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OBSERVATION OF THE ION-ACOUSTIC FEATURE IN THE SPECTRUM OF FAR-INFRARED RADIATION SCATTERED FROM A HE-PLASMA IN A TOKAMAK

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Observation of the Ion-acoustic Feature in the Spectrum of Far-infrared Radiation Scattered from a He-plasma in a Tokamak.

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Abstract :

The ion-acoustic feature in the spectrum of a He plasma produced in a tokamak has been observed by collective Thomson scattering of far-infrared radiation. The spectral distribution and the intensity of the scattered radiation correspond to density fluctuations at the thermal level. Since the resonant feature is very sensitive to the ratio T_e/T_i , good precision of a T_i measurement can be obtained when T_e is known. The results confirm the interpretation of earlier measurements in H and D plasmas.

We have recently reported on first measurements of the ion temperature (T_i) in a tokamak plasma via collective Thomson scattering of far-infrared laser radiation [1] . A high power D_2O laser emitting at 385 μm and a multichannel heterodyne receiver comprising a Schottky diode mixer were used for this purpose. The parameters describing the experimental set-up are summarized in table 1. For the given plasma conditions (Z_{eff} = 2 to 4) and the geometry of the scattering experiment the shape of the scattered light spectrum was strongly influenced by the contributions from the impurity ions and by the magnetic field. Since the difference wave vector $\underline{k}$ ($\underline{k} = \underline{k}_s - \underline{k}_i$; $\underline{k}_i, \underline{k}_s$ are the wave vectors of the incident and the scattered radiation respectively) was almost perpendicular to the magnetic field vector $\underline{B}$, a significant distortion of the spectrum was expected [2]. In the experiment a strong enhancement of the scattered intensity towards the centre of the spectrum has been observed in agreement with these predictions. However, under these conditions the evaluation of the ion temperature relies strongly on the information about the species and the local concentrations of the various impurity ions. As these parameters are not well known for the plasmas in the TCA tokamak, the interpretation of our results is difficult and has left some doubts about the T_i values obtained.

Therefore another series of measurements has been carried out in a He plasma choosing an observation angle such that the influence of the magnetic field is small (angle between $\underline{k}$ and $\underline{B}$: 86°). Calculations of the spectra for a He plasma and a range of realistic values for Z_{eff} , T_e and T_i show that the shape is rather insensitive to Z_{eff} under these conditions (see fig. 1). For ratios $T_e/T_i > 1$ the spectrum is dominated by the ion acoustic resonance . Fig. 2 shows calculated spectra for various ion temperatures with the other plasma parameters kept constant. At fixed T_e a variation of T_i leads to a significant change in position and half-width of the resonance peak which allows a precise evaluation of T_i.

Figures 3 and 4 show two typical spectra - each obtained during a single laser shot - for He plasmas with similar parameters. The circles represent the measured signals per spectral channel of 80 MHz bandwidth after integration over the 1.4μs pulse length of the D_2O laser. The solid curves are the fitted spectra using T_i and a vertical scaling factor as the only free parameters. The electron density has been measured by interferometry and the electron temperature by ruby laser scattering; both values are used as known input parameters by the fitting routine. In order to obtain the "error bars" for a single shot measurement we determine the statistical fluctuations of the signal from the heterodyne receiver. For this purpose the data acquisition system has been set to take 18 additional samples of the signal during a period of 100μs before and after each laser shot. The standard deviation of the signal is then obtained by applying a correction depending on the signal level to the standard deviation of the receiver noise. Both the noise and the signal are assumed to follow the statistics of gaussian random variables [3],*). It should be noted that the uncertainty intervals have been centered on the fitted curve representing the "true values" and not on the experimental data points which are subject to statistical fluctuations.

The spectra show clearly the ion-acoustic feature in agreement with the theoretical model assuming scattering from thermal density fluctuations. We observe a remarkably large difference between T_e and T_i which cannot be explained by uncertainties in the measurement. This difference is surprising since for the parameters of these ohmically heated He plasmas the ion-electron collision time should be about 5 ms. A similar difference between T_e and T_i has already been observed during our earlier experiments in H and D plasmas. To our understanding the results obtained for He confirm the interpretation of the measurements in H and D plasmas.

At present there is no other diagnostic system operational on TCA which could provide local T_i values under these particular plasma conditions. Therefore an attempt has been made to evaluate the inherent precision of our T_i measurement. The analysis is based on the results obtained during a single shot. Taking the curve fitted to a set of experimental data points and the "error bars" for each spectral channel a numerical simulation code has been used to evaluate T_i values from an artificially generated data set. A Monte-Carlo method is used to simulate a measurement by picking a value within the interval defined by the error bars such that the distribution within a series of trials follows gaussian statistics. From 30 of these artificial measurements we determine the mean and the standard deviation of the ion temperature and obtain relative errors of 20 and 25% respectively, for the cases presented in figs. 3 and 4. This precision is in agreement with the predictions based on a signal-to-noise evaluation for the typical parameters of our experiment. Investigations under study indicate that this precision can be maintained if the uncertainties associated with the other plasma parameters required by the fitting routine (especially T_e) are less than 10%.

Acknowledgements:

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References:

[1] R. Behn, D. Dicken, J. Hackmann, S.A. Salito, M.R. Siegrist "Ion Temperature Measurement of a Tokamak Plasma by Collective Thomson Scattering of D_2O Laser Radiation" submitted for publication to Phys. Rev. Letters 1988

[2] W. Kasparek, E. Holzhauer "Simultaneous Measurement of Magnetic Field Direction and Ion Temperature in a Plasma by Collective Scattering with a CO_2 Laser" Appl. Phys. Lett. 43 (7), 637 (1983)

[3] R.L. Watterson, M.R. Siegrist, M.A. Dupertuis, P.D. Morgan and M.R. Green "Numerical Simulation of a System for Ion Temperature Measurements by Thomson Scattering in a Tokamak" J. Appl. Phys. 52 (5), 3249 (1981)

Footnote:

*) In a strict sense these are χ^2 distributions which are indistinguishable from gaussian distributions for a high degreee of freedom (220 in our case).

Figure captions :

Fig.1 Calculated spectra for a He plasma for N_e = 7.10^{19} m^{-3}, T_e = 670eV, T_i = 250 eV and angle ($\underline{k}$,$\underline{B}$) = 86°. Curve 1 : pure He, Curves 2 to 4 : impurities included with Z_{eff} = 2.7, 3.1, and 4.4 respectively.

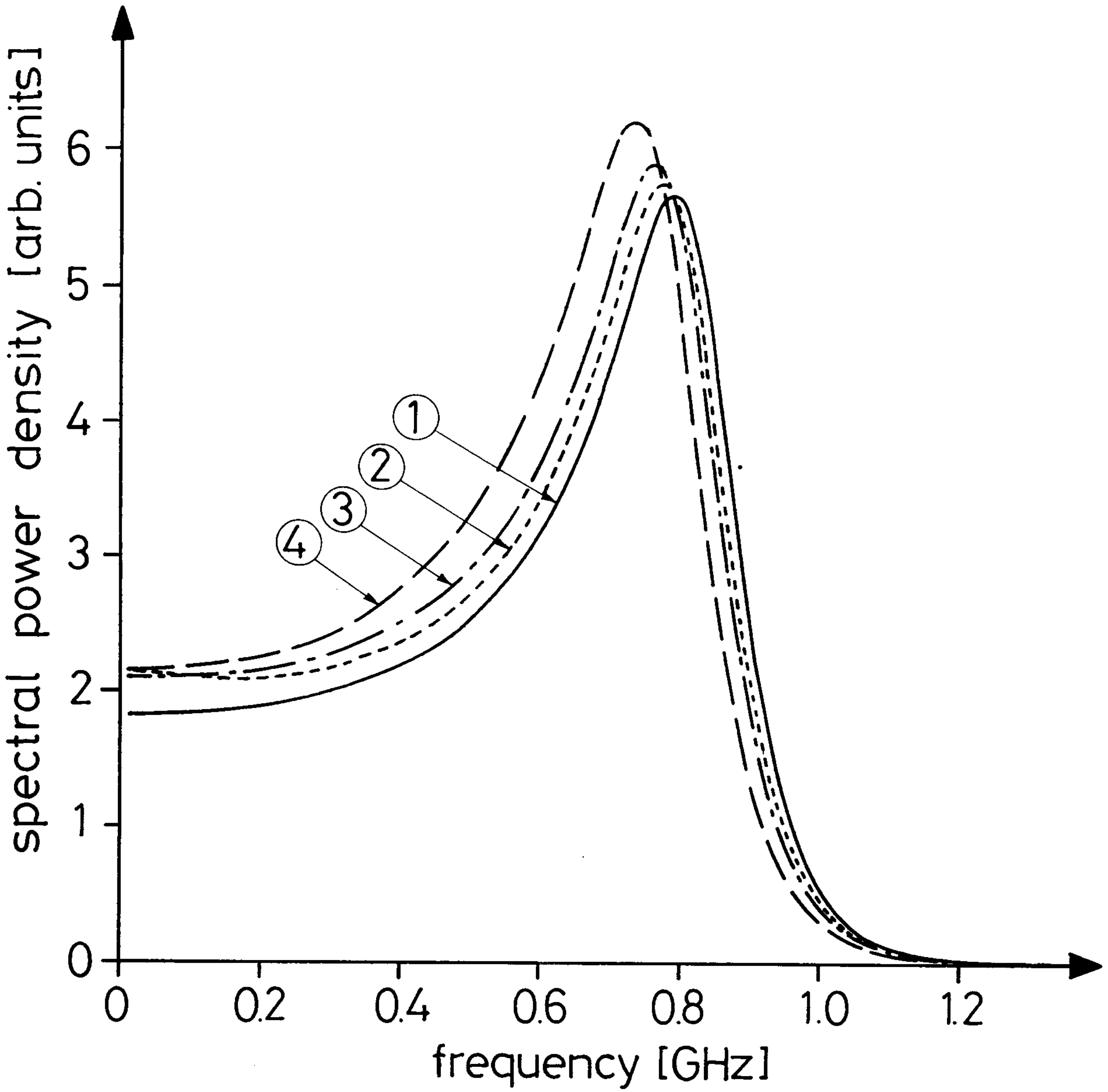
Fig.2 Calculated spectra for a He plasma for the plasma parameters of Fig.1 but varying the ion temperature. Curves 1 to 4 :T_i = 100 eV, 200 eV, 300 eV, and 400 eV. Note that curve 1 (T_i = 100 eV) has been reduced by a vertical scaling factor of 3.

Fig.3 Measured spectrum from single-shot data points (circles). The solid curve is a least-square-fitted spectrum for a He plasma with : N_e = 7.10^{19} m^{-3}, T_e = 670 eV, angle ($\underline{k}$,$\underline{B}$) = 86°, and Z_{eff} = 4.4. The fit yields T_i = 250 eV.

Fig.4 Same as fig. 3 with slightly different plasma parameters : N_e = 8.10^{19} m^{-3}, T_e = 620 eV, angle ($\underline{k}$,$\underline{B}$) = 86°, and Z_{eff} = 4.2. The fit yields T_i = 260 eV.

Table I FIR Thomson scattering system parameters

Parameters of the TCA tokamak :		
major radius	R_0	= 0.62 m
minor radius	a	= 0.18 m
toroidal field	B_t	= 1.5 T
Scattering geometry :		
scattering angle	θ	= 90°
scattering parameter	α	= 2 (typical value)
scattering volume	near plasma centre	
diameter	d	= 10 mm
solid angle	$\Delta\Omega$	= 4.3 10^{-3} sterad
Laser system :		
CO_2 laser (pump)	λ_1	= 9.26 µm 9R(22), single mode
pulse energy	E_1	= 600 J
D_2O laser	λ_2	= 385 µm
pulse energy	E_2	= 0.5 J
pulse duration	τ	= 1.4 µs
Heterodyne receiver :		
mixer	Schottky barrier diode	
local oscillator	c.w. FIR laser (CD_3Cl)	
	λ_3	= 383.3 µm
IF-filters	f	2.26 to 3.78 GHz
bandwidth	Δf	= 80 MHz
noise equiv. power	NEP	= 2.2 10^{-19} W/Hz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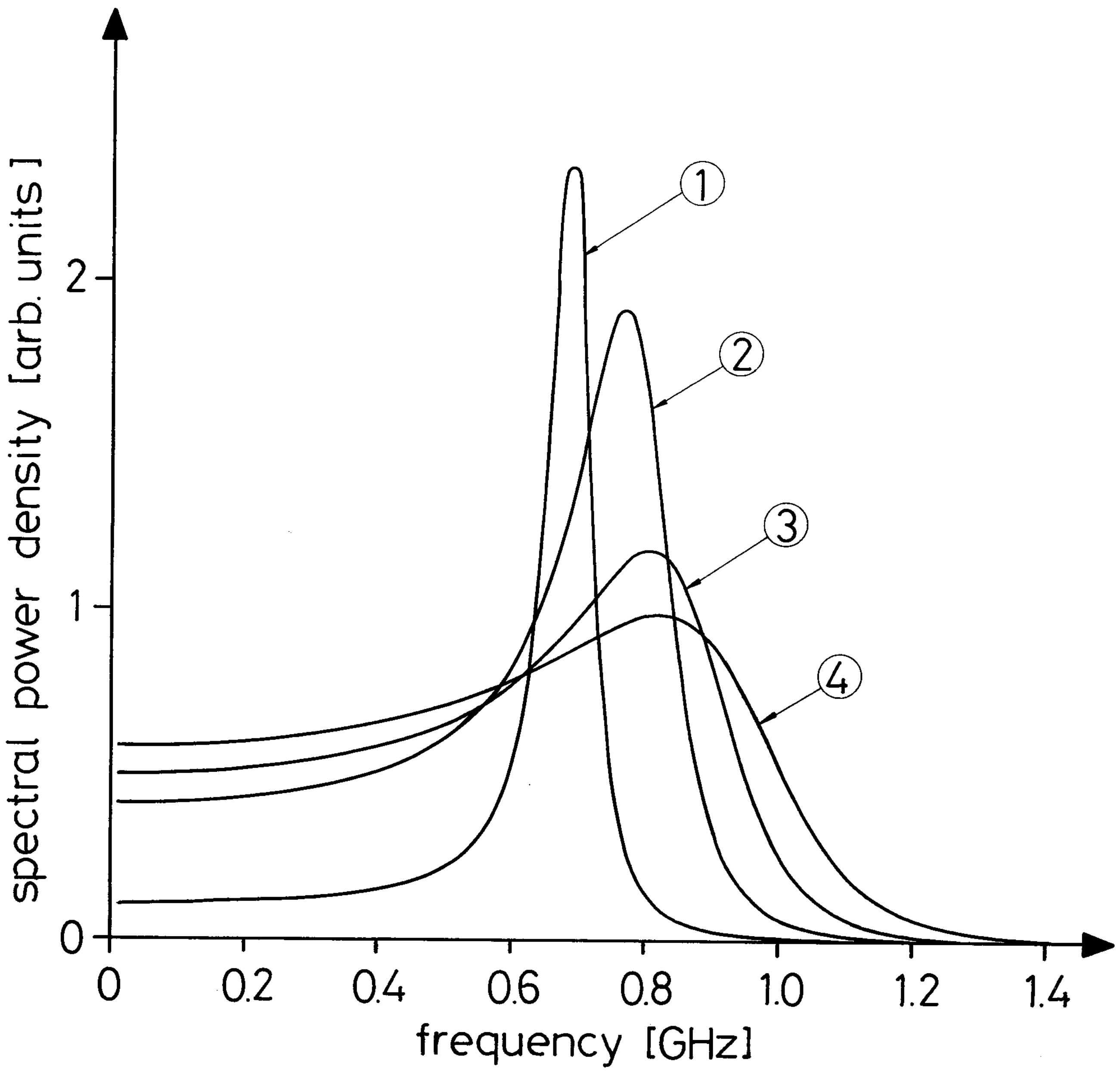
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1.0
1.2
frequency [GHz]
①
②
③
④

Fig. 1



spectral power density [arb. units]
2
1
0
0
0.2
0.4
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0.8
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1.2
1.4
frequency [GHz]
①
②
③
④

Fig. 2

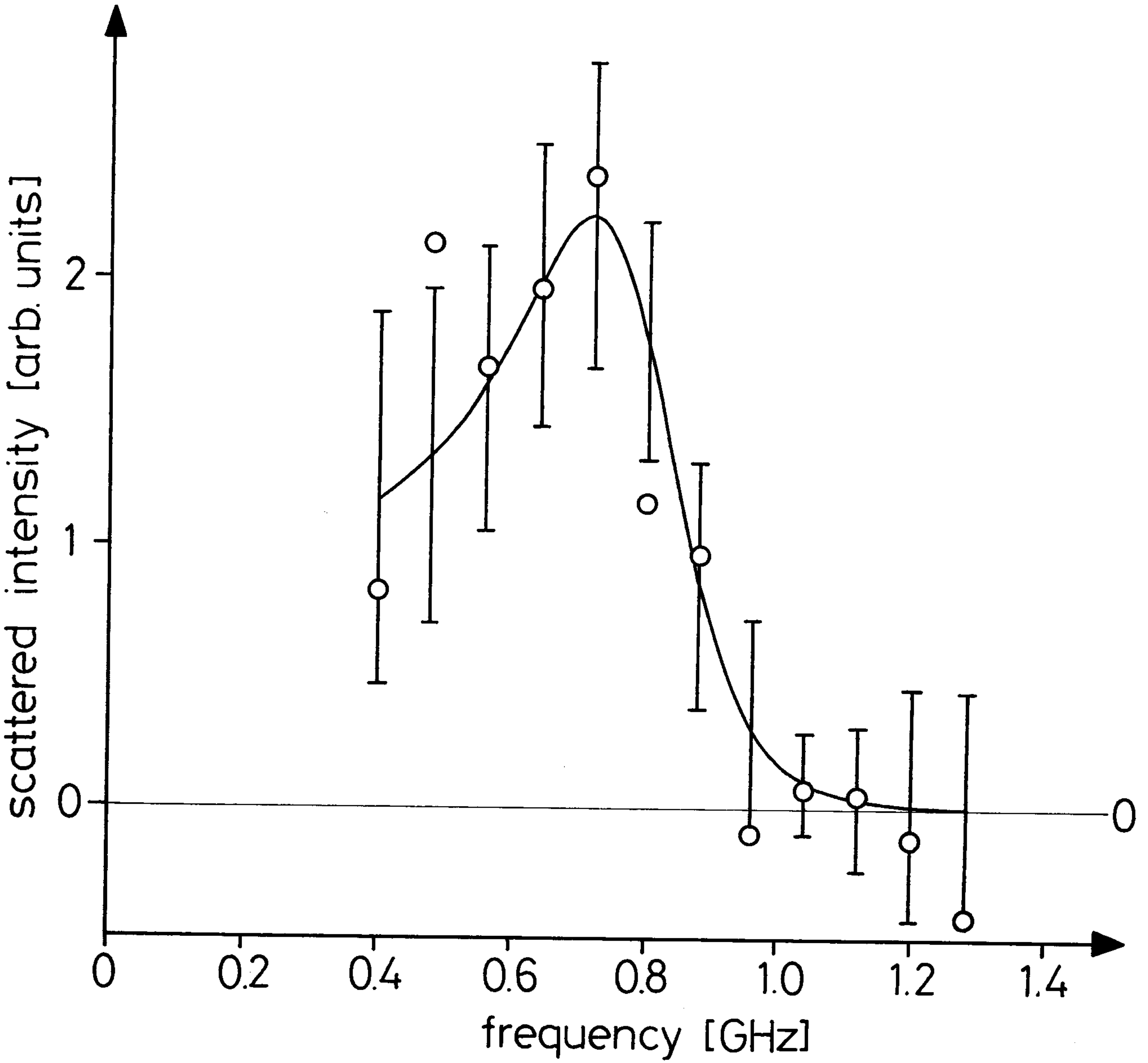
scattered intensity [arb. units]
2
1
0
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
frequency [GHz]

Fig. 3

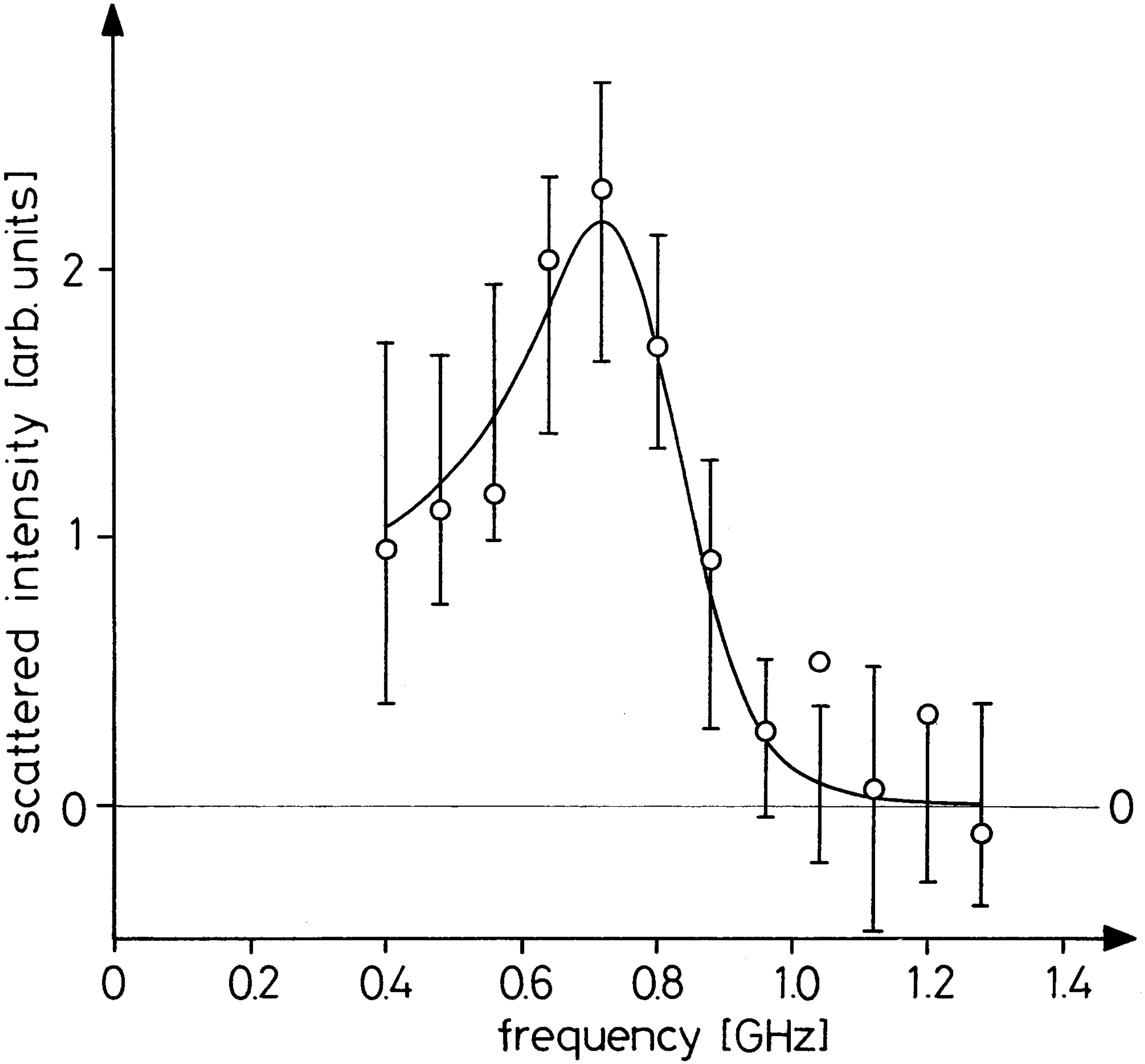
scattered intensity [arb. units]
0
1
2
0
frequency [GHz]
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Fig. 4