Discovery brings autonomous interplanetary navigation closer to reality

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An accurate method for spacecraft navigation takes a leap forward today as the National Physical Laboratory (NPL) and the University of Leicester publish a paper that reveals a spacecraft's position in space in the direction of a particular pulsar can be calculated autonomously, using a small X-ray telescope on board the craft, to an accuracy of 2 km. The method uses X-rays emitted from pulsars, which can be used to work out the position of a craft in space in 3-D to an accuracy of 30 km at the distance of Neptune. Pulsars are dead stars that emit radiation in the form of X-rays and other electromagnetic waves. For a certain type of pulsar, called 'millisecond pulsars', the pulses of radiation occur with the regularity and precision of an atomic clock and could be used much like GPS in space.

The paper, published in *Experimental Astronomy*, details simulations undertaken using data, such as the pulsar positions and a craft's distance from the Sun, for a European Space Agency feasibility study of the concept. The simulations took these data and tested the concept of triangulation by pulsars with current technology (an X-ray telescope designed and developed by the University of Leicester) and position, velocity and timing analysis undertaken by NPL. This generated a list of usable pulsars and measurements of how accurately a small telescope can lock onto these pulsars and calculate a location. Although most X-ray telescopes are large and would allow higher accuracies, the team focused on technology that could be small and light enough to be developed in future as part of a practical spacecraft subsystem. The key findings are:

- At a distance of 30 astronomical units – the approximate distance of Neptune from the Earth – an accuracy of 2km or 5km can be calculated in the direction of a particular pulsar, called PSR B1937+21, by locking onto the pulsar for ten or one hours respectively
- By locking onto three pulsars, a 3-D location with an accuracy of 30km can be calculated

This technique is an improvement on the current navigation methods of the ground-based Deep Space Network (DSN) and European Space Tracking (ESTRACK) network as it:

- Can be autonomous with no need for Earth contact for months or years, if an advanced atomic clock is also on the craft. ESTRACK and DSN can only track a small number of spacecraft at a time, putting a limit on the number of deep space manoeuvres they can support for different spacecraft at any one time.
- In some scenarios, can take less time to estimate a location. ESTRACK and DSN are limited by the time delay between the craft and Earth which can be up to several hours for a mission at the outer planets and even longer outside the solar system.

Dr Setnam Shemar, Senior Research Scientist, NPL, said:

"Our capability to explore the solar system has increased hugely over the past few decades; missions like Rosetta and New Horizons are testament to this. Yet how these craft navigate will in future become a limiting factor to our ambitions. The cost of maintaining current large ground-based communications systems based on radio waves is high and they can only communicate with a small number of craft at a time. Using pulsars as location beacons in space, together with a space atomic clock, allows for autonomy and greater capability in the outer solar system. The

use of these dead stars in one form or another has the potential to become a new method for navigating in deep space and, in time, beyond the solar system."

Dr John Pye, Space Research Centre Manager, University of Leicester, concludes:

"Up until now, the concept of pulsar-based navigation has been seen just as that – a concept. This simulation uses technology in the real world and proves its capabilities for this task. Our X-ray telescope can be feasibly launched into space due to its low weight and small size; indeed, it will be part of a mission to Mercury in 2018. NPL's timing analysis capability has been developed over many years due to its long heritage in atomic clocks. We are entering a new era of space exploration as we delve deeper into our solar system, and this paper lays the foundations for a potential new technology that will get us there."

More information: Setnam Shemar et al. Towards practical autonomous deep-space navigation using X-Ray pulsar timing, *Experimental Astronomy* (2016). DOI: 10.1007/s10686-016-9496-z

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