Spectroscopy Using the Tracker Video Analysis Program

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Spectroscopy has important applications in many fields and deserves more attention than is the norm in introductory optics labs. This poster describes a set of inexpensive, quantitative spectroscopy experiments that use a digital camera to capture images of spectra and Tracker to measure their intensity profiles. The spectra, produced by a diffraction grating in front of the camera lens, include two laser spots with known wavelengths for calibration. Tracker's line profile tool generates a "live" plot of relative intensity versus wavelength, enabling students to interactively explore the spectra in detail. Experiments include gas and laser line spectra, thermal spectra, color filters and absorption, and fluorescence.

Introduction

Most students are fascinated by the bright "color" spectra projected or observed through a holographic diffraction grating--seeing color is after all one of our most cherished senses. The use of a **video camera** to record images of these spectra is a natural and intuitive way to introduce **quantitative spectroscopy** in an introductory lab since students are familiar with video and can relate the images directly to what they see.

Even with video, however, there are major conceptual hurdles for beginning students. For instance, their fascination with **color** (a property of the **observer**) often hinders their understanding of **spectral intensity** (a property of the **source**) that is so fundamental to spectroscopy. A common student mistake, for example is to associate a spectral line with its color rather than its wavelength. Another difficulty is relating the observed spectrum to its spectral intensity graph, since it is easier to perceive subtle differences in color than intensity. This is particularly problematic when spectral intensity graphs are not *experimentally* connected with observed spectra, a common situation since such measurements have been traditionally difficult.

The development of the **Open Source Physics** Java framework and the free **Tracker** video analysis program now makes spectral intensity measurements easy, inexpensive and interactive. Students use a mouse-controlled **line profile tool** to generate "live" spectral intensity graphs of video spectra. The spectra are recorded in both **color** and **grayscale** to help assess or eliminate color information, and two **laser spots** are included for easy calibration. A downloadable **video spectroscopy** library allows quantitative video spectroscopy to be incorporated into introductory labs with or without local video camcorders.

The Open Source Physics () framework is a set of Java software packages used for curriculum development, computational physics, and physics education research. Tracker is a free video analysis program built on the OSP framework that combines position-based tools from traditional video analysis (motion tracking) with RGB-based tools from image processing (line profiles and filters). It is designed to be used in introductory college physics labs and lectures. Tracker and the video spectroscopy library are available for download at **www.cabrillo.edu/~dbrown/tracker**. Open Source Physics resources are available at **www.opensourcephysics.org.**

This poster describes video spectroscopy experiments undertaken by 54 students in my Spring 2005 sophomore calculus-based general physics. Over the course of two 3-hr lab periods, students measured and analyzed the following spectra:

1. **Thermal incandescence**
2. **Color filters**
3. **Gas lamps**
4. **Solid-state lasers**
5. **Fluorescent dyes**
6. **Fluorescent lamps**
7. **Sunlight**

Equipment and Procedure
Each light source was placed behind a vertical slit at a distance of 1.5±0.5m from a holographic grating (Project Star) as shown in **Figure 1**. Red and green HeNe laser beams were reflected from a small tab protruding below the slit.

The video camcorder was placed immediately behind the grating, aimed at the first-order maximum for λ=545±5nm, and zoomed to cover the range 310±5nm to 780±5nm. The sharpest images were obtained by orienting the grating perpendicular to the optical axis of the camera, not that of the source. Live or recorded DV-encoded video was captured via FireWire using Ulead Video Studio software and saved in QuickTime format (though any video capture utility could be used that saves videos in QuickTime or AVI format).

While consumer-grade video cameras have linearity, noise and resolution limitations that make the quality of their images unsuitable for serious work, they did a fine job in our lab when the following steps were taken:

1. Since RGB values in a digital video image have a range of only 0-255, video cameras employ a non-linear intensity-to-value function that compresses the highlights to avoid saturation. A **manual aperture** was used to keep the recorded video relatively dim.
2. Since CCD sensors have a different spectral sensitivity curve than the human eye, cameras shooting in color mode introduce wavelength-dependent brightness distortions that result in more natural-looking colors on a monitor or TV screen (compare the color and grayscale thermal spectra). These distortions were eliminated by shooting in **grayscale** mode ("black and white"). Some spectra (e.g., gas lamps and solid-state lasers) were shot in color mode when intensities were unimportant.
3. Background light, often non-uniform, is a common problem in a typical student optics lab. This background was reduced in Tracker using a **baseline video filter** that subtracts a "baseline" image (background alone) from each of the video frames. The baseline image was sometimes a separate image file and sometimes a captured frame from the video itself.
4. Sensor noise was reduced using a **sum video filter** that averages the pixels from multiple video frames. This smoothed the line profile data significantly.

Note that the standard 720x480 pixel DV format uses non-square pixels. This was not a problem in these spectroscopy experiments since only the horizontal scale was used, but when using DV video for motion experiments it is important to convert to a 640x480 square pixel format during compression to eliminate distortion.

Red and green HeNe **laser spots** in the spectra were used to establish and calibrate a wavelength scale. The scale was assumed to be linear even though this is only an approximation. (The horizontal pixel position in the video image is very nearly a linear function of the angle θ measured from the optical axis, but since $\lambda = d \sin\theta$ the spectrum is compressed at longer wavelengths. Fortunately, this compression is relatively minor for the first-order spectrum. Students were encouraged but not required to estimate the errors introduced by this assumption at various points in the spectrum.) The linear calibration was accomplished using

Tracker's **calibration points** track --the calibration points were simply placed on the two laser spots in the spectrum and assigned the known wavelengths.

The spectral intensities were measured using Tracker's **line profile** track. The line profile measures brightness and other pixel data along a horizontal line on a video image. At each pixel point along the line, it can average additional image pixels above and below the line to reduce noise and/or increase sensitivity.

Experiments

1. **Thermal spectra: color/grayscale, hot/cool (Figure 2)**
   Students studied the spectrum of a "soft white" incandescent lamp. When the spectrum was recorded in color mode, the spectral intensity curve was bimodal with a dip in the center, but in grayscale the curve had a single peak in qualitative (but not quantitative) agreement with the Planck equation. Students observed that operating the lamp at a lower temperature decreased the peak intensity and increased the peak wavelength.

2. **Color filters: transmission curves (Figure 3)**
   The "soft white" incandescent lamp was again the light source. Students held color filters over the upper half of the slit so the grayscale spectra of the filtered and unfiltered light could be directly observed and compared. The spectral transmission for the filter was then determined by dividing the filtered by the unfiltered spectral intensity. These experimental transmission curves were compared with published filter characteristics. Working with grayscale was very effective here.

3. **Gas lamps: line spectra (Figure 4)**
   Students studied spectra of the following gas lamps: H, He, Hg, Ar, Kr, Ne, O. For the hydrogen spectrum, measured wavelengths of the bright lines were compared with theory. Several lamps were presented as unknowns to the students who then identified them by comparing their spectra with those of known gases.

4. **Solid-state lasers (Figure 4)**
   Red or green solid-state laser light diffusely reflected from a painted vertical wire (unfolded heavy paper clip) was the light source for these spectra. No surprises here, but look what came next!

5. **Fluorescent dyes: UV and laser illumination (Figure 5)**
   Vertical wires were painted with red, yellow and green fluorescent dyes and illuminated with both long wave UV (365 nm) and a green solid-state laser (532nm). First students compared the relatively broad spectra of the three fluorescent dyes produced by UV illumination. They then predicted how the dyes would respond to 532nm illumination and compared with observed spectra. The red dye fluoresces brightly and beautifully with the laser!

6. **Fluorescent lamps: lines and dyes (Figure 6)**
   Students studied the spectra of five fluorescent tubes with different rated "color temperatures". They were asked to identify and evaluate both the bright gas lines and the broader fluorescent bands. The relative RGB content of the different lamps was related to the color temperature.

7. **Sunlight: absorption lines (figure 6)**
   Sunlight was reflected into the lab onto a white sheet of paper for the source. Hints of the absorption lines were seen in the spectrum, but the resolution was too low for quantitative analysis.

Discussion
The benefit of these experiments to my students was not assessed formally, but students did turn in both lab notes and a formal lab report. The discussions in their reports on fluorescent lamps clearly showed a more sophisticated understanding of spectra and the RGB color model than in previous classes I have taught.

The most time-consuming activities in these experiments were setting up the light sources and recording and capturing the videos. I assigned each lab group a single spectrum to capture and compress which was then shared with the whole class. For the second lab, I set up a video capture station in advance instead of having the students do it. This did save time and result in better quality videos, but several students commented that it was more satisfying to do it themselves.

Additional video spectroscopy experiments that could be performed are (1) determining optical density using multiple color filters, and (2) relating LED spectra to their diode characteristics.

Tracker and the video spectroscopy library are available for download at **www.cabrillo.edu/~dbrown/tracker**. The library includes "baseline" images that can be used to reduce the background as described in *Equipment and Procedures*.

References
1. Candice Miller and Rebecca S Lindell, **A Qualitative Investigation of College Astronomy Students' Understanding of Spectroscopy,** 2005 AAPT Winter Meeting: Albuquerque, NM
2. Robert G. Fuller and Vicki L. Plano Clark, **Spectrophotometry and Human Applications,** 128th AAPT National Meeting: Miami Beach, FL
3. Kenneth Brecher et al, **Project LITE Spectroscopy,** 128th AAPT National Meeting: Miami Beach, FL
4. Douglas A. Brown, **Open Source Video Analysis of Interference Patterns and Spectra,** 127th AAPT National Meeting: Madison, WI
5. Wolfgang Christian and Joshua Gould, **Open-Source Java for Teaching Computational Physics,** 125th AAPT National Meeting: Boise, ID
6. Randolph S. Peterson, **A Simple and Inexpensive Optical Spectrometer with an Array Detector,** 122nd AAPT National Meeting: San Diego, CA
7. Mickey D. Kutzner and Dewey A. Murdick, **A Digital Spectrometer Using Low-cost Equipment,** 117th AAPT National Meeting: Lincoln, NE
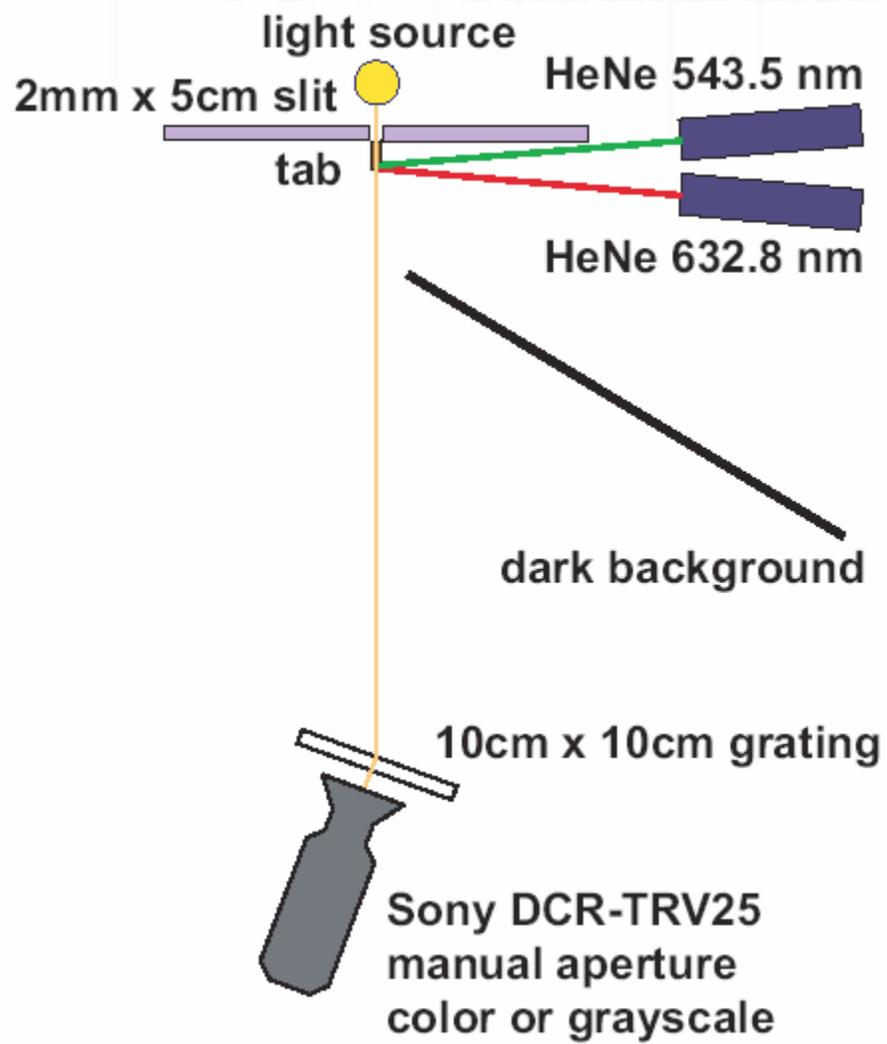
light source

2mm x 5cm slit

HeNe 543.5 nm

tab

HeNe 632.8 nm

dark background

10cm x 10cm grating

Sony DCR-TRV25
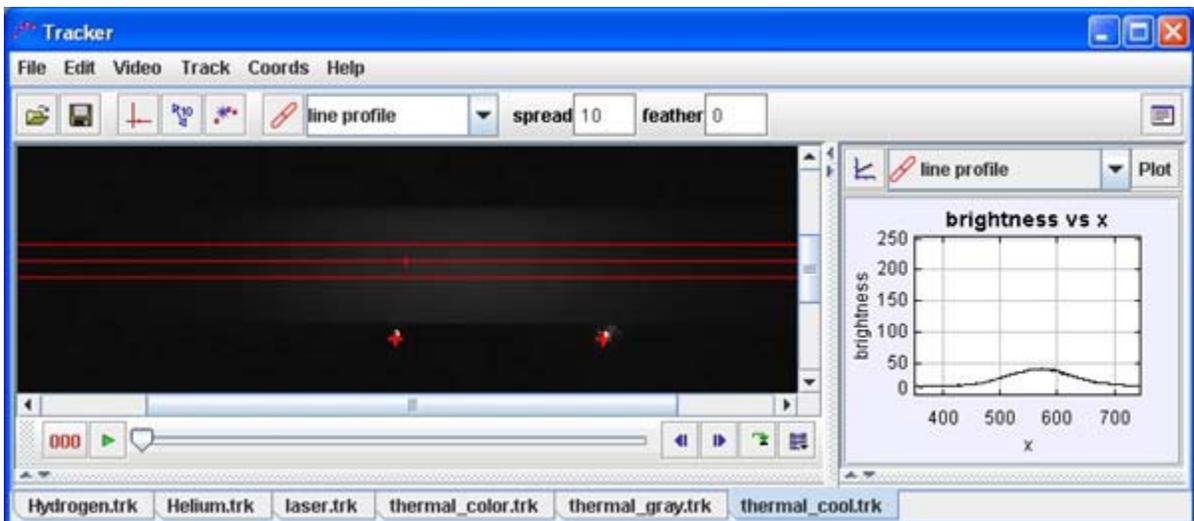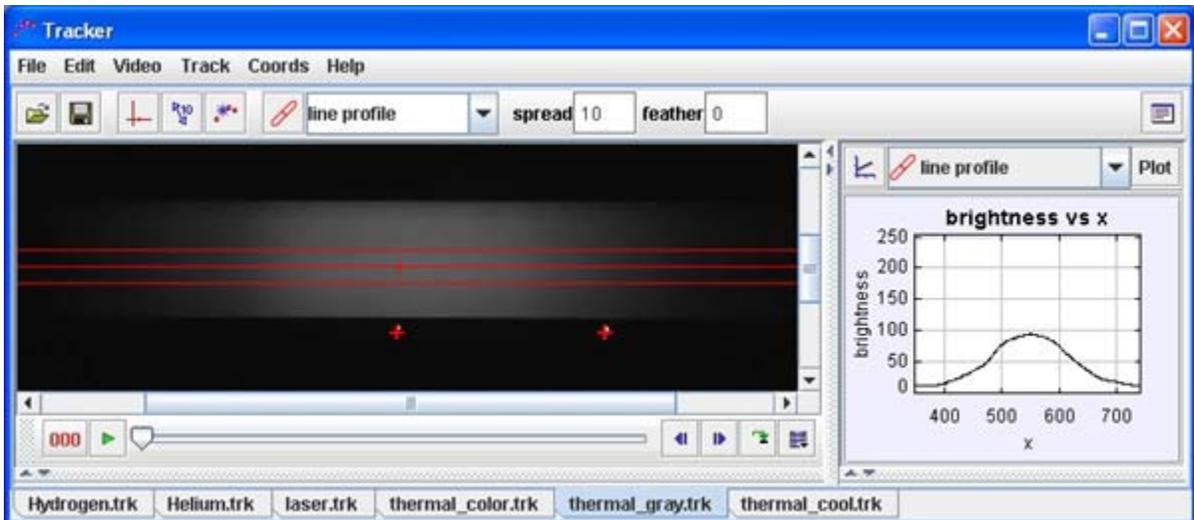manual aperture
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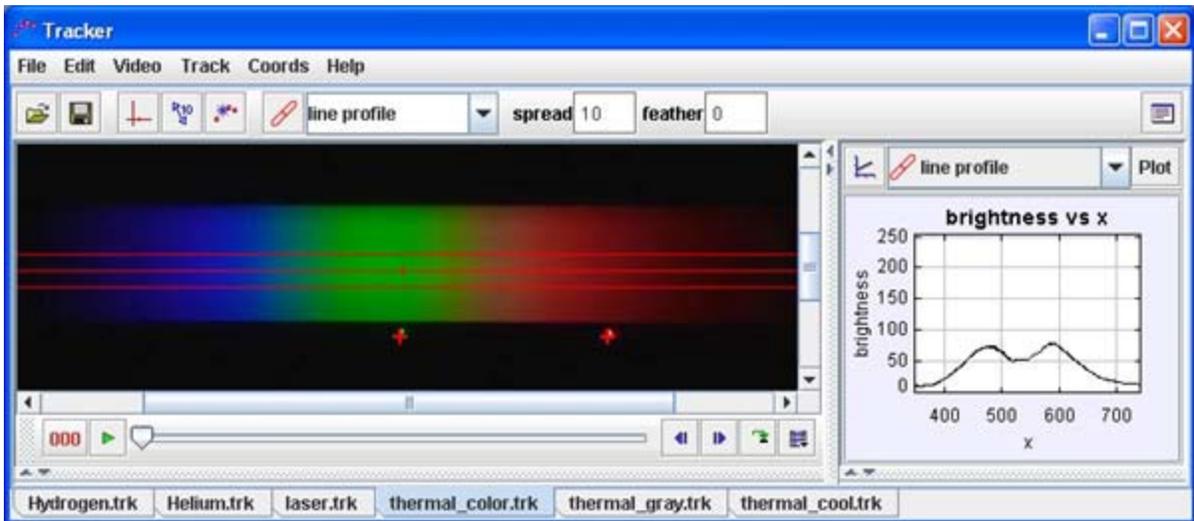
Figure 1 Experimental Setup (Top View)
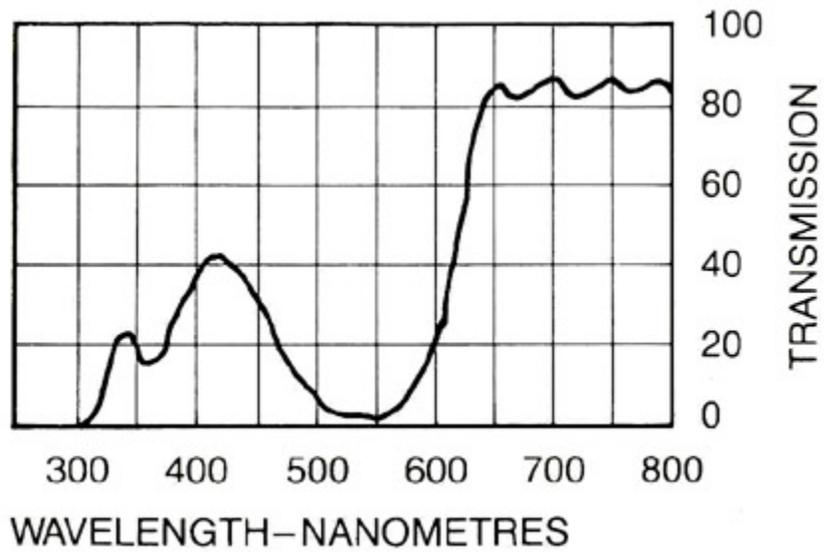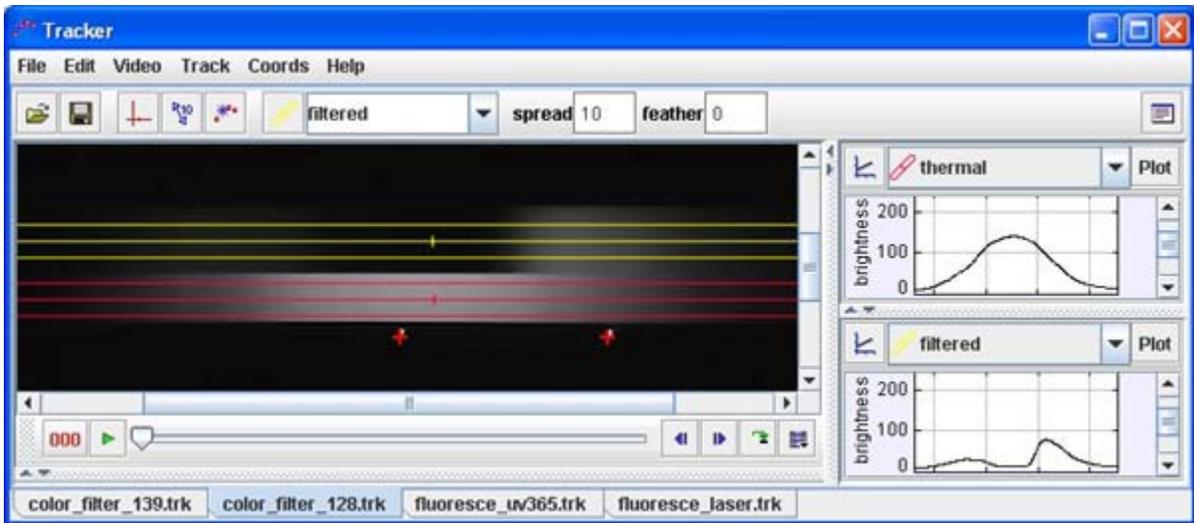
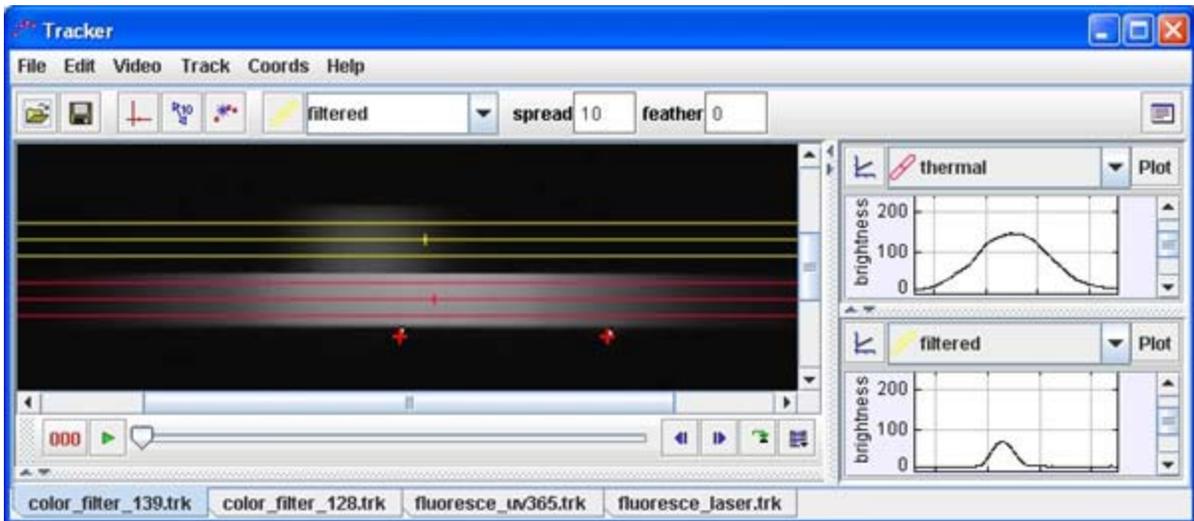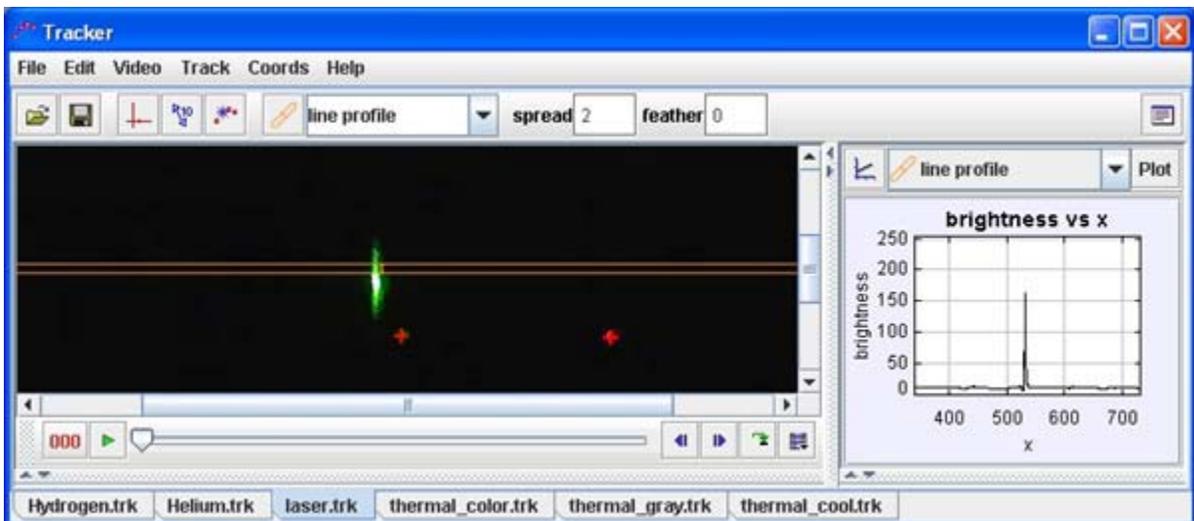**Figure 2 Thermal Spectra: Color, Grayscale, Cool**

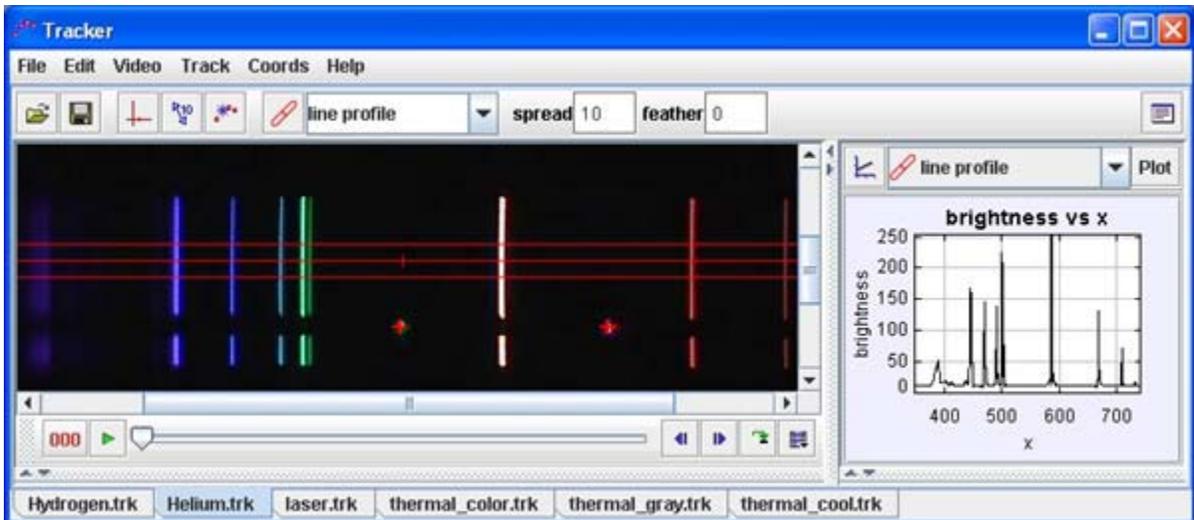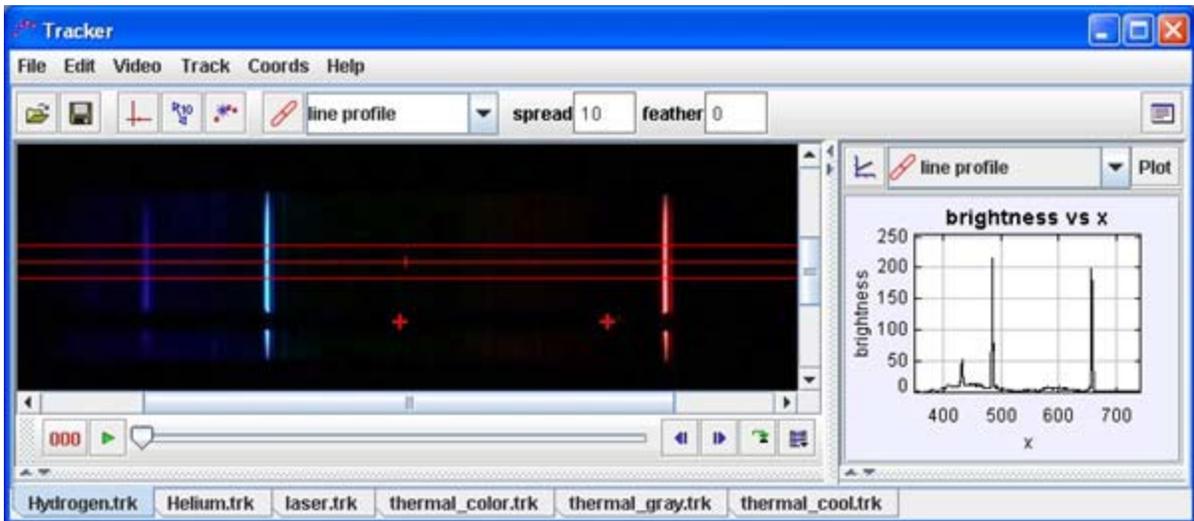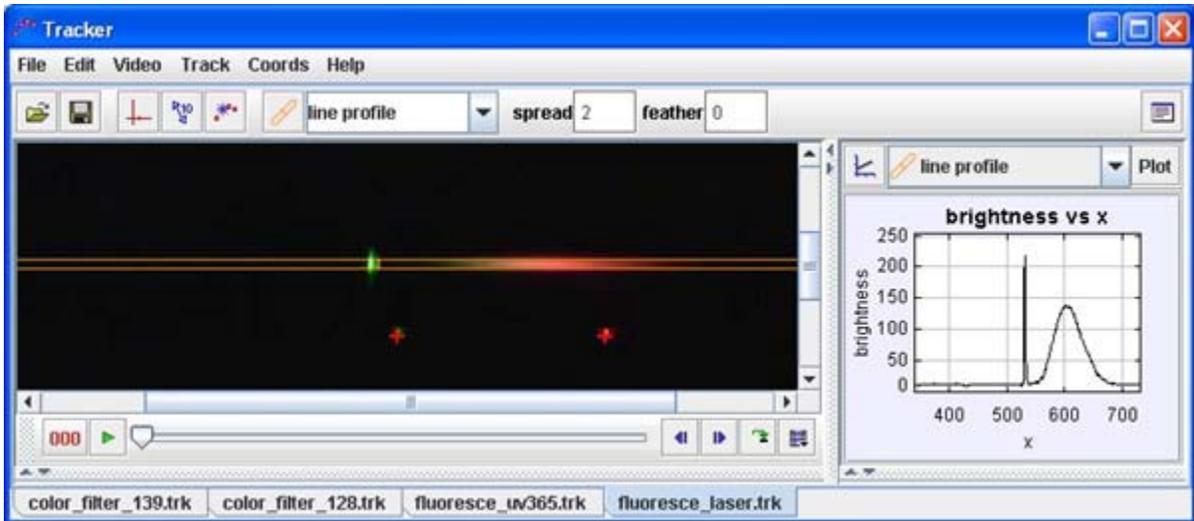**Figure 3 Color Filters: Transmission Curves**
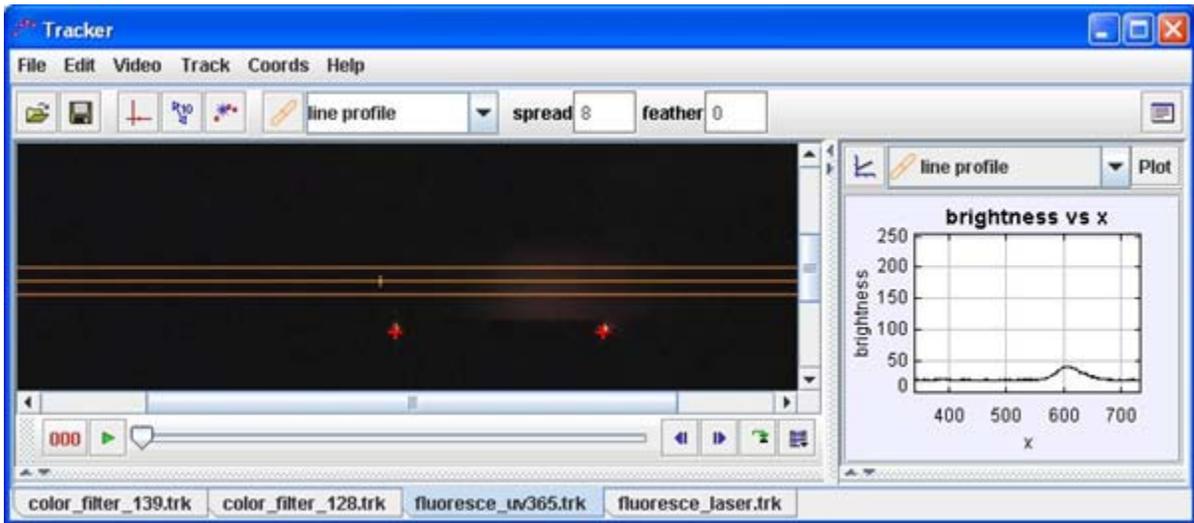
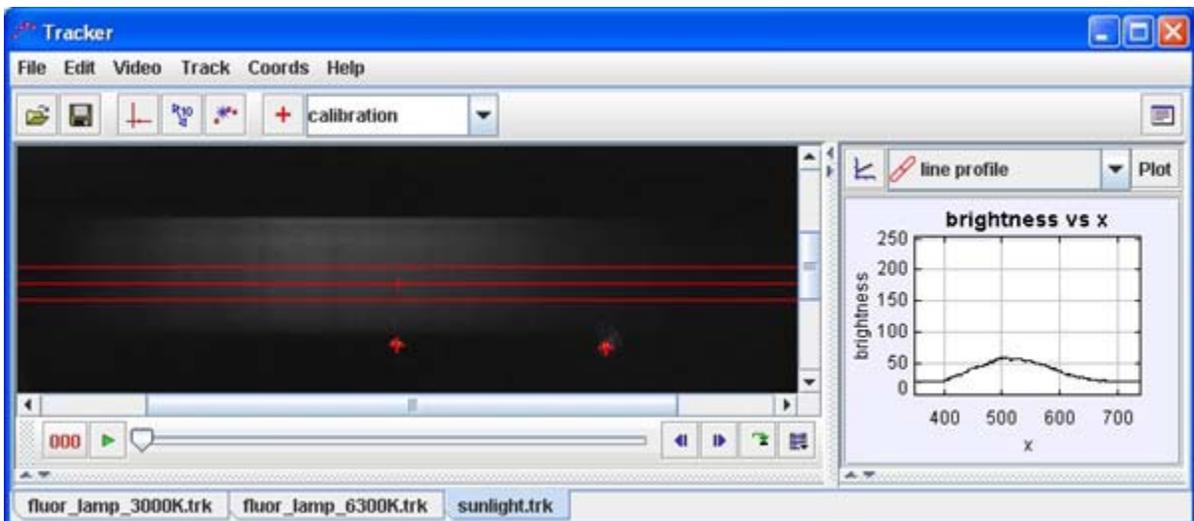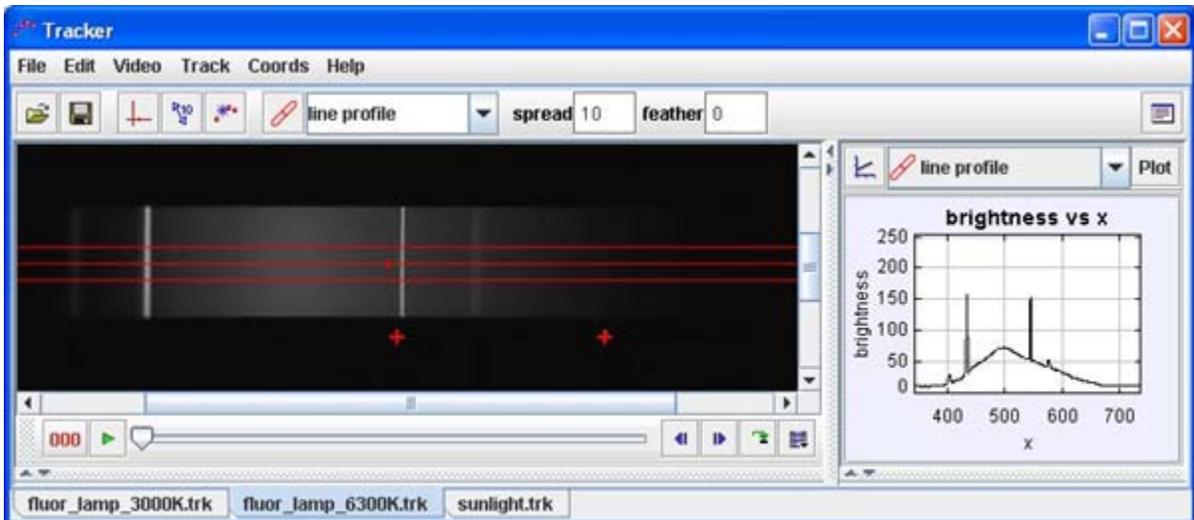**Figure 4 Gas Lamps and Solid-State Lasers**
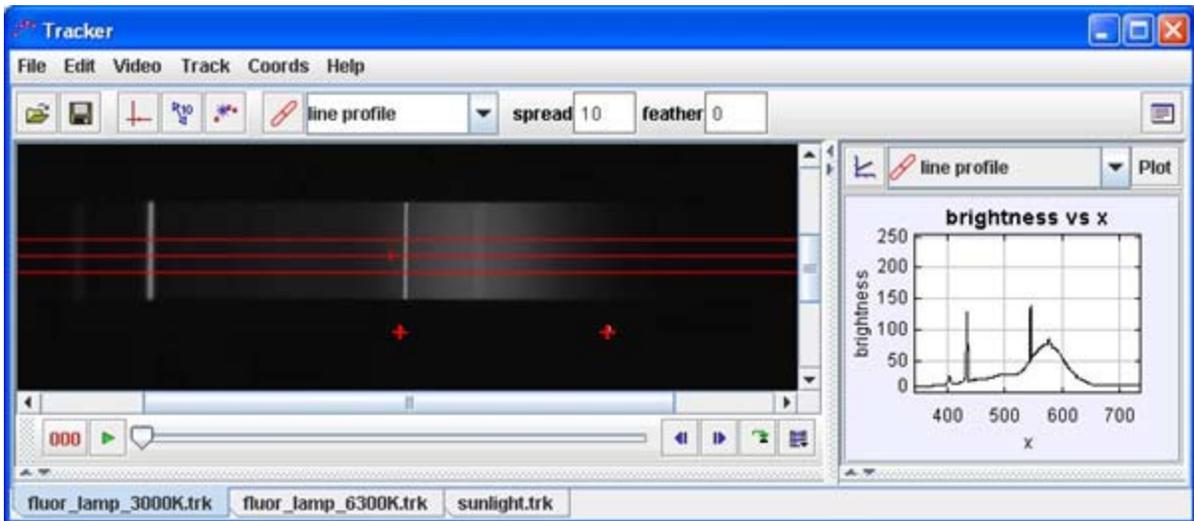
Figure 5 Fluorescent Dyes: UV and Laser Illumination

Figure 6 Fluorescent Lamps and Sunlight