2D NMR

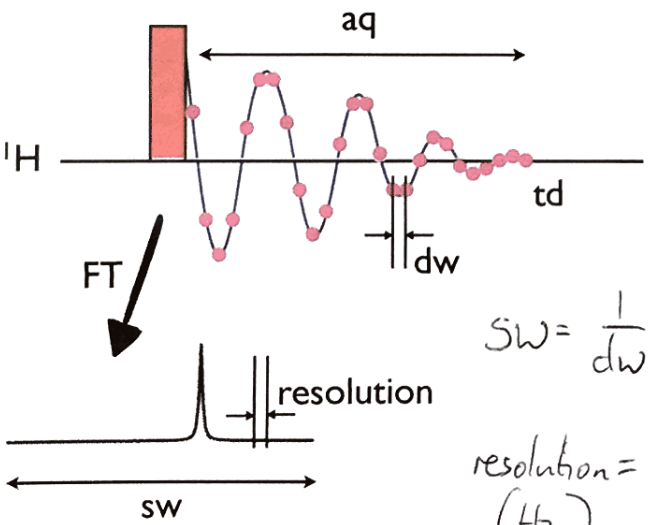
Chris Waudby

c.waudby@ucl.ac.uk

2D NMR

- Many spin systems and pulse sequences to choose between! Focus on general aspects first…
- sw, td, aq
- Field strength, resolution and sensitivity

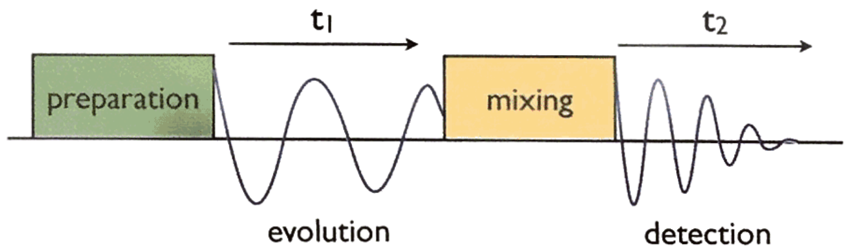
Recap: aq, td, sw and spectrum resolution



$sw = \frac{1}{dw} = \frac{td}{aq}$

$\text{resolution (Hz)} = \frac{1}{aq}$

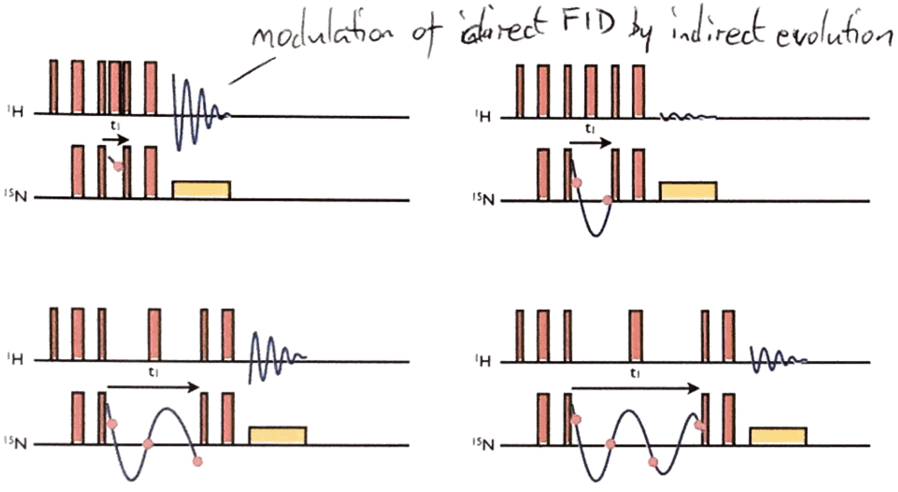
2D NMR



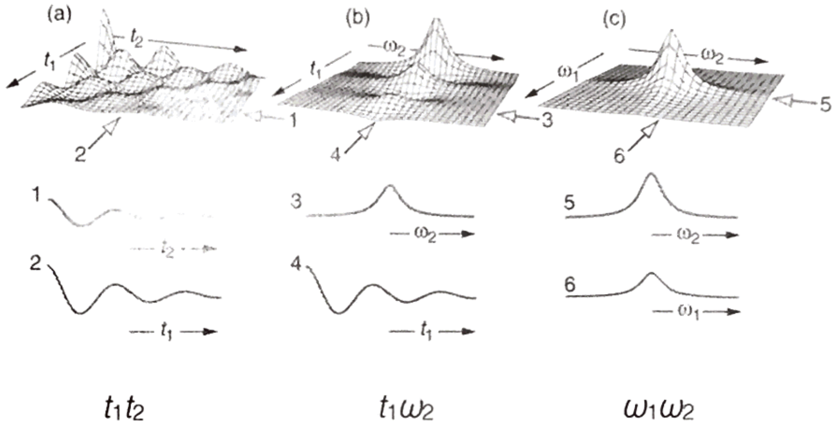
- Now we have two time dimensions
- Analysis of sw and resolution exactly the same as 1D
- Key difference from direct detection – long aq in t_1 isn't free!

(+ obvious extension to 3D etc.)

2D NMR

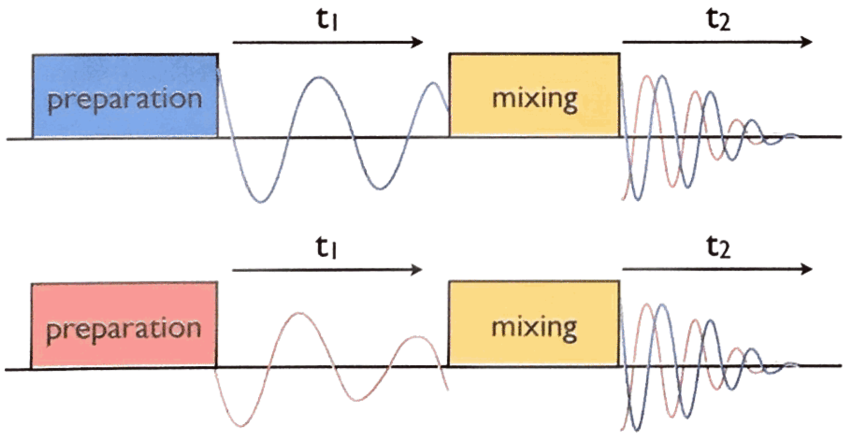


2D Fourier transformation



(Keeler, Understanding NMR Spectroscopy)

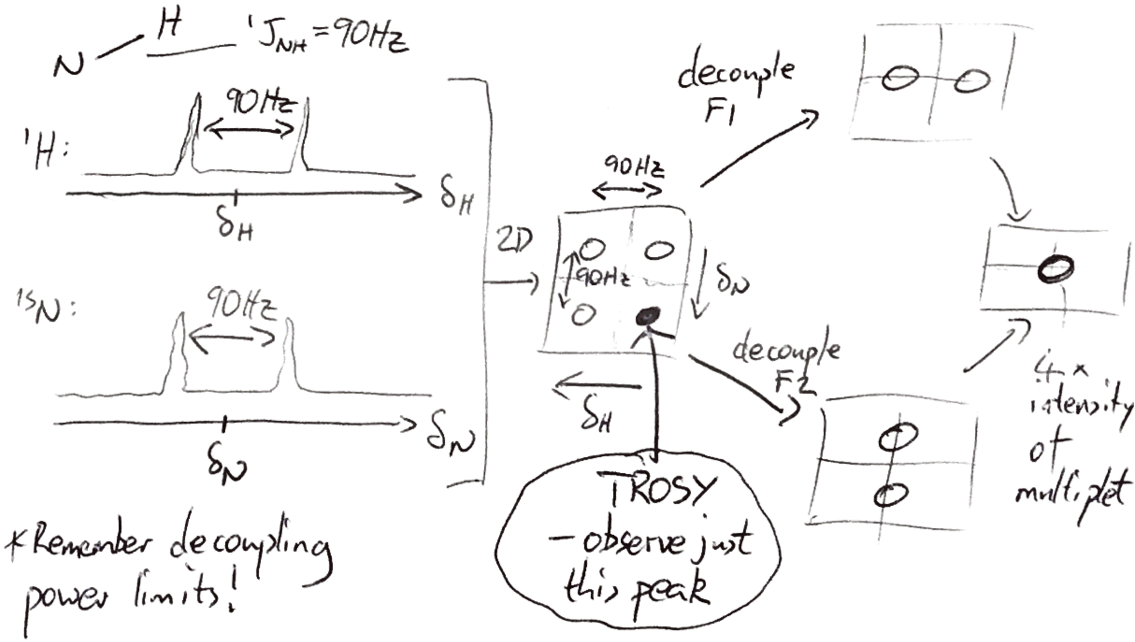
Quadrature detection in 2D



2 seperate expts needed, unlike direct dimension

hypercomplex data
(RR, RI, IR, II)

Multiplet structures



*Remember decoupling power limits!

Resolution in the indirect dimension

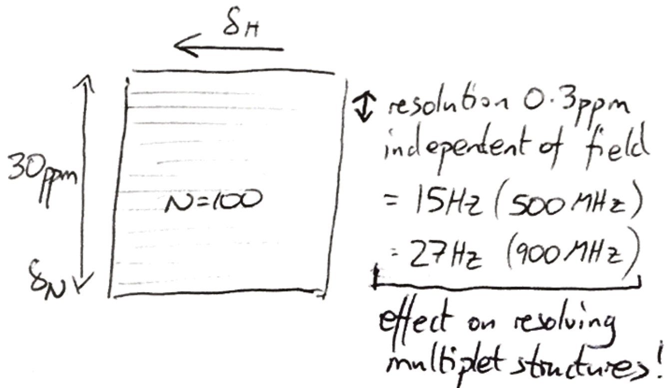
$$sw(Hz) = \frac{\gamma B_0}{2\pi} \cdot sw(ppm) \times 10^{-6}$$

$$\Delta t = \frac{1}{sw(Hz)} \propto \frac{1}{B_0}$$ Stronger fields ⇒ shorter delays

$$resolution(Hz) = \frac{1}{t_{aq}} = \frac{1}{N \cdot \Delta t} \propto \frac{sw(ppm) \cdot B_0}{N}$$

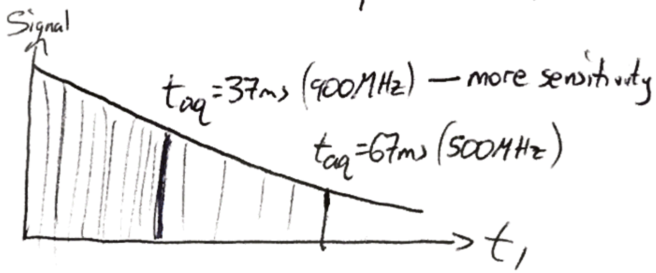
$$resolution(ppm) \propto \frac{sw(ppm)}{N}$$ (independent of B_0)

Resolution, sensitivity and field strength



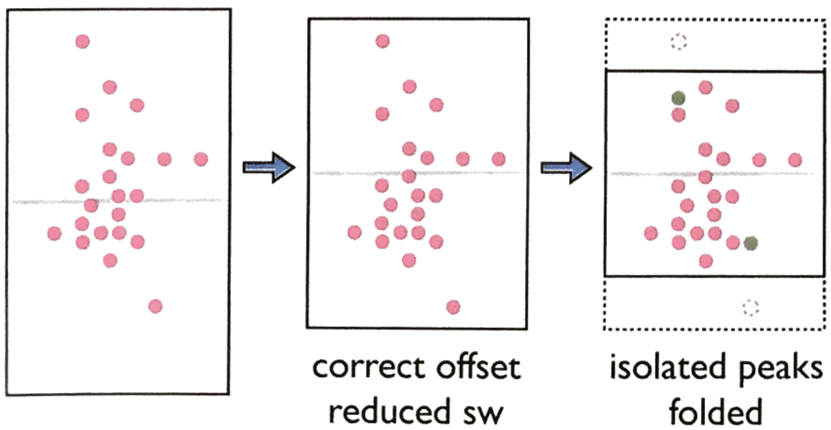
Higher B_0, fixed td and sw(ppm):

- same ppm resolution
- lower frequency resolution (Hz)
- higher sensitivity (on top of $B_0^{3/2}$ scaling)



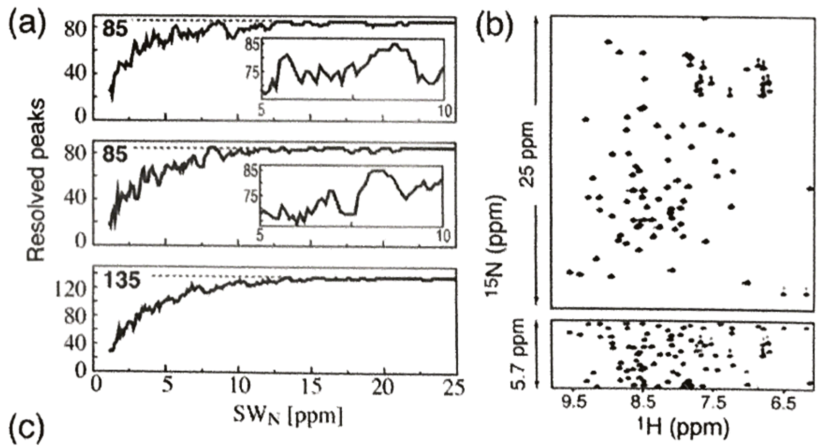
Spectrum width in the indirect dimension: folding / aliasing

- Maximise resolution in indirect dimension by optimising the offset and minimising the spectrum width



Automated Spectral Compression for Fast Multidimensional NMR and Increased Time Resolution in Real-Time NMR Spectroscopy

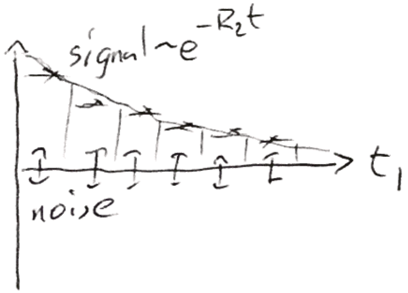
Ewen Lescop, Paul Schanda, Rodolfo Rasia, and Bernhard Brutscher*



JACS 2007

A bit extreme! but potentially useful for fast kinetics, eg. HD exchange

Sensitivity



$$\text{signal} \propto \sum e^{-R_2 t_1} \approx \int_0^{t_{aq}} e^{-R_2 t}\,dt = \frac{1-e^{-R_2 t_{aq}}}{R_2}$$

same amount of noise in each FID

$\Rightarrow$ noise $\propto \sqrt{t_{aq}}$

$$\therefore \text{sensitivity} \propto \frac{1-e^{-R_2 t_{aq}}}{R_2\sqrt{t_{aq}}}$$

WHEN SPECTROMETER TIME OR SAMPLE LIFETIME NOT LIMITING!

N.B. weird units $[Hz^{-1/2}]$!

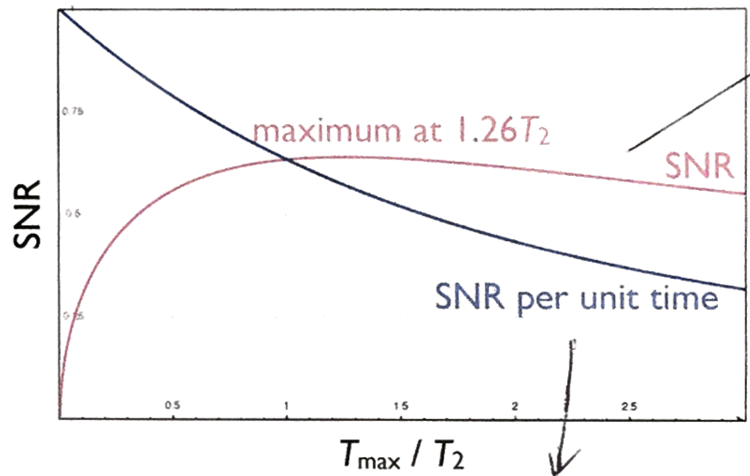
For fixed amount of wall-clock time:

$$\text{SNR} \propto \frac{1-e^{-R_2 t_{aq}}}{R_2\, t_{aq}}$$

2D experiments: COSY

Sensitivity

— What question are you asking?



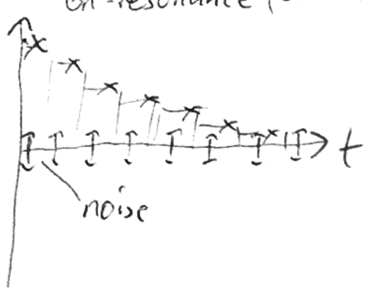
Sample is stable – will SNR improve if I record longer evolution times?

How do I get most signal in fixed amount of time? – trade off with resolution

2D experiments: NOESY

Sensitivity

on-resonance ($\omega = 0$):



$$\text{signal} \propto \sum e^{-R_2 \cdot t} \approx \int_0^{t_{aq}} e^{-R_2 t} = \frac{1 - e^{-R_2 t_{aq}}}{R_2}$$

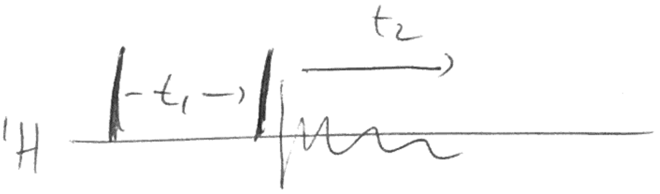
same amount of noise in each FID

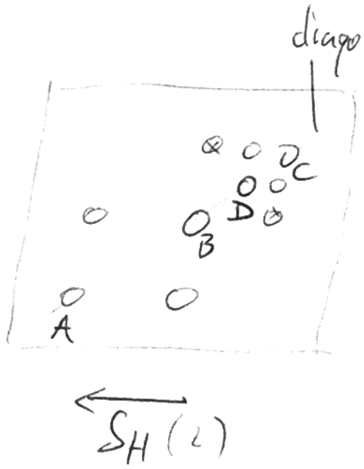
$\Rightarrow$ noise $\propto \sqrt{t_{aq}}$

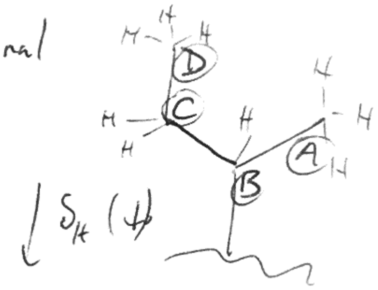
$$\therefore \text{sensitivity} \propto \frac{1 - e^{-R_2 t_{aq}}}{R_2 \sqrt{t_{aq}}} \quad (\text{NB units: } s^{-1/2})$$

For fixed amount of wall-clock time: $$\text{SNR} \propto \frac{1 - e^{-R_2 t_{aq}}}{R_2 t_{aq}}$$

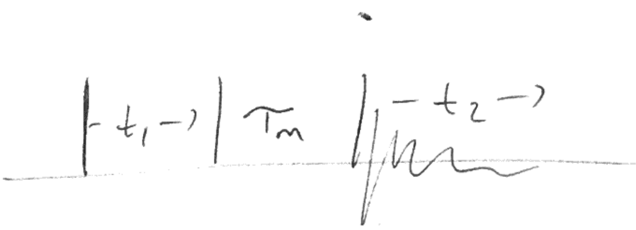
COSY

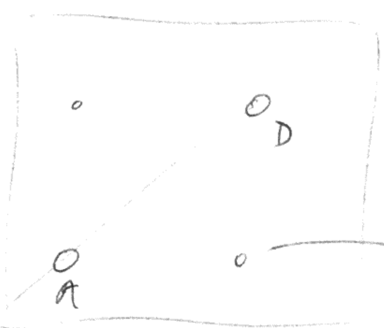


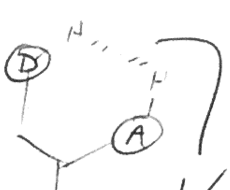




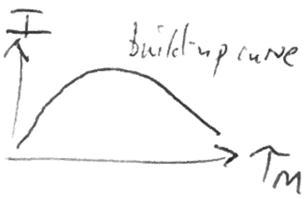
NOESY



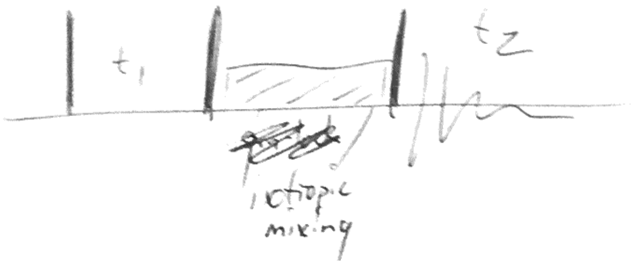


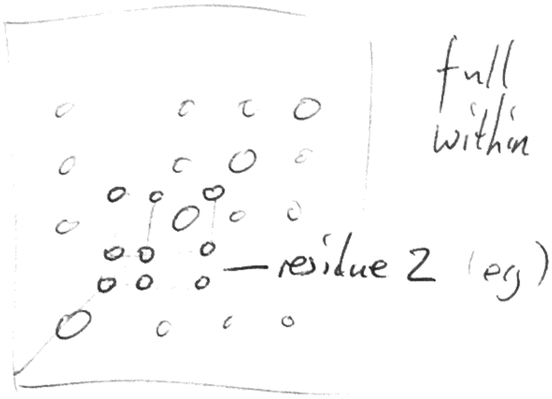


$I \propto 1/r^6$



TOCSY





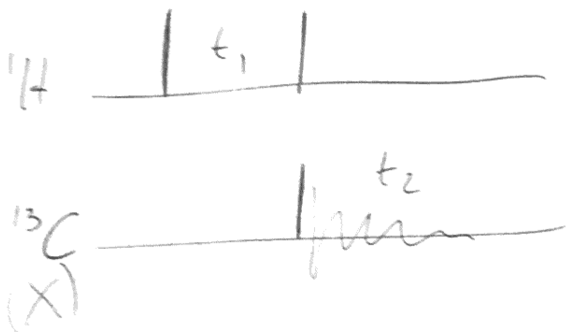
full connectivity within spin system

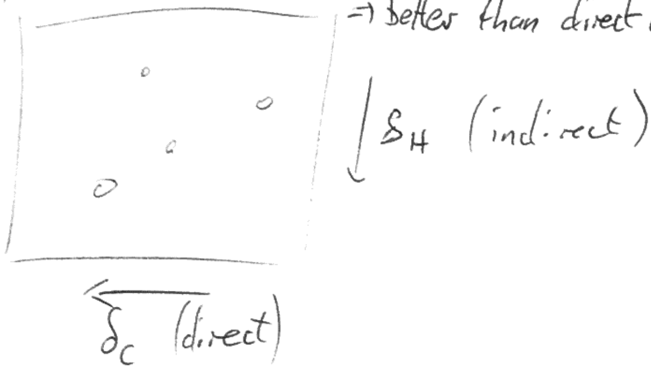
HETCOR

$^1H \rightarrow {}^{13}C \rightarrow$ detect
(X)

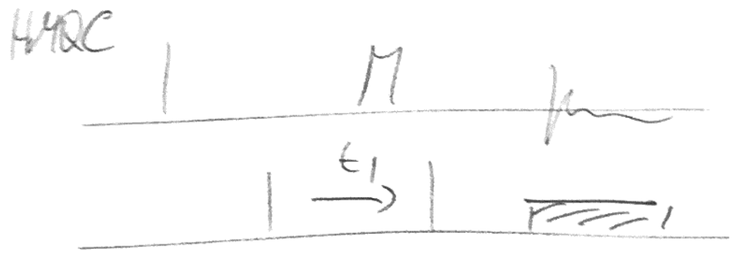
$SNR \propto \gamma_{ex} \gamma_{obs}^{3/2}$

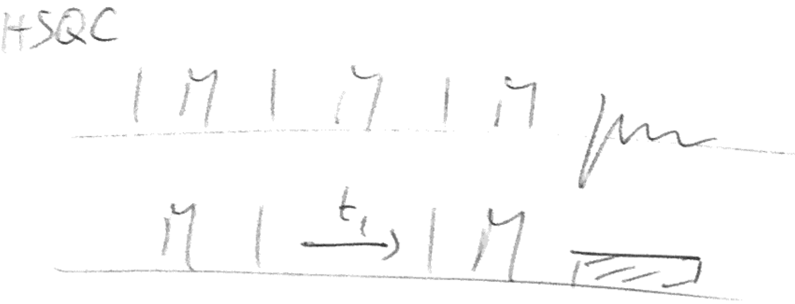
⇒ better than direct detection





HMQC / HSQC





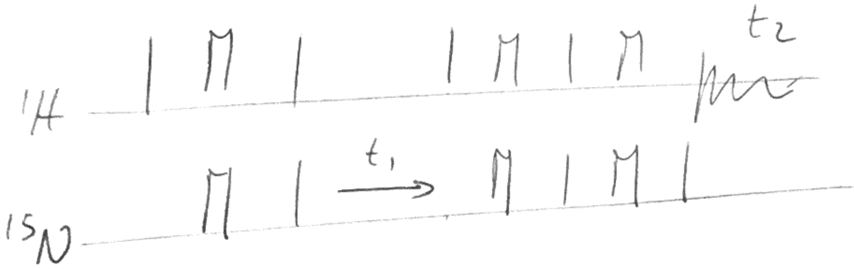
$^1H \rightarrow X \rightarrow {}^1H$

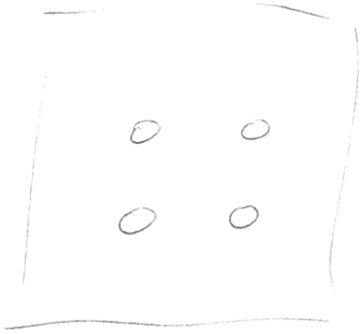
$SNR \propto \gamma_{ex} \gamma_{obs}^{3/2}$

$\gamma_H / \gamma_C = 4 \Rightarrow 500\times$

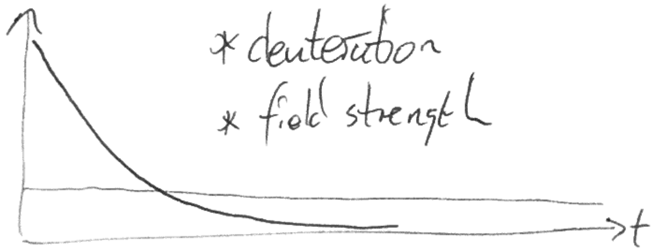
$\gamma_H / \gamma_N = 10 \Rightarrow 50{,}000\times$

TROSY





25% of signal – but ↓ R_2



* deuteration
* field strength