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CONFERENCE ON FUNDAMENTAL SYMMETRIES AND FUNDAMENTAL CONSTANTS

15 - 18 September 2004

NEW SEARCHES FOR VARYING α

Carlos Martins
CFP (U. Porto) & DAMTP (U. Cambridge)

New Searches for Varying α

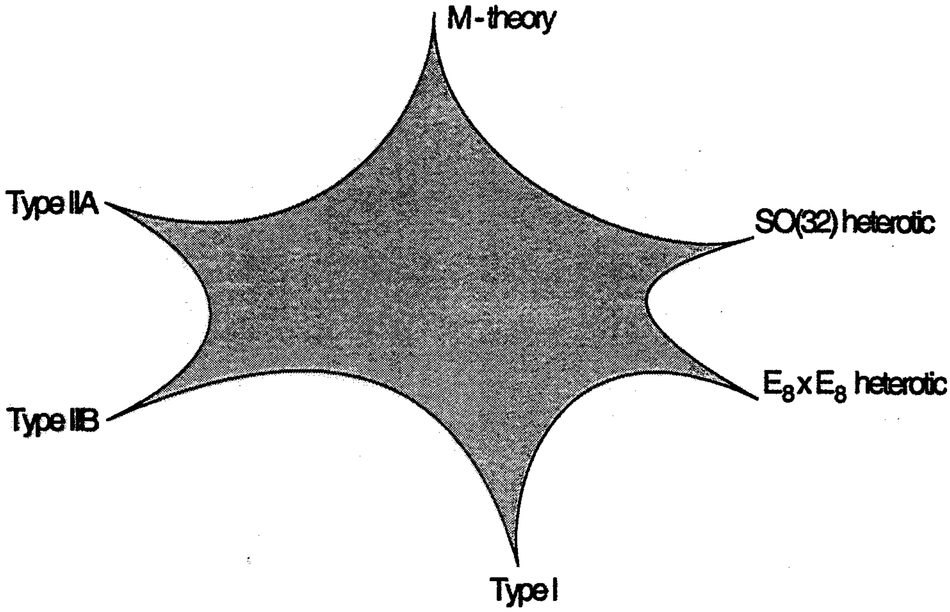
Carlos Martins

CFP (U. Porto) & DAMTP (U. Cambridge)

With: P. Avelino, J.Brinchmann, D.McIntosh, A. Melchiorri, A.Moorwood, J. Oliveira, G. Rocha, G.Rudnick, R. Trotta, P. Viana et al.

MOTIVATION

○ *From D=4+n to D=4 cosmology...*



✸ Dimensional reduction and (possibly) compactification needed in order to obtain standard cosmology from higher dimensional theories...

☞ *(3+1)D effective constants typically related to true constants via characteristic lenghtscale of extra dimensions*

✍ *Expect time and/or space variations of the effective coupling constants!*

Kaluza–Klein Models: **Chodos & Detweiler (1980), Marciano (1981)**

Superstring theories: **Wu & Wang (1986)**

Brane worlds: **Kiritsis (1999), Alexander (2000)**

EEP, STRING THEORY AND VARYING α

See, e.g., Damour (2003), JENAM 2002 Proceedings

✶ *Nearly all unification theories violate the Einstein Equivalence Principle at some level. In particular, string theory does.*

☞ In all theoretical models where the time variation of α is linked to the spacetime variation of a light scalar field, be it

the dilaton in string theory

Damour & Polyakov (1994)
Damour, Piazza & Veneziano (2002)

a field constrained (by hand) to couple only to electromagnetism

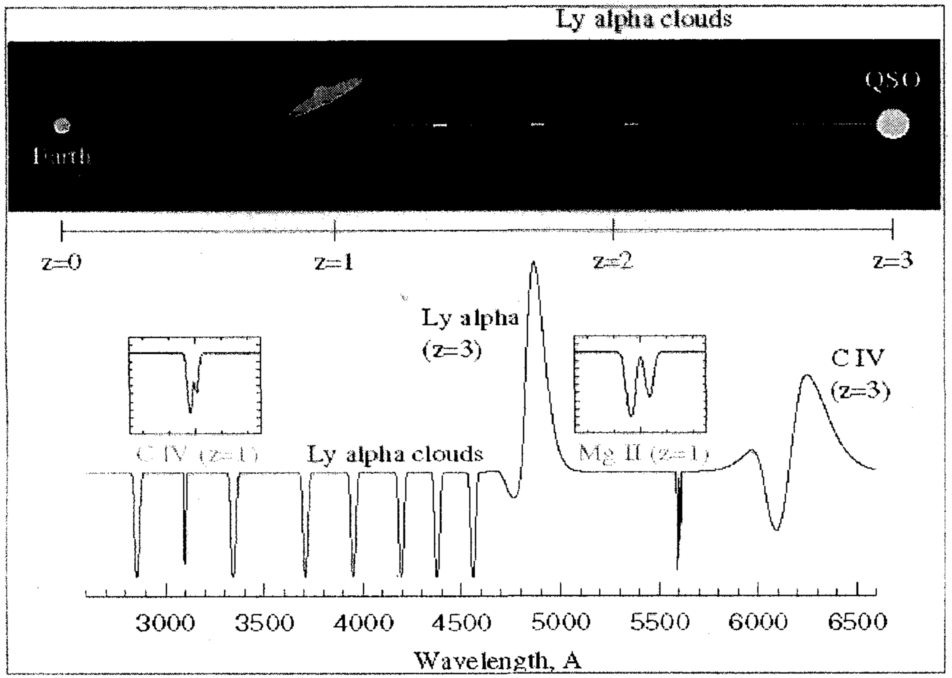
Bekenstein (1982)
Sandvik, Barrow & Magueijo (2002)
Olive and Pospelov (2002)

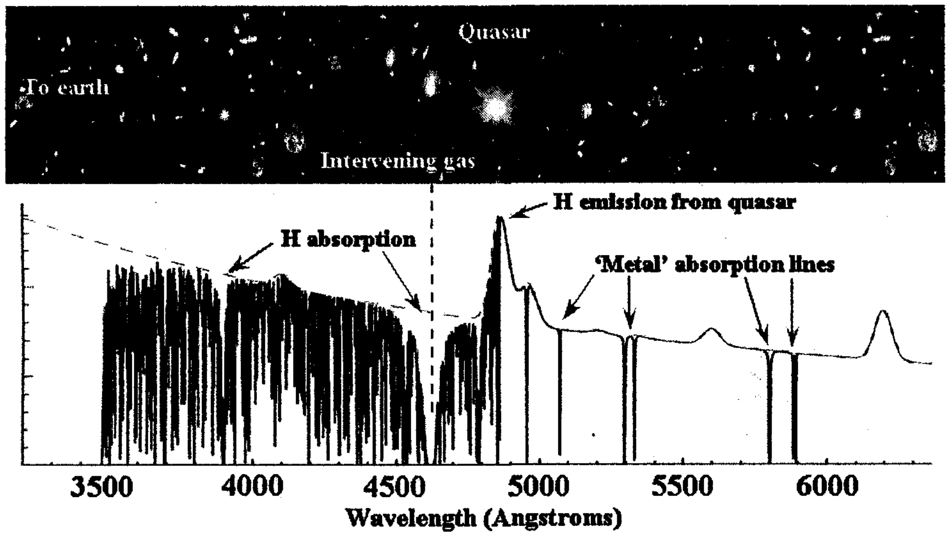
having a fractional variation $\Delta\alpha/\alpha \sim 10^{-5}$ on cosmological timescales necessarily implies having a violation of the universality of free fall at a level $\eta \gtrsim 10^{-13}$ i.e. just below current bounds. Hence tests of the universality of free fall (and the Einstein Equivalence Principle in general) are the best experimental probe of varying constants (nad arguably string theory itself).

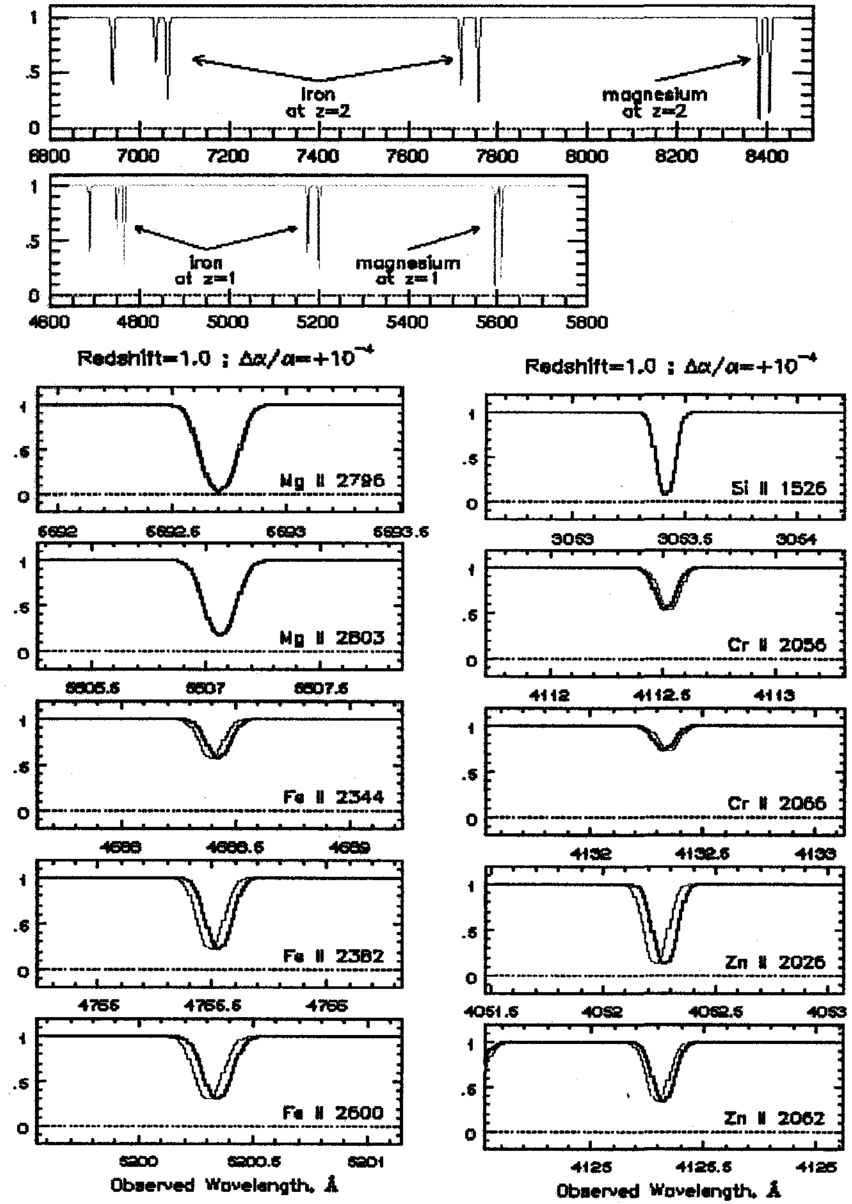
Varying Alpha and Dark Energy

- Motivation to replace Λ by ϕ comes from superstring models, where any dimensionful parameter is expressed in terms of the string mass scale and a scalar field VEV
- The requirements of slow-roll (mandatory for $p < 0$) and present-day domination imply, if the minimum of the potential is zero, that (see *[Carroll 1998]*)
  - The field is very light, $m \sim H_0 \sim 10^{-33} eV$
  - The VEV of the quintessence field today is of order m_{Pl}
- Hence couplings of this field lead to observable long-range forces and time dependence of the constants of nature

Measuring α from Quasars







A Further Alternative: Emission Lines

- First used by Savedoff (1956, NII & NeII from CygA), Bahcall & Salpeter (1965, OIII & NeIII from a quasar); first use of absorption is Bahcall *et al.* (1967, SiII & SiIV)
- Bahcall *et al.* *[Astrophys. J. 600, 520 (2004)]* measured α from strong [OIII] emission lines from quasars in the SDSS
- Dataset of 165 spectra, at $0.16 < z < 0.80$ (median $z_{med} \sim 0.37$), found

$$\boxed{\frac{\Delta\alpha}{\alpha} = (1.2 \pm 0.7) \times 10^{-4}}$$

- Method quite simple and straightforward in principle, but less sensitive, and hard to apply to high redshift?

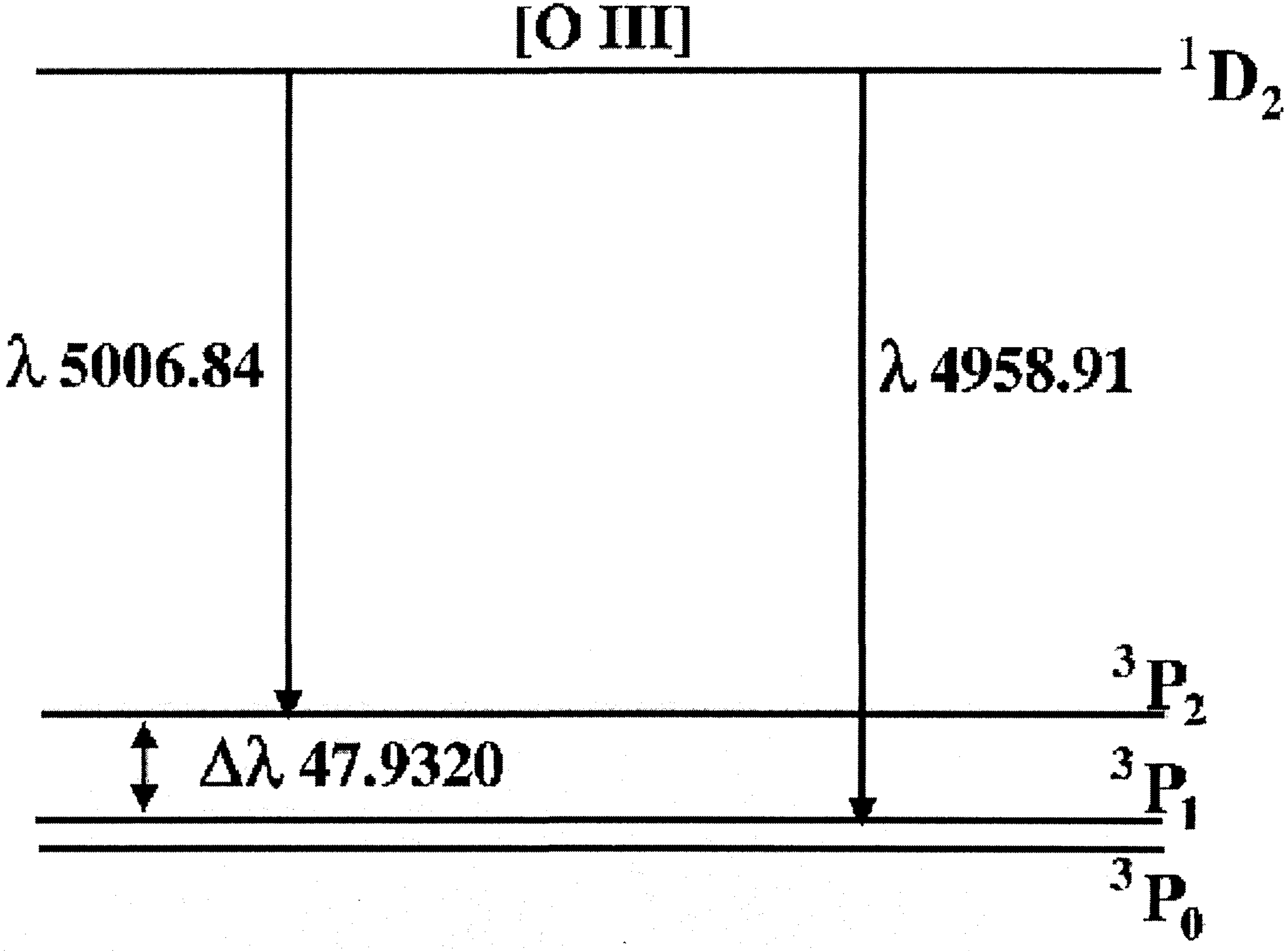
The OIII Method

- Uses the [OIII] emission lines ($\lambda\lambda$5007 & 4959 A)
- Wavelength separation is set by LS-coupling so depends on α^4. This would require very good absolute calibration, but the wavelengths themselves depend on α^2 so

$$\boxed{R = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2} \propto \alpha^2}$$

- A change in wavelength separation of $0.1A$ gives $\Delta\alpha/\alpha \sim 10^{-3}$, $0.001A$ gives $\Delta\alpha/\alpha \sim 10^{-5}$

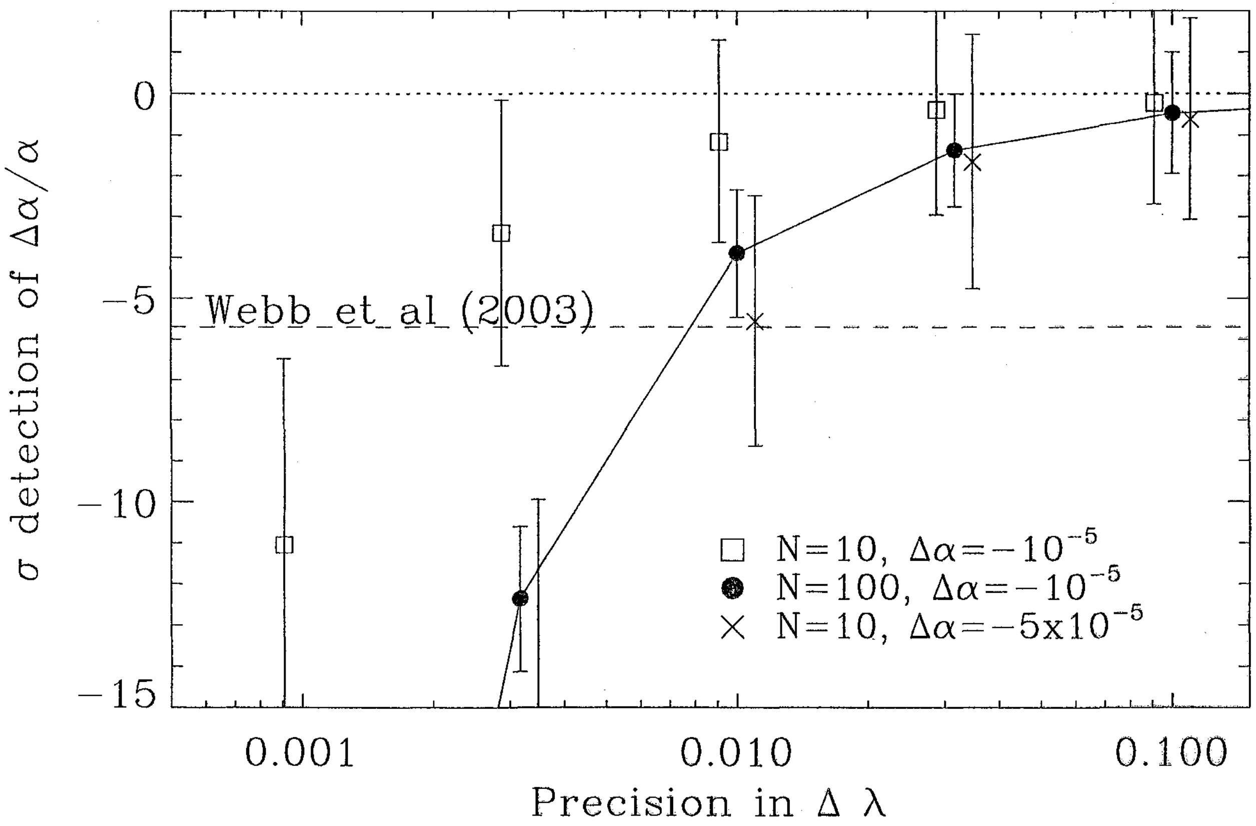
The [O III] transition



Bahcall et al (2004)

Moving On: Our Improvements

- The latest Bahcall *et al.* was limited to $z < 0.8$, but the most interesting region is at $z \sim 2-3$. Here the [OIII] lines are in the near-IR
- Downsides: Fainter because of distance; much harder because of bright sky and strong skylines
- Advantages: Quasars intrinsically brighter at high z, many skylines mean accurate wavelength calibration (also larger time-span improves constraints on time evolution)


σ detection of Δα/α
Precision in Δ λ
Webb et al (2003)
N=10, Δα=−10⁻⁵
N=100, Δα=−10⁻⁵
N=10, Δα=−5x10⁻⁵
0
−5
−10
−15
0.001
0.010
0.100

Our Data [VLT 072.A-0703(A)]

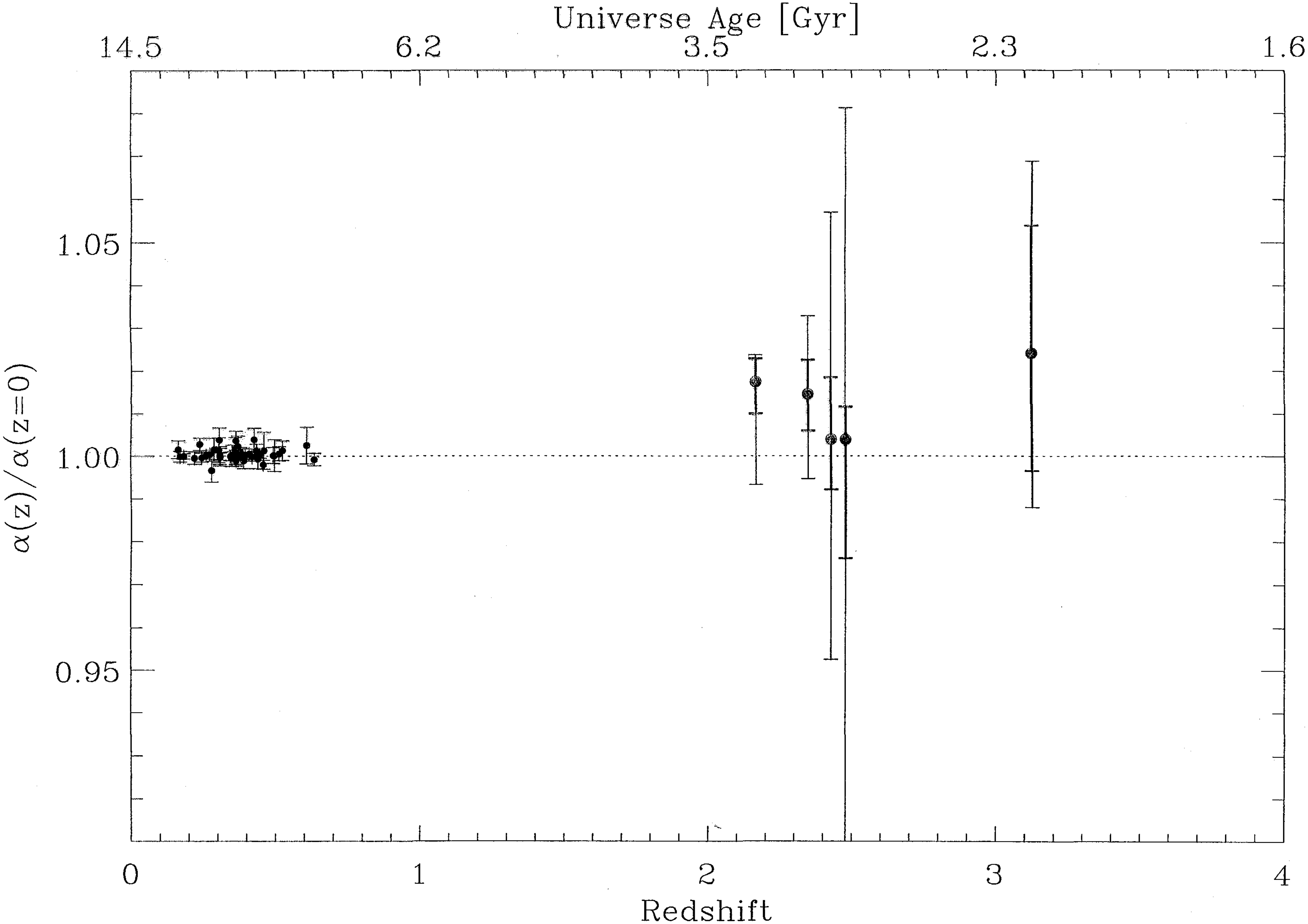
- 10 hours of VLT time in service mode (1h per target, observed from 2003/11/13 to 2004/03/16)
- 5 radio galaxies, 5 QSOs with $1.981 < z < 3.126$, 5 observations good for our purposes
- We use the ISAAC instrument to do near-IR spectroscopy. The resolution was the highest possible ($R \sim 10000$)
- This gives about 1 Angstrom per pixel (ideally we want to reach accuracies of $1/1000^{th}$ of this)

Uncertainties: Our MC Method

- The data reduction is done with a special purpose pipeline (not the VLT one)
- Draw a random realisation of each raw frame assuming Poissonian arrival statistics for photons
- Reduce the data for each such realisation (301 in total for each object)
- Calculate all necessary quantities for each realisation and use the variation between the realisations to construct a likelihood distribution for each quantity

Data Reduction

- Cosmic ray removal
- Flat fielding and straightening of images
- Individual frames must be matched
- Sky contribution subtracted
- Spectra must be extracted
- Wavelength calibration (OH lines)
- Position of [OIII] lines measured, separation constrained


Universe Age [Gyr]
14.5
6.2
3.5
2.3
1.6
1.05
1.00
0.95
α(z)/α(z=0)
0
1
2
3
4
Redshift

What Could Go Wrong?

- Wavelength calibration:
  The OH line wavelengths could be systematically offset (quite unlikely, but not inconceivable)
- Emission line measurements:
  The [OIII] lines could be affected by other emission (typically iron lines)
  Hβ emission could affect the 4959 line (but not the peak position?)
- More?

Status and Outlook

- We constrained $\alpha(z)$ at $2 < z < 3$ using emission lines. Our results are consistent with zero change, but show consistently high values
- Method has few systematic uncertainties in the physics, and is therefore well suited for evolution studies
- Wavelength calibration is the best ever for ISAAC data, currently good enough to detect $\Delta\alpha/\alpha \sim few \times 10^{-5}$
- Improvements require larger sample: will apply to become ESO Large Programme in 2005 (meets TAC requests)
- In progress: Repeat observations of individual objects or large sample? High S/N and few objects or medium S/N and many objects?

A Prelude to an Interlude

Any model that fits all the data at a given time is necessarily wrong, because at any given time not all the data is correct.

The purpose of models is not to fit the data but to sharpen the questions.

Afterthought

Absorption methods tend to give lower values of α, emission methods tend to give higher values. Why?

- Absolute systematics in both methods?
- Relative systematics?
- Spatial variations?

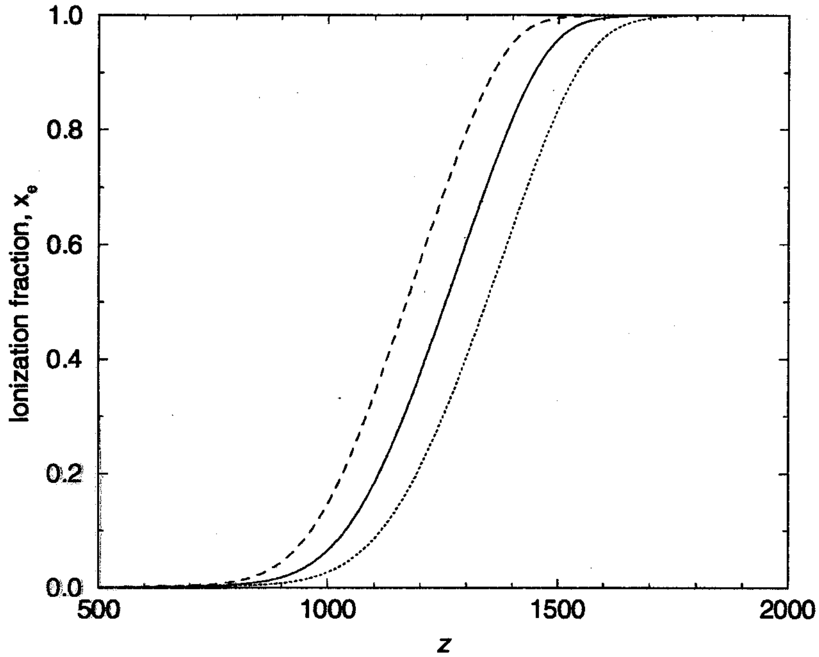
VARYING α AND THE CMB

Hannestad (1999); Kaplinghat, Scherrer and Turner (1999)

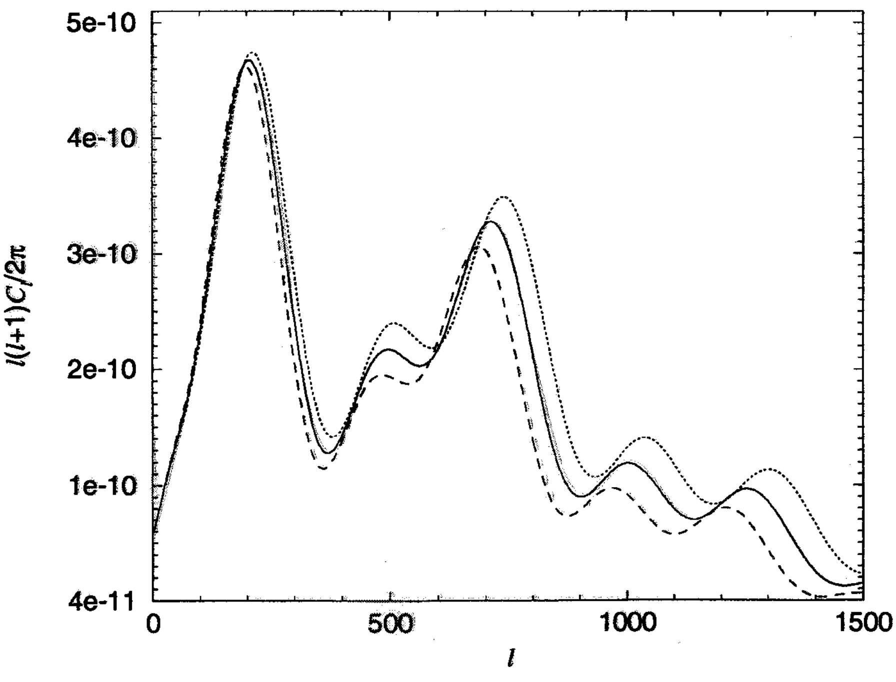
☞ Changes ionization history of the universe;

Energy levels and binding energies are shifted: changes zrec

Changes Thomson cross–section for all particles (effect goes as α^2)



✍ Say α increases, then so does z_{ls}, and



Position of 1st peak moves to higher l

Amplitude of 1st peak increases (larger early ISW)

Smaller high–l damping (which is due to finite LSS thickness)

☆ Expected constraints: $|\Delta\alpha/\alpha| < 10^{-3}$ $(z \sim 10^3)$

VARYING α AND NUCLEOSYNTHESIS

Gasser and Leutwyler (1982); Bergstrom, Iguri & Rubinstein (1999)

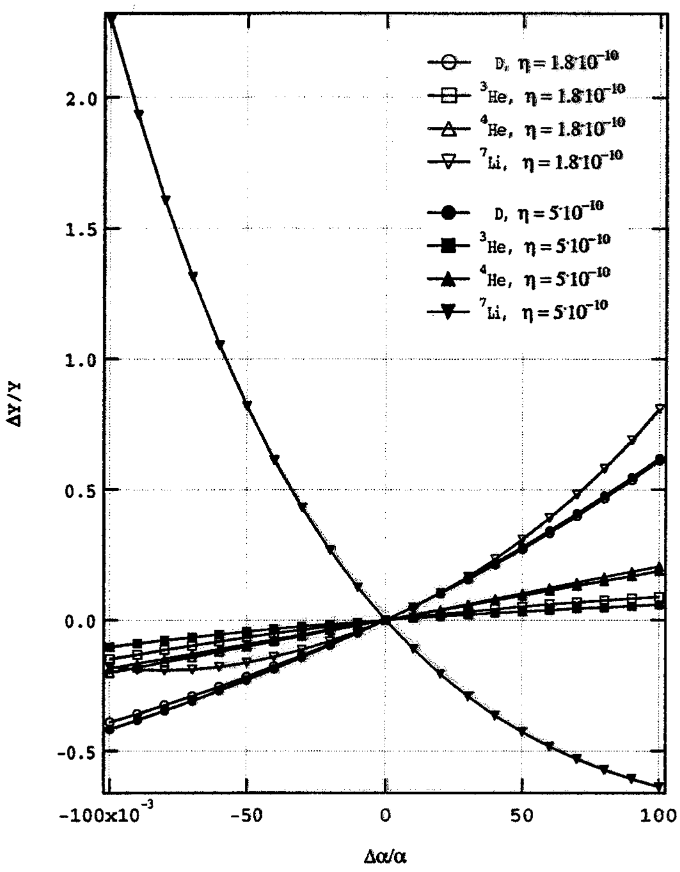
☞ Very high–redshift, but model–dependent!

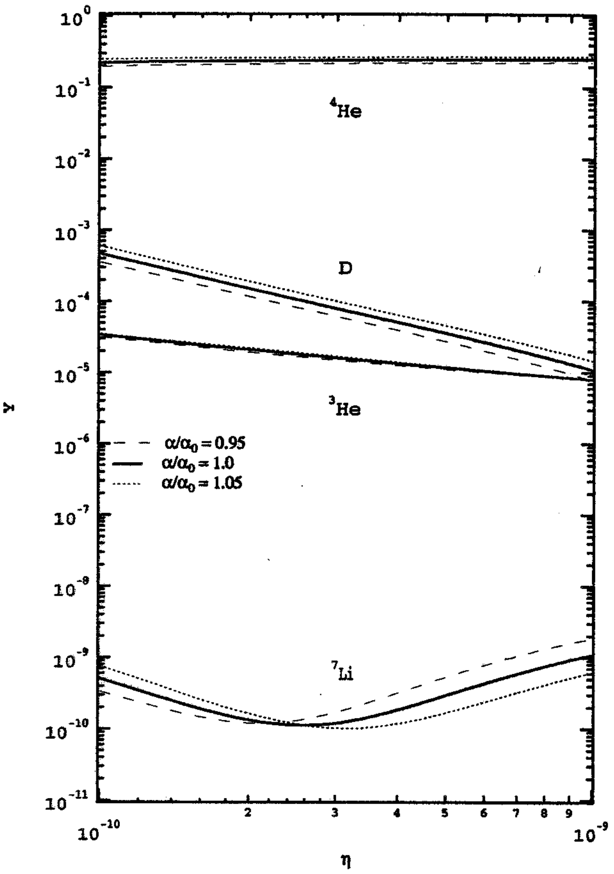
Affects neutron/proton mass diference

Changes Coulomb barrier in nuclear reactions

✍ A phenomenological fit:

$$\Delta m \sim 2.05 - 0.76\,(1 + \Delta\alpha/\alpha)$$



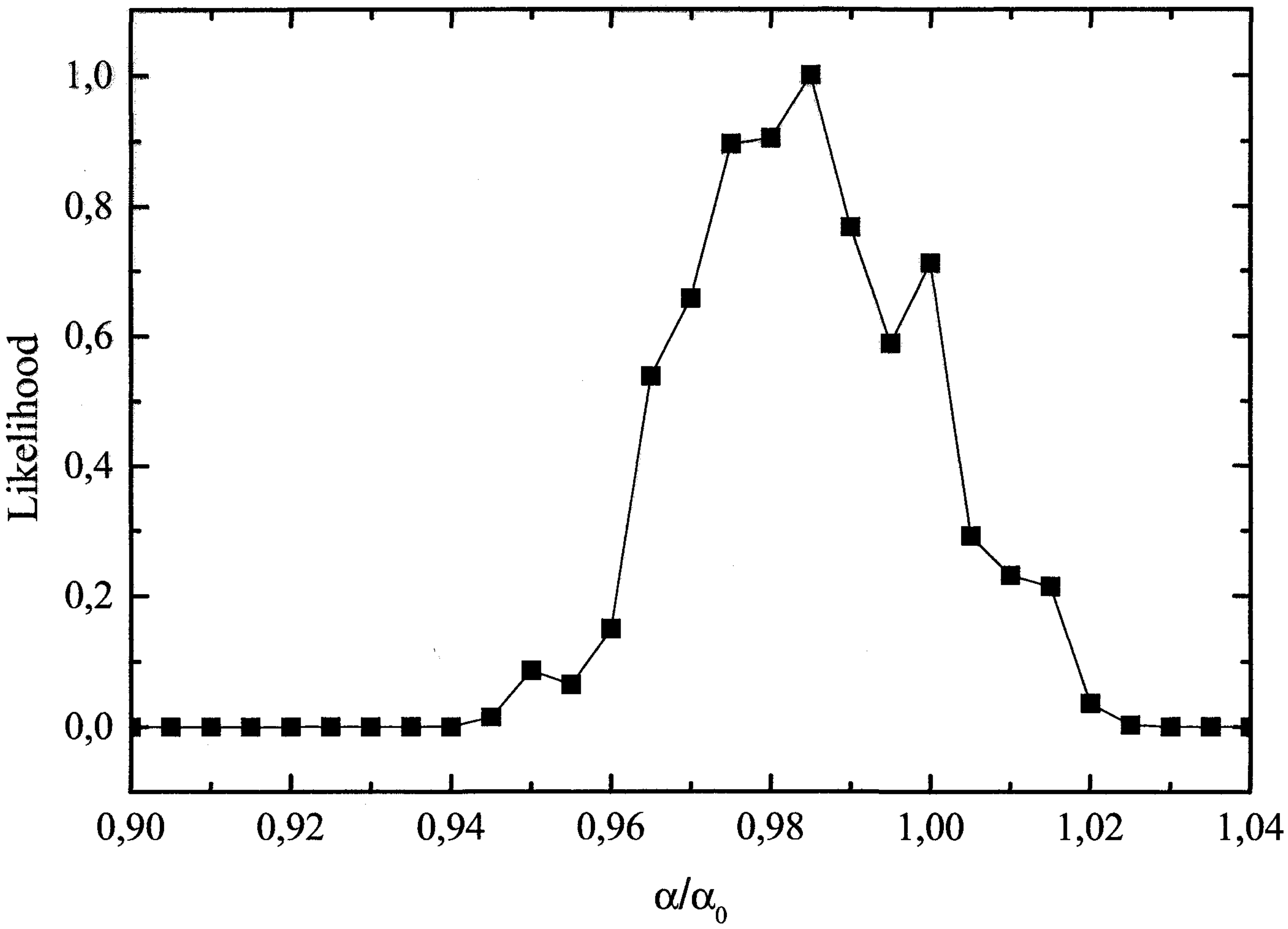


☆ Current constraints:

$|\Delta\alpha/\alpha| < 0.02\ (z \sim 10^{10})$

$|\Delta\beta/\beta| < 0.06\ (z \sim 10^{10})$

(note that G_F is independent of gauge coupling in standard EW model)


1,0
0,8
0,6
0,4
0,2
0,0
Likelihood
0,90
0,92
0,94
0,96
0,98
1,00
1,02
1,04
α/α0

WMAP1 Data Analysis

- Grid-based analysis on COSMOS with
  - $\Omega_c h^2 : 0.05(0.01)0.20,$ $\Omega_b h^2 : 0.01(0.001)0.02$
  - $\alpha_{dec}/\alpha_0 : 0.80(0.05)1.18,$ $\tau : 0.00(0.02)0.30$
  - $n_s : 0.88(0.005)1.08,$ $dn_s/dlnk : -0.15(0.005) + 0.05$
  - $\Omega_{tot} = 1$, no gravity waves or isocurvature modes
- We find, at 95% C.L.

$$\boxed{0.95 < \frac{\alpha_{dec}}{\alpha_0} < 1.02}$$

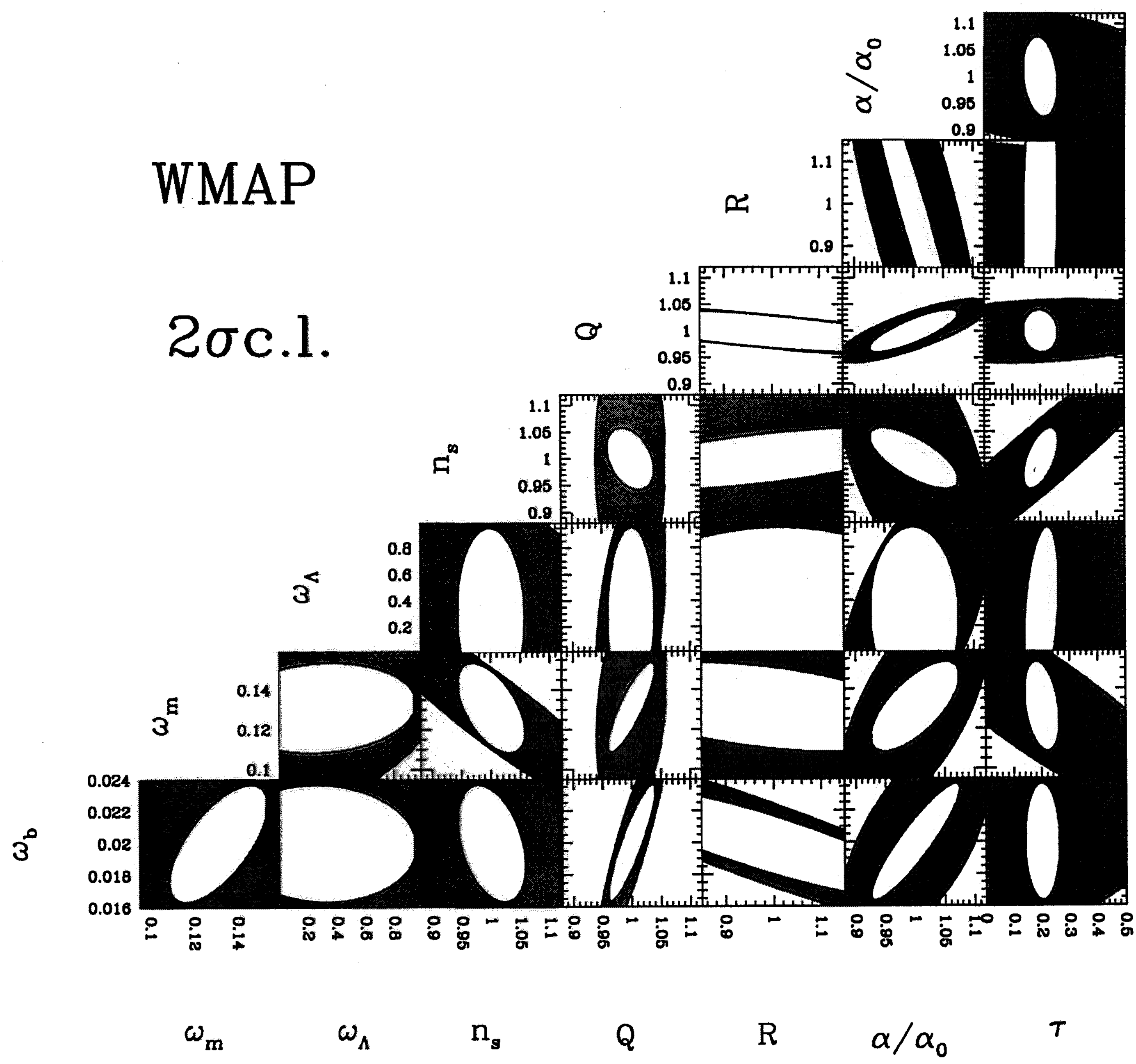
or, if we impose $dn_s/dlnk = 0$

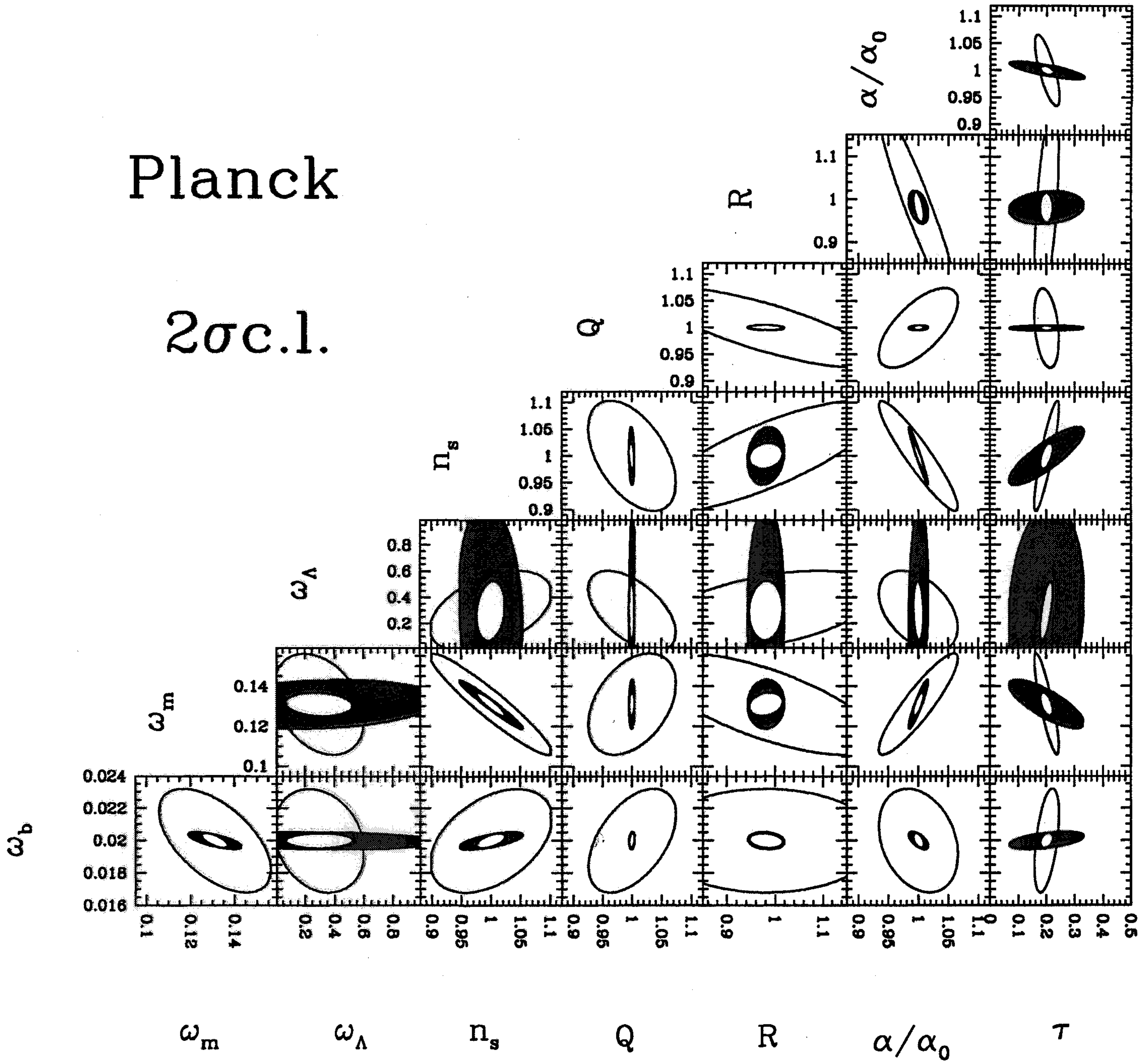
$$\boxed{0.94 < \frac{\alpha_{dec}}{\alpha_0} < 1.01}$$

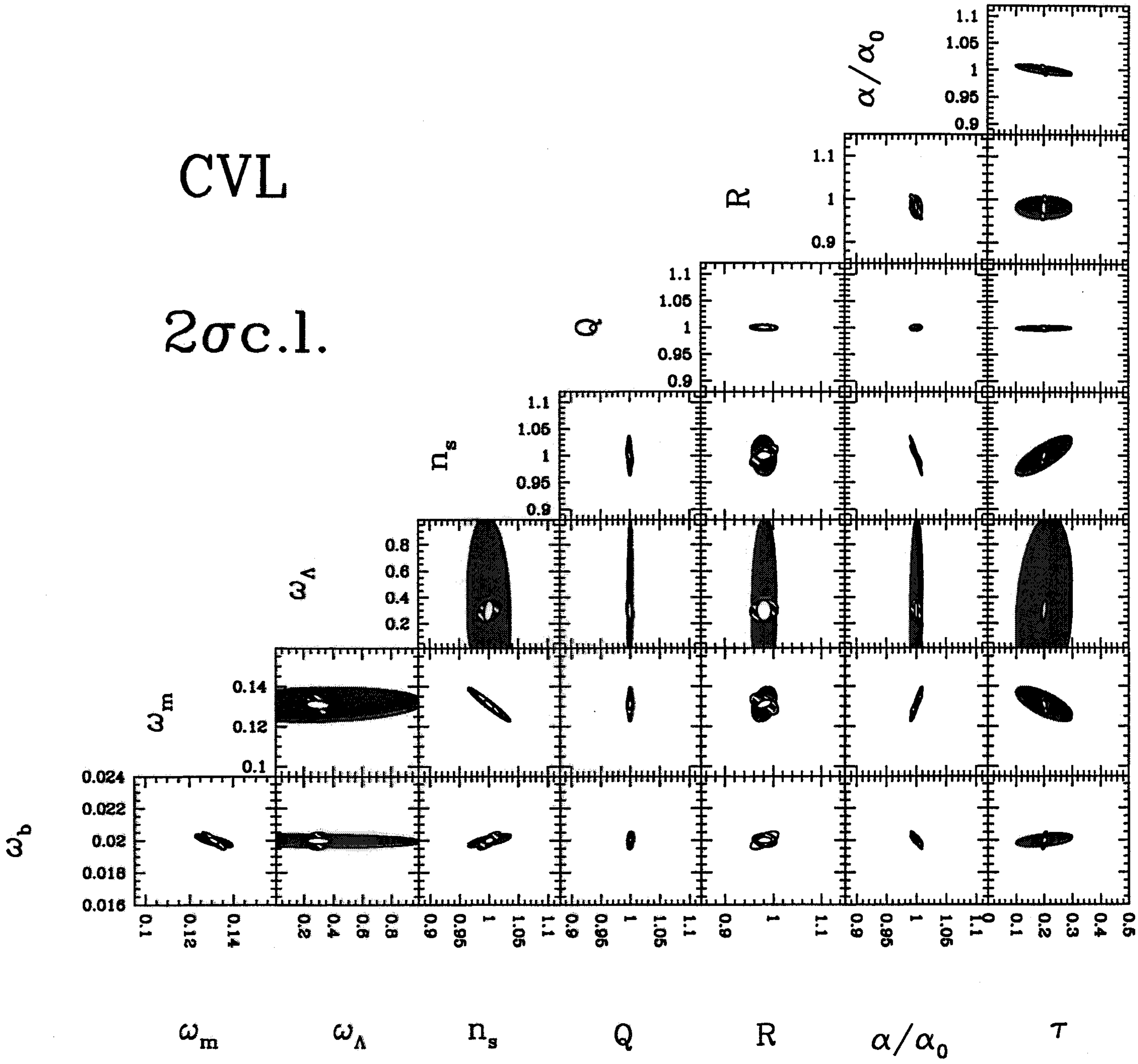
FMA ML model

$\omega_b = 0.02$, $\omega_m = 0.131$, $\omega_\Lambda = 0.2957$
$R = 0.9815$, $n_s = 1$, $Q = 1$
$\tau = 0.20$, $\frac{\alpha_{dec}}{\alpha_0} = 1$
Adiabatic IC's, no tensors

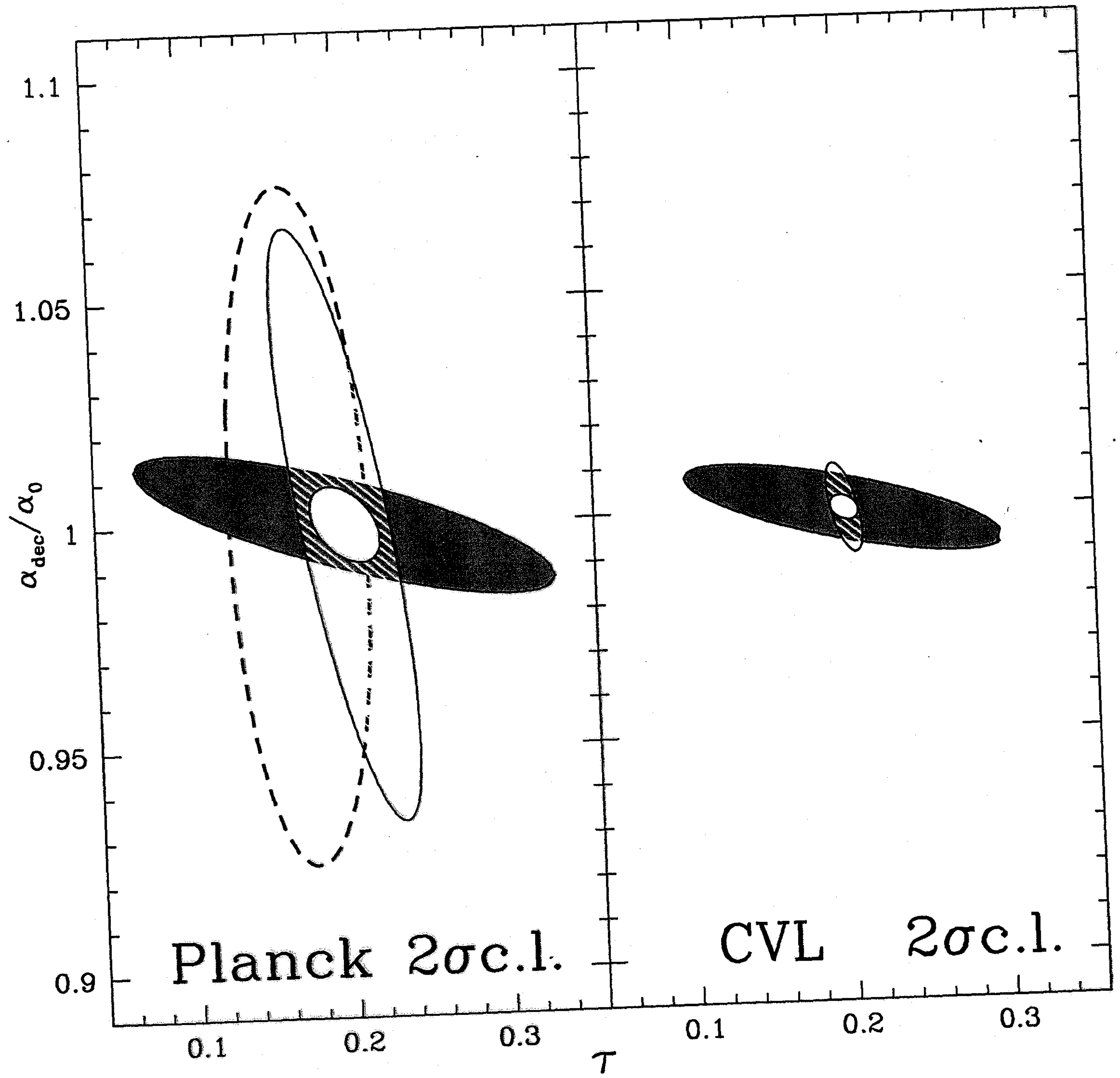
<u>NB</u>: $\Omega_{tot} = 1.01$




Planck
2σc.l.
ω_b
ω_m
ω_Λ
n_s
Q
R
α/α_0
τ


CVL
2σc.l.
ω_b
ω_m
ω_Λ
n_s
Q
R
α/α_0
τ

1σ Accuracy	WMAP4	Planck HFI	CVL
α	3%	0.3%	0.1%
τ	11%	4.5%	1.8%

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