Indian scientists find new way to measure distances in deep space

The dense and rapidly spinning remnant cores of dead stars are called pulsars. They emit beams of radio waves that sweep across the earth like light from a lighthouse sweeps across ships at sea. Pulsars have an extraordinarily fixed spinning rate, so the pulses arrive very regularly

Published - April 09, 2026 07:30 am IST

SHREEJAYA KARANTHA

The Vela pulsar wind nebula. Light blue represents X-ray polarisation data from the NASA Imaging X-ray Polarimetry Explorer. Pink and purple colours correspond to data from the NASA Chandra X-Ray observatory. | Photo Credit: NASA

Indian astronomers, including from IIT-Kanpur, have developed a new way to measure distances in the universe using the pulsating cores of dead stars, by studying how their radio emissions are distorted as they travel through space. The technique combines a pair of subtle effects that occur when pulsar signals pass through clouds of ionised gas in the Milky Way.

The dense and rapidly spinning remnant cores of dead stars are called pulsars. They emit beams of radio waves that sweep across the earth like light from a lighthouse sweeps across ships at sea. Pulsars have an extraordinarily fixed spinning rate, so the pulses arrive very regularly. So astronomers have used them as cosmic clocks.

Pulsar timing experiments use millisecond pulsars, which spin hundreds of times per second, to create precise timing models that predict the arrival of following pulses. Any difference in arrival time indicates the presence of another astrophysical event, such as those producing gravitational waves.

But as these radio waves travel through the galaxy before reaching the earth, they also pass through clouds of ionised gas, or plasma, that contain free electrons that slightly alter the radio signal.

Way of light

Astronomers measure one of these effects using a quantity called the dispersion measure (DM). As radio waves travel through the interstellar medium, free electrons slow down lower frequency waves more than higher frequency ones. This causes different frequencies to arrive at the earth at slightly different times. By measuring the delay caused by dispersion, astronomers can estimate how many electrons lie between the earth and the pulsar.

In general, signals from more distant pulsars pass through more interstellar plasma and encounter more electrons. As a result, DM provides a rough estimate of how far away the pulsar is.

Astronomers have long used DM to estimate the distance to pulsars. However, this method relies on models of electron distribution throughout the Milky Way that can be unreliable in complex regions such as the Gum Nebula, a vast region of ionised gas and one of the largest known nebulae in our galaxy. Possibly associated with a supernova explosion or ionisation by hot stars, the nebula contains the Vela Pulsar and regions that can strongly influence radio signals passing through it.

Wobbling signals

The interstellar medium also affects pulsar signals in another way. As plasma is not perfectly smooth, its irregularities scatter radio waves as they travel through it. This scattering causes the signals to follow multiple paths before reaching the earth. The scattered waves interfere with each other, causing the pulsar's brightness to vary with time.

The term for this is scintillation, similar to the twinkling of stars in the night sky. Since the signals arrive by different paths and at slightly different times, the signal appears stretched out or smeared. This effect is known as scatter broadening.

In the new study, published in the *Monthly Notices of Royal Astronomical Society*, the team combined DM with scatter broadening to refine the distance estimates. As scattering depends on how turbulent the plasma is, the electron density, and the location of the scattering region along the line of sight, the joint method revealed where the turbulent plasma is located between the earth and the pulsar much more accurately.

"Previously, we had only one 'soldier'— dispersion — to solve the problem," the study's lead author Ashish Kumar, formerly at IIT-Kanpur and now at the National Centre for Radio Astrophysics, said. "Now we have two: dispersion and scattering."

The study was carried out with co-authors Avinash Deshpande, former professor at the Raman Research Institute, and Pankaj Jain, a professor at IIT-Kanpur.

Systematic application

"The authors have done a careful job of utilising a variety of measurements on 10 pulsars to constrain the structure of the interstellar medium in this region, including the distance to the dominant scattering region [the Gum Nebula]," Cornell University professor James Cordes, who wasn't involved in the study, said.

He also said combining scattering and dispersion to estimate pulsar distances is not entirely new and has been explored in pulsar studies for decades. In this study, however, the team applied the approach in a systematic way: they used both dispersion and scattering measurements together and adjusted their model step by step until it matched both the observed DM and the scatter broadening. The distance where the model and observations agreed was then taken to be the pulsar's distance.

Their work shows that much of the scattering affecting pulsars in this direction likely comes from turbulent layers of the Gum Nebula. Using observations of 10 pulsars in the same region of the sky as Gum Nebula, researchers also developed a refined model of the nebula's electron distribution. Results showed that the Vela pulsar lies behind the nebula's front shell.

No hard limit

Scatter broadening depends on how strongly a pulsar's signal is scattered along the line of sight. Calculating this exactly requires extensive analysis. So to simplify it, researchers combined the dependencies into a single parameter, called the *k*-factor, at a given frequency.

Estimating the *k*-factor was the main technical challenge of the study, Dr. Kumar said, as it varies significantly in complex regions. However, one can determine its value for the target pulsar from a nearby pulsar at a known distance.

For the Gum Nebula, the team analysed several pulsars in the region and calculated their individual *k*-factors. Instead of adopting a single number, they used a range of possible values to account for uncertainties in the scattering properties of the plasma. The team is now working on a follow-up study of roughly 300 pulsars across our galaxy to determine how the *k*-factor varies in different directions.

Parallax-based measurements are extensively used in distance measurements. While the novel method offers several advantages over DM-only estimates, it cannot beat the "gold standards" of the parallax method in terms of accuracy, Dr. Kumar said.

However, while certain parallax techniques have a "hard limit" on distance, the new method has no specific distance limitation. It could even be used to measure distances to objects outside the Milky Way, like the enigmatic fast radio bursts.

Shreejaya Karantha is a freelance science writer.

Published – April 09, 2026 07:30 am IST