Ultrafast Electron-Electron Dynamics in Graphene

Daniele Brida

Universität
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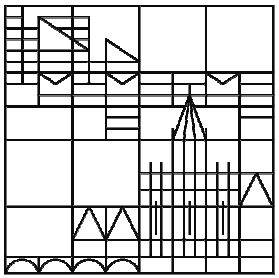
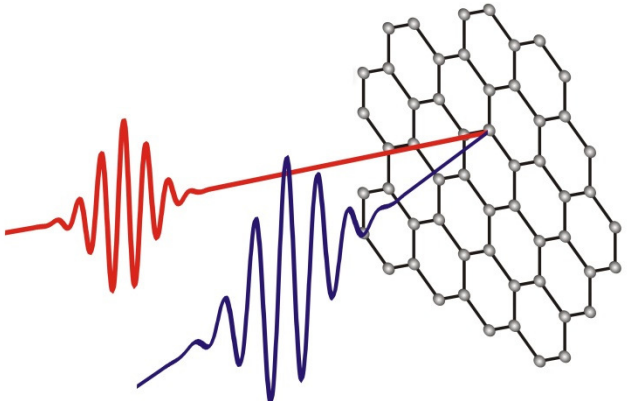
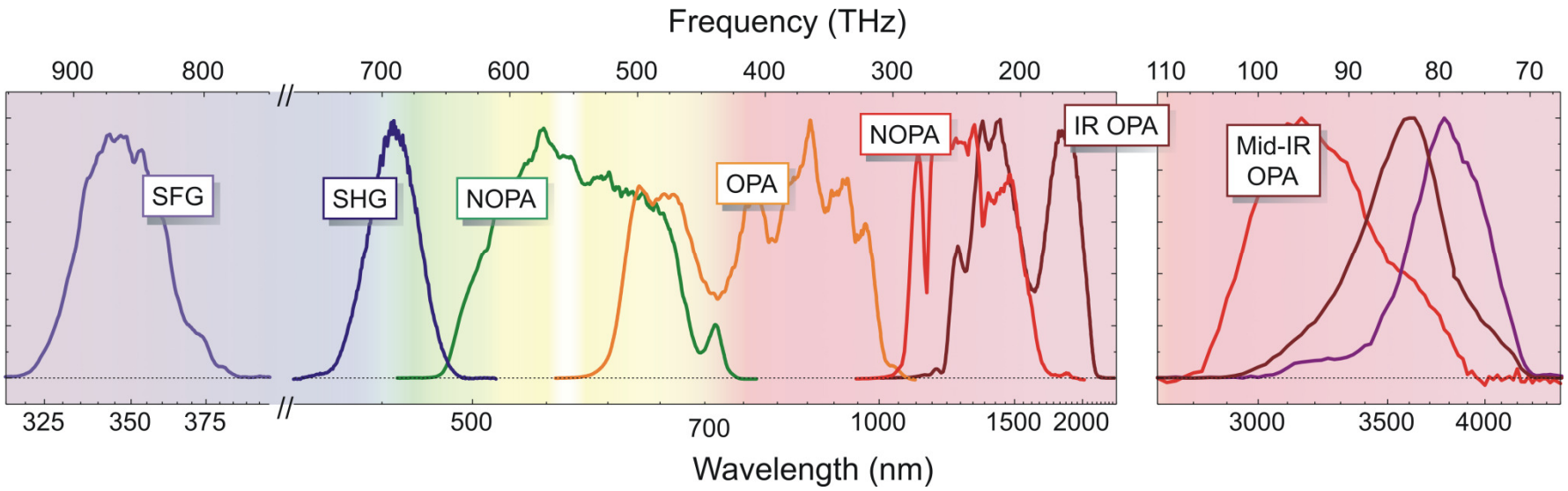


Ultrafast Spectroscopy

Light-matter interaction on timescale of **fundamental physical processes**:

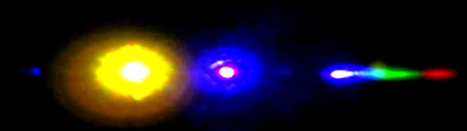
electron scattering, phonon emission, energy transfer …



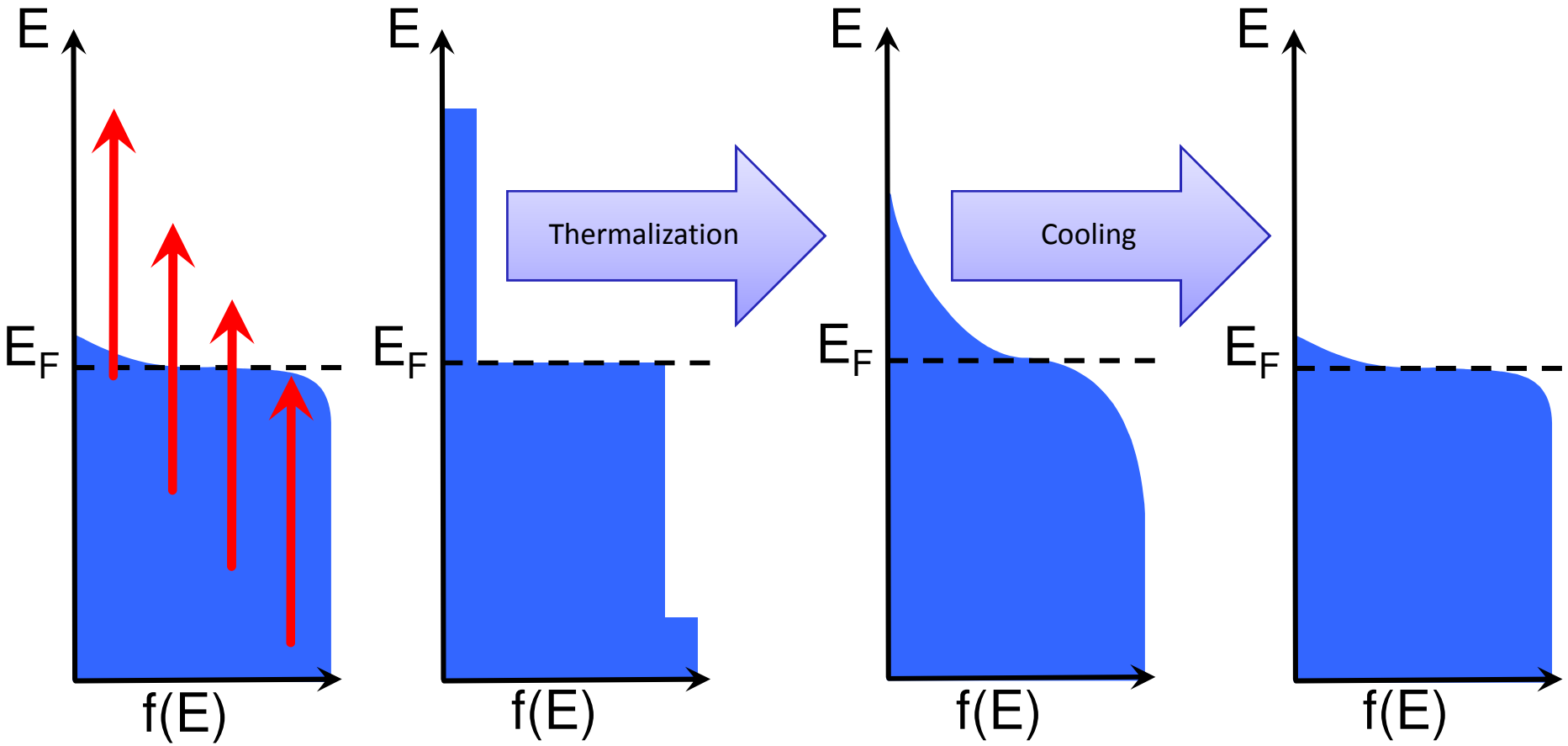


D. Brida *et al.*, J. Opt 12, 013001 (2010).

Electron Thermalization in Graphene



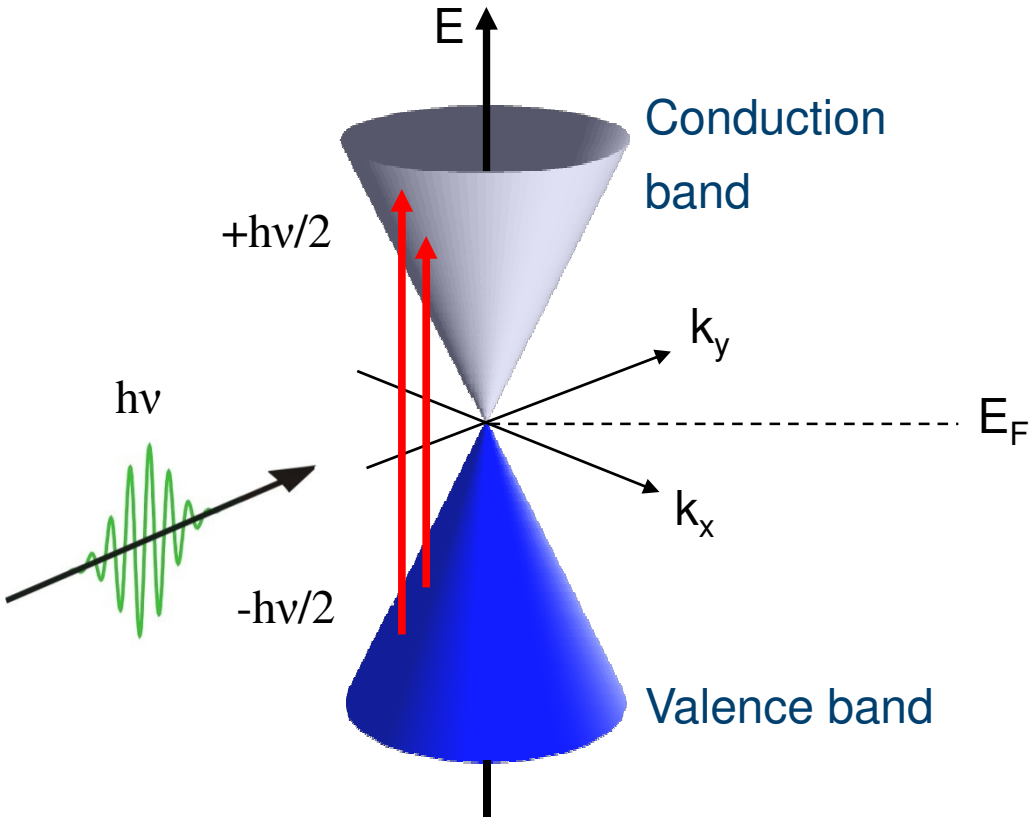
First: how it happens in metals



Beyond two-temperature model

G. Della Valle *et al.*, *PRB*, (2012).

Electron Thermalization in Graphene



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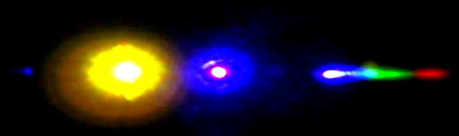

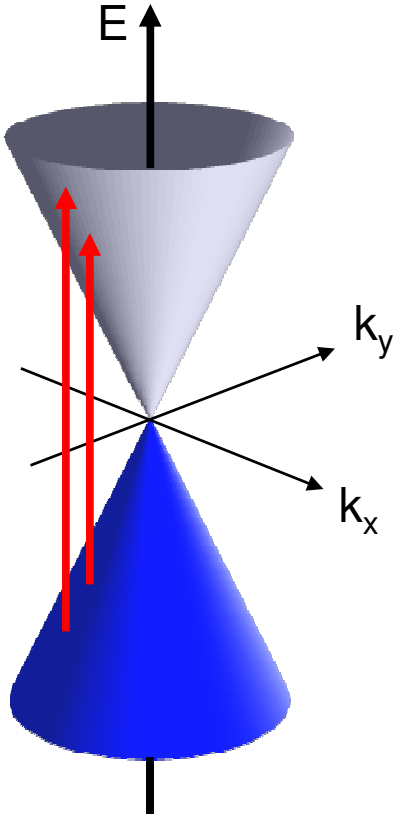

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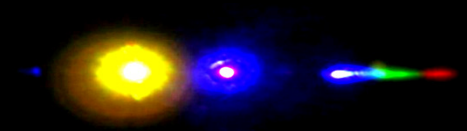
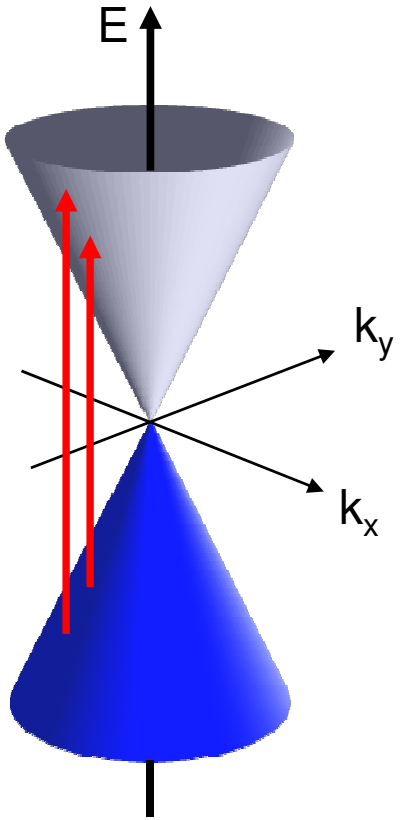
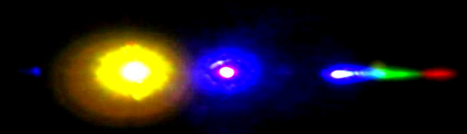
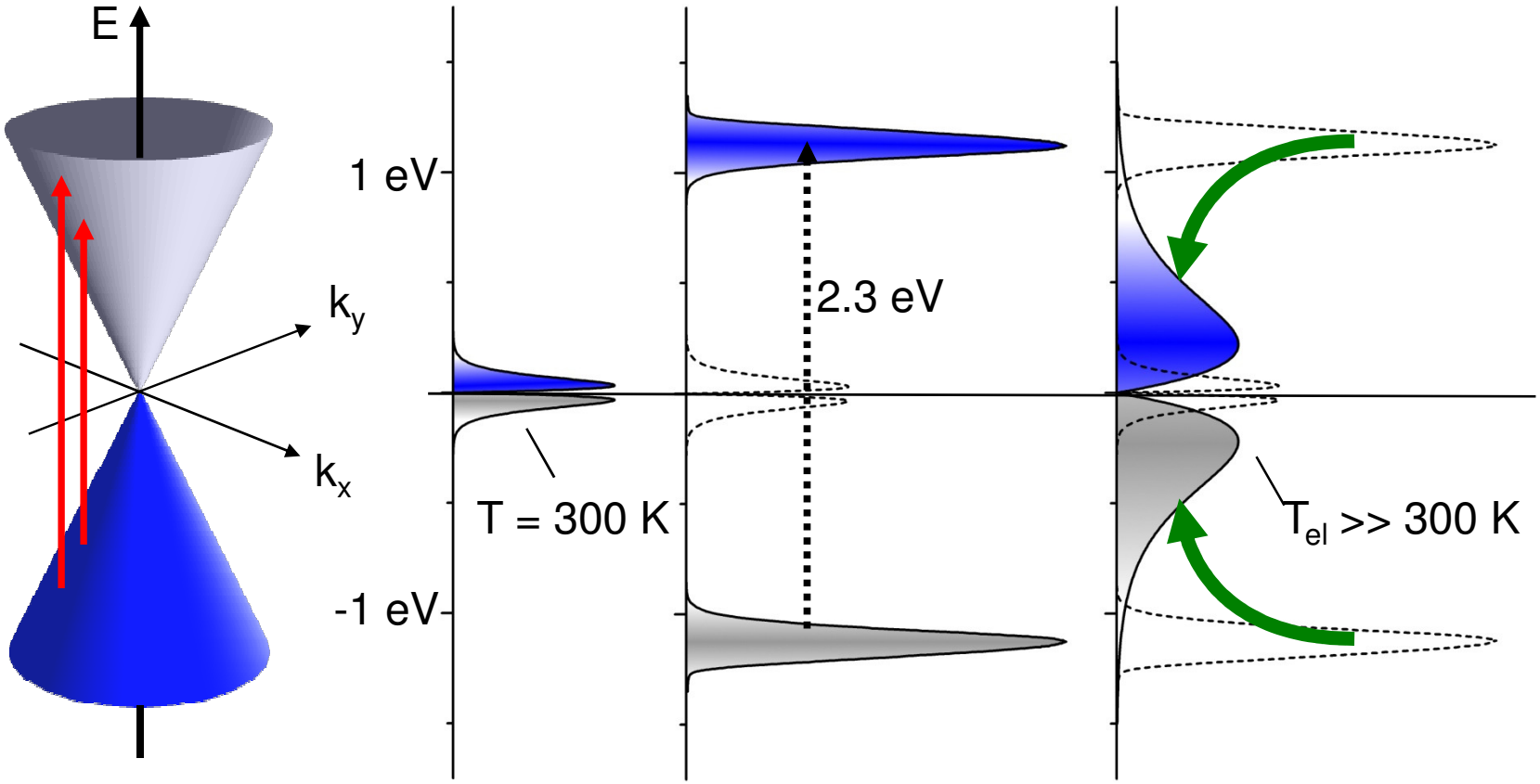




Electron Thermalization in Graphene





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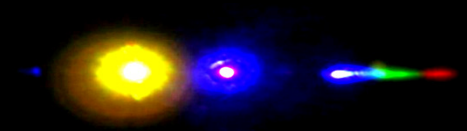
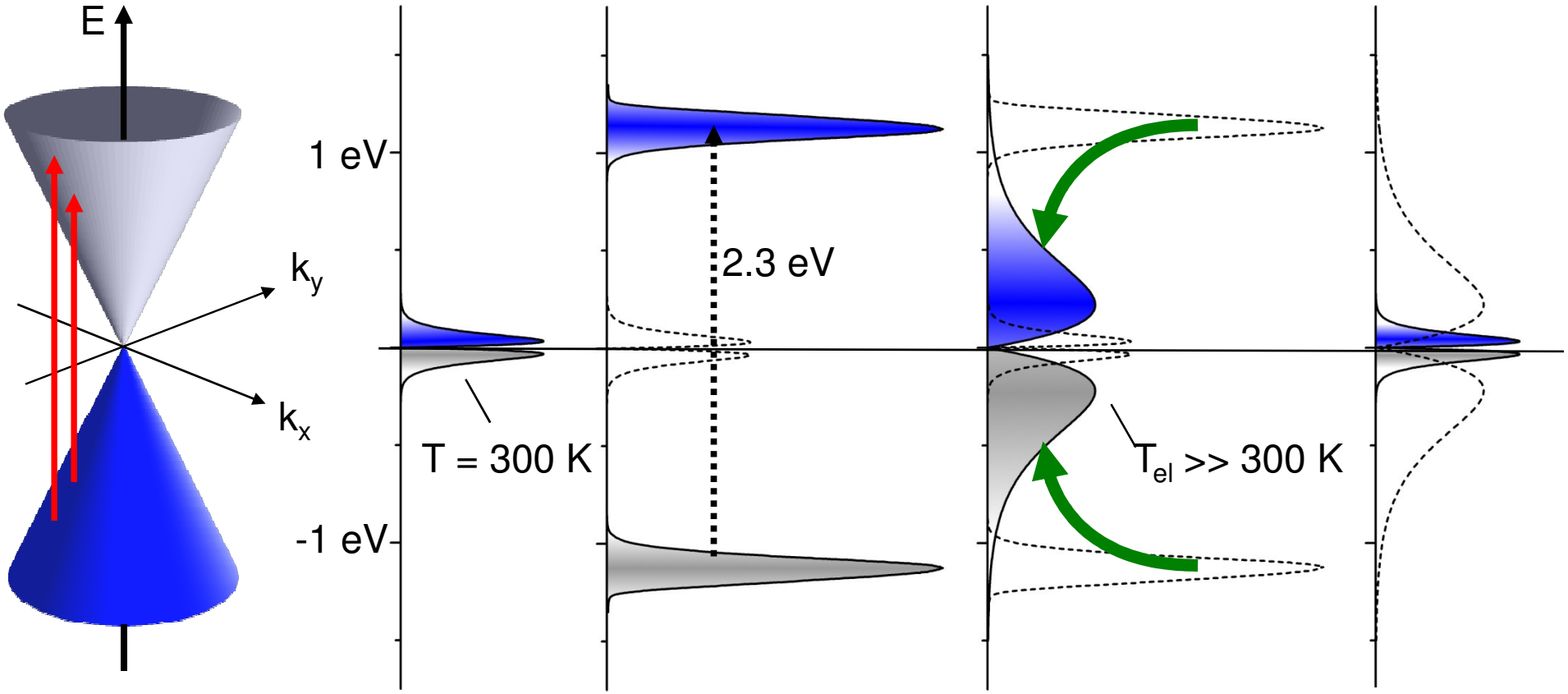
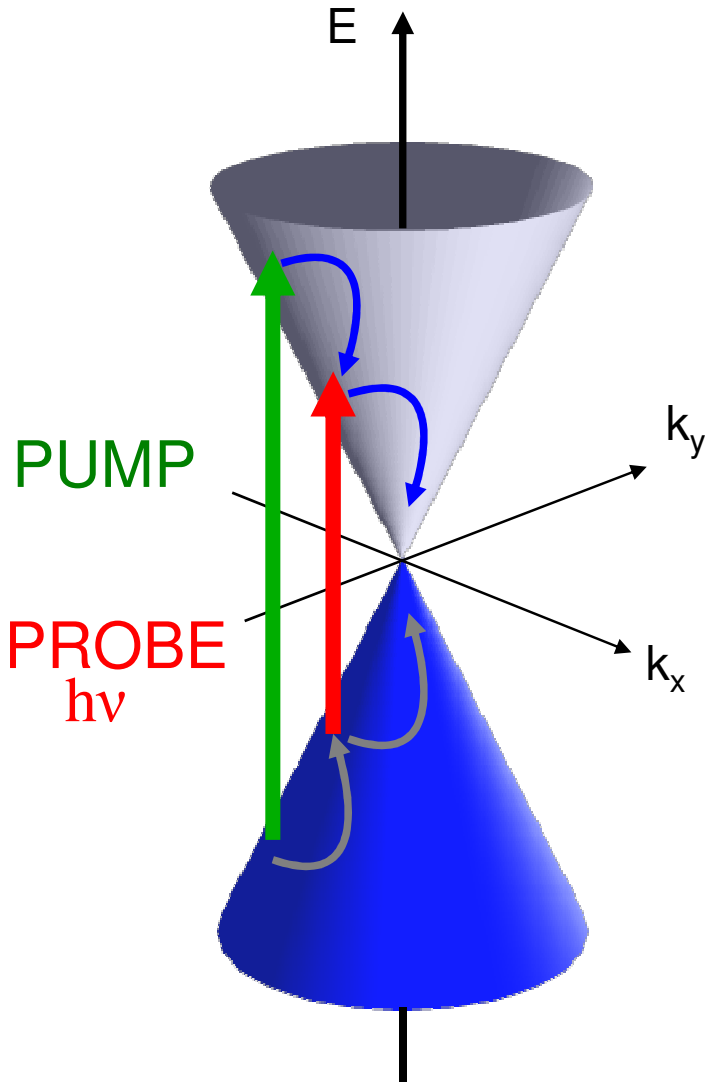


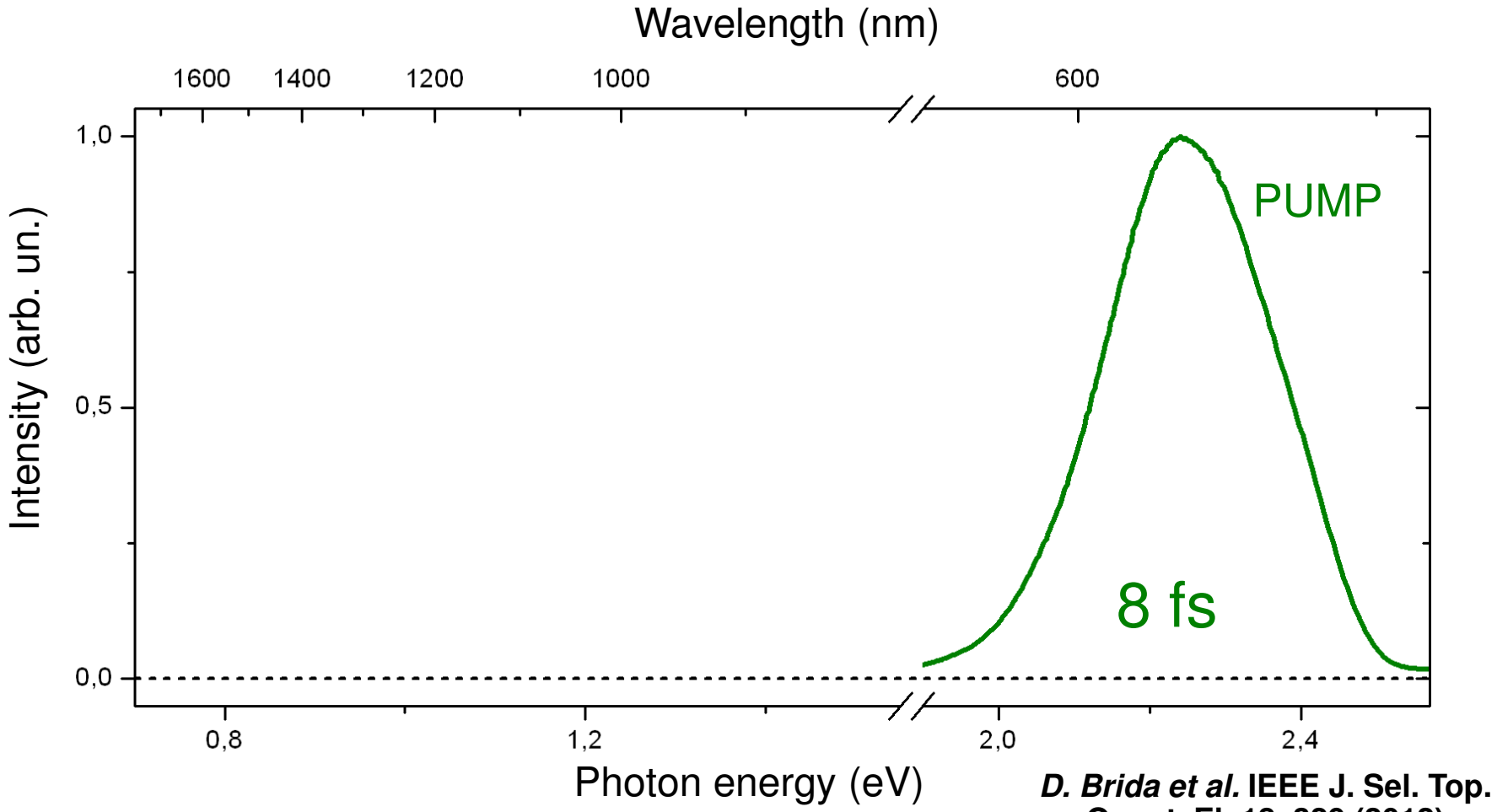


Ultrafast Spectroscopy



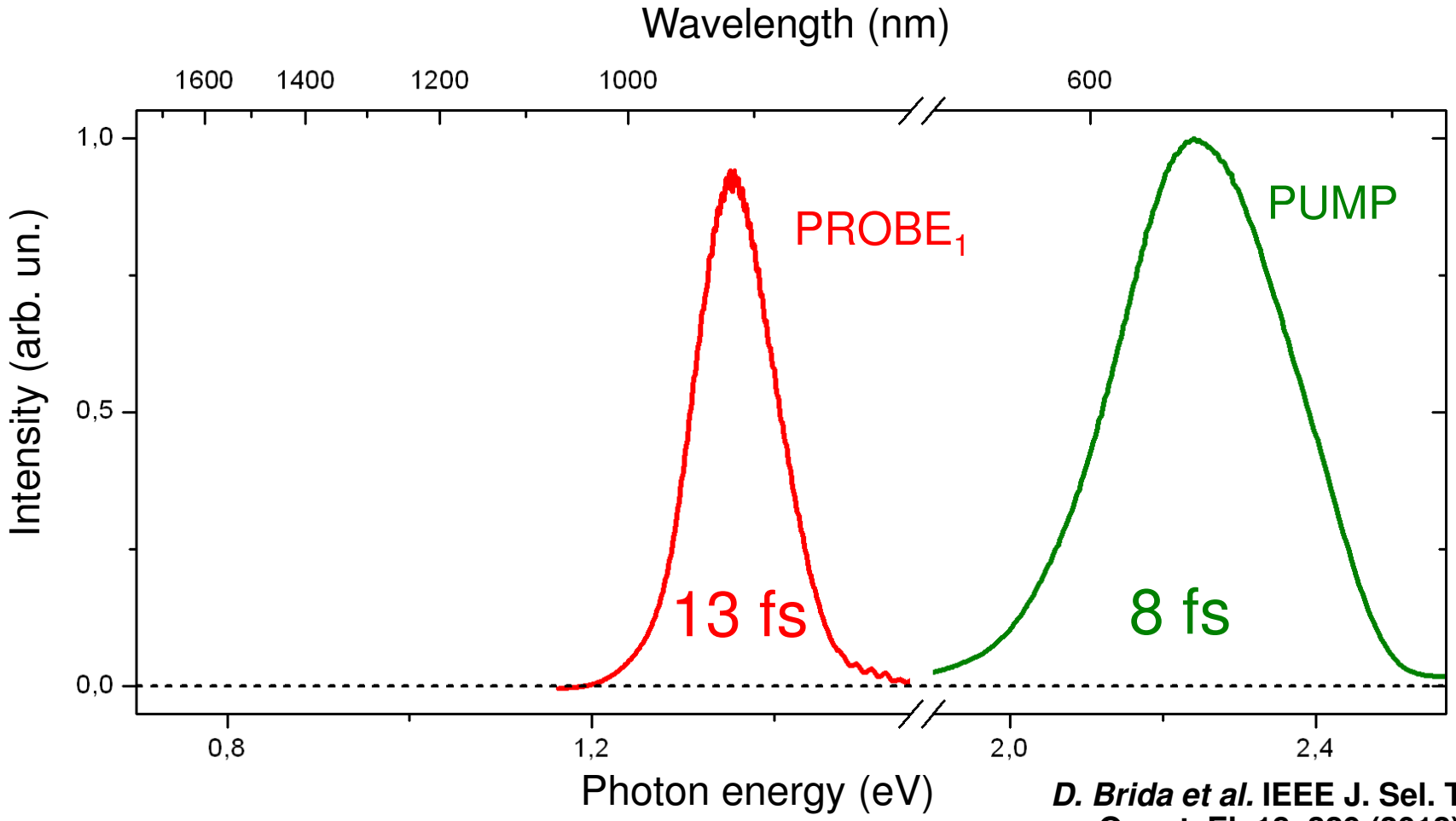
- PUMP pulse impulsevely excite an out-of-equilibrium electron/hole distribution
- A photobleaching signal (Pauli blocking) appears in the PROBE spectral window when electrons reach hv/2 above Fermi energy.

Ultrashort tunable pulses from OPAs



D. Brida et al. **IEEE J. Sel. Top. Quant. El. 18, 329 (2012)**

Ultrashort tunable pulses from OPAs



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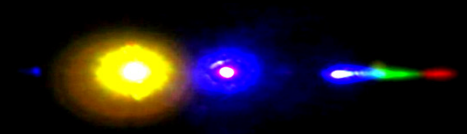
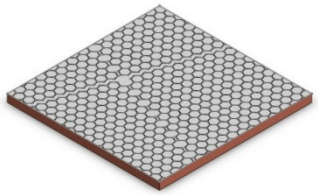
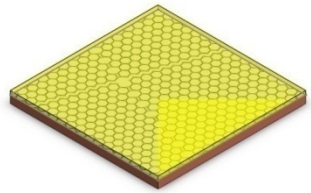


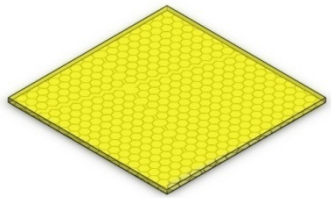
Sample: single layer graphene growth by CVD



Graphene layer growth by CVD on a copper substrate

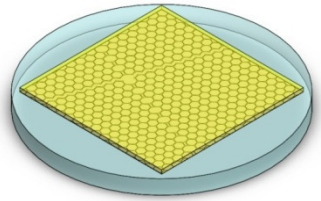
A polymer is spin-coated on top of the sample

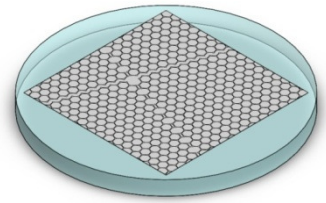




Copper is selectively etched away

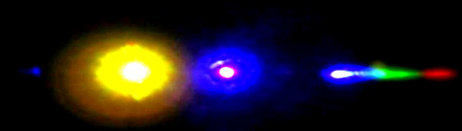
The graphene layer is moved to a SiO2 substrate



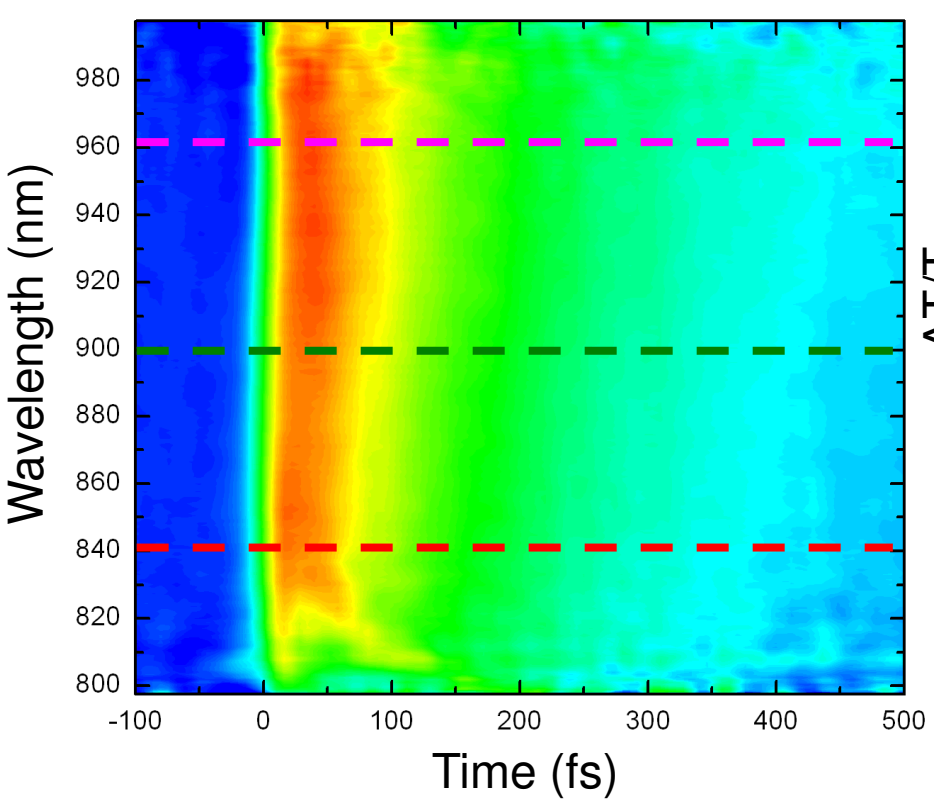


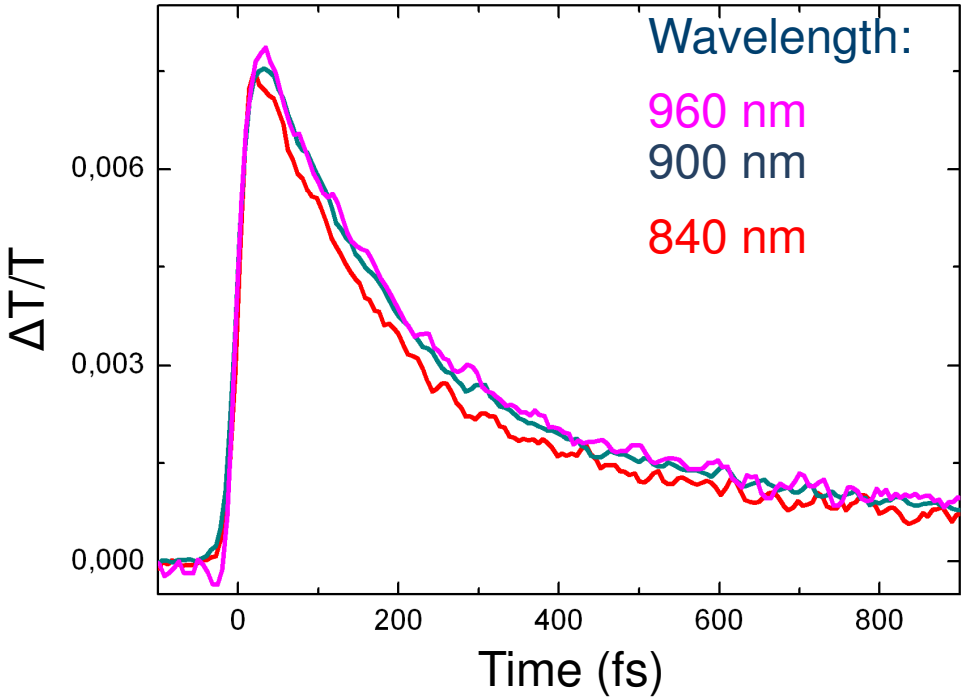
The polymer is then dissolved with acetone

Experimental Results



PUMP Visible - PROBE NIR





Experimental Results

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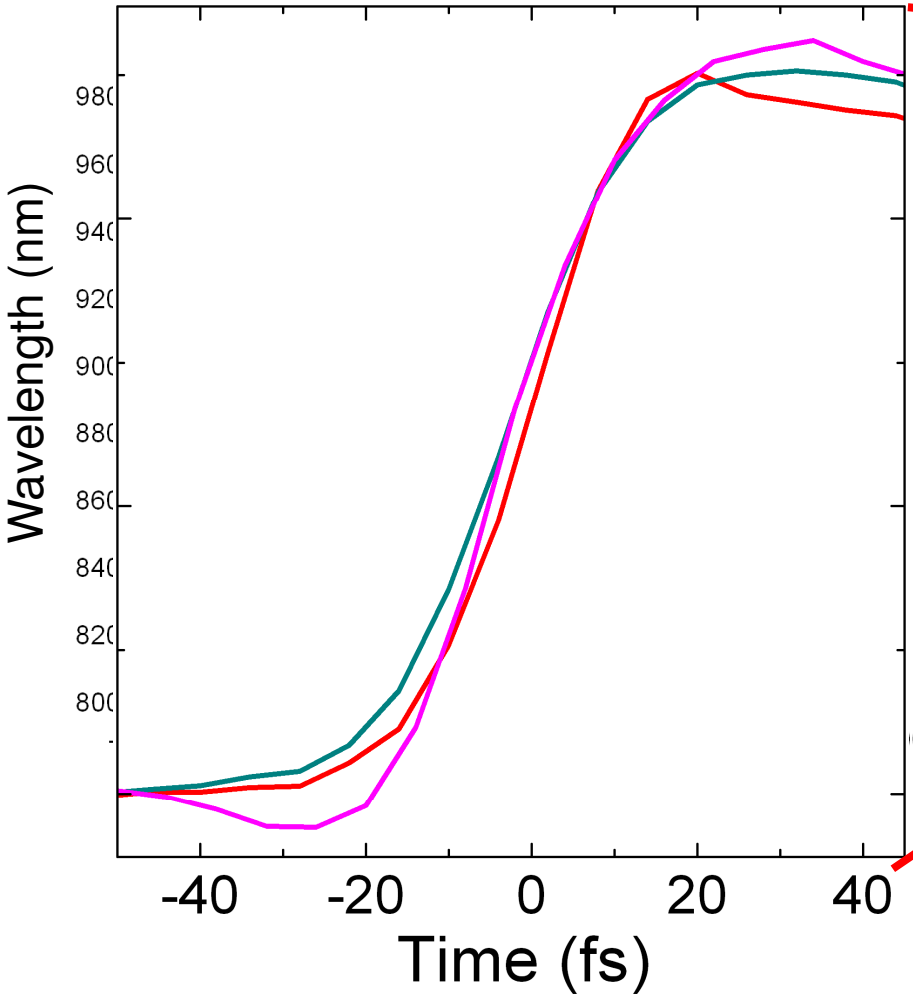
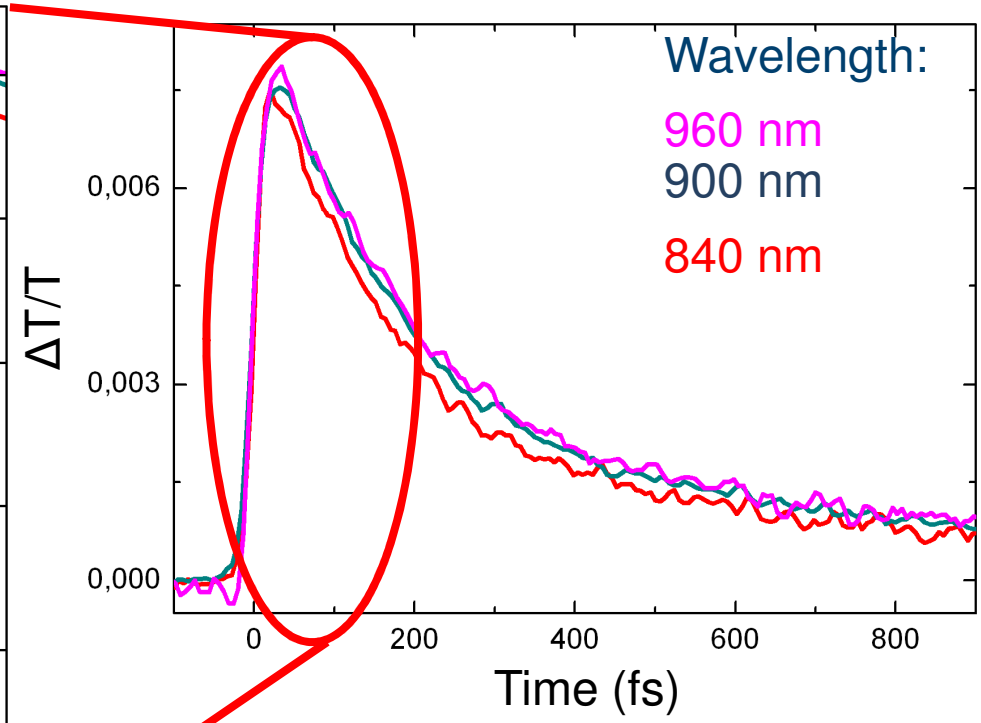
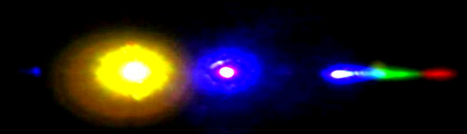




$\tau_1 \cong 140 - 170$ fs

$\tau_2 > 1$ ps

Experimental Results



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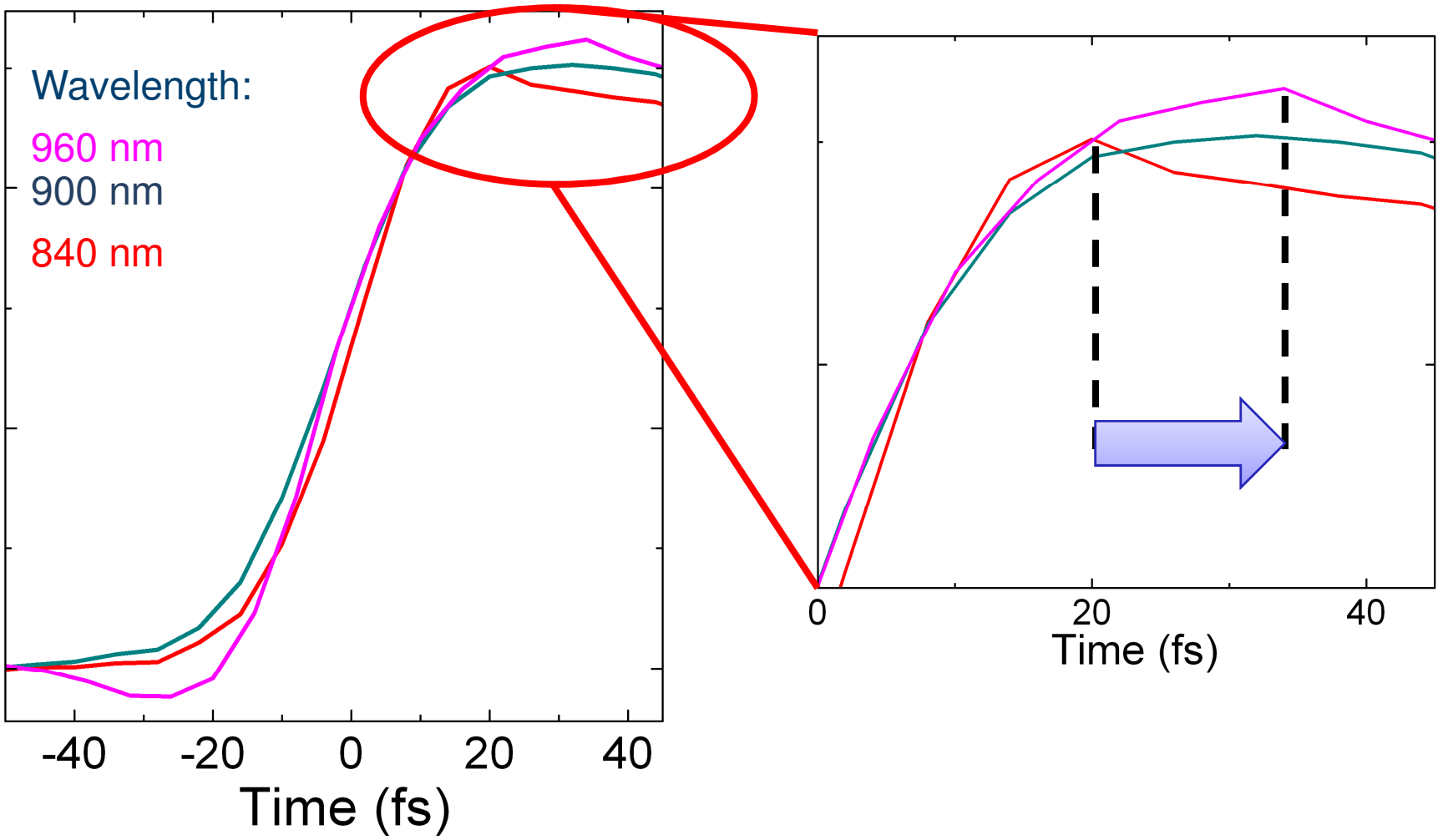
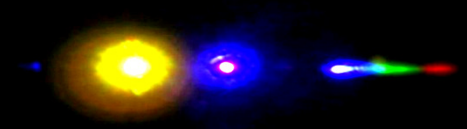
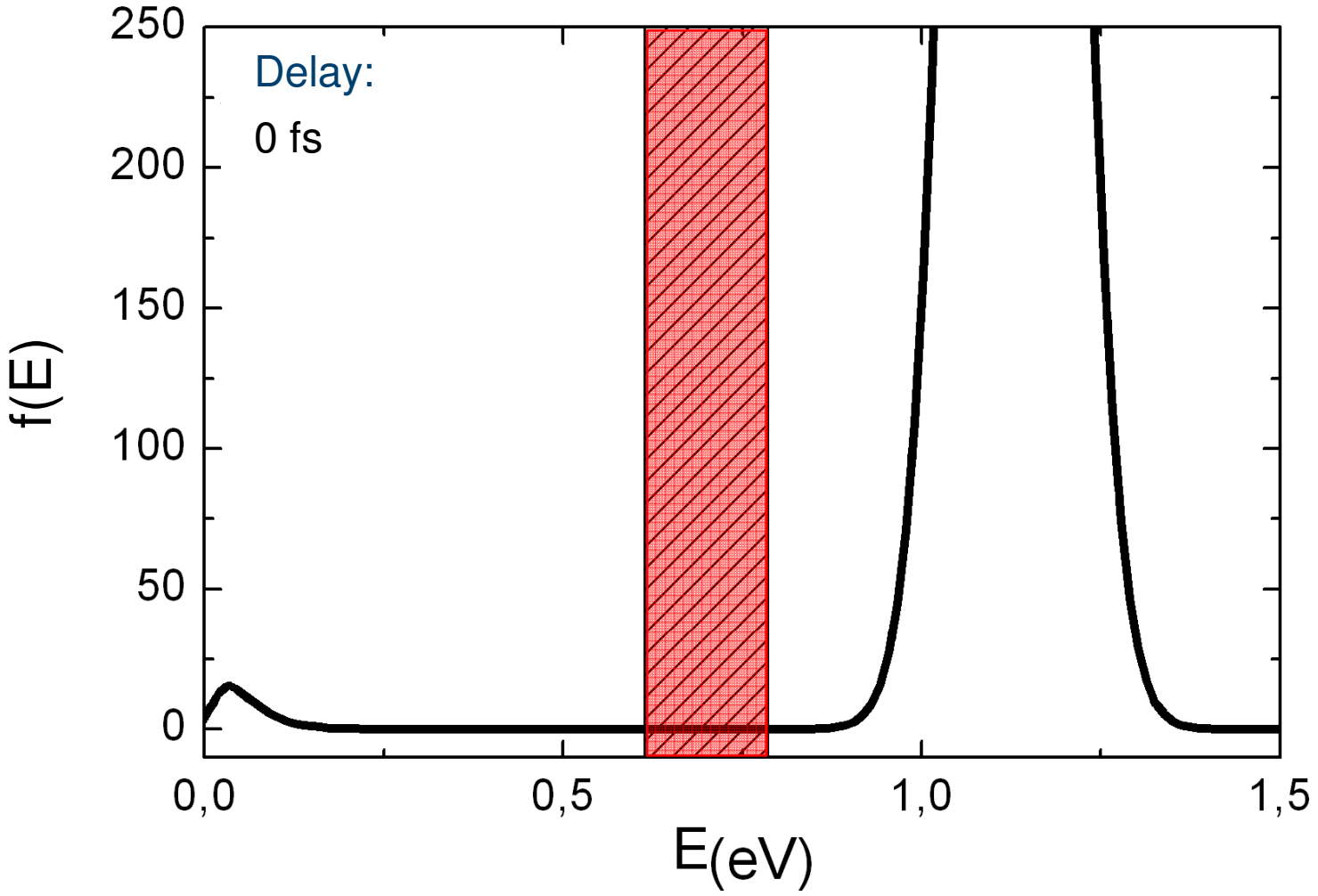


Theoretical model





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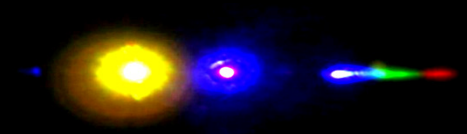

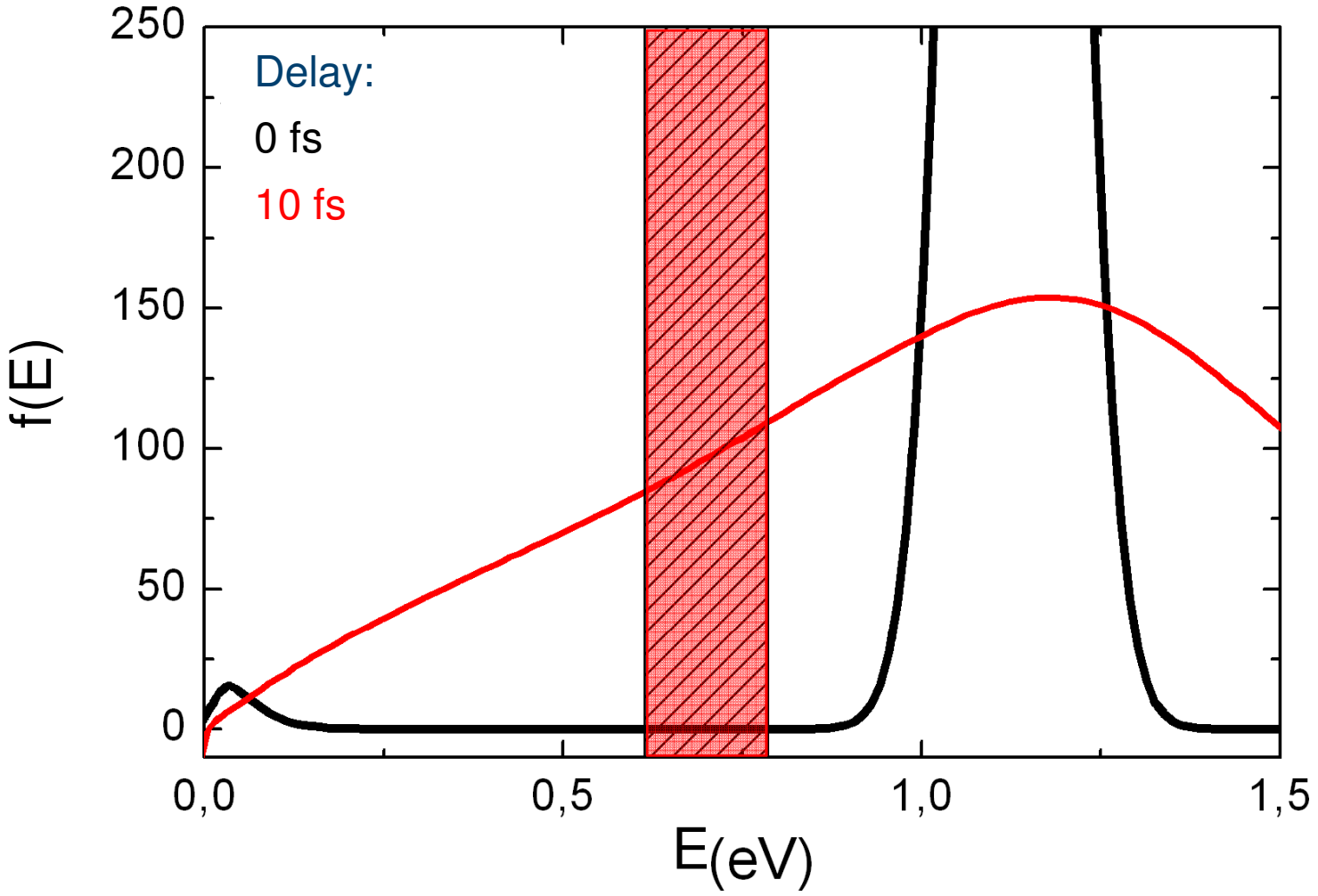

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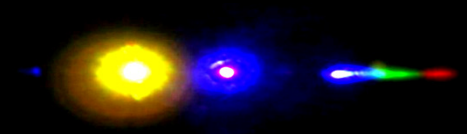

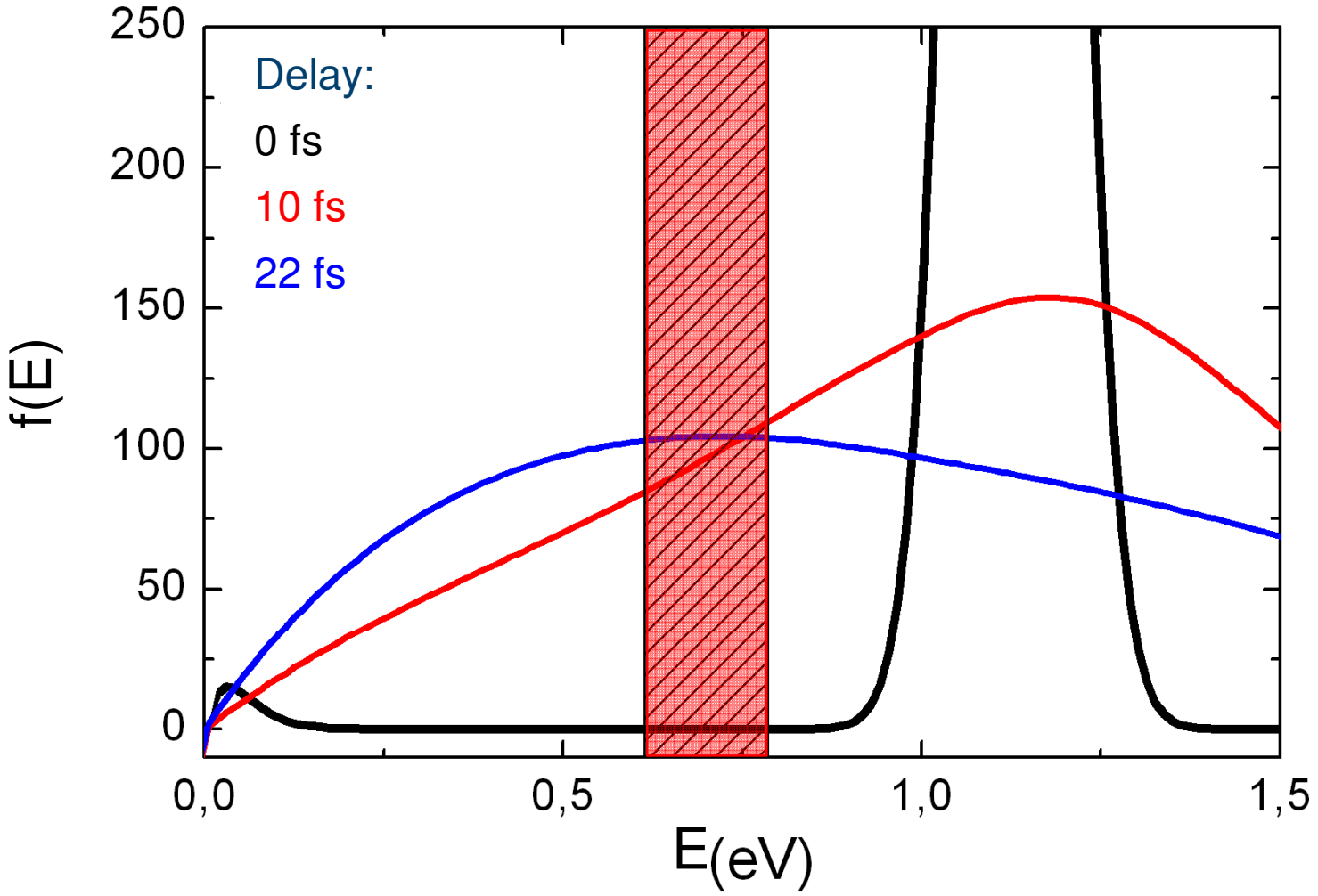

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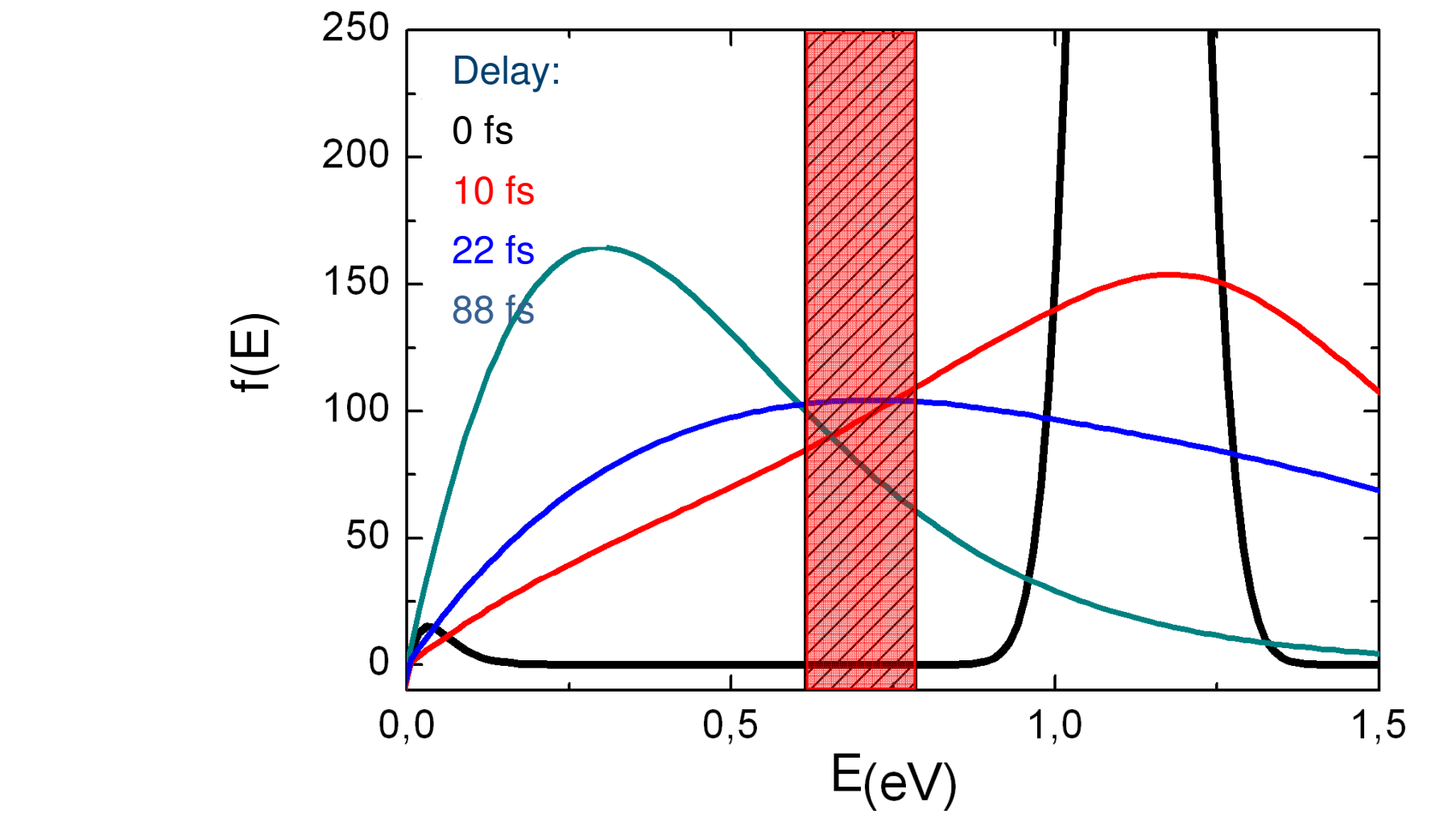

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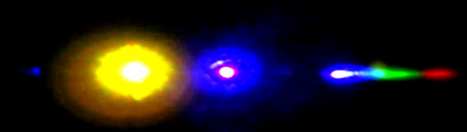

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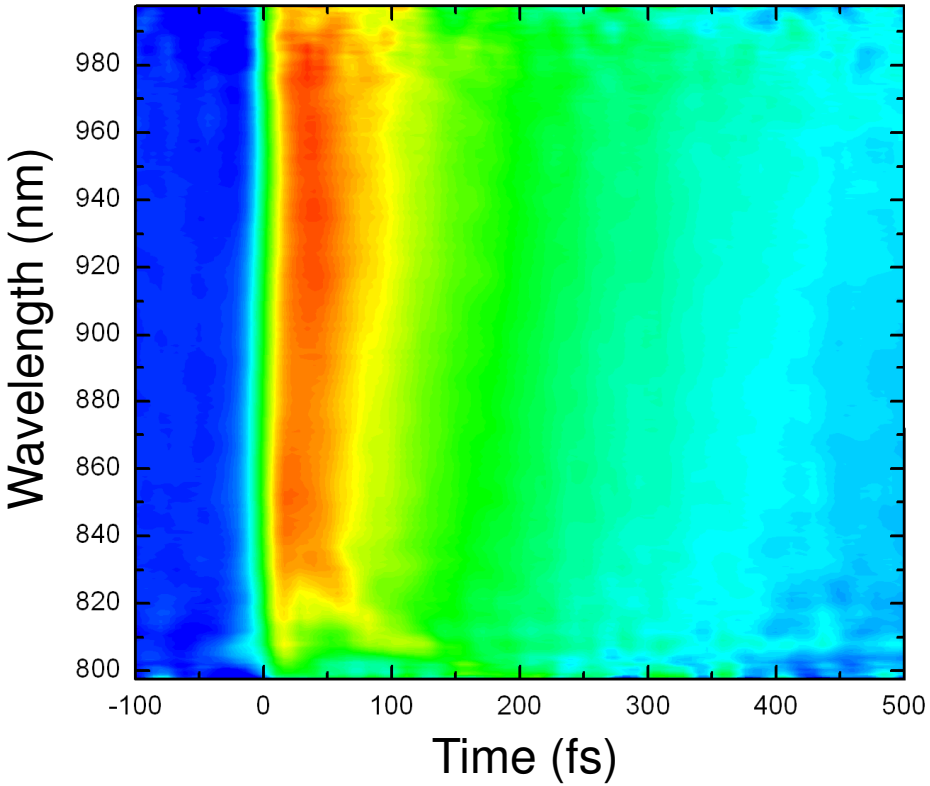

Theoretical model

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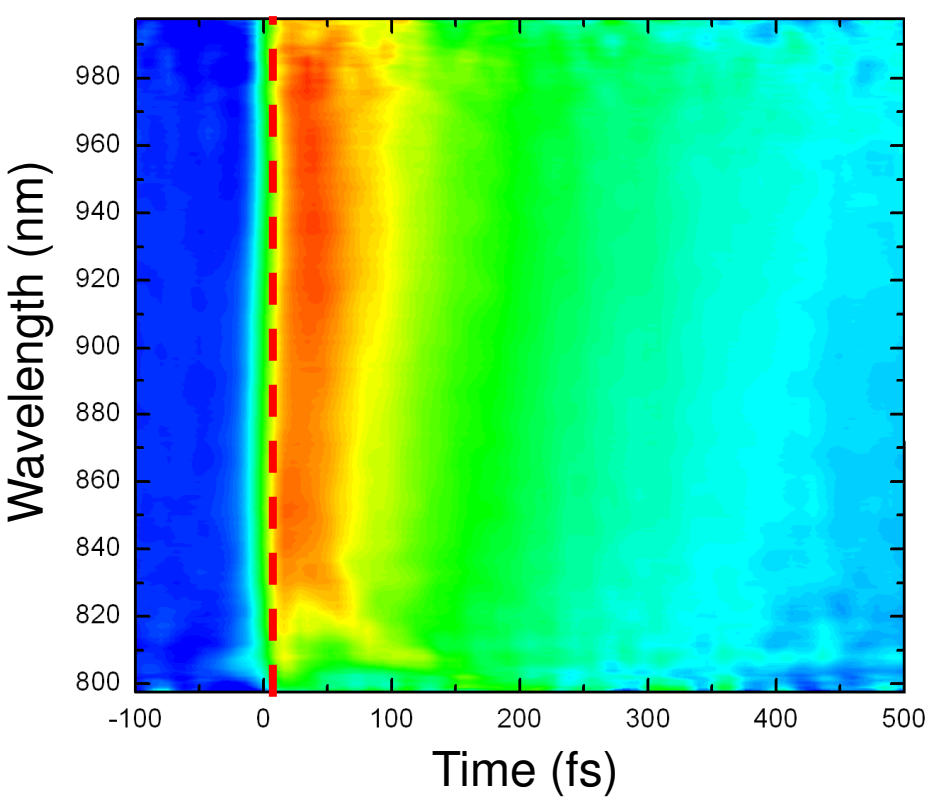

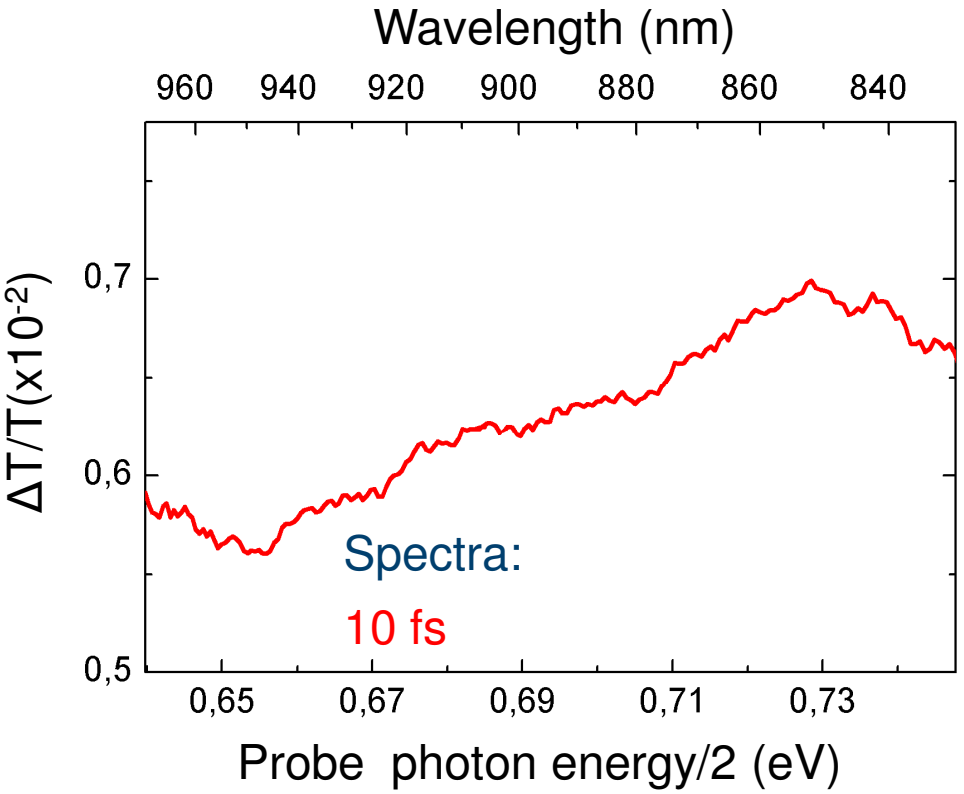

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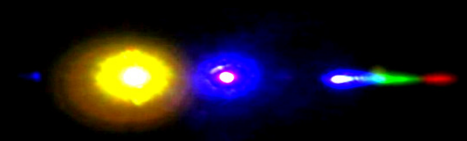

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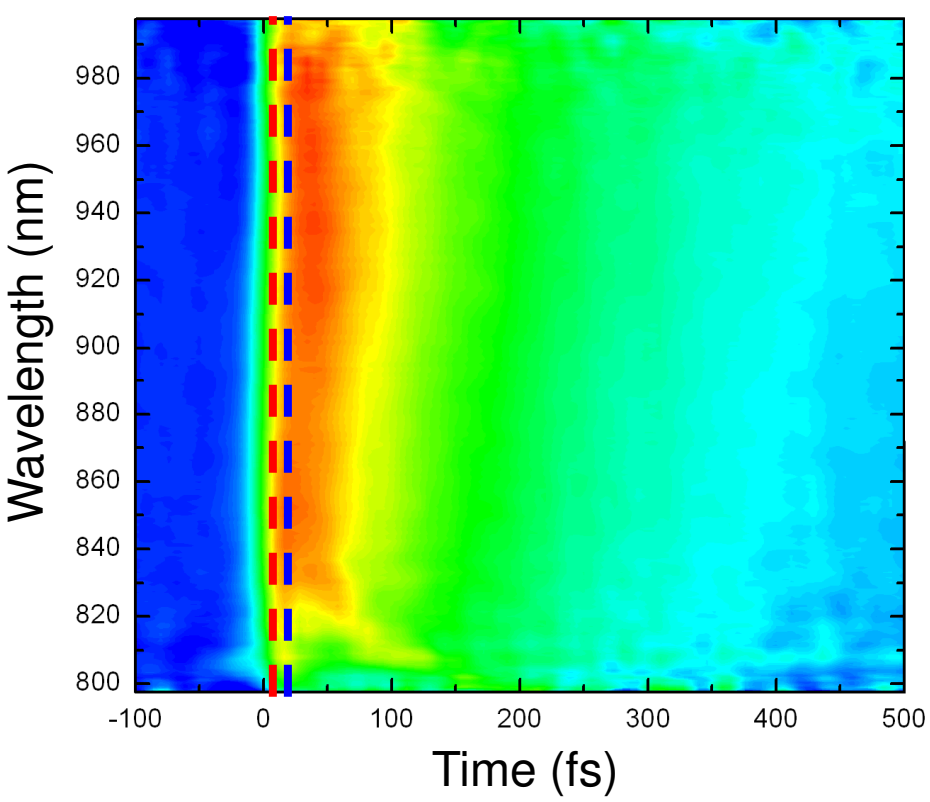

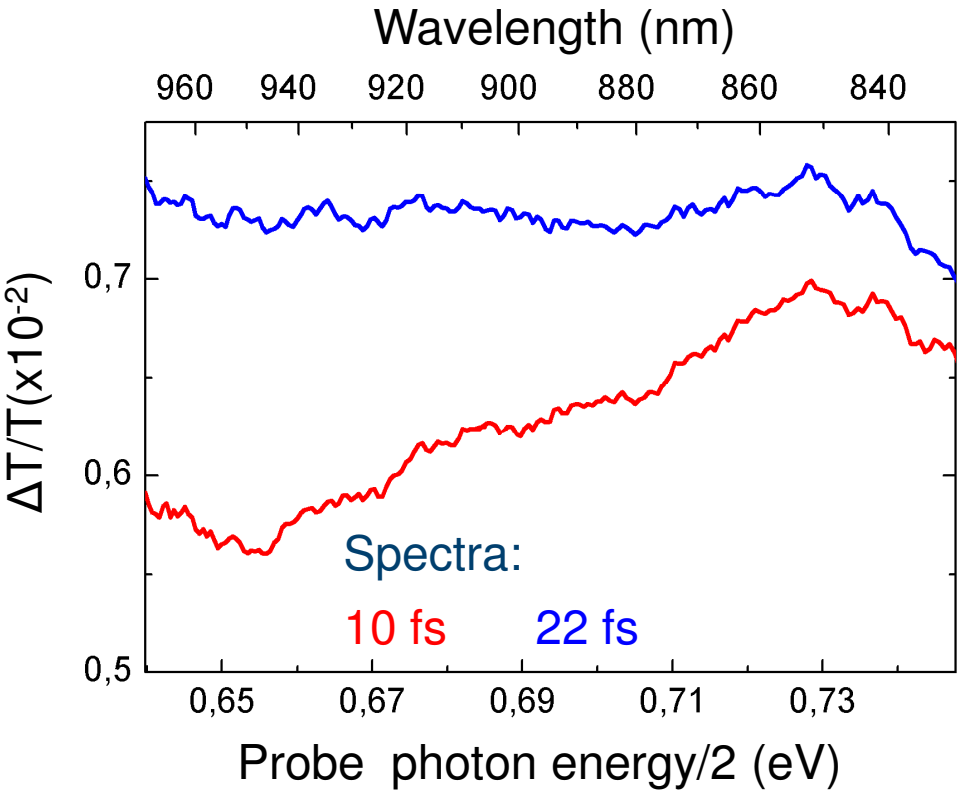

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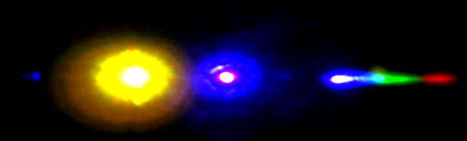

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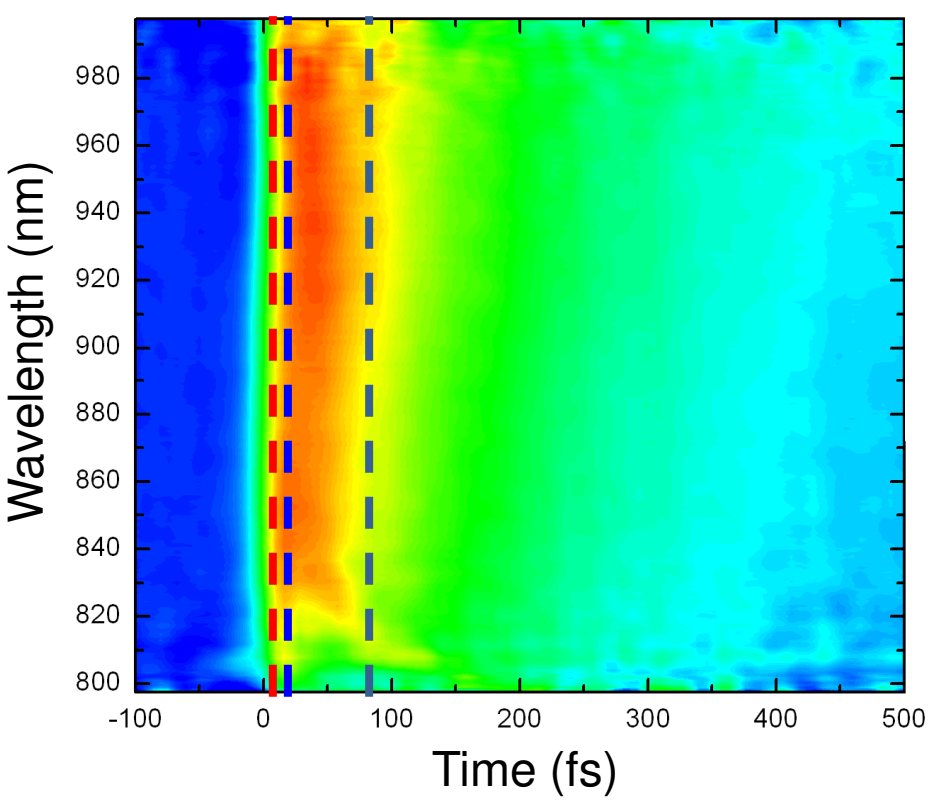
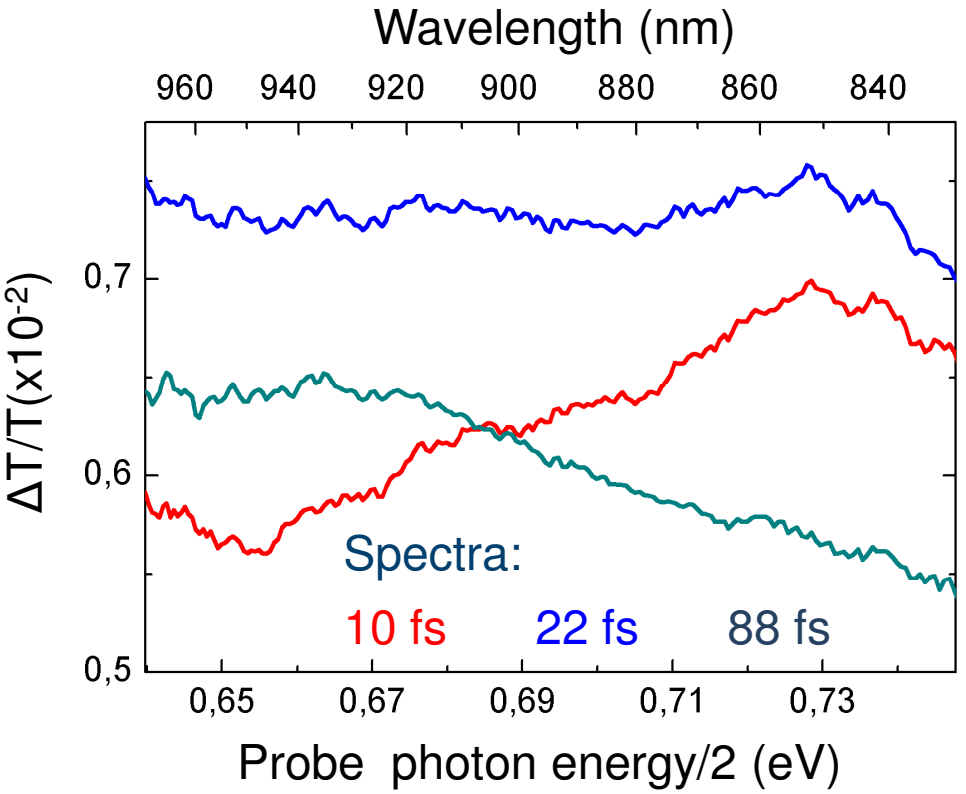
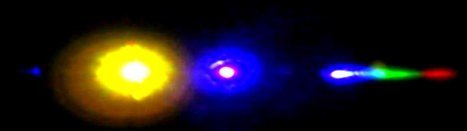
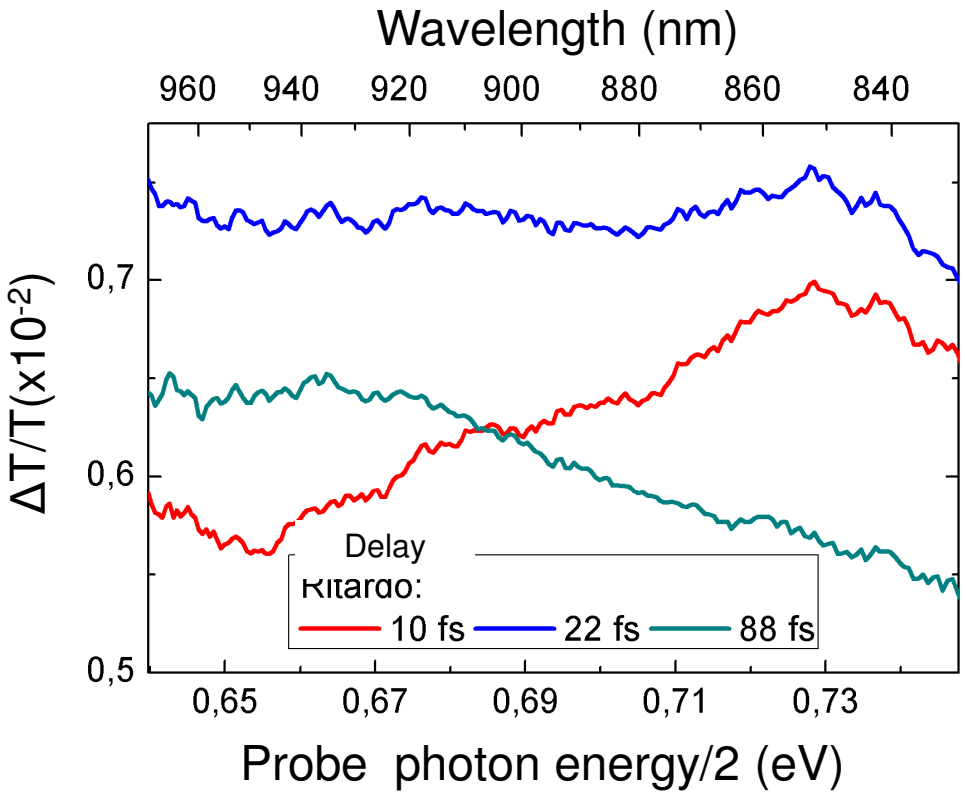
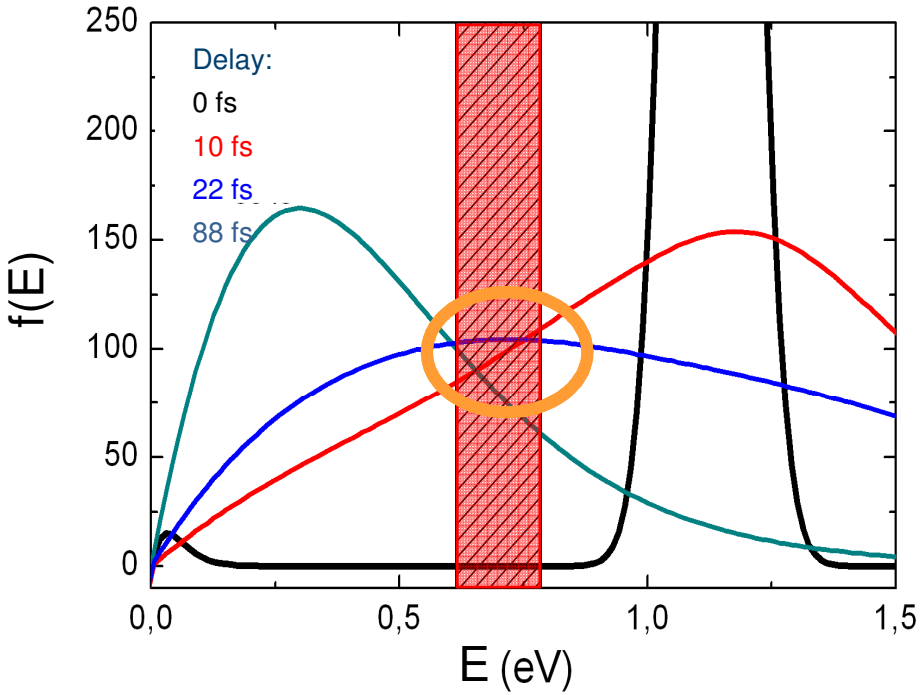




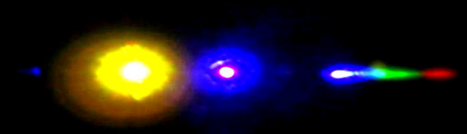
Experiments/Simulations

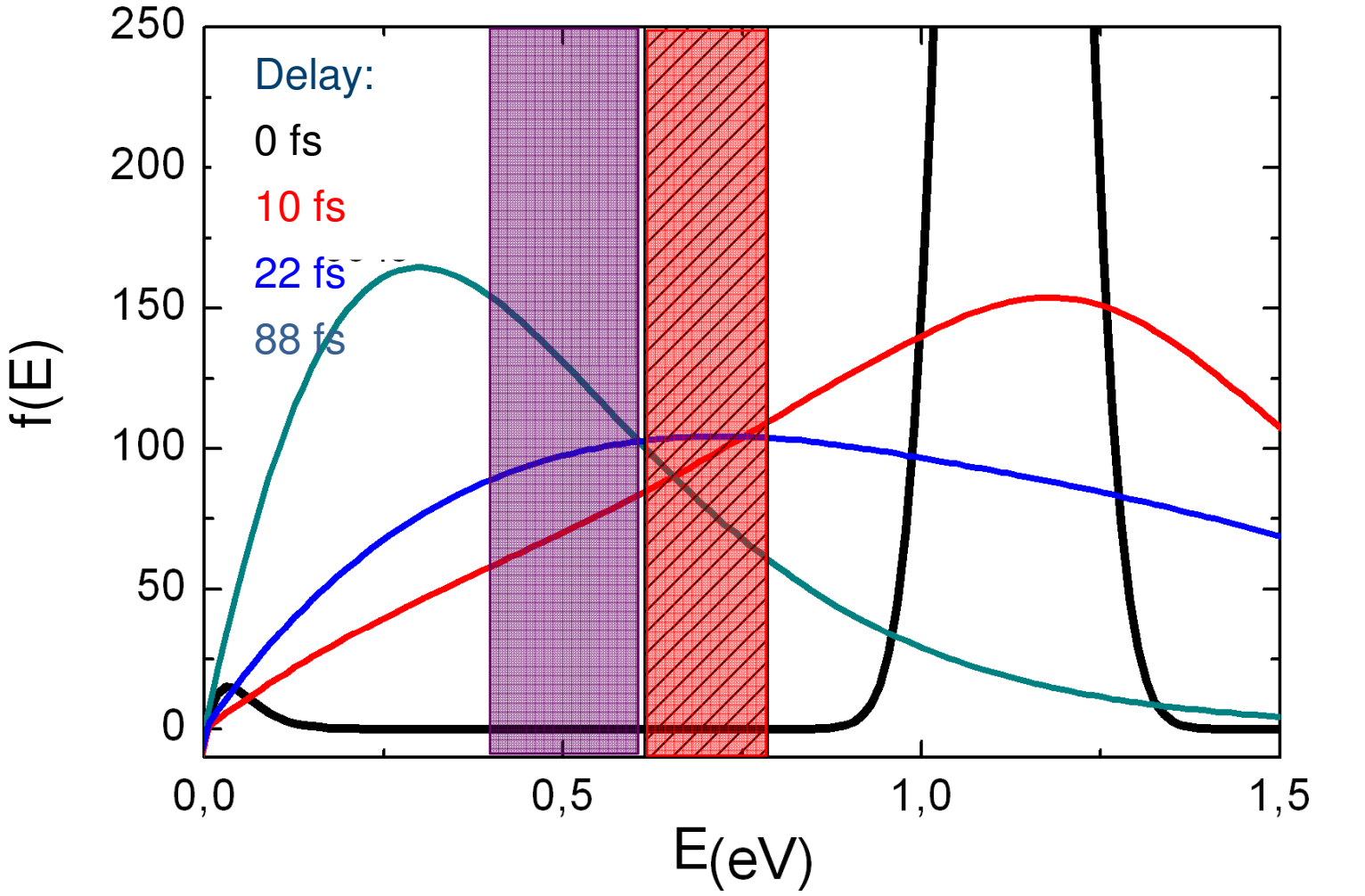




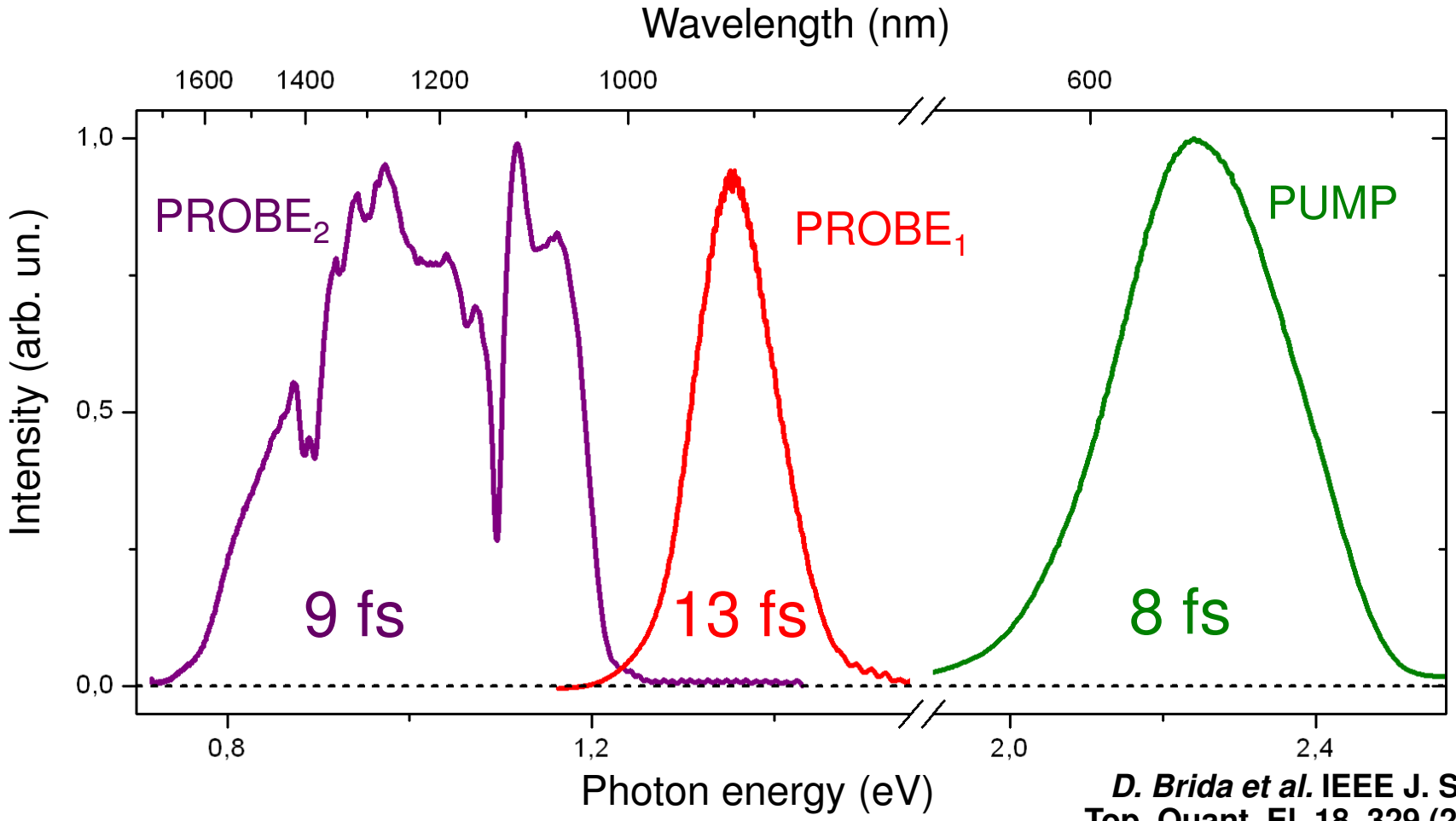


Theoretical model





Ultrashort tunable pulses from OPAs



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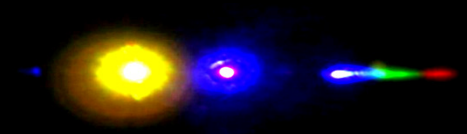
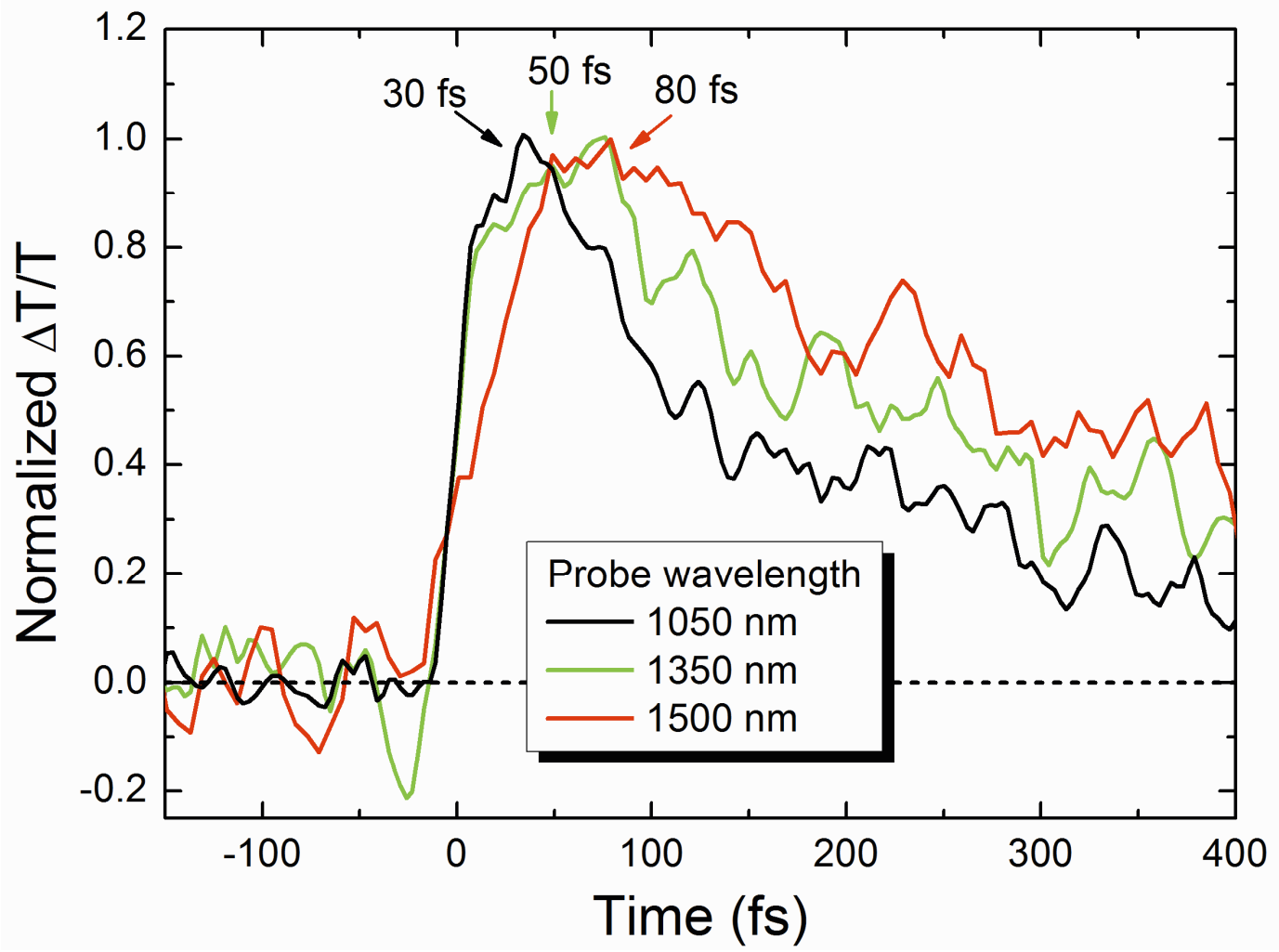
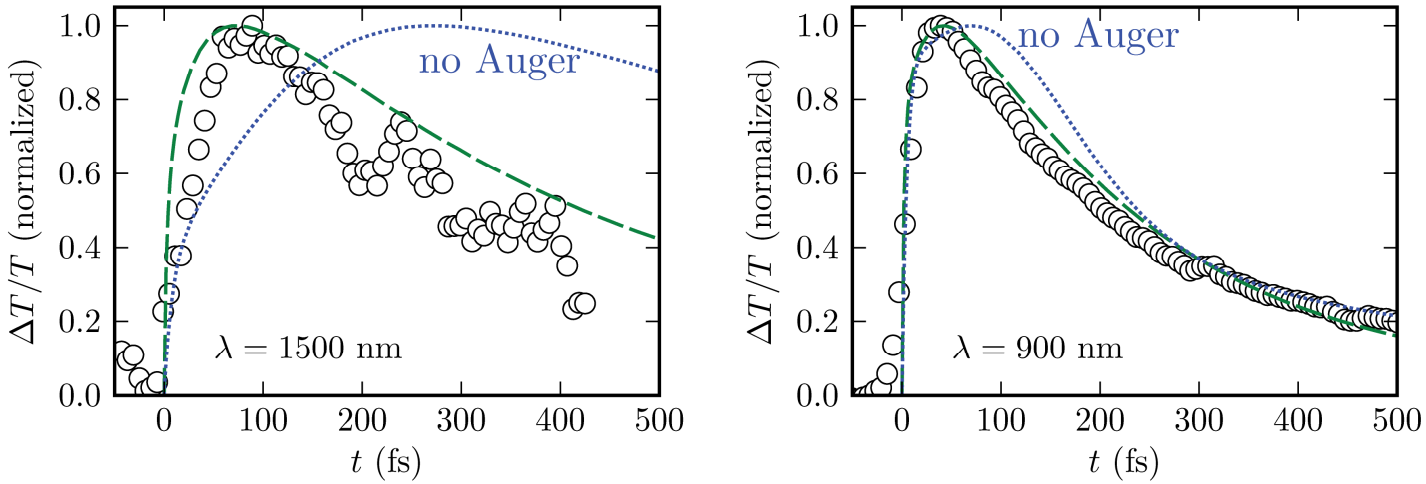
Experimental Results

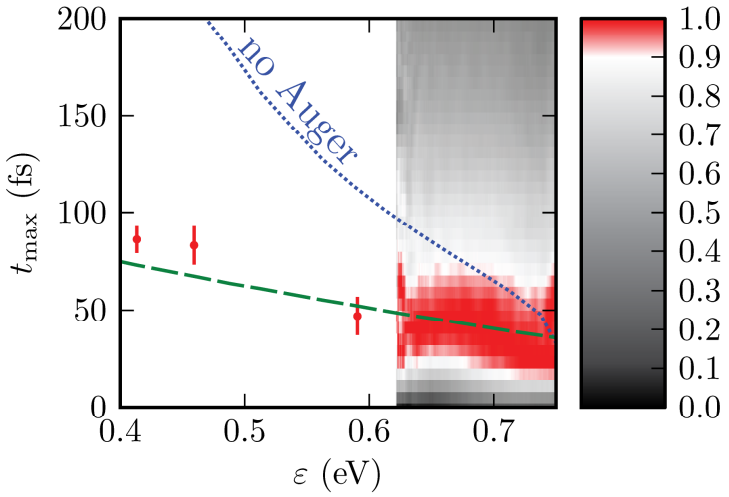


PUMP Visible - PROBE IR



Theoretical model: Auger recombination





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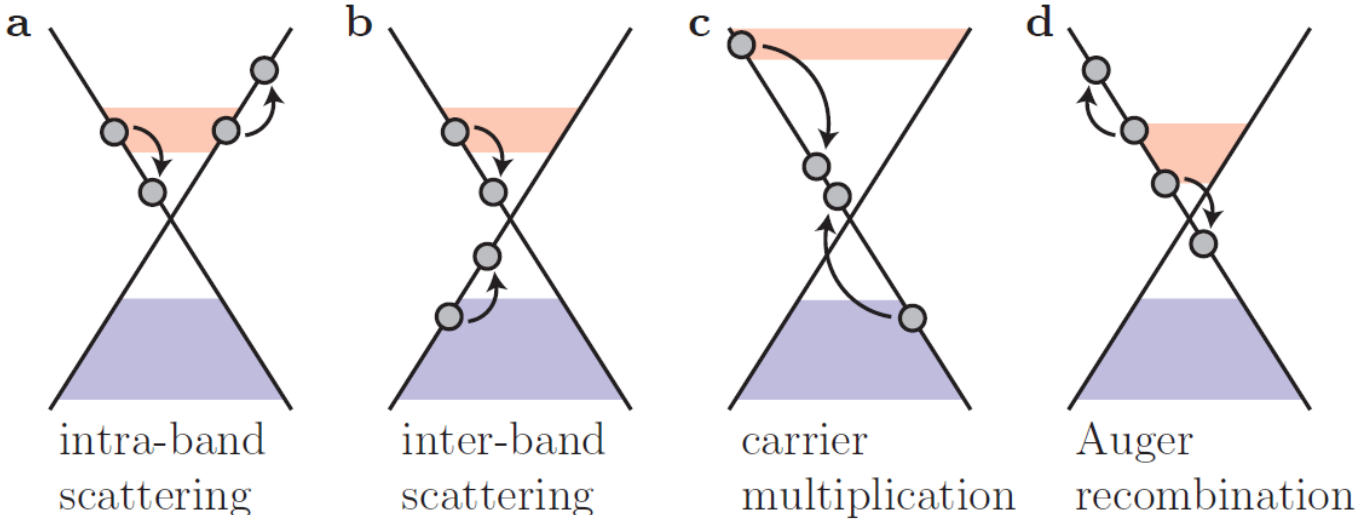
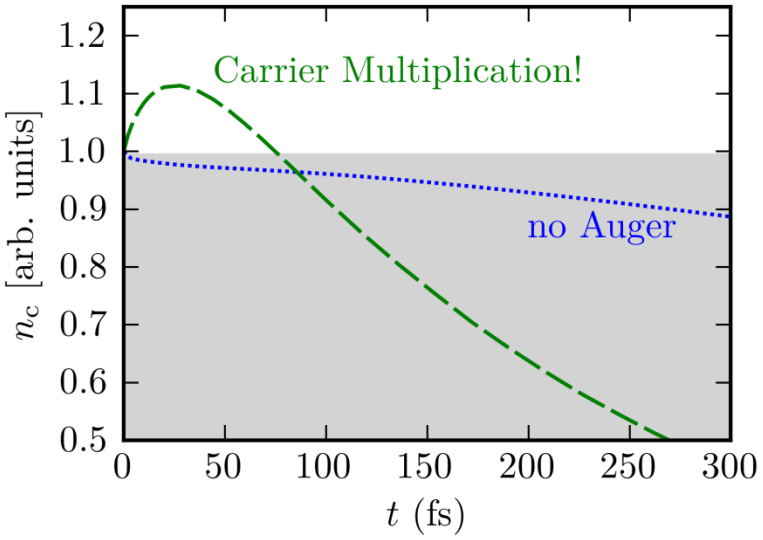
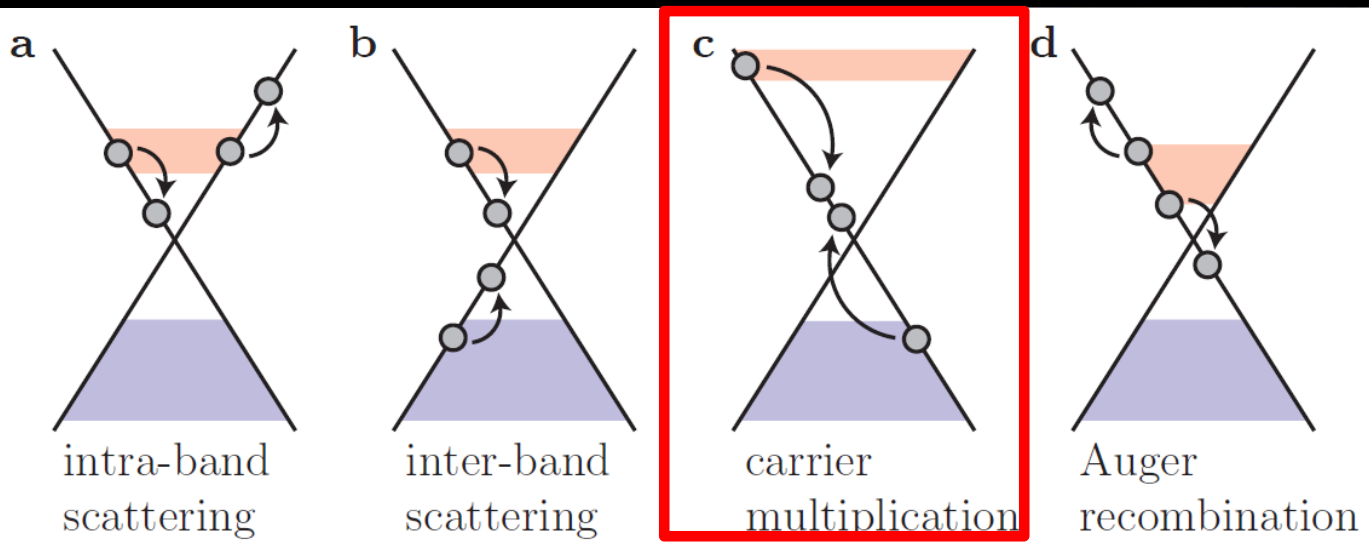
Theoretical model

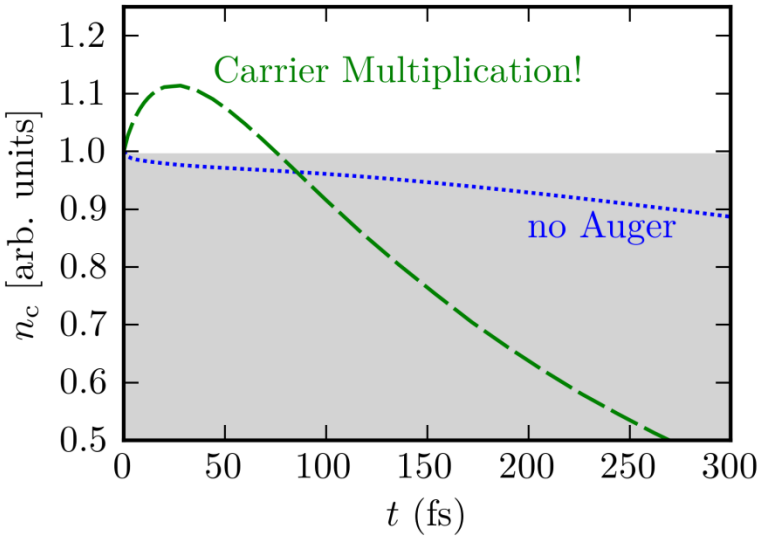




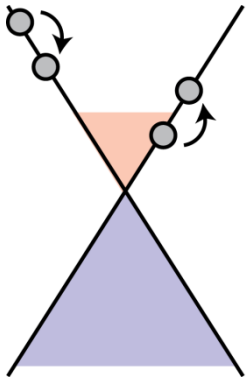
Carrier Multiplication
and
Auger Recombination
into play

Theoretical model



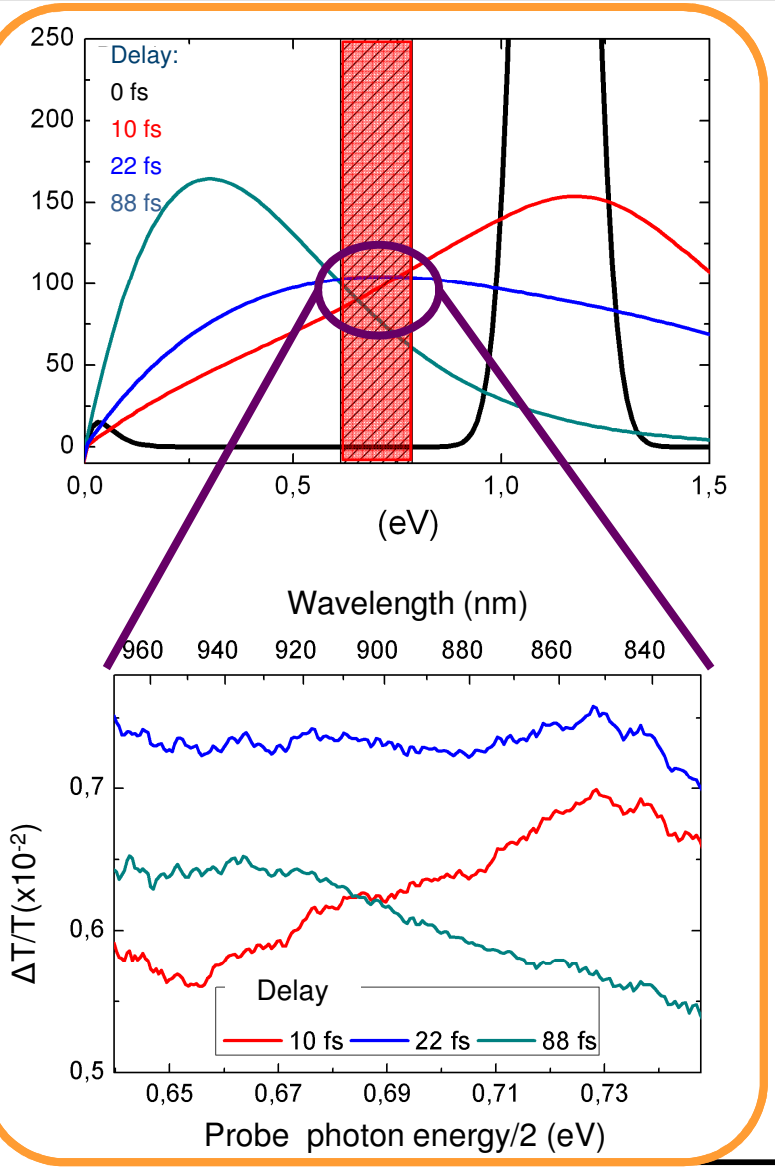


Vs

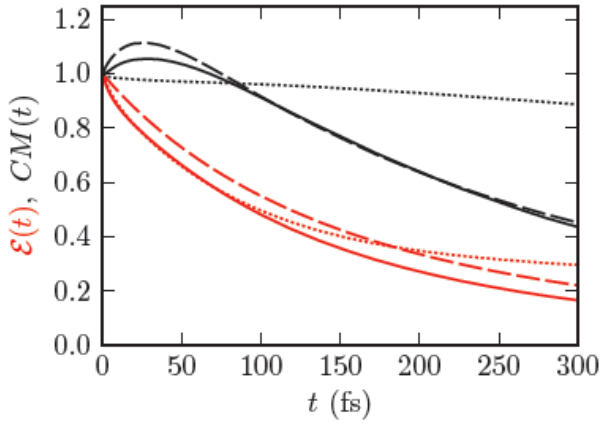


Koppens, Nat. Phys. (2013)

CONCLUSIONS



- ultrafast non-thermal dynamics of elctrons in graphene
- e-e scattering occurs in the 10 fs timescale and dominates early thermalization events
- Auger recombination unveiled



D. Brida *et al.*, submitted.

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Ultrafast Electron-Electron Dynamics in Graphene

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