Piercing the mystery of the cosmic origins of gold

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Credit: Prawny/Pixabay

Where does gold, the precious metal coveted by mortals through the ages, come from? How, where and when was it produced? Last August, a single astrophysical observation finally gave us the key to answer these questions. The results of this research were published on October 16, 2017.

Gold pre-exists the formation of Earth: this is what differentiates it from, for example, diamond. However valuable it may be, this precious stone is born out of mere coal, whose atomic structure is modified by enormous pressure from the earth's crust. Gold is totally different – the strongest forces in the earth's mantle are unable to change the composition of its atomic nucleus. Too bad for the alchemists who dreamed of transforming lead into gold.

Yet there is gold on Earth, both in its deep core, where it has migrated together with heavy elements such as lead or silver, and in the planet's crust, which is where we extract this precious metal. While the gold in the core was already there at the formation of our planet, that in the crust is mostly extraterrestrial and arrived after the formation of Earth. It was brought by a gigantic meteor shower that bombarded the Earth (and the Moon) about 3.8 billion years ago.

Formation of heavy elements

How gold is produced in the universe? The elements heavier than iron, including gold, are partially produced by the *s* process during the ultimate evolution phases of the stars. It is a slow process (*s* stands for slow) that operates in the core of what are referred to as AGB stars – those of low and intermediate mass (less than 10 solar masses) that can produce chemical elements up to polonium. The other half of the heavy elements is produced by the *r* process (*r* stands for rapid). But the site where this nucleo-synthesis process takes place has long remained a mystery.

To understand the discovery enabled by the August 17, 2017, observation, we need to understand the scientific *status quo* that existed beforehand. For about 50 years, the dominant assumption among the scientific community was that the *r* process took place during the final explosion of massive stars (specialists speak of a core collapse supernova). Indeed, the formation of light elements (those up to iron) implies nuclear reactions that ensure the stability of the stars by counteracting contraction induced by gravity. For heavier elements – those from iron and beyond – it is necessary to add energy or to take very specific paths, such as the *s* and *r* processes. Researchers believed that the *r* process could occur in ejected matter from the explosion of massive stars, capturing a part of the released energy and participating to the dissemination of material in the interstellar medium.

Despite the simplicity of this explanation, numerical modelling of supernovae has proved extremely complicated. After 50 years of efforts, researchers have just begun to understand its mechanism. Most of these simulations do unfortunately not provide the physical conditions for the *r* process.

These conditions are however quite simple: you need a lot of neutrons and a really warm environment.

Fusion of neutron stars

In the last decade or so, some researchers have begun to seriously investigate an alternative scenario of the heavy-element production site. They focused their attention on neutron stars. As befits their name, they constitute a gigantic reservoir of neutrons, which are released occasionally. The strongest of these releases occurs during their merging, in a binary system, also called kilonova. There are several signatures of this phenomenon that luckily were seen on August 17: a gravitational-wave emission culminating a fraction of a second before the final fusion of the stars and a burst of highly energetic light (known as a gamma-ray burst) emitted by a jet of matter approaching the speed of light. Although these bursts have been observed regularly for several decades, it is only since 2015 that gravitational waves have been detectable on Earth thanks to the Virgo and LIGO interferometers.

August 17 will remain a major date for the scientific community. Indeed, it marks the first simultaneous detection of the arrival of gravitational waves – whose origin in the sky was fairly well identified – and a gamma-ray burst, whose origin was also fairly well localized and coincided with the first one. Gamma-ray burst emissions are focused in a narrow cone, and the astronomers' lucky break was that this one was emitted in the Earth's direction.

In the following days, telescopes continuously analysed the light from this kilonova and found confirmation of the production of elements heavier than iron. They were also able to estimate the frequency of the phenomenon and the amount of material ejected. These estimates are consistent with the average abundance of the elements observed in our galaxy.

In a single observation, the hypothesis that prevailed until now – of a *r* process occurring exclusively during supernovae – is now seriously under question and it is now certain that the *r* process also takes place in kilonovae. The respective contribution of supernovae and kilonovae for the heavy elements' nucleo-synthesis remains to be determined, and it will be done with the accumulation of datum related to the next observations. The August 17 observation alone has already allowed a great scientific advance for the global understanding of the origin of heavy elements, including gold.

A new window on the universe

A new window to the universe has just been opened, like the day that Galileo focused the first telescope on the sky. The Virgo and LIGO interferometers now make it possible to "hear" the most violent phenomena of the universe, and immense perspectives have opened up for astronomers, astrophysicists, particle physicists and nuclear physicists. This scientific achievement was only possible thanks to the fruitful collaboration between highly supportive nations, in particular the United States, Germany, France and Italy. As an example, there is only one laboratory in the world capable of reaching the required precision for the mirrors reflecting lasers, LMA in Lyon, France. New interferometers are under development in Japan and Indian, and this list will surely soon become longer given huge discoveries expected for the future.

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