Ground-based asteroseismology of α Cen : An urgent need for space observations

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1. Introduction

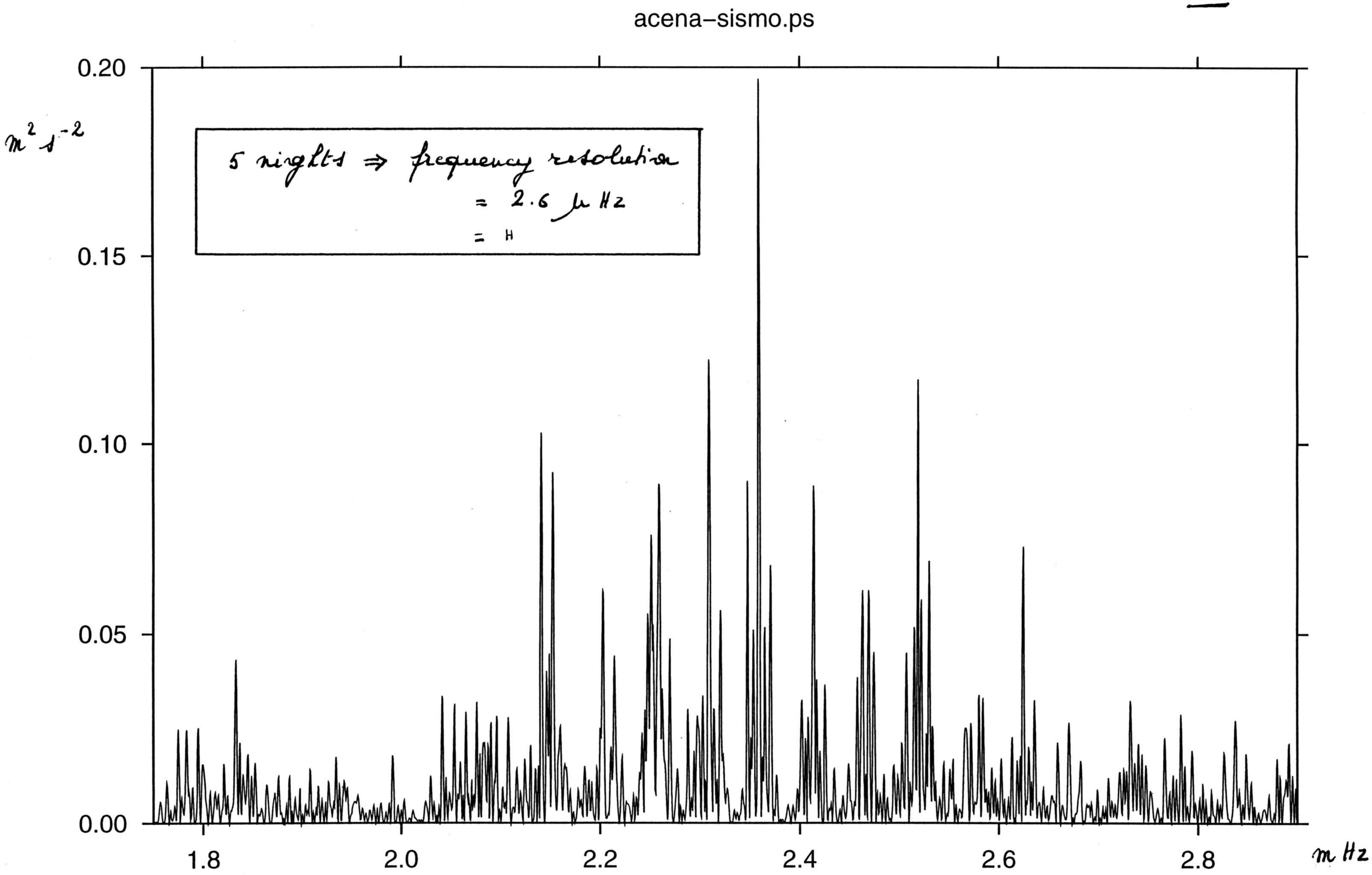
The binary system α Cen offers a unique opportunity to test our knowledge of stellar physics in other stars than the Sun. A number of calibrations of this system have already been carried out. The reader will find references to earlier works in the recent publications of Guenther and Demarque (2000) and Morel et al. (2000). In the present work, we aim at seeing how the asteroseismological data obtained by Bouchy and Carrier (2001) can help improving the parameters and evolutionary status of the system.

2. Observational constraints

Using data from different sources, Pourbaix et al. (2002) have recently improved the precision of the orbital parameters of α Cen. They have adopted the parallax derived by Söderhjelm (1999), $\varpi = 747.1 \pm 1.2$ mas, and give for the masses $M_A/M_\odot = 1.105 \pm 0.0070$, $M_B/M_\odot = 0.934 \pm 0.0061$. On the basis of this same parallax, Guenther and Demarque (2000) have estimated the luminosities of both components: $\log L_A/L_\odot = 0.1969 \pm 0.017$ and $\log L_B/L_\odot = -0.2932 \pm 0.011$. Morel et al. (2000) have used $T_{\rm eff}$ and $\log g$ rather than $T_{\rm eff}$ and L for their calibration. With the values they derive for the luminosities, we would have $\log L_A/L_\odot = 0.1858 \pm 0.029$ and $\log L_B/L_\odot = -0.2487 \pm 0.049$, which are compatible with the values of Guenther and Demarque.

3. P-mode observations on α Cen A*

Bouchy F. and Carrier F., 2001,
A&A 374, L5-L8



4. The models

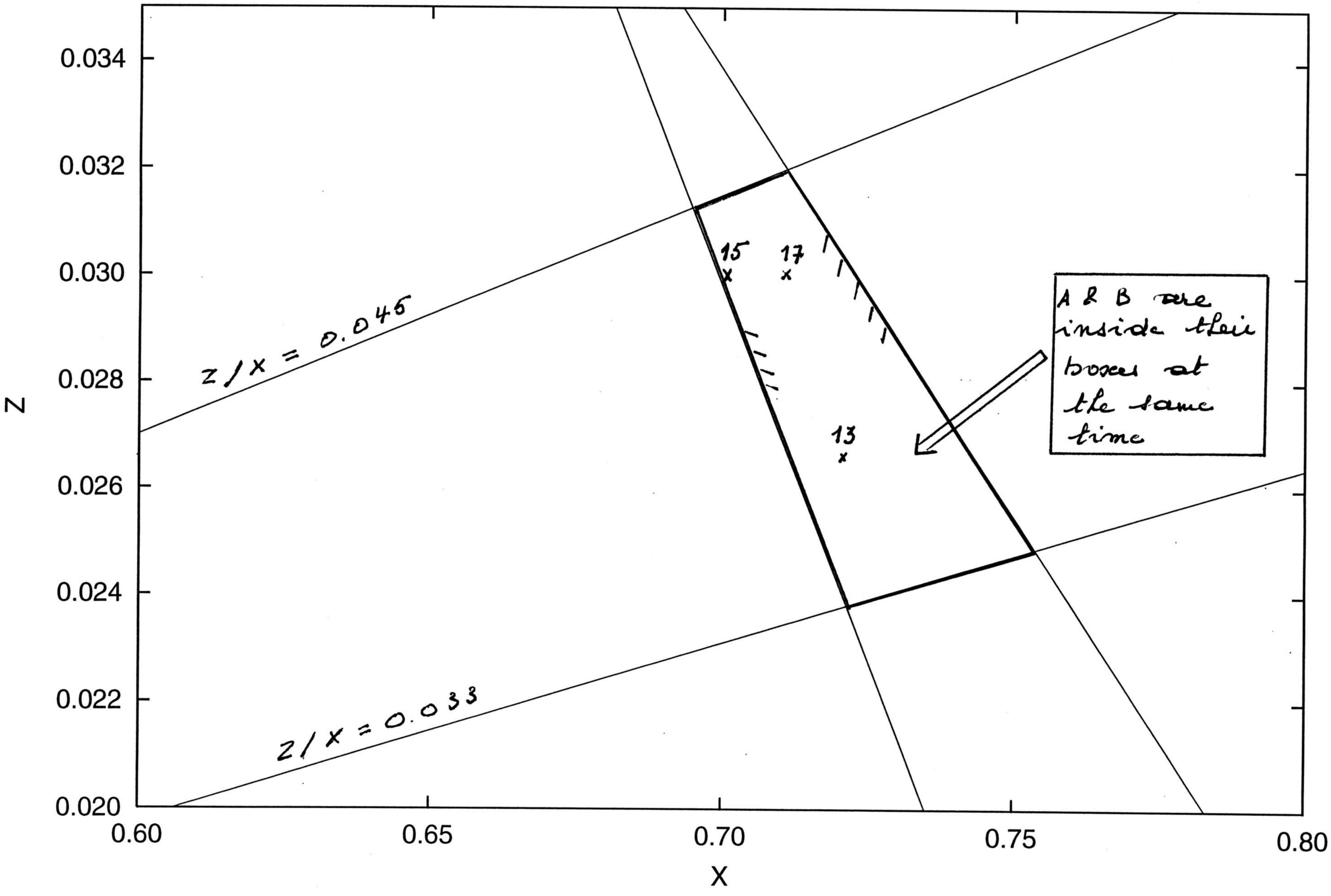
A number of evolutionary sequences have been computed from the main sequence with CLÉS (Code Liégeois d' Évolution Stellaire). We use the CEFF equation of state (Christensen-Dalsgaard and Däppen 1992). The opacities are those of the Lawrence Livermore National Laboratory (Iglesias and Rogers 1996) completed with the Alexander and Ferguson (1994) opacities at low temperature, both tables being smoothly joined in the range of temperature defined by $3.95 < logT < 4.10$. The nuclear reaction rates are from Caughlan and Fowler (1988) and the screen factor from Salpeter (1954). The boundary conditions at the photosphere are deduced from a Kurucz (1998) model. We use the mixing length theory of convection with the same value of the parameter $\alpha = \ell/H_P$ for both components of α Cen. This parameter is free. However, let us notice that for the same physics, a solar calibration gives $\alpha = 1.77$. Of course, we require that both components attain their respective positions in the HR-diagram at the same age.

We have computed a number of models for both components with different values of X, Z, defining the initial chemical composition, and the convection parameter α. For a given chemical composition, it turned out that we could make both evolutionary tracks cross their respective error boxes in the HR diagram with the same choice of the convection parameter α. The requirement of the simultaneity of these crossings define permitted zones in the (X, Z)-diagram (see Fig. 1).

	X	Z	α
13	.72	.027	2.0
15	.70	.030	2.0
17	.71	.030	2.1

Composition chimique d'α Centauri

Code CLES

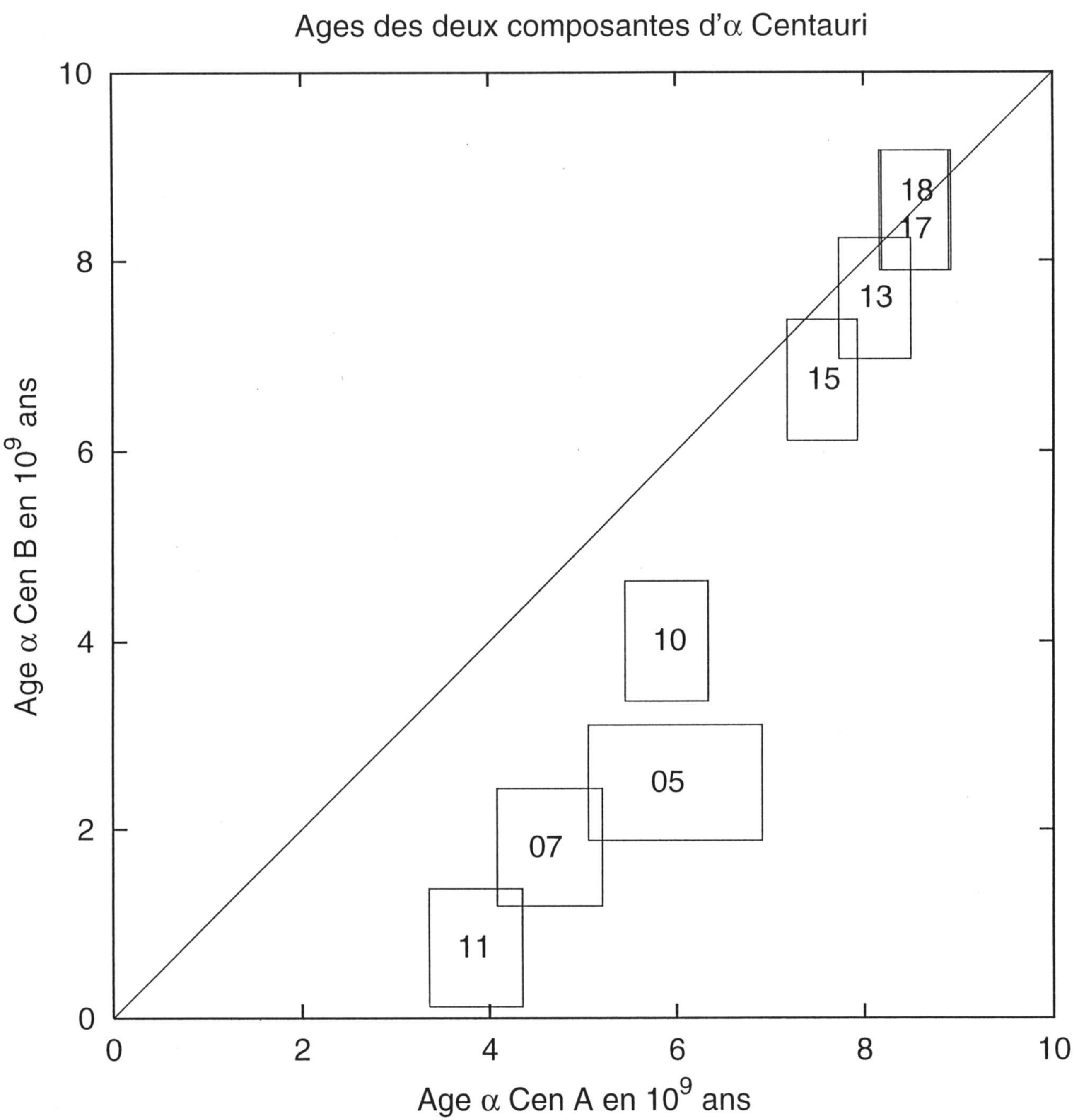


We use the effective temperatures given by the spectroscopic analyses of Neuforge and Magain (1997): $T_{\rm eff,A} = 5830 \pm 30$ and $T_{\rm eff,B} = 5255 \pm 50$. For the metallicity, they obtained $[{\rm Fe/H}]_A = 0.25 \pm 0.02$ and $[{\rm Fe/H}]_B = 0.24 \pm 0.03$. To deduce Z/X, we suppose that this ratio is proportional to [Fe/H] and we adopt the solar value $(Z/X)_\odot = 0.023$ with an uncertainty of 10 %, given by Grevesse and Sauval (1998). In this way, we obtain, for the components of α Cen $Z/X_A = 0.0409 \pm 0.0048$ and $Z/X_B = 0.0400 \pm 0.0052$. As both components must have the same chemical composition, we adopt $Z/X = 0.040 \pm 0.005$ for both components. However, Grevesse and Sauval (2002) now favour a lower value $(Z/X)_\odot = 0.0209$ with the same uncertainty. With this solar value, we would adopt $Z/X = 0.037 \pm 0.004$. It seems safe to say that Z/X is between 0.033 and 0.045.

The above constraints are summarized in Table 1.

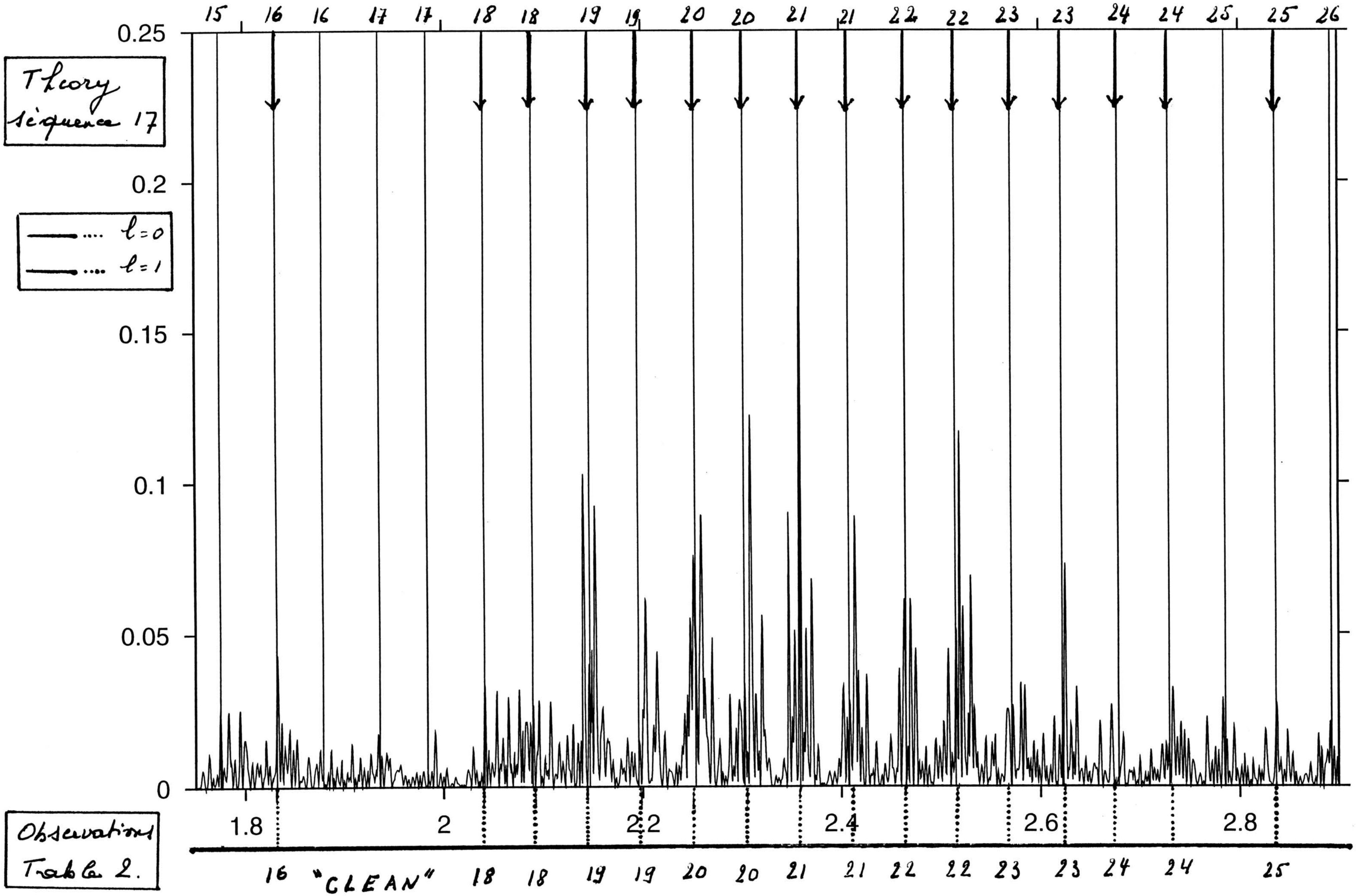
Table 1. Non seismological constraints

	A	B
$M/M_\odot$	1.105 ± 0.0070	0.934 ± 0.0061
$\log L/L_\odot$	0.1969 ± 0.017	-0.2932 ± 0.011
$T_{\rm eff}$	5830 ± 30	5255 ± 50
Z/X	0.039 ± 0.006	



Ages des deux composantes d'α Centauri
Age α Cen B en 10^9 ans
Age α Cen A en 10^9 ans
0
2
4
6
8
10
18
17
13
15
10
05
07
11

5. Comparison between observational and theoretical frequencies



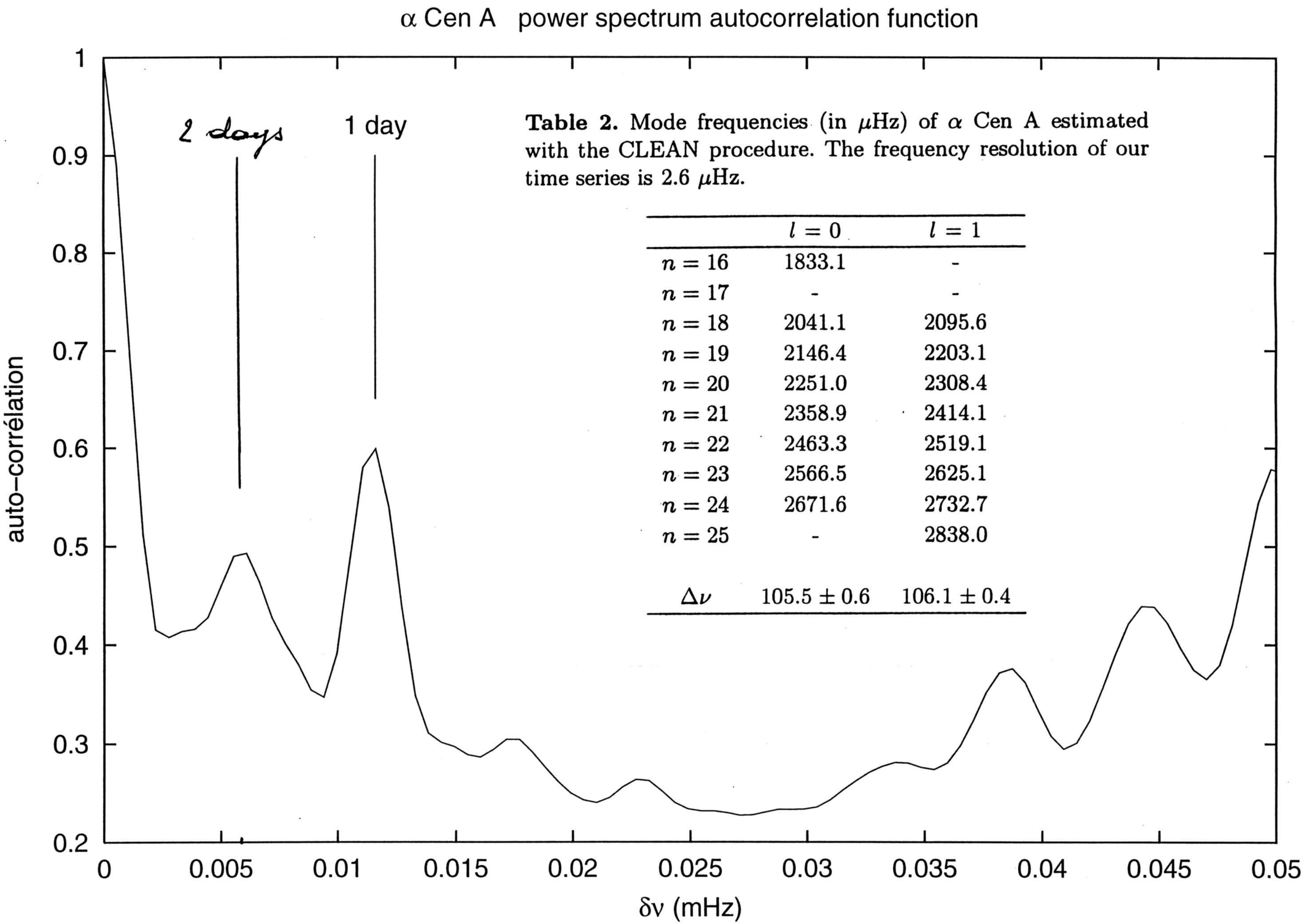
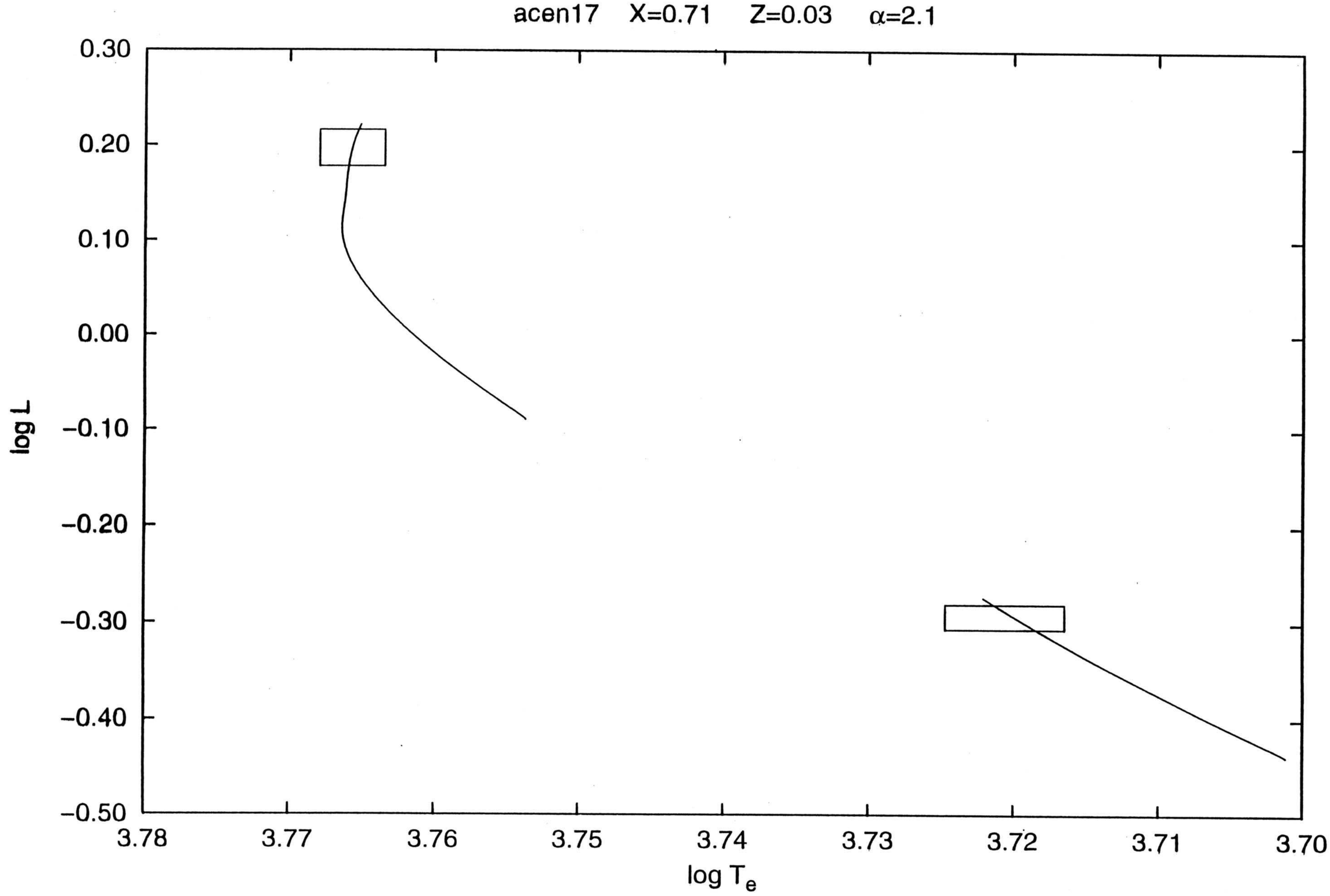


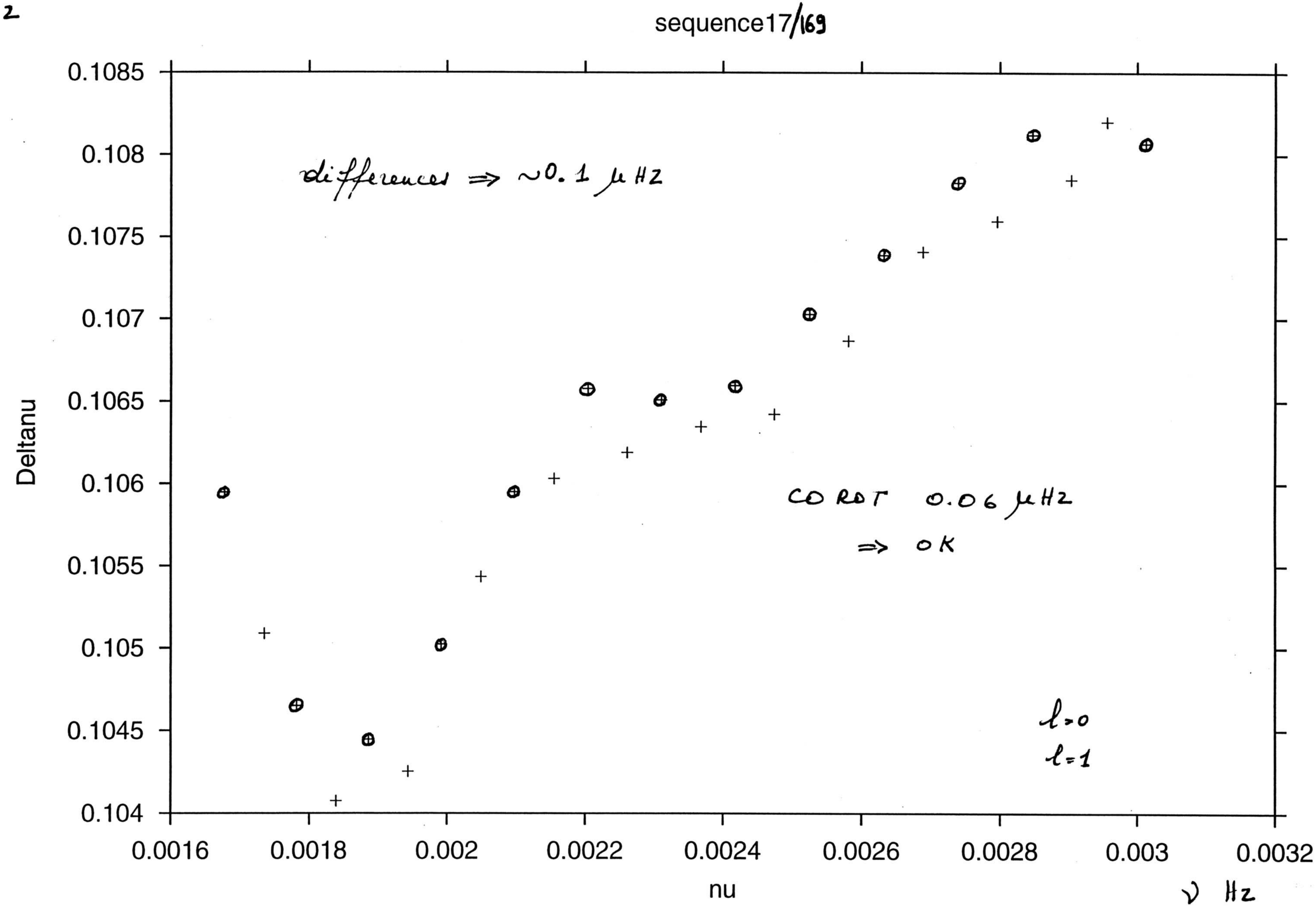
Table 2. Mode frequencies (in μHz) of α Cen A estimated with the CLEAN procedure. The frequency resolution of our time series is 2.6 μHz.

	$l = 0$	$l = 1$
$n = 16$	1833.1	-
$n = 17$	-	-
$n = 18$	2041.1	2095.6
$n = 19$	2146.4	2203.1
$n = 20$	2251.0	2308.4
$n = 21$	2358.9	2414.1
$n = 22$	2463.3	2519.1
$n = 23$	2566.5	2625.1
$n = 24$	2671.6	2732.7
$n = 25$	-	2838.0
$\Delta\nu$	105.5 ± 0.6	106.1 ± 0.4


acen17 X=0.71 Z=0.03 α=2.1
0.30
0.20
0.10
0.00
−0.10
−0.20
−0.30
−0.40
−0.50
log L
3.78
3.77
3.76
3.75
3.74
3.73
3.72
3.71
3.70
log T_e

$\Delta\nu = \nu(n,\ell) - \nu(n-1,\ell)$

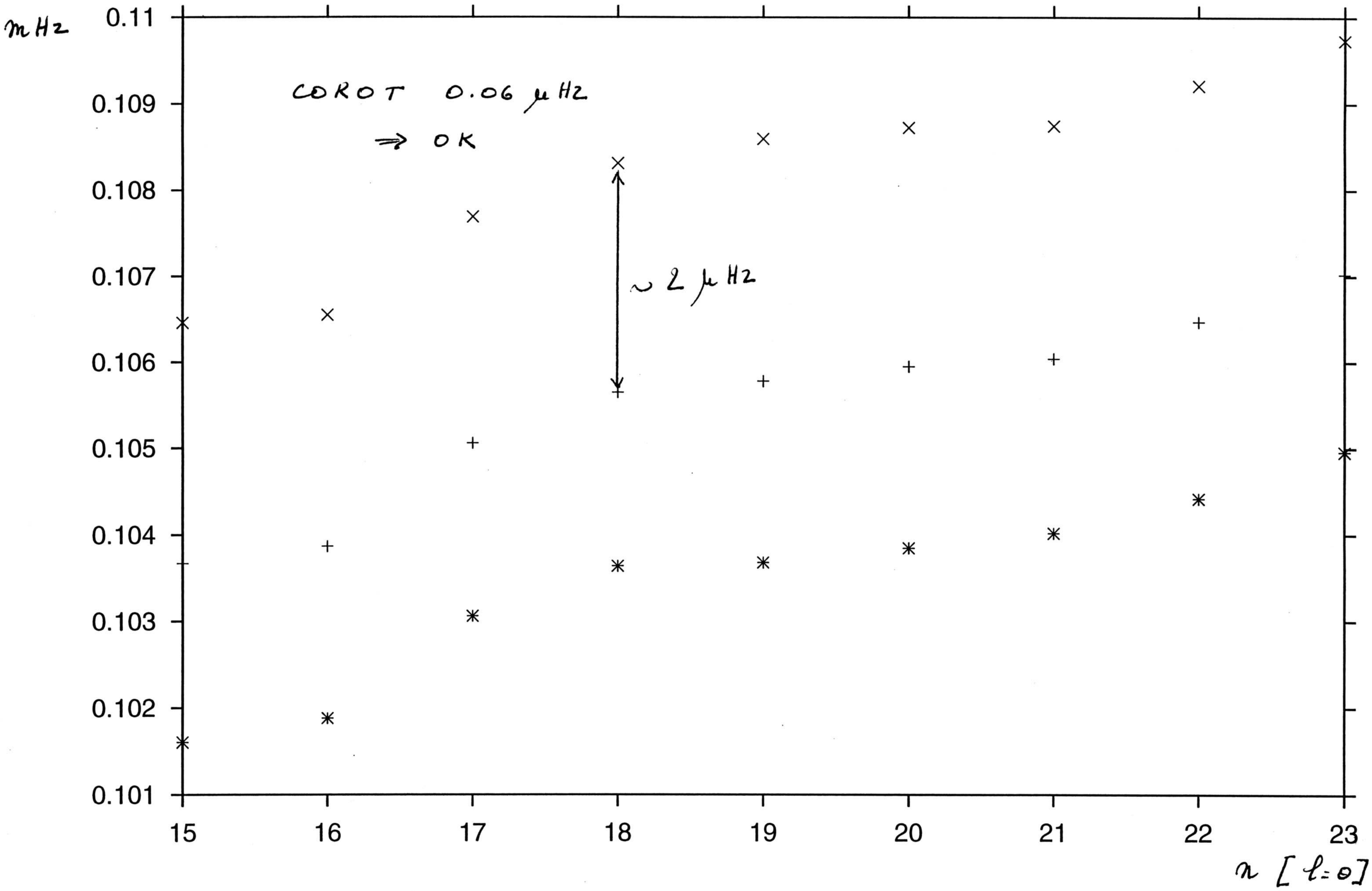
mHz



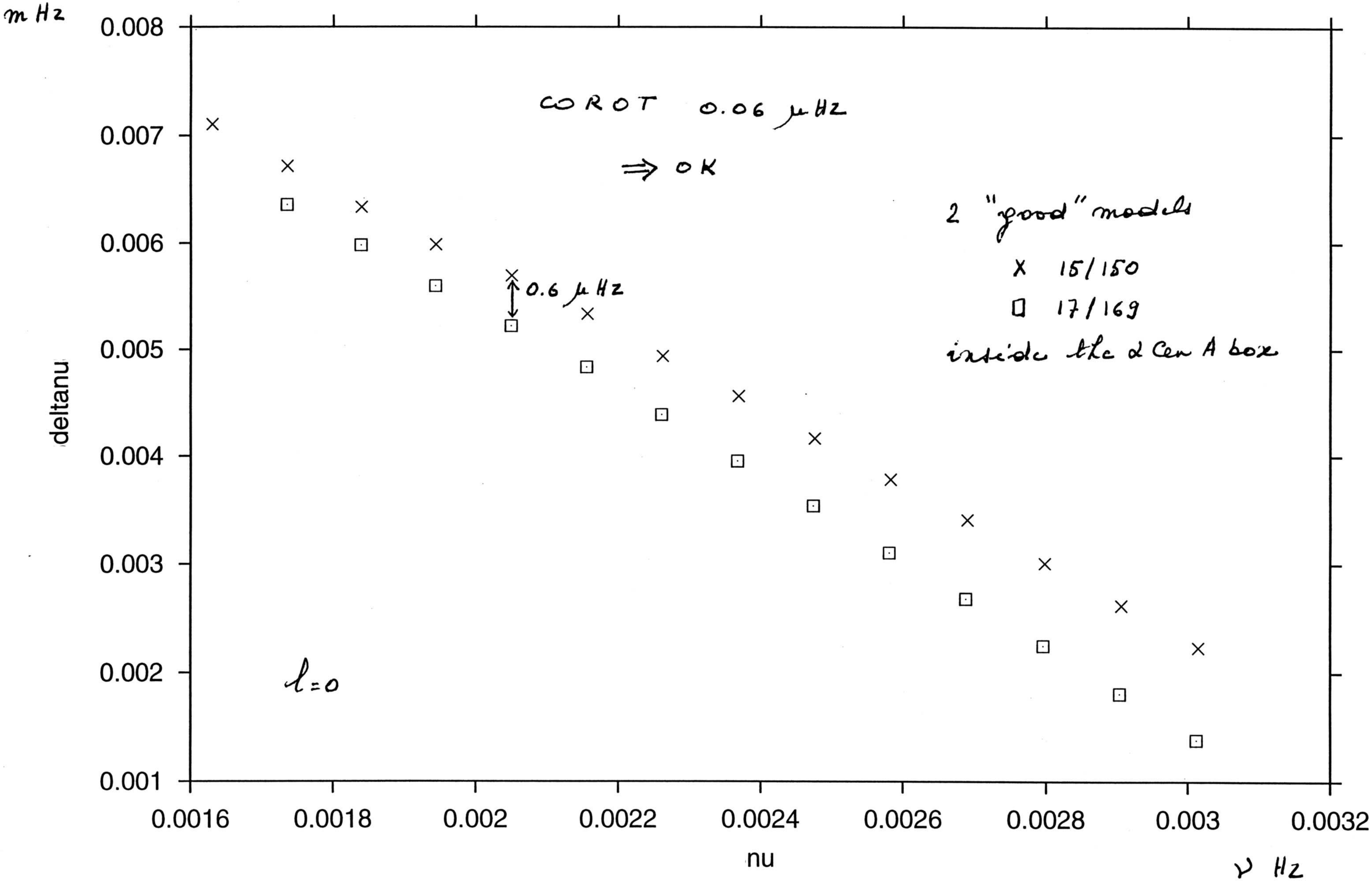
ν Hz

$\Delta\nu = \nu(n,0) - \nu(n-1,0)$

3 "good" models for sequence 17
⇓
inside the α Cen A box



$$\delta\nu = \nu(n,\ell) - \nu(n-1,\ell+2)$$



6. Conclusions

Even if α Cen A is not a COROT target, it illustrates very clearly the need for space missions with long observing time in order to give to asteroseismology its full meaning. α Cen A is an ideal star for asteroseismology since its mass can be derived from the orbital parameters of the α Cen binary system. Its chemical composition is also well determined. Moreover, the binarity, imposing the same age to both components of the α Cen system, constrains the chemical composition within an even smaller range.

- For each evolutionary sequence fulfilling these requirements, three models have frequencies in excellent agreement with the ground-based seismological data. They differ by

  $$D(\Delta\nu) \sim 2\mu Hz$$

  This value is smaller than the frequency resolution of the ground-based observations, of the order of 2.6 μHz, but well within the reach of COROT.

- For each model, $\delta\nu$ is of the order of the ground-based frequency resolution. All the $l = 2$ modes are lost but within the reach of COROT.

- For a given model, the identification of modes $l = 1$ or $l = 0$ needs a precision of

  $$D(\Delta\nu) \sim 0.1\mu Hz$$

  within the reach of COROT.

- For two models slightly different in X (0.70 and 0.71), the values of $\delta\nu$ differ only by

  $$D(\delta\nu) \sim 0.6\mu Hz$$

  within the reach of COROT.