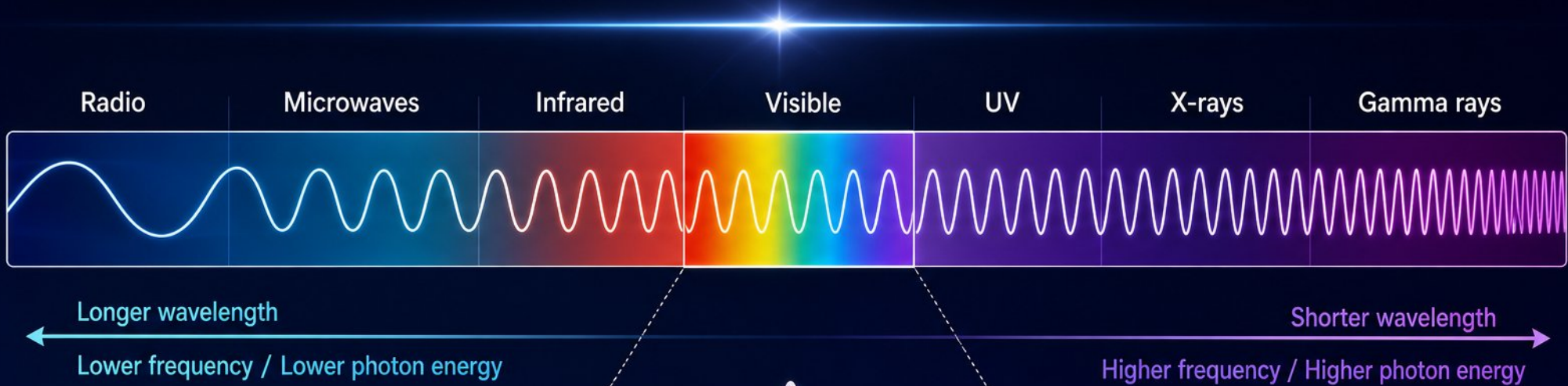


Light, Spectra, and What They Reveal

- Light carries chemical fingerprints through spectral patterns
- Spectra reveal composition, motion, and temperature
- Identify elements without visiting distant objects physically
- Neon signs, street lamps, and starlight all share this principle



The Electromagnetic Spectrum: One Light, Many Energies



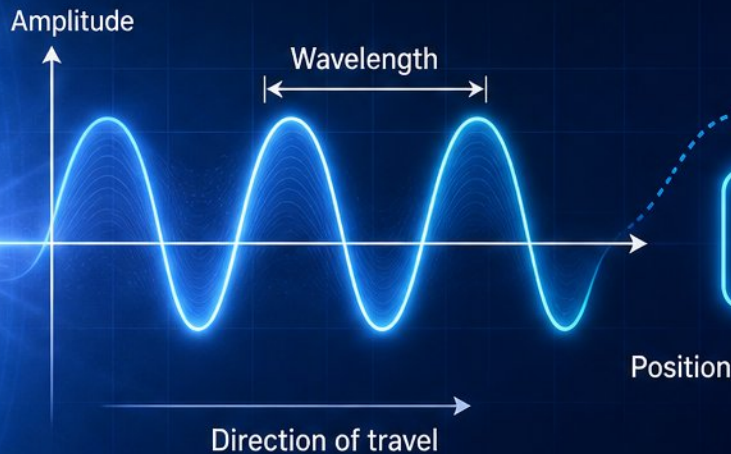
- Radio, microwaves, infrared, visible, UV, X-rays, gamma rays
- $\lambda = c / \nu$ and $E = h \times \nu$
- Shorter wavelength = higher frequency = higher photon energy
- Visible light is only a narrow band
- Microwave ovens, heat, color, UV, X-rays: same phenomenon



Waves, Photons, and the Dual Nature of Light

WAVE MODEL

Continuous, spread out



PHOTON MODEL

Discrete, particle-like

$$E = h \times \nu$$



- Wave model: wavelength, frequency, amplitude, and speed in a vacuum



- Photon model: discrete energy quanta; $E = h \times \nu$



- Duality: two descriptions for different observations



- Photons interact with atoms; waves explain diffraction

Emission and Absorption: Two Faces of Spectra

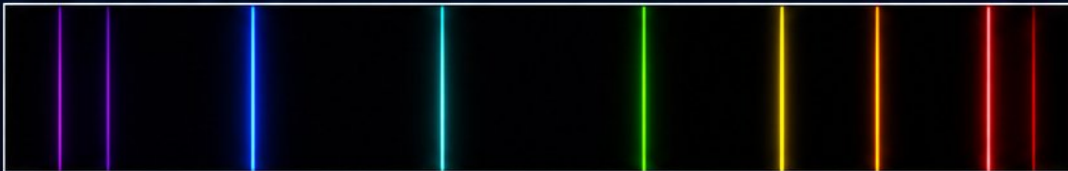
1. Continuous Spectrum

Hot dense sources emit all wavelengths



2. Emission Spectrum

Hot thin gas produces bright lines



3. Absorption Spectrum

Cool gas in front of hot source creates dark lines



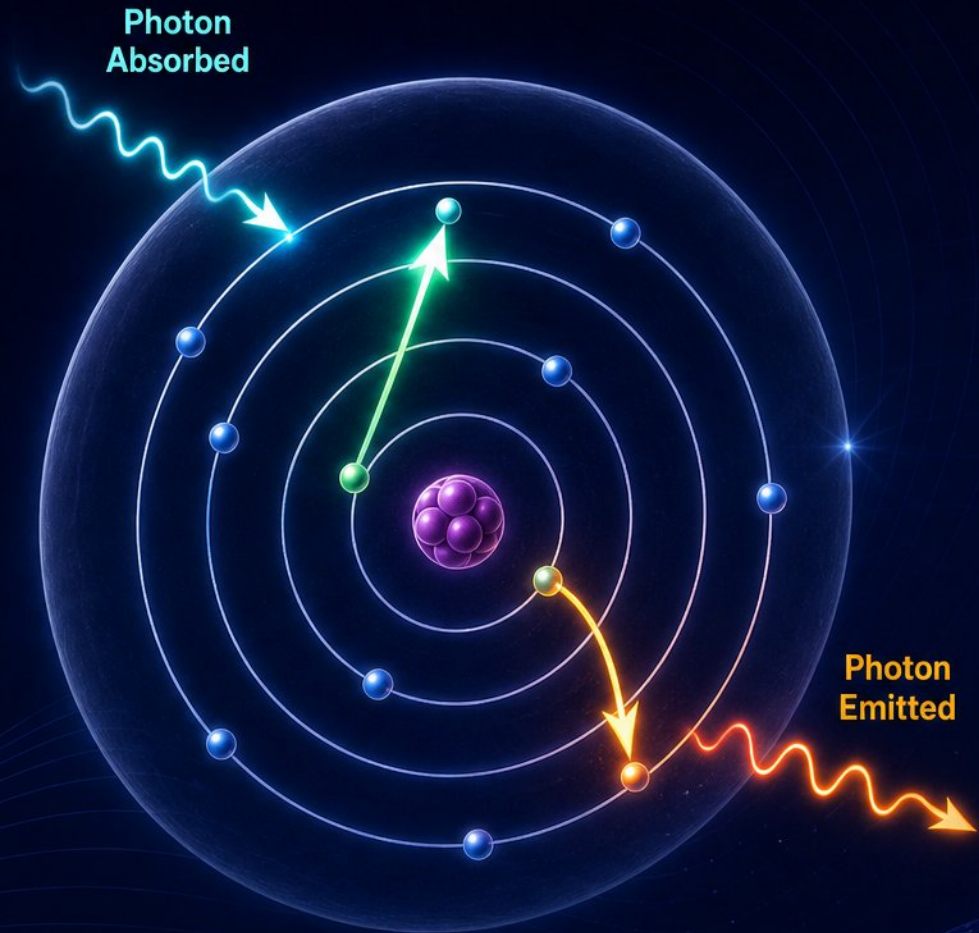
- Continuous: hot dense sources emit all wavelengths
- Emission: hot thin gas produces bright lines
- Absorption: cool gas in front of hot source creates dark lines
- Kirchhoff's laws link physical conditions to spectral patterns
- Recognizing these patterns is the first step in reading any spectrum



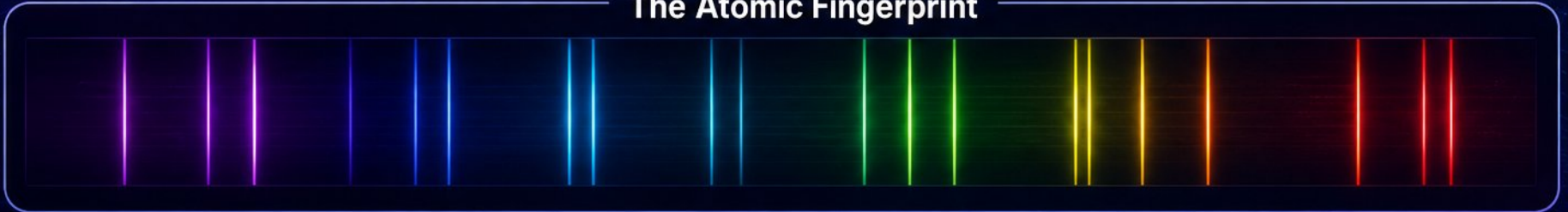
THE ATOMIC FINGERPRINT

Atoms Create Spectral Signatures

- Electrons occupy discrete energy levels, not a continuous range
- Photons are absorbed or emitted only during level jumps
- Each element has a unique set of allowed transitions
- Spectral lines act as atomic fingerprints for identification



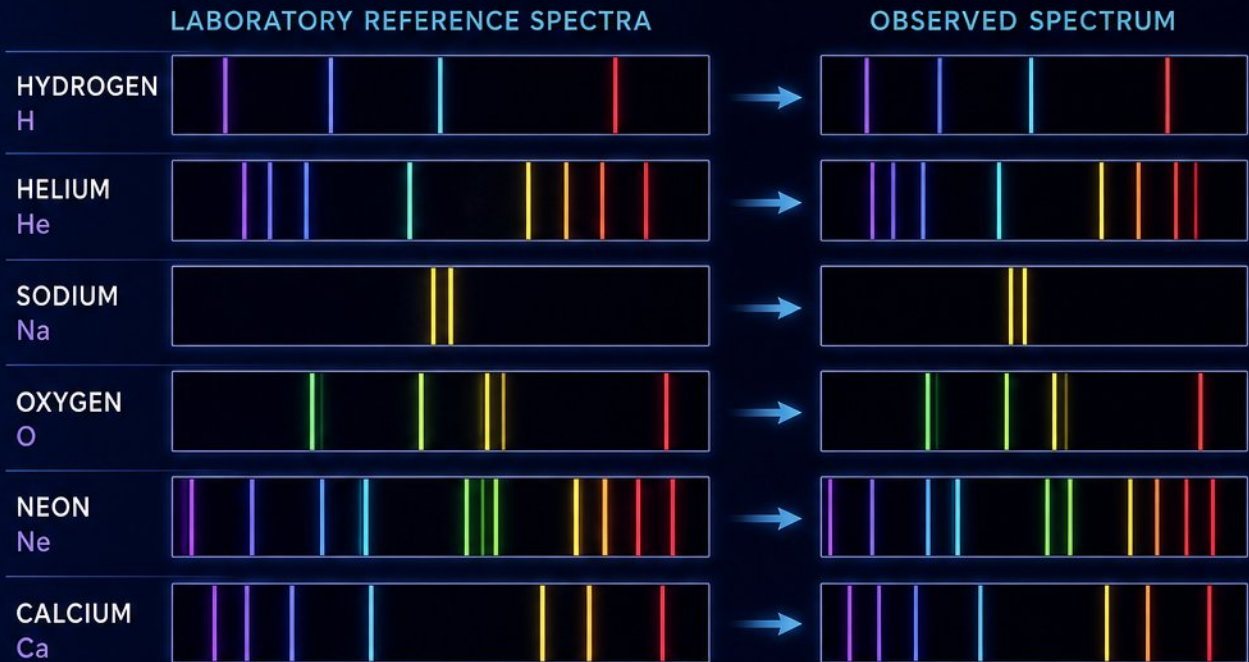
The Atomic Fingerprint



Reading Composition From Spectral Lines

- Match observed lines to laboratory-measured wavelengths of known elements
- Works across the Sun, stars, nebulae, and planetary atmospheres
- Sodium street lamps, neon signs, hydrogen Balmer lines are examples
- Missing lines do not always mean missing elements; temperature and ionization matter

THE ATOMIC FINGERPRINT



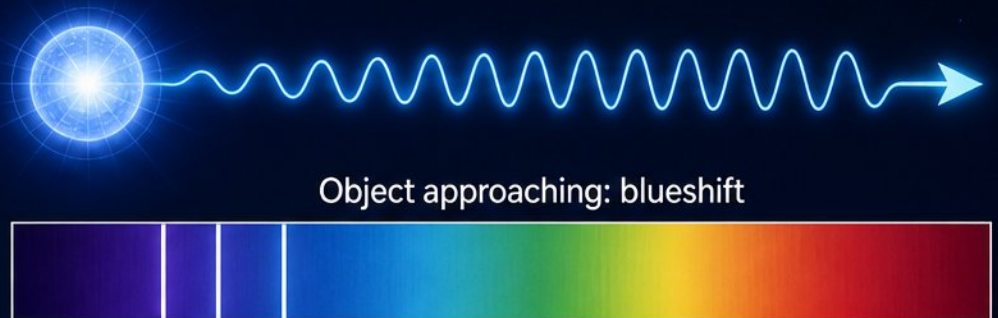
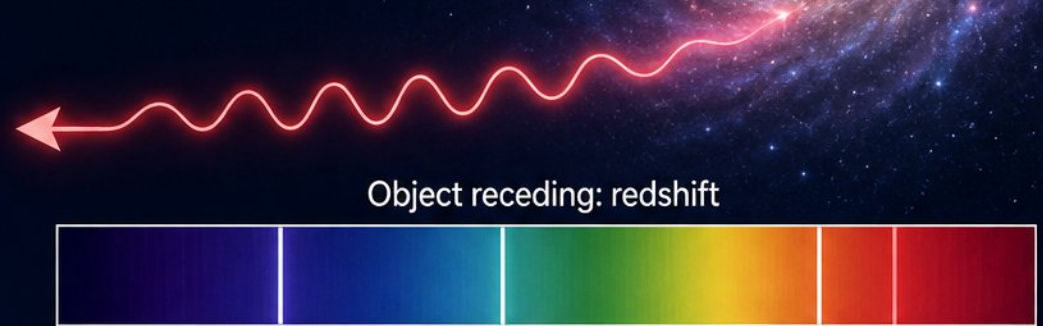
OBSERVED STAR SPECTRUM



Dark lines (absorptions) occur where elements absorb light at the same wavelengths as their emission lines.

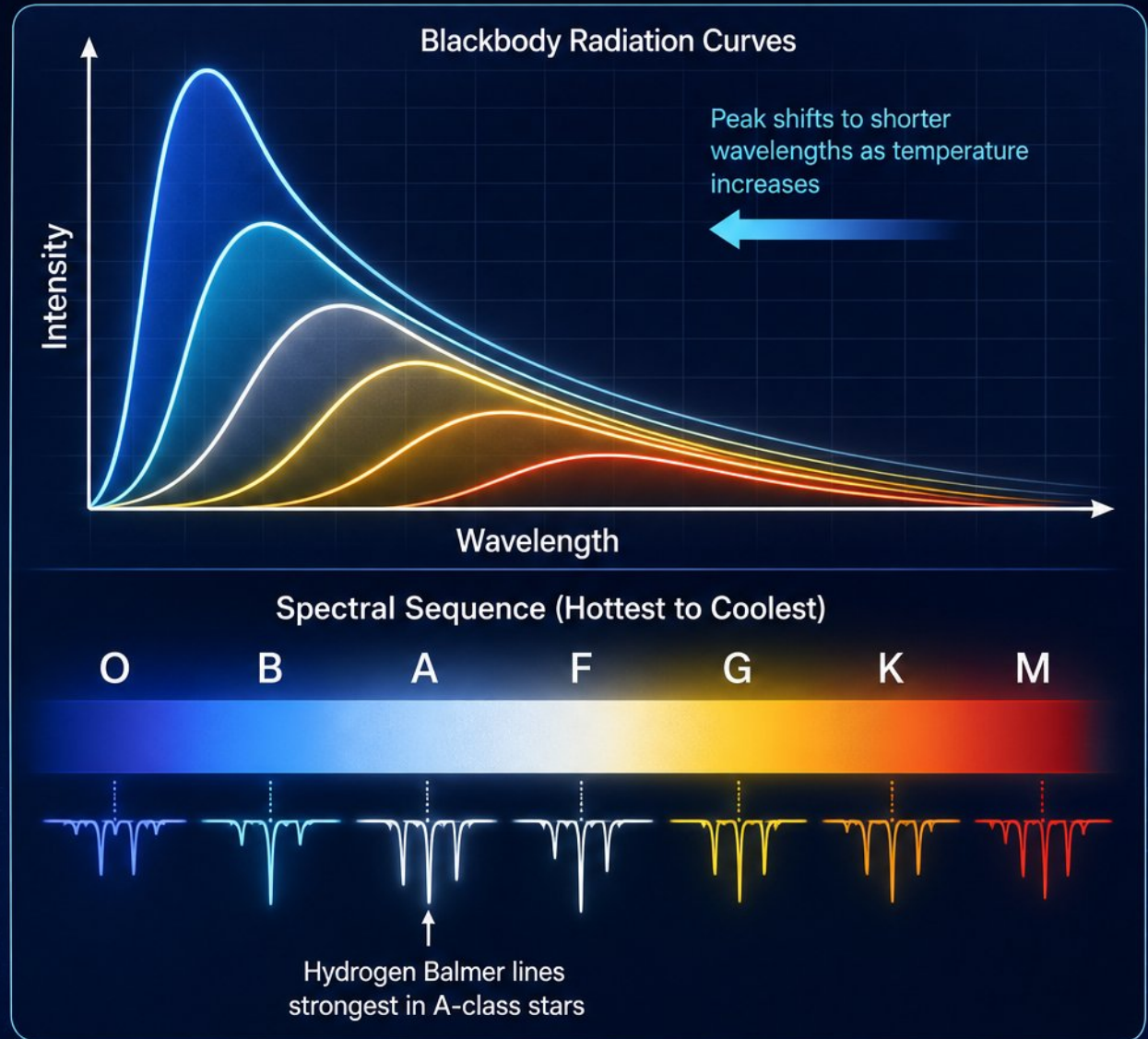
Motion and the Doppler Effect

- Redshift: light stretched when an object recedes from us
- Blueshift: light compressed when an object approaches us
- Radial velocity from wavelength shift:
 $\Delta\lambda / \lambda = v / c$
- Doppler shifts reveal exoplanets, binary stars, and galaxy motion
- Cosmological redshift comes from expanding space, not ordinary motion



Temperature, Color, and the Spectral Sequence

- Temperature shapes the overall spectrum and determines visible features
- Blackbody peak shifts to shorter wavelengths for hotter objects
- Spectral sequence O, B, A, F, G, K, M goes from hottest to coolest
- Spectral class reveals approximate surface temperature and dominant lines
- Hydrogen Balmer lines are strongest in A-class stars



Spectra Across the Sciences



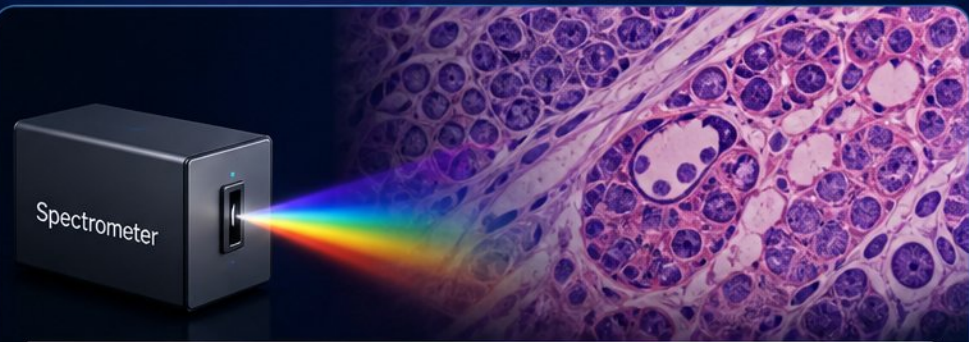
- **Astronomy:** stellar composition, galaxy motion, exoplanet atmospheres, and interstellar gas



- **Earth science:** satellite remote sensing, atmospheric monitoring, ocean color, and mineral mapping



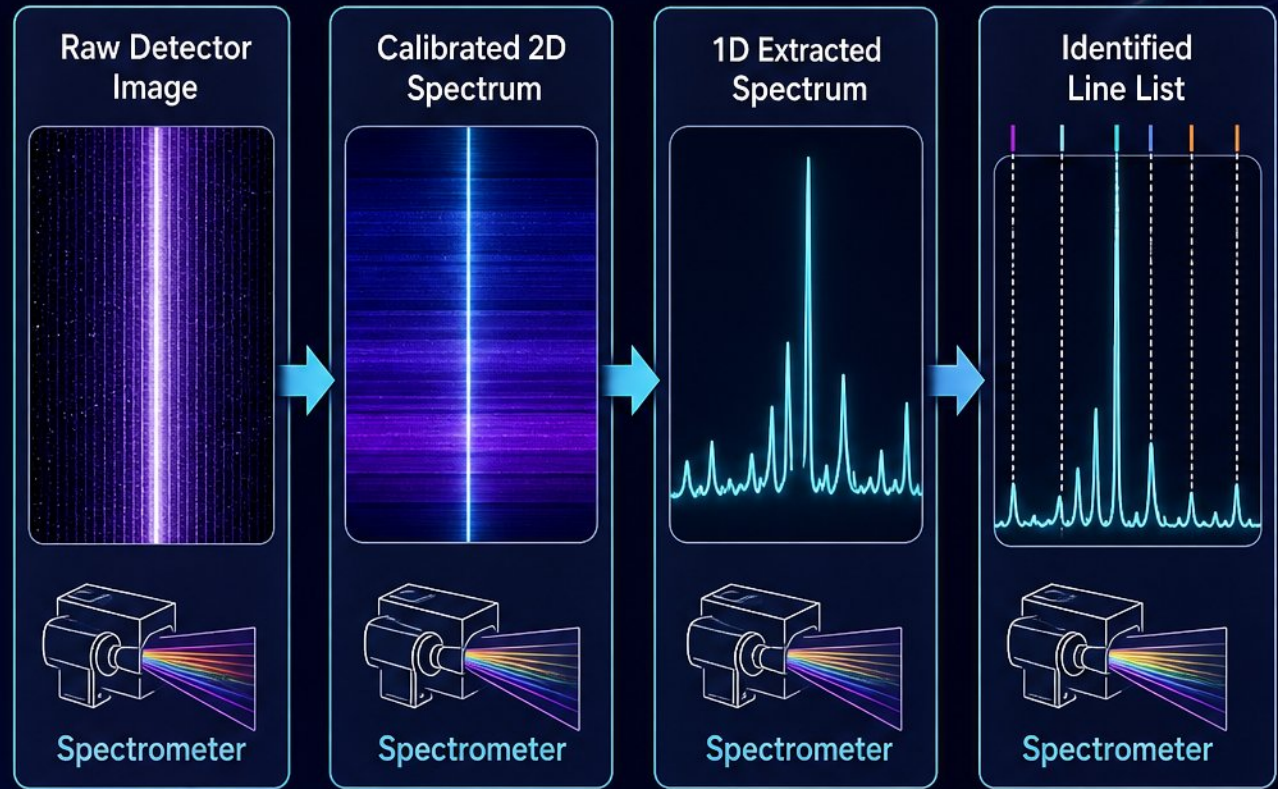
- **Chemistry:** identifying substances, molecular structure, and trace element detection



- **Medicine and forensics:** tissue diagnosis, breath analysis, imaging, and trace evidence

How Scientists Read a Spectrum

- Begin with file classification and master bias, flat-field frames
- Correct for detector noise, pixel variations, and cosmic rays
- Apply wavelength calibration using an arc-lamp spectrum
- Subtract sky background, then extract the 1D object spectrum
- Use a standard star for flux calibration and telluric correction



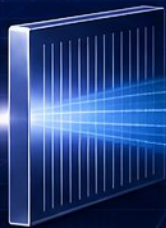
1. File Classification
& Master Calibration

2. Data Correction
(Cleaning)

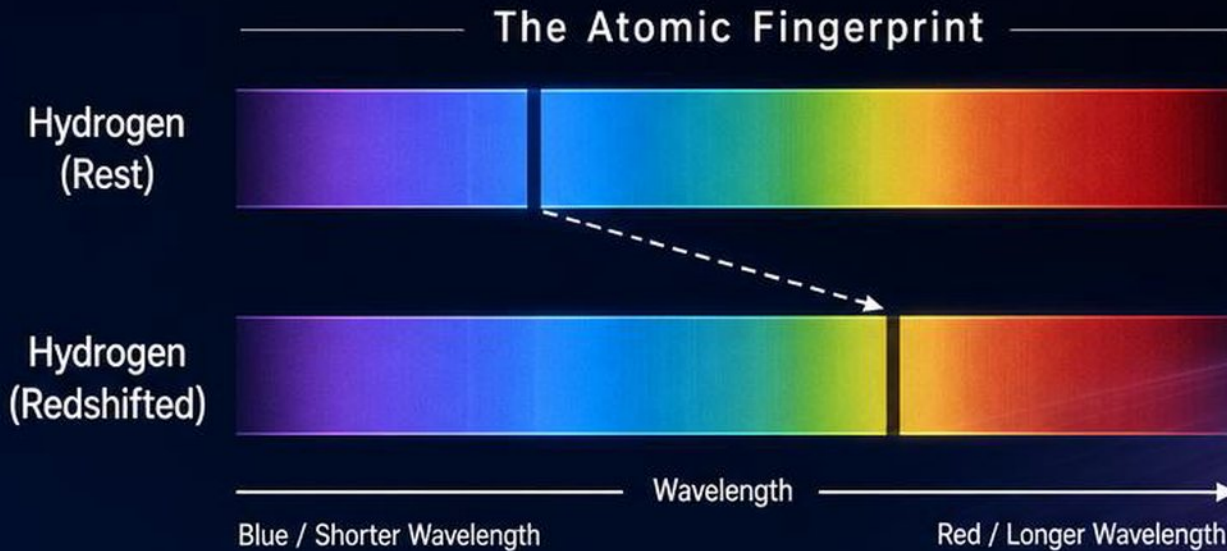
3. Wavelength
Calibration

4. Sky Subtraction
& 1D Extraction

5. Flux Calibration
& Telluric Correction

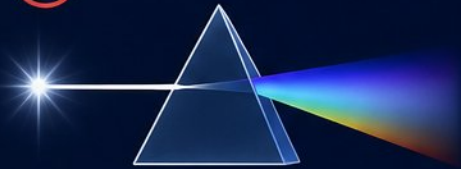


From Spectrum to Insight: A Simple Case Study

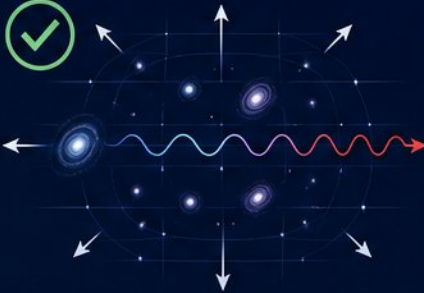


- Hydrogen's shifted line reveals radial velocity
- Stellar line patterns identify elements and temperature class
- Distant galaxies' redshifted hydrogen supports cosmic expansion
- Same logic applies to chemistry and remote sensing

Common Misconceptions and Pitfalls



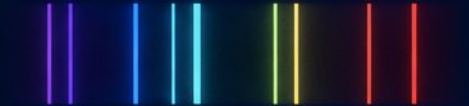
- Visible light differs only in wavelength and photon energy



- Redshift is not always Doppler; space itself can expand



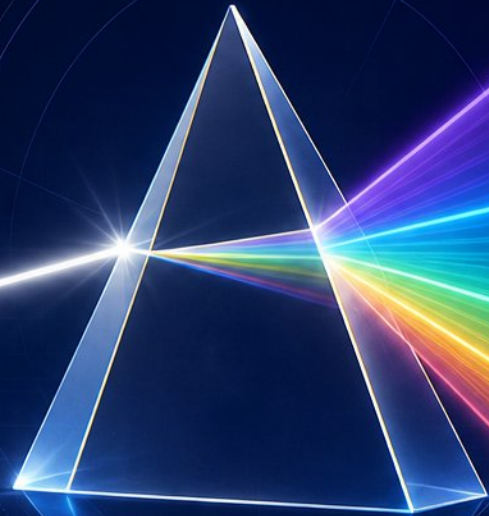
- Missing lines may mean temperature or ionization, not absence



- Color is broad; precise spectral lines reveal composition

Review and Key Takeaways

- Light carries information: wavelength, intensity, and spectral patterns encode physical conditions
- Spectral lines reveal composition, motion, temperature, density, and more
- Emission and absorption features are complementary views of the same atomic transitions
- Spectroscopy is a practical, cross-disciplinary tool used in astronomy, Earth science, chemistry, medicine, and forensics



COMPOSITION

Identifying the elements and molecules present



MOTION

Measuring Doppler shifts and velocities



TEMPERATURE

Determining thermal conditions



DENSITY

Inferring particle densities and pressures

Next Steps: Explore and Apply Spectroscopy



- Build a simple spectroscope and compare light sources



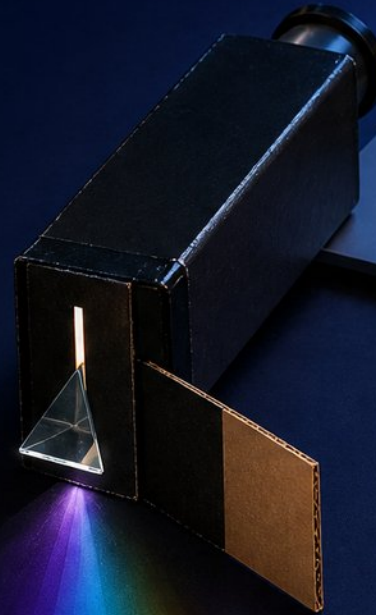
- Use CLEA to classify stellar spectra by line strength



- Measure redshift and Hubble-law distances with LivePhysics tools



- Practice identifying at least one feature in a real spectrum



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