Potential new medical applications of synchrotron radiation

Jarosław Duda, article, slides, talk

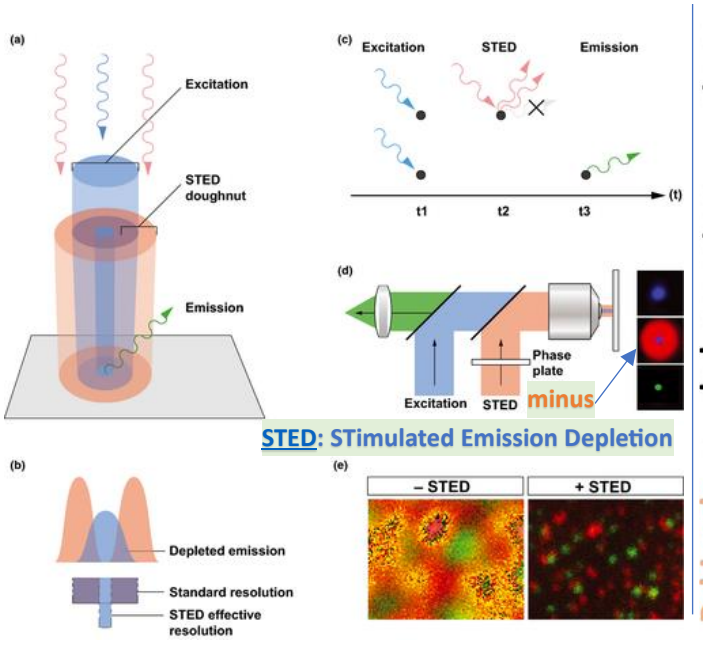
While naively photon sources **heat**, **push**, **excite** target, there is also **laser cooling**, **optical pulling**, **negative radiation pressure** and **stimulated emission** – currently applied e.g. in **STED microscopes** (with second **laser causing deexcitation**) or **Rabi cycle** (cyclically causing excitation – deexcitation).

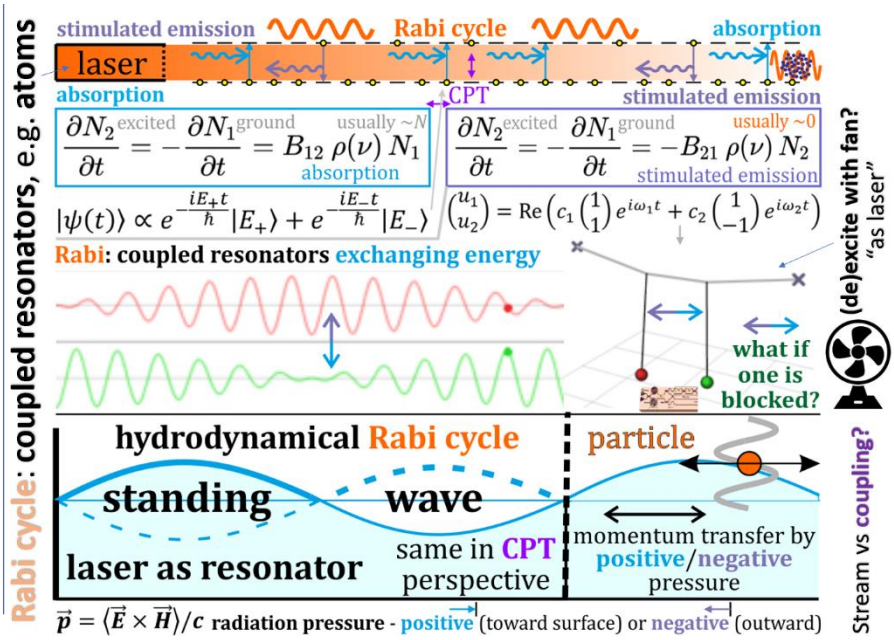
Being able to **act only with stimulated emission** on target, it should have much **better transparency** as blocked by N_2 excited atoms instead of N_1 blocking absorption, allowing **new applications** like:

- **radiotherapy**: e.g. **starve deep tumors** (better transparency), much weaker for intermediate tissues, e.g. locally **stimulate** NADH $\rightarrow$ $NAD^+ + H^+ + 2e^- + \gamma$ (**~460nm**) for NADH crucial in metabolism.

- **medical scanners** - **emission RTG/CT**: color, harmless (no ionizing radiation), mapping e.g. NADH.

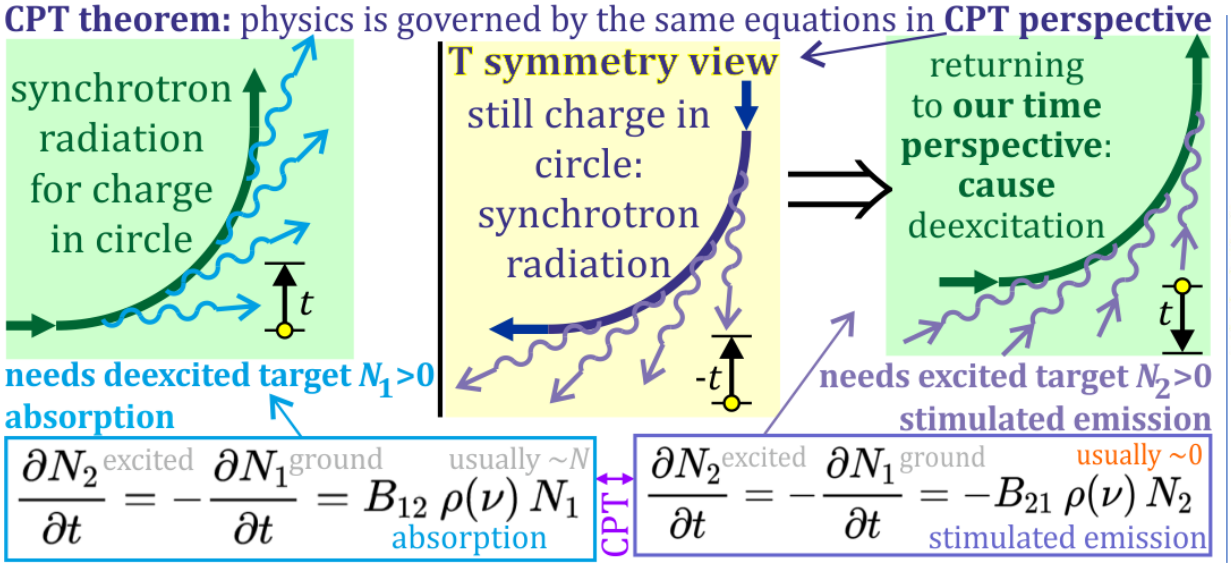
CPT symmetry suggests how to obtain **stimulated emission alone** e.g. by **synchrotron radiation**.

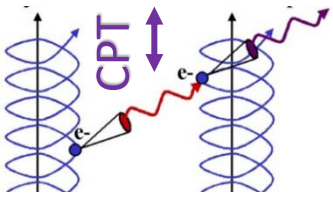




CPT symmetry is crucial for modern physics: "CPT theorem says that CPT symmetry holds for all physical phenomena, or more precisely, that any Lorentz invariant local quantum field theory with a Hermitian Hamiltonian must have CPT symmetry", basically saying that **running evolution backward in time, it is governed by practically the same equations** (+CP).

Electron traveling on a circle should emit **synchrotron radiation**, usually leading to excitation of some target. From **perspective of CPT symmetry** (or T), it is still charge traveling on a circle, hence should also cause excitation of target – what from our time perspective means **causing its deexcitation through stimulated emission** (**target would need to be initially excited**):





stimulated **coupling of electrons**, also in CPT

$$\frac{\partial N_2}{\partial t}^{\text{excited}} = -\frac{\partial N_1}{\partial t}^{\text{ground}} = B_{12}\,\rho(\nu)\,N_1 \quad \text{absorption} \quad (\text{usually } \sim N)$$

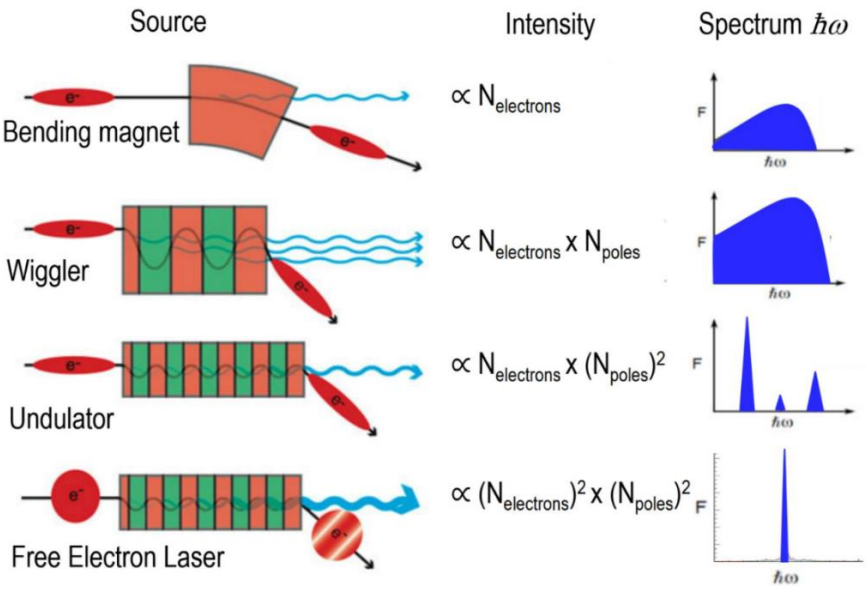
CPT

$$\frac{\partial N_2}{\partial t}^{\text{excited}} = -\frac{\partial N_1}{\partial t}^{\text{ground}} = -B_{21}\,\rho(\nu)\,N_2 \quad \text{stimulated emission} \quad (\text{usually } \sim 0)$$

Mathematically, there is **absorption**-**stimulated emission** pair of equations, which are **switched in perspective of CPT symmetry**. Hence to evaluate the strength of such **CPT analog of absorption**, we should **calculate $\rho(\nu)$ radiation density assuming reversed electron trajectory**, then apply it to the **stimulated emission equation** (instead of **absorption equation**).

The **strength of stimulated emission** effect is also **proportional to N_2: number of excited atoms**, which is **usually close to zero**, preventing such stimulated emission effect – to observe/apply the effect, we would need to prepare $N_2 \gg 0$ excited target ($N_1 \sim N$ **hence absorption is much easier**).

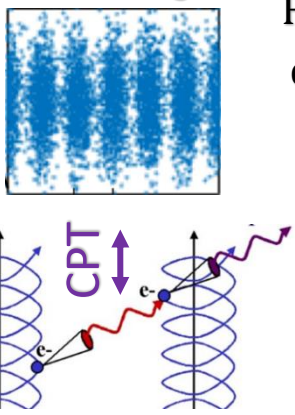
Such CPT analog of emission is probably exploited by free electron laser beam formation (to be confirmed): it suggests that further electrons stimulate emission from the earlier ones – what would lead e.g. to narrowing of beam spectrum and angle, also bunching - like observed (diagram source):



$$\frac{1}{\gamma}$$

cone angle

$$\frac{1}{\gamma\sqrt{N_u}}$$



self-amplified SE, synchrotron self-absorption

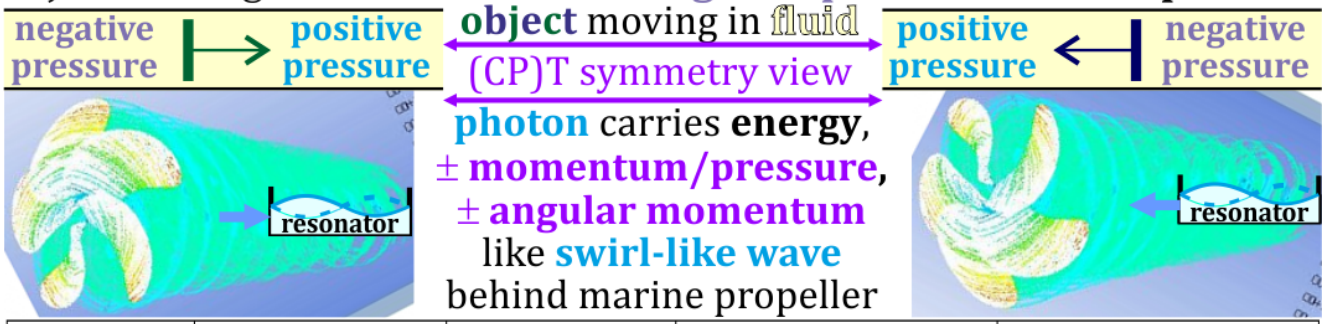
coupled electrons, also in CPT

EM-hydrodynamics analogy is valuable to gain intuitions for such CPT analog of absorption as **EM uses nearly the same equations as superfluid** (without viscosity). Moving object in fluid creates both **positive**, but also **negative pressure**, and they are **switched** in perspective of CPT symmetry.

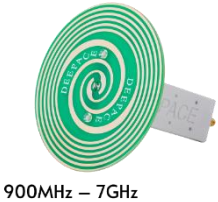
Behind marine propeller there is formed twist-like wave: carrying energy, momentum and angular momentum – like photon, but without quantization. Just reversing rotation direction, we get CPT analog – reversing velocity and pressure, it could **pull energy from excited resonator**.

Impulse powered spring-like antenna is also reversed in T symmetry e.g. for proof-of-concept (?)

object moving in fluid creates also **negative pressure**, **EM ~superfluid**



Theory	Gauge fields	Circulation	Gauge condition	Matter field
Electro-dynamics	φ , $\vec{A}$ four-potential	$\vec{B} = \vec{\nabla} \times \vec{A}$ magnetic f.	$\vec{\nabla} \cdot \vec{A} + \frac{1}{c^2}\frac{\partial \varphi}{\partial t} = 0$	$\vec{E}_e = -\frac{\partial \vec{A}}{\partial t} - \vec{\nabla}\varphi$
Hydro-dynamics	$\chi = v^2/2, \vec{v}$ flow velocity	$\vec{\omega} = \vec{\nabla} \times \vec{v}$ vorticity	$\vec{\nabla} \cdot \vec{v} + \frac{1}{c_s^2}\frac{\partial \chi}{\partial t} = 0$	$\vec{E}_h = -\frac{\partial \vec{v}}{\partial t} - \vec{\nabla}\chi$

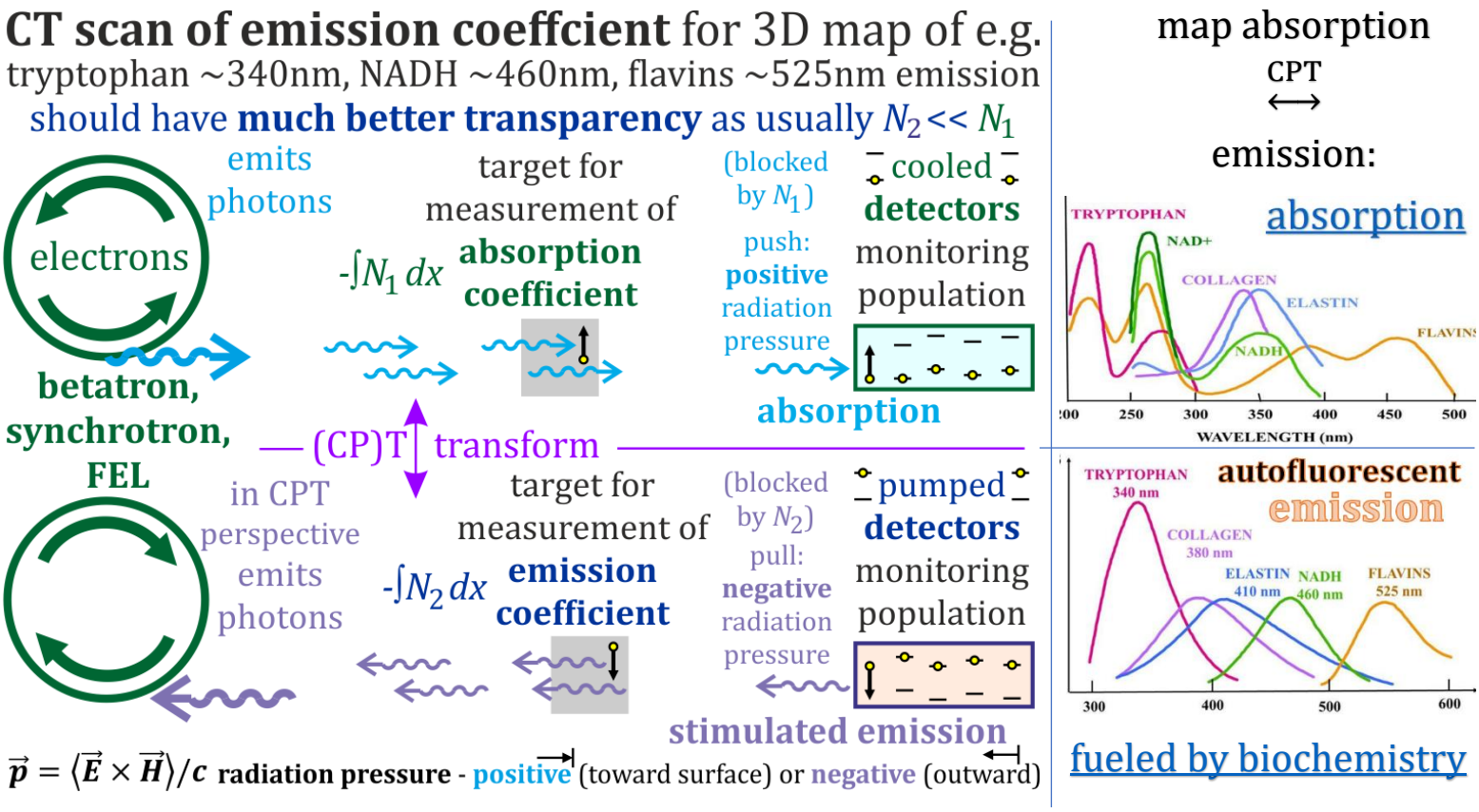


marine propeller-like antenna for positive/negative

Emission CT medical scanners: **"complementary, harmless, color CT"**

In radiography, CT (computer tomography) there is photon source, its intensity would be reduced by $\int N_1 dx$ ground state atoms on the way, and then it is absorbed by (cooled) detector - monitoring its population allows to **map absorption coefficients**.

Preparing CPT analog of this scenario should allow to **map emission coefficient** instead. It requires replacing photon source with situation emitting photons in CPT perspective, like synchrotron sources: just accelerating charges in both perspectives. **Detector** needs to be **focused on stimulated emission** acting on it – has to to be initially excited ($N_2 \gg 0$), for example as some 3-state dye used in STED microscopy, its population needs to be monitored – if it deexcites faster than usually.



This way we should **measure $\int N_2 dx$ numbers of excited atoms** – which usually is much lower than N_1, hence should have **much better transparency** ($N_2 \ll N_1$) – allowing to **map emission coefficients inside human body**, also in visible and infrared spectrum.

While such mapping could use **contrast agents**, inside living organisms there already are autofluorescent molecules powered by biochemistry, like NADH – emission radiography/CT should allow to **map such various molecules**, providing "**color harmless radiography**":

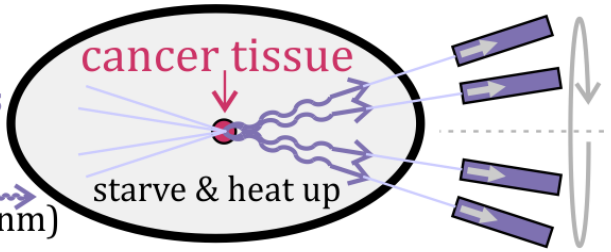
- **complementary information**: currently unavailable maps of autofluorescent molecules,

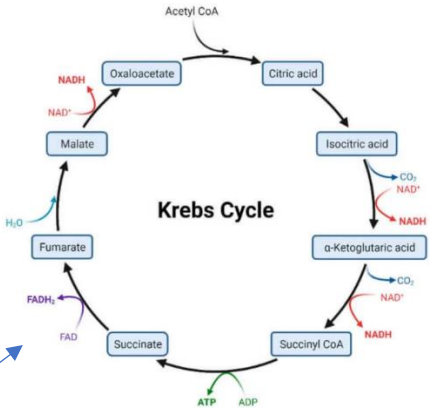
- by **non-ionizing** radiation: harmless, could be used e.g. as **continuous camera**,

- working in **multiple frequencies** – mapping various molecules to recognize tissues/pathologies.

Precisely describing local metabolism, should easily find deep e.g. cancer tissues and changes.

Backward ASE radiotheraphy?
amplify chosen photon emission
by intersecting **backward beams**
e.g. stimulate NADH degradation
to starve, release energy heating
$NADH \rightarrow NAD^+ + H^+ + 2e^- + \gamma$ (~460nm)





Stimulated emission radiotherapy: non-ionizing e.g. to starve cancer tissue

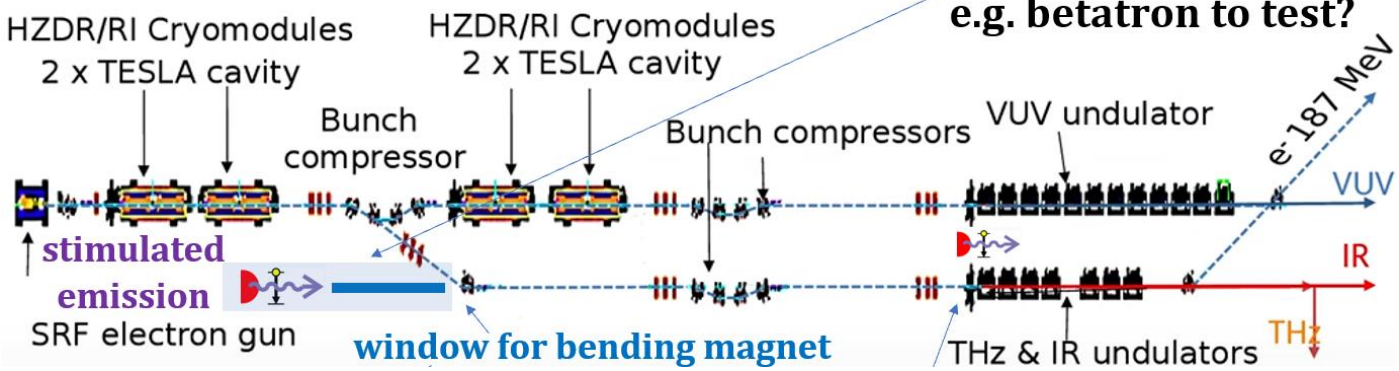
As such EM impulse, analogous to pulling twist-like wave behind marine propeller, should be blocked by excited N_2 instead of ground state N_1 resonators like atoms, it should have much better transparency: allowing to **focus stimulated emission in deep tissues**. For example of photons emitted during degradation of **autofluorescent** molecules, like **NADH** (~460nm), **FADH** (~525nm) crucial for cell metabolism to locally starve target cancer tissue (avoiding metastasis), being practically negligible for intermediate tissues. Also could allow therapies of various metabolic issues.

Realization on betatron, synchrotron, ideally PoLFEL – behind IR undulators

Proposed medical applications would require synchrotron source for reversed electron trajectory, preferably close to visible spectrum – simple betatron should be sufficient for scanning, or synchrotron like Solaris, or ideally free-electron laser like PoLFEL - preferably behind IR undulator. Especially if confirming the effect e.g. on betatron, such additional capabilities/motivations should essentially help financing PoLFEL.

Alternatively, **betatron**, or **electron gun**/X-ray-like lamp **+ magnet**, proof-of-concept with antenna? How to organize it?

Additional capability/motivation for PoLFEL? Behind IR undulator?
e.g. betatron to test?



In **Solaris**? Need to place target for synchrotron radiation assuming reversed electron trajectory: above/below synchrotron (mirror), or behind linac
(**planned windows in bending magnet** ~2027)