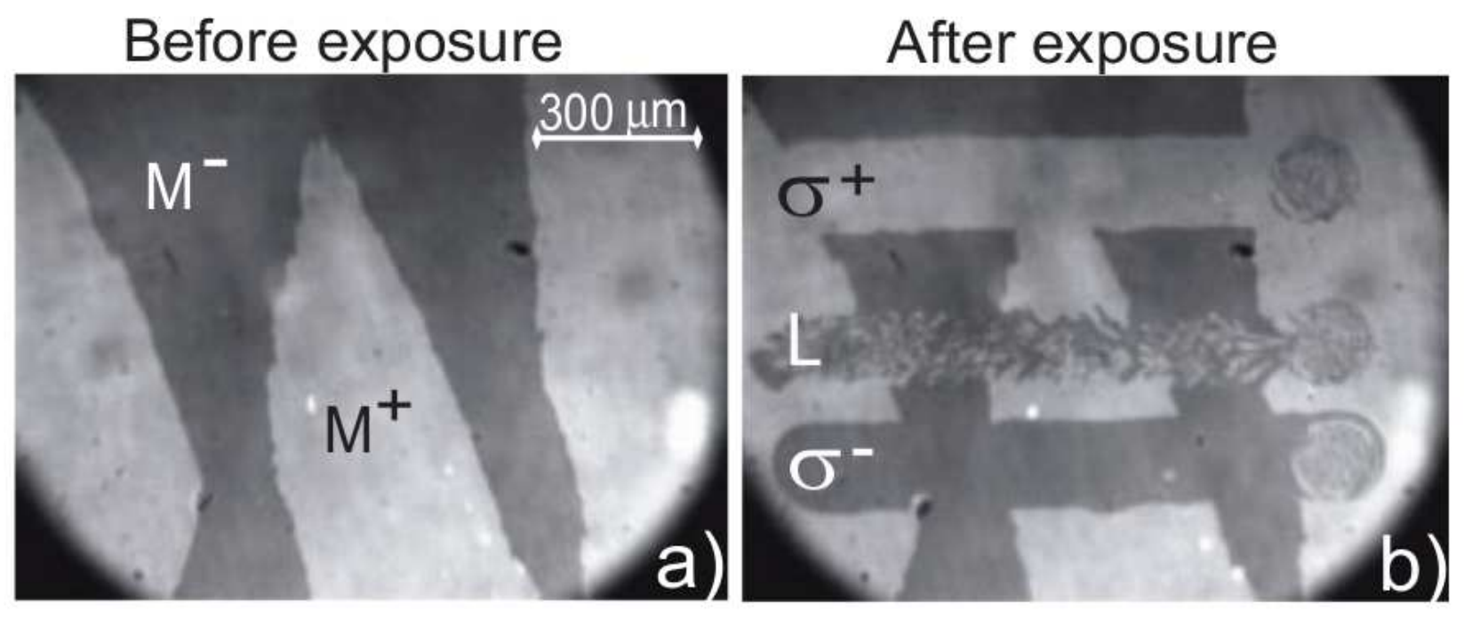
Static and Dynamic Properties of GdFeCo Using an Atomistic Model

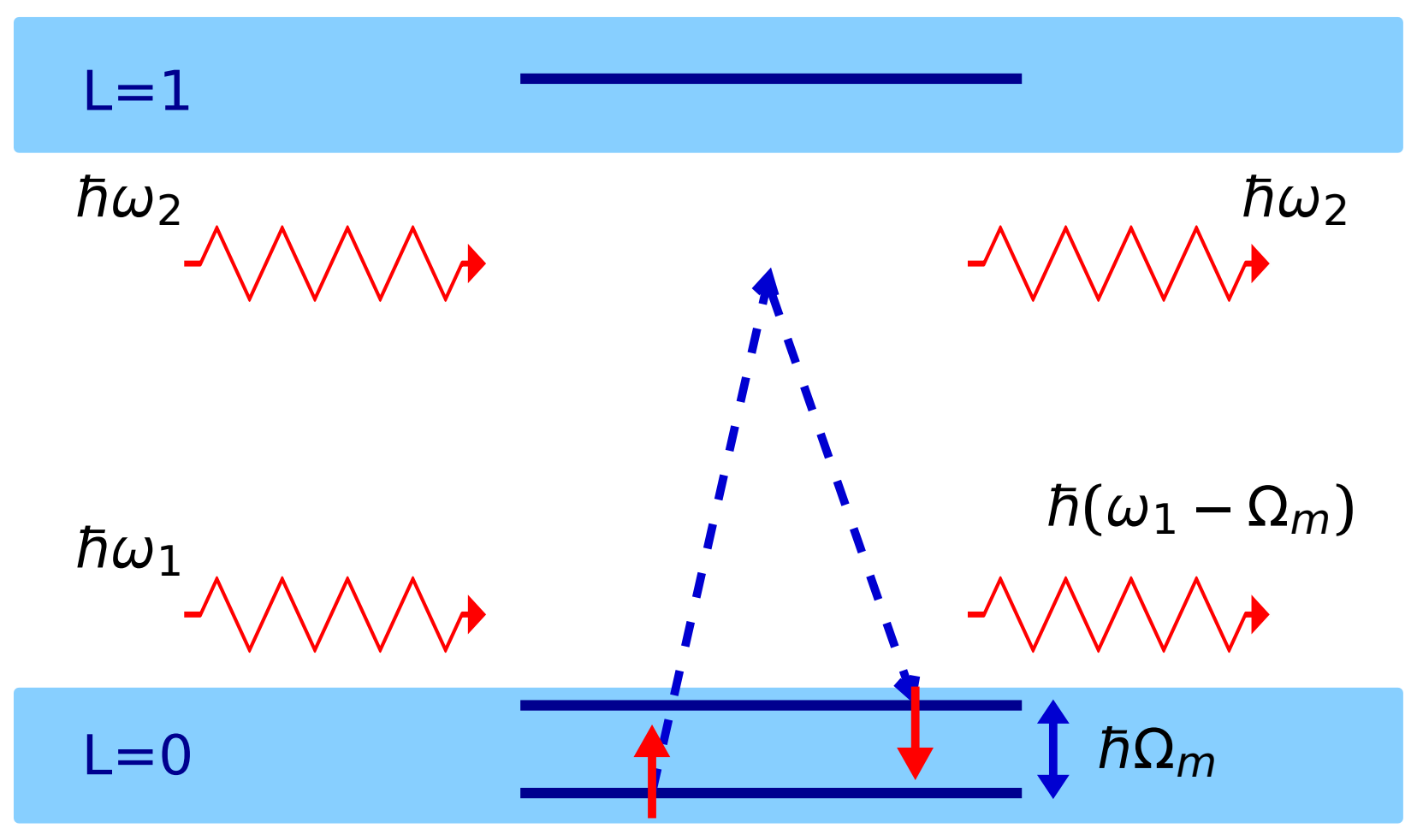
T. Ostler, R. Evans and R. W. Chantrell

Department of Physics, University of York, York, UK

1. Magneto-Optical experiment:

- **Ultrafast laser** induced heating using a circularly polarised laser pulse (right) [1]
- Induces an **effective** magnetic field $\propto \boldsymbol{E} \times \boldsymbol{E}$ in electron plasma, via Inverse Faraday effect (*IFE*)
- **Application**: New ultrafast writing mechanism
- Stimulated **Raman** like scattering (right), causes a spin-flip in the ground state, due to mixing of a fraction of the L=1 state wavefunction into that of the L=0 state by circularly polarised light





2. Ferrimagnetic Model

- Two sublattice Ferrimagnet FeCo=*TM*, Gd=*RE*
- **Hamiltonian**: Heisenberg Exchange, Uniaxial Anisotropy and Zeeman term

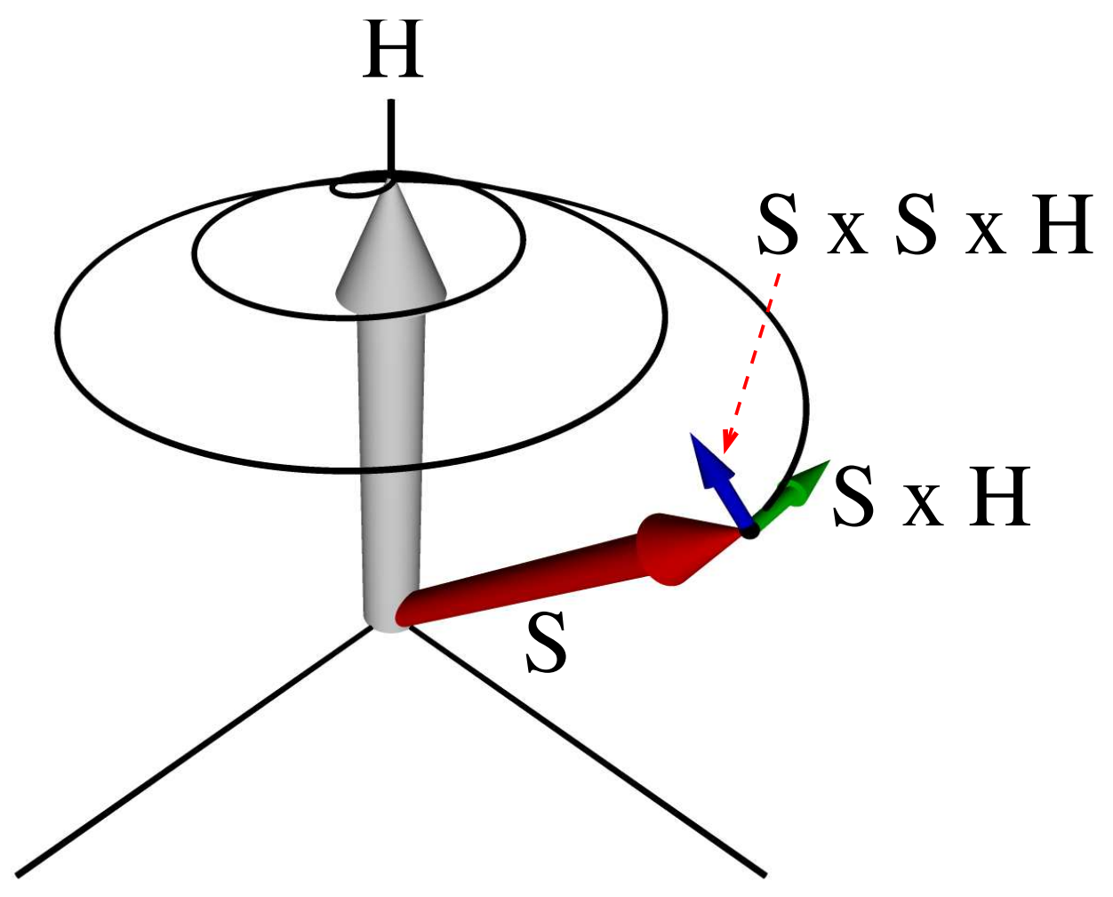
$$\mathcal{H} = -\sum_{i=1}^{N}\sum_{j=1}^{nn} J_{ij}\boldsymbol{S}_i\cdot\boldsymbol{S}_j - \sum_{i=1}^{N}\boldsymbol{D}(\boldsymbol{S}_i\cdot\boldsymbol{n}_i)^2 - \sum_{i=1}^{N}\mu_i\boldsymbol{B}\cdot\boldsymbol{S}_i$$

- Stochastic thermal term included which obeys the conditions:

$$\langle\boldsymbol{\zeta}_i(t)=0\rangle;\quad \langle\zeta^a_i(t)\zeta^b_j(t')\rangle = 2\delta_{ij}\delta_{ab}\delta(t-t')\frac{\lambda_i k_B T}{\mu_i\gamma_i}$$

- Landau-Lifshitz-Gilbert equation of motion of spin in a local field. Contains precession and damping terms

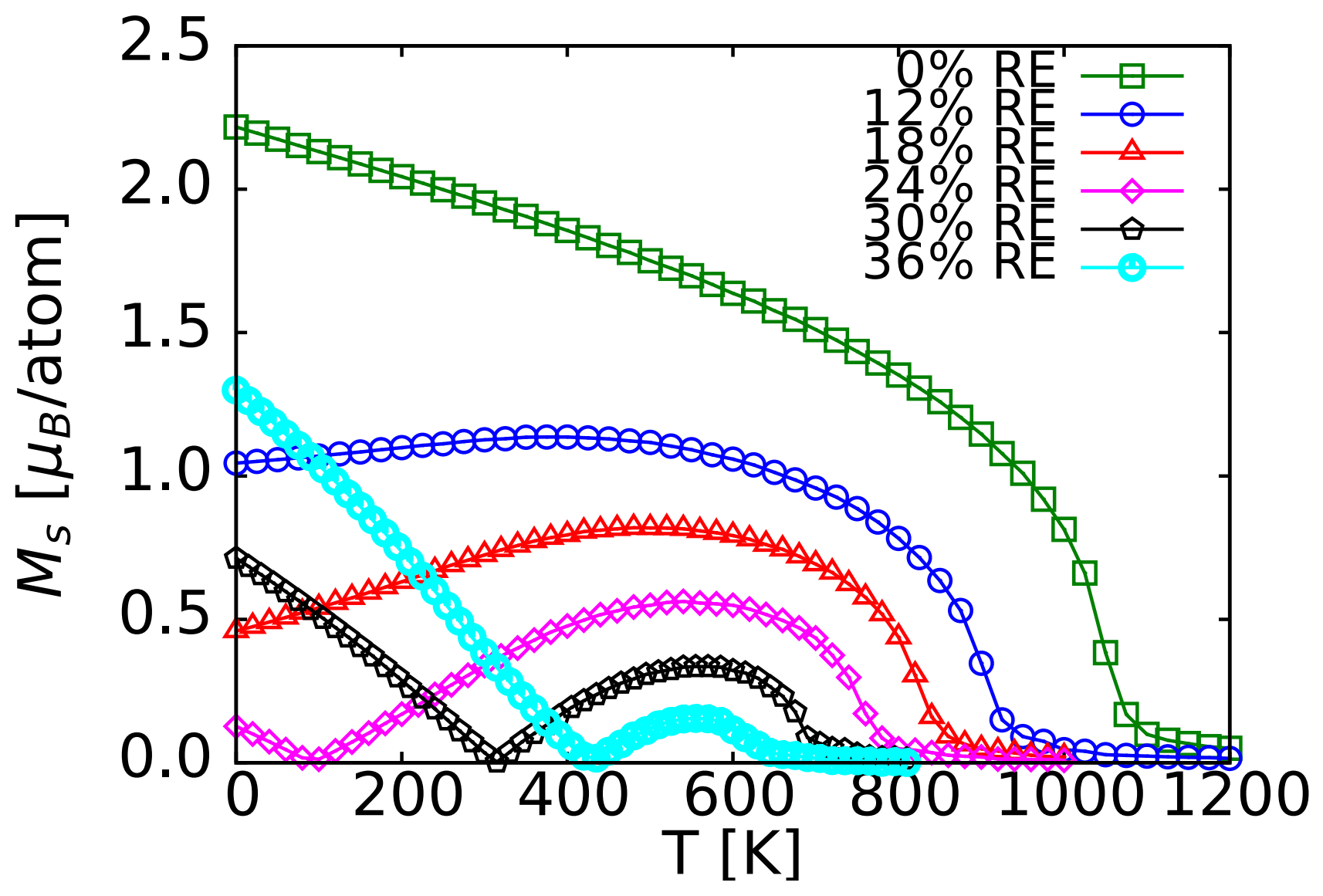
$$\dot{\boldsymbol{S}}_i = -\frac{\gamma_i}{(1+\lambda_i^2)\mu_{s_i}}\{\boldsymbol{S}_i(t)\times\boldsymbol{H}_i(t) + \lambda_i\boldsymbol{S}_i(t)\times[\boldsymbol{S}_i(t)\times\boldsymbol{H}_i(t)]\}$$



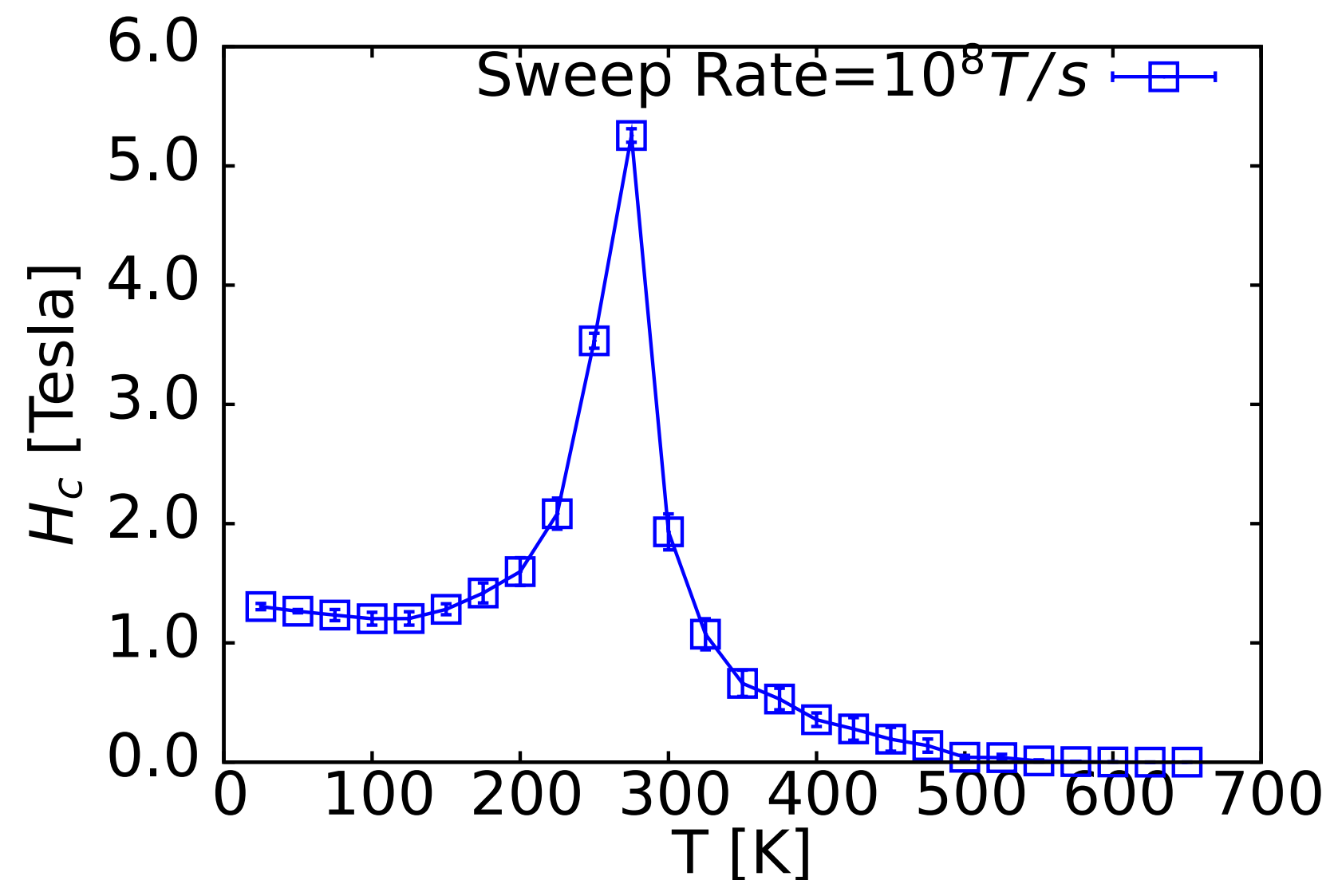
- **Spins** localised to atomic sites are $\boldsymbol{S}_i = \boldsymbol{\mu}_i/\mu_s$
- Effective magnetic field $\boldsymbol{H}_i = -\frac{\partial\mathcal{H}}{\partial\boldsymbol{S}_i} + \boldsymbol{\zeta}_i(t)$
- Model allows for complete description of *longitudinal* and *transverse* relaxation

3. Magnetic Compensation Point

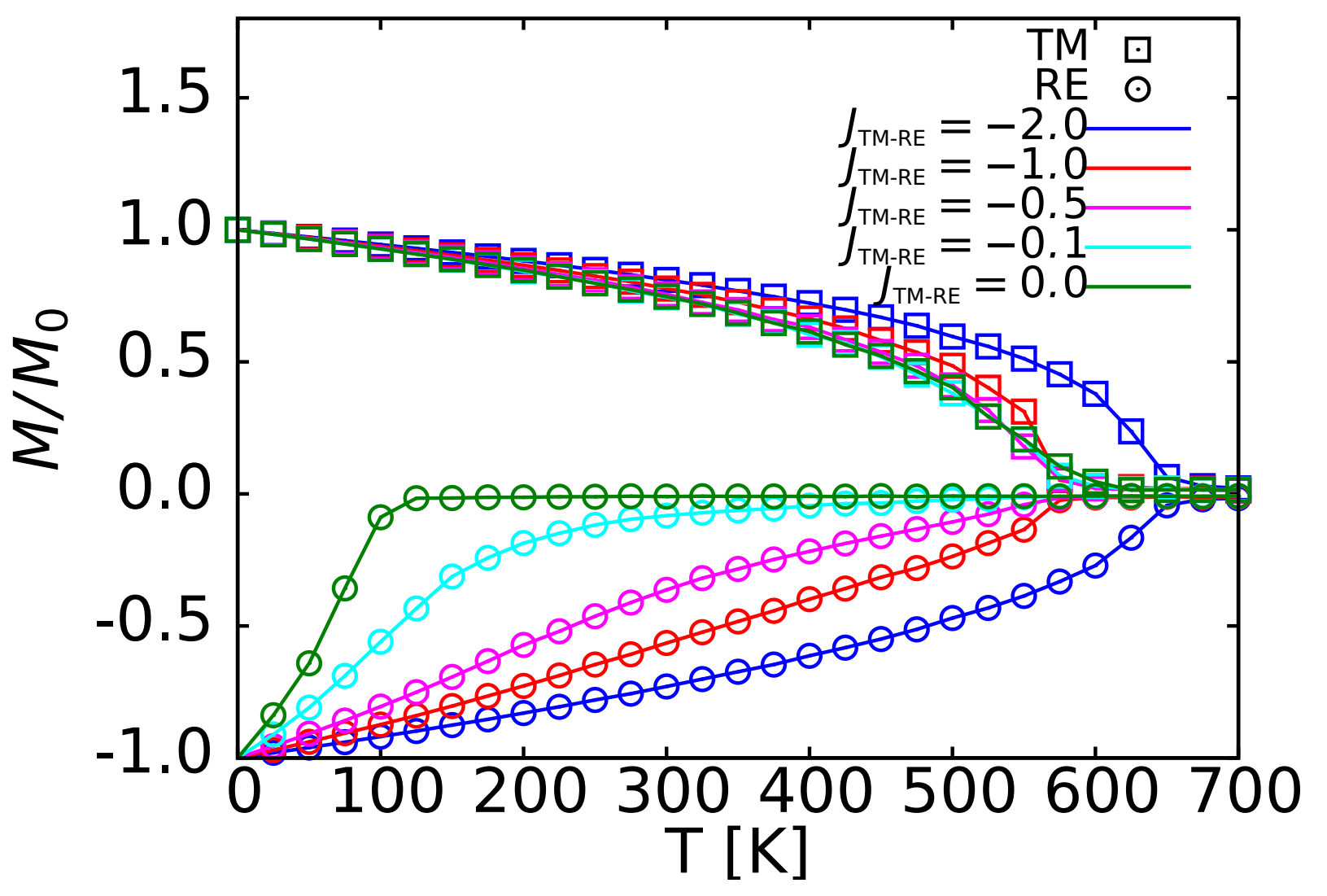
- Magnetic **compensation** point (T_M) is found with increasing RE content



- **Diverging *coercivity* at T_M**



- Exchange
  - ⇝ **TM-TM** Bulk Fe, **RE-RE** Bulk Gd
  - ⇝ **TM-RE** adjusted for T_M, as polarisation effect causes shift

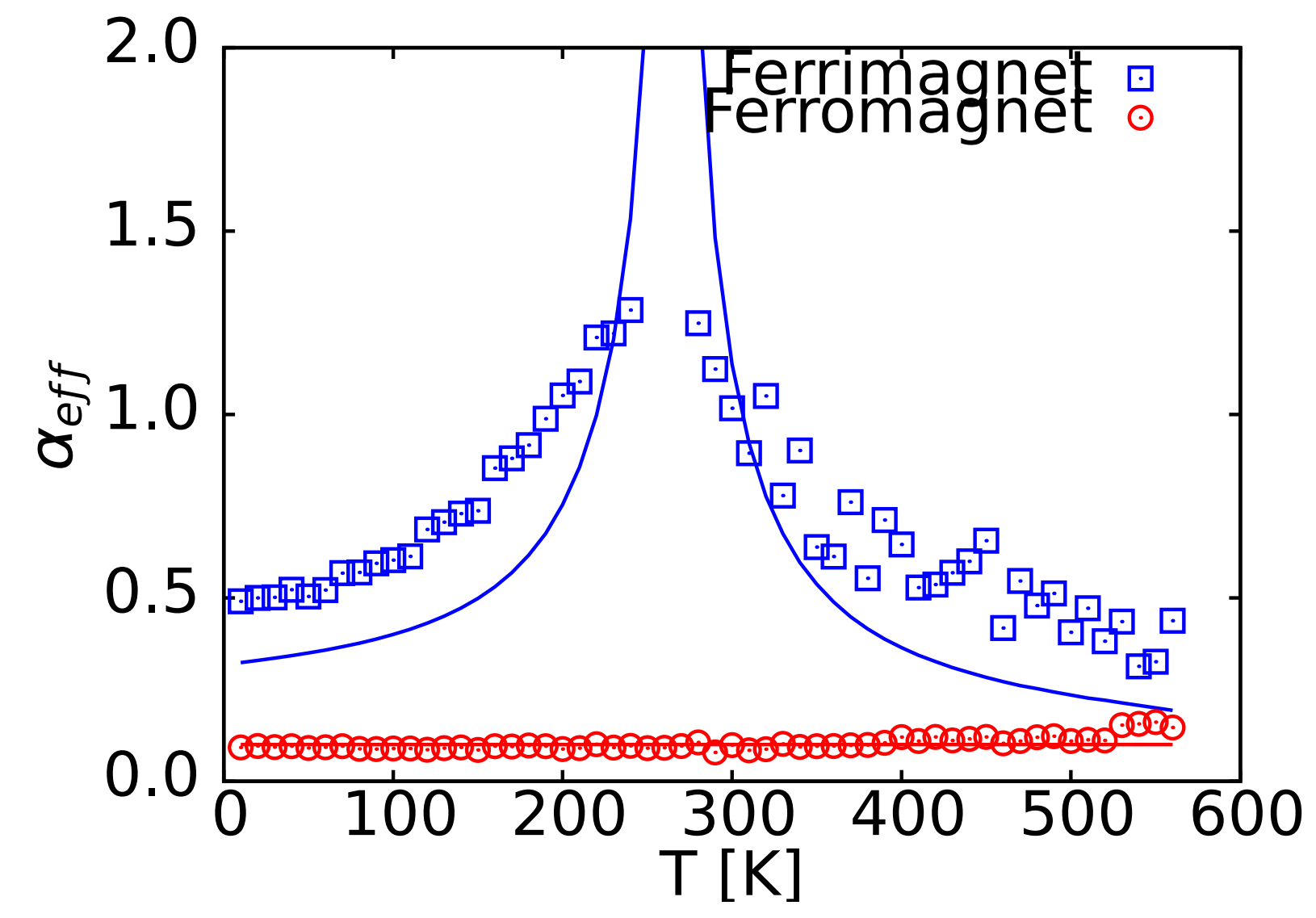


- Increasing TM-RE exchange creates a **polarisation** effect → TM and RE share same T_C
- μ_{TM}=2.217μ_B (Fe), μ_{RE}=7.55μ_B (Gd)

4. Damping

- Damping in Ferrimagnetic materials higher than Ferromagnetic. **Large increase** in effective damping (α_{eff}) at *angular momentum* compensation point *(T_A)* [2]

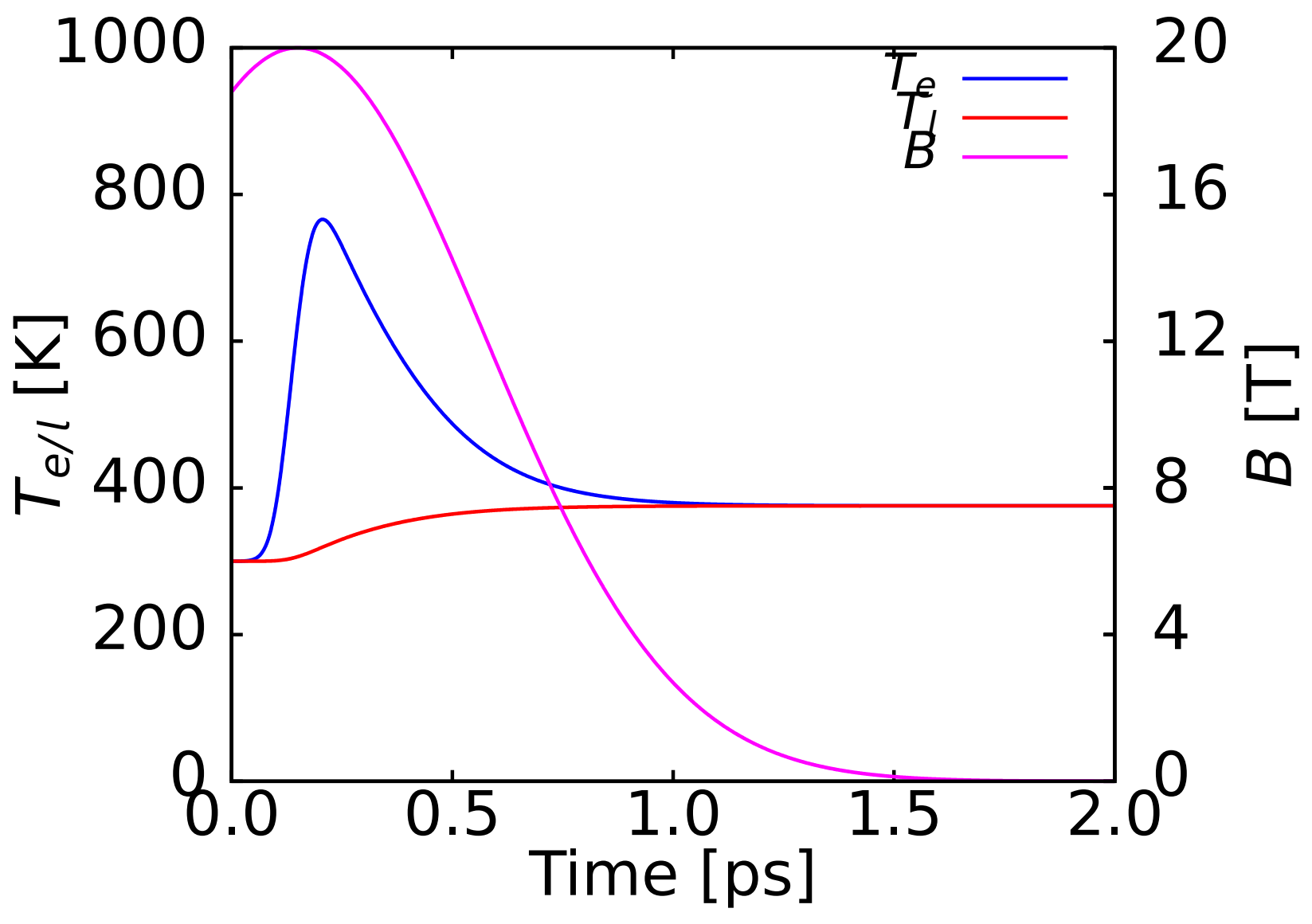
$$\alpha_{eff}(T) = \frac{\lambda_{TM}M_{TM}/|\gamma_{TM}| + \lambda_{RE}M_{RE}/|\gamma_{RE}|}{M_{TM}(T)/|\gamma_{TM}| - M_{RE}(T)/|\gamma_{RE}|} = \frac{A_0}{A(T)}$$



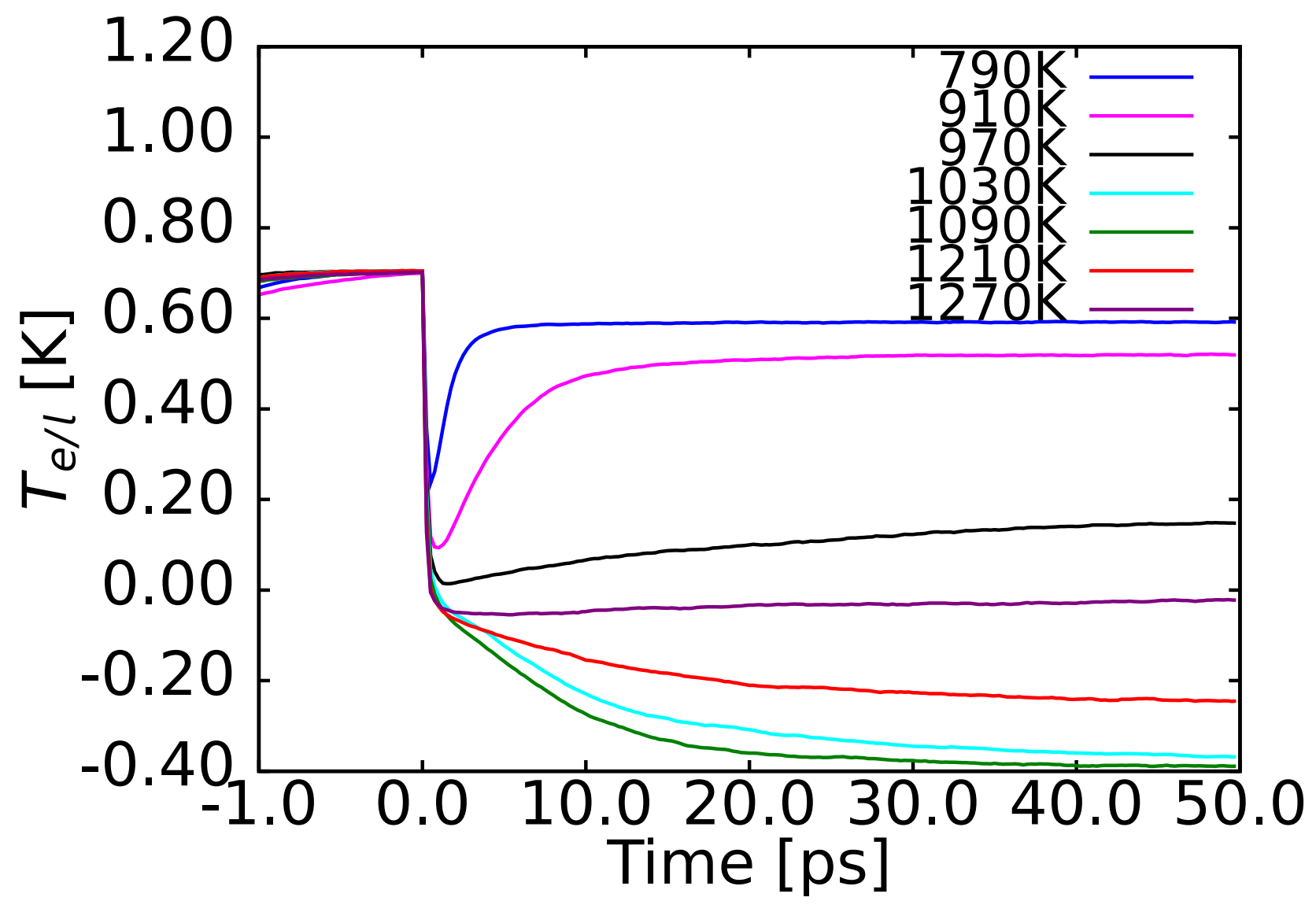
- Calculations involved 100 × 100 × 100 spins, applied field (B) of 2.0 Tesla
- Coherent rotation → precession. Fit to $\cos(\omega t)\exp(-t/\tau)$, $\alpha_{eff} = 1./\gamma B_z\tau$
- Macroscopic damping (α_{eff}) → collective behaviour ≠ microscopic λ_i even at 0K, due to Ferrimagnetic dynamics
- Explains fast domain wall motion at T_A

5. Laser Dynamics

- **IFE**
  - ⇝ Gaussian, $B_{max} \approx 20T$ (below)
  - ⇝ Change width of pulse (Δt) leads to reversal window (bottom right)
- **Two temperature model [3]**
  - ⇝ Couple T_e to **spins** (below)

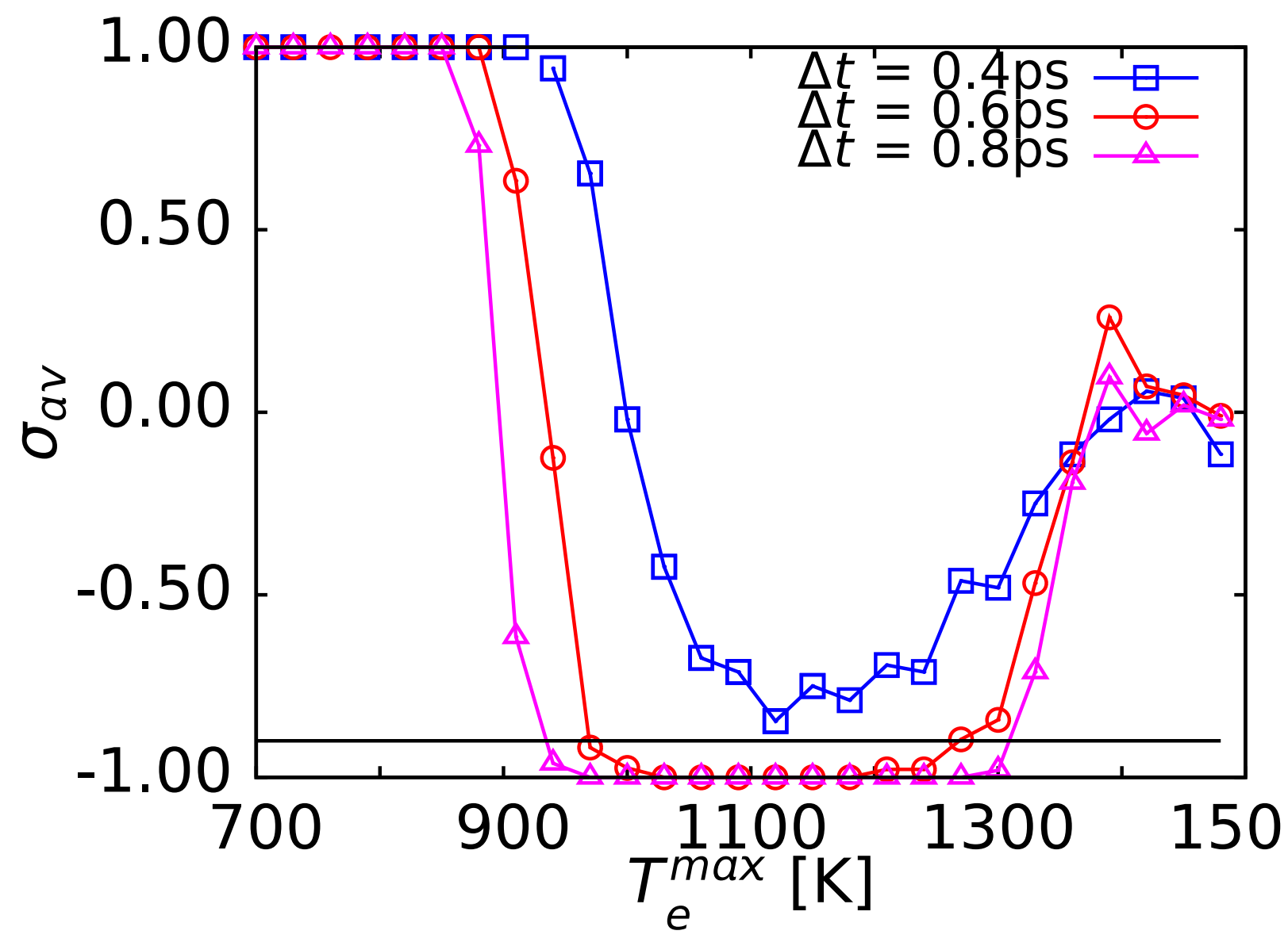


- For low peak electron temperatures the magnetisation is decreased but then **recovers without reversal**
- At temperatures close to T_C a *"linear" reversal* [4] sets in which essentially involves a destruction of the magnetisation and *recovery* into the *reversing field direction*
- Linear reversal **does not** involve *precession* and is fast because the timescale is determined by the (sub-picosecond) *longitudinal* relaxation time
- If the temperature is too high the reversed magnetisation is destroyed by **thermal activation**



- This defines a temperature *window for reversal* dependent on the width of the field pulse. For figure below

$$\sigma = \begin{cases} +1 & \text{if } m_z\text{ (50ps)} > 0 \\ -1 & \text{otherwise} \end{cases}$$



6. Conclusions

- LLG Ferrimagnetic model describes static and dynamics properties of GdFeCo well
- **Damping** and **relaxation** times provide interpretation of experimental results
- **Time dependence** of relaxation times and coercivity are consistent with experiment
- **Optomagnetic** reversal process shows a well defined temperature window for reversal involving a linear reversal mechanism
- **Linear** reversal avoids precessional motion of macrospin

References

[1] - C. D. Stanciu, F. Hansteen, A. V. Kimel and A. Kirilyok, A. Tsukamoto, A. Itoh and Th. Rasing, All-Optical Magnetic Recording with Circularly Polarized Light, Phys. Rev. Lett. **99**, 047601, 2009.
[2] - R. K. Wangsness, Magnetic Resonance in Ferrimagnetics, Phys. Rev. **93**, 1, 1954.
[3] - J. K. Chen, D. Y. Tzou and J. E. Beraun, A semi-classical two-temperature model for ultrafast laser heating, International Journal of Heat and Mass Transfer **49**, 307-316, 2006.
[4] - N. Kazantseva, D. Hinzke, R. W. Chantrell and U. Nowak, Linear and elliptical magnetization reversal close to the Curie temperature, Euro. Phys. Lett **86**, 27006, 2008.