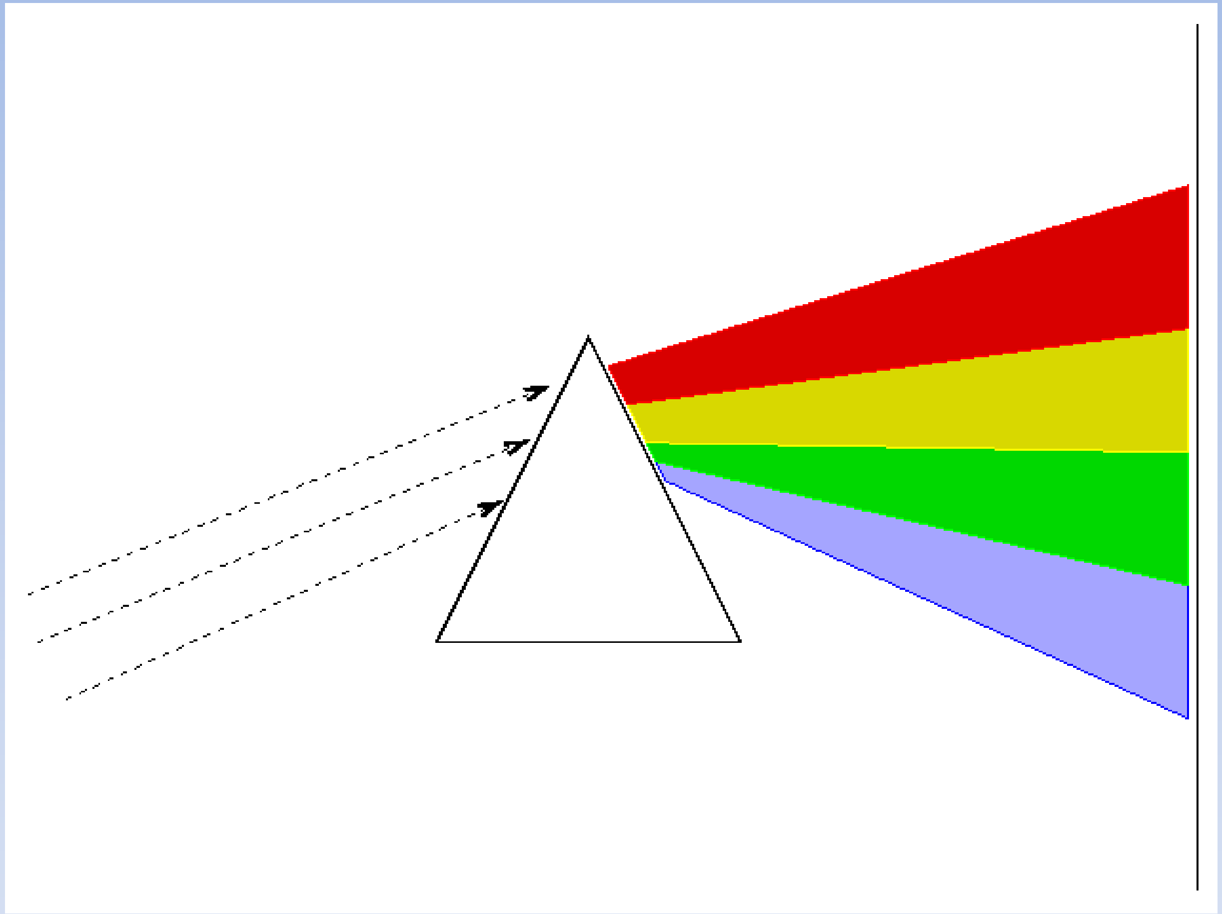
How to Detect What Stars Are Made of

Report on a project to make an amateur-friendly instrument

Outline

- How do we know the composition of stars? The story of spectroscopy
- How interference patterns reveal spectral information
- The Michaelson interferometer versus a common-path interferometer
- Demonstration

The development of spectroscopy



In 1665, Isaac Newton experimented with a glass prism in beams of light and showed that white light from the Sun is a mixture of different colored light that can be split apart and recombined. Each color is characterized by a different amount of bending by the prism.

How do we know the composition of stars?*

For the first half of the 1800s, the answer seemed to be “Why that’s impossible.” All we could do was look at light from the stars. A philosopher and scientist of the time wrote:

Of all objects, the planets are those which appear to us under the least varied aspect. We see how we may determine their forms, their distances, their bulk, and their motions, but we can never know anything of their chemical or mineralogical structure; and, much less, that of organized beings living on their surface ...

Auguste Comte, *The Positive Philosophy*, Book II, Chapter 1 (1842)

On his website, Michael Richmond (a professor of astrophysics at the Rochester Institute of Technology), notes: “Within thirty years, however, scientists were indeed starting to investigate the chemical composition of the Sun, planets, and some bright stars.“

*The title of a website by Michael Richmond: http://spiff.rit.edu/richmond/asras/chemcomp_i/chemcomp_i.html

Application of spectroscopy to astronomy

- Passing light of the Sun or a star from a telescope through a prism (or diffraction grating) produces a "spectrum."
- Physicists Joseph Fraunhoffer, Gustov Kirchoff, and Robert Bunsen were pioneers of this technique not long after Comte's death.
- Fraunhoffer discovered dark lines in the Sun's spectrum. Kirchoff and Bunsen showed these lines were related to bright lines produced by different chemical elements in a laboratory flame, and showed evidence for sodium in the Sun's spectrum.

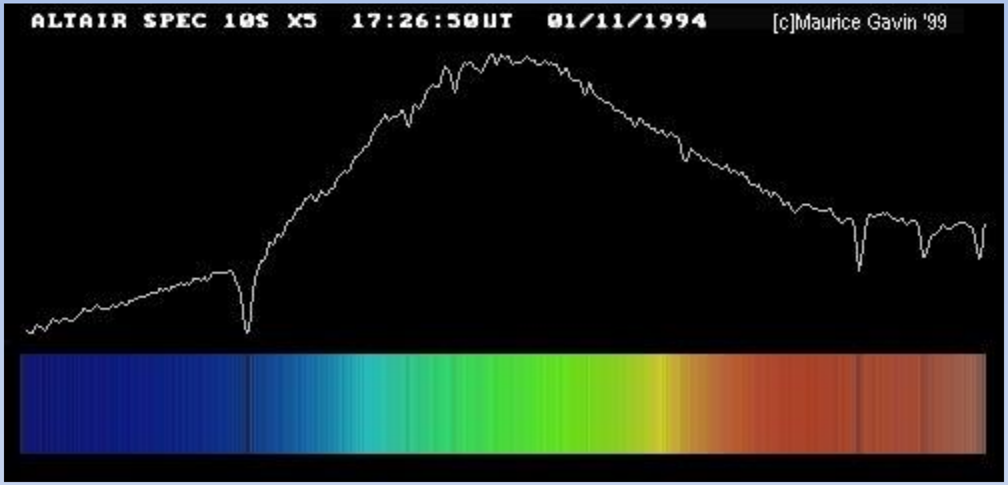
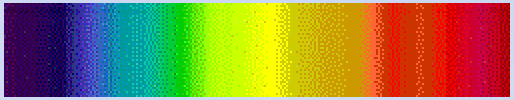
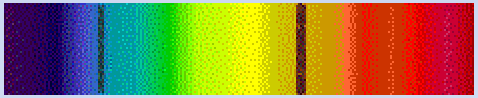


Image by Maurice Gavin, from the wpo-amateur spectroscopy web site.



Solids, liquids, and dense gases produce a continuous spectrum

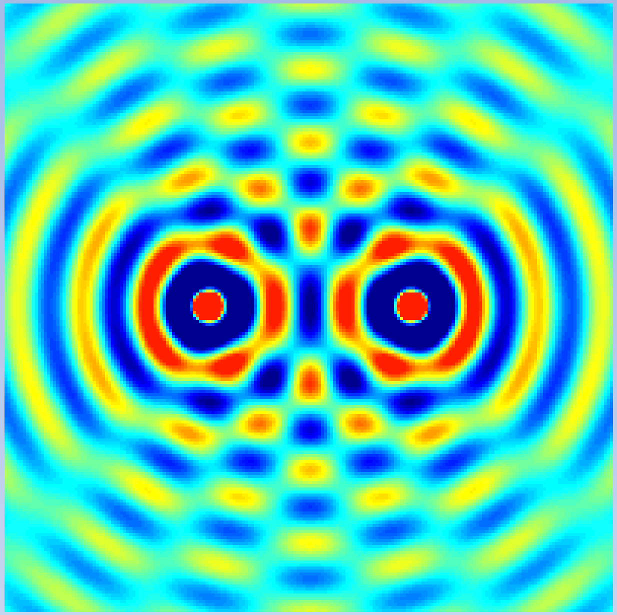
Thin gases produce an emission line or bright line spectrum



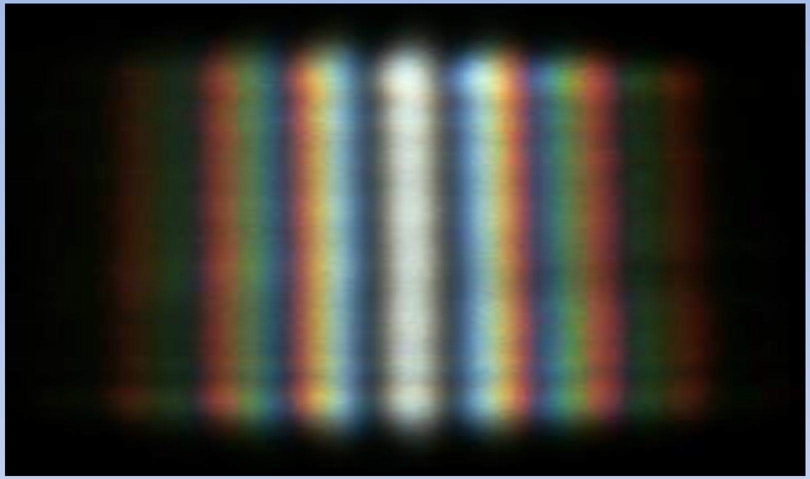
Thin gases with a light source behind them produce an absorption line or dark line spectrum

From Michael Richmond's website

Examples of interference effects

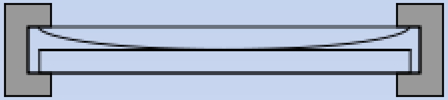


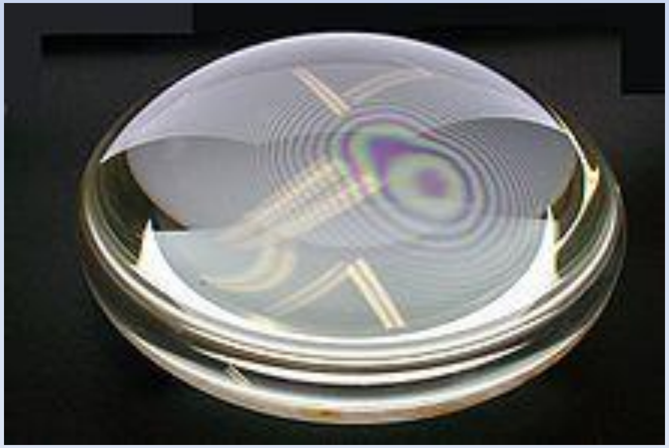
Pattern like that produced by water waves (source: Wikipedia)



Double-slit pattern in white light (source: Wikepedia)

Soap bubbles (source: Wikipedia)

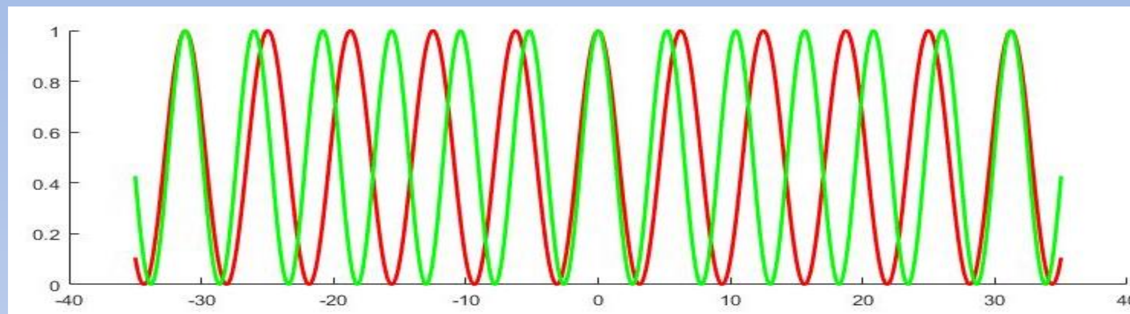


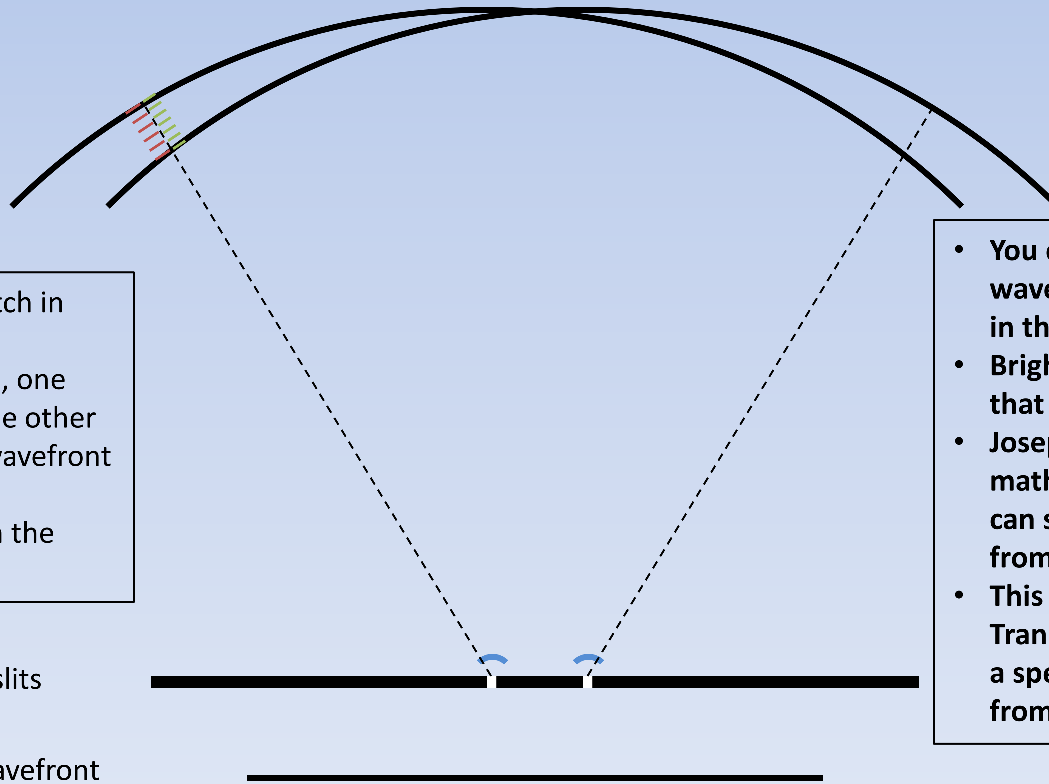


Newton's rings (source: Wikipedia)

Spectroscopy and interferometry

Interferogram

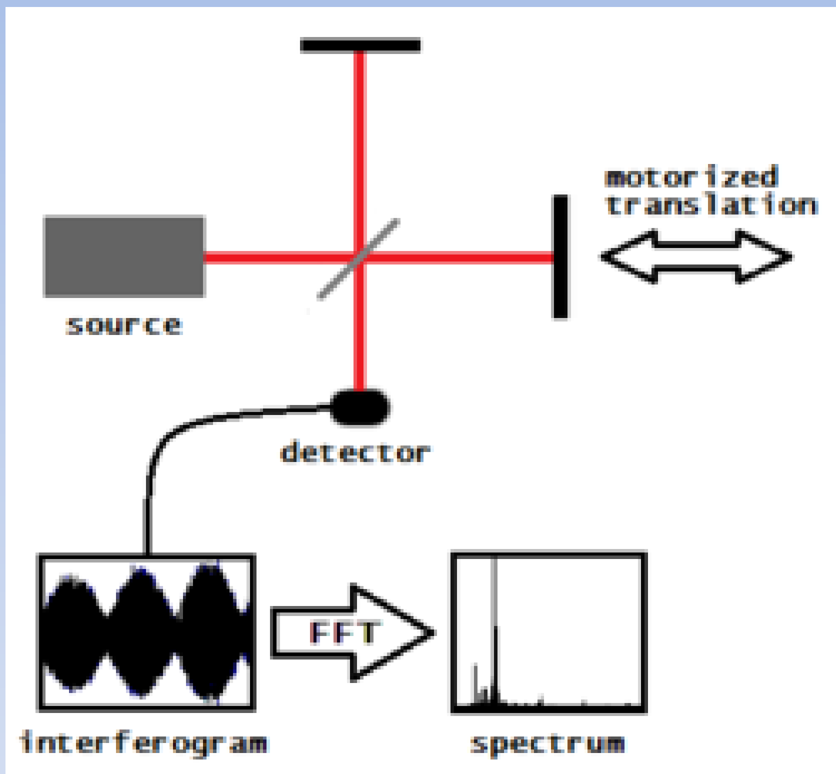




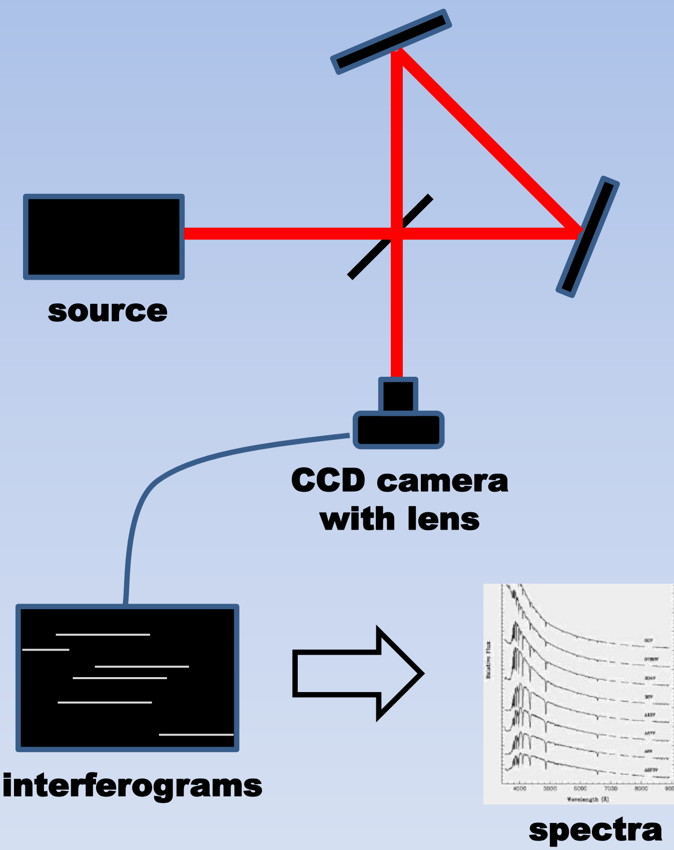
- The two wavefronts match in the middle
- Along the line at the left, one wavefront is ahead of the other
- On the right the other wavefront is ahead
- The amount depends on the wavelength of the light

- **You can determine the wavelength by counting fringes in the interferogram**
- **Brighter fringes = more light at that wavelength**
- **Joseph Fourier provided a mathematical technique that can sort out patterns resulting from a mixture of wavelengths**
- **This technique, called Fourier Transform Spectroscopy, allows a spectrum to be calculated from an interferogram**

The Michaelson interferometer versus a common-path interferometer



Michelson interferometer (source: Wikipedia)



- If you're a professional, use the Michaelson interferometer. It's expensive but it can change the path by many wavelengths, producing many fringes. That allows distinguishing very narrow spectral lines. However, it is touchy to align, sensitive to vibrations, and has moving parts.
- In the common path interferometer, the two components of light remain close to each other. That makes it easy to align and insensitive to vibrations – good properties for an amateur. It needs no motor to adjust the path differences because they depend only on the angle of the light going to the camera. Star trails will trace out the pattern, so you can even do spectroscopy with a Dobsonian telescope!

DEMONSTRATION