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Spectroscopic Determination of White Dwarf Candidates for the Dark Energy Survey

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Abstract

The Dark Energy Survey (DES) is a current project in Fermilab's Cosmic Frontier, which is a 5000-square-degree optical/near infrared imaging survey conducted over 5 years (2013-2018) for purposes of measuring the properties of dark energy. Synthetic photometry of pure-hydrogen-atmosphere ("DA") white dwarfs is currently the preferred technique for absolute zero point calibration of large sky surveys. For absolute calibration of the DES a "Golden Sample" of 30-100 DA white dwarfs needs to be developed. The starting point is a photometric and spectroscopic observational campaign of approximately 1000 candidate white dwarfs in the DES field. Analyzing imaging and spectroscopic data will allow us to narrow down this sample. About 37 percent of the candidates are DA white dwarfs.

Keywords: Dark energy, White Dwarf, Spectroscopy

1. Introduction

Early in the twentieth century Edwin Hubble made the discovery that the universe is expanding[1]. According to the standard model of cosmology, this expansion was initiated in the Big Bang. Until the 1990's the science community was in general agreement that the initial velocity of expansion imparted during the Big Bang has been gradually diminishing over the history of the universe due to the mutual gravitational attraction of matter within the universe. But in 1998 scientists discovered that the universe was not only expanding but this expansion was accelerating[2,3]. Our understanding of physics requires that there has to be some source that is responsible for this acceleration but there is no visible or explainable reason. This is what is now called "dark energy".

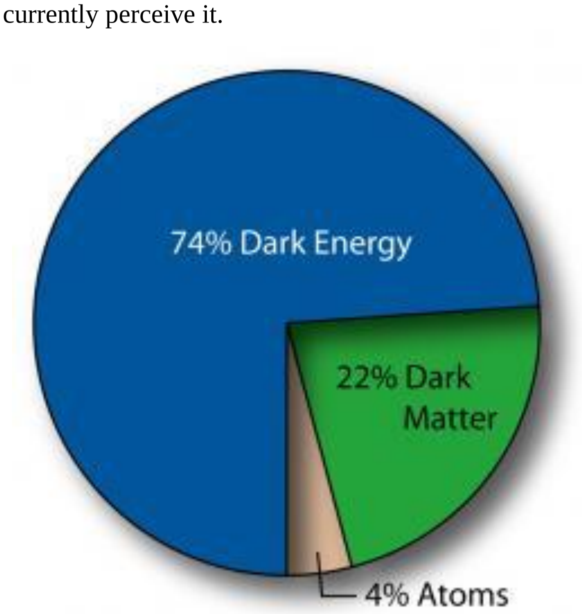
2. Background

2.1. History Of Dark Energy

When modifying his equations for the General Theory of Relativity, Albert Einstein introduced what he called the cosmological constant L. Einstein believed the universe was static, which means that the universe is not moving, changing shape or size but is standing still. This constant was introduced into the equations to balance the attractive force of gravity against any (then unknown) repulsive forces or velocities that might be driving the universe to expand. Shortly after these modifications Edwin Hubble discovered that the universe was not static but indeed expanding. This led to Einstein abandoning his idea of the cosmological constant, which he later said was "the biggest blunder of my career"[4]. For the remainder of the twentieth century most scientists believed the universe was expanding at a decreasing rate until the late 1990's when two independent teams discovered that the expansion of the universe is accelerating. These teams were awarded the Noble Prize in physics in 2012.

2.2. The Standard Model Of Cosmology

After the discovery that the expansion of the universe was indeed accelerating led to what we now call the Standard Model of Cosmology. The model states that most of universe is composed of things we cannot directly observe like dark energy and dark matter. Although we haven't observed these things via electromagnetic radiation we can see their effects on normal (baryonic) matter by gravitational interaction. Figure 1 shows the ratios of everything that composes the universe, as we currently perceive it.



1. Figure 1. The composition of the universe according to the standard model of cosmology.
(Credit: http://phys.org/news195720060.html)

2.3. The Dark Energy Survey

The Dark Energy Survey (DES) involves more than 120 collaborating scientists from 23 different organizations who have bound together to survey a large portion of the sky in the southern hemisphere using state-of-the-art-equipment. The DES will cover a 5000 square degree area of the sky over 525 nights using the Dark Energy Camera (DECam) which is mounted on the 4-meter Blanco Telescope at the Cerro Tololo Inter-American Observatory (CTIO) in the Andes of Chile[5,6]. The DES will survey objects to a magnitude of 24, and a red shift of 1.5 using DECam[7]. DECam is a 570 mega-pixel CCD-based research camera built at Fermilab, composed of 74 different CCDs, and has a focalplane-area of 3.1 square degrees[7]. The DES will observe over 300 million galaxies in 5 different filters (grizY) to obtain as much information about the galaxies as possible to hopefully explain some of the properties of dark matter.

2.4. Dark Energy Probes

The DES science teams will use four probing methods to constrain the parameters of the dark energy equation-of-state. These four probes are[5]:

- Type Ia Supernovae (SN)
- Baryon Acoustic Oscillations (BAO)
- Galaxy Clusters (GC)
- Weak Gravitational Lensing (WL)

These four techniques are complementary in that information they provide will better explain the cosmic expansion. The first two (SN and BAO) constrain the expansion of the universe as a whole and are referred to as completely geometric. The last two (GC and WL) better explain the expansion and the growth of large-scale structures within the universe.

2.4. Photometric Standard Stars, White Dwarfs, And The DES

Using standards to explain physical phenomenon are important for calibration in any experiment but are more challenging for objects in space. The best method for setting a baseline in astronomy is what is called a photometric standard star. A photometric standard star is a star, which has had its magnitude (brightness) measured carefully through different filters. In other words, the apparent magnitude of the star can be repeated experimentally and shows the star is stable. The tool of choice for calibration of large astronomical surveys is synthetic photometry of white dwarfs developed using the observational data. A white dwarf is the degenerate core of main sequence star that is approximately eight solar masses or less that has shed it's outer layers during the later periods of evolution. Our current understanding of process leads us to believe that approximately 97 percent of stars will become white dwarfs. White dwarfs are also very dense and can be compared to taking all the mass of the sun and shrinking it down to the size of Earth. Just as stars are classified using the Morgan-Keenan system, white dwarfs have their own classification and spectral characteristics. The white dwarf that we are interested in for absolute calibration have pure hydrogen atmosphere and are classified as “DA”. This classification of white dwarfs accounts for approximately 75 percent of all white dwarfs in the universe and have temperatures ranging from 6000K to 80000K[8]. A way to easily identify DA white dwarfs is through spectroscopic reductions because of the broadened Balmer absorption lines observed in the spectrum. We use these standard stars by comparing the flux of the standard to other objects in the survey and thereby derive brightness for the science targets. For the absolute calibrations of the DES it is important to have a "Golden Sample" of DA white dwarfs, which will be the calibration standards of the project. Development of the "Golden Sample" is accomplished through spectroscopic identification of the candidate white dwarfs and analysis of the spectrum to derive the surface gravity, effective temperature, and atmospheric compositions of each star. My project to support this effort is to obtain basic one-dimensional spectra of these white dwarf candidates which have been wavelength and flux calibrated.

3. Observations

All of the data presented were collected at the Cerro Tololo Inter-American Observatory (CTIO) using the 1.5-m telescope with a RC spectrograph in the Chilean Andes and Apache Point Observatory (APO) with the 3.5-m ARC telescope with a Dual-Imaging Spectrograph (DIS) in New Mexico. The RC spectrograph has a slit width of 110 microns with a 26/Ia grating that covers 1725 Å and has 4.3-Å/pix resolution. The DIS spectrograph uses a red and blue CCD to get a larger range of visible wavelengths. The blue CCD uses the B400 grating which covers 3600 Å with 1.83-Å/pix resolution. The red CCD uses the R300 grating which covers 4620 Å with 2.31-Å/pix resolution. Both the red and blue CCD's use the 2.0 arc second slit.

4. Methods

Both sets of spectroscopic data were reduced using the packages from the Image Reduction and Analysis Facility (IRAF) software. IRAF is general-purpose software that is used for the reduction and analysis of scientific data written and supported by the IRAF programming group at the National Optical Astronomy Observatories (NOAO) in Tucson, AZ. IRAF has many practical purposes that span from analyzing Hubble Space Telescope, X-ray, EUV, photometric, and spectroscopic data. Most of the reduction procedures were pulled from the *onedspec* and *longslit* packages in IRAF.

5. Results

Using the methods described above a list of all the white dwarf candidates observed and reduced are listed below. This is broken up into the night the objects were observed, which instrument was used, the number of candidates, and how many candidates are DA white dwarfs. Examples of spectra obtained and processed during this project are shown in Figures 1 and 2. In a future step, the spectra will be fitted to models of white dwarf atmospheres, and these fits will yield the 2 parameters that fully describe a DA white dwarf atmosphere: the effective surface temperature and surface gravity. The results of these fits and their quality will then allow the DES team to determine whether or not these candidate white dwarfs are worthy of being included in the "Golden Sample". The fits will also be used to extract the synthetic colors and magnitudes as well.

Table 1. A list of the date the candidates were observed, the instrument used, the number of candidates and the number of confirmed DA's.

Date-Obs	Instrument	Candidates	Confirmed DA's
01/04/2013	CTIO 1.5 meter	5	1
01/10/2013	CTIO 1.5 meter	6	0
01/22/2013	CTIO 1.5 meter	2	1
02/03/2013	CTIO 1.5 meter	1	1
02/11/2013	CTIO 1.5 meter	4	1
02/17/2013	CTIO 1.5 meter	4	2
02/20/2013	CTIO 1.5 meter	2	2

Table 2. A list of the date the candidates were observed, the instrument used, the number of candidates and the number of confirmed DA's.

Date-Obs	Instrument	Candidates	Confirmed DA's
01/03/2013	APO 3.5 meter	6	0
12/09/2013	APO 3.5 meter	7	2
12/15/2013	APO 3.5 meter	9	6
01/10/2014	APO 3.5 meter	12	4
01/13/2014	APO 3.5 meter	12	6

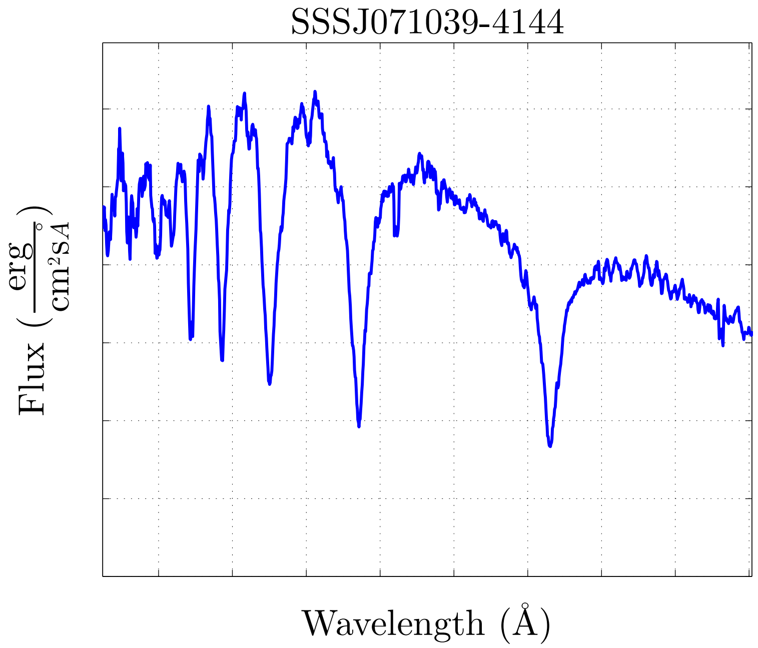


Figure 2. A flux and wavelength calibrated white dwarf spectrum from the 1.5-meter telescope at Cerro Tololo Inter-American Observatory. Note the broad hydrogen Balmer absorption features.

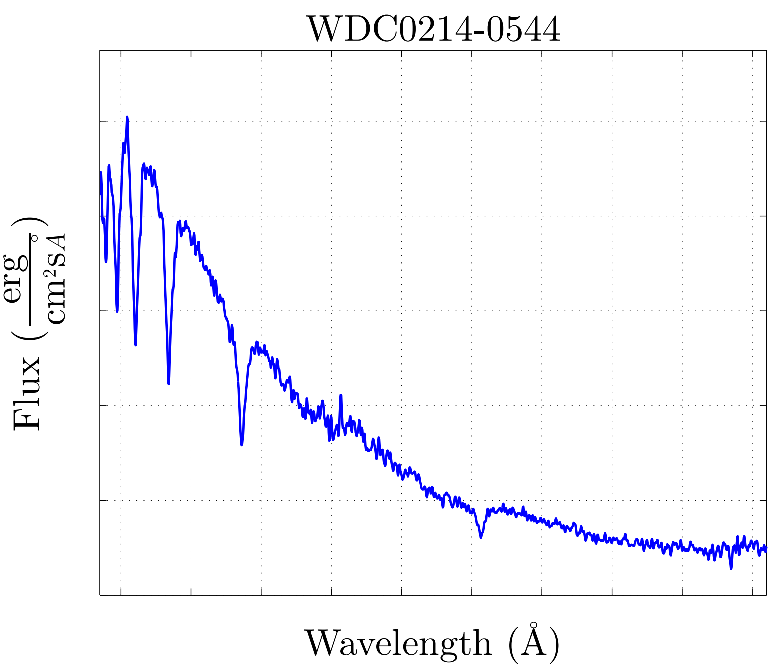


Figure 3. A flux and wavelength calibrated white dwarf spectrum from the 3.5-meter telescope at Apache Point Observatory. Note the broad hydrogen Balmer absorption features.

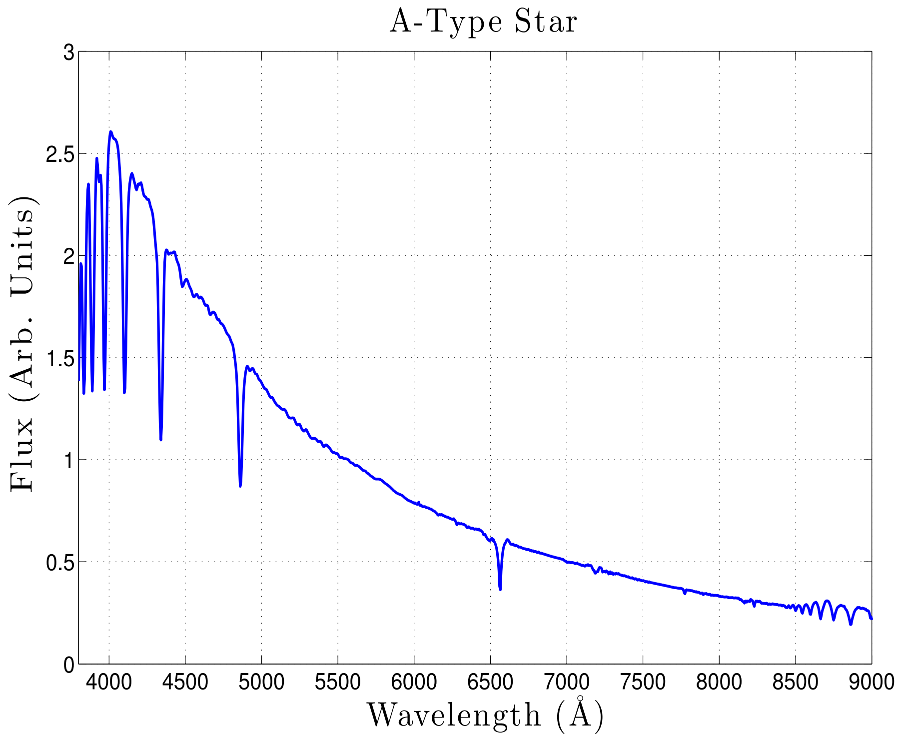


Figure 4. A flux and wavelength calibrated spectrum of a main sequence A-type star from the Pickles Spectral Atlas[9]. Note the Balmer lines are present but they are narrower than the lines in Figures 2 and 3.

6. Conclusions

In summary, using the spectroscopic reduction packages in IRAF makes it possible to obtain spectra to classify possible white dwarf candidates for the DES. The total number of candidates so far is 70 with the CTIO dataset having 33 percent of the candidates being DA white dwarfs and the APO dataset having 39 percent of the candidates being DA white dwarfs. Knowing the classifications of these white dwarf candidates allows for further follow up observations to determine whether these candidates are worthy of being included into the "Golden Sample" and which can be rejected from the sample but now have a stellar classification. The contribution of these spectra is another step forward in the absolute calibrations for the DES.

7. Acknowledgements

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