DLR

GPI

New Approach to Single Shot CARS Thermometry of High Pressure, High Temperature Hydrocarbons Flames

V.I.Fabelinsky,[1] V.V.Smirnov[1], O.M.Stel'makh[1*], K.A.Vereschagin[1] A.K.Vereschagin[1]

W.Clauss[2], , M.Oschwald[2],

1. A.M. Prohorov General Physics Institute, IOFAN, Vavilov Str. 38, 119991 Moscow, Russia.
2. German Aerospace Research Center, DLR, Langer Grund, D-74239 Hardthausen, Germany.

HIGH RESOLUTION SINGLE SHOT DBB-CARS SPECTROMETER

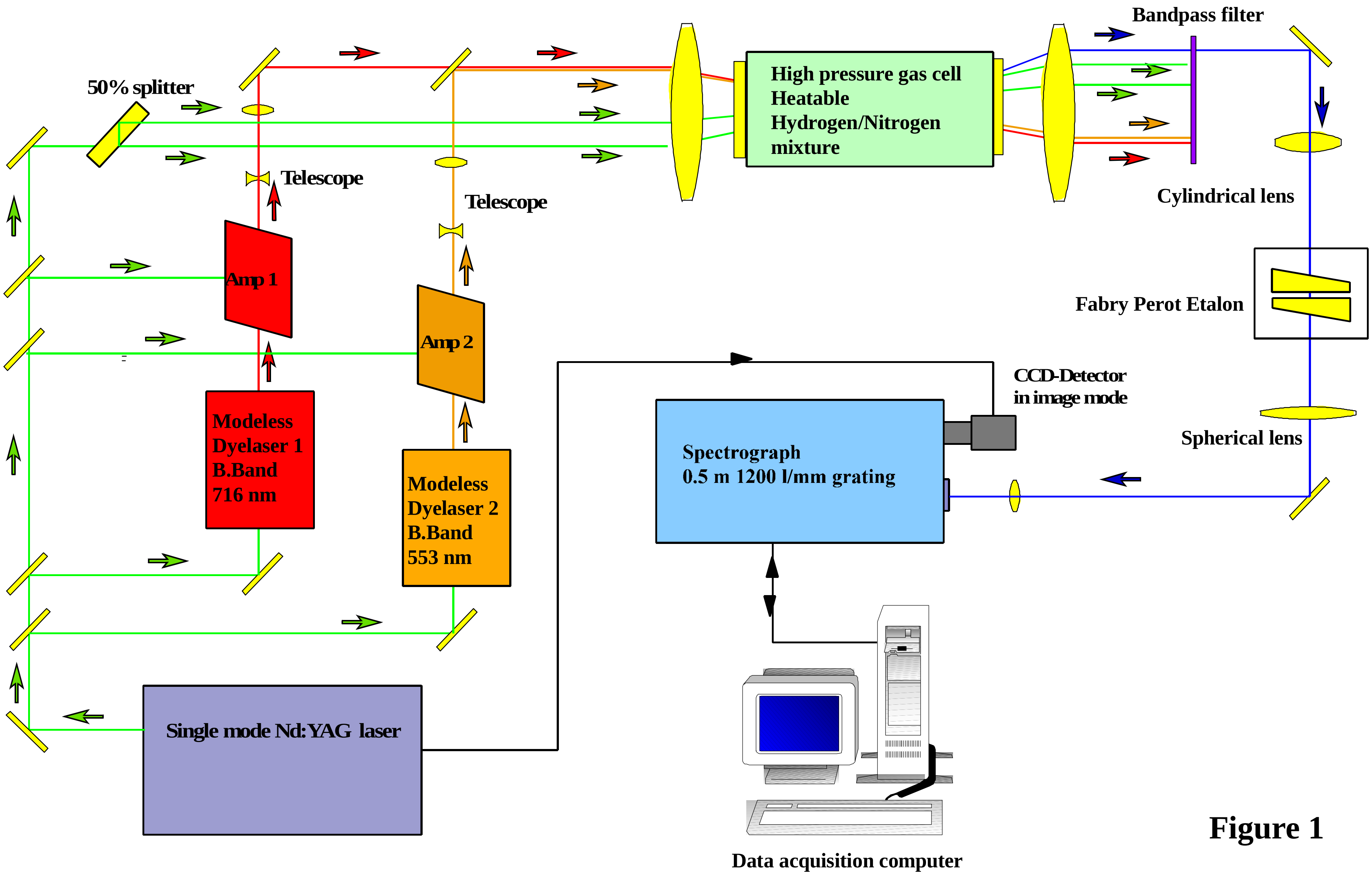
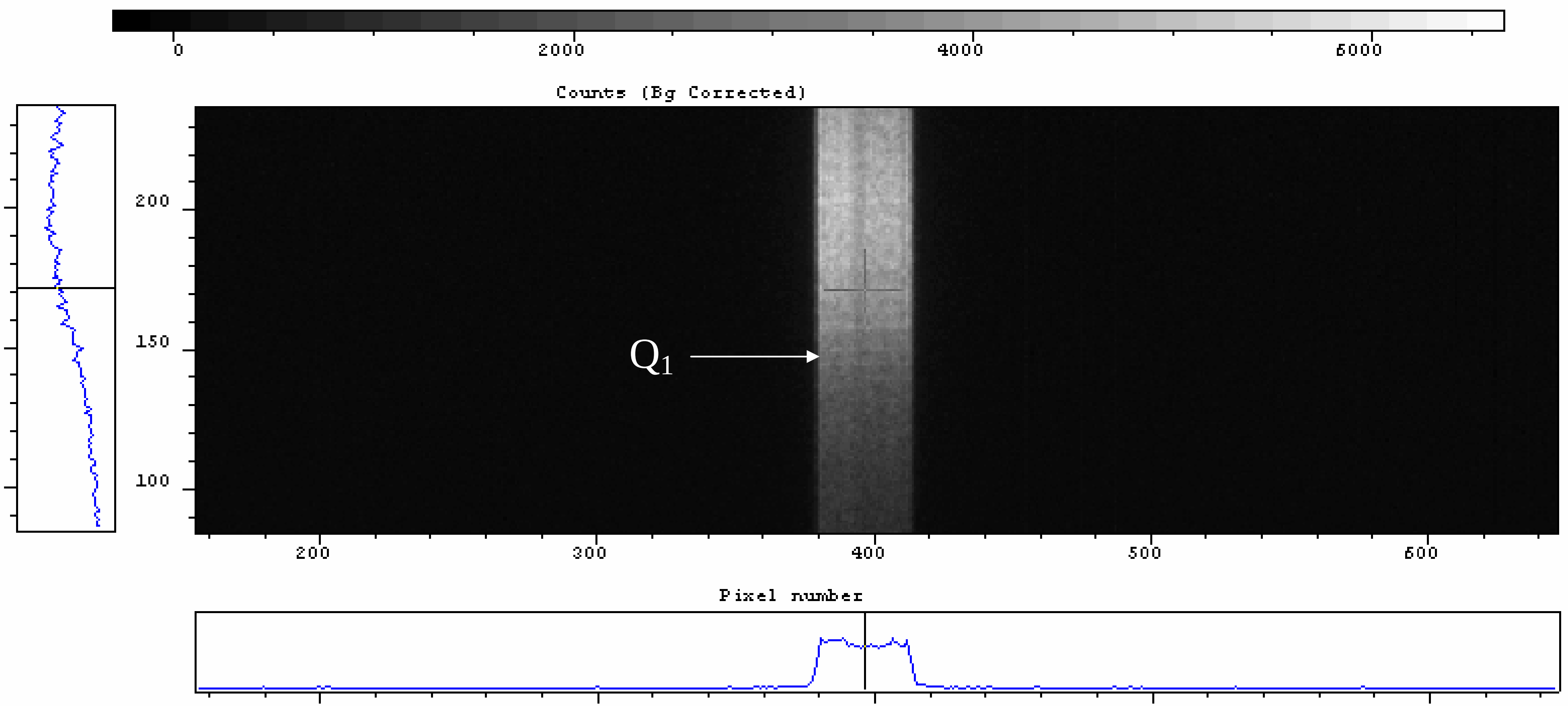


Figure 1

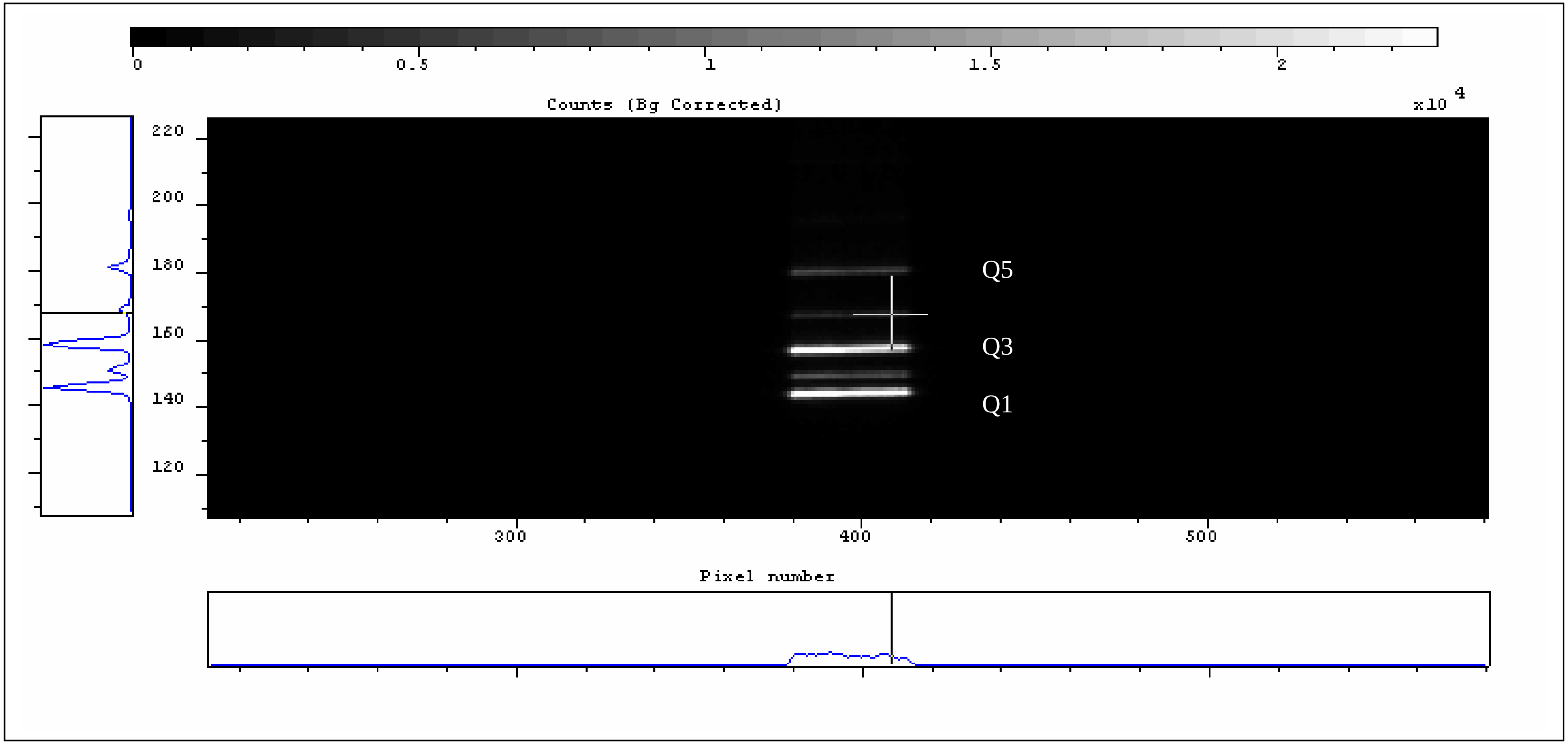
NON- RESONANT DBB-CARS SPECTRA



Interferometer Fabry-Perot removed

Figure 2

DBB - CARS SPECTRA OF H_2 Q-BRANCH



Heated cell with mixture $H_2 : N_2 = 1 : 10$, T = 960 K, P=5 bar
Interferometer Fabry-Perot removed

Figure 3

DBB-CARS OF H_2 Q-BRANCH

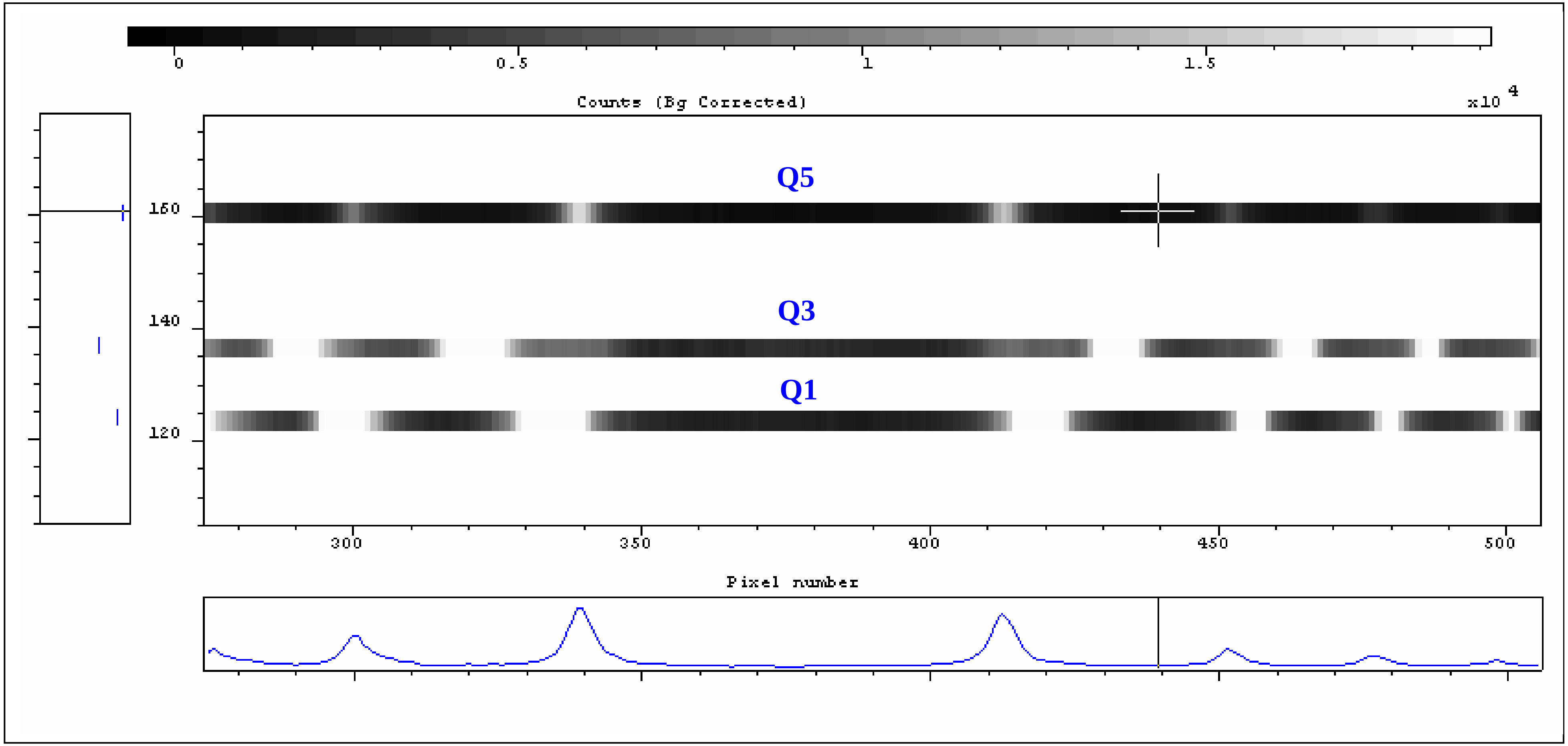
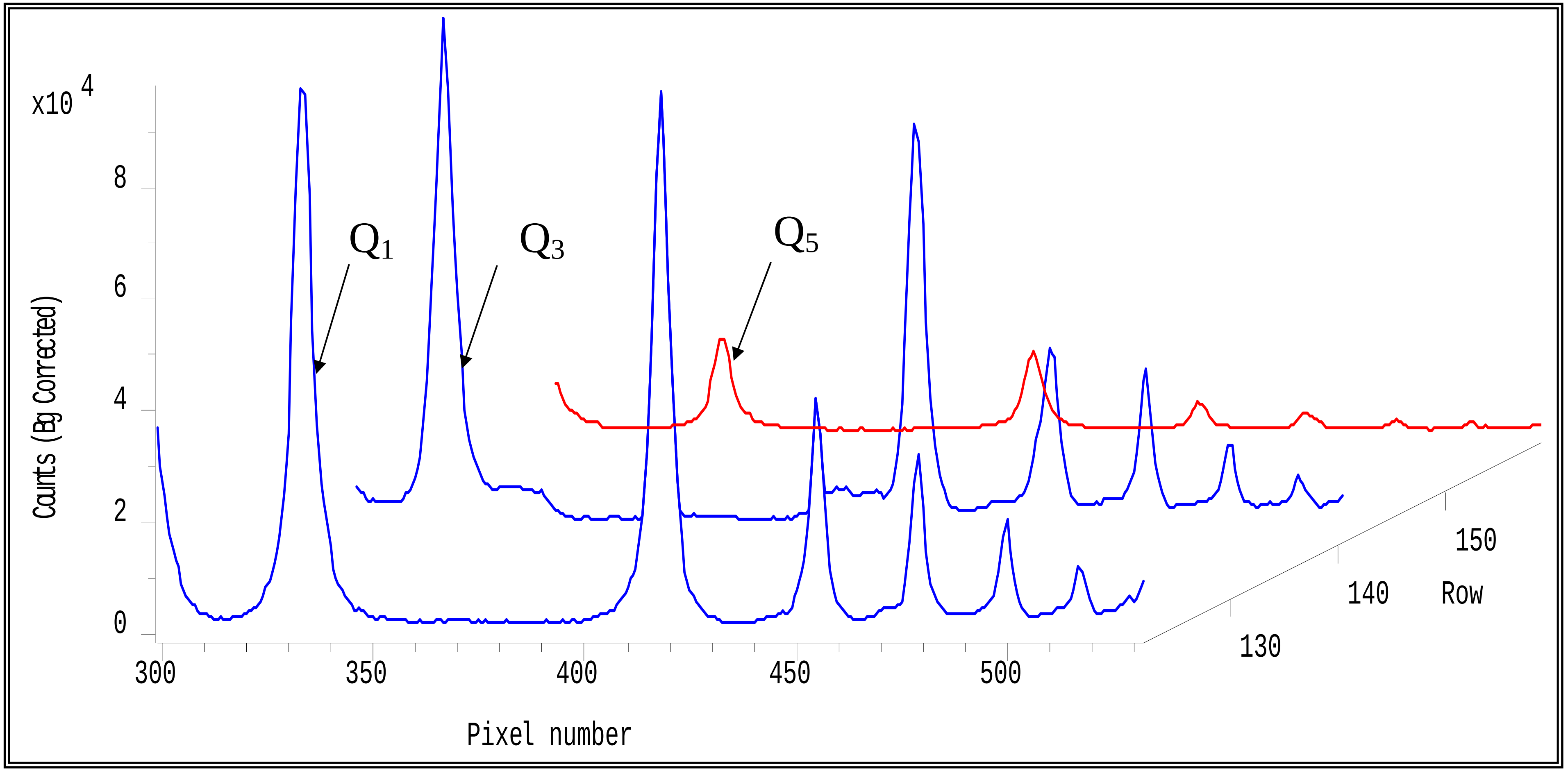


Image of Single shot Fabry-Perot Interferogram

Figure 4

DBB-CARS OF H_2 Q- BRANCH



3D Fabry-Perot Interferogram

Figure 5

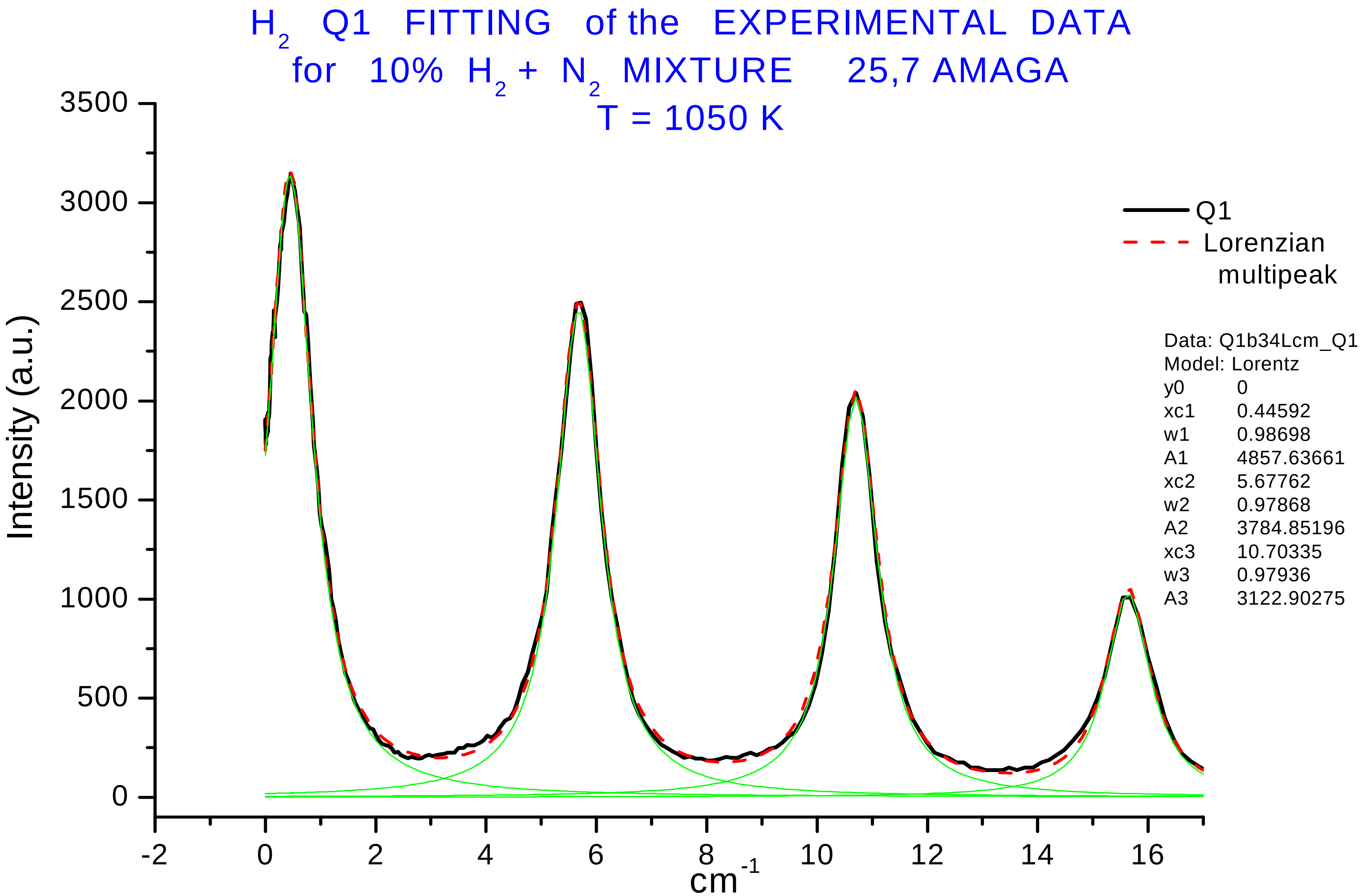
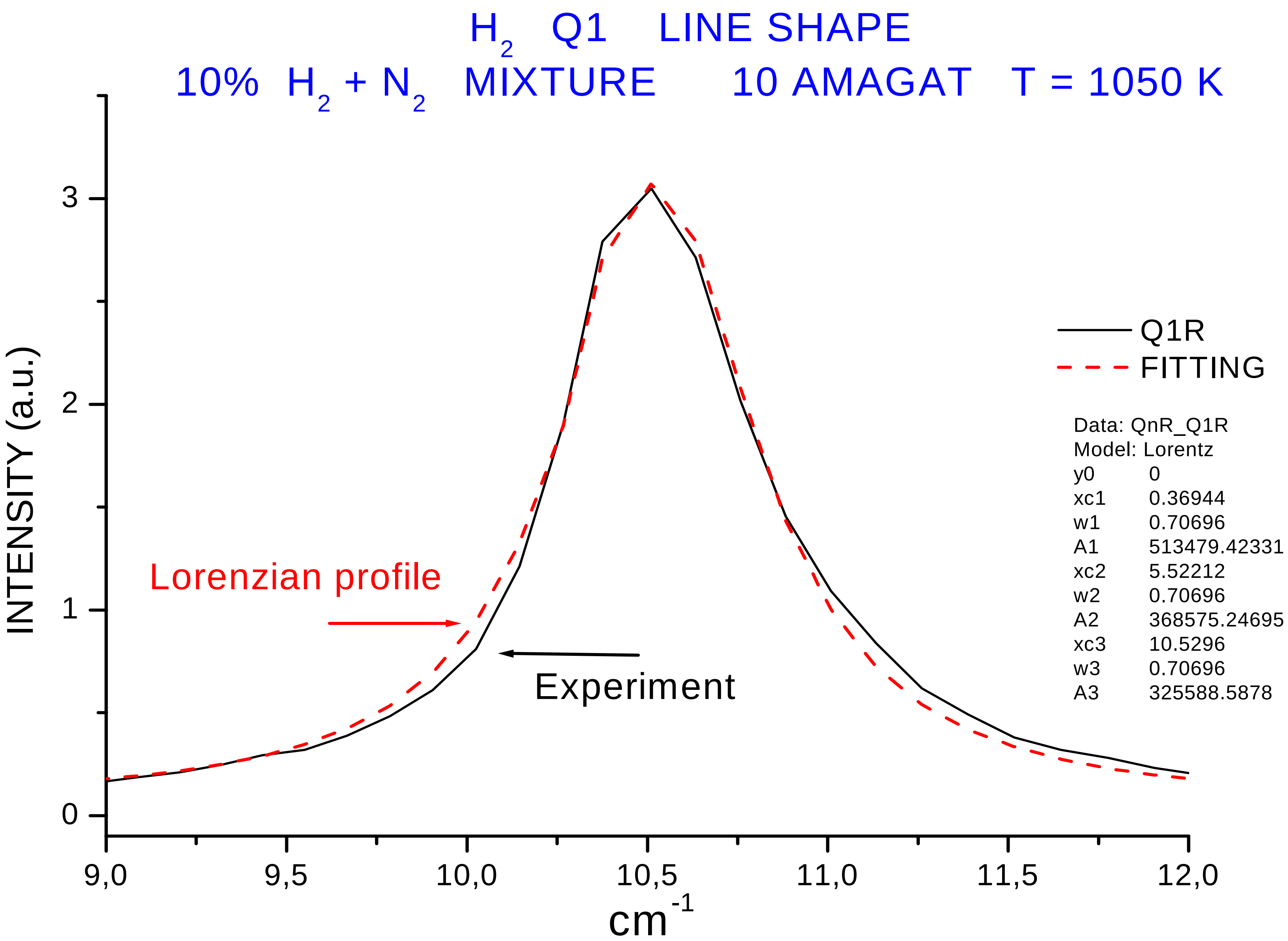
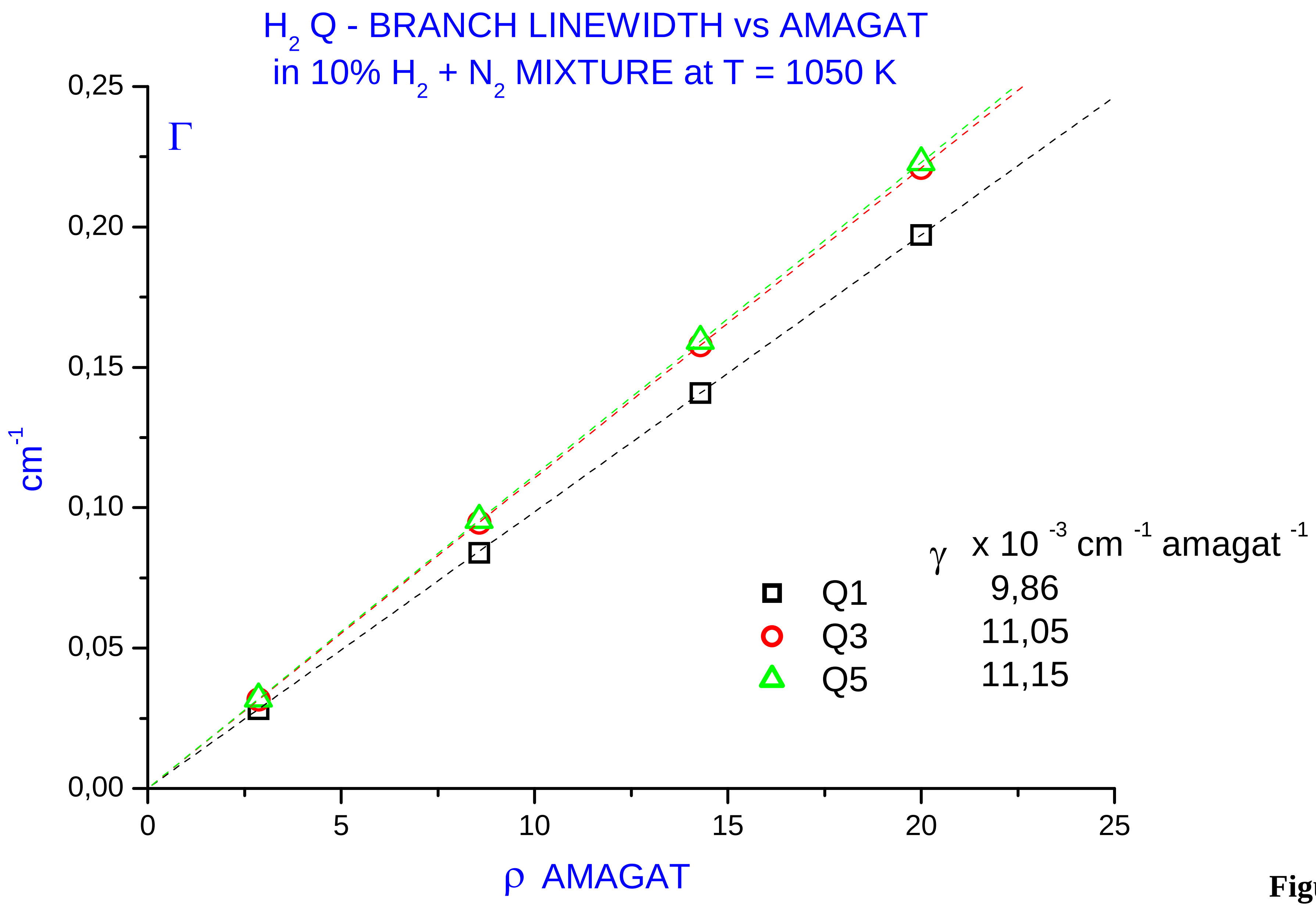

H2 Q1 FITTING of the EXPERIMENTAL DATA
for 10% H2 + N2 MIXTURE 25,7 AMAGA
T = 1050 K
Intensity (a.u.)
3500
3000
2500
2000
1500
1000
500
0
-2
0
2
4
6
8
10
12
14
16
cm-1
Q1
Lorenzian multipeak
Data: Q1b34Lcm_Q1
Model: Lorentz
y0 0
xc1 0.44592
w1 0.98698
A1 4857.63661
xc2 5.67762
w2 0.97868
A2 3784.85196
xc3 10.70335
w3 0.97936
A3 3122.90275

Figure 7



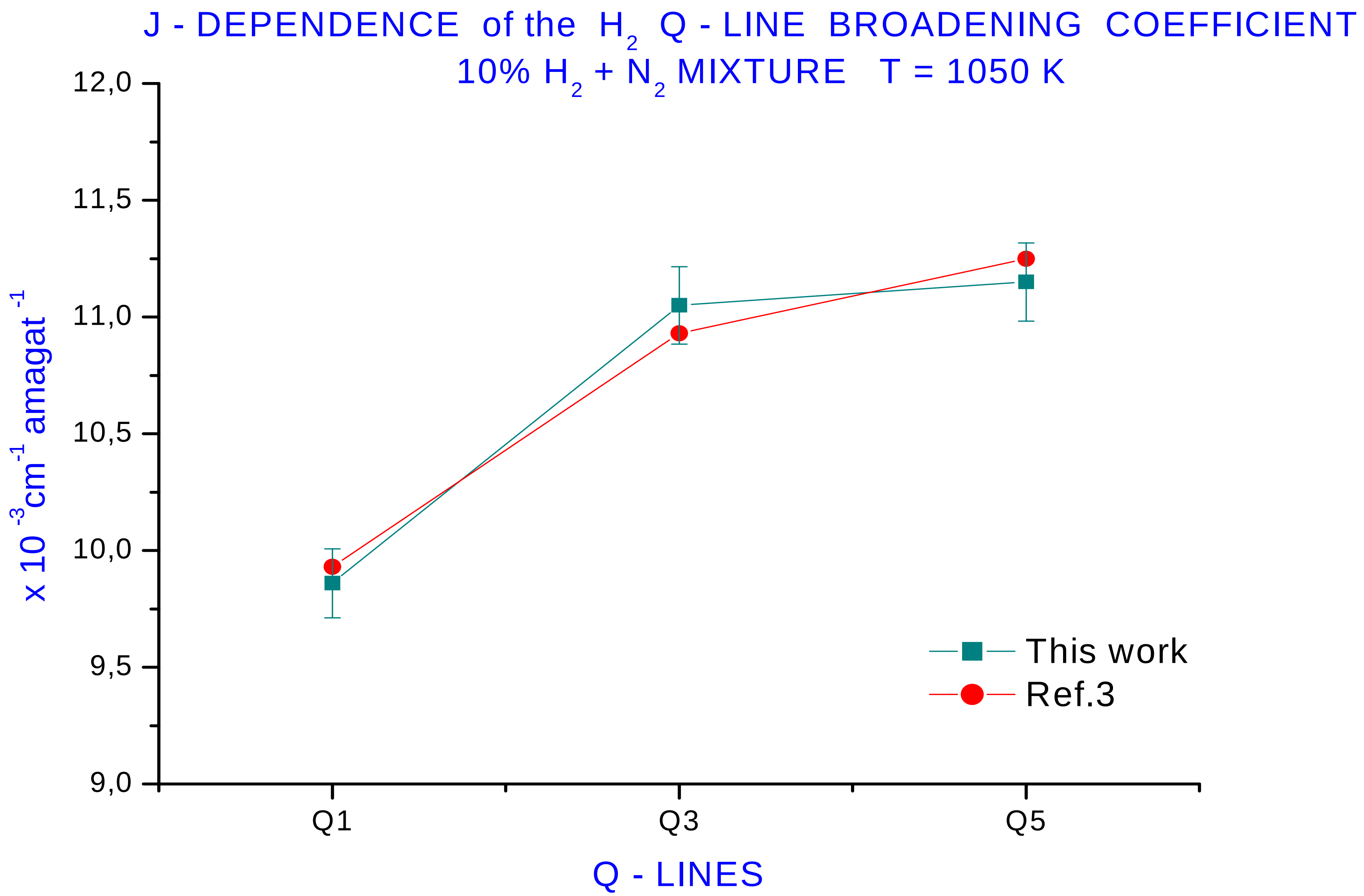
H2 Q1 LINE SHAPE
10% H2 + N2 MIXTURE 10 AMAGAT T = 1050 K
INTENSITY (a.u.)
0
1
2
3
9,0
9,5
10,0
10,5
11,0
11,5
12,0
cm-1
Lorenzian profile
Experiment
Q1R
FITTING
Data: QnR_Q1R
Model: Lorentz
y0 0
xc1 0.36944
w1 0.70696
A1 513479.42331
xc2 5.52212
w2 0.70696
A2 368575.24695
xc3 10.5296
w3 0.70696
A3 325588.5878

Figure 6



H2 Q - BRANCH LINEWIDTH vs AMAGAT
in 10% H2 + N2 MIXTURE at T = 1050 K
Γ
cm-1
0,25
0,20
0,15
0,10
0,05
0,00
0
5
10
15
20
25
ρ AMAGAT
γ x 10 -3 cm -1 amagat -1
Q1 9,86
Q3 11,05
Q5 11,15

Figure 8



J - DEPENDENCE of the H2 Q - LINE BROADENING COEFFICIENT
10% H2 + N2 MIXTURE T = 1050 K
x 10 -3 cm -1 amagat -1
12,0
11,5
11,0
10,5
10,0
9,5
9,0
Q1
Q3
Q5
Q - LINES
This work
Ref.3

Figure 9

- **Single shot CARS-thermometry can resolve spatial and temporal details of the combustion process and provide information on the combustion efficiency. Accuracy depends on knowledge about collision processes.**

- **In CARS thermometry of H_2/O_2 flames using H_2 as probe molecule, experimentally measured and extrapolated broadening coefficients of various H_2 Q-branch lines by collisions with water molecules, can be successfully used [1,2].**

- **For hydrocarbon-fuelled flames the problem of correct temperature evaluation still persists. This is mainly due to the lack of knowledge of H_2-CH_4, H_2-CO, H_2-CO_2 etc. collisional line broadening coefficients and influence on these measurements speed –dependence effects [1,3] at elevated temperatures.**

- **Additional experimental complications arise from the necessity of simultaneous measurements of H_2O, CO, CO_2, and CH_4 concentration during a single laser pulse.**

- **To overcome this difficulty of CARS gas thermometry in HC-O_2 combustion a new experimental modification of DBB CARS-spectroscopy is proposed.**

- **The idea is in simultaneous detection of intensities of hydrogen *Q*-branch lines with the help of a spectrometer combined with an interferometer having orthogonal direction of dispersions for line width measurement. A scheme of this layout is shown on a Fig.1. In such an approach, the information on line widths obtained from a single-shot CARS spectrum is directly used in temperature evaluation routines and does not require knowledge of species concentration and of medium density.**

- **Here we report the results of application of this approach to single shot CARS thermometry of hydrogen-nitrogen (1:10) mixture in a heatable cell at high pressure (90 bar) and temperature (~1000 K).**

- **The main aim of this preliminary experiments was to approve the technique from the sensitivity and reliability point of view in course of intensity and linewidth of the hydrogen Q lines measurements at high temperature and high pressure conditions.**

- **In the first step of this experiments, the Fabry – Perot interferometer has been removed and DBB CARS nonresonant signal from 10 bar of N_2 (which is shown on Fig2) as far as positions of lines Q-branch in pure hydrogen (Fig.3) have been received.**

- **In the next step, the interferometer has been placed back inside the optical system and illuminated by the CARS beam. Care has been taken to match the aperture of the 0,5m focal length spectrometer and to avoid distortions of the interference pattern image on CCD matrix.**

- **The resulting image (Fig4), for one of the experimental conditions and corresponding 3D graphical representation (Fig.5) shows good signal to noise ratio. The slit function was found as 0,294cm^{-1} at FSR 5cm^{-1} . Asymmetry of the lineshape which can be seen in Fig.6 is attributed more to resonant-nonresonant CARS signal interference then to speed-dependent effects.**

- **Lorenzian profiles have been used for fitting procedure (Fig.7) to deduce linewidth and linebroadening coefficient (Fig.8/9) and co-called J – dependence of this values. The same procedure was proposed in [4].**

- **These data demonstrate good agreement with the data from reference [3] and have been directly employed in the subsequent temperature evaluation procedure. Of course, for the mixture 10% H_2 + N_2 such procedure don't allow to receive high accuracy of the temperature measurements due to the complicity of the lineshape.**

- **The values of gas mixture temperature, which were defined from DBB CARS spectra in a wide range of pressures (10 – 90 bar), coincide with thermocouple measurements within ~ 5%.**

- **Finally, it should be noted that H_2 /O_2 or CH_4 /O_2 combustion mixtures contain water vapour as main product (Fig.10), and as was shown in [5] $H_2$0 demonstrates pure collisional broadening behaviour. Therefore, the proposed approach can be employed to temperature measurements in such combustion investigation.. The following question for CH_4 +O_2 mixture is on the measurements of the collisional properties CO and CO_2 molecules, but there concentrations are not so high at the ROF in a real combuster.**

.

References

[1] F.Shaussard , X.Michaut, R.Saint-Loup, H.Berger, P.Joubert, B.Lance, J.Bonamy, D.Robert, J. Chem. Phys.; **112**,158,(2000).

[2] W.Clauss, D.N.Klimenko, M.Oschwald, K.A.Vereschagin, V.V.Smirnov, O.M.Stelmakh, and V.I.Fabelinsky, J. Raman Spectrosc. **33**, 906, (2002).

[3] R.L. Farrow, L.A. Rahn, G.O. Sitz, G.J. Rosasco. Phys. Rev. Lett. 63, N 7. (1989)

[4] P.M.Sinclair,J.Ph.Berger,X.Michaut,R.Saint-Loup,R.Chaux,andH.Berger ,J.Bonamy, and D.Robert Phys.Rev. A, v.54, N1,(1996).

[5] J. Hussong, R Lückerath, W. Stricker, X Bruet, P. Joubert, J. Bonamy, D. Robert. Appl. Phys. B. 73, 165 (2001).