Half-life heresy

Nothing is supposed to speed up or slow down radioactive decay. So how come the sun seems to be messing with some of our elements? Stuart Clark investigates

IT WAS one of those evenings. You know the kind: after a draining day at work, all you want to do is relax in front of the television. The last thing you expect to do is make a breakthrough that could change the face of modern physics.

Yet that's exactly what happened to Jere Jenkins on 13 December 2006. After a busy day in the lab, he recalls watching the news in a "semi-catatonic" state. The story was about how astronauts had been outside the International Space Station during a solar storm and had caught a blast of X-rays.

Jenkins sat up and took notice. This could be the answer to a puzzle he had stumbled across at work. Results from one of his experiments suggested that the sun was somehow speeding up the radioactive decay of an isotope he was studying – something that was not supposed to happen. The news report gave him an idea about how to test this peculiar finding. If the sun was indeed affecting radioactive half-lives, he wondered, what would happen when a solar storm slammed straight into Earth? He pulled out his laptop, logged into the university server and checked his experiment. What he saw stunned him.

The decay rates had dropped during the storm, as if the miasma of solar radiation was shielding the isotope in some way. It was either some sort of cruel coincidence, or another piece of evidence in an increasingly weird puzzle. But that wasn't all: a more detailed analysis showed that the decay rate had begun to fall more than 24 hours before the flare was even visible.

"We are seeing things that all look tied to the sun," says Ephraim Fischbach, who works with Jenkins at Purdue University in Indiana. But for the sun to be truly responsible for the isotope's strange behaviour, a central pillar of nuclear physics would have to be toppled and perhaps even a fifth force of nature invoked.

Back in the 1930s, the nuclear pioneer and person who first split the atom, Ernest Rutherford, concluded that nothing influences the half-life of radioactive decay. Each isotope decays according to its own rules in isolation from the environment. In the decades since, Rutherford's idea has become enshrined in physics law. So, unsurprisingly, when Jenkins and Fischbach published their results showing that when Earth's mildly elliptical orbit carries our planet closer to the sun, isotopes decay faster, they were greeted not just with scepticism but with hostility.

"The criticism was blistering," says Fischbach, "even from people who knew me and knew how carefully I work. There is an overwhelming belief that we are wrong even if our critics cannot tell us why."

Yet they were not the first to notice what looked like an annual variation in radioactive decay rates. In 1986, Dave Alburger of Brookhaven National Laboratory in New York state published similar behaviour in the decay rate of silicon-32. The decay was at its fastest in February and slowest in August – exactly what Jenkins and Fischbach were seeing in manganese-54. It emboldened them to carry on despite the poor reception their paper received.

Fifth force

Knowing that the finding might be down to a glitch in their equipment, the pair also studied the results of other experiments including Alburger's and one using radium-226 at the German national metrology institute, or PTB, in Braunschweig. For the two years that these experiments overlapped, they claim that the decays changed at the same time and by the same amount. If true, this would indicate that the effect is real and not the result of equipment errors.

Such an argument does not sway Jenkins and Fischbach's arch-critic, Eric Norman at the University of California in Berkeley. "They have reanalysed other people's data to find these signatures, yet the people who know ›

ALUN COCKS

THE MESSAGE ON MESSENGER

When NASA launched the Messenger mission to Mercury on 3 August 2004, the agency had no idea it was going to be conducting a nuclear physics experiment as well. Yet that's exactly what ended up happening. Shortly after launch, the spacecraft's gamma ray and neutron spectrometer, which was intended to map the composition of the planet's surface, began to send readings back indicating that something on the craft was radioactive.

Analysis showed that it had to be a small amount of caesium-137. No one knows how this got onto the spacecraft, although it could have been in contaminated steel. As NASA tried to work around these readings, Ephraim Fischbach began analysing them. Unlike other beta decayers he has studied (see main story), caesium-137's half-life barely changes with the seasons. He wanted to see if venturing that close to the sun would change that.

Unfortunately for his theory, the effect is so small that the putative increase in the effect remains equivocal.

the most about how that data was collected are not coming out and supporting them," he says.

Indeed, since 2006 there have been a number of refutations from Norman and others. One of the most damning is from Peter Cooper at Fermilab in Batavia, Illinois. He looked to NASA's Cassini spacecraft, which is powered by a radioisotope. Cooper reasoned that since Cassini was flying 10 times further from the sun than the Earth, any solar effect would be a hundred times smaller – meaning the isotope should decay more slowly than it would on Earth. However, Cooper saw nothing out of the ordinary.

Undeterred, Jenkins and Fischbach pressed on, finding evidence of annual variations in decay rates in other isotopes. So, who is right? Perhaps they both are. According to Fischbach and Jenkins, the effect they are seeing only occurs in isotopes that undergo one of the three forms of radioactive decay: the emission of beta particles. "We haven't seen anything in alpha decays," says Jenkins. This would explain why Cooper found no signature from Cassini, which is powered by alpha decay from plutonium-238.

However, Norman sees a problem with that interpretation. Rather than simply experiencing a single decay, most radioactive materials undergo a series of transformations from one isotope or element to another. Each stage can emit alpha, beta or gamma radiation and has its own half-life. Norman points out that the radium-226 isotope used in the PTB experiment decays first by spitting out an alpha particle. As this process has a half-life of 1600 years – much longer than any of the other half-lives in the chain – he says that it should drive the chain's decay rate. If the decay of alpha particles is unaffected, as Jenkins and Fischbach suspect, then the PTB results should remain steady with the seasons.

Fischbach counters that the PTB source was 40 years old at the time of the experiment and so contained plenty of the daughter isotope radon-222, which does undergo beta decay. He believes that the changes they were seeing came from this stage of the decay process.

In order to move his ideas on, Fischbach has come up with a possible mechanism to explain the findings: a new form of nuclear reaction that emits a hypothetical particle called the neutrello and is prevalent in stars.

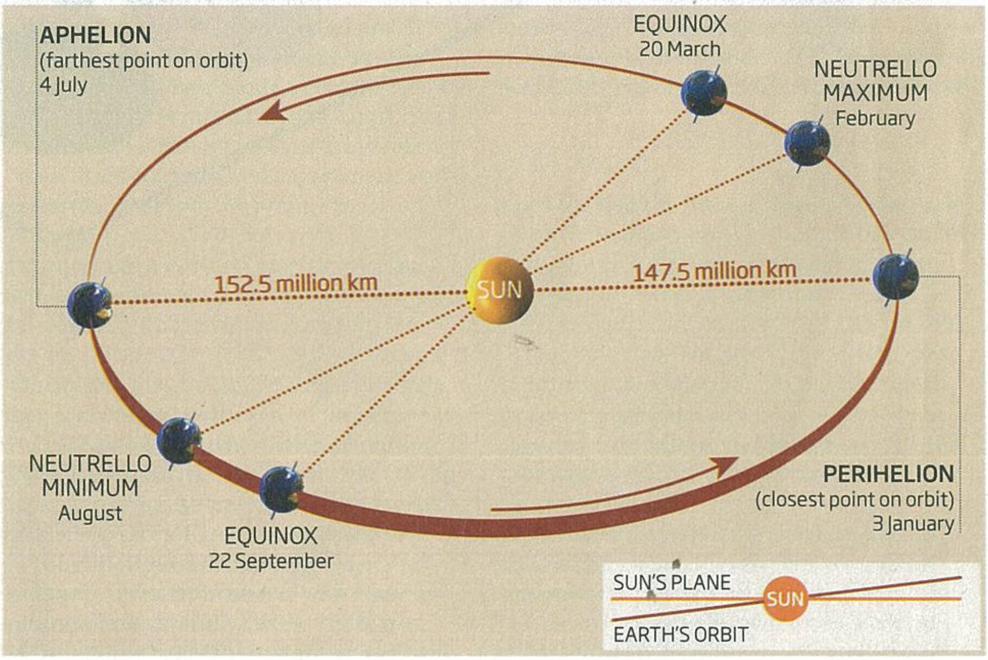
Fischbach has already started narrowing down the neutrello's properties. For them to influence his experiment, they must be able to pass through the Earth because the solar flare of 13 December 2006 took place during the night in Indiana. Similarly, a solar event on 16 December 2008, which took place on the far side of the sun, showed up in their data, meaning that the sun, too, must be transparent to neutrellos.

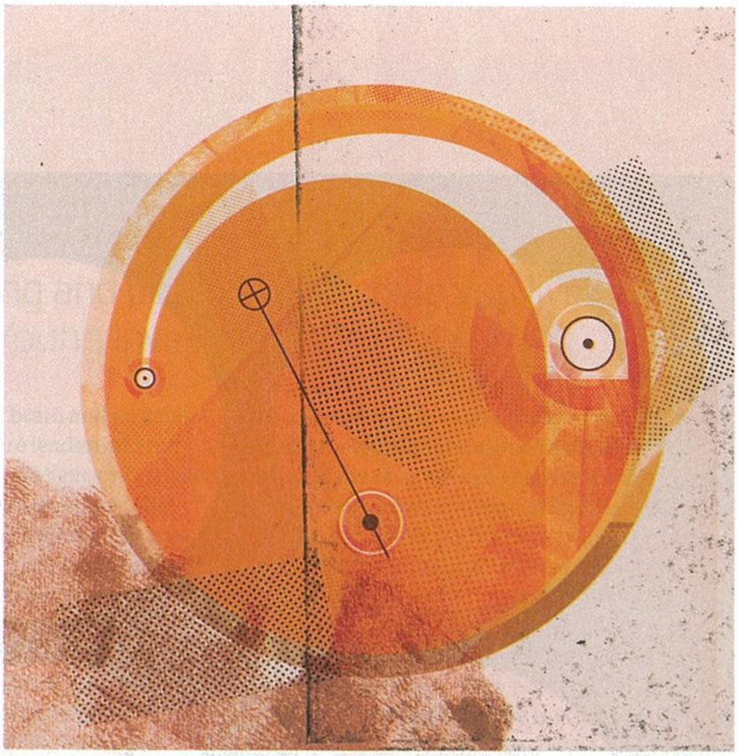
This ability isn't the only reason why, at first glance, neutrellos appear very much like neutrinos, the ghostly particles produced in nuclear reactions at the heart of the sun. Unlike light, which takes tens of thousands of years to travel from the sun's core to its surface, neutrinos fly straight out into space in vast numbers. Here on Earth, around 60 billion of them pass through every square centimetre every second. This isn't a constant: when Earth is closer to the sun in its orbit, the number of neutrinos reaching the planet goes up by a few per cent. This has been confirmed by the Super-Kamiokande neutrino detector in Japan, which catches a few dozen neutrinos every day, with a small rise seen in January, when we are closer to the sun.

It takes 50,000 tonnes of ultra-pure water for Super-Kamiokande to be sensitive enough to see this. Jenkins and Fischbach see their effect in just 10 picograms of manganese-54. And therein lies the problem: neutrellos must be interacting with radioactive nuclei much more strongly than any theory of physics says is possible, suggesting there is a fifth force of nature beyond gravity, electromagnetism and the weak and strong nuclear forces.

Seasonal nuclear decay

If the sun is producing particles called neutrellos that speed up nuclear decay, then the decay rate will be greatest in February when the Earth is both close to the sun and sees more of its northern hemisphere





So far, Fischbach has no idea how such a particle or a force would fit with the ones we know. "We understand this is crazy," says Fischbach. "But when you've eliminated all the possibles, the improbable must be true. Everything else we have tried to explain this data just doesn't work."

Another complicating factor is that the variation in radioactive decay rates isn't strictly in line with Earth's distance from the sun. Although Earth is closest to the sun in January, the decay rate is at its greatest in February. Similarly the decay rate reaches a minimum in August, a month after Earth's orbit takes the planet farthest from the sun (see diagram, page 44). Fischbach thinks this is because Earth's orbit isn't simply around the sun's middle, it is inclined by about 7 degrees. In March our planet reaches its greatest height above the solar equator, so we see more of the sun's northern hemisphere than at any other time of year. Six months later in September, we see more of the south. If more neutrellos are produced in the sun's northern hemisphere than the south, then combining this with our closest orbit in January would push Earth's peak bombardment by neutrellos into February.

This isn't such a far-fetched idea. Solar physicists are well aware of a number of asymmetries between the sun's hemispheres. In the mid-1990s, the European Space Agency's Ulysses spacecraft scanned the entire sun and found that the average speed of the solar wind was about 15 to 25 kilometres per second faster near the North Pole than the South Pole. There is also a rich literature of north-south asymmetries in solar activity. What's not yet clear, however, is whether this extends to the way neutrinos are produced. If it does, that might also suggest differences in neutrellos from the north and south.

Although neutrellos seem to interact much more strongly than neutrinos, Jenkins would dearly love to place a beta-decaying isotope in a neutrino beam, such as the one that CERN fires from Geneva in Switzerland to Gran Sasso in Italy. This would seem to be the best possible way to test whether neutrellos are a type of neutrino, or something more exotic. Raising the money to build the experiments is an uphill struggle, however. "The level of criticism against us may be lessening," says Jenkins, "but we still look like we're on the fringe."

Then there is the purported link to solar flares, which implies that whatever neutrellos are, they are linked to or possibly even trigger solar activity. This aspect of the work gained attention in June when Jenkins and his colleagues suggested that they could provide a future early-warning system for solar flares.

Daniele Fargion, a physicist at Sapienza University in Rome, Italy, has studied the production of neutrinos during solar storms. According to his calculations, such particles are produced from the decay of pion particles in the aftermath of collisions between protons and other atomic nuclei in the storm, increasing the amount of neutrinos streaming away from the sun. Yet not even Super-Kamiokande is sensitive enough to detect this increase.

"Neutrellos must interact with nuclei more strongly than any physics theory says is possible"

So how can Fischbach and Jenkins see the beginnings of an isotopic effect a day before the solar flare takes place? They also cannot explain why solar flares would dampen the decay rate. "I am very sceptical. I just cannot imagine a reasonable effect that would make this possible," says Fargion.

Just when the whole thing seems to be getting top heavy with contradictions and complications, a new twist has put everything back on the table. Jenkins and Fischbach's fiercest critic Norman has himself found a signal in the reanalysis of one of his own experiments. He is preparing to publish a paper but cautions that the signal is very weak.

That's good enough for Fischbach. He has been studying beta decay his whole career and quips: "If you think you understand beta decay, you probably don't. There are now too many loose ends that people are trying to sweep under the rug." He points out that since half-lives vary from 0.5 seconds to 10 billion years, radioactivity must be dependent on nuclear structure and so any influence on beta decay should not be felt the same way by each isotope. This may also explain why some beta decay isotopes show little or no effect (see "The message on Messenger", page 44).

Norman remains unimpressed. "I'm still very sceptical," he says. "My feeling is that this is a systematic effect with the detectors." To test this, he is running new experiments using an alpha emitter and two different beta decay isotopes. He is tight-lipped about his findings so far, saying only that he expects to publish results in early 2013.

Jenkins and Fischbach are pressing forward, too. Having secured a new source of manganese-54, they have been collecting data for the last three years. They have also set up an identical experiment at the US Air Force academy in Colorado Springs. And they can count 20 cases of variable radioactive decay rates published by half a dozen independent research groups. Even if they are just detector issues, they need to be explained.

"The joke of this is that to some we're heroes; to others we're pariahs," says Fischbach. "The truth is that we are neither. We're just doing our jobs. We have no choice but to go on." ■

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