OPTI-583: Computational Optics I:
Ultrafast pulses and strong-field light-matter interactions.

Time: TR 11:00-12:15
Classroom: OPTI-410

Instructor: **Miroslav Kolesik**
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Target:

Introduction to physics and computational methods for extreme nonlinear optics in high-power femtosecond pulses.

Prerequisites:

Knowledge of basic electromagnetic theory (e.g. Phys-241). While previous experience with compiled-language programming is not a prerequisite, students will be expected to perform some practical numerical work under mentorship of the instructor and interact with computers and software.

Structure:

The course material is organized in two parallel-running tracks: Physics fundamentals, and Numerical methods. The Physics fundamentals track provides an introduction into effects that govern the interaction of ultrashort pulses with various media, and the Numerical methods track explains methods to model these processes on a computer. This course has a practical exercise component and will provide the student with basic computer simulation experience.

Course outline:

Note: Topics included in the course may change as deemed appropriate by the instructor

- Maxwell's equations:
  Numerical modeling aspects of Maxwell's equations, characteristics of the pulse propagation problem, implications for the simulator design.

- Linear and nonlinear media response in the femtosecond regime:
  Overview of various effects that govern optical field evolution at extreme intensities and ultrashort time scales (chromatic and geometric dispersion, Kerr effect, stimulated Raman effect, multiphoton and tunneling ionization, low-order harmonic radiation, high-harmonic generation, supercontinuum generation).

- Brief overview of computer modeling methods in electromagnetics:
  Time-domain solvers, frequency domain methods, finite element methods,

beam propagation. Appreciation and comparison of computational complexities.

- Maxwell's equations solvers:
  FDTD method, Yee scheme. Stability, dispersion, initial conditions, boundary conditions, domain-decomposition and simple six-function approach to MPI parallelization.

- Pulse propagation equations:
  Nonlinear Schrödinger Equation and other envelope equations. Derivation, physical assumptions and limitations. Correction terms for improving applicability beyond original limits. Numerical solution strategies.

- Operator splitting approach for envelope equations:
  Finite difference and spectral formulations. Working with spectral transforms in various geometries (part I). Simple simulator design.

- Unidirectional pulse propagation equations and modern methods for extreme nonlinear optics:
  Derivations and relations to envelope and NLS equations. Transition to carrier-resolved representations, working with spectral transforms (part II).

- Unidirectional pulse propagation simulator design:
  Simulator components, and libraries. Parallelization for the shared memory architecture.

- Light-matter interactions modeling:

  - Kerr effect. Modeling self-focusing and catastrophic beam collapse.
  - Chromatic dispersion. Modeling arrest of collapse in a dispersive medium.
  - Multiphoton ionization and interaction with dilute plasmas. Modeling light filaments in gases and condensed matter.
  - Third harmonic generation. Carrier-resolving models versus envelope approaches.
  - Supercontinuum generation in bulk media. Far-field spectrum diagnostics for understanding intra-filament pulse dynamics.
  - White-light generation in microstructure fibers. Comparison to bulk media. Specific modeling issues.

- Current research issues:
  Applications to hollow-core and other novel-type of fibers. Computer modeling challenges and opportunities in attosecond optics and strong-field light-matter interactions.