A quasioptical SIS receiver with normal metal tuning for the 800-900 GHz band

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We describe a quasi-optical SIS receiver designed for operation in the 800 - 900 GHz atmospheric window. First results obtained during an observation period in January 1997 at the Heinrich-Hertz-Telescope (HHT) on Mt. Graham, Arizona are presented.

The receiver employs the well established design of using a diffraction limited substrate-lens made of crystalline quartz fed by a double-slot antenna to couple to the incoming radiation [1]-[3]. In contrast to the design variant using silicon as lens material [4], our antenna configuration includes a moveable reflecting backplane to avoid losses due to the backward radiation into the vacuum side. Without backplane these losses would be higher as compared to silicon due to the lower refractive index of the quartz dielectric; on the other hand for the silicon lens an antireflection coating usually has to be applied to reduce the higher reflection loss of the silicon lens. Currently we use no antireflection coating on the quartz lens. A schematic drawing of our optical setup is shown in Fig. 1. It was designed using a theoretical method developed by Prof. V. Hansen and his group [5], which gives the antenna's impedance and its radiation characteristic into a dielectric half space. Results from the calculation of the double-slot input impedance versus reflector distance are shown in Fig. 2. The extended hyperhemispherical lens was shown to provide good quality amplitude and phase patterns by scaled measurements at microwave frequencies [6].

A photography illustrating the mechanical design of the mixer block is shown in Fig. 3. Only few mechanical components are necessary due to the use of a commercially available microwave substrate with thick copper groundplane [7]. It carries the lens assembly on the front side whereas the microwave and bias lines are etched on the substrate side which also supports the superconducting magnet with pole pieces and the reflecting backplane assembly.

The SIS junctions used for this experiment were produced in 1994 at IRAM-Grenoble (France) during a guest period in the junction laboratory. Because the desired operating band of the receiver is well above the gap frequency for niobium films, we decided to use a normal conducting embedding network for the Nb- (Al-oxide)-Nb junction [8]. DC measurements of sputtered aluminum films at 295 K and 4.2 K gave a resistivity near the bulk limit at room temperature and a resistivity ratio (RR) of roughly 11 for a variety of films. At high frequency and low temperature anomalous skin effect losses are the limiting factor for the achievable minimum RF loss in the Al films. According to the theory of metallic conduction, size effects impose an upper limit on the DC conductivity of thin films. At low temperatures scattering of the conduction electrons from the film surface becomes important if the electron's bulk mean free path is comparable to the film thickness. The result is a maximum $RR \approx 10$ for our film thickness of about 200nm, meaning that no further improvement of the RF surface resistance can be expected if this RR is reached. This is because in the pure bulk limit (clean films with thickness large compared to anomalous penetration depth) the RF surface resistance does not depend on the RR [9]. The mixer chip used for the measurements reported here is shown in Fig. 4. It employs the double-junction tuning circuit with antisymmetric feed configuration introduced by Zmuidzinas et al.[10]. We used the cross-line technique [11] to define junctions of roughly 0.8x0.8 μm^2 by optical lithography on two tiny islands of trilayer deposited on the aluminum groundplane. The junction current density is about 15 kA/cm^2. A microphotograph of the junction area of the mixer chips is shown in Fig. 5. These photographs also show the two different thicknesses of the sputtered SiO_2 dielectric layer that were used in the design. In order to realize line impedances of 15-25 Ω with acceptable linewidth (losses) for the antenna feed circuit, 800 nm SiO_2 was used. In contrast, for the radial stub dc-blocks at the slots and for the tuning inductor between the junctions 400 nm SiO_2 was used to realise a low impedance level. This thickness of the dielectric layer results naturally from the crossline-process because about 200nm of SiO_2 are needed for each of the two RIE and liftoff steps.

The receiver cryostat is a standard liquid helium bath type (IR-labs HD3-8). The measurements reported here were done at a mixer block temperature of 4.2 K. The cryostat's atmospheric window is made of 100 µm mylar foil. IR filtering is done by means of a crystalline quartz plate with polyethylene antireflection coating on both sides at 77 K and a resonant fluorogold foil at 4.2 K. The cooled IF section consists of a 3 stage 2 - 4 GHz HEMT amplifier developed at MPIfR; no IF transformer between mixer output and amplifier was used.

During first laboratory tests of the receiver in 1995, a DSB receiver noise temperature of 850 K without any correction for losses had been obtained at a single frequency of 803 GHz using a stabilized FIR laser with $^{15}NH_3$ isotope gas as local oscillator [12]. From subsequent measurements of the receiver bandpass shown in Fig. 6 using a Martin-Puplett interferometer [13], good heterodyne performance could be expected for the entire atmospheric window. When a solid state local oscillator system for the frequency range 795 - 875 GHz got available, we set up a tunable telescope system. The LO system consists of an InP Gunn-oscillator followed by a doubler and tripler stage [14]. A 15 µm mylar beamsplitter couples the local oscillator power to the mixer, two ellipsoidal mirrors at ambient temperature are used to match the mixer beam to the telescope and to the dual-mode horn at the tripler output. Fig. 7 shows the DSB receiver noise temperatures achieved in the laboratory at 4.2 K bath temperature, no corrections for losses were made. The radiation temperatures of the loads at room and liquid nitrogen temperature were corrected according to the Callen and Welton formula [15].

The noise temperature of the IF chain including a cooled isolator was measured by means of a heated 50 Ω load to be12.5 K in a measurement bandwidth of 60 MHz centered at 3 GHz. From these results a conversion loss of ≈11 dB was estimated at 803 GHz. The single measurement included in the figure indicates a DSB noise temperature of 680 K achieved at 810 GHz at the HHT. A plot of the corresponding conversion curves and the junction's IV-curve is given in Fig. 8. The improved sensitivity is attributed to the replacement of the cooled IF amplifier prior to the observation run and to the lower bath temperature of about 3.85 K on the mountain.

During our ten day technical observing run at the HHT in January, an astronomical verification of the receiver's performance could be obtained. As an example Fig. 9 shows the average of 4 continuum subscans across Mars (scanning in azimuth). Deconvolved from the intrinsic size of the planet, a FWHP main beam width of $\Theta_{mb} \approx 9''$ was deduced from the measurements which corresponds to the telescope's diffraction limit. No evidence for side lobe or broad pedestal structure was found to a level of 10-13 dB from this and other measurements carried out. Heterodyne response is demonstrated in Fig. 10, showing the CO (7-6) transition detected towards the carbon rich circumstellar envelope IRC 10216. The integration time was 3 min only for this spectrum taken in rather poor atmospheric conditions ($\tau_{\text{line-of-sight}} \geq 3$).

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References

[1] D.B. Rutledge, M. S. Muha, "Imaging Antenna Arrays", IEEE Trans. Antennas Prop., vol. 30, pp. 535-540, July 1982

[2] M. Wengler, D. P. Woody, R.E. Miller, T.G. Phillips, "A Low Noise Receiver for Millimeter and Submillimeter Wavelengths", Int. J. IR and MM Waves, vol. 6, pp. 697-706, 1985

[3] J. Zmuidzinas, H.G. LeDuc, "Quasi-Optical Slot Antenna SIS Mixers", IEEE Trans. MTT, vol. 40, pp1797-1804, Sept. 1992

[4] J. Zmuidzinas, N.G. Ugras, D. Miller, M. Gaidis, H.G. LeDuc, J.A. Stern, "Low-Noise Slot Antenna SIS Mixers", IEEE Trans. Appl. Supercond., vol. 5, pp.3053ff., 1995

[5] H. Aroudaki, T. Vaupel, V. Hansen, F. Schäfer, "Full-Wave Analysis of CPW Fed Slot Antennas for the Submillimeter Wave Region by the Spectral Domain Method", Prog. in Electromagnetic Research Symp. (PIERS), 1994, Nordwijk, Netherlands, Proc., pp. 1-4

[6] F. Schäfer, E. Kreysa, T. Lehnert, K. H. Gundlach, "A Planar SIS Receiver with Logperiodic Antenna for Submillimeter Wavelengths", Proc. 4th Intl. Symp. on Space Terahertz Technologie, 1993, Los Angeles, CA

[7] Duroid 6002, Rogers Corporation, Chandler, Arizona 85226, USA

[8] R.L. Kautz, "Miniaturization of Normal-State and Superconducting Striplines", J. Res. Natl. Bur. Stand., vol. 84, pp 247-259, 1979

[9] R.W. Keyes, E.P. Harris, K.L. Konnerth, "The Role of Low Temperatures in the Operation of Logic Circuitry", Proc. IEEE, vol. 58, pp. 1914-1932, 1970

[10] J. Zmuidzinas, H. G. LeDuc, J. A. Stern, S. R. Cypher, "Two-Junction Tuning Circuits for Submillimeter SIS Mixers", IEEE Trans. MTT, vol. 42, pp. 698-706, April 1994

[11] M. Voss, A. Karpov, K.H. Gundlach, "Submicron Nb-Aloxide-Nb Junctions for Frequency Mixers", Superconductor Science and Technol., vol. 6, pp.373ff, 1993

[12] F. Schäfer, J. Kuhnert, E. Kreysa, K.H. Gundlach, "A quasioptical SIS receiver for the 800-900 GHz band", Proc. of the 3rd Intl. Workshop on Terahertz Electronics, Sept. 1995, Zermatt, Switzerland

[13] J. Gromke, "Spektrale Kalibration von Radiometern im Submm Bereich mit Hilfe eines Martin-Puplett-Interferometers", diploma thesis, Universität Bonn, 1996

[14] Radiometer Physics GmbH, Bergerwiesenstrasse 15, D-53340 Meckenheim, Germany

[15] S.-K. Pan, A.R. Kerr, M.J. Feldman, A. Kleinsasser, J. Stasiak, R.L. Sandstrom, and W.J. Gallagher, "An 85-116 GHz SIS Receiver using Inductively Shunted Edge Junctions", IEEE Trans. MTT, vol. 37, pp. 580ff, 1989

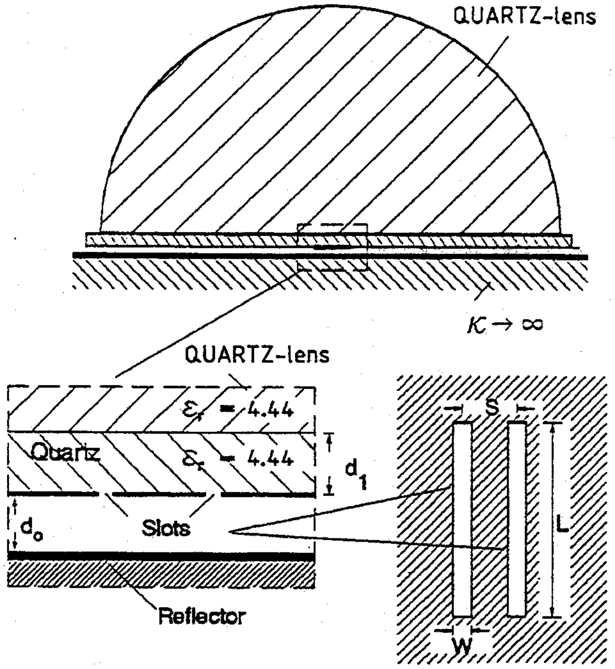

Figure 1: Schematic diagram of the antenna configuration

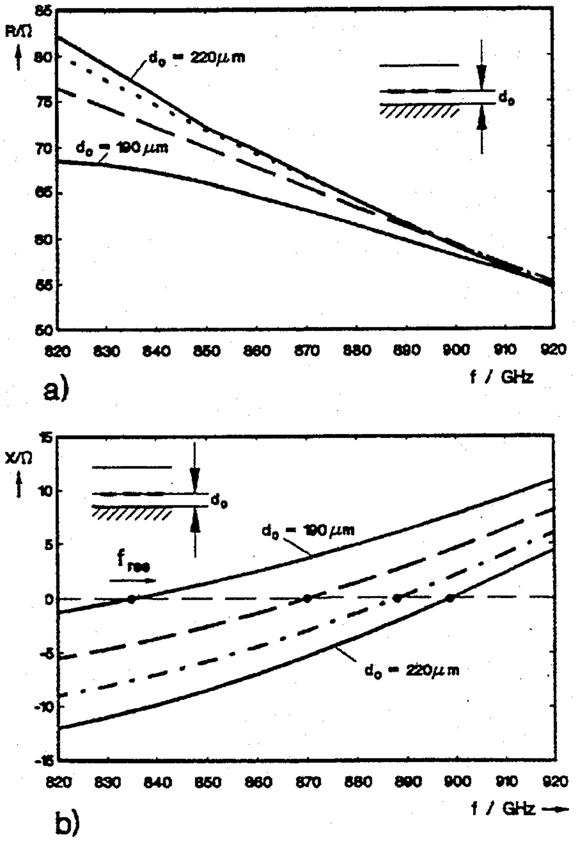

Figure 2: Single slot input impedance for a double slot antenna

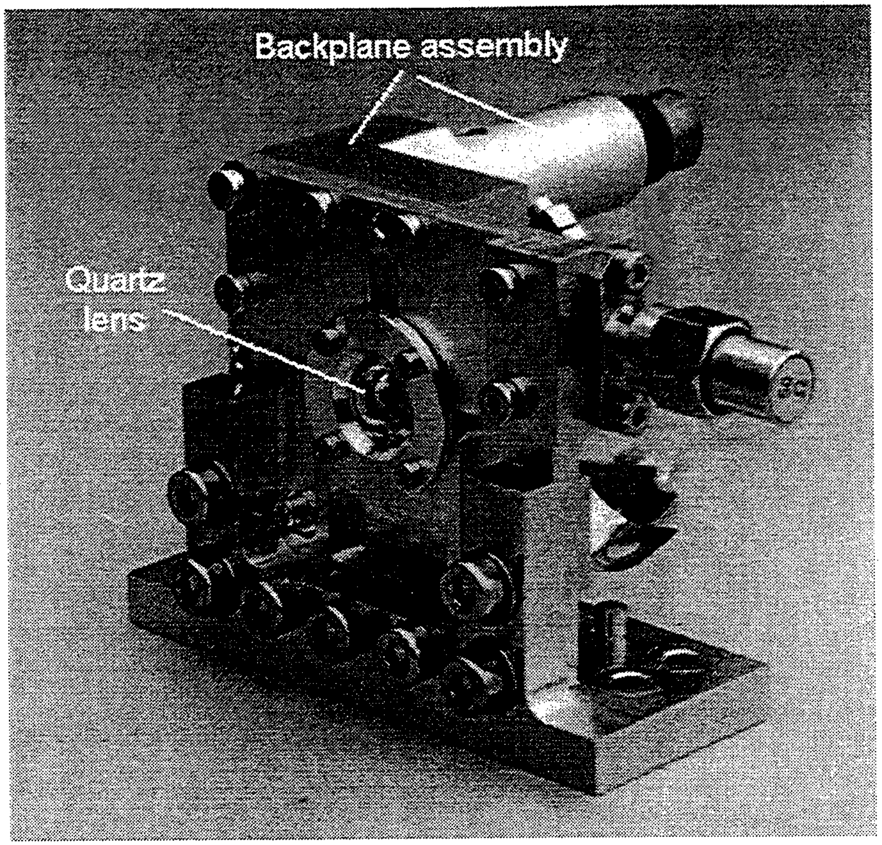

Figure 3: Photograph of the mixer block

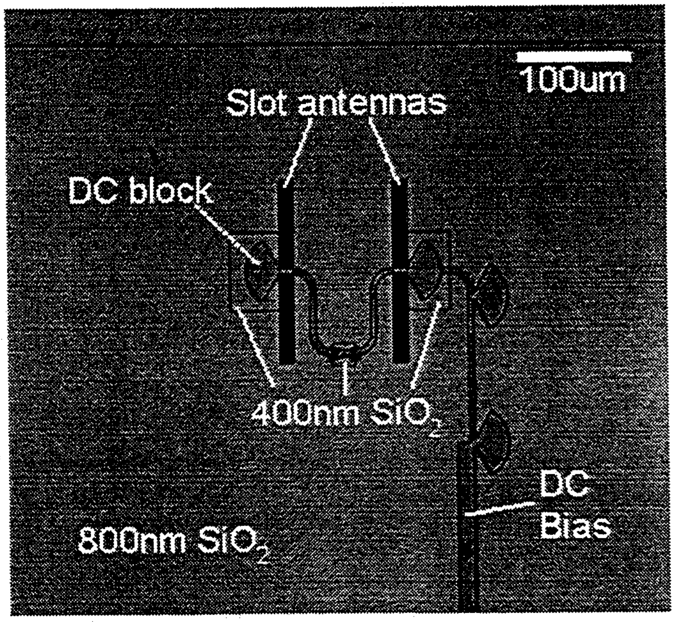

Figure 4: Mixer chip for 800-900 GHz

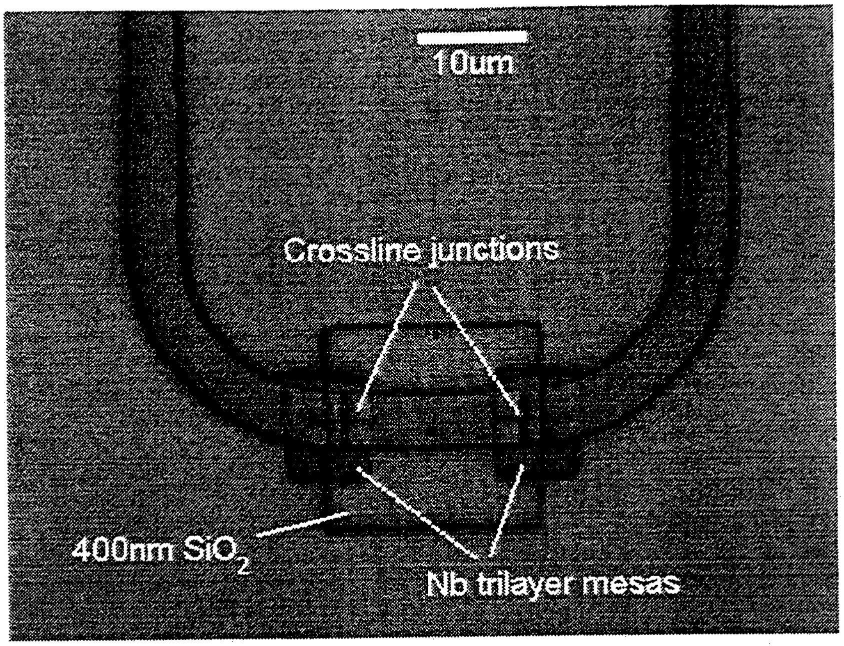

Figure 5: Junction area of the mixer chip

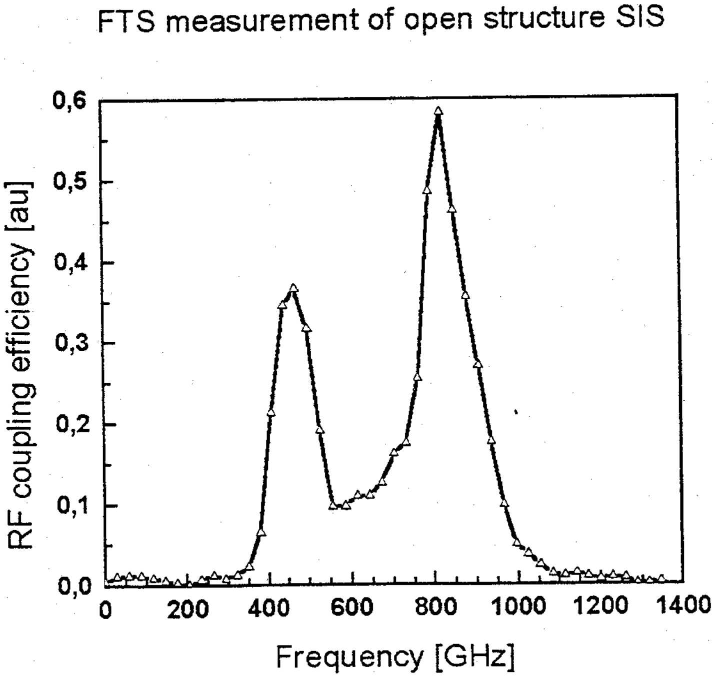

Figure 6: FTS measurement of receiver bandpass

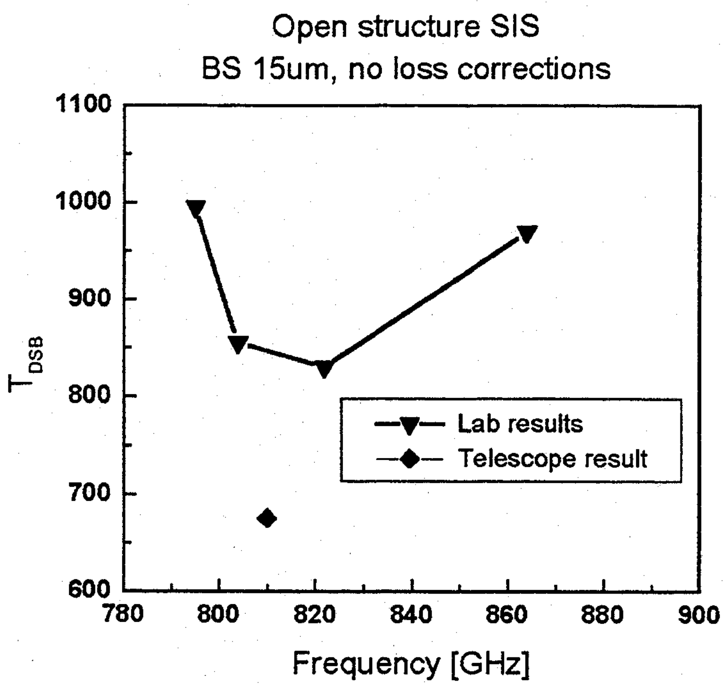

Figure 7: Receiver noise temperatures

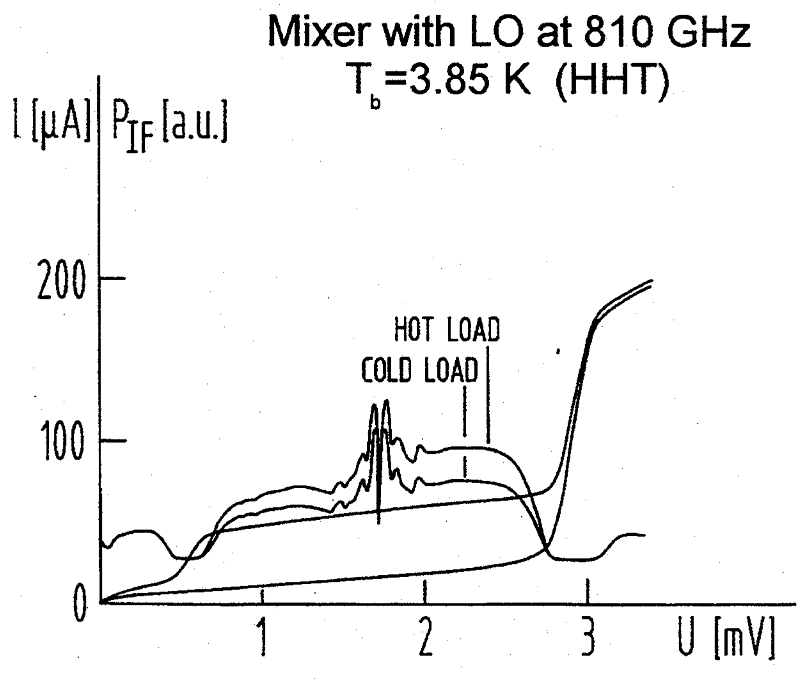

Figure 8: IV and conversion curves for telescope result

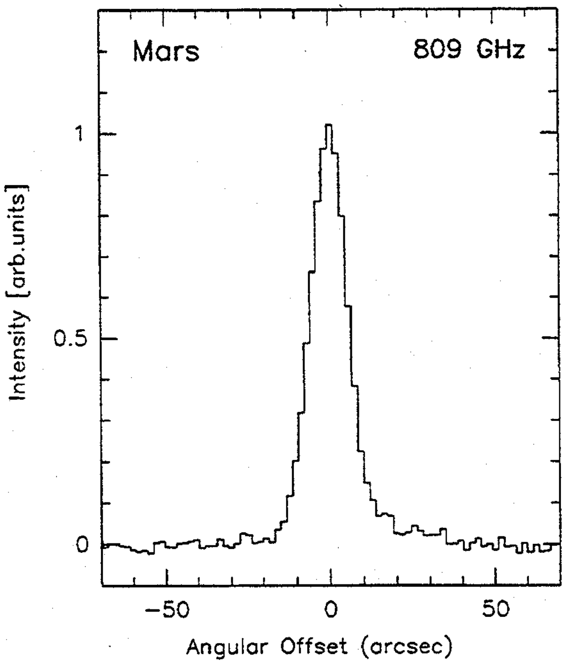

Figure 9: Continuum subscans in azimuth across Mars

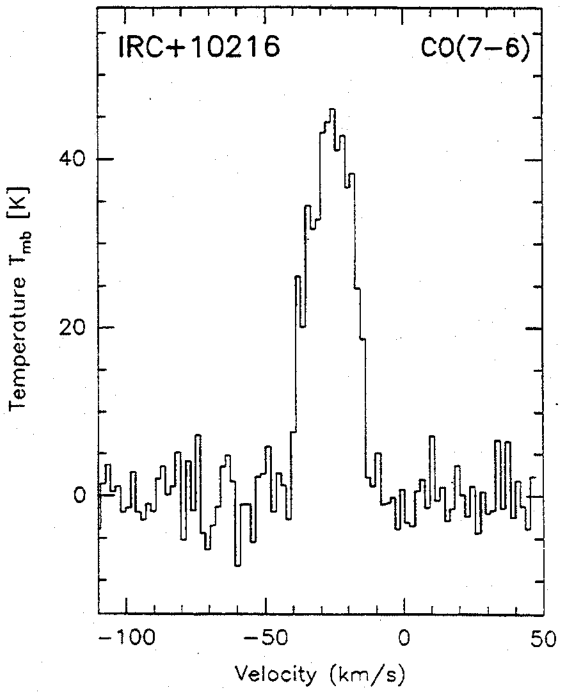

Figure 10: Spectrum of CO (7-6) towards IRC 10216