10 µm HETERODYNE SPECTROSCOPY AT TELESCOPES WITH 1 m APERTURE

H. Rothermel, U. Schrey, H.U. Käufl, S. Drapatz,
Max-Planck-Institut für Physik und Astrophysik,
Institut für Extraterrestrische Physik,
8046 Garching bei München, FRG.

ABSTRACT. Heterodyne spectroscopy combines high instrumental transmission with virtually unlimited spectral resolution. For 250 K bodies like Mars and Venus resolution is limited to 10^7 (= 30 m/s) because of photon statistics whereas for solar measurements the cm/s velocity range, desirable for study of solar oscillations, is feasible. Since a single heterodyne receiver is conserving its etendu, smaller collecting area results in larger field of view. The signal remains unchanged as long as the source is large enough to fill the beam. For Mars, Venus and the Sun heterodyne observation with 1 m aperture is competitive.

1. PRINCIPLE OF OPERATION

A heterodyne spectrometer converts by superposition with laser radiation an infrared spectrum down into the radio frequency (RF) range; where it is analysed with electrical rather than with optical filters. The RF heterodyne signal produced in the photomixing process is a function of both signal power P_S and laser power P_L:

$$\bar{i^2} = 2\eta \; (e/h\nu)^2 \; P_S \; P_L$$

where η = quantum efficiency, $h\nu$ = photon energy. With sufficient laser power (~ 1 mW) the heterodyne signal can be increased to a level where other sources of noise such as preamplifier and RF electronics no longer are important. The heterodyne system works now in the quantum noise limited regime where it approaches the sensitivity of a hypothetical photon counter working at 10 µm wavelength with a quantum efficiency of 0.6. In addition a multiplex advantage is accomplished by use of a filter spectrometer analyzing the spectrum with 100 to 200 filters in parallel.

Heterodyne systems[1] are conserving the product of beam solid angle Ω and effective telescope area A_e:

$$A_e \cdot \Omega = \lambda^2$$

where λ = wavelength. This relation indicates that a heterodyne spectrometer exploits the telescope at the diffraction limit (about 2 arcsec. for λ = 10 µm and 1 m aperture).

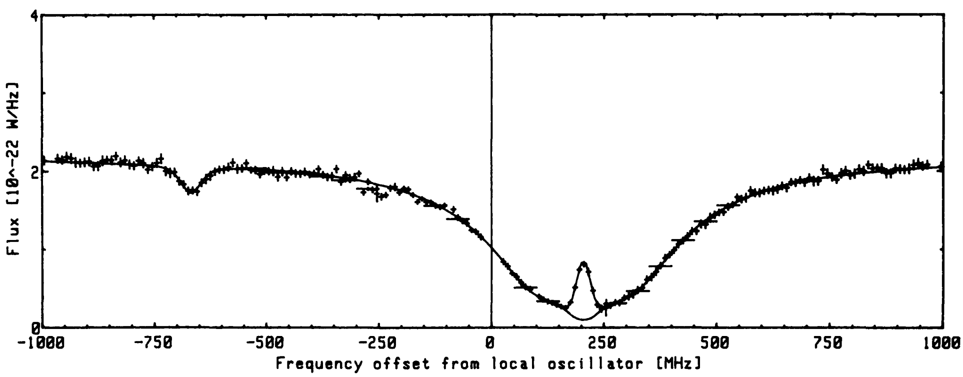
J. B. Hearnshaw and P. L. Cottrell (eds.), Instrumentation and Research Programmes for Small Telescopes, 431–433.

2. INSTRUMENT

The spectrometer[2] working between 9.5 and 12.5 µm wavelength is based on a sealed-off CO_2 laser, a Hg Cd Te photovoltaic detector and a 200 channel filter spectrometer. In contrast to competitive instruments it is portable and operates at the Cassegrain focus. It was used first with a 1 m reflector on the Gornergrat (3200 m elevation in Switzerland). Five different isotopic combinations of CO_2 laser gas present about 250 discrete laser frequencies. This provides a sufficient number of coincidences with lines of other interesting molecules such as NH_3, SiH_4, C_2H_2, C_2H_4, OH and H_3O^+.

3. MEASUREMENTS

A heterodyne spectrum covers only one, in rare cases two molecular lines. These lines are perfectly resolved and have precise wavelength and flux calibration. Below is an example of a heterodyne spectrum from the Martian atmosphere[3]. The continuum is emitted by the Martian surface. The weak absorption on the left is $^{12}C^{16}O^{18}O$, the saturated absorption profile is normal CO_2. Adjusting synthetic line profiles results in temperature and pressure as a function of altitude. Furthermore isotopic ratios are derived with a precision competitive to in situ measurement by the Viking landers. The narrow emission line in the centre of the CO_2 absorption is a fluorescence produced by sunlight in the Martian atmosphere about 70km above the surface. From the line width or (better) comparing integrated fluxes in the emission for different rotational transitions, temperature mapping in the high atmosphere of Mars and Venus is possible. These investigations are beyond the capability of space probes. In future comets, outer planets and planetary nebulae will be investigated by heterodyne spectroscopy for thermal condition, isotopic abundances and expansion velocities.



Line profiles of isotopic and normal CO_2 on Mars.

REFERENCES

1. A.E. Siegman, Proc. IEEE 54, 1350 (1966)
2. H. Rothermel, H.U. Käufl, Y. Yu, Astron. Astrophys. 126, 387 (1983)
3. U. Schrey, H. Rothermel, H.U. Käufl, S. Drapatz, Astron. Astrophys. in press (1985)

DISCUSSION

A'Hearn: How long an integration time is required to obtain a spectrum of Mars at one laser line?

Rothermel: About 10 minutes.

Genet: Is this telescope dedicated to this type of work?

Rothermel: No, it is not dedicated to IR work.