
MATTER's
LIMITS

1
00:00:07,749 --> 00:00:05,269
matter at the heart of a neutron star

2
00:00:10,390 --> 00:00:07,759
the crushed remnant of a massive sun is

3
00:00:12,150 --> 00:00:10,400
on the brink of becoming a black hole

4
00:00:14,310 --> 00:00:12,160
for decades scientists have wondered

5
00:00:16,390 --> 00:00:14,320
about the properties of that matter the

6
00:00:18,870 --> 00:00:16,400
densest in the universe we can measure

7
00:00:20,950 --> 00:00:18,880
and what form it takes

8
00:00:23,269 --> 00:00:20,960
now they have new insights thanks to

9
00:00:25,180 --> 00:00:23,279
nasa's nicer x-ray telescope on the

10
00:00:26,630 --> 00:00:25,190
international space station

11
00:00:28,790 --> 00:00:26,640
[Music]

12
00:00:32,069 --> 00:00:28,800
a neutron star forms when a massive

13
00:00:34,150 --> 00:00:32,079

star's core runs out of fuel

14
00:00:36,069 --> 00:00:34,160
with nothing left to fight gravity the

15
00:00:38,470 --> 00:00:36,079
star collapses

16
00:00:40,630 --> 00:00:38,480
here protons and electrons crush

17
00:00:42,709 --> 00:00:40,640
together to form neutrons as well as

18
00:00:44,470 --> 00:00:42,719
lightweight particles called neutrinos

19
00:00:46,549 --> 00:00:44,480
that escape the star

20
00:00:48,310 --> 00:00:46,559
the core continues to collapse until the

21
00:00:51,029 --> 00:00:48,320
matter at its center has twice the

22
00:00:53,350 --> 00:00:51,039
density of an atom's nucleus but on a

23
00:00:55,350 --> 00:00:53,360
city-sized scale

24
00:00:56,709 --> 00:00:55,360
when the core can't compress further it

25
00:00:58,709 --> 00:00:56,719
rebounds

26
00:01:01,270 --> 00:00:58,719
the expanding core crashes into the

27
00:01:03,110 --> 00:01:01,280
star's collapsing inner layers creating

28
00:01:04,310 --> 00:01:03,120
a shock wave that rips outward through

29
00:01:06,469 --> 00:01:04,320
the star

30
00:01:09,270 --> 00:01:06,479
the result is a powerful supernova

31
00:01:11,030 --> 00:01:09,280
explosion with a newborn neutron star at

32
00:01:12,950 --> 00:01:11,040
its center

33
00:01:15,350 --> 00:01:12,960
scientists have many questions about

34
00:01:18,390 --> 00:01:15,360
neutron star physics including how

35
00:01:20,469 --> 00:01:18,400
squeezable is the matter in their cores

36
00:01:22,550 --> 00:01:20,479
in more squeezable models the internal

37
00:01:24,630 --> 00:01:22,560
pressure and density break neutrons in

38
00:01:26,550 --> 00:01:24,640

the center into a sea of even tinier

39
00:01:29,109 --> 00:01:26,560
particles or combinations of those

40
00:01:32,230 --> 00:01:29,119
particles resulting in a squishy core

41
00:01:34,069 --> 00:01:32,240
and a smaller star for a given mass

42
00:01:36,390 --> 00:01:34,079
in some less squeezable models the

43
00:01:39,990 --> 00:01:36,400
neutrons hold up against those forces

44
00:01:42,710 --> 00:01:40,000
resulting in a larger star

45
00:01:45,429 --> 00:01:42,720
scientists used nicer's precise mass and

46
00:01:48,069 --> 00:01:45,439
size measurements of two pulsars a kind

47
00:01:49,910 --> 00:01:48,079
of rapidly rotating neutron star to

48
00:01:51,830 --> 00:01:49,920
narrow down how compressible these

49
00:01:54,149 --> 00:01:51,840
objects are

50
00:01:56,950 --> 00:01:54,159
a pulsar is so dense that its strong

51
00:01:58,950 --> 00:01:56,960
gravity warps nearby space-time allowing

52
00:01:59,990 --> 00:01:58,960
us to see light emitted from its far

53
00:02:01,749 --> 00:02:00,000
side

54
00:02:03,510 --> 00:02:01,759
this distortion makes it look bigger

55
00:02:05,749 --> 00:02:03,520
than it actually is

56
00:02:08,790 --> 00:02:05,759
the more massive the pulsar the greater

57
00:02:11,029 --> 00:02:08,800
the warping and the larger it appears

58
00:02:12,790 --> 00:02:11,039
scientists measure this distortion by

59
00:02:15,190 --> 00:02:12,800
tracking the brightness of x-ray

60
00:02:16,869 --> 00:02:15,200
emitting hot spots on the pulsar surface

61
00:02:18,550 --> 00:02:16,879
as it spins

62
00:02:20,710 --> 00:02:18,560
they can then precisely determine the

63
00:02:22,710 --> 00:02:20,720

pulsar's mass and radius and obtain

64
00:02:24,390 --> 00:02:22,720
important clues about conditions in the

65
00:02:28,070 --> 00:02:24,400
core

66
00:02:30,949 --> 00:02:28,080
nicer used this method to analyze j0740

67
00:02:32,949 --> 00:02:30,959
the heaviest known pulsar with about 2.1

68
00:02:34,790 --> 00:02:32,959
times the sun's mass

69
00:02:37,589 --> 00:02:34,800
two research groups using different

70
00:02:39,830 --> 00:02:37,599
approaches both estimate it's about 16

71
00:02:42,869 --> 00:02:39,840
miles across

72
00:02:46,309 --> 00:02:42,879
nicer's measurements of j0740 and pulsar

73
00:02:48,390 --> 00:02:46,319
j0030 disfavor squeezable models where

74
00:02:52,150 --> 00:02:48,400
cores contain only quarks or other

75
00:02:54,229 --> 00:02:52,160
exotic matter and j0740s size and mass

76
00:02:56,150 --> 00:02:54,239
together challenge less squeezable

77
00:02:57,750 --> 00:02:56,160
theories where cores contain only

78
00:02:59,509 --> 00:02:57,760
neutrons

79
00:03:02,309 --> 00:02:59,519
physicists will have to develop new

80
00:03:04,390 --> 00:03:02,319
models perhaps containing both neutrons

81
00:03:07,589 --> 00:03:04,400
and quarks to explain nicer's

82
00:03:12,710 --> 00:03:09,830
the cores of neutron stars represent

83
00:03:15,270 --> 00:03:12,720
matter's final stable form short of

84
00:03:16,869 --> 00:03:15,280
becoming a black hole scientists can't

85
00:03:19,509 --> 00:03:16,879
recreate those conditions in earth

86
00:03:22,070 --> 00:03:19,519
laboratories so nicer will continue to

87
00:03:24,550 --> 00:03:22,080
measure pulsars to probe deeper and

88
00:03:28,050 --> 00:03:24,560

deeper into the hearts of these