Measuring Variations in the Fundamental Constants with the SKA

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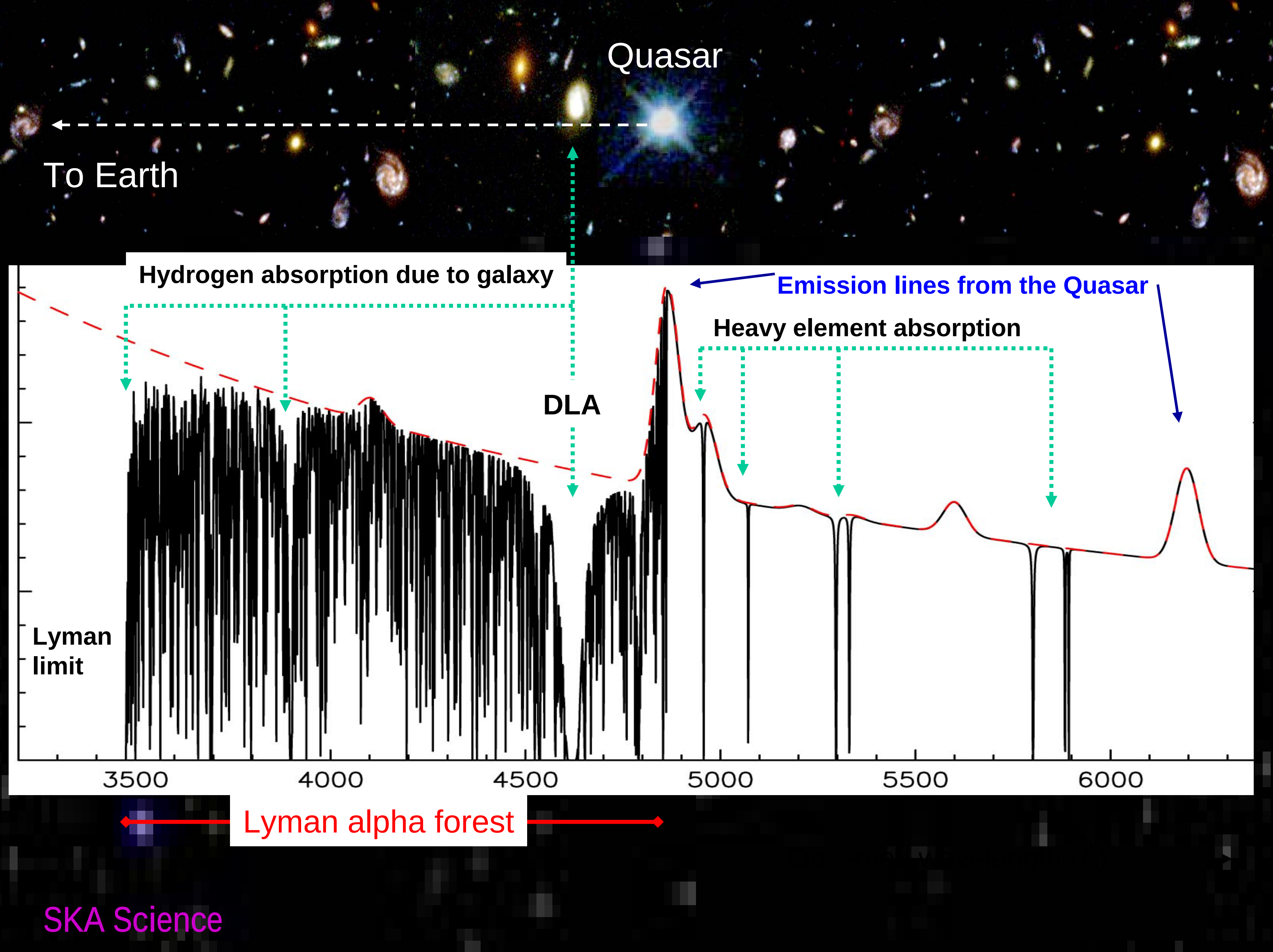


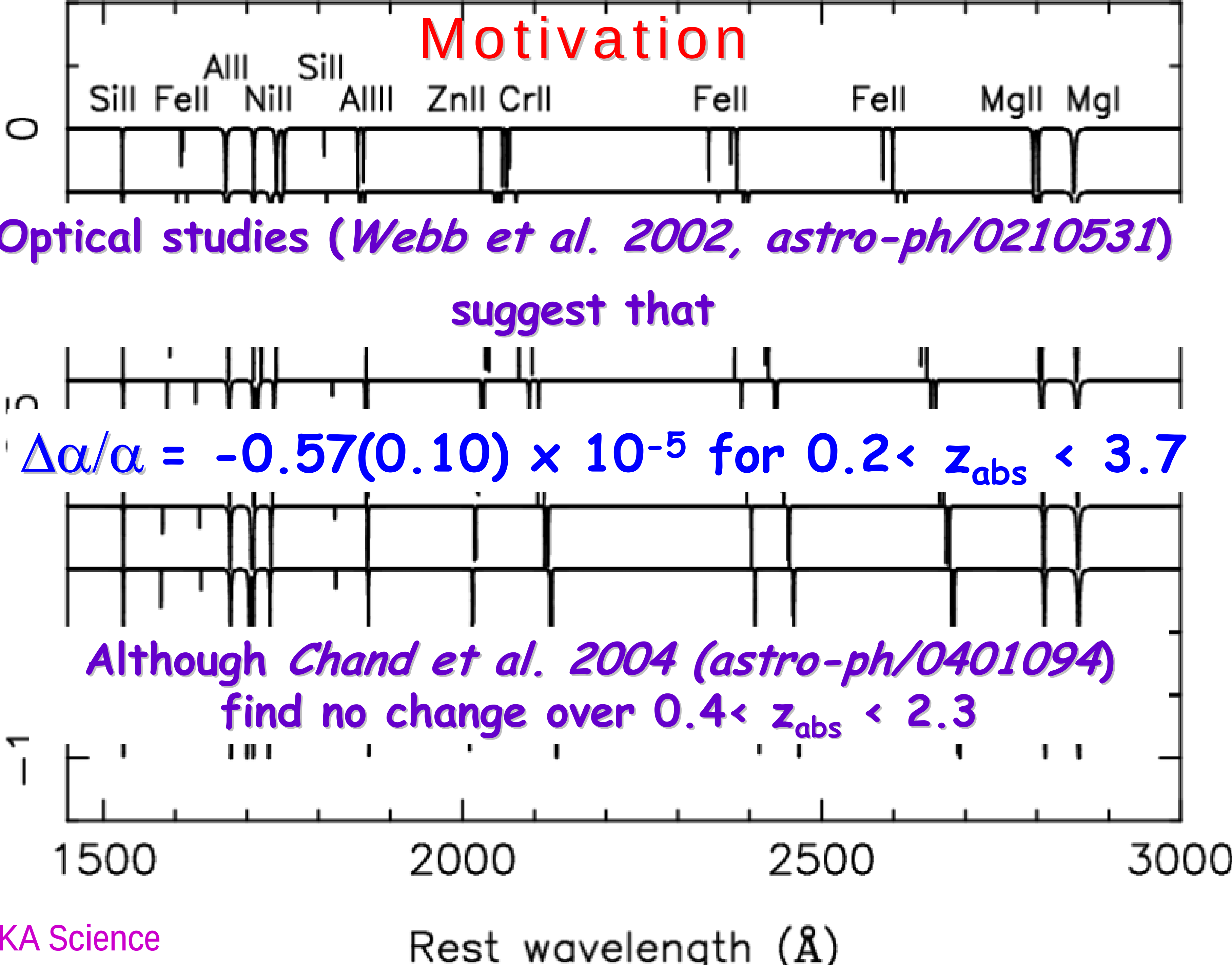
Quasar
To Earth
Hydrogen absorption due to galaxy
Emission lines from the Quasar
Heavy element absorption
DLA
Lyman limit
3500
4000
4500
5000
5500
6000
Lyman alpha forest
SKA Science

Motivation

Optical studies (*Webb et al. 2002, astro-ph/0210531*) suggest that

$$\Delta\alpha/\alpha = -0.57(0.10) \times 10^{-5} \text{ for } 0.2 < z_{abs} < 3.7$$

Although *Chand et al. 2004 (astro-ph/0401094*) find no change over $0.4 < z_{abs} < 2.3$



Advantage of Radio Lines

Optical Transitions

Interaction is Coulombic, so

ν_{opt} is proportional to $(1 + 0.03\alpha^2)$

(*Flambaum & Dzuba*)

21-cm Spin-Flip (HI) Line Transition

Interaction of electron and proton magnetic fields

ν_{21} is proportional to $\alpha^2 g_p \mu$

That is, comparing radio and optical gives an order of magnitude the sensitivity of the purely optical comparisons.

See Drinkwater et al., 1998, MNRAS 295, 457.

Furthermore, using molecular lines...

CO, HCO^+, etc – $\nu_{21} / \nu_{mm} \propto \alpha^2 g_p$

OH (18 cm) – $\nu_{1665} + \nu_{1667} \propto \alpha^{-1.1} \mu^{2.57}$

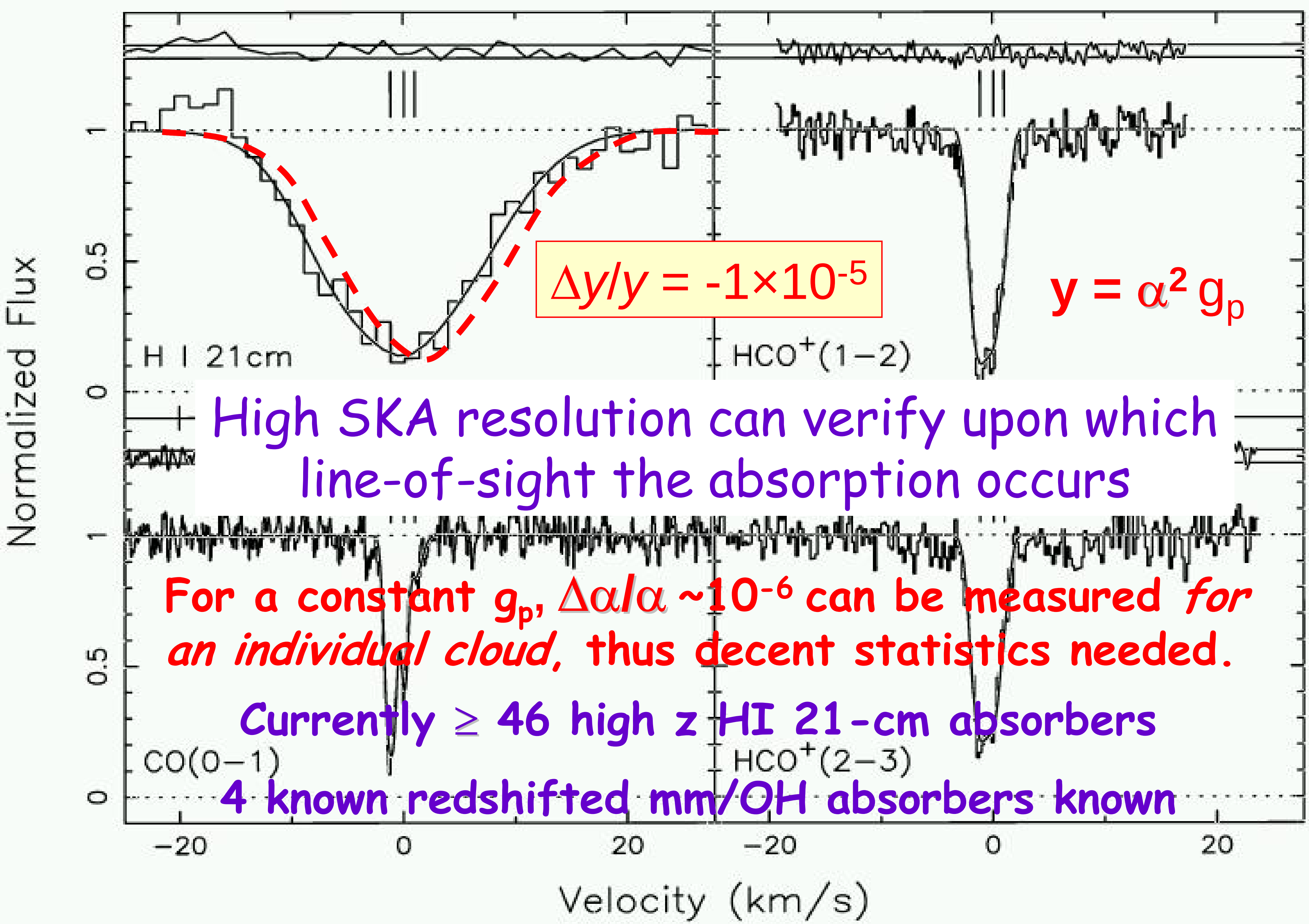
$\nu_{1665} - \nu_{1667} \propto \alpha^{-0.9} \mu^{2.4} g_p$

$\nu_{1720} - \nu_{1612} \propto \alpha^{2.6} \mu^{0.7} g_p$

also – $\nu_{1667} / \nu_{mm} \propto \alpha^{-1.1} \mu^{1.57}$

no g_p

Also constraints from other OH ($\lambda \geq 6$ cm) transitions –
Chengalur & Kanekar, 2003, PRL 91, 241302.



$\Delta y/y = -1\times10^{-5}$

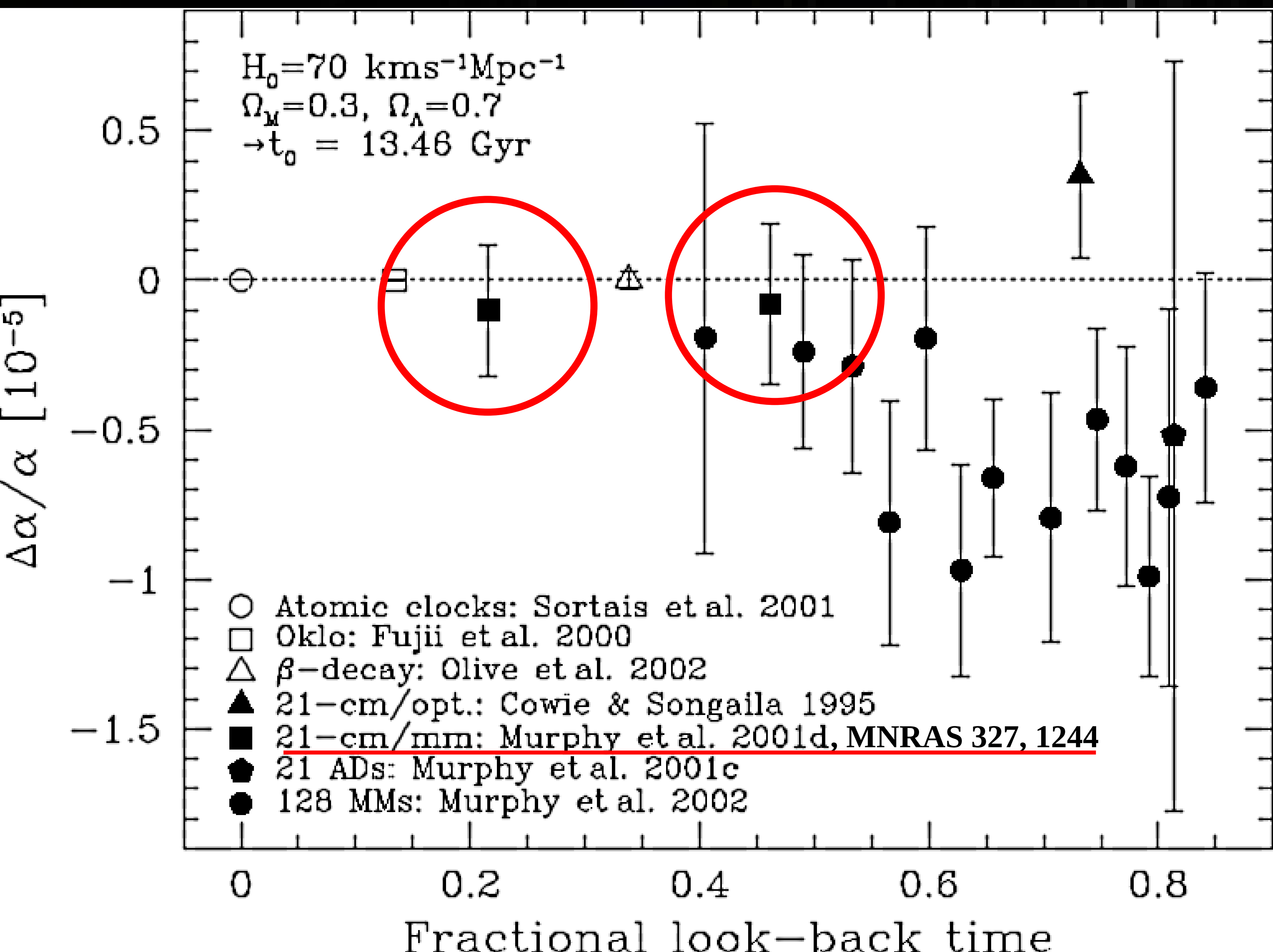
$y = \alpha^2 g_p$

High SKA resolution can verify upon which line-of-sight the absorption occurs

For a constant g_p, $\Delta\alpha/\alpha \sim 10^{-6}$ can be measured *for an individual cloud*, thus decent statistics needed.

Currently ≥ 46 high z HI 21-cm absorbers

4 known redshifted mm/OH absorbers known



H0=70 kms-1Mpc-1
ΩM=0.3, ΩΛ=0.7
→t0 = 13.46 Gyr
0.5
0
−0.5
−1
−1.5
Δα/α [10−5]
Atomic clocks: Sortais et al. 2001
Oklo: Fujii et al. 2000
β−decay: Olive et al. 2002
21−cm/opt.: Cowie & Songaila 1995
21−cm/mm: Murphy et al. 2001d, MNRAS 327, 1244
21 ADs: Murphy et al. 2001c
128 MMs: Murphy et al. 2002
0
0.2
0.4
0.6
0.8
Fractional look−back time

With the SKA ...

After 1 hour at 1 km/s resolution

S_{rms} ~ 0.2 mJy @ 200 MHz

~ 0.04 mJy @ 0.5 to 5 GHz

~ 0.01 mJy @ 25 GHz

Frequency range 0.1 - 25 GHz

OH	$z_{abs} \leq 16$	≤ 13
HI	$z_{abs} \leq 13$	
CO, HCO^+, HCN	$z_{abs} \geq 2.6$	2.6 - 13

c.f. z_{abs} < 0.7 for today's HI/molecular comparisons!

HI 21-cm Absorption

$\Delta v \approx$ FWHM $\approx$ 10 km/s, $S \approx 0.3$ Jy, after 1 hour

$N_{HI} \approx 2 - 50 \times 10^{14}\ T_s/f\ \ cm^{-2}$ (3σ) , $z_{abs} < 6.$

$T_s \approx 100$ K (f ~ 1) $\Rightarrow N_{HI} \sim 10^{17}\ cm^{-2}$ LLSs!

For $\geq 10^{20}\ cm^{-2}$ (DLAs) , $T_{spin} \geq 10^5$ K or $f \leq 10^{-4}$

Currently 17/34 detected, $T_{spin} \leq 10^4$ K (f ~ 1)

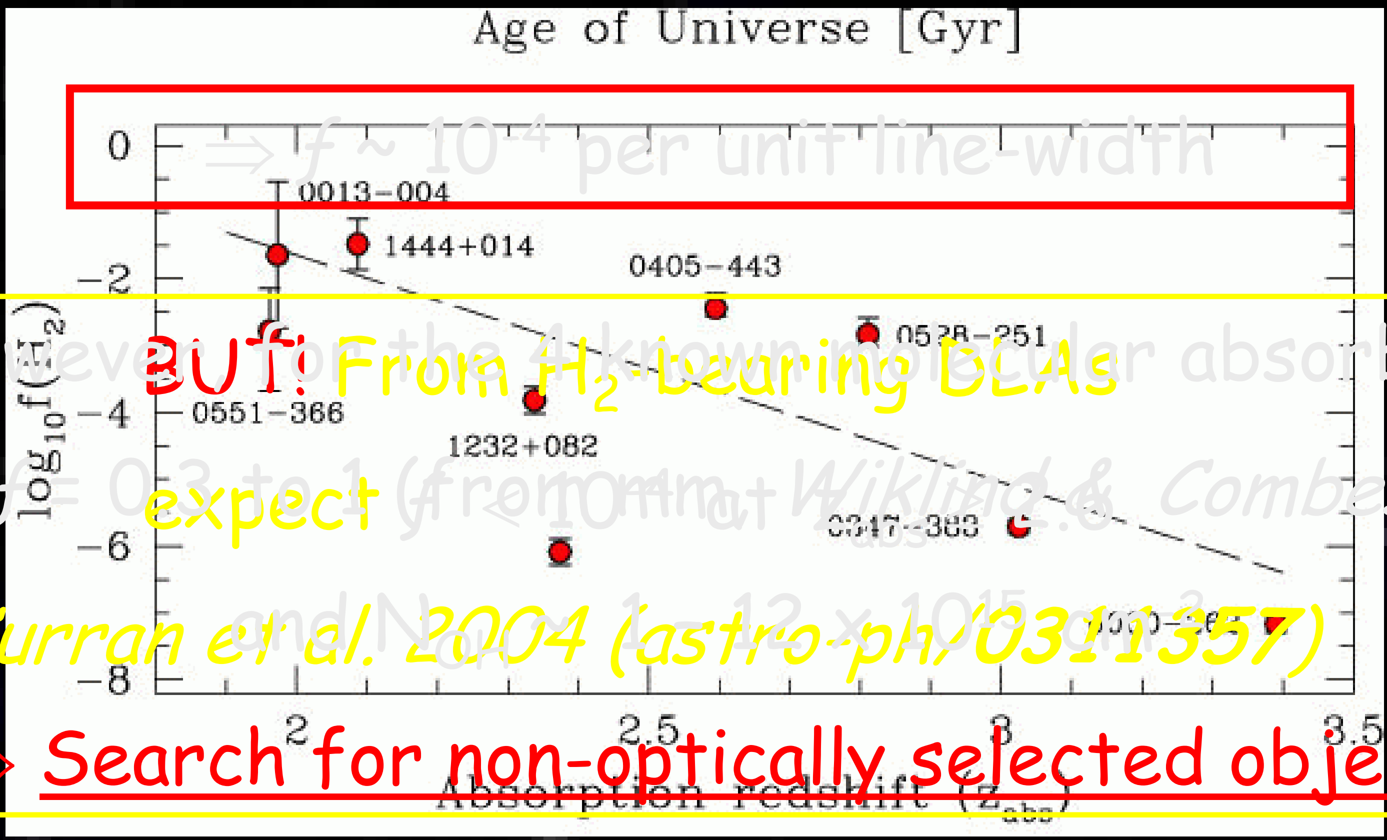
Detect HI in 87 known DLAs, plus those << 0.3Jy as well as gazillions of other absorbers

Molecular Absorption

$\Delta v \approx$ FWHM $\approx$ 10 km/s, S $\approx$ 0.1 Jy, after 1 hour

$N_{OH} \sim 10^{12}$ - 10^{14} ($0 \geq z_{abs} \geq 16$), T_x=10 K @ z = 0

$N_{CO} \sim 10^{13}$ ($z_{abs} \geq 3.6$), $N_{HCO+} \sim 10^{10}$ ($z_{abs} \geq 2.6$) cm^{-2}



$\Rightarrow f \sim 10^{-4}$ per unit line-width

However, for the 4 known molecular absorbers

f = 0.3 to 1 (from mm Wiklind & Combes)

and $N_{OH} \sim 1 - 12 \times 10^{15}$ cm^{-2}

BUT! From H_2-bearing DLAs

expect $f < 10^{-4}$ at $z_{abs} > 2$

Curran et al. 2004 (astro-ph/0311357)

$\Rightarrow$ Search for non-optically selected objects

SKA Science

Summary

- Detect HI absorption in > 1/4 of all DLAs as well as in all other absorbers with $N_{HI} \geq 10^{17}$ cm^{-2}, i.e. a large sample of absorbers of known redshifts

- SKA ideal for surveys unbiased by dust extinction for HI & OH (and possibly high-z mm) absorption

SKA will vastly increase number of HI/OH absorbers yielding redshifts with which to search for mm-lines ($N_{OH} \cong 30 \times N_{HCO+}$) with ALMA

$\Rightarrow$ Accurate constraints of various combinations of α, g_p, & μ