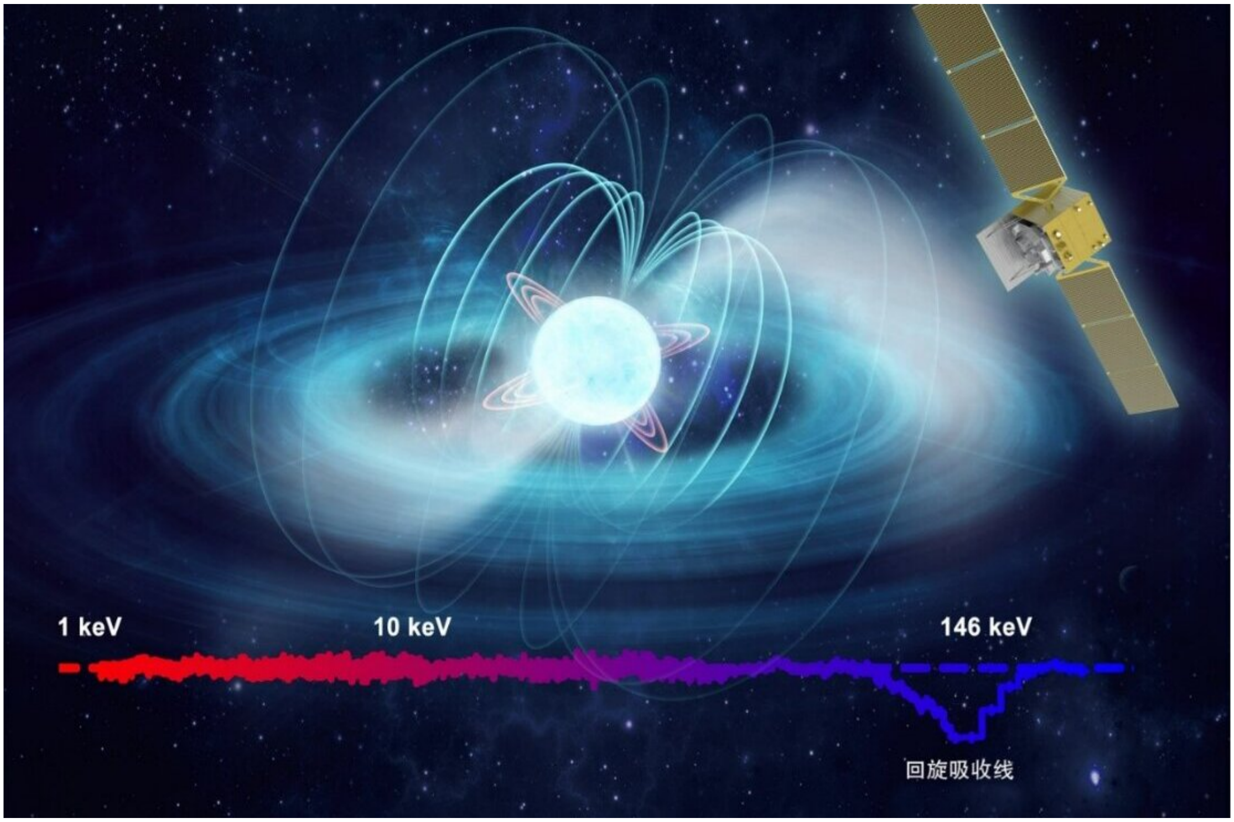
A new measurement record for strongest magnetic field in universe

July 12 2022



Insight-HXMT's discovery of the fundamental electron cyclotron absorption line near 146 keV for the first Galactic ultraluminous X-ray pulsar Swift J 0243.6+6124. Credit: IHEP

Neutron stars have the strongest magnetic fields in the universe, and the only way to measure their surface magnetic field directly is to observe the cyclotron absorption lines in their X-ray energy spectra. The Insight-HXMT team has recently discovered a cyclotron absorption line with an energy of 146 keV in the neutron star X-ray binary Swift J0243.6+6124, corresponding to a surface magnetic field of more than 1.6 billion Tesla. After direct measurement of the strongest magnetic field in the universe at about 1 billion Tesla in 2020, the world records for the highest energy cyclotron absorption line and direct measurement of the strongest magnetic field in the universe have been broken.

The findings, obtained jointly by the Key Laboratory for Particle Astrophysics at the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences and the Institute for Astronomy and Astrophysics, Kepler Center for Astro and Particle Physics, University of Tübingen (IAAT), were published on June 28 in *Astrophysical Journal Letters* (ApJL). Dr. Kong Lingda, Prof. Zhang Shu, and Prof. Zhang Shuangnan from IHEP are the corresponding authors of the paper. Dr. Victor Doroshenko and Prof. Andrea Santangelo from the University of Tübingen significantly contributed to the discovery.

A neutron star X-ray binary system consists of a neutron star and its companion star. Under the strong gravitational force of the neutron star, the gas of the companion star falls towards the neutron star, forming an accretion disk. The plasma in the accretion disk will fall along magnetic lines to the neutron star's surface, where powerful X-ray radiation is released. Along with the rotation of the neutron star, such emissions result in periodic X-ray pulse signals, hence the name "X-ray accretion pulsar" for these objects.

Many observations have revealed that these types of objects have absorption structures in their X-ray radiation spectra, namely cyclotron absorption lines, which are thought to be caused by resonant scattering and thus absorption of X-rays by electrons moving along the strong magnetic fields. The energy of the absorption structure corresponds to the strength of the surface magnetic field of a neutron star; therefore, this phenomenon can be used to directly measure the strength of the magnetic field near the surface of the neutron star.

Ultraluminous X-ray pulsars are a class of objects whose X-ray luminosity far exceeds that of canonical X-ray accreting pulsars. They have previously been discovered in several galaxies far from the Milky Way. Astronomers have speculated that their pulsars have high magnetic field strengths even though direct measurement evidence is still lacking.

Insight-HXMT made detailed and broadband observations of the outburst of Swift J0243.6+6124, the Milky Way's first ultraluminous X-ray pulsar, and unambiguously discovered its cyclotron absorption line. This line revealed energy up to 146 keV (with detection significance of about 10 times the standard deviation), which corresponds to a surface magnetic field of more than 1.6 billion Tesla. This is not only the strongest magnetic field directly measured in the universe to date but also the first detection of an electron cyclotron absorption line in an ultraluminous X-ray source, thus providing direct measurement of the neutron star's surface magnetic field.

It is believed that the surface magnetic fields of neutron stars have complex structures, ranging from dipole fields very far from the neutron star to multipole fields only influencing the area close to the neutron star. However, most earlier indirect estimates of the magnetic fields of neutron stars have probed only the dipole fields.

This time, the direct magnetic field measurement by Insight-HXMT based on the cyclotron absorption line is about an order of magnitude greater than that estimated using indirect means. This serves as the first concrete evidence that a neutron star's magnetic field structure is more complex than that of a traditional symmetric dipole field, and it also provides the first measurement of the nonsymmetric component of a neutron star's magnetic field.

Insight-HXMT is the first Chinese X-ray astronomy satellite. It comprises scientific payloads including a high-energy telescope, medium-energy telescope, low-energy telescope, and a space environment monitor. Insight-HXMT has advantages over other X-ray satellites in terms of broadband (1-250 keV) spectral coverage, large effective area at high energies, high time resolution, low dead-time, and no pile-up effects for bright sources, thus opening up a new window for observing black holes, neutron stars with hard X-ray fast transitions, and energy spectrum studies.

In 2020, the Insight-HXMT team reported the detection of a 90 keV cyclotron absorption line from a neutron star in the X-ray binary system GRO J1008-57, corresponding to a surface magnetic field of 1 billion Tesla, which set a world record for direct measurement of the universe's strongest magnetic field at the time. Later, a new record for a cyclotron absorption line—with its highest energy around 100 keV—was detected by Insight-HXMT from another neutron star in 1A 0535+262. Insight-HXMT has demonstrated its exceptional capacity to explore the energy spectrum by breaking its own records for cyclotron absorption line discoveries.

More information: Ling-Da Kong et al, Insight-HXMT Discovery of the Highest-energy CRSF from the First Galactic Ultraluminous X-Ray Pulsar Swift J0243.6+6124, *The Astrophysical Journal Letters* (2022). DOI: 10.3847/2041-8213/ac7711

Provided by Chinese Academy of Sciences