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PRESS RELEASE

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At the origin of mega-magnetic stars

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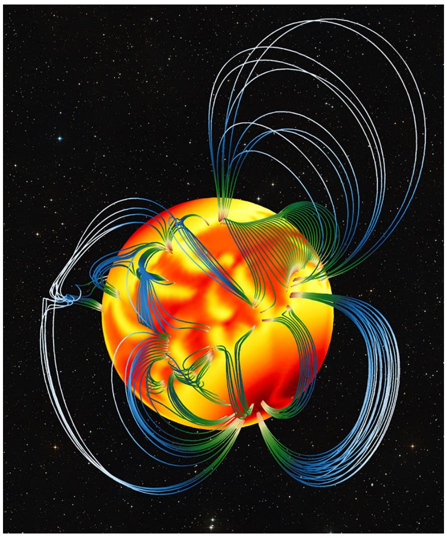

A simulated magnetar with magnetic field lines and surface temperature (temperature increases with colour, tending from red to yellow).

Pictures

Magnetars are a class of neutron stars with the strongest magnetic fields in the Universe. These incredibly dense objects are central in the landscape of extreme phenomena such as hypernovae, fast radio bursts and gamma-ray bursts. Yet, their origin remains unclear. An international research team, including the University of Geneva (UNIGE), has reproduced for the first time the formation and evolution of a magnetar by using numerical simulations. This major advance in our understanding of these stars is published in the journal *Nature Astronomy*.

At the end of their lives, stars with a mass eight times that of the Sun undergo core collapse due to gravity. This event marks the beginning of the star explosion into a supernova: the outer layers are ejected, while the core contracts very violently, forming a neutron star, the densest known object in the Universe. One teaspoon of its matter weighs one billion tonnes, or 100,000 Eiffel Towers!

While neutron stars are typically observed in radio waves, some emit powerful bursts of X-rays and gamma rays. They are commonly called “magnetars”, because their emissions are thought to be caused by the dissipation of extreme magnetic fields, a million billion times more intense than those on Earth!

The mystery of magnetar origin

Since the magnetic fields of magnetars play a crucial role in the luminous phenomena they are associated with, scientists are working to understand their origin. Several theories have been proposed, but the most promising suggests magnetic field generation through dynamo action in the proto-neutron star, just seconds after the explosion begins.

“Dynamo action enables a conducting fluid, such as a plasma, with sufficiently complex motions, to amplify and maintain its own magnetic fields against the diffusive effects, which weaken them. This amplification effect is undoubtedly at the origin of the majority of astrophysical magnetic fields, such as those of the Sun or Earth”, explains Paul Barrère, a postdoctoral researcher in the Department of Astronomy at the UNIGE Faculty of Science, and second author of this study. “Unlike the others, this theory is supported by a large number of numerical simulations.”

A new magnetar formation scenario

Many of these dynamos require rapid rotation of the progenitor star's core to be effective. However, these rotational velocities are poorly understood due to a lack of observations. Paul Barrère and researchers Jérôme Guilet and Raphaël Raynaud from the Department of Astrophysics at CEA Saclay have therefore studied an alternative scenario. It suggests that the proto-neutron star is spun up by some of the matter initially ejected during the supernova, which later falls back onto the star's surface. "This makes our new formation scenario independent of the progenitor star rotation," says Paul Barrère.

The favoured mechanism to amplify the magnetic field in this proto-neutron star is a specific type of dynamo, known as the Tayler-Spruit dynamo. "This mechanism feeds off the difference of rotation inside the star and an instability of the magnetic field. This dynamo is well known to researchers working on stars, as it could explain core rotation in stars," explains the researcher.

Simulating magnetar evolution

Despite its relevance, this new scenario focuses only on the first few seconds after the supernova, which is very brief compared to the age of the observed magnetars. Collaboration with scientists from the Universities of Newcastle and Leeds, who specialise in neutron star evolution, was therefore crucial to produce the first numerical simulation of the evolution, on a million-year timescale, of a neutron star harbouring an initial complex magnetic field produced by the Tayler-Spruit dynamo. "The combination of our expertise has, for the first time, bridged the gap between our studies of formation in proto-neutron stars and research on the evolution of evolved neutron stars," states Paul Barrère.

The neutron star simulated in this study reproduces the observational characteristics of the so-called weak-field magnetars discovered in 2010. These magnetars have magnetic dipoles that are ten to one hundred times weaker than those of classical magnetars. This study therefore demonstrates that these magnetars are probably formed in neutron protostars accelerated by the accretion of supernova matter and in which the Tayler-Spruit dynamo operates.

"Our work is a major breakthrough in our understanding of magnetars and opens very interesting new perspectives in the study of other dynamo effects. Our results suggest that each dynamo leaves its imprint on the complex magnetic field configuration and therefore on the observed emission from magnetars. While the Tayler-Spruit dynamo is associated with low-field magnetars, we hope to identify in the future the mechanisms associated with the other magnetars," concludes Paul Barrère.

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