1
00:00:05,240 --> 00:00:08,800
By taking our sense of sight far
beyond the realm of our forebears'

2
00:00:08,880 --> 00:00:13,200
imagination, these wonderful instruments,
the telescopes, open the way to

3
00:00:13,280 --> 00:00:17,240
a deeper and more perfect understanding
of nature. - René Descartes, 1637

4
00:00:17,720 --> 00:00:22,520
For millennia mankind gazed out
into the mesmerising night sky

5
00:00:22,600 --> 00:00:28,320
without recognising the stars of our
own Milky Way Galaxy as other suns

6
00:00:28,400 --> 00:00:33,400
or the billions of sister galaxies
making up the rest of our Universe

7
00:00:35,440 --> 00:00:38,760
or that we are merely
punctuation in the Universe’s

8
00:00:38,840 --> 00:00:42,480
13.7 billion year-long story.

9
00:00:42,560 --> 00:00:46,080
With only our eyes as observing
tools we had no means of

10
00:00:46,160 --> 00:00:50,120
finding solar systems around
other stars, or of determining

11
00:00:50,200 --> 00:00:55,000
whether life exists elsewhere
in the Universe.

12
00:00:58,080 --> 00:01:00,320
Today we are well on our way
to unravelling many of the

13
00:01:00,400 --> 00:01:03,520
mysteries of the Universe, living in
what may be the most remarkable

14
00:01:03,600 --> 00:01:05,920
age of astronomical discovery.

15
00:01:05,960 --> 00:01:08,960
I am Dr. J and I will be
your guide to the telescope -

16
00:01:09,040 --> 00:01:11,840
the amazing instrument that
proved to be mankind's

17
00:01:11,920 --> 00:01:15,480
gateway to the Universe.

18
00:01:17,920 --> 00:01:21,840
EYES ON THE SKIES
400 Years of Telescopic Discovery

19
00:01:22,200 --> 00:01:26,920
1. New views from the skies

20
00:01:28,960 --> 00:01:32,120
Four centuries ago, in 1609,
a man walked out

21
00:01:32,240 --> 00:01:34,600
into the fields near his home.

22
00:01:34,680 --> 00:01:39,000
He pointed his homemade telescope at
the Moon, the planets and the stars.

23
00:01:39,080 --> 00:01:42,560
His name was Galileo Galilei.

24
00:01:44,040 --> 00:01:47,280
Astronomy would never
be the same again.

25
00:02:07,440 --> 00:02:12,400
Today, 400 years after Galileo
first pointed a telescope to the skies

26
00:02:12,600 --> 00:02:18,280
astronomers use giant mirrors on remote
mountaintops to survey the heavens.

27
00:02:18,360 --> 00:02:23,480

Radio telescopes collect faint chirps
and whispers from outer space.

28
00:02:23,560 --> 00:02:27,640
Scientists have even launched
telescopes into Earth orbit

29
00:02:27,720 --> 00:02:31,920
high above the disturbing
effects of our atmosphere.

30
00:02:33,440 --> 00:02:38,640
And the view has been
breathtaking!

31
00:02:42,960 --> 00:02:46,600
However, Galileo did not, in fact,
invent the telescope.

32
00:02:46,680 --> 00:02:49,720
That credit goes to Hans Lipperhey,
a slightly obscure

33
00:02:49,800 --> 00:02:53,400
Dutch-German spectacle maker.

34
00:02:53,480 --> 00:02:57,840
But Hans Lipperhey never used
this telescope to look at the stars.

35
00:02:57,920 --> 00:03:00,800
Instead, he though his new
invention would mainly benefit

36
00:03:00,880 --> 00:03:03,600
seafarers and soldiers.

37
00:03:03,760 --> 00:03:07,240
Lipperhey came from Middelburg,
then a large trading city

38
00:03:07,320 --> 00:03:10,440
in the fledgling Dutch Republic.

39
00:03:13,960 --> 00:03:18,040
In 1608 Lipperhey found that
when viewing a distant object

40
00:03:18,120 --> 00:03:24,000
through a convex and a concave lens,

the object would be magnified, if the

41
00:03:24,080 --> 00:03:29,600
two lenses were placed at just the
right distance from one another.

42
00:03:29,680 --> 00:03:33,760
The telescope was born!

43
00:03:33,840 --> 00:03:37,480
In September 1608, Lipperhey
revealed his new invention to

44
00:03:37,560 --> 00:03:39,840
Prince Maurits of the Netherlands.

45
00:03:39,920 --> 00:03:42,800
He could not have chosen a more
advantageous moment because

46
00:03:42,880 --> 00:03:45,840
at that time the Netherlands
were embroiled in the

47
00:03:45,920 --> 00:03:49,320
80 Years' War with Spain.

48
00:03:55,320 --> 00:03:59,080
The new spyglass could magnify
objects and so it could reveal

49
00:03:59,160 --> 00:04:02,280
enemy ships and troops that
were too distant to be seen

50
00:04:02,360 --> 00:04:04,360
by the unaided eye.

51
00:04:04,440 --> 00:04:07,440
A very useful invention indeed!

52
00:04:07,520 --> 00:04:12,000
But the Dutch government never granted
Lipperhey a patent for his telescope.

53
00:04:12,080 --> 00:04:15,400
The reason was that other merchants
also claimed the invention

54

00:04:15,480 --> 00:04:19,200
especially Lipperhey's competitor
Sacharias Janssen.

55
00:04:19,280 --> 00:04:21,480
The dispute was never resolved.

56
00:04:21,560 --> 00:04:27,880
And to this day, the true origins of the
telescope remain shrouded in mystery.

57
00:04:28,880 --> 00:04:32,680
Italian astronomer Galileo Galilei,
the father of modern physics

58
00:04:32,760 --> 00:04:37,600
heard about the telescope
and decided to build his own.

59
00:04:38,320 --> 00:04:42,360
About ten months ago, a report
reached my ears that a certain

60
00:04:42,440 --> 00:04:48,200
Fleming had constructed a spyglass
by means of which visible objects

61
00:04:48,280 --> 00:04:52,960
though very distant from the eye
of the observer, were distinctly

62
00:04:53,040 --> 00:04:56,120
seen as if nearby.

63
00:04:56,480 --> 00:04:59,440
Galileo was the greatest
scientist of his time.

64
00:04:59,520 --> 00:05:02,560
He was also a strong supporter
of the new worldview advocated

65
00:05:02,640 --> 00:05:06,160
by the Polish astronomer Nicolaus
Copernicus, who proposed that

66
00:05:06,240 --> 00:05:10,440
the Earth orbited the Sun,
instead of the other way around.

67

00:05:11,520 --> 00:05:14,240
Based on what he had heard of
the Dutch telescope, Galileo

68
00:05:14,320 --> 00:05:16,560
constructed his own
instruments.

69
00:05:16,640 --> 00:05:19,160
They were of a much better quality.

70
00:05:20,520 --> 00:05:25,320
Finally, sparing neither labour
nor expenses, I succeeded

71
00:05:25,400 --> 00:05:29,640
in constructing for myself so
excellent an instrument that

72
00:05:29,720 --> 00:05:33,880
objects seen by means of it
appeared nearly one thousand

73
00:05:33,960 --> 00:05:38,800
times larger than when
regarded with our natural vision.

74
00:05:39,680 --> 00:05:43,600
It was time to train the
telescope on the heavens.

75
00:05:45,880 --> 00:05:49,640
I have been led to the opinion
and conviction that the surface

76
00:05:49,760 --> 00:05:53,480
of the moon is not smooth,
uniform and precisely spherical

77
00:05:53,720 --> 00:05:57,440
as a great number of
philosophers believe it to be

78
00:05:57,520 --> 00:06:01,680
but is uneven, rough, and full
of cavities and prominences

79
00:06:01,760 --> 00:06:06,240
being not unlike the
face of the Earth.

80
00:06:11,600 --> 00:06:15,320
A landscape of craters,
mountains, and valleys.

81
00:06:15,400 --> 00:06:18,320
A world like our own!

82
00:06:19,560 --> 00:06:24,040
A few weeks later, in January
1610, Galileo looked at Jupiter.

83
00:06:24,120 --> 00:06:28,560
Close to the planet he saw four
pricks of light that changed

84
00:06:28,680 --> 00:06:32,960
their position on the sky night
after night along with Jupiter.

85
00:06:33,040 --> 00:06:37,880
It was like a slow, cosmic ballet of
satellites orbiting the planet.

86
00:06:37,960 --> 00:06:40,720
These four pricks of light would
come to be known as

87
00:06:40,800 --> 00:06:43,560
the Galilean moons of Jupiter.

88
00:06:43,680 --> 00:06:46,240
What else did Galileo discover?

89
00:06:46,320 --> 00:06:48,400
The phases of Venus!

90
00:06:48,520 --> 00:06:51,880
Just like the Moon, Venus waxes
and wanes from crescent to

91
00:06:51,960 --> 00:06:54,200
full and back again.

92
00:06:54,280 --> 00:06:58,560
Strange appendages on
either side of Saturn.

93
00:06:58,680 --> 00:07:01,160
Dark spots on the face of the Sun.

94
00:07:01,280 --> 00:07:03,440
And, of course, stars.

95
00:07:03,520 --> 00:07:06,400
Thousands of them,
maybe even millions.

96
00:07:06,480 --> 00:07:09,320
Each too faint to be
seen by the naked eye.

97
00:07:09,440 --> 00:07:13,880
It was as if mankind had suddenly
thrown off its blindfold.

98
00:07:13,960 --> 00:07:18,000
There was a whole Universe
to discover out there.

99
00:07:23,440 --> 00:07:27,720
News about the telescope spread
across Europe like wildfire.

100
00:07:27,840 --> 00:07:32,080
In Prague, at the court of Emperor
Rudolph II, Johannes Kepler

101
00:07:32,200 --> 00:07:34,760
improved the design
of the instrument.

102
00:07:34,840 --> 00:07:38,800
In Antwerp, Dutch cartographer
Michael van Langren produced

103
00:07:38,920 --> 00:07:41,880
the first reliable maps of the Moon
showing what he believed to be

104
00:07:41,960 --> 00:07:44,400
continents and oceans.

105
00:07:44,520 --> 00:07:49,640
And Johannes Hevelius, a wealthy
brewer in Poland, built huge

106
00:07:49,720 --> 00:07:53,200
telescopes at his
observatory in Danzig.

107
00:07:53,280 --> 00:07:57,840
This observatory was so large
that it covered three rooftops!

108
00:07:59,200 --> 00:08:02,240
But the best instruments of the
time were probably constructed

109
00:08:02,320 --> 00:08:05,360
by Christiaan Huygens
in the Netherlands.

110
00:08:05,440 --> 00:08:11,080
In 1655, Huygens discovered Titan,
the largest moon of Saturn.

111
00:08:11,160 --> 00:08:15,160
A few years later, his observations
revealed Saturn's ring system

112
00:08:15,240 --> 00:08:20,320
something Galileo had
never understood.

113
00:08:20,400 --> 00:08:24,600
And last but not least, Huygens
saw dark markings and bright

114
00:08:24,680 --> 00:08:27,360
polar caps on Mars.

115
00:08:27,440 --> 00:08:31,080
Could there be life on
this remote, alien world?

116
00:08:31,160 --> 00:08:35,240
The question occupies
astronomers to this day.

117
00:08:35,880 --> 00:08:39,480
The earliest telescopes were all
refracting telescopes that used

118
00:08:39,560 --> 00:08:42,640
lenses to collect and bring
together the starlight.

119
00:08:42,720 --> 00:08:45,440
Later the lenses were

replaced with mirrors.

120
00:08:45,520 --> 00:08:49,080
This reflecting telescope was
first built by Niccolò Zucchi

121
00:08:49,160 --> 00:08:52,000
and later refined by
Isaac Newton.

122
00:08:52,080 --> 00:08:55,720
Now in the late 18th century,
the largest mirrors in the world

123
00:08:55,800 --> 00:08:59,560
were cast by William Herschel,
an organist turned astronomer

124
00:08:59,640 --> 00:09:02,480
who worked with his
sister Caroline.

125
00:09:02,560 --> 00:09:06,200
In their house in Bath, in England,
the Herschels poured red-hot

126
00:09:06,280 --> 00:09:09,840
molten metal into a mould and
when the whole thing had cooled

127
00:09:09,920 --> 00:09:15,440
off, they would polish the surface
so that it would reflect starlight.

128
00:09:15,520 --> 00:09:20,320
During the course of his life,
Herschel built more than 400 telescopes.

129
00:09:24,480 --> 00:09:28,360
The largest of these was so huge
that he needed four servants to

130
00:09:28,440 --> 00:09:31,560
operate all the various ropes,
wheels and pulleys that were

131
00:09:31,640 --> 00:09:36,000
required to track the motions
of the stars across the night sky

132

00:09:36,080 --> 00:09:39,440
which is of course caused
by the Earth's rotation.

133
00:09:39,520 --> 00:09:43,080
Now Herschel was like a surveyor,
he scanned the heavens and

134
00:09:43,160 --> 00:09:46,680
catalogued hundreds of new
nebulae and binary stars.

135
00:09:46,760 --> 00:09:50,280
He also discovered that the
Milky Way must be a flat disc.

136
00:09:50,360 --> 00:09:54,120
And he even measured the motion of
the Solar System through that disk

137
00:09:54,200 --> 00:09:58,800
by observing the relative motions
of the stars and the planets.

138
00:09:58,880 --> 00:10:06,360
And then on the 13th of March in 1781,
he discovered a new planet - Uranus.

139
00:10:06,440 --> 00:10:10,640
It was over 200 years until
NASA's Voyager 2 spacecraft

140
00:10:10,720 --> 00:10:15,840
gave astronomers their first
close-up look of this distant world.

141
00:10:16,760 --> 00:10:21,240
In the lush and fertile countryside
of central Ireland, William Parsons

142
00:10:21,320 --> 00:10:26,520
the third Earl of Rosse, built the
largest telescope of the 19th century.

143
00:10:26,600 --> 00:10:30,520
With a metal mirror a whopping
1.8 metres across, the giant

144
00:10:30,600 --> 00:10:35,240
telescope became known
as "The Leviathan of Parsonstown".

145
00:10:35,320 --> 00:10:39,320
On the occasional clear, moonless
nights, the Earl sat at the eyepiece

146
00:10:39,440 --> 00:10:44,400
and sailed on a journey
through the Universe.

147
00:10:45,280 --> 00:10:50,160
To the Orion Nebula - now known
to be a stellar nursery.

148
00:10:50,280 --> 00:10:55,880
On to the mysterious Crab Nebula,
the remnant of a supernova explosion.

149
00:10:55,960 --> 00:10:57,880
And the Whirlpool Nebula?

150
00:10:57,960 --> 00:11:02,520
Lord Rosse was the first to note
its majestic spiral shape.

151
00:11:02,600 --> 00:11:08,400
A galaxy like our own, with intricate
clouds of dark dust and glowing gas

152
00:11:08,480 --> 00:11:12,400
billions of individual stars,
and who knows -

153
00:11:12,480 --> 00:11:16,520
maybe even planets like Earth.

154
00:11:18,880 --> 00:11:24,880
The telescope had become our
vessel to explore the Universe.

155
00:11:29,400 --> 00:11:33,800
2. Bigger is better

156
00:11:35,760 --> 00:11:38,160
At night, your eyes adapt to the dark.

157
00:11:38,240 --> 00:11:42,320
Your pupils widen to let more
light into your eyes.

158

00:11:42,400 --> 00:11:47,560
As a result, you can see dimmer
objects, and fainter stars.

159
00:11:47,640 --> 00:11:51,400
Now imagine you had pupils
one metre across.

160
00:11:51,480 --> 00:11:55,640
You'd look pretty strange but you'd
also have supernatural eyesight!

161
00:11:55,720 --> 00:11:59,120
And that's what telescopes do for you.

162
00:12:01,600 --> 00:12:04,320
A telescope is like a funnel.

163
00:12:04,400 --> 00:12:09,920
Its main lens or mirror collects the starlight
and brings it all together into your eye.

164
00:12:12,760 --> 00:12:17,480
The bigger the lens or the mirror of a telescope,
the fainter the objects you can see.

165
00:12:17,560 --> 00:12:20,400
So size really is everything.

166
00:12:20,480 --> 00:12:23,080
But how big can you make a telescope?

167
00:12:23,160 --> 00:12:26,120
Well, actually not too big if it's a refractor.

168
00:12:29,160 --> 00:12:32,400
The starlight has to pass through the main lens.

169
00:12:32,480 --> 00:12:35,760
And so you can only support it around its edge.

170
00:12:35,840 --> 00:12:41,600
Now if you make the lens too big it becomes too heavy,
and it starts deforming under its own weight.

171
00:12:41,680 --> 00:12:45,320
That means that the image will be distorted.

172
00:12:47,080 --> 00:12:54,040

The largest refractor in history was completed in 1897,
at Yerkes Observatory outside Chicago.

173
00:12:54,120 --> 00:12:57,200
Its main lens was just over one metre across.

174
00:12:57,280 --> 00:13:01,800
But its tube was an incredible 18 metres long.

175
00:13:01,880 --> 00:13:08,400
With the completion of the Yerkes telescope, the builders of
refracting telescopes had pretty much reached their limit.

176
00:13:08,480 --> 00:13:10,560
You want bigger telescopes?

177
00:13:10,640 --> 00:13:12,520
Think mirrors.

178
00:13:16,760 --> 00:13:22,760
In a reflecting telescope, the starlight bounces
off a mirror instead of passing through a lens.

179
00:13:22,840 --> 00:13:29,120
That means that you can make the mirror a lot thinner
than a lens, and you can support it from the back.

180
00:13:29,200 --> 00:13:34,320
The result is that you can build
a lot larger mirrors than lenses.

181
00:13:35,320 --> 00:13:39,400
Big mirrors came to southern
California a century ago.

182
00:13:39,480 --> 00:13:44,600
Back then, Mount Wilson was a remote peak in
the wilderness of the San Gabriel mountains.

183
00:13:44,680 --> 00:13:48,800
The sky was clear and the nights were dark.

184
00:13:48,880 --> 00:13:53,360
Here, George Ellery Hale first built
a 1.5 metre telescope.

185
00:13:53,440 --> 00:13:58,080
Smaller than Lord Rosse's retired Leviathan,
it was of much better quality.

186
00:13:58,160 --> 00:14:01,880
And at a much better site, too.

187
00:14:01,960 --> 00:14:07,360
Hale talked local businessman John Hooker
into financing a 2.5 metre instrument.

188
00:14:07,440 --> 00:14:12,240
Tonnes of glass and riveted steel
were hauled up Mount Wilson.

189
00:14:12,320 --> 00:14:15,720
The Hooker telescope was completed in 1917.

190
00:14:15,800 --> 00:14:19,960
It would remain the largest telescope
in the world for 30 years.

191
00:14:20,040 --> 00:14:25,120
A big piece of cosmic artillery,
ready to attack the Universe.

192
00:14:28,200 --> 00:14:30,800
And attack it did.

193
00:14:30,880 --> 00:14:33,920
Along with the incredible size of
the new telescope came

194
00:14:33,960 --> 00:14:36,920
transformations in the way
the image was viewed.

195
00:14:36,960 --> 00:14:40,480
Astronomers no longer peered through
the eyepiece of the new giant.

196
00:14:40,560 --> 00:14:45,640
But instead collected the light on
photographic plates for hours on end.

197
00:14:45,720 --> 00:14:50,520
Never before had anyone peered
so far into the cosmos.

198
00:14:50,600 --> 00:14:54,840
Spiral nebulae turned out to be
brimming with individual stars.

199

00:14:54,920 --> 00:14:59,280
Could they be sprawling stellar
systems like our own Milky Way?

200
00:14:59,360 --> 00:15:03,480
In the Andromeda Nebula, Edwin Hubble
discovered a particular type of star

201
00:15:03,560 --> 00:15:07,080
that changes its brightness with clocklike precision.

202
00:15:07,160 --> 00:15:11,440
From his observations Hubble was able
to deduce the distance to Andromeda:

203
00:15:11,520 --> 00:15:15,680
almost a million light-years.

204
00:15:15,760 --> 00:15:22,440
Spiral nebulae, like Andromeda, were clearly
individual galaxies in their own right.

205
00:15:24,160 --> 00:15:27,040
But that wasn't the only incredible thing.

206
00:15:27,120 --> 00:15:31,720
Most of these galaxies were found to be
moving away from the Milky Way.

207
00:15:31,800 --> 00:15:37,320
At Mount Wilson, Hubble discovered that the
nearby galaxies were receding at small velocities

208
00:15:37,360 --> 00:15:42,200
whereas the distant galaxies were
moving away at a much faster pace.

209
00:15:42,280 --> 00:15:43,440
The conclusion?

210
00:15:43,520 --> 00:15:46,240
The Universe was expanding.

211
00:15:46,320 --> 00:15:53,120
The Hooker telescope had given scientists the most
profound astronomical discovery of the 20th century.

212
00:15:55,800 --> 00:16:00,320
Thanks to the telescope, we have
traced the history of the Universe.

213
00:16:00,400 --> 00:16:04,600
A little less than 14 billion years ago,
the Universe was born

214
00:16:04,680 --> 00:16:08,920
in a huge explosion of time and space,
matter and energy, called

215
00:16:08,960 --> 00:16:11,280
the Big Bang.

216
00:16:11,360 --> 00:16:17,160
Tiny quantum ripples grew into
dense patches in the primordial brew.

217
00:16:17,240 --> 00:16:19,880
From these, galaxies condensed.

218
00:16:19,960 --> 00:16:23,520
A stunning variety of sizes and shapes.

219
00:16:26,280 --> 00:16:30,120
Nuclear fusion in the cores of
stars produced new atoms.

220
00:16:30,200 --> 00:16:34,560
Carbon, oxygen, iron, gold.

221
00:16:34,640 --> 00:16:39,320
Supernova explosions blew these
heavy elements back into space.

222
00:16:39,400 --> 00:16:42,800
Raw material for the formation of new stars.

223
00:16:42,880 --> 00:16:44,520
And planets!

224
00:16:46,560 --> 00:16:54,600
Someday, somewhere, somehow, simple
organic molecules evolved into living organisms.

225
00:16:54,680 --> 00:17:00,280
Life is one miracle in an
ever-evolving Universe.

226
00:17:00,360 --> 00:17:02,600
We are stardust.

227
00:17:02,680 --> 00:17:06,720
It's a grand vision and a sweeping story.

228
00:17:06,800 --> 00:17:10,880
Brought to us through telescopic observations.

229
00:17:10,960 --> 00:17:15,360
Imagine: without the telescope we
would know about just six planets

230
00:17:15,400 --> 00:17:17,880
one moon, and a few thousand stars.

231
00:17:17,960 --> 00:17:22,120
Astronomy would still be in its infancy.

232
00:17:23,360 --> 00:17:27,160
Like buried treasures, the outposts of
the Universe have beckoned to the

233
00:17:27,240 --> 00:17:29,720
adventurous from immemorial times.

234
00:17:29,800 --> 00:17:35,160
Princes and potentates, political or
industrial, equally with men of science

235
00:17:35,240 --> 00:17:39,920
have felt the lure of the uncharted
seas of space, and through their provision

236
00:17:39,960 --> 00:17:45,120
of instrumental means the sphere
of exploration has rapidly widened.

237
00:17:59,480 --> 00:18:02,360
George Ellery Hale had one final dream:

238
00:18:02,440 --> 00:18:06,640
to build a telescope twice as large
as the previous record holder.

239
00:18:06,720 --> 00:18:10,600
Meet the grand old lady of
20th century astronomy.

240
00:18:10,680 --> 00:18:15,600
The five metre Hale telescope at Palomar Mountain.

241
00:18:15,680 --> 00:18:20,240
Over five hundred tonnes of moving weight,
yet so precisely balanced

242
00:18:20,320 --> 00:18:24,360
that it moves as gracefully as a ballerina.

243
00:18:24,440 --> 00:18:29,920
Its 40 tonne mirror reveals stars
40 million times fainter than the eye can see.

244
00:18:29,960 --> 00:18:34,920
Completed in 1948, the Hale telescope
gave us unsurpassed views of planets

245
00:18:34,960 --> 00:18:38,520
star clusters, nebulae and galaxies.

246
00:18:40,760 --> 00:18:44,680
Giant Jupiter, with its many moons.

247
00:18:44,760 --> 00:18:48,760
The stunning Flame Nebula.

248
00:18:48,840 --> 00:18:53,920
Faint wisps of gas in the Orion Nebula.

249
00:18:59,560 --> 00:19:01,800
But could we go bigger still?

250
00:19:01,880 --> 00:19:05,920
Well, soviet astronomers
tried in the late 1970s.

251
00:19:05,960 --> 00:19:10,320
High up in the Caucasus mountains,
they built the Bolshoi Teleskop Azimutalnyi

252
00:19:10,400 --> 00:19:14,600
sporting a primary mirror
six metres in diameter.

253
00:19:14,680 --> 00:19:17,320
But it never really lived
up to its expectations.

254
00:19:17,400 --> 00:19:21,440
It was simply too big, too expensive,

and too difficult.

255
00:19:21,520 --> 00:19:24,680
So did telescope builders have
to give up at that point?

256
00:19:24,760 --> 00:19:28,200
Did they have to bury their dreams
of even bigger instruments?

257
00:19:28,280 --> 00:19:31,680
Had the history of the telescope
come to a premature end?

258
00:19:31,760 --> 00:19:33,080
Well, of course not.

259
00:19:33,160 --> 00:19:36,200
Today we have 10 metre
telescopes in operation.

260
00:19:36,280 --> 00:19:38,840
And even bigger ones are
on the drawing board.

261
00:19:38,920 --> 00:19:40,400
What was the solution?

262
00:19:40,480 --> 00:19:42,320
New technologies.

263
00:19:44,000 --> 00:19:48,760
3. Technology to the rescue

264
00:19:48,960 --> 00:19:52,800
Just as modern cars don't look like
a Model T Ford anymore, so are present

265
00:19:52,880 --> 00:19:56,280
day telescopes radically different
from their classic predecessors

266
00:19:56,360 --> 00:19:58,680
like the five metre Hale telescope.

267
00:19:58,760 --> 00:20:01,880
For one thing, their
mounts are much smaller.

268

00:20:01,960 --> 00:20:05,840
The old-style mount is an equatorial
one where one of the axis

269
00:20:05,920 --> 00:20:09,720
is always mounted parallel
to the Earth's rotation axis.

270
00:20:09,800 --> 00:20:13,480
In order to keep track of the sky's
motion, the telescope simply

271
00:20:13,560 --> 00:20:18,200
has to rotate around this axis at the
same speed with which the Earth rotates.

272
00:20:18,280 --> 00:20:21,160
Easy, but space-hungry.

273
00:20:21,240 --> 00:20:26,040
The modern day altitude azimuth
mounts are much more compact.

274
00:20:26,080 --> 00:20:30,440
With a mount like that, the telescope
is pointed much like a cannon.

275
00:20:30,480 --> 00:20:35,240
One simply chooses the bearing,
chooses the altitude, and off you go.

276
00:20:35,320 --> 00:20:38,640
The problem is to keep
track of the sky's motion.

277
00:20:38,720 --> 00:20:44,240
The telescope pretty much has to rotate
around both axis, and at varying speeds.

278
00:20:44,320 --> 00:20:50,720
Essentially this only became possible once
telescopes were computer controlled.

279
00:20:50,800 --> 00:20:52,840
A smaller mount is cheaper to build.

280
00:20:52,920 --> 00:20:57,520
Moreover, it fits into a smaller dome
which reduces the cost even further

281

00:20:57,600 --> 00:21:00,320
and it improves the image quality.

282
00:21:00,400 --> 00:21:03,800
Take the twin Keck Telescopes
on Hawaii, for example.

283
00:21:03,880 --> 00:21:06,600
Although their 10 metre mirrors
are twice as large as the one

284
00:21:06,680 --> 00:21:10,440
of the Hale telescope, they
nevertheless fit into smaller domes

285
00:21:10,520 --> 00:21:13,240
than the one on Palomar Mountain.

286
00:21:15,080 --> 00:21:17,440
Telescope mirrors have evolved too.

287
00:21:17,520 --> 00:21:19,120
They used to be thick and heavy.

288
00:21:19,200 --> 00:21:21,840
Now they're thin and lightweight.

289
00:21:21,920 --> 00:21:26,800
Mirror shells that can be many metres
wide are cast in giant, rotating ovens.

290
00:21:26,880 --> 00:21:30,320
And they are still less
than 20 centimetres thick.

291
00:21:30,400 --> 00:21:32,960
An intricate support structure
prevents the thin mirror

292
00:21:33,080 --> 00:21:35,200
from cracking under its own weight.

293
00:21:35,280 --> 00:21:39,120
Computer controlled pistons and actuators
also help to keep the mirror

294
00:21:39,200 --> 00:21:40,840
in perfect shape.

295

00:21:43,400 --> 00:21:45,520
This system is called active optics.

296
00:21:45,600 --> 00:21:49,840
The idea is to compensate and to correct
any deformations of the main mirror

297
00:21:49,920 --> 00:21:54,560
caused by gravity, the wind,
or temperature changes.

298
00:21:54,640 --> 00:21:58,240
Now, a thin mirror also
weighs much less.

299
00:21:58,320 --> 00:22:01,440
That means that its whole supporting
structure, including the mount

300
00:22:01,560 --> 00:22:03,440
can also be a lot trimmer and lighter.

301
00:22:03,520 --> 00:22:05,560
And cheaper!

302
00:22:05,640 --> 00:22:08,360
Now here's the 3.6 metre
New Technology Telescope

303
00:22:08,440 --> 00:22:11,760
built by European astronomers
in the late 1980s.

304
00:22:11,840 --> 00:22:14,840
It served as a testbed for
many of the new technologies

305
00:22:14,920 --> 00:22:16,120
in telescope building.

306
00:22:16,200 --> 00:22:20,960
And even its enclosure has nothing in
common with traditional telescope domes.

307
00:22:21,080 --> 00:22:24,240
The New Technology Telescope
was a great success.

308
00:22:24,320 --> 00:22:27,280
It was time to break

the six metre barrier.

309
00:22:27,600 --> 00:22:31,400
Mauna Kea Observatory sits on
the highest point in the Pacific

310
00:22:31,480 --> 00:22:34,960
4200 metres above sea level.

311
00:22:36,960 --> 00:22:41,120
On the beaches of Hawaii, tourists
enjoy the Sun and the surf.

312
00:22:41,200 --> 00:22:44,520
But high above them astronomers
face chilling temperatures

313
00:22:44,600 --> 00:22:51,160
and altitude sickness in their quest to
unravel the mysteries of the Universe.

314
00:22:51,240 --> 00:22:54,120
The Keck Telescopes are among
the largest in the world.

315
00:22:54,200 --> 00:22:59,120
Their mirrors are 10 metres
across, and wafer-thin.

316
00:22:59,200 --> 00:23:04,040
Tiled like a bathroom floor, they
consist of 36 hexagonal segments

317
00:23:04,120 --> 00:23:07,480
each controlled to nanometre precision.

318
00:23:07,560 --> 00:23:11,200
These are true giants, devoted
to observing the heavens.

319
00:23:11,280 --> 00:23:14,120
The cathedrals of science.

320
00:23:14,200 --> 00:23:16,600
Nightfall on Mauna Kea.

321
00:23:16,680 --> 00:23:21,720
The Keck Telescopes begin collecting
photons from the far reaches of the cosmos.

322
00:23:21,800 --> 00:23:24,520
Their twin mirrors combining
to be effectively larger

323
00:23:24,600 --> 00:23:27,440
than all earlier telescopes.

324
00:23:27,520 --> 00:23:30,360
What will be tonight's catch?

325
00:23:34,680 --> 00:23:39,520
A pair of colliding galaxies,
billions of light-years away?

326
00:23:39,600 --> 00:23:45,320
A dying star, gasping its last
breath into a planetary nebula?

327
00:23:45,400 --> 00:23:51,040
Or maybe an extrasolar planet
that might harbour life?

328
00:23:51,120 --> 00:23:55,920
On Cerro Paranal in the Chilean Atacama
Desert - the driest place on Earth -

329
00:23:55,960 --> 00:24:00,040
we find by far the biggest
astronomy machine ever built:

330
00:24:00,120 --> 00:24:03,560
the European Very Large Telescope.

331
00:24:16,200 --> 00:24:19,520
The VLT is really four telescopes in one.

332
00:24:19,600 --> 00:24:22,760
Each sporting an 8.2 metre mirror.

333
00:24:22,840 --> 00:24:24,120
Antu.

334
00:24:24,200 --> 00:24:25,240
Kueyen.

335
00:24:25,320 --> 00:24:26,320
Melipal.

336

00:24:26,400 --> 00:24:27,760
Yepun.

337
00:24:27,840 --> 00:24:33,440
Native Mapuche names for the Sun,
the Moon, the Southern Cross and Venus.

338
00:24:33,520 --> 00:24:37,800
The huge mirrors were cast in Germany,
polished in France, shipped to Chile

339
00:24:37,880 --> 00:24:41,240
and then slowly transported
across the desert.

340
00:24:41,320 --> 00:24:44,960
At sunset, the telescope
enclosures open up.

341
00:24:45,040 --> 00:24:48,560
Starlight rains down on
the VLT mirrors.

342
00:24:49,280 --> 00:24:52,080
New discoveries are made.

343
00:24:55,920 --> 00:24:58,160
A laser pierces the night sky.

344
00:24:58,240 --> 00:25:00,680
It projects an artificial star
into the atmosphere

345
00:25:00,760 --> 00:25:03,840
90 kilometres above our heads.

346
00:25:03,920 --> 00:25:06,920
Wavefront sensors measure how
the star's image is distorted

347
00:25:06,960 --> 00:25:09,120
by the atmospheric turbulence.

348
00:25:09,200 --> 00:25:12,960
Then, fast computers tell a
flexible mirror how it has to

349
00:25:13,040 --> 00:25:15,800
deform itself in order to
correct the distortion.

350
00:25:15,880 --> 00:25:18,960
In effect untwinkling the stars.

351
00:25:19,040 --> 00:25:22,600
This is called adaptive optics
and it's the big magic trick

352
00:25:22,680 --> 00:25:24,320
of present day astronomy.

353
00:25:24,400 --> 00:25:28,840
Without it, our view of the Universe
would look blurred by the atmosphere.

354
00:25:28,920 --> 00:25:32,880
But with it, our images
are razor-sharp.

355
00:25:35,480 --> 00:25:39,480
The other piece of optical wizardry
is known as interferometry.

356
00:25:39,560 --> 00:25:43,360
The idea is to take the light from two
separate telescopes and to

357
00:25:43,440 --> 00:25:46,640
bring it together in a single point,
while preserving the

358
00:25:46,720 --> 00:25:49,320
relative shifts between
the lightwaves.

359
00:25:49,400 --> 00:25:53,160
If it is done precisely enough the
result is that the two telescopes

360
00:25:53,240 --> 00:25:56,600
act as if they were part of
a single, colossal mirror

361
00:25:56,680 --> 00:25:59,920
as large as the distance
between them.

362
00:25:59,960 --> 00:26:04,040
In effect, interferometry gives
your telescope eagle-like vision.

363
00:26:04,120 --> 00:26:07,600
It allows smaller telescopes
to reveal a level of detail that

364
00:26:07,680 --> 00:26:12,440
would otherwise only be visible
with a much larger telescope.

365
00:26:12,520 --> 00:26:15,600
The twin Keck Telescopes on
Mauna Kea regularly team up

366
00:26:15,680 --> 00:26:17,520
as an interferometer.

367
00:26:17,600 --> 00:26:21,440
In the case of the VLT, all four
telescopes can work together.

368
00:26:21,520 --> 00:26:24,760
In addition, several smaller
auxiliary telescopes can also

369
00:26:24,840 --> 00:26:28,880
join the ranks in order to
sharpen up the view even more.

370
00:26:29,840 --> 00:26:33,400
Other big telescopes can
be found all over the globe.

371
00:26:33,480 --> 00:26:37,480
Subaru and Gemini North
on Mauna Kea.

372
00:26:37,560 --> 00:26:42,240
Gemini South and the
Magellan Telescopes in Chile.

373
00:26:42,320 --> 00:26:46,280
The Large Binocular Telescope
in Arizona.

374
00:26:48,200 --> 00:26:50,800
They are constructed at
the best available sites.

375
00:26:50,840 --> 00:26:53,720
High and dry, clear and dark.

376
00:26:53,840 --> 00:26:56,640
Their eyes are as large
as swimming pools.

377
00:26:56,760 --> 00:27:00,400
All kitted out with adaptive optics
to counteract the blurring

378
00:27:00,440 --> 00:27:02,080
effects of the atmosphere.

379
00:27:02,200 --> 00:27:05,960
And sometimes they can have the
resolution of a virtual behemoth

380
00:27:06,040 --> 00:27:08,640
thanks to interferometry.

381
00:27:09,680 --> 00:27:11,800
Here's what they've shown us.

382
00:27:11,920 --> 00:27:13,400
Planets.

383
00:27:16,600 --> 00:27:18,240
Nebulae.

384
00:27:19,360 --> 00:27:23,960
The actual sizes - and squashed
shapes - of some stars.

385
00:27:23,960 --> 00:27:27,160
A cool planet orbiting
a brown dwarf.

386
00:27:27,200 --> 00:27:31,480
And giant stars whirling around
the core of our Milky Way Galaxy

387
00:27:31,600 --> 00:27:36,720
governed by the gravity of
a supermassive black hole.

388
00:27:36,840 --> 00:27:40,400
We've come quite a
way since Galileo's day.

389
00:27:40,000 --> 00:27:44,760

4. From silver to silicon

390
00:27:45,840 --> 00:27:49,000
400 years ago, when Galileo Galilei
wanted to show others what he

391
00:27:49,120 --> 00:27:53,000
saw through his telescope,
he had to make drawings.

392
00:27:53,120 --> 00:27:56,240
The pockmarked face
of the Moon.

393
00:27:56,360 --> 00:28:00,400
The dance of the
Jovian satellites.

394
00:28:00,520 --> 00:28:02,160
Sunspots.

395
00:28:02,280 --> 00:28:04,160
Or the stars in Orion.

396
00:28:04,280 --> 00:28:06,720
He took his drawings and published
them in a small book

397
00:28:06,760 --> 00:28:08,400
The Starry Messenger.

398
00:28:08,440 --> 00:28:10,800
That was the only way he
could share his discoveries

399
00:28:10,920 --> 00:28:12,400
with others.

400
00:28:12,440 --> 00:28:16,640
For well over two centuries,
astronomers also had to be artists.

401
00:28:16,760 --> 00:28:19,000
Peering through their eyepieces,
they made detailed

402
00:28:19,120 --> 00:28:20,960
drawings of what
they saw.

403
00:28:21,040 --> 00:28:23,080
The stark landscape
of the Moon.

404
00:28:23,200 --> 00:28:25,960
A storm in the atmosphere
of Jupiter.

405
00:28:26,040 --> 00:28:29,000
The subtle veil of gas
in a distant nebula.

406
00:28:29,120 --> 00:28:32,320
And sometimes they over-interpreted
what they saw.

407
00:28:32,440 --> 00:28:36,560
Dark linear features on the surface
of Mars were thought to be canals

408
00:28:36,680 --> 00:28:39,880
suggesting civilised life on
the surface of the red planet.

409
00:28:39,960 --> 00:28:43,480
We now know that the canals
were an optical illusion.

410
00:28:43,600 --> 00:28:47,160
What astronomers really needed
was an objective way to record

411
00:28:47,280 --> 00:28:51,480
the light collected by the telescopes
without the information first having to

412
00:28:51,520 --> 00:28:54,480
pass through their brains
and their drawing pens.

413
00:28:54,600 --> 00:28:57,400
Photography came
to the rescue.

414
00:28:58,760 --> 00:29:01,160
The first daguerreotype
of the Moon.

415
00:29:01,200 --> 00:29:03,880
It was made in 1840

by Henry Draper.

416
00:29:03,920 --> 00:29:07,240
Photography was less than
15 years old, but astronomers

417
00:29:07,360 --> 00:29:10,880
had already seized on
its revolutionary possibilities.

418
00:29:10,920 --> 00:29:13,080
So how did photography work?

419
00:29:13,120 --> 00:29:17,160
Well the sensitive emulsion of
a photographic plate contained

420
00:29:17,280 --> 00:29:19,400
small grains of silver halide.

421
00:29:19,440 --> 00:29:22,160
Expose them to light,
and they turn dark.

422
00:29:22,200 --> 00:29:24,800
So the result was a
negative image of the sky

423
00:29:24,920 --> 00:29:28,080
with dark stars on
a light background.

424
00:29:28,200 --> 00:29:31,560
But the real bonus was that
a photographic plate can be

425
00:29:31,680 --> 00:29:33,960
exposed for hours on end.

426
00:29:34,040 --> 00:29:36,720
When you take in the night
sky with your own eyes

427
00:29:36,760 --> 00:29:39,640
once they're dark adapted,
you don't see more and more

428
00:29:39,680 --> 00:29:42,320
stars just by looking longer.

429
00:29:42,440 --> 00:29:45,240
But with a photographic
plate you can do just that.

430
00:29:45,360 --> 00:29:48,480
You can collect and add up
the light over hours on end.

431
00:29:48,600 --> 00:29:52,880
So a longer exposure reveals
more and more stars.

432
00:29:52,920 --> 00:29:54,160
And more.

433
00:29:54,200 --> 00:29:55,240
And more.

434
00:29:55,360 --> 00:29:57,320
And then some.

435
00:29:58,360 --> 00:30:02,000
In the 1950s, the Schmidt telescope
at the Palomar Observatory

436
00:30:02,120 --> 00:30:05,160
was used to photograph
the entire northern sky.

437
00:30:05,280 --> 00:30:10,080
Almost 2000 photographic plates,
each exposed for nearly an hour.

438
00:30:10,120 --> 00:30:12,960
A treasure trove of discovery.

439
00:30:12,960 --> 00:30:17,080
Photography had turned observational
astronomy into a true science.

440
00:30:17,200 --> 00:30:21,480
Objective, measurable,
and reproducible.

441
00:30:21,600 --> 00:30:23,240
But silver was slow.

442
00:30:23,280 --> 00:30:25,480
You had to be patient.

443
00:30:27,120 --> 00:30:29,880
The digital revolution
changed all that.

444
00:30:29,920 --> 00:30:31,640
Silicon replaced silver.

445
00:30:31,760 --> 00:30:34,480
Pixels replaced grains.

446
00:30:36,360 --> 00:30:40,000
Even in consumer cameras, we
no longer use photographic film.

447
00:30:40,120 --> 00:30:43,560
Instead, images are recorded
on a light-sensitive chip:

448
00:30:43,600 --> 00:30:47,800
a charge coupled device,
or CCD for short.

449
00:30:47,920 --> 00:30:51,560
Professional CCDs are
extremely efficient.

450
00:30:51,680 --> 00:30:54,640
And to make them even more
sensitive, they are cooled down

451
00:30:54,680 --> 00:30:57,960
to well below freezing,
using liquid nitrogen.

452
00:30:58,040 --> 00:31:00,720
Almost every photon
is registered.

453
00:31:00,760 --> 00:31:05,640
As a result, exposure times
can be much shorter.

454
00:31:05,760 --> 00:31:09,480
What the Palomar Observatory
Sky Survey achieved in an hour

455
00:31:09,600 --> 00:31:13,160
a CCD can now do in
a few short minutes.

456
00:31:13,200 --> 00:31:15,560
Using a smaller telescope.

457
00:31:15,600 --> 00:31:18,080
The silicon revolution
is far from over.

458
00:31:18,200 --> 00:31:21,080
Astronomers have built
huge CCD cameras with

459
00:31:21,200 --> 00:31:23,560
hundreds of millions of pixels.

460
00:31:23,600 --> 00:31:26,320
And there's more to come.

461
00:31:28,120 --> 00:31:32,560
The big advantage of digital
images is that they're, well, digital.

462
00:31:32,600 --> 00:31:35,800
They're all set and ready to
be worked on with computers.

463
00:31:35,840 --> 00:31:38,800
Astronomers use specialised
software to process their

464
00:31:38,840 --> 00:31:40,880
observations of the sky.

465
00:31:40,880 --> 00:31:45,080
Stretching, or contrast enhancing,
reveals the faintest features

466
00:31:45,200 --> 00:31:47,640
of nebulae or galaxies.

467
00:31:47,760 --> 00:31:51,240
Colour coding enhances and
brings out the structures that

468
00:31:51,280 --> 00:31:53,640
would otherwise be
difficult to see.

469
00:31:53,680 --> 00:31:57,880

Moreover, by combining multiple
images of the same object that

470
00:31:57,920 --> 00:32:00,400
were taken through different
colour filters, one can

471
00:32:00,520 --> 00:32:04,320
produce spectacular composites
that blur the boundary

472
00:32:04,440 --> 00:32:06,720
between science and art.

473
00:32:06,840 --> 00:32:09,880
You too can benefit from
digital astronomy.

474
00:32:09,960 --> 00:32:13,960
It has never been so easy to
dig up and enjoy the amazing

475
00:32:13,960 --> 00:32:15,800
images of the cosmos.

476
00:32:15,920 --> 00:32:20,080
Pictures of the Universe are
always just a mouse click away!

477
00:32:20,680 --> 00:32:24,160
Robotic telescopes, equipped with
sensitive electronic detectors

478
00:32:24,280 --> 00:32:27,800
are keeping watch over
the sky, right now.

479
00:32:27,920 --> 00:32:30,880
The Sloan telescope in New
Mexico has photographed

480
00:32:30,960 --> 00:32:34,000
and catalogued over a hundred
million celestial objects

481
00:32:34,120 --> 00:32:38,160
measured distances to a
million galaxies, and discovered

482
00:32:38,280 --> 00:32:41,480

a hundred thousand
new quasars.

483
00:32:41,520 --> 00:32:44,000
But one survey is not enough.

484
00:32:44,120 --> 00:32:47,400
The Universe is an ever-changing place.

485
00:32:47,520 --> 00:32:51,240
Icy comets come and go,
leaving scattered debris

486
00:32:51,280 --> 00:32:53,640
in their wake.

487
00:32:53,760 --> 00:32:56,720
Asteroids zip by.

488
00:32:56,840 --> 00:33:00,560
Distant planets orbit their
mother stars, temporarily

489
00:33:00,680 --> 00:33:02,880
blocking part of the
star's light.

490
00:33:02,960 --> 00:33:08,800
Supernovas explode, while
elsewhere new stars are born.

491
00:33:08,840 --> 00:33:17,960
Pulsars flash, gamma-ray bursts
detonate black holes accrete.

492
00:33:18,040 --> 00:33:21,720
To keep track of these grand
plays of Nature, astronomers

493
00:33:21,840 --> 00:33:25,240
want to carry out all-sky
surveys every year.

494
00:33:25,360 --> 00:33:26,840
Or every month.

495
00:33:26,920 --> 00:33:28,640
Or twice a week.

496

00:33:28,680 --> 00:33:33,800
At least that's the ambitious goal
of the Large Synoptic Survey Telescope.

497
00:33:33,920 --> 00:33:39,400
If completed in 2015, its three-
gigapixel camera will open up

498
00:33:39,440 --> 00:33:42,080
a webcam window on
the Universe.

499
00:33:42,200 --> 00:33:45,960
More than fulfilling astronomers'
dreams, this reflecting telescope

500
00:33:46,040 --> 00:33:51,080
will photograph almost the
entire sky every three nights.

501
00:33:56,000 --> 00:34:00,760
5. Seeing the invisible

502
00:34:02,360 --> 00:34:05,080
When you listen to your favourite
piece of music, your ears pick up

503
00:34:05,160 --> 00:34:08,800
on a very wide range of frequencies,
from the deepest rumblings of the

504
00:34:08,920 --> 00:34:12,120
bass to the very highest
pitched vibrations.

505
00:34:12,200 --> 00:34:14,960
Now imagine your ears were
only sensitive to a very limited

506
00:34:15,360 --> 00:34:16,920
range of frequencies.

507
00:34:16,960 --> 00:34:19,520
You'd miss out on most
of the good stuff!

508
00:34:19,600 --> 00:34:23,000
But that's essentially the situations
that astronomers are in.

509

00:34:23,080 --> 00:34:26,160
Our eyes are only sensitive
to a very narrow range

510
00:34:26,240 --> 00:34:29,000
of light frequencies:
visible light.

511
00:34:29,080 --> 00:34:31,560
But we are completely blind
to all other forms of

512
00:34:31,640 --> 00:34:33,600
electromagnetic radiation.

513
00:34:33,680 --> 00:34:36,640
However, there are many objects
in the Universe that do emit

514
00:34:36,720 --> 00:34:39,960
radiation at other parts of
the electromagnetic spectrum.

515
00:34:40,040 --> 00:34:43,760
For example, in the 1930s it
was discovered by accident

516
00:34:43,840 --> 00:34:47,240
that there are radio waves
coming from the depths of space.

517
00:34:47,320 --> 00:34:49,960
Some of these waves have the
same frequency as your favourite

518
00:34:50,040 --> 00:34:53,160
radio station, but they are
weaker and of course there's

519
00:34:53,240 --> 00:34:55,280
nothing to listen to.

520
00:34:56,520 --> 00:34:59,960
In order to "tune in" to the radio
Universe, you need some sort

521
00:35:00,040 --> 00:35:02,560
of receiver: a radio telescope.

522
00:35:02,680 --> 00:35:06,960

Now for all but the longest wavelengths,
a radio telescope is just a dish.

523
00:35:07,040 --> 00:35:10,080
Much like the main mirror
of an optical telescope.

524
00:35:10,200 --> 00:35:14,400
But because radio waves are so
much longer than visible lightwaves

525
00:35:14,440 --> 00:35:17,240
the surface of a dish doesn't
have to be nearly as smooth

526
00:35:17,360 --> 00:35:19,000
as the surface of a mirror.

527
00:35:19,120 --> 00:35:21,640
And that's the reason why it's
so much easier to build a

528
00:35:21,680 --> 00:35:26,800
large radio telescope than it is to
build a large optical telescope.

529
00:35:26,840 --> 00:35:30,960
Also, at radio wavelengths, it is
much easier to do interferometry.

530
00:35:30,960 --> 00:35:34,080
That is, to increase the level
of detail that can be seen

531
00:35:34,120 --> 00:35:37,960
by combining the light from two
separate telescopes, as if

532
00:35:38,040 --> 00:35:41,560
they were part of a
single, giant dish.

533
00:35:41,600 --> 00:35:44,640
The Very Large Array in New Mexico,
for example, consists of

534
00:35:44,680 --> 00:35:49,720
27 separate antennas, each
measuring 25 metres across.

535

00:35:49,760 --> 00:35:52,960
Now each antenna can be moved
around individually, and in

536
00:35:53,040 --> 00:35:56,400
its most extended configuration,
the virtual dish mimicked by the

537
00:35:56,520 --> 00:36:00,800
array measures 36
kilometres across.

538
00:36:00,920 --> 00:36:03,560
So what does the Universe
look like in the radio?

539
00:36:03,680 --> 00:36:08,000
Well, for a start our Sun shines
very brightly at radio wavelengths.

540
00:36:08,120 --> 00:36:10,720
So does the centre of our
Milky Way Galaxy.

541
00:36:10,760 --> 00:36:12,400
But there's more.

542
00:36:12,520 --> 00:36:16,480
Pulsars are very dense stellar
corpses that emit radio waves

543
00:36:16,520 --> 00:36:18,640
only into a very narrow beam.

544
00:36:18,680 --> 00:36:21,800
In addition, they rotate at speeds
of up to several hundred

545
00:36:21,840 --> 00:36:23,720
revolutions per second.

546
00:36:23,760 --> 00:36:27,800
So in effect, a pulsar looks like
a rotating radio lighthouse.

547
00:36:27,920 --> 00:36:31,320
And what we see from them is
a very regular and fast

548
00:36:31,360 --> 00:36:34,320

sequence of very
short radio pulses.

549
00:36:34,440 --> 00:36:36,640
Hence the name.

550
00:36:36,680 --> 00:36:39,320
The radio source known as
Cassiopeia A is in fact

551
00:36:39,440 --> 00:36:43,640
the remnant of a supernova that
exploded in the 17th century.

552
00:36:43,680 --> 00:36:48,240
Centaurus A, Cygnus A and Virgo A
are all giant galaxies that

553
00:36:48,280 --> 00:36:50,640
pour out huge amounts
of radio waves.

554
00:36:50,680 --> 00:36:55,960
Each galaxy is powered by a
massive black hole at its centre.

555
00:36:56,040 --> 00:37:00,000
Some of these radio galaxies
and quasars are so powerful that

556
00:37:00,120 --> 00:37:05,320
their signals can still be detected
from a distance of 10 billion light-years.

557
00:37:05,360 --> 00:37:08,880
And then there's the faint,
relatively short-wavelength radio hiss

558
00:37:08,960 --> 00:37:11,320
that fills the entire Universe.

559
00:37:11,360 --> 00:37:14,160
This is known as the cosmic
microwave background

560
00:37:14,200 --> 00:37:16,400
and it is the echo of
the Big Bang.

561
00:37:16,440 --> 00:37:20,560

The very afterglow of the hot
beginnings of the Universe.

562
00:37:22,120 --> 00:37:26,400
Each and every part of the
spectrum has its own story to tell.

563
00:37:26,440 --> 00:37:29,960
At millimetre and submillimetre
wavelengths, astronomers study

564
00:37:29,960 --> 00:37:33,080
the formation of galaxies in the
early Universe, and the origin

565
00:37:33,200 --> 00:37:37,240
of stars and planets
in our own Milky Way.

566
00:37:37,280 --> 00:37:41,400
But most of this radiation is blocked
by water vapour in our atmosphere.

567
00:37:41,520 --> 00:37:44,400
To observe it, you need
to go high and dry.

568
00:37:44,440 --> 00:37:47,320
To Llano de Chajnantor, for example.

569
00:37:47,440 --> 00:37:50,960
At five kilometres above sea
level, this surrealistic plateau

570
00:37:50,960 --> 00:37:53,960
in northern Chile is the
construction site of ALMA:

571
00:37:54,040 --> 00:37:56,880
the Atacama Large Millimeter Array.

572
00:37:56,920 --> 00:38:01,880
When completed in 2014, ALMA
will be the largest astronomical

573
00:38:01,920 --> 00:38:04,320
observatory ever built.

574
00:38:04,840 --> 00:38:09,960
64 antennas each weighing

100 tonnes, will work in unison.

575
00:38:09,960 --> 00:38:13,880
Giant trucks will spread them out
over an area as large as London to

576
00:38:13,960 --> 00:38:16,800
increase the detail of the image,
or bring them close together to

577
00:38:16,880 --> 00:38:19,000
provide a wider view.

578
00:38:19,120 --> 00:38:23,240
Each move will be made
with millimetre precision.

579
00:38:24,680 --> 00:38:28,160
Many objects in the Universe
also glow in the infrared.

580
00:38:28,280 --> 00:38:31,960
Discovered by William Herschel,
infrared radiation is often also called

581
00:38:32,040 --> 00:38:36,720
"heat radiation" because it is
emitted by all relatively warm objects

582
00:38:36,760 --> 00:38:39,080
including humans.

583
00:38:41,840 --> 00:38:45,240
You may be more familiar with
infrared radiation than you think.

584
00:38:45,360 --> 00:38:48,240
Because on Earth, this kind
of radiation is used by

585
00:38:48,360 --> 00:38:51,160
night vision goggles
and cameras.

586
00:38:51,280 --> 00:38:55,160
But to detect the faint infrared glow
from distant objects, astronomers

587
00:38:55,280 --> 00:38:58,960
need very sensitive detectors,

cooled down to just a few degrees

588
00:38:59,040 --> 00:39:04,000
above absolute zero, in order to
suppress their own heat radiation.

589
00:39:06,920 --> 00:39:11,720
Today, most big optical telescopes are
also equipped with infrared cameras.

590
00:39:11,760 --> 00:39:15,320
They allow you to see right through
a cosmic dust cloud, revealing the

591
00:39:15,440 --> 00:39:20,240
newborn stars inside, something that
just cannot be seen in the optical.

592
00:39:20,280 --> 00:39:25,080
For example, take this optical image
of the famous stellar nursery in Orion.

593
00:39:25,200 --> 00:39:27,400
But look how different it is
when seen through the eyes

594
00:39:27,520 --> 00:39:30,080
of an infrared camera!

595
00:39:30,200 --> 00:39:33,320
Being able to see in the infrared
is also very helpful when studying

596
00:39:33,360 --> 00:39:35,960
the most distant galaxies.

597
00:39:35,960 --> 00:39:41,000
The newborn stars in a young galaxy
shine very brightly in the ultraviolet.

598
00:39:41,120 --> 00:39:45,000
But then this ultraviolet light has to
travel for billions of years across

599
00:39:45,120 --> 00:39:46,640
the expanding Universe.

600
00:39:46,760 --> 00:39:50,560
The expansion stretches the lightwaves
so that when they are received

601
00:39:50,600 --> 00:39:55,240
by us, they've been shifted all
the way into the near-infrared.

602
00:39:56,600 --> 00:40:00,240
This stylish instrument is the
MAGIC telescope on La Palma.

603
00:40:00,360 --> 00:40:02,960
It searches the sky for
cosmic gamma rays

604
00:40:02,960 --> 00:40:06,800
the most energetic form
of radiation in Nature.

605
00:40:08,360 --> 00:40:10,960
Lucky for us, the lethal gamma
rays are blocked by the

606
00:40:10,960 --> 00:40:12,320
Earth's atmosphere.

607
00:40:12,360 --> 00:40:16,000
But they do leave behind footprints
for astronomers to study.

608
00:40:16,120 --> 00:40:19,000
After hitting the atmosphere,
they produce cascades of

609
00:40:19,120 --> 00:40:20,640
energetic particles.

610
00:40:20,760 --> 00:40:25,320
These, in turn, cause a faint
glow that MAGIC can see.

611
00:40:26,920 --> 00:40:30,640
And here's the Pierre Auger
Observatory in Argentina.

612
00:40:30,680 --> 00:40:33,080
It doesn't even look
like a telescope.

613
00:40:33,120 --> 00:40:38,960
Pierre Auger consists of 1600
detectors, spread over 3000

614
00:40:38,960 --> 00:40:40,240
square kilometres.

615
00:40:40,360 --> 00:40:44,560
They catch the particle fallout of
cosmic rays from distant supernovas

616
00:40:44,600 --> 00:40:46,480
and black holes.

617
00:40:47,680 --> 00:40:52,400
And what about neutrino detectors,
built in deep mines or beneath the

618
00:40:52,520 --> 00:40:55,720
surface of the ocean,
or in the Antarctic ice.

619
00:40:55,840 --> 00:40:57,880
Could you call those telescopes?

620
00:40:57,960 --> 00:40:59,400
Well, why not?

621
00:40:59,520 --> 00:41:03,800
After all, they do observe the Universe,
even if they don't capture data from

622
00:41:03,840 --> 00:41:06,080
the electromagnetic spectrum.

623
00:41:06,120 --> 00:41:09,880
Neutrinos are elusive particles
that are produced in the Sun

624
00:41:09,960 --> 00:41:12,240
and supernova explosions.

625
00:41:12,360 --> 00:41:15,800
They were even produced
in the Big Bang itself.

626
00:41:15,920 --> 00:41:20,640
Unlike other elementary particles,
neutrinos can pass through regular

627
00:41:20,680 --> 00:41:25,640
matter, travel near the speed

of light and have no electric charge.

628
00:41:25,760 --> 00:41:30,240
Although these particles may be
difficult to study, they are plentiful.

629
00:41:30,280 --> 00:41:34,160
Each second more than 50 trillion
electron neutrinos from the Sun

630
00:41:34,200 --> 00:41:36,560
pass through you.

631
00:41:36,680 --> 00:41:40,800
Finally, astronomers and physicists have
joined forces to build gravitational

632
00:41:40,920 --> 00:41:42,640
wave detectors.

633
00:41:42,680 --> 00:41:46,640
These "telescopes" do not observe
radiation or catch particles.

634
00:41:46,680 --> 00:41:51,240
Instead, they measure tiny ripples in
the very structure of space-time -

635
00:41:51,280 --> 00:41:56,960
a concept predicted by
Albert Einstein's theory of relativity.

636
00:41:57,040 --> 00:42:01,160
With a stunning variety of instruments,
astronomers have opened up the full

637
00:42:01,200 --> 00:42:06,960
spectrum of electromagnetic radiation,
and have even ventured beyond.

638
00:42:07,040 --> 00:42:11,240
But some observations simply
can't be done from the ground.

639
00:42:11,280 --> 00:42:12,800
The answer?

640
00:42:12,920 --> 00:42:15,240
Space telescopes.

641
00:42:22,000 --> 00:42:26,560
6. Beyond Earth

642
00:42:28,560 --> 00:42:30,400
The Hubble Space Telescope.

643
00:42:30,480 --> 00:42:33,360
It is by far the most famous
telescope in history.

644
00:42:33,440 --> 00:42:34,800
And for good reason.

645
00:42:34,880 --> 00:42:38,560
Hubble has revolutionised so
many fields in astronomy.

646
00:42:38,640 --> 00:42:42,040
By modern standards, Hubble's
mirror is actually quite small.

647
00:42:42,120 --> 00:42:45,040
It only measures about
2.4 metres across.

648
00:42:45,120 --> 00:42:48,640
But its location is literally
out of this world.

649
00:42:48,720 --> 00:42:52,360
High above the blurring effects of the
atmosphere, it has an exceptionally

650
00:42:52,440 --> 00:42:54,600
sharp view of the Universe.

651
00:42:54,680 --> 00:42:59,360
And what's more, Hubble can see
ultraviolet and near-infrared light.

652
00:42:59,440 --> 00:43:02,480
This light just cannot be seen by
ground-based telescopes because

653
00:43:02,560 --> 00:43:05,880
it is blocked by the atmosphere.

654
00:43:05,960 --> 00:43:09,880
Cameras and spectrographs,

some as big as a telephone booth

655
00:43:09,960 --> 00:43:14,600
dissect and register the light
from distant cosmic shores.

656
00:43:14,680 --> 00:43:19,320
Just like any ground-based telescope,
Hubble is upgraded from time to time.

657
00:43:19,400 --> 00:43:22,760
Spacewalking astronauts carry
out servicing missions.

658
00:43:22,840 --> 00:43:24,440
Broken parts get refurbished.

659
00:43:24,520 --> 00:43:27,000
And older instruments get
replaced with newer and

660
00:43:27,080 --> 00:43:29,800
state-of-the-art technology.

661
00:43:29,880 --> 00:43:33,280
Hubble has become the powerhouse
of observational astronomy.

662
00:43:33,360 --> 00:43:37,240
And it has transformed our
understanding of the cosmos.

663
00:43:39,840 --> 00:43:44,800
With its keen eyesight, Hubble
observed seasonal changes on Mars

664
00:43:45,920 --> 00:43:48,800
a cometary impact on Jupiter

665
00:43:50,520 --> 00:43:53,880
an edge-on view of Saturn's rings

666
00:43:56,920 --> 00:44:00,400
and even the surface of tiny Pluto.

667
00:44:00,480 --> 00:44:06,320
It revealed the life cycle of stars,
from their very birth and baby days

668

00:44:06,600 --> 00:44:12,560
in a nursery of dust-laden clouds
of gas, all the way to their final farewell:

669
00:44:12,640 --> 00:44:17,800
as delicate nebulae, slowly
blown into space by dying stars

670
00:44:17,920 --> 00:44:24,960
or as titanic supernova explosions
that almost outshine their home galaxy.

671
00:44:25,040 --> 00:44:28,960
Deep in the Orion Nebula, Hubble even
saw the breeding ground of new

672
00:44:29,040 --> 00:44:34,080
solar systems: dusty disks around
newborn stars that may soon

673
00:44:34,120 --> 00:44:36,080
condense into planets.

674
00:44:36,200 --> 00:44:40,320
The space telescope studied thousands
of individual stars in giant globular

675
00:44:40,440 --> 00:44:45,960
clusters, the oldest stellar
families in the Universe.

676
00:44:46,040 --> 00:44:48,320
And galaxies, of course.

677
00:44:48,440 --> 00:44:51,960
Never before had astronomers
seen so much detail.

678
00:44:51,960 --> 00:44:58,800
Majestic spirals, absorbing dust
lanes, violent collisions.

679
00:45:01,040 --> 00:45:05,480
Extremely long exposures of blank
regions of sky even revealed

680
00:45:05,520 --> 00:45:10,080
thousands of faint galaxies
billions of light-years away.

681

00:45:10,120 --> 00:45:13,960
Photons that were emitted
when the Universe was still young.

682
00:45:14,040 --> 00:45:18,400
A window into the distant past,
shedding new light on the

683
00:45:18,440 --> 00:45:21,560
ever-evolving cosmos.

684
00:45:22,200 --> 00:45:24,880
Hubble is not the only
telescope in space.

685
00:45:24,920 --> 00:45:29,800
This is NASA's Spitzer Space
Telescope, launched in August 2003.

686
00:45:29,920 --> 00:45:33,720
In a way, it is Hubble's
equivalent for the infrared.

687
00:45:33,760 --> 00:45:37,960
Spitzer has a mirror that is only
85 centimetres across.

688
00:45:37,960 --> 00:45:41,080
But the telescope is hiding behind
a heat shield that protects

689
00:45:41,200 --> 00:45:42,480
it from the Sun.

690
00:45:42,520 --> 00:45:47,160
And its detectors are tucked away
in a dewar filled with liquid helium.

691
00:45:47,200 --> 00:45:50,080
Here the detectors are cooled
down to just a few degrees

692
00:45:50,200 --> 00:45:51,800
above absolute zero.

693
00:45:51,920 --> 00:45:55,560
Making them very very sensitive.

694
00:45:55,680 --> 00:45:58,720
Spitzer has revealed a dusty Universe.

695
00:45:58,760 --> 00:46:02,560
Dark, opaque clouds of dust glow
in the infrared when heated

696
00:46:02,680 --> 00:46:04,560
from within.

697
00:46:04,600 --> 00:46:08,720
Shock waves from galaxy collisions
sweep up dust in telltale rings

698
00:46:08,760 --> 00:46:13,480
and tidal features, new sites
for ubiquitous star formation.

699
00:46:15,520 --> 00:46:19,080
Dust is also produced in the
aftermath of a star's death.

700
00:46:19,200 --> 00:46:23,080
Spitzer found that planetary nebulae
and supernova remnants are laden

701
00:46:23,200 --> 00:46:28,320
with dust particles, the prerequisite
building blocks of future planets.

702
00:46:28,440 --> 00:46:32,080
At other infrared wavelengths, Spitzer
can also see right through a dust

703
00:46:32,200 --> 00:46:37,720
cloud, revealing the stars
inside, hidden in their dark cores.

704
00:46:37,840 --> 00:46:40,960
Finally, the space telescope's
spectrographs have studied

705
00:46:40,960 --> 00:46:44,880
the atmospheres of extrasolar
planets - gas giants like Jupiter

706
00:46:44,920 --> 00:46:48,880
that race around their parent
stars in just a few days.

707
00:46:50,680 --> 00:46:52,880
So what about X-rays

and gamma rays?

708
00:46:52,920 --> 00:46:55,560
Well, they are completely blocked
by the Earth's atmosphere.

709
00:46:55,680 --> 00:46:59,160
And so without space telescopes,
astronomers would be totally blind

710
00:46:59,200 --> 00:47:02,080
to these energetic forms
of radiation.

711
00:47:03,680 --> 00:47:07,080
X-ray and gamma ray space
telescopes reveal the hot

712
00:47:07,120 --> 00:47:11,800
energetic and violent Universe of
galaxy clusters, black holes

713
00:47:11,840 --> 00:47:16,080
supernova explosions,
and galaxy collisions.

714
00:47:18,760 --> 00:47:20,840
They are very hard to build, though.

715
00:47:20,920 --> 00:47:24,440
Energetic radiation passes right
through a conventional mirror.

716
00:47:24,520 --> 00:47:29,680
X-rays can only be focused with
nested mirror shells made of pure gold.

717
00:47:29,760 --> 00:47:33,120
And gamma rays are studied with
sophisticated pinhole cameras

718
00:47:33,200 --> 00:47:36,560
or stacked scintillators that give
off brief flashes of normal light

719
00:47:36,640 --> 00:47:39,680
when struck by a
gamma ray photon.

720
00:47:40,960 --> 00:47:45,120

In the 1990s, NASA operated the
Compton Gamma Ray Observatory.

721
00:47:45,200 --> 00:47:48,280
At the time, it was the largest
and most massive scientific

722
00:47:48,360 --> 00:47:49,880
satellite ever launched.

723
00:47:49,960 --> 00:47:53,120
A fully fledged physics
lab in space.

724
00:47:53,200 --> 00:47:56,480
In 2008, Compton was
succeeded by GLAST:

725
00:47:56,560 --> 00:48:00,520
the Gamma Ray Large
Area Space Telescope.

726
00:48:00,600 --> 00:48:04,120
It will study everything in the
high-energy Universe from dark

727
00:48:04,200 --> 00:48:06,520
matter to pulsars.

728
00:48:08,440 --> 00:48:12,360
Meanwhile, astronomers have
two X-ray telescopes in space.

729
00:48:12,440 --> 00:48:17,400
NASA's Chandra X-ray Observatory
and ESA's XMM-Newton Observatory

730
00:48:17,480 --> 00:48:21,480
are both studying the
hottest places in the Universe.

731
00:48:23,960 --> 00:48:27,680
This is what the sky looks
like with X-ray vision.

732
00:48:27,760 --> 00:48:32,160
Extended features are clouds of gas,
heated to millions of degrees by

733
00:48:32,240 --> 00:48:35,680

shock waves in
supernova remnants.

734
00:48:35,760 --> 00:48:39,960
The bright point sources are X-ray
binaries: neutron stars or

735
00:48:39,960 --> 00:48:43,640
black holes that suck in matter
from a companion star.

736
00:48:43,720 --> 00:48:47,280
This hot, infalling gas emits X-rays.

737
00:48:47,360 --> 00:48:51,560
Likewise, X-ray telescopes reveal
supermassive black holes in

738
00:48:51,640 --> 00:48:53,760
the cores of distant galaxies.

739
00:48:53,840 --> 00:48:57,800
Matter that spirals inward gets
hot enough to glow in X-rays

740
00:48:57,880 --> 00:49:02,160
just before it plunges into the
black hole and out of sight.

741
00:49:02,240 --> 00:49:06,840
Hot but tenuous gas also fills the
space between individual galaxies

742
00:49:06,920 --> 00:49:08,320
in a cluster.

743
00:49:08,400 --> 00:49:12,240
Sometimes, this intracluster gas is
shocked and heated even more

744
00:49:12,320 --> 00:49:16,480
by colliding and merging
galaxy clusters.

745
00:49:16,560 --> 00:49:20,760
Even more exciting are gamma
ray bursts, the most energetic

746
00:49:20,840 --> 00:49:22,600
events in the Universe.

747
00:49:22,680 --> 00:49:26,920
These are catastrophic terminal
explosions of very massive, rapidly

748
00:49:26,960 --> 00:49:28,760
spinning stars.

749
00:49:28,840 --> 00:49:32,760
In less than a second, they release
more energy than the Sun does in

750
00:49:32,840 --> 00:49:35,760
10 billion years.

751
00:49:38,200 --> 00:49:42,160
Hubble, Spitzer, Chandra,
XMM-Newton and GLAST

752
00:49:42,240 --> 00:49:44,600
are all versatile giants.

753
00:49:44,680 --> 00:49:47,640
But some space telescopes are much
smaller and have much more

754
00:49:47,720 --> 00:49:49,240
focused missions.

755
00:49:49,320 --> 00:49:51,280
Take COROT, for example.

756
00:49:51,360 --> 00:49:54,880
This French satellite is devoted to
stellar seismology and the study

757
00:49:54,960 --> 00:49:56,880
of extrasolar planets.

758
00:49:56,960 --> 00:50:01,240
Or NASA's Swift satellite, a combined
X-ray and gamma ray observatory

759
00:50:01,320 --> 00:50:05,720
designed to unravel the
mysteries of gamma ray bursts.

760
00:50:05,800 --> 00:50:10,160
And then there's WMAP, the Wilkinson

Microwave Anisotropy Probe.

761
00:50:10,240 --> 00:50:13,840
In just over two years in space, it
had already mapped the cosmic

762
00:50:13,920 --> 00:50:17,280
background radiation to
unprecedented detail.

763
00:50:17,360 --> 00:50:21,200
WMAP gave cosmologists the best
view yet of one of the earliest

764
00:50:21,280 --> 00:50:26,680
phases of the Universe,
more than 13 billion years ago.

765
00:50:26,760 --> 00:50:29,640
Opening up the space frontier has
been one of the most exciting

766
00:50:29,720 --> 00:50:32,240
developments in the
history of the telescope.

767
00:50:32,320 --> 00:50:34,760
So what's next?

768
00:50:37,400 --> 00:50:40,280
7. What's next?

769
00:50:42,286 --> 00:50:45,080
In Arizona, the first mirror
has been cast for the

770
00:50:45,160 --> 00:50:47,000
Giant Magellan Telescope.

771
00:50:47,080 --> 00:50:50,280
This huge instrument will be
built at the Las Campanas

772
00:50:50,360 --> 00:50:51,960
Observatory in Chile.

773
00:50:52,040 --> 00:50:55,640
Its seven mirrors, each well
over eight metres across

774
00:50:55,720 --> 00:50:58,800
will be arranged like
the petals of a flower.

775
00:50:58,880 --> 00:51:01,800
And together they will capture
more than four times the

776
00:51:01,880 --> 00:51:05,399
amount of light any
current telescope can catch.

777
00:51:05,480 --> 00:51:09,840
The Californian Thirty Meter
Telescope, planned for 2015

778
00:51:09,920 --> 00:51:12,680
is more like a giant
version of Keck.

779
00:51:12,760 --> 00:51:15,960
Hundreds of individual segments
make up one enormous mirror

780
00:51:16,040 --> 00:51:20,120
as tall as a six-storey
apartment.

781
00:51:20,200 --> 00:51:24,920
In Europe, plans are ready for a
European Extremely Large Telescope.

782
00:51:25,399 --> 00:51:28,760
At 42 metres in diameter

783
00:51:28,840 --> 00:51:32,240
its mirror will be as large as an Olympic swimming pool - twice the surface area of the

784
00:51:32,320 --> 00:51:34,440
Thirty Meter Telescope.

785
00:51:34,520 --> 00:51:39,000
These future monsters, optimised
for infrared observations, will

786
00:51:39,080 --> 00:51:43,760
all be outfitted with sensitive
instruments and adaptive optics.

787

00:51:43,840 --> 00:51:46,440
They should reveal the very
first generation of galaxies

788
00:51:46,520 --> 00:51:49,720
and stars in the history
of the Universe.

789
00:51:49,800 --> 00:51:52,720
Moreover, they may provide
us with the first true picture

790
00:51:52,800 --> 00:51:55,760
of a planet in another
solar system.

791
00:51:55,840 --> 00:51:59,600
For radio astronomers,
42 metres is peanuts.

792
00:51:59,680 --> 00:52:02,320
They hook up many smaller
instruments to synthesise

793
00:52:02,399 --> 00:52:04,680
a much larger receiver.

794
00:52:04,760 --> 00:52:08,399
In the Netherlands, the Low
Frequency Array, or LOFAR

795
00:52:08,480 --> 00:52:10,120
is under construction.

796
00:52:10,200 --> 00:52:15,440
Fibre optics will connect 30 000
antennas to a central supercomputer.

797
00:52:15,520 --> 00:52:19,040
The novel design has no moving
parts, but it can observe in

798
00:52:19,120 --> 00:52:22,440
eight different directions
simultaneously.

799
00:52:22,520 --> 00:52:25,720
LOFAR technology will probably
find its way into the Square

800

00:52:25,800 --> 00:52:28,200
Kilometre Array, which is
now topping the wish-list

801
00:52:28,280 --> 00:52:30,160
of radio astronomers.

802
00:52:30,240 --> 00:52:34,240
The international array will be
built in Australia or South Africa.

803
00:52:34,320 --> 00:52:38,160
Large dish antennas and small
receivers will team up to provide

804
00:52:38,240 --> 00:52:42,520
incredibly detailed views
of the radio sky.

805
00:52:42,600 --> 00:52:46,320
And with a total collecting area
of one square kilometre, the

806
00:52:46,399 --> 00:52:50,040
new array will be by far the
most sensitive radio instrument

807
00:52:50,120 --> 00:52:52,520
ever constructed.

808
00:52:52,600 --> 00:52:57,640
Evolving galaxies, powerful quasars,
blinking pulsars

809
00:52:57,760 --> 00:53:01,399
no single source of radio waves will
be safe from the spying eyes

810
00:53:01,480 --> 00:53:04,360
of the Square Kilometre Array.

811
00:53:04,399 --> 00:53:07,880
The instrument will even look
for possible radio signals from

812
00:53:07,960 --> 00:53:11,440
extraterrestrial civilisations.

813
00:53:11,520 --> 00:53:14,760
And what about space?

814
00:53:14,840 --> 00:53:18,640
Well, after its fifth and final
servicing mission, the Hubble Space

815
00:53:18,720 --> 00:53:24,080
Telescope will be on active
duty until 2013 or so.

816
00:53:24,160 --> 00:53:28,320
Around that time, its
successor will be launched.

817
00:53:30,360 --> 00:53:34,320
Meet the James Webb Space
Telescope, a space infrared

818
00:53:34,399 --> 00:53:40,080
observatory named after
a former NASA administrator.

819
00:53:40,160 --> 00:53:44,440
Once in space, its 6.5 metre
segmented mirror unfolds

820
00:53:44,520 --> 00:53:48,080
like a blooming flower - one
seven times as sensitive

821
00:53:48,160 --> 00:53:50,960
as Hubble's.

822
00:53:51,040 --> 00:53:54,120
A large sunshade keeps the
optics and the low-temperature

823
00:53:54,200 --> 00:53:57,560
instruments in permanent shadow,
allowing them to operate near

824
00:53:57,640 --> 00:54:02,600
a whopping minus
233 degrees Celsius.

825
00:54:03,800 --> 00:54:07,480
The James Webb Space Telescope
won't orbit the Earth.

826
00:54:07,560 --> 00:54:11,240
Instead, it will be parked 1.5

million kilometres from our

827
00:54:11,320 --> 00:54:15,480
planet, in a wide orbit
around the Sun.

828
00:54:15,560 --> 00:54:18,680
Half a century ago, the Hale
telescope on Palomar Mountain

829
00:54:18,760 --> 00:54:20,560
was the largest in history.

830
00:54:20,600 --> 00:54:24,720
Now, an even bigger one will be
flying into the depths of space.

831
00:54:24,760 --> 00:54:29,040
We can only speculate about the
exciting discoveries it will make.

832
00:54:29,120 --> 00:54:31,280
Stay tuned!

833
00:54:31,760 --> 00:54:34,480
Meanwhile, creative engineers
come up with revolutionary

834
00:54:34,560 --> 00:54:37,320
designs for new
telescopes all the time.

835
00:54:37,399 --> 00:54:41,640
In Canada, scientists have built a
so-called "liquid mirror telescope".

836
00:54:41,720 --> 00:54:44,800
In this kind of telescope the
starlight is reflected not by

837
00:54:44,880 --> 00:54:48,960
a solid mirror but rather by
the curved surface of a rotating

838
00:54:49,040 --> 00:54:52,200
reservoir of liquid mercury.

839
00:54:52,280 --> 00:54:55,960
Because of their design, mercury
telescopes can only look straight up,

840
00:54:56,040 --> 00:54:58,720
but their advantage is
that they're relatively cheap

841
00:54:58,800 --> 00:55:00,960
and easy to build.

842
00:55:01,040 --> 00:55:04,040
Radio astronomers want to put
a LOFAR-like array of small

843
00:55:04,120 --> 00:55:06,960
antennas onto the surface of
the Moon, as far away as

844
00:55:07,040 --> 00:55:10,480
possible from terrestrial
sources of interference.

845
00:55:10,560 --> 00:55:13,120
Who knows, one day there
might even be a big optical

846
00:55:13,200 --> 00:55:15,960
telescope on the far
side of the Moon.

847
00:55:16,040 --> 00:55:18,960
And using space telescopes
and occulting disks, X-ray

848
00:55:19,040 --> 00:55:21,560
astronomers hope to improve
their eyesight tremendously

849
00:55:21,640 --> 00:55:22,640
in the future.

850
00:55:22,720 --> 00:55:25,320
They may even succeed in
imaging the very edge

851
00:55:25,399 --> 00:55:27,360
of a black hole.

852
00:55:29,160 --> 00:55:32,160
One day, the telescope may
answer one of the most profound

853
00:55:32,240 --> 00:55:38,440
questions puzzling humanity:
are we alone in the Universe?

854
00:55:42,080 --> 00:55:45,400
We know that there are other
solar systems out there.

855
00:55:45,520 --> 00:55:47,880
We suspect there are even
planets like Earth, with

856
00:55:48,000 --> 00:55:49,800
liquid water.

857
00:55:49,920 --> 00:55:50,800
But

858
00:55:50,920 --> 00:55:53,040
is there life?

859
00:55:53,920 --> 00:55:57,720
Locating such extrasolar
planets proves difficult.

860
00:55:57,840 --> 00:56:00,280
They are often hidden from
astronomers by the intense

861
00:56:00,320 --> 00:56:03,560
light radiated by
their mother stars.

862
00:56:04,520 --> 00:56:07,640
Interferometers launched into
the darkness of space may

863
00:56:07,760 --> 00:56:10,360
provide a novel answer.

864
00:56:10,399 --> 00:56:13,120
Right now NASA is considering
a project called the

865
00:56:13,160 --> 00:56:15,720
Terrestrial Planet Finder.

866
00:56:15,840 --> 00:56:20,280
And in Europe, scientists are

designing the Darwin Array.

867
00:56:20,399 --> 00:56:23,960
Six space telescopes orbit
the Sun in formation.

868
00:56:24,080 --> 00:56:28,120
Lasers control their mutual distances
to the nearest nanometre.

869
00:56:28,160 --> 00:56:31,800
Together they have incredible
resolving power, cancelling out

870
00:56:31,840 --> 00:56:35,640
the light from overbearing stars
so scientists can actually see

871
00:56:35,760 --> 00:56:39,400
Earth-like planets
around other stars.

872
00:56:40,240 --> 00:56:44,480
Next astronomers must study
the light reflected by the planet.

873
00:56:44,600 --> 00:56:49,560
It carries the spectroscopic
fingerprint of the planet's atmosphere.

874
00:56:49,600 --> 00:56:52,880
Who knows, in 15 years time
we may detect the signatures

875
00:56:52,920 --> 00:56:55,200
of oxygen, methane and ozone.

876
00:56:55,320 --> 00:56:58,400
The signposts of life.

877
00:57:00,600 --> 00:57:03,120
The Universe is full of surprises.

878
00:57:03,240 --> 00:57:05,560
The sky never ceases to impress.

879
00:57:05,680 --> 00:57:08,560
No wonder that hundreds of
thousands of amateur astronomers

880
00:57:08,600 --> 00:57:11,120
across the globe go out
every clear night to marvel

881
00:57:11,240 --> 00:57:12,800
at the cosmos.

882
00:57:12,840 --> 00:57:15,120
Their telescopes are much
better than the instruments

883
00:57:15,240 --> 00:57:16,560
used by Galileo.

884
00:57:16,600 --> 00:57:20,200
Their digital images even surpass
the photographic images taken

885
00:57:20,240 --> 00:57:23,360
by professionals just a
few decades ago.

886
00:57:23,480 --> 00:57:26,800
Astronomers' quest for cosmic
understanding, their telescopic

887
00:57:26,840 --> 00:57:30,360
exploration of the Universe,
is only 400 years old.

888
00:57:30,399 --> 00:57:34,640
There's still a lot of uncharted
territory out there.

889
00:57:35,160 --> 00:57:38,480
We've come a long way since
Galileo began charting the heavens

890
00:57:38,600 --> 00:57:41,800
with his telescope
four centuries ago.

891
00:57:41,840 --> 00:57:45,040
Today we still observe the
Universe with telescopes

892
00:57:45,080 --> 00:57:50,400
not only from Earth but in
the limitless regions of space.

893
00:57:50,520 --> 00:57:54,120
The seed of humanity lies in
our seemingly endless supply

894
00:57:54,240 --> 00:57:57,280
of ingenuity and curiosity.

895
00:57:57,399 --> 00:57:59,960
We have just begun answering
some of the greatest

896
00:58:00,000 --> 00:58:02,040
questions conceived.

897
00:58:02,080 --> 00:58:04,720
We have charted over 300
planets around other stars in

898
00:58:04,760 --> 00:58:08,800
our own Milky Way and located
organic molecules on planets

899
00:58:08,840 --> 00:58:12,360
around far flung stars.

900
00:58:12,399 --> 00:58:17,040
These incredible discoveries may
seem like the zenith of human exploration,

901
00:58:17,120 --> 00:58:21,120
but the best is
undoubtedly yet to come.

902
00:58:21,240 --> 00:58:24,040
You too can join the discoverers.

903
00:58:24,080 --> 00:58:28,800
Look up and wonder.