THE GREAT PHOTON ESCAPE

NARRATED BY ALIA SHAWKAT

1
00:00:01,280 --> 00:00:03,280
The Great Photon Escape

2
00:00:09,800 --> 00:00:18,220
Our Sun is a star — one of hundreds of billions
of stars in our galaxy, the Milky Way.

3
00:00:19,800 --> 00:00:24,960
The Milky Way is one of billions of
galaxies in the universe.

4
00:00:24,960 --> 00:00:28,750
Where did all these stars and galaxies come from?

5
00:00:28,750 --> 00:00:35,089
Astronomers think that soon after the universe
was born, it was plunged into total darkness.

6
00:00:35,089 --> 00:00:41,069
If anything had been around to witness this period — well, there wouldn't have been much to see.

7
00:00:41,140 --> 00:00:45,120
Everywhere you looked would have
been complete blackness.

8
00:00:45,340 --> 00:00:49,040
But the seeds of what would one day become
stars and galaxies

9
00:00:49,260 --> 00:00:52,060
were planted during these "Dark Ages."

10
00:00:52,280 --> 00:00:57,920
Eventually, the first stars and galaxies emerged
to illuminate the darkness.

11
00:00:57,929 --> 00:01:01,069
We call this time "reionization."

12
00:01:01,260 --> 00:01:07,300
But we don't know when that happened...
or what the first sources of light were,

13
00:01:07,400 --> 00:01:09,520
because we've never seen them.

14
00:01:09,520 --> 00:01:13,939
What was the universe like when the darkness lifted?

15
00:01:13,939 --> 00:01:17,539
The James Webb Space Telescope could show us.

16
00:01:17,760 --> 00:01:21,960
Telescopes are like time machines. They see the past.

17
00:01:22,140 --> 00:01:26,900
It takes time for light to travel from the
distant corners of the universe.

18
00:01:27,120 --> 00:01:31,580
When light from faraway stars and galaxies finally reaches our telescopes,

19
00:01:31,820 --> 00:01:37,960
it shows us those stars and galaxies as they were
when the universe was young.

20
00:01:37,960 --> 00:01:42,600
The oldest pictures we have today are of
our universe's "teen years"

21
00:01:42,700 --> 00:01:47,700
except for one photo, one "baby picture" of the universe:

22
00:01:47,920 --> 00:01:50,980
the Cosmic Microwave Background.

23
00:01:50,990 --> 00:01:55,439

It shows us the cosmos just before
darkness fell upon it.

24
00:01:55,439 --> 00:01:59,639
Today the universe is more than 13.7 billion years old.

25
00:01:59,880 --> 00:02:02,420
But the Cosmic Microwave Background is a map

26
00:02:02,620 --> 00:02:08,340
of the universe when it was just 378,000 years old.

27
00:02:08,340 --> 00:02:12,480
The image is similar to a temperature map
of the United States.

28
00:02:12,560 --> 00:02:17,920
But instead of showing a wide range of temperatures, the Cosmic Microwave Background shows

29
00:02:18,140 --> 00:02:23,099
tiny, almost unperceivable temperature differences
in the newborn universe.

30
00:02:23,099 --> 00:02:30,279
In fact, the temperature variations from place
to place are less than one-ten-thousandth of a degree.

31
00:02:30,480 --> 00:02:34,200
If you wanted to change the temperature
in your living room by that amount,

32
00:02:34,400 --> 00:02:37,520
you would need to run your heater for less than a hundredth of a second!

33
00:02:37,660 --> 00:02:38,720
sound effect: Huh?

34
00:02:38,780 --> 00:02:44,780
Amazingly, these little temperature fluctuations

grew into all the structures in the universe:

35
00:02:44,960 --> 00:02:48,200
galaxies, stars, and planets.

36
00:02:48,640 --> 00:02:53,060
Over time, the slightly hotter areas
pulled in more and more material,

37
00:02:53,240 --> 00:02:57,380
and the slightly colder areas grew
colder and emptier.

38
00:02:57,620 --> 00:03:04,360
Today, hot, dense stars and galaxies
are surrounded by cold, mostly empty space.

39
00:03:04,640 --> 00:03:10,640
Maps of the Cosmic Microwave Background tell
us about the early history of the universe,

40
00:03:10,650 --> 00:03:12,710
when it was hotter and denser.

41
00:03:17,580 --> 00:03:23,739
The universe is made up of energy and matter.
The light that we see by is a type of energy,

42
00:03:23,739 --> 00:03:29,159
and comes in the form of individual particles
called "photons."

43
00:03:29,160 --> 00:03:36,160
The universe's matter includes atoms, made up of particles like electrons, protons, and neutrons.

44
00:03:36,340 --> 00:03:40,980
Temperature is a measure of how fast particles of matter move around.

45
00:03:41,180 --> 00:03:45,320

When things are hot, particles zip around quickly.

46
00:03:45,680 --> 00:03:49,000
When it's cold, they wander slowly.

47
00:03:49,540 --> 00:03:57,060
Taking the universe's temperature shows us the density and energy of the universe at that time and place.

48
00:03:57,060 --> 00:04:01,320
And when the universe was first born,
it was dense and hot.

49
00:04:01,540 --> 00:04:06,520
In these cramped and heated conditions, particles
of light and matter were rushing around,

50
00:04:06,620 --> 00:04:08,580
continuously running into each other.

51
00:04:08,760 --> 00:04:16,200
No atoms could form, because matter particles were traveling too fast to stay together.

52
00:04:16,209 --> 00:04:20,929
But as the universe expanded,
it became less dense and it cooled.

53
00:04:21,060 --> 00:04:23,220
The particles slowed down.

54
00:04:23,220 --> 00:04:28,470
Soon, it was cool enough for protons and neutrons
to glue themselves together and combine into

55
00:04:28,470 --> 00:04:35,250
these small units called nuclei. But electrons
couldn't gather onto these nuclei,

56
00:04:35,520 --> 00:04:40,900
because they were relentlessly smashed aside

by powerful photons.

57
00:04:40,900 --> 00:04:47,680
This made the nuclei "ionized" — they had
protons, which are positively charged,

58
00:04:47,860 --> 00:04:54,080
but no negatively charged electrons to balance
out their charge and make them "neutral."

59
00:04:54,220 --> 00:05:00,600
Meanwhile, the photons couldn't go very far without crashing into electrons and newly formed nuclei.

60
00:05:00,760 --> 00:05:05,740
The photons bounced around
like sunlight does in a dense fog.

61
00:05:05,750 --> 00:05:11,850
Because all the light was scattered around,
the entire universe was foggy.

62
00:05:12,080 --> 00:05:20,420
But as time passed, the universe continued to
expand and cool, and it became much less dense.

63
00:05:20,600 --> 00:05:25,700
With more space between them, photons
and electrons collided less often.

64
00:05:25,880 --> 00:05:30,820
Electrons began joining with nuclei to
form neutral atoms.

65
00:05:31,060 --> 00:05:41,419
And now, with the electrons out of the photons' way,
the path was clear for light's "Great Escape."

66
00:05:41,419 --> 00:05:48,599
378,000 years after the Big Bang,
the fog finally lifted.

67
00:05:48,720 --> 00:05:53,160
The photons stopped scattering
and sped off into the distance.

68
00:05:53,360 --> 00:05:57,880
That fugitive light is the
Cosmic Microwave Background.

69
00:05:57,889 --> 00:06:01,649
No matter how big or powerful our telescopes become,

70
00:06:01,880 --> 00:06:07,260
the Cosmic Microwave Background
is the oldest light we will ever be able to see.

71
00:06:07,360 --> 00:06:09,480
Because before that moment,

72
00:06:09,600 --> 00:06:13,500
not a single photon could escape to be seen.

73
00:06:13,680 --> 00:06:20,980
After these photons made their Great Escape,
however, the universe was plunged into the Dark Ages.

74
00:06:21,060 --> 00:06:27,820
That's because no other sources of light
existed yet to illuminate the expanding universe.

75
00:06:28,100 --> 00:06:32,780
But slowly, atoms accumulated into larger structures —

76
00:06:32,980 --> 00:06:39,680
molecules, then clouds of gas,
then stars, and eventually galaxies.

77
00:06:39,840 --> 00:06:44,940
Light from these new stars and galaxies

burst forth into their surroundings,

78
00:06:45,100 --> 00:06:51,400
and these photons began stripping electrons off atoms, "reionizing" them.

79
00:06:51,600 --> 00:06:55,600
This is the dawn of "reionization."

80
00:06:55,750 --> 00:07:02,150
At this time, the universe was much larger
than it was in the early, foggy universe.

81
00:07:02,150 --> 00:07:07,730
Matter was more spread out, and while some
photons were busy ionizing atoms,

82
00:07:07,900 --> 00:07:13,280
most other photons easily escaped
without ricocheting off particles of matter.

83
00:07:13,460 --> 00:07:17,820
These freely moving photons brought an end to the Dark Ages,

84
00:07:17,940 --> 00:07:22,760
lighting up the universe and heralding in
the age of reionization,

85
00:07:22,920 --> 00:07:25,560
which continued for about a billion years.

86
00:07:25,569 --> 00:07:29,869
Yet, it's still a mystery how long the Dark Ages lasted

87
00:07:30,040 --> 00:07:33,340
and exactly when reionization began.

88
00:07:33,500 --> 00:07:36,480
What were the first stars and galaxies like?

89
00:07:36,700 --> 00:07:39,800
And when did they shed light on the universe?

90
00:07:40,020 --> 00:07:44,280
The James Webb Space Telescope
will find the answers,

91
00:07:44,520 --> 00:07:50,419
peering back to the time when the light
from the first stars burst forth into the cosmos.

92
00:07:50,419 --> 00:07:56,539
The Hubble Space Telescope is currently pushing
the limits of detection as far back in time as it can.

93
00:07:56,760 --> 00:07:59,540
But the Webb Telescope is designed

94
00:07:59,740 --> 00:08:04,440
specifically to find this special time
in the early history of the universe.

95
00:08:04,540 --> 00:08:08,420
Equipped with the latest technology,
Webb will allow us to see

96
00:08:08,430 --> 00:08:14,930
the objects that brought light to the cosmos and
unravel the mysteries of reionization.

97
00:08:14,930 --> 00:08:18,850
Only then will we have a better idea
of how the universe grew