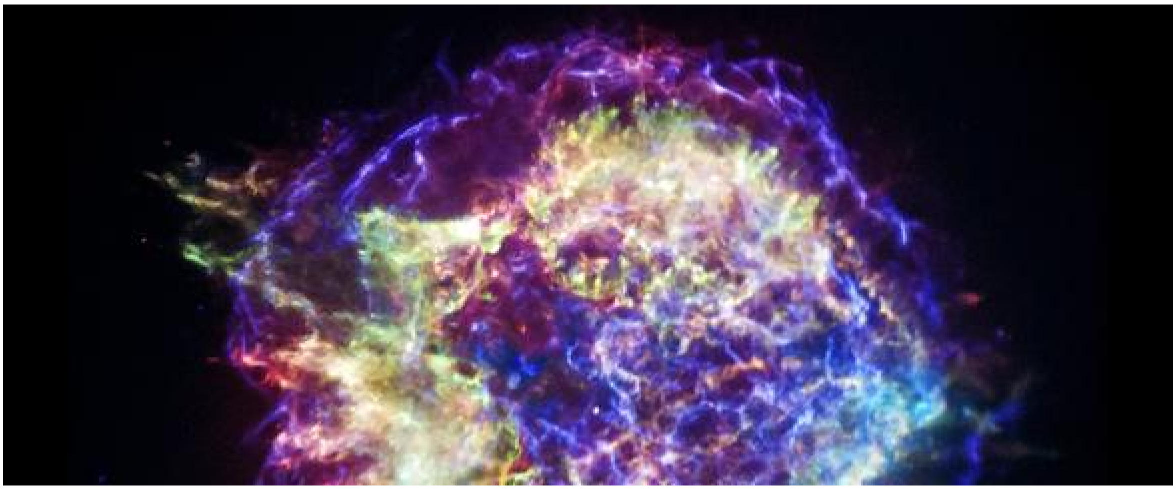
Horizon
The EU Research
& Innovation Magazine

European Commission



Giant laser recreates imploding star

An experiment performed at a UK laboratory has recreated a supernova in miniature to settle a longstanding mystery about how some of these explosions travel through space.

29 August 2014 - By JON CARTWRIGHT

Supernovas are perhaps the most dramatic events to occur in the universe, emitting – for a few days, at least – more light than an entire galaxy. They occur either when nuclear fusion reignites an old star, or when a very massive star collapses under its own gravity.

Once the initial explosion is over, a shockwave rips through the surrounding space at thousands of kilometres per second. For most supernovas this shockwave, while impressive, is fairly uniform.

But Cassiopeia A, a supernova remnant in the Cassiopeia constellation 11 000 light years away, is different. Its shockwave, which is believed to have first reached earth 300 years ago, is full of twists and knots – not to mention a peculiarly strong magnetic field.

Since astronomers first discovered these odd features of Cassiopeia A in the 1970s, they have been wondering what causes them. Now Professor Gianluca Gregori, a physicist at the University of Oxford, and his team believe they have found the answer by creating an experimental model supernova.

This is the first time that scientists have been able to recreate a turbulent form of these stellar explosions in miniature. Professor Gregori, backed by a EUR 1.1 million grant from the European Research Council as part of the COSMOLAB project, is not surprised that a laboratory experiment can demystify a phenomenon that, in its real form, is trillions of times bigger and longer-lasting. ‘The equations are the same,’ he said. ‘The time, instead of nanoseconds, is years.’

One billion megawatts

The model was created at the Vulcan laser facility at the Rutherford Appleton Laboratory in the UK. The Vulcan is one of the most powerful lasers in the world, capable of delivering one billion megawatts of light - equivalent to the output of around a million nuclear reactors - for a fraction of a second.

The researchers focused the Vulcan laser onto a very thin carbon rod – just a bit thicker than a human hair – which was inside a chamber filled with rarefied gas.

Laser beams fire at a small carbon rod inside a chamber filled with argon gas to replicate the shockwave of Cassiop

Laser beams fire at a small carbon rod inside a chamber filled with argon gas to replicate the shockwave of Cassiopeia A. Photo taken by Stephen Kill, STFC

*Laser beams fire at a small carbon rod inside a chamber filled with argon gas to replicate the shockwave of Cassiopeia A. Photo taken by Stephen Kill, STFC*The rod heated to a few million degrees Celsius before exploding and emitting a shockwave, which was captured on high-speed cameras.

The researchers thought that the shockwave might make the surrounding gas unstable. This is because one of the leading theories of Cassiopeia A says its twisted features are caused by a natural instability in the surrounding interstellar medium, which falls apart to create turbulence in the shockwave.

But the cameras did not record much turbulence in the model supernova, suggesting this theory is incorrect. Therefore, the researchers created their model supernova again, but this time they added a plastic grid around the carbon rod in order to test the other leading theory of Cassiopeia A.

This second theory says that the supernova's puzzling features are caused by dense gaseous patches in the interstellar medium, represented in the model by the crosses in the plastic grid.

As the shockwave travels it is disturbed by these dense patches – similar to when a strong tide passes over pebbles on a shore – and twists and knots form. The patches also concentrate any magnetic field lines, which would explain the presence of unusually strong magnetic fields in both the real and model supernova.

This time, the shockwave exhibited turbulence as well as a strong magnetic field – much like the real thing – which adds weight to this explanation.

'The experiment produces an excellent analogue of what is almost certainly occurring at and behind real interstellar shockwaves,' said Professor Randy Jokipii, an expert in theoretical astrophysics at the University of Arizona in Tuscon, US, who has been following the research but was not directly involved.

A model example

The supernova model is not perfect, however. The magnetic field it creates is not quite as strong in relation to the turbulence as the equations suggest it should be.

Prof. Gregori thinks this could be because the gas in the chamber is not as hot or as rarefied as the plasma that would surround a real supernova. As a result the magnetic field lines all too easily 'slip out' of the shockwave, he says. The next step, then, is to tinker with the gas until the magnetic field properties match Cassiopeia A.

After that, Prof. Gregori believes the research may help solve astrophysical mysteries beyond supernovas, such as why galaxy clusters are surrounded by strong magnetic fields. 'Nobody knows why there are fields, and why they are that strong,' he said.

Physicist Dongsu Ryu, an expert on cosmological shockwaves from the Ulsan National Institute of Science and Technology in the Republic of Korea, believes this and other recent studies have been 'beginning the era of laboratory astrophysics.'

'In the future, I hope these experiments will discover something new for theories and observations to work on and confirm,' he said. 'For this to happen, larger-scale experiments may be required.

'In any case,' he added, 'there is no doubt that the work by Professor Gregori and collaborators is pioneering, and they will continue to lead the field in laboratory astrophysics using high-power lasers.'

More info

Paper in Nature Physics

Vulcan laser facility

COSMOLAB

Gianluca Gregori