

A cosmic background featuring vibrant nebulae in shades of red and green, set against a dark space filled with numerous stars. The text is centered over this scene.

OUR VIOLENT UNIVERSE

1
00:00:02,066 --> 00:00:04,000



2
00:00:23,957 --> 00:00:26,858
[APPLAUSE]

3
00:00:26,858 --> 00:00:27,792
-THANK YOU VERY MUCH.

4
00:00:27,792 --> 00:00:29,165
AND THIS IS KIND
OF A NEAT SLIDE.

5
00:00:29,165 --> 00:00:31,858
THAT ACTUALLY IS A PICTURE
OF ME TAKEN BY DREW FEUSTEL

6
00:00:31,858 --> 00:00:34,363
AS I WAS REPAIRING
THE HUBBLE SPACE TELESCOPE.

7
00:00:34,363 --> 00:00:37,198
AND AS CHRIS SCOLESE SAID,
I STARTED OUT LIFE --

8
00:00:37,198 --> 00:00:40,033
UH, WELL, I'M NOT GONNA
TELL YOU THE LONG STORY --

9
00:00:40,033 --> 00:00:42,033
BUT AS A HIGH-ENERGY
ASTROPHYSICIST,

10
00:00:42,033 --> 00:00:45,759
AND I WAS JUST FASCINATED BY
BLACK HOLES AND NEUTRON STARS.

11
00:00:45,759 --> 00:00:47,132
MY FIRST SCIENTIFIC PAPER

12

00:00:47,132 --> 00:00:50,132
WAS AN OBSERVATION
OF A NEUTRON STAR --

13

00:00:50,132 --> 00:00:51,363
A STAR THE SIZE

14

00:00:51,363 --> 00:00:53,660
OF WASHINGTON, D.C.,
ROTATING RAPIDLY

15

00:00:53,660 --> 00:00:56,165
WITH THE DENSITY
OF NUCLEAR OF MATTER --

16

00:00:56,165 --> 00:00:59,099
AND WENT ON TO BUILD
BALLOON PAYLOADS

17

00:00:59,099 --> 00:01:01,429
AND DO EXPERIMENTS AND WORK
WITH SPACE EXPERIMENTS,

18

00:01:01,429 --> 00:01:03,693
INCLUDING
THE COMPTON OBSERVATORY,

19

00:01:03,693 --> 00:01:07,462
THAT I WAS CONVINCED
WAS GONNA BE MY CAREER.

20

00:01:07,462 --> 00:01:10,132
AND I LOOKED VERY JEALOUSLY
AT THE HUBBLE SPACE TELESCOPE,

21

00:01:10,132 --> 00:01:12,066
THINKING, "OH,
IT'S JUST AN OPTICAL TELESCOPE.

22

00:01:12,066 --> 00:01:13,264

IT'S TAKING ALL THE MONEY.

23

00:01:13,264 --> 00:01:16,957

THE REAL ACTION
IS IN HIGH-ENERGY ASTROPHYSICS."

24

00:01:16,957 --> 00:01:21,066

YOU KNOW, BUT I THINK WE SHOULD
ALL BE CONTINUOUS LEARNERS,

25

00:01:21,066 --> 00:01:22,825

AND I LEARNED
HOW IMPORTANT HUBBLE IS.

26

00:01:22,825 --> 00:01:25,000

AND THE NEXT SPEAKER
WILL REFER TO THAT.

27

00:01:25,000 --> 00:01:26,429

AND, IN FACT, I BECAME,

28

00:01:26,429 --> 00:01:29,231

ACTUALLY, QUITE TRANSFORMED
BY THE HUBBLE SPACE TELESCOPE.

29

00:01:29,231 --> 00:01:32,165

BUT I ALSO BECAME TRANSFORMED
BY THE FACT THAT WHEN

30

00:01:32,165 --> 00:01:35,264

THE COMPTON OBSERVATORY WAS
ON THE END OF THE ROBOTIC ARM,

31

00:01:35,264 --> 00:01:37,363

THE HIGH-GAIN ANTENNA
DIDN'T DEPLOY.

32

00:01:37,363 --> 00:01:39,066

AND IT WAS JERRY ROSS
AND JAY APT WHO WENT OUT

33

00:01:39,066 --> 00:01:40,858
AND DID A SPACE WALK
AND DEPLOYED IT,

34

00:01:40,858 --> 00:01:43,264
ENABLING MY RESEARCH
AND MANY OF THE FOLKS

35

00:01:43,264 --> 00:01:44,627
THAT ARE IN THIS ROOM

36

00:01:44,627 --> 00:01:47,000
TO BE ABLE TO UNRAVEL
THE MYSTERIES OF THE UNIVERSE --

37

00:01:47,000 --> 00:01:48,330
THE HIGH-ENERGY UNIVERSE --

38

00:01:48,330 --> 00:01:49,759
WITH COMPTON.

39

00:01:49,759 --> 00:01:51,528
AND WE'RE GONNA
HEAR MORE ABOUT, YOU KNOW,

40

00:01:51,528 --> 00:01:55,330
SOME OF THE FOLLOW-ON GREAT
SPACE CRAFT AND EXPERIMENTS

41

00:01:55,330 --> 00:01:57,330
AND THE SCIENCE.

42

00:01:57,330 --> 00:02:00,132
BUT IT REALLY COMES DOWN
TO WHAT NASA'S ALL ABOUT.

43

00:02:00,132 --> 00:02:01,363
YOU KNOW, WE INNOVATE,

44

00:02:01,363 --> 00:02:02,627
WE EXPLORE,

45

00:02:02,627 --> 00:02:04,033
WE DISCOVER,

46

00:02:04,033 --> 00:02:05,264
AND WE INSPIRE.

47

00:02:05,264 --> 00:02:07,924
AND WE INNOVATE TO BUILD
THE KIND OF TECHNOLOGIES

48

00:02:07,924 --> 00:02:10,561
THAT ALLOW US TO BUILD
SPACE CRAFT LIKE NuSTAR,

49

00:02:10,561 --> 00:02:12,363
WHICH YOU'LL HEAR ABOUT.

50

00:02:12,363 --> 00:02:16,396
WE USE THOSE INNOVATIONS
TO EXPLORE THE UNIVERSE.

51

00:02:16,396 --> 00:02:18,363
AND WHEN WE EXPLORE,
WE DISCOVER THINGS.

52

00:02:18,363 --> 00:02:21,033
AND THAT'S WHERE THE HUMAN
ELEMENT IS AT ITS STRONGEST.

53

00:02:21,033 --> 00:02:22,165
WE'RE DRIVEN.

54

00:02:22,165 --> 00:02:23,561

I THINK WE'RE GENETICALLY
PROGRAMMED

55

00:02:23,561 --> 00:02:26,528

TO BE ENERGIZED
BY THOSE DISCOVERIES.

56

00:02:26,528 --> 00:02:28,726

AND WHEN WE'RE ENERGIZED
AS SCIENTISTS,

57

00:02:28,726 --> 00:02:32,231

WE'RE ABLE TO INSPIRE A COUNTRY,
A WORLD, STUDENTS,

58

00:02:32,231 --> 00:02:33,594

EVERYONE.

59

00:02:33,594 --> 00:02:36,231

AND I THINK THAT'S
THE IMPORTANCE OF THE SCIENCE

60

00:02:36,231 --> 00:02:37,528

THAT WE DO.

61

00:02:37,528 --> 00:02:40,264

WE'RE ALSO ASKING
HUMAN QUESTIONS, IN ESSENCE.

62

00:02:40,264 --> 00:02:42,759

WE'RE ASKING FUNDAMENTAL PHYSICS
QUESTIONS, SCIENCE QUESTIONS,

63

00:02:42,759 --> 00:02:44,693

BUT WE'RE TRYING
TO FIND OUT, YOU KNOW,

64

00:02:44,693 --> 00:02:47,066

WHERE DID WE COME FROM,
WHERE DID THE UNIVERSE

65

00:02:47,066 --> 00:02:48,231

THAT WE LIVE IN COME FROM,

66

00:02:48,231 --> 00:02:49,627

AND WHY DOES IT LOOK THE WAY
THAT IT DOES.

67

00:02:49,627 --> 00:02:51,264

WHERE DO THE CHEMICAL ELEMENTS

68

00:02:51,264 --> 00:02:53,396

THAT WE'RE MADE
OUT OF COME FROM?

69

00:02:53,396 --> 00:02:55,957

AND IT TURNS OUT THEY CAME
FROM A VERY VIOLENT UNIVERSE.

70

00:02:55,957 --> 00:02:57,957

AND WE'LL HEAR, HOPEFULLY,
A LITTLE BIT ABOUT THAT.

71

00:02:57,957 --> 00:02:59,363

YOU KNOW, WE'RE MADE
OUT OF STAR STUFF

72

00:02:59,363 --> 00:03:02,066

THAT HAD TO GET FROM THE INSIDE
OF STARS, OUT OF STARS,

73

00:03:02,066 --> 00:03:05,396

TO FORM NEW STARS, PLANETS,
AND US.

74

00:03:05,396 --> 00:03:06,462

WHERE ARE WE GOING?

75

00:03:06,462 --> 00:03:08,297

WHAT'S THE FUTURE
OF THE UNIVERSE?

76

00:03:08,297 --> 00:03:10,693

THAT'S ALSO DOMINATED
BY HIGH-ENERGY PROCESSES.

77

00:03:10,693 --> 00:03:12,726

BUT ALSO, WHERE ARE WE
GOING ON PLANET EARTH?

78

00:03:12,726 --> 00:03:15,462

THAT'S ONE OF THE THINGS
THAT WE DO IN EARTH SCIENCE.

79

00:03:15,462 --> 00:03:16,957

AND THEN THE BIG QUESTION,

80

00:03:16,957 --> 00:03:19,429

WHICH I DON'T THINK HIGH-ENERGY
ASTROPHYSICS IS GONNA ANSWER,

81

00:03:19,429 --> 00:03:22,792

BUT ONE I'M FASCINATED BY IS
"ARE WE ALONE?"

82

00:03:22,792 --> 00:03:24,792

AND THAT'S WHY SOME
OF OUR PLANETARY MISSIONS

83

00:03:24,792 --> 00:03:27,726

AND OUR EXOPLANET MISSIONS, I
THINK, ARE SO INTERESTING NOW.

84

00:03:27,726 --> 00:03:29,198

BECAUSE WE ARE ONE STEP

85

00:03:29,198 --> 00:03:32,495

AWAY FROM HAVING
THE TECHNOLOGICAL CAPABILITY

86
00:03:32,495 --> 00:03:35,264
TO ANSWER THE QUESTION
THROUGH TELESCOPIC OBSERVATION

87
00:03:35,264 --> 00:03:36,462
OF NEARBY EXOPLANETS,

88
00:03:36,462 --> 00:03:38,132
INTERROGATING THEIR ATMOSPHERES,

89
00:03:38,132 --> 00:03:39,825
TO FIND OUT
IF WE'RE ALONE IN THE UNIVERSE.

90
00:03:39,825 --> 00:03:43,231
OR A FUTURE
PLANETARY SCIENTIST --

91
00:03:43,231 --> 00:03:44,759
AND THERE'S SOME YOUNG PEOPLE
IN THE AUDIENCE

92
00:03:44,759 --> 00:03:46,825
THAT ARE THOSE FUTURE
PLANETARY SCIENTISTS --

93
00:03:46,825 --> 00:03:48,231
WHO ARE GONNA WALK
ON THE SURFACE

94
00:03:48,231 --> 00:03:49,660
OF MARS WITH ANALYTIC TOOLS

95
00:03:49,660 --> 00:03:51,825
THAT MAY BE ABLE TO TELL US
WHETHER THERE'S LIFE

96
00:03:51,825 --> 00:03:55,561

ON MARS OR A PLANETARY MISSION
EXPLORING EUROPA.

97

00:03:55,561 --> 00:03:58,033
SO, THIS IS ONE OF MY FAVORITE
EVENTS, BECAUSE EVERY YEAR,

98

00:03:58,033 --> 00:03:59,561
WE GET TO HEAR
ABOUT THE GREAT SCIENCE

99

00:03:59,561 --> 00:04:01,462
THAT'S GOING ON AT
THE GODDARD SPACE FLIGHT CENTER

100

00:04:01,462 --> 00:04:03,825
AND THROUGH ITS PARTICIPATING
SCIENTISTS

101

00:04:03,825 --> 00:04:06,396
AND REALLY LEARN
SOMETHING IMPORTANT.

102

00:04:06,396 --> 00:04:09,495
AND SO, WHAT I'D LIKE TO DO
IN MY FINAL COMMENT TONIGHT

103

00:04:09,495 --> 00:04:11,330
IS ADDRESS THE "INSPIRE" PART

104

00:04:11,330 --> 00:04:12,528
OF OUR MISSION,

105

00:04:12,528 --> 00:04:15,396
WHICH IS TO ASK
ALL OF YOU TONIGHT,

106

00:04:15,396 --> 00:04:16,594
AFTER YOU LEAVE, YOU KNOW,

107

00:04:16,594 --> 00:04:17,957

DRIVE SAFELY GOING HOME,

108

00:04:17,957 --> 00:04:20,495

BUT TOMORROW AND THE NEXT DAY
AND, YOU KNOW,

109

00:04:20,495 --> 00:04:22,198

FOR REALLY, HOPEFULLY,

110

00:04:22,198 --> 00:04:23,561

THE REST OF YOUR LIVES,

111

00:04:23,561 --> 00:04:25,825

AS YOU LEARN ABOUT OUR GREAT
SCIENTIFIC ACHIEVEMENTS,

112

00:04:25,825 --> 00:04:27,330

AS YOU YOURSELVES,

113

00:04:27,330 --> 00:04:29,132

YOU KNOW, DISCOVER THINGS,

114

00:04:29,132 --> 00:04:30,759

SHARE IT WITH YOUR NEIGHBORS.

115

00:04:30,759 --> 00:04:32,693

CERTAINLY SHARE IT
WITH YOUR FAMILY MEMBERS.

116

00:04:32,693 --> 00:04:35,198

YOU KNOW, MANY OF US GO TO WORK
IN THE SCIENCE COMMUNITY.

117

00:04:35,198 --> 00:04:36,594

WE WORK REALLY HARD,
WE COME HOME,

118

00:04:36,594 --> 00:04:38,726
WE'RE TIRED, YOU KNOW,
WE HAVE A MEAL, WE GO TO SLEEP,

119
00:04:38,726 --> 00:04:41,231
AND WE DON'T TELL OUR FAMILIES
ABOUT THE GREAT WORK

120
00:04:41,231 --> 00:04:43,693
AND INCREDIBLE WORK WE'RE DOING
STUDYING THE ENVIRONMENT

121
00:04:43,693 --> 00:04:46,066
AROUND A BLACK HOLE
OR A ROTATING NEUTRON STAR

122
00:04:46,066 --> 00:04:48,198
OR AN ACTIVE GALACTIC NUCLEI,

123
00:04:48,198 --> 00:04:49,495
AND IT REALLY IS AMAZING.

124
00:04:49,495 --> 00:04:51,627
PEOPLE ARE AMAZED BY WHAT WE DO.

125
00:04:51,627 --> 00:04:53,066
SHARE IT WITH YOUR COMMUNITY
GROUPS.

126
00:04:53,066 --> 00:04:54,858
SHARE IT WITH LOCAL SCHOOLS,

127
00:04:54,858 --> 00:04:56,495
BECAUSE IT'S
THROUGH THAT COMMUNICATION

128
00:04:56,495 --> 00:04:58,099
THAT WE INSPIRE THE WORLD.

129

00:04:58,099 --> 00:05:00,330
SO, I HOPE
YOU'RE ALL INSPIRED TONIGHT.

130
00:05:00,330 --> 00:05:03,363
AND I WAS INSPIRED WHEN I
WAS A HIGH SCHOOL STUDENT --

131
00:05:03,363 --> 00:05:05,132
I LIKE TO SAY EVERYTHING
I LEARNED ABOUT ASTRONOMY,

132
00:05:05,132 --> 00:05:06,858
I LEARNED
AS A HIGH SCHOOL STUDENT --

133
00:05:06,858 --> 00:05:09,891
IN A PROGRAM AT A SMALL
PLANETARIUM IN CHICAGO

134
00:05:09,891 --> 00:05:12,033
CALLED THE ADLER PLANETARIUM.

135
00:05:12,033 --> 00:05:16,066
AND ONE OF THE GRADUATE
ASSISTANTS THAT WAS TEACHING US

136
00:05:16,066 --> 00:05:18,165
WAS SOMEBODY WHO HAS,
THROUGHOUT MY CAREER,

137
00:05:18,165 --> 00:05:20,066
BECOME A MENTOR

138
00:05:20,066 --> 00:05:21,297
AND WAS MY PREDECESSOR.

139
00:05:21,297 --> 00:05:24,759
AND SO, I'D LIKE TO BRING UP
DR. ED WEILER

140

00:05:24,759 --> 00:05:27,759

TO GIVE US AN INTRODUCTION.

141

00:05:27,759 --> 00:05:30,165

[APPLAUSE]

142

00:05:30,165 --> 00:05:34,594

-THANKS, JOHN.

143

00:05:34,594 --> 00:05:36,297

I'M REALLY NOT THAT OLD.

144

00:05:36,297 --> 00:05:37,495

[LAUGHTER]

145

00:05:37,495 --> 00:05:39,462

BUT I AM RETIRED,
IF YOU WONDER WHERE I'VE BEEN

146

00:05:39,462 --> 00:05:41,429

THE LAST FOUR YEARS.

147

00:05:41,429 --> 00:05:43,561

UH, BUT WHEN YOU'RE RETIRED,

148

00:05:43,561 --> 00:05:44,759

YOU HAVE LOTS OF TIME,

149

00:05:44,759 --> 00:05:48,198

FINALLY, ESPECIALLY
BETWEEN TENNIS MATCHES,

150

00:05:48,198 --> 00:05:49,660

TO GAIN PERSPECTIVE

151

00:05:49,660 --> 00:05:52,429

ON WHAT'S HAPPENED

IN YOUR FIELD OF ASTROPHYSICS

152

00:05:52,429 --> 00:05:54,528

OVER THE PAST 40 YEARS.

153

00:05:54,528 --> 00:05:56,528

THAT'S HOW LONG
MY CAREER HAS BEEN.

154

00:05:56,528 --> 00:05:58,099

BACK IN THE '70s AND '80s,

155

00:05:58,099 --> 00:06:01,330

WHEN MANY OF US WERE IN GRAD
SCHOOL OR JUST STARTING COLLEGE,

156

00:06:01,330 --> 00:06:03,792

WE THOUGHT WE KNEW A LOT
ABOUT THE UNIVERSE.

157

00:06:03,792 --> 00:06:05,429

WE WERE PRETTY ARROGANT.

158

00:06:05,429 --> 00:06:08,033

WE KIND OF KNEW
HOW STARS WERE FORMED

159

00:06:08,033 --> 00:06:11,792

AND HOW THEIR ATMOSPHERES
WORKED, ET CETERA.

160

00:06:11,792 --> 00:06:14,825

BUT THERE WERE SOME AWFULLY BIG
PROBLEMS LEFT UNSOLVED,

161

00:06:14,825 --> 00:06:16,264

WHICH WERE NAGGING AT US.

162

00:06:16,264 --> 00:06:18,033

AND THOSE ARE THE ONES
WE'LL BE ADDRESSING,

163

00:06:18,033 --> 00:06:19,891
SOME OF THEM, TONIGHT.

164

00:06:19,891 --> 00:06:24,660
FOR INSTANCE, DO SUPERMASSIVE
BLACK HOLES REALLY EXIST?

165

00:06:24,660 --> 00:06:26,396
OR ARE THEY
JUST MERE SCIENCE FICTION

166

00:06:26,396 --> 00:06:30,957
AND FODDER FOR SHOWS
LIKE "STAR TREK"?

167

00:06:30,957 --> 00:06:33,528
WHAT ARE QUASI-STELLAR OBJECTS,
QUASARS?

168

00:06:33,528 --> 00:06:36,231
THEY APPEAR AS PINPOINTS
OF LIGHT IN THE SKY,

169

00:06:36,231 --> 00:06:39,495
BUT EXTREMELY DISTANT
AND THUS VERY ENERGETIC.

170

00:06:39,495 --> 00:06:43,198
SOME ARE RELATIVELY QUIET WHILE
OTHERS SEEM HIGHLY VARIABLE.

171

00:06:43,198 --> 00:06:45,858
DO THEY HAVE HOMES
IN THE UNIVERSE,

172

00:06:45,858 --> 00:06:50,198
OR ARE THEY SOLITARY OBJECTS

IN THE VAST DARKNESS?

173

00:06:50,198 --> 00:06:52,528

IN THE EARLY '80s,
DIFFUSE X-RAY BACKGROUND

174

00:06:52,528 --> 00:06:54,858

WAS DISCOVERED
TO FILL THE NIGHTTIME SKY.

175

00:06:54,858 --> 00:06:57,198

WHAT WAS IT?

176

00:06:57,198 --> 00:06:59,957

GAMMA-RAY BURSTS
WERE SEEN ALMOST ONCE A DAY.

177

00:06:59,957 --> 00:07:02,066

THEY LAST VERY SHORT PERIODS
OF TIME -- SECONDS,

178

00:07:02,066 --> 00:07:03,627

OR UP TO A DAY.

179

00:07:03,627 --> 00:07:08,297

ARE THEY NEARBY OR EXTREMELY
DISTANT AND THUS VERY ENERGETIC?

180

00:07:08,297 --> 00:07:11,132

AND FINALLY, WE THINK
SUPERNOVA -- BACK IN THE '80s,

181

00:07:11,132 --> 00:07:13,957

WE KNEW SUPERNOVA WERE PROBABLY
VIOLENT EXPLOSIONS,

182

00:07:13,957 --> 00:07:16,429

BUT WHAT WAS THEIR EXACT NATURE?

183

00:07:16,429 --> 00:07:18,891
WE KNOW THAT THEY CREATED
ELEMENTS IN OUR BODIES --

184
00:07:18,891 --> 00:07:21,627
CALCIUM, IRON, ET CETERA.

185
00:07:21,627 --> 00:07:24,825
AND THUS, IT WAS IMPORTANT
TO BETTER UNDERSTAND

186
00:07:24,825 --> 00:07:27,000
THESE VIOLENT PHENOMENA.

187
00:07:27,000 --> 00:07:29,825
IT WAS RECOGNIZED
BY MANY BACK THEN TO TACKLE

188
00:07:29,825 --> 00:07:32,165
AS BROAD A RAY OF MYSTERIES,

189
00:07:32,165 --> 00:07:35,495
IT WOULD TAKE LARGE SPACE
OBSERVATORIES OPERATED

190
00:07:35,495 --> 00:07:40,891
IN MULTIPLE WAVELENGTH BANDS
FROM GAMMA RAY TO INFRARED.

191
00:07:40,891 --> 00:07:43,462
AND SOON, WE'LL SEE --

192
00:07:43,462 --> 00:07:45,198
YOU CAN THINK
YOU'LL HEAR THE TERM WAVELENGTH

193
00:07:45,198 --> 00:07:46,198
TONIGHT, PERHAPS.

194

00:07:46,198 --> 00:07:47,792
THINK OF WAVELENGTH AS COLORS.

195
00:07:47,792 --> 00:07:49,891
OUR EYES CAN ONLY SEE
IN THIS LITTLE AREA

196
00:07:49,891 --> 00:07:51,495
OF VISIBLE LIGHT HERE.

197
00:07:51,495 --> 00:07:53,594
IF YOU WANT TO LOOK
IN THE ULTRAVIOLET, X-RAY,

198
00:07:53,594 --> 00:07:55,000
GAMMA RAY, MUCH OF THE INFRARED,

199
00:07:55,000 --> 00:07:58,561
YOU HAVE TO GO INTO SPACE
TO GET -- TO SEE, BASICALLY,

200
00:07:58,561 --> 00:08:00,297
THE REST OF THE UNIVERSE.

201
00:08:00,297 --> 00:08:01,858
I REMEMBER AFTER WE SOLD HUBBLE,

202
00:08:01,858 --> 00:08:04,495
WE WERE TRYING TO SELL
A GAMMA-RAY OBSERVATORY

203
00:08:04,495 --> 00:08:06,165
AND SIRTf AND AXAF.

204
00:08:06,165 --> 00:08:07,462
AND ONE CONGRESSIONAL STAFFER,

205
00:08:07,462 --> 00:08:09,165
WHO SHALL REMAIN UNNAMED,

206

00:08:09,165 --> 00:08:11,132

CAME UP TO ME AND SAID, "HEY,
YOU GUYS ARE GETTING HUBBLE.

207

00:08:11,132 --> 00:08:12,594

WE'RE PAYING A LOT FOR HUBBLE.

208

00:08:12,594 --> 00:08:15,924

WHY IN THE WORLD DO YOU NEED
ALL THESE OTHER OBSERVATORIES?"

209

00:08:15,924 --> 00:08:18,957

AND I'LL USE THE ANALOGY
I USED THAT DAY WITH HIM,

210

00:08:18,957 --> 00:08:21,660

AND I SAID, "WELL, IF YOU HAD
A REALLY BAD DISEASE

211

00:08:21,660 --> 00:08:23,330

AND YOU WENT TO THE DOCTOR
TO GET DIAGNOSED,

212

00:08:23,330 --> 00:08:25,627

WOULD YOU GO TO A DOCTOR
WHO BASICALLY USES

213

00:08:25,627 --> 00:08:28,066

THEIR EYES AND THEIR HANDS
TO DIAGNOSE YOU?

214

00:08:28,066 --> 00:08:29,231

OR WOULD YOU PREFER A DOCTOR

215

00:08:29,231 --> 00:08:31,000

THAT MIGHT USE
STATE-OF-THE-ART TECHNOLOGY

216

00:08:31,000 --> 00:08:33,033
LIKE MRIs, CAT SCANNERS,

217

00:08:33,033 --> 00:08:34,726
STETHOSCOPES, EVEN,

218

00:08:34,726 --> 00:08:36,429
ULTRASOUNDS?"

219

00:08:36,429 --> 00:08:38,099
AND ASTRONOMERS
ARE IN THE SAME BOAT.

220

00:08:38,099 --> 00:08:39,165
IF YOU REALLY WANT TO UNDERSTAND

221

00:08:39,165 --> 00:08:40,759
A LOT OF OBJECTS
IN THE UNIVERSE,

222

00:08:40,759 --> 00:08:43,033
YOU'VE GOT TO LOOK
AT ALL WAVELENGTH AREAS.

223

00:08:43,033 --> 00:08:45,726
BECAUSE THESE WAVELENGTH AREAS
REALLY TELL YOU

224

00:08:45,726 --> 00:08:48,594
ABOUT THE TEMPERATURE
OF THE MATTER IN THE OBJECT.

225

00:08:48,594 --> 00:08:49,957
GAMMA RAYS AND X-RAYS --

226

00:08:49,957 --> 00:08:52,132
TENS OF MILLIONS,
HUNDREDS OF MILLIONS OF DEGREES.

227

00:08:52,132 --> 00:08:54,693
ULTRAVIOLENT -- HUNDREDS
OF THOUSANDS OF DEGREES.

228
00:08:54,693 --> 00:08:57,066
VISIBLE LIGHT -- TENS
OF THOUSANDS OF DEGREES.

229
00:08:57,066 --> 00:08:58,924
INFRARED -- HUNDREDS OF DEGREES.

230
00:08:58,924 --> 00:09:00,462
SO, IF YOU WANT
TO UNDERSTAND AN OBJECT,

231
00:09:00,462 --> 00:09:04,858
YOU REALLY HAVE TO LOOK AT IT
IN MANY, MANY DIFFERENT WAYS.

232
00:09:04,858 --> 00:09:07,462
AN EXAMPLE
OF MULTISPECTRAL IMAGINING IS

233
00:09:07,462 --> 00:09:10,528
DISPLAYED IN THE NEXT TWO IMAGES
THAT WILL BE COMING UP.

234
00:09:10,528 --> 00:09:14,957
ON THE LEFT HERE IS A HUBBLE
IMAGE OF CASSIOPEIA A.

235
00:09:14,957 --> 00:09:18,132
IT'S THE RESULT OF A SUPERNOVA
THAT HAPPENED A LONG TIME AGO.

236
00:09:18,132 --> 00:09:19,891
SUPERNOVA OCCURRED HERE.

237
00:09:19,891 --> 00:09:22,429
AND WHAT YOU'RE SEEING NOW IS

THE LEFTOVERS OF THE SUPERNOVA

238

00:09:22,429 --> 00:09:26,495
GLOWING AT ABOUT 10,000,
20,000 DEGREES.

239

00:09:26,495 --> 00:09:29,033
AND UNTIL WE LAUNCHED X-RAY
TELESCOPES,

240

00:09:29,033 --> 00:09:30,759
THAT'S AS MUCH AS WE SAW.

241

00:09:30,759 --> 00:09:34,297
THIS IS A CHANDRA IMAGE
HERE ON THE RIGHT.

242

00:09:34,297 --> 00:09:36,066
LET'S SEE -- YOUR RIGHT.

243

00:09:36,066 --> 00:09:37,627
AND AS YOU CAN SEE,

244

00:09:37,627 --> 00:09:39,627
THIS IS NOW SHOWING US
MILLION-DEGREE GAS,

245

00:09:39,627 --> 00:09:41,429
TENS-OF-MILLIONS-DEGREE GAS.

246

00:09:41,429 --> 00:09:43,858
AND YOU CAN SEE THE VERY BIG
DIFFERENCE IN STRUCTURE.

247

00:09:43,858 --> 00:09:46,429
YOU LEARN UNIQUE THINGS BY
LOOKING AT DIFFERENT WAVELENGTHS

248

00:09:46,429 --> 00:09:49,825

AND A DIFFERENT TEMPERATURE
OF OBJECTS.

249

00:09:49,825 --> 00:09:51,297
IN THE EARLY 1980s,

250

00:09:51,297 --> 00:09:53,363
THE GREAT OBSERVATORY PROGRAM
WAS CREATED

251

00:09:53,363 --> 00:09:55,825
BY DR. CHARLIE PELLERIN.

252

00:09:55,825 --> 00:09:59,066
HE WAS A VISIONARY
AT HEADQUARTERS WHO REALIZED IT

253

00:09:59,066 --> 00:10:02,726
WOULD BE DIFFICULT TO SELL
INDIVIDUAL FLAGSHIP MISSIONS

254

00:10:02,726 --> 00:10:05,231
THAT COVERED THE WHOLE SPECTRUM
FROM GAMMA RAY TO INFRARED,

255

00:10:05,231 --> 00:10:08,231
SO HE CREATED
A SCIENTIFICALLY DRIVEN PROGRAM

256

00:10:08,231 --> 00:10:11,330
THAT INCLUDED THE ALREADY-FUNDED
HUBBLE AND COMPTON MISSIONS

257

00:10:11,330 --> 00:10:14,858
AND THE AXAF AND SIRTf MISSIONS
THAT WERE UNDER STUDY.

258

00:10:14,858 --> 00:10:17,066
HE WAS OBVIOUSLY SUCCESSFUL,

259

00:10:17,066 --> 00:10:19,891

AND THE EARLY DISCOVERIES
FROM THESE OBSERVATORIES

260

00:10:19,891 --> 00:10:22,132

ALLOWED US TO LAUNCH
FOLLOW-ON MISSIONS

261

00:10:22,132 --> 00:10:23,231

THAT YOU'LL HEAR ABOUT TONIGHT,

262

00:10:23,231 --> 00:10:24,792

SUCH AS FERMI, SWIFT,

263

00:10:24,792 --> 00:10:26,000

AND NuSTAR,

264

00:10:26,000 --> 00:10:27,891

TO NAME A FEW.

265

00:10:27,891 --> 00:10:29,231

NOW, FOR THE REST
OF THE EVENING,

266

00:10:29,231 --> 00:10:30,891

WE'LL BE DESCRIBING THE PROGRESS

267

00:10:30,891 --> 00:10:33,000

WE HAVE MADE
OVER THE PAST 30 YEARS

268

00:10:33,000 --> 00:10:34,429

IN TACKLING
SOME OF THE QUESTIONS

269

00:10:34,429 --> 00:10:37,264

I JUST DISCUSSED
IN OUR VIOLENT UNIVERSE.

270

00:10:37,264 --> 00:10:40,858

I HOPE THAT WE WILL CONVINCING YOU
THAT THE LAST 30 YEARS --

271

00:10:40,858 --> 00:10:42,231

THREE DECADES -- HAVE TRULY BEEN

272

00:10:42,231 --> 00:10:46,858

AN AGE OF DISCOVERY AND AN
ASTROPHYSICAL RENAISSANCE.

273

00:10:46,858 --> 00:10:49,396

I WILL DISCUSS BRIEFLY
THREE MAJOR BREAKTHROUGHS,

274

00:10:49,396 --> 00:10:52,099

INCLUDING THE EXISTENCE
OF SUPERMASSIVE BLACK HOLES,

275

00:10:52,099 --> 00:10:54,891

THE NATURES OF QUASARS
AND THEIR POWER SOURCE,

276

00:10:54,891 --> 00:10:57,825

AND THE NATURE
OF DIFFUSE X-RAY BACKGROUND.

277

00:10:57,825 --> 00:11:00,099

JEREMY WILL FOLLOW ME
WITH A MORE DETAILED LOOK

278

00:11:00,099 --> 00:11:01,759

INTO THE NATURE OF BLACK HOLES.

279

00:11:01,759 --> 00:11:05,429

FIONA WILL DISCUSS SUPERNOVA
EXPLOSIONS AND THEIR AFTERMATH.

280

00:11:05,429 --> 00:11:07,924

AND NEIL WILL CONCLUDE
BY TELLING US HOW FAR

281
00:11:07,924 --> 00:11:11,759
WE'VE COME IN UNDERSTANDING
MYSTERIOUS GAMMA-RAY BURSTS.

282
00:11:11,759 --> 00:11:13,957
FIRST, ONE OF THE MOST
INTRIGUING MYSTERIES

283
00:11:13,957 --> 00:11:15,264
OF ASTROPHYSICS,

284
00:11:15,264 --> 00:11:17,396
ESPECIALLY BACK
IN THE '70s AND '80s.

285
00:11:17,396 --> 00:11:20,957
DO SUPERMASSIVE BLACK HOLES
EXIST?

286
00:11:20,957 --> 00:11:23,000
AND, UH, ACTUALLY, THAT QUESTION

287
00:11:23,000 --> 00:11:27,891
CAME TO AN ABRUPT END IN 1994
WHEN SOME OF THE FIRST IMAGES

288
00:11:27,891 --> 00:11:30,792
FROM THE REPAIRED
HUBBLE TELESCOPE CAME BACK.

289
00:11:30,792 --> 00:11:34,330
THIS IS THE GALAXY M87 HERE.

290
00:11:34,330 --> 00:11:36,132
YOU SEE THE RADIO JET.

291

00:11:36,132 --> 00:11:37,264
AND FOR THE FIRST TIME,

292

00:11:37,264 --> 00:11:39,594
WE WERE ABLE TO IMAGE THE GAS --

293

00:11:39,594 --> 00:11:44,297
HOT GAS GOING
AROUND THE CENTRAL OBJECT.

294

00:11:44,297 --> 00:11:46,858
AND WE WERE ABLE
TO MEASURE THE VELOCITIES

295

00:11:46,858 --> 00:11:48,429
WITH THE FAINT OBJECT
SPECTROGRAPH.

296

00:11:48,429 --> 00:11:50,594
AND LITERALLY USING
HIGH-SCHOOL MATH,

297

00:11:50,594 --> 00:11:53,231
YOU COULD DETERMINE --
KNOWING THE DISTANCE OF M87,

298

00:11:53,231 --> 00:11:55,000
KNOWING THE VELOCITY OF THE GAS,

299

00:11:55,000 --> 00:11:56,330
KNOWING THE SCALE
OF THIS PICTURE --

300

00:11:56,330 --> 00:11:58,858
YOU WERE ABLE
TO VERY QUICKLY DISCOVER THAT,

301

00:11:58,858 --> 00:12:01,825
WITHIN A VOLUME
OF LESS THAN A SOLAR SYSTEM,

302

00:12:01,825 --> 00:12:06,033

THERE WERE THREE BILLION TIMES
THE MASS OF THE SUN.

303

00:12:06,033 --> 00:12:08,363

EINSTEIN WAS RIGHT,
BECAUSE NOTHING THAT DENSE

304

00:12:08,363 --> 00:12:10,363

CAN BE ANYTHING
BUT A BLACK HOLE.

305

00:12:10,363 --> 00:12:13,627

THIS ONE OBSERVATION
BASICALLY PUT TO AN END

306

00:12:13,627 --> 00:12:18,726

THE DISCUSSION OF WHETHER
BLACK HOLES EXISTED OR NOT.

307

00:12:18,726 --> 00:12:20,066

OKAY.

308

00:12:20,066 --> 00:12:22,132

OVER THE FOLLOWING YEARS,
MORE DISCOVERIES WERE MADE

309

00:12:22,132 --> 00:12:24,792

BY VARIOUS SPACE OBSERVATORIES
THAT DEMONSTRATED

310

00:12:24,792 --> 00:12:28,495

THAT NOT ONLY DID
SUPERMASSIVE BLACK HOLES EXIST

311

00:12:28,495 --> 00:12:30,825

BUT THEY MAY BE AT THE CORE
OF EVERY GALAXY,

312

00:12:30,825 --> 00:12:33,924
EVEN OUR OWN MILKY WAY.

313

00:12:33,924 --> 00:12:37,462
HERE WE HAVE A BLACK HOLE
GOING THROUGH SPACE.

314

00:12:37,462 --> 00:12:39,132
AND AN UNSUSPECTING STAR.

315

00:12:39,132 --> 00:12:40,561
BY THE WAY,
THIS IS AN ARTIST'S RENDITION.

316

00:12:40,561 --> 00:12:41,726
[CHUCKLES]

317

00:12:41,726 --> 00:12:43,627
AN UNSUSPECTING STAR GETS
A LITTLE TOO CLOSE,

318

00:12:43,627 --> 00:12:45,594
GETS CAUGHT UP
IN THE WEB OF GRAVITY,

319

00:12:45,594 --> 00:12:47,330
STARTS GETTING TORN APART,

320

00:12:47,330 --> 00:12:50,330
CREATES AN ACCRETION DISK
OF HOT GAS AND DUST

321

00:12:50,330 --> 00:12:52,693
ROTATING RAPIDLY
AROUND THE BLACK HOLE.

322

00:12:52,693 --> 00:12:55,231
BLACK HOLES --
CONTRARY TO POPULAR BELIEF,

323

00:12:55,231 --> 00:12:56,924

THEY'RE NOT
THE ULTIMATE ROACH MOTEL.

324

00:12:56,924 --> 00:12:58,396

THEY DON'T EAT EVERYTHING.

325

00:12:58,396 --> 00:13:00,693

THEY'RE VERY MESSY EATERS.

326

00:13:00,693 --> 00:13:02,957

THEY EAT,
AND THEY'RE VERY, VERY MESSY.

327

00:13:02,957 --> 00:13:04,726

YOU'VE GOT
TREMENDOUS MAGNETIC FIELDS

328

00:13:04,726 --> 00:13:08,132

CREATED BY THE RAPIDLY ROTATING
CHARGED PARTICLES HERE,

329

00:13:08,132 --> 00:13:09,660

WHICH CREATE MAGNETIC FIELDS.

330

00:13:09,660 --> 00:13:11,396

AND SOME OF THE MATTER
THAT DOESN'T GET TRAPPED IN

331

00:13:11,396 --> 00:13:13,462

GETS SHOT OUT IN JETS.

332

00:13:13,462 --> 00:13:15,429

THIS IS -- THE CLOSER YOU
GET TO A BLACK HOLE,

333

00:13:15,429 --> 00:13:16,891

THE TEMPERATURES

GET HOTTER AND HOTTER.

334

00:13:16,891 --> 00:13:18,627

IF YOU REALLY WANT TO STUDY
THE INNER PARTS

335

00:13:18,627 --> 00:13:20,660

OF THE ACCRETION DISK, YOU
HAVE TO LOOK IN THE GAMMA RAYS,

336

00:13:20,660 --> 00:13:22,726

X-RAYS, 'CAUSE WE'RE TALKING
ABOUT GAS

337

00:13:22,726 --> 00:13:24,825

THAT'S 10 MILLION
OR MORE DEGREES.

338

00:13:24,825 --> 00:13:26,396

AND THE OUTER PORTIONS
OF THE RING --

339

00:13:26,396 --> 00:13:29,495

OF THE ACCRETION DISK
ARE A LITTLE COOLER.

340

00:13:29,495 --> 00:13:31,297

BUT WHAT WE DISCOVERED HERE

341

00:13:31,297 --> 00:13:34,165

WAS THE ACTUAL POWER SOURCE
OF QUASARS.

342

00:13:34,165 --> 00:13:37,759

THIS IS WHAT POWERS QUASARS --
ACTIVELY EATING BLACK HOLES.

343

00:13:37,759 --> 00:13:40,429

THE QUIESCENT QUASARS
ARE QUIET EATERS,

344

00:13:40,429 --> 00:13:41,792
NOT EATING TOO MUCH AT A TIME,

345

00:13:41,792 --> 00:13:44,627
AND THE ACTIVE QUASARS
THAT ARE HIGHLY VARIABLE

346

00:13:44,627 --> 00:13:48,660
ARE PROBABLY CONSUMING
AT A HIGH RATE.

347

00:13:48,660 --> 00:13:50,858
NOW THE STAGE IS SET
FOR THE NEXT MYSTERY.

348

00:13:50,858 --> 00:13:54,033
ARE QUASARS THE HOMELESS
CITIZENS OF OUR UNIVERSE

349

00:13:54,033 --> 00:13:57,924
OR ARE THEY AN INTEGRAL PART
OF SOME LARGER STRUCTURES?

350

00:13:57,924 --> 00:14:00,561
MY FRIEND AND COLLEAGUE
FROM PRINCETON,

351

00:14:00,561 --> 00:14:02,462
WHEN I WAS AT PRINCETON,
WAS JOHN BAHCALL,

352

00:14:02,462 --> 00:14:04,297
AND HE WAS LOOKING FORWARD
TO USING HUBBLE

353

00:14:04,297 --> 00:14:08,165
BECAUSE HIS THEORY WAS THAT
QUASARS WERE REALLY IN GALAXIES,

354

00:14:08,165 --> 00:14:10,264

THAT QUASARS WEREN'T HOMELESS,
SO TO SPEAK,

355

00:14:10,264 --> 00:14:11,957

THAT THEY LIVED IN GALAXIES.

356

00:14:11,957 --> 00:14:14,099

AND INDEED, WITH HUBBLE
IMAGING CAPABILITY --

357

00:14:14,099 --> 00:14:15,495

THIS IS A HUBBLE IMAGE.

358

00:14:15,495 --> 00:14:18,099

THIS IS A RADIO JET
COMING OUT OF THIS GALAXY.

359

00:14:18,099 --> 00:14:20,396

AND ZOOMING IN ON THE CENTER
OF THE GALAXY WITH HUBBLE,

360

00:14:20,396 --> 00:14:21,594

WE SEE THE ACCRETION DISK

361

00:14:21,594 --> 00:14:23,891

AND WE SEE WHAT LOOKS
LIKE A BLACK HOLE.

362

00:14:23,891 --> 00:14:25,297

SO, JOHN WAS RIGHT.

363

00:14:25,297 --> 00:14:27,660

AND SUBSEQUENT OBSERVATIONS
HAVE SHOWN THAT ALL QUASARS

364

00:14:27,660 --> 00:14:31,660

SEEM TO HAVE A HOME
IN SOME GALAXY, AT THEIR CENTER,

365

00:14:31,660 --> 00:14:33,462

AND THAT THE POWER SOURCE
IS PROBABLY

366

00:14:33,462 --> 00:14:36,231

A SUPERMASSIVE BLACK HOLE.

367

00:14:36,231 --> 00:14:37,924

THE LAST MYSTERY
THAT I'LL BE ADDRESSING

368

00:14:37,924 --> 00:14:42,792

IS THAT OF THE COSMIC
SOFT X-RAY BACKGROUND.

369

00:14:42,792 --> 00:14:45,594

BACK IN THE '80s --
THIS IS LOW RESOLUTION --

370

00:14:45,594 --> 00:14:50,000

THE FIRST X-RAY SATELLITES
SAW THIS FUZZ IN THE UNIVERSE --

371

00:14:50,000 --> 00:14:52,561

LOW-ENERGY X-RAYS.

372

00:14:52,561 --> 00:14:54,858

MY ANALOGY HERE IS IF YOU --

373

00:14:54,858 --> 00:14:56,891

IF I GAVE ALL OF YOU A CANDLE

374

00:14:56,891 --> 00:14:59,462

AND YOU HELD IT UP, RIGHT NOW,

375

00:14:59,462 --> 00:15:00,957

I WOULDN'T SEE
INDIVIDUAL LIGHTS.

376

00:15:00,957 --> 00:15:03,033

I'D JUST SEE A FUZZ

'CAUSE MY GLASSES ARE OFF.

377

00:15:03,033 --> 00:15:04,132

RIGHT?

378

00:15:04,132 --> 00:15:06,594

IF I PUT MY GLASSES ON,

20/20 VISION,

379

00:15:06,594 --> 00:15:08,561

SUDDENLY I'D SEE

IT'S NOT A FUZZ.

380

00:15:08,561 --> 00:15:10,759

IT'S ALL INDIVIDUAL CANDLES.

381

00:15:10,759 --> 00:15:12,858

AND THAT'S EXACTLY

WHAT HAPPENED HERE.

382

00:15:12,858 --> 00:15:15,792

THE EARLY SATELLITES

DIDN'T HAVE THE RESOLUTION.

383

00:15:15,792 --> 00:15:17,198

THIS IS A CHANDRA IMAGE

384

00:15:17,198 --> 00:15:19,726

THAT SHOWED THIS FUZZ WAS

ACTUALLY CREATED BY THOUSANDS,

385

00:15:19,726 --> 00:15:22,561

IF NOT HUNDREDS OF THOUSANDS

OF POINT SOURCES.

386

00:15:22,561 --> 00:15:24,066

IN FACT, THIS LITTLE AREA --

387

00:15:24,066 --> 00:15:28,033
THESE FIVE OBJECTS HERE
IN THE CHANDRA IMAGE

388

00:15:28,033 --> 00:15:29,165
MATCH UP BEAUTIFULLY

389

00:15:29,165 --> 00:15:32,165
WITH GALAXIES
IN THE HUBBLE DEEP FIELD.

390

00:15:32,165 --> 00:15:35,066
AS IT TURNS OUT,
ABOUT 80% OF THIS BACKGROUND --

391

00:15:35,066 --> 00:15:38,759
THESE INDIVIDUAL SOURCES --
TURN OUT TO BE QUASARS.

392

00:15:38,759 --> 00:15:42,528
ANOTHER MYSTERY SOLVED.

393

00:15:42,528 --> 00:15:45,165
NOW I'D LIKE TO WRAP UP
BY GETTING A BIT PHILOSOPHICAL,

394

00:15:45,165 --> 00:15:46,957
IF I COULD.

395

00:15:46,957 --> 00:15:49,363
I'VE TALKED ABOUT SEVERAL
LONG-STANDING MYSTERIES

396

00:15:49,363 --> 00:15:51,726
THAT HAVE BEEN SOLVED
OVER THE PAST 30 YEARS,

397

00:15:51,726 --> 00:15:55,726

BUT THE UNIVERSE IS
A VERY, VERY BIG PLACE.

398

00:15:55,726 --> 00:15:58,957

THIS IS THE DEEPEST IMAGE
OF THE SKY EVER OBTAINED --

399

00:15:58,957 --> 00:16:01,462

THE HUBBLE ULTRA-DEEP FIELD.

400

00:16:01,462 --> 00:16:06,363

THERE ARE OVER 10,000 GALAXIES
IN THIS ONE IMAGE.

401

00:16:06,363 --> 00:16:09,264

SOME OF THE GALAXIES ARE SO FAR
AWAY THEY'RE ONLY BABIES

402

00:16:09,264 --> 00:16:12,066

AS THEY APPEARED 13 BILLIONS
YEARS AGO,

403

00:16:12,066 --> 00:16:15,660

700 MILLION YEARS
AFTER THE UNIVERSE WAS BORN.

404

00:16:15,660 --> 00:16:20,858

YET THE IMAGE IS ONLY
ONE-FORTY-MILLIONTH OF THE SKY.

405

00:16:20,858 --> 00:16:22,000

IN OTHER WORDS, IT WOULD TAKE

406

00:16:22,000 --> 00:16:25,561

40 MILLION HUBBLE
ULTRA-DEEP FIELDS TO COVER

407

00:16:25,561 --> 00:16:27,924

THE ENTIRE SKY.

408

00:16:27,924 --> 00:16:29,627

IF YOU WANTED A HUMAN ANALOGY,

409

00:16:29,627 --> 00:16:32,726

GO OUT ON A CLEAR NIGHT,
GET A STANDARD SEWING NEEDLE,

410

00:16:32,726 --> 00:16:33,858

HOLD IT UP AT ARM'S LENGTH

411

00:16:33,858 --> 00:16:36,165

AND LOOK AT A HOLE
IN THE SEWING NEEDLE.

412

00:16:36,165 --> 00:16:40,033

THAT'S THE SIZE OF THE SKY
YOU'RE SEEING PORTRAYED HERE.

413

00:16:40,033 --> 00:16:44,099

SO, DESPITE ALL THE MYSTERIES
WE HAVE SOLVED,

414

00:16:44,099 --> 00:16:45,264

LET'S NOT GET TOO ARROGANT.

415

00:16:45,264 --> 00:16:46,891

AS I SAID, THE HUBBLE IS --

416

00:16:46,891 --> 00:16:49,792

I MEAN, THE UNIVERSE IS
A VERY, VERY BIG PLACE,

417

00:16:49,792 --> 00:16:52,528

AND THERE'S A WEE BIT OF WORK
TO BE DONE.

418

00:16:52,528 --> 00:16:55,132

IF THIS MAKES YOU FEEL SMALL,

IT SHOULD.

419

00:16:55,132 --> 00:16:56,363
WE HUMANS, AFTER ALL,

420

00:16:56,363 --> 00:16:59,033
HAVE ONLY BEEN AROUND
FOR ABOUT 100,000 YEARS

421

00:16:59,033 --> 00:17:02,924
ON A PLANET THAT'S BEEN HERE
FOR FOUR BILLION YEARS OR SO.

422

00:17:02,924 --> 00:17:04,924
WE LIVE ON A SMALL ROCK
CALLED THE EARTH,

423

00:17:04,924 --> 00:17:07,924
WHICH ORBITS A ROUTINE STAR
CALLED THE SUN.

424

00:17:07,924 --> 00:17:10,330
AND THE SUN IS ONE OF HUNDREDS
OF BILLIONS OF STARS

425

00:17:10,330 --> 00:17:12,066
IN OUR GALAXY.

426

00:17:12,066 --> 00:17:14,429
AND, SORRY, OUR GALAXY
ISN'T REALLY SPECIAL.

427

00:17:14,429 --> 00:17:19,594
IT'S JUST ONE OF HUNDREDS
OF BILLIONS OF GALAXIES.

428

00:17:19,594 --> 00:17:21,660
BUT BEFORE YOU GET
TOO DEPRESSED,

429

00:17:21,660 --> 00:17:23,429

ON THE POSITIVE SIDE,

430

00:17:23,429 --> 00:17:27,429

WE MERE HUMANS,
JUST IN THE PAST 30 YEARS,

431

00:17:27,429 --> 00:17:30,825

HAVE BUILT SPACE OBSERVATORIES
WHICH AN ENABLED OUR MINDS

432

00:17:30,825 --> 00:17:35,099

AND OUR SPIRITS TO TRAVEL
ANY PLACE IN THIS VAST UNIVERSE

433

00:17:35,099 --> 00:17:39,561

AND EXPERIENCE SOME OF THE MOST
VIOLENT PHENOMENA IMAGINABLE,

434

00:17:39,561 --> 00:17:43,165

PLACES OUR PHYSICAL BODIES
CAN NEVER GO.

435

00:17:43,165 --> 00:17:46,330

AND NOW, SPEAKING ABOUT PLACES
YOUR BODY SHOULD AVOID,

436

00:17:46,330 --> 00:17:48,132

OUR NEXT SPEAKER,
JEREMY, WILL TAKE US

437

00:17:48,132 --> 00:17:49,561

ON A MUCH MORE DETAILED JOURNEY

438

00:17:49,561 --> 00:17:52,660

THROUGH THE WORLD
OF BLACK HOLES.

439

00:17:52,660 --> 00:17:55,495

[APPLAUSE]

440

00:18:01,264 --> 00:18:04,528

-THANK YOU, ED,
FOR THAT WONDERFUL INTRODUCTION.

441

00:18:04,528 --> 00:18:07,033

I'D LIKE TO JUST START
WITH A PERSONAL REQUEST

442

00:18:07,033 --> 00:18:10,924

TO ALL THE STUDENTS IN THE ROOM
THAT WERE MENTIONED EARLIER.

443

00:18:10,924 --> 00:18:13,363

IF YOU SEE ANYTHING
OR HEAR ANYTHING

444

00:18:13,363 --> 00:18:15,693

THAT PIQUES YOUR CURIOSITY
IN MY TALK TONIGHT,

445

00:18:15,693 --> 00:18:18,660

PLEASE, PLEASE, DON'T
HESITATE -- LOOK UP MY E-MAIL.

446

00:18:18,660 --> 00:18:20,561

I'M THE ONLY JEREMY SCHNITTMAN
IN THE WORLD.

447

00:18:20,561 --> 00:18:21,627

[LAUGHTER]

448

00:18:21,627 --> 00:18:24,033

SEND ME AN E-MAIL
AND ASK ME YOUR QUESTION.

449

00:18:24,033 --> 00:18:26,231

I'D BE HAPPY TO TALK
TO YOU MORE.

450

00:18:26,231 --> 00:18:27,693

OR EVEN BETTER,
NEXT TIME YOU'RE AT GODDARD,

451

00:18:27,693 --> 00:18:30,000

JUST STOP BY MY OFFICE.

452

00:18:30,000 --> 00:18:31,396

SO, AS ED MENTIONED,

453

00:18:31,396 --> 00:18:33,660

I'M GOING TO TALK
ABOUT BLACK HOLES TONIGHT.

454

00:18:33,660 --> 00:18:36,165

SO, UH, LET'S START
WITH THE BASICS.

455

00:18:36,165 --> 00:18:38,561

WHAT EXACTLY IS A BLACK HOLE?

456

00:18:38,561 --> 00:18:41,561

JUST LIKE SAURON
IN HIS DARK TOWER...

457

00:18:41,561 --> 00:18:42,759

[LAUGHTER]

458

00:18:42,759 --> 00:18:45,033

BLACK HOLES ARE KNOWN
FOR BEING TERRIFYING,

459

00:18:45,033 --> 00:18:48,495

INVISIBLE SOURCES
OF DEATH AND DESTRUCTION,

460

00:18:48,495 --> 00:18:51,396

MUCH FEARED

BUT LITTLE UNDERSTOOD,

461

00:18:51,396 --> 00:18:54,132

FAR OFF IN THE LAND OF SHADOWS,

462

00:18:54,132 --> 00:18:58,594

VEILED IN AN IMPENETRABLE CLOAK
OF MYSTERY.

463

00:18:58,594 --> 00:19:02,033

WELL, I'M AFRAID I'VE GOT
SOME DISAPPOINTING NEWS FOR YOU.

464

00:19:02,033 --> 00:19:04,693

BLACK HOLES ARE ACTUALLY BORING.

465

00:19:04,693 --> 00:19:07,858

THERE IS LITERALLY NOTHING
TO THEM.

466

00:19:07,858 --> 00:19:13,066

NOW, THE COSMIC WEB OF GALAXIES
IS INTRICATE AND BEAUTIFUL.

467

00:19:13,066 --> 00:19:17,396

STARS ARE SOURCES
OF TWINKLING WONDER.

468

00:19:17,396 --> 00:19:21,000

PLANETS ARE GRACEFUL
AND MAJESTIC.

469

00:19:21,000 --> 00:19:23,000

BUT BLACK HOLES...

470

00:19:23,000 --> 00:19:24,726

ARE BLACK.

471

00:19:24,726 --> 00:19:27,264

LET'S ZOOM IN
FOR A CLOSER LOOK, PLEASE.

472
00:19:27,264 --> 00:19:28,264
[LAUGHTER]

473
00:19:28,264 --> 00:19:31,066
YEP, STILL BORING.

474
00:19:31,066 --> 00:19:34,099
IT'S REALLY ONLY
WHEN WE ZOOM OUT

475
00:19:34,099 --> 00:19:36,594
AND SEE THE BLACK HOLE
IN THE CONTEXT

476
00:19:36,594 --> 00:19:40,198
OF ITS SURROUNDING ENVIRONMENT
DO WE BEGIN TO APPRECIATE

477
00:19:40,198 --> 00:19:42,858
HOW THEY MIGHT NOT BE SO BORING
AFTER ALL.

478
00:19:42,858 --> 00:19:44,264
TRULY, IT'S THE STUFF

479
00:19:44,264 --> 00:19:48,264
AROUND BLACK HOLES
THAT MAKES THEM SO INTERESTING.

480
00:19:48,264 --> 00:19:50,429
AND WHEN THIS STUFF IS GAS,

481
00:19:50,429 --> 00:19:53,033
IT USUALLY FORMS SOMETHING
CALLED AN ACCRETION DISK,

482

00:19:53,033 --> 00:19:54,462
LIKE ED MENTIONED.

483
00:19:54,462 --> 00:19:58,528
WHAT WE'RE WATCHING HERE
IS AN ARTIST'S IMPRESSION

484
00:19:58,528 --> 00:20:01,825
OF WHAT AN ACCRETION DISK
WOULD LOOK LIKE CLOSE UP.

485
00:20:01,825 --> 00:20:04,297
NOW, THAT IS BEAUTIFUL.

486
00:20:04,297 --> 00:20:07,858
AND WHILE I ADMIT I AM CERTAINLY
BIASED ON THE SUBJECT,

487
00:20:07,858 --> 00:20:12,066
I CAN'T HELP BUT THINK THAT
THE ASTROPHYSICIST'S IMPRESSION

488
00:20:12,066 --> 00:20:15,363
OF AN ACCRETION DISK IS
EVEN MORE BEAUTIFUL.

489
00:20:15,363 --> 00:20:20,000
BLACK HOLES ARE SUCH POWERFUL
GRAVITATIONAL MONSTERS

490
00:20:20,000 --> 00:20:21,396
THAT THEY WARP AND TWIST

491
00:20:21,396 --> 00:20:25,429
THE VERY FABRIC OF SPACE-TIME
ITSELF AROUND THEM.

492
00:20:25,429 --> 00:20:27,264
THEY CAN ACTUALLY BEND LIGHT,

493

00:20:27,264 --> 00:20:30,462

LEADING TO IMAGES

LIKE THIS OF AN ACCRETION DISK

494

00:20:30,462 --> 00:20:34,396

SIMULTANEOUSLY VIEWED

FROM ABOVE AND BELOW.

495

00:20:34,396 --> 00:20:38,660

WE CAN EVEN SEE AN INNER RING

CAUSED BY LIGHT

496

00:20:38,660 --> 00:20:40,891

THAT GOES ALL THE WAY

AROUND THE BLACK HOLE

497

00:20:40,891 --> 00:20:45,396

BEFORE ESCAPING

AND EVENTUALLY MAKING IT TO US.

498

00:20:45,396 --> 00:20:47,957

I COULD WATCH THIS MOVIE

FOR HOURS.

499

00:20:47,957 --> 00:20:51,660

IT'S REALLY MORE -- IT'S

MORE PEACEFUL THAN TERRIFYING.

500

00:20:51,660 --> 00:20:56,033

AND THE TRUTH IS, JUST LIKE

A VORTEX IN A POOL OF WATER,

501

00:20:56,033 --> 00:20:58,429

BLACK HOLES REALLY

AREN'T THAT DANGEROUS

502

00:20:58,429 --> 00:21:01,363

UNLESS YOU GET EXTREMELY CLOSE

TO THEM.

503
00:21:01,363 --> 00:21:02,858
AND IN PRACTICE,

504
00:21:02,858 --> 00:21:07,462
IT'S REALLY VERY DIFFICULT
TO GET CLOSE TO A BLACK HOLE.

505
00:21:07,462 --> 00:21:09,792
WHY? BECAUSE --
FOR THE SAME REASON

506
00:21:09,792 --> 00:21:12,330
THAT PLANETS JUST GO
'ROUND AND 'ROUND THE SUN

507
00:21:12,330 --> 00:21:15,330
WITHOUT EVER
GETTING SUCKED IN --

508
00:21:15,330 --> 00:21:17,561
BECAUSE OF ANGULAR MOMENTUM.

509
00:21:17,561 --> 00:21:20,660
SO, GAS ORBITING
AROUND A BLACK HOLE

510
00:21:20,660 --> 00:21:23,627
CAN NEVER ACTUALLY
REACH THE EVENT HORIZON

511
00:21:23,627 --> 00:21:27,066
UNLESS IT FIRST SHEDS
ITS ANGULAR MOMENTUM.

512
00:21:27,066 --> 00:21:29,528
AND IT TURNS OUT
THIS IS QUITE DIFFICULT TO DO

513
00:21:29,528 --> 00:21:33,330

IF IT DOESN'T HAVE
ANYTHING TO PUSH OFF OF.

514
00:21:33,330 --> 00:21:35,726
IF YOU WERE A BLOB
OF GAS ORBITING

515
00:21:35,726 --> 00:21:38,363
AROUND A BLACK HOLE
AT HALF THE SPEED OF LIGHT,

516
00:21:38,363 --> 00:21:41,099
I MEAN, WHAT --
WHAT WOULD YOU PUSH OFF OF?

517
00:21:41,099 --> 00:21:44,924
I SUGGEST WE COULD ACTUALLY
LEARN FROM ROLLER DERBY.

518
00:21:44,924 --> 00:21:47,825
THERE'S A MANEUVER
CALLED THE WHIP.

519
00:21:47,825 --> 00:21:51,396
AND THE SKATER
ON THE INSIDE TRACK STARTS OFF

520
00:21:51,396 --> 00:21:55,330
BY GOING FASTER, AND THEN
SHE WHIPS HER PARTNER AROUND,

521
00:21:55,330 --> 00:21:59,165
TRANSFERRING
ANGULAR MOMENTUM OUTWARDS.

522
00:21:59,165 --> 00:22:02,000
AFTERWARDS, THE INNER SKATER
IS GOING SLOWER

523
00:22:02,000 --> 00:22:04,165

AND, IF SHE WERE ORBITING
A BLACK HOLE,

524

00:22:04,165 --> 00:22:07,330

IS ONE STEP CLOSER
TO GETTING SUCKED IN.

525

00:22:07,330 --> 00:22:09,462

AROUND REAL BLACK HOLES,

526

00:22:09,462 --> 00:22:13,363

MAGNETIC FIELDS
TAKE THE ROLE OF THE WHIPPERS,

527

00:22:13,363 --> 00:22:16,858

PULLING SOME GAS IN AND THROWING
THE REST OUT INTO SPACE.

528

00:22:16,858 --> 00:22:19,660

AGAIN, LIKE ED MENTIONED,
THEY'RE MESSY EATERS.

529

00:22:19,660 --> 00:22:22,495

IN THE ACCRETION DISK,
THE GAS IS THREADED

530

00:22:22,495 --> 00:22:26,528

WITH THIS COMPLEX, TURBULENT
NETWORK OF MAGNETIC FIELDS

531

00:22:26,528 --> 00:22:29,264

CONSTANTLY GETTING TWISTED
AND WRAPPED AROUND

532

00:22:29,264 --> 00:22:31,033

LIKE RUBBER BANDS.

533

00:22:31,033 --> 00:22:33,957

AND JUST LIKE RUBBER BANDS,
THESE MAGNETIC FIELDS

534

00:22:33,957 --> 00:22:36,726

CAN STRETCH UNTIL THE POINT
WHERE THEY SNAP,

535

00:22:36,726 --> 00:22:39,231

RELEASING MASSIVE AMOUNTS
OF ENERGY,

536

00:22:39,231 --> 00:22:42,924

HEATING THE GAS TO MILLIONS
OR EVEN BILLIONS OF DEGREES,

537

00:22:42,924 --> 00:22:45,891

JUST LIKE IN THE CORONA
OF OUR SUN.

538

00:22:45,891 --> 00:22:49,957

NOW, THIS SUPER-HEATED GAS
SHINES VERY BRIGHTLY IN X-RAYS,

539

00:22:49,957 --> 00:22:52,924

WHICH IS EXACTLY
WHY WE LIKE TO USE TELESCOPES

540

00:22:52,924 --> 00:22:57,231

LIKE CHANDRA AND NuSTAR
TO STUDY BLACK HOLES.

541

00:22:57,231 --> 00:22:59,495

NOW, ACCRETION DISKS
AREN'T THE ONLY WAY

542

00:22:59,495 --> 00:23:04,495

THAT YOU CAN STUDY THE CURVED
SPACE AROUND BLACK HOLES.

543

00:23:04,495 --> 00:23:06,330

ONE OF THE REMARKABLE
PREDICTIONS

544

00:23:06,330 --> 00:23:09,099

OF EINSTEIN'S THEORY
OF RELATIVITY IS

545

00:23:09,099 --> 00:23:14,495

THAT SPACE-TIME IS NOT ONLY
CURVED BUT IT'S ALSO TWISTED.

546

00:23:14,495 --> 00:23:16,429

IN THIS COMPUTER SIMULATION

547

00:23:16,429 --> 00:23:19,033

OF PARTICLES
PLUNGING INTO A BLACK HOLE,

548

00:23:19,033 --> 00:23:22,132

WE CAN SEE THIS EFFECT
OF THE TWISTING OF SPACE TIME

549

00:23:22,132 --> 00:23:23,825

MOST PROMINENTLY RIGHT

550

00:23:23,825 --> 00:23:25,528

OUTSIDE OF THE EVENT HORIZON,

551

00:23:25,528 --> 00:23:26,825

WHERE PARTICLES

552

00:23:26,825 --> 00:23:30,264

ARE BEING SWEEPED AROUND
IN A COUNTERCLOCKWISE SWIRL

553

00:23:30,264 --> 00:23:32,165

AT NEARLY THE SPEED OF LIGHT.

554

00:23:32,165 --> 00:23:35,231

WE'RE WATCHING
NATURE'S OWN PARTICLE COLLIDER

555

00:23:35,231 --> 00:23:36,594

IN ACTION HERE --

556

00:23:36,594 --> 00:23:39,396

A FURIOUS MAELSTROM GENERATING

557

00:23:39,396 --> 00:23:43,495

HIGHER ENERGY PHOTONS

CALLED GAMMA RAYS.

558

00:23:43,495 --> 00:23:47,066

NOW, ALTOGETHER, THE PULLING,

THE TWISTING, THE SLINGING,

559

00:23:47,066 --> 00:23:50,000

THE WHIPPING OF GAS

BY THE BLACK HOLE

560

00:23:50,000 --> 00:23:55,165

LEADS TO TREMENDOUS HIGH-ENERGY

PARTICLES AND RELATIVISTIC JETS,

561

00:23:55,165 --> 00:23:56,726

BOTH OF WHICH CAN BE SEEN

562

00:23:56,726 --> 00:24:00,858

WITH TELESCOPES THAT LOOK

IN THE X-RAYS AND GAMMA RAYS.

563

00:24:00,858 --> 00:24:04,099

AND TO CONCLUDE, I WOULD LIKE

TO OBSERVE THAT THIS YEAR

564

00:24:04,099 --> 00:24:08,495

DOES MARK THE 100th ANNIVERSARY

OF EINSTEIN'S THEORY

565

00:24:08,495 --> 00:24:10,396

OF GENERAL RELATIVITY.

566

00:24:10,396 --> 00:24:14,693

AND WE'RE JUST BEGINNING
TO START TO SCRATCH THE SURFACE

567

00:24:14,693 --> 00:24:17,363

OF WHAT THIS REMARKABLE THEORY
PREDICTS.

568

00:24:17,363 --> 00:24:20,858

WE LOOK FORWARD
TO THE NEXT 100 YEARS OF FINDING

569

00:24:20,858 --> 00:24:23,759

AND CONQUERING THE BEASTS
OF THE COSMOS.

570

00:24:23,759 --> 00:24:27,462

AND NOW, TO TELL US EXACTLY
HOW YOU FIND THESE BEASTS

571

00:24:27,462 --> 00:24:29,858

AND TAME THEM
WITH THE NuSTAR TELESCOPE IS

572

00:24:29,858 --> 00:24:31,594

DR. FIONA HARRISON.

573

00:24:31,594 --> 00:24:32,693

THANK YOU.

574

00:24:32,693 --> 00:24:34,627

[APPLAUSE]

575

00:24:41,825 --> 00:24:43,033

-OKAY.

THANKS, JEREMY.

576

00:24:43,033 --> 00:24:45,429
SO, I'M GONNA TELL YOU
ABOUT DISCOVERIES

577
00:24:45,429 --> 00:24:46,858
FROM THE NuSTAR MISSION,

578
00:24:46,858 --> 00:24:48,759
WHICH IS THE FIRST
REAL TELESCOPE

579
00:24:48,759 --> 00:24:51,495
TO LOOK AT THE UNIVERSE
IN HIGH-ENERGY,

580
00:24:51,495 --> 00:24:53,297
OR BLUE, X-RAYS.

581
00:24:53,297 --> 00:24:56,297
SO, VISIBLE LIGHT IS MADE
UP OF A RAINBOW OF COLORS,

582
00:24:56,297 --> 00:24:58,330
AND SO IS X-RAY LIGHT.

583
00:24:58,330 --> 00:25:00,561
THIS IS A HUBBLE SPACE
TELESCOPE IMAGE

584
00:25:00,561 --> 00:25:05,561
OF THE NEARBY GALAXY MESSIER 82,
SEEN IN BLACK AND WHITE.

585
00:25:05,561 --> 00:25:07,396
WE GET MUCH MORE INFORMATION

586
00:25:07,396 --> 00:25:10,099
WHEN WE LOOK AT ASTRONOMICAL
OBJECTS IN DIFFERENT COLORS.

587

00:25:10,099 --> 00:25:13,264

WE GET INFORMATION
ABOUT HOW HOT, DUSTY,

588

00:25:13,264 --> 00:25:14,792

AND ENERGETIC DIFFERENT REGIONS

589

00:25:14,792 --> 00:25:15,891

ARE.

590

00:25:15,891 --> 00:25:18,924

MAKING AN ANALOGY
WITH THE VISIBLE PORTION

591

00:25:18,924 --> 00:25:20,792

OF THE ELECTROMAGNETIC SPECTRUM,

592

00:25:20,792 --> 00:25:22,066

BEFORE NuSTAR,

593

00:25:22,066 --> 00:25:24,297

WE COULD ONLY MAKE
CRISP PICTURES OF THE UNIVERSE

594

00:25:24,297 --> 00:25:27,627

IN RED, ORANGE,
AND YELLOW X-RAY LIGHT.

595

00:25:27,627 --> 00:25:30,462

THIS IS WHAT M82 WOULD LOOK
LIKE IF YOU COULD ONLY SEE IT

596

00:25:30,462 --> 00:25:33,429

IN RED, ORANGE,
AND YELLOW IN VISIBLE.

597

00:25:33,429 --> 00:25:36,792

MOSTLY WHAT YOU'RE SEEING HERE
IS DUSTY, WARM REGIONS.

598

00:25:36,792 --> 00:25:38,957

WHEN YOU ADD THE BLUE TO M82,

599

00:25:38,957 --> 00:25:40,957

THE BLUE HIGHLIGHTS HOT REGIONS

600

00:25:40,957 --> 00:25:42,957

WHERE STARS

ARE ACTIVELY FORMING.

601

00:25:42,957 --> 00:25:44,858

SO, NuSTAR HAS ADDED BLUE,

602

00:25:44,858 --> 00:25:47,594

INDIGO, AND VIOLET

TO THE X-RAY PALETTE.

603

00:25:47,594 --> 00:25:49,396

THIS IS BRINGING A RICHNESS

TO OUR VIEW

604

00:25:49,396 --> 00:25:51,924

OF THE ENERGETIC UNIVERSE

THAT WE'VE NEVER HAD.

605

00:25:51,924 --> 00:25:55,297

IT'S LIKE BEING AN ARTIST

THAT HAS A FULL SET OF PAINTS

606

00:25:55,297 --> 00:25:56,627

TO WORK WITH.

607

00:25:56,627 --> 00:26:00,561

SO, HOW DID WE ADD THESE COLORS

TO THE X-RAY BAND?

608

00:26:00,561 --> 00:26:03,165

WELL, IT WAS BY MAKING

A NEW KIND OF TELESCOPE

609

00:26:03,165 --> 00:26:04,627
TO IMAGE BLUE X-RAYS,

610

00:26:04,627 --> 00:26:07,066
GOING FROM
A PINHOLE-CAMERA TECHNOLOGY

611

00:26:07,066 --> 00:26:09,297
TO A REAL FOCUSING TELESCOPE.

612

00:26:09,297 --> 00:26:13,759
NOW WE CAN PAINT THE HIGH-ENERGY
X-RAY SKY IN ITS FULL GLORY.

613

00:26:13,759 --> 00:26:16,198
USING THE SAME ENERGY
OR COLOR X-RAYS

614

00:26:16,198 --> 00:26:19,495
THAT YOUR DOCTOR AND DENTISTS
USE TO X-RAY YOUR BODY,

615

00:26:19,495 --> 00:26:21,726
NuSTAR OBSERVES SOME
OF THE HOTTEST, DENSEST,

616

00:26:21,726 --> 00:26:24,759
AND MOST ENERGETIC REGIONS
IN THE UNIVERSE.

617

00:26:24,759 --> 00:26:27,825
BECAUSE HIGH-ENERGY X-RAYS
PROBE THROUGH YOUR SKIN,

618

00:26:27,825 --> 00:26:30,627
THEY ALSO PROBE THROUGH DUST
AND GAS IN THE UNIVERSE,

619

00:26:30,627 --> 00:26:31,858

ILLUMINATING OBJECTS

620

00:26:31,858 --> 00:26:34,594

THAT WOULD OTHERWISE BE HIDDEN
FROM OUR VIEW.

621

00:26:34,594 --> 00:26:37,858

BY EMPLOYING NEW TECHNOLOGIES
DEVELOPED OVER MANY YEARS,

622

00:26:37,858 --> 00:26:39,165

ON A SMALL MISSION,

623

00:26:39,165 --> 00:26:42,231

NuSTAR IS MAKING IMAGES
THAT ARE HUNDREDS OF TIMES

624

00:26:42,231 --> 00:26:45,858

DEEPER AND CRISPER THAN PREVIOUS
HIGH-ENERGY MISSIONS

625

00:26:45,858 --> 00:26:48,627

THAT WERE 10 TIMES
THE COST AND SIZE.

626

00:26:48,627 --> 00:26:51,825

SO, NuSTAR IS A SMALL EXPLORER.

627

00:26:51,825 --> 00:26:54,693

THIS IS THE SMALLEST SCALE
STANDALONE ASTROPHYSICS MISSION

628

00:26:54,693 --> 00:26:55,858

THAT NASA SUPPORTS,

629

00:26:55,858 --> 00:26:58,132

AND SO IT HAS TO LAUNCH
ON A SMALL ROCKET.

630

00:26:58,132 --> 00:27:01,462

NUSTAR WAS ATTACHED TO THE BELLY
OF AN L-1011 AIRCRAFT

631

00:27:01,462 --> 00:27:04,726

AND LAUNCHED INTO SPACE ON
A SMALL ROCKET CALLED A PEGASUS.

632

00:27:04,726 --> 00:27:06,792

THERE'S NOT MUCH ROOM
FOR THE PAYLOAD,

633

00:27:06,792 --> 00:27:10,825

WHICH HAS TO BE A SMALL FRACTION
OF THE LENGTH OF THE AIRPLANE,

634

00:27:10,825 --> 00:27:13,891

SO THE PROBLEM HERE IS
THAT X-RAY TELESCOPES

635

00:27:13,891 --> 00:27:15,297

ARE INHERENTLY BIG,

636

00:27:15,297 --> 00:27:17,462

USUALLY THE LENGTH
OF A SCHOOL BUS.

637

00:27:17,462 --> 00:27:19,660

THE WAY NUSTAR
ACHIEVED SCHOOL-BUS LENGTH

638

00:27:19,660 --> 00:27:20,924

WAS THE FOLLOWING.

639

00:27:20,924 --> 00:27:22,594

NINE DAYS AFTER LAUNCH,

640

00:27:22,594 --> 00:27:24,792

WE EXTENDED
A TINKER-TOY-LIKE STRUCTURE

641
00:27:24,792 --> 00:27:28,891
CONSISTING OF TENS OF THOUSANDS
OF PIECE PARTS, PIECE BY PIECE,

642
00:27:28,891 --> 00:27:30,198
LOCKING THEM ALL INTO PLACE

643
00:27:30,198 --> 00:27:31,858
UNTIL, 24 MINUTES LATER,

644
00:27:31,858 --> 00:27:35,132
WE HAD A STIFF TELESCOPE
WITH WHICH TO VIEW THE HEAVENS.

645
00:27:35,132 --> 00:27:36,957
MIND YOU, WE WERE NEVER ACTUALLY

646
00:27:36,957 --> 00:27:40,561
ABLE TO DEPLOY THIS FULLY
ASSEMBLED ON THE GROUND.

647
00:27:40,561 --> 00:27:41,726
SO, WHEN THE MARS GUYS

648
00:27:41,726 --> 00:27:43,891
TALK ABOUT THEIR SEVEN MINUTES
OF TERROR --

649
00:27:43,891 --> 00:27:46,363
THIS WAS MY 24 MINUTES
OF TERROR.

650
00:27:46,363 --> 00:27:48,693
BUT IT ALL WORKED PERFECTLY,

651
00:27:48,693 --> 00:27:51,297

AND NuSTAR'S BEEN ON ORBIT,

652

00:27:51,297 --> 00:27:54,825

MAKING UNPRECEDENTED IMAGES
OF THE HIGH-ENERGY X-RAY SKIES

653

00:27:54,825 --> 00:27:57,165

SINCE JUNE OF 2012.

654

00:27:57,165 --> 00:27:59,561

SO, MAKING
SUCH A HUGE OBSERVATIONAL LEAP

655

00:27:59,561 --> 00:28:02,759

MEANS YOU'RE GONNA DISCOVER NEW
AND EXCITING THINGS.

656

00:28:02,759 --> 00:28:06,528

NuSTAR WAS ABLE TO MAKE THE VERY
FIRST HIGH-QUALITY IMAGES

657

00:28:06,528 --> 00:28:07,825

IN HIGH-ENERGY X-RAYS

658

00:28:07,825 --> 00:28:10,033

OF THE REGION AROUND
THE SUPERMASSIVE BLACK HOLE

659

00:28:10,033 --> 00:28:13,165

THAT RESIDES IN THE HEART
OF OUR OWN MILKY WAY GALAXY.

660

00:28:13,165 --> 00:28:15,660

WHAT WE DISCOVERED
WAS A SWARM OF DEAD STARS,

661

00:28:15,660 --> 00:28:18,759

CREATING A HAZE AROUND
THE SUPERMASSIVE BLACK HOLE.

662

00:28:18,759 --> 00:28:20,924

THIS HAZE HAD
NEVER BEEN SEEN BEFORE

663

00:28:20,924 --> 00:28:23,297

BECAUSE WE DIDN'T HAVE
HIGH ENOUGH RESOLUTION IMAGES

664

00:28:23,297 --> 00:28:25,528

IN PENETRATING
HIGH-ENERGY X-RAYS.

665

00:28:25,528 --> 00:28:27,495

AS YOU CAN SEE,
THE PRESS PICKED UP ON THIS

666

00:28:27,495 --> 00:28:29,693

IN AN INTERESTING WAY.
[CLEARS THROAT]

667

00:28:29,693 --> 00:28:30,825

[LAUGHTER]

668

00:28:30,825 --> 00:28:32,495

SO, WHAT I'M GONNA
SPEND THE REST OF MY TIME

669

00:28:32,495 --> 00:28:35,099

TELLING YOU ABOUT
IS THE FUNDAMENTALLY NEW THINGS

670

00:28:35,099 --> 00:28:37,066

THAT WE'RE LEARNING
ABOUT THE PROCESSES

671

00:28:37,066 --> 00:28:38,561

THAT CREATED THE PLACE

672

00:28:38,561 --> 00:28:41,891

WE LIVE TODAY FROM THE SOUP
OF HOT HYDROGEN AND HELIUM

673

00:28:41,891 --> 00:28:45,066
THAT EXISTED SHORTLY
AFTER THE UNIVERSE WAS BORN.

674

00:28:45,066 --> 00:28:48,264
TODAY, 13.8 BILLION YEARS
AFTER THE BIG BANG,

675

00:28:48,264 --> 00:28:50,429
WE HAVE A RICH MIX
OF CHEMICAL ELEMENTS,

676

00:28:50,429 --> 00:28:52,594
RANGING FROM THE NITROGEN
IN THE ATMOSPHERE,

677

00:28:52,594 --> 00:28:53,957
THE CALCIUM IN YOUR BONES,

678

00:28:53,957 --> 00:28:55,660
AND THE GOLD
IN YOUR WEDDING RING.

679

00:28:55,660 --> 00:28:58,396
THIS MOVIE FOLLOWS THE EVOLUTION
OF THE UNIVERSE,

680

00:28:58,396 --> 00:29:01,330
AS IMAGINED BY THEORISTS USING
SUPERCOMPUTERS.

681

00:29:01,330 --> 00:29:03,594
FILAMENTS OF HYDROGEN
AND HELIUM FORM,

682

00:29:03,594 --> 00:29:06,165
SHAPED BY THE GRAVITY

OF DARK MATTER.

683

00:29:06,165 --> 00:29:08,726

IN THESE FILAMENTS,
CLOUDS OF DUST AND GAS CONDENSE

684

00:29:08,726 --> 00:29:10,231

AND FORM STARS.

685

00:29:10,231 --> 00:29:12,528

THE MASSIVE ONES BURN HYDROGEN
AND HELIUM

686

00:29:12,528 --> 00:29:14,066

TO PROGRESSIVELY HEAVIER
ELEMENTS,

687

00:29:14,066 --> 00:29:16,330

LIKE CARBON, NITROGEN, OXYGEN,

688

00:29:16,330 --> 00:29:17,726

AND EVENTUALLY IRON.

689

00:29:17,726 --> 00:29:20,264

AND FINALLY, THESE STARS
RUN OUT OF NUCLEAR FUEL

690

00:29:20,264 --> 00:29:23,363

AND EXPLODE IN DRAMATIC EVENTS
CALLED SUPERNOVAE.

691

00:29:23,363 --> 00:29:24,726

WHEN THE UNIVERSE IS OLDER,

692

00:29:24,726 --> 00:29:28,660

SUPERNOVAE EXPLODE ALL OVER,
AS YOU SEE IN THIS VIDEO,

693

00:29:28,660 --> 00:29:30,132

MANUFACTURING ELEMENTS,

694

00:29:30,132 --> 00:29:32,099

SPEWING THEM
OUT INTO THE COSMOS,

695

00:29:32,099 --> 00:29:35,693

WHERE THEY CAN CONDENSE
INTO GALAXIES, STARS, PLANETS,

696

00:29:35,693 --> 00:29:37,033

AND LIFE.

697

00:29:37,033 --> 00:29:39,627

THIS MOVIE IS BASED
ON SOME GOVERNING PRINCIPLES,

698

00:29:39,627 --> 00:29:41,330

WHAT SCIENTISTS
THINK IS REASONABLE,

699

00:29:41,330 --> 00:29:44,924

BUT KEY COMPONENTS
ARE LARGELY BASED ON THEORY.

700

00:29:44,924 --> 00:29:47,099

HOW THIS ALL WORKS
IN PRACTICE IS A DANCE --

701

00:29:47,099 --> 00:29:48,792

A BACK AND FORTH
BETWEEN THEORISTS

702

00:29:48,792 --> 00:29:51,627

AND OBSERVERS WITH TELESCOPES,
INCLUDING NASA'S

703

00:29:51,627 --> 00:29:54,099

PANCHROMATIC FLEET
OF INFRARED, OPTICAL, X-RAY,

704

00:29:54,099 --> 00:29:56,132

AND GAMMA-RAY MISSIONS.

705

00:29:56,132 --> 00:29:59,891

SO, HOW STARS ACTUALLY EXPLODE
IS A PROFOUND MYSTERY.

706

00:29:59,891 --> 00:30:02,198

IT TURNS OUT
TO BE REALLY HARD TO MAKE A STAR

707

00:30:02,198 --> 00:30:04,429

THAT'S IMPLODING
UNDER THE FORCE OF GRAVITY

708

00:30:04,429 --> 00:30:08,198

TO EXPLODE AND EXPAND OUT
INTO THE UNIVERSE.

709

00:30:08,198 --> 00:30:12,198

STELLAR EXPLOSIONS HAVE A LOT
OF SIMILARITIES TO ATOMIC BOMBS.

710

00:30:12,198 --> 00:30:14,891

AND SIMILAR TO BOMBS,
HUGE COMPUTATIONAL POWER

711

00:30:14,891 --> 00:30:17,891

AND THEORETICAL RESOURCES HAVE
GONE IN TO UNDERSTANDING THEM.

712

00:30:17,891 --> 00:30:20,891

BUT IN A HUGE FAILURE OF THEORY,

713

00:30:20,891 --> 00:30:24,462

MOST COMPUTERS CAN'T ACTUALLY
MAKE A STAR EXPLODE.

714

00:30:24,462 --> 00:30:26,594
WHAT YOU SEE HERE IS AN EXAMPLE.

715
00:30:26,594 --> 00:30:28,825
THIS IS A NUMERICAL SIMULATION
ON A COMPUTER

716
00:30:28,825 --> 00:30:30,429
OF A STELLAR EXPLOSION.

717
00:30:30,429 --> 00:30:33,891
WE CAN SEE HERE
THAT THE EXPLOSION HALTS

718
00:30:33,891 --> 00:30:35,957
UNTIL AN AD HOC MECHANISM --

719
00:30:35,957 --> 00:30:39,231
HERE, THE SLOSHING AROUND OF
THE CENTRAL PART OF THE STAR --

720
00:30:39,231 --> 00:30:43,264
IS PUT IN BY THEORISTS
TO MAKE THE STAR FLY APART.

721
00:30:43,264 --> 00:30:46,132
THIS CAN MAKE THE STAR EXPLODE,
BUT IS IT IMAGINATION

722
00:30:46,132 --> 00:30:48,396
OR IS IT REALLY
WHAT HAPPENS IN NATURE?

723
00:30:48,396 --> 00:30:51,792
TO DECIDE THIS,
WE NEED OBSERVATIONS.

724
00:30:51,792 --> 00:30:54,264
SO, PREVIOUS LOW-ENERGY
X-RAY TELESCOPES,

725

00:30:54,264 --> 00:30:57,165

LIKE NASA'S CHANDRA MISSION,

726

00:30:57,165 --> 00:30:58,924

HAVE TAKEN PICTURES

OF THE REMNANTS

727

00:30:58,924 --> 00:31:01,924

OF SUPERNOVA EXPLOSIONS HUNDREDS

TO THOUSANDS OF YEARS

728

00:31:01,924 --> 00:31:03,231

AFTER THE EVENT.

729

00:31:03,231 --> 00:31:05,231

AND LIKE CRIME-SCENE

INVESTIGATORS

730

00:31:05,231 --> 00:31:07,198

WHO LOOK AT THE SHRAPNEL

AND OTHER DEBRIS

731

00:31:07,198 --> 00:31:09,594

TO FIGURE OUT

HOW AN EXPLOSION HAPPENED,

732

00:31:09,594 --> 00:31:12,363

ASTRONOMICAL TELESCOPES PIECE

TOGETHER THE WORKINGS

733

00:31:12,363 --> 00:31:14,264

OF THE BOMB

FROM WHAT'S LEFT OVER,

734

00:31:14,264 --> 00:31:17,165

WHAT'S STILL VISIBLE LONG

AFTER THE EVENT.

735

00:31:17,165 --> 00:31:19,297
AND AS YOU SEE HERE,
PREVIOUS X-RAY MISSIONS

736

00:31:19,297 --> 00:31:21,594
HAVE BEEN ABLE TO LOOK
AT THE HOT, GLOWING DEBRIS

737

00:31:21,594 --> 00:31:23,132
OF THESE EXPLOSIONS,

738

00:31:23,132 --> 00:31:25,297
BUT BECAUSE OF THE LIMITED RANGE
OF COLORS,

739

00:31:25,297 --> 00:31:28,000
THEY COULD NOT SEE
WHAT THE HEART OF THE EXPLOSION

740

00:31:28,000 --> 00:31:29,528
ACTUALLY LOOKS LIKE.

741

00:31:29,528 --> 00:31:32,924
NuSTAR HAS PROVIDED
A COMPLETELY NEW TOOL --

742

00:31:32,924 --> 00:31:36,033
THE ABILITY TO LOOK
AT THE RADIOACTIVE MATERIAL

743

00:31:36,033 --> 00:31:38,330
CREATED IN THESE COSMIC BOMBS.

744

00:31:38,330 --> 00:31:40,363
THE RADIOACTIVE EMBERS GLOW

745

00:31:40,363 --> 00:31:42,759
AS ONE CHEMICAL ELEMENT
CHANGES INTO ANOTHER.

746

00:31:42,759 --> 00:31:45,693

HERE, TITANIUM
IS CHANGING INTO CALCIUM.

747

00:31:45,693 --> 00:31:49,528

ON COSMIC SCALES, IN ONLY GLOWS
FOR A SHORT TIME --

748

00:31:49,528 --> 00:31:50,891

A FEW HUNDRED YEARS --

749

00:31:50,891 --> 00:31:53,297

BUT THE RESULTING RADIATION
IS ONLY VISIBLE

750

00:31:53,297 --> 00:31:54,660

IN THE HIGH-ENERGY X-RAYS.

751

00:31:54,660 --> 00:31:58,132

AND SO NuSTAR CAN USE THESE
TO DIAGNOSE THE NATURE

752

00:31:58,132 --> 00:32:00,099

OF THE EXPLOSION.

753

00:32:00,099 --> 00:32:02,660

HERE ARE IMAGES OF THE DEBRIS

754

00:32:02,660 --> 00:32:05,495

FROM THE HISTORICAL SUPERNOVA
REMNANT CASSIOPEIA A,

755

00:32:05,495 --> 00:32:08,660

THAT ED SHOWED YOU BEFORE,
IN DIFFERENT X-RAY COLORS,

756

00:32:08,660 --> 00:32:10,297

SHOWING DIFFERENT ELEMENTS.

757

00:32:10,297 --> 00:32:11,693

THE RED AND THE GREEN IMAGES

758

00:32:11,693 --> 00:32:14,825

WERE MADE FROM THE LOW-ENERGY
CHANDRA X-RAY TELESCOPE,

759

00:32:14,825 --> 00:32:20,660

WHICH SEES THE UNIVERSE IN RED
AND YELLOW AND GREEN COLORS.

760

00:32:20,660 --> 00:32:22,198

NuSTAR HAS ADDED THE BLUE,

761

00:32:22,198 --> 00:32:24,594

THE FIRST IMAGE
IN RADIOACTIVITY.

762

00:32:24,594 --> 00:32:27,363

THIS ENABLES US TO SEE
THE VERY HEART OF THE EXPLOSION

763

00:32:27,363 --> 00:32:28,429

FOR THE FIRST TIME,

764

00:32:28,429 --> 00:32:30,363

AND YOU CAN SEE
IT LOOKS QUITE DIFFERENT

765

00:32:30,363 --> 00:32:35,363

THAN WHAT YOU SEE IN RED
AND GREEN.

766

00:32:35,363 --> 00:32:37,000

THIS NEW EVIDENCE IS TELLING US

767

00:32:37,000 --> 00:32:39,693

THAT THE SHAPE OF THE EXPLOSION
WAS BUBBLY,

768

00:32:39,693 --> 00:32:42,165

LIKE WHAT YOU WOULD EXPECT
OF THAT SLOSHING MECHANISM

769

00:32:42,165 --> 00:32:47,396

THEORISTS PREDICTED
REALLY HAPPENS IN LIFE.

770

00:32:47,396 --> 00:32:49,660

THE CRIME-SCENE INVESTIGATORS
HAVE DETERMINED

771

00:32:49,660 --> 00:32:52,165

THAT THE SLOSHING AROUND
OF THE CORE OF THIS STAR

772

00:32:52,165 --> 00:32:54,429

WAS KEY TO MAKING IT EXPLODE.

773

00:32:54,429 --> 00:32:57,297

SO, FILLING IN THE PIECES
OF THIS COSMIC PUZZLE OF HOW

774

00:32:57,297 --> 00:33:00,396

WE GET FROM AN AMORPHOUS SOUP
TO WHERE WE ARE TODAY.

775

00:33:00,396 --> 00:33:05,132

SO, HERE'S CASSIOPEIA A
IN ITS PANCHROMATIC X-RAY GLORY.

776

00:33:05,132 --> 00:33:08,627

WHAT MADE THIS STAR EXPLODE
IS UNDERSTOOD FOR THE FIRST TIME

777

00:33:08,627 --> 00:33:11,066

THANKS TO THE BROAD PALETTE
OF X-RAY COLORS

778

00:33:11,066 --> 00:33:14,000

FROM NASA'S SUITE
OF HIGH-ENERGY X-RAY MISSIONS.

779

00:33:14,000 --> 00:33:16,660

AND NEXT,
NEIL GEHRELS IS GONNA TELL YOU

780

00:33:16,660 --> 00:33:22,462

ABOUT EXTREME AND UNUSUAL KINDS
OF COSMIC EXPLOSIONS.

781

00:33:22,462 --> 00:33:24,396

[APPLAUSE]

782

00:33:30,462 --> 00:33:32,957

-THANK YOU, FIONA.

783

00:33:32,957 --> 00:33:34,627

IT'S A PLEASURE
TO BE HERE THIS EVENING

784

00:33:34,627 --> 00:33:37,264

TO TALK TO YOU
ABOUT SPECTACULAR EXPLOSIONS

785

00:33:37,264 --> 00:33:40,858

CALLED GAMMA-RAY BURSTS
AND THE BIRTH OF BLACK HOLES.

786

00:33:40,858 --> 00:33:43,594

AND I'D LIKE TO START OUT
WITH A COUPLE OF COOL MOVIES

787

00:33:43,594 --> 00:33:44,858

THAT WE PUT TOGETHER,

788

00:33:44,858 --> 00:33:47,396

THE FIRST ONE BEING

AN ATOMIC BOMB EXPLOSION

789

00:33:47,396 --> 00:33:49,363
THAT FIONA MENTIONED.

790

00:33:49,363 --> 00:33:51,726
SO, AN H-BOMB IS
THE MOST POWERFUL

791

00:33:51,726 --> 00:33:56,198
AND DESTRUCTIVE EXPLOSION
THAT WE HAVE HERE ON THE EARTH.

792

00:33:56,198 --> 00:33:58,132
[RUMBLING]

793

00:34:06,231 --> 00:34:09,330
THESE EXPLOSIONS PALE
IN COMPARISON

794

00:34:09,330 --> 00:34:11,726
TO THAT OF AN EXPLODING STAR.

795

00:34:21,396 --> 00:34:24,594
THIS IS A GAMMA-RAY BURST
WITH THE ENERGY EQUIVALENT

796

00:34:24,594 --> 00:34:27,693
OF 1 TO THE POWER OF 30 H-BOMBS.

797

00:34:27,693 --> 00:34:31,330
THAT'S 1 WITH 30 ZEROES
AFTER IT.

798

00:34:31,330 --> 00:34:34,924
GAMMA-RAY BURST IS A RARE TYPE
OF SUPERNOVA EXPLOSION

799

00:34:34,924 --> 00:34:37,924

IN WHICH A BLACK HOLE FORMS
AT THE CENTER.

800

00:34:37,924 --> 00:34:42,165
AND THEY'RE THE MOST ENERGETIC
EXPLOSIONS IN THE UNIVERSE.

801

00:34:42,165 --> 00:34:45,330
I'D LIKE TO TELL YOU ABOUT
THE HISTORY OF GAMMA-RAY BURSTS.

802

00:34:45,330 --> 00:34:47,759
THEY WERE FIRST DISCOVERED
BY THE VELA SATELLITES,

803

00:34:47,759 --> 00:34:52,231
BUILT AT LOS ALAMOS
NATIONAL LABORATORIES.

804

00:34:52,231 --> 00:34:55,594
THE VELAS WERE DESIGNED
TO MONITOR THE TEST BAN TREATY

805

00:34:55,594 --> 00:34:59,198
THAT THE U.S. SIGNED
WITH THE SOVIET UNION

806

00:34:59,198 --> 00:35:03,165
TO PROHIBIT EXPLOSIONS
IN OUTER SPACE.

807

00:35:03,165 --> 00:35:05,759
THEY ACTUALLY DISCOVERED FLASHES
OF GAMMA RAYS.

808

00:35:05,759 --> 00:35:08,759
THE FIRST ONE OCCURRED IN 1967.

809

00:35:08,759 --> 00:35:11,693
BUT LUCKILY,

IT WAS NOT A NUCLEAR WEAPON.

810

00:35:11,693 --> 00:35:16,858

IT WAS THE DISCOVERY
OF GAMMA RAY BURSTS.

811

00:35:16,858 --> 00:35:20,165

SO, GAMMA-RAY BURSTS
ARE EXPLOSIONS

812

00:35:20,165 --> 00:35:24,594

THAT ARE BRIGHT FLASHES
OF X-RAYS AND GAMMA RAYS.

813

00:35:24,594 --> 00:35:26,132

THEY OCCUR ABOUT ONCE PER DAY

814

00:35:26,132 --> 00:35:30,099

AND SPREAD OUT UNIFORMLY
ACROSS THE SKY.

815

00:35:30,099 --> 00:35:31,561

IN THE EARLY DAYS,

816

00:35:31,561 --> 00:35:35,528

THERE WAS NO UNDERSTANDING OF
WHAT COULD CAUSE THESE EVENTS.

817

00:35:35,528 --> 00:35:38,528

IN FACT, I REMEMBER A TIME
WHEN THERE WERE MORE THEORIES --

818

00:35:38,528 --> 00:35:39,627

PUBLISHED THEORIES --

819

00:35:39,627 --> 00:35:42,000

OF WHAT COULD CAUSE
A GAMMA-RAY BURST

820

00:35:42,000 --> 00:35:47,396
THAN THERE WERE GAMMA-RAY BURSTS
DETECTED.

821
00:35:47,396 --> 00:35:50,759
THIS IS ONE OF MY FAVORITE ONES
ON THE NEXT SLIDE,

822
00:35:50,759 --> 00:35:52,429
WHICH WERE ALIENS
IN OUTER SPACE.

823
00:35:52,429 --> 00:35:54,858
THIS WAS AN ACTUAL NEWSPAPER
ARTICLE.

824
00:35:54,858 --> 00:35:58,891
ALIEN WARS.

825
00:35:58,891 --> 00:36:01,165
IN 1998,

826
00:36:01,165 --> 00:36:04,495
AN ITALIAN AND DUTCH SATELLITE

827
00:36:04,495 --> 00:36:06,693
MADE AN IMPORTANT DISCOVERY --

828
00:36:06,693 --> 00:36:10,198
THAT GAMMA-RAY BURSTS WERE NOT
OCCURRING NEAR THE SOLAR SYSTEM

829
00:36:10,198 --> 00:36:11,957
OR EVEN IN OUR OWN GALAXY,

830
00:36:11,957 --> 00:36:16,495
BUT WERE OCCURRING
IN DISTANT, FAR-AWAY GALAXIES.

831

00:36:16,495 --> 00:36:18,429
SO, THEY'RE
EXTREMELY BRIGHT EVENTS --

832
00:36:18,429 --> 00:36:20,924
THE BRIGHTEST EVENTS
WE KNOW OF IN THE SKY

833
00:36:20,924 --> 00:36:22,462
IN THE GAMMA-RAY BAND.

834
00:36:22,462 --> 00:36:24,363
BUT THEY'RE OCCURRING FAR AWAY.

835
00:36:24,363 --> 00:36:28,231
SO, THAT MEANS THAT THEY'RE
INCREDIBLY POWERFUL EXPLOSIONS.

836
00:36:28,231 --> 00:36:30,297
THIS IS AN HST IMAGE.

837
00:36:30,297 --> 00:36:33,891
YOU CAN SEE THE GAMMA-RAY BURST
IS THE WHITE LIGHT

838
00:36:33,891 --> 00:36:37,627
AND THE FUZZ IS THE GALAXY
IN THE DISTANCE.

839
00:36:37,627 --> 00:36:39,099
AND SO, THIS WAS REALLY PROOF

840
00:36:39,099 --> 00:36:43,165
THAT THE GAMMA-RAY BURSTS WERE
OCCURRING IN DISTANT GALAXIES.

841
00:36:43,165 --> 00:36:46,561
IN THAT SAME YEAR, IN 1998,

842

00:36:46,561 --> 00:36:49,033

I PUT TOGETHER
A TEAM OF SCIENTISTS

843

00:36:49,033 --> 00:36:51,957

TO PROPOSE
A MISSION CALLED SWIFT.

844

00:36:51,957 --> 00:36:55,165

AND WE PROPOSED THIS MISSION
TO THE NASA EXPLORER PROGRAM,

845

00:36:55,165 --> 00:36:58,264

WHICH HAS OPPORTUNITIES
EVERY COUPLE OF YEARS.

846

00:36:58,264 --> 00:37:00,429

THERE WERE 40 PROPOSALS
SUBMITTED.

847

00:37:00,429 --> 00:37:02,330

EACH ONE IS A PRETTY THICK
DOCUMENT.

848

00:37:02,330 --> 00:37:05,330

I STILL HAVE THE SWIFT PROPOSAL
IN MY OFFICE.

849

00:37:05,330 --> 00:37:09,429

AND WE WERE LUCKY ENOUGH
TO BE SELECTED.

850

00:37:09,429 --> 00:37:12,594

SO, WITH A TEAM
OF NASA, UNIVERSITY,

851

00:37:12,594 --> 00:37:14,660

AND INDUSTRY PARTNERS,

852

00:37:14,660 --> 00:37:18,033

WE BUILD THIS MISSION
IN A VERY FAST TIME --

853
00:37:18,033 --> 00:37:19,792
ABOUT FOUR YEARS FROM THE TIME

854
00:37:19,792 --> 00:37:24,528
WE STARTED WORKING ON IT
UNTIL WE LAUNCHED IT.

855
00:37:24,528 --> 00:37:27,099
IT WAS LAUNCHED IN 2004,

856
00:37:27,099 --> 00:37:30,363
AND IT'S BEEN WORKING SPLENDIDLY
SINCE THAT TIME,

857
00:37:30,363 --> 00:37:33,792
EVEN AS WE SPEAK TONIGHT.

858
00:37:33,792 --> 00:37:36,627
SWIFT IS A STATE-OF-THE-ART
OBSERVATORY PUSHING

859
00:37:36,627 --> 00:37:39,759
THE FRONTIERS OF ASTROPHYSICS
IN MANY DIFFERENT WAYS.

860
00:37:39,759 --> 00:37:41,330
YOU SEE ON THIS SLIDE HERE

861
00:37:41,330 --> 00:37:44,627
AN ULTRAVIOLET IMAGE WE TOOK
WITH OUR ULTRAVIOLET TELESCOPE

862
00:37:44,627 --> 00:37:49,693
ON BOARD OF THE NEARBY GALAXY
CALLED THE LMC.

863

00:37:49,693 --> 00:37:52,462
IT'S A BEAUTIFUL PICTURE.

864
00:37:52,462 --> 00:37:56,462
BUT I'D LIKE TO GET BACK
TO GAMMA-RAY BURSTS.

865
00:37:56,462 --> 00:38:01,693
AS OF TODAY,
WE'VE DETECTED 991 BURSTS,

866
00:38:01,693 --> 00:38:04,066
AND WE'LL CELEBRATE
DETECTING 1,000 BURSTS

867
00:38:04,066 --> 00:38:07,231
IN THE NEXT COUPLE OF WEEKS.

868
00:38:07,231 --> 00:38:10,297
WE'VE SIMULATED WHAT THAT LOOKS
LIKE ON THIS ANIMATION

869
00:38:10,297 --> 00:38:11,660
OF THE SKY.

870
00:38:11,660 --> 00:38:14,726
EACH BURST IS A FLASH OF LIGHT.

871
00:38:14,726 --> 00:38:18,231
AND IT'S SHOWN ON THE BACKGROUND
OF THE BEAUTIFUL IMAGE

872
00:38:18,231 --> 00:38:22,759
OF THE GAMMA-RAY SKY
FROM THE FERMI SATELLITE.

873
00:38:22,759 --> 00:38:26,660
EVERY TIME THAT SWIFT OR FERMI
DETECTS A GAMMA-RAY BURST,

874

00:38:26,660 --> 00:38:28,957

WE'RE PAGED ON OUR CELLPHONES.

875

00:38:28,957 --> 00:38:31,825

AND SCIENTISTS GET THE PAGE,
AND THEY GO RUNNING

876

00:38:31,825 --> 00:38:34,924

TO THEIR COMPUTERS TO SEE
WHAT THE UNIVERSE HAS SENT US

877

00:38:34,924 --> 00:38:37,792

AND WHAT WE CAN LEARN
ABOUT THE UNIVERSE.

878

00:38:37,792 --> 00:38:40,528

AND I WAS AT A RECENT
GAMMA-RAY BURST CONFERENCE

879

00:38:40,528 --> 00:38:42,297

WHEN A BURST WENT OFF,

880

00:38:42,297 --> 00:38:45,495

AND YOU COULD SEE PEOPLE IN THE
AUDIENCE SLOWLY FILTERING OUT.

881

00:38:45,495 --> 00:38:47,693

AND THEN, AT SOME POINT,
THE SPEAKER LEFT, SO...

882

00:38:47,693 --> 00:38:49,165

[LAUGHTER]

YEAH.

883

00:38:49,165 --> 00:38:54,231

YOU KNOW, THIS WAS AN EVENT THAT
EVERYBODY WANTED TO LOOK AT.

884

00:38:54,231 --> 00:38:56,957

ONE OF THE THINGS WE'RE LEARNING
FROM SWIFT AND FERMI

885

00:38:56,957 --> 00:39:00,297

IS WHAT'S CAUSING
GAMMA-RAY BURSTS.

886

00:39:00,297 --> 00:39:01,561

WHEN A STAR EXPLODES,

887

00:39:01,561 --> 00:39:04,825

ITS CORE COLLAPSES
TO A BLACK HOLE,

888

00:39:04,825 --> 00:39:08,726

AND THE GAS IN THE REGION
AROUND IT IN THIS GALAXY

889

00:39:08,726 --> 00:39:12,660

FLOWS ONTO THE BLACK HOLE
AND DISAPPEARS FOREVER,

890

00:39:12,660 --> 00:39:15,330

AS WE HEARD
FROM JEREMY SCHNITTMAN.

891

00:39:15,330 --> 00:39:20,231

BUT A SMALL FRACTION OF IT GETS
ENERGIZED AND ESCAPES IN JETS.

892

00:39:20,231 --> 00:39:24,132

WE SAW BEAUTIFUL IMAGES FROM HST
THAT ED SHOWED US.

893

00:39:24,132 --> 00:39:27,033

AND THESE JETS
ARE WHAT CAUSE GAMMA-RAY BURSTS.

894

00:39:27,033 --> 00:39:32,231

IT'S WHEN THE JET IS AIMED AT US

THAT WE SEE A BURST.

895

00:39:32,231 --> 00:39:33,891

ANOTHER IMPORTANT DISCOVERY

896

00:39:33,891 --> 00:39:37,660

COMES FROM USING GAMMA-RAY
BURSTS AS DISTANT BEACONS.

897

00:39:37,660 --> 00:39:40,495

THEY'RE SO BRIGHT
WE CAN SEE STARS --

898

00:39:40,495 --> 00:39:42,693

YOU KNOW, THEY'RE THE EVIDENCE
OF STARS OCCURRING

899

00:39:42,693 --> 00:39:45,198

IN THE VERY EARLY UNIVERSE.

900

00:39:45,198 --> 00:39:51,264

IT'S REALLY THE ONLY WAY WE CAN
DETECT EARLY STARS EXPLODING.

901

00:39:51,264 --> 00:39:53,627

AND WE CAN USE GAMMA-RAY BURSTS
AS TRACERS

902

00:39:53,627 --> 00:39:55,726

TO SEE HOW MANY SUPERNOVAE
WERE OCCURRING

903

00:39:55,726 --> 00:39:58,561

IN THIS EARLY PART
OF THE UNIVERSE

904

00:39:58,561 --> 00:40:05,264

AND HOW MANY STARS
WERE BEING FORMED.

905

00:40:05,264 --> 00:40:10,495

THESE EXPLOSIONS SPEW MATERIAL
OUT INTO SPACE AROUND THEM,

906

00:40:10,495 --> 00:40:14,165

AND FROM THEM, NEW STARS
AND NEW ELEMENTS ARE MADE.

907

00:40:14,165 --> 00:40:16,924

AND THEY'RE SPEWED
OUT INTO SPACE.

908

00:40:16,924 --> 00:40:20,561

GENERATION BY GENERATION,
THE ABUNDANCE OF ELEMENTS

909

00:40:20,561 --> 00:40:23,693

EVOLVES UNTIL WE END UP
WITH THE MIX

910

00:40:23,693 --> 00:40:25,429

THAT WE HAVE IN OUR SOLAR SYSTEM

911

00:40:25,429 --> 00:40:29,825

AND THAT OUR BODIES ARE MADE OF.

912

00:40:29,825 --> 00:40:31,396

WE'RE ALSO LEARNING
ABOUT THE EFFECTS

913

00:40:31,396 --> 00:40:35,495

OF GAMMA-RAY BURSTS
ON LIFE IN THE UNIVERSE.

914

00:40:35,495 --> 00:40:38,363

THEY'RE SO INTENSE
THAT THEY AFFECT

915

00:40:38,363 --> 00:40:43,627

AND DESTROY THE ATMOSPHERE
ON PLANETS THAT ARE NEARBY.

916

00:40:43,627 --> 00:40:47,594

LUCKILY FOR US, THIS IS
AN EXTREMELY RARE PROCESS,

917

00:40:47,594 --> 00:40:51,627

AND SO THE CHANCE OF THAT
HAPPENING IS INFINITESIMAL --

918

00:40:51,627 --> 00:40:53,231

YOU KNOW,
IT'S MUCH LESS PROBABLE

919

00:40:53,231 --> 00:40:56,858

THAN AN ASTEROID CAUSING
AN EXTINCTION ON THE EARTH --

920

00:40:56,858 --> 00:40:58,957

IN THE CURRENT ERA.

921

00:40:58,957 --> 00:41:02,561

BUT IF WE GO BACK
SEVERAL BILLION YEARS AGO,

922

00:41:02,561 --> 00:41:06,231

SORT OF IN THE MIDDLE AGE
OF THE UNIVERSE,

923

00:41:06,231 --> 00:41:08,660

THE MATERIAL IS
MUCH CLOSER TOGETHER,

924

00:41:08,660 --> 00:41:13,033

AND GAMMA-RAY BURSTS WERE
A MAJOR FORCE IN PREVENTING LIFE

925

00:41:13,033 --> 00:41:17,528

FROM FORMING THROUGH MUCH

OF THE HISTORY OF THE UNIVERSE.

926

00:41:17,528 --> 00:41:19,462
SO, ON THAT CHEERY NOTE,

927

00:41:19,462 --> 00:41:23,495
I'M GONNA END MY TALK
ABOUT GAMMA-RAY BURSTS,

928

00:41:23,495 --> 00:41:25,792
AND WE'LL TURN OVER
TO JOAN CENTRELLA,

929

00:41:25,792 --> 00:41:29,066
WHO WILL GIVE US
CLOSING REMARKS.

930

00:41:29,066 --> 00:41:30,660
THANK YOU.

931

00:41:30,660 --> 00:41:32,594
[APPLAUSE]

932

00:41:39,693 --> 00:41:43,132
[INSECTS CHIRPING]

933

00:41:43,132 --> 00:41:44,330
-THANK YOU, NEIL.

934

00:41:44,330 --> 00:41:45,759
[OWL HOOTING]

935

00:41:47,495 --> 00:41:51,297
IT IS A DARK, QUIET NIGHT.

936

00:41:51,297 --> 00:41:55,561
YOU LOOK UP AND SEE OVERHEARD
THE MILKY WAY SPREADING

937

00:41:55,561 --> 00:41:58,792

ACROSS THE NIGHT SKY.

938

00:41:58,792 --> 00:42:00,858

SURVEYING THE BEAUTY
AND GRANDEUR

939

00:42:00,858 --> 00:42:04,924

OF JUST THIS ONE PORTION
OF OUR OWN GALAXY,

940

00:42:04,924 --> 00:42:07,363

YOU ARE MOVED
TO ASK SOME VERY IMPORTANT

941

00:42:07,363 --> 00:42:11,165

AND VERY DEEP QUESTIONS.

942

00:42:11,165 --> 00:42:14,132

WHAT IS THIS MARVELOUS UNIVERSE?

943

00:42:14,132 --> 00:42:16,198

HOW BIG IS IT?

944

00:42:16,198 --> 00:42:19,066

WHAT MAKES IT TICK?

945

00:42:19,066 --> 00:42:22,924

HOW DID ALL THIS COME TO BE?

946

00:42:22,924 --> 00:42:26,660

ARE WE ALONE
IN THIS VAST COSMOS?

947

00:42:26,660 --> 00:42:31,660

OR ARE THERE OTHER PLANETS
THAT HAVE LIFE, AS WELL?

948

00:42:31,660 --> 00:42:37,132
AND HOW DO WE FIT IN
TO ALL OF THIS?

949
00:42:37,132 --> 00:42:40,792
ASTROPHYSICS, THE STUDY
OF THE UNIVERSE

950
00:42:40,792 --> 00:42:47,462
AND HOW IT WORKS,
HELPS US TO PROBE FOR ANSWERS.

951
00:42:47,462 --> 00:42:49,396
AS WE'VE HEARD TONIGHT,

952
00:42:49,396 --> 00:42:52,033
THE BEAUTIFUL
AND MAJESTIC NIGHT SKY

953
00:42:52,033 --> 00:42:54,627
THAT WE SEE LOOKING OUT
FROM THE SURFACE OF THE EARTH

954
00:42:54,627 --> 00:42:57,297
IS JUST THE BEGINNING.

955
00:42:57,297 --> 00:43:01,429
MUCH OF THE STORY CAN ONLY BE
LEARNED USING INSTRUMENTS

956
00:43:01,429 --> 00:43:03,726
THAT ARE NOT SUBJECT
TO THE LIMITATIONS

957
00:43:03,726 --> 00:43:08,429
IMPOSED BY OUR ATMOSPHERE.

958
00:43:08,429 --> 00:43:13,363
AND SO WE GO OUT INTO SPACE WITH
NASA'S ASTROPHYSICS MISSIONS,

959

00:43:13,363 --> 00:43:16,561
SUCH AS FERMI, NuSTAR,

960

00:43:16,561 --> 00:43:19,693
AND SWIFT.

961

00:43:19,693 --> 00:43:23,660
THESE HIGH-ENERGY MISSIONS
UNCOVER A DYNAMIC UNIVERSE,

962

00:43:23,660 --> 00:43:27,165
ONE DRAMATICALLY DIFFERENT
FROM THE TRANQUIL TAPESTRY

963

00:43:27,165 --> 00:43:33,660
WE SEE ABOVE ON A NIGHT SKY
FROM EARTH.

964

00:43:33,660 --> 00:43:38,066
BY OBSERVING COSMIC GAMMA RAYS
AND X-RAYS, THESE MISSIONS

965

00:43:38,066 --> 00:43:41,330
REVEAL THAT THE COLD,
DARK REACHES OF SPACE

966

00:43:41,330 --> 00:43:44,165
AND PUNCTUATED
BY TURBULENT FORCES --

967

00:43:44,165 --> 00:43:47,660
BLACK HOLES,
BURSTS OF RADIATION,

968

00:43:47,660 --> 00:43:52,891
COSMIC EXPLOSIONS.

969

00:43:52,891 --> 00:43:55,132

TONIGHT, YOU HAVE SEEN AND HEARD

970

00:43:55,132 --> 00:43:58,297

ABOUT SOME
OF THESE EXOTIC EVENTS.

971

00:43:58,297 --> 00:44:02,429

YOU HAVE ENCOUNTERED THE MOST
POWERFUL COSMIC EXPLOSIONS

972

00:44:02,429 --> 00:44:06,924

AND THE INFINITE DEPTHS
OF BLACK HOLES.

973

00:44:06,924 --> 00:44:09,330

YOU'VE LEARNED THAT THE ELEMENTS

974

00:44:09,330 --> 00:44:10,858

THAT MAKE UP OUR BODIES --

975

00:44:10,858 --> 00:44:12,231

THE CALCIUM IN OUR BONES,

976

00:44:12,231 --> 00:44:13,759

THE IRON IN OUR BLOOD --

977

00:44:13,759 --> 00:44:18,330

THESE ELEMENTS ARE PRODUCED
IN THE FIERY FURNACES OF STARS

978

00:44:18,330 --> 00:44:24,495

AND HURLED OUT INTO THE COSMOS
THROUGH GIGANTIC EXPLOSIONS.

979

00:44:24,495 --> 00:44:28,891

THESE AND OTHER
DYNAMIC PHENOMENA HAVE TAUGHT US

980

00:44:28,891 --> 00:44:36,495

THAT VIOLENT ENERGY IS VERY MUCH
A PART OF THE UNIVERSE.

981

00:44:36,495 --> 00:44:40,033

SO, WHEN WE GO OUTSIDE
ON A CLEAR NIGHT,

982

00:44:40,033 --> 00:44:46,495

WE LOOK UP AND ASK OURSELVES THE
GREAT QUESTIONS OF THE COSMOS.

983

00:44:46,495 --> 00:44:49,462

AND WE KNOW THAT WHAT WE
SEE WITH OUR EYES

984

00:44:49,462 --> 00:44:53,198

IS JUST THE BEGINNING
OF A MARVELOUS STORY --

985

00:44:53,198 --> 00:44:57,132

A STORY THAT IS STILL UNFOLDING,
FAR FROM FINISHED,

986

00:44:57,132 --> 00:45:02,726

AND EVER MORE EXCITING
AS WE EXPLORE AND OBSERVE,

987

00:45:02,726 --> 00:45:04,891

QUESTION AND REFLECT,

988

00:45:04,891 --> 00:45:07,726

DISCOVER AND LEARN.

989

00:45:07,726 --> 00:45:09,462

THANK YOU ALL FOR COMING WITH US