

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

2
00:00:09,800 --> 00:00:18,219
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 --> 00:00:35,088
Astronomers think that soon after the universe
was born, it was plunged into total darkness.

6
00:00:35,088 --> 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 --> 00:00:45,119
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
00:00:49,259 --> 00:00:52,059
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
00:01:01,259 --> 00:01:07,299
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
00:01:09,519 --> 00:01:13,938
What was the universe like when the darkness lifted?

15
00:01:13,938 --> 00:01:17,538
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 --> 00:01:31,579
When light from faraway stars and galaxies finally reaches our telescopes,

19
00:01:31,819 --> 00:01:37,959
it shows us those stars and galaxies as they were
when the universe was young.

20
00:01:37,959 --> 00:01:42,599
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
00:01:50,989 --> 00:01:55,438
It shows us the cosmos just before
darkness fell upon it.

24
00:01:55,438 --> 00:01:59,638
Today the universe is more than 13.7 billion years old.

25
00:01:59,879 --> 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 --> 00:02:12,479

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

00:02:18,139 --> 00:02:23,098

tiny, almost unperceivable temperature differences in the newborn universe.

30

00:02:23,098 --> 00:02:30,278

In fact, the temperature variations from place to place are less than one-ten-thousandth of a degree.

31

00:02:30,479 --> 00:02:34,199

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

00:02:37,659 --> 00:02:38,719

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

00:02:48,639 --> 00:02:53,059

Over time, the slightly hotter areas pulled in more and more material,

37

00:02:53,240 --> 00:02:57,379

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

00:03:04,639 --> 00:03:10,639

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 --> 00:03:29,158

and comes in the form of individual particles called "photons."

43

00:03:29,159 --> 00:03:36,159

The universe's matter includes atoms, made up of particles like electrons, protons, and neutrons.

44

00:03:36,340 --> 00:03:40,979

Temperature is a measure of how fast particles of matter move around.

45

00:03:41,180 --> 00:03:45,319

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

00:03:49,539 --> 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 --> 00:04:01,319

And when the universe was first born, it was dense and hot.

49

00:04:01,539 --> 00:04:06,519

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

00:04:08,759 --> 00:04:16,199

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

00:04:35,519 --> 00:04:40,899

because they were relentlessly smashed aside
by powerful photons.

57

00:04:40,899 --> 00:04:47,679

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

00:05:00,759 --> 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

00:05:12,079 --> 00:05:20,419

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

00:05:25,879 --> 00:05:30,819

Electrons began joining with nuclei to form neutral atoms.

65

00:05:31,060 --> 00:05:41,418

And now, with the electrons out of the photons' way, the path was clear for light's "Great Escape."

66

00:05:41,418 --> 00:05:48,598

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 --> 00:05:57,879

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

00:06:01,879 --> 00:06:07,259

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 --> 00:06:27,819

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
00:06:39,839 --> 00:06:44,939
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 --> 00:07:02,149
At this time, the universe was much larger
than it was in the early, foggy universe.

81
00:07:02,149 --> 00:07:07,729
Matter was more spread out, and while some
photons were busy ionizing atoms,

82
00:07:07,899 --> 00:07:13,279
most other photons easily escaped
without ricocheting off particles of matter.

83
00:07:13,459 --> 00:07:17,819
These freely moving photons brought an end to the Dark Ages,

84
00:07:17,939 --> 00:07:22,759
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

00:07:36,699 --> 00:07:39,800

And when did they shed light on the universe?

90

00:07:40,019 --> 00:07:44,279

The James Webb Space Telescope
will find the answers,

91

00:07:44,519 --> 00:07:50,418

peering back to the time when the light
from the first stars burst forth into the cosmos.

92

00:07:50,418 --> 00:07:56,538

The Hubble Space Telescope is currently pushing
the limits of detection as far back in time as it can.

93

00:07:56,759 --> 00:07:59,539

But the Webb Telescope is designed

94

00:07:59,740 --> 00:08:04,439

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

98

00:08:19,040 --> 00:08:23,620

from those miniscule fluctuations in the
Cosmic Microwave Background

99

00:08:23,819 --> 00:08:25,560

into what we see around us today.