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TECHNICAL REPORT

Low cost equipment for astronomical spectroscopy

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Abstract: The purpose of this paper is to show how we can obtain spectra for different astronomical objects using low coat equipment. Where a high-efficiency diffraction grating named "The Star Analyzer" was used by the International Astronomical Center (IAC) in Abu Dhabi, UAE to get the spectrum of different astronomical objects. Balmer series was readily visible when observing an "A" type star. TiO absorptions lines were distinguished by observing an "M" type star. Methane absorption lines were visible by observing Uranus and Neptune. Whereas HI and HeI emission lines were detected by observing a blue hypergiant. In addition, C2 Swan band absorption lines were identified by observing a red giant carbon star. This type of observation is very interesting for public outreach as well as university students, because it shows astrophysical principles for public and students practically and by using low cost equipment.

Keywords: Image processing; Imaging spectroscopy

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2021 JINST 16 T12009

Contents

1 Introduction **1**

2 Equipment for spectroscopy **1**
2.1 Alayzer 1
2.2 Camera 2
2.3 Telescope 3
2.4 Software 3

3 Emission and absorption lines **4**

4 Observation results **4**
4.1 Star of spectral class A 4
4.2 Star of spectral class M 6
4.3 Blue hypergiant star 7
4.4 Red giant carbon star 7
4.5 Planet Uranus 9

5 Conclusion **9**

1 Introduction

Spectroscopic observations transform the light from an astronomical source into its components, so that we may observe the intensity of the source as a function of wavelength. This is achieved via different methods.

One of these methods is using a prism, which splits light into its various wavelengths, because the index of refraction of the glass of the prism has a wavelength dependence. Another method is to split light into its components by interference. Diffraction gratings are collections of many slits that act to disperse the light, and therefore are used frequently in astronomical spectrographs.

Looking at the spectrum, absorption lines are usually seen as dark lines, or lines of reduced intensity, on a continuous spectrum. This is seen in the spectra of stars, where gas in the outer layers of the star absorbs some of the light from the underlying thermal blackbody spectrum. On the other hand emission lines might appear on the stellar spectrum as bright lines.

2 Equipment for spectroscopy

2.1 Alayzer

The devise used to get the spectrum is "The Star Analyzer 100" from Field Tested Systems, which is a high-efficiency 100 lines/mm transmission diffraction grating. It is mounted in a standard 1.25-inch diameter threaded cell, and it was designed to produce low-resolution spectrum images of a wide range of pin-point astronomical objects. This is an inexpensive analyzer, which costs less than 200 USD!

2021 JINST 16 T12009

2.2 Camera

As for the camera, two low-mid cost cameras were used, which are: ZWO ASI224MC color camera, and ZWO ASI174mm monochrome camera. Both are recommended for general spectroscopy observations since the sensor used in both is known for its linear response and great signal to noise ratio. In other words, these cameras give extreme accuracy and precision when measuring the spectra of the stars.

Color camera might be better for public outreach or teaching, as live video preview of the spectrum is the more interesting and intuitive rainbow rather than just black. However, Mono camera produces smoother and more detailed spectra and it is more sensitive. Also, it does not show the confusing dips produced by the overlap of the response of the three R G B color filters. Figure 1 and figure 2 show the quantum efficiency of the colored camera ZWO ASI224MC and the mono camera ZWO ASI174mm, respectively.

The specifications of ZWO ASI224MC Camera:

- Sensor: 1/3″ CMOS IMX224
- Resolution: 1.2 Mega Pixels 1304×976
- Pixel Size: 3.75 µm
- Sensor Size: 4.8 mm × 3.6 mm
- Protect window: AR coated window
- Bit rate: 12bit output (12bit ADC)

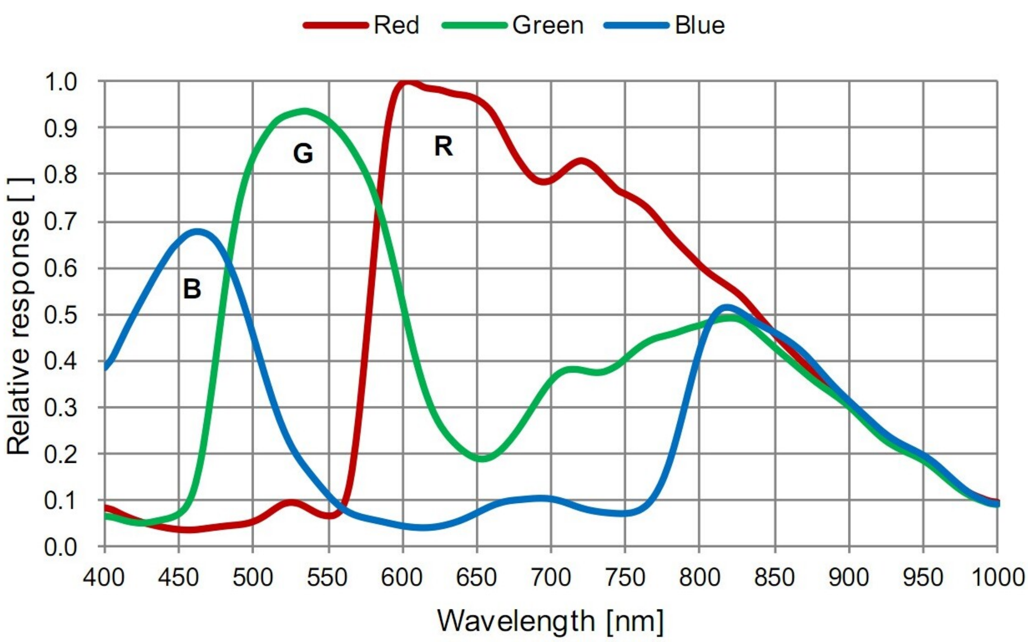

Figure 1. Relative QE Curves for the camera ZWO ASI224MC.

The specifications of ZWO ASI174MM-Cooled Camera:

- Sensor: 1/1.2″ CMOS IMX174
- Resolution: 2.3Mega Pixels 1936 × 1216
- Pixel Size: 5.86 µm
- Sensor Size: 11.3 mm × 7.1 mm
- Protect window: AR coated window
- Bit rate: 12bit output(12bit ADC)

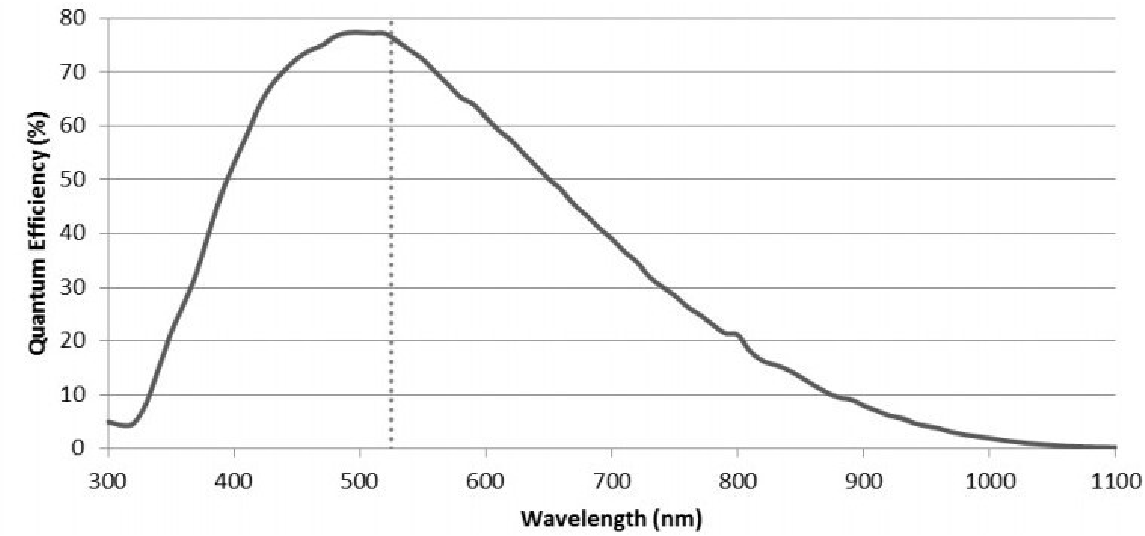

Figure 2. Quantum efficiency curve for the camera ZWO ASI174MM.

2.3 Telescope

The telescope used for spectrometry is Explore Scientific carbon fiber apochromatic refractor telescope, with the following specifications:

- Model: FCD100 Series, Triplet ED APO.
- Diameter: 127 mm.
- Focal Length: 952 mm
- Focal Ratio: $f/7.5$

2.4 Software

The software used to analyze the photos and videos is RSpec software, which is easy to use and it provides professional results. It has excellent documentations and videos to explain each required step. Also, its support is extremely fast and helpful.

2021 JINST 16 T12009

3 Emission and absorption lines

Stellar blackbody spectra have a characteristic shape, with a steep rise, a peak in or near to the visual passband, and a slow decrease in the infrared. Hotter stars have higher peak amplitudes, and peak at shorter wavelengths.

Absorption lines are usually seen as dark lines on a continuous spectrum. This is seen in the spectra of stars, where cooler gas in the outer layers of the star absorbs some of the light from the underlying thermal blackbody spectrum.

The lines seen in a star's spectrum act like thermometers. Some compounds, like titanium oxide, appear in the spectra of very cool stars. Others, like helium, appear in the spectra of very hot stars.

If the stellar atmosphere gives off more light than it absorbs, the spectrum will have a peak instead of a valley. These peaks are called "emission lines". They are usually seen as bright lines on a continuous spectrum.

4 Observation results

In order to obtain spectra with different lines, stars with different spectral classes and different luminosity classes were observed, as well as some planets. Below are the details of the observed objects.

4.1 Star of spectral class A

- Name: Vega, Alpha Lyrae, HIP 91262, HD 172167.
- Constellation: Lyra.
- Spectral Class: A0 [4].
- Luminosity Class: V (Main Sequence).
- Surface Gravity (log g): 4.1 [1].
- Magnitude (Mv): +0.026 [3].
- Effective Temperature: 9602 K [2].
- Distance: 25 Ly.
- Mass: 2.1 $M_\odot$
- Radius: 2.4 $R_\odot$
- Luminosity: 40.1 $L_\odot$ [9].

In low-resolution spectrometry, the dominant lines for stars of spectral class A are Balmer series lines, which are absorptions lines because of Hydrogen atom excitation for its electron from the 2$^{\text{nd}}$ orbit to higher orbits. Below are the results of the observations, knowing that the blue lines are predefined lines by the software, and the match of troughs with these lines shows how accurate are these results using such low cost equipment. The below graphs are calibrated but not corrected for the camera response. Figure 3 and figure 4 show Vega spectrum using colored and mono cameras, respectively.

2021 JINST 16 T12009

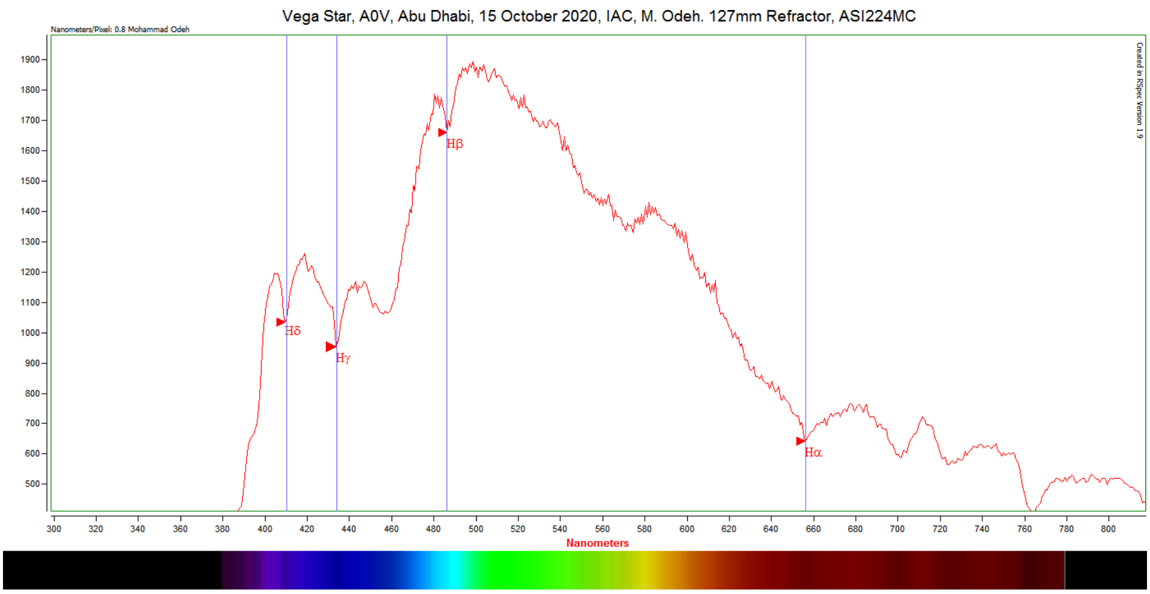

Figure 3. Vega spectrum using color camera, showing Balmer lines: Hydrogen Alpha, Beta, Gamma and Delta.

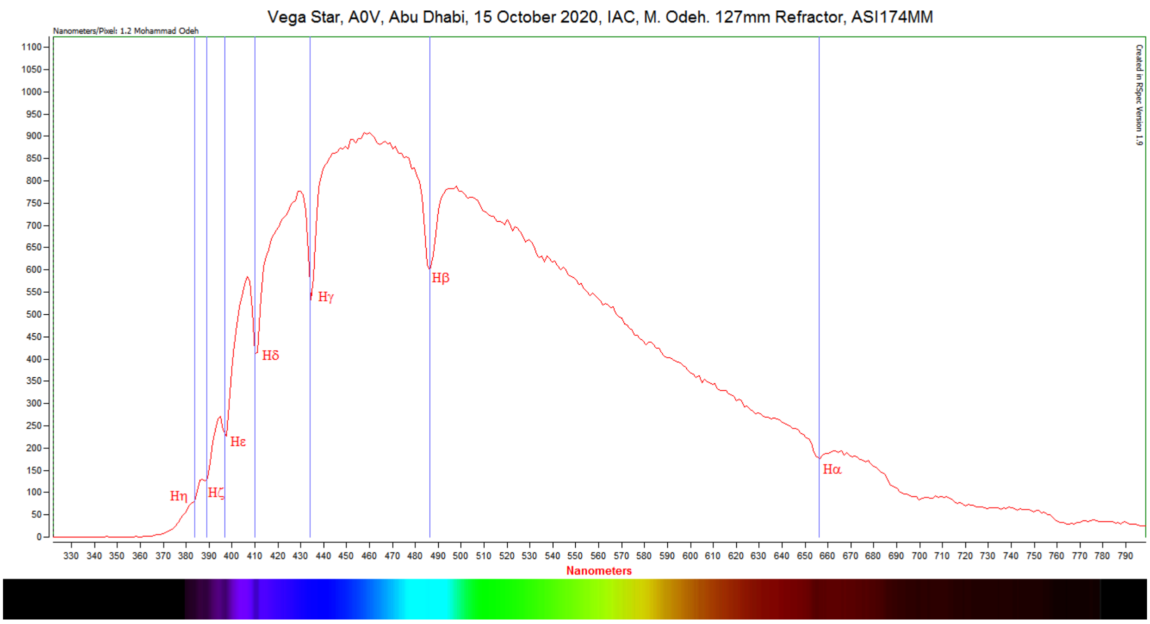

Figure 4. Vega spectrum using mono camera, showing Balmer lines: Hydrogen Alpha, Beta, Gamma, Delta, Eta, Zeta.

It is very interesting to see the match between the pre-defined blue lines with the troughs of the curve obtained by such low cost equipment. Also, it is clear that the curve of the mono camera is smoother and more accurate.

4.2 Star of spectral class M

- Name: Scheat, Beta Pegasi, HIP 113881, HD 217906.
- Constellation: Pegasus.
- Spectral Class: M2.5
- Luminosity Class: II-III (Variable Red Giant).
- Surface Gravity (log g): 1.2
- Magnitude (Mv):+2.42
- Effective Temperature: 3689 K.
- Distance: 196 Ly.
- Mass: 2.1 $M_\odot$
- Radius: 95 $R_\odot$
- Luminosity: 1500 $L_\odot$

Stars of spectral class M have strong molecular absorption bands of Titanium Oxide (TiO) and the Hydrogen lines disappear, as shown in figure 5.

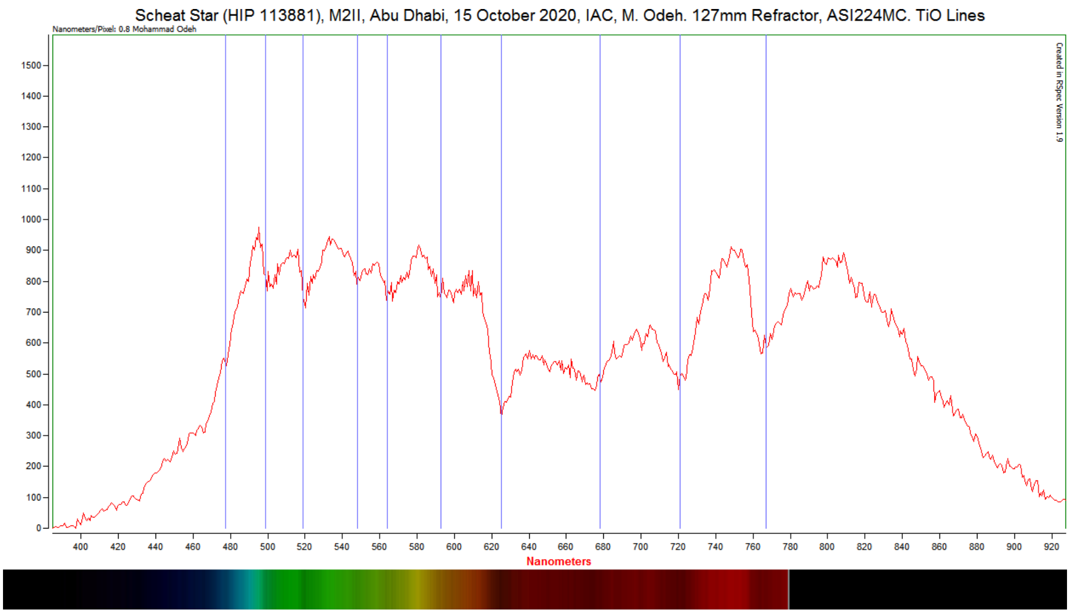

Figure 5. Scheat spectrum using color camera, showing TiO bands.

2021 JINST 16 T12009

4.3 Blue hypergiant star

- Name: P Cygni, HIP 100044, HD 193237.
- Constellation: Cygnus.
- Spectral Class: B1
- Luminosity Class: Ia+ (Hypergiant) [8].
- Surface Gravity (log g): 2.25
- Magnitude (Mv): +4.76
- Effective Temperature: 18700 K.
- Distance: 6272 Ly.
- Mass: 37 $M_\odot$
- Radius: 76 $R_\odot$
- Luminosity: 610,00 $L_\odot$ [7].

P Cygni is one of the most luminous stars in the Milky Way, it is a blue hypergiant star, and it is the prototype of an extremely rare group of stars called "luminous blue variables." They are massive stars with high mass outflow. Eruptions of luminous blue variables are accompanied by the ejections of vast amounts of matter. The star is surrounded by a faint nebula that has been created over the past 900 years by the current eruptive mass loss, and by faint shells. P Cygni stars lines show a profile type called "P Cyg", which is an emission component to the red side of an absorption line. The graph shown in figure 6 is from our observation for this star shows Helium and Hydrogen emission lines, which arise from the dense stellar wind near the star.

4.4 Red giant carbon star

- Name: V460 Cyg, HIP 107129, HD 206570.
- Constellation: Cygnus.
- Spectral Class: C6.3-N5 (Carbon Star) [7].
- Magnitude (Mv): +5.84 [7].
- Effective Temperature: 3400 K [2].
- Distance: 2038 Ly.
- Mass: 1.0 $M_\odot$ [2].
- Luminosity: 5200 $L_\odot$ [2].

2021 JINST 16 T12009

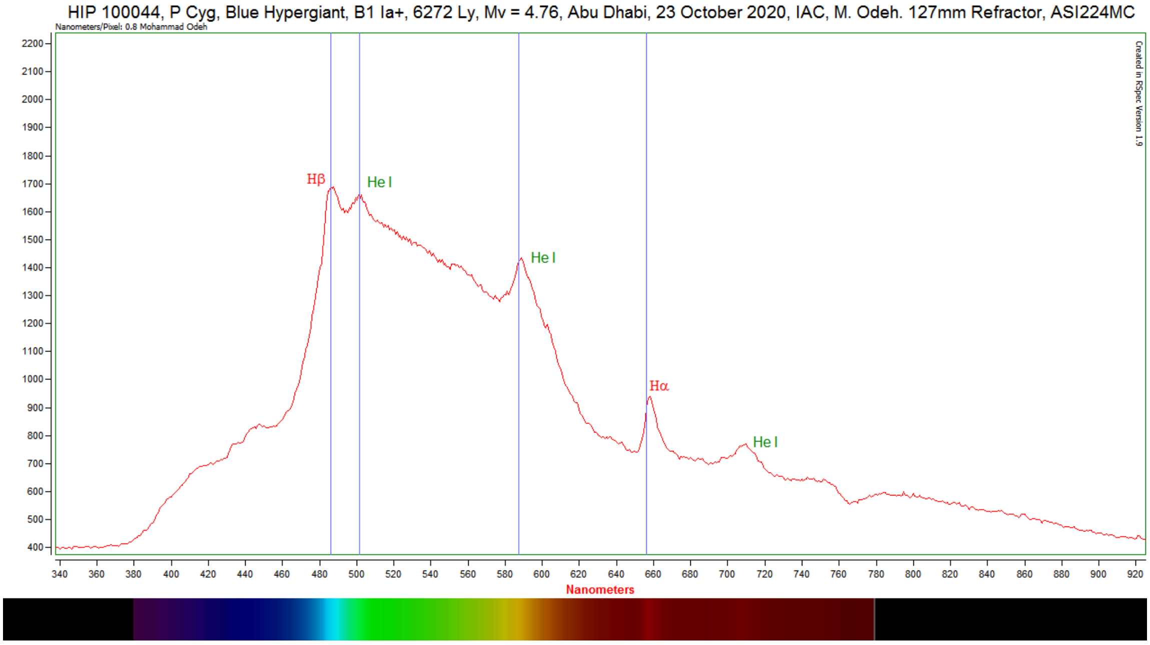

Figure 6. P Cygni spectrum using color camera, showing the emission lines of Helium and Hydrogen.

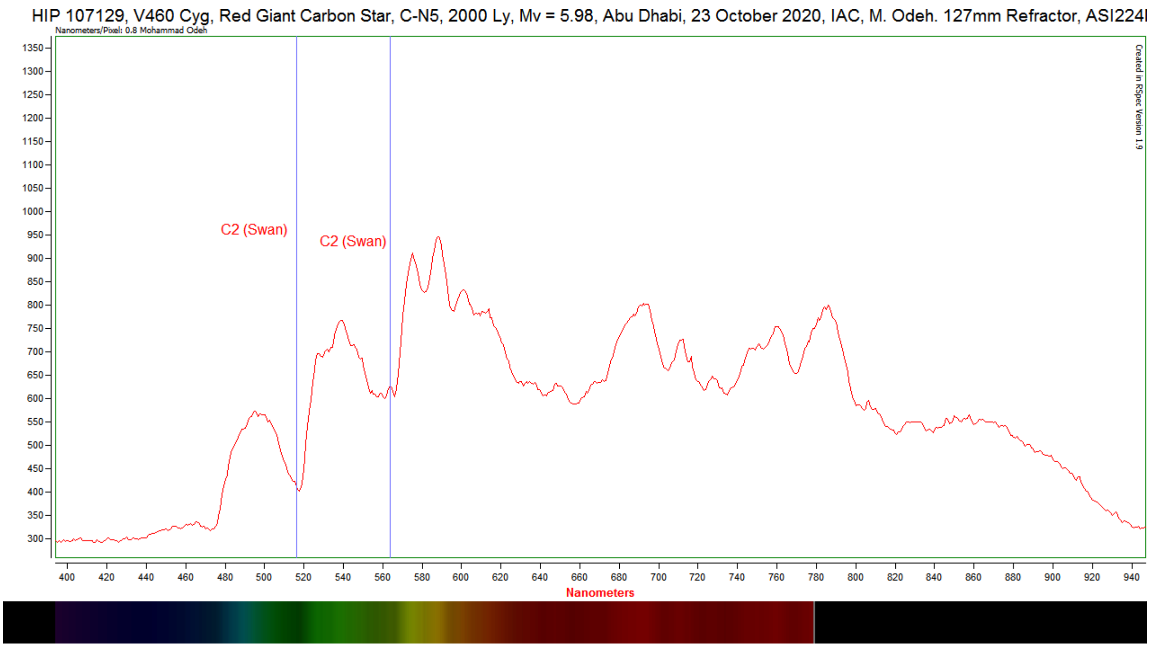

Figure 7. V460 Cyg spectrum using color camera, showing the C2 Swan absorption bands.

V460 Cyg is variable red giant carbon star, laying in the Asymptotic Giant Branch (AGB). Carbon stars are typically evolved cool giants with some circumstellar material. Carbon compounds are present in the photosphere after a star enters the red giant evolutionary phase. The C2 Swan bands are the dominate spectral features, they consist of several sequences of vibrational bands scattered throughout the visible spectrum. Figure 7 shows the spectrum of the star V460 Cyg.

4.5 Planet Uranus

The atmosphere of Uranus is composed primarily of hydrogen and helium, and it has noticeable amount of Methane (CH4). Thus, their spectra show clear absorption lines of the Methane as well as some Hydrogen absorption lines. Figure 8 shows the spectrum of Uranus.

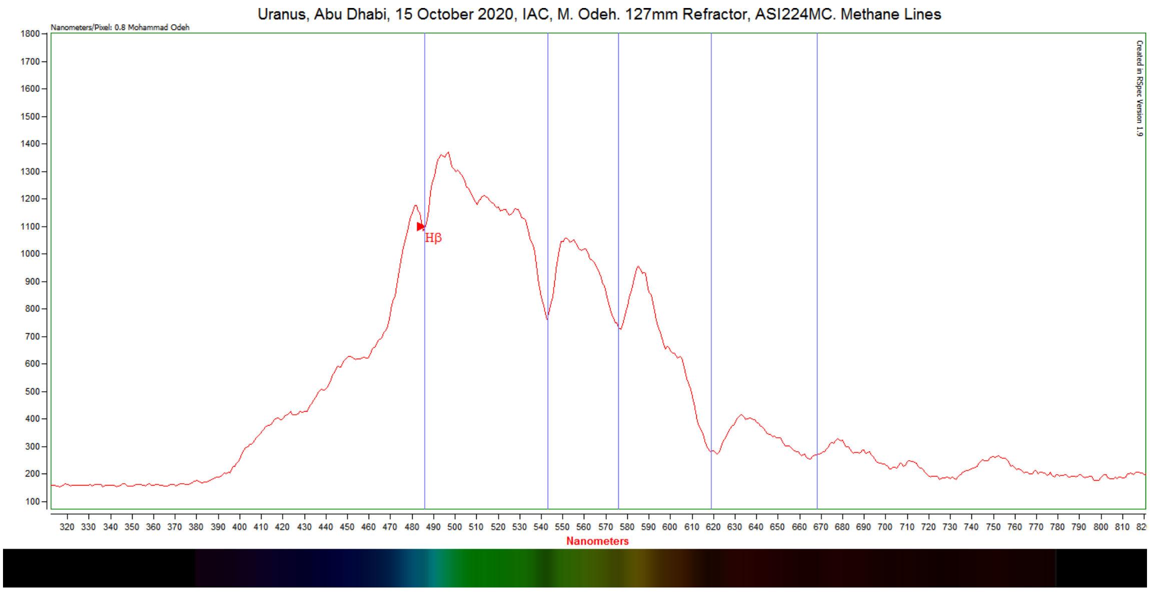

Figure 8. Uranus spectrum by color camera. Methane and Hydrogen-Beta lines are inline with the blue predefined line by the software.

5 Conclusion

It is evident that basic astrophysical concepts, such as blackbody radiation, absorption and emissions lines, and spectral classes can be presented easily and by inexpressive equipment to the public outreach as well as school and university students and for astronomical society members.

By such low-cost equipment, the attendee can see on alive screen the Balmer series lines for type A star, TiO bands for M star, Helium and Hydrogen emission lines for P Cygni stars, C2 Swan bands for carbon stars, CH4 absorption lines for Uranus and Neptune, and many other stellar spectral phenomena for other stars.

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