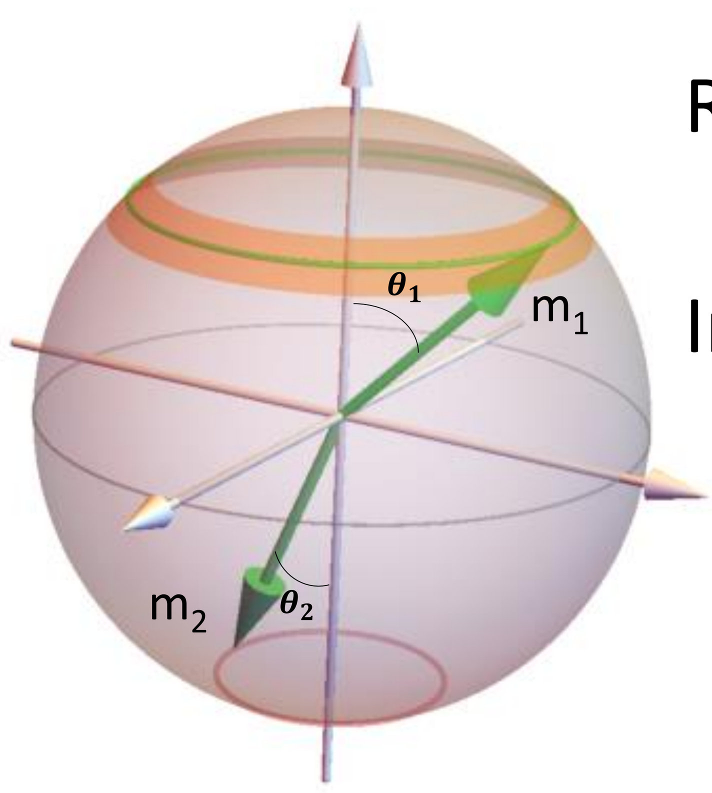
Enhancement of the damping in two-sublattice antiferromagnet

Yutian Wang 1, Jiang Xiao 1
1. Department of Physics, Fudan University, Shanghai, China

Take home message: The enhancement of the damping in antiferromagnet without requiring an increased Gilbert parameter is observed. In dynamic analysis, the phase delay is found to be of great importance. On the other hand, level attraction of the resonance frequency may count for the amplification of effective damping.

Antiferromagnet resonance(AFMR)

$$\dot{\boldsymbol{m}}_1 = -\boldsymbol{m}_1 \times \left(+\omega_A\,\hat{\boldsymbol{z}} - \omega_J \boldsymbol{m}_2\right) + \alpha\, \boldsymbol{m}_1 \times \dot{\boldsymbol{m}}_1$$
$$\dot{\boldsymbol{m}}_2 = -\boldsymbol{m}_2 \times \left(-\omega_A\,\hat{\boldsymbol{z}} - \omega_J \boldsymbol{m}_1\right) + \alpha\, \boldsymbol{m}_2 \times \dot{\boldsymbol{m}}_2$$



Resonance frequency

Real part(procession)

$$Re(\omega) = \pm\sqrt{\omega_A(\omega_A + 2\omega_J)}$$

Imaginary part(damping)

$$Im(\omega) = +\alpha(\omega_A + \omega_J)$$

$$\frac{\theta_1}{\theta_2} = 1 + \frac{\omega_A}{\omega_J} \pm \frac{\sqrt{\omega_A(\omega_A + 2\omega_J)}}{\omega_J} = \eta \left(or\ \frac{1}{\eta}\right)$$

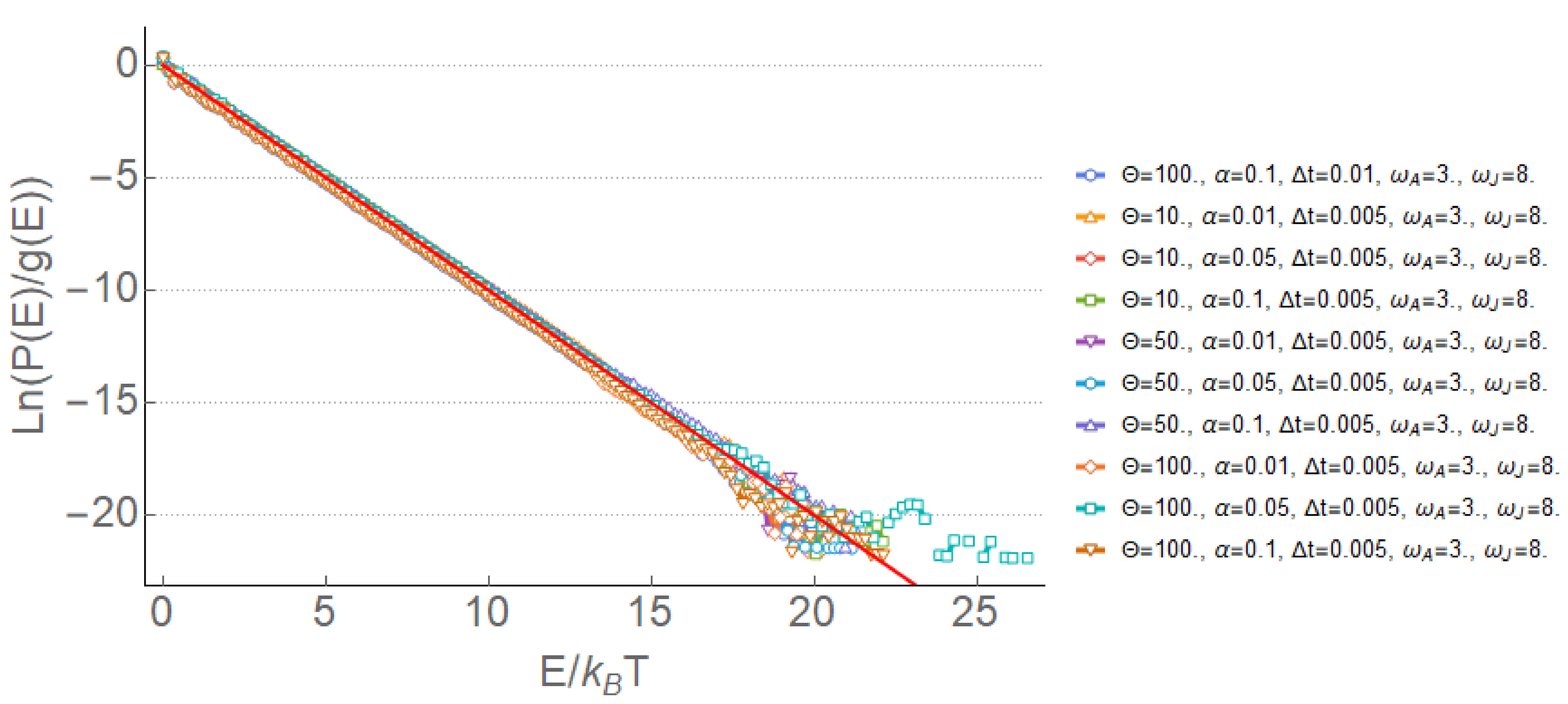
Enhancement of Effective damping

Dissipation per period, calculated by $Im(\omega)/\mathrm{Re}(\omega)$

$$\left|\frac{Im(\omega)}{\mathrm{Re}(\omega)}\right| = \frac{\alpha(\omega_A + \omega_J)}{\sqrt{\omega_A(\omega_A + 2\omega_J)}} \approx \alpha\sqrt{\frac{\omega_J}{2\omega_A}} \gg \alpha,$$

as $\omega_J \gg \omega_A$

while the fluctuation dissipation theorem is correct with usual Gilbert parameter



Reference:

[1] Kamra et al., Physical Review B 98, no. 18 (November 2, 2018): 184402.

[2] Tserkovnyak, Yaroslav. Physical Review Research 2, no. 1 (January 9, 2020): 013031

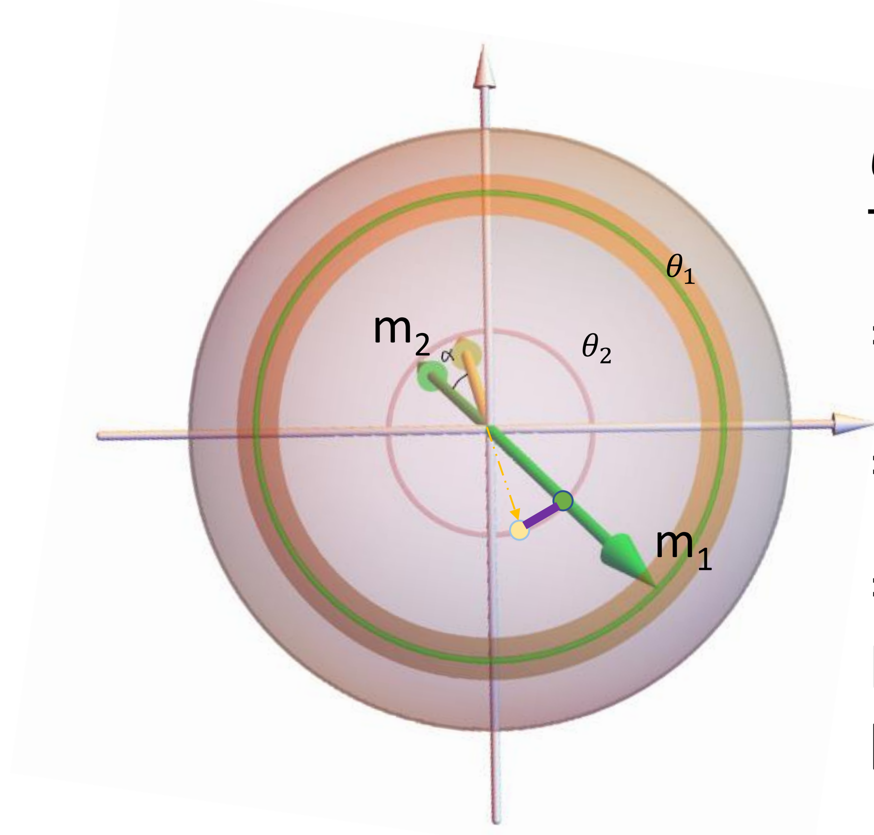
[3] Bender, Carl M., and Stefan Boettcher. Physical Review Letters 80, no. 24 (June 15, 1998): 5243–46

[4] Yang, Fan, Yong-Chun Liu, and Li You. Physical Review A 96, no. 5 (November 21, 2017): 053845.

Phase delay

$$\begin{cases} \omega = \pm\omega_0 \mp \dfrac{2\omega_0^2 + \omega_j^2}{2\omega_0}\alpha^2 \\ \eta = \eta_0 - \left(\dfrac{\eta_0}{2} + \dfrac{J\gamma}{2\omega_0}\right)\alpha^2 \\ \varphi_1 - \varphi_2 = -\pi + \alpha \end{cases}$$

When Gilbert damping is considered, the phase difference between two sublattice is no longer π, but with a small delay which is equal to α.



Procession:

$$\frac{\theta_1\omega_A + (\theta_1 - \theta_2)\omega_J}{\theta_1} = \omega_A + (1 - \eta)\omega_J = \sqrt{\omega_A(\omega_A + 2\omega_J)} = \omega_0$$

It is almost the same for both cases.

m_1 will process around the dot and $\hat{z}$ axis(with damping/without damping)

Damping: apart from the Intrinsic damping from the Gilbert term, the exchange coupling will provide a damping like torque(m_1 will process around the purple bar)

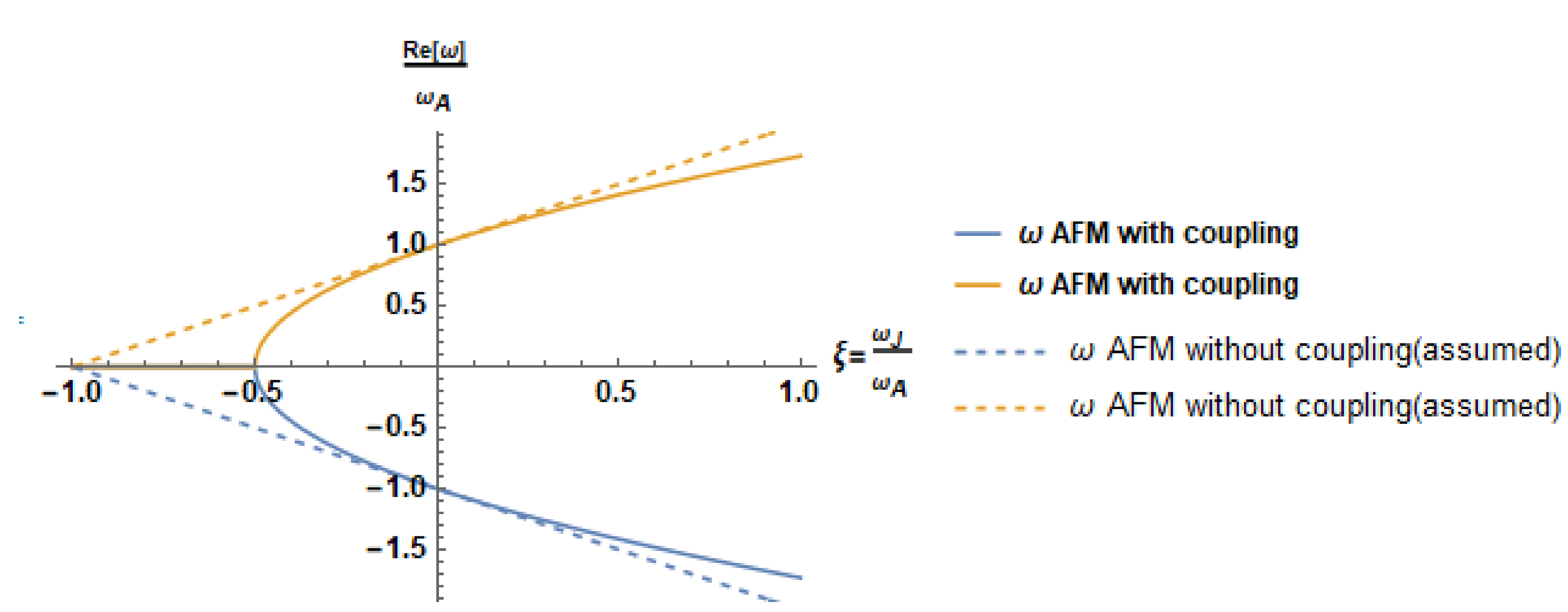
$$\frac{\theta_1\omega_0\alpha + \alpha\theta_2\omega_J}{\theta_1} = \alpha\omega_0 + \alpha\eta\omega_J = \alpha(\omega_A + \omega_J)$$

Level Attraction and non-Hermitian Hamiltonian

$$\begin{pmatrix} \omega_a + \omega_J & \omega_J \\ -\omega_J & -\omega_a - \omega_J \end{pmatrix}\begin{pmatrix} u_1 \\ u_2 \end{pmatrix} = -i\begin{pmatrix} \dot{u}_1 \\ \dot{u}_2 \end{pmatrix} \quad \text{With } u_j = m_j^x + i\, m_j^y$$

Effective Hamiltonian $\widehat{H}$.

While $\widehat{\boldsymbol{H}}^\dagger \neq \widehat{\boldsymbol{H}}$, the non-Hermitian mechanics predicts the level attraction.



The resonance frequency is decreased compared to uncoupling case(an assumption that the off-diagonal term is set to be 0).

The damping term remains the same.

Reduction of frequency → Enhancement of Effective damping $\left|\frac{Im(\omega)}{\mathrm{Re}(\omega)}\right|$