Spectroscopic Measurements of CO_2 Lasers at the Infrared Spatial Interferometer

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Abstract
The UC Berkeley Infrared Spatial Interferometer at the Mt. Wilson Observatory (ISI) operates three mid-IR telescopes, each with a heterodyne system. Light from a master laser is propagated to each telescope to serve as a reference for the laser local oscillators. Astronomical observations at the Infrared Spatial Interferometer (ISI) are conducted by the technique of heterodyning, which is the combining of starlight with the light of a CO2 laser to get a lower frequency. Starelight with frequencies close to our laser lines, which are at ~30THz, are down-converted to a radio-frequency baseband signal with frequencies up to 3GHz. Tuning the wavelength of the CO2 laser changes the center frequency of the bandwidth that is observed from stars. These laser lines are selected by adjusting a grating position. We mapped the frequency of these lines as a function grating position using a CO2 spectrometer. We mapped approximately 60 laser lines in four branches, at each of four CO2 lasers at ISI.

Introduction
The unique procedure of heterodyne detection requires specialized equipment for the down converting of starlight into intermediate frequency ranges. For this a CO2 laser of the Littrow configuration type is used. Basically it is a cylindrical drum type cavity, with a piezoelectric device attached to a mirror on one side, with a grating attached to a silver platted mirror on the other side. There is an anode and a cathode inside the laser, along with two high voltage probes mounted inside of it to excite the molecules of CO2. The excited molecules spontaneously emit photons with energies associated with the quantized rotational and vibrational modes. When these photons collide with other excited molecules, they stimulate the emission of photons with the same energies. A particular photon energy level, or infrared frequency, is selected by tuning the grating angle and laser cavity length using the piezo. The grating also allows ~10% of the light to be reflected out of the laser cavity. The maximum power that we obtained from the lasers was around 0.8 W (in Tel2, using a filter). The isotopologue (same element, in same ratios, but with different isotopes) of CO2 that is used inside the laser is 13 CO2. The piezo changes the cavity length of the laser by moving the flat mirror it is attached to and shifting it forward or backwards. This varies the length and frequency of the standing waves produced inside the laser.

The spectrometer that was used was a CO2 spectrograph. The IR laser beam was brought through a single slit at the front of the spectrometer. Once the laser beam passes through the slit, it is then reflected off a collimating mirror, which parallelizes the beam before sending it off to the diffraction grating. The grating then disperses different frequencies onto an anti-fluorescence screen. UV light causes the screen to glow, and the IR lines show up as dark areas. These wavelengths of individual CO2 lines can then be determined to a high degree of accuracy.

Mathematical Principal for Heterodyning:
Heterodyning is based on a trigonometric identity.

$$\sin\theta\sin\varphi = \frac{1}{2}\cos(\theta-\varphi) - \frac{1}{2}\cos(\theta+\varphi)$$

The product on the left side represents the mixing of a sine wave with another sine wave. The right side represents the resulting signal, which happens to be the difference of the two sinusoidal terms. The frequency of the one term becomes the sum and the other the difference of the original frequencies.

Procedure
Since the Infrared Spatial Interferometer uses the technique of heterodyne detection, the CO2 laser plays a crucial role in nightly observations. Starlight is down-converted to an intermediate frequency range, on both sides of our laser line frequency. These laser lines are selected by adjusting a grating position. The laser frequencies were mapped out at all of the three telescopes, and at the master laser. We managed to get about 60 laser lines per telescope. The procedure used for the first set of mappings was straight forward. First a CO2 spectrometer was installed and lined up with the Laser line, via its slit in the middle. Once the CO2 spectrometer was lined up, we made sure that it was reading around 11.15 microns. Afterward, the grating was slowly turned clockwise in 20 micron intervals to reach peaks on the power meter, which was directly in front of the infrared laser beam's path. The grating needed to be carefully read, to avoid the common mistake of parallax error, which would invalidate our measurements. Then a piezoelectric (piezo) device was tuned even further to get the maximum peak of power, not the local maximums, which are small peaks within a peak. Since each of the laser lines peak at a specific piezo setting, which is different for neighboring lines, this can make it difficult to determine when we should see a new line. For this reason, it is important to scan the entire piezo range for the highest maximum, not just the local maximum associated with the previously detected line.

Once the lines were observed, the data was then mapped out into a graph of power as a function of grating position. There were a few technical problems encountered along the way. In telescope three, the grating's spring became stuck at around the 5.000 microns reading, which ultimately had to be taken apart and reassembled. In order for the data to be valid for that CO2 laser, it had to be taken from the beginning. Problems of hysteresis were thought to have plagued laser three. To make sure that the data held true, it was checked at the P20 and P40 lines, by setting the grating at those specific points and maximizing the power with the piezo to get the right frequency and power output of the laser. In the end it was the first technique that was used for obtaining those lines that caused the erratic readings of the laser. The 20 micron interval was too large to detect all of the lines and therefore all of their associated peaks. Also the fact that the piezo was not tuned thoroughly to make sure that we got the highest maximum possible per laser line, we did not cover the full range. So all four of the CO_2 lasers on site had to be redone with a different technique. This new technique involved the data region from the previous attempts, but mapped out lines and peaks at regular intervals. The first time we measured the laser lines, we ended up skipping lines and peaks in between, and we needed to know all of these data. So now the grating was moved from a position above the highest grating position, downwards at 8 micron intervals to obtain all of the missing data in between. Along with this procedure we tuned the piezo setting through its full motion of travel, very gently and slowly as to not miss the highest maximum, and therefore avoid the confusion of the local maximums. So far it has been done for telescope three's laser, with the master laser left to be completed.

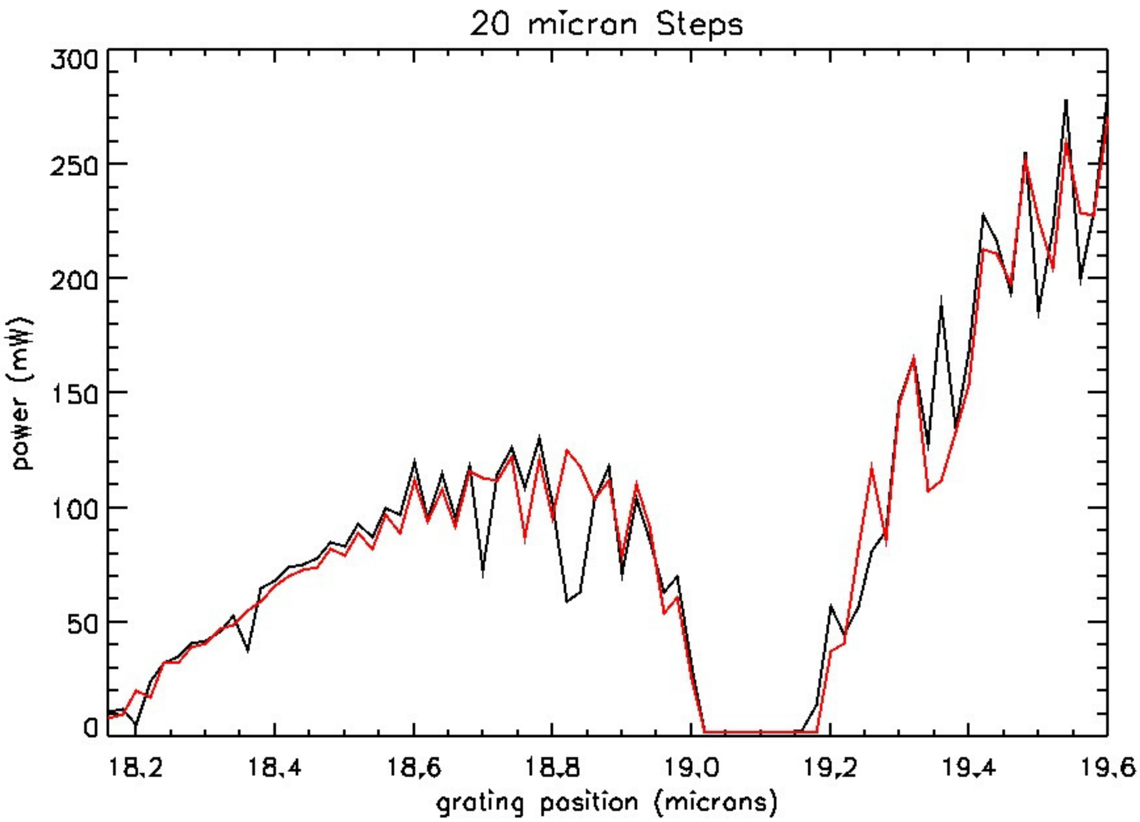

Figure 1: This is the first graph that was generated using an IDL program. As can be seen, the black line has fewer peaks in power, while the red line shows all the area that has been skipped. This graph represents the data gathered from the first method.

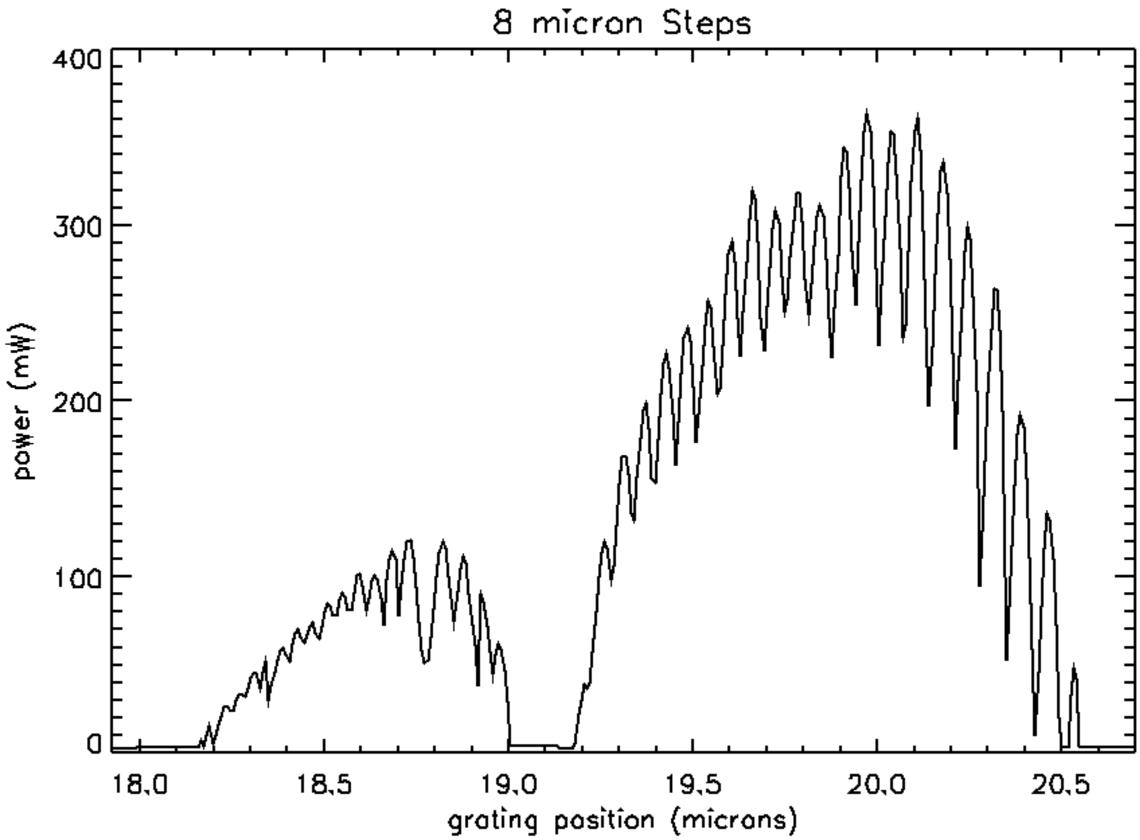

Figure 2: This graph represents the second procedural method that was used to gather the data. As it can be seen all of the necessary peaks in power have been covered.

Figure 3: Two of the three Infrared Spatial Interferometer telescopes

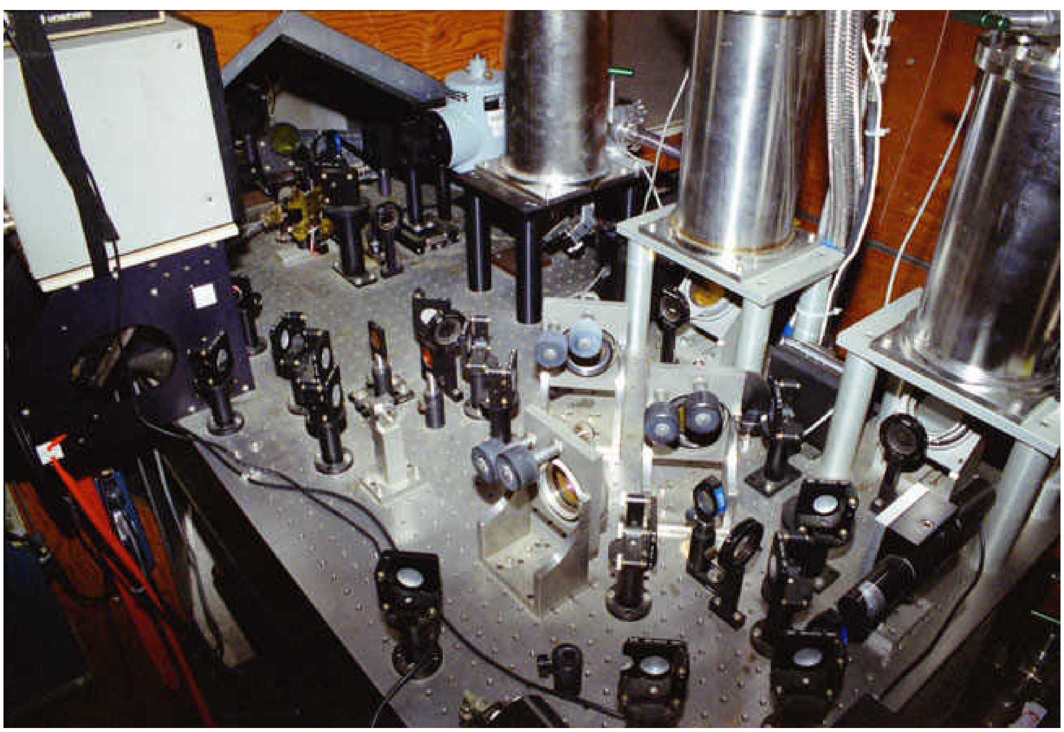

Figure 4: One of the optics tables inside one of the telescopes.

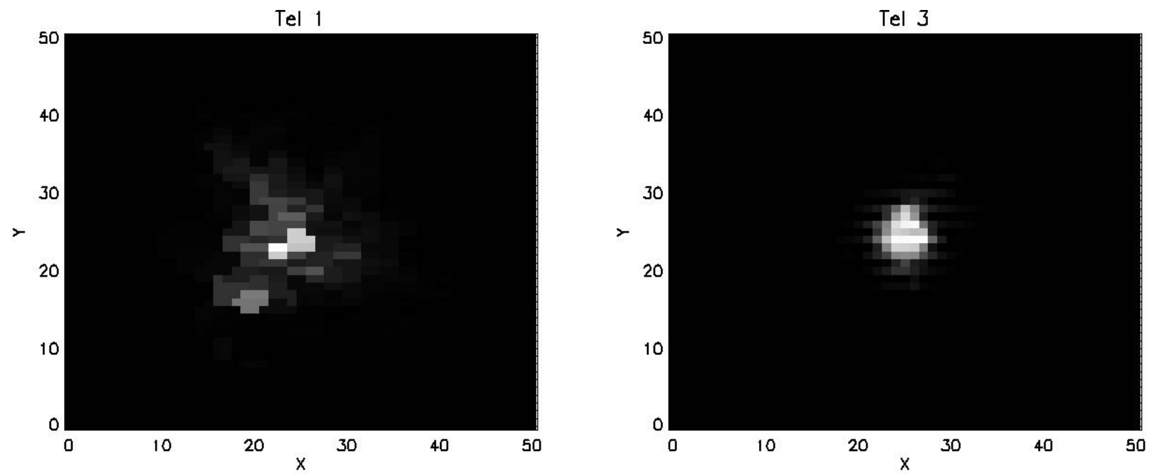

Figure 5: Photograph taken by telescope 2 and 3's guider cameras of Alpha Scorpios (Alp_Sco).

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