Explaining Complex Astronomical Observation Experiments to Middle School Students Using Simple Physics Methods

Authors: Li Li

Date: 2025-10-17T00:00:00+00:00

Abstract

Like other branches of physics, astronomy encompasses both experiment and theory. Theoretical astronomy employs the same tools and methods as other branches of theoretical physics. However, experimental astronomy differs from other experimental disciplines in that we cannot control the objects of astronomical experiments, but can only observe various astronomical phenomena in the universe. Nevertheless, in practice, there is scarcely any distinction between the design and execution of experiments in physics and those of astronomical observations. Naturally, there is also no particular difference in the scientific methodology of inquiry between the two cases. This paper specifically employs the simplest physical methods to explain complex astronomical observation experiments to middle school students.

Full Text

Explaining Complex Astronomical Observation Experiments to Middle School Students Using Simple Physics Methods

National Astronomical Observatories, Chinese Academy of Sciences; Huizhou No.1 Middle School

Like other branches of physics, astronomy involves both experiment and theory. Theoretical astronomy employs the same tools and methods as other branches of theoretical physics. However, experimental astronomy differs from other experimental disciplines in that we cannot control the objects of our experiments and can only observe various astronomical phenomena in the universe. Nevertheless, in practice, there is almost no distinction between the design and execution of

experiments in physics and the design and execution of astronomical observations. Naturally, there is no particular difference in the scientific methodology of inquiry between the two cases. This paper precisely adopts the simplest physics methods to explain complex astronomical observation experiments to middle school students.

Keywords: astronomy; observational experiments; optics; data images

Astronomy is a branch of physics. Broadly speaking, astronomy investigates large-scale phenomena—the Sun, planets, stars, galaxies, and the entire universe. Moreover, much of astronomy involves phenomena at the microscopic particle level. Currently, we generally define astronomy as the physics of studying distant objects and phenomena. We know that the physical phenomena covered by astronomy are diverse, and witnessing these physical phenomena firsthand is indeed an important method for obtaining evidence in astronomical research.

2 Advantages of Telescope Observation Over Human Eye Observation

We conduct astronomical observations and experiments by detecting and measuring electromagnetic radiation from distant celestial bodies. To record and characterize electromagnetic radiation, at minimum, a camera is needed to focus the approximately planar electromagnetic waves from distant light sources, and a detector located at the camera’ s focal plane to record the signal. Thus, the so-called astronomical telescope is simply another term for a camera specifically designed for observing distant objects. The most basic camera-detector combination is the human eye, which consists of a lens (the camera) that focuses images onto the retina (the detector). Photoreceptor cells on the retina then convert the light intensity of the image into neural signals transmitted to the brain.

Before Galileo introduced the telescope into astronomical observation experiments, astronomy relied solely on the naked eye. However, the eye has numerous shortcomings as an astronomical tool. The dark-adapted pupil has an aperture smaller than 1 centimeter, with limited light-collecting area and angular resolution. A camera’ s light-collecting capability depends on its aperture area (for example, the aperture of an objective lens, or the primary mirror of a reflecting telescope). The larger the aperture, the more photons can be detected per unit time, thus enabling observation of fainter light sources. Currently, the largest operational visible-light telescope on Earth has a primary mirror diameter of

3 Physical Explanation of Telescope Angular Resolution

Telescope angular resolution refers to the minimum angular separation between two light sources in the sky that can be recognized as distinct sources by the camera. According to wave optics principles, when a plane wave of wavelength λ passes through a circular aperture of diameter D and focuses on a detector, it produces a concentric ring diffraction pattern. The center of these rings coincides with the position expected from geometric optics, and the angular radius of the central spot (in radians) is =1.22. For example, consider an image of a star field captured by a camera equipped with a band-pass filter that only allows light within a specific wavelength range to pass. This image will consist of a set of such diffraction patterns, with each star position corresponding to one diffraction pattern. To actually observe these diffraction patterns, it is necessary to ensure the image is not blurred, whether due to imperfections in the optical system construction or other factors such as Earth' s atmosphere. When the angular separation between the central points of diffraction patterns from two adjacent sources in the sky is less than λ/D, they will overlap and become difficult to distinguish.

Similarly, light sources with angular sizes smaller than this diffraction limit will produce unresolved images indistinguishable from those produced by point sources of zero angular extent. Therefore, in principle, a 10-meter telescope operating at the same visible wavelengths as the eye can have an angular resolution 1000 times higher than that of the eye. In practice, due to the constantly changing and blurring effects of the atmosphere, ground-based optical telescopes rarely achieve diffraction-limited performance. The optical wavelength range of electromagnetic radiation is roughly defined as 0.32-1 micrometers. However, in radio and infrared astronomy, diffraction-limited angular resolution observations are routine, and significant progress has been made in this area in the optical range in recent years. Angular resolution is crucial not only for discerning details of astronomical sources (for example, observing Jupiter' s moons and surface features, the composition of star-forming regions, or fine details in galaxies), but also for detecting faint unresolved sources against the background of Earth' s atmospheric emission.

4 Principles of Astronomical Data and Image Formation

We know that the night sky' s glow originates from scattered light of stars, the Moon, and artificial light sources, as well as fluorescence from atoms and molecules in the atmosphere. The higher a telescope' s angular resolution, the smaller the solid angle over which starlight is spread, and thus the higher the contrast between the star' s image and statistical fluctuations of the sky background.

In astronomical observations, detectors can collect faint signals over arbitrarily long exposures, thereby detecting extremely faint light sources. A disadvantage of the human eye is that it is only sensitive to a narrow visual range of electromagnetic radiation wavelengths (approximately 0.4-0.7 micrometers, i.e., within the optical range defined above), whereas astronomical information exists across all regions of the electromagnetic spectrum, from radio to infrared, visible, ultraviolet, X-ray, and gamma-ray bands. Finally, detectors other than the eye can preserve objective records of observations that can then be examined, analyzed, and disseminated.

Astronomical data are always saved in digital format for subsequent computer processing. Today, all telescopes used for professional astronomy are equipped with detectors for recording data. The detectors used in optical, near-ultraviolet, and X-ray astronomy are almost all Charge-Coupled Devices (CCDs), the same type used in digital cameras. A CCD is a silicon wafer divided into numerous pixels through an insulating buffer layer etched onto the silicon and selected voltage differences applied across its area. Photons arriving at the CCD liberate photoelectrons via the photoelectric effect. The photoelectrons accumulated in each pixel during exposure are then read out and amplified, producing an electric current proportional to the number of photons reaching the pixel. This enables the formation of digital images of the observed sky region. The astronomical observation technique of generating images by focusing a portion of the sky onto a detector is called imaging. Every parameter characterizing electromagnetic waves can carry useful astronomical information, and different techniques have been designed to measure these parameters.

Furthermore, we can measure the signal intensity produced by a light source. For example, in photon-counting devices, this is done by counting the total number of photons collected from the source during an integration time. Photon flux is related to intensity, which is the square of the time-averaged electric field amplitude ( ). Measuring a source’ s photon flux is called photometry. In time-resolved photometry, we can make repeated measurements of brightness variations over time, thereby measuring the time dependence of .

5 Spectroscopy in Astronomical Observation Experiments

The wavelength λ (or frequency) of light can be determined in various ways. A band-pass filter placed in front of the detector allows only electromagnetic radiation within a specific wavelength range to reach the detector while blocking all other wavelengths. Alternatively, light can be reflected or transmitted through a dispersive element such as a prism or diffraction grating before reaching the detector. Light of different wavelengths will be deflected at different angles, thus landing at different positions on the detector. Consequently, a single light source will be spread out into a spectrum, with the signal at each position in the spectrum proportional to the intensity at different wavelengths. This technique is called spectroscopy.

The phase shift ϕ of a light wave arriving at the detector can reveal its precise direction of arrival and effects such as scattering that the wave experienced along its path from the source to the detector. Phase can be measured by combining electromagnetic waves received from the same source to create an interference pattern, a method known as interferometry. In interferometry, the baseline distance B between the two most widely separated telescopes replaces the aperture in determining angular resolution as λ/B.

In radio astronomy, signals from radio telescopes distributed across the globe and even in space are often combined, providing baselines on the order of 10^4 kilometers and very high angular resolution. The polarization amount, polarization type (linear, circular), and the direction of the polarization vector in the sky can be determined. In optical astronomy, this can be achieved by placing a polarization filter in the beam, allowing only specific polarization components to reach the detector. Measuring the polarization properties of a light source is called polarimetry.

There has always been a desire to characterize all parameters of electromagnetic waves emitted by sources, but this is rarely feasible in practice. However, multiple characteristics can often be measured simultaneously, and these techniques are given appropriate names, such as spectropolarimetry, where both the intensity and polarization degree of light from a source are measured as functions of wavelength.

1. Nie Qingxiang et al., *Fundamentals of Astronomy*, Beijing: China Personnel Publishing House, 1996
2. He Xiangtao, *Observational Cosmology*, Beijing: Science Press, 2002
3. Cui Zhenhua et al., *Astronomy Museum*, Zhengzhou: Henan Education Publishing House, 1995
4. Ye Shuhua, *Concise Dictionary of Astronomy*, Shanghai: Shanghai Dictionary Publishing House, 1986
5. Xuan Huancan, *History of Astronomy*, Beijing: Higher Education Press, 1992

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.