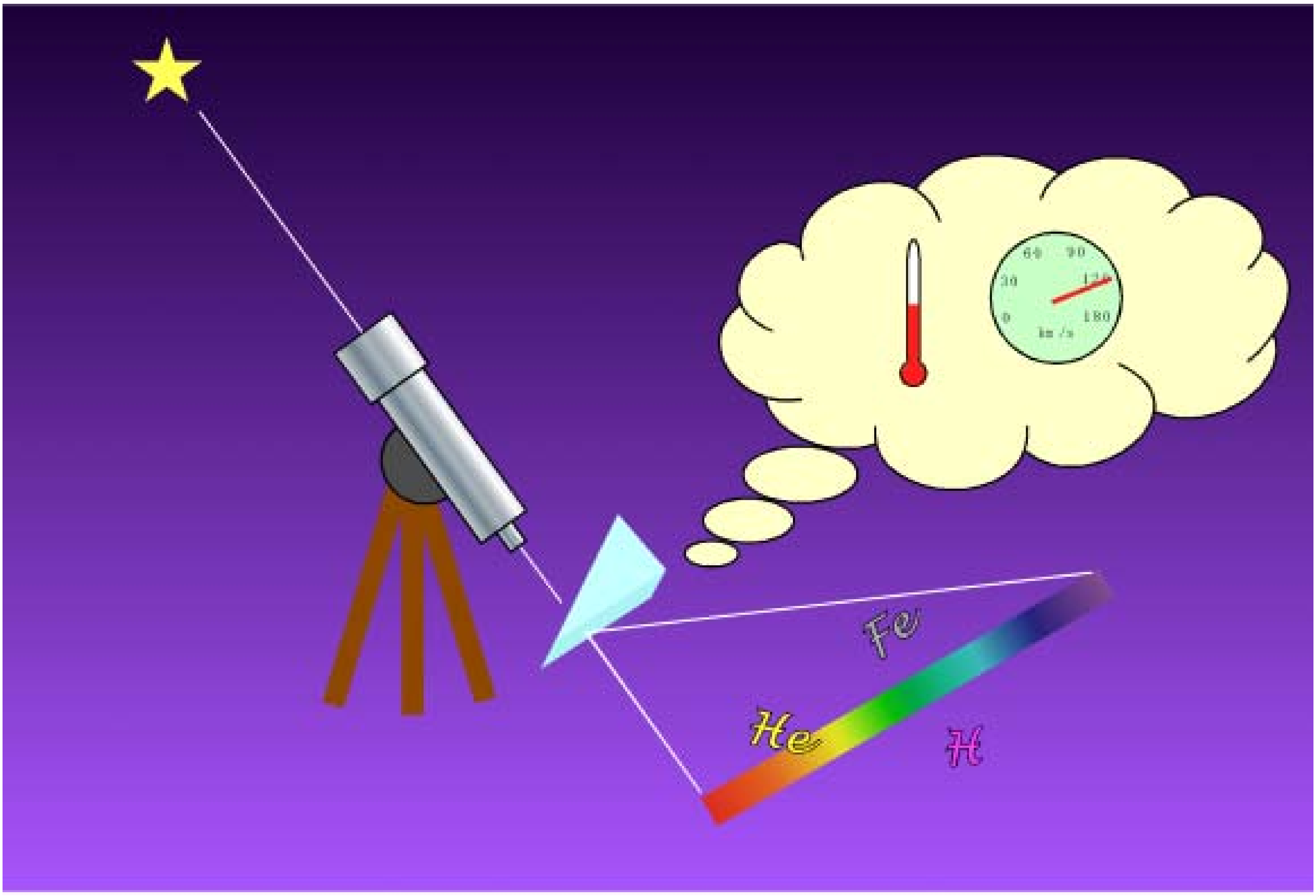
JAHOU curriculum

on astronomical spectroscopy

Teacher's Notes

ver.1



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Dependences of the lessons

Chapter	Lesson	concept to know	Correspond lesson
Chapter 1. Knowledge over a rainbow	1-1. Let's watch a rainbow	(none)	(none)
	1-2. What can we know through a spectrum?	observation of spectra	1-1
	1-3. Light and waves	(none)	(none)
	1-4. Motion and Doppler effect	light as a wave, basics of spectroscopy	1-1, 1-3
Chapter 2. Fingerprints of materials on a spectrum	2-1. Watch a rainbow of a star	basics of spectroscopy, flame reaction	1-1, 1-2
	2-2. What is a star made of?	basics of spectroscopy, spectra of element (absorption lines), stellar spectra	1-1, 1-2, 2-1
	2-3. Watch a spectrum of a nebula	basics of spectroscopy, spectra of element (emission lines)	1-1, 1-2
Chapter 3. A thermometer through a spectrum	3-1. Temperature of a star	basics of spectroscopy, spectra of element, stellar spectra	1-1, 1-2, (2-1)
Chapter 4. A speedometer through a spectrum	4-1. Rotation of Sun	basics of spectroscopy, solar spectrum, Doppler effect	1-1, 1-3, 1-4
	4-2. Rotation of a galaxy	basics of spectroscopy, Doppler effect	1-1, 1-3, 1-4
	4-3. Expansion of the universe	basics of spectroscopy, Doppler effect	1-1, 1-3, 1-4

	4-4. Expansion of Crab nebula	basics of spectroscopy, Doppler effect, nebula spectrum	1-1, 1-3, 1-4 (2-3)

General remarks for English versions

The English versions of “JAHOU curriculum for astronomical spectroscopy” is translated from its original in Japanese language. A main purpose to make the English version is international use of our products. Therefore, we do not consider any national curriculums nor commonsense of daily life in the English-spoken world. Moreover, the English version may not be written in a plain English understandable by your student, because the translators are not familiar to write a plain English. We write this English version to read by teachers, curators, and scientists living in any country on Earth who want to teach astronomical spectroscopy. We hope to make re-translation of this version into a plain language of your own for your students and/or to modify it to fit your educational environment.

We will revise the Workbook and the Teacher’s note from time to time. Please visit the official web site of JAHOU (http://jahou.riken.go.jp/). Through this web page we will notice about updating and revising of JAHOU curricula.

0. Preface

This is a courseware for high school students on astronomical spectroscopy, which may be more important than imaging in modern astronomy. They can learn about basic concepts on astronomical spectroscopy through their own experiences. Although Japanese high school students are assumed, junior high school and university students and adult citizens who are interested in astronomical spectroscopy can use this courseware, because it is independently designed of any national curriculum.

Most of conclusions in modern astronomy are based upon many results using spectroscopic observations. However, many teachers and scientists do not talk about spectroscopy, because they believe that detail understanding of modern physics is required to learn about spectroscopy and that spectroscopy is much more difficult than astronomical imaging. We hope to change this situation with this courseware.

The set of an HOU Workbook and Teachers' Note makes us to decide to write this courseware. Using the HOU workbook students can learn about astronomical imaging observations through their own experiences, although it contains latest and complex concepts of modern astronomical investigations. This courseware may be though to be a counter part of HOU's.

Under the circumstances shown above this courseware is not designed to use at school, although it is designed to use by students at a classroom. Therefore, some difficulties may be found when you use whole of this course in your classroom. Nevertheless, this courseware should be effective when it is used to make motivation to study physics, chemistry, and mathematics for students, because the modern astronomy highly depends on these sciences. And you can skip some parts of this courseware, when they have already been learnt in the standard classroom of these sciences. To help for use of selected lessons we have attached a table of dependences of the lessons.

This curriculum has two books. One is the workbook for a student and the other is the teacher's note for a teacher. This book is the latter. The workbook is a main part of the curriculum and you should give it to your student. Through lessons in the workbook your student can learn about spectroscopy in astronomy and how to derive astrophysical parameters from spectrum of a celestial object with many questions. In the teacher's note we show many points and advices when you instruct the curriculum to your student.

It is better for your student to display and make a process actual data by him/herself. You can obtain the data used in the workbook from the JAHOU web page shown in this note. They are also stored in the attached CD-ROM. The data are written in FITS format. So, you can use any software to process the data if it can deal with FITS data. For example, an HOU member can use HOU-IP, and a Japanese teacher can use JIP (Junior Image Processor) released by PAOFITS working group or Makali'i released by National Astronomical Observatory Japan. Note that some software shows a spectrum upside down or in mirror image of another. In the workbook and the teacher's note all instructions are written when you use HOU-IP. Before using in your classroom we strongly recommend to confirm the specification of your software about this "mirroring problem".

Most of questions written in the workbook have no definite answers, which is similar to other HOU curricula. It is because we believe that the process to get an answer is more important to "know the correct answer" itself. You should remember that no scientist knows a "true answer" in actual scientific research and we hope that your student also learns how an actual science research is done besides current scientific results itself. You should know this concept before start using this curriculum. This curriculum is not ready-to-go for any teacher but basic examples in your classroom. You can arrange the curriculum and practical applications to your class strongly depend on yourself. The curriculum is not an instruction manual for a novice teacher. We believe that this curriculum is strongly helpful to catch a student's mind and his/her interest in your class. We recommend this curriculum for a teacher who knows a limit of old-style curriculum in Japan.

Some authors of this curriculum are not school teachers. So, this is not well organized in a modern theory of education. However, this may become a breakthrough of a current limit in science education in Japan. To improve the contents and to extend our society, we hope you to make contact with us. The contact e-mail address is spectra@jahou.riken.go.jp.

This curriculum will be revised and extended from time to time. After getting this version, please visit our web site to get the latest news on the curriculum. The web page of this curriculum is linked from JAHOU web page, of which URL is http://jahou.riken.go.jp/.

1. Knowledge over a rainbow

1-1. Let's watch a rainbow

An aim of this lesson is to get a basic concept of a spectrum of light through experiences on light and color.

Note: You should understand a relation between physics of light and its recognition by human eyes. For example, a trichromatic color technology (color synthesis from the three primary colors or RGB) deeply depends on a function of human eyes. It is completely independent of physical characters of light itself.

[Experiment 1] - [Experiment 3]

In these experiments we use color filters. You can use any transparent film with color as a color filter. In Japan many people call such a color filter as “a color cellophane sheet” even if it is not made from cellophane. Nevertheless, the best color filter we find is a color filter used for stage lighting, because it is good characteristics as a color filter and highly transparent.

During these experiments the room must be in dark, because human eyes quickly change their response depending on light around them and it may make improper color recognition.

If you have no idea to select colors for the set of papers and filters, we recommend the following colors for these experiments:

colors of papers: pink, yellow, green, white, and olive green

colors of filters : red, green, and blue

What is color?

(Q1), (Q2) and (Q3): The aim of these questions is to recognize through experiment 1 that color itself is not a property of an object but of light. This fact should be found through the answers to these questions; dependences of an apparent color on a color of the filter on the light source and on the watching eyes are the same.

Rainbow and its order of color

[Experiment 2]

It is easy to see a rainbow in Step 1. In Step 3 and Step 4 a skill to enter the ray from a flashlight into the slit of a spectroscope is required.

(Q4) and (Q5): An aim of these questions is to find that any rainbow has the same order of colors; it is independent how to make the rainbow. We hope that your student find that there is another color between any two colors and that it is difficult to distinguish colors by words. Through these experiences your student should find that a statement that “A rainbow has seven colors” is not real.

In various cultures in the world the different number of colors is counted in rainbows. Some rainbows various commercial films and logos are drawn in less than seven colors. They may be good examples that “seven rainbow colors” are not all colors in a real rainbow.

Measuring colors

[Experiment 3]

The brightness template image shown in the workbook is stored in the attached CD-ROM as the file named *bsample.gif*.

(Q6)-(Q8): The aim of these questions is to notice that color can be quantified by using color filters. If all students understand the relationship without (Q8), you may skip it to answer and you may show the relationship graphically by using a PC software.

We used a color strip in the order of a rainbow to make it easy to notice the relationship. Instead of this color strip color photographs and/or color charts for a color blindness test are useful. Through a color filter these photographs and charts are look different. A color-blind-test chart is impressive. The chart through a color filter may look very different from the chart without the filter, and the chart with a proper filter may appear a similar pattern as you would see in color although the image itself is in monochromatic.

An image scanner in monochromatic mode is useful, because you can show the resultant image on a screen. When the scanner is not available, you can use a digital camera instead of the scanner. If many of the students do not know what a scanner is but are familiar to a digital camera, a digital camera is better. A machine of which function is not familiar is often thought as a “magic box”. It is not good. When you show an image with a color filter, you should take it in a gray scale mode. It is because an image with some color gives different impression from in gray scale even it is a monochromatic.

When you use a digital camera, you can try other experiments. A game to guess an actual color of clothing using grayscale photographs of your student with several color may be impressive.

The final goal of this section is to learn that the more color filters with the narrower transparent wavelength range, the more precise color of light can be distinguishable. This concept will lead your student to spectroscopy as a “multi-color measurement”.

A handy spectroscope

[Handicraft 1]

We draw an unfolded plan of a handy spectroscope in the workbook without any tabs for sticking, because some student can make the box without them using thickness of the cardboard or using an adhesive tape. If you think the tabs are required, please add them by yourself. Proper extension of these tabs itself may be a good practice for students to understand a 3-dimentional geography.

Our plan is a singe spectroscope with two different dispersion windows using two gratings. A single dispersion spectroscope has performance enough to learn the lessons in the workbook.

When the geometry of the grating sheet and the slit is proper, the wavelength of an emission line can be estimated easily from the separation angle between the slit and the emission line appeared.

In the workbook we show how to make a spectroscope from a cardboard. However, you can use a kit and a finished-product spectroscope released by various science toy venders and museum shops. For example, “Project STAR spectrometer” is a good kit, which can be finished less than 10 minutes without any scissors (Contact address in US: Project STAR Hands-on Science Materials. Visit their web site at http://www.starlab.com/psprod.html in detail). We do not recommend to use a finished-product, because it is important to know how simple the structure of a spectroscope is.

(Q9): The aim of this question is to understand that there is a relationship between a rainbow and a spectrograph. In other words, the aim is learning that a rainbow can be seen through a spectrograph.

Using the spectroscope

(Q10)-(Q12): The aim of these questions is to understand that each color corresponds to a position in a spectrograph. In other words, each position in a spectrum corresponds to a different filter with appropriate color. When you have more time for this lesson, we recommend answering these questions with a florescent lump instead of a light bulb. The results will be interesting.

(Q13) -(Q14): The aim of these questions is to understand that a basic function of a spectroscope is separation of light with a lot of narrow-band color filters.

[Advanced learning]

It is beyond the bottom line of this lesson, but you can induce fundamentals of spectroscopy and spectroscope using the concepts of interference and dispersion of light, when your students have already reached these concepts.

1-2. What can we know through a spectrum?

The aim of this lesson is to learn which characteristics of a spectrum should we watch intensively and what you can know from the spectrum through several experiments.

[Experiment 1]-[Experiment 4]

The spectroscope made by your student in lesson 1-1 is the best for these experiments. Although a completed-product spectroscope is available for these experiments, a hand-made spectroscope is better because your student knows what it is (or he/she believe what it is). Usage of a “magic box” should be worse to understand the results. Note that many spectroscopes show spectral images in the direction different from that of incident light. Some skill is required to watch a spectrum properly.

An apparent color you see and its spectrum

(Q1)-(Q4): An aim of these questions is to know there are two types of spectra; a continuum spectrum and an emission line spectrum. Another aim is to learn that an apparent color of light is not enough to know what kind of light it is.

(Q5)-(Q6): The aim of these questions is to know the relation between temperature and a spectrum. In this lesson we mention amount of electric current of a light bulb instead of its temperature, because it is difficult to measure the temperature. If you can show the temperature of the light bulb directly, it is the better, because the relation can be shown more straightforwardly through these experiments.

Emission line spectrum

[Experiment 2]

We direct this experiment as a quiz show. If you follow this scenario, put the labels of A, B, and C on each gas tube before the class. If you feel a quiz-show type presentation is not good, you can just explain the types of gas tubes and skip (Q8).

(Q7)-(Q9): The aim is to watch spectra of light from various gas tubes actually.

(Q8) It is more impressive to show template spectra in color. You can make a color print of this page or you can show them on screen. (In the attached CD-ROM there are color image files of these spectra as Hg_sp.jpg, Na_sp.jpg, Cd_sp.jpg.)

The spectrum images of Hg_sp.gif, Na_sp.gif and Cd_sp.gif are taken by Mr. Oshima with a digital camera through the “Project STAR Spectrometer”. (Contact address in US: Project STAR Hands-on Science Materials. Visit their web site at http://www.starlab.com/psprod.html in detail.) Note that all these jpeg images are shown that the longer wavelength (redder) is leftward, which are mirror images of those on the workbook.

Materials and spectra

The aim of this section is to watch emission and absorption line spectra of various materials and to know that wavelengths of both emission and absorption lines are the same of the material; the wavelength of both lines is the material proper.

[Experiment 3]

We strongly recommend you to use pure ethanol (ethyl alcohol) provided as a regent, because some fuel ethanol contains sodium to give a color to its flame for a safety reason. Ethanol flames with sodium ruin your experiment.

In step 5 you may use a continuum light or a light with many emission lines such as a fluorescent light, if it is bright enough.

In many books on basic chemistry the colors of flames are shown for various chemical regents, such as copper sulfate shows green flames. They are helpful. Make sure that you must not use flammable materials or chemicals which will emit any poison gas for this experiment.

(Q10)-(Q11): The aim of these questions is that many materials show their proper colors of flames. It is called as “flame reaction”. The proper color is actually due to the proper emission lines. The straightforward way is watching the sodium flame through a spectroscope. However, it is actually too dark in many cases. Therefore, we show “a shadow of the flame” in this lesson. We recommend you to add a step of watching them before this experiment, because your student should know that spectra of a sodium lamp and sodium flames are identical.

The image for the answer of (Q11) is stored in the attached CD-ROM as Na_Na_shadows.jpg .

(Q13)-(Q14): Through these questions we hope you to talk that a flame reaction is directly due to a material and its proper spectrum. The straightforward way is watching a spectrum of each color flame using a spectroscope. Please try it in your class, although we find that the best conditions and a fine spectroscope are required. Also try this experiment using mixed materials and watch their flame colors and spectra.

$CuSO_3$ and NaCl are typical reagents for this experiment. Seasonings in your kitchen may be good.

Spectrum with absorption lines

(Q15)-(Q16): The aim of these questions is to know that the solar spectrum shows continuum with many absorption lines. The solar spectrum can be watched even in a cloudy day. Make sure that no student makes a direct watch of the sun. It is enough understanding that there should be some materials on the solar surface which make these absorption lines. Complete understanding the last part of this lesson is not required to any student, because it is written as an introduction to Chapter 2. It may be interesting to compare spectra in a sunny day and a cloudy day.

reference : Tsubota Yukimasa, Matsumoto Naoki (2000), astronomical education No.44, Vol.12, NO.3 Practice of research “demonstrative experiment about the principle of Fraunhofer line”

1-3. Light and waves

This lesson is designed to understand light shows characteristics of wave through discussions and experiments.

[Experiment 1]

The most important point is that students actually watch the experiment, because the result is beyond their expect in most cases. Neither teacher's talk nor movies are enough to what actually happens. We propose to use a laser pointer, because you can get it easily and you can show the interference pattern (fringe) more easily than using normal light with a slit. However, you should use a normal light source instead of laser light, if you can show the pattern clearly. It is because some students feel that a laser light is completely different from normal light and that the interference pattern might appear only with a laser light. You should take the same kind care for the double slit experiment. It is important that your student understands that the result is "natural" and is not a trick. For skilled students, we recommend you to make a double slit by themselves. At least your student can check the double slit on his/her own hand.

To make the experiment successfully you must make and find what is the best dimension of the double slit before the demonstration. A separation and width of the double slit are delicate to make a clear fringe. You should check the laser pointer whether it can make a point-like spot, because some laser pointers make a diffuse image with some optics.

The interference fringes may be much finer than you expected. If you cannot resolve any fringes, you should go much closer to the screen closer than the double slit.

You should take care that anybody never watches a direct laser ray, because it may give a fatal trouble to his/her eye.

If you have no chance to demonstrate the double slit experience, you should show a demonstration of the Fraunhofer diffraction pattern with a single slit. Instead of it a diffraction pattern with a very thin line, such as a hair, is also impressive. However, we expect that the diffraction pattern with a double slit, which is NOT two bright strips but much more strips, is much more impressive for your student than that with a single slit. The experiment will be much improved if you can show that a diffraction pattern with a double slit changes to that of a single slit by hiding one of the slits.

A good double slit should be made from a sooty slide glass or a blackened photographic film slitting with two piled razor blades. If you cannot get them, you can make it from a black Kent paper or an aluminum tape as written in the workbook.

In (Q1) and (Q2), and also in (Q6) and (Q7) of [Experiment 2], it is important that your student makes a guess of the result before the experiment, because the difference between an actual result and his/her own guess make motivation to think more deeply.

Explain your expectations and the actual results

We can often find that an explanation to another person itself is the best way to understanding. In (Q5) and (Q10) we apply this to your students' benefit. Deep discussions will lead persons to a good explanation. When students can get a good explanation, write it down.

Conclusions of the experiments

This last fill-in question is for summary of this lesson and introduction to the next. The correct answer is “wave” of cause. But you should not make a shortcut to reach this answer. When students make active discussions, you may skip this last question.

1-4. Motion and Doppler effect

This lesson is designed on an assumption that your student has already known that sound is a wave. If he/she has not, you should give supplemental experiments to him/her. A typical supplemental experiment is that showing a relation between motion of small pieces of papers on a drum and its sound.

The first step to understand of the Doppler effect is that not only sound but a wave of any kind shows the Doppler effect. This and anther knowledge that “light is a wave” make your student to understand that “light should show the Doppler effect”. It is the aim of this lesson.

However, we do not experience any results of the Doppler effect on light in our daily life, although we do it on sound. We hope to resolve this discrepancy by estimating velocity ratios. This is another aim of this lesson.

Some teachers and students want to skip a quantitative estimation in a short class, but through this estimation your student can understand that a quantitative difference in the several orders of magnitudes looks quantitative difference in some cases.

Wave change caused by motion

In (Q1) and (Q2) it is important that students enjoy the experiment. A teacher’s performance may be a good help to start performance of initiation by students. Instead of a precise experiment in a laboratory, students can do experiment through their own experiences in daily life.

Some students might point out the change in loudness of sound instead of its tone. In this case a reverse play of a sound track may give a good hint to them.

Change of wave caused by motion

Actual demonstration is much more preferable, because your student feel there is no trick. However, a CG animation may be instructive enough to understand what happens actually, because the phenomenon observed in this experiment is simple,

The aim of (Q3) and (Q4) is to extract what is the essence of the phenomenon he/she watches through a process of explaining not by graphics but by words. The students require a lot of paper to complete the “message game” successfully.

Speeds of a wave propagation and that of the wave source - Speed of Earth around Sun

Although (Q7) through (Q9) require calculation, the aim of them is to know how different they are in the order of magnitudes. This is a reason why the questions do not give exact numbers for calculations. Therefore, the answered values by students are different and you and your students should not consist “it is different”. For example, the answers using 50km/h and 100km/h for speeds of a car must be different. But the different between them is not much smaller than difference between Doppler effects of sound and light. A hidden aim of these questions is understanding that difference in the order of magnitudes is the most important in such cases.

Radial velocity

We introduce a term of “radial velocity” here, because it is used in the following lessons. You may skip this section if your student understand its concept before this section.

2. Fingerprints of materials on a spectrum

Appendix: a slit spectroscope and a spectrogram

Nothing to say for this appendix.

2-1. Watch a rainbow of a star

In this lesson your student learns that stars show various spectra. Your student will find characteristics of stellar spectra, and compare and classify them. In the case that a classification found by your student is reasonable, a teacher must not require that his/her classification is the same as any established classifications, such as the Yarkees or the Harvard classification. Your student will find any relations (or no relation) between a spectral feature and other different characteristics of a star, such as brightness, constellation, and color.

The Spectrum of Alpha Lyrae

The original data of this spectrum is essentially one-pixel height, because an observed star is point-like. However, most FITS image processing software, such as HOU-IP, cannot show a FITS image only one-pixel width. Therefore, we have extended the spectra to be 20-pixel width by coping the original raw. It means that all pixel values along the vertical axis are identical.

A graph whose horizontal axis is wavelength

We propose using HOU-IP or any other software which can read FITS image file to learn characteristics of a spectrum. For this purpose a plot made with the slice function of the software is effective.

The aim of (Q1) is to find out characteristics of a spectrum. As the first step we use the spectrum of alpha Lyrae (α Lyrae or Vega). Your student can answer whatever he/she finds in the spectrum.

Spectra of various stars

In this section your student watches spectra of various stars. The spectra are stored as FITS image files in the attached CD-ROM. There are 49 stars in our catalogue.

In (Q2) your student compares the stars with Vega and find stars which show similar spectra to Vega's.

In (Q3) your student classifies the stars by spectral characteristics. In this question it is also an important point what your student notices to make his/her classification. A process to answer (Q2) may help your student to classify various stars. Either images or plots with a proper software to show FITS image, such as HOU-IP, are useful to classify the stars. Even cards printed of spectral images may be enough to use. The color images (JPEG files) of some stars in the catalogue are stored in the attached CD-ROM. They may be helpful.

Through (Q4) your student finds any relations (or no relation) between a spectral feature and other different characteristics of a star, such as brightness, constellation, and color. “No relation” or “random” may be one of good answers for some parameters.

Table of stars and file names

Each bright star has a systematic name made from one Greek letter with its constellation, such as α Lyrae. It is given by Bayer. The Greek letter is fixed from the brightest to fainter in the order of Greek alphabet in most constellations. But in some constellations he gives a Greek letter in a different order.

We use Bayer’s naming system to give a file name. Each file name is made from two sets of Roman letters combined with the letter “_”. The first two or three Roman letters are for one Greek letter, and the last three Roman letters are for a constellation.

2-2. What is a star made of?

In this lesson your student can learn what elements are content in the atmosphere of a star with its spectrum because each element shows its own line spectral pattern, which is made of emission or absorption lines at a given wavelengths.

Spectra of various elements

The aim of this section is to know that each element has its own spectral pattern. In the attached CD-ROM spectra of hydrogen (H), helium (He), iron (Fe), sodium (Na) and calcium (Ca) are stored.

The aim of (Q1) is to find that spectrum of each element shows a series of emission lines and each line always appears at the given wavelength.

Emission line spectra of elements and spectra of stars

In both (Q2) and (Q3), your student will identify the elements in a star through comparison between emission line spectra of elements watched in (Q1) and a spectrum of a star. The identification done in these questions only depends on matching of patterns by eye. We say nothing about wavelengths of these lines, because precise measurements are not done in this section.

For this purpose you should present a stellar spectrum with simple pattern for (Q3). A spectrum of a “cool” star, such as an M type star, shows a lot of absorption lines (some of them are made by molecules) and it is too difficult to identify the elements for a beginner. We recommend some bright stars in Cygnus and Ursa Major. The best five stars with some variation are the following; Alp_Lyr.fts (α Lyra) , Bet_Uma.fts (β UMa) , Gam_Boo.fts (γ Bootis), Del_Cap.fts (δ Capricorni), and Kap_Oph.fts (κ Ophiuchi).

Nevertheless, you may not select the “best” samples, because your student should know that “many stars contain the same elements” and that “the element identification in a complex spectrum is not so simple in many practical cases.”

Absorption lines by various elements are superposed on an actual stellar spectrum, although it is not mentioned in the workbook. When your student assume that a stellar spectrum shows absorption lines by a single element and he/she has much trouble in identifying the element, you should point it out.

Photographic images of constellations are stored in the attached CD-ROM in a folder “JPGImgs” in the jpeg format. Each file is named by the “3 letter code” or international abbreviation such as And.jpg for Andromeda, Aql.jpg for Aquila, Boo.jpg for Bootes, Boo_CrB.jpg for Bootes and Corona Borealis, Cap_Aqr.jpg for

Capricornus and Aquarius, Cyg.jpg for Cygnus, Her.jpg for Hercules, Lib.jpg for Libra, Lyr.jpg and Lyrl.jpg for Lyra (Lyrl.jpg is a large format version), Oph_Ser.jpg for Ophiuchus and Serpens, UMa.jpg for Ursa Major, UMa_CVn.jpg for Ursa Major and Canes Venatici. See table 2 in lesson 2-1 for the international abbreviations of constellations. Additionally, images of star fields around the following stars are stored; Arcturus.jpg for Arcturus or α Boo, Deneb.jpg for Deneb or α Cyg, Vega.jpg for Vega or α Lyr.

The aim of (Q4) is to learn elements contained in stars are the same as that found on Earth. Your student should answer the daily goods which contain the elements found in the answers of (Q2) and (Q3). The answer should not be restricted goods which contain the element itself but contains its chemical compounds.

2-3. Watch a spectrum of a nebula

Aim of this lesson is to learn that a nebula shows an emission line spectrum.

A spectrum of a nebula

(Q1) Sketch drawing makes your student to confirm that a spectrogram of a nebula is taken with a slit in a certain direction on the sky and is two-dimensional. One axis of the spectrogram is along wavelength and the other is along a direction on the sky.

Your student should not assume that a space scale of the spectrum is the same as that on the image. The slit directions of these spectrograms are aligned in the north-south direction on the sky. Due to imperfectness of a spectroscope the special and wavelength axes of the spectrogram is not exactly orthogonal, although this imperfectness is small and less affects to interpret the spectrogram.

(Q2) Your student knows that a spectrum of a nebula shows emission lines without continuum. The actual spectrograms of NGC2892 and M57 show spectra of stars and terrestrial atmosphere superposed on the nebula spectra. Your student should know how to distinguish them.

Background stories of spectra shown in this lesson

Spectra of two planetary nebulae: M57 and NGC2392

A star with less then 8 solar-masses (less than 8 times as massive as Sun) expands and becomes a red giant in its late phase. When it burns out a nuclear fuel, the core of a red giant collapses and its reaction makes the envelope to expand and to release into the outer space. The released gas becomes a planetary nebula.

The collapsed core becomes a white dwarf which is located at the center of the planetary nebula. It is as hot as fifty thousands Kelvin and emits strong ultra violet radiation, which ionize the gas around the white dwarf. The ionized gas shows emit line spectra. Besides this main process, free electrons in the nebula gas emit free-free emission which is a continuum spectrum (continuous light along wavelength). This is the reason why a faint continuum is also seen in a spectrum of a nebula. A white dwarf shows a continuum spectrum like that of a normal star. Spectra of most white dwarfs are O-type. After a long time a white dwarf cools down and become a black dwarf.

In a spectrograph of NGC2392 (which is known as Eskimo nebula) a spectrum of a star near the nebula, which shows the Balmer series of absorption lines of hydrogen, is seen.

A spectrum of an H II region: M42

Stars are born within a molecular cloud with a dense hydrogen gas. The Orion nebula is a site where a star has just been born and has blown away the gas around it.

At the center of the Orion nebula, there is a group of young stars known as the Trapezium. These stars are very massive and short life. They are hot and emit strong ultra violet radiation. The ultra violet radiation ionizes the gas around the stars and the ionized gas emits a visible emission lines.

The file “hr1895sp.fts” is a spectrum of a star named θ 1C Orionis (or HR1895), which is one of the Trapezium stars. In the spectrograph we see spectra of the star and of the Orion nebula.

A spectrum of a supernova remnant: M1

A star over 8 solar-masses (more than 8 times as massive as Sun) explodes at the last phase of its life. The nebula M1 is a remnant of such explosion observed in 1054 and a nebula of this type is called a supernova remnant.

There is a pulsar with rapid rotation and it emits electromagnetic wave periodically in every 33 milliseconds. A synchrotron radiation, which is electromagnetic emission by interaction between electron and magnetic field, itself and ionization by the synchrotron radiation are main processes of a supernova remnant radiation from radio wavelength to X-ray regime, although a nebula of other types (planetary nebula and HII region) emits electromagnetic wave (or light) due to ultra violet radiation from a central hot star.

You can find that emission line features in the M1 spectrum are bent and split, which is not seen in spectra of other types of nebulae. It is due to Doppler effect by expanding motion of the nebula. A lot of filaments are found in the image of the nebula. These filaments show complex structure in the nebula spectrum, because each of them moves with different velocity.

A spectrum of terrestrial atmosphere

A spectrum of terrestrial atmosphere shows the same pattern along the direction on the sky, because it is the same everywhere along the slit. In the spectrogram shown in this lesson the most intense emission lines are Hg I lines from city light. Using figure 3 in the Appendix “a slit spectroscope and a spectrogram” your student can identify the emission lines seen in the spectrogram of a nebula. Spectra heavily contaminated by city light may be a good chance to talk about an effect of “light pollution” on astronomical spectroscopy.

Note that the terrestrial spectrum is too dim in the M42 spectrogram (hr1895sp.fts).

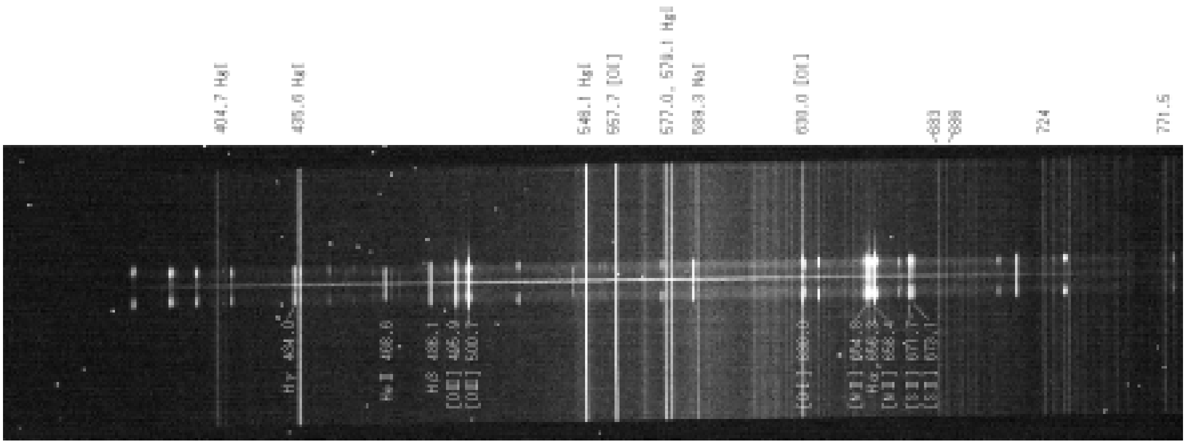


Figure 1: An identification chart of a spectrum of the nebula M57

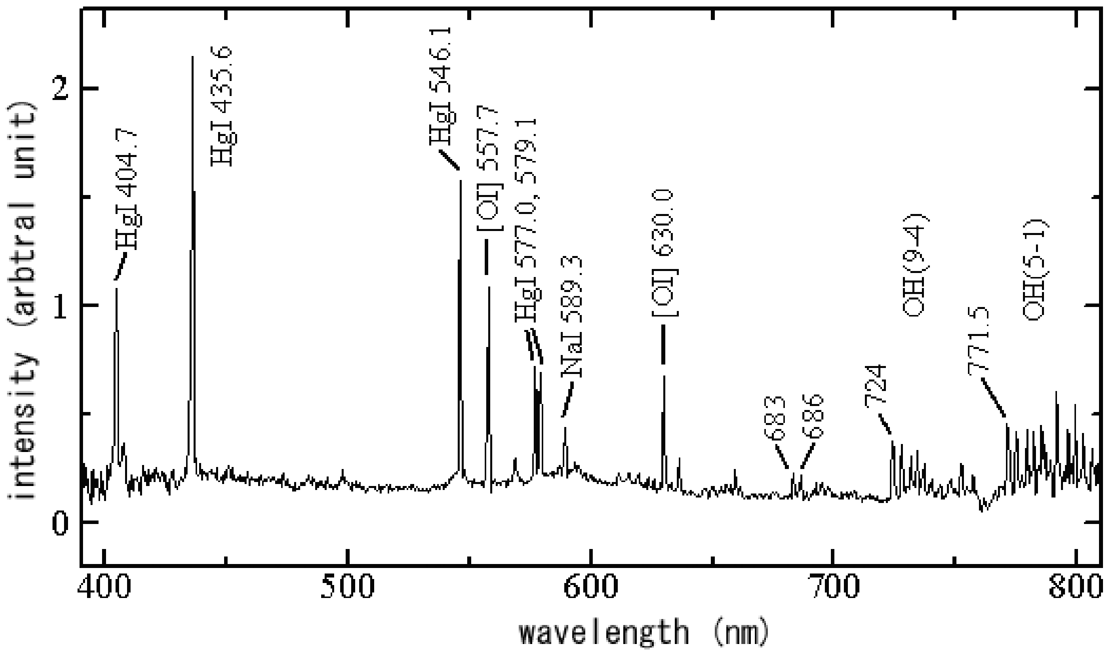


Figure 2: a typical spectrum of the sky at Bisei Astronomical Observatory (airglow and city light)

3. A thermometer through a spectrum

3-1. Temperature of a star

In this lesson your student try to make a classification of stellar spectra. We show 7 stars of different spectral types as the minimum sample. However, the more samples are the better to classify, because the more samples make the easier to find the similar spectra. It is not important to make an established classification. The most important point of this lesson is the fact that stellar spectra CAN be classified.

Characteristics of stellar spectra

Each spectrum used through (Q1) to (Q3) is not a full range spectrum of visible light but a part of visible light spectrum corresponding to blue light. The reasons why we use narrow spectra instead of those for whole visible light region are:

(1) A spectrum for narrower wavelength region can be shown in enlarged picture along wavelength and we can investigate details of the spectrum more easily.

(2) In this wavelength region there are many lines both at high and low temperature.

(3) Historically, many spectroscopic studies of stars have been done in this region.

(4) It is actually difficult to get well-calibrated spectra in sensitivity over wide wavelength range. Therefore, many spectroscopic studies are done using spectra over narrow wavelength range.

You should not expect that your student can get the same classification as established for a few hours, because it takes about 40 yours to establish the Harvard classification in the early 20th century since the pioneer work by A. Secchi in the 1860's.

You can choose one of the following methods depending on what is available for you.

Method 1: Compare the spectra printed on papers. Cut and sort them out on a desk.

Method 2: Compare the spectra on a computer screen with HOU-IP or another software.

Table 1: Harvard spectral types and luminosity class of the 7 stars

star name	spectral type	luminosity class
BD+63 137	M1	V
HD 10032	F0	V
HD 116608	A1	V
HD 215835	O5.5	V

HD 23524	K0	V
HD 240344	B4	V
HD 66171	G2	V

All 7 spectra come from “A library of stellar spectra”

Spectral line features of a star and its temperature

In this section, your student compares the strength of absorption lines. At first your student should focus on one absorption line in the spectra of various stars. Comparison between relative strength of absorption lines of one star is very confusing, because strength of absorption line changes not only by stellar temperature but also by pressure and element abundance. (Note that Astronomers often call this abundance as “chemical abundance.”)

The figure shown in this lesson shows results of a model calculation of absorption line strength of a star with the same chemical abundance as Sun. Electron pressure of stellar gas is assumed to 100 dyne/cm^2 which is a typical value for a star. The result shown here with these assumptions is accurate enough to be used for any main sequence star in this lesson.

We use the astronomical notation to express the element with its ionization stage in this workbook, which is not used in chemistry or physics. This notation is a combination of an element symbol and a roman number which shows “the stage of ionization plus unity” (I is for neutral, II is for the first-stage-ionization, and so on). For example, H I is for neutral hydrogen. He I and He II are for neutral and first-stage-ionized helium, respectively. Na I and Na II are for neutral and first-stage-ionized sodium, respectively. The wavelengths of these lines are:

H I is at 434.0 nm. (This line is called as Hγ.)

He I is at 447.1 nm.

Na I is at 422.6 nm.

Na II is at 394.5 nm.

How to calculate these absorption strength data: detail explanation

The absorption strength is a product of the number density *N* of each excited atom or ion and chemical abundance *A* and the oscillator strength *f*. The number density *N* is calculated using the Saha-Boltzmann equation. The chemical abundance *A*, which is a relative content of the element to hydrogen, is set to the value of that of Sun. The oscillator strength *f* is used that for a typical absorption line of the element in visible light, because *f* for other absorption lines of the same element in visible light show a similar values. We assume the value of *f* for He II to be 1.0, because we cannot find the actual value. Although the strength of the absorption line for He II is inaccurate for detail investigation, this is valid enough to use in this lesson.

The trend in the figure can be explained like following: In hot gas below some critical temperature, electrons at the higher temperature are populated at the higher energy levels. (This situation is expressed by Boltzmann's equation). This makes absorption lines stronger. However, as the gas is too hot beyond the critical temperature, the outmost electron of an atom will be removed by collision with other atoms and it becomes an ion or an ion is further ionized. (This situation is called as thermal ionization and expressed by Saha's equation.) So, after a certain temperature, an absorption line will became weaker (and the next stage ion's absorption line will became stronger).

Continuum spectra of stars

In this topic, the students should learn that the continuum spectra of stars are similar to that of a black body and corresponds to the temperature of the stars.

In (Q6), some students may notice that there are differences between the spectra of blackbodies and the spectra of stars. This is because the spectra of stars are not blackbody spectra will some absorption lines but is also affected by bound-free transitions, free-free transitions, broad absorption features by negative hydrogen ions, etc. Some of the images there are quite strong differences in certain wavelength regions.

4. A speedometer through a spectrum

4-1. Rotation of Sun

Using the Doppler shifts of absorption lines at both edges of Sun, your student can estimate rotation velocity of Sun.

An introduction part of this lesson shows that using a spectral difference we can estimate velocities. However, your student should have already learned about the Doppler effect which can be learn in lesson 1-4.

Although many calculations are required in this lesson, the calculation itself is not an aim of this lesson. Simple arithmetic mistakes are acceptable, because understanding the process to derive the answer is much more important.

Spectra of different sections of Sun

The FITS images stored in the attached CD-ROM are explained here. Although the rotation velocity can be derived only using the spectra at the edges, a spectrum at the center of Sun is also stored in the attached CD-ROM as a reference.

Spectra of the eastern and western rims of Sun

Through (Q1) and (Q2) your student may find that all absorption lines in the spectra are not shifted. Based on this finding your student should think why some lines are shifted and the others are not.

Note that the x coordinate value of the slice function depends on where he/she starts to make the slice.

Identify materials which make these absorption lines

The Aim of (Q3) is to learn how to identify absorption lines; which are of Sun and which are of terrestrial atmosphere. Terrestrial atmosphere is (almost) rest against the observer in any direction, while the rims of Sun move in different velocity. That is what we hope to find by your student.

Measuring the Doppler Shift

From (Q4) through (Q9) your student can measure the Doppler shifts and estimate the radial velocity of the rims of Sun.

From (Q4) through (Q6) your student estimates a scale of wavelength per pixel using the absorption lines identified in (Q3). In (Q7) and (Q8) your student estimates observed wavelengths of solar absorption lines using the result of (Q6). And your student can derive the Doppler shifts $\Delta\lambda$ as differences between the observed wavelengths and the rest wavelengths listed in the table.

Velocity of the rims

In (Q9) your student estimates a radial velocity for each solar line using the wavelength shift $\Delta\lambda$ estimated in (Q8).

In (Q10) and (Q11) your student check the estimated radial velocities for the all solar lines are consistent or not. Although the radial velocities on each rim of Sun may be different due to the observational error, the radial velocities at the eastern and western rims are different beyond the observational error. This difference should be due to the solar rotation.

Distance to Sun

As the last question in this lesson your student estimates the distance from Earth to Sun using the results estimated above. We have already introduced that Sun is rotating from observations of sun spots motion. Combined with rotation period derived from the sun spot motion we can derive the solar radius from the radial velocity of both rim of Sun. Compared this value with an apparent size of Sun, we can estimate the distance to Sun.

4-2. Rotation of a galaxy

The aim of this lesson is to understand that the distribution of radial velocity of a celestial object using the Doppler effect suggests its internal motion. Through this lesson we hope that your student knows power of this methodology in astronomy. In the supplemental activities, your student may learn about internal motion of a galaxy as a practical example. The same method can be applied to many spectral data obtained at universities and observatories to research many galaxies.

In this lesson radio astronomy data are used, because high velocity-resolution data can be obtained easier in radio astronomy than any other wavelength astronomies which are suitable to estimate a rotation speed of a galaxy. However, spectral data in optical astronomy and others can be used in the same way in principle. You may extend this lesson to spectral data in other wavelength regions.

Visible light and radio wave

We assume your student knows the definition of “optical light” or “visible light”. When he/she does not know it, you should explain it. Because relation between radio wave and visible light is an extension of spectrum, the lessons 1-1 and 1-2 may be helpful.

In (Q1) you may use typical wavelengths of radio wave and visible light which are given in a reference book. Because any electromagnetic wave of which wavelength is longer than a limit is called as “radio wave”, it is impossible to give a pinpoint value of wavelength. We hope your student finds that the typical wavelength of radio wave is more then 100 times longer than that of visible light; For example, the shortest radio wavelength is 0.1 mm and the longest optical wavelength is 1000 nm.

(Q2) and (Q3) have no definite answers. Your student can answer to these questions in many aspects to figure out what radio wave and visible light are.

Radio emission lines

If you cannot find any good answer to (Q4), you should read the lesson 1-2.

In (Q5) actual materials which show radio emission lines can be found by your student or be present by you. You can choose either of them according to time you can use. Actually, many molecules show emission lines in radio regime and atoms show optical emission lines. However, this is a minute topic in the context of this lesson.

The following molecules are found to show radio emission lines in space:

H_2O (water vapor), NH_3 (ammonia), H_2CO, CH_3OH(methanol), SiO (silicon mono-oxide), CS(carbon sulfide), OH(hydroxyl radical), and HCN(cyan)

Spectra of an extended object

Questions between (Q6) and (Q8) have no definite answers to introduce many methods to observe and to present spectra of an extended object. We hope your student shows many ideas beyond traditional presentations. We show examples actually used below. However, your student can go beyond them. When time schedule is too tight, these questions may be skipped and you may show these examples.

The following methods are actually used to observe spectra of an extended object in astronomy:

- Long-slit spectrogram: a two-dimensional image of wavelength and position along a slit
- Multi-object spectrograms: a set of spectrograms at different positions on the sky
- Fabry-Perot spectrogram: a set of images at different wavelengths with narrow spectral width

Beside data with a radio interferometer, radio observation is measured only one direction (one point) of the sky. Therefore, imaging in radio astronomy is done by “taking spectra at many position of the sky” in many cases. This corresponds to the “Multi-object spectrogram” shown above.

The following methods are actually used to show spectra of an extended object in astronomy:

- Position-velocity diagram (or spectrogram): a two-dimensional image of intensity distribution along wavelength (or velocity, converted through the Doppler effect) and one direction on the sky
- Profile map: place small plots of spectral profiles according to their positions on the sky
- Velocity channel map: a series of two-dimensional images of intensity distribution at various wavelengths (or velocity, converted through the Doppler effect).

A position-velocity diagram

Although there are many ways to express a position-velocity diagram, these are essentially the same variations as used for a usual image. Both axes of an image may not be along the directions on the sky. Many ways to express an image are explained in the HOU curriculum on astronomical imaging. Astronomers often use a contour map, a gray scale image and pseudo-color map.

Let’s display radio astronomy data

Your student can understand that the galaxy investigated in this lesson is edge-on view of a spiral galaxy. Photos of galaxies with different inclinations are helpful. A good example is composed of M51, M101, M33 and M31.

Reading the position-velocity diagram

In (Q9) your student should focus that the distribution is nearly point symmetric, and lowest and highest velocity edges show nearly consistent difference from the center.

In (Q11), when your student cannot determine the sampling positions, you may suggest 10 positions between the center and the most distant location of the galaxy image. (You can know your student's sense for science by how he/she distributes his/her sampling points.) When your student cannot define "the edge of the intense area", the "slice" function of the image processing software is helpful. This dataset is actually observed by astronomers, and it is not ideal quality due to weather conditions. We hope your student can deal with the dataset beyond this imperfectness.

In (Q12) there are several interpretation of "an average". A simple arithmetical average of the all sample data is acceptable. Some students might think that the arithmetical average is not good because of inhomogenity of brightness distribution. In astronomy, "a mean weighted by intensity and/or observational error" is often used. However this is beyond the aim of this lesson. In some cases an astronomer chooses a different weight depending on what he/she wants to know.

In (Q13), your student should find that a galaxy is symmetric not only in spatial shape but also in motion.

Rotation of a galaxy

This part is separated as a supplementary activity, because it contains an advanced topic. To get a conclusion which is consistent with modern astronomy, some additional information is actually required.

Radial velocity is the same at everywhere along the same line of sight, if a galaxy rotates as a whole (rotation angular velocity is the same at all the position; called rigid rotation) as assumed in (Q14).

In (Q15) we assume rotation velocity is independent of radius and rotation period is proportional to the radius. Non-rigid rotation like this is called differential rotation. The rotation assumed here is called flat rotation, which is a kind of differential rotation.

Radial velocity of a flat rotating disk is the largest on the line perpendicular to the line of sight, and radial velocity at the nearer or farther position on the same line of sight is slower. Therefore, the emission appears only between the systemic velocity and the rotating velocity plus or minus the systemic.

In (Q17), your student can remember that the actual galaxy shows the similar pattern to the flat rotating disk. From this result your student might find that the disk of the galaxy cannot be rigid.

Discovery of the flat rotation was the reason why astronomers discussed about the `winding-up dilemma' of spiral galaxies in the last century (a problem that the spiral would wind more and more tightly in a short time). In the case that your student understands about the balance of gravity and centrifugal force, you can go further on to the discussion about the “missing mass”.

The dataset used in this lesson is the same as used in Sakamoto et al. (1997) Astrophys. J. 475, 134.

4-3. Expansion of the universe

The aim of this lesson is to understand that the Doppler effect can be used to measure the relative motions of various astronomical objects. In this lesson we focus expansion of the universe, because it very famous topic which is tightly related to observations with Doppler shift. Expansion of the universe is frequently covered in various mass-medias. However, most of them are not enough explanation about the concept, what is its observational proof, and how the concept can be derived from the observed data.

There are many methods to measure the distance to a galaxy. So, you do not have to stick to the method used in this lesson: using the maximum intensity of supernovae. If your student can understand and accept another method to estimate the distance to a galaxy, you can use data of other galaxies which distances are measured with that method.

How is the universe expanding?

(Q1) and (Q2) have no definite answers. Your student can answer to these questions to figure out what is his/her own preconception before learning the actual concept. In (Q2), your students may go further to discuss whether some of the answers can be used actually.

Peak intensity of a supernova

If the student do not understand the inverse square law, supplemental activity 3-b of this curriculum or supplemental activity 19 of the HOU should be helpful.

Spectra of galaxies where supernovae have already appeared

In this section we use either HOU-IP or Makali`i. No practical instruction of usage of the software is shown in this workbook, so your student must learn it beforehand. The required skills are how to read the position of a pixel, how to read the wavelength of a spectrum line from the position of a pixel, and calculating speed from wavelength shift, etc.

In (Q4) it is a cue to identify emission lines that there are the same patterns of emission lines which change their positions along wavelength axis from galaxy to galaxy. All spectra of galaxies used here show emission lines and their spectral ranges are between 649 nm and 673 nm around Hα line. The spectra also show emission lines of terrestrial atmosphere which appear at the same wavelengths. Read lesson 2-3 to learn how to identify which are which.

Some of your students may find other criteria to identify emission lines of the galaxy.

For example, “all emission lines of the galaxy are warped (due to rotation of the galaxy)”, and “intensity of some emission lines changes from position to position in the galaxy (due to internal structure of the galaxy)”.

In (Q5), measured wavelength changes its value depending on where your student measures because of rotation of the galaxy. A flinch of your student may lead him/her to find what happens in the galaxy. Though it is preferable to measure it at the center of the galaxy, the difference between the measured position and the center does not affect the result severely. This subject is dealt in more detail in section 4-2.

In (Q6), your student should use the values shown just before (Q4) as wavelengths at both edges. We hope your student measures both emission lines, although the workbook requires measuring either of two emission lines. Your student should measure both lines when he/she has enough time or works as a collaboration with other students.

Although the slice function of image processing software is helpful, your student will find a good way by him/herself. (It is often seen in HOU activities.)

In (Q7) your student makes identification of emission lines. It is not simple to identify a line actually. In academic research a scientist also uses other information to identify it. For example, wavelength, spectrum pattern with other lines, popularity of material emitting that line from similar objects, etc. In the case of a line shifted beyond his/her expectation, even professional can overlook them; identification of lines in quasar spectra is of this kind.

Through an activity in this lesson your student should reduce a concept that line identification is not referred from a textbook.

In (Q9), light speed is accurate enough about 300,000km/s. Your student may get the formula for the Doppler effect by him/herself.

In (Q10), your student can find that radial velocity of a galaxy is proportional to the distance to it. This is the “Hubble’s Law” found by Hubble.

Finding a general trend using observed data

In most cases actual observed data show less clear relation than expected by most people or shown in textbooks. It is because actual observed data always contain observational errors and affected by secondary effects. Although we mentioned about observational errors in the workbook, your student may not understand it only by this lesson.

The data used here are also affected by “proper motion” of each galaxy. A galaxy shows random velocity deviated from the universe expansion. This random motion is called as “proper motion of a galaxy” and is up to the order of 1000 km/s for some galaxies. To avoid the proper motion the simplest way is to measure as many galaxies as possible and find an averaged trend. The reason why Edwin Hubble found the law using only several galaxies is these galaxies show a trend between distance and radial velocity far beyond random motion.

When your student is advanced in scientific thinking, you may suggest him/her to make a discussion from a question why the data dose not show exactly proportional relation to observational error and sampling effect (an apparent relation is not real when sample is too small).

A diagram of time, distance, and velocity of trains

The aim of this section is to understand a relation between distance, time and speed on a plot. This should help your student to understand the relation between two plots in (Q11) and (Q15).

The timetable present here is that of Shinkansen (bullet trains) in March 2001. The distances shown here are used to account a fare and the actual distances are about 10% closer. These four trains are different speed because train types are different. You should change the data depending on your country, because the most important point of this section is to get concept what the plot represents through an example which your student is familiar. For example, a TVG timetable may be good for a French student, an ICE may be good for German, an airline timetable may be good for a US student.

In (Q12) your student is required to understand that the gradient of the plotted line is related to the velocity.

Radial velocities of galaxies and expansion of the universe

(Q13) is an introduction to the converting from km/s to light years per year. Two words light-year and year may be confusing for your student. In such cases you should use pc (parsec) instead of light-year, which is often used in astronomy. 1 pc=3.26 light-year.

In (Q15) your student makes a plot from the table made in (Q14). When your student does not understand the relation between velocity and gradient of a plotted line, you may give some suggestion to him/her.

The point of (Q16) is that all distances to any galaxies become 0 at the same time in the past. This is because the radial velocity of a galaxy is proportional to its distance. From this relation Hubble concluded that the universe is expanding. However, your student does not require getting the same conclusion in this section by him/herself.

Comparison between the conclusion reached here and the first impression answered in (Q1) is effective to understand what the expanding universe means.

4-3b. Why is a night sky dark?

The aim of this section is what we should think when a logical result does not match an observed fact through consideration of the paradox of Olverse. You may be skip this section, because this section is out of main stream of astronomical spectroscopy itself

Is a star a point source?

Through (Q1) and (Q2) your student can feel a relative size of a star with its distance by drawing. It may be helpful to present relative sizes of Sun and planets with its orbit sizes in the same scale. For example, in the scale of 1 to 2 x 10^{10} the diameter of Sun is about 7 cm, and the distance to the nearest star α Centauri is about 2000 km. (In the same scale the distance between Sun and Earth is 7.5m.)

The number of stars which you can see

The point of (Q3) to (Q5) is to understand that the number of stars in a unit volume increases in the second power of the distance through drawing. An advanced student who has already understood a relation between two- and three-dimensional geometry can solve (Q3) and (Q4) as a single question and can understand the second inverse proportion law directly.

Brightness of a night sky

To answer (Q7) your student has already understood that intensity decreases second inversely proportional to the distance. This can be learned in the Supplemental Activity 19 of HOU and 4-3c of this workbook. The exact answer to this question is that night sky brightness should be infinite. However, your student is only required to understand that the sky would not be dark. Of cause, this conclusion is not true. This paradox is called as Olverse's paradox.

Why we get the paradox?

There are many answers to solve the Olverse's paradox. The point of (Q8) is that your student find there are many possibility to solve a problem. In most cases your student cannot conclude that the universe is expanding. Historically many other hypotheses were proposed such as "stars are located only near the solar system." or "the universe is finite." Instead of (Q8) you can ask to your student "How the answer to (Q7) changes, if we assume the universe is expanding?"

4-3c. Distance and apparent intensity

The aim of this lesson is to understand that apparent intensity is inversely proportional to the square of the distance. Your student can learn this law in the supplemental activity 19 in the original HOU workbook through experiments. It may be more impressive to your student. Please read it, too. You can choose either of them for your student.

Area where a light source illuminates

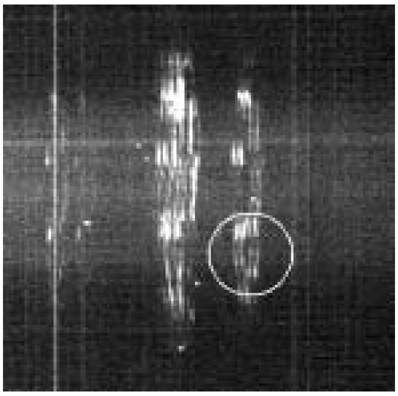
With (Q3) your student will find the relation between distance and apparent intensity by consideration that the same amount of light illuminates on the two areas one of which just shades the other. A three-dimensional model with cardboards, wire, and thread might be more helpful to understand.

You can skip (Q4) and (Q5) when your student has already understood the relation between a two-dimensional draw and three-dimensional figure. And you can directly introduce the inverse square law.

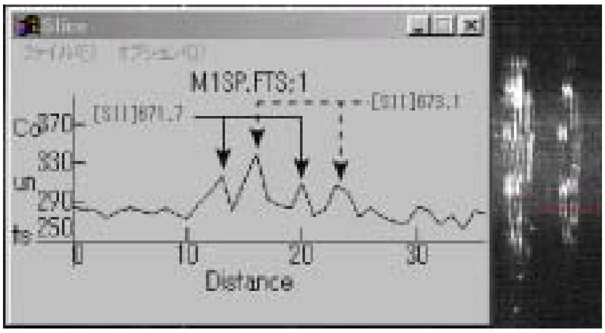
4-4. Expansion of Crab nebula

The aim of this lesson is to measure expanding velocity of Crab nebula.

In (Q1) your student will find where an emission line of an atom/ion is split due to Doppler shift. In this lesson your student can find several emission lines which show split. Note that there are pairs of emission lines which are close in wavelength not due to Doppler shift.



In (Q2) your student measure the splitting width of emission lines using the “slice” function of the “data process” menu. Your student must take care to identify the emission lines. In some cases emission line structure is so complicated that wavelength order is inverted as shown below.



In the next table we show a result of identification of emission lines appeared in figure 2.

Name of the emission line	Interval
[S II] 671.7nm	8 pixels

In (Q3) your student can estimate the relation between pixel and wavelength using two emission lines. For example, when an [S II] line at 671.1 nm and another [SII] line at 673.1 nm separate 4 pixels, we can estimate the conversion ratio as (673.1 – 671.7)/4 = 0.35 nm/pixel.

In (Q4) we can derive a Doppler split of [S II] line (at 671.7 nm in the rest frame). When the split is measured as 8 pixels, it should be 2.8 nm using the results from (Q2) and (Q3) by calculation of 8[pixel] x 0.35 [nm/pixel].

In (Q5) we can estimate the expanding velocity from the result of (Q4) with the formula of the Doppler effect. When the split is 2.8 nm, the velocity difference is (2.8/673.1)×299800＝1247.1[km/s] and the expanding velocity is 623.6 km/s because it should be half of the velocity difference. An actual estimation may be different from point to point of the nebula. Through this estimation your student knows that expanding velocity of the nebula is much faster than motion seen on the earth in his/her daily life.

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Reference of lesson 1-2: “Fraunhofer-sen no geniri ni kansuru enji jikken (Demonstration on principle with Fraunhofer lines)”, Yukimasa Tsubota & Naoki Matsumoto (2000), “Tenmon Kyoiku (Astronomy Education)” No.44, vol.12-3; text in Japanese

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Lesson 2-2: Reiko Furusho, Tetsuya Kawabata

Lesson 2-3: Tetsuya Kawabata, Tatsuyuki Arai

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Lesson 1-3: Kaoru Kimura

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