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IPAC18

Overview of Undulator Concepts for Attosecond Single-Cycle Light

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SUFEL

STOCKHOLM-UPPSALA CENTRE FOR FREE ELECTRON LASER RESEARCH

Motivation

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- Production of *intense* **attosecond** (1 as = 10^{-18} s) light pulses is an emerging area in accelerator research.
- Within one attosecond, light travels across *one water molecule* (H_2O).
- Stringent demands of **attosecond science**:
  i. *Shorter* pulse duration to increase temporal resolution
  ii. *Higher* photon flux to improve precision
- Example application: *imaging* and *controlling* the behaviour of electron wavepackets within atoms
- **Novel undulator-based concepts** proposed in recent years to meet the stringent demands
- Overcoming the limitations of existing technologies
- Opening up *unchartered territories* in attosecond science
- In this talk: three of such concepts

The LUSIA Collaboration

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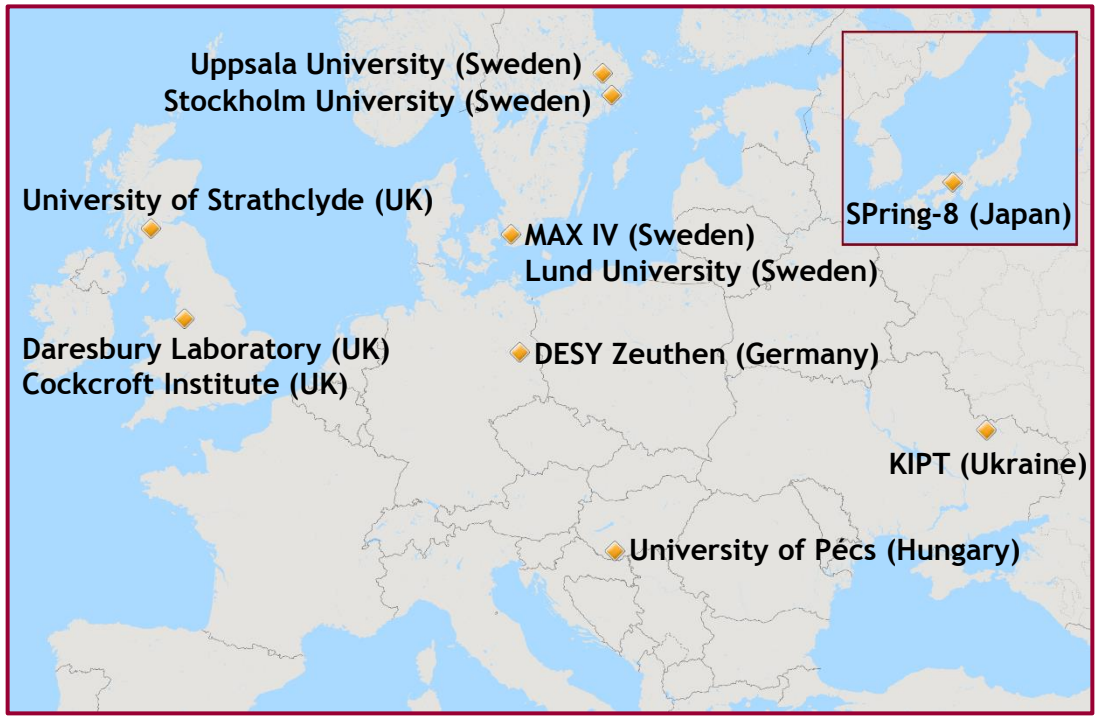
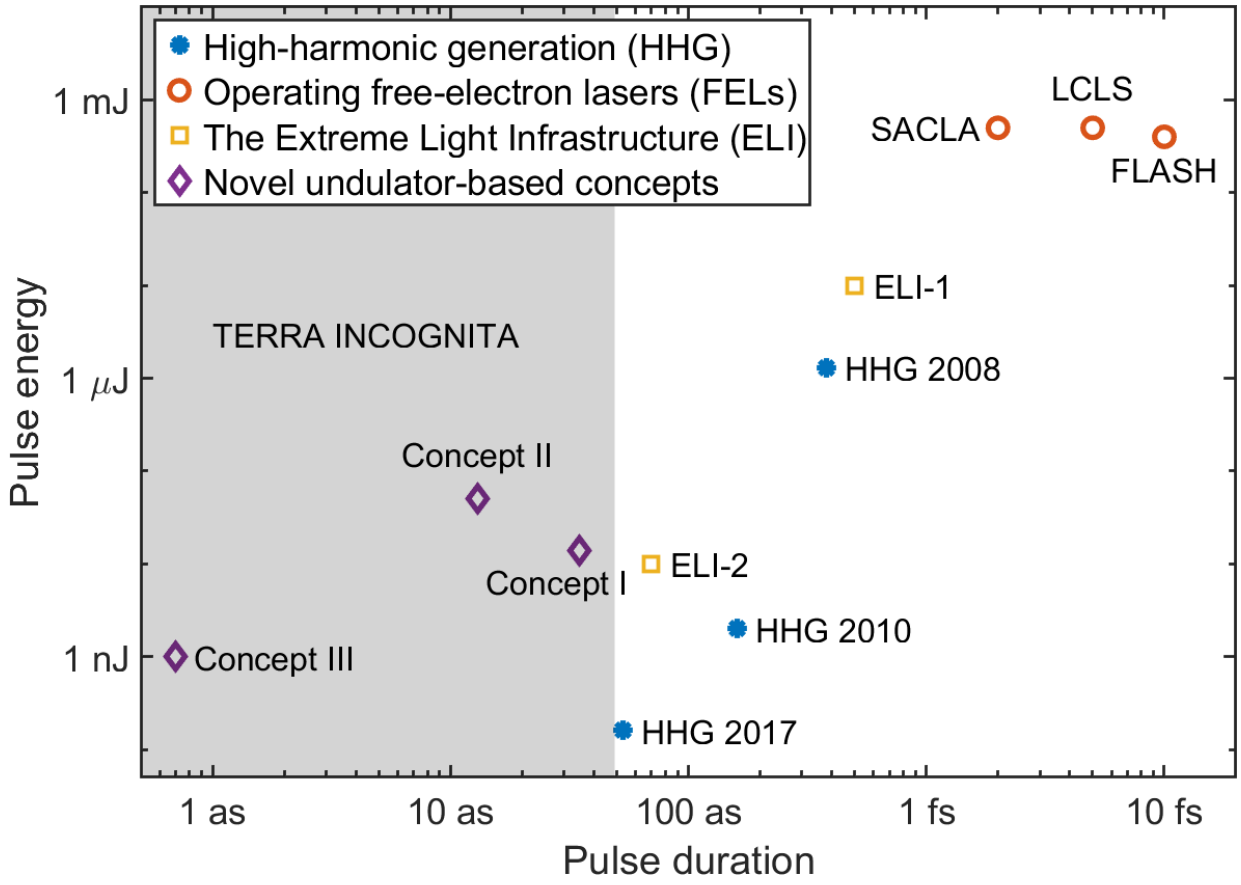
- Consortium established in 2017 for furtherance of this emerging field
- LUSIA = **A**ttosecond **SI**ngle-cycle **U**ndulator **L**ight
- Immediate goal: **Experimental demonstration** of the undulator-based concepts at DESY Zeuthen
- **Potential implementation**: future Soft X-Ray Laser (SXL) of MAX IV



State of the Art



Entering the **terra incognita**

- Obtain the pulse *energy* by exploiting the FEL principle
- Obtain the pulse *duration* by a *paradigm shift*: bringing x-ray FELs from the *femtosecond* to the *attosecond* regime

Paradigm Shift

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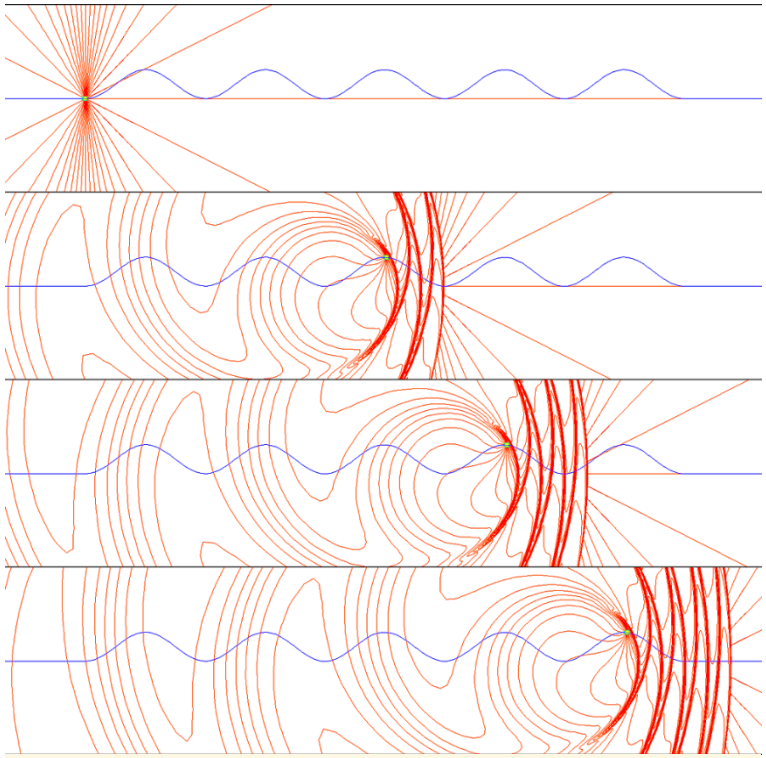
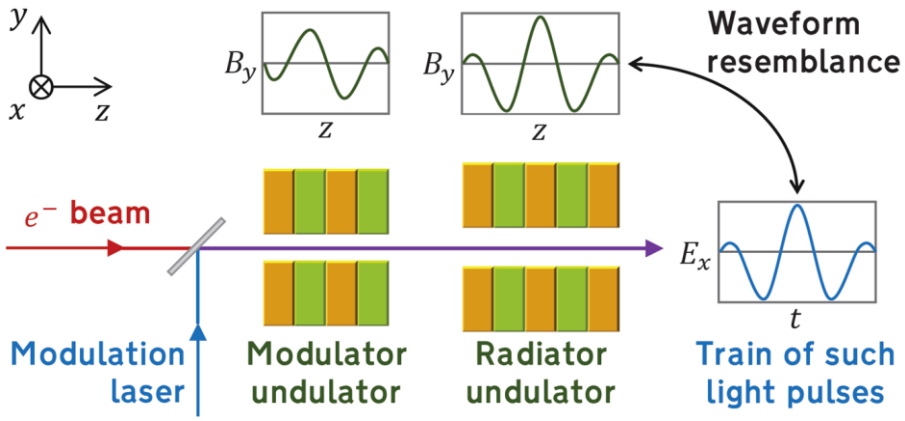
- Question: What **precludes** existing FELs from entering the *attosecond* regime?
- Answer: Inherent *pulse lengthening* in the FEL interaction
- **Paradigm**: *many*-cycle FEL pulses
- **Shift**: towards *single*-cycle pulses
- Example: $\lambda = 0.3$ nm and $N_{cycle} = 1$ $\Longrightarrow \Delta t = 1$ attosecond
- Problem: N_{cycle} increases with N_{period}
- A possible solution: Make $N_{period} = 1$

Microbunch through undulator



Snapshots obtained from the simulation tool of T. Shintake [Nucl. Instr. Meth. Phys. Res. A **507**, 89–92 (2003)].

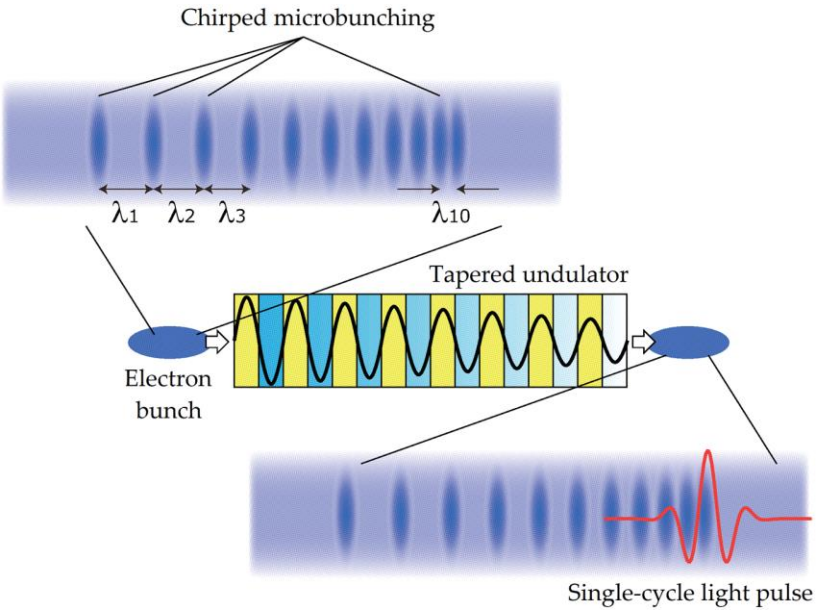
Concept I: Compact Undulators

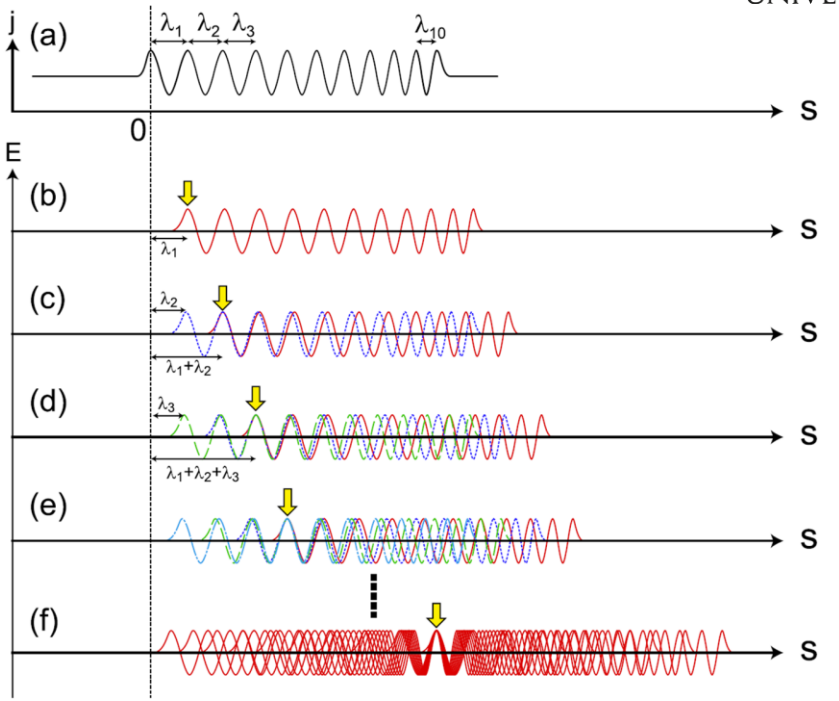


- Proposed by the J. Hebling group in Hungary [1]
- Two *single-period* undulators with *tailored* magnetic field profiles
- Waveform resemblance shown analytically in [2]
- Direct control of $E_x(t)$; reproducible from pulse to pulse
- Stability of **carrier-envelope phase** (CEP); important for attosecond science
- Concept extended to *helical* undulators in [3]

1. Z. Tibai et al., *Phys. Rev. Lett.* **113**, 104801 (2014).
2. G. Shamuilov, A. Mak, P. Salén, V. Goryashko, *Opt. Lett.* **43**, 819 (2018).
3. G. Tóth et al., *Opt. Lett.* **40**, 4317 (2015).

Concept II: Chirped Microbunching

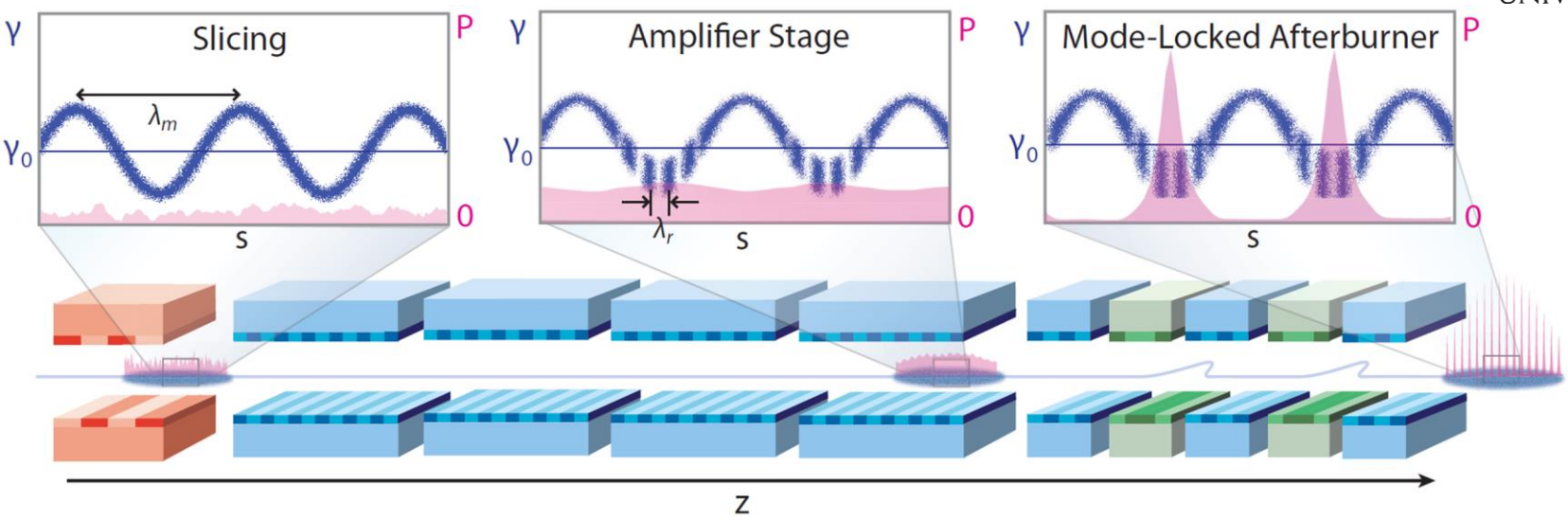




- Proposed by the T. Tanaka group in Japan [1]
- Concept further developed in [2, 3]
- Prebunching schemes explained in [1, 2]
- n^{th} spacing between microbunches equals resonant wavelength at n^{th} undulator period

1. T. Tanaka, *Phys. Rev. Lett.* **114**, 044801 (2015).
2. Y. Kida, R. Kinjo, T. Tanaka, *Appl. Phys. Lett.* **109**, 151107 (2016).
3. V. Goryashko, *Phys. Rev. Accel. Beams* **20**, 080703 (2017).

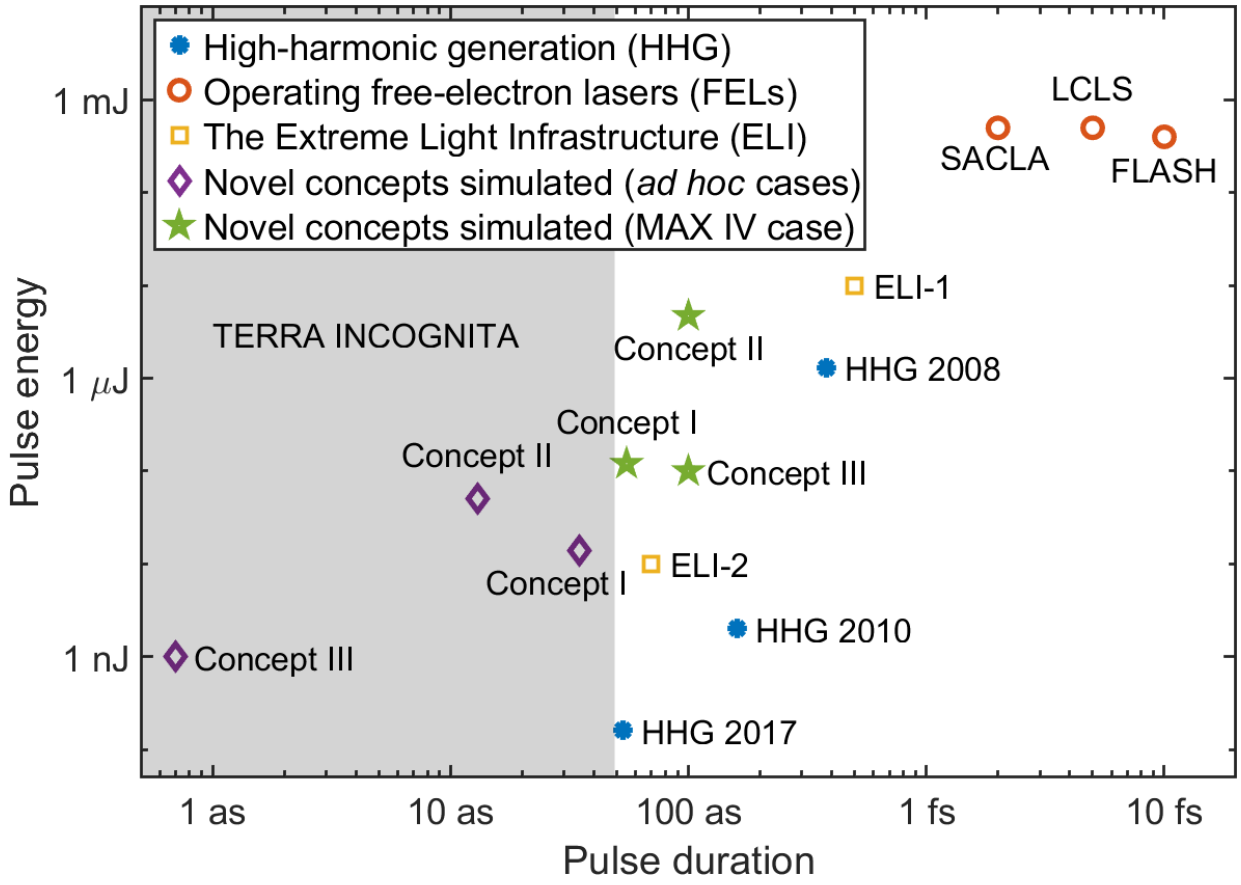
Concept III: Mode-Locked FEL



- Proposed by the B. W. J. McNeil group in the United Kingdom [1, 2]
- **Mode-Locked Afterburner**: Few-period undulators between magnetic chicanes
- Chicanes maintain *overlapping* between temporal combs of electrons and radiation, resulting in a train of amplified few-cycle light pulses.

1. N. R. Thompson, B. W. J. McNeil, *Phys. Rev. Lett.* **100**, 203901 (2008).
2. D. J. Dunning, B. W. J. McNeil, N. R. Thompson, *Phys. Rev. Lett.* **110**, 104801 (2013).

Summary & Outlook



Novel undulator concepts as a **breakthrough:**

- **Overcome limitation** of HHG by exploiting the *FEL principle*
- **Paradigm shift** from *many-cycle* towards *single-cycle* FEL pulses

Acknowledgement

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- **Scientific Committee of IPAC 2018**

More on attosecond single-cycle light:
Poster **THPMK142** (!)