LECTURE 4

Pulse: frequency

B_0: 9 T–27 T

^{1}H: 400 MHz–1200 MHz

^{13}C: 100 MHz–300 MHz

^{15}N: 40 MHz–120 MHz

Pulse: phase

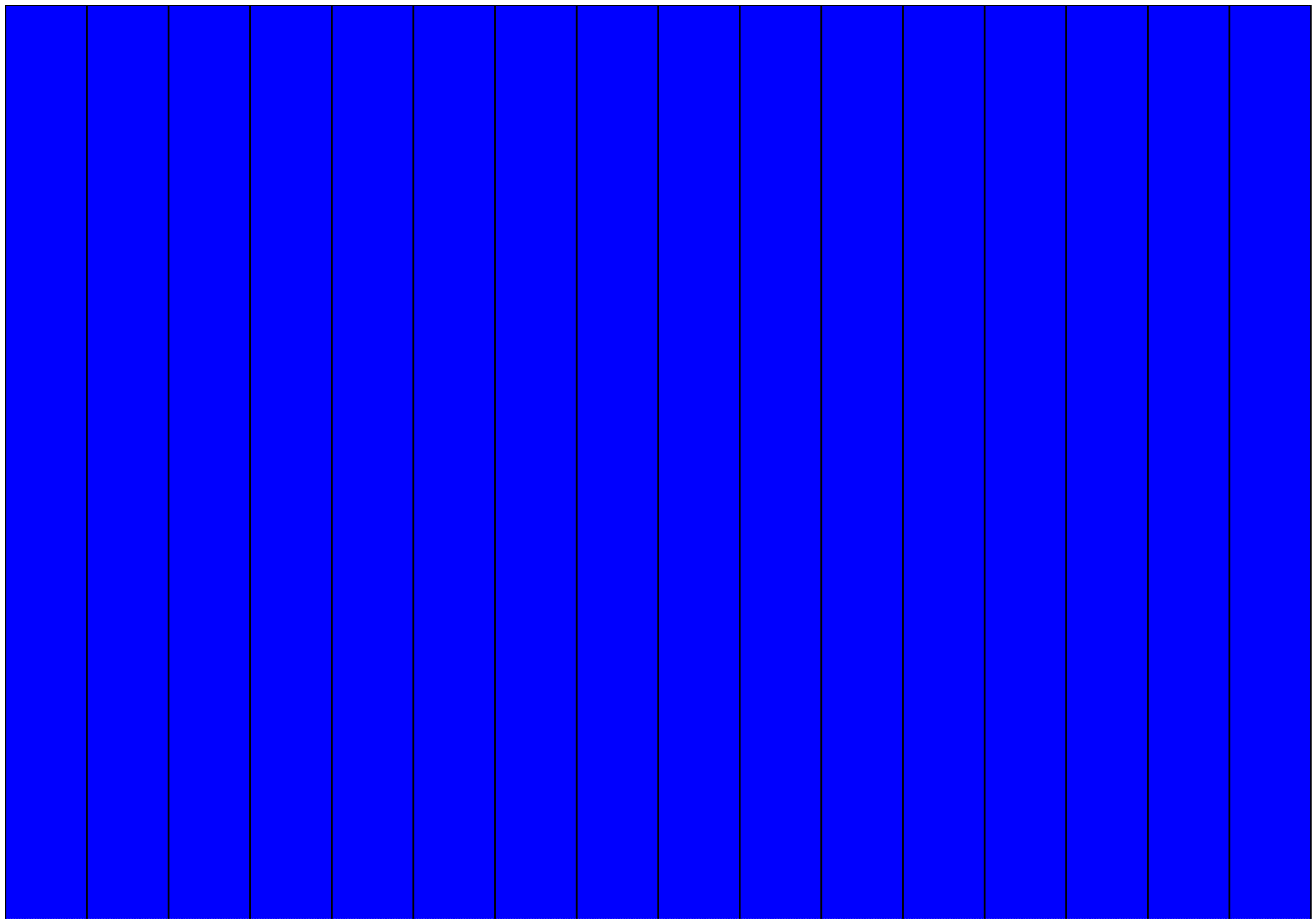
first pulse:

convention: 180° for $\gamma > 0$
convention: 0° for $\gamma < 0$

other pulses:

0°	x
90°	y
180°	$-x$
270°	$-y$

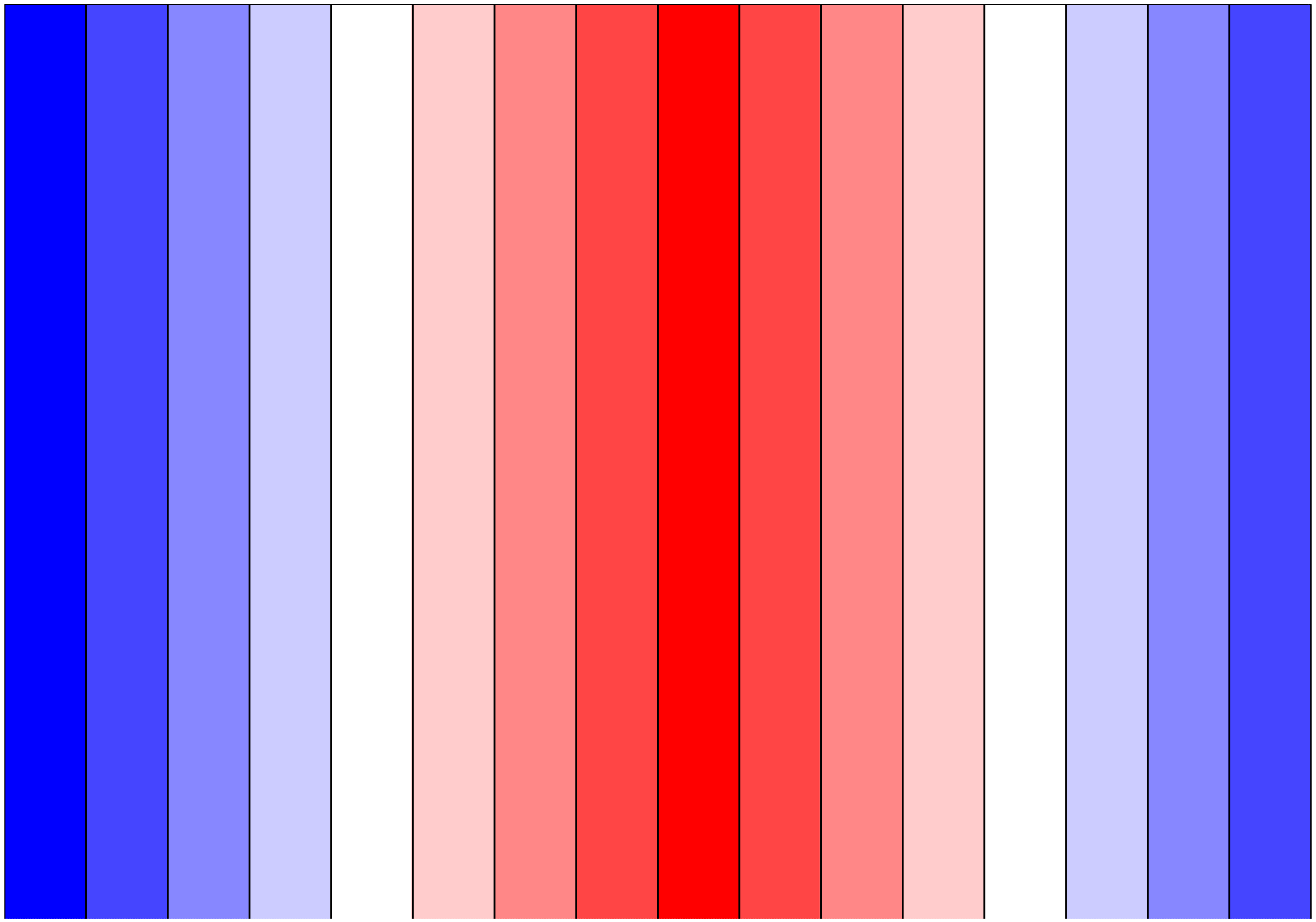
Pulse: phase modulation



0 cycle per pulse

100 μs pulse: $+0$ kHz

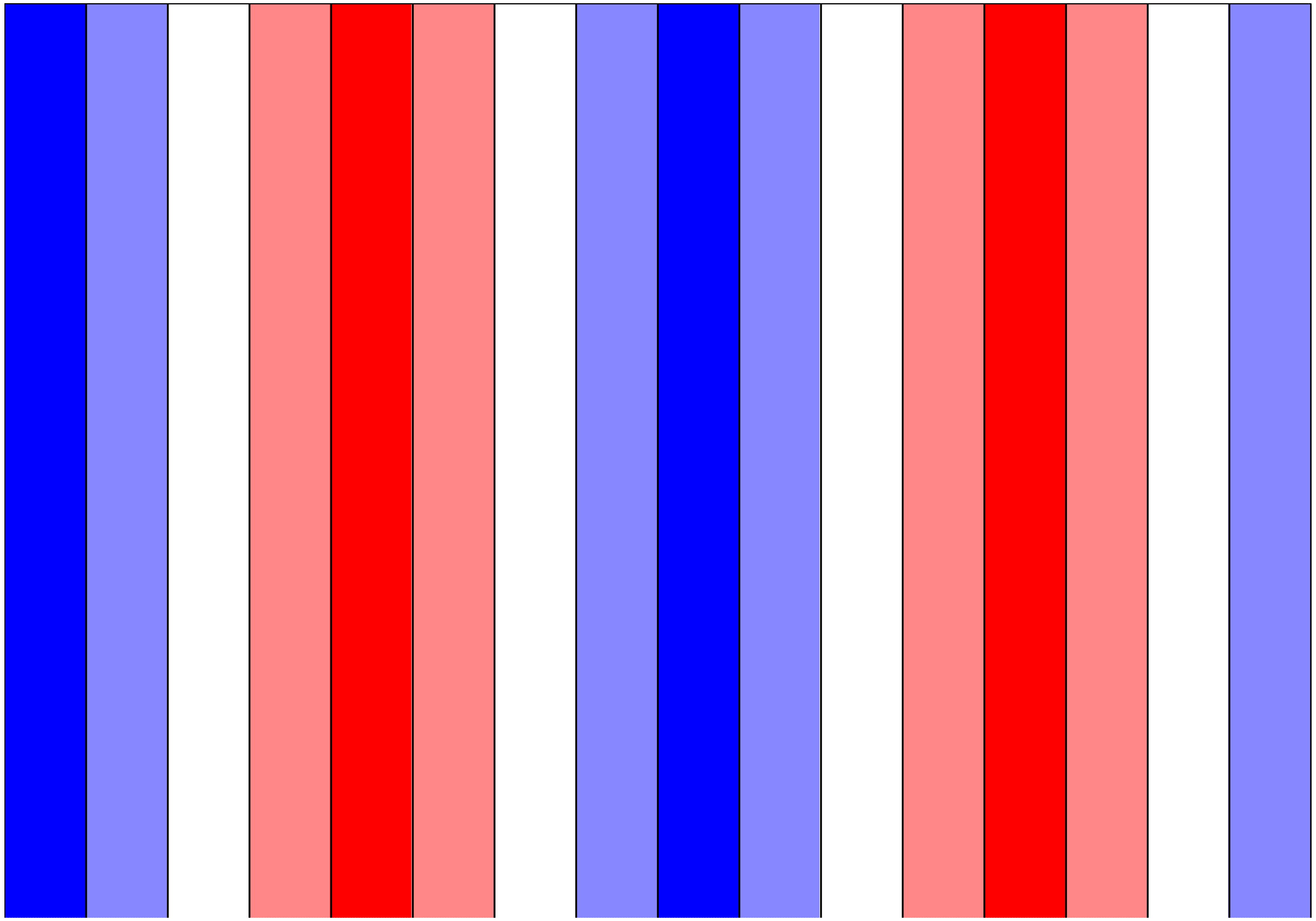
Pulse: phase modulation



1 cycle per pulse

100 μs pulse: $+10$ kHz

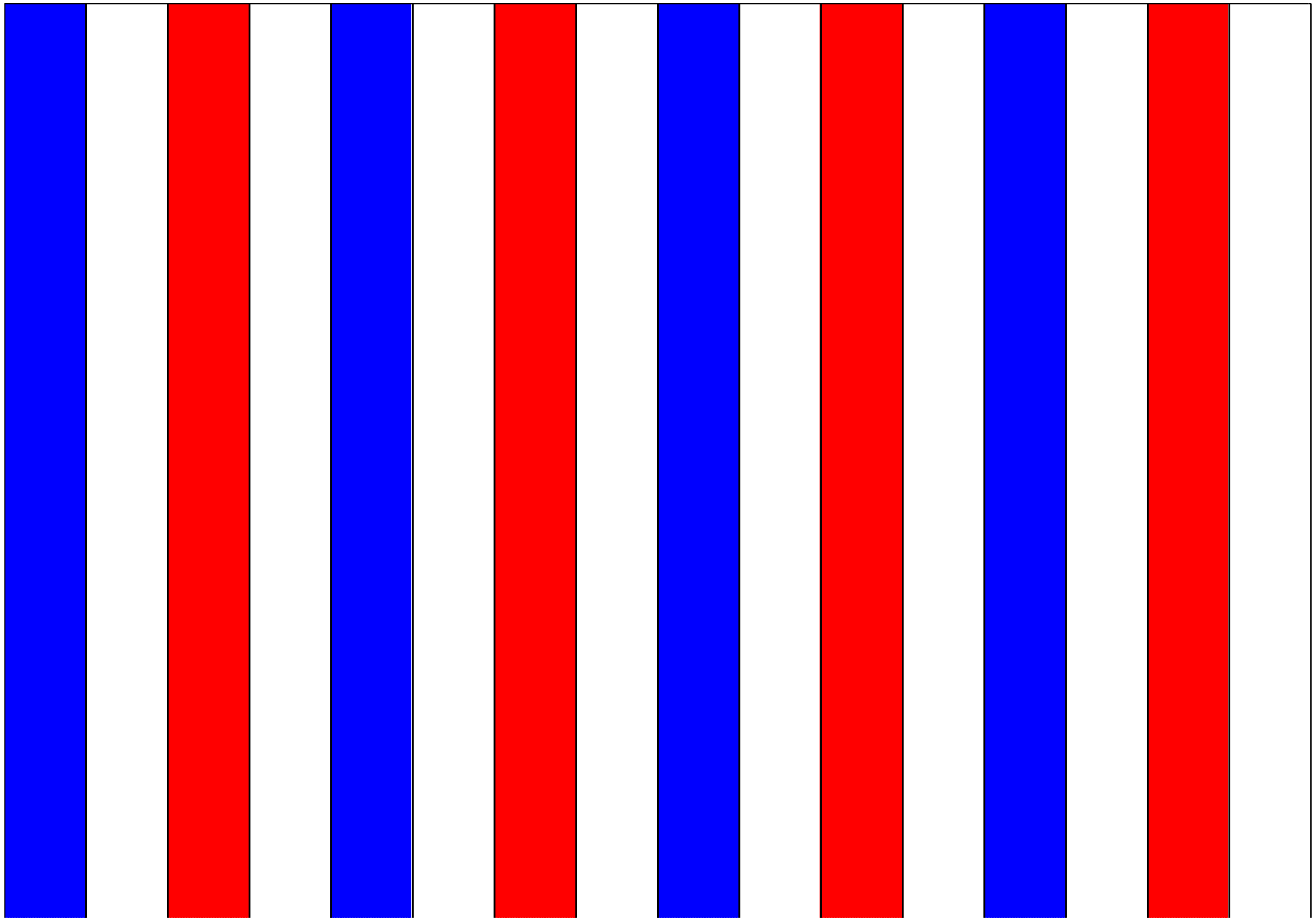
Pulse: phase modulation



2 cycles per pulse

100 μs pulse: $+20$ kHz

Pulse: phase modulation



4 cycles per pulse

100 μs pulse: $+40$ kHz

Pulse: power / amplitude

field strength	$\lvert\omega_1\rvert = \lvert\gamma B_1\rvert$	kHz
power	$P \propto B_1^2$	W
attenuation	$10\log_{10}\frac{P_2}{P_1}$	dB

$$20\log_{10}\frac{|\vec{B}_1|_2}{|\vec{B}_1|_1} = 10\log_{10}\frac{|\vec{B}_1|_2^2}{|\vec{B}_1|_1^2} = 10\log_{10}\frac{P_2}{P_1}$$

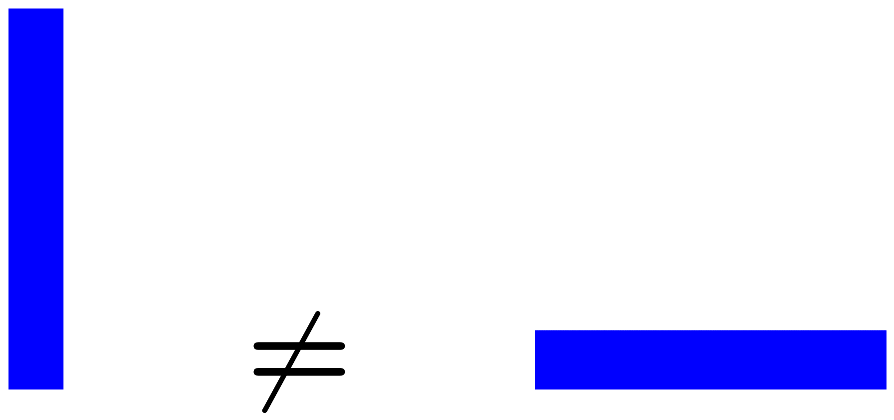
typical: $P < 1000\,W$, $|\omega_1| < 50$ kHz

limit: sample/coil heating

Pulse: length

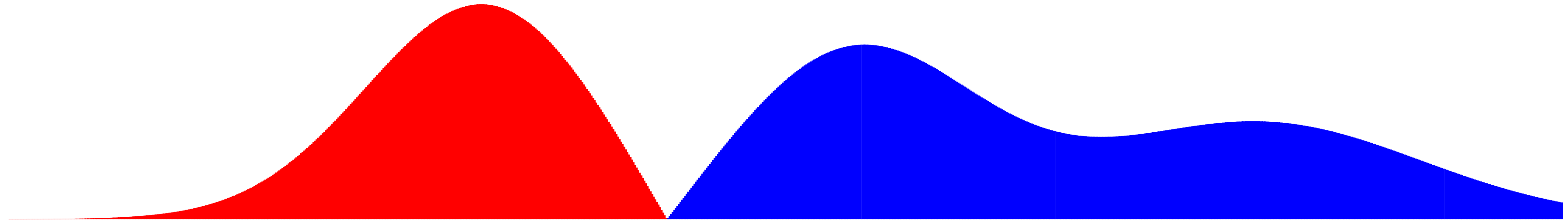
calibrate so that $\alpha = |\omega_1| t_\mathrm{p}$

where $\alpha = 90^\circ, 180^\circ, \ldots$



OFFSET EFFECTS!

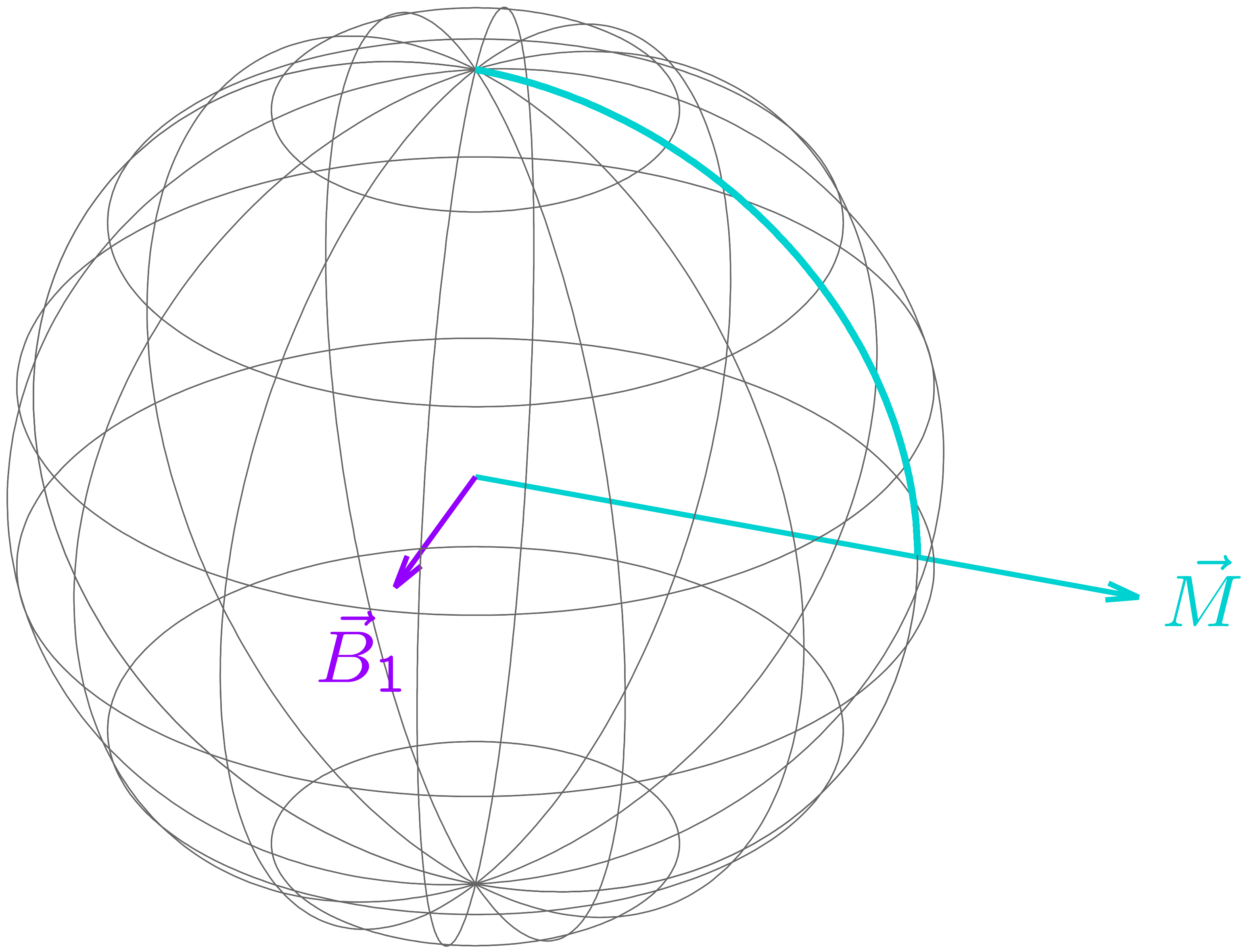
Pulse: amplitude modulation



calibrate/calculate power so that $\alpha = |\omega_1| t_\mathrm{p}$

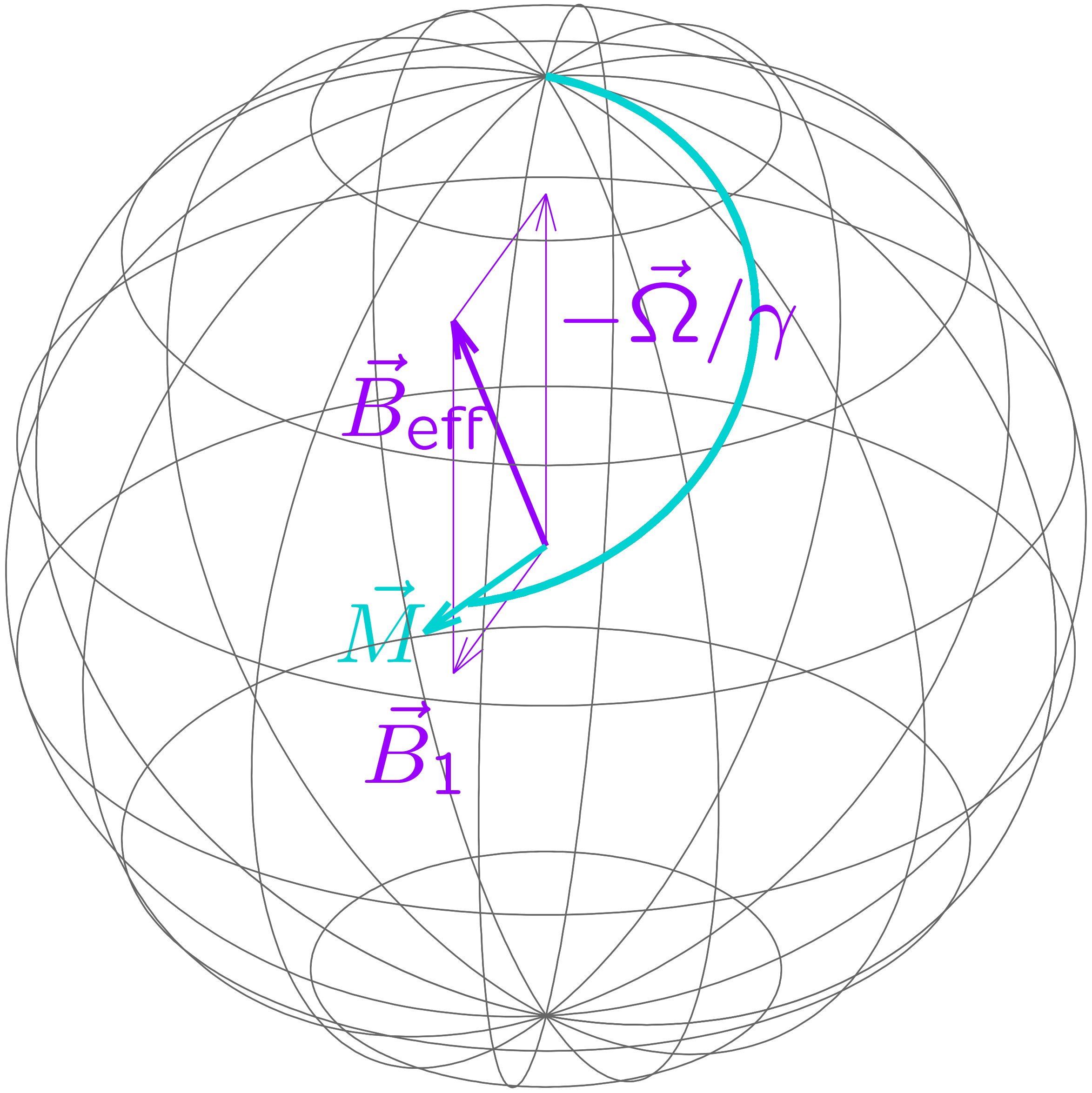
where $\alpha = 90^\circ, 180^\circ, \ldots$

Offset effects / selectivity



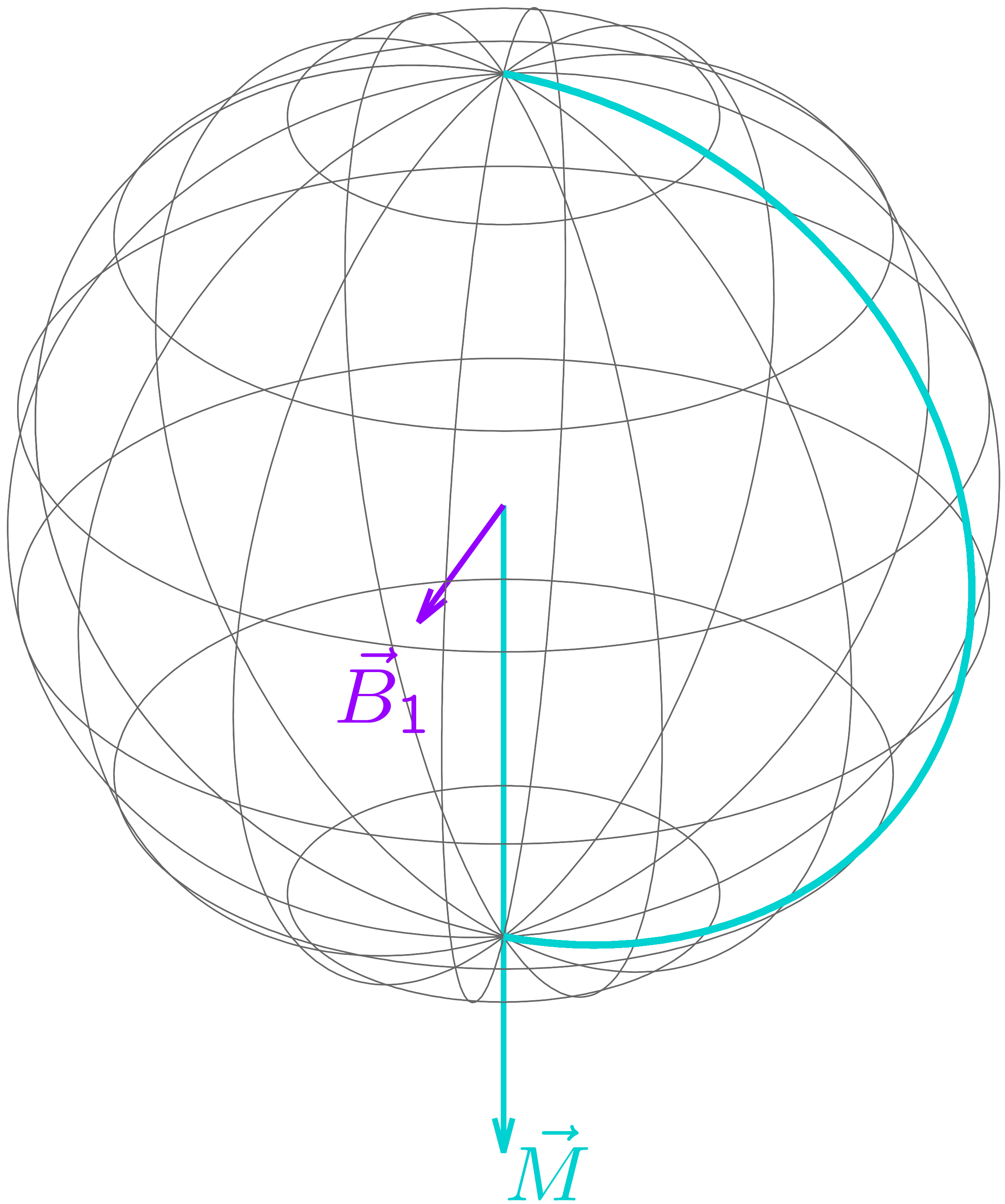
$\Omega = 0$ on resonance

Offset effects / selectivity



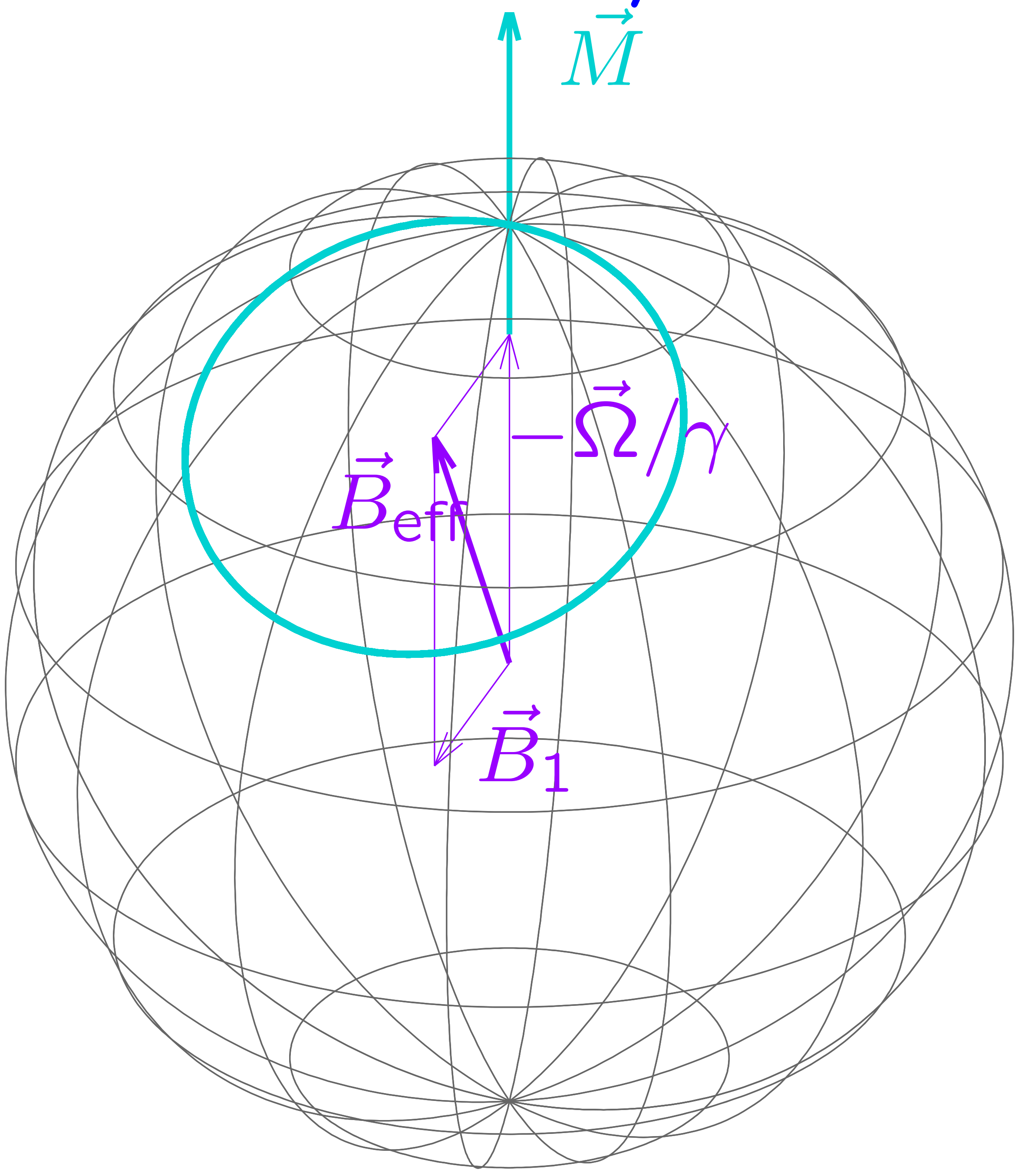
$\Omega \neq 0$ off resonance

Offset effects / selectivity

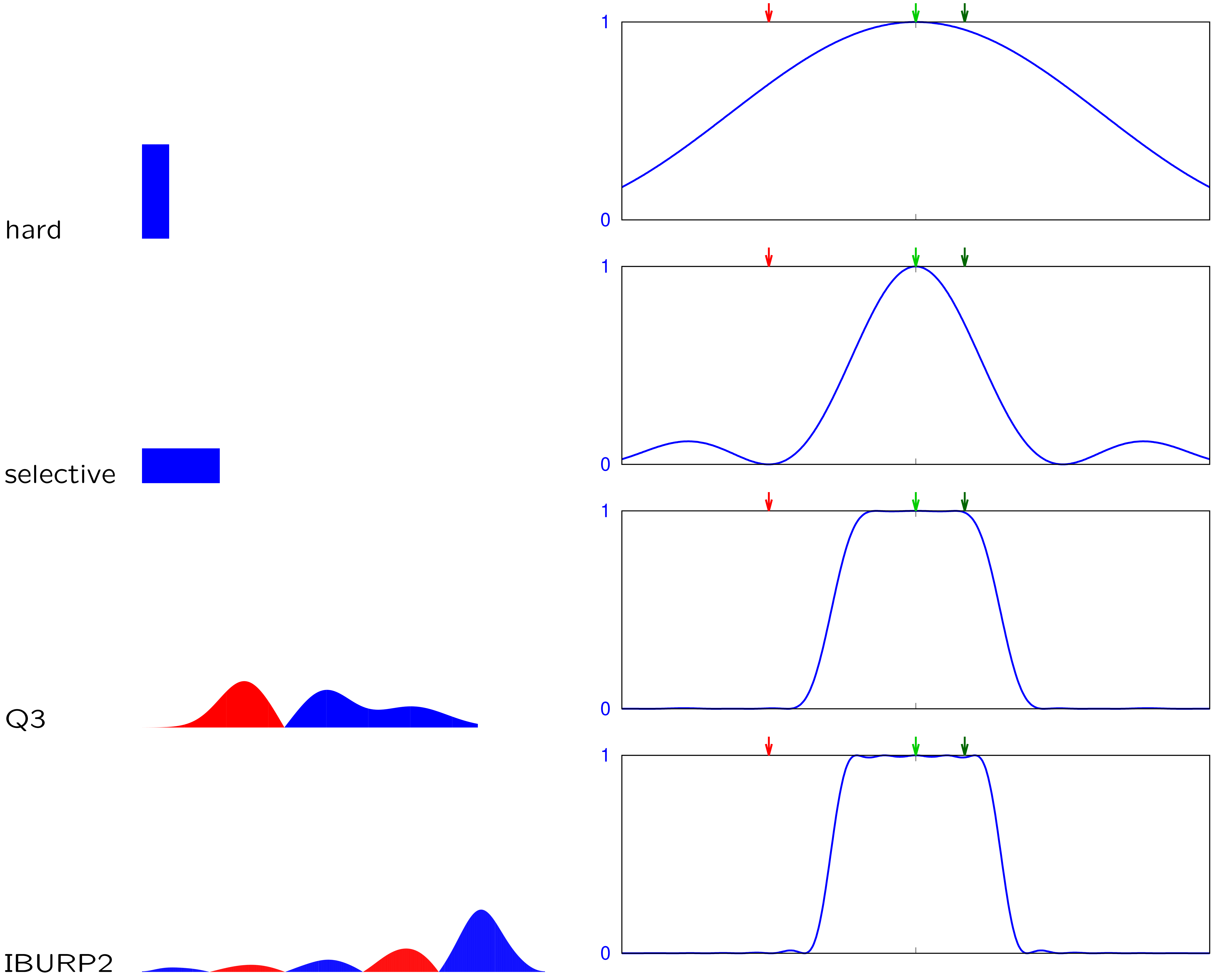


$\Omega = 0$ on resonance

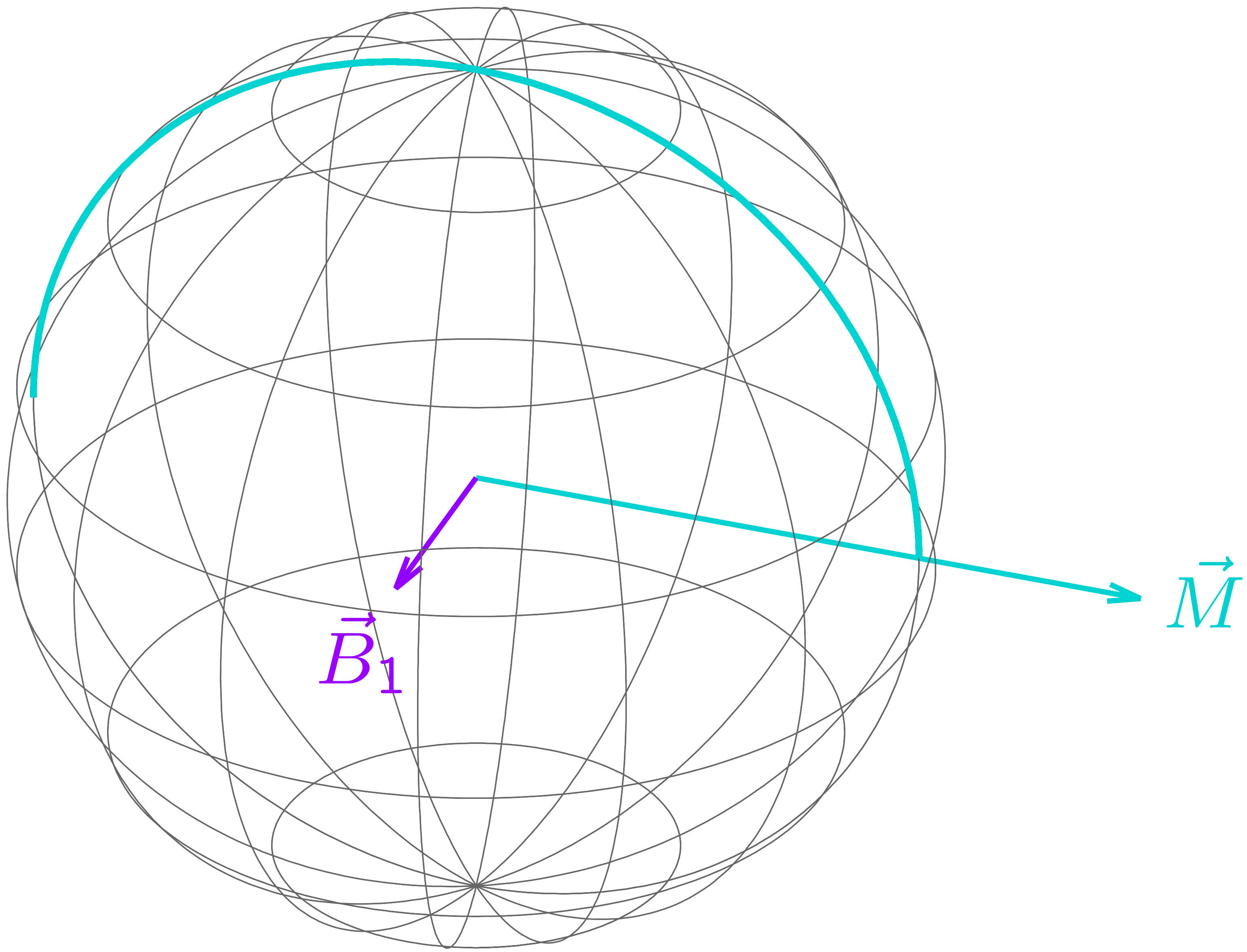
Offset effects / selectivity



$$\omega_1 = \Omega/\sqrt{3}; \quad \omega_{\text{eff}} = \sqrt{1+3}\,\omega_1 = 2\omega_1$$

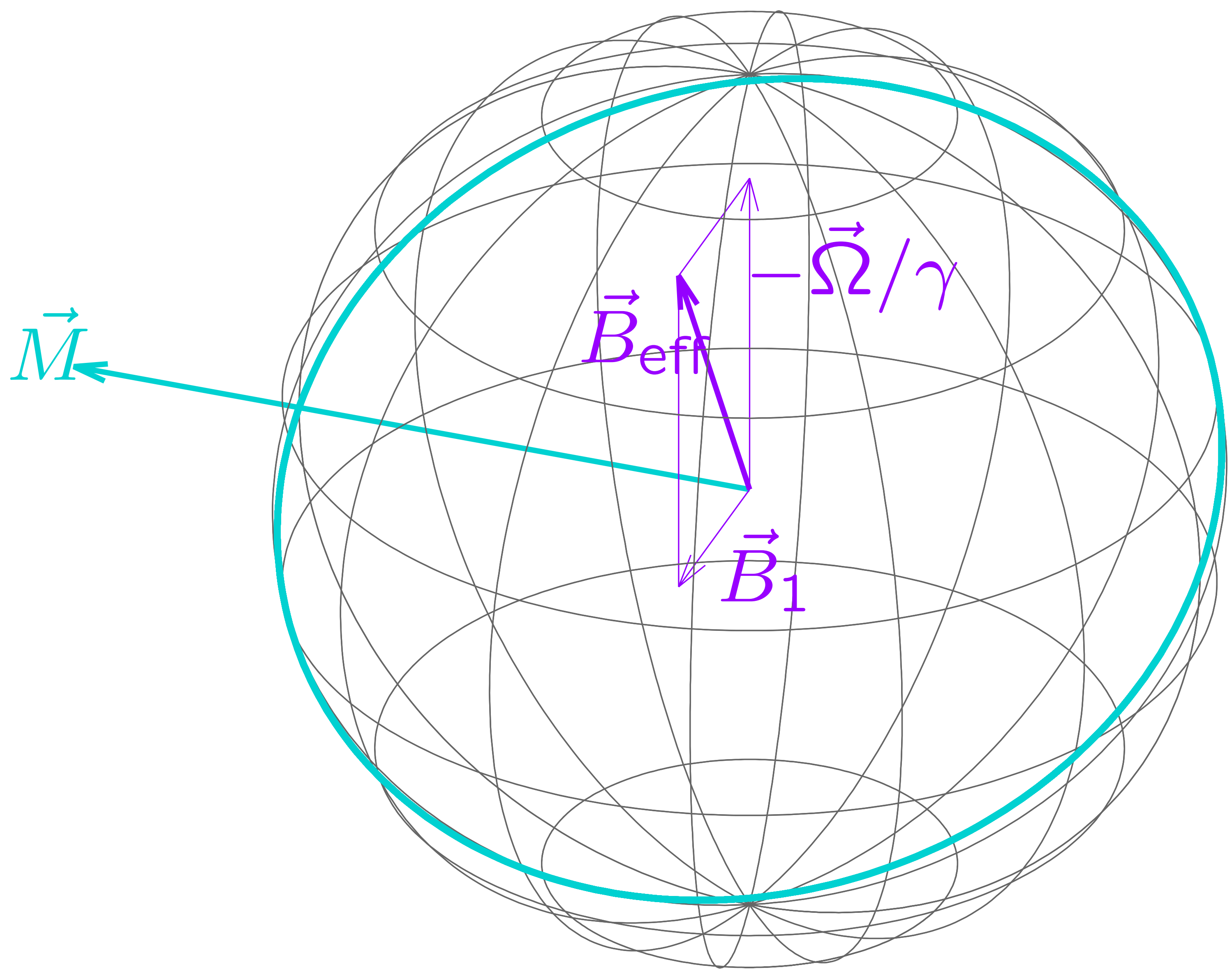

hard
selective
Q3
IBURP2
1
0
1
0
1
0
1
0

Offset effects / selectivity

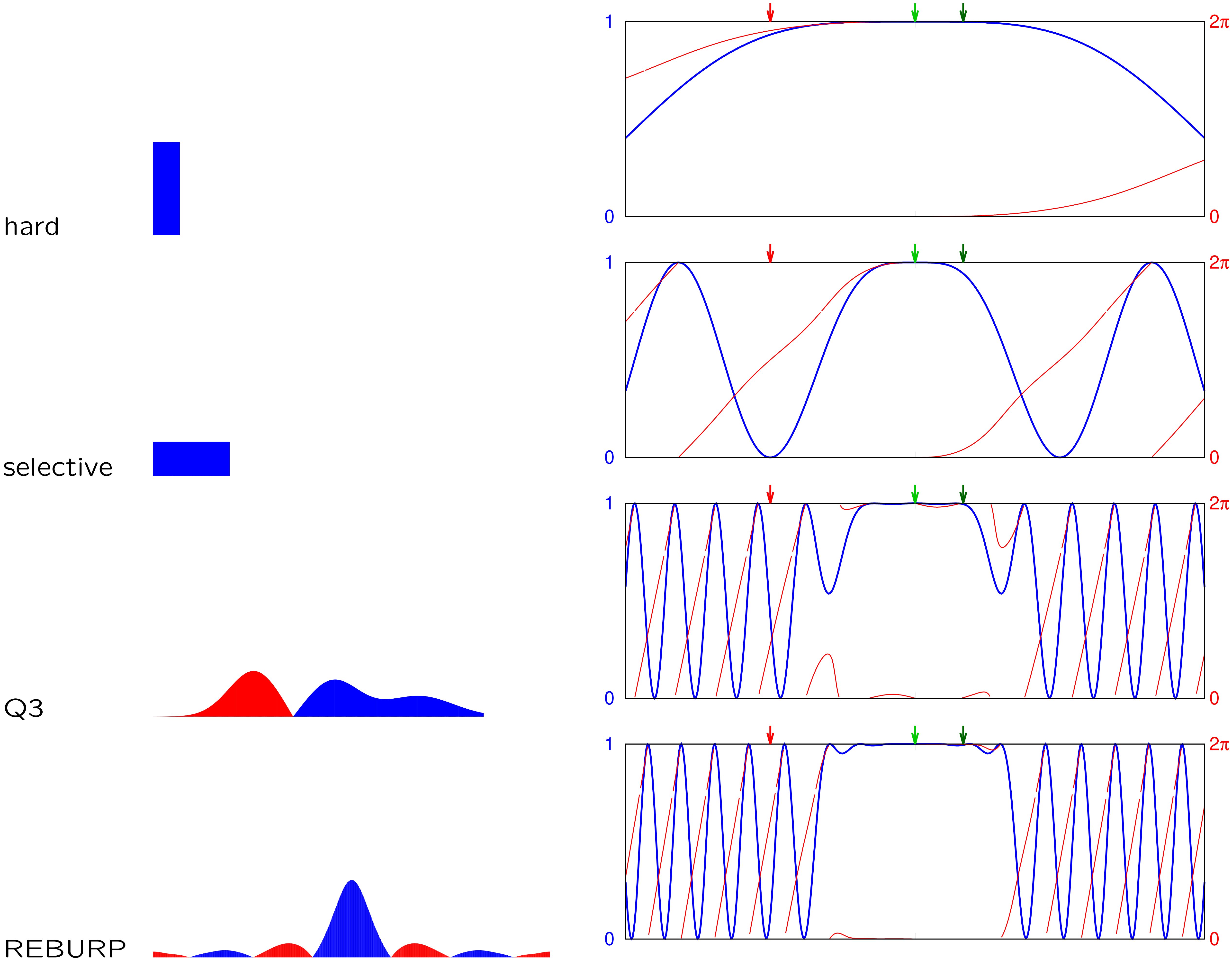


$\Omega = 0$ on resonance

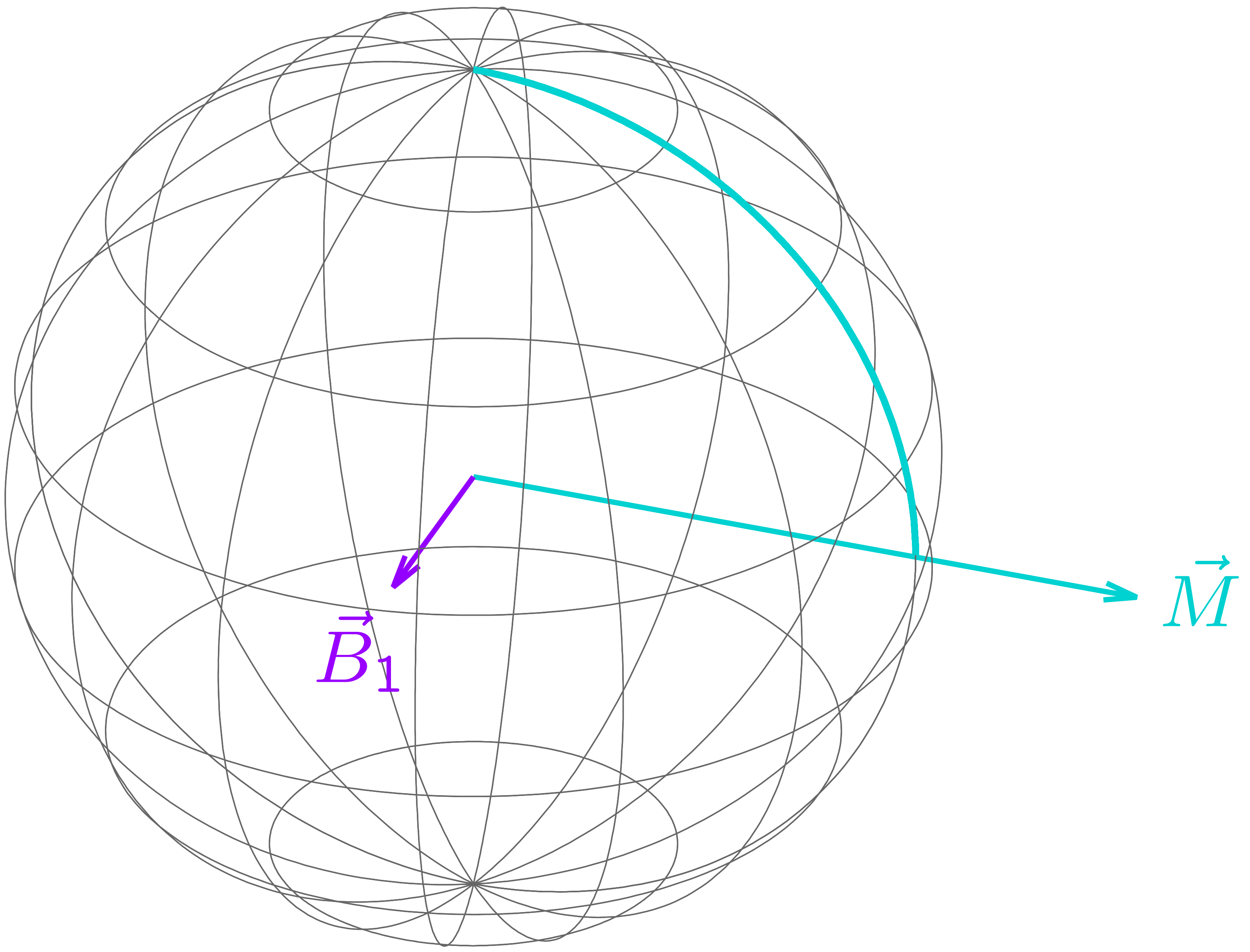
Offset effects / selectivity



$$\omega_1 = \Omega/\sqrt{3}; \quad \omega_{\text{eff}} = \sqrt{1+3}\,\omega_1 = 2\omega_1$$

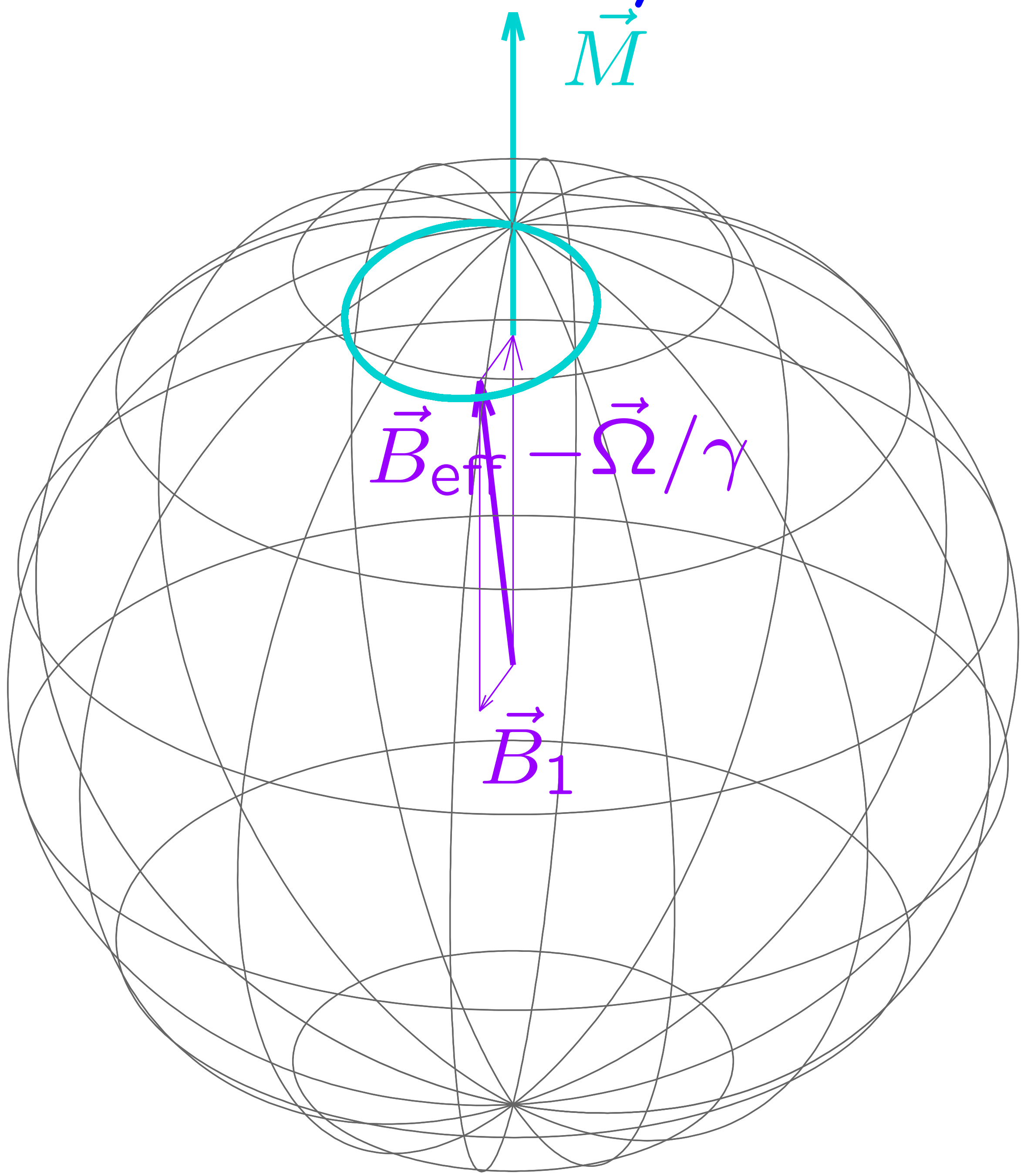

hard
selective
Q3
REBURP
1
0
2π
0

Offset effects / selectivity

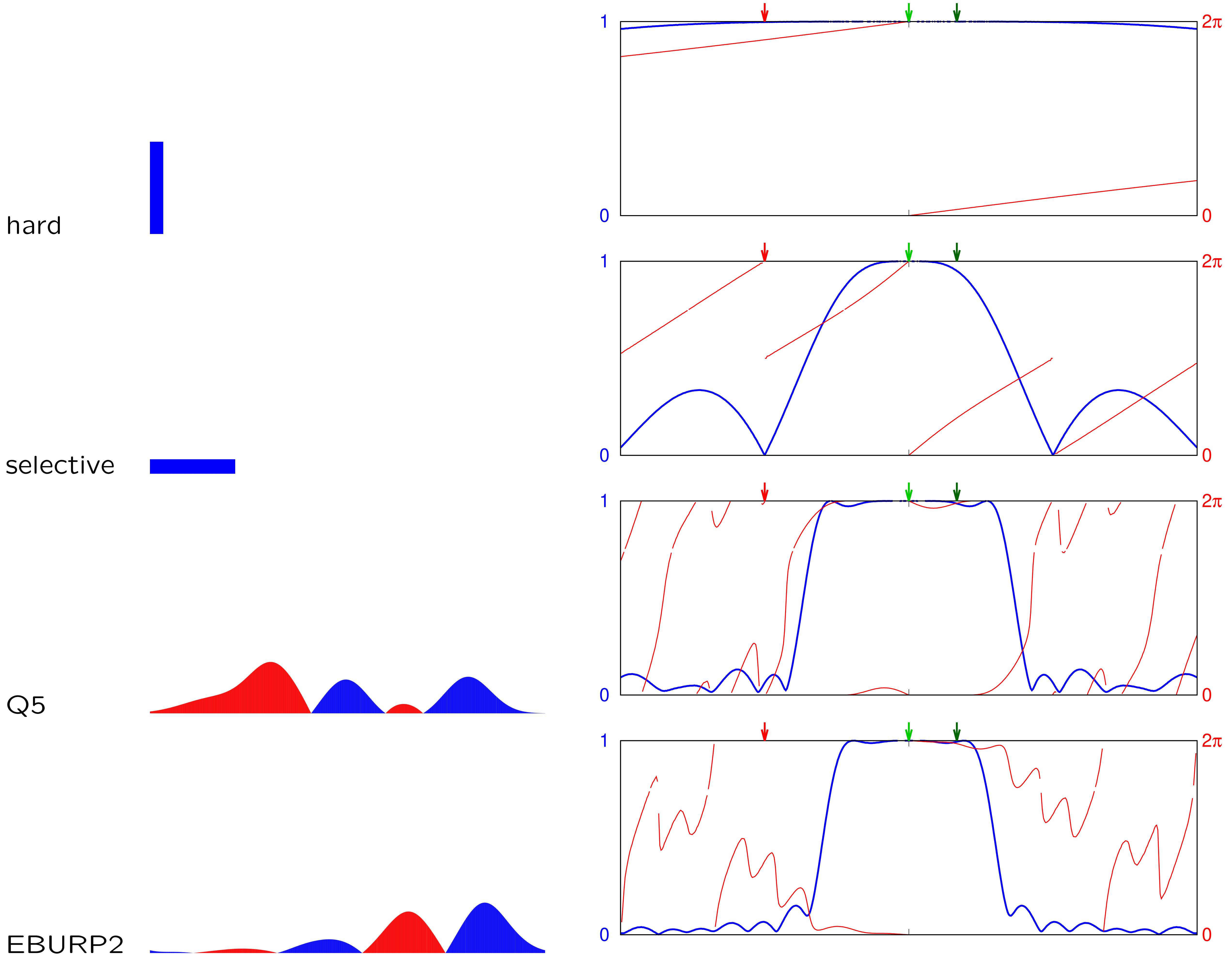


$\Omega = 0$ on resonance

Offset effects / selectivity



$$\omega_1 = \Omega/\sqrt{15}; \quad \omega_{\text{eff}} = \sqrt{1+15}\,\omega_1 = 4\omega_1$$



hard
selective
Q5
EBURP2
1
0
2π
0

Quadrature detection / frequency discrimination

$$\cos(\omega_0 t) \to \begin{cases} \frac{1}{2}\cos(\omega_0 t) \to \frac{1}{2}\cos(\omega_0 t)\cos(-\omega_{\text{radio}} t) & \text{channel } a \\ \frac{1}{2}\cos(\omega_0 t) \to \frac{1}{2}\cos(\omega_0 t)\sin(-\omega_{\text{radio}} t) & \text{channel } b \end{cases}$$

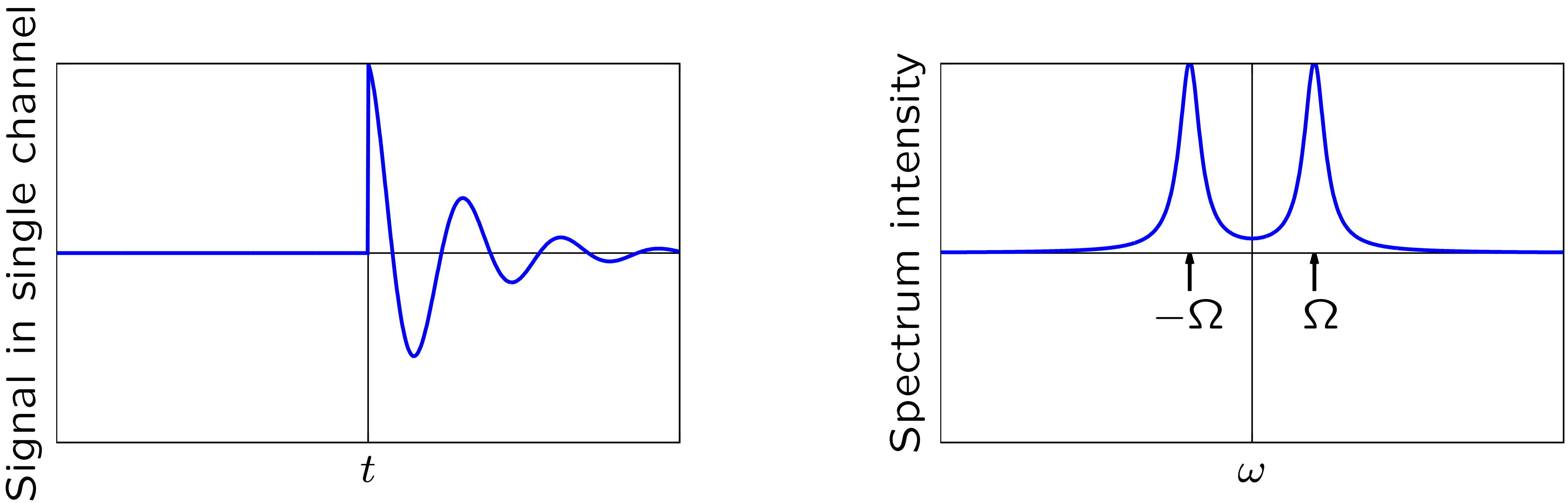
$$\frac{1}{2}\cos(\omega_0 t)\cos(-\omega_{\text{radio}} t) = \frac{1}{4}\cos(\overbrace{(\omega_0 - \omega_{\text{radio}})}^{\text{high}} t) + \frac{1}{4}\cos(\overbrace{(\omega_0 + \omega_{\text{radio}})}^{\Omega\ \text{low}} t)$$

$$\frac{1}{2}\cos(\omega_0 t)\sin(-\omega_{\text{radio}} t) = \frac{1}{4}\sin((\omega_0 - \omega_{\text{radio}})t) - \frac{1}{4}\sin((\omega_0 + \omega_{\text{radio}})t)$$

$$\cos(\omega_0 t) \to \begin{cases} \frac{1}{4}\cos(\Omega t) & \text{channel } a & a = A\cos(\Omega t) \\ \frac{1}{4}\sin(\Omega t) & \text{channel } b & b = A\sin(\Omega t) \end{cases}$$

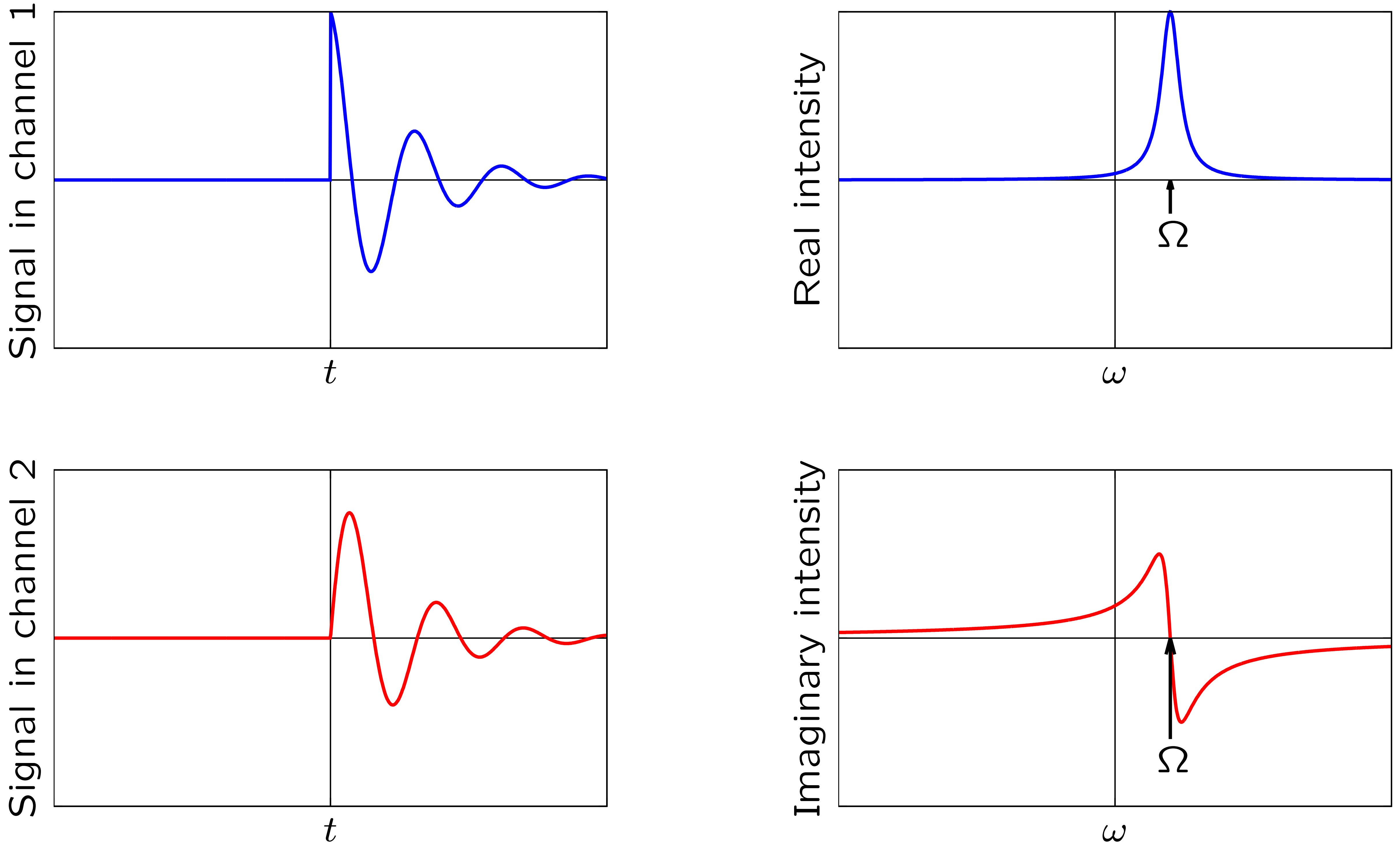
data storing option:		conventionally labeled:
	$a, \quad b$	x
	$b, -a$	y
	$-a, -b$	$-x$
	$-b, \quad a$	$-y$

Single channel, real Fourier transformation

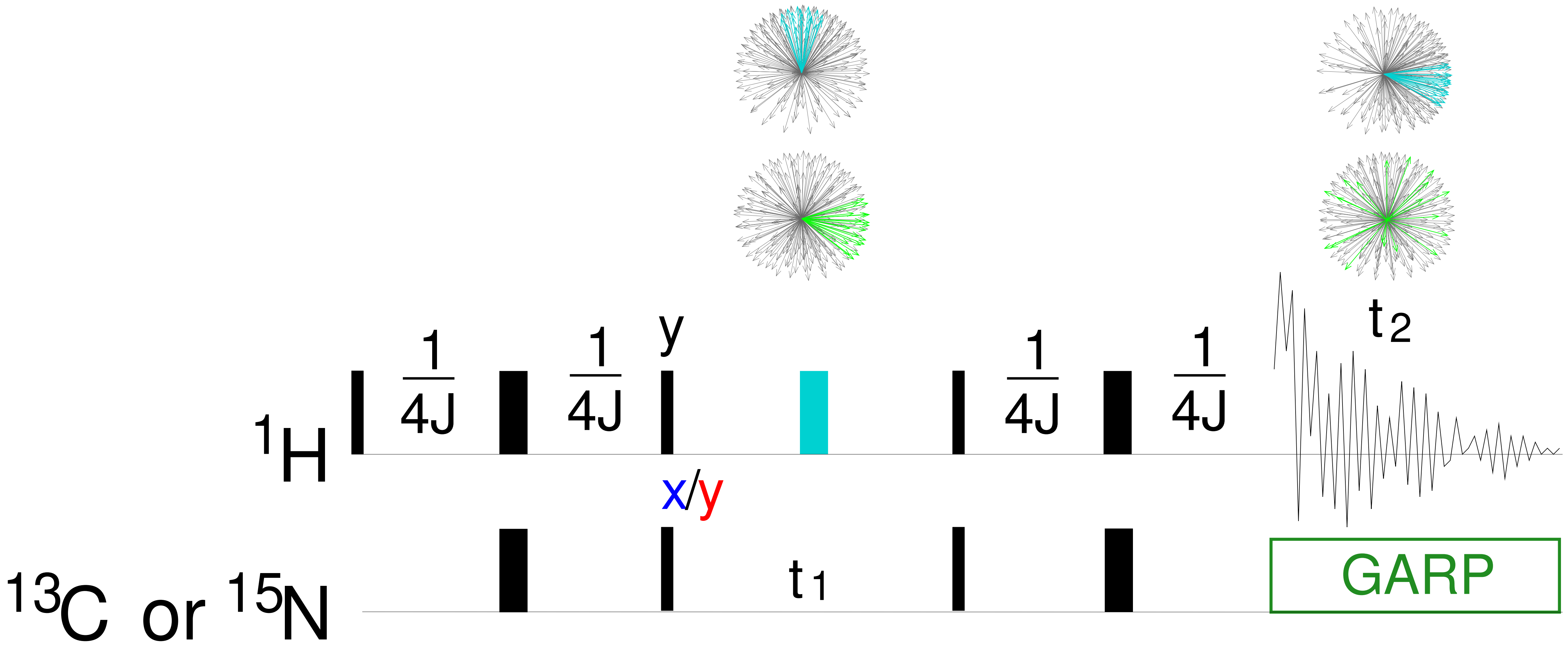


Two channels, complex Fourier transformation

$$a + \mathrm{i}b \longrightarrow X + \mathrm{i}Y$$



Complex signal in indirect dimension



Repeat with y and y

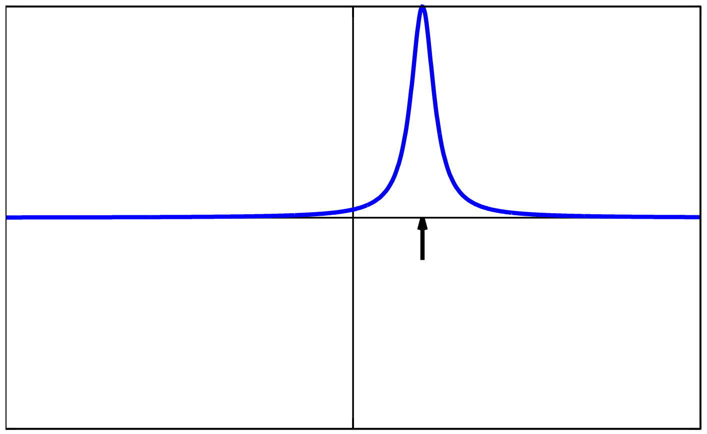
Complex signal in indirect dimension

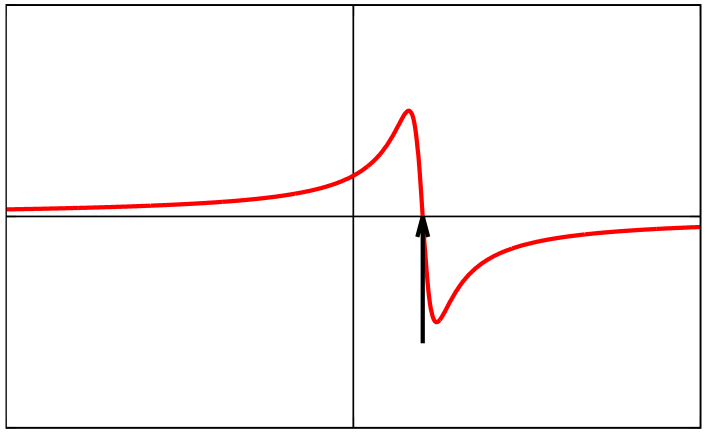
$$\left.\begin{array}{lll} r_1 = A_\mathsf{C} a = \cos(\Omega_\mathsf{C} t_1)\cos(\Omega_\mathsf{H} t_2) & \text{channel } a, & \text{pulse } x \\ r_2 = A_\mathsf{C} b = \cos(\Omega_\mathsf{C} t_1)\sin(\Omega_\mathsf{H} t_2) & \text{channel } b, & \text{pulse } x \\ r_3 = A_\mathsf{S} a = \sin(\Omega_\mathsf{C} t_1)\cos(\Omega_\mathsf{H} t_2) & \text{channel } a, & \text{pulse } y \\ r_4 = A_\mathsf{S} b = \sin(\Omega_\mathsf{C} t_1)\sin(\Omega_\mathsf{H} t_2) & \text{channel } b, & \text{pulse } y \end{array}\right\} (A_\mathsf{C} + \mathrm{i} A_\mathsf{S})(a + \mathrm{i} b)$$

x/y	receiver	acquired as	stored as records r_j
$+x$	$+x$	$a : A_\mathsf{C}\sin(\Omega_\mathsf{H} t_2)$	$r_1, r_2 = A_\mathsf{C}\sin(\Omega_\mathsf{H} t_2), A_\mathsf{C}\cos(\Omega_\mathsf{H} t_2)$
		$b : A_\mathsf{C}\cos(\Omega_\mathsf{H} t_2)$	
$+y$	$+x$	$a : A_\mathsf{S}\sin(\Omega_\mathsf{H} t_2)$	$r_3, r_4 = A_\mathsf{S}\sin(\Omega_\mathsf{H} t_2), A_\mathsf{S}\cos(\Omega_\mathsf{H} t_2)$
		$b : A_\mathsf{S}\cos(\Omega_\mathsf{H} t_2)$	

Complex signal in indirect dimension

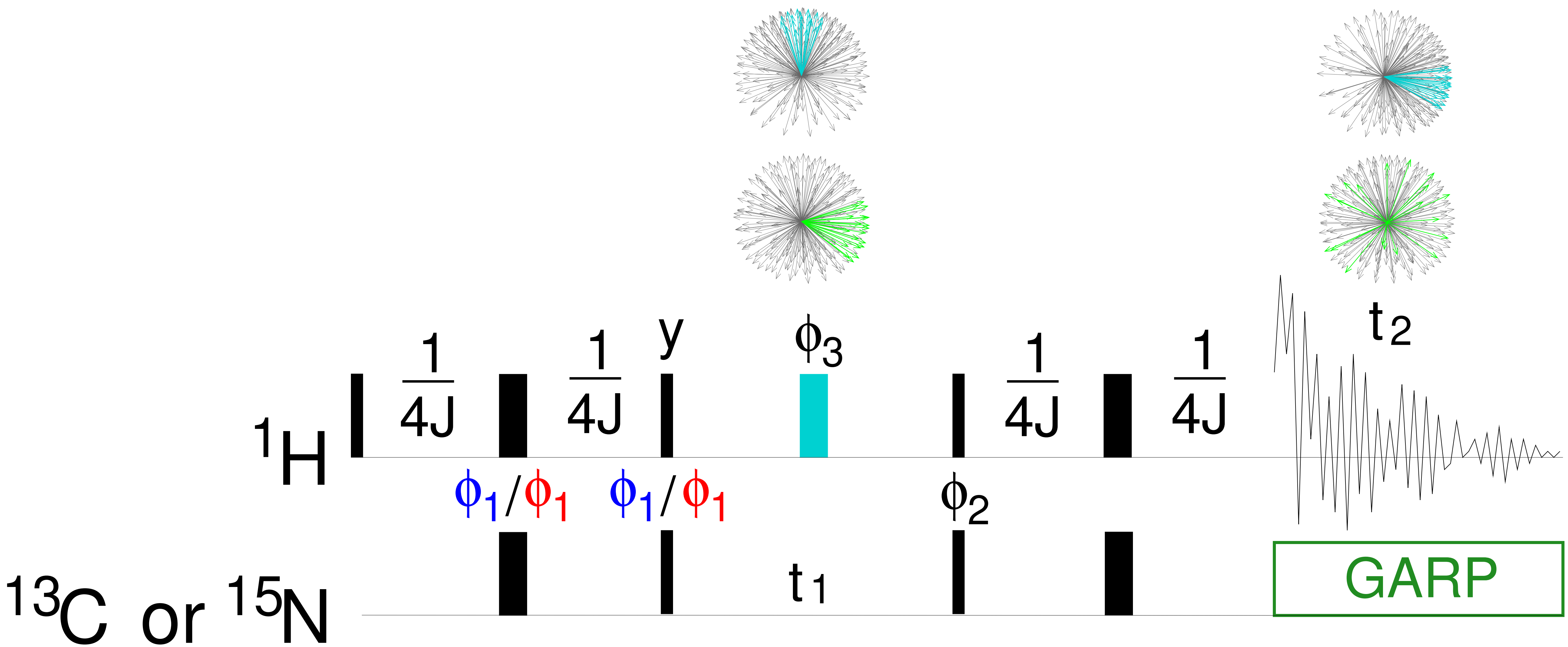
$$(A_c + iA_s)(a + ib) \longrightarrow (A_c + iA_s)(X_2 + iY_2) \longrightarrow (X_1 + iY_1)(X_2 + iY_2) = X_1X_2 - Y_1Y_2 + i(X_1Y_2 + Y_1X_2)$$

$X_j =$ 

$Y_j =$ 

$$(A_c + iA_s)(a + ib) \longrightarrow (A_c + iA_s)(X_2 + iY_2) \longrightarrow (A_c + iA_s)X_2 \longrightarrow (X_1 + iY_1)X_2 = X_1X_2 + iY_1X_2$$

Phase cycling

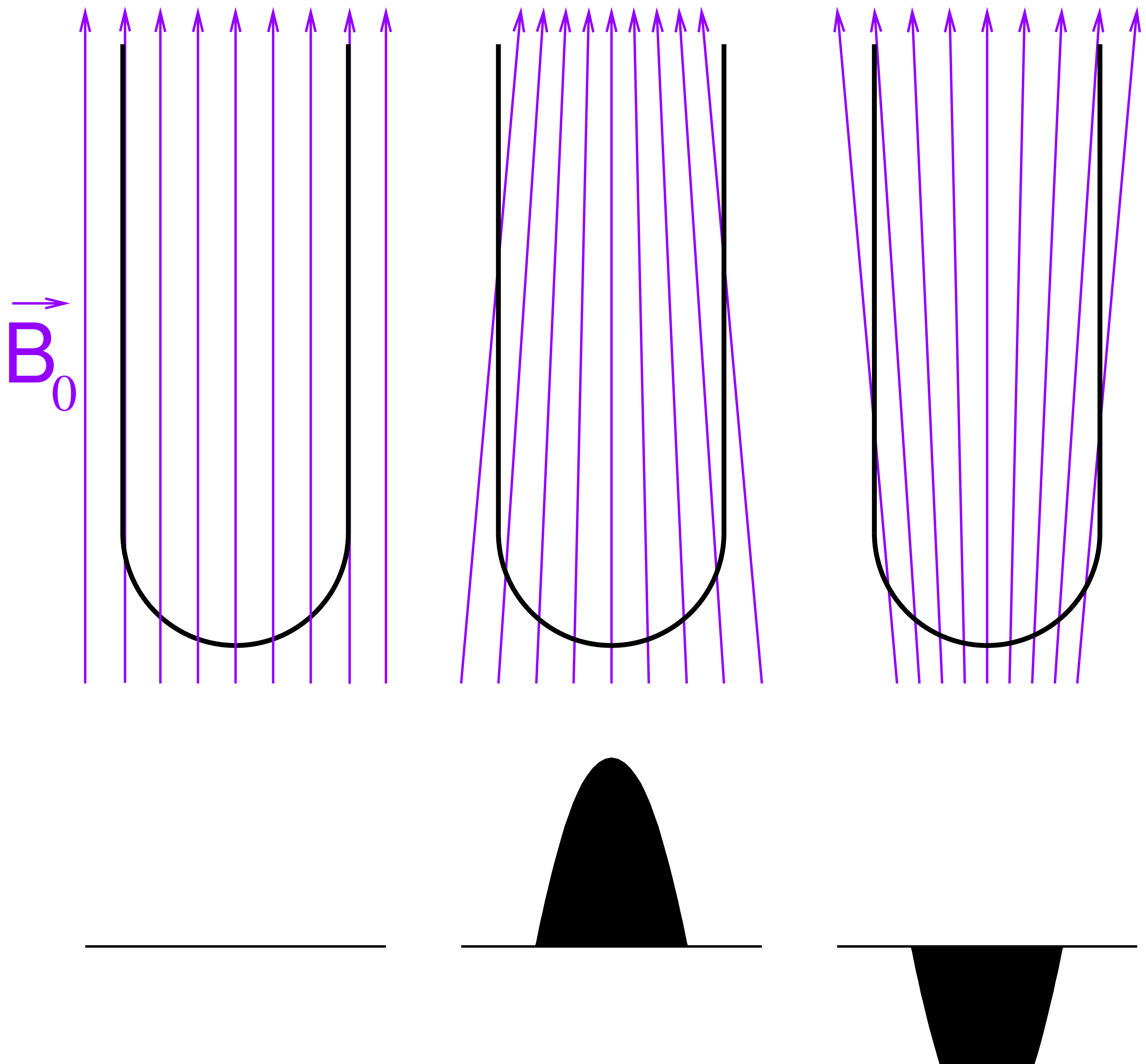


ϕ_1=x,−x,x,−x,x,−x,x,−x ϕ_2=x,x,−x,−x,x,x,−x,−x

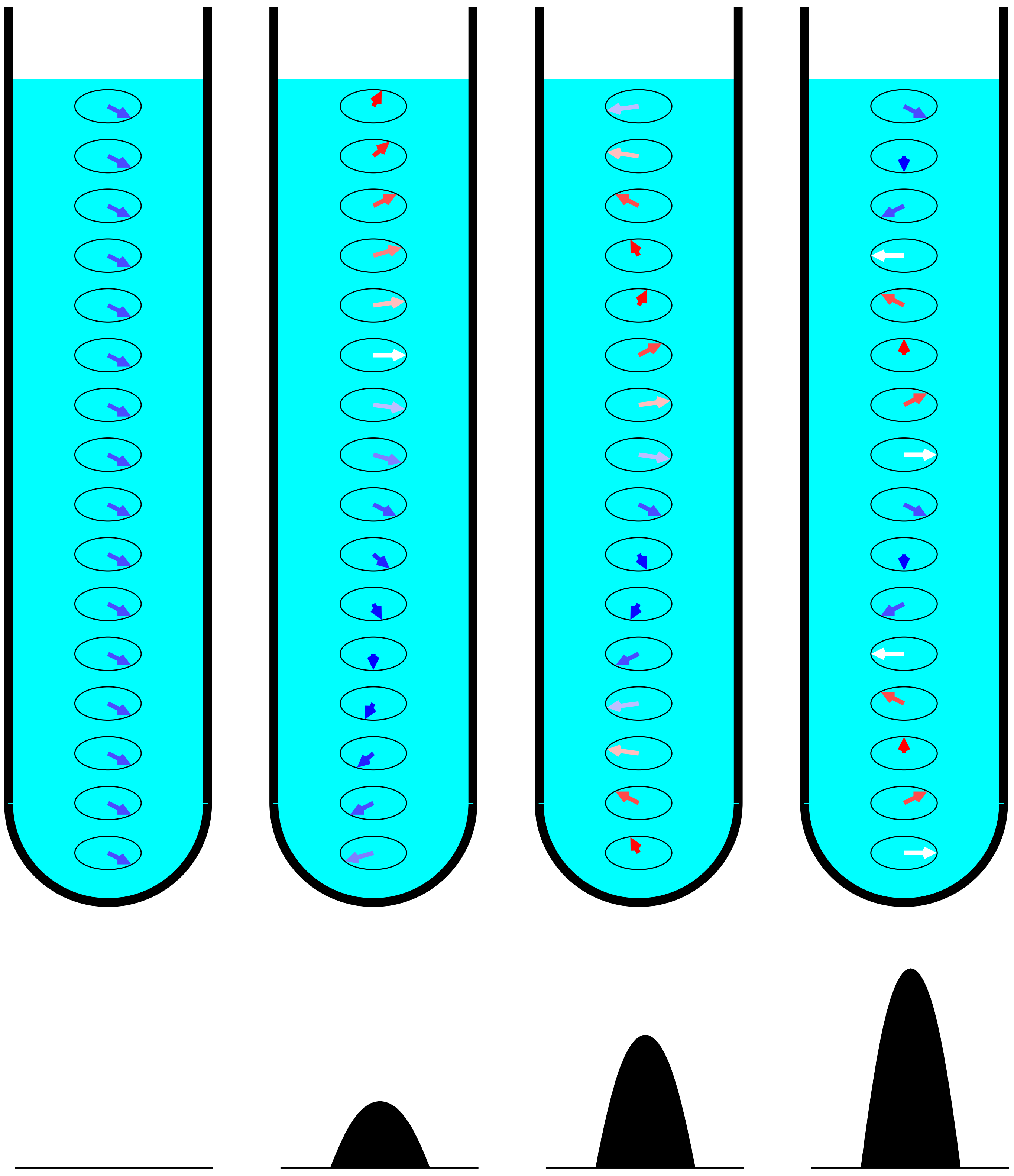
ϕ_1=y,−y,y,−y,y,−y,y,−y ϕ_3=x,x,x,x,−x,−x,−x,−x

receiver phase: x,−x,−x,x,x,−x,−x,x

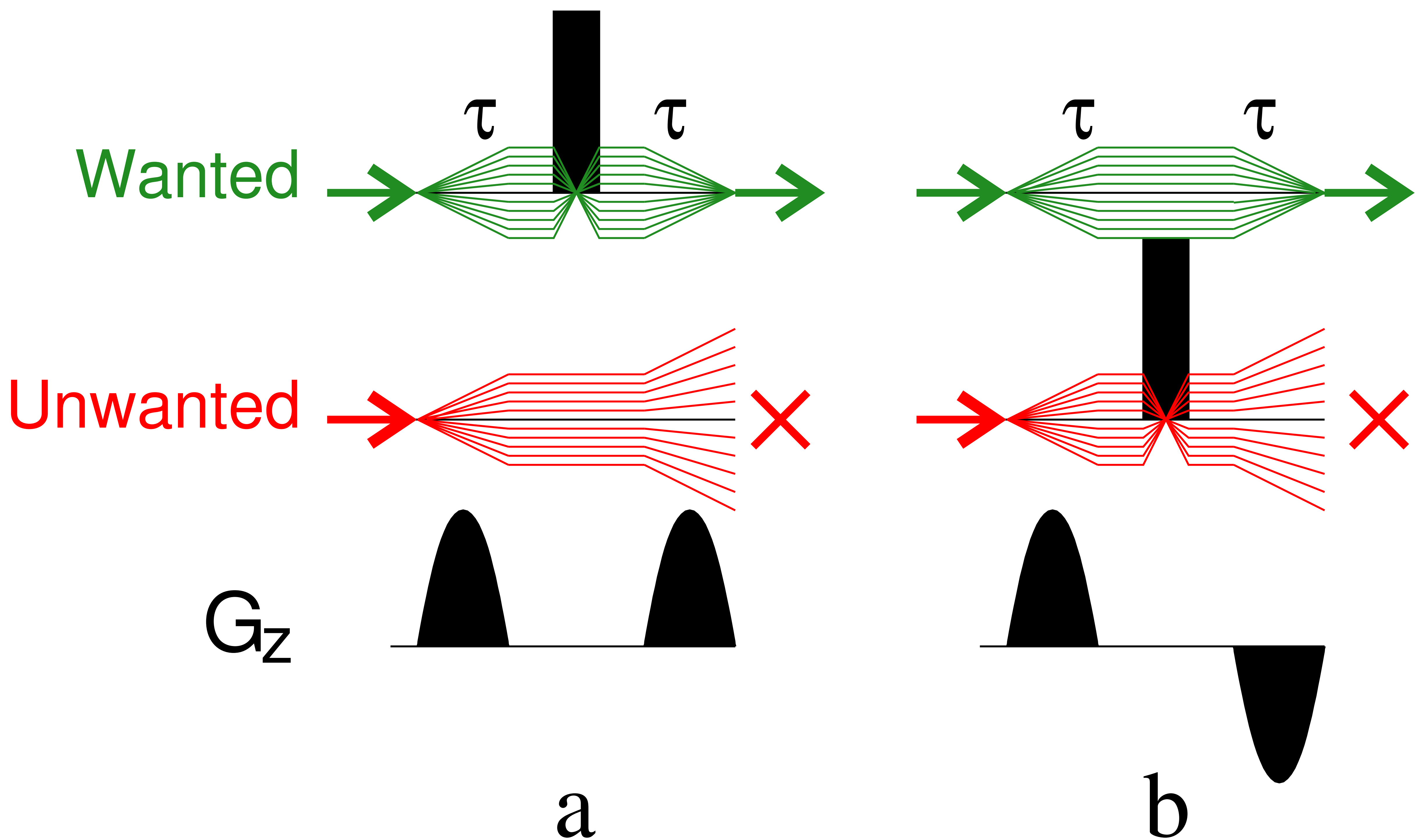
Pulsed-field gradients



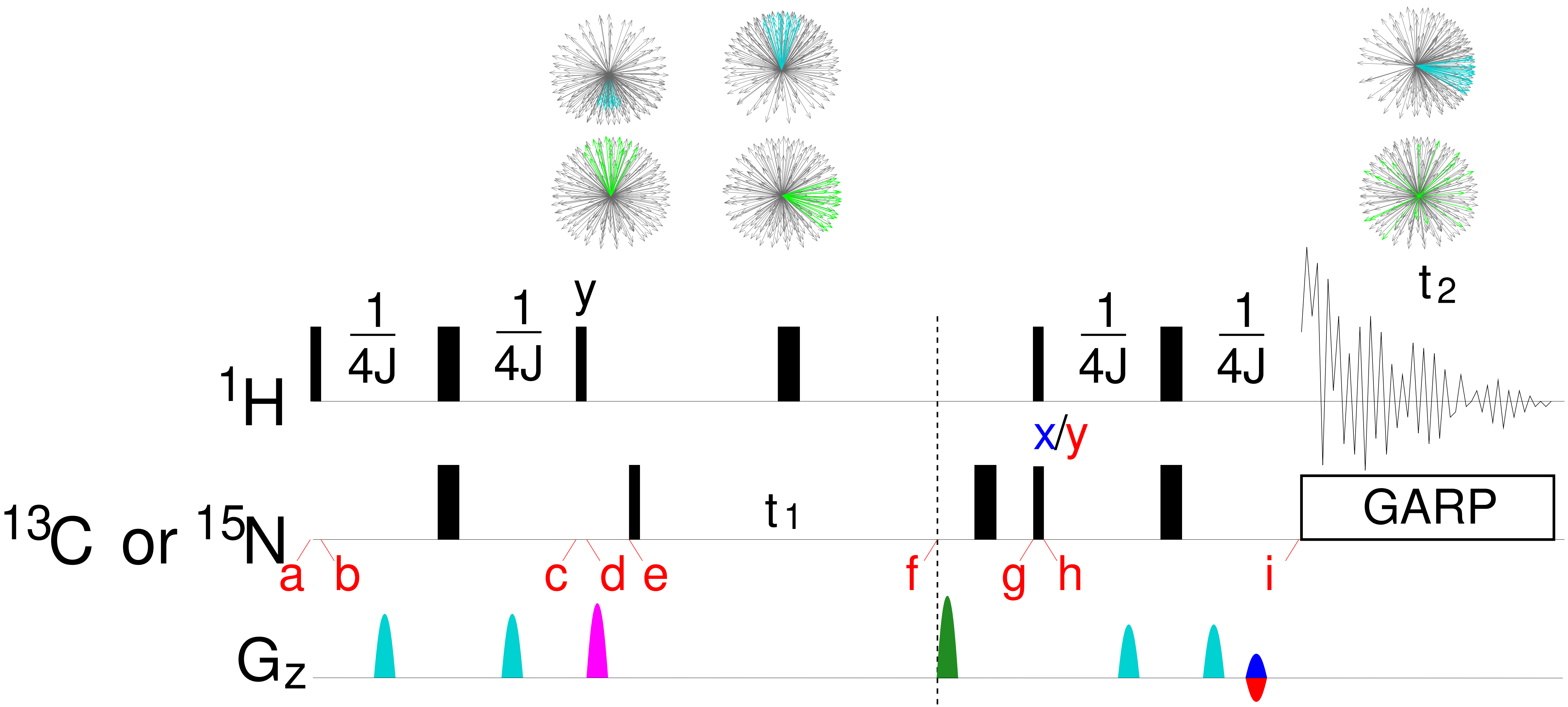
Pulsed-field gradients



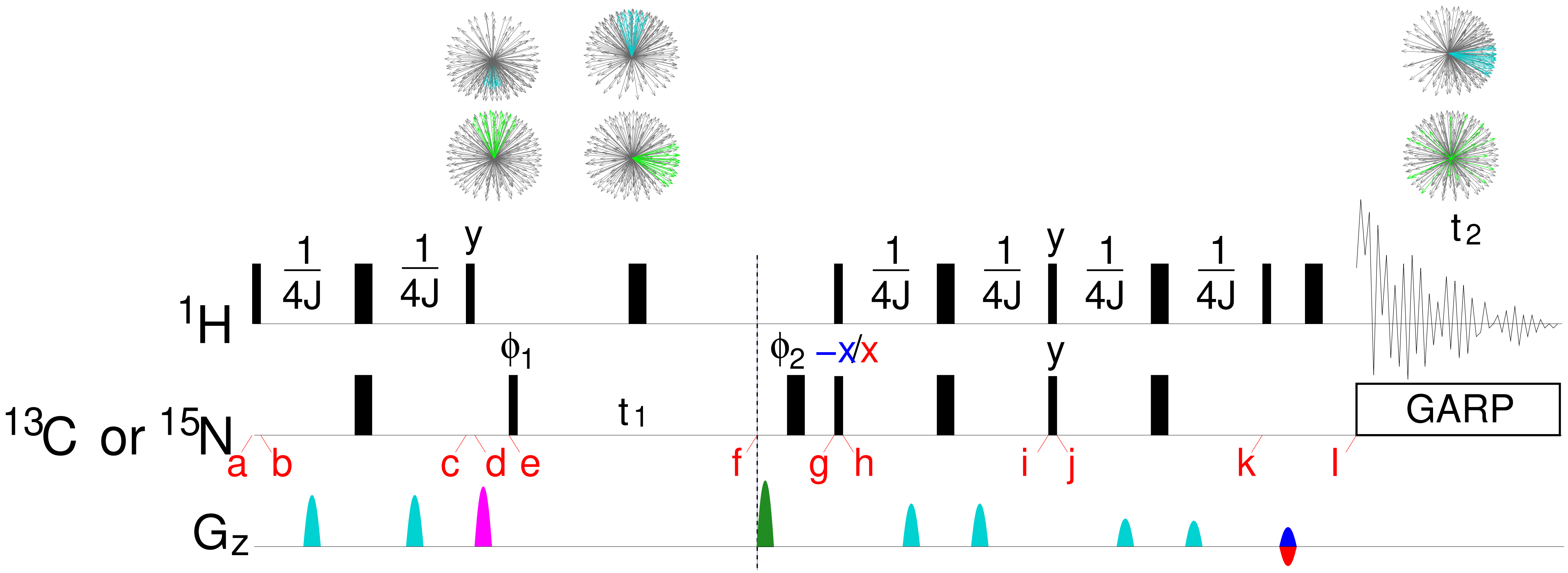
Gradient echoes



Gradients in HSQC



Preservation of equivalent pathways



ϕ_1=x,−x,x,−x,x,−x,x,−x and receiver phase x,−x,−x,x,x,−x,−x,x for odd increments of t_1

ϕ_1=−x,x,−x,x,−x,x,−x,x and receiver phase −x,x,x,−x,−x,x,x,−x for even increments of t_1

ϕ_2=x,x,y,y,−x,−x,−y,−y