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Wavelength Control for a Potassium Resonance Lidar

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Abstract

An important ground-based way to measure temperatures and winds in the transition region between the upper mesosphere and lower thermosphere (80 to 105 km) is with a resonance-scatter lidar. An alexandrite laser, with a wavelength in the near infrared at 770 nm, is being added to the Atmospheric Lidar Observatory to make this type of observation of potassium. These observations will complement those that have been made for many years with the green Rayleigh-scatter lidar. For these resonance-scatter observations it is necessary to accurately and precisely control the laser wavelength. The intent is to carefully step across the 4 pm (2 GHz) wide potassium spectrum (**Figure 1**). The width of the spectrum has to be determined within 6.0 fm (3.0 MHz) to obtain a temperature precision of ±5 K. The Doppler shift of the spectrum has to be determined within 5.1 fm (2.6 MHz) to obtain a wind-speed precision of ±2 m/s. This project is a step in that direction. It involves developing a method, based around a scanning Fabry-Perot interferometer (FPI), to control a CW seed laser that, in turn, controls the alexandrite laser.

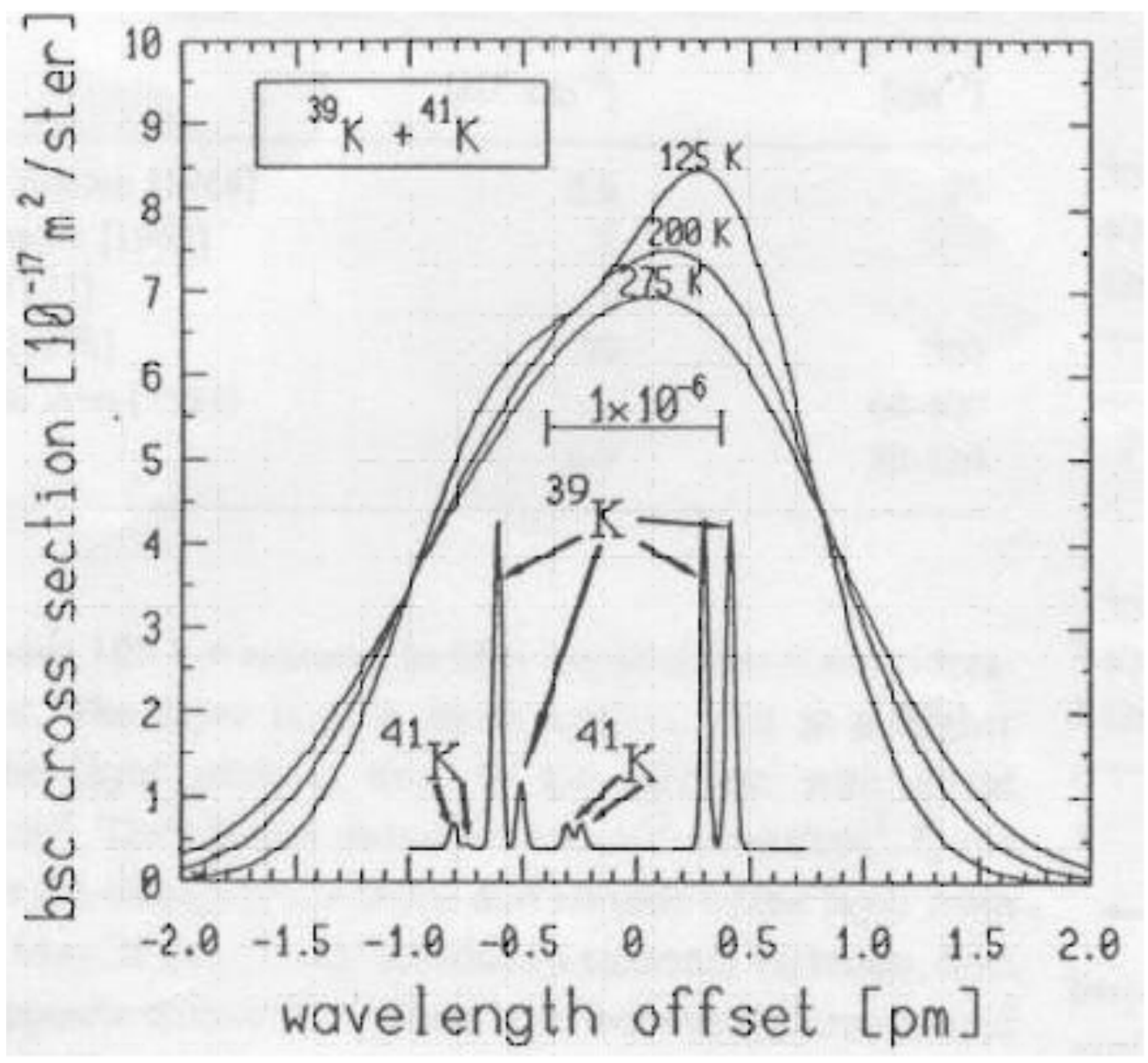

Figure 1. Variation of the potassium spectrum with respect to temperature [*U. von Zahn and J. Höffner*, 2003].

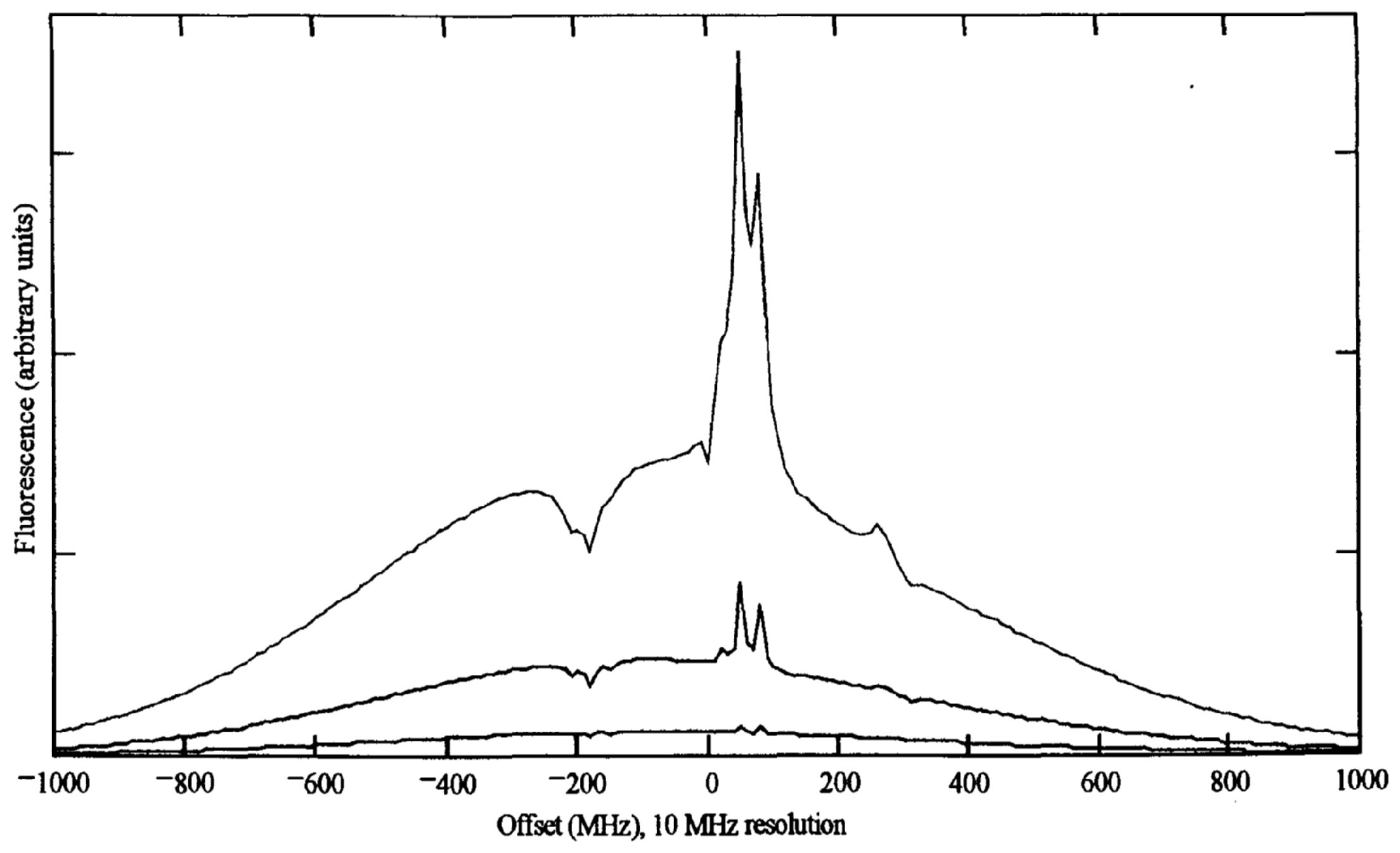

Figure 2. The effects of different power inputs on the Doppler-free potassium spectrum at 333 K [*P. Johnson*, 2003]. The center wavelength is at a vacuum wavelength of 770.1093 nm, in the near infrared. The spectrum has spikes or inflections at crossover offsets of 23, 51, and 78 MHz. The large spike, at 51 MHz, provides a well defined wavelength reference. In wavelength, it is at 0.1 pm less than the center of the of the Doppler-free spectrum. It will provide the absolute wavelength reference for the lidar measurements.

The Fabry-Perot Interferometer

In order to step across the potassium spectrum, a FPI is used to control a CW seed laser. The basic idea behind the FPI (**Figure 3**) is the interference of light waves. The FPI is built around an etalon, which is two parallel plates with highly reflective dielectric coatings. Incident light passes through the first plate. The light then reflects back and forth between the two plates, with a small amount transmitted after each reflection. Each transmitted ray will have a fixed phase offset with respect to the previous transmitted ray. The light from all the transmitted rays is then focused by a converging lens, creating an interference pattern (**Figure 4**). Bright rings will form where the transmitted rays are in phase, i.e., when the condition $2t \cos \theta_r = m\lambda$ is satisfied [*Pedrotti and Pedrotti*, 1993].

The etalon in the FPI used in this project is equipped with piezoelectric crystals between the two plates, which expand or contract in very small steps when a high voltage is applied to them. (They can vary through 1024 steps.) This allows the etalon spacing to be varied by known amounts, causing the ring pattern to expand and contract. We observe the very center of the FPI ring pattern. When we scan the seed laser, discussed next, the signal will vary between small and large values. Similarly, when we adjust the spacing between the plates the signal will vary between small and large values.

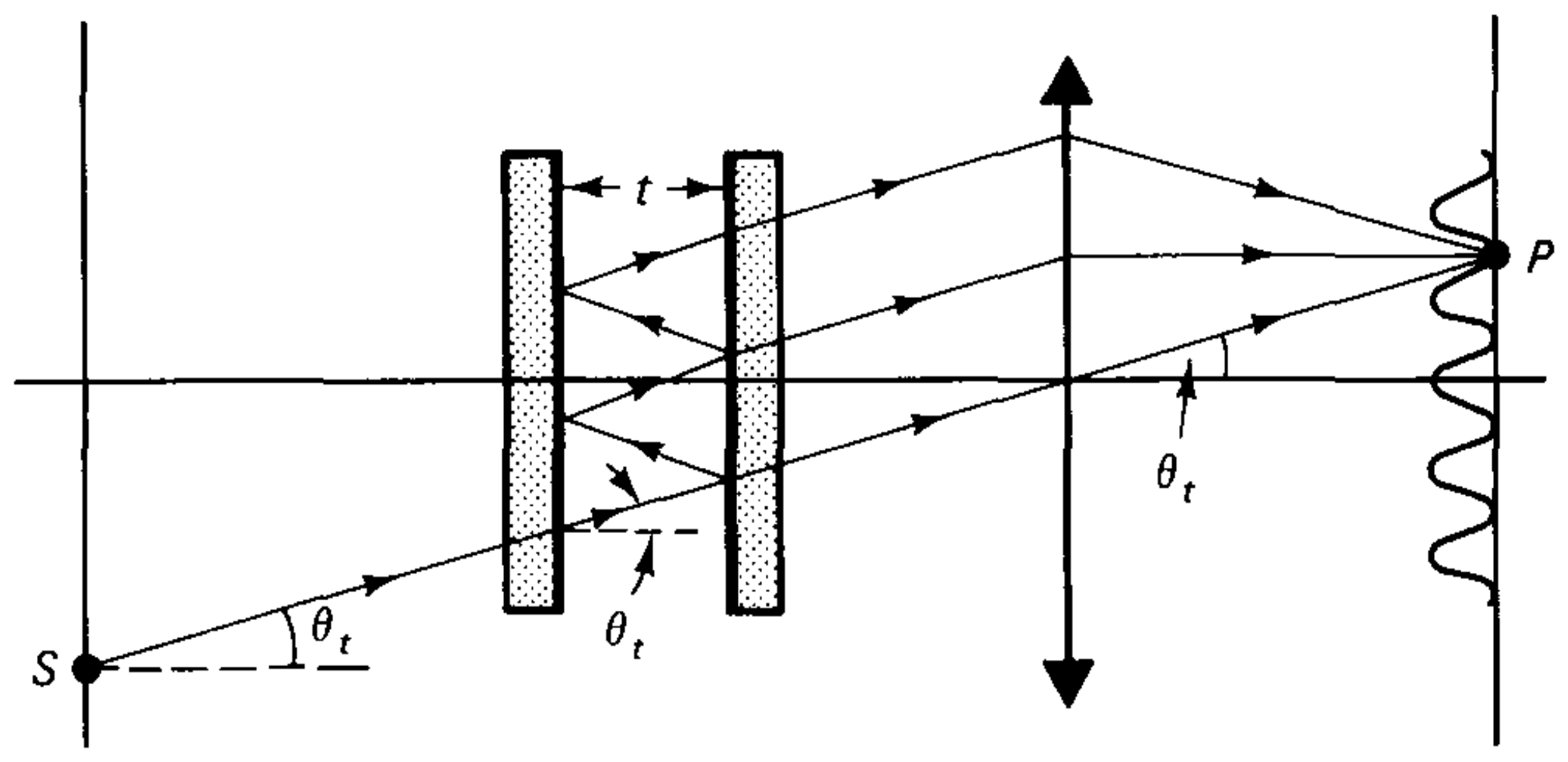

Figure 3. Diagram of a FPI [*Pedrotti and Pedrotti*, 1993].

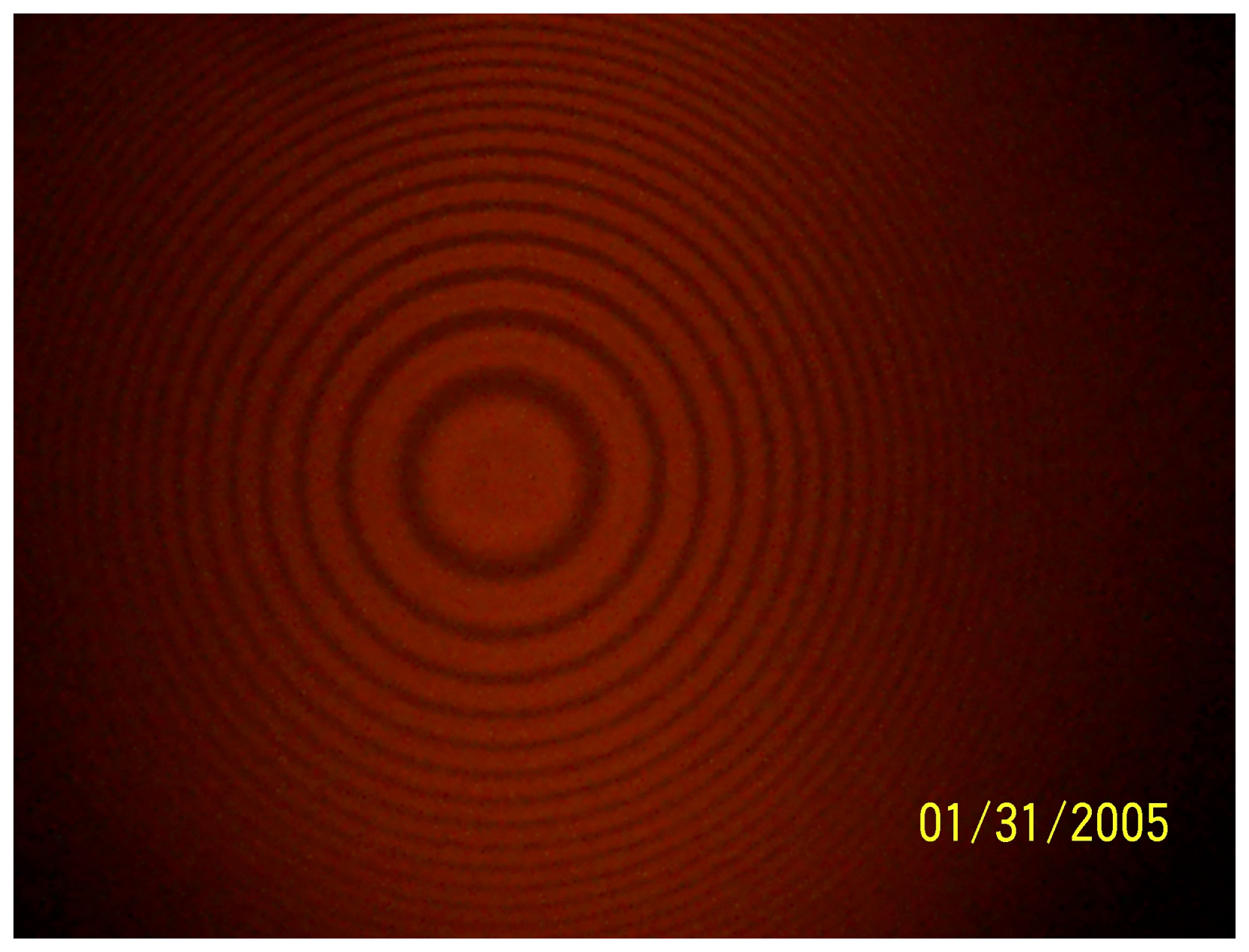

Figure 4. Example of an interference pattern from a FPI.

Wavelength scanning

A block diagram for controlling the lidar wavelength is shown in **Figure 6**. Some of the control components are shown in **Figure 5**. The intent is to step across the potassium spectrum illustrated in **Figure 1** by going to a sequence of known wavelengths. To find the absolute wavelength, we will do Doppler-free spectroscopy using a potassium cell. The Doppler-free spectrum is obtained using detector 2 when oppositely directed beams from the seed laser pass through the potassium cell. An example is shown in **Figure 2**. **Procedures a and b** in the box below are combined to vary the FPI and seed laser to find the etalon step corresponding to the spike in the Doppler-free spectrum at an offset of 51 MHz. (This project involved implementing these procedures in LabVIEW.) The system is now calibrated. From the properties of the FPI, we know the size of each FPI step, and hence can work out how many steps to go to reach particular wavelengths in the spectrum. Using **procedure b**, the seed laser and hence the alexandrite laser can be made to step across the potassium spectrum. The return signal from the atmosphere can then be analyzed for temperature and Doppler shift.

Procedure a: Finding the absolute wavelength

1. Check detector 2 output
2. Step the CW laser by a small Δλ (See Procedure b)
3. Is detector 2 at its maximum?
   No: repeat step 2
   Yes: the calibration is complete

Procedure b: Stepping the CW laser in wavelength

1. Step the FPI by a known Δλ
2. Vary the CW laser (via computer) to maximize the signal in detector 1

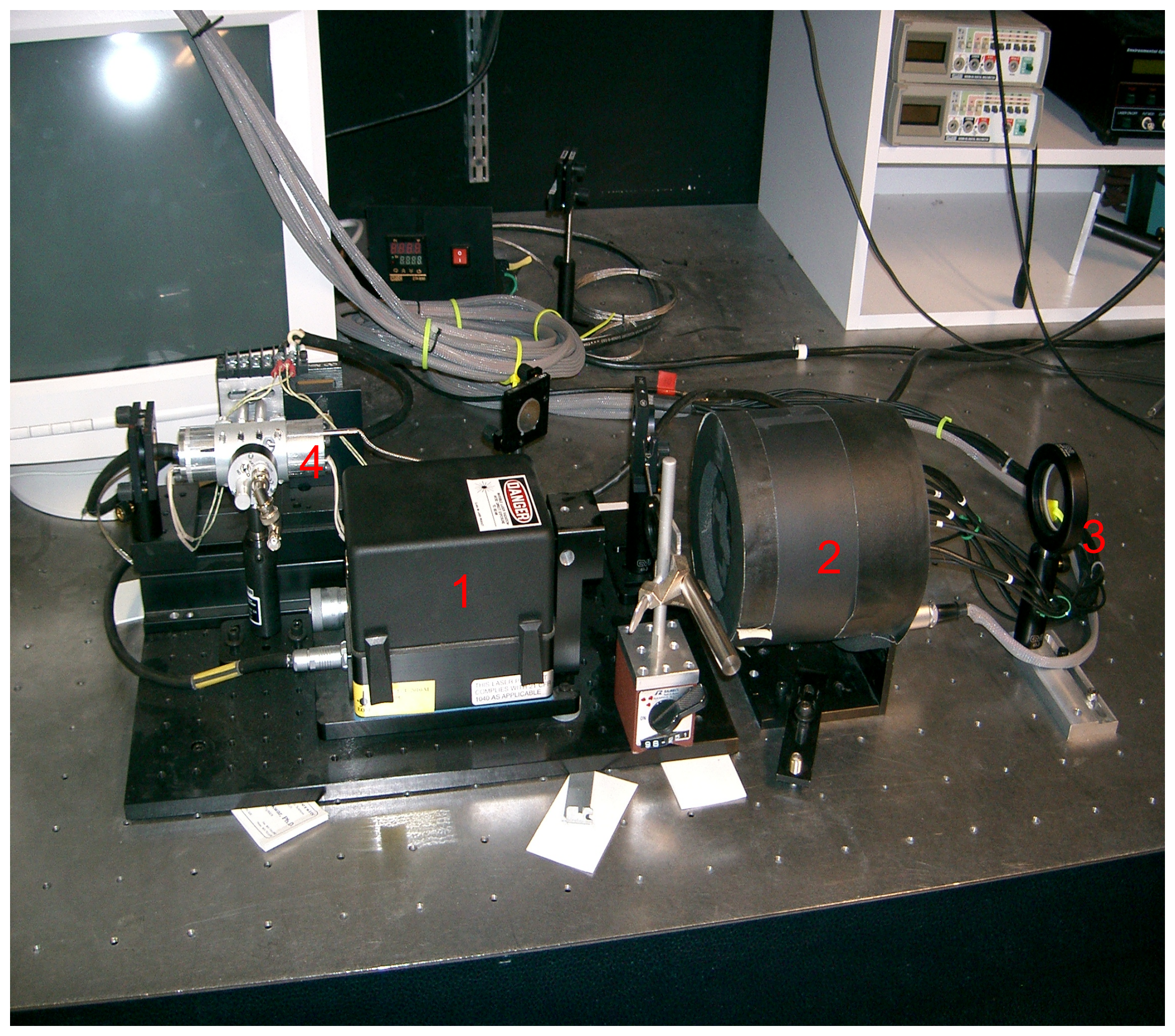

Figure 5. Experiment setup: 1-CW seed laser, 2-FPI, 3-converging (focusing) lens, 4-potassium cell.

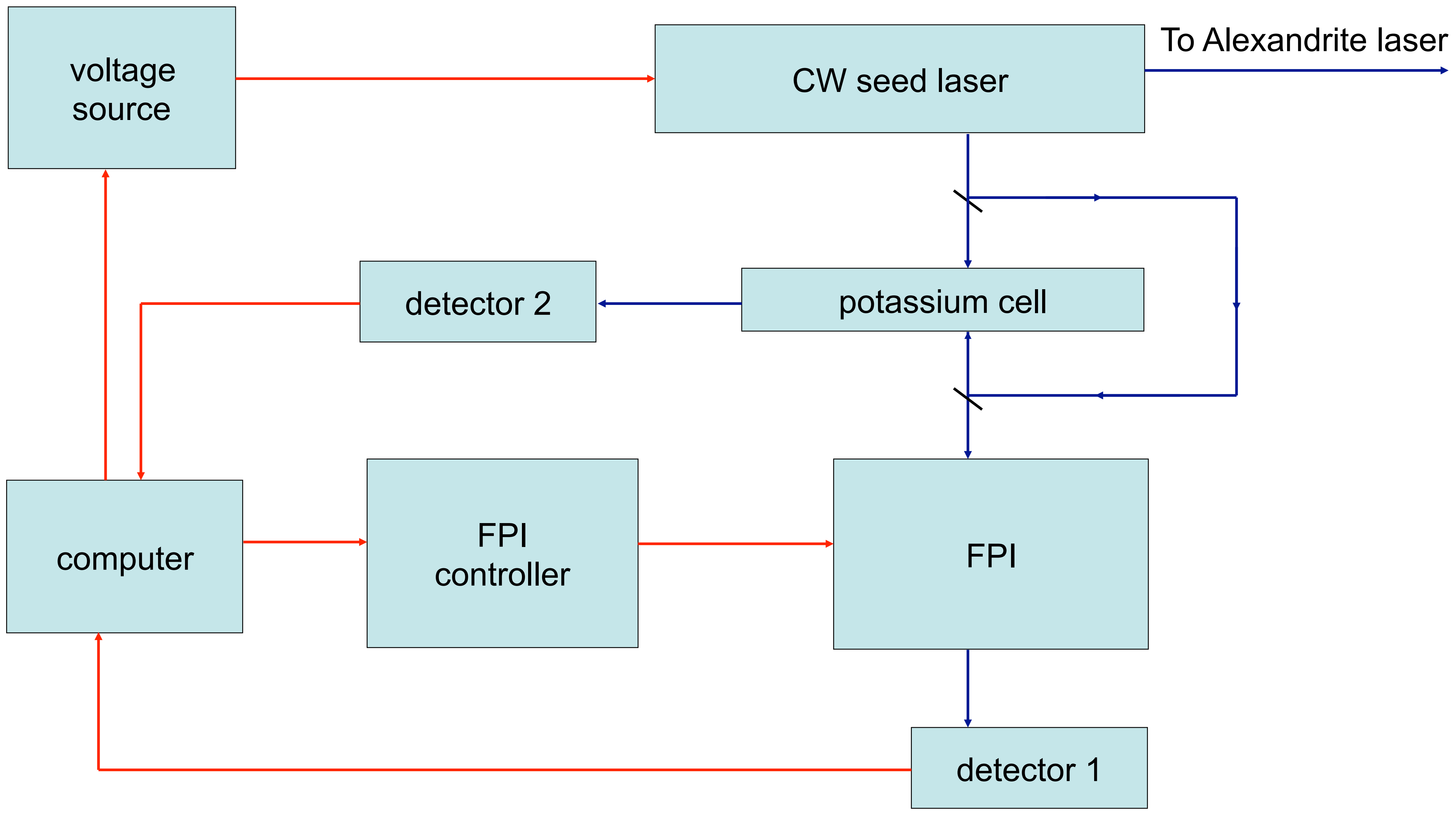

Figure 6. Setup for scanning the potassium spectrum: blue arrows represent light from the CW seed laser and the potassium cell; red arrows represent electronic signals.

References

P. Johnson, “Simulating the Doppler-free fluorescence spectrum for the Potassium D_1 transitions,” (2003).
F. L. Pedrotti and L. S. Pedrotti, Introduction to Optics, 2nd ed. (Prentice Hall, Englewood Cliffs, New Jersey, 1993).
U. von Zahn and J. Höffner, Mesopause temperature profiling by potassium lidar, *Geophys. Res. Letts.*, *23* (2), 141-144 (1996).