Ultrafast Applications with Energy Recovery Linac (ERL) Source

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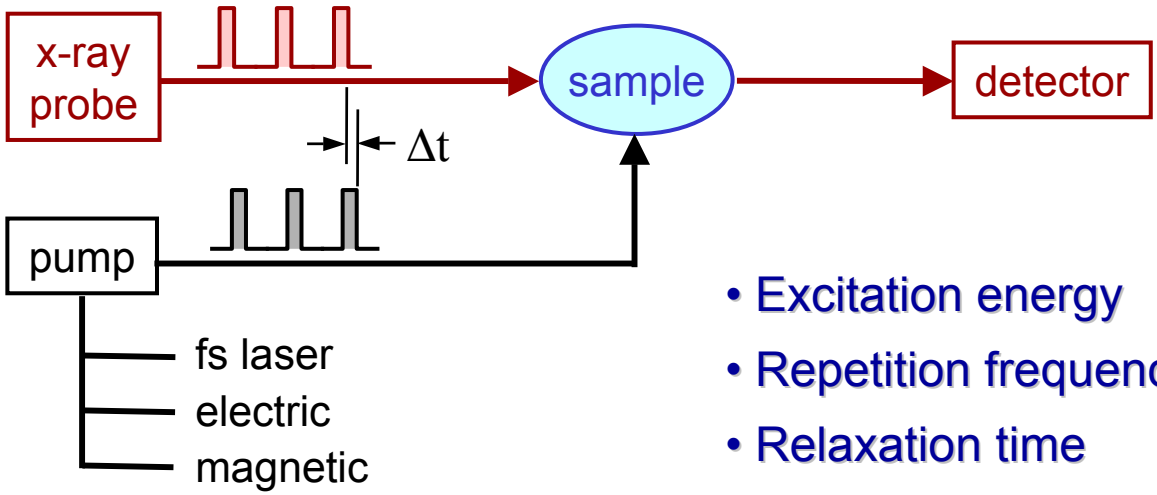
Cornell University, Ithaca, NY 14853

- ⇒ Scientific motivations
- ⇒ ERL Project at Cornell:
  - what is ERL
  - expected performance
- ⇒ Potential Application Areas:
  - nano-beam
  - coherence
  - ultrafast
- ⇒ Summary

Ultrafast Science



- Excitation energy
- Repetition frequency
- Relaxation time

Mode-locked Ti:Al_2O_3 Laser
78 MHz repetition rate
50-70 fs pulse width
λ≈800 nm (1.58 eV)
100 μm spot
0.1 – 1 μJ/cm^2

EXAMPLE:

Ultrafast Real-Time Spectroscopy of Low Dimensional Charge Density Wave Compounds

Demsar, J., D. Mihailovic, V.V. Kabanov, and K. Biljakovic, *Ultrafast Real-Time Spectroscopy of Low Dimensional Charge Density Wave Compounds.* arXiv:cond-mat/0401059v1, 2004.

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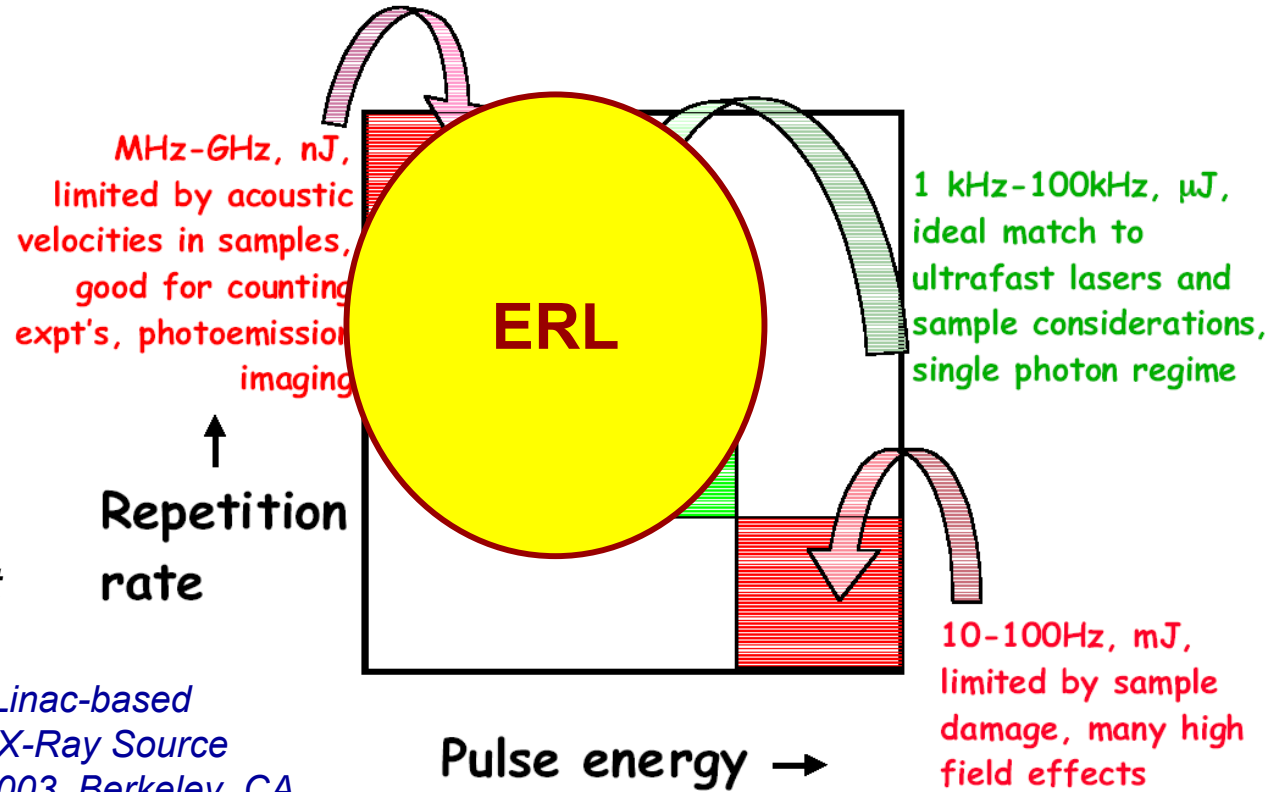
Different Regimes of Ultrafast …

- ERL is ideally suited for studying electronic transition states in condensed matter at high repetition rate

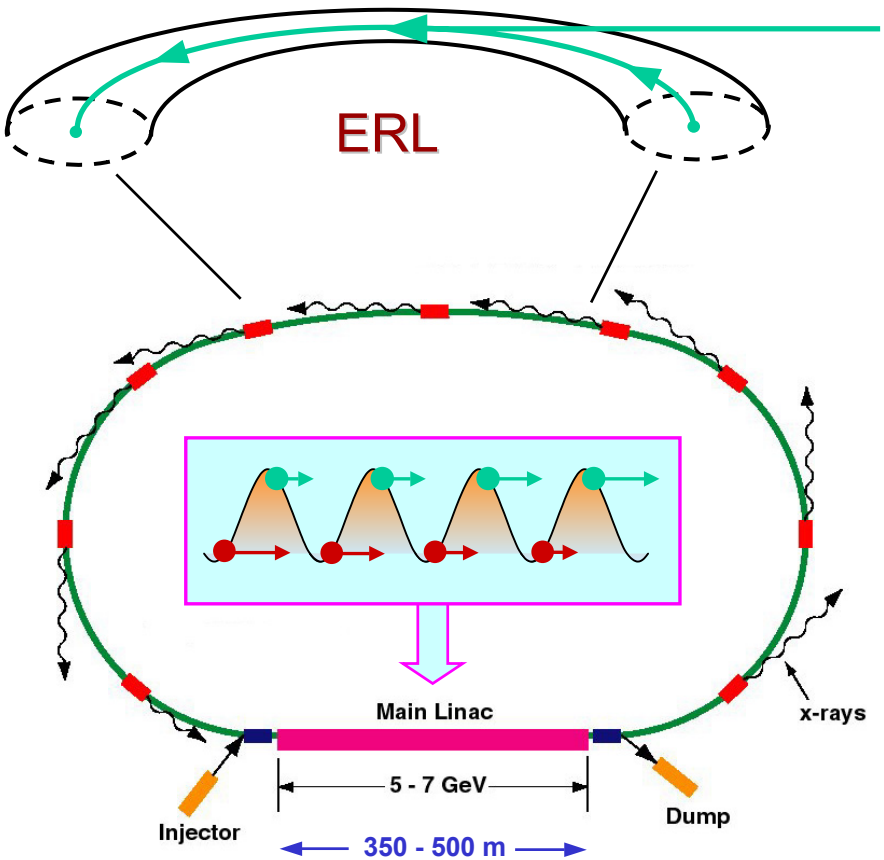


John Corlett

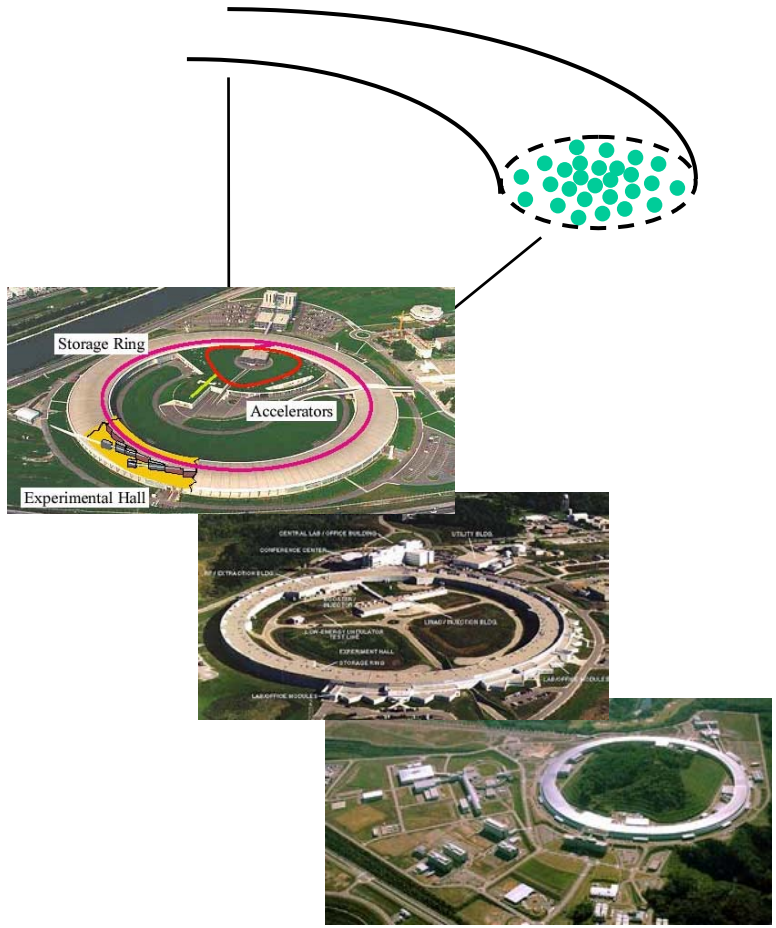
LUX – Linac-based Ultrafast X-Ray Source
September 2003, Berkeley, CA

Energy Recovery Linac (ERL)

Tigner, *Nuovo Cimento* 37, 1228 (1965)

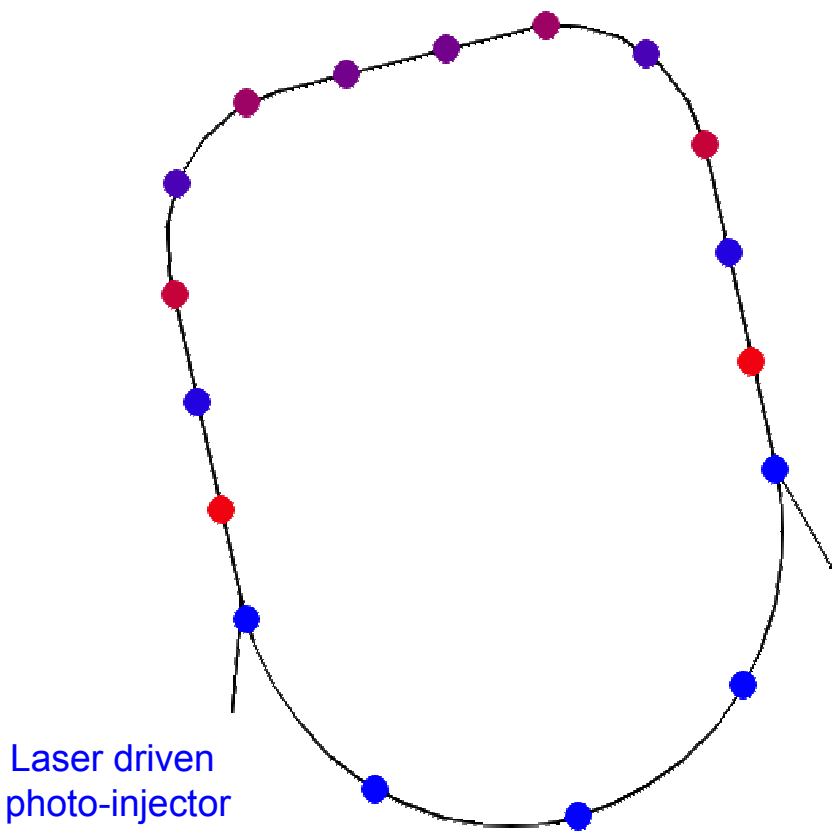


Storage Rings



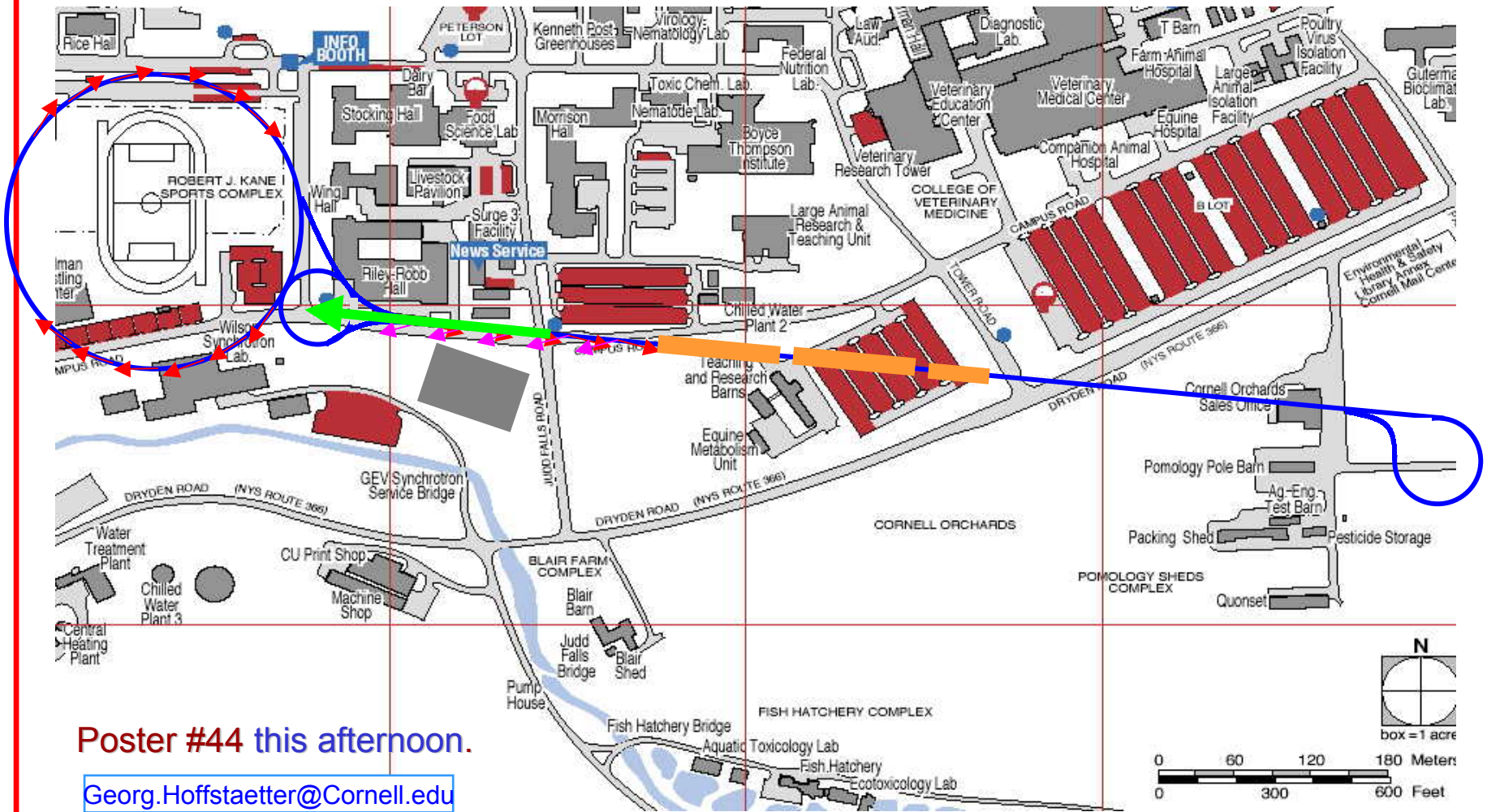
ERL at CESR

One option:
ERL @ CESR



Georg Hoffstaetter
LEPP / Physics
Cornell University

ERL as Possible Upgrade Path to Existing Facilities



Poster #44 this afternoon.

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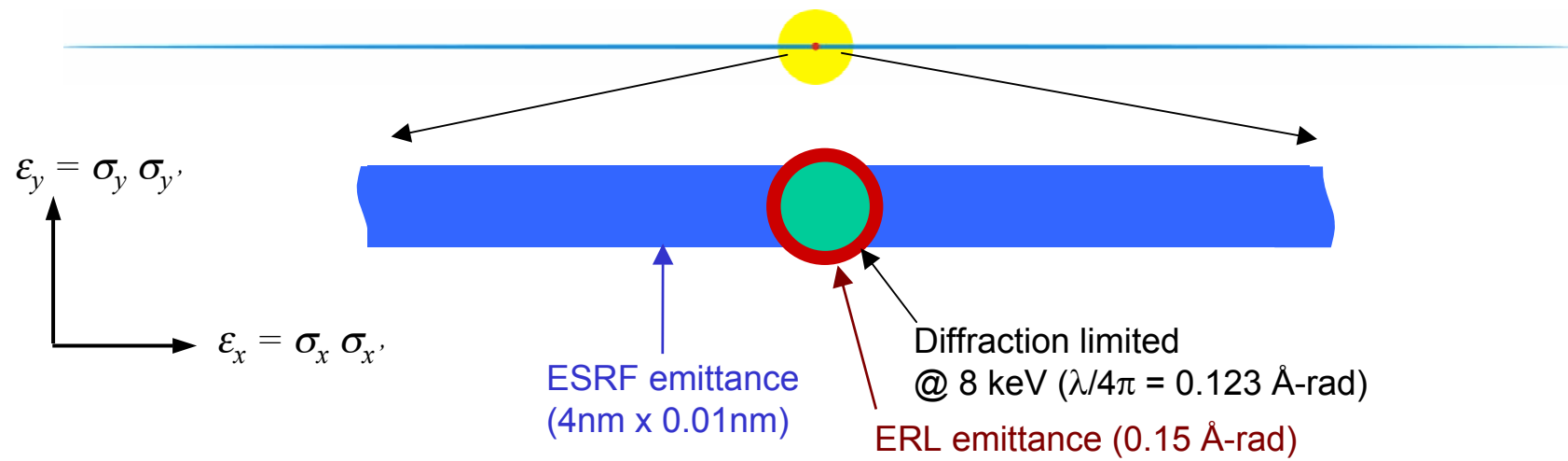
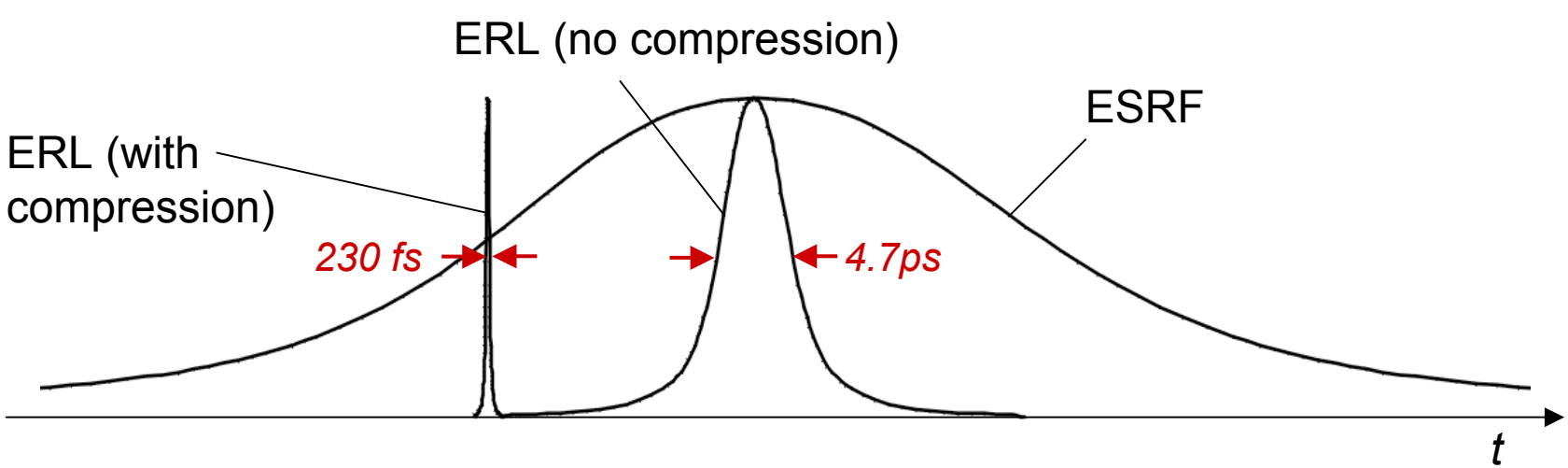
Proposed Properties of Cornell ERL

	High coherence	High flux	Short pulse
Energy (GeV)	5.3	5.3	5.3
Average current (mA)	10	100	1
Charge per bunch (nC)	0.008	0.08	1.0
Transverse emittance (nm-rad)	0.015	0.1	1x0.1
Bunch rms length (ps)	2	2	0.1
Maximum repetition rate (Hz)	1.3×10^{9}	1.3×10^{9}	1×10^{6}
Highest diffraction-limited energy (keV)	6.6	1	1
Undulator fundamental energy (keV)	8.3	8.3	8.3
Average flux (ph/s/0.1%)	9×10^{14}	9×10^{15}	8×10^{12}
Average brilliance (ph/s/0.1%/mm^2/mr^2)	3×10^{22}	1.6×10^{22}	1.4×10^{18}
Peak brilliance (ph/s/0.1%/mm^2/mr^2)	5×10^{24}	2×10^{24}	5×10^{24}
Peak flux (ph/s/0.1%)	1.3×10^{17}	1.3×10^{18}	3×10^{19}
Photons per pulse	8×10^{6}	8×10^{5}	1×10^{8}

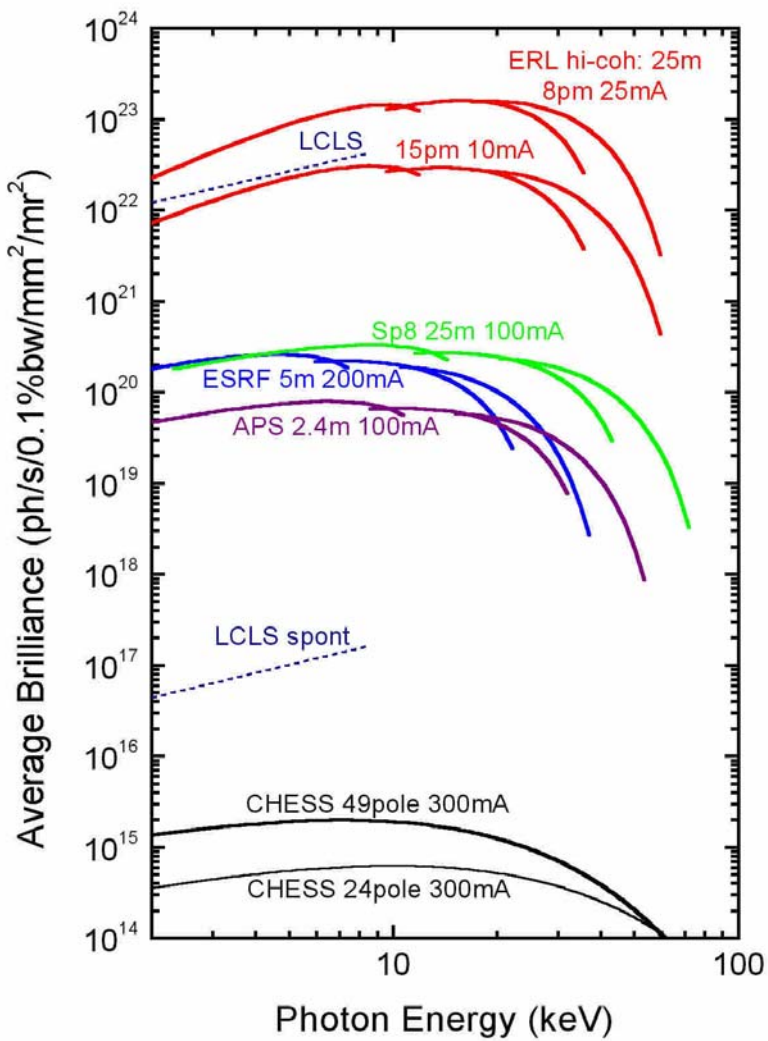
Note: The parameters listed in the table above are based on extensive studies by the ERL group at Cornell, with computer simulations and proper scaling procedures. Three different modes of operation are envisioned: high flux, high coherence, and short pulses (ultrafast). The values in these columns represent the expected initial performance at the start of the ERL operation, and future improvements may be possible after multiple years of successful R&D using the ERL X-ray source.

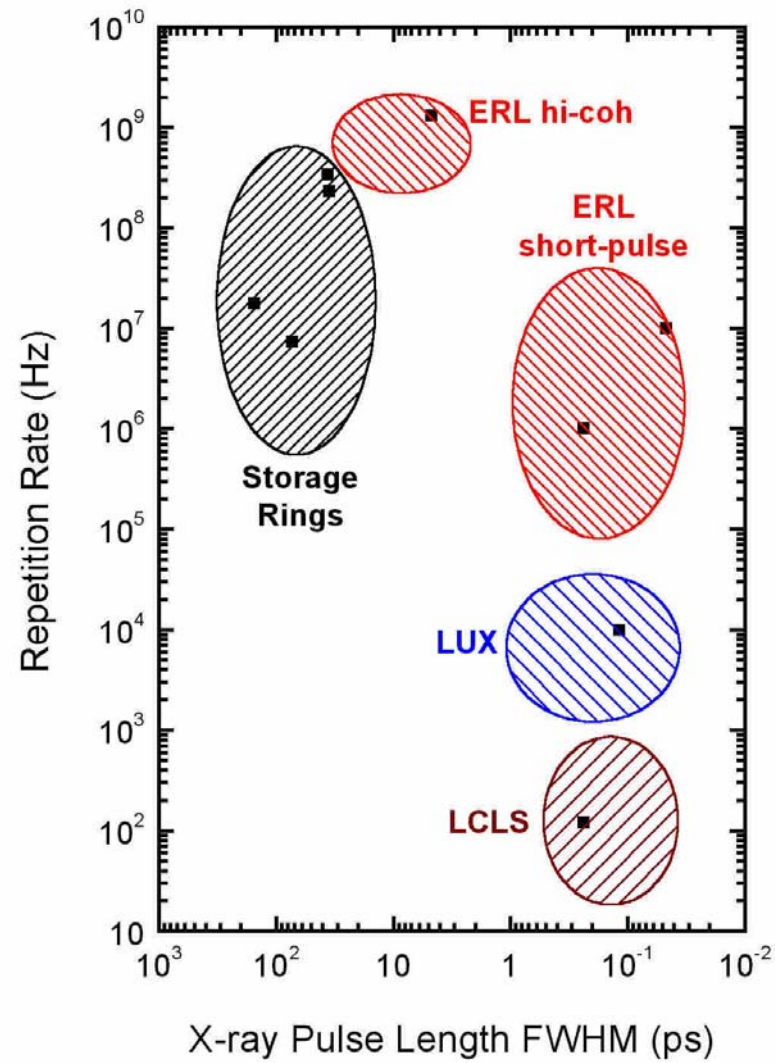
Transverse & Longitudinal Properties





Expected Performance of ERL Source





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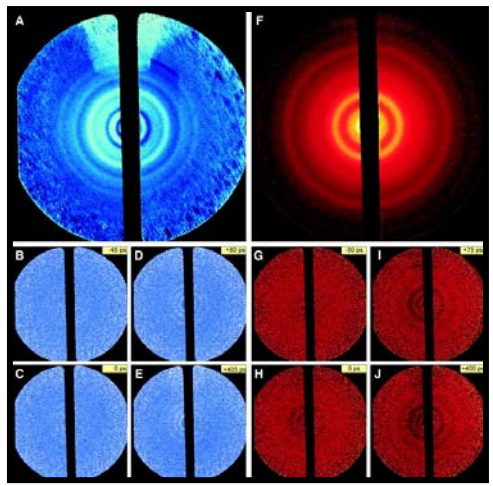
Ultrafast Science with ERL

- Ultrafast structural studies
  - ❖ ultrafast crystallography (*Wulff, Moffat, …*)
  - ❖ ultrafast wide-angle scattering (*Zawail, Wulff, …*)
- Ultrafast x-ray spectroscopy
  - ❖ high-spectral-resolution XAS (*Cavalleri, Chen, …*)
  - → ❖ coherent spectroscopy ($\Delta E \Delta t \sim \hbar$)
- Ultrafast materials physics
  - → ❖ magnetic pump-probe studies
  - → ❖ collective mode excitations
  - ❖ perturbative nonlinear phenomena

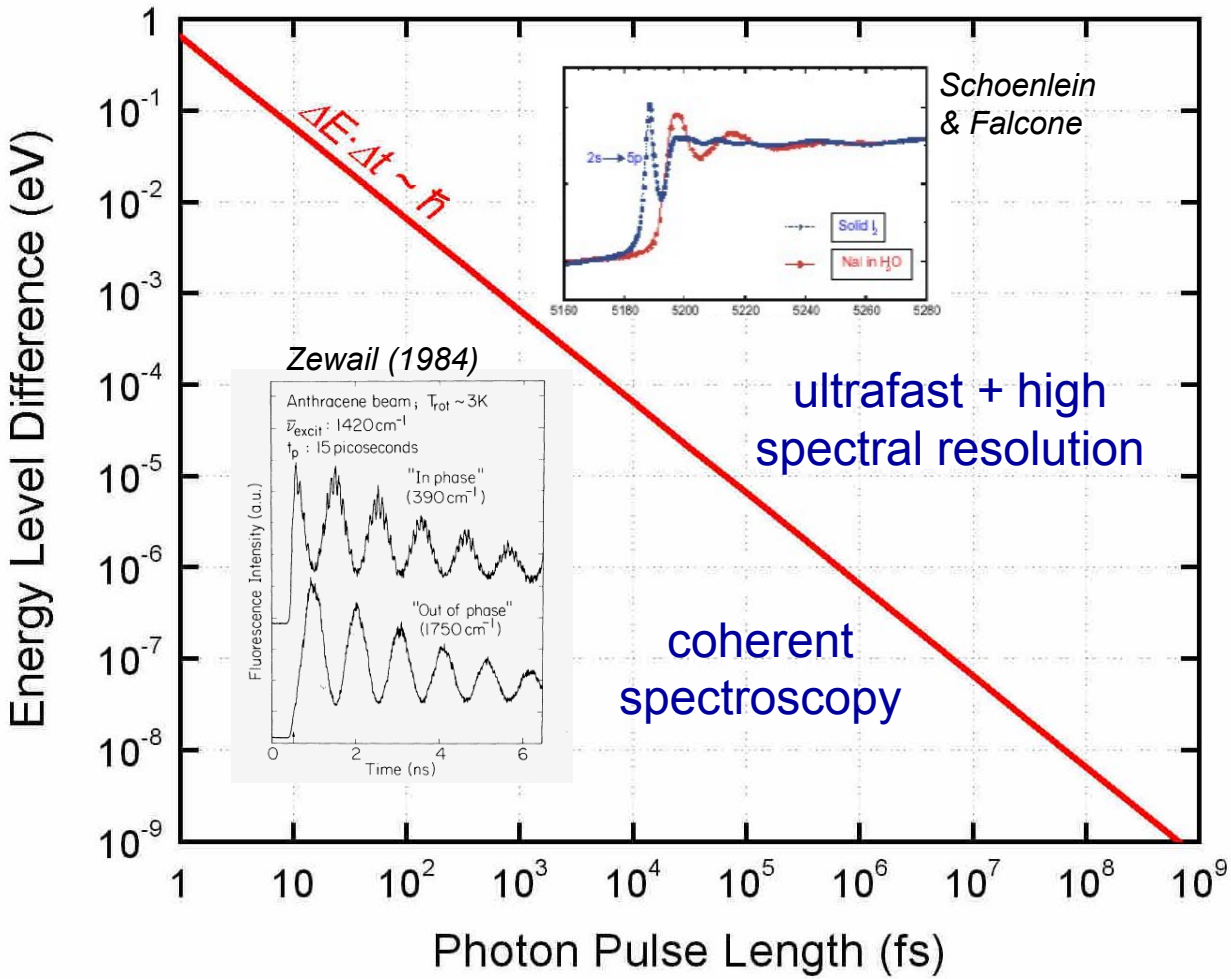
Ihee, et al., Science **291**, 458-462 (2001).

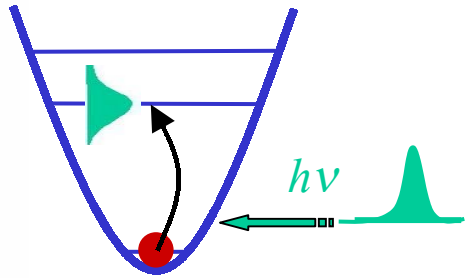


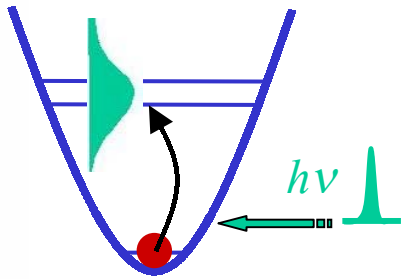
→ **Short fs pulses**

→ **High rep-rate**

Ultrafast X-ray Spectroscopy
– two regimes

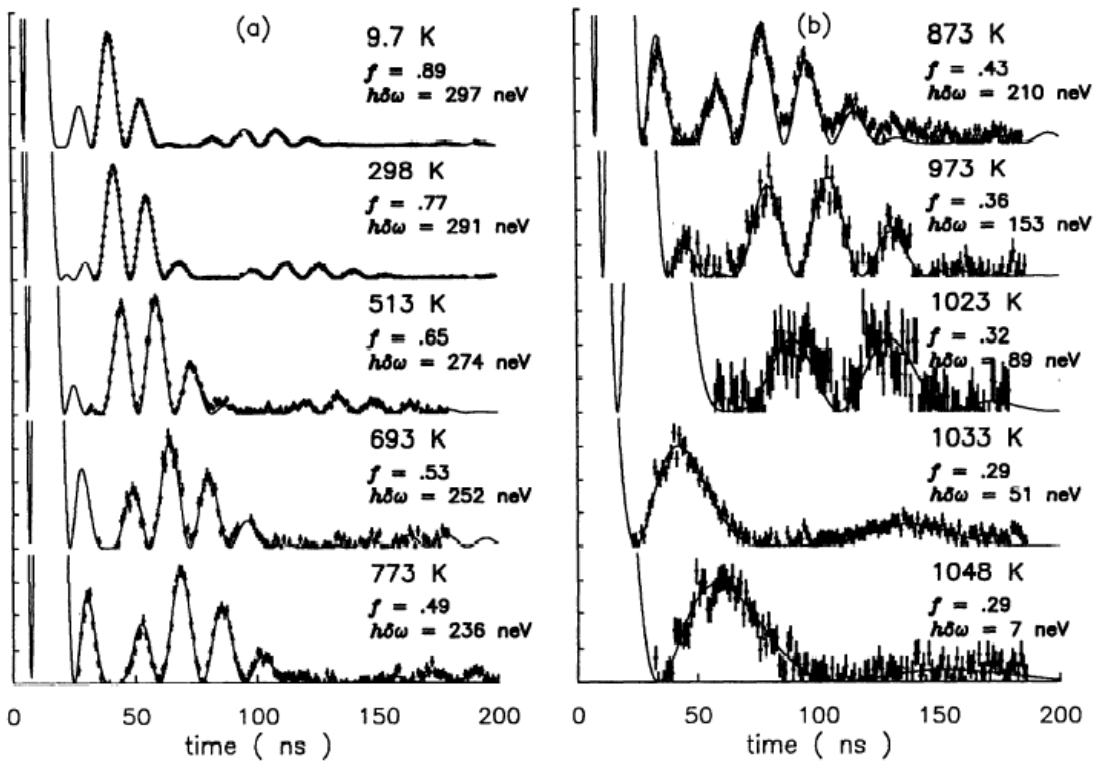




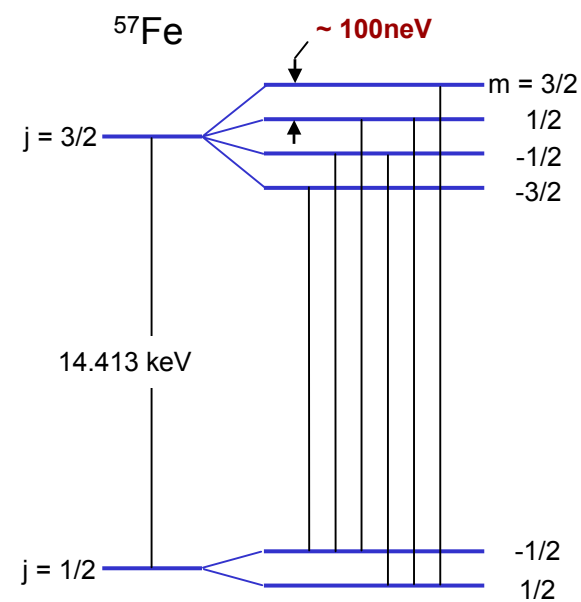


Analogy to X-ray Nuclear Scattering

Bergmann, Shastri, Siddons, Batterman, Hastings,
Phys. Rev. B 50 (1994) 5957-5961

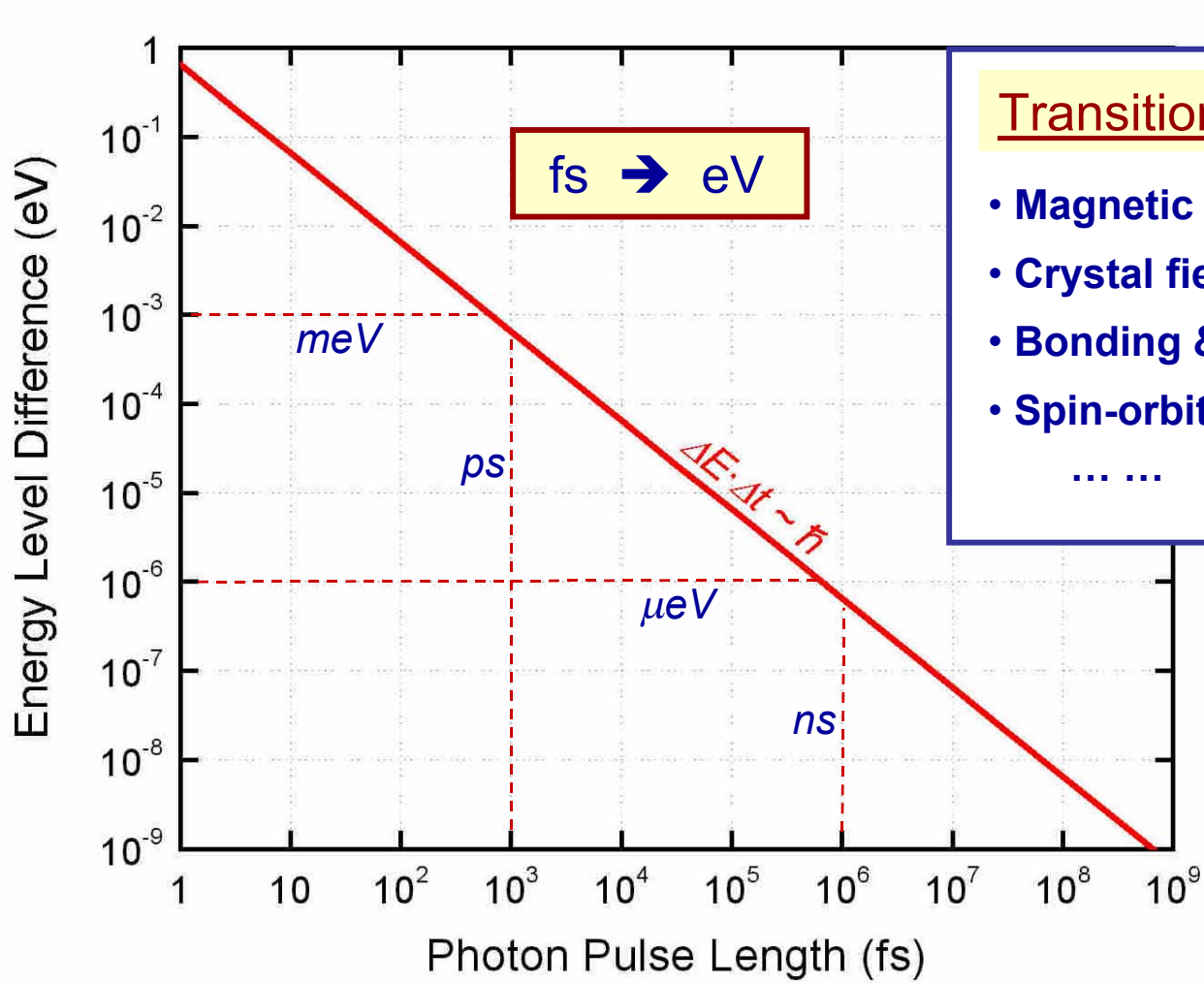


- Hyperfine splitting in nuclear levels (Zeeman splitting due to internal magnetic field)



X-ray pulse ~ 100 ps
→ ΔE ~ 6.6 μeV

Coherent X-ray Spectroscopy in fs-regime

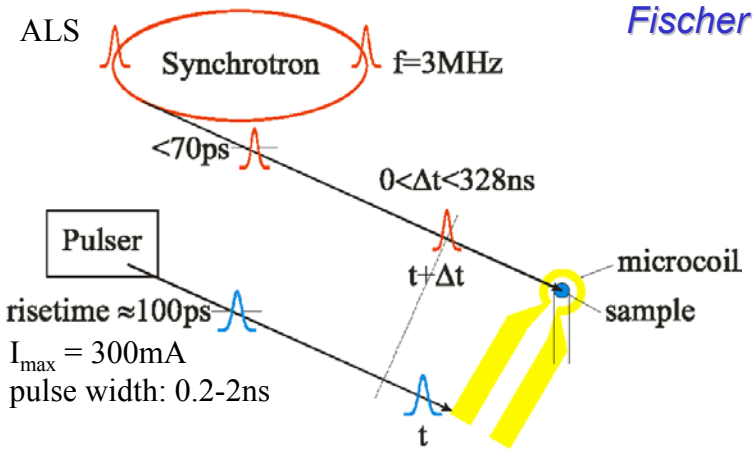


Transition States of :

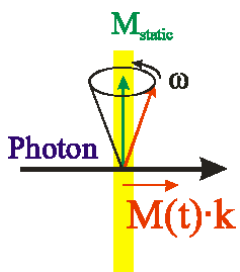
- **Magnetic field effect ?**
- **Crystal field effect ?**
- **Bonding & antibonding ?**
- **Spin-orbit coupling ?**

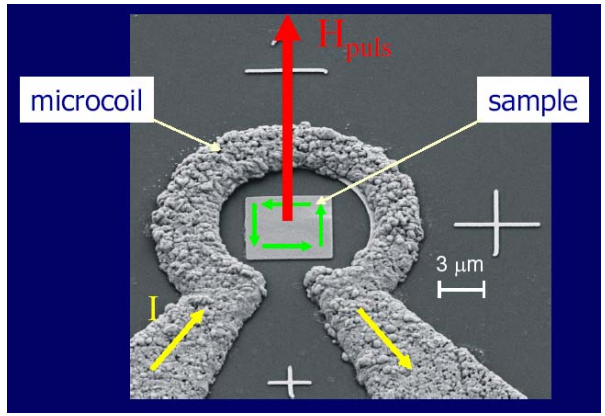
… …

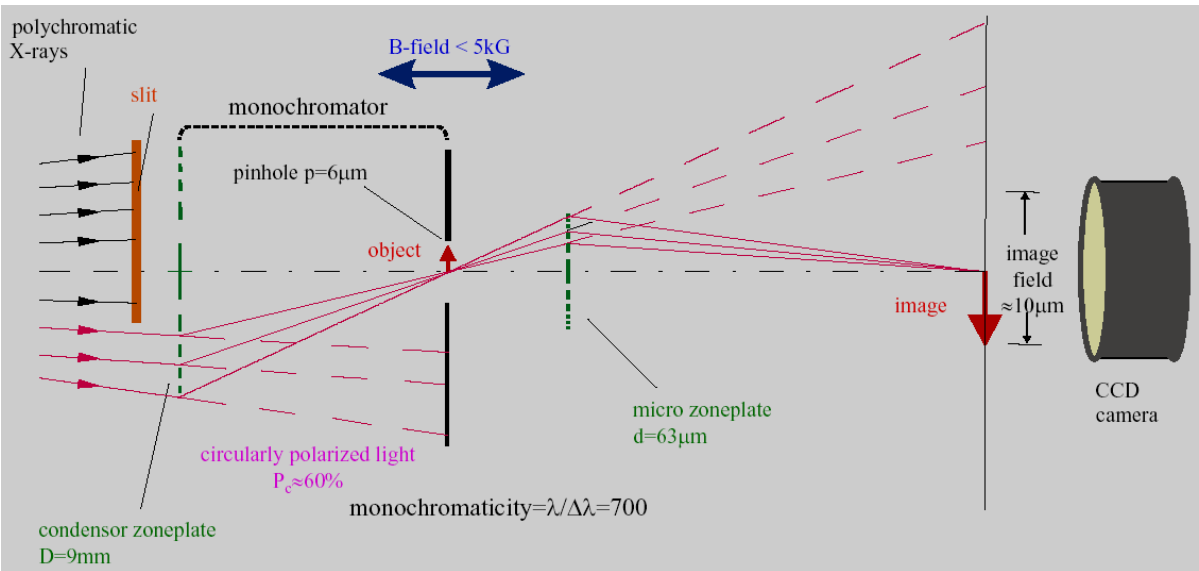
Pump-Probe Magnetic Imaging

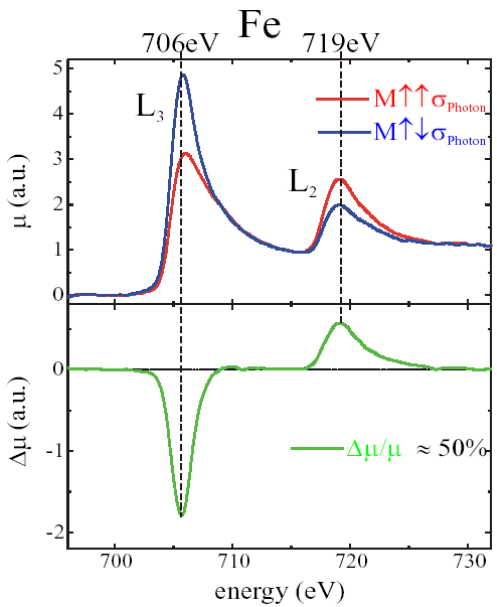


Fischer et al. (SRI 2003)

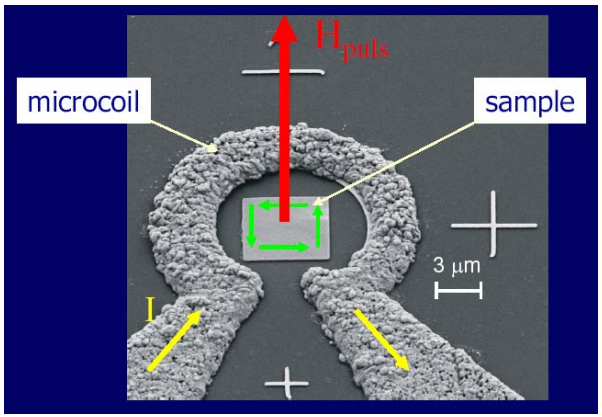






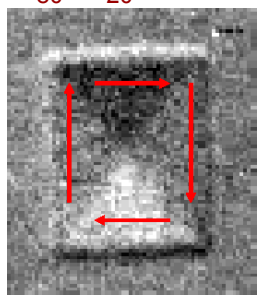


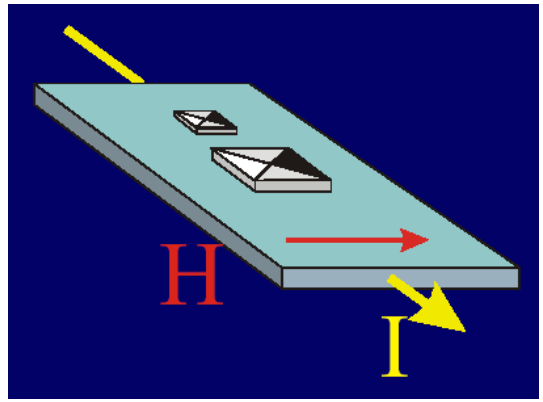
Pump-Probe Magnetic Imaging

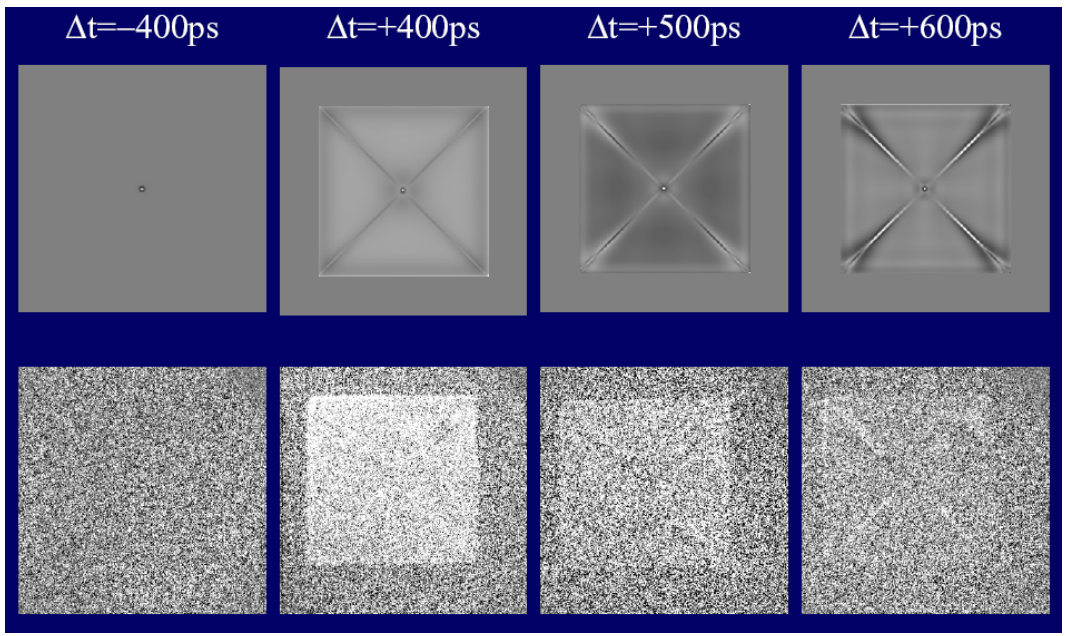


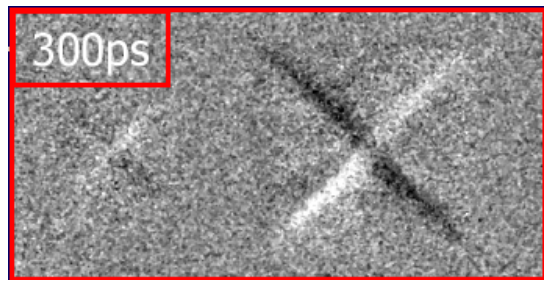
Fischer et al.
(SRI 2003)

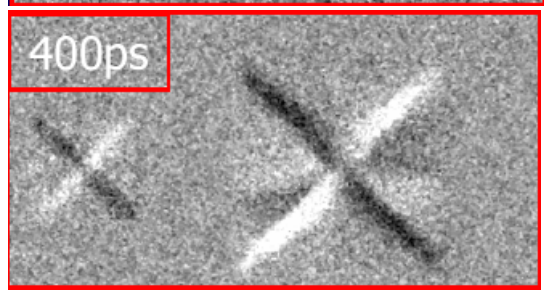
$Ni_{80}Fe_{20}$ (50 nm)



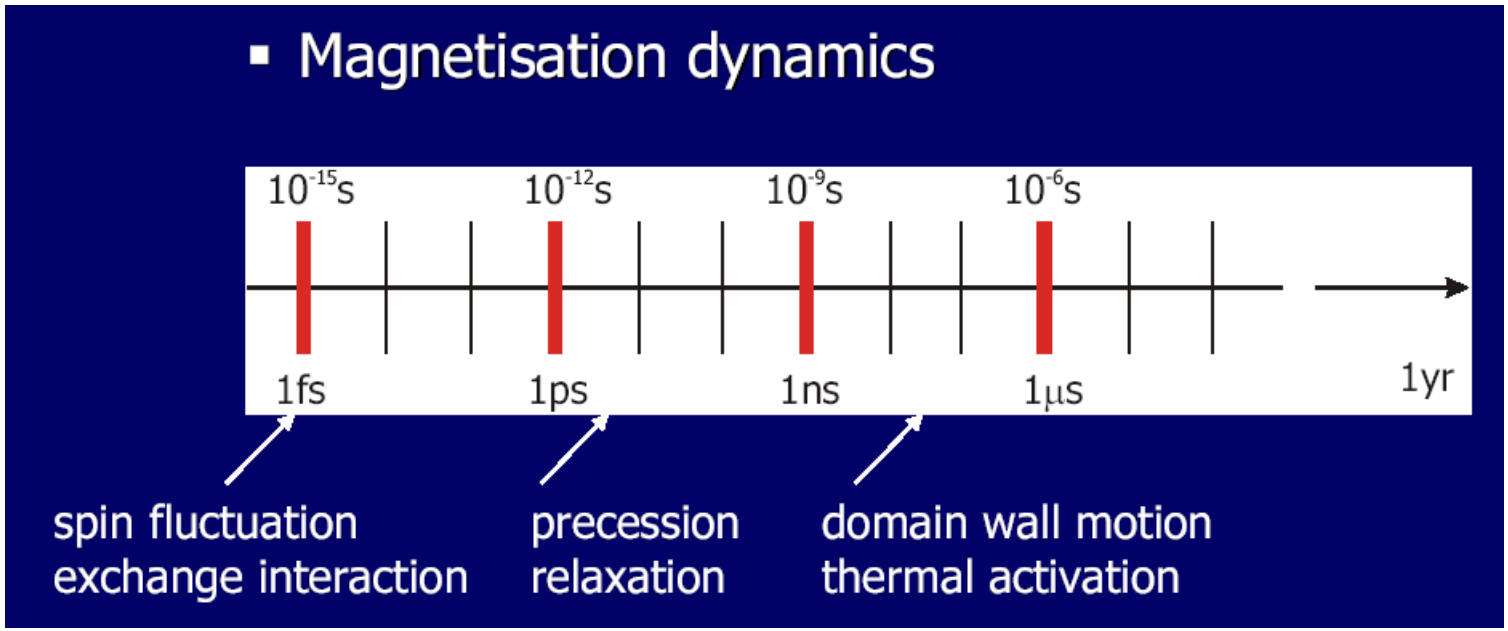








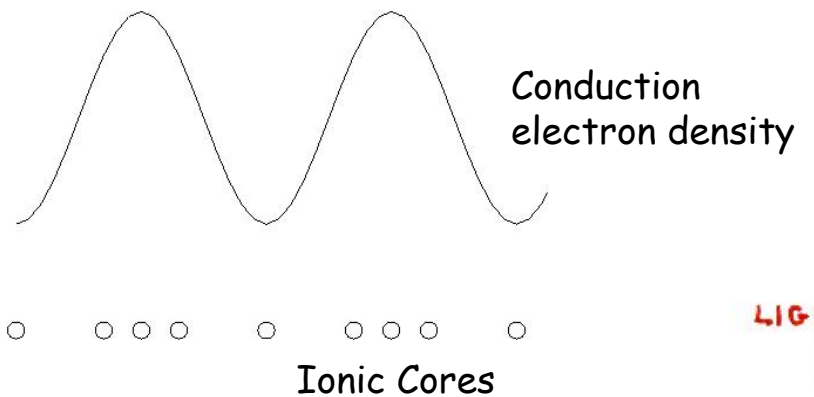
Pump-Probe Magnetic Studies

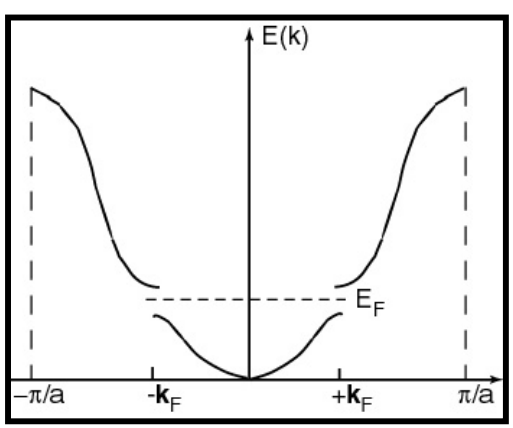


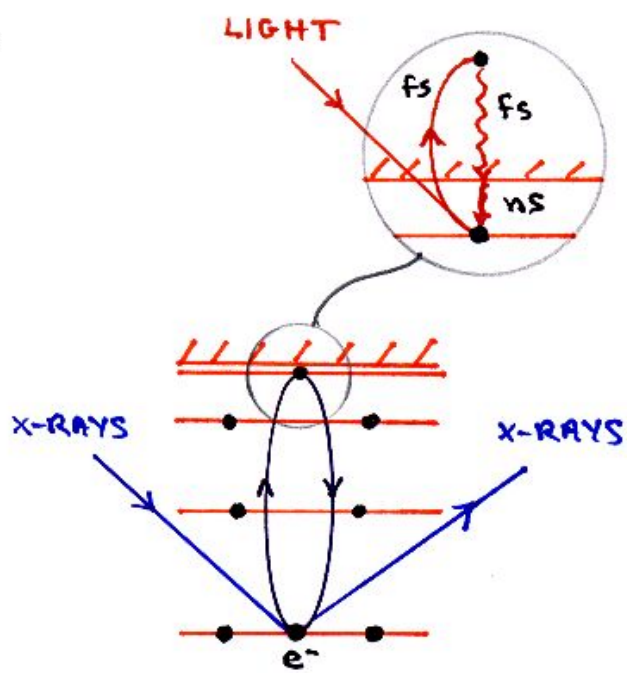
- Present: sub-ns magnetic pump-probe,
  coherent scattering (Goedkoop et al., SRI 2003)
  XMCD imaging (Fischer et al., SRI 2003)
- Future: spin dynamics in fs regime?

Resonance-Enhanced Charge Density Wave Studies

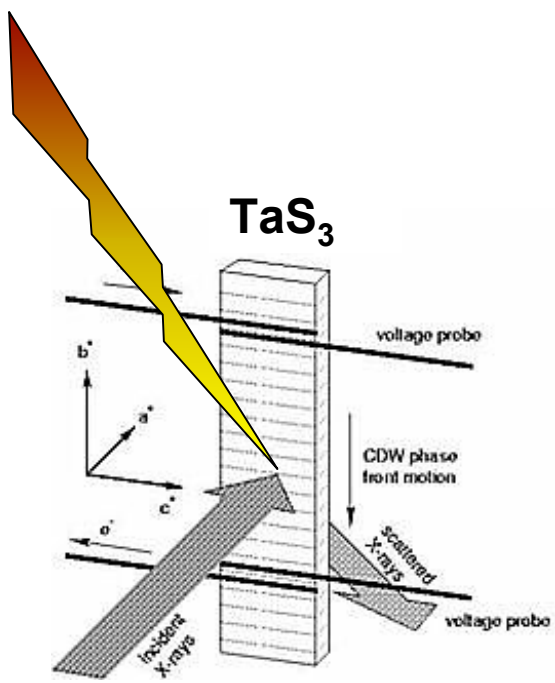
Joel Brock et al. (2004)



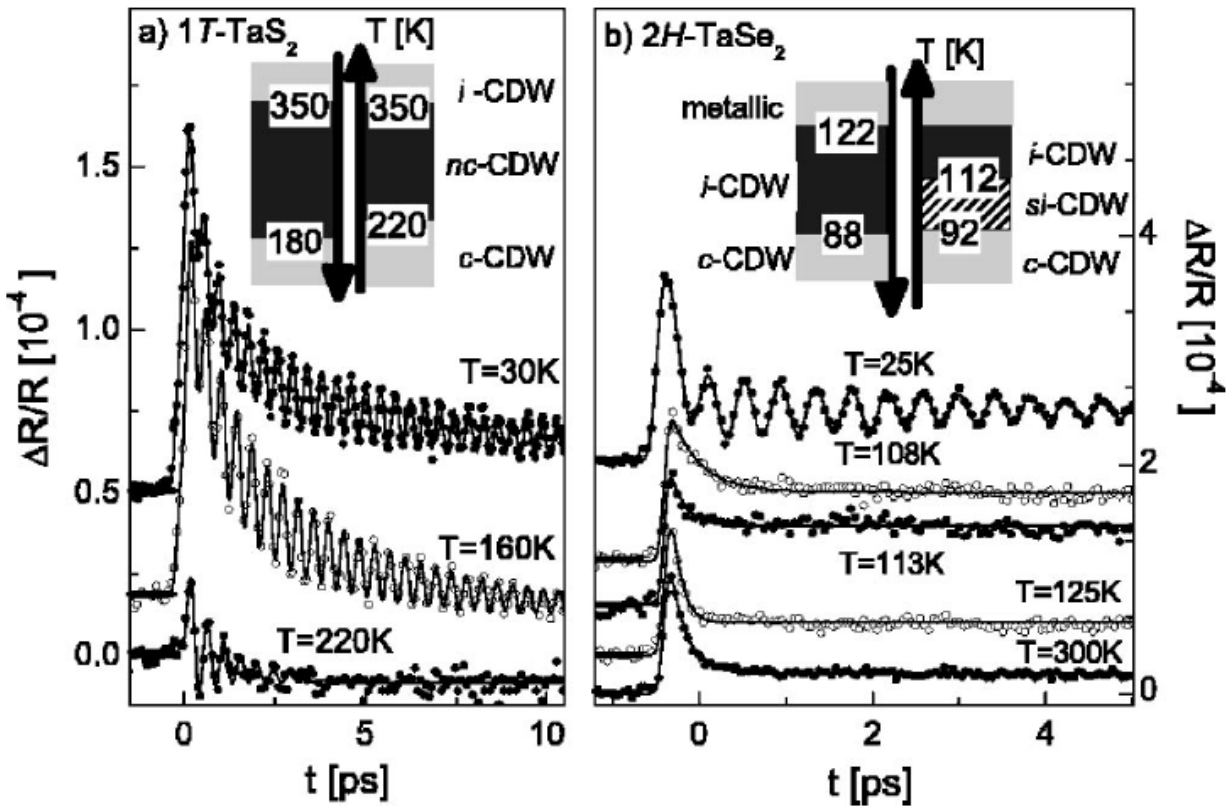




fsec pump laser pulses at 80 MHz

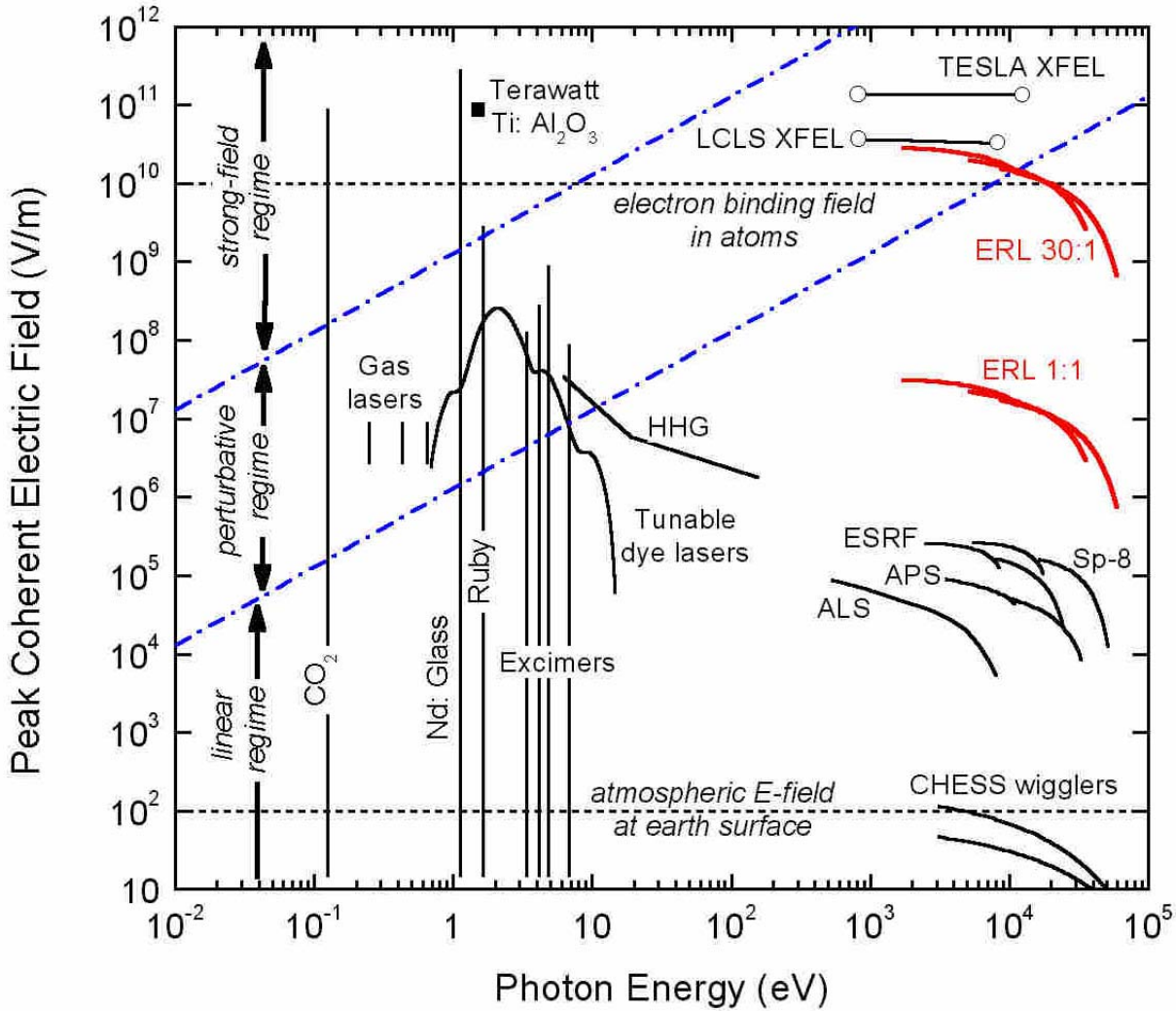


Optical Reflectivity on TaS_2 & $TaSe_2$



Demsar, J., L. Forro, H. Berger, and D. Mihailovic, *Femtosecond snapshots of gap-forming charge-density-wave correlations in quasi-two-dimensional dichalcogenides 1T-TaS_2 and 2H-$TaSe_2$.* Physical Review B, 2002. **66**, 041101.

Perturbative Nonlinear Phenomena ?



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Summary

- Proposed ERL source at Cornell provides nano-beam, high-coherence, and ultrafast capabilities at high rep-rate, and would open up new application areas of synchrotron x-rays.

- In the ultrafast area, the ERL would allow:
  - Ultrafast structural studies
    - ultrafast crystallography & WAXS
  - Ultrafast x-ray spectroscopy
    - ultrafast hi-resolution + coherence
  - Ultrafast materials physics
    - magnetic pump-probe
    - collective mode excitations
    - perturbative nonlinear x-ray physics

- Novel application ideas are always welcome.

For more info, please visit http://erl.chess.cornell.edu/

→ Poster #44 this afternoon.

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Acknowledgment

- Cornell University:

  I.V. Bazarov, D.H. Bilderback, J.D. Brock, K.D. Finkelstein, S.M. Gruner, G. Hoffstaetter, H.S. Padamsee, C. Sinclair, R. Talman, M. Tigner

- Thomas-Jefferson National Accelerator Facility:

  G. A. Krafft, L. Merminga

- NSF, DOE, Cornell