they're that

314

00:13:40,350 --> 00:13:38,139

which they were formed hasn't fully

315

00:13:43,350 --> 00:13:40,360

dissipated away and so you're seeing

316

00:13:46,229 --> 00:13:43,360

some of the gas around them

317

00:13:49,289 --> 00:13:46,239

reflecting the light of the stars if

318

00:13:51,269 --> 00:13:49,299

instead you go to the Orion Nebula well

319

00:13:54,419 --> 00:13:51,279

the hot stars at the core of the Orion

320

00:13:56,699 --> 00:13:54,429

Nebula have heated this gas so the gas

321

00:13:58,710 --> 00:13:56,709

and this nebula is glowing it's heated

322

00:14:00,299 --> 00:13:58,720

up to high enough temperature that the

323

00:14:02,449 --> 00:14:00,309

gas itself is glowing

324

00:14:05,369 --> 00:14:02,459

alright so it's important to recognize

325

00:14:07,259 --> 00:14:05,379

as an astronomer when something is

326

00:14:08,609 --> 00:14:07,269

actually glowing in that light and when

327

00:14:11,609 --> 00:14:08,619

it is just reflecting the light around

328

00:14:15,479 --> 00:14:11,619

it we have to an analyze the situation

329

00:14:19,949 --> 00:14:15,489

and for things like a supernova remnant

330

00:14:21,210 --> 00:14:19,959

this is the Crab supernova the interior

331

00:14:23,879 --> 00:14:21,220

of this was actually heated to millions

332

00:14:26,819 --> 00:14:23,889

of degrees this is a visible light image

333

00:14:28,710 --> 00:14:26,829

of specific wavelengths detecting

334

00:14:30,960 --> 00:14:28,720

specific elements in the out and the

335

00:14:33,989 --> 00:14:30,970

external parts of the supernova remnant

336

00:14:37,019 --> 00:14:33,999

of this of course is also gas that is

337

00:14:39,809 --> 00:14:37,029

glowing there also gas that is absorbing

338

00:14:42,090 --> 00:14:39,819

that is easily seen in this image of the

339

00:14:43,470 --> 00:14:42,100

Whirlpool Galaxy so we have these pink

340

00:14:45,629 --> 00:14:43,480

regions which are the star forming

341

00:14:47,819 --> 00:14:45,639

regions we have the blue stars and the

342

00:14:50,609 --> 00:14:47,829

yellow stars on in here but we also see

343

00:14:52,859 --> 00:14:50,619

this marbling this dark stuff here well

344

00:14:55,319 --> 00:14:52,869

that's gasps that's not emitting light

345

00:14:57,119 --> 00:14:55,329

that is absorbing the light it's

346

00:14:59,909 --> 00:14:57,129

blocking the light so we have bright

347

00:15:02,489 --> 00:14:59,919

nebula we have reflection nebula we have

348

00:15:04,079 --> 00:15:02,499

emission nebula we also have dark nebula

349

00:15:07,109 --> 00:15:04,089

that we can't see that's actually

350

00:15:09,359 --> 00:15:07,119

blocking the light of other stars so

351
00:15:11,970 --> 00:15:09,369
when we consider visible light our base

352
00:15:14,609 --> 00:15:11,980
spacing how do we remember it well

353
00:15:17,220 --> 00:15:14,619
probably in school you learn something

354
00:15:19,640 --> 00:15:17,230
like Roy G Boop now how many of you

355
00:15:22,080 --> 00:15:19,650
actually had indigo in there VI D

356
00:15:24,330 --> 00:15:22,090
yes the older kids even the younger ones

357
00:15:28,830 --> 00:15:24,340
okay your textbooks having been updated

358
00:15:31,890 --> 00:15:28,840
lately ad they uh-huh I don't know when

359
00:15:35,280 --> 00:15:31,900
indigo was removed from this but it was

360
00:15:39,960 --> 00:15:35,290
many decades ago I thought a lot of

361
00:15:42,360 --> 00:15:39,970
people learned roy gb IV the indigo was

362
00:15:45,240 --> 00:15:42,370
no longer used so it's just red orange

363
00:15:47,070 --> 00:15:45,250

yellow green blue and violet for the

364

00:15:49,860 --> 00:15:47,080

colors of the spectrum of visible light

365

00:15:52,710 --> 00:15:49,870

and the important point about this is

366

00:15:54,920 --> 00:15:52,720

recognizing that these are all the same

367

00:15:57,060 --> 00:15:54,930

phenomenon of light but they have one

368

00:15:58,650 --> 00:15:57,070

characteristic different and you can

369

00:16:01,460 --> 00:15:58,660

consider that characteristic of energy

370

00:16:04,620 --> 00:16:01,470

that red is lower energy than violet or

371

00:16:06,570 --> 00:16:04,630

frequency or wavelength okay and

372

00:16:09,840 --> 00:16:06,580

wavelength actually increases the

373

00:16:11,430 --> 00:16:09,850

opposite direction of frequency now on

374

00:16:13,560 --> 00:16:11,440

this next slide I'm going to get into an

375

00:16:15,840 --> 00:16:13,570

equation this is something that I

376

00:16:17,100 --> 00:16:15,850

definitely do for the teachers but since

377

00:16:19,020 --> 00:16:17,110

some teachers will probably watch this

378

00:16:22,010 --> 00:16:19,030

in the archive let's I want to put it up

379

00:16:24,000 --> 00:16:22,020

there okay so for the fundamental

380

00:16:26,340 --> 00:16:24,010

equations alright the fundamental

381

00:16:29,010 --> 00:16:26,350

properties of light to understand is

382

00:16:30,450 --> 00:16:29,020

that it it's a wave okay all right and

383

00:16:32,490 --> 00:16:30,460

the energy of the wave is proportional

384

00:16:35,760 --> 00:16:32,500

to the frequency the higher the

385

00:16:38,970 --> 00:16:35,770

frequency the more energy you can have a

386

00:16:41,520 --> 00:16:38,980

slow frequency your low energy all right

387

00:16:43,890 --> 00:16:41,530

then you get up that's higher energy

388

00:16:45,780 --> 00:16:43,900

makes sense right and the

389

00:16:47,100 --> 00:16:45,790

proportionality constant is called

390

00:16:50,310 --> 00:16:47,110

Planck's constant that's what this

391

00:16:54,570 --> 00:16:50,320

little h is here this is the v is

392

00:16:56,610 --> 00:16:54,580

traditionally a Greek letter ν for the

393

00:16:59,220 --> 00:16:56,620

oscillations per second measured in

394

00:17:01,650 --> 00:16:59,230

hertz okay and then the other thing to

395

00:17:03,690 --> 00:17:01,660

recognize is the other equation that we

396

00:17:06,060 --> 00:17:03,700

need to know for λ is that frequency

397

00:17:08,310 --> 00:17:06,070

times wavelength is equal to the speed

398

00:17:10,680 --> 00:17:08,320

of light okay they're inversely

399

00:17:12,810 --> 00:17:10,690

proportional to one another so we've got

400

00:17:14,990 --> 00:17:12,820

this frequency which is ν the

401

00:17:17,939 --> 00:17:15,000

wavelength is represented by λ

402

00:17:19,470 --> 00:17:17,949

together they combine to make the speed

403

00:17:22,199 --> 00:17:19,480

of light and this is constant throughout

404

00:17:24,780 --> 00:17:22,209

it okay so that as frequency goes up

405

00:17:26,520 --> 00:17:24,790

wavelength has to go down as wavelength

406

00:17:28,050 --> 00:17:26,530

goes up frequency has to go out they're

407

00:17:30,660 --> 00:17:28,060

inversely proportional to one another

408

00:17:33,190 --> 00:17:30,670

all right so if you want to make a real

409

00:17:42,100 --> 00:17:33,200

geek joke somebody says hey what's

410

00:17:44,200 --> 00:17:42,110

do you say C over λ it takes a

411

00:17:45,759 --> 00:17:44,210

while for that one synced yes okay so

412

00:17:47,950 --> 00:17:45,769

that's your physics joke for the night

413

00:17:53,169 --> 00:17:47,960

there are actually a few more jokes here

414

00:17:55,570 --> 00:17:53,179

leave that alone so when we think about

415

00:17:57,879 --> 00:17:55,580

this visible spectrum we're now taking

416

00:18:00,129 --> 00:17:57,889

an increasing wavelength here okay so

417

00:18:01,470 --> 00:18:00,139

longer wavelengths are over here all

418

00:18:04,210 --> 00:18:01,480

right so we reversed it from the ROYGBIV

419

00:18:06,279 --> 00:18:04,220

all right but the visible spectrum is

420

00:18:09,519 --> 00:18:06,289

only a tiny part of the entire

421

00:18:11,049 --> 00:18:09,529

electromagnetic spectrum okay so those

422

00:18:12,519 --> 00:18:11,059

are the different properties of visible

423

00:18:15,070 --> 00:18:12,529

light but they are also the same

424

00:18:17,200 --> 00:18:15,080

properties of the entire electromagnetic

425

00:18:20,500 --> 00:18:17,210

spectrum which includes gamma rays

426

00:18:23,590 --> 00:18:20,510

x-rays ultraviolet infrared microwave

427

00:18:25,980 --> 00:18:23,600

and radio waves the whole point is that

428

00:18:28,539 --> 00:18:25,990

all of these are the exact same

429

00:18:30,549 --> 00:18:28,549

phenomenon just having different

430

00:18:33,340 --> 00:18:30,559

wavelengths or different frequencies or

431

00:18:36,820 --> 00:18:33,350

different energies okay so when we think

432

00:18:38,740 --> 00:18:36,830

of the electromagnetic spectrum we don't

433

00:18:40,419 --> 00:18:38,750

think that x-rays are something totally

434

00:18:42,639 --> 00:18:40,429

crazy different from the normal visible

435

00:18:45,549 --> 00:18:42,649

light or that radio waves are something

436

00:18:48,190 --> 00:18:45,559

you know unfathomable comparative is

437

00:18:50,649 --> 00:18:48,200

like they're all the same thing but

438

00:18:53,019 --> 00:18:50,659

these have shorter wavelength higher

439

00:18:55,090 --> 00:18:53,029

frequency and larger energy these have

440

00:18:58,240 --> 00:18:55,100

longer wavelength lower frequency and

441

00:19:00,460 --> 00:18:58,250

smaller energies that's the point of the

442

00:19:02,200 --> 00:19:00,470

arc magnetic spectrum so let's take a

443

00:19:04,210 --> 00:19:02,210

trip across this electromagnetic

444

00:19:07,000 --> 00:19:04,220

spectrum and see what we see we're gonna

445

00:19:10,060 --> 00:19:07,010

start with the low energy and the long

446

00:19:12,820 --> 00:19:10,070

wavelengths radio waves okay wavelengths

447

00:19:14,470 --> 00:19:12,830

roughly and I gotta say these divisions

448

00:19:16,629 --> 00:19:14,480

aren't set in stone

449

00:19:18,549 --> 00:19:16,639

here are some rough rough divisions the

450

00:19:21,580 --> 00:19:18,559

wavelength is longer than a meter okay

451
00:19:25,299 --> 00:19:21,590
so this is a wave about that long okay

452
00:19:27,310 --> 00:19:25,309
and longer and longer this is why we

453
00:19:30,370 --> 00:19:27,320
need giant radio dishes okay

454
00:19:33,850 --> 00:19:30,380
the frequency is low frequency less than

455
00:19:36,940 --> 00:19:33,860
300 million Hertz yeah 300 million Hertz

456
00:19:38,710 --> 00:19:36,950
is low frequency folks okay could we get

457
00:19:40,330 --> 00:19:38,720
up to other things it'll be and it'll

458
00:19:42,430 --> 00:19:40,340
get unfathomable and actually I'll stop

459
00:19:45,090 --> 00:19:42,440
using frequencies so when we think of

460
00:19:48,120 --> 00:19:45,100
radio in our everyday life well we think

461
00:19:50,610 --> 00:19:48,130
radio this is actually a multiband radio

462
00:19:52,830 --> 00:19:50,620
that has not only your familiar AM and

463
00:19:55,980 --> 00:19:52,840

FM channels but also a bunch of

464

00:20:00,210 --> 00:19:55,990

shortwave and other wave channels

465

00:20:02,460 --> 00:20:00,220

across here if we look at the AM n FM

466

00:20:05,370 --> 00:20:02,470

that you're used to a M stands for

467

00:20:08,640 --> 00:20:05,380

amplitude modulation and that's 540 to

468

00:20:12,990 --> 00:20:08,650

1600 kilohertz okay Killough meaning a

469

00:20:16,140 --> 00:20:13,000

thousand so the most listened-to AM

470

00:20:21,210 --> 00:20:16,150

radio station in the country is WABC AM

471

00:20:23,880 --> 00:20:21,220

770 that's 770 kilohertz or 770,000

472

00:20:25,919 --> 00:20:23,890

Hertz so the oscillations are going

473

00:20:28,590 --> 00:20:25,929

seven hundred seventy thousand times a

474

00:20:30,870 --> 00:20:28,600

second in order for you to listen to

475

00:20:32,700 --> 00:20:30,880

that from that radio station that's a

476

00:20:35,370 --> 00:20:32,710

lot of frequencies okay that's a lot of

477

00:20:37,590 --> 00:20:35,380

up and down FM radio which uses

478

00:20:41,070 --> 00:20:37,600

frequency modulation to send it's a

479

00:20:45,419 --> 00:20:41,080

signal of the sound is 88 to 108

480

00:20:47,399 --> 00:20:45,429

megahertz alright and again the this is

481

00:20:48,990 --> 00:20:47,409

a New York City radio station we have

482

00:20:51,740 --> 00:20:49,000

another New York City radio station

483

00:20:54,450 --> 00:20:51,750

that's number one in the rankings for FM

484

00:20:56,820 --> 00:20:54,460

WPLJ ninety five point five megahertz

485

00:21:00,180 --> 00:20:56,830

which is ninety five and a half million

486

00:21:02,340 --> 00:21:00,190

Hertz alright so these are the

487

00:21:04,080 --> 00:21:02,350

frequencies that you're used to you're

488

00:21:06,029 --> 00:21:04,090

working with them all the time whenever

489

00:21:08,130 --> 00:21:06,039

you turn your radio dial your getting

490

00:21:11,039 --> 00:21:08,140

either hundreds of thousands or millions

491

00:21:13,919 --> 00:21:11,049

of cycles a second when you turn on that

492

00:21:15,510 --> 00:21:13,929

radio dial astronomers when we turn on

493

00:21:18,750 --> 00:21:15,520

that radio down while I showed you one

494

00:21:21,299 --> 00:21:18,760

giant radio dish we can also tune it

495

00:21:24,270 --> 00:21:21,309

even larger this is the Very Large Array

496

00:21:26,370 --> 00:21:24,280

in Socorro New Mexico which has a whole

497

00:21:30,240 --> 00:21:26,380

bunch of these dishes

498

00:21:33,690 --> 00:21:30,250

alright arranged out in a Y formation so

499

00:21:36,510 --> 00:21:33,700

we can set them apart to synthesize a

500

00:21:37,980 --> 00:21:36,520

telescope that's even larger as I said

501
00:21:40,200 --> 00:21:37,990
radio waves we're talking a metre or

502
00:21:42,750 --> 00:21:40,210
larger this we're talking things that

503
00:21:44,549 --> 00:21:42,760
can be set across distances of miles and

504
00:21:47,430 --> 00:21:44,559
actually astronomy uses something called

505
00:21:50,610 --> 00:21:47,440
very large baseline interferometry where

506
00:21:53,940 --> 00:21:50,620
we have astronomy radio dishes across

507
00:21:55,890 --> 00:21:53,950
the globe acting as a single telescope

508
00:21:57,070 --> 00:21:55,900
to try and do really really large

509
00:21:59,650 --> 00:21:57,080
baseline

510
00:22:01,960 --> 00:21:59,660
Ronna me okay so radio waves can we can

511
00:22:05,080 --> 00:22:01,970
it can get up as far as you can set a

512
00:22:07,990 --> 00:22:05,090
standard pace for them what do we see

513
00:22:08,860 --> 00:22:08,000

well here is a picture of Jupiter in

514

00:22:11,590 --> 00:22:08,870

visible light

515

00:22:14,170 --> 00:22:11,600

okay now Jupiter has a very large

516

00:22:16,270 --> 00:22:14,180

magnetic field that's actually a very

517

00:22:19,210 --> 00:22:16,280

it's actually the size of its magnetic

518

00:22:21,730 --> 00:22:19,220

field is larger than our entire Sun and

519

00:22:23,860 --> 00:22:21,740

in terms of it but inside that magnetic

520

00:22:26,710 --> 00:22:23,870

field there are electrons bouncing up

521

00:22:28,540 --> 00:22:26,720

and down those magnetic field lines and

522

00:22:32,260 --> 00:22:28,550

when we look in radio waves

523

00:22:35,650 --> 00:22:32,270

Jupiter looks like this where you can

524

00:22:37,810 --> 00:22:35,660

see those magnetic field lines all right

525

00:22:40,630 --> 00:22:37,820

and what we call the Decca metric radio

526
00:22:43,120 --> 00:22:40,640
wavelengths of the electrons bouncing up

527
00:22:45,690 --> 00:22:43,130
and down inside those magnetic field

528
00:22:50,440 --> 00:22:45,700
lines so the magnetic field of Jupiter

529
00:22:52,330 --> 00:22:50,450
emits a lot in radio the Whirlpool

530
00:22:54,430 --> 00:22:52,340
Galaxy the galaxy that I showed you

531
00:22:57,040 --> 00:22:54,440
before all right this is what it looks

532
00:22:59,560 --> 00:22:57,050
like in visible light I'm gonna shrink

533
00:23:01,630 --> 00:22:59,570
it down to this size this is a Hubble

534
00:23:05,020 --> 00:23:01,640
image with visible light and I'm gonna

535
00:23:07,090 --> 00:23:05,030
show you what we see in radio waves in

536
00:23:08,500 --> 00:23:07,100
radio noise you can see the visible

537
00:23:11,920 --> 00:23:08,510
light you can see these beautiful spiral

538
00:23:14,740 --> 00:23:11,930

pattern but in radio waves we can see

539

00:23:16,780 --> 00:23:14,750

the gas that extends off of it all right

540

00:23:20,230 --> 00:23:16,790

you can see that there's a lot more gas

541

00:23:23,290 --> 00:23:20,240

stretching out here this is the neutral

542

00:23:25,390 --> 00:23:23,300

hydrogen gas that you can see that

543

00:23:29,170 --> 00:23:25,400

there's evidence here of a lot more

544

00:23:31,240 --> 00:23:29,180

dynamic ISM happening due to what we can

545

00:23:32,680 --> 00:23:31,250

see in the radio waves so what this is

546

00:23:34,960 --> 00:23:32,690

this is actually a composite image with

547

00:23:37,390 --> 00:23:34,970

a ground-based visible light composited

548

00:23:40,330 --> 00:23:37,400

onto the radio ways and you can see that

549

00:23:42,610 --> 00:23:40,340

there are in radio we can detect a lot

550

00:23:46,810 --> 00:23:42,620

more gas extending well beyond the

551
00:23:49,300 --> 00:23:46,820
visible extent of a Whirlpool Galaxy one

552
00:23:52,660 --> 00:23:49,310
other example for radio we'll talk about

553
00:23:55,090 --> 00:23:52,670
a supernova remnant okay so this is the

554
00:23:57,430 --> 00:23:55,100
supernova remnant Cassiopeia A the

555
00:24:00,280 --> 00:23:57,440
result of the star that just blew itself

556
00:24:03,130 --> 00:24:00,290
apart okay so in visible light we can

557
00:24:06,820 --> 00:24:03,140
see that shell the shell of material of

558
00:24:09,310 --> 00:24:06,830
a star that blew itself apart in radio

559
00:24:09,930 --> 00:24:09,320
waves we can see a lot more complex

560
00:24:13,440 --> 00:24:09,940
structure

561
00:24:15,149 --> 00:24:13,450
all right because visible light gets

562
00:24:17,220 --> 00:24:15,159
things that are at thousands of degrees

563
00:24:19,049 --> 00:24:17,230

or tens of thousands of degrees if you

564

00:24:20,730 --> 00:24:19,059

are heated up to thousands to tens of

565

00:24:23,730 --> 00:24:20,740

thousands of degrees you are hot enough

566

00:24:25,529 --> 00:24:23,740

and you radiate invisible light radio

567

00:24:27,869 --> 00:24:25,539

waves will take the lower energy stuff

568

00:24:30,990 --> 00:24:27,879

and see a lot more structure throughout

569

00:24:33,210 --> 00:24:31,000

the surrounding of that supernova

570

00:24:35,639 --> 00:24:33,220

remnant oh what I actually I forgot that

571

00:24:37,379 --> 00:24:35,649

I had one more one more of these the

572

00:24:40,740 --> 00:24:37,389

other thing that's fun to do is to take

573

00:24:43,769 --> 00:24:40,750

a visible light image and compare it to

574

00:24:46,019 --> 00:24:43,779

a radio image now here is a composite

575

00:24:48,629 --> 00:24:46,029

image from Hubble and the Very Large

576

00:24:50,730 --> 00:24:48,639

Array so what we've got here is we've

577

00:24:53,730 --> 00:24:50,740

got a galaxy a giant elliptical galaxy

578

00:24:56,159 --> 00:24:53,740

at the core of that giant elliptical

579

00:24:59,310 --> 00:24:56,169

galaxy there's a super massive black

580

00:25:03,240 --> 00:24:59,320

hole and that supermassive black hole is

581

00:25:05,430 --> 00:25:03,250

spewing out high-energy radiation okay

582

00:25:07,799 --> 00:25:05,440

around that supermassive black hole

583

00:25:09,570 --> 00:25:07,809

they're oppositely directed jets spewing

584

00:25:11,789 --> 00:25:09,580

out from that supermassive black hole

585

00:25:13,710 --> 00:25:11,799

and that although that supermassive

586

00:25:16,860 --> 00:25:13,720

black hole is on the scale of a solar

587

00:25:18,810 --> 00:25:16,870

system those Jets of radiation extend

588

00:25:22,560 --> 00:25:18,820

not only across the solar system scale

589

00:25:26,159 --> 00:25:22,570

not only across stellar scales but

590

00:25:29,820 --> 00:25:26,169

across the entire galaxy and outside the

591

00:25:31,919 --> 00:25:29,830

galaxy as seen in this radial image so

592

00:25:33,990 --> 00:25:31,929

there is something in here that's on

593

00:25:36,659 --> 00:25:34,000

order of a solar system scale spewing

594

00:25:39,919 --> 00:25:36,669

out Jets that extend five times further

595

00:25:44,730 --> 00:25:39,929

than the visible extent of this galaxy

596

00:25:46,919 --> 00:25:44,740

so if you want to see the power of a

597

00:25:49,950 --> 00:25:46,929

supermassive black hole you don't use

598

00:25:52,470 --> 00:25:49,960

visible light you go to radio where you

599

00:25:54,930 --> 00:25:52,480

see these radio galaxies and these giant

600

00:25:56,610 --> 00:25:54,940

radio lobes spewed out from the

601
00:26:00,090 --> 00:25:56,620
supermassive black holes at the core of

602
00:26:01,799 --> 00:26:00,100
these galaxies kind of cool all right

603
00:26:04,350 --> 00:26:01,809
radio wavelengths get us all sorts of

604
00:26:05,399 --> 00:26:04,360
fun stuff but that's not the only place

605
00:26:08,490 --> 00:26:05,409
we're gonna go we're gonna go to

606
00:26:10,590 --> 00:26:08,500
microwaves now radio waves were longer

607
00:26:12,570 --> 00:26:10,600
than a meter for microwaves we're going

608
00:26:14,369 --> 00:26:12,580
to go from a meter down to about a

609
00:26:17,369 --> 00:26:14,379
millimeter okay so it's about a factor

610
00:26:19,560 --> 00:26:17,379
of a thousand in scale per millimeter

611
00:26:21,149 --> 00:26:19,570
and here we're getting frequency in

612
00:26:23,470 --> 00:26:21,159
again a factor of thousand in frequency

613
00:26:25,360 --> 00:26:23,480

from 300 million Hertz to 300

614

00:26:27,730 --> 00:26:25,370

gigahertz all right you might have heard

615

00:26:30,460 --> 00:26:27,740

the phrase gigahertz used in some some

616

00:26:32,410 --> 00:26:30,470

things in particularly you might have

617

00:26:34,480 --> 00:26:32,420

heard it related to what do we think of

618

00:26:37,630 --> 00:26:34,490

microwaves right where do you go

619

00:26:40,380 --> 00:26:37,640

microwave ovens all right and microwave

620

00:26:42,580 --> 00:26:40,390

ovens heat your food by basically

621

00:26:44,530 --> 00:26:42,590

heating the water all right it's

622

00:26:46,360 --> 00:26:44,540

dielectric heating it causes basically

623

00:26:48,820 --> 00:26:46,370

the water molecules to spin because

624

00:26:50,590 --> 00:26:48,830

water molecules are not C1MMYT symmetric

625

00:26:52,090 --> 00:26:50,600

in terms of their electric charge

626

00:26:54,310 --> 00:26:52,100

they're electrically neutral but that's

627

00:26:57,580 --> 00:26:54,320

not symmetry and you can get those water

628

00:27:00,760 --> 00:26:57,590

molecules to spin by either exciting

629

00:27:03,880 --> 00:27:00,770

them with a 2.5 gigahertz or a 12

630

00:27:05,470 --> 00:27:03,890

centimeter so it's about 12 centimeters

631

00:27:08,590 --> 00:27:05,480

that's about 12 centimeters a 12

632

00:27:10,540 --> 00:27:08,600

centimeter wavelength or a 915 megahertz

633

00:27:13,090 --> 00:27:10,550

which is about a 32 centimeter

634

00:27:14,680 --> 00:27:13,100

wavelength okay using that you can

635

00:27:16,870 --> 00:27:14,690

excite though the water molecules in

636

00:27:19,750 --> 00:27:16,880

your food which causes them to heat up

637

00:27:22,650 --> 00:27:19,760

all right so microwave ovens do use

638

00:27:24,370 --> 00:27:22,660

microwaves to heat your food

639

00:27:26,410 --> 00:27:24,380

astronomers when we want to look at

640

00:27:28,540 --> 00:27:26,420

microwaves well we use something similar

641

00:27:31,870 --> 00:27:28,550

to what we use for radio but they can be

642

00:27:33,820 --> 00:27:31,880

smaller dishes this is the Atacama Large

643

00:27:36,910 --> 00:27:33,830

millimeter ray or otherwise known as

644

00:27:40,840 --> 00:27:36,920

Alma it's on the atacama plateau in

645

00:27:44,290 --> 00:27:40,850

Chile which is up at like 15,000 feet

646

00:27:47,860 --> 00:27:44,300

all right and it's incredibly dry and

647

00:27:50,560 --> 00:27:47,870

this is a place where you actually you

648

00:27:52,360 --> 00:27:50,570

can't breathe very well okay I like to

649

00:27:55,510 --> 00:27:52,370

make the joke that astronomers now need

650

00:27:57,520 --> 00:27:55,520

Sherpas in order to do astronomy because

651

00:27:59,800 --> 00:27:57,530

the astronomers you know can't think

652

00:28:01,060 --> 00:27:59,810

very well this numbers when they go to

653

00:28:03,400 --> 00:28:01,070

this telescope they don't go to this

654

00:28:06,130 --> 00:28:03,410

telescope they go down the mountain and

655

00:28:08,320 --> 00:28:06,140

there are about 9,000 feet okay the same

656

00:28:10,120 --> 00:28:08,330

is true on Mauna Kea when you go to that

657

00:28:11,830 --> 00:28:10,130

telescope you're at 9,000 feet the

658

00:28:15,670 --> 00:28:11,840

telescope's are much much higher above

659

00:28:19,120 --> 00:28:15,680

you but only the workers who trained

660

00:28:21,340 --> 00:28:19,130

trained and can use this are working up

661

00:28:22,990 --> 00:28:21,350

there the astronomers all stayed down so

662

00:28:25,960 --> 00:28:23,000

you really don't go to the telescopes

663

00:28:28,270 --> 00:28:25,970

well when they're this high but Alma has

664

00:28:30,250 --> 00:28:28,280

produced and we'll be producing some

665

00:28:32,410 --> 00:28:30,260

amazing images I'm going to show you one

666

00:28:33,980 --> 00:28:32,420

of its most amazing coming forward so

667

00:28:36,590 --> 00:28:33,990

let's return to that

668

00:28:38,390 --> 00:28:36,600

Whirlpool Galaxy and take a look in

669

00:28:40,040 --> 00:28:38,400

millimeter wavelengths okay

670

00:28:42,110 --> 00:28:40,050

so when we look in millimeter

671

00:28:45,530 --> 00:28:42,120

wavelengths you can see all that dark

672

00:28:47,690 --> 00:28:45,540

gas in here all right that gas is dark

673

00:28:51,350 --> 00:28:47,700

with visible light and millimeter

674

00:28:54,169 --> 00:28:51,360

wavelengths it shows up really strongly

675

00:28:58,070 --> 00:28:54,179

what we're seeing in here is the really

676

00:29:01,370 --> 00:28:58,080

dense cold gas that very densest coldest

677

00:29:03,919 --> 00:29:01,380

gas along those spiral arms these are

678

00:29:06,080 --> 00:29:03,929

the densest cloud regions along inside

679

00:29:08,530 --> 00:29:06,090

inside this galaxy so if I go back here

680

00:29:11,360 --> 00:29:08,540

you can see the densest regions

681

00:29:14,240 --> 00:29:11,370

all right the densest regions an

682

00:29:16,549 --> 00:29:14,250

invisible light all right show up as the

683

00:29:18,799 --> 00:29:16,559

brightest regions in millimeter

684

00:29:22,850 --> 00:29:18,809

wavelengths so if we want to study the

685

00:29:25,970 --> 00:29:22,860

molecular gas in a galaxy we go to the

686

00:29:28,340 --> 00:29:25,980

the millimeter microwave region in order

687

00:29:32,020 --> 00:29:28,350

to see the details of what's going on

688

00:29:35,570 --> 00:29:32,030

inside we can also do the same thing for

689

00:29:40,760 --> 00:29:35,580

just around stars now this is a Hubble

690

00:29:43,760 --> 00:29:40,770

image of the disc around a star 107 1 4

691

00:29:45,020 --> 00:29:43,770

6 HD 107 146 I always have to read that

692

00:29:48,020 --> 00:29:45,030

because I can't memorize these phone

693

00:29:50,540 --> 00:29:48,030

numbers now what we've done here is that

694

00:29:53,630 --> 00:29:50,550

we blocked out the light of the star in

695

00:29:56,150 --> 00:29:53,640

order to see that the material in a disc

696

00:29:59,210 --> 00:29:56,160

so this is basically a base on disc a

697

00:30:01,820 --> 00:29:59,220

thin disc around a forming star all

698

00:30:04,490 --> 00:30:01,830

right and in that disc is where we

699

00:30:07,520 --> 00:30:04,500

expect to see planets form all right and

700

00:30:10,430 --> 00:30:07,530

so Hubble can see that these discs

701
00:30:13,880 --> 00:30:10,440
exists but it can't see a lot of the

702
00:30:17,299 --> 00:30:13,890
details microwaves can actually show us

703
00:30:21,320 --> 00:30:17,309
a lot more so this is a star called HL

704
00:30:23,660 --> 00:30:21,330
Tauri it is Hubble's view of it and HL

705
00:30:25,820 --> 00:30:23,670
Tauri is in here and it's all shrouded

706
00:30:28,549 --> 00:30:25,830
by all sorts of dust we really can't see

707
00:30:31,490 --> 00:30:28,559
much about HL Tauri in visible light but

708
00:30:35,930 --> 00:30:31,500
if you go to the Alma array and you take

709
00:30:39,110 --> 00:30:35,940
a picture you get this image here this

710
00:30:41,060 --> 00:30:39,120
is not an artist's illustration all

711
00:30:42,799 --> 00:30:41,070
right this looks to me like it's an

712
00:30:45,290 --> 00:30:42,809
artist drew these concentric circles

713
00:30:46,010 --> 00:30:45,300

this is an actual image from the Alma

714

00:30:50,120 --> 00:30:46,020

array

715

00:30:52,549 --> 00:30:50,130

looking at a disk around HL Tauri and we

716

00:30:56,390 --> 00:30:52,559

can see that there are these wonderful

717

00:30:59,450 --> 00:30:56,400

beautiful concentric disk gaps in the

718

00:31:01,520 --> 00:30:59,460

disk around HL Tauri this is exactly

719

00:31:04,250 --> 00:31:01,530

what we expect from planet formation

720

00:31:06,650 --> 00:31:04,260

when you start to form planets you get

721

00:31:08,960 --> 00:31:06,660

gravitational perturbations and the

722

00:31:11,510 --> 00:31:08,970

material flows onto these planets and

723

00:31:13,790 --> 00:31:11,520

they will pull out these gaps inside

724

00:31:15,230 --> 00:31:13,800

these disks now we can't say that

725

00:31:17,570 --> 00:31:15,240

there's a planet inside every one of

726

00:31:18,950 --> 00:31:17,580

these gaps because of course what we get

727

00:31:21,770 --> 00:31:18,960

is not only just the gaps where the

728

00:31:23,360 --> 00:31:21,780

planets form but you also get gaps in

729

00:31:25,850 --> 00:31:23,370

terms of resonances gravitational

730

00:31:28,370 --> 00:31:25,860

resonances in that same disk so if

731

00:31:30,680 --> 00:31:28,380

you're you know if if this thing orbits

732

00:31:32,660 --> 00:31:30,690

one twice for every time this orbits

733

00:31:34,549 --> 00:31:32,670

once you get a resonance there and you

734

00:31:36,890 --> 00:31:34,559

can actually get a gap not where the

735

00:31:40,220 --> 00:31:36,900

planet is but where a resonance for that

736

00:31:42,320 --> 00:31:40,230

planet is so in using the idea the Alma

737

00:31:44,000 --> 00:31:42,330

array they're able to get this amazing

738

00:31:46,250 --> 00:31:44,010

image this is one of the first images

739

00:31:47,810 --> 00:31:46,260

released from Alma and shows that there

740

00:31:50,810 --> 00:31:47,820

should be some amazing more things

741

00:31:52,760 --> 00:31:50,820

coming up one other thing that I have to

742

00:31:55,160 --> 00:31:52,770

go through from microwaves is taking a

743

00:31:57,080 --> 00:31:55,170

look at some all-sky photographs now I

744

00:31:59,299 --> 00:31:57,090

want to prep you for that by showing you

745

00:32:01,370 --> 00:31:59,309

an image of Earth okay

746

00:32:03,140 --> 00:32:01,380

we know that Earth is a globe but when

747

00:32:04,700 --> 00:32:03,150

we want to put it onto a map we

748

00:32:07,460 --> 00:32:04,710

generally have to distort it to put it

749

00:32:09,710 --> 00:32:07,470

onto a map right the Mercator projection

750

00:32:12,140 --> 00:32:09,720

is all things all sorts of distorted

751
00:32:14,180 --> 00:32:12,150
Greenland looks way too huge so when we

752
00:32:15,830 --> 00:32:14,190
try to take a sphere and put it on a

753
00:32:18,290 --> 00:32:15,840
flat piece of paper we use various

754
00:32:21,080 --> 00:32:18,300
projections this is one called an eighth

755
00:32:24,260 --> 00:32:21,090
off projection okay which takes a sphere

756
00:32:24,620 --> 00:32:24,270
and roughly distorts things less all

757
00:32:26,419 --> 00:32:24,630
right

758
00:32:28,760 --> 00:32:26,429
creates a nice oval out of the sphere

759
00:32:30,620 --> 00:32:28,770
and distorts things a little less than

760
00:32:31,610 --> 00:32:30,630
other projections all right so

761
00:32:34,460 --> 00:32:31,620
everything I'm going to show you from

762
00:32:37,160 --> 00:32:34,470
here on in is not the earth but it's the

763
00:32:40,940 --> 00:32:37,170

entire sphere of the sky projected in

764

00:32:44,350 --> 00:32:40,950

this 8th off projection alright so now I

765

00:32:50,570 --> 00:32:44,360

have for you an amazing image an image

766

00:32:54,440 --> 00:32:50,580

worthy of two two Nobel prizes okay this

767

00:33:02,350 --> 00:32:54,450

next image led to two Nobel prizes you

768

00:33:08,930 --> 00:33:05,659

that's two Nobel prizes worth okay let

769

00:33:13,100 --> 00:33:08,940

me explain this is an image of the

770

00:33:15,320 --> 00:33:13,110

Cosmic Microwave Background okay as we

771

00:33:18,649 --> 00:33:15,330

look out into space we're also looking

772

00:33:20,600 --> 00:33:18,659

back into time okay when the universe

773

00:33:24,110 --> 00:33:20,610

was really really young and really

774

00:33:26,899 --> 00:33:24,120

really small and really really hot it

775

00:33:28,210 --> 00:33:26,909

actually glowed and the light from what

776

00:33:31,580 --> 00:33:28,220

we call the surface of last scattering

777

00:33:33,460 --> 00:33:31,590

has free streamed across the universe it

778

00:33:35,899 --> 00:33:33,470

started out at several thousand degrees

779

00:33:38,389 --> 00:33:35,909

but because of the expansion of the

780

00:33:41,840 --> 00:33:38,399

universe it has cooled down to about

781

00:33:44,299 --> 00:33:41,850

three degrees all right and the house

782

00:33:47,630 --> 00:33:44,309

that it's at three degrees that means

783

00:33:51,980 --> 00:33:47,640

it's emission is now observable in the

784

00:33:55,760 --> 00:33:51,990

microwaves so Penzias and Wilson at Bell

785

00:33:58,159 --> 00:33:55,770

Labs found a radio signal in their

786

00:34:01,700 --> 00:33:58,169

microwave antenna that they couldn't

787

00:34:03,500 --> 00:34:01,710

identify and it was uniform across the

788

00:34:07,310 --> 00:34:03,510

entire sky which is why this is such a

789

00:34:11,149 --> 00:34:07,320

boring image k but this is the remnant

790

00:34:13,399 --> 00:34:11,159

radiation of the early universe from

791

00:34:16,579 --> 00:34:13,409

about half a million years 400,000 years

792

00:34:19,550 --> 00:34:16,589

after the Big Bang as the universe

793

00:34:22,220 --> 00:34:19,560

expanded and cooled there's a surface at

794

00:34:24,109 --> 00:34:22,230

which the last light leaves and that

795

00:34:26,119 --> 00:34:24,119

light comes across universe and it's

796

00:34:27,560 --> 00:34:26,129

available in every direction because in

797

00:34:30,020 --> 00:34:27,570

every direction we're looking out into

798

00:34:32,329 --> 00:34:30,030

space we're looking back into time we're

799

00:34:35,899 --> 00:34:32,339

seeing the relics of the early universe

800

00:34:37,760 --> 00:34:35,909

and so just getting this discovering

801

00:34:39,740 --> 00:34:37,770

this three degree Kelvin microwave

802

00:34:42,829 --> 00:34:39,750

background radiation was worthy of a

803

00:34:44,960 --> 00:34:42,839

Nobel Prize the second Nobel Prize comes

804

00:34:47,659 --> 00:34:44,970

when you look deeper into this image so

805

00:34:49,250 --> 00:34:47,669

let's take that average that average

806

00:34:51,139 --> 00:34:49,260

three degrees I'd like to point seven

807

00:34:53,540 --> 00:34:51,149

three degrees and we'll subtract it off

808

00:34:55,669 --> 00:34:53,550

to see what we get okay so we get taken

809

00:34:58,370 --> 00:34:55,679

rid of the average and we come and we

810

00:35:00,050 --> 00:34:58,380

get a cosmic yin-yang symbol well that's

811

00:35:01,640 --> 00:35:00,060

not actually what you're seeing what

812

00:35:03,320 --> 00:35:01,650

you're seeing here is it's a little bit

813

00:35:05,599 --> 00:35:03,330

hotter in this direction a little bit

814

00:35:07,520 --> 00:35:05,609

colder in this direction because the

815

00:35:09,079 --> 00:35:07,530

Milky Way galaxy is moving through the

816

00:35:11,720 --> 00:35:09,089

universe okay

817

00:35:14,120 --> 00:35:11,730

so that actually is what

818

00:35:16,220 --> 00:35:14,130

we're seeing is as actually the Doppler

819

00:35:18,260 --> 00:35:16,230

shift of the galaxy moving through the

820

00:35:19,970 --> 00:35:18,270

universe so this isn't really any any

821

00:35:21,980 --> 00:35:19,980

cosmic signal it's just due to the

822

00:35:25,160 --> 00:35:21,990

motion of our galaxy so let's subtract

823

00:35:27,500 --> 00:35:25,170

that off and what do we see we see this

824

00:35:30,080 --> 00:35:27,510

big red line across here well that

825

00:35:32,780 --> 00:35:30,090

actually is the emission from stuff

826
00:35:33,770 --> 00:35:32,790
inside our galaxy that has nothing to do

827
00:35:35,720 --> 00:35:33,780
with the cosmos

828
00:35:37,940 --> 00:35:35,730
that's just our galaxy so we work really

829
00:35:39,680 --> 00:35:37,950
really hard to model the emission of our

830
00:35:42,800 --> 00:35:39,690
galaxy in microwaves and then we

831
00:35:44,470 --> 00:35:42,810
subtract that off and what do we get we

832
00:35:47,120 --> 00:35:44,480
get the result from the Coby satellite

833
00:35:49,070 --> 00:35:47,130
okay so you're taking out the average

834
00:35:50,840 --> 00:35:49,080
you've taken out the Doppler motion of

835
00:35:52,730 --> 00:35:50,850
the galaxy you've taken out the emission

836
00:35:56,900 --> 00:35:52,740
from the galaxy and what you are left

837
00:35:58,720 --> 00:35:56,910
with is the tiny variations in the

838
00:36:01,820 --> 00:35:58,730

cosmic microwave background radiation

839

00:36:04,099 --> 00:36:01,830

all right so you're seeing the universe

840

00:36:06,320 --> 00:36:04,109

as it was half a million years after the

841

00:36:09,020 --> 00:36:06,330

Big Bang and now you're seeing that it

842

00:36:11,810 --> 00:36:09,030

has tiny little variations those tiny

843

00:36:13,849 --> 00:36:11,820

little variations are actually density

844

00:36:15,830 --> 00:36:13,859

variations it's a little bit more dense

845

00:36:18,470 --> 00:36:15,840

here a little bit less dense there

846

00:36:20,599 --> 00:36:18,480

you're seeing the seeds of structure

847

00:36:22,670 --> 00:36:20,609

formation these are the tiny tiny seeds

848

00:36:24,920 --> 00:36:22,680

of structure formation that will then

849

00:36:27,800 --> 00:36:24,930

grow into galaxies and clusters of

850

00:36:30,050 --> 00:36:27,810

galaxies and superclusters of galaxies

851

00:36:32,240 --> 00:36:30,060

and this is so important it's not just

852

00:36:34,550 --> 00:36:32,250

the Coby satellite but we followed that

853

00:36:36,740 --> 00:36:34,560

with aw Maps satellite and that was

854

00:36:40,250 --> 00:36:36,750

followed up but the Planck satellite in

855

00:36:42,470 --> 00:36:40,260

order to get more and more detail in the

856

00:36:44,720 --> 00:36:42,480

Cosmic Microwave Background we're

857

00:36:47,270 --> 00:36:44,730

studying the seeds of structure

858

00:36:50,270 --> 00:36:47,280

formation in the universe in microwaves

859

00:36:53,030 --> 00:36:50,280

and not just this and just bursts of the

860

00:36:54,080 --> 00:36:53,040

initial discovery of it merited a Nobel

861

00:36:56,810 --> 00:36:54,090

Prize but the discovery of the

862

00:36:59,720 --> 00:36:56,820

variations in it also merited a Nobel

863

00:37:01,880 --> 00:36:59,730

Prize seeing the beginnings of structure

864

00:37:04,400 --> 00:37:01,890

forming in the universe that's what we

865

00:37:06,520 --> 00:37:04,410

see in microwaves all right let's move

866

00:37:09,710 --> 00:37:06,530

on to a little bit longer infrared light

867

00:37:12,950 --> 00:37:09,720

okay so let's see we've got about one

868

00:37:15,349 --> 00:37:12,960

millimeter down to about 700 nanometers

869

00:37:18,050 --> 00:37:15,359

so that's a little over a factor of a

870

00:37:19,460 --> 00:37:18,060

thousand for infrared light now when you

871

00:37:20,599 --> 00:37:19,470

think about infrared light in your daily

872

00:37:24,020 --> 00:37:20,609

life all right

873

00:37:25,550 --> 00:37:24,030

anybody here computer gamers okay and

874

00:37:28,070 --> 00:37:25,560

you play call of duty and

875

00:37:30,590 --> 00:37:28,080

that mode that you know we can see

876

00:37:32,990 --> 00:37:30,600

things in the dark right okay that's

877

00:37:34,880 --> 00:37:33,000

called night vision and a lot of people

878

00:37:37,580 --> 00:37:34,890

think that that's infrared vision all

879

00:37:39,320 --> 00:37:37,590

right and it's not night vision

880

00:37:41,240 --> 00:37:39,330

especially as it would be used in call

881

00:37:43,340 --> 00:37:41,250

of duty or anything it's just enhanced

882

00:37:45,740 --> 00:37:43,350

low-light vision okay so when you see a

883

00:37:47,690 --> 00:37:45,750

picture like this you're amplifying the

884

00:37:49,790 --> 00:37:47,700

light around it okay it's not infrared

885

00:37:52,490 --> 00:37:49,800

light there is some infrared light that

886

00:37:54,590 --> 00:37:52,500

you can use like that but really when

887

00:37:56,630 --> 00:37:54,600

you want to look at the infrared you're

888

00:37:58,580 --> 00:37:56,640

gonna get pictures like this okay so

889

00:38:00,920 --> 00:37:58,590

this is a visible light image of a

890

00:38:03,620 --> 00:38:00,930

firefighter all right and the same

891

00:38:06,320 --> 00:38:03,630

infrared image of that firefighter shows

892

00:38:09,590 --> 00:38:06,330

him glowing but also shows that human

893

00:38:11,810 --> 00:38:09,600

person on the floor glowing all right

894

00:38:15,260 --> 00:38:11,820

using infrared light you're seeing heat

895

00:38:17,090 --> 00:38:15,270

radiation okay all right and where

896

00:38:19,850 --> 00:38:17,100

things may be obscured in visible light

897

00:38:22,520 --> 00:38:19,860

the heat radiation can go through you

898

00:38:25,280 --> 00:38:22,530

are all emitting infrared radiation

899

00:38:28,730 --> 00:38:25,290

right now okay objects at room

900

00:38:30,350 --> 00:38:28,740

temperature emit infrared radiation okay

901
00:38:32,420 --> 00:38:30,360
all right they're at hundreds of degrees

902
00:38:34,100 --> 00:38:32,430
in Kelvin you are emitting infrared

903
00:38:36,170 --> 00:38:34,110
radiation if you're thousands of Riis

904
00:38:37,990 --> 00:38:36,180
Kelvin you're emitting visible light you

905
00:38:41,230 --> 00:38:38,000
aren't that hot I hope not okay

906
00:38:45,050 --> 00:38:41,240
sincerely hope you're not that hot but

907
00:38:47,570 --> 00:38:45,060
you are emitting infrared radiation now

908
00:38:50,660 --> 00:38:47,580
for astronomers infrared radiation has a

909
00:38:52,280 --> 00:38:50,670
variety of ways that we detect it some

910
00:38:53,930 --> 00:38:52,290
infrared radiation makes it through our

911
00:38:56,420 --> 00:38:53,940
atmosphere to the ground so we can

912
00:38:58,550 --> 00:38:56,430
observe infrared radiation with normal

913
00:39:00,350 --> 00:38:58,560

telescopes okay so these are the twin

914

00:39:02,480 --> 00:39:00,360

tech telescopes that talk Mauna Kea

915

00:39:04,970 --> 00:39:02,490

alright they're giant light buckets

916

00:39:07,700 --> 00:39:04,980

really really good for observing in the

917

00:39:09,590 --> 00:39:07,710

infrared however if you get up above

918

00:39:11,210 --> 00:39:09,600

higher in the atmosphere the higher in

919

00:39:13,190 --> 00:39:11,220

the atmosphere you get the better your

920

00:39:16,370 --> 00:39:13,200

view is so why not take an infrared

921

00:39:18,200 --> 00:39:16,380

telescope and put it on a plane okay

922

00:39:20,630 --> 00:39:18,210

this is Sofia the stratospheric

923

00:39:22,910 --> 00:39:20,640

Observatory for infrared astronomy and

924

00:39:26,030 --> 00:39:22,920

that is the hatch that is open for an

925

00:39:28,520 --> 00:39:26,040

infrared telescope you fly it up at high

926

00:39:31,310 --> 00:39:28,530

plane altitudes you get a better view of

927

00:39:33,590 --> 00:39:31,320

the universe okay and of course you can

928

00:39:36,530 --> 00:39:33,600

go up into space you can take it further

929

00:39:37,900 --> 00:39:36,540

up into space and you can have the

930

00:39:40,180 --> 00:39:37,910

Spitzer Space Telescope which

931

00:39:42,010 --> 00:39:40,190

an infrared telescope and the upcoming

932

00:39:44,950 --> 00:39:42,020

James Webb Space Telescope that will

933

00:39:47,770 --> 00:39:44,960

launch in 2018 also an infrared Space

934

00:39:49,480 --> 00:39:47,780

Observatory all right so I'm Freret is

935

00:39:51,880 --> 00:39:49,490

able to do from the ground from

936

00:39:54,190 --> 00:39:51,890

airplanes and from space oh by the way I

937

00:39:56,260 --> 00:39:54,200

will also note that these two are not to

938

00:40:00,099 --> 00:39:56,270

scale okay

939

00:40:02,289 --> 00:40:00,109

the the main mirror of keV of Spitzer is

940

00:40:05,589 --> 00:40:02,299

smaller than one of these mirrors for

941

00:40:08,049 --> 00:40:05,599

James Webb okay so this is a point eight

942

00:40:10,270 --> 00:40:08,059

meter telescope mirror telescope this is

943

00:40:11,859 --> 00:40:10,280

a six and a half meter telescope so you

944

00:40:14,500 --> 00:40:11,869

can see what an incredible improvement

945

00:40:18,010 --> 00:40:14,510

this will be over that for infrared for

946

00:40:20,289 --> 00:40:18,020

infrared space astronomy so I told you

947

00:40:23,410 --> 00:40:20,299

to Pater's actually glowing in the

948

00:40:26,440 --> 00:40:23,420

infrared this is a visible light view of

949

00:40:28,569 --> 00:40:26,450

Jupiter and here is an infrared view of

950

00:40:31,240 --> 00:40:28,579

Jupiter all right and you can see the

951
00:40:33,099 --> 00:40:31,250
emission coming from coming from the

952
00:40:35,650 --> 00:40:33,109
internal of Jupiter and in particular

953
00:40:39,010 --> 00:40:35,660
one of my favorite things is that the

954
00:40:41,799 --> 00:40:39,020
Great Red Spot as well as Red Spot jr.

955
00:40:44,289 --> 00:40:41,809
okay Great Red Spot and Red Spot jr. are

956
00:40:47,650 --> 00:40:44,299
sources where infrared light is escaping

957
00:40:50,079 --> 00:40:47,660
from the internal on Jupiter if you look

958
00:40:52,359 --> 00:40:50,089
at infrared one of my favorite infrared

959
00:40:54,519 --> 00:40:52,369
images you can see how bright it is here

960
00:40:56,890 --> 00:40:54,529
and the end the Great Red Spot and for

961
00:40:59,890 --> 00:40:56,900
Red Spot jr. in terms of seeing the

962
00:41:03,970 --> 00:40:59,900
infrared light coming from them what a

963
00:41:05,710 --> 00:41:03,980

gorgeous infrared view infrared is also

964

00:41:07,599 --> 00:41:05,720

incredibly useful we're not just looking

965

00:41:10,750 --> 00:41:07,609

at the planets but in terms of looking

966

00:41:12,609 --> 00:41:10,760

at nebulae this is one of the famous

967

00:41:16,809 --> 00:41:12,619

images we released for servicing mission

968

00:41:18,910 --> 00:41:16,819

4 in 2009 and here we have the pillar in

969

00:41:20,529 --> 00:41:18,920

the Carina Nebula and you can see that

970

00:41:22,630 --> 00:41:20,539

you've got a good number of stars around

971

00:41:25,420 --> 00:41:22,640

it but you can see there's all this gas

972

00:41:28,059 --> 00:41:25,430

emission well infrared light has longer

973

00:41:30,250 --> 00:41:28,069

wavelengths than visible light so the

974

00:41:33,519 --> 00:41:30,260

wavelengths penetrate through that gas

975

00:41:37,349 --> 00:41:33,529

all right and so the infrared version of

976
00:41:40,480 --> 00:41:37,359
this image from Hubble is this all right

977
00:41:43,240 --> 00:41:40,490
there's the visible light there's the

978
00:41:45,370 --> 00:41:43,250
infra red look at all the stars you see

979
00:41:48,670 --> 00:41:45,380
because you are peering through some of

980
00:41:51,460 --> 00:41:48,680
that gas furthermore if you go in in

981
00:41:54,280 --> 00:41:51,470
detail there is a star forming in

982
00:41:57,099 --> 00:41:54,290
here okay there is a star forming inside

983
00:41:59,140 --> 00:41:57,109
there that is not clearly visible in

984
00:42:02,920 --> 00:41:59,150
visible light yeah visible invisible

985
00:42:05,770 --> 00:42:02,930
light recognizable in optical light how

986
00:42:08,349 --> 00:42:05,780
about that okay but if we go to the

987
00:42:11,349 --> 00:42:08,359
infrared there you see it right there

988
00:42:14,410 --> 00:42:11,359

okay there is a star you can see the jet

989

00:42:16,270 --> 00:42:14,420

of emission from that newborn star we go

990

00:42:18,040 --> 00:42:16,280

back you can see that there's a little

991

00:42:21,040 --> 00:42:18,050

bit of something here that you can see

992

00:42:23,859 --> 00:42:21,050

with visible light but there you can see

993

00:42:26,109 --> 00:42:23,869

the star so if you want to study star

994

00:42:28,570 --> 00:42:26,119

formation all right you want to go to

995

00:42:30,370 --> 00:42:28,580

the infrared this is one of the main

996

00:42:33,160 --> 00:42:30,380

tasks of the James Webb Space Telescope

997

00:42:36,070 --> 00:42:33,170

will be to look at places where stars

998

00:42:39,190 --> 00:42:36,080

are forming to peer into that that dense

999

00:42:41,740 --> 00:42:39,200

gas and see deeper in to see the

1000

00:42:44,410 --> 00:42:41,750

structure of star formation in the

1001
00:42:46,570 --> 00:42:44,420
infrared let's go back to the Whirlpool

1002
00:42:49,120 --> 00:42:46,580
Galaxy this is not that Hubble image of

1003
00:42:51,400 --> 00:42:49,130
it because we're going to compare it to

1004
00:42:54,310 --> 00:42:51,410
an infrared Spitzer image this is a

1005
00:42:56,410 --> 00:42:54,320
ground-based image from the National

1006
00:42:58,060 --> 00:42:56,420
optical Astronomy Observatory and here

1007
00:42:59,920 --> 00:42:58,070
you can see that beautiful pattern of

1008
00:43:03,070 --> 00:42:59,930
the Whirlpool again let's highlight

1009
00:43:06,310 --> 00:43:03,080
those dark dust lanes because in the

1010
00:43:09,640 --> 00:43:06,320
infrared though those dust lanes are

1011
00:43:13,089 --> 00:43:09,650
glowing all right there's the visible

1012
00:43:14,980 --> 00:43:13,099
light there's the infrared all right if

1013
00:43:19,180 --> 00:43:14,990

you look right along here you can see

1014

00:43:21,760 --> 00:43:19,190

visible light infrared all right those

1015

00:43:23,950 --> 00:43:21,770

got instead of C being dominated by the

1016

00:43:26,470 --> 00:43:23,960

stars and the bright stars in the galaxy

1017

00:43:29,109 --> 00:43:26,480

you are now not that this view is

1018

00:43:30,880 --> 00:43:29,119

dominated by the cool gas in the galaxy

1019

00:43:33,780 --> 00:43:30,890

the warm gas in the galaxy not the very

1020

00:43:34,930 --> 00:43:33,790

cold gas the dense gas that we saw in

1021

00:43:37,359 --> 00:43:34,940

microwaves

1022

00:43:39,040 --> 00:43:37,369

all right millimeter observations but

1023

00:43:43,180 --> 00:43:39,050

instead this is slightly warmer than

1024

00:43:44,380 --> 00:43:43,190

that for that again infrared is

1025

00:43:47,050 --> 00:43:44,390

generally hundreds of degrees

1026

00:43:49,839 --> 00:43:47,060

temperature in the gas so we can see

1027

00:43:52,359 --> 00:43:49,849

different phases of the gas by looking

1028

00:43:54,130 --> 00:43:52,369

in different wavelengths of light okay

1029

00:43:57,010 --> 00:43:54,140

so now we've gone half way through we've

1030

00:43:58,270 --> 00:43:57,020

got up to visible light and what I want

1031

00:43:59,230 --> 00:43:58,280

to notice above this will like is I've

1032

00:44:01,210 --> 00:43:59,240

already talked about visibly

1033

00:44:04,910 --> 00:44:01,220

observations is that it only goes from

1034

00:44:07,130 --> 00:44:04,920

400 to 700 nanometers

1035

00:44:08,750 --> 00:44:07,140

than a factor of two we were talking

1036

00:44:10,760 --> 00:44:08,760

about factories about thousand for these

1037

00:44:12,970 --> 00:44:10,770

wavelength regions all right when we

1038

00:44:16,040 --> 00:44:12,980

look at the electromagnetic spectrum

1039

00:44:19,370 --> 00:44:16,050

just drawing in all these colors over

1040

00:44:21,650 --> 00:44:19,380

States the size of visible light in that

1041

00:44:24,470 --> 00:44:21,660

it's not that important or region

1042

00:44:26,480 --> 00:44:24,480

the only reason reason that visible

1043

00:44:28,550 --> 00:44:26,490

light is important is because it happens

1044

00:44:32,060 --> 00:44:28,560

to be the region with which we see it's

1045

00:44:35,060 --> 00:44:32,070

a tiny tiny region within the

1046

00:44:36,650 --> 00:44:35,070

electromagnetic spectrum because most of

1047

00:44:40,130 --> 00:44:36,660

the other regions are much much larger

1048

00:44:42,140 --> 00:44:40,140

than that in terms of the the size of

1049

00:44:43,640 --> 00:44:42,150

wavelengths that they cover all right

1050

00:44:46,580 --> 00:44:43,650

but since it's ours

1051
00:44:48,020 --> 00:44:46,590
well we'll keep it as a real segment but

1052
00:44:49,970 --> 00:44:48,030
you know it's not really a respectable

1053
00:44:51,230 --> 00:44:49,980
one okay you know we've kicked Pluto out

1054
00:44:53,060 --> 00:44:51,240
as a planet maybe we should kick

1055
00:44:54,800 --> 00:44:53,070
visible-light out as a as a band of the

1056
00:44:56,630 --> 00:44:54,810
wavelengths right you know it just

1057
00:45:03,010 --> 00:44:56,640
should be a subset of infrared or a

1058
00:45:07,640 --> 00:45:06,410
ultra violet light from ten nine years

1059
00:45:10,160 --> 00:45:07,650
to four hundred entries you can see

1060
00:45:12,710 --> 00:45:10,170
that's a factor of 40 okay so a factor

1061
00:45:15,200 --> 00:45:12,720
of two for visible light that's my point

1062
00:45:17,660 --> 00:45:15,210
all right we think of ultraviolet light

1063
00:45:19,730 --> 00:45:17,670

in our everyday we start thinking about

1064

00:45:21,950 --> 00:45:19,740

going to the beach and going out in the

1065

00:45:23,980 --> 00:45:21,960

Sun and getting a tan and everything

1066

00:45:25,850 --> 00:45:23,990

okay and of course when we think about

1067

00:45:28,970 --> 00:45:25,860

ultraviolet we talk about ultraviolet

1068

00:45:31,460 --> 00:45:28,980

protection and what's the UV blockage of

1069

00:45:34,040 --> 00:45:31,470

your sunglasses and does your

1070

00:45:37,570 --> 00:45:34,050

broad-spectrum sunscreen protect you

1071

00:45:39,620 --> 00:45:37,580

against the ultraviolet rays well I

1072

00:45:41,600 --> 00:45:39,630

happen to have kind of you know

1073

00:45:44,660 --> 00:45:41,610

sensitive skin okay I need to use lots

1074

00:45:47,570 --> 00:45:44,670

and lots of lots of sunblock okay but

1075

00:45:50,360 --> 00:45:47,580

I'm really really glad that we have an

1076
00:45:53,510 --> 00:45:50,370
atmosphere because our atmosphere

1077
00:45:57,320 --> 00:45:53,520
actually absorbs most of the ultraviolet

1078
00:46:00,200 --> 00:45:57,330
radiation okay we cannot do ultraviolet

1079
00:46:02,900 --> 00:46:00,210
astronomy from the ground all right you

1080
00:46:06,770 --> 00:46:02,910
can see by this diagram here is the of

1081
00:46:07,910 --> 00:46:06,780
the penetration depth of the various

1082
00:46:10,520 --> 00:46:07,920
wavelengths you can see without the

1083
00:46:12,890 --> 00:46:10,530
optical window we have the radio window

1084
00:46:15,140 --> 00:46:12,900
you can see how all true infrared get

1085
00:46:17,240 --> 00:46:15,150
some gets to the ground some you know

1086
00:46:17,840 --> 00:46:17,250
can go there but we really still need to

1087
00:46:19,340 --> 00:46:17,850
do in for

1088
00:46:22,370 --> 00:46:19,350

to do it Fred right you got to go to

1089

00:46:24,530 --> 00:46:22,380

space well for ultraviolet and longer

1090

00:46:26,570 --> 00:46:24,540

you got to go to space to do astronomy

1091

00:46:28,520 --> 00:46:26,580

all right which also means that if we

1092

00:46:30,950 --> 00:46:28,530

didn't have that atmosphere there it

1093

00:46:32,390 --> 00:46:30,960

would be really really bad because you

1094

00:46:35,470 --> 00:46:32,400

know we get some serious serious

1095

00:46:38,390 --> 00:46:35,480

sunburns okay where we go up into space

1096

00:46:39,680 --> 00:46:38,400

we have one of the telescopes up there

1097

00:46:44,330 --> 00:46:39,690

is the galaxy

1098

00:46:45,740 --> 00:46:44,340

the Galaxy Evolution Explorer and infra

1099

00:46:48,350 --> 00:46:45,750

telescope that seems to have only one

1100

00:46:50,180 --> 00:46:48,360

press release drawing of it I was

1101

00:46:54,590 --> 00:46:50,190

looking around saying this is kind of

1102

00:46:56,630 --> 00:46:54,600

you know overdone a little bit with with

1103

00:46:58,520 --> 00:46:56,640

the the Sun peeking over there I was

1104

00:46:59,690 --> 00:46:58,530

trying to find another galaxy but that's

1105

00:47:02,420 --> 00:46:59,700

it that's all I could find on the

1106

00:47:04,430 --> 00:47:02,430

internet today for Galax in terms of

1107

00:47:07,070 --> 00:47:04,440

being I think but this is an ultraviolet

1108

00:47:09,170 --> 00:47:07,080

telescope and as you may know the Hubble

1109

00:47:12,050 --> 00:47:09,180

Space Telescope observes a little bit of

1110

00:47:15,890 --> 00:47:12,060

the ultraviolet so you can use normal

1111

00:47:17,300 --> 00:47:15,900

optics to absorb ultraviolet and so and

1112

00:47:19,700 --> 00:47:17,310

this is of course tune with the

1113

00:47:22,910 --> 00:47:19,710

ultraviolet detectors to see in the

1114

00:47:25,190 --> 00:47:22,920

ultraviolet with Galax so what is our

1115

00:47:27,920 --> 00:47:25,200

favorite targets astronomical targets in

1116

00:47:30,950 --> 00:47:27,930

the ultraviolet one of them is our Sun

1117

00:47:33,380 --> 00:47:30,960

now our Sun and visible light looks kind

1118

00:47:35,960 --> 00:47:33,390

of boring okay it's just kind of smooth

1119

00:47:37,970 --> 00:47:35,970

and it has a few freckles right you put

1120

00:47:40,910 --> 00:47:37,980

that you observe it in ultraviolet and

1121

00:47:43,720 --> 00:47:40,920

then you start to see the energy in the

1122

00:47:46,760 --> 00:47:43,730

Sun so these are four different

1123

00:47:48,890 --> 00:47:46,770

wavelength bands four different

1124

00:47:51,440 --> 00:47:48,900

observation reading regions within the

1125

00:47:53,180 --> 00:47:51,450

ultraviolet okay and one of the great

1126
00:47:55,880 --> 00:47:53,190
things these solar astronomers have done

1127
00:47:58,490 --> 00:47:55,890
they they've decided that for the

1128
00:48:01,160 --> 00:47:58,500
various wavelengths they're going to use

1129
00:48:03,590 --> 00:48:01,170
single colors so whenever you see this

1130
00:48:07,730 --> 00:48:03,600
red you can know that it's 30.4

1131
00:48:11,420 --> 00:48:07,740
nanometers or 304 angstroms okay I think

1132
00:48:13,100 --> 00:48:11,430
this blue is as 19.1 I can't remember

1133
00:48:15,620 --> 00:48:13,110
all of them all right but you can see

1134
00:48:18,320 --> 00:48:15,630
the structure and you can also see the

1135
00:48:20,300 --> 00:48:18,330
magnetic storms that are going on with

1136
00:48:21,290 --> 00:48:20,310
those sunspots those sunspots with

1137
00:48:24,050 --> 00:48:21,300
visible light they just look like

1138
00:48:26,210 --> 00:48:24,060

freckles on the Sun here you can see the

1139

00:48:28,880 --> 00:48:26,220

energy that is in the magnetic

1140

00:48:30,620 --> 00:48:28,890

concentration around those sunspots the

1141

00:48:32,210 --> 00:48:30,630

energy that is that

1142

00:48:35,089 --> 00:48:32,220

is working through here and if you ever

1143

00:48:37,339 --> 00:48:35,099

see anything with you know with magnetic

1144

00:48:39,049 --> 00:48:37,349

storms on the Sun and there's exciting

1145

00:48:41,630 --> 00:48:39,059

images well you're looking in the

1146

00:48:43,549 --> 00:48:41,640

ultraviolet matter-of-fact ultraviolet

1147

00:48:45,980 --> 00:48:43,559

because of the ultraviolet images gotten

1148

00:48:47,870 --> 00:48:45,990

so popular you'll see a lot in textbooks

1149

00:48:49,640 --> 00:48:47,880

that says that the art director will say

1150

00:48:51,650 --> 00:48:49,650

oh I want to use that image all right

1151

00:48:53,089 --> 00:48:51,660

because it's the ultraviolet of course

1152

00:48:55,009 --> 00:48:53,099

you know have to make sure people mark

1153

00:48:57,410 --> 00:48:55,019

it as ultraviolet so that you know if

1154

00:48:58,999 --> 00:48:57,420

you see the Sun looking exciting you're

1155

00:49:01,700 --> 00:48:59,009

probably looking at an ultraviolet image

1156

00:49:03,289 --> 00:49:01,710

of the Sun another thing that we've can

1157

00:49:05,799 --> 00:49:03,299

see in ultraviolet that we can't see in

1158

00:49:08,690 --> 00:49:05,809

visible light is the Aurora on Saturn

1159

00:49:10,609 --> 00:49:08,700

now this is a composite image okay these

1160

00:49:13,370 --> 00:49:10,619

are three images of Saturn composited

1161

00:49:16,220 --> 00:49:13,380

together their visible light images of

1162

00:49:18,529 --> 00:49:16,230

Saturn added on to it is ultraviolet

1163

00:49:22,220 --> 00:49:18,539

images that show off the Aurora of

1164

00:49:24,230 --> 00:49:22,230

Saturn now our Aurora on earth we can

1165

00:49:28,039 --> 00:49:24,240

see what have you how many people here

1166

00:49:29,829 --> 00:49:28,049

have seen the Aurora okay I highly

1167

00:49:31,490 --> 00:49:29,839

recommend it if you can get North

1168

00:49:34,220 --> 00:49:31,500

sometimes you don't have to go too far

1169

00:49:35,960 --> 00:49:34,230

north to make an effort to see it

1170

00:49:40,900 --> 00:49:35,970

because it's really great to stash or to

1171

00:49:43,670 --> 00:49:40,910

see the shimmering misguide I was on a

1172

00:49:44,749 --> 00:49:43,680

cruise back from Alaska and we're

1173

00:49:47,420 --> 00:49:44,759

standing on the back of the boat just

1174

00:49:49,609 --> 00:49:47,430

watching the Aurora dance in the sky it

1175

00:49:52,490 --> 00:49:49,619

was really great so I highly recommend

1176

00:49:53,990 --> 00:49:52,500

taking the effort okay alright take the

1177

00:49:55,609 --> 00:49:54,000

effort to go out and see see these

1178

00:49:56,960 --> 00:49:55,619

things because you know you live in

1179

00:49:58,910 --> 00:49:56,970

cities with lights and all that stuff

1180

00:50:01,279 --> 00:49:58,920

you don't get to really experience the

1181

00:50:03,499 --> 00:50:01,289

sky make the effort to see it so see the

1182

00:50:06,349 --> 00:50:03,509

aurora on earth but i can't tell you to

1183

00:50:09,009 --> 00:50:06,359

go do that on Saturn because on Saturn

1184

00:50:11,809 --> 00:50:09,019

it's not visible light Aurora its

1185

00:50:13,999 --> 00:50:11,819

ultraviolet Aurora you cannot see that

1186

00:50:15,980 --> 00:50:14,009

of that Aurora on Saturn unless you have

1187

00:50:18,829 --> 00:50:15,990

an ultraviolet detector which is why

1188

00:50:20,539 --> 00:50:18,839

these are Hubble images from from Hubble

1189

00:50:22,549 --> 00:50:20,549

up in space to be able to do the

1190

00:50:25,999 --> 00:50:22,559

ultraviolet astronomy to see the Aurora

1191

00:50:27,920 --> 00:50:26,009

on Saturn we can also look at galaxies

1192

00:50:30,349 --> 00:50:27,930

in the ultraviolet again we're getting

1193

00:50:32,599 --> 00:50:30,359

to higher energy here so instead of

1194

00:50:34,279 --> 00:50:32,609

looking at that low dense that that cold

1195

00:50:36,319 --> 00:50:34,289

gas will be getting at the higher energy

1196

00:50:39,339 --> 00:50:36,329

the hotter stuff and so this is the

1197

00:50:42,650 --> 00:50:39,349

visible light image of a galaxy called

1198

00:50:43,880 --> 00:50:42,660

m74 and in ultraviolet

1199

00:50:46,250 --> 00:50:43,890

you only see

1200

00:50:49,370 --> 00:50:46,260

the star forming regions okay you see

1201
00:50:51,740 --> 00:50:49,380
the high-energy regions because it is as

1202
00:50:53,750 --> 00:50:51,750
I talked about those hotter stars that

1203
00:50:55,910 --> 00:50:53,760
actually emit in the ultraviolet and

1204
00:50:58,940 --> 00:50:55,920
those hot stars are the more massive

1205
00:51:01,430 --> 00:50:58,950
stars those very massive stars only live

1206
00:51:03,890 --> 00:51:01,440
short lives so they don't get outside of

1207
00:51:06,440 --> 00:51:03,900
their star forming regions so studying

1208
00:51:09,410 --> 00:51:06,450
star forming regions in galaxies you can

1209
00:51:12,170 --> 00:51:09,420
find them very easily just by looking in

1210
00:51:14,930 --> 00:51:12,180
the ultraviolet moving up an energy

1211
00:51:18,319 --> 00:51:14,940
scale we go to x-rays which from roughly

1212
00:51:20,539 --> 00:51:18,329
10 nanometers down to 1/100 of a

1213
00:51:23,690 --> 00:51:20,549

nanometer again about a factor of a

1214

00:51:27,289 --> 00:51:23,700

thousand in wavelength region and for

1215

00:51:30,319 --> 00:51:27,299

our purposes we think of x-rays as being

1216

00:51:32,120 --> 00:51:30,329

these medical observations and as you

1217

00:51:35,089 --> 00:51:32,130

can see that there is a fracture here in

1218

00:51:38,690 --> 00:51:35,099

one of these bones now are these bones

1219

00:51:41,569 --> 00:51:38,700

emitting x-rays no the bones are not

1220

00:51:44,769 --> 00:51:41,579

emitting x-rays rather the x-rays are

1221

00:51:47,480 --> 00:51:44,779

created by a machine that pass through

1222

00:51:50,089 --> 00:51:47,490

the skin and the bones right

1223

00:51:51,859 --> 00:51:50,099

the ara the x-rays are actually absorbed

1224

00:51:53,390 --> 00:51:51,869

by the bones and what you are seeing

1225

00:51:56,870 --> 00:51:53,400

you're seeing the bones in shadow

1226
00:51:58,279 --> 00:51:56,880
because the bones actually are absorbing

1227
00:52:00,380 --> 00:51:58,289
the x-rays whereas the skin and

1228
00:52:03,529 --> 00:52:00,390
soft-tissue let the x-rays pass through

1229
00:52:05,900 --> 00:52:03,539
right so what you are seeing here is not

1230
00:52:09,650 --> 00:52:05,910
an emission of x-rays but rather an

1231
00:52:12,529 --> 00:52:09,660
absorption of x-rays so knowing that can

1232
00:52:15,040 --> 00:52:12,539
anybody explain to me how Superman has

1233
00:52:19,490 --> 00:52:15,050
x-ray vision

1234
00:52:21,560 --> 00:52:19,500
because ya are his eyes x-ray detectors

1235
00:52:23,330 --> 00:52:21,570
or are the x-ray emitters and if their

1236
00:52:24,980 --> 00:52:23,340
x-ray emitters are the x-rays sort of

1237
00:52:27,320 --> 00:52:24,990
somehow coming back to and so that it

1238
00:52:31,280 --> 00:52:27,330

can inject them it's never made any

1239

00:52:34,220 --> 00:52:31,290

sense whatsoever okay but astronomers

1240

00:52:36,890 --> 00:52:34,230

truly do have x-ray vision all right and

1241

00:52:40,940 --> 00:52:36,900

our favorite x-ray vision satellite is

1242

00:52:43,310 --> 00:52:40,950

the Chandra x-ray Observatory and x-ray

1243

00:52:45,170 --> 00:52:43,320

observatories on is really cool looping

1244

00:52:47,330 --> 00:52:45,180

orbit around Earth it's got this big

1245

00:52:50,570 --> 00:52:47,340

long elliptical orbit alright and

1246

00:52:52,250 --> 00:52:50,580

observing x-rays is not like observing

1247

00:52:55,070 --> 00:52:52,260

with visible light because we usually

1248

00:52:56,510 --> 00:52:55,080

bounce light off a mirror right well you

1249

00:52:58,490 --> 00:52:56,520

take x-rays you it's going to go

1250

00:53:01,520 --> 00:52:58,500

straight through the mirror okay so you

1251
00:53:03,950 --> 00:53:01,530
can't use a standard mirror to observe

1252
00:53:06,350 --> 00:53:03,960
an x-rays but you do use mirrors and

1253
00:53:09,500 --> 00:53:06,360
instead what you use are what we call

1254
00:53:11,960 --> 00:53:09,510
grazing incidence mirrors okay so the

1255
00:53:14,540 --> 00:53:11,970
light comes in and it just deflects a

1256
00:53:17,150 --> 00:53:14,550
little bit off of these mirrors okay so

1257
00:53:20,570 --> 00:53:17,160
you can see this is a concentric cone of

1258
00:53:25,700 --> 00:53:20,580
mirrors that are graduated down to focus

1259
00:53:27,290 --> 00:53:25,710
the x-rays on to the detector all right

1260
00:53:28,340 --> 00:53:27,300
so instead of bouncing things off

1261
00:53:30,050 --> 00:53:28,350
mirrors you're just trying to give them

1262
00:53:31,070 --> 00:53:30,060
just all tiny little deflection you're

1263
00:53:33,050 --> 00:53:31,080

giving them a nudge

1264

00:53:36,470 --> 00:53:33,060

all right to try and eventually focus

1265

00:53:38,120 --> 00:53:36,480

them to focus focus x-rays so I thought

1266

00:53:40,930 --> 00:53:38,130

that was a kind of a kind of cool thing

1267

00:53:46,160 --> 00:53:40,940

so they have these basically these big

1268

00:53:49,250 --> 00:53:46,170

concentric cones of mirrors that that

1269

00:53:52,280 --> 00:53:49,260

allow us to observe in x-rays and we can

1270

00:53:54,380 --> 00:53:52,290

look in x-rays at things like this oh we

1271

00:53:56,720 --> 00:53:54,390

can look at the Sun okay like we

1272

00:53:58,670 --> 00:53:56,730

observed ultraviolet which is where most

1273

00:54:00,650 --> 00:53:58,680

of the activity is there's still some

1274

00:54:04,100 --> 00:54:00,660

even higher energy activity on the Sun

1275

00:54:06,320 --> 00:54:04,110

that shows up in x-rays and this is from

1276

00:54:08,420 --> 00:54:06,330

the Yoko satellite which observed for

1277

00:54:11,630 --> 00:54:08,430

several years and the Yoko satellite

1278

00:54:14,180 --> 00:54:11,640

also observe prefer over the course of a

1279

00:54:16,130 --> 00:54:14,190

solar cycle and so here you can see the

1280

00:54:19,370 --> 00:54:16,140

high energy activity during a solar

1281

00:54:21,710 --> 00:54:19,380

maximum and then the low energy during a

1282

00:54:24,770 --> 00:54:21,720

solar minimum our Sun goes through these

1283

00:54:26,300 --> 00:54:24,780

cycles of activity right and on when we

1284

00:54:27,940 --> 00:54:26,310

look at visible light we just see more

1285

00:54:30,400 --> 00:54:27,950

sunspots or fewer Sun

1286

00:54:33,640 --> 00:54:30,410

spots okay lots of sunspots and almost

1287

00:54:35,770 --> 00:54:33,650

no sunspots right here it's much more

1288

00:54:38,589 --> 00:54:35,780

apparent you can see that's a seething

1289

00:54:40,060 --> 00:54:38,599

cauldron of activity and this is kind of

1290

00:54:42,430 --> 00:54:40,070

boring okay let's go check back next

1291

00:54:45,940 --> 00:54:42,440

week all right so this was a really nice

1292

00:54:48,130 --> 00:54:45,950

in the 1990s to see the vivid

1293

00:54:51,280 --> 00:54:48,140

illustration of the solar cycle observed

1294

00:54:54,310 --> 00:54:51,290

in x-rays we can also go back to that

1295

00:54:57,069 --> 00:54:54,320

supernova remnant Cassiopeia A which I

1296

00:54:58,780 --> 00:54:57,079

showed you in radio but this time let's

1297

00:55:01,180 --> 00:54:58,790

take that visible light which is just

1298

00:55:04,150 --> 00:55:01,190

the shell at the edge and let's take a

1299

00:55:07,359 --> 00:55:04,160

look in x-rays and in x-rays you see all

1300

00:55:09,940 --> 00:55:07,369

the heated gas interior to it because

1301
00:55:12,339 --> 00:55:09,950
this is a star that has exploded its

1302
00:55:14,530 --> 00:55:12,349
guts across space it stuff has been

1303
00:55:16,839 --> 00:55:14,540
moving at tens of millions of miles an

1304
00:55:19,960 --> 00:55:16,849
hour across space it's heated up to

1305
00:55:24,609 --> 00:55:19,970
millions of degrees and in millions of

1306
00:55:27,160 --> 00:55:24,619
degrees you emit x-rays okay so this is

1307
00:55:29,589 --> 00:55:27,170
the gas that's interior this shows you

1308
00:55:31,569 --> 00:55:29,599
just the edge of the bubble this shows

1309
00:55:34,180 --> 00:55:31,579
you the gas and the interior bubble

1310
00:55:37,059 --> 00:55:34,190
emitting x-rays so supernova remnants

1311
00:55:40,089 --> 00:55:37,069
are much more interesting to view in

1312
00:55:43,870 --> 00:55:40,099
x-ray light another thing that shows up

1313
00:55:46,059 --> 00:55:43,880

in x-ray light is the gas in clusters of

1314

00:55:48,040 --> 00:55:46,069

galaxies all right so this is going to

1315

00:55:51,280 --> 00:55:48,050

take a little bit of comprehension here

1316

00:55:53,770 --> 00:55:51,290

so we look at this image of a galaxy

1317

00:55:55,359 --> 00:55:53,780

cluster I forget which one this one is I

1318

00:55:57,160 --> 00:55:55,369

think this is one of the max clusters

1319

00:55:59,920 --> 00:55:57,170

all right and you can see all these

1320

00:56:02,349 --> 00:55:59,930

galaxies here and if you look at those

1321

00:56:04,059 --> 00:56:02,359

galaxies all right and you say okay well

1322

00:56:06,099 --> 00:56:04,069

each galaxy has a certain amount of mass

1323

00:56:08,589 --> 00:56:06,109

associated with it and you can come up

1324

00:56:12,460 --> 00:56:08,599

with a mass map okay and so we're gonna

1325

00:56:15,640 --> 00:56:12,470

color the mass in blue so based upon all

1326

00:56:17,319 --> 00:56:15,650

the galaxies out there okay that you can

1327

00:56:20,380 --> 00:56:17,329

see and identify as part of this cluster

1328

00:56:23,020 --> 00:56:20,390

here is a rough bass map of that cluster

1329

00:56:25,780 --> 00:56:23,030

based upon the light all right we can

1330

00:56:28,690 --> 00:56:25,790

also look at this cluster in x-rays and

1331

00:56:30,790 --> 00:56:28,700

when you form a cluster of galaxies you

1332

00:56:32,920 --> 00:56:30,800

bring in not just the visible light of

1333

00:56:35,770 --> 00:56:32,930

the galaxies but all the associated gas

1334

00:56:37,720 --> 00:56:35,780

associated with it and you bring galaxy

1335

00:56:40,150 --> 00:56:37,730

after galaxy swooshing together to make

1336

00:56:41,210 --> 00:56:40,160

this really big cluster that intra

1337

00:56:44,030 --> 00:56:41,220

cluster gas

1338

00:56:45,830 --> 00:56:44,040

heats up it heats up to hundreds of

1339

00:56:48,830 --> 00:56:45,840

thousands and millions of degrees and

1340

00:56:50,330 --> 00:56:48,840

actually glows in x-rays so when you

1341

00:56:54,050 --> 00:56:50,340

look at a cluster of galaxies like this

1342

00:56:56,380 --> 00:56:54,060

and you look in x-rays you see a what we

1343

00:56:59,300 --> 00:56:56,390

call and what we call here a red blob

1344

00:57:02,420 --> 00:56:59,310

alright that is the gas between the

1345

00:57:04,070 --> 00:57:02,430

galaxies very low-density gas that has

1346

00:57:06,109 --> 00:57:04,080

been heated up to hundreds of thousands

1347

00:57:08,240 --> 00:57:06,119

and millions of degrees and glows in

1348

00:57:10,520 --> 00:57:08,250

x-rays which gives you another measure

1349

00:57:13,040 --> 00:57:10,530

of the structure of the material in the

1350

00:57:15,080 --> 00:57:13,050

galaxies and the extent of this cluster

1351

00:57:19,040 --> 00:57:15,090

of galaxies so if we put them all

1352

00:57:21,470 --> 00:57:19,050

together we've got the galaxy image and

1353

00:57:23,660 --> 00:57:21,480

the yellowish stuff we got the blue for

1354

00:57:27,589 --> 00:57:23,670

the mass and we've got the red for the

1355

00:57:29,720 --> 00:57:27,599

x-ray gas all right and shows us that by

1356

00:57:33,170 --> 00:57:29,730

looking in x-rays we can discover the

1357

00:57:35,240 --> 00:57:33,180

true extent of a cluster of galaxies of

1358

00:57:37,130 --> 00:57:35,250

all the stuff can cluster of galaxies it

1359

00:57:39,080 --> 00:57:37,140

actually gives us another check on how

1360

00:57:41,240 --> 00:57:39,090

we can compare the mass that is in

1361

00:57:43,400 --> 00:57:41,250

visible light to the total mass that's

1362

00:57:47,359 --> 00:57:43,410

in the entire cluster measured by the

1363

00:57:48,980 --> 00:57:47,369

x-ray gas all right last wavelength

1364

00:57:51,380 --> 00:57:48,990

region the gamma rays

1365

00:57:54,290 --> 00:57:51,390

all right wavelengths less than 100 one

1366

00:57:57,800 --> 00:57:54,300

hundredth of a nanometer and we don't

1367

00:58:00,800 --> 00:57:57,810

have a lot o everyday experience with

1368

00:58:02,390 --> 00:58:00,810

gamma rays but to do get them a little

1369

00:58:03,320 --> 00:58:02,400

bit gamma rays can be produced by

1370

00:58:07,760 --> 00:58:03,330

lightning strikes

1371

00:58:09,230 --> 00:58:07,770

just a little bit of gamma rays of

1372

00:58:11,359 --> 00:58:09,240

course where do we normally think of

1373

00:58:13,820 --> 00:58:11,369

gamma rays besides the Incredible Hulk

1374

00:58:16,010 --> 00:58:13,830

and you know mutants like that ok we

1375

00:58:21,470 --> 00:58:16,020

think of it with nuclear explosions ok

1376

00:58:26,180 --> 00:58:21,480

in only in the highest energy events do

1377

00:58:27,560 --> 00:58:26,190

we get gamma rays and so where would you

1378

00:58:29,150 --> 00:58:27,570

get them in the universe how would you

1379

00:58:30,740 --> 00:58:29,160

look for them in the universe ok

1380

00:58:33,440 --> 00:58:30,750

well of course you have to go up into

1381

00:58:36,050 --> 00:58:33,450

into space and the current gamma ray

1382

00:58:37,970 --> 00:58:36,060

Observatory is called Famy it used to be

1383

00:58:40,130 --> 00:58:37,980

called classed gamma ray large area

1384

00:58:42,620 --> 00:58:40,140

space telescope and now it's the Fermi

1385

00:58:45,740 --> 00:58:42,630

gamma-ray Space Telescope and here is a

1386

00:58:48,859 --> 00:58:45,750

drawing of it and in this cube are lots

1387

00:58:51,050 --> 00:58:48,869

of detectors for measuring the gamma ray

1388

00:58:52,730 --> 00:58:51,060

radiation okay and in particular when

1389

00:58:54,270 --> 00:58:52,740

you get up to these high energies you're

1390

00:58:56,070 --> 00:58:54,280

not measuring particularly the

1391

00:58:57,900 --> 00:58:56,080

raise themselves you're measuring the

1392

00:59:00,570 --> 00:58:57,910

gamma rays are absorbed and they create

1393

00:59:02,850 --> 00:59:00,580

follow on radiation showers of radiation

1394

00:59:04,560 --> 00:59:02,860

as they're absorbed and you're actually

1395

00:59:06,630 --> 00:59:04,570

detecting some of that showers or

1396

00:59:08,130 --> 00:59:06,640

radiation not necessarily the gamma rays

1397

00:59:10,050 --> 00:59:08,140

themselves but you know you can

1398

00:59:13,500 --> 00:59:10,060

calibrate it really really well to see

1399

00:59:17,360 --> 00:59:13,510

it so here is some of the results from

1400

00:59:22,860 --> 00:59:17,370

Fermi this is an all-sky image from fami

1401
00:59:26,970 --> 00:59:22,870
alright before and after and after when

1402
00:59:28,500 --> 00:59:26,980
we see this giant Squatch okay this is a

1403
00:59:33,630 --> 00:59:28,510
gamma-ray burst

1404
00:59:36,800 --> 00:59:33,640
okay it is a single point of gamma rays

1405
00:59:40,280 --> 00:59:36,810
emitted from somewhere in the universe

1406
00:59:41,640 --> 00:59:40,290
secret astronomers didn't discover these

1407
00:59:44,700 --> 00:59:41,650
all right

1408
00:59:47,850 --> 00:59:44,710
because gamma rays come from nuclear

1409
00:59:51,180 --> 00:59:47,860
test explosions all right the Department

1410
00:59:53,610 --> 00:59:51,190
of Defense put up gamma-ray satellites

1411
00:59:55,260 --> 00:59:53,620
Cameron area detectors to monitor

1412
00:59:57,270 --> 00:59:55,270
whether or not there were nuclear

1413
01:00:02,040 --> 00:59:57,280

explosions going around around the world

1414

01:00:04,500 --> 01:00:02,050

and they saw bursts and they saw another

1415

01:00:09,480 --> 01:00:04,510

burst and they saw approximately one

1416

01:00:11,340 --> 01:00:09,490

burst every single day how many nuclear

1417

01:00:14,760 --> 01:00:11,350

bombs were there the world to get an

1418

01:00:16,140 --> 01:00:14,770

explosion every single day well they

1419

01:00:17,430 --> 01:00:16,150

quickly determined that no they weren't

1420

01:00:19,740 --> 01:00:17,440

coming from Earth they're actually

1421

01:00:20,910 --> 01:00:19,750

coming from space and of course this was

1422

01:00:22,650 --> 01:00:20,920

classified so they didn't bother telling

1423

01:00:24,960 --> 01:00:22,660

astronomers but we put up our own

1424

01:00:26,730 --> 01:00:24,970

satellites and found it ourselves so

1425

01:00:28,620 --> 01:00:26,740

we've got these gamma-ray bursts

1426

01:00:31,230 --> 01:00:28,630

coming from somewhere these are huge

1427

01:00:32,820 --> 01:00:31,240

incredible energetic events all right

1428

01:00:35,850 --> 01:00:32,830

and there's not just one of them okay

1429

01:00:37,710 --> 01:00:35,860

there are lots of them here are two

1430

01:00:39,960 --> 01:00:37,720

thousand observed by the Compton

1431

01:00:42,630 --> 01:00:39,970

gamma-ray Observatory with the Batsy

1432

01:00:46,380 --> 01:00:42,640

experiment all right two thousand of

1433

01:00:48,120 --> 01:00:46,390

these all across the sky and remember

1434

01:00:51,030 --> 01:00:48,130

when we're looking at this projection of

1435

01:00:53,520 --> 01:00:51,040

the sky the galaxy is right across the

1436

01:00:57,000 --> 01:00:53,530

center so you can see these gamma-ray

1437

01:00:59,670 --> 01:00:57,010

bursts are not associated with our

1438

01:01:02,190 --> 01:00:59,680

galaxy they're either really close to us

1439

01:01:04,470 --> 01:01:02,200

in space all right around us within our

1440

01:01:06,870 --> 01:01:04,480

small portion of the galaxy therefore

1441

01:01:07,180 --> 01:01:06,880

they can appear isotropic or they're

1442

01:01:09,910 --> 01:01:07,190

much

1443

01:01:11,350 --> 01:01:09,920

further beyond our galaxy and it's a

1444

01:01:14,140 --> 01:01:11,360

further beyond our galaxy they have to

1445

01:01:16,300 --> 01:01:14,150

be incredible energies okay because the

1446

01:01:17,800 --> 01:01:16,310

further away they are the more energetic

1447

01:01:20,350 --> 01:01:17,810

they have to be in order for us to see

1448

01:01:23,530 --> 01:01:20,360

them in gamma raised here well it turns

1449

01:01:26,350 --> 01:01:23,540

out they are actually at cosmological

1450

01:01:29,320 --> 01:01:26,360

distances all right here is a picture of

1451
01:01:31,990 --> 01:01:29,330
a gamma-ray burst and visible light can

1452
01:01:35,560 --> 01:01:32,000
you see it yeah I wouldn't know unless I

1453
01:01:38,110 --> 01:01:35,570
put this arrow in okay this is an object

1454
01:01:40,900 --> 01:01:38,120
that produced a gamma-ray burst so after

1455
01:01:43,510 --> 01:01:40,910
seeing a gamma-ray burst in in gamma

1456
01:01:45,550 --> 01:01:43,520
rays they they put out the coordinates

1457
01:01:47,800 --> 01:01:45,560
and we take you take images to try and

1458
01:01:50,200 --> 01:01:47,810
see what you can find Hubble has looked

1459
01:01:52,180 --> 01:01:50,210
to see what it can find at the positions

1460
01:01:56,790 --> 01:01:52,190
of these gamma-ray bursts and what does

1461
01:02:00,610 --> 01:01:56,800
it find it finds very distant galaxies

1462
01:02:03,340 --> 01:02:00,620
these gamma-ray bursts are incredibly

1463
01:02:05,110 --> 01:02:03,350

energetic events coming to us from

1464

01:02:06,790 --> 01:02:05,120

cosmological distances we're talking

1465

01:02:09,090 --> 01:02:06,800

billions of light years hundreds of

1466

01:02:12,940 --> 01:02:09,100

millions to billions of light-years away

1467

01:02:14,830 --> 01:02:12,950

okay all right what we surmise them to

1468

01:02:18,550 --> 01:02:14,840

be or something called not just a

1469

01:02:24,250 --> 01:02:18,560

supernova not a nova not a supernova but

1470

01:02:27,160 --> 01:02:24,260

a hyper nova okay which would be an

1471

01:02:28,540 --> 01:02:27,170

incredible burst burst of energy such

1472

01:02:31,450 --> 01:02:28,550

that we can observe gamma rays from

1473

01:02:33,670 --> 01:02:31,460

billions of light-years away across in

1474

01:02:35,470 --> 01:02:33,680

this and that's why they are produced

1475

01:02:37,870 --> 01:02:35,480

all the way across the sky so it's an

1476

01:02:40,150 --> 01:02:37,880

amazing and astounding idea that we can

1477

01:02:42,100 --> 01:02:40,160

see these gamma rays from across the

1478

01:02:44,290 --> 01:02:42,110

universe from these absolutely

1479

01:02:45,790 --> 01:02:44,300

incredible explosions and of course

1480

01:02:50,050 --> 01:02:45,800

that's not the only thing we see in

1481

01:02:53,860 --> 01:02:50,060

gamma rays here is an all-sky map above

1482

01:02:55,540 --> 01:02:53,870

a hundred million electron volts which

1483

01:02:58,540 --> 01:02:55,550

is a really high energy let me just say

1484

01:03:00,400 --> 01:02:58,550

that and what we see a lot in that you

1485

01:03:03,520 --> 01:03:00,410

here you can see the structure of our

1486

01:03:05,670 --> 01:03:03,530

galaxy because we start seeing the x-ray

1487

01:03:08,290 --> 01:03:05,680

binaries we start seeing pulsars

1488

01:03:10,030 --> 01:03:08,300

basically black holes all of those

1489

01:03:12,310 --> 01:03:10,040

things that can produce really high

1490

01:03:14,620 --> 01:03:12,320

energies are the only things that are

1491

01:03:16,660 --> 01:03:14,630

going to be able to produce these these

1492

01:03:18,980 --> 01:03:16,670

gamma rays that we see with gamma-ray

1493

01:03:20,300 --> 01:03:18,990

telescopes all right

1494

01:03:22,850 --> 01:03:20,310

we've covered the electromagnetic

1495

01:03:25,070 --> 01:03:22,860

spectrum alright we've gone across all

1496

01:03:27,560 --> 01:03:25,080

these wavelengths let's summarize in

1497

01:03:29,180 --> 01:03:27,570

terms of what do we get out of it ok

1498

01:03:32,420 --> 01:03:29,190

you've seen that we see lots of things

1499

01:03:35,090 --> 01:03:32,430

in lots of different different ideas of

1500

01:03:37,340 --> 01:03:35,100

light we have three Great observatories

1501
01:03:39,080 --> 01:03:37,350
currently operating the Compton gamma

1502
01:03:41,120 --> 01:03:39,090
ray Observatory isn't operating anymore

1503
01:03:43,910 --> 01:03:41,130
Hubble which is mostly visible Spitzer's

1504
01:03:46,520 --> 01:03:43,920
infrared Chandra x-ray we've done a

1505
01:03:49,240 --> 01:03:46,530
variety of presentations where we take

1506
01:03:52,220 --> 01:03:49,250
the state observations with the with the

1507
01:03:55,640 --> 01:03:52,230
with these telescopes of the same object

1508
01:03:58,190 --> 01:03:55,650
I like to show this one here which is a

1509
01:04:01,160 --> 01:03:58,200
supernova remnant supernovae 1604 also

1510
01:04:03,560 --> 01:04:01,170
called Kepler supernova because here is

1511
01:04:05,570 --> 01:04:03,570
where Hubble has the wimpiest of all the

1512
01:04:08,360 --> 01:04:05,580
images we're so used to elbow having the

1513
01:04:10,010 --> 01:04:08,370

most beautiful images well when it comes

1514

01:04:12,770 --> 01:04:10,020

to supernova remnants at least this one

1515

01:04:15,020 --> 01:04:12,780

here even Spitzer in the infrared has

1516

01:04:17,720 --> 01:04:15,030

more detail and more in traditional

1517

01:04:20,300 --> 01:04:17,730

interest and Chandra of course getting

1518

01:04:22,760 --> 01:04:20,310

that hot x-ray gas inside the supernova

1519

01:04:25,160 --> 01:04:22,770

in it has the most interesting ok so

1520

01:04:27,140 --> 01:04:25,170

Hubble doesn't always have the most

1521

01:04:29,930 --> 01:04:27,150

beautiful image but even when Hubble

1522

01:04:31,940 --> 01:04:29,940

does have a beautiful image such as for

1523

01:04:33,740 --> 01:04:31,950

the crab supernova remnant all right

1524

01:04:37,100 --> 01:04:33,750

then when we look in other wavelengths

1525

01:04:40,130 --> 01:04:37,110

we get a lot more information ok in

1526
01:04:42,260 --> 01:04:40,140
terms of the from the radio the various

1527
01:04:44,000 --> 01:04:42,270
infrared bands from Spitzer we've got

1528
01:04:46,190 --> 01:04:44,010
the visible light here we've got the

1529
01:04:48,440 --> 01:04:46,200
ultraviolet in here and down in the

1530
01:04:50,270 --> 01:04:48,450
x-ray we can actually see the disk of

1531
01:04:53,330 --> 01:04:50,280
material around the pulsar at the core

1532
01:04:55,610 --> 01:04:53,340
of the Crab Nebula all right this is

1533
01:04:57,470 --> 01:04:55,620
what astronomy is progressive - it's

1534
01:04:59,690 --> 01:04:57,480
being able to look in these various

1535
01:05:02,450 --> 01:04:59,700
wavelengths of light and get different

1536
01:05:04,460 --> 01:05:02,460
aspects of the same objects in these

1537
01:05:06,590 --> 01:05:04,470
different wavelength regions and I'm

1538
01:05:07,850 --> 01:05:06,600

gonna finish with my favorite object to

1539

01:05:09,860 --> 01:05:07,860

do for this which is of course the

1540

01:05:10,850 --> 01:05:09,870

Whirlpool Galaxy I've shown you the

1541

01:05:13,340 --> 01:05:10,860

Hubble invisible

1542

01:05:16,880 --> 01:05:13,350

the Spitzer infrared here is the

1543

01:05:18,620 --> 01:05:16,890

ultraviolet image I believe that sale

1544

01:05:20,930 --> 01:05:18,630

for violet image from galaxy and here's

1545

01:05:23,590 --> 01:05:20,940

the x-ray image from Chandra we're able

1546

01:05:26,210 --> 01:05:23,600

to see different structures

1547

01:05:27,800 --> 01:05:26,220

understanding it together and so this is

1548

01:05:30,309 --> 01:05:27,810

a poster that we produced in the office

1549

01:05:32,799 --> 01:05:30,319

of public outreach where we work

1550

01:05:36,459 --> 01:05:32,809

through it to try and help express the

1551

01:05:38,079 --> 01:05:36,469

idea that over the last century we have

1552

01:05:39,819 --> 01:05:38,089

gone from just visible light

1553

01:05:42,339 --> 01:05:39,829

observations with the normal telescopes

1554

01:05:44,499 --> 01:05:42,349

that you think about adding in radio and

1555

01:05:46,539 --> 01:05:44,509

infrared and ultraviolet and cross the

1556

01:05:50,499 --> 01:05:46,549

entire electromagnetic spectrum

1557

01:05:53,439 --> 01:05:50,509

so astronomy has grown up to explore the

1558

01:05:55,630 --> 01:05:53,449

entire spectrum and there truly is more

1559

01:06:09,460 --> 01:05:55,640

to the universe than meets the eye

1560

01:06:16,340 --> 01:06:12,800

so I filled with all sorts of things all

1561

01:06:19,070 --> 01:06:16,350

around happiness on happy Russian music

1562

01:06:22,160 --> 01:06:19,080

yes nice never thought this question

1563

01:06:25,430 --> 01:06:22,170

until I see this presentation for the

1564

01:06:28,000 --> 01:06:25,440

visible spectrum it's pretty obvious but

1565

01:06:30,680 --> 01:06:28,010

for all these other named spectrums are

1566

01:06:34,100 --> 01:06:30,690

there scientific properties that define

1567

01:06:36,800 --> 01:06:34,110

the edges for did Steve discover x-rays

1568

01:06:48,200 --> 01:06:36,810

I'm playing this set of spectrum for

1569

01:06:50,810 --> 01:06:48,210

x-rays and that's it I would say that

1570

01:06:53,780 --> 01:06:50,820

they're more defined by the detectors

1571

01:06:55,730 --> 01:06:53,790

and they would be by the way okay so a

1572

01:06:57,500 --> 01:06:55,740

detector that can detect you know

1573

01:07:00,020 --> 01:06:57,510

wavelengths from here to here well that

1574

01:07:03,470 --> 01:07:00,030

would define a region right so if x-rays

1575

01:07:10,790 --> 01:07:03,480

you you have a detector that can detect

1576

01:07:12,740 --> 01:07:10,800

the x-rays you can see we have

1577

01:07:15,140 --> 01:07:12,750

near-infrared min infrared and far

1578

01:07:16,550 --> 01:07:15,150

infrared we use slightly different type

1579

01:07:18,650 --> 01:07:16,560

of detectors for each one of those

1580

01:07:20,030 --> 01:07:18,660

regions okay we talked about millimeter

1581

01:07:22,310 --> 01:07:20,040

wave and microwave which are really the

1582

01:07:23,810 --> 01:07:22,320

same thing but you know there's

1583

01:07:26,030 --> 01:07:23,820

different ways that that you use to

1584

01:07:28,970 --> 01:07:26,040

detect them okay as you're working

1585

01:07:30,590 --> 01:07:28,980

through them yeah the visible light yet

1586

01:07:33,460 --> 01:07:30,600

it's defined by what the human eye can

1587

01:07:36,410 --> 01:07:33,470

see but the other ones they're more

1588

01:07:38,870 --> 01:07:36,420

analytic a types of the detectors that

1589

01:07:40,460 --> 01:07:38,880

kind of carved that out for that one

1590

01:07:41,120 --> 01:07:40,470

spectrum and then somebody gave it the

1591

01:07:45,680 --> 01:07:41,130

name x-rays

1592

01:07:46,970 --> 01:07:45,690

sure let's go back the names for them I

1593

01:07:50,270 --> 01:07:46,980

really don't know the history about

1594

01:07:52,590 --> 01:07:50,280

Holly got named for that but really you

1595

01:07:54,960 --> 01:07:52,600

know what you're gonna

1596

01:07:56,730 --> 01:07:54,970

that I truly believe it's the detectors

1597

01:08:00,270 --> 01:07:56,740

that sort of carved out the regions for

1598

01:08:02,400 --> 01:08:00,280

that yes you showed a slide of the black

1599

01:08:05,340 --> 01:08:02,410

hole and some radio waves emitting from

1600

01:08:11,220 --> 01:08:05,350

yeah black hole such a strong

1601
01:08:13,590 --> 01:08:11,230
gravitational pull the escapes okay so

1602
01:08:16,200 --> 01:08:13,600
what happening is it's not black holes

1603
01:08:17,940 --> 01:08:16,210
in it it's the material around the

1604
01:08:19,080 --> 01:08:17,950
supermassive black hole that's this

1605
01:08:20,820 --> 01:08:19,090
you've got this disk of material

1606
01:08:21,300 --> 01:08:20,830
spinning around the supermassive black

1607
01:08:22,650 --> 01:08:21,310
holes

1608
01:08:24,420 --> 01:08:22,660
you've got magnetic fields and they're

1609
01:08:26,610 --> 01:08:24,430
being spun up like this and you have

1610
01:08:29,370 --> 01:08:26,620
material being flung off those magnetic

1611
01:08:31,050 --> 01:08:29,380
fields okay so it's not it's not the

1612
01:08:32,880 --> 01:08:31,060
emission isn't coming from a black hole

1613
01:08:43,280 --> 01:08:32,890

itself it's coming from the region

1614

01:08:48,450 --> 01:08:46,230

had a picture up there of collection of

1615

01:08:52,320 --> 01:08:48,460

galaxies and then you did a picture of

1616

01:08:55,320 --> 01:08:52,330

it in x-rays and it was a red block yes

1617

01:08:58,140 --> 01:08:55,330

you use the term hundreds of thousands

1618

01:09:03,720 --> 01:08:58,150

degrees for all this gas yes quite a

1619

01:09:07,170 --> 01:09:03,730

five the gas is at very low density okay

1620

01:09:09,990 --> 01:09:07,180

but the temperature is basically

1621

01:09:12,120 --> 01:09:10,000

measurement of its motion in that okay

1622

01:09:13,800 --> 01:09:12,130

so if we were a hundred thousand degrees

1623

01:09:15,840 --> 01:09:13,810

that the density of earth it would be

1624

01:09:17,610 --> 01:09:15,850

really really hot right but really

1625

01:09:20,880 --> 01:09:17,620

really low density you're just measuring

1626

01:09:23,070 --> 01:09:20,890

what the temperature of a gas is a

1627

01:09:24,990 --> 01:09:23,080

statistical measure of how fast on

1628

01:09:27,270 --> 01:09:25,000

average the molecules are moving so you

1629

01:09:30,180 --> 01:09:27,280

can have now one particle per cubic

1630

01:09:32,610 --> 01:09:30,190

centimeter or one particle per cubic

1631

01:09:34,980 --> 01:09:32,620

mile and they're moving at the same

1632

01:09:37,770 --> 01:09:34,990

speed they have the same temperature but

1633

01:09:39,210 --> 01:09:37,780

the the the way you and I would

1634

01:09:41,450 --> 01:09:39,220

experience temperature would be totally

1635

01:09:46,110 --> 01:09:41,460

different for those okay thank you okay

1636

01:09:48,840 --> 01:09:46,120

yes the gamma bursts from long ago and

1637

01:09:49,269 --> 01:09:48,850

far away if they're obscene a billion

1638

01:09:51,640 --> 01:09:49,279

light years

1639

01:09:55,720 --> 01:09:51,650

away they were happened a billion years

1640

01:10:04,200 --> 01:09:55,730

ago every stop so we ever see the in

1641

01:10:09,430 --> 01:10:07,810

the gamma ray person I know are you know

1642

01:10:11,379 --> 01:10:09,440

hundreds of millions to billions of

1643

01:10:14,819 --> 01:10:11,389

light years away I'm not an expert on

1644

01:10:20,350 --> 01:10:14,829

that but I don't know of any that are

1645

01:10:25,750 --> 01:10:20,360

that nearby okay that were cool yeah I

1646

01:10:30,609 --> 01:10:25,760

would say in infrared with the center

1647

01:10:32,890 --> 01:10:30,619

thing pretty much like red what sound

1648

01:10:37,450 --> 01:10:32,900

like what color is that brighter or

1649

01:10:40,600 --> 01:10:37,460

dimmer okay so in the mixer of view of

1650

01:10:44,470 --> 01:10:40,610

the whole galaxy alright so these blue

1651
01:10:45,250 --> 01:10:44,480
here is actually going to be hotter in

1652
01:10:47,500 --> 01:10:45,260
the infrared

1653
01:10:49,450 --> 01:10:47,510
okay a lot of times what they will do is

1654
01:10:52,000 --> 01:10:49,460
for the infrared which doesn't have any

1655
01:10:54,790 --> 01:10:52,010
colors right so they'll take the lower

1656
01:10:57,339 --> 01:10:54,800
energy and bread and map it to red and

1657
01:11:00,040 --> 01:10:57,349
the higher energy map it to blue so just

1658
01:11:01,689 --> 01:11:00,050
sort of corresponding to and so these

1659
01:11:04,060 --> 01:11:01,699
are actually this is the satellite

1660
01:11:19,859 --> 01:11:04,070
galaxy okay and what you're seeing there

1661
01:11:23,620 --> 01:11:19,869
are the stars from this team okay

1662
01:11:28,419 --> 01:11:23,630
yes right there Oh seems like James Webb

1663
01:11:31,620 --> 01:11:28,429

is infrared Jessica why why is that so

1664

01:11:36,729 --> 01:11:31,630

important now that wavelength okay so

1665

01:11:38,890 --> 01:11:36,739

look at this our main look into see of

1666

01:11:40,569 --> 01:11:38,900

the formation of stars and planets okay

1667

01:11:42,729 --> 01:11:40,579

because you'll be looking through the

1668

01:11:44,799 --> 01:11:42,739

dense gas the public for example can't

1669

01:11:46,990 --> 01:11:44,809

look through the other thing that why

1670

01:11:48,580 --> 01:11:47,000

infrared is really important is to look

1671

01:11:51,850 --> 01:11:48,590

at this very distant regions of the

1672

01:11:53,919 --> 01:11:51,860

universe because as the universe expands

1673

01:11:55,779 --> 01:11:53,929

light waves the traveling across the

1674

01:11:57,910 --> 01:11:55,789

universe gets stretched along with the

1675

01:12:00,129 --> 01:11:57,920

expansion of the universe so light that

1676

01:12:00,850 --> 01:12:00,139

started out in visible light gets

1677

01:12:02,650 --> 01:12:00,860

trapped

1678

01:12:08,560 --> 01:12:02,660

it becomes infrared by the time we

1679

01:12:11,290 --> 01:12:08,570

observe it okay no okay this is the

1680

01:12:12,760 --> 01:12:11,300

expansion of light especially like the

1681

01:12:16,540 --> 01:12:12,770

stretching of light due to the expansion

1682

01:12:19,810 --> 01:12:16,550

of the universe all right and so observe

1683

01:12:22,270 --> 01:12:19,820

the universe in Bermondsey all radiation

1684

01:12:25,420 --> 01:12:22,280

from various universe that light has

1685

01:12:28,780 --> 01:12:25,430

been stretched now to the infrared so we

1686

01:12:31,660 --> 01:12:28,790

have you see there are some things

1687

01:12:33,430 --> 01:12:31,670

Hubble can observe simply because their

1688

01:12:35,560 --> 01:12:33,440

light has been stretched beyond Hubble's

1689

01:12:39,150 --> 01:12:35,570

observing wavelengths that's another

1690

01:12:42,400 --> 01:12:39,160

reason why it will be so important

1691

01:12:45,160 --> 01:12:42,410

hey I got a question if you're a way way

1692

01:13:24,390 --> 01:12:45,170

out of space and look back at our galaxy

1693

01:13:32,650 --> 01:13:27,550

which only shines like like have a

1694

01:13:41,530 --> 01:13:32,660

little bit of vision but mostly one see

1695

01:13:44,080 --> 01:13:41,540

that we see the light really far away in

1696

01:13:46,000 --> 01:13:44,090

the cosmological expansion stretches

1697

01:13:48,630 --> 01:13:46,010

that with those wavelengths then they

1698

01:13:52,630 --> 01:13:48,640

would go towards the infrared right okay

1699

01:13:55,240 --> 01:13:52,640

so our our solar system doesn't have a

1700

01:13:56,620 --> 01:13:55,250

lot of dust and gas in it like the HL

1701

01:13:59,200 --> 01:13:56,630

Tauri system that i showed you from that

1702

01:14:01,510 --> 01:13:59,210

ama observation that's a pot system

1703

01:14:02,210 --> 01:14:01,520

still in formation there's still lots of

1704

01:14:04,250 --> 01:14:02,220

dusting

1705

01:14:06,500 --> 01:14:04,260

and colds and stuff floating around in

1706

01:14:10,100 --> 01:14:06,510

that system so you that's why I'm using

1707

01:14:11,990 --> 01:14:10,110

the millimeter already better but since

1708

01:14:14,180 --> 01:14:12,000

ours is a system that's ultimately

1709

01:14:18,110 --> 01:14:14,190

devoid of that stuff you'd want to use

1710

01:14:19,730 --> 01:14:18,120

visible or infrared okay great

1711

01:14:23,060 --> 01:14:19,740

most of what you've been talking about

1712

01:14:24,590 --> 01:14:23,070

our objects are emitting light at these

1713

01:14:26,840 --> 01:14:24,600

various wavelengths man now what about

1714

01:14:29,770 --> 01:14:26,850

observing objects that are reflecting

1715

01:14:35,630 --> 01:14:29,780

light at these various wavelengths and

1716

01:14:40,700 --> 01:14:35,640

does observing at some of these shorter

1717

01:14:47,300 --> 01:14:40,710

wavelengths give you more detail than at

1718

01:14:49,400 --> 01:14:47,310

the longer wavelengths Wow let's see so

1719

01:14:51,530 --> 01:14:49,410

first of all there's only there are only

1720

01:14:54,050 --> 01:14:51,540

a few cases where we observe reflective

1721

01:14:56,450 --> 01:14:54,060

light and get a lot of get a lot of it

1722

01:15:02,060 --> 01:14:56,460

okay I showed you the reflection nebula

1723

01:15:04,490 --> 01:15:02,070

around the Pleiades etc around around

1724

01:15:06,110 --> 01:15:04,500

supermassive black holes where there's a

1725

01:15:08,210 --> 01:15:06,120

light that when there's energy being

1726

01:15:11,000 --> 01:15:08,220

emitted from those that hits a disc of

1727

01:15:12,770 --> 01:15:11,010

material that this ends up reradiating

1728

01:15:16,460 --> 01:15:12,780

that can absorb it and reradiates so

1729

01:15:18,740 --> 01:15:16,470

that can also be reflected in there but

1730

01:15:20,270 --> 01:15:18,750

not a tub not a ton of cases where

1731

01:15:22,970 --> 01:15:20,280

there's a lot of reflected light to it

1732

01:15:25,640 --> 01:15:22,980

to observe do you see my point that it

1733

01:15:28,280 --> 01:15:25,650

with the shorter wavelengths you would

1734

01:15:31,100 --> 01:15:28,290

be able to see more detail than with

1735

01:15:32,870 --> 01:15:31,110

longer wavelengths is that so this is

1736

01:15:34,370 --> 01:15:32,880

not a thing to recognize especially

1737

01:15:36,230 --> 01:15:34,380

mature in terms of the James Webb Space

1738

01:15:38,600 --> 01:15:36,240

Telescope the James Webb Space Telescope

1739

01:15:40,490 --> 01:15:38,610

being six and a half meters Hubble is

1740

01:15:44,240 --> 01:15:40,500

only two Knack meters but the resolution

1741

01:15:45,710 --> 01:15:44,250

is roughly the same because this is jus

1742

01:15:47,210 --> 01:15:45,720

T's that infrared wavelength which the

1743

01:15:49,790 --> 01:15:47,220

longer wavelength so the shorter

1744

01:15:52,160 --> 01:15:49,800

wavelengths do give you higher

1745

01:15:54,200 --> 01:15:52,170

resolution on things like that however

1746

01:15:56,450 --> 01:15:54,210

the fact that we can get a radio

1747

01:15:58,910 --> 01:15:56,460

telescope to stretch across miles and

1748

01:15:59,729 --> 01:15:58,920

miles and miles actually gives radio

1749

01:16:04,859 --> 01:15:59,739

some

1750

01:16:08,310 --> 01:16:04,869

the highest resolution alright versus

1751

01:16:12,180 --> 01:16:08,320

the size right that gives you your

1752

01:16:15,810 --> 01:16:12,190

resolution so if you have you know gamma

1753

01:16:17,549 --> 01:16:15,820

rays are hard to pinpoint etc it goes

1754

01:16:22,140 --> 01:16:17,559

they guess we get scattered if you're

1755

01:16:24,359 --> 01:16:22,150

observing him the the way we detect them

1756

01:16:26,669 --> 01:16:24,369

doesn't doesn't in point them exactly

1757

01:16:28,439 --> 01:16:26,679

right because we see that there's a

1758

01:16:29,850 --> 01:16:28,449

shower coming up coming off of them it

1759

01:16:32,370 --> 01:16:29,860

doesn't give you that that hyperfine

1760

01:16:37,350 --> 01:16:32,380

resolution the way a mirror observation

1761

01:16:39,569 --> 01:16:37,360

would okay so but radios by having these

1762

01:16:41,220 --> 01:16:39,579

very very large arrays alright which

1763

01:16:43,080 --> 01:16:41,230

simulated a telescope having a car

1764

01:16:44,549 --> 01:16:43,090

through that big compared to the

1765

01:16:47,489 --> 01:16:44,559

wavelength can actually give you

1766

01:16:48,839 --> 01:16:47,499

extremely high resolution imagery so

1767

01:16:50,609 --> 01:16:48,849

when we say hull is the highest

1768

01:16:52,379 --> 01:16:50,619

resolution right it's the highest

1769

01:16:53,970 --> 01:16:52,389

resolution visible light telescope out

1770

01:16:57,029 --> 01:16:53,980

there that's not the highest resolution

1771

01:16:58,709 --> 01:16:57,039

telescope at all up there you can see

1772

01:17:02,580 --> 01:16:58,719

that the Alma array has much higher

1773

01:17:05,279 --> 01:17:02,590

resolution do you get more information

1774

01:17:08,129 --> 01:17:05,289

from the VLA with the fact that it's

1775

01:17:33,270 --> 01:17:08,139

moving around as the Earth rotates and

1776

01:17:34,890 --> 01:17:33,280

as the earth moves around the Sun so the

1777

01:17:39,089 --> 01:17:34,900

wavefront can be correlated between the

1778

01:17:43,709 --> 01:17:39,099

tool alright any other questions yes

1779

01:17:48,540 --> 01:17:43,719

down front there good question visible

1780

01:17:51,359 --> 01:17:48,550

life yes is it possible to utilize for a

1781

01:17:52,890 --> 01:17:51,369

very very distant objects across the

1782

01:17:57,569 --> 01:17:52,900

Google as a website for the sake of

1783

01:18:00,359 --> 01:17:57,579

argument different frequencies we use

1784

01:18:02,640 --> 01:18:00,369

some expect spectroscopy is not limited

1785

01:18:05,129 --> 01:18:02,650

to just visible light okay we can take

1786

01:18:06,729 --> 01:18:05,139

infrared spectra we can take ultraviolet

1787

01:18:10,270 --> 01:18:06,739

spectrum

1788

01:18:13,720 --> 01:18:10,280

we're looking for the when we're looking

1789

01:18:16,600 --> 01:18:13,730

at the the atmospheres of extrasolar

1790

01:18:19,990 --> 01:18:16,610

planets right we want to take a spectra

1791

01:18:21,850 --> 01:18:20,000

of in the infrared to try and identify

1792

01:18:23,979 --> 01:18:21,860

the molecules in the atmosphere and

1793

01:18:25,390 --> 01:18:23,989

control a planet so to see the details

1794

01:18:28,300 --> 01:18:25,400

of the juicy details that we want

1795

01:18:30,580 --> 01:18:28,310

they're actually in the infrared okay so

1796

01:18:35,290 --> 01:18:30,590

we can do spectra across across the

1797

01:18:37,660 --> 01:18:35,300

spectrum and their various things a lot

1798

01:18:39,550 --> 01:18:37,670

of them in some of the weight bands it's

1799

01:18:41,830 --> 01:18:39,560

just unity you take a detection here

1800

01:18:44,080 --> 01:18:41,840

adaptation here detection here you sort

1801
01:18:45,459 --> 01:18:44,090
of synthesize a spectrum through it as

1802
01:18:46,800 --> 01:18:45,469
opposed to taking many many many

1803
01:18:51,970 --> 01:18:46,810
wavelengths as we do with visible light

1804
01:18:53,950 --> 01:18:51,980
okay all right we know that visible

1805
01:18:58,120 --> 01:18:53,960
light is affected by gravity

1806
01:19:01,209 --> 01:18:58,130
I assume all energies now would one

1807
01:19:03,700 --> 01:19:01,219
movie star there this one is no

1808
01:19:12,070 --> 01:19:03,710
different from the red light on my life

1809
01:19:14,560 --> 01:19:12,080
though Hey so look the liquid one one

1810
01:19:16,330 --> 01:19:14,570
end of the spectrum be heavier than the

1811
01:19:20,470 --> 01:19:16,340
other in other word he would be more

1812
01:19:21,729 --> 01:19:20,480
bent worthless if it affects the effect

1813
01:19:23,380 --> 01:19:21,739

that you're talking about is dependent

1814

01:19:27,760 --> 01:19:23,390

upon energy yes

1815

01:19:30,130 --> 01:19:27,770

all right so then life high energy

1816

01:19:32,050 --> 01:19:30,140

wavelengths are refracted more than

1817

01:19:34,390 --> 01:19:32,060

lower anyway like when you create a

1818

01:19:37,990 --> 01:19:34,400

spectrum with a prism all right the red

1819

01:19:50,800 --> 01:19:38,000

light is diffracted less than the violet

1820

01:19:53,890 --> 01:19:50,810

light visible light you have the

1821

01:19:56,560 --> 01:19:53,900

gravitational lenses those like the blue

1822

01:19:59,770 --> 01:19:56,570

works you get images like that in the

1823

01:20:00,820 --> 01:19:59,780

other wavelengths so I'm not I said the

1824

01:20:03,070 --> 01:20:00,830

question is doing it gravitational

1825

01:20:05,229 --> 01:20:03,080

lensing in other wavelengths the answer

1826
01:20:06,850 --> 01:20:05,239
would be yes we should theoretically

1827
01:20:10,660 --> 01:20:06,860
there's no reason we shouldn't get

1828
01:20:13,930 --> 01:20:10,670
gravitational I do not know that I've

1829
01:20:14,830 --> 01:20:13,940
seen you sure because you need it we

1830
01:20:20,379 --> 01:20:14,840
need really high

1831
01:20:22,060 --> 01:20:20,389
I mean Hubble's amazing invisible I like

1832
01:20:24,040 --> 01:20:22,070
left okay

1833
01:20:27,430 --> 01:20:24,050
and it's gonna get it's gonna be

1834
01:20:29,879 --> 01:20:27,440
affected by the gravity even if it's a

1835
01:20:31,600 --> 01:20:29,889
different wavelength yes you should get

1836
01:20:33,550 --> 01:20:31,610
gravitational lensing I know we get

1837
01:20:35,410 --> 01:20:33,560
gravitational lensing of infrared okay

1838
01:20:36,760 --> 01:20:35,420

even Hubble's observations the inbred

1839

01:20:39,250 --> 01:20:36,770

sees gravitational lensing in the

1840

01:20:40,990 --> 01:20:39,260

infrared but I can't say I've seen it in

1841

01:20:43,240 --> 01:20:41,000

other wavelengths beyond visible and

1842

01:20:53,439 --> 01:20:43,250

infrared it's late a wave or a particle

1843

01:20:55,479 --> 01:20:53,449

yeah no not just an observation

1844

01:21:10,689 --> 01:20:55,489

thank you for more accurately locating

1845

01:21:15,160 --> 01:21:10,699

the EPL in columbia as opposed to yeah

1846

01:21:39,029 --> 01:21:15,170

because the gerrymandered zip code it's

1847

01:21:42,790 --> 01:21:40,989

if you would like to go to the

1848

01:21:45,279 --> 01:21:42,800

observatory we have our observatory

1849

01:21:47,290 --> 01:21:45,289

person here yes over here this gentleman

1850

01:21:49,379 --> 01:21:47,300

in the brown shirt if you would like to

1851

01:21:51,729 --> 01:21:49,389

go to Maryland Space Grant Observatory

1852

01:21:53,109 --> 01:21:51,739

come down here and talk to him he'll

1853

01:22:15,580 --> 01:21:53,119

take you across the street for the

1854

01:22:26,020 --> 01:22:23,200

see if gravitational waves so what we've

1855

01:22:28,959 --> 01:22:26,030

got such good observations of it we can

1856

01:22:30,910 --> 01:22:28,969

now look for tiny variations in way and