NOTA DE PRENSA

A Waltz of Millions of Years in the Milky Way: An Ultracool Subdwarf with a White Dwarf. First Age Reference

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Most stars near the Sun are made of the same balance of elements, but there exists a rare class of stars called subdwarfs which have far fewer heavy elements such as carbon and iron. The lowest temperature examples of these, which include low-mass stars and brown dwarfs, are called ultracool subdwarfs. Ultracool subdwarfs are difficult to characterise. Not only are they faint and cooling over time, their ages cannot be directly measured. An international team led by Prof. Zenghua Zhang of Nanjing University just found the first age benchmark ultracool subdwarf, VVV1256-62B, with an age of about 10.5 billion years. Dr. MariCruz Gálvez Ortiz, from the department of Astrophysics at Centro de Astrobiología (CAB), CSIC-INTA, is co-author of the research paper.

VVV1256-62B was formed in a wide binary system with a white dwarf, VVV1256-62A, located 250 light years away from the Sun. These two companions are separated by about 1400 au (1 au = 150 million kilometres is the distance between the Earth and the Sun) and orbit each other with a period of about 60,000 years. Our lifetime would be too short to see their orbital motion; instead, we see these two companions appear as a co-moving pair in images observed in different years with the Visible and Infrared Survey Telescope for Astronomy (VISTA) telescope.

VVV1256-62B was initially identified as an ultracool subdwarf due to its high angular velocity in the VISTA Variables in the Via Lactea (VVV) Infrared Astrometric Catalogue (VIRAC; Smith et al. 2018). It was subsequently confirmed as an L3 subdwarf (the spectral type sequence for stars and brown dwarfs is: OBAFGKMLTY) by Zhang et al. (2019) based on optical and near infrared spectroscopy obtained with the Very Large Telescope (VLT) of the European Southern Observatory (ESO). VVV1256-62A was not detected by VIRAC because it is too faint and in a crowded field of the Galactic plane. Luckily, both VVV1256-62A and B were bright enough to be detected in the third data release by the Gaia space observatory of the European Space Agency (ESA). In these data, the team could clearly see that these two objects are co-moving at the same distance, making it a wide binary system.

Currently, VVV1256-62AB is passing by the solar neighbourhood and is moving away from the Galactic centre with a speed of 406 km/s. The radial velocity of the system measured from VVV1256-62B is about ten times smaller than its total velocity. “This is because the current direction of the binary is close to perpendicular to the line of sight”,

explained Dr. MariCruz Gálvez-Ortiz. The system's angular velocity, is very high for objects outside of our solar system. The Gaia mission has measured distances and angular velocities of 1.5 billion stars, and only three have both a further distance and a higher angular velocity than VVV1256-62AB. The binary has an angular separation of 18 arcsec, which is smaller than the resolution of the human eye (40-60 arcsec). It will take another 16 years for the trailing white dwarf to reach the current position of its companion.

“The velocity of the binary is very high, but not high enough to escape from the Milky Way. So we are able to constrain its Galactic orbit based on its current position, distance, angular and radial velocities”, said Dr. Roberto Raddi of Universitat Politècnica de Catalunya, a co-author of the research paper. The binary has a very eccentric orbit along the Galactic plane, passing as close as 3,000 light years to the Galactic centre every 400 million years (note our Sun is about 26,700 light years from the Galactic centre). As the binary has such a high velocity, it also goes as far as 100,000 light years away from the Galactic centre at its furthest point. The Galactic orbit of VVV1256-62AB is better seen in the figure and the dancing between components can be better visualized in its orbital video: https://drive.google.com/file/d/1BBsOYtN7_yuD76mSeRa4VcJwrHyQvGRA/view?usp=drive_link .

The origin of such an eccentric orbit has yet to be clarified, but could be related to the existence of an in-situ inner halo or to a past merger of the Milky Way with a satellite galaxy.

An optical spectrum of VVV1256-62A was observed with the Gemini South telescope, one half of the International Gemini Observatory, supported in part by the U.S. National Science Foundation and operated by NSF NOIRLab. "The spectrum looks featureless, because the white dwarf is too cold to have detectable Balmer lines", said Dr. Sarah Casewell of the University of Leicester, a co-author of the research paper. VVV1256-62A has a temperature of 4440 K. The white dwarf is cooler than our Sun (5800 K), and should have a light orange colour in visible light, not white or blue like the majority of white dwarfs.

"We usually assume that ultracool subdwarfs have ages between 8-14 billion years like other stars in the Galactic halo. But that assumption was never confirmed by observation", said Prof. Zhang. VVV1256-62AB provides the first opportunity for us to determine the age of an ultracool subdwarf from its white dwarf companion, as white dwarfs are well modelled and we can have precise age constraints of them. The team determined that VVV1256-62A has a total age of 10.5 billion years. "The age of the white dwarf is composed of the main sequence lifetime (2 billion years) of its progenitor star (1.9 solar mass), and the cooling time of the white dwarf (8.5 billion years)", explained Dr. Raddi.

VVV1256-62B has a temperature of 2200-2300 K, and a sub-solar metallicity according to fitting its spectrum to atmosphere models. The team inferred the chemical

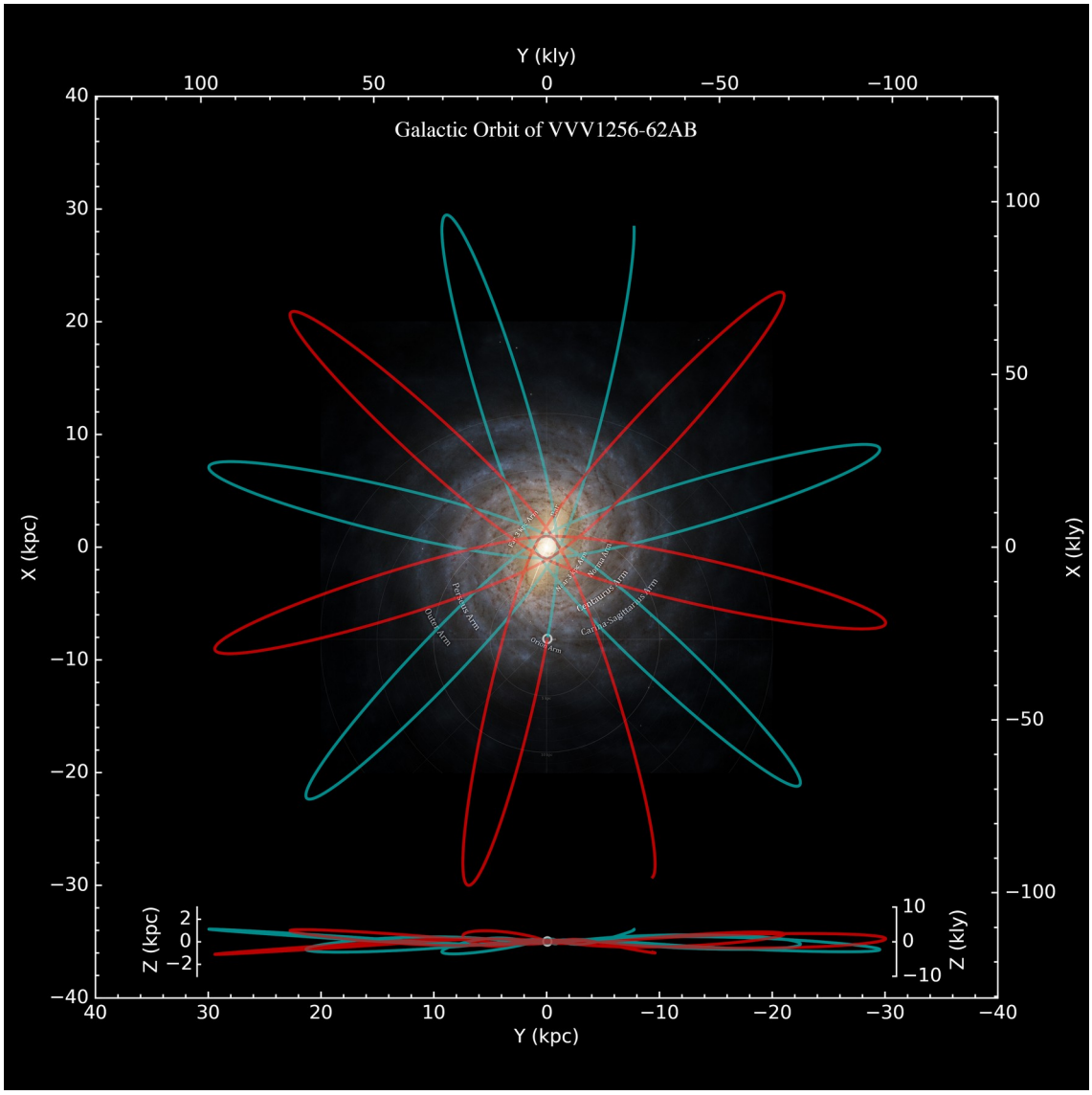
abundance of VVV1256-62B to be only 15% of an average nearby star. Thus VVV1256-62B has a more transparent atmosphere than ultracool dwarfs. VVV1256-62A is seven times more massive but seven times smaller than VVV1256-62B. Thus the white dwarf is much denser and has a much higher surface gravity (74,000 g, where g is the surface gravity of the Earth) than the ultracool subdwarf (270 g).

"VVV1256-62B is the first L dwarf age benchmark at sub-solar metallicities, and it is a very important source for characterising other ultracool subdwarfs and for calibrating atmosphere models," said Prof. Adam Burgasser of the University of California, San Diego, a co-author of the research paper. "We are looking forward to observing this object with the James Webb Space Telescope (JWST) in an upcoming approved program," Prof. Burgasser added.

The Gaia mission measures stars in optical light, and could only observe perhaps tens of L subdwarfs as these objects are very faint in optical light and emit most of their light in the near infrared. "A new astrometry space observatory that works in the near infrared, like the proposed GaiaNIR mission, would be able to observe many more ultracool subdwarfs", said Dr. Richard Smart of Osservatorio Astronomico di Torino, a co-author of the research paper.

This binary was identified by accident, during a research course for junior students at Nanjing University. Prof. Zhang said: "I was giving an instruction to three undergraduates on how to find wide binaries with the Gaia Catalogue of Nearby Stars. As a show-how, on a whim, I decided to search for white dwarf + ultracool dwarf wide binaries with very tight criteria, and found 5 pairs. VVV1256-62B is a companion on the list, which surprised me, as I had written a paper on this object in 2019 and knew it was an L subdwarf with a very special Galactic orbit."

ESA press note can be found here:
https://www.cosmos.esa.int/web/gaia/iow_20240820



VVV 1256−62AB's average orbit from the past 2 Gyr (cyan curves) to the future 2 Gyr (red curves). Its current location is near the Sun and indicated by a white circle. The background image is the spiral structure of the Milky Way based on Gaia DR3 (Credits: ESA/Gaia/DPAC, Stefan Payne-Wardenaar, CC BY-SA 4.0 IGO). The edge-on orbit view in [Y, Z] space is plotted on the same scale and shown at the bottom. Credit: Roberto Raddi, Zenghua Zhang, MNRAS. Video can be seen at: https://drive.google.com/file/d/1BBsOYtN7_yuD76mSeRa4VcJwrHyQvGRA/view?usp=drive_link

This work was recently published in the Monthly Notices of the Royal Astronomical Society (MNRAS) as the 8th paper of a series titled "Primeval very low-mass stars and brown dwarfs".
Research paper: https://ui.adsabs.harvard.edu/abs/2024arXiv240719219Z/abstract
The "Primeval" series focus on discoveries and characterization of ultracool subdwarfs, and is collected in the astrophysics data system (ADS) library:
https://ui.adsabs.harvard.edu/public-libraries/gVGomDWcQGyKPWw2CGg3dg

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