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Prediction of saturation effects on potassium lidar returns

Joel R. Drake

Vincent B. Wickwar
Utah State University

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Joel R. Drake and Vincent B. Wickwar — Physics Department & CASS, Utah State University

How does lidar work?

A basic lidar system consists of a powerful laser, a telescope, a receiver, and a data acquisition device. The laser is set up to emit light at the proper wavelength. What that wavelength is depends on what the system is for. For a Rayleigh scatter lidar (or "Green Beam") the wavelength is 532 nm.

The laser light is reflected off a few mirrors so that it points into the sky. In the sky, it interacts with the gases in the atmosphere. Some gases scatter the light. Others absorb the light and then re-emit it, or fluoresce.

The light that is directed back along the laser beam – the return signal – is collected by a telescope and transferred to the receiver. The receiver is usually a photomultiplier tube (PMT). The PMT counts the signal and sends the information to the data acquisition system. The acquisition system places the signal in bins based on when it was received. These bins correspond to different altitudes.

These when all the data has been collected, it is used to determine temperatures and even wind speeds in the mesosphere.

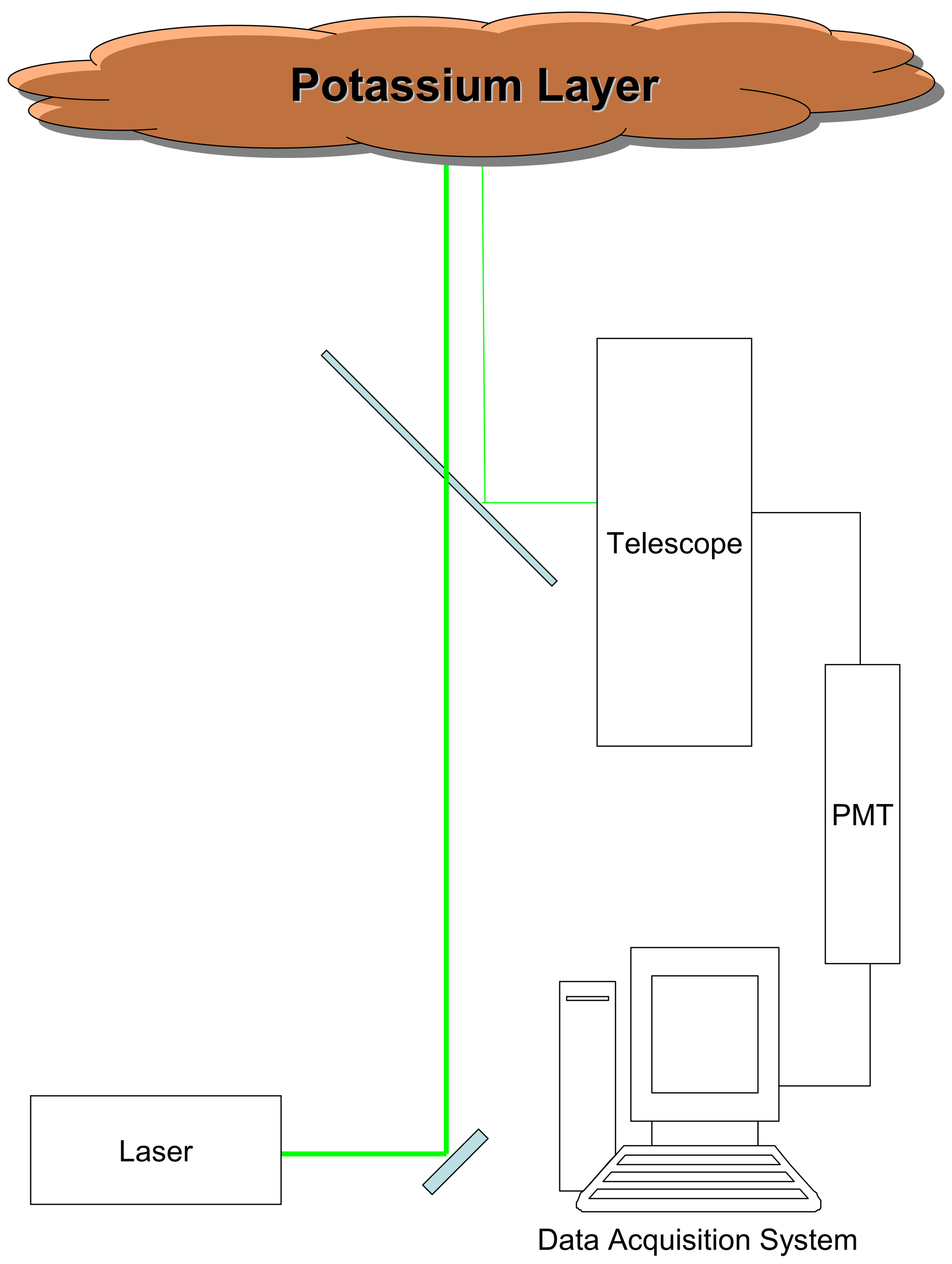

Figure 1: Schematic of a basic lidar system

The Atmospheric Lidar Observatory, on the Utah State University campus, will add a potassium lidar to its existing Rayleigh scatter system in the near future. The current system accurately measures temperatures from 40 km to 85 km in altitude.

Beginning at 80 km, a potassium layer forms due to the disintegration of meteors as they enter earth's atmosphere. ALO plans to probe this layer using an alexandrite laser scanning a wavelength region near 770 nm, where potassium absorbs light. When the light is re-emitted, it can be measured in the same manner as scattered light in a Rayleigh lidar.

Usually, the return signal is proportional to the number density of potassium atoms. However, if the laser light is too powerful, the potassium layer will become saturated and the return signal will be weaker than it should be.

What is saturation?

Under normal circumstances, an excited atom will radiate by spontaneous emission and return to a lower state. The D1 lines of potassium have two ground states. Some atoms will return to their original state; some to the other. Those that return to the other ground state will no longer be available to be excited by the same frequency (wavelength) laser light as before. For a "weak" beam, this has no significant effect on the number of atoms that can be excited. For a "strong" beam, it does.

Another manifestation of saturation is simulated emission. If the laser light illuminates an excited atom, the atom will emit a photon at the same wavelength and in the same direction as the laser beam, or away from the lidar. We will not detect this emission. Stimulated emission does not significantly affect the detected signal for a "weak" laser. For a "strong" beam, it does.

Under saturated conditions, the return signal will become distorted from the unsaturated ideal. This distortion becomes more pronounced as the saturation increases. The saturated signal distorts significantly in the lower frequencies but distorts relatively little as the frequency increases. As a result of this asymmetrical distortion, saturated spectra may be readily identified.

The parameters control the degree of saturation in the potassium layer are: pulse energy, pulse length, beam spectral width, beam divergence

Pulse Energy

Pulse Energy is the energy output of the laser per pulse. As Figure 2 shows, the return signal is based on the total energy of the laser signal. The greater the energy, the greater the return. The nonsaturated return is the highest possible return for the given laser parameters. If the pulse energy is too high in relation to the other parameters, it will saturate the potassium layer and decrease the return signal.

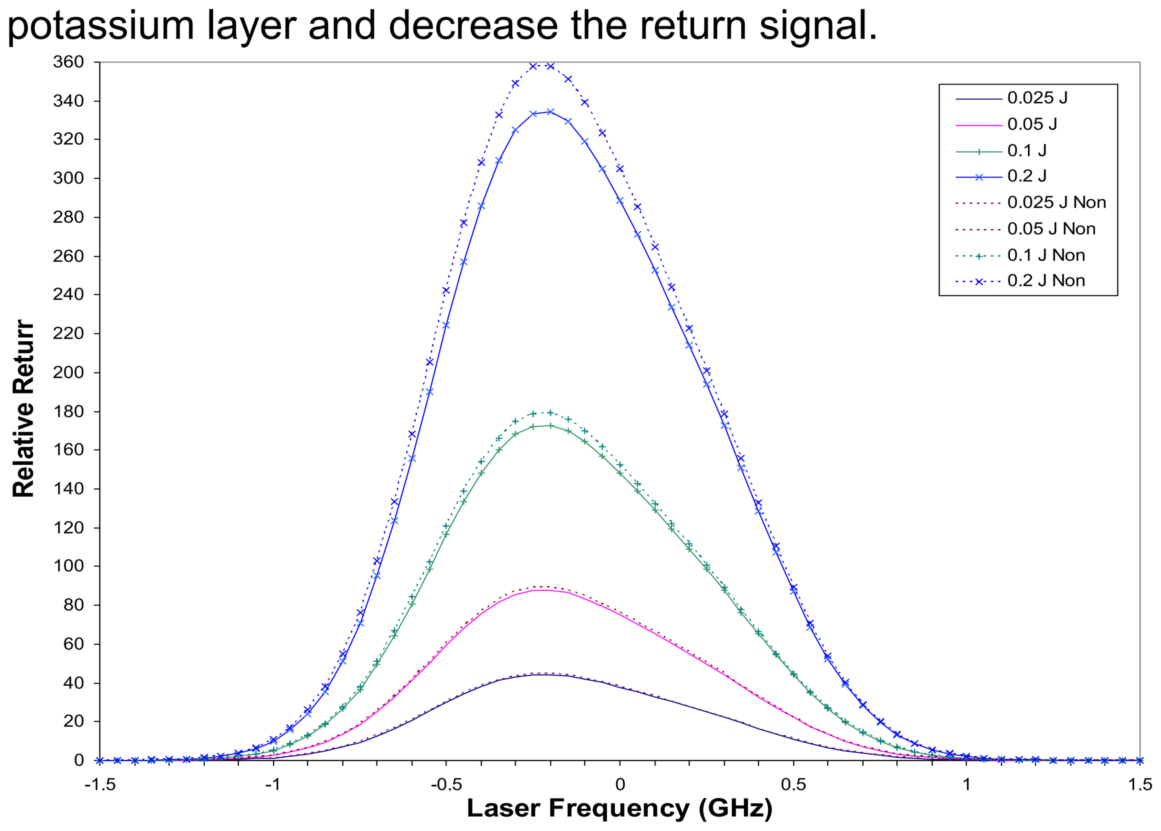

Figure 2: Saturation curves for several pulse energies. All plots are at 1 mrad divergence, 30 MHz spectral width, 80 ns pulse length, .05 J pulse energy, and 200 K with the exception of the parameter being tested.

Pulse Length

Pulse length affects only the saturated return. Longer pulse lengths spread the pulse energy over a longer period of time, thus reducing the saturation effects. Figure 3 shows the effect of pulse length on saturation.

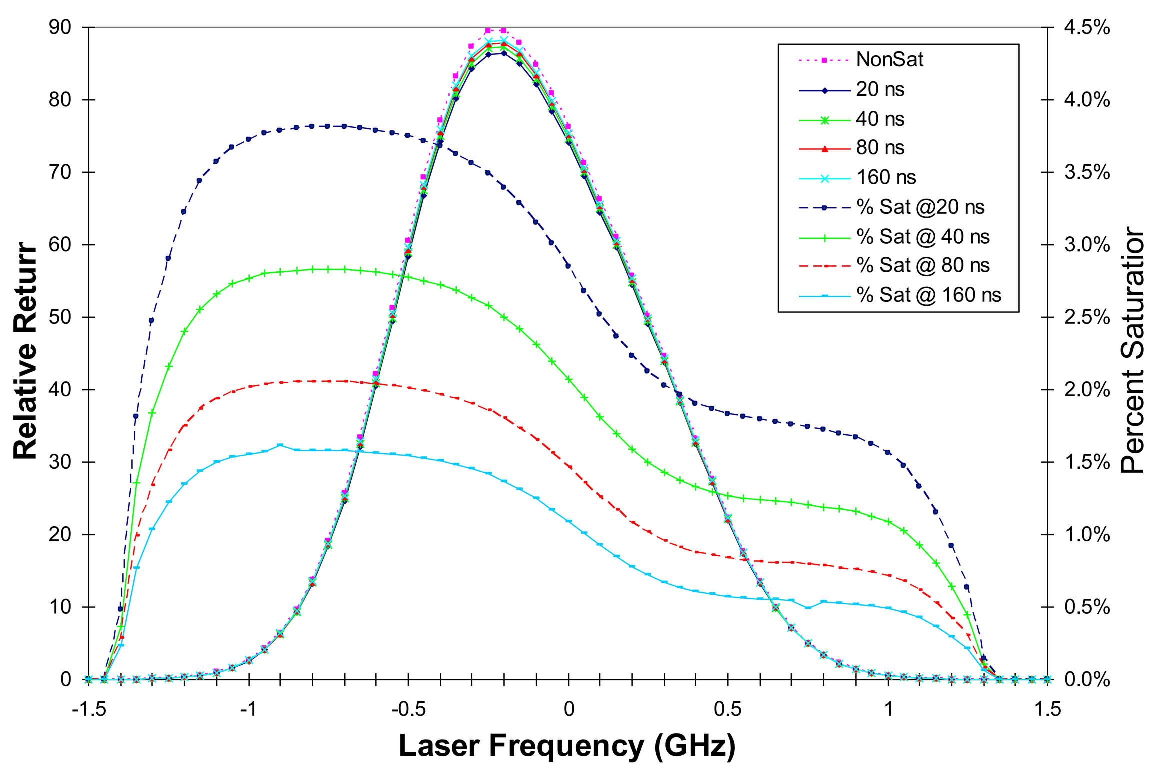

Figure 3: Saturation Comparison for several pulse lengths.

Spectral Width

No light source can emit perfectly monochromatic light. Even lasers emit light in a span of frequencies – the spectral width. The wider the spectral width, the greater the number of frequencies the laser emits. Wider spectral widths spread the laser's energy over more frequencies than narrow spectral widths. Like the longer pulse length, a wider spectral width will reduce saturation.

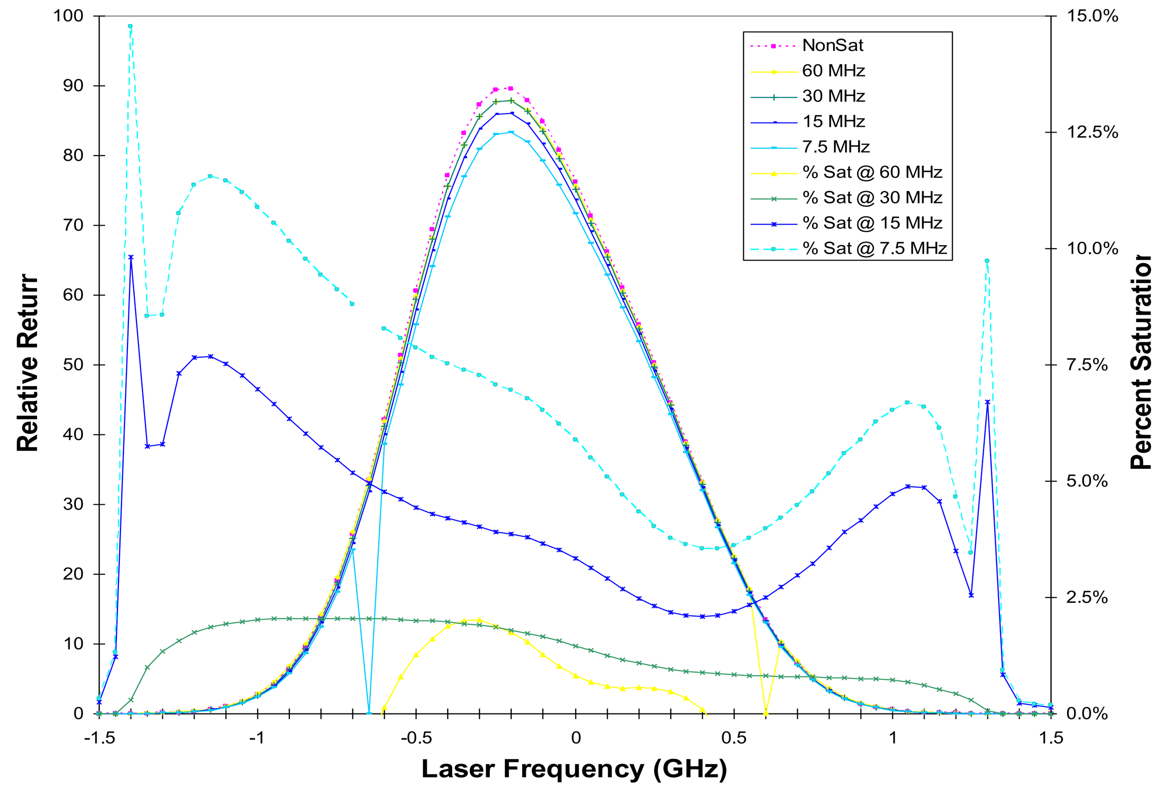

Figure 4: Saturation comparison for various spectral widths.

Divergence

Laser beams spread out as they get further from the laser. The divergence is a measure of the spread. Since the potassium layer peaks at about 90 km, a beam with a large divergence will cover a broad area when it reaches the layer. Large divergences will distribute the beam energy over a large area, decreasing saturation. Beam divergence does not affect the total energy reaching the layer and, thus, does not affect the nonsaturated return.

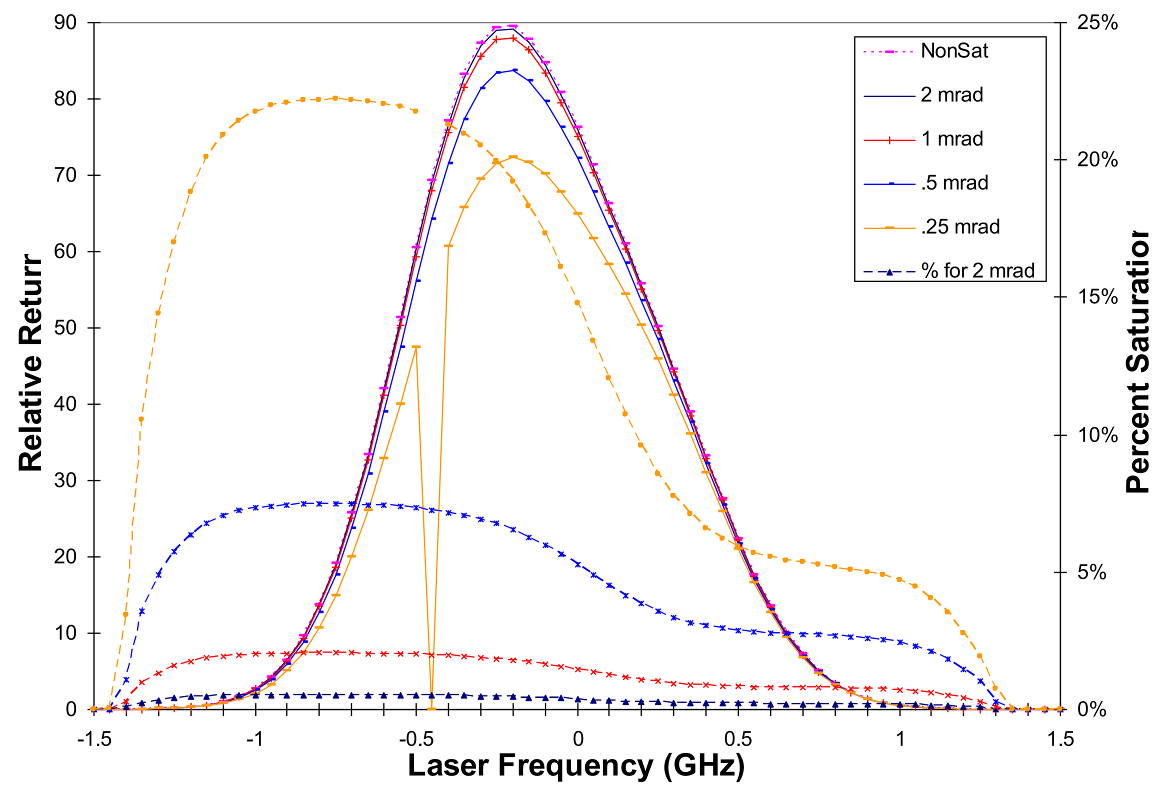

Figure 5: Saturation comparison for various beam divergences.

Why is saturation important?

The return signal is used to determine the temperature of the atmosphere where potassium atoms are present. As Figure 6 shows, changes in temperature change the spectral shape of the return signal. Saturation also changes the shape of the signal. If a highly saturated signal returns, it could be interpreted as indicating that the atmosphere is at a much lower temperature than it truly is. Saturation is unavoidable; however, it can be reduced by choosing laser parameters carefully.

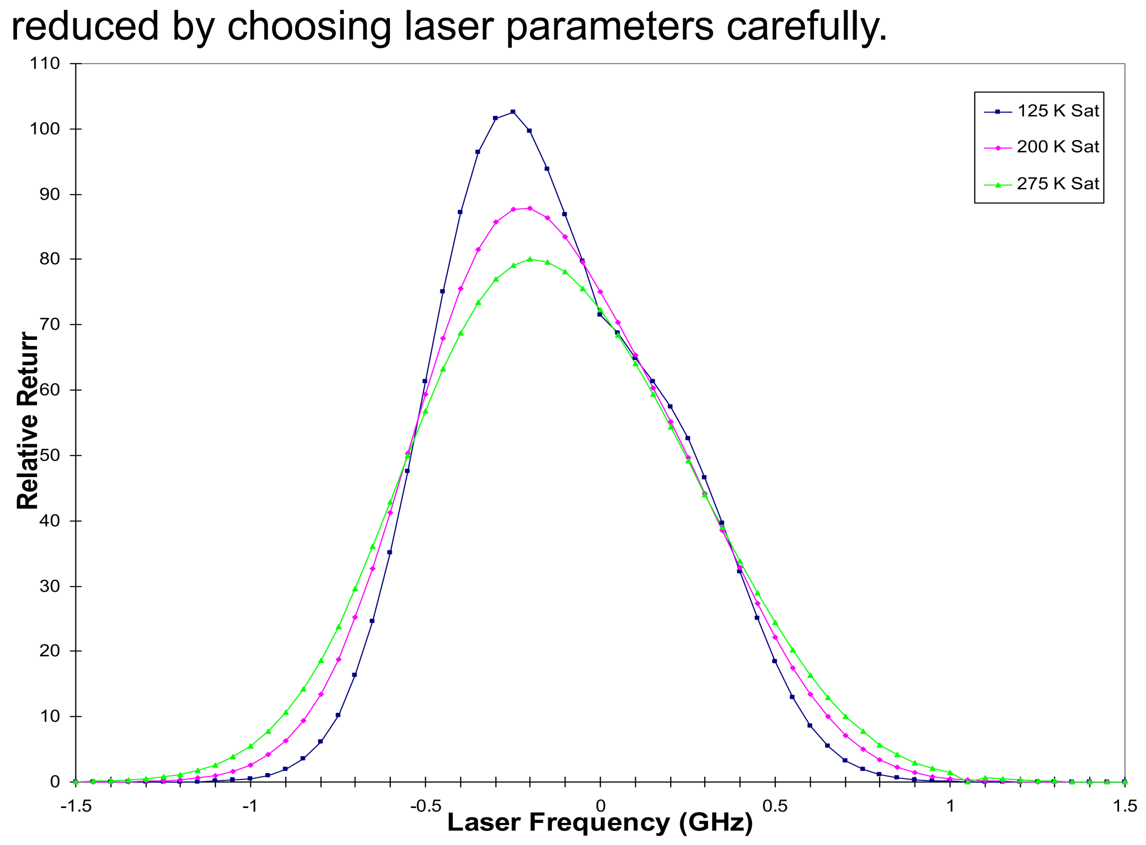

Figure 6: Saturation curves for varying atmospheric temperatures. The parameters were chosen to minimize saturation effects.