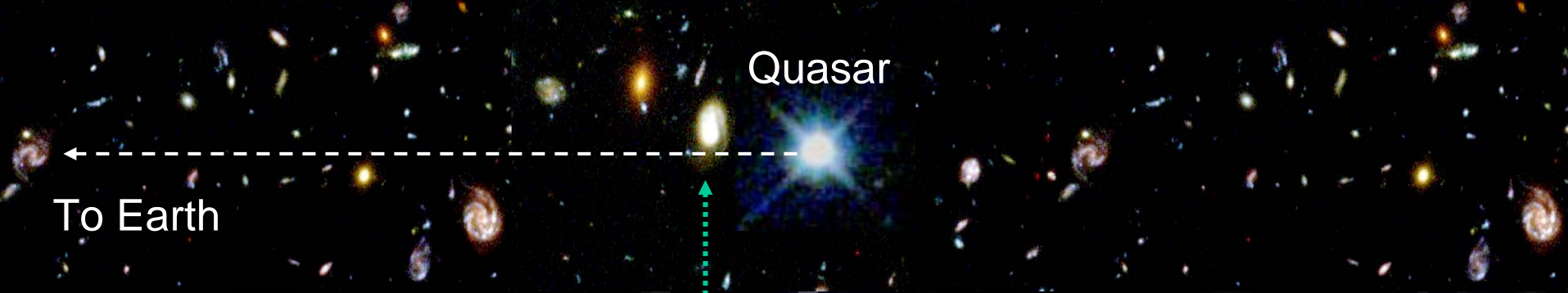


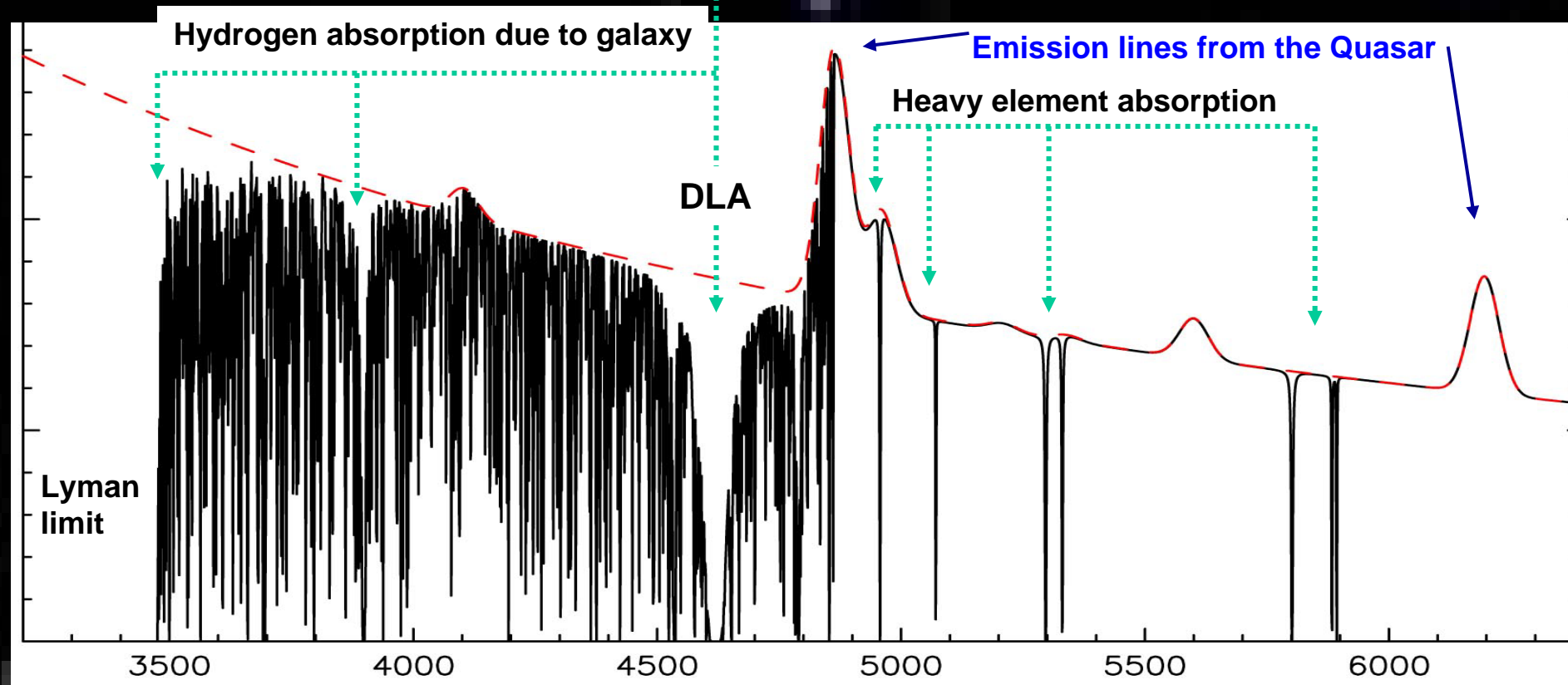
# Measuring Variations in the Fundamental Constants with the SKA

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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

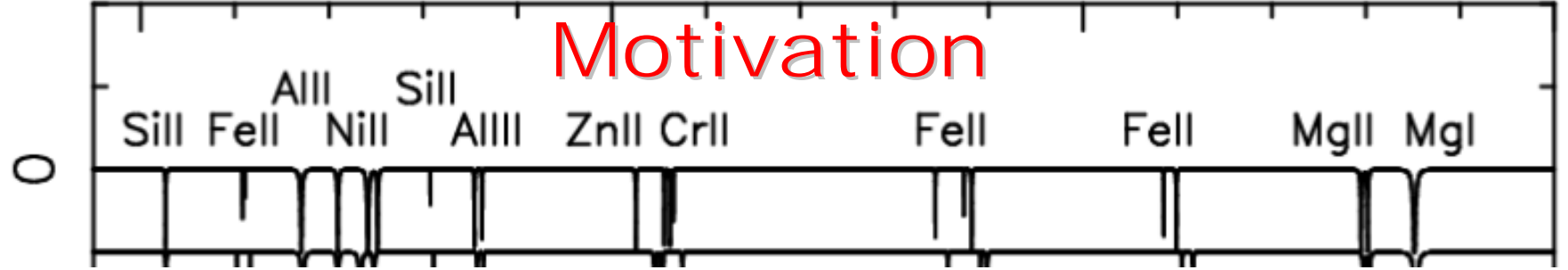
5000

5500

6000

Lyman alpha forest

# Motivation



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

suggest that

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

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

1500

2000

2500

3000

# Advantage of Radio Lines

## Optical Transitions

Interaction is Coulombic, so

$V_{\text{opt}}$  is proportional to  $(1 + 0.03\alpha^2)$   
(*Flambaum & Dzuba*)

## 21-cm Spin-Flip (HI) Line Transition

Interaction of electron and proton magnetic fields

$V_{21}$  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...

$$\text{CO, HCO}^+, \text{ etc} - v_{21} / v_{\text{mm}} \propto \alpha^2 g_p$$

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

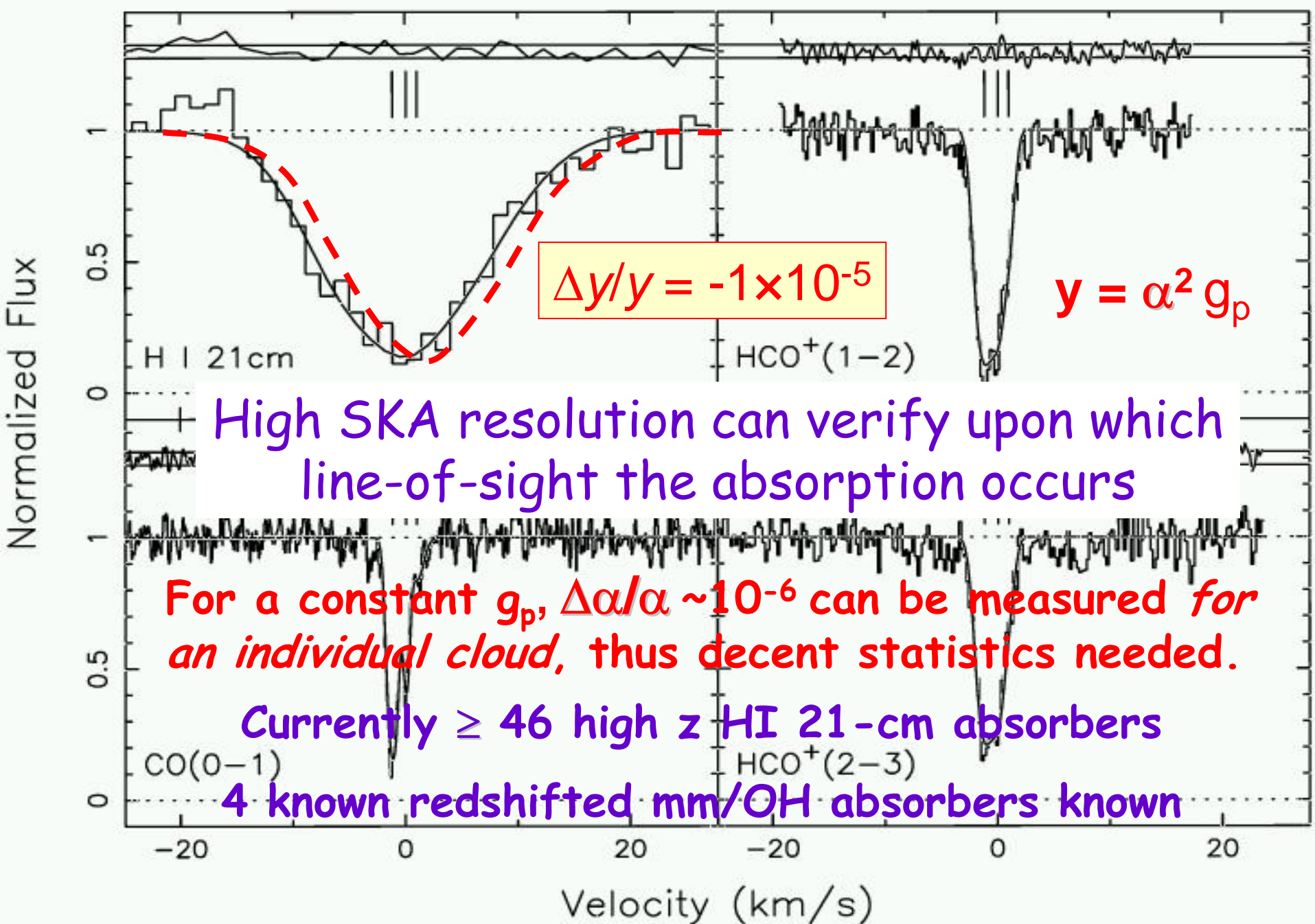
$$v_{1665} - v_{1667} \propto \alpha^{-0.9} \mu^{2.4} g_p$$

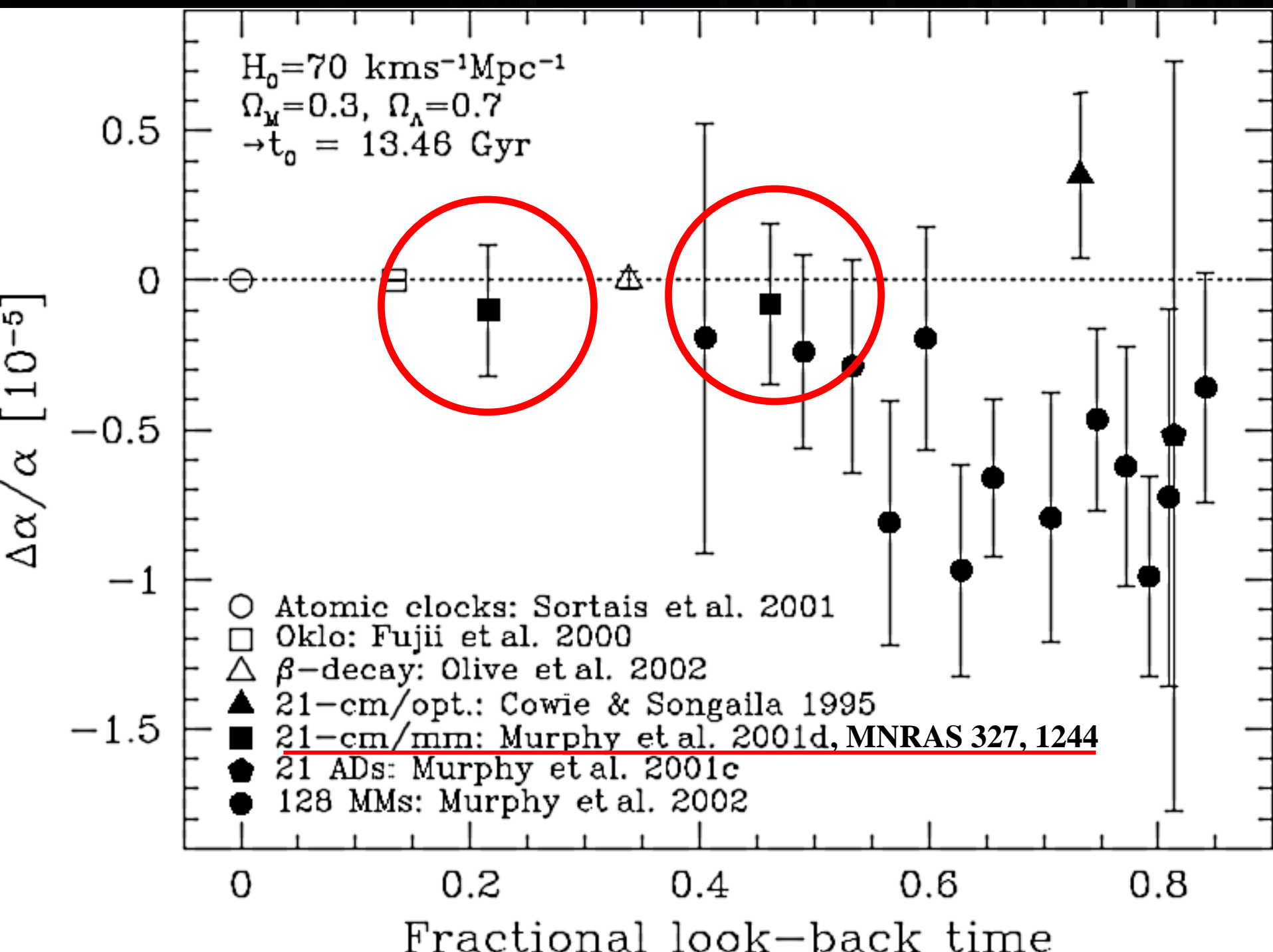
$$v_{1720} - v_{1612} \propto \alpha^{2.6} \mu^{0.7} g_p$$

$$\text{also - } v_{1667} / v_{\text{mm}} \propto \alpha^{-1.1} \mu^{1.57}$$

no  $g_p$

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





# With the SKA ...

After 1 hour at 1 km/s resolution

$$S_{\text{rms}} \sim 0.2 \text{ mJy @ 200 MHz}$$

$$\sim 0.04 \text{ mJy @ 0.5 to 5 GHz}$$

$$\sim 0.01 \text{ mJy @ 25 GHz}$$

Frequency range 0.1 - 25 GHz

OH	$z_{\text{abs}} \leq 16$	] $\leq 13$
HI	$z_{\text{abs}} \leq 13$	
CO, HCO <sup>+</sup> , HCN	$z_{\text{abs}} \geq 2.6$	2.6 - 13

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

# HI 21-cm Absorption

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

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

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

LLSs!

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

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

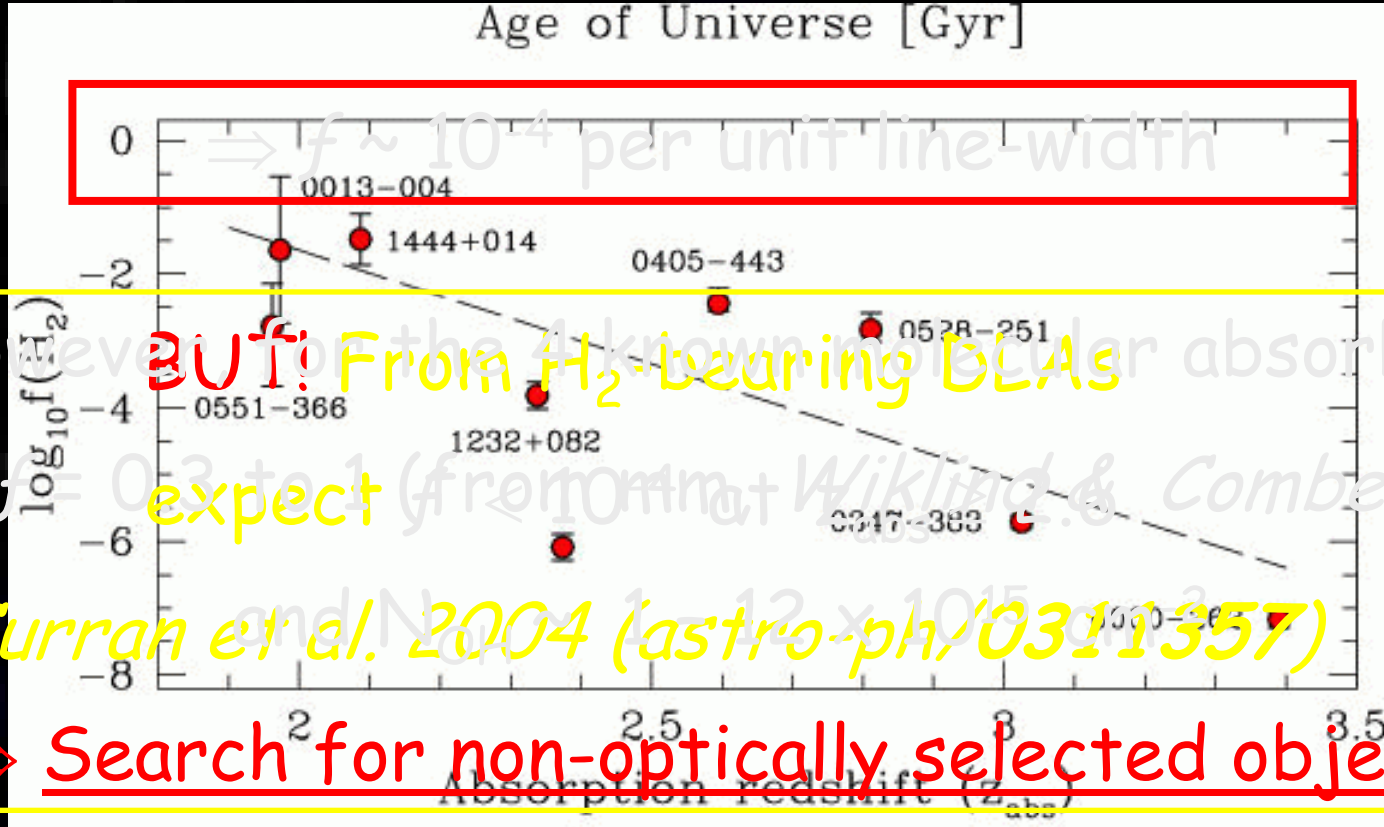
Detect HI in 87 known DLAs, plus those  $\ll 0.3 \text{ Jy}$   
as well as gazillions of other absorbers

# Molecular Absorption

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

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

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



How **BUT!** From  $\text{H}_2$ -bearing DLAs expect  $f = 0.3$  to 1 (from Wiklind & Combes)

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

$\Rightarrow$  Search for non-optically selected objects

# Summary

- Detect HI absorption in  $> 1/4$  of all DLAs as well as in all other absorbers with  $N_{\text{HI}} \geq 10^{17} \text{ cm}^{-2}$ , 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 ( $N_{\text{OH}} \cong 30 \times N_{\text{HCO}^+}$ ) with ALMA

$\Rightarrow$  Accurate constraints of various combinations of  $\alpha$ ,  $g_p$ , &  $\mu$