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The engine that powers short gamma-ray bursts

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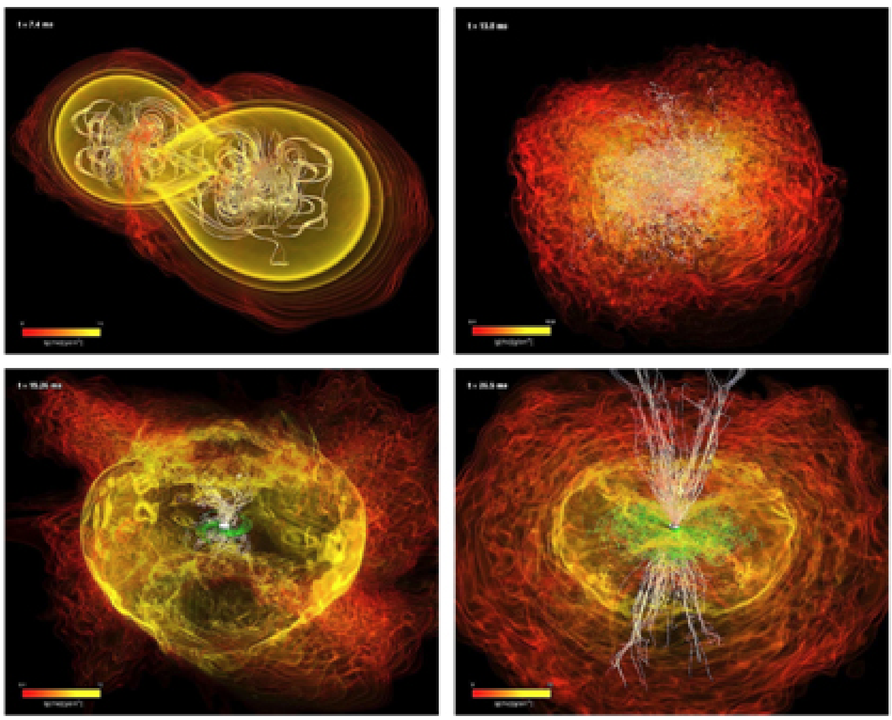

Two neutron stars merge within milliseconds to form a black hole. A strong magnetic field is formed along the rotational axis, which creates a jet that shoots ultra-hot matter out into space. Gamma-ray bursts can occur in the jet. © L. Rezzolla (AEI) & M. Koppitz (AEI & Zuse Institute Berlin)

(PhysOrg.com) -- These explosions have been puzzling scientists for years: those brief flashes of gamma light can in fact release more energy in a fraction of a second than what our entire galaxy releases in one year – even with its 200 billion stars. What causes those explosions?

Scientists working with Luciano Rezzolla at the Max Planck Institute for Gravitational Physics are now one step closer to solving the riddle. In six-week-long computations they carried out on the Institute's supercomputer, the researchers simulated the merger of two neutron stars which have a small magnetic field and which, when merge, form a black hole surrounded by a hot torus. In this process, an ultra-strong magnetic field with a jet-like structure is formed along the rotational axis. And it was this magnetic field that could lie behind the generation of short gamma-ray bursts: out of the chaos that resulted from the collision, an ordered structure was formed – a jet in which short gamma-ray bursts can occur.

The first astrophysical gamma-ray explosion was observed by pure coincidence: in the late 1960s, an American spy satellite looking for evidence of above ground atomic bomb tests detected the first gamma-ray burst (GBR). It came not from Earth, but from outer space. Between 1991 and the date it crashed in June 2000, America's Compton satellite registered about one GBR per day – yet the cause of these massive explosions in the universe remained a mystery.

State-of-the-art supercomputer models show that merging neutron stars can power a short gamma-ray burst.

Coalescing neutron stars were believed to be the most likely culprits. However, the scientists did not understand how the chaos that resulted from the merger of these 20-kilometer wide, extremely dense spheres could produce a stream of gas – a jet – orientated along the rotational axis. Yet the jet is an essential ingredient in the occurrence of gamma-ray bursts. So how can the driving force behind the process create this order and release such enormous amounts of energy?

Luciano Rezzolla, leader of the Numerical Relativity Group at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute/AEI), has been working with fellow scientists in an international collaboration, and they have now found an explanation for the short gamma-ray bursts that can last up to three seconds. The team solved the Einstein equations and the magnetohydrodynamic equations for two neutron stars coalescing into a black hole and let the simulation run on much longer timescales after they merged.

What they found is that the resulting rapidly rotating black hole is initially surrounded by a ring of hot matter with a relatively weak and chaotic magnetic field. The rotating movement of this unstable system generates an extremely strong, vertically orientated magnetic field of 10^{15} Gauss along the rotational axis. As a comparison, this magnetic field is 10^{16} (10,000,000,000,000,000) times stronger than the Earth's magnetic field. This highlights the importance of this new result: for the first time it has been shown that a magnetic jet-like structure can be formed in which the ultra-hot matter shoots out into space two collimated outflows which can then lead to the brief flashes in the gamma wavelength.

"This is the first time we have studied the entire process from the merger of the neutron stars to the formation of the jets," says Luciano Rezzolla. "This marks a breakthrough, because we previously did not know how the order that was needed for the jets to form and the gamma-ray bursts to occur was created out of the chaos." Through a considerable computational effort, the scientists run the simulation for twice as long as normal. The supercomputer Damiana performed its calculations for a whole six weeks. The complete simulation shows what happens in just 35 milliseconds.

"We have now lifted an important veil, which was hiding the central engine of short GRBs and provided a link between the theoretical modelling and the observations, by showing that a jet-like structure is indeed produced through the self-organization of the magnetic field in a neutron star merger," adds Chryssa Kouveliotou from the American space agency, NASA.

In addition to huge amounts of gamma radiation, a process of this type also produces gravitational waves in space whose waveform the scientists have simulated. These tiny ripples in spacetime were predicted by Albert Einstein in his General Theory of Relativity, but they have never been measured directly. It is hoped that the simulated gravitational-wave signals will help the scientists discover real gravitational waves in the data jungle from the detectors. That's why having a very precise picture of what they look like increases the likelihood of the researchers actually identifying the fingerprints of gravitational waves in the detector data.

There are currently five interferometric gravitational wave detectors throughout the world: the German/British GEO600 project near Hanover, Germany, the three LIGO detectors in the US states of Louisiana and Washington, and the Franco/Italian Virgo project in Pisa, Italy. A new space-based detector by the name of LISA (Laser Interferometer Space Antenna) is also planned by the European Space Agency (ESA) and NASA, with the launch scheduled to take place in 2020. Scientists from the Max Planck Institute for Gravitational Physics are playing a leading role in the GEO600 and LISA projects and are working closely with fellow scientists on the other projects within the framework of the LIGO-Virgo Collaboration.

More information: Luciano Rezzolla, Bruno Giacomazzo, Luca Baiotti, Jonathan Granot, Chryssa Kouveliotou, Miguel A. Aloy, The Missing Link: Merging Neutron Stars naturally produce Jet-like Structures and can power short Gamma-Ray Bursts, *Astrophysical Journal Letters*, 732:L6, 2011. iopscience.iop.org/2041-8205/732/1/L6

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