Calibrating the luminosity of nearby stars to refine calculations of universe age and expansion

September 23 2022

Astronomers use the brightness of a type of exploding star known as a supernova type IA (seen here as bright blue dot to the left of a remote spiral galaxy) to determine the age and expansion rate of the universe. New calibrations of the luminosity of nearby stars, observed by NIST researchers, could help astronomers refine their measurements. Credit: NASA, ESA, J. DePasquale (STScI), M. Kornmesser and M. Zamani (ESA/Hubble), A. Riess (STScI/JHU) and the SH0ES team, and the Digitized Sky Survey

A picture may be worth a thousand words, but for astronomers, simply recording images of stars and galaxies isn't enough. To measure the true size and absolute brightness (luminosity) of heavenly bodies, astronomers need to accurately gauge the distance to these objects. To do so, the researchers rely on "standard candles"—stars whose luminosities are so well known that they act like light bulbs of known wattage. One way to determine a star's distance from Earth is to compare how bright the star appears in the sky to its luminosity.

But even standard candles need to be calibrated. For more than a decade, scientists at the National Institute of Standards and Technology (NIST) have been working to improve the methods for calibrating standard stars. They observed two nearby bright stars, Vega and Sirius, in order to calibrate their luminosity over a range of visible-light wavelengths. The researchers are now completing their analysis and plan to release the calibration data to astronomers within the next 12 months.

The calibration data could aid astronomers who use more distant standard candles—exploded stars known as type Ia supernovas—to determine the age and expansion rate of the universe. (Comparing the brightness of remote type Ia supernovas to nearby ones led to the Nobel-prize winning discovery that the expansion of the universe is not slowing down, as expected, but is actually speeding up.)

Astronomers may be able to use the NIST calibrations of Vega and Sirius to better compare the brightness of nearby and faraway type Ia supernovas, leading to more accurate measurements of the expansion of the universe and its age.

In the ongoing NIST study, scientists observe the two nearby stars with a four-inch telescope they designed and placed atop Mount Hopkins in the desert of southern Arizona. John Woodward, Susana Deustua, and their colleagues have repeatedly observed the spectra, or colors, of light emitted by Vega (25 light-years away) and Sirius (8.6 light-years). One light-year, the distance that light travels through a vacuum is one year, is 9.46 trillion kilometers.

At the beginning and end of each observing night, the researchers tilt the telescope downwards so that they can compare the stellar spectra to that of an artificial star—a quartz lamp whose luminosity has been exactly measured and placed 100 meters from the telescope.

Before the scientists can directly make the comparisons, they must account for the effect of Earth's atmosphere, which scatters and absorbs some of the starlight before it can reach the telescope. Although light from the ground-based lamp does not travel through the full depth of the atmosphere, some of it is scattered by air during its short, horizontal journey to the telescope.

To assess how much of the ground-based light is scattered from the lamp, the NIST team measures the relative ratio of power generated by a helium-neon laser at its output and 100 m away, at the site of the lamp.

To determine how much starlight is lost to the Earth's atmosphere, the researchers record the amount of starlight reaching the telescope as it points in different directions, peering through different thicknesses of the atmosphere during the night. Changes in the amount of light recorded by the telescope as the night progresses allow astronomers to correct for the atmospheric absorption.

Once Vega and Sirius are calibrated, astronomers can use those stars as steppingstones to calibrate the light from other stars. For instance, by using the same telescope, researchers can observe a set of slightly fainter stars—call them Set 2. The luminosity of those fainter stars can then be calibrated using Vega and Sirius as reference standards.

The four-inch telescope on Mt. Hopkins in Arizona. Credit: J. Woodward/NIST

Switching to a telescope large enough to observe both the newly calibrated Set 2, and a group of even fainter stars (call them Set 3), astronomers can calibrate the light from Set 3 in terms of Set 2. Astronomers can repeat the process as needed to calibrate light from extremely remote stars. In this way, astronomers will be able to transfer the NIST calibration of Vega and Sirius to stars that lie thousands to millions of light-years away.

Next year, Deustua and Woodward will move their small telescope, now back at NIST, to the European Southern Observatory's (ESO's) Paranal Observatory in the high-altitude desert of northern Chile. With drier climate than Mt. Hopkins, the Chilean site promises more clear nights to observe Sirius and Vega and less moisture to absorb or scatter the light. The telescope will reside on a mountaintop away from ESO's Very Large Telescope, a suite of four 8.2-m telescopes and four 1.2-m telescopes, so that the light from NIST's quartz lamp won't interfere with observations of distant galaxies.

The team also plans to expand its repertoire of bright nearby stars to include Arcturus (37 light-years), Gamma Crucis (89 light-years), and Gamma Trianguli Australis (184 light-years) and to observe stars at longer, infrared wavelengths. The recently launched James Webb Space Telescope and the Roman Space Telescope, set for launch by the end of the decade, are designed to examine the universe at these wavelengths.

The NIST researchers recently received seed money to build a larger telescope which could observe and calibrate fainter, more distant stars. That would allow astronomers to transfer the NIST calibration to remote standard candles more directly. Reducing the number of stepping stones between the stars observed by NIST and the stars astronomers are studying reduces calibration errors.

Provided by National Institute of Standards and Technology