Oklo natural fission reactors & dynamical models of dark energy

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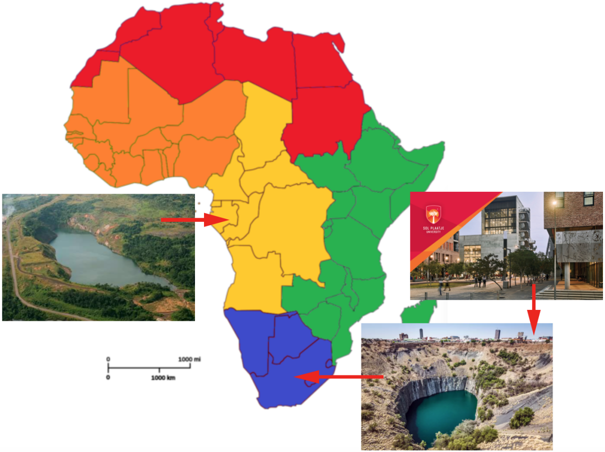


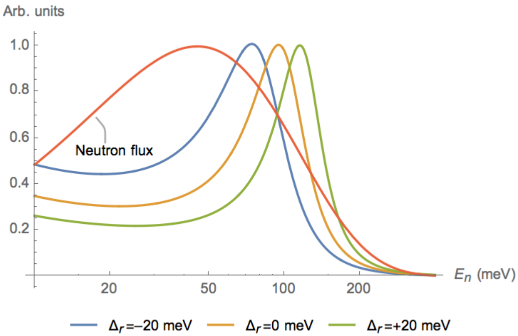
- Background
  - Shlyakhter's insight: Oklo = sensitive record of the past

    Shlyakhter, *Nature* **264**, 340 (1976)
  - Damour-Dyson analysis: bound on change in $\alpha = \frac{e^2}{\hbar c}$

    Damour & Dyson, *Nuclear Physics B* **480**, 37 (1996)
- Reappraisal of bound on $\Delta\alpha = \alpha_{\text{Oklo}} - \alpha_{\text{now}}$
  - Justifications & corrections

    Davis & Hamdan, *Physical Review C* **92**, 014319 (2015)
  - Non-zero change in fine-structure constant since Oklo?
- Concluding remarks

- Oklo geochemical data on neutron capture fix resonance energies $E_{r,\text{Oklo}}$



Small change in E_r $\rightarrow$ Large change in neutron capture

- Most tightly constrained $\Delta_r = E_{r,\text{Oklo}} - E_{r,\text{now}}$

Δ_r(meV)	n + ^{149}Sm (97.3 meV resonance)
4±16	NuclPhysB.573.377
7.2±9.4	PhysRevC.74.024607
1.9±4.5	ModPhysLettA.27.1250232

I. Relate Δ_r to changes in *fine-structure* constant $\alpha = \frac{e^2}{\hbar c}$

$$|\Delta_r| \geq |k_\alpha| \frac{|\Delta\alpha|}{\alpha_{\text{now}}} \quad \text{where} \quad k_\alpha \equiv \alpha \frac{dE_r}{d\alpha}$$

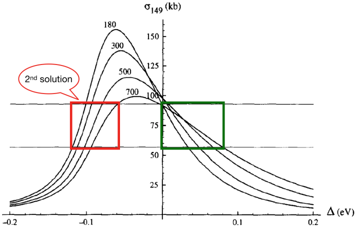
Influence of changes in parameters of QCD?

II. Use (cold) liquid drop model to set lower bound $|k_\alpha| \geq |k_{\text{DD}}|$

$$k_{\text{DD}} = -\frac{(Ze)^2}{2R^3}\left(\langle r^2\rangle_{150} - \langle r^2\rangle_{149}\right)$$

Effect of deformation, excitation & Coulomb self-energy approximation?

III. Interpretation of second solution for Δ_r



If physically relevant implies $\Delta\alpha > 0$!

I. Relation of Δ_r to $\Delta\alpha$

$$|\Delta_r| \geq |k_\alpha| \frac{|\Delta\alpha|}{\alpha_{\mathrm{now}}}$$

Justified in Grand Unified Theories provided

$$\frac{d(\ln m_q/\Lambda_{\mathrm{QCD}})}{d(\ln\alpha)} > \frac{1}{2}$$

m_q: light quark mass ($\sim$ 5 MeV), Λ_{QCD}: QCD energy scale ($\sim$ 1 GeV)

II. Bound $|k_\alpha| \geq |k_{\mathrm{DD}}|$

$$k_{\mathrm{DD}} = -\frac{(Ze)^2}{2R^3}\left(\langle r^2\rangle_{150} - \langle r^2\rangle_{149}\right)$$

III. 2nd solution for Δ_r?

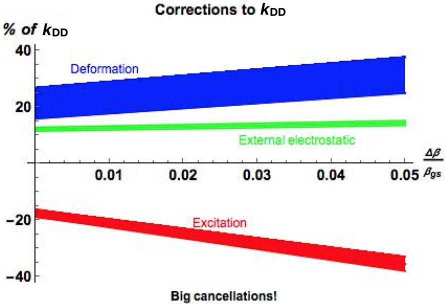
I. Relation of Δ_r to $\Delta\alpha$

$$|\Delta_r| \geq |k_\alpha| \frac{|\Delta\alpha|}{\alpha_{\text{now}}}$$

II. Bound $|k_\alpha| \geq |k_{\text{DD}}|$

$$k_{\text{DD}} = -\frac{(Ze)^2}{2R^3}\left(\langle r^2\rangle_{150} - \langle r^2\rangle_{149}\right)$$

$$= -2.51 \pm 0.20 \text{ MeV}$$



Net correction to k_{DD} is $k_{\text{corr}} = 0.33 \pm 0.16$ MeV

III. 2^{nd} solution for Δ_r?

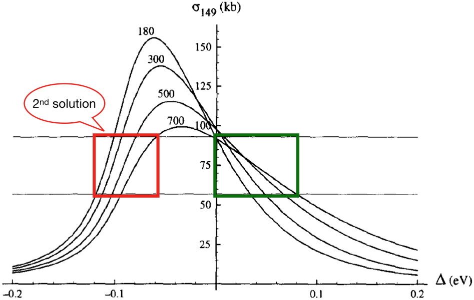
I. Relation of Δ_r to $\Delta\alpha$

$$|\Delta_r| \geq |k_\alpha| \frac{|\Delta\alpha|}{\alpha_{\text{now}}}$$

II. Bound $|k_\alpha| \geq |k_{\text{DD}}|$

$$k_{\text{DD}} = -\frac{(Ze)^2}{2R^3}\left(\langle r^2\rangle_{150} - \langle r^2\rangle_{149}\right)$$

III. 2^{nd} non-zero solution for Δ_r?



Inconsistent with predicted systematics of Δ_r

$$\Delta_r = \underbrace{k_q\,\Delta(\ln m_q/\Lambda_{\text{QCD}})}_{\text{Independent of } A,Z} + \underbrace{k_\alpha\,\Delta(\ln\alpha)}_{\text{Negligible}}$$

$\Rightarrow$ All non-zero Δ_r's have same sign

(Non-zero Δ_r's artefact of symmetry of resonance profile)

In summary

1. Revised Damour-Dyson scheme reliable for order of magnitude estimates

2. New bound on $\Delta\alpha$ at 95% C.L.: $$\frac{|\Delta\alpha|}{\alpha_{\text{now}}} < 1.1 \times 10^{-8}$$

   - Includes uncertainty of 10% or so in lower bound on $|k_\alpha|$
   - More restrictive than other bounds on $\Delta\alpha$

	Redshift	$\Delta\alpha/\alpha_{\text{now}}$
Meteorites	0.43	$(-0.25 \pm 1.6) \times 10^{-6}$
Quasar (QSO) absorption spectra	0.2 – 4.2	$(-5.7 \pm 1.1) \times 10^{-6}$
Cosmic μwave background	$\sim 10^3$	$-0.013 \mapsto 0.15$
Big-bang nucleosynthesis (BBN)	$\sim 10^9$	$< 6 \times 10^{-2}$

Thank you for your attention!