INFRARED HETERODYNE SPECTROSCOPY: A TOOL FOR HELIOSEISMOLOGY

D.A. Glenar
Colgate University
Physics Department
Hamilton, NY 13346

H.U. Käufl, D. Deming, T. Kostiuk and M.J. Mumma
NASA Goddard Space Flight Center
Planetary Systems Branch
Greenbelt, MD 20771

ABSTRACT. Heterodyne spectroscopy at infrared (IR) wavelengths is a technique well suited for measuring small velocities in the solar atmosphere. An IR heterodyne spectrometer for solar oscillation measurements has been located at the McMath Solar Telescope of the Kitt Peak National Solar Observatory. It is now being used for single point Doppler shift measurements of 11 micron OH absorption features formed in the upper photosphere, with sampling rates as high as 33 mHz. The instrument employs a stabilized CO_2 laser permitting absolute velocity measurements with an uncertainty of < 10 ms^{-1}.

1. BACKGROUND

IR heterodyne spectroscopy near 10 microns wavelength has been used for remote sensing of planets and cool stars by fully resolving spectral absorption features of atmospheric gases.[1] Recently it has also been used to probe the temperature structure of the upper photosphere $\tau_{5000} \sim 10^{-3}$ to 10^{-2}) by recording spectral line shapes from pure rotational transitions of solar OH, which is formed in this region.[2]

With the advantages of laser heterodyne spectroscopy, these OH features also enable precision measurements of the spatial and temporal velocity distribution in the upper photosphere.[3] Both position and central intensity in the line can be accurately measured, since the full spectral line shape is acquired. Moreover, the local oscillator is usually a CO_2 laser with a long-term frequency stability of about 1 part in 10^9 (< 1 ms^{-1}) when properly stablized. The coherent nature of heterodyne spectroscopy also provides diffraction-limited spatial resolution, which can be used to isolate high degree oscillatory modes, up to the limit of seeing. At good observing sites, this limit can be less than 1 arcsec.

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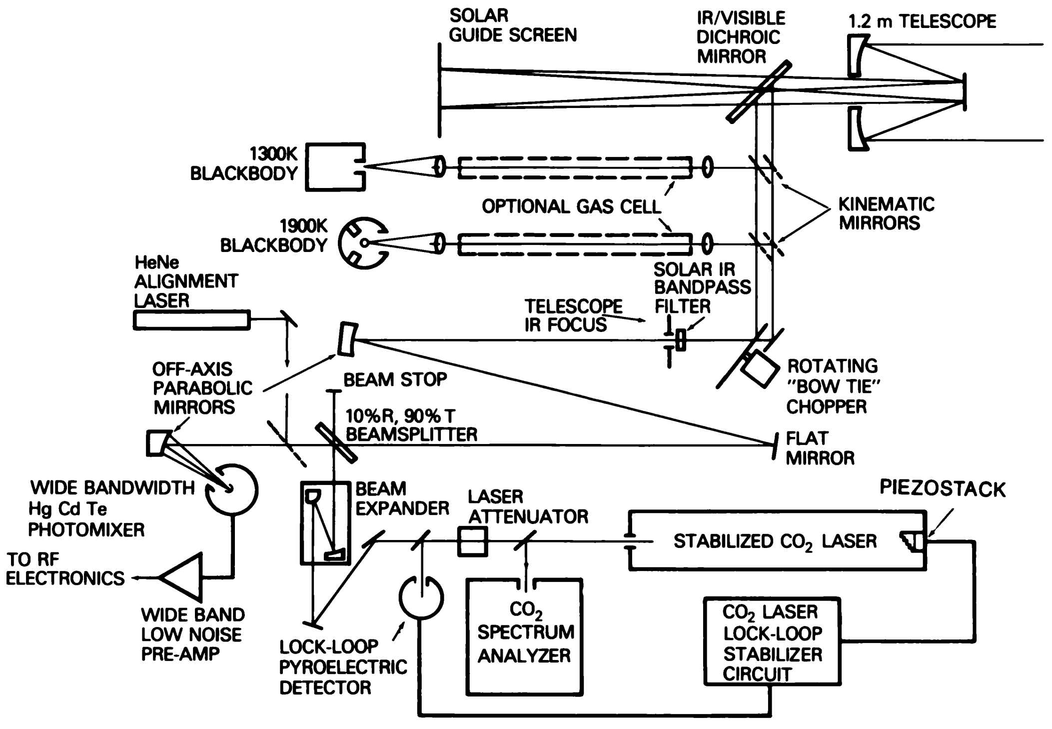

Figure 1. Optical front-end of the CO_2 laser IR heterodyne system used for solar velocity measurements at Kitt Peak.

2. OPERATION OF THE KITT PEAK FIELD SYSTEM

Figure 1 shows the optical front end of the heterodyne spectrometer now located at the McMath solar telescope of the National Solar Observatory at Kitt Peak. Signal radiation from the Sun or local high temperature blackbody is imaged at the entrance iris which lies at the focus of both the instrument and telescope. The diverging beam that exits from the iris is collimated using a parabolic mirror and combined at a beamsplitter with the radiation from a peak-power stabilized CO_2 laser. This laser has recently been stabilized more precisely by locking to the Lamb-dip of a separate NH_3 cell. The co-propagating beams are then imaged onto a wideband photodiode heterodyne detector which translates a portion of the IR spectrum near the laser LO frequency to radio frequencies. The IF information is then amplified and processed using a microcomputer controlled multi-channel RF receiver which records the shape of spectral features at sub-doppler resolution ($\nu/\Delta\nu > 10^6$). A rotating chopper near the entrance iris switches the receiver between the source and a matched blackbody continuum source. This "null-balanced" detection scheme eliminates noise in the data resulting from small instrument gain fluctuations.

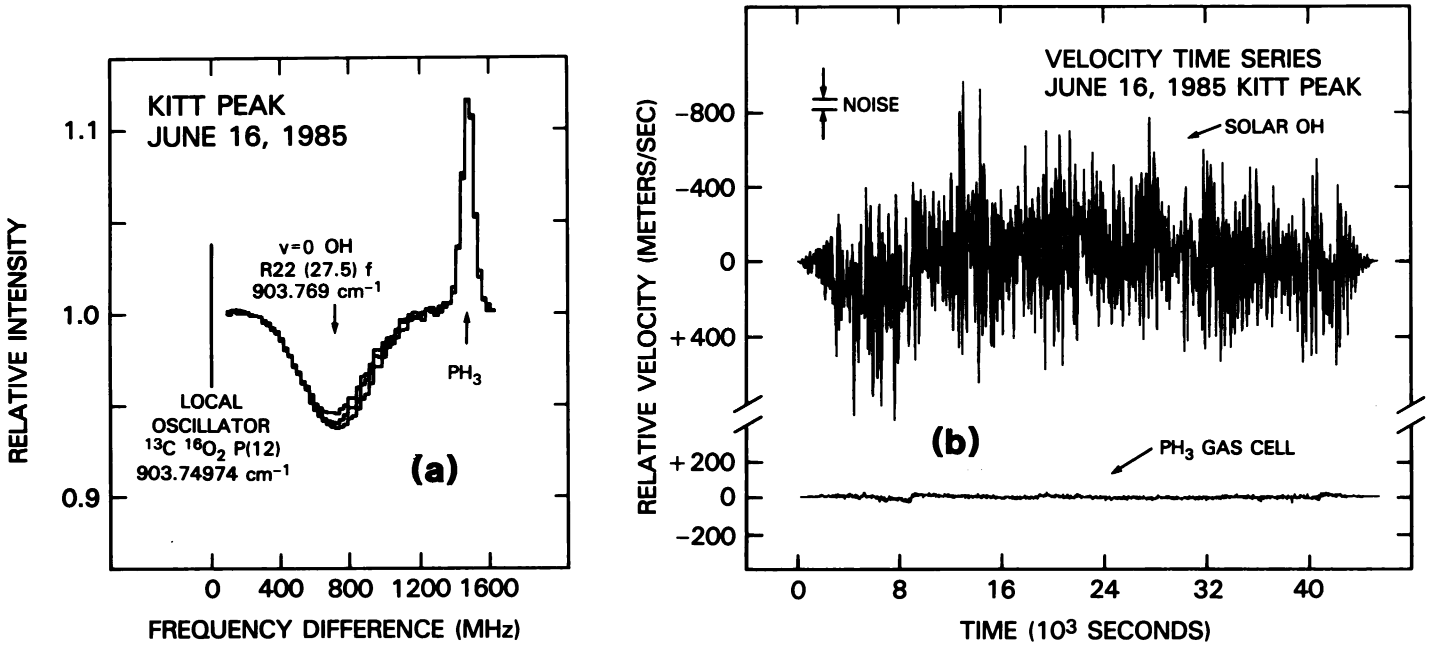

Figure 2. Sample solar velocity measurement data. (a) Shows three consecutive ∿ 25 second heterodyne measurements of an OH rotational transition at solar disk center. Fluctuations in line center position and central intensity are apparent. The inverted feature at 1575 MHz is a reference PH_3 absorption line which monitors the LO frequency stability. The top part of (b) is an apodized velocity time series produced from 1 full day of OH line center position measurements.

3. SAMPLE RESULTS

Figure 2a shows 3 successive 30 second disk-center measurements of a solar OH absorption feature which lies close in frequency to the I-band P12 laser transition of $^{13}C^{16}O_2$. A PH_3 absorption cell in the reference blackbody beam is used to continuously monitor the laser frequency stability. This produces the inverted PH_3 absorption feature at 1475 MHz. Even over the ∿ 60 second observing period, the solar OH line shows large fluctuations in both line center position and central intensity. Figure 3b is an apodized 13 hour OH velocity time series which was produced by least squares fitting to each OH line shape to precisely define its center position. An identical procedure applied to the set of PH_3 measurements (bottom trace) shows that the instrument is normally stable to within 10 ms^{-1}. This is much less than the ∿ 300 ms^{-1} rms velocity fluctuations in the time series itself. The deviation at 8600 seconds was caused by a change in the detector response, but this is not repetitive and will not significantly affect the resulting velocity power spectra. Power spectra of both the velocity and line depth time series establish the existence of a chromospheric resonance, as discussed elsewhere in these proceedings.[4]

4. FUTURE PROSPECTS

Efforts are presently underway at NASA Goddard to construct a one-dimensional heterodyne imager using a 12 element linear detector array. A miniaturized, remote controlled heterodyne system using a waveguide CO_2 laser LO is also being built, in order to demonstrate the suitability of this class of instrument for orbiting satellites.

REFERENCES

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