LIGO Detects Gravitational Waves for Third Time

Results confirm new population of black holes

LIGO 第三次直接探测到引力波

这一结果将为新一类黑洞的存在提供有力的证据

The Laser Interferometer Gravitational-wave Observatory (LIGO) has made a third detection of gravitational waves, ripples in space and time, demonstrating that a new window in astronomy has been firmly opened. As was the case with the first two detections, the waves were generated when two black holes collided to form a larger black hole.

激光干涉引力波天文台第三次成功捕捉到宇宙时空的涟漪－引力波。这项成果将全面开启人类认识宇宙的新窗口。与前两次探测到的引力波信号（GW151226、GW150914）类似，本次信号来自于双黑洞系统融合为更大质量黑洞过程中释放的引力波

The newfound black hole, formed by the merger, has a mass about 49 times that of our sun. This fills in a gap between the masses of the two merged black holes detected previously by LIGO, with solar masses of 62 (first detection) and 21 (second detection).

本次引力波的发现从实验上证实了新一类双黑洞系统的存在。本次观测对应的双黑洞合并组成的新型黑洞质量约为太阳的 49 倍。这刚好介于 LIGO 前两次观测到的双黑洞系统的质量，其中第一次观测对应的双黑洞系统质量为太阳质量为 62 倍，第二次为太阳质量的 21 倍。

"We have further confirmation of the existence of stellar-mass black holes that are larger than 20 solar masses—these are objects we didn't know existed before LIGO detected them," says MIT's David Shoemaker, the newly elected spokesperson for the LIGO Scientific Collaboration (LSC), a body of more than 1,000 international scientists who perform LIGO research together with the European-based Virgo Collaboration. "It is remarkable that humans can put together a story, and test it, for such strange and extreme events that took place billions of years ago and billions of light-years distant from us. The entire LIGO and Virgo scientific collaborations worked to put all these pieces together."

作为 LIGO 科学合作组新当选的发言人，麻省理工学院的 David Shoemaker 教授谈到：“我们已经进一步证实了质量大于 20 个太阳质量的黑洞的存在，这是在 LIGO 观测到相应引力波信号之前我们所不能确定的事情。”。LIGO 科学合作

组是一个拥有一千多名来自世界各国科学家组成的科学合作研究机构，他们与欧洲的 Virgo 科学合作组一起进行引力波的联合探测。

The new detection occurred during LIGO's current observing run, which began November 30, 2016, and will continue through the summer. LIGO is an international collaboration with members around the globe. Its observations are carried out by twin detectors—one in Hanford, Washington, and the other in Livingston, Louisiana—operated by Caltech and MIT with funding from the National Science Foundation (NSF).

本次观测到的引力波是发生在 LIGO 现阶段观测运行中，该运行从 2016 年 11 月 30 日开始一直采集数据到 2017 年夏季结束。涉及到的两架结构完全相同的探测器位于 hanford, Washington 和路易斯安娜州 livingston，这两架探测器都由美国国家自然科学基金（NSF）资助。这两座探测器都是由美国国家自然科学基金（NSF）的资助

LIGO made the first-ever direct observation of gravitational waves in September 2015 during its first observing run since undergoing major upgrades in a program called Advanced LIGO. The second detection was made in December 2015. The third detection, called GW170104 and made on January 4, 2017, is described in a new paper accepted for publication in the journal Physical Review Letters.

经过主体升级后的 LIGO 称为高新 LIGO，即第二代激光干涉引力波天文台。在 Advanced LIGO 在开始第一轮数据观测期间，就第一次成功捕捉到了来自于双黑洞系统融合过程释放的引力波信号，该信号被观测到的时间为 2015 年 9 月。紧接着在同年 12 月，它第二次检测到了另一双黑洞源释放的引力波信号。第三次于今年 1 月 4 日观测到，命名为 GW170104。针对这一结果，LIGO 科学合作小组（LSC）共同撰写了一篇论文，在 Physical Review Letters 期刊上发表。

In all three cases, each of the twin detectors of LIGO detected gravitational waves from the tremendously energetic mergers of black hole pairs. These are collisions that produce more power than is radiated as light by all the stars and galaxies in the universe at any given time. The recent detection appears to be the farthest yet, with the black holes located about 3 billion light-years away. (The black holes in the first and second detections are located 1.3 and 1.4 billion light-years away, respectively.)

在这三次探测中，LIGO 的每一个探测器都能直接观测从双黑洞融合瞬间释放的引力波。这种引力辐射比宇宙中所有发光星体以及星系在相同时间内的光辐射还要强。最近这次观测到的双黑洞系统所处的位置最远，它距离地球约 30 亿光年 （第一次和第二次观测到的黑洞距离地球分别为 13 和 14 亿光年）

The newest observation also provides clues about the directions in which the black holes are spinning. As pairs of black holes spiral around each other, they also spin on their own axes—like a pair of ice skaters spinning individually while also circling around each other. Sometimes black holes spin in the same overall orbital direction as the pair is moving—what astronomers refer to as aligned spins—and sometimes they spin in the opposite direction of the orbital motion. What's more, black holes can also be tilted away from the orbital plane. Essentially, black holes can spin in any direction.

最新的观测结果进一步给出了与双黑洞相互旋转以及自旋方向有关的参数。由于双黑洞系统中的两成员彼此旋转，同时它们具有自旋，这如同一对在冰上各自旋转又绕着彼此旋转的滑冰运动员。双黑洞系统中单个黑洞的自旋方向有时与两者相互旋转轨道的旋转方向一致- 天文学家称之为平行自旋 - 有时它们的自旋与轨道旋转方向相反，这被称为反平行自旋。此外，黑洞自旋平面也可以与轨道平面倾斜。一般而言，黑洞可以在任何方向上自旋。

The new LIGO data cannot determine if the recently observed black holes were tilted but they imply that at least one of the black holes may have been non-aligned compared to the overall orbital motion. More observations with LIGO are needed to say anything definitive about the spins of binary black holes, but these early data offer clues about how these pairs may form.

新的 LIGO 数据无法确定最近观测到的双黑洞的自旋正方向是否倾斜，但是它们可以显示出与相互旋转轨道运动方向是否一致或相反，并且能提供如何形成这一现象的依据。要想更加明确地给出双黑洞自旋的任何信息需要更多的被 LIGO 观测到的双黑洞引力波事件，但这些早期的数据可以为寻求双黑洞形成机制提供线索。

"This is the first time that we have evidence that the black holes may not be aligned, giving us just a tiny hint that binary black holes may form in dense stellar clusters," says Bangalore Sathyaprakash of Penn State and Cardiff University, one of the editors of the new paper, which is authored by the entire LSC and Virgo Collaborations.

作为该论文的主要作者之一的宾夕法尼亚州立大学和加迪夫大学的教授 Bangalore Sathyaprakash 说：“这是我们第一次有证据表明黑洞可能为反向旋转型，这给我们一个暗示，双黑洞系统可能在密集的恒星簇中形成。”。

There are two primary models to explain how binary pairs of black holes can be formed. The first model proposes that the black holes are born together: they form when each star in a pair of stars explodes, and then, because the original stars were spinning in alignment, the black holes likely remain aligned.

目前，对于双黑洞的形成有两个主流的模型来解释。在第一个模型中，处于稠密恒星簇中的黑洞在其生命后期会逐渐聚集到一起。当它们陷入星簇中心后就形成了双黑洞系统。在这种情况下，黑洞的自旋可以在任何方向。

In the other model, the black holes come together later in life within crowded stellar clusters. The black holes pair up after they sink to the center of a star cluster. In this scenario, the black holes can spin in any direction relative to their orbital motion. Because LIGO sees some evidence that the GW170104 black holes are non-aligned, the data slightly favor this dense stellar cluster theory.

另一种模型预言双黑洞是同时诞生的：它们形成于双星系统塌缩，由于最初的双星具有同向自旋，因此产生的双黑洞系统应该也具有同向自旋特征。从 LIGO 最新一次的探测结果来看，GW170104 引力波信号反映出相应的双黑洞系统具有反向自旋。这样，貌似前一种模型（致密恒星簇模型）与实验更相符。

"We're starting to gather real statistics on binary black hole systems," says Keita Kawabe of Caltech, also an editor of the paper, who is based at the LIGO Hanford Observatory. "That's interesting because some models of black hole binary formation are somewhat favored over the others even now and, in the future, we can further narrow this down."

该论文的另一位作者，加州理工学院的资深科学家 Keita Kawabe 谈到“最近我们开始收集关于双黑洞系统的真实统计数据。这很有趣，因为目前有一些双黑洞系统的形成过程更倾向于另一些理论模型。通过类似的引力波观测，将来我们可以进一步筛选出合理的理论模型。

The study also once again puts Albert Einstein's theories to the test. For example, the researchers looked for an effect called dispersion, which occurs when light waves in a physical medium such as glass travel at different speeds depending on their wavelength; this is how a prism creates a rainbow. Einstein's general theory of

relativity forbids dispersion from happening in gravitational waves as they propagate from their source to Earth. LIGO did not find evidence for this effect.
这项研究能再次通过实验来验证爱因斯坦的一些理论。 例如，研究人员企图寻找一种称为色散的物理效应，当自然光进入某种物理介质如玻璃后，不同波长的光波以不同的速度在介质中传播就会产生色散效应。这就是棱镜将白光分成彩虹色的过程。 爱因斯坦在广义相对论中预言，当引力波从波源传播到地球时不会产生类似的色散现象。目前， LIGO 的确没有发现引力波有色散效应的证据。
"It looks like Einstein was right—even for this new event, which is about two times farther away than our first detection," says Laura Cadonati of Georgia Tech and the Deputy Spokesperson of the LSC. "We can see no deviation from the predictions of general relativity, and this greater distance helps us to make that statement with more confidence."
Shoemaker 说："对于这个新的黑洞事件，它的发生地点比我们第一次探测到的波源要远两倍。我们仍然没有找到偏离广义相对论的结果，这种更大的距离使我们能够更有信心地认为爱因斯坦的理论看来是正确的。"
"The LIGO instruments have reached impressive sensitivities," notes Jo van den Brand, the Virgo Collaboration spokesperson, a physicist at the Dutch National Institute for Subatomic Physics (Nikhef) and professor at VU University in Amsterdam. "We expect that by this summer Virgo, the European interferometer, will expand the network of detectors, helping us to better localize the signals."
荷兰国家亚原子物理研究所（Nikhef）的物理学家，阿姆斯特丹 VU 大学的教授， Virgo 团队发言人 Jo van den Brand 表示："LIGO 探测器的灵敏度已经达到惊人的程度。我们预计到今年夏天，Virgo，欧洲激光干涉仪，将扩大联合探测网络，帮助我们更好地对信号进行定位。
The LIGO-Virgo team is continuing to search the latest LIGO data for signs of space-time ripples from the far reaches of the cosmos. They are also working on technical upgrades for LIGO's next run, scheduled to begin in late 2018, during which the detectors' sensitivity will be improved.
LIGO-Virgo 科学家们将继续从最新的 LIGO 数据中搜索宇宙中更遥远地方传来的引力波信号。 同时，他们将于 2018 年年底开始为 LIGO 的下一次运行进行技术升级，届时探测器的灵敏度将得到进一步提高。

"With the third confirmed detection of gravitational waves from the collision of two black holes, LIGO is establishing itself as a powerful observatory for revealing the dark side of the universe," says David Reitze of Caltech, executive director of the LIGO Laboratory. "While LIGO is uniquely suited to observing these types of events, we hope to see other types of astrophysical events soon, such as the violent collision of two neutron stars."

LIGO 天文台负责人 David Reitze 说："通过第三次明确探测到由两个黑洞碰撞产生的引力波，LIGO 逐步建立起探索宇宙黑暗区域的强大观测能力。虽然 LIGO 对观测双黑洞碰撞产生引力波这类事件比较敏感，但我们仍希望将来它能观测到其他类型的天体物理事件，例如两个中子星的碰撞。"。

LIGO is funded by the National Science Foundation (NSF), and operated by MIT and Caltech, which conceived and built the project. Financial support for the Advanced LIGO project was led by NSF with Germany (Max Planck Society), the U.K. (Science and Technology Facilities Council) and Australia (Australian Research Council) making significant commitments and contributions to the project. More than 1,000 scientists from around the world participate in the effort through the LIGO Scientific Collaboration, which includes the GEO Collaboration. LIGO partners with the Virgo Collaboration, a consortium including 280 additional scientists throughout Europe supported by the Centre National de la Recherche Scientifique (CNRS), the Istituto Nazionale di Fisica Nucleare (INFN), and Nikhef, as well as Virgo's host institution, the European Gravitational Observatory. Additional partners are listed at: http://ligo.org/partners.php.

LIGO 由 NSF 资助，由加州理工学院和麻省理工学院经营、负责构建和建造该项目。 来自世界各地的 1000 多名科学家通过 LIGO 科学合作组参与该项目具体工作，包括 GEO。LIGO 与 Virgo 合作，将另外的 280 位欧洲科学家联合起来，得到了包括欧洲国家科学中心（CNRS），国际自然科学基金委员会（INFN）和 Virgo 主体机构及欧洲重力观测站的资助。 其他合作伙伴参见：http://ligo.org/partners.php。

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