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Measuring Radial Velocities of Two Stars in Horologium I

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Abstract

In recent years, the Dark Energy Survey has discovered dozens of candidate satellite galaxies of the Milky Way. These low luminosity, dark matter dominated galaxies provide a laboratory in which we may test theories of galaxy formation and evolution in the Lambda-Cold Dark Matter (ΛCDM) model of cosmology. Here, we present the results of radial velocity calculations for two stars in Horologium I, one such satellite galaxy. High-resolution spectra were obtained with the Ultraviolet and Visual Echelle Spectrograph (UVES) on the European Southern Observatory's Very Large Telescope. Data were processed using the FLAMES-UVES Pipeline and radial velocities, along with their associated errors, were calculated with the data reduction software IRAF. The measured velocities are consistent with the mean systemic velocity of Horologium I, increasing the number of member stars of this galaxy. By studying the kinematics of stars in Milky Way satellite galaxies we may begin to probe their histories, leading to a deeper understanding of the formation of these galaxies as well as the structure of the universe.

Introduction

Since its inception, the Dark Energy Survey (DES) has observed dozens of small ultra-faint dwarf galaxies that are gravitationally bound to the Milky Way (Figure 1). These dwarf satellite galaxies are dark matter dominated—the majority of their mass consists of matter that does not give off or absorb light—and have exhausted their star-forming gas billions of years ago. Because these galaxies are so small and faint, they can only be observed with the most advanced telescopes available today.

Studying these galaxies is critical to understanding the origin and structure of the universe. The ΛCDM model predicts that galaxies like the Milky Way formed along with many associated dark matter-dominated dwarf satellites. Observing stars within these satellite galaxies provides a method to test this theory of cosmology; these stars' chemical compositions and velocities give information about the galaxy's past star formation history and dark matter content. Here, we present calculations of the velocities of two stars in a Milky Way satellite galaxy called Horologium I—an important step toward further studies of Milky Way satellites.

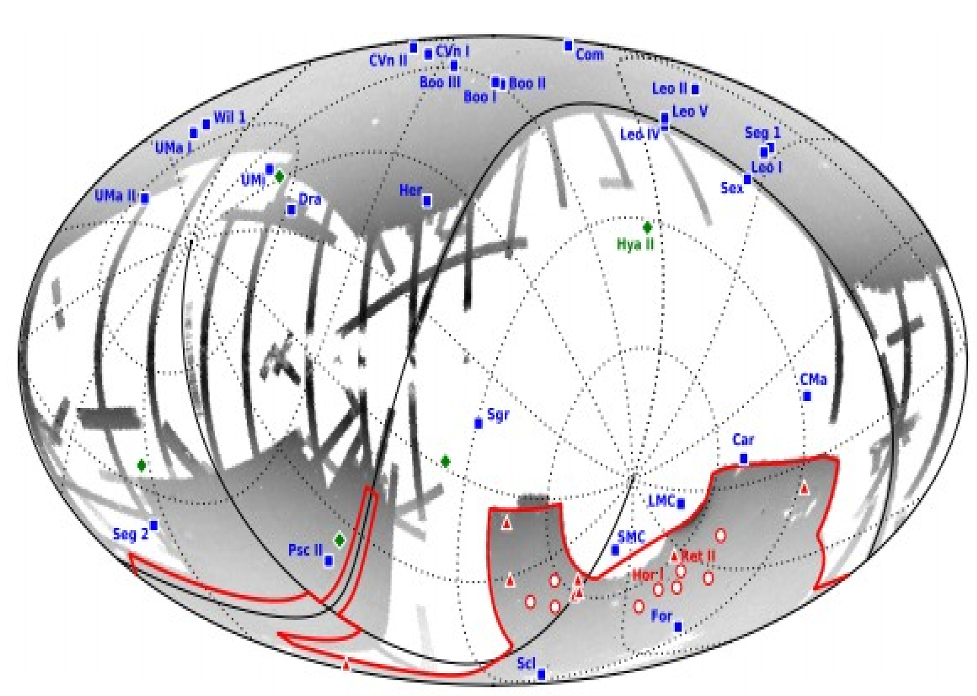

Figure 1. Locations of Milky Way satellites, including Horologium I, discovered in DES year 2 data (red circles and triangles). From Drlica-Wagner et al. (2015).

Data Analysis

Data were obtained using UVES, a spectrograph on the Very Large Telescope in Chile. Two stars in Horologium I were observed for five nights during December 2015 and January 2016. The stars are DES J025540-540807, a confirmed member of Horologium I, and DES J025543-544349, a likely member of Horologium I based on its spatial position and location on color magnitude diagrams. Data from each observation were then processed using the FLAMES-UVES Pipeline (Figure 2), which extracts spectra after bias subtraction and flat fielding. Spectra were Doppler-shifted by the Earth's heliocentric velocity using the IRAF task DOPCOR and were then cross-correlated to a standard star's spectra using FXCOR (Figure 3). This was done over the wavelength range 5100-5300 Å in order to calculate heliocentric radial velocities using the redshift of the magnesium triplet absorption lines. This gave 14 unique radial velocity measurements for each star. In order to determine the accuracy of these velocity calculations, spectra for each star were coadded and cross-correlated with the standard star's spectra to determine a coadded radial velocity. In both instances, this coadded velocity was within 1σ of the average velocity.

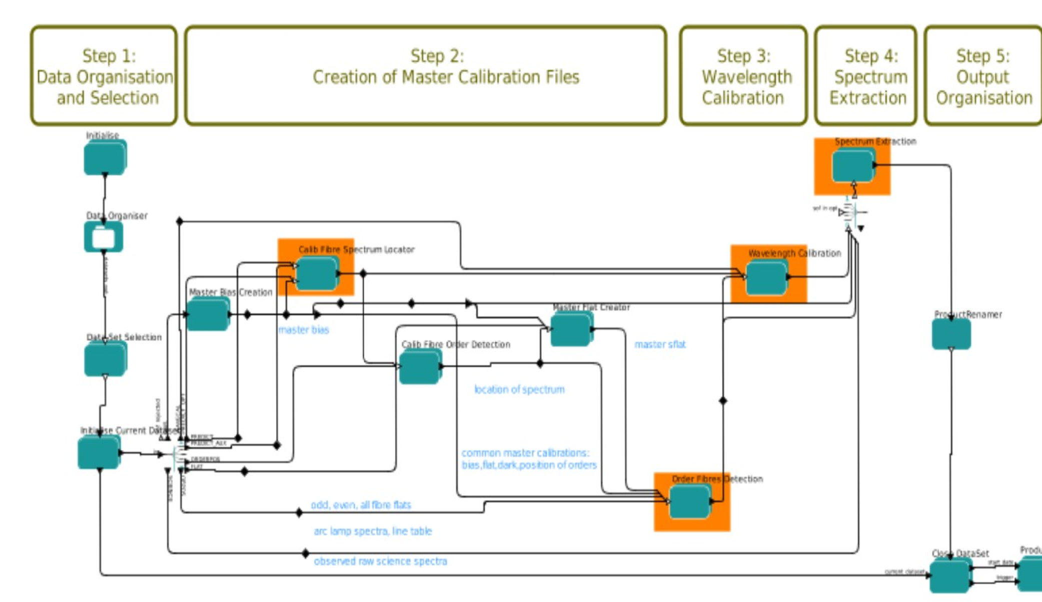

Figure 2. The FLAMES-UVES Pipeline Graphical User Interface. From Dekker et al. (2000).

Total error was calculated from a combination of statistical and systematic effects. Statistical error for each star was taken to be the standard deviation of the 14 radial velocities. Systematic error was taken to be the average of the night-to-night velocity differences. For each star, all spectra obtained on a given night were combined and cross-correlated with coadded spectra from a different night. The total error was calculated as the square root of the sum of the squares of the statistical and systematic errors.

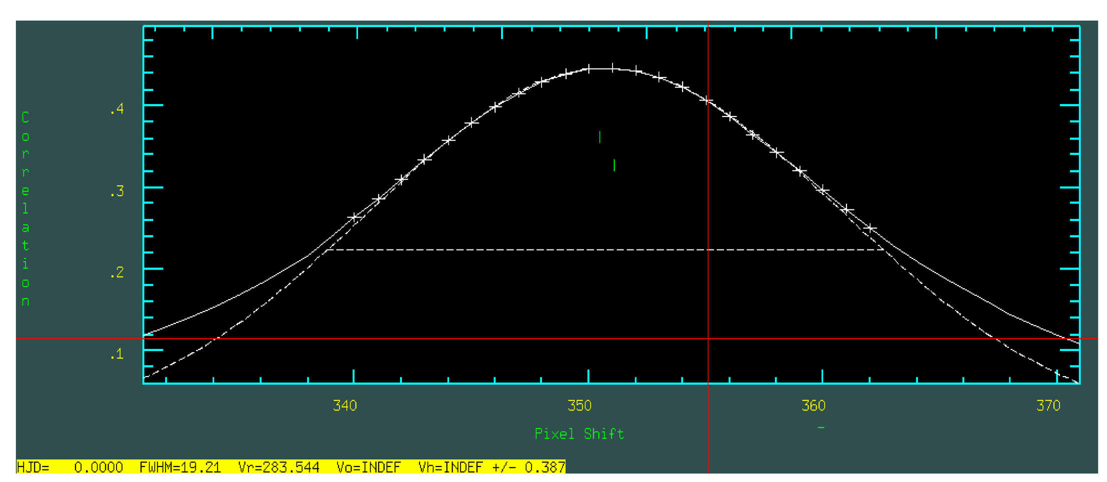

Figure 3. IRAF's GUI for the FXCOR task. The relative velocity between the observed and standard star is given by Vr.

Results

Star	Average Heliocentric Radial Velocity (km/s)	Total Error (km/s)
DES J025540-540807	118.6	± 0.73
DES J025543-544349	114.3	± 0.50

Table 1. Average heliocentric radial velocity measurements, with error, for both stars.

Table 1 shows the average heliocentric radial velocity of each star along with associated error. A zoom-in of the coadded spectra of each star focused on the magnesium triplet is shown in Figure 4, and the same wavelength range for the standard star's spectrum is shown in Figure 5.

Our reported velocity of DES J025540-540807 is in excellent agreement with previous velocity calculations of this star (Koposov et al., 2015). Furthermore, our reported velocity of DES J025543-544349 is consistent with the mean systemic velocity of Horologium I. Therefore, we conclude that this star is also a member of Horologium I. This increases the number of known stars in the galaxy from five to six.

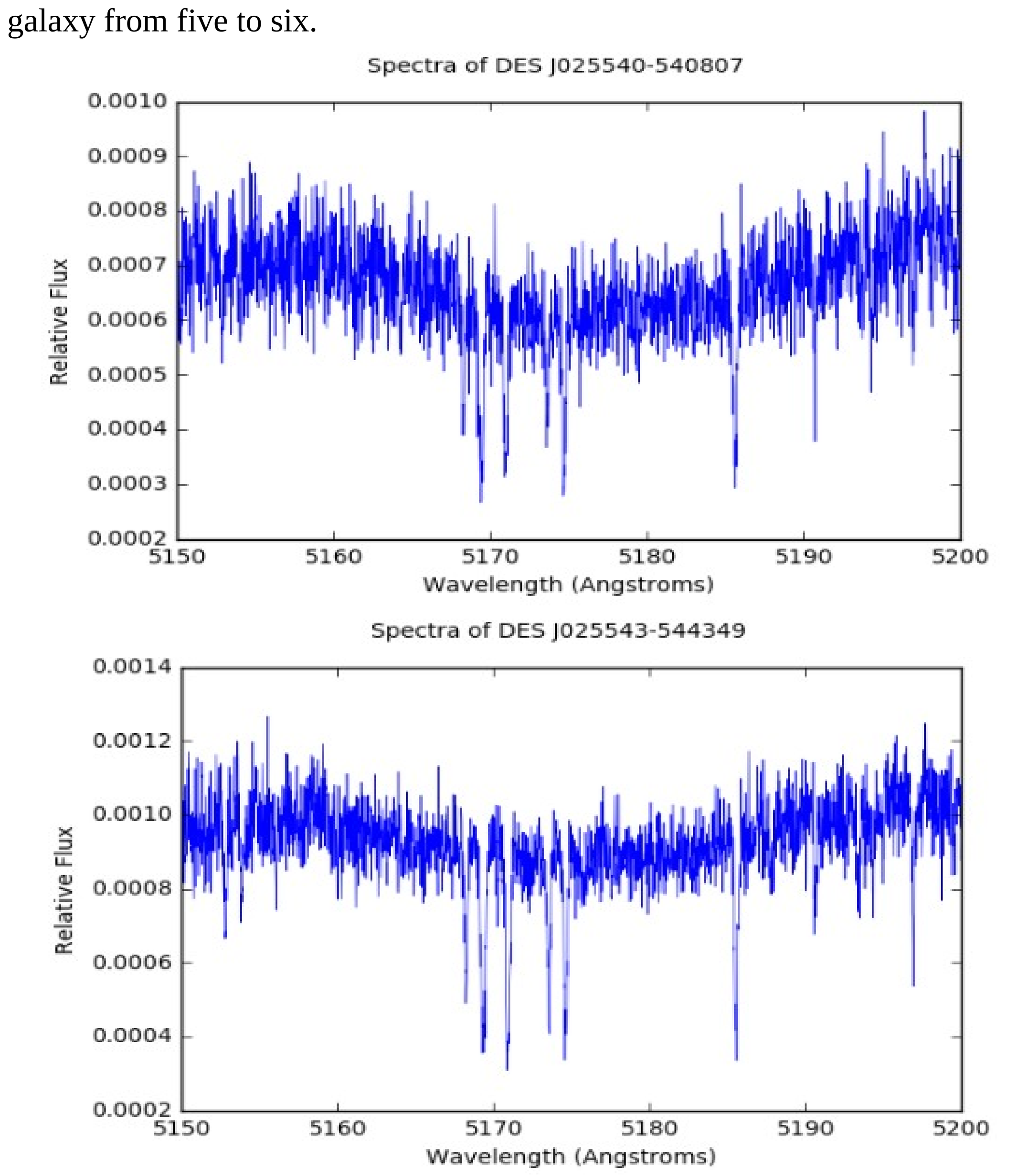

Figure 4. The magnesium triplet from the coadded spectra of DES J025540-540807 (top) and DES J025543-544349 (bottom). The strong dips in the spectra correspond to the wavelengths of light that magnesium atoms absorb.

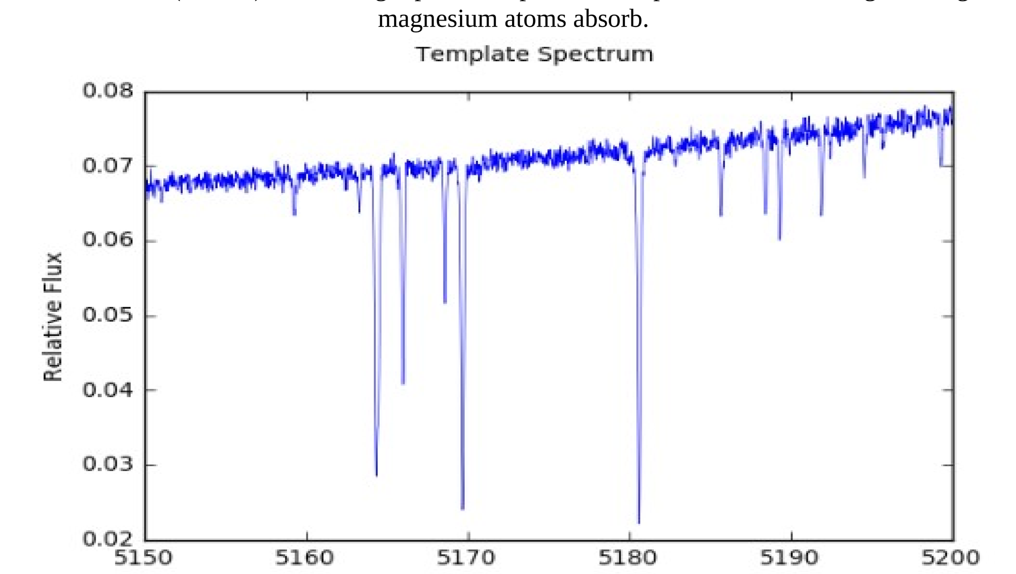

Figure 5. The magnesium triplet from the spectrum of the standard star.

Conclusions

We have calculated the radial velocities of two stars in Horologium I, a dwarf galaxy that is gravitationally bound to the Milky Way. Data taken with the Very Large Telescope were processed using the FLAMES-UVES pipeline and IRAF. We find that our velocities agree well with previous work and we conclude that DES J025543-544349 is also a member of Horologium I. Through this project we have increased the number of known stars in Milky Way satellites as well as provided important information about their kinematics. The measured velocities will be used in chemical abundance calculations to determine the chemical properties of these stars and will be published in a refereed journal article by Nagasawa et al. (in prep). In further studies, we may probe other properties of these galaxies, such as their dark matter content and star formation histories, in order to test theories of cosmology.

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