

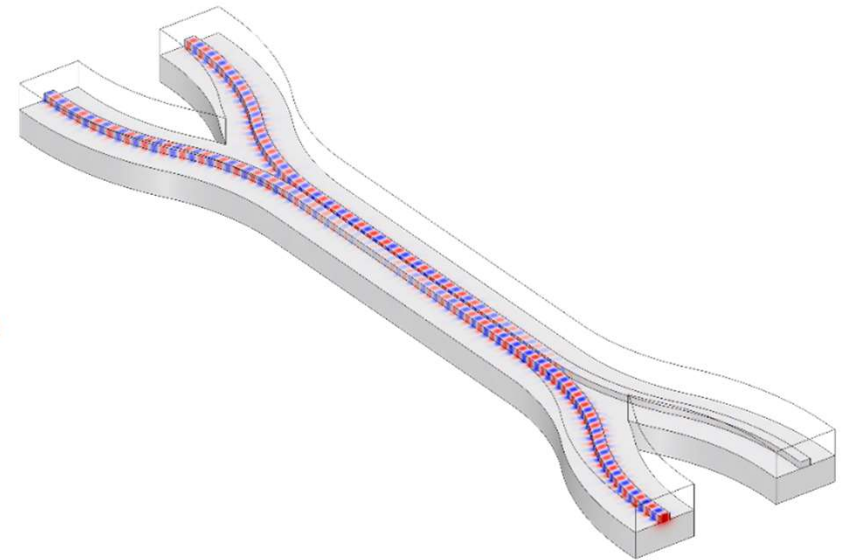


# P&S COMSOL® Design Tool

## Lecture 1: Introduction to Optical Simulations

Manuel Kohli, Tobias Blatter, Raphael Schwanninger

# Welcome to the P&S: COMSOL Design Tool – Design of Optical Components



# Outline for Today

- **General organization**
  - Presence check
  - Protection concept
  - Learning objectives
- **Why do we need simulations?**
  - Electromagnetics in our daily life
  - EM Simulation
    - What will you be able to do...
  - Examples
- **Tutorial**
  - Introduction to the Software

# Learning Objectives

- In this course, we aim to teach you the process of optical component design
- You will learn to:
  - ... **develop** a component idea into a specific design problem
  - ... **create** the correct simulation environment (model the photonic device)
  - ... **analyze** simulation results and **interpret** different physical effects involved
  - ... **evaluate** the design according to initial specifications and recommend improved solution
  - ... **summarize** the results and report them

# Semester Outline

- Simulation concept
  - EM review
  - 2D EM simulation
- Intro to COMSOL tools
  - Wave optics
  - Mode solver
  - Boundary mode solver
- Project
  - Presentation
  - Report

# Semester Outline

- Simulation concept
  - EM review
  - 2D EM simulation
- Intro to COMSOL tools
  - Wave optics
  - Mode solver
  - Boundary mode solver
- Project
  - Presentation
  - Report

**6 weeks**

**6 weeks**

**Final presentation: Monday, 27.05.2022**

**Report : Monday, 03.06.2023**

**If there is a conflict, please let us know early**

# Projects

- Design a passive optical structure for given specifications
  - Teams of 2 or individual
  - A list of possible projects will be given / implement own idea

# Projects

- Design a passive optical structure for given specifications
  - Teams of 2 or individual
  - A list of possible projects will be given / implement own idea
  
- Steps of Project
  1. Build model
  2. Set physics and boundary conditions
  3. Simulate
  4. Evaluate preliminary results
  5. Optimize
  6. Analyze and report



# Projects

- Design a passive optical structure for given specifications
  - Teams of at least 2 or individual
  - A list of possible projects will be given / implement own idea
  
- Steps of Project
  1. Build model
  2. Set physics and boundary conditions
  3. Simulate
  4. Evaluate preliminary results
  5. Optimize
  6. Analyze and report
  
- Evaluation
  1. **Presentation** (12 minutes talk and 3 minutes questions, **Monday 27.05.2024**)
  2. **Written report** (<10 pages with pictures and references, **Monday, 03.06.2024**)

## Practical Information – Administrative

- Time: Mondays from **13:15h** to **~15:00 h**
- Location: **ETZ D61.1**
- Our availability: office hours ETZ K-floor

*(Send email to schedule a meeting)*

Manuel	(ETZ K 95)	→ <a href="mailto:manuel.kohli@ief.ee.ethz.ch">manuel.kohli@ief.ee.ethz.ch</a>
Tobias	(ETZ K82)	→ <a href="mailto:tobias.blatter@ief.ee.ethz.ch">tobias.blatter@ief.ee.ethz.ch</a>
Raphael	(ETZ K 60.1)	→ <a href="mailto:raphael.schwanninger@ief.ee.ethz.ch">raphael.schwanninger@ief.ee.ethz.ch</a>

# Practical Information – Online Material

- Online material
  - [https://blogs.ethz.ch/ps\\_comsol/](https://blogs.ethz.ch/ps_comsol/)
    - Presentations
    - Exercises
    - Literature
- Literature
  - B. Salah and M. Teich, *Fundamental of Photonics*, 2nd ed., 2007.
  - K. Okamoto, *Fundamentals of optical waveguides*, 2nd ed., Elsevier, 2006.

# Questions?

# About us

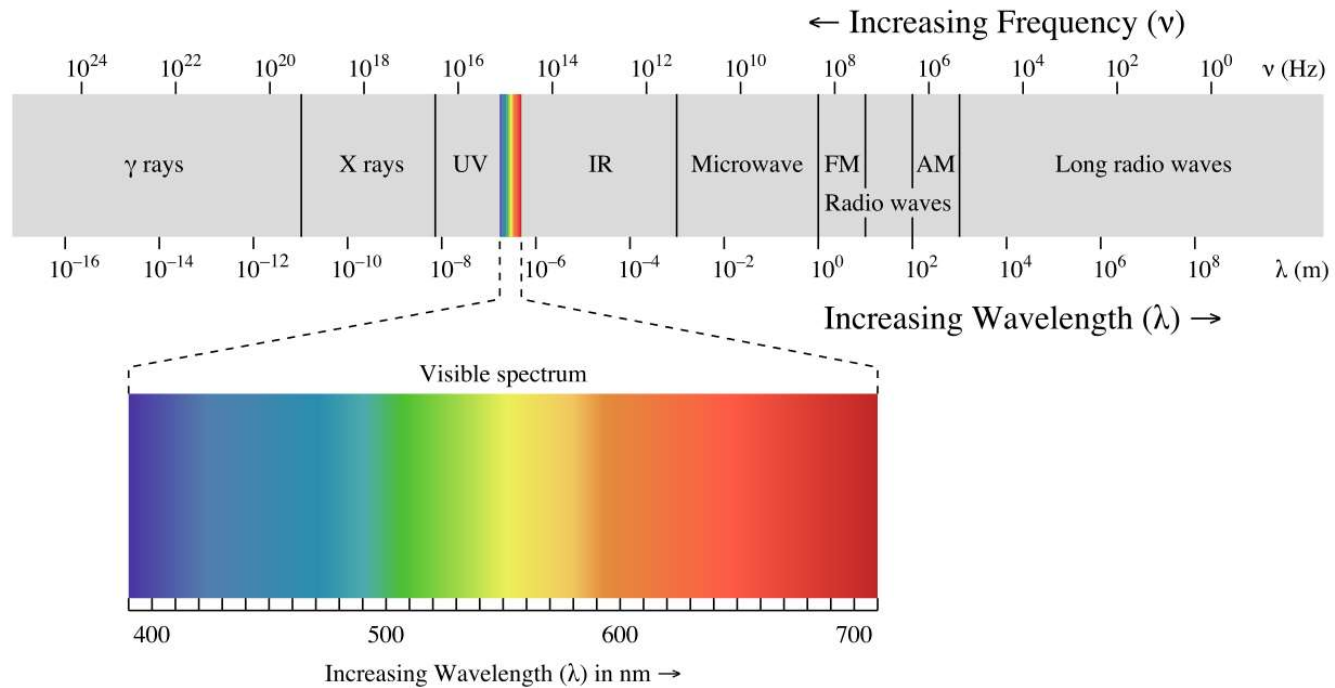
- Tobias Blatter
  - Advanced plasmonic modulators for Systems
    - Design of THz antennas
    - Simulation of photonic circuit parts:
      - Multimode interferometer
      - Directional couplers
      - Spatial switching using on-chip beam steering
  
- Manuel Kohli
  - Ferroelectric electro-optic modulators on SiN
    - Photonic integration of different platforms
    - Design, fabrication, and measurement
    - “Optical Machine” Assembly (PIC + EIC)
  - 3D Nanofabrication for novel components
  
- Raphael Schwanninger
  - Mid Infrared Photodetectors
    - Colloidal quantum dots & metamaterials
    - Simulation of electric and optical properties
    - Fabrication & Characterization

## Folie 13

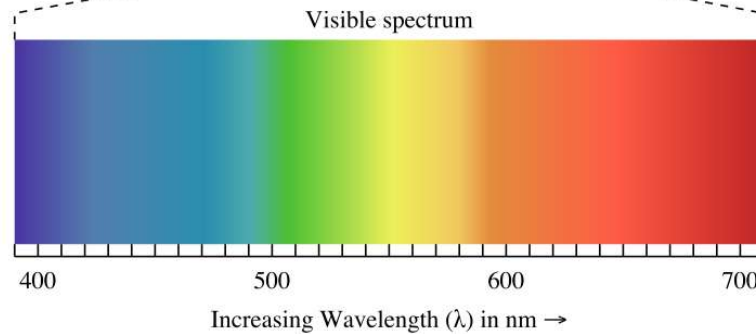
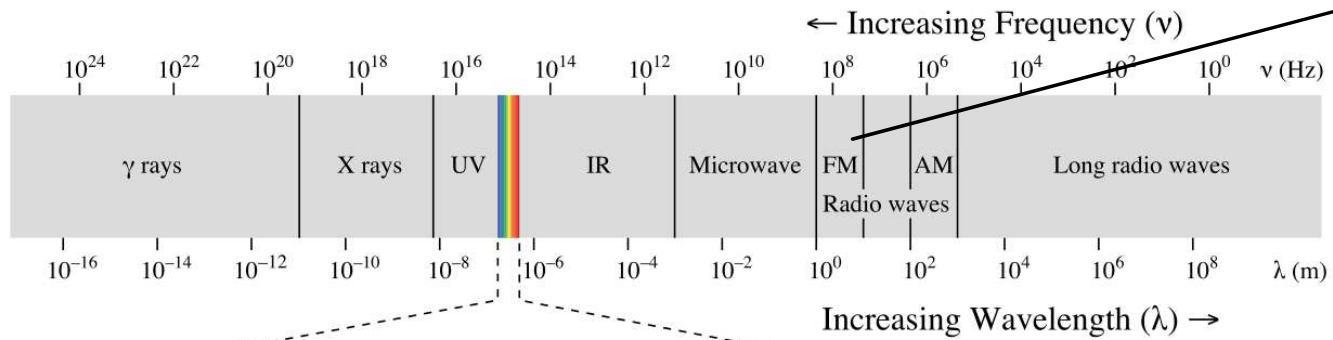
---

**J K1** @Arif, can you explain to me what these plots show?  
Jentner Kaja; 19.09.2019

# Electromagnetics in Our Daily Life

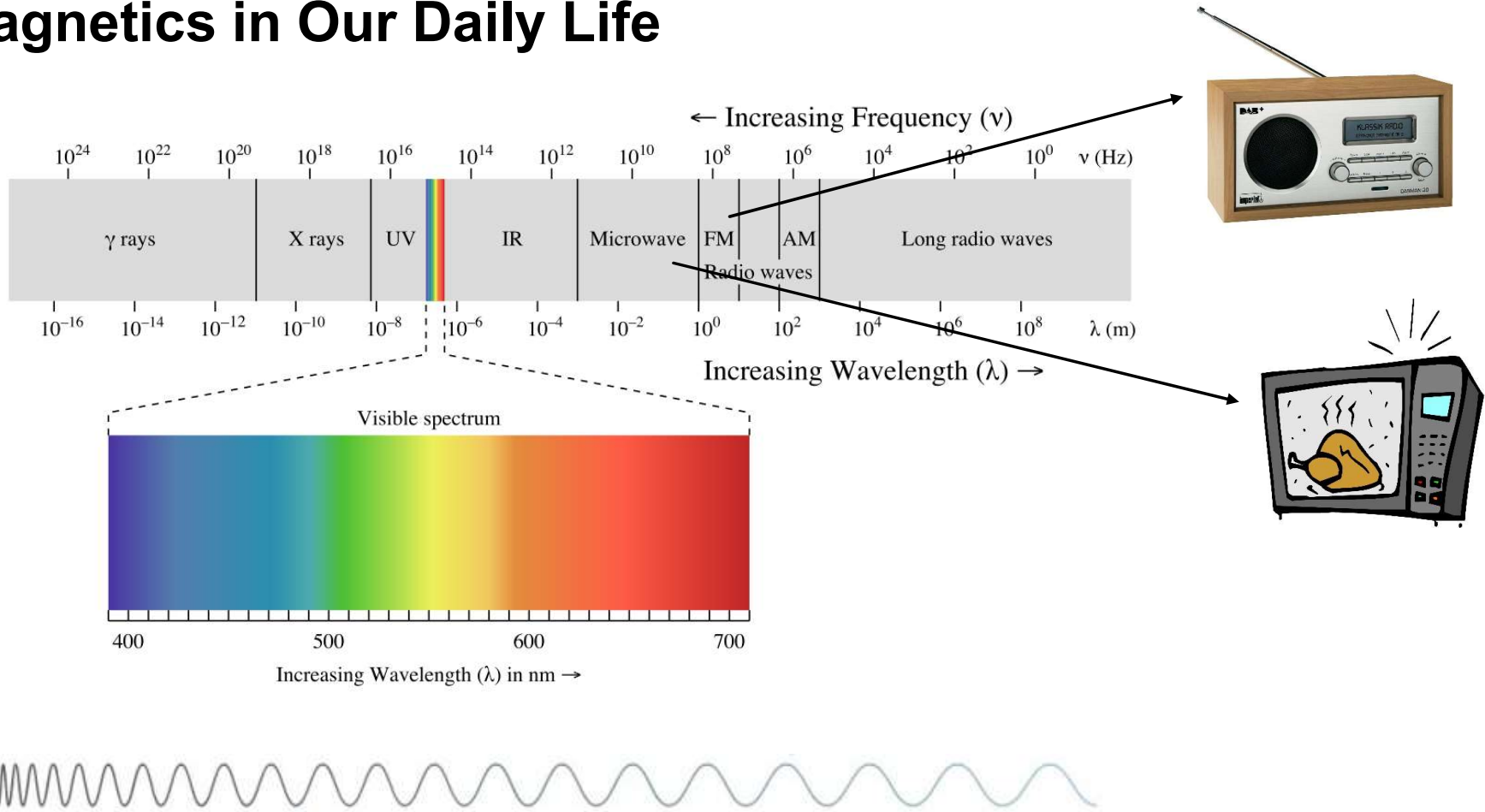


# Electromagnetics in Our Daily Life

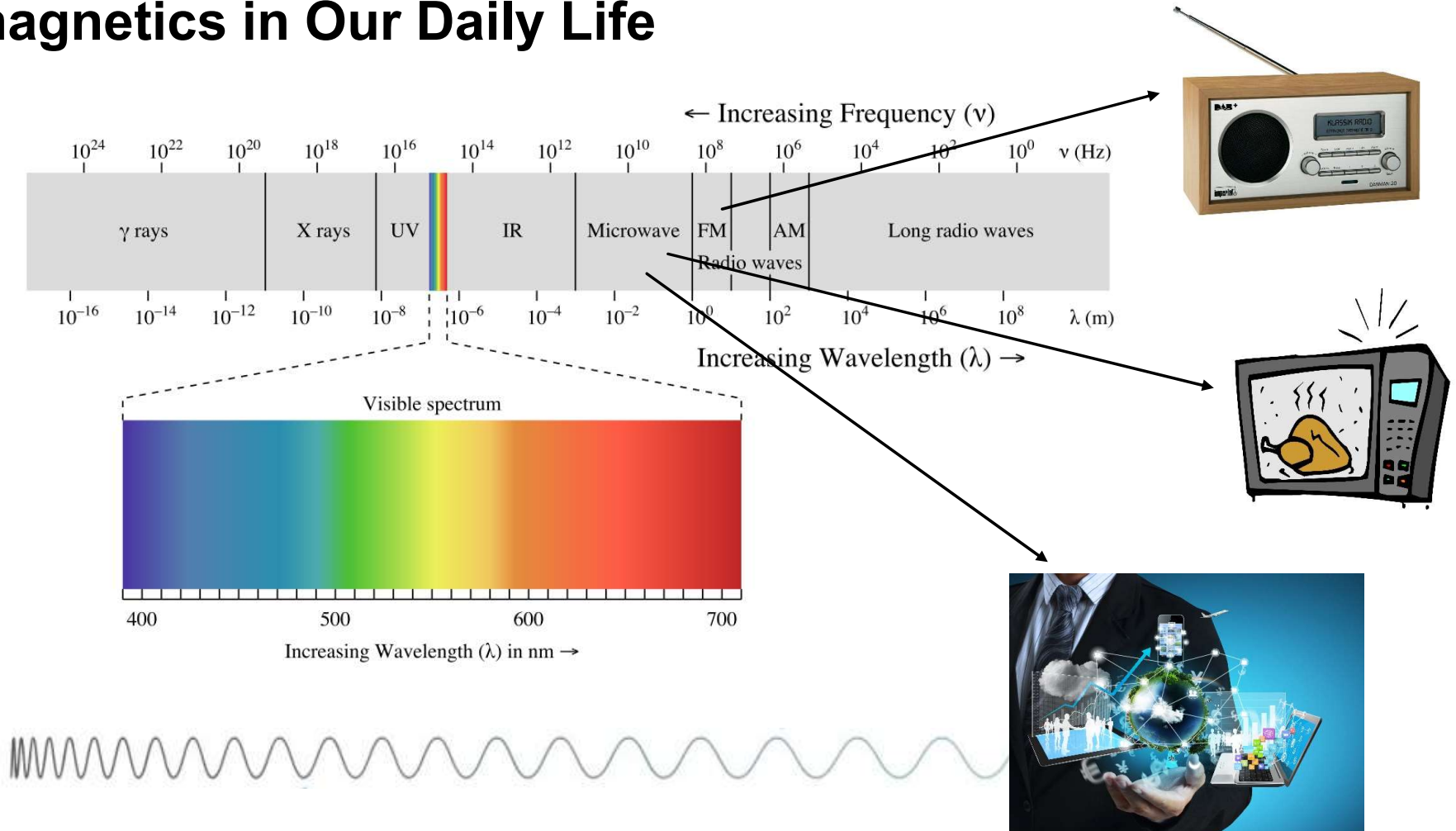




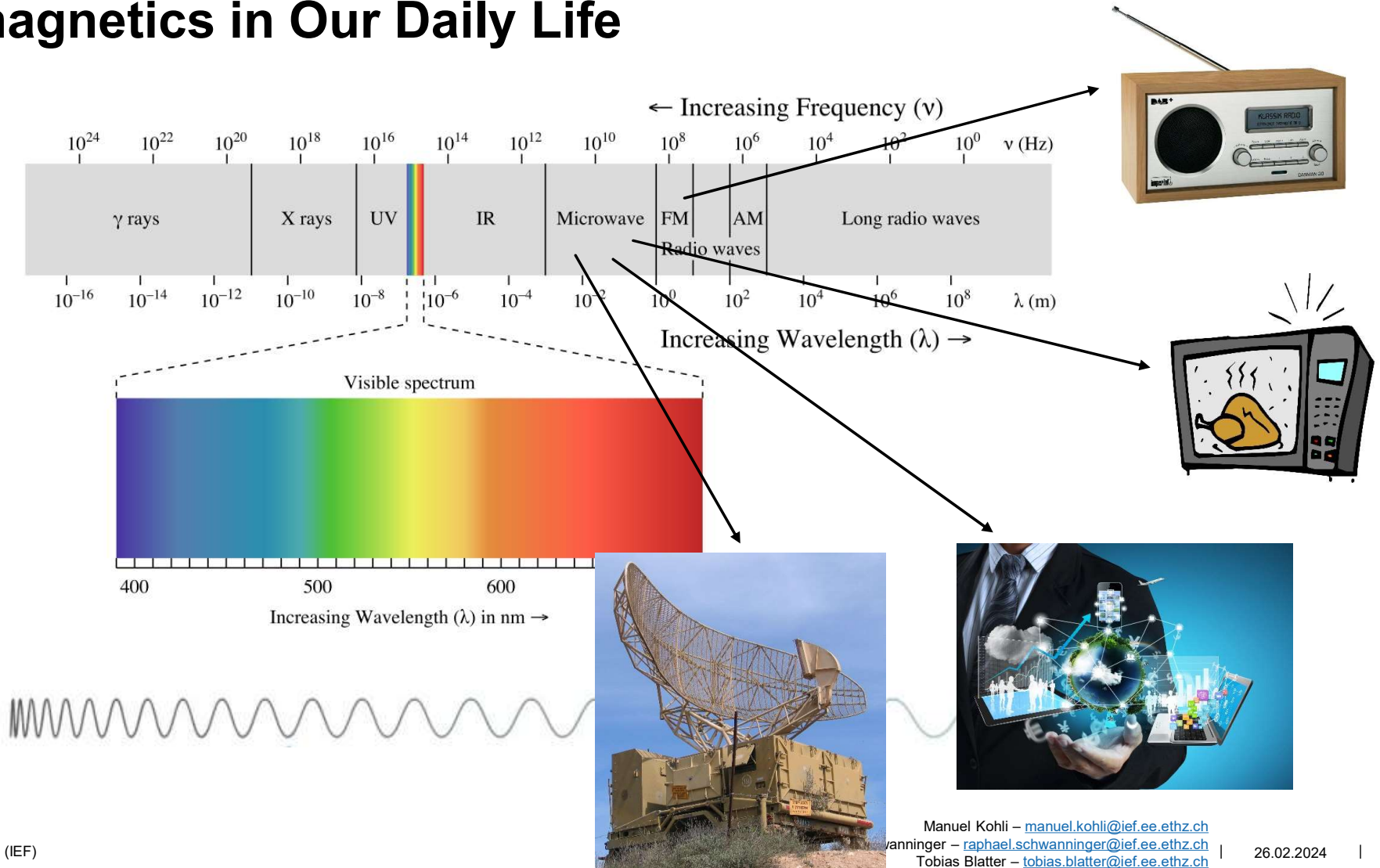
# Electromagnetics in Our Daily Life



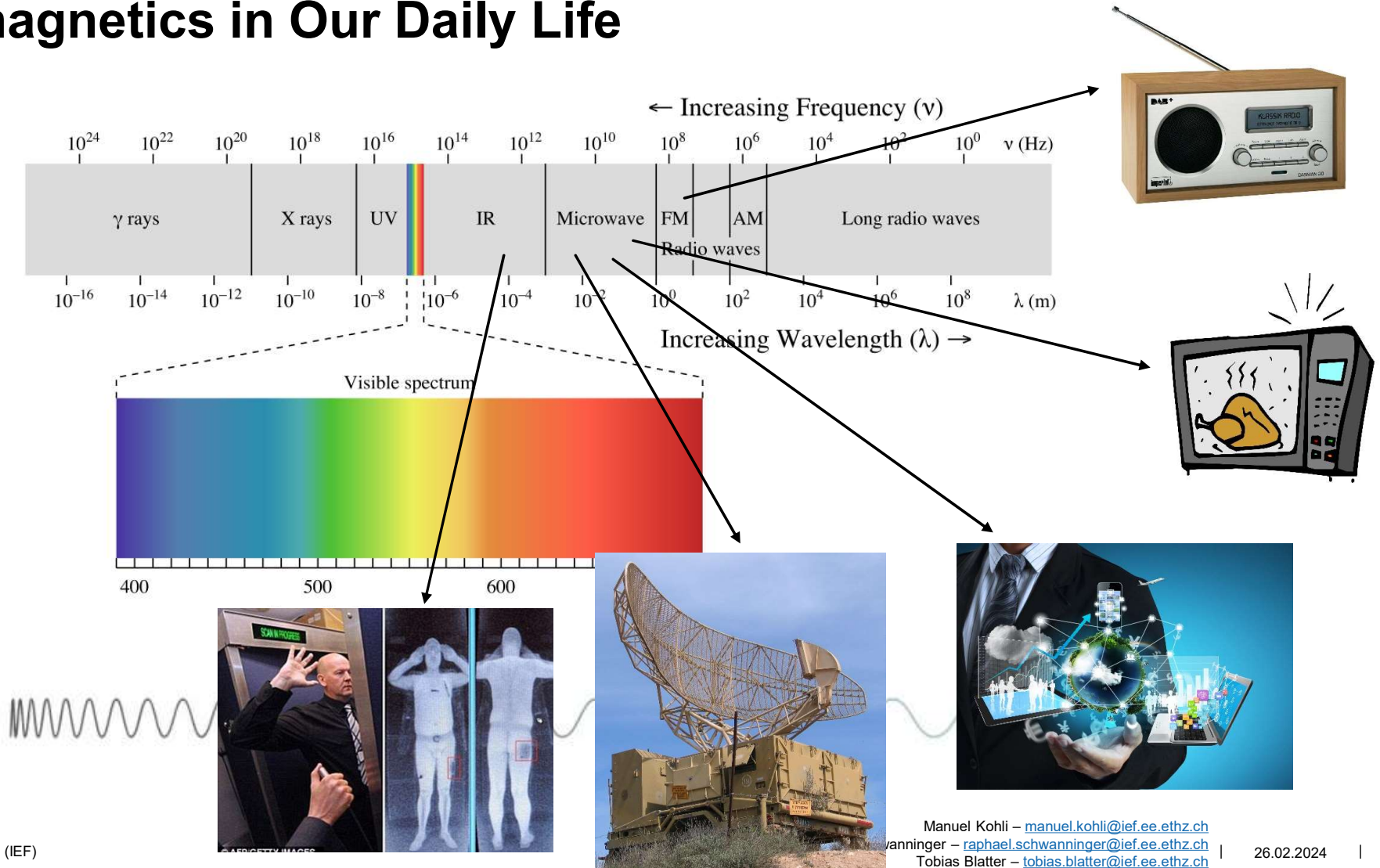
# Electromagnetics in Our Daily Life



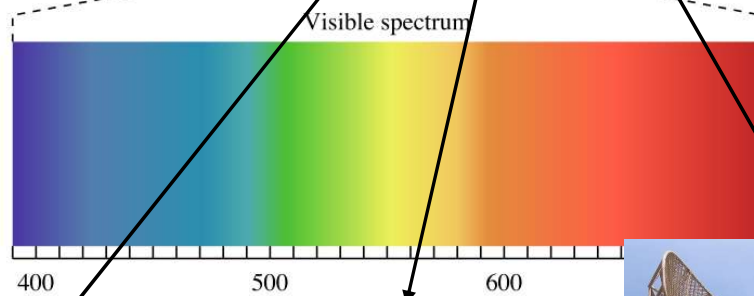
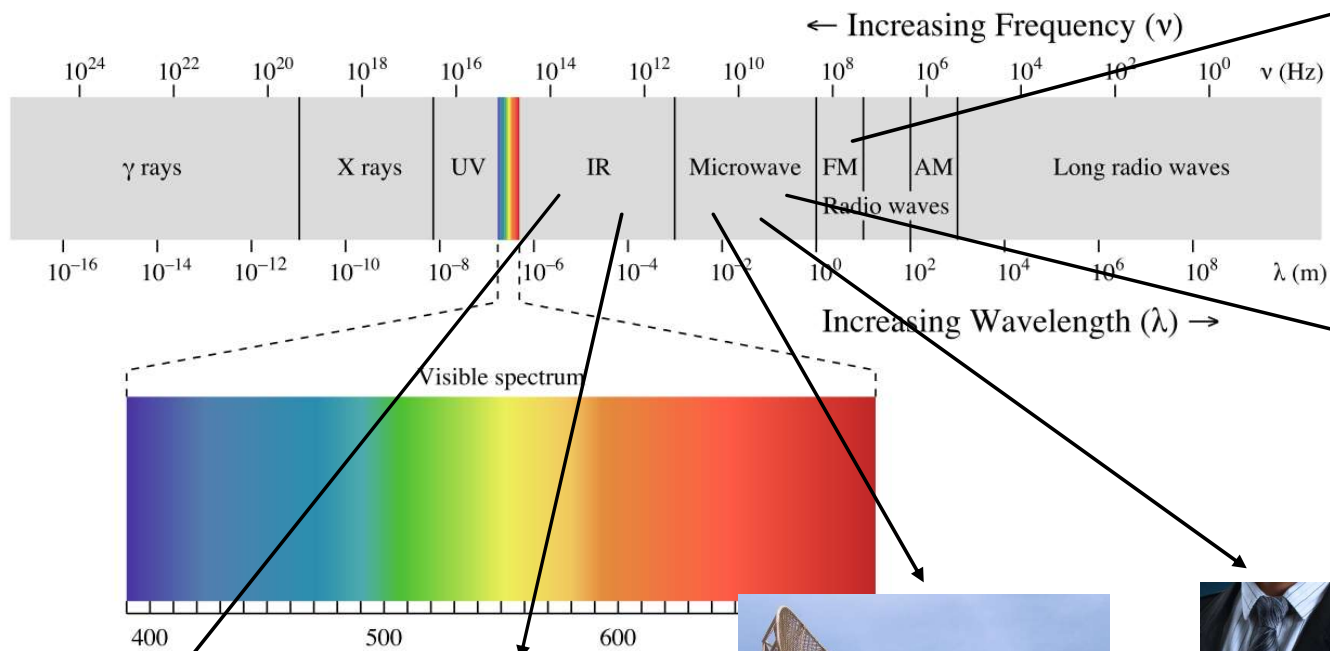
# Electromagnetics in Our Daily Life



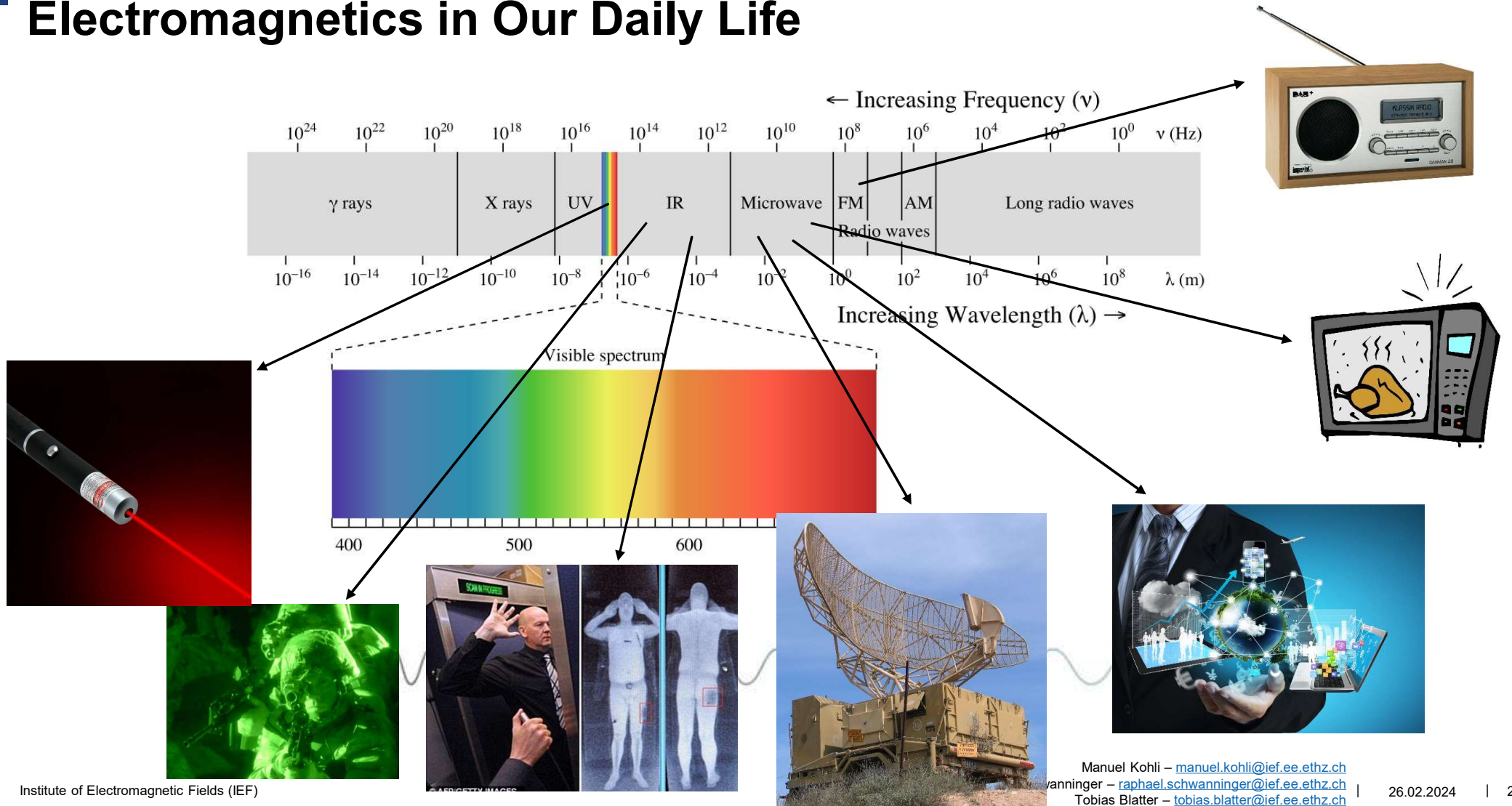
# Electromagnetics in Our Daily Life



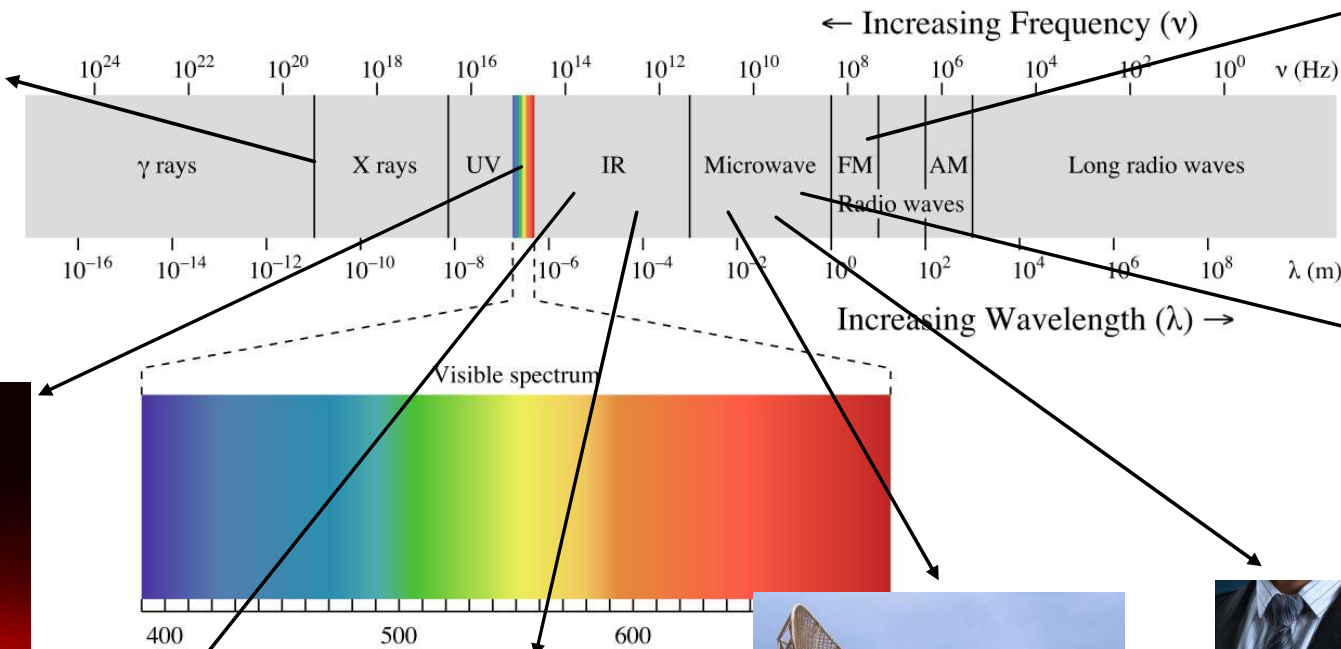
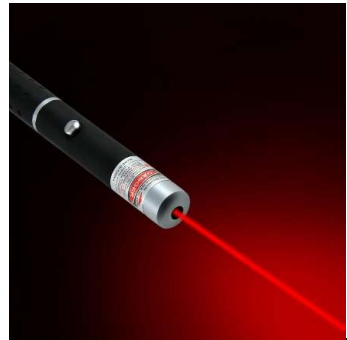
# Electromagnetics in Our Daily Life



# Electromagnetics in Our Daily Life

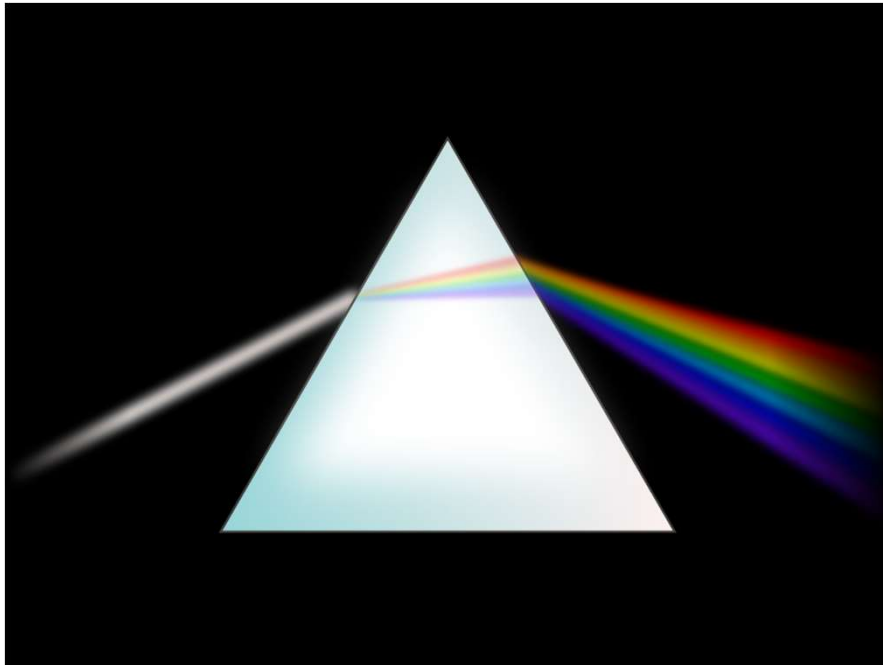


# Electromagnetics in Our Daily Life



# Photonics

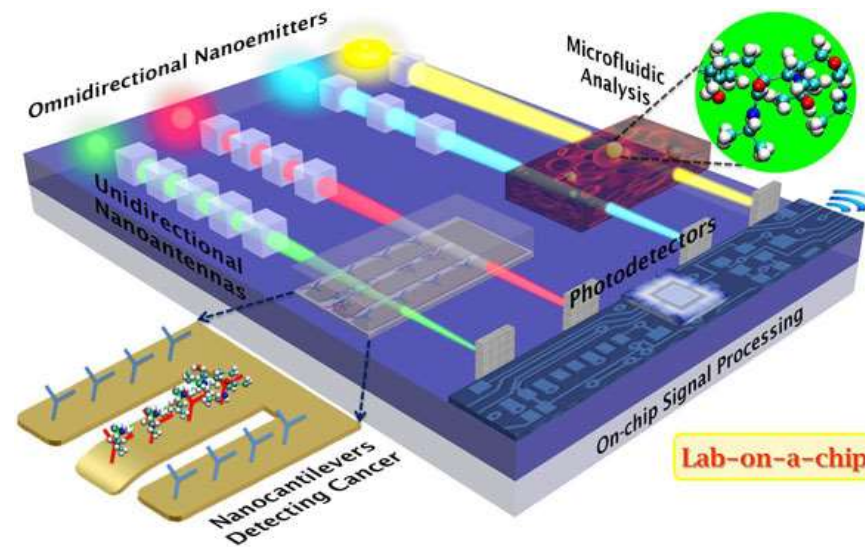
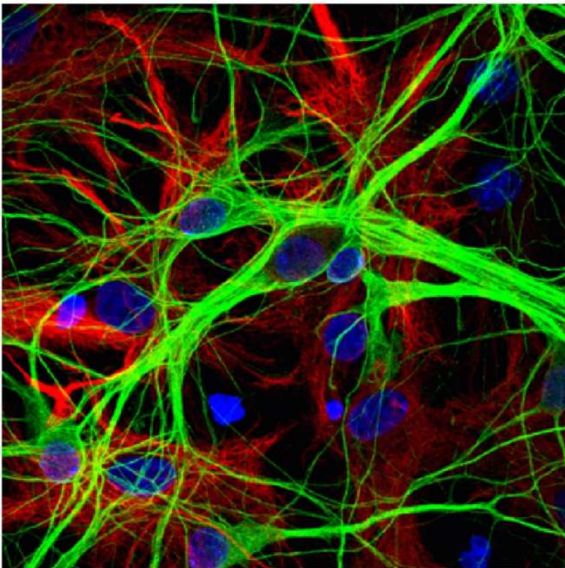
- Photonics – studying the properties of light





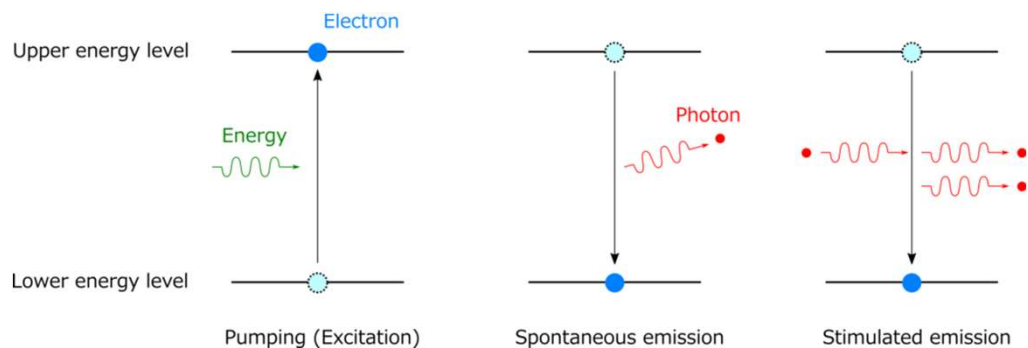
# Photonics Today

- Photonics – studying the properties of light
- Where do we use it today?
  - **Biology – Lab-on-Chip**

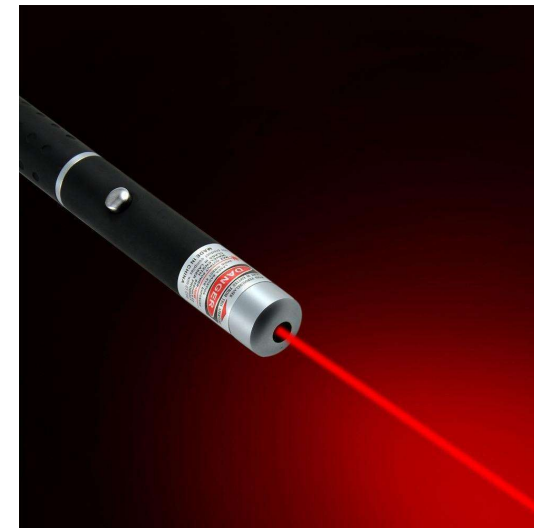


# Photonics Today

- Photonics – studying the properties of light
- Where do we use it today?
  - *Biology – Lab-on-Chip*
  - **Quantum effects**

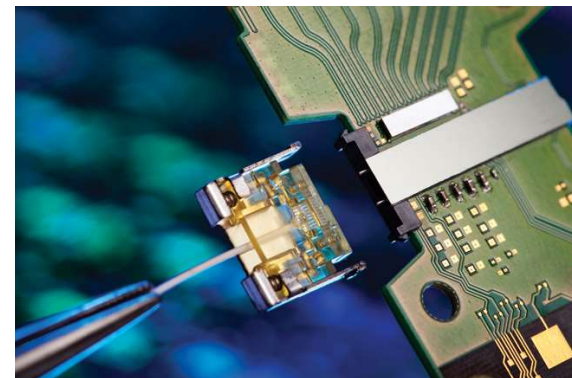
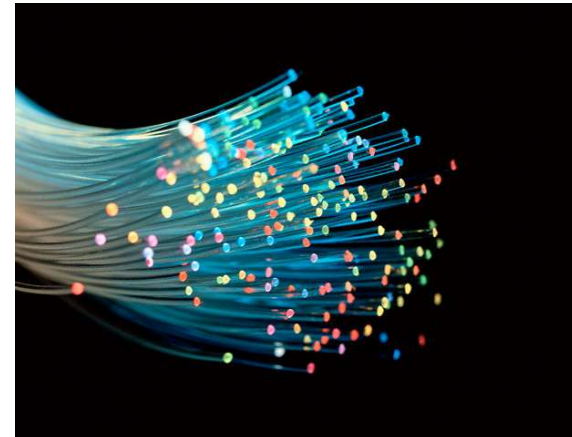


Laser Pointer



# Photonics Today

- Photonics – studying the properties of light
- Where do we use it today?
  - *Biology – Lab-on-Chip*
  - *Quantum effects*
  - **Telecommunications**
    - *Fiber replaces traditional copper wires*
    - **5G**



Source: Intel

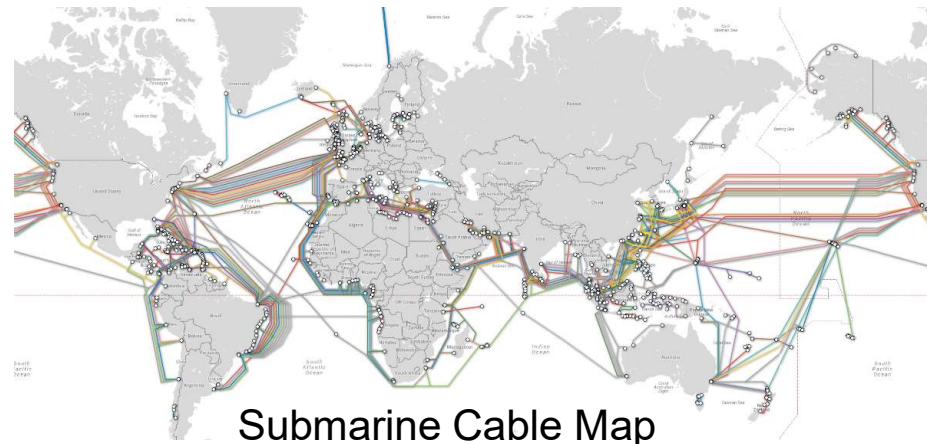
# Communication: From Radio to Fiber

- Radio waves
  - Copper wires (TV/Phone)
  - Broadcasting



# Communication: From Radio to Fiber

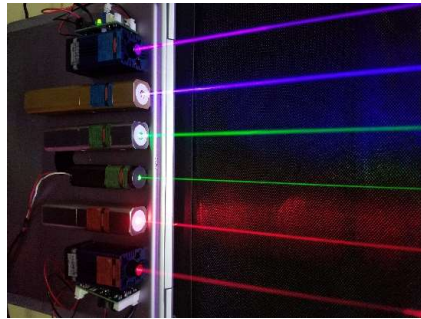
- Radio waves
  - Copper wires (TV/Phone)
  - Broadcasting
- Fiber optics (NIR)
  - Advantages
    - Large bandwidth
    - Low losses
  - Fiber deployment
    - Long distances: Submarine Cables
    - Short distances: Server



# Photonics for Communications: Basic Principles

- Light manipulation
  - *Generation*

*Lasers generate light*



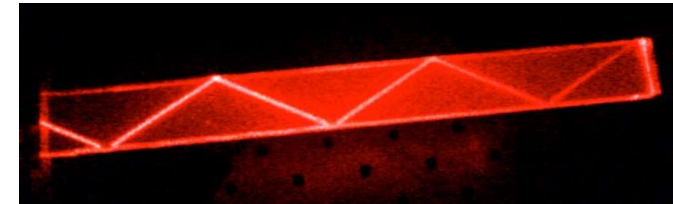
# Photonics for Communications: Basic Principles

- Light manipulation
  - *Generation*
  - *Guiding*

*Lasers generate light*



*Fiber guides light*



# Photonics for Communications: Basic Principles

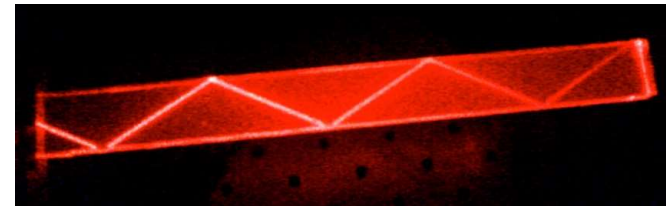
- Light manipulation

- Generation
- Guiding

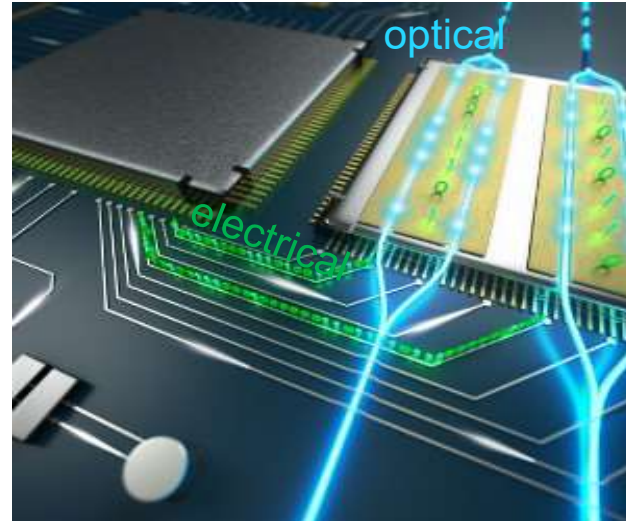
*Lasers generate light*



*Fiber guides light*



- Modulation
- Detection



*Modulator: From **electrical data** to **optical data***

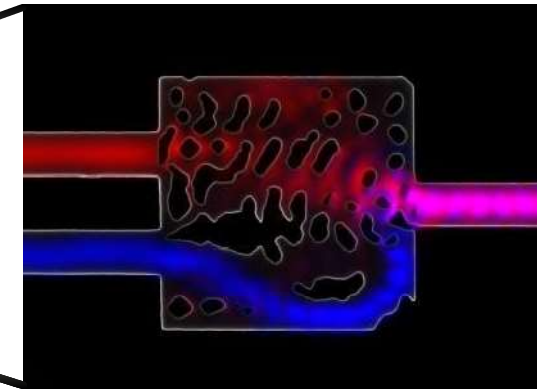
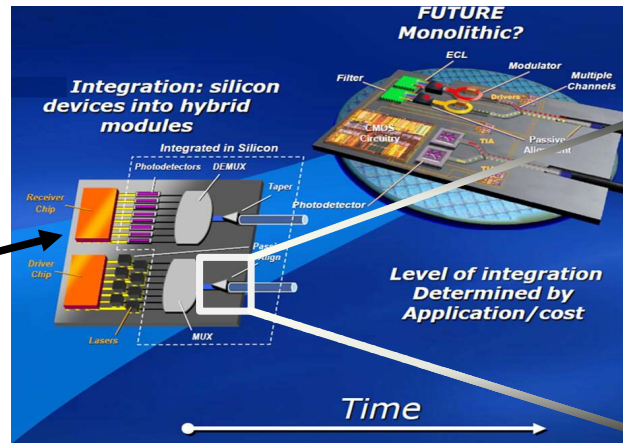
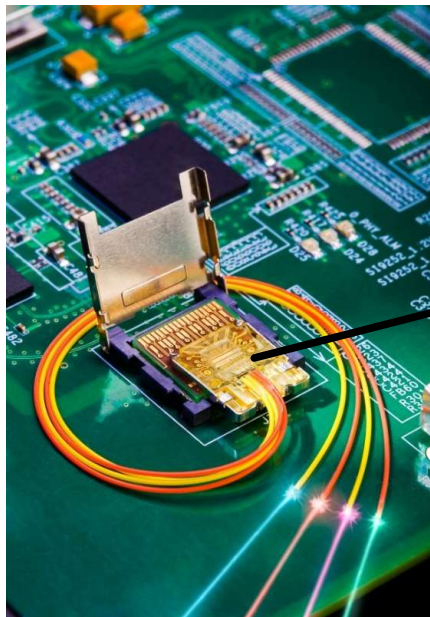
*Detector: From **optical data** to **electrical data***



# Why do we need simulations?

# Why Simulate?

- Implementation of devices
    - Devices **need a design!**
    - Fabrication & characterization (test)
    - Improvement of the design
- } Time & money



# Why Simulate?

- Implementation of devices
    - Devices **need a design!**
    - Fabrication & characterization (test)
    - Improvement of the design
- } Time & money
- We perform simulations to...
    - Shorten the developing time
      - Fast
      - Cost effective
    - Test physical models
    - Confirm experimental data
    - Investigate ideas



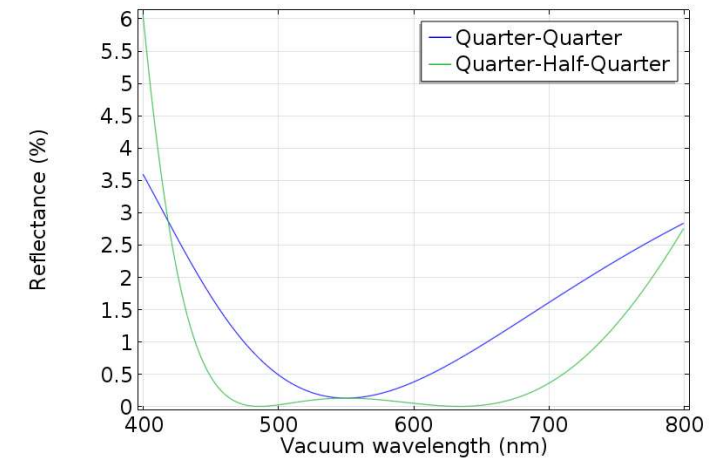
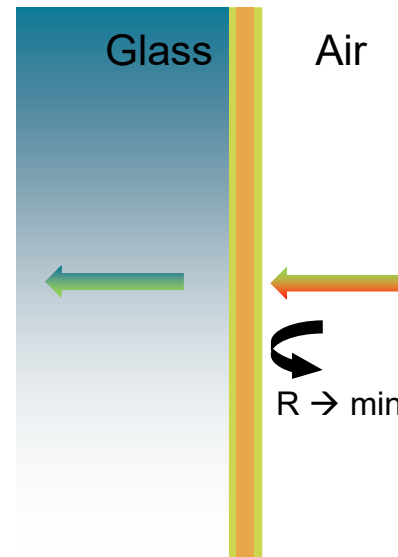
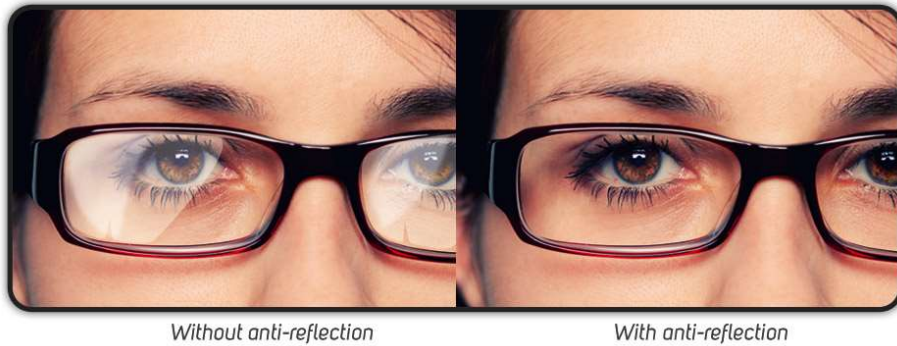
## Work flow

1. Idea
2. Design & Simulate
3. Optimize
4. Fabricate
5. Characterize



# What you will be able to simulate...

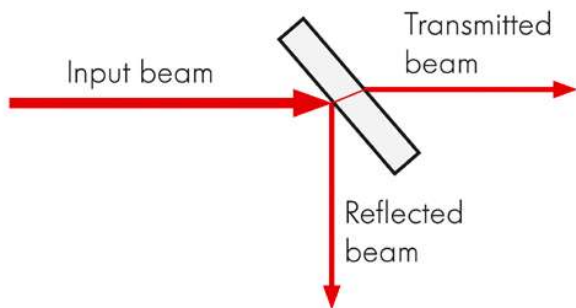
- Anti – reflection coating



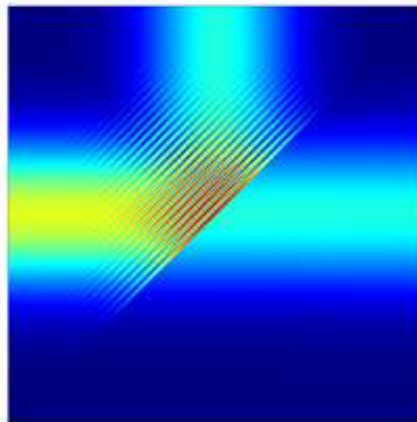
# What you will be able to simulate...

- Beam Splitter

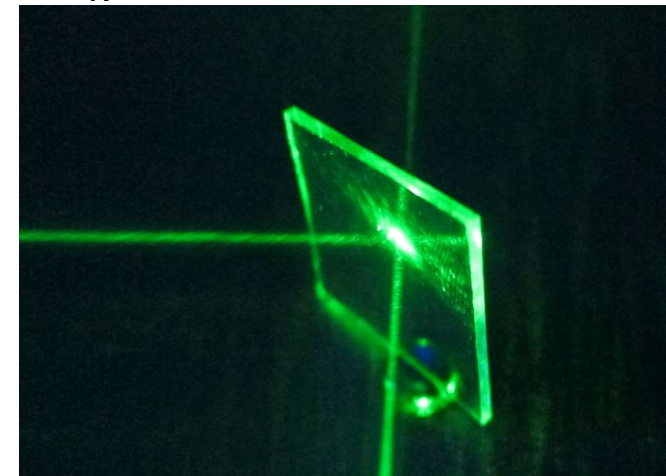
1.



2. & 3.



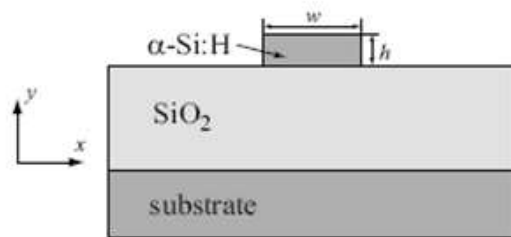
4.



# What you will be able to simulate...

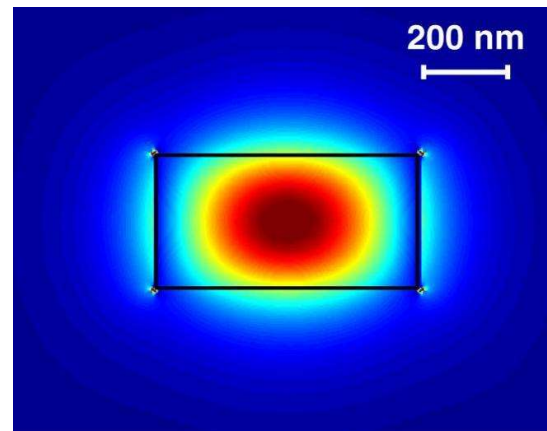
- Silicon waveguide

1.

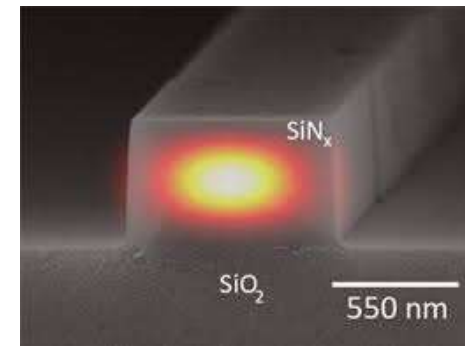


(a)

2. &amp; 3.



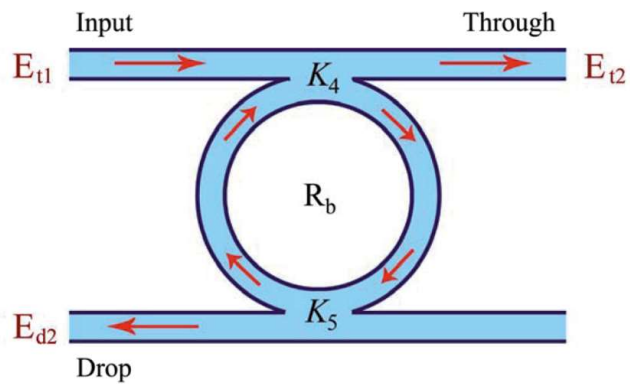
4.



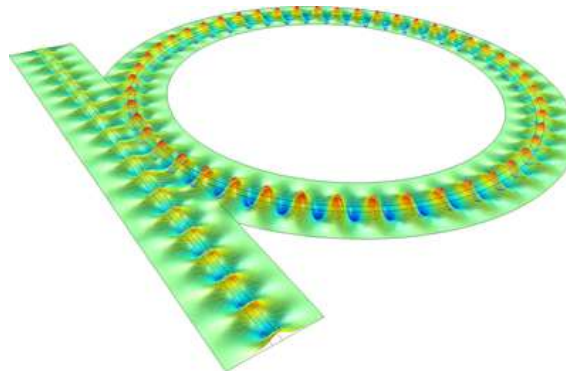
# What you will be able to simulate...

- Optical add-drop filters

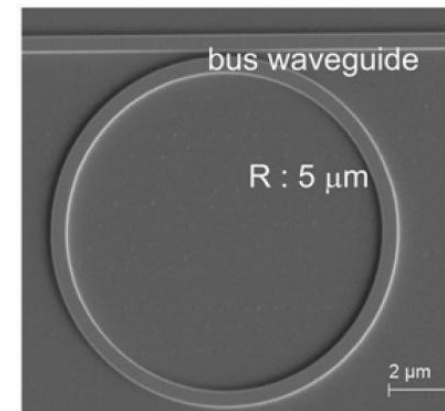
1.



2. & 3.



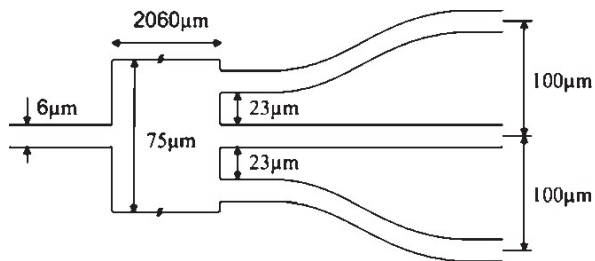
4.



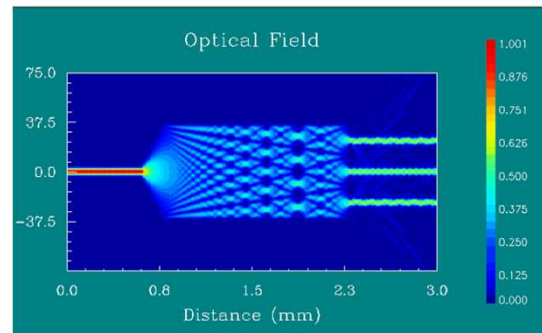
# What you will be able to simulate...

- Multi-mode interferometer

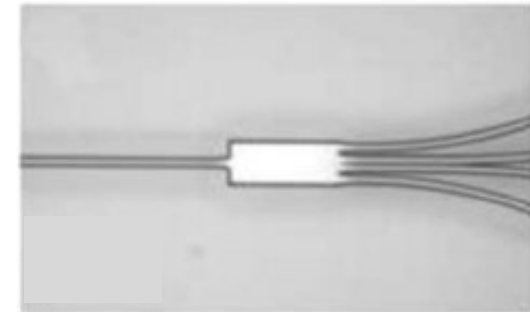
1.



2. &amp; 3.



4.

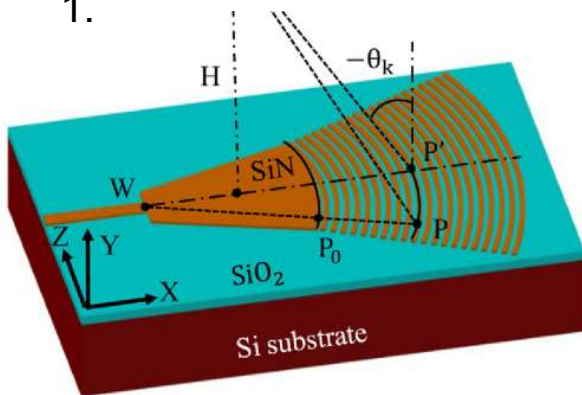




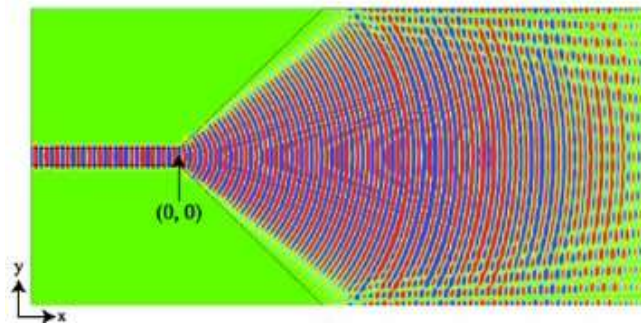
# What you will be able to simulate...

- Grating coupler

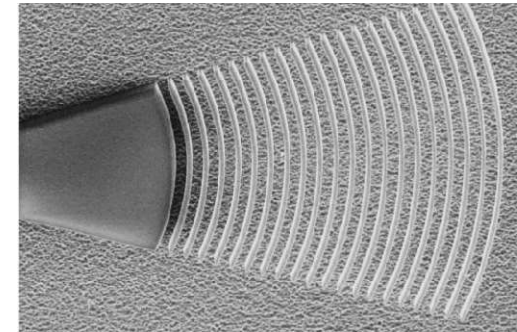
1.



2. & 3.



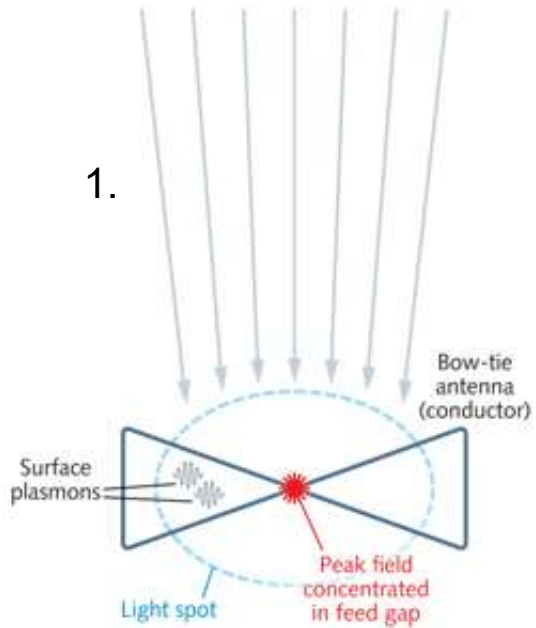
4.



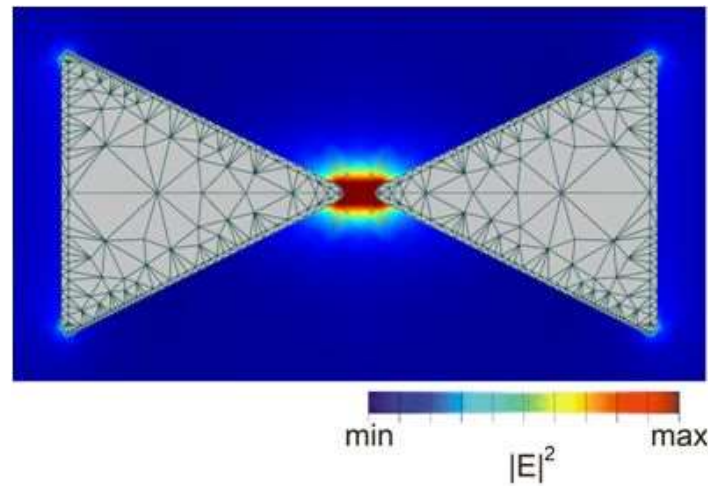
# What you will be able to simulate...

- Optical Antennas

1.



2. & 3.



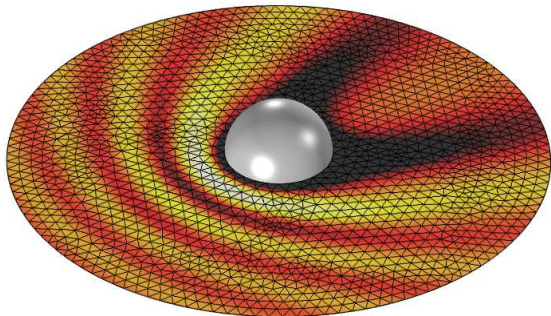
4.



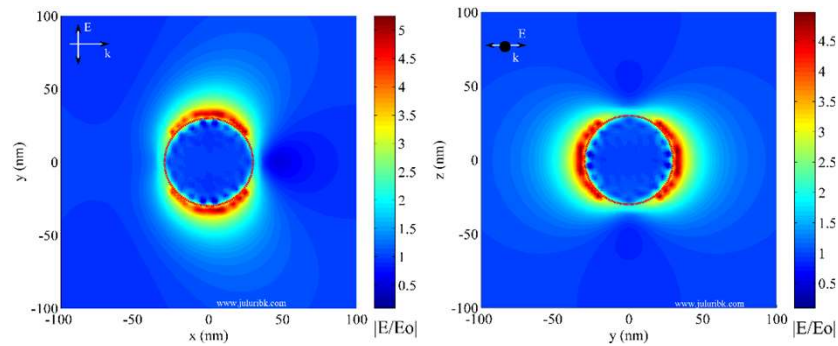
# What you will be able to simulate...

- Scattering from metallic nanoparticle

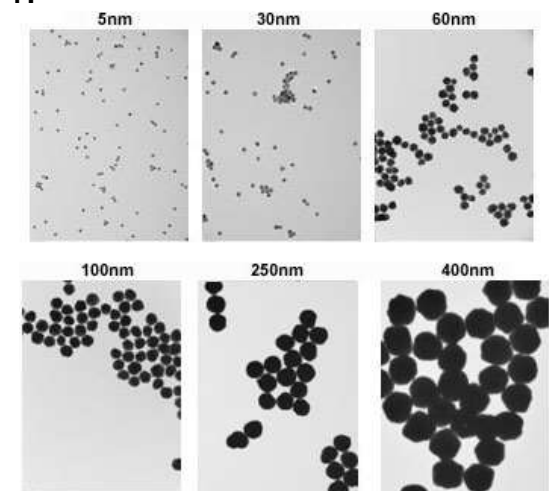
1.



2. &amp; 3.



4.



# Questions?

# Tutorial

# Starting COMSOL

- Every Student has access to Linux Server

## Connection to Linux Server

1) Download and install Cisco Anyconnect: <https://ethz.ch/content/dam/ethz/special-interest/hest/isg-hest-dam/documents/pdf/vpn-de.pdf>

Available for MS,MAC & Linux

2) Connect to ETH network using Ciso Anyconnect

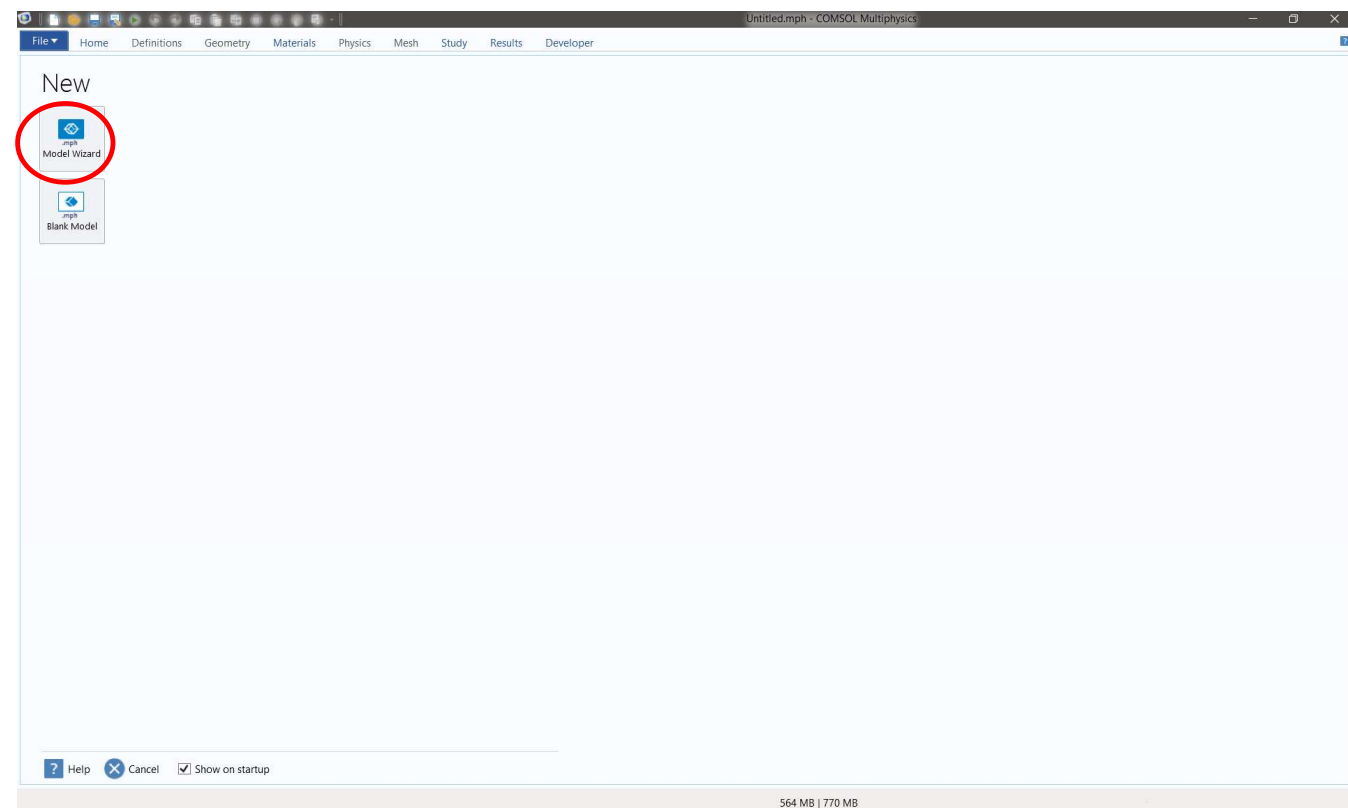
3) Connect to Linux Server

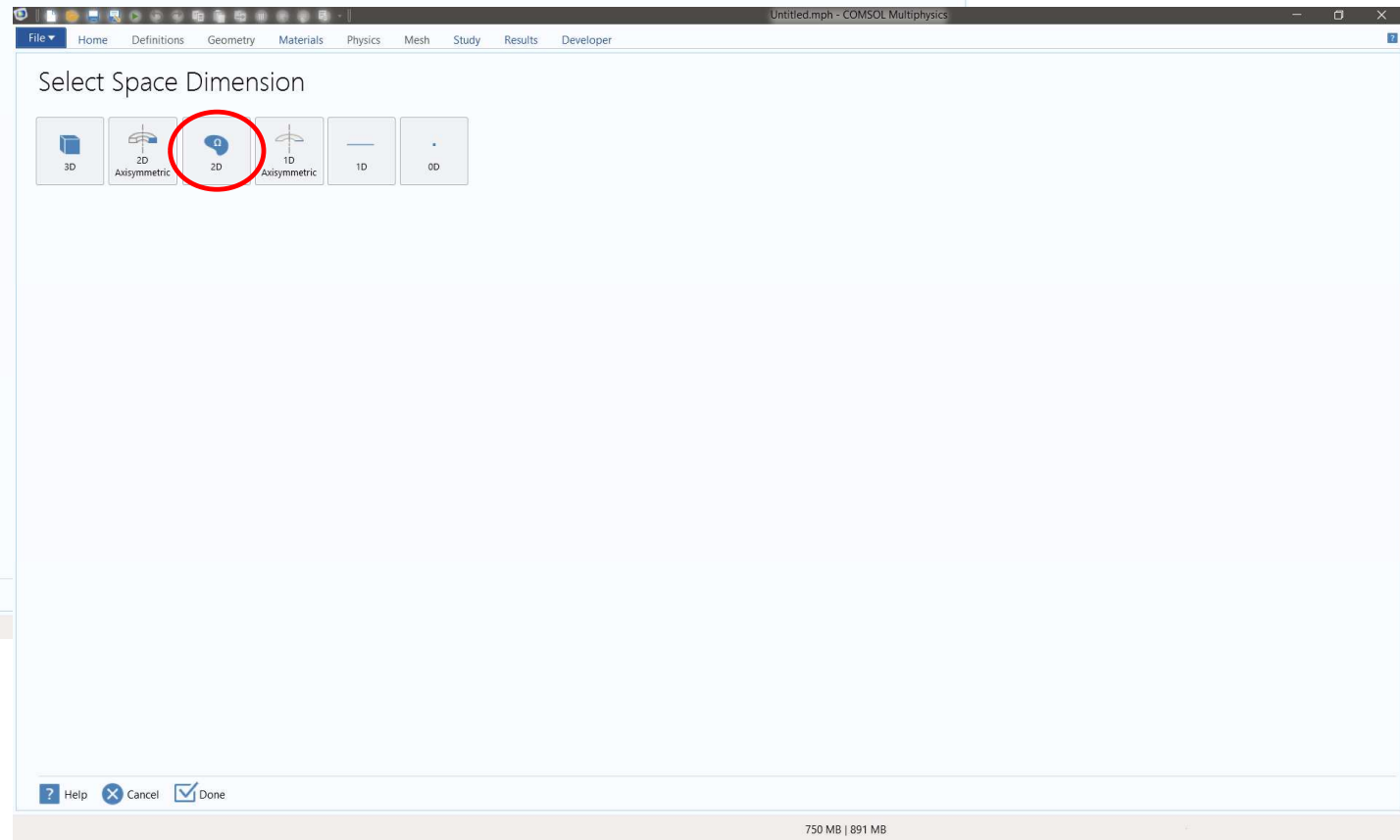
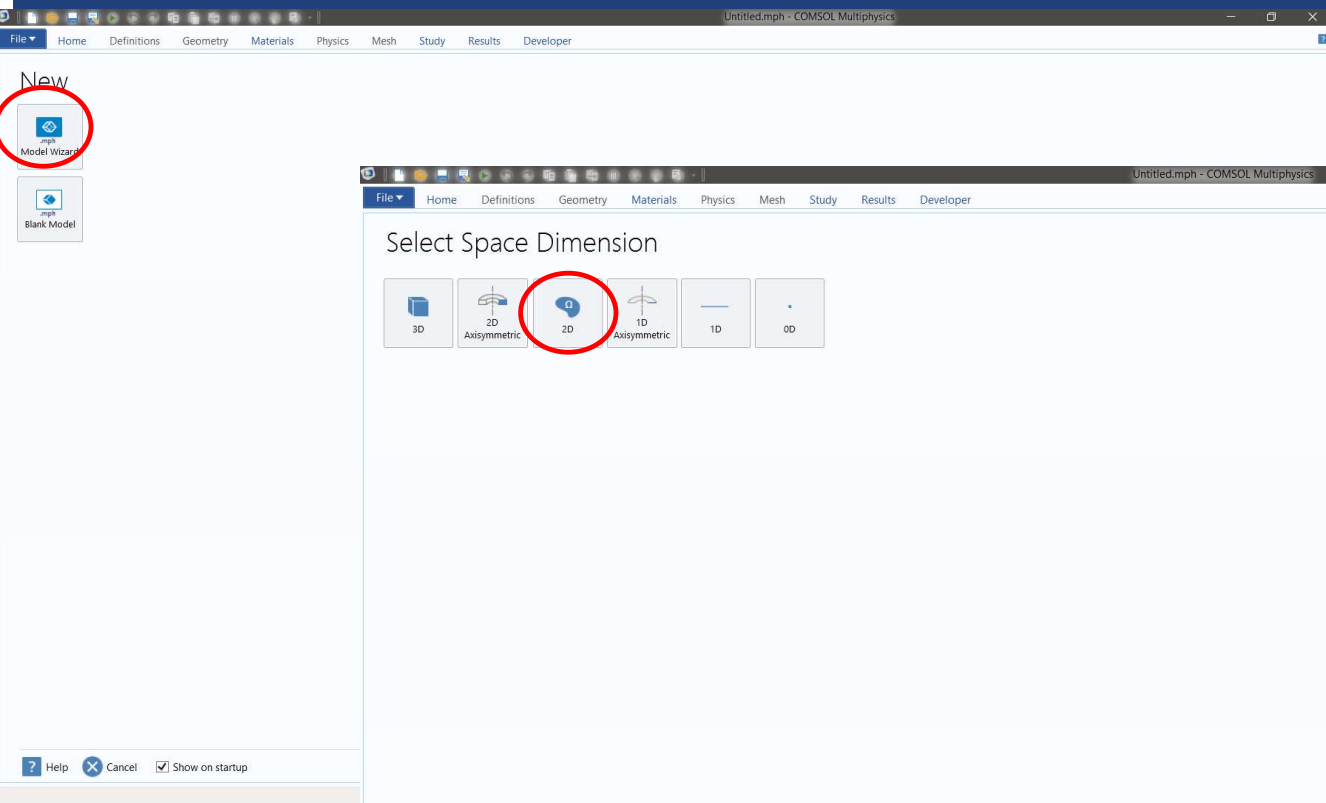
- Linux & Mac: using terminal type «ssh [\\$username@itet-ief-10.ethz.ch](mailto:$username@itet-ief-10.ethz.ch) -X»
- Windows, Linux, Max: using any remote desktop with xserver capability (e.g. Remmina)

4) Enter Username and Password

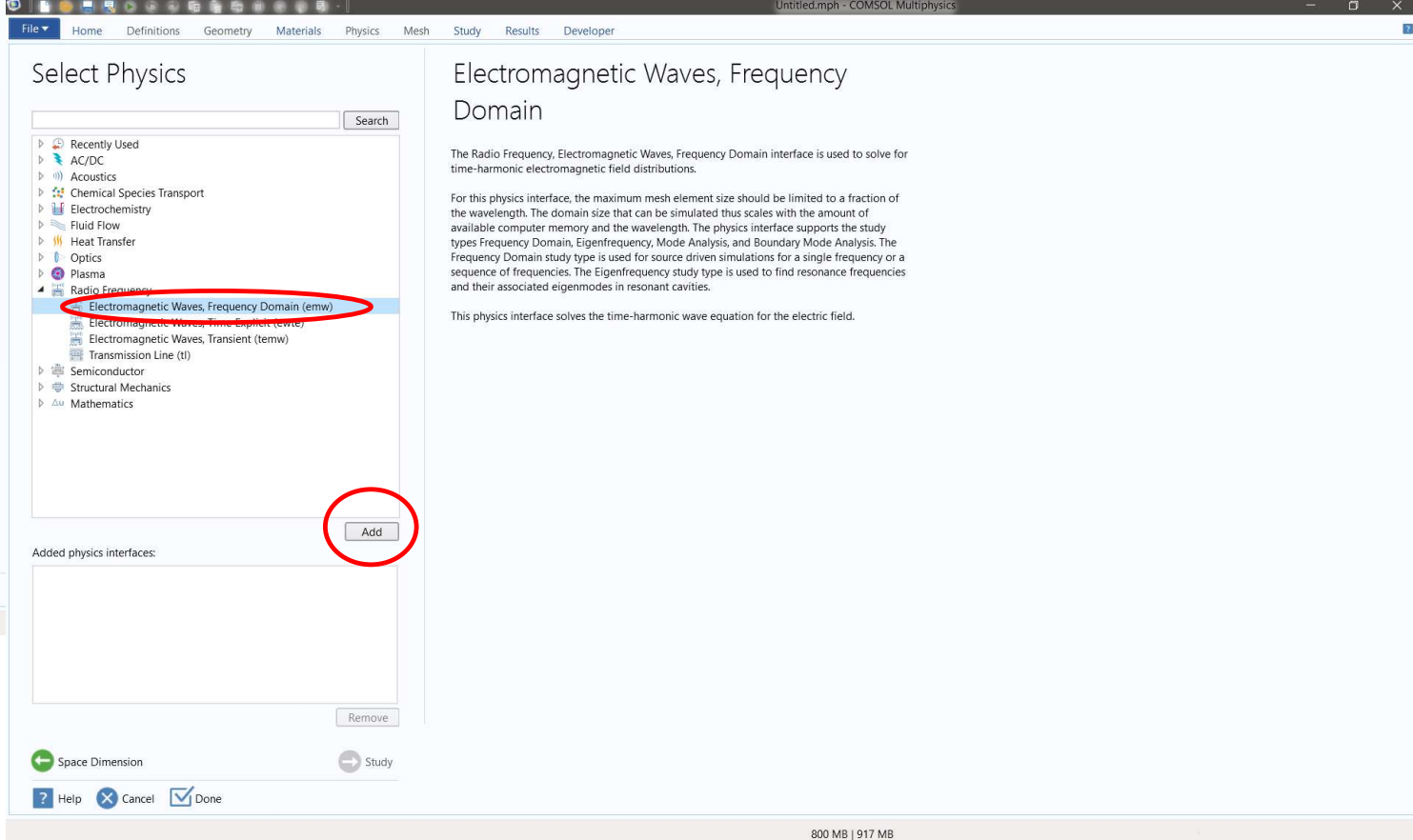
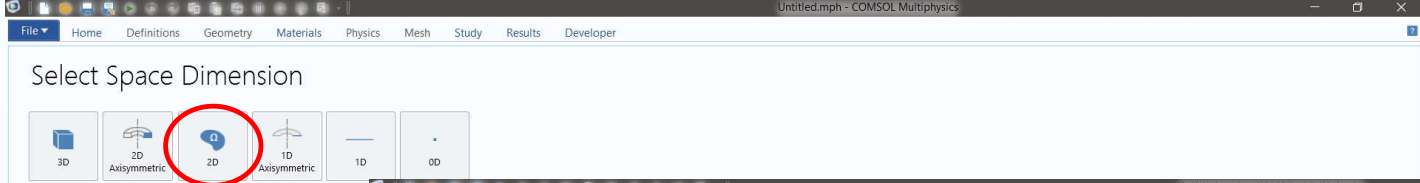
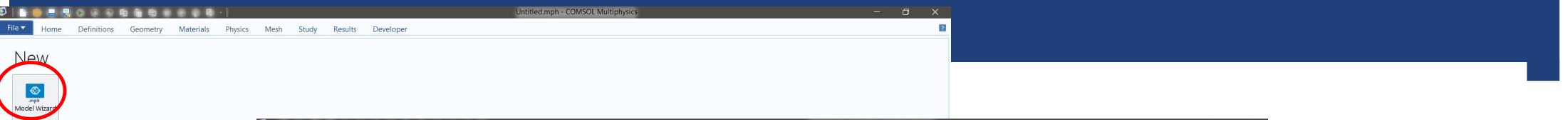
5) Start COMSOL

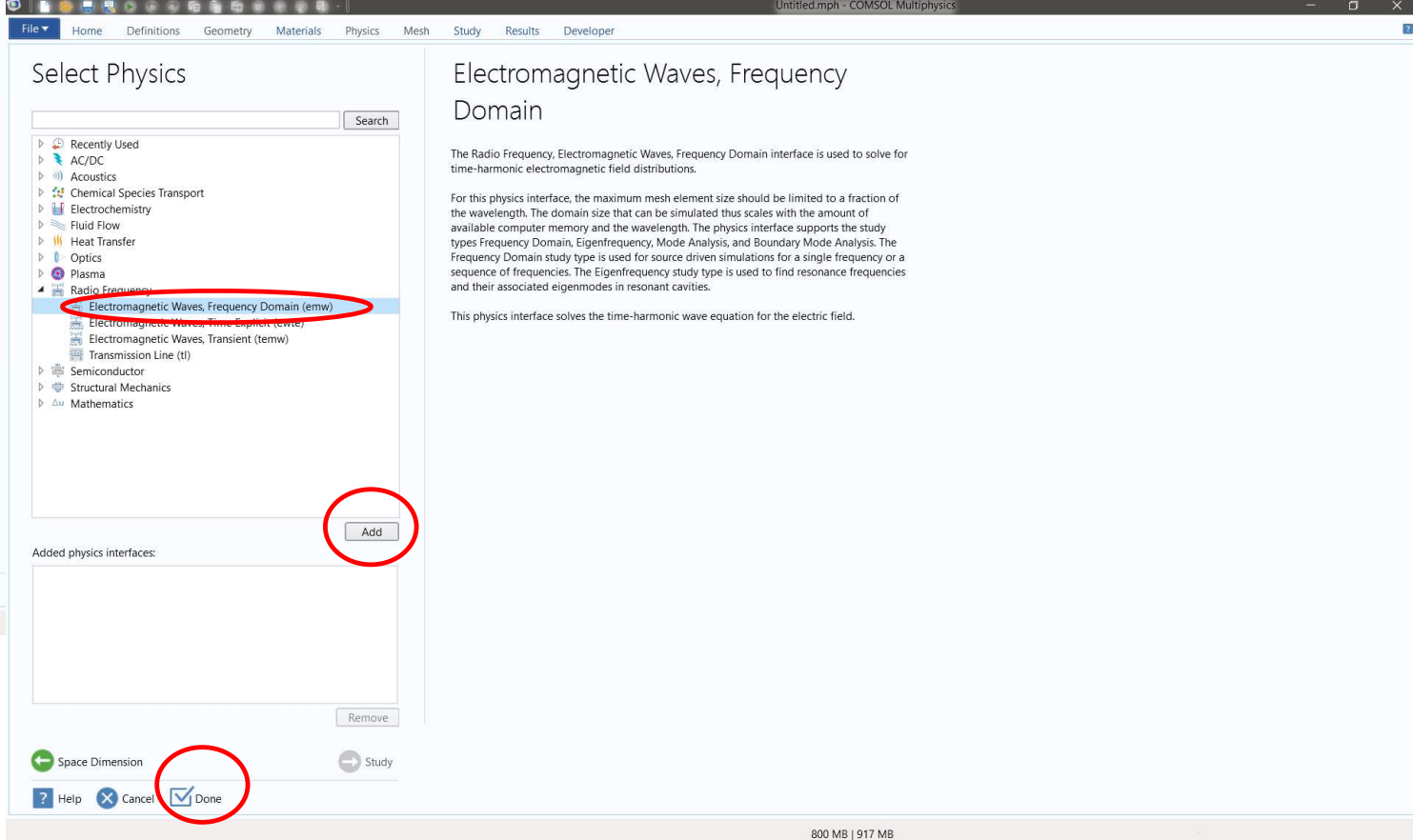
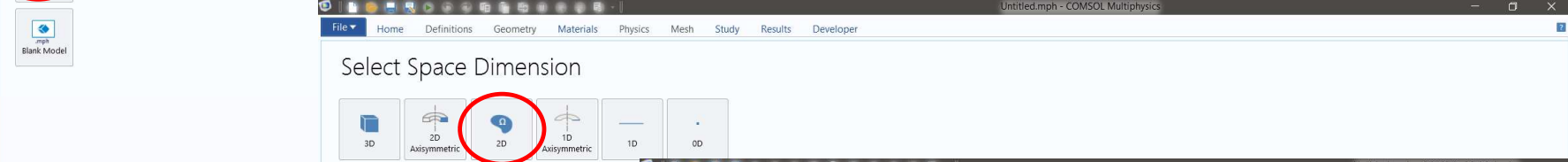
type: «comsol &» into the terminal

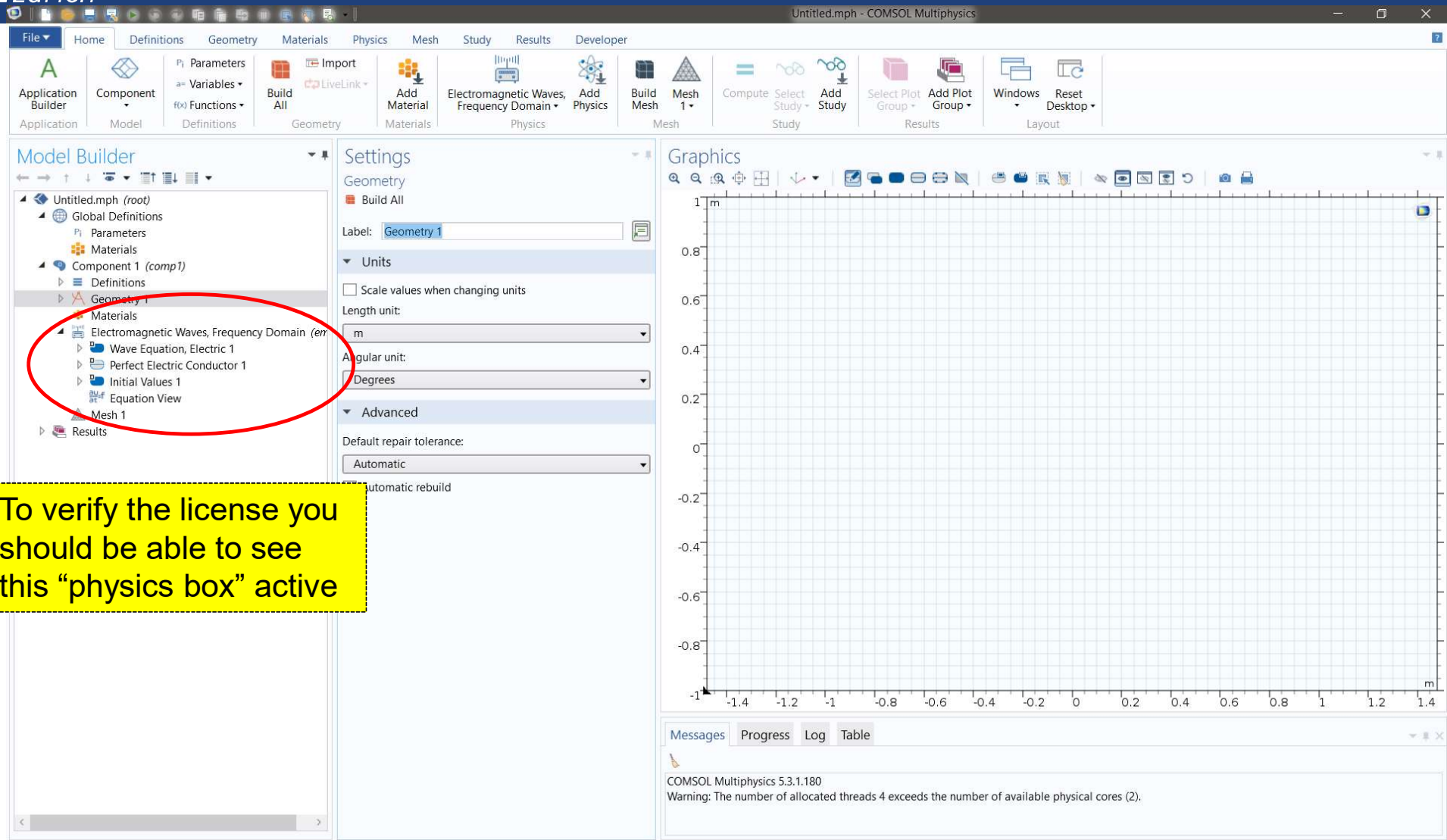










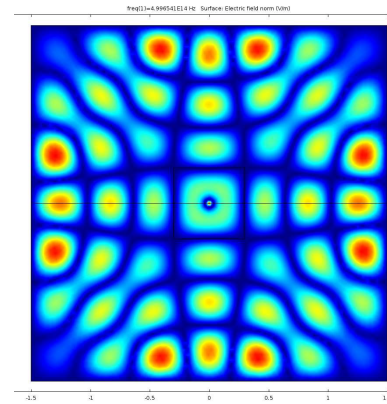


The screenshot displays the COMSOL Multiphysics software interface. The 'Model Builder' tree on the left shows a red circle around the 'Electromagnetic Waves, Frequency Domain' physics interface. The 'Settings' panel on the right shows the 'Geometry 1' settings, including units (m, Degrees) and repair tolerance (Automatic). The 'Graphics' window on the right shows a 2D plot area with axes ranging from -1 to 1.4. The 'Messages' window at the bottom shows a warning: 'Warning: The number of allocated threads 4 exceeds the number of available physical cores (2).'

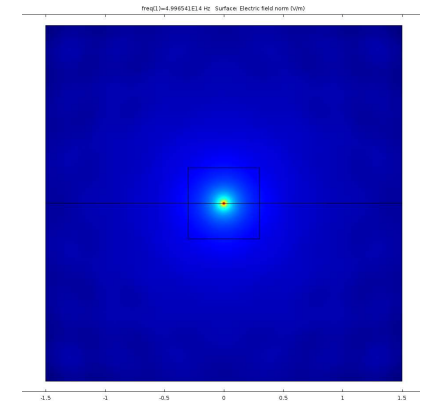
To verify the license you should be able to see this “physics box” active

# COMSOL: Boundary Condition

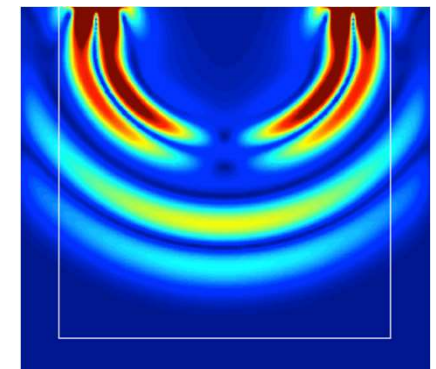
- Purpose of boundary conditions → define simulation domain
- Types of boundary conditions in COMSOL
  - Perfect Electric Conductor (PEC)
  - Perfect Magnetic Conductor (PMC)
  - Scattering Boundary Condition
  - Periodic Boundaries Condition (PBC)
  - Perfectly Matched Layer (PML)



PEC Boundaries



Scattering Boundaries



PML Boundaries