Variation of the constants in the early and late universe

Jean-Philippe Uzan

Laboratoire de Physique Théorique, Orsay

Institut d’Astrophysique de Paris

Outline

- Tests of gravity on astrophysical scales
- Update of constraints on variation of some constants

  G / α / μ mainly
- Variation of the constants in the late universe

  Links with quintessence

  Model building
- Variation of the constants in the early universe

Tests of gravity on astrophysical scales

In the standard cosmological model:

1- gravitation is supposed to be described by general relativity

2- spacetime geometry is assumed to have FLRW symmetries

It follows that most observations depend only on *E(a)*

$$H(a) = H_0\,E(a)$$

$$E^2(z) = \Omega_m^0(1+z)^3 + \Omega_r^0(1+z)^4 + \Omega_K^0(1+z)^2$$

e.g. : luminosity distance, angular distance, growth factor of perturbations

If matter content of the universe = matter + radiation

Combined data of SNIa, CMB, LSS

1- Not in agreement with (standard) matter content

2- Universe is accelerating $\Omega_\Lambda^0 \sim 0.7$, $\Omega_m^0 \sim 0.3$

Gravitation = any long range force that cannot be screened

Variety of scenarios

Ordinary matter $\longleftrightarrow g_{\mu\nu} \longleftrightarrow \phi$

Ex : quintessence, ...

Ordinary matter $\longleftrightarrow g_{\mu\nu} \longleftrightarrow \phi$

Ex : scalar-tensor, ...

Matière ordinaire $\longleftrightarrow g_{\mu\nu}$

A_μ

$\updownarrow$

a_μ

Ex : axion-photon mixing

Ordinary matter $\longleftrightarrow \tilde{g}^{(i)}_{\mu\nu}$

Ex : brane induced gravity
multigravity,...

JPU, Aghanim, Mellier, astro-ph/0405620

What can/should we test?

Many tests from mm to Solar System size both on a possible fifth force and universality of free fall

(See Adelberger and Esposito-Farèse talks)

Very few tests on astrophysical scales

Cluster scale (2 Mpc): X-ray vs lensing. Allen et al. MNRAS **324** (2001) 877

but: galaxy rotation curves Aguire et al. CQG **18** (2001) R223

No direct test on cosmological scales

entangle properties of matter and gravity

acceleration of the universe

What to test:

field equations (Poisson equation in the Newtonian limit)

EEP: local Lorentz invariance Jacobson et al., gr-qc/0404067

local position invariance: **constants**

universality of free fall

Growth of cosmic structures

In a flat FLRW with Λ=0, growth factor $D_+ \propto a$

In fact scaling depends on the equation of state and of the matter components.

In the weakly NL regime, the growing modes bring independent information on:

1- equation of state

Benabed and bernardeau, PRD **64** (2001) 083501

2- Poisson equation

Sealfon et al., astro-ph/0404111

3- various couplings of quintessence to e.g. dark matter

Amendola and Quercellini, PRL **92** (2004) 181102; Reis et al., PRD**69** (2004) 101301

Test of the Poisson equation

On sub-Hubble scales, the gravitational potential and density contrast are related by

$$\Delta\Phi = 4\pi G\rho a^2\delta$$

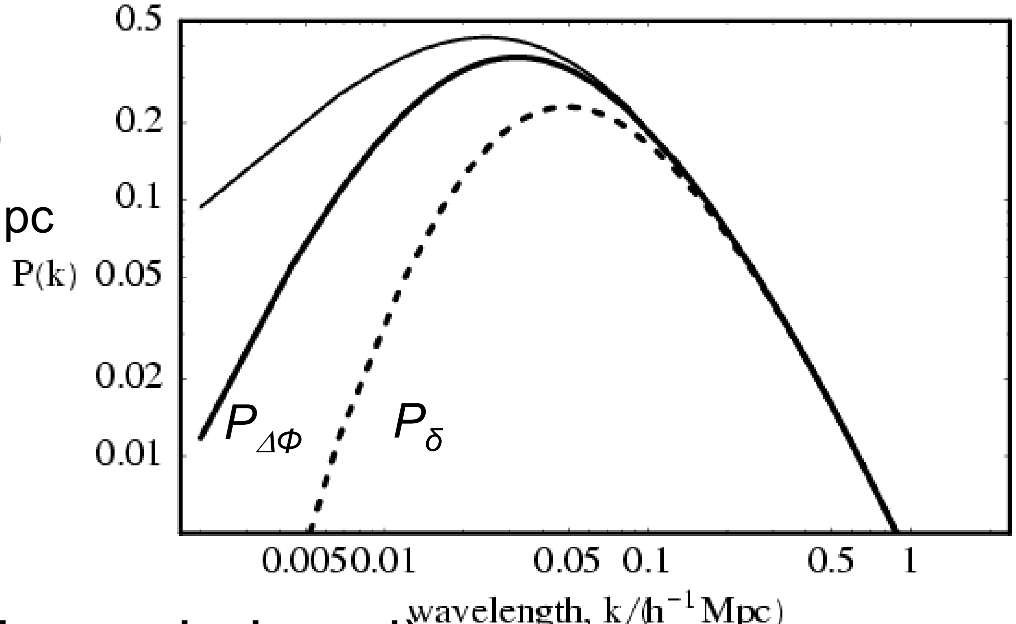
Galaxy catalogs (SDSS,...)

measurement of $\xi(r)$ up to 500h^{-1}Mpc

Weak lensing

has been detected up to 2h^{-1}Mpc

will be measured upto 100h^{-1}Mpc



Toy model: 4D-5D gravity (brane induced)

perturbations freeze on large scales (idem as effect of Λ)

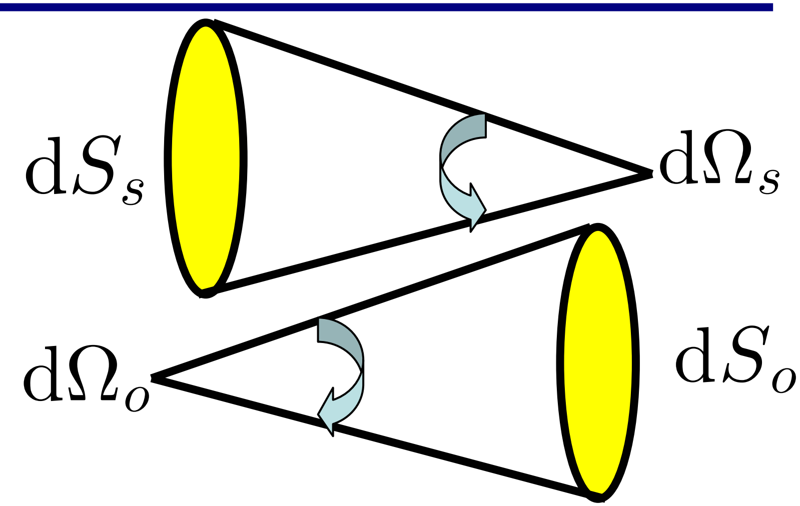
power spectra of Φ and δ are not identical

JPU and Bernardeau, Phys. Rev. D **64** (2001) 083004; White and Kochanek, ApJ 560 (2001) 539

Distance duality relation

Photons travel on null geodesics
Geodesic deviation equation holds

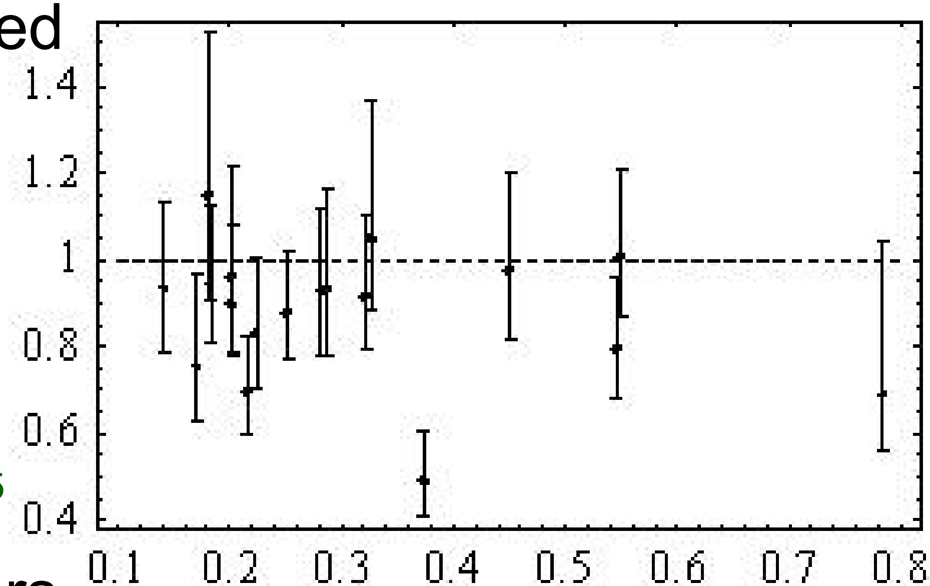
Etherington, Phil. Mag. **15** (1933) 761; Ellis, 1971



Reciprocity relation: $r_s = r_o(1+z)$

If number of photons is conserved

$$D_{\mathrm{lum}}(z) = (1+z)^2 D_A(z)$$



SNIa data+radio galaxies

2σ violation

Basset and Kunz, PRD**69** (2004)101305

X-ray + SZ observation of clusters

no indication of violation

JPU, Aghanim, Mellier, astro-ph/0405620

Observational prospects

Background observations (D_L, D_A,...) alone cannot allow to make the difference.

e.g. Reconstruction of ST theories requires H(z) and δ(z)

(Esposito-Farèse talk)

Weak lensing observation + SNIa data will allow to reconstruct H(z), δ(z) and Φ(z).

in particular, one can apply the test of the Poisson equation

Variation of the constants is a test of

Einstein equivalence principle on astrophysical scales

Strong equivalence principle (G)

Constraints on variation of some constants

Many tests concerning various constants
α, μ, G mainly.

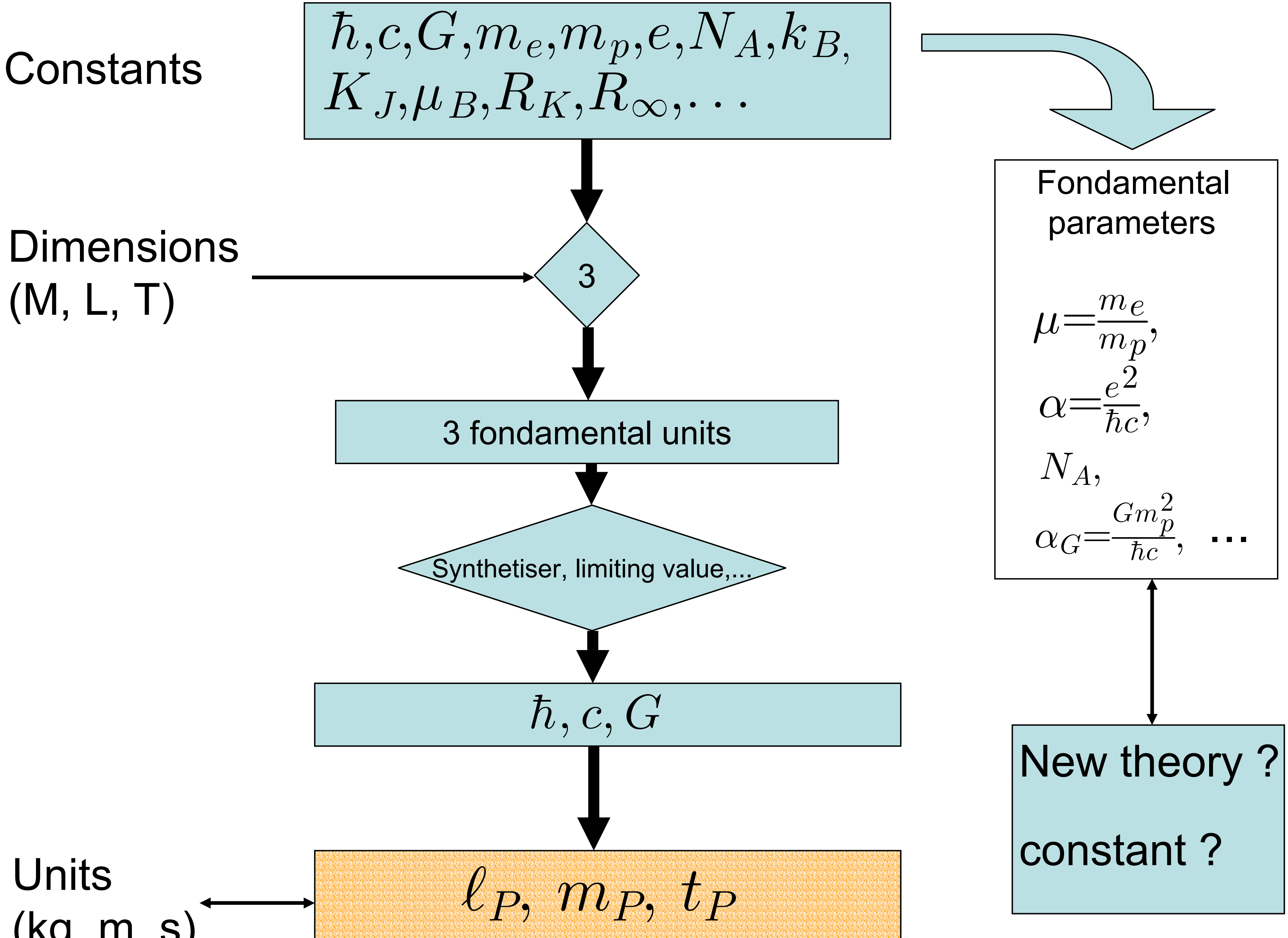
Tests on different time scales:

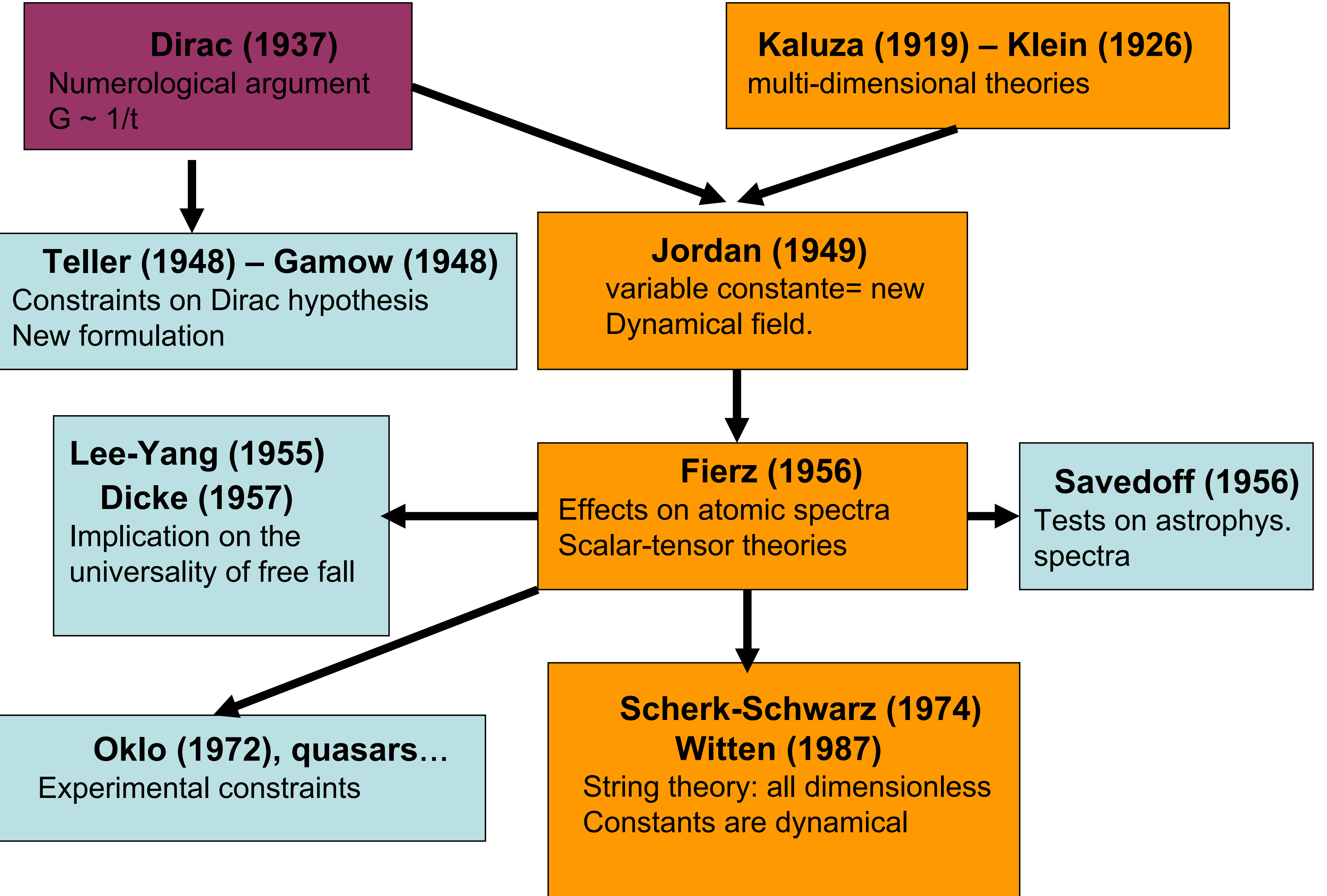
local	($z=0$)	atomic clocks, Solar System
geophysical	($z=0.1..0.4$)	Oklo, meteorites
astrophysical	($z=0.2-3.5$)	quasars
cosmological	($z=10^3$, 10^8)	CMB, BBN.

I consider only dimensionless constants

Okun, Sov. Phys. Usp. **34** (1991) 818, Ellis and JPU, Am. J. Phys. (2004)

General reviews: JPU, RMP **75** (2003) 425; Ann. H. Poincaré **4** (2003) 347;
Damour, gr-qc/0210059; gr-qc/0306023; Martins, astro-ph/0405630.


Constants
$\hbar, c, G, m_e, m_p, e, N_A, k_B, K_J, \mu_B, R_K, R_\infty, \ldots$
Dimensions
(M, L, T)
3
3 fondamental units
Synthetiser, limiting value,...
$\hbar, c, G$
Units
(kg, m, s)
ℓ_P, m_P, t_P
Fondamental parameters
$\mu = \frac{m_e}{m_p}$, $\alpha = \frac{e^2}{\hbar c}$, N_A, $\alpha_G = \frac{G m_p^2}{\hbar c}$, ...
New theory ?
constant ?

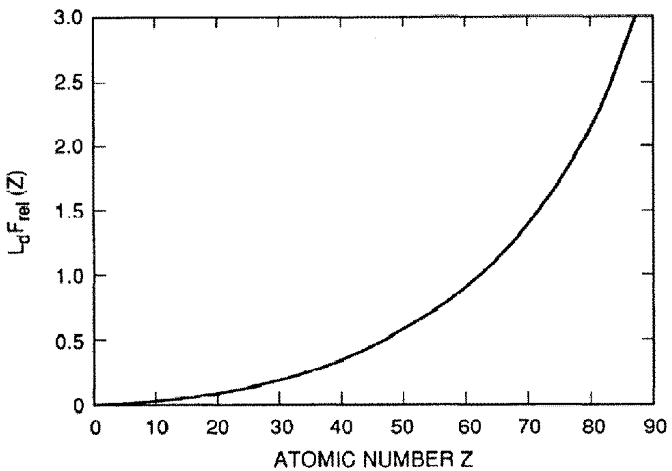

Dirac (1937)
Numerological argument
G ~ 1/t
Kaluza (1919) – Klein (1926)
multi-dimensional theories
Teller (1948) – Gamow (1948)
Constraints on Dirac hypothesis
New formulation
Jordan (1949)
variable constante= new
Dynamical field.
Lee-Yang (1955)
Dicke (1957)
Implication on the
universality of free fall
Fierz (1956)
Effects on atomic spectra
Scalar-tensor theories
Savedoff (1956)
Tests on astrophys.
spectra
Oklo (1972), quasars…
Experimental constraints
Scherk-Schwarz (1974)
Witten (1987)
String theory: all dimensionless
Constants are dynamical

Fine structure constant : laboratory

Based the comparison of atomic clocks using different transitions and atoms:

e.g. hfs Cs vs fs Mg : $g_p\mu$;

hfs Cs vs hfs H: $(g_p/g_I)\alpha$



$$\nu \sim \alpha^2(\mu/\mu_N)(m_e/m_p)R_y c F_{rel}(Z\alpha)$$

$\delta F_{rel}/F_{rel} \sim 0.74\ \delta\alpha/\alpha$ Cs

0.30 Rb

Comparison of ^{133}Cs and ^{87}Rb

4 years, assume g_p constant

$$\dot{\alpha}/\alpha = (-\,0.4 \pm 16) \times 10^{-16}\,\mathrm{yr}^{-1}$$

Marion et al., PRL **90** (2003) 150801

Comparison of ^{199}Hg+ and ^{133}Cs

3 years, in fact constraint on $g_{cs}\mu\alpha^{0.6}$

$$|\dot{\alpha}/\alpha| < 1.2 \times 10^{-15}\,\mathrm{yr}^{-1}$$

Bize et al., PRL **90** (2003) 150802

Fine structure constant : laboratory

Comparison of H (1s-2s) and ^{133}CS

4 years combined with data on Rb gives

Fischer et al., physics/0312086

$$\dot{\alpha}/\alpha = (-\,0.4 \pm 16) \times 10^{-16}\,\mathrm{yr}^{-1}$$

$$\mathrm{d}\ln(\mu_{cs}/\mu_{rb})/\mathrm{d}t = (-\,0.5 \pm 1.7) \times 10^{-15}\,\mathrm{yr}^{-1}$$

Comparison ^{171}Yb+ and ^{133}Cs

$$\dot{\alpha}/\alpha = (-\,0.3 \pm 2.0) \times 10^{-15}\,\mathrm{yr}^{-1}$$

Peik et al., physics/0402132

Local constraints

What is measured: relative drift of the frequencies of two transitions

Give constraints on combination of various constants

Modelisation of F_{rel} / dependence of magnetic moments

Necessity to use various atoms

Karshenboim, physics/0311080

Fine structure constant : Oklo

Natural nuclear reactor in Gabon,
operating 1.8 Gyr ago (**z~0.14**)

Shlyakhter, Nature **264** (1976) 340
Damour, Dyson, NPB **480** (1996) 37
Fujii et al., NPB **573** (2000) 377
Lamoreaux, torgerson, nucl-th/0309048
Flambaum, shuryak, PRD**67** (2002) 083507

Abundance of Samarium isotopes

$$^{149}\mathrm{Sm} + n \rightarrow ^{150}\mathrm{Sm} + \gamma \qquad E_r = 0.0973\,\mathrm{eV}$$

From isotopic abundances of Sm, U and Gd, one can measure the cross section averaged on the thermal neutron flux

$$\hat{\sigma}_{149}(T, E_r) = 91 \pm 6\,\mathrm{kb}$$

From a model of Sm nuclei, one can infer $s = \Delta E_r / \Delta \ln \alpha$

s~1Mev so that $\Delta\alpha/\alpha \sim 1\mathrm{Mev}/0.1\mathrm{eV} \sim 10^{-7}$

$\Delta\alpha/\alpha = (0.5 \pm 1.05) \times 10^{-7}$ Damour, Dyson, NPB **480** (1996) 37

Fujii et al., NPB **573** (2000) 377 2 branches.

Fine structure constant : meteorites

Bounds on the variation of couplings can be obtained by Constraints on the lifetime of long-lives nuclei (α and β decayers)

For β decayers, $\lambda \sim \Lambda(\Delta E)^p \propto G_F^2 \alpha^s$

Rhenium: ${}^{187}_{75}\mathrm{Re} \longrightarrow {}^{187}_{76}\mathrm{Os} + \bar{\nu}_e + e^-$ Peebles, Dicke, PR **128** (1962) 2006

$$\Delta E \sim 2.5\,\mathrm{keV}, \qquad s \sim -18000$$

Use of laboratory data +meteorites data

$$-24 \times 10^{-7} < \Delta\alpha/\alpha < 8 \times 10^{-7}$$

Olive et al., PRD **69** (2004) 027701

Caveats: meteorites datation / averaged value

Fine structure constant : CMB

It changes the recombination history

1- modifies the optical depth

2- induces a change in the hydrogen and helium abundances (x_e)

$$\dot{\tau} = x_e n_e c \sigma_T$$

Effect on the position of the Doppler peak

on polarization (reionisation)

Degeneracies:

cosmological parameters

electron mass

$$\sigma_T \propto \alpha^2 / m_e$$

origin of primordial fluctuations

Analysis of WMAP data

$$\Delta\alpha/\alpha = (-1.5 \pm 3.5) \times 10^{-2} \qquad z \sim 10^3$$

Martins et al. PLB **585** (2004) 29; G. Rocha et al, N. Astron. Rev. **47** (2003) 863; **see G. Rocha talk**

Fine structure constant : BBN

Big bang theory predicts abundances of D, ^3He, ^4He, ^7Li

Mainly based on the balance between

1- expansion rate of the universe

2- weak interaction rate which controls n/p at the onset of BBN

Helium abundance

Campbell and Olive (1995); Kolb et al. (1986)

$$Y = \frac{2(n/p)_N}{1+(n/p)_N} \qquad (n/p)_f \sim \mathrm{e}^{-Q/kT_f} \qquad Q = a\alpha\Lambda_{QCD} + bv$$

Depends mainly on Q, T_f and τ_n

$$G_F^2 (kT_f)^5 = \sqrt{GN}(kT_f)^2$$

Dependence of the nuclear rates on α

Bergström et al (1999); Ichikawa and Kawasaki (2002)

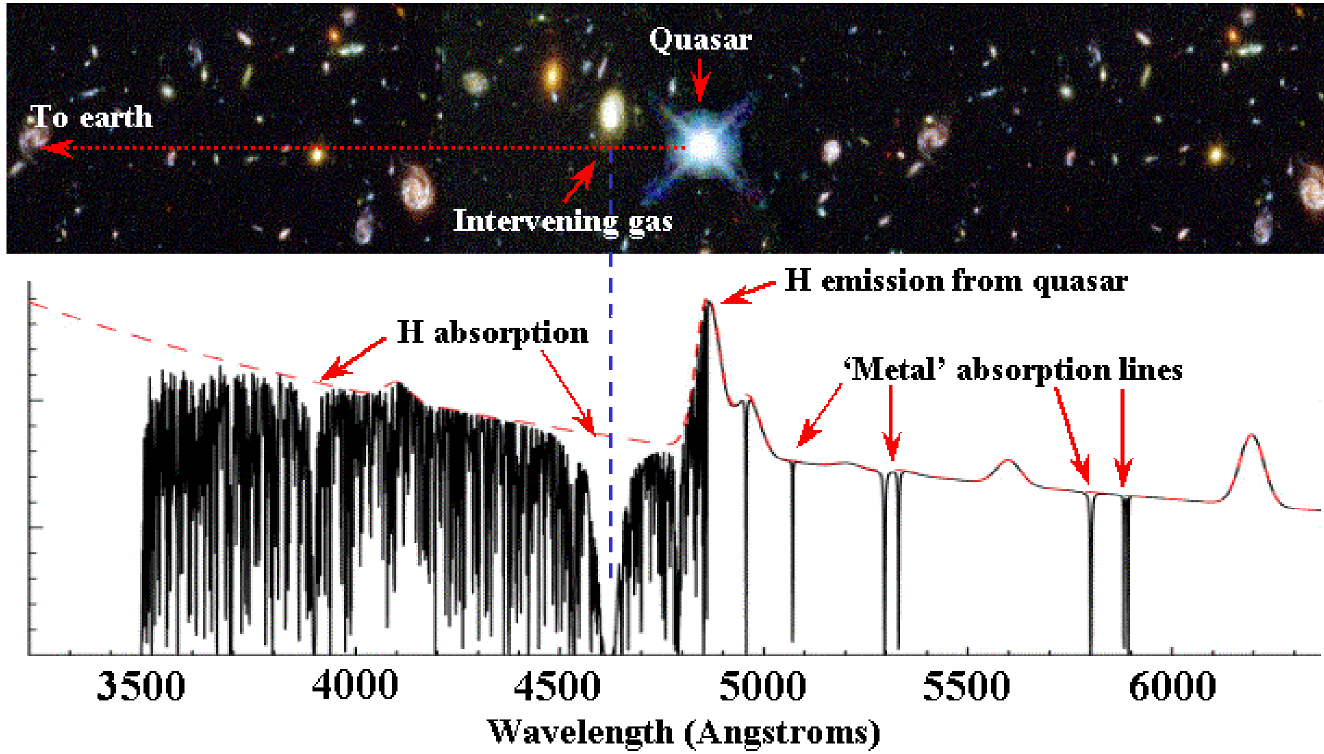
Effects of 6 parameters: G, α, v, m_e, m_q, Q

$$\Delta\alpha/\alpha = (6 \pm 4) \times 10^{-4} \qquad z \sim 10^{10}$$

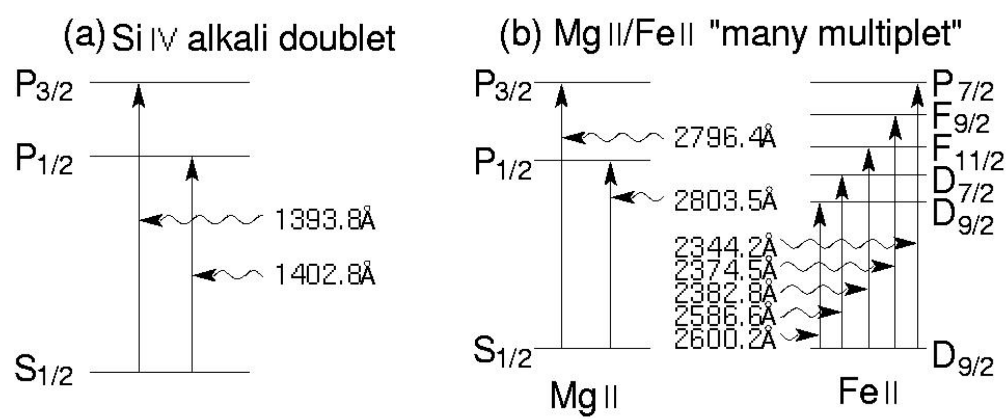
Müller et al, astro-ph/0405373

Quasar observations

Savedoff, 1956



Alkali doublet $\Delta\lambda/\lambda \propto \alpha^2$



Many multiplets using several transition lines from several elements allow to reach sensitivity of 10^{-6}

Webb et al., PRL **82** (1999) 884

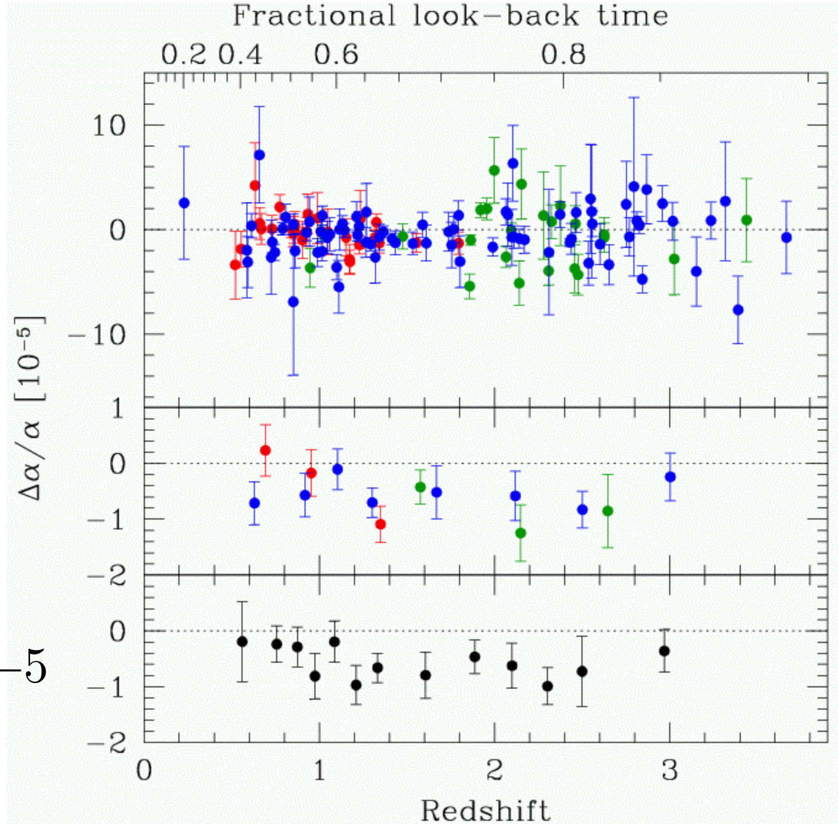
What news from the quasars

Many Multiplets method

Webb et al., PRL **82** (1999) 884

low z (<1.8): Mg vs Fe
higher z: Fe vs Si

First hint of a detection in 1999 with the Keck/Hires data



Latest analysis:

128 quasar absorption systems (0.5<z<3)

Murphy et al. MNRAS **345** (2003) 609

$$\Delta\alpha/\alpha = (-0.54 \pm 0.12) \times 10^{-5}$$

Detailed study of a possible systematic effect

Alkali doublet

Si IV, 21 systems

Murphy et al. MNRAS **327** (2003) 1237

$$\Delta\alpha/\alpha = (-0.5 \pm 1.3) \times 10^{-5} \qquad 2 \leq z \leq 3$$

To vary or not to vary, that is the question

Recent observations with VLT/UVES.

Chand et al., astro-ph/0401094
Srianand et al., astro-ph/0402177

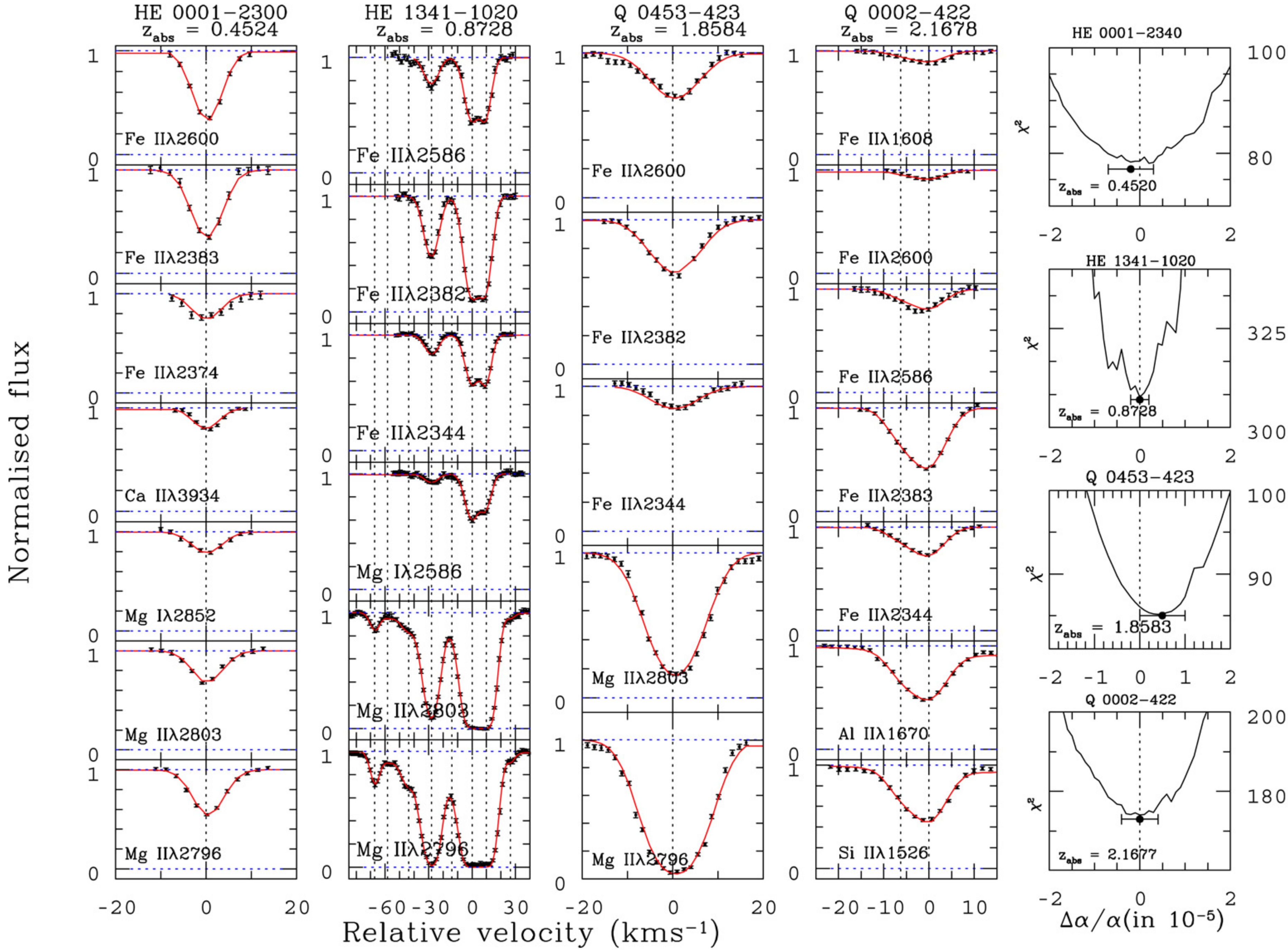
MM have not been able to duplicate the previous results

Mg and Fe lines in a set of 23 systems

Systems selected with care

(prevent as much as possible from systematics instead of looking for them)

* only species with similar ionisation potential (MGII, FeII, SiII, Al II)
  (most likely to originate from similar regions in the cloud)
* reject absorption lines contaminated by atmospheric lines
* keep only FeII where multiplet detected at 5σ
* anchors (MgI an II) are not saturated.



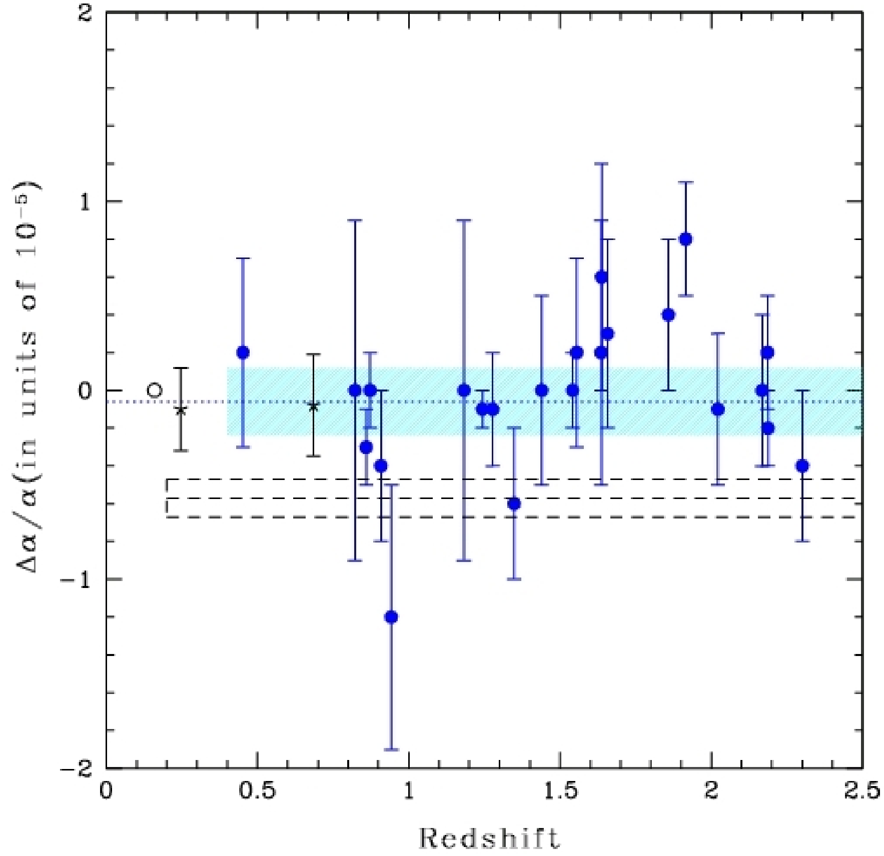
HE 0001-2300
z_{abs} = 0.4524
HE 1341-1020
z_{abs} = 0.8728
Q 0453-423
z_{abs} = 1.8584
Q 0002-422
z_{abs} = 2.1678
Fe IIλ2600
Fe IIλ2383
Fe IIλ2374
Ca IIλ3934
Mg Iλ2852
Mg IIλ2803
Mg IIλ2796
Fe IIλ2586
Fe IIλ2382
Fe IIλ2344
Mg Iλ2586
Mg IIλ2803
Mg IIλ2796
Fe IIλ2600
Fe IIλ2382
Fe IIλ2344
Mg IIλ2803
Mg IIλ2796
Fe IIλ1608
Fe IIλ2600
Fe IIλ2586
Fe IIλ2383
Fe IIλ2344
Al IIλ1670
Si IIλ1526
Normalised flux
Relative velocity (kms^{-1})
HE 0001-2340
z_{abs} = 0.4520
HE 1341-1020
z_{abs} = 0.8728
Q 0453-423
z_{abs} = 1.8583
Q 0002-422
z_{abs} = 2.1677
χ^2
$\Delta\alpha/\alpha$(in 10^{-5})

Much ado about nothing?

Mg and Fe lines in a set of 23 systems

$$\Delta\alpha/\alpha = (-\,0.06 \pm 0.06) \times 10^{-5}$$

Shand et al., astro-ph/0401094
Srianand et al., astro-ph/0402177



Analysis of a single quasar (z=1.15) Fe lines

$$\Delta\alpha/\alpha = (-\,0.1 \pm 1.7) \times 10^{-6}$$

Quast et al., astro-ph/0311280

From quasars to stellar nucleosynthesis

Results of both teams are sensitive to isotopic abundance of Mg.

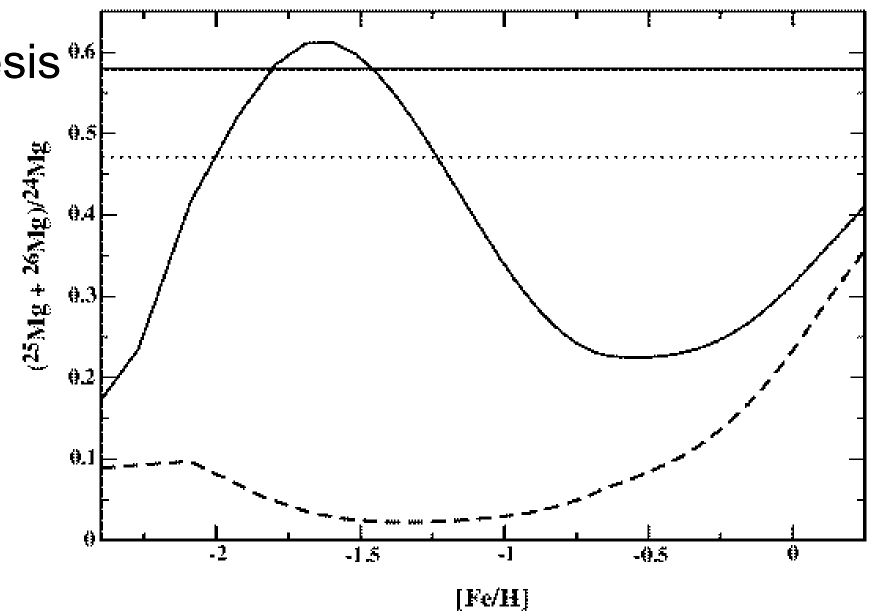
Solar ratio are assumed $^{24}Mg:^{25}Mg:^{26}Mg=79:10:11$

If one assumes pure ^{24}Mg then

$$\Delta\alpha/\alpha = (-\,0.98 \pm 0.13) \times 10^{-5} \qquad \text{Keck/Hires}$$
$$\Delta\alpha/\alpha = (-\,0.36 \pm 0.06) \times 10^{-5} \qquad \text{VLT/UVES}$$

It was proposed that apparent variation of α can be explained by early nucleosynthesis of $^{25,26}Mg$.

Ashenfelter et al., PRL**92** (2004) 041102



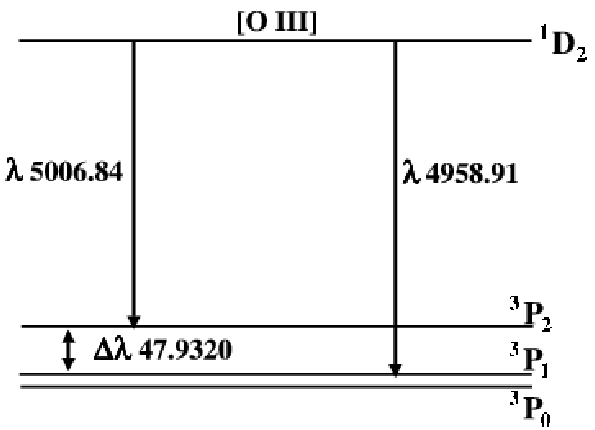
Hypothesis can be tested by correlations among other heavy elements.

First explanation that does not involve new physics.

New tests: OIII emission lines

OIII **emission** lines of distant quasars or galaxies

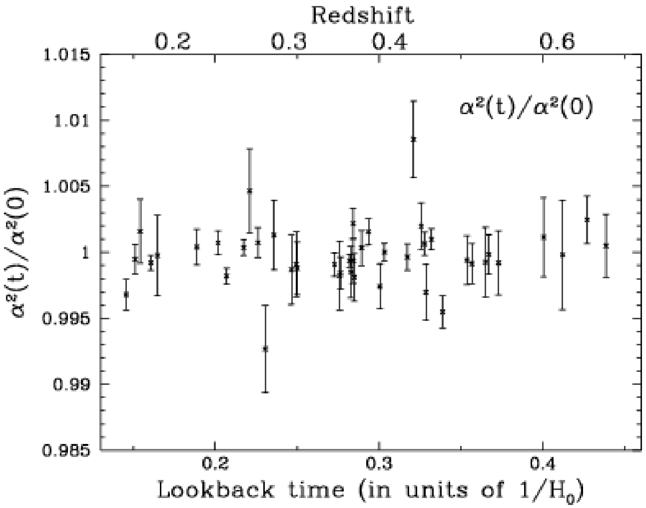
$$\Delta\lambda/\lambda \propto \alpha^2$$



Application on SDSS EDR

(42 quasars between z=0.16 to 0.80)

$$\Delta\alpha/\alpha = (0.7 \pm 1.4) \times 10^{-4}$$



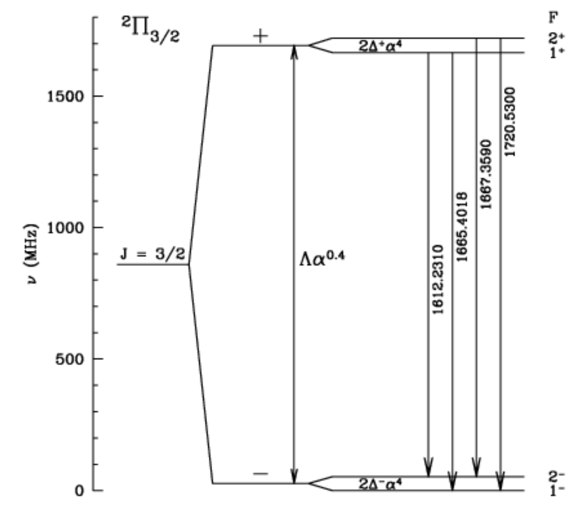
Analysis of SDSS DR1 (165 quasars)

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

Bahcall et al., ApJ **600** (2004) 520.

New tests: OH microwave transitions

The 18cm OH line is both a hyperfine transition and a transition between lambda-doublet levels .



The transitions can be shown to behave as

$$\nu_{3/2} = \Lambda\alpha^{0.4} \pm (\Delta^+ \pm \Delta^-)\alpha^4$$

Darling, PRL **91** (2003) 011301

Preliminary application to quasar PKS 1413+135

$$\Delta\alpha/\alpha = (0.51 \pm 1.26) \times 10^{-5}, \qquad z = 0.2467$$

Darling, astro-ph/0405240

Method can be extended to z~5

Can improve sensitivity by correlating with CO lines

Gravitational constant

Few improvements in the past years

Constancy of G: test of the strong equivalence principle

e.g. ST theories have EEP but not SEP

Solar System experiment

LLR: $\dot{G}/G = (0 \pm 6) \times 10^{-12}\,\mathrm{yr}^{-1}$ Dickey et al. (1994)

PPN can give a bound but in a theoretical frame

Stellar constraints

white dwarfs: $\dot{G}/G = (2 \pm 2) \times 10^{-11}\,\mathrm{yr}^{-1}$ Garcia-Berro et al. (1998)

heliosysmology: $\dot{G}/G = (0 \pm 1.6) \times 10^{-12}\,\mathrm{yr}^{-1}$ Guenther et al. (1998)

BBN: roughtly 20%

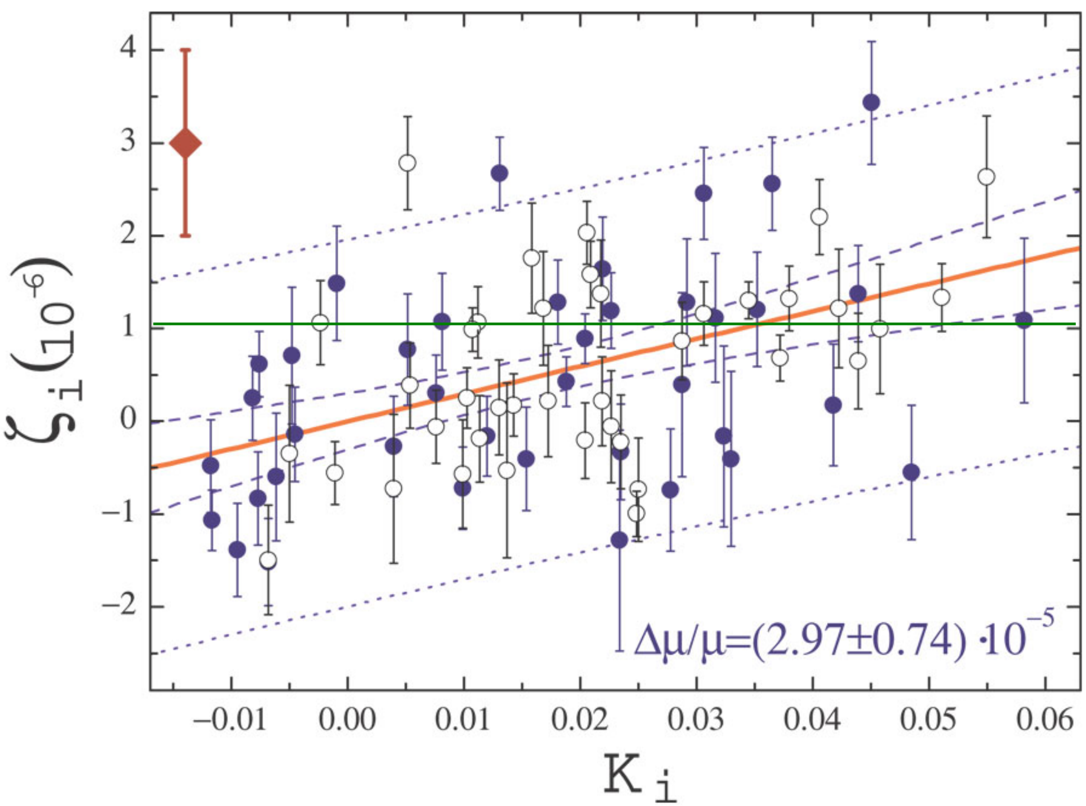
Other studies

Effects of other constants have started to be investigated

e.g. Mass of quarks (BBN, Oklo...)

m_e/m_p: vibrorotation lines of H2

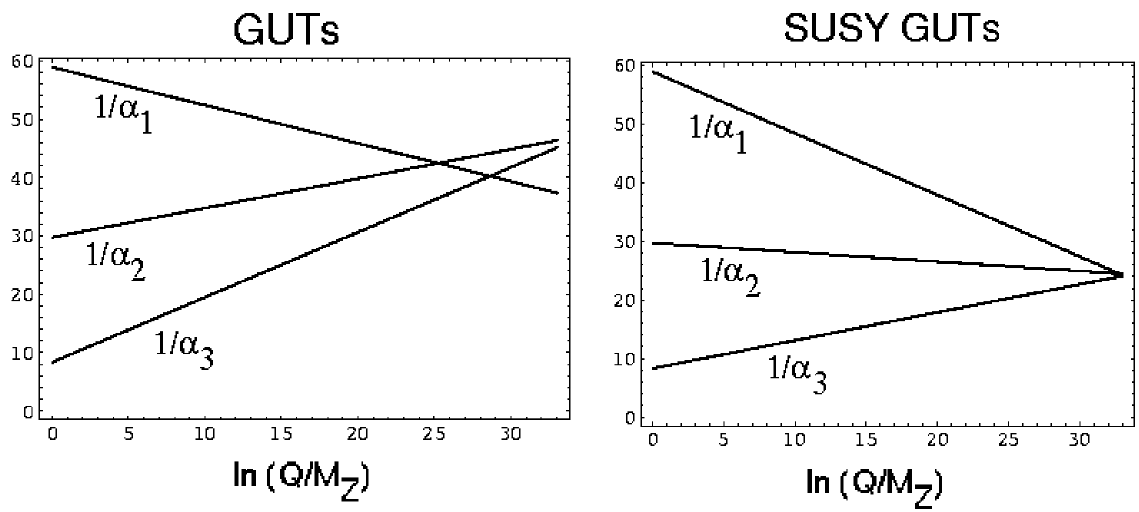
$$\zeta_i \equiv \frac{\Delta E_i(z)}{\Delta E_i(0)} = 1 + K_i \frac{\Delta\mu}{\mu}$$



Ivanchik et al., Astrophys. Space Sci. **283** (2003) 583

Simultaneous variations

In GUT and string inspired theories, gauge couplings are related at some unification scale

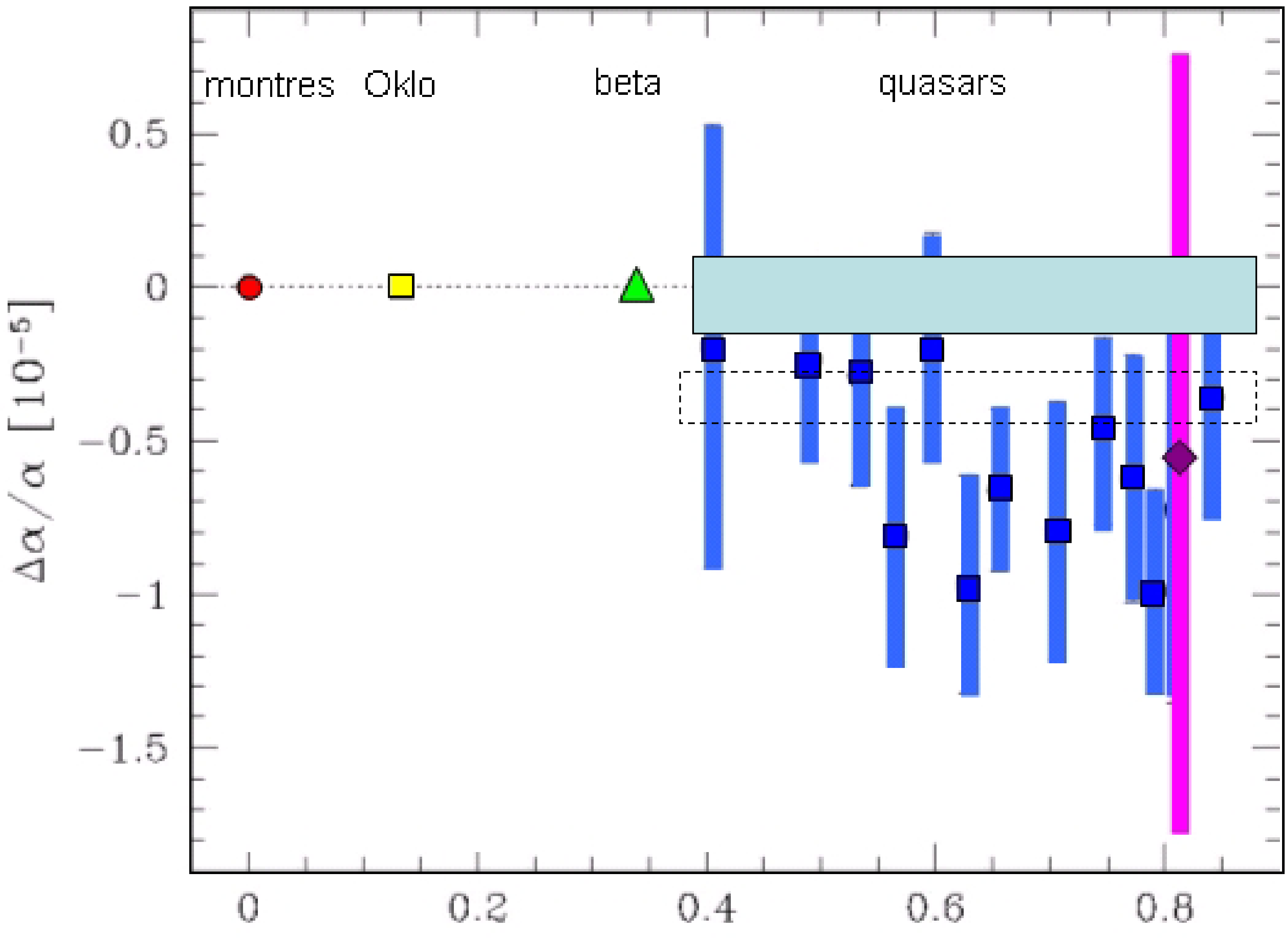


$$\Delta\Lambda/\Lambda \sim 30\Delta\alpha/\alpha \qquad \Delta v/v \sim 80\Delta\alpha/\alpha$$

Calmet, Fritzsch, EPJ C24 (2002) 639; Dent, Fairbairn, NPB 653 (2003) 256

Allow to derive sharper bounds on variation of constants (BBN / Oklo)

Summary



montres
Oklo
beta
quasars
0.5
0
−0.5
−1
−1.5
$\Delta\alpha/\alpha\ [10^{-5}]$
0
0.2
0.4
0.6
0.8

Theory and phenomenology

Comparison of the compatibility of data can not be done in a model independent way.

Low energy limit of string theory: dilaton

dimensionless constants depend on dilaton and volume of extra-dimensions.

Slow rolling field: quintessence field (?)

But some problems to be faced:

1- fields are light

2- UFF

Large number of studies.

Theoretical motivations

In string theory, all dimensionless parameters become VEV of some fields: **dynamical**.

e.g. $M_4^2 = \mathrm{e}^{-2\Phi} V_6 M_I^8$ $\qquad g_{YM}^{-2} = \mathrm{e}^{-\Phi} V_6 M_I^6 \quad (+\, c_i M_i)$

$G \propto R^{-D}, \qquad g_{YM}^{-2} \propto K_i(D) G R^2$

The low energy limit are scalar-tensor theories (dilaton) at tree level.

Loop corrections: need to be understood better
couplings are not universal

Dudas (2000)

$$M_4^2 = \phi M_H^8, \qquad g_{YM}^{-2} = \phi M_H^6, \qquad \phi = V_6\, \mathrm{e}^{-2\Phi}$$

$$g_{YM}^{-2} = \phi M_H^6 - \tfrac{b_a}{2}(R M_H^2) + \ldots$$

Phenomenologically: couplings of the quintessence field
brane models

Palma et al PRD **68** (2003) 123519.

Phenomenology: general frameworks

Bekenstein model: $e = e_0\,\varepsilon(x^\mu)$

reduces to a coupling of a scalar field to electromagnetism

Bekenstein (1982)
Olive, Pospelov (2002)
Sandvik et al (2002)
Avelino et al. (20004)
Lee et al. (2004)

String inspired models

$$S = \int \mathrm{d}^4x\,\sqrt{-g}\,\Big(B_g(\phi)R - B_\phi(\phi)(\partial\phi)^2 - \tfrac{1}{4}B_F(\phi)\,F^2 - V(\phi) - \textstyle\sum_a m_a(\phi)\,\sqrt{-g_{\mu\nu}}\,\mathrm{d}x^\mu\mathrm{d}x^\nu\Big)$$

$$B_i(\phi) = \mathrm{e}^{-\phi} + c_i^0 + c_i^1\,\mathrm{e}^{\phi} + \ldots$$

Damour, Polyakov (1994)

Problems with light fields

A light scalar field satisfies a Klein-Gordon equation of the type

$$\ddot{\phi} + 3H\dot{\phi} = -m^2\phi + \ldots$$

For the field to be slow-rolling today, one needs

$$m \sim H_0 \sim 10^{-33}\,\mathrm{eV}$$

How can is the mass protected (symmetry?)

SUSY broken around the TEV

general problem of quintessence models

Various solutions:

pseudo-Goldstone boson

Carroll, PRL81 (1998) 3067.

shape moduli: in the case of ST-quintessence, the total volume is coupled to gravity while shape moduli play the role of quintessence field

Peloso, Poppitz, hep-ph/0307379

Dangers with the universality of free fall

Universality of free fall is tested with great accuracy

$$\eta_{12} \equiv \frac{|\vec{a}_1 - \vec{a}_2|}{|\vec{a}_1 + \vec{a}_2|}$$

<u>Laboratory</u>: $|\eta| < 5.5\ 10^{-13}$ Baessler et al. (1999)

<u>LLR</u>: $|\eta| < 4\ 10^{-13}$ Williams et al. (1996)

If there is a coupling of the form $B(\phi)F_{\mu\nu}F^{\mu\nu}$ then the electromagnetic self energy contributes to the mass and $m_i(\phi)$

Predictions require to know this $m(\phi)$ (model dependent)

We expect a violation of UFF of order $\eta_{12} \simeq M_p f_{\rm ext} \partial_\phi \left|\ln(m_1/m_2)\right|$

e.g. from Baessler constraint:

$$|\nabla \ln \alpha| < 10^{-33}\,\mathrm{cm}$$

Avoiding UFF problems

In the Damour-Polyakov model, there is a cosmological attractor mechanism

Damour, Polyakov (1994)

1- requires all the $B_i(\phi)$ to have a common local maximum

$$B_i(\phi) \simeq \text{const.} - \frac{1}{2}\kappa(\phi - \phi_m)^2$$

2- Einstein frame mass of hadrons are proportional to

$$\Lambda_{\text{QCD}} \propto B_F^{-1/2}(\phi)\, \mathrm{e}^{\,-8\pi^2 b_3^{-1} B_F(\phi)} \Lambda_s$$

3- All deviations from GR (PPN parameters, $d\ln\alpha/dt$, η) are proportional to $\Delta\phi^2 = (\phi_0 - \phi_m)^2$

The light scalar field can couple to different charges, e.g. in the case of dilaton fifth force

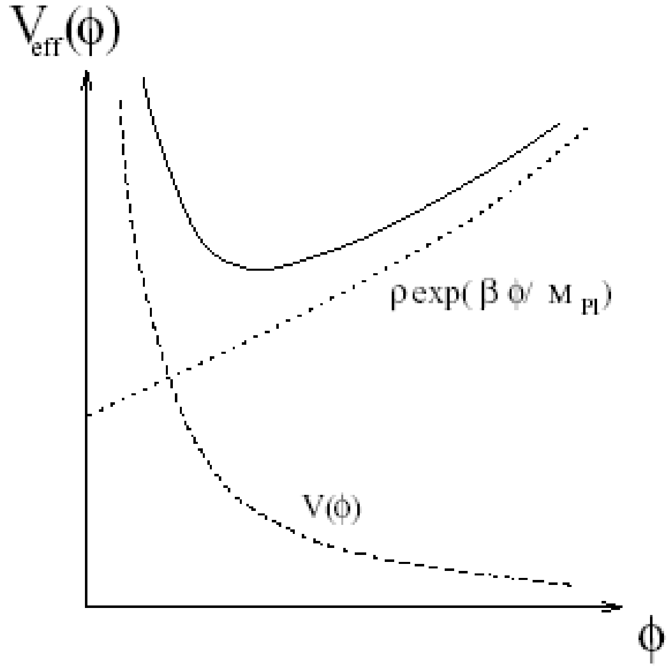
	B=N+Z	baryon number
	D=N-Z	neutron excess
	$E=Z(Z-1)B^{1/3}$	Coulomb energy

$$\eta_{12} = \kappa^2 \Delta\phi^2 \left(C_B \Delta B + C_D \Delta D + C_E \Delta E\right) / M$$

Avoiding UFF constraints (2)

Another recent (possibly) interesting proposal are chameleon fields.

Kouhri, Weltman, astro-ph/0309300



ST theory with runaway potential
Implementation in braneworld,

See Brax talk

Universal coupling
Generalisation to varying α?

Quintessence and varying constants

Gravitational constant:
In the framework of quintessence, extended models were shown to exhibit the same attractor mechanism
JPU, PRD **59** (1999) 123510; Chiba gr-qc/9904120; Amendola gr-qc/9908023;
Riazuelo, JPU, PRD66 (2002) 023525

WEP valid: no problem with UFF
Reconstruction problem studied Polarski,Esposito-Farèse,

Fine structure constant:
1- investigation of Bekenstein like models

2- generalization of Damour-Polyakov model to runaway dilaton Damour et al , PRD (2003)

Dark matter:
Possibility of coupling ϕ to DM / few tests Amendola
Damour et al. PRL64 (1990) 123

Varying constants in the early universe

During inflation:

all light fields developp super-Hubble correlations

Two aspects:

1- couplings during inflation can be modulated

2- there may exist a spatial distribution of the constants after inflation

Modulated fluctuations

In the case of hybrid-inflation, the couplings may depend on light moduli

$$V = \frac{\lambda(\chi)}{4}(\sigma^2 - v^2)^2 + \frac{g^2(\chi)}{2}\varphi^2\sigma^2 + V(\varphi)$$

Spinodal instability at $\varphi_c = \frac{\sqrt{\lambda}v}{g}$

If moduli fields are light then φ_c will fluctuate and inflation will not end at the same « time » everywhere.

Kofman astro-ph/0303614;
Dvali et al, PRD 69 (2004) 023505

Observational imprint: consistency relation of inflation is modified

Bernardeau, Kofman, JPU, astro-ph/0403315

Distribution of light fields at the end of inflation

Light field: superhubble correlation.

Expect a spatial distribution of the constant

1- amplitude is typically of order 10^{-5}
This may alter the analysis of quasars
It may be correlated with density fluctuations

Mota, Barrow, MNRAS **349** (2004) 281

2- CMB: the recombination may be modulated by the local value of the fine structure constant

-modification of the temperature power spectrum
-generate polarisation B modes
-induce non-Gaussianity

Sigurdson et al,PRD **68** (2003) 103509

Conclusions

Tests of gravity will substantiate the physics of the dark sector

go beyond pure scalar field interacting with gravity
local predictibility hypothesis

Variation of constants may be golden plate observations
for quintessence-like models.

But, still models have to satisfy sharp constraints concerning

1- smallness of the mass
2- UFF

From an observational point of view, quasar analysis and compatibility between the 2 groups will require a long work

Future tests: e.g. ACES, μSCOPE, STEP

Interpretation of cosmological data in non GR frame needs care

String issue: **Why are the constants so constant?**