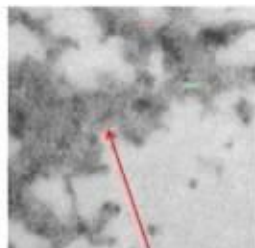
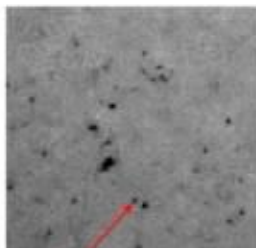




Synthesis of clusters of iron oxide and conversion to iron sulfide

- Incubate SubE/HFn with Fe^{2+} , allow air oxidation to form yellow-brown solution
 - pH control directs iron oxide formation to cage interior
- Place oxide-mineralized SubE/HFn under an H_2S atmosphere
 - Oxide-sulfide conversion forms inky black solution
- Filter to remove any large FeS particles, run over drip column to remove unreacted S^{2-} or dissolved Fe^{2+}



5100 Fe/cage

3420 Fe/cage



NASA
Astrobiology
Institute

Team Overview Seminars
Montana State University

1
00:00:05,510 --> 00:00:02,659
good morning or good afternoon everyone

2
00:00:08,360 --> 00:00:05,520
welcome to the continuation of the

3
00:00:11,570 --> 00:00:08,370
series of seminars by each of the NAI

4
00:00:14,780 --> 00:00:11,580
teams this is origins of life week here

5
00:00:17,180 --> 00:00:14,790
at nai central plaza and we're going to

6
00:00:20,090 --> 00:00:17,190
hear today from John Peters for the

7
00:00:21,679 --> 00:00:20,100
Montana State team John got his BS in

8
00:00:24,859 --> 00:00:21,689
microbiology at the university of

9
00:00:26,779 --> 00:00:24,869
oklahoma in norman and a PhD in

10
00:00:30,109 --> 00:00:26,789
biochemistry from Virginia Tech and then

11
00:00:33,410 --> 00:00:30,119
was a postdoc at Caltech before moving

12
00:00:37,010 --> 00:00:33,420
on to msu john is also the director of

13
00:00:40,430 --> 00:00:37,020

the thermal biology institute at msu in

14

00:00:43,160 --> 00:00:40,440

addition to being the pi/4 the NAI team

15

00:00:45,590 --> 00:00:43,170

and the thermal biology Institute

16

00:00:48,709 --> 00:00:45,600

investigates the geothermal environments

17

00:00:51,799 --> 00:00:48,719

of yellowstone national park which the

18

00:00:54,080 --> 00:00:51,809

NAIA ec will have the privilege of

19

00:00:57,110 --> 00:00:54,090

seeing and being shown by John in

20

00:01:00,860 --> 00:00:57,120

September at our next in person ec

21

00:01:03,200 --> 00:01:00,870

meeting after the asu workshop and we're

22

00:01:06,020 --> 00:01:03,210

all looking forward to that and without

23

00:01:17,450 --> 00:01:06,030

any further ado I will turn the floor

24

00:01:22,760 --> 00:01:17,460

over to John god I think your

25

00:01:27,080 --> 00:01:22,770

microphones muted that's right I'm

26
00:01:32,960 --> 00:01:27,090
hopeful ok ok ok thanks Carl can you can

27
00:01:36,710 --> 00:01:32,970
they hear me now Margo yes ok you know

28
00:01:38,630 --> 00:01:36,720
you said about the delay if if if I'm

29
00:01:46,280 --> 00:01:38,640
not observing the delay can you reel me

30
00:01:48,230 --> 00:01:46,290
in Marco please sir ok thanks ok so I'm

31
00:01:50,510 --> 00:01:48,240
going to talk about our project it's

32
00:01:52,460 --> 00:01:50,520
really centered on structure and

33
00:01:54,950 --> 00:01:52,470
reactivity at iron sulfur motifs I've

34
00:01:57,830 --> 00:01:54,960
got the number of my p.i is here with me

35
00:02:01,700 --> 00:01:57,840
so if and I'm going to try to feel the

36
00:02:04,200 --> 00:02:01,710
whole centers threats by myself but if I

37
00:02:05,760 --> 00:02:04,210
see them wave in their arms or

38
00:02:08,540 --> 00:02:05,770

role in their eyes or something like

39

00:02:12,330 --> 00:02:08,550

that I make Paul on some of my pee is to

40

00:02:16,410 --> 00:02:12,340

clarify some things that all be

41

00:02:17,880 --> 00:02:16,420

disgusting okay so our team is a number

42

00:02:20,760 --> 00:02:17,890

of investigators here at Montana State

43

00:02:23,010 --> 00:02:20,770

University Martin skinnin and John

44

00:02:28,559 --> 00:02:23,020

previous Stony Brook University and damn

45

00:02:32,490 --> 00:02:28,569

strong in at Temple University and it's

46

00:02:35,330 --> 00:02:32,500

a disciplinary team of different flavors

47

00:02:38,930 --> 00:02:35,340

of chemists mainly and so we have

48

00:02:41,880 --> 00:02:38,940

metallic a biochemist or biochemists and

49

00:02:44,790 --> 00:02:41,890

all the way to a computational and

50

00:02:48,690 --> 00:02:44,800

physical chemists or were spanning that

51
00:02:51,479 --> 00:02:48,700
range of chemistry so John Broderick and

52
00:02:54,390 --> 00:02:51,489
I are our expertise is in the tallow

53
00:02:59,190 --> 00:02:54,400
biochemistry Martin student in

54
00:03:01,430 --> 00:02:59,200
geochemistry and John Parise in

55
00:03:04,410 --> 00:03:01,440
geochemistry as well being strong in

56
00:03:06,900 --> 00:03:04,420
surface science Trevor Douglas in nano

57
00:03:09,870 --> 00:03:06,910
material science that Tim mitten in

58
00:03:12,350 --> 00:03:09,880
molecular beam science mark young

59
00:03:14,880 --> 00:03:12,360
molecular biologist and neurologist

60
00:03:17,420 --> 00:03:14,890
Roberts loggia spectroscopy and

61
00:03:21,870 --> 00:03:17,430
computational chemist and a philosopher

62
00:03:26,370 --> 00:03:21,880
prashanta baba bhai pretty good job with

63
00:03:28,650 --> 00:03:26,380

that one I say okay so so it's a fairly

64

00:03:30,030 --> 00:03:28,660

focused center where we're probing the

65

00:03:34,650 --> 00:03:30,040

relationships between structure and

66

00:03:37,050 --> 00:03:34,660

reactivity of iron sulfur motifs and the

67

00:03:39,479 --> 00:03:37,060

role of iron sulfur motifs in prebiotic

68

00:03:41,970 --> 00:03:39,489

chemistry and the origin of blood so

69

00:03:45,440 --> 00:03:41,980

there's been a lot of ideas about the

70

00:03:48,479 --> 00:03:45,450

origin of life and those have evolved

71

00:03:50,729 --> 00:03:48,489

with time so to speak and I think

72

00:03:54,780 --> 00:03:50,739

without going through this slide you

73

00:03:58,470 --> 00:03:54,790

know our project is really can be tied

74

00:04:00,539 --> 00:03:58,480

to metabolism first ideas for the

75

00:04:03,750 --> 00:04:00,549

original life that are really focused

76
00:04:09,800 --> 00:04:03,760
more on prebiotic chemistry so relevant

77
00:04:13,530 --> 00:04:09,810
to RNA world with the world making proto

78
00:04:15,840 --> 00:04:13,540
biomolecules of any kind but I think you

79
00:04:18,060 --> 00:04:15,850
know vodka Hauser's ideas on

80
00:04:20,940 --> 00:04:18,070
sofa world and Mike Russell's ideas I

81
00:04:24,090 --> 00:04:20,950
think that our project is in line mostly

82
00:04:25,740 --> 00:04:24,100
with those out here so what we're

83
00:04:28,560 --> 00:04:25,750
interested in we're interested in the

84
00:04:31,220 --> 00:04:28,570
reactions of raw materials important for

85
00:04:33,450 --> 00:04:31,230
the production of proto biomolecules or

86
00:04:38,730 --> 00:04:33,460
prebiotic chemistry and I've listed some

87
00:04:45,200 --> 00:04:38,740
of the those molecules those small

88
00:04:48,180 --> 00:04:45,210

molecules here and in the hypothetical

89

00:04:51,030 --> 00:04:48,190

origin alive broken into four stages

90

00:04:54,450 --> 00:04:51,040

here a Hadean stage in which we have

91

00:04:57,020 --> 00:04:54,460

inter conversion of small molecules to

92

00:04:59,370 --> 00:04:57,030

increase the pool of raw materials for

93

00:05:00,540 --> 00:04:59,380

condensation reactions in the second

94

00:05:03,500 --> 00:05:00,550

stage which is followed by

95

00:05:07,350 --> 00:05:03,510

polymerization reactions and then

96

00:05:11,250 --> 00:05:07,360

organization and so enough I haven't

97

00:05:12,870 --> 00:05:11,260

drawn a line here where life emerges but

98

00:05:15,450 --> 00:05:12,880

we all know that you know at this stage

99

00:05:18,120 --> 00:05:15,460

when we have cells and organization we

100

00:05:20,790 --> 00:05:18,130

have luck so the interconversion between

101

00:05:24,090 --> 00:05:20,800

small molecules these molecules that

102

00:05:26,370 --> 00:05:24,100

I've shown above maintaining the pool of

103

00:05:28,410 --> 00:05:26,380

raw materials for condensation reaction

104

00:05:30,650 --> 00:05:28,420

the second stage that result the

105

00:05:33,210 --> 00:05:30,660

formation of proto biomolecules is

106

00:05:35,640 --> 00:05:33,220

critical for the original so again we're

107

00:05:39,600 --> 00:05:35,650

talking about hating chemistry of his

108

00:05:42,510 --> 00:05:39,610

first stage so when Dave Desmarais gave

109

00:05:46,890 --> 00:05:42,520

his talk he presented this slide from

110

00:05:49,400 --> 00:05:46,900

Andrew portillo about the integration of

111

00:05:52,950 --> 00:05:49,410

original life research across the

112

00:05:57,380 --> 00:05:52,960

Institute which includes the studies at

113

00:06:00,780 --> 00:05:57,390

Goddard origin and evolution of organic

114

00:06:04,170 --> 00:06:00,790

studied that wrestler that got catalytic

115

00:06:06,000 --> 00:06:04,180

potential of clays and then to Carnegie

116

00:06:09,810 --> 00:06:06,010

the geochemical steps leading to the

117

00:06:12,180 --> 00:06:09,820

emergence of catalysis then our project

118

00:06:15,780 --> 00:06:12,190

origin and evolution of iron sulfur of

119

00:06:18,429 --> 00:06:15,790

protein enzyme the aims groups research

120

00:06:21,320 --> 00:06:18,439

on that foraging and evolution of in

121

00:06:24,559 --> 00:06:21,330

then the Georgia Tech group looking at

122

00:06:27,080 --> 00:06:24,569

the ribosome and RNA and protein

123

00:06:29,689 --> 00:06:27,090

translation I think you know now that I

124

00:06:32,029 --> 00:06:29,699

have this in my hands I can say that you

125

00:06:34,040 --> 00:06:32,039

know i think our project really in

126
00:06:37,520 --> 00:06:34,050
addition to focusing on this area really

127
00:06:39,709 --> 00:06:37,530
expands from these studies on the

128
00:06:42,709 --> 00:06:39,719
catalytic potential of things through

129
00:06:47,059 --> 00:06:42,719
the origin and evolution of the

130
00:06:49,300 --> 00:06:47,069
influence ok so in biology hating

131
00:06:52,040 --> 00:06:49,310
chemistry or the like is catalyzed by

132
00:06:53,990 --> 00:06:52,050
iron sulfur enzymes and some complex

133
00:06:56,600 --> 00:06:54,000
iron sulfur enzymes and iron sulfur

134
00:07:00,100 --> 00:06:56,610
proteins and enzymes are ubiquitous in

135
00:07:03,980 --> 00:07:00,110
life almost all organisms have these

136
00:07:05,860 --> 00:07:03,990
smaller simpler versions to iron sulfur

137
00:07:10,879 --> 00:07:05,870
clusters four on four so four clusters

138
00:07:13,189 --> 00:07:10,889

three iron for sulfur clusters in many

139

00:07:15,769 --> 00:07:13,199

cases those clusters involved in

140

00:07:17,749 --> 00:07:15,779

electron transfer reactions are involved

141

00:07:20,899 --> 00:07:17,759

in photosynthesis in respiration

142

00:07:22,939 --> 00:07:20,909

involved in many other processes but we

143

00:07:25,670 --> 00:07:22,949

also have these more complex versions

144

00:07:28,129 --> 00:07:25,680

like the metal clusters associated with

145

00:07:31,279 --> 00:07:28,139

nitrogenase the key cluster iron origina

146

00:07:35,149 --> 00:07:31,289

sofa the metal cluster associated with

147

00:07:38,329 --> 00:07:35,159

the iron iron hydrogen aah cluster and

148

00:07:40,730 --> 00:07:38,339

these costs are associated with the

149

00:07:43,899 --> 00:07:40,740

carbon monoxide dehydrogenase acetyl co

150

00:07:46,790 --> 00:07:43,909

raise synthase complex which has nickel

151

00:07:50,409 --> 00:07:46,800

iron sulfur clusters in a couple

152

00:07:53,589 --> 00:07:50,419

different terms so those reactions

153

00:07:57,019 --> 00:07:53,599

catalyzed by these complex iron-sulfur

154

00:07:58,999 --> 00:07:57,029

cluster containing enzymes again these

155

00:08:01,369 --> 00:07:59,009

are reactions hey team chemistry

156

00:08:04,939 --> 00:08:01,379

reactions that would have been important

157

00:08:07,730 --> 00:08:04,949

in the early Earth or at least reactions

158

00:08:09,260 --> 00:08:07,740

that are very similar to the reactions

159

00:08:12,429 --> 00:08:09,270

that would have been important in her

160

00:08:15,890 --> 00:08:12,439

life the hydrogen AIDS reaction the

161

00:08:18,079 --> 00:08:15,900

reversible oxidation of hydrogen the

162

00:08:18,900 --> 00:08:18,089

nitrogenase reaction the reduction of

163

00:08:22,050 --> 00:08:18,910

nitrogen

164

00:08:25,500 --> 00:08:22,060

ammonia the inter conversion between co

165

00:08:29,060 --> 00:08:25,510

and co₂ or the condensation of CO and

166

00:08:32,460 --> 00:08:29,070

methyl groups to form activated absolute

167

00:08:34,230 --> 00:08:32,470

so iron sulfur mineral and other

168

00:08:37,770 --> 00:08:34,240

derivatives have interesting structural

169

00:08:40,110 --> 00:08:37,780

relationships with enzymes and have also

170

00:08:42,540 --> 00:08:40,120

been able to have been shown to catalyze

171

00:08:46,410 --> 00:08:42,550

these type of reaction well this is a

172

00:08:50,610 --> 00:08:46,420

fired from unintentionally created a

173

00:08:53,970 --> 00:08:50,620

strange animation hibbett this this is a

174

00:08:56,370 --> 00:08:53,980

fired from my Brussels work that Mike

175

00:09:00,270 --> 00:08:56,380

Russell bill bill martin just looking at

176

00:09:02,340 --> 00:09:00,280

the similarities between the clusters

177

00:09:04,410 --> 00:09:02,350

the active site clusters co

178

00:09:08,940 --> 00:09:04,420

dehydrogenase and sedo cow attentive and

179

00:09:12,840 --> 00:09:08,950

the structure of a nickel containing ray

180

00:09:16,890 --> 00:09:12,850

got mineral lattice and so you have

181

00:09:20,550 --> 00:09:16,900

nickel the themes the nickel and iron

182

00:09:22,560 --> 00:09:20,560

sulfur clusters and association and you

183

00:09:24,630 --> 00:09:22,570

know we would assert that the

184

00:09:26,970 --> 00:09:24,640

relationship between aerosol for mineral

185

00:09:29,700 --> 00:09:26,980

and iron sulfur enzyme structure

186

00:09:32,520 --> 00:09:29,710

function and reactivities just too

187

00:09:36,050 --> 00:09:32,530

strong to be coincidental and especially

188

00:09:38,820 --> 00:09:36,060

with the you know what we know the

189

00:09:44,690 --> 00:09:38,830

abundance of iron supplemental at the

190

00:09:46,860 --> 00:09:44,700

origin okay another that's an example of

191

00:09:51,480 --> 00:09:46,870

structural relationships here's a couple

192

00:09:55,350 --> 00:09:51,490

reaction or examples of reactivity in

193

00:09:57,330 --> 00:09:55,360

iron sulfur minerals or the why this is

194

00:10:00,260 --> 00:09:57,340

an example from good good job octa

195

00:10:04,320 --> 00:10:00,270

Hauser looking at the formation of

196

00:10:08,880 --> 00:10:04,330

activated after cake under primordial

197

00:10:12,450 --> 00:10:08,890

conditions with small molecule small

198

00:10:16,020 --> 00:10:12,460

molecule precursors and a nickel iron

199

00:10:19,320 --> 00:10:16,030

sulfur amalgam as a catalyst forming an

200

00:10:22,650 --> 00:10:19,330

activated a potato thursday miss

201
00:10:26,569 --> 00:10:22,660
proposed mechanism this is an example

202
00:10:29,419 --> 00:10:26,579
from our kopi I Martin student where

203
00:10:31,460 --> 00:10:29,429
been able to show that he can get

204
00:10:33,619 --> 00:10:31,470
nitrogen reduction under hydrothermal

205
00:10:35,660 --> 00:10:33,629
vent conditions are really know if

206
00:10:37,400 --> 00:10:35,670
you're compared to that predict the

207
00:10:39,949 --> 00:10:37,410
conditions where we produce nitrogenous

208
00:10:44,090 --> 00:10:39,959
fertilizers milder conditions and

209
00:10:47,960 --> 00:10:44,100
temperature and pressure and so this on

210
00:10:52,150 --> 00:10:47,970
this flawed just showings it that the

211
00:10:57,169 --> 00:10:52,160
rate of nitrogen reduction to ammonia

212
00:11:01,429 --> 00:10:57,179
with oxygen sulfide is increased in the

213
00:11:03,350 --> 00:11:01,439

presence of pyrite and Martin and a

214

00:11:07,600 --> 00:11:03,360

number of under other investigators have

215

00:11:10,369 --> 00:11:07,610

been able to show that defects in

216

00:11:12,919 --> 00:11:10,379

mineral structure actually enhance the

217

00:11:17,689 --> 00:11:12,929

reactivity or enhance the catalytic

218

00:11:21,639 --> 00:11:17,699

activity I'll get back to the so those

219

00:11:24,739 --> 00:11:21,649

that three examples really implicate a

220

00:11:27,769 --> 00:11:24,749

iron sulfur or the Royal of iron simple

221

00:11:30,710 --> 00:11:27,779

mineral in these two stages of the

222

00:11:35,449 --> 00:11:30,720

original life in the fourth stage model

223

00:11:39,109 --> 00:11:35,459

that I've already shown and know when

224

00:11:45,530 --> 00:11:39,119

you think about a marker am i doing okay

225

00:11:47,720 --> 00:11:45,540

with the delay yes I'm okay um so you

226

00:11:50,569 --> 00:11:47,730

know if you think about it iron so for

227

00:11:52,460 --> 00:11:50,579

minerals serving as catalysts for these

228

00:11:54,889 --> 00:11:52,470

varying reactions than you have to think

229

00:11:57,109 --> 00:11:54,899

of a variety of iron sulfur minerals it

230

00:11:59,720 --> 00:11:57,119

showed you know the Greg I'd example

231

00:12:01,639 --> 00:11:59,730

that's one modification nickel

232

00:12:05,329 --> 00:12:01,649

association with iron sulfur minerals

233

00:12:07,549 --> 00:12:05,339

but you know to catalyze nitrogen

234

00:12:08,960 --> 00:12:07,559

reduction or reversible hydrogen

235

00:12:10,850 --> 00:12:08,970

oxidation have to take a variety of

236

00:12:13,039 --> 00:12:10,860

different minerals and I think that you

237

00:12:15,919 --> 00:12:13,049

know hydrothermal vent systems or the

238

00:12:17,479 --> 00:12:15,929

effluence of iron sulfidic rich thermal

239

00:12:20,150 --> 00:12:17,489

springs are really inspiration for this

240

00:12:25,239 --> 00:12:20,160

idea to get gradients of temperature and

241

00:12:28,579 --> 00:12:25,249

pressure and different gas solubility

242

00:12:30,590 --> 00:12:28,589

mineral solubility really combinatorial

243

00:12:32,780 --> 00:12:30,600

chemistry with respect to the types of

244

00:12:37,670 --> 00:12:32,790

iron sulfur minerals that you could

245

00:12:39,860 --> 00:12:37,680

right in these systems ok so our project

246

00:12:41,810 --> 00:12:39,870

overall it's really asking this question

247

00:12:43,430 --> 00:12:41,820

can we think about the active sites of

248

00:12:45,740 --> 00:12:43,440

iron sulfur enzymes of highly evolved

249

00:12:48,170 --> 00:12:45,750

derivatives that aren't a tremendous and

250

00:12:50,570 --> 00:12:48,180

from that we have and I'm showing here

251

00:12:55,130 --> 00:12:50,580

the active site of unit h cluster of

252

00:12:57,440 --> 00:12:55,140

hydrogen a and the Armos and cofactor of

253

00:12:59,890 --> 00:12:57,450

nitrogenase a couple of our favorite

254

00:13:02,450 --> 00:12:59,900

model systems with the structure of

255

00:13:05,210 --> 00:13:02,460

minerals and a mineral lattice and you

256

00:13:06,800 --> 00:13:05,220

know from that overarching question the

257

00:13:10,940 --> 00:13:06,810

number of different questions that we

258

00:13:12,410 --> 00:13:10,950

can attach experiments to including g

259

00:13:15,200 --> 00:13:12,420

mineral modifications enhanced

260

00:13:17,060 --> 00:13:15,210

reactivity to minerals be modified in a

261

00:13:20,900 --> 00:13:17,070

manner inspired by the biochemistry to

262

00:13:22,520 --> 00:13:20,910

enhance reactivity what is the influence

263

00:13:26,120 --> 00:13:22,530

of organic nesting or the protein

264

00:13:27,890 --> 00:13:26,130

environment on structuring cell what are

265

00:13:30,620 --> 00:13:27,900

the structural determinants totality

266

00:13:33,020 --> 00:13:30,630

catalysis and how they're derived our

267

00:13:34,970 --> 00:13:33,030

modifications chemically conferred what

268

00:13:37,130 --> 00:13:34,980

is the evolutionary history and origin

269

00:13:39,830 --> 00:13:37,140

of violence such an engine and so this

270

00:13:41,180 --> 00:13:39,840

really these list of questions that I

271

00:13:43,280 --> 00:13:41,190

just rattled off where you really

272

00:13:47,540 --> 00:13:43,290

represent sort of a continuum that's

273

00:13:50,420 --> 00:13:47,550

going across scale and that's really in

274

00:13:53,390 --> 00:13:50,430

a way how our project is set up in three

275

00:13:55,280 --> 00:13:53,400

thrusts series the first thrust area of

276

00:13:57,470 --> 00:13:55,290

focusing on iron sulfur mineral and

277

00:14:00,310 --> 00:13:57,480

modified arms of a mineral structure and

278

00:14:02,630 --> 00:14:00,320

reactivity that's our mineral thrust a

279

00:14:04,520 --> 00:14:02,640

bridging thrust and the medic

280

00:14:07,100 --> 00:14:04,530

iron-sulfur cluster synthesis and

281

00:14:11,060 --> 00:14:07,110

organic nesting thrust probing the

282

00:14:14,420 --> 00:14:11,070

transition between abiotic and biotic or

283

00:14:16,490 --> 00:14:14,430

the relationship between abiotic and

284

00:14:18,860 --> 00:14:16,500

biotic iron sulfur catalysis and that's

285

00:14:20,980 --> 00:14:18,870

our mimetic thrust and then iron super

286

00:14:25,640 --> 00:14:20,990

enzyme structure reactivity and

287

00:14:27,770 --> 00:14:25,650

biosynthesis our enzyme threats so are

288

00:14:30,640 --> 00:14:27,780

our mineral thrusts really the

289

00:14:33,290 --> 00:14:30,650

hypothesis the overarching hypothesis

290

00:14:36,230 --> 00:14:33,300

metal centers in enzymes are more likely

291

00:14:38,360 --> 00:14:36,240

related to mineral defects and ideal

292

00:14:41,050 --> 00:14:38,370

mineral structural motifs and really

293

00:14:43,970 --> 00:14:41,060

sort of probing the effects of defined

294

00:14:44,950 --> 00:14:43,980

modifications or defect I hate it and I

295

00:14:46,360 --> 00:14:44,960

work on these

296

00:14:49,480 --> 00:14:46,370

enzymes that have these beautiful

297

00:14:52,050 --> 00:14:49,490

iron-sulfur clusters I have a reluctance

298

00:14:57,730 --> 00:14:52,060

to connect them to defects so their

299

00:15:00,940 --> 00:14:57,740

modification but you know examining the

300

00:15:03,340 --> 00:15:00,950

relationship between defects the

301
00:15:06,460 --> 00:15:03,350
structure of Defense and the effects on

302
00:15:09,240 --> 00:15:06,470
reactivity and so within that we have

303
00:15:12,670 --> 00:15:09,250
three different levels of which we're

304
00:15:15,970 --> 00:15:12,680
looking at minerals one is to synthesize

305
00:15:21,400 --> 00:15:15,980
these mineral surfaces modify those

306
00:15:25,630 --> 00:15:21,410
mineral surfaces or if we must introduce

307
00:15:29,140 --> 00:15:25,640
defined defects in that characterize the

308
00:15:30,490 --> 00:15:29,150
nature of the defects use a combination

309
00:15:33,970 --> 00:15:30,500
of advanced experimental and theoretical

310
00:15:36,840 --> 00:15:33,980
techniques to develop insight into the

311
00:15:39,700 --> 00:15:36,850
reactions look at the reactivity

312
00:15:42,250 --> 00:15:39,710
directly and the intermediates in those

313
00:15:44,230 --> 00:15:42,260

reactions and then and looking at

314

00:15:46,110 --> 00:15:44,240

defining the energy barriers of

315

00:15:49,120 --> 00:15:46,120

processes connecting the reaction

316

00:15:52,660 --> 00:15:49,130

intermediate together really defining

317

00:15:55,260 --> 00:15:52,670

the reaction mechanism for mineral a lot

318

00:16:00,700 --> 00:15:55,270

of this mineral trust has focused on

319

00:16:04,000 --> 00:16:00,710

reactivity dinitrogen reduction it's

320

00:16:07,950 --> 00:16:04,010

sort of the tour de force you mean this

321

00:16:11,080 --> 00:16:07,960

one is the most challenging reactivity

322

00:16:13,510 --> 00:16:11,090

ok so for from the slide I've already

323

00:16:16,840 --> 00:16:13,520

shown you the real what the mineral

324

00:16:18,850 --> 00:16:16,850

thrust is focusing on is these two

325

00:16:21,490 --> 00:16:18,860

questions here de mineral modifications

326

00:16:24,790 --> 00:16:21,500

enhancer activity and communal be

327

00:16:27,640 --> 00:16:24,800

modified inspired by the biochemistry to

328

00:16:32,880 --> 00:16:27,650

enhance reactivity aurelia driven ligand

329

00:16:36,210 --> 00:16:32,890

accelerated catalysis okay so the first

330

00:16:38,350 --> 00:16:36,220

generating these mineral surfaces or

331

00:16:41,320 --> 00:16:38,360

defective mineral surfaces and

332

00:16:44,170 --> 00:16:41,330

characterizing those that's really a

333

00:16:48,130 --> 00:16:44,180

thrust that damn strong and spearheading

334

00:16:53,020 --> 00:16:48,140

and so we introduces defects and you can

335

00:16:55,780 --> 00:16:53,030

see here hydrogen and barting hydrogen

336

00:16:56,670 --> 00:16:55,790

on this mineral surface hydrogen sulfide

337

00:17:03,690 --> 00:16:56,680

in

338

00:17:05,699 --> 00:17:03,700

defects eyes by six town-based

339

00:17:11,220 --> 00:17:05,709

photoemission or even photoelectron

340

00:17:14,549 --> 00:17:11,230

spectroscopy in the last the next part

341

00:17:17,340 --> 00:17:14,559

of the mineral thrust is looking at

342

00:17:19,770 --> 00:17:17,350

reactivity directly spearheaded by

343

00:17:23,610 --> 00:17:19,780

Martin skinnin who's looking at nitrogen

344

00:17:29,060 --> 00:17:23,620

reduction reactivity but also nitrate

345

00:17:31,850 --> 00:17:29,070

and nitrite sources for abiotic ammonia

346

00:17:36,210 --> 00:17:31,860

reduction of those molecules as well

347

00:17:39,750 --> 00:17:36,220

he's in this first part of grammar

348

00:17:42,240 --> 00:17:39,760

developed a system to in a very

349

00:17:45,380 --> 00:17:42,250

sensitive way detect nitrogen reduction

350

00:17:49,080 --> 00:17:45,390

or of sensitive method for analyzing

351

00:17:51,480 --> 00:17:49,090

ammonia using this making this

352

00:17:56,940 --> 00:17:51,490

fluorescence derivative and has a flow

353

00:17:59,549 --> 00:17:56,950

system where he can analyze the same he

354

00:18:01,860 --> 00:17:59,559

and Dan strong in our team not to look

355

00:18:05,280 --> 00:18:01,870

at intermediates in those reactions

356

00:18:08,760 --> 00:18:05,290

using IR spectroscopy and a significant

357

00:18:11,910 --> 00:18:08,770

challenge with these as was or a barrier

358

00:18:15,299 --> 00:18:11,920

that had to be over time was just with

359

00:18:18,090 --> 00:18:15,309

the sample apparatus having hydrogen

360

00:18:21,210 --> 00:18:18,100

sulfide around very corrosive there was

361

00:18:29,490 --> 00:18:21,220

some problems with the sample apparatus

362

00:18:31,530 --> 00:18:29,500

now and now this feeling the support by

363

00:18:33,870 --> 00:18:31,540

gold plating is actually allowed them to

364

00:18:41,310 --> 00:18:33,880

overcome those challenges and you're

365

00:18:43,770 --> 00:18:41,320

generating results so the third part of

366

00:18:45,630 --> 00:18:43,780

this defining energy barriers of the

367

00:18:47,940 --> 00:18:45,640

processes and connecting reaction

368

00:18:51,270 --> 00:18:47,950

intermediates is the thrust that

369

00:18:53,600 --> 00:18:51,280

spearheaded by Tim Minton and involves

370

00:18:57,440 --> 00:18:53,610

molecular beam songs and here's the

371

00:19:00,030 --> 00:18:57,450

instrument that Tim uses for these

372

00:19:02,070 --> 00:19:00,040

studies that like Labine studies in

373

00:19:03,210 --> 00:19:02,080

attempt to jump to me that if you

374

00:19:04,650 --> 00:19:03,220

wouldn't have become a physical chemist

375

00:19:05,820 --> 00:19:04,660

he would have become a plumber and I

376

00:19:07,200 --> 00:19:05,830

think they've killed is the plumber

377

00:19:10,070 --> 00:19:07,210

really come in handy

378

00:19:12,750 --> 00:19:10,080

terms of maintaining the instrumentation

379

00:19:18,180 --> 00:19:12,760

after I did get my trophy eyes to roll

380

00:19:21,240 --> 00:19:18,190

their eyes advanced Africa ok so what

381

00:19:23,100 --> 00:19:21,250

ten is looking at models of prebiotic

382

00:19:25,320 --> 00:19:23,110

chemical transformations mechanisms for

383

00:19:27,510 --> 00:19:25,330

hydrogen and nitrogen reactions at iron

384

00:19:30,960 --> 00:19:27,520

supplemental services so really bringing

385

00:19:34,340 --> 00:19:30,970

together the results from Dan and

386

00:19:38,430 --> 00:19:34,350

Martin's work and focusing on energy so

387

00:19:40,169 --> 00:19:38,440

what a mark to a level description of

388

00:19:41,820 --> 00:19:40,179

the mechanism nitrogen production and

389

00:19:46,289 --> 00:19:41,830

guide our understanding what kinds of

390

00:19:48,180 --> 00:19:46,299

services are likely to be react and so

391

00:19:50,539 --> 00:19:48,190

these studies will provide an input for

392

00:19:52,620 --> 00:19:50,549

theory and experiments by other groups

393

00:19:55,039 --> 00:19:52,630

explanation of the observed phenomenon

394

00:19:57,480 --> 00:19:55,049

and complex experimental system and

395

00:20:00,930 --> 00:19:57,490

insight in the structural motifs that

396

00:20:01,889 --> 00:20:00,940

have been seen in nature and so really

397

00:20:04,080 --> 00:20:01,899

what we're talking about is

398

00:20:09,149 --> 00:20:04,090

understanding reaction at the molecular

399

00:20:11,549 --> 00:20:09,159

level with these studies and well what

400

00:20:13,950 --> 00:20:11,559

Tim has is you know really it's

401
00:20:16,380 --> 00:20:13,960
basically a closed system where you can

402
00:20:18,090 --> 00:20:16,390
modulate a lot of different variables

403
00:20:20,880 --> 00:20:18,100
and the variables some of the variables

404
00:20:23,159 --> 00:20:20,890
are shown here and look at what comes

405
00:20:25,799 --> 00:20:23,169
out at the end with mass spec and then

406
00:20:30,510 --> 00:20:25,809
from that infer what's going on at the

407
00:20:34,100 --> 00:20:30,520
surface you can look at inelastic

408
00:20:37,740 --> 00:20:34,110
scattering which will be indicative of

409
00:20:41,880 --> 00:20:37,750
energy related to bond breakage and bond

410
00:20:45,299 --> 00:20:41,890
formation okay and here's an example of

411
00:20:48,690 --> 00:20:45,309
experiment here bombarding or using a

412
00:20:51,860 --> 00:20:48,700
molecular beam deuterium atoms on pyrite

413
00:20:58,289 --> 00:20:51,870

surface and looking at the formation of

414

00:21:02,340 --> 00:20:58,299

d2f which looking at d2s and that's

415

00:21:05,159 --> 00:21:02,350

shown here and the maxwell-boltzmann

416

00:21:08,190 --> 00:21:05,169

distribution indicates that the

417

00:21:11,580 --> 00:21:08,200

formation is in thermal equilibrium and

418

00:21:13,500 --> 00:21:11,590

then here is a set of images showing

419

00:21:16,390 --> 00:21:13,510

what happens to the mineral surface

420

00:21:18,400 --> 00:21:16,400

after exposure five minutes and

421

00:21:22,090 --> 00:21:18,410

three hundred twenty minutes here and

422

00:21:26,140 --> 00:21:22,100

these are fpm images of that searches

423

00:21:29,410 --> 00:21:26,150

and Robert who's not with us today

424

00:21:32,010 --> 00:21:29,420

Robert szilágyi one of our co p oz is

425

00:21:34,750 --> 00:21:32,020

actually at the synchrotron source

426

00:21:38,350 --> 00:21:34,760

analyzing what's happening at this

427

00:21:40,000 --> 00:21:38,360

mineral surface using excess so what's

428

00:21:43,240 --> 00:21:40,010

happening to the bonding of iron and

429

00:21:45,160 --> 00:21:43,250

Soviet businesses so tim is also going

430

00:21:47,760 --> 00:21:45,170

to show that the evolution of nitrogen

431

00:21:53,350 --> 00:21:47,770

scattering on these surfaces the

432

00:21:57,040 --> 00:21:53,360

modified surfaces is affected by the

433

00:21:58,840 --> 00:21:57,050

surface roughness and so this may tie us

434

00:22:03,300 --> 00:21:58,850

back to what we were saying earlier

435

00:22:10,690 --> 00:22:03,310

about the that the defect stocks or

436

00:22:12,160 --> 00:22:10,700

defects affecting reactivity okay I got

437

00:22:16,660 --> 00:22:12,170

through that one that one's actually the

438

00:22:20,830 --> 00:22:16,670

toughest women and on to the next dress

439

00:22:22,570 --> 00:22:20,840

the mimetic thrust and this is Trevor

440

00:22:24,670 --> 00:22:22,580

Douglas the leader of that threaten both

441

00:22:27,880 --> 00:22:24,680

Trevor Douglas mark young and John

442

00:22:31,060 --> 00:22:27,890

trivia Stoney group and so this is

443

00:22:33,400 --> 00:22:31,070

iron-sulfur cluster synthesis or organic

444

00:22:36,520 --> 00:22:33,410

nesting so this is really looking at the

445

00:22:38,140 --> 00:22:36,530

effect in a controlled way of a protein

446

00:22:40,920 --> 00:22:38,150

environment on the physical and

447

00:22:44,440 --> 00:22:40,930

catalytic properties of metal clusters

448

00:22:48,370 --> 00:22:44,450

and what you know the systems that use

449

00:22:50,770 --> 00:22:48,380

our protein cages as templates templates

450

00:22:53,980 --> 00:22:50,780

for the synthesis of clusters and they

451
00:22:56,500 --> 00:22:53,990
can do this in a controlled way this is

452
00:22:59,530 --> 00:22:56,510
one example of the ferritin molecule

453
00:23:02,680 --> 00:22:59,540
from pyrococcus furiosus is it done a

454
00:23:04,360 --> 00:23:02,690
stable template you're breaking news for

455
00:23:07,360 --> 00:23:04,370
synthesis which is you know greater

456
00:23:11,890 --> 00:23:07,370
flexibility and so do these syntheses

457
00:23:14,170 --> 00:23:11,900
under hydrothermal vent conditions okay

458
00:23:17,530 --> 00:23:14,180
so that's thrust the mimetic thrust

459
00:23:19,630 --> 00:23:17,540
spans these questions in our continuum

460
00:23:22,180 --> 00:23:19,640
of questions looking at the relation

461
00:23:25,810 --> 00:23:22,190
between iron silver kingdoms and iron

462
00:23:30,400 --> 00:23:25,820
super minions and so the simple system

463
00:23:34,240 --> 00:23:30,410

and showing that the synthesis of or the

464

00:23:38,110 --> 00:23:34,250

protection of iron oxide clusters here

465

00:23:41,350 --> 00:23:38,120

in this mineral pad so in this in this

466

00:23:46,060 --> 00:23:41,360

end picture we have and cage and you can

467

00:23:48,550 --> 00:23:46,070

see this is unstained stained image

468

00:23:50,380 --> 00:23:48,560

where you can see the protein here and

469

00:23:52,570 --> 00:23:50,390

then these are unstained images we're

470

00:23:55,060 --> 00:23:52,580

looking at the density of the metal

471

00:23:58,780 --> 00:23:55,070

clusters here I are not Cyrus and even

472

00:24:00,910 --> 00:23:58,790

here iron sulphide then iron oxide can

473

00:24:04,240 --> 00:24:00,920

be produced by the procedure shown here

474

00:24:09,970 --> 00:24:04,250

and iron sulfide or iron oxide can then be

475

00:24:12,100 --> 00:24:09,980

converted to iron hopefully these

476

00:24:15,240 --> 00:24:12,110

clusters it can be characterized in a

477

00:24:17,230 --> 00:24:15,250

number of ways and this is an example of

478

00:24:19,780 --> 00:24:17,240

characterization by small-angle x-ray

479

00:24:22,810 --> 00:24:19,790

scattering and pear distribution

480

00:24:24,790 --> 00:24:22,820

function which allows us to look at you

481

00:24:27,310 --> 00:24:24,800

know these clusters there really they

482

00:24:29,380 --> 00:24:27,320

don't have a well-defined mineral

483

00:24:33,010 --> 00:24:29,390

lattice and so that the bonding is a

484

00:24:35,970 --> 00:24:33,020

uniform ensue this approach which gives

485

00:24:39,310 --> 00:24:35,980

a similar information to the excess on

486

00:24:43,260 --> 00:24:39,320

someone and that we can get the the

487

00:24:45,520 --> 00:24:43,270

bonding of iron and sulfur in these

488

00:24:51,730 --> 00:24:45,530

somewhat heterogenous that when our

489

00:24:54,790 --> 00:24:51,740

closest and also control and monitor the

490

00:24:58,150 --> 00:24:54,800

cluster size and again you know this is

491

00:25:00,460 --> 00:24:58,160

really an organic template we're growing

492

00:25:04,180 --> 00:25:00,470

mineral clusters and then looking at the

493

00:25:06,610 --> 00:25:04,190

effect of cluster size and the protein

494

00:25:09,670 --> 00:25:06,620

environment what the protein environment

495

00:25:13,660 --> 00:25:09,680

imposes on the clusters in terms of its

496

00:25:18,790 --> 00:25:13,670

physical properties and reactivity this

497

00:25:21,370 --> 00:25:18,800

is one example of effect of the protein

498

00:25:24,550 --> 00:25:21,380

environment on the properties of these

499

00:25:27,370 --> 00:25:24,560

mineral clusters and this is looking at

500

00:25:30,130 --> 00:25:27,380

magnetism and this is showing here a

501
00:25:32,020 --> 00:25:30,140
cluster with the protein environment

502
00:25:34,930 --> 00:25:32,030
here showing that in the presence of the

503
00:25:37,170 --> 00:25:34,940
protein environment in this particle all

504
00:25:40,000 --> 00:25:37,180
the spindle on but if we remove the

505
00:25:43,600 --> 00:25:40,010
protein environment here the spins at

506
00:25:45,550 --> 00:25:43,610
the surface randomized and then can

507
00:25:49,960 --> 00:25:45,560
introduce that protein environment and

508
00:25:52,180 --> 00:25:49,970
restore that the alignment so the

509
00:25:53,970 --> 00:25:52,190
protein environment impacting the

510
00:25:57,160 --> 00:25:53,980
physical property of those clusters

511
00:25:59,920 --> 00:25:57,170
another example here is looking at the

512
00:26:01,720 --> 00:25:59,930
effect of size on the physical

513
00:26:04,690 --> 00:26:01,730

properties of those clusters and this is

514

00:26:07,210 --> 00:26:04,700

again a an example of magnetism with

515

00:26:08,740 --> 00:26:07,220

particle five nanometers eight

516

00:26:11,350 --> 00:26:08,750

nanometers and twenty nanometers

517

00:26:14,320 --> 00:26:11,360

applying a magnetic field for those

518

00:26:18,310 --> 00:26:14,330

particles and working as a change in

519

00:26:21,070 --> 00:26:18,320

momentum and can see in this 5 nanometer

520

00:26:24,640 --> 00:26:21,080

particle in the 8th animator particle it

521

00:26:28,000 --> 00:26:24,650

returns to the same moment here but the

522

00:26:30,460 --> 00:26:28,010

larger particle actually has some memory

523

00:26:34,870 --> 00:26:30,470

so there's a difference in the physical

524

00:26:38,950 --> 00:26:34,880

property that larger partisan so size

525

00:26:42,000 --> 00:26:38,960

affects the physical properties that the

526

00:26:44,710 --> 00:26:42,010

particle or the cluster in this state

527

00:26:46,840 --> 00:26:44,720

another example to influence of the

528

00:26:50,050 --> 00:26:46,850

protein environment on catalytic

529

00:26:56,220 --> 00:26:50,060

activity and this is an example of epic

530

00:26:59,130 --> 00:26:56,230

03 in ferritin and looking at that that

531

00:27:01,120 --> 00:26:59,140

cluster terms of its reactivity as a

532

00:27:04,120 --> 00:27:01,130

photocatalyst and actually be enough to

533

00:27:08,620 --> 00:27:04,130

measure this as a photo carry and so

534

00:27:10,480 --> 00:27:08,630

that that's a an example of reactivity

535

00:27:13,210 --> 00:27:10,490

of reactivity that we can measure them

536

00:27:16,570 --> 00:27:13,220

and that's a an objective and the thrust

537

00:27:22,450 --> 00:27:16,580

and now you know we've lips go back to

538

00:27:26,500 --> 00:27:22,460

that flood we have a facile means to

539

00:27:29,890 --> 00:27:26,510

convert these iron oxide clusters to

540

00:27:32,560 --> 00:27:29,900

iron-sulfur clusters and you know of the

541

00:27:33,190 --> 00:27:32,570

parallel analysis is now on going for

542

00:27:37,299 --> 00:27:33,200

the iron

543

00:27:41,649 --> 00:27:37,309

clusters and then they have some data on

544

00:27:44,470 --> 00:27:41,659

that and that will see the ready for

545

00:27:45,639 --> 00:27:44,480

prime time okay so that's the second

546

00:27:47,649 --> 00:27:45,649

thrust and I'm actually doing pretty

547

00:27:50,919 --> 00:27:47,659

good on time animes but I think I'm

548

00:27:53,529 --> 00:27:50,929

going like a mile event here and I can

549

00:27:58,870 --> 00:27:53,539

go into our iron sulfur ends on dress

550

00:28:01,029 --> 00:27:58,880

and so this is that John Broderick and

551
00:28:02,470 --> 00:28:01,039
and I are spearheading and what we're

552
00:28:05,049 --> 00:28:02,480
doing is rubbing the structural

553
00:28:07,090 --> 00:28:05,059
determinants with developers were

554
00:28:09,759 --> 00:28:07,100
probing complex called the biosynthesis

555
00:28:12,120 --> 00:28:09,769
and the evolutionary origin and history

556
00:28:15,220 --> 00:28:12,130
of iron sulfur proteins in England

557
00:28:19,180 --> 00:28:15,230
couple of our favorite systems the iron

558
00:28:22,360 --> 00:28:19,190
iron hydrogenase so this is an enzyme

559
00:28:27,029 --> 00:28:22,370
that has a number of different metal

560
00:28:29,769 --> 00:28:27,039
clusters one of these complex

561
00:28:32,560 --> 00:28:29,779
iron-sulfur clusters there's a 4-iron

562
00:28:35,500 --> 00:28:32,570
for sulfur cluster that's bridge to this

563
00:28:38,740 --> 00:28:35,510

really organometallic e to iron unit

564

00:28:41,529 --> 00:28:38,750

that has carbon monoxide and cyanides as

565

00:28:44,460 --> 00:28:41,539

ligands I'm these hydrogenation systems

566

00:28:48,909 --> 00:28:44,470

are the only known systems that have

567

00:28:53,470 --> 00:28:48,919

this variation of modification to an

568

00:28:57,930 --> 00:28:53,480

iron-sulfur cluster these diatomics and

569

00:29:02,379 --> 00:28:57,940

then my charge note and this is the

570

00:29:05,080 --> 00:29:02,389

protein that harbors the active site for

571

00:29:08,139 --> 00:29:05,090

nitrogen reduction to a milling at the

572

00:29:10,000 --> 00:29:08,149

iron molybdenum cofactor so this shows

573

00:29:12,549 --> 00:29:10,010

the protein environment here this is a

574

00:29:14,680 --> 00:29:12,559

mono merrick protein as these five

575

00:29:16,930 --> 00:29:14,690

different metal clusters that has these

576

00:29:20,049 --> 00:29:16,940

accessory clusters that were presumably

577

00:29:22,779 --> 00:29:20,059

involved in shuttling electrons to or

578

00:29:25,870 --> 00:29:22,789

from that active site in reversible

579

00:29:28,299 --> 00:29:25,880

hydrogen oxidation and nitrogenase which

580

00:29:32,200 --> 00:29:28,309

is a hetero tetra mer two types of

581

00:29:34,690 --> 00:29:32,210

subunit two types of metal clusters 12 p

582

00:29:37,360 --> 00:29:34,700

clusters which are again intermediates

583

00:29:38,150 --> 00:29:37,370

and electron transfer to the business

584

00:29:42,270 --> 00:29:38,160

sizes

585

00:29:44,340 --> 00:29:42,280

co-factors which I it's a complex

586

00:29:48,210 --> 00:29:44,350

iron-sulfur cluster but it's hetero

587

00:29:52,310 --> 00:29:48,220

metallic it has molybdenum in addition

588

00:29:55,830 --> 00:29:52,320

to iron and sulfur and again some

589

00:30:00,060 --> 00:29:55,840

organic groups that are present to tune

590

00:30:03,510 --> 00:30:00,070

the reactivity of that system okay so

591

00:30:05,280 --> 00:30:03,520

now we're in this threat moving through

592

00:30:07,500 --> 00:30:05,290

this continuum what are the structural

593

00:30:11,040 --> 00:30:07,510

determinants of catalysis and how they

594

00:30:14,280 --> 00:30:11,050

derive really what are the structure and

595

00:30:17,090 --> 00:30:14,290

reactivity of these ends on how is

596

00:30:21,570 --> 00:30:17,100

modifications confer that's the bottom

597

00:30:26,520 --> 00:30:21,580

and then what's the evolutionary history

598

00:30:28,530 --> 00:30:26,530

of the origin of iron sisters okay so in

599

00:30:31,410 --> 00:30:28,540

this far i'm just showing what kind of

600

00:30:33,150 --> 00:30:31,420

known about the biosynthesis of the iron

601
00:30:37,710 --> 00:30:33,160
molybdenum cofactor in nitrogen

602
00:30:40,170 --> 00:30:37,720
interestingly you know that making a

603
00:30:43,310 --> 00:30:40,180
complex iron-sulfur cluster these unique

604
00:30:45,750 --> 00:30:43,320
modifications to the variations on the

605
00:30:49,200 --> 00:30:45,760
conflict or this iron sulfur

606
00:30:52,440 --> 00:30:49,210
coastertheme requires an enzymatic

607
00:30:54,990 --> 00:30:52,450
pathway requires a lot of biochemical

608
00:30:58,350 --> 00:30:55,000
machinery requires scaffolds and

609
00:30:59,970 --> 00:30:58,360
carriers and enzymes and a bunch of

610
00:31:02,460 --> 00:30:59,980
things that are thus far it might know

611
00:31:05,760 --> 00:31:02,470
this side really isn't from our work

612
00:31:07,200 --> 00:31:05,770
here this represents about 30 years of

613
00:31:09,870 --> 00:31:07,210

work from a number of different

614

00:31:13,860 --> 00:31:09,880

investigators to really at least at this

615

00:31:16,500 --> 00:31:13,870

level of insight on ironwood them

616

00:31:20,400 --> 00:31:16,510

cofactor bio synthesis and so what this

617

00:31:24,330 --> 00:31:20,410

slide is showing us just to simplify the

618

00:31:26,490 --> 00:31:24,340

if you have a scaffold and a scaffold

619

00:31:30,210 --> 00:31:26,500

that structurally similar to the

620

00:31:32,310 --> 00:31:30,220

molybdenum iron protein where a bunch of

621

00:31:36,620 --> 00:31:32,320

different enzymes and carriers at to

622

00:31:39,210 --> 00:31:36,630

build an iron molybdenum cofactor and

623

00:31:44,250 --> 00:31:39,220

after that i erm live in and cofactors

624

00:31:47,700 --> 00:31:44,260

built that's inserted into an organic

625

00:31:50,519 --> 00:31:47,710

mass or an 80 protein

626

00:31:52,289 --> 00:31:50,529

to give it its reactivity so this is

627

00:31:54,090 --> 00:31:52,299

really interesting in terms of the

628

00:31:55,980 --> 00:31:54,100

prebiotic chemistry the way we're

629

00:31:58,440 --> 00:31:55,990

thinking about things because you have

630

00:32:01,380 --> 00:31:58,450

the apparatus for the cluster is really

631

00:32:04,320 --> 00:32:01,390

separate to building the mess and in the

632

00:32:06,960 --> 00:32:04,330

final step to make the cluster reactive

633

00:32:13,560 --> 00:32:06,970

you insert the cluster in the nest to

634

00:32:16,909 --> 00:32:13,570

make an active India okay so there's

635

00:32:20,549 --> 00:32:16,919

some really interesting ties between the

636

00:32:23,669 --> 00:32:20,559

biosynthesis of the cluster I just

637

00:32:26,539 --> 00:32:23,679

showed you that the iron ilysm cofactor

638

00:32:30,659 --> 00:32:26,549

and our hydrogenation system and that

639

00:32:34,100 --> 00:32:30,669

link is in iron sulfur face radical

640

00:32:36,990 --> 00:32:34,110

chemistry so there's two enzymes in the

641

00:32:40,350 --> 00:32:37,000

biosynthesis of this cluster the H

642

00:32:43,760 --> 00:32:40,360

cluster and one enzyme involved in the

643

00:32:47,909 --> 00:32:43,770

synthesis of the iron ilysm cofactor

644

00:32:52,470 --> 00:32:47,919

that are radical Salmons iron sulfur

645

00:32:54,870 --> 00:32:52,480

based radical generating in zones so

646

00:32:57,720 --> 00:32:54,880

this is the active side of that in front

647

00:33:01,769 --> 00:32:57,730

of this whole class of radical fanzines

648

00:33:06,060 --> 00:33:01,779

on which hi-de-hi g and myth be our

649

00:33:08,940 --> 00:33:06,070

members where you have an iron-sulfur

650

00:33:11,430 --> 00:33:08,950

cluster and epidemic feel defining and

651
00:33:14,580 --> 00:33:11,440
that iron-sulfur clusters please

652
00:33:17,610 --> 00:33:14,590
epidemic feel defining form of dining

653
00:33:19,889 --> 00:33:17,620
and and erratic and that radical is

654
00:33:25,139 --> 00:33:19,899
coupled to a lot of different chemistry

655
00:33:29,399 --> 00:33:25,149
in nature generating radicals of amino

656
00:33:31,590 --> 00:33:29,409
acids it can be intermediate a radical

657
00:33:34,139 --> 00:33:31,600
of a minute and maybe a radical

658
00:33:36,360 --> 00:33:34,149
intermediate of an amino acid is

659
00:33:43,049 --> 00:33:36,370
involved in amino acid isomerization

660
00:33:44,909 --> 00:33:43,059
reaction is the reaction who the radical

661
00:33:47,669 --> 00:33:44,919
generation is important for sulfur

662
00:33:50,909 --> 00:33:47,679
insertion like the filter insertion to 5

663
00:33:54,659 --> 00:33:50,919

10 and shown here and this five consent

664

00:33:59,410 --> 00:33:54,669

brave soul for insertion for generating

665

00:34:04,690 --> 00:33:59,420

lopaka those

666

00:34:06,940 --> 00:34:04,700

so the known radical Sam chemistry

667

00:34:09,130 --> 00:34:06,950

really sparked us to kind of generate a

668

00:34:12,640 --> 00:34:09,140

hypothesis how that type of chemistry

669

00:34:14,409 --> 00:34:12,650

could be involved in hydrogenase H

670

00:34:16,600 --> 00:34:14,419

cluster biosynthesis and as I mentioned

671

00:34:18,430 --> 00:34:16,610

that's a really interesting variation on

672

00:34:21,100 --> 00:34:18,440

the iron sort of thing that has very

673

00:34:25,300 --> 00:34:21,110

unique ligands and that we can see this

674

00:34:28,510 --> 00:34:25,310

up here we have a byways ligand only

675

00:34:31,419 --> 00:34:28,520

place in nature that scene it's a non

676

00:34:33,760 --> 00:34:31,429

protein-dye pilot this isn't 15 this is

677

00:34:36,430 --> 00:34:33,770

a thigh late ligand that's not

678

00:34:38,950 --> 00:34:36,440

associated with approaching and these

679

00:34:42,940 --> 00:34:38,960

carbon monoxide and cyanide ligands

680

00:34:45,159 --> 00:34:42,950

again a unique feature to hydrogenate so

681

00:34:48,300 --> 00:34:45,169

we started to ask question you know how

682

00:34:50,950 --> 00:34:48,310

could those ligands be generated by

683

00:34:53,350 --> 00:34:50,960

radical same chemistry and we thought

684

00:34:55,480 --> 00:34:53,360

about that in the context of known

685

00:34:58,420 --> 00:34:55,490

radical Sam chemistry and came up with

686

00:35:01,200 --> 00:34:58,430

the hypothesis a hypothesis that if we

687

00:35:05,470 --> 00:35:01,210

started with a simple iron-sulfur

688

00:35:09,880 --> 00:35:05,480

cluster precursor we could introduce a

689

00:35:12,160 --> 00:35:09,890

dive bar leg leg in from a central

690

00:35:15,070 --> 00:35:12,170

metabolite amino acid or glycolytic

691

00:35:19,630 --> 00:35:15,080

intermediate we don't know the substrate

692

00:35:23,980 --> 00:35:19,640

for that yet by chemistry that's very

693

00:35:25,870 --> 00:35:23,990

similar to known sulfur insertion

694

00:35:29,760 --> 00:35:25,880

chemistry chemistry that we know that

695

00:35:33,130 --> 00:35:29,770

these radical salmon's on will catalyze

696

00:35:35,530 --> 00:35:33,140

and we could generate an intermediate

697

00:35:38,140 --> 00:35:35,540

that actually shifts the reactivity in

698

00:35:39,810 --> 00:35:38,150

this small iron-sulfur cluster to the

699

00:35:42,490 --> 00:35:39,820

iron atoms and we can think about

700

00:35:46,270 --> 00:35:42,500

reactivity occurring at the iron atom

701
00:35:49,090 --> 00:35:46,280
and the generation of these diatomic

702
00:35:51,460 --> 00:35:49,100
alliances unique diatomic physics and

703
00:35:53,830 --> 00:35:51,470
then again we go back to this known

704
00:35:56,620 --> 00:35:53,840
reactivity for the radical salmon runs

705
00:35:58,300 --> 00:35:56,630
and we've proposed that if we formed an

706
00:36:02,950 --> 00:35:58,310
amino acid radical through this

707
00:36:06,280 --> 00:36:02,960
chemistry that that access iron die

708
00:36:08,660 --> 00:36:06,290
violently or iron violates sites that we

709
00:36:12,319 --> 00:36:08,670
could get decomposition of an

710
00:36:15,079 --> 00:36:12,329
mastered radical to form carbon monoxide

711
00:36:18,589 --> 00:36:15,089
and cyanide if you think about that you

712
00:36:22,099 --> 00:36:18,599
think about glycine well I've seen if

713
00:36:24,559 --> 00:36:22,109

you take glycine you bind it at an iron

714

00:36:27,890 --> 00:36:24,569

thiolate side a glycine radical if you

715

00:36:30,799 --> 00:36:27,900

shuffle around the electrons you can

716

00:36:33,170 --> 00:36:30,809

generate carbon monoxide cyanide and

717

00:36:37,789 --> 00:36:33,180

water very similar to the legand

718

00:36:41,349 --> 00:36:37,799

arrangement received in the iron ion

719

00:36:45,920 --> 00:36:41,359

hydrogen so this is our really this is a

720

00:36:48,740 --> 00:36:45,930

hypothesis and it's very intriguing and

721

00:36:51,770 --> 00:36:48,750

very intriguing in terms of astrobiology

722

00:36:53,630 --> 00:36:51,780

and Robert szilagyi generated a

723

00:36:57,470 --> 00:36:53,640

potential energy surface to map this

724

00:37:01,819 --> 00:36:57,480

reaction and if we have an iron one file

725

00:37:04,700 --> 00:37:01,829

a and this is an in silico experiment

726

00:37:07,250 --> 00:37:04,710

here we can generate a potential energy

727

00:37:09,859 --> 00:37:07,260

surface or a reaction coordinate that

728

00:37:12,770 --> 00:37:09,869

describes a favorable reaction of the

729

00:37:15,140 --> 00:37:12,780

decomposition of glycine the carbon

730

00:37:17,450 --> 00:37:15,150

monoxide cyanide and water that is iron

731

00:37:19,370 --> 00:37:17,460

high wavelength we have a favorable

732

00:37:22,130 --> 00:37:19,380

reaction we have an activation barrier

733

00:37:26,750 --> 00:37:22,140

that the activation barrier in this

734

00:37:29,450 --> 00:37:26,760

reaction is generating that amino acid

735

00:37:31,700 --> 00:37:29,460

radical and we know that we can overcome

736

00:37:33,859 --> 00:37:31,710

those barriers with radical same enzyme

737

00:37:37,160 --> 00:37:33,869

so this is you know if you think about

738

00:37:38,900 --> 00:37:37,170

this reaction you have the decomposition

739

00:37:41,990 --> 00:37:38,910

going in this direction to decomposition

740

00:37:44,900 --> 00:37:42,000

of an amino acid to form carbon monoxide

741

00:37:46,760 --> 00:37:44,910

cyanide and water if we think about the

742

00:37:49,339 --> 00:37:46,770

reaction in the reverse which we can get

743

00:37:52,160 --> 00:37:49,349

a favorable reaction immersively monkey

744

00:37:54,589 --> 00:37:52,170

with the oxidation of the metal side of

745

00:37:56,990 --> 00:37:54,599

the iron filings then we're talking

746

00:38:01,220 --> 00:37:57,000

about a condensation reaction where we

747

00:38:04,190 --> 00:38:01,230

have co and cyanide and water to form an

748

00:38:07,609 --> 00:38:04,200

immense and so really this represents in

749

00:38:10,430 --> 00:38:07,619

another potential leg involving iron

750

00:38:12,740 --> 00:38:10,440

sulfur motives linking hating chemistry

751

00:38:15,160 --> 00:38:12,750

and abiotic chemistry or inter

752

00:38:24,990 --> 00:38:15,170

conversion between small molecules and

753

00:38:29,049 --> 00:38:27,730

again you know in these studies and I'm

754

00:38:32,170 --> 00:38:29,059

just going to talk about a few examples

755

00:38:35,829 --> 00:38:32,180

of what we're doing instruction function

756

00:38:37,809 --> 00:38:35,839

of nitrogenase and hydrogenation you

757

00:38:40,359 --> 00:38:37,819

know an interesting and I've already

758

00:38:42,270 --> 00:38:40,369

drawn your attention to this is an

759

00:38:46,960 --> 00:38:42,280

interesting observation deck for

760

00:38:49,059 --> 00:38:46,970

nitrogenase has the synthesis of the

761

00:38:54,250 --> 00:38:49,069

iron molybdenum cofactor occurs on a

762

00:38:57,490 --> 00:38:54,260

scaffold and we've been examining this

763

00:39:00,160 --> 00:38:57,500

process or the synthesis just showing

764

00:39:02,440 --> 00:39:00,170

you that hypothesis for iron iron

765

00:39:04,809 --> 00:39:02,450

hydrogen's clusters and a lot of the

766

00:39:07,299 --> 00:39:04,819

ideas that we generated in terms of

767

00:39:09,609 --> 00:39:07,309

developing its experimental line to

768

00:39:12,599 --> 00:39:09,619

probe H poster biosynthesis was really

769

00:39:15,010 --> 00:39:12,609

based on some of the observations in

770

00:39:17,049 --> 00:39:15,020

nitrogenated device and system one of

771

00:39:21,279 --> 00:39:17,059

the questions that we've been asking is

772

00:39:24,430 --> 00:39:21,289

that theme carry over to hydrogenous do

773

00:39:28,390 --> 00:39:24,440

you make a cluster independent of the

774

00:39:30,910 --> 00:39:28,400

protein on a scaffold and then insert

775

00:39:33,549 --> 00:39:30,920

the cluster into the organic nest to

776

00:39:36,910 --> 00:39:33,559

define its reactivity and we have some

777

00:39:40,660 --> 00:39:36,920

new results that we're we're looking at

778

00:39:44,799 --> 00:39:40,670

the structure of that a PO end zone for

779

00:39:48,490 --> 00:39:44,809

the hydrogenase before it's been acted

780

00:39:51,490 --> 00:39:48,500

on by those biosynthetic genes and what

781

00:39:54,789 --> 00:39:51,500

we've been able to show is that a PO

782

00:39:57,339 --> 00:39:54,799

enzyme is devoid of not the whole

783

00:39:58,990 --> 00:39:57,349

cluster but just that to iron Union and

784

00:40:02,230 --> 00:39:59,000

from that we can get the insight that

785

00:40:04,740 --> 00:40:02,240

all this machinery is directed at just

786

00:40:06,849 --> 00:40:04,750

that to iron unit just that

787

00:40:09,970 --> 00:40:06,859

organometallic key thing with co and

788

00:40:12,579 --> 00:40:09,980

cyanide and dilate and that's kind of

789

00:40:15,130 --> 00:40:12,589

what we have proposed in this hypothesis

790

00:40:17,470 --> 00:40:15,140

because these iron-sulfur clusters these

791

00:40:19,390 --> 00:40:17,480

who are for sulfur clusters which is the

792

00:40:22,599 --> 00:40:19,400

other component of that cluster are

793

00:40:26,019 --> 00:40:22,609

typically made by host you know

794

00:40:30,190 --> 00:40:26,029

housekeeping cell machine but what we've

795

00:40:32,160 --> 00:40:30,200

been also able to show is in showing the

796

00:40:35,910 --> 00:40:32,170

AVO protein

797

00:40:37,190 --> 00:40:35,920

ways to accept this to iron unit that

798

00:40:40,079 --> 00:40:37,200

there are really just amazing

799

00:40:45,960 --> 00:40:40,089

similarities between this hydrogen egg

800

00:40:48,569 --> 00:40:45,970

and the nitrogenous into in the 80

801
00:40:51,720 --> 00:40:48,579
proteins of both of those systems you

802
00:40:54,510 --> 00:40:51,730
have a channel leading to the active

803
00:40:57,359 --> 00:40:54,520
site ready to be the recipient of this

804
00:41:00,450 --> 00:40:57,369
cluster it's a positively charged

805
00:41:05,089 --> 00:41:00,460
channel here we have the hydrogenase in

806
00:41:07,829 --> 00:41:05,099
the positively charged channel and the

807
00:41:10,849 --> 00:41:07,839
nitrogenous it's positively charged

808
00:41:13,680 --> 00:41:10,859
general in both of these metal clusters

809
00:41:16,170 --> 00:41:13,690
without the influence of their protein

810
00:41:21,299 --> 00:41:16,180
environment are negatively charged

811
00:41:24,450 --> 00:41:21,309
clusters so amazing of parallels between

812
00:41:28,950 --> 00:41:24,460
the two systems and a general theme of

813
00:41:35,420 --> 00:41:28,960

in terms of the final step the organic

814

00:41:43,069 --> 00:41:35,430

nesting these catalytic clusters okay

815

00:41:46,859 --> 00:41:43,079

another nor study or this team for

816

00:41:48,690 --> 00:41:46,869

nitrogenase see moco biosynthesis is

817

00:41:50,870 --> 00:41:48,700

really kind of inspiration for our

818

00:41:53,370 --> 00:41:50,880

studies aimed at looking at the

819

00:41:58,530 --> 00:41:53,380

evolutionary origins of nitrogen

820

00:42:01,230 --> 00:41:58,540

fixation as I mentioned this nifty n or

821

00:42:06,390 --> 00:42:01,240

this scaffold protein is structurally

822

00:42:12,420 --> 00:42:06,400

similar to nifty k for the hydrogen's

823

00:42:15,690 --> 00:42:12,430

and so this was generated this scaffold

824

00:42:18,569 --> 00:42:15,700

in defining the entire process were

825

00:42:21,000 --> 00:42:18,579

getting an active nitrogenase this was

826
00:42:25,260 --> 00:42:21,010
generated from gene duplication event

827
00:42:28,190 --> 00:42:25,270
where DK was duplicated as a unit to

828
00:42:32,190 --> 00:42:28,200
form en and so we've been using that

829
00:42:35,700 --> 00:42:32,200
gene duplication event as well as gene

830
00:42:38,280 --> 00:42:35,710
fusions of events or the traits of seven

831
00:42:40,190 --> 00:42:38,290
different genetic loci to trace the

832
00:42:43,770 --> 00:42:40,200
evolutionary or

833
00:42:45,930 --> 00:42:43,780
nitrogen fixation in extant organisms

834
00:42:48,690 --> 00:42:45,940
and this work was just submitted for

835
00:42:51,930 --> 00:42:48,700
publication and I don't have time to go

836
00:42:53,790 --> 00:42:51,940
through and describe all the facets of

837
00:42:57,720 --> 00:42:53,800
the work but basically the bottom line

838
00:43:01,470 --> 00:42:57,730

is that we can we can say from the

839

00:43:03,840 --> 00:43:01,480

occurrence that nitrogen fixation was

840

00:43:06,960 --> 00:43:03,850

not likely to be present in the last

841

00:43:10,220 --> 00:43:06,970

Universal common ancestor and that

842

00:43:12,780 --> 00:43:10,230

nitrogen fixation or at least molybdenum

843

00:43:15,540 --> 00:43:12,790

nitrogenase catalyzed biological

844

00:43:18,480 --> 00:43:15,550

nitrogen fixation original in

845

00:43:22,560 --> 00:43:18,490

methanogenic archaea and I think you

846

00:43:25,770 --> 00:43:22,570

know this line has been of interest to

847

00:43:28,290 --> 00:43:25,780

the Arizona group and the work of Bob

848

00:43:31,500 --> 00:43:28,300

Blankenship in Jason Raymond who's a

849

00:43:33,060 --> 00:43:31,510

part of their in 18 and but also you

850

00:43:36,330 --> 00:43:33,070

know where do we find nitrogen fixation

851
00:43:39,120 --> 00:43:36,340
or where do we find hydrogen metabolism

852
00:43:42,240 --> 00:43:39,130
where were these processes likely to

853
00:43:45,180 --> 00:43:42,250
emerge on earth our topics that really

854
00:43:50,010 --> 00:43:45,190
bridge the interests of our teams and

855
00:43:52,830 --> 00:43:50,020
Arizona team aims Penn State with Greg

856
00:43:55,860 --> 00:43:52,840
ferry the carnegie team at which john

857
00:43:59,460 --> 00:43:55,870
Barris is is a member so there are some

858
00:44:07,940 --> 00:43:59,470
a lot of good connections to make in

859
00:44:12,150 --> 00:44:07,950
these areas okay so to pour the our

860
00:44:14,670 --> 00:44:12,160
experimental to kind of come to a

861
00:44:17,760 --> 00:44:14,680
conclusion with our experimental line in

862
00:44:21,420 --> 00:44:17,770
terms of our project really robert

863
00:44:24,180 --> 00:44:21,430

szilagy is he's a computational chemist

864

00:44:27,240 --> 00:44:24,190

theoretical chemist physical chemist

865

00:44:31,500 --> 00:44:27,250

that is really using theoretical

866

00:44:35,340 --> 00:44:31,510

chemistry and x-ray absorption

867

00:44:38,700 --> 00:44:35,350

spectroscopy to bridge all our three

868

00:44:40,830 --> 00:44:38,710

thrusts together so Robert is able to

869

00:44:42,780 --> 00:44:40,840

use one approach or these two approaches

870

00:44:45,390 --> 00:44:42,790

theoretical chemistry and x-ray

871

00:44:48,420 --> 00:44:45,400

absorption spectroscopy to analyze all

872

00:44:50,130 --> 00:44:48,430

materials across the continuum so he can

873

00:44:52,920 --> 00:44:50,140

use one approach to look at all these

874

00:44:53,339 --> 00:44:52,930

different things that are we're

875

00:44:54,870 --> 00:44:53,349

listening

876

00:45:00,779 --> 00:44:54,880

in the mineral thrust the pneumatic

877

00:45:03,120 --> 00:45:00,789

thrust and iron sulfur enzyme thrust we

878

00:45:04,799 --> 00:45:03,130

have a very strong philosophy component

879

00:45:07,109 --> 00:45:04,809

and have been developing a strong

880

00:45:08,999 --> 00:45:07,119

philosophy components and in these

881

00:45:12,180 --> 00:45:09,009

origin alive studies and war Jenna

882

00:45:14,779 --> 00:45:12,190

catalysis there's some number of

883

00:45:17,160 --> 00:45:14,789

interesting questions that can be posed

884

00:45:20,039 --> 00:45:17,170

philosophically the traditional

885

00:45:22,999 --> 00:45:20,049

questions the analysis of RNA versus

886

00:45:26,460 --> 00:45:23,009

metabolism debate the analysis of that

887

00:45:29,160 --> 00:45:26,470

those questions whether we're asking the

888

00:45:32,940 --> 00:45:29,170

right questions whether we can use

889

00:45:35,039 --> 00:45:32,950

traditional philosophical approaches to

890

00:45:38,059 --> 00:45:35,049

analyze that question and that really

891

00:45:40,920 --> 00:45:38,069

brings in can you use traditional

892

00:45:46,499 --> 00:45:40,930

philosophical approach to take a look at

893

00:45:48,390 --> 00:45:46,509

emerging sciences and and review them

894

00:45:51,420 --> 00:45:48,400

and theories about the definitions was

895

00:45:53,549 --> 00:45:51,430

really creating framework to pursue

896

00:45:57,289 --> 00:45:53,559

philosophical questions related to the

897

00:46:01,229 --> 00:45:57,299

nature of living things in this group

898

00:46:04,559 --> 00:46:01,239

from shortly after our project started

899

00:46:06,180 --> 00:46:04,569

we had a weekly working grid for the

900

00:46:09,779 --> 00:46:06,190

philosophy component of this in this

901
00:46:12,380 --> 00:46:09,789
group consists of students in philosophy

902
00:46:14,579 --> 00:46:12,390
and students in our science programs

903
00:46:18,150 --> 00:46:14,589
graduate students and undergraduate

904
00:46:22,559 --> 00:46:18,160
students students and faculty and this

905
00:46:25,079 --> 00:46:22,569
has really been a powerful tool for

906
00:46:27,539 --> 00:46:25,089
actually for all of us in the center of

907
00:46:31,950 --> 00:46:27,549
thinking about how we think about our

908
00:46:35,690 --> 00:46:31,960
problems we've traditionally at MSU had

909
00:46:39,420 --> 00:46:35,700
a strong outreach program in

910
00:46:42,450 --> 00:46:39,430
astrobiology relevant areas with our

911
00:46:45,469 --> 00:46:42,460
thermo biology Institute and we're

912
00:46:49,259 --> 00:46:45,479
continuing that tradition in our

913
00:46:51,559 --> 00:46:49,269

outreach program really now kind of

914

00:46:55,469 --> 00:46:51,569

catering that to this new thrust of

915

00:46:57,479 --> 00:46:55,479

prebiotic chemistry and we have a lot of

916

00:47:00,870 --> 00:46:57,489

successes in this train the trainer

917

00:47:03,200 --> 00:47:00,880

molecule and just their model stuck on

918

00:47:05,200 --> 00:47:03,210

molecules it's a train-the-trainer model

919

00:47:08,400 --> 00:47:05,210

where we're

920

00:47:10,960 --> 00:47:08,410

we have a number of classes aimed at

921

00:47:12,850 --> 00:47:10,970

science teachers and mainly science

922

00:47:15,910 --> 00:47:12,860

teachers at the middle school level and

923

00:47:18,400 --> 00:47:15,920

so this is part of their curriculum and

924

00:47:21,100 --> 00:47:18,410

professional advancement their masters

925

00:47:23,770 --> 00:47:21,110

in signs in science education courses

926
00:47:26,200 --> 00:47:23,780
most of them are classes that are held

927
00:47:29,500 --> 00:47:26,210
here at MSU but we're having we're

928
00:47:35,440 --> 00:47:29,510
developing distance learning components

929
00:47:37,360 --> 00:47:35,450
for these classes we have a firm of this

930
00:47:39,280 --> 00:47:37,370
class that's really more traditionally

931
00:47:42,100 --> 00:47:39,290
the thermal biology Institute's threat

932
00:47:46,540 --> 00:47:42,110
that's on more microbiology and more the

933
00:47:48,790 --> 00:47:46,550
abrc stress which is on chemistry so for

934
00:47:52,930 --> 00:47:48,800
chemistry teachers and formal biology

935
00:47:56,440 --> 00:47:52,940
teachers we have developed online

936
00:47:59,830 --> 00:47:56,450
learning tools we have this year a

937
00:48:03,880 --> 00:47:59,840
couple of very successful community

938
00:48:06,220 --> 00:48:03,890

lectures and a lot of programs there and

939

00:48:08,560 --> 00:48:06,230

a lot of those programs they can be you

940

00:48:11,800 --> 00:48:08,570

can take a look at our website and we'll

941

00:48:13,300 --> 00:48:11,810

be highlighting what's going on with the

942

00:48:16,510 --> 00:48:13,310

outreach program as well as the

943

00:48:19,090 --> 00:48:16,520

scientific program at thanks to rest on

944

00:48:20,920 --> 00:48:19,100

our website so i encourage you to take a

945

00:48:24,100 --> 00:48:20,930

look at what's going on at the website

946

00:48:26,230 --> 00:48:24,110

so i'll just close here and they can't

947

00:48:29,740 --> 00:48:26,240

believe it's like almost exactly 50

948

00:48:34,090 --> 00:48:29,750

minutes close here with the slide that

949

00:48:38,020 --> 00:48:34,100

is really just some cover art that we've

950

00:48:40,390 --> 00:48:38,030

made for a research that just come out

951

00:48:42,880 --> 00:48:40,400

in dalton transactions which is a

952

00:48:47,400 --> 00:48:42,890

chemical journal where we're kind of

953

00:49:00,260 --> 00:48:47,410

showing this continuum from minerals to

954

00:49:07,410 --> 00:49:05,340

John thank you very much we are going to

955

00:49:09,420 --> 00:49:07,420

open up for questions in just a second

956

00:49:11,760 --> 00:49:09,430

so if you have a question either raise

957

00:49:13,440 --> 00:49:11,770

your hand in Adobe Connect or if no one

958

00:49:16,320 --> 00:49:13,450

raises their hand you can just jump in I

959

00:49:18,270 --> 00:49:16,330

just wanted to make an observation and

960

00:49:21,840 --> 00:49:18,280

that is that one other connection

961

00:49:24,870 --> 00:49:21,850

between your work and work of the other

962

00:49:28,470 --> 00:49:24,880

teams that struck me thinking back to

963

00:49:30,450 --> 00:49:28,480

the Wisconsin seminar and Nita saw highs

964

00:49:33,080 --> 00:49:30,460

description of that very nice work

965

00:49:35,910 --> 00:49:33,090

looking at the very detailed

966

00:49:39,180 --> 00:49:35,920

interactions between mineral surfaces

967

00:49:41,400 --> 00:49:39,190

and small molecules seems that your the

968

00:49:43,710 --> 00:49:41,410

techniques that she's applying probably

969

00:49:45,780 --> 00:49:43,720

are applicable to the work that you're

970

00:49:49,820 --> 00:49:45,790

doing as well so just drop me as one

971

00:49:52,170 --> 00:49:49,830

additional connection and I suspect

972

00:49:54,300 --> 00:49:52,180

something that could have to mention

973

00:49:58,620 --> 00:49:54,310

I've met to mention that and that really

974

00:50:00,840 --> 00:49:58,630

also is Todd to radical chemistry and

975

00:50:03,480 --> 00:50:00,850

some other things so I think that you

976
00:50:07,830 --> 00:50:03,490
know thanks very much for making that

977
00:50:11,370 --> 00:50:07,840
point okay I John chalk is open for

978
00:50:13,380 --> 00:50:11,380
questions please including questions

979
00:50:15,330 --> 00:50:13,390
from right there at Montana State I

980
00:50:16,440 --> 00:50:15,340
could imagine with all those folks in

981
00:50:18,510 --> 00:50:16,450
the room there might be a question or

982
00:50:20,880 --> 00:50:18,520
two for you John I think we have went

983
00:50:28,440 --> 00:50:20,890
from Lauren William okay Lauren please

984
00:50:30,360 --> 00:50:28,450
go ahead oh that's hot me bout the part

985
00:50:33,570 --> 00:50:30,370
because I I didn't really have a

986
00:50:40,290 --> 00:50:33,580
question formulated oh okay I saw your

987
00:50:41,970 --> 00:50:40,300
hand raised my top five it's like George

988
00:50:45,570 --> 00:50:41,980

looks like George cody has a question

989

00:50:48,120 --> 00:50:45,580

okay John there was a wonderful talk

990

00:50:50,100 --> 00:50:48,130

thank you very much this radical Sam

991

00:50:51,870 --> 00:50:50,110

chemistry is really something that's

992

00:50:53,250 --> 00:50:51,880

intriguing and not something that I know

993

00:50:54,780 --> 00:50:53,260

a lot about side like two talked about

994

00:50:57,600 --> 00:50:54,790

in the future but I just had two

995

00:50:59,190 --> 00:50:57,610

questions the enzymes associated with

996

00:51:00,600 --> 00:50:59,200

this radical Sam chemistry do you find

997

00:51:02,520 --> 00:51:00,610

that these tend to be a conservative

998

00:51:04,320 --> 00:51:02,530

group of enzymes and the other is are

999

00:51:05,880 --> 00:51:04,330

there any metallo centers associated

1000

00:51:07,680 --> 00:51:05,890

with these enzymes so sir transition

1001
00:51:09,750 --> 00:51:07,690
metal chemistry associated with the

1002
00:51:12,339 --> 00:51:09,760
radical Sam chemistry for the Assembly

1003
00:51:15,789 --> 00:51:12,349
of the H Center for example in hydrology

1004
00:51:19,329 --> 00:51:15,799
that's my question Joan do you want me

1005
00:51:23,200 --> 00:51:19,339
okay so they have a four-on-four sulfur

1006
00:51:26,079 --> 00:51:23,210
cluster is the inorganic part of those

1007
00:51:29,920 --> 00:51:26,089
guns they all have a foreign force

1008
00:51:32,200 --> 00:51:29,930
officer and it's a differentiated forum

1009
00:51:34,589 --> 00:51:32,210
for such a cluster we have three of the

1010
00:51:37,229 --> 00:51:34,599
irons have 15 ligands and the other

1011
00:51:39,940 --> 00:51:37,239
ligation is provided by the

1012
00:51:42,249 --> 00:51:39,950
s-adenosylmethionine and then has a

1013
00:51:45,849 --> 00:51:42,259

group evolutionarily they're you know

1014

00:51:48,729 --> 00:51:45,859

they're not all that conserved there's

1015

00:51:54,099 --> 00:51:48,739

enough conservation to actually identify

1016

00:51:57,430 --> 00:51:54,109

them and annotate them as a class if you

1017

00:51:59,019 --> 00:51:57,440

look at the end zones and the way

1018

00:52:02,920 --> 00:51:59,029

they're annotated in terms of their

1019

00:52:05,380 --> 00:52:02,930

function most of them now I won't say

1020

00:52:10,059 --> 00:52:05,390

most of the many of them are incorrect

1021

00:52:11,710 --> 00:52:10,069

so they're hard to put into their

1022

00:52:14,380 --> 00:52:11,720

different functional classes but we're

1023

00:52:17,099 --> 00:52:14,390

looking at that and we're trying to look

1024

00:52:19,989 --> 00:52:17,109

at the evolutionary trajectory of those

1025

00:52:23,440 --> 00:52:19,999

those radical sammons ons and you know

1026

00:52:25,599 --> 00:52:23,450

like in the context of a whip a or by OB

1027

00:52:29,319 --> 00:52:25,609

or some of these other enzymes involved

1028

00:52:32,259 --> 00:52:29,329

in isomerization of amino acids and our

1029

00:52:33,819 --> 00:52:32,269

enzymes involved in cluster biosynthesis

1030

00:52:35,529 --> 00:52:33,829

we're trying to look at the evolutionary

1031

00:52:42,279 --> 00:52:35,539

relationships there which I think will

1032

00:52:51,039 --> 00:52:44,349

and we have a question from jen maca

1033

00:52:53,979 --> 00:52:51,049

lady hi John thanks for your nice

1034

00:52:55,989 --> 00:52:53,989

overview I have a question you may or

1035

00:52:57,789 --> 00:52:55,999

may not want to speculate about but I

1036

00:53:01,359 --> 00:52:57,799

was just reminded this weekend about

1037

00:53:05,529 --> 00:53:01,369

Paul Davies ideas about weird life and

1038

00:53:08,469 --> 00:53:05,539

it strikes me that if iron-sulfur

1039

00:53:11,589 --> 00:53:08,479

chemistry was a feature of Hadean of

1040

00:53:14,079 --> 00:53:11,599

Haiti in the 80 in the world you might

1041

00:53:16,419 --> 00:53:14,089

expect both normal life in weird life to

1042

00:53:22,329 --> 00:53:16,429

have iron sulfur catalysis have you

1043

00:53:24,939 --> 00:53:22,339

thought about that at all um no I

1044

00:53:28,329 --> 00:53:24,949

haven't that interesting i'll think

1045

00:53:32,499 --> 00:53:28,339

about that i'm not sure what to say

1046

00:53:34,839 --> 00:53:32,509

about that we have a question from barry

1047

00:53:38,549 --> 00:53:34,849

bloomberg carried in any I central ferry

1048

00:53:42,009 --> 00:53:38,559

you can just go right ahead it does it

1049

00:53:46,539 --> 00:53:42,019

thanks for that talk how does this

1050

00:53:49,839 --> 00:53:46,549

relate to the formation of big neither

1051

00:53:55,439 --> 00:53:49,849

somes that occur in bacteria arcade

1052

00:53:59,309 --> 00:53:55,449

other organization or organisms is there

1053

00:54:01,569 --> 00:53:59,319

someone standing of that connection

1054

00:54:03,749 --> 00:54:01,579

terminal yes there is there definitely

1055

00:54:07,719 --> 00:54:03,759

is on a mechanistic level there's a

1056

00:54:09,009 --> 00:54:07,729

similarity those are deposited what we

1057

00:54:12,939 --> 00:54:09,019

know about them is that there are metal

1058

00:54:15,399 --> 00:54:12,949

transporters that pump metals across a

1059

00:54:17,349 --> 00:54:15,409

membrane into a vesicle and those things

1060

00:54:19,209 --> 00:54:17,359

have grown from very very small

1061

00:54:23,019 --> 00:54:19,219

particles into their final state and are

1062

00:54:25,029 --> 00:54:23,029

confined by the vesicle and they make

1063

00:54:27,159 --> 00:54:25,039

both an iron oxide in and iron sulfide

1064

00:54:33,189 --> 00:54:27,169

and sometimes a mixed oxide sulphide

1065

00:54:37,079 --> 00:54:33,199

phase and how high up at the

1066

00:54:43,120 --> 00:54:37,089

evolutionary scheme do you find the

1067

00:54:45,899 --> 00:54:43,130

formed begged in zones Oh John I don't

1068

00:54:49,040 --> 00:54:45,909

know the answer yet I don't know that

1069

00:54:56,810 --> 00:54:54,320

and we have a question from Goddard yeah

1070

00:55:00,200 --> 00:54:56,820

hi it was very interesting talk and I

1071

00:55:03,170 --> 00:55:00,210

wanted to ask you a question which isn't

1072

00:55:07,130 --> 00:55:03,180

directly related to the mineralogy are

1073

00:55:10,400 --> 00:55:07,140

doing but no related to the piece of the

1074

00:55:12,680 --> 00:55:10,410

phrase which will my question will

1075

00:55:16,490 --> 00:55:12,690

reveal my own ignorance and so I hope to

1076
00:55:19,550 --> 00:55:16,500
be educated and the question is what do

1077
00:55:24,710 --> 00:55:19,560
you mean by evaluative methods of the

1078
00:55:28,280 --> 00:55:24,720
philosophy of science yeah well I

1079
00:55:29,810 --> 00:55:28,290
prashanta birthday well what we do in

1080
00:55:32,120 --> 00:55:29,820
philosophy of science we have some

1081
00:55:34,160 --> 00:55:32,130
standard criteria to evaluate two

1082
00:55:36,320 --> 00:55:34,170
competing theories for example the skull

1083
00:55:38,450 --> 00:55:36,330
of a theory the fruitfulness of theory

1084
00:55:40,430 --> 00:55:38,460
theory and the predicate part of a

1085
00:55:42,110 --> 00:55:40,440
theory but when you look at it finished

1086
00:55:44,750 --> 00:55:42,120
theory for example general theory of

1087
00:55:46,940 --> 00:55:44,760
relativity so we have a very specific

1088
00:55:49,790 --> 00:55:46,950

way to evaluate that theory whether the

1089

00:55:51,500 --> 00:55:49,800

cure is better than the Newtonian theory

1090

00:55:53,270 --> 00:55:51,510

of gravitation but in the case of

1091

00:55:55,400 --> 00:55:53,280

emerging science like you know when you

1092

00:55:57,440 --> 00:55:55,410

are concerned with the metabolism first

1093

00:55:59,930 --> 00:55:57,450

theory versus the ordinal world

1094

00:56:03,170 --> 00:55:59,940

hypothesis so it's very difficult to

1095

00:56:04,910 --> 00:56:03,180

apply those criteria in you know in

1096

00:56:06,800 --> 00:56:04,920

knowing whether which one is a better

1097

00:56:10,130 --> 00:56:06,810

fuel than the other so we are hoping

1098

00:56:12,110 --> 00:56:10,140

that by analyzing our by looking at

1099

00:56:14,810 --> 00:56:12,120

those different hypotheses like the

1100

00:56:17,240 --> 00:56:14,820

ordinary world all the metabolism first

1101
00:56:19,370 --> 00:56:17,250
hypothesis we as a philosopher of

1102
00:56:21,530 --> 00:56:19,380
science we'd like to know what

1103
00:56:24,020 --> 00:56:21,540
philosophy of science can learn from

1104
00:56:28,250 --> 00:56:24,030
also astrobiology not also the other way

1105
00:56:32,290 --> 00:56:28,260
around well of course I'm very familiar

1106
00:56:35,060 --> 00:56:32,300
with the standard scientific method for

1107
00:56:37,670 --> 00:56:35,070
drawing predictions from a hypothesis

1108
00:56:39,740 --> 00:56:37,680
and then testing those by going into the

1109
00:56:42,260 --> 00:56:39,750
experimental world and making

1110
00:56:46,370 --> 00:56:42,270
measurements that can affect quantify

1111
00:56:49,940 --> 00:56:46,380
those predictions and ever i iterate the

1112
00:56:52,250 --> 00:56:49,950
theory when hypothesis unless clear on

1113
00:56:56,309 --> 00:56:52,260

how one does this in the philosophical

1114

00:57:00,460 --> 00:56:56,319

world other than through this course

1115

00:57:02,140 --> 00:57:00,470

how do you do it well you know the

1116

00:57:04,450 --> 00:57:02,150

standard philosophers of science you

1117

00:57:06,730 --> 00:57:04,460

know the way scientists evaluate why

1118

00:57:08,290 --> 00:57:06,740

general serial to exhibit is better than

1119

00:57:12,370 --> 00:57:08,300

the other so there are like three

1120

00:57:15,490 --> 00:57:12,380

classical tests like one is you know the

1121

00:57:16,990 --> 00:57:15,500

painting of light case then we have in

1122

00:57:19,720 --> 00:57:17,000

the mercury spill is very hidden

1123

00:57:21,819 --> 00:57:19,730

precision explanation so those are so

1124

00:57:24,880 --> 00:57:21,829

the classical test you know scientists

1125

00:57:26,500 --> 00:57:24,890

use you know to explain whether general

1126

00:57:29,200 --> 00:57:26,510

relativity successfully explaining the

1127

00:57:31,870 --> 00:57:29,210

theory so similarly question is whether

1128

00:57:34,180 --> 00:57:31,880

we can apply those criterion you know

1129

00:57:37,510 --> 00:57:34,190

better explanation better confirmation

1130

00:57:39,849 --> 00:57:37,520

in evaluating two competing hypotheses

1131

00:57:41,680 --> 00:57:39,859

like that metabolism products versus the

1132

00:57:43,599 --> 00:57:41,690

oar in the water hypothesis it's very

1133

00:57:46,240 --> 00:57:43,609

difficult to you know clean point their

1134

00:57:47,380 --> 00:57:46,250

predictions and you know because we are

1135

00:57:59,669 --> 00:57:47,390

mostly doing the speculative

1136

00:58:07,929 --> 00:58:04,359

mm I a question I could get in please go

1137

00:58:09,489 --> 00:58:07,939

ahead oh hey John I judge yourself

1138

00:58:12,999 --> 00:58:09,499

something I'm not ready to ask a

1139

00:58:15,459 --> 00:58:13,009

question and I think maybe this was a

1140

00:58:20,409 --> 00:58:15,469

mass before but I just so clarify it for

1141

00:58:23,349 --> 00:58:20,419

me if you would if if these helicopters

1142

00:58:25,089 --> 00:58:23,359

are so ancient and I would assume that

1143

00:58:28,569 --> 00:58:25,099

would mean the proteins that bind them

1144

00:58:30,789 --> 00:58:28,579

should be ancient so what kind of

1145

00:58:32,529 --> 00:58:30,799

sequence conservation do you anticipate

1146

00:58:35,679 --> 00:58:32,539

what's predicted by them and what's

1147

00:58:38,049 --> 00:58:35,689

observe you know I'm just thinking of

1148

00:58:42,999 --> 00:58:38,059

course always in terms of ribosomal RNA

1149

00:58:45,509 --> 00:58:43,009

genes and which are ancient and you can

1150

00:58:49,929 --> 00:58:45,519

see that and so how would you compare

1151

00:58:51,309 --> 00:58:49,939

that Pacific Ocean society well i think

1152

00:58:53,169 --> 00:58:51,319

you know that's the interesting question

1153

00:58:55,239 --> 00:58:53,179

because I kind of just close with an

1154

00:58:58,120 --> 00:58:55,249

example saying that they're not ancient

1155

00:59:00,579 --> 00:58:58,130

or at least that you know there's one

1156

00:59:03,099 --> 00:59:00,589

example for nitrogenase our results

1157

00:59:05,199 --> 00:59:03,109

indicate that they're not present that

1158

00:59:07,629 --> 00:59:05,209

they're not likely to be present in the

1159

00:59:09,579 --> 00:59:07,639

last common ancestor and interpolated

1160

00:59:11,739 --> 00:59:09,589

you know what talking about is you've

1161

00:59:14,949 --> 00:59:11,749

got a number of different mineral

1162

00:59:18,249 --> 00:59:14,959

catalysis going on some of that mineral

1163

00:59:20,799 --> 00:59:18,259

catalysis is providing the raw materials

1164

00:59:24,909 --> 00:59:20,809

maybe the raw materials for life-forms

1165

00:59:27,939 --> 00:59:24,919

and you know eventually those are taken

1166

00:59:30,069 --> 00:59:27,949

up and made up into biological processes

1167

00:59:31,449 --> 00:59:30,079

of course I'm you know speculating and

1168

00:59:33,909 --> 00:59:31,459

kind of represent in our point of view

1169

00:59:36,639 --> 00:59:33,919

or maybe hydrogen metabolism that

1170

00:59:38,319 --> 00:59:36,649

happened earlier and maybe it is present

1171

00:59:40,269 --> 00:59:38,329

in the first life forms and we'll have

1172

00:59:42,609 --> 00:59:40,279

to figure out an approach that we've

1173

00:59:45,069 --> 00:59:42,619

used that's similar to what we use for

1174

00:59:47,589 --> 00:59:45,079

nitrogenase to ask those questions or a

1175

00:59:52,959 --> 00:59:47,599

fourth you know acetyl co a synthase or

1176

00:59:54,939 --> 00:59:52,969

for co dehydrogenase etc so i don't

1177

00:59:57,069 --> 00:59:54,949

think you know they don't necessarily is

1178

01:00:00,519 --> 00:59:57,079

that we see relationships between

1179

01:00:03,039 --> 01:00:00,529

mineral catalysis and iron sulfur enzyme

1180

01:00:06,099 --> 01:00:03,049

catalysis doesn't mean to say that those

1181

01:00:08,349 --> 01:00:06,109

were the first enzymes necessarily i

1182

01:00:09,560 --> 01:00:08,359

think that probably find a subset of

1183

01:00:12,860 --> 01:00:09,570

those or

1184

01:00:17,720 --> 01:00:12,870

maybe product testers for those perhaps

1185

01:00:20,480 --> 01:00:17,730

work but they don't have to do that make

1186

01:00:23,870 --> 01:00:20,490

them yeah yeah I got that very good

1187

01:00:28,820 --> 01:00:23,880

thank you we have a question at Penn

1188

01:00:32,540 --> 01:00:28,830

State John this chris house I was just

1189

01:00:38,420 --> 01:00:32,550

curious how if any iron-sulfur clusters

1190

01:00:44,960 --> 01:00:38,430

are known from viruses from what I know

1191

01:00:48,080 --> 01:00:44,970

no and I'm getting for my virus

1192

01:00:51,400 --> 01:00:48,090

colleagues they say now as well so John

1193

01:00:53,900 --> 01:00:51,410

that's not totally true that's there

1194

01:00:55,670 --> 01:00:53,910

that that people that we don't actually

1195

01:00:59,360 --> 01:00:55,680

know there are lots of viruses that

1196

01:01:02,000 --> 01:00:59,370

carry disease algo viruses Prince's

1197

01:01:04,280 --> 01:01:02,010

carry photosynthetic jeans I don't know

1198

01:01:06,560 --> 01:01:04,290

that anybody's actually looked well so I

1199

01:01:08,750 --> 01:01:06,570

think that the answer the question is no

1200

01:01:11,690 --> 01:01:08,760

nobody's made that connection and

1201

01:01:15,020 --> 01:01:11,700

nobody's found an iron-sulfur cluster

1202

01:01:17,660 --> 01:01:15,030

containing protein in the virus you know

1203

01:01:19,070 --> 01:01:17,670

for standard like ferredoxin like motifs

1204

01:01:21,350 --> 01:01:19,080

and stuff which people have looked at

1205

01:01:24,710 --> 01:01:21,360

fairly extensively nobody found that

1206

01:01:33,210 --> 01:01:24,720

either so I think that there maybe

1207

01:01:39,430 --> 01:01:35,500

okay are there any other questions for

1208

01:01:43,030 --> 01:01:39,440

John John I would just make the

1209

01:01:45,970 --> 01:01:43,040

observation that in response to your

1210

01:01:48,850 --> 01:01:45,980

last comment about the the enzymes may

1211

01:01:49,930 --> 01:01:48,860

not be ancient by which I think you

1212

01:01:52,020 --> 01:01:49,940

meant that they may not have been

1213

01:01:55,840 --> 01:01:52,030

present in the very first life-forms

1214

01:01:57,970 --> 01:01:55,850

methanogenesis where you suggested they

1215

01:02:00,850 --> 01:01:57,980

may have originated may very well be an

1216

01:02:02,860 --> 01:02:00,860

extremely ancient metabolism so it could

1217

01:02:07,210 --> 01:02:02,870

have been not all that long after Luca

1218

01:02:09,700 --> 01:02:07,220

conceivably absolutely and I think that

1219

01:02:11,710 --> 01:02:09,710

you know that's what something that our

1220

01:02:13,180 --> 01:02:11,720

study says you know we haven't put any

1221

01:02:16,450 --> 01:02:13,190

sort of clock on these and that's

1222

01:02:21,010 --> 01:02:16,460

something that we we can do we can do

1223

01:02:24,970 --> 01:02:21,020

and we're trying to learn to do any

1224

01:02:32,740 --> 01:02:24,980

other questions for John ok well let's

1225

01:02:35,020 --> 01:02:32,750

thank him again as I think you all know

1226

01:02:37,090 --> 01:02:35,030

we'll continue this series on Wednesday

1227

01:02:39,850 --> 01:02:37,100

this week with Lauren Williams also

1228

01:02:42,300 --> 01:02:39,860

talking about the origin of the earliest

1229

01:02:45,010 --> 01:02:42,310

proteins particularly how the ribosome

1230

01:02:47,410 --> 01:02:45,020

came to be and how RNA learned to make