Spectroscopy in Astronomy

XUVI-Lecture 2

Table of contents

01 What is Spectroscopy

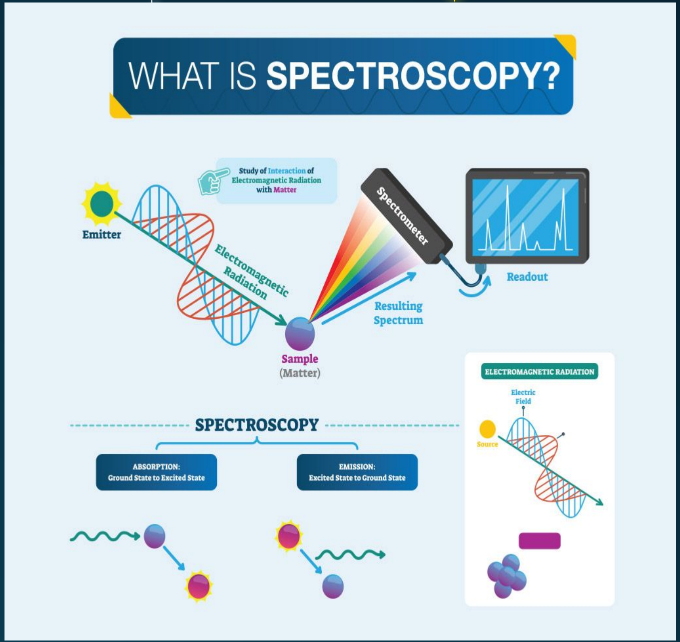
02 Spectroscopy for Astronomy

03 Working of spectroscope

04 Conclusion

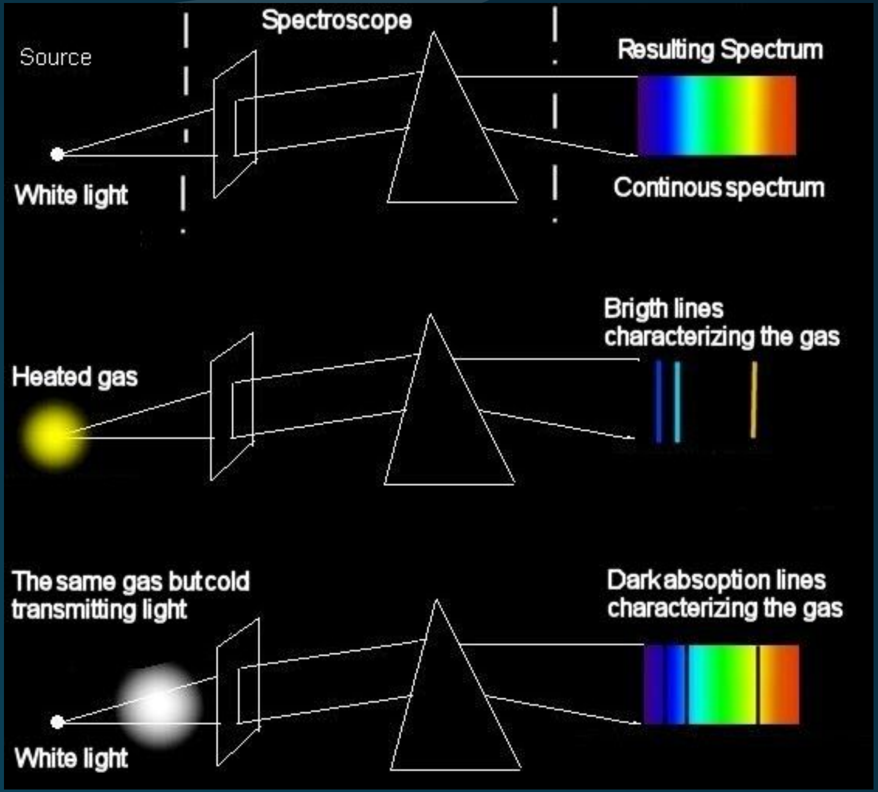
Spectroscopy

1. Spectroscopy is a technique in which the visible light that comes from objects(like stars and nebulae) is examined to determine the object’s composition,temperature,motion and density.
2. Spectroscopic techniques have been applied in virtually all technical fields of science and technology. Radio-frequency spectroscopy of nuclei in a magnetic field has been employed in a medical technique called magnetic resonance imaging(MRI) to visualise the internal soft tissue of the body with unprecedented resolution.



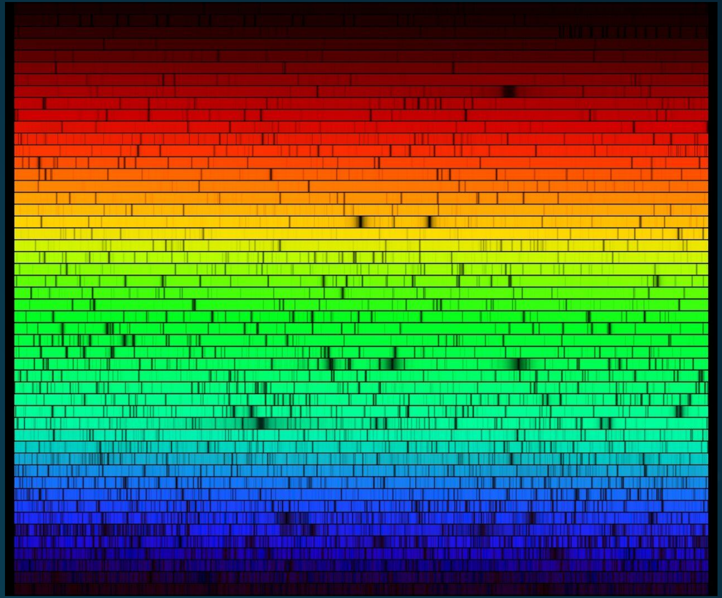
3. A continuous spectrum can identify elements by the presence of dark bands, and it also tells scientists how hot the object is: As the temperature goes up, the spectrum has increasing amounts of green, blue and violet colors.

4. In addition, different cool gases will absorb different wavelengths of light and generate a signature spectrum with dark lines at characteristic places. Because of this, we can determine the composition of gases by observing light that has passed through them.



Astronomical Spectroscopy

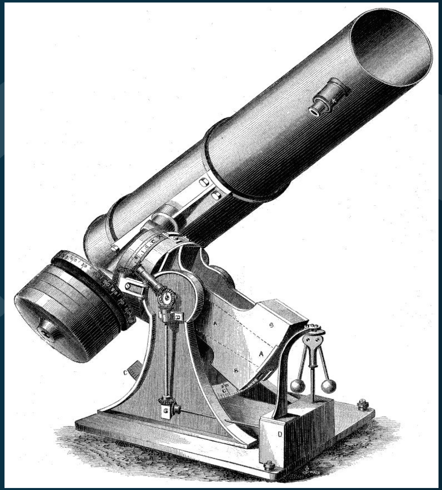
1. Astronomical spectroscopy is used to measure three major bands of radiation in the electromagnetic spectrum- Radio waves,X-rays, and visible light.
2. It is used to derive many properties of stars and galaxies, such as their composition and movement.
3. Astronomical Spectroscopy began with Issac Newton's initial observations of the light of the sun, dispersed by a prism.
4. However, when the spectrum was closely examined, the rainbow was found to be interrupted by hundreds of tiny dark lines(called Fraunhofer lines). These lines showed that some wavelengths are being absorbed by gases in the outer atmosphere of the Sun, and from this, we can determine which elements are in the Sun's atmosphere.

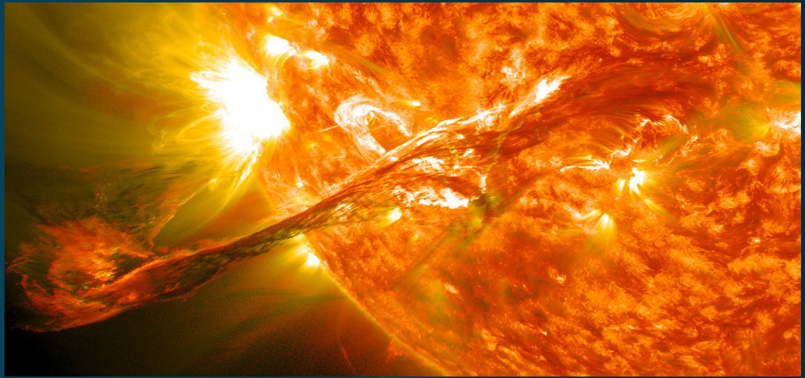


Extremely high resolution spectrum of the Sun

Discovery of Helium

1. In 1868, Sir Norman Lockyer observed strong yellow lines in the solar spectrum which had never been seen in laboratory experiments. He deducted that they must be due to an unknown element, which he called helium, from the Greek helios (sun)
2. It was only 25 years later that Helium was detected on earth.

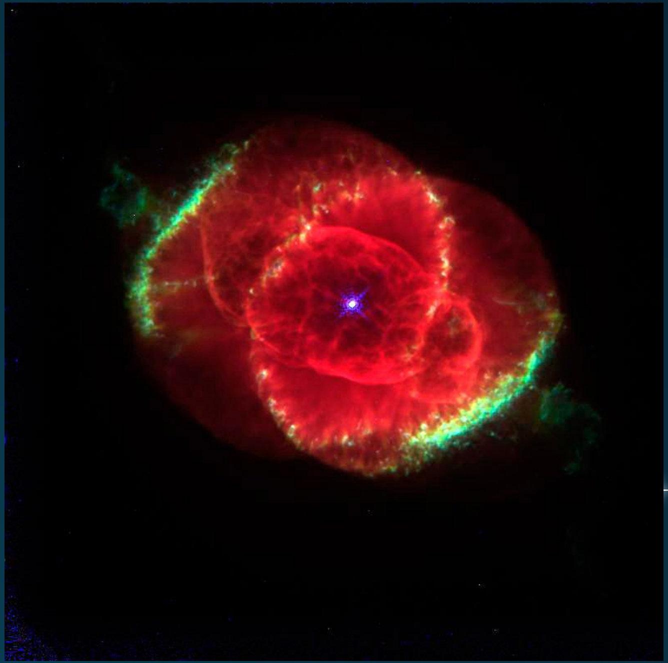




Helium in solar prominences

Nebulae

1. In earlier times, the word ‘nebula’ was used to describe any fuzzy patch of light that didn’t look like a star.
2. However, when their spectra were studied, it was found that many of these nebulae, such as the Andromeda Nebula, had spectra that looked similar to stellar Nebula, and these turned out to be galaxies.
3. Others, such as the Cat’s Eye Nebula, had very different spectra consisting of few strong emission lines rather than the continuous spectrum seen in the sun.
4. These lines did not correspond to any element seen on Earth, and astronomers suggested them to be from a new element nebulium. However, later studies showed that because of the extremely rarified vacuum found in nebulae, atoms behaved differently, leading to the strange spectrum.



Galaxies

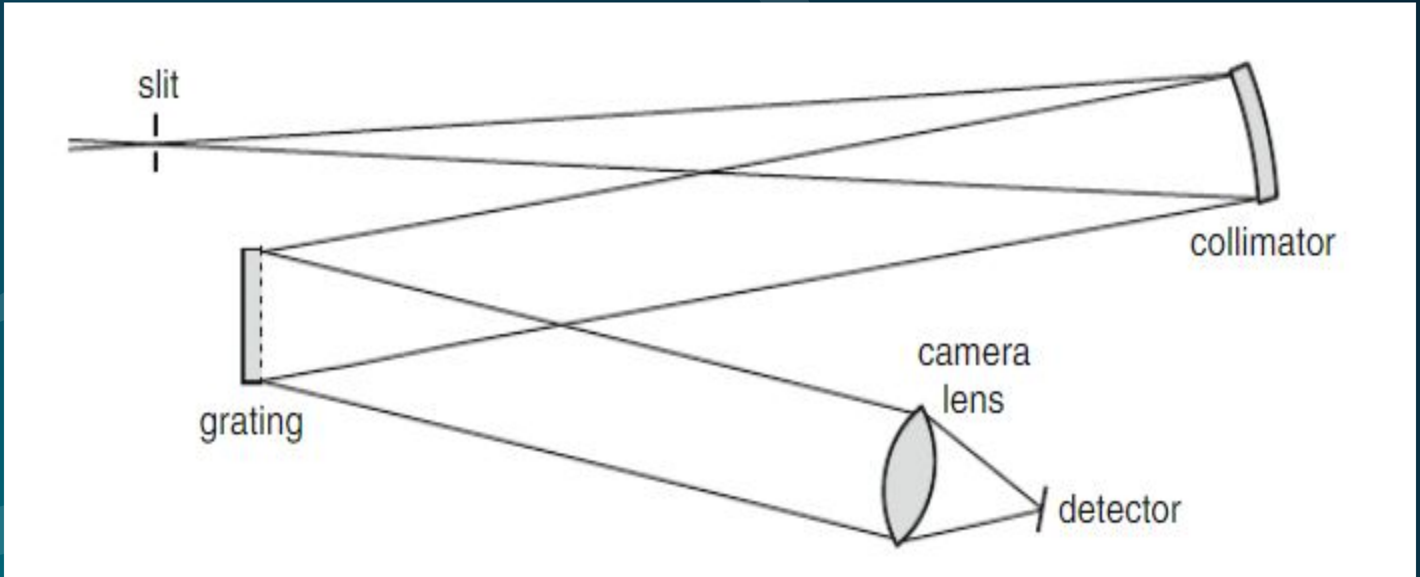
1. Galactic Spectroscopy has led to many fundamental discoveries. Edwin Hubble discovered in the 1920s that, apart from the nearest ones(those in what is known as the Local Group), all galaxies are receding from the Earth. The further away a galaxy, the faster is it receding.

   How? All known elements emit and absorb particular wavelengths of light, which is part of the electromagnetic spectrum. By studying the wavelengths of light (as indicated by 'lines' within the electromagnetic spectrum) emitted by an object in space, astronomers can get a range of information. One thing they examine is the change in position of lines in the spectrum from a star–this can tell astronomers how far away the star is, whether it is moving towards or away from us and how fast it is moving

2. This was the first indication that the universe originated from a single point, in a Big Bang.

   Learn more about it here .

Spectroscope- Parts and Functions



1. Astronomical spectrographs contains these essential elements: a slit on to which the light from the telescope would be focused; a collimator, which would take the diverging light beam and turn it into parallel light; a disperser (usually a reflection grating); and a camera that would then focus the spectrum onto the detector.
2. In a multi-object fiber spectrometer, such as Hectospec on the MMT ,the slit is replaced with a series of fibers. In the case of an echelle, such as MagE on the Clay 6.5 m telescope, prisms are inserted into the beam after the diffraction grating to provide cross-dispersion.

More about multi-object fiber spectrometer: Link

3. In the case of an objective-prism spectroscopy, the star itself acts as a slit “and the Universe for a collimator”

Working:

The slit sits in the focal plane, and usually has an adjustable width w. The image of the star(or galaxy or other object of interest) is focused onto the slit. The diverging beam continues to the collimator, which has focal length L_{coll}. The f-ratio of the collimator (its focal length divided by its diameter) must match that of the telescope beam, and hence its diameter has to be larger the further away it is from the slit, as the light from a point source should just fill the collimator. The collimator is usually an o-axis paraboloid, so that it both turns the light parallel and redirects the light toward the disperser.

In most astronomical spectrographs the disperser is a grating, and is ruled with a certain number of grooves per mm,usually of order 100–1000. If one were to place one's eye near where the camera is shown in the image present in two slides before, the wavelength λ of light seen would depend upon exactly what angle i the grating was set at relative to the incoming beam (the angle of incidence), and the angle θ the eye made with the normal to the grating (the angle of diffraction). How much one has to move one's head by in order to change wavelengths by a certain amount is called the dispersion,and generally speaking the greater the projected number of grooves/mm (i.e., as seen along the light path), the higher the dispersion, all other things being equal. The relationship governing all of this is called the grating equation and is given as: $\mathbf{m\lambda = \sigma(\sin i + \sin \theta)}$

04 Conclusion

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Modern spectroscopes often replace the prism with narrow slits called diffraction grating. The slits spread the light into different wavelengths by different amounts, which makes it possible to measure the wavelengths.

Multi Object Spectroscopy: MOS is an efficient way to observe the spectra of an aggregate of sources that are within the field of view of an instrument at a single pointing. Most MOS instruments are wide field instruments with fields of view covering several square arcminutes up to a square degree. Typically, the source light exiting the telescope optics is focused onto the aperture plane of an instrument where the light passes through narrow slits or fiber optics and becomes dispersed by a refractive element like a prism or grating. The spectra are then imaged onto a detector. The data undergo rectification, registration, and extraction, as well as wavelength and flux calibration, typically using software designed specifically to handle multiplexed spectra.

Spectroscopes need not be limited to professional scientists. Building your own spectroscope using everyday items takes just under an hour, which we will cover next week.

Astronomical Spectroscopy- Read upto section 2.6