
AbSciCon
2017
MESA, ARIZONA

1
00:00:12,250 --> 00:00:06,150
you

2
00:00:17,650 --> 00:00:14,190
[Music]

3
00:00:18,850 --> 00:00:17,660
so as I said I am here to open the

4
00:00:22,359 --> 00:00:18,860
plenary session this morning

5
00:00:24,010 --> 00:00:22,369
and I'm going to leave you guys with

6
00:00:24,999 --> 00:00:24,020
leave you guys off with the idea that

7
00:00:26,410 --> 00:00:25,009
what we're going to hear about today is

8
00:00:28,900 --> 00:00:26,420
no less than a turning point in the

9
00:00:33,220 --> 00:00:28,910
history of the universe or maybe at

10
00:00:35,680 --> 00:00:33,230
least the earth and we'll start with

11
00:00:39,040 --> 00:00:35,690
some of the major turning points I'll

12
00:00:43,060 --> 00:00:39,050
give you the origin of life I'm going to

13
00:00:46,240 --> 00:00:43,070

throw plate tectonics into that idea but

14
00:00:48,040 --> 00:00:46,250
right up there in the top three was the

15
00:00:50,619 --> 00:00:48,050
ability for life to harvest light from

16
00:00:53,200 --> 00:00:50,629
the Sun and early stages that would have

17
00:00:56,770 --> 00:00:53,210
been like I an oxygen 'ok photosynthesis

18
00:00:59,380 --> 00:00:56,780
and followed pretty closely by that the

19
00:01:02,979 --> 00:00:59,390
great oxidation event and the evolution

20
00:01:06,100 --> 00:01:02,989
of oxygenic photosynthesis so these are

21
00:01:10,690 --> 00:01:06,110
some of these are like the big four I

22
00:01:12,370 --> 00:01:10,700
would give you for the earlier so I'm

23
00:01:14,770 --> 00:01:12,380
very pleased to be able to introduce Bob

24
00:01:16,120 --> 00:01:14,780
Blankenship he's a Lucille Marquis

25
00:01:17,920 --> 00:01:16,130
distinguished professor of Arts and

26
00:01:19,600 --> 00:01:17,930
Sciences and the department's of biology

27
00:01:23,469 --> 00:01:19,610
and chemistry at Washington University

28
00:01:24,670 --> 00:01:23,479
in st. Louis I had the great pleasure of

29
00:01:26,800 --> 00:01:24,680
listening to Bob talk about the

30
00:01:29,440 --> 00:01:26,810
chemistry of photosynthesis a long time

31
00:01:31,600 --> 00:01:29,450
ago even before I got to ASU and it was

32
00:01:33,039 --> 00:01:31,610
really kind of a profound experience for

33
00:01:36,130 --> 00:01:33,049
me I had never really thought about it

34
00:01:37,630 --> 00:01:36,140
from a chemistry standpoint Bob's been

35
00:01:39,999 --> 00:01:37,640
studying photosynthesis for his entire

36
00:01:43,420 --> 00:01:40,009
career and he has a long-standing

37
00:01:45,640 --> 00:01:43,430
interest in addition to the gory details

38
00:01:47,440 --> 00:01:45,650

of how photosynthesis works in the

39
00:01:50,230 --> 00:01:47,450
origin and early evolution of

40
00:01:51,640 --> 00:01:50,240
photosynthesis and so today he's going

41
00:01:53,590 --> 00:01:51,650
to talk to us about the evolutionary

42
00:01:56,020 --> 00:01:53,600
transition from oxygenic to an toxigenic

43
00:01:57,120 --> 00:01:56,030
photosynthesis and I'd like you all to

44
00:02:07,490 --> 00:01:57,130
welcome Bob Blankenship

45
00:02:16,050 --> 00:02:13,800
Thank You Hillary as you can see it's

46
00:02:18,720 --> 00:02:16,060
the transition from anoxygenic to

47
00:02:24,720 --> 00:02:18,730
oxygenic we do think that an oxy genic

48
00:02:27,210 --> 00:02:24,730
came first so anyway I'd like to thank

49
00:02:29,490 --> 00:02:27,220
Hillary for the invitation and the

50
00:02:31,050 --> 00:02:29,500
organizing committee for the for the

51
00:02:34,320 --> 00:02:31,060
invitation to come and talk with you

52
00:02:38,280 --> 00:02:34,330
today it's I always enjoy coming to

53
00:02:40,310 --> 00:02:38,290
these apps icon meetings and interacting

54
00:02:44,070 --> 00:02:40,320
they're always very mind expanding

55
00:02:47,100 --> 00:02:44,080
events and it's it's really a lot of fun

56
00:02:49,740 --> 00:02:47,110
and so I'm pleased today to sort of give

57
00:02:53,700 --> 00:02:49,750
you an overview of what we know and what

58
00:02:55,590 --> 00:02:53,710
we don't know about the origin and early

59
00:02:58,740 --> 00:02:55,600
development of photosynthesis and I'll

60
00:03:01,350 --> 00:02:58,750
focus in on that transition between an

61
00:03:03,300 --> 00:03:01,360
toxigenic and oxygenic photosynthesis

62
00:03:06,660 --> 00:03:03,310
which as Hillary said was one of the

63
00:03:11,670 --> 00:03:06,670

great turning points in the history of

64
00:03:17,190 --> 00:03:11,680
life on Earth now I like this this

65
00:03:20,310 --> 00:03:17,200
diagram and this is was drawn by Michael

66
00:03:22,560 --> 00:03:20,320
Haegele Berg from ASU some years ago and

67
00:03:24,720 --> 00:03:22,570
it's I think it's a nice metaphor for

68
00:03:27,120 --> 00:03:24,730
the process of photosynthesis and I like

69
00:03:29,610 --> 00:03:27,130
to start talks out with this because we

70
00:03:31,979 --> 00:03:29,620
have a machine a device that takes the

71
00:03:34,830 --> 00:03:31,989
sun's energy and through some sort of a

72
00:03:39,590 --> 00:03:34,840
mechanism converts it into a more usable

73
00:03:42,330 --> 00:03:39,600
form and in the in the case of

74
00:03:45,330 --> 00:03:42,340
photosynthesis we're absorbing sunlight

75
00:03:49,500 --> 00:03:45,340
and we're doing chemical redox chemistry

76
00:03:54,300 --> 00:03:49,510
to store that energy and ultimately use

77
00:03:56,910 --> 00:03:54,310
it to power life now in terms of what

78
00:03:58,650 --> 00:03:56,920
organisms can do photosynthesis I think

79
00:04:02,240 --> 00:03:58,660
that's a useful place to sort of start

80
00:04:05,610 --> 00:04:02,250
our discussion we look at this

81
00:04:08,190 --> 00:04:05,620
16's Tree of Life I think this is one

82
00:04:10,380 --> 00:04:08,200
that norm pace did some years ago and we

83
00:04:12,320 --> 00:04:10,390
color in all those taxa that are capable

84
00:04:14,720 --> 00:04:12,330
of some form

85
00:04:16,640 --> 00:04:14,730
of chlorophyll based photosynthesis I'll

86
00:04:19,009 --> 00:04:16,650
limit my discussion today to chlorophyll

87
00:04:22,460 --> 00:04:19,019
based photosynthesis will see that we

88
00:04:24,500 --> 00:04:22,470

find a lot of different groups that can

89
00:04:26,810 --> 00:04:24,510
do photosynthesis in the bacterial

90
00:04:29,600 --> 00:04:26,820
domain and several of course in the

91
00:04:34,640 --> 00:04:29,610
eukaryotic eukaryote domain

92
00:04:38,060 --> 00:04:34,650
plants and so on surprisingly perhaps we

93
00:04:42,620 --> 00:04:38,070
find nothing in the archaeal genome that

94
00:04:48,770 --> 00:04:42,630
photosynthesis has ever existed in the

95
00:04:51,200 --> 00:04:48,780
ark he'll do mean and if we look at the

96
00:04:54,470 --> 00:04:51,210
process of photosynthesis that goes on

97
00:04:59,210 --> 00:04:54,480
in eukaryotic organisms it's clear that

98
00:05:04,670 --> 00:04:59,220
that process has has taken place because

99
00:05:06,020 --> 00:05:04,680
of a large-scale horizontal gene

100
00:05:08,530 --> 00:05:06,030
transfer if you will called

101
00:05:12,140 --> 00:05:08,540
endosymbiosis in which a cyanobacterium

102
00:05:15,110 --> 00:05:12,150
was incorporated into a proto eukaryotic

103
00:05:17,990 --> 00:05:15,120
cell and ultimately became the

104
00:05:19,700 --> 00:05:18,000
eukaryotic chloroplast and the the

105
00:05:21,970 --> 00:05:19,710
mechanism of photosynthesis in

106
00:05:25,210 --> 00:05:21,980
eukaryotes is actually surprisingly

107
00:05:27,590 --> 00:05:25,220
similar to how it works in cyanobacteria

108
00:05:28,700 --> 00:05:27,600
so really if you want to understand the

109
00:05:30,500 --> 00:05:28,710
sort of early development of

110
00:05:33,950 --> 00:05:30,510
photosynthesis we really don't need to

111
00:05:37,520 --> 00:05:33,960
go any farther than the cyanobacteria so

112
00:05:40,580 --> 00:05:37,530
the bacteria are the place where we look

113
00:05:43,220 --> 00:05:40,590

to to try to understand the origin and

114
00:05:48,140 --> 00:05:43,230
the early development of photosynthesis

115
00:05:50,600 --> 00:05:48,150
and the we can sort of arbitrary well

116
00:05:53,659 --> 00:05:50,610
not arbitrarily but logically divide the

117
00:05:55,670 --> 00:05:53,669
different groups of phototrophs into the

118
00:05:59,060 --> 00:05:55,680
so called oxygenic which means they

119
00:06:01,400 --> 00:05:59,070
produce oxygen and the only group of

120
00:06:07,100 --> 00:06:01,410
oxygen 'ok Photosynth phototrophs

121
00:06:09,140 --> 00:06:07,110
are the cyanobacteria in the bacterial

122
00:06:10,550 --> 00:06:09,150
domain or an toxigenic and there are

123
00:06:12,830 --> 00:06:10,560
several different groups all these

124
00:06:17,900 --> 00:06:12,840
groups that have either a green or a

125
00:06:20,300 --> 00:06:17,910
purple oval on them are are an toxigenic

126
00:06:24,720 --> 00:06:20,310
and the one that has a bicolor oval here

127
00:06:30,550 --> 00:06:28,330
so just a couple of slides on sort of

128
00:06:34,180 --> 00:06:30,560
the basics of how photosynthesis works

129
00:06:38,200 --> 00:06:34,190
as a as an energy storage process and

130
00:06:39,490 --> 00:06:38,210
there's a universal organ organ izing

131
00:06:42,670 --> 00:06:39,500
principle that we find in all

132
00:06:45,630 --> 00:06:42,680
photosynthetic organisms that most of

133
00:06:47,440 --> 00:06:45,640
the pigments and these green circles are

134
00:06:49,240 --> 00:06:47,450
representative of pigments whether

135
00:06:51,400 --> 00:06:49,250
they're chlorophylls or carotenoids or

136
00:06:53,440 --> 00:06:51,410
villains or other types of pigments that

137
00:06:56,500 --> 00:06:53,450
drive photosynthesis

138
00:06:59,380 --> 00:06:56,510

most of those serve as an energy light

139
00:07:01,480 --> 00:06:59,390
harvesting antenna and carry out energy

140
00:07:04,210 --> 00:07:01,490
transfer so a photon will be absorbed

141
00:07:06,220 --> 00:07:04,220
cause an electronic transition in a

142
00:07:09,160 --> 00:07:06,230
molecule and one of the Piglet molecules

143
00:07:13,000 --> 00:07:09,170
and then that energy will will migrate

144
00:07:16,300 --> 00:07:13,010
through a pigment array and eventually

145
00:07:17,560 --> 00:07:16,310
be delivered to a protein complex in the

146
00:07:21,400 --> 00:07:17,570
membrane that's called the reaction

147
00:07:24,460 --> 00:07:21,410
center and that drives electron flow so

148
00:07:27,700 --> 00:07:24,470
that's the sort of schematic picture of

149
00:07:29,350 --> 00:07:27,710
how photosynthesis is organized really

150
00:07:34,840 --> 00:07:29,360
an all known chlorophyll based

151
00:07:36,880 --> 00:07:34,850
phototrophs and so all photosynthetic

152
00:07:39,850 --> 00:07:36,890
organisms have a light gathering antenna

153
00:07:42,340 --> 00:07:39,860
system and an electron transferring

154
00:07:45,340 --> 00:07:42,350
reaction Center you can sort of think of

155
00:07:47,230 --> 00:07:45,350
this as analogous to a satellite dish

156
00:07:49,450 --> 00:07:47,240
where the antenna is the dish and the

157
00:07:54,400 --> 00:07:49,460
reaction Center is the receiver which

158
00:07:56,740 --> 00:07:54,410
transduces is the signal if we look in

159
00:07:58,540 --> 00:07:56,750
more detail at these antenna systems I'm

160
00:08:00,490 --> 00:07:58,550
not going to dwell too much on antennas

161
00:08:05,100 --> 00:08:00,500
although we actually spend most of our

162
00:08:07,570 --> 00:08:05,110
time in my lab working out the sort of

163
00:08:10,000 --> 00:08:07,580

details of how these antennas are put

164
00:08:11,710 --> 00:08:10,010
together and how they work you see this

165
00:08:16,300 --> 00:08:11,720
is just a little rogues gallery of

166
00:08:20,410 --> 00:08:16,310
different types of antenna complexes and

167
00:08:24,310 --> 00:08:20,420
they're remarkably diverse they clearly

168
00:08:27,520 --> 00:08:24,320
have multiple different structural

169
00:08:30,070 --> 00:08:27,530
motifs in terms of the types of proteins

170
00:08:32,340 --> 00:08:30,080
usually the pigments are are bound to

171
00:08:35,409 --> 00:08:32,350
two proteins in very specific

172
00:08:43,420 --> 00:08:40,659
and and the the antenna complexes are

173
00:08:48,389 --> 00:08:43,430
physically nearby to the reaction center

174
00:08:50,949 --> 00:08:48,399
complexes some of them are actually

175
00:08:54,160 --> 00:08:50,959
surround the reaction center which is in

176
00:08:56,769 --> 00:08:54,170
the in the core in the in the hole in

177
00:08:59,949 --> 00:08:56,779
the middle there and so their variety of

178
00:09:07,000 --> 00:08:59,959
direct of ways that this is accomplished

179
00:09:09,730 --> 00:09:07,010
and the the overall picture that one

180
00:09:12,670 --> 00:09:09,740
comes away with from this is that these

181
00:09:15,460 --> 00:09:12,680
antenna complexes almost certainly have

182
00:09:17,980 --> 00:09:15,470
arisen through evolution on multiple

183
00:09:20,860 --> 00:09:17,990
occasions and they've solved a

184
00:09:22,750 --> 00:09:20,870
particular problem that an organism

185
00:09:24,400 --> 00:09:22,760
might have in terms of its photic

186
00:09:25,300 --> 00:09:24,410
environment whether it's deep in the

187
00:09:27,850 --> 00:09:25,310
water column

188
00:09:30,040 --> 00:09:27,860

whether it's underneath another layer of

189
00:09:33,009 --> 00:09:30,050
organisms that are shading out part of

190
00:09:36,280 --> 00:09:33,019
the solar spectrum whether it's in

191
00:09:39,370 --> 00:09:36,290
extremely dim light conditions such as

192
00:09:43,269 --> 00:09:39,380
this corazon that you find in the green

193
00:09:46,210 --> 00:09:43,279
sulfur bacteria which have incredibly

194
00:09:51,790 --> 00:09:46,220
strong light gathering light absorbing

195
00:09:58,120 --> 00:09:51,800
powers and so these things have evolved

196
00:10:00,389 --> 00:09:58,130
multiple times after the initial origin

197
00:10:02,829 --> 00:10:00,399
and evolution of photosynthesis so

198
00:10:04,449 --> 00:10:02,839
that's one sort of take-home message

199
00:10:08,139 --> 00:10:04,459
that the antennas have appeared on

200
00:10:10,329 --> 00:10:08,149
multiple occasions here's one just sort

201
00:10:13,000 --> 00:10:10,339
of schematic picture to kind of give you

202
00:10:18,160 --> 00:10:13,010
a flavor of how these antennas work this

203
00:10:21,850 --> 00:10:18,170
is a computational model that was built

204
00:10:26,410 --> 00:10:21,860
on a lot of biochemical information and

205
00:10:28,420 --> 00:10:26,420
it shows this green is a is one of the

206
00:10:30,069 --> 00:10:28,430
antenna complexes that was on that

207
00:10:32,319 --> 00:10:30,079
earlier slide and you can actually see

208
00:10:33,730 --> 00:10:32,329
the chlorophyll molecules there a photon

209
00:10:36,699 --> 00:10:33,740
comes in and there will be an energy

210
00:10:39,490 --> 00:10:36,709
transfer process energy will migrate and

211
00:10:41,050 --> 00:10:39,500
then to this red which is another type

212
00:10:43,870 --> 00:10:41,060
of antenna complex and then it will

213
00:10:45,250 --> 00:10:43,880

finally hop into the purple reaction

214
00:10:47,199 --> 00:10:45,260
center there and that's where the

215
00:10:48,370 --> 00:10:47,209
photochemistry that the electron

216
00:10:50,380 --> 00:10:48,380
transfer process

217
00:10:54,130 --> 00:10:50,390
place and there's a lot of interesting

218
00:10:55,870 --> 00:10:54,140
things that one can learn about the the

219
00:10:57,280 --> 00:10:55,880
structure of these complexes the

220
00:11:00,390 --> 00:10:57,290
mechanism of how the energy is

221
00:11:02,260 --> 00:11:00,400
transferred the kinetics of it

222
00:11:06,070 --> 00:11:02,270
pathways there's a lot of really

223
00:11:07,600 --> 00:11:06,080
interesting science that has been done

224
00:11:11,500 --> 00:11:07,610
and it continues to be done on these

225
00:11:15,430 --> 00:11:11,510
sorts of systems in contrast the

226
00:11:19,210 --> 00:11:15,440
reaction center complexes have a much

227
00:11:22,360 --> 00:11:19,220
more sort of conservative design element

228
00:11:25,870 --> 00:11:22,370
to them and if you fortunate enough to

229
00:11:28,330 --> 00:11:25,880
have high resolution x-ray structures of

230
00:11:29,950 --> 00:11:28,340
several different reaction center

231
00:11:33,310 --> 00:11:29,960
complexes from different kinds of

232
00:11:35,290 --> 00:11:33,320
organisms and they don't look so similar

233
00:11:37,150 --> 00:11:35,300
up here with all the proteins that extra

234
00:11:39,580 --> 00:11:37,160
subunits on them but if you strip away

235
00:11:41,950 --> 00:11:39,590
the protein and just put the cofactors

236
00:11:44,770 --> 00:11:41,960
in it and these cofactors are buried in

237
00:11:48,970 --> 00:11:44,780
these structures up above you can see

238
00:11:50,800 --> 00:11:48,980

there's a sort of a unified arrangement

239
00:11:53,830 --> 00:11:50,810
of the way these cofactors work there's

240
00:11:55,150 --> 00:11:53,840
a dimer of pigments that is down here at

241
00:12:00,040 --> 00:11:55,160
the bottom and that's sort of the

242
00:12:01,900 --> 00:12:00,050
initial place where the photochemistry

243
00:12:06,070 --> 00:12:01,910
starts an electron is transferred from

244
00:12:08,200 --> 00:12:06,080
one of these chlorophylls

245
00:12:10,630 --> 00:12:08,210
to a second chlorophyll and then often

246
00:12:12,460 --> 00:12:10,640
up a chain and depending on the type of

247
00:12:16,630 --> 00:12:12,470
reaction center there'll be a difference

248
00:12:19,600 --> 00:12:16,640
in the in the electron acceptor whether

249
00:12:23,890 --> 00:12:19,610
it's a quinone type system that you see

250
00:12:32,920 --> 00:12:23,900
in in photosystem two and in the purple

251
00:12:34,600 --> 00:12:32,930
bacterial reaction centers or a a iron

252
00:12:37,750 --> 00:12:34,610
sulfur centers that you see in

253
00:12:40,450 --> 00:12:37,760
photosystem one and the other type

254
00:12:42,460 --> 00:12:40,460
so-called type one reaction centers and

255
00:12:45,160 --> 00:12:42,470
we classify the reaction centers in

256
00:12:49,210 --> 00:12:45,170
terms of the type of acceptor they have

257
00:12:51,220 --> 00:12:49,220
the type ones the ones that have iron

258
00:12:53,140 --> 00:12:51,230
sulfur centers and the type twos are the

259
00:12:55,900 --> 00:12:53,150
ones that have these quinone acceptors

260
00:12:57,430 --> 00:12:55,910
and for a long time it was not clear

261
00:12:59,620 --> 00:12:57,440
whether or not there was any sort of

262
00:13:02,440 --> 00:12:59,630
deeper homology

263
00:13:04,750 --> 00:13:02,450

evolutionary unity between these

264
00:13:06,160 --> 00:13:04,760
reaction centers or whether it ended and

265
00:13:08,170 --> 00:13:06,170
there had been two independent

266
00:13:10,360 --> 00:13:08,180
inventions but as the structures of

267
00:13:15,880 --> 00:13:10,370
these things started to accumulate in

268
00:13:18,940 --> 00:13:15,890
the late 90s and and that it became

269
00:13:22,180 --> 00:13:18,950
clear that there was an underlying very

270
00:13:24,340 --> 00:13:22,190
deep structural homology amongst these

271
00:13:27,820 --> 00:13:24,350
things and you can see that this is now

272
00:13:30,160 --> 00:13:27,830
a what we call an energy kinetic diagram

273
00:13:33,330 --> 00:13:30,170
and you've probably all seen the famous

274
00:13:35,770 --> 00:13:33,340
Z scheme of photosynthesis that is

275
00:13:39,010 --> 00:13:35,780
applicable to cyanobacteria and other

276
00:13:41,710 --> 00:13:39,020
oxygenic organisms with photosystem 2

277
00:13:48,760 --> 00:13:41,720
which oxidizes water to molecular oxygen

278
00:13:52,330 --> 00:13:48,770
and reduces nad P and an inner complex

279
00:13:55,090 --> 00:13:52,340
electron transport chain and then the

280
00:13:58,690 --> 00:13:55,100
the various anoxygenic forms and the

281
00:14:01,180 --> 00:13:58,700
type to have a very similar structure to

282
00:14:03,700 --> 00:14:01,190
the photosystem ii and the type 1

283
00:14:07,410 --> 00:14:03,710
reaction centers from the an oxygen

284
00:14:11,830 --> 00:14:07,420
exhale a similar structure to the

285
00:14:15,940 --> 00:14:11,840
photosystem 1 and so it became clear

286
00:14:17,620 --> 00:14:15,950
that these sorts of structural

287
00:14:19,780 --> 00:14:17,630
similarities applied between the

288
00:14:22,900 --> 00:14:19,790

different classes and then if you'd

289
00:14:24,700 --> 00:14:22,910
really got down deep into the system it

290
00:14:26,620 --> 00:14:24,710
became clear and I'll come back to this

291
00:14:29,200 --> 00:14:26,630
a little bit later I guess I got a

292
00:14:31,480 --> 00:14:29,210
little ahead of myself and that all the

293
00:14:35,080 --> 00:14:31,490
reaction centers ultimately come from a

294
00:14:39,180 --> 00:14:35,090
common evolutionary origin and really

295
00:14:44,140 --> 00:14:39,190
only have only been invented one time

296
00:14:47,230 --> 00:14:44,150
during the course of evolution so this

297
00:14:50,020 --> 00:14:47,240
is a diagram which is obviously

298
00:14:54,960 --> 00:14:50,030
impossible to assimilate in a short look

299
00:14:57,460 --> 00:14:54,970
which details the various types of

300
00:15:01,480 --> 00:14:57,470
photosynthetic prokaryotes and there

301
00:15:06,460 --> 00:15:01,490
there are now seven different bacterial

302
00:15:08,440 --> 00:15:06,470
phyla that can do photosynthesis that's

303
00:15:12,170 --> 00:15:08,450
up from six just a couple of years ago

304
00:15:20,240 --> 00:15:16,870
that they have remarkably diverse set of

305
00:15:24,410 --> 00:15:20,250
cofactors or complexes that are involved

306
00:15:27,410 --> 00:15:24,420
in photosynthesis and this shows just

307
00:15:31,040 --> 00:15:27,420
sort of the the different possibilities

308
00:15:33,230 --> 00:15:31,050
that are there and you can think of them

309
00:15:34,940 --> 00:15:33,240
as different modules for example this is

310
00:15:37,040 --> 00:15:34,950
one of the antenna modules here's a

311
00:15:39,800 --> 00:15:37,050
different type of antenna here's a

312
00:15:42,800 --> 00:15:39,810
reaction Center we have cytochrome

313
00:15:46,360 --> 00:15:42,810

complexes in the middle that connect the

314
00:15:49,940 --> 00:15:46,370
photosystems or connect the cyclic

315
00:15:53,870 --> 00:15:49,950
schemes and each of these modules

316
00:15:56,120 --> 00:15:53,880
actually has a unique evolutionary

317
00:15:58,660 --> 00:15:56,130
history not just the reaction centers

318
00:16:01,820 --> 00:15:58,670
but the antenna complexes and the

319
00:16:04,670 --> 00:16:01,830
cytochrome complexes and so on so it

320
00:16:07,370 --> 00:16:04,680
becomes a very sort of nonlinear complex

321
00:16:08,750 --> 00:16:07,380
process to try to understand so I'm

322
00:16:13,130 --> 00:16:08,760
going to take just a couple of minutes

323
00:16:15,290 --> 00:16:13,140
here to introduce a little bit of detail

324
00:16:20,330 --> 00:16:15,300
about some of the different types of an

325
00:16:22,160 --> 00:16:20,340
oxygen ik bacteria and the one that's

326
00:16:24,260 --> 00:16:22,170
probably the best understood or the

327
00:16:27,020 --> 00:16:24,270
Proteobacteria are oftentimes called the

328
00:16:29,180 --> 00:16:27,030
purple bacteria and they're the ones

329
00:16:32,020 --> 00:16:29,190
that the first photosynthetic reaction

330
00:16:35,690 --> 00:16:32,030
Center structure was determined for some

331
00:16:39,220 --> 00:16:35,700
some years ago and they operate in a

332
00:16:41,960 --> 00:16:39,230
completely cyclic electron transfer

333
00:16:43,940 --> 00:16:41,970
pathway and that light drives the

334
00:16:46,580 --> 00:16:43,950
electrons across the membrane and these

335
00:16:49,820 --> 00:16:46,590
are always membrane-associated phenomena

336
00:16:52,670 --> 00:16:49,830
and that electron then comes back across

337
00:16:54,440 --> 00:16:52,680
the membrane and ultimately gets

338
00:16:56,300 --> 00:16:54,450

transferred through a soluble carrier

339
00:16:59,090 --> 00:16:56,310
back to the reaction center so the light

340
00:17:00,770 --> 00:16:59,100
basically drives electrons clockwise

341
00:17:02,570 --> 00:17:00,780
around this circle and you might say

342
00:17:04,190 --> 00:17:02,580
well what's what's the point of that

343
00:17:07,660 --> 00:17:04,200
does that get you anything

344
00:17:10,730 --> 00:17:07,670
well coupled to that electron flow is a

345
00:17:13,130 --> 00:17:10,740
directional flow of protons or a pumping

346
00:17:15,260 --> 00:17:13,140
of protons across the membrane this is

347
00:17:18,260 --> 00:17:15,270
the periplasm of the cell down here at

348
00:17:20,780 --> 00:17:18,270
the bottom and so protons accumulate

349
00:17:23,270 --> 00:17:20,790
here and they then flow back through the

350
00:17:25,289 --> 00:17:23,280
ATP synthase and that's really how the

351
00:17:28,950 --> 00:17:25,299
organism is able to train

352
00:17:31,139 --> 00:17:28,960
Douce the energy of the photon into

353
00:17:34,680 --> 00:17:31,149
chemical energy is through the cyclic

354
00:17:39,499 --> 00:17:34,690
electron flow coupled to directional

355
00:17:46,590 --> 00:17:42,330
synthesis and this proton motive force

356
00:17:49,169 --> 00:17:46,600
as the proton and electrical gradient is

357
00:17:52,379 --> 00:17:49,179
is called can actually power a number of

358
00:17:54,840 --> 00:17:52,389
things besides just ATP synthesis and

359
00:17:58,560 --> 00:17:54,850
that sort of forms the the nature the

360
00:18:04,320 --> 00:17:58,570
basis of the energetic budget of these

361
00:18:06,720 --> 00:18:04,330
cells these organisms do this cyclic

362
00:18:08,729 --> 00:18:06,730
electron flow they can do a reverse

363
00:18:12,389 --> 00:18:08,739

electron flow to reduce purity

364
00:18:14,369 --> 00:18:12,399
nucleotide to serve as the reductant for

365
00:18:16,379 --> 00:18:14,379
carbon fixation they use the Calvin

366
00:18:20,450 --> 00:18:16,389
Benson cycle the same as you find in

367
00:18:24,090 --> 00:18:20,460
higher plants for their carbon fixation

368
00:18:26,489 --> 00:18:24,100
mechanism here's another one of my

369
00:18:29,129 --> 00:18:26,499
favorite organisms these are the green

370
00:18:31,710 --> 00:18:29,139
sulfur bacteria and these are the

371
00:18:34,590 --> 00:18:31,720
champions of low light photosynthesis

372
00:18:37,080 --> 00:18:34,600
they have this giant chloros ohm complex

373
00:18:40,259 --> 00:18:37,090
here which is packed with hundreds of

374
00:18:46,999 --> 00:18:40,269
thousands of pigments and it can operate

375
00:18:51,779 --> 00:18:50,099
energy photons will be absorbed by these

376
00:18:54,090 --> 00:18:51,789
chlorophylls which are generally not

377
00:18:56,970 --> 00:18:54,100
associated with pig with proteins in

378
00:18:58,729 --> 00:18:56,980
this chloros ohm they're their self

379
00:19:01,229 --> 00:18:58,739
assembled into large oligomeric

380
00:19:03,389 --> 00:19:01,239
complexes and then there's a directional

381
00:19:07,200 --> 00:19:03,399
energy flow that goes back down into the

382
00:19:10,099 --> 00:19:07,210
membrane and to the reaction center this

383
00:19:14,070 --> 00:19:10,109
is a one of the type one or iron-sulfur

384
00:19:16,320 --> 00:19:14,080
cluster acceptor reaction centers and so

385
00:19:18,419 --> 00:19:16,330
they're very very capable of living

386
00:19:19,340 --> 00:19:18,429
under extreme low light intensities you

387
00:19:22,739 --> 00:19:19,350
can do a back-of-the-envelope

388
00:19:26,279 --> 00:19:22,749

calculation and convince yourself that

389
00:19:28,769 --> 00:19:26,289
the each photon each chlorophyll in this

390
00:19:30,450 --> 00:19:28,779
antenna complex under the sort of

391
00:19:33,149 --> 00:19:30,460
limiting light limiting conditions will

392
00:19:36,659 --> 00:19:33,159
absorb one photon every eight hours and

393
00:19:38,640 --> 00:19:36,669
so they really have figured out how to

394
00:19:40,680 --> 00:19:38,650
how to make

395
00:19:42,210 --> 00:19:40,690
how does your photosynthesis at the very

396
00:19:45,269 --> 00:19:42,220
low limit and so if you're looking for a

397
00:19:48,630 --> 00:19:45,279
system that might be operable under

398
00:19:50,880 --> 00:19:48,640
extreme low light conditions say on

399
00:19:54,510 --> 00:19:50,890
Europa or something of that sort you

400
00:19:58,950 --> 00:19:54,520
might look to this system as a as a

401
00:20:01,289 --> 00:19:58,960
model they're strict anaerobic organisms

402
00:20:03,180 --> 00:20:01,299
generally and they use a different

403
00:20:06,330 --> 00:20:03,190
carbon fixation cycle to use a reverse

404
00:20:08,399 --> 00:20:06,340
TCA cycle for carbon fixation and so

405
00:20:12,690 --> 00:20:08,409
it's really quite different in the in

406
00:20:14,340 --> 00:20:12,700
what the purple bacteria will do now one

407
00:20:16,049 --> 00:20:14,350
of my favorite organisms the one that

408
00:20:23,130 --> 00:20:16,059
we've seen several pictures of are the

409
00:20:26,669 --> 00:20:23,140
filamentous and oxygenic photosynthesis

410
00:20:30,330 --> 00:20:26,679
or antiochus and core flexus is a really

411
00:20:32,370 --> 00:20:30,340
interesting organism because it's sort

412
00:20:35,549 --> 00:20:32,380
of a poster child for horizontal gene

413
00:20:38,070 --> 00:20:35,559

transfer it has the reaction Center

414
00:20:41,010 --> 00:20:38,080
complex that's very structurally and

415
00:20:42,630 --> 00:20:41,020
mechanistically similar to what you find

416
00:20:44,940 --> 00:20:42,640
in the purple bacteria I mean it's

417
00:20:47,370 --> 00:20:44,950
really remarkably similar and it has

418
00:20:49,080 --> 00:20:47,380
this antenna complex the corazon like I

419
00:20:51,180 --> 00:20:49,090
was describing before that's very

420
00:20:54,389 --> 00:20:51,190
similar to what you find in the green

421
00:20:57,510 --> 00:20:54,399
sulfur bacteria it uses a completely

422
00:21:01,049 --> 00:20:57,520
different carbon fixation pathway this 3

423
00:21:06,600 --> 00:21:01,059
hydroxy propionate cycle and it also has

424
00:21:09,269 --> 00:21:06,610
its own type of cytochrome complex it

425
00:21:11,340 --> 00:21:09,279
does not use the cytochrome B C complex

426
00:21:16,860 --> 00:21:11,350
that's found in many of the other types

427
00:21:19,560 --> 00:21:16,870
of organisms it uses a newly discovered

428
00:21:21,510 --> 00:21:19,570
complex called alternative complex 3

429
00:21:24,000 --> 00:21:21,520
which is mechanistically and

430
00:21:26,279 --> 00:21:24,010
structurally entirely different from the

431
00:21:28,590 --> 00:21:26,289
one that's found in other organisms but

432
00:21:31,799 --> 00:21:28,600
it is also found in the number of non

433
00:21:33,510 --> 00:21:31,809
photosynthetic bacteria so here's an

434
00:21:37,200 --> 00:21:33,520
organism that's kind of been assembled

435
00:21:40,799 --> 00:21:37,210
from parts it seems like and it's a it's

436
00:21:43,080 --> 00:21:40,809
a wonderfully sort of charismatic

437
00:21:44,639 --> 00:21:43,090
organism those of us who've been to

438
00:21:47,520 --> 00:21:44,649

Yellowstone have seen it everywhere

439
00:21:49,440 --> 00:21:47,530
there and it's it's that we've worked on

440
00:21:52,049 --> 00:21:49,450
it for many years and it's been

441
00:21:53,670 --> 00:21:52,059
always a surprise whatever Cora flexus

442
00:21:57,600 --> 00:21:53,680
does always does it a little bit

443
00:21:59,520 --> 00:21:57,610
different from any other organism this

444
00:22:03,810 --> 00:21:59,530
is another these are like my children so

445
00:22:07,860 --> 00:22:03,820
yeah realize that I love each one of

446
00:22:09,750 --> 00:22:07,870
them but in a different way these are

447
00:22:11,580 --> 00:22:09,760
the Helio bacteria and these are really

448
00:22:13,740 --> 00:22:11,590
interesting organisms they were

449
00:22:15,780 --> 00:22:13,750
discovered some years ago by Howard

450
00:22:20,220 --> 00:22:15,790
guests from Indiana now the only

451
00:22:22,380 --> 00:22:20,230
gram-positive phototrophic bacteria so

452
00:22:29,000 --> 00:22:22,390
they're interesting in that respect they

453
00:22:33,140 --> 00:22:29,010
they have the simplest known

454
00:22:36,330 --> 00:22:33,150
photosynthetic apparatus they have no

455
00:22:38,820 --> 00:22:36,340
separate antenna system the antenna

456
00:22:42,360 --> 00:22:38,830
there are some antenna pigments that are

457
00:22:45,419 --> 00:22:42,370
part of the reaction center core complex

458
00:22:47,010 --> 00:22:45,429
and so there's like 30 or so antenna

459
00:22:48,870 --> 00:22:47,020
pigments that are associated with that

460
00:22:51,169 --> 00:22:48,880
but they don't have any of these of

461
00:22:56,460 --> 00:22:51,179
these other distinct or these large

462
00:22:58,169 --> 00:22:56,470
peripheral antenna complexes they we

463
00:22:59,700 --> 00:22:58,179

don't really quite understand the

464
00:23:02,340 --> 00:22:59,710
mechanism of their inner of their

465
00:23:06,380 --> 00:23:02,350
electron flow very well probably they do

466
00:23:12,210 --> 00:23:06,390
a cyclic flow and it probably involves

467
00:23:16,140 --> 00:23:12,220
the complex one ndh dehydrogenase type

468
00:23:18,030 --> 00:23:16,150
of complex the other thing about them is

469
00:23:21,270 --> 00:23:18,040
that they're not capable of photo

470
00:23:24,930 --> 00:23:21,280
autotrophic metabolism so they don't

471
00:23:27,540 --> 00:23:24,940
know how to do carbon fixation and so

472
00:23:29,820 --> 00:23:27,550
they have to live photo heterotrophic li

473
00:23:31,620 --> 00:23:29,830
they're found in in places like rice

474
00:23:35,280 --> 00:23:31,630
paddies and so on where they actually

475
00:23:37,770 --> 00:23:35,290
make up a fairly significant population

476
00:23:39,780 --> 00:23:37,780
and they're very active nitrogen-fixing

477
00:23:42,630 --> 00:23:39,790
organisms and so they they have

478
00:23:44,790 --> 00:23:42,640
interesting properties in that respect

479
00:23:48,000 --> 00:23:44,800
but if you're looking for the most

480
00:23:52,080 --> 00:23:48,010
primitive photo troph the Helio bacteria

481
00:23:54,270 --> 00:23:52,090
probably your best candidate this one's

482
00:23:55,890 --> 00:23:54,280
interesting because it is the most

483
00:23:58,970 --> 00:23:55,900
recently discovered and I'm not going to

484
00:24:02,130 --> 00:23:58,980
try to pronounce that name but it's a

485
00:24:03,870 --> 00:24:02,140
phylum of bacteria that just

486
00:24:07,320 --> 00:24:03,880
few years ago and there's really just a

487
00:24:10,580 --> 00:24:07,330
couple of papers on this group now was

488
00:24:13,350 --> 00:24:10,590

discovered to be phototrophic

489
00:24:15,690 --> 00:24:13,360
photosynthetic and it has an apparatus

490
00:24:17,970 --> 00:24:15,700
that if you look at the spectra and the

491
00:24:19,620 --> 00:24:17,980
kinetic properties and so on you swear

492
00:24:23,010 --> 00:24:19,630
it was a purple photosynthetic bacteria

493
00:24:25,260 --> 00:24:23,020
it has exactly the same sort of antenna

494
00:24:28,740 --> 00:24:25,270
complexes and reaction center and so on

495
00:24:30,840 --> 00:24:28,750
and in fact if you look at the way the

496
00:24:32,400 --> 00:24:30,850
genes are clustered for doing

497
00:24:34,770 --> 00:24:32,410
photosynthesis and the purple bacteria

498
00:24:36,840 --> 00:24:34,780
there's what's called a photosynthesis

499
00:24:39,390 --> 00:24:36,850
gene cluster in that you've got about

500
00:24:41,100 --> 00:24:39,400
40-some kilobases of genetic material

501
00:24:43,350 --> 00:24:41,110
that's all clustered together that's

502
00:24:47,040 --> 00:24:43,360
basically everything you need to know to

503
00:24:52,230 --> 00:24:47,050
do photosynthesis and this this group

504
00:24:54,690 --> 00:24:52,240
has basically stolen that that cluster

505
00:24:57,630 --> 00:24:54,700
and ported it through horizontal gene

506
00:25:00,780 --> 00:24:57,640
transfer and has made it work in in this

507
00:25:06,210 --> 00:25:00,790
other other group so here's a sort of a

508
00:25:12,450 --> 00:25:06,220
smoking gun case of a horizontal gene

509
00:25:13,800 --> 00:25:12,460
transfer for that that has just recently

510
00:25:16,350 --> 00:25:13,810
been discovered so we don't know too

511
00:25:19,080 --> 00:25:16,360
much about how it works but it's it's

512
00:25:21,360 --> 00:25:19,090
still a very interesting system and

513
00:25:24,270 --> 00:25:21,370

finally the cyanobacteria which is the

514
00:25:27,890 --> 00:25:24,280
ones that everyone knows about and these

515
00:25:30,360 --> 00:25:27,900
are the the most sort of mechanistically

516
00:25:33,450 --> 00:25:30,370
sophisticated of all the photosynthetic

517
00:25:35,670 --> 00:25:33,460
prokaryotes they have both photos they

518
00:25:38,670 --> 00:25:35,680
have photosystem one and photosystem two

519
00:25:41,730 --> 00:25:38,680
and they have so they have a type one

520
00:25:44,130 --> 00:25:41,740
and a type ii reaction center and

521
00:25:46,440 --> 00:25:44,140
they're connected together through an

522
00:25:50,040 --> 00:25:46,450
electron transport chain and so that you

523
00:25:53,130 --> 00:25:50,050
do primarily a non cyclic electron flow

524
00:25:57,660 --> 00:25:53,140
which extracts electrons from water and

525
00:26:02,370 --> 00:25:57,670
delivers them to to nad P which then

526
00:26:05,460 --> 00:26:02,380
goes on to to reduce co2 in the Calvin

527
00:26:10,200 --> 00:26:05,470
Benson cycle and they have also proton

528
00:26:12,300 --> 00:26:10,210
pumping and ATP synthesis that they can

529
00:26:15,230 --> 00:26:12,310
do and they are also capable of a cyclic

530
00:26:18,200 --> 00:26:15,240
form of electron flow around four

531
00:26:20,030 --> 00:26:18,210
system-1 these wonderful giant antenna

532
00:26:22,580 --> 00:26:20,040
complex is called FICO Billy's ohms

533
00:26:27,470 --> 00:26:22,590
which looks like a space alien of some

534
00:26:30,650 --> 00:26:27,480
sort and they have these rod elements

535
00:26:32,600 --> 00:26:30,660
here that are packed with billon

536
00:26:35,630 --> 00:26:32,610
pigments these are open chain

537
00:26:37,900 --> 00:26:35,640
tetrapyrrole or fills but they are

538
00:26:40,850 --> 00:26:37,910

covalently linked to the proteins and

539
00:26:44,150 --> 00:26:40,860
sort of like little light pipes that

540
00:26:46,040 --> 00:26:44,160
that direct the energy down to a core

541
00:26:48,520 --> 00:26:46,050
structure and then it comes into the

542
00:26:51,470 --> 00:26:48,530
reaction centers and these show this

543
00:26:53,270 --> 00:26:51,480
shows both photosystem ii and recently

544
00:26:55,669 --> 00:26:53,280
we discovered that photosystem one can

545
00:26:58,610 --> 00:26:55,679
also be associated with this so this is

546
00:27:00,830 --> 00:26:58,620
a sort of a little module that can do at

547
00:27:04,250 --> 00:27:00,840
least the majority of the electron

548
00:27:07,040 --> 00:27:04,260
transfer part of photosynthesis so these

549
00:27:11,390 --> 00:27:07,050
are really organisms that have had a lot

550
00:27:14,060 --> 00:27:11,400
of attention they they they do the

551
00:27:21,290 --> 00:27:14,070
Calvin Benson cycle for carbon fixation

552
00:27:23,919 --> 00:27:21,300
and the the evolutionary origin of the

553
00:27:26,930 --> 00:27:23,929
cyanobacteria is one of the really great

554
00:27:28,160 --> 00:27:26,940
unsolved questions and interesting

555
00:27:33,830 --> 00:27:28,170
questions they'll come back to that

556
00:27:35,810 --> 00:27:33,840
right at the end of the talk so we want

557
00:27:37,820 --> 00:27:35,820
to try to understand the origin and the

558
00:27:39,890 --> 00:27:37,830
early evolution of photosynthesis I hope

559
00:27:42,110 --> 00:27:39,900
by now you get the sense that there are

560
00:27:44,750 --> 00:27:42,120
all these modules the antennas the

561
00:27:47,169 --> 00:27:44,760
reaction centers of different types the

562
00:27:50,150 --> 00:27:47,179
electron transfer components and so on

563
00:27:52,130 --> 00:27:50,160

carbon fixation machineries and each of

564
00:27:55,730 --> 00:27:52,140
these modules has its own unique

565
00:27:57,620 --> 00:27:55,740
evolutionary history and so they in a

566
00:27:59,650 --> 00:27:57,630
way it's kind of mix and match what you

567
00:28:02,360 --> 00:27:59,660
find in the different classes of

568
00:28:04,430 --> 00:28:02,370
photosynthetic organisms one will have

569
00:28:06,350 --> 00:28:04,440
this type of antenna and another one

570
00:28:10,870 --> 00:28:06,360
will have this type of reaction center

571
00:28:18,280 --> 00:28:13,630
machinery and you really need to try to

572
00:28:21,380 --> 00:28:18,290
understand all of these different

573
00:28:23,450 --> 00:28:21,390
modules if you will and their unique

574
00:28:25,070 --> 00:28:23,460
evolutionary histories to try to get the

575
00:28:27,409 --> 00:28:25,080
big picture of the evolution and

576
00:28:29,150 --> 00:28:27,419
development of photosynthesis and it's

577
00:28:30,800 --> 00:28:29,160
very clear from a lot of

578
00:28:33,040 --> 00:28:30,810
lines of evidence now that horizontal

579
00:28:35,210 --> 00:28:33,050
gene transfer has been widespread

580
00:28:37,640 --> 00:28:35,220
amongst the bacteria and a lot of these

581
00:28:40,670 --> 00:28:37,650
modules have been passed around and that

582
00:28:43,910 --> 00:28:40,680
has what ultimately has given rise to

583
00:28:46,850 --> 00:28:43,920
this very for scattered pattern that you

584
00:28:48,920 --> 00:28:46,860
find in the bacterial domain why that

585
00:28:56,180 --> 00:28:48,930
never transferred over to the R keeled

586
00:28:59,780 --> 00:28:56,190
over for okay so let's put a few dates

587
00:29:02,120 --> 00:28:59,790
down unfortunately we don't really know

588
00:29:07,010 --> 00:29:02,130

when photosynthesis started almost

589
00:29:12,290 --> 00:29:07,020
certainly it appeared well after Luca

590
00:29:14,570 --> 00:29:12,300
and so it's not something that was was

591
00:29:17,180 --> 00:29:14,580
one of the very earliest metabolic

592
00:29:20,540 --> 00:29:17,190
processes there's evidence for an

593
00:29:22,990 --> 00:29:20,550
toxigenic photosynthesis at 3.4 billion

594
00:29:27,110 --> 00:29:23,000
years ago it's from Don Lowe's lab and

595
00:29:29,620 --> 00:29:27,120
so um certainly by then I think some

596
00:29:32,870 --> 00:29:29,630
form of an oxygen 'ok photosynthesis was

597
00:29:35,330 --> 00:29:32,880
operating oxygenic photosynthesis

598
00:29:38,000 --> 00:29:35,340
there's such a lot of discussion about

599
00:29:39,590 --> 00:29:38,010
that of course the great oxidation event

600
00:29:42,880 --> 00:29:39,600
that I'm sure you're all familiar with

601
00:29:45,500 --> 00:29:42,890
it took place around 2.4 billion is

602
00:29:48,110 --> 00:29:45,510
generally accepted to be due to the

603
00:29:49,850 --> 00:29:48,120
action of cyanobacteria so that's sort

604
00:29:54,770 --> 00:29:49,860
of the latest possible time that

605
00:29:57,590 --> 00:29:54,780
oxygenic photosynthesis was invented but

606
00:30:00,020 --> 00:29:57,600
earlier constraints on the the earliest

607
00:30:02,840 --> 00:30:00,030
appearance of it are a lot trickier and

608
00:30:05,230 --> 00:30:02,850
I think I won't say there's consensus

609
00:30:09,560 --> 00:30:05,240
but there's at least a lot of

610
00:30:12,620 --> 00:30:09,570
indications at 2.7 or so might have been

611
00:30:14,360 --> 00:30:12,630
a reasonable time and probably it didn't

612
00:30:16,940 --> 00:30:14,370
just sort of appear all at once in

613
00:30:18,950 --> 00:30:16,950

full-blown glory like we see it in the

614
00:30:22,550 --> 00:30:18,960
cyanobacteria undoubtedly there was a

615
00:30:25,100 --> 00:30:22,560
significant development where it didn't

616
00:30:27,380 --> 00:30:25,110
work very well at first and of course

617
00:30:29,540 --> 00:30:27,390
once you start producing oxygen you're

618
00:30:32,570 --> 00:30:29,550
poisoning your neighbors and yourselves

619
00:30:35,660 --> 00:30:32,580
and so you have to deal with developing

620
00:30:40,910 --> 00:30:35,670
oxygen protection systems and so on so

621
00:30:42,310 --> 00:30:40,920
there's a lot of a lot of questions

622
00:30:43,600 --> 00:30:42,320
about that

623
00:30:46,800 --> 00:30:43,610
in terms of the pigments I haven't

624
00:30:50,140 --> 00:30:46,810
talked too much about the types of

625
00:30:51,970 --> 00:30:50,150
pigments but we we have these beautiful

626
00:30:53,470 --> 00:30:51,980
chlorophyll pigments that you find in

627
00:30:56,140 --> 00:30:53,480
all types of photo chokes those are

628
00:30:58,510 --> 00:30:56,150
certainly not the original pigments

629
00:31:01,330 --> 00:30:58,520
probably they were simpler porphyrin

630
00:31:04,630 --> 00:31:01,340
type pigments that even some of those

631
00:31:06,940 --> 00:31:04,640
can be prebiotic or they share the first

632
00:31:10,690 --> 00:31:06,950
part of that biosynthetic pathway with

633
00:31:14,440 --> 00:31:10,700
cytochrome heme biosynthesis and so

634
00:31:15,010 --> 00:31:14,450
probably the first pigments were of that

635
00:31:17,380 --> 00:31:15,020
sort

636
00:31:19,270 --> 00:31:17,390
those don't absorb light very well in

637
00:31:21,850 --> 00:31:19,280
the visible region and so once you start

638
00:31:26,050 --> 00:31:21,860

sort of fiddling with the substituents

639
00:31:28,000 --> 00:31:26,060
making them less symmetric putting on

640
00:31:30,580 --> 00:31:28,010
different types of functional groups

641
00:31:33,220 --> 00:31:30,590
then you get a significant change in the

642
00:31:35,560 --> 00:31:33,230
absorption properties that the pigment

643
00:31:38,680 --> 00:31:35,570
absorbs much more in the red region and

644
00:31:42,390 --> 00:31:38,690
has a much higher extinction coefficient

645
00:31:44,920 --> 00:31:42,400
so it becomes much better suited to be a

646
00:31:47,290 --> 00:31:44,930
photosynthetic pigment and so there's

647
00:31:50,770 --> 00:31:47,300
undoubtedly a long process of that kind

648
00:31:52,360 --> 00:31:50,780
of evolution that went on I think it's

649
00:31:55,870 --> 00:31:52,370
certainly the case that the reaction

650
00:31:58,120 --> 00:31:55,880
centers predate the antennas the sort of

651
00:31:59,860 --> 00:31:58,130
the worst idea you can have is an

652
00:32:01,480 --> 00:31:59,870
antenna without a reaction center

653
00:32:03,580 --> 00:32:01,490
because then you're absorbing a bunch of

654
00:32:06,910 --> 00:32:03,590
light and you don't have any way to

655
00:32:09,160 --> 00:32:06,920
process it and so you really that

656
00:32:11,470 --> 00:32:09,170
wouldn't have worked at all and so and

657
00:32:14,170 --> 00:32:11,480
the evolutionary picture of the right of

658
00:32:16,410 --> 00:32:14,180
the antenna sort of support that idea

659
00:32:20,680 --> 00:32:16,420
that they're very buried and seem to

660
00:32:26,380 --> 00:32:20,690
have almost certainly come in at a at a

661
00:32:28,900 --> 00:32:26,390
late time if we try to understand and a

662
00:32:30,370 --> 00:32:28,910
little bit more detail the evolution of

663
00:32:32,560 --> 00:32:30,380

the reaction center this is now just

664
00:32:38,530 --> 00:32:32,570
focusing in on that one module the

665
00:32:40,120 --> 00:32:38,540
reaction center and try to to get a sort

666
00:32:42,940 --> 00:32:40,130
of a unified picture of this this is not

667
00:32:45,520 --> 00:32:42,950
so easy because the the residual

668
00:32:48,310 --> 00:32:45,530
sequence identity between the type one

669
00:32:50,220 --> 00:32:48,320
and the type to reaction centers is down

670
00:32:55,139 --> 00:32:50,230
around ten percent or so so they're very

671
00:32:57,129 --> 00:32:55,149
distant but when you do those structural

672
00:33:01,330 --> 00:32:57,139
comparisons when you look at the

673
00:33:05,489 --> 00:33:01,340
structures and you can you can realize

674
00:33:09,129 --> 00:33:05,499
that the structural

675
00:33:11,289 --> 00:33:09,139
conservation persists much longer than

676
00:33:14,109 --> 00:33:11,299
sequence conservation this is well known

677
00:33:18,099 --> 00:33:14,119
in likely revolution so some years ago

678
00:33:23,099 --> 00:33:18,109
we used the known structures of the

679
00:33:26,830 --> 00:33:23,109
reaction centers to do a global sort of

680
00:33:30,430 --> 00:33:26,840
phylogenetic analysis and came up with

681
00:33:32,349 --> 00:33:30,440
it a tree and then based that tree then

682
00:33:33,970 --> 00:33:32,359
did some additional sequence analysis on

683
00:33:37,960 --> 00:33:33,980
that tree and this is sort of what came

684
00:33:39,820 --> 00:33:37,970
out and what we have is this is an

685
00:33:42,789 --> 00:33:39,830
inferred position for the route but we

686
00:33:44,739 --> 00:33:42,799
have these early reaction centers then a

687
00:33:48,070 --> 00:33:44,749
time will flow out in both directions

688
00:33:50,379 --> 00:33:48,080

here that we're almost certainly what we

689
00:33:53,200 --> 00:33:50,389
call homo dimers all the reaction

690
00:33:54,729 --> 00:33:53,210
centers or most of them are what we call

691
00:33:58,450 --> 00:33:54,739
heterodimers and that you've got two

692
00:34:00,099 --> 00:33:58,460
protein subunits in the core which are

693
00:34:02,739 --> 00:34:00,109
similar but not identical and they've

694
00:34:04,299 --> 00:34:02,749
clearly resent resulted from a gene

695
00:34:06,039 --> 00:34:04,309
duplication event and here in

696
00:34:07,690 --> 00:34:06,049
photosystem one you can see that very

697
00:34:09,129 --> 00:34:07,700
clearly and that's shown there are

698
00:34:11,889 --> 00:34:09,139
actually three of these events that are

699
00:34:13,780 --> 00:34:11,899
inferred from the tree and they're

700
00:34:15,899 --> 00:34:13,790
indicated by stars here and so we have

701
00:34:18,309 --> 00:34:15,909
the two halves of the photosystem one

702
00:34:20,440 --> 00:34:18,319
heterodimer which originated from this

703
00:34:22,780 --> 00:34:20,450
gene duplication and then subsequent

704
00:34:25,000 --> 00:34:22,790
divergence but there are actually two

705
00:34:26,829 --> 00:34:25,010
groups and the green sulfur bacteria and

706
00:34:28,690 --> 00:34:26,839
the Helio bacteria I didn't mention this

707
00:34:30,669 --> 00:34:28,700
at the time they have what's called a

708
00:34:34,000 --> 00:34:30,679
homodimer reaction center there's only

709
00:34:36,940 --> 00:34:34,010
one gene and it forms a complex with two

710
00:34:39,520 --> 00:34:36,950
identical subunits and that's clearly a

711
00:34:44,349 --> 00:34:39,530
more primitive arrangement and so these

712
00:34:46,059 --> 00:34:44,359
things we think fit into the and they

713
00:34:48,970 --> 00:34:46,069

and they enter the tree here in a

714
00:34:51,520 --> 00:34:48,980
position that it indicates that they're

715
00:34:54,490 --> 00:34:51,530
more closely related to the ancestral

716
00:34:57,010 --> 00:34:54,500
reaction center now if you want to look

717
00:35:01,240 --> 00:34:57,020
at where the oxygen evolution occurs in

718
00:35:06,880 --> 00:35:01,250
photosystem ii you've got only this one

719
00:35:08,380 --> 00:35:06,890
group is capable of oxygen oxygen ik

720
00:35:10,509 --> 00:35:08,390
photosynthesis and that's photo

721
00:35:13,390 --> 00:35:10,519
system two in the cyanobacteria and

722
00:35:15,759 --> 00:35:13,400
that's clearly a more derived position

723
00:35:18,670 --> 00:35:15,769
in the tree and so that is something

724
00:35:20,470 --> 00:35:18,680
that developed at a much later time so

725
00:35:23,650 --> 00:35:20,480
this kind of gives an overall picture of

726
00:35:27,940 --> 00:35:23,660
the of the evolution of the reaction

727
00:35:30,279 --> 00:35:27,950
center of part of the system and go skip

728
00:35:33,279 --> 00:35:30,289
this slide so if we just summarize

729
00:35:35,230 --> 00:35:33,289
there's what I would call mosaic

730
00:35:38,529 --> 00:35:35,240
evolution of photosynthesis if we want

731
00:35:40,720 --> 00:35:38,539
to find a photosynthetic cell nowadays

732
00:35:43,049 --> 00:35:40,730
we have to understand that different

733
00:35:47,470 --> 00:35:43,059
parts of that photosynthetic apparatus

734
00:35:49,420 --> 00:35:47,480
may have had different evolutionary

735
00:35:53,109 --> 00:35:49,430
origins and have been brought in through

736
00:35:56,009 --> 00:35:53,119
horizontal gene transfer at at different

737
00:35:59,829 --> 00:35:56,019
times and in different from different

738
00:36:04,809 --> 00:35:59,839

different sources so that means that

739
00:36:06,460 --> 00:36:04,819
there's no sort of single evolution of

740
00:36:08,920 --> 00:36:06,470
photosynthesis that you can point to a

741
00:36:11,200 --> 00:36:08,930
single sort of branching tree it's a I

742
00:36:13,089 --> 00:36:11,210
used to think that that was sort of the

743
00:36:16,870 --> 00:36:13,099
Holy Grail that we'd try to find that

744
00:36:19,299 --> 00:36:16,880
that one branching tree for how

745
00:36:21,400 --> 00:36:19,309
photosynthesis evolved and then at some

746
00:36:24,220 --> 00:36:21,410
point it dawned on me that such a thing

747
00:36:26,200 --> 00:36:24,230
really wasn't possible it didn't exist

748
00:36:33,940 --> 00:36:26,210
and you have to think of it in this much

749
00:36:38,049 --> 00:36:33,950
more nor sort of nonlinear way okay

750
00:36:40,569 --> 00:36:38,059
cyanobacteria have the distinction of

751
00:36:44,319 --> 00:36:40,579
being the only phototrophs that can do

752
00:36:46,240 --> 00:36:44,329
oxygenic only prokaryote that can do

753
00:36:48,039 --> 00:36:46,250
oxygenic photosynthesis and I talked a

754
00:36:49,990 --> 00:36:48,049
bit about them but there's just recently

755
00:36:54,940 --> 00:36:50,000
been a very interesting paper that came

756
00:36:58,319 --> 00:36:54,950
out in science by sue at all and what

757
00:37:00,690 --> 00:36:58,329
they did was analyzed a bunch of

758
00:37:05,549 --> 00:37:00,700
cyanobacterial genomes but they've also

759
00:37:08,230 --> 00:37:05,559
analyzed a bunch of non-photosynthetic

760
00:37:10,349 --> 00:37:08,240
relatives of the cyanobacteria and these

761
00:37:12,910 --> 00:37:10,359
were just discovered recently and that

762
00:37:15,880 --> 00:37:12,920
the first one that was discovered it

763
00:37:18,249 --> 00:37:15,890

called the milena bacteria and then they

764
00:37:20,319 --> 00:37:18,259
have another group that they discovered

765
00:37:21,510 --> 00:37:20,329
in this recent paper just came out about

766
00:37:24,390 --> 00:37:21,520
a month ago

767
00:37:30,059 --> 00:37:24,400
called the series cytochrome atta and

768
00:37:32,700 --> 00:37:30,069
these are both clearly the closest known

769
00:37:36,660 --> 00:37:32,710
relatives to the cyanobacteria in terms

770
00:37:41,609 --> 00:37:36,670
of and they did it's not just 16s but

771
00:37:44,849 --> 00:37:41,619
they did I think 100 gene analysis whole

772
00:37:48,530 --> 00:37:44,859
genome or partial genome analysis and it

773
00:37:51,000 --> 00:37:48,540
shows this kind of a topology this is

774
00:37:56,220 --> 00:37:51,010
oversimplified but the basic idea here

775
00:37:59,210 --> 00:37:56,230
is that these the cyanobacteria what we

776
00:38:03,569 --> 00:37:59,220
what we call the cyanobacteria the

777
00:38:05,490 --> 00:38:03,579
oxygen-evolving phototrophs are related

778
00:38:07,319 --> 00:38:05,500
to these organisms and if you look in

779
00:38:11,099 --> 00:38:07,329
the genomes of these organisms there's

780
00:38:15,750 --> 00:38:11,109
not a single trace of any photosynthesis

781
00:38:18,290 --> 00:38:15,760
genes at all and so the simplest

782
00:38:21,390 --> 00:38:18,300
explanation of that is that this

783
00:38:24,500 --> 00:38:21,400
ancestor of all these groups was almost

784
00:38:27,240 --> 00:38:24,510
certainly a non-photosynthetic cell and

785
00:38:30,450 --> 00:38:27,250
probably was also an anaerobic

786
00:38:34,740 --> 00:38:30,460
the appearance of different types of

787
00:38:38,630 --> 00:38:34,750
terminal respiratory systems and that

788
00:38:41,010 --> 00:38:38,640

that suggests that the cyanobacteria

789
00:38:43,289 --> 00:38:41,020
when they first branched off were

790
00:38:46,140 --> 00:38:43,299
probably also not photosynthetic and

791
00:38:48,240 --> 00:38:46,150
they imported various aspects of their

792
00:38:50,309 --> 00:38:48,250
photosynthetic apparatus through

793
00:38:53,370 --> 00:38:50,319
horizontal gene transfer and then

794
00:38:55,470 --> 00:38:53,380
developed into the the rich group that

795
00:38:57,150 --> 00:38:55,480
we know them today I mean there are

796
00:38:58,740 --> 00:38:57,160
there are possible ways around this

797
00:39:00,210 --> 00:38:58,750
conclusion but it's certainly the

798
00:39:02,940 --> 00:39:00,220
simplest conclusion given the

799
00:39:05,990 --> 00:39:02,950
information that we have now that this

800
00:39:10,079 --> 00:39:06,000
ancestor of the cyanobacteria was not

801
00:39:12,539 --> 00:39:10,089
photosynthetic and it clearly has has

802
00:39:15,390 --> 00:39:12,549
developed that ability because of the

803
00:39:20,190 --> 00:39:15,400
the queer evolutionary connection to the

804
00:39:23,069 --> 00:39:20,200
various and oxygenic modules of the of

805
00:39:27,200 --> 00:39:23,079
the photosynthetic apparatus clearly has

806
00:39:30,329 --> 00:39:27,210
developed that not de novo but through a

807
00:39:34,109 --> 00:39:30,339
horizontal gene transfer so this is an

808
00:39:36,809 --> 00:39:34,119
interesting fairly recent development

809
00:39:38,640 --> 00:39:36,819
solve the question sort of big question

810
00:39:42,749 --> 00:39:38,650
of where did the ability to make oxygen

811
00:39:46,650 --> 00:39:42,759
really come from and that that's the so

812
00:39:50,700 --> 00:39:46,660
called oxygen evolving complex and I

813
00:39:53,430 --> 00:39:50,710

think this is just a sort of schematic

814
00:39:58,289 --> 00:39:53,440
picture that shows how these an oxygen

815
00:40:03,089 --> 00:39:58,299
ik organisms at some point transition to

816
00:40:05,249 --> 00:40:03,099
be the cyanobacteria and what we have

817
00:40:08,120 --> 00:40:05,259
are a lot of missing links here in terms

818
00:40:14,460 --> 00:40:08,130
of we don't really have any intermediate

819
00:40:19,140 --> 00:40:14,470
stages of those but the business end of

820
00:40:22,769 --> 00:40:19,150
the cyanobacteria is photosystem ii and

821
00:40:25,529 --> 00:40:22,779
this is we now have very nice structures

822
00:40:27,630 --> 00:40:25,539
of these and there's a lot of effort to

823
00:40:30,359 --> 00:40:27,640
try to understand the mechanistic

824
00:40:32,640 --> 00:40:30,369
aspects of how the oxygen is produced

825
00:40:35,220 --> 00:40:32,650
from water and thermodynamically this is

826
00:40:37,079 --> 00:40:35,230
a very difficult problem this just shows

827
00:40:39,390 --> 00:40:37,089
the arrangement of the cofactors and

828
00:40:42,989 --> 00:40:39,400
again here's this dimer and the electron

829
00:40:45,630 --> 00:40:42,999
flow because of this heterodimeric

830
00:40:48,150 --> 00:40:45,640
nature it goes just down one side of

831
00:40:50,519 --> 00:40:48,160
this electron transport chain and then

832
00:40:52,559 --> 00:40:50,529
down here is the oxygen evolving center

833
00:40:56,849 --> 00:40:52,569
and this is the famous manganese center

834
00:40:59,309 --> 00:40:56,859
that will take oxidizing equivalents

835
00:41:02,359 --> 00:40:59,319
which are generated here at the

836
00:41:08,430 --> 00:41:02,369
chlorophyll and through a tyrosine

837
00:41:10,259 --> 00:41:08,440
residue the electrons the holes if you

838
00:41:13,259 --> 00:41:10,269

will will be transferred down to the

839
00:41:16,069 --> 00:41:13,269
oxygen evolving Center and here's a

840
00:41:18,420 --> 00:41:16,079
little bit of a blow-up of the of the

841
00:41:21,839 --> 00:41:18,430
structure of that Center consists of

842
00:41:24,329 --> 00:41:21,849
four manganese ions and one calcium and

843
00:41:29,069 --> 00:41:24,339
it has a very sort of unique structure

844
00:41:32,640 --> 00:41:29,079
in the protein the complications of this

845
00:41:34,559 --> 00:41:32,650
are that it's a four electron process so

846
00:41:36,690 --> 00:41:34,569
you have to in a sense store up for

847
00:41:39,720 --> 00:41:36,700
oxidizing equivalents before you can

848
00:41:42,779 --> 00:41:39,730
oxidize waters to molecular oxygen so

849
00:41:45,239 --> 00:41:42,789
that gives you a mechanistic constraint

850
00:41:47,370 --> 00:41:45,249
that's that's quite severe it's also a

851
00:41:49,349 --> 00:41:47,380
very thermodynamically

852
00:41:51,470 --> 00:41:49,359
difficult reaction as you know it's it's

853
00:41:54,720 --> 00:41:51,480
hard to oxidize water it's not a good

854
00:41:57,749 --> 00:41:54,730
reductant and so you need to have a very

855
00:42:01,859 --> 00:41:57,759
strongly oxidizing system to to pull the

856
00:42:04,650 --> 00:42:01,869
electrons away from water and so you

857
00:42:07,620 --> 00:42:04,660
need a very strong redox potential of

858
00:42:11,309 --> 00:42:07,630
the of the complex to oxidize the water

859
00:42:15,259 --> 00:42:11,319
and you have this charge accumulating

860
00:42:18,289 --> 00:42:15,269
system to accumulate for oxidizing

861
00:42:21,680 --> 00:42:18,299
equivalents and these are thought to be

862
00:42:23,999 --> 00:42:21,690
resident on these manganese ions as

863
00:42:26,819 --> 00:42:24,009

successively more and more oxidized

864
00:42:28,890 --> 00:42:26,829
forms of the manganese and there's been

865
00:42:31,259 --> 00:42:28,900
a huge amount of research done to try to

866
00:42:31,890 --> 00:42:31,269
understand the mechanism of how this

867
00:42:34,259 --> 00:42:31,900
works

868
00:42:38,309 --> 00:42:34,269
using all kinds of different techniques

869
00:42:41,759 --> 00:42:38,319
EPR and and x-ray absorption and and so

870
00:42:43,019 --> 00:42:41,769
on it's really a very intense area and I

871
00:42:44,880 --> 00:42:43,029
think there's been a lot of progress

872
00:42:46,559 --> 00:42:44,890
although I think it's safe to say we

873
00:42:49,589 --> 00:42:46,569
still don't really understand the

874
00:42:53,640 --> 00:42:49,599
detailed elements of the mechanism of

875
00:43:00,180 --> 00:42:53,650
the water oxidation and so that's still

876
00:43:01,710 --> 00:43:00,190
a very active research area and so just

877
00:43:04,349 --> 00:43:01,720
to come back to this question of the

878
00:43:06,120 --> 00:43:04,359
transition from the an oxygen 'ok this

879
00:43:09,480 --> 00:43:06,130
sort of shows the purple bacterial

880
00:43:11,549 --> 00:43:09,490
reaction center in a in a very sort of

881
00:43:13,559 --> 00:43:11,559
simplified manner and then this is the

882
00:43:16,109 --> 00:43:13,569
energetics of it the length of this

883
00:43:19,559 --> 00:43:16,119
arrow represents the type of photon the

884
00:43:23,099 --> 00:43:19,569
energy of the photon that's used to to

885
00:43:26,460 --> 00:43:23,109
do the electron transfer and when you

886
00:43:30,109 --> 00:43:26,470
get to the oxygen-evolving system you

887
00:43:32,970 --> 00:43:30,119
use a much higher energy photon and that

888
00:43:35,880 --> 00:43:32,980

probably represents a shift of types of

889
00:43:38,609 --> 00:43:35,890
pigments that are in the system and to

890
00:43:40,799 --> 00:43:38,619
make this sort of transition from this

891
00:43:43,109 --> 00:43:40,809
much simpler system to this much more

892
00:43:45,269 --> 00:43:43,119
complex system it's too large of a

893
00:43:47,640 --> 00:43:45,279
change to occur in one step and there

894
00:43:49,259 --> 00:43:47,650
had to have been multiple intermediates

895
00:43:51,630 --> 00:43:49,269
and we really don't understand the

896
00:43:53,819 --> 00:43:51,640
nature of those intermediates very much

897
00:43:57,450 --> 00:43:53,829
very well and there have been various

898
00:44:00,430 --> 00:43:57,460
suggestions about well where might the

899
00:44:05,800 --> 00:44:00,440
oxygen-evolving system have originated

900
00:44:09,819 --> 00:44:05,810
in terms of evolutionary source and so

901
00:44:12,910 --> 00:44:09,829
on and some of these are shown some of

902
00:44:16,319 --> 00:44:12,920
these ideas are shown here in this slide

903
00:44:19,319 --> 00:44:16,329
and these include things such as

904
00:44:21,490 --> 00:44:19,329
manganese catalase which is a

905
00:44:24,609 --> 00:44:21,500
interesting system because it does

906
00:44:27,700 --> 00:44:24,619
actually produce oxygen and it has a

907
00:44:29,530 --> 00:44:27,710
diamond dye manganese system has some

908
00:44:31,450 --> 00:44:29,540
similarity this is actually an older

909
00:44:34,059 --> 00:44:31,460
version of the structure which is not

910
00:44:35,890 --> 00:44:34,069
quite right anymore but the idea here is

911
00:44:38,829 --> 00:44:35,900
the manganese catalase may have some

912
00:44:40,780 --> 00:44:38,839
structural similarity there there's a

913
00:44:42,960 --> 00:44:40,790

new paper by Jim barber that just came

914
00:44:47,770 --> 00:44:42,970
out that talks about the carbon monoxide

915
00:44:49,930 --> 00:44:47,780
dehydrogenase complex and how it has

916
00:44:52,210 --> 00:44:49,940
some structural similarity to it that

917
00:44:53,589 --> 00:44:52,220
doesn't include manganese so I'm not

918
00:44:55,839 --> 00:44:53,599
sure that one's really quite as relevant

919
00:44:57,579 --> 00:44:55,849
and then there are some suggestions and

920
00:44:59,530 --> 00:44:57,589
this is from a paper by Ken Sauer and

921
00:45:02,260 --> 00:44:59,540
Billie Jean drew but it goes back really

922
00:45:05,140 --> 00:45:02,270
to some suggestions of Mike Russell's

923
00:45:07,410 --> 00:45:05,150
some years ago that manganese minerals

924
00:45:09,670 --> 00:45:07,420
may have served as sort of a templating

925
00:45:12,010 --> 00:45:09,680
structure I don't understand how that

926
00:45:14,559 --> 00:45:12,020
then can get incorporated into the

927
00:45:16,900 --> 00:45:14,569
system and ultimately be genetically

928
00:45:18,880 --> 00:45:16,910
encoded and so on so there's still a lot

929
00:45:20,140 --> 00:45:18,890
of questions about how that happened and

930
00:45:23,349 --> 00:45:20,150
I'd say that's really the biggest

931
00:45:30,730 --> 00:45:23,359
unsolved question about how this whole

932
00:45:33,670 --> 00:45:30,740
thing works so just as a final slide

933
00:45:35,109 --> 00:45:33,680
here the the question comes up and

934
00:45:38,109 --> 00:45:35,119
especially relevant for this group is

935
00:45:44,710 --> 00:45:38,119
oxygenic photosynthesis and inevitable

936
00:45:46,930 --> 00:45:44,720
evolutionary development and oxygenic

937
00:45:48,809 --> 00:45:46,940
photosynthesis is mechanistically much

938
00:45:52,059 --> 00:45:48,819

more complicated than an toxigenic

939
00:45:56,920 --> 00:45:52,069
photosynthesis so I think anytime you go

940
00:46:00,220 --> 00:45:56,930
to any world once photosynthesis can get

941
00:46:03,280 --> 00:46:00,230
started it will probably start with some

942
00:46:06,069 --> 00:46:03,290
form of an toxigenic photosynthesis it's

943
00:46:12,510 --> 00:46:06,079
just so much simpler mechanistically

944
00:46:17,070 --> 00:46:12,520
energetically and so on and so it's

945
00:46:18,840 --> 00:46:17,080
it's a the advantage of oxygen ik

946
00:46:22,920 --> 00:46:18,850
photosynthesis is it uses this

947
00:46:26,820 --> 00:46:22,930
ubiquitous electron donor water and so

948
00:46:29,730 --> 00:46:26,830
that gives you essentially an unlimited

949
00:46:31,650 --> 00:46:29,740
source of reductant that you don't have

950
00:46:34,380 --> 00:46:31,660
with a lot of the reductants that are

951
00:46:36,359 --> 00:46:34,390
used in the various and oxygen existence

952
00:46:38,970 --> 00:46:36,369
so it gives you a tremendous upside

953
00:46:42,810 --> 00:46:38,980
potential and it's also the case that it

954
00:46:46,140 --> 00:46:42,820
has this very you're using you're

955
00:46:49,890 --> 00:46:46,150
creating a redox couple with oxygen and

956
00:46:52,080 --> 00:46:49,900
the reduced acceptor that has a lot of

957
00:46:55,140 --> 00:46:52,090
free energy stored in it and so it's

958
00:46:58,680 --> 00:46:55,150
really thermodynamically probably the

959
00:47:03,840 --> 00:46:58,690
most efficient system that that you'll

960
00:47:05,790 --> 00:47:03,850
have so it's it's perhaps an inevitable

961
00:47:08,670 --> 00:47:05,800
and evolutionary development but it's

962
00:47:12,240 --> 00:47:08,680
certainly not the initial one and you

963
00:47:15,000 --> 00:47:12,250

might well find a world that have not

964
00:47:19,080 --> 00:47:15,010
yet made that transition from anoxygenic

965
00:47:19,710 --> 00:47:19,090
to oxygenic photosynthesis and that's

966
00:47:22,200 --> 00:47:19,720
the end

967
00:47:23,520 --> 00:47:22,210
just acknowledge this is a question that

968
00:47:25,370 --> 00:47:23,530
we've thought about in our group for

969
00:47:26,760 --> 00:47:25,380
many years and some of my former

970
00:47:29,790 --> 00:47:26,770
students

971
00:47:31,170 --> 00:47:29,800
Jason Raymond who was a student with me

972
00:47:34,320 --> 00:47:31,180
some years ago in West Wing

973
00:47:36,210 --> 00:47:34,330
swingley who's here contributed a lot to

974
00:47:38,760 --> 00:47:36,220
some of the early work on this Martin

975
00:47:42,599 --> 00:47:38,770
Holman Marriott and summated Sadiq are

976
00:47:45,570 --> 00:47:42,609
also did a lot of work and we've had

977
00:47:47,940 --> 00:47:45,580
various collaborators and this has been

978
00:47:50,370 --> 00:47:47,950
supported by NASA for many years through

979
00:47:52,160 --> 00:47:50,380
the exobiology in the astrobiology and

980
00:47:55,020 --> 00:47:52,170
right now I'm a member of the the

981
00:47:56,460 --> 00:47:55,030
virtual planetary laboratory and so

982
00:48:09,029 --> 00:47:56,470
thank you for your attention and I'm

983
00:48:13,329 --> 00:48:10,720
yeah hi Bob

984
00:48:15,789 --> 00:48:13,339
Dave da so clearly established that an

985
00:48:17,289 --> 00:48:15,799
Occidental kosis came first then you had

986
00:48:18,849 --> 00:48:17,299
this duplication to give you the two

987
00:48:20,859 --> 00:48:18,859
photosystems and then of course you have

988
00:48:22,450 --> 00:48:20,869

the sign bacterial development what's

989
00:48:25,269 --> 00:48:22,460
the evidence for the relative timing

990
00:48:27,549 --> 00:48:25,279
between the duplication to form the two

991
00:48:29,500 --> 00:48:27,559
and autogenic things and oxygenic

992
00:48:30,940 --> 00:48:29,510
photosynthesis seems like that was a

993
00:48:33,190 --> 00:48:30,950
very exciting time when you got the

994
00:48:35,140 --> 00:48:33,200
duplication work out was not a possible

995
00:48:37,120 --> 00:48:35,150
time also to to do the other

996
00:48:39,130 --> 00:48:37,130
well these gene duplications didn't

997
00:48:40,599 --> 00:48:39,140
there as I showed on that one diagram

998
00:48:43,120 --> 00:48:40,609
there were three separate gene

999
00:48:45,309 --> 00:48:43,130
duplication events that caused the

1000
00:48:46,660 --> 00:48:45,319
heterodimeric structure of the reaction

1001
00:48:48,819 --> 00:48:46,670
center and those didn't all happen at

1002
00:48:52,150 --> 00:48:48,829
the same time clearly the one that

1003
00:48:54,670 --> 00:48:52,160
formed the photosystem one is a much

1004
00:48:56,950 --> 00:48:54,680
more recent development because if you

1005
00:48:58,660 --> 00:48:56,960
look at the two halves of photosystem

1006
00:49:00,910 --> 00:48:58,670
one they're actually quite similar to

1007
00:49:04,450 --> 00:49:00,920
each other and so that gene duplication

1008
00:49:06,789 --> 00:49:04,460
was a fairly recent one the other one is

1009
00:49:09,880 --> 00:49:06,799
actually the most interesting the sort

1010
00:49:11,890 --> 00:49:09,890
of the type to reaction centers and that

1011
00:49:15,460 --> 00:49:11,900
you have this long edge on the tree and

1012
00:49:19,240 --> 00:49:15,470
then you get the the divergence into the

1013
00:49:22,420 --> 00:49:19,250

the what I would call the purple

1014
00:49:25,029 --> 00:49:22,430
bacterial type of type ii reaction

1015
00:49:28,269 --> 00:49:25,039
centers and photosystem 2 and then

1016
00:49:33,059 --> 00:49:28,279
independent gene duplications there and

1017
00:49:35,680 --> 00:49:33,069
there's a long long period there that

1018
00:49:38,740 --> 00:49:35,690
probably was not oxygen almost certainly

1019
00:49:40,779 --> 00:49:38,750
was not oxygen evolving I I don't see

1020
00:49:43,750 --> 00:49:40,789
how the oxygen if evolution part could

1021
00:49:47,740 --> 00:49:43,760
really work until after the duplication

1022
00:49:50,380 --> 00:49:47,750
in the photosystem two part because the

1023
00:49:58,609 --> 00:49:50,390
oxygen evolving complex is is very

1024
00:50:03,599 --> 00:50:01,049
nope yeah yeah

1025
00:50:05,579 --> 00:50:03,609
you use the term the mosaic evolution of

1026
00:50:08,400 --> 00:50:05,589
photosynthesis you referred to the I

1027
00:50:10,650 --> 00:50:08,410
guess the independent origin of antenna

1028
00:50:12,210 --> 00:50:10,660
and reaction centers and pigments do you

1029
00:50:13,710 --> 00:50:12,220
have any idea what those three

1030
00:50:15,569 --> 00:50:13,720
components were doing before they were

1031
00:50:18,530 --> 00:50:15,579
assembled as a mosaic well that's the

1032
00:50:21,390 --> 00:50:18,540
interesting question in some cases the

1033
00:50:24,480 --> 00:50:21,400
these modules for example the carbon

1034
00:50:27,390 --> 00:50:24,490
fixation machineries are shared with non

1035
00:50:29,130 --> 00:50:27,400
photosynthetic organisms so like the

1036
00:50:31,200 --> 00:50:29,140
Calvin Benson cycle it's found in a

1037
00:50:33,180 --> 00:50:31,210
number of non photosynthetic organisms

1038
00:50:35,160 --> 00:50:33,190

and some of these other carbon cycles

1039
00:50:38,270 --> 00:50:35,170
and so there you can imagine that this

1040
00:50:41,280 --> 00:50:38,280
carbon fixation capability developed

1041
00:50:43,140 --> 00:50:41,290
independently and then different

1042
00:50:46,020 --> 00:50:43,150
photosynthetic organisms sort of

1043
00:50:50,780 --> 00:50:46,030
imported one or another of these carbon

1044
00:50:53,819 --> 00:50:50,790
fixation cycles that suited its needs

1045
00:50:55,620 --> 00:50:53,829
others other parts of the system are a

1046
00:50:58,319 --> 00:50:55,630
little harder to see that way for

1047
00:51:00,180 --> 00:50:58,329
example the the reaction center complex

1048
00:51:03,180 --> 00:51:00,190
we don't really have any idea of whether

1049
00:51:07,370 --> 00:51:03,190
it had any kind of previous life as a

1050
00:51:10,559 --> 00:51:07,380
different type of electron transfer

1051
00:51:12,210 --> 00:51:10,569
complex it doesn't really show much

1052
00:51:14,190 --> 00:51:12,220
similarity in terms of structure to

1053
00:51:18,480 --> 00:51:14,200
anything other than other reaction

1054
00:51:21,930 --> 00:51:18,490
centers and so other things some of them

1055
00:51:23,730 --> 00:51:21,940
are clearly shared with other organisms

1056
00:51:26,700 --> 00:51:23,740
non photosynthetic organisms and

1057
00:51:28,589 --> 00:51:26,710
probably were imported in such a way

1058
00:51:30,960 --> 00:51:28,599
while others were almost certainly

1059
00:51:33,750 --> 00:51:30,970
invented along the way by the

1060
00:51:36,120 --> 00:51:33,760
photosynthetic organisms themselves but

1061
00:51:38,789 --> 00:51:36,130
pigments well the pigments are

1062
00:51:41,099 --> 00:51:38,799
interesting cases I briefly alluded to

1063
00:51:44,640 --> 00:51:41,109

the fact that the biosynthesis of

1064
00:51:46,799 --> 00:51:44,650
chlorophyll is the same as the heme

1065
00:51:49,109 --> 00:51:46,809
biosynthesis up to a point and then they

1066
00:51:51,539 --> 00:51:49,119
branch off you put iron in and make a

1067
00:51:54,599 --> 00:51:51,549
heme you put magnesium in and it goes

1068
00:51:58,339 --> 00:51:54,609
down the chlorophyll branch so clearly

1069
00:52:03,020 --> 00:51:58,349
that that's a shared pathway up to that

1070
00:52:05,640 --> 00:52:03,030
branch point and probably the first

1071
00:52:08,490 --> 00:52:05,650
photosynthetic pigments were were

1072
00:52:10,750 --> 00:52:08,500
similar to the sort of more symmetric

1073
00:52:12,550 --> 00:52:10,760
porphyrins that you see as he

1074
00:52:14,950 --> 00:52:12,560
but those don't actually absorb light

1075
00:52:19,930 --> 00:52:14,960
very well and so there'd be a very

1076
00:52:22,690 --> 00:52:19,940
strong selection pressure to to fiddle

1077
00:52:25,900 --> 00:52:22,700
with the structure of those molecules to

1078
00:52:28,450 --> 00:52:25,910
make them better light absorbers and the

1079
00:52:30,010 --> 00:52:28,460
the core fills are really amazing in the

1080
00:52:32,680 --> 00:52:30,020
in the sort of all the different

1081
00:52:34,510 --> 00:52:32,690
functional groups and that they've got a

1082
00:52:36,580 --> 00:52:34,520
symmetry built into them now which

1083
00:52:38,470 --> 00:52:36,590
shifts the absorption to longer

1084
00:52:41,550 --> 00:52:38,480
wavelengths and so on and so that

1085
00:52:51,750 --> 00:52:41,560
undoubtedly is a product of a long

1086
00:52:53,710 --> 00:52:51,760
evolutionary progression as well yeah

1087
00:52:56,830 --> 00:52:53,720
yes Bob that's awesome

1088
00:52:58,180 --> 00:52:56,840

so as you know that the pigments are

1089
00:53:02,430 --> 00:52:58,190
sort of something that I care a lot

1090
00:53:05,109 --> 00:53:02,440
about so this is my segue to this so

1091
00:53:06,609 --> 00:53:05,119
currently to get to get oxygen and close

1092
00:53:08,740 --> 00:53:06,619
senses you need a lot of energy which we

1093
00:53:10,390 --> 00:53:08,750
get in two stages through two different

1094
00:53:12,849 --> 00:53:10,400
reaction centers what a sort of

1095
00:53:14,380 --> 00:53:12,859
wavelength would it take in a single

1096
00:53:16,870 --> 00:53:14,390
photon absorbance event to give you

1097
00:53:18,190 --> 00:53:16,880
enough energy if we had started not from

1098
00:53:20,200 --> 00:53:18,200
wherever we started we still don't know

1099
00:53:22,870 --> 00:53:20,210
where that sifts that first start even

1100
00:53:24,700 --> 00:53:22,880
was if it started somewhere else with a

1101
00:53:28,030 --> 00:53:24,710
different set of pigments might we have

1102
00:53:30,160 --> 00:53:28,040
gotten there in one shot having a single

1103
00:53:32,530 --> 00:53:30,170
photo photon so what kinda wavelength

1104
00:53:34,000 --> 00:53:32,540
would that again there's been a lot of

1105
00:53:36,880 --> 00:53:34,010
thinking about this question as you

1106
00:53:38,830 --> 00:53:36,890
might imagine at one of the one of the

1107
00:53:40,690 --> 00:53:38,840
efforts it's very active now is to try

1108
00:53:42,940 --> 00:53:40,700
to improve the efficiency of

1109
00:53:45,040 --> 00:53:42,950
photosynthesis mostly from a sort of an

1110
00:53:48,190 --> 00:53:45,050
agricultural or bioenergy point of view

1111
00:53:50,470 --> 00:53:48,200
and that the existing architecture of

1112
00:53:52,090 --> 00:53:50,480
photosynthesis obviously has this long

1113
00:53:54,400 --> 00:53:52,100

evolutionary history and it's probably

1114
00:53:58,300 --> 00:53:54,410
it's almost certainly not the most

1115
00:54:01,870 --> 00:53:58,310
optimum arrangement that one could could

1116
00:54:05,800 --> 00:54:01,880
imagine and the fact that you have the

1117
00:54:08,349 --> 00:54:05,810
two coupled photo systems allows you to

1118
00:54:11,109 --> 00:54:08,359
have this very large redox pan from

1119
00:54:13,810 --> 00:54:11,119
oxygen on one end and NADP on the other

1120
00:54:16,540 --> 00:54:13,820
end to do that all with a single photon

1121
00:54:18,760 --> 00:54:16,550
you'd have to probably use a much

1122
00:54:21,820 --> 00:54:18,770
shorter wavelength photons say something

1123
00:54:23,900 --> 00:54:21,830
in the 500 nanometer range and then

1124
00:54:25,970 --> 00:54:23,910
anything beyond that would

1125
00:54:30,170 --> 00:54:25,980
perhaps not have sufficient energy

1126
00:54:33,109 --> 00:54:30,180
because of the Planck law to to cause

1127
00:54:36,109 --> 00:54:33,119
the to be able to create this very large

1128
00:54:39,319 --> 00:54:36,119
redox pan so you'd be losing out on a

1129
00:54:41,420 --> 00:54:39,329
large part of the of the electromagnetic

1130
00:54:43,130 --> 00:54:41,430
spectrum to do that now there are

1131
00:54:46,009 --> 00:54:43,140
various scenarios that people are

1132
00:54:47,690 --> 00:54:46,019
talking about so-called radical redesign

1133
00:54:49,910 --> 00:54:47,700
of the reaction center of the

1134
00:54:52,009 --> 00:54:49,920
photosynthetic process to have one

1135
00:54:55,220 --> 00:54:52,019
system that sort of works on that green

1136
00:54:56,990 --> 00:54:55,230
light and the goes all the way to NADP

1137
00:54:59,559 --> 00:54:57,000
and then have a second system that works

1138
00:55:02,390 --> 00:54:59,569

way out in the near-infrared and does

1139
00:55:07,400 --> 00:55:02,400
cyclic electron flow to generate a bunch

1140
00:55:10,099 --> 00:55:07,410
of ATP and that way you could circle

1141
00:55:15,309 --> 00:55:10,109
fill the energetic needs and cover the

1142
00:55:18,680 --> 00:55:15,319
spectrum in a more comprehensive way and

1143
00:55:22,099 --> 00:55:18,690
and perhaps and increase the efficiency

1144
00:55:26,749 --> 00:55:22,109
but that's there's a lot of lot of steps

1145
00:55:28,640 --> 00:55:26,759
to get there the question of a long

1146
00:55:32,420 --> 00:55:28,650
wavelength limit is something that has

1147
00:55:34,759 --> 00:55:32,430
been looked at a lot lately and these

1148
00:55:36,950 --> 00:55:34,769
chlorophyll D containing organisms have

1149
00:55:39,259 --> 00:55:36,960
kind of pushed that level of that long

1150
00:55:41,539 --> 00:55:39,269
wavelength limit out it used to be

1151
00:55:45,769 --> 00:55:41,549
thought it was 700 nanometers now it's

1152
00:55:48,049 --> 00:55:45,779
thought to be at least 750 mike wang

1153
00:55:49,849 --> 00:55:48,059
from Caltech i think my question has to

1154
00:55:51,890 --> 00:55:49,859
do with the previous two questions so

1155
00:55:54,829 --> 00:55:51,900
astronomers often think about looking

1156
00:55:56,329 --> 00:55:54,839
for the red edge as a bio signature so

1157
00:55:57,529 --> 00:55:56,339
as an expert in photosynthesis i was

1158
00:56:00,049 --> 00:55:57,539
wondering if you can tell us a little

1159
00:56:01,700 --> 00:56:00,059
bit more about where that comes from in

1160
00:56:03,829 --> 00:56:01,710
particular whether or not there are

1161
00:56:05,359 --> 00:56:03,839
actually many different red edges for

1162
00:56:07,460 --> 00:56:05,369
the different types of antenna that you

1163
00:56:10,609 --> 00:56:07,470

just arrived and also whether or not you

1164
00:56:12,829 --> 00:56:10,619
think that the red edge would shift for

1165
00:56:14,809 --> 00:56:12,839
life on planets around stars that emit a

1166
00:56:16,130 --> 00:56:14,819
different wavelength right well there's

1167
00:56:18,529 --> 00:56:16,140
been a lot of discussion about that at

1168
00:56:19,970 --> 00:56:18,539
niki Parenteau gave a very nice talk on

1169
00:56:24,440 --> 00:56:19,980
just that question earlier in the week

1170
00:56:26,349 --> 00:56:24,450
but with different types of pigments you

1171
00:56:28,700 --> 00:56:26,359
will certainly get that red edge

1172
00:56:30,769 --> 00:56:28,710
occurring at different wavelengths so

1173
00:56:32,170 --> 00:56:30,779
it's not always is the reason it occurs

1174
00:56:34,930 --> 00:56:32,180
at 700 Nm

1175
00:56:37,210 --> 00:56:34,940
leaders on earth is because you're

1176
00:56:39,910 --> 00:56:37,220
you're looking at the terrestrial

1177
00:56:42,370 --> 00:56:39,920
vegetation the red edges if you look

1178
00:56:44,920 --> 00:56:42,380
from a reflectance spectrum from the

1179
00:56:46,530 --> 00:56:44,930
Earth from space back at the earth you

1180
00:56:49,299 --> 00:56:46,540
look at light reflected off the

1181
00:56:51,370 --> 00:56:49,309
vegetation there's very little visible

1182
00:56:53,530 --> 00:56:51,380
light that's that's reflected and once

1183
00:56:55,930 --> 00:56:53,540
you get to 700 nanometers it shoots up

1184
00:56:58,299 --> 00:56:55,940
and much higher intensity and that's the

1185
00:56:59,980 --> 00:56:58,309
so-called red edge and that simply I

1186
00:57:02,920 --> 00:56:59,990
mean there are various explanations for

1187
00:57:06,160 --> 00:57:02,930
but the sort of biggest reason for that

1188
00:57:08,950 --> 00:57:06,170

is that the the core fill absorbs all

1189
00:57:13,599 --> 00:57:08,960
that light from 400 to 700 nanometers

1190
00:57:15,700 --> 00:57:13,609
the visible range and so most of that

1191
00:57:19,930 --> 00:57:15,710
light gets taken in and never comes back

1192
00:57:22,630 --> 00:57:19,940
out of the of the organism the light

1193
00:57:24,880 --> 00:57:22,640
past 700 nanometers is not absorbed at

1194
00:57:26,920 --> 00:57:24,890
all and so that light can easily be

1195
00:57:31,270 --> 00:57:26,930
scattered back and that's what's the

1196
00:57:33,520 --> 00:57:31,280
sort of idea about the red edge or the

1197
00:57:35,559 --> 00:57:33,530
the source of the red edge and there's

1198
00:57:39,520 --> 00:57:35,569
been also discussion about this question

1199
00:57:41,620 --> 00:57:39,530
of other stars for example m-class stars

1200
00:57:44,950 --> 00:57:41,630
and so on a Nancy King has done some

1201
00:57:46,780 --> 00:57:44,960
nice simulations on that and probably

1202
00:57:50,170 --> 00:57:46,790
you would find that the pigments that

1203
00:57:52,450 --> 00:57:50,180
you find on us on a world that's doing

1204
00:57:54,780 --> 00:57:52,460
photosynthesis from an m-class star

1205
00:57:57,549 --> 00:57:54,790
would be different and they D further

1206
00:57:59,260 --> 00:57:57,559
redshifted and the mechanism you could

1207
00:58:03,970 --> 00:57:59,270
have some significant mechanistic

1208
00:58:07,720 --> 00:58:03,980
differences so I think that the the the

1209
00:58:10,089 --> 00:58:07,730
the life would adapt to that particular

1210
00:58:12,010 --> 00:58:10,099
photic environment just like all the

1211
00:58:17,470 --> 00:58:12,020
different types of antenna complexes

1212
00:58:19,720 --> 00:58:17,480
have evolved to adapt organisms on earth

1213
00:58:21,970 --> 00:58:19,730

to different photic environments you'd

1214
00:58:24,940 --> 00:58:21,980
see a similar sort of process that we'd