

***Where the fundamental
constants of physics different
in the early Universe?***

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Fundamental Physical Constants...

c – the speed of light, better called the
“speed of spacetime”

$$3.00 \times 10^8 \text{ m/s} = 3.00 \times 10^{10} \text{ cm/s}$$

1 light-year/year

\hbar – Planck's Constant, a fundamental scale
in Quantum Mechanics

$$\hbar = 1.0546 \times 10^{-34} \text{ m}^2 \text{ kg} / \text{s} = 1.0546 \times 10^{-27} \text{ cm}^2 \text{ g} / \text{s}$$

Heisenberg's Uncertainty Principle

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

Fundamental Physical Constants...

e - the charge of the electron

$$e = 4.803 \times 10^{-10} \text{ esu} = 1.602 \times 10^{-19} \text{ C}$$

α - The fine structure constant

$$\alpha = \frac{e^2}{\hbar c} = \frac{1}{137}$$

μ - Proton-to electron mass ratio

$$\mu = \frac{m_p}{m_e} = 1836$$

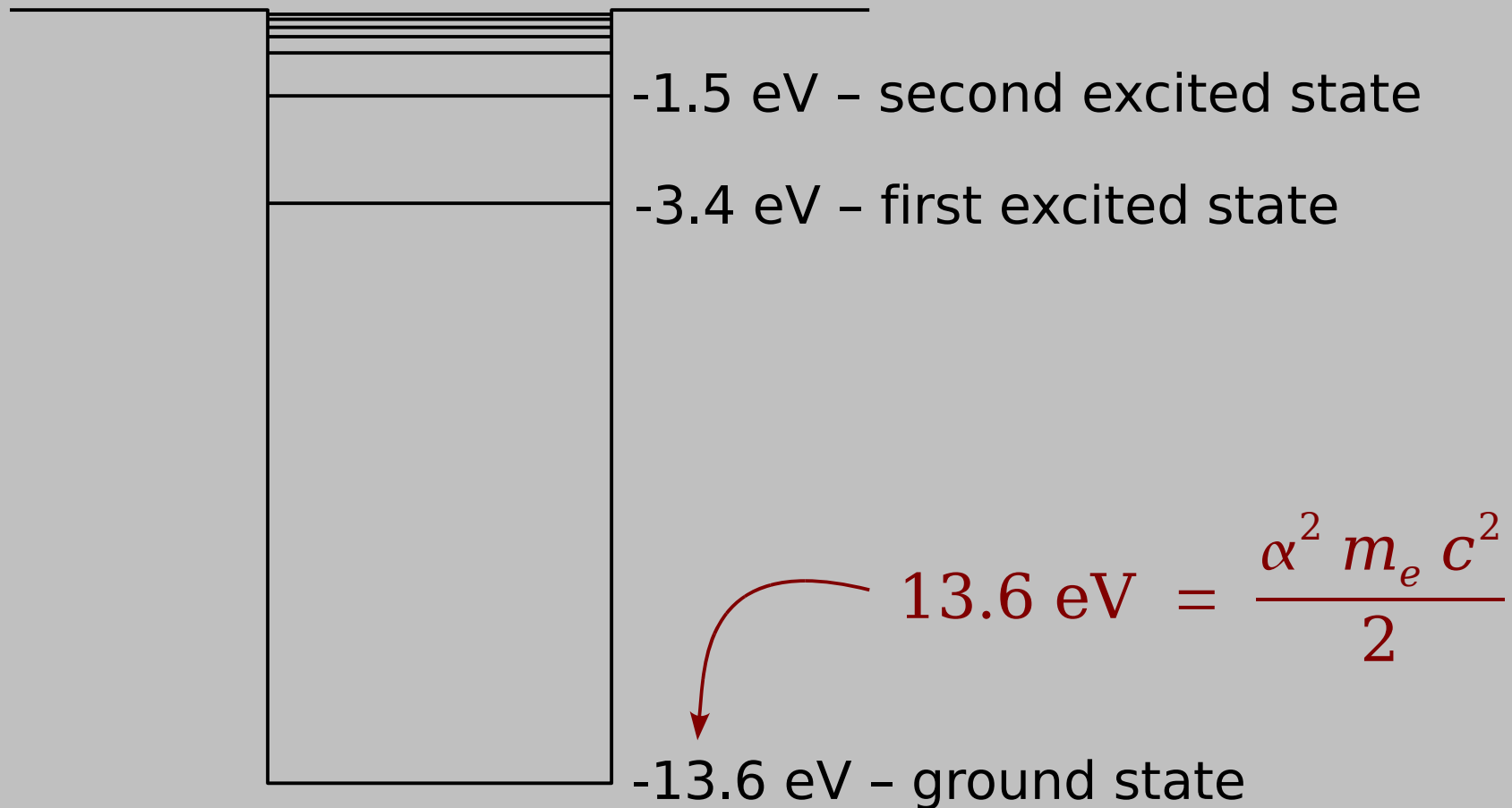
g_p - Proton gyromagnetic ratio

$$g_p = 2.675 \times 10^8 \text{ s}^{-1} \text{ T}^{-1}$$

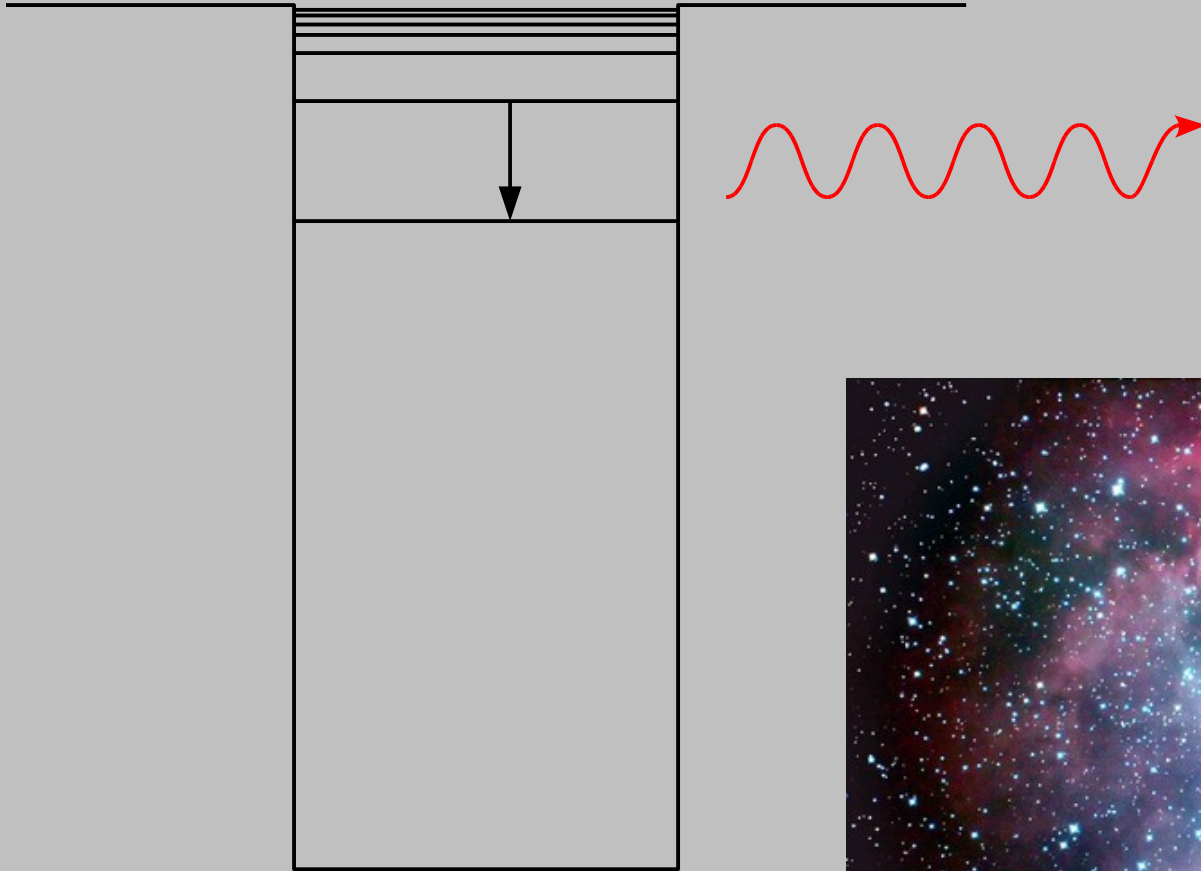
Atomic Physics

Atoms have very specific allowed states (orbitals) that electrons can occupy. These states are at different energies.

Hydrogen



H α - 6563 Å



The Rosette Nebula

Photo by John Lanoue

Looking for changes since the Early Universe

Astronomers have a time machine : when we observe distant objects, we observe them as they were in the past.

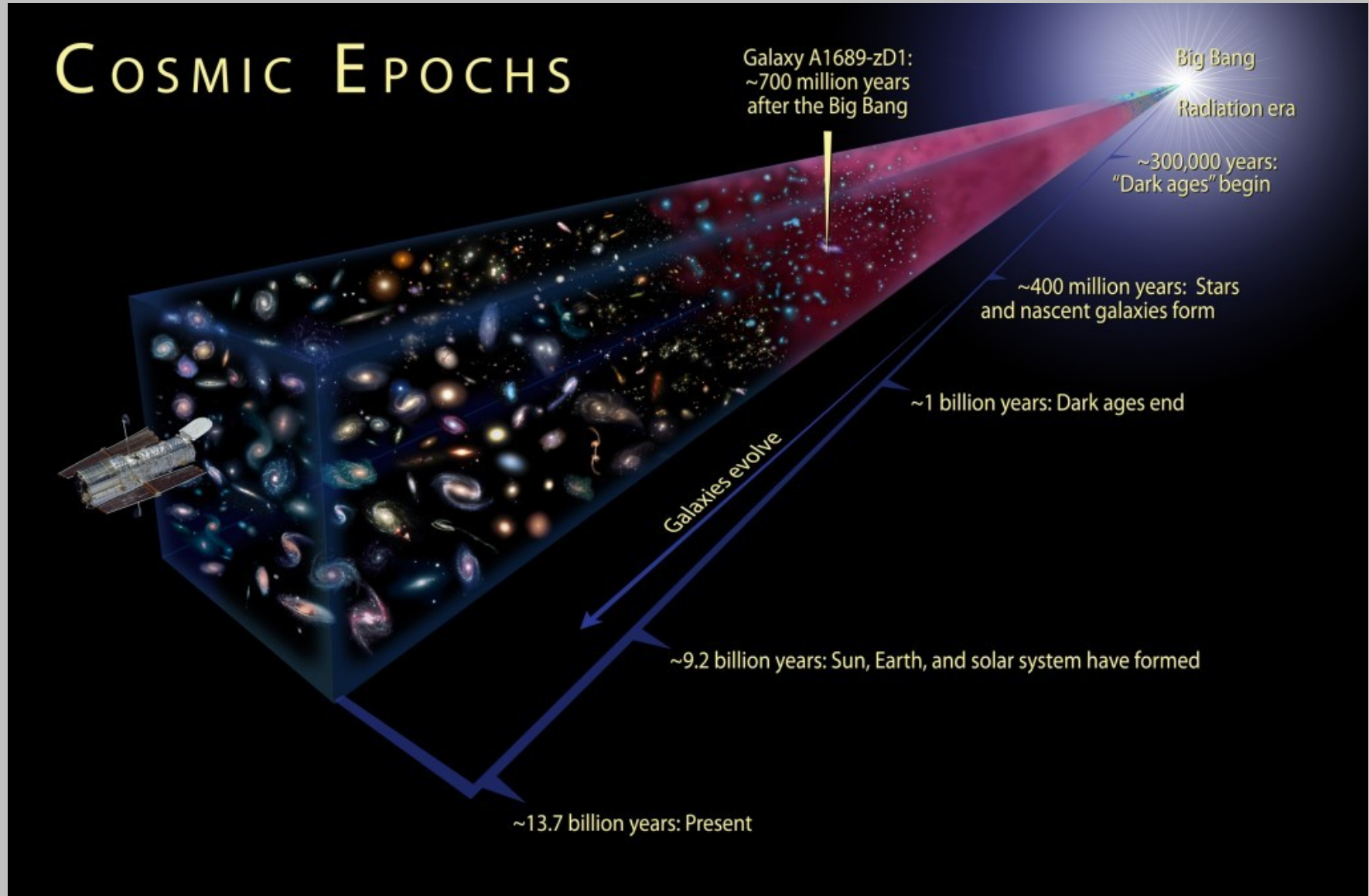


Image : NASA, ESA, A. Field

Higher redshift = farther away = further back in time

Object

Lookback Time

Sun

8 minutes

Alpha Centauri

4 years

Andromeda Galaxy

2 million years

NGC 1068 @ $z=0.0038$

52 million years

SN1994M @ $z=0.024$

320 million years

Quasar 3C273 @ $z=0.158$

1.9 billion years

Galaxy at $z=1$

7.7 billion years

Galaxy AD1689-zD1 @ $z=7.2$

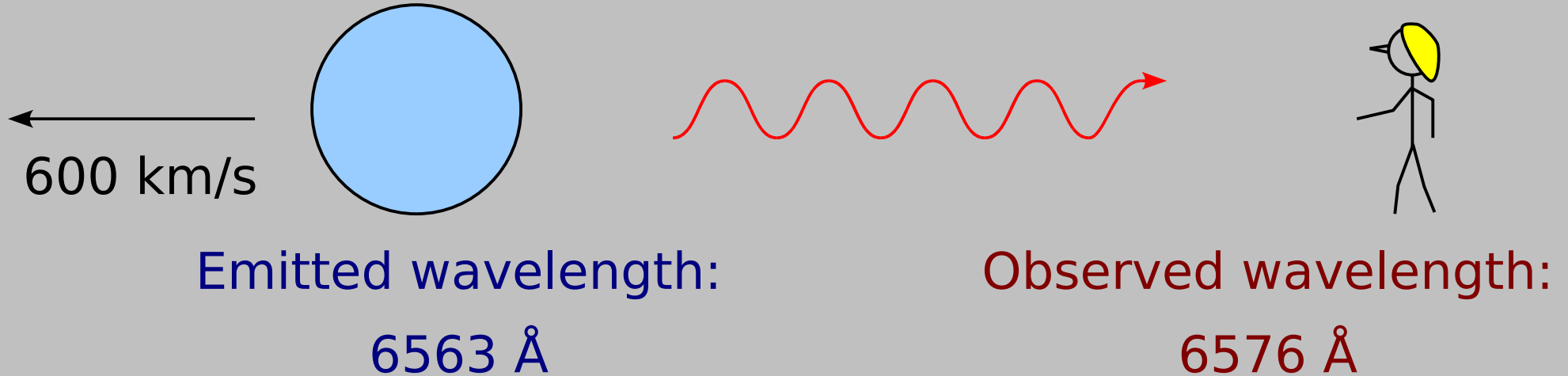
12.9 billion years

Age of Universe

13.7 billion years

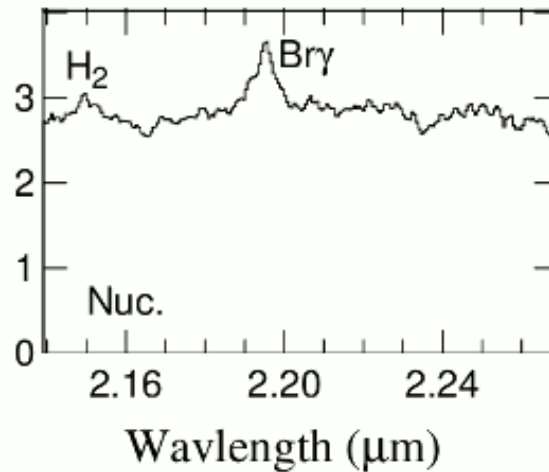
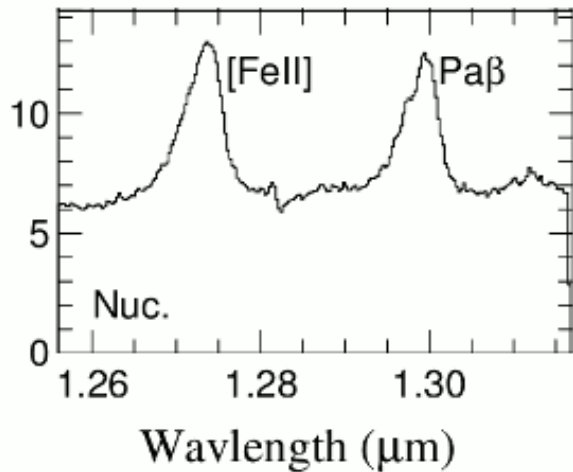
Observing a transition at a different wavelength isn't enough....

e.g. the Doppler Effect

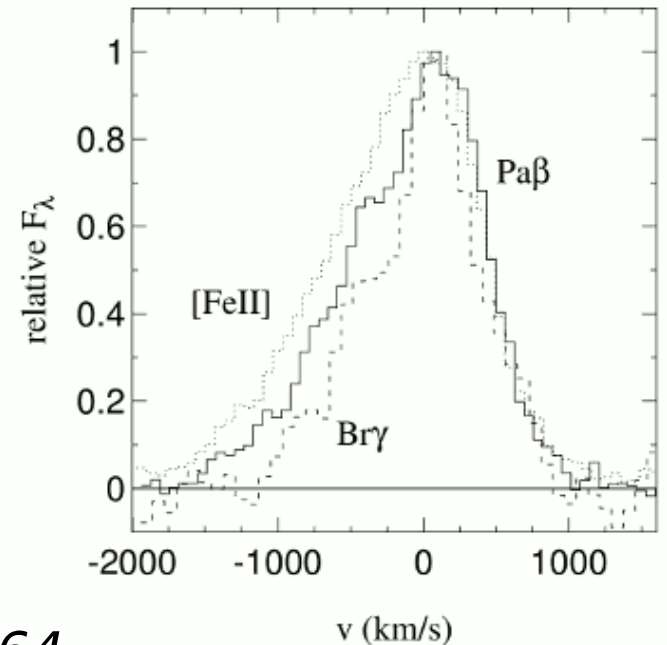
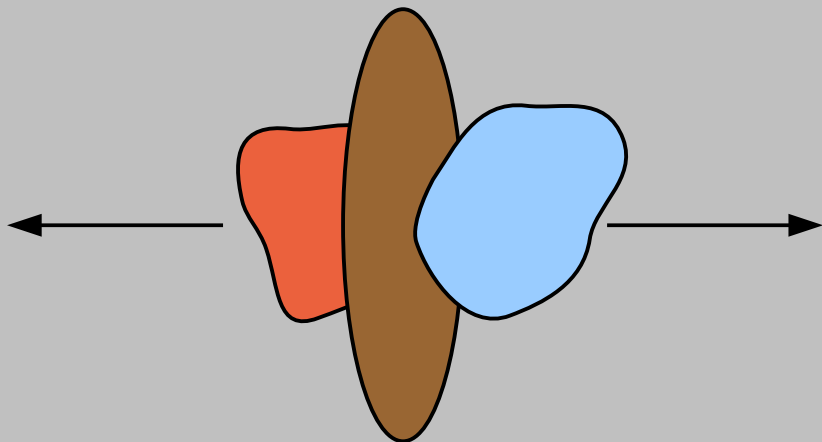


...instead, you have to look at multiple lines and see *different* shifts (where each line has a wavelength that depends differently on α)

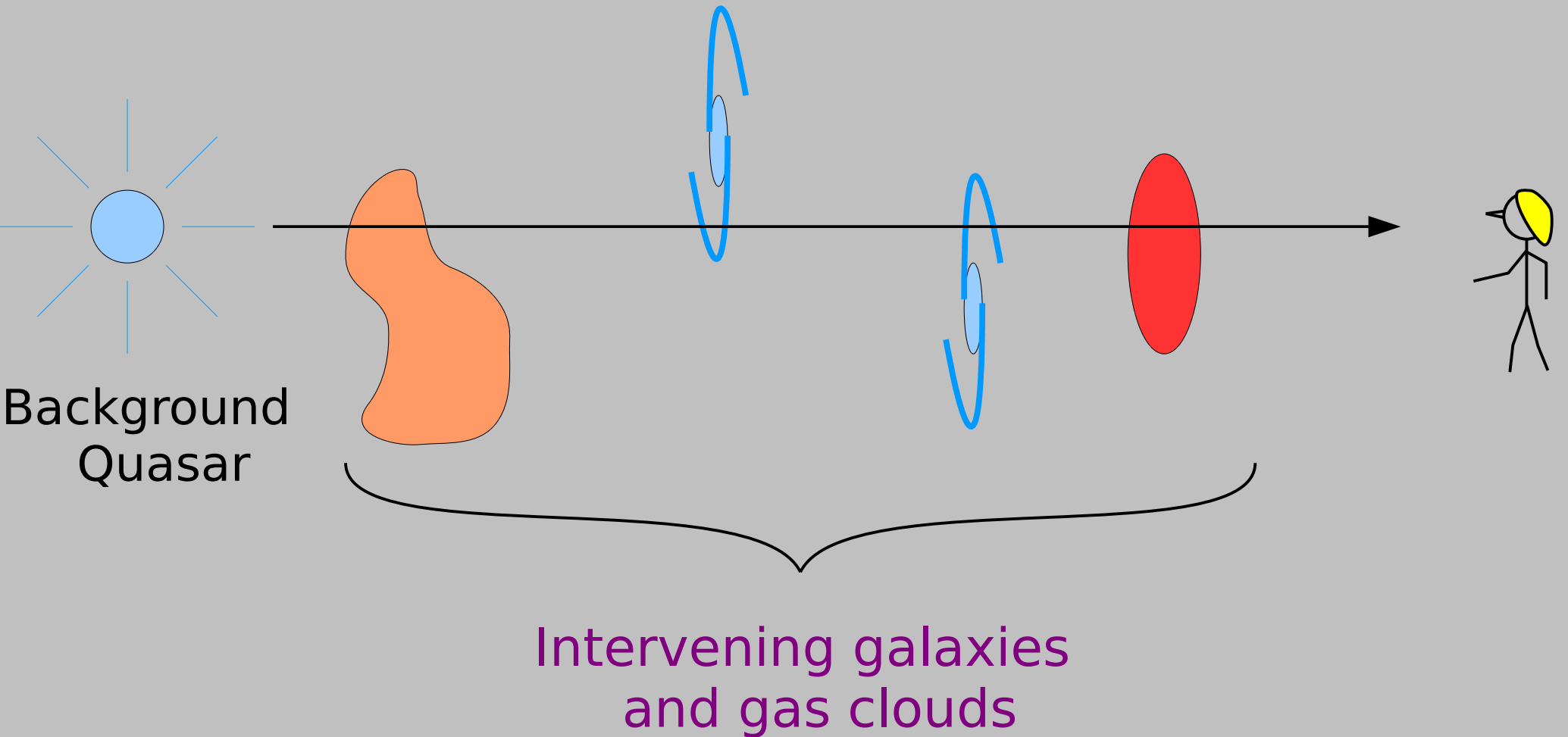
You have to be careful when looking at multiple lines... galaxies are complicated!



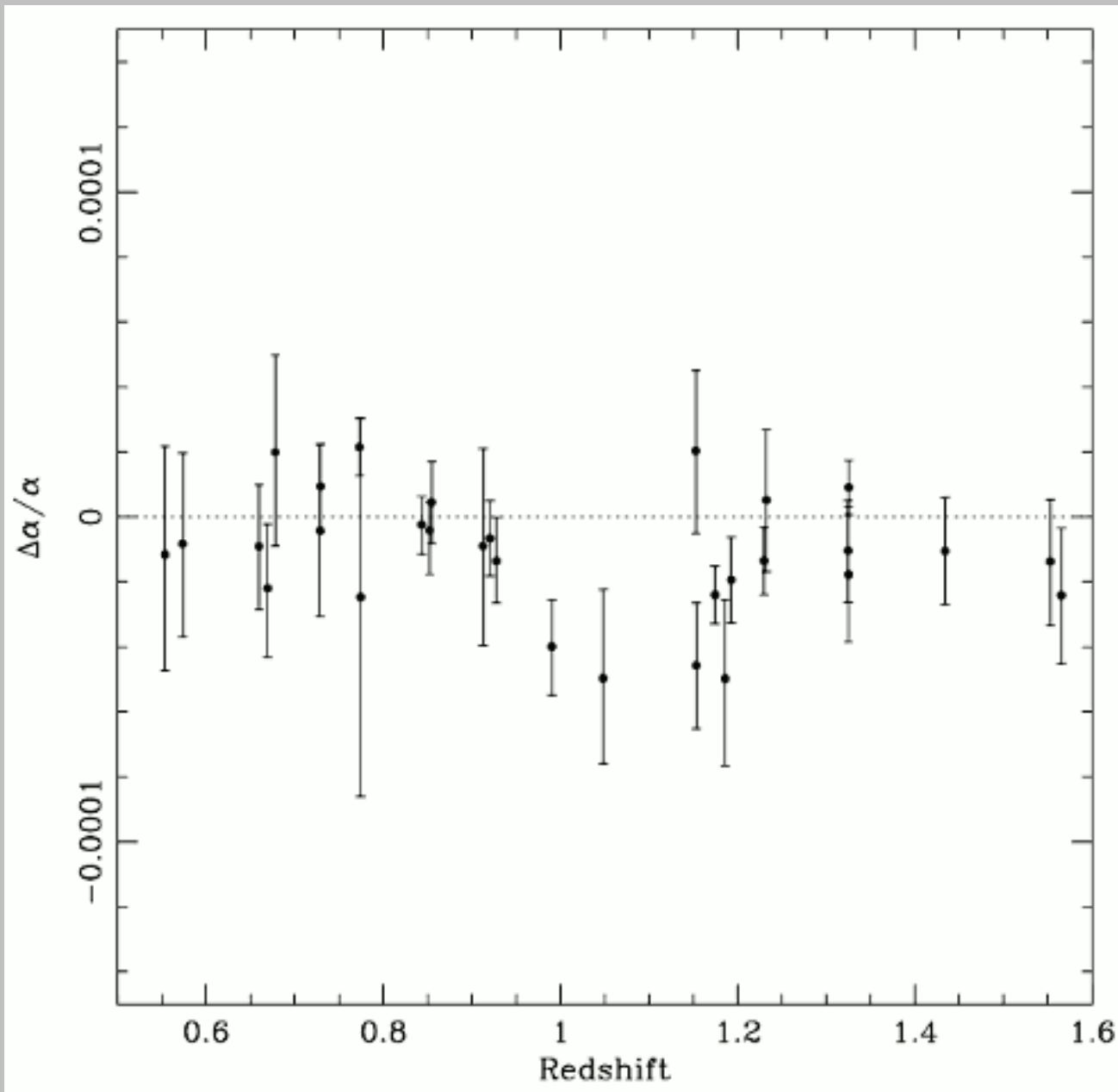
Seyfert Galaxy Mk 3



Quasar Absorption Systems



Possible detection in 1999 (not confirmed)



$z < 1$

$$\frac{\Delta\alpha}{\alpha} = -0.2 \pm 0.4 \times 10^{-5}$$

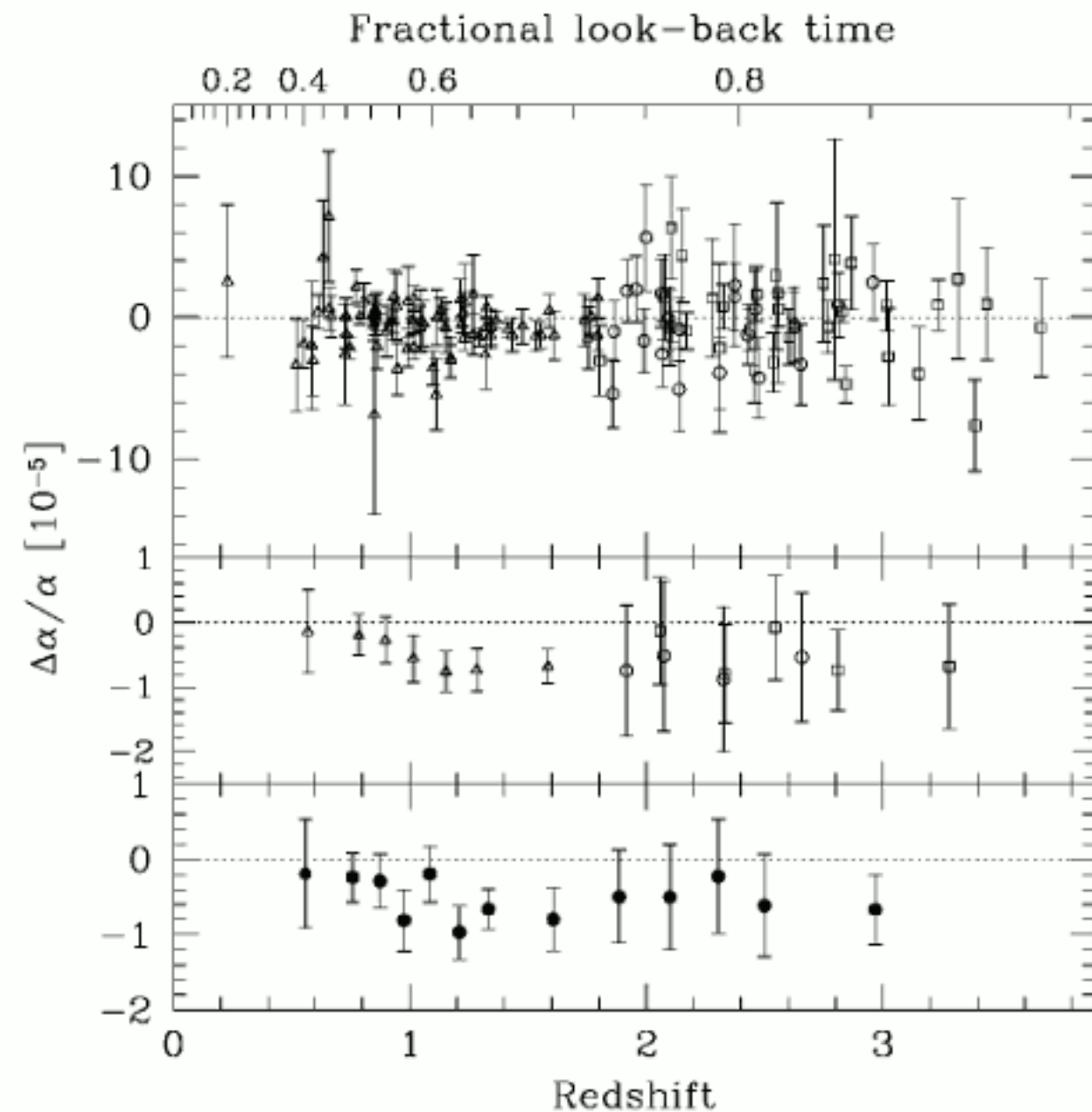
$z > 1$

$$\frac{\Delta\alpha}{\alpha} = -1.9 \pm 0.5 \times 10^{-5}$$

Based on quasar absorption lines of ionized iron and magnesium, using Keck HIRES

Webb, J.K., *et al.*,
1999, 82, 884

A 2003 detection of a change



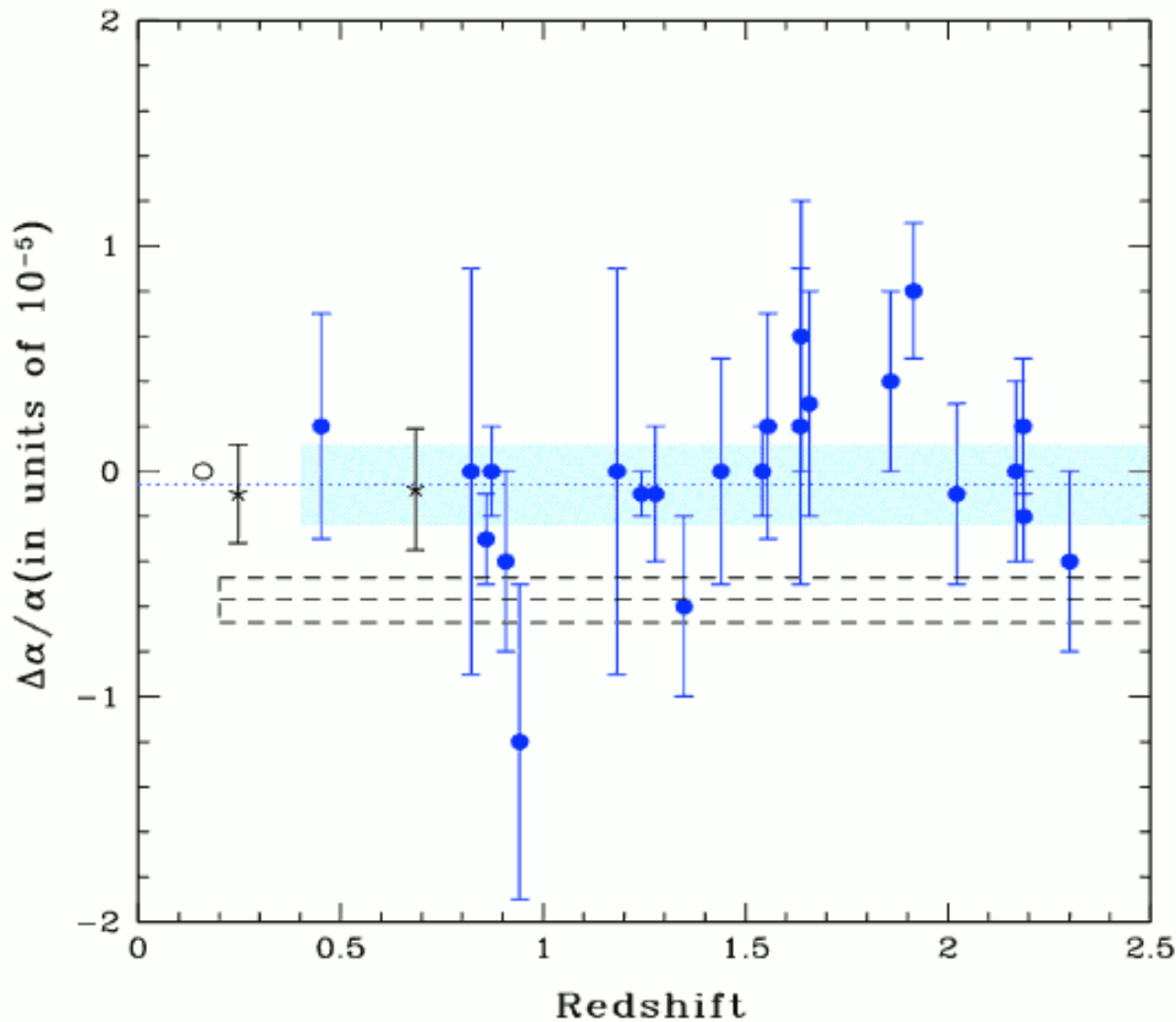
$$\frac{\Delta\alpha}{\alpha} = -0.54 \pm 0.12 \times 10^{-5}$$

These results
haven't been
independently
confirmed!

Murphy, M.T., *et al.*, 2003,
MNRAS, 345, 609

A 2004 failed confirmation of the previous detection

$$\frac{\Delta\alpha}{\alpha} = -0.06 \pm 0.06 \times 10^{-5}$$



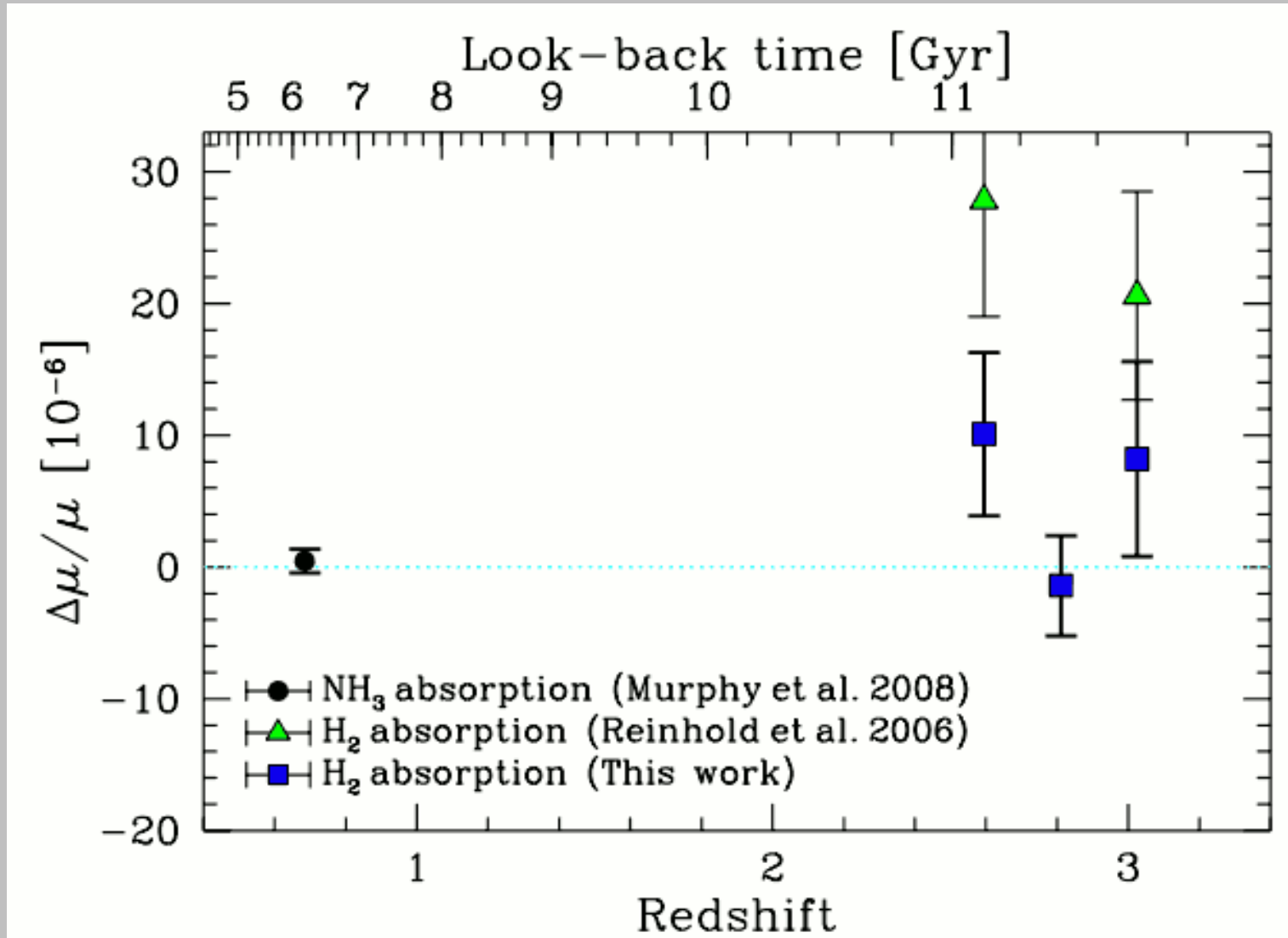
In 2008, the Webb/Murphy group claims this group didn't analyze their data well; in a response, this group claims they did.

(arXiv:0711.1742)

Chand, H., et al., 2004, A&A, 417, 853

A detection of no shift in $\mu = m_p/m_e$

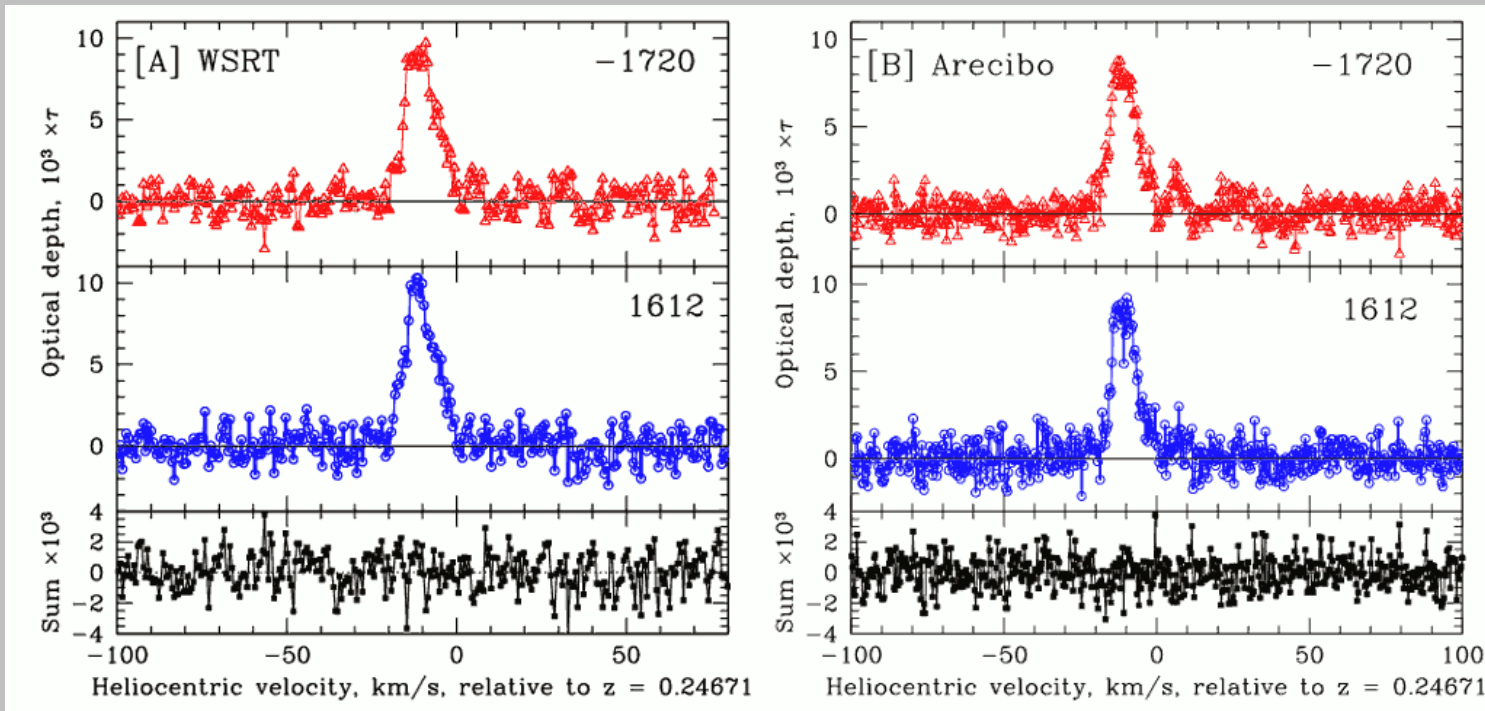
Following some detections (Reinhold *et al.* 2006) that likely resulted from uncorrected instrument systematics...



A different technique : radio “conjugate” OH lines

Radio – less likely to suffer from different absorption

Conjugate lines – profiles indicate exact same gas



Absorption

Emission

Difference

Kanekar *et al.*, 2010, arXiv:1004.5383v1

Radio OH lines results:

Sensitive to $G \equiv g_p (\mu \alpha)^{1.85}$

In Centaurus A ($z=0.0018$) : no shift

In PKS 1413+235 ($z=0.25$) :

w/ WSRT telescope : $\frac{\Delta G}{G} = (-1.9 \pm 1.1) \times 10^{-5}$

w/ Arecibo telescope : $\frac{\Delta G}{G} = (-1.03 \pm 0.51) \times 10^{-5}$

Combined result : $\frac{\Delta G}{G} = (-1.18 \pm 0.46) \times 10^{-5}$

A 2.6σ result is not something to get too worked up about...

Radio OH lines results:

If all of the “detected” change in G is due to α :

$$\frac{\Delta \alpha}{\alpha} = -0.31 \pm 0.12 \times 10^{-5}$$

Compare to Murphy's result from optical MgII & FeII :

$$\frac{\Delta \alpha}{\alpha} = -0.54 \pm 0.12 \times 10^{-5}$$

But Murphy's result was mostly $z > 1$, and didn't show a shift at lower z !!! Also, remember Chand from optical MgII & FeII :

$$\frac{\Delta \alpha}{\alpha} = -0.06 \pm 0.06 \times 10^{-5}$$

Grouchy Curmudgeon Aside

Press releases and news articles too often overstate results like this 2.6σ “detection” for sexy impact



(The article itself is not nearly as overstated as the title, but I might have been more cautious.)

<http://news.discovery.com/space/our-weird-universe-not-as-constant-as-we-thought.html>

Were the fundamental constants of physics different in the early Universe?

ANSWER : dunno

- There have been detections, but they both low significance and are controversial
- This is a very difficult business, involving weak signals that are very sensitive to instrument and cosmic systematic errors
- It's worth looking for, but so far there is no convincing evidence that any of the constants are different at high redshift.
- We haven't yet really looked at the **early** Universe!

*Here be
Dragons*

A History of the Universe

