Optical-clock local-oscillator universal interrogation protocol for zero probe-field-induced frequency-shifts

S3-5

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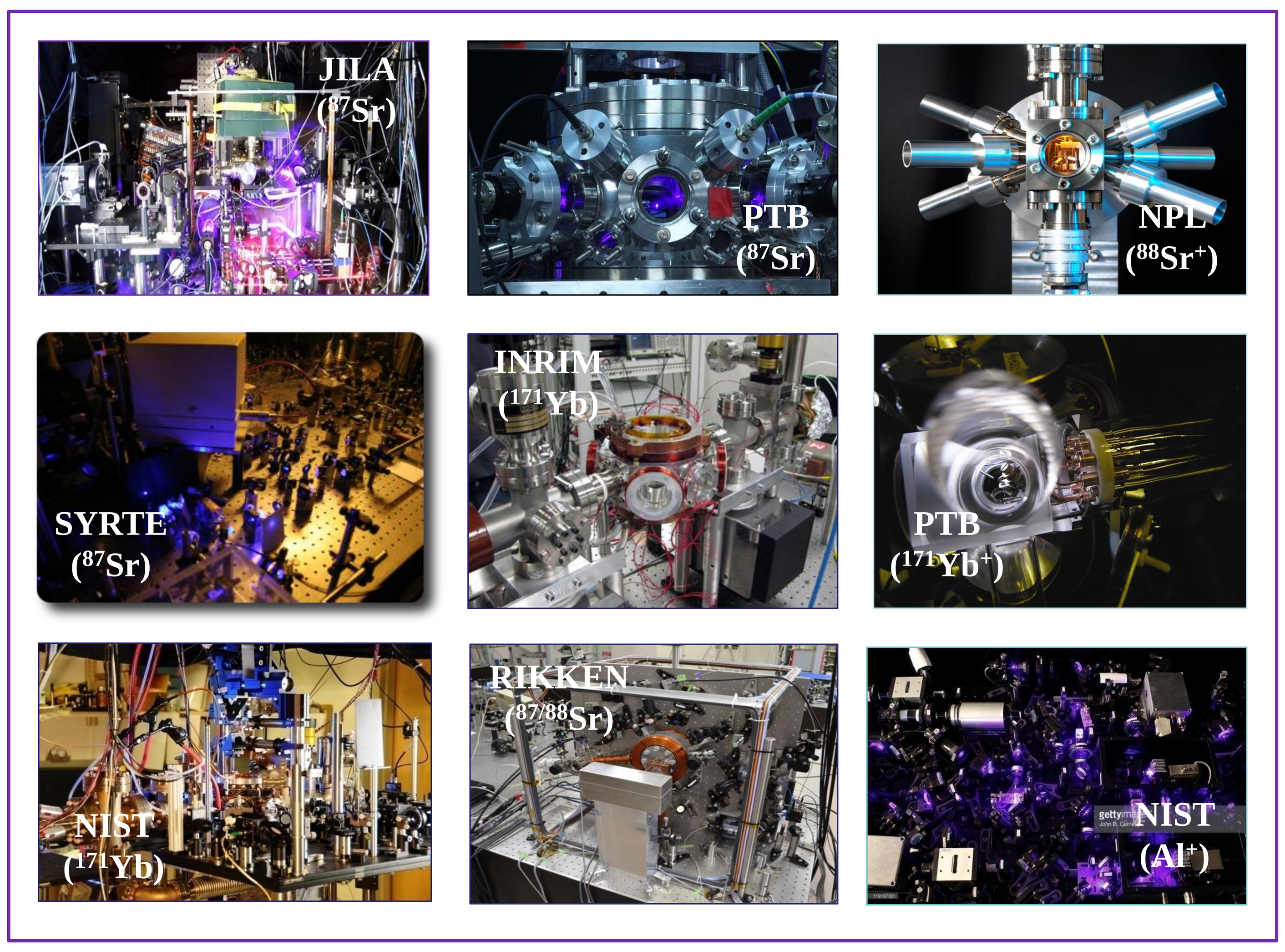
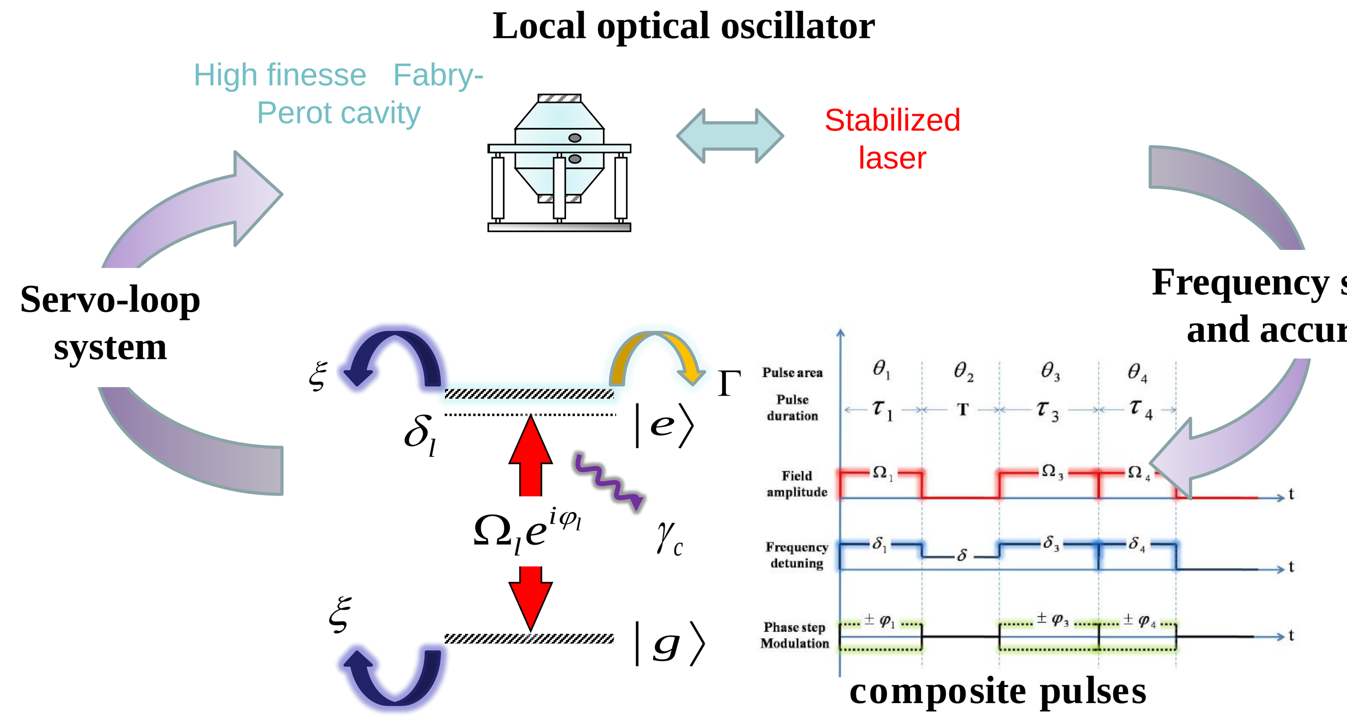
I. Optical frequency standards in quantum metrology (optical lattice clocks and single trapped ions)



II. Local oscillator (LO) stabilization scheme based on light-shift compensation and composite Ramsey pulses



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$$\Delta E = \mathrm{P}_{|g\rangle\mapsto|e\rangle}(\varphi^{+}_{\{l\}}) - \mathrm{P}_{|g\rangle\mapsto|e\rangle}(\varphi^{-}_{\{l\}}).$$
$$= \tilde{\mathrm{A}} + \tilde{\mathrm{B}}(\tilde{\Phi})\cos(\delta\mathrm{T} + \tilde{\Phi}).$$

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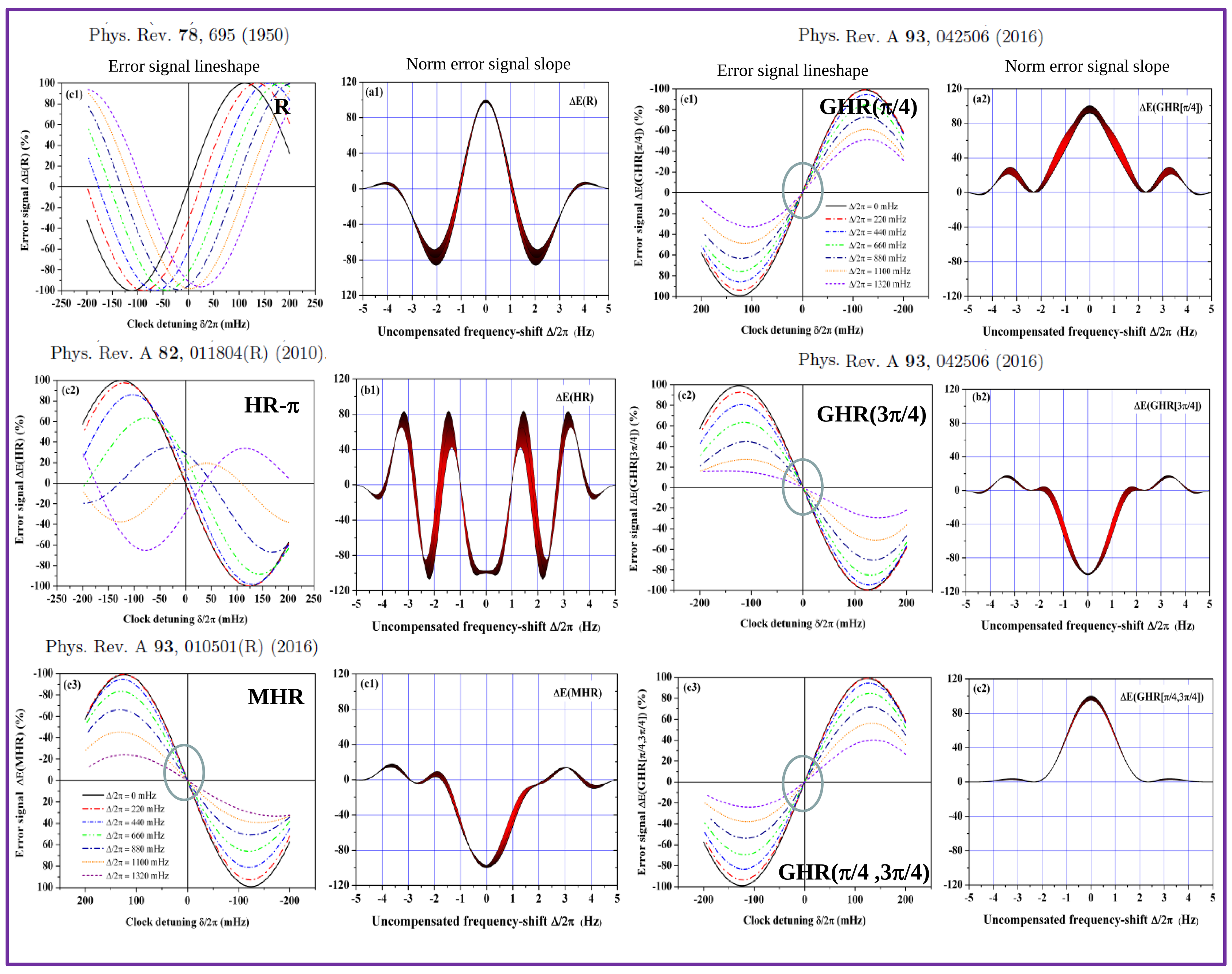
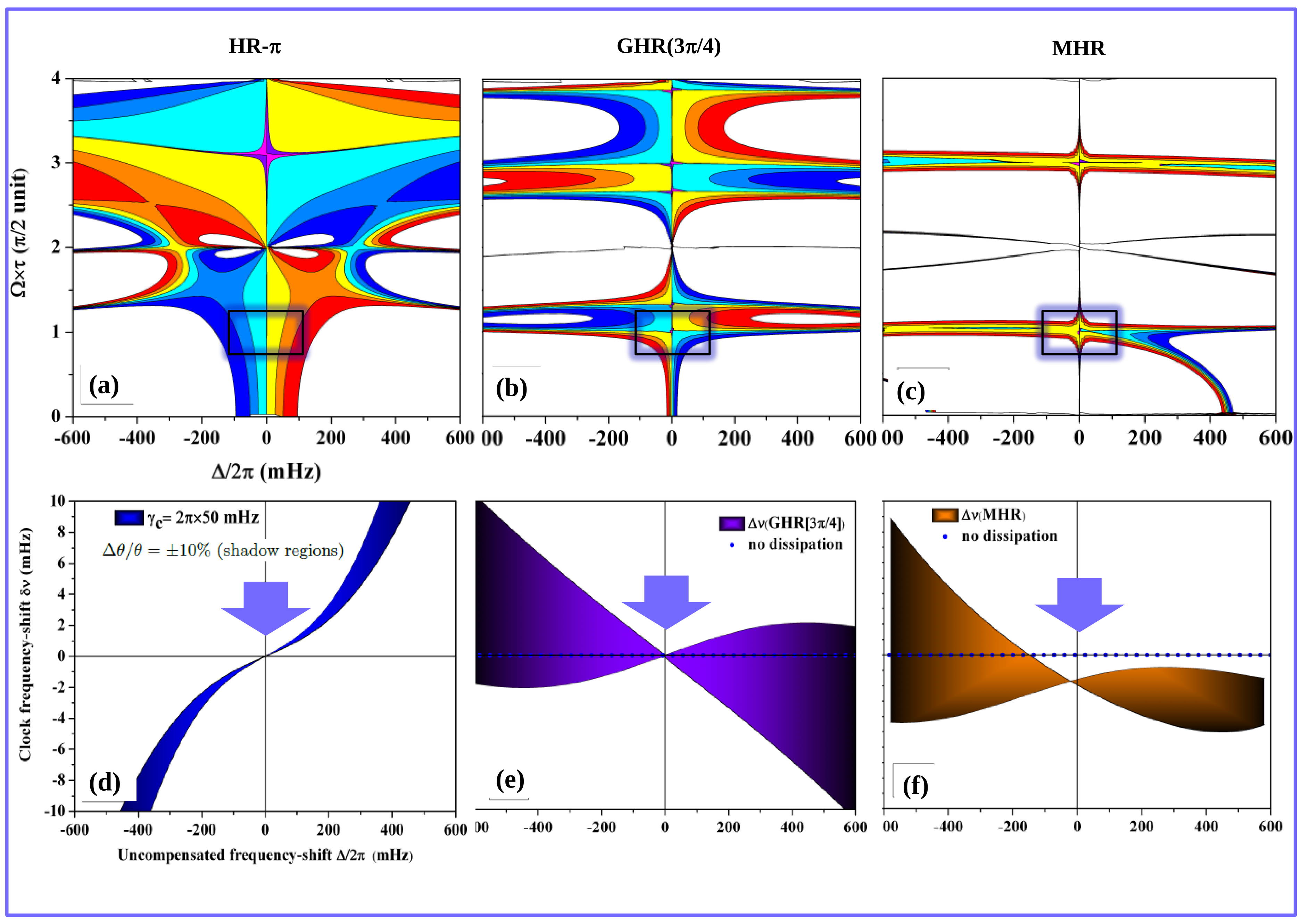
protocols	composite pulses θ_l $_{(\varphi_{l+},\varphi_{l-})}$
R	$90_{(\frac{\pi}{2},-\frac{\pi}{2})} \dashv \delta\mathrm{T} \vdash 90_{(0,0)}$ $(\dagger)90_{(0,0)} \dashv \delta\mathrm{T} \vdash 90_{(-\frac{\pi}{2},\frac{\pi}{2})}$
HR-π	$90_{(\frac{\pi}{2},-\frac{\pi}{2})} \dashv \delta\mathrm{T} \vdash 180_{(\pi,\pi)}90_{(0,0)}$ $(\dagger)90_{(0,0)}180_{(\pi,\pi)} \dashv \delta\mathrm{T} \vdash 90_{(-\frac{\pi}{2},\frac{\pi}{2})}$
MHR	$90_{(\frac{\pi}{2},0)} \dashv \delta\mathrm{T} \vdash 180_{(\pi,\pi)}90_{(0,-\frac{\pi}{2})}$ $(\dagger)90_{(-\frac{\pi}{2},0)}180_{(\pi,\pi)} \dashv \delta\mathrm{T} \vdash 90_{(0,\frac{\pi}{2})}$
GHR($\frac{\pi}{4}$)	$90_{(0,0)} \dashv \delta\mathrm{T} \vdash 180_{(\frac{\pi}{4},-\frac{\pi}{4})}90_{(0,0)}$ $(\dagger)90_{(0,0)}180_{(-\frac{\pi}{4},\frac{\pi}{4})} \dashv \delta\mathrm{T} \vdash 90_{(0,0)}$
GHR($\frac{3\pi}{4}$)	$90_{(0,0)} \dashv \delta\mathrm{T} \vdash 180_{(3\frac{\pi}{4},-3\frac{\pi}{4})}90_{(0,0)}$ $(\dagger)90_{(0,0)}180_{(-\frac{3\pi}{4},\frac{3\pi}{4})} \dashv \delta\mathrm{T} \vdash 90_{(0,0)}$

III. Robustness of error signal laser frequency lock-points ignoring decoherence

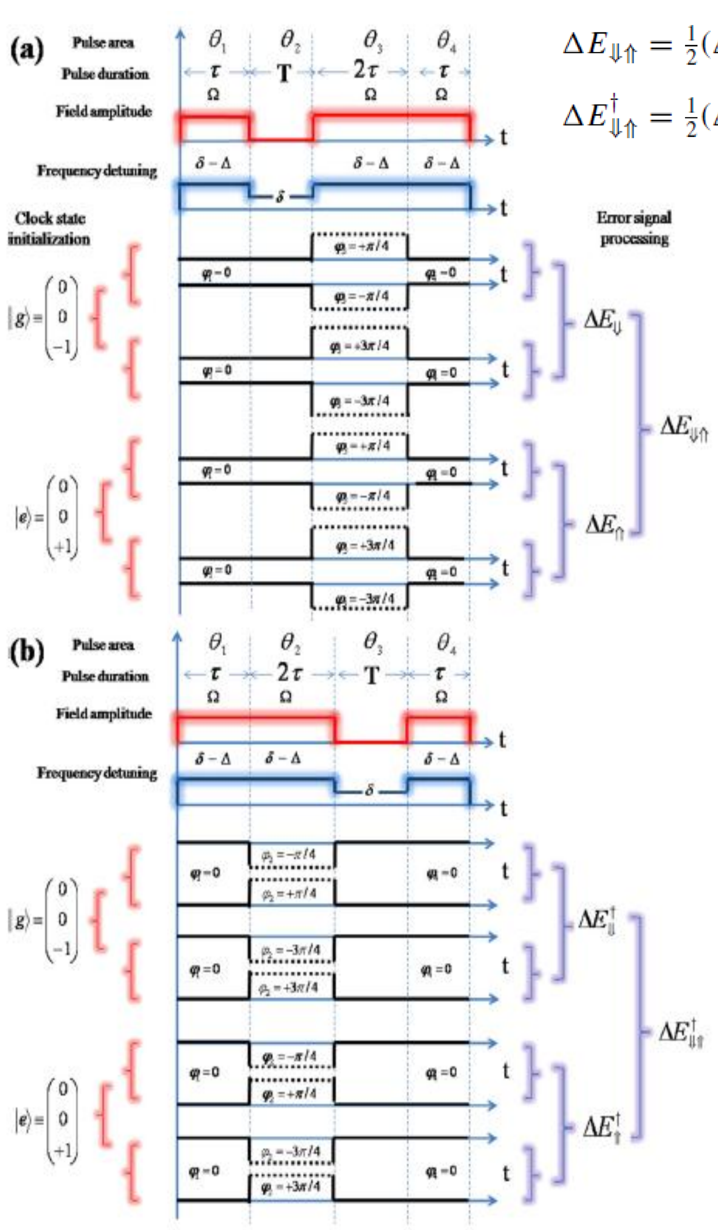


IV. 2D maps of clock frequency-shifts versus pulse area variation and offset detuning errors when decoherence is active



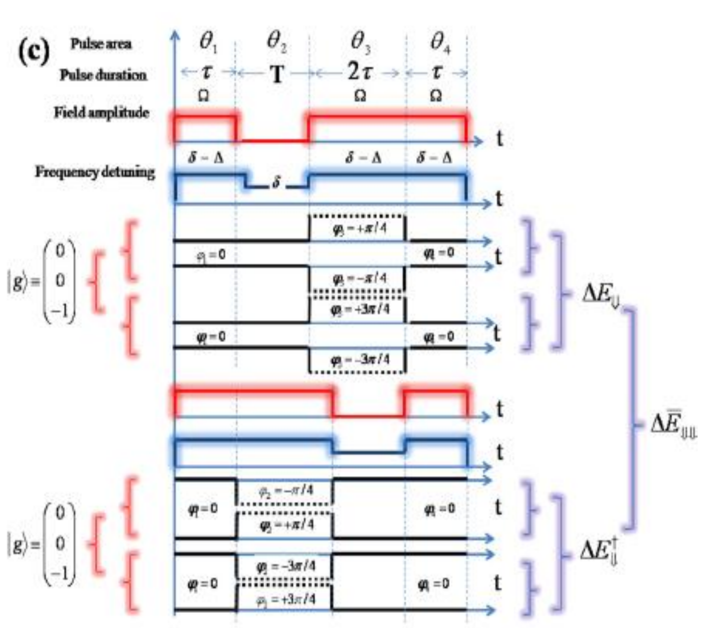
V. Universal protocols for robust laser frequency lock-point against dissipation

$$\Delta E_{\Downarrow\Uparrow} = \frac{1}{2}(\Delta E_{\Downarrow} - \Delta E_{\Uparrow}) = F_{\Downarrow\Uparrow}[M(0),\theta_1,\theta_3]\sin(\delta T)$$
$$\Delta E^{\dagger}_{\Downarrow\Uparrow} = \frac{1}{2}(\Delta E^{\dagger}_{\Downarrow} - \Delta E^{\dagger}_{\Uparrow}) = F^{\dagger}_{\Downarrow\Uparrow}[M(0),\theta_1,\theta_3]\sin(\delta T)$$

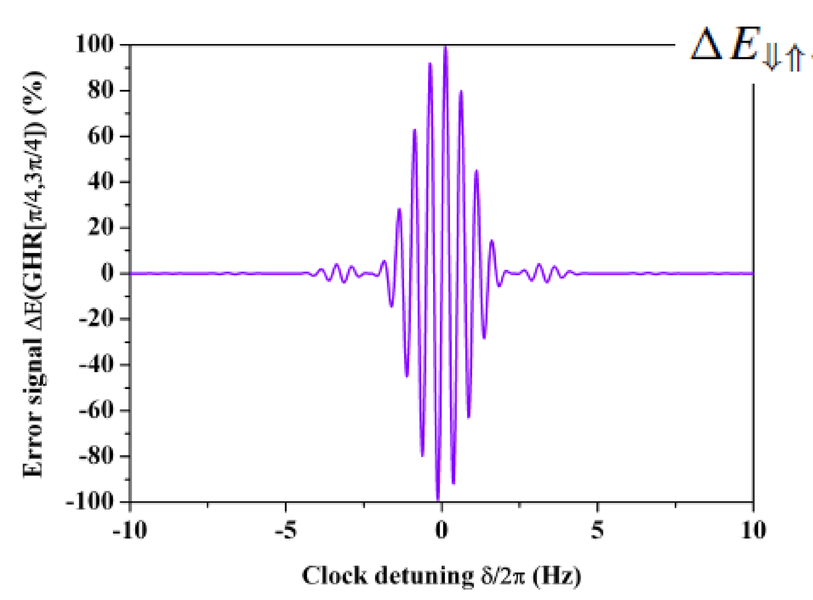


Method 1: state preparation

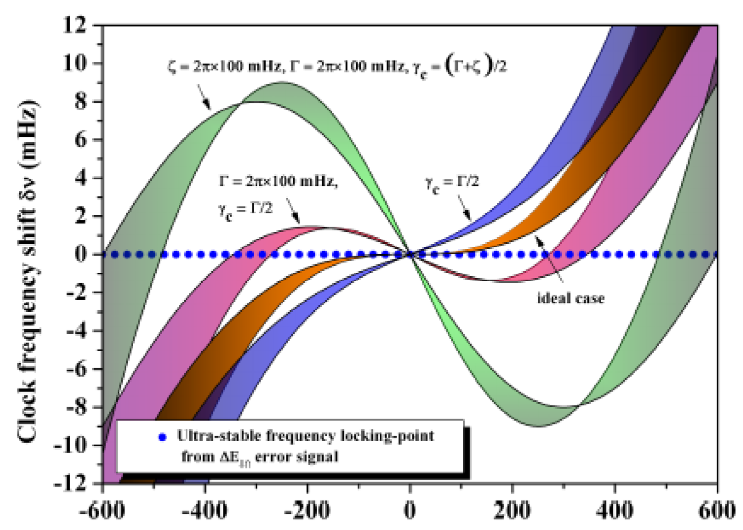
Method 2: pulse order reversal



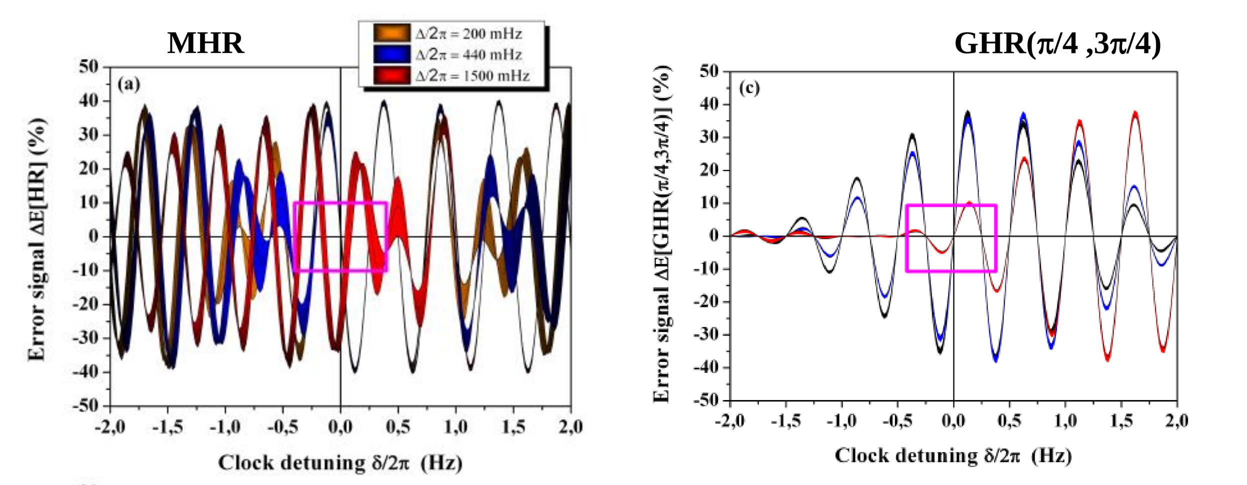
$$\Delta\overline{E}_{\Downarrow\Downarrow} = \frac{1}{4}(\Delta E^{\dagger}_{\Downarrow} + \Delta E_{\Downarrow}) = F_{\Downarrow\Downarrow}[M(0),\theta_1,\theta_3]\sin(\delta T)$$



(a) $GHR(\pi/4, 3\pi/4)$ protocol: Error signal



(b) $GHR(\pi/4, 3\pi/4)$ protocol: Lock point sensitivity



Absolute robustness of various error signal laser frequency locking points to individual or multiple {} dissipative parameters γ_c,Γ,ξ for a closed two-level system. The number of atomic state population measurements N required to build the error signal is also indicated. A perfect phase stepping of the laser for all protocols is considered here. Note if $\Gamma \neq 0$, then $\gamma_c = \Gamma/2$ to be consistent with a pure radiative process.

Error signal	N	γ_c	ξ	$\{\gamma_c,\xi\}$	$\{\gamma_c,\Gamma\}$	$\{\gamma_c,\Gamma,\xi\}$
ΔE[HR] ΔE[GHR($\pi/4$)] ΔE[MHR] ΔE[GHR($3\pi/4$)]	2	NO	NO	NO	NO	NO
$\Delta E_{\Downarrow(\Uparrow)}$, $\Delta E^{\dagger}_{\Downarrow(\Uparrow)}$	4	✓	✓	✓	NO	NO
$\Delta E_{\Downarrow\Uparrow}$, $\Delta E^{\dagger}_{\Downarrow\Uparrow}$, $\Delta\overline{E}_{\Downarrow\Downarrow}$	8	✓	✓	✓	✓	✓

Our publications:

Report on Progress in Physics in preparation

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